OCEANOGRAPHY FROM SPACE

The Woods Hole Oceanographic Institution

Woods Hole, Massachusetts 02543

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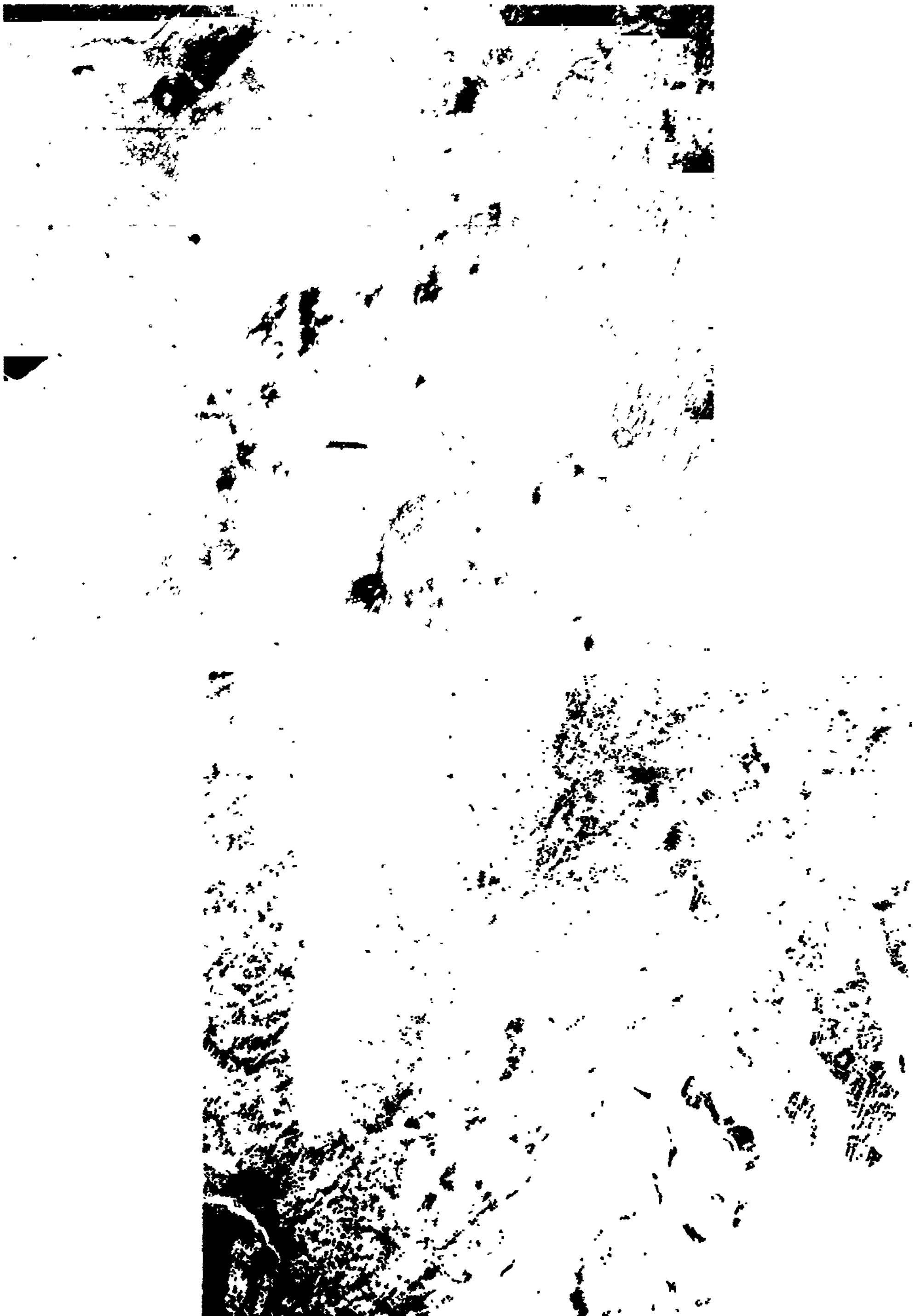

Frontispiece. The Hooghly River in the western part of the Ganges delta, India. Above, a print of a 70 mm color transparency taken by L. G. Cooper during the MA-9 orbital flight below, black and white print of same transparency (Lowman p. 86).

OCEANOGRAPHY FROM SPACE

Proceedings of Conference on The Feasibility of Conducting Oceanographic Explorations from Aircraft, Manned Orbital and Lunar Laboratories. Held at Woods Hole, Massachusetts, 24 - 28 August 1964.

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Edited by
Gifford C. Ewing, Chairman

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Woods Hole, Massachusetts, 02543
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FOREWORD

During the past 14 years reconnaissance of the ocean surface by air-borne remote sensors has undergone rapid expansion until it is now widely used in marine meteorology, physical oceanography and marine biology. The Woods Hole Oceanographic Institution has taken a leading role in the development of this science since its inception. The use of extended strip photography and air-borne infrared radiometry to map large scale features such as the Gulf Stream are two research areas in which WHOI made early contributions.

The advent of earth-orbiting vehicles constitutes a dramatic enlargement of available means for rapid scanning of the ocean. It is, of course, essential that oceanographers be cognizant of these developments and that their usefulness for scientific purposes be correctly assessed. WHOI therefore readily responded to the suggestion of the National Aeronautics and Space Administration, Office of Space Science and Application, that such an evaluation be undertaken. In order to sample the opinion of a representative cross section of oceanographers, a conference was convened at Woods Hole on 24-28 August, 1964 under the chairmanship of Gifford C. Ewing. The papers presented in this document represent the formal result of this conference.

Response to invitations to the conference was such that attendance considerably exceeded our capacity. In this emergency, John S. Coleman assisted by arranging for use of the National Academy of Science's summertime facility at Little Farm. This timely assistance is gratefully acknowledged.

Paul M. Fye, Director
Woods Hole Oceanographic Institution

PREFACE

"Oceanography from a satellite" — the words themselves sound incongruous and, to a generation of scientists accustomed to Nansen bottles and reversing thermometers, the idea may seem absurd. This is all the more so because decades of technological constraint have all but forced oceanographers into consideration of the class of problems that derive from the vertical distribution of properties at stations widely separated in space and time.

But this is a new age, when spacecraft, circling the globe in ninety minutes, reconnoiter the whole planet surface on a daily schedule with remote sensors of great power and refinement These sensors exploit the entire electromagnetic spectrum, they come in active and passive modes, their sensitivity and angular resolution are high and their response is ultra rapid. Remote sensing is, of course, not new to oceanographers. For nearly fifty years they have, by acoustic means, looked at the ocean bottom through thick layers of water. Now, using a variety of electromagnetic devices, they are learning to look at the ocean surface through ever thicker layers of atmosphere.

Of course the millenium is not yet upon us. It is easy to point out the difficulties that lie in the way of making useful scientific observations through haze and clouds. It is easy to see that, even if our view of the ocean surface were perfect in every detail, many of the classical problems of oceanography would not thereby be resolved.

But when all is said and done, the ocean is essentially a thin film of moisture on the face of the earth — its horizontal exaggeration relative to the vertical being of the order of 6000. All the significant exchange of energy between the ocean and its external environment passes through its upper surface, fully exposed to examination from above. So intuition tells us that future generations of investigators, scanning the ocean from a new vantage point, will have the imagination to ask new questions of it and the ingenuity to devise ways of answering them. It is unthinkable that oceanographers will not find ways to exploit this burgeoning technology for the advancement of their science.

It was to encourage this new look at oceanography from space that in August of 1964 the Woods Hole Oceanographic Institution, with the support of the National Aeronautics and Space Administration Office of Space Science and Application, convened a group of 150 oceanographers to review the capabilities of satellite sensors and to consider what areas of oceanographic endeavor might be advanced by these means. The participants represented the various component disciplines of oceanography; physical, biological, chemical and geological. They listened and deliberated for one week, producing the seventy-eight contributions presented herewith. Admittedly, one week is not very long to orient oneself in an unfamiliar context, especially since, for many, this was a new exposure not only to satellite characteristics but to remote sensing of the sea. The reader should bear this in mind. Here he will not find a coherent book or even a clearly defined consensus. This is a collection of papers not yet seasoned by criticism or matured by reflection. That will come later. The papers must speak for themselves. Some are cautiously pessimistic and a few are perhaps too sanguine. But, as a group, they reflect a restrained enthusiasm that has the ring of real scientific innovation. The purpose in publishing them is to stimulate fresh ideas, and this goal, hopefully, will be achieved.

After the formal papers had been presented to the conference, the participants spent a working day divided into panels organized around specific topics, as follows:

- Sea level
- Waves
- Sea ice
- Currents
- Sea surface temperature
- Marine meteorology
- Marine biology
- Coastal geology and geography
- Instrumented buoys

The recommendations of these panels are grouped in the text with papers by individual authors bearing on related topics. For easy reference they are prominently emphasized in the table of contents. The ideas contained in these panel reports are, perhaps, the main dividend to be derived from the conference and from this publication.

It was widely agreed by several panels that a most important use of satellites in oceanography would be in gathering and retransmitting information telemetered by various sensors located on the surface. These would include drifting and fixed instrument buoys, ships, stations, tags attached to migrating animals, markers on ice and drifting bergs. If tele. ing is lacking in novelty, it rates high in workability. On the one hand it capitalizes the satellite's capabilities for frequent and complete coverage of the world, and on the other it takes advantage of all the conventional techniques that have been evolved. Characteristically these give detailed measurement of the intensity of physical, chemical, geological and biological variables at or beneath a single point in the sea. However, for the description of field variables the extensive characteristics of the distribution are as important as the intensive ones, and for horizontally continuous observations, aircraft and satellites have intrinsic utility. This advantage can be measured in terms of perspective, gaining directly in proportion to the elevation of the viewpoint. It is in this area that we search for programs uniquely suited to the capabilities of remote sensors mounted in orbiting satellites in place of telemetering sensors at the sea surface.

For example, precise leveling of the sea surface by direct measurement from a known orbit would not only refine estimates of the shape of the geoid but would define the geostrophic current and barotropic distortions due to storms. It would provide entirely new data on the characteristics and propagation of tides, surges, and tsunami waves. The required datum would be provided by precise altimetry with a relative accuracy of 5 cm over an area of 1000 sq km. The outlook for adequate instrumentation is not too discouraging. It can safely be said that this would be the most general and fundamental contribution that satellites could make to the science of physical oceanography. Far reaching benefits would accrue to other branches of marine science, including biology, fisheries, geology, engineering, surveying, offshore drilling, and marine safety.

A closely related endeavor would be the classification and recognition of the surface exposure of water masses and their interfacial boundaries or "fronts". Although oceanographers wish to trace the masses at all depths these are, in so far as conservative properties are concerned, formed at the surface and surface processes are the most important determinants of their characteristics. Thus the key to the temperature and salinity of the central water masses in all oceans is to be found in the surface water of the subtropical convergence. Useful instruments are microwave and infrared radiometers, multispectral devices to measure the heat flux through the surface, and photocolorimetric devices. Photography and visual observation of clouds, foam, trash lines, and the shape of the glitter pattern of the sun, moon or stars may give valuable auxiliary information. The desired thermal resolution of 0.5°C over distances of 50 km from satellite altitudes appears to be somewhat beyond the ability of present technology because the intervening atmosphere introduces severe problems of environmental noise. But these impediments, however formidable they may appear, may be circumvented by ingenious means not yet conceived.

Biologists share a need for a wide range of oceanic data in common with other oceanographers. To this extend their requirements are not unique. Their most generally needed special data is the photosynthetic rate in the upper sunlit layers of the sea. This is a most difficult process to quantize, even by conventional means. However, considerable information can be inferred from maps of the chlorophyll concentration of the water. This chemical has a strong and unique spectrographic signature of absorption bands. Therefore, the possibility exists of a photometric method of remote sensing of this parameter. It would give data of fundamental importance. Less elaborate methods of recognizing areas of discolored water would also be of use.

Windwaves and swell constitute another field which requires the extended perspective of an elevated viewpoint for complete observation. Attempts to derive the wave field from data taken at a few discreet points are always hopelessly incomplete. What is needed is the directional and energy spectrum of waves in a two-dimensional surface, and for this the vantage point offered by a satellite is ideal. It is within the capability of present day radar technology to give a complete description of the sea state. The usefulness of such information both to the theoretical oceanographer and to the marine engineer would be difficult to overestimate.

To the geographer, geologist, and coastal engineer the chief appeal of a satellite as an observing platform lies in its readiness to monitor large scale features and events wherever and whenever they occur. These include inaccessible coastlines and their modification by storms, floods, surges, tsunamis and wave attack. Other significant events are submarine earthquakes, slumping, eruption and emergence of new volcanos, and the appearance or disappearance of transient bars and islands. The requirements for definition are 10 meters in plan and 50 cm in elevation. These goals appear to be within the reach of the very best photographic and radar techniques.

The survey of sea ice is a relatively straightforward application of satellite reconnaissance. Here the attraction is the availability of complete and continuous air coverage of the relatively inaccessible polar regions. The resolution required, of the order of 30 meters, seems to be realizable, and ice, because of its dielectric and optical properties, is readily differentiated from water by radar, microwave, infrared and optical imagery. Stimulated by the U. S. - Canadian TIREC survey, the usefulness of ice surveillance is already well established.

Several recommendations of a general nature were made. It was suggested that an atlas be prepared showing representative examples of the best photographic infrared and radar imagery available so as to arouse the interest of earth scientists. Where possible, these examples should be supported by data and analytic interpretation.

A system of rapid scanning of data flowing from various satellites is needed to insure its prompt and timely dissemination to potential users.

Adequate "ground truth" test facilities must be provided to serve as calibration areas over which new instruments can be proved.

The problem of security classification was singled out as a major impediment to the development of scientific interest in and use of satellite data. Numerous speakers made allusion to the handicap of not being allowed to show simple examples of modern remote sensing apparently on the assumption that some military advantage might be compromised thereby. Most participants felt that indiscriminate security classification may well be a detriment rather than an advantage to the national interest.

After the adjournment of the conference many letters were received expressing the enthusiasm and interest aroused by the papers and discussion. Favorable comments was also made on the imagination and energy shown by Dr. Peter C. Badgley in launching the manned space science program in oceanography. It is a pleasant duty of the chairman to note these comments as an expression of appreciation addressed to all who, in various ways, contributed to the success of the conference.

Gifford C. Ewing, Editor

Woods Hole, Massachusetts
March 1965

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INTRODUCTORY BRIEFING

Peter C. Badgley

Chief, Advanced Missions, Manned Space Science Program,
Office of Space Sciences and Applications, NASA Headquarters, Washington, D. C. 20546

It is a great pleasure to see so many of you here. You are already aware of the purpose of this meeting, which is to determine the interest of oceanographers in utilizing manned earth orbital spacecraft for the study of the oceans. Drs. Fye and Ewing expressed this purpose and the challenges anticipated in a very clear manner in the July 1 letter of invitation which you have all received.

It would be impossible to convene all interested oceanographers and space scientists for a meeting of this type, but I feel that an excellent representation is present. I hope that you will bring additional scientists to our attention if you feel that they can make a valuable contribution and are desirous of doing so.

This conference is just the beginning of what we hope will be a strong association between space scientists and oceanographers. We would like you to recommend those experimental areas which you consider most promising for inclusion in our forthcoming manned earth orbital spacecraft. In a few minutes I am going to give you some idea of the spacecraft schedules we contemplate currently. You will see that an adequate period of time exists for you to look into the feasibility phases of your most important experimental areas and to work on preliminary design of spacecraft instruments.

You will note that this conference is being convened to explore the interest of oceanographers in participating as eventual experimenters on manned earth orbiting spacecraft. Many of you are being exposed to earth orbiting spacecraft for the first time so that the difference between manned and unmanned spacecraft means very little to you. What we would like you to tell us is this: What natural phenomena do you wish to observe? Which of these are most important? With what resolution do you wish to observe these phenomena (to the nearest centimeter? foot? $0.1^{\circ}C$?)? Do you wish to observe these phenomena with a number of visual and electromagnetic sensors at the same time or by only one sensor at a time? How often do you wish to observe these phenomena? What weight, power and telemetry requirements will your instruments call for? How selective must you be in acquiring the data? You will be able to answer some of these questions. We shall have to answer some of them. Some of our own philosophy on this subject is as follows: The use of various sensors over the same terrain or ocean will provide comparative data that will explicitly define the capabilities of each sensor.

You should study the data returns from TIROS and NIMBUS very carefully. What degree of improvement in resolution (temperature, distance, etc.) will you need to study the oceans? These needs will determine the weight and power requirements of your instrument packages. We have plans to publish albums containing photographs, imagery and other data returns from TIROS, NIMBUS, U-2 and our current aircraft multispectral program, to aid you in determining the usefulness of observations of the oceans and land areas from very high altitudes.

How important will it be to have a trained observer aloft with the instruments? We shall have to inform you how many pictures (and other data) you can take. This will depend upon the power and telemetry facilities of the spacecraft at our disposal. My own guess is that you will want very accurate data and will want an observer during the early years when you are exploring the usefulness of each device. If you already have a high degree of confidence and satisfaction in the applications, resolution and merits of certain light weight instruments then you should bring these to our attention so that we can put them in the available light payload satellites at NASA's disposal. You must state your overall needs and we shall work with you in an iterative manner to develop the most useful missions to meet your objectives. You must bear in mind that your objectives must be coordinated with the objectives of other scientific disciplines also.

We would like to come out of this conference with a firm indication of the experimental areas which you are going to propose for detailed feasibility studies. A subcommittee for each area might be a useful approach. For the terrestrical geosciences, I should point out that we already have a very substantial feasibility and instrument design effort underway in a number of areas. It would be most valuable for you to become intimately acquainted with this effort and for coordination and budgetary reasons it would be advisable for you to appoint representatives to the existing NASA instrument committees. For example, we already have an infra-red group, a radar group, a multispectral photography group. It would be inappropriate to form two radar groups, one for oceanographic radar and one for all other radar geoscience applications. However, you will no doubt have a number of committee areas not common to the other areas of geoscience in general. Actually the observation of natural phenomena is the prime objective that we see. We want you as scientists to control the experiments rather than letting the instruments or the spacecraft do this for you.

Obviously, it would be nice to investigate many areas but we do not have the funds to take a shot gun approach. We have budgeted for a strong feasibility program but I am going to be quite frank in saying that this can be a much stronger program if some of you from other agencies and other countries join with us in joint support of research projects. I might say that a number of other agencies are making strong contributions to our existing program already (e.g. the NRL radar aircraft contribution.)

Let me now run through some figures which will attempt to relate this oceanographic activity to other NASA areas of interest.

Figure 1 — Note the position of various missions. Our effort is devoted mainly to the development of scientific payloads for the 35 - 60 day A.E.S. orbital flights (initially) and for the permanent earth orbital research laboratories (ORL).

Figure 2 — This is a rough estimate of the time schedule involved.

Figure 3 — Note the relationship of current feasibility studies to other mission phases.

Figure 4 — Note the relationship of current feasibility studies in aircraft to future missions.

Figure 5 — Note the relationship of current feasibility studies to future terrestrial applications in a number of disciplines.

Figure 6 — Questions being investigated during our feasibility studies.

Figure 7 — Note the data exchange problems being encountered during our feasibility studies and contemplated for our future missions. Note the interdependency of various portions of the spectrum and the need for rapid exchange of information.

Figures 8, 9 — These figures will give you an idea of the configuration of the earliest generation spacecraft (manned earth orbital-extended stay time).

Figure 10 — Note Man's role in future missions. In the less complicated light weight satellites man can play a part in calibration, adjustment and so forth. In large payload vehicles like the ones we are considering, with tremendous data gathering capabilities, man's powers of selectivity and decision making are going to be extremely valuable if not mandatory. His ability to capitalize on the unknown elements which are encountered will be most important.

I have purposely said little about individual research areas which we are investigating already. These will be nicely covered by the following speakers. I would ask you to consider the test site approach, using sensor equipped aircraft which we are now involved in developing for terrestrial objectives. I believe it would be very appropriate to oceanographic and coastal problems also. We now have a group of remote sensor equipped aircraft at our disposal and I can assure you that we shall do everything we can to help you in solving some of your feasibility programs prior to spacecraft missions.

Figures 11-14 will give you an idea of the guidelines which we are using to select test sites. I hope that the volume resulting from this conference will include a list of test sites for our consideration in the immediate future.

In closing, I wish to assure you that NASA is most anxious for all of your work and reporting to be carried on in a completely unclassified manner. We shall work with you vigorously to achieve this and other goals which you recommend.

RELATIONSHIP OF EARTH AND LUNAR ORBITAL FLIGHTS TO OVERALL NASA MISSION PLANS

REGION OF SPACE	UNMANNED	MANNED	
		DEVELOPMENTAL	OPERATIONAL
EARTH ORBIT	**1. SCIENTIFIC SATELLITES:** EXPLORERS OBSERVATIONS (OGO, OAO, OSO ETC.) APPLICATION: COMMUNICATION (TELSTAR, SYNCOM) METEOROLOGY (TIROS, NIMBUS) NAVIGATION ENGINEERING RESEARCH	**4. SATELLITES:** MERCURY GEMINI APOLLO EARTH-ORB. SAT. 1B + SAT. V QUAL FLIGHTS 35-60 DAY ORBITAL FLIGHTS (A.E.S.) ORBITAL RES. LAB. (ORL)	**7. LABORATORIES:** FERRY VEHICLES RECOVERABLE BOOSTERS ENGINEERING EXPERIMENTS DEVELOPMENT
LUNAR	**2. LUNAR PROBES:** RANGER SURVEYOR LUNAR ORBITER	**5. LUNAR EXPLORATION:** INITIAL APOLLO LANDINGS 2-4 DAY SURFACE TRAVERSES ORBITAL SCIENTIFIC SURVEYS 14 DAY SURFACE TRAVERSES	**8. LUNAR STATION:** EXPLORATIONS SCIENTIFIC OBSERVATIONS
PLANETARY	**3. DEEP-SPACE PROBES:** MARINER INTERPLANETARY MONITOR SATELLITES VOYAGER SOLAR PROBE OUTER PLANETS & SATELLITES BIOSATELLITE	**6. EXPEDITIONS:** MARS FLY - BY VENUS RECONNAISSANCE SEARCH FOR LIFE ON PLANETS	**9. PLANETARY OPERATIONS:** MARS STATION ADVANCED EXPEDITIONS VENUS JUPITER SATELLITES MERCURY ASTEROIDS

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Figure 1

POSSIBLE MANNED SCIENTIFIC MISSIONS

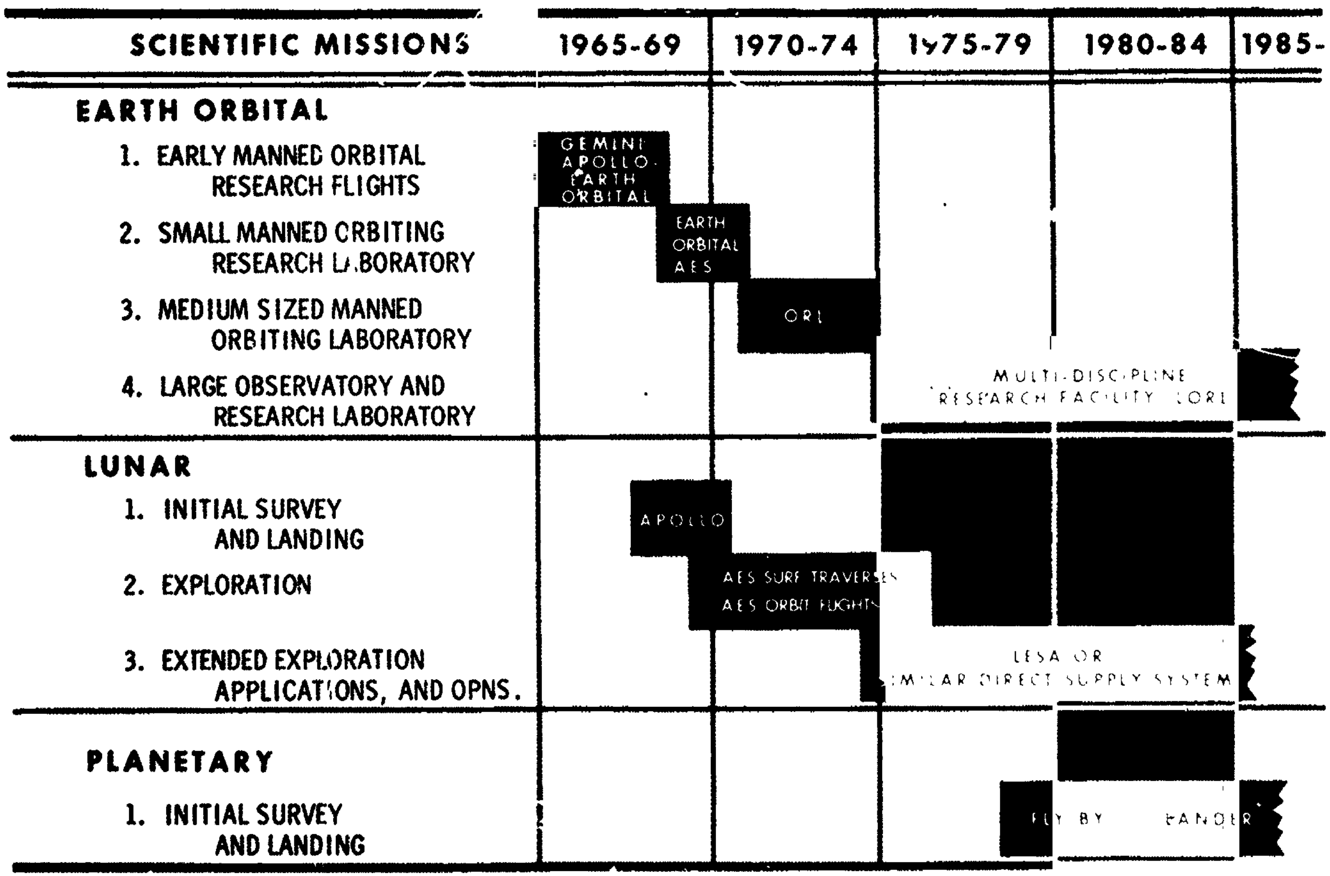


Figure 2

EXPERIMENT DEVELOPMENT FLOW PLAN FOR A.E.S. MISSIONS

July 1964-Dec. 1967	FEASIBILITY STUDIES (EG. SCIENTIFIC APPLICATIONS OF MULTISPECTRAL RESPONSES)
Oct. 1964-June 1965	PRELIMINARY DESIGN STUDIES OF INSTRUMENT REQUIREMENTS FOR SPACE FLIGHT EXPERIMENT
July 1, 1965-Feb. 1, 1966	DETAILED INSTRUMENT DESIGN, AND PROTOTYPE DEVELOPMENT
Feb. 1, 1966-Mar. 1, 1968	HARDWARE DEVELOPMENT AND INTEGRATION WITH SPACECRAFT
Mar. 1, 1968-Sept. 1, 1968	TESTING IN ORBIT FOR LUNAR ORBITAL SCIENTIFIC SENSORS AND MODULE
Sept. 1, 1968	OPERATIONAL READINESS FOR LUNAR ORBITAL SCIENTIFIC SURVEY MISSION
Mar. 1968- - - - - - - - - -	DATA RETURNS AND ANALYSIS FROM A. E. S. MISSION (A WELL ESTABLISHED DATA CENTER IS EXPECTED TO BE FUNCTIONING BY THIS TIME)

Figure 3

RELATIONSHIP OF CURRENT MANNED SPACE SCIENCE ADVANCED MISSION S.R.&T. STUDIES TO FUTURE A.E.S. MISSIONS

CURRENT - 1968	1968 - 69	1968 - 70
REMOTE SENSOR GEOLOGIC MAPPING CAPABILITY:	EARTH ORBITAL OVERFLIGHT OF SAME GEOLOGIC TEST SITES:	MANNED LUNAR ORBITAL SCIENTIFIC SURVEY CARRYING MANY OF SAME SENSORS USED IN EARTH ORBIT.
AERIAL OVERFLIGHT OF TERRESTRIAL & OCEANIC SITES TO DETERMINE SCIENTIFIC SIGNIFICANCE OF MULTISPECTRAL RESPONSES PLUS ASSOCIATED "GROUND TRUTH" CALIBRATION IN LAB & FIELD	WILL PERMIT ADDITIONAL CALIBRATION OF SENSORS FROM ORBITAL ALTITUDES	A.E.S. GROUND TRAVERSES PROVIDE ADDITIONAL "GROUND TRUTH" CALIBRATION

Figure 4

RELATIONSHIP OF CURRENT MANNED SPACE SCIENCE ADVANCED MISSION S.R.&T. STUDIES TO FUTURE APPLICATIONS

SOME OF STUDIES UNDERWAY		APPLICATIONS
RADAR GEOLOGY	U S ARMY N. R. L. KANSAS U. OHIO STATE	GEOLOGIC MAPPING CAPABILITY FROM EARTH & LUNAR ORBITAL ALTITUDES
INFRARED GEOLOGY	U. S. G. S. AMES	
MULTISPECTRAL PHOTOGRAPHY	A F C R L J P L BERKELEY	
GEOGRAPHIC, AGRICULTURAL, OCEANOGRAPHIC HYDROLOGIC APPLICATIONS OF ORBITAL SENSORS	O. N. R. NORTHWESTERN U. U S ARMY UNIV. MICHIGAN PURDUE UNIV. U S GEOL. SURVEY WOODS HOLE O. I.	DATA SYSTEM FOR STUDY OF METROPOLITAN GROWTH STUDY OF AIR POLLUTION STUDY OF WATER RESOURCES, RELATIONSHIP TO INDUSTRIAL GROWTH OPTIMUM USE OF HABITABLE LAND DATA SYSTEM FOR AGRICULTURAL RESOURCE SURVEYS AND CROP PREDICTIONS SPACE DERIVED EARTH ATLAS FOR USE IN INDUSTRIAL REGIONS AND UNDERDEVELOPED COUNTRIES. NATURAL RESOURCE SURVEYS, ETC. SYNOPTIC ANALYSIS OF SEA STATE, AIR-SEA INTERACTION, WEATHER FORECASTING, ETC.

Figure 5

SOME QUESTIONS NASA IS TRYING TO ANSWER BY AERIAL SURVEYS AND EARTH ORBITAL MISSIONS PRIOR TO LUNAR ORBITAL FLIGHTS

SPECTRAL EMISSION STUDIES

- WHAT RELATIONSHIPS EXIST BETWEEN SPECTRAL EMISSION ANOMALIES AND MAJOR GEOSCIENTIFIC FEATURES ON PLANETARY SURFACES?
- HOW CAN THE EMPIRICAL RELATIONSHIPS ESTABLISHED BY ANOMALY MAPPING LEAD TO A BETTER UNDERSTANDING OF EMITTANCE THEORY?
- CAN TERRESTRIAL "GROUND TRUTH" SURVEYS REMOVE MANY OF THE UNCERTAINTIES ASSOCIATED WITH THE INTERPRETATION OF EMISSION ANOMALIES?
- CAN SPACEBORNE SPECTRAL RADIATION DETECTORS BE USED TO DETERMINE THE CHEMICAL AND MINERALOGICAL COMPOSITION OF PLANETARY SURFACES?

SPECTRAL IMAGERY

- DO MULTIBAND PHOTOGRAPHY AND SPECTRAL IMAGERY (FROM ORBITAL ALTITUDES) PROVIDE ADVANTAGES OVER CONVENTIAL PHOTOGRAPHY?
- HOW IMPORTANT ARE THE FOLLOWING ADVANTAGES:

  SYNOPTIC COVERAGE AND CONTINUITY OF OBSERVATION. RECOGNITION OF GROSS PATTERNS NOT DETECTABLE ON SMALLER AREA IMAGERY (REGIONAL TECTONICS, GEOGRAPHIC PATTERNS, ETC.)

  AVOIDANCE OF MOSAIC DEGRADATION

ACTIVE SENSORS

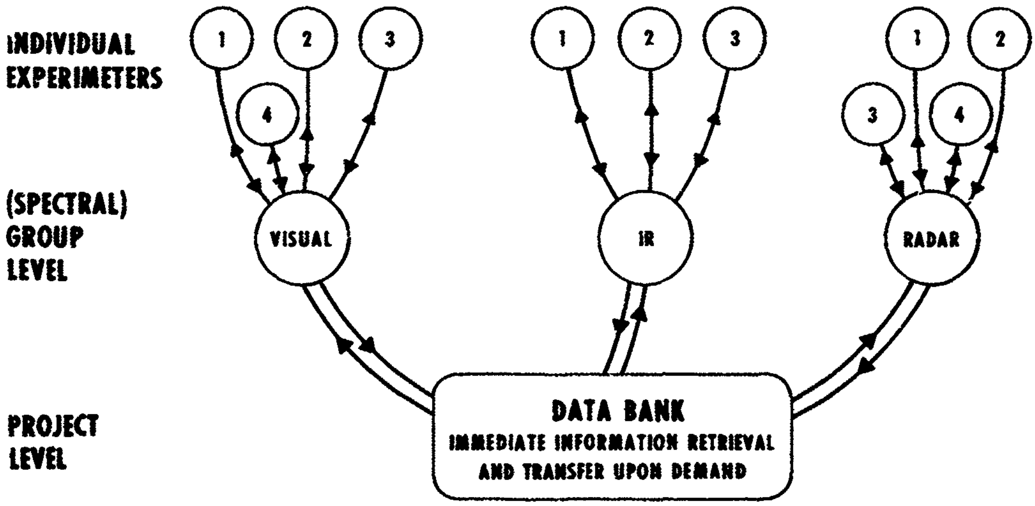
- HOW WELL CAN RADAR PICK UP STRUCTURAL DETAILS NOT REVEALED BY CONVENTIONAL PHOTOGRAPHY?
- HOW EFFECTIVE IS RADAR IN DETERMINING THE THICKNESS OF SOIL AND GLACIAL TILL?
- DOES RADAR PERMIT THE MAPPING OF GEOLOGICAL CONTACTS WHICH CANNOT BE DETECTED BY CONVENTIONAL PHOTOGRAPHY OR BY SPECTRAL EMITTANCE?
- HOW ACCURATELY CAN ACTIVE MICROWAVE SENSORS (RADAR) PREDICT THE SURFACE ROUGHNESS AND DETAILED TOPOGRAPHY OF PLANETARY AND OCEANIC SURFACES?

REMOTE SENSORS (ALL TYPES)

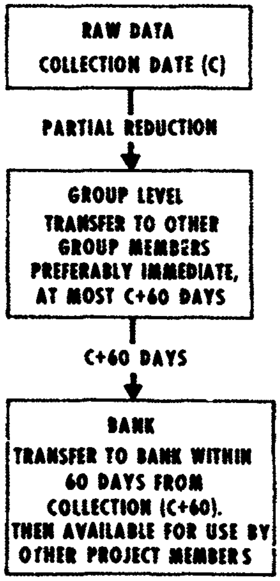
- CAN SPACEBORNE REMOTE SENSORS AID IN OUR UNDERSTANDING OF AIR POLLUTION, INDUSTRIAL GROWTH, MAJOR HYDROLOGIC DISTRIBUTION PROBLEMS?

Figure 6

TYPICAL INTERRELATION BETWEEN EXPERIMENTERS



TIMING



PUBLICATION RIGHTS *

PROTECTION PERIOD

INDIVIDUAL EXPERIMENTER HAS 90 DAYS (C+90) TO ESTABLISH PROPRIETARY RIGHTS TO NOTABLE FACTS IN HIS DATA AND TO PREPARE AN IDENTIFIABLE REPORT WHICH CAN BE DISTRIBUTED TO ALL PROJECT PERSONNEL. REPORT MUST BE SUFFICIENTLY DETAILED THAT LATER MANUSCRIPTS CAN BE RELATED TO AN ORIGINAL REPORT OF THIS TYPE.

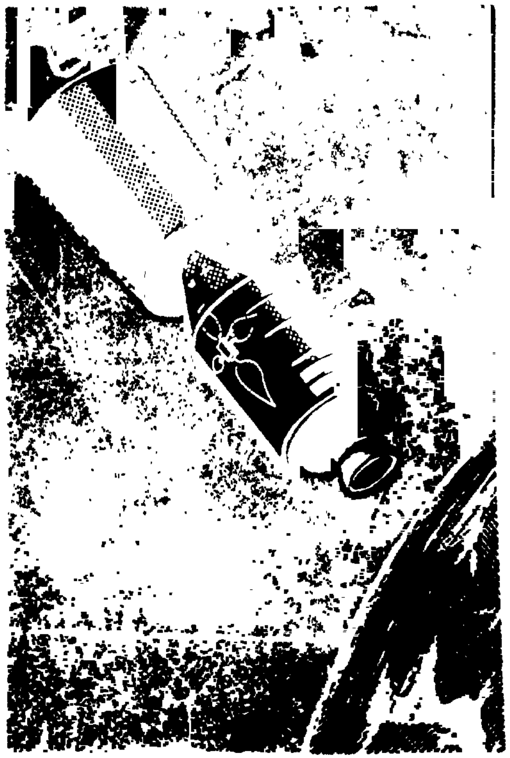
GROUP EXPERIMENTERS HAVE 1 YEAR (C+1 YEAR) TO SUBMIT A MANUSCRIPT FOR PUBLICATION PROVIDED THE INDIVIDUAL RIGHTS WERE ESTABLISHED AND HAVE BEEN MET.

PROJECT PUBLICATIONS MAY BE PREPARED BY NASA AT THE PROJECT LEVEL AT ANY TIME AFTER 90 DAYS (C+90) FOR GENERAL PLANNING PURPOSES.

* CLASSIFIED DATA RAISE SPECIAL PROBLEMS, BUT COMPARABLE REPORTS (AS DEFINED ABOVE) CAN BE SIMILARLY GENERATED.

Figure 7

APOLLO ORBITAL RESEARCH LABORATORY (AORL)

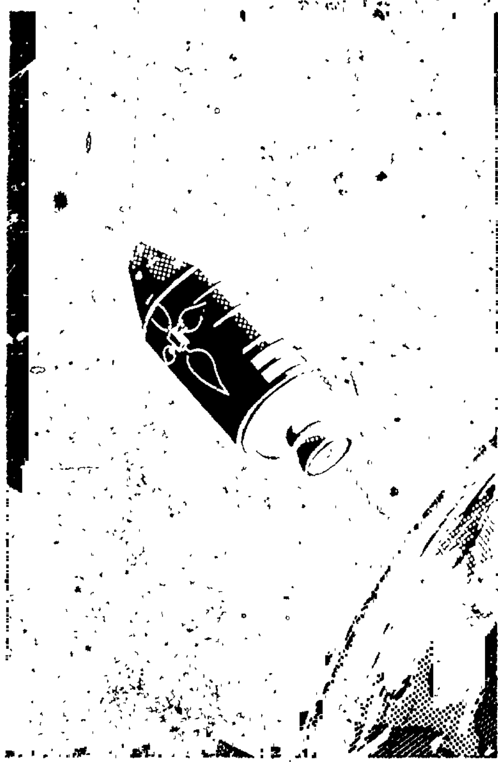


TOTAL WEIGHT	32,000
DIMENSIONS OF LAB	154"D x 300"
INTERNAL VOLUME	5600 CU FT
NO. MEN	3-6
ORBIT STAY	30 DAYS - 1 YR
NOMINAL ALTITUDE	200 NM
NOMINAL ORBIT PLANE INCLINATION	29.5
LAUNCH VEHICLE	S-IB
NOMINAL RESUPPLY	30 - 120 DAYS
VEHICLE STABILIZATION CAPABILITIES	.01 - .001 RAD/SEC.
VOLUME FOR EXPERIMENTS	5600 CU FT
WEIGHT AVAILABLE FOR EXPERIMENTS	500 LB INITIALLY
NOMINAL RESUPPLY PAYLOAD	5000 LB
NOMINAL RESUPPLY FOR EXPERIMENTS	4000 LB
POWER	1 KW
TEMPERATURE IN LAB	65 - 75°F
POSSIBLE SCHEDULE	1971 -

NASA SM64-1,35

Figure 8

EXTENDED APOLLO



TOTAL WEIGHT	27,520 lbs
NUMBER OF MEN	2
ORBITAL STAY TIME	45 days
NOMINAL ALTITUDE	200 n. mi.
NOMINAL ORBIT PLANE INCLINATION	28.5°
LAUNCH VEHICLE	S-IB
VEHICLE STABILIZATION CAPABILITY	.01-.001 rad/sec
VOLUME AVAILABLE FOR EXPERIMENTS	
COMMAND MODULE (Pressurized)	190 cu ft
SERVICE MODULE (Unpressurized)	1000 cu ft
WEIGHT AVAILABLE FOR EXPERIMENTS	5000 lbs
POWER AVAILABLE FOR EXPERIMENTS	1 kw
POSSIBLE SCHEDULE	1968 -

NASA SM64-1444

Figure 9

RATIONALE FOR MAN'S ROLE ON SCIENTIFIC SPACE MISSIONS

- SELECTIVITY IN ACQUIRING AND TRANSMITTING DATA (CONSIDER THE MASSES OF UNSTUDIED TIROS DATA)
- TO REPLACE COMPLEX COMMAND AND CONTROL SYSTEMS (MAN HIMSELF IS AN EXCELLENT COMPUTER)
- TO INSURE EQUIPMENT CALIBRATION AND RELIABILITY (e.g. THE RECENT RELIABILITY PROBLEMS OR RANGER)
- TO PERMIT CONTINUOUS OBSERVATION AND REFINEMENT OF EXPERIMENTS, AND MAXIMUM EXPERIMENTAL DIVERSIFICATION
- MAN'S ROLE AS AN EXPERIMENTER IN A LABORATORY CANNOT BE PREPROGRAMMED OR REPLACED BY AN ANALOG COMPUTER
- TO TAKE ADVANTAGE OF UNFORSEEN EVENTS—MAN'S IMAGINATION AND ENTHUSIASM CANNOT BE REPLACED BY A "BLACK BOX"

NASA SM64-1440

Figure 10

NASA REMOTE SENSOR FEASIBILITY STUDIES GUIDELINES COMMON TO BOTH LUNAR ANALOG AND TERRESTRIAL APPLICATIONS TEST SITES

1. OF INTEREST TO AS MANY DISCIPLINES AS POSSIBLE (BOTH DOMESTICALLY AND INTERNATIONALLY)
2. AMENABLE TO SIMULTANEOUS TESTING BY AS MANY SENSORS AS POSSIBLE
3. MAXIMUM AVAILABILITY OF EXISTING "GROUND TRUTH"
4. AVAILABILITY OF POST-FLIGHT INTERPRETIVE INTEREST AND CAPABILITIES
5. NON-RESTRICTED FROM MILITARY VIEWPOINT (PRESENT & FUTURE)

NASA SM64-1324

Figure 11

NASA REMOTE SENSOR FEASIBILITY STUDIES GUIDELINES COMMON TO BOTH LUNAR ANALOG AND TERRESTRIAL APPLICATIONS TEST SITES

6. READILY ACCESSIBLE FOR "GROUND TRUTH" PURPOSES
7. FAVORABLE GROUND & AIR SUPPORT LOGISTIC FACILITIES
8. SIZE OF SITES SHOULD BE LIMITED, PARTICULARLY IF NEW "GROUND TRUTH" IS NEEDED, AND IF DESIRED RESOLUTION OF SENSORS IS HIGH (SMALL SENSOR INTEGRATION AREAS INVOLVED)
9. NUMBER OF SITES SELECTED MUST BE SMALL BECAUSE OF FUNDING LIMITATIONS
10. INITIAL EMPHASIS ON 0-28° LATITUDES
11. ASSOCIATED LANDMARKS FOR RECOGNITION FROM ORBITAL ALTITUDES

NASA SM64-1824a

Figure 12

TEST SITE AREA TYPES BEING CONSIDERED BY NASA IN EVALUATING TERRESTRIAL APPLICATIONS OF REMOTE SENSORS

COASTAL - GEOLOGIC AND SEA STATE SITES

AGRICULTURAL, SOIL, ECOLOGIC SITES

METROPOLITAN COMPLEXES, AIR POLLUTION PROBLEMS, ETC

AIR - SEA INTERACTION AREAS (POLAR ? CARIBBEAN ?)

HYDROLOGIC BASINS (IRRIGATION GROUND CONTROL)

MINERAL DISTRICTS (ALTERATION HALOES?)

FORESTRY PRESERVES & FOREST FIRE CONTROL SITES

NASA SM64-1825

Figure 13

GUIDELINES FOR SELECTING TERRESTRIAL GEOLOGIC TEST SITES WHICH WILL BE USED IN EVALUATING LUNAR REMOTE SENSING APPLICATIONS

1. SHOULD INCLUDE SEVERAL LUNAR ROCK TYPES

2. LARGE SEGMENTS OF THE TERRAIN IN EACH SITE SHOULD BE UNIFORM CHEMICALLY AND PHYSICALLY

3. FREE FROM VEGETATION

4. RELATIVELY FLAT, UNIFORM ELEVATIONS

5. LOWER ALTITUDES, FAVORABLE CLIMATE FOR ALL YEAR STUDY PURPOSES

6. LUNAR ANALOG GEOLOGIC SITUATIONS (VOLCANIC CONES, LAVA FLOWS, LARGE IMPACT AREAS, EJECTA BLANKETS ETC.)

NASA SM64-1823

Figure 14

CHAPTER 1

CURRENTS AND THE SHAPE OF THE GEOID

RECOMMENDATIONS OF THE PANEL ON CURRENTS

Chairman: Robert W. Stewart
University of British Columbia
Vancouver, British Columbia

Members

D. F. Bumpus
W. V. Burt
H. L. Cameron
J. H. Carpenter
F. C. Fuglister
J. A. Knauss
A. R. Miller
P. M. Moser
M. Rattray, Jr.

Sea Level. The difference between the local mean sea level and a true level surface (the geoid) is a quantity of the greatest importance to physical oceanography, and not only to the study of tides and tsunamis. Spacial variations of this quantity determine the surface geostrophic currents, and if precisely known would give information on the oceanic "depth of no motion." Temporal variations largely determine the barotropic time dependent motion, lack of knowledge of which is one of the greatest stumbling blocks in present day oceanography.

The required precision seems to be about one order of magnitude beyond the present radar capability. If the instrument does not permit measurement of relative elevation to within 50 cm, the information is of essentially no oceanographic use. The value increases very rapidly with improvements over this figure, and if a precision of 5 cm could be achieved, the resulting information would be of immense value. Obviously, to obtain such precision some refined technique of averaging over, or otherwise compensating for, wave motion is required. For the purpose envisaged here, averages over areas in the neighborhood of 1000 sq. km would be suitable, so the mean level is in fact definable to suitable precision in spite of the presence of even high waves.

To repeat, if the precision required can be met, measurement of sea level would be of such value as to warrant a large effort, but less than the required precision is useless to oceanographers.

Surface Mapping. It is conceivable that surface mapping might reveal many features associated with current systems. Large temperature gradients accompany the boundaries of many of the most vigorous ocean currents. It is also well known that in fluid mechanical systems the isolines of contaminants of any kind tend to become aligned with stream lines. For this reason, devices which enhance the "color" contrasts of sea water - whether in the visible or not - should be tried out.

The strongest case for manned, as opposed to unmanned satellites in this connection is the possibility that large scale variations in some parameter not yet appreciated may turn out to be visible. It is possible that current shears, either horizontal or vertical, may modify surface wave parameters so as to produce effects visible in the glitter patterns. Wakes may be seen from some islands, or even from some kinds of fully submerged bottom relief, and it would be unwise to prejudge the possibility of some entirely unsuspected contrast proving visible to a trained observer. (That such contrasts are not obvious to untrained observers can be inferred from the silence, on this subject, kept by those, both American and Soviet, who have been in a position to observe from orbit.)*

Mapping of ice-covered regions, either optically or by line-scan radar, is likely to reveal structure from which it will be possible to infer the orientation of surface stream lines. The ultimate value of these mapping techniques is still of uncertain value. They are widely used by glaciologists, but little used by limnologists, each of whom need only aircraft to gain

*Note: Glenn reports having seen the Gulf Stream during the MA-6 flight. Ed.

corresponding information. It would seem that a program in this direction should develop step by step and be subject to constant review, for the results may not be worth the candle.

Multiple Look Techniques. The most direct measurement of velocity involves the measurement of displacement during a known time interval. For the ocean, a single satellite is not well suited to this purpose. During a single pass, a low satellite (1000 km or lower) from which reasonably detailed resolution is feasible, can view a particular area on the surface for times only of the order of a minute. In this time, typical ocean currents produce translations of only a few meters. Since the horizontal translation produced by surface waves is of the same order, any measurement of displacement over such a time interval would not only be difficult to make, but would be heavily contaminated by noise.

For a single satellite, looks on successive passes occur twice daily. This is exactly the wrong interval. Among the largest motions of the ocean are tides and particularly inertial oscillations, both of which have periods of the order of one-half day. Observations at this time interval would thus be subject to a very large noise component which would be aliased through the whole spectrum, and make the interpretation extremely difficult.

However, if three satellites were used, on polar orbits displaced by 60°, sufficient information could be obtained to smooth tidal and inertial motions and remove the aliasing.

Objects which might be followed in this way include deliberately planted buoys which may follow surface motion or be attached to drogues at some desired depth. The trajectories of such buoys can provide some information on both large scale mean currents and on turbulent diffusion, but it should be recognized that such techniques are subject to some very fundamental difficulties which preclude interpretation in other than a very general way.

Again, this technique is especially suitable for following ice movement. It may also prove valuable in following identifiable water features such as Gulf Stream meanders. In these cases, the use of stereo methods to reveal flow patterns may prove particularly valuable.

It should be noted that the comments in this section apply equally to optical, infrared or radar scanning.

Communication. It was widely agreed among contributors to the discussion leading to this paper that probably the most important use of satellites in oceanography would be as communication aids in transmitting information from instrumented buoys. The discussion of the nature of such buoys lay outside the scope of this conference, but the resulting briefness of this section should not be taken as an indication of its importance. Some participants feel that the only really valuable role of satellites in oceanography will be this one of communication, and that of navigation.

Navigation. This paper would be incomplete without mention of the fact that perhaps the greatest improvement in existing shipborn velocity determinations would be obtained by making deep sea navigation as precise as is now possible in some near-shore regions. Navigational satellites have frequently been discussed, and if the perfection of such devices can be achieved, the gain would be indisputable.

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N65-30??

OCEANOGRAPHIC SATELLITE RADAR ALTIMETER AND WIND SEA SENSOR

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In Dr. Ewing's opening remarks on Monday afternoon, he asked us all to consider that a new generation of oceanographers will be asking new questions of the ocean and we should attempt to anticipate this when considering what can or should be observed and measured from a Manned Orbital Oceanographic Laboratory.

As a non-oceanographer I would like to run through some of the things the oceans are to the space effort.

Most obvious is the use of the space over the ocean as a safe laboratory to conduct experiments on that potentially explosive, often unpredictable beast called a space booster. Just as important is the use of the ocean as a junk yard for the separated booster stages and other hardware which is not placed into orbit.

The ocean was used as a landing place for our Mercury Astronauts and will be used for the Gemini, Apollo and other manned space flight recovery phases. Oceanographic prediction, especially accurate wave forecasts, will be necessary to assure the survival of the Astronauts after the ocean landing.

The ocean also gives us a broad, accessible platform on which we can place as many range instrumentation, tracking, telemetry and/or command and control stations as we need or wish. All of this is rent free and doesn't have to involve special treaty arrangements with other countries.

A characteristic of the ocean which is potentially very useful but which has not been exploited is that the ocean is the reference radius of the earth. The ocean is at zero altitude and therefore when accurate altitude measurements are made from a space vehicle to the ocean, the vehicle's radial position, radial rate and radial acceleration can be more rapidly and precisely determined than with any other measuring device known.[1] Accurate, real time altitude and altitude rate information and a velocimeter is all that is needed to control an orbit injection maneuver and a single point measurement of altitude, altitude rate and altitude acceleration from an "orbiting" vehicle is sufficient to determine the in-plane orbit parameters. General Electric Company's studies[2] of this type of system show orders of magnitude improvement in orbit injection and measurement over presently implemented systems.

During the course of these studies we naturally had to determine the effect that changes of the ocean surface's radar return characteristics would have on the altimeter's transmitted power and frequency, its minimum and maximum altitude capability and its altitude measurement accuracy. What we found was that from altitude greater than 50 NAUTICAL MILES the altitude tracking accuracy capability of a properly designed pulse altimeter is not a function of sea state at all since the noise characteristic of the return is the result of so many million individual back scattering facets of the ocean that increasing or decreasing their number by two or three orders of magnitude has no appreciable effect on the return's mean or variance.

We also found that for radar wave lengths less than 10 cm the large scale structure of the ocean will not be sensed by the altimeter but that the small scale (i.e., local wind sea) structure will make the received pulse power change by a factor of about 200 to 1 from 5 knot windwaves to 60 knot windwaves.

Dr. Moore and Dr. Katz described this change of radar return per unit area as a function of both angle from the vertical and of wind speed in their presentations yesterday.

Figure 1 is a compilation of measured average radar cross section per unit area as a function of angle from local vertical, $\overline{\sigma_{sea}(\theta)}$, and local wind. It is presented here to summarize what they told us about the oceans radar section at, and near, vertical incidence.

In a classic case of serendipidy it occurred to us that not only accurate altitude could be measured but also the "local wind-sea state" could be determined with the same instrument. We felt that such a measurement would be useful to oceanographers and so after discussing this with Dr. Moore he decided we should present the idea to Dr. Pierson.

The immediate result of these meetings was a joint proposal by Dr.'s Pierson and Moore to fly this experiment as part of a more comprehensive radar experiment on NASA's Polar Orbital Geophysical Observatory (POGO)[3].

Quoting from this proposal, ---

"Objectives dealing with wave height are outlined in the separate section prepared by Dr. Pierson. It appears relatively certain that their objectives can be met.

"It is not certain that enough precision in the range (i.e. altitude) measurement can be achieved to determine mid-ocean tides, but it is quite possible. It is also quite possible that bulges in the mean surface of the ocean caused by long fetches of wind will also show up. It may be possible to determine variations in the mean surface height across a hurricane or typhoon, and use this information to draw conclusions about the storm intensity".

This morning, Dr. Pierson and Dr. Stewart both touched again on this need to measure sea-level changes in the open ocean. They also mentioned one of the key characteristics of thes sea level changes which make it feasible to use altimetry from a satellite to measure them, that is, their large dimensions. This makes it not only feasible but necessary to average the altitude residuals over long periods of time (1000 to 10,000 sample data points) to obtain very accurate mean sea level measurements.

It is not proposed that this data reduction be done on board the satellite even in such a well equipped orbital laboratory as the one proposed by Dr. Badgley.

Notice that I said we would average the atltitude measurement residuals. This means that the altitude measurements, obtained at about a 100 per second rate, will each be subtracted from the Orbit Ephemeris altitude for the particular time and Geodetic position at which the measurement was taken. This implies that the Ephemeris and the Geoid have been determined very accurately, by using data from many tracking stations (and possibly the same altitude data) for many orbits to obtain maximum likelihood estimates of their true dimensions. The altitude measurement residuals then would be exactly zero, except for Sea Level variations, if there were no bias or random errors in either of the measured or estimated quantities. Ephemeris estimates errors will be strictly of the bias variety, Geoid estimates will be mostly of the bias kind but there will also be random errors on the estimates of the distribution of radius with position. These Geoid random errors are not however random in time whereas the variation of sea-level will be; so that day to day, week to week, and month to month variations in sea level can be eventually detected.

The Altimeter measurement errors are going to be both of the bias and random variety but the random noise will have a frequency spectrum from zero to the sample data rate of 100 per second. Thus, with a one signal random noise of 5 feet, 100 altitude residuals will reduce this standard error to 0.5 ft., a 1,000 sample running average reduces the standard error to 0.158 ft., and a 10,000 sample running average reduces the error to 0.05 ft. Digital data smoothing also offers the capability of obtaining the slope and the acceleration of the sea-level changes if this is desired.[4] Obtaining the derivatives of the altitude residuals will be a useful thing to do anyhow since the weighting functions on the noise are different from the simple averaging described for a stationary signal. Thus if a sea level variation is indicated from the smoothed data a derivatives check will help to decide whether this is a true sea level change or merely a noise residual drift.

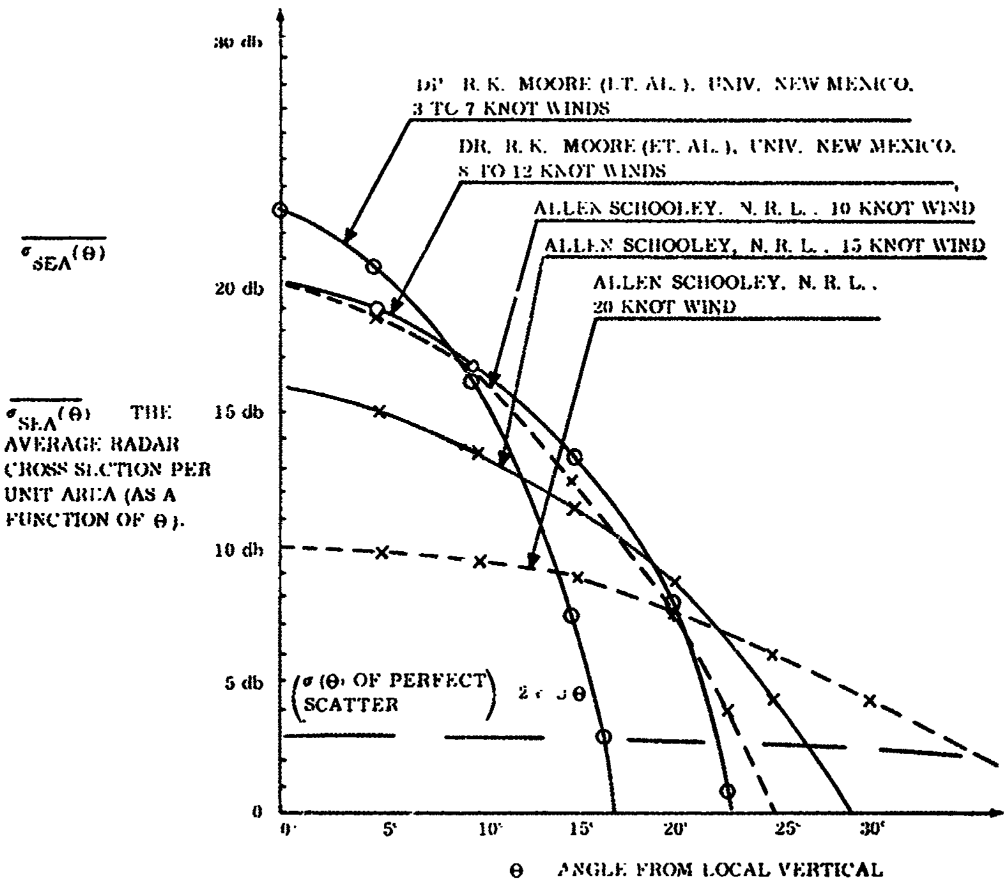

Figure 1. Average Radar Cross Section Per Unit Area From Ocean Plotted as a Function of Angle of Incidence, θ. The Plot Shows That the Greatest Expected Change in the Radar Cross Section Per Unit Area (.'. The Greatest Change in the Received Signal Strength) Occurs at Near Vertical Angles (θ≤5°).

Now the next thing to discuss is how does one get altitude measurements from a satellite over the ocean with only 5 ft. standard error per measurement?

It isn't easy, but it is feasible within the present "State of the Art". It is not "off the shelf" chiefly because no one has ever been convinced that their particular problem could only be solved with this good or better altimeter measurements from satellites.

Ability to track the return pulse accurately is a function of the gain-bandwidth of the tracking loop, the noise characteristics of the return, and the transmitted pulse width, amplitude and rise time stabilities. Amplitude instability itself can be eradicated as a major error contributor by centroid (split gate) tracking. Pulse width and rise time errors can largely be eliminated by both selection of a stable transmitter and by measuring the transmitted pulse and adapting the tracking circuit gates to compensate for variations. At any rate these extreme measures are probably not necessary since the largest improvement can be made simply by choosing a good transmitter with a 10 nanosecond rise time and a 100 nanosecond pulse duration.

A optimum split gate tracker will be able to track the ocean returns to about 2 ft. random error, whereas a leading edge threshold tracker would have about 4 foot random error.

The next error sources to consider are the timing errors. These consist of the clock error, quantizing errors, logic function errors and uncertainty on the propagation time of the return pulse through the receiver. If the fastest solid state logic circuitry available today is used in the critical areas we can count at near kilomegacycle rates.

This speed is not necessary for the altimeter round trip time counter but will be useful in calibrating the propagation time through the receiver and its variations with temperature so that this error source can be corrected for using temperature measurements.

The round trip time counter in the altimeter should count a 200 megacycle clock frequency which will give a two ended quantizing error of only $2.5/\sqrt{6} = 1.02$ ft.

A clock accuracy of one part in 10^8 with short term stability of one part in 10^9 is obtainable with crystal oven oscillators. The error due to the clock from an altitude of 3 million feet will therefore be much less than the quantizing error (about 10^{-3} ft) so there is no problem here.

Logic function errors come from the fact that switching and gating commands are recognized by threshold detection of pulses sent from one subsystem or element to another in the altimeter. Propagation time variations, rise time slope variations, and response time delay variations are the error generators. The total random timing error at each of these critical function interfaces from all these causes can generally be held to ±10% of the rise time of the circuits.

A timing error budget for the altimeter which needs to be developed is shown in Table 1. Altimeter characteristics are listed in Table 2.

A discussion of the error uncertainties due to propagation vertically through the atmosphere follows these tables and a short summary concludes the presentation.

Mr. Gordon Thayer of The National Bureau of Standards has studied and tested the atmospheric refraction errors for radars at all elevation angles. Tests have been conducted all over the world. He found that at elevation angles of 90° (Vertical paths through the total atmosphere) the mean range error will be 8.0 ft.[5] In a private communication Mr. Thayer said that if the satellite's geodetic position is roughly known (to a few degrees in latitude and longitude) and the day of the year is known then a standard correction for atmospheric range delay will result in a residual standard error of about ±0.1 ft. This is the reason for not including the propagation error as part of the altimeter error budget since ±0.1 ft will have no effect on either the bias or the random error when compared to the other error sources.

TABLE 1

Radar Altimeter Timing Error Budget (1 Sigma)

Item	Source	Spec (nanosec)	Bias (nanosec)	Random (nanosec)
Transmitted Pulse	1. Detection & Start Counter Pulse	2	±.2	±.2
	2. Rise Time	10	± 1	± 1.0
	3. Pulse Shape	Square	± 10	± 1.0
	4. Pulse Width	100	± 10	± 2.0
Range Counter	1. Quantizing Noise			± 2.0
	2. Frequency Stability	-	-	-
Local Oscillator & IF Strip	1. Automatic Frequency Control of Local Oscillator		± 2.5	± 2.0
	2. Time for Received Pulse to Pass Through IF Strip	25	± 2.5	± 2.5
	3. Temperature Changes Both AFC & IF	-	± 10	± 1.0
Range Tracking Circuitry	1. 1st Gate Width	63	± 3.0	± 3.0
	2. 2nd Gate Width	37	± 2.0	± 2.0
Receiver Noise	1. at S/N Ratio of 20 db	-	± 2.0	± 0.6
Sea Return Noise	1. Always S/N Ratio of $\pi/(4 - \pi)$	-	-	± 4.0

(NOTE - Timing Error Converts to Range Error at 1/2 foot per nanosecond. The RMS Bias and Random Errors are converted to feet in Table 2.)

TABLE 2

Pulsed Radar Altimeter Characteristics

Power Transmitted	10 KW Peak
Center Frequency	X Band
Transmitted Pulse Width	100 nanosec
Rise Time of Transmitted Pulse	10 nanosec
Pulse Repetition Frequency	100 cps
Range Accuracy	
Bias Errors Uncertainty after Correction for Measured Temperature	± 12 ft (1 sigma)
Pulse to Pulse Random Error	± 3.5 ft (1 sigma)
Output Information	Range - 100 times/sec Resolution 2.5 ft.
Power Required at 28 vdc	27 watts
Weight	10 lbs.
Size	4.0 x 8.6 x 12.0 in.
Antenna Requirement	3^{o} x 20^{o} Beamwidth with wide angle aligned to the satellite flight path.

SUMMARY

I've described how a radar altimeter can measure both the Local Wind-Sea State and altitude when operating from a satellite. It appears that both of these measurements can be very useful to the Oceanographic and Geodetic Communities. All that is required now is development of the altimeter to operational status and a satellite.

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SEA LEVEL AND TSUNAMIS

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SEA LEVEL -- The Problem -- "Sea level" is a concept rather than a reality, for in addition to wind waves and swell the height of the surface of the sea varies due to other factors including astronomic tides, currents, wind set-up, air pressure, the distribution of water density, and secular changes due to variations in total amount of water available. The height of the sea surface at any point in space and time is the net effect of these factors, and the range at some places may be as much as 9m over one tidal cycle. Interest in knowing the height or, on an aerial basis, the topography of the sea surface stems primarily from the fact that "sea level" is a highly sensitive, quantitative indicator of dynamic processes taking place in both the atmosphere and the ocean.

Tide predictions for coastal areas and the prediction and warning of destructive storm surges are two economic aspects of the problem, but it is towards the over-all understanding of oceanic processes that the oceanographer is most interested in the variations in the height of the sea surface. There is, for example, now no means of direct measurement of the slope of the sea surface across an ocean. There is not even a means for measuring the actual slope across the Gulf Stream. Traditionally sea slope has been computed by assuming a level surface of no motion at depth and determining the distribution of density above this level, but actual measurements have not heretofor been possible and are needed as a check on theory. Traditionally the oceanographer has been limited to sea-level measurements made from shoreline tide gauges providing data on variations of sea level with time at discrete coastal points. What is now needed is the ability to look synoptically or quasi-snyoptically at the aerial variations of sea surface height. Ideally the ability to discriminate slopes of a few centimeters over distances of a few tens of miles is desired.

The Solution -- Satellite altimetry offers the possibility of adding a new dimension to sea level measurements. It is realized that the degree of precision given above as "desired" is beyond the capability of present instrumentation, but it is felt that the ultimate uses to which the data could be put justify the development of the instrumentation to procure them. Satellites have built into them two qualities which are important to this problem: replication and smoothing time. For a satellite traveling at 8km/sec, a ten-second average of altitude would represent an ocean path of 80 km. Aside from errors introduced by equipment bias, a precision of about one foot by smoothing over this ten-second period is not beyond the reach of present technology and data even of this type (approximately 1 part in 10^5) would be extremely useful. The absolute height of the satellite is not important to this problem. What is needed is knowledge of the apparent variations in this height as a function of variations in the height of the sea surface against which the platform altitude is measured. It is, therefore, urged that satellite altimetry continue to be refined and that special attention be paid to high accuracy radar altimetry and to stereo radar imagery using interferometric techniques as possible means of solving this problem. Studies of the small scale variations in the shape of the geoid must be continued as the geoidal variations must be known to within the precision limits and smoothing areas being considered in sea-level measurements.

TSUNAMIS -- The Problem -- On a rough average of once every four years, highly destructive seismic sea waves (tsunamis) generated by earthquakes beneath the sea race across the Pacific to endanger life and property on low-lying coastal and island areas. They are extremely rare, however, in both the Atlantic and Indian Oceans. An effective tsunami warning system for the Pacific has been devised utilizing seismographs, tide gauges, tsunami travel-time charts, and a communications network to warn of the impending arrival of potentially destructive waves. However, little is known of the coupling mechanism between the ocean bottom and the water, and as yet is is impossible to predict the height to which any given tsunami will rise along a coast. Research in this area is progressing but is seriously hampered by lack of data on the characteristics of the waves in the open ocean. Wave heights at sea are probably one or two feet, wave lengths are on the order of a hundred

. iles, and speeds run to 500 or 600 miles per hour. Since the wave acts as a shallow water wave, the bottom topography, even in the deep sea, modifies the shape of the wave front, yet there is now no means of obtaining any actual measurements of the height, speed, direction of propagation, or shape of the wave frent on the open ocean. These data are essential if the phenomenon is to be more fully understood.

The Solution -- Satellite and spacecraft observations may provide information to assist in solving this problem. If high resol-tion optical photography or radar imagery c arge area of the ocean at a time when a tsunamis is in transit could discriminate to the extent that the tsunamis wave train could be identified, our knowledge of these intriguing but destructive waves could be greatly advanced. The infrequency of tsunami occurrence would not justify the development of a continuously monitoring satellite system for this purpose alone. Any satellite or spacecraft instrumentation that could detect tsunamis would be so useful for other purposes that it would probably be in continuous operation. Otherwise, the orbiting equipment could be triggered from the tsunami warning system whenever an undersea earthquake was detected. As earth-observing equipment is developed for use in orbiting satellites, it is urged that its application to tsunami research be borne in mind.

CURRENTS AND PHOTOGRAMMETRY

by H. L. Cameron

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INTRODUCTION

Currents have long posed a challenge both to practical men and theoretical scientists. Water currents were the first to be noticed by man in his efforts to cross streams and arms of the sea; air currents are now of equal interest and importance in this day of world wide air travel, and today the currents of both the liquid and gaseous oceans are receiving intensive study and measurement.

The measurement of water currents has been carried out largely by means of current meters. These are based on a propeller, held immovable in the current, which gives the velocity by the number of revolutions in a given time interval. Electrical methods using currents induced by the flow of the salt water electrolyte through the earth's magnetic field, have been developed. These devices give mass flow, but still have the defect of the meter method in that they do not give a synoptic picture of the flow pattern. In attempting to measure ocean currents the added complication of ship positioning has been overcome by electronic navigational systems such as Decca, Loran and Shoran.

A new method of water current measurement has been developed using air photos, space photos, or radar scope photos. This is based on the movement of moving objects relative to fixed objects during a time period fixed by successive photographs. The photographs are stereoscopic, or at least cover the same general area from approximately the same position. The speed determination is made from the false parallax which give a false "topographic" position to the moving object, e.g. a ship or boat will appear to be floating above the water surface, or to be many feet beneath the surface, depending on whether it is moving in the opposite direction or the same direction as the aircraft. The basis of the method is shown in Fig. 1 which is largely self-explanatory.

APPLICATIONS

The time lapse stereo method has been applied in a number of places in Canada and has been officially adopted by the U. S. Coast Guard and Geodetic Survey. It is now being used by the Canadian Hydrographic Survey on an experimental basis.

Petit Passage in southwestern Nova Scotia is one of the narrow entrances to the Bay of Fundy. When problems of small boat anchorage arose at the village of Tiverton due to the high tides (17 feet) and strong tidal currents, the Canadian Federal Department of Public Works decided to try this method to obtain a synoptic picture of the currents. The RCAF took photo strips at 15 minute intervals both here and at Grand Passage to the West. These were worked up into a series of charts showing the configuration of the currents and the conclusion was reached that the mooring difficulties arose from eddy and counter currents created by the jet which forms in the constriction at Tiverton. The only solution is a dam or causeway which will eliminate the jet. Fig. 2 is an example of one of the current maps and Fig. 3 is a stereo pair showing the false topographic effect of the moving water.

Minas Channel and Chignecto Bay are the two major extension of the Bay of Fundy. Their size and shape make them difficult to survey by conventional hydrographic methods so they were chosen for the second experiment. Because neither the RCAF or any civilian agency had the altitude capability required for side to side photography of these bodies of water, the RAF was approached, and very kindly consented to carry out the work as an exercise. This is one more example of the pioneering spirit of this great service. The photography was very successful and Fig. 4 is a map showing diagrammatically the results of the preliminary current surveys.

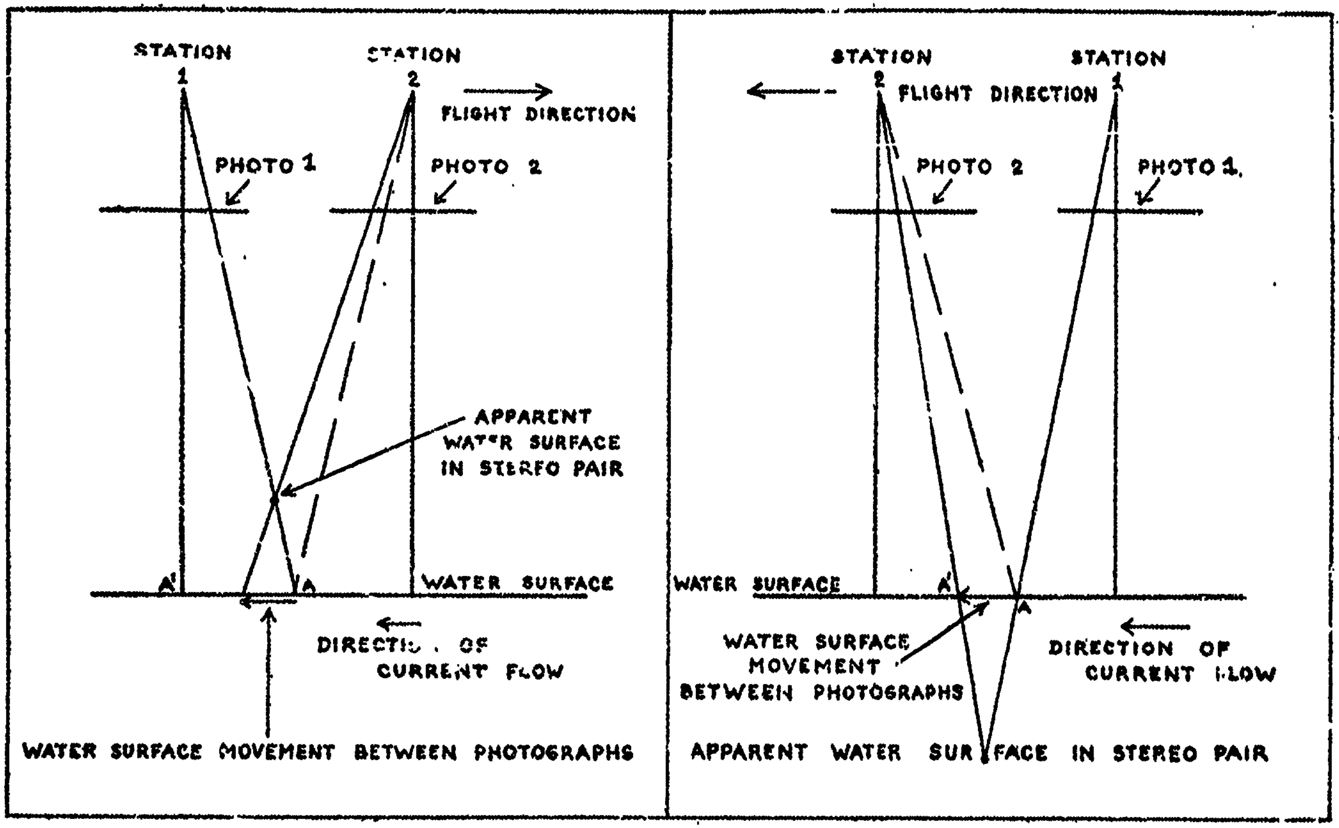

Figure 1. Illustrating Principle of Time-Lapse Measurement of Water Currents by Aerial Photography.

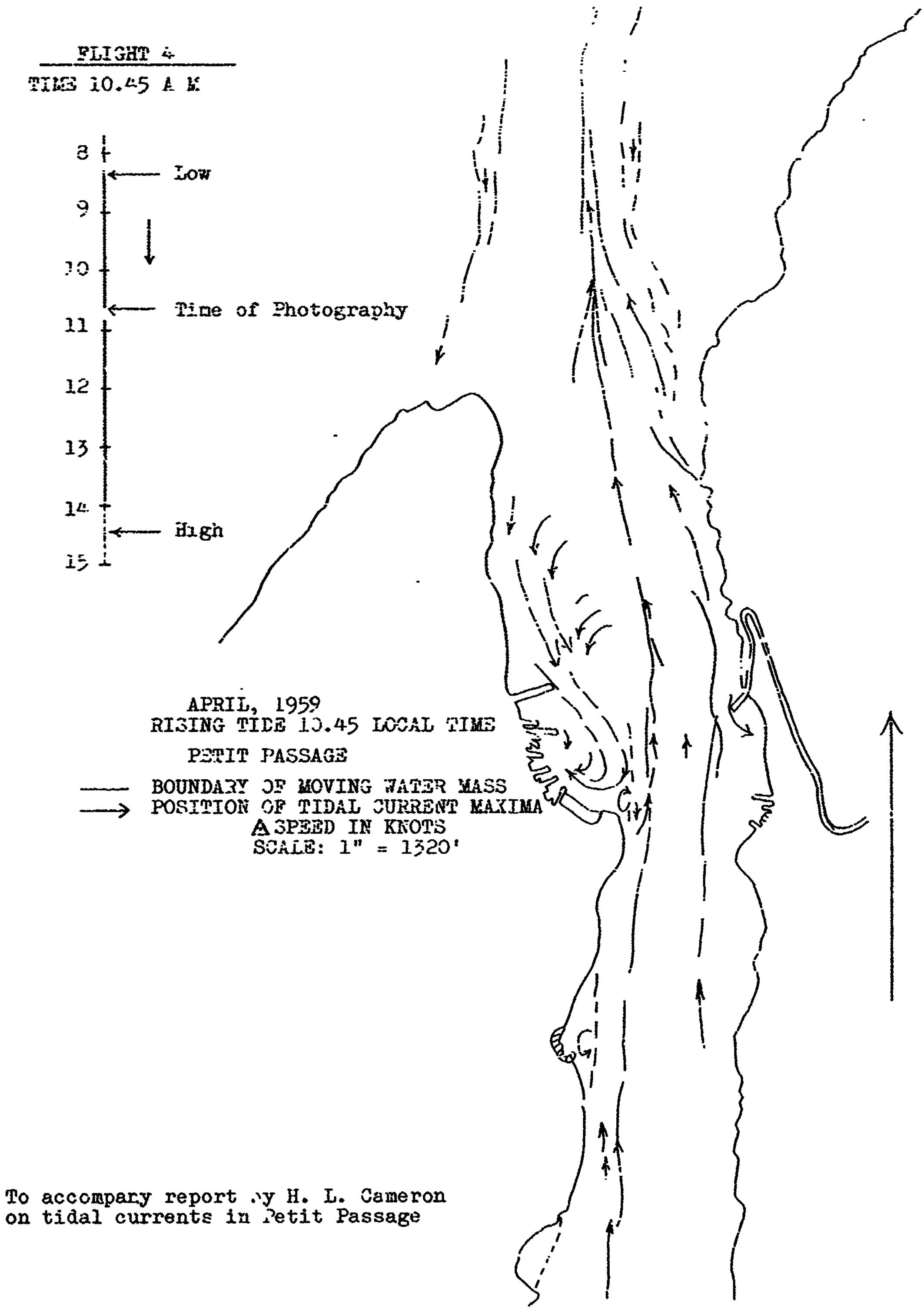

Figure 2. Current Map of Petit Passage, Southwest Nova Scotia

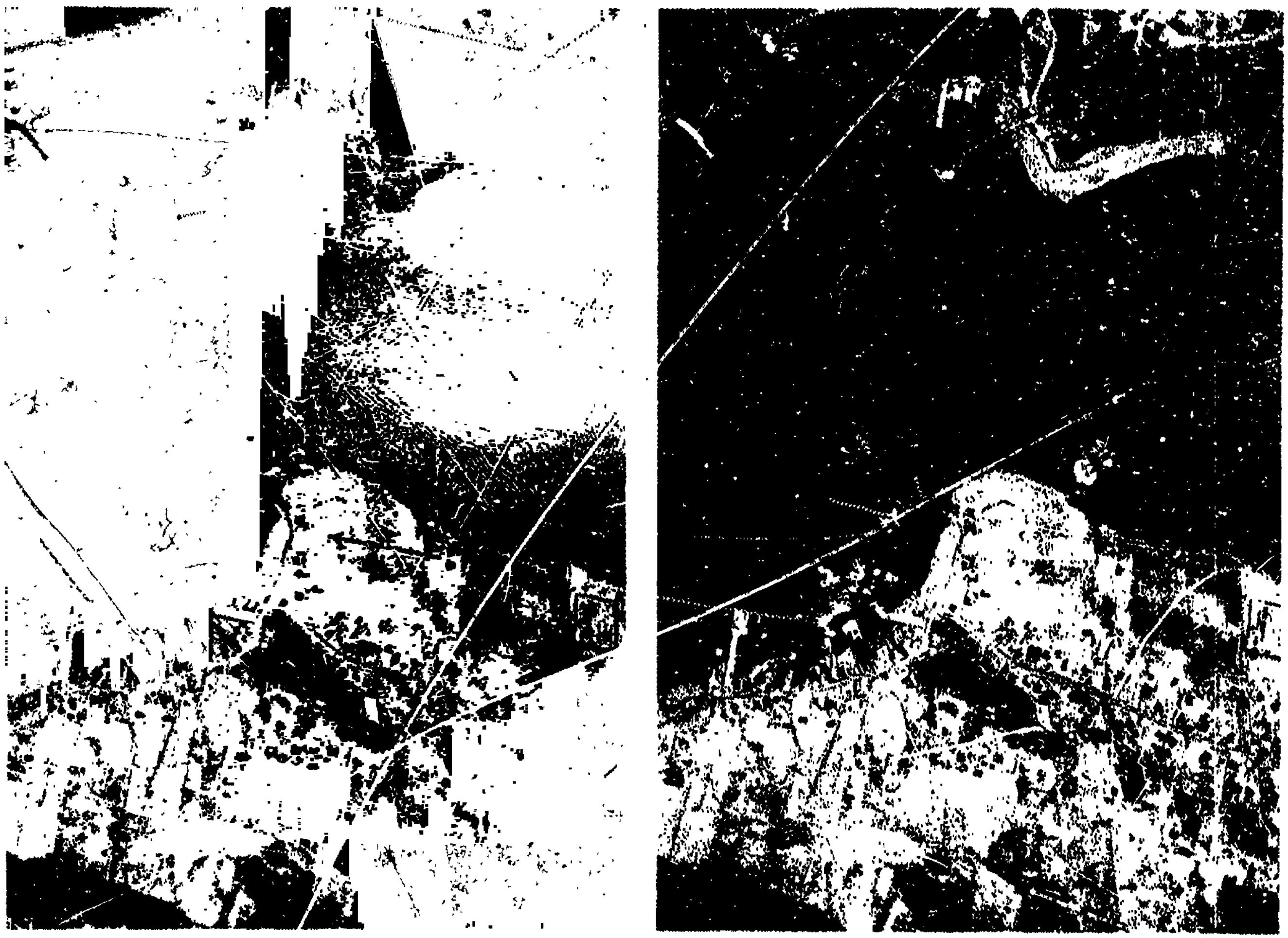

Figure 3. Stereophotos Showing Current Running North in Petit Passage, Nova Scotia.

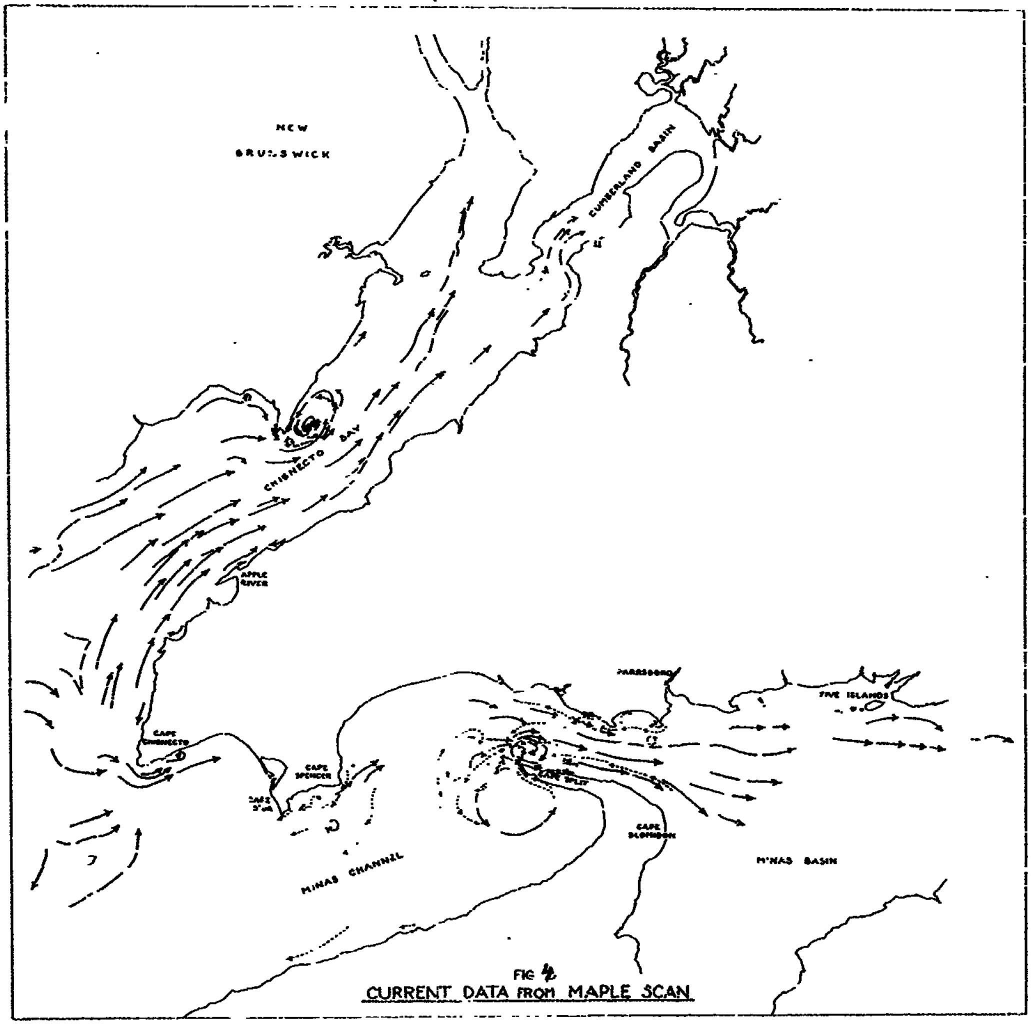

Figure 4. Current Data From Maple Scan.

As soon as space photography from the Tiros satellites became available checks were made to test the possibility of using this method. The resolution of the Tiros from I to VIII is such that even large ships are indistinguishable: indeed there is a great argument as to whether land areas will stereo, and if so, how much can be done with the relief as presented. However, when ice marked sea and gulf areas were studied it became obvious that the method might be applied, if sufficient time lapse could be obtained. Fig. 5 is an example of a stereo time lapse pair of Tiros II photographs which were used to measure the speed of ice field motion in the Gulf of St. Lawrence. The right hand photo was taken on one orbit of the satellite, and the left hand one on the next orbit, giving a time lapse of 101 minutes. The speed was calculated at .49 miles per hour and it was confirmed by the U. S. Hydrographic Office using conventional photography taken on the same day. By using photos from adjacent flight lines they obtained a figure of .5 miles per hour. These rather high speeds can be explained by an easterly gale of 30 knots on the same day. With the better resolution and 100% cover of the Nimbus photography it should be possible to map ice areas and their movements in the polar zones of the earth.

The application of this technique to radar photography has been made as part of experiments in ice surveys in the Gulf of St. Lawrence. It is well known (and often reiterated by radar experts) that stereo viewing of overlapping radar will not give topographic relief effects. However, if an area with a definite configuration, such as an ice field, is translated between radar scope photos, then the topographic effect is produced. Fig. 6 is an example showing the ice masses in the Gulf of St. Lawrence. The ice appears to be at a different elevation than the land areas.

SUMMARY AND CONCLUSIONS

Stereo time lapse photography can be used to measure the speeds of moving objects by stereo measurement of the false parallax produced by motion between photos. The method has been used successfully with conventional aerial photography from low, medium and high altitudes. (1,500, 15,000, 43,000 and 70,000 feet) It has also been used with space photography from Tiros II and with radar scope photography from 41,000'.

It is concluded that this method should be usable from manned space platforms for the study of ocean currents using both photography and radar. In the meantime, a great deal of work can be done using high flying aircraft and Nimbus cover from space.

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Figure 5

Figure 6

CHAPTER 2

IDENTIFICATION OF WATER MASSES

OPTICS

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INTRODUCTORY REMARKS

The preliminary agenda stated that optics was to be the topic of this afternoon's session. Let us say, rather, that we are to discuss visual observations from manned orbiters, photography from extreme altitude aircraft, the problems of visibility and some unconventional photographic technique.

Most of what you will see today was flown for purposes other than oceanography yet its usefulness to the oceanographer should be apparent to all. It should also be obvious that if certain of these manned flights had been designed for oceanographic objectives with a trained observer-scientist aboard, the information return would have been greatly increased.

To act as a moderator and to lead the discussion during this afternoon's matters of moment I believe we have the preeminent choice in Dr. S. Q. Duntley, director of the Visibility Laboratory at Scripps Institution of Oceanography. His career in a measure represents the progress of oceanography during the last two decades, from his days in 1944 spent in a glass bottomed boat peering down into the Gulf Stream's waters, to this summer's concern with man peering through the earth's atmosphere from an earth-circling orbiter. Today, in addition to being moderator, he will also speak to us briefly on the subject of wind velocity and sea-state measurements from satellites.

Prof. Cameron of Acadia University, Nova Scotia, who is well known among us for his geologic oceanographic and photogrammetric studies of the Maritime provinces and their bordering waters will describe to us, shortly, certain experiments in radar mapping of ice fields in the Gulf of St. Lawrence and also his efforts to measure ice field movement from TIROS photography. In tomorrow's program he will present the substance of what I believe to be the original study in the measurement of wave velocity from stereo photography. Although this paper was first presented (1952) more than a decade ago, the technique is still either untried or unknown to most oceanographers.

Dr. Wanta and I had been scheduled to describe a study of a rather unusual cloud pattern in TIROS photography of the Bay of Bengal. The origin may be, in part, seismic and oceanographic rather than simply meteorological. The paper will not be given today, but it will be a part of the published proceedings of these sessions.

Joe Morgan of the Infrared Laboratory, University of Michigan, had been scheduled to present material given earlier this year at the spring meeting of the Optical Society of America. Certain infrared imagery had been declassified for that meeting alone; inexplicably a similar dispensation could not be obtained for this week's conference. We shall hear then about certain qualitative aspects of this imagery -- imagery of sea ice and snow in the Gulf of St. Lawrence and the north polar basin.

I have been asked to present a few examples of photographic techniques that will become, I believe, of considerable value to the oceanographer. We shall see refractive wave trains photographed by panoramic cameras from extreme altitude aircraft, satellite photography of "clear" seas plus narrow band, multispectral, image enhancement experiments.

The astronauts of NASA's Mercury program were not scientists, yet with the briefest of training brought back photography and visual observations of considerable scientific interest. One such example, photographic observations of the earth's airglow layer by Gordon Cooper during his 16th orbit of earth, has been reported earlier this summer by Cooper and the University of Minnesota team of Gillett, Huch and Ney (1964). This afternoon we shall hear from Dr. Lowman of Goddard Space Flight Center who will review other such accomplishments of our first manned orbital program.

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OCEANOGRAPHY FROM MANNED SATELLITES BY MEANS OF VISIBLE LIGHT

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INTRODUCTION

The possibility of conducting oceanographic studies by human observers in an Apollo Orbital Research Laboratory (AORL) suggests the use of every known sensor that can be applied to the scientific surveillance of the world ocean from orbital altitude. The most obvious and the most immediately available spectral region in which remote sensing can be performed includes that to which the human eye is sensitive and the immediately adjoining near-ultraviolet and near-infrared. Here direct visual observations can be made from the orbital laboratory and visual aids, including telescopic, photographic, and electronic devices, can easily be brought to bear upon oceanographic problems. The information obtainable through the use of this spectral region is at least as interpretable as that obtainable with any other.

In the following discussion of the potentialities of oceanographic observations from manned satellites by means of visible light, it will be the plan to consider first the direct capabilities of the human observer and then to discuss certain photographic and electronic visual aids which he might employ. It is probable that an Orbital Research Laboratory will also have at its disposal a variety of non-optical sensors and that the research output of the scientific team (comprised of the astronauts and their fellow scientists at stations on land, at sea throughout the world, and in central computer-equipped laboratories) will be the result of multi-sensor techniques. The rapidity of motion (approximately 5 mps) over the ocean may, however, impose a temporal limitation on the number of techniques which can be brought to bear on any one occasion, but this consideration need not be dealt with here since the choice of sensors and techniques will be made during the planning of particular missions.

VISUAL OBSERVATIONS

The experience of the Mercury astronauts indicates that on some occasions a considerable amount of detail on the surface of our planet can be observed by naked eye from orbit. It must be remembered that these were busy men during flight, that they were in a capsule possessing only one small window affording a very limited field of view, and that their attention through this window was directed to matters of astronomy, to luminous layers on the horizon, and to observations designed to indicate the flight performance of their vehicles. Limitations on fuel supplies served as a deterrent from maneuvering the capsule in order to gain a near-vertical view of the earth through the narrow window. Thus, it is not surprising that terrain sighting reports were not extensive; conversely, it would not be surprising to find that astronaut teams in the Gemini and Apollo orbital missions report the sighting of significantly more surface details that did the Mercury astronauts. Scientists in an Orbital Research Laboratory will have the time, the windows, and the freedom of movement to do much more visual observation than any of their predecessors.

There can be no question that visual observations will be useful and rewarding, despite the fact that the time for observation over any specific location is short (e.g., 30 seconds to 2 minutes) and that the unaided eye is distinctly limited in its resolution with respect to man-made objects and natural features of similar size. Many planetary features of interest to oceanographers, however, are large enough to be seen and these can be appreciated and understood in a unique way by professionally trained, thoroughly prepared, and well-oriented scientific observers. Even so, it is important to note that the poor quantum efficiency of the human visual system at daylight levels (10^{-3}) and the slow time-constant (>0.1 sec) which characterizes the perceptual system restrict human observation to a low area search rate, hopelessly inadequate to cover even a tiny fraction of the available field of view from orbit.

If the visual capabilities of men in orbit do not differ from those of men in aircraft or on the ground, sufficient knowledge exists today to enable reliable quantitative statements to be made about the visual area search rate for specified objects under specific circumstances of observation. Thus, the planning of all MORL experiments involving direct human observations (naked eye or telescopic) can take advantage of this capability, particularly from the standpoint of not expecting the astronaut to perceive too much.

VISUAL CAPABILITIES OF ASTRONAUTS

There have been speculations concerning the visual capabilities of astronauts, particularly with reference to the possible effects of weightlessness. Most physiologists share the opinion that no adverse effect on the visual mechanism will result from prolonged weightlessness, but there seems no way to settle this matter unambiguously until long-duration space flights have occurred during which quantitative measures of visual performance are made. With this in mind, a visibility experiment is in preparation for inclusion in the long-duration (7-day and 14-day) Gemini flights

The Gemini visibility experiment is under the supervision of the Visibility Laboratory and has two inflight phases: First, the capsule will be equipped with a vision testing device which both astronauts will use daily and with which it is hoped to recognize and measure any longitudinal effects which may occur. Second, there will be an out-of-the-window experiment in which one of the astronauts will be asked to perform a simple form discrimination task along a nearly vertical, downward path of sight over a prepared and monitored ground target. Psychophysical studies will be made on each astronaut prior to his flight. The men will also be flown in aircraft over simulations of the target area, partly for practice in observing and partly to enable the result of visibility prediction calculations to be compared with actual visual performance in an aircraft environment. Thus, it is hoped to ascertain whether man's visual capability is in any way different in orbit than in an aircraft when the visual task is as similar as possible. Since the experiment will be done on a long-duration flight in the Gemini program, longitudinal effects, if any, may become apparent in the out-of-the-window experiments.

It is possible that still other visual experiments will be conducted in the course of the orbital Apollo program and as a result of all of this work, the visual performance characteristics of man in orbit should become well-known before MORL is launched. Those responsible for preparing and planning for MORL should review on a continuing basis the accumulating visual taks to be performed by MORL astronauts in order to make sure that no form of visual capability is being relied upon which has not been effectively tested by the Gemini and Apollo experiments. Conversely, it may be possible to include in the Gemini or the Apollo programs tests to meet any special needs which may develop in the course of preparations for MORL.

ATMOSPHERIC LIMITATIONS

The atmosphere of the earth is a major deterrent to visual observation from orbit. Large sections of the surface of the earth are obscured by clouds and most other regions are blanketed by haze which drastically reduces the ability of the orbital observer to discriminate planetary features or to make observations leading to oceanographic data. This is not to say, however, that useful visual observations are impossible. Many of the intuitions possessed by us all are generated from experience in conducting our lives on the surface of the earth and in flying as passengers in commercial aircraft. It is a rare circumstance, indeed, when an airline passenger is afforded a truly vertical view of the ground. During straight and level flying a passenger, even with his nose against the window, has difficulty in seeing steeply downward from most airliners. There is an important difference in atmospheric clarity between long oblique paths of sight and the downward vertical. This is well-known to those who practice aerial photography; many haze conditions which seem discouraging to observers on the surface of the earth are surprisingly transparent when the observation is vertically downward or within a few degrees of that path of sight.

Observers of ocean areas from high altitude aircraft and those who have studied ocean photographs from TIROS are aware of the low contrast and indistinctness of coastlines which often characterize these scenes and photographs. There are, of course, occasions where atmospheric clarity is too poor to permit coastlines to be seen, but in addition there are times when the atmosphere is very clear and yet coastlines are not seen. This occurs whenever the luminance of the sea matches the luminance of the adjacent land. The luminance of the sea is governed by wind velocity as well as by the nature of the lighting provided by the sun and the sky. The luminance of land masses also depends upon the nature of the lighting and, of course, upon the nature of the soils, rocks, and vegetation of which the terrain is composed. Quantitative studies of the luminance of land masses and ocean surfaces under the same lighting conditions show that under wind conditions of common occurrence, the luminance of the ocean often matches that of the adjoining land. Low resolution sensors will then fail to reveal coastlines.

The oceanographer in orbit will often find himself contrast-starved in his visual observations. He will experience more difficulty in orienting himself and in performing oceanographic surveillance than would be the case if coastlines and other natural features always appear in high contrast. It is likely, therefore, that observers in an Orbital Research Laboratory will require pointing systems and other navigational aids to show them where to look. They will seldom attempt to perform unrestricted visual search but will ordinarily inspect pre-selected areas. Visibility calculation studies can ascertain the extent to which free visual observation can be afforded on the chance of observing unexpected phenomena.

When visual observations are pre-planned, visual aids to observation should be employed. Polarizing filters, color filters, and magnifying or de-magnifying devices (telescopes) can and should be used. Image-intensifiers may permit night observations and image storage systems can provide stereo pairs. Viewing devices providing contrast enhancement can offset, at least in part, the loss of contrast imposed by atmospheric haze during daylight hours. The items of equipment just enumerated are available at the present time or can be produced in special form by routine engineering and manufacturing procedures. Ingenuity can, of course, create new and improved forms of visual aids for use by oceanographers in Orbiting Research Laboratories. If the MORL flights are to take place in the early 1970's, it is probable that significant new viewing devices can by then be available.

SEA STATE DETERMINATIONS

Two of the oceanographic parameters that can be measured from a Manned Orbital Research Laboratory are sea state and surface wind velocity, and two methods for making such measurements by means of visible light exist. First, the shape and size of the glitter pattern due to the reflection of the sun by the surface of the sea is interpretable in terms of surface wind velocity. Second, the spatially averaged inherent radiance of the ocean varies in a known way with sea state. Part, but not all, of the latter effect is attributable to the presence of whitecaps. If low resolution photometric measurements are made from MORL, and if due allowance is made for atmospheric effects, sea state and surface wind velocity can be deduced from visible light radiometric measurements. Sea-state determination by radiometry is not limited to the region of sun-glitter, but can be accomplished in any part of the field of view that is available from the MORL. Research on atmospheric properties, already well advanced, has provided a means for making the required allowance for atmospheric effects. Commercially available, battery-operated visible light radiometers small enough to fit in a coat pocket can make the necessary measurements. Identification of cloud patterns and their correlation with meteorological information received from the ground by an astronaut trained in meteorology is an important part of the process for introducing the correction for atmospheric effects. Thus, the presence of man in space makes sea-state determination by visible light radiometry much easier, quicker, and more certain than in any unmanned counterpart system.

Each of the two visible light methods for measuring sea state from orbit have certain inherent advantages and disadvantages:

1. Observation of the shape and size of the glitter pattern requires [illegible] allowance for atmospheric effects and, therefore, does not depend critically upon metr[illegible]al information. The application of this method is, however, limited to only one po[illegible] the field of view and the observable pattern is ordinarily very large in terms of distances on the surface of the earth. For example, in a typical instance the pattern might occupy the entire width of the Mediterranean Sea, making it difficult or impossible to obtain information about the differences in sea state or wind velocity in different parts of the Mediterranean. The sun-glitter method has its greatest sensitivity at very low wind velocities, corresponding with sea states more calm than those ordinarily of importance in the operation of ships at sea. Discrimination of the higher sea states, ordinarily found in the fringes of wave-generating areas, is poor.

2. The visible light radiometry method has the disadvantage of an intimate reliance upon meteorological techniques for making the required allowance for atmospheric effects. It tends to be insensitive to sea-state changes corresponding with very low wind velocities, but it has excellent sensitivity in the determination of higher sea states. It has the very great advantage of being applicable to any part of the field of view from the MORL and the advantage that sea state or wind velocity can be determined with resolution which is governed only on that of the radiometer, up to the point where individual waves are sufficiently resolved to make the readings of the instrument noisy. Thus, details of wind distributions near land masses, in the vicinity of islands, in straits, in openings in the Arctic ice, and in other restricted waters are possible by this method.

In neither case is any appreciable equipment development required. Either method could be used from an MORL today.

Some indication of the potential sensitivity of the visible light radiometry method for sea-state determination is afforded by Figs. 1 and 2. The first depicts the results of calculations of the apparent radiance of the ocean as it appears to a red-light radiometer directed vertically downward. The three curves relate to three cloud-free conditions that were documented by the instrumented research aircraft of the Visibility Laboratory during over-ocean flights; they represent a high sun, a medium sun, and a low sun condition, respectively. The apparent radiance of the ocean is seen to vary systematically as a function of wind speed. The curious shape of the upper, high-sun curve is a result of the invasion of the nadir by the edge of the glitter pattern as wind speed increases.

In order to gain some index of sea-state discriminability, horizontal marks have been made along each of the curves at approximately 1 db intervals. Thus in the upper curve, 7 such intervals are seen to occur between 0 wind speed and 35.6 knots. Even th[illegible]st photoelectric radiometer is capable of this precision. Arbitrarily, therefore, a se[illegible]ate discriminability index of 7 has been associated with the upper curve. Obviously, [illegible]her path of sight from an MORL under the same high-sun lighting condition and the same atmospheric condition for which the calculation was made, could be assigned a sea-sta[illegible]scriminability index under the same basis. Figure 2 represents an angular map of [illegible] of view beneath an MORL for one illustrative circumstance. In this polar plot, [illegible] have been drawn to represent 10° increments in the field of view centered about [illegible]r. Obviously, the sea-state determinability index remains high in all parts [illegible]d of view out to at least 60° from the nadir.

The two presently available techniques for sea-state determina[illegible] such different properties and capabilities that they are seen as supplementing each [illegible] rather than as competing techniques. Neither will penetrate clouds, and since these invariably accompany storms, optical techniques are unsuitable for studying sea states in stormy areas unless rifts or holes appear in the cloud pattern. The radiometric method for sea-state determination can be applied to radiometric measurements through any breaks in cloud cover large enough to supply a path of sight for the radiometer. An advantage of the MORL is the ability of man to direct the radiometer through such openings in the clouds.

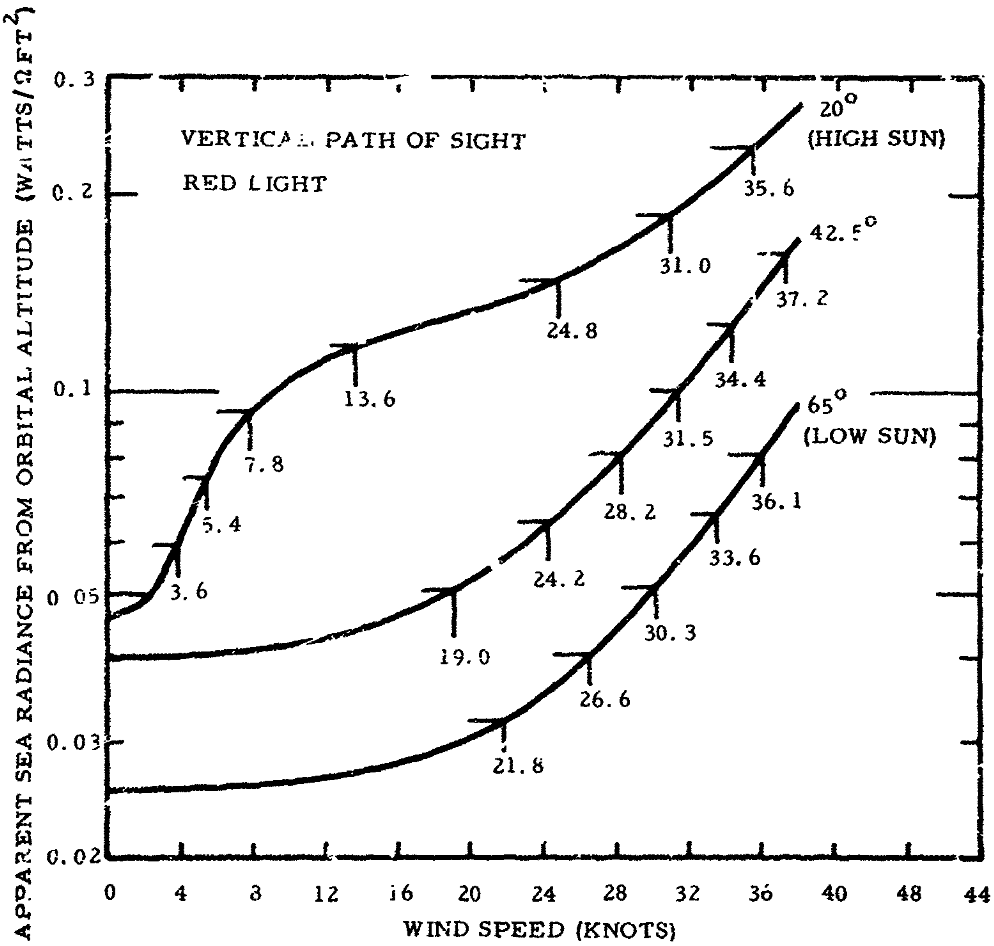

Figure 1. Apparent Sea Radiance From Orbital Altitude (Watts/Ω Ft²)

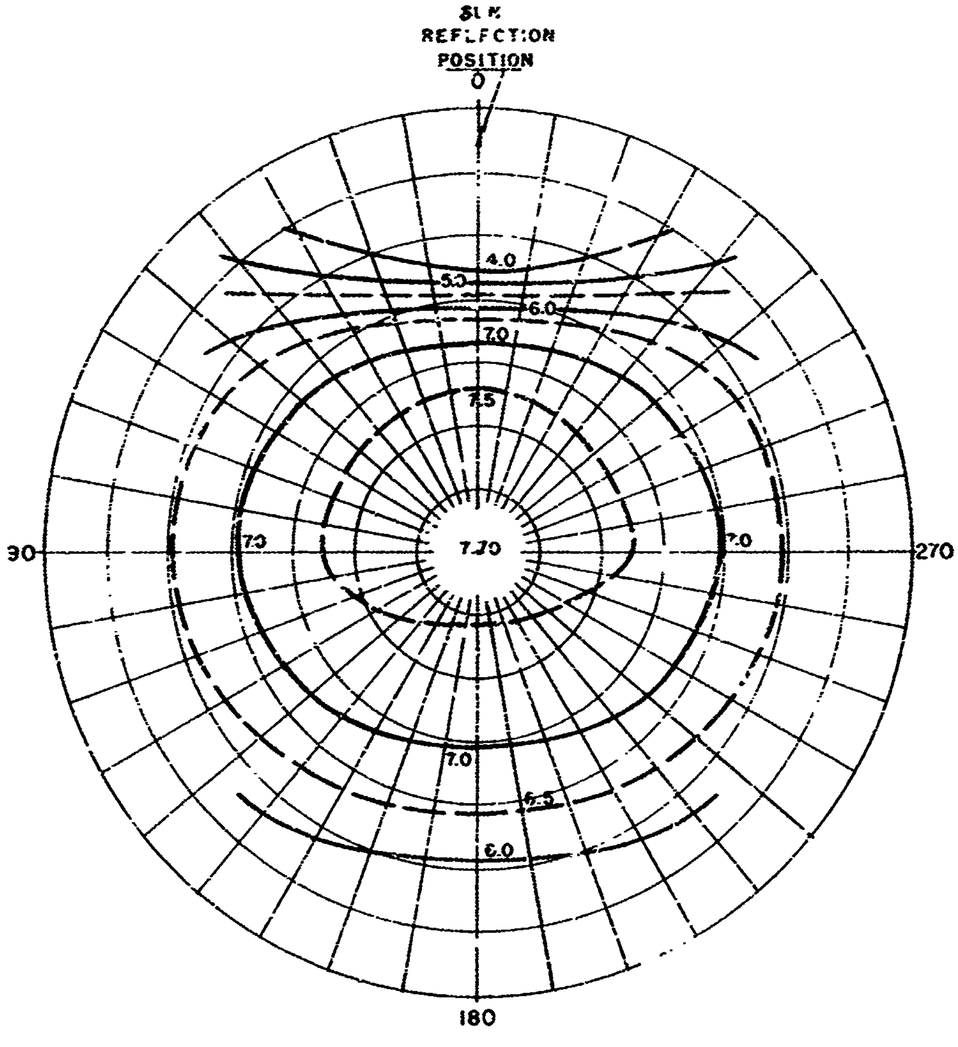

Figure 2. Sea State Determinability Index

WAVE PATTERNS

High resolution telescopic and photographic systems are capable of observing ocean wave patterns from an MORL. This capability is enormously greater in the glitter pattern formed by reflection of the sun than elsewhere in the field of view. Visual observation as well as photographic observation tends to be difficult here because of the steep gradients of luminance which are present. Development work on automatic exposure control and automatic control of luminance in the field of view provided by telescopes is desirable and probably necessary to achieve a satisfactory capability for the observation of wave patterns by oceanographers in an MORL.

CHLOROPHYLL ASSAY

Multi-spectral photography (perhaps merely bi-spectral photography) should enable a quantitative assay of chlorophyll in sea water. The dramatic absorption edge between 0.68 and 0.70 microns in the deep red portion of the visible spectrum provides a means for making a remote assay of this biological parameter. Narrow-band photographs at wavelengths just above and just below the absorption edge should provide a means for detecting even a modest concentration of chlorophyll, provided due allowances for atmospheric effects and sky reflection (sea state) effects are made. The same meteorological techniques used in the measurement of sea state by visible light radiometry can be brought to bear here to make these allowances and to improve, thereby, the sensitivity of chlorophyll determinations. It appears probable that special color film (bi-pack or tri-pack) can probably be devised to detect the presence of chlorophyll-bearing water masses and chart their distribution in medium and high resolution photographs of the ocean surface. Conceivably densitometric techniques involving such special color films might be employed for quantitative measurements of chlorophyll concentrations within these patters. Special films might provide an automatic photographic means for the contour mapping of chlorophyll concentrations.

Other biological features of the ocean as, for example, the occurrence and distribution of red tide is readily observable from aircraft, and, therefore, should be observable under clear weather conditions from an MORL. Specialized film-filter combinations and/or specialized color film can probably be devised for the detection and mapping of red tide.

Dichroic viewing devices, analogous to the Wratten 97 filter, can probably be developed to enhance the visual detectability of chlorophyll and other biological features of the ocean for use in conjunction with high resolution telescopes in MORL.

Preparations for the oceanographic missions of MORL should begin with flights of aircraft bearing spectrographic equipment over ocean areas containing known biologic features in order that film and filters for conventional or multi-spectral photographic systems and for visual sightings can be ascertained. Atmospheric and lighting conditions should be documented during such spectroscopic reconnaissance in order that calculations can be made of the achievable sensitivity of such techniques from an MORL. Such studies will serve as a basis for studying the technical and economic trade-offs and the engineering requirements to be met by optical systems for biological oceanography from space.

OTHER OBSERVATIONS

Most of the remarks made above concerning sea state, ocean waves, and biological features of the sea have counterparts in discussing other oceanographic observations by means of visible light which may be possible from an MORL. Among these topics might be such items as shallow water submarine geography, beach and erosion observations, the detection and tracking of large ocean animals (e.g., whales) and other ocean surface effects, such as the schooling of fish. The development of such capabilities as well as those discussed in greater detail earlier in this account can be accomplished most surely, most economically, and best by means of aircraft over-flights of known ocean areas where sea-surface measurements are made and atmospheric conditions are properly monitored, and with adequate airborne research equipment which will permit parametric studies of sufficient sensitivity and detailed to reveal the optimum techniques to be used in an MORL. If preparation is adequate, there seems little doubt that many physical and biological features of the world ocean can be brought under surveillance from a manned orbiting research laboratory.

NOTE ON ASTRONAUTS TRAINING

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With the introduction of radiosondes, radar and other remote control sensors we lost the air-going meteorologist, the man who daily, in an open plane with a 360° free field of vision, saw the weather up to the ceiling height of his plane. Also the importance of mountain observatories was played down. A typical synoptic working group at a University Department of Meteorology is located in a windowless basement. Special lectures about clouds encompass more the physical laws of cloud microstructure than the visible forms of clouds as related to weather, orography, ocean currents, etc. I wonder whether the old art of making weather maps without the knowledge of isobars is still in use.

The future astronauts who are to fly the meteorological-oceanographic missions discussed at this meeting are in high school today. They should be exposed to systematic viewing studies, essentially from above. Targets are geology, oceans, clouds, haze layers, etc. This view training will not hinder but in fact further the hard study of basics such as math, physics and geophysics.

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LIMITATIONS TO NIGHTTIME VISUAL OBSERVATIONS FROM SATELLITES

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When planning nighttime visual observation from a satellite of objects or conditions near the surface of the earth, consideration must be given to the Night Airglow. Since the airglow consists of an active, light emitting layer in the upper atmosphere between the satellite and the object to be viewed, the desired objects can be seen only if enough brighter than the airglow to provide adequate contrast. Because the problem is principally one of contrast and not of illumination intensity, improved light sensitivity in the viewing sensor is insufficient by itself to remedy the situation.

The night airglow, which forms an interfering shield between the satellite and the objects below, has three principal origins in the visible spectrum:

At 0.5577 micron atomic oxygen[1,2] emits due to the forbidden transition between the ^1S and ^1D state. This emission band is generated between 88 and 110 kilometers altitude with a magnitude of 260 Rayleighs. (A Rayleigh is defined as 10^6 photons/cm^2/second.)

The second spectral line is due to the D doublets of sodium, 0.5889 and 0.5895 micron[2]. The emission band is generated between 80 and 110 kilometers with the peak occurring at 92 kilometers. Its magnitude was found to be about 149 Rayleighs.

The third spectral band at 0.6300 micron and 0.6364 micron are produced by two of the red triplets of atomic oxygen[2]. The emission level of this line is relatively constant over a night period and over a year average. The emission is generated between 230 and 300 kilometers with the peak located at about 270 kilometers[3]. The 0.6300 micron line has an intensity of about 146 Rayleighs, and the 0.6364 micron line has about one-third of this intensity.

Minus the effects of the red triplets of oxygen, the night airglow emission is about 9×10^{-5} foot-candles; it is 1×10^{-4} foot-candles with the red triplet.

The above spectral lines will vary in intensity with latitude, time of the year, and auroral activity.

In addition to the interference band effect of the airglow, the atmospheric albedo and the reflectance or emission of the objects to be viewed as compared to the background reflectance determine the observing ability of a satellite system. The minimum target illumination for a useful satellite system is governed by the night illumination required to overcome the night airglow and the transmittance-reflectance losses in the scene. For example, calculation of cloud albedos indicates that the illumination available at the satellite will exceed 2×10^{-4} foot-candles when 10^{-3} foot-candles (corresponding to a quarter moon) is incident on the scene. The average illumination at the satellite due to the night airglow is about 10^{-4} foot-candles. It is reasonable to surmise that useful meteorological information can be obtained under these conditions. Since sea ice albedoes are of the same order as those of clouds, similar values should be applicable to nighttime ice observations.

Determination of the feasibility of nighttime satellite observations of luminescent biological phenomena would require calculations of the anticipated intensity and wavelengths of the light created by such luminescence.

The minimum illumination required will be modified by auroral activity as well as the latitude observed by the satellite.

Because of the number of airglow spectral bands of concern, their frequencies compared to the ranges of sensitivity of most low light level sensing systems, and the very low light levels at best available, filtering to eliminate the airglow lines is a questionable solution.

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N65 30357

POSSIBLE OCEANOGRAPHIC AND RELATED OBSERVATIONS FROM SATELLITES

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These notes primarily are concerned with some suggestions as to observations of optical phenomena that might be made from satellites and which would yield insight into the earth's meteorological events as well as those of other planets.

OPTICAL PHENOMENA

Dr. Orlo Myers of the Visibility Laboratory recently has published a resume of optical phenomena (SIO REF. 63-4). In this he points out the considerable number of optical phenomena (anti-coronae, rain and cloud bows, coronae, aureoles, etc.) that are diagnostic of the meteorological events on earth but also are applicable to the determination of the nature of the particulate material and meteorological events in the atmospheres of other planets. A number of these observations of other planets could be carried out from earth. Observation of earthly clouds appear to present the possibility of rather sophisticated measurements. For example, the displacement of the specular image of the sun in ice clouds (compared with the specular image on some colinear water body) appears to be a direct measure of horizontal acceleration of the cloud. Such measurements are in addition to the determination of partical size, and composition from refractive-diffractive effects.

I believe that satellite observation of earth clouds in these particularly discriminating ways not only would yield considerable insight into terrestrial meteorology but provide a sounder basis for the study of planetary atmospheres from earth, earth satellite and flyby.

GENERAL OBSERVATIONS

The conference undoubtedly will consider the satellite observation of IR for water temperature; water color as a tracer of currents and productivity; biluminescence; fogs over upwelling regions; relay telemetering of oceanographic data; glitter; etc.

Satellites should be able to detect splashes of large meteorites during the day. Large meteorite trails also might be tracked and, in some areas, the impact pinpointed by examination of Sosus records. They can then be catalogued for eventual recovery by DSV.

Cavitation over the epicenter of underwater earthquakes might be inadvertantly observed and should be identified.

It is possible that the evaporative and the condensive molecular events give rise to particular sharp peaks in the IR spectra. These should be searched for in the laboratory, later in the ocean from satellites.

Cherenkov flashes from the 10^{20} to 10^{21} ev. cosmic primaries (occurring once or twice a night over any particular area) possess the qualities of gated light. Perhaps these flashes could be used (vice Laser) for unusually penetrating observations or (improbably) photos through the surface of the ocean at night.

Special unusually shaped clouds appear to be associated with special local watermasses. A discoidal cloud 70 mi. in diameter was observed associated with an offshore discoidal pool of river water in the Bay of Bengal. Such unusual clouds may appear in satellite photos.

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N65-30358

EXTRAORDINARY CLOUD PATTERN OVER BAY OF BENGAL

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In January 1963 during what had been a routine examination of TIROS photography Cronin noticed a crescent cloud pattern unique in size and shape off the east coast of India. His initial conclusion, that this may be a pattern of oceanographic and seismic origin, has not yet been fully explored and is still under study.

On the 70th orbit of TIROS V, 24 June 1962, from 15:39 to 15.44 I.S.T. (Indian Standard Time) a camera of this meteorological satellite photographed a long crescent wave of cloud over the Bay of Bengal (Fig. 1). Crest to crest its distance is 340 nautical miles; its total length is 880 miles. The bulge extends as far as 320 miles from the coastal city of Madras. In a composite photograph the deltas of the Krishna and Godavari Rivers are easily recognizable (Fig. 2). The pattern has also been transferred to a base map by sketching from suitably enlarged projections (Fig. 3).

METEOROLOGIC AND OCEANOGRAPHIC ASPECTS

Although the arrival of the monsoon may be delayed as much as three weeks, the "burst" of the monsoon occurs fairly regularly about 15 June. It was somewhat earlier in 1962. On 24 June, the onset of the southwest monsoon is already well to the north of our area of interest.

Precipitation in Madras State was 89 per cent above normal in each of the weeks ending 20 and 27 June. Neighboring states, however, had generally subnormal precipitation amounts.

According to pilot charts for June, 74 per cent of the winds off Madras are from the southwest, averaging Force 3. At low latitudes, the geostrophic wind is comparatively strong for the isobar spacing. In our case with a spacing of approximately 5 degrees of latitude for 2-millibar isobars, the geostrophic wind speeds are 15 knots at 15 degrees latitude and 23 knots at 10 degrees latitude.

Currents in the Bay of Bengal are generally variable according to Chatterjee (1954), depending on local conditions; in winter they are clockwise. At the Madras coast the set is 10 - 60 miles per day southward but changes to northward in summer, extending up as far as the Godavari delta in July. Salinity according to Sverdrup (1942) is 34.92 o/oo at 10 deg north and 35.07 o/oo at 15 deg north on the average. These figures are used in a water budget yielding an excess of evaporation over precipitation of 37 and 52 cm/yr respectively. Charts in Sverdrup (1942), however, indicate a summer surface salinity of 33.5 to 34.0 o/oo. At times it is as low as 30 0 o/oo, e.g., at Calcutta after heavy rains. Charts of swell and sea for June show a maximum frequency from the southwest; near Ceylon it is between southwest and west.

More recent pilot charts (1955) indicate for June a clockwise current, at or near shore, starting through Palk Strait. Farther off shore one finds an eastward and southeastward current of 10 miles per day, indicating divergence at or near the shore. The current off the eastern coast of Ceylon is southeastward. But Balaramamurty and Ramasastry (1957) remark that "even though the southwest monsoon sets in a northeasterly or north northeasterly current in the open Bay, the coastal current flows from the head of the Bay southwards bending almost following the coast line. This water can be traced to the extreme south of the Peninsular India." Such a coastal flow makes pertinent the floods which occurred in northern India.

SEISMOLOGIC ASPECTS

Recently Anjoneyula (1961) and Iyer and Punion (1962), in discussing the microseismicity of the Bay of Bengal, concluded that immediate to the coast of Madras is an area of high

Figure 1. Frame 13, Orbit 7C, TIROS V, 1011:06Z, 24 June 1962.

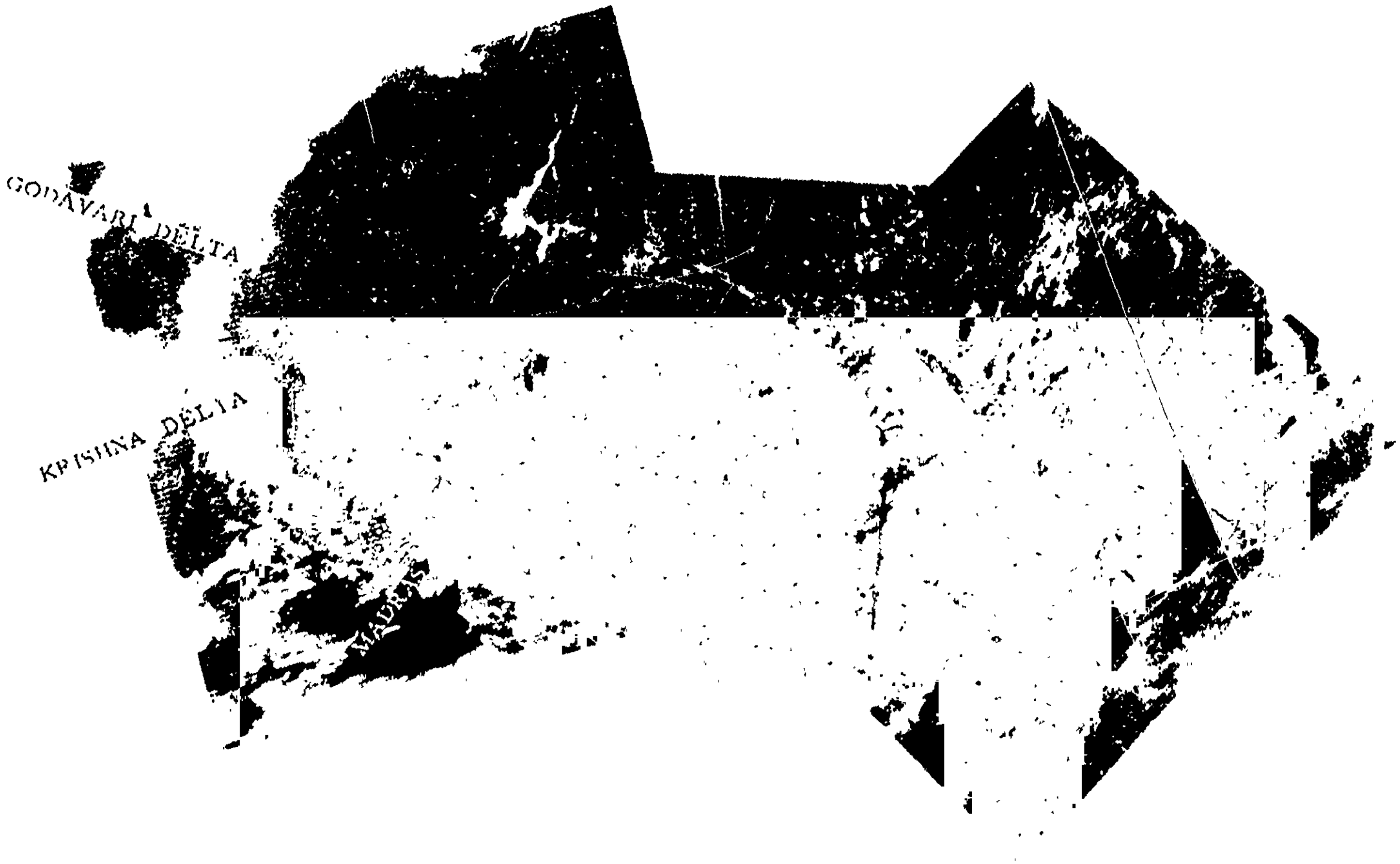

Figure 2. Composite of Frames 11, 12, and 15, Orbit 70, TIROS V, 24 June 1962.

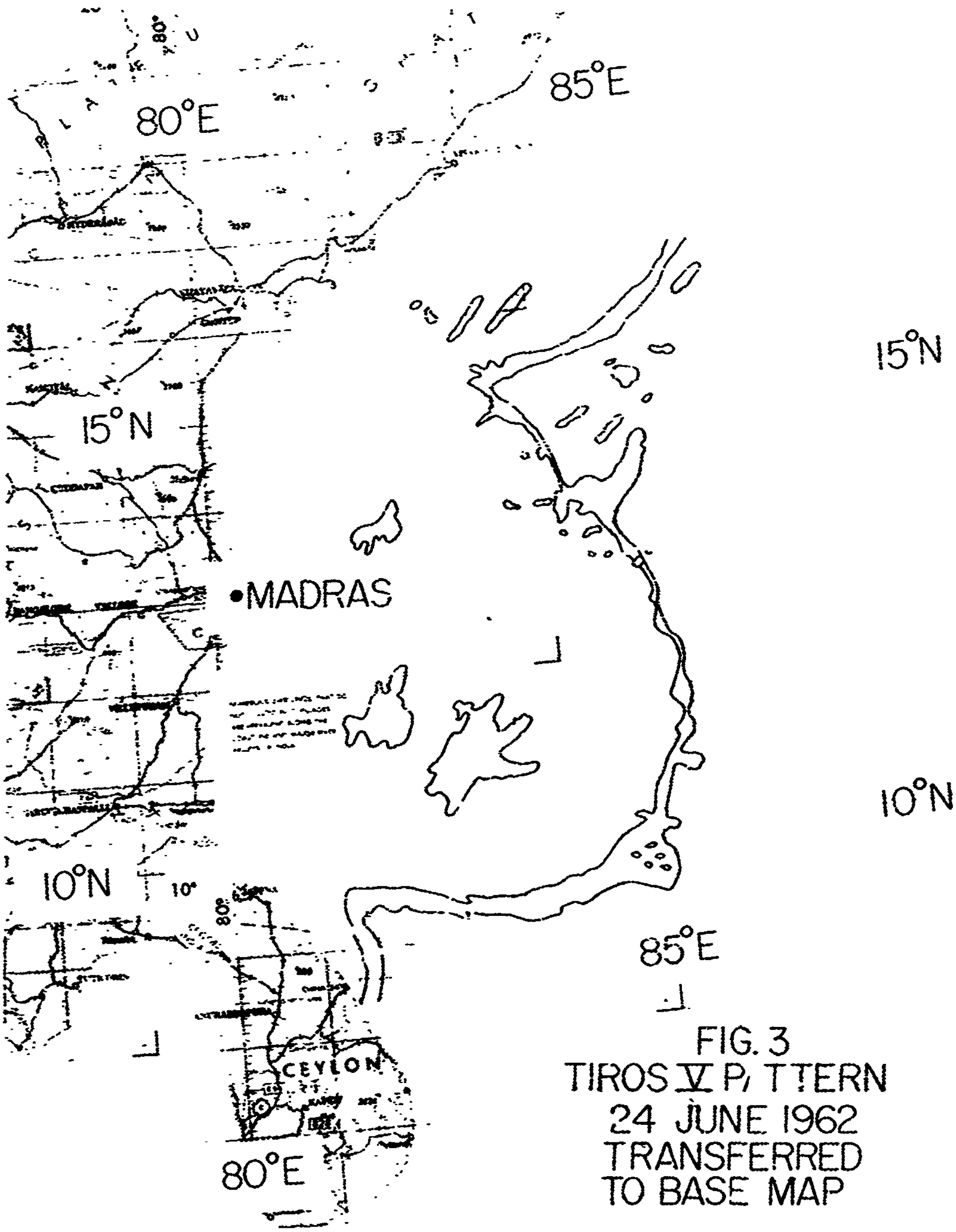

Figure 3. TIROS V Pattern 24 June 1962 Transferred to Base Map.

seismicity. The main outline under investigation encompasses the "high." If there is continual replenishment of sediment along the coast south of and from the outflow of the Godavari and Krishna Rivers, we should expect an unusual amount of turbid flow, slump, or slope failure during periods of unusual microseismic activity.

Finally we consider the following note from Indian Daily Weather Report, Tuesday 26 June 1962: "Earthquake report. - An earthquake shock of moderate intensity at its origin with epicentre near Lat. 25° N and Long. 100° E YUNAN Province (China) about 2,946 km away from Poona, was recorded by the seismographs in the Meteorological Office, Poona, at 05 hrs 57 mts I.S.T. on 24 June 1962." The Seismological Bulletin for June 1962 of the U.S. Coast and Geodetic Survey reports a quake, origin time 01 21 17.9 G.C.T., Lat. 25.6° N., Long. 101.2° E., Yunan Province, China. Focal depth was 33 km. Origin time is thus approximately 8 hours and 50 minutes before the time of frame 13 (Fig. 1).

It has been noticed that the crests of the cloud pattern quite closely approximate the third and fourth of four equally spaced crests originating from the computed epicenter. What significance, if any, one might attach to these crestal spacings of "wave lengths" is extremely problematical.

CANDIDATE HYPOTHESES AND DISCUSSION

We first inquire into meteorological causal factors. Examination of the weather map for 1200Z on 24 June 1962 reveals a weak southwesterly pressure gradient in the area, with the northern limit of the monsoon well to the northward in the seasonal trough (Fig. 4). Aloft at 1.5 km above sea level at 1200Z we notice light west wind at Madras and northwest wind at Vishakhapatnam (Fig. 5). It is as if the northernmost of the two crests in the cloud pattern represents a dividing point between the two offshore motions. The descending and presumable drier air from the peninsula seems to have cleared back eastward the cloudiness present in most of the Bay of Bengal, with the strongest convergence indicated by the somewhat brighter and larger patterns along the rope of cloud. From this point of view one would question whether the rope of cloud is necessarily continuous in the neighborhood of the southernmost crest, that is, that the short tail of cloud north of Ceylon may be independent of the arcs of cloud to the northeastward.

The principal weakness of this hypothesis is the small intensity of the offshore wind relative to the large amplitude of the pattern. Other, possibly cooperative, causes are therefore sought.

It should be noted that the wave length of 340 nautical miles (630 km) lies at the bottom of the zone of unstable cyclone waves (Fig. 6). Smaller wave lengths fall into a stable regime which holds down to roughly 30 km. This result is based upon assumptions of two layers, infinite in thickness, with an inclination of 1 part in 1000 and with friction negligible.

A possible contributory cause is upwelling, although the distance from the shore of 340 nautical miles goes beyond ordinary experience. The surface winds are along shore or slightly offshore so that we do expect some degree of upwelling along the coast. At some distance from the coast upwelling may have been induced by turbidity flow, sediment slump, or slope failure triggered by the quake in Yunan province. Whatever the causes -- and all are being explored -- it does seem probable that (1) the comparatively cloud-free sea surface within the area bounded by the pattern and the coast is colder than adjacent waters, and (2) at the convergent region along the interface of these water masses of differing temperatures the cloud crescent has formed. Initially the boundary could have been fairly linear, only some 100 nautical miles from shore. We can speculate that the length of the pattern made it unstable and open to some outside influence. Events in the train of the earthquake may have been sufficient.

It should be remarked that the rarity of the pattern, at least in the TIROS films to date, might be due to the rarity of a rope of cloud 800 nautical miles in length or longer. We would expect instability to set in and the pattern rapidly to dissociate.

Figure 4. Surface Weather, Indian Daily Weather Report, 24 June 1962.

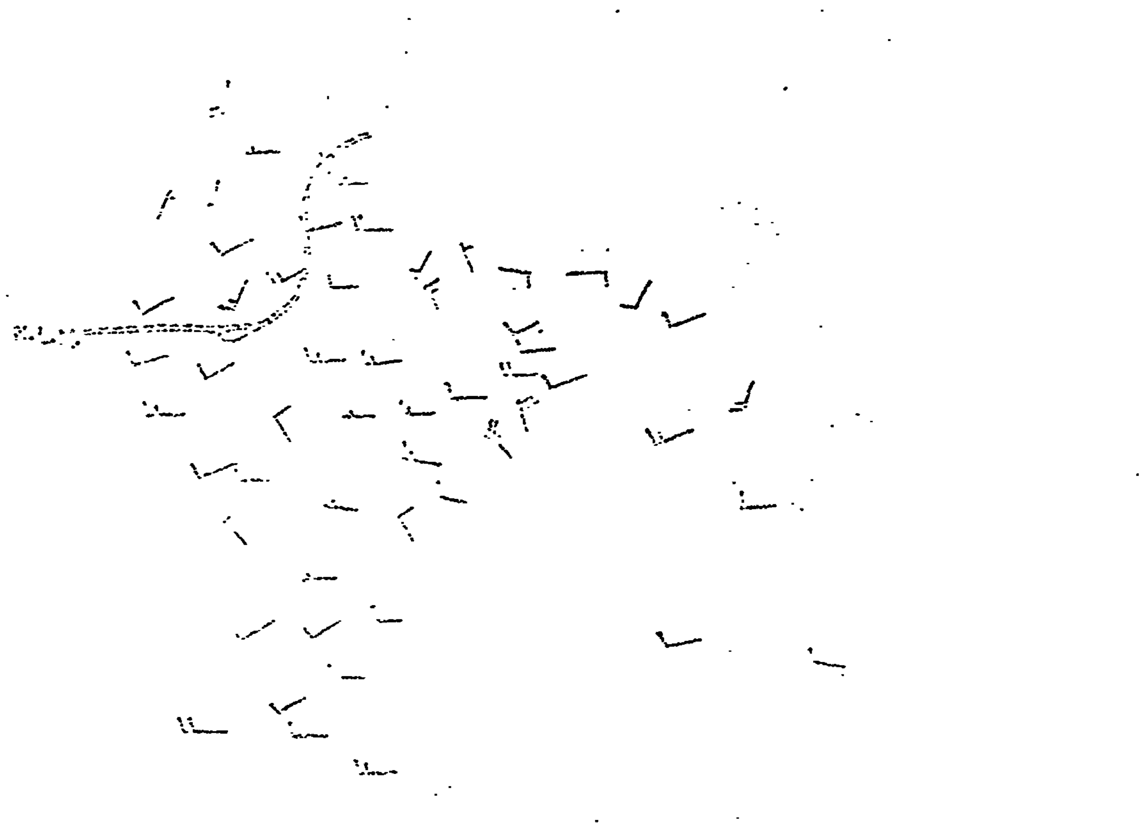

Figure 5. Winds Aloft at 1.5 km, Indian Daily Weather Report, 1200Z, 24 June 1962.

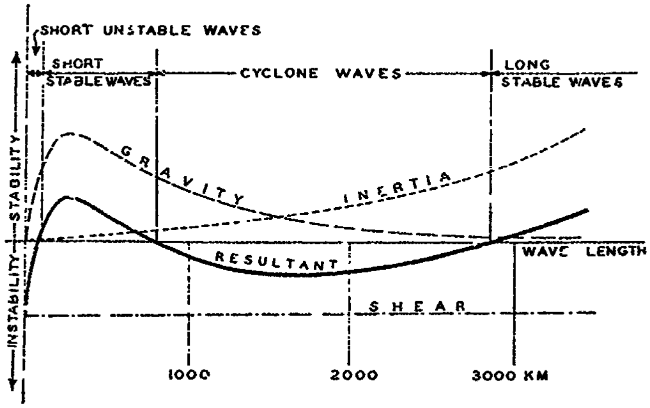

Figure 6. Stability vs Wavelength (From Pettersen, 1940).

We are handicapped in this analysis by having so few observations from ships in the Bay of Bengal off the Coromandel Coast. There is but one ship that passes through the rope region from the convectively cloudy east side to the clear west side between 1200 and 1800Z. This is a common difficulty in the use of meteorological satellites not only over water but over land. The deficiency is not necessarily forbidding but costs investigators both time and certainty. However the proposed use of data buoys which are read out by orbiting oceanographic platforms, manned or unmanned, would remove or reduce such shortcomings.

UNCONVENTIONAL PHOTOGRAPHY AND OCEANOGRAPHY

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I intend to illustrate a few applications of photography, or types of photography, that I believe are not too well known to oceanographers. It might be well to note, first, where photographic surveillance of oceanographic processes is of particular value. Such a list should include the following areas of investigation, all of which could be the subject of the techniques illustrated in these notes.

- Marine biology
  - Bioluminescence
  - Plankton bloom
- Physical oceanography
  - Color
  - Slicks
  - Sun glitter
  - Sea ice and bergs
  - Water mass boundaries
  - Wind waves
- Coastal processes
  - Beach erosion
  - Coastal circulation
  - Bottom visibility

HIGH ALTITUDE PHOTOGRAPHY

The first series of photographs are four views of refracted waves taken by a panoramic camera at altitudes of 60-70,000 feet over the Bahamas. This particular camera sweeps from horizon to horizon, taking successive 180° exposures with a continuously rotating scanning head prism. Angular coverage is 42° x 180°. Each picture is 2.4 inches x 9.4 inches on 70 mm film. However, what you will see here is an enlargement of a portion of each frame. The photography was flown for meteorological purposes and the exposure chosen for cloud photography; land and sea surface therefore are quite dark. However, as you will see in these four slides (Figures 1-4) the choice of exposure results in an enhancement of surf and wave crests.

All four figures were from the same flight and, as it happens, from the only such over-water photography as I have been able to obtain. In my opinion it was not simply a matter of good fortune that this one flight should produce frames of such excellence and content. The technique is ideal for any requirement of high resolution and a wide view, as, for example, the program of wave study off southern California by Emery (1958) in 1957 and 1958. He had concluded that photography was a poor method for making primary observations (in his study) because (1) of the small area of each picture, (2) the uncertainty of orientation and (3) the need for long or continuous observations. All such objections can be overcome by the technique just illustrated.

MULTISPECTRAL PHOTOGRAPHY

The technique of multispectral photography, which has variously been termed spectrozonal, multiband, or narrow-band photography, is that of photographing an area or object in several narrow spectral ranges simultaneously. The purpose is to detect areas, objects or patterns whose subtle differences in spectral characteristics may not be visible in conventional wide band photography. The technique has had considerable success in medicine, astronomy, and agriculture.

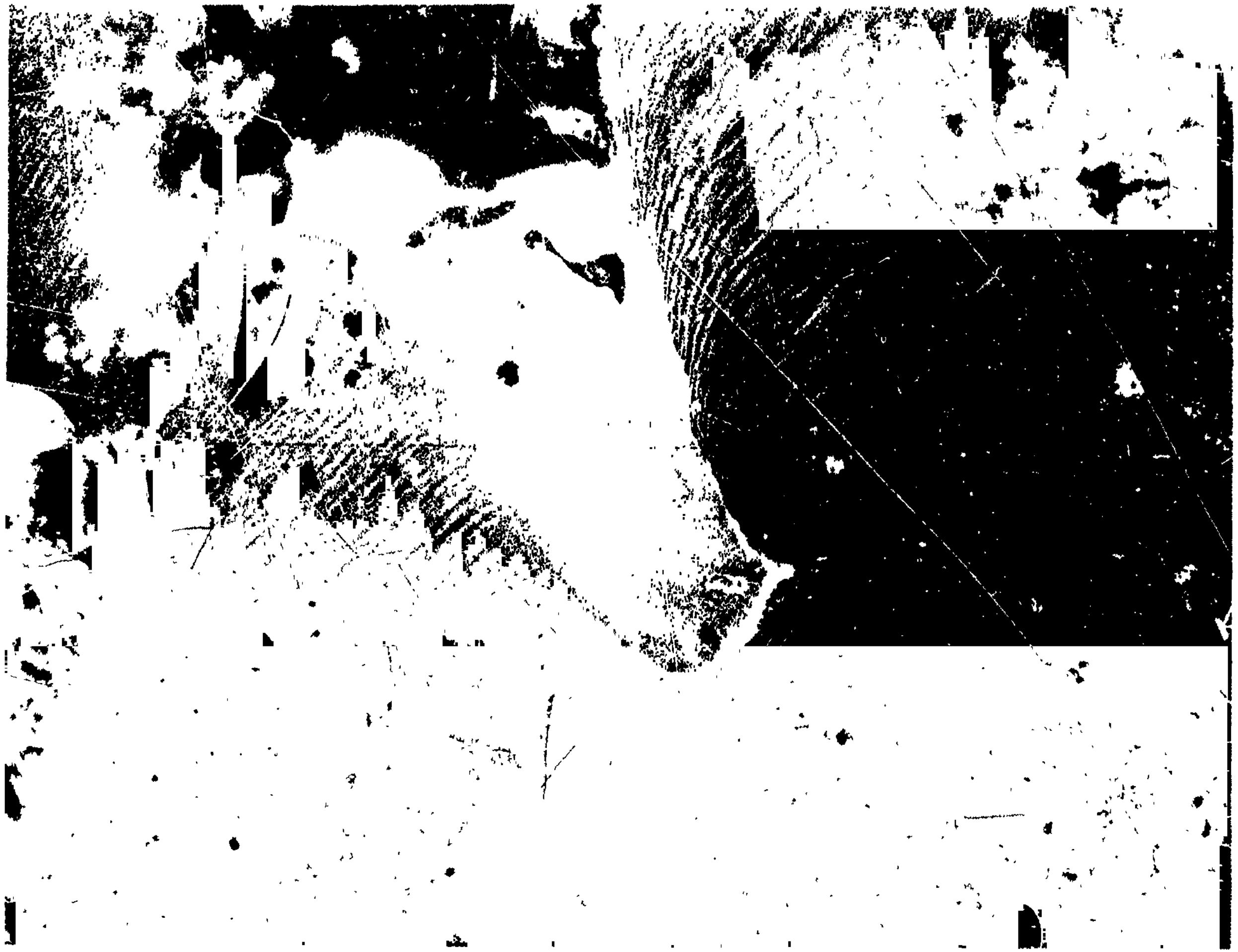

Figure 1. Wave Diffraction at Mayaguana Island, Southeast Pt., N. 22° 17', W. 72° 44'. Air Force Cambridge Research Laboratories (USAF)

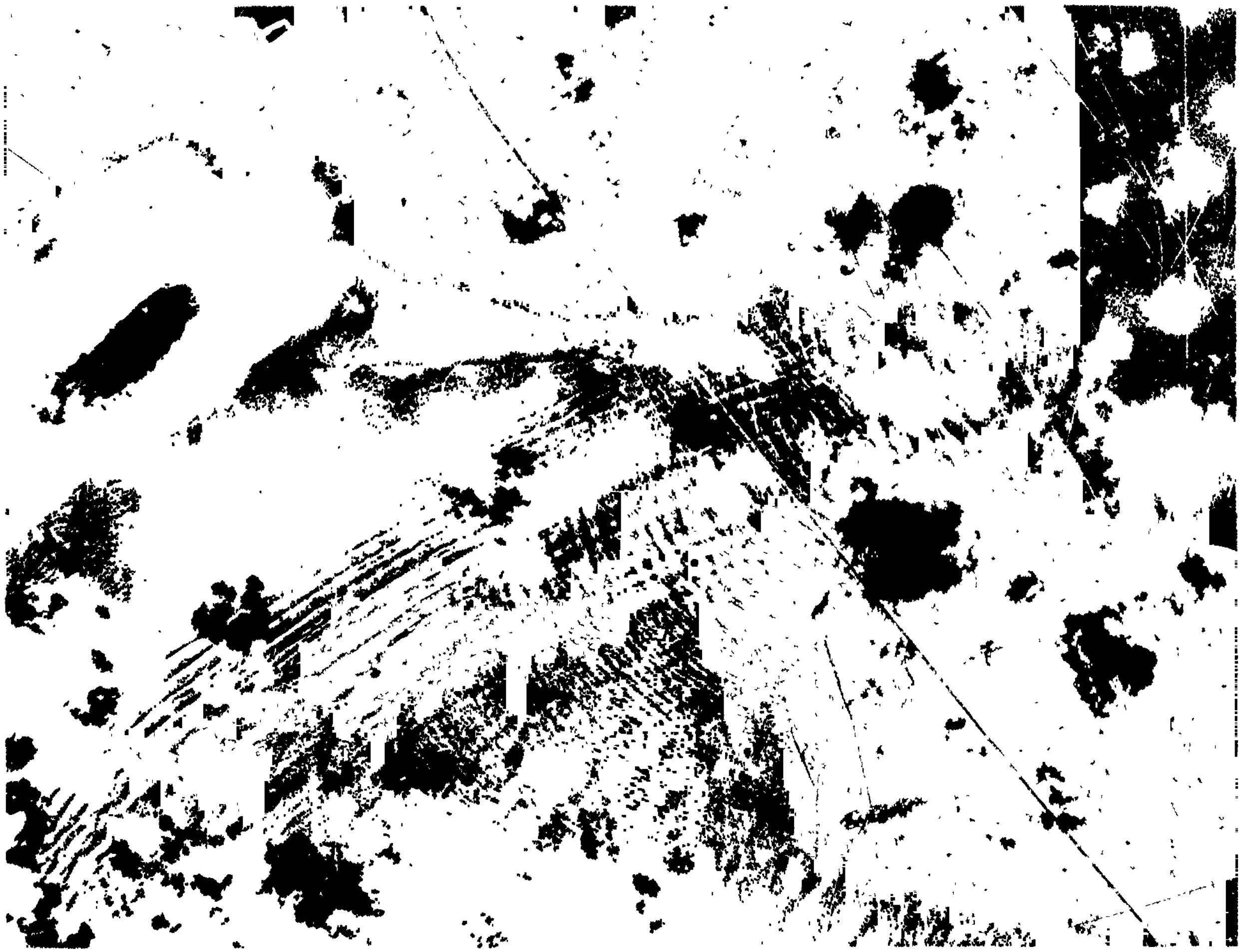

Figure 2. Wave Diffraction at Grand Turk Island, N. 21° 31', W. 71° 08'. Air Force Cambridge Research Laboratories (USAF)

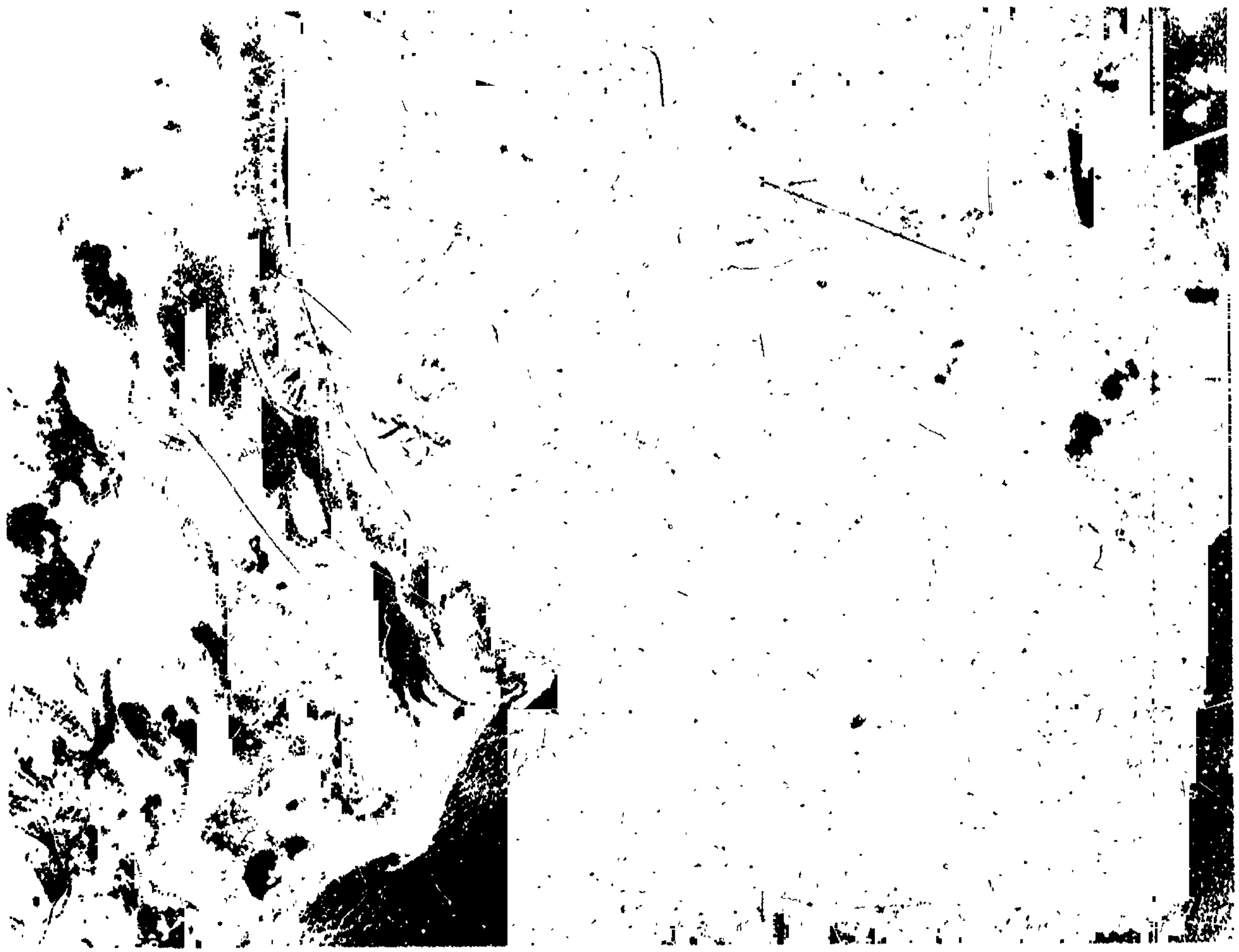

Figure 3 Wave Diffraction at East Caicos Island, N. 21° 43', W. 71° 28' Compare With Figure 4. Air Force Cambridge Research Laboratories (USAF)

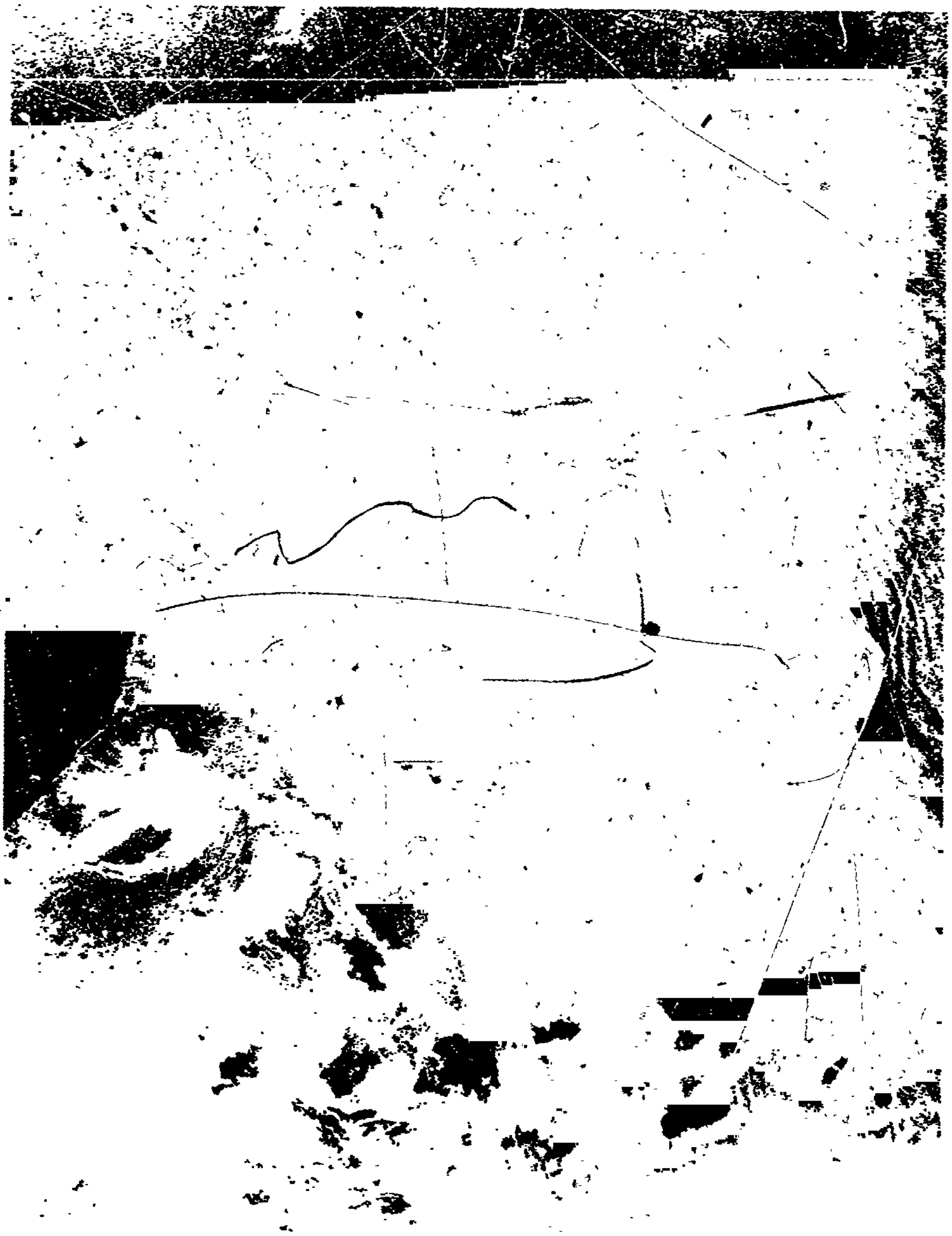

Figure 4: Same as Figure 3, But One Frame Later. Air Force Cambridge Research Laboratories (USAF)

Several of us, as geologists, are exploring its use in our own and allied fields. The camera we use is a nine-lens instrument, Figure 5, that provides photographic coverage in contiguous narrow bandwidths from 0.4 to 0.9 microns. Our particular choice of bandwidths is given in Table I. Other choices are possible of course.

Table I

Lens	Bandwidth (m u)
1	400-500
2	450-510
3	520-550
4	550-600
5	590-640
6	670-720
7	700-810
8	810-900
9	Full range of IR film

A simultaneous exposure at these bandwidths is shown in Fig. 6. It is not a particularly good example, but there is still little to choose from, since there has been no attempt by oceanographers to use multispectral techniques. This view of a portion of San Francisco Bay from 20,000 feet is without certain data that should have been recorded, such as time of day or sun angle, meteorological conditions, sea state, etc., but the figure is, nevertheless, rather interesting and deserves study.

Clarke and Denton (1962) have pointed out that fresh waters and coastal waters have their maximum transparency at 500-600 mμ and that the maximum transparency of ocean waters is 400-500 mμ. Maximum information content in Fig. 6 appears to be at bands 590-640 mμ and 670-720 mμ.

VISIBILITY FROM TIROS

Not too infrequently I have observed in TIROS photography the distinct outline of the Little Bahama Bank and the less distinct north end of the Great Bahama Bank (Fig. 7a). Note particularly the similarity in pattern of the Little Bahama Bank in both 7a and 7b. Apparently, with the proper sun angle the calcareous bottom sediments of the Bahama Banks are equally as visible from satellite altitudes as from more conventional altitudes. Most regions of the Banks are less than 60 feet deep. It should be noted also in Fig. 7a that the light halo along the southwest coast of Florida is another area of shallow carbonate sediment.

A second example of bottom visibility from TIROS is Palk Strait between Ceylon and the Coromandel coast of India (Fig. 3). Here bottom depths are nowhere more than 5 to 7 fathoms.

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Emery, K. O. (1958), J. Mar. Res., v. 17, p. 133-140.
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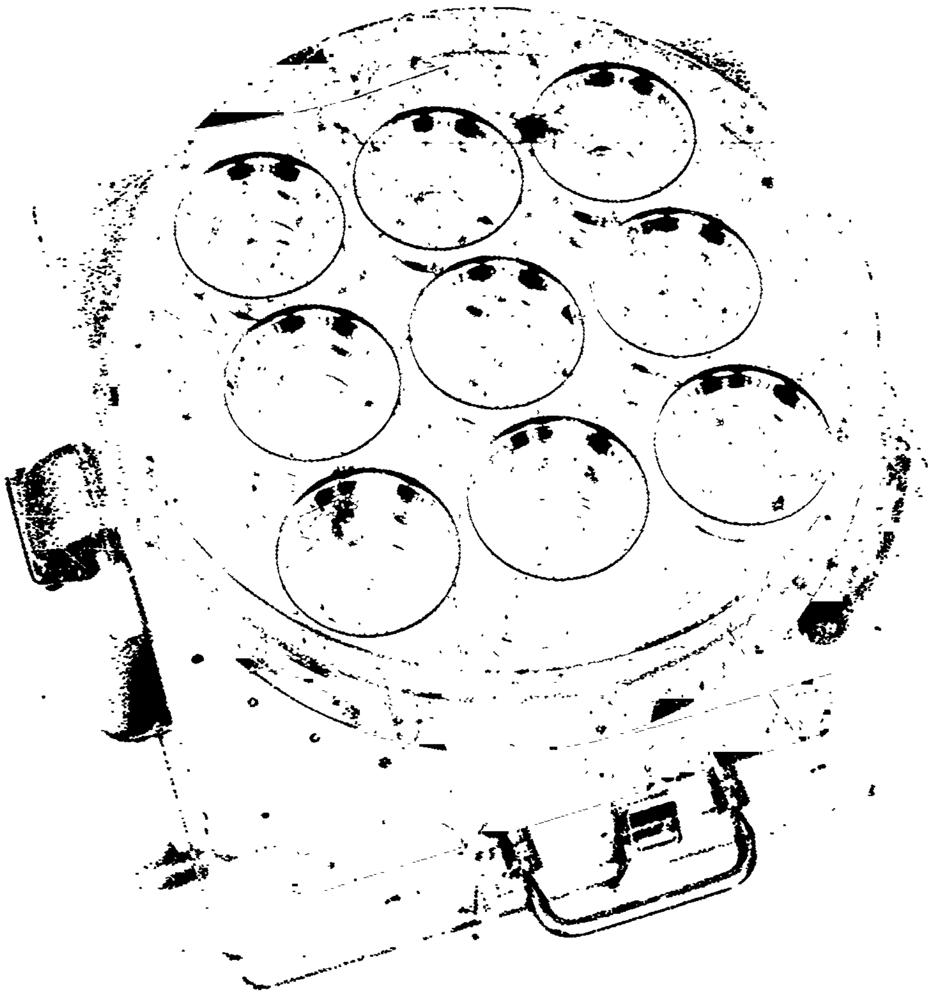

Figure 5. Nine-Lens Multiband Camera.

Figure 6. Multiband Exposure from 20,000 Feet Over Island in Bay of San Francisco. Bandwidths For Each Lens Given in Table I. 2 Oct 1963. Time Unknown. Photograph Courtesy of Advanced Research Projects Agency.

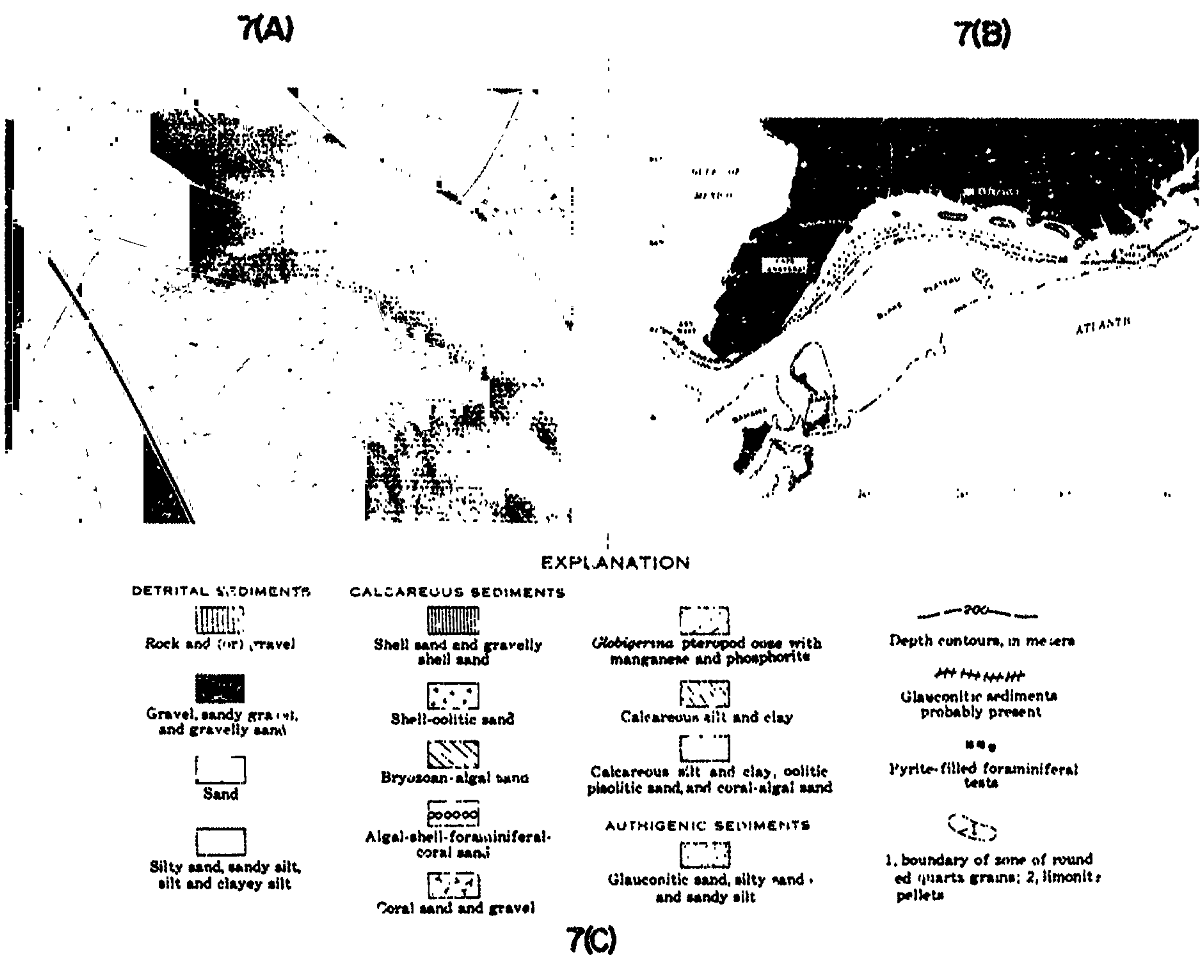

Figure 7. (a) View of Florida and Bahama Banks From TIROS I, Orbit 76, 174130 Z.
(b) Sediments of Continental Margin Off Southeastern United States, From Uchupi, E., U. S. Geol. Sur., Prof. Paper 475-C, p. 134 (1963).
(c) Key to 7(b).

Figure 8. View of Palk Strait From TIROS VI, Orbit 57, 22 Sept 1962, 12:35:30 IST.

N65-30360

SPACE PHOTOGRAPHY: A REVIEW

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ABSTRACT

This paper reviews the history, present status, and unique capabilities of photography of the earth from space, and presents representative space photographs. Space photography has the following main advantages over conventional aerial photography: wider perspective, potential world-wide coverage, greater speed, and rapid repetition of coverage. In addition, it can partially duplicate aerial photography in producing large scale pictures by the use of long focal-length cameras. Potential applications of space photography based on these characteristics lie in geologic reconnaissance, topographic mapping, oceanography, and several other fields.

INTRODUCTION

Since the development of large rockets in World War II, thousands of photographs of the earth have been taken from altitudes of 50 miles or higher, i.e., from space. The purpose of this paper is to review briefly the history, present status, and unique capabilities of what may be called "space photography," or "hyperaltitude photography." In addition, its potential applications will be reviewed.

Stress will be on pictures of the earth's surface rather than on those of cloud patterns, since such photography is of interest primarily to meteorologists. Military space photography is exlcluded from the scope of this paper.

HISTORY OF SPACE PHOTOGRAPHY

Although photographs were reportedly taken from rockets before World War I (Katz, 1963), space photography began in earnest with the use of small cameras carried by V-2 rockets fired from White Sands Proving Ground after World War II. Since that time, numerous flights which performed photography have been made by a variety of sounding rockets, ballistic missiles, satellites, and manned spacecraft; these are listed in Table I. Representative pictures taken during these flights are presented in Figures 1, 2, 3, 4, 6, 7, and 8. It should be kept in mind, in judging the quality of these pictures, that nearly all of these flights were made for purposes other than photography, which was usually an auxiliary experiment.

Useful references on certain aspects of space photography include papers by Katz (1963), Merifield (1964), Bird and Morrison (1964), Rochlin (1962), and Lowman (1964).

CURRENT PROJECTS

Topics which will be discussed under this heading include interpretation of existing space photographs, planning of space photography for presently approved programs, and long-range planning and investigations for possible future space missions.

In the area of interpretation, current or recently-completed efforts include studies of the MA-4 photos of North Africa by Morrison, et al (in press), of the Viking, Tiros, and certain MA-4 photos by Merifield (1964), and of Tiros pictures of the United States by Cronin (1963). Although not yet published, efforts are being made at Goddard Space Flight Center and elsewhere to extract the maximum amount of nonmeteorological information from the 27,000 images transmitted by the Nimbus I during its brief but productive lifetime. Other interpretive research by specialists is in progress; an interesting example is the recent comparison of Martian surface features with seif dunes in North Africa photographed by the MA-4 camera (Gifford, 1964).

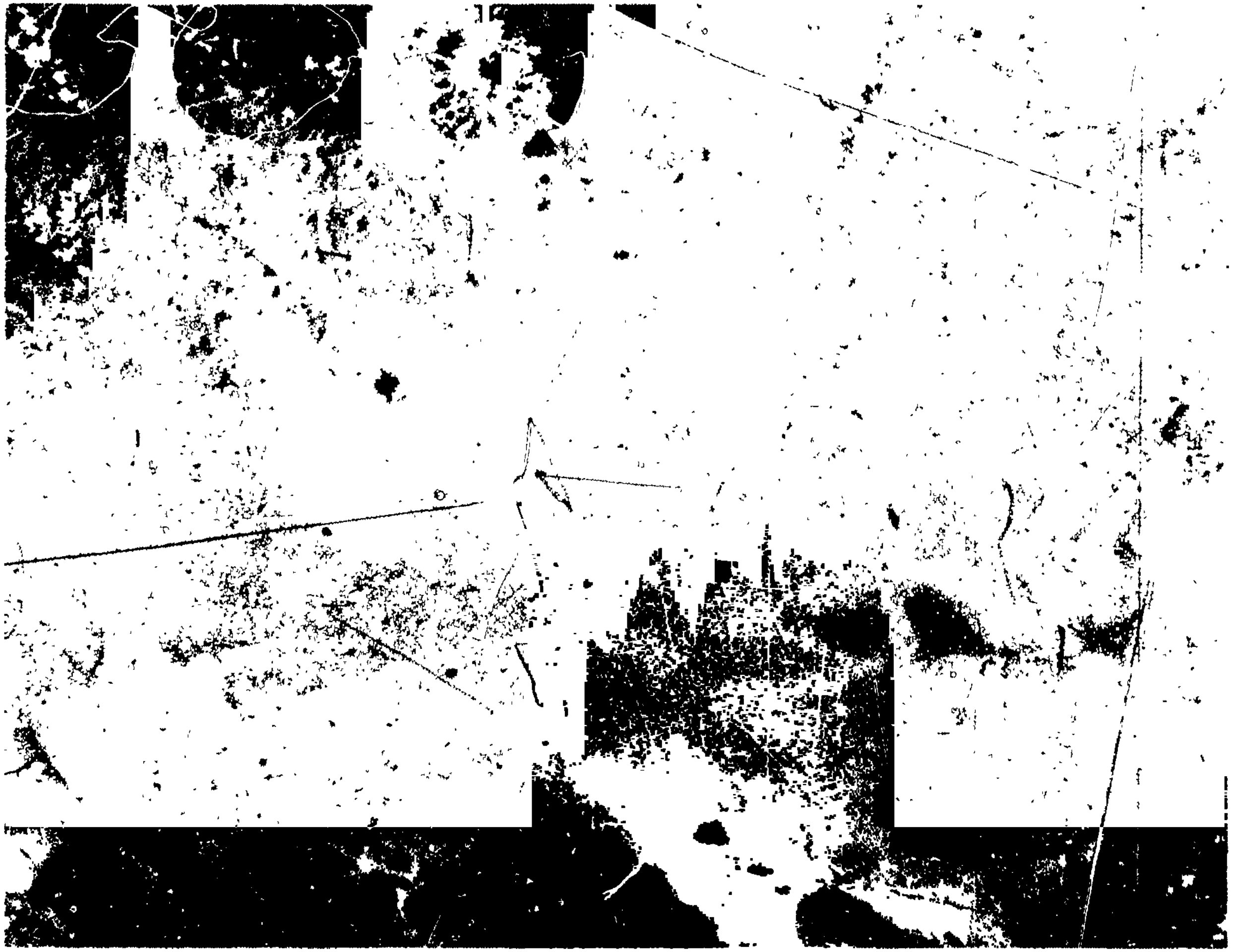

Figure 1. Viking II Photo of El Paso and Rio Grande River from About 158 Miles Altitude. North of Top Left.

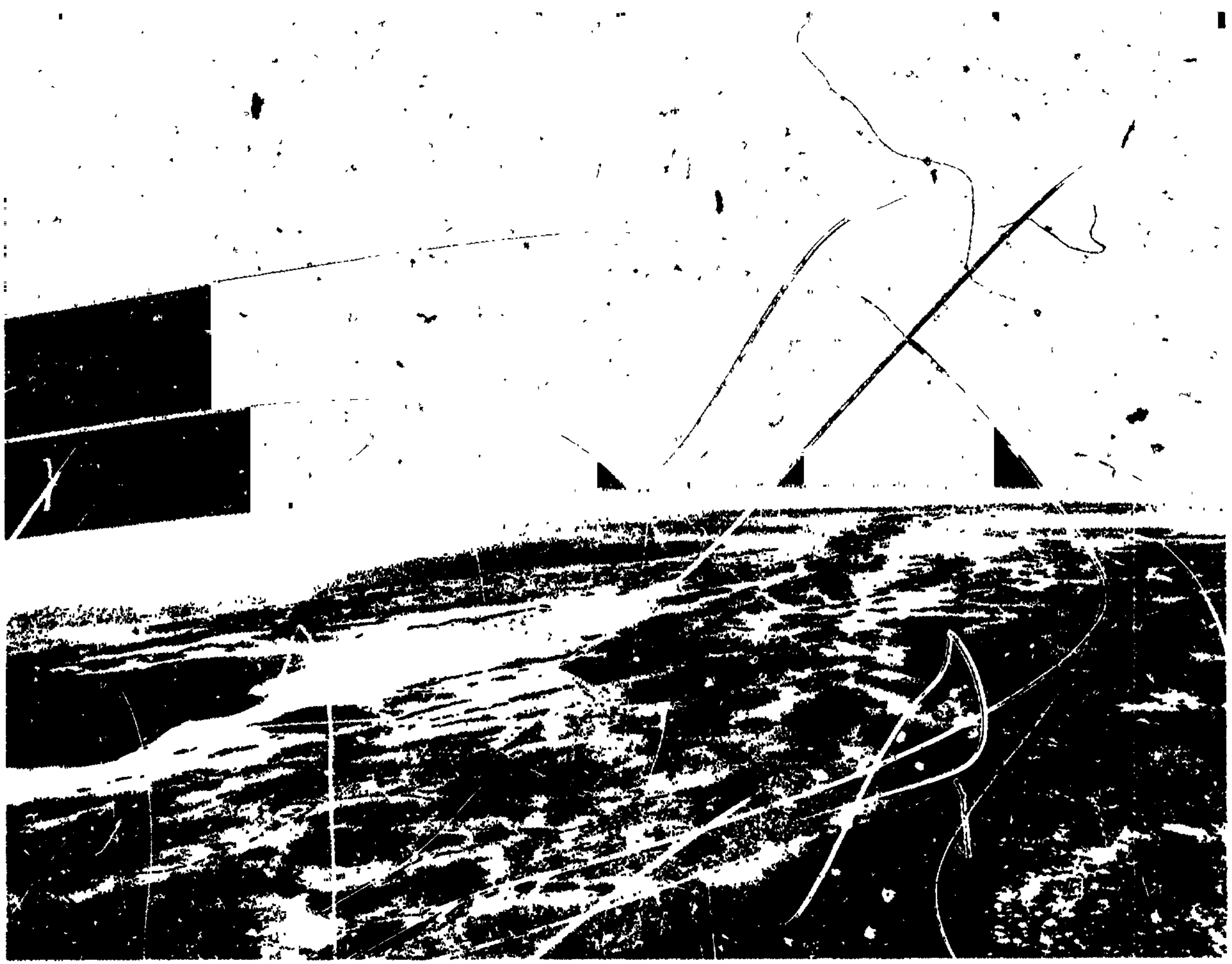

Figure 2. Viking 12 Photo of Southwest U.S.A. From About 140 Miles Altitude. View to Southwest.

Figure 3. Black and White Print of a 70mm Color Transparency Taken by L. G. Cooper During MA-9 Flight, Showing Southwest Tibet. Lakes in Upper Left of Photo are Rakas Tal (Left; About 10 Miles in East-West Width) and Manasarowar (Right); Snow-Covered Mountain in Upper Left Center of Photo is Gurla Mandhata (25,335'). North at Top.

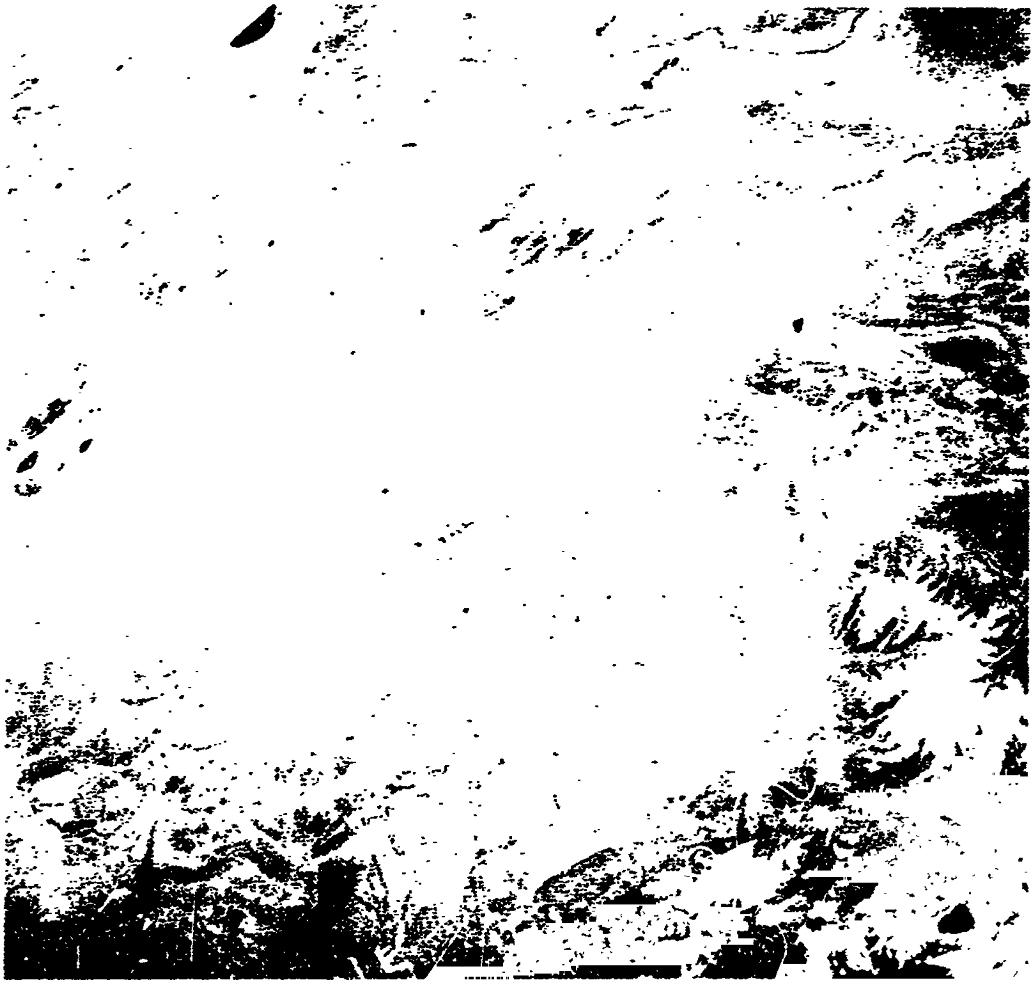

Figure 4. Black and White Print of a 70mm Color Transparency Taken by L. G. Cooper During MA-9 Flight. Showing Central Tibet. North at Top

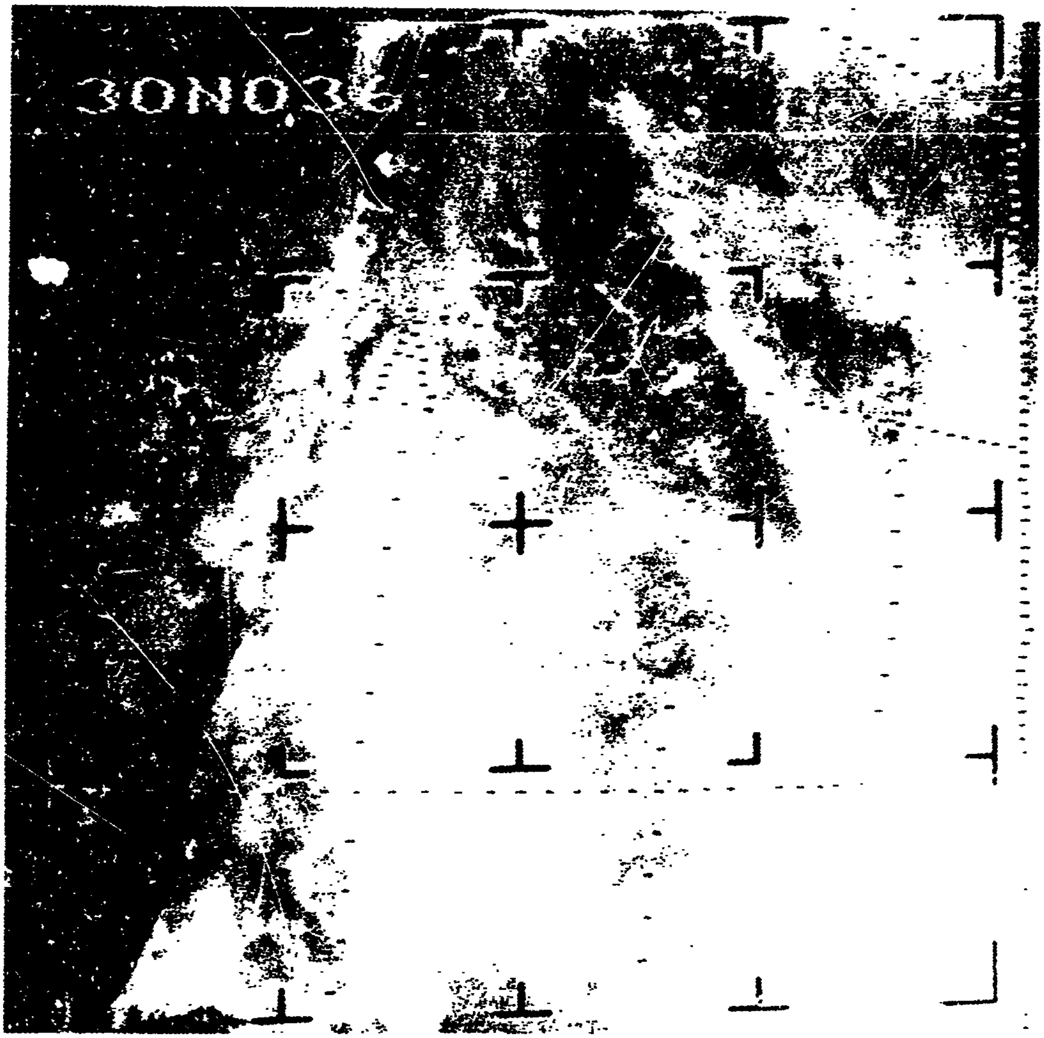

Figure 5. Geologic Sketch of Area Shown in Figure 4.

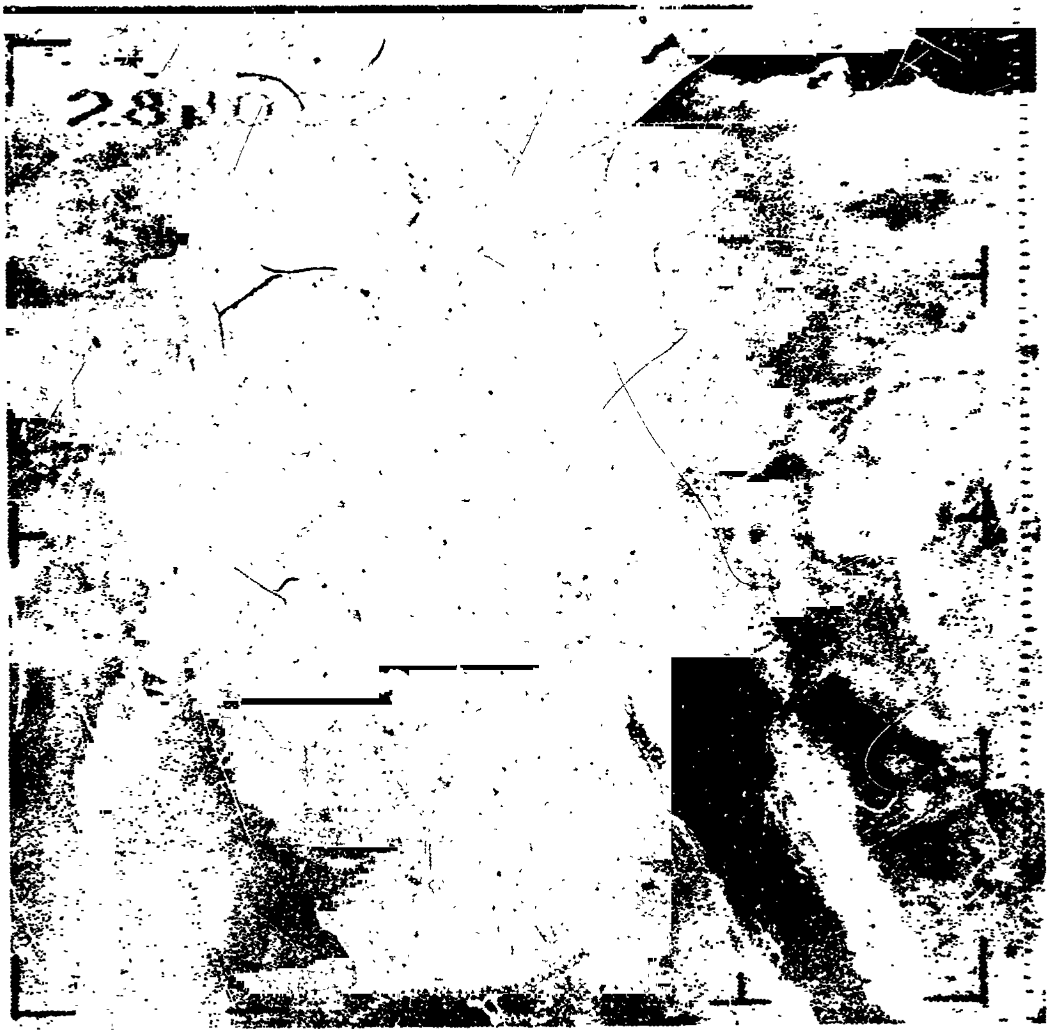

Figure 6. Nimbus I AVCS Picture of Dead Sea (Top Left) and Red Sea Showing Rift Valley. Altitude 371 Miles.

Figure 7. Nimbus I AVCS Picture Showing Gulf of Suez, Suez Canal, and Nile River. Altitude 371 Miles.

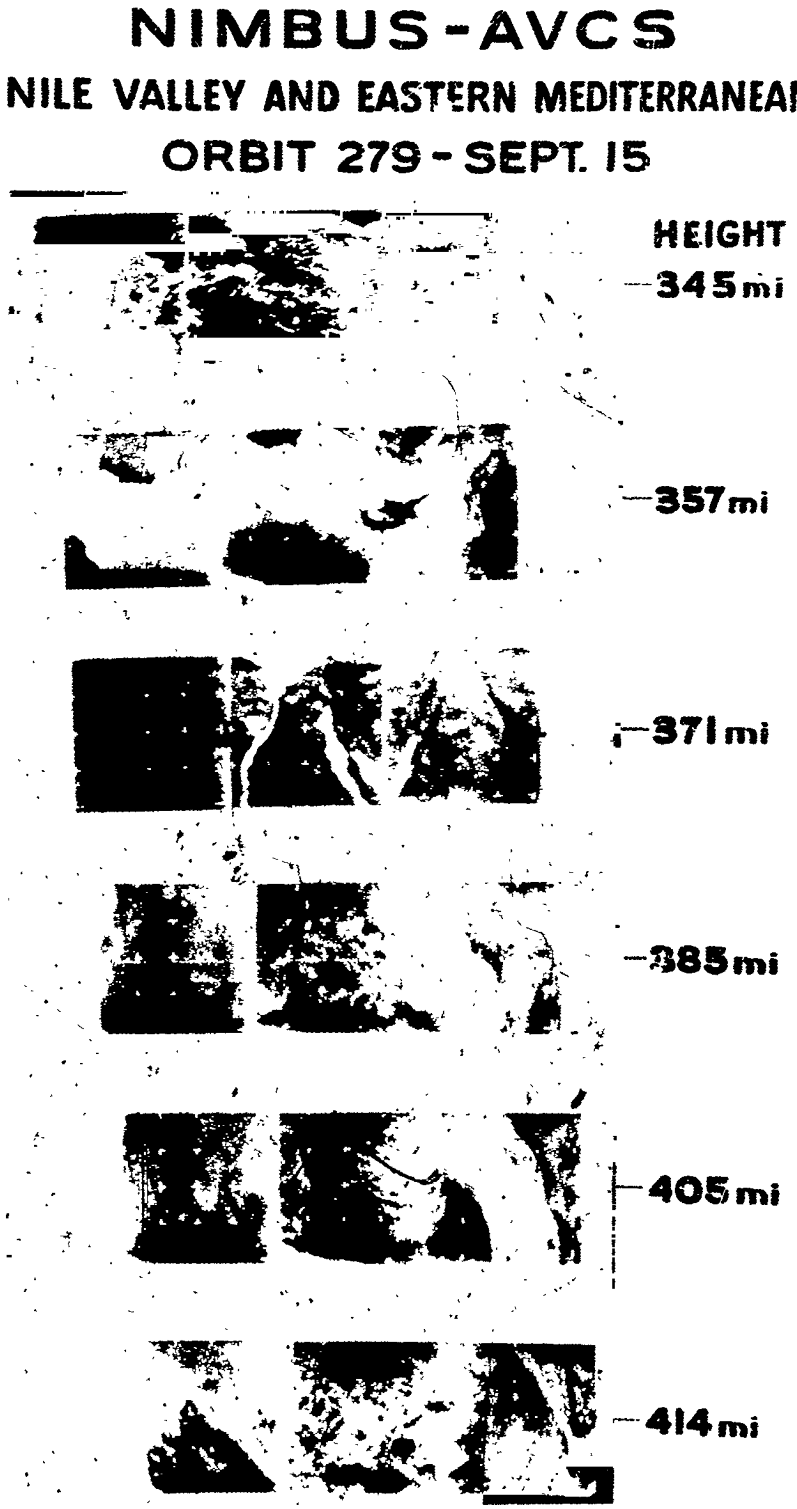

Figure 8. Mosaic of Nimbus 1 Pictures Including Areas Shown in Figures 6 and 7.

TABLE I

Summary of Successful Space Photography Flights

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)	Reference
V-2	1946	35 mm Motion Picture	Super XX (25A)	SW U.S.A.	76	Holliday, 1954
V-2	1947	K-25 Aircraft	Infrared Reconnaissance Base (25A)	SW U.S.A.	100	Bergstrahl, 1947
Aerobee and V-2	1946-50	K-25 Aircraft	Aerographic Super XX (25A)	SW U.S.A.	60-80	Holliday, 1954 Newell, 1953 Newell, 1959
		35 mm Motion Picture	Eastman IN Spectroscopic (29A)	SW U.S.A.		
		16 mm Gunsight	Kodachrome	SW U.S.A.		
Vikings 11 and 12	1954-55	K-25 Aircraft	Eastman Hi-Speed Infrared	SW U.S.A.	Up to 158	Baumann and Winkler, 1955 Baumann and Winkler, 1959
Atlas	1959	16 mm Time-Lapse	Recordak Fine-gr. Panchromatic	Atlantic Ocean SE of Atlantic Missile Range	Up to 230	Lathrop and Rush, 1959
Aerobee	1960	Maurer 220 70 mm Aerial	Kodak IR Aerographic (88A) Kodak Experimental Ektachrome (8778) Kodak High-Definition Negative (3)	North-Central Canada, Hudson Bay	47-140	Evans, Baumann, and Andryshak, 1962

TABLE I

(Cont.)

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)	Reference
Mercury Flight MR-1†	December 1960	Maurer 220G 70 mm	Super Anscochrome	Florida, Bahama Islands	Maximum over 130	
Mercury Flight MA-3	April 1961	Maurer 220G 70 mm	Super Anscochrome	Not Known	Low Altitude Abort Flight	
Mercury Flight MR-3	May 1961	Maurer 220G 70 mm	Super Anscochrome	Florida, Bahama Islands, Mainly Cloud Covered		
Mercury Flight MA-4 (1961αα1)	September 1961	Maurer 220G 70 mm	Super Anscochrome	First Orbit Flight Path: Atlantic Ocean, North and Central Africa	86-123	
Mercury Flight MA-5 (1961αι1)	November 1961	Maurer 220G 70 mm	Super Anscochrome	SE U.S.A., West Coast of Mexico	86-123	
		Milliken DBM7, 16 mm (periscope observer camera)	Kodachrome EK Type II	North Africa		
Mercury Flight MA-6 (1962γ1)	February 1962	Ansco Autoset, 35 mm	Eastman Color Negative	Florida, North Africa	87-141	Glenn, 1962
Mercury Flight MA-7 (1962τ1)	May 1962	Robot Recorder, 35 mm	Eastman Color Negative	West Africa, Atlantic Ocean, and other areas	87-145	Carpenter, 1962
Mercury Flight MA-8 (1962βδ1)	October 1962	Hasselblad 500C, Modified 70 mm	Anscochrome 200	Western U.S.A., Mexican Gulf Coast, South Atlantic Ocean	87-145	Schirra, 1962

TABLE I

(Cont.)

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)	Reference
Mercury Flight MA-9 (1963 15A)	May 1963	Hasselblad 500C Modified 70 mm	Anscochrome 200	South-Central Asia, Philippine Islands, Pacific Ocean, Middle East, North Africa	87-144	Cooper, 1963

*Wratten filter numbers.

†MR refers to suborbital flights with a Redstone launch vehicle; MA to flights with an Atlas launch vehicle. The MR-2 flight carried the chimpanzee Ham; MR-3, A. Shepard; MR-4, V. Grissom; MA-4, a simulated man; MA-5, the chimpanzee Enos; MA-6, J. Glenn; MA-7, M. Carpenter; MA-8, W. Schirra; MA-9, L. Cooper.

The only currently approved manned spaceflight program involving photography of the earth is Project Gemini. Although primarily an operational and engineering test program, several of the Gemini earth-orbital flights will have provision for scientific experiments, including synoptic terrain and weather photography (Gill and Gerathewohl, in press). The terrain photography is being planned to secure pictures of the United States, for which ground truth and large scale air photos are available. Pictures thus obtained can be used as a base of experience for interpretation of space photographs of remote parts of the earth.

Several possible future space programs may involve space photography. Foremost among these is the Manned Orbiting Research Laboratory (MORL) (Badgley and Lyon, in press); to aid in mission planning, NASA hopes to make calibration test flights over selected parts of the United States with an aircraft equipped with a variety of sensors, including cameras. Another program under consideration is the Lunar Orbital Survey System (LOSS), which would use modified Apollo spacecraft in circumlunar orbits to map the moon with cameras and a variety of nonvisual sensors such as infrared, ultraviolet, and gamma-ray detectors. The results of planning and experimentation for possible MORL and LOSS missions will, of course, be applicable to flyby probes of the planets by manned and unmanned spacecraft, such as the forthcoming Mars Mariner flights. A detailed discussion of planetary exploration from orbiting vehicles is presented by Badgley and Lyon (in press).

UNIQUE CAPABILITIES OF SPACE PHOTOGRAPHY

It is apparent, from the examples presented here, that the scale numbers and coverage per picture of available space photographs are orders of magnitude greater than those of conventional air photos. We now ask what space photography can offer which aerial photography cannot. Before discussing this question, however, it must be pointed out that space photography can duplicate, to an unknown but probably high degree, the functions of aerial photography in producing large-scale, high resolution pictures of the ground. Katz (1963), for example, points out that a ground resolution of 2.4 feet should be obtainable from 150 miles altitude on a photograph with resolution of 100 lines/millimeter, using a 120-inch focal length camera. Neglecting this possible duplication of aerial photography, however, we see that space photography from orbiting vehicles offers the following unique advantages:

1. Greater perspective
2. Wider coverage
3. Greater speed
4. Rapid repetition of coverage

The perspective afforded by the great altitude of orbiting spacecraft is, of course, the most striking characteristic of space photographs, permitting us to see entire orogenic belts, drainage basins, and wrench fault systems at a glance. This perspective affords a continuity of observation which might permit, for example, the detection of large geologic structures unnoticed on large scale air photos. In Figures 4 and 6, many lineaments scores of miles long are easily seen. The value of small scale photographs has, of course, been recognized before (Hamphill, 1958; Cameron, 1961). and is demonstrated by the wide use of mosaics. Space photographs, however, have an advantage over mosaics in showing the terrain as it is, without the necessity for dodging, which must destroy many of the tonal clues to structure (Miller, 1961). This advantage may be especially useful in delineating structure in heavily vegetated areas, where interpretation must depend largely on subtle tone or color differences.

World-wide coverage can be provided for space photography by high-inclination or polar orbits. The importance of this advantage for photography of the polar regions is obvious, but it may be pointed out that camera carrying satellites will also cover large areas, such as the central Pacific, which would be very difficult and expensive to photograph from aircraft. A related characteristic of space photography from orbiting vehicles is the speed of areal coverage which is possible. Kochlin (1962) points out that one satellite at a 300 mile altitude in polar orbit could photograph the entire surface of the earth in about 4 1/2 days. This extremely rapid coverage will also permit, if the satellite stays up for a few weeks or months, rapid repetition of coverage which would be very difficult to achieve with aircraft. This would permit the repeated photography of cloud-covered areas and detection of seasonal changes in features such as vegetation, snow fields, and ocean currents.

POTENTIAL APPLICATIONS OF SPACE PHOTOGRAPHY

The unique benefits offered by space photography, coupled with the possibility of duplicating conventional aerial photography with long focal length cameras, suggests applications in many areas, such as the following.

GEOLOGIC RECONNAISSANCE

The most obvious application of space photography to geology is the photomapping of remote areas not previously mapped, such as parts of the interior of Antarctica. An even more interesting possibility is that of photographing previously mapped areas to show large geologic structures unnoticed on conventional air photos (Figure 4 is of interest in this connection). For example, the existence of transcontinental fracture zones, such as the Clipperton Vema lineament crossing Venezuela (Fuller, 1964), might be investigated by space photography. Other geologic applications are suggested by the fact that color film adds a negligible amount to the cost of space photography; the spectacular pictures taken by Cooper during the MA-9 flight demonstrated the practicability of color space photography (Lowman, 1964). See frontispiece.

TOPOGRAPHIC MAPPING

The Army Map Service study previously referred to (Spencer, 1959) concluded tentatively that 1:1,000,000 scale topographic mapping might be done with satellite photography with good accuracy, and that somewhat larger scales might be possible with lower accuracy. The requirements for attitude and altitude control of a cartographic satellite are considerably more stringent than those for one used only for reconnaissance mapping. However, even the present Mercury spacecraft would meet most of these requirements.

FORESTRY

The fact that aerial photography has become a nearly indispensable tool of the modern forester makes it seem likely that space photography will have application in this field. The scale and resolution possible with small cameras would prevent the use of space photographs for detailed studies such as crown counts, but reconnaissance forest mapping might be possible. The use of color film for space photography would increase its value in forestry. The great potential value of multispectral photography (Colwell, 1961) in detecting changes in vegetation suggests that it would be useful to carry out such photography from space using instruments such as the recently-developed 9-lens Multiband camera (Yaffee, 1963).

ICE PACK RECONNAISSANCE

It was discovered shortly after Tiros I was put into orbit that sea and river ice could be seen on the telemetered images despite their relatively low resolution. This led rapidly to the joint Canadian-American Project Tirec to investigate the application of weather satellites to ice reconnaissance. Using Tiros photographs in conjunction with aircraft photography and ground observations the project demonstrated that satellite ice reconnaissance in areas such as the Gulf of St. Lawrence was clearly feasible and of great potential value (Balites and Neiss); Singer and Popham (1963) report that as much as $1,700,000 might have been saved in 1961 by the United States and Canada through ice observations from a Nimbus satellite had one been in orbit. It may be pointed out that a figure of this sort is misleadingly conservative; an operational Nimbus satellite could provide similar ice reconnaissance over the approaches to western Europe, Russia, and Antarctica at very little extra cost.

Film photography would have the advantage of greater resolution than television. But in day-to-day ice pack monitoring, methods of rapid image retrieval would have to be utilized, such as facsimile transmission of films developed in flight. It seems safe to say that both television and photography from orbiting vehicles promise to be immensely useful in ice studies.

HYDROLOGY

Although relatively little application has been made of space photography to hydrology, it might be useful in several ways. One of these is the measurement, over large areas, of snow cover; the National Weather Satellite Center and other agencies in the United States and Canada are currently investigating the use of Tiros pictures for this purpose. As shown by the MA-9 photographs, deep snow, light snow, and valley glaciers can be distinguished easily, indicating that methods involving film recovery should also be valuable because of the high resolution of the film.

The fact that entire drainage basins of major rivers can be photographed quickly from satellites suggests that many other hydrologic applications can be found for space photography.

SUPPLEMENTAL WEATHER PHOTOGRAPHY

The greater resolution obtainable with film-recovery methods of space photography makes space photographs valuable for synoptic studies of the fine structure of cloud systems (S. Soules and K. Nagler, personal communication), similar to those already conducted from aircraft (Malkus, 1963). The Arctic Meteorology Photo Probe (Evans, Baumann, and Andryshak, 1962) further demonstrated the usefulness of rocket photography in supplementing and supporting meteorological satellites.

These applications would not be considered photogrammetry in the usual sense, but are worth mentioning because a surprisingly large part of the earth's surface is covered with clouds at any one time. This will obviously hamper terrain photography, but the pictures of the cloud cover itself will be of value.

OCEANOGRAPHY

The ability to take individual photographs covering scores of thousands of square miles should prove invaluable in oceanographic studies. In addition to the obvious benefits of weather observations over remote oceanic areas, the following applications may be possible:

1. Multispectral photography covering the near infrared, visible, and ultraviolet can show the distribution of currents and possibly of areas with differing salinity. That such photography is possible even from space vehicles was suggested by Glenn's ability to see the Gulf Stream during the MA-6 flight (Glenn, 1962). A knowledge of the structure of such major near-surface currents would obviously be of value to the fishing and shipping industries, and from a broader viewpoint to nations whose climate is strongly influenced by these currents, such as Iceland, England, and Chile.

2. The discovery by Cameron (1952, 1962) that water currents in oceans, bays, and rivers could be mapped by pseudo-stereoscopic time-lapse air photography opens another possible application of space photography. Small areas can, of course, be mapped with low altitude photography, but to map large currents, such as those in the Bay of Fundy, Cameron found it necessary to use photographs with scales of 1:35,000. He suggests extension of the method to major currents such as the Gulf Stream (and to large physiographic features) by the use of 1:270,000 photographs taken from altitudes of 80,000 ft. or higher, or by the use of satellite photography.

3. L. G. Cooper, during the MA-9 flight, noticed striking color differences in the water around islands in the Bahamas, which he attributed, presumably correctly, to water depth. Conventional air photos have been used to study this, and it is interesting to note the possibility raised by Cooper's observation that space photographs can also be used to map bottom topography.

EXTRATERRESTRIAL PHOTOINTERPRETATION

The most immediate extraterrestrial use for space photography of the earth is its application to the study of pictures of other planetary surfaces, that of Mars in particular. It is interesting to note that nearly all the efforts to interpret the thousands of available pictures have been made in essentially complete ignorance of what the earth would look like under similar conditions. The problem of deducing the nature of the Martian surface is complicated by the fact that experience gained by the study of lunar features cannot be applied reliably to Mars, because the existence of a Martian atmosphere and an intermittent hydrosphere may have produced physiography more nearly terrestrial than lunar. An interesting example of the use of space photography in the study of Mars is presented by Gifford (1964).

SUMMARY

It is, of course, obvious that photography from orbital distances cannot replace aerial photography, especially for applications requiring extremely large scales. Nevertheless, it seems clear that the uniquely great coverage and perspective possible with space photography will make it an invaluable tool for many purposes, and may uncover broad features of the earth's structure whose existence has been only conjectured.

ACKNOWLEDGMENTS

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ORBITAL SENSORS FOR OCEANOGRAPHY

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ABSTRACT

ORBITAL SENSORS FOR OCEANOGRAPHY

The technique of coordinated, simultaneous multi-spectral sensing in the infrared, visible and ultraviolet bands is described and discussed. Modern infrared scanning devices producing pictorial output are described and a non-imaging radiometer for sensing ocean surface temperatures is discussed. Some previous scanner applications of oceanographic interest are described and oceanographic problems in which this type of instrumentation may be useful are listed.

INTRODUCTION

I have been asked to say something about infrared sensors as applied to oceanography and will do so shortly. First, however, I would like to say a few words about simultaneous, coordinated multispectral sensing which includes the infrared and also the visible and ultraviolet bands. Also, given some modest advancement in techniques, it will include passive microwave sensing. Following the remarks on multispectral sensing I will describe some of the modern infrared instruments and their capabilities, mention some previous applications of those instruments of interest to oceanographers and finally indicate some oceanographic problems in which infrared sensors may prove useful.

MULTISPECTRAL SENSING

It has been traditional, for the most part, to develop and use pictorial sensors in single spectral bands. In recent years some of us at The University of Michigan have begun to question whether this is the best procedure. As a result, for more than a year now we have been studying, experimentally and analytically, the utility of imagery produced simultaneously in many narrow spectral bands distributed throughout the infrared, visible and ultraviolet regions and combined in unconventional ways. Our motivation has been as follows:

Sensors of electromagnetic radiation in the optical regions, 0.3 to 15 microns, have been of the three major types

1. Calibrated radiometers
2. Relative spectrometers
3. Imaging sensors

Each of these produces a distinct type of information and is employed for a distinct purpose. The calibrated radiometers produce absolute measures of power within specified bands due to emission or reflection which are used to infer states and processes present in the object within the field of view. Spectrometers produce relative spectral power distributions due to emission, reflection, absorption and transmission which are used to infer the constituents of objects within the field of view. The imaging sensors produce pictorial data in which shapes and tones are utilized to effect detection and gross identification of objects within the field of view.

The first two instruments, radiometers and spectrometers, are normally employed in such a fashion that their precision is limited by fundamental physical processes. The same is not true for the imaging sensors so it should be possible to make significant improvements in their performance. The radiometer is limited by the irreducible internal noise power of the instrument relative to the available signal power in the spectral band used. This is a fundamental limit. Potentially the spectrometer has two types of fundamental limit. First, like the radiometer, is the limit set by the irreducible internal instrument noise in relation to the available signal power in each of the spectral bands resolvable by the device. Second is the extent of the uniqueness of spectral signatures present in nature. There is every reason to believe that the former is the effective limit. In other words, no improvements in sensitivity and spectral resolution have yet failed to yield additional meaningful spectral structure. The fundamental limits on imaging sensors are the same two which limit spectrometers. However, as normally used, imaging sensors are contrained, not by either of these fundamental limits, but by the mode of employment. Normally imaging sensors are employed to record spatial distributions of power within a single spectral band. Thus performance is constrained by the uniqueness of spectral signatures within single bands. This is equivalent to attempting to do spectral analyses using single lines rather than using the entire series or some distinctive part thereof, i.e., the spectral distribution, and is the reason why the popular search for a "best" film-filter combination cannot produce more than isolated improvements. It is obvious from spectroscopic results that improved and additional image contrasts can be obtained by producing images simultaneously in more than one spectral band. Since pictorial use of both tone and shape rests ultimately on the presence of contrast, this is the natural route to improvement of imaging sensors. Furthermore, this route involves overcoming engineering difficulties rather than struggling to approach asymptotically some fundamental limit.

It is clear that imaging sensors making use of many spectral bands will provide much additional information but it will not be useful unless improved methods of handling and displaying the information are developed. The three most common methods of displaying multispectral image data are demonstrably deficient; they are the simultaneous presentation of the image in each band, the use of color film and the use of multiple pass band filters with a black and white film.

The simultaneous presentation of images from a number of different spectral bands is currently being practiced to some extent. It is clear that, in general, this places additional burdens on an already overloaded interpreter. Furthermore, many kinds of joint use of such information are very difficult for a human being to effect. In the restricted case of comparing the spectral series from several samples the method is feasible but it breaks down when the several photographs are pictorial with complex structure containing many different types of objects.

The use of color film permits superimposing simultaneous images in different bands and makes the interpreter's task manageable. It, however, is restricted to no more than three simultaneous spectral channels and there are good reasons for believing that the optimum number is much greater than three. For instance, color film cannot simultaneously do full justice to the three dominant visible colors and display the distinctive behavior of botanical materials just outside the red end of the visible spectrum.

It is not so immediately obvious that the multiple band-pass filter used with a single black and white film is not optimum but it, and in fact any film-filter combination, can be shown to be unduly restrictive in capability.

As a simplified example consider a black and white film filter combination having a composite pass band consisting of the joint effects of three sub-bands. Then the film density, d, will be

$$d = t_1p_1 + t_2p_2 + t_3p_3$$

where t_i is the transmission and p_i the incident power in the i^{th} sub-band. The equation is linear and both the t_i and the p_i are positive so d is represented by a very restricted class of equation. To illustrate further assume each product t_ip_i to have values of only either 0 or 1. Then all the possible different conditions are given in Figure 1. It is apparent that there are eight different conditions of power passing through the filter. However, in recording on film one-half of these possibilities are not realized because the film cannot distinguish among conditions 2, 3, and 5, nor among 4, 6, and 7.

$$d = t_1 p_1 + t_2 p_2 + t_3 p_3$$

Condition	Band 1	Band 2	Band 3	d
1	0	0	0	0
2	0	0	1	1
3	0	1	0	1
4	0	1	1	2
5	1	0	0	1
6	1	0	1	2
7	1	1	0	2
8	1	1	1	3

Figure 1

A much more flexible method is needed to put the information in each sub-band in some form (probably electronic) which does not restrict unnecessarily the operations which can be performed. A typical operation required to recognize a spectral signature or to enhance contrast is to classify an object on the basis of both having specified powers in some bands and no power in some other bands as in the identification of a spectral series. This operation cannot be performed by the linear equation above. Given the freedom to perform the required operations on the outputs of the individual channels of a multispectral sensor, a scanning printer can be programmed to form an image having enhanced contrast for any objects having spectral differences from their surroundings. Objects having no spectral differences from their surroundings cannot be differentiated from those surroundings by any electromagnetic technique. In this sense the method is optimum.

In an effort to evaluate the improvements attainable by the simultaneous multispectral technique The University of Michigan has, for slightly more than a year, been generating aerial multispectral imagery in a number of narrow bands distributed throughout the infrared, visible and ultraviolet bands. One program, for the U. S. Army Electronics Command, has generated imagery at two week intervals for one complete annual cycle. On each occasion imagery was generated at intervals of two to three hours for a complete diurnal cycle. Thus the parameters of target type, spectral band, diurnal cycles and annual cycles may be studied. The data reduction is just starting, so only preliminary examples of special effects are available. The imagery is classified, so it cannot be shown here.

More recently, under sponsorship of the National Aeronautics and Space Administration, another program has been started. It is generating multispectral imagery of crops and soils at the U. S. Department of Agriculture Experimental Station adjacent to Purdue University. It is being carried out jointly by The University of Michigan and Purdue University with support from the U. S. Army Electronics Command and the U. S. Department of Agriculture. Imagery is being generated on five occasions distributed throughout the 1964 growing season. On each occasion imagery is obtained at six times, distributed throughout a diurnal cycle. This imagery is also classified, so it cannot be shown here.

Examination of the imagery produced in the many individual bands under these programs verifies that nature does have the spectral structure upon which we hope to capitalize. In order to realize the implied benefits two things must be done: the nature of the processes for combining the multiband information into single images must be deduced by examination of the spectral characters of objects of interest relative to their backgrounds, and means for implementing the processes must be found. A method exists for implementing virtually any realistic processing scheme. It consists of reading the densities of the individual images or channels into a digital computer and printing out of the computer a composite picture based on joint use of the information in the many bands. To implement this operationally will require solving some engineering problems associated with automatic channel synchronizers and printers but no basic problems remain unsolved. We are attacking the problem of deducing processing methods by examining the imagery in an attempt to write rules directly and also by manually reading densities for selected groups of targets for insertion into a computer where certain types of statistical manipulation will be performed.

INFRARED INSTRUMENTATION

I assume you are all more or less familiar with radiometers and spectrometers so there is no need to describe them here. The same may not be true of the image forming instruments so they will be described briefly.

At present there exists no photographic films which will function satisfactorily at wavelengths longer than approximately one micron. Infrared image tubes do exist but none now exhibit simultaneously the sensitivity and speed of response obtainable with small non-image forming thermal detectors. Therefore the latter are employed in all critical applications. To obtain images with these, it is necessary to focus a small instantaneous field of view on the detector and then scan the IFOV in some regular pattern. The signal resulting at the output of the detector is electronically processed and used ultimately to activate a light source which is scanned in the same pattern and recorded on film or displayed dynamically on a cathode ray tube. The most common scan pattern is shown in Figure 2. The scan perpendicular to the flight line is caused by a rotating element in the instrument. The displacement of successive scan lines is caused by the motion of the carrying vehicle. The result is an endless television-type raster.

A typical scanning optical system is shown in Figure 3. The detector rests at the Newtonian or Cassegrainian focus of a simple telescope. In front of the telescope is a multi-faced prism with flat reflecting surfaces inclined usually at 45° to the optical axis of the telescope. The prism rotates about an axis coincident with the axis of the telescope and generates the scan normal to the flight path when the optical axis and flight path are parallel.

So much for the gross features of the instrument. Now consider an example of interest in oceanography. The infrared signal to be expected from the sea is illustrated in Figure 4 for sea temperatures of + 35° and - 2° Centigrade. The curves are blackbody curves since water has an average emissivity of 98% in the region 4 to 12.5 microns. Also plotted on the same curve is a portion of the atmospheric transmission curve for a 1,000 foot path. (A more complete atmospheric transmission curve is shown in Figure 5.) Notice that the peak emission for temperatures between +35° and -2° Centigrade lie between 9 and 11 microns in a region of good atmospheric transmission. The transmission in this region is as good or better than it is in the visible. Approximately 29% of the total emitted sea radiation falls in the good transmission range between 7.5 and 12.5 microns. In the worst case, the lower temperature, the incremental radiation for a 1° Centigrade temperature difference is 4×10^{-5} watts/cm² steradian.*

Some fraction of the emitted power will be focussed on a detector by the optical system of a scanner. Detectivity curves for most of the important modern detectors are shown in Figure 6. The detectivity D^* is normalized for detector area and electrical bandpass, i.e.

$$D^* = \frac{\sqrt{A \Delta f}}{NEP}$$

where A is detector area and Δf is electrical bandpass. NEP is a radiant power level which will cause the same mean detector output as the inherent noise power of the detector. For a 1 cm² area and a 1 cps bandpass, D^* is the inverse of NEP. For that simple case, detector sensitivities of between 10^{-10} and 10^{-11} watts are available in the region of interest.

Rather than go through some calculations here, I will present in Figure 7 some calculations first presented by Mr. Eric Wormser at one of The University of Michigan summer courses several years ago. Subsequently, Mr. Wormser built this equipment for which the calculations were made and the figure presents a comparison between the calculations and the measured performance of the instrument. They compare favorably.

That instrument is a calibrated radiometer designed and built for measuring sea surface temperatures from an altitude of 1,000 feet. Extrapolation of this performance to an orbit altitude of 150 miles indicates conservatively that for fields of view not more than one mile in diameter at the surface it is feasible to map temperature differences of 1° Centigrade or less with collector diameters less than 30" diameter. Hence it appears practical to map sea surface temperatures from orbiting platforms. The details of an adequate instrument and its precise performance will require a more refined design study.

EXISTING APPLICABLE INFRARED RESULTS

A significant amount of infrared radiometric and pictorial measurements applicable to oceanographic problems have been made. Unfortunately they are, for the most part, classified and efforts to obtain permission to show some of them at this meeting were unsuccessful. Therefore, I can only describe some representative cases.

*Holter, et al, p. 384

Strip Mapping Scanner - Method of Scan

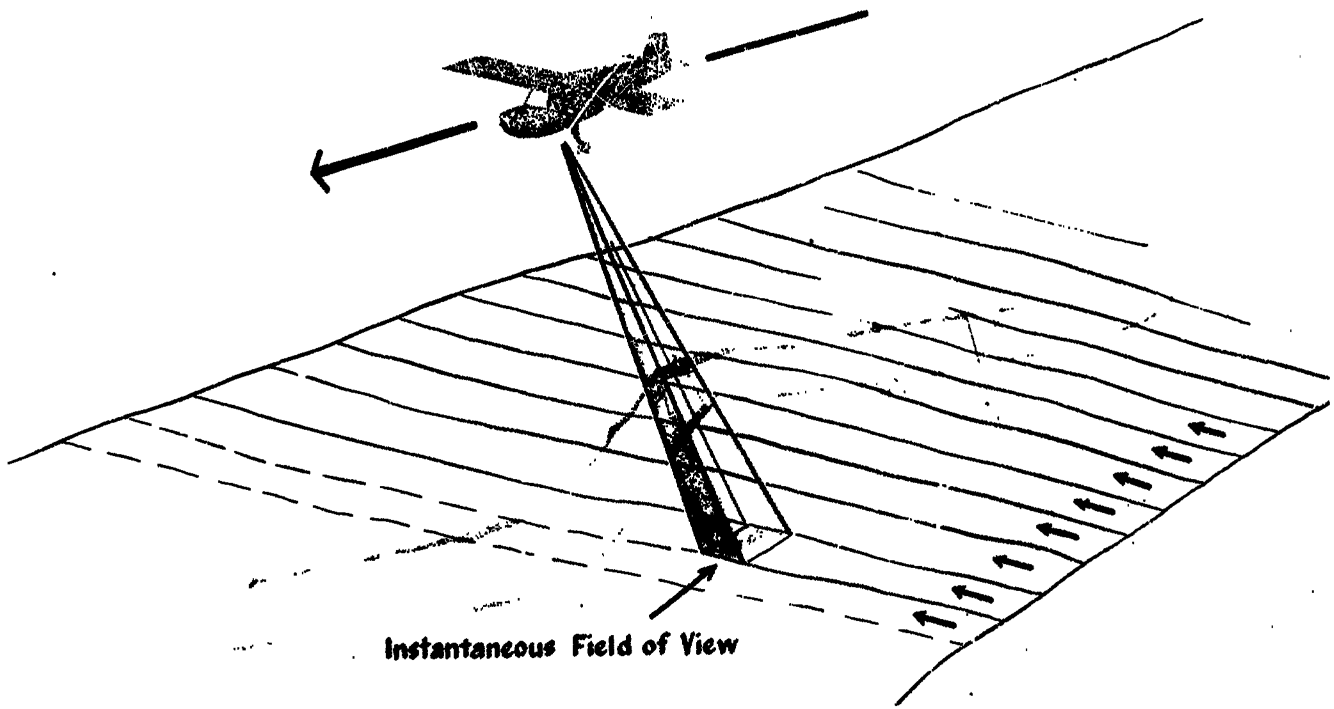


Figure 2

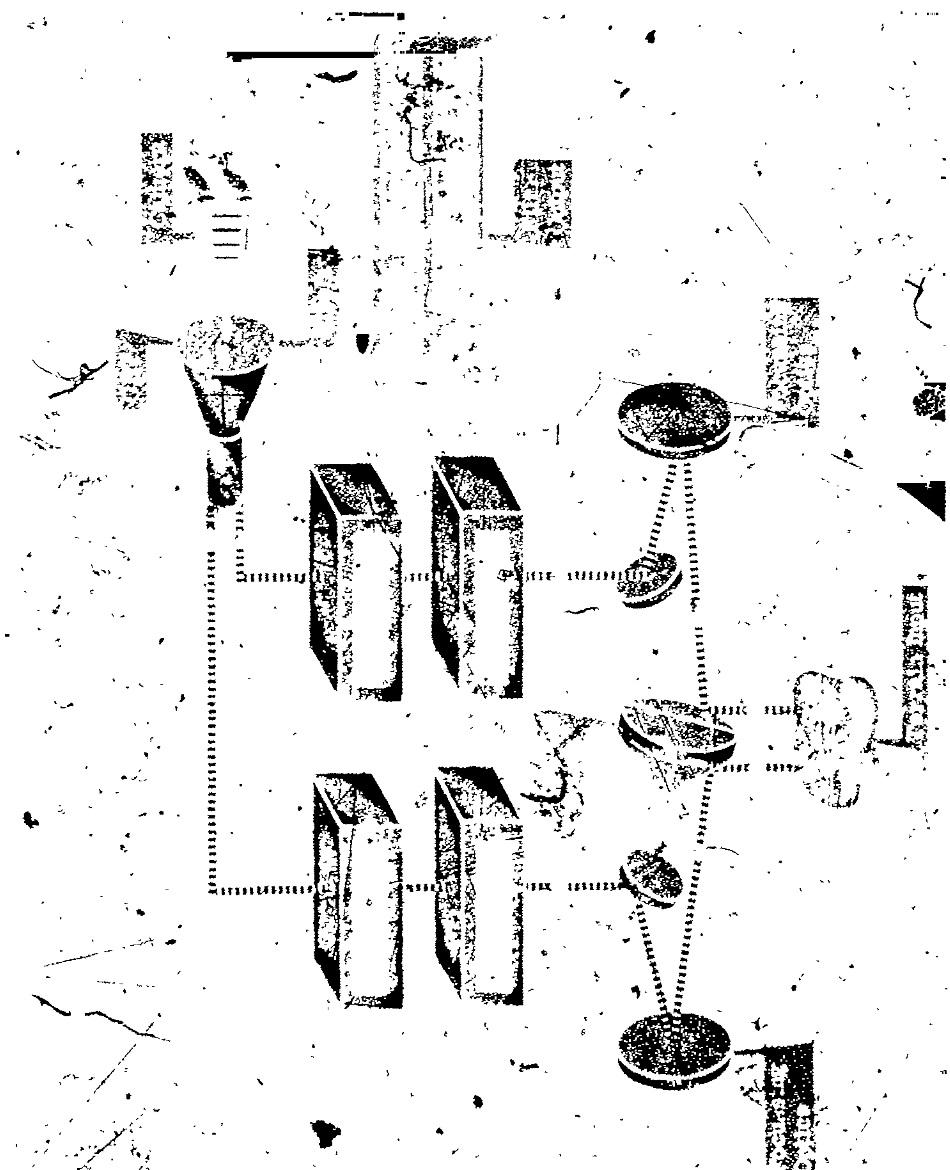


Figure 3

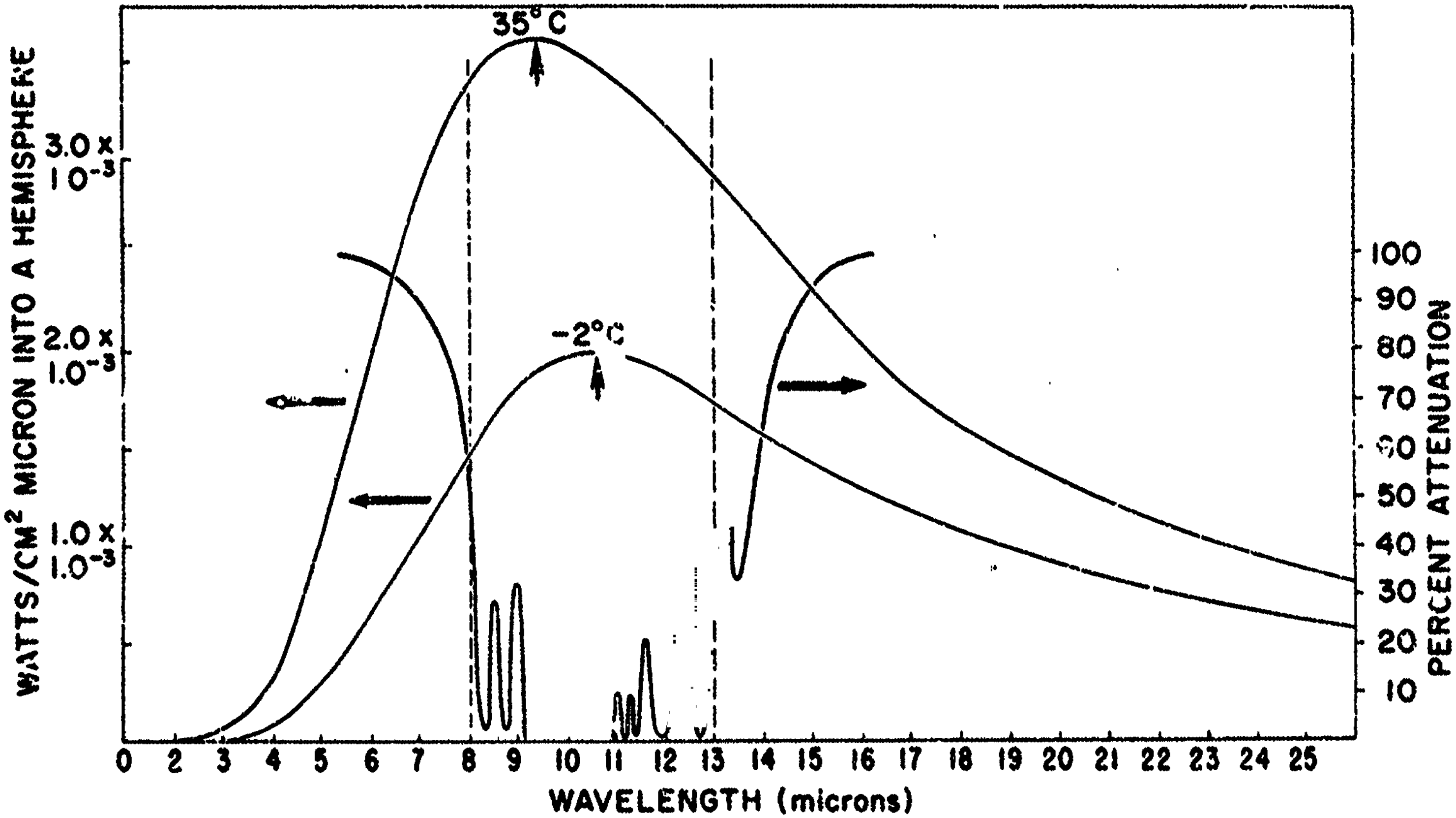

35°C
-2°C
3.0 x 10^-3
2.0 x 10^-3
1.0 x 10^-3
WATTS/CM² MICRON INTO A HEMISPHERE
0 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
WAVELENGTH (microns)
100 90 80 70 60 50 40 30 20 10
PERCENT ATTENUATION

Figure 4

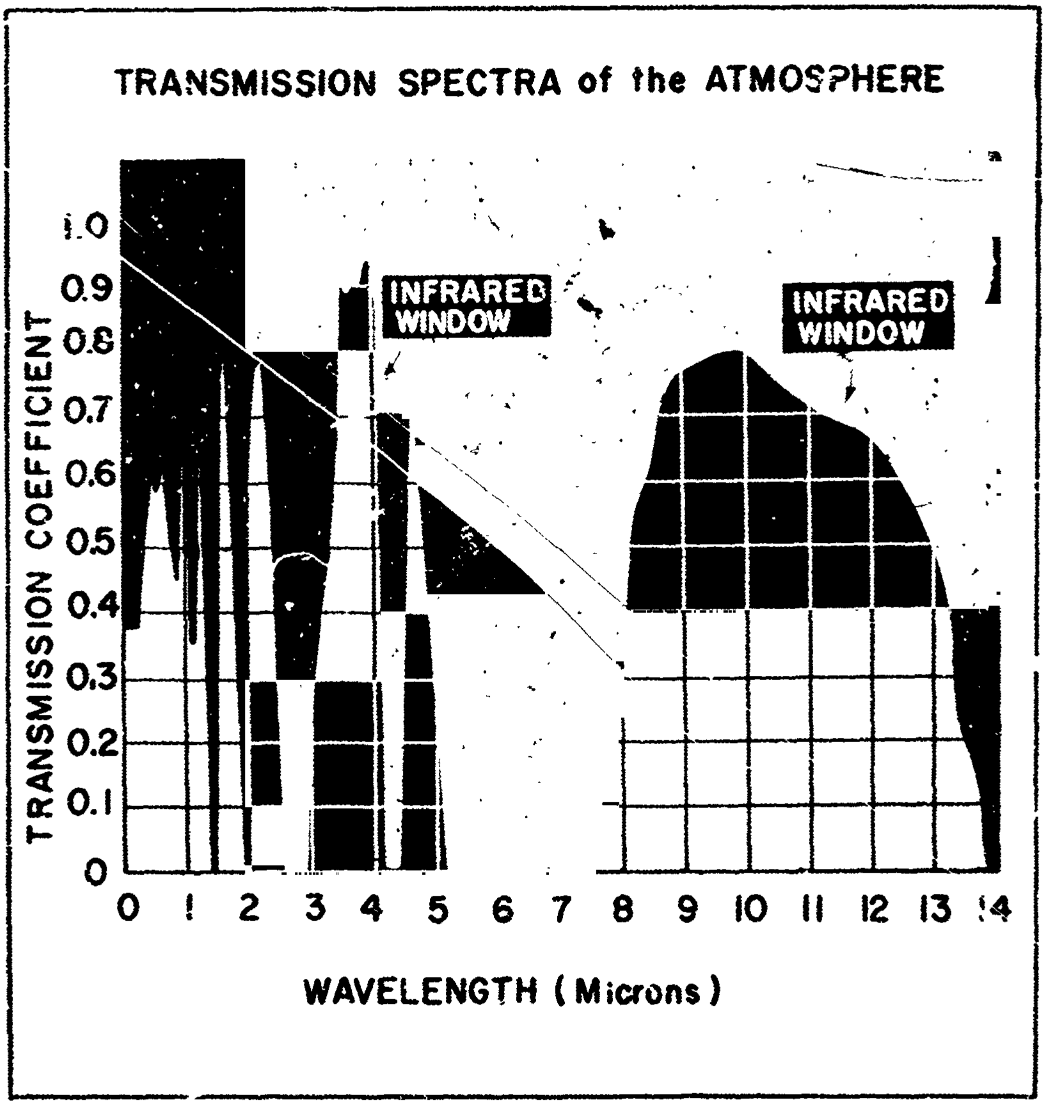

TRANSMISSION SPECTRA of the ATMOSPHERE
INFRARED WINDOW
INFRARED WINDOW
TRANSMISSION COEFFICIENT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
WAVELENGTH (Microns)

Figure 5

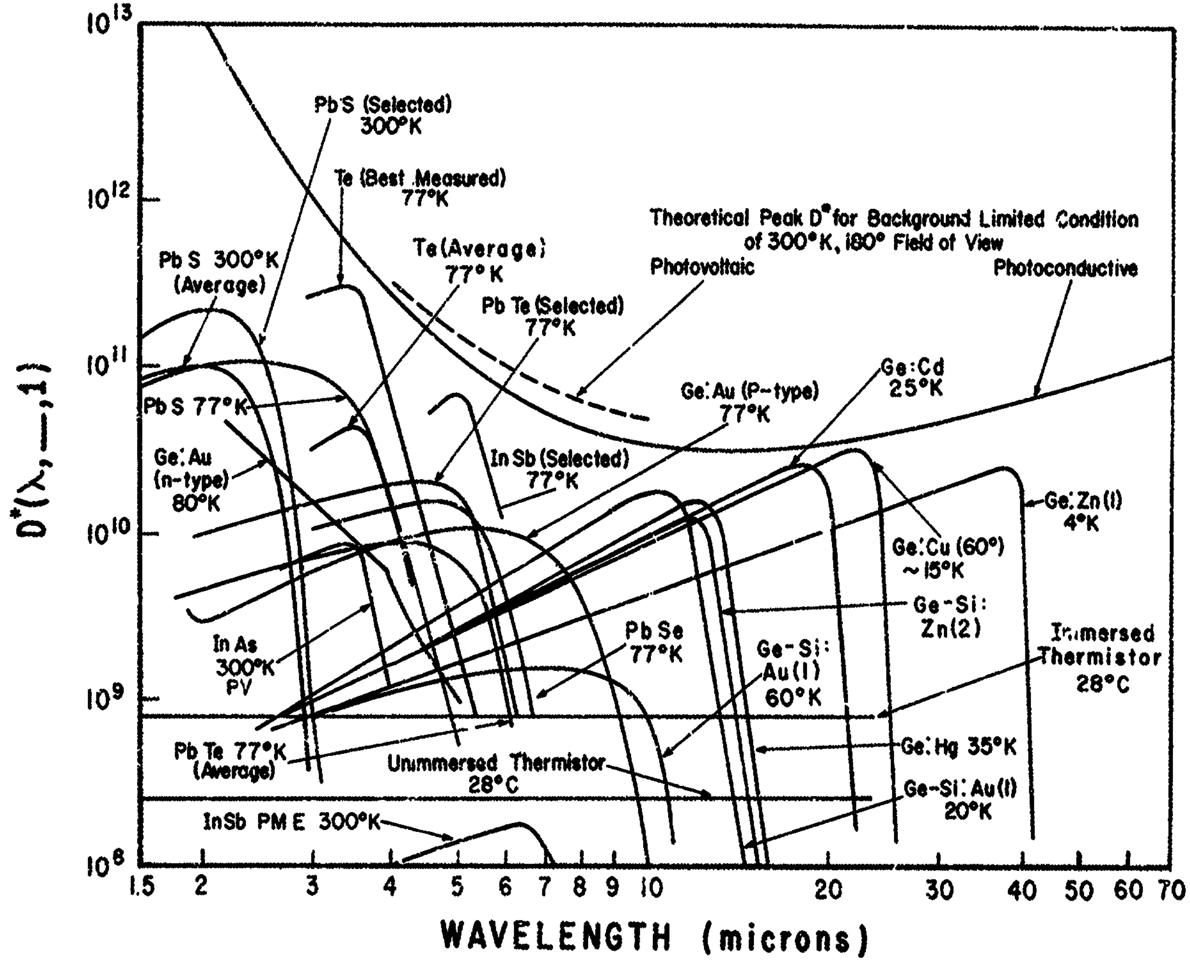


Figure 6. Published in "Fundamentals of Infrared Technology", by M. Holter et al, Macmillan, 1962. Courtesy The Macmillan Publishing Company.

Infrared imagery of Ford Lake, a dammed portion of the Huron River near Ypsilanti, Michigan, has been made showing surface thermal structure in the relatively stagnant lake. Imagery also exists of the efflux of the Detroit River into Lake Erie showing current patterns and vessel wakes. Imagery further upstream in the Detroit River shows industrial discharges into the river, e.g., cooling water from steel mills enters the river at considerably higher than stream temperature and shows clearly.

Imagery in the vicinity of the Florida Keys clearly shows current patterns and the presence of submerged reefs.

Imagery exists of the St. Lawrence Gulf and the Arctic basin showing patterns of sea ice. Much structure is apparently related to the age of the ice and amount of snow cover. Also coastlines covered by ice extending well out over the adjacent sea are sometimes discernable by thermal patterns in the ice surface at the coast line. Thermal structure is also apparent on the surface of the Greenland Ice Cap. These are especially noticeable in the snow bridges over crevasses and provide a good means of detecting hidden crevasses.

All of the imagery referred to was obtained from airborne platforms and in many cases a calibrated radiometer was operated in conjunction with the imagery scanner.

It is the general conclusion of those of us who have examined such imagery and radiometric measurements that the instrumentation and capability for making measurements of use in oceanography are in relatively satisfactory shape and can be extended to orbiting vehicles. On the other hand, experience with these methods is, as yet, very limited, so the greatest current need is much increased utilization of the methods to assess their full capabilities and limitations in oceanography.

The question of security classification is a serious obstacle and is receiving the attention of a great many people. There are indications that within the coming year a significant relaxation of those restrictions will be achieved.

Figures 8 through 13 show some of the few infrared images that have been declassified to date. Figures 8 through 12 have been reproduced from half-tone prints so the quality is somewhat degraded as compared with the originals.

Figure 8 shows the tip of Manhattan Island at night. Figures 9, 10 and 11 are enlargements of sections of Figure 8. The wavelength band represented is approximately 1 to 6 microns. The picture tones are due entirely to emitted radiant power, the lighter tones corresponding to greater powers (i.e., usually due to higher temperatures). Notice that the water in the rivers and the lake in Central Park is warmer than the terrain. Terrain typically cools faster than water so it is normal for water to appear warmer some time after sunset.

There is physically much thermal structure in the surface of the water but it does not show in the Manhattan images because the instrument gain was set to show terrain thermal structure. This illustrates a general feature of these instruments. The dynamic range of the thermal signals present in nature and available in the detectors and electronics is greater than can be displayed on film in a form available to the human eye. Therefore the instrument gain must be set to show either, but not both, the terrain or water thermal structure. A later figure shows thermal structure on a water surface.

Figure 12 shows Love Field in Dallas, Texas. The spectral region is approximately 8 to 14 microns. Notice the white streaks behind the jet aircraft in the center of the figure. The aircraft is taxiing and the white streaks are the hot jet exhaust gasses.

Figure 13 shows a lake in the western United States with a stream emptying into it. The spectral region is 8 to 14 microns and the instrument gain is set to show surface thermal structure in the water, and there is a great deal of such structure. The thermal structure of the terrain in the upper left of the figure does not show well at this gain setting.

Design Criteria Compared with Performance

	Initial Design Criteria	*Actual System Characteristics*
Thermistor detector		
Area	$1 \times 1 = 1\ mm^2$	$2 \times 2 = 4\ mm^2$
Time constant	8 msec	2.5 msec
NEP	1.25×10^{-9}	8×10^{-9}
Optics		
Diameter	2 in. (50 mm)	3 in.
Focal length	2 in.	2 in.
Field of view	$0.02 \times 0.02 = 4 \times 10^{-4}$ sterad	$0.04 \times 0.04 = 16 \times 10^{-4}$ sterad
Chopping rate	20 cps	20 cps
Reference bandwidth	30 cps	100 cps
NEPD for 1-cps system bandwidth		
$\frac{\text{detector NEP} \times \text{bridge factor} \times \text{chop factor}}{\text{effective aperture} \times \text{bandwidth ratio}}$	$= \frac{1.25 \times 10^{-9} \times 2 \times 4}{6.4 \times \sqrt{30/1}}$	$= \frac{8 \times 10^{-9} \times 2 \times 4}{9.6 \times \sqrt{100/1}}$
	$= 2.8 \times 10^{-10}$ watt/cm^2	$= 6.6 \times 10^{-10}$ watt/cm^2
Energy received per $\Delta T = 1°C$ at instrument	1.6×10^{-8} watt/cm^2	6.4×10^{-8} watt/cm^2
NET	$= \frac{2.8 \times 10^{-10}}{1.6 \times 10^{-8}} \sim 0.02°C$	$= \frac{6.6 \times 10^{-10}}{6.4 \times 10^{-8}} \sim 0.01°C$

Figure 7. Courtesy The Macmillan Publishing Company.

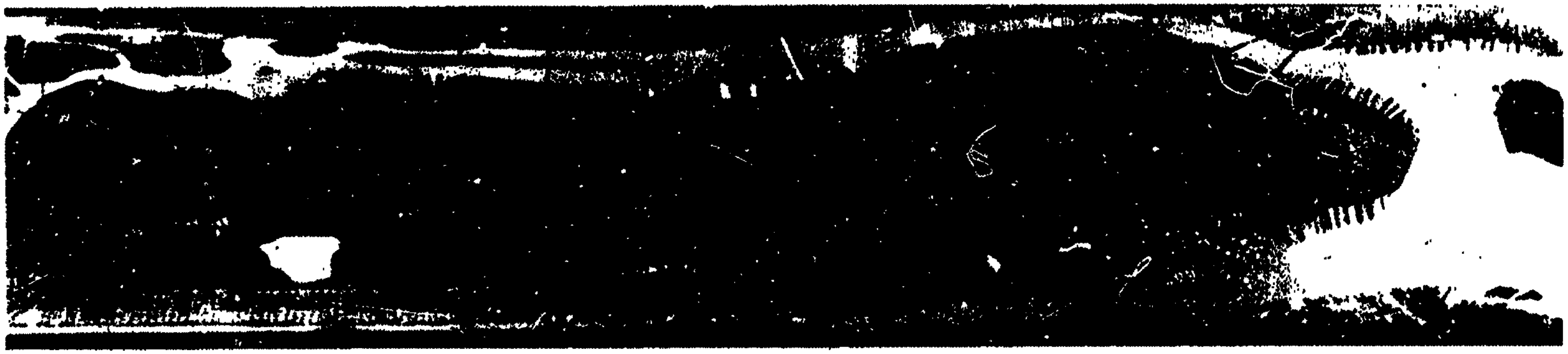


Figure 8. Infrared Image of Manhattan Island at Night. Courtesy Aviation Week and Space Technology.

Fi[illegible]. Infrared Image of Manhattan Island at Night. Courtesy Aviation Week and Space Technology.

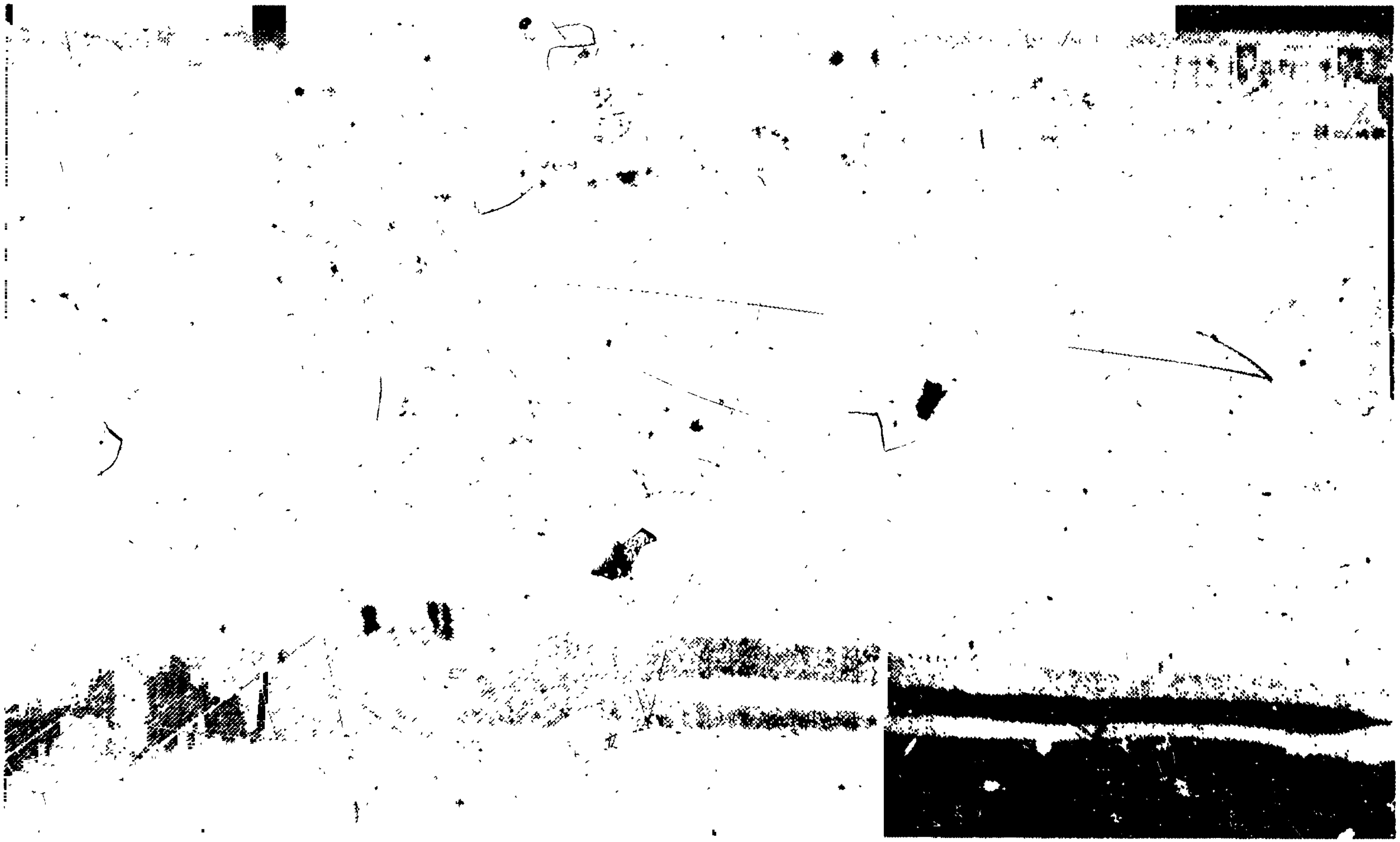


Figure 10. Infrared Image of Manhattan Island at Night. Courtesy Aviation Week and Space Technology.

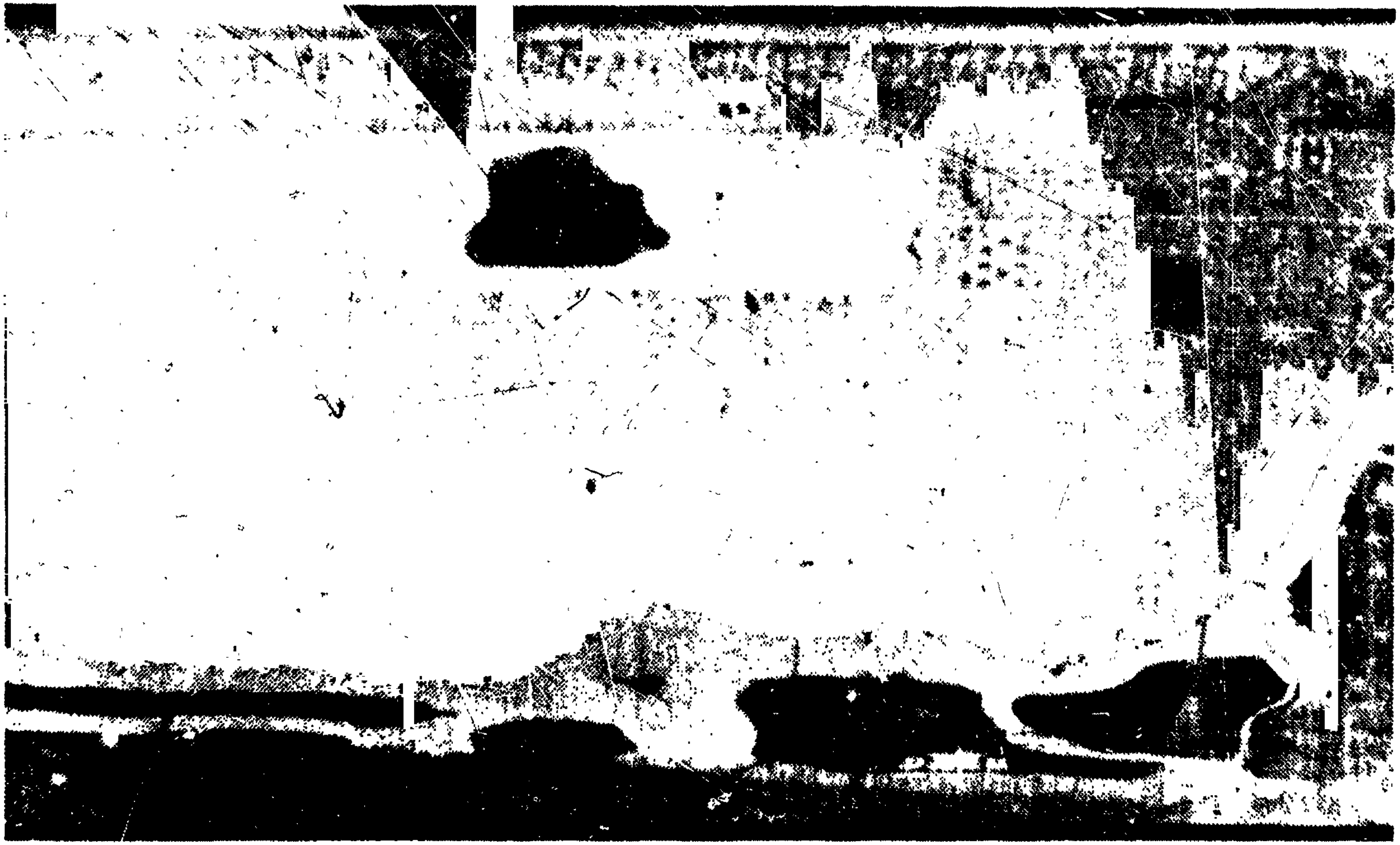


Figure 11. Infrared Image of Manhattan Island at Night. Courtesy Aviation Week and Space Technology.

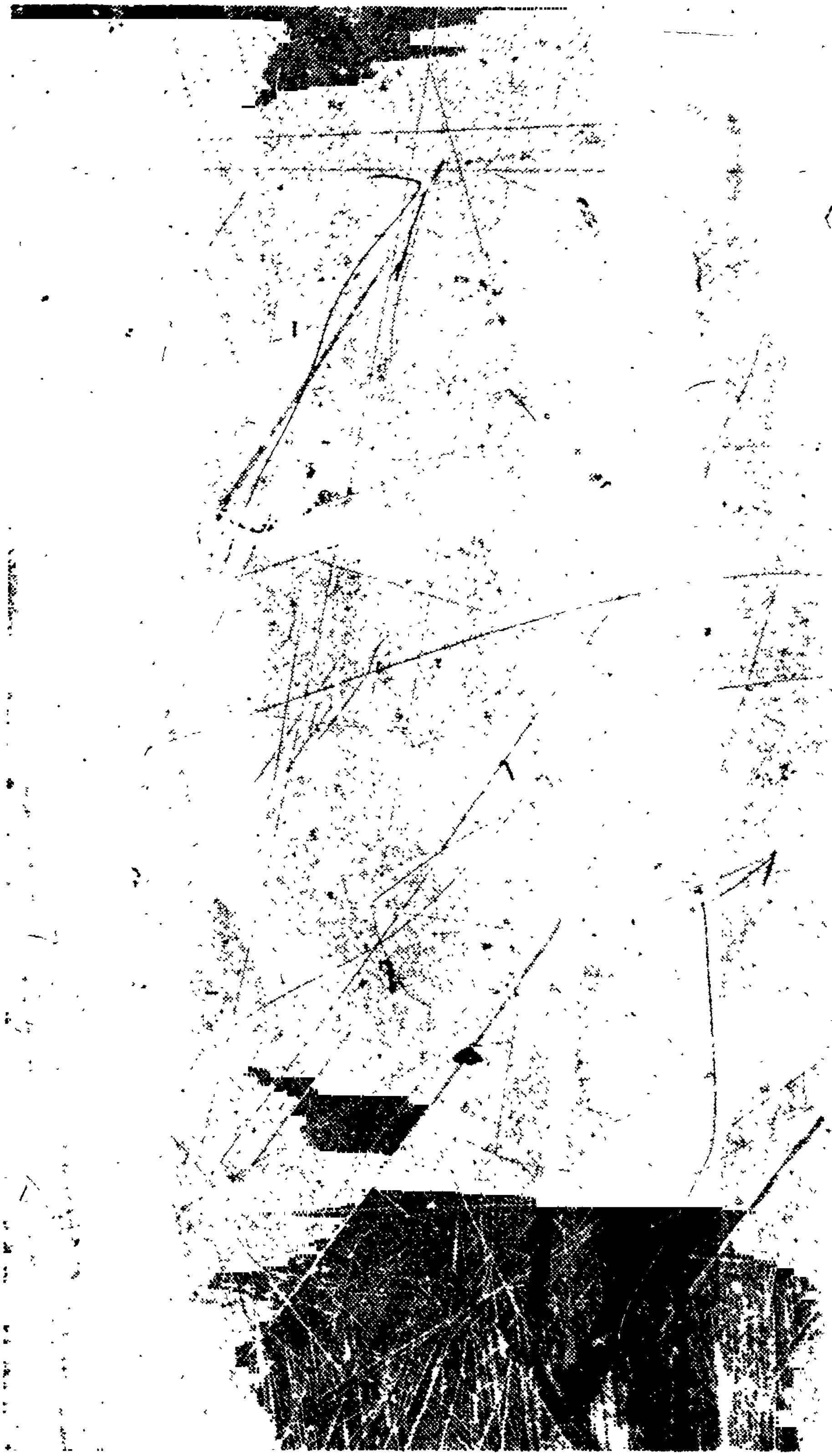
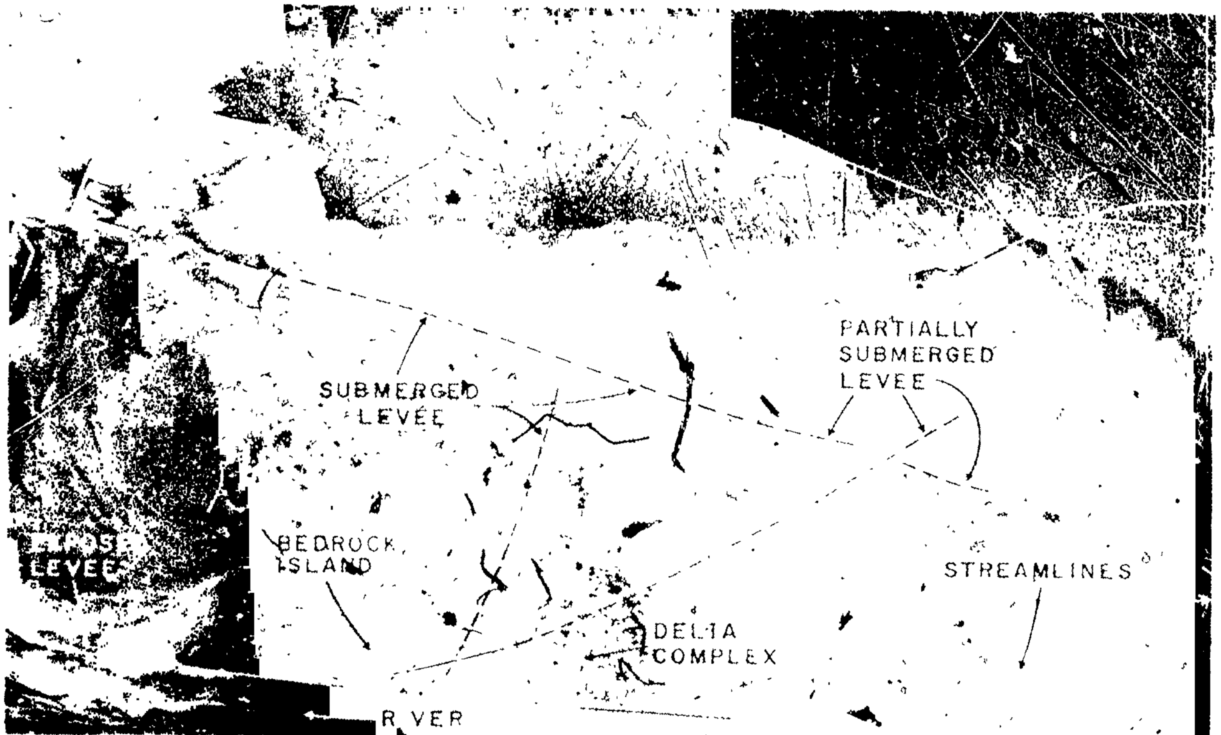


Figure 12. Love Field in Dallas. Courtesy Aviation Week and Space Technology



ANALYSIS OF NEARSHORE AREA INFRARED IMAGERY

This image demonstrates the application of IR mapping techniques to analysis of marine near-shore physical features. The annotations pinpoint a few aspects of such investigations and are illustrative of the features which may be identified in such imagery by interpretation specialists skilled in IR image analysis.

Figure 13. Courtesy HRB-Singer, Inc., a subsidiary of The Singer Company.

CONCLUSION

In conclusion infrared radiometers and imaging scanners, or preferably calibrated radiometers coupled with a simultaneous multispectral imaging system, are in their present state of development applicable to many oceanographic problems. Furthermore, it is clear that those techniques can be extended to orbital usage. They appear to be capable of generating data of importance to all but one (Item m, Thermocline depth) of the oceanographic problems listed for Wednesday's discussion in the tentative agenda.

The greatest current need is for extensive oceanographic use of these instruments from airborne platforms to establish optimum methods of application. This will require a four engine aircraft capable of operation up to at least 10,000 feet altitude. It is recommended that the initial operation not be above 10,000 feet because of the difficulties associated with crew requirements for oxygen and special equipment requirements above that altitude. Simultaneously design work for an orbiting system should proceed. It is desirable that the initial orbiting experiments be carried out on manned orbiting vehicles because of equipment set up, aiming and detector cooling operations. If initial orbiting operation is on unmanned vehicles, some sacrifices in capability will probably have to be made and probably uncooled detectors will need to be used.

THE IMPORTANCE OF MAN IN THE STUDY OF WAVES AND CURRENTS FROM MANNED SATELLITE

John C. Freeman, Jr.

National Engineering Science Company

The obvious function of a man in a measuring system is that of a weak power source which shows discretion. (e.g. He can select and pull a significant switch).

The importance of the man is emphasized by my experience in preparing for this conference:

When I asked myself how to measure waves from an unmanned satellite the answers all included devices in the ocean. When the question of measuring waves from a manned satellite is considered the possibility of photographing surf and infrared photography of waves radiating from a storm present themselves immediately.

The reason that we can consider a man as making this possible is that he is a good "shoreline seeker" and a good "storm seeker." A good telescopic camera guided by a man can take good enough photographs to study wave lengths and possibly some indication of wave heights.

When satellites and aircraft are compared as vehicles for study of the ocean, the satellite becomes less expensive for gathering routine world-wide data over areas measured on a planetary scale.

MAN IN SPACE

Bernard Scheps

U. S. Army Engineer, Geodesy, Intelligence & Mapping Research
& Development Agency, Fort Belvoir, Virginia

1. Man will be in space - how can we use him?

2. What better decision and discrimination machine can we make and how can we pack it in less volume with less weight?

3. What more efficient set of servos, circuit monitors and error correcting devices can be made with less weight and volume?

4. How will we instrument for an effect or phenomenon which we don't know exists in a visible form (or otherwise)? Man is needed to turn the disadvantage of the unanticipated into a gain.

5. How could we better discriminate between data to be recorded and stored and data of transitory or realtime interest?

6. If we don't start exporting people where will we put them?

EXPRESSION OF OPINION

Robert G. Paquette

GM Defense Research Laboratories, Santa Barbara, California

1. We know the technological ability exists to do many of the things we want, if we want them badly enough.

2. The program will be a waste unless there are oceanographers actively associated with the program who want the data badly enough to analyze it, interpret it, be sure it has real meaning, and to go through the struggles of communicating with the instrument designer.

3. The probability is high that the first instrumental techniques will be faulty or worse. Here is where interest in the results and devotion to the idea will be a paramount requirement in the oceanographer. There needs to be a mechanism for continual improvement in equipment until satisfactory results are being obtained. There needs to be a communications bridge between oceanographer and instrument designer.

4. You need to go slowly enough to be sure your results are good for something before going on.

5. You must face the economic question: "Does the data justify the cost?" I don't think it does if you don't start using it immediately and keep up with interpretation. Even then it may be too expensive.

This isn't really a pessimistic attitude. I would just like to see people think of finding a good, devoted oceanographer to live with any measurement program which is to begin.

RECOMMENDATIONS OF THE PANEL ON SEA SURFACE TEMPERATURE

John P. Tully, Chairman
Pacific Oceanographic Group, Nanaimo, B. C.

Members

J. J. Shule, Jr. | J. F. T. Saur, Jr. | T. Laevastu
M. K. Robinson | H. J. Wetzstein | and others

BACKGROUND

Climatological charts are (or soon will be) available, which define the mean monthly sea surface temperature and its standard deviation both numerically and in isotherms.

Oceanographic information services (1) are in existence which can accept numerical weather and oceanographic information by radio and teletype, construct synoptic charts of many parameters, combine these into derived products, and distribute the product by radio and telex in numerical or facsimile format, all within a space of a few hours. Resources are available to accept, process, interpret and disseminate oceanographic data on a daily or shorter time basis. The major weakness is the lack of daily data input from large areas where there are few or no observatories.

Polar orbiting satellites may provide means to increase the frequency, range and density of observations.

REQUIREMENTS

The ultimate requirement is for synoptic sea surface temperature charts with observations on a 50-mile or less grid spacing (both directions) at daily intervals. One hundred mile spacing or weekly intervals are the limits of acceptability. Consideration should also be given to providing a resolution area of not greater than 5 nautical miles for special coastal studies.

The data should show the real temperature at a point, or the mean value in an area 25 miles square or less, within ± 0.5 C°. The data should discriminate local variations within 0.2 C° in a distance of 50 miles. The data should be corrected for diurnal heating and cooling.

If this accuracy can be provided it will identify ambient variation in space from day to day and in successive years. Also, it will define the seasonal sequence of change.

In addition to sea surface temperature it is necessary to know the heat budget in order to forecast possible changes. This implies intimate knowledge of cloud cover, moisture content of the near surface air, wind speed, and low level air temperature.

These data should be processed through existing weather and oceanographic service facilities*.

These data are required for existing fisheries, military and civil purposes. These purposes have been defined in detail at a number of conferences and may be obtained from the Federal agencies concerned. Once the service is established, considerable user expansion should be anticipated.

*U. S. Navy Oceanographic Office, Environmental Prediction Section, Suitland, Maryland; U. S. Fleet Numerical Weather Facility, Monterey, California; Royal Canadian Navy, Weather/Oceanographic Centers at Halifax and Esquimalt, Etc.

PROCEDURES

On the basis of current experience with airborne infra-red radiometry, Tiros satellite data, and recent advances in active and passive radiometry in the far infra-red and microwave parts of the electromagnetic spectrum, it appears that it may be possible to provide adequate sensing equipment. A polychromatic sensing array is indicated in which the combined data could be analysed to determine the pertinent parameters.

A games (oceanometric, multiple correlation) analysis should be made of several type situations defined by existing Tiros, meteorological and oceanographic data to determine the minimum optimum combinations of sensors that would be required. This is a computer project. From such an analysis the hardware requirements would be defined. Then the feasibility of construction, orbiting, data readout, processing and analysis could be determined.

A second and no less important application is to use the satellite as a means of interrogating anchored or drifting weather/oceanographic buoys. The necessary technology appears to be well developed.

It appears evident that crucial experiments in the development of system components for these requirements will be made from the manned satellites. However, the short duration of such projects precludes their use for continuous monitoring.

AIRBORNE OCEANOGRAPHIC PROGRAMS OF THE TIBURON MARINE LABORATORY AND SOME OBSERVATIONS ON FUTURE DEVELOPMENT AND USES OF THIS TECHNIQUE

James L. Squire, Jr.

U. S. Department of the Interior
Fish and Wildlife Service
Bureau of Sport Fisheries and Wildlife
Tiburon Marine Laboratory, Tiburon, California

The Tiburon Marine Laboratory is presently conducting two synoptic oceanographic programs utilizing low altitude aircraft. The program objectives are the determination of infrared radiation from the sea surface and the monitoring of the distribution and abundance of pelagic schooling species. Both programs have been in operation for more than one year, and from the results to date certain conclusions can be made as to the effectiveness of the programs and what research may be desirable to make maximum use of the increase in scope and frequency of observation that high altitude scanning systems may provide.

CURRENT LOW ALTITUDE PROGRAMS

INFRARED RADIATION (SEA SURFACE TEMPERATURES)

In August 1963, a monthly survey was initiated of three Pacific coastal areas using an airborne infrared thermometer. These surveys are conducted in cooperation with the U. S. Coast Guard, who furnishes a UF-2G (Grumman Albatross) for flights of 6 to 7 1/2 hours duration in each area. These flights serve a dual purpose of providing an aircraft from which we can conduct oceanographic studies and a navigation and familiarization mission for Coast Guard pilots and crew.

The primary objective of the synoptic program is to provide a more detailed picture of surface isotherms on the continental shelf than previously available to assist in determining how the ocean environment influences the distribution of fishery resources. During the past year 40 synoptic charts have been produced and distributed to interested persons and oceanographic and meteorological laboratories.

Surveys are conducted over the continental shelf; the northern survey area extends from off Cape Flattery, Washington, south to Cape Lookout, Oregon, approximately 102 kilometers (55 nautical miles) south of the Columbia River. The central survey area extends along the coast of California from Point Arena south to Point Sur. The third survey area extends south from Point Arguello to Point Salsipuedes, approximately 61 km. (33 n.m.) south of the United States--Mexican border. All survey areas use a sawtooth flight pattern and cover from the shore to approximately 74 km. (40 n.m.) offshore in the northern and central areas and up to 148 km. (80 n.m.) offshore from southern California. The flight elevation on the track line is maintained at about 152 meters (500 ft.) or less to minimize the effect of haze. The infrared unit is now being calibrated in flight, and comparative simultaneous surface and airborne observations are being made with the assistance of U.S.C.G. lightvessels and the U.S. Navy Electronics Laboratory's oceanographic tower at San Diego.

The infrared equipment used in these surveys is manufactured by the Barnes Engineering Company, Stamford, Conn., and models 14-312 and IT-2 are currently in use. Information from the infrared unit is recorded continuously on a Varian G-14 graphic recorder.

The optical field of view of the infrared detector is $3^{\circ} \times 3^{\circ}$, equalling a field of view approximating 209.2 $m.^2$ (686.4 sq. ft.) at a 152 meter (500 ft.) elevation. The usual flying speed of the UF-2G during the surveys is 250 km. per hour (135 knots) (69.5 meters/sec.), resulting in the infrared system averaging surface temperature observations at a rate of 1,820 $m.^2$ per second. The chart record is read out every 30 seconds, and four observations

(2 min.) are averaged. These two-minute averages are then placed on the master chart at the midpoint of travel and isotherms are drawn to these data.

PELAGIC FISH MONITORING

In several commercial fishing areas along the U. S. mainland aerial fish spotters are used to guide surface fishing craft to areas having an abundance of schooling fish (Squire, 1961). Such fisheries for species such as salmon, tuna, menhaden, herring (Maine sardine), sardine, mackerel, bonito, sea bass, mullet, thread herring, blueback herring and swordfish utilize intermittently about 70 aircraft.

In 1962, a pelagic fish monitoring program was initiated for the southern and central California area. Six fish spotter pilots are now under contract to provide information on all surface schooling species seen during each flight, their location, number of schools, and estimate of abundance. Species most commonly observed are anchovies, sardines, mackerel, barracuda, yellowtail, sea bass, bonito, sharks, rays and tuna. Information is tape recorded by pilots, and the results are transcribed in the laboratory to a coded log form. During the past year over 340 separate flight records were obtained from contract pilots.

Present statistical methods employ dockside catch statistics as an indication of abundance. Results from this program are indicating abundance and distribution information for species such as the anchovy (E. mordax), a species that is not presently the subject of an intensive fishery, in addition to developing information on species subjected to sport and commercial fishing.

Flight operations are conducted at low elevations of from 152 to 365 meters (500'-1,200'), and more than half the flight operations are at night during the absence of moonlight. Each pilot operating from the southern California area flies 800 to 1,000 hours per year. However, some of this time is spent surveying off Mexico and the central American coast when operating with the tuna fleet, and this flight time is not recorded for our program. The program as presently operating in the southern and central California area has a maximum potential of about 4,800 observational hours per year.

OBSERVATIONS AND SUGGESTIONS ON FUTURE USES OF MANNED HIGH ALTITUDE AIRCRAFT AND MANNED OR UNMANNED SATELLITES IN THE FIELD OF BIOLOGICAL OCEANOGRAPHY

The potential of orbiting laboratories to produce oceanographic data on a global basis of interest to researchers in many fields may be exceedingly great. However, the suggestions offered here are of particular interest to researchers in the field of bio-oceanography. If the suggestions are technically possible to develop, they would fill a very practical need in determining the reaction of the pelagic fishery resources to changes in environment.

It would appear from our experience gained from about 400 hours of flight operation off the west coast with the infrared unit that cloud cover of all degrees, from high, thin cirrus to haze and fog, will be one of the more important factors in limiting high altitude observation of the sea surface. Infrared flight operations over the west coast continental shelf have required postponement of one day or more for greater than 50 percent of the monthly flights in the central survey area due to very low overcast <152 meters (<500 ft.) and fog conditions. The northern and southern areas have experienced less cancellation due to weather; however, in all areas more than 50 percent of the flight time has been under a low overcast of 91 to 365 meters (300-1,200 ft.).

Data now available from the U. S. Weather Bureau should allow an estimate of the percent of time various portions of the ocean could be observed from a very high altitude.

Three related areas of research that, if conducted from very high altitudes, may provide considerable reward in bio-oceanography are:

1. Infrared observations of the continental shelf and associated oceanic areas.

A further development of infrared mapping technique to determine the gross isothermal picture (in 1° C.) of the oceans of the world is desirable. At the present time several isolated, small areas about the continental United States are being mapped in limited detail, and it would be desirable to produce at a greater frequency information in comparable detail.

The oceans surrounding the North and South American continents should be given particular emphasis in any advance program. Isotherm charts similar in scale to those presently produced by the Tiburon Marine Laboratory and other laboratories, but covering the entire coastal zone, could be obtained by readings taken from individual 9.3 km. (5 n.m.) square areas. If resolution of satellite infrared equipment to a 9.3 km. square area is possible, then the charts produced from the data would not only have the basic picture as found in current charts, but would scan the areas not presently observed by the low altitude aircraft and should result in charts of much greater detail.

2. Observations of water color as a method of defining water mass, the coastal and convergence zones in particular.

Water color in coastal and oceanic areas is the result of the presence of a fairly stable metabolic product related to production of phytoplankton (Kalle, 1938) or the presence of suspended inorganic and organic particles. Discoloration by algae or dinoflagellates or other small invertebrates, and suspended minerals all may contribute to this feature of the ocean's surface that is readily observable from the air. An optical, photographic or electronic system to map the color differences of blue to green in the offshore areas, and brown to green and blue in the inshore areas would be useful to those studying plankton distribution and the related environmental characteristics of the ocean.

A gross picture might be obtained of such features as discharge and flow patterns within the inshore and estuarine area, and the convergence areas between major water masses off the North American continent. Identification of these convergence areas off the west coast should be useful in plotting the relationship of albacore and bluefin and other species of tuna to the convergence zone of the upwelled waters and the California current and the relationship of such species as yellowfin tuna and marlin to water mass off Central and South America. The convergence zone of the Gulf Stream and the slope water south of New England appears to be productive for bluefin tuna in the spring, and for yellowfin tuna in the summer, and shows promise as a productive fishing area (Squire, 1963). A better definition of this zone in relation to tuna fishing may result in a method of short period predictions on the movements of the tuna populations relative to these convergences.

The determination of true water color (quantitative color measurements) is difficult due to the many uncontrollable interfering factors. Therefore, the determination of the relationship of true color to any biological or physical phenomena would also be difficult unless a standardized technique is developed to give a record that will be as near true color as possible. Aerial color photography should yield useful data of a qualitative nature. To strike an optimum balance among faithful color rendition of the emulsion, the light penetration of the water, the minimum surface reflections, the removal of ultraviolet and near ultraviolet, and the reduction of atmospheric haze, Dr. Boyd E. Olson (personal communication) suggests the following technique to obtain a reasonable color rendition:

(a) All color film used should be from a single batch.
(b) The cameras should be pointed at a right angle to the sun and down at about 45°.
(c) The lens should be capped with a polarizing filter properly oriented for maximum absorbency of surface reflection.
(d) Photography be limited to the hours when the sun is between 45° and 55° above the horizon with the sky free of clouds.

3. Observations of the abundance, distribution and migration of near surface pelagic fish schools.

This phase of research has much in common with the previous section on water color. The identification of pelagic near surface school groups requires a system to discriminate subtle color differences of a target of < 15.2 meters (< 50 ft.) in diameter, and this may be beyond present technical ability from very high altitudes.

The low altitude fish spotter pilot, during daylight hours, has developed an ability to distinguish subtle differences to be found in the color composition of water masses containing near surface schooling fish and those without fish. After discerning gradation of luminosity emitted from the surface, the observer discriminates between color and light intensity. He then "recognizes" or perceives some distinctive inherent characteristic associated with the fish school target. The second phase of the recognition process is the attempt at determination of species. This determination may be on the basis of color, shape, behavior, and may be a combination of these factors.

During observation of near surface schooling species at night during periods when moonlight is absent, the spotter pilot relies on the perception of very low, bio-luminescent light levels. The bio-luminescence of plankton created as a result of the activity of schooling fish is used to vector the fishing vessels to productive areas.

In summary it is suggested that the following research be considered:

1a. Development of IR satellite equipment capable of a resolution and readout of a 9.3 km. (5 n.m.) square area at an accuracy of > 1° C.

b. Comparative tests between low altitude IRT observations and very high altitude IR scanner systems capable of mapping a 148 kilometer strip (80 n.m.). If use of the very high altitude system is successful, substitution of the high altitude scanner technique for the present synoptic low altitude surveys should be considered.

c. Consideration be given to the production of IR isotherm gradient charts for all oceans, with particular emphasis on the continental shelf and the major current systems surrounding the North and South American continents.

2a. Research on the development of a technique to determine and record with reasonable accuracy true water color from low altitude and very high altitude aircraft, preliminary to development of scanner systems for satellites.

b. Research on the relationship of water color as observed from above the surface to the biological organisms and organic and inorganic suspended matter that may be in the near surface layers.

3a. Experiments using photographic techniques to determine the height from which fish schools can be observed during both day (color difference) and night (bio-luminescence).

b. Determination of the true color of fish school and the relationship of the true color to species composition.

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OPERATIONAL ANALYSES AND FORECASTING OF OCEAN TEMPERATURE STRUCTURE

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ABSTRACT

A brief review is given of the factors affecting the thermal structure of the ocean as well as of sources of errors in the surface temperature reports.

The heat budget of the interaction between the oceans and the atmosphere has been analyzed and adapted to routine numerical computations at Fleet Numerical Weather Facility, Monterey. The dependence of the temperature structure in the ocean on atmospheric events is demonstrated.

The effects of the constraints of grid mesh size, instrument and transmission errors are considered in the production of sea surface temperature analyses. The underwater temperature structure is analyzed using a simple model. Finally, the integrated effects of the calculated energy exchange at the surface are applied to the initial analysis to obtain a two day prediction.

Examples of thermal structure analyses and predictions are presented and the factors affecting their interpretations are briefly pointed out. Brief notes are also given on the future plans for improvement, extension and utilization of oceanographic predictions.

INTRODUCTION

The Fleet Numerical Weather Facility (FNWF) located at the U. S. Naval Postgraduate School in Monterey is developing an expanding program in meteorology and physical oceanography. This report is a condensed summary of the existing operational program in sea surface temperature (SST) analysis and of the program for the analysis and prediction of ocean temperature structure variability with time, space and depth.

Development programs at FNWF produce operational computer routines whose end product is designed to be useful environmental information for naval operations. Most efforts are engineering applications using computers to imitate successful manual operations. Gains are in speed, quality control, and the ability to accomplish the 7 billion computations involved in a day's production in a useful time.

The atmosphere and the ocean should be treated as two closely related parts of the total environment. All of the energy which produces changes in the ocean comes to it through the atmosphere. The same basic equations of motion govern both fluids; in fact the equations are simpler in the oceans. The existence of clouds and moisture and the large-scale turbulent motions are particularly difficult atmospheric problems not present in the ocean.

The sea surface temperature is the most commonly recorded observation available on a synoptic basis. Its key importance in environmental analyses and prediction will be demonstrated. The first section of this paper attempts to establish the appropriateness of the present FNWF approach to this pivotal variable.

DATA AVAILABILITY AND ACCURACY

Numerical analyses are made for convenience at coordinate intersections in a regular x, y array. The problem of deriving analyzed values at these intersections from a randomly located array of data has many solutions. The final result is obtained by combinations of fitting and smoothing. The proper scale for the grid is determined by the avarage data density in space and time and the scale and persistence of the variations in the scalar variable to be analyzed.

In order to study the scale in terms of typical data coverage, all unique observations of SST received for a 3-1/2 day period in May 1964 were located on a hemispheric chart. Under the assumption that an average density of one observation per two grid squares is required for meaningful analysis, the grid square side dimension was determined. Figure 1 shows this chart with isopleths of allowable mesh length. For most water areas of the hemisphere a 200 mile mesh is all that 3-1/2 days of data justifies. A grid 50 miles on a side is supported in only a few narrow areas in major shipping lanes. Of course concentrated fleet operations may make denser grids usable in small operating areas such as the one off San Diego. Figure 1A summarizes the differences between sea level pressure and SST data as inputted to a scalar analysis program.

Figure 2 shows the basic grid on which FNWF computes and outputs most meteorological data.

SEA SURFACE TEMPERATURE ANALYSIS

Sea surface temperature reports are subject to several kinds of error. Careful recent studies (typically Saur's) report a standard error of 1.65° F. and a positive bias. The analysis procedure presently used at FNWF is Carstensen's linear method.

Carstensen's linear analysis scheme is a combination of fitting and smoothing. The last analysis provides a smooth first guess field. New data is considered in the neighborhood of each grid point and moves the guess value up or down by a fixed small amount (.2° F.). This amount is a function of data density and is less in dense reporting areas and more in sparse areas. The changed points are combined with the first guess by a successive relaxation process alternated with weak smoothing. The resulting cyclical alternation of fitting, relaxation and smoothing is not carried to complete convergence since the first guess has independent information content. In dense data areas the final grid-point analysis is determined entirely by the data and in no-data areas by the first guess with a combination of the two in between.

This method produces an error distribution summarized for one recent run in Figure 3. Of the 6000 unique reports, 100 were rejectedin the gross error procedure. The remaining differences between the observations and the analysis have a somewhat normal distribution but with a higher frequency in the tails. This is attributed to a combination of a few large, essentially random numbers interpreted by the data sort as valid ship observations with a group of errors less than 10° F. The 2.4° F. standard deviation is typical and not excessive.

Earlier FNWF employed Carstensen's Relaxation method in SST analysis. The fitting computation was cubic in this method which has been unsurpassed in its quality in the analysis of meteorological pressure data. Figure 4 shows the results of a simple experiment establishing the superiority of a simpler linear fitting over the cubic. Three types of linear temperature distributions were te[illegible] with data having a normally distributed standard error of 2.4° F. Figure 5 shows the an[illegible]d contours produced by this method when applied with a grid spacing of 100 miles (16000 p[illegible]/hemisphere).

PATTERN DECOMPOSITION

Recently an iterative procedure has been developed at FNWF which permits a scale separation by a heat diffusion analogue equation. When this operation is performed on the same SST analysis, one can readily see the different pattern scales which compose the whole. Figure 5A shows the small space scale disturbances. Major current boundaries are outlined and the remaining irregularities are shown as warm spots (interpreted as areas of recent net heat additions or stable meanders) and cold spots (probably due to wind mixing or upwelling).

Removal of these small-scale disturbances from the initial analyses produces the large-scale pattern Figure 5B. This chart is similar to long term time averages. The components of this chart are more apparent and useful when the purely zonal portion is subtracted.

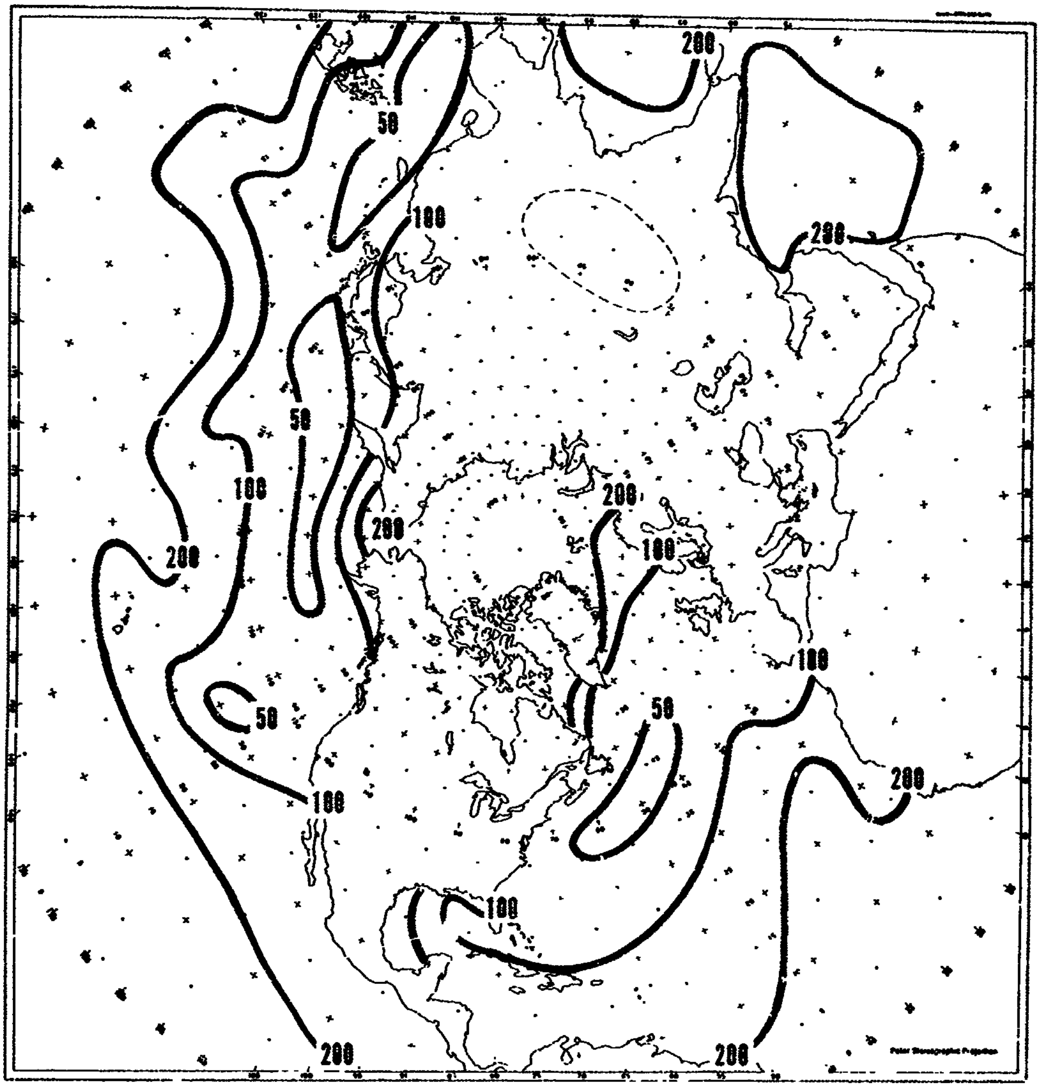


Figure 1. Mesh Length in Nautical Miles Justified For Use in Analysis of Sea Surface Temperature Observations Covering a Collection Period of 84 Hours.

DATA AVAILABILITY CONTRAST

ATMOSPHERIC PRESSURE VS SEA SURFACE TEMPERATURE

	SEA LEVEL PRESSURE	SEA SURFACE TEMPERATURE
NUMBER OF OBSERVATIONS	5000 / 6 HOURS / 2000 GRID SQUARES 5 / GRID SQUARE / 12 HOURS	7000 / 84 HOURS / 1000 GRID SQUARES 1 / GRID SQUARE / 12 HOURS
ANNUAL LOCAL RANGE	30 - 100 MILLIBARS	10 - 30°F
ERROR OF OBSERVATION	0.1 - 1.0 MILLIBAR	0.2 - 2°F
REPORTING INTERVAL	0.1 MILLIBAR	0.9°F
RMSE COMBINED	0.7 MILLIBAR 1/2% - 2% OF ANNUAL RANGE	2.0°F 7% - 20% OF ANNUAL RANGE

Figure 1A. Typical Data Availability Contrast For Sea Level Pressure and Sea Surface Temperature Data Used as Input to Analysis Programs.

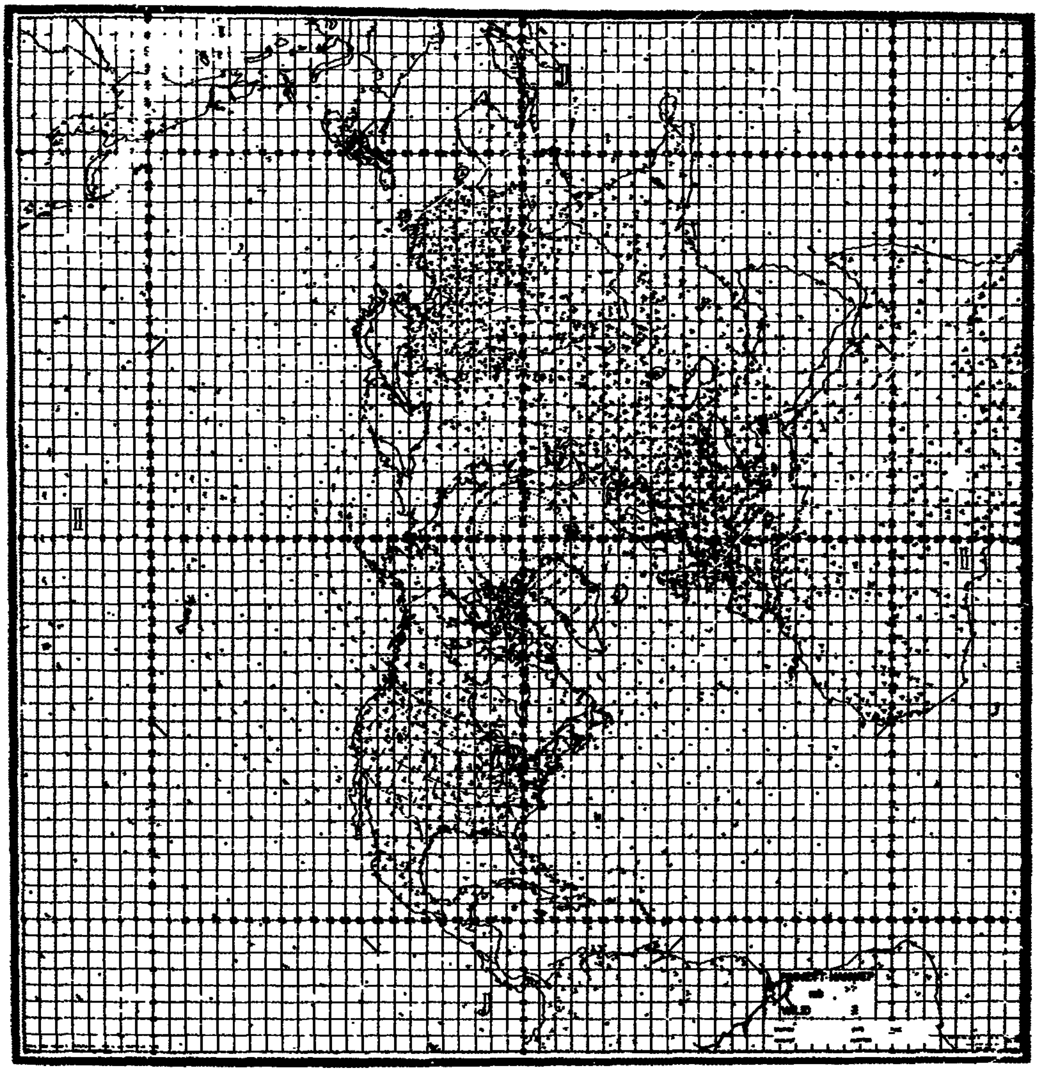


Figure 2. Basic FNWF, Monterey Grid Used For Computation and Output of Most Environmental Data.

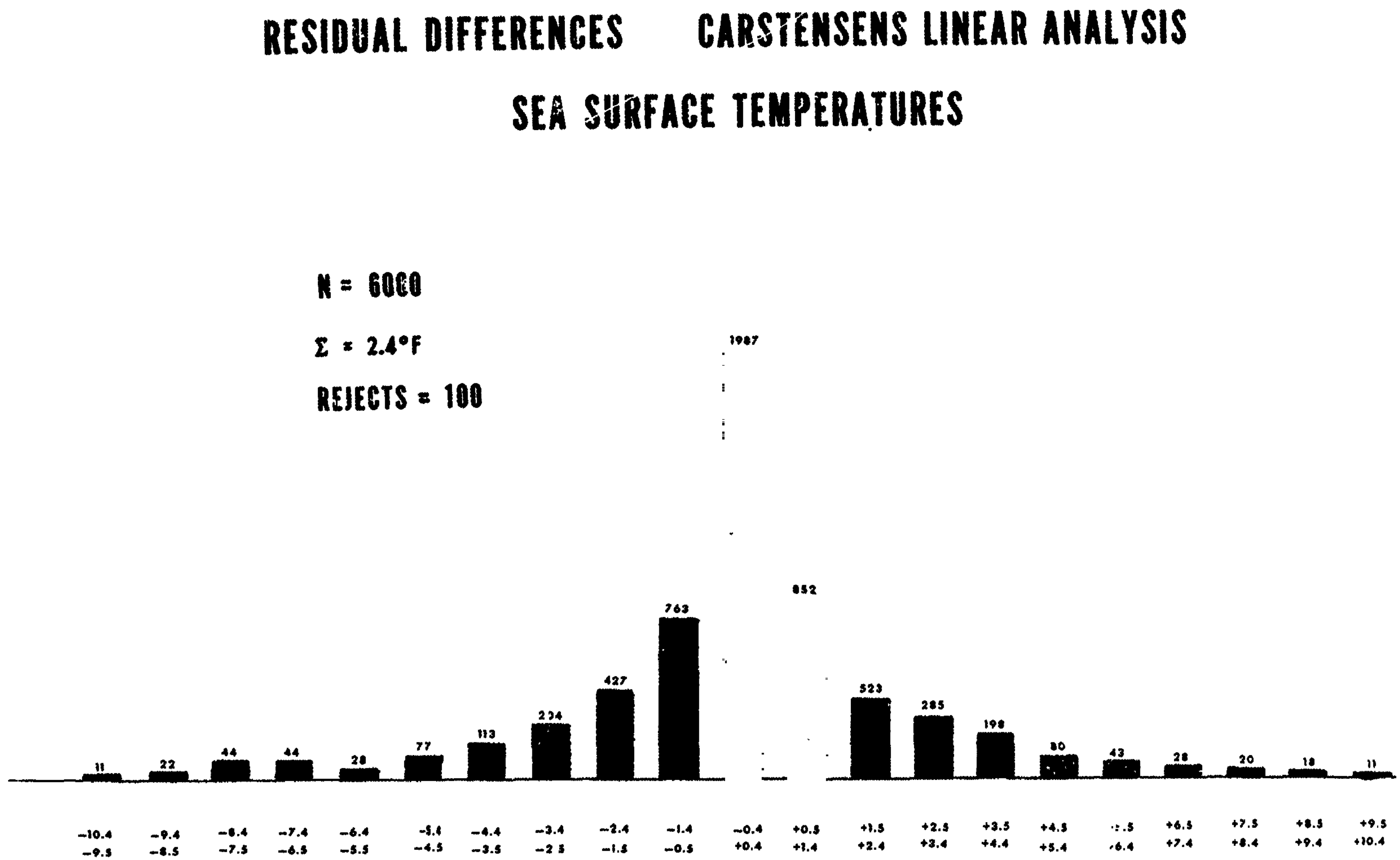


Figure 3. Error Distribution Resulting From Carstensen's Linear Analysis Program App 'ed to an 84-hour Collection of SST Observations.

ANALYSIS METHOD COMPARISON

	FITTING	SMOOTHING
I. CARSTENSEN'S RELAXATION METHOD	EXACT INTERIOR CUBIC	HEAT DIFFUSION ANALOGUE $A_1 = A_0 + K\nabla^2 A_0$
II. CARSTENSEN'S LINEAR METHOD	LINEAR QUADRATIC WITH ONE DEGREE OVERSPECIFICATION	SAME

STANDARD ERROR IN F° DUE TO ANALYSIS METHOD

	CONSTANT	LINEAR GRADIENT	LINEAR GRADIENTS WITH LINE OF DISCONTINUITY
METHOD I (CUBIC)	2.4	2.5	3.4
METHOD II (LINEAR)	2.0	2.0	2.8

Figure 4. Comparison of Standard Errors Resulting From Linear and Cubic Analysis of Typical SST Data Distribution Under Three Field Conditions.

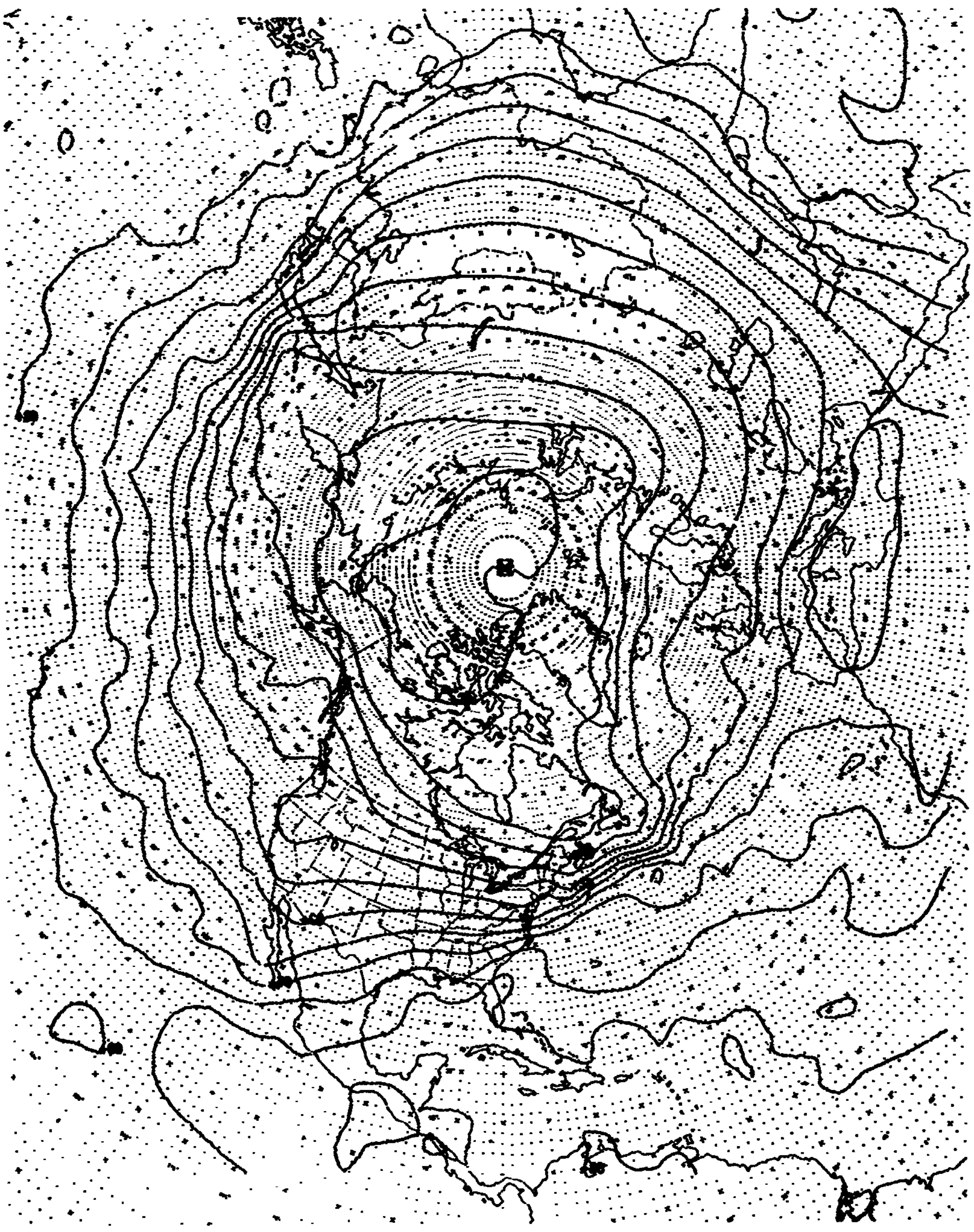


Figure 5. Sea Surface Temperature Analysis (Degrees F) From Carstensen's Linear Analysis Method.

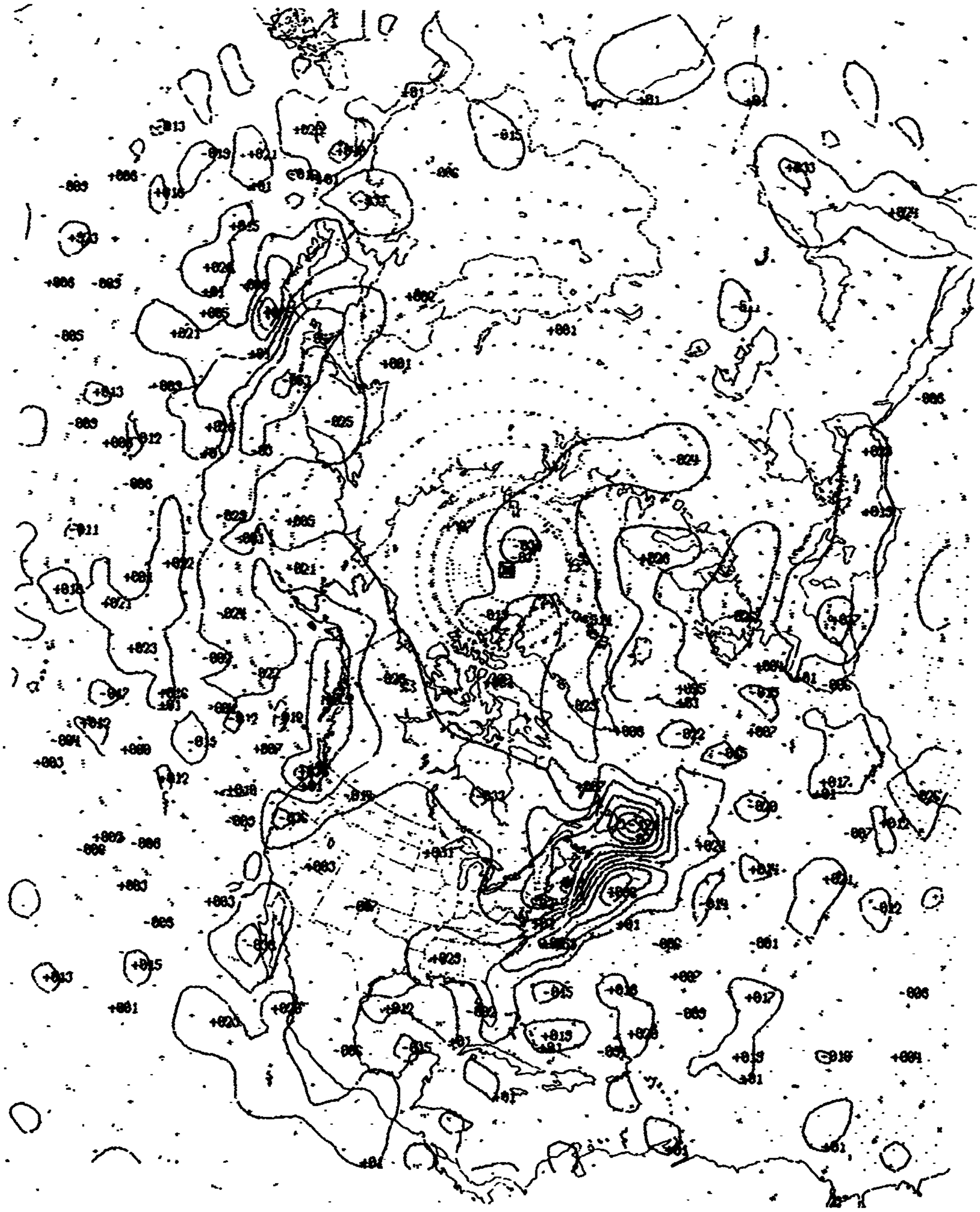


Figure 5A. Pattern Separation of SST Chart (Figure 5) Showing Small Space Scale Disturbances (Degree. F).

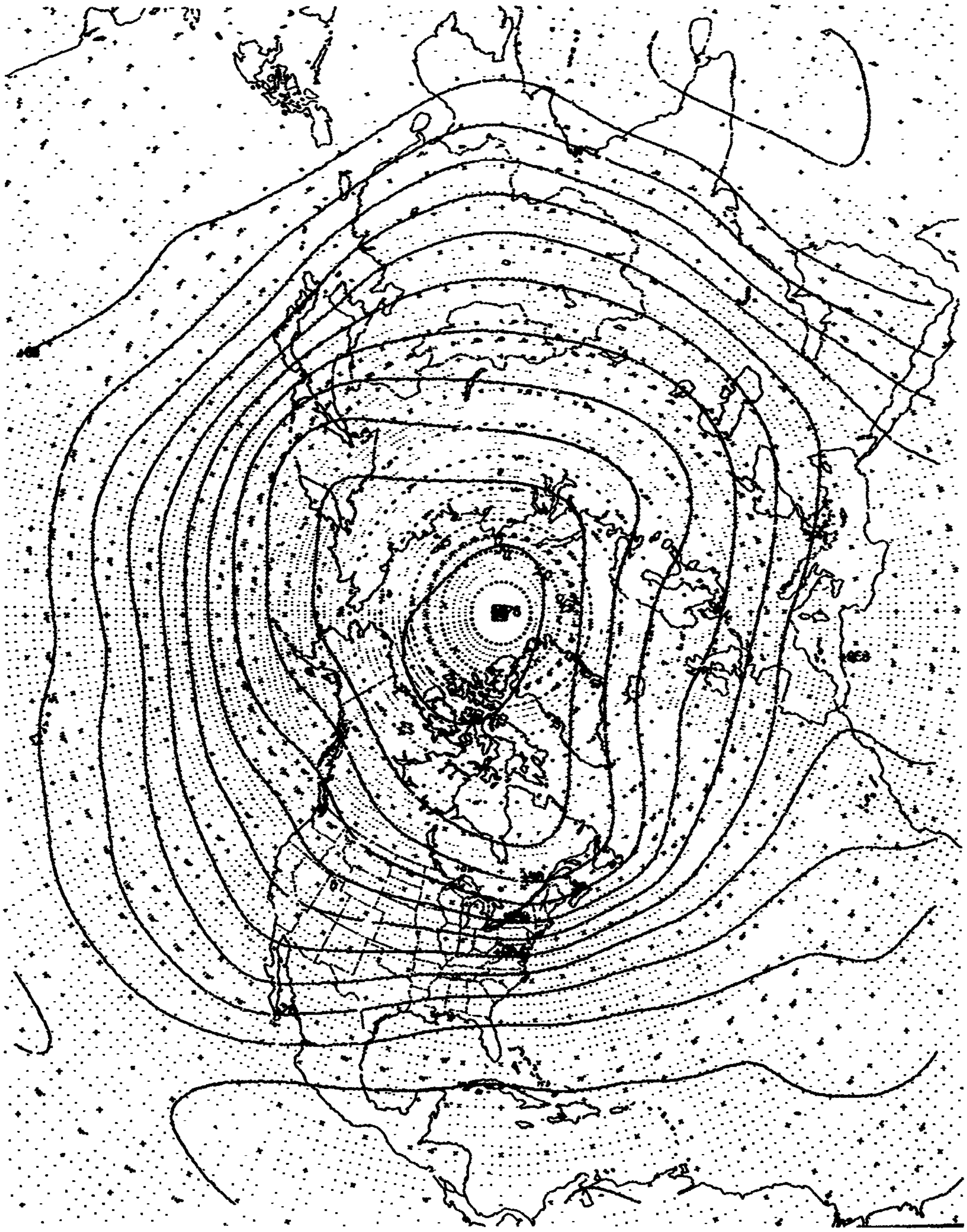


Figure 5B. Pattern Separation of SST Chart (Figure 5) Showing Large Scale Pattern (Degrees F).

Figure 5C shows these large-scale anomalies and makes possible direct comparisons of locations and intensities of the larger scale SST anomalies.

ATMOSPHERE - OCEAN ENERGY EXCHANGE

The preceding section of this paper described the SST analysis program which has been under development during twice daily operations at FNWF for over two years. This section describes research in progress which will be placed in daily operation in the fall of 1964. Feasibility computations, and in some parts, computer test runs have been made on all parts of the program. Experience indicates, however, that many changes and refinements will be required after routine operation of the program begins.

Figure 6 shows schematically the proposed environmental cycle. The entire system will operate once a day and produce an analysis of the initial temperature structure and a 48-hour prediction. The initial variables are predominantly atmospheric including only sea/swell history and SST in the ocean. The last day's analysis is modified by the heat flux terms, the mechanical mixing by waves and the divergence effects to produce computed estimates of the 24-hour structure change. This structure is combined with the current SST analysis at the surface and climatological data below 600 feet to produce a second estimate to the current structure. The temperature at 3000 feet is constant with time but has a small space variability. At 1500 feet the temperature fields have more space variability and are changed monthly. At 600 feet Schroeder's monthly charts from Woods Hole are used while in the Pacific a field of temperatures at 600 feet will be generated from Anderson's equations each day.

This second estimate of structure will then be modified by the addition of all available BT data producing the completed current analysis.

This structure is shown in Figure 7. Next the initial structure is modified by integrating the effects of heat balance, mechanical mixing and divergence over the next 48 hours. The variables involved will come from atmospheric forecasts. Figures 8 through 10 illustrate these effects. Computations will be made initially on the basic FNWF grid but will be moved to a 50-mile grid in four areas soon. These areas are shown in Figure 11. The smaller grids (Figure 12) will be used only in very limited operating areas.

The applicability of this method is illustrated by some recent results obtained by T. Laevastu at the University of Hawaii. The computations were made by hand from geophysical year historical data.

Figure 13 shows the total heat exchange for 15 Feb. 1957 and for 15 May 1957. The patterns are cellular and have a space scale clearly related to the major surface pressure systems in the atmosphere.

Figure 14 shows the air-sea heat exchange for two successive days in May 1957. Excellent continuity is observable between the patterns with the motions of the centers associated with the movement of the atmospheric features.

The results of Laevastu's study indicate the interdependence of events in the two parts of the environment with this dependence more evident in the changes produced in the oceans.

In longer range plans (6 months to 1 year) it is proposed to include currents, advection, shallow water effects, and ice in the computations. Large eddies and internal waves may also be handled.

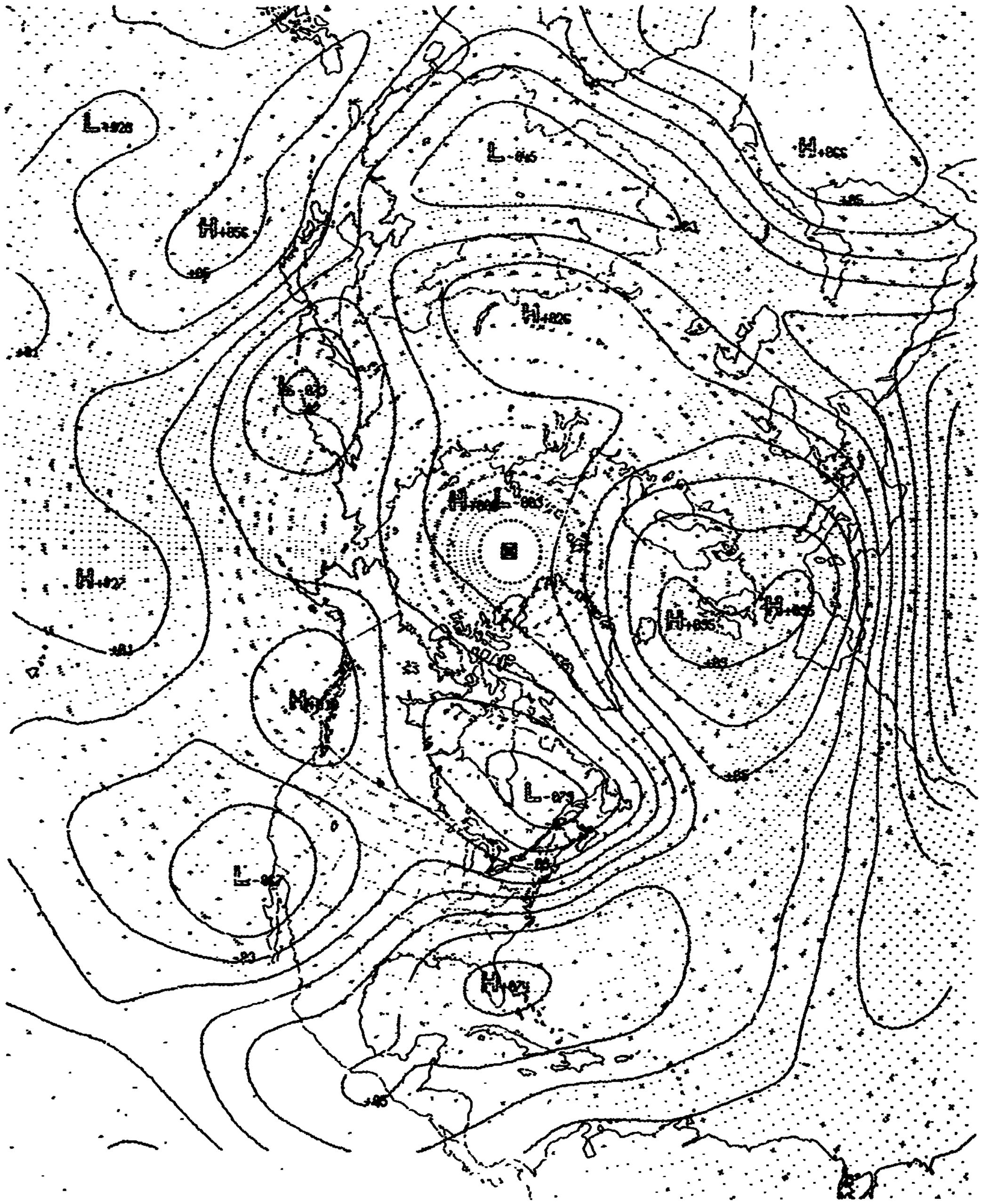


Figure 5C. Pattern Separation of SST Chart (Figure 5) Showing Large Scale Disturbances (Degrees F).

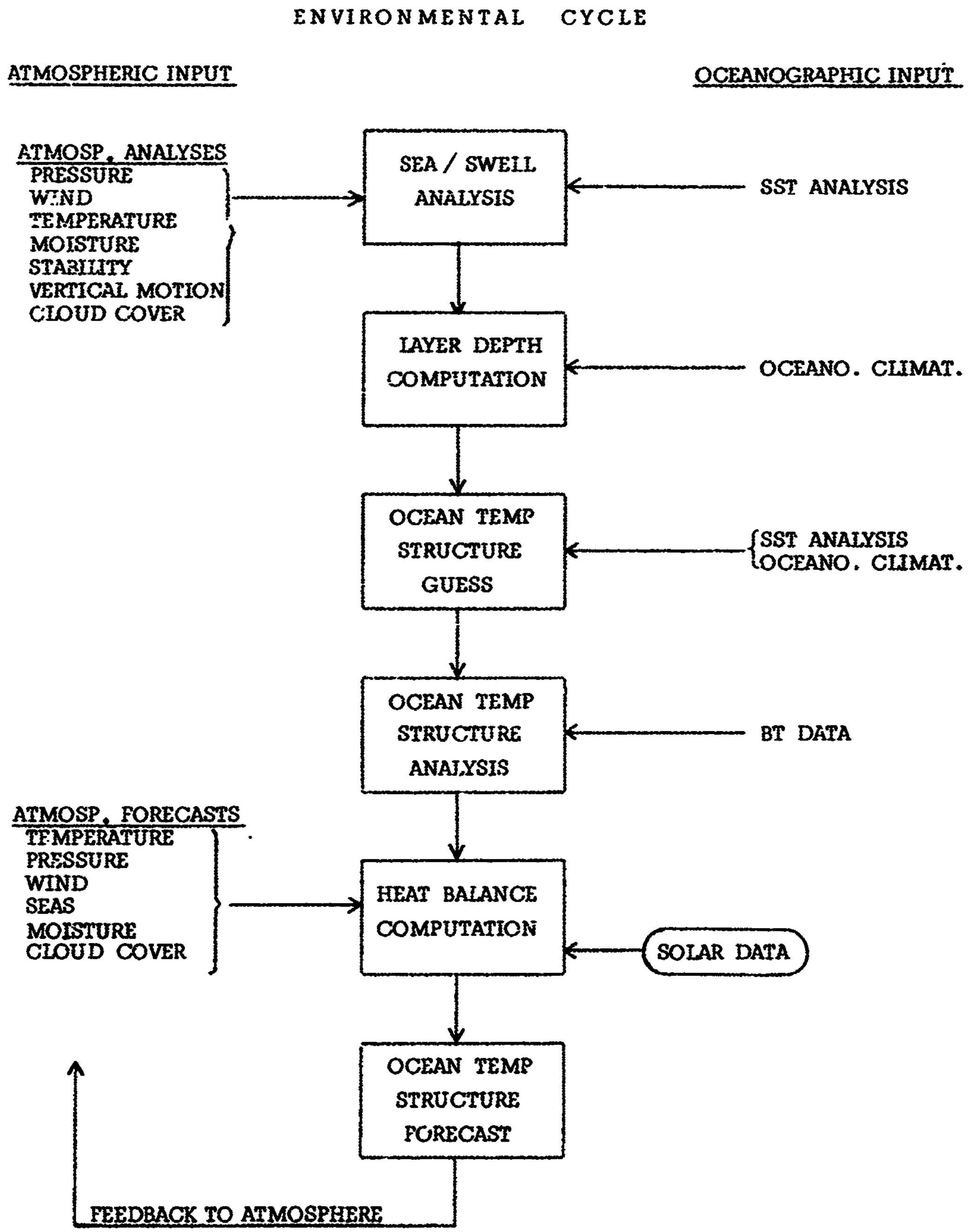


Figure 6. FNWF, Monterey Proposed Cycle For Analysis and Prediction of Environmental Parameters.

FNWF OCEANOGRAPHIC MODEL

Obtain Guess of Temp at Standard Depths.

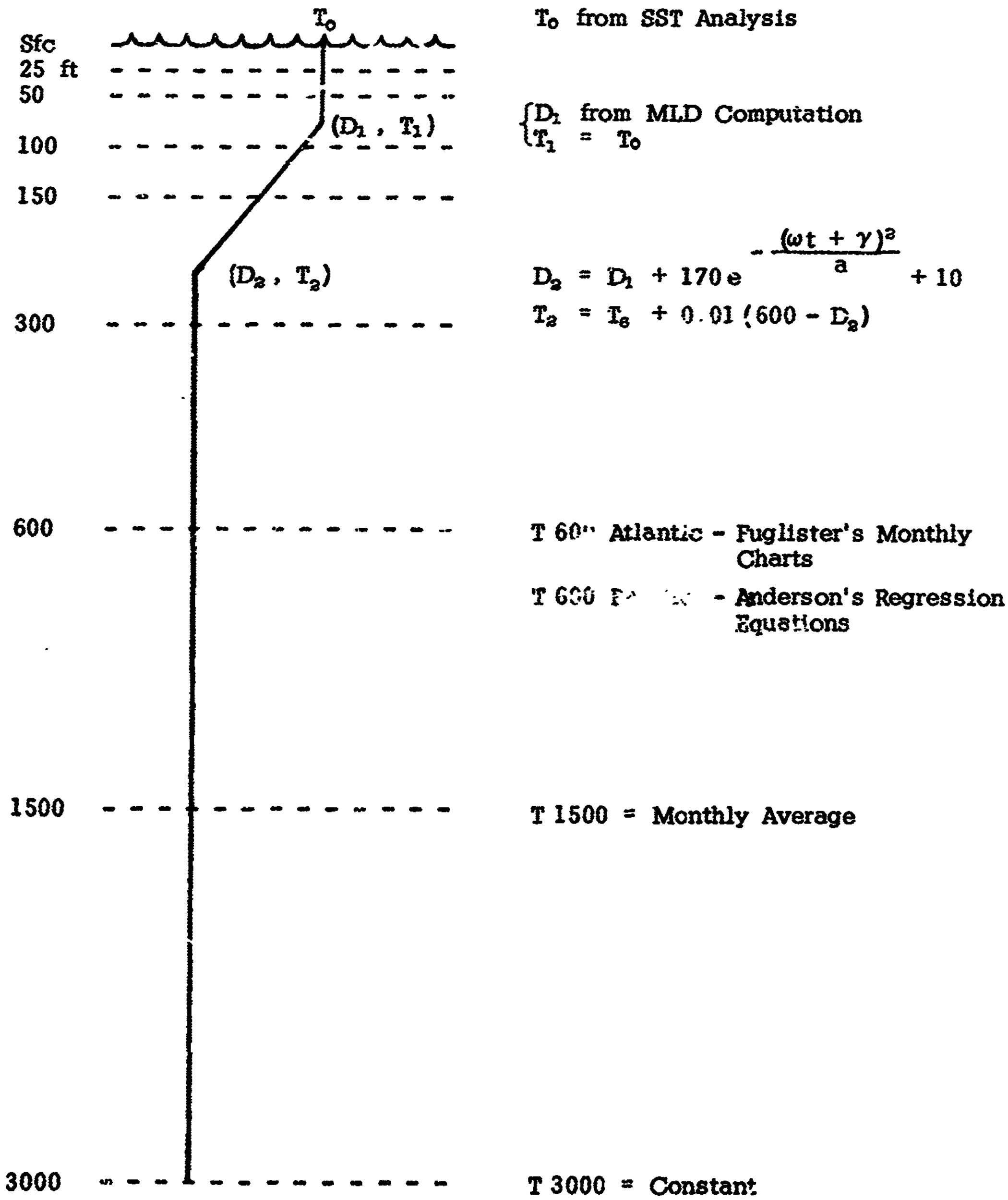


Figure 7. Summary of FNWF, Monterey Method For Determining the First Estimate of Ocean Temperature Structure.

LAYER DEPTH FORECAST FROM HEAT FLUX CONSIDERATIONS

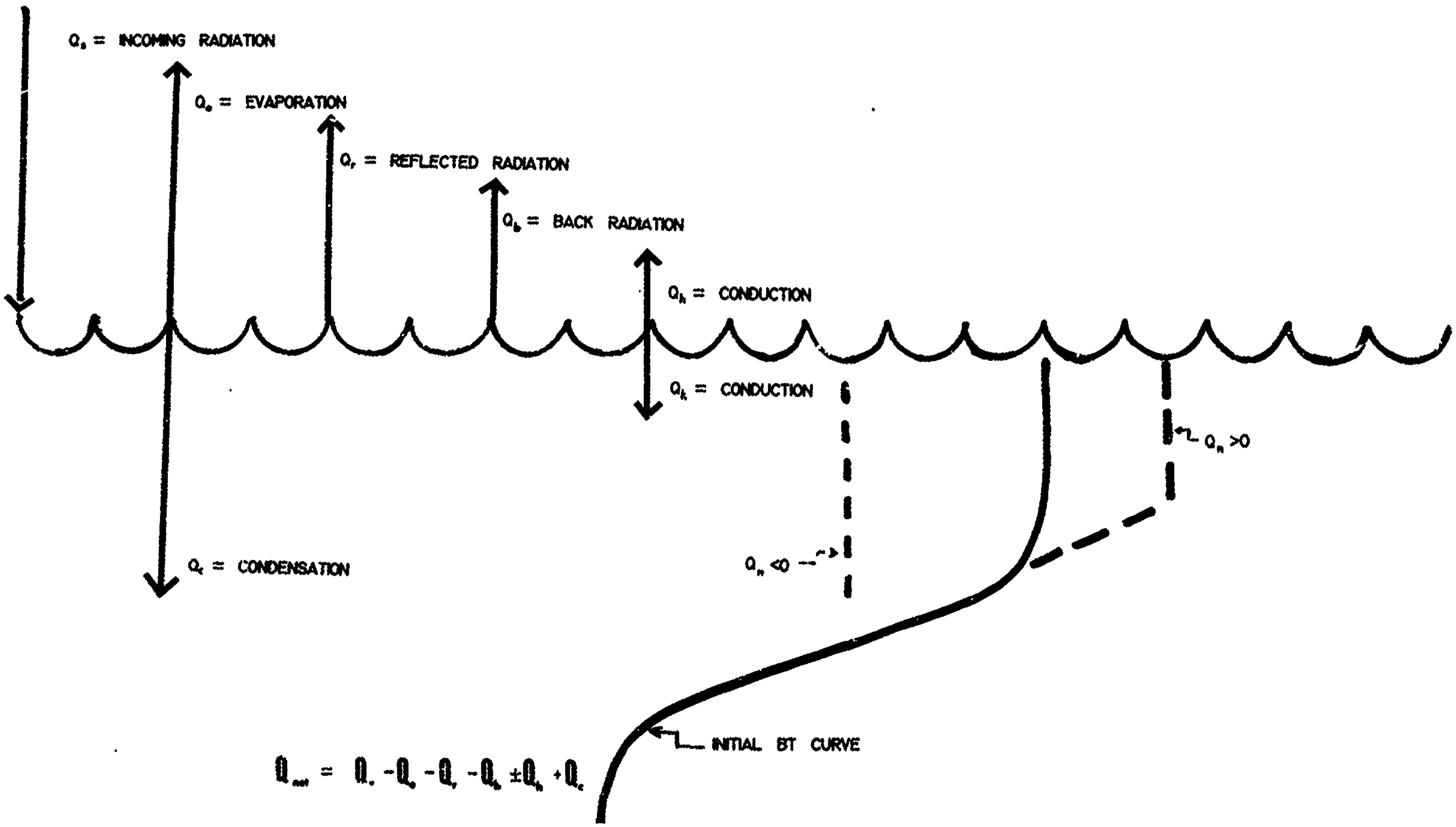
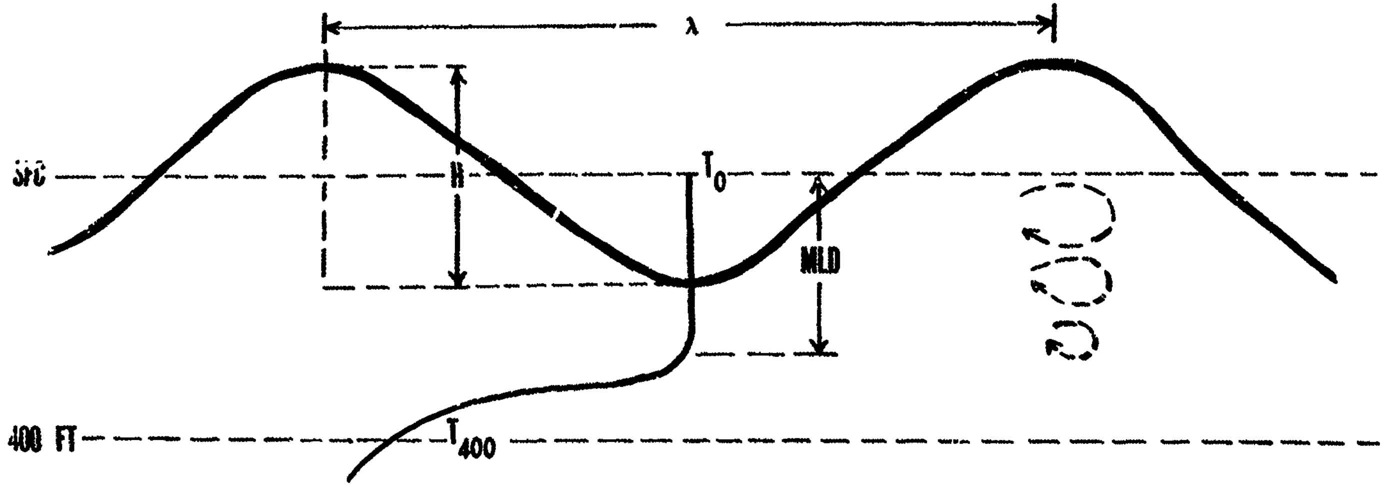


Figure 8. Pictorial Representation of Heat Flux Considerations Used in Layer Depth Computations.

A. MIXING DUE TO WAVE ACTION

B. FOR TROCHOID WAVES

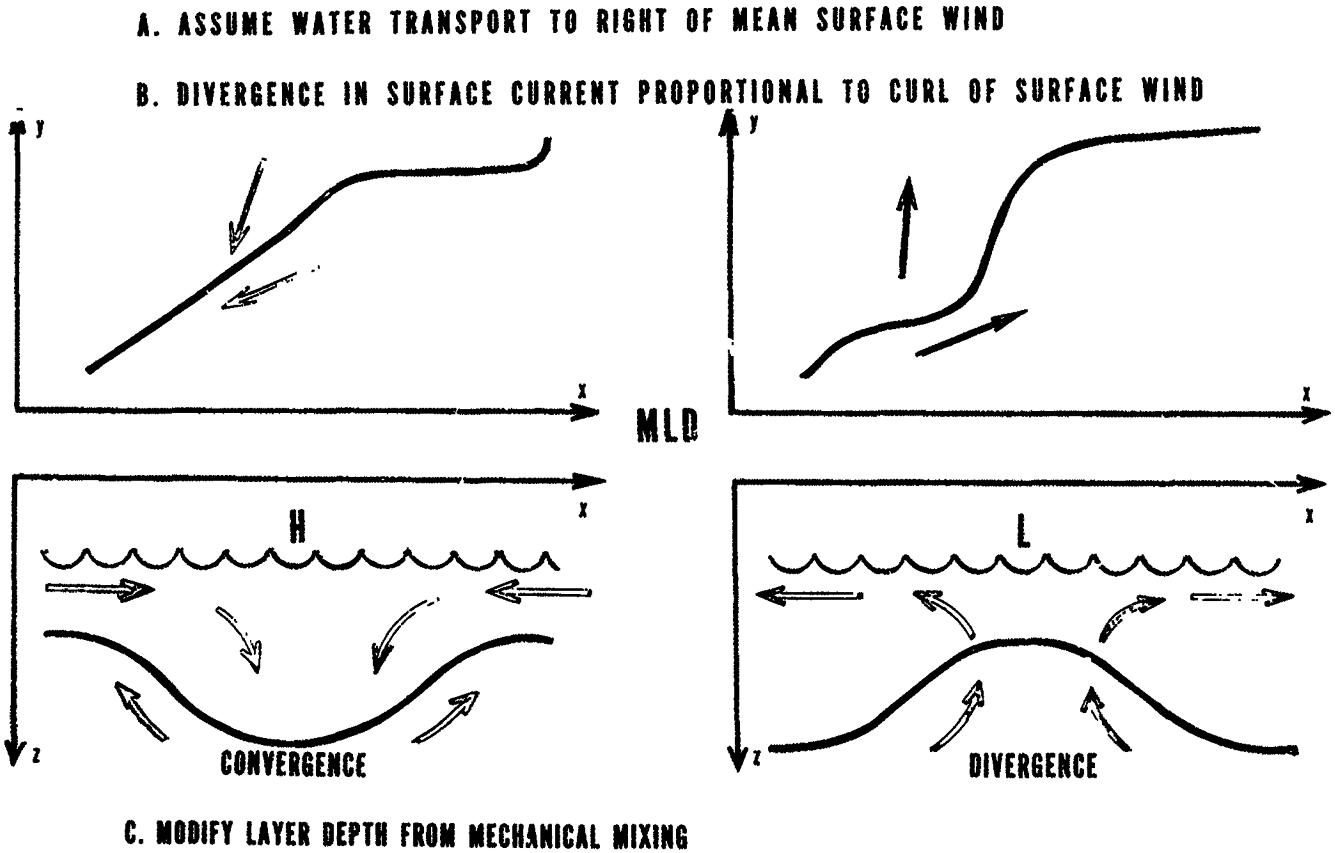
$$MLD = \frac{\lambda}{2\pi} \ln \frac{A}{K}$$



C. MIXING PARAMETER K DEPENDS UPON WAVE PERIOD, WAVE HEIGHT AND TEMPERATURE DIFFERENCE SFC TO 400 FT.

$$K = \left[0.25 \times 10^5 \left(\bar{H}T\right)^2 + 0.014\right]\left(T_0 - T_{400}\right) + 0.06$$

Figure 9. Pictorial Representation of Mechanical Mixing Considerations in Layer Depth Computations.



$$MLD_c = MLD\,[1 - C_1 \ \mathrm{curl}\,V]$$

F'gure 10. Pictorial Representation of Layer Depth Modification Due to Surface Divergence/Convergence.

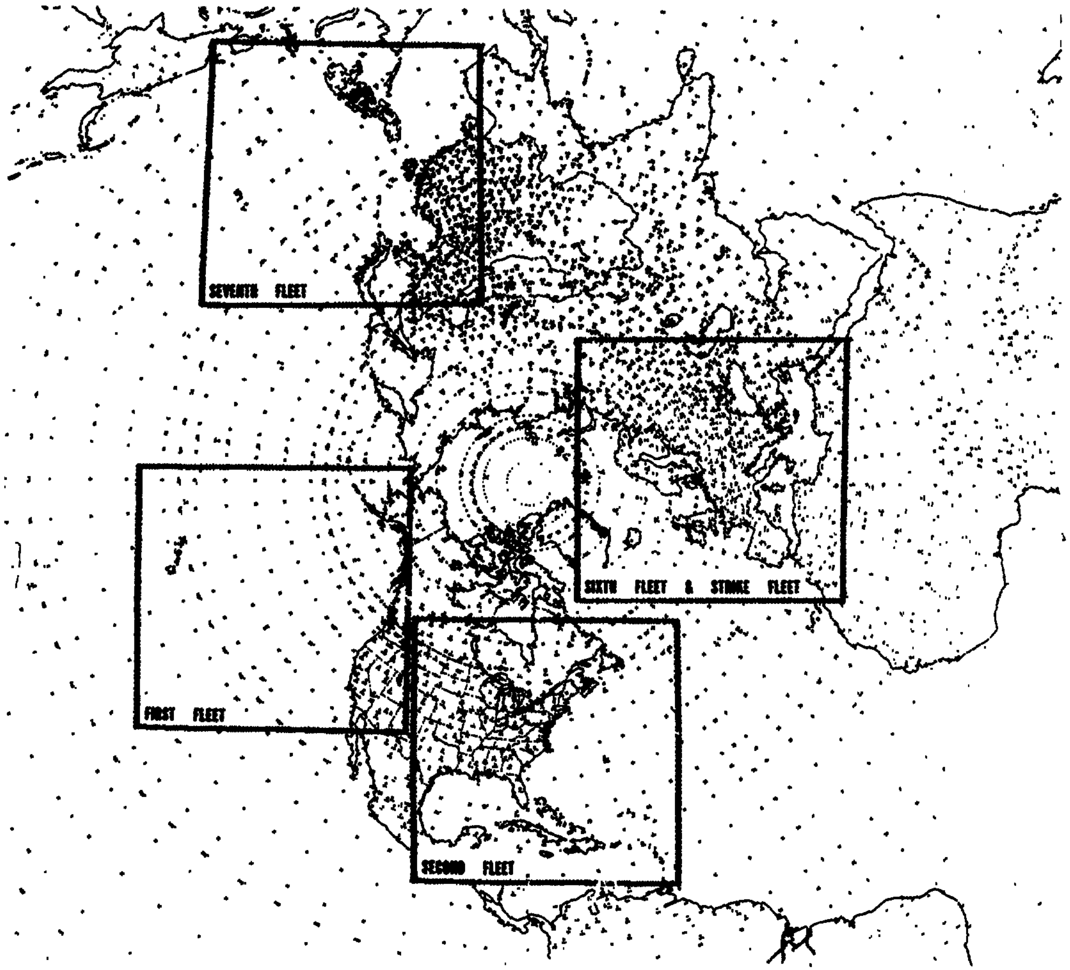


Figure 11. Fifty-Mile Grid Areas to be Used by FNWF, Monterey in Fleet Support Programs.

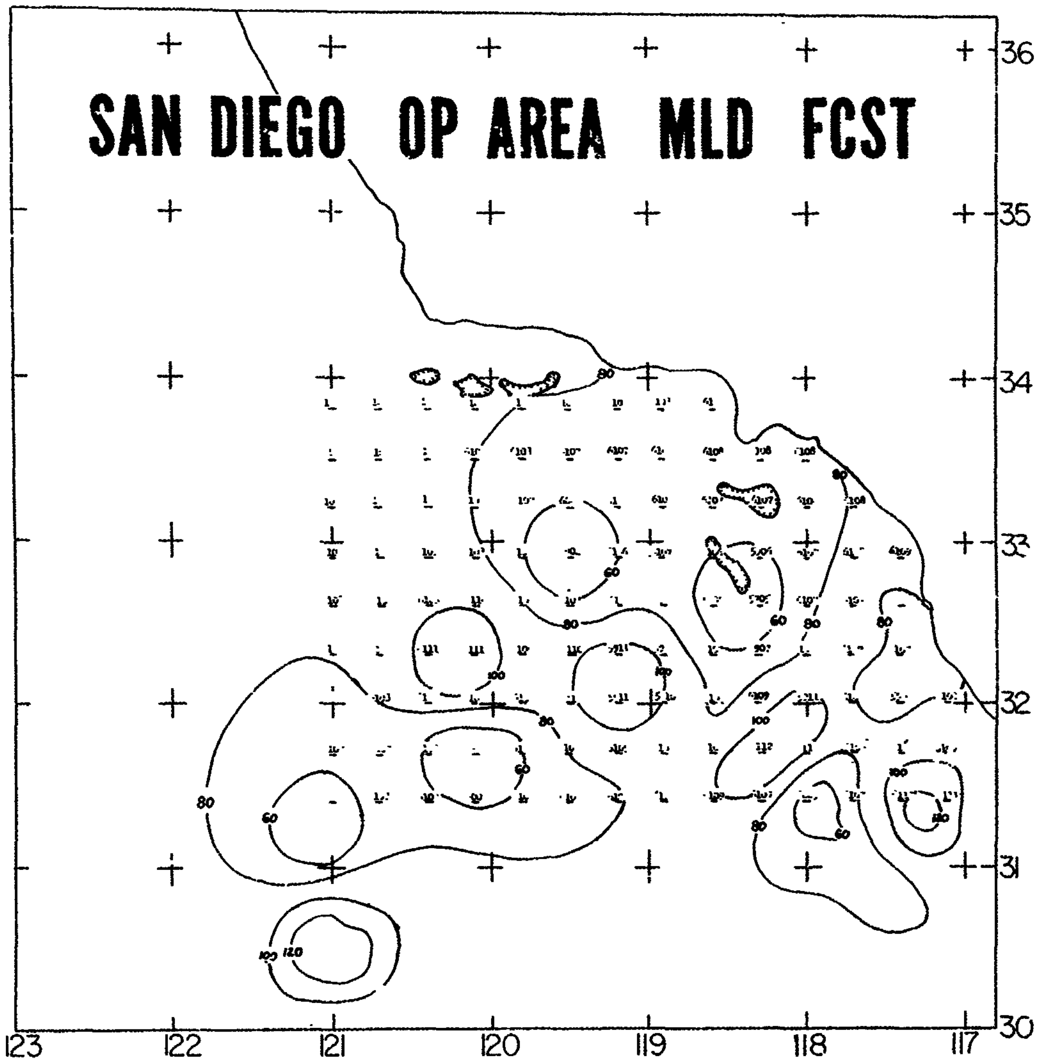


Figure 12. Typical Small Grid Areas Used by FNWF, Monterey in Special Operating Areas.

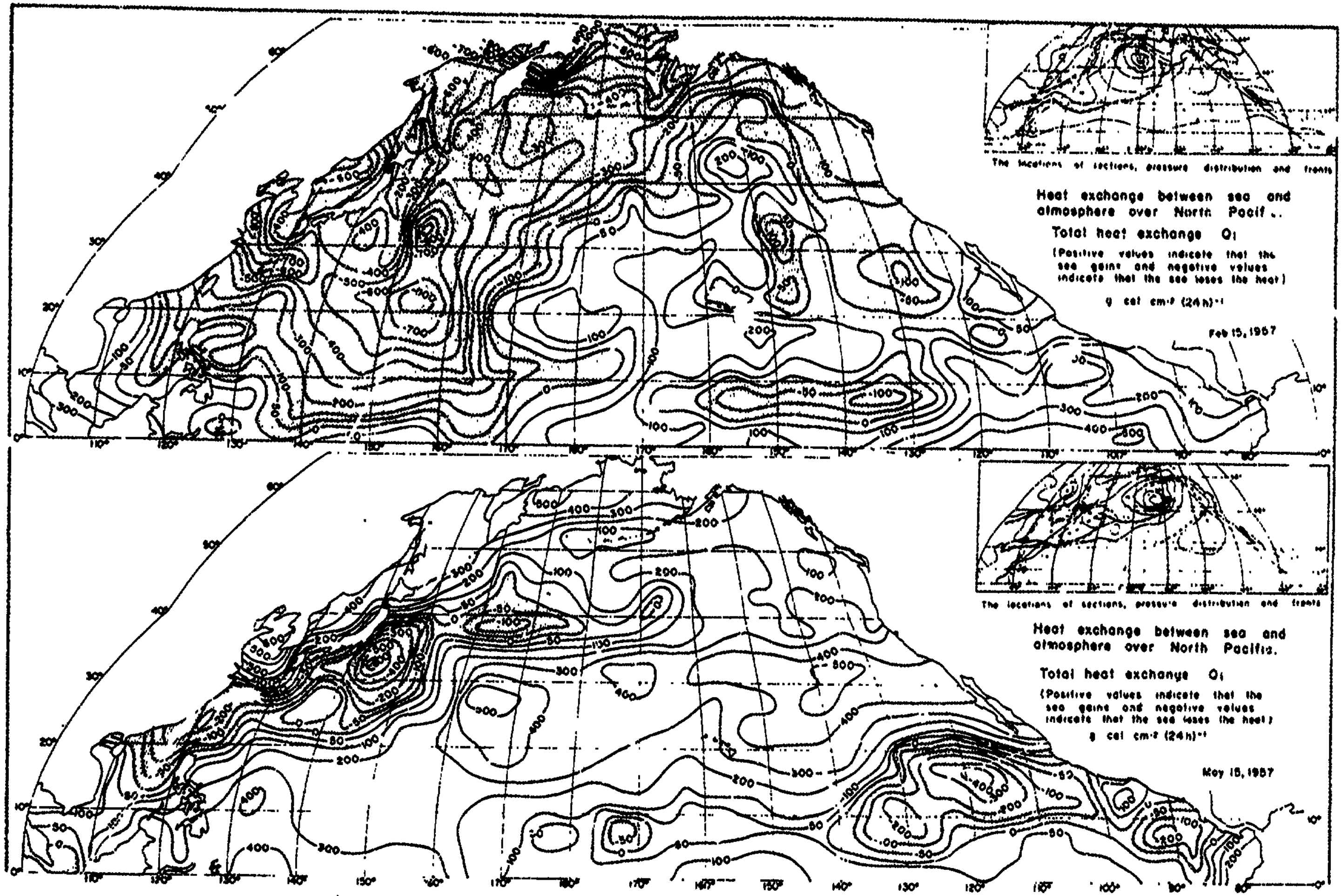


Figure 13. Total Heat Exchange (g cal/cm^2/day) Over the North Pacific For 18-19 May 1957 (After Laevastu).

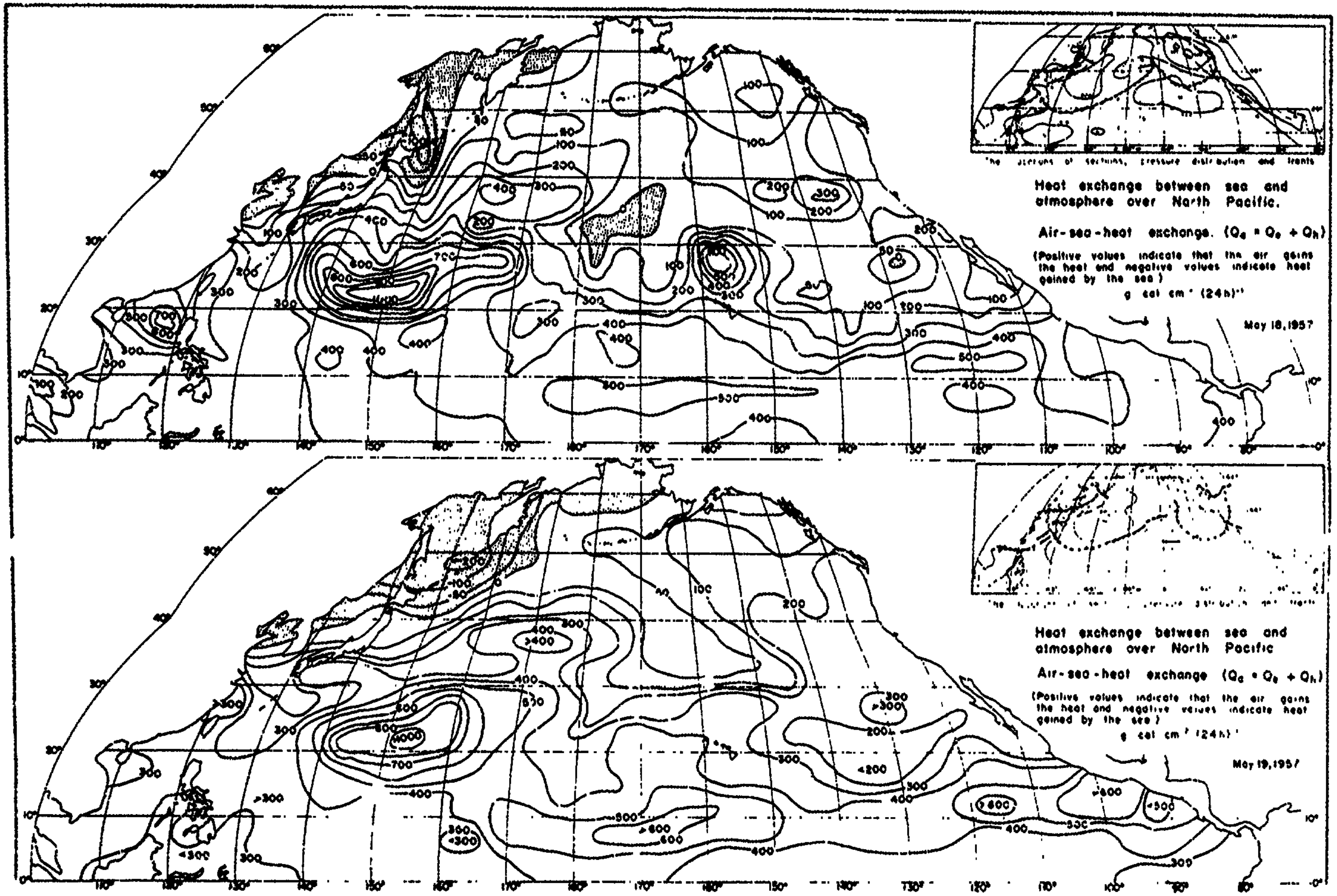


Figure 14. Air-Sea Heat Exchange (g cal/cm^2/day) Over the North Pacific For 18-19 May 1957 (After Laevastu).

REFERENCES

Laevastu, T., Energy exchange in the North Pacific; its relations to weather and its oceanographic consequences. Hawaii Institute of Geophysics, University of Hawaii, Report No. 30, 11 p. March 1963.

Saur, J. F. T., A study of the quality of sea water temperatures reported in logs of ships' weather observations. Journal of Applied Meteorology, Vol. 2, No. 3, pp. 417-425. June 1963.

Schroeder, Elizabeth H., Serial atlas of the marine environment, Folio 2. Woods Hole Oceanographic Institution. 1963.

ACCURACY OF MEASUREMENTS AT SEA

(from WMO-CMM III/Doc 71, APPENDIX A)

1	2	3	4
Element	Required accuracy of measurement	Approximate maximum error under bad conditions at sea	Prescribed precision of instrumental reading
Apparent mean wind direction	$\pm 5^{\circ}$	$\pm 15^{\circ}$	5°
Apparent mean wind speed	± 1 kts	± 5 kts	1 kts
Dry bulb temperature Wet bulb temperature Dew point temperature	$\pm 0.1^{\circ}C$	$\pm 0.5^{\circ}C$	$0.1^{\circ}C$
Atmospheric pressure	± 0.1 mb	± 3 mb	0.1 mb
Pressure tendency	± 0.1 mb	± 3 mb	0.1 mb
Sea surface temperature	$\pm 0.1^{\circ}C$	$\pm 1^{\circ}C$	$0.1^{\circ}C$
Mean wave period	± 0.5 sec	Insufficient information available	0.5 sec[1)]
Mean wave height	± 10%	(2 m ± 0.2< 4 m ± 0.5) 6 m ± 1	0.2 m[2)]
Precipitation	± 0.2 mm (≤ 10 mm) ± 2% (> 10 mm)		0.2 mm (≤ 10 mm) 2% (> 10 mm)

1) Period of individual wave.
2) Height of individual wave.

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FUTURE USE OF SHIPS, BUOYS, AIRPLANES AND SATELLITES IN OBTAINING OCEANOGRAPHIC OBSERVATIONS FOR ENVIRONMENTAL PREDICTION SYSTEMS

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FNWF PHILOSOPHY ON ENVIRONMENTAL OBSERVATION

1. GENERAL

The general FNWF philosophy concerning the gathering of environmental data both in the atmosphere and in the oceans is that:

a. The sensing element should generally be at the location being sampled, i.e., remote sensing should be avoided unless circumstances dictate otherwise.
b. Maximum use should be made of observing platforms already available before money and effort is expended on new platforms.
c. For data gathering from regions where platforms are not already available, sensing devices and telementry equipment should first be tested on land, then on ships, aircraft and finally satellites.
d. The frequency at which a given location reports should be related to the density of the reporting network and to the time variability of the data involved.
e. Preprocessing should be done at regional centers which then forward "clean" collectives to research or analysis and prediction centers over high-speed communication links.

2. PRESENT SHORTCOMINGS IN OBSERVATIONAL DATA

At present it is possible to receive, at a given synoptic time, about 800 meteorological reports from ships at sea. These reports contain only two truly oceanographic elements--wave data and sea surface temperature in the form of a difference from air temperature. In addition about 25 bathythermograph soundings can be received, mainly from weather ships, naval units and a few fishing vessels.

The density of weather reports from frequented shipping lanes is reasonably sufficient. Outside these lanes, there are large ocean areas where virtually no reports are received. First priority in obtaining more information in these areas should be enlistment of voluntary reporting from smaller cargo ships, fishing vessels, etc. The accuracy of the meteorological parameters in ship weather reports is generally satisfactory; it is the two oceanographic elements (waves and sea surface temperature) which are notoriously poor in quality. Emphasis should be directed toward; (1) automatic recording of these elements and (2) code changes which would permit direct (not differential) reporting and greater significance.

The number of subsurface (BT) oceanographic observations is not sufficient in any area of the world for making detailed synoptic analyses. The bathythermograph equipment now available fulfills a good part of the instrumental requirements here and could be used on many more ships if distributed together with proper winches and booms. However, it would be desirable to construct cheap, expendable BTs which would signal back temperatures while sinking.

For synoptic, operational problems these expendable BTs would be useful even if depth were not transmitted as bodies could be designed to give a constant sinking rate within the desired limits of accuracy.

Cloud observations from both ships and satellites are valuable inputs to oceanographic prediction programs. For many numerical problems, insolation data would be equally useful. Ships and buoys should be equipped with cheap, reliable pyrheliometers.

More accurate observation and reporting of surface currents on a synoptic basis is also an urgent requirement. Increased use of navigational satellites may permit increased accuracy of navigation to the point where current drift should be reported by all ships at sea. Drifting buoys should have the positions fixed with sufficient accuracy to permit computation of drift.

3. USE OF DIFFERENT PLATFORMS IN OBTAINING SYNOPTIC OCEANOGRAPHIC DATA

The ships are, and will remain the most ideal platforms for maritime meteorological and oceanographic observations. There are about 5,000 ships at sea, of which about 800 are voluntarily observing and reporting meteorological elements. Although the report density is sufficient on frequented routes, there is a definite need to recruit fishing vessels and others on less frequented routes. If reliable automatic weather stations have been constructed for land, they could also be distributed to ships and interrogated by satellites. However, it is not feasible to get ships reports from large ocean areas which are not crossed by ships and other means must be sought here.

Buoys, drifting or moored, might come to use in the future to fill the aforementioned gap when reliable ones have been manufactured. Moored buoys will always be expensive and only a few of them might be used in "key" positions. Shortlived drifting buoys, dropable from airplanes would have extensive use, if these could be interrogated from satellites. An accurate positioning during interrogation would be highly desirable, to gain data on surface currents. The first task in development of these buoys should be to construct a simple reliable instrument which would work for several weeks.

Airplanes are at present in synoptic use in ice reconnaisance flights and in sea surface temperature measurements in limited areas. Some additional use of existing low-flying flights (e.g. U. S. Coast Guard's flights) could be made in reporting current boundaries, fog and a few other specific observations. Any equipment to be used in oceanographic satellites should first be flown and tested in aircraft.

Satellites will in the future find their principle use in communication, including the interrogation of automatic stations. Some extended use of satellites will also be made in measurement of cloudiness and radiation.

4. SUMMARY EVALUATION

In the past most of the developments in synoptic meteorology have been relatively slow due to considerable international bureaucracy and conservative routine national services with little flexibility. The advances are usually made outside these established systems. The routine meteorological services should try to improve the quality of present maritime observations by better instruction of observers, by selective recruitment of additional ships and by distribution of additional instruments and their checking.

In order to utilize fully the existing reports a speedup in communications is urgent. Although the development of automatic weather stations has proceeded for several years, we still do not have a cheap and reliable model.

The ships are, and will be the principal platforms of maritime observations. The use of drifting buoys is waiting the development of proper automatic stations. The use of planes will increase with the use of automatic stations. The satellites are expected to assist mainly in interrogation, communication, and improvement of navigation (for current drift use).

N65-30

OCEANOGRAPHIC FORECASTING

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In most cases, oceanographic forecasts do not have to emphasize the future because the sea conditions change much more slowly than do the conditions in the atmosphere. In general, if one can describe the sea conditions as of the date of the "forecast" this constitutes a useful prediction, except near some coastlines, for the next week or more. The principal exception to this statement is in wave forecasting because the characteristics of the waves can change nearly as rapidly as the winds.

There are three principal practical objectives in oceanographic forecasts.

a) Ship Routing. This involves avoiding ice and head seas having a dominant period corresponding to the natural period of pitch of the ship. The objectives are to avoid cargo damage and by maintaining speed to shorten the time of the voyage. Often one day or more can be saved on a transocean voyage. If, in addition, information is available about the position of strong currents, a further equal saving in time can be made.

b) Fisheries Management. This involves not only the currents and the associated positions of oceanographic fronts, but also the depth and existence of seasonal thermoclines.

c) Horizontal Sound Transmission. Much the same factors are involved, but in addition there is also the question of whether or not a slight diurnal thermocline will develop.

Oceanographic forecasts start off with statistical information concerning the seasonal and geographical near surface conditions (down to about 200 meters) and then one tries to predict how these have been modified by the existing and past weather. Obviously insofar as weather forecasts can be improved and lengthened the usefulness of oceanographic forecasts will also be increased.

The data gathering network for oceanographic forecasts can be much more open than in the case of weather forecasting over land areas. However, the present network is inadequate because ships are very unevenly distributed and their reports contain many errors which must be screened on the basis of good statistical information. Data gathering buoys will have to be added, but a serious radio communication problem will remain. A satellite communication system that could locate and interrogate ships and buoys would be most helpful.

The principal needs at present are for precise low level wind information, especially in summer, and for means of mapping sharp horizontal thermal gradients at the surface. Only a low level of absolute accuracy is necessary in mapping the oceanographic fronts.

It should perhaps be pointed out that the present need for oceanographic forecasts is now largely confined to the northern hemisphere. However, it will soon spread to the southern hemisphere and would then make a major contribution to weather forecasting over the land areas. The United States can gain much good will be developing such a service on a worldwide basis.

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N65-30366

THE POSSIBLE USE OF SATELLITE DATA IN ESTIMATING THE DEPTH OF THE THERMOCLINE

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INTRODUCTION

I doubt, very much, if there are any means of estimating the depth of the thermocline in the ocean, directly from satellites alone. However, it is possible that, by application of erudition, satellite data can be used in conjunction with existing data or techniques now in development, to provide much needed information. Mr. Schule and I will try to elucidate some of the possibilities.

INFORMATION SERVICES

Oceanographic Information Services, similar in scope and philosophy to the National Weather Services, are being developed in Japan, the United States and Canada. Their object is to provide regular assessments and forecasts of the oceanographic conditions (properties and structure of the water) in the contiguous Atlantic and Pacific Oceans. The original efforts were sponsored by fisheries researchers who have produced summaries of sea-surface temperatures every ten days or every month. Recently the military in United States and in Canada have created independent services. Eventually, these fisheries and military efforts will be coordinated because the requirements are essentially the same for both groups. Meanwhile, they provide the driving force for high-speed wholesale assessment of the oceans.

One of the primary requirements of these oceanographic services is to assess and forecast the depth of the mixed layer overlying the seasonal thermocline. At the present time, the assessment is inadequate and there is very little forecasting.

A number of naval and fisheries research vessels have been provided with bathythermographs. They make observations several times a day and radio the oceanographic and accompanying weather data to centers where they are interpreted and collated onto charts. Because the oceanographic data are sparse it is necessary to accumulate them for periods of about a week. Even so, the data are not adequate to be independently definitive. However, the picture is not all black. It is possible to assume persistence of the primary and, sometimes, of the secondary features. Considerable weight can be placed on historical data. Models of seasonal and regional behavior can be invoked. Correlations can be sought between the desired quantity, such as depth of the thermocline, and more readily observable features, such as sea-surface temperature. The problem is to improve these procedures.

THE ROLE OF SATELLITES IN OCEANOGRAPHY

There is an evident need for high-speed wholesale assessment of the oceans. Although observations from ships are the primary source of data, they are not adequate. The use of maritime patrol aircraft to collect sea surface temperature data is being developed in the United States and Canada. Also, some thought has been given to the use of satellites.

There are three, apparently obvious ways of using satellites in oceanography; to determine the sea-surface temperature by sensing radiation from the sea surface, to aid in the assessment of the surface weather, and to communicate with seaborne sensing devices.

SEA-SURFACE TEMPERATURE

There has been considerable research, particularly in the Gulf Stream region of the Atlantic Ocean, to show relations between sea-surface temperature and the depth of the thermocline. From this there is an immediate temptation to suggest that sea-surface temperature should be inferred from the infrared radiation scanned by satellites. It may be argued that the inherent air path error would be nearly constant, or varies regularly with latitude, and could be compensated in such procedure. Also, on the basis of research now in progress (Scripps Institution of Oceanography, U. S. Naval Oceanographic Office, Pacific Oceanographic Group) it is probable that it will be possible to correlate the sea-surface radiation with the representative temperature in the mixed layer. However, one major difficulty remains. The infrared radiometer cannot "see" through clouds. Much of the ocean is cloud covered much of the time. Hence, the technique would depend on glimpses of the sea surface. It would be necessary to piece the picture together for periods of a week or more to obtain significant cumulative results. Presumably this would be somewhat more adequate than the present input of sea surface temperature data from ships, but certainly it would fall far short of the requirement, particularly in high latitudes. Finally, the correlation between sea-surface temperature and depth of the thermocline is by no means universally applicable.

WEATHER ASSESSMENT

Gradient wind speed over the ocean can be estimated, with acceptable accuracy, from detailed barometric pressure charts. The primary data are available from transitting ships and ocean weather stations via the weather services. These are adequate only in the principal shipping routes. Elsewhere there is considerable intuition in the interpretation of the sparse data. The analyses of wind speed can be greatly improved by satellite pictures of cloud cover such as shown in Figure 1. Such pictures allow considerable improvement in the interpretation of the isobaric patterns and, hence, of relative wind speed and depth of the thermocline.

The utilization of satellites for such purposes is economically feasible. A cheap ($12,000) real-time photographic read-out facility has been developed by the Canadian National Research Council and proven on TIROS VIII. On the Pacific coast we are giving thought to acquiring such a facility for our weather/oceanographic information services. However, the processing, "inclined-ecliptic" orbit of the TIROS satellite series reaches our northern area of interest, during daylight hours, for only a few days each month. To be of real use, such pictures must be available daily. Therefore, our venture into satellites must wait until there are enough polar-orbiting NIMBUS satellites to provide daily data.

I draw your attention to another feature that can be derived from adequate cloud pictures. Present researches are showing that the thermocline rises in regions of divergence and sinks in regions of convergence. In oceanic areas these conditions are dependent on the curl of the wind stress, which is adequately revealed in these cloud patterns.

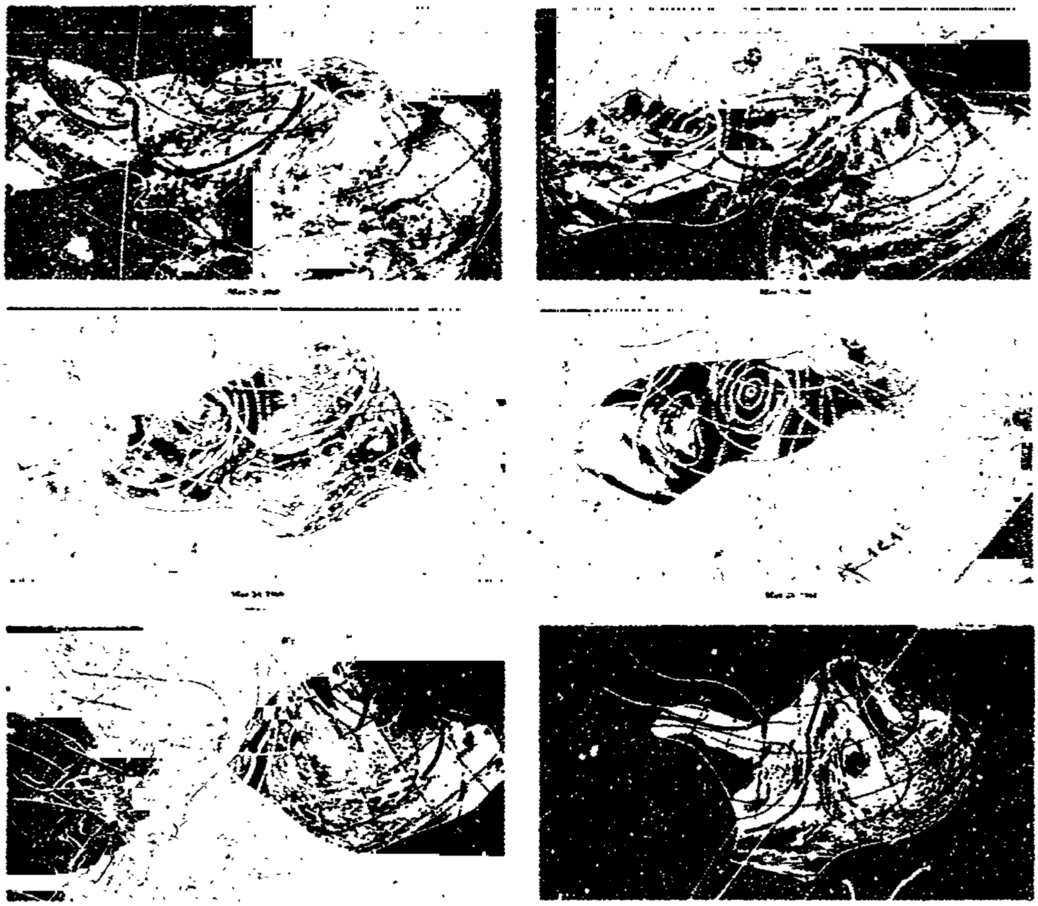
COMMUNICATIONS

Turning now to utilizing the communications features of satellites, it is worthwhile to consider coordination of some developments in the United States. The Stanford Research Institute, under a contract with NASA is exploring the possible uses of a satellite that would communicate with wandering radio stations, such as telemetering weather/oceanographic buoys, and locate them accurately.

As reported at the buoy conference in Washington last spring the problems of a buoy vehicle, power, sensing devices, data storage, and telemetering are, or soon will be, satisfactory. The unsolved problem is how to moor them. Hence, thought is being given to the use of drifting buoys.

The U. S. Bureau of Commercial Fisheries, Seattle has maintained radio contact through three months with three free-floating telemetering buoys in the eastern subarctic Pacific. At the conclusion of the test they were able to find and recover them. They propose to launch buoys in the confluence region of the Kuroshio and Oyashio, allow them to cross the ocean in the West Wind Drift and recover them on the American side of the ocean. The main problem is to provide radio monitoring facilities which are limited by available channels and monitoring stations. The latter are scarce in the Pacific Ocean.

Cloud Patterns Over the North Pacific



TIROS I 1960

Figure 1

With existing sensing equipment this drifting buoy system is capable of revealing temperature and sound velocity structure to at least 100 meters depth, and perhaps more. Also, by comparison of successive positions it will reveal the detail of surface drift. All these are parameters of concern to the customers of the oceanographic services.

Bringing these two ideas together, it is evidently practical to consider such drifting sensing buoys in any part of the world ocean, located and monitored by polar-orbiting satellites. Such a system, by itself, would require a large number of buoys, and would probably be limited by communication facilities. However, taken together with present data income and knowledgeable weather assessment as outlined above, it may be possible to devise a system of oceanographic assessment which can be economically based on the utilization of all available facilities.

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RELATION OF THERMOCLINE DEPTH TO SURFACE TEMPERATURE IN THE ATLANTIC

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At the Oceanographic Office we have a rather large program in synoptic oceanography and provide services not unlike those Dr. Tully has described. We are, therefore, extremely interested in the sea surface temperature, not only because of its direct value in many applications, but also because it is basic to understanding subsurface conditions. Many more surface observations are received than subsurface and the surface temperature field can be contoured more accurately than any other level. It is only natural, therefore, that one would wish to use the surface data as an aid in any way possible when assessing subsurface conditions, and, of course, one of the parameters we are all interested in is the depth to the top of the thermocline.

Unfortunately, no quantitative relationships exist for directly inferring the thermocline depth from the surface temperature. In the relatively stable waters with which Dr. Tully is concerned, changes in the thermocline depth are due mainly to local changes brought about by such processes as heating, cooling, mixing, and convection. One would not expect any quantitative relationship to exist between thermocline depth and surface temperature in these waters except perhaps in Autumn, when convection mixing due to heat loss at the surface is the dominating process. At all other times the problem is mainly one of estimating the strength of these factors which will change the thermocline depth.

In areas such as the Western North Atlantic the situation is somewhat different. The presence of the Gulf Stream and Labrador Current with the resulting extremely complicated structure preclude the possibility of quantitative correlations in any season. On the other hand, the fact that both cold and warm water masses, each with its own characteristics, exist in this area separated by rather sharp discontinuities, enables rough qualitative inferences to be drawn concerning the depth of the thermocline. In winter, for instance, the presence of relatively cold surface water would lead one to expect an extremely deep convective layer in that area, while the relatively warmer waters would have shallower thermoclines. While the picture is not quite so clear in summer, the effect tends to be just the opposite, the warmer surface water having the deeper thermocline.

We are taking many steps to improve our understanding of the sea surface temperature field. One of these efforts has been the development of our version of the Airborne Radiation Thermometer built by the Barnes Engineering Co. We have been flying this instrument for about two years and have found it to be a valuable tool in assisting in the assessment of the sea surface temperature field.

Several experiments have been conducted to compare airborne radiation thermometer measurements with surface observations taken by other means. One such experiment is illustrated in Figure 1. The contours are of sea surface temperature taken from the chart prepared routinely from injection thermometer observations from ships for the period during which the flight was flown; the flight track is also shown. Figure 2 shows a comparison of the actual airborne radiation thermometer readings and temperature values interpolated along the flight track from the contours. Agreement is good except in one area where the contoured values were considerably higher. This discrepancy happened to occur in the northeastern portion of the flight track where the track paralleled the contours; the discrepancy between the readings is, therefore, very sensitive to the exact placement of the contours in that area. If the contours are adjusted twelve miles to the east, the resulting comparison is shown in Figure 3. This suggests that the airborne radiation thermometer has value in interpreting data obtained by other means.

Our experience with the airborne radiation thermometer makes the possibility of obtaining similar data from satellites very attractive, in view of the greatly expanded

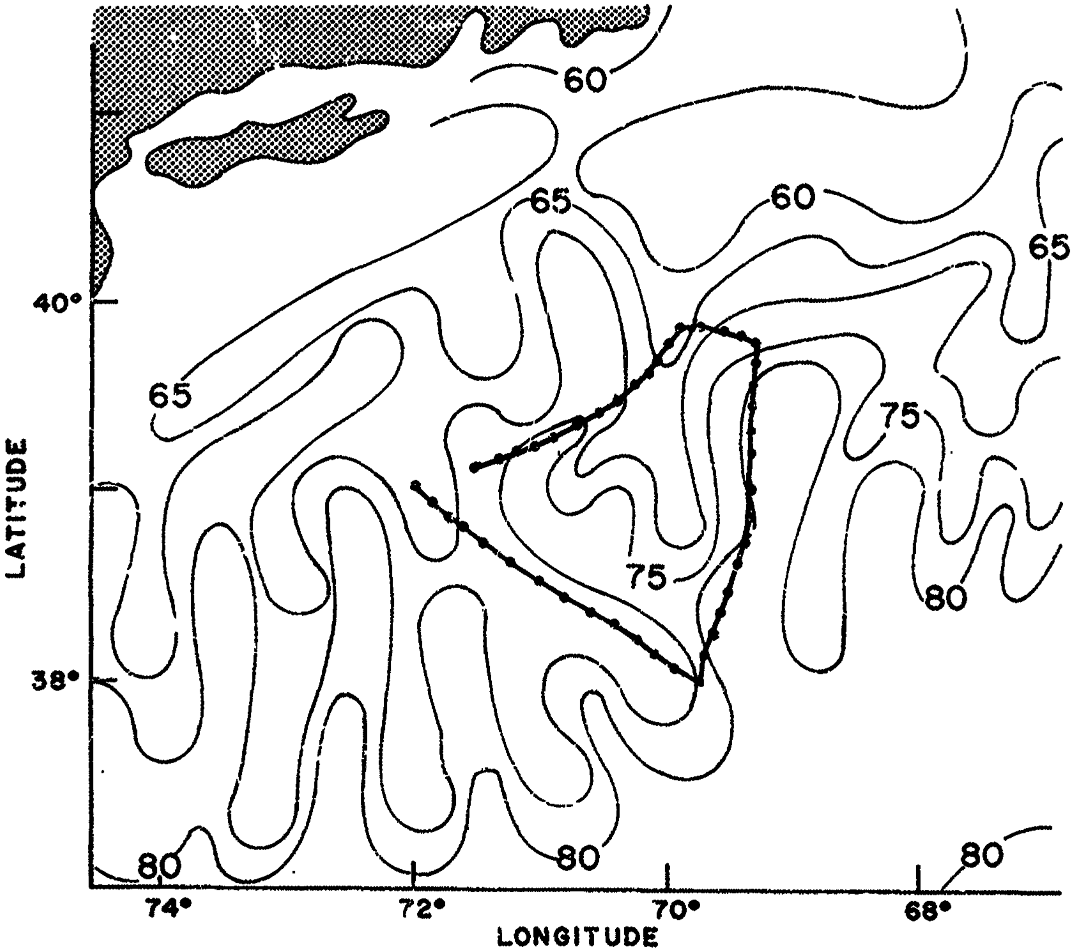

Figure 1. Flight Track of Airborne Radiation Thermometer Flight.

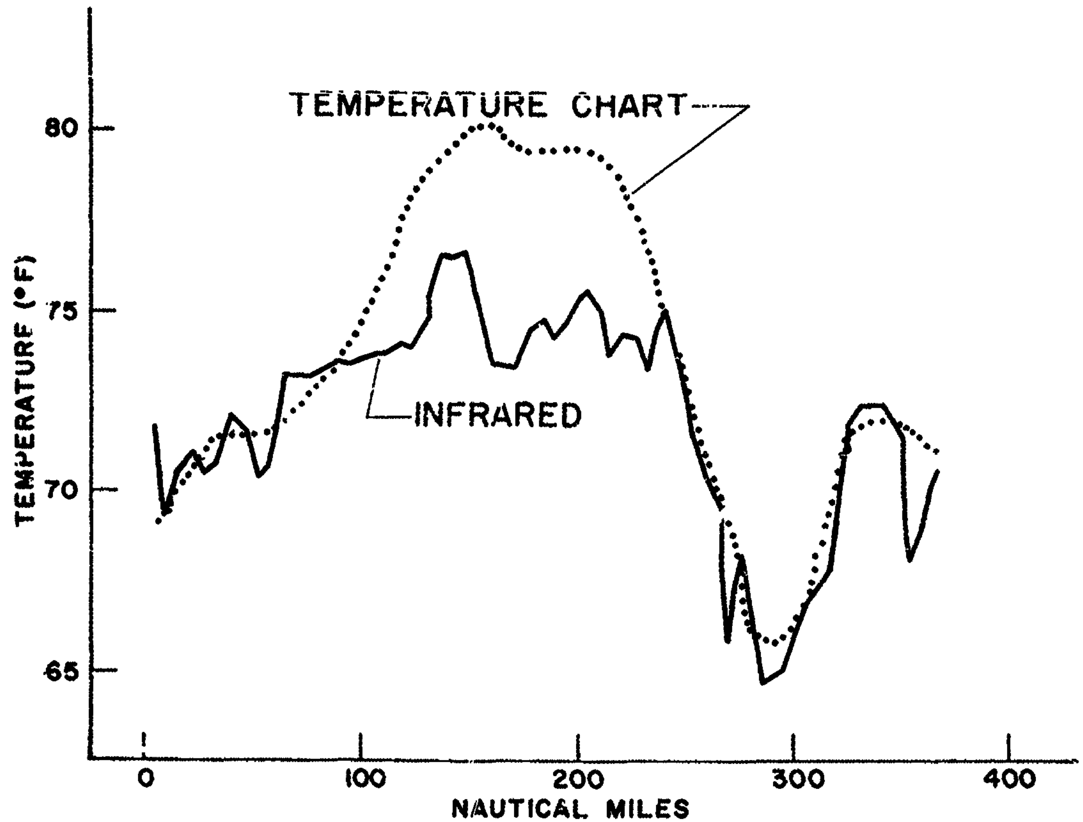

Figure 2. Comparison of Surface Temperatures as Measured by the Airborne Radiation Thermometer with Analyzed Sea Surface Temperature Chart.

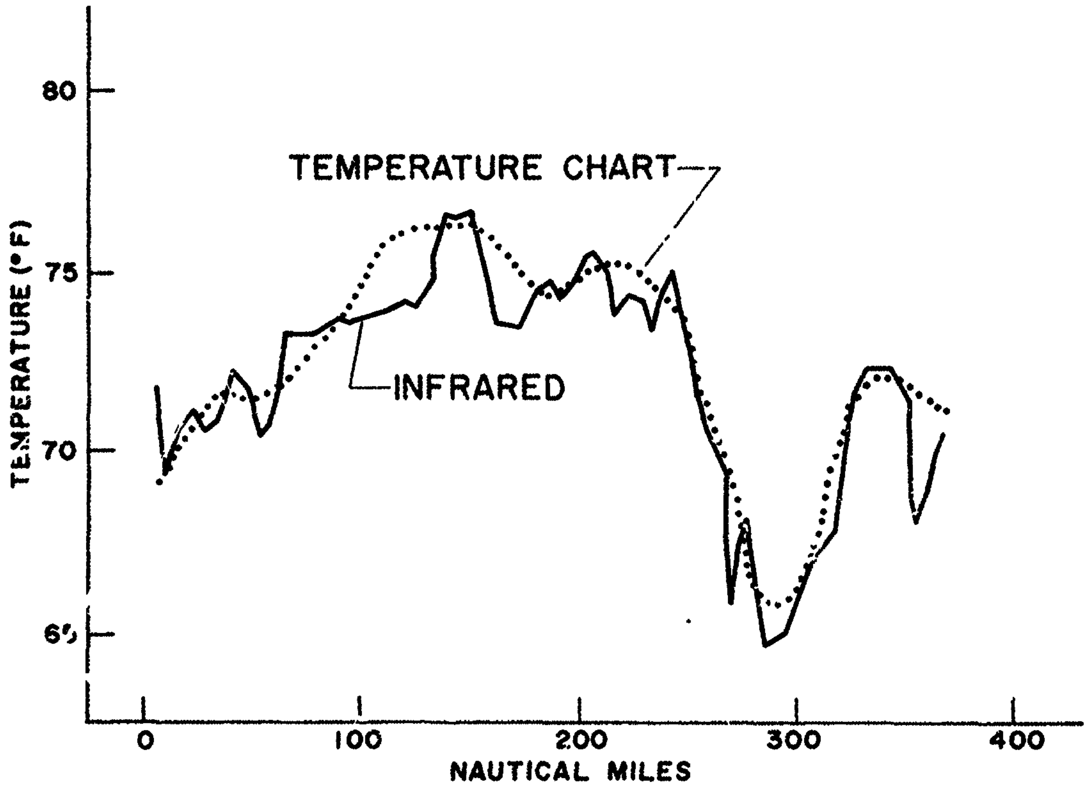

Figure 3. Comparison of Airborne Radiation Thermometer Measurements with Sea Surface Temperature Chart, with One Contour Adjusted.

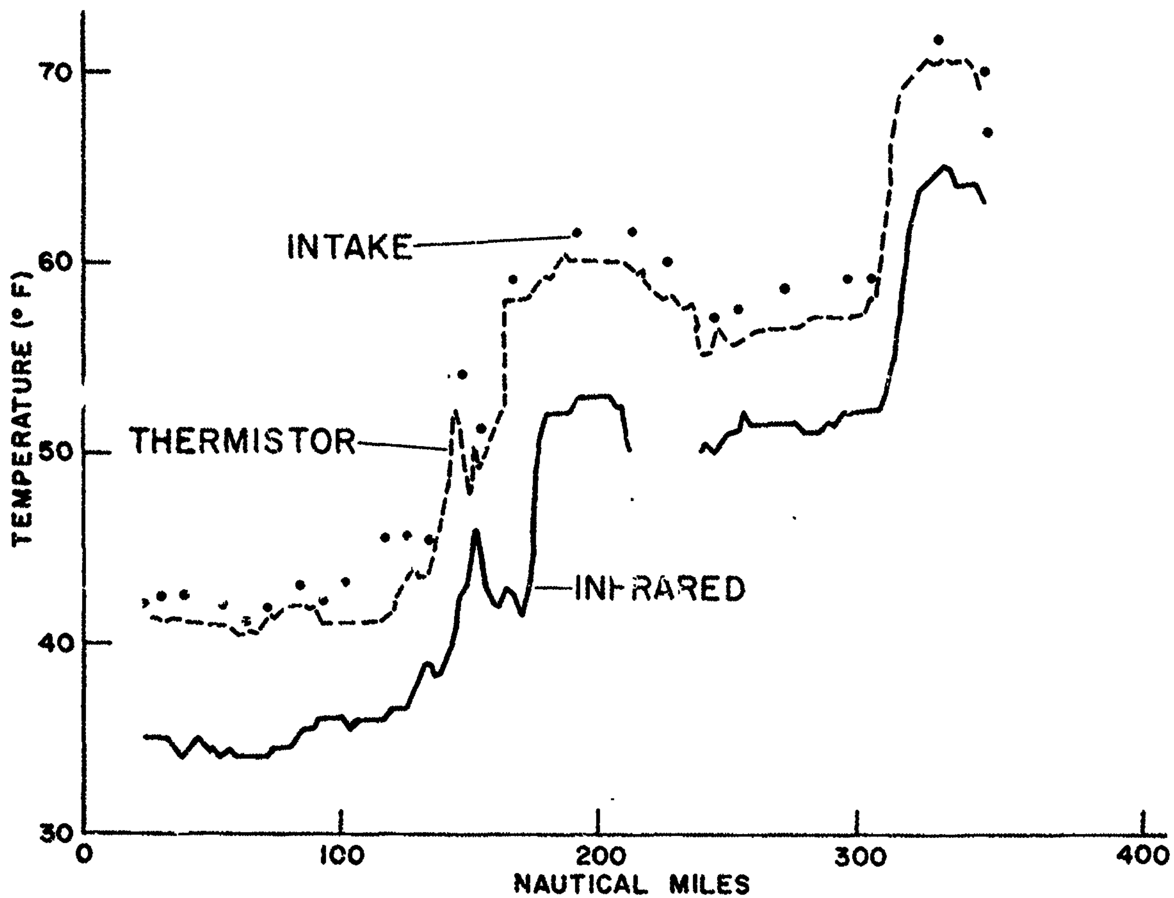

Figure 4. Comparison of Airborne Radiation Thermometer with Intake Probe and Towed Termistor.

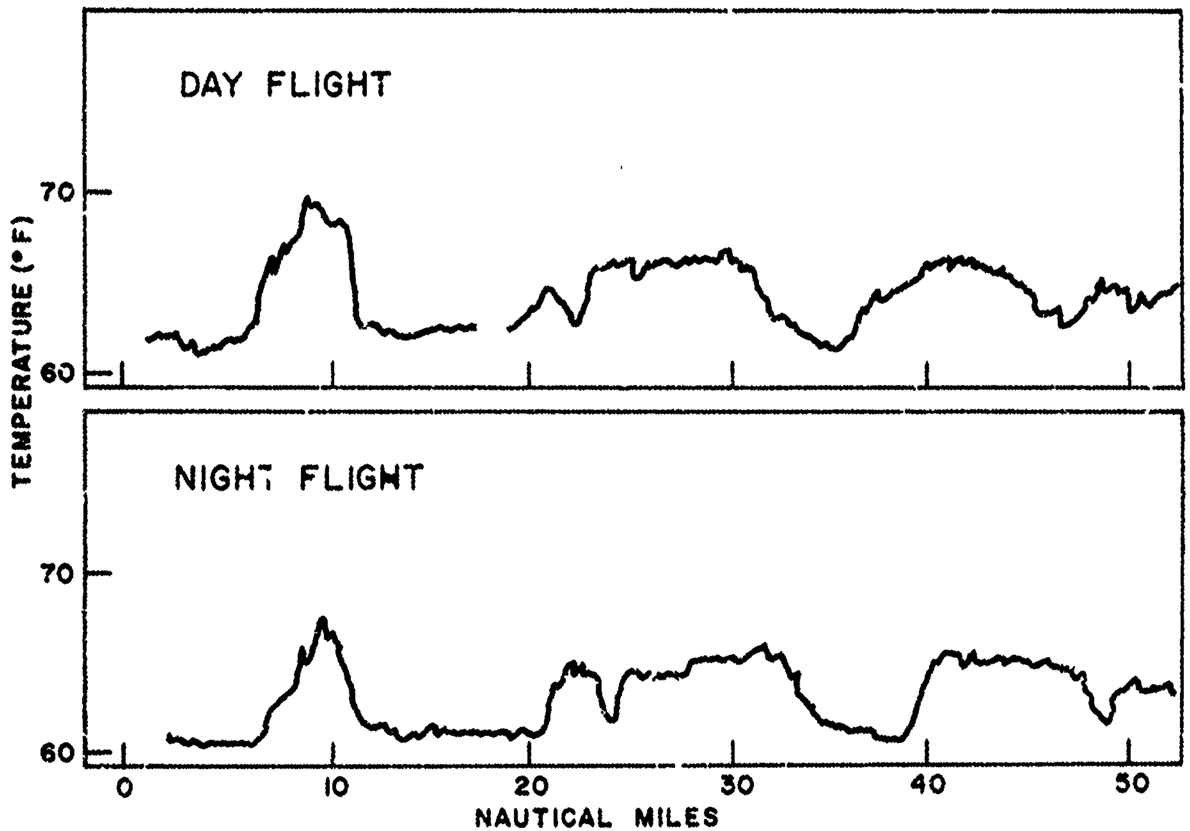

Figure 5. Comparison of Day and Night Airborne Radiation Thermometer Flights.

coverage such a system would provide. If the state of the art can be developed to the point where satellite data can be obtained which is of even comparable quality to that now obtainable from aircraft, our capability to assess the sea surface temperature field and to understand oceanic structure will be greatly enhanced.

Figure 4 shows another comparison between surface temperatures measured by the airborne infrared radiation thermometer and those taken by conventional means. In Figure 5 results are shown for a repeated run of the radiation thermometer in daylight and at night. The night flight is slightly lower but the gradient temperatures are reasonably repeated.

RECOMMENDATIONS OF THE PANEL ON BUOY AND COMMUNICATIONS

James Bush, Chairman

Members

Takashi Ichiye
Albert H. Oshiver
C. H. Jeffress
R. G. Terwilliger
William K. Widger, Jr.

The buoy and communication committee has considered the problem of obtaining oceanographic data. Rapid collection of data may be facilitated by the use of airplanes, balloons, rockets, and satellites. The following briefly summarizes our present feeling.

1. There is a present limitation on the imagination imposed by the limits of today's technology. There is a further limitation enforced by the nonavailability of information veiled under the security regulations. We, therefore, do not at this time desire to set limitations on accuracy and precisions necessary for future instrumentation.

2. We desire to look at as large a portion of the ocean as possible, both areally and vertically.

3. The only feasible way of obtaining other than interface zone data is with buoy systems at the present time.

4. We could start collecting important information within the next few years from selected locations of the ocean if development started in the immediate future.

5. We recommend the use of expendable and nonexpandable systems. anchored and unanchored systems, free floating and controlled course buoys.

6. Technical discussions of the feasibility of this application of data collection is embodied in the Transactions of the Buoy Technology Symposium of the Marine Technology Society held in March 1964; the Datacol System report by Sylvania Electric Company written for NASA, and the STROBE report.

7. The tentative NASA program calls for a feasibility experiment with a first model of a satellite-borne Interrogation, Recording, and Locating Subsystem (IRLS) on board a Nimbus B meteorological satellite in the second half of 1966. The size of the available command memory will severely limit the number of sensing platforms which can be accomodated by the initial experimental system in any given orbit. This limitation is due to available memory capability; it is not inherent in the system design. Within this limitation, representative user groups will be invited to participate if they so desire. Participating user groups will have the responsibility for providing the sensing platforms having the desired satellite interface characteristics. Among the NASA planning milestones for later experiments is the development of greater memory capability to permit access to a larger number of sensor platforms. The IRLS is so designed that an increased memory capability can be incorporated without other changes being required.

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OCEANOGRAPHIC PROBLEMS OF UTILIZATION OF SATELLITES

by Takashi Ichiye

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INTRODUCTION

The operation of satellites has increased the scope of data collection beyond imagination in various fields of sciences including oceanography. In general, satellites can be used in data collection in two different ways. One way is to obtain data directly through sensors attached to satellites and send back the signal to ground stations. This method is used by most of scientific satellites including probers of the moon and the planets and meteorological satellites. The other way is to relay the data collected by other means to ground stations. Both ways have applications to oceanographic data collection problems.

DIRECT MEASUREMENTS WITH SATELLITES

In the present state of development of sensors attached to satellites, sea-surface temperature and ice coverage of the ocean might be the only oceanographic data measurable with one of such sensors, namely the infrared radiation thermometer. However, infrared sensors can measure the water temperature to a depth of only a few millimeters below the surface. Also the readings of the sensor depend on the air temperature and humidity between the sensor and water surface. Since the skin temperature of the water is influenced by many factors of meteorological origins, it does not necessarily reflect oceanographic conditions such as circulation and water mass distributions. This limitation, as well as errors in the readings due to the condition along the ray path, lessens the usefulness of infrared sensors severely. Therefore, the only significant use of infrared sensors will be to detect the paths of the western boundary currents and the locations of oceanic polar fronts in a large scale, because the gradients of the surface temperature are usually so conspicuous in these areas that even the skin temperature does indicate the boundaries.

Ice coverage of the ocean can be successfully measured with infrared photographs taken from a satellite. This program has been partly accomplished with a Tiros satellite. In order to use the data of ice coverage for scientific as well as operational purposes, systematic measurements which might cover the ice-covered areas more frequently and densely will be necessary. Increase of resolution of photographs, in addition to increase of frequency and density of orbits of satellites, will make it possible to study the freezing process of the ocean on a large scale and even to detect the circulation of the northernmost or southernmost seas by tracing floating ice.

BUOY SYSTEMS FOR OCEANOGRAPHIC MEASUREMENTS

The most promising use of the satellites for oceanography is to relay the data obtained at floating or fixed unmanned stations to shore stations. Appraisal of various kinds of buoys developed by different organizations for oceanographic purposes has been made in connection with use of satellites for relay, by O'Rourke (1964). According to this appraisal, a yearly cost for maintaining one buoy for collecting oceanographic data and transmitting them at the rate of about 300 bits at a time to a satellite overhead is about $20,000. It is possible to monitor about 1,000 buoys with one satellite and thus over long periods the buoy-satellite system will be much cheaper and reliable than the conventional ship operation for oceanographic purposes. However, limited number of buoy stations and their limited capacity for transmission of data inevitably make it urgent for oceanographers to examine more carefully kinds of data to be collected by buoy systems, geographic distribution of buoy stations, choice of right kinds of buoys, frequencies of data collection and so on.

In this paper two oceanographic problems which might effectively be solved by application of a buoy-satellite system are discussed. One problem is world-wide measurements of internal waves of tidal and longer periods. The other problem is to determine generation and distribution of eddies with scales of geostrophic motion in the ocean. In fact these two phenomena are inter-related with each other and are essential factors in governing the dynamics of the general circulation of the ocean. It is obvious that the final goal of the buoy-satellite system is to obtain the data on in situ conditions of the world ocean quickly and widely. These two phenomena have long been believed to be main causes of the changes of oceanic conditions and yet have never before been fully explored owing to the difficulties of their measurements with the conventional techniques.

MEASUREMENTS OF INTERNAL WAVES

Occasional measurements at anchored stations in the mid-oceans indicate that the vertical fluctuations of isotherms and thermoclines with periods close to tidal periods are very common. (Ichiye, 1964) A hydrodynamic theory can predict only the relationships between periods and wave lengths (frequency equations) for different modes of internal waves in the stratified ocean, (Eckart, 1960). In order to determine the geographical distribution of the occurrence of such waves or the causes of the waves, measurements of wave elements in different areas are needed. Since the density structure of the water is almost constant during several tidal periods, the amplitudes of internal waves can be determined by measuring vertical temperature profiles. In fact the occasional observations of fluctuations with tidal periods of subsurface temperatures, particularly near the thermocline, seem to be due to internal waves. However, the difficulties in maintaining anchored stations in deep seas keep the data on internal waves scarce and sporadic.

The main purposes of the buoy system for measurement of internal waves of tidal periods can be itemized as follows:

1. To determine processes of occurrence and modes of propagation of internal waves in various parts of the oceans.

2. To study relationships between the surface tides and internal waves.

3. To study causes of internal waves.

4. To determine interaction between internal waves and the general circulation of the oceans.

5. To determine frequencies of occurrence of these waves.

In order to achieve purposes 1 and 2, measurements with the buoy system have to be continued only for a period of about one month. For purposes of 3 to 5, at least one year's operation may be necessary.

The wave length L of internal waves is given approximately by

$$L \approx \frac{2h}{n}\left(\frac{N^2 - \sigma^2}{\sigma^2 - f^2}\right)^{\frac{1}{2}} \qquad (1)$$

Where h is the depth, n is the order of the mode, σ is the frequency, f is the Coriolis coef cient and N is the Vaisala frequency given by

$$N = -\left(\frac{g}{\rho}\frac{d\rho}{dz} - \frac{g^2}{c^2}\right)^{\frac{1}{2}} \qquad (2)$$

in which ρ is the density of the water and c is the velocity of sound in water (Cox, 1962). Observed maximum values of N are of order 10^{-2} sec^{-1} and those of $\sigma^2 - f^2$ are of order 10^{-4} sec^{-1} for tidal periods. Therefore, the wave length of the first mode is about 800 km in water of 4 km depth. The waves of higher modes or for smaller values of N are shorter than this.

Analysis by Barber (1963) indicates that the simplest array of wave detectors with a sufficient directional resolving power may be a triangle of three detectors, with equal sides of half the wave length to be detected. In order to cover the world oceans with networks of triangular arrays with sides of 400 km, almost 4,000 buoys are necessary. Therefore, it might be better to set up a system of about 500 master buoys distributed at ten degree intervals of latitudes and longitudes, each of the master buoys having two slave buoys at about 200 km distance. Master buoys would receive and store the data from their slave buoys and transmit their own data, as well as the data from the slave buoys, to a satellite. Since the most essential data of the internal waves are temperature at several depths near the thermocline, the accumulated data at master buoys can be limited to 300 bits, which is the capacity of transmission to the satellite.

EDDIES OF GEOSTROPHIC SCALES

From the detailed isotherms obtained with a bathythermograph which he had invented, Spilhaus (1940) recognized the existence of eddies of three distinctly different sizes on the shore side of the Gulf Stream. Eddies of the largest scale were detected even with the routine hydrographic techniques and its dimension was of the order of magnitude of about 150 kilometers. The intermediate eddy and the smallest eddy, which was called parasite eddy by him, had a dimension of about 30 and 5 kilometers, respectively.

Both were detected only by closely-spaced temperature measurements using the bathythermograph. He suggested that intermediate and parasite eddies would be numerous enough for their effect on oceanic circulation to be capable of statistical treatment. However, there was neither statistical nor synoptic study on these eddies in observational and theoretical phases of oceanography thereafter.

It was ten years later that details of generation of a eddy of the largest size was determined by a multiple-ship survey called "Operation Cabot" (Fuglister & Worthington, 1951). In this survey seven ships were used in the area south of Grand Banks to observe the process in which the eddy, with a dimension of 200 kilometers, was detached from the Gulf Stream in a couple of weeks. The eddy was at first a tongue of warm water protruding to the southwest from the main part of the Gulf Stream but afterwards it became an isolated cyclonic vortex of an elliptic shape with a long axis of 300 km and a short axis of 100 km. The current distribution in the eddy was measured with GEK and drifts of the ships and temperature distribution with BT. Although there was no salinity data corresponding to detailed temperature data, a comparison of the mean temperature of the upper 200-meter layer, with the surface currents determined directly with GEK and ships' drifts, indicates that the geostrophic relation was valid within the eddy and the isotherms were almost parallel to the currents.

As for the intermediate and parasite eddies no study was made until recently, except occasional investigations about the Reynolds' stresses, which might be due to the eddies of such sizes along the edge of the Gulf Stream (Stommel, 1955. Webster 1961) of the Kuroshio (Ichiye, 1957). Even the name of parasite eddies has been rarely used. The first extensive measurement of the intermediate size eddy was made by a group from Scripps Institution of Oceanography off northern Baja California in October, 1959, using parachute drogues in conjunction with the conventional hydrographic techniques (Reid, 1963). The significant result of this measurement is that the currents measured with drogues are found to satisfy the geostrophic relationships, even in an eddy with a dimension of 20 to 50 kilometers when they are compared with results of dynamic calculation. It is also noted that an ordinary network of hydrographic stations of 30 to 60 mile interval off California (and in most other areas) may often fail to spot eddies of intermediate sizes, as illustrated by this example, because the eddy would be unnoticed in the dynamic topography of the area without an extra station occupied between the regular stations.

MEASUREMENTS OF GEOSTROPHIC EDDIES WITH A BUOY-SATELLITE SYSTEM

A synoptic measurement of development of eddies of geostrophic scale can be made with a local scale of operations using either ships or buoy systems, as in cases of the "Operation Cabot" and of California Cooperative Surveys. The most effective use of the buoy-satellite system for measurements of these eddies is to obtain the data which reveal the statistical features of these eddies, such as frequencies of occurrence in various areas and distributions of their sizes and energies. In order to achieve this purpose, networks of closely spaced buoys must be maintained for a long period of time. Therefore, it is necessary to determine the most effective spacing for detection of eddies with the minimum number of buoys.

It is assumed that the fixed buoy stations are set up in a rectangular array of equal spacing a. Also the eddies are considered to be circular with a radius r. Further, for simplicity, it is assumed that the eddies can be detected if any station is within the radius of the eddy (for instance, eddies are considered to have different water characteristics from the ambient water). Then the probability $P(r,a)$ that the eddy is detected with four stations of a rectangular array is given by:

$$\left.\begin{aligned} P(r,a) &= \pi r^2 a^{-2} && \text{for } a > 2r \\ P(r,a) &= \left\{\pi r^2 - 2r^2 \operatorname{Arc\,cos}\left(\frac{a}{2r}\right) + 2a\sqrt{r^2 - \left(\frac{a}{2}\right)^2}\right\} a^{-2} && \\ & && \text{for } a \le 2r \end{aligned}\right\} \quad (3)$$

The frequency of occurrence of eddies with a radius r is taken $F(r)$. Then, the most effective networks with the minimum numbers of buoys can be determined by obtaining the maximum value of a, satisfying the relation:

$$\int_0^\infty F(r)\, P(r,a)\, dr = \min \quad (4)$$

In actual situations, the function $F(r)$ depends on the geographic location and the time. In fact, it is the purpose of the buoy system to determine this function. However, if we consider that the largest geostrophic eddies with dimensions of 200 km are our main concern and also assume that the frequency $F(r)$ is an error function, a simple estimation gives the necessary numbers of buoys to cover the whole ocean as of the order of four thousands, which is too many to be realized. Therefore, it will be necessary to set up the system only in areas of the most importance. However, in the areas where strong permanent currents flow, floating buoys would be more effective in detecting eddies of geostrophic scales when the buoys are released at certain time intervals. The analysis of the data may be executed according to the theories of turbulence in shear flow (Townsend, 1956).

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IMPRESSIONS OF THE CONFERENCE

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My impression of the conference is that there are three main areas in oceanography in which observations from satellites may be of considerable value:

1. Use of infrared, radar, and microwave for ice reconnaissance. (As used here, the term radar pertains to an active system and the term microwave to a passive system, i.e., microwave radiometry.)
2. Use of all methods for world-wide reconnaissance of beaches, their changes in size and shape, and possibly of spectrographic methods to determine mineral content.
3. Use of radar backscattering from the sea surface to determine a roughness parameter of the sea surface for wave research reconnaissance and prediction.

The outlook for using satellites to obtain data for sea surface temperature (SST) charts, which would be of great interest to our Laboratory, is less optimistic. Even in the so-called "atmospheric window" within the infrared band, the absorption of radiation by atmospheric water vapor produces an error of 10-20°C which may be corrected only to an accuracy of about ± 3.0°C. These techniques, which can scan a relatively narrow field and have a rapid response, could be used in the absence of clouds for delineation of sharp temperature gradients, such as along the boundary of the Gulf Stream, but do not seem suitable for studying year-to-year changes in temperature. The working group on sea surface temperature, chaired by J. P. Tully and one in which I participated, felt that for mapping of surface temperature an average temperature accurate to ± 0.5°C integrated over an area of no more than about 600 square nautical miles was necessary to give new useful information. Use of microwave radiometry, which will penetrate clouds, is hampered by changes in the emissivity of the sea surface with changes in surface roughness or waves, and little quantitative information is available as yet about this. Element response time is slow so that an integration time of 3 seconds (satellite movement: 15 miles) or more is necessary.

I made some brief comments on our Laboratory's interest in SST data. In these I noted that, although determination of SST is beset with certain problems, it is well to keep in mind the potential value that would arise should a method be developed for determination of water vapor and the correction to give SST accurate to 0.5°C. A satellite in a polar orbit would probably get 3 daytime and 3 night looks at a geographic location, which would be 180 per month. Thus, if a clear observation without clouds could be obtained only about 2% of the time, this would give a sampling of about 3-4 observations per month. There are now large areas of the tropical and south Pacific and the Indian Ocean in which we now get observations only a few times a year, so that this would be an increase in data essentially by an order of magnitude.

The purpose of the conference was to consider observations which could be made with the sensor in the satellite. However, the potential value of satellite communications from buoys, fixed stations, and ships was deemed so great that a working group was organized by Dr. James Bush, I.I.T. Research Institute, Chicago, on this subject. Its recommendations, which are to be included in the report, are general but serve to point out the importance of this aspect.

Another thought which arose throughout the conference was of the value of just placing a trained observer in a satellite in orbit around the earth. It was felt that such an observer might well discover sources of information which could be obtained from the satellite, but which would never occur to the persons sitting in the conference room. One scientist stated the problem in the following words, "We need the manned satellite to find out what to look for with the unmanned satellites." Dr. Badgely assured the conference that NASA is aware of this and is already thinking along these lines.

The report of the Panel on Marine Biology noted that visual observations of bioluminescence, discolored areas, animal life and convergences; selective spectrometry for chlorophyll concentration; and monitoring of commercial and sport fishing fleets; would be of great use to biologists, as would telemetered information on surface and subsurface sensors.

A difficulty relating to the orientation of the satellite is encountered when one wishes to determine the geographic location of something in a photograph in order to use stereo methods for measurement of height or speed of movement from two photographs separated in time, e.g., on consecutive orbits. The track of a satellite is quite stable and can be measured and predicted with great accuracy, so that this can be used by surface ships with electronic gear to determine their position accurately–the navigational satellite. However, if one has a satellite photograph (visual, infrared, or microwave) the vertical orientation of the satellite cannot at present be governed nor measured to give a location better than about ± 30 miles in the photograph when there are no fixed reference points in the photograph, i.e., physical features of known geographic location.

A number of participants were apprehensive that much of the proposed effort might become classified because of security regulations. NASA personnel indicated that they have attempted to get observational information released and have had fair success in this, even though the full capabilities of the sensor might be classified. The conference went on record to the effect that "present security restrictions are: (1) impeding the applications of many sensory techniques to important scientific problems and (2) preventing interpretation of existing data by scientists of recognized ability, which results in a loss to both military and non-military projects of scientific nature.

APPLICATION OF SATELLITES OR HIGH-FLYING AIRCRAFT TO STUDIES OF CETACEANS AND OTHER LARGE MARINE ANIMALS

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(This is a special case of buoy work. But these buoys are found already launched, and are hard to hold during instrument-mounting.)

In this note we offer suggestions for some biological tasks that might be added to the program of a satellite or aircraft with other major tasks. Were there a chance of a vehicle primarily for oceanographic work, further suggestions could be offered.

The utilization of satellites or high-flying aircraft as an aid in cetacean research has been considered from time to time, but as far as I am aware, only a few tentative steps have been taken in this direction. Of course, a number of workers have used low-flying aircraft (sometimes as low as about 5 meters), chiefly in spotting or observation, but occasionally in conventional inert-mark tagging attempts.

At the Woods Hole Oceanographic Institution we have made several attempts to use radio transmitters as tags to trace the migrations of whales in the western North Atlantic, using ships or low-flying airplanes for detection and location. If satellites or high-flying aircraft could be utilized for this purpose, we could expect far greater coverage and improved tracking.

We have, to begin with, questions about the readiness of such vehicles to detect and localize short transmissions (probably shorter than a second) at unpredictable intervals (from perhaps 4 to 40 or more minutes). Precision of localization would be acceptable at ±100 miles, though finer fixes would always be welcome, even in the first program.

It would be desirable for the receiving vehicle to discriminate between individual tags, so that individual whales could be distinguished. The transmission might be coded, or several frequencies might be used.

It is intended to use the aircraft or satellite only as a receiver or relay station, the source to be on the whale or other animal being tracked. (This sort of system would of course be equally applicable to drifting buoys, which would have longer and more predictable transmissions.)

Another possibility would be a transponding whale tag, to be triggered by radar sweeps from the aircraft or satellite, using either sidelooking or PPI radars. For whales, whose surfacing time is unpredictable, this would be preferable to interrogation at longer intervals, since the chances of finding the transmitter at the surface would diminish rapidly as the sweep (interrogation) interval increases.

A whale-tracking project is already in operation at WHOI, and this is ready to join in any such operation right now. Doubtless a number of other biologists would wish to make use of such a system. The Woods Hole project has been trying to track the migration of *Eubalaena glacialis* (right whale) in the western North Atlantic. The conventional inert tags (Discovery type) are of no use here, since this whale is no longer hunted, so that these tags would not be recovered. It is so long since this whale has been hunted in the North Atlantic that we have been unable to find off-shore records of its occurrence, except for one region south of Iceland where the hunting seems to have stopped about 1915. All we are sure of nowadays is that a small population (probably not more than a very few hundred) turns up on the North American coast between Florida and Cape Cod in March and April, departing by early May.

For the beginning, we have been content to try simple tracking, leaving till later the addition of telemetry of such items as diving depth, swimming speed, temperature, heart beat, etc.

The tags we have used in our experiments have been uncoded transmitters on 140 mc. We have obtained 50-mile ranges from aircraft at 5000 feet. At present we have been limited by the range of our small airplane to distances of about 200 miles from shore. With the possibility of sustained tracking over the ocean, we are of course prepared to modify the transmitting characteristics of our tag to suit another receiver.

The detection and localization of our tag signals are of course only part of our problem. The transmitter has a number of conflicting requirements, such as the compromise between optimum antenna size and hydrodynamic requirements so as to be tolerable by the whale. There is also the sporting uncertainty of the actual tagging of the whale. These and ancillary problems remain, whatever receiving system is used, but we welcome the possibility of help in the receiving and tracking department.

Of the possibilities mentioned, the radar-transponder is so far the most attractive. For the present application, orbiting receivers are not required; for example, any trans-Atlantic flights or suitably instrumented aircraft would suffice.

N65-30370

INTRODUCTORY REMARKS ON INFRARED SENSING

R. J. P. Lyon

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Today we are commencing the study of the electromagnetic spectrum in greater detail. This morning we will deal with the infrared portion of the spectrum.

Even the infrared portion of the spectrum is wide and one must identify the wavelength or band of wavelengths in which one is working. It's a little like saying that you come from Texas, and the next questioner wants to know 'where in Texas'? The visible portion of the spectrum only covers the range from 0.4 to 0.7 microns - the infrared portion stretches from 0.7 to beyond 300 microns.

We are splitting the infrared (IR) spectrum into several segments — photographic IR - 0.7 to 1 microns, near IR - 1.0 to about 6 microns. And far IR from 6 microns to beyond 25 microns.

When infrared radiation is transmitted through the atmosphere, several windows appear. These are areas of relatively good transmission (70 - 80%) separated by areas of strong absorption. The absorptions are primarily due to H_2O and CO_2. These peaks are sharply bounded, but also have the less strong "wing" absorptions characteristic of gases. Thus, even the windows have varying transmission, as a function of the H_2O content of air from day to day.

This absorption markedly attenuates the IR transmissions with increasing altitude and will be one of the major problems with satellite-IR operations.

But these absorption bands and their attendant weaker wings can yield important information to the atmospheric physicist and also to the oceanographer. Penetration depth (or optical depth, attenuation depth) is a function of the optical constants of the gas or liquid being studied. Knowledge of the optical constants is being accumulated and temperature measurements as a function of depth in both the air and water can be performed. The 15.0 micron band of CO_2 and the 6.2 micron band of water can be studied with narrow band radiometers for temperature gradient data.

This brings me to my first main point: increasing sophistication in the IR equipment now enables the scientists to select narrow wavelength bands for detailed study where before only radiometers could be used. Detectors now only require fractions of the energy of the earlier thermistors, and the integration of wide energy bands is not required.

The second main point is this: radiometers respond to radiant energy received. Radiant emission is a function not only of the temperature of the source but also of an efficiency factor (emittance),

$$\text{Radiance (R)} = \underline{k} \times \underline{\text{emittance}} \times \underline{(\text{temperature})}^4$$

where k is a constant.

If the emittance is known then the true temperature can be easily obtained from the radiance. This is a fundamental physical fact and no advance in the state of the art of equipment will bypass it. If the emittance is not known then it must be presumed - and for water, in a steady, flat sea state, at near-normal incidence, and in the 8 to 12 micron band, a factor of 0.98 may be used. Waves and whitecaps markedly change this value.

This emittance factor (and its converse - reflectance) are even more worrysome in the microwave region where for water values as low as 0.5 to 0.6 must be used.

"Temperatures" should be called "apparent" or "equivalent balckbody" temperatures until the emittances (or reflectances) have been calculated and allowed for in the measurements.

Thus, while "thermal contrast" maps may be readily prepared by thermal scanning and image-producing units it always must be remembered that these are essentially "radiance contrast maps" and may be maps of sea state rather than true temperature differences. The case is much more clearly made for land rock and soil IR emission and for the microwave areas, but it is important not to be mislead by the excellence of the picture shown on the TV screen into thinking that there is a unique interpretation.

EVALUATION OF INFRARED SURFACE SIGNALS RECEIVED BY WEATHER SATELLITES

by Konrad J. K. Buettner and Capt. Clifford D. Kern, U.S.A.F.

University of Washington, Seattle, Washington

Surface signals penetrate the atmosphere in a series of windows from 4µ to the microwaves. For emitters of the order of 300°K the 4µ signal depends so much on temperature that the emissivity variance may be neglected. In the microwaves the opposite is true. For the 8 - 12µ window, true temperature changes influence the received signal about as much as emissivity variations. The latter have been investigated already by R. Lyon. We measured many natural surfaces with a new device. We also demonstrated from Tiros III data that the Sahara emissivity is substantially below unity. Water, snow, and ice are nearly black emitters; however, water and ice deviate from blackness at oblique angles. Therefore wave formation lowers emissivity. A very thin layer of oil also lowers the emissivity by about 2% or the apparent temperature by about 2°K.

Buettner, Konrad J. K. and Clifford D. Kern, Science 142; 671, 1963

OCEANOGRAPHIC USES FOR AN AIRBORNE INFRARED DETECTION DEVICE

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Technical Director for Oceanography,
Texas Instruments Incorporated, Dallas, Texas

The characteristics of high mobility and day and night operation makes this method of remote sensing very useful for synoptic oceanographic observations. The ability of an infrared sensing device remotely to determine oceanographic parameters is limited by several constraints:

1. The resolving power of the optical system that forms the image for the scanning system;
2. the minimum radiometric temperature differential that the infrared part of the system can sense; and
3. the amount of cloud cover and certain other meteorological conditions.

The first application of this instrument to oceanographic research could consist of taking an infrared look at the world's oceans. This is an entirely new method to obtain oceanographic information and the only method that directly measures parameters in the surface layer. This device would be suitable for collecting temperature data that could be used to prepare charts of the surface temperature distribution for the world's oceans. The radiometric temperature can be related to the thermodynamic temperature by a calculation if some value for emissivity is assumed or determined.

The information collected could be used to revise the surface temperature charts already existing or to prepare an entirely new set. This work could also be extended to determine the annual variation in surface temperatures of the ocean. In such a large-scale endeavor it might be possible to determine if there is a seasonal repetition of isotherms on a ocean-wide basis. This infrared device could also chart the diurnal variations in the surface temperature of the world's oceans.

It is possible that these data could be used to track large water masses whose surface radiometric temperatures differ from that of the surrounding surface water by an amount greater than the resolving power of the infrared system. It could be used to take a synoptic look at the major surface ocean currents of the world.

Areas of upwelling could be discovered and observed provided that the upwelling water was a different radiometric temperature than the surface water where the upwelling occurred. It might also be possible to study small-scale convective activity that occurs in the thermocline. The scale of convective activity that could be studied would be directly related to the resolving power of the optical system of the infrared device. It is possible that areas of unusual activity where some process was converting another form of energy into heat energy could also be observed. For example, in an area where there was a rapid conversion of kinetic energy into heat energy or an area where there was unusual chemical or biological activity.

A region of unusual surface radioactivity could possibly be found with this device. The above conditions would have to be of such a nature that the surface temperature of the area in which they were occurring was affected.

This infrared sensing device appears to have general applicability in problems concerning the heat budget of the world's oceans.

The availability of "ground truth" to provide accurate calibration information for remote sensing data is imperative, if significant information to solve oceanographic problems is to be obtained with these methods. Provisions have been made in the kit shown in Figure 1 to measure in an accurate and efficient manner the necessary key variables. These include

Figure 1

temperature, relative humidity, wind direction, barometric pressure and velocity, etc. Some of the apparatus in the kit are designed for use on land, but these could also be applied to study properties in the intertidal zone where this information might be applicable.

Oceanographic surveys using infrared sensors have been conducted by some organizations. The evolution of infrared systems by one of these, namely Texas Instruments, is shown in Figure 2. It also includes suggestions for future advances and applications. A flow diagram illustrating a possible new application is shown in Figure 3.

EVOLUTION OF INFRARED SYSTEMS TECHNOLOGY AT TEXAS INSTRUMENTS INCORPORATED

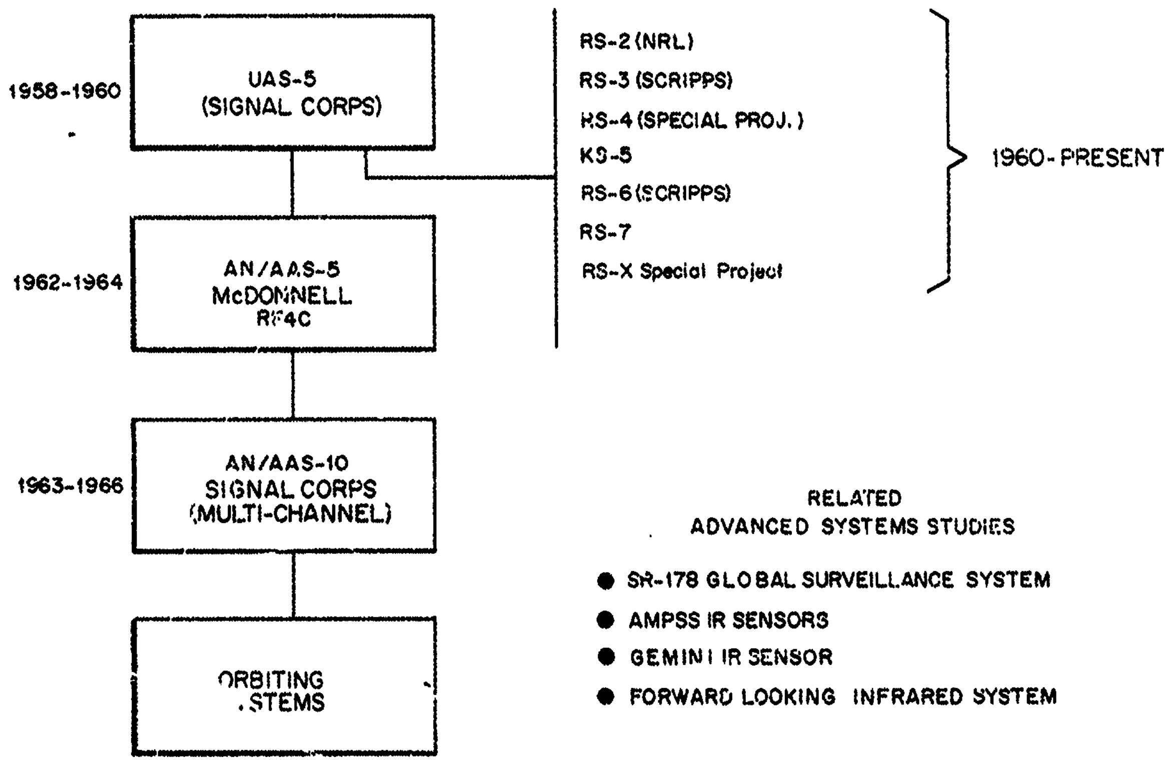

Figure 2

TEXAS INSTRUMENTS INCORPORATED CAPABILITIES APPLICABLE TO SUPPORT OF THE USAF MANNED ORBITING LABORATORY (MOL)

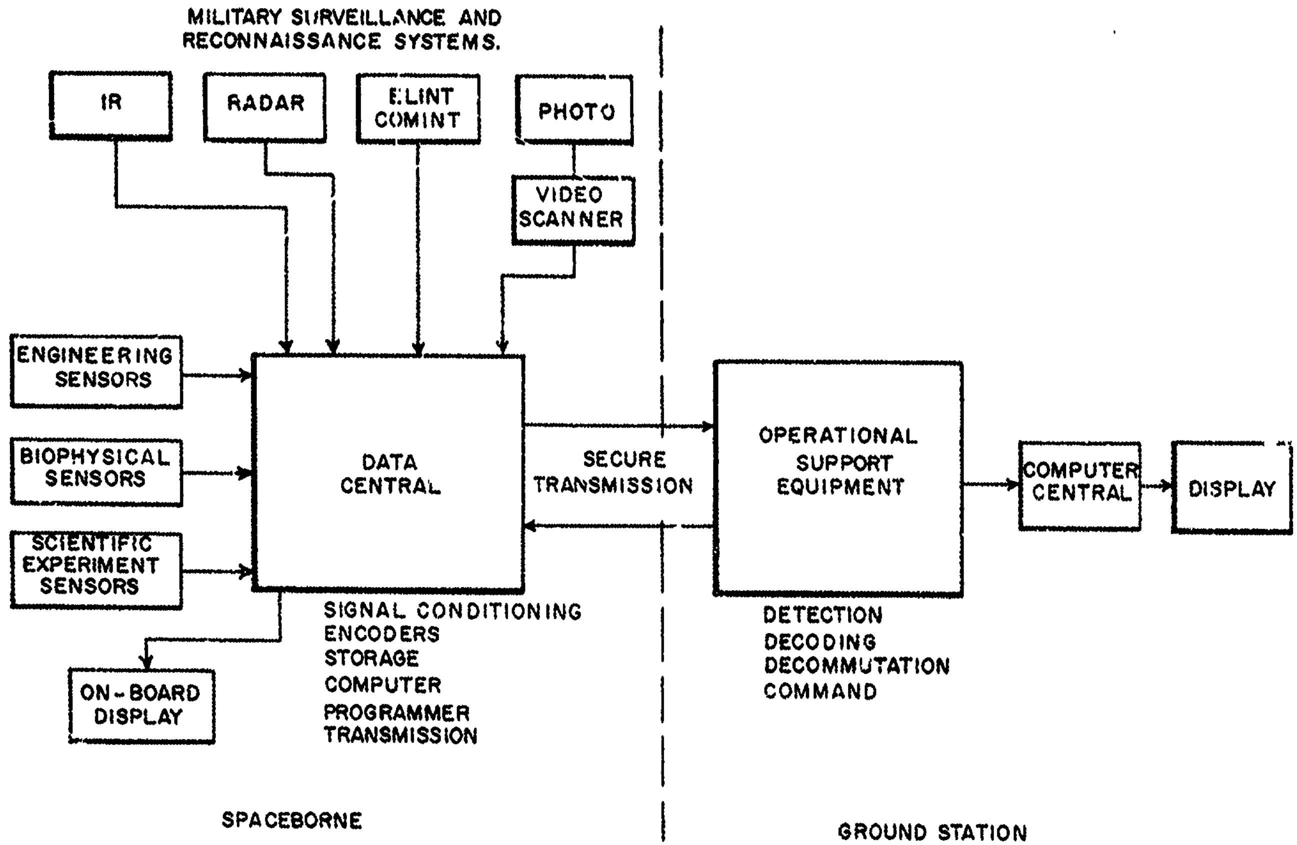

Figure 3

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OCEANOGRAPHIC MEASUREMENTS WITH AIRBORNE INFRARED EQUIPMENT AND THEIR LIMITATIONS

2. A TWO-WAVELENGTH MICROWAVE RADIOMETER FOR TEMPERATURE AND HEAT EXCHANGE MEASUREMENTS AT THE SEA SURFACE OF POSSIBLE USE IN MANNED SATELLITES

E. D. McAlister and W. L. McLeish

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University of California, San Diego; La Jolla, California

INTRODUCTION

A part of the experimental study program at the Applied Oceanography Group of the Scripps Institution of Oceanography is to describe the infrared radiance of the sea surface, its variation in time and space--the noise background of the sea--and relate it to the oceanic factors producing the variation. Infrared radiometers, a scanner, and meteorological equipment installed in a DC-3 and a surface vessel for simultaneous oceanographic measurements are the essential equipments used.

The Office of Naval Research has acted under OpNav Instruction 01550.63 to declassify records from these equipments which are of general oceanographic and geophysical interest. Parts of the infrared scanner and its performance characteristics remain classified.

These studies have shown that a number of oceanographic features on the sea surface and some underwater phenomena can be observed with airborne infrared equipment.

INFRARED SCANNER RECORDS WITH INTERPRETATIONS

Some Physical Features of the Ocean Surface Shown by an Infrared Mapper. The infrared scanner used by the Applied Oceanography Group provides images which, except for a transverse distortion, constitute temperature photographs of the ocean surface. In these photographs the warmer areas are lighter in tone and the colder areas darker. The broad horizontal dark bands in these photographs result from sky reflection and do not represent the temperature structure of the sea surface. The accompanying figures show the relatively small-scale horizontal temperature structure of an oceanic front, an eddy, convective regions, and various slicks. These figures imply certain features of the internal structure of the ocean, and it is suggested that correspondingly, much larger features might be observed from a satellite to give similar implications of the larger-scale internal structure of the ocean.

A horizontal temperature discontinuity found 37 miles offshore near San Diego is shown in Figure 1. The definition proposed by Cromwell and Reid[1] for an oceanic "front" is satisfied here, since there is an abrupt change in temperature along this line. The apparent rise of the water temperature beyond the front on the cold side is due to the instrument response of the infrared scanner. Note that the ocean surface has different temperature patterns on either side of the front. Thus, there are some irregular cloudlike features on the warm side of the front which do not appear on the cold side. In Figure 1, the front consists of a single temperature discontinuity; in a number of other cases a front has been seen to have up to four parallel discontinuities, a few hundred of feet apart.

An eddy encountered along the northeast shore of Santa Catalina Island is shown in Figure 2. The island itself lies outside the lower portion of the picture. The direction of rotation of this eddy indicates it to be the result of a southeast current along the shore, encountering a point of land immediately upstream, that is, to the left of the figure. The several features of this eddy are remarkably similar to those shown in a recently published color photograph of the Smith-Benton eddy in the Caribbean[2]. The cold marks on the water on the right portion of the figure might represent oil slicks from the nearshore kelp beds observed in the area.

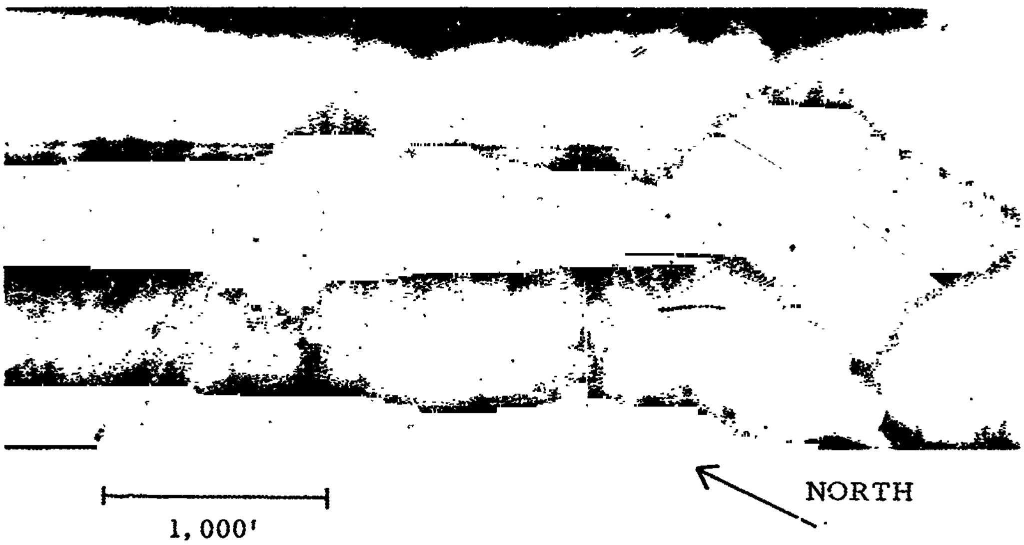


Figure 1. Ocean Front at 32° 19' N, 117° 49' W.

Figure 2. Infrared Image of Ocean Eddy Along Santa Catalina Island.

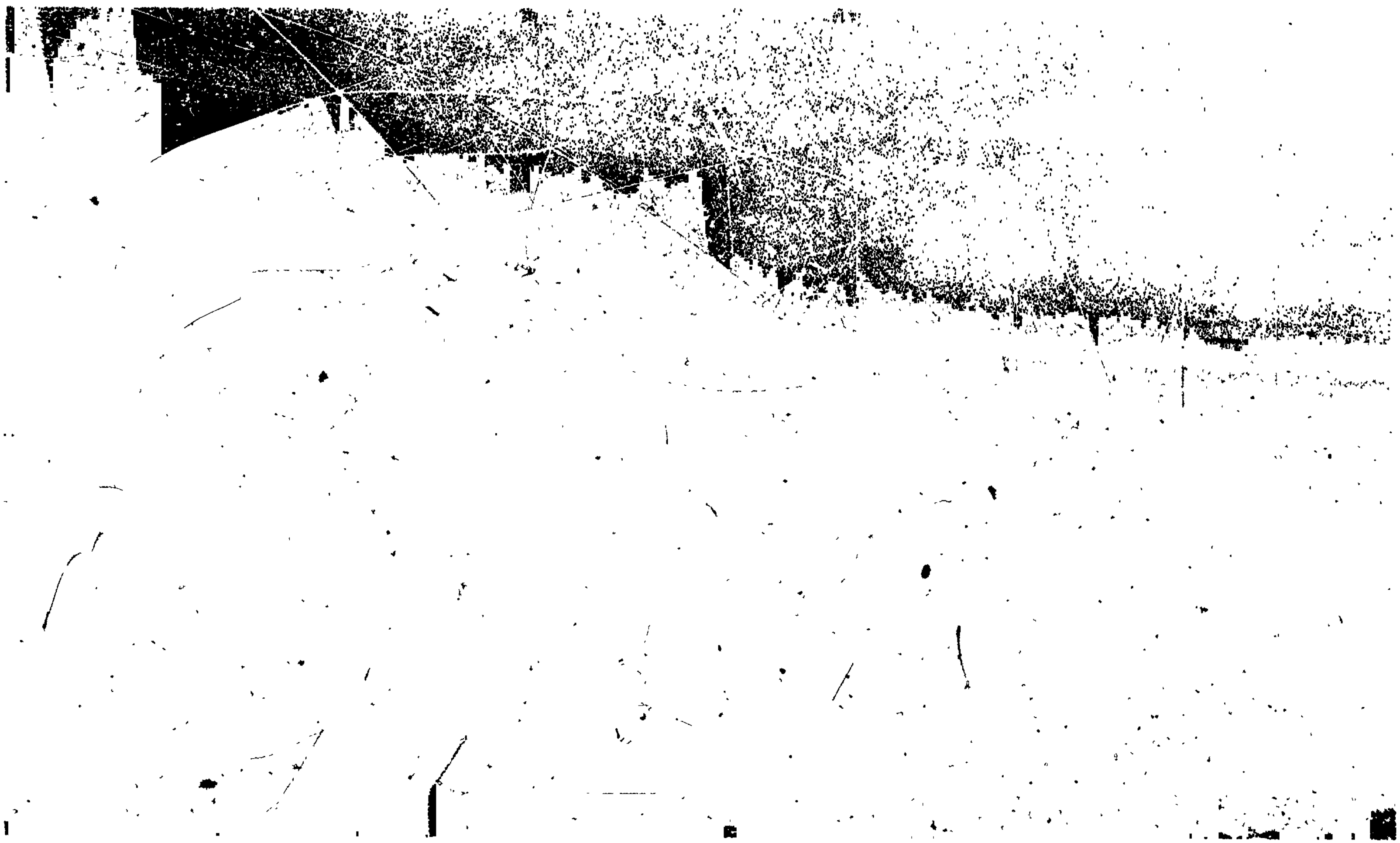


Figure 2A. Photograph of Slick Eddy in Same Area as Figure 2. Photo by Herbert J. Summers.

The two patterns in Figure 3 were found together in the Gulf of Mexico in autumn. This type of pattern is found on calm, clear nights when the ocean is losing heat to the atmosphere and sky. The white warm spots are presumed to be the result of convective cells disrupting the cooled surface layer of the sea. These spots are from twenty feet in diameter to more than one hundred feet; in fact, much larger such features can at times be found. Measurements of the mixed layer depth of the ocean when these convective patterns are present shows generally shallow convective layers. The individual warm spots shown here, then, must not represent individual convective cells, but instead must result from many such cells. A slight tendency is seen in the lower picture for the warm marks to form rows. This tendency is presumed to result from a very light wind.

The remainder of the figures in this section demonstrate wind-induced surface temperature patterns; these patterns are far more common than the features described above. Figure 4 shows a pattern quite commonly observed at sea, with the "S" shape being due to the transverse distortion of the infrared mapper. The cold lines are roughly straight, and approximately parallel to the wind. The wind-driven ocean circulation has apparently collected a cooled ocean surface layer into lines. These lines are referred to as wind streaks, and must be related to the wind slicks occasionally seen on the ocean by eye. Note that there are secondary lines between the main ones, and that the lines join on occasion to give an irregular pattern. The wind speed here was nine knots.

The flight path was parallel to these lines in Figure 5, so that this figure allows a good opportunity to observe their structure. Note the tendency to branch and join, the irregularity of individual lines, and that some lines can be traced almost continuously for distances up to one-half mile.

A different type of wind-generated pattern is seen in Figure 6, where the cold lines seem much less well developed than in the previous two figures. Note the wide range of line widths seen on this picture and the higher frequency with which they intersect.

Figure 7 was made in the Long Beach area not far from a large sewer outfall. This region is noted for its high concentration of organic surface film. The general pattern of lines is similar to those of previous figures, but the individual lines are here much wider.

The patterns of cold lines parallel to the wind seen in these previous figures seem to be almost entirely destroyed at higher wind speeds. Figure 8 was obtained near Hawaii when the wind speed was near 22 knots. The strong cold (that is, black) spots are presumed to be foam from whitecaps. The warm spots may be regions from which the cooled surface film was carried away by steep waves which were nearly breaking.

Discussion. In the ensuing discussion it was brought out that the infrared radiation recorded in these figures came from depths of water of ten microns or less. The question was raised whether these figures represented day or night scenes. The reply, all night scenes, was later realized to be incorrect--Figure 2 was made near midday.

DIRECT RADIOMETER MEASUREMENT OF THE TOTAL HEAT FLOW FROM THE SEA SURFACE

A brief paper from the Applied Oceanography Group by McAlister[3], describing measurements of the total heat flow from the sea surface, was published in the May 1964 issue of Applied Optics. Only enough details are included here to show the optical principles involved in this two-wavelength radiometer and its application to this important oceanographic problem. The reader is referred to the referenced paper for more details.

The absorption coefficient k for water versus wavelength λ is shown in Figure 9. k is in cm^{-1} and λ in microns. A value of 1 for k means that one centimeter thickness of water absorbs $\frac{1}{e}$ or 63%, i.e., the "optical depth", $\frac{1}{k}$, is one centimeter. This concept and its dependence on a linear temperature gradient in the water is described in reference 3. One

Figure 3. Convective Patterns at Night With Light Wind.

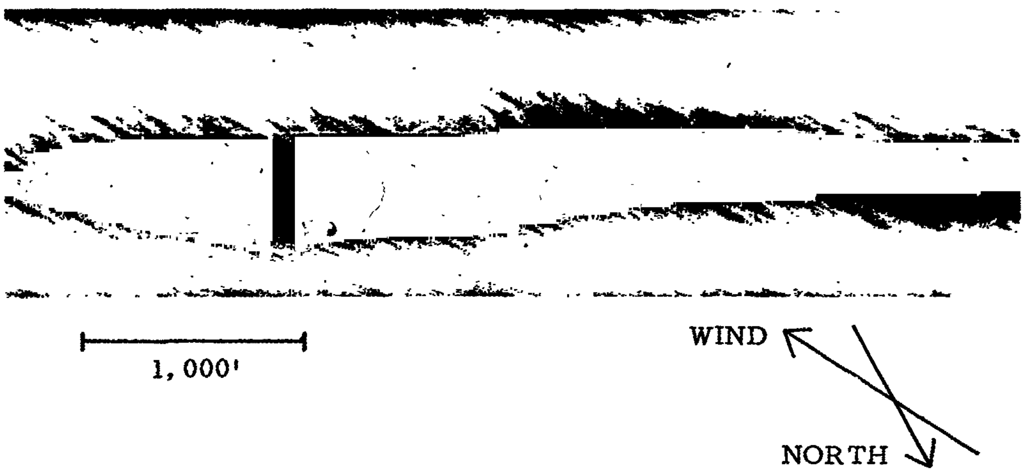


Figure 4. Representative Wind Streaks With Wind Speed 9 Knots.

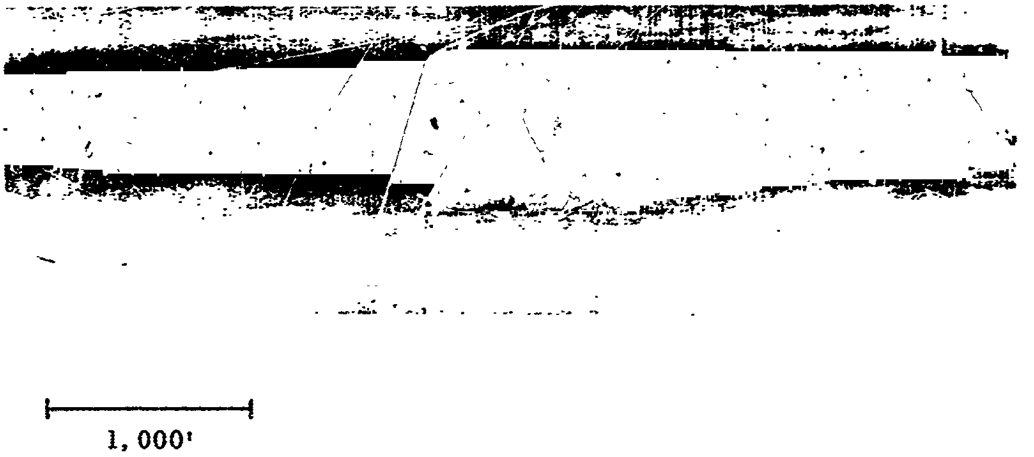


Figure 5. Surface Pattern Along Wind Streaks.

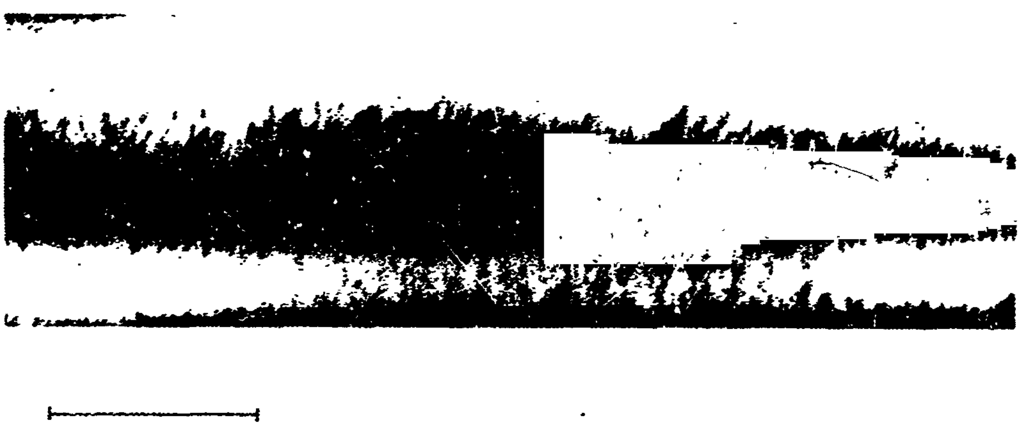


Figure 6. A Fine Network of Wind Streaks.

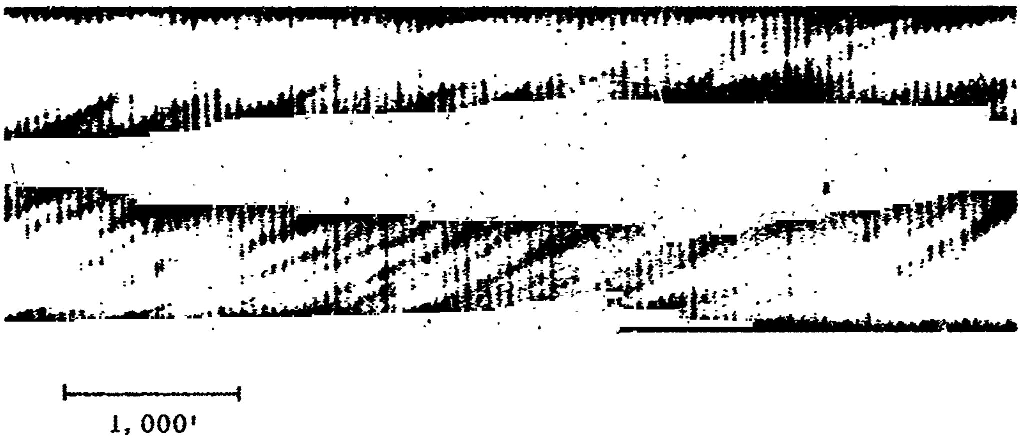


Figure 7. Pattern With Sewage Contamination of the Ocean Surface.

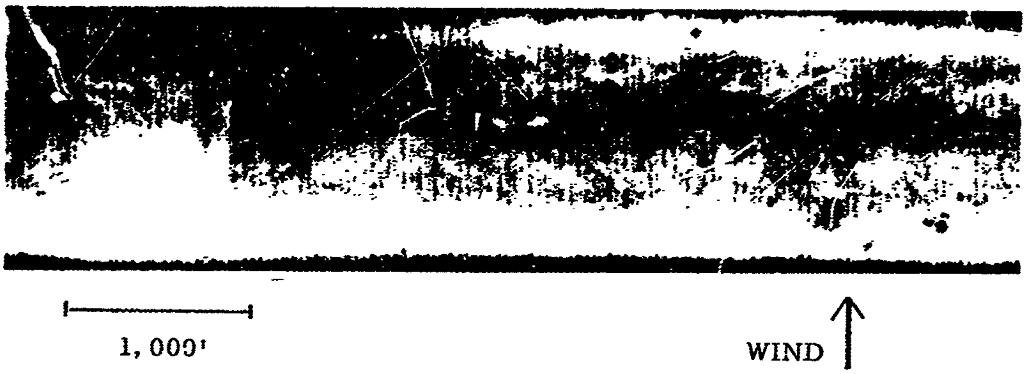


Figure 8. Ocean Thermal Appearance at Wind Speed 22 Knots.

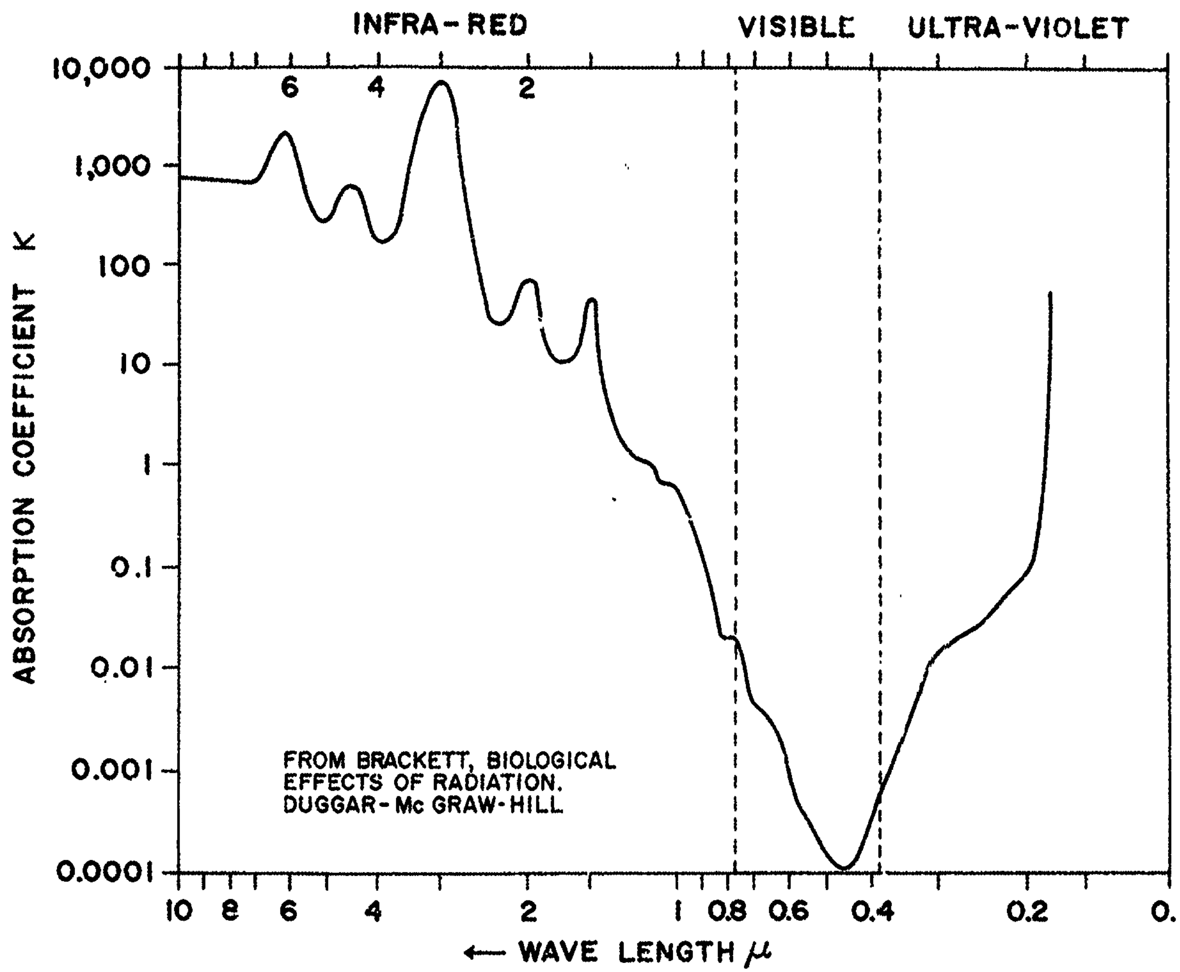


Figure 9. Absorption of Radiation by Sea Water.

notices in this figure that for the 2.2 micron region $\frac{1}{k}$ is about 0.5 mm and at 3.7 microns $\frac{1}{k}$ is near 0.06 mm.

The absorption of water versus thickness for a 2.0 to 2.4 and a 3.5 to a 4.0 micron band isolated by "sharp edged" filters is shown in Figure 10. These interference type filters isolate wave length bands where the effective or optical depths are about 0.5 mm and 0.06 mm.

THE HEAT EXCHANGE AT THE SEA SURFACE AT NIGHT

The heat loss from the sea surface by radiation comes from the top 0.02 mm. The evaporation loss occurs at the interface, as does the possible loss of heat to warm the air at the surface. If the transfer of heat by vertical convection in the upper 0.5 mm layer is small in comparison to conduction, the flow of heat by conduction between the 0.5 mm depth and the 0.06 mm depth is a measure of the total heat flow from the sea surface.

THE RADIANCE FROM THE SEA SURFACE AT NIGHT

The infrared radiance from the water I_W is the sum of two parts: $I_w(1 - r)$ from below the surface and $I_S r$ from the sky to reflection from the water surface, as seen in Figure 11. The radiometer compares this total with that from the reference blackbody I_B, i.e.,

$$(I_B - I_W) = I_B - I_w(1 - r) - I_S r . \tag{1}$$

This reduces to

$$(I_B - I_W) = (I_B - I_w)e + (I_B - I_S)r , \tag{2}$$

where the emissivity $e = (1 - r)$.

When the radiation is restricted by a bandpass filter, Eq. (2) applies, if applicable values for r and e are used. The experimental procedure is to obtain a 30-sec. record of $(I_B - I_W)$ on the recorder for the 2.0 to 2.4 micron region and then a similar record for the 3.5 to 4.0 micron region. Next, a sky record $(I_B - I_S)$ is obtained. Finally, another blackbody, B_1, is viewed by the radiometer for calibration purposes. Its temperature, T_1, is accurately known and held 1°C to 2°C different from the internal reference. This provides a calibration record where $(I_B - I_{B_1})/(T_B - T_{B_1}) = C$, where the calibration constant C is in intensity units per °C temperature difference.

At the start of the experiment, the temperature of the internal reference is set and controlled at 1°C or 2°C different from sea surface temperature. With this precaution, C remains constant for small temperature differences and $(I_B - I_w) = C(T_B - T_w)$, Eq. (2) becomes

$$T_w = T_B - \frac{(I_B - I_W) - (I_B - I_S)r}{e\,C} \tag{3}$$

EXPERIMENTAL RESULTS

Equation (3) was used to reduce data obtained from the measurements made at night from the end of Scripps pier. Sky readings $(I_B - I_S)$ and C (calibration constant), were taken at the beginning and end of the run. Values of $(I_B - I_W)$ averaged over 30 minutes or more of recordings were obtained for each of the two-wavelength regions, 2.0 to 2.4 microns and 3.5 to 4.0 microns. For these regions, the reflectivity of water is 0.016 and 0.022, and the emissivity is 0.984 and 0.978, respectively.

Figure 12 shows measurements of T_w at optical depths of 0.5 and 0.06 mm taken on 16 November 1962 as a function of elpased time. Data points plotted here for each depth are an average of two adjacent 30-sec. recordings. The temperature difference for the 24-min.

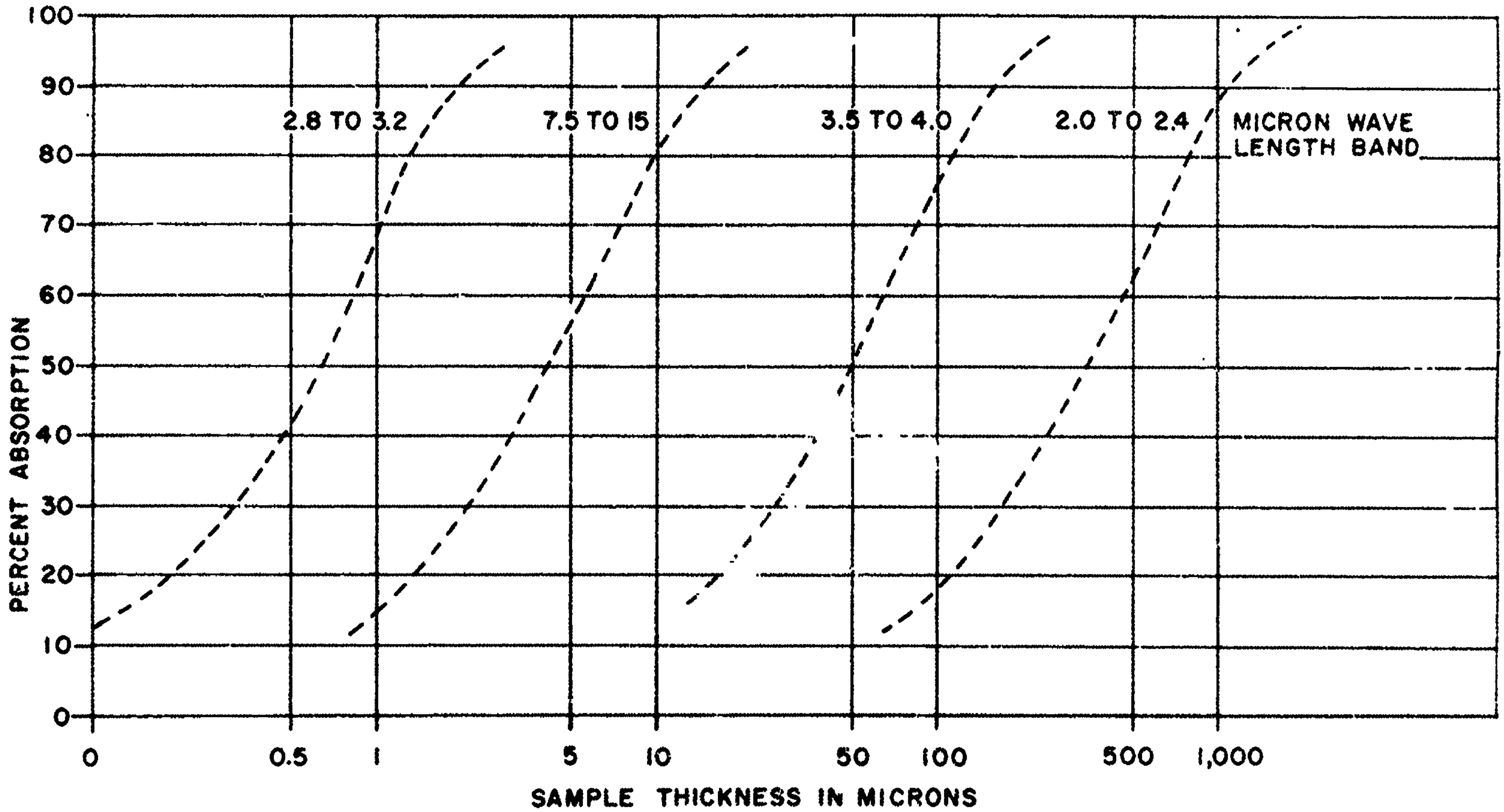
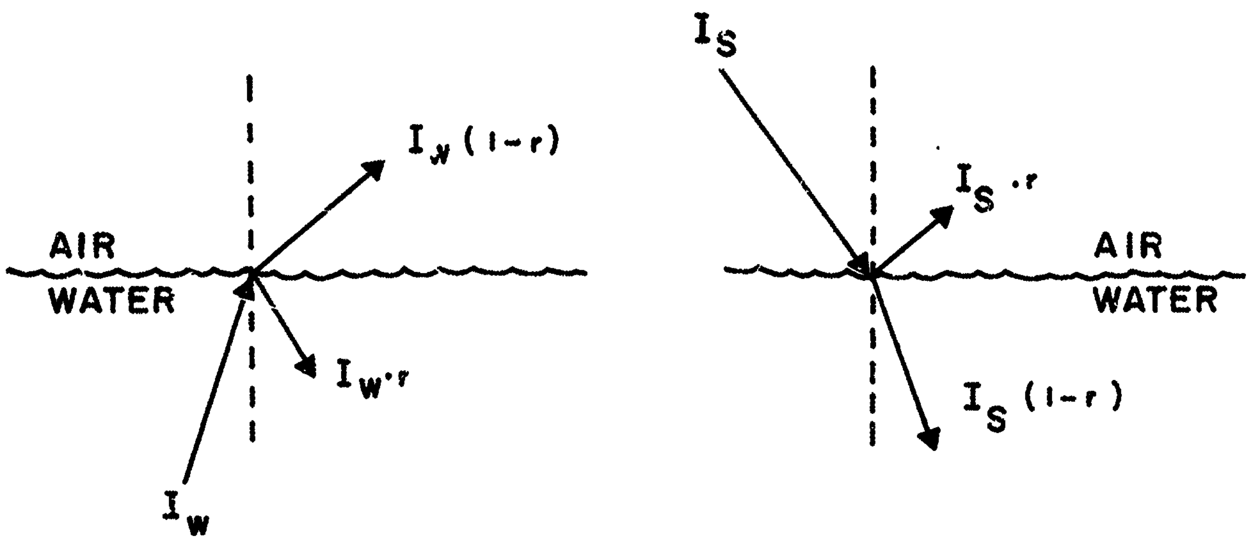


Figure 10. Absorption of Radiation by Sea Water For Selecteu Wavelength Regions.



$$I_W = I_w(1-r) + I_S \cdot r$$

Figure 11. Radiance From Sea Surface at Night.

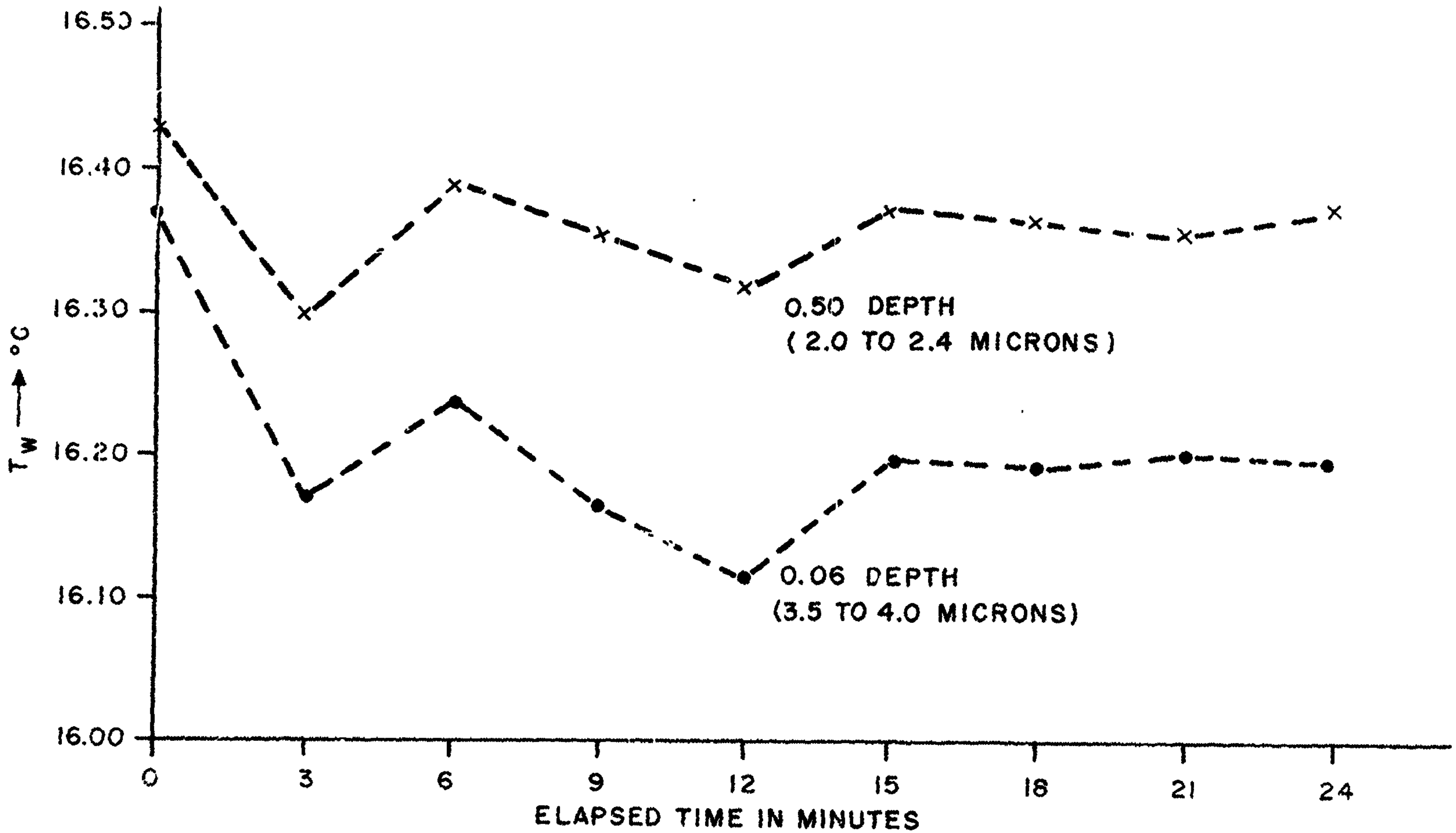


Figure 12. Radiometer Record.

interval averages 0.15°C. This value is entered in Table 1 under ΔT for this date. Similar recordings taken on 2 January 1963 (early and again later in the night) showed averages for ΔT of 0.12°C and 0.19°C which appear in Table 1.

TABLE 1

EXPERIMENTAL RESULTS

	ΔT (°C)	H (cal cm^{-2} min^{-1})	B (cal cm^{-2} min^{-1})	H/B
Nov. 1962	0.15	0.27	0.26	1.0
Jan. 1963 (a)	0.12	0.22	0.22	1.0
Jan. 1963 (b)	0.19	0.34	0.22	1.5
Average	0.15	0.28	0.23	1.2

The heat flow by conduction between these two depths is calculated next and tabulated under column H in cal cm^{-2} min^{-1}. Some measure of total heat loss for comparison with H is needed. For this purpose a value was calculated by means of the Kraus and Rooth equation[4], using the observed cloud cover, water temperature, and standard meteorological observations. These values appear under column B. The ratio H/B is shown in the last column.

The average value of 0.28 cal cm^{-2} min^{-1} for the latitude of San Diego is shown as the circled dot in Figure 13 which is the radiation loss from the earth plus atmosphere to space as measured from the satellite Explorer VII and averaged for the period December 1959 to February 1960, from F. Möller[5]. Even though the average from Table 1 is the total loss (radiation plus evaporation plus conduction to the air), the value is low here since the atmosphere emits energy that it has absorbed directly from the sun and earth. The values in Table 1 are for night only.

In summary, the heat flow from the sea surface at night by evaporation and air conduction is from the interface. The radiation loss comes from the top 0.02 mm. Water temperature at greater optical depths was measured experimentally by infrared radiometry with wavelength regions selected for $1/k = 0.06$ and 0.50 mm. Calculation of the heat flow by conduction through this half-millimeter layer is within experimental error of the total heat flow from the surface. This result indicates that the heat transfer by convection in this layer is small compared to conduction, and that such equipment, preferably airborne, can be used to measure the total heat flow from the sea at night.

THE OCEANOGRAPHIC AND METEOROLOGICAL VALUE OF DIRECT MEASUREMENT OF TOTAL HEAT LOSS AT THE SEA-AIR INTERFACE

The total solar energy absorbed by the sea is lost by evaporation, reradiation, to the air by conduction, in local heating and is carried elsewhere by advection (currents), i.e.,

$$Q_S = Q_e + Q_r + Q_a + Q_{\Delta T} + Q_v .$$

The total of the first three losses is measured by the two-wavelength radiometer.

If it were possible to make these measurements from a satellite in polar orbit and obtain daily or even weekly maps of sea surface temperature and total heat flow for every degree or two of latitude and longitude of the oceans, a major contribution to physical oceanography and meteorology would result.[a,b]

WEATHER AND ATMOSPHERIC ABSORPTION LIMITATIONS ON INFRARED RADIOMETRY

Unfortunately, it is impossible to use these particular infrared techniques from satellite altitudes. For meaningful results of measurements on the sea surface even at 1,000 foot altitude, both infrared scanners and radiometers require very favorable weather and atmospheric conditions--one might say unusually favorable conditions. Clouds are opaque to the infrared and in fact radiate about as a blackbody at cloud temperature. "Clear" atmosphere is not 100% transparent, therefore, it radiates as a "grey body" at its effective temperature. Thus, if air temperature is different than that of the sea surface, any radiometric reading of the sea is in error and cannot be corrected unless atmospheric transmission and effective air temperature are known.

Some idea of the restrictions on the use of satellite-borne infrared radiometers for sea surface temperature measurement can be obtained from the Marine Climatic Atlas[6] which provides the following information.

World ocean average amount	Cloudiness Usable	Distribution
≤ 0.2	15%	Some areas more frequently clear
< 0.6	35%	others not seen for weeks.

These numbers mean that over a 30 mile diameter circle, 15% of the time 0.2 or less of this area is cloud covered and 35-40% of the time 0.6 or less is cloud covered. In other words, it is impossible to obtain detailed information on large areas of the oceans with infrared radiometry from high altitude.

Figure 14 illustrates the influence of weather on infrared measurements taken from Tiros VII off the east coast of Africa[7]. This satellite was rotating so that the radiometers scanned outer space, the earth below, then outer space again. Outer space serves as a zero radiation calibration reference. Six successive scans are illustrated and simultaneous records of radiation in the indicated wavelength regions are duplicated. Of interest here is the 8 to 12 micron record (2) which on each successive scan shows an increasing fall in apparent temperature (near the center of the scan) from 280°K down to 220°K. The reason for this change in apparent temperature becomes clear upon comparing record (2) with records (3) and (5). The latter are the total of energy received in the 0.2 to 5 micron and the 0.55 to 0.75 micron region which represent solar energy reflected--largely from clouds. Thus, the drop in apparent temperature from the 8 to 12 micron record (2) is where clouds are radiating at a much lower temperature than the earth's surface; in other words, infrared radiometers "see" the cloud tops only and the earth only between the clouds. Even between the clouds the readings differ from true temperature because of attenuation and grey body radiation due to the clear atmosphere.

If this problem of frequent and large area surveillance is to be solved, it must be done with more nearly all weather wavelengths of radiation. With this in mind, the microwave region will be examined.

THE TRANSMISSION OF THE TOTAL ATMOSPHERE TO MICROWAVES

The Proceedings of the Second Symposium on Remote Sensing of Environment[8] contains several papers describing the transmission of the total atmosphere including clouds (p. 157), and the additional effect of various amounts of rainfall (p. 134).

The electro-magnetic transmission of the total atmosphere from 1 to 30 millimeters is shown in Figure 15 which is from reference 8, page 157. From 3 cm to longer wavelengths the attenuation is less. Thus, more nearly all weather capability is approached in the 3 centimeter region. A reduced capability exists at 8 mm wavelength.

THE ABSORPTION COEFFICIENT OF WATER FOR MICROWAVES

Examination of the literature (9, 10, 11, 12) reveals that the recent measurements of Stanevich and Yaroslavskii[12] in the extreme infrared, 42 to 2,000 microns, effectively close the gap in values for k determined experimentally by infrared and by microwave techniques. No discontinuity is apparent where the two join. A comparison of values for this coefficient

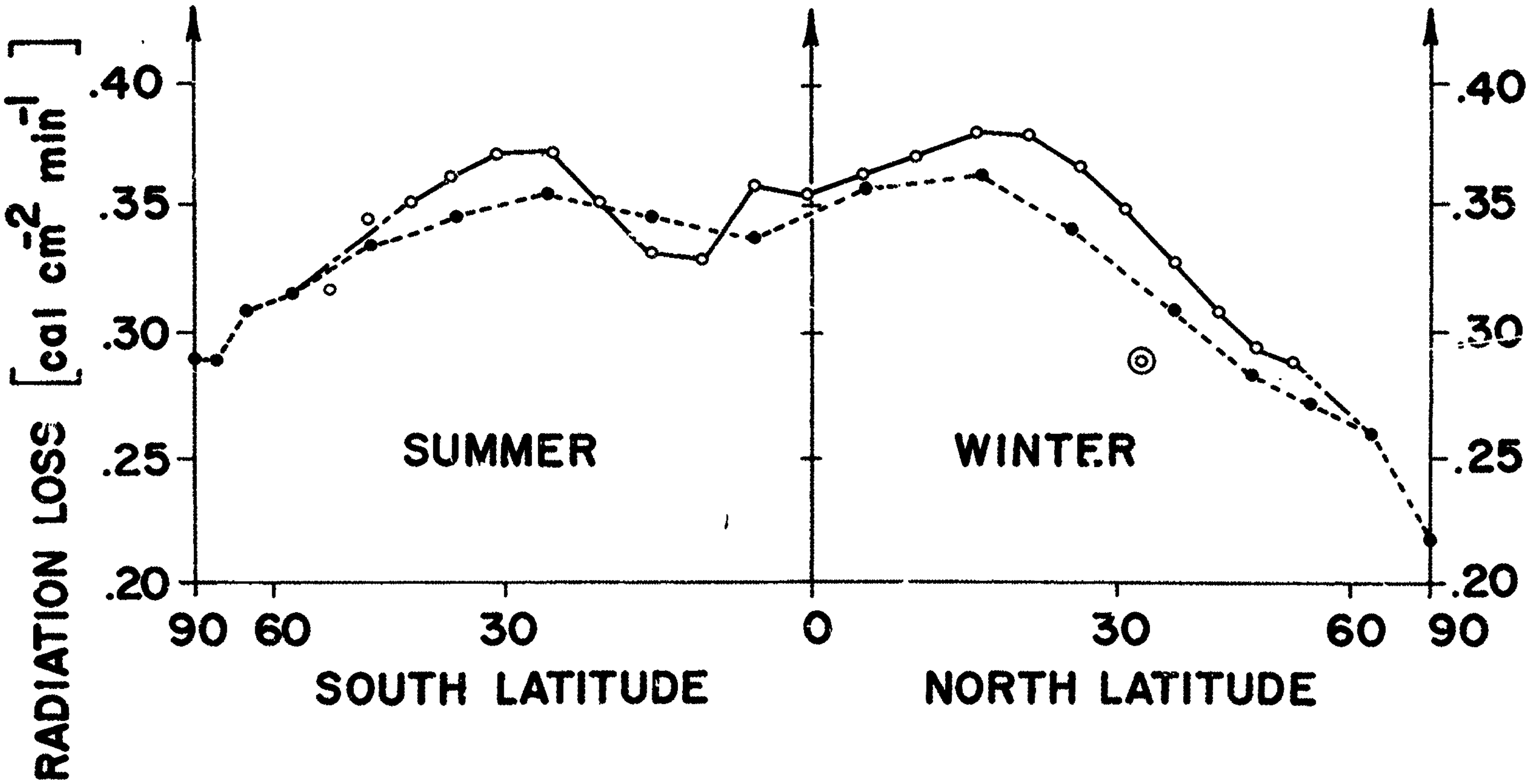


Figure 13. Terrestrial Radiation Loss of Earth Plus Atmosphere to Space, Averages of EXPLORER VII Data For Dec. 1959 to Feb. 1960.

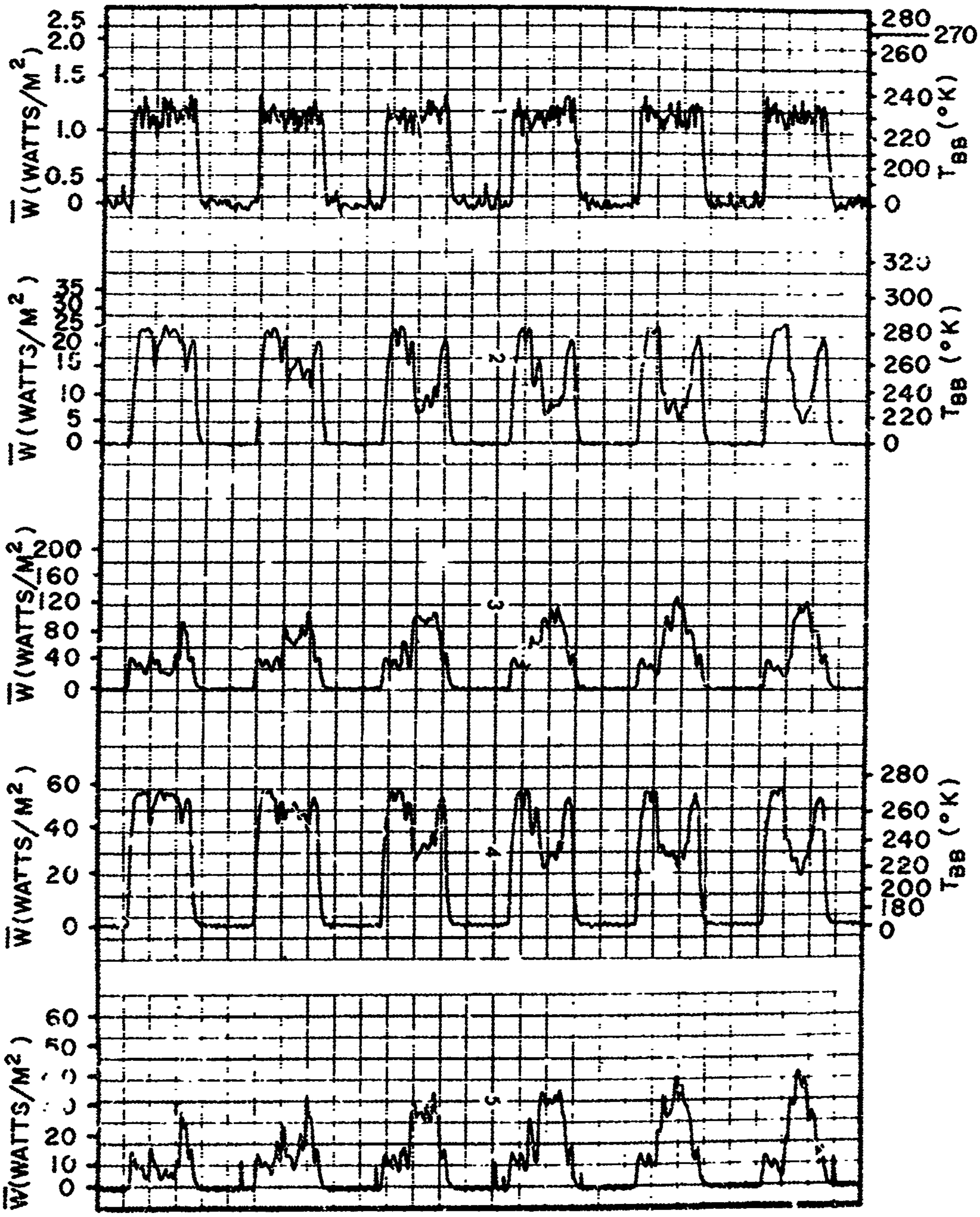


Figure 14. Oscillogram Showing Six Scans Off the East Coast of Africa by the TIROS VII Radiometer. The Approximate Wavelength Intervals of the Channels From Top to Bottom Are: 14.8–15.5μ, 8–12μ, 0.2–5μ, 8–30μ, and 0.55–0.75μ. The Effects of High Clouds Are Illustrated.

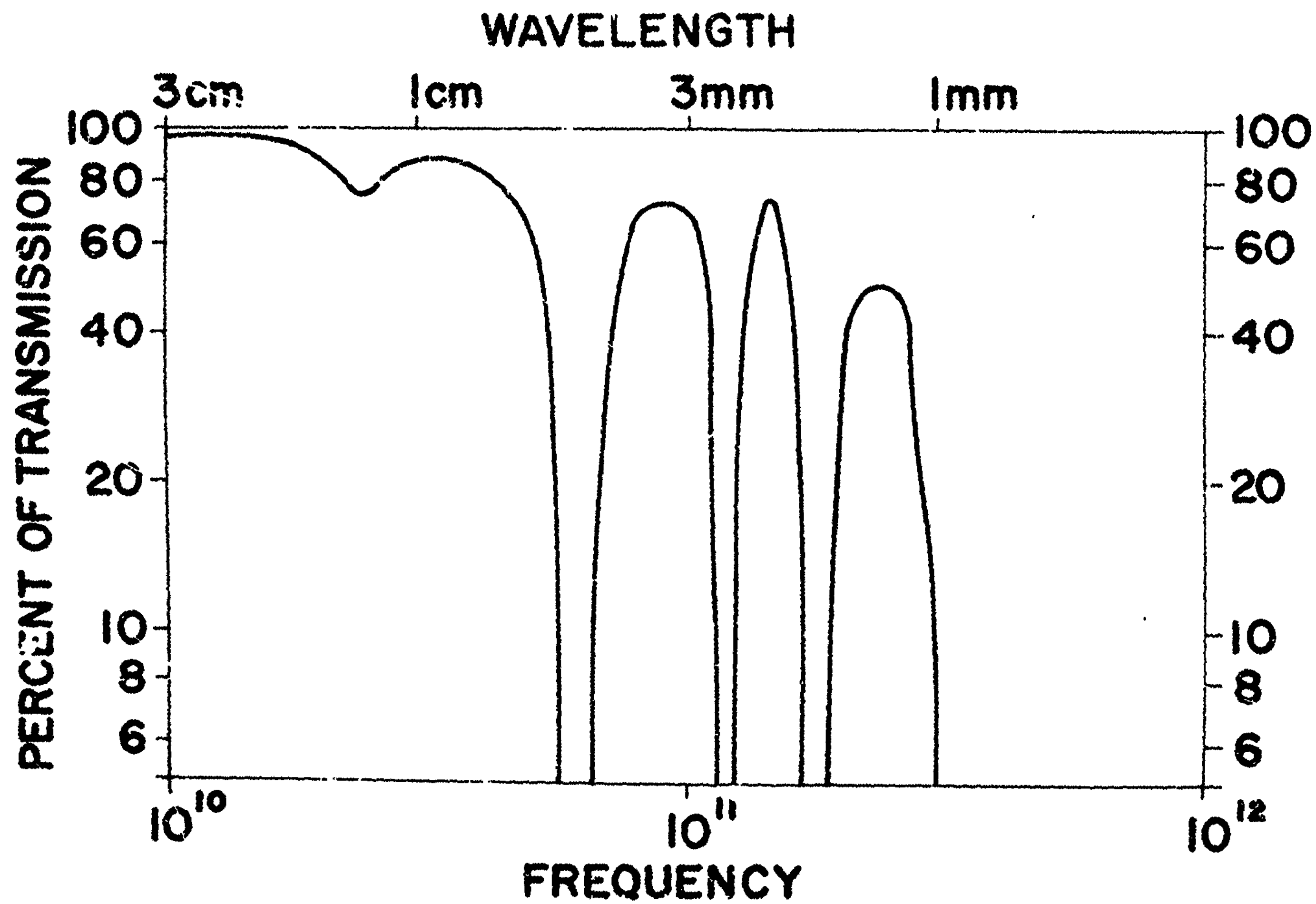


Figure 15. Total Atmospheric Transmission.

(cgs units) in the infrared and in the microwave region is made in Figure 16. The infrared part of this curve is, in part, a duplicate of Figure 9 with reduced abscissal scale. The microwave values are largely from 9.

Of immediate interest here is that the absorption coefficient decreases from a maximum at 15 microns down to a value near 10 for k at about 3 cm wavelength. In other words, the absorption coefficient for microwaves runs through the same range of values for this microwave region at it does for the infrared. Therefore, it is <u>theoretically</u> possible to use a two-wavelength microwave radiometer to measure the total heat flow from the sea surface as has been done with selected infrared wavelengths.

Experimental values for k vary widely and a real departure from the solid line (calculated from electromagnetic theory) occurs from 10 centimeters to about 10 meters wavelength

MICROWAVES WITH OPTICAL DEPTHS $(\frac{1}{K})$ IN WATER OF ONE MILLIMETER AND LESS

The one millimeter depth in water which has a linear temperature gradient[3] has been located in Figure 16. Here for $k = 10\ cm^{-1}$ the optical depth is one millimeter. For $k = 100\ cm^{-1}$, the optical depth is 0.1 millimeter and so on. The experimental values for k indicated by the open circles[11] are believed best. If so, a wavelength of about 3 cm has an optical depth of one millimeter and a wavelength of 8 mm has an optical depth of about 0.4 millimeters.

It is clear that better values for k are needed before these extrapolations can be depended upon. However, experiments are in order with a 3 cm and 8 mm wavelength radiometer to determine the absorption coefficient of sea water and how it varies with temperature, salinity, etc.

THE REFLECTIVITY AND EMISSIVITY OF SEA WATER IN THE SHORT MICROWAVE REGION

The reflectivity of water for normal incidence is about 50% and 60% at 8 mm and 3 cm wavelength respectively. The emissivity is therefore 50% and 40% for these two wavelengths. This is an order of magnitude less favorable for water temperature measurement than is the case for infrared wavelengths. However, these constants are subject to precise measurement so that appropriate values for emissivity (e) and reflectivity (r) can be used in Eq. 3 (which is repeated here),

$$T_w = T_{ref} - \frac{(I_{ref} - I_W) - (I_{ref} - I_S)r}{e\,C} . \qquad (4)$$

This will provide a value for the "real" temperature of the water at the optical depth of interest.

It is not certain that 3 cm and 8 mm are the best wavelengths to use. Experimental measurements of k, r, and e and their dependence on temperature, salinity, etc., for sea water must be carried out as precisely as possible for these and other wavelengths. Once these facts are known, a decision can be made on wavelengths to provide the best compromise for optical depth, atmospheric attenuation and temperature sensitivity (smallest ΔT detectable).

CONCLUSIONS

In conclusion, it has been shown that it is <u>theoretically</u> possible to construct a two-wavelength microwave radiometer that will duplicate the results of the present infrared instrument[3]. The great advantage of the microwave radiometer would be that measurements of the sea surface could be made through heavy overcasts.

The possibility exists therefore to obtain sea surface temperature and total heat flow from the sea with airborne microwave equipment and with little interference due to overcasts.

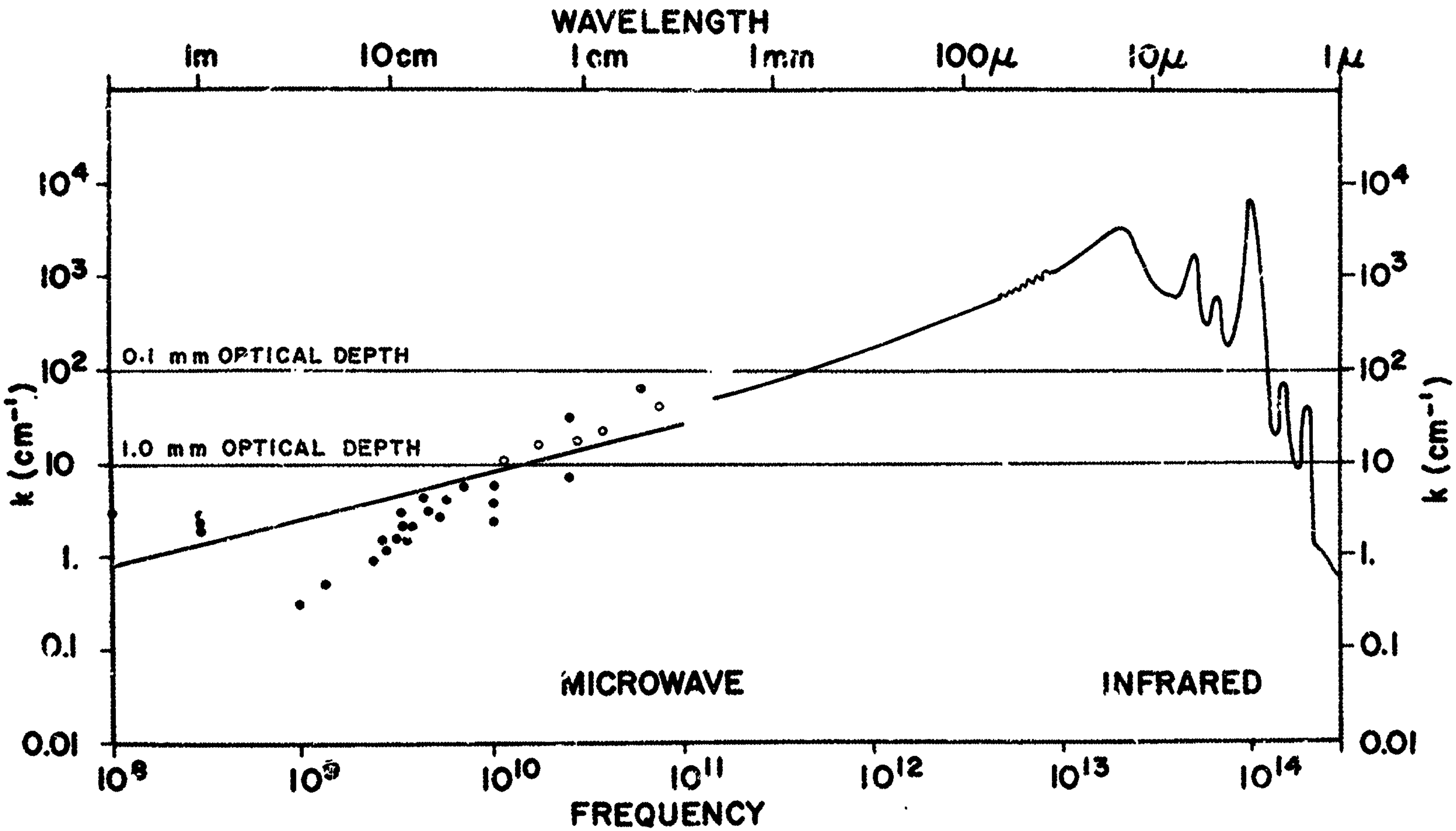


Figure 16. Absorption Coefficient (k) of Sea Water Versus Wavelength.

Once this has been demonstrated experimentally, extrapolation to manned satellite usage can be made.

RECOMMENDATIONS

A. The Applied Oceanography Group of the Scripps Institution of Oceanography is presently engaged in a program to measure the infrared radiance of the sea surface, its variation in time and space--the noise background of the sea--and relate it to the oceanic factors producing the variation. Infrared equipment airborne in a DC-3 as shown in Figure 17 is used in conjunction with a surface vessel taking simultaneous oceanographic records.

With the experience obtained in the last two years in this manner and the additional information to be obtained with the two-wavelength infrared radiometer, it is clear that an ideal situation exists here to make an exact and detailed comparison of microwave and infrared capabilities. In addition, of course, the performance of a microwave radiometer through heavy overcast and from high altitude can be determined by comparison of records from the aircraft with simultaneous records from the surface vessel.

B. It is therefore recommended that a single wavelength, 3 cm, microwave radiometer be obtained and eventually mounted in the left wing of the aircraft so that simultaneous readings on sky radiation and sea radiation can be made. This radiometer should be assembled by an experienced manufacturer using the latest and best "state of the art" components so as to provide the best possible sensitivity and reliability.

The radiometer should be designed and constructed so that conversion at a later date to two-wavelength capability is possible.

C. It will be used at first in the laboratory to make precise measurement of k, r, and e for sea water and the dependence of these constants on temperature, salinity, etc. With these constants determined for the exact wavelength band of the radiometer, airborne tests of its capability are then possible.

The oceanographic and meteorologic value of direct measurement of total heat loss at the sea-air interface was pointed out in Section VII.[a,b] The first step of determining the possibility of such measurement with microwave equipment lies in the airborne tests of a single wavelength instrument to determine the accuracy with which "real" sea surface temperature can be read. The cost of this initial feasibility study is very small in comparison to the potential value of a successful two-wavelength microwave radiometer.

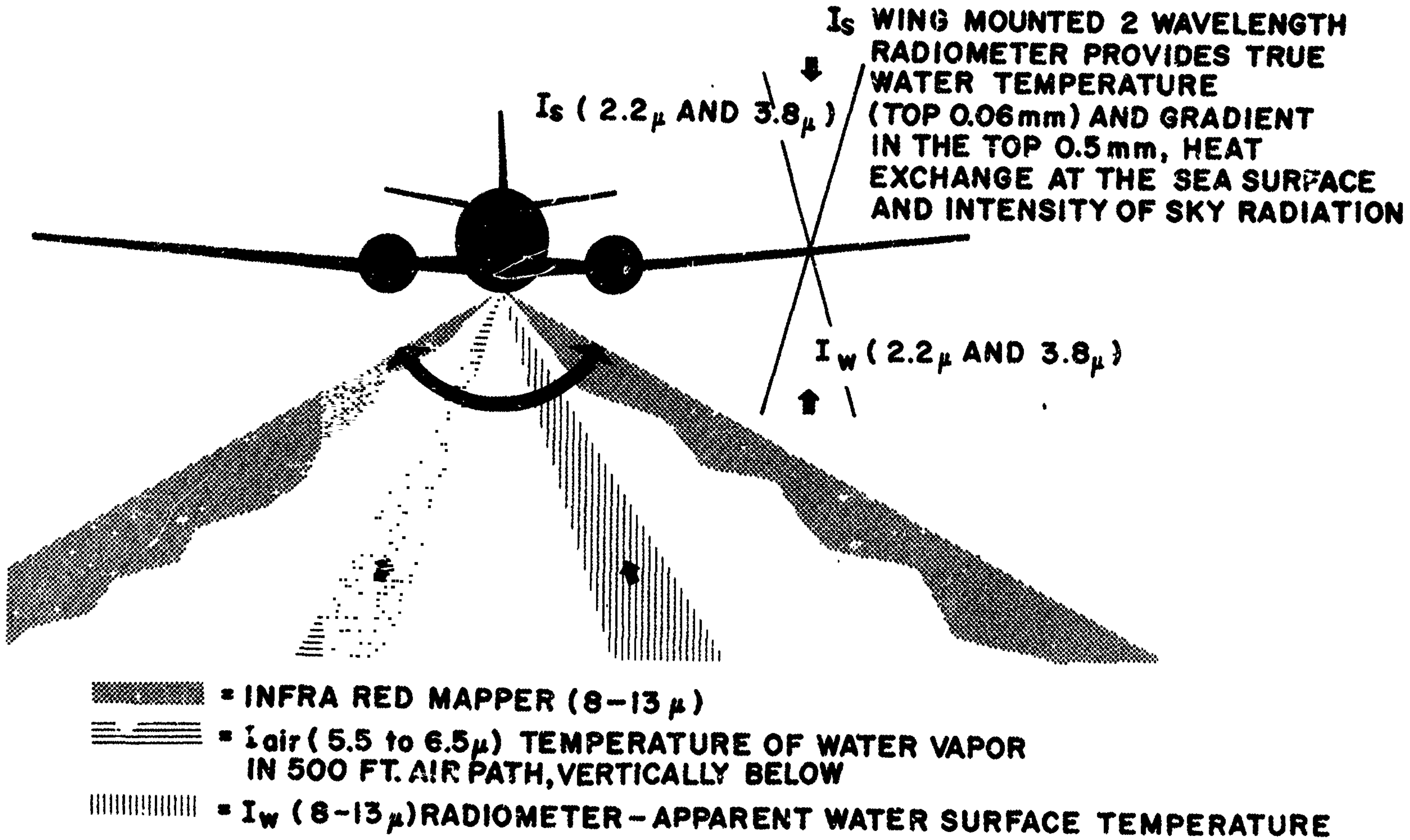


Figure 17. Aircraft Instrumentation.

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NOTE ON ATMOSPHERIC INTERFERENCE

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It should be emphasized that clouds "interfere" with I.R. imaging by emitting I. R. Radiation at low temperature. Water vapor, cloud drops, rain drops and ice crystals in the atmosphere do not emit microwave signals of sufficient strength to interfere with measurement of surface temperature by microwaves.

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BRIEF FOR CONFERENCE ON OCEANOGRAPHIC EXPLORATION FROM SATELLITES

A bert Oshiver

United States Coast and Geodetic Survey

Observations to and under the sea surface from satellite altitudes primarily require devices sensitive to electromagnetic energy. A careful reappraisal should be made of the reflective, transmissive, and scattering properties of sea water and the overlying atmosphere with respect to electromagnetic radiation. Anomalous bandwidths of highly penetrative or strongly attenuated radiation may permit discrimination of variables from properties to be measured.

The following applications should be considered:

1. Radiometry (temperature, atmospheric moisture, evaporation, carbon dioxide).

Measurement of horizontal temperature distribution of the sea surface would have benefits in physical, meteorological, and biological oceanography. Such measurements on a large synoptic scale could delineate current patterns, water masses, and mixing zones. They could show areas of upwelling and warm patches which may be related to coastal processes and marine life distribution. On an absolute basis, they could add to knowledge of the energy balance of the earth and the origin and distribution of weather conditions.

In infrared radiometry, the principal problem in measuring the temperature of the liquid interface between atmosphere and hydrosphere is the atmosphere itself -- the uncertainty of its moisture content in any vertical section, and at times its opacity. The atmospheric water vapor window in the 8 to 13 micron wavelength region still introduces significant ambiguities in apparent temperature readings due to moisture. The Coast and Geodetic Survey is engaged in experiments to develop techniques for accurate remote measurement of absolute sea surface temperature. Direct measurements of relative humidity profiles to the radiometer altitude were made for preliminary establishment of relationships. Techniques for remote measurement of atmospheric moisture need development. In order to measure a vertical section of the atmospheric moisture remotely from a satellite to correct for the temperature ambiguity, a double radiometer system and possibly even an active system are envisioned which would receive energy at different wavelength regions where the moisture absorptions are distinct. Somehow, air temperature and droplet size may need to be measured. A sky-pointing radiometer may be included to compensate for additional effects due to reflection. Thus, the unknown variables may be resolved by simultaneous measurements. A by-product of this system would be the mapping of atmospheric moisture distribution.

To use this arrangement for accurate absolute temperature measurements, an adequate inherent stability or a reference temperature system may be required to nullify system drift. Relative temperature measurements would still have value in determining the location of thermal fronts, areas of upwelling, and current patterns. Infrared mappers should have applications for these purposes.

Other parts of the spectrum, such as the microwave regions, should be investigated for possible advantages in atmospheric transparency.

The relationship between the temperature of the liquid interface and the subsurface water is a variable dependent somewhat on evaporation. Thus the possibility of remote evaporation rate surveys over all the oceans should be explored using sub-surface temperature information telemetered from buoys to the satellite for comparison with the remote surface temperature measurements.

Survey of atmospheric carbon dioxide distribution may be possible by use of certain infrared wavelengths to which CO_2 is strongly opaque, again in combination with receivers at other wave lengths to subtract out the other variables.

2. Currents

Stereo photogrammetric techniques are used by the Coast and Geodetic Survey for remote measurement of surface flow rates and directions. High resolution optics in combination with visible large targets (flotsam, icebergs, artificial targets) may permit such measurements and possible systems should be considered. The infrared mapper may be useful in indicating boundaries and meanders of currents.

3. Bottom Topography

Several techniques should be considered for possible ocean bottom mapping in shallow areas from a satellite. We are initiating a systematic study of the influence of known bottom features on the spectrum of shoaling waves as determined by stereo photogrammetry. This should be followed by the application of a suitable high angular resolution system. Color photography, which is being used extensively by the Coast and Geodetic Survey, should be explored for high altitude discrimination of bottom features. High spectral resolution techniques may prove advantageous. The wide instantaneous field from satellite altitude may provide perspective advantages. Lasers in the blue-green region should be investigated for use as ranging devices to whatever depth capability can be achieved in shelf areas as available peak power increases. In this connection the Coast and Geodetic Survey has initiated a study of light scattering at depth. Also polarization may prove to be an enhancement technique for increasing depth capabilities.

4. Sea Level and Gravity

In the area of gravimetric geodesy, a continuous effort is being made to improve our knowledge of the potential field in the immediate neighborhood of the physical surface of the earth by the collection of gravity information at sea and on land. It is especially the lack of adequate marine observations which leads to an undesirable non-uniformity of the distribution of gravity measurements and causes errors larger than those caused by the defects of the theoretical developments.

The surface of the ocean represents the geoid, aside from the disturbing factors of tides and currents. Close-to-earth satellites could provide a tool of considerable theoretical and economical value when used to determine the geometry of the ocean surface by measuring the height of the satellite above the ocean surface. Methods and instrumentation systems for accurately determining the geometry of the satellite orbit itself are available as a result of the effort conducted in satellite geodesy. If, therefore, a system for measuring the height of the satellite over the ocean with sufficient accuracy can be developed, both geodesy and oceanography could be served by determining geoid profiles and at the same time measuring the magnitude of tidal effects and their progress with time over the ocean surface.

Such data would not only contribute essential information to the determination of the configuration of the potential surface close to the physical surface of the earth, as needed especially for developing a significant model of the mass distribution in the crust of the earth, but would, even if executed only locally, be of assistance in the study of off-shore regions for locating geological deposits.

A capability for remote measurements of sea level differences should be further explored as an indicator of surface wind and barometric pressure and for detecting tsunamis.

5. Geomagnetism

It should be pointed out that a polar orbiting satellite could be used to map the earth's magnetic field patterns in important ways and this might conceivably provide additional incentive for carrying out the proposed program. This would be particularly relevant if technology should advance to the stage of measuring components of the field.

THE APPLICABILITY OF TIROS AND NIMBUS DATA TO INVESTIGATION OF THE FEASIBILITY OF SEA SURFACE TEMPERATURE MEASUREMENTS FROM SATELLITES

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Since the oceans cover nearly three-quarters of the earth's surface, sea surface temperature is a most significant geophysical quantity. This is true operationally, in the applied sciences of meteorology and oceanography, and from the viewpoint of basic research. It now appears probable that such temperatures can be observed from satellites through the passive measurement of the emission in certain bands in the infrared and/or the microwave regions of the electromagnetic spectrum. The presently available TIROS infrared data are the most pertinent observations for further investigating this matter. It may be questioned whether these TIROS data will provide really new information over areas where the short term variability of sea surface temperatures is small and climatology already provides information accurate to within a few degrees Centigrade. But the TIROS data can certainly shed light on the general feasibility of using satellite infrared data and will in all probability provide new and improved information in areas, such as the Gulf Stream, where temperature variations and gradients are comparatively large.

By proper processing and analysis of existing TIROS data, it should be possible to:

1. Determine the feasibility of deriving useful sea surface temperature or temperature gradient measurements from existing and foreseeable satellite radiometric observations.
2. Develop preliminary techniques for converting satellite radiometric measurements to useful sea surface temperature data.
3. Prepare selected case study maps or other presentations of sea surface temperature data to illustrate the types, accuracies, and limitations of the data that satellites can provide.

1. REQUIREMENTS FOR IMPROVED SEA SURFACE TEMPERATURE DATA

From a meteorological viewpoint, numerous investigations have been conducted in both the tropics and middle latitudes on the effect of varied sea surface temperature conditions on atmospheric storm systems. In the tropics, Palmèn[7] demonstrated that hurricanes rarely form when the sea surface temperature is colder than 79°F; Fisher[4] produced tentative evidence supporting a hypothesis that hurricanes move (prior to recurvature) along the band where the sea surface is warmest. More recently Perlroth[8] has shown a connection between the intensity of hurricane Esther (1961) and the sea surface temperature averaged over a two-week period.

In mid latitude synoptic analysis, sea surface temperatures are used extensively, when available, in air mass determinations as an aid to proper placement of fronts. Reed [11] found that the mean polar front was very closely related to the strong sea surface temperature gradients which exist off the east coasts of Asia and North America. Petterssen et al[9], in a study of east coast cyclonic development relating to dynamic weather prediction, found evidence indicating that the temperature of the sea surface was significant in the development process.

From an oceanographic viewpoint, the need for an accurate indication of sea surface temperature on a daily basis for large areas of the world is even more acute, not only from the basic need to describe the motion and temperature of the sea surface, but also to support both military requirements and commercial activities such as fishing and shipping.

All of these applications are severely hampered by the lack of adequate sea surface temperature information[2]. In a gross climatological sense (i.e., seasonal means and to a limited degree seasonal variability), sea surface temperatures are rather well known over many, although far from all, of the oceans of the world. However, the temperature distributions and variations at the time and space scales of synoptic and mesoscale observations are far less well determined. Along the routes frequently followed by ocean vessels, something approaching an adequate synoptic density of measurements does exist, but such routes traverse only a small fraction of the some 140 million square miles (nearly three-quarters of the earth's total surface) covered by the oceans. Observations more closely spaced in distance and more frequently repeated in time have been confined to a few extremely limited areas, such as parts of the Gulf Stream, and to short and discrete periods of time. Even in these few instances of intense sampling, the areas to be traversed and the few oceanographic ships and aircraft available have necessarily resulted in observations comparatively widely spaced in time and/or distance. Regular true measures of instantaneous gradients of sea surface temperatures over distances of the order of several tens to a few hundred miles are very rare, as are repeated observations (on a day-to-day basis) of the temporal variations.

2. APPLICABILITY OF SATELLITE OBSERVATIONS

The satellite has provided a world-wide observing tool which, it appears highly probable, can do much to fill present deficiencies in sea surface temperature measurements. For example, in the absence of clouds, or where the breaks in the cloud cover are sufficient in size and frequency, the Channel 2 (8-12 micron) data from the TIROS radiometer would appear to be able to provide a useful measure of instantaneous sea surface temperature gradients, perhaps of the day-to-day temperature variations, and possibly of the temperatures themselves. At least equivalent and probably better capabilities may come into being in the future using such systems as the Nimbus I High Resolution Infrared Radiometer (HRIR) (probably at night only) and in later Nimbus launches the Medium Resolution Infrared Radiometer (MRIR).

Practical utilization, for sea surface temperature measurements, of the satellite radiometric capabilities will be principally dependent on being able to deal satisfactorily with two problem areas: (1) intervening cloud cover and (2) the partial absorption and emission of radiant energy by certain variable gases in the atmosphere at levels well above the sea surface. The effects of these factors in determining surface temperatures and ways to deal with them will be discussed below.

3. ATMOSPHERIC MODIFICATIONS AND DEGRADATIONS OF SURFACE INFRARED EMISSION

While the infrared emission of a surface as observed from a satellite is rather directly related to the temperature of that surface, the actual energy reaching the satellite sensors is seldom identical with that to be expected from a black body at the temperature of the surface. The energy is attenuated by the atmosphere and, to a lesser extent, reduced by the lack of perfect surface emissivity. These effects must be taken into account to interpret properly the surface temperature and its gradients and variations. Accordingly, we will discuss here the problems related to atmospheric attenuation of infrared radiation. For convenience, we will also include in this section, prior to the discussion of atmospheric effects, a brief discussion of surface emissivities.

3.1 Surface Emissivity

The ratio of the amount of radiant energy emitted by a substance, at a particular temperature and wavelength, to the amount of radiant energy emitted by a black body (at the same temperature and wavelength) is the emissivity of the substance. For a black body the ratio would be one at all wavelengths, but for natural substances the ratio varies from perhaps nearly one at some wavelengths to significantly smaller values at other wavelengths. Surface emissivities of sea water, in the infrared, fortunately are within a few percent of unity.

The effect of surface emissivity will be of even less significance when only gradients and variations are of primary concern.

If the earth is viewed in sunlight, the effects of reflection of solar radiation must be considered when using data at shorter infrared wavelengths, such as those used in the Nimbus High Resolution Infrared Radiometer.

3.2 Atmospheric Absorption and Re-emission; Limb Darkening

Infrared radiation emitted by the sea's surface may be greatly modified by the atmosphere before it reaches satellite sensors. Gases in the atmosphere absorb the radiation and then re-emit it, both upward and downward, at their temperature, which is usually lower than that of the surface. The net result is a depletion of this radiation with height and so an apparent reduction in the observed surface temperature. The exact amount of this depletion varies with both the wavelength at which the observation is made and the existing atmospheric conditions.

Table 3-1 lists the important absorption bands of the main atmospheric absorbers. The absorption spectra of atmospheric gases are extremely complex and are influenced by the temperature, pressure, and amount of gas present. It is nevertheless possible to estimate the depletion of infrared radiation from the surface from measured and/or assumed atmospheric temperatures and the distribution of the absorbers in the atmosphere. The depletion is small, and thus easier to take into consideration, in the 8-12μ band (the so called atmospheric window). A satellite sensor looking straight down at the sea's surface and measuring the intensity of radiation in this band (proportional to the emissivity and fourth power of the surface temperature) can obtain a measure of the surface temperature, especially after correction for the small depletion in this band.

Further corrections for limb darkening effects have to be applied when the sensor is not looking straight down. Limb darkening normally occurs through the combined effects of the decrease of temperature with height in the troposphere and increase of optical path length and so of atmospheric absorption with increase in zenith angle. Semi-empirical corrections for limb darkening effects have been developed and employed by Wexler[18, 19, 20] and by Wark et al.[17] to estimate surface temperatures from TIROS measurements of the radiation in the 8-12μ band (Channel 2).

Table 3-1

Absorption Bands Of The More Significant Atmospheric Absorbers

Gas	Band Center	Strength of Absorption
Water Vapor	6.3μ	Very Strong
	>20μ	Strong
Carbon Dioxide	4.3μ	Strong
	10μ	Weak
	15μ	Strong
Ozone	9.0μ	Weak
	9.6μ	Moderate
	15μ	Moderate

The important absorbers for the 8-12 micron range, and the limits within which they are effective, are shown in Table 3-2. The indicated limits of the absorption intervals are reasonable but arbitrary, since they depend on the level of absorption considered significant, path length through the atmosphere, etc.

Table 3-2

Absorbers Of Infrared Radiation In The Terrestrial Atmosphere
In The Wavelength Interval 8-12 Microns

Gas	Absorbing interval* (microns)	Strength of Absorption	Remarks
Water Vapor	<9	Moderate	Important at large nadir angles
	11.2 - >12	Moderate	Important at large nadir angles
Ozone	9.1 - 10	Intense	
Carbon Dioxide	9.25 - 9.55	Weak	
	10.15 - 10.75	Weak	

*Arbitrary limits

3.3 Cloud Problems

Since clouds (except for very thin cirrus) are opaque to infrared radiation, clouds in the field of vision of the satellite sensor would prevent it from "seeing" the sea's surface, and a determination of surface temperatures from infrared radiation measurements would not be possible. Thus, in determining sea surface temperatures, only measurements of infrared radiation from cloudless areas should be used. Methods for deleting cloud contaminated points from the infrared data must be applied, as will be discussed later.

3.4 Atmospheric Particulates

In addition to atmospheric gases, particulate matter within the terrestrial atmosphere can affect or even prevent infrared surface observations from satellites. This is especially true of water and ice (cirrus) clouds, as was discussed in Section 3.3, but can also be true of dust clouds. Thick water clouds radiate as black bodies, at the temperature of the cloud tops, but thin clouds, especially certain kinds of cirrus, are partially transparent to infrared radiation and have emissivities smaller than one.[6] Dust clouds are apt to be composed of particles smaller than those of water clouds, particle concentrations are likely to be smaller, and thickness may be comparable, so that, in general, dust clouds are likely to be more transparent to infrared radiation than water clouds.

4. DATA PROCESSING AND ANALYSIS

4.1 Data Formats and Computer Programs

As mentioned earlier, it will be necessary to eliminate data in which clouds are within the field of view. For the TIROS medium resolution infrared radiation data, which have been recorded on magnetic tapes to which orbital and attitude information have been added (FMR tapes),[12, 14] the problem of deleting suspected cloud data is relatively simple. One sets up criteria for rejection of data and then either lets the computer reject the unwanted data, or prints out all the data and rejects suspected data "manually".

The extraction of the actual data point information from the FMR tapes can be achieved using a processing program developed by NASA* for the IBM 7094. This program selects and lists each data point obtained by the radiometer, for each channel, for a specific time period (and thus geographical area) within a given orbit. These operations will be discussed more fully below.

*NASA Data Listing Program (MS 500)

4.2 Geographical Location, Rectification, and Scale of Resolution

An important problem in connection with use of radiation data for oceanographic purposes is determination of the geographic locations of the viewed areas. For TIROS data, aside from timing problems, this is based on TIROS ephemeris and satellite attitude data. Improvements of various kinds in attitude sensing and determination have been continually effected, so that the geographic locations presented on the later TIROS FMR tapes should be much better than those given on the FMR tapes for TIROS II data.[1]

While it is difficult to give a precise figure for location errors, since they may vary from orbit to orbit as well as within an orbit, the following statement has been made regarding TIROS III data: "Uncertainties in attitude lead to an estimated maximum error of 1^{o} to 2^{o} in great circle arc."[14] Presumably, then, most position errors for this satellite would be of the order of $1/2^{o}$, and those for later TIROS smaller. The IR sensor subtends about $1/2^{o}$ of great circle arc in the horizontal for zero nadir angle and significantly greater distances, in the direction of the principal line, as nadir angle increases.[9]

4.3 Detection of and Correction for Atmospheric Effects on Satellite Observed Surface Temperatures

As indicated in Section 3, the major problem areas anticipated in the use of satellite radiometric data for deriving sea surface temperatures are (1) clouds and (2) atmospheric absorption of the energy originating at the surface, with re-emission at a cooler radiating temperature.

4.3.1 Consideration of Cloud Interference, and Elimination of Data with Clouds

Wherever a cloud or a portion thereof falls within the instantaneous 5^{o} (approximately 30 n.m. at zero nadir angle) field of view of the TIROS Channel 2 radiometer (or of any other satellite radiometer), it will prevent any reasonably accurate measurement of surface temperature. In these cases, the temperature recorded by the radiometer will not only be modified by atmospheric absorption and emission (to be considered later) but will provide a value representative of the integrated emission from both the clouds and the cloud free areas. Since the portion of the emission from each source cannot be resolved by the TIROS radiometers, it will not be possible to interpret these measurements and, therefore, it will be necessary to eliminate data when clouds fill any part of the field of view.

A survey of the nephanalyses published in the Catalogs of TIROS Television Cloud Photography[16] has made it very obvious that sizeable areas completely free of clouds are comparatively rare, especially over the oceans. While the determination, selection, and use of such cases, using the TV photographs, will be useful in the research work proposed herein, to be dependent on such situations would be so limiting as to cripple significant sea surface temperature use of satellite radiometric data. Accordingly, a way must be found to select those specific radiometric data points, from areas of scattered and possibly broken clouds, where the radiometer is viewing only the surface through a break in the clouds.

Fortunately, a way of making such selections during conditions of daylight is available. When a cloud is significantly within the field of view of the TIROS radiometer, the comparatively intense reflection of solar radiation from its surface will be measured by Channel 3 (0.2 - 5 micron, albedo) and Channel 5 (0.5 - 0.7 micron, visible reflected radiation) of the same radiometer. The matters to be investigated here can essentially be confined to (a) whether it is best to use Channel 3 data, Channel 5 data or some combination of both to detect data points including clouds and (b) what threshold value(s) of either or the combined data should be chosen to insure elimination of data points which include cloud within the field of view.

A more difficult problem will exist during the night when no measurements are available in either Channel 3 or 5. The best approach to this problem appears to be attempted use of the difference between Channel 4 and Channel 2 measurements.* This difference varies from 5C at -40C to 15-20C at 20C and is essentially a constant at any temperature. However, with high water vapor amounts, the difference between the two is decreased. It may be possible to relate this decrease to the presence of cloudiness. It is not, however, obvious that such techniques will prove to be practical for determining areas of clear skies and it may be necessary to limit the usable observations of sea surface temperature to the daylight hours or to areas known from conventional meteorological observations to be free of clouds. Since elimination of night cases would, however, restrict the observable areas because of (a) the inclined orbit used for TIROS and (b) the lower probability of cloud free observations when night cases are excluded, for any satellite, it would approximately halve the possibly usable passes over a given area.

4.3.2 Data Processing to Determine and Eliminate Data Points Subject to Cloud Interference

Essentially all of the routine processing required to perfect or determine cloud detection techniques, and to eliminate those data points where clouds occur, (as discussed in Section 4.3.1) can be accomplished from TIROS data as already suitably recorded on magnetic tapes and using Electronic Data Processing (EDP) procedures.

All of the meteorologically useful orbits of TIROS radiation data, from which the cases to be used would be selected, have been processed by NASA and placed in binary form on the so-called Final Meteorological Radiation (FMR) magnetic tapes. The FMR tapes list radiation values for each channel, time and location of observation, etc. Complete listings of the available data tapes and descriptions of the data therein have been published by NASA.[1, 12, 13, 14, 15]

The extraction of the actual data point information from the FMR tapes can be achieved using a processing program developed by NASA** for the IBM 7094. This program selects and lists each data point obtained by the radiometer, for each channel, for a specific time period (and thus geographical area) within a given orbit. Other programs for the processing and analysis of the Tiros radiation data have been developed by ARACON Geophysics Company for use in synoptic and heat balance studies based on these data, as reported by Wexler[18, 19]; any may be applicable to some aspects of the studies proposed herein. The 7094 can be instructed to eliminate those points where clouds appear to be within the field of view as determined by the Channel 2 and/or the concurrent Channel 3, 4, and/or 5 values. Some initial experimental trials, data inspection, and re-runs would be used to determine optimum Channel 3, 4, and/or 5 thresholds for cloud point rejections.

The remaining (cloud-free) Channel 2 points, representative of surface temperatures or temperature gradients, can be entered on charts for further analyses.

It is estimated that approximately 60 separate orbits of TIROS radiation data would be required for the studies proposed herein. Extraction and printing of the useful data points from an average length of applicable TIROS record is expected to require about six minutes of IBM 7094/1401 time per orbit.

4.3.3 Consideration of Atmospheric Absorption and Emission, and Ways to Correct for Them

This problem area is expected to be significantly more difficult than elimination of daylight clouds, but less so than elimination of nighttime clouds.

*Channel 4 (7-30 microns) differs from Channel 2 (8-12 microns) by the energy emitted in the Rotational H_2O band (17.9-40 microns) and in the 15μ CO_2 band (12.5-17.9 microns); thus the apparent radiating temperature measured by the radiometer is normally less in Channel 4 than in Channel 2 for the same atmosphere.

**NASA Data Listing Program (MS 500).

As has been demonstrated by Wexler.[19] and by Wark, Yamamoto, and Lienesch,[17] the apparent black body temperature of an underlying surface as measured by the Channel 2 radiometer is usually several degrees cooler than the true surface temperature as deduced from conventional observations. This results from the fact that the 8-12 micron window is not completely transparent, and part of the radiation reaching the satellite sensor originates from water vapor, carbon dioxide, and ozone emissions from levels of the atmosphere where temperatures are normally cooler than those at the surface. Some of the problems created by these effects (and very likely also by the presence of some scattered clouds) as regards sea surface temperatures have been treated by Rao and Winston.[10] These matters were also discussed in Section 3.

Solutions to this problem are expected to involve several approaches, as described below, and will probably eventually utilize a combination thereof:

(1) For many purposes, sea surface temperature gradient data will be nearly as valuable as absolute values. Radiometric measurements are expected to be able to provide reliable gradients over significant areas, since the parameters that create the discrepancies between the measured and actual values will often be only slowly changing with distance. Furthermore, regions of rapid changes in these parameters (and so of erroneous gradients) will most often occur at air mass boundaries where the highly correlated existence of extensive and overcast (or nearly overcast) cloud cover will prevent any satellite measurements of sea surface temperatures over substantial distances. Accordingly, the use of the temperature gradients alone, over homogeneous areas as regards atmospheric effects, will be the one possible solution.

(2) Within areas where the radiometrically measured temperature gradient would be expected to be reliable, a single surface ship observation may provide a benchmark for calibrating the corresponding and other satellite measurements. More than one observation in such an area would, of course, be even better. One of the studies that should be conducted under this program would be to use areas with several surface temperature observations to test the validity of the hypothesis that the observed gradients are reliable, to determine the probable error to be expected in using this hypothesis, and to attempt to determine indicators of those areas or conditions where the hypothesis is valid and of those where it is not.

(3) The studies of Wexler[18, 20], of Wark Yamamoto, and Lienesch[17], and other similar investigations have suggested quantitative or semi-quantitative corrections to be applied to radiometrically measured surface temperatures as functions of the nadir angle of view (which is generally known), moisture content of the atmosphere, etc. The rate of change of the moisture correction with variation in atmospheric moisture content appears sufficiently small to suggest that in many cases corrections based on climatological values or deduced from the general nature of the synoptic situation may very well be adequate. The determination of the validity of using climatological, or gross synoptic corrections would be an important area for investigation in this program.

These and other approaches that may be developed to attack the problem of atmospheric absorption/emission corrections should be studied and tested, both individually and in combination, to determine the optimum method of determining and applying such corrections, and the probable degree of the residual error.

5. APPLICABILITY OF NIMBUS HIGH RESOLUTION INFRARED RADIOMETER (HRIR) DATA TO SEA SURFACE TEMPERATURE OBSERVATIONS

While these discussions were being edited into their final form, the first samples of Nimbus HRIR data became available in the form of photo-facsimile strips as reproduced principally for public information releases. It is obvious from these samples that the HRIR data are of extremely high geometric resolution (approximately equivalent to that of TIROS pictures). The fine detail visible in the pictures over land areas, and along coasts and lake shores, suggests the ability to detect small temperature differences is also excellent. The design of HRIR insures excellent calibration and ±3°C accuracy.

These data should most definitely be investigated to determine their applicability to sea surface temperature observations, especially since their high resolution (approximately 2-5 miles) would permit surface observations through cloudfree gaps far too small to be of use with the TIROS data.

On the other hand, it must be realized that it is not at all clear that the HRIR data can be successfully applied to sea surface temperature measurements, although their meteorological value is obvious. Because of the spectral range of sensitivity (about 3.7-4.0 microns), the sensor responds, during daytime, to reflected solar as well as emitted terrestrial radiation. The reflected solar radiation component may well be sufficient to prevent quantitative daytime analysis of the emitted component. In fact, a single sample of low latitude daytime HRIR data suggests the reflected component is predominant. But it is only during daytime that the concurrent Advanced Vidicon Camera System pictures permit accurate determination of areas with cloud cover.

At night, when only emitted radiation is detected. Nimbus I has no operational sensor other than HRIR. Thus a multi-spectral approach to cloud detection and elimination is not possible. Even when HRIR and MRIR are flown concurrently, the problems of nighttime detection of small or low altitude cloudy areas will still be analogous to those for TIROS, as discussed in Section 4.3.1.

It might be that careful examination of quantitative analog (Visicorder) traces of the nighttime HRIR data would reveal characteristic shapes of high temperature portions of the traces that could be used to identify areas where cloudfree surface temperature measurements are being made. In any event, the early samples of the Nimbus HRIR data clearly call for careful investigation of their application to sea surface temperature determination.

6. FORESEEABLE IMPROVEMENTS IN SATELLITE SENSORS PERTINENT TO SEA SURFACE TEMPERATURE DETERMINATION

The Nimbus MRIR sensor (not included on Nimbus I but scheduled for flight on a later Nimbus) will use an atmospheric window channel narrowed to approximately the ten to eleven micron wavelengths. This will significantly reduce the attenuating influences of water vapor, carbon dioxide, and ozone as compared to the situation for the TIROS Channel 2 data.

The satellite infrared spectrometer being developed for the USWB's National Weather Satellite Center[3] will provide surface observations in the particularly clear window, about 0.1 micron wide, at about 11.1 microns. Furthermore, this spectrometer will provide some information on the vertical distribution of atmospheric temperatures through a series of measurements along the shorter wavelength wing of the 15 micron carbon dioxide band. If these were to be made with suitable precision, and similar measurements were to be made concurrently along the long wavelength wing of the 6.3 micron water vapor band, the vertical distribution of water vapor could be calculated and used to determine improved values of the effect of attenuation on satellite observed surface temperatures.

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N65-30310

MICROWAVE SPECTRAL MEASUREMENTS APPLICABLE TO OCEANOGRAPHY*

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The sea and the atmosphere interact with microwave radiation in several different ways. The major interaction mechanisms are resonant absorption by gases such as water vapor and oxygen, nonresonant absorption and scattering by clouds or precipitation, and the radiation coupling at the air-sea interface. This coupling is affected by the sea state and by the dielectric constant and electrical conductivity of the sea. Each of these interactions has spectral characteristics which can be exploited for remote sensing of the atmosphere and the ocean surface.

These spectral characteristics are presented here in terms of the microwave brightness temperature that would be seen by an observer above the atmosphere over a smooth sea. These predicted brightness temperature spectra are then compared with the temperature sensitivities of currently available radiometers.

The spectral region directly considered here extends from ~10cm to ~3mm in wavelength. This region is the most pertinent to oceanographic problems because this region is least affected by the ionosphere and by atmospheric absorption.

The upwelling radiation that would be seen from space is considered here to have three components: the thermal radiation originating within the sea, the downwelling radiation that is reflected upward by the sea, and the upwelling radiation emitted directly by the atmosphere.

The sea strongly affects the brightness temperature seen from space because the sea reflects approximately half the energy incident upon it. The reflection coefficient can be derived from standard electromagnetic theory[1] and a knowledge of the conductivity and complex dielectric constant of the sea water. This dielectric constant is a function of frequency and of temperature.[2] At these short wavelengths the reflectivity of water is affected primarily by the dielectric constant, rather than the conductivity. Spectrum I in Fig. 1 shows the microwave brightness temperature spectrum which would be seen for a sea temperature of 285°K (53.6°F). In order to emphasize the sea's effect on the microwave spectrum this first spectrum includes only the microwave thermal emission of the sea and entirely neglects the effects of the atmosphere. Variations in sea temperature and sea state would shift this spectrum up or down and only small changes in spectral shape would occur. However, the spectral effects introduced by sea state should be verified experimentally.

The temperature distribution in the top millimeter of the sea can also affect the spectrum because different frequencies emanate from slightly different depths. However, because the surface temperature gradients are small, this contribution to the microwave spectrum is quite small compared to the other effects described here.

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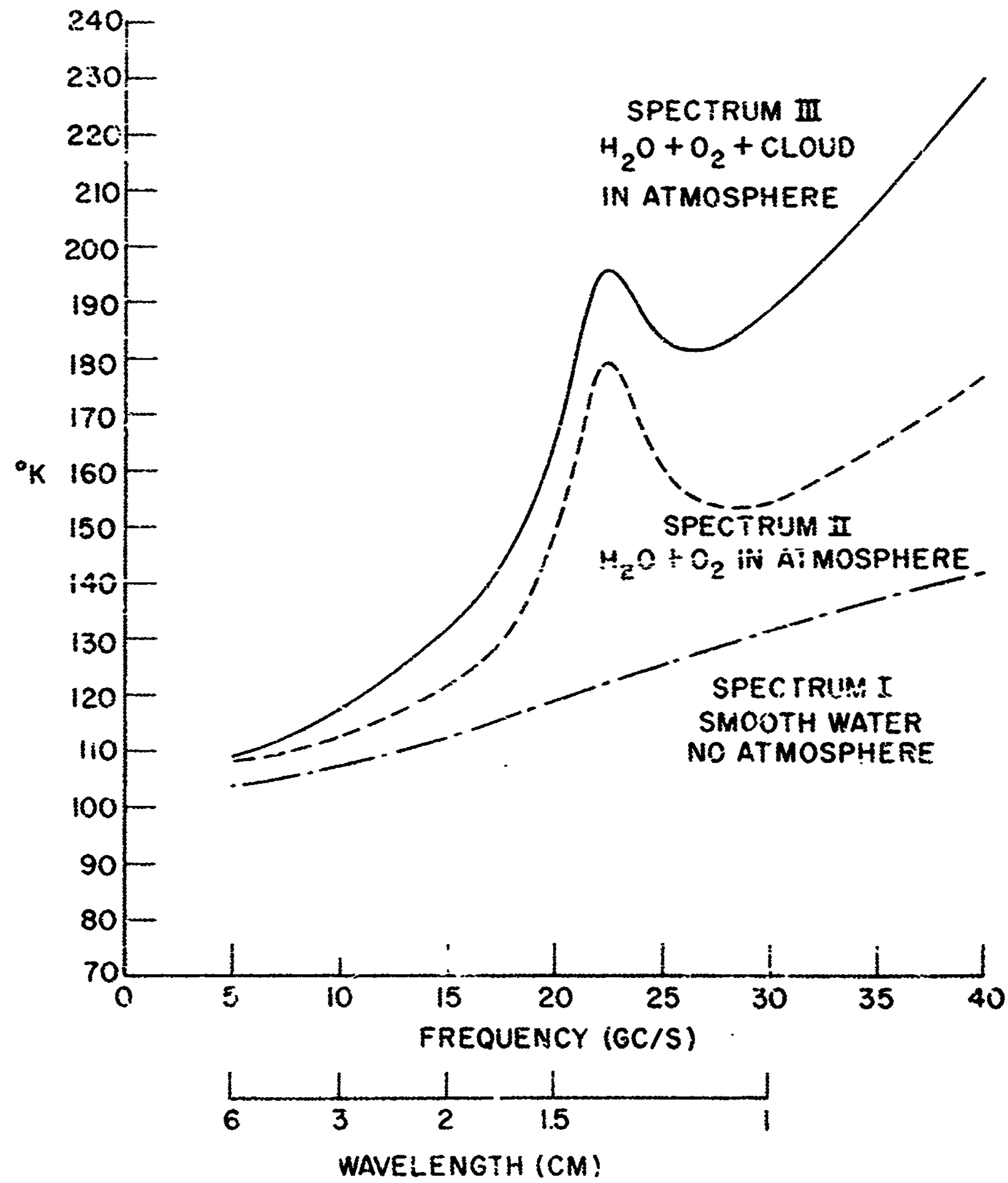

Figure 1. Microwave Brightness Temperature Seen From a Satellite Over Water.

Next the effects of atmospheric gases can be considered. The two gases which dominate the microwave spectrum are water vapor and oxygen. Water vapor has a resonance at 13.5-mm wavelength and oxygen has a series of resonances in the 4-mm to 6-mm wavelength band. These gases have been studied theoretically and in the laboratory[3,4,5] and their contribution to the microwave spectrum can be computed. The spectrum is dependent upon the altitude distribution of atmospheric composition, pressure, and temperature. Nevertheless, information available at present about climatic averages of these parameters permits the 10-cm to 0.6-cm spectrum to be moderately well defined except for the variations introduced by fluctuations in the amount of atmospheric water vapor. Ordinary variations in the temperature distribution have smaller effects. Spectrum II of Fig. 1 is the spectrum applicable for an atmosphere with water vapor density equal to $10\, e^{-a/2.2}$ (gm/m^3) where a is the altitude in kilometers.

A good first approximation is that the area under the water vapor resonance curve is proportional to the integrated water vapor over the sea. The linewidth is approximately proportional to atmospheric pressure, which means that if this water vapor were at 1000 mb pressure the line would be two times wider and shorter than if the water vapor were all at 500 mb pressure.

Evidence that the theoretical computations of the H_2O-O_2 spectrum are applicable has recently been obtained from spectral measurements of the 8-mm to 14-mm atmospheric opacity. These measurements were made by observing several sunsets using a multichannel radio telescope.[6] The resulting spectra were correlated with simultaneous ground level and radiosonde measurements of humidity and temperature. Preliminary results show the agreement between theory and experiment is within ten percent and within experimental error.

Clouds and precipitation can also strongly affect the spectrum. Empirical measurements show that the microwave opacity of clouds becomes important for wavelengths less than ~3 cm, and is approximately proportional to the square of the frequency. Scattering can become important if the cloud droplets are large enough, but it generally can be neglected at the longer wavelengths except in the case of precipitation. Spectrum III of Fig. 1 shows the effect on Spectrum II of a cloud 1-km thick centered at 2.5 km altitude and containing 1 gm/m^3 liquid H_2O. Even this moderately dense cloud would not obscure the water vapor resonance and could be distinguished from the water vapor by its essentially different spectral shape.

Precipitation absorbs microwaves and would usually appear about the same as a heavy cloud. Scattering becomes important for precipitation and could strongly affect the spectrum at wavelengths shorter than about 10 times the droplet diameter. When scattering is important the spectra that result are strongly dependent on frequency and particle size distribution. Thus precipitation would yield spectral features that might partially obscure simultaneous water vapor or cloud measurements.

Clearly there is a separation problem in interpreting spectral data obtained from a microwave satellite, but as can be seen in Fig. 1, the major atmospheric parameters have distinct spectral features that could be used to provide separate measurements of these parameters. It should be noted that the cases considered in Fig. 1 imply almost an all-

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weather capability for microwave sensors as opposed to optical devices, which are affected much more strongly by clouds.

The spectra shown in Fig. 1 are all for an antenna beam perpendicular to the sea. At other receiving angles and at different polarizations the various spectral features could be enhanced, thus permitting greater sensivity.

The spectra shown in Fig. 1 can now be compared to the sensitivities of currently available radiometers suitable for spacecraft. All the radiometric systems considered here are of the Dicke[7] comparison type.

The simplest radiometer is the crystal video type consisting primarily of a crystal detector followed by a video amplifier (Fig. 2A). These are wide-bandwidth devices and are therefore useful primarily for wavelengths less than 10 cm. The Mariner R spacecraft[8] carried two radiometers of this type to Venus. The wavelengths were 19.0 and 13.5 mm and the rms fluctuations in the radiometer output were equivalent to about 20-30°K for a 30 second integration time. The package weight including the calibration equipment, etc. was less than 21 lb. and consumed less than 5 watts average 10 watts peak. At 8-mm wavelength with a bandwidth of about 5 Gc/sec, an rms deviation of about 5°K for a 10 second integration time can be obtained. These sensitivities almost make this type of radiometer suitable for coarse measurements of clouds and water vapor. For accurate measurements of temperature or narrow spectral features other types of radiometers must be used.

The second class of radiometers includes those with an RF amplifier in front of the detector. (Fig. 2B) Tunnel diode amplifiers are among the most promising and can provide, for example, ± 0.1°K rms sensitivity for a 1-second integration time and a 1 Gc/sec bandwidth. These amplifiers can be quite small and lightweight, and require a little more power than the crystal video system. The major restriction is one of frequency -- at present such amplifiers are available only for wavelengths longer than ~2 cm.

Still greater sensitivities, perhaps .01°K for 1-second integration, can be obtained using parametric amplifiers. Because they require a moderately powerful RF oscillator to pump the amplifier, these devices are somewhat heavier and consume more power than the tunnel diode amplifiers. Their bandwidth is typically a few hundred megacycles but can be made narrow at the expense of sensitivity. Their performance is generally improved when they operate at low temperatures, but room temperature is satisfactory. At present such systems are available at wavelengths longer than ~3 cm and are being developed for wavelengths as short as 3 mm.

Clearly both tunnel diode amplifiers and parametric amplifiers are sufficiently sensitive to detect the spectral features shown in Fig. 1.

At present however, the best available systems for use in the higher frequency portions of the spectrum are superheterodyne radiometers (Fig. 2C). These are quite commonly used for radiometric systems operating at wavelengths shorter than 2 or 3 cm. They are similar to the RF amplifier system except they have another crystal detector before the amplifier. This detector mixes the incoming signal with the signal from a local oscillator so as to produce a new signal at some low frequency where amplification is simple. The system sensitivity (for ~1-cm wavelength) is usually ~1 or 2°K rms fluctuation for 1 second integration time and a bandwidth of 20 Mc/sec. These radiometers are generally heavier than the tunnel diode systems and require more power. This is primarily because of the local oscillator which must generate moderate amounts (a few milliwatts) of RF power, although this is less power than is usually required by a parametric amplifier. Their bandwidth is generally

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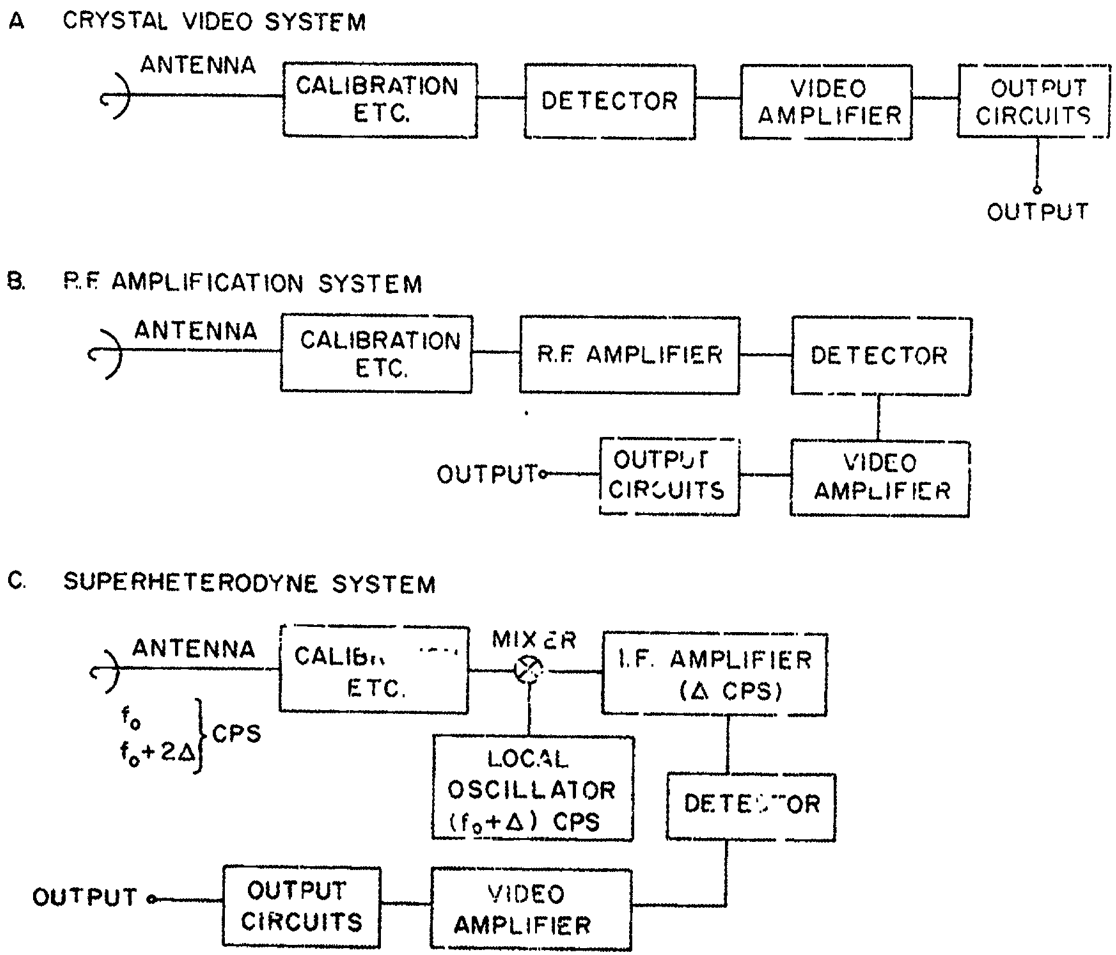

Figure 2. Microwave Systems Diagram.

8 Mc/sec up to a few hundred Mc/sec, thus making them quite suitable for narrow spectral features.

Fig. 1 indicates that 1°K rms fluctuation permits good identification of the important spectral parameters, and if the integration time is lengthened, the sensitivity increases. Of course longer integration times imply less spatial resolution. These systems have usually operated at wavelengths longer than 4 mm but can be used at shorter wavelengths.

Other radiometric systems employing traveling wave amplifiers, masers, etc. are also feasible for future experiments but at present are not so practical for spacecraft as the systems considered above.

MICROWAVE RADIOMETRY AND APPLICATION TO OCEANOGRAPHY

N65-30376

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"Microwave" radiometry has been done from essentially DC to 0.1 mm (100 micron) and even shorter, near-IR, wavelengths. As opposed to radars which are active systems in the sense that they measure reflections of power that they first transmitted and which are eminently suited for ranging (through pulse coding) and for velocity measurements (through Doppler shift), radiometers measure the passive microwave emission of targets and determine their apparent, or "brightness" temperature T_B. Microwave radiometers have the following range of characteristics:

Item	Typical	Best	Unit
Sensitivity	1	0.01	Degree K, RMS
Integration time	1	0.001	sec.
Resolution	1	0.01	degree
Bandwidth	0.1	20 to 0.01	%
Frequencies	10	0 to 3000	Gc
Wavelength	30	large to 0.1	mm

Generally, three types of instruments are available, a) Single fixed frequency, b) Spectrometer, c) Imaging.

All bodies radiate electromagnetic waves if their temperature is higher than absolute zero according to Planck's radiation law. The energy in the microwave portion of the spectrum, however, is very low, typically 4 orders of magnitude less than at visible or IR wavelengths. This is the reason for the typically long integration time required for microwave radiometers. The measured temperature, or brightness temperature T_B of the target is affected by several parameters:

- -Thermometric temperature
- -Emissivity / reflectivity
- -Physical state
- -Wavelength of observation
- -Intervening medium target-observer
- -Polarization

These six parameters will now be explored in same detail in the special case of the ocean.

1. Thermometric temperature T_T: In the case of the oceans, typically 250 to 300°K. T_B is directly proportional to T_T, all other parameters being constant.
2. Emissivity ε - Reflectivity ρ: In the case of the ocean water, the emissivity is very low, in the order of 0.4, and the reflectivity correspondingly very high, in the order of 0.6. This implies that the apparent temperature of the sea will be low since mostly cold sky reflection will be measured. The emissivity depends on polarization, angle of viewing and wavelength used. Figure 1 shows the variation of emissivity with viewing angle for two polarizations, for pure water. Note that emissivity reaches 1 in vertical polarization (electric vector vertical) at about 53°; this is the Brewster angle. For salt water, the curves would start at about 0.4 rather 0.75, but the shapes are similar. Note also the importance of angle of viewing and polarization. The effect of wavelength on reflectivity is illustrated in Figure 2.
3. Physical state: Roughening of the observed surface introduces multiple effective viewing angles, multiple reflections, scattering and other phenomena, generally resulting in a higher T_B than in a smooth situation. A wavelength dependence exists

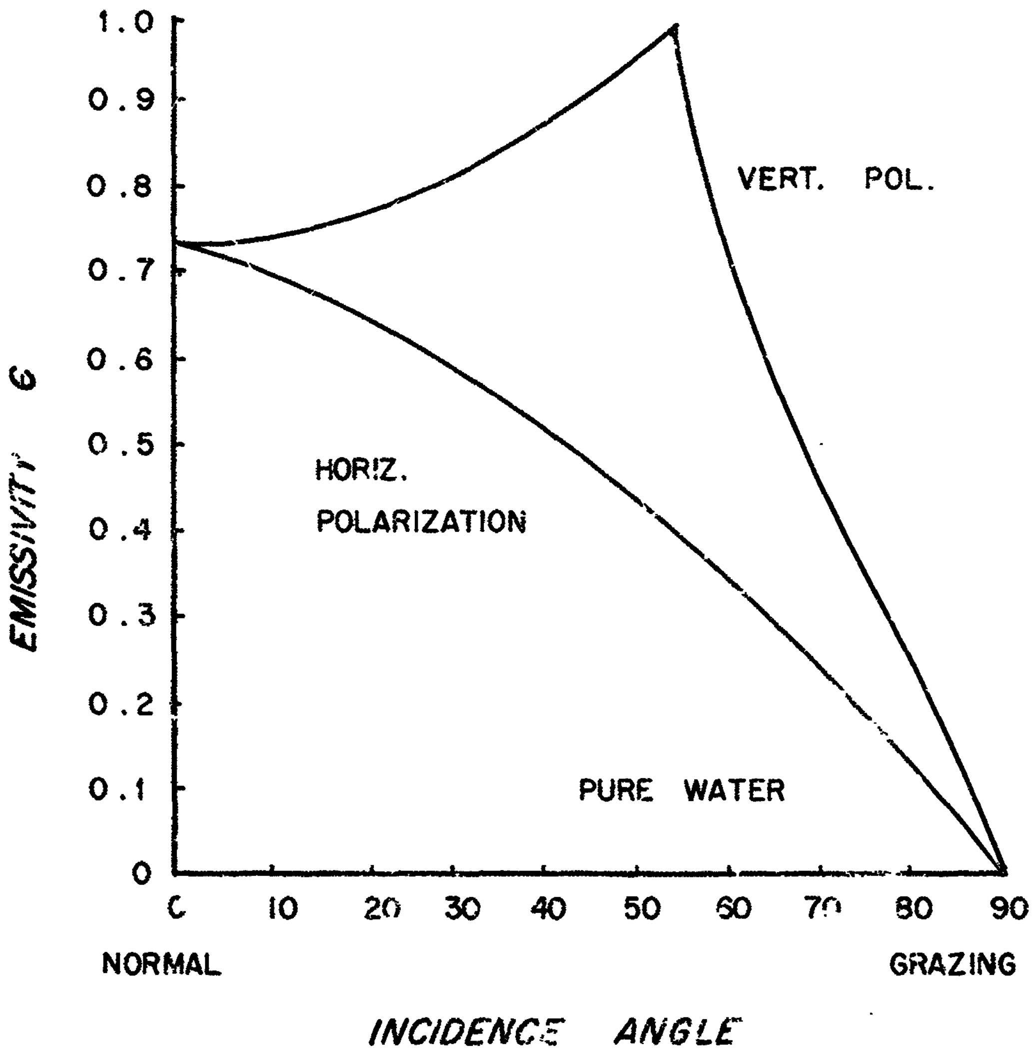

Figure 1. The Variation of Emissivity With Viewing Angle for Two Polarizations for Pure Water.

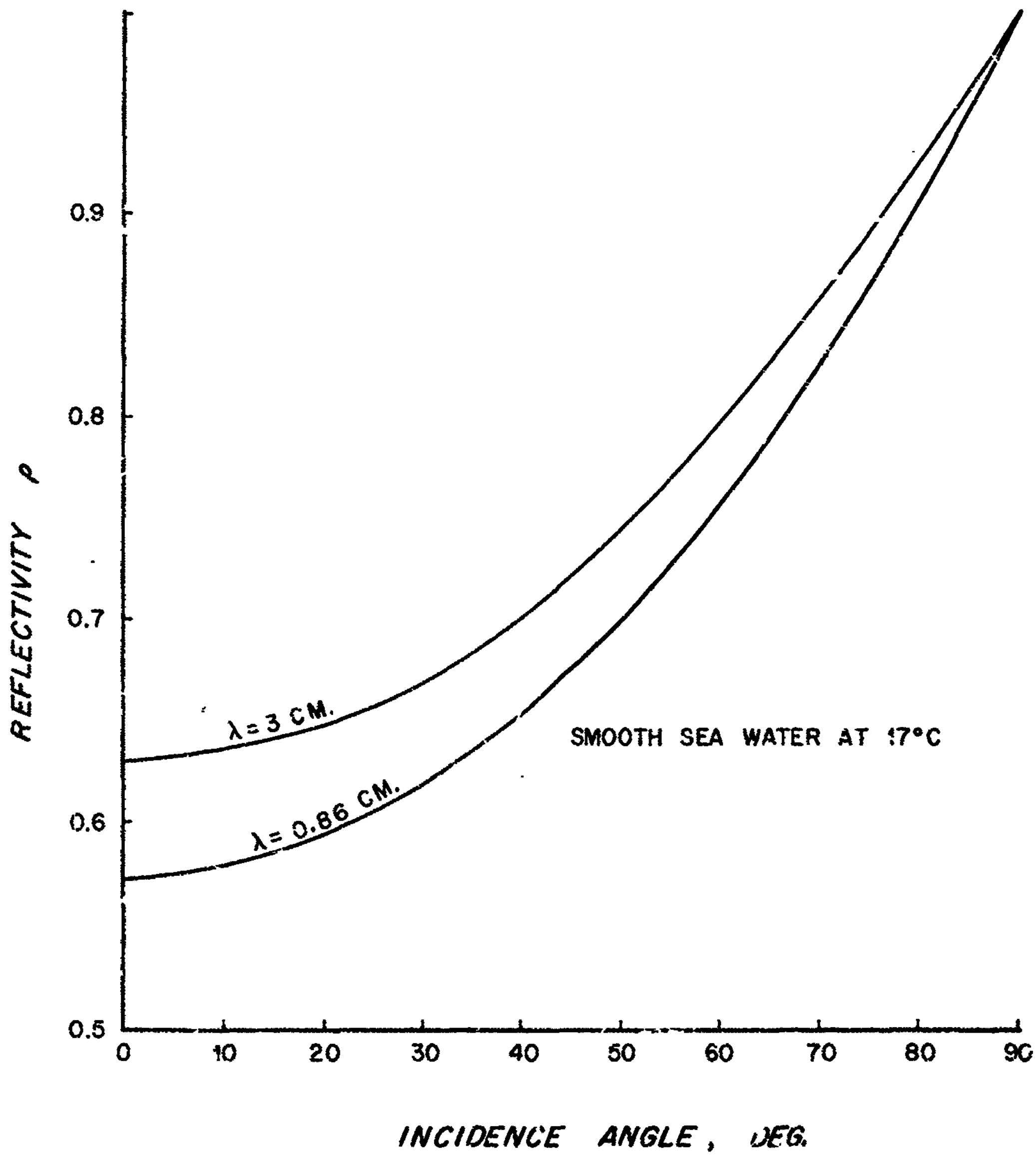

Figure 2. The Effect of Wavelength on Reflectivity.

here: If the roughness is much smaller than the wavelength it will have little or no effect on T_B.

4. Wavelength: In addition to the reflectivity and roughness dependence on wavelength, as explained above, a penetration effect as a function of wavelength exists. Microwave energy easily penetrates low dielectric constant materials such as sands. Water, and in particular sea water is a fair conductor, and penetration in the ocean is extremely small. Typically, penetration is less than one wavelength. To give an idea of attenuations, we have 54 db of attenuation per undersea wavelength, (λ_s = 18m for f = 10 kc; λ_s = 0.01m for f = 500 Mc) or we can use the equation attenuation = $0.03\sqrt{f}$ db/meter. At a typical frequency of 10Gc (X band), the attenuation would be 3000 db/meter.
5. Intervening medium: Two effects, one an attenuation effect, one a radiation effect. In the case of the ocean as observed from an aircraft or satellite, the principal media are water (cloud, rain) and atmosphere. These effects are completely negligible for all purposes if the wavelength used is greater than 3 cm. At shorter wavelength, water has a line at 13.5 mm (22.2 Gc) and oxygen at around 5mm (60 Gc). Figure 3 shows T_B as a function of frequency in the vicinity of the water vapor line: emission from the atmospheric water, warmer than the sky reflection, is evident. At wavelengths shorter than about 5mm, the attenuation progressively increases until the IR region is reached.
6. Polarization: The importance of polarization has been already mentioned in conjunction with the emissivity and the physical state of the ocean.

CONCLUSION

Microwave brightness temperatures as measured by radiometers are affected by at least six important factors. It is thus necessary to be extremely careful in minimizing all but one or possibly two, factors during measurements. Only then will it be possible to extract the desired parameter from T_B measurements.

In particular, microwave radiometers are extremely well suited to determine ice formations due to the very high emissivity of ice as compared to sea water. Precise ice area maps could be obtained easily from aircraft or satellite altitudes, and this independently from weather conditions.

Less obviously, the thermometric temperature of the top layers of the seas, sea state, and thickness of ice over water could be determined by the use of two or multi-frequency radiometers; several frequencies being necessary to calibrate out all but the pertinent parameter. In ocean meteorology, the distribution of water vapor and condensed water above the ocean, and atmospheric temperature profiles could be obtained by similar multi-frequency techniques.

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1. "The Applications of Passive Microwave Technology to Satellite Meteorology: a symposium" edited by Y. H. Katz, Rand Corporation, Memorandum RM-3401-NASA.

2. "Physical Properties of the Ocean". Report No. NADC-AW-6234. U.S. Naval Air Development Center, Johnsville, Pennsylvania. Astia Document No. AD 410486.

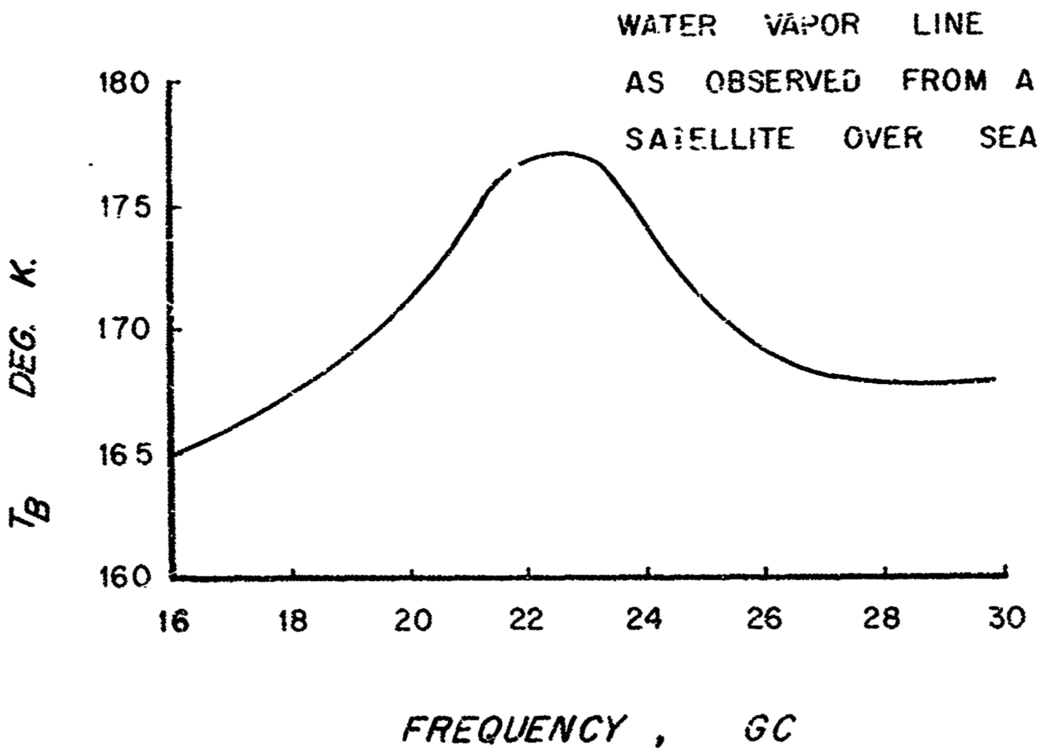

Figure 3. The Brightness Temperature as a Function of Frequency.

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MICROWAVE RADIOMETERS FOR OCEAN AND WEATHER MEASUREMENTS

William H. Conway and Austin Mardon

Space General Corporation, El Monte, California

PART I: SUMMARY DISCUSSION OF MICROWAVE RADIOMETRY

W. Conway

It is the purpose of this part to provide an introduction to the subject of microwave radiometers and also to provide a small amount of background on the subject. Part II will discuss the specific applications of microwave radiometry to ocean and weather measurements.

A microwave radiometer detects the energy emitted by all bodies having a temperature other than absolute zero. In this respect it is quite similar in operation to the infrared radiometer; however, the wavelength region and the amount of available energy differ considerably. Figure 1 shows a plot of Planck's Law. It shows that the amount of energy available at infrared is considerably larger than that available in the microwave region. However, in the microwave region the sensors can be made with a much better sensitivity than is possible in the infrared region. These two factors approximately compensate to allow equivalent operation in the microwave spectrum.

Another difference between the two regions is the effect of emissivity. In both regions a quantity called apparent temperature is utilized. The apparent temperature is defined as the temperature at which a perfect blackbody radiator would radiate the same amount of energy. In the infrared region the majority of surfaces have emissivities that lie very close to one, with very few materials exhibiting emissivities of less than 0.9. In the microwave region very few natural materials have emissivities that are close to one. The majority are distributed over the range of 0.6 to 0.9. Certain materials exhibit changes of frequency over the microwave region. Water, for instance, ranges from a low of the order of 0.05 at the low microwave frequencies to a value of approximately 0.3 at the 70 Kmc region. It is also known that water reaches an emissivity of approximately one in the far infrared region: therefore, it is reasonable to assume that this transition occurs somewhere between 70 Kmc and the far infrared region.

Since the emissivity of objects in the microwave range is not unity and since the emissivity and the absorptivity must be equal, to satisfy thermodynamic constraints, the energy that is not absorbed must be reflected. If there is energy reflected from a surface, it must be considered when the apparent temperature of that surface is determined. Figure 2 shows a sketch of how this reflected energy is combined with the emitted energy to determine the total received radiation. This is, admittedly, a rather simple sketch; however, the reflected energy can be simply handled as is depicted. A more detailed sketch is shown in Part II. As shown, the received radiation will consist of two components: a steady state or dc component, and a point-to-point variation in energy. It is this point-to-point variation that provides the vast majority of information that can be obtained with a microwave radiometer, and discussions of the signal will refer to this point-to-point variation.

The ability of a microwave radiometer to detect this point-to-point variation is usually expressed in terms of an equivalent value of temperature for which this signal-to-noise ratio is equal to one. The noise, in this case, is primarily generated by receiver noise. The simpler equation in Figure 3 expresses this level of internal noise as a function of the various parameters of the radiometer system. In this case the K is a detection constant (generally considered $\pi/2$ for a switched (Dickie) system); F is the overall noise figure of the radiometer system; B_V is the video or signal bandwidth of the system; and B_{rf} is the predetection or rf bandwidth of the system. This, again, is a relatively simplified equation which adequately describes the operation of the radiometer system. The more complicated expression for ΔT, also shown in Figure 3, refers to the point-to-point signal variation previously discussed. In

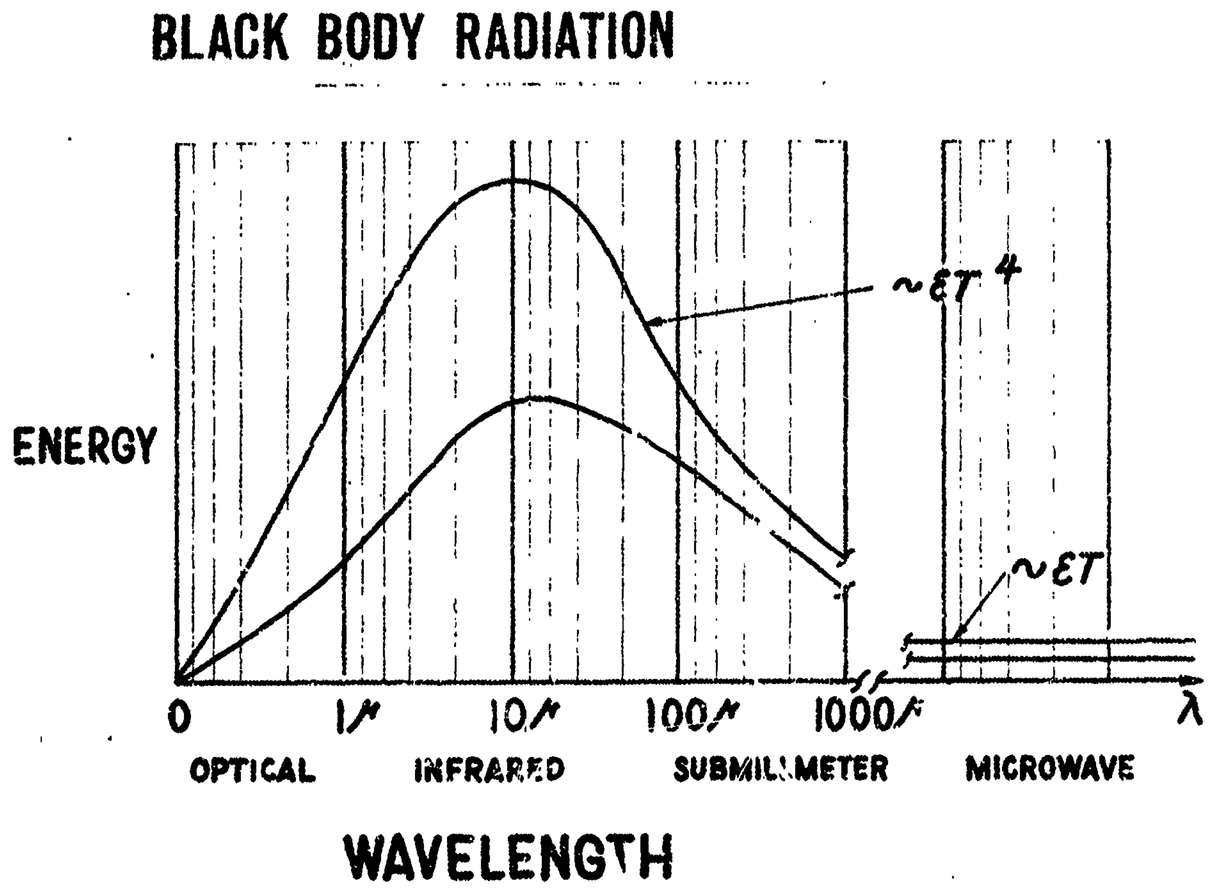

BLACK BODY RADIATION
ENERGY
~εT 4
~εT
0
1μ
10μ
100μ
1000μ
λ
OPTICAL
INFRARED
SUBMILLIMETER
MICROWAVE
WAVELENGTH

Figure 1

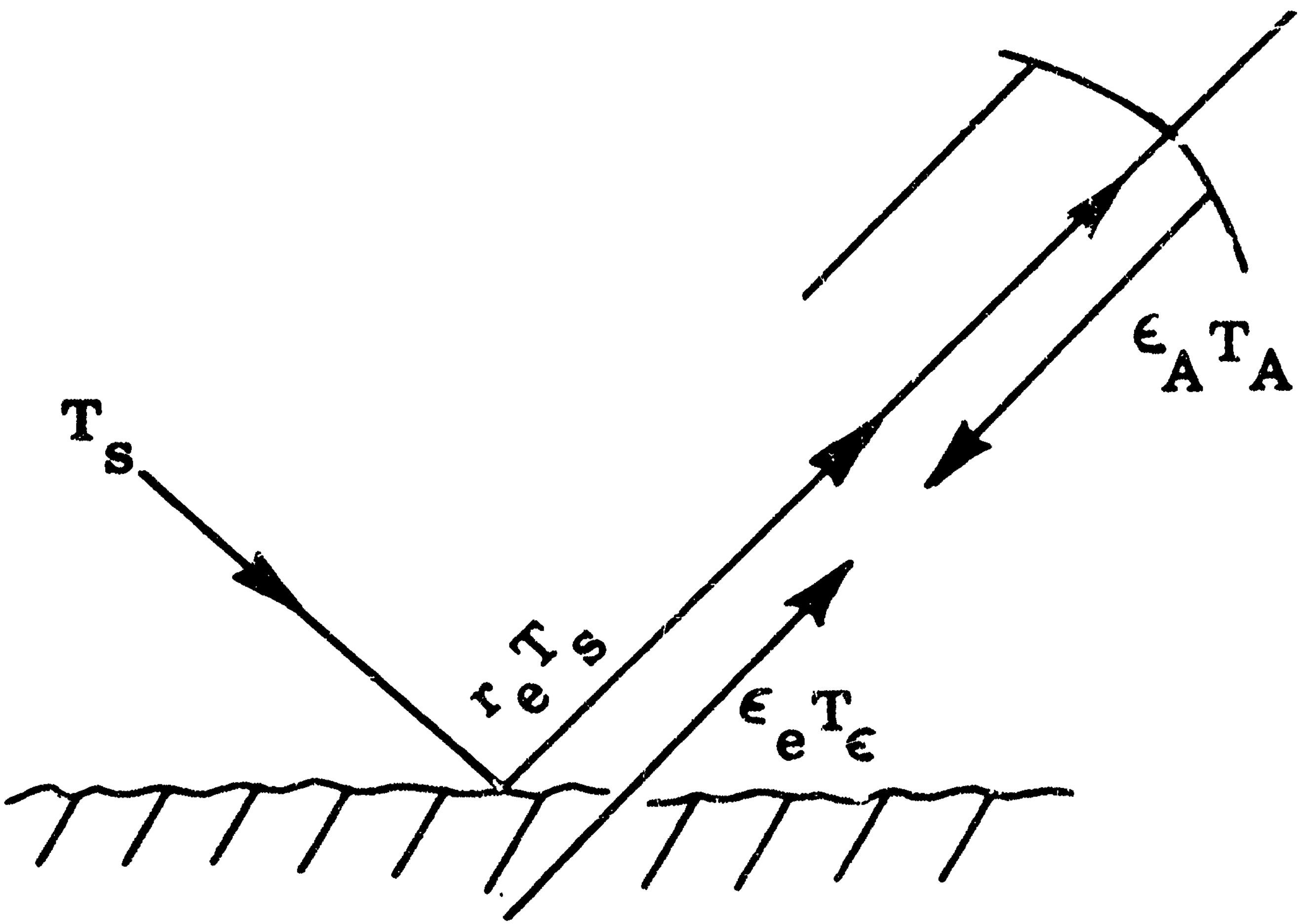


Figure 2. RADIATION FROM TERRESTRIAL OBJECTS. Emitted - reflected = total received radiation. Signal = $\epsilon_{antenna} \cdot T_{antenna} = (\epsilon_{earth} \cdot T_{earth} + r_{earth} \cdot T_{sky}) =$ (d-c component) - (point-to-point variations).

$$\frac{\Delta T}{T_o} = \frac{KF\sqrt{B_v}}{\sqrt{B_{rf}}}$$

$$\Delta T = \left| \left\{ T_s - \left[T_B (1-\mathcal{E}_{at})^2 + T_{at}(1-\mathcal{E}_t) + T_t \mathcal{E}_t \right] \right\} \left(\frac{D_T D_A}{4\lambda R} \right)^2 (1-\mathcal{E}_{at}) \right|$$

Figure 3

this case the script ε's are the emissivities, the T's refer to the temperatures encountered such as sky and terrain background, atmosphere and target. The squared term with the D's and R refer to the case when the target does not entirely fill the antenna beamwidth. The apparent temperature difference in this case is reduced approximately by the ratio of areas. This equation is not presented here as a basic equation of radiometry, but as an example of how the various parameters involved in the detection scheme are handled.

Space-General Corporation became interested in microwave radiometry almost five years ago. At that time the primary application in mind was development of a mapping sensor to be used in a position fix system. As a portion of the system's development program, a scanning airborne microwave radiometer was flown over a variety of target areas. Figure 4 shows some of the pertinent data associated with this program. The most significant information here is the number of target areas that were examined and the number of individual runs that were made. This flight test program lasted over a period of almost two years.

During this flight test program it was determined that the significant information was the point-to-point variation in energy levels that was previously discussed. As a result, all of the steady state information was discarded and, thus, was not processed. This type of operation has been referred to as gradiant radiometer operation. Figure 5 shows a sample of the type of map obtained by this airborne gradiant radiometer. An interesting feature of the maps are their repeatability as demonstrated by the correlation curve shown on the right side of the figure. A more complete discussion of this flight test program has been presented at a University of Michigan Symposium on Remote Sensing of Environment.[1]

Several other organizations have also been interested in microwave radiometry, and Figure 6 presents a short summary of representative programs. It is interesting to note, here, that the programs are a mixture of flight test programs and ground test programs.

Having successfully conducted a flight test program, Space-General came to the conclusion that a ground test program should also be conducted to gather the basic, rigidly controlled, data that is necessary for proper interpretation and prediction of flight test data. Figure 7 shows a short summary of the program that SGC is presently conducting. It should be noted that the primary emphasis is on controlled experiments.

Figure 8 is shown to indicate the extent of frequency coverage that is being considered and a further elaboration on the types of measurements being made. The two dots on the K_u and V Band instruments indicate that it is these frequencies that will be primarily discussed in the remainder of this paper.

Figure 9 shows some of the representative measurements of terrain background that have been made. It is interesting to note here that there is a difference between the vertical and horizontal polarization apparent temperatures for all materials except metals.

A variety of information had been previously obtained concerning the apparent temperature of materials as a function of incidence angle. Figure 10 shows some apparent temperatures that have been measured for a variety of materials as a function of incidence angle. The most interesting material for the purposes of SGC's military program is metal and it was not available.

A method of measurement was required that would allow separation of the metal radiation from the background radiation. This was accomplished by allowing the metallic surface to rotate about a fixed axis; in this way, the only variables are the plate incidence angle and, unfortunately, its area; however, since the plate is a simple rectangle, its area is relatively east to account for. Figure 11 shows the test set-up and some of the data obtained. In this chart, the effect of the area of the metal plate has not been removed and the raw measured data is presented.

1. "A Gradient Microwave Radiometer Flight Test Program," W. H. Conway, et al. Second Symposium on Remote Sensing of Environment, University of Michigan, October 1962

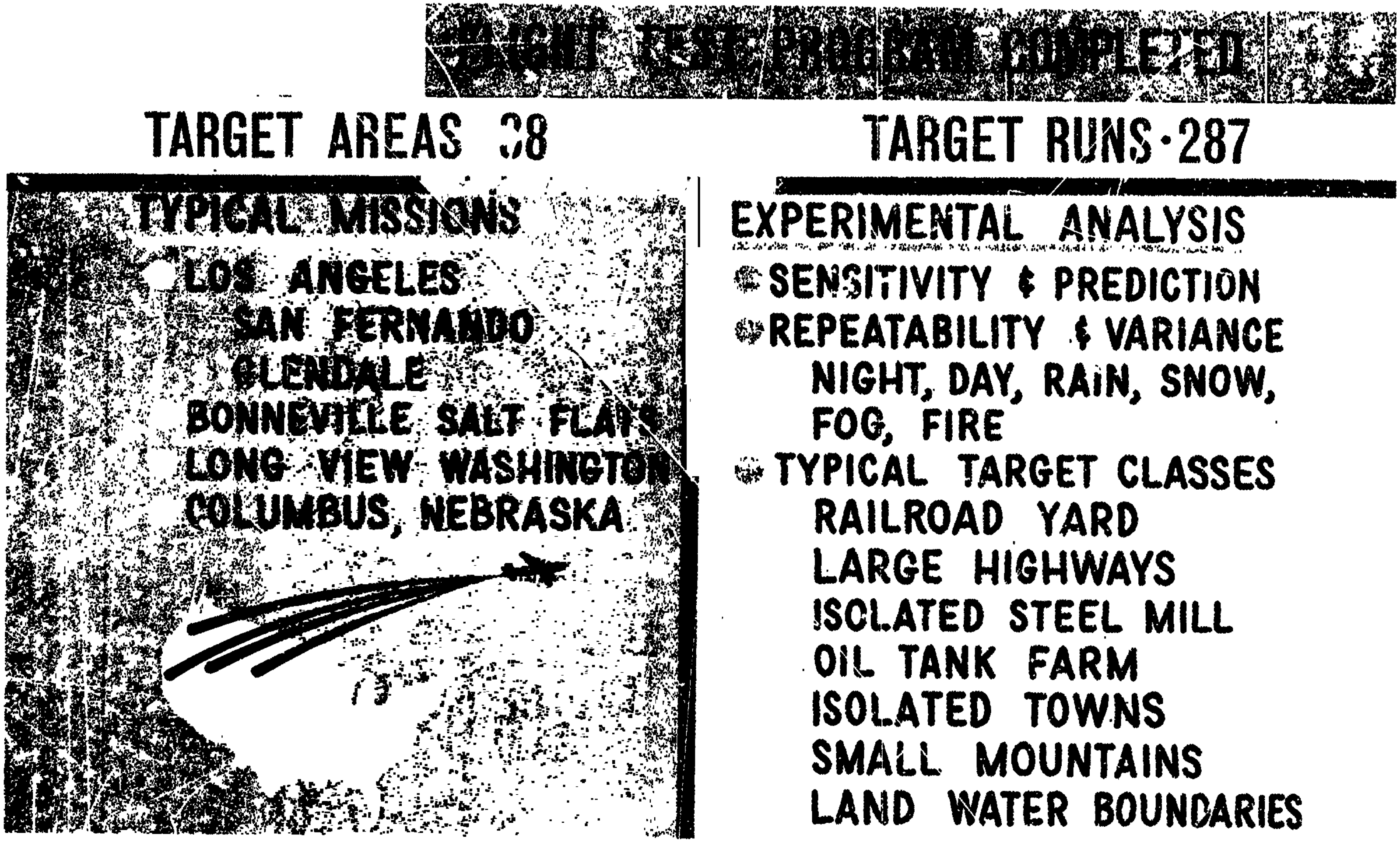

TARGET AREAS
TARGET RUNS·287
TYPICAL MISSIONS
LOS ANGELES
SAN FERNANDO
GLENDALE
BONNEVILLE SALT FLATS
LONG VIEW WASHINGTON
COLUMBUS, NEBRASKA
EXPERIMENTAL ANALYSIS
SENSITIVITY & PREDICTION
REPEATABILITY & VARIANCE
NIGHT, DAY, RAIN, SNOW,
FOG, FIRE
TYPICAL TARGET CLASSES
RAILROAD YARD
LARGE HIGHWAYS
ISOLATED STEEL MILL
OIL TANK FARM
ISOLATED TOWNS
SMALL MOUNTAINS
LAND WATER BOUNDARIES

Figure 4

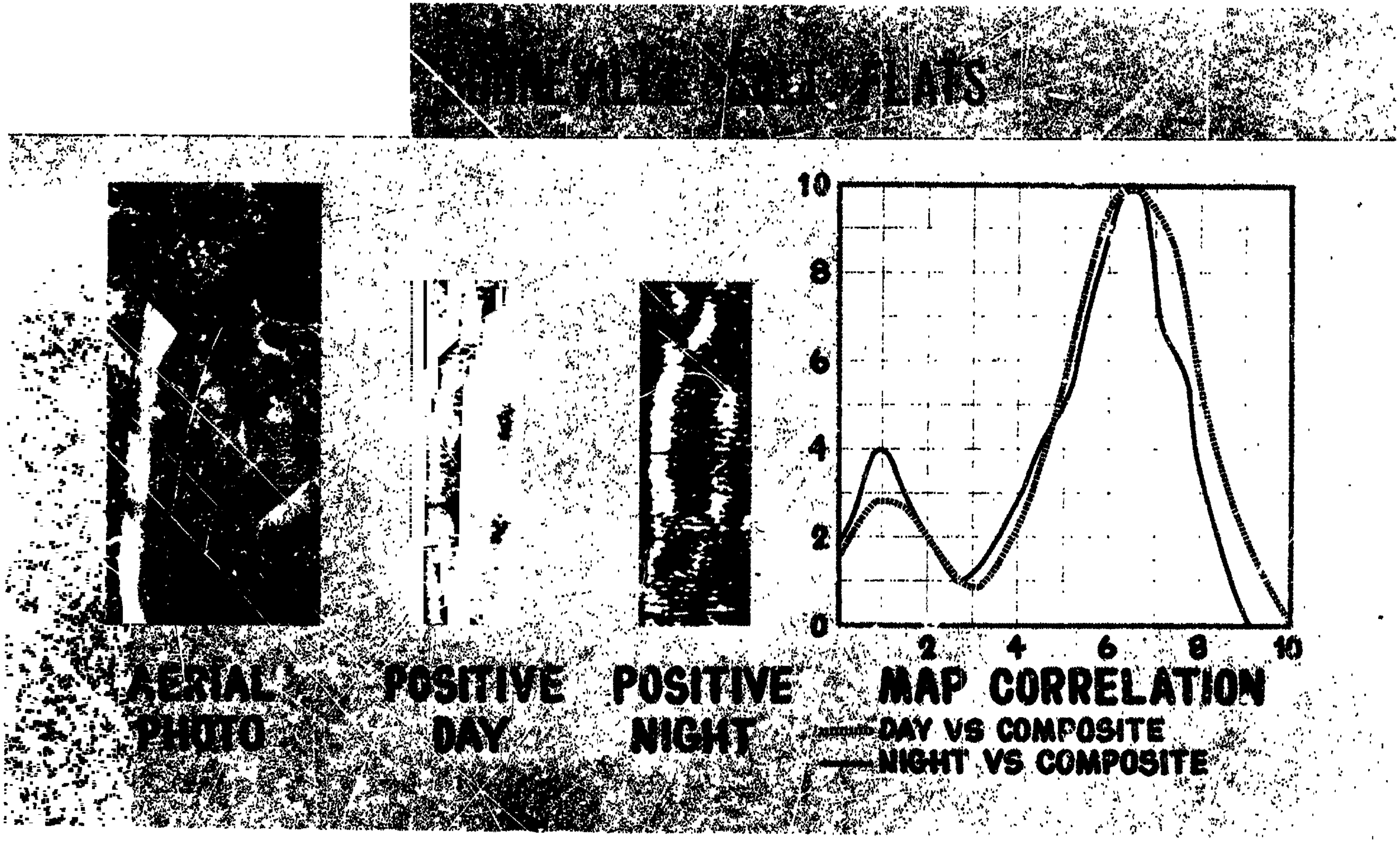

10
8
6
4
2
0
2
4
6
8
10
AERIAL PHOTO
POSITIVE DAY
POSITIVE NIGHT
MAP CORRELATION
DAY VS COMPOSITE
NIGHT VS COMPOSITE

Figure 5

REPRESENTATIVE PROGRAMS

Organization	Frequency Regime (Wavelength in cm)	Type Measurements
Space-General Corporation	0.1 cm,* 0.21 cm,* 0.43 cm, 0.85 cm, 1.8 cm, 3.3 cm, 25-30 cm * To be in operation this year	Aircraft Flight Test - gradient mapping - land-water boundaries - snow data - ice data - precipitation data Ground Tests - terrain materials - apparent temperature - cooled and heated bodies - apparent temperature - freezing water data - snow data - ice data - sky temperature - atmospheric data
Bell Telephone Laboratories	0.36	Ground Tests - terrain materials - detailed apparent temperature - sky background - average readings - rain, snow effects - scanning - radiometer pictures
Cambridge Research Center	0.86, 1.25, 2.2 3.2	Aircraft Flight Tests - mapping (0.86, 1.25, 3.2 cm) propagation and atmospheric Ground Measurements - terrain materials (1.25 cm)
Coast Guard	3.0	Aircraft Flight Tests - detection of icebergs
E. E. Laboratory (University of Texas)	0.16, 0.215, 0.27 - 0.32, 0.43, 0.5	Ground Tests - terrain materials - detailed apparent temperatures (0.43 cm) Propagation and Atmospheric
Ohio State University	0.86, 1.8, 0.06	Radiometer, Radar Theoretical Work Radar Ground Tests - terrain materials (0.86, 1.8, 0.86 cm)
Royal Radar Establishment	0.86	Aircraft Flight Tests - mapping absolute temperatures - some snow readings
Sperry-Gyroscope	1.8, 3.3	Aircraft Flight Tests - mapping, high resolution, primarily land-water boundaries
University of Wisconsin	3.3	Aircraft Flight Tests - qualitative terrain gradients, some ice and snow
Wiley Electronics	3.3	Aircraft Flight Tests - qualitative mapping, high resolution

Figure 6

PROGRAM OBJECTIVES

MEASUREMENTS

MODELS
FLAT PLATE, CONE, COMPLEX TARGETS

TARGETS OF OPPORTUNITY
MISSILES, AIRCRAFT, VEHICLES

ATMOSPHERIC
PROPAGATION, ATTENUATION, SKY TEMP.

TERRAIN
TERRAIN ELEMENTS, DIURNAL, SNOW

INSTRUMENTATION

Ku BAND (16-18 GC)
V BAND (50-75 GC)
F BAND (90-140 GC)

THEORETICAL & SYSTEMS ANALYSIS

RADIATION PHENOMENON
BASIC PHENOMENON, MULTILAYER/ CONTINUUM VS SPECTRAL

ATMOSPHERE
FLUCTUATIONS, WEATHER

MISSION
TARGET CLASSES, DYNAMICS

PERFORMANCE
DETECTION, DISCRIMINATION, ACCURACY

TECHNIQUES

LOW NOISE RECEIVERS
THINWIRE, CRYOGENIC DETECTORS

ANTENNAS
PHASED ARRAYS, LENS

Figure 7

MICROWAVE RADIOMETER TARGET MEASUREMENTS

CONTROLLED EXPERIMENTS

INSTRUMENTATION	MEASUREMENTS
	MODELS
L .6 - 1 GC	FLAT PLATE
	SPHERE
Ke 12 - 15 GC	CONE
	TARGETS OF OPPORTUNITY
Ku 16 - 18 GC	VEHICLES
	AIRCRAFT
Ka 35 - 38 GC	MISSILES
V 65 - 75 GC	**BACKGROUND**
	VARIOUS TERRAIN
F 90 - 120 GC	SKY
	MULTI-LAYER COMPOSITION
G 140 - 300 GC	WATER ICE SNOW

Figure 8

TYPICAL RADIOMETER TEMPERATURES

	TEMPERATURE °K VERTICAL	HORIZONTAL
ASPHALT	271	243
SOIL	275	268
VEGETATION	277	270
METAL	85	85
WATER	157°	101

Figure 9

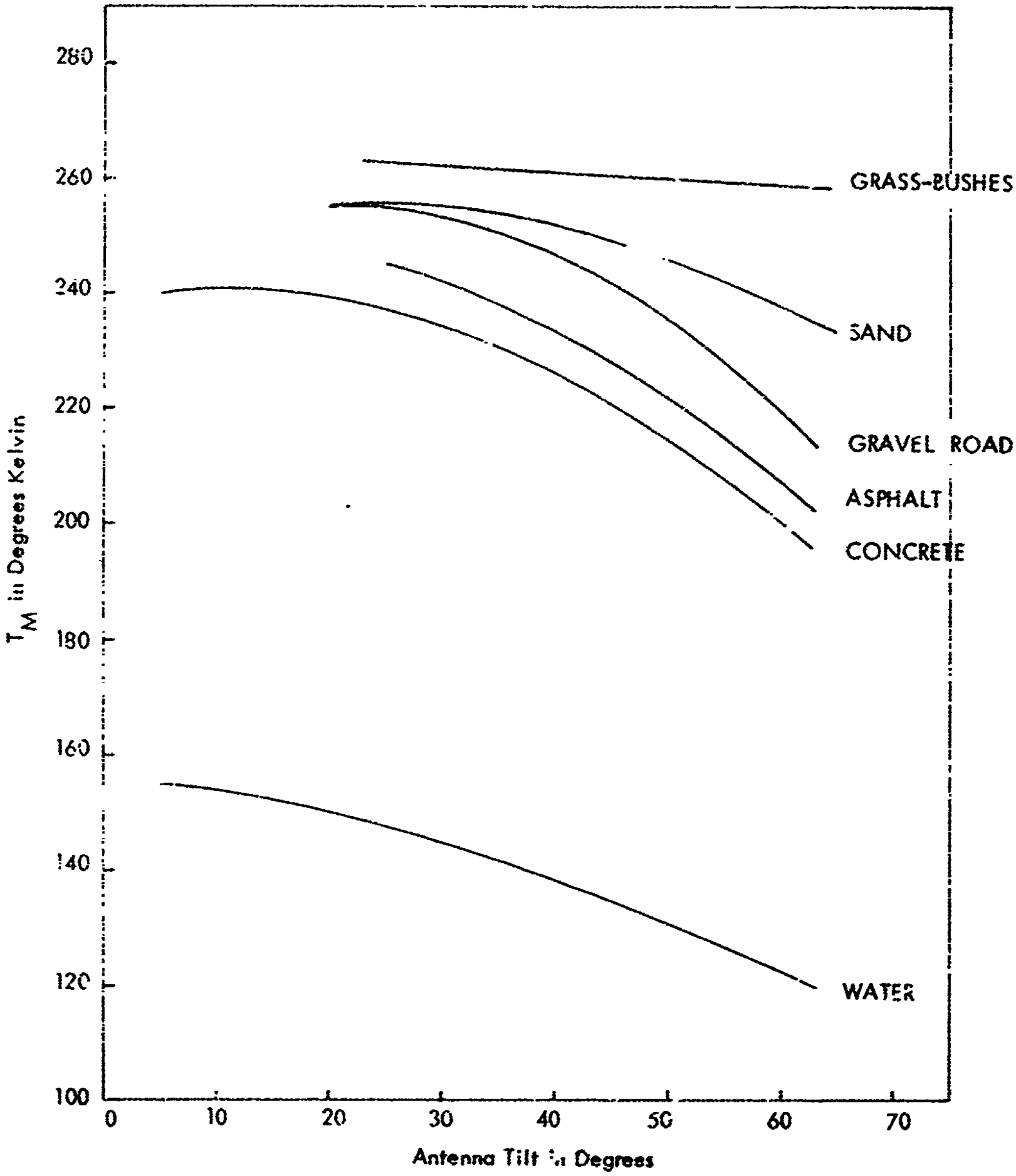


Figure 10. Measured Target Temperature vs. Antenna Temperature

PLATE TEMPERATURE

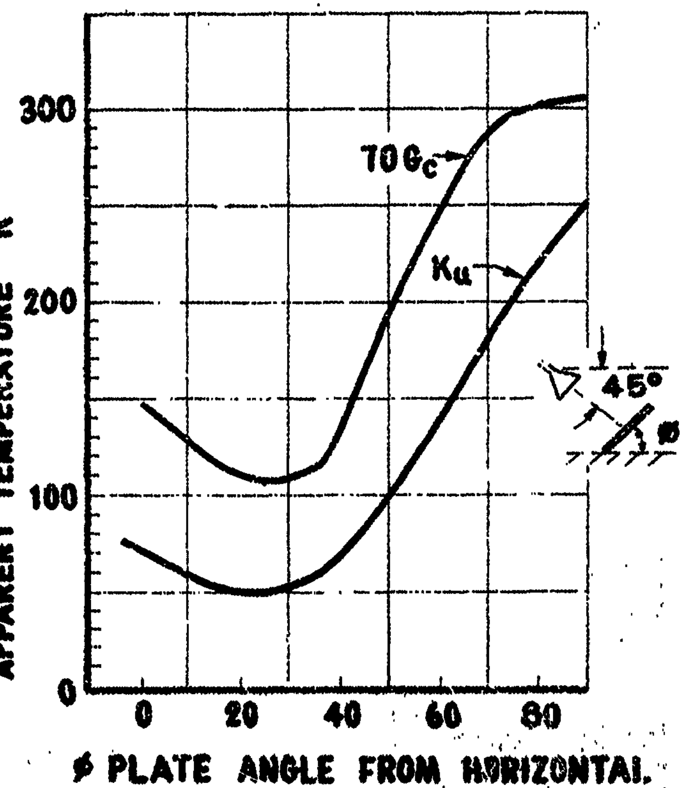


Figure 11

One class of targets are targets of opportunity. For a metallic surface target of opportunity, nothing was more opportune than a series of measurements on automobiles. This is especially true since the experiments were being conducted on the edge of the company's parking lot. Figure 12 shows two of the measurements that were made on automobiles. In this case it is interesting to note that even though the beamwidth of the antenna was considerably larger than the size of the automobile, almost by a factor of ten, a difference can be seen between the small, almost symmetrical cars and the large station wagon, indicating the signature possibilities available with this kind of sensor.

Concurrent with the metallic surface measurements, a measurement of the sky temperatures being reflected by the metal is necessary to be sure that the measured temperatures could be correlated. Figure 13 shows a representative series of sky temperature measurements.

A problem that confronted the data analyst, in this instance, was the depth of the surface which would be adequate to mask the effects of the underlying materials. A series of measurements were run to ascertain this value by measuring an aluminum plate under a variable thickness of materials. Figure 14 shows some of the information that was obtained at 16 Gc from these measurements. The materials that were chosen for this initial measurement were, of necessity, dry, very powdery, easy to handle substances. Subsequent measurements at 70 Kmc indicate that the depth of penetration is directly proportional to the wavelength. Another interesting series of measurements were run using a thickness of ice over a body of water, and this will be discussed in Part II of this paper.

With the background just discussed and having an interest in finding new applications for microwave radiometry, several potential applications, directed particularly to ocean and weather problems, have been investigated. Figure 15 shows five of these possible applications. The following paper will consider some of them in more detail to examine their feasibility, discuss some of the possible methods of implementation, and draw some conclusions about the time scale in which some definitive measurements might be accomplished.

PART II: APPLICATION OF MICROWAVE RADIOMETERS TO OCEANOGRAPHY

A. Mardon

INTRODUCTION

The following material is intended to complement my colleague's paper with a more specific discussion of the application possibilities of radiometers to oceanographic measurements. Fortunately, the experimental and analytical work already cited can be directly related to such a possibility. Parameters of specific interest to oceanographers which we are confident will be ultimately measured with radiometers include:

1. Thermometric temperature of the sea (through fog)
2. Distribution of water vapor above the sea
3. Determination of the sea state and sea swell vector
4. Distribution of ice (through fog)
5. Thickness of level ice over water
6. Distribution of condensed water vapor over the sea
7. Atmospheric temperature as a function of altitude

It is noted that all material bodies, above absolute zero temperature, generate thermal energy. This energy is related to the random motion of the elementary particles of electromagnetic energy postulated by Planck. It can be shown that the spectral distribution and intensity of this energy is such that sensitive millimicrowave receivers can detect it. These receivers are usually operated in the radiometric or Dicke mode, e.g. the input circuit is alternately switched between the antenna and a known thermal reference in order to preclude the drifts in receiver gain, which limit the performance of standard receivers. This technique is comparable to the common practice of using choppers in dc amplifiers to stabilize gain.

AUTOMOBILE TEMPERATURE

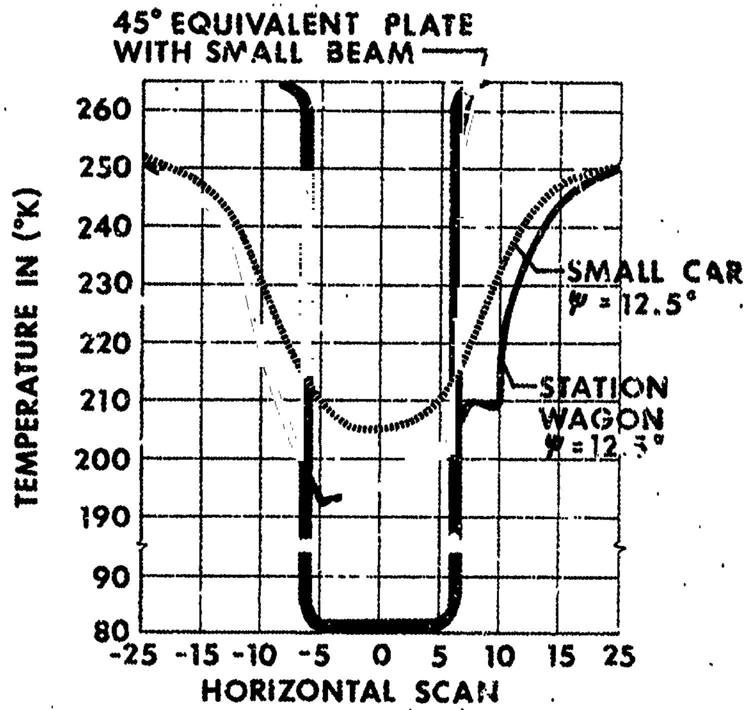
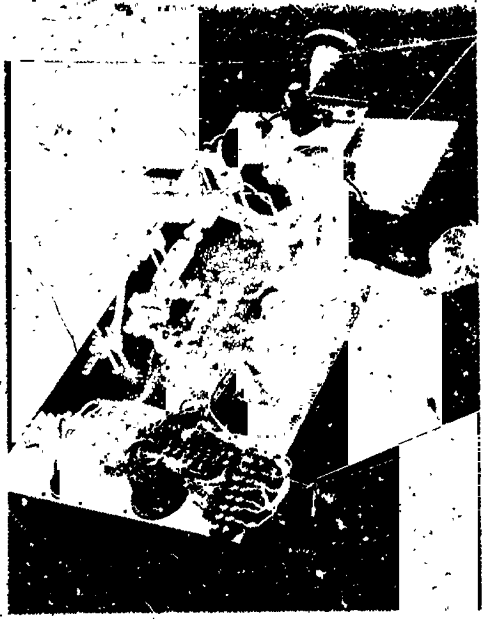


Figure 12

SKY TEMPERATURE



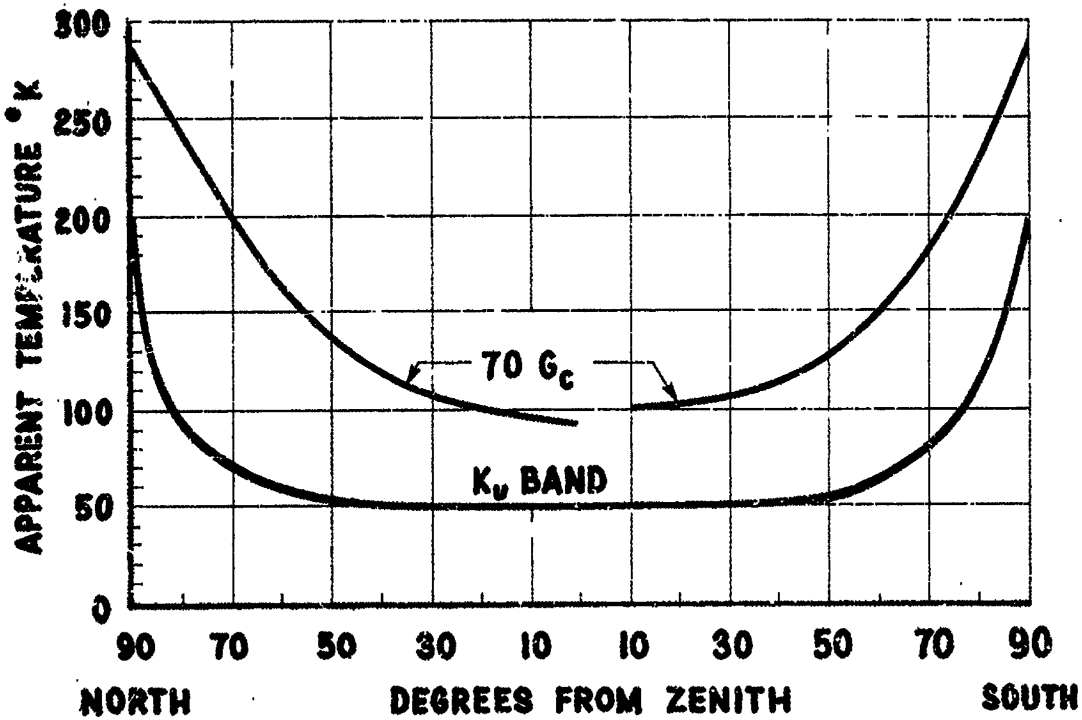


Figure 13

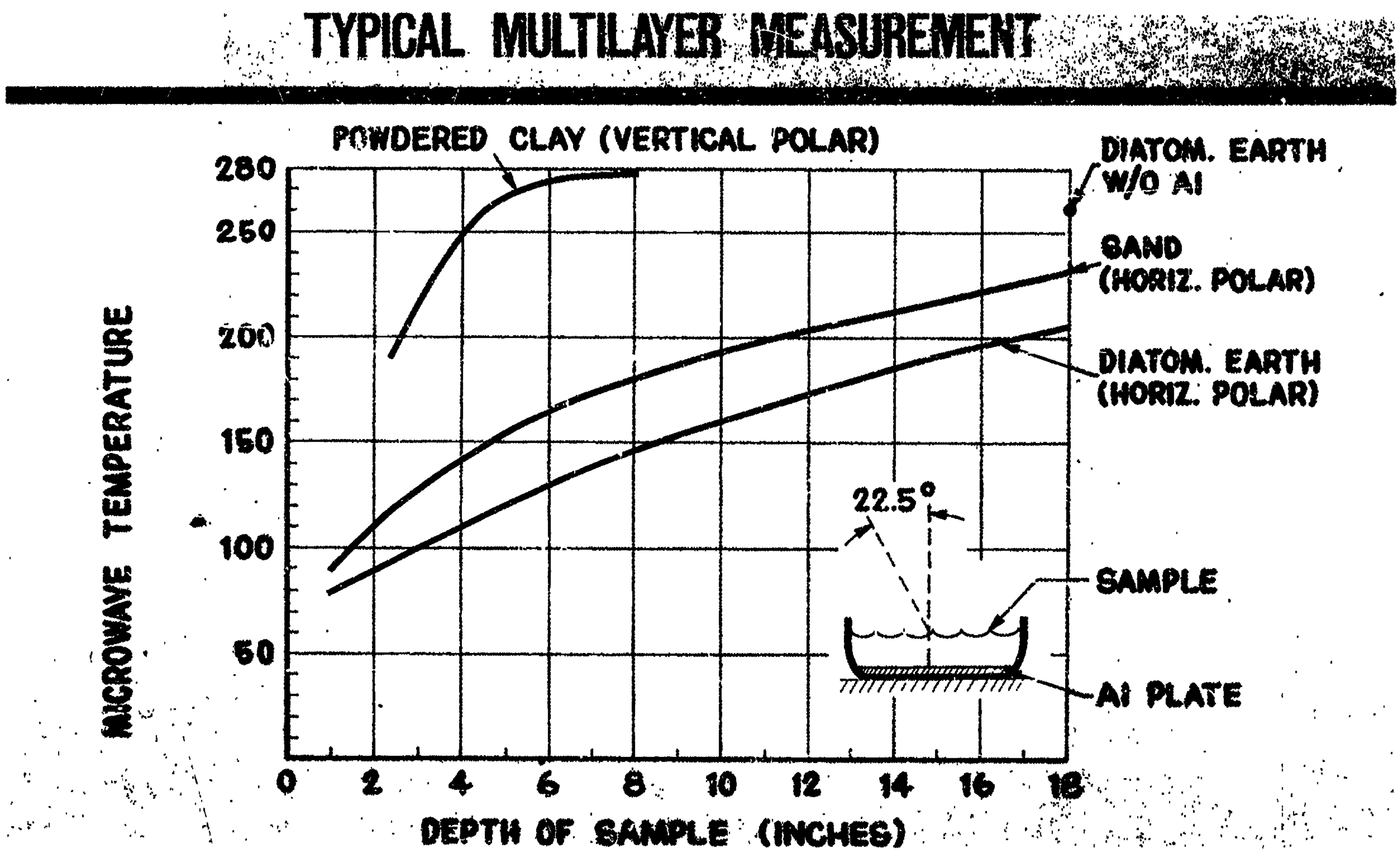

TYPICAL MULTILAYER MEASUREMENT
POWDERED CLAY (VERTICAL POLAR)
DIATOM. EARTH W/O Al
SAND (HORIZ. POLAR)
DIATOM. EARTH (HORIZ. POLAR)
22.5°
SAMPLE
Al PLATE
MICROWAVE TEMPERATURE
280
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
DEPTH OF SAMPLE (INCHES)

Figure 14

POTENTIAL MICROWAVE METEOROLOGY APPLICATIONS

- ICE, SNOW & WATER COVERAGE OF LAND MASSES
- SEA ICE COVERAGE
- SNOW PACK DEPTH AND MOISTURE CONTENT
- ATMOSPHERIC TEMPERATURE & HUMIDITY PROFILES
- SEA STATE CHARACTERISTICS

Figure 15

The resulting narrow band video output of the receiver is filtered, allowing the detection of effective temperature changes of a few degrees. It should be noted at this point that sensitive laboratory-type radiometers have been fabricated for most of the millimicrowave range of interest. These receivers are capable of detecting changes of ten degrees or less with greater than 95% certainty when using an effective video bandwidth of one cycle (or an observation and integration time of one second).

Radio engineers are familiar with thermal radiation in the microwave spectrum because solar, stellar or galactic noise background noise limits the performance of even the most sensitive receiver. The radio astronomer studies this noise and its distribution in an attempt to derive the structure of the universe. In the millimicrowave spectrum from 10,000 to 300,000 mcs. the atmosphere becomes important to the microwave engineer. For example, oxygen gas has magnetic dipole moments centered at 60,000 and 120,000 mc, water vapor has electric dipole moments at 22,000; 183,000 mc, etc. The result is an attenuation of an rf wave of appropriate wavelength and random radiation within these bands. By analogy with the radio astronomer the meteorologist is interested in the degree of attenuation that can be measured at 22,000 mcs for possible derivation of the distribution of water vapor in the atmosphere. Furthermore, condensed water vapor in the form of fog, rain or snow is comparable in size to the wavelength of millimicrowave energy and also tends to attenuate this energy. It, too, may be analyzed with radiometric equipment.

GENERALIZED EQUATION FOR THE APPARENT RADIOMETRIC TEMPERATURE OF SEA WATER

The apparent temperature of an opaque object is comparable to the absolute temperature of a black body which would radiate the same power; this apparent temperature is made up of the following terms:

1. An absorption term to account for the attenuating medium between the observing instrument, the object and the sky. It will include an absorption component from water vapor gas and oxygen and an additional scattering component from fog or rain.

2. A radiation term which is the product of the thermometric temperature of the object or gas and its emissivity (ϵ).

3. A reflectivity term which is the product of the apparent temperature of the reflected surroundings and its reflectivity. This reflectivity coefficient from elementary thermodynamics must equal $(1-\epsilon)$ assuming zero transmissivity.

In the case of sea water, a fourth term might be added to account for the apparent temperature due to the sea state. This complex term presumably is a function of the wind force and vector and ocean current force and vector.

From these considerations we can establish a simplified general expression for the apparent temperature (T_a) of the quiet sea as observed through water vapor, as presented in Figure 1:

$$T_a = T_v \epsilon_v (1-\epsilon_w) L_v + \sum L_v^2 (1-\epsilon_w) + T_w \epsilon_w L_v + T_v \epsilon_v$$

Where T are the apparent temperatures with subscripts v and w that refer to the water vapor cloud and the water, respectively.

L_v is an absorption loss term related to θ the zenith angle.

ϵ are the emissivities with subscripts v and w that refer to the water vapor cloud and the water, respectively.

$\sum$ is the absolute temperature of the sky (above the atmosphere).

If there is a fog bank over the sea, the absorption term L_v of water vapor may be lumped with a scattering loss term and using the subscript f, the equation becomes:

$$T_a = \left[T_f \epsilon_f (1-\epsilon_w) L_f\right] + \left[\sum L_f^2 (1-\epsilon_w)\right] + \left[T_w \epsilon_w L_f + T_f \epsilon_f\right]$$

$\sum$ is close to absolute zero. This means that the second term in the above expression is extremely small and may be neglected

$$T_a \sim T_f \epsilon_f (1-\epsilon_w) L_f + T_w \epsilon_w L_f + T_f \epsilon_f$$

An antenna at sea level pointed up to the sky will record the $T_f \epsilon_f$ term which thus becomes the apparent temperature of the sky T_s.

$$\therefore T_a \simeq L_f \left[T_s (1-\epsilon_w) + T_w \epsilon_w\right] + T_s$$

Setting values to the terms in the above equation:

1. A plot of apparent zenith sky temperature (T_s) as a function of frequency has been calculated and is presented in Figure 1.

2. The emissivity terms for sea water over a range of water temperatures and frequencies have been calculated using the complex dielectric values derived by Saxton.

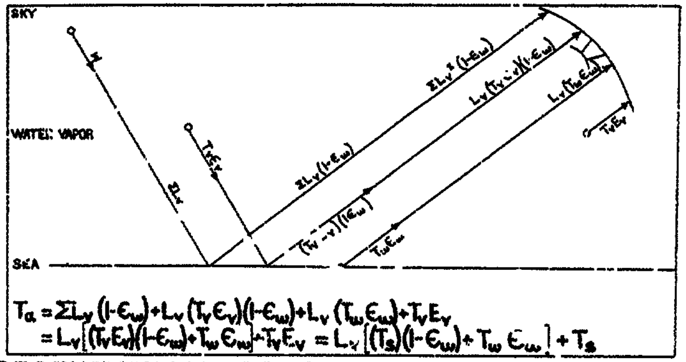
Presupposing that there is no fog or rain and that the sea is calm, the apparent water temperature can be calculated from the above equation for some typical cases. These apparent water temperatures are presented as a function of zenith angle for horizontal and vertical polarization at several frequencies in Figure 2, assuming one percent (7.5 gm/m^3) water vapor at standard temperature and pressure and a 0^o water temperature. The significance of this plot is that it leads to the first radiometer application: determination of the total water vapor column over the sea.

DETERMINATION OF THE DISTRIBUTION OF WATER TEMPERATURES, WATER VAPOR, FOG AND SEA STATE

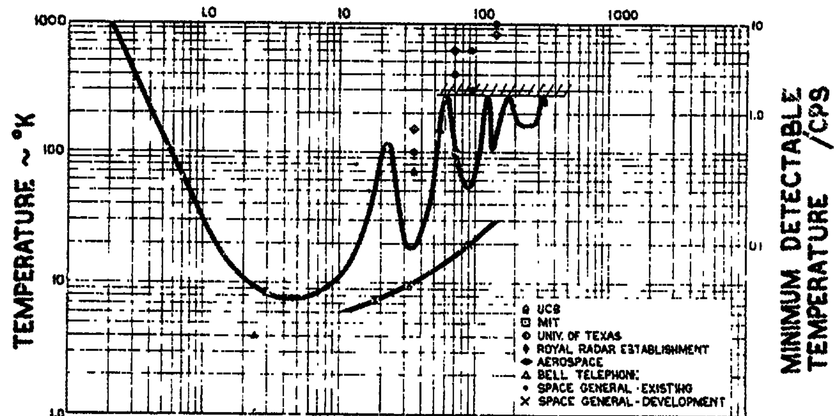
As Dr. Barett of MIT has suggested, the difference in apparent temperature between the water vapor resonance line at 22,235 mcs and other frequency points such as 19,000 mcs or 35,000 mcs offers a measure of the water vapor concentration in the atmosphere. As the concentration rises so will the apparent temperature difference. A map of these apparent temperature differences should afford a rough measure of the total water vapor distribution over the oceans. Changes in water temperature are automatically accounted for by this difference technique. However, complications arise when we consider the effect of fog. Fortunately, the attenuation in fog follows a well defined law and analytical techniques permit us to correct for it. In addition the effect of sea state on apparent temperatures is required but very difficult to resolve. However, analytical work on this problem has brought to light interesting results.

The sea state cases so far considered are the relatively simple ones where the sea surface has the cross-section of a saw tooth. Depending on the observation angle, multiple reflections of the apparent sky temperature will occur. The second graph in Figure 2 shows how the apparent temperature changes as a function of zenith angle. Note that there is a pronounced change in apparent vertical polarization temperature where the zenith angle is the complement of the angle of tilt of the saw tooth (grazing angle). This implies that a surveillance radiometer scanning in azimuth as well as zenith angle could measure the average vector or set of the sea swell.

Again, by selecting an appropriate set of polarizations, frequencies and viewing angles we expect to be able to determine the water vapor column. Definitive measurements on models

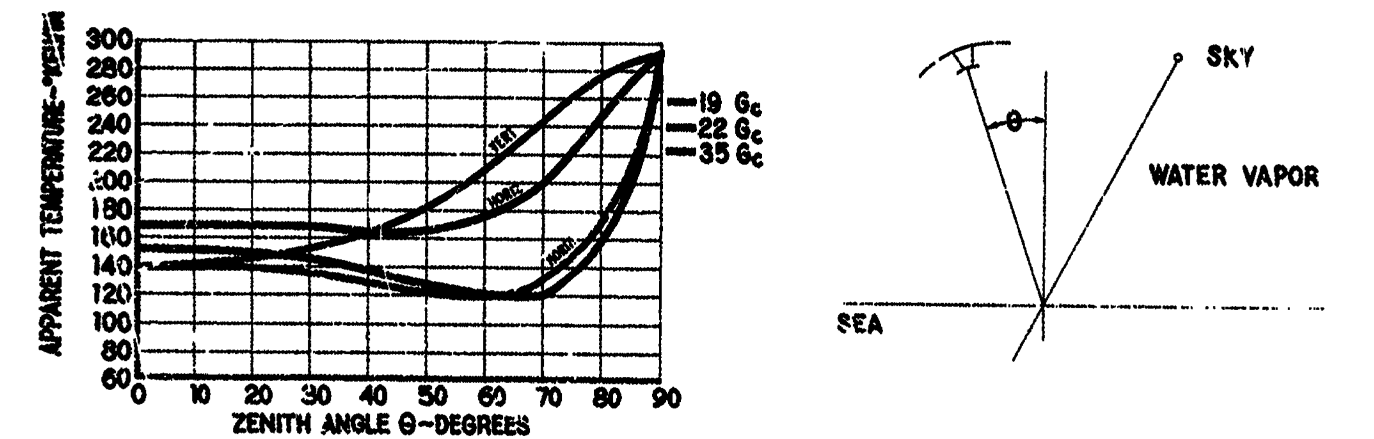


REPRESENTATION OF SKY, WATER VAPOR AND SEA CONTRIBUTIONS TO APPARENT TEMPERATURE

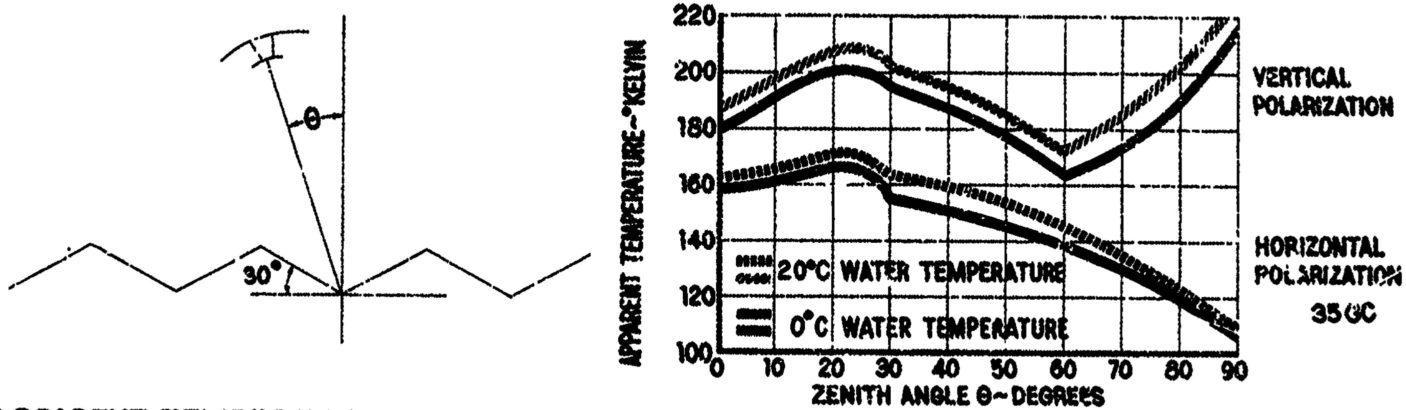


APPARENT ZENITH BY TEMPERATURE AND MINIMUM DETECTABLE TEMPERATURE VS FREQUENCY

Figure 1



APPARENT TEMPERATURE OF CALM SEA VS. ZENITH ANGLE FOR 1% WATER VAPOR LOSS ONLY



APPARENT TEMPERATURE OF SEA SWELL VS. ZENITH ANGLE FOR 1% WATER VAPOR LOSS ONLY

Figure 2

of typical sea swells or states are planned. For the moment, we can make the following generalizations:

1. The thermometric temperature of the sea in clear weather can be derived from the apparent water temperature at 19 Gc; in fog the measurement must be made as low as 6 Gc, assuming a quiet sea.

2. The set or vector of the sea swells can be determined with a scanning array of radiometers at several frequencies.

3. The fog column can be measured at 94 Gc after deriving the water temperature and sea state.

4. The water vapor column can be determined from the apparent temperature difference between a 22.235 Gc and either a 35 Gc or 19 Gc signal.

EMISSIVITY OF MULTILAYER SPECULAR SURFACES

An analysis has been completed of the emissivity of multilayered specular surfaces. It can be shown that if the principal frequencies lie within a small frequency interval the amplitudes and phase of radiation can be represented by

$$V(t) = A(t)e^{i[\phi(t) - 2\pi ft]}$$

where the A and ϕ are real valued functions of time. Because the spectral amplitudes are assumed to be appreciably different from zero only in some small neighborhood of f, it can be shown that A and ϕ are slowly varying compared to $2\pi ft$ and $\phi(t)$ is a random function of time. If the thickness of the layered media is sufficiently small then, in the time it takes the radiation to reflect back and forth at the boundaries, the function A and ϕ will have changed by only a small amount and an interference phenomena may be expected to occur.

The emissivity may be defined as follows:

$$\varepsilon = 1 - R_t^2$$

where R_t is the overall voltage reflection coefficient. For a case where a plane (TEM) wave impinges on (n-1) semi-infinite parallel sheets, R_t is most easily obtained by a transmission line analogy. A paper is being prepared by Space-General showing the derivation of reflectivity for thin specular multilayers, thick specular multilayers, two layered media of uniform temperature with no incident radiation, two layered media with no incident radiation and non-uniform temperature and three layered media with no incident radiation and uniform temperature. The case for ice has been derived and checked experimentally.

From the general equation and assuming a quiet sea, the apparent differential temperature (ΔT) between ice and the sea under a bank of fog is given by:

$$\Delta T = \left\{ L_f\left[T_w\varepsilon_w + T_s(1-\varepsilon_w)\right] - \left[T_i\varepsilon_i + T_s(1-\varepsilon_i)\right]\right\},$$

using the subscripts f, w, s and i for fog, water, sky and ice, respectively. Assuming that $T_w = T_i = 273°$ Kelvin,

$$\Delta T = L_f(273-T_s)(\varepsilon_w-\varepsilon_i)$$

The apparent differential temperature is equal to the difference between the thermometric temperature and the apparent sky temperature multiplied by both the difference in emissivities between water and ice and the scattering/absorption loss through the atmosphere corrected for zenith angle θ. The effective difference in emissivity between ice and water is shown plotted as a function of incidence angle in Figure 3.

As anticipated, calculations of emissivity showed that as the ratio of ice-thickness to wavelength (ℓ/λ) increase, the reflectivity r and hence the apparent temperature exhibits a damped oscillatory effect. Assuming T = 273°K, a sky temperature of 11.9°K and a frequency of 18 Gc. the apparent temperature of ice as it thickened was calculated. Results are presented in Figure 4. A completed oscillatory cycle was obtained between ℓ = 0 and ℓ = .48 cm and this was subsequently verified by cooling a bath of water with liquid nitrogen and recording the apparent temperature of the surface with an 18,000 mc radiometer as ice formed and thickened.

Since apparent temperature is dependent on either (ℓ) thickness or (λ) wavelength, an estimate of thickness can be made from values of apparent temperature at several frequencies. Although caution would be necessary in interpretation for cases of hummocked ice, there is a definite possibility of indirectly determining ice thickness with multifrequency radiometers. The economic importance of such a capability, particularly in the Baltic, goes without saying.

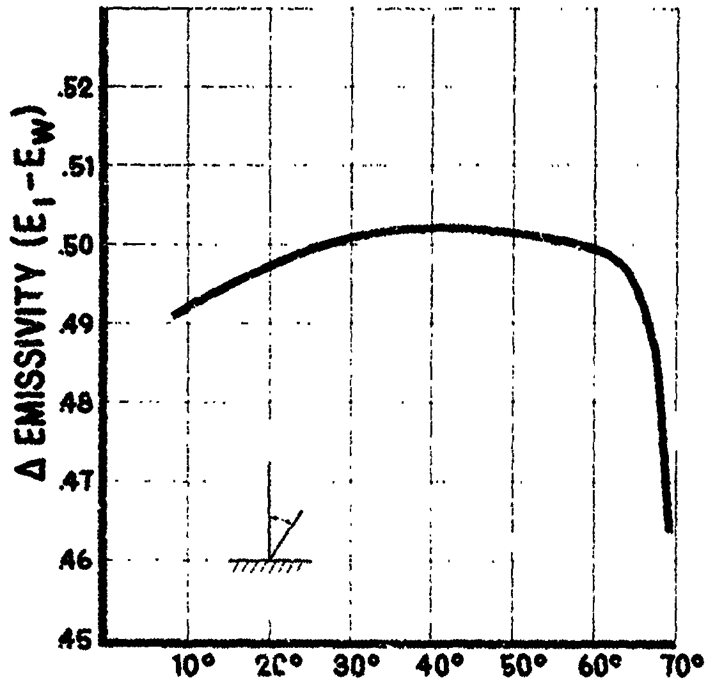
It can be shown that ice covered with wet snow measures warmer than smooth ice. Analytical work is continuing to estimate the depth of snow over ice and also its liquid water content.

Typical values of apparent sky temperatures for a series of weather conditions at 18,000 mcs; 35,000 mcs; 70 000 mcs; 94,000 mcs and 140,000 mcs have been calculated analytically and checked at several discrete frequency points with existing radiometers. In the table in Figure 3, values are presented for typical arctic conditions at a frequency of 35,000 mcs.

It should be noted that early test measurements, at 10,000 mcs, of the iceberg to water temperature difference, ΔT, indicated that the analytically determined differential values were roughly twice those actually observed. This discrepancy can be attributed to layers of slush and pools of water which form on top of the icebergs resulting in lower values of emissivity for the iceberg and hence a smaller $\Delta\varepsilon$ term in the apparent temperature equation. Even so, the prospective system margin in heavy fog is such that accurate radiometric maps can be constructed <u>today</u> showing the distribution of ice in the arctic. This is particularly important when it is recalled that ice observations (visual) from aircraft is already the most important method of ice cover study, allowing examination of huge areas of the arctic in a short time. For example, survey flights are flown by the USSR along the arctic coastline throughout the year. By duplicating flight paths from season to season, the changes in ice conditions and coverage can be followed. This detailed information is then used for navigation courses when shipping begins its seasonal move along the coast. As A. K. Laktinov noted, these aircraft observations are greatly hindered by short days and frequent fogs since they are visual. Efforts by both the USSR and USA shipping authorities to use radar have met with limited success. The reason is that icebergs are poor radar targets because they are highly absorbent to microwaves. The smaller bergs, known as growlers, are dangerous to navigation as they are virtually undetectable by radar.

However, the very property which makes the iceberg an unattractive target to a radar, its absorptivity, makes it an excellent one for a microwave radiometer. The iceberg shows up nominally 100° hotter than the sea. State-of-the-art radiometers would be powerful and valuable recording instruments for determination of ice distribution and for setting accurate quantitative values to the scale of ice closeness numbers suggested by Ya C .kkel. This scale is reproduced in Figure 3.

With accurate ice maps of the Eastern Greenland littoral extending roughly from Iceland north to the Channel between Spitsbergen and Greenland, some long range weather predictions for Europe and Northeastern United States are suggested. Good correlation has been established by Rodewald and Mertins between the occurrence of ice in this zone and meteorological conditions in the North Atlantic. Visual observations are difficult because of fog and overcast but a microwave radiometer would serve irrespective of fog conditions.

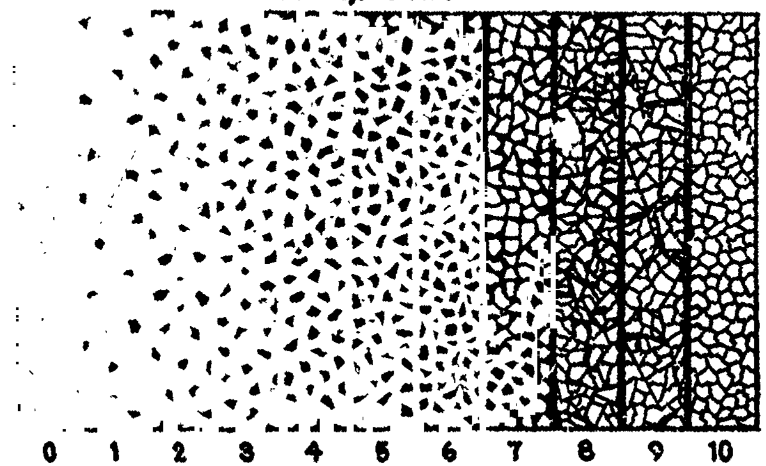


INCIDENCE ANGLE ~ DEGREES

EFFECTIVE Δ EMISSIVITY BETWEEN ICE AND SEA VS INCIDENCE ANGLE

	TOTAL VERTICAL ATTENUATION	APPARENT SKY TEMP	APPARENT AT @ 45°
1gm/m³ WATER VAPOR CLEAR DAY	0.2db	17°	120°
LIGHT FOG 1000' VISIBILITY (.03 gm/m³)	0.4db	33°	106°
HEAVY SEA FOG 1000' VISIBILITY 2000' THICK (1gm/m³)	0.6db	49°	100°
SNOW STORM 5 mm/hr WATER AND ICE CLOUD	1.5db	108°	51°

TOTAL VERTICAL ATTENUATION AND APPARENT SKY TEMPERATURES AT 35,000 MCS



SCALE OF ICE CLOSENESS NUMBERS BY YA.GAKKEL

Figure 3

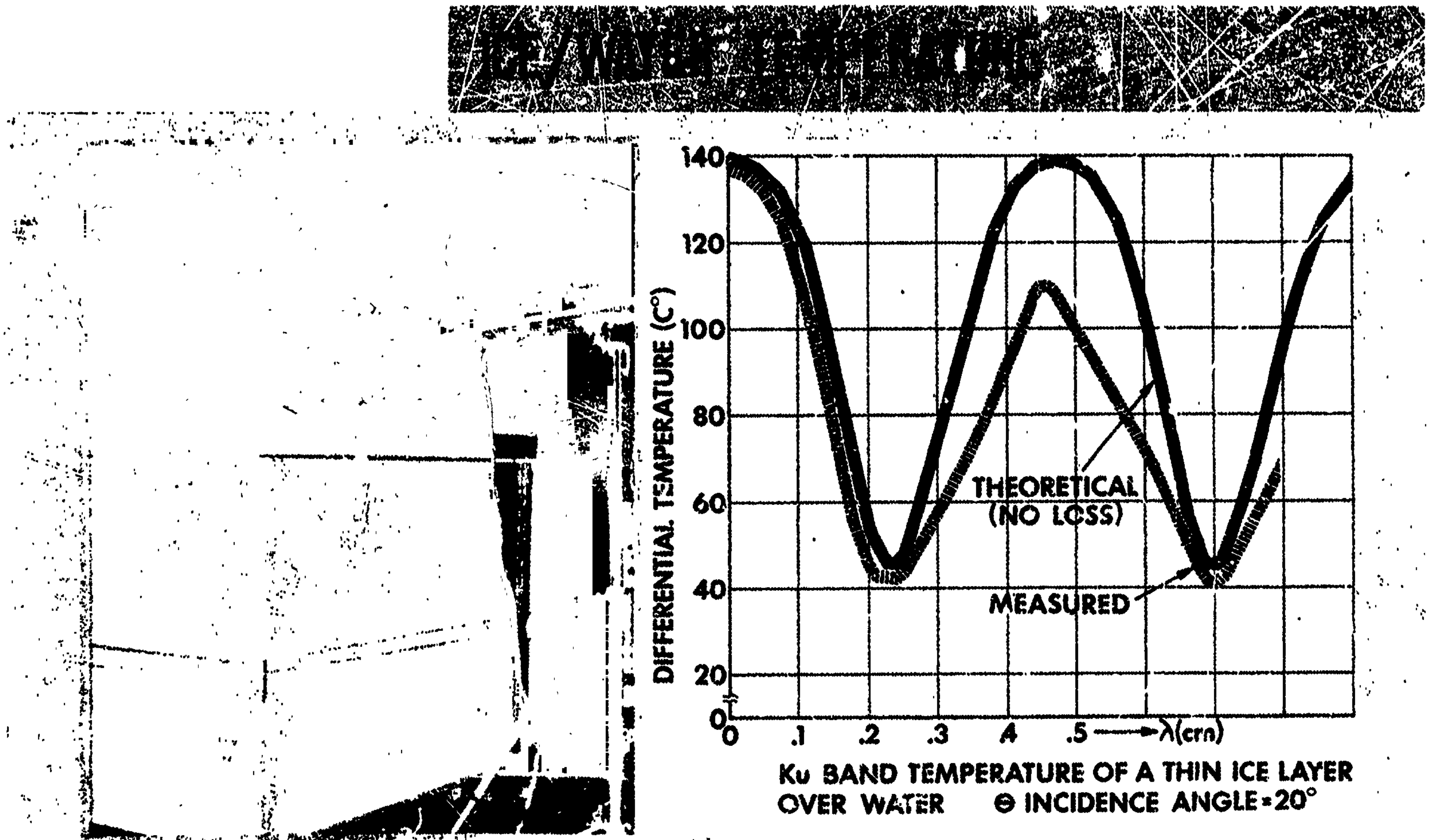

140
120
100
80
60
40
20
0
DIFFERENTIAL TEMPERATURE (C°)
0
.1
.2
.3
.4
.5 ——→ λ(cm)
THEORETICAL
(NO LOSS)
MEASURED
Ku BAND TEMPERATURE OF A THIN ICE LAYER
OVER WATER   Θ INCIDENCE ANGLE = 20°

Figure 4

With the advanced solid state radiometer arrays now under development, having effective sensitivities up to one hundred fold better than present day radiometers, complete radiometric strip maps can be taken from a satellite in conjunction with the Nimbus weather and cloud cover camera data. Ice closeness numbers could be determined for the entire polar region making possible the continuous updating of an ice distribution Atlas of the Arctic.

EFFECT OF RAIN ON APPARENT SKY TEMPERATURES

When a plane polarized wave passes over a spherical drop of condensed water vapor, it induces osillating electric and magnetic dipoles within the drop. Energy is absorbed from the field; part is absorbed as heat and part is reradiated with the drop acting as the spherical radiator, i.e. the energy is scattered.

At the higher frequencies in the EHF band, the scattering cross-section of precipitation particles becomes significant and modifies, thereby, the apparent sky temperature. Space-General has performed an analysis to set quantitative values to the magnitude of the scattering losses for a series of representative cases. The basic transfer equations for two orthogonally polarized beams of radiation traveling at an angle θ with respect to the normal at height Z with $T_p(Z,\theta)$ and $T_s(Z,\theta)$ representing the apparent temperatures have been derived. Because the effect of scattering is expressed as an integral in the equations for adiative transfer, these basic equations have an integral differential form which complicates the solution. Moreover, polarization effects arise over specular reflecting surfaces because of the difference in reflection of horizontally and vertically polarized radiation. A paper is now being prepared at SGC to present this analysis and the results of the computer calculations. It will be published in the very near future.

RADIOMETERS FOR LAB, AIRBORNE AND SPACE APPLICATIONS

Dickie radiometers may be conveniently compared in terms of the noise power sensitivity for an integration time τ.

$$\Delta T = \pi/2\left[\frac{FT_o}{\sqrt{B\tau}}\right] \qquad \text{(signal-to-noise ratio equals one)}$$

where F is the receiver noise figure

T_o is 290°K

B is the total rf bandwidth over which noise is received

τ is the post detection integration time

A number of excellent radiometers have been built by radio astronomers, research physicists and others. The symbols in Figure 1 are representative of the performance that has been secured to date with equipments designed for laboratory or ground field measurements. The majority of such equipments are capable of suitably detecting temperatures in the 1-10° Kelvin range and are quite adequate for most purposes. Airborne equipments should be roughly an order of magnitude more sensitive because of the less favorable intercept conditions encountered and satellite-borne equipments must be 100 fold more sensitive. Such an improvement is well within the state-of-the-art.

Representative lab/field radiometers are shown in Figures 5 and 6. The breadboard packages are no particular handicap for lab or ground field work and standard design will produce an overall package like the unit shown in Figure 7. This radiometer is designed to measure ground geophysical parameters, at 1000 mcs, from an aircraft. Apart from the antenna, the size of most radiometers is directly related to the calibration circuitry power supplies needed. Note that the local oscillator, essential in a superheterodyne receiver, could be a solid state source in which case the entire receiver package would occupy no more than 1 cu ft, while retaining an overall system ΔT of better than 1° Kelvin. Ultimately, all

MOBILE K_e AND K_a BAND RADIOMETERS

Figure 5

Ku BAND GRADIENT RADIOMETER

DUAL MODE, VARIABLE SCAN-RATE
ANTENNA

HORIZONTAL & VERTICAL SYNC-
SIGNAL GENERATOR

7 CHANNEL AMPEX RECORDER

BORESIGHT CAMERA

AERIAL MAPPING CAMERA K 17

V O R RECEIVERS

Figure 6

AIRBORNE L-BAND RADIOMETER

(MODEL L-1000)

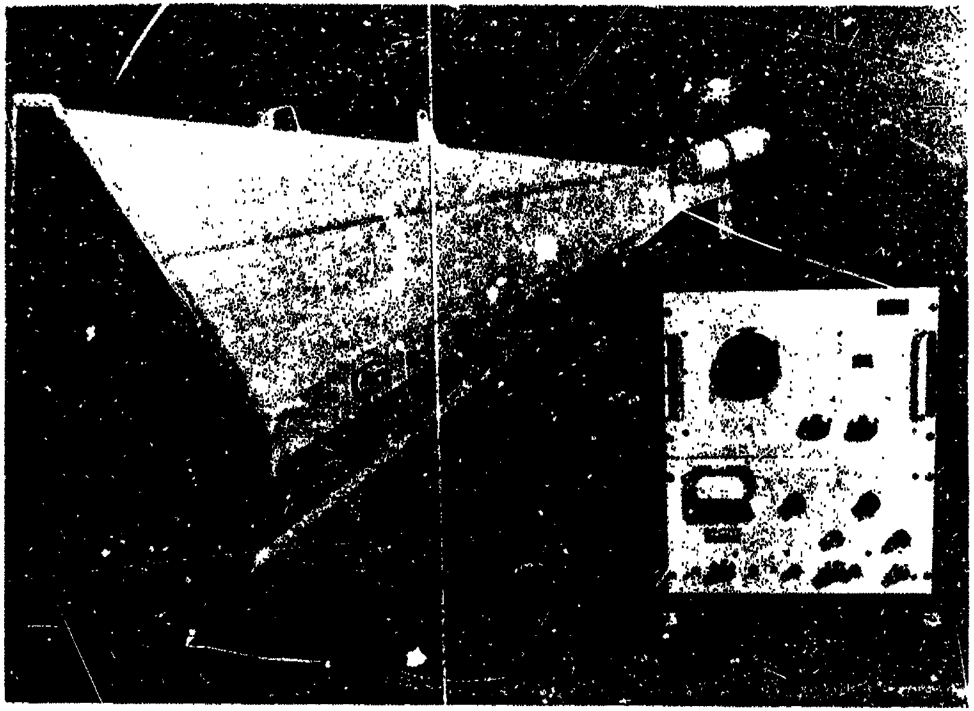


Figure 7

airborne-type equipments with operating frequencies up to 100,000 mcs will be of this type.

The next step would be to an integrated quasi-stripline low noise radio frequency head and integrated module amplifiers and phase detectors. The package size would then be less than 6 cu in. and the temperature sensitivity would be of the order of 0.1^{o} Kelvin/cps. Such a package would be ideal for single or array radiometer payloads in satellite surveillance systems.

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OCEANOGRAPHIC APPLICATIONS FOR RADAR

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The purpose of these brief observations is to give a rapid appreciation of the present unclassified state-of-the-art in side-looking radar imaging and to suggest broadly the oceanographic applications of this technology. An initial viewing of several radar photos will establish for you the context in which these remarks are made.

Figure 1 shows a radar photo of a large tear fault northwest of Knoxville in the Virginia-Tennessee border area. The geomorphology of the area is easily appreciated. The differential dissection of areas of varied slope and composition is quickly regionalized. At the next lower order of detail, specific fault lines, fractures and probably fracture traces are visible. This radar photo represents about 2400 square miles of terrain. It was obtained with a Ku band radar as also were the next three photos.

Figure 2 shows a transition area in Missouri near the Lake of the Ozarks, southwest of Jefferson City. The transition from steep slopes and thin soils to the deeper soils in the Missouri River bottom lands is evident both in change of tone and in the obvious difference in land utilization. Below where the dam holds the lake, the river is visible as an almost dry channel.

Figure 3 is a radar photo of the Berks Garden Dome of western Virginia which shows portions of the Alleghanies, the Appalachians and the Blue Ridge. Differentiation of structures, rock classes and drainage systems is readily apparent and a number of fault lines and systematic orientations of lineaments are seen.

Figure 4 shows the Chesapeake Bay shoreline just north of Newport News. The York and Rappahannock Rivers drain the area. A number of interesting features may be observed. There appears to be a periodic wave-form in the water area offshore and in the estuaries. Wavelength is about 3000' to 4000'. This may be a swell with some cross-currents also being expressed. Note that a number of shore features are oriented the same way. Speculation is dangerous in view of the lack of control data for this photography, however, lack of cloud shadows tend to eliminate this possibility (Note 1). Sandy areas show bright - in fact as bright as the bridge. There are also persistent orientations which seem to indicate structural controls beneath the deep soils. These are noted in the linearities and angularities of the river banks. A history of old meanders can be read further upstream. Note the very specular behavior of quiet water in the back bays and close in-shore as contrasted to the reflectivity of deep water which is presumably rougher and thus more of a diffuse reflector.

Figure 5 and the two which follow are an example of what may be done when there is sufficient knowledge of ground conditions to permit a degree of quantitative analysis. The area is in New Mexico between Vaughn to the north and Carrizzozo to the south. This southern portion is characterized by sedimentary rocks into which massive igneous intrusions were thrust in tertiary and quaternary times. Except for these lavas in the southwest, most of the slopes are soil covered and vegetated, in many cases by a dense tree cover. In the north somewhat deeper soils are mixed with windblown sand. These are the only areas to have been cultivated. Complete field and photo-geologic mapping for this area was done by U. S. Geological Survey. William A. Fischer of that agency subsequently ran a densitometer trace across this portion of the radar photo.

Figure 6 is an aerial photo across a portion of the densitometer trace. It shows much of the area as being so densely vegetated that geologic interpretation would be difficult.

Note 1: Comment by Dr. K. O. Emery, WHOI, tends to confirm this phenomenon as probable sand waves. Such waves do exist in that area with the same orientation.

Figure 1

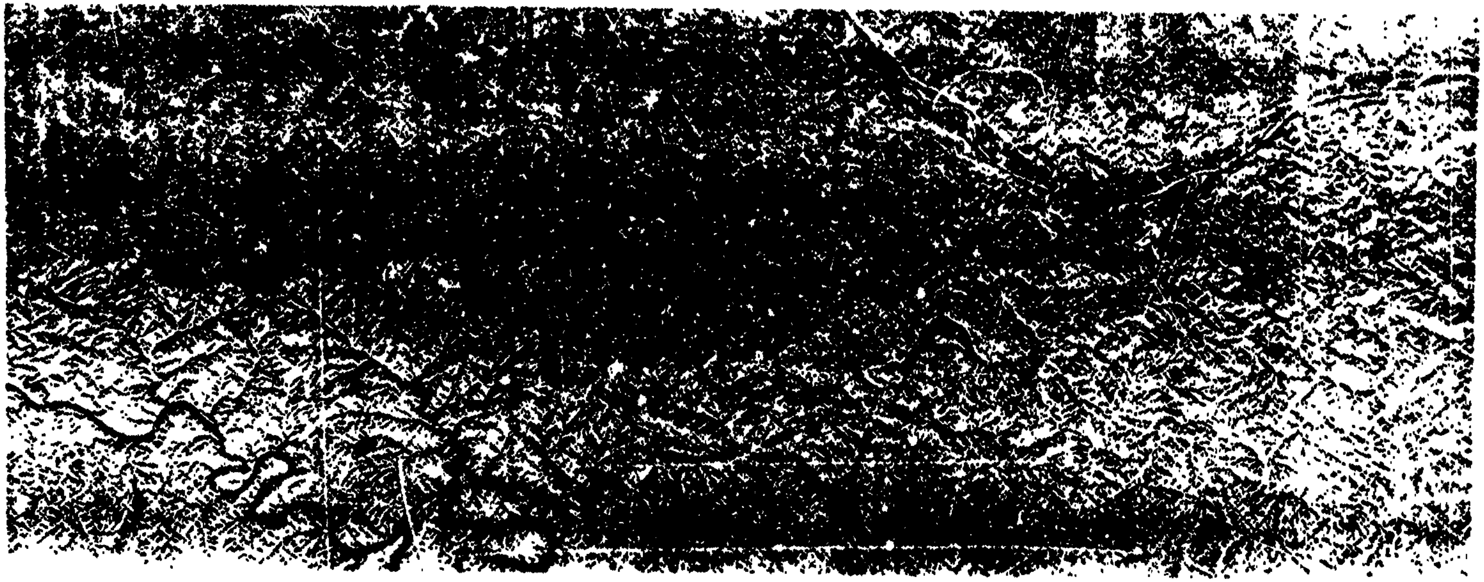


Fig 2

2. Location - Missouri

Figure 2 illustrates the tonal and textural differences caused by land use and difference in topography. The northern half of the picture shows a relatively undisected area. Its use for farming can be deduced from the field patterns. The southern portion has been disected to a medium-to-fine texture and shows no evidence of farming activity. Such an area, in a region of ample rainfall, would lead one to infer that this section is wooded as, in fact, it is. Further, though less obvious, distinctions can be drawn among soil types a,b,c and d. Again, changes in texture and differences in land use enable us to delineate soils of different types.

Also shown is a meander which became entrenched due to uplift and was subsequently cut off.

Figure 2

Figure 3

Figure 4

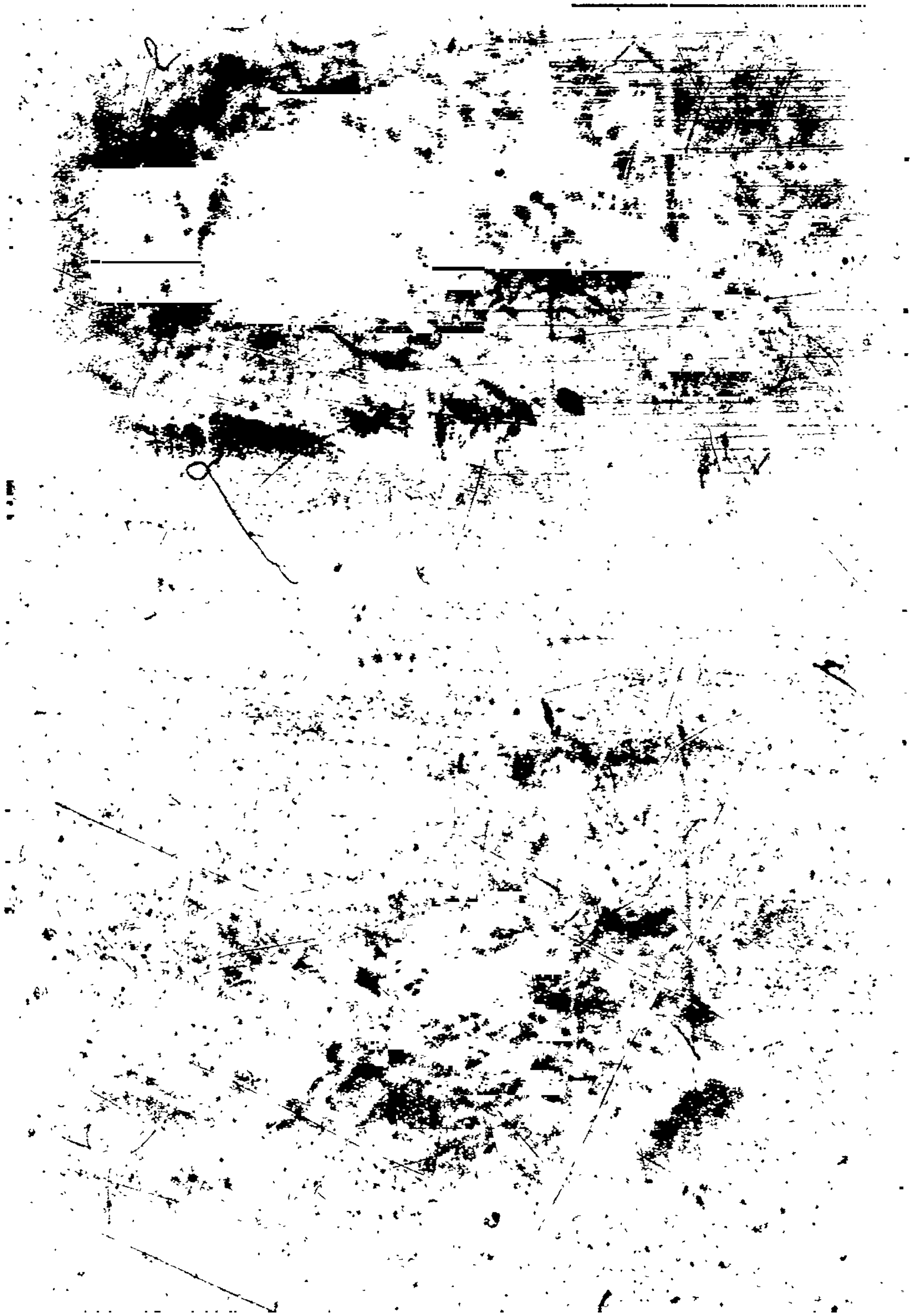


Figure 5. Exampl- of Analysed Radar ..nage.

Figure 6

Figure 7 is the set of curves indicating Mr. Fischer's highly interesting densitometer analysis. The top curve is the topographic cross section showing the geologic units. Beneath this is a plot of depth of soil cover. The third curve is the densitometer trace scaled in arbitrary units. It can be seen that all igneous rock falls above 8 in this scale. Between 5 and 8 are contained all ferruginous sandstones. All other rocks and soils fall below 5. This raises the point of performing additional work on a more controlled basis to develop adequate grey scale - material relationships.

Figure 8 is a final example. This very fine radar photo of Baltimore Harbor is left to your own imagination to establish a figure for resolution and detection.

Having established the context of what side-looking radar photography is, and presented some broad notions of its geologic and oceanographic potentials, we may now proceed somewhat backwards to explain the mechanics involved in obtaining such photography.

The normal radar presentation with which most are familiar is the doughnut shaped Plan Position Indicator (PPI) display. This is generated when a transmitter-receiver antenna is rotated 360° in time synchronization with a sweep line on a cathode ray tube. Professor Cameron's images were of this type and I have used them to good advantage in reconnaissance mapping of ice features in Greenland and Antarctica. Such systems have proven too unwieldy to permit their technical growth in the important factor of increased resolution. Resolution for radar, as with any other electro-magnetic sensor, is proportional to wavelength and to the size of the aperture, which in this case should be translated to mean antenna. The analogy with photography, however, is complete in that photography at shorter wavelengths with cameras of large physical aperture yields higher resolving power. Side-looking radars have overcome this problem by firmly fixing the antenna to the side of the aircraft and propagating the energy broadside in a fixed beam. The ground is scanned by the forward motion of the aircraft. The sweep of the cathode ray tube is then time synchronized with the speed of propagation of the radar energy and the recording film is traced past this week line at a properly scaled down ground speed, thus recording the radar echoes as strip images which you have seen. The physically large antennas are easily carried flush against an aircraft fuselage in the side-looking case, though an antenna of like size could not have been rotated beneath the aircraft. Physical limitations still apply, although not so strongly, and a 50 foot antenna was actually flown for about two years by a B-58. Operating at X-band, this equipment produced some very remarkable resolutions though it must be admitted that lifting such an antenna was a difficult chore even for such a powerful aircraft. Manipulating, therefore, the second variable, airborne radars have been produced to operate at wavelengths from the .85 cm range through the 15 cm range. Resolution would indicate a preference for the use of the shorter wavelengths. However, these can be seriously attenuated by clouds and storms. The shortest wavelength at which little appreciable attenuation occurs is about 3 cm. This wavelength also appears to be least affected by transmission through thermal boundary layers and strongly ionized layers. Fortuitously components for this wave band are more easily available than for others and they are generally cheaper and more reliable. For these reasons most development has occurred in this wave band. Other techniques for improving resolution by synthesizing an antenna of very great length are also being utilized but will not be discussed. However, as with any gain a price must be paid. In this latter case it is in terms of additional equipment complexity and antenna and vehicle stabilization requirements.

Depression angles for the radar beam have typically been 25° to 60° from the horizontal. At such angles most incidence of radar energy with the theoretical plane of the earth's surface is shallower than 45°. This is the dominating factor in the appearance of the radar photos and accounts for flat smooth textures being specular and therefore dark while elevated and rough surfaces reflect diffusely and show bright. Smooth and rough are relative terms and linked to wavelength. Thus while grass is somewhat rough at .85 cm it is smoother at 3 cm and absolutely mirrorlike at 15 cm. The effects of this geometry on reflectivity are, of course, very angle dependent. Wherever facets in the terrain are so angled as to form corner reflectors, these geometric effects are heightened.

The second factor which strongly affects the image quality is the dielectric constant of the reflecting surface. An empirical relationship which demonstrates the magnitude of this

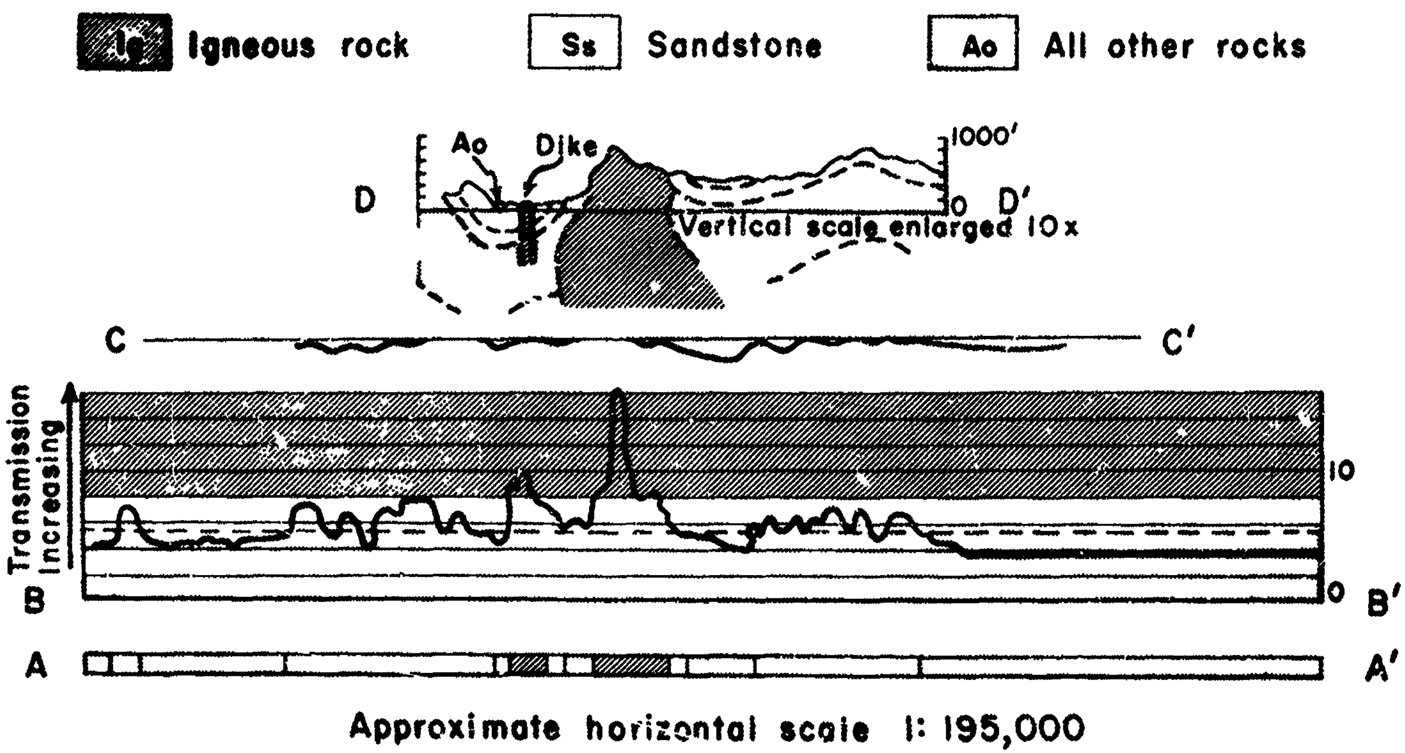


Figure 7. Example of Analysed Radar Image

Figure 8

parameter is that there is a factor of ten spread in grey scale values on 3 cm radar photos between average earth and metal, with wood and brick or stone intervening. Smooth water and very flat terrain, such as in a dry lake bed, probably extend the scale by at least another factor of 10. Inclusion of geometric factors further extends this scale. Received signals from terrain will probably have a total spread of about 40 db, although more sensitive receivers may actually detect as much as 90 db. Rather severe compression of the dynamic range or grey scale occurs in all the subsequent processing steps, through amplifiers, displays and film recording. For this reason the 40 db figure appears to be a more realistic one. Dielectric constants of natural materials may be rapidly altered by changes in moisture. The moist soils of the humid east are better reflectors than the dry soils of the arid areas, where much initial radar flight testing is done. Test crews trained in the arid areas almost always set their radar gain and contrast too high when flying a humid area for the first time.

The factors of geometry and dielectric constant may combine to give an object a greater or smaller effective radar cross section than its physical dimensions. At 3 cm wavelength a 1 meter tetrahedral metal corner reflector focuses and returns energy equivalent to a 1000 sq meter area. Thus it is detected and imaged by radars whose resolution in terms of ability to separate objects a given distance apart is several orders of magnitude poorer.

Penetration is a third, but poorly known factor. Theory would seem to indicate that at useful wavelengths penetration is so shallow that it should be dismissed from further consideration. Poorly understood indications of structure overlain by soils seem to contradict this view. Work in progress at U. S. Army Engineer Waterways Experiment Station at Vicksburg, Mississippi also tends to indicate penetrations to greater depths than previously suspected. Regardless of cause, radar photos frequently appear to indicate subsurface features in a most useful manner. It is already apparent, however, that careful work will be required to separate out direct and parasitic effects and to avoid semantic difficulties in ascribing causes to effects. In connection with NASA geoscience radar programs, GIMRADA will design and install a series of well controlled test patches on the floor of Wilcox Dry Lake, Arizona. This very smooth, specular surface has already been equipped with a radar resolution range. The intent now is to augment it with patches of natural rock materials which are laid out on the surface and under the surface to known depths.

With this very brief, basic understanding of the more important processes which go into the making of a radar photo, it is now possible to explore the utility of this sensor for oceanographic research.

Greatest applicability appears to be in the study of shore and estuarine morphology. This is the area of strongest contrast in a radar presentation. Radar can give data day or night, in any weather. With its very rapid acquisition rates, large areas can be imaged almost simultaneously. The "before and after" data regarding catastrophic storms can be rapidly compared. In fact GIMRADA has under development a Change Detector for comparing sequential coverage and displaying only the changes. The small scales and the generalized nature of radar photos enhances interpretability of large scale features, lineaments and overall trends.

It would appear that at the shallower angles of incidence some information concerning sea state may be available. In a manned satellite it would be an easy task to change the radar gain settings over all-water areas to optimize the low level signals from the sea surface.

Radar can work cooperatively with ships at sea and unmanned buoys. The radar, in its passage, could interrogate transponders which would respond with not only position but also, by encoding and modulating the response, such data as temperature of air and water. These data are also available day or night in all weather. Comparative cover should reveal diurnal trends and tide and current information.

Radar will definitely define land - ice - open water interfaces. It will also distinguish several textures of ice and may be able to distinguish between snow and ice on a moderately reliable basis.

It may be possible to utilize the shorter wavelengths which are cloud attentuated to determine cloud heights either by ranging or by shadow displacement. Cloud morphology and composition and presence or absence of precipitation should also be interpretable.

Satellite borne imaging radars will require solution of some difficult, but not impossible, engineering problems connected with power needs, antenna size and antenna stabilization and pointing. These problems are very closely allied with the need to carefully specify, in terms of expected signal strength, the nature and scale of information which must be detected and recorded. It is to be expected that we can only come to know these parameters well enough through an initial non-orbital experimental program utilizing aircraft in conjunction with careful ground controls and careful airborne instrumentation.

In conjunction with the comments on controls and the obvious importance of knowing the radar grey scale rather precisely, GIMRADA with the U. S. Air Force is presently seeking to build a grey scale calibration capability into an advanced airborne radar. A grey scale will be recorded on the film in such a manner that it will bear a direct and unvarying relationship to the transmitted and received radar power.

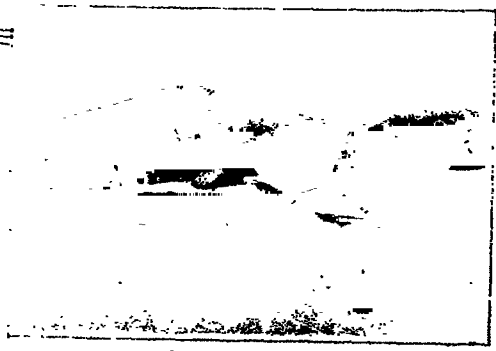
Finally, it is important to give consideration to the best use of the entire spectrum.

Figure 9 shows the configuration of a tri-sensor aircraft which will be flown by Air Force in the NASA - GIMRADA geoscience program. It is the only truly tri-sensor configuration in existence in that it simultaneously images exactly the same ground patch in the radar, I.R. and visual ranges and displays the images in the same geometry and scale. No single sensor is sufficient to uncover the nature of the multitude of effects which we are seeking to study. Only well integrated systems of this sort will yield the spectral data in useful form. The question has been asked whether the instruments in such integrated systems will interfere with each other electronically. With good engineering they do not. Several integrated systems have been flown successfully.

In conclusion the Corps of Engineers is vitally interested in oceanographic programs and would like to participate in them and help make them succeed. Engineers' obvious interests are in shore and beach processes, a better understanding of catastrophic storms and waves, silting and all the processes which bear on the missions of the Corps. They are also interested in the sensing and interpretive techniques in themselves.

There is obviously much left unsaid in a summary of this scope and brevity. A necessary next step is coordination on a specific problem basis to explore possible applications of orbital radar systems to oceanography and the implementation of initial airborne experimentation to support this effort.

Research Equipment Aboard JC-131 B53-7788....
-for use in Project 6239
'CONCURRENT RECONNAISSANCE/ANALYSIS"



Q-55 Radar Antenna

DISPLAY CONSOLE

Depicts concurrent, equal scale target coverage with radar (Q-55) infrared, and visual (electro optical) Sensors.

Dual Spectrum Sensor
(Infrared and Visual)

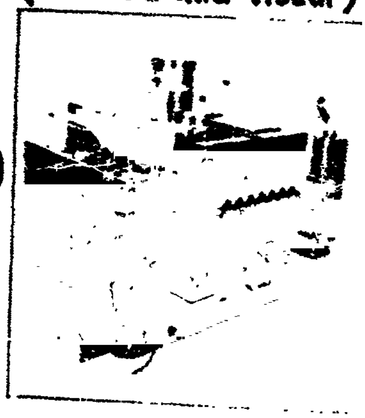


Figure 9

MICROWAVE EMISSION OF RAINING CLOUDS

Konrad J. K. Buettner

University of Washington, Seattle, Washington

Rain showers attenuate radio signals of cm microwaves in a roughly known manner. The attenuation is due to scattering and absorption. The ratio of these two effects is known from D. Deirmendjan's application of the Mie theory to a polydisperse cloud. Accordingly, heavy rain clouds for $\lambda > 1.4$ cm emit substantially more than the ocean for the same λ. Inclusion of the unknown, but likely, effect of multiple scattering increases the signal difference between ocean and a cloud. The counteracting temperatures effect is small. It should therefore be possible to discriminate between raining clouds and ocean. Optimal wavelength seems to be 1.6 cm. A passive system receiver could also be used to discover sea state, icebergs, and openings in Arctic ice fields.

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N65-30379

RECOMMENDATIONS OF THE PANEL ON MARINE METEOROLOGY

Chairman: Claes Rooth
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Members

D. C. Blanchard	P. M. Saunders
H. Charnock	R. Wexler
J. Levine	A. H. Woodcock
E. S. Merritt	R. C. Terwilliger

Since a separate program of feasibility studies within the meteorological problem sphere is planned by NASA, it was felt that the discussion should be limited to those questions which deal directly or indirectly with the air-sea exchange processes and their manifestations observable from satellites. It was the consensus of the participating group:

a. That the techniques for remote sensing and processing, as almost available for non-military applications today, offer some promising avenues for work from low level or intermediate level platforms (ships, towers, airplanes). The technical presentations given during the meeting provided a very valuable source of inspiration for those not in contact with the classified research in these fields. Indications of greater capabilities raised demands for an effort to achieve further declassification of such material.

b. That capabilities in the infrared and microwave ranges of the spectrum seem marginal at the moment from the point of view of surface observations from satellites, but that the potential value of heat flux measurements and stress estimates is great enough to warrant an appreciable development effort. By cooperative arrangements between instrument developers and information users, the development phase itself should yield valuable results from airborne platforms.

c. That apart from his capability of pointing a camera or an instrument at the unusual event, man in space seems to offer hardly any advantages but a few drawbacks, e.g. limited endurance, compared to orbiting instrument packages. This does not mean that once he goes up there he would not be given a list of a hundred-and-some things to look for while he is orbiting.

Specific Comments By Chairman:

Our knowledge of the meteorological phenomena allow us to deduce only some crude qualitative facts about the state of the ocean on the basis of the meteorological information readily obtainable by satellite information. Direction of heat flux can to some extent be inferred from the character of the cloud cover. Rate of displacement of clouds and possibly pattern character in cloud groups may yield information on winds and hence on sea state and stress (cf various publications on interpretation of Tiros data). A special case of this is the location of temperature discontinuities by correlation with discontinuities in cloud cover or type, at best a delicate problem in intelligent inference since neither necessarily involves the presence of the other.

The most promising avenue for further work seems to lie along the lines suggested by McAlister in terms of direct observations of the microsurface temperature gradients, i.e. the upward heat flux in the water. Coupled with the obvious possibilities of estimating radiative energy balance by photographic estimates of cloud cover combined with IR estimates of water vapor in the atmospheric column, we have an important inroad to the thermodynamic forcing both in the sea and in the atmosphere.

The stress problem is much further away from solution. It seems unlikely that we shall be able to estimate mean monthly values of the stress curl significantly better than from climatological maps, unless a major technical advance is made. But, given a significant improvement in sea state detection and wind determination techniques, or the latter alone, together with the results of surface level work on relations between wind speed, sea state, and stress, which is in progress at several places, we may yet see the day when our theoretical understanding of the ocean circulation can be severely tested against observations.

THE ROLE OF SATELLITE AND MANNED SPACECRAFT IN MARINE METEOROLOGY

Earl S. Merritt

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Major interactions between the atmosphere and the oceans occur continuously over a wide variety of scales.[6] The meteorological observations required for investigation of these interactions (and their effects on vessels, coastal geology, and on the oceans and atmosphere themselves) were adequately available prior to TIROS at only two scales: (a) averages in time and space obtainable from climatic summarizations; and (b) micro-scale observations obtained from oceanographic research vessels and projects over very restricted areas and periods of time.

Transient ships and the ocean navigation and weather ships provide synoptic scale space and time observations over the restricted areas of the major shipping lanes, but are too infrequent in their passage outside of these areas to provide useful observations at even the synoptic scale. Thus large volumes of the atmosphere have been inadequately unobserved in both space and time. Satellites and perhaps manned spacecraft can provide many of the needed observations. Some of the desired data have already been obtained, in rough form, from the TIROS observations.

Discussion of the application of observations from satellites and manned spacecraft to marine meteorology may be aided by first listing some of the specific problem areas where meso-scale or synoptic scale observations would be useful. Such a list would include:

a. Surface wind wave generation.
b. Ocean current variability due to wind effects.
c. Ocean surface temperature variability as related to evaporation, cloud cover* and the short term local effects of precipitation.
d. Pressure and wind effects on tidal enhancement.
e. Sea ice drift and erosion; formation of pressure ridges in polar region ice fields due, in part, to the wind.
f. The effects of wind driven ocean waves on coastlines and beaches.
g. The interactions between wind driven waves, currents, and winds which effect ship routings and other marine operations, commercial, military and research.

Since the atmospheric-oceanic interchange is a two-way interaction, we can also deduce information useful to meteorological analysis from derived and observed measures of the physical state of the sea. For example, sea surface temperature variations are an important factor in air mass modification; synoptic scale meteorological developments are effected by sea surface temperatures and temperature gradients, and in some cases by the local sea state.

Fortunately we need not operate from a position of complete ignorance in our consideration of the applications of satellites and manned spacecraft to marine meteorological problems. Observations from the TIROS meteorological satellites provide excellent data which can be used to examine specific synoptic scale problems and thereby assist in defining plans of attack. Some pertinent preliminary analyses of these TIROS data have already been prepared[1, 2]. For example, low level wind velocity[1] can be estimated from certain types of characteristic cellular cloud patterns extending over vast areas of middle and high latitude oceans, especially in the wake of cyclonic activity. These are broad areas where the wind speeds are frequently high and the fetches are long. The spatial and temporal distributions of wind in these areas are essential to the forecasting of wind driven waves. Clouds can also

*An allied, but separate, discussion of the problems associated with cloud distributions over the oceans and their effects on satellite sensor design is included elsewhere in these proceedings.

provide information about the existence of coastal upwelling of cold water and variations thereof; a study[2] of the stratiform cloud masses of the Canary Island region of Africa observed by TIROS I and III provides some preliminary data relating to this problem. Specification of the departure from climatological sea level pressures, from TIROS observations of cyclonic cloud vortices, has been tentatively examined[3]; this information may be useful when considering tidal enhancement and sea level variations due to atmospheric pressures.

Specifications of the surface temperature field from satellites and manned spacecraft appears feasible. Use of satellite infrared data to further examine the feasibility and to define the problems associated with this mode of observation is discussed in depth elsewhere in these proceedings*.

In the more specific application of air-ocean effects on the navigation of ships, minimum time routings, and other marine operations, the meteorological data acquired over normally unobserved** areas by TIROS and Nimbus satellites already provide the data necessary for the increased meteorological analysis accuracies required for effective application. Sherr[4], among others, has shown that a greatly increased accuracy of analysis is permitted by the TIROS data; this can be of great value in predicting weather-related operational conditions over the oceans that will be encountered by commercial, military and research vessels and programs. This is an area of great economic impact.

There are indications[5] that forecasts of the position of the primary ice fields and fronts in the Antarctic may be of use to the whaling industries of the world. The whales are frequently observed to follow the movements of the main ice fronts. Data on the pressure and wind distributions are necessary to prepare these forecasts. Satellite observations of both the ice and the pressure and wind distributions can provide these data.

It is clear that observations from satellites and manned spacecraft can be of assistance in providing a fuller understanding and picture of the day to day synoptic scale variations in the atmosphere over ocean areas and, in that, will contribute to an understanding of synoptic scale air-sea interaction problems and to related areas of physical oceanography. It is not as clear, however, to what extent observations from satellites and manned spacecraft can assist in the more basic studies of the several microscale processes which take place right at the boundary between the sea and the atmosphere and which have been examined at some length in Reference 6. Detailed micro- or meso-scale observational programs are still required for these measurements.

In order to permit optimum use of satellite observations in operational and research interpretations of the marine meteorological environment, a program of study should be undertaken utilizing TIROS and Nimbus observations concurrent with periods of extensive corroborating conventional data. The data from oceanographic programs, such as EQUILANT and the International Indian Ocean Expedition, would be excellent in this regard.

The role of man in these observations is, at best, unclear. He is well suited to take advantage of unusual events, he can discriminate, he can perform specialized multiple operations which may be extremely difficult to program into an unmanned satellite. But he requires far greater logistic support than an unmanned satellite. All of these factors must be weighed to determine if man has a useful, continuing role, in marine meteorological observations from space.

In any event, man will go into space for extended periods within the next decade, and marine meteorologists and oceanographers will be derelict if they do not provide the astronauts with the tools and training necessary to make useful observations. Analysis of available

*Glaser, A. H., E. S. Merritt, R. Wexler, and W. K. Widger, Jr.: The Applicability of TIROS and Nimbus Data to Investigation of the Feasibility of Sea Surface Temperature Measurements from Satellites, ARACON Geophysics Company, Concord, Mass.

**A Study by the U. S Weather Bureau showed large areas of the southern hemisphere with less than 10 ship observations per year.

data from TIROS, Nimbus and similar satellites can provide material for system designs, and for training of the astronauts who will make the observations.

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THE NEED FOR STUDIES OF OCEANIC CLOUD CLIMATOLOGY

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For many of the wavelengths and sensors proposed for oceanic observations from a satellite, the presence of clouds will seriously degrade and often completely prevent the desired observations. A survey of the nephanalyses published in the Catalogs of TIROS Television Cloud Photography for TIROS IV-VII has made it very obvious that sizeable areas normally completely free of cloud are comparatively rare over the oceans except for special, small areas such as that south-east of Arabia. Accordingly, observations requiring the absence of clouds must be made through the small, individual clear patches within areas of scattered or broken clouds if they are to be made with any reasonable frequency.

For determining the design and feasibility of such observations, a much improved knowledge of the cloud climatology of ocean areas is needed. Since the most pertinent factors are the frequency, for various geographic locations, of clear patches of various sizes within areas of scattered-to-broken clouds, these studies cannot be made solely from existing surface observations. The TIROS cloud picture data, in spite of a shorter length of record than is to be climatologically desired, could be appropriately analyzed to contribute significantly to this problem area and so to the optimum design of satellite sensors for oceanographic purposes.

NOTE ON THE CAPABILITIES OF RADAR FOR MEASURING CLOUDS, PRECIPITATION, EVAPORATION, AND SEA STATE

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The capabilities of radar for measuring clouds and precipitation from the ground are exploited routinely in the U. S. by a network of Weather Bureau radar stations and by all commercial aircraft. A side-looking radar in a satellite can map these same phenomena with higher precision and on a world-wide basis. By using two or three frequencies properly chosen, the sea state, shipping, and bergs beneath the clouds may be mapped simultaneously with the clouds themselves, and precipitation is easy to distinguish.

Even a simple 10 - 20 lb. package used like an altimeter can be designed to observe precipitation beneath the satellite. It also (with a different frequency) can observe sea state, so that winds and evaporative rates may be inferred.

The properties of an imaging radar for 3-dimensional portrayal of cloud and precipitation data are somewhat different from those for ground and surface mapping, but the same radar, with (perhaps) an antenna resonably large in vertical dimension (but not larger than planned horizontal dimension) can obtain this information by having its highest frequency operate in a cloud/precipitation mode on command. Without these complications it can still provide a 2-dimensional presentation with cloud thickness data from directly below.

COMMENTS

Allyn Vine

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Woods Hole, Massachusetts

Some general comments are:

1. The meeting certainly accomplished the purpose of getting more thinking about how the ocean looks from the air and from space.

2. I strongly suggest that the final report emphasize satellites and oceanography and try to keep the manned and unmanned satellites represented and in perspective. I believe failure to do this will cause considerable kickback and create an unhealthy political type of atmosphere.

3. Better weather predictions in the Antarctic Ocean would be of special interest. Certainly satellites can give us data on a global basis. They will drive us to think about all oceans and all latitudes and they will go through the seasons every hour. I believe this will be their most significant contribution.

4. I did not hear much about the time scale for professional, interested oceanographers to be in space stations. What is an estimated data for five oceanographic trips per year? When can a good graduate student do space field work?

5. In retrospect, I'm a little surprised (and somewhat disturbed in my own lack of thinking) that there wasn't more discussion about what oceanographers might contribute to the study of other planets. Even though Terra may have the only conventional ocean, the hoar frost, liquid hydrocarbons, underlying MOHO, or a deep dust with liquid like characteristics may present problems in which oceanographers are interested and knowledgeable.

MEASUREMENT OF CLOUD HEIGHT

John Freeman

National Engineering Science Company

A precision camera in space opens up the possibility of measuring cloud heights and cloud motions (perhaps winds) on a synoptic basis over much of the world.

As a means of making cloud motion estimates, TIROS telemetry is strained to its utmost.

OCEANOGRAPHY FROM SPACE

CHAPTER 3

MARINE BIOLOGY

RECOMMENDATIONS OF PANEL ON MARINE BIOLOGY

Cochairmen: Carl L. Hubbs, Scripps Institution of Oceanography
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Members

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D. F. Bumpus	G. I. Murphy
W. V. Burt	J. H. Ryther
A. W. Collier	J. F. T. Saur
H. W. Graham	M. B. Schaefer
W. V. Kielhorn	W. Schevill
F. F. Koczy	T. J. Walker

The biologists attending the conference have had hopes and expectations raised that much information of value to them can be obtained from high-flying planes, from unmanned and manned orbiting satellites and space craft, and perhaps from relatively stationary satellites. What type of space vehicle would be most appropriate for each objective is rather beyond our competence to decide. For many objectives we assume that planes will be used for local, detailed, and fine-grid surveys, even though large-scale features may be monitored by satellites. A main function of the satellites would likely be to locate areas where more intensive surveys by high-flying or low-flying planes or even ships would be auspicious. Some sorts of probably obtainable information of biological concern are as follows:

I. DIRECT OBSERVATIONS OF THE SEA SURFACE

Biologists as well as physical oceanographers are definitely concerned with many physical features of the sea, with large-scale and small-scale features. For example:

Sea-surface temperatures are already being surveyed by fishery agencies using infra-red gear. Such surveys could be improved by increasing coverage and frequency by using higher flying vehicles.

Temperature fronts are of great concern to biologists and fishery scientists, and call for continual monitoring.

Frequent mapping of currents and water masses, such as may differ in color, would be most useful.

N.B.: Whether such observations can best be made visually, by light photography, by infra-red images, by radar, or by other means is hardly in our competence to suggest.

II. OBSERVATION OF BIOLOGICAL PROPERTIES

The biologists have agreed that monitoring of certain essentially biological properties will be of high value. In particular:

Bioluminesence would seem to be measurable, and could help to locate large moving animals and moving fish schools (also submarines, the record of which should be distinguished if possible from luminescence produced by whales, fish schools, etc.).

Discolored areas (red water, etc.) need to be monitored.

Chlorophyll concentration in the mixed layer (well represented in the uppermost levels) should be monitored by selective spectrometry.

III. TELEMETERED INFORMATION FROM SUBSURFACE AS WELL AS [illegible]E SENSORS

Much information of biological value can, we hope, be obtained by gear already developed or being developed, to be telemetered directly or on command to receivers overhead on various vehicles, including satellites. The transmitters would be on anchored and on drifting buoys (also on animals, as indicated below).

Such information could be sensed from a considerable depth range, at least through the thermocline. Parameters in mind include temperature, current direction and velocity, salinity (by conductivity), transparency (by beam transmission), dissolved oxygen, various nutrients, particulate organic matter, acoustic properties (particularly biological noise).

IV. DETERMINATION OF ANIMAL LIFE

Of prime concern is the identification of animals and determination of their distribution, abundance, and movements. Particularly in mind are marine mammals (whales, porpoises, seals, etc.), marine birds (in larger dense flocks), sea turtles, larger fishes and schools of smaller fishes (showing as shadows). Presence of the animals may be determined by linear or intermittent slicks, ruffled surfaces, flocks of active birds, etc.

V. PHYSIOLOGICAL AND OTHER TELEMETERED DATA ON LARGER ANIMALS

For animals large enough to carry telemetering equipment, either on the body or on an attached buoy, much valuable information could be obtained on:

Depth of dive
Instaneous speed and rate of migration
Course of migration (especially needed)
Body temperature, environmental temperature
Heart beat
Blood flow, etc.

At present we would anticipate that planes rather than satellites would be most appropriate for most such research, but satellites might also pick up the data, especially from long-migrating creatures.

VI. LOCATION OF FISHING VESSELS

Monitoring of the commercial and sport fishing fleets, off our coasts and on more distant waters, such as Georges Bank, Bering Sea, and the Antarctic, would also be of value.

MARINE BIOLOGY AND REMOTE SENSING

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Application in marine biology of remote sensing from manned orbital spacecraft lies mostly in measuring characteristics of the physical environment at the sea surface. Measurements of the oceanic environment which could be obtained from spacecraft would be related to information about marine organisms originating from other sources. The object of remote sensing would be for studying ecology, i.e., to measure those parameters of the environment which most influence distribution, behavior and abundance of marine species.

Ecology is an important field of biological oceanography but because of the high cost of obtaining environmental observations by conventional shipboard techniques it is much neglected. The result is that most oceanic ecology is descriptive and based upon sparse data from unsystematic collection programs. There will be little encouragement for modern workers to carry ecological studies to a higher level of accomplishment until systematic, continuing measurements of the environment are available.

Fish studies might be given first consideration in the design of ecological programs since fish affect the national economy more than other marine organisms. However, an environmental program established primarily for fish studies could be designed to provide data of value in all fields of marine ecology.

It is at the edge of the sea that biological productivity is highest. This includes the estuarine zone, the inner protected waters, the open coast, and the continental shelves of the world. Although the oceanic zone contiguous to the coast should receive the highest consideration in research priorities, it is realized that deep sea features have pronounced effects on the coastal regime. Thus, an understanding of such deep sea phenomena as the Gulf Stream is important to an understanding of the condition of continental shelf waters.

Of those ocean parameters subject to remote sensing, temperature measurement is perhaps of the greatest significance to marine biology. All ocean species are limited in their distribution by their temperature tolerance. In the following paragraphs a suggestion is made for a practical feasibility study for a systematic temperature survey in marine biology.

FISH AND TEMPERATURE

It is widely accepted in marine biology that temperature is the primary factor in limiting the occurrence of marine fish species. This is well stated by Taylor, Bigelow and Graham[1] "We doubt whether any marine biologist today would dispute that temperature of the water is the factor chiefly responsible for setting geographical boundaries to the ranges of marine animals along the seaboard of eastern North America. Consequently, any alteration in the temperature or any continuing trend, either upward or downward, would be of great importance both ecologically, and from the commercial fisheries standpoint, if the alteration in temperature is wide enough and if it persists long enough to affect successful reproduction of the species or the well-being of the individual".

In the same way, temperature has short term effects on patterns of fish distribution. For example, recent studies at the Sandy Hook Marine Laboratory indicate that the annual spring influx of warm season fishes into the mid-Atlantic coastal area is controlled by temperature conditions for such species as bluefish, striped bass and mackerel. These studies have been made possible by the collection of temperature data by aerial survey with infrared sensing equipment. To date, the extent of the areas surveyed and the frequency of flights in the sea surface temperature survey program have been restricted. However, results are sufficiently promising to warrant extension in area and frequency of coverage on a trial basis.

If detailed thermal patterns now available from low altitude aircraft survey can be shown to be of value in marine ecology studies, the way will be paved for effective use of remote thermal measurements of the ocean from high altitude spacecraft.

AERIAL SEA TEMPERATURE SURVEY

The Sandy Hook Marine Laboratory initiated use of the infrared thermometer (IRT) in a large scale survey of sea surface temperature patterns in 1962. The coastal area surveyed monthly has varied but now extends from Delaware Bay to Cape Cod, from the shore seaward over the Continental Shelf to the deep slope (see Fig. 1). Quasi-synoptic charts of sea surface temperature patterns for 20,000 sq. miles of Continental Shelf are drawn and published each month. In addition to the thermal mapping, surface circulation patterns are studied from return of free drifting current markers (drift bottles and sea-bed drifters) released at intervals of ten miles along the flight track. The study area is covered in three flights of approximately five hours each on consecutive days. An in-flight "biological watch" is kept to record occurrence of sharks, fishes, turtles, mammals, etc.

The Sandy Hook Marine Laboratory furnishes personnel and instruments for the survey. Aircraft are provided by the U. S. Coast Guard Air Stations, Brooklyn, N. Y. and Salem, Mass. The Coast Guard's standard search and rescue plane, the Grumman UF2G (Albatross) has proved excellent for this study although more speed would be advantageous. Air speed varies between 120 and 140 knots. An altitude of 500 ft. is normally maintained during flight. On calm days the relatively slow speed and low altitude of the aircraft permits detailed reconnaisance of the surface waters immediately below for marine life. The survey plan and techniques are reported in more detail by Clark and Frank[2].

The demountable IRT is tripod mounted in the aircraft at the rear hatch with a view path of about 15° to 20° from vertical. The instrument used is the Barnes Engineering Co. Model IT-2S, which senses water temperature through use of a thermistor bolometer detector. The ocean surface approximates a black body; emissivity from the ocean in the region from 8μ to 14μ is 0.98 for radiation normal to the surface. The optical filters in the IT-2S have a spectral passband confined effectively to the 8μ to 14μ region. In this region atmospheric absorption is negligible, but water vapor in the view path can cause error. Correction for this error can be made from the following reported by Frank[3].

$$T_o = \sqrt[4]{\frac{T_I^{\,4} - (1-\epsilon t)T_a^{\,4}}{\epsilon t}}$$

where T_o = true surface temperature

T_I = indicated (IRT) temperature

T_a = air temperature

ϵ = emissivity of the ocean

t = transmissivity of the atmosphere

A more extensive exploration of problems affecting the accuracy of the IRT for absolute temperature determination is reported in "Report of a Workshop on Techniques for Infrared Survey of Sea Temperature"[4]. The joint opinion of the Workshop was that absolute temperature of the micro surface of the sea can be estimated with present instrumentation to ±0.5° C. Better instrumentation and techniques can improve this accuracy considerably, but accuracy to ±0.5° C. is adequate for most purposes in marine ecology. An example of the accuracy with which the airborne IRT can measure sea surface layer temperatures is given in Fig. 2. This data is from a study comparing a shipboard IRT record with the record from a thermistor towed 6 inches beneath the surface.

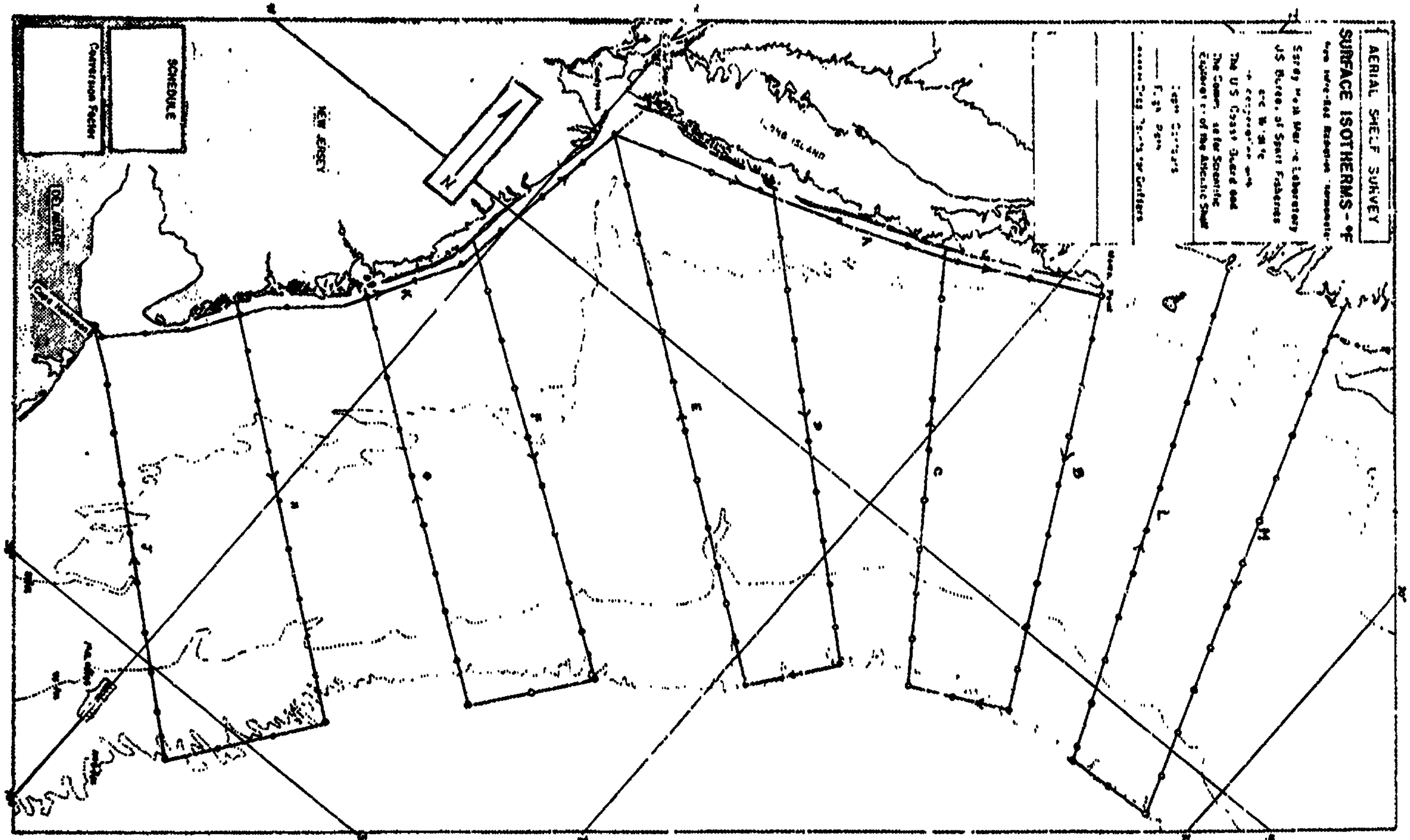

Figure 1. Flight Track of Monthly Airborne Infrared Survey of Sea Surface Temperature Conducted by the Sandy Hook Marine Laboratory.

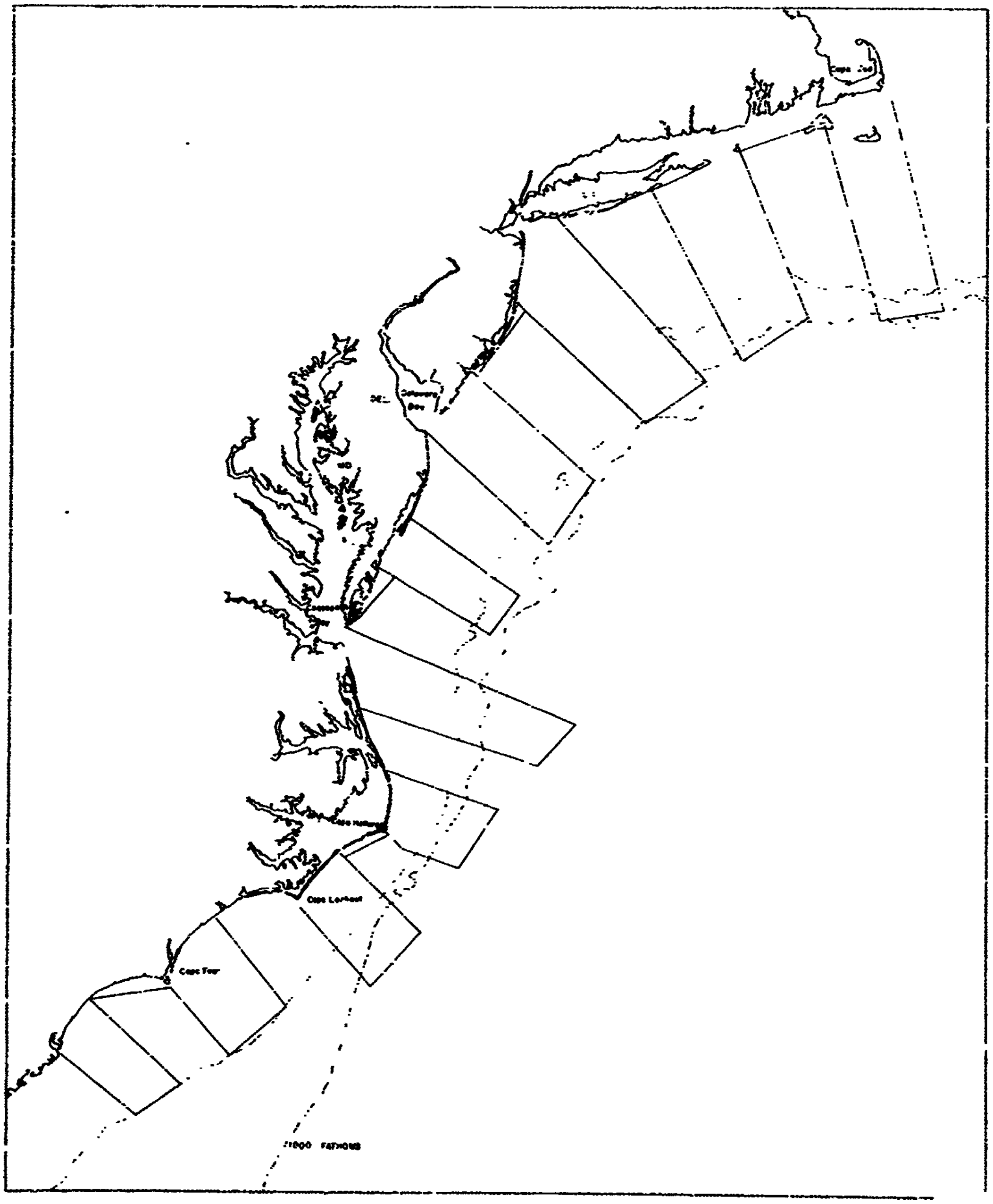

Figure 2. Proposed Flight Track For Expanded Cooperative Infrared Survey Program.

Survey activities for coastal areas conducted by other laboratories reported at the Workshop mentioned above also show promising results. Regular surveys have been made in the Pacific by the Tiburon Marine Laboratory and for the Gulf of Mexico by the Gulf Coast Marine Laboratory, and the results published. Other efforts, confined to the Atlantic have not resulted in regular distribution of thermal maps. Only one of these programs is separately funded, the rest being inadequately supported adjuncts to regular research programs.

PLANS FOR THE FUTURE

Improvement of ecological studies in the North Atlantic area depends upon increase in both the area and frequency of study and intensifying the collection of distributional data on fish species. It now appears to be feasible to consider expansion of the systematic sea temperature survey to include the Continental Shelf from Cape Cod to Cape Fear with specific transects extending to the Gulf Stream front, as shown in Fig. 2. Following this basic pattern the survey could be extended south along the coast to the Florida Keys. The flights, in all parts of the survey area, should be as near concurrent as possible. The survey should be reported at least biweekly for optimum value. The most practical approach to an enlarged survey plan is through participation by several laboratories in strategic locations along the coast. Each laboratory would maintain a schedule of flights coordinated with the other participating laboratories. Techniques would be standardized and copies of all data forwarded to a central point for compilation. A temperature map for the whole area would then be drawn up and distributed to all interested agencies. The coordination could best be provided by the Committee for Scientific Exploration of the Atlantic Shelf.

A coordinated broad survey plan based upon biweekly coverage would provide the basis for analysis of environmental factors involved in large scale migrations of marine animals. Analysis of migrations based upon the present limited survey program of the Sandy Hook Marine Laboratory is promising. An example given in Fig. 3, shows temperature patterns from the May 1964 survey. The large schools of migrating mackerel observed are evidently restricted within a narrow temperature zone as shown below:

Temperature Zone Boundaries (F.°)	Number of Mackerel Schools Observed
46-48	-
48-50	5
50-52	11
54-56	8
56-58	-
58-60	-
60-62	-

The distribution of the schools suggests that northward migration in May proceeds within a narrow temperature pass bounded by water of 48° and 56° F. At the time of the survey, the pass was being closed on the south by increasing temperatures. To the northeast the fish were pressed close in to shore by colder, offshore water. Most schools were concentrated in a broad 50° to 53° zone south of Montauk Point.

A more frequent series of flights extending to the east and to the south of our own survey area would have enabled us to analyze the whole progress of the mackerel migration, from the time they passed from the deeper ocean in over the Continental Shelf (somewhere south of our area) until they moved over to Nantucket Shoals and off to the east. On the Pacific Coast albacore occurrence was shown to have a close association with the position of the 60° F. isotherm.

VALUE TO OTHER DISCIPLINES

Maps of sea surface temperature along the North Atlantic Coast are of use to disciplines other than ecology. The maps produced by the Sandy Hook Marine Laboratory are received and studied by meteorologists interested in such phenomena as fog formation. Physical

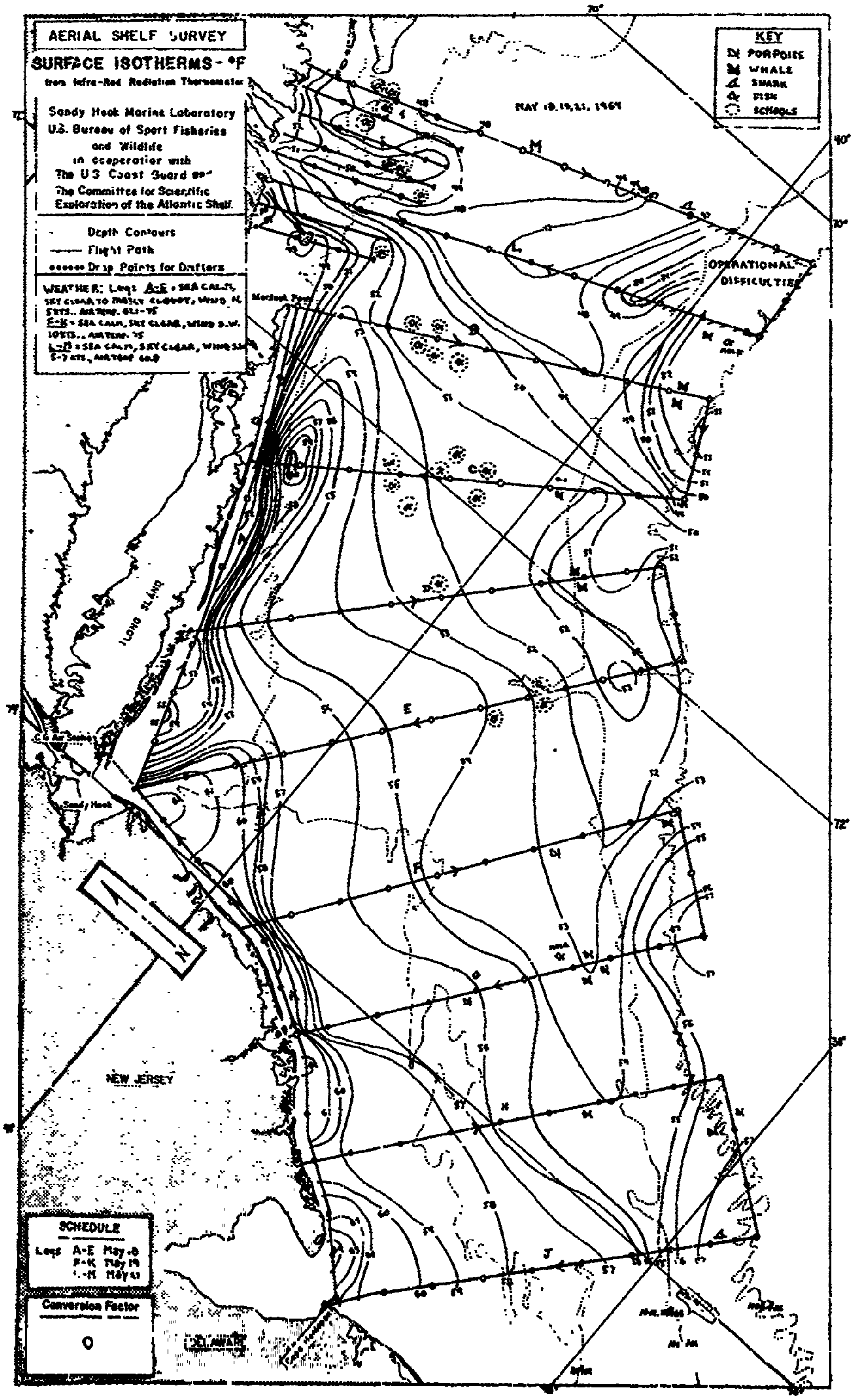

Figure 3. Monthly Sea Surface Isotherms Chart For May 1964. Fish Schools Indicated Are Thought to be Atlantic Mackerel.

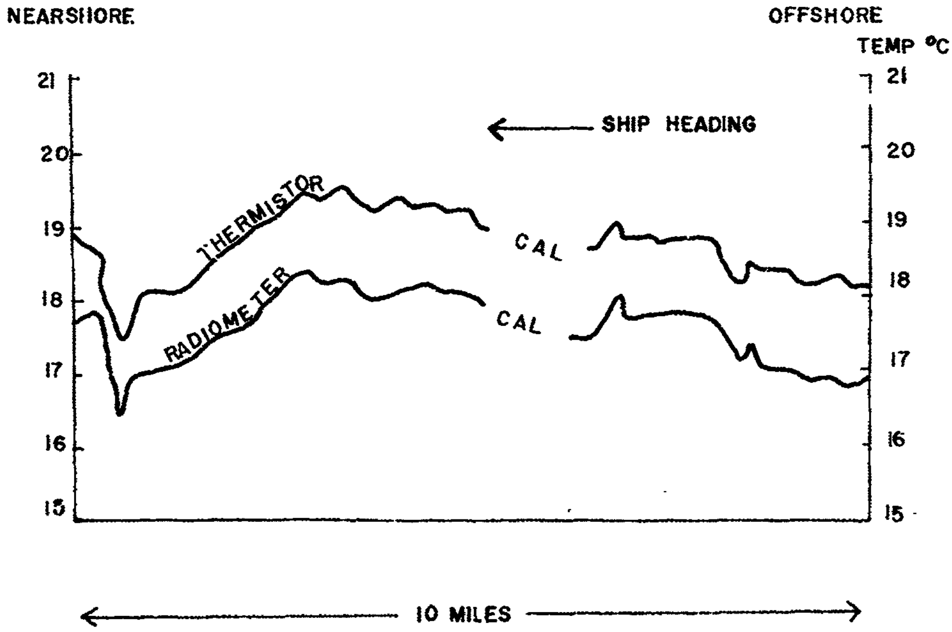

Figure 4. Simultaneous Recording From Shipboard Infrared Thermometer and Towed Thermistor.

oceanographers interested in circulation patterns of the Continental Shelf and Slope and the effect of Gulf Stream and other deep sea influences on the shallower zone have also made use of the data. An expanded survey would provide data of far greater value to physical studies.

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OCEANOGRAPHIC OBSERVATIONS FROM MANNED SATELLITES FOR FISHERY RESEARCH AND COMMERCIAL FISHERY APPLICATIONS

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The broad mission of the Bureau of Commercial Fisheries (BCF) is to conserve the Nation's fishery resources and strengthen its fishing industry through research, development and services. At the Biological Laboratory, Stanford, California, our research in "fisheries oceanography" is directed toward establishing the effects of changes in the meteorological and oceanographic environments upon the changes in abundance and availability of commercial fishes. Although I have sought to determine general interests of BCF Laboratories in the Pacific area, the thoughts and emphasis which are placed on oceanographic observations from heavy payload or manned satellites will naturally be colored by my own interests in physical oceanography.

When we attempt to establish some history of events in the North Pacific Ocean, the glaring lack of time-space continuity in any form of oceanographic observations, with the possible exception of poor quality sea surface temperature data, becomes immediately apparent. The use of satellites as a communication link to shore from ships, buoys, and fixed stations as a method to extend and improve geographic coverage and to obtain data, particularly below the surface, on a real-time or synoptic basis stands out as an obvious, and perhaps the most promising, benefit to be derived from the use of satellites for oceanography. This subject has received much attention, e.g., by R. T. H. Collis and R. E. Nagle*, and it seems unnecessary to dwell further on it here. It is well to remind ourselves, however, that it is not necessary to await the perfection of complex oceanographic buoy systems, because there are many rocks, shoals, uninhabited islands, and inaccessible coastal regions on which a fixed automatic station could be constructed for making observations. It could even be advantageous to have sites offshore from present coastal stations which were tied into a single communication system.

This conference, however, is concerned primarily with observations which would be made with sensors located in the satellite. The development of methods for obtaining cloud cover, radiation balance, and sea surface temperature (SST) has already begun in the TIROS series of satellites. Here I might suggest that for synoptic charts of SST the instrumentation goal be a resolution of a 50-mile diameter circle and an accuracy of $\pm 0.5^{\circ}$ C. Greater resolution would be necessary for special studies, such as meanders in the Gulf Stream or oceanic fronts.

Turning now to other observations which might be made for oceanographic or fisheries research, it seems appropriate only to set forth a few thoughts or brief suggestions for conference discussion. The order of listing has no particular significance as to importance or priority.

Visual, photographic or televised observations of marine flora and fauna: seaweed fixed or drifting; plankton blooms, such as red tide; fish schools, eg., herring, sardine, tuna, anchovy, etc.; large sharks, e.g., the basking shark and great white shark, and whales. Not only is the identification, number and size of schools important, but also the movement or migration and the behavioral patterns. Such observations would require resolution at scales of one meter to one mile. Until such resolutions become available the satellite could be used to relay observations from surface ships on a real-time basis as noted in the next paragraph.

Locations of fishing boats and fishing fleets on a daily basis: This would help to increase efficiency of fishing operations. An associated problem is the failure to receive on a short-

*Survey of Requirements for a Geophysical Data Collection System. Stanford Research Institute, Final Report to NASA on Contract NASr-49(12), August 1963, pp. 66.

time basis many potentially valuable meteorological and oceanographic observations made by fishing boats because many are unwilling to use the marine radio and possibly reveal their locations to competitors. VHF communication to satellite might provide the "security" which would engender greater cooperation by the fishing boats in reporting these observations. It should also be noted that a continuous monitoring of the location of all ships at sea would be a great factor in improving marine safety.

Marker, transponding and command buoys: In addition to the normal tracking of drifting buoys and communication of observations from instrumented buoys, some buoys, when visible from the satellite, might be commanded to release smoke, fluorescent particles, or dye for assessing wind and current structure and for making diffusion observations in the atmosphere and ocean. Deep currents might also be measured over long periods of time by adapting Swallow floats with time-release pop-up markers to be detected by satellites.

Laser radar or LIDAR (light detecting and ranging): These devices have shown promise for detecting clear air turbulence and atmospheric pollutants below the level of detection of the human eye. Potential uses which might merit further investigation are (1) for the determination of corrections for atmospheric absorption to improve the accuracy of sea surface temperature charts and (2) for observations of turbulence near the surface to assist in the evaluation of evaporation and heat transfer, and thereby increase accuracy of heat budget computations.

Productivity of the ocean: The possibility of assessing and monitoring the productivity seems indeed remote, because there is difficulty even now in standardizing and interpreting observations which can be made from ships. Nevertheless, there are a few possibilities for making qualitative or semi-quantitative observations, such as color and changes in color. Perhaps it would be possible to use LIDAR instruments at several different frequencies to determine the back scattering in the surface layers and thus obtain a measure of particle size and concentration.

The above comments indicate that I have come to this conference as a user of data, seeking information on instrumentation and methods of obtaining data of interest to me. I can assure you there are other scientists of the Bureau of Commercial Fisheries Laboratories in the Pacific area who are also deeply interested in obtaining the types of data I have mentioned.

POSSIBLE CONTRIBUTIONS OF MANNED (AND UNMANNED) SATELLITES TOWARD ADVANCING THE FIELDS OF MARINE BIOLOGY AND BIOLOGICAL OCEANOGRAPHY

Sidney R. Galler

Office of Naval Research
Washington, D. C.

Orbiting satellites both manned and unmanned could provide oceanic biologists with an opportunity to transmit comparative ecological information simultaneously from several environmental stations to selected laboratories throughout the world.

The Biology Branch in the Office of Naval Research is supporting a program of hydrobiological (oceanic biological) research. This program has included a plan to construct underwater audio-video stations and telemeter the field data to laboratories on shore thereby providing scientists with unique opportunities to observe visually and acoustically the behavior of unrestrained marine animals in their native environments. The first successful underwater audio-video research facility was constructed at the Lerner Marine Laboratory of the American Museum of Natural History located on Bimini in the Bahamas. In fact, this project, under the direction of Dr. John Steinberg of the University of Miami has been successful beyond our expectations. The establishment of a network of observation stations located in other scientifically interesting marine environments with the data telemetered to several associated marine laboratories represents a logical next step. This system would provide an intellectual focusing lens enabling our most competent scientists to join in and participate in actual field research programs of world wide significance. For example, it would facilitate international cooperation on fundamentally important problems of biological behavior and productivity of the sea. It is our considered opinion based on discussions with scientists and engineers conversant with orbiting satellites that these vehicles could be ideally suited for relaying the data derived from ground stations linked with the underwater observation stations.

Although the novelty of observing the bottom of the sea by means of a space vehicle may obscure the scientific merits of this system a compelling case can be made for a world wide comparative environmental observational network; one designed to facilitate the acquisition of basic oceanic biological information of interest to many scientists.

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TRANSPARENCY, BIOLUMINESCENCE AND PLANKTON

George L. Clarke

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The following is a summary of the conditions of light in the sea, especially in relation to biological phenomena, to serve as a basis for a consideration of possible observations to be made from high-flying craft by NASA.

Light studies in the ocean were greatly accelerated and extended when the photomultiplier tube became available. Our deep-sea photometer contains a RCA phototube number 5819 placed in a water-tight, pressure-resistant tube with a plexiglass receiving window. The photometer is lowered from a four-conductor Amergraph logging cable. A depth sensor containing a Bourns potentiometer is attached to the photometer. A two-channel Sanborn recorder provides a record in the deck laboratory of the changes in light and depth.

For measuring transparency the photometer is used with the receiving surface upwards. The response of the photometer itself is logarithmic and can be used over seven decades. When used above water and in the upper layers a neutral filter is placed over the receiving window to reduce the light reaching the photomultiplier by six decades. At greater depths measurements are made with this filter removed. The total range of the instrument with and without the filter is thus thirteen decades.

The spectral sensitivity of the photometer extends from 320 to 650 mμ with a maximum at 480 mμ. It thus includes the whole of the visible spectrum and peaks in the region where ocean water is most transparent. The instrument and the measurements which have been made with it are described in the publications which are referred to at the end of this report.

As radiation from the sun and from the sky pass into the sea the infrared is removed very rapidly. The ultraviolet and violet at the short wavelength end of the spectrum and the red, yellow, and green at the longer end of the visible region are attenuated at faster rates than the blue region in clear ocean water. Accordingly, the attenuation coefficient in the upper layers for visible light as a whole is large because of the high rates of attenuation at both ends of the spectrum. Below a depth of about 30 meters no further significant narrowing of the spectrum takes place. After this selective absorption has essentially come to an end, only blue light remains, and it is this radiation that the photometer measures at the deeper levels.

Using 10^5 $\mu w/cm^2$ as an approximate maximum figure for visible radiation reaching the sea's surface, we may plot the reduction in energy with depth. In regions where the sea water is optically uniform a semilogarithmic plot relating light intensity to depth gives a straight line. In the very clear water of the Bronson Deep, north of Puerto Rico, the presence of daylight was detected at a depth of 1,000 m. This water, and the slightly clearer water found south of the equator in the Indian Ocean, have the highest transparency values ever reported (except for a few instances of shallow strata reported by Jerlov). Attenuation coefficients as low as $k = .021$ were obtained in the Indian Ocean.

Below a depth of about 600 m in clear water during the middle of the day flashes of luminescence began to appear on the records of downwelling light. As the photometer was lowered to greater depths the ambient light was reduced, with the result that luminescent flashes stood out more prominently. In some instances luminescent flashes overlapped to such an extent as to raise the general level of the illumination above the ambient for many seconds at a time. The pattern of luminescent flashing was found to differ markedly from place to place, from depth to depth, and at different times of the day. The differences in intensity, frequency, and duration of the flashes indicated the presence of very different populations of organisms. Below 1,000 m the amount of luminescence began to drop off rather rapidly but some luminescence was found at every level tested down to the deepest recording of 3750 m where an average of one flash per minute was recorded. During the night luminescent flashing in great profusion was detected in the upper levels. On many occasions 100 to 200 flashes per minute were observed. Flashes could be detected at depths up to the very surface during periods when there was no moon and the night sky was dark.

Observations on transparency and on luminescent flashing were made at a variety of stations off the northeast coast of the United States, across the continental shelf into the slope water and the Gulf Stream, as well as on George's Bank and in the deep basin of the Gulf of Maine. In addition, observations were made off Greenland, in the Caribbean, in the Mediterranean Sea, and in the western Indian Ocean. At every station at least some luminescence was found at every depth below that at which light from the surface interfered. The Bodens working from Scripps Institution have reported luminescent flashing in the Pacific off the coast of California and off the Hawaiian Islands as well as in other localities.

A chart summarizing the relation between light penetration and biological activities is given by Clarke and Denton (1962). In the clearest ocean water sufficient light for phytoplankton growth extends to a depth of only about 180 m, but light of sufficient intensity to be detected by the eye of man and probably by many marine animals with eyes extends to a depth of 1,000 m. Probably many deep-sea fishes can tell the difference between day and night at this depth in the clearest ocean water. In clear coastal water animals with eyes could probably see at a depth of about 200 m but vision would be correspondingly curtailed in less transparent waters nearer shore or in other regions of turbid water. Full moonlight is about 10^{-6} of noon sunlight, and light reaching the surface on a dark night with no moon is about 10^{-3} lower than that of full moonlight. However, even on the darkest nights enough illumination exists in the clearest ocean water for animals to use their eyes in the upper few 100 m.

Many kinds of animals in the sea carry out a diurnal vertical migration in relation to the change of light during the course of the day. Animals of the scattering layer appear to flash more frequently during periods of rapid migration at sunrise and sunset.

Luminescent flashes may have an intensity as high as 10^{-2}mμ/cm^2 and are thus well above the visual threshold for man and probably for many marine animals as well. A very great variety of organisms are luminescent. Included are animals of many kinds and sizes from the fishes down to the protozoans. In the plant kingdom it is primarily the dinoflagellates which are luminescent. Among the more primitive organisms luminescence may have no value today. It may be a useless byproduct or it may be an evolutionary survival from an earlier period when it had some physiological significance. Among the multicellular animals luminescence may be useful in providing illumination, in attracting prey, in species or sex recognition, in keeping members of a group in contact with each other, in countershading, or in distracting potential enemies.

Our observations have indicated that most luminescent organisms produce their light only when stimulated. Since the vessel from which the measurements are made is always rolling to some extent the motion is transmitted to the photometer at whatever depth it may be. The moving photometer may sometimes strike the organisms but more frequently it causes a turbulence which stimulates their discharge of light. Since there is some difference in the amount of ship motion from time to time, a method has been developed for standardizing the amount of turbulence by placing an agitator in front of the photometer window. This device consists of a centrifugal pump which draws in water through a one-inch tube of black rubber, spins it in front of the window, and discharges it at the other side of the photometer. Since the intake and outlet tubes were bent in a complete circle, no ambient light from the surface can enter the instrument. Thus, it was possible to make measurements of luminescence at all depths from the surface downward even during daylight periods. With this light-tight agitator added to the photometer, luminescent organisms were shown to be present in the surface layers. Organisms which had been exposed to bright daylight were found to flash after having been in the dark only for a fraction of a second while moving through the intake pipe. Many more near-surface organisms were luminescent during the night period. The ability of many of them to flash persisted until about 7 o'clock in the morning, when the light at the surface was almost as bright as in the middle of the day. Thus, a diurnal periodicity in the tendency of these organisms to flash was demonstrated. The most pronounced difference between day and night was found in the upper 50 m but a noticeable change in amount of flashing in response to agitation was recorded down to 200 m at a station in the slope water about 200 miles southeast of New York.

A large amount of information is now available on transparency, reflection, and scattering in the sea. We also have records of the intensity, frequency, and duration of flashing produced by luminescent organisms. Calculations may be made of the attenuation of radiation passing upward through the water and then through the overlying air to a height suitable for detection by airplanes or spacecraft. Of course, light from objects of interest will have to be distinguished from other radiation. It is hoped that, using the foregoing information, instruments can be designed for use from high-flying vehicles which can respond to light reflected from or emitted by living organisms. Also instruments in the air should be able to detect the movement of schools of fishes, large animals, or underwater craft by means of the luminescence produced by the disturbance of the water. It should be possible to map the occurrence of bioluminescence and the positions of large objects rapidly over great areas and probably to considerable depths.

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DETECTION OF MARINE ORGANISMS BY AN INFRARED MAPPER

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Detection of marine organisms by infrared scanners is limited to those animals which are near enough to the surface to generate gravity waves or turbulent eddies. The magnitude of these features depends upon size of the animal, its speed and orientation to the surface. Marine mammals must surface frequently to breathe, and these range in size from a few feet to over one hundred feet in length for the largest, the blue whale. Fish also can be seen at the surface, particularly schooling fishes which may even momentarily leave the water in an effort to avoid their predators. One should not lose sight of the fact, however, that marine birds which prey on fish when they are near the surface, tend to keep the fish submerged during daylight hours, Nonetheless, fish surface when under attack by predatory whales or fish. The situation at night is different inasmuch as most marine birds are at rest, and the multitudinous fishes, partially protected by darkness from their other predators, have moved up near the surface to feed on plankton.

Detections of organisms by infrared requires the surface of the water to be either warmer or colder than the layer just below. Such conditions result from influx of solar radiation during the day and evaporational cooling and out-radiation at night. Air, sea temperature, wind, and relative humidity determine the intensity of the temperature difference. All that is theoretically needed for a detection is a propulsive jet of subsurface water directed upward to shove aside the topmost layer to expose the subsurface water as a temperature discontinuity. In the paper by McAlister & McLeish, a series of infrared maps of the sea surface were shown to illustrate the temperature patterns obtainable over different parts of the ocean. These patterns represent the natural background on which may be superimposed patterns generated by organisms. How does one with certainty identify patterns so produced? Daytime flights were scheduled out over the ocean from San Diego in order to observe biologically generated disturbances. These were photographed at the same altitude as the line scanner. Also, the flights were needed in order to determine the most likely locations for concentration of fish and whales, and on the basis of these results, followup night flights were scheduled.

Schools of fish were seen occasionally. Our search for these was facilitated by watching for circling birds which soon congregate around a school of surfaced fish. The smaller whales which feed on fish are gregarious and can often be picked up at distance, and when approached are found herding a school of fish at the surface. Figure 1 shows a number of submerged schools of anchovies found in the coastal waters of Baja California. Note that the schools are not all circular. Figure 2 shows a portion of a fish school that extended much like a doughnut around a school of porpoises. The porpoises were actively feeding on a small school of fish in the center of the doughnut. Of course we were at too low an altitude to photograph more than a bit of the total perimeter. Figure 3 shows the area of roughened water in the center where the porpoises were feeding. This water is stirred violently by the fish when they jump clear of the water. In the lower left hand corner of this photograph will be noted a school of fish which have broken away from the melee. Figure 4 shows another school of fish under attack by porpoise. Note the number of white marine birds, probably sea gulls, circling the site to feed. This type of disturbance also frequently happens when a group of predatory fish such as tuna find a school of bait or forage fish. Fishermen keep a sharp lookout for such disturbances which they call "breezing". The identification and location of fish schools at night by fishermen is done by watching for their turbulence shown by the excitation of phosphorescent organisms. Unfortunately, these populations vary widely in space and time, and in fact the light produced cannot be seen except in the dark of the moon. We have at the AOG noted fish schools at night from the air by phosphorescence, and the shapes of the schools range from those pictured to cloudlike nebulosities. It was accidentally noted on these flights, that the aircraft noise drove the fish downward to excite the bioluminescence, and above 700 feet, the fish were not disturbed nor seen. Similar effect was noted in a daytime flight with Dr. Gifford Ewing, when a school of fish breezing at the surface promptly disappeared

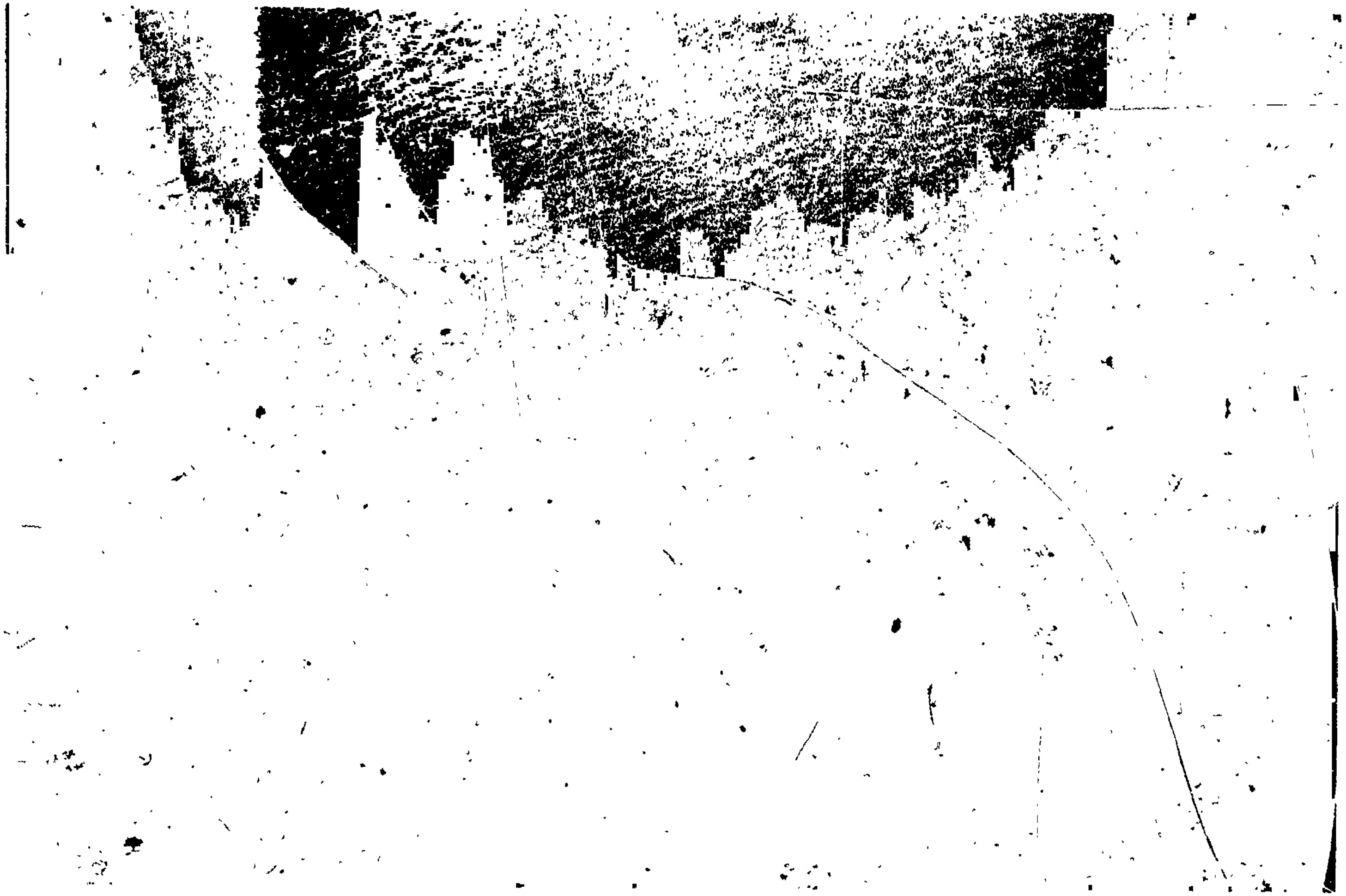

Figure 1. Schools of Anchovies. Viewed at 1,000 Feet.

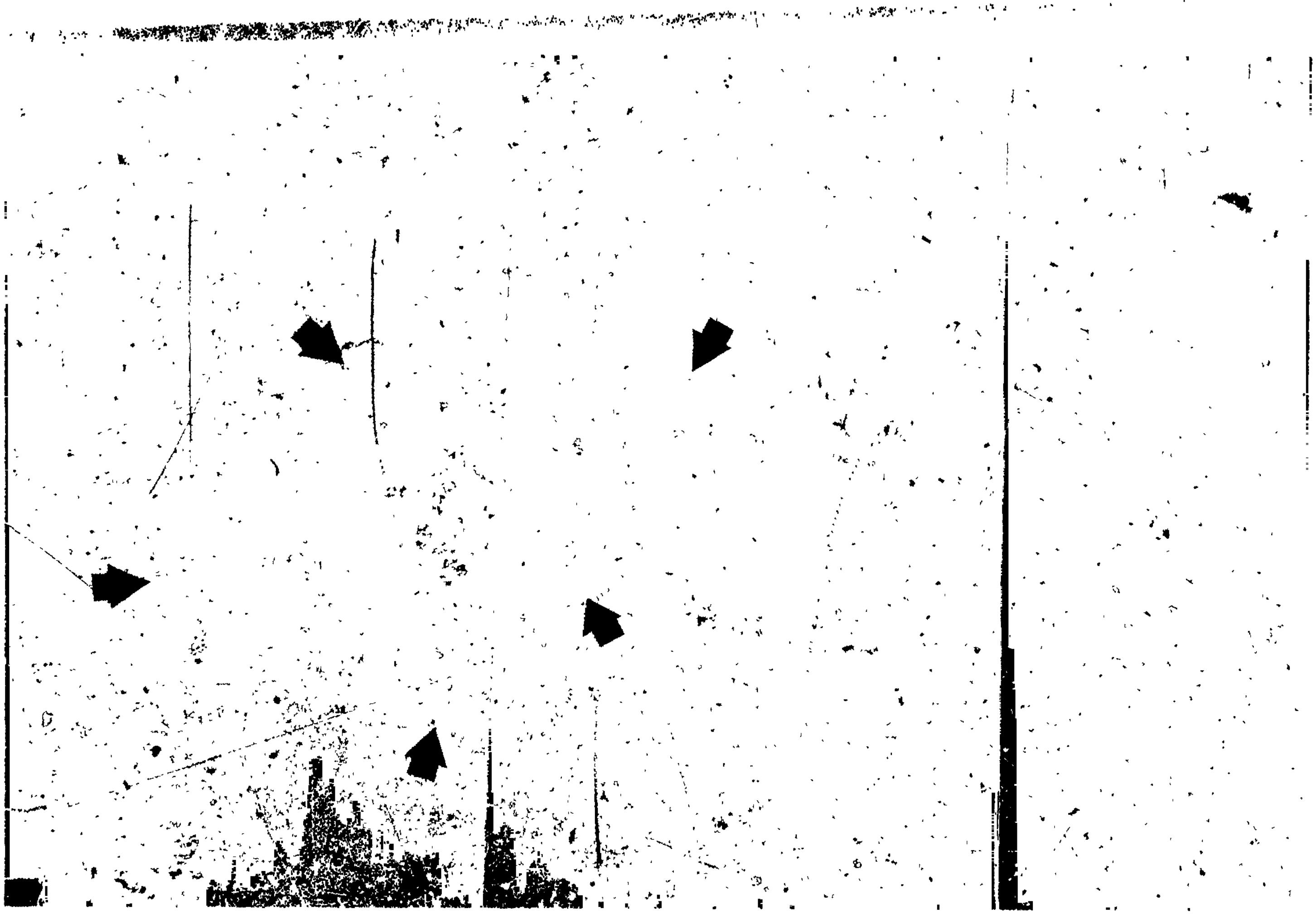

Figure 2. School of Fish Loosely Schooling 1/2 Mile From a School of Porpoises. Viewed at 1,000 Feet.

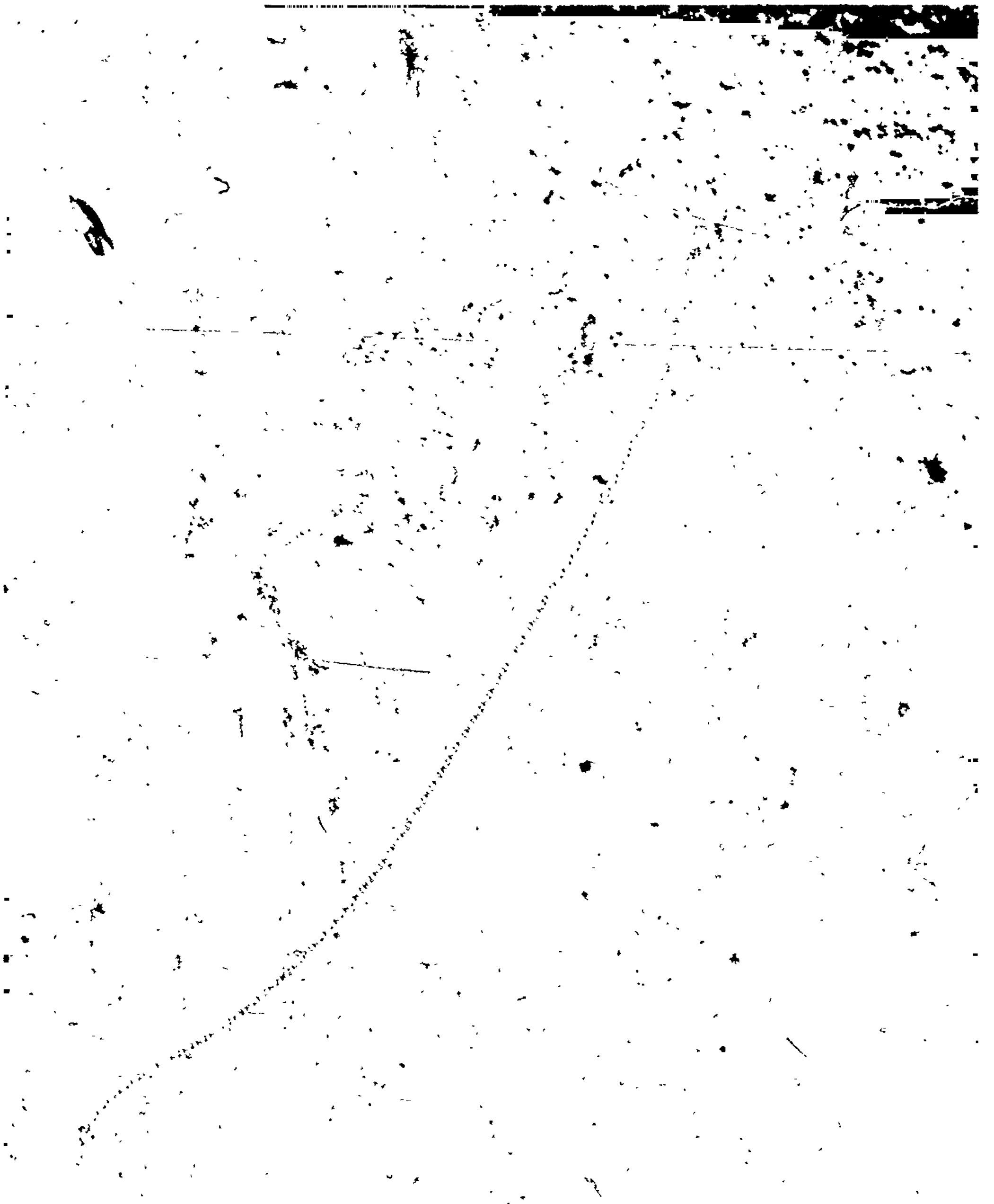

Figure 3. Disturbed Sea Surface Produced by Surface Escape Reaction of Forage Fish Under Attack by a School of Porpoises. Viewed at 1,000 Feet.

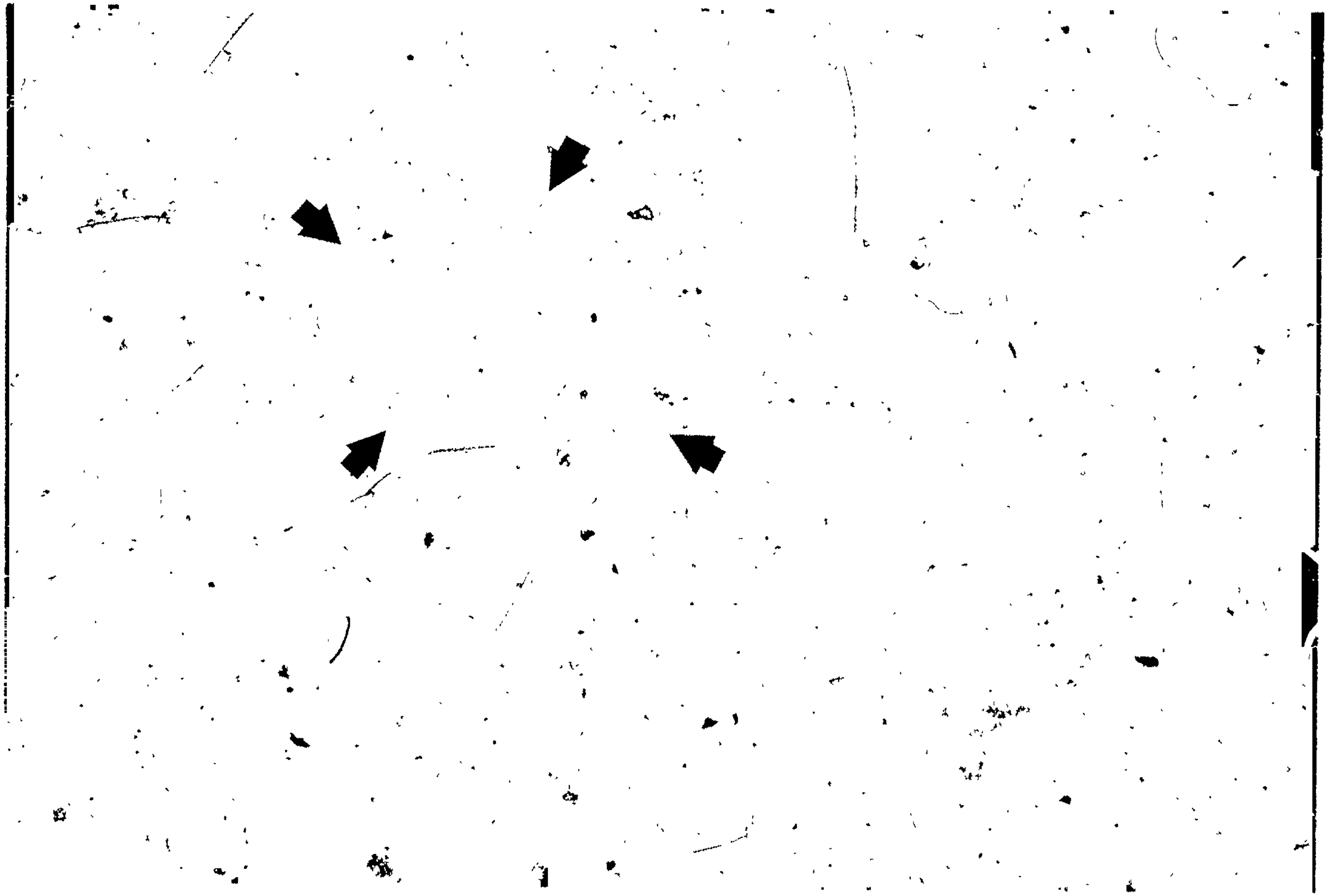

Figure 4. School of Fish Compacted Near Surface Under Attack by Small Whales and Birds. Viewed at Tanner Bank at 500 Feet.

whenever we attempted closer scrutiny, at 300-500 feet, whereas observations at 1,000 feet had been carried on for over an hour. This effect was noted several times, and was not believed to be visually produced as the plane merely circled them. Figure 5 is a line scanner map of the sea surface at night showing patterns of cold water intruding on the surface. These patches are very suggestive of schooling fish. Figure 6 is a similar map obtained by a night-time flyover of a purse seiner with its net set out around a school of fish. Note the very strong warm patch of water in the net. One is inclined to suspect from the patterns of similar disturbances outside the net that there were more fish out of the net than in.

Whales, of course, in addition to producing a visible wake, break the surface of the water to breathe, and the exhaled breath is visible by the moisture condensing from it by its sudden expansion. There are droplets in the breath which fall back on to the sea surface around the head of the whale to produce a marked calming of the sea surface. It is suspected that this is due to surface reactive material, which spreads to produce a sizable circle. Figure 7 shows the fall-out of droplets onto the surface just after a whale (California Gray) has exhaled. Figure 8 shows how conspicuous these circular patches of smoothed water are from the air. A pair of migrating gray whales have finished blowing and are diving, leaving the patches astern and to one side. Note also the foam marking the edge of these patches. Figure 9 is another aerial photograph of a school of 5 California Gray Whales on migration on and near the surface. In order to interpret the event more properly, one must know that the whales generally surface one after another. The spout from an exhaling whale shows strongly. Note also the breaking waves and the turbulent wake churned up by these 40-50 foot specimens. Figure 10 is an oblique view of a surfaced Gray whale showing how conspicuous the whale is when surfaced.

Ordinarily the whale generates a surface wake during the minute or two it is at the surface for breathing. After this has been completed, the whale submerges to greater depth for varying lengths of time, depending on whether it is just travelling or feeding. In our studies of this species, we attempted to follow the migrating groups by ship in daylight hours up to dusk in order to facilitate infrared detections at night by the plane. In the course of doing this it was noted that the California Gray Whale shortly before dusk stops diving deeply, and swims along just below the surface, leaving a continuous wake, see Figure 11. Figure 12 shows the infrared map of the same group obtained slightly later. Each wake is warm, and continuous, and the whales have spread out in a more open formation. Small whales should also produce surface scars and wakes. Figure 13 is an infrared map of an area in which two groups of porpoise can be detected by their wakes. These wakes are interrupted frequently by the diving and surfacing of the animals, and the tracks are not necessarily straight.

Infrared mapping devices do under appropriate conditions detect whales, and fish at or near the surface. The detection of fish schools of all sizes at the surface is practical, whenever the surface has an adequate temperature contrast with the underlying water. The system as operated from moving aircraft does best at 1,000 feet and this altitude permits resolution of at least the larger biological targets.

Figure 5. Schools of Fish Reveal. d at Night by an Infrared Line Scanner. Disturbances Are Cold. Elevation is 1,000 Feet.

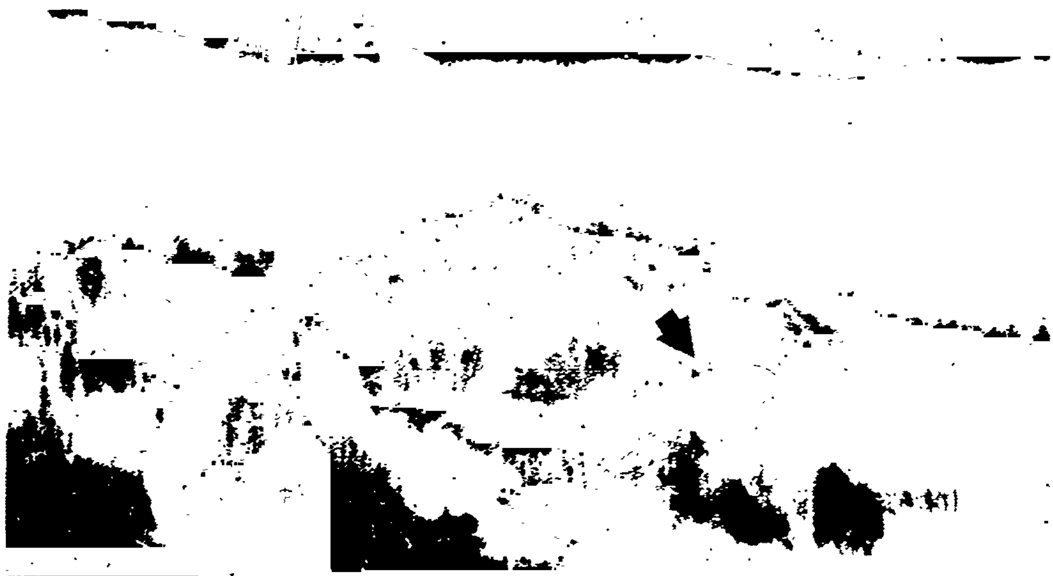

Figure 6. Purse Seiner Adrift Inside a Purse Seine. Note the Intense Black Center Caused by Fish Within Net. Elevation is 1,000 Feet.

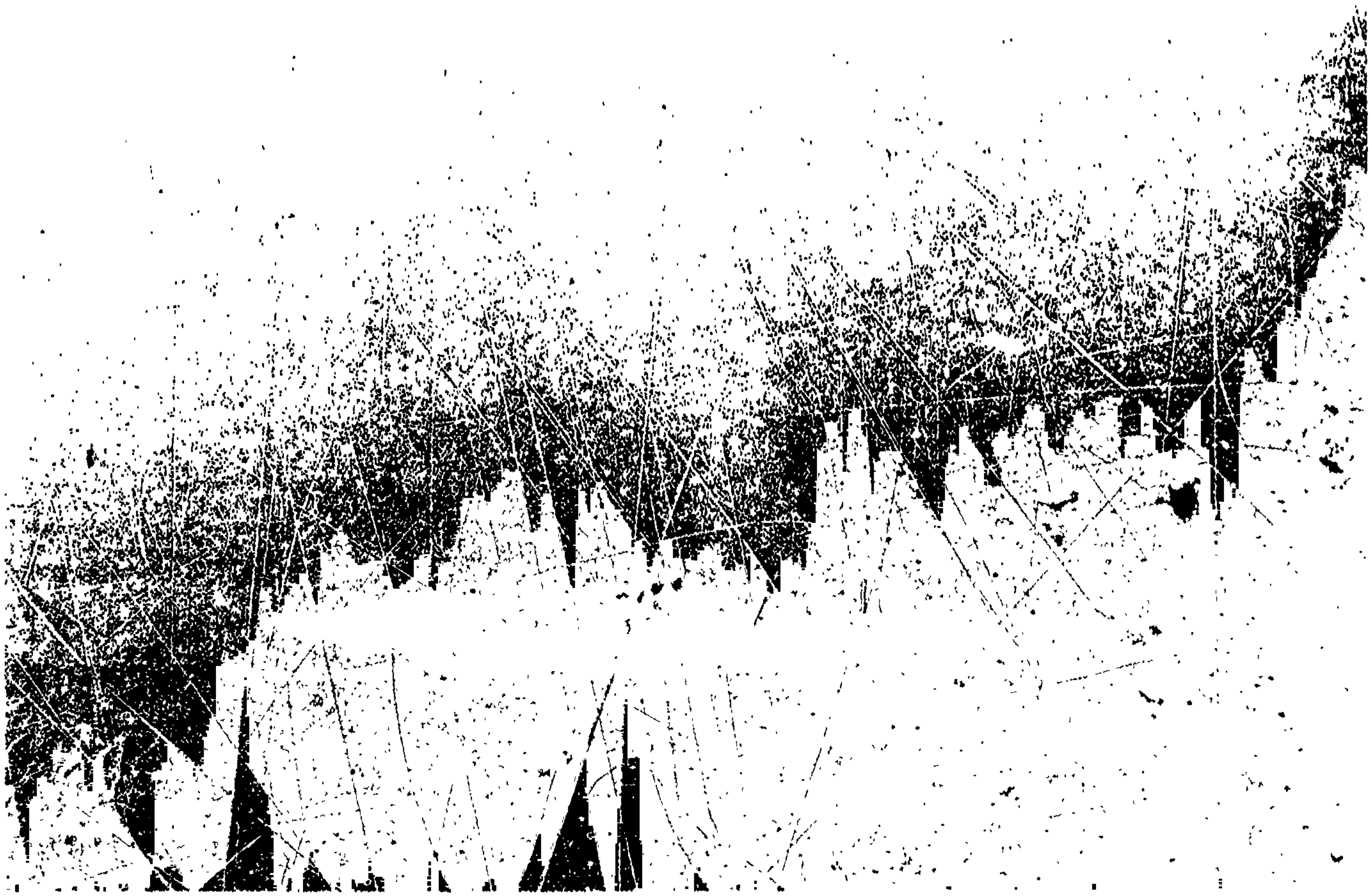

Figure 7. Spouting Gray Whale. Note the Disturbed Patch Around Head Caused by Fallout of Particles.

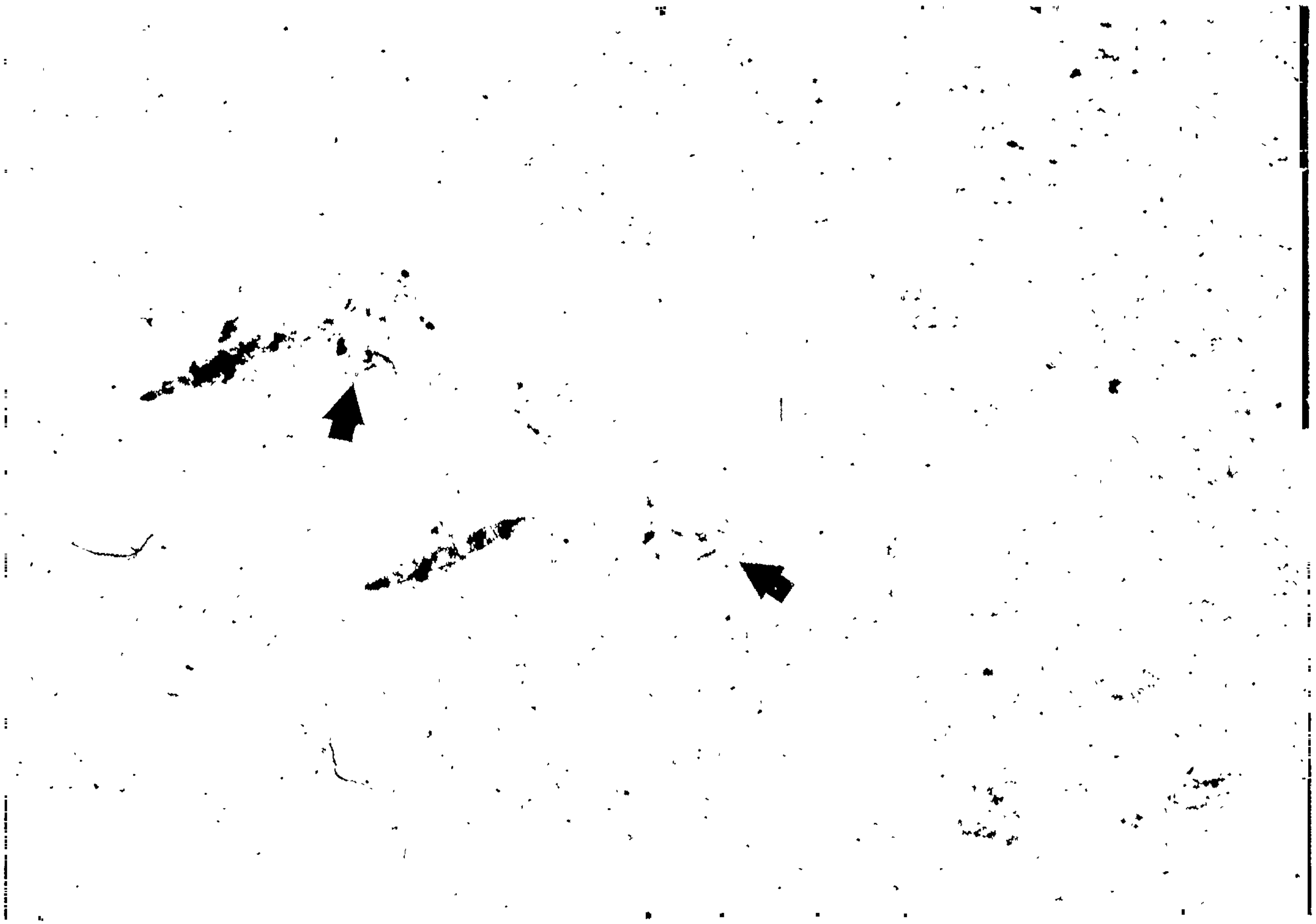

Figure 8. Pair of California Gray Whales at Surface Ready to Dive. Arrows Point to Circular Disturbances Left by Fallout From Spouts.

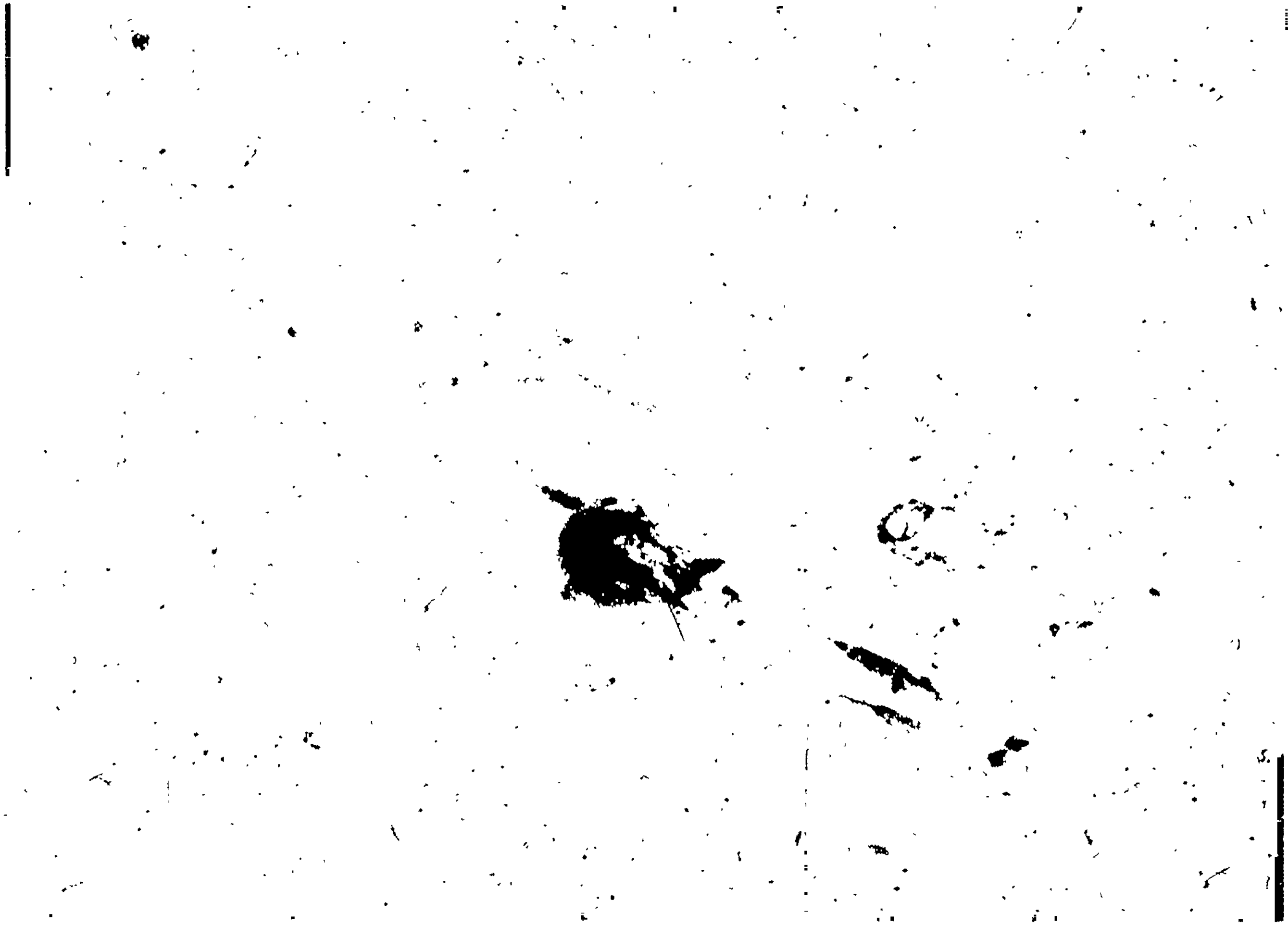

Figure 9. School of Migrating California Gray Whales. Note Size of the Spout and the Turbulent Wake.

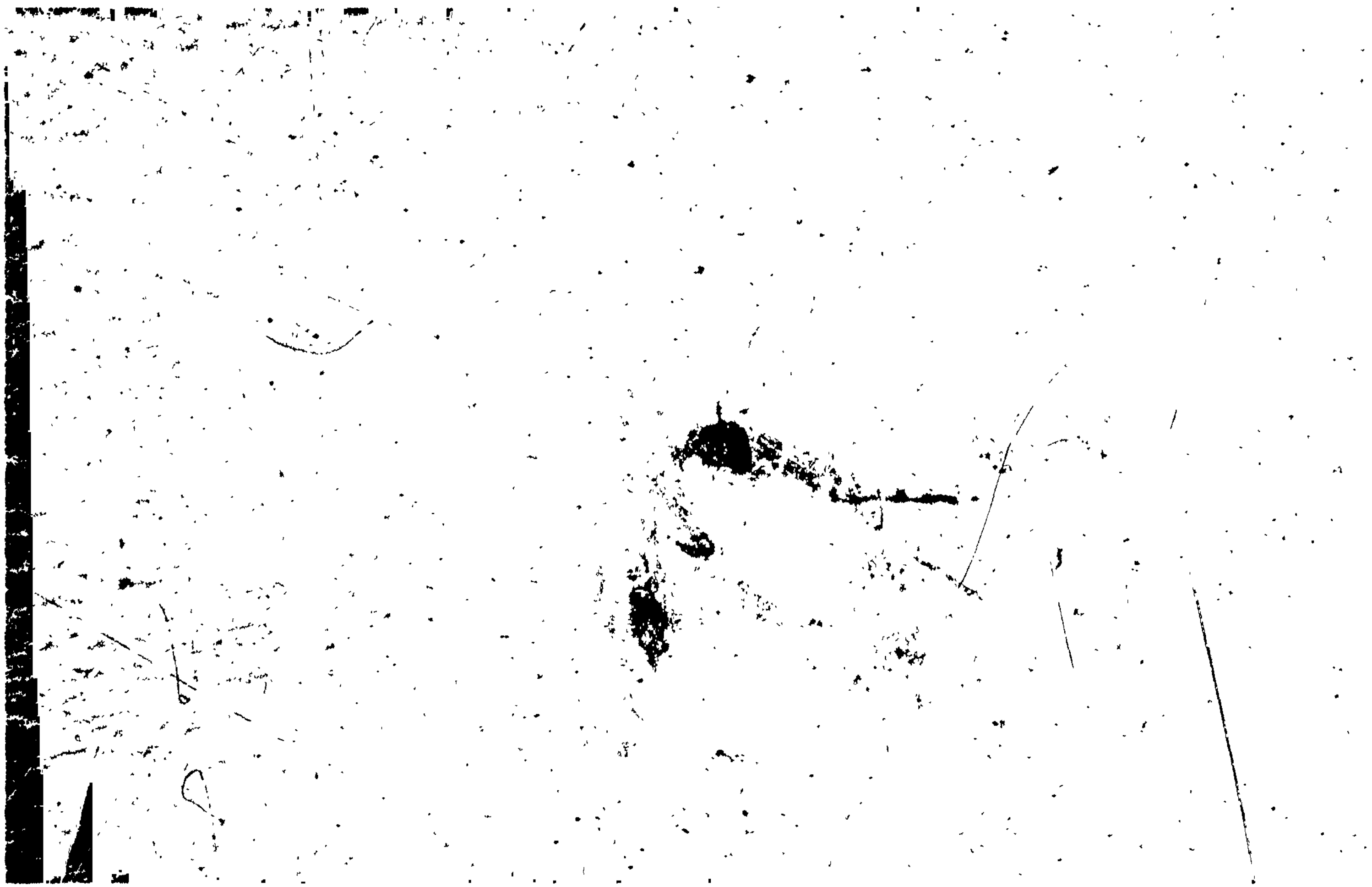

Figure 10. Oblique Aerial of a Surfaced California Gray Whale at 1,000 Feet.

Figure 11. Migrating Gray Whale Exhaling at Dusk. Note the Continuous Wake.

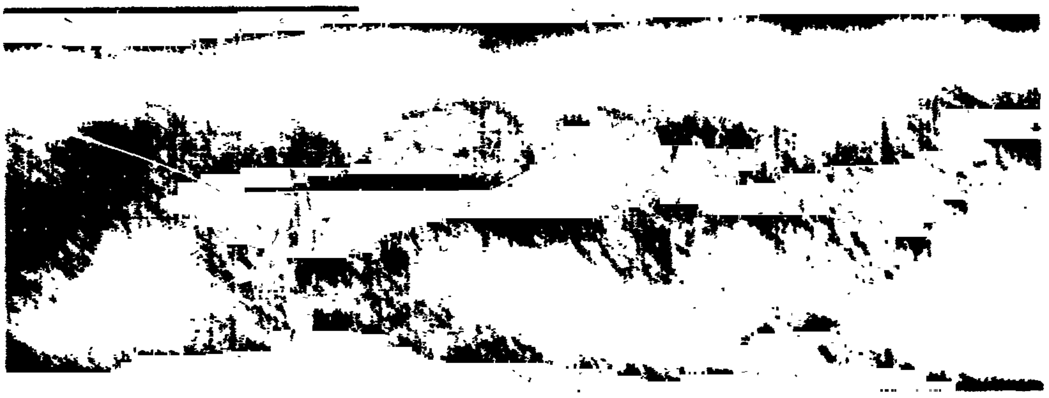

Figure 12. Same Group as Figure 11. Viewed by an Infrared Line Scanner at 1,000 Feet.

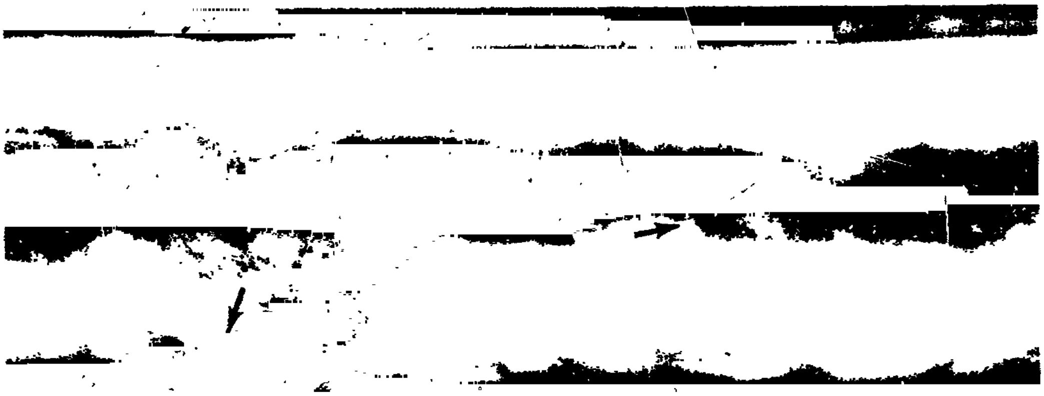

Figure 13. Two Groups of Porpoises Surfacing Leaving Discontinuous Wakes. Scanner at 1,000 Feet.

A FEW COMMENTS ARISING FROM THE NASA CONFERENCE

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Insofar as biology is concerned it appears to me that the most important, and feasible, space programs are those concerning physical parameters. Among these are temperature, currents, and thermocline depth. If we had these on a routine basis, say monthly or weekly situation maps, for the world ocean, they would certainly provide the basis for exciting and significant advances in our understanding of the ecology of the sea, and this would certainly result in enhancing man's ability to use the resources of the sea.

With respect to temperature we would like a measurement that compares well with "bucket temperature." However, among the most critical phenomena of interest are masses of unusually warm or unusually cold water, unusual in the sense that they differ from the climatic expectation. Such masses are more likely to be out of equilibrium with the overlying air and thus have a good chance of being undetected by ordinary infrared measurements. I can't suggest a solution, but simply want to emphasize that the temperature phenomena of greatest interest may in fact be the most difficult to measure.

Turning now to biological phenomena, I have asked myself the following questions:

1. Are we considering rare events or curiosa, or important continuing processes?
2. Can they be measured directly or indirectly?
3. Can meaningful interpretations be made of the measurements?
4. Is there need for continuing measurements?

Most of the biological programs that came to my attention failed one or more of the above questions.

The only suggestion that really seemed worthwhile was measuring the chlorophyll content of the world ocean. This possibility has been elaborated elsewhere, and I'll not comment further except to note that the "laser technique" outlined by Dr. Duntley was most appealing.

Stemming from this problem is a suggestion for an experiment, an experiment that assumes we can measure the chlorophyll content of the upper layers of the ocean. Let us first pick an interesting ocean area in terms of circulation. Then let us ascertain a season when some or several nutrients are limiting the size of the standing crop of the local phytoplankton. Then appropriate quantities of the limiting nutrients would be added. This would serve to test all of our previous information and theory on the relations between physiology, the physical and chemical environment, and productivity. If we were correct and had added the correct substance(s) in the appropriate amount, a local bloom should be created. The appropriate observations from space and the sea surface should elucidate the net motion and eddy diffusivity of the surface waters, i.e., the nutrients added would be self-enhancing dye marks. This may be enough on this as in all likelihood the suggestion isn't practical. It intrigues me though, because if feasible, it would test and bring together an important spectrum of our conceptual and factual understanding of the sea.

MANNED VS. UNMANNED VEHICLES?

I think this is a divisive question. We don't even consider it in surface oceanography, excepting that for reasons of economy, objectivity, and reproducibility we try to get man out of the picture as much as possible. Our judgment is based not on any philosophy but rather on the pragmatic situation at hand. The same problem existed in the days of the Challenger, i.e., whether to send a scientist or let the bridge record observations.

OCEANOGRAPHY FROM SPACE

CHAPTER 4

SEA ICE

RECOMMENDATIONS OF PANEL ON SEA ICE

LCDR. Richard M. Morse, USCG, Chairman

Members

Trevor Harwood	George Prehmus
Austin Mardon	H. L. Cameron
W. K. Widger	Edwin Shykind

It was previously pointed out in plenary session that the statement of requirements, a review of actual and predicted TIROS and NIMBUS satellite programs and a summary of the results of Project TIREC* is available in the June 1963 report of a Conference on Satellite Ice Studies (U. S. Department of Commerce, Weather Bureau, Meteorological Satellite Laboratory Report No. 20.) It was further noted that Mr. R. W. Popham of the U. S. National Weather Satellite Center has provided a staff study to the Naval Weather Service on satellite vs. aerial and surface vessel ice reconnaissance. This panel's report upon requirements for an ice-study program to be conducted from a polar orbiting vehicle constitutes, for the most part, a restatement of previously noted requirements.

Research involving studies of the world's sea ice will have ramifications in many associated fields of physical oceanography and meteorology. Researches of the nature described will have immediate application in commerce and within the military establishment. Four general problem areas are recognized. First, and perhaps least complicated, is the study of the sea ice of the south polar area. The study will be simplified because locally formed sea ice rarely, if ever, exceeds one year in age, thus allowing its thickness to be closely approximated. Thus the ice volume, brine entrapment and, upon melting, the fresh water discharge into the Antarctic system can be calculated. Simple measurement of the geographic extent of the sea ice boundary will provide basic information on the winter formation of the Antarctic Deep and Bottom Water and the contribution of the intermediate waters. The distribution and movement of the huge, tabular Antarctic bergs from the ice shelves can readily be determined as an aid in the understanding of the surface circulation contiguous to the continent.

Secondly, we consider the north polar pool, the Arctic Ocean. The water system here is nearly a closed system except for the transfers across the sills between Greenland and Norway. The basic problems of oceanic circulation in this area are really little different than those of Antarctica, but appear in a considerably more complicated form. Research into the brine entrapment, seasonal discharge of great quantities of fresh water, lateral extent of ice fields, formation and dissolution of winter ice is greatly complicated by the fact that much of the area is covered by a relatively permanent sea ice field whose thickness is a seasonal variable. Observations of the geographic extent of this cover throughout the year will need to be coupled with spot sampling of ice thickness, oceanographic measurements of seasonal transports, etc. to provide the correlation parameters to allow long-range forecasting of ice conditions as well as those oceanographic features of the North Atlantic Ocean which are so dependent upon the Arctic circulation.

Thirdly, the area of the Grand Banks of Newfoundland should be studied in some detail. This area, so important to world fisheries and trade, will benefit directly from the studies of the Arctic Ocean mentioned above, through knowledge gained of the fresh water contribution to and the circulation patterns of the East and West Greenland Currents, the Irminger, Baffin and Labrador Currents. Independent studies of the specific circulation in The Grand Banks area should be provided to specifically define the presence, extent and movement of sea ice and of ice bergs, the latter occurring in the area during the season of historically semi-permanent fog.

*Project TIREC - a joint U.S.-Canadian effort to investigate (through TIROS) the use of satellites for ice reconnaissance and surveillance.

Finally, consideration must be given to those inland sea, gulfs and estuaries ... which are characteristically ice-clogged during portions of their winter seasons. As these areas are inherently of lesser geographic extent than the areas previously mentioned they are more amenable to study by airborne methods and there is a lesser need for such sophisticated studies as may be carried out from satellites.

In consideration of the general problems delineated, more specific requirements can be set forth. First, the satellite sensing systems must have an all-weather capability, i.e., must not be significantly attenuated by the presence of cloud or water vapor and must not be dependent upon sunlight as they must operate seasonally through the long polar nights. Secondly, the orbiting frequency (90-100 minutes) of a single satellite will provide an adequate sampling frequency. Thirdly, the system must meet the resolution requirements stated below.

a. For general polar research, a 5 mile resolution and complete polar coverage in 48 hours or less of the areas 70° N to the pole and 60° S to the pole. Coverage of lesser latitudes is not required at the 48-hour frequency.
b. For specific researches, operational and tactical needs in the arctic areas, a resolution which will detect, identify and position a polynya, lead, or lake having a width of 150-200 feet. If possible, special equipment should be developed with a resolution sufficient to determine the structure of the sea ice, i.e. puddles, pressure ridges, rafting, etc.
c. For the gulf and inland sea areas, a resolution of less than 1000 feet, preferably of 200 feet is required, - sufficient to provide an operational delineation of ice location, concentration and movement.
d. For the Grand Banks of Newfoundland area, additional capability of detecting and positioning individual pieces of floating ice of 100' diameter and preferably of 15 foot diameter. Inherent in this requirement is the capability of distinguishing ice from any other target-type such as a ship or boat. Fallout from this type of detection system will be of great assistance to the maritime agencies of the world in positioning surface vessel traffic and greatly simplify the "search" problem of search and rescue activities.

In conclusion, it is to be noted that discussions with instrumentation personnel lead us to believe that the present state of sensor art is very close to being that which has been stated above as required. It is therefore to be hoped that systems for the detection of sea ice will be among the very first to be incorporated into future satellites.

N65-30385

RADAR AND ICE SURVEYS

H. L. Cameron

Acadia University, A.F.C.R.L. and D.R.B. of Canada

INTRODUCTION

The theme of the present meetings is the possible oceanographic applications of data obtained from space vehicles. The most obvious advantages of obtaining data from space are speed of acquisition and great areal coverage. The present paper is based on the same advantages obtained by the use of high altitude aircraft and high definition radar. The added advantage of all weather capability suggests that radar must be considered in any projected oceanographic, or earth science satellite, or manned orbital laboratory. Finally, it is suggested that regardless of future space developments, radar can be applied in its present form with existing aircraft to extensive polar ice studies.

TIREC

Tirec was a joint U.S.-Canadian project involving the U.S Weather Bureau Tiros Satellite Group, the U.S. Navy, the Canadian Department of Transport, the Canadian Defense Research Board, and the Royal Canadian Air Force. It was designed to test the possibility of using Tiros photography for ice surveys in the Gulf of St. Lawrence and off Newfoundland. The first phase was carried out in February 1962 and the second in March, 1962. Excellent Tiros photos were obtained and extensive high and medium altitude photography was carried out by USN and RCAF aircraft. Radar photography was also obtained and was sufficiently interesting to indicate that further tests should be carried out. It was of particular significance that the radar gave ice cover data when cloud and other weather conditions prevented conventional photography and masked the Tiros cover.

RAF

Because of lack of suitable radar and aircraft in Canada, the Royal Air Force was approached, and with their usual keen interest in new projects, kindly consented to obtain radar cover of the Gulf of St. Lawrence on practice missions in the area. These were obtained during the winters of 1962, 1963 and 1964. The radar was the standard RAF radar installed in one of the V bombers. Operating altitudes were approximately 41,000', and radar scope photos were taken using 35 mm black and white film. The results were excellent and the photos were readily worked up into ice cover maps. These were compared with the visual ice reconnaissance maps obtained on the same, or nearest day, by the Canadian D.O.T. The reader may judge for himself as to the value of radar for such ice cover surveys from the illustrations which accompany this report.

The writer wishes to thank the Royal Air Force for their great interest and cooperation in this work. He is especially grateful for their permission to publish the photography and hopes that this good example will be followed by other groups and services.

GULF OF ST. LAWRENCE

Fig. 1 is a reduced copy of the Canadian Department of Transport Ice Reconnaissance Map of the Gulf of St. Lawrence for March 15, 1963. This map was the result of two flights of DC-3 aircraft from Sydney, Nova Scotia, and Baie Comeau, Quebec. These were of approximately six hours duration, during which trained observers made visual observations which were recorded on maps. Positioning was approximate and based on elapsed time between land falls. Flying heights varied but were between 1500' and 2000'. Standard ice type and cover symbols are used: These are not given here, but can be obtained from the various agencies. It should be noted that the entire area of the Gulf of St. Lawrence, Northumberland Strait, and Strait of Belle Isle is not covered, though the main shipping routes are traversed several times.

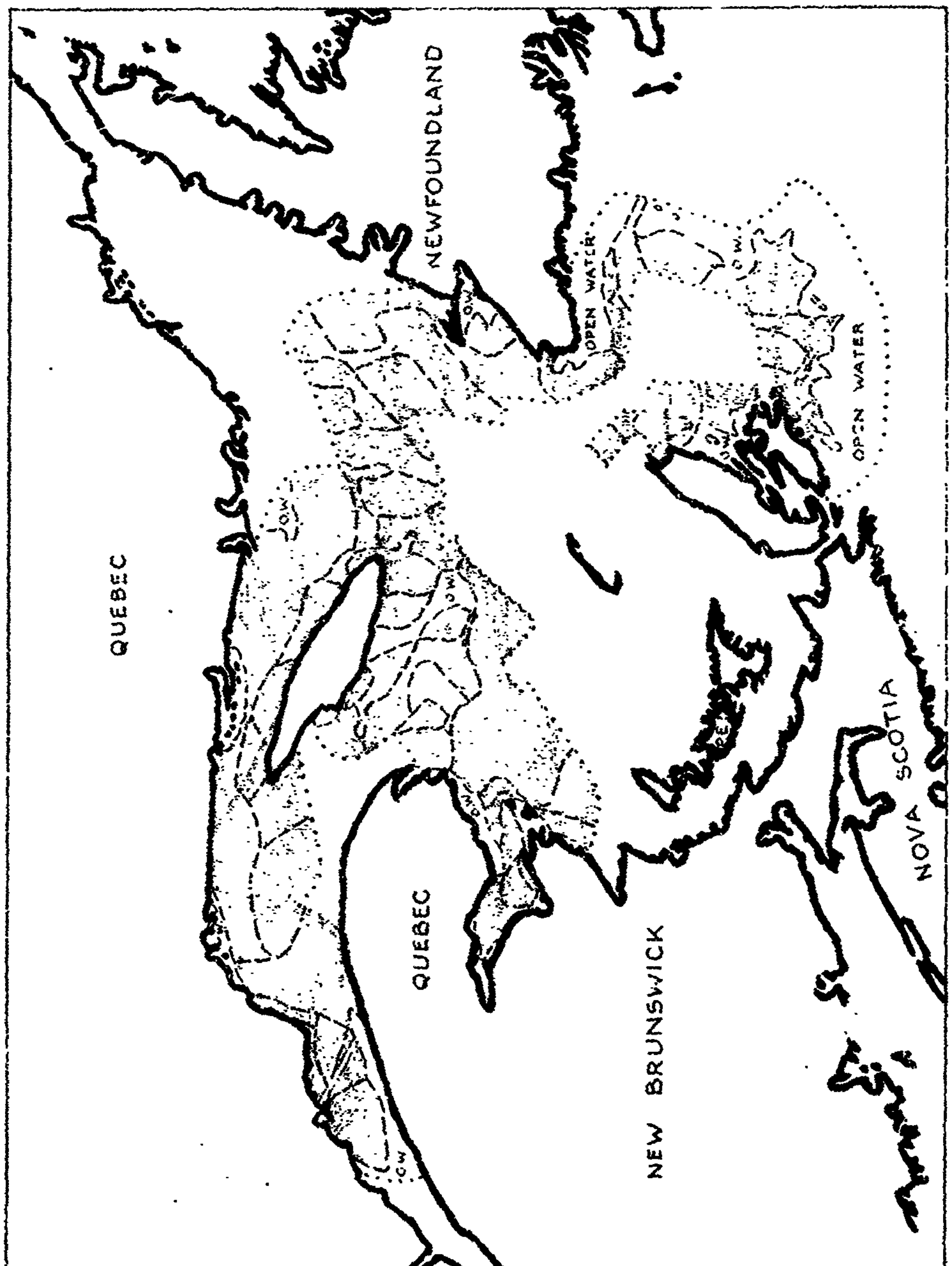

QUEBEC
NEWFOUNDLAND
OPEN WATER
OPEN WATER
QUEBEC
NEW BRUNSWICK
NOVA SCOTIA

Figure 1

Fig. 2 is an ice reconnaissance map prepared from radar photography for March 14, 1963. It is not as detailed as the visual map but it covers the entire Gulf. Fig. 3 is a radar cover map showing the actual coverage of the flight. The scales used were 1,1,000,000 and 1:3,000,000. One is struck at once by the great areal coverage of both scales, and the ease with which ice data can be related to land masses by simple projection of the photo onto the map.

Fig. 4 is a radar scope photo from the group used to prepare the map (Fig. 2). The spectacular spiral is a slob ice-slush feature off the south coast of Anticosti Island, and is believed to be the result of current and coriolis effects. The dark areas on the ice near the open water are polynas. This was confirmed by conventional tri-camera photos taken at the same time as the radar.

Fig. 5 is a radar scope photo showing the Cabot Strait exit to the Gulf of St. Lawrence. The fine detail of the ice masses and streamers can be clearly seen. The curl of slush streamers northeast of the Magdalen Islands suggests a spiral or eddy, formed by the incoming tidal current working against the wind and current drift out of the Gulf from the West. The latter can be seen in the open water to the east of the Magdalenes and St. Pauls Island in the Cabot Strait.

Fig. 6 is a radar scope photo showing the ice masses in Northumberland Strait. Pans of old ice are prominant as they are relatively smooth and tend to reflect the radar waves off to infinity. This makes them appear as dark holes in the mosaic of ice floes

Figs. 7 and 8 are successive radar scope photos which are separated by five minutes in time. They constitute a "time lapse" pair, rather than a "stereo" pair. If they are placed under a stereoscope a topographic effect is produced due to the movement of the ice masses relative to the immovable land masses. Using the principle of stereo time lapse velocity determination, the speed of ice mass movement can be determined.* This method has been successfully applied to Tiros photography using successive orbits. The resolution of the RAF radar is of about the same order or slightly better than Tiros VII so it is not surprising that the movement of ice masses can be detected and measured.

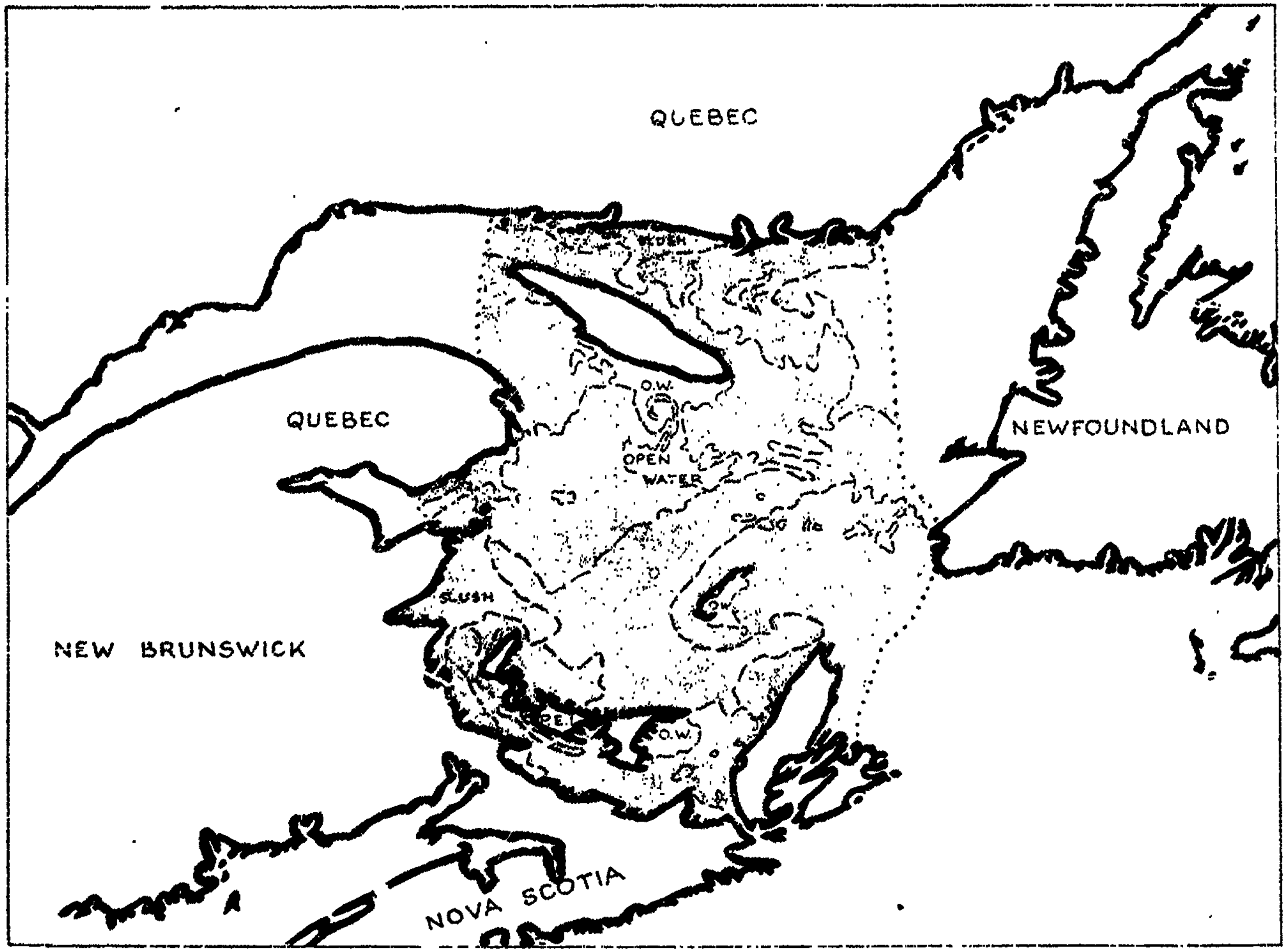
CONCLUSIONS

It is concluded that with high resolution radar from altitudes of 40,000' it is possible to make accurate ice cover surveys in subarctic and arctic areas. With suitable aircraft and radar a complete survey of the arctic ice conditions is now possible at a reasonable cost.

It is further concluded that with time lapse photography and successive covers it should be possible to determine the speed of ice field movement and to plot the seasonal pattern of such movements.

The relative all weather and all season capability of this sensor is also of great importance. This could be of particular value in operations from satellites or manned orbital laboratories as so much of the earth's surface is obscured by clouds.

*Water Current and Movement Measurement by Time-Lapse Air Photography-An Evaluation; H. L. Cameron, Photogrammetric Engineering, March, 1962. Ice Cover Surveys in the Gulf of St. Lawrence by Radar; H. L. Cameron, Photogrammetric Engineering. (In Press)


QUEBEC
SLUSH
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NEWFOUNDLAND
SLUSH
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O.W.
NEW BRUNSWICK
NOVA SCOTIA

Figure 2

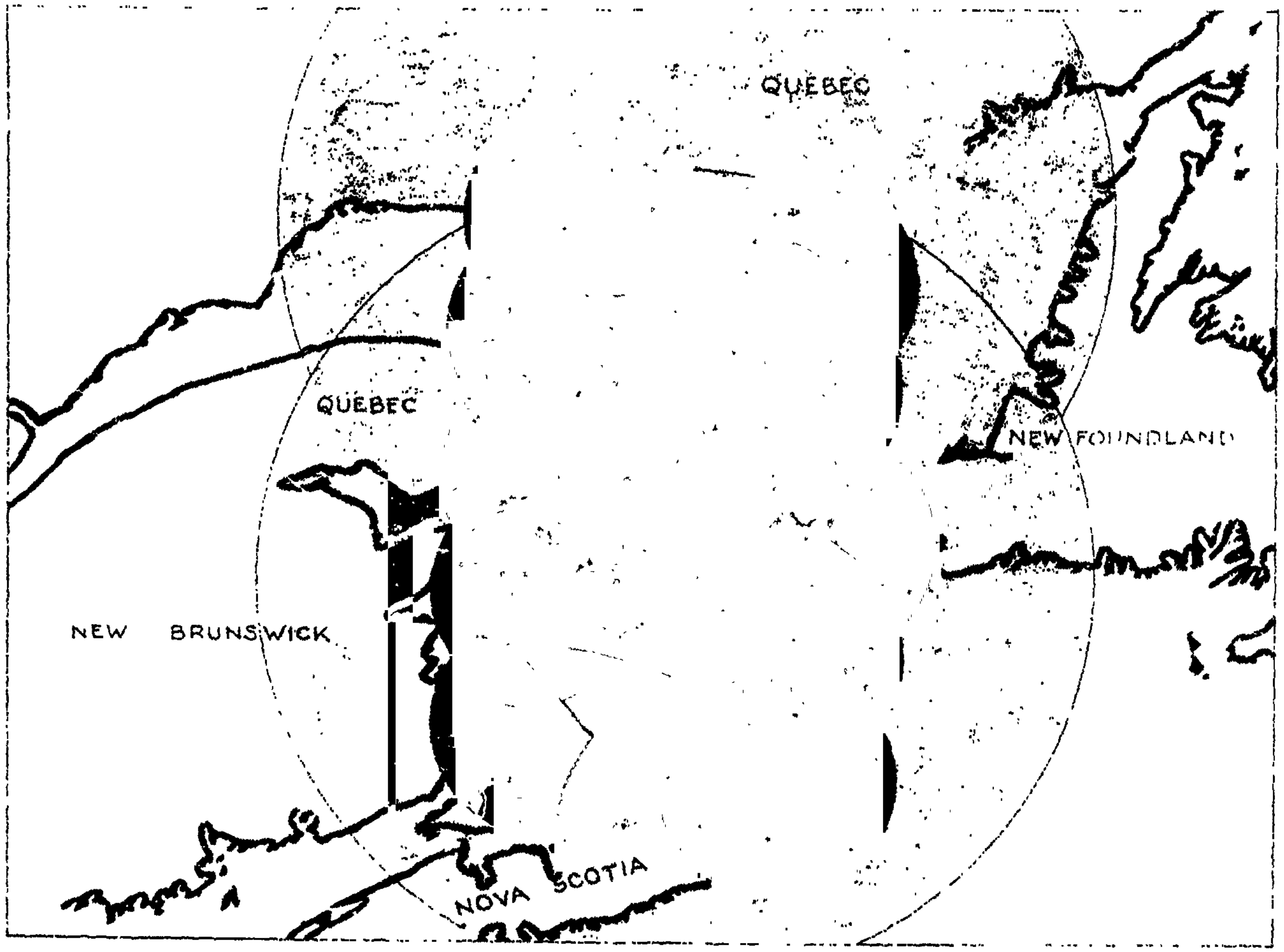

Figure 3. Radar Cover Map

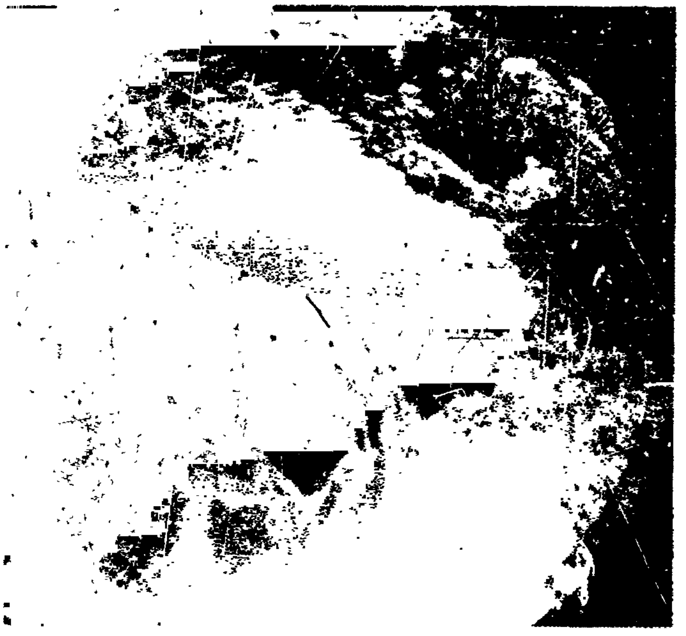

Figure 4. Anticosti Island, 14 March 1963

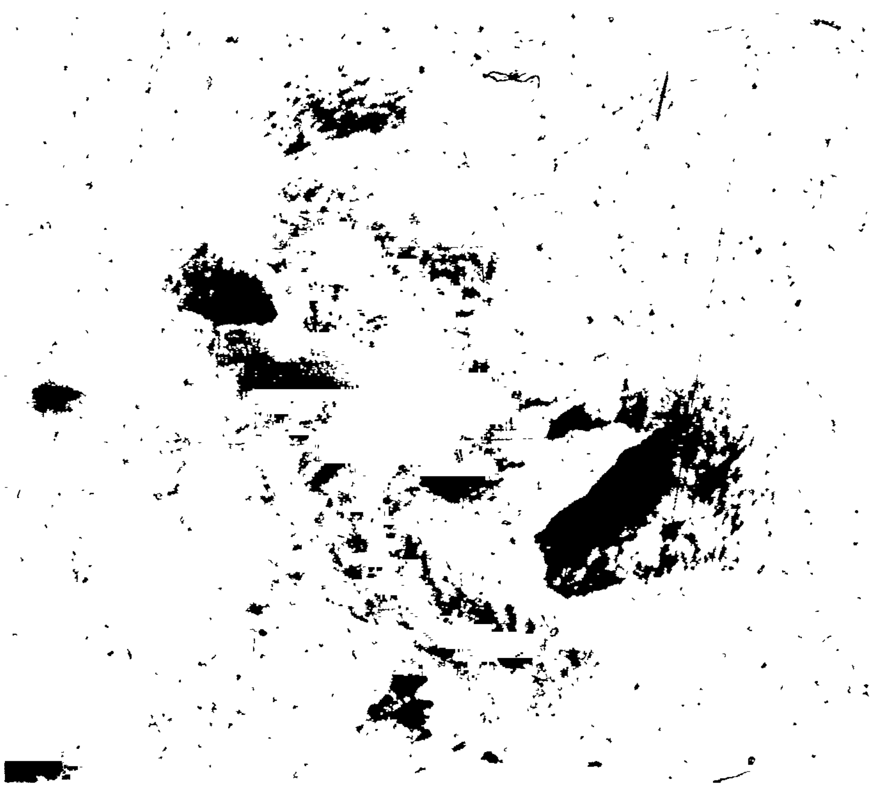

Figure 5. Gulf of St. Lawrence, February 11, 1964

Figure 6. Ice Masses in Northumberland Strait.

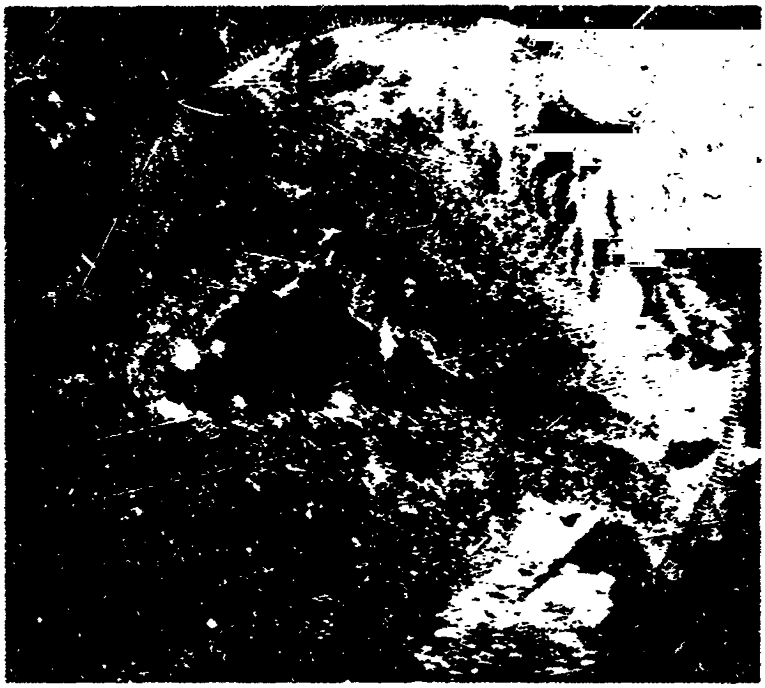

Figure 7

"Stereo" or Time Lapse Pair Showing Cabot Strait and Gulf of St. Lawrence to Madgalen Islands. Ice Movement Shows by Stereo Effect and by Open Water Areas in lee of Land Masses.

Figure 8

."Stereo" or Time Lapse Pair Showing Cabot Strait and Gulf of St. Lawrence to Madgalen Islands. Ice Movement Shows by Stereo Effect and by Open Water Areas in lee of Land Masses.

CHAPTER 5

SEA STATE

RECOMMENDATIONS OF THE PANEL ON WINDWAVES AND SWELL

Chairman

W. J. Pierson, Jr.

Members

F. T. Barath — W. Marks
T. W. Godbey — R. K. Moore
I. Katz — D. H. Staelin
A. Mardon — H. B. Stewart, Jr

MEASUREMENT FROM AIRCRAFT AND SPACE VEHICLES OF QUANTITIES ASSOCIATED WITH WINDWAVES AND SWELL

SCOPE OF MATERIAL COVERED

This panel considered the problem of obtaining data pertinent to describing features of the full directional spectrum of wind seas and swell, the frequency spectrum, the slope spectrum, and integrals of the frequency spectrum of the waves.

An assortment of radars, all within the capability of present technology, was discussed. Microwave radiometry was considered. Optical techniques, though useful in areas of good visibility, were judged to be of limited interest because important wave-generating storm areas are masked by storm clouds.

RADAR

It seems possible to build radars that will yield data on the windwave part of the wave spectrum as distinct from that portion due to swell. For high frequency radar the variation in scattering cross section with antenna zenith angle depends on the roughness of the sea in the short wavelength region of the wave spectrum, and this region appears to vary directly with the local windwaves. Verification of this relation for winds over 30 knots is still needed.

A lower frequency radar, or a frequency sweep radar, should give information on the area under the whole wave spectrum. This radar would yield a wave height greater than that obtained from the high frequency radar, and the difference would lie in the long wavelength part of the ocean wave spectrum. The two combined would give a procedure for determining swell and dead seas.

Lastly, side-looking, high resolution, image producing radars offer the promise of data on the directional wave spectrum. One such radar presently offers the essentials of stereopsis.

With further development of radar technology it should be possible to collect from airborne vehicles information needed to describe the state of the sea completely. With the advent of larger payload space vehicles, we believe that by using appropriate radars in a satellite or spacecraft the following measurements can be made of the surface structure of the ocean:

1. root mean square wave height
2. the wave spectrum
3. pictorial presentation of major wave structures, including direction.

Four possible techniques are considered feasible for obtaining the foregoing items. These are described briefly in terms of their capabilities and in increasing order of complexity.

1. NEAR-VERTICAL SCATTERING CROSS SECTION SENSOR -- This would be a low-power radar with antenna directed vertically, but with an angular beam pattern

permitting reception along the orbit to about 45°. With such a device the scattering coefficient (or a related parameter) can be measured as a function of angle. The angular response depends on the roughness of the surface. The optimum radar frequency has not been determined. The average power required will be less than 15 watts.

2. VARIABLE OR DISCREET FREQUENCY LOW-POWER VERTICAL RADAR — Below a certain frequency determined by the rms wave height, the sea reflects electromagnetic waves essentially as a mirror. Above this frequency it is a scatterer. The transition point can be determined by varying the radio frequency and determining the resulting degree of fading. The critical frequency for determining the long wavelength components of the sea lies in the region from 100 to 400 megacycles. For an operational system a narrower range probably would suffice. Peak power requirement is probably under 10 watts in the low frequency range but may reach 1000 watts near the high frequency extreme. Average power requirement is under 10 watts, plus what may be required by the recording system. The shorter wavelength components of the local windwaves would require a radar in the kilomegacycle range.

3. SCATTERING CROSS SECTION SENSOR FOR ALL ANGLES OF INCIDENCE — By elaboration of the near-vertical sensor to include all angles of incidence, the complete scattering cross section vs. angle curve would be obtained. With fixed frequency this should permit evaluation of several parts of the ocean wave spectrum. With multiple or scanning antennas the upwind-downwind ratio and consequently the directional properties of the sea may be obtained. It is possible that polarization properties of the return can be observed with little additional complication, but their interpretation awaits further research now under way. Average power of the order of 100 watts appears appropriate.

4. HIGH-RESOLUTION IMAGING RADAR — High-resolution radar can, with minor modification, yield all the information obtainable from the simpler radars. In addition it permits imaging the surface features with a resolution element perhaps better than 100 feet. This allows studying long ocean waves quantitatively and pictorially. Power requirements will probably be several hundred watts, and space requirements will be several cubic feet.

All of the above types of radar incorporate an altimetric feature permitting one foot resolution of mean sea level by appropriate averaging techniques. Such accuracy appears obtainable over distances of hundreds of thousands of miles. This topic is discussed by H. B. Stewart, Jr. in the section on Tides and Storm Surges.

MICROWAVE RADIOMETRY

Passive microwave radiometry has a history of technological development that lags behind that of radar. It employs a receiver without a transmitter and receives the signal radiated from the sea surface and the atmosphere. The properties of this signal are not so well understood as those of the radar-return signal, but it has been claimed that microwave radiometry can duplicate, for less logistic cost, some of the things that radars can do. High precision altimetry is, of course, not possible by passive means. This important capability would, of itself, justify the oceanographer's preference for radar over microwave if they were in all other respects equal.

The brightness temperature of the sea as measured with a microwave radiometer depends on three parameters: (1) the reflected brightness temperature of the sky (which is related to the absorption of the atmosphere); (2) the skin temperature of the sea; and (3) the emissivity of the sea surface (which varies with the angle of incidence, the polarization and the sea state).

A simple case has been considered analytically, and it would appear that the slope distribution of the sea surface can be estimated from comparison of the vertically and horizontally polarized brightness temperatures at the higher microwave frequencies.

Because of the obvious logistic advantages in terms of size, weight, and power requirements enjoyed by this technique when compared to radar, further investigation of the feasibility of passive radiometric determination of wave parameters would be of value.

IMPLICATIONS

The implications of the ability to measure wave parameters from satellites must be stressed. If the world ocean can be kept under day-to-day surveillance storms in remote areas, now sometimes completely missed by conventional coverage, would be detected. It would thus be possible to observe the generation of swell systems that in recent studies have been tracked halfway around the earth. The ability to forecast waves a day or so in advance would be enhanced. Such forecasts feed into the day-to-day affairs of mankind in many ways — in science, military operations, ship routing, fishing, and so on. Nor is the ability to forecast waves the only benefit derivable from the world-wide ocean reconnaissance herein envisioned. It is conceivable that the information obtained may also be of use in long range weather forecasting and ocean prediction.

Reference: Moore, R. K., T. W. Godbey, and W. J. Pierson. August 1963. "Proposal for an Electromagnetic Active Sensor of the Earth for Pogo-3" submitted University of Kansas. CELMED Proposal No. 23-036-3A

SATELLITE RADAR AND OCEANOGRAPHY, AN INTRODUCTION

Richard K. Moore

Center for Research in Engineering Science
The University of Kansas, Lawrence Kansas

Radar techniques have progressed a long way since World War II. Radar applications for military purposes, for air traffic control, and for operational meteorology have also progressed a long way. Use of radar in scientific investigations, however, appears to have lagged, possibly because it is such a powerful operational tool that its potentials as a scientific instrument have often been overlooked.

All of you are familiar with the use of radar for navigation aboard ships and aircraft. We hope, however, that you will expand your thinking about radar and realize that it is a type of remote sensor of the environment that has many possible forms and uses that may be less familiar.

The only radar flown to date in a satellite was intended to look at the ionosphere, not the ground. This is on the Alouette Canadian satellite. We at the University of Kansas are examining its ground return signals. Its frequency is low and its pulse length is long, so that it is far from an ideal instrument for earth science.

Today we shall talk about technically feasible radars that can be used as remote sensors when flown in satellites. We shall attempt to point out some ways these radars might be of help to the oceanographic community. These ideas, however, are intended primarily to stimulate your imagination so that you may help us in identifying the significant oceanographic experiments.

I shall start by going quickly through the geometric description of radar return so that pertinent parameters may be defined and identified. This will be followed by a discussion of the radar parameters that may be separately adjusted in any experiment, and of the surface parameters that may cause differences in the radar response of earth, sea or cloud. A brief description of the types of radar displays available and the sorts of systems one might use in a satellite will follow along with a discussion of some of the possible oceanographic uses of satellite radars.

This introduction will be followed by a series of talks related to certain oceanographic problems as spelled out on the agenda for this meeting. Mr. Isador Katz will concentrate especially on simple radar techniques for sensing of properties of surface waves. Mr. Bernard Schepe will concentrate especially on the mapping aspects of high resolution radar and their application to coastal geography and shore processes. Mr. Thomas W. Godbey will describe the evolution of a sea-state sensor altimeter. Each will also describe some of the properties of modern radar systems, and of the returns and imagery obtainable from them as determined by his own personal experience.

SECTION 2. RADAR RETURN PRINCIPLES

The wide variety of radars and sonars are all modifications of the same basic idea. They use some method to measure the distance to some object which returns a signal after they have transmitted it. They may also measure the amplitude or strength of the return, its polarization, its Doppler frequency shift and other properties. Radars are distinguished from passive sensors such as microwave radiometers, infrared radiometers and cameras by their observation of a known and controllable transmitted signal which permits use of time and phase information to measure range and to determine resolvable regions and targets.

Figure 1 shows the basic elements of any radar or sonar. The transmitter is the source of the radiation. It is modulated in some fashion so that travel time for the waves may be utilized to determine range or to separate signals at various ranges. Some of the simplest

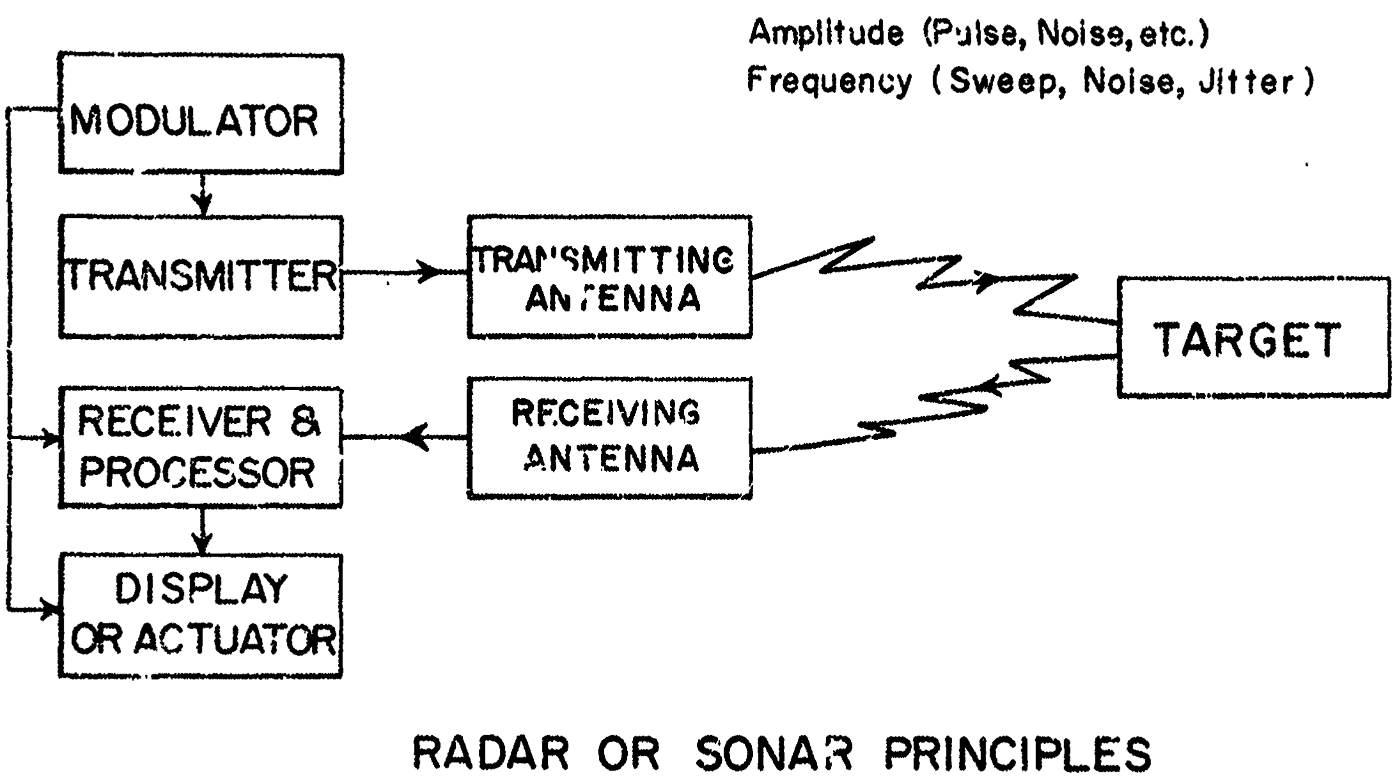

Figure 1. Basic Elements of Radar or Sonar.

radars such as proximity fuzes and velocity meters used by police do not have any modulation. The output of the transmitter is coupled to some sort of transmitting antenna (transducer in the case of sonar) and travels through space to the target (object sensed). The target reradiates the energy (it may be a beacon that amplifies it and modulates it as well) and sends it to the receiving part of the radar. It is picked up on a receiving antenna which may or may not be the same as the transmitting antenna; in fact, so called "bistatic radars" have transmitting and receiving stations in different locations. The received signal is sent to a receiver and processor which amplifies it and otherwise processes it to determine information that is desired from the signal. Processing may occur before any amplification or at various stages through the amplification and detection in the receiver. The output of the processor is presented to some sort of a display and sometimes to an actuator, as in the case of an altimeter to fire retro-rockets on a lunar landing vehicle. Information about the modulation is supplied directly to the processor and display units. This direct link is not available for passive devices.

Although transmitters have been made larger and more efficient in power as well as smaller in physical size and there have been numerous improvements in antennas, the biggest improvement in radar since World War II has been in modulation techniques and in the type of processing that is used at the receiver.

The radar equation is the basis for operation of any radar. It will be reviewed here for the benefit of those of you who do not work with it daily as some of us do.

TABLE 1

Development of the Basic Radar Equation

{Received power W_r}	=	[Power per unit area at receiver]	x	Effective area of Receiving Antenna A_r
[Power per unit area at receiver]	=	(Power scattered in all directions / $4\pi R^2$)	x	Relative power in direction of receiver f
[Power scattered in all directions]	=	(Power received at target)	x	Fraction of power not absorbed s
{Power received at Target}	=	[Power per unit area at target]	x	Effective area of target a
[Power per unit area at target]	=	(Power radiated in all directions / $4\pi R^2$)	x	Antenna gain in direction of target G_t

$$W_r = \left\{\left[\left(\frac{W_t}{4\pi R^2}\right) G_t\right] a\right\}\left\{\left[\left(\frac{s}{4\pi R^2}\right) f\right] A_r\right\}$$

Table 1 shows the development of the basic radar equation. The power received is determined by the product of the power per unit area at the receiver and the effective area of the receiving antenna. The power per unit area is the total power scattered in all directions by the target divided by $4\pi R^2$ the area of a sphere centered on the target and passing through the receiving antenna. If power were scattered uniformly in all directions by the target, there would be no muliplying factor, but it is not scattered uniformly so a factor f showing the relative power in the direction of the receiver must be inserted. This is a property of the target. The power that is scattered in all directions is a product of the total power received by the target, and the fraction of power not absorbed or transmitted into the ground or sea.

This fraction we call s. The power received at the target is the power per unit area at the target multiplied by the effective area of the target a. The power per unit area at the target is power radiated by the antenna over $4\pi R^2$ times the antenna gain the direction of the target. This chain is indicated in the equation at the bottom of the table.

It is customary to combine all three properties of the target in this equation into one quantity called the target cross section.

$$\sigma = asf$$

The effective area of the receiving antenna can be shown to be related to its gain and to the wave length, λ, as indicated by

$$A_r = \frac{G_r \lambda^2}{4\pi}$$

Making these substitutions and combining terms gives us the radar equation for a single target.

$$W_r = \frac{W_t G_t G_r \lambda^2}{(4\pi)^3 R^4} \sigma$$

If we were concerned only with ships or aircraft, or icebergs for that matter, this equation would suffice if modified to take care of the effects of atmospheric attenuation and refraction.

Most surface targets consist of numerous facets. If the illuminated area is large enough, the power received on the average is the sum of the powers received from individual facets, although for any particular pulse the signals received from the different facets may add more or less in phase so that this value is not the level for any one pulse. Thus:

$$\overline{W}_r = W_{r_1} + W_{r_2} + W_{r_3} + \dots$$

Since time fluctuations of transmitted power are translatable into distance, and since distance and direction for each of the various target facets may be different from that for another, the mean received power is indicated by

$$W_r = \left[\frac{\lambda^2}{(4\pi)^3}\right]\left[\frac{W_{t_1} G_{t_1} G_{r_1}}{R_1^4} + \frac{W_{t_2} G_{t_2} G_{r_2}}{R_2^4} + \dots\right]$$

If we had to determine the scattering cross section for each individual target facet to describe radar returns, there would be no hope of describing the signals from most complex targets. The usual technique is to talk about a mean scattering cross section per unit area for these targets. We obtain this as follows: Suppose we pick a small area ΔA_a over which W_t, the antenna gains, and the range are essentially constant. The mean power received in this area is therefore given by

$$\overline{W}_{ra} = \frac{\lambda^2 W_{ta} G_{ta} G_{ra}}{(4\pi)^3 R_a^4}\left[\sigma_{a1} + \sigma_{a2} + \sigma_{a3} + \dots\right]$$

We define the mean scattering cross section per unit area as that number which, when multiplied by the area, gives the sum of all the components from the scatters in the small area. Actually, this definition must include an average over a number of comparable areas. The next equation indicates its form for one particular area.

$$\sigma_{oa}\Delta A_a = \left[\sigma_{a1} + \sigma_{a2} + \sigma_{a3} + \ldots\right]$$

If we designate a series of these areas with subscripts a, b, c, the total mean return is given by the next two equations

$$\overline{W}_r = \overline{W}_{ra} + \overline{W}_{rb} + \overline{W}_{rc} + \ldots$$

$$W_r = \frac{\lambda^2}{(4\pi)^3}\left[\frac{W_{ta}\,G_{ta}\,G_{ra}\,\sigma_{oa}\,\Delta A_a}{R_a^{\,4}} + \frac{W_{tb}\,G_{tb}\,G_{rb}\,\sigma_{ob}\,\Delta A_b}{R_b^{\,4}} + \ldots\right]$$

It is customary to replace a sum of this sort by an integral on the assumption that the small areas may be decreased without limit. In fact, of course, this is not strictly legitimate, for shrinking the areas to the size of a wavelength will violate the requirement of many scatterers within a given area. Nevertheless, it is a convenient description that ordinarily is applicable. The result is shown in the final equation,

$$\overline{W}_r = \frac{\lambda^2}{(4\pi)^3}\underbrace{\int\frac{W_t G_t G_r \sigma_o \Delta A}{R^4}}_{\text{area contributing to returns taken together}}$$

This is the radar equation for an area-extensive target. Note that the integral or summation is carried over the area contributing to the returns considered together. This area may be determined by antenna beam width, by pulse length, by modulation wave form of a frequency modulation or a noise modulation character, by some property of the processing system, etc.

Table 2 shows the factors determining this area for some simple radars. For an ordinary pulse radar, it is determined by the pulse length and/or the beam width. For an FM radar, pulse length is replaced by width of a filter determining a selection in the difference frequency between transmitted and received signals. The beam width is again a factor. For Doppler radar, a filter width may be pertinent. The beam width is, as always, pertinent and the radar may involve a pulse which also can determine the area contributing. Other types of modulation result in other factors determining the properties of this equation.

TABLE 2

Parameters Which Set Area Contributing To Radar Return

Type	Area set by
Straight pulse radar	Pulse length, beam width
Frequency modulated radar	Filter width, beam width
Doppler radar	Pulse length, filter width, beam width
Other types	Set in other ways

I should like to reiterate that the signal calculated using the radar equation is an average signal, and individual signals fluctuate widely from this value. Figure 2 is an example of the fading that can take place at a particular range from a single area target as a radar flies past the target. This fading occurs in distances that are quite short.

The radar equation can be readily modified from an area integral to a volume integral to take into account the type of scatter that occurs in precipitation or cloud.

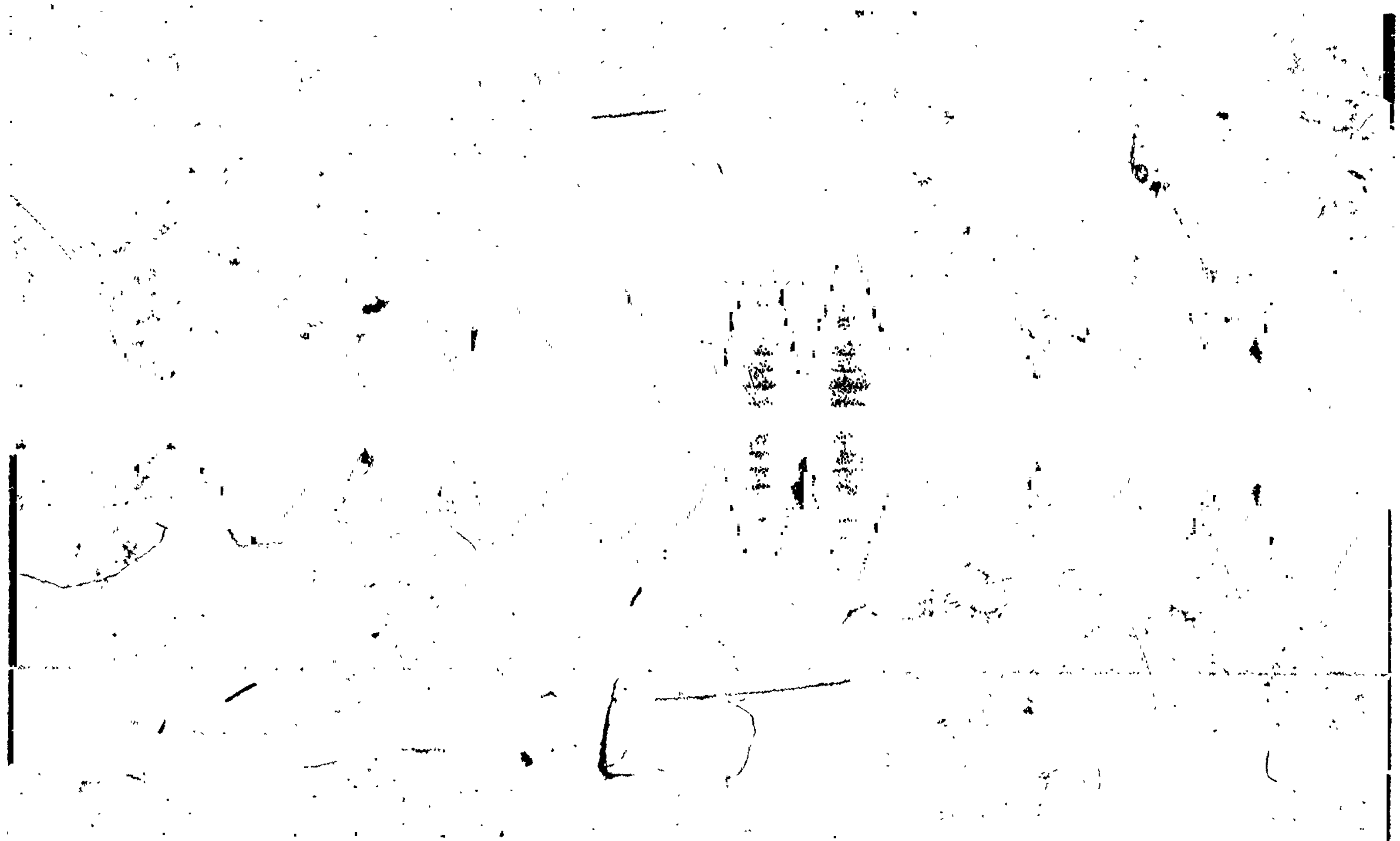

Figure 3. Fading of Signal as Radar Flies Past the Target.

In the radar equation, the only thing that cannot be controlled in the systems design and operation is the scattering cross section itself. It is this scattering cross section per unit area that, by its fluctuation, makes it possible to detect ships on the sea, rivers in the land, buildings in cities, and all the numerous other things that a radar can show. Thus, it is extremely important to consider properties of the scattering cross section.

SECTION 3. PROPERTIES OF SCATTERING CROSS SECTION

The scattering cross section is a function of many conditions of the use of the radar as a sensor. Table 3 indicates this. The angle of incidence or angle of depression strongly influences the scattering cross section. The azimuth angle at which we look at a surface may influence the cross section too. For example, the radar cross section near grazing incidence is significantly different when we look upwind at the sea at the steep slopes of waves coming toward us or downwind at the less steep slopes of waves going away from us.

TABLE 3

Variable Parameters of Radar and Target That Determine Scattering Cross Section Per Unit Area

1. Angle of incidence	4. Frequency
2. Azimuth angle	5. Size of region averaged
3. Polarization	6. Distance

Scattering Cross Section Set By

1. Structure heights	3. Dielectric properties of material
2. Slopes of surfaces	4. Orientation of structure

Scattering is a function of the polarization of the wave transmitted, and in some cases one can receive a quite different polarization from that transmitted, depending upon the properties of the surface. Scattering cross section varies with frequency, the variation with frequency being different for different types of target. The effective cross section depends to some extent upon the size of the region averaged. For example, the effective scattering cross section of a city would be quite different from that for a single street, building roof, or park.

A scattering cross section may be a slowly varying function of distance as individual facets that appear large at close range become relatively small at greater ranges. No systematic study has been made of this.

Given any set of conditions that we may control, such as those listed, the scattering cross section is determined by properties of the target surface. At radar frequencies commonly used, structural properties of the surface are most important, both structural heights and slopes. Surfaces one would describe as rough do not return as great a signal at normal incidence as smooth surfaces, but they return much stronger signals at grazing incidence. For a given set of structural properties, the dielectric properties of the material can make a big difference in the signal returned. With the ocean, dielectric properties are essentially constant as far as radio waves are concerned, but there would be a big difference in signal returned from ice and sea having the same relief.

Scattering properties may be quite strongly influenced by the orientation of structures and their regularity or irregularity.

More information is available about the variation of scattering cross section with angle of incidence than with respect to any of the other parameters. Figure 3 indicates roughly the sort of variation of scattering with angle one observes for smooth and rough seas and for smooth sand having the same structure as smooth sea. The return from a smooth sea is very strong near the vertical but weak at large angles and, in fact, it becomes very weak only a short distance from the vertical. With rougher sea, the signal is not as strong near the vertical, but is considerably stronger out at angles. We are familiar with this from shipboard

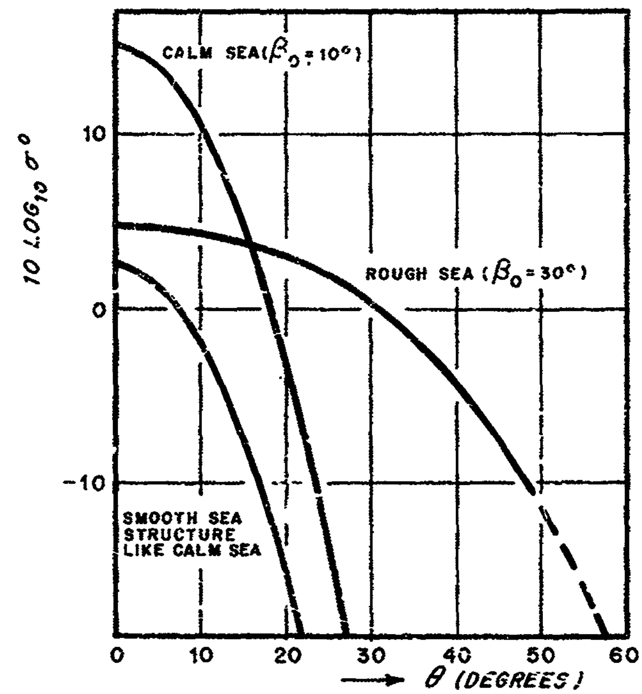

Figure 3. Observed Scattering Angle.

radar. When the sea is smooth, the "sea return circle" is small because the signal at the large angles from the vertical is so weak that we cannot see it very far. When the sea is rougher, the "sea return circle" is larger because the signal near the horizontal is stronger, and therefore detectable at longer range.

The curve for sand having the same structure as the smooth sea, has the same shape as the comparable sea curve, but the dielectric properties of sand cause a smaller reflection coefficient and consequently a weaker echo.

The structure of the curve of scattering versus angle near the vertical is determined by large scale properties of the surface (in terms of wavelength). This has been ascertained experimentally and theoretically. Near the horizontal, the scattering is more likely to be determined by the small scale structures. Furthermore, near the horizontal the effect of aspect angle is more important so that, for example, in this region the scattering coefficient may be quite different for upwind and downwind echoes from the sea.

The effect of polarization as a function of angle has not been studied nearly so widely as the scattering coefficient. Near the vertical, polarization has little effect, although a cross-polarized component can be observed from rough surfaces. Near the horizontal, polarization can be quite significant, but the effect depends upon the type of surface. For example, on a relatively smooth surface near the Brewster angle one does not expect much return from vertical polarization, but the Brewster angle does not exist for horizontal polarization so it is not so affected. On the other hand, one expects a strong return from vertical polarization with a forest where there is a great deal of vertical structure and not so much horizontal structure.

SECTION 4. RADAR DISPLAYS

Various types of radar displays have been known for some time. Figure 4 shows some of these pictorially. A meter may be used to show distance as in an altimeter, speed as in a velocimeter or direction. An A-scope shows amplitude of return as a function of time and therefore distance for a fixed position of the antenna. It can be quite useful in such applications as the landing of aircraft using GCA (Ground Controlled Approach) or even in locating ships at sea from an aircraft. Certainly, it is not much help in handling interpretation of signals from a complex target such as a city.

The B-scope is a distorted map with range as one coordinate, antenna angle as the other, and signal intensity appearing as light intensity on the screen. It is distorted because it is a rectangular presentation of a polar plot and also because it uses slant range rather than ground range. The PPI (Plan Position Indicator) is a less distorted picture of the same type. By computing ground range from the slant range and applying this as a distortion correction prior to the application of the signal to the cathode ray tube, it is possible to make this essentially an undistorted map.

Accuracy has been improved since the war so that range measurements at quite long distances can be made to only a few feet and quite small areas can be resolved on the PPI or B-scope. The biggest improvement in mapping has come with the use of side-looking radars, especially those having synthetic apertures.

A side-looking radar map is generated by flying parallel to the strip to be mapped and pointing an antenna directly to the side. A presentation of one line at a time on an oscilloscope, with intensity as a function of range, is photographed continuously with motion of the film corresponding to motion of the aircraft or satellite. This, if the difference between slant range and ground range is compensated for electronically, this presents a true map of a strip of terrain to the side of the flight path.

It has always been relatively easy with radar to resolve in range because it has been easy to obtain short pulses or to achieve the same effect by other modulation schemes. Resolution in angle, on the other hand, has always been difficult, although for particular

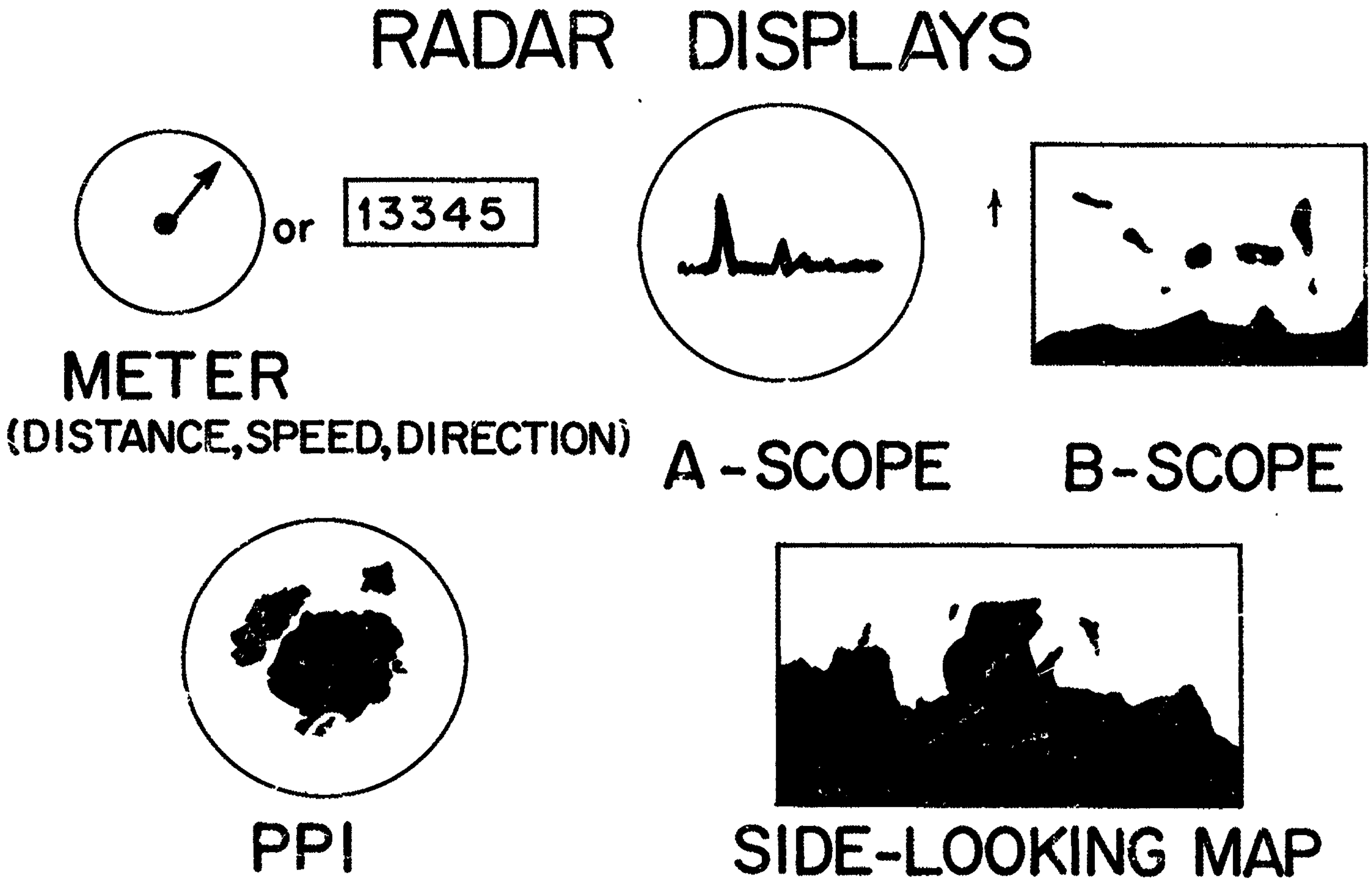

Figure 4. Types of Radar Displays.

isolated targets such as aircraft or ships, such resolution has been possible by nulling systems.

The angular resolution of an atenna is determined by its length in wavelengths. To get a realy narrow-beam one must use a really long antenna. Thus, antennas used for radio astronomy get to be quite monstrous. Carrying these monsters aloft in an airplane or a satellite is another matter!

By the end of World War II some really large antennas were carried aloft in the AEW (Airborne Early Warning) systems. These are still in use in modified and improved versions, and we have all seen the pregnant Constellations that carry these antennas out to sea.

For a given size of aircraft or satellite, it is easy to make a fixed antenna long in the direction of the length of the aircraft so that it can look to the side easily with good resolution. So called "brute-force" high-resolution radars use this technique to generate very high quality maps. For example, a 10 meter long antenna at 1 centimeter wavelength has a beam width of less than 0.1 degrees. This means that at 20 miles it can resolve about 150 feet. By combining pulse and frequency modulation, it is possible to get its range resolution down to 5 or 10 feet at quite long distances.

In recent years, synthetic aperture techniques have been developed which permit extending the effective length of the antenna far beyond the length of the airplane or satellite and separately focusing at different ranges so that the width of the resolvable patch is independent of range and, in theory, about equal to the physical length of the antenna. The practical resolution capabilities of these radars is classified. I have carefully avoided learning any of this classified information prior to this meeting so that I may speculate on the basis of unclassified information. It seems reasonable to assume that practical resolution as good as twice the physical length of a fairly large antenna may be achieved from ranges as far away as those of satellites. Thus, it should be possible, for example, to resolve patches 20 feet on a side from satellite altitudes. Even if the mechanization of the theory is not nearly as good as I think it is, it would certainly seem that resolution of patches less than 100 feet from satellite altitudes should be feasible.

When we talk about mapping to an accuracy of a few tens of feet from a satellite on a world wide basis, we are truly discussing a kind of accuracy that permits radar performance greatly superior to anything dreamed of at the end of World War II.

SECTION 5. POSSIBLE SATELLITE EXPERIMENTS OF OCEANOGRAPHIC INTEREST

Two quite different remote sensing experiments using radars in satellites have been proposed by The University of Kansas. The first uses a 10 pound package on an unmanned satellite. The second uses a much larger package, of which the size is not yet determined, on a manned Orbiting Research Laboratory.

The simplest experiment involves a radar that is basically an altimeter. Its antenna pattern is narrow in one direction (perpendicular to the flight path) and about 45 degrees wide along the path. The signal returned to this sensor is sampled at various time delays so that a curve of scattering coefficient versus angle can be determined from the information telemetered to earth. In addition, altitude can be measured to an accuracy of about 10 feet. Table 4 shows some possible uses of this simple radar. Recalling the difference between the scattering coefficient variation for smooth and rough seas, you can see that the curve obtained should allow world wide mapping of sea state. The accurate altitude information permits determination of midocean sea levels, or profiles of the mean sea level across a tropical storm (where one expects the sea level to be highest near the periphery and lowest in the middle). Difference in the amplitude of return as well as shape should permit detection of the boundaries of sea ice and the boundary between frozen and moist ground. Heavy precipitation over a sufficiently wide area (20 or 30 square miles) should also be detectable.

TABLE 4

Possible Uses of Simple Satellite Altimeter-type Radar

Sea state

Mid-ocean sea levels

Profile of mean sea level across a tropical storm

Boundary of sea ice and open spaces

Boundary between frozen and moist ground

Heavy precipitation

Radar weight - 10 lbs. Radar volume 350 cu. in.

The second proposed experiment uses a "Rolls Royce of radar" - a mapping radar obtaining its high resolution by synthetic aperture techniques, using several frequencies, and presenting the results for the different frequencies on a polychromatic display. The next slide shows some of the types of oceanographic work that might be done from such a radar. It can of course do anything that the altimeter-type radar can do, but it can also map icebergs and shipping (even indicating the size of ships and icebergs). With its increased sensitivity, precipitation in much smaller cells can be distinguished from the non-precipitating clouds. It can make accurate maps of coast lines around the world, including quick surveys after large storms. It can map floods in remote areas (and it might be the best way to map floods even in this country). It has been suggested that it might track buoys in various oceanic currents, probably using some kind of transponder on the buoy rather than depending on the radar return from it.

SECTION 6. CONCLUSION

Radar in satellites, we believe, has great potential for oceanography. I have tried to stimulate your imagination with some examples. No doubt many more interesting ones will turn up during this week.

N65 30387

RADAR BACKSCATTERING FROM THE SEA

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Applied Physics Laboratory, Johns Hopkins University

INTRODUCTION

In this paper we wish to discuss the relationship between radar backscattering from the ocean surface and the structure of that surface. Energy incident on the ocean surface is scattered in a manner dependent upon the structure of the surface. When the ocean is smooth the scattering is essentially a specular reflection. When the surface is rough, scattering takes place in all directions; some of the energy returns to the radar receiver and is detected just as any target would be at that same range. Generally, returns from sea and land surfaces compete with signals from discrete targets and are regarded as a nuisance; it is referred to as "clutter". In that there exists a direct relation between the backscattering and some aspects of the wave structure it is the thesis here that we can employ the characteristics of the return from clutter to measure waves.

We wish to describe how the ocean appears to a radar mounted in an airplane flying above the surface and how these returned signals are interpreted. Then we will discuss our present program to learn more about this problem and we will close with a statement suggesting the basis on which one could build a satellite-borne radar to determine the ocean surface structure.

SEA CLUTTER

Let us turn our attention to the clutter problem[1]. A smooth, conducting surface backscatters only at normal incidence. For all angles other than 90 degrees there is no backscattered energy. A rough surface, however, also scatters energy in other directions. Radars aboard ships and aircraft are frequently limited in their operation because of such clutter. If the clutter signal is larger than the return from a target the target will be obscured. While the physical nature of the backscattering problem is not yet completely understood, there are certain features of the problem which are gradually becoming clear and which we can use to our advantage in a manned satellite.

Sea clutter is generally described in terms of the radar cross section per unit area of the sea surface, σ_o. This is a dimensionless measure of the reflective property of the surface and it depends on grazing or depression angle, polarization, sea roughness and orientation of the radar with respect to the sea.

SCATTERING VERSUS ROUGHNESS, POLARIZATION AND WIND DIRECTION

An example of such scattering is shown in Figure 1. This is a pair of curves obtained by the Naval Research Laboratory in flights over Lake Michigan. Here we see the normalized radar cross section plotted against depression angle (90 degrees means normal incidence, i.e., the radar is looking straight down at the water surface). These are two curves drawn through the experimental points, one for horizontal polarization and one for vertical. At large depression angles there is no significant difference between the two polarizations; at smaller angles the returns on vertical polarization are larger than on horizontal. There is a large return at the large depression angles and the analytical shape of the curve follows $\exp(-k \cot^2\theta)$ where θ is the depression angle. At the smaller angles the curves may be fitted with a curve whose form is $\exp(-k \cot\theta)$. At the larger angles we think of the scattering as coming from groups of reflecting facets on the sea, each facet acting as a mirror. The distribution of the slopes of these facets determines the shape of the peak of the curve. At the lower angles the scattering is more "diffuse" and we think of the individual scattering elements as smaller and hence more isotropic. For rougher seas these curves become "flatter" and approach a sin θ dependence. At the same time the difference between the two polarizations tends to disappear. We illustrate the specular (directive) scattering and the diffuse (less

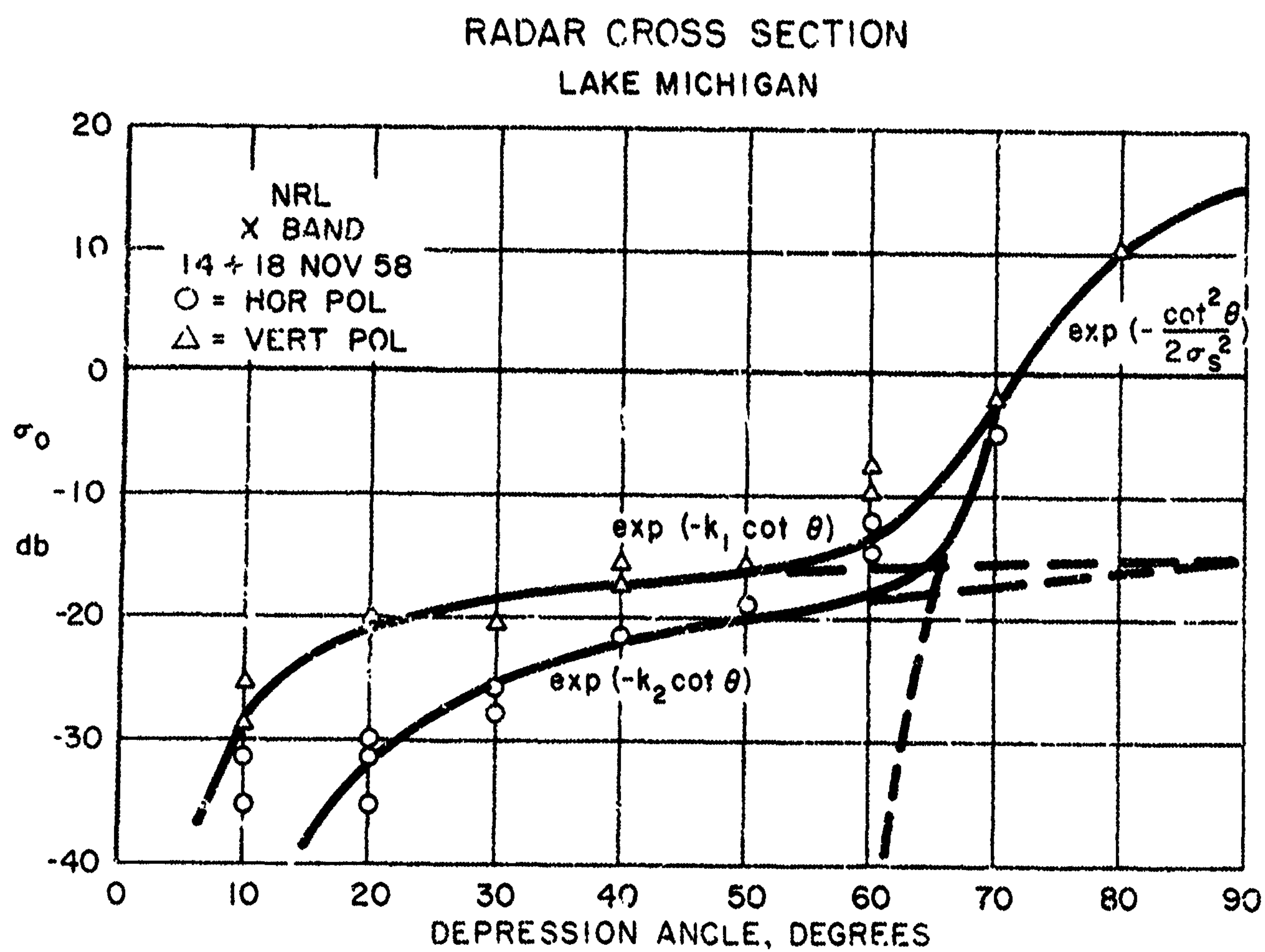
RADAR CROSS SECTION
LAKE MICHIGAN
NRL
X BAND
14 + 18 NOV 58
O = HOR POL
Δ = VERT POL
σ_0
db
exp $(-k_1 \cot\theta)$
exp $(-k_2 \cot\theta)$
exp $(-\frac{\cot^2\theta}{2\sigma_s^2})$
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
90
DEPRESSION ANGLE, DEGREES

Figure 1

directive) scattering in Figure 2. At the very small depression angles there may be yet a third mechanism: scattering caused by vertical structures which yield a rise in scattering with decreasing angle. This type of angle dependence has been measured over land but not over water, to our knowledge. However, at the small depression angles there does seem to be a reversal between the two polarizations. In Figures 3 and 4 we see σ_o versus θ for smooth and somewhat rougher conditions. These are results of experiments performed by the Royal Radar Establishment at Great Malvern, England. Note, that σ_o for horizontal polarization is greater than for vertical and that the curves are perhaps 10 db higher in reflectivity for the higher sea states. These curves are merely illustrative of the fact that the return is dependent on roughness. There now exists an imposing array of curves from experiments performed at various laboratories which indicates the same qualitative behavior. There is also a clear-cut dependence on wave (or wind) direction, upwind scattering is greater than downwind. There is ample proof of the dependence of radar clutter on wave height, polarization and wind direction.

It has been known for a long time that the small irregularities on the water surface are important in determining backscattering. Gages of various kinds are available to measure water height at one point on the ocean, but none could yield the two dimensional space-spectrum of the small waves. The method being used for the present purpose was developed by Oceanics, Inc. under contract with ONR which was supervised by APL. It consists of a pair of specially modified aircraft stereo cameras mounted 20 feet above the water and about the same distance forward of the ship's bow. The mounting is shown in Figure 5. The ship moves forward at a slow speed while stero photographs are taken of the water.

These stereo photographs are processed by Aero Service Corporation to obtain wave heights for any designated portions of the water surface. During the 1965 tests in Chesapeake Bay and in the Atlantic Ocean, it was found that with cloudy skies the stereo photographs were of excellent quality. When the sky was clear good quality stereo photographs could be obtained only during early morning and late afternoon hours, when the sun is at a relatively low angle in the sky. Under optimum lighting conditions wave height measurements to a sensitivity of 0.02-inch have been made. To our knowledge this is the finest resolution yet achieved in any wave measurement program anywhere.

Sea reflectivity measurements are being made by NRL with their multi-band airborne radar installed in a Navy WV-2 airplane. In Figure 6 is shown a photograph of the airplane in flight during one of the experiments. The radar has a 5-degree beamwidth, a pulse length of 0.3-microsecond, and a repetition rate of 1000 per sec. Both polarizations are used.

SCATTERING VERSUS ELECTROMAGNETIC WAVE LENGTH

Whether the sea surface can be considered smooth or rough, of course depends on the wave length of the radar. One criterion of roughness was given by Rayleigh. He showed that a surface was rough when

$$\frac{h \sin \theta}{\lambda} < \frac{1}{8}$$

where h is the roughness element height, θ the depression angle and λ the electromagnetic wave length. Clearly, one may postulate that if the radar wave length were varied or if one could build a multi-frequency radar (polychromatic) one should have a good tool with which to probe the nature of the surface. Such a radar has been proposed[2] but to our knowledge not yet built. Theoretical analyses have indicated[3] that the backscattering should vary inversely with λ and the dependence should be between λ^{-2} and λ^{-6}. To date, there is insufficient organized experimental data to yield a clear-cut answer to the wave-length dependence.

EXPERIMENTAL PROGRAM TO STUDY RADAR REFLECTIVITY

Experiments to find radar sea reflectivity at microwave frequencies have been performed for many years at various laboratories. Although some progress has been made, there remained a gap in our knowledge. This gap was a result of our inability to describe the

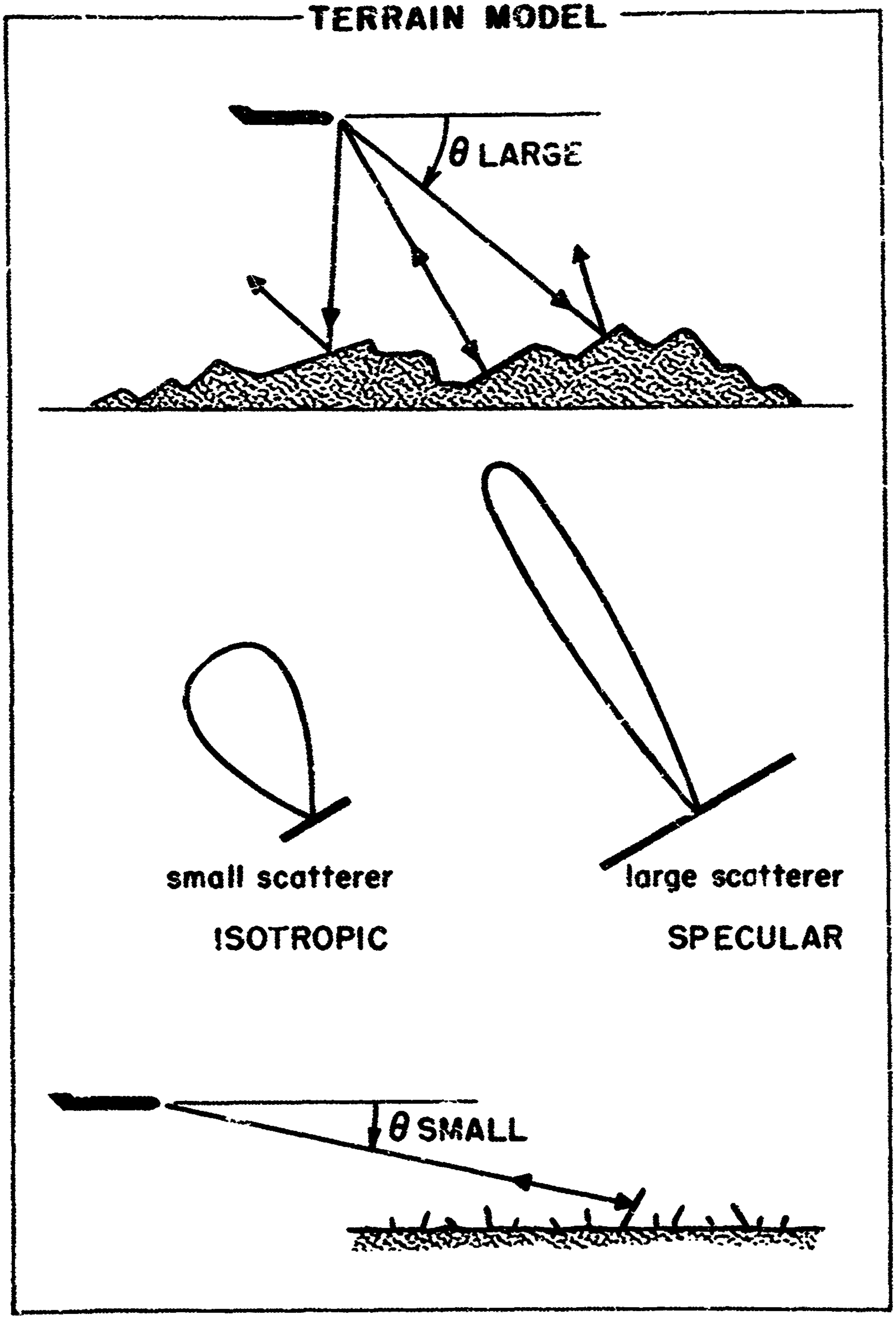
TERRAIN MODEL
θ LARGE
small scatterer
ISOTROPIC
large scatterer
SPECULAR
θ SMALL

Figure 2

RADAR CROSS SECTION

SEA RETURN

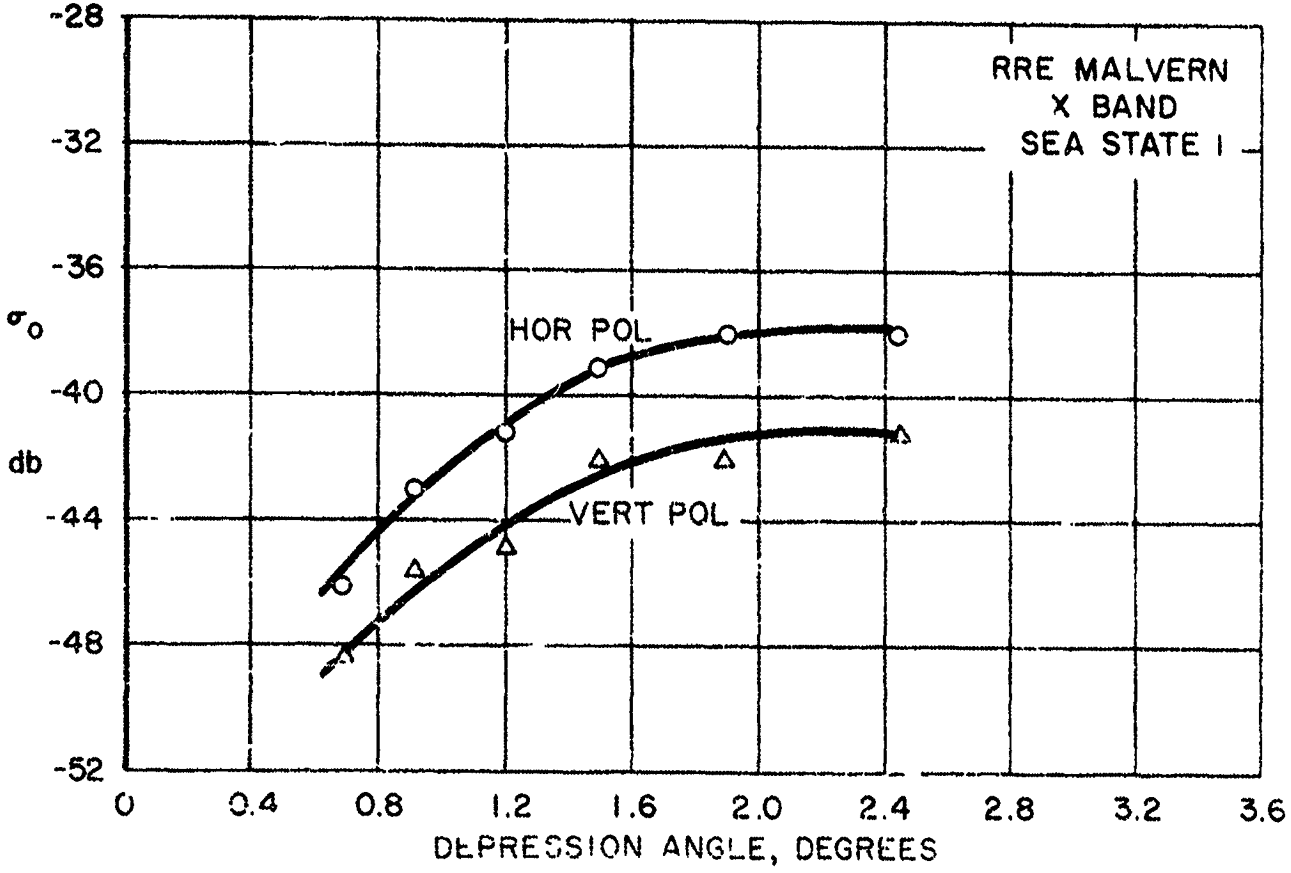

Figure 3

RADAR CROSS SECTION
SEA RETURN

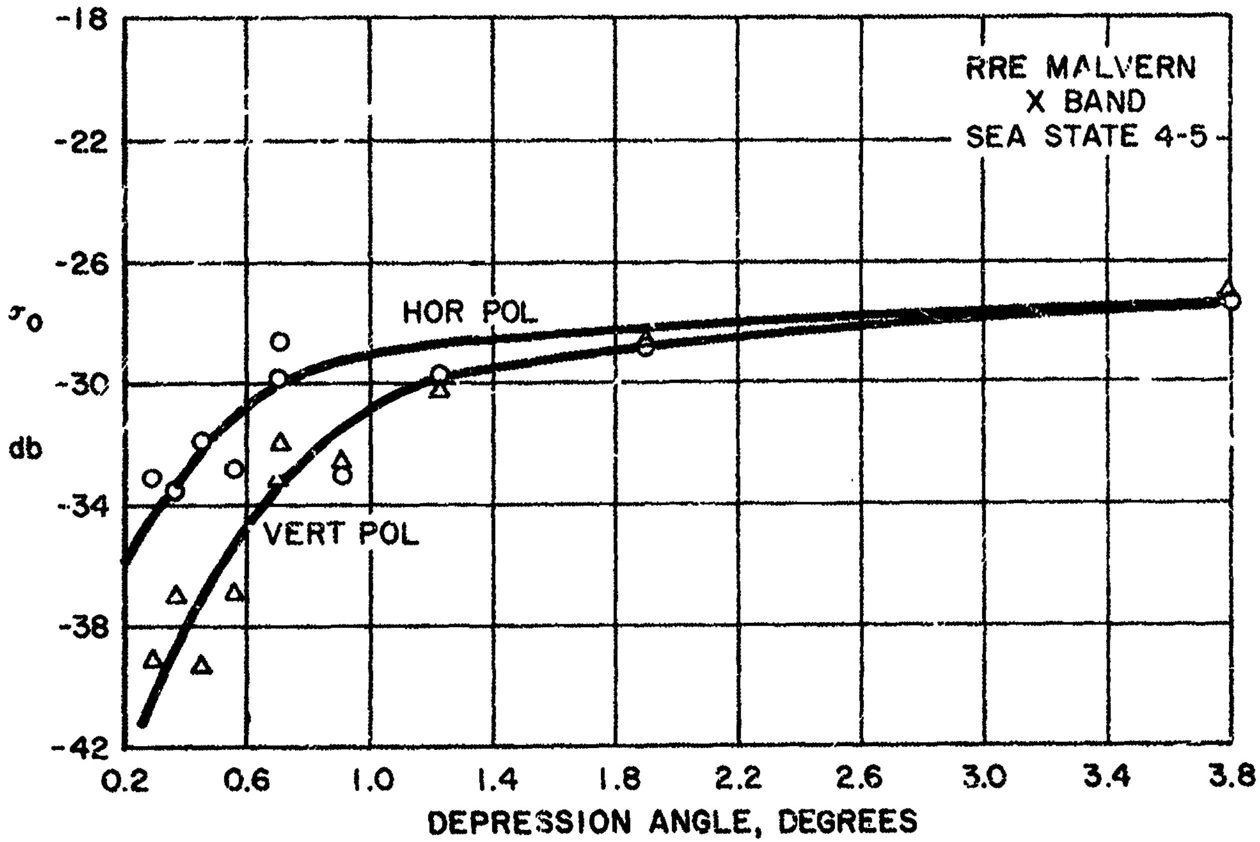

Figure 4

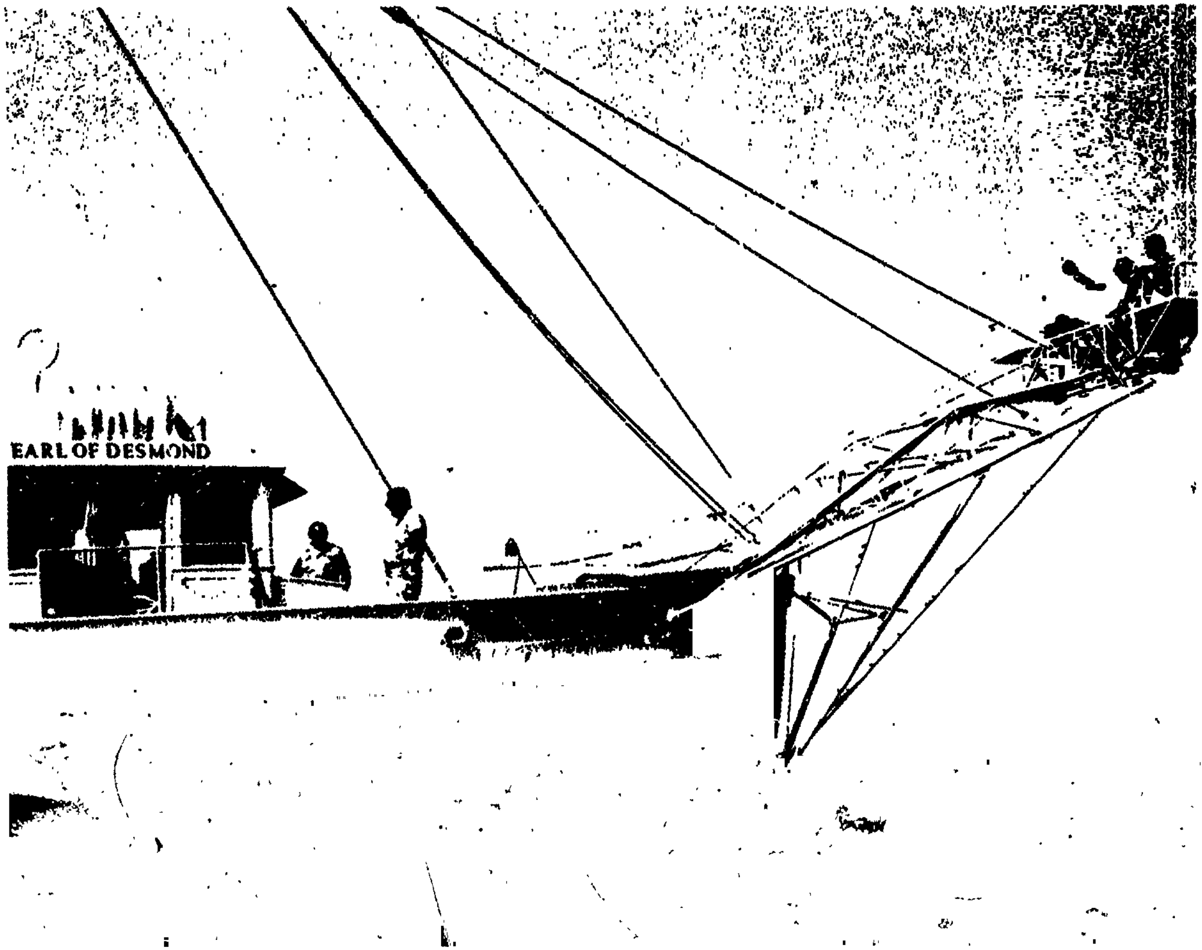

Figure 5. Stereo Cameras Mounted on a Vessel.

Figure 6. Airplane in Flight During an Experiment.

sea in a quantitative manner. Radar measurements with no simultaneous sea measurements are relatively meaningless. A series of tests was designed to measure clutter and the sea in a quantitative and meaningful manner.

The attack on the problem has two main directions: a shipborne system designed to measure the ripples and waves on the water, and an airborne calibrated radar to determine the reflection characteristics of the sea.

During the operation the airplane flies in the vicinity of the ship making reflectivity measurements, while the waves are being recorded with the stereo cameras and a spar-buoy wave gage.

A POSSIBLE RADAR FOR MANNED SPACE SHIP

Although the problem of scattering from a rough surface has yet to be solved completely we know that a radar can be designed which will yield information regarding the state of the roughness of the surface. Figure 7 illustrates this point. We plot σ_0 versus depression angle over the entire angular region. Three curves are shown for three different surfaces: smooth, intermediate and rough. The smooth surface as discussed previously, results in a curve with a large peak about 90 degrees but small reflectivity at the lower angles. When the sea is rough the curve is flat as indicated. For the varying sea states between these extremes we obtain curves of different shape. On this basis alone (disregarding polarization and wavelength dependence) we can determine the wave roughness from a single set of measurements from a satellite.

A radar whose parameters are:

Transmitted peak power	=	10^6 watts
Pulse length	=	10^{-4} sec
Antenna gain	=	4.5×10^3
Wave length	=	3 cm
Noise factor	=	3.2
Losses	=	10
Beamwidth	=	2.5 degrees,

can give a signal-to-noise ratio of unity at a distance of about 1000 miles on a surface whose reflectivity is 10^{-6}. This means if our radar is in a satellite whose orbit is about 200 miles above the earth it is able to obtain information 20 db below the lowest value shown in Figure 7. The average power of such a radar transmitting one pulse per second is about 100 watts.

CONCLUSION

Radar reflectivity of the ocean surface depends on the structure of the surface. It depends also on the wavelength and polarization of the electromagnetic energy transmitted A satellite-borne radar could be used to determine the water surface roughness of ocean below by measuring radar cross section as a function of depression angle.

REFERENCES

(1) For a more detailed discussion of the clutter problem see: Katz, I., "Radar Reflectivity of the Earth's Surface", APL Technical Digest, January 1963.

(2) Katz, I., and L. M. Spetner, "A Polychromatic Radar", APL Report No. CF-2898, 24 October 1960.

(3) Spetner, L. M., and I. Katz, "Two Statistical Models for Radar Terrain Return", IRE Trans on Antennas and Propagation, Vol AP-8 No. 3, May 1960.

RADAR CROSS SECTION

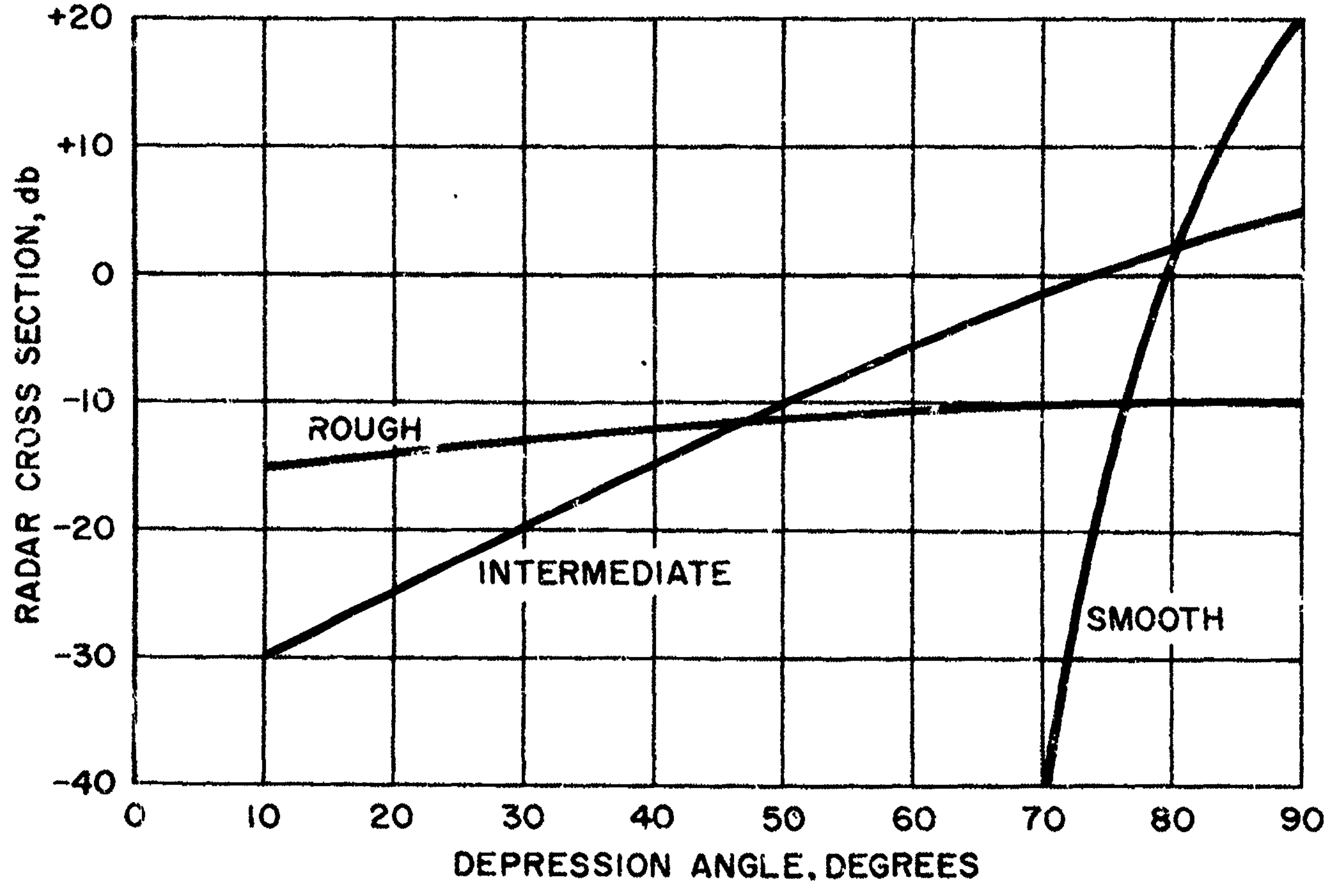

Figure 7

THE APPLICATION OF AIRBORNE RADAR BACKSCATTER TO MEASUREMENT OF THE STATE OF THE SEA*

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ABSTRACT

This paper explores the possibility of using radar backscatter from the sea surface as a measure of the waves present. Wave profiles read from stereo-photographs of the waves, obtained on a ship, are reduced to statistics of a kind that may be compared with radar backscatter measured simultaneously. The wave statistic are also compared with model tank data. It appears, from these preliminary experiments, that good correlation can be obtained between wave and radar statistics, the best statistic for correlation remains to be determined. The uniqueness of correlation will depend on further analysis in different states of sea.

ACKNOWLEDGMENTS

The work presented herein was supported by the Office of Naval Research and administered by the Geophysics Branch. Helpful discussion in the organization of the program was provided by Messrs. Isadore Katz, Frank Macdonald, and Dr. W. J. Pierson, Jr. Miss Virginia Amantia carried out the calculations and Louis Muller prepared the figures.

INTRODUCTION

The destructive effect of ocean waves on structures and beaches along the coasts of the world's land masses needs no elaboration here. For day-to-day operation as well as for long-range shore-protection planning, it is as necessary to predict waves as it is to forecast meteorological variables at any inland point. Unlike the meteorologist who is able to collect many hundreds of weather reports as input data to his prediction technique, the wave analyst is, in effect, starved for input. His basic wave data derives from wind fields inferred from sparse observations at sea; the occasional visual wave report is not much help.

The need for ocean-wide wave information, on a routine basis, is apparent and considerable thought and effort is now going into schemes that will provide such data. Among the ideas being considered for synoptic wave-coverage is an ocean-wide buoy network and the polar-orbiting satellite.

Another possible source of synoptic wave information may come as a by-product of research that is entirely unrelated to wave prediction. This is the study of radar backscatter from the sea surface and its relation to wave characteristics (Katz, 1963).

The development of the radar as an instrument for detection and classification has been considerably hampered as regards targets in the sea, because the backscattered radiation from waves often obscures the return sought from the target. This "clutter" frequently limits the search capability of ships and planes. If the physical nature of the backscatter were well understood, it might be possible to separate a weak target signal from such background noise. Consequently, much effort is being spent to determine the relationship between the electromagnetic radiation observed by a radar and the ocean-wave surface from which the radiation is reflected (Macdonald, 1963). Since the reflectivity of the surface depends on the state of the sea, it is also necessary to relate changes in radar backscatter to changes in wave development. It is therefore logical to conclude that a necessary feature of ultimate radar detection will be a reasonable correlation of radar backscatter with state of sea. By the same token, successful achievement of such a correlation will permit identification of wave conditions from radar measurements.

*Sponsored by ONR under Contract Nonr 3961(00). This paper submitted to: Proceedings IXth Conference on Coastal Engineering, Lisbon, 1964.

This paper discusses the way in which profiles of the sea surface are converted into wave statistics that may be compared with radar statistics of the same kind. Some of the initial experiments will be described and some wave-radar correlations will be shown. The ultimate application of such a successful correlation might be the systematic reporting of sea state along lines of flight of aircraft equipped with appropriate radar or from orbiting satellites.

CONVERSION OF WAVE DATA TO RADAR STATISTICS

The radar observes reflections from facets on the surface of a wave; the strength of the reflected signal depends on the size and orientation of the facets with respect to the angle of incidence and frequency of the radiated signal. For the purposes of this experiment, the radar scanned the wave surface in a direction generally perpendicular to the wave crests, first upwind (against the waves) and then downwind (with the waves). Figure 1 shows a typical recording of radar backscatter. During the run, direction, polarization, and rate are held constant while the return at different power-input levels is recorded as a function of radar depression angle (that is, the angle with respect to the horizon) for periods of 20-30 seconds. On successive runs, the experimental parameters are varied one at a time. From data such as shown in Figure 1, the average amplitude of the radar return, at the 50% level, is tabulated for each depression angle in terms of the other parameters. The ratio of the upwind-downwind return from the sea surface is a measure of the backscattered radiation and is one of the statistics that might successfully define the state of sea. Since the upwind-downwind ratio will change with radar depression angle, the final "radar signature" of the sea surface will be a curve of upwind-downwind ratios versus depression angle.

In this section, the way in which wave profiles are converted to radar statistics is described. This method was introduced by Schooley (1961, 1962) who studied the problem, in a model tank. Schooley also provided partial justification for the basic assumption of this study; that is, that the wind speed is the primary factor that influences the roughness and slope distributions of the tiny wavelets in the sea and that these distributions are significantly unique in different states of sea. By carrying out a dimensional analysis, it was shown that air momentum (M) and air viscosity (η) acting on a water surface that resists deformity through gravity (g), water density (ρ_w) and surface tension (T), produces a roughness condition (R), characterized by a slope distribution (s)

$$s = f\left[R, \frac{g\rho_w\rho_a}{T\eta}(Fhv)\right]$$

In this expression, the air momentum is expressed in terms of air density (ρ_a), fetch (distance over which wind blows) (F), the effective height of the wind (h) and the wind speed (v). The term

$$\frac{g\rho_w\rho_a}{T\eta}$$

is considered to be constant. The fetch determines the state of wave development for any given wind speed and the effective height prescribes uniformity in correlation of wind speed with sea state. Therefore, it is the wind speed that primarily governs the slope characteristics of the waves. The successful application of the method proposed here will depend upon significant changes in the slope distribution with changes in wind speed and corresponding significant changes in the radar signature.

Figure 2 shows some portions of wave profiles (originally 6 meters long) obtained from different stereo-photographs of waves made in the same sea condition. Figure 3 is an enlargement of a small section of a wave profile. This profile lies in the dominant direction of the waves as well as in the path of the NRL* radar plane which was overhead at the time the wave information was obtained. Some basic definitions can be derived from Figure 3. Flatness

*Naval Research Laboratory, U. S. Navy.

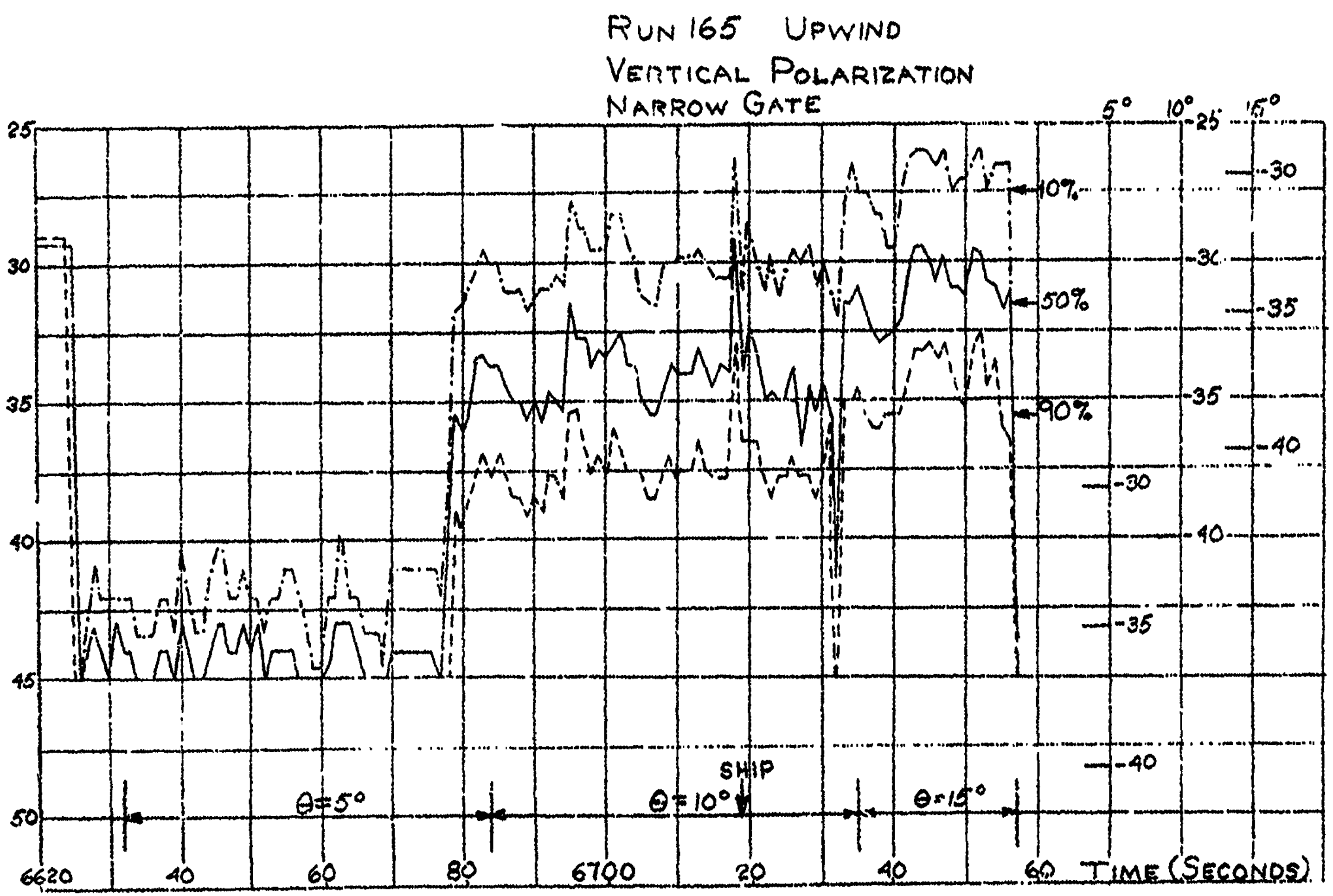

Figure 1. Typical Record of Radar Return Data

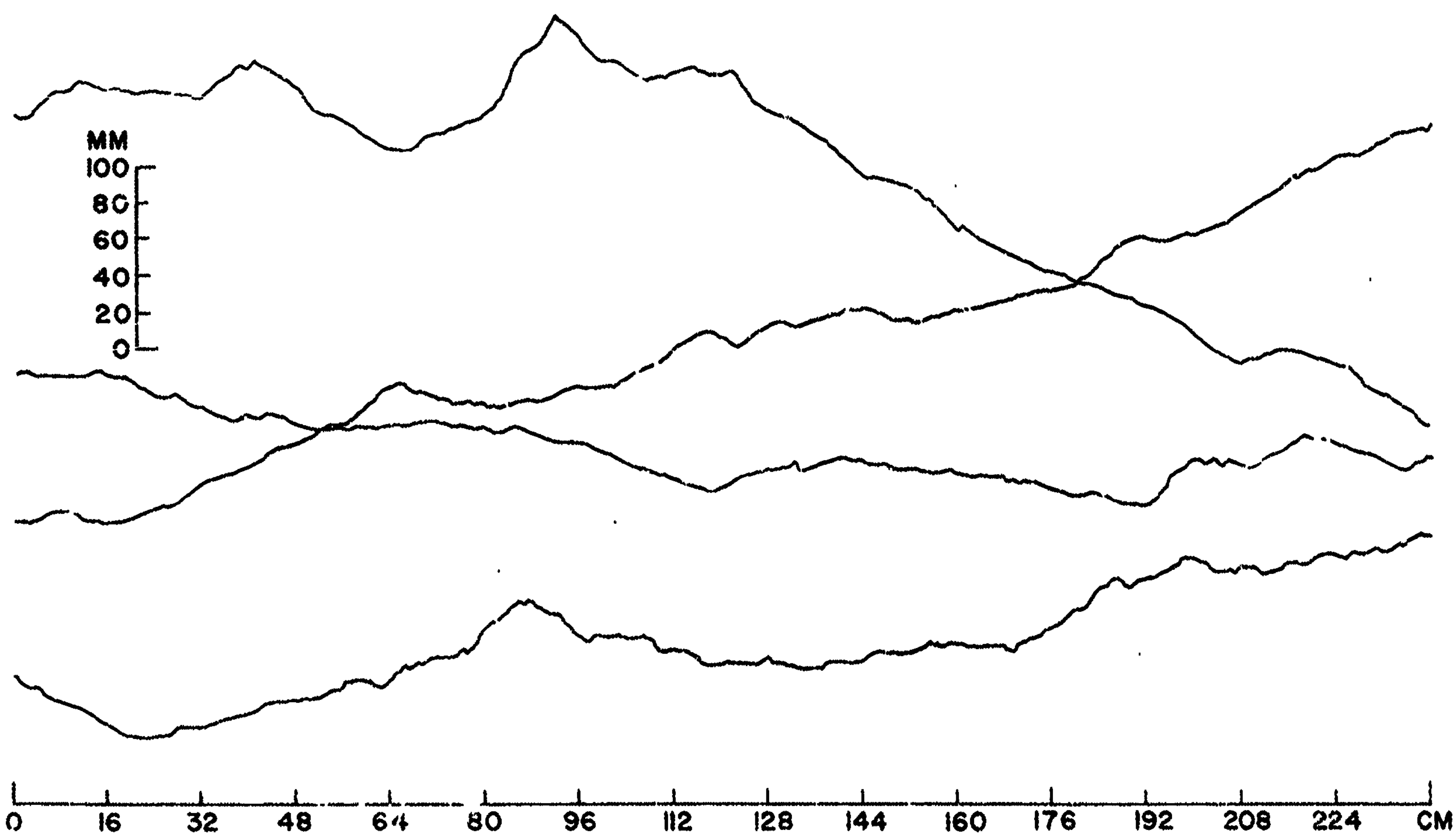

Figure 2. Portions of Wave Profiles Obtained From Stereophotographs

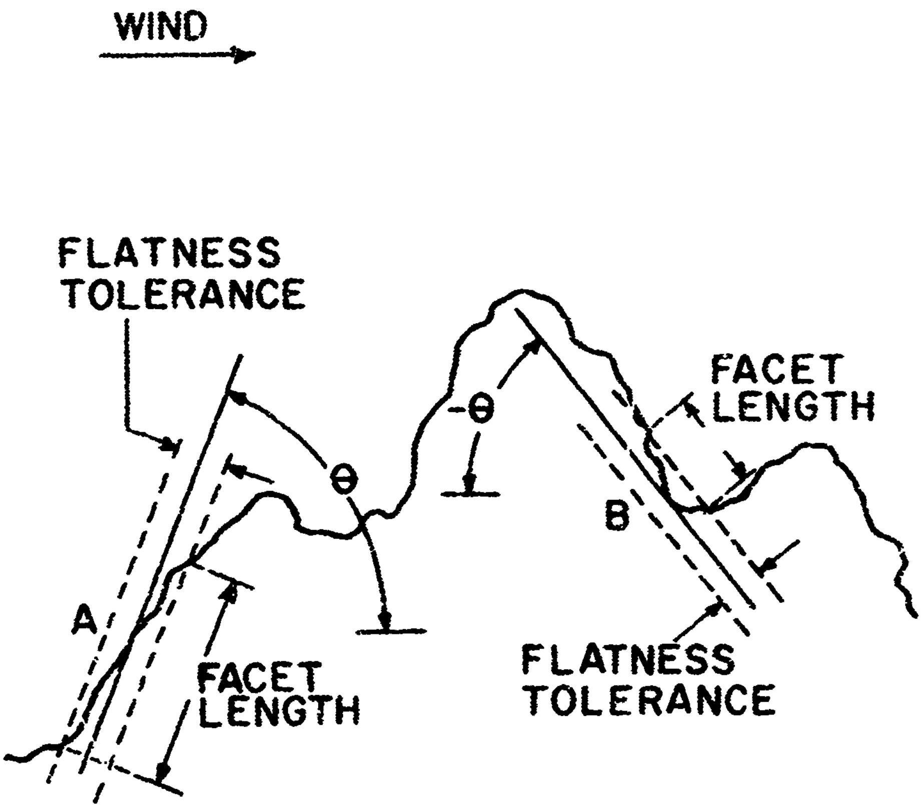

Figure 3. Facet Length As Determined By Flatness Tolerance

tolerance is defined as 1/10 the radar wavelength. In these experiments, the radar wavelength was about 3 cm. so the flatness tolerance is 3 mm. At any point on the wave profile, the slope is found by a line drawn tangent to the profile at that point (A). The angle θ of the tangent line with respect to the horizontal will be referred to as the slope of the tangent. The flatness tolerance is then drawn parallel to the tangent line and equidistant from it; that is, 1.5 mm. on either side. The two lines representing the flatness tolerance will intersect the wave profile and thereby define the facet length associated with the slope θ. At the point B, the facet length is obtained by intersection of only one parallel of the flatness tolerance with the profile. The ratio of flatness tolerance to facet length is called roughness factor (R).

If the profile is now sampled randomly (equally-spaced intervals will do), a sequence of facet lengths appropriate to each slope is obtained. The facet lengths are collected in 2-degree intervals and averaged. The result is a relation between average facet length and slope as shown in Figure 4. Negative slopes correspond to the downwind direction of wave travel. In each of the cases considered, about 200 slopes were read.

The contribution to the radar return or backscatter depends not only on the slopes of the facets and their size, but upon their frequency of occurrence as well. Consequently, the next step is to obtain a relationship between probability of occurrence of average facet length and associated slope. Such a relationship is shown in Figure 5.

In order to estimate the quantity of radiation reflected from the irregular wave surface, it is necessary to consider the effective radar scattering area of the facets. This was done by first considering the return of radar waves impinging on disks of known area (Schmitt, 1957; Katzin, 1957). If the wave facets are assumed to be circular then the facet area is known and the theoretical results of Schmitt may be used to infer the effective radar scattering area for the real condition. Furthermore, the information in Figure 5 permits a table to be calculated that describes the probability density of effective radar scattering area with respect to slope.

Each facet receives and reradiates energy over a limited angle which is greatest at normal incidence (90°). This effective beamwidth (or beamwidth at half power in radar terminology) is a function of facet size and radar wavelength (Silver, 1951). The effective beamwidth thus obtained relates also to the effective radar scattering area.

The radar depression angle (ϕ) is the angle the radar beam (center) makes with respect to the horizontal. For a constant radar depression angle, the facets that have sufficient beamwidth to contribute to the total radar return from the water surface are known and so is the probability density of facet occurrence. Thus, the total effective scattering area for different depression angles may be obtained for all the facets oriented in the upwind and downwind direction. If the ratio of effective scattering area in the upwind and downwind directions is plotted (in decibels) against the depression angle (Figure 6), then this statistic is equivalent to the radar measurements and a direct comparison can be made.

DISCUSSION OF RESULTS

The calculations presented here are the first of this type ever made from actual sea wave data. (Schooley's work was based on model tank experiments.) Consequently, this initial effort is basically exploratory and should not be regarded as a proven technique for treatment of such data.

Each profile provided approximately 200 slopes with its associated data. All the profiles were made in the same sea state where the waves were about 1 - 1.5 feet high. Figure 7 shows a comparison of the average facet-length distribution with distributions obtained in the water tunnel (for 50 slopes). The agreement is fairly good as is Figure 8 which shows comparisons of the slope probability distributions. These comparisons are not to be judged on the basis of the reported wind speeds, but rather on the general shape of the distributions. Figure 9 shows the upwind-downwind ratio of 3 sets of data with radar observations and with model-tank measurements made by optical means superposed, as well as the water tunnel results that are

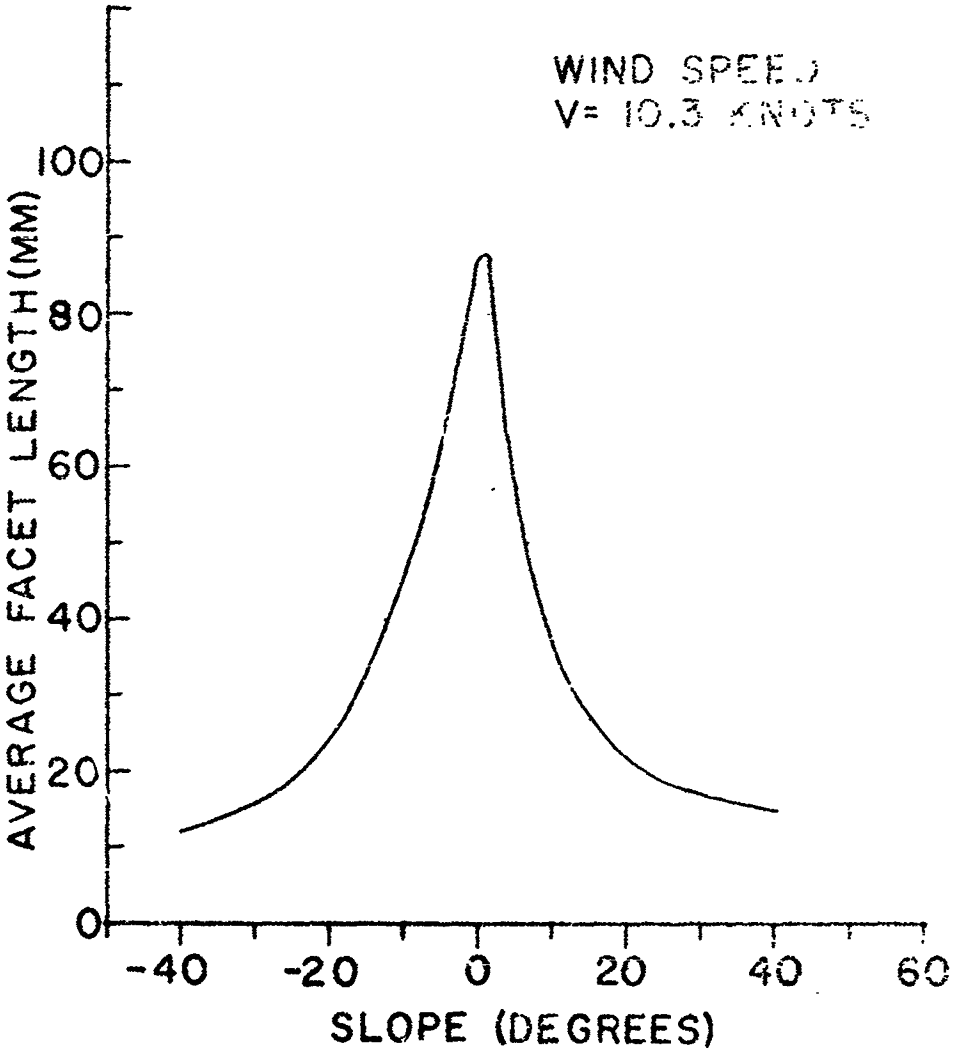

Figure 4. Average Facet Length Versus Slope For Waves 1-1.5 Feet High

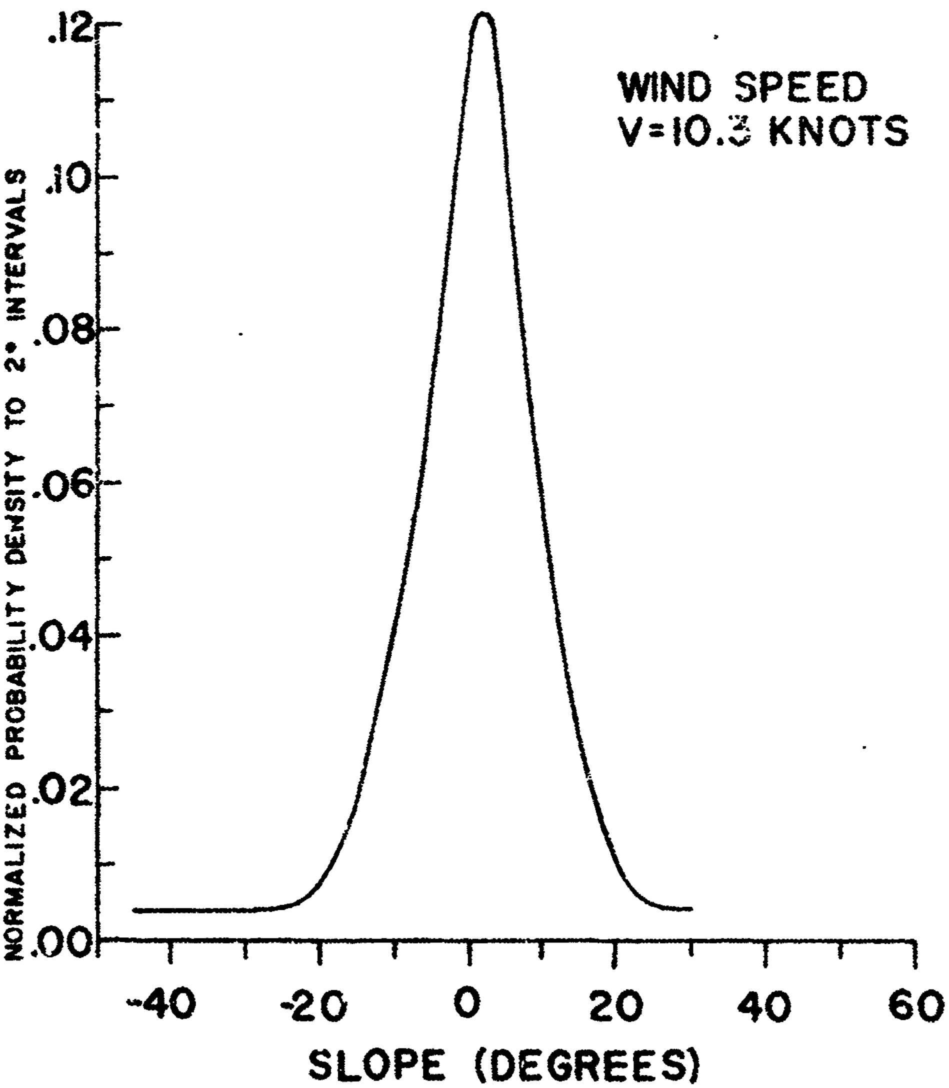

Figure 5. Slope Probability For Waves 1-1.5 Feet High

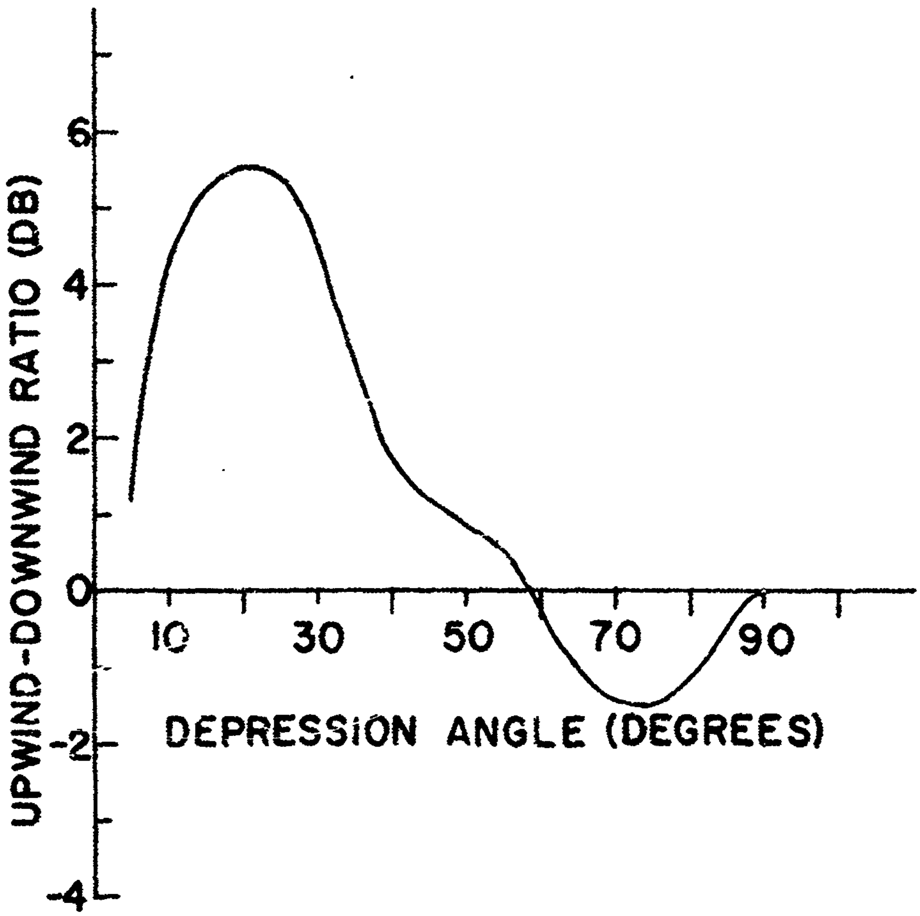

Figure 6. Upwind-Downwind Ratio Versus Depression Angle

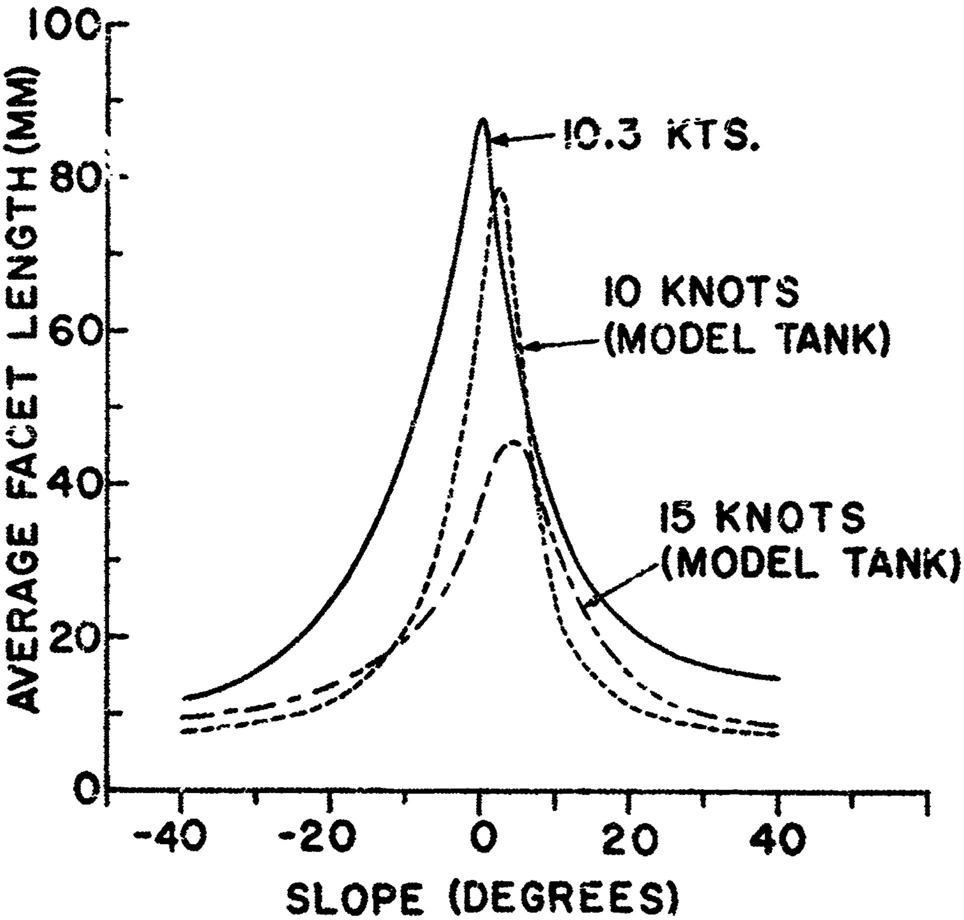

Figure 7. Comparison of Facet Length Distribution Obtained at Sea With Model Tank Observations

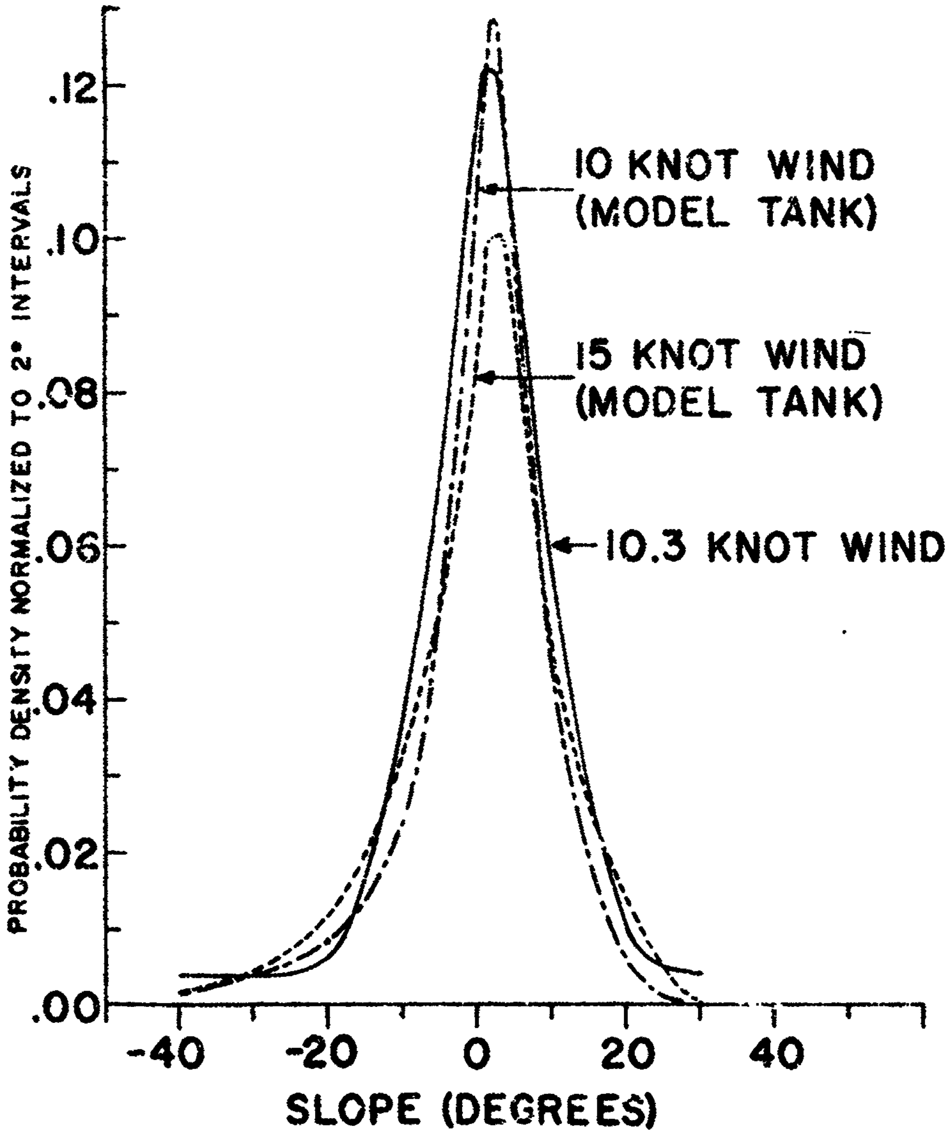

Figure 8. Comparison of Slope Probability Obtained at Sea With Model Tank Observations

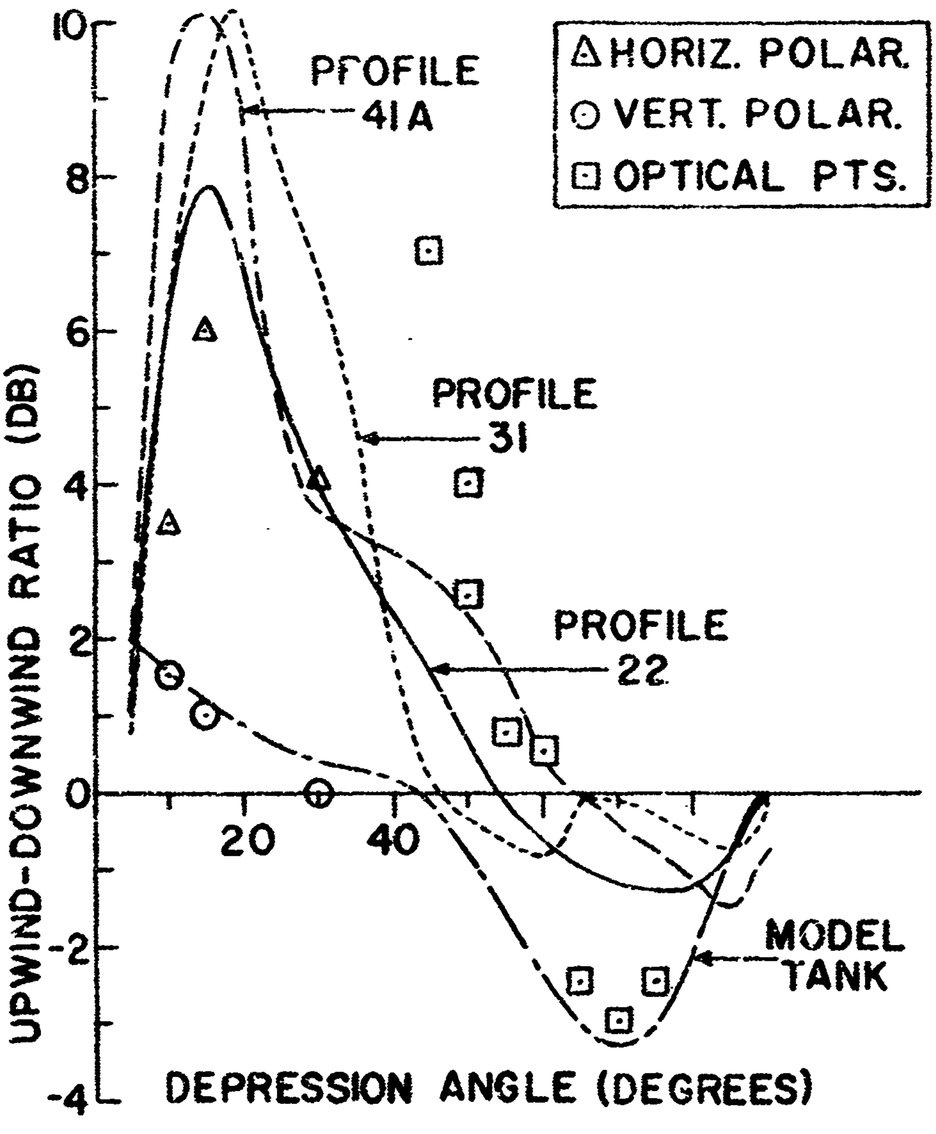

Figure 9 Comparison of Upwind-Downwind Ratios

appropria· :o this situation. The important feature to note is the agreement of positive values at low depression angle and negative values at high depression angles.

Figures 10 and 11 deal with averages of the results from different profiles and generally confirm the observations already made.

In general, it can be said at this early stage of the study that radar observations tend to confirm the positive nature of the upwind-downwind ratios as calculated from wave profiles. The negative ratios are confirmed by optical experiments in the tank. Calculations from tank-generated waves are also in general agreement, with the exception of the area at very low depression angles where the "real-wave" calculations tend to zero, while the tank wave calculations appear to be increasing positively. Also, it appears that horizontal polarization produces results that are in better agreement with calculation than does vertical polarization.

For the particular sea-state condition studied here, it is evident that the ratio of effective radar backscattering areas in the upwind and downwind directions is related to the radar return as observed by aircraft. The question is whether this relationship is unique as regards change of sea state. In order for radar backscatter to be applied as a sea-state indicator it would be necessary for the curves (that is, radar data) in Figures 9-11 to change significantly as the waves build up. In particular, the degree of variation of the amplitudes of the positive and negative lobes and the depression angle of crossover will determine whether this technique can be successful.

At present, wave profiles for a sea of 2 - 2.5 feet are being prepared. If significant departure from the "radar-signature" for the 1 - 1.5 foot high waves results, then there is a good chance of success.

Experiments planned for the future will provide for radar observations of depression angles in excess of 30° in order to verify the crossover angle as well as the magnitude of the negative area.

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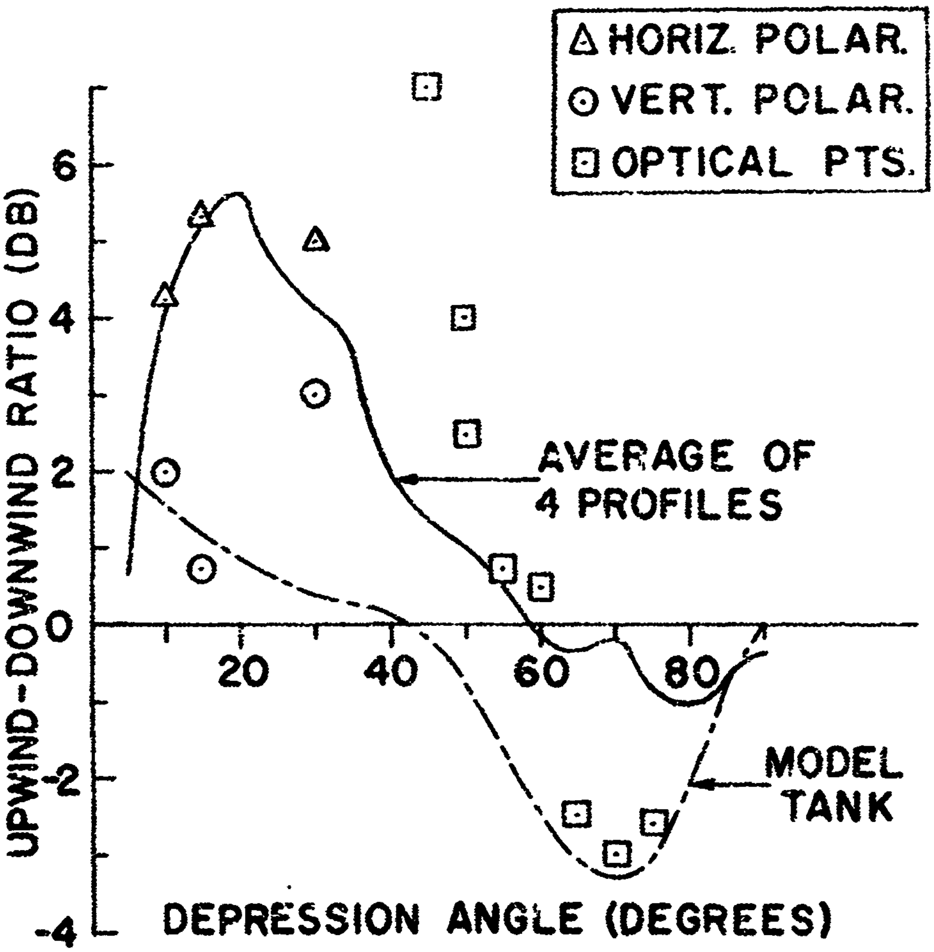

Figure 10. Comparison of Upwind-Downwind Ratios

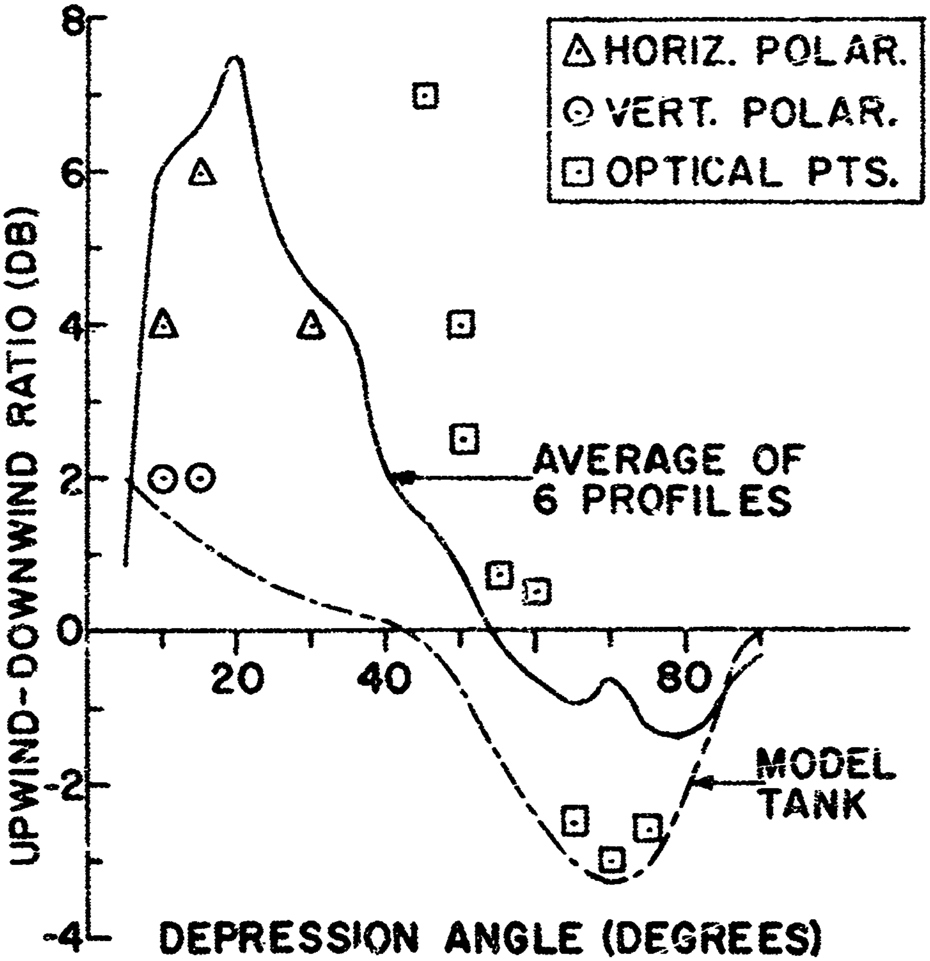

Figure 11. Comparison of Upwind-Downwind Ratios

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N65-30389

WINDWAVES AND SWELL

Willard J. Pierson, Jr.
New York University

INTRODUCTION

Probably the first waves observed by man were waves on water: the concept of wave-length, speed, and period (or frequency) probably arose with study of these waves. The physical laws of truly periodic long crested waves were understood more than a century ago.

The spectrum of waves on water covers a range from wavelengths comparable to the circumference of the earth to fractions of a centimeter with certain frequencies corresponding to periods of years, a year, a lunar month, a lunar day, a solar day, a half lunar day, a half solar day, various fractions of these, and on down to hours, minutes, seconds, and tenths of seconds.

Waves generated by the action of wind on the water will be the first subject of discussion. The subject of storm surges also caused by wind, tides, and the slope of the sea surface due to currents will be discussed by others.

Waves caused by the wind on the water can be interpreted by a combination of physical and probabilistic concepts. The irregular moving bumps and hollows that make up waves can be represented as a large sum of different superimposed waves propagating in different directions and with different wavelengths, where

$$(1) \quad k = \frac{2\pi}{L} = \frac{\omega^2}{g} = \frac{4\pi^2}{gT^2}$$

Such probabilist models are described within a linear theory by a function of the form, $S(\omega, \theta)$ which resolves the total variance (the square of the departure of $\eta(x, y, t)$ at some fixed time) into the frequencies that contribute to this variance and the directions toward which these long crested elements are traveling.

If the rise and fall of the sea surface at a fixed point as a function of time is considered, then one can obtain only the frequency information, and not the directional information, that is

$$(2) \quad S(\omega) = \int_{-\pi}^{\pi} S(\omega, \theta)\, d\theta$$

Finally; the total variance is the one number of probably maximum usefulness. Derivable from the total variance is the significant wave height which can be defined to be the average of the crest to trough heights of the one third highest waves to pass a given point.

The significant height is given by

$$(3) \quad \overline{H}_{1/3} = 4\sqrt{\text{Variance}}$$

$$\text{Variance} = \int_{0}^{\infty} S(\omega)\, d\omega$$

SAMPLING VARIABILITY

When ocean waves are measured, and they can be measured in quite a variety of ways such as stereophotogrammetry, radar altimeters, and assorted wave recorders that put out electrical signals representing the waves as functions of time at a fixed point, one ends up with a sample in the statistical sense. By techniques due to time series methods and statistical concepts, this sample can be converted to a spectral estimate. We worry about resolution, aliasing and the degrees of freedom of the individual bands of the spectrum. A selected bibliography is appended. A good place to start is the book 'Ocean Wave Spectra' published by Prentice Hall.

A STORM AT SEA

To obtain an idea of what waves are like in the open ocean consider the sequence of figures that follows. These figures show what happened at a particular point at sea as an extratropical cyclone passed a British Weather Ship that recorded the waves by means of a ship borne wave recorder.

WAVE FORECASTING

If the wind has a constant velocity, U, and blows for a long enough time over a large enough area, a fully developed wind sea at that velocity should occur. If the frequency spectra for various wind speeds are properly combined according to a theory of Kitaigorodkii (1961), and

if $\omega = 2\pi f$, and if the quantity

(5) $\bar{S}(f) = S(f) g^3 / U^5$

is plotted at

(6) $\tilde{f} = f U/g$

then the function

(7) $\bar{\bar{S}}(\tilde{f})$ should have the same shape for any U.

Figure 6 shows that indeed, within our present accuracies in measuring wind over water, this is the case. Given a small percentage difference between the nominal values of 20, 25, 30, 35, and 40 knots, these spectral shapes coincide. When put back into a dimensional form, this spectrum can be represented by:

$$S(\omega)\,d\omega = [\alpha g^2 e^{-\beta(\omega_0/\omega)^4} / \omega^5]\,d\omega$$

where $\alpha = 8.10 \times 10^{-3}$, $\beta = 0.74$ and $\omega = g/_U$ (where U is measured at 19.5 meters).

The wind over the water varies in speed with height. There are a variety of different theories as to exactly how this variation is described. Uder the assumptions of one theory as to the variation of wind with height the significant wave height in a fully developed wind sea is shown in Figure 7 as if the mean wind were measured at different elevations.

SATELLITES

One lonely British Weather Ship provided the data described above. Our U. S. Weather Ships should soon provide similar data. But the vastness of the oceans makes these data not enough. From a synoptic wave forecasting point of view, it would be nice to get data from all the oceans once a day say from a polar orbiting vehicle, that could measure something about the waves every 200 miles (or so) along its path. The ultimate would be enough data to provide an estimate of the directional spectrum at each point. The frequency spectrum alone would be extremely useful. Even something like the variance, needed to compute the significant height would be most useful.

Radar altimeters and optical stereophotographs are possibilities. The new side scanning radars point down with a long narrow illumination path remind one of an early paper by

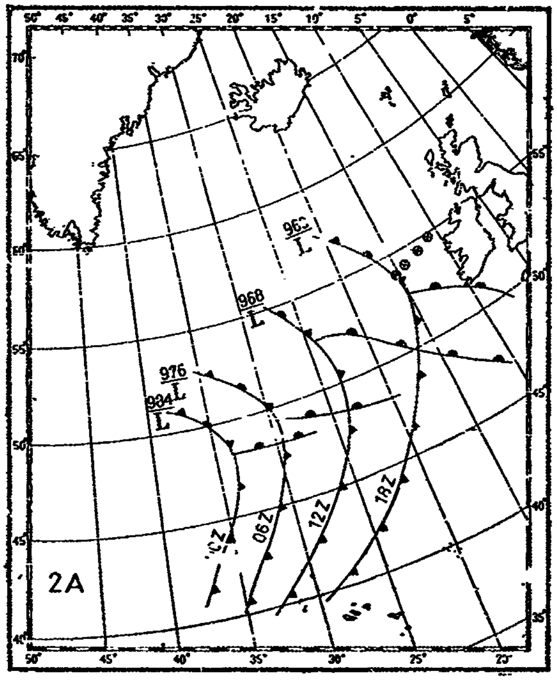

Fig. 1A. 6 hourly major frontal position and positions of the OWS "Weather Reporter" (⊗) for 16 December 1959 ("z" = GMT)

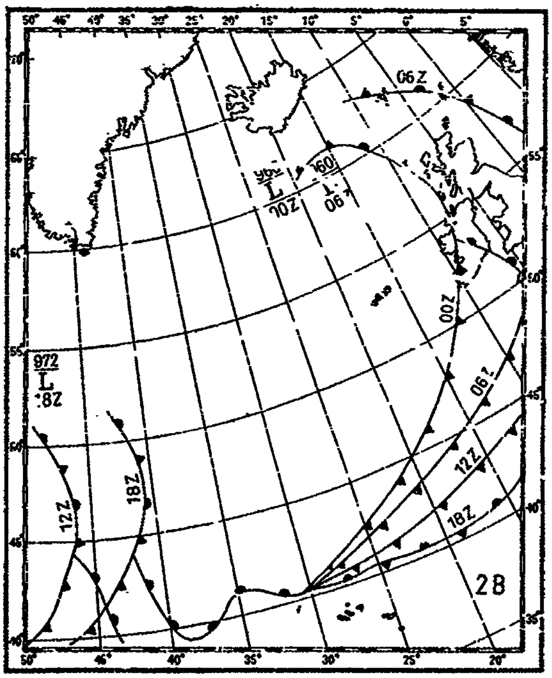

Fig. 1B. 6 hourly major frontal position and positions of the OWS "Weather Reporter" (●) for 17 December 1959 ("z" = GMT)

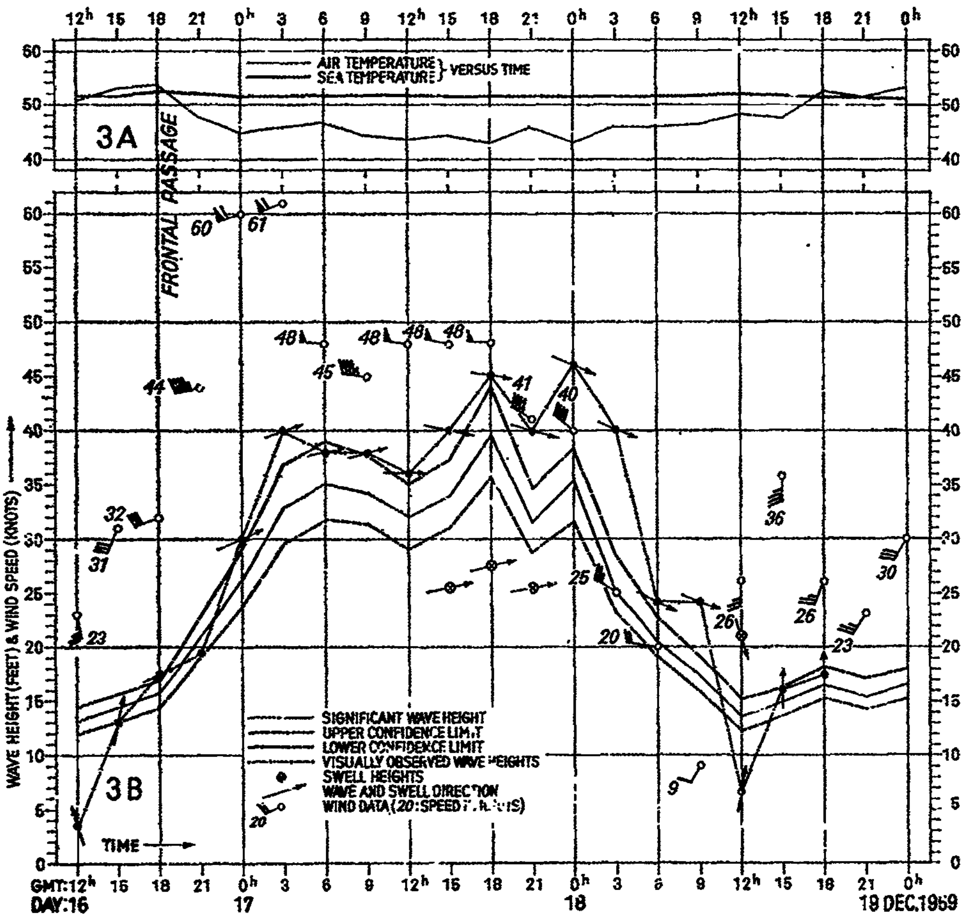

Fig. 2A, 2B. Graph of conditions observed and reported by the OWS "Weather Reporter"

(After Bretschneider et al. (1962))

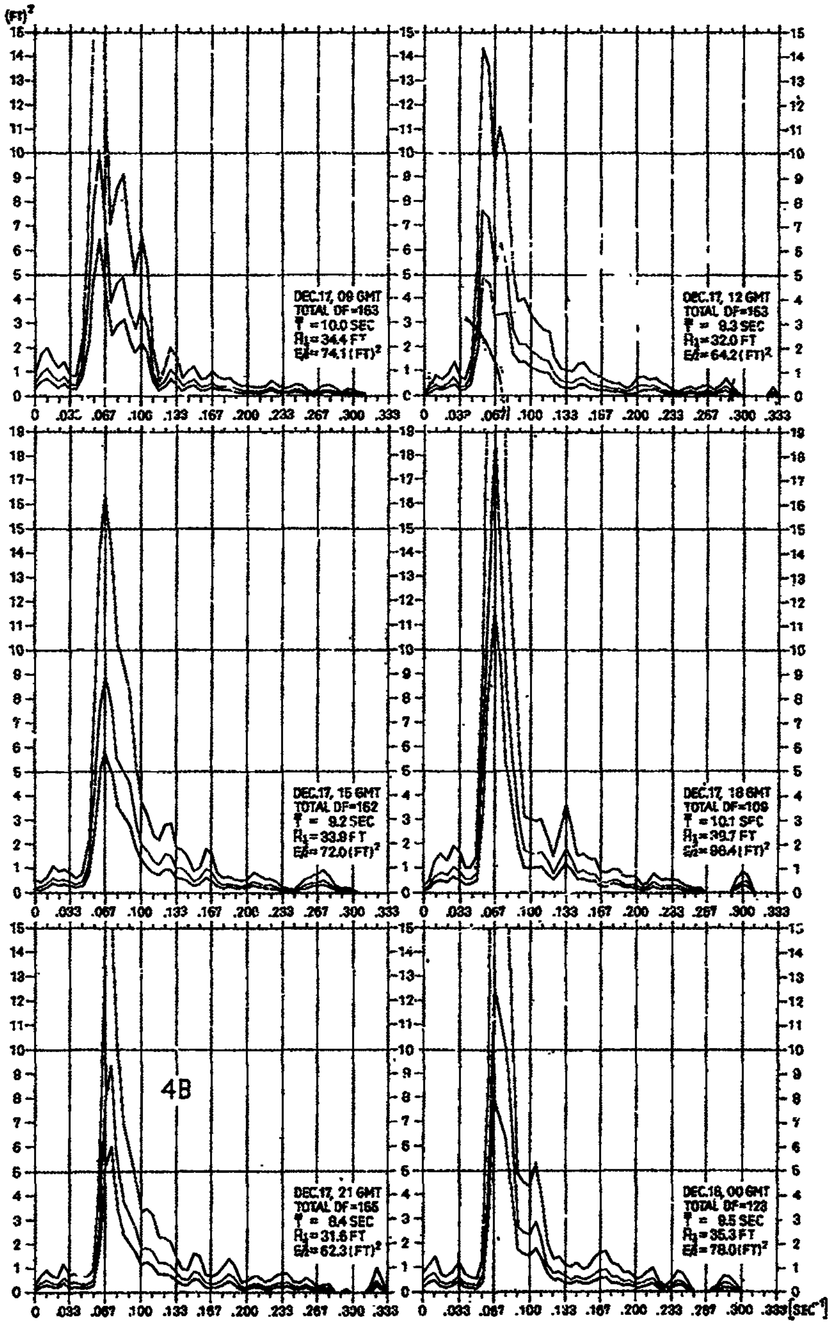

Fig. 3. Graph of selected spectra for 17 December 09 GMT through 18 December 00 GMT with 5% and 95% confidence limits

(After Bretschneider et al. (1962))

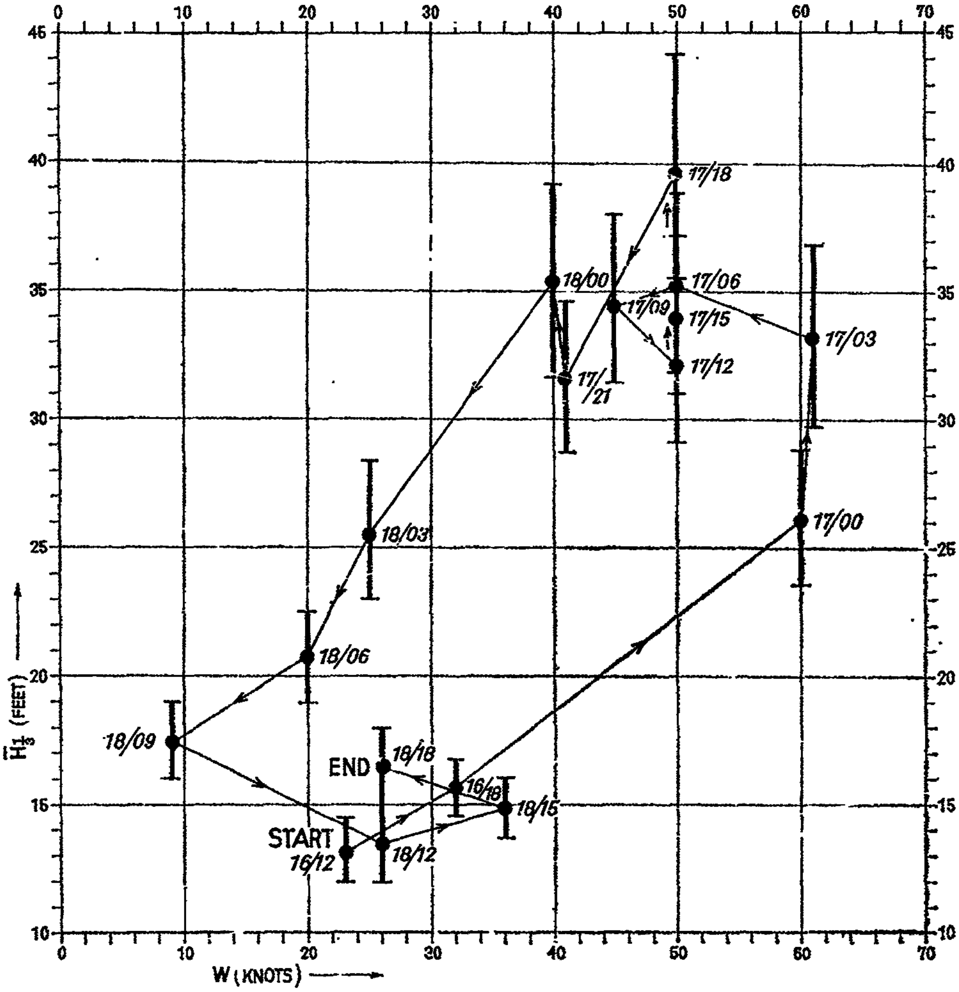

Fig. 4. Graph of significant wave heights (with upper 95% and lower 5% confidence limits) versus wind speed with time as the parameter

(After Bretschneider et al. (1962))

LOCATION OF SHIP & TIME OF OBSERVATION		TOT. CLD. AMT. & WIND	VIS. & WEA.	PRES. & TEMP.	CLOUDS	SHIP DIR. SPEED & PRES. CHG.	SEA TEMP. DIF. & DEW PT.	WAVES	SHIP NO.
591215									
30632	22306	72626	98010	80545					
30550	32000	60905	94505	93040	865--	55640	05535	127--	
30532	34600	82520	97180	51047	875--	54600	00245	12544	
30511	11200	92528	99021	08548			05939		
30508	18400	82929	98278	09547	855--	64406	05839	17962	11172
30504	22600	2.. 1	97258	07546		26737	05945	12856	0123
30503	19000	82733	98022	12548	854--	55200	05637	12747	0058
30502	17400	82750	98032	11952	23410	23712	00236		
30488	22600	82317	97505	13291	873--	26834	05347	12355	0157
30487	22500	92540	98258	..650	884--	64724	05842	12565	0211
30482	31600	82530	98022	12455			005		
30480	35100	82534	97022	12552	864--	64603	05346	12558	0023
30474	21500	82518	98205	17652			054		
30469	27800	72534	98028	17559	23520	64718	00146	12544	
30462	18200	63225	98142	19652	62420	55217	05137	13266	0525
30461	27100	82618	99632	21556	853--	15730	00449	12633	1729
30457	27300	82953	98032	22055		65720	052	13059	
30455	26600	82813	98022	26859			005		
30446	16600	43205	99181	22250		54	063	127-8	
30632	23706	80230	98022	87236			068	152-1	
30575	28706	52909	98022	91699	6				
30543	34206	80909	97505	89344	864--	55715	05140	171-0	
30535	39106	82205	97202	89050		26400	014	122-1	
30508	20806	82525	96636	94952		43830	05152	12553	11172
30505	19906	2220	97258	98351		26727	05351	12345	0123
30502	15406	82227	97818	48					
30501	20606	82347	98022	98348	873--	63714	05437	12759	0058
30492	20006	92428	96636	04154		26744	00053	12433	0157
30485	24006	82550	97632	06834		63727	00453	12566	0211
30479	32206	82530	97032	09657			009		
30477	34206	82330	97022	10459	863--	63711	00454	12357	0023
30477	19806	82424	96636	08254			052		
30467	25006	82628	98032	14758	853--	15733	00651	12633	1729
30465	32506	82534	97021	14854	863--	54725	00353	12553	
30460	25006	72524	98021	17559			005		
30456	20206	2625	77626	16653		55720	00047	12755	0525
30452	29206	22734	98010	21057	22400	65615	000	12949	
30602	15912	72626	98828	86056			059		
30573	29912	80900	97502	93245	866--				
30565	27312	72905	98022	94143					
30536	34012	82513	97022	91048	863--	55400	00548		
30533	38412	82218	97032	93345		26220	002	122-3	
30505	17812	2721	97255	98055		26400	05153	12756	0123
30503	17212	92730	96758	98055		54430	001	127-8	
30502	14412	81944	96636	96354	864--	73835	00492		
30501	22512	82747	98022	[illegible]	[illegible]	65203	00453	12749	0058
30498	[illegible]	82726	96542	97054	6722-	65705	00352	12733	
30494	17112	92730	97616	11755		26400	00153	12756	0157
30485	24712	82542	96608	09856	874--	62210	00651	12566	0211
30482	17912	62730	96515	04957			002		
30477	32712	82524	96022	09057			009		
30475	34512	82330	97022	09158	864--	63705	00353	12368	0023
30475	22812	82459	96152	12059	853--	15712	00754	12433	1729
30465	23112	82537	97022	16263			019		
30461	33612	82332	98022	14959	853--	64704	00355	12333	
30450	21712	2630	97022	18656		55207	00353	12755	0525
30579	26415	63109	98021	93841		25400	058	13143	
30632	25718	80229	98022	91834			072	17151	
30581	25218	632..	98021	93841		25400	058	13243	
30569	32918	80000	98021	92741					
30535	34118	82209	96102	93046	33--	26400	001	12233	
30529	38018	82207	97025	89545	864--	55715	05741	122-9	
30514	30618	82515	98022	00051	862--	25400	00349	12535	0079
30508	24918	2728	96186	00394		65310	05047	17732	11172
30503	15018	2720	97205	98654		26307	05550	12756	0123
30499	23218	82747	97022	03756	874--	63014	00453	12759	0058
30497	17518	82726	97602	00055	872--	65215	00255	12733	
30495	15918	82724	96525	03855			002		
30484	25518	82550	97605	09856	87 --	62210	00456	12567	0211
30484	19918	82244	96596	02552		54	052	122-6	
30478	20818	82528	96157	08558	553--	15708	00655	12433	1729
30476	33518	82324	96011	05157			009		
30475	38718	82030	97258	97561			00457		
30467	21918	82524	97022	12963			013		
30465	15118	82725	97182	06153	6642-	57727	05054	12745	11275
30458	26418	82530	98032	18659					
30459	14118	82624	97616	164..			002		

LOCATION OF SHIP & TIME OF OBSERVATION		TOT. CLD. AMT. & WIND	VIS. & WEA.	PRES. & TEMP.	CLOUDS	SHIP DIR. SPEED & PRES. CHG.	SEA TEMP. DIF. & DEW PT.	WAVES	SHIP NO.
591216									
40578	16800	52418	95021	95446	52501	65207	054	17455	
40548	34200	2016	97022	89244		16620	05144		0036
40532	31600	82213	07952	90048	9-0--	26730	003	122-3	
40507	27700	7528	96818	99355		65400	00153	17542	11.72
40500	11900	77830	97258	97855		63214	00452		
40497	24500	82747	98022	05155	854--	63.07	00353	12758	0058
40496	19400	82724	96502	05555	872--	65223	00153	12733	
40488	13900	62724	96525	63957			004		
40484	25600	82540	97205	09555	874--	62712	.0355	12566	0211
40484	18500	82527	97152	08557		15400	00556	12433	1729
40481	11300	82650	97596	03054			000		
40478	.7200	82424	97818	93254			05248		
40474	54100	82324	75921	98259			011		
40472	19600	82524	97505	12459			007		
40464	33800	82320	97025	0356.	.743-	25715	00654	123--	
40464	24200	82550	98205	18359			000	12552	
40462	15300	82740	97508	13454	884--	53225	00048	12735	
40457	23000	72624	98022	19497			005		
40457	16600	82725	97205	13256	873--	57227	00154	12758	11275
40451	15600	72937	97015	14057			00454		
40632	23706	80530	97848	89932			077	155-0	
40577	18406	82413	92036	88246	394--	65630	054	12440	
40555	31106	1425	97212	97044		16740	05244		0038
40552	16106	72015	98031	97042	73400	65007	05445	12077	0277
40531	28606	820.3	94104	82046		26640	003	120-1	
40518	25706	82525	98022	92954	863--	25714	00150	12535	0079
40511	21706	33120	98011	01251	54410	68235	05448	13134	0093
40505	29006	2530	96538	91954		65730	05450	17534	11.72
4050.	13506	62913	97808	04054	5343-	63220	00046	129-4	
40498	16306	83121	97022	05257	6732-	64708	00555	13176	
40496	2 506	82747	58022	99057	679--	63713	00551	129.8	0058
40493	21406	82424	96622	02555	672--	65819	00555	12334	
40492	11906	33024	98035	04955			004		
40487	16806	82525	97152	07958	853--	15705	00653	12433	1729
40483	26806	82345	97022	07458		63624	00857	12366	0211
40477	12.06	82630	.4035	09054			000		
40474	18506	62518	96505	11555			002		
40473	34906	72837	98011	01850			054		
40469	21306	82430	97205	14155			052	12447	
40466	32706	82721	97025	03854	4542-	25302	05255	127--	
40459	16506	82927	97600	16354	884--	632.8	00254	12735	
40451	19206	.2720	98025	18356	873--	57234	05055	12736	11275
40584	19309	82005	98022	90146		25719	054	13042	
40635	18712	80911	95058	87030					
40605	26012	80313	98022	83539			064		
40582	18112	81524	97022	85146		25750	057	11543	
40571	21912	81518	94418	74348	6552-	55799	053	12449	
40563	28512	71824	98012	70244	62300	16741	05440		0038
40558	39812	73624	97256	82841	755--				
40557	35512	73015	98806	73845					
40550	18512	91790	95216	87750	9-0--	65798	05248	11452	0277
..30	26112	82044	98032	82046	44--	26400	000	120-8	
40506	30212	62640	97032	91948	68505	63400	05442	17657	11172
40503	15212	82421	96108	02855	862--	64812	00152	12595	
40500	23512	92544	96258	98055		63	000	175-3	
40497	18112	82330	96022	03757	4732-	64713	00354	12565.	
40495	26712	72547	98022	64051	73400	63220	05248	12558	0058
40488	13712	82724	97284	07955	855--	64209	00254		
40485	33712	62744	97818	04848					
40482	28612	72548	98021	04756	78400	62220	00449	12566	0211
40477	16612	82518	96505	12559			007		
40476	.9012	82551	97122	13057	12548				
40476	18912	82530	97122	13057			005	125-8	
40474	14112	82636	96585	11554			000		
40472	18512	82324	97505	13457			007		
40471	35412	62750	98011	10848			043		
40469	36812	72725	98022	09551	42540	25225	0 ..3	127--	
40453	25512	97319	97052	15263		25703	00 56	12324	0194
40452	18212	72727	97052	19659	78460	63211	00553	12734	
40581	16915	81537	96108	76546		24782	053	11546	
40633	18518	80960	95038	82030					
40570	25518	72525	98022	66144	78300	16730	05645		0030
40564	23..8	72344	94252	64646	74300	52760	..74	17452	
40548	20718	725.0	97186	76347	57463	64708	05445	17366	0277
40516	19518	52653	98022	93252	52400	.2420	0511.	12467	0079
40512	18118	62645	.9012	95053	54410	..8.10	0515.	17655	3093
40505	31518	72855	971.8	98645	77400	.5255	05940	17858	11172

Fig. 5. Sample reports from ships at sea. Under "waves" 12544 tells us that the waves are coming from 250° and have a height of 2 meters, and 17962 tells us that the waves are coming from 290°, [(79-50) x 10] and have a height of 6 meters [(10 + 2)/2]. (After Bretschneider et al. (1962))

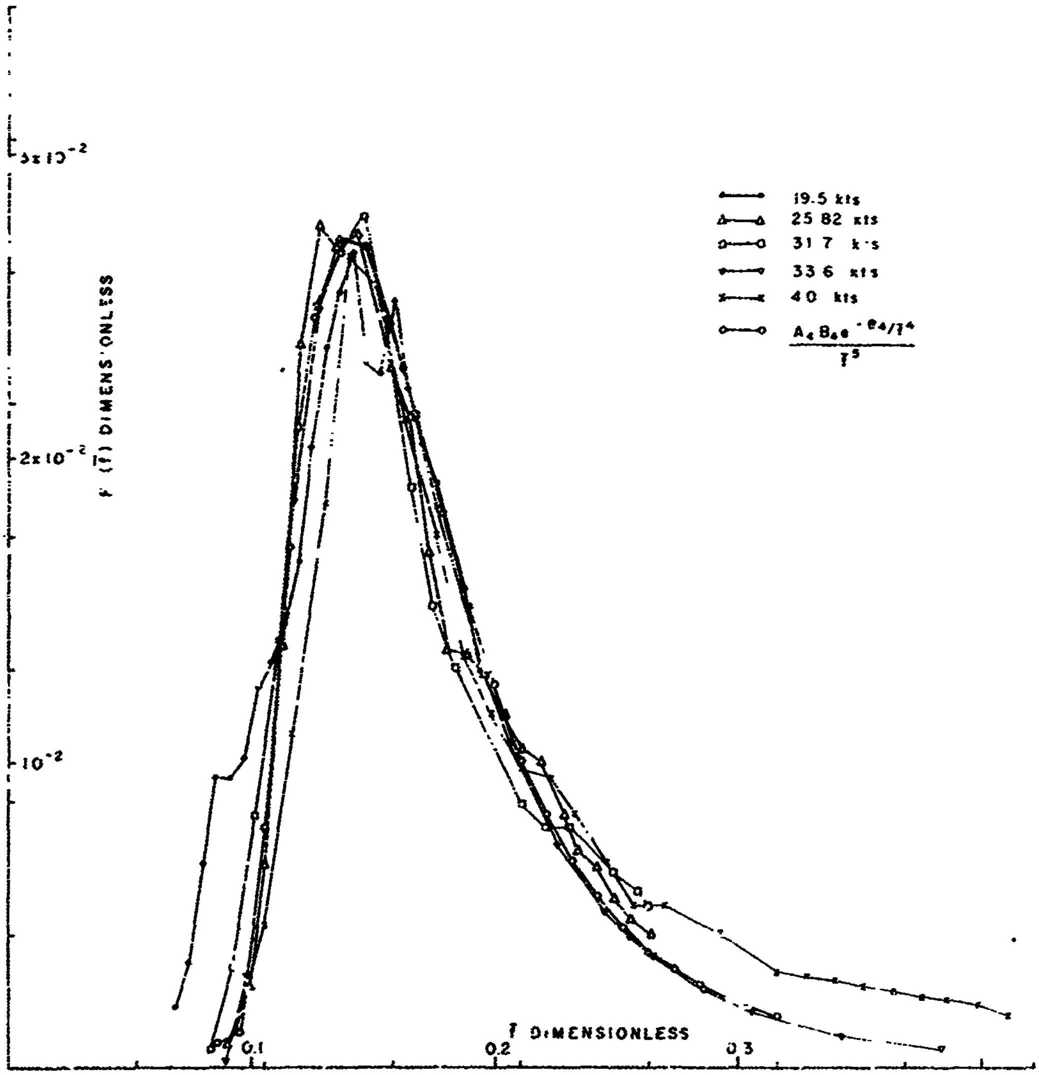

Fig. 6. Dimensionless plot of $\overline{S}(\bar{f}) = F(\bar{f})$ for averaged spectra with winds near 20, 25, 30, 35, and 40 knots. (After Pierson and Moskowitz (1964))

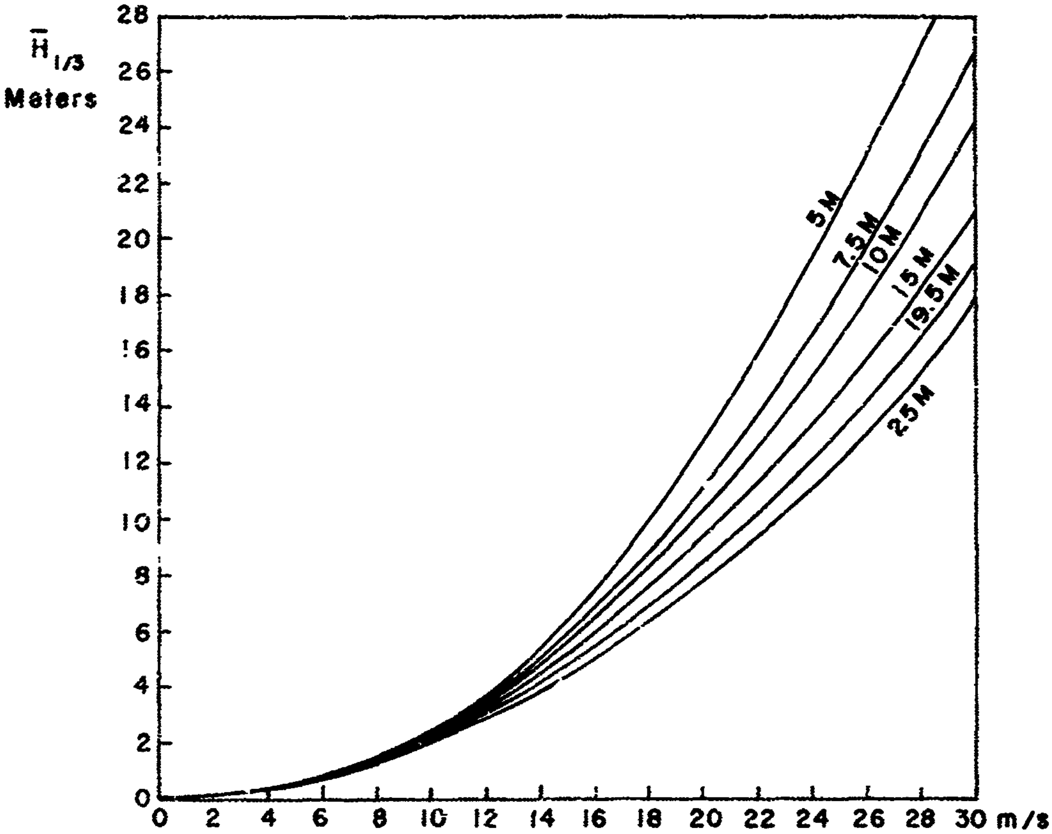

Fig. 7. If the wind in meters/sec is measured at the elevation above the surface given in the wave, the significant wave height will be found on the left hand axis if the waves are fully developed. (After Pierson (1964))

Mr. Marks in which a directional spectra could be gotten from similar averaging techniques.

The challenge of satellites is that it is possible to survey the whole world ocean on a synoptic scale from day to day and to keep track of what is happening from day to day as an aid to shipping and commerce. These data can serve as an initial value input to the problem of forecasting the waves a day or so into the future.

There are other ways beginning with the winds over the oceans to describe waves and to forecast them. Large parts of the world ocean are poorly covered by ship reports and wave data and the techniques presently under development suffer from this lack of data. Wave forecasting data and satellite data can enhance each other to provide a better understanding of waves on the surface of the sea.

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SATELLITE RADAR BEAM GEOMETRY

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When considering radar observations of the earth's surface from a satellite, certain adverse aspects of beam geometry as nadir angle increases should not be overlooked. Since the earth curves away from the satellite subpoint, range increases, inclination angle at the target decreases, and resolution degrades far faster than for a plane surface.

The resolution, d', along the Great Circle from subpoint to target is given by[1]

$$d' = r\Phi\left[\frac{R+H}{R}\cos\alpha - \frac{r}{R}\right] + \frac{c\tau}{2}\left[\frac{R+H}{R}\right]\sin\alpha ,$$

where r is the slant range, Φ is the beam width, R the radius of the earth, H the satellite height, α the nadir angle, c the speed of light, and τ the pulse duration, as shown in Figure 1.

The resolution in height, h', is given by

$$h' = r\Phi\left[\frac{R+H}{R}\sin\alpha\right] + \frac{c\tau}{2}\left[\frac{R+H}{H}\cos\alpha - \frac{r}{R}\right]$$

Many aspects of satellite radar observations have been investigated by satellite meteorologists and are discussed, for example, in Reference 1, which also has a rather comprehensive bibliography.

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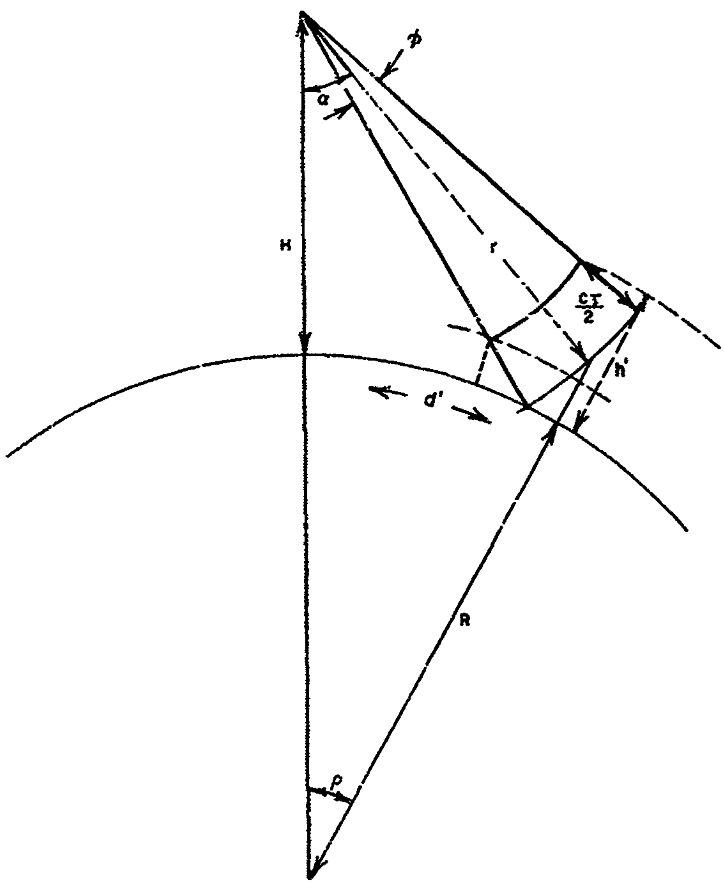

Figure 1. Vertical and Horizontal Resolution Components For a Pulsed Satellite Radar.

AN AIRBORNE WAVE METER

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Use of FM CW radar for measuring waves began at the British National Institute of Oceanography. Woods Hole Oceanographic Institute initiated work in this country by evaluating one of the British instruments. The work was later continued at the Oceanographic Office and then at the Naval Research Laboratory. The Oceanographic Office has recently revived the work by awarding competitive contracts on two systems. One system is modeled after the most recent system developed at NRL. The other is a modified flareout altimeter. The systems were designed to measure wave heights between 2 to 50 feet with an accuracy of 10% from an aircraft flying at a 500' altitude and a speed of 180 knots. Flight tests were made at Argus Island near Bermuda. The aircraft measurements were compared to fixed wave staff located at the tower. The analysis used for the comparison is the Tukey method for computing power spectra; estimates of waves energy are then plotted as a function of wave length. The aircraft energy estimates were mapped in wave number space to correct for the doppler effect resulting from aircraft motion. Figure 1 shows the results of the NRL type system. This system responded well at the short wave lengths, but failed to reproduce the energy peaks accurately. A large amount of energy was introduced at wavelengths of 2,000 feet and longer. This was due to failure of the aircraft motion compensating circuitry. Results of the modified FM CW ultimates are shown in Figure 2. With this instrument the effects due to aircraft motion were minimized and the energy peaks were well reproduced, however the instrument demonstrated a lack of sensitivity at the higher frequencies or shorter wave lengths.

Work to improve both instruments is now underway.

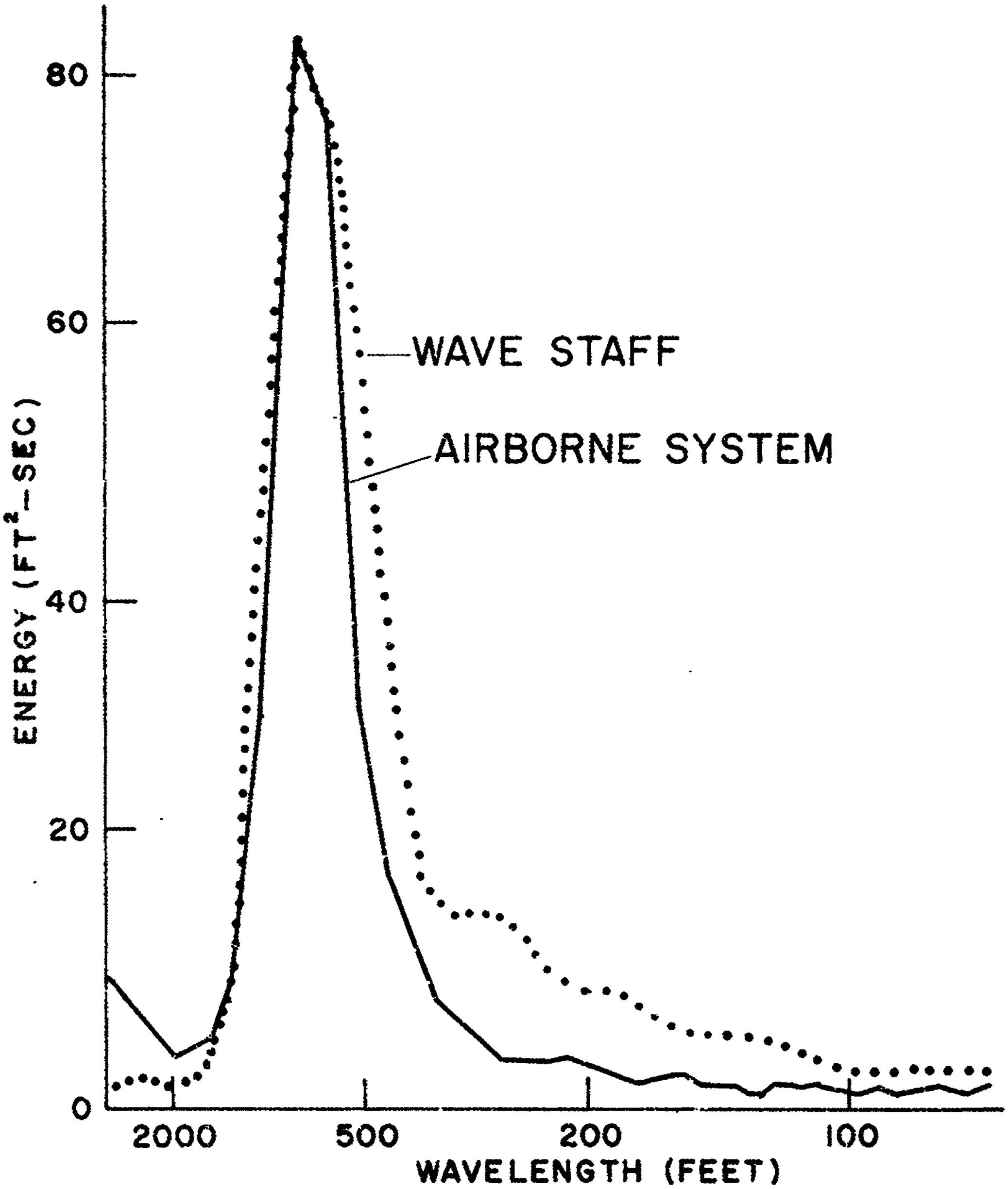

Figure 1. Comparison of Wave Spectra from Records Obtained by ARGUS ISLAND Wave Staff and First Airborne Radar System

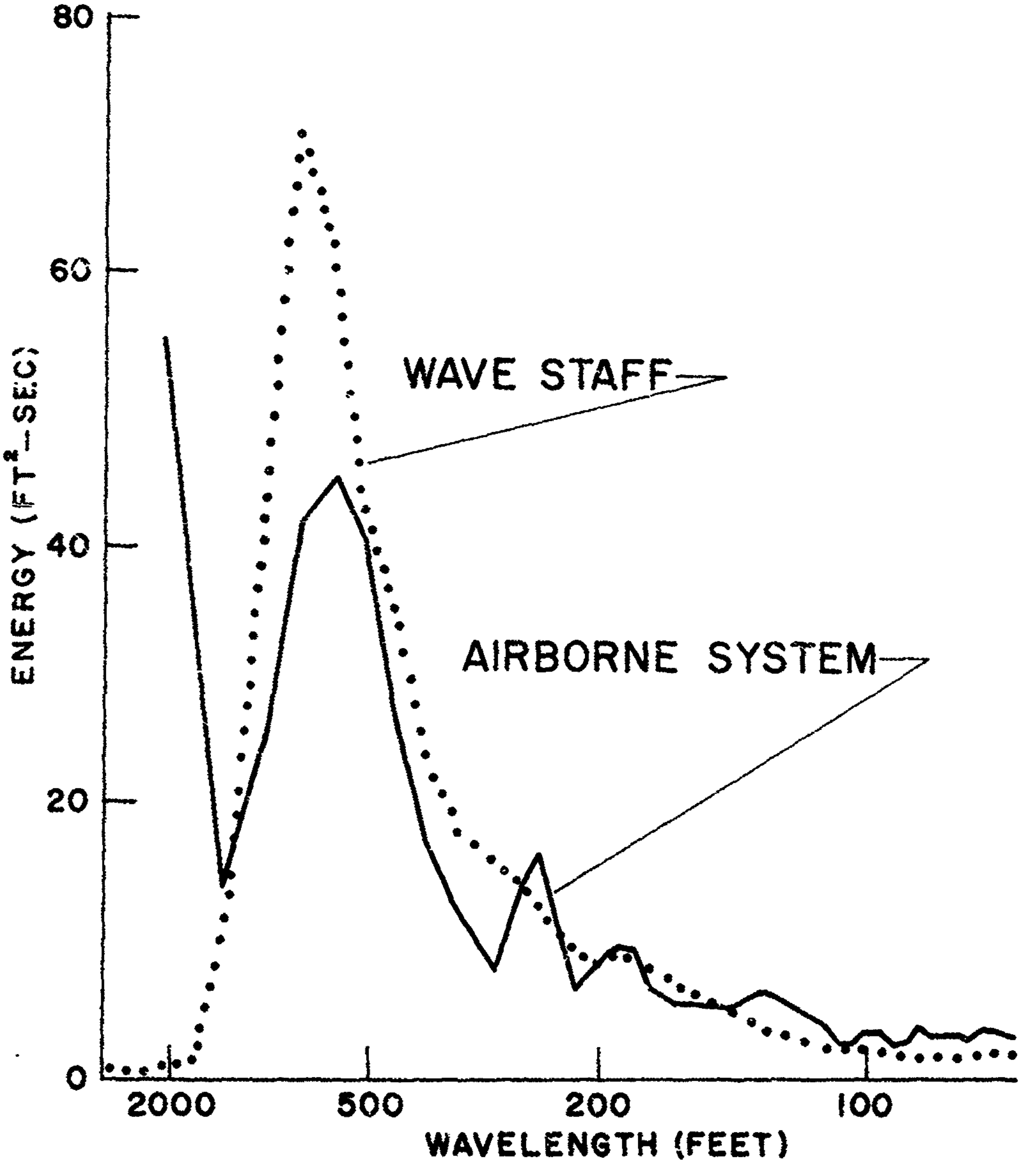

Figure 2. Comparison of Wave Spectra from Records Obtained by ARGUS ISLAND Wave Staff and Second Airborne Radar System.

THE IMPORTANCE OF LOW ALTITUDE WORK

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Throughout this conference it has rightly been implied that experiments performed from aircraft are merely pilot models of experiments ultimately to be performed from satellites. Nevertheless such pilot experiments, whether performed from fixed wing aircraft, blimps, kites, or balloons, employ advanced and costly instruments. They should be made to advance oceanography even if the radius of rapid reconnaissance is small when compared to the global scale anticipated in the case of orbiting satellites.

Thus, exploratory instrumentation should, if possible, be planned with this low altitude use in view as well as the ultimate satellite application. Perhaps as an expansion of oceanographic research capability low altitude airborne instruments should, in some cases, be designed for this use alone. Funds should be made available to encourage the development of the maximum sensitivity and resolution that available technology permits.

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MICROWAVE REFLECTIVITY MEASUREMENTS

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As an extension of Dr. McAlister's suggestion for sea surface temperature measurement by passive microwave radiometry I would like to suggest the following.

As Dr. McAlister responded during question time correctly the lack of quanta emitted in the microwave region requires a long integration time and large irregular field of view, hence coarse resolution.

As Lieberman states in "The Sea", Vol. I, page 473, "a 1 C° change in sea surface temperature causes a 2.4% change in conductivity" which can perhaps be measured by <u>active</u> microwave reflectivity measurements. As changes in salinity likely to be encountered produce less pronounced changes in conductivity this will be an <u>indirect</u> way of measuring sea surface temperature.

It may offer:

a. Higher resolution if the microwave radiometer "optics" can be made large enough.

b. Penetration of the order of millimeters or even centimeters may be obtained depending on the wavelength used.

From satellite altitude however

c. The optics size for resolution mentioned under (a) above will be a problem. Especially if due to the dielectric constant of water one is forced below 800 megacycles in frequency. <u>However</u> the use of synthetic aperture techniques for this type of somewhat stationary target may help with the resolution problem.

d. Power requirements for active techniques are likely to be a problem for some time. Perhaps a "low" altitude aircraft illuminator for certain regions could be used initially, and then its use as a receiver also is possible.

Many ramifications may be possible The above brief remarks are in the nature of a suggestion for thought.

Prof. W. Richardson of the University of Miami informs me that in the past he has suggested a very low altitude (50 feet) simultaneous surface temperature and conductivity measurement to determine salinity indirectly, without water contact.

CHAPTER 6

COASTAL GEOGRAPHY, GEOLOGY AND ENGINEERING

RECOMMENDATIONS OF THE PANEL ON COASTAL GEOGRAPHY

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Members

A. Ayala-Castanares	D. L. Inman
F. Bonet	R. L. Miller
P. Bruun	F. B. Phleger
J. M. Caldwell	E. L. Pruitt
H. L. Cameron	G. P. Salas
P. Cloud	B. B. Scheps
J. F. Cronin	W. Thompson
K. O. Emery	S. D. Tuttle
R. W. Fairbridge	E. L. Winterer
R. A. Geyer	J. M. Zeigler

We start with two premises: (1) that manned satellites are to be placed in orbit and will be available as a tool for studies of coastal geography, and (2) that satellite observations have their chief value for large-area studies, synoptic studies, and monitoring at hourly or longer intervals. Detailed precision studies and studies in water depths of more than about 20 meters are probably best left for other platforms. The term coastal geography includes, but is not limited to marshes, beaches, deltas, estuaries, lagoons, dunes, offshore bars (their topography, water cover, and air cover) for both marine and lake environments.

Recommendations are in three groups: general, small calibration sites, and large-area problems. For general aspects, there are three recommendations.

1. An album should be prepared to disseminate information on the kinds of data available now, and to recruit full-time workers and casual users of satellite data. The album should contain the best available images by photography, infrared, and radar from rockets, U-2 planes, and TIROS. Fifty to 200 images should be reproduced by lithograph in a 3000-edition printing, each image accompanied by some interpretation or brief discussion. NASA should handle compilation and distribution, probably through John F. Cronin (AFCRL). Declassification of images is required for the national interest in providing experience in evaluation of existing images by the best qualified people, in recruitment, and in training.

2. Based upon experience gained from TIROS, ship-board geophysics, and other large-data-producing activities, plans must be made for rapid scanning of satellite data for immediate dissemination to competent interested workers, and for storage and retrieval. Much of this scanning is routine and can be done by trained technicians. It must be done to insure (a) that use can be made of the data, and (b) that workers not be deluged by non-pertinent data. Obviously, these plans must include the attraction, training, and hiring of competent technicians and scientists. This should be a NASA responsibility.

3. The need for precise and accurate positioning and timing of all records made cannot be overstressed, for it has in the past been frequently overlooked. Images or patterns whose precise coordinates in space and time are not known have only esthetic or illustrative value. If they are to serve as the basis for maps or for evaluation of processes and their effects, the locality and time must be known as closely as it can be specified.

RECOMMENDED PROGRAM FOR NEAR FUTURE

CALIBRATION AND EVALUATION

A problem that should be attacked immediately is the calibration and evaluation of the imagery from available sensors. It is not clear at present how useful the data from various sensors will be, that is, whether significant absolute values will be obtainable on objects of interest in coastal research. One of the first steps, therefore, is to attempt to calibrate some or all available sensors, and this can be done by using test sites of known properties, such as known types of beach materials, known currents, known tides, etc. 'Known' is here used to mean that the absolute properties are measured on the ground at the time the sensor is flown across the area so that numbers can be attached to the sensor records or images.

In addition to calibrating the sensors, the resultant imagery or records should be evaluated to determine their total information content so that better, more precise specifications can be formulated concerning scale and object resolution, object enhancement, and other characteristics and capabilities of the instruments to obtain the kinds of data in useful form for coastal research.

There seems to be every likelihood at present that available sensors, properly calibrated and possibly redesigned or modified for specific coastal purposes, could be used to provide needed data on beach width, beach slope, characteristics of waves, angles of wave approach, dimensions of surf zone, and water circulation near shore and in tidal marshes and lagoons. Calibration and evaluation to obtain useful data on these and perhaps other coastal properties could best be accomplished by using as test sites (1) the beach at Scripps Institution of Oceanography, (2) one or more lagoons along the Gulf of Mexico (such as Laguna de Terminos in Campeche), (3) Cape Cod, (4) Virginia Beach, Virginia, and possible other sites where an abundance of data is available and where interested scientists are available to obtain critical ground truth during tests.

REGIONAL STUDIES

Delineation of Surface Characteristics: Information about the structure and composition of coasts and coastal waters, both of the sea and of large lakes, and over large distances, is an obvious early objective. Such regional data could be of great value in classifying, economic evaluation, and selecting smaller areas for future intensive study. Currently available radar and infra-red sensors could probably discriminate between beach surfaces of quartz sand, calcite sand, rock, or organic mats. Heavy mineral sands of economic significance might be detectable. Moisture content of the beach and back-shore, and zones of fresh-water seepage, could probably be detected. Submarine springs and hence approximate traces of outcropping aquifers below sea level might be detected. Coastal currents and zones of upwelling should be mappable. Coastal zonation would be mappable in many places, especially from aircraft and especially around tropical reefs where it should be possible to discriminate between concentration of red and green algae, living and dead corals, loose sediment, pools and channels of water of varying salinity and temperature, and a variety of reef-front features related to prevailing winds and currents.

Synoptic Observation of Processes and Effects of Such Processes: The action of waves, currents, gravity, slumping, aerosol transport, etc. along beaches and coasts could be monitored on a global or orbital basis and their progress and effects with time observed and possibly related to generating factors. For example, wave trains might be traced from offshore storm centers and slumps correlated with inshore events. Slumps or flooding rivers may generate turbidity currents and upwelling of cold, nutrient-rich waters from such causes or as a result of offshore winds may produce plankton blooms, colored water, and fish mortalities. All of these processes and events are interrelated in space and time and with other sedimentary, circulatory, and biologic processes, and many of them should be detectable with available sensors.

LISTING OF USEFUL MEASUREMENTS RELATING TO COASTAL AREA

Listed below are a number of factors which are under active study in the coastal zone. A brief description is given of these factors together with a statement of the degree of accuracy (or discrimination) which is needed to make the measurement highly useful. Lesser degrees of accuracy would still be helpful and an attempt has been made to indicate the lowest degree of accuracy (or discrimination) which should be at all helpful. Whether or not it is practical to make these observations from satellites (or high-altitude aircraft) is not considered in the presentation.

A. HYDROGRAPHY AND TOPOGRAPHY

Beach Width: This is probably the most useful single measurement in the short area, as it (coupled with the elevation) determines to a large degree the protection given the backshore from storm action. The measurement of beach width to the nearest five feet would be very useful; measurement of width to the nearest 25 feet would be helpful. The change in the beach width from week to week during storm seasons would be desirable.

Beach Elevation: The beach and dune elevations also enter into the degree of protection given the backshore by the beach. The measurement of beach elevations to the nearest one foot will be very useful. while measurements to the nearest five feet would be helpful.

Nearshore Hydrography: The nearshore area is in many ways and to a large degree determines the uses to which the adjacent shore may be put. The topography of this area (MSL to -100 ft.) is a dominant feature of this area and it is useful to know the depths to the nearest foot. Particularly in the area shoreward of the -12 ft. contours. The absolute accuracy needed of course decreases seaward, but is in the order of 3 feet at the 40-ft. contour. Accuracies of 1/3 of these values would be helpful for many areas of the world.

Offshore Hydrography: Bottom topography often influences water circulation patterns, both horizontal and vertical, and these interactions might therefore be studied as a means of detecting certain kinds of bottom topography. Sand waves, for example, may reveal themselves even in turbid waters by perturbations in the surface currents that could be measured or mapped by stereo-photographs or perhaps in infra-red means. The influences of submarine canyons on surface currents described in an appendix to this report by F. P. Shepard, provide another subject for study. Banks, reefs -- perhaps even some seamounts -- may affect surface currents sufficiently to be detected and studied.

Fresh Water Inflow: Contrasts in temperature or turbidity can be used to map the points of entry and the patterns of dispersal of fresh water. Sediment-laden stream waters (discussed in an appendix by F. P. Phleger), nearshore springs, or even submarine springs, can be thus studied by photographic or infrared means.

Wave Spectrum: The characteristics of the wave spectrum in the beach zone are of considerable interest as they determine the accretion or erosion of the shore. Determination of the spectrum to the degree presently possible with fixed surface gages would be very useful. Measurements comparable to those presently obtained with radar or sun glitter from aircraft would be useful.

B. CURRENTS AND SEDIMENTATION

Longshore Currents: The longshore wave-generated currents (litteral currents) determine the rapidity with which sediment (chiefly sand) is moved along the shore face. These currents have velocities of significance varying from 5 feet per minute to 180 feet per minute or more. Rip currents with velocities to 300 feet per minute may also be a factor in the longshore current pattern. It would be helpful if velocities as low as 5 feet per second could be measured to the nearest 1/2 ft./sec. with the higher velocities measured to a comparable degree of accuracy in per cent. Measurements of velocities of 20 ft/min. with a fair degree of accuracy would be useful.

Tidal and Fresh-Water Currents: The velocities and directions of tidal and fresh-water currents in the coastal zone are factors in sedimentation, flushing, pollutions, and navigation. Concurrent measurements of these currents as well as successive measurements in time are needed. Velocity measurements as low as 1/2 ft/sec. would be very useful while measurements as low as 2 ft/sec. would be helpful. In deeper water in offshore approaches, velocity measurements as low as 0.1 feet per sec. would be useful.

Sediment Transport: Sediment transport causes the massive changes (erosion, accretion, and shoaling) occurring in the coastal area. Two important sediment movements are: (1) the transport on the shore face by waves and inshore currents, and (2) the sediment load brought down by the fresh-water streams. While it would be most useful to know both the quantity and size distribution of the sediments being transported, even qualitative information on either quantity or size would be helpful. It should be recognized that the sediments may travel as both bed-load or suspended load, though the distinction may be rather small in the surf zone. The sediment concentration usually does not exceed a few parts per thousand and in many cases is much less than one part per thousand.

Shore Ice Shore ice or grounded ice entrains sediment and carries it offshore The details of this process, especially its quantitative aspects, may fruitfully be studied by frequent surveys of the extent and motions of the ice.

Glaciers: Glaciers bring huge amounts of sediment to the sea, and icebergs calving from glaciers may carry the sediment thousands of miles from its source. Periodic surveys of glaciers in Antarctica and Greenland from a satellite should indicate rates of addition of sediment-laden ice to the sea; and more frequent surveys would show the patterns of dispersal of the ice. It might even be possible to get a measure of the sediment content of the ice by spectral analysis.

Biogenous Sediment: The biogenic contributions to sediments are quantitatively important, not only in warm shallow seas where carbonate deposition is prevalent but also in the deep seas and in the cold seas, where the remains of planktonic organisms such as diatoms, radiolarians and foraminifers settle to the bottom. Naturally, then marine geologists are interested in means of determining patters of distribution of these creatures. Our interests thus coincide here with those of the marine biologists.

C. GEOLOGY AND GEOMORPHOLOGY OF COASTAL AREAS

Composition of Beach Face: The type and size of the material composing the beach face determines to a large degree the stability of the shore face. Also, in certain areas, the silica sand or other components may have commercial value. It would be helpful to know whether beachers were dominatly silica or calcium carbonate, or some other mineral. Percentage definition to the nearest 5% would be useful, but even qualitative information would be helpful. It is also useful to know the mean grain size of the beach, i.e., mud, fine sand, coarse sand, gravel, or boulders.

Composition of Nearshore Area: The composition of the offshore area (from MSL to -60 ft.) is of an importance similar to that of the beach face. Of particular importance is the presence or absence of sand in quantities suitable for dredging and placing on the beach to restore and stabilize the beach face, or for building construction.

Coastal Vegatation: The type of vegetation or the backshore and dune area is of interest and any definition of this cover (grass, scrub, or forests) would be useful. Also knowledge of the density of the cover would be helpful.

Coastal Geology: Besides the regional coverage of the subaerial parts of the coasts, where older beaches, terraces, reefs, etc. can be studied, high-altitude photography will provide especially in the clear waters of many of the tropical and desert coasts a view of the sea floor, where we may expect to see the patterns of underwater rock outcrops.

Geological Controls of Coastlines: The grand scale of images obtained from satellites may show much more clearly than we now know, what relations maintain between large geologic structures -- great lineaments for example -- and coastlines. The scale of some of the geologic features may be so large that they have so far escaped our attention.

D. WATER CHARACTERISTICS

Temperature: Temperature distribution in surface water often provides useful data on circulation patterns, both horizontally, as in rip and longshore currents and vertically, as in upwelling. An ability to measure differences of 0.1 degree C are desirable but 1° C differences would be very useful.

Salinity: The salinity of coastal water determines to a large degree the fish and shellfish life which will be found therein. It also influences the rate of intermixing of the coastal water with the inflowing sea water and the inflowing fresh water. The salinity gradients in such cases may determine the shoaling pattern or the flushing pattern of an estuary. Determination of the differences between fresh water and sea water in twenty steps would be very useful. Even the ability to identify salinity fronts would be helpful.

Pollution: Pollution has a great influence on the usefulness of coastal waters to mankind. Fish and shellfish life, recreation, and even human habitation of the shore, are affected by the degree of pollution. The pollutants may be man-made or may be the result of unusual blooms of diatoms and the like. An ability to define the source, degree, and extent of pollution would be very useful. Although quantative information would be most useful, even qualitative data would be very helpful in many cases.

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USE OF ORBITING RESEARCH LABORATORIES FOR EXPERIMENTS IN COASTAL GEOGRAPHY

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Many challenging and exciting possibilities suggest themselves for the use of orbiting laboratories in conducting research experiments in the field of coastal geography. At the very minimum, this offers opportunities for the first time to obtain synoptic coverage of coastal areas throughout the zone of orbit and to obtain repeated detailed coverage of particular coasts. The value of such coverage to coastal research would be tremendous. The ability to observe in detail the conditions in many areas almost simultaneously would permit regional comparisons that are now out of the question because the data are stretched across months and even years, thus blotting out variations occurring on a lesser time scale.

SAMPLING PROBLEMS

The matter of time-scale has traditionally posed serious problems in coastal geography, problems which might be solved through the use of orbital platforms. One such fundamental question is, how fast do conditions change in the coastal zone? Obviously, different phenomena change at different rates, and undoubtedly rates of change vary on a regional or seasonal basis. These rates of change need to be measured, not only with regard to real time for each phenomena, such as waves, currents, and sediment transport, but also in relative time with rates of one phenomenon compared with other phenomena. An experiment should be designed that would measure the significant rates of change. The experiment would include attempts to discover if there is a best time-scale for making observations of individual phenomena and of groups of factors, a time-scale that will assure acquisition of information on all critical changes in conditions that effect coastal processes of erosion and sedimentation. Part of the experiment will certainly concern determination of which sensors can best detect these changes, and detect them in real time so that the data can be handled.

The problems of time-scale for observations are closely related to problems of spatial-scale in the coastal zone. For example, assuming that details of the surf can be detected, possibly at the sacrifice of area of coverage, there is the question of what is the best resolution scale to detect the essential character of the surf, and how far areally can this local detailed data be considered as valid or representative of conditions? In other words, what should be the areal spacing of these detailed samples to assure validity of interpolation between samples.

Experiments from an orbiting laboratory designed to solve, or at least explore these basic problems of time-scale and spatial-scale of nearshore and coastal phenomena would be broadly applicable as sampling system guides to a host of other studies, such as those concerned with particular phenomena or particular coastal places. Some of these latter studies are suggested in the following paragraphs, and in all cases it is assumed that the experiments will include tests to determine which sensor or group of sensors is most suitable to detect the needed information.

ENVIRONMENTS OF SHORE, SHELF AND BASIN ZONES

A question that would be particularly suitable for examination from an orbiting laboratory concerns the nature and extent of differences in conditions in the three zones: the shore zone, continental shelf, and ocean basin. Is there some real change at the edge of the shelf in current and wave patterns? Are there discernible differences in water and sediment behavior on the shelf vs the basin? Are there, in fact, clear and detectable zones? Are there identifiable differences that validate the assumptions that environments in these three zones are distinctive? To what measureable extent do these zones influence each other? What is going on in each zone?

NEARSHORE-CIRCULATION AND SEDIMENTATION

With regard to the nearshore zone, it would be valuable to determine major circulation patterns, such as eddies from the Gulf Stream, and to define their diffusion patterns, especially as they influence sediment transport. Measurements should also be made of tidal currents, and of the effectiveness of these currents as compared with longshore wave-produced currents in regard to coastal erosion and sedimentation. Related to this would be an effort to trace the sediments from rivers along coasts. Under non-storm conditions rivers carry very little sediment to the coast but during storms which flood rivers, large volumes of fresh water and sediments outflow. By choosing a meteorological situation in which a drainage basin receives abundant rainfall, entrained sediments could be traced as they disperse along the coast. Patterns of dispersion and deposition are poorly known and beclouded by a lot of misconceptions. A sensor could be selected which would most clearly distinguish the sediment laden waters, although even ordinary photography if well-taken can provide considerable information, as shown by Cooper's MA-9 photograph of the Ganges River Basin. Undoubtedly sensors could be selected or designed that would detect at least certain kinds of pollutants in coastal waters, and the spread of the pollution could be traced. The orbiting laboratory also offers an excellent opportunity to observe and measure sediment dispersion around an entire tropical island, particularly to discover how it relates to reef development and to flows across the sandy bottoms. Through the use of infrared or similar sensors, much needed information could be obtained on the extent and character of coral reefs, both alive and dead.

SURF ZONE

Since the surf zone is the active area where details of beach morphology are determined, it deserves attention in several experiments. Many coasts are characterized by having one or more submerged bars in or near the surf zone. These bars change outline frequently, and it has been suggested that tidal rips determine the gross patterns, but more closely spaced irregularities exist and their explanation should be the subject of an experiment. Repeated sensing should be made along short segments, say one quarter mile, of sandy beaches such as along the Outer Banks of North Carolina, and on the ends and middle parts of cove beaches such as Half Moon Bay, California, in waters not over 7 fathoms deep. Bar shapes should be sensed at times of both high and low tides. This would yield some greatly needed information. In addition, an experiment should be designed to locate and measure the properties of a new storm at sea, and then trace the generated wave train to the shore to measure the changes in wave dimensions and patterns as the waves move into increasingly shoal water and to the breaker zone. Several such studies of discrete storms would aid materially in our understanding of transformation from deep-water to shallow-water waves. It would also be especially valuable if synoptic data could be obtained on the width of the surf zone throughout the area of orbit inasmuch as the width of the surf zone is indicative of many other nearshore environmental characteristics and processes.

COMPOSITION OF BEACHES

Another series of experiments should focus on identification of gross mineral composition of beaches, and, of course, on the selection of the most suitable sensors for such identification. If beach morphology is related to the minerals present, then it would be of extreme interest to find ways to sense the minerals. It would be desirable to be able to differentiate the beaches composed of:

1. Predominantly quartz
2. Predominantly calcium carbonate
3. Considerable amounts of magnetite
4. Considerable amounts of ilmenite
5. Considerable amounts of epidote
6. Considerable amounts of mafic minerals
7. Considerable amounts of non-calcareous organics

The Lesser Antilles would be a good locale for such investigations because their beaches display a wide variety of mineral groups, and the mineral composition of many of these beaches is already known so a certain amount of ground truth is available for calibrating the sensed data.

CAROLINA BAYS

There is a good possibility that a long-standing scientific controversy over the origin of Carolina Bays could be resolved through information gained from an orbiting laboratory. One hypothesis attributes the Bays to the impact of meteorite fragments. This thesis could be substantiated or refuted by taking advantage of the high altitude of the laboratory to obtain regional geomagnetic data, with a resolution of one mile or less. It would be essential to establish strong geographic or ground control to tie down the geomagnetic data. The hypothesis which attributes the Carolina Bays to ground water movement could also be checked through the use of infrared or some other sensor to detect the ground water patterns in the Bays section of the Atlantic Coastal Plain.

TIDAL STREAMS

If it is possible to detect the difference between fresh and salt water, very useful data could be obtained on the extent, timing and pattern of incursion of salt water in the tidal streams of coastal lowlands, and also of the outflow of fresh water. The distribution of sediments in these waters might also be detected, and thus provide important information relating to tidal channel erosion and deposition and to the whole problem of development of drainage systems in coastal marshes.

REGIONAL STRUCTURE AND LITHOLOGY

Tiros photography, as well as Project Mercury pictures taken by Cooper and other Astronauts, show the great potential of a space platform for obtaining new information on broad regional ground patterns that are not easily discernible on conventional photography from airplanes. From an orbiting laboratory, big sections of the earth can be covered in a single image or on a very few, easily handled images. The area represented on a photograph from a satellite is many thousands of square miles (MA-9 flight photos were at a scale of 1:800,000) as compared with a few tens of square miles on conventional aerial photographs (average scale of 1:20,000 to 1:40,000). This potential of acquiring broad regional coverage should be exploited to discover the extent to which regional, structural and lithologic conditions influence shorelines and coastal forms. Studies of maps and aerial photographs, even of Recent alluvial surfaces, commonly display numerous lineations, a large number of which trend northwest or northeast. It would be especially useful if lineations for broad regions or continents could be detected, for this might shed new light not only on problems of coastal behavior, but also on fundamental questions of the structural history of the earth, and on hypotheses of continental drift and migration of poles. If both the lineations and the types of bedrock along coasts could be detected, any relations of these factors might be discovered which could help to explain the morphology and world distribution of certain coastal forms.

Acknowledgment is made of suggestions by W. C. Krumbein, W. C. McIntire, R. J. Russell, and B. Thom that are incorporated in this paper.

EFFECT OF SUBMARINE VALLEYS ON WATER MASSES AND CURRENTS

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Experience in the investigation of submarine valleys indicates that their existence has an important effect on water masses and currents. It is well known, for example, that the cold deeper waters up well from time to time along the axis of the La Jolla submarine canyons. The trough-shaped continental shelf valleys off the Ganges and Indus deltas have indications of the importance of this current relation to valleys. In May of this year in approaching the margin of the Ganges shelf valley on the Pioneer we were repeatedly discovering a change in the water color so that a bluer shade or a less intense brown shade was found over the valley with a sharp contact at the break in slope of the valley margin. Similarly the Pakistan Navy in surveying the Indus shelf valley found streaks of foam running parallel to the boundaries on both sides. Features of this type can be photographed from the air.

We know that from time to time there are mass movements of sediments along the axes of submarine canyons, very likely producing turbidity currents. It is likely that these movements stir mud up into the surface waters above the canyons and that these movements could be detected by air photographs. In this way the frequent crossing of the large submarine canyons by camera equipped satellites may allow us to keep a record of the major canyon flushing episodes. This in turn could give us a better conception of the causes of these movements.

Among other indications of the importance of submarine valleys in influencing ocean currents has been the rather frequent observation that a ship positioned over the axis of a submarine valley will remain over the axis during a period of drifting amounting to as much as several hours. In view of the narrowness of the usual canyon axis there seems to be little doubt but what these cases of adhering to the axes, always with movement down or up the axis, are related to currents controlled by the canyon direction. This phenomenon was observed twice over the canyons off Baja California, once off La Jolla, twice in the Bahamas (over a canyon 1,900 fathoms deep), and once off the east side of Ceylon. As yet there is no evidence that any of these currents that are influenced by underlying valleys have surface phenomena that could be detected by air photographs, but further investigation may show that this is the case. For such an investigation the combined use of ships and air photographs would be necessary.

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STUDY OF RIVER EFFLUENTS FROM SPACE VEHICLES

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Use of space vehicles to study the Earth's oceans should be planned to take advantage of the following potential abilities of such vehicles:

1. World-wide surveillance.
2. Quasi-synoptic observations.
3. Frequent surveillance.

The suggestions made below are based on these unique capabilities of space platforms. It is urged that priority be given to large-scale applications instead of detailed investigations which may be more efficiently pursued by other techniques.

It is assumed that the present instrumentation, or at least improved instrumentation anticipated within the next five to ten years, is adequate for this proposal. It appears that photographic techniques are now excellent and can be improved considerably with little effort. Infrared sensing can map water temperature differences and future improvements may include determining actual temperatures.

Two problems concerning runoff from rivers have world wide implications. Reliable quantitative estimates of the total supply of fresh water and sediment would be of considerable importance in many areas of study involving the world ocean. Few rivers have accurate flow metering equipment and thus total runoff of fresh water from the land is not known. The total rate of supply of sediment to the ocean also is unknown. Essentially all sediment furnished from the land is from river flow, with minor amounts from coastal erosion and by wind and ice transport. These two problems are interrelated and can be investigated essentially as a single problem.

River effluents seen from above are characterized by one or more of the following: a) muddy water, b) differences in apparent color or shading, and c) lines of foam or floating debris. These are easily photographed by color or black and white film. River effluents also are usually characterized by water temperatures which differ from those of the surrounding sea water. These differences can be detected by temperature sensing techniques.

River effluents are generally wedge-shaped in cross-section, thinning upwards on the seaward edge and composed of water less saline than sea water. This water is less dense than sea water and thus floats on top of the more saline water.

The surface area of a river effluent can be mapped from an airplane or space vehicle using photographic and temperature sensing techniques. The next stage is to determine the exact shape of the wedge of river water and to make a realistic estimate of the volume of fresh water and quantity of sediment in suspension. This can be done by depth surveys of water salinities using recording salinometers and by direct measurement of sediment concentrations. Total fresh water and sediment load can be estimated from such surveys.

The three dimensional shape of the wedge of river water and sediment will be a function of a) the amount of river runoff, b) the submarine topography at the location of the effluent, c) wind and wave conditions, d) surface currents, e) tides and f) ice. The submarine topography underlying many areas of river discharge is fairly well known or can be easily mapped, and tidal regimes are sufficiently known at most locations. It appears that waves and currents can be surveyed by remote satellite sensing and wind can be inferred from wave patterns. The dynamic interrelationships of these various factors must be understood, however, before reasonable estimates of volume of fresh water and sediment load can be made by mapping of the surface.

It would be impractical to make a detailed analysis of even a large percentage of the world's river effluents. It is suggested that as an alternative river effluents may be divided into a small number of classes and that studies be made of a representative of each class selected. River effluents may be divided into classes using the following criteria:

a. Total flow. The actual flow is known for many rivers. Relative flow of others may be estimated by size and rainfall regime of the drainage basin.

b. Ephemeral or perennial. Many ephemeral rivers have significant flow during times of runoff, as in some areas surrounding the Arctic Ocean.

c. Marine conditions at the effluent, such as wind, waves, tides, currents and ice, insofar as known or estimated.

d. Sediment load. Sediment load is measured in some rivers, such as the Mississippi. In others relative sediment load may be estimated by color density of the outflow.

e. Size and shape of the effluent.

Close correlation of ground analysis and overhead surveillance will be required for this study. There is essentially no pertinent information available on the nature of river effluents, and basic ground studies will be necessary before sensing from high flying airplanes or satellites can be used.

A suggested beginning in such a program is to study one small, muddy river plume such as the Rio Balsas on the Pacific coast of Mexico. This should be mapped at various times from an airplane. Ground studies would be determination of the three dimensional shape of the plume and calculation of the amount of fresh water and sediment load at different times and under different conditions. The effect on the effluent of tide, topography, wind, waves and currents would be analyzed. An attempt would be made to determine whether the volume of water and sediment can be estimated by surface mapping techniques alone.

The second stage would be study of the more complex effluent of a large, relatively well-known river such as the Mississippi. Procedures would be modified based on experience. If both the studies were considered successful the next stage would be classification of the river effluents of the world and ground studies of representatives of each class. After completion of this stage it should be possible to determine total volumes of water and of sediment being supplied and their variations geographically and with time.

There are several probable by-products of such an investigation. Among these are effects of catastrophic events such as floods and hurricanes. Considerable insight into the dynamics of river effluents and processes of deposition in a delta is expected. There is now little understanding of these processes.

Reject

ESTUARIES

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Estuaries are usually relatively small bodies of water which display however, and often in an extreme form, the variety of surface conditions observed in the open sea. Thus, there are present marked gradients in salinity temperature and turbidity, drifting ice, and varied sea state, all of which display characteristic and changing pattern under the influence of strong currents due to tidal action. Most estuaries are sufficiently small to be readily surveyed synoptically from conventional aircraft, and the data so obtained may be easily checked by observations on the "ground". From these considerations it would appear that their value in the present connection may be in the preliminary testing of techniques to be subsequently employed over oceanic areas from high flying platforms. Some of the larger estuaries such as the Gulf of St. Lawrence or the Gulf of California are sufficiently extensive so that the transient phenomena they display may be profitably studied from satellites as the contribution of Dr. Cameron amply illustrates.

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POSSIBILITIES FOR USE OF SPACE AND OTHER HIGH ALTITUDE VEHICLES FOR GATHERING OF COASTAL ENGINEERING DATA

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The various kind of data needed for use in Coastal Engineering are mentioned briefly for each specific type of information.

METEOROLOGY

The distribution of winds, barometric pressure and humidity is responsible for waves, short as well as long period and certain type of currents. The more meteorological data which can be secured, particularly from areas which are not easily accessible, the better possibility exists for prediction of waves including normal storm waves as well as long period waves as storm surges, barometric pressure waves and waves caused by large scale irregularities in wind fields. Little is known about wave action penetrating from the arctic as well as antarctic regions. Space vehicles seem to offer excellent opportunities for gathering of such data as is already proven in specific cases. The recent experience with hurricane DORA demonstrated the need for more adequate data on the hurricane structure which may be picked up from space vehicles.

WAVES

Short period wave forecasting is based on knowledge about wind fields and/or barometric pressure which must be recorded. As outlined by Mr. W. J. Pierson, it should be possible to observe wave characteristics including sea roughness and actual wave dimensional and directional spectrum by the use of radar. Certain types of radar seem to be useful for studies of detailed nature requiring wave heights with 1/2 to 1 ft. accuracy and details on the directional spectrum. Evaluation of the sea state over larger areas using space vehicles provided with sensor of high resolution will be valuable in the forecasting technique as well as in estimation of the relative wave energy input on shores, particularly such shores as would be very difficult to observe otherwise. Propagation of long period waves including tides and waves of surge character observed from space crafts or other high altitude vehicles will be of large scale economic importance by providing data useful for accurate forecasting and thereby for an adequate warning system.

Two examples should be mentioned, the March 9-11, 1962 swell activity in the Atlantic Ocean which caused considerable damage on the Eastern Seaboard and the March 28, 1964 tsunami caused by the Alaskan earthquake.

CURRENTS

Coastal Engineering is mainly concerned with tidal and longshore currents caused by wave breaking. Some studies also include pollution problems. Aerial photography of current pattern in estuaries has proven very useful but the same technique may be possible for operations covering much larger areas if space or other high altitude vehicles with sensors of high accuracy and penetration can be secured. Data on density currents and internal waves may be secured thereby.

Information on wave induced longshore currents must be fairly accurate (1/4 to 1/2 ft/sec) in order to be of value. Radar has been used in Holland and in Canada for such purpose. High altitude stereo as well as infrared photography seems to offer excellent opportunities for detailed studies of current pattern and velocities in the surface. This technique has not been developed in any detail. It should be noted that longshore currents caused by wave breaking usually carry water with higher temperature than the water outside the breaker zone. Upwelling currents which may occur with strong offshore winds will normally carry water of lower temperature. Possibilities of penetration for observation of currents to deeper layers seem to exist. For computation of sediment transport, cu~~ nt data within the 1 ft. range from the bottom are needed and may be secured by a combi· .echnique using dyes, staffs, drift bottles or similar devices to be observed from airc ·r observation of open ocean currents, a multiple-look technique using satellites may ·ssible.

TIDES

Observation of the propagation of long period waves was mentioned above and tidal currents may be observed by infrared and stereo-photography. Observation of tidal heights along shores is done by photography. A more developed technique may make observation in the open sea possible if sufficient accuracy can be secured. This will be of great advantage for estimation of barometric squall and tsunami waves and their penetration from the deep sea into coastal waters, especially in funnel-shaped bays where the geometry may favor concentration of wave energy endangering coastal zones.

SEDIMENT TRANSPORT

Sediment transport is caused by the action of waves and currents on alluvial shores. Information of quantitative character on sediment transport must include data on the suspended-load as well as the bed-load transport. It is possible to observe the pattern of longshore currents with suspension load by photography, and it seems likely that it should also be possible to evaluate concentrations by the use of various kinds of photography combined with a proper calibration technique. But to be of value, it must be possible to measure concentration in various depths below sea surface. Infrared photography from aircraft or space vehicles may be of some value inasmuch as the temperature of nearshore water may differ from the temperature of offshore waters by several centigrade degrees. Wave breaking in itself causes a rise of temperature of measurable size. The difficulty with infrared is its very low depth penetration. Sediment transport in estuaries has for long been studied by aerial photography.

With respect to transport of material as bed-load, it is somewhat difficult to visualize how much transport may be observed from high altitudes. There is a possibility that modern tracing technique, particularly by fluorescent tracers, may be able to furnish details if proper light sources covering large areas can be arranged, and water is shallow enough to allow sufficient penetration of light and concentration of tracers in the bottom material can be made large enough. It is desirable to observe concentration as low as 10^{-10}. At the first instant this figure may sound absurd.

With respect to large scale transport of bed material in migrating sand waves on the bottom, aerial photography is already at this time very useful, and even larger scale phenomenon may be observed from high altitude vehicles. The existing photographs from the Cape Kennedy area are very interesting in this respect.

COASTAL TOPOGRAPHY AND MORPHOLOGY

It is now possible to undertake hydrographic surveys using color photography down to about 100 ft. depth under favorable conditions (very clear water). Accuracy must be high on the order of 1 to 2 ft. It may be possible to develop this technique further, particularly with respect to possibilities of penetration in turbid waters. Aerial photography using infrared spectra is already used for studies of vegetation. Other types of high altitude photography will be very important for studies of sand deposits useful for beach nourishment.

Changes in shoreline geometry is observed by periodic aerial surveys. It should be possible to develop this technique much further by the use of high altitude vehicles with proper photographic equipment making it possible to distinguish horizontal fluctuations on the order of 10 ft. and vertical changes of approximately 1 ft. Such information will be valuable in evaluation of technical as well as scientific matters, particularly if combined with ability to penetrate shallow waters thereby allowing evaluation of large scale sediment transport. Periodic surveys of shorelines and special surveys following storms will give information of great scientific and economic value. High resolution photography from space vehicles may be very important.

Use of buoys moored in offshore waters telemetering wave data to shore would allow a correlation between wave data and shore movements. Longshore currents must be recorded simultaneously.

FORCES

There seems at this time to be little possibility for evaluation of actual forces on objects by the use of sensors installed in low or high altitude vehicles. Meanwhile information secured on sea state will be able to furnish wave data and thereby information on wave energy and its propagation. Current data will be of similar value, if it becomes possible to observe currents at different elevations above the sea bottom. Low flying aircraft are useful for evaluation of details of the wave spectrum at wave breaking and the character of the wave breaking. This technique should be developed to secure more details.

CONCLUSION

In conclusion, it may be said that even in "a field of details" like coastal engineering, high flying vehicles seem to open possibilities in the future of great value for coastal engineering research. At this time certain details may be studied by low flying aircraft using a properly calibrated technique. Radar, stereo-photography and infrared photography seem to offer excellent opportunities.

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COASTAL PROCESSES

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1. In view of the close interaction between COASTAL PROCESSES and such diverse phenomena as gravity waves, currents, tides and runoff from rivers, it would appear that any sort of overall observation or recording that could help integrate those phenomena should be pronounced a GOOD THING and worthy of close study.

2. The present status of COASTAL GEOGRAPHY studies lies in the area of small-scale, local, concentrated investigations, for the most part. When considering the problem of long-shore sand movement along beaches, for example, which have billion-dollar economic price-tags, we are often involved in complex interactions, the parameters of which cannot be established within a local area. The major swell source may, for instance, originate several thousand km. away. Forces which produce erosion and damage to coastal installations at one point will logically lead to harbor and channel siltation in another. The recent program of air photographic coverage along the eastern U. S. seaboard from low-flying aircraft has been a valuable step, but essentially only an extension of the local study viewpoint.

3. A world pilot-study of coastal sediment dynamics has recently been issued by R. SILVESTER (at present in Berkeley, Dept. of Engineering). Calling for a concentrated effort would be a sequence of high-level records of swell-sediment motion reactions at close intervals over a 12-month period.

4. In addition to obviously seasonal, repetitive dynamics, there are long-term secular phenomena that are much less easy to observe, but which nevertheless ultimately reach crescendo points which may have vast and catastrophic results. One may consider the case of Dutch dike catastrophes, which reflect the coincidence of more or less predictable meteorologic/oceanographic phenomena (low pressure, high tides, onshore winds, seiche effects) and secular phenomena (the slow subsidence of the North Sea Basin, about 1-2 mm. annually, and the recent eustatic rise of sea level, 1-5 mm. annually). The geomorphology of such regions, in contrast to stable or uplift areas, is very distinctive, but difficult to analyse systematically on the basis of local studies alone.

5. Climatologists now clearly recognize the existence of long-term climatic oscillations (related variously to UV solar transmission, volcanic dust/albedo control and other factors). Oceanic circulation must be geared to these oscillations, but the relationships have yet to be worked out in detail, notably the time or retardation factors. Since the Coriolis Force is involved, variations in the energy of any major coastwise current such as the Gulf Stream will lead to variations in the tilt of the mean water surface, to be recorded by anomalies in coastal tide gauges. Any device that could be used to measure the Gulf Stream velocity, for correlation against the east coast tide gauges would be of inestimable value.

6. Coordination with ground studies is evidently essential if any of the above projects were to be implemented. This has always been a sine qua non for the proper appraisal of air photography. It would seem that observations and recordings from satellites, manned or otherwise, involve two new dimension changes:

a. Scale, raising the mean height of the observer from about 10 km. (in conventional a photography) to 100 km. and over, thus at least one order of magnitude in elevation but two orders of magnitude for the area covered by a given picture with a conventional camera.

b. Sensing Equipment. It is evident that cloud and smog obliteration factors must be avoided by use of new devises. The effectiveness of radar photography at intermediate altitudes has already been demonstrated. We should explore the possibility of "seeding" major currents, such as the Gulf Stream, with metal-impregnated cork chips or plastic-balls weighted to float at predetermined depths. Methods for the large-scale tagging of beach sands should also be investigated.

7. Administrative Procedure. As far as COASTAL GEOGRAPHY, ENGINEERING, GEOMORPHOLOGY, and OCEANOGRAPHY are concerned, a first step would be the establishment of a planning and coordination committee, to bring together existing national and international authorities and study groups. These should include representatives, amongst others, of:

- International Conference on Coastal Engineering Council for Wave Research
- International Association for Quaternary Research (INQUA Commission on Shorelines)
- International Geographical Union (IGU Commission on Coastal Geomorphology)
- International Union of Geodesy and Geophysics (Int. Oceanographic Assoc., Commission on Shallow Water Research)
- U. S. Coast and Geodetic Survey
- U. S. Army, Corps of Engineers (Beach Erosion Laboratory)
- U. S., Office of Naval Research, Geography Branch
- U. S., National Science Foundation, Earth Sciences Division.

STATUS OF MARINE GEOLOGY STUDIES IN MEXICO

N65-30396

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INTRODUCTION

It is notable that the importance of Marine Geology and oceanographic studies in Mexico had been overlooked by the Mexican government and scientific institutions until recently. Apparently it made no difference that Mexico is one of the largest countries in the world with regard to the length of its coasts of littorals which extend for more than 2,270 kms. on both the Atlantic and the Pacific Oceans.

Moreover, the continental platform off the coasts of Mexico add up to more than 477,500 kms^2, down to the 200 m isobath.

With the advent of oceanography as a modern coordination of a group of marine disciplines in the past decades, some Mexican scientists started oceanographic activities at the Universidad Nacional Autónoma de México.

Thus, as shown in the text later tide observations were begun in a systematic and scientific way for the first time early in the past decade. Later, expeditions to study volcanic islands in the Pacific Ocean gave rise to a series of marine and littoral observations by geologists in Mexico so that, under the encouragement of Drs. F. B. Phleger and Gifford C. Ewing, of the Scripps Institution of Oceanography the senior author started the Marine Geology Department at the Instituto de Geología in the Universidad Nacional Autónoma de México.

This new Department stimulated the use of marine biology studies to complement geological surveys in littoral lagoons and thus marine biology came into its own in the last few years.

A selected bibliography presented at the end of this paper will contribute to fulfill the scope sought in presenting it so that more information will be available to the international oceanographic researcher.

The authors acknowledge sincere thanks to Drs. P. M. Fye, Director of Woods Hole Oceanographic Institution and G. C. Ewing, Chairman of this Conference convened to evaluate the feasibility of conducting oceanographic explorations from aircrafts, and manned orbital or lunar laboratories.

BRIEF HISTORICAL BACKGROUND

Although Mexican littorals and nearby islands have been explored since the XV Century by the first European explorers, as Amerigo Vespucci, in 1497, it was not until the conquest of Mexico was consumated by Hernan Cortés, and afterwards, that the first systematic exploration for strategic mapping of the Mexican littorals and islands was initiated.

On the Atlantic side in the XVI Century Pinzón, Alamino, Grijalva, and others contributed to the mapping of the Mexican coast in the Gulf. On the Pacific side at approximately the same time, Cortés, Sandoval, Oñate, Vizcaino, and others mapped along the littorals on the mainland at the Baja California Península.

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Mapping and littoral studies continued throughout colonial times but maritime transportation did not require intensive or extensive knowledge of the Mexican coast; except around the two or three harbors in use at the time, on each ocean.

By the XIX Century, both the British and the American Admiralties, effected extensive mapping of the coast of Mexico and its Continental Platform close to shore, so that excellent coastal maps became available after the USS Narragansett (1873-1875) and the USS Tuscarora (1878-1879) expeditions on the Pacific. On the Atlantic side and in the Gulf of Mexico and Caribbean, excellent maps were put forth by the H.M.S. Challenger (1873-1876) expedition of the British Admiralty (1852) and by the USS Wyoming (1873-1874) and the USS Fortune (1873-1874).

Naturally, these bathimetric and geographic maps were limited solely to navigation requirements and may be taken as the predecessors of actual oceanographic studies in Mexican waters.

With the advent of modern and more scientific equipment for the oceanographic disciplines, Mexican shores and oceanic waters have been explored and studied by several foreign Institutions so that within the past two decades literature on marine geology and allied subjects has grown profusely in amount and in quality.

Thus, it is hoped by the authors that the main objective sought in presenting this paper, which is to bring up to date the state of oceanographic and marine geologic knowledge regarding Mexican littorals and oceanographic waters, will be fulfilled by the following brief summaries of most of the works done in Mexican waters and by presenting what is believed to be an up to date bibliography on Mexican oceanography and marine geology, etc.

The Revillagigedo Archipelago and the Gulf of California were studied several times, especially in 1921 and 1925. The basic knowledge of the physical and biological characteristics of those islands was obtained from expeditions.

The same areas were surveyed by the vessel "Velero III" of the Allan Hancock Foundation in several expeditions. Most of the results are described in the "General Account of the scientific work of the 'Velero III' in the Eastern Pacific", 1931-1941, published by the Foundation in 1943.

Cruises to the Gulf of California were organized by the Scripps Institution of Oceanography, during 1939 and 1940, in the vessel "E. W. Scripps". Results of the Marine Geology research were published by various authors, in 1950 in a Memoir of the Geological Society of America.

An expedition to the Revillagigedo Archipelago was made by the Scripps Institution of Oceanography, in 1952, to study the birth and development of the new volcanco "Bárcena", in the San Benedicto Island, under the leadership of Dr. A. F. Richards. The islands, submarine bottom and structural characteristics of the Clarion Fault were studied. Another expedition to the area was made in 1955, in the vessel "Crest".

An exploration to the reefs south of the Triangulo Island, in the northern portion of the Campeche Bank and other reefs north and east of Yucatan Peninsula was organized in 1955 by the Politechnical Institute, under Dr. F. Bonet, in a vessel of the Mexican Navy, the "David Porter". General geologic observations were made on the reefs, particularly concerning their mechanism of growing, related to sea currents, especially the Gulf Stream. Biological studies also were made, under Drs. E. Caballero and C. Bolivar.

Another expedition to the Revillagigedo Islands was organized by the Scripps Institution of Oceanography in 1957, under the scientific direction of Dr. A. F. Richards in the vessel "Stranger", with participation of Ing F. Mooser of the Instituto de Geología. The main geological purposes were to study the large Clarion Fault, and the petrographic composition of cores and rock samples of the Clarion, Socorro and San Benedicto Islands.

Investigations in the Campeche Bank area by the Agricultural and Mechanical University of Texas, were begun in 1957, under Drs. K. H. Drummond and R. G. Bader, in the vessel "Jakkula", Dr. F. Bonet of the Instituto de Geología participating. Geophysical, geological and biological studies were carried out. Cores of sediments from the continental shelf and deeper portions of the Bay of Campeche were obtained, 25 hydrographic stations were established, bathytermographic observations were made each hour (with plankton collecting), and meteorological data was obtained, accompanied by information of the upper atmosphere. Later cruises in the vessel "Hidalgo", in 1952 under Dr. L. S. Kornicker, in close relationship with the Instituto de Geología, were developed, with the participation of Ing. A. Yáñez and Ing. R. Pérez Priego.

A Mexican expedition to the Socorro of the Revillagigedo Archipelago was organized in 1958 in the vessel "Tehuantepec" of the Mexican Navy, by the Instituto de Geofísica of the National Autonomous University of Mexico, under the leadership of Dr. J. Adem, covering geophysical, geological and biological aspects. Ing. L. Blásquez of the Instituto de Geología participated, and studied the hydrogeology and edafology. A monograph of the research done was published by the Institute, 1960.

Although the increasing interest of Mexican scientists in oceanographic disciplines was great, lack of research facilities and trained personnel kept them from participating actively in such explorations until 1959, when a coordinated effort was made towards the execution of definite research programs in the Instituto de Geología.

Marine geological and general oceanographic studies at the Instituto de Geología began early in 1959. Mutual cooperation programs were undertaken with the Scripps Institution of Oceanography of the University of California, the Instititute of Marine Sciences of the University of Texas, and the Department of Oceanography and Meteorology of the Agricultural and Mechanical University of Texas. Three of the members of the staff of the Instituto de Geología have been on board several oceanographic cruises in the Pacific Ocean, Gulf of Mexico and Caribbean Sea, and visited the Scripps Institution of Oceanography several times, studying the laboratory organization and specialized methods employed, for improving their scientific preparation.

Special efforts have been made to educate a group of Mexican scientists in different fields of Marine Geology. Twelve scientists constitute the staff working on the projects in process, covering the basic field work, the study of inorganic and organic fractions of the sediments, and some experimental ecological work.

The Instituto de Geología initiated its first formal marine geology project in 1959 under the direction of the senior author. With the encouragement and sponsorship of Drs. F. B. Phleger and J. Curray of the Scripps Institution of Oceanography, a program was initiated to study the Mexican coastal lagoons on the Gulf of Mexico shores (Laguna Madre, Tamaulipas; Laguna de Tamiahua, Veracruz; and Laguna de Términos, Campeche).

This work was facilitated by N.S.F. Grant No. 19105. To carry out this program sedimentology laboratories were established at the Instituto headquarters and the Laguna de Términos was chosen to begin the program. Results of this work were published late in 1963.

General studies of the Laguna Madre began in 1962 and it is hoped to publish results early in 1965. The Laguna de Tamiahua field work was completed in June 1964, and probably the results will be published late in 1965. These studies are coordinated by the junior author.

A program for the joint study of the Alacran Reff, Campeche Bank, by the Instituto de Geología and the Institute of Marine Sciences of the University of Texas was established and field work done in 1959, 1960 and 1961, under the leadership of Dr. L. S. Kornicker and the senior author of this report. Dr. F. Bonet and Ing. A. Yáñez, of the Instituto de Geología participated, several papers have been published and many others are in progress.

An important research program in the Gulf of California was started by the Scripps Institution of Oceanography, in close relationship with the Instituto de Geología. The vessels "Baird" and "Horizon" were used. Studies included part of the mainland, and some portions of the coastal and offshore Baja California areas. Members of the Instituto de Geología participated sporadically in the project. Aircraft, ship and land operations were carried out.

A Geophysical study of the Sigsbee Deep, was organized for the Lamont Geological Observatory of Columbia University, in 1961, in the vessel "Vema" under the leadership of Dr. M. Ewing. The Instituto de Geología was invited to participate and Ing. A Yáñez was commissioned to the cruise. At the request of the senior author seismic profiles were shot across the Continental Platform to tie in to the Pemex wells at the North Yucatan mainland.

Minor Marine geological studies, have been made by personnel of the Instituto de Geología under a cooperation contract with the Mexican Navy, particularly concerning sedimentary studies for Harbor development in various areas of the country.

Physical Oceanography studies have been carried out mainly by the Instituto de Geofísica in the U.N.A.M. That institute established, in cooperation with the Inter-American Geodetic Survey, a series of tidal guages on both coasts, in 1947; some of these were discontinued soon after for technical reasons and others are still in use. Determinations of salinity, temperature and other data have been made more or less continuously at those stations. Results have been published for several years. It may be said that study of such aspects of the physical regime of the sea became more appropriate in 1961 when numerical data began to be processed by a computing machine for tide prediction.

Meteorologial, gravimmetrical and seismological studies have also been made. Their results are published mainly in the Anales del Instituto de Geofísica. Meteorology and Climatology of the ocean-continent-system in the Gulf of Mexico are covered by the Institute of Nautical Meteorology of the Directorate of Geography and Meteorology of the Secretariat of Agriculture.

Efforts will be continued in the future, and it is hoped to obtain enough economic support to train more specialists, and to carry out more ambitious programs such as the study of the continental shelf adjoining the coastal lagoons already studied. This requires necessarily more expensive equipment and larger laboratory facilities.

Marine biological studies are carried out at the Universidad Nacional by scientists of the Instituto de Biología. They are concerned with taxonomic, ecologic and evolutionary aspects of different groups of flora and fauna from both Mexican littorals. Results are published in specialized journals, particularly the Anales del Instituto de Biología. Biological studies of marine organisms are also conducted in the National Schools of Biological Sciences of the Mexican Politechnical Instutute, and the results published mainly in the Anales de la Escuela Nacional de Ciencias Biológicas. The Directorate of Fisheries and Related Industries of the Secretaria de Industria y Comercio, through the National Institute of Fisheries Biology, is responsible for the technical study and conservation of marine and inland water organic resources, mainly fisheries; this agency is publishing occasional papers on Marine biology, and informational pamphlets.

The sudden development of Marine geological research in the country since 1959 acted as a catalytic agent to increase interest of Mexican Institutions and scientists in the oceanographic disciplines. The First National Oceanographic Congress, celebrated in Chilpancingo and Acapulco, in March, 1963, with a presentation of nearly 100 papers, was an indication of such reaction. The Second National Oceanographic Congress will be held in Ensenada, Baja California, in March, 1965.

A discussion of the different regional or specific studies of Marine Geology in Mexico, particularly those conducted with the participation of the Instituto de Geología follows, including in each case the more significant references and a map (Fig. 1) showing the specific areas of study.

FIGURE 1.- MAP OF MEXICO SHOWING THE SPECIFIC AREAS OF MARINE GEOLOGICAL STUDIES DISCUSSED IN THIS REPORT

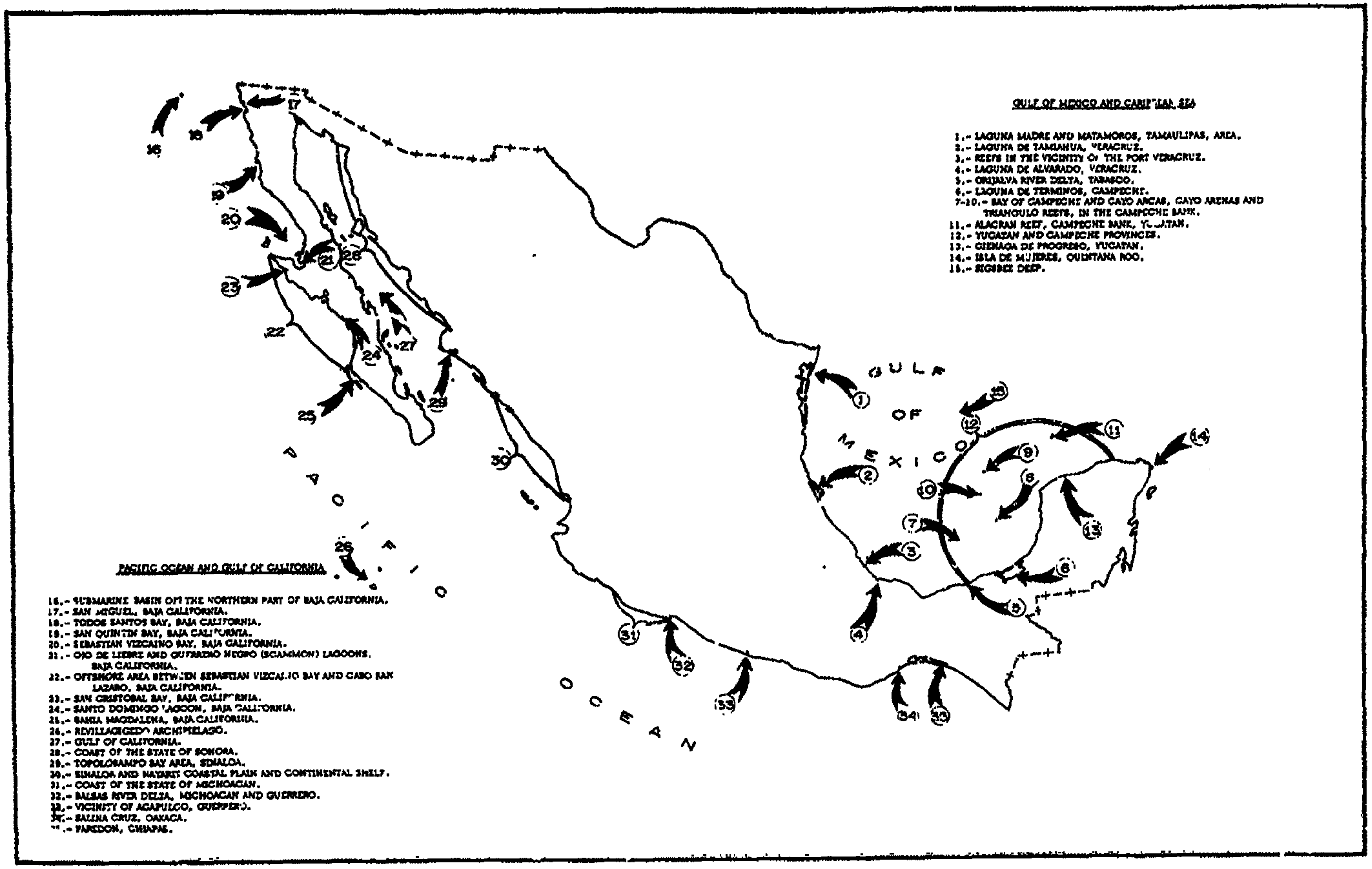

Figure 1. Map of Mexicc Showing the Specific Areas of Marine Geological Studies Discussed in This Report.

A COMPREHENSIVE ANOTATED BIBLIOGRAPHY

A short, but realistic historical description of oceanographic studies in México to 1957 was published by Maldonado-Koerdell (1958a). This author stressed the fact that no Mexican Institution was doing Marine Geological studies, and probably the Institute of Geology of Petróleos Mexicanos could be interested in this field.

The Panamerican Institute of Geography and History published two papers (1958, 1960), including American Bibliographies in Oceanography and Geophysics, respectively.

Alvarez del Villar et al (1961) made a complete analysis of Hydrobiologic and fisheries investigations in Mexico, including an extensive bibliography with 1831 references, some of them concerned with papers in Marine Geology.

Ayala-Castañares (1963a) summarized the oceanographic and Marine geological studies in which the Institute of Geology participated between 1959 and 1963, with special attention to the independent programs carried out by scientist of that Institute.

GULF OF MEXICO AND CARIBBEAN SEA REGIONAL STUDIES

REGIONAL FRAMEWORK

Geology, shorelines and coasts, Marine Meteorology, physics and chemistry of the waters, Physical Oceanography, light penetration and Foraminifera are discussed regionally by Lynch (1954), Price (1954), Leipper (1954a), Marmer (1954), Leipper (1954b), Shoemaker (1954), and Phleger and Parker (1954), respectively. Important biological aspects are described in the important monograph "Gulf of Mexico, Its Origin, Waters and Marine Life", Lynch (1954).

EAST MEXICO COASTAL LAGOONS

A short contribution describing the general program of the Institute of Geology studies in the larger East Mexico coastal lagoons was presented by Salas and Phleger (1962).

EASTERN MEXICO CONTINENTAL SHELF

General aspects of the oil exploration studies made by Petróleos Mexicanos on the continental shelf of Eastern Mexico were discussed by García Rojas (1963). The paper refers specifically to the area from Isla de Lobos, off the Laguna de Tamiahua, to the Santa Ana Area, off the State of Tabasco.

SPECIFIC AREAS OF STUDY

1. LAGUNA MADRE, TAMAULIPAS AND MATAMOROS AREA, GENERAL STUDY

Field work was done in 1962-1963. The general reconnaissance of the area was made by aircraft, by Ing. A. Yanez and the authors, laboratory studies, under the coordination of the junior author, of the material collected in 200 stations will be finished this year. It is hoped to publish several papers giving the general description of the area early in 1965. Bathymetry, salinity, temperature as well as sedimentological investigations of the inorganic (grain size, heavy minerals and internal structure features through X-Ray exposures) and organic (diatoms, foraminifera, ostracods and molluscs) fractions are included. An ecologic study of the vegetation of the beaches and areas surrounding the lagoon and the island is being made. Experimental ecologic studies on living foraminifera are also in process. Although a paper by Segura (1963) has already been published, dealing with the foraminifera of the "Playa Washington" south of the Rio Grande Mouth near Matamoros, Tamps; detailed studies are planned for future activities.

2. LAGUNA DE TAMIAHUA, VERACRUZ, GENERAL PROJECT

Field work was done in June, 1964 by Ing. A Yáñez, under the supervision of the junior author. A helicopter was used in part of the field work, 60 stations for ecologic observations and measurements were established and dredged and core sediment samples were collected for sedimentological studies of both the inorganic and organic fractions, covering the same aspects as the Laguna Madre studies. Water samples for suspended sediment content as well as plankton tows and bottom vegetation samples were obtained.

Detailed laboratory studies of those materials, under the coordination of the junior author are in process, including some biological studies of bottom vegetation and plankton, made by specialists of the Department of Biology of the Faculty of Sciences and the Institute of Biology respectively.

Technical biologist of the Institute of Fisheries Biology also participated for studying some specific biological aspects. The Coastal Studies Institute of Louisiana State University began a few years ago a geomorphologic, ecologic and geographic study of this area. As part of their results Poggie (1962) published a paper dealing with pioneer plants and their habitat in the Cabo Rojo Area.

3. REEFS IN THE VICINITY OF THE PORT OF VERACRUZ

A detailed sedimentological study of the reefs and sand sediments in the vicinity of Veracruz was begun in 1963, by J. Morelock of the Department of Oceanography and Meteorology of the Agricultural and Mechanical University of Texas in close cooperation with the Instituto de Geología. The project is still in progress.

Emery (1963) described briefly the sedimentology of the reefs near the Port of Veracruz.

4. LAGUNA DE ALVARADO, VERACRUZ

Sedimentological analyses were made in this area, as part of a cooperative research program for Harbor development with the Mexican Navy in 1963.

5. GRIJALVA RIVER DELTA

Sedimentological studies were made in this delta, in 1962, as part of the joint projects with the Mexican Navy.

6. LAGUNA DE TERMINOS AND CARMEN ISLAND, CAMPECHE

A) General study. General oceanographic and sedimentologic studies were begun early 1959, under the leadership of the senior author and Dr. F. B. Phleger of the Scripps Institution of Oceanography, with collection of ecologic data and 200 samples of sediments (dredge and core samples). Laboratory studies were done under the coordination of the junior author, and papers published late in 1963, covering the bathymetry, salinity, temperature and recent sediments (Yáñez, 1963), generic distribution of recent diatoms in the sediments (Silva-Bárcenas, 1963), systematics and distribution of the foraminifera in the sediments (Ayala-Castañares, 1963b), and systematics and distributions of the micromolluscs (García Cubas, 1963). Studies on distribution of ostracods and experimental ecologic research with living foraminifera are still in process.

Zarur (1961-1962) published some biological results as a guest research fellow on this project representing the Inst. Tecnologico de Veracruz.

Folk (1962) discussed briefly the sorting of the carbonate beaches on Carmen Island

B) Advanced studies. More detailed and advanced studies in the area were planned in early 1963, and Dr. F. B. Phleger, Dr. A. Ayala-Castañares and Ing. A. Yáñez visited the area in May, of that year, to locate 17 stations for ecologic observations and sampling. The purpose of this study is to determine the variability of the ecologic factors in the whole area, as well as the relative organic productivity and relative rates of deposition, employing mainly standing crops, and the rate of total number of living foraminifera, diatoms and micromolluscs by uniform volume of sample parameters as depositional rate norms. This project will be continued during at least three more years. Plankton and bottom vegetation seasonal productivity studies are carried out by personnel of the Institute of Biology and the Department of Biology of the School of Sciences respectively. Technical biologists of the Institute of Fisheries Biology are also participating in this program.

Sampling and detailed studies of Carmen Island, which is believed to be a barrier island, were started in May, 1963. Detailed topographic and geologic studies will be done trying to determine its origin, evolution and rate of growth. The Northern beach of the island was carefully sampled by means of 30 sampling sections along the coast. Carbon 14 determinations will be made for age dating.

7-10. BAY OF CAMPECHE, CAYO ARCAS, CAYO ARENAS AND TRIANGULO REEFS IN THE CAMPECHE BANK

A research program for studying those areas was begun in 1957, by the Department of Oceanography and Meteorology of the Agricultural and Mechanical University of Texas, under Drs. D. H. Drummond and R. G. Bader, with participation of Dr. F. Bonet of the Institute of Geology. Some results have been published by Creager (1958a, 1958b), covering a submarine canyon-like feature, and bathymetry and sediments of the Bay of Campeche respectively. Results on wave refraction and wave energy in Cayo Arcas, Campeche Bank were published by Walsh, Reid and Bader (1962).

Another series of investigations of the area, by the same institution under Dr. L. S. Kornicker was made in 1961, Ing. A. Yáñez and Ing. R. Pérez Priego, participated. The description of one of the cruises was published by Perez Priego (1962).

11. ALACRAN REEF, CAMPECHE BANK, YUCATAN

The integral study of physical, geological and biological characteristics of the reef complex was carried out as a cooperative program between the Institute of Marine Sciences of the University of Texas, and the Instituto de Geología, under the leadership of Dr. L. S. Kornicker and the senior author. The Institute commissioned Dr. F. Bonet and Ing. A. Yáñez for the field work done in 1959, 1960 and 1961. Several scientists of different institutions in Mexico and the United States are studying the materials collected. Marine geological studies of the sediments are designed to define the sedimentary patterns. A diamond bit hole was drilled down to 150 feet, cores and samples are being studied at the Institute. Several papers have been published, covering the general description (Kornicker, Bonet, Cann and Hoskin, 1959), shallow water geology and environments of the reef complex (Kornicker and Byd, 1962), molluscs (Rice and Kornicker, 1962), sorting of some carbonate beaches (Folk 1962), carbonate sedimentation (Hoskin, 1963), carbonaceous sand (Folk and Robles, 1964) short foraminiferal study (Davis, 1964), and vegetation of the islands (Bonet and Rzedovski, 1964). Sediments of the well in Isla Perez will be published shortly by Dr. F. Bonet. Detailed ecology and distributional studies of the foraminifera in sediments (surface and subsurface) will be published early in 1965 by the junior author and C. González.

12. YUCATAN AND CAMPECHE PROVINCES

Harding (1964) published an important contribution dealing with the petrology and petrography of the Campeche Lithic Suite, Yucatán Shelf, as part of the cooperative studies made by the Department of Oceanography and Meteorology of the Agricultural and Mechanical University of Texas and the Instituto de Geología.

Logan (1962) described the submarine topography of the Yucatán platform.

13. CIENAGA DE PROGRESO, YUCATAN

Physical studies, some of them concerning sedimentation were made by the Mexican Navy. The results are published by the Dirección General de Obras Marítimas (1963a).

14. ISLA DE MUJERES, QUINTANA ROO

Folk, Hayes and Shoji (1962) described the carbonate sediments of Isla de Mujeres and vicinity, as part of the guide book of a field trip to Yucatán, organized by the New Orleans Geological Society.

Folk (1962) discussed briefly the sorting of carbonate beaches in that area.

Shoji (1963) wrote a detailed review of the first mentioned study.

15. SIGSBEE DEEP

Excellent geophysical research was conducted in 1961 by the Lamont Geological Laboratory in the Sigsbee deep, under the leadership of Dr. M. Ewing. The Instituto de Geología was invited to participate and Ing. A. Yáñez (1962) published a short paper describing the program and mode of operation of that cruise.

PACIFIC OCEAN AND GULF OF CALIFORNIA
REGIONAL PAPERS

Regional papers have been published concerning the Baja California Peninsula area or with the Mexican portion of the Pacific Ocean, concerning the general geology and historical geology of Baja California (Durham and Allison, 1950; Mina, 1956, 1957). The volcanological and some structural features of Mexico, including some submarine characteristics, the submarine topography of the Pacific Ocean West of Mexico (Heacock and Worzell, 1955), the gravimetric and Cortical Structure of Mexico (Woollard and Monges Caldera, 1956) and the seismic-refraction results on the Middle America Trench, from Puerto Vallarta South (Shor and Fisher, 1961).

SPECIFIC AREAS OF STUDY

16. SUBMARINE BASIN OFF THE NORTHERN PART OF BAJA CALIFORNIA

A survey of this new basin was published by Emery (1953), showing details of the submarine topography.

17. SAN MIGUEL LAGOON, B. C.

Sedimentary significance of depositional environment in this lagoon, and a general oceanographic description of the area were covered by Stewart (1958).

18. TODOS SANTOS BAY, B. C.

This area has been explored by different researchers. Walton (1955) wrote a general oceanographic description and discussed in detail the Ecology of the living Foraminifera, with a view to understanding deposition of these materials. The Ecology of the recent Ostracods of the area was studied by Benson (1956, 1959).

Emery, Gorsline, Uchupi and Terry (1957) discussed the sediments of Todos Santos Bay.

Recently Ing. C. Obregón of the School of Marine Sciencies of Baja California, in Ensenada has been studying the bathymetry and geologic interpretation of the Todos Santos submarine canyon. He is also studying the sedimentation process that is sanding up Ensenada Harbor.

19. SAN QUINTIN BAY, BAJA CALIFORNIA

Some aspects of the recent history of this area were explained briefly by Gorsline (1962).

20-21. SEBASTIAN VIZCAINO BAY, OJO DE LIEBRE AND GUERRERO NEGRO (SCAMMON) LAGOONS, BAJA CALIFORNIA

These areas have been explored during the past several years by scientists of various institutions, especially Scripps Institution of Oceanography, Drs. F. B. Phleger, J. S. Bradshaw, H. Postma, G. C. Ewing, et al. The authors of this report participated in some field operations either by aircraft, boats or on land. Sedimentology and Oceanography of the Ojo de Liebre and Guerrero Negro Lagoons was studied by Phleger and Ewing (1962). Phleger (1964) mentioned some ecological aspects of Ojo de Liebre Lagoon. Some sedimentary characteristics of Scammon Lagoon were discussed by Stewart (1958).

22. OFFSHORE AREA BETWEEN SEBASTIAN VIZCAINO BAY AND CABO SAN LAZARO BAJA CALIFORNIA

(Studies of the genetic process of the offshore.) Recent phosphorites North of Sebastian Vizcaino Bay on the western shores of Baja California, have been completed and are awaiting publication. Preliminary results were published by D'Anglejan (1962), as part of the cooperative programs between the Scripps Institution of Oceanography and the Instituto de Geologia of the Universidad Nacional Autónoma de México.

23. SAN CRISTOBAL BAY, BAJA CALIFORNIA

Some sedimentological aspects of this bay were described by Emery, Gorsline, Uchupi and Terry (1957).

24. BAHIA MAGDALENA, BAJA CALIFORNIA

Physical characteristics, including sediment composition were made by the Mexican Navy, with the cooperation of the Institute of Geology. Results were published by the Dirección General de Obras Marítimas (1963).

25. SANTO DOMINGO LAGOON, BAJA CALIFORNIA

Phleger and Ewing (1962) discussed briefly some of the physical oceanographic aspects of this area as well as sedimentary patterns.

26. REVILLAGIGEDO ARCHIPELAGO

These islands have been studied several times, as may be noticed in the foregoing historical review. Papers have been published relative to several expeditions of the California Academy of Sciences (Hanna, 1926, 1927); hydrogeology and edafology of the Socorro Island (Blásquez, 1960a, 1960b), and volcanology (Maldonado-Koerdell, 1958c, Richards, 1953, 1956, Richards and Dietz, 1956, Snodgrass and Richards, 1956, and Williams, 1952).

27. GULF OF CALIFORNIA

Comprehensive studies of the Gulf of California have been made during the past 15 years by both Mexican and foreign institutions or individual scientists. These include many aspects of the marine environment, submarine basins and surrounding land forms. The major stimulus to this kind of research was originally given in 1940 by the "E. W. Scripps" cruise, of which the results were published some years later in a Memoir of the Geological Society of America (vide Anderson and other authors in the Bibliography). The work published is mainly dedicated to the geology and paleontology of the Gulf environments.

For the purposes of this report, the pertinent papers will be referred to as follows: a) general and Marine geology including submarine topography, b) Sedimentology and geochemistry, c) Paleontology and Stratigraphy, including taxonomy.

a) The structure and tectonics of the elongated trough that constitutes the Gulf of California, as well as the geology of its coasts and island have been dealt with by Anderson (1950), Byrne (1957), Shepard (1950), Sverdrup (1941) and Thompson (1962).

b) The sedimentary pattern and geochemical composition of sediments have been discussed by Bandy (1961, 1962, 1963), Bradley (1949), Byrne and Emery (1960), Keen (1962, 1964), Parker (1962), Phleger (1962, 1964, and in press), ""velle (1950), Taft and Harbough (1964), and Van Andel (in press).

c) Invertebrate Paleontology and stratigraphy is rather poorly represented and in need of stimulus for a better knowledge of organic remains in the area: Mention can only be made of two papers, one by Durham (1950) on megascopic paleontology and Marine Stratigraphy, and another by Natland (1950) on Pleistocene and Pliocene Foraminifera.

d) Similarly, the general geophysical aspects of the Gulf of California have only these references; the first by Harrison and Spiess (1961) on gravity measurements in the submarine bottom, the second by Kovach and Monges Caldera (1961) on results of a gravity survey in the delta of the Colorado River, and the third by Spiess (in press) on the gravimetry, seismology and heat flow characteristics; and general geophysics (gravity, seismology, magnetometry, etc.), and physical oceanography. Obviously by reason of facilities and opportunity, some of these special fields are greatly developed while others are only represented by a few contributions.

e) The physical oceanographic aspects have been reported upon only by Roden (1958) covering oceanographic and meteorologic aspects, and Roden and Groves (1959) on some physical oceanographic traits.

However, in the four special fields above mentioned, a number of papers are either in the process of preparation or are in print. Furthermore, within the International Upper Mantle project of the International Union of Geology and Geophysics (I.U.G.G.), the Instituto de Geofísica de la U.N.A.M., in collaboration with the University of California at Los Angeles and the California Institute of Technology, in Pasadena, is conducting a seismological program of study of long-wave propagation through a network of four stations on both sides of the Gulf. The codirectors of the project are Prof. L. Knopoff and Dr. I. Herrera.

28. COAST OF THE STATE OF SONORA

The Scripps Institution of Oceanography has been carrying out studies along the coast and on the continental shelf off the State of Sonora. This is a part of the Gulf of California Project and the Instituto de Geología has cooperated in this work.

Nichols (1962) described briefly the tidal flat sedimentation of the Sonoran coast.

Benson and Kaesler (1963) studied the recent marine and lagoonal ostracods from the Eastero de Tastiota, Son.

Phleger (1964) mentioned that the barrier island and marsh foraminiferal faunas elsewhere are different from the mangrove marsh fauna of Sonora and the slightly hipersaline marsh faunas in Ojo de Liebre Lagoon in Baja California.

29. TOPOLOBAMPO BAY AREA, SINALOA

The Institute of Geology, in a cooperative program with the Mexican Navy is conducting a general oceanographic survey of this area. Detailed sedimentological studies will be carried out to include both the organic and inorganic fractions trying to define the sedimentary dynamics of the region.

30. SINALOA AND NAYARIT COASTAL PLAIN AND CONTINENTAL SHELF

J. R. Curray of the Scripps Institution of Oceanography and D. G. Moore of the U. S. Navy Electronics Laboratory have been working for several years on the sediments and history of the coastal plain and continental shelf of this area. Some papers have already appeared as part of their results (Curray, 1962; Curray and Moore, in press; Curray and Moore, 1964; and Moore and Curray, 1964). These studies also are a part of the Gulf of California Project as a coventure with the Institute of Geology.

31. COAST OF THE STATE OF MICHOACÁN, MEXICO

Geomorphological and geographical studies, especially concerning the river deltas were carried out and published by Brand (1957, 1958). These studies cover the whole coast of the State of Michoacán, from the Mouth of the Coahuayama River (Boca de Atasta) to the Barra de San Francisco, in the Balsas River Delta.

32. BALSAS RIVER DELTA AREA STATES OF GUERRERO AND MICHOACAN

The Instituto de Geología under the patronage of the Secretary of the Navy has started a periodic ecologic and sedimentologic study of this area. This study will define the modifications that the large Infiernillos Dam will cause in the delta's morphology. This study is extremely important to learning about geomorphological, biological and sedimentological changes in the modified streams and delta. The study will continue over an extended period. Preliminary results were published by the Dirección General de Obras Marítimas (1963c).

33. VICINITY OF ACUPULCO, GUERRERO

Isolated sediment samples for recent foraminiferal distributions were studied by Bandy and Arnal. This paper deals with the foraminiferal distribution off the west coast of Central America and Mexico.

De Cserna, in Fries and de Cserna (1956), described the Bay of Acapulco, in a field trip guide of the International Geologic Congress XX Session, México, 1956

34. SALINA CRUZ, OAXACA, BEACHES

Feld (1962) discussed briefly the sorting of beach sands in the Salina Cruz, area.

35. PAREDON, CHIAPAS

Physical studies, including some sedimentologic aspects of the Mar Muerto and Paredon, were done in this area in a cooperative program between the Instituto de Geología and the Directorate of Marine Works (Dirección General de Obras Marítimas) of the Mexican Navy. This agency published (1963b) some of the results.

CONCLUSIONS

Marine geology studies in Mexico, conducted by the Instituto de Geología of the Universidad Nacional Autónoma de México began, under modern techniques, early in 1959. The first independent project was the study of the Coastal Lagoons along the Gulf of Mexico. Cooperative programs have been carried out with foreign institutions to improve the knowledge of marine geological resources of the country and to train Mexican specialists in different oceanographic disciplines.

Efforts will be continued hopefully with enough economic support to prepare more scientists to carry out a more ambitious program. This will require more equipment and laboratory facilities. The investigation of the continental shelf off the coastal lagoons under study will be the next step in the program.

Marine geological research started by the Instituto de Geología early in 1959, acted as a catalytic agent to increase the interest of Mexican institutions and scientists in oceanographic disciplines. Celebration of the First National Oceanographic Congress in Chilpancingo, Guerrero, in March, 1963, with the presentation of nearly 100 papers, was an indication of such a positive reaction. The Second National Oceanographic Congress will be held in Ensenada, Baja California, in March 15-18, 1965.

The Instituto de Geología is now able to coordinate any general oceanographic or Marine geological study in Mexico, in cooperation with interested institutions.

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OCEANOGRAPHY FROM SPACE

CHAPTER 7

SECURITY CLASSIFICATION

RECOMMENDATIONS ON SECURITY AND DECLASSIFICATION

E. D. Mc Alister, Chairman

Scripps Institution of Oceanography
University of California, San Diego; La Jolla, California

The problem of restrictive security classification particularly that governing airborne electromagnetic sensory devices and data was raised during the symposium. In the ensuing discussion, several scientists became apprehensive that much of this proposed effort might become classified at a later date. If this happened, many present would lose interest in the project since such action would interfere with the free exchange of ideas and information which is basic to progress in science. To allay this fear, Dr. Peter Bagley of NASA made a statement to the effect that no part of this effort will become classified.

Several participants stated that classification had not been removed in some areas as has been authorized by a DOD directive and hence, certain data could not be used to further the objectives of this NASA-WHOI conference. OPNAV instructions, 01550.63, have done this for CNO in all U. S. Navy projects.

Several examples of the benefits of this DOD directive to both unclassified and classified projects became apparent during the symposium. In these cases, material recently declassified under this directive was interpreted by a scientist of recognized authority which resulted in a benefit to this conference and also to the military project sponsoring the work.

After some discussion, it was agreed that participants in the symposium wished it to go on record to the effect that present security restrictions are: (1) impeding the applications of many sensory techniques to important scientific problems; (2) preventing the interpretation of existing data by scientists of recognized ability which results in a loss to both military and nonmilitary projects of scientific nature.

Cognizant security agencies are requested to act under existing directives to remove these restrictions.

CLASSIFICATION

Fred B. Phleger

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Some of us feel that there is a danger that some or much of the oceanography which may be done by techniques discussed may be subject to classification. This has occurred many times and prevents free exchange of information and ideas. This creates an intolerable situation.

I believe that most of the established workers in oceanography have "clearance" or have had clearance in the past. Most or all of the senior people worked on military problems during World War II. Many of us, however, are opposed to classification in principle - unless acceptable reasons can be demonstrated. I believe that many of the most competent and experienced oceanographers will refuse to be associated with classified research - except under wartime conditions.

Bernard B. Scheps

U. S. Army Engineer Geodesy Intelligence & Mapping
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Fort Belvoir, Virginia

A typical payoff from declassification was my experience in having Dr. Emery support what, for me, could only be speculation.

I refer to the probable sand waves of the York & Rappahannock Rivers in Chesapeake Bay. This was a very useful and gratifying encounter for both Dr. Emery and myself in that it illuminated new possibilities for radar utilization - both civil and military in implications.

The information content of an image is not a function of lines/mm resolution, or bits per square cm - rather it is a function of the knowledge of the interpreters. I use the plural advisedly because the information content varies with the background of the observer.

It is apparent therefore that the greatest payoff to the military capability for image interpretation will result from making imagery available for interpretation to the widest range of experts in various fields.

This is the way we developed our photo-interpretation capability - unclassified.

Within reason - this is the best way to develop radar and infrared interpretation.

CLASSIFICATION

W. V. Kielhorn

Lockheed California Company, Burbank, California

It has become apparent during the NASA-WHOI conference that many scientists not directly involved with modern radar and other electromagnetic detection techniques are suffering from inadequate information as to how these may be profitably applied to their specialized field.

It is implausible to expect learned opinions and accurate, quantitative forecasts from expert people who are deliberately denied either access or use of knowledge of the tools they must use now, or can expect to use in the forseeable future.

Classification as a philosophy is defensible only when its employment is relatively detrimental to an enemy. The criteria for the several degrees of security control of information are generally reasonable, but rarely followed. We believe that these criteria should be examined, and that wherever possible information not meeting them fully should be at once released to those requiring it for the advancement of technology.

COMMENTS ON DECLASSIFICATION

Walter H. Bailey

Division of Earth Science, National Academy of Science, National Research Council

The major change in ground rules is that in all decisions the classifier must weight both the pros and cons of secrecy and determine net value to the nation.

The NAS-NRC is establishing a Committee on Remote Sensing of Environment. The committee likely will establish a Panel on Declassification which will, in a responsible fashion, advocate declassification by drawing together and presenting information on the "cons" of secrecy.

The DCM Committee and NAS-NRC Panel probably will develop a close cooperative working relation.