

Woods Hole Oceanographic Institution



1930



(NASA-CR-127073) ELECTRONIC RESEARCH AND
TECHNOLOGY REQUIREMENTS FOR MARINE
RESOURCES G.C. Ewing (Woods Hole
Oceanographic Institution), Dec. 1971 33 p

N72-26269

CSCI 08C G3/13

Unclas
28944

REFERENCE NO. 71-71

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Woods Hole, Massachusetts

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TECHNICAL REPORT

*Supported by the National Aeronautics and Space
Administration under Contract No. ^{NAS} 12-631.*

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Final Report

Prepared under Contract No. NAS 12-631 by
WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

Electronics Research Center
Cambridge, Massachusetts

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ELECTRONIC RESEARCH AND TECHNOLOGY
REQUIREMENTS FOR MARINE RESOURCES

By Gifford C. Ewing

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Woods Hole, Massachusetts

INTRODUCTION

Observations of the distribution patterns of phenomena in the upper layers of the world ocean are rapidly becoming available due to development of more sophisticated remote sensing instruments mounted in earth orbiting satellites. During the next decade these efforts are scheduled to be much expanded. In order fully to evaluate these methods it is necessary to compare the data on a quasi-realtime basis to those acquired by more conventional means such as ships, buoys and aircraft.

BACKGROUND

The 1967 Summer Study by the National Research Council on Space Application to Earth Resources resulted in the following Program Recommendations:

"The seven oceanographic parameters that appear to have the most significance for satellite applications, listed in order of their current feasibility are:

- (1) sea surface temperature, (IR, microwave and telemetry),
- (2) imagery, (photography, imaging radar, IR),
- (3) drift rate of floating objects, (IRLS, buoys, etc.),
- (4) sea ice and bergs, (imagery by radar),
- (5) spectrograms (chlorophyll detection, sea color, bioluminescence, fluorescence),

- (6) sea state (by radar roughness), and
- (7) dynamic topography of sea surface (by radar or laser altimeter).

... "The greatest benefit to oceanography should eventually result, however, from a combined system using (1) satellites with various remote sensors, (2) satellite collection and relay of data from buoys and ships, and (3) central oceanographic data handling banks.

The buoy program appears to be essential, at least for the present, to provide ground truth for the satellite program and oceanographic data not yet obtainable from remote sensors."

The Space Oceanography program at Woods Hole during 1969 was designed to implement items 1, 2, 3 and 5 of the above recommendations since these appear most suited to our capabilities and to the current state of the art. One of the most spectacular features of the ocean is the Gulf Stream, which is easily visible because of temperature and color contrast. It has been "seen" by the NIMBUS II HRIR. It is presently under intensive investigation by Woods Hole in cooperation with the Environmental Sciences and Services Administration and the Navy Oceanographic Office. Because of its strong color and temperature contrast, it is peculiarly suited to remote sensing. Furthermore, the adjacent slope and shelf water supports one of the world's most productive fisheries. Since nearly all the major surface current systems of the world, (the Kuro Shio, the Agulhas, the Benguela, the Peru, and the California), have now been mapped by the NIMBUS HRIR, it appeared that experience gained in interpreting Gulf Stream phenomena could be usefully applied to these other more inaccessible regions, both as to the physical processes involved and as to the related fisheries. These more inaccessible currents would perhaps be most effectively studied from Earth-orbiting satellites.

An equally striking feature of primary importance to the biological productivity of the sea are the regions of upwelling of nutrient-rich cold water along coasts and along the Equator. These regions appear to be reflected in the cloud-cover pictures transmitted by various satellite systems. They may also be discernible in the infrared data from NIMBUS.

The Woods Hole Air/Space Oceanographic Program for 1969 consisted of six closely related parts:

1. Monitoring the sharp temperature boundary of the Gulf Stream by microwave and IR. (Daubin, with C. Wiley et al, North American Autonetics).
2. Spectrophotometry of the Gulf Stream and adjacent Slope and Shelf water over Georges Bank (Clarke, Ewing, with A. Conrod of MIT Experimental Astronomy Laboratory).
3. Interpretation of cloud and other meteorological data in terms of the effects of wind and sun on the upper ocean (Bunker, Ewing, Ronne).
4. Sea State test plan (Daubin).
5. Systems research (Daubin).
6. Ocean data recovery by aircraft and satellite (Striffler, Halverson).

This program was designed to make oceanographic use of present and future satellite data and to provide interpretation and confirmation obtained by ship and low-level aircraft.

1. Microwave radiometry

The experiment was designed to obtain sea-surface temperature from aircraft and eventually from satellite altitudes by passive microwave.

The problem was essentially to employ a radiometer system that would be relatively unaffected by clouds or changes in sea state so that the "brightness temperature" would bear a known relation to the molecular temperature under all weather and sea conditions.

One proposed method depended on circular polarization of the microwave antenna. Details can be found in the oceanography report of the NAS Summer Study, section 3.1.5 -- "Measurement of Ocean Surface Temperature and Surface Temperature Gradient by Microwave Radiometry", contributed by C. A. Wiley of Sensors Panel. The theory is summarized as follows, "Analysis of the microwave radiometric emission from the sea surface shows that in the vicinity of 20° angle of inclination, the average of the vertically polarized and horizontally polarized microwave emissivity from the sea is nearly constant over a range of r.m.s. sea slopes varying from specular to 22° . This average ... can be observed by use of a circularly polarized radiometer antenna... Sea water having a molecular temperature of 300° will have a radiant brightness varying by only $\pm 0.3^{\circ}$ K over the total range of sea roughness when viewed at a 20° inclination...

