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Climate Observing System Studies: An Element of The NASA Climate Research Program

Workshop Report

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Goddard Space Flight Center
Greenbelt, Maryland 20771

CLIMATE OBSERVING SYSTEM STUDIES:
AN ELEMENT OF THE NASA CLIMATE RESEARCH PROGRAM

WORKSHOP REPORT

FIRST CLIMATE OBSERVING SYSTEM STUDY WORKSHOP
FEBRUARY 21-22, 1980

September 1980

Goddard Space Flight Center
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PREFACE

A Climate Observing System Study (COSS) was initiated by NASA in 1980 as a key space research thrust in support of the National Climate Program and in anticipation of the U.S. participation in the World Climate Program. Because of their broad interests and expertise in the realms of climate and space observations, Dr. P. K. Rao, NOAA/NESS, Professor Verner Suomi, University of Wisconsin, and Professor Thomas Vonder Haar, Colorado State University, were asked to join me in this study as co-investigators.

To initiate this effort, a Climate Observing System Study Workshop was held on February 21 and 22, 1980 at the Goddard Space Flight Center. The purpose of this first COSS workshop was to begin the process of laying out a map of where we should be heading in the near and long term and to begin developing a plan for an effective space component of a global climate observing system. More specifically our workshop objectives were:

a. To develop a reasonably clear set of targets for a comprehensive observing system for the early 1990's. This will determine where we should be heading.

b. To identify a realistic stepwise program of action which will provide useful climate data in the near and mid-term and provide for feasibility assessment of instruments and methods for the development of the long-term system.

c. To identify those important climate parameters which cannot now be measured from space and outline a program of research and development to produce the required capabilities or alternative in-situ measurement methods, including hybrid approaches involving both space and in-situ techniques together.

d. To identify the spectrum of ancillary problems which need to be addressed to insure satisfactory performance of the climate observing system, including long-term calibration, intercomparison, standards, ground truth, and the like.

e. To set down non-technical issues which need to be resolved at the national and international levels.

As will be seen from the following report, all these objectives were not adequately addressed. Nevertheless, the workshop did make good headway and reached a reasonable consensus on a range of significant issues.

To set the tone for the COSS, I want to provide some personal perceptions. Over the last three years there have been many meetings, much discussion, and many documents produced in connection with plans for both the U.S. National and World Climate Programs. Much effort has also gone into the design and development of new instruments and the improvement of others. But there is a lack of coherence, at least in my mind, as to the grand picture. Do the instruments which we are conceiving, studying, and developing fit into some overall coherent observing system? By and large this evident lack of coherency is due to the fact that the Climate Program itself has only recently emerged as an identified entity with reasonably well defined goals and a clear national commitment. Accordingly, most of the developmental efforts have been done for a variety of other purposes. No wonder then that we have been unable to organize a focused and integrated set of activities.

But the observational requirements for climate research, diagnosis, and impact assessment are so broad in scope, so demanding in terms of accuracy and precision, and of such a long term nature that we can no longer rely upon piecing together the data from a fragmented set of observations. Rather, we must look at the picture as a whole and design an integrated observing system which will permit us to visualize climate in all its dimensions.

With the exception of the Earth Radiation Budget Experiment (ERBE) program, there is no major observing program dedicated to climate. Meanwhile, the National Oceanic Satellite System (NOSS) has come along and although it is operationally focused, it really is the first new major satellite system which has an opportunity of meeting the climate requirements in a major way. But, if we are not careful, and we fail to move expeditiously, we may lose some of the great opportunities that this system has to offer. I think that we would all agree that the observational tools for climate are likely to be so costly that it is virtually out of the question that we shall be able to justify a dedicated climate observing system. Rather, as noted in the recent report of the Climate Research Board*, we are going to have to build the climate observing system around existing and planned operational and research satellites.

Whether or not we realize it, the foundations of that system are being laid now. NOSS and ERBE are immediate examples. Very shortly, firm decisions will have to be made about research and operational meteorological satellites and the operational Landsat systems. For example, decisions will have to be made soon concerning Earth radiation budget satellite measurements after ERBE. To a large extent, I am convinced, and I think that many involved in this study are as well, that these will be the building blocks of the climate observing system of the 1990's. So it behooves us to plan ahead and to make sure that the pieces ultimately fit together into some rational integrated system. Time constants being what they are in the space business, 1990 is just around the corner. So we really had better get moving. Although NOSS will not be launched until 1986, the system design will be frozen shortly.

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*A Strategy for the National Climate Program; Climate Research Board, National Research Council, National Academy of Science, 1980.

Moreover, we have to get moving on developing various techniques to measure those climate parameters which are not now measurable. In fact, if we pull out all the stops today, we are looking at a decade before we can get instruments that are flyable. In short, I feel a sense of urgency; I hope I can convey that sense of urgency to the climate community, and through them, to the decision makers. It doesn't mean that we should rush headlong into building systems, but that we should proceed with all deliberate speed and purpose.

At the very least, I hope that out of this Workshop will emerge the framework for a climate observing system which evolves from what we do not have to what we think we should have and will need in the decade ahead. In a sense, this first workshop is also a dress rehearsal for the COSPAR special panel meeting to be held in England at the end of March, 1980 dealing with the same subject, i.e., directions for the space observing system for the World Climate Program. Thus, what is decided at this initial Workshop, is likely to have impact upon the approach to be taken by the international community. Subsequent to the COSS Workshop and prior to the completion of this document, a draft of the COSPAR panel meeting report entitled "Space-Based Observations in the 1980's and 1990's for Climate Research: A Planning Strategy" was prepared. While there is a great deal of commonality between the two reports, there are also significant differences both in terms of the material covered and the perspectives with which they are presented. Thus, the two documents should be viewed as mutually complementary.

Finally, this workshop is just the beginning. I hope it will be a solid beginning. We are not going to be able to cover everything. We realized in a brief workshop of this kind, that we couldn't cover all subjects. You'll notice, for example, that except in passing, problems in the upper atmosphere, stratospheric aerosols or gaseous constituents are not included. We do hope to cover these and other more specific aspects of the program in one or more subsequent workshops.

Note that the recommendations coming from this workshop are in preliminary form and are likely to be altered during future deliberations.

David Atlas

David Atlas
Workshop Chairman

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EXECUTIVE SUMMARY

The meteorological satellite program has just completed its second decade, and U.S. leadership in space-based observations of the global weather helped fashion the beginnings of a world weather system through the Global Weather Experiment in which more than 150 countries participated. Now, as we enter the third decade, a new opportunity arises to fashion a global climate program in which contributions from other countries could similarly benefit the U.S Climate Program initiative.

In developing a National Climate Program, which will be the most complex and scientifically difficult geophysical program in the nation's history, it was recognized that a climate observing system with a strong space-based component would be an essential element for the success of the program. NASA, in its space research role, initated a Climate Observing System Study (COSS) to respond to this need.

To proceed with the study, a COSS science workshop was convened February 21-22, 1980 to produce preliminary recommendations for designing and building a climate observing system. It was concluded early during the workshop that the climate observing system could not be separated entirely from an overall data acquisition and distribution capability. The participants therefore addressed themselves to other aspects of the total information problem in addition to the observing system recommendations. It was agreed in principle that a climate observing system must be able to utilize every bit of information from existing data sources, before general support for new or additional instruments and systems could be expected. Thus, the workshop produced a number of specific recommendations to improve the useability of existing and already planned data. For example, it was recommended that software development be emphasized to learn to utilize available data sets fully and to extend capabilities (both software and hardware) for on-line data reduction and analysis for currently operating and planned satellites. It was further noted that data archiving techniques could be improved by unifying data processing procedures, and the coordination of planned imaging from different satellites was encouraged.

The next important consideration concerns improvement of observations already being made in order to satisfy climate data needs. Substantial increases in the number and accuracy of observations of such parameters as sea surface temperatures, tropical wind vectors, temperature profiles, and cloud cover to satisfy the needs of climate information users was emphasized. Some of these needs can be addressed in some cases by changing operational modes of current satellites and by improving the accuracy of instrumentation presently being planned for later series of operational satellites. Also, improvements in instrument calibration and increased use of ground truth data with satellite data will yield greater accuracy and higher reliability of the data. The inclusion of other future operational satellite data, such as NOSS and perhaps Landsat data, will increase the density of measurement, particularly for ocean and land surface parameters.

A third important consideration is data continuity, for a climate observing system must provide a long baseline of data. Furthermore, the data must be taken on a global scale at frequent and regular intervals and processing should be in a prescribed, pre-defined manner so that a large community can easily make use of the data. This requires that the climate observing system be an operational system, utilizing wherever possible, systems already in place or actively planned to provide climate data. Only an operational system can take the number of measurements required to support the National Climate Program. In planning such a system, the need for, and value of, international cooperation and coordination must be recognized in acquiring climate data.

Finally, after carefully considering and recommending what can be done for existing and planned climate observations activities, it becomes logical to begin planning what new steps should be taken. For example, even though the inclusion of operational satellite data is necessary for the study of climate, it is frequently not sufficient to perform research. Operational instruments must be tried-and-true, while research instruments are frequently new and untested. Also, the nature of operational systems is such that they cannot be turned over to research projects for extended periods to perform experiments. For this reason it was strongly recommended that a Geostationary Test Platform (GTP) be provided to furnish data that meets the need for the study of local and regional weather and climate.

Another major problem facing climate research involves the complicated interactions between clouds and radiation fields. The first step in understanding these phenomena is making the appropriate observations. One such crucial observation is the measurement of cloud height, independent of cloud temperature. Two techniques are presently being considered for passive determination of cloud top height. One approach is to measure the absorption due to oxygen in the near IR. The other approach is to obtain stereo images from two different geosynchronous satellites or from a polar orbiter at two different times and viewing angles. Improved cloud height information would be highly relevant to the international cloud climatology project being organized to develop a global cloud data set. In addition to the examples cited, the need for new or improved basic sensor technology for climate observations was noted as well as the need for upgrading existing instruments and developing new ones. Sets of complementary instruments such as an active/passive microwave and most notably a lidar sensor system was frequently noted. It was also recommended that plans be formulated for providing support for ground data systems to satisfy climate data needs, including a real-time data processing system for climate projects.