"Autonetics and the Space Division of North American have built 10 and 3 GC radiometers for measurement of ocean surface data...

"After aircraft and pier tests...the system should be tested in one of the Nimbus or Apollo application satellites."

Autonetics offered Woods Hole the use of its two radiometers and technical assistance in installing and using them in our C54Q aircraft to demonstrate the ability of the system to "see" the Gulf Stream. Because of its strong temperature contrast, this was a favorable target. They would carry out preliminary pier tests to check the efficacy of circular polarization.

It was contemplated that this program would lead to a satellite experiment.

2. Spectrophotometry of the Sea Surface

a) Objectives and Significance

This research was a continuation of our basic investigation of the role of light in the ecology of the sea. The amount of light available at any point in the water depends upon the radiation incident upon the surface and its attenuation as it passes into the sea. The absorption and scattering of light by pure sea water is constant, but under natural conditions attenuation and spectral distribution change from time to time and from place to place according to the amount and kind of dissolved and particulate matter (living or non-living) in the water. Optical properties may thus be used to identify water masses and to provide information as to the organisms or their by-products which are present. Measurements of total attenuation and of spectral alteration of the light are therefore of great significance.

Furthermore, since sunlight provides the energy for the photosynthesis of all green plants in the ocean, a knowledge of its availability at various depths and in various regions was essential for an understanding

of the control of marine productivity. Quantitative study of this first step in the ecological cycle required measurements of incident radiation and of the wide variations in transparency.

Distribution studies using upwelling light

Since most organisms contain some pigment, the presence in the water of living populations, or of material resulting from decomposition, produces changes in the spectral composition of light passing through the water as well as in the total attenuation. Any organic material present may also have a selective effect. These spectral changes in absorption and scattering had been observed in the laboratory, using samples of sea water, and also, to a limited extent, at sea using underwater spectrophotometers. These procedures were valuable for intensive studies in individual areas but were laborious when dealing with large regions. In order to carry out rapid surveys of the horizontal changes in the spectral action of different water masses, a new technique was devised which could be used from surface ships or from airplanes or satellites. In this procedure a downward-directed radiometer was employed -- either suspended over the water from the boom of a ship or placed in the open floor hatch of an airplane. The instrument scanned the spectrum from 360 $m\mu$ to 650 $m\mu$ once or more per second, reporting the energy in each of 25 narrow bands. The recorded upwelling radiation consisted of light reflected from the surface and light which had passed into the water before being scattered out again. After adjusting for the effects of surface reflection, the spectral distribution of incident daylight, and the selective action of pure sea water, a curve was obtained which characterized the spectral action of the particulate and dissolved materials in the water as observed from above the surface. Preliminary

tests off the coast of Massachusetts both from a ship and from an airplane showed that the method could distinguish between the water masses thus far tested.

It was proposed to extend these observations to different water masses and to examine each area for patches of plankton or other material which might be revealed by spectral changes in upward scattered light. Intensive and repeated studies of changes in the water at one locality would be made from a "Texas tower" such as the one off the entrance to Buzzards Bay. In all cases samples of water would be taken by ship from each area whose spectral emission was measured from the air. A portion of each sample would be examined microscopically for identification of the planktonic organisms present and another portion would be filtered for spectroscopic analysis to aid in recognizing the materials having the selective effect. When the spectral characteristics of the upwelling radiation were determined for particular water masses containing certain populations of plankton or amounts of non-living material, the horizontal extent of these water masses could be quickly mapped. Various extensions of the technique could be employed. When used from a ship, the radiometer could be operated floating on the sea surface with its receiving window submerged, thus eliminating the air-water reflection. Underwater flares dropped to known depths at night could be used as a light source instead of working with daylight. This also would eliminate reflection from the surface of the sea. A more sensitive radiometer, or one of the present style with improved discrimination, could be constructed and such an instrument might be able to detect patches of plankton, possibly distinguishing between types, if sufficiently different.

The radiometer could also be placed in a pressure resistant case so that it could be employed at various depths under the sea and oriented in various directions. Even though the proposed technique proved to be reliable for detecting broad differences only, the rapid delineation of areas occupied by distinctly different water masses, or plankton populations, from fast ships or airplanes would obviously constitute a valuable new tool in the study of the sea.

b) Procedure for Work

The problems emerging from our previous research would be attacked as follows.

Intensive measurements of light in the sea had been made in certain localities, but great areas of the ocean remained uninvestigated. In order to draw general conclusions of value for the sea as a whole, these gaps in our knowledge had to be filled. Thus, comparative measurements of the availability of light energy at different depths would be made in other areas of importance and related to the control of phytoplankton productivity and the control of the vertical distribution of pelagic animals. The depths and distances at which vision can be employed by animals to recognize their food and to distinguish between friend and foe would be determined.

Quantitative determination of sea color from the air is of potential use in physical oceanography in conjunction with sea-surface temperature as a method of discriminating water masses. Temperature alone is often inadequate to delineate differing water masses since water masses of very different origin can easily have identical surface temperature. Classical oceanography correlates salinity with temperature to provide the T-S

curves which indicate the source and distribution of water types. Since salinity is not amenable to remote sensing, another independent parameter would be helpful. Although the Gulf Stream is easily mapped from satellites during the months of the year when the thermal contrast between the stream and adjacent water is strong, there are other seasons when the surface thermal contrast is vanishingly small. In these seasons, the blue color of the stream may serve to distinguish it from the highly colored water of the adjacent slope.

The color of the slope water is in part due to runoff from rivers carrying tanins and other chromatinas as well as mud. For this reason, the color of shore water is strongly related to the freshness or salinity of the water. This is specially obvious in the outflow plumes of rivers. An example of these color differences is illustrated in the chromaticity diagram attached herewith. (Fig. 1)

An additional cause of water discoloration is the absorption of color in the blue and yellow portions of the spectrum by chlorophyll a. Thus, chlorophyll coloration of ocean water is an indicator of biological productivity. As is illustrated in Figure 2, the upwelling of cold nutrient-rich water along the coast of Baja, California is shown to coincide with a tongue of chlorophyll-rich water which in turn sustains a heavy concentration of red crab and the tuna which they attract.

For these several reasons, the analytical measurement of light upwelling from the sea was an attractive undertaking for space oceanography. The Gemini photographs, though unsuitable for quantitative spectral measurement, nevertheless illustrated in a qualitative way the feasibility of such assessment.

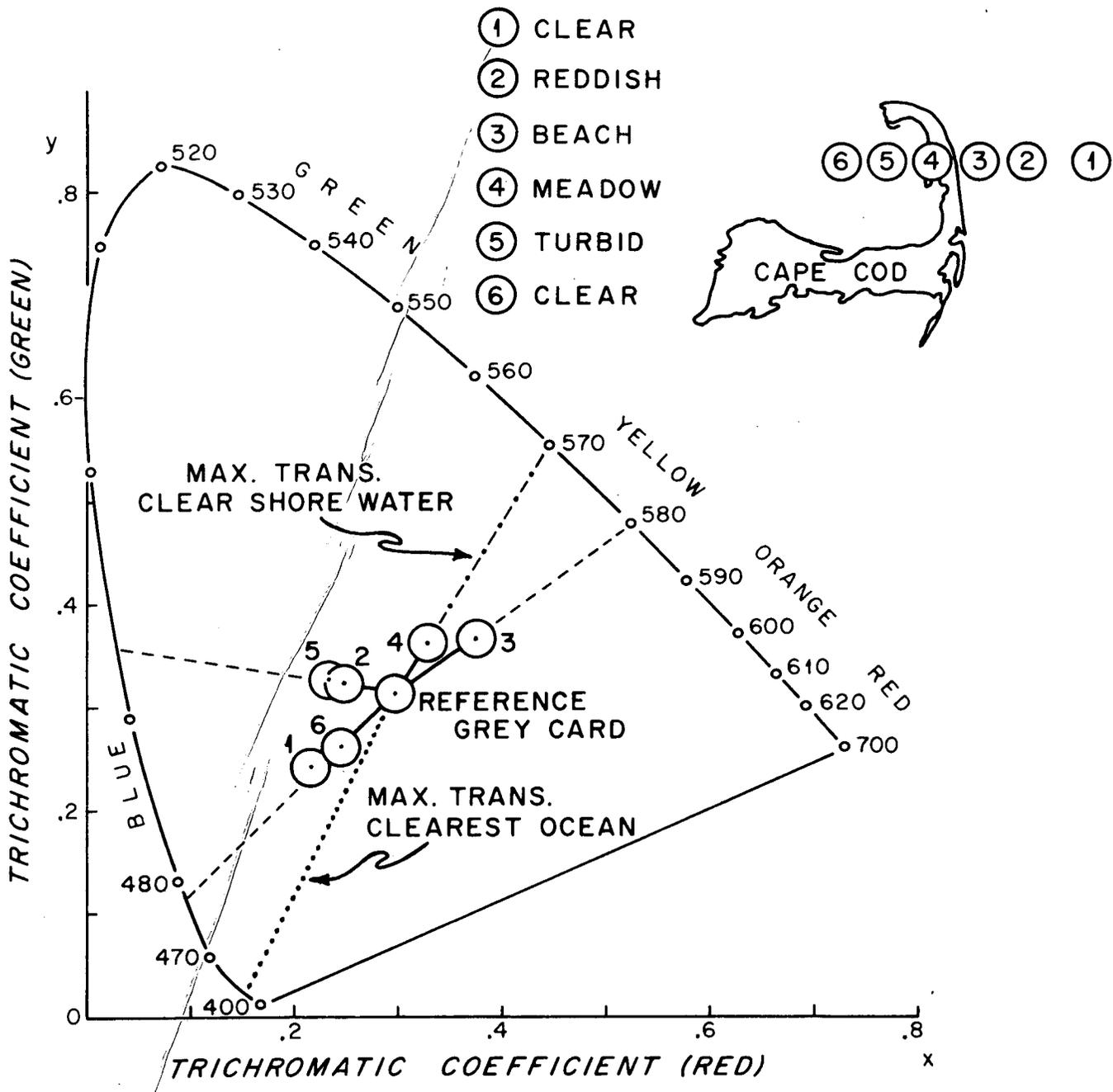


Figure 1. Chromaticity Diagram

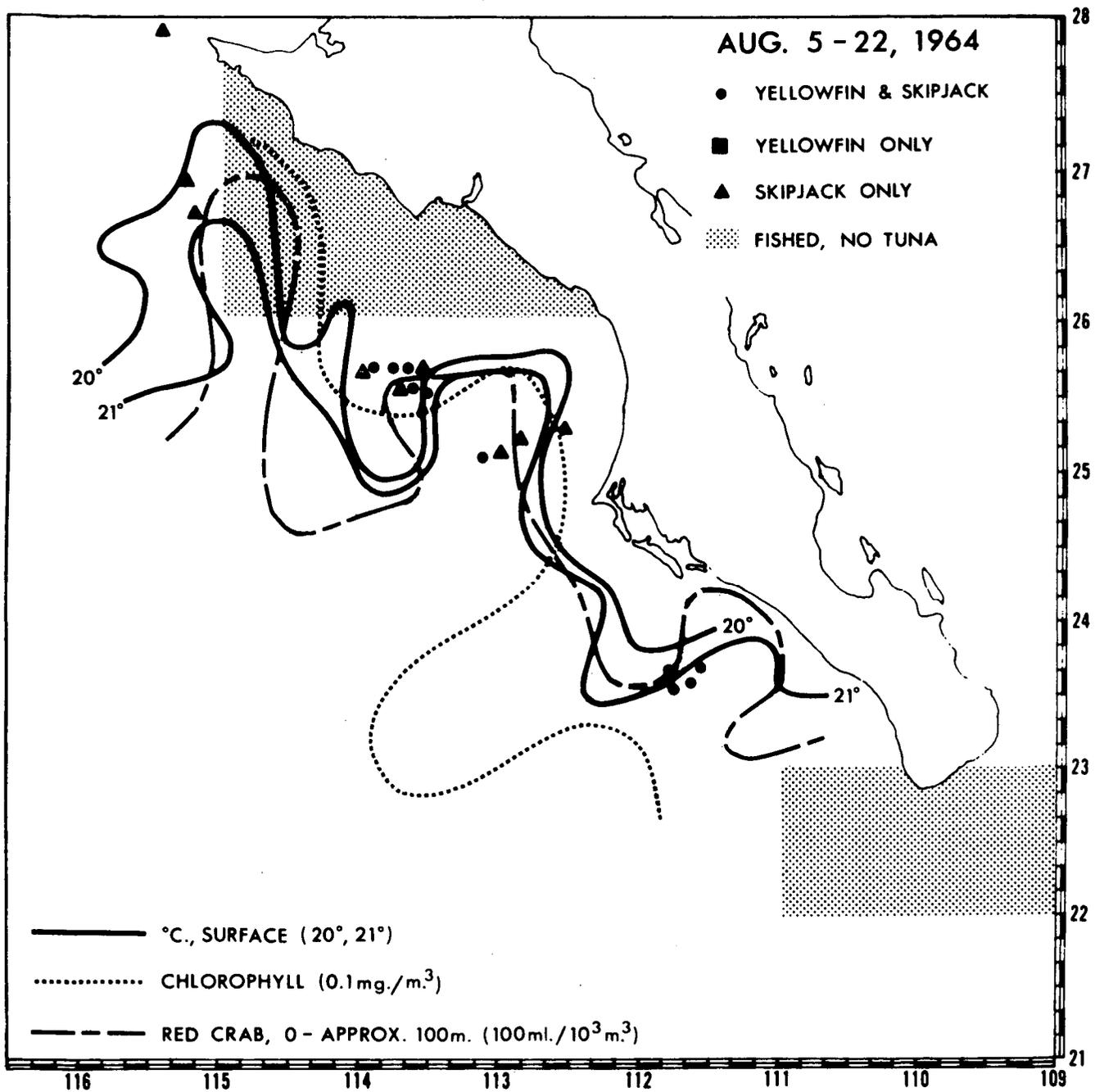


Figure 2. --Isolines of certain property concentrations and positions of tuna catches in August 1964.

During the past, attempts have been made at Woods Hole by Clarke and Conrod (of MIT) to measure the quality of upwelling light near the sea surface and by Ewing and Conrod to make correlated measurements from an aircraft. The instruments used were a pair of so-called "spot" spectrometers which use 28 interference filters and a photomultiplier with logarithmic response electronics to split the incoming light from 450 to 600 millimicrons into a series of narrow spectral bands. The instruments, loaned by the Experimental Astronomy Laboratory of MIT, were designed for a quite different application, and their logarithmic response made them relatively insensitive to small differences that arose in light backscattered from water of slightly varying constitution. Perhaps the most obvious deficiency was the cutoff of red light at 600 millimicrons, far short of the band of anomalous dispersion at 670 millimicrons due to chlorophyll a. Nevertheless, these instruments have been the means of acquiring valuable data and experience which encouraged the belief that a more suitable device was well within the state of the art. On the basis of measurements already made and with the assistance of the E. A. L. it was planned to build a pair of simple linear spectrophotometers, one for airborne use and the other for simultaneous use under water. Thus ground truth would be readily available and the water column could be assayed to determine the depth of the source of backscattered light and the absorbing constituents that produce the color.

The experiment in simplest form used noon sunlight as the illuminating source. The airborne spectra were taken in approximately the anti-solar direction to eliminate sun glitter, and residual glints from the north

sky were suppressed by a polarizing filter. When the effective angle of incidence was near the angle of maximum polarization (Brewster's angle), the sky light contributed less than 2% of the light collected by the spectrometer, the balance being light backscattered from under the water surface and therefore colored by the absorbing constituents of the upper layer of the sea. The color shifts observed when passing from clearest ocean water to inshore water showed the expected absorption of blue-green light. The source of this absorption had not been unequivocally determined and was in no sense quantitative.

The proposed experiment was to monitor the spectral composition of light upwelling through the sea surface simultaneously from the air and from the sea surface. Measurements of the radiance in the zenith and nadir directions would be made underwater to determine the effective depth from which the upward scattered light originates. The effective optical path traversed by the light would be assayed chemically and biologically to identify and measure the concentration of the optically active absorbers. Supporting laboratory measurements would be carried out as warranted.

3. Oceanographic Interpretation of TOS Cloud Data

Cloud pictures derived from the Nimbus satellites and the Tiros Operational Satellite (TOS) system and the Applied Technology Satellites (ATS) showed many features with implications important to oceanography. Clouds were the most clearly definable data seen from earth orbiters. Additional data were derived from HRIR and 3-color photography. The importance to oceanography of these facilities was that the data contained information about insolation and perhaps about wind stress. These are

the prime forces that drive and modify the ocean. The ultimate aim of understanding and forecasting oceanographic phenomena, especially on a planetary scale, depended on effective use of this type of information. Means would have to be found to optimize the collection, retrieval and interpretation of such data.

To illustrate, cloud pictures have frequently shown a rim of clear skies over coastal waters especially adjacent to high mountains. Examples have been seen along the coast of Peru extending into the South Pacific Equatorial system and also around the whole Indian sub-continent. A similar situation is observed along the California coast during Santa Anna conditions when a high pressure system over the Rocky Mountains produces hot land winds. In California this condition is reflected in intensified upwelling in the ocean and concomitant changes in the marine biology of the coastal waters.

These phenomena are potentially of prime importance in relating biological productivity to observable meteorological events. The relationships have not been adequately studied. To understand them would require systematic matching of cloud distribution with changes in the underlying ocean. The clouds could be studied by satellite photography supplemented by atmospheric soundings taken from sea level and from low altitude aircraft. The oceanic reaction could be studied by ship observations, by buoy telemetry and by infrared radiometry from satellites. On a global scale, the oceanic data were available from the daily teletype broadcast of the U.S. Navy Fleet Numerical Weather Central in Monterey, California. Needed was an organized program of bringing all these data together under the scrutiny of a team of marine

meteorologists and oceanographers. The potential of such a facility appeared promising.

4. Sea State Test Plan

Acoustic methods are in current use to observe the sea state from below. These methods would be examined to determine their suitability as a sea truth reference against which airborne or satellite-borne sensors might be tested.

5. Systems Research

Orbital parameters, launch windows, etc. suitable for an oceanographic satellite would be studied.

6. Ocean Data Recovery by Aircraft and Satellite

In our long-term study of the circulation of the waters on the continental shelf, the area of chief importance, from the point of view of fisheries research, is Georges Bank. Yet this was the area about which we knew the least due to the eddy type flow around the shoals during the early summer and its apparent subsequent breakdown once the water column became stratified. In view of the prospect of an IRLS system, it was our choice to insert a drogued buoy, surface temperature sensitive near the northern edge of Georges Bank at about 42° N, 68° W in August of 1968. This was handy for aircraft surveillance, auxiliary to the IRLS observations, and reasonably long residence time in the general area was anticipated.

WORK ACCOMPLISHED

Item 1. -- Microwave Radiometry

Co-Investigator: Scott C. Daubin

A radiometer system has been sufficiently developed to measure antenna temperature with a resolution of 0.2°K with a one-second integration time. This has been accomplished by means of tunnel diode amplifiers with a bank width of 100 magacycles. However, the TVA's delivered by the manufacturer had their peak sensitivity outside of the quiet 2690-2700 radio astronomy band. Consequently, the first full-scale attempt to operate the system outside of the laboratory had to be conducted at a frequency within the 2700 to 2900 radar band where intense interference was encountered. This interference had an equivalent brightness temperature of 25°K compared to the 6° environmental temperature that is contemplated for a fully operational system. Interference of this magnitude proved entirely incompatible with the operation of so sensitive a radiometer.

The antenna system appeared to have a beam efficiency of 98% between null points, 14° on either side of the main beam axis. The total beam spread between 1/2 power points was 16° . Under the pressure to produce timely preliminary results, the antenna was tuned up to the frequency matching the amplifiers and therefore was accepting through its back lobes an unacceptable amount of interference from S-band radars located in the test area. It was not possible, because of the interference problem, to substantiate the theory experimentally.

The program proceeded in two directions:

- a. The short-time effort consisted of locating a quiet area on some mountain lake protected by surrounding hills from radar

interference where the front end and the antenna could be used to feed a radio spectrum analyzer. The purpose of this interim program was to substantiate the efficacy of the polarized antenna in measuring the molecular temperature of a water surface in the presence of waves and ripples.

b. A second approach was to retune the antenna into the radio astronomy band. This would require retuning and recalibration of the amplifier and redesigning new filters to narrow the band width of the receiver. This narrowing of the band width would somewhat reduce the thermometric resolution attainable but, considering the high performance of the amplifiers, such an adjustment would be accepted in the interest of isolating the equipment from interference.

Pollution of the radio spectrum posed a problem. However, any radiometer of the necessary sensitivity would be vulnerable to radar interference spilled over from neighboring frequency bands at the tremendous power levels used by large radars.

If and when the prototype equipment could be successfully demonstrated on the ground, the next step would be the construction of a new radiometer specifically designed for flight testing. In view of the foregoing it appeared that W.H.O.I.'s participation in the radiometric program would be held in abeyance for an indefinite period.

Item 2. -- Spectrophotometry of the Sea Surface

Co-Investigator: George L. Clarke

Records of the spectrum of backscattered light from the ocean were made from our research vessel CRAWFORD and our C-54-Q research aircraft.

The spectrometer used was an electrooptical sensor of the off-plane Ebert type with an RCA 7265 (S-20 response) photomultiplier. The spectral range was 400 to 700 nm with a spectral resolution of 5 to 7.5 nm, a scan time of 1.2 seconds, and a field of view of 3° by 0.5° . A continuous curve of the spectrum was provided by a Sanborn recorder for each scan. The spectrum of the incident light from the sun and sky was determined before and after each series of measurements by recording the light reflected from a horizontally placed Eastman Kodak "gray card" with a nonselective reflectivity of 18 percent. A series of tests was made to detect changes in the spectral distribution of incident light during the 3 hours before and after noon due to changes in the sun's altitude and to changes in sky conditions from clear to light cloudiness. Changes found were not great enough to affect significantly our investigation of the differences in backscattered light from the ocean. By taking advantage of the fact that light reflected from a plane surface at Brewster's angle (approximately 53° from vertical incidence for normal sea water) is plane polarized with its vibration plane perpendicular to the plane of incidence, we could reduce the light received as reflection from the water surface. We placed a polarizing filter, oriented at right angles to the major axis of polarization, over the receiving aperture of the spectrometer and tilted the instrument at Brewster's angle (directed away from the sun).

When we operated the spectrometer from our C-54-Q research aircraft, the signal that we wished to measure, namely the spectrum of the light backscattered from beneath the sea surface, was sometimes difficult to detect because of interference from "noise" caused not only by surface

reflection but also by "air light." Air light is light that has been scattered to the instrument by the air and by material in the air between the sea surface and the aircraft. As the altitude of observation increases, the area of the sea from which light can enter the instrument enlarges, reaching the dimensions of about 52 by 9 feet (16 by 3 m) at 1000 feet (305 m). Smaller irregularities in surface reflection or in the nature of the seawater will be averaged out. At the same time interference from air light will increase with altitude because of the greater path length through the atmosphere. As altitude increased, the values for upwelling light received increased markedly and regularly in all parts of the spectrum.

Representative spectral measurements were obtained over water with high chlorophyll content (about 4 mg/m^3 , Buzzards Bay), with low chlorophyll content (about 0.3 mg/m^3 , north of the Gulf Stream), and with very low chlorophyll content (less than 0.1 mg/m^3 , Sargasso Sea). The values for the backscattered light from these areas have been calculated as percentages of the incident light. The curves display characteristic differences in shape. For the water with high chlorophyll content the backscattered light rose from values mostly about 2.2 percent of the incident light in the blue region of the spectrum to about 2.5 percent in the green, and then dropped to about 0.3 percent in the red. For water with low chlorophyll content the values were higher in the blue, dropped rapidly to much lower values in the green, and continued to drop in the red. Where chlorophyll content was very low, the backscattering was higher at all wavelengths shorter than 500 nm and reached a maximum of 7 percent at 400 nm.

A more extensive survey of the changes in backscattered light from contrasting bodies of water was conducted during a flight from Buzzards Bay and Nantucket Sound to a point in the Sargasso Sea south of the Gulf Stream, then north on a 556-km transect that crossed successively the Gulf Stream, the slope water, a transition zone, Georges Bank, Georges Shoals, and the southern part of the Gulf of Maine, and returned via Cape Cod Bay. Records of the spectrum were taken at frequent intervals and a continuous trace of the surface temperature was obtained by means of a Barnes infrared radiometer. A continuous record of the temperature and the chlorophyll concentration of the surface water was obtained from the R/V CRAWFORD by means of a thermistor and a continuous-flow Turner fluorometer. Water for this purpose was drawn from an intake valve through the hull of the vessel 2 m below the surface. Analysis of these data shows that the surface temperature and the surface chlorophyll of the slope water, the Bank water, and the Gulf of Maine are statistically differentiated to a highly significant degree. We also have evidence from a previous study that surface chlorophyll values may be useful as an index of biological productivity. During four cruises in the Atlantic and Pacific, 91 samples were collected which covered a range of surface chlorophyll concentrations from 0.04 to 28.3 mg/m³. Analysis showed highly significant correlations with measurements of the total chlorophyll in the euphotic zone and with the primary productivity of the phytoplankton in the waters studied. Temperature values obtained from the aircraft agreed closely with values obtained from the ship. Owing to the relative sterility of warm Gulf Stream water, the lower chlorophyll measurements tend to be associated with higher sea temperatures.

Our investigation shows that large differences occur in the spectra of the light backscattered from the ocean and that they can be recorded from aircraft. In the present instance, the slopes of the spectra correlate quite closely with differences in chlorophyll concentration. The discrepancies are believed to be due to difference in time within paired observations, to differences in surface reflection, to scattered air light, and to the presence in the water of material other than chlorophyll that affected the light selectively. If such interference can be eliminated, or identified and allowed for, spectrometric procedures from aircraft (and perhaps from satellites will be of great value in the rapid investigation of oceanic conditions, including conditions important for biological productivity.

Item 3. -- Data Analysis and Interpretation of TOS Cloud Data

Co-investigator: Andrew F. Bunker

Originally this item of the contract was to relate cloud information obtained from various satellites with oceanographic data acquired by the ships, aircraft and an IRLS buoy. The participation of the aircraft was aborted due to diplomatic troubles in Peru. Since a start had already been made in cooperation with Allied Research Associates, Inc. to study the satellite data which would be available during this expedition, we decided to proceed with the investigation as fully as would be consistent with the absence of the aircraft. Their report concluded that, "for the most part, surface temperature patterns are well reflected in the overhead cloud structure. With the broad overall view that only a spacecraft can afford, the boundaries of major currents may be delineated, localized upwelling centers may be detected, and the onset of unusual oceanographic events may be predicted.

"The ability to see the forest but not the trees is at once the strength and the weakness of satellite data. In this study, features were found which may never have been noticed using ship or aircraft observations. But to interpret these features and to discover their cause is a task which can only be accomplished through the use of these more conventional means. The isolated cloud band off the coast of southern Peru, and the mid-ocean patches of apparently calm water, are just two examples of oceanographic phenomena which will require a coordinated study of surface and spacecraft observations to properly interpret."

To augment the data analysis an Oceanographic Information Center has been established at the Institution in cooperation with the Bureau of Commercial Fisheries. Support received from the Bureau during 1969 has been applied in part to the purchase of a teletype machine and accessory equipment for interfacing with the leased line circuit from the U.S. Navy Fleet Numerical Weather Central. Synoptic information about the ocean is closely related to that which will in the future be provided by orbiting satellites, and we are using this facility to gain experience in utilizing oceanographic data gathered in real time on a global scale. In addition to the analyzed charts routinely transmitted over the telephone data link, the Fleet Numerical Weather Central at Monterey provides the Institution with a monthly record of all data received from ships in the North Atlantic.

Item 4. -- Sea State Test Studies

Co-Investigator: Scott C. Daubin

This item was completed by Westinghouse Electric Corporation, Ocean Research and Engineering Center, Annapolis, Maryland, and Ocean Research

Laboratory, San Diego, California, with the following summation:

1. One of the ocean properties most amenable to observation from the air or space is the roughness of the surface. The utility of this observation lies partly in its relation to surface wind velocity.
2. To convert an observation to a measurement requires calibration. Calibration in this instance means sea truth.
3. Further experimental and theoretical work needs to be done to establish the relationship between time series statistics at a single point to the wide area surface roughness statistics at a single instant.
4. Many instruments based on a number of principles have and will be applied to ocean surface roughness from the air or space. For example, these principles include the black body radiation of the sea surface and the reflectivity of the sea surface to electromagnetic energy.
5. For the calibration and comparison of the various measurement systems as referred to in "4" above and to serve as a data point for field work to treat question "3" above and for operational purposes, a deepwater sea truth wave station would be useful.

Item 5. -- Satellite Systems

Co-Investigator: John C. Allred, University of Houston

Dr. Allred presented the following report as a definition of the problem:

"It is useful at this time to define the OSS in terms of its major requirements for performance and system elements. This definition then permits a statement of tasks and a schedule of time, manpower and resource requirements for OSS to fly.

"The overall system is a closed loop. The Program Requirements are well established in part by studies such as the Panel 5 (Ewing) report of the NAS-NRC Summer Study on Space Applications. One knows what is to be observed (sea-surface temperature, imagery, drift rate, sea ice and icebergs, spectrograms, sea state, and dynamic topography). Program Requirements must also include the why of these observations in justifications related to factors such as economic gain, human safety, meteorological warning systems and the like, and these are treated in the Ewing report. Finally, a statement is needed as to where the observational data are to be obtained, and this statement will have important bearing on the orbital parameters.

"The Program Requirements determine the design of three sub-systems, designated Launch, Satellite, and Ground Processing and Interpretation; these three in turn feed a Dissemination and Evaluation sub-system, whose feedback must modify Program Requirements.

"I propose that we adopt this overall framework for the OSS. Within it we can establish sub-system requirements which can be individually dissected into task requirements. These in turn will be subject to PERT or similar review. In what follows I try to list most major task requirements for each sub-system.

"Program Requirements

As previously noted, the major program capabilities and justifications are already stated. Present thinking appears to be that there are no geographic latitude limits desirable on OSS, at least for the first satellite, for the reason that one wants to observe all major oceans, currents, and upwellings. Launches from Cape Kennedy are limited to latitudes of 32.5° N-S, because range safety does not permit aiming at northerly bearings which will result in orbits of larger northerly latitude. Hence a choice of higher latitudes will mean selection of Vandenberg AFB as the launch site, with whatever consequences this selection may have for the program.

"Launch System

Definition of the Launch System is determined by the following principal parameters:

- Payload
- Location of orbital plane (maximum latitudes)
- Period of orbit (mean radius)
- Eccentricity of orbit
- Lifetime of satellite (electronic or aerodynamic)
- Time requirements on observations (launch windows)
- Launch Site

A second order consideration is orbital perturbation and precession due to electro-magnetic and aerodynamic drag and non-central gravitational force.

When these parameters are established, design of the Launch System can proceed in the requirements for booster thrust, control and telemetry, and booster-satellite interfacing.

"Satellite System

Principal parameters of the satellite which need to be established are:

- Linear resolution of sensors
- Angular resolution
- Angular aperture (footprint)
- Onboard propulsion for major or vernier orbit modification (or not)
- Platform requirements - direction, stability, error
- Data management - storage, on-board processing requirements
- Frequency of interrogation and updating
- Atmospheric effects on sensors

The Satellite System is here defined to consist of sensors, onboard data storage and computer, telemetry, and power supplies. The requirement on these elements will be established by the above parameters.

"Ground Processing and Interpretation System

The GPIS appears not to be very well defined at this point and some thought needs to be given to it. GPIS includes ground telemetry and interrogation capability. Consideration needs to be given to the question of the extent of continuous information flow versus keyed interrogation. No doubt there will be a substantial requirement for digital data processing capability on the ground. An effort should be made to determine compatibility with existing systems such as the Fleet Numerical Weather Facility; need for real-time data flow to users; and need for other short-time delay information propagation after processing.

Another portion of the ground system which needs future definition is the ground truth system. Probably more stations than one off Woods Hole will be required. The number and type of these stations needs to be determined as future knowledge permits.

"Dissemination and Evaluation System

There are several recipients and evaluators of OSS information including scientific engineering, commercial, military, congressional and public. W.H.O.I. is, of course, well cognizant of these entities, and doubtless of others as well. One might begin soon to activate channels to some of these groups, especially in the scientific community, to provide a continuing two-way flow of information and involvement with the eventual users of the OSS data."

Mr. Glenn Larson of ERC made the following notes of a discussion regarding the ocean satellite experiment:

"As a first cut, consider the following observational constraints:

Repetitive Contiguous Coverage every 3 days

Ground Resolution	Microwave	10 miles
	Visible	1 mile

Solar Elevation Angle 40° to 90°

Circular orbit, approximately sun-synchronous

"The coverage every 3 days requires a minimum swath-width of about 500 miles.

"The orbit altitude should be chosen for approximately sun-synchronous which restricts us to around 300 or 500 or 800 miles.

"A 500-mile altitude orbit with a 500-mile swath-width requires an imaging system which scans approximately ± 26 degrees. For a horizontally layered atmosphere, this corresponds to a set of slant paths which will not introduce a significant error. The lower orbit (350) is probably also acceptable from an atmospheric degradation point of view even though the scan angle becomes much larger. Other considerations come into play such as ground-station access time, drag effects, geodetic perturbations, etc.

The ERTS A/B orbit has been chosen tentatively at 496 n.m. (Circular 99° sun-synchronous) and this will probably hold for ERTS C unless certain oceanographic requirements would call for a change."

Item 6. -- Ocean Data Recovery by Aircraft and Satellite

Co-Investigators: Foster L. Striffler and L. C. Halverson

Two methods were tested for direct sampling of ocean parameters from low aircraft flight altitudes. This capability is needed to increase the efficiency of flight operations by releasing the aircraft from dependence on slow surface vessels for "ground truth". One system developed by All American Engineering Co. consists of trailing a long wire from the airplane while circling. The line, properly weighted and equipped with sampling devices, stabilizes at the apex of an inverted cone in the center of the circle, the aircraft track forming a trace of the conic base. This technique was tested both from the slow flying Helio Courier airplane and from the C-54-Q. The tests were marginally successful but proved to require excessively radical flight attitudes for operational use and were abandoned in favor of other alternatives.

The second method consisted of a free-drifting buoy designed and developed by Striffler to locate and acquire oceanic data by means of an IRLS from satellites. The buoy itself is a spar buoy 10' long by 22" in diameter. The IRLS antenna is a cavity backed archimedian spiral antenna resembling a large mushroom on top of the buoy. In addition to the IRLS electronics and its battery supply there was a high intensity xeon lamp and a UHF beacon transmitter used as a back-up locating device. The buoy, drogued at 10 meters, was located and interrogated successfully. The ability of the IRLS system to transmit oceanographic data in real

time from a known location in the field of view to satellites passing overhead makes it a primary candidate for acquiring and transmitting ground truth. Mr. Striffler is designing a variety of sensors which can be used either at fixed locations or deployed from aircraft as needed to authenticate the observations made from earth resources satellites.

CONCLUSIONS

Because of the disestablishment of the Electronics Research Center, it became necessary to terminate many items of this project before the work had arrived at logical stopping points. However, the following conclusions can be reached on the basis of work accomplished.

1. Monitoring large scale current systems such as the Gulf Stream and its eddies from satellites is a feasible and efficient undertaking. The gross geometry is plainly visible in the infrared imagery and the mean velocity can be determined in a general way by means of drogued buoys equipped with IRLS transponders.
2. Monitoring the position of the sharp temperature boundary of the surface outcrop of the Gulf Stream can be accomplished by infrared radiometry, and some of the details of this boundary preserved in the imagery. It appears that microwave radiometry can, in the present state of the art, contribute only marginally to studies on this scale because of lack of spatial resolution and because the interpretation of microwave brightness temperature in terms of sensible temperature is obscured by many factors not presently understood, including the

effects of foam and ripple structure. Although the literature contains a great deal of information on gravity waves in the open ocean, there has been almost no work done in describing the spectrum of capillary waves shorter than 1 or 2 cm. Since these are commensurate with the electromagnetic wavelengths of suitable microwave radiometers, further progress must await a clearer understanding of the generation of such very short waves.

3. Spectroscopy conducted between the Gulf Stream and Georges Bank as well as observations made over Buzzards Bay and Vineyard Sound have shown that small changes in the content of chlorophyll a, biochromes and terrigenous particulate matter produce changes in water color that are plainly detectable from low flying aircraft. The outlook for relating some of these effects to the biological primary productivity is encouraging. The most important area of uncertainty is whether or not small color contrast ratios observed at low altitude can still be detected at hyperaltitudes.
4. Drift rates over Georges Bank were followed successfully by means of our IRLS buoy in an experiment related to investigations by the Woods Hole Biological Laboratory of the Bureau of Commercial Fisheries. The object of the experiment was to follow the distribution of haddock eggs and spawn by the tidal currents. The performance of the IRLS buoy in locating these drifts was quite satisfactory, and the outlook for useful employment of satellite transponders in this type of investigation is promising.

5. Interpretation of clouds as an indirect means of locating areas of intense upwelling such as occur along the eastern edge of the Peru Current was successfully demonstrated. Although permission to enter the Peruvian coastal air space by aircraft was denied, and therefore we were unable to carry out planned ground truth observations, data obtained from the ATS satellite was checked against historic oceanographic data and showed a satisfactory degree of correlation. It appears to be quite feasible to monitor the onset of coastal upwelling and its seasonal development to maximum conditions by this method. An advantage of this approach is that it supplements data obtained by infrared radiometry during those periods where the ocean surface is obscured by clouds.
6. Analysis of program requirements for an oceanographic satellite system shows that no geographic latitude limits are desirable and that because launches from Cape Kennedy are limited to low latitudes, a more suitable launch site would be Vandenburg Air Force Base.

The ground processing and interpretation system requires further definition..

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