In summary, the climate observing system should be a composite system to support hydrologic, cryospheric, and oceanic observations. It should include observations from near-term NOAA and DOD low and geosynchronous orbiting satellites, including the NOAA TIROS and GOES series, and NOSS. Eventually, it should include observations from the GEO, LEO, and DCPL systems of a future operational environmental satellite system. In view of this, NASA should develop a long-term space research strategy consistent with the requirements of NOAA and the national and world climate programs. An oceanic/cryospheric/radiation budget monitoring experiment centered around NOSS, ERBS, and other existing satellites in the 1986 time frame should be included in this plan as a precursor to a world climate experiment.

The gist of the key workshop recommendations are as follows: (Since these reflect both joint national program recommendations as well as specific initiatives for NASA's program, they are not necessarily in order of priority nor do they imply acceptance by NASA management or by the National Climate Program.)

- Make maximum use of the space climate information that is now available. Summarize and analyze this existing information for the purpose of climate studies and future operational specifications.

- Formulate a plan to provide ground data systems that satisfy climate data needs for the current and future operational GOES and TIROS satellites.

- Initiate studies aimed at defining optimized techniques and detailed recommendations for modification and/or use of the current satellite systems that will support the development of a future integrated international operational global satellite system.

- Improve sensor calibration techniques; develop ground truth techniques that are more appropriate for verification of satellite measurements.

- Obtain improved and new climate observations from near-term NOAA and DoD low and geosynchronous orbiting satellites; specific plans to select the most valuable instrument complements within built-in growth limits should be made at an early date.

- Initiate a program to develop a geostationary test platform for research purposes. Geostationary satellites should complement low Earth orbiting satellites for climate research and operational requirements.

- Stimulate a vigorous program with university participation to develop in-situ sensors for data collection and platform location systems.

- Make every effort to optimize the design of NOSS and accompanying data systems for climate research.

- Place a laser altimeter on NOSS for monitoring ice sheet dynamics and mass balance, and for certain cloud top experiments and for measuring boundary layer heights from aerosol backscatter.

- Add a 94-GHz channel to NOSS LAMMR for improved cryosphere measurements and cloud liquid water content measurements and the detection of precipitation events.

- Initiate a study to determine the feasibility of modifying the AVHRR to alternately view forward and rearward to provide stereo cloud height and water vapor height measurements.

- The new Advanced Moisture and Temperature Sounder (AMTS) and the AVHRR-X should be flown on the NOAA weather satellites at the earliest opportunity.

- Add a "climate data pipeline" to the NOSS data system.

- Develop a space research mission for an Ice and Climate Experiment (ICEX).

- Provide a calibration program for NOSS that will ensure the long-term integrity of the data for climate purposes.

Note

> NOSS recommendations related to science requirements relative to this study will undergo further examination at the request of Dr. Francis Bretherton, Chairman of the NOSS Science Advisory Panel, a special committee formed by NASA to identify the various ways that NOSS can achieve oceanic and climatic goals.

- Conduct a mid-term oceanic/cryospheric/radiation budget monitoring experiment centered around NOSS, ERBE, and other existing satellites in the 1986 time frame as a precursor to a world climate experiment.

- Conduct sensitivity studies to establish the relative importance of various climate parameters to substantiate climate requirements.

- Develop a long-term NASA space research strategy consistent with the climate requirements and with NOAA operational missions and those of the national and world climate programs.

- Accelerate research and development in space-based meteorological lidar systems.
- Accelerate feasibility studies and follow-on aircraft and ground truth validation experiments of instruments and/or systems aimed at satellite measurement of soil moisture and precipitation.
- Initiate a strong program to explore and develop a space-based system for precipitation measurements over land and oceans.

FIRST
CLIMATE OBSERVING SYSTEM STUDY
WORKSHOP

1. INTRODUCTION

The objective of NASA's Climate Research Program (NCRP) is to develop a space capability for global observations of parameters which will contribute to our understanding of Earth's climate. The first Climate Observing System Study (COSS) workshop was convened to provide recommendations and rationale for a Climate Observing System (COS). Development of a COS is one of four principal areas in which research will be sponsored by NASA.

The results of previous climate studies were incorporated as background into the COSS workshop. Examples of such background material include: The Climate Parameter Observational Requirements (table 1-1) from the 1977 "Proposed NASA Contribution to the Climate Program"; and Possible Approaches for Acquiring Key Climate Observations (table 1-2) from the "Climate Science Working Group" convened in December 1977.

Basic assumptions are that the ultimate goal of a global climate observing system will be achieved through the evolution of combined conventional observing systems and a mutually supportive constellation of operational and research satellites that will include low Earth orbiting and geosynchronous satellites with data collection and platform location (DCLP) capability for in situ sensors. Critical to this goal is that all operational systems be designed for maximum compatibility with the requirements of the Climate Observing System. An interim goal will be a preliminary integrated Global Climate Observing System in place by approximately 1990 to support an anticipated national and world climate program goal of a World Climate Experiment (WCE). These assumptions do not represent any

Table 1-1. Climate Parameter Observational Requirements

	Parameter	Desired Accuracy	Base Requirement	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Index No
Weather Variables (● Basic FGGE Meas.)	● Temp Profile	1°C	2°C	500 km	200 mb	12-24 Hrs.	1
	● Surface Pres	1 mb	3 mb	500 km	–	12-24 Hrs	2
	● Wind Velocity	3 m/sec	3 m/sec	500 km	200 mb	12-24 Hrs.	3
	● Sea Sfc. Temp	0.2°C	1°C	500 km	–	3 Days	4
	● Humidity	7%	30%	500 km	400 mb	12-24 Hrs	5
	Precipitation	10%	25%	500 km	–	12-24 Hrs.	6
	Clouds			100 km	–	1 Day	7*
	a. cloud cover	5%	20%				
	b. cloud top temp.	2°C	4°C				
	c. albedo	0.02	0.04				
	d. total liq. H_2O Content	10 mg/cm^2	50 mg/cm^2				
Ocean Parameters	Sea Sfc. Temp	0.2°C	1°C	500 km	–	1 Month	4a
	Evaporation	10%	25%	500 km	–	1 Month	9
	Sfc. Sens. Heat Flux	10 W/m^2	25 W/m^2	500 km	–	1 Month	10
	Wind Stress	0.1 Dyne/cm^2	0.3 Dynes/cm^2	500 km	–	1 Month	11
Radiation Budget	Clouds (Effect on Radiation)			500 km		1 Month	7a
	a. cloud cover	5%	20%				
	b. cloud top temp	2°C	4°C				
	c. albedo	0.02	0.04				
	d. total liq. H_2O Content	10 mg/cm^2	50 mg/cm^2				
	Regional Net Rad. Components	10 W/m^2	25 W/m^2	500 km	–	1 Month	16
	Eq.-Pole Grad	2 W/m^2	4 W/m^2	1000 km Zones		1 Month	17
	Sfc. Albedo	0.02	0.04	50 km	–	1 Month	18
	Sfc. Rad Budget	10 W/m^2	25 W/m^2	500 km	–	1 Month	19
	Solar Constant	1.5 W/m^2	1.5 W/m^2	–	–	1 Day	20
	Solar UV Flux	10% per 50 Å Interval		–	–	1 Day	21
Land Hydrology, and Vegetation	Precipitation	10%	25%	500 km	–	1 Month	6a
	Sfc. Albedo	0.02	0.04	500 km	–	1 Month	18a
	Sfc. Soil Moist.	0.05 gm H_2O/cc Soil	4 levels	500 km	–	1 Month	22
	Soil Moisture (Root Zone)	0.05 gm H_2O/cc Soil	4 levels	500 km	–	1 Month	23
	Vegetation Cover	5%	5%	500 km	–	1 Month	24
	Evapotranspiration	10%	25%	500 km	–	1 Month	25
	Plant Water Stress	4 levels/2 levels		500 km	–	1 Month	26
Cryosphere Parameters	Sea Ice (% Open Water)	3%	3%	50 km	–	3 Days	27
	Snow (% Coverage)	5%	5%	50 km	–	1 Week	28
	Snow (Water Content)	+1 cm	±3 vm	50 km	–	1 Week	29

*NOTE. Under "Weather Variables" (Index No 7), histograms of all four cloud parameters will be generated for 100 km x 100 km boxes.

Table 1-1. Climate Parameter Observational Requirements (cont.)

	Parameter	Desired Accuracy	Base Requirement	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Index No.
Ocean Parameters	Sea Sfc. Elevation	1 cm	10 cm	Variable	(As Indicated)	1 Week	12
	Upper Ocean Heat Storage	1 KCal/cm^2	5 KCal/cm^2	500 km	–	1 Month	13
	Temp. Profile	0.2°C	1.0°C	Variable	–	1 Month	14
	Velocity Profile	2 cm/sec (near sfc)	10 cm/sec	Variable	–	1 Month	15
		0.2 cm/sec (at depth)	1 cm/sec	Variable	–	1 Year	15
Cryosphere Parameters	Ice Sheet SFC. Elevation	10 cm	1 m	1-3 km	–	1 Year	30
	Ice Sheet Horiz. Velocity	50 m/yr	100 m/yr	Point targets	–	1 Year	31
	Ice Sheet Boundary	1 km	5 km	1-3 km	–	1 Year	32
Variable Atmos. Composition	Solar UV Flux	10% per 50Å	Interval	–	–	1 Day	21a
	Stratos. Aerosol Opt. Depth	0.002	0.01	250 km N-S 1000 km E-W	3 km	1 Month	33
	Tropos. Aerosol Opt. Depth	0.005	0.02	500 km	3 km	1 Month	34
	Ozone	0.005	0.02 cm (total) 10% at effective alt.	250 km N-S 1000 km E-W	3 km	1 Month	35
	Stratospheric H_2O	0.5 ppm	0.5 ppm	250 km N-S 1000 km E-W	3 km	1 Month	36
Reasonably Well-Mixed Tropospheric Gases (ground-based observations)	N_2O	0.01 ppm	0.03 ppm	–	–	1 Year	37
	CO_2	0.5 ppm	10 ppm	–	–	1 Year	38
	CFM's	0.03 ppt	0.1 ppb	--	–	1 Year	39
	CH_4	0.05 ppm	0.15 ppm	–	–	1 Year	40

NOTE: All Climate B parameters are also required by Climate C & X.

Table 1-2. Possible Approaches for Acquiring Key Climate Observations (December 1977)

CATEGORIES OF CLIMATE PARAMETER REQUIREMENTS	PARAMETERS	RESPONSIBLE OR RELATED PROGRAM	SPACE OBSERVATIONAL SYSTEM
REMAINING KEY CLIMATE PARAMETERS (OF 40 PREVIOUSLY IDENTIFIED) NOT BEING ADDRESSED OR INADEQUATELY COVERED BY OPERATIONAL OR OTHER RESEARCH SYSTEMS TO WHICH SPACE OBSERVATIONS CAN CONTRIBUTE.	• SURFACE PRESSURE	GLOBAL WEATHER/OPER.	*RTP - µWAVE OR LIDAR (PRESS)
	• CLOUD CHARACTERISTICS (RAD)	CLIMATE PROGRAM	RTP - CPR
	ALBEDO		
	TOP HEIGHT		
	PHASE		
	• CLOUD LIQUID H_2O	CLIMATE PROGRAM	RTP - LAMMR
	• SURFACE ALBEDO	EARTH RESOURCES/OPER. CLIM.	LANDSAT/NOAA-AVHRR-3/ERBSS
	• SURFACE SOIL MOIST.	EARTH RESOURCES/OCEANS	SOIL MOISTURE SAT./NOSS-LAMMR
	• TROPOSPHERIC AEROSOLS	CLIMATE/ENV. QUAL./DOD	RTP-LIDAR; DMSP-SSV
	• VEGETATION	CLIMATE PROGRAM/OPER.	RTP-HRVH/NOAA-AVHRR-3
PRIORITY PARAMETERS AS RECOMMENDED BY THE CLIMATE SCIENCE WORKING GROUP (CSWG)	PARAMETERS REQ. IMPROVEMENT		
	• SEA. SURF. TEMP.	OPER./NAT'L OCEANS PR.	NOAA-AVHRR-3/NOSS-LAMMR
	• TEMP. PROFILE	OPER./GLOBAL WEATHER	NOAA-TOVS/RTP-AMTS or HIS
	• WIND SPEED	OPER./OCEANS/UP. ATM./CLIM.	GOES-VISSR/NOSS-LAMMR/UARS/LACA
	SPACE CAPABILITY DEV. REQ.		
	• PRECIPITATION (LAND)	CLIMATE PROGRAM	RTP - PRECIP. RADAR/
	• SOIL MOIST. (RT. ZONE)	EARTH RESOURCES	SOIL MOISTURE SATELLITE - LBMR
	• ICE SHEET (ELEV.)	OCEANS/ICE PROCESSES/CLIM.	NOSS-ALT./ICESAT-ALT./RTP-ALT.
	• ICE SHEET HORIZ. VEL.	ICE PROCESSES/CLIMATE	NOSS-ALT./ARGOS
PARAMETERS REQUIRING AN EXTENDED DATA BASE	• PRECIPITATION (OCEANS)	OCEANS/OPER.	NOSS LAMMR/SYS.-85-µWAVE
	• WIND STRESS	OCEANS	NOSS-LAMMR
	• SEA ICE	OCEANS/CLIMATE	NOSS-LAMMR/RTP-LAMMR
	• STRATO. TEMP.	UPPER ATMOSPHERE	UARS
	• STRATO. H_2O	UPPER ATMOSPHERE	UARS
	• STRATO. AEROSOLS	UPPER ATMOSPHERE	AEM-SAGE/ERBSS-SAGE
	• SOLAR FLUX (TOTAL AND SPECTRAL)	OSS/CLIMATE/OPER.	SMM-ACR/SHUTTLE CALIBRATION FAC./ERBSS
	• RADIATION BUDGET (NET)	CLIMATE PROGRAM/OPER.	ERBSS/SYSTEMS-85-GEO

BOXED PARAMETERS — INDICATES THOSE PARAMETERS FOR WHICH OBSERVATIONS THROUGH OTHER PROGRAMS ARE LEAST ASSURED.

*RTP - RESEARCH TEST PLATFORM

(NOTE: GLOSSARY OF ACRONYMS)

national or agency policy, but merely an assessment by the investigators of what seems a logical basis on which to proceed.

As we enter the third decade of meteorological satellites, a new opportunity to fashion a global climate program develops where contributions from other countries could again benefit the U.S. Climate Program directly. This document is an initial feasibility study to provide space-based climate observations taking into account interests of other nations as well as our own in a well integrated weather and climate observing system of the future.

This document deals with opportunities in the early and mid-80's as well as activities more appropriate for the 90's. We attempt to make use, wherever possible, of operational and experimental systems already in place or under active planning. This initial attempt is not a fixed or firm single system, but consists of several candidates of different cost and performance.

The definition and development of climate observing system requirements is essential to the early phase of the Climate Observing System Study (COSS). To meet this need, the Office of Space and Terrestrial Applications (OSTA) has approved and assigned to the Goddard Space Flight Center (GSFC) a study to assess current space capabilities and to develop options for near, intermediate, and long-term applications of space technology to climate observations. GSFC realized that the participation of the scientific community at a very early stage of the planning process was important. This led to the first COSS workshop. The results in terms of new concepts, problem areas and recommendations from the COSS workshop will be part of the inputs used for analysis, synthesis and integration of climate observing system requirements.

The approach to achieve the goals of future COS must be multi-disciplinary and international in scope, and be supported by a combination of measurements from satellite or space-based systems, earth-based systems, and ocean-based systems. However, the key to implementation of the COS requires a stepwise program to develop new operational space-based instruments and systems to monitor climate variables, to upgrade and augment the existing network of earth-based climate observing facilities for acquiring data on atmospheric trace constituents, radiation, and other measurements, and to develop and establish a global ocean monitoring system. The next step will be to identify lead roles for specific tasks to the maximum extent possible. For example, NOAA should be expected to have the lead role for earth-based and ocean-based observational facilities, while NASA should be expected to continue with instrument development and experimental systems for climate research.

Key topics addressed and discussed at the workshop were:

a. Needs for the observations: i.e., climate monitoring, climate impact assessment, climate diagnosis, the development, initialization, and validation of models, sensitivity and predictability studies, and experimental predictions.

b. Recommended steps related to data systems, observational systems and instruments, for near (to 1984), mid (1985-88) and long (beyond 1988) term action.

c. The role of in-situ data collection and location platforms (DCLP's) to obtain and transmit measurements of parameters for which there are now no reasonable remote sensing schemes or concepts.

d. Experimental programs to validate remote sensing methods, and ground/air truth observations to support, interpret, or extend those made from space.

e. Special problems of calibration, stability, intercomparison, standards, etc.

f. The role of low Earth orbiting satellites (LEOS) and geosynchronous Earth orbiting satellites (GEOS).

Based on these topics, recommendations and rationale were developed that exploit existing and planned observational systems and point out opportunities where coordination and integration of the entire system can vastly improve overall performance. These recommendations were based on a set of strawman recommendations prepared by the GSFC/COSS group and revised utilizing inputs from the COSS co-investigators and the valuable discussions and suggestions from the working groups of the first COSS workshop.

A variety of topics including remarks on the National Climate Program, Earth's radiation budget and cloudiness, hydrological and cryospheric processes, ocean, precipitation, soil moisture, wind and air-sea interaction are summarized in section 3 from talks given at the workshop. Participant comments, both oral and written, helped balance the views presented in each talk.

2. WORKSHOP RECOMMENDATIONS AND RATIONALE

GENERAL CONSIDERATIONS

The climate problem is one of the most critical environmental issues facing the nation and the world today and is likely to remain so for the next few decades. Since climate must be observed globally, implying heavy reliance on space observations, NASA has a fundamental role in developing a long-term space research strategy consistent with the requirements of NOAA and in support of the National Climate Program that would assure a vigorous continuing commitment to the development of a Global Climate Observing System.

Climate encompasses virtually all of the disciplinary and applications problems with which NASA has been concerned in the areas of local, regional, and global weather, upper atmosphere, environmental quality, oceans, cryosphere, hydrology, land surface properties, agriculture, and solar-terrestrial relations. For this spectrum of activities, the Climate Program provides a unique unifying and motivating force. The wide array of available expertise and resources related to remote sensing within NASA provides the capability for successfully carrying out development of the space systems essential to this challenging task. The Climate Program must be regarded as a key element of NASA's future environmental observations.

This section recommends a wide range of actions and approaches to be taken in developing COS. These recommendations address the overall system, COS's use of existing facilities and data, the necessary improvements to present observational and data systems to achieve research goals, areas requiring new instrumentation or research and development, and the use of discipline-dedicated systems for climate research. They are not restricted to recommendations which apply solely to NASA. They have been developed to address the needs of the entire climate research community and necessarily cut across agency lines. This implies varying lead role responsibilities among agencies involved. Most, if not all, of the recommendations require multi-agency collaboration and/or university support.

UTILIZATION OF PRESENT AND PLANNED OBSERVATIONAL DATA AND DATA FACILITIES

As a first step in addressing the backlog of data, pilot studies should be initiated to identify climate data sets that can be extracted from existing and on-going satellite archives for climate operations and research purposes and for guiding development of future systems. As a later part of this effort, data from the Global Weather Experiment as well as previous operational and experimental satellites should be analyzed and summarized. This information is of great value for ongoing climate research as well as having many practical applications. Resources for analysis should be increased as a matter of urgency.

Regarding planned systems, if provisions are not made for immediate development, processing and archiving of climate data sets which should be in place when satellites fly, we can never catch up with the vast data backlog within any realistic budget; in some instances data would be permanently lost. For these reasons we will probably never extract maximum useful climate information from the past satellites. In effect, near-real-time climate data extraction is required even though the actual application of it is normally far from real-time.

To ensure that these provisions are made, plans should be formulated now and support should be provided for climate data set extraction from current and future operational and research satellites. Present support and commitment to this activity is inadequate. Much climate data could be extracted simply by modifying current operational data archiving procedures.

SYSTEM CONSIDERATIONS

Climate analysis must move toward the philosophy of developing total systems that meet the requirements of both operational and research problems by combinations of data from all contributing satellites and conventional observing systems. The climate system includes significant, if not major, elements of all the other disciplines with which NASA is concerned in environmental and Earth observations. Therefore, the time is ripe to approach the problems holistically. Conceptual studies suggest the feasibility of this approach (Atlas et al., 1978: Visions of the Future Operational Meteorological Satellite System). The costs of an overall climate system can be greatly reduced through the use of operational systems properly designed to meet climate requirements. Virtually no single operational problem can be satisfied by data from a single satellite. For example, global weather depends on TIROS-N largely for soundings but requires GOES for wind determination. The Climate Observing System will require data from every operational satellite.

As a first step within this holistic approach, a study should be initiated immediately to define optimized techniques and detailed recommendations for modification and/or use of the current and future integrated international operational global satellite systems to assure meeting the space observational requirements of the Climate Research Program. Particular emphasis was placed on the inclusion of geostationary satellites to complement low Earth orbiting satellites for climate research and operations, since a number of vital observations from geostationary orbit are required for both regional and global climate and for ocean measurements (cloud climatology, regional land hydrology, air-sea interactions, etc.).

Many of the research instruments included in the COSS Workshop Recommendations are probably too large and complex to be accommodated on an operational satellite. In view of this, NASA should consider developing an applications research satellite devoted to climate research. Furthermore, experience with the data obtained from a research satellite is needed to help define the optimum future operational systems. The use of weather research satellites (Nimbus) to support an operational system configuration (TIROS/GOES) is a good precedent.

A plan should be formulated to provide support for ground data systems from current and future operational and research satellites, in order to satisfy climate research needs. However, in many cases, satellite data alone, without supporting ground truth measurements, are inadequate either to measure or to infer the required parameters. This is especially true of ocean and Earth subsurface characteristics where the large coverage and repetition of satellite observations can be used to interpolate in time and space between in situ measurements. Therefore, a vigorous program with university participation should be stimulated to develop in-situ sensors for data collection and platform location systems.

OPERATIONAL INSTRUMENTS

COS will require data from virtually every instrument on existing and planned operational spacecraft. In order to take advantage of the opportunities to obtain new and improved climate observations, the most valuable instrument complements should be selected for near-term NOAA and DoD LEOS and GEOS at an early date. In addition, any future meteorological satellite should be designed to accommodate growth and have the capability for climate research. Recommendations regarding NOSS instrumentation are discussed later in this section.

An AMTS and AVHRR-X on TIROS would provide means of making improved SST measurements in cooperation with a LAMMR on NOSS. The increased vertical resolution of the AMTS provides some hope for inferring air-sea exchanges. Since an AVHRR-X and LAMMR are so tightly interrelated and mutually dependent, it is necessary to fly them as nearly simultaneously as possible. Of course, the imaging capabilities of AVHRR-X in a multiplicity of channels also would have many other applications to the oceanic and cryospheric problems and to the ancillary climate problems of surface albedo, snow cover, vegetation, and land-hydrology problems. A study should be initiated to determine the feasibility of modifying the AVHRR to alternately view forward and rearward to provide stereo cloud height and water vapor height measurements.

The AVHRR-X and the new AMTS are recommended to be flown on TIROS weather satellites and to be reasonably complementary to NOSS, i.e., they should be in the same orbit plane and separated by ± 3 hours.

PLANNED OPERATIONAL AND RESEARCH SYSTEMS

As noted earlier, COS will require data from many operational and research systems and programs which are dedicated to one discipline. These include NOSS (ocean measurements), ERBE (Earth radiation budget measurements), and ICEX (cryosphere measurements). To fully exploit these systems for climate research, their designs must be optimized for this purpose. Recommendations for optimizing these systems are included in this section.

National Oceanic Satellite System (NOSS)

NOSS is the first operational satellite focused on oceanic problems. As such, it also represents a new opportunity for meaningful climatic research. The Nation simply cannot afford not to exploit it to the fullest extent possible. NOSS and some of the proposed improvements to it are critical to the success of the Ocean Climate Monitoring Experiment, a major thrust of the National Climate Program. Therefore, every effort should be made to optimize the design of NOSS and accompanying data systems for oceanic climate research as well as for operational requirements. It is strongly recommended that a program be initiated to provide facilities, resources and investigators capable of absorbing, processing, and analyzing the NOSS data set for climate studies.

The NOSS spacecraft, as the first shuttle optimized platform design, should not be limited to the across-the-board 25 percent built-in growth. The basic design should be expandable in area, power, and data handling to accommodate up to 150 percent growth so that NOSS can serve as the prototype of the next generation operational "bus." Thus, in the late 1980's, proven operational hardware will exist that can carry operational as well as climate research instruments. If an expandable capability for the operational satellites is not implemented, NASA should implement a climate research satellite series to provide a low Earth orbit test platform for climate research.

The NOSS operational data processing and analysis facility is now constrained in size and capability to support only operationally useful oceanic data (and cryospheric data if the ice payload is added). There are a variety of other climate parameters to be derived from the data (e.g., oceanic precipitation, possibly snow depth over land, cloud liquid water content, etc.). In view of this, a "climate data pipeline" should be added to the NOSS data management system so that processing of climatologically important data can be accomplished in a timely way. In addition, a program should be established to design and implement a continuous calibration and ground truth capability for ensuring valid algorithms for climate data sets from NOSS observations. The algorithm validation to be funded under the NOSS program will be too limited in scope and duration for this purpose. The effect of these recommendations, when taken together, will make NOSS a fully integrated part of COS.

During the lifetime of the NOSS dual spacecraft system (assuming both are flown in the same orbit plane), operations and data acquisition from both for a one year period should be planned. It is understood that the NOSS altitude is such that the LAMMR swath at the equator is approximately half of what is required for contiguity. Phased operation (half orbit separation) will create a one-year data set of contiguous global day and global night climate data (such as rainfall) that can be derived from the LAMMR data. This is necessary to evaluate the effect of reduced sampling on future missions.

Note

> NOSS recommendations related to science requirements will undergo further examination as requested by Dr. Francis Bretherton, Chairperson of the NOSS Scientific Advisory Panel, a special committee formed by NASA to identify the various ways that NOSS can achieve oceanic and climatic goals.

Ice and Climate Experiment (ICEX)

The cryosphere research objectives, observational requirements, and associated investigations of ICEX thoroughly address the space-related cryospheric needs of the National Climate Program. (Refer to Report of the ICEX Science Working Group, December 1979.) ICEX can be partially implemented in the late 1980's using NOSS and its 25 percent research component. The addition of the cryosphere research complement of sensors to NOSS and implementation of a research data processing and analysis facility that would also meet climate data requirements is recommended. Such a facility is essential for continued development of parameter extraction techniques, special studies of cryospheric processes, and production processing of higher level ice climate data sets.

To achieve partial implementation of ICEX, the following additions are recommended for NOSS:

- The addition of a laser altimeter/ranger within the NOSS 25 percent research component and the adaptive tracking modification of the radar altimeter because investigation of ice sheet mass balance and stability or instability (inherent and with respect to natural or CO_2-induced climate changes) is a major objective of ICEX. It is extremely important to begin monitoring of the ice sheets and the potential for ice sheet surges so that consequent impact on climate can be determined. The development of such an observational capability for ice sheet elevation and horizontal velocity was one of four observational developments recommended for the 1980's by the NASA Climate Science Working Group (CSWG) in December 1977. The techniques are ready for implementation on the NOSS schedule, and are highly complementary to the NOSS operational payload. These research additions would also fulfill the operational NOSS requirement for ice sheet height, which cannot be met by the operational payload alone. Moreover, the laser ranger system would enable valuable research on improved orbit dynamics as required for sea surface height which was another of the four observational developments recommended by the CSWG and is a high priority of the ocean research program.

- The addition of a 94-GHz channel for improved sea ice type determination and research and mapping of snow on land and "yes-no" detection of precipitation events.

- A data collection and location system to obtain simultaneous in-situ surface data to complement data collected with NOSS sensors.

Earth Radiation Budget Experiment (ERBE)

The radiation budget, consisting of the incoming solar radiation and the outgoing reflected and emitted radiation, has a long history of scientific interest dating back before the 19th century. The importance of the radiation budget, and its variability over a large range of time scales, to understanding the Earth's climate leads to the need for long, homogeneous data sets. Calibration and the stability of the measurements is consequently a primary concern, with the data reduction being of equal importance.

Since validated measurements are required on a regular basis, a radiation budget observing capability, including monitoring of the solar constant and incoming and outgoing radiation in narrow and broad spectral bands, should eventually be incorporated into the long term operational system. Continuity of effort and stepwise development of the observing system are of considerable importance. Currently, satellite measurements of the Earth radiation budget are being made with the ERB on Nimbus 6 and 7; they will continue with the Earth Radiation Budget Experiment (ERBE) on the Earth Radiation Budget Satellite, and on NOAA F and NOAA G. The presently planned ERBE system should be considered as a prototype for follow-on Earth radiation budget operational measurements to ensure data consistency. The same instrument complement is then a logical candidate for inclusion on the NOAA H, I, and J missions. The instrument complement on ERBE includes both solar monitoring and Earth viewing channels that provide a range of spatial resolutions. In addition, ERBE includes both shortwave and longwave calibration sources which are essential for detecting changes in instrument response in space from that during ground calibration.

An operational radiation budget system for climate observations must recognize that it is essential to measure the reflected and emitted radiation with broadband instruments that have as flat a spectral response as can be designed. Generally speaking, it is difficult to design radiation detectors whose uncertainties are smaller than 0.5%, even if careful attention is paid to calibration. It is perhaps optimistic to expect overlapping narrowband instruments to provide highly accurate measurements of the spectrally integrated radiation fields. Beyond the question of error propagation with different sensors observing limited spectral bands is that of estimating the total field when only selected intervals are observed. Variations that occur between the gaps will be completely missed, although they may be significant for the total radiation budget. For example, radiation budget estimates based on limited spectral data, such as a few channels in the visible and in the infrared window do not observe:

- changes due to water vapor
- changes due to CO_2
- changes in the near infrared due to vegetation growth, death, or stress
- changes due to ozone concentration changes
- the actual albedo of clouds
- much of the thermal infrared emission from polar regions.

Thus a wide variety of "climate change" on scales ranging from a few days (over which rainfall could affect vegetation), to interannual to years (over which CO_2 or ozone concentration changes) could be unobserved or misinterpreted as changes in the radiation budget by estimates of the SR or AVHRR type.

Our understanding of the causes of climate change also requires information from limited spectral bands. Thus, future Earth radiation budget measurements should include broad, but limited, spectral intervals designed to detect expected changes in the Earth's radiation budget, such as a 4 W/m^2 decrease between 12-18 μm due to the doubling of CO_2 and a compensating increase in the radiation emitted in the 8-12 μm spectral interval. Owing to the sizeable changes expected in the trace gas concentration, such as that of N_2O, CH_4, O_3, and CFMs, a high resolution spectrometer should be used periodically to assess the impact of these trace gases on the energy budget.

CALIBRATION REQUIREMENTS

For climate studies, precision and/or repeatability are often as important or more important than absolute accuracy. Reproducible data can do much to monitor and advance our understanding of the climate. However, the accuracy, precision and compatibility of data necessary for the climate program have not been achieved with measurements from previous satellites because present radiometric standards and techniques for transferring calibration to flight sensors are inadequate.

Long-term observations, such as the SBUV Monitoring Program, have shown the importance of maintaining calibration of individual sensors, of cross-calibration of similar sensors on different satellites, and of intercalibration of instruments on successive satellites. Ground truth calibration will be required for virtually all of the parameters important to the Climate Program. The importance of a given parameter to the Climate Program and the feasibility of implementing the required ground-based network will establish the priority of development of those networks.

A joint program should be developed to meet these sensor calibration requirements necessary to the climate program to insure valid initial calibration of sensors and long-term continuity of calibrations among sensors flying simultaneously and/or successively. Special ground-based networks or observing systems should be developed and operated continuously at selected sites as ground truth calibration and intercomparison facilities.

NEW INSTRUMENTATION

Lidar

Research and development in space-based meteorological lidar systems should be accelerated to improve the measurements of aerosols and cloud height, of winds, and of atmospheric temperature and pressure distribution. These systems would potentially include a differential absorption lidar to measure atmospheric temperature, humidity, and pressure profiles, a single wavelength lidar to measure atmospheric aerosol distributions, and a Doppler lidar to measure horizontal wind fields.

Passive infrared and microwave temperature sounding from space is limited to accuracies of about 2°C with an altitude resolution of 5-8 km. Small scale features such as the tropopause and the boundary layer cannot be resolved. Potentially, a differential absorption lidar system could measure temperature profiles to about 1° C accuracy with an altitude resolution of 2 km and pressure profiles to 1-2 mb accuracy with an altitude resolution of 1 km. While these lidar capabilities remain to be proven, they do promise a significant improvement in atmospheric sounding, and a unique ability to measure pressure profiles.

Range resolved laser backscatter from atmospheric aerosols can provide an effective method for inferring the altitude of the planetary boundary layer and the tropopause on a global basis. Both the tropopause and the boundary layer are marked by a discontinuity in aerosol backscatter as detectable by lidar. In addition, global measurements of aerosol backscatter profiles in the stratosphere and troposphere will be valuable in assessing the influence of particulates on atmospheric radiative transfer.

In data-sparse regions of the global ocean, we are presently limited to rough estimates of wind based on three techniques: cloud tracking, surface winds from ocean roughness, and in mid to high latitudes, the geostrophic approximation. In the band ± 20^0 about the equator, little wind information can be derived or measured. The lidar technique, which depends on measuring the Doppler-shifted backscatter from aerosols holds the only promise to infer, on a global basis, the clear air wind fields. Recent studies (subsequent to the COSS Workshop) indicate the promise of an alternative lidar wind measurement technique based upon the displacement of the aerosol backscatter pattern at a selected height as viewed successively ahead of and to the rear of the spacecraft at an interval of a few minutes.

Because of the clear potential for lidar to provide accurate measurements of the basic state variables and winds, even though limited to clear or partly cloudly conditions, and to furnish important ancillary cloud and aerosol data, a vigorous lidar development effort is proposed.

Precipitation and Soil Moisture Instrumentation

Both soil moisture and precipitation are important climate parameters. A great deal of research and development has been done in each of these areas, but the feasibility of space measurements remains controversial. Feasibility studies and follow-on aircraft and ground truth validation experiments should be accelerated to develop the techniques, instruments, and systems necessary for satellite measurements of precipitation and soil moisture.

A strong program is needed to develop a space-based system for uniformly measuring precipitation over land and oceans. Recent studies have raised doubts about the adequacy of microwave radiometric methods for measuring rainfall over the oceans, even where problems of surface background brightness temperatures are thought to be minimal. The limitations include serious bias due to beam filling, inadequate corrections for "effective rainfall height" and highly variable effects of cloud liquid water content. Higher resolution radiometers such as LAMMR (to be flown on NOSS) will reduce beam filling errors. The shortcomings of microwave radiometers over land are equally difficult. While present algorithms which depend on statistical regression to relate the visible and/or IR properties of cloud to rainfall appear to provide reasonable measurements over the tropical oceans, they have serious problems measuring stratiform precipitation. Moreover, they are not transferable from one region to another for measuring rainfall over land.

The only other reasonable approaches for measuring rainfall over land are spaceborne radar and/or in-situ ground stations and surface radars. While the problems of a spaceborne radar are not trivial, they relate mainly to resolution and power. These problems appear soluble within state-of-the-art technology. A spaceborne meteorological radar would also have very broad applicability to other research problems of interest to NASA and NOAA (e.g., severe storms, hurricanes, global weather, hydrology, weather modification assessment, agriculture, and water resources). Such a radar would also contribute to measurements of soil moisture, sea surface scatterometry, and a broad range of cryospheric parameters.

Despite the limitations of L-band radiometry from space, it is the only approach which promises to provide useful soil moisture measurements, as well as being important to cryospheric applications. Since both the L-band radiometer and meteorological radar require large aperture antennas, and since they provide mutually supporting measurements related to the hydrological cycle, it makes sense to fly them simultaneously.

A combined space-based meteorological radar and microwave (20 cm) soil moisture radiometer should be seriously considered for a research mission.

The 15 m diameter antenna proposed for the space radar would provide a radiometric footprint of 2 km at 5 cm wavelength and 8 km at 20 cm wavelength from an altitude of 600 km. This would meet agricultural, hydrological and climatological needs. Flying both the precipitation radar and soil moisture radiometer together would be an economical means of conducting definitive trials.

OCEANIC/CRYOSPHERIC/RADIATION BUDGET MONITORING EXPERIMENT

The importance of the oceans and air-sea interaction to the climate system is broadly acknowledged (see Guidelines for the Air-Sea Interaction Special JPL Report, December 1979). However, measurement problems are formidable and will require combinations of in-situ and satellite sensing along with well-designed field experiments. A major interim ocean monitoring experiment is considered to be a critical step to: (1) consolidate understanding of the role of the oceans in the climate system, (2) provide a means of parameterizing the interactive ocean-atmosphere processes in coupled GCM models, (3) extend and assess abilities to sense the critical oceanic parameters, and (4) set the stage for the 1990 Climate Observing System and World Climate Experiment. In connection with this, an expanded experiment involving oceanic/cryospheric and radiation budget monitoring as a joint effort centered around NOSS, ERBE, and other existing satellites is recommended in the mid-term time frame as a precursor to a World Climate Experiment.

The ocean monitoring experiment is already one of the major thrusts of the National Climate Program. It will be needed to test the system, validate measurment capabilities, elucidate component physical processes in conjunction with supportive ground truth experiments, and provide data sets for use in mid-term assessment of climate model prediction and sensitivity experiments.

FUTURE PLANS

As a follow-on to this first COSS workshop effort, we will proceed toward more specific studies and implementation plans as priorities are developed under these general categories:

a. Identify climatically useful data which are not now being extracted and propose mechanisms to obtain these data.

b. Study the array of candidate climate oriented improvements to the next generation of operational meteorological satellites and recommend the sequence of developmental events necessary to bring them to flight readiness. Prime near term candidates are the Advanced Microwave Sounding Unit (AMSU), Advanced Moisture and Temperature Sounder (AMTS), and Advanced Very High Resolution Radiometer (AVHRR-X).

c. Provide a conceptual design of the next generation of geosynchronous satellites which simultaneously meets the range of operational meteorological and climate research requirements.

d. Define the climatic applications of NOSS and the conceptual design of a "climate pipeline" which will assure the availability of data to the climate archives.

e. Collaborate with NOAA and NCAR scientists in the definition of the ocean climate monitoring system.

f. Complete definition of overall candidate integrated global climate observing systems and assess their relative feasibility and costs. Conduct preliminary overall system and tradeoff studies.

g. Prepare priority listing of candidate instruments for the long-term observing system and define a recommended development program. Prime candidates are Lidar Temperature and Pressure Sounder, Doppler

Lidar Wind System, and combined soil moisture radiometer and precipitation radar.

h. Define ground truth systems required for validation of space-based remote sensors and networks of in-situ sensors needed as calibration "tie-points".

3. SUMMARY OF WORKSHOP PRESENTATIONS

Material presented at the Workshop, as summarized in the following section, contain additional or complementary recommendations which will be important in developing follow-on studies and implementation objectives for the various elements of a climate observing system.

The opening talks were concerned with National Climate Program aims and policy (Dr. Epstein) and general climate observational needs (Professors Suomi and Vonder Haar). They were followed by a series of topical presentations, emphasizing the unique climate requirements placed on an observational system in the following areas: land surface and hydrology, ocean climate monitoring, earth radiation budget and cloudiness and cryospheric processes. Also included were discussions of important climate parameters that are difficult to measure. The remaining topical presentations covered current operational meteorological satellites, together with recommended improvements (Dr. Yates, Dr. Arking, and Dr. Miller). The final talk of the day, given by Dr. Atlas, summarized all the requirements and projected them into a global climate observing system for the 1990's.

The evening session was opened by Dr. Greenwood, who briefly outlined NASA's role and expected participation in the climate program, citing that two key decisions concerning the future climate program should be made soon about the implementation of the 1987 follow-on operational meteorological satellite program and the NOSS mission. These decisions will be important in the planning process for a climate observing system. Reactions to the day's proceedings with emphasis on modelling needs, were then reviewed by Dr. Leith, Dr. Hansen, and Professor Gates.

Summaries of the workshop talks and other distributed material follow. In the opening talk Dr. Epstein, of the National Climate Program Office, pointed out that the success of the Climate Program will depend strongly upon new ideas and new approaches to solving climatic problems. To this end, the Climate Research Board recommends making maximum use of climate information available now. The broad priorities of the National Climate Program's draft 5-year plan are: (1) to provide climate data; (2) to respond to impacts and policy implications of climate in such areas as world food production, and (3) to understand climate and its mechanisms (solar radiation, ocean heat transport, etc.).

The plan is expected to be completed and presented in the near future. However the more detailed priorities contained in it may be changed based on future workshop recommendations and results of feasibility studies. Undoubtedly, better sets of priorities will be generated and improved directions given as the National Climate Program evolves.

GENERAL CLIMATE OBSERVATIONAL NEEDS

Professor Suomi spoke next on the philosophy for the development of a climate observing system and key elements of that development. Briefly stating the dictionary definition of philosophy, Suomi concluded that development of a climate observing system requires both hard work and patience.

His discussion focused on aspects of the climate observation system useful for determining the extent of climate predictability and understanding the extent of man's influence on climate. The institutional problems in the development of weather and climate measurement systems and the need for their minimization were emphasized. The accomplishments of each system will guide identification and selection of future operational instruments and systems needed to develop a climate observing system.

The status of the FGGE system was carefully reviewed. Experience with the FGGE data set shows that the greatest deficiency occurred in the equatorial wind set. Even in the delayed data transmission mode, half the data over equatorial Africa did not arrive. In the real time mode a large fraction of data over South America was missing although recovery was much more satisfactory in the delayed mode (see GARP Newsletter). These deficiencies are all the more severe when one realizes that the tropics were only marginally observed during the intensive observing periods of SOP I and II. Fortunately, the recovery of cloud drift winds from e geostationary satellites makes up part of this deficiency but they lack the needed height resolution.

Prospects for the adequate coverage of the equatorial tropics in the early 80's by any method looks bleak indeed. GOES I has been moved away from its Indian Ocean position; unfortunately Meteosat is no longer operating, the tropical wind observing ships have returned to former programs, and the aircraft dropsonde has been concluded. It is economically impossible to continue this costly portion of FGGE. Thus a large data gap will continue through the first half of the 80's.

Dr. Suomi then discussed the removal of key deficiencies in the present World Weather Watch, building a case for a tropical orbiting satellite.

a. Cloud heights. Thanks to a suggestion by H. Yates a remarkably simple method of adding a stereo imaging capability to the US type of line scanner imagers seems quite feasible. The camera is re-positioned so its rotating scan mirror is vertical rather than horizontal.

Two plane mirrors are added to look forward and aft and an excellent set of stereo images can result. A spacecraft equipped with this modified scanner could provide superb cloud height information. Since the stereo imagers are not simultaneous an error due to cloud drift will result; however, this error is easily removed because one has additional information on the cloud drift from geostationary satellites. Three important benefits arise: (1) cloud winds will have more accurate heights; (2) cloud heights and their control of radiation can now be realistically investigated; (3) wind estimates in the data sparse regions can be provided.

In the zones not covered by geostationary satellites, the time difference between the stereo views for the low clouds is long enough and the parallax effect small enough to provide useful winds. In the tropics we have a good idea of low cloud heights anyway. At higher altitudes, the cloud lifetime is much longer so in addition to providing cloud heights (with some error due to motion estimate errors) one could get motion information in overlap portions of the images between orbits.

Further there are likely to be many samples when the satellites in polar orbit view the same area as the inclined orbit so a total data gap is quite unlikely.

b. Ocean surface topography. The equatorial and subtropical zones have both large rainfall and large evaporation rates while at the same time receiving strong radiation from the sun (see later paragraph). The heat transport by ocean currents out of the tropical regions is one of the most important parameters in climate modelling.

An inclined orbit precesses more rapidly than a sun-synchronous one and precession is very important for the earth radiation experiments mentioned later.

A detailed description of the benefits of ocean surface topography which also require an inclined orbit is given elsewhere in this document. We wish to point out here, most strongly, the additional benefit of an inclined orbit for this program also. Obviously, compromises as to the degree of inclination will have to be studied, but it is clear that an important class of ocean surface topography problems, such as the equatorial undercurrents and the weaker circulation, exists in the equatorial region itself. In order to achieve the orbit precision needed, a non sun synchronous orbit is required.

c. Water vapor stereo. The remarkable images in the 6.7μm band of water vapor obtained with Meteosat provide a wealth of information on the flow patterns where there are no cloud tracks. L. Johnson has shown that winds can be derived from these images. Unfortunately the heights of the winds calculated from water vapor tracks have a large uncertainty due to the broad weighting function of this channel. Stereo images of the water vapor images would improve the height resolution significantly and the addition of other H_2O channels would help even more.

d. Sea surface temperature. A near equatorial orbit will provide considerable overlap in all images including the IR. Up to now the main technique of SST retrieval has been to estimate the water vapor correction and to use a simple adjacent cloud field scheme to provide clear column radiances. When views from different angles of the same area of the sea are available, as they would be in the aforementioned overlap areas, it is possible to remove the water vapor contamination by extrapolating the differing air masses in the several observations to a zero air mass. Thus the vapor contamination can be removed.

Further, the ocean current system in the equatorial regions is very interesting and there is mounting evidence that warm areas control the convection location.

e. Earth radiation budget. Earth radiation budget work so far clearly shows that at mid and high latitudes the main variations occur with changes in latitude. On the other hand, in the equatorial tropics the main variations occur with longitude, thus a low inclination orbiting spacecraft would be an ideal platform for earth radiation budget observations as well.

f. Soil moisture stress. If the orbit inclination is large enough the tropical spacecraft can sample the boundary zones of the largest deserts on earth. The inclusion of an imaging channel in the so-called chlorophyll band of the solar IR could be used to determine whether this method is viable for the observation of this important parameter.

g. Radiative and thermodynamic properties of clouds. Curran has shown, in a SkyLab experiment, that one can obtain estimates of phase and liquid water content of clouds using 0.74μm to 1.61μm energy ratio of the solar reflection from clouds. Inasmuch as this spacecraft will also provide cloud coverage, cloud heights, water vapor, and excellent radiation budget observations, the addition of these channels to aid in the estimate of the thermodynamic properties of clouds should provide a rather complete set of observations for investigations into the control of both shortwave and longwave radiation by clouds, both extended field stratiform clouds as well as those of deep convection.

h. Stratosphere trace gases and winds from solar occultation. If the orbit is inclined to 23 1/2^0 one could get year-round occultation measurements of trace gases on Doppler shifts of the Fraunhofer lines for winds in the stratosphere.

i. Temperature and moisture profiles. Despite the limited performance of both IR imagers and vertical sounders - as mentioned elsewhere in this document - they should be included on the tropical orbiter also. There is mounting evidence that heat is added through deep convection to the top of the tropical troposphere.

These actual cloud cluster zones often form the roots of intense subtropical jets which extend to high latitudes. These effects must be better understood in any viable climate modelling activity.

A very limited capability equatorial low altitude satellite was proposed as part of the original Global Observing System but never implemented. Perhaps this was fortunate because of its very limited objectives. Now it seems a very strong case can be made for a Tropical Workhorse, low inclination, low altitude orbiter. It does not replace the geostationary satellites, but augments and complements them. It can even provide valuable information in existing gaps in the geostationary coverage.

There are not any known national plans to provide such a capability. Suomi recommends that the JSC explore this needed addition to the World Weather Watch of the 80's.

The last talk concerning general climate observational needs was given by Professor Vonder Haar from Colorado State University. Several satellites now or presently in orbit can be exploited for climate studies. Some of these are the Nimbus 7, the Solar Maximum Mission, and the ERBE, as well as the GOES and TIROS operational satellites. Each of these satellites carries one or more experiments dedicated or applicable to climate studies. Vonder Haar described how these satellites may be used with reference to four key climate parameters the solar constant, the radiation budget, clouds and precipitation.

Both the Nimbus 7 and Solar Maximum Mission satellites are currently monitoring the solar constant. The solar constant, being a measure of the energy output of the sun, is an important climate parameter which has now been measured for one year by the Nimbus 7 ERB experiment (see figure 3-1). The accuracy of both experiments, being within 0.5%, is sufficient to monitor solar constant changes which will affect climate. ERBE's continuation of these observations puts the status of this COSS objective in good shape. However, continued support in the way of rockets and radiation standards is necessary to reconcile satellite differences.

The radiation budget is another climate parameter which is being measured by current satellites (Nimbus 7, GOES, TIROS). Radiation budget and climate data from these sources are shown in figures 3-2 through 3-6. Regions with large dispersions in radiation budget measurements are regions where significant climate events can occur. In other words, events in the atmosphere-ocean system which cause significant changes in the radiation budget are most likely to recur where they have been seen before. Climate modeling and prediction schemes must simulate these regions of high variability better than the regions of low variability.

In figures 3-4 and 3-5 the variance of each set of monthly observations about the monthly mean was calculated and then the 12 month average dispersion was determined (Eq. 1).

$$\text{Dispersion} = \sqrt{\sum_{m=12} \left[\sum_{obs} (X_n^m - \overline{X}^m)^2 / N^m \right] /12} \qquad (1)$$

X_L^m = n^{th} observation of the m^{th} month

$\overline{X}^m$ = mean of month m

N^m = number of observations in month

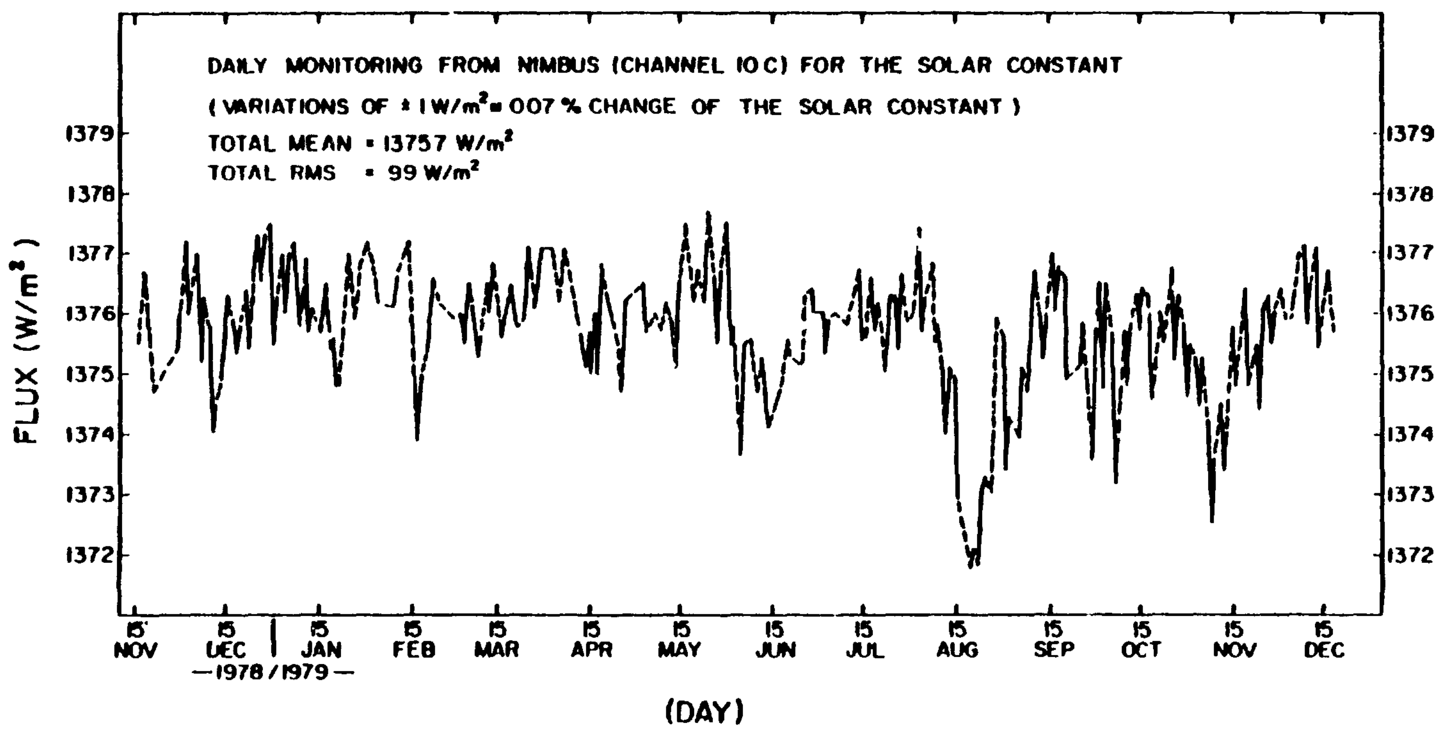


Figure 3-1. Solar Constant as Measured by Nimbus 7 ERB Experiment

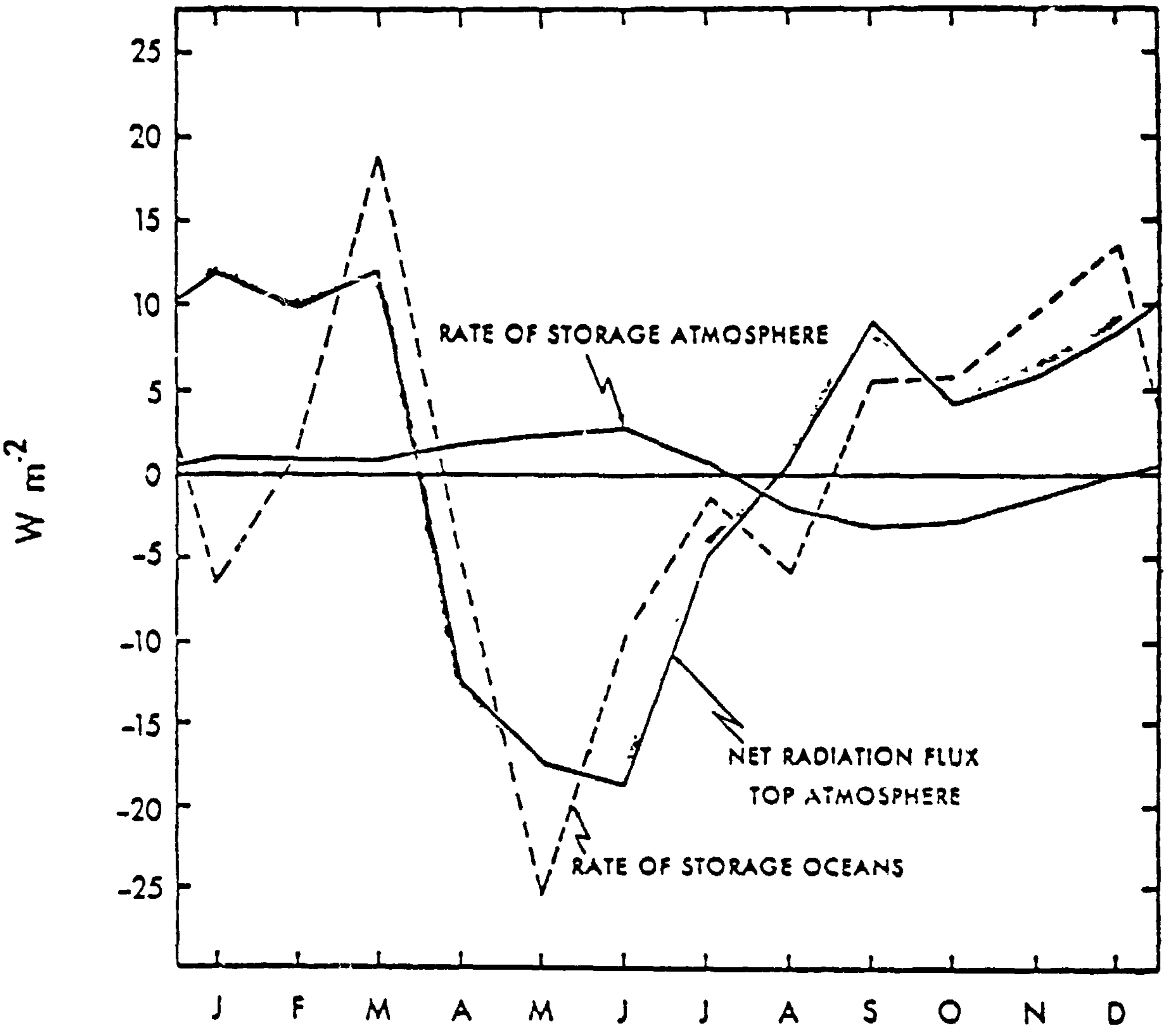


Figure 3-2. Global Heat Balance

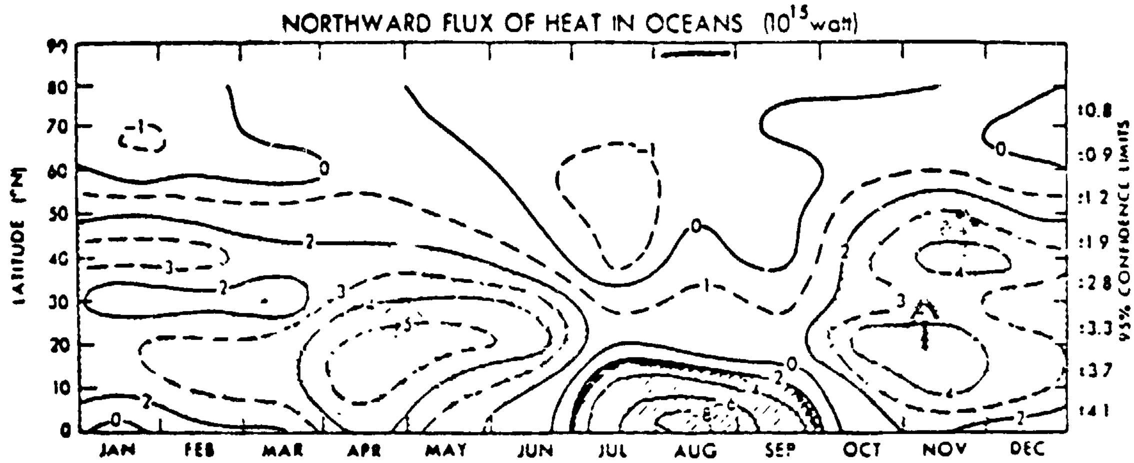


Figure 3-3. Northward Transport of Heat Due to Oceanic Motions (T_0) Computed as a Residual Term in the Earths Heat Balance. Units are in 10^{15} watt.

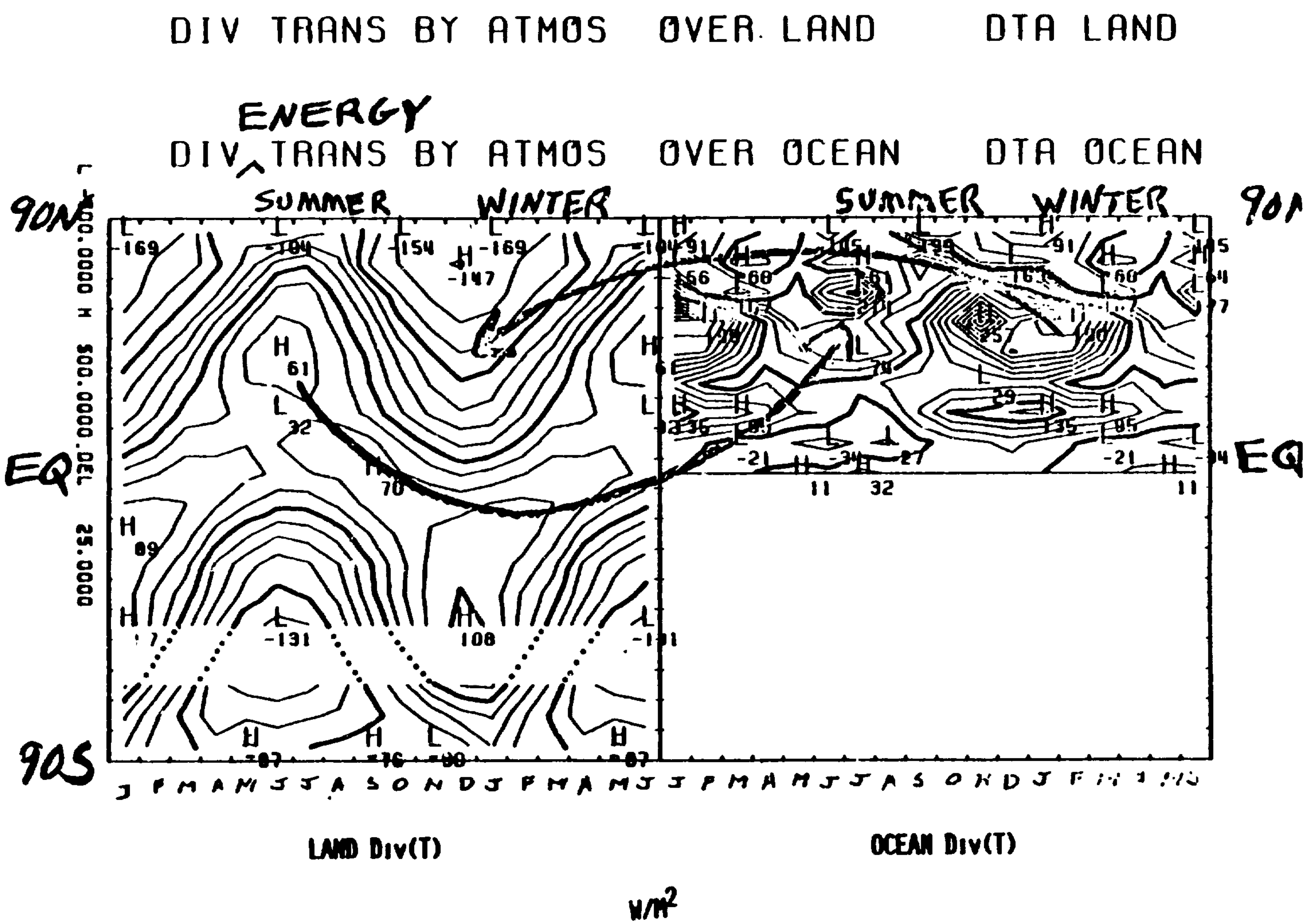


Figure 3-4 W/M^2 Energy Transport by Atmosphere Over Ocean

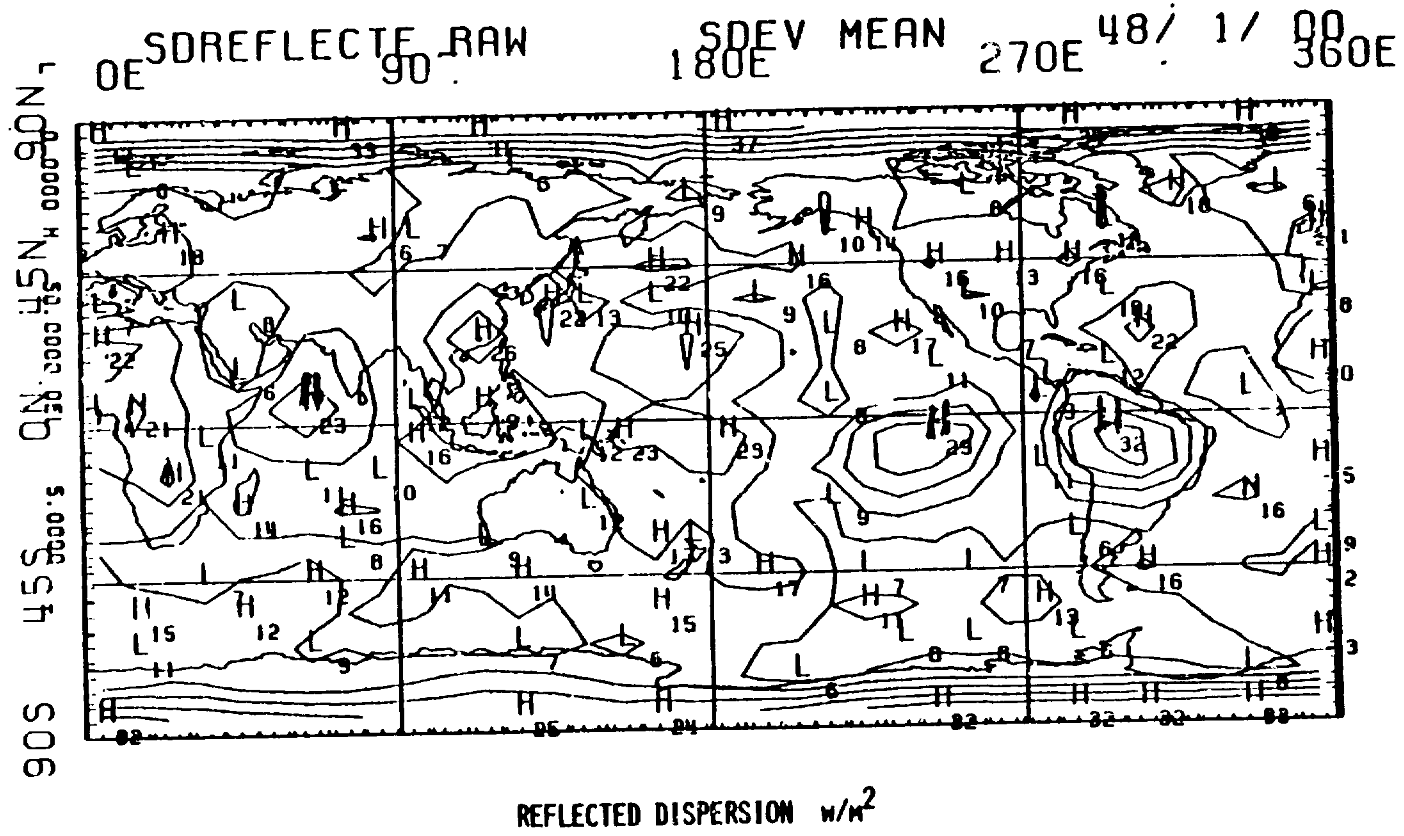


Figure 3-5. Reflected Energy Dispersion (48 Month Data Set with Annual Cycle Removed)

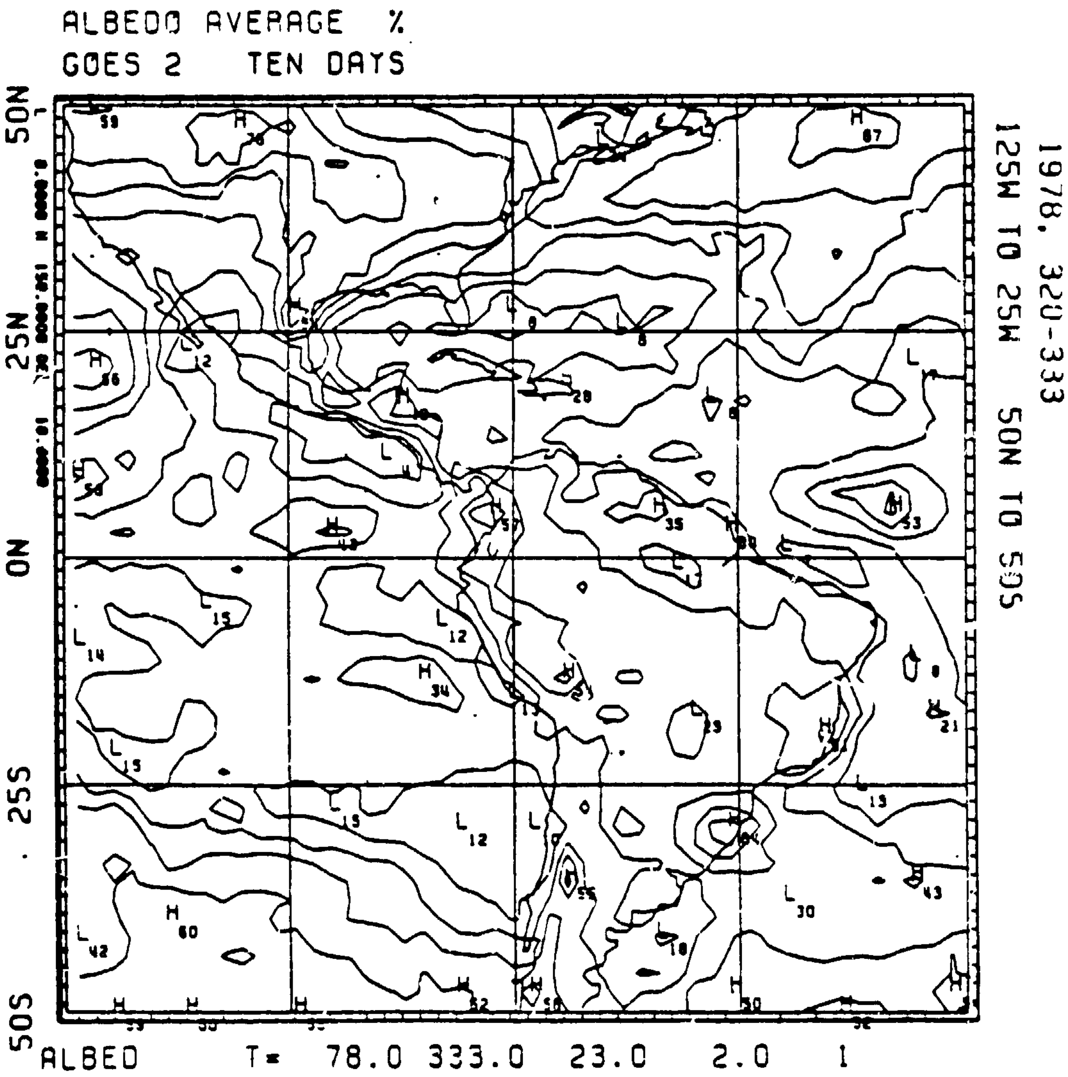


Figure 3-6. Earth Albedo, Averaged Over 10 Days in November 1978, from Geostationary Satellite

The normalized maps were used to remove inter-satellite differences. Strictly speaking this dispersion is the standard deviation of any particular month from the monthly mean. The small sample size, about 4 observations for any month, makes this rather imprecise. The dispersion of reflected exitance rather than albedo is presented because it provides the proper energy weighting.

One can see in the maps that large dispersions occur at the edges of large amplitude features in the mean maps. East and west of the monsoon there are regions of high variability in both the reflected and emitted radiation. This is probably produced by different sized monsoons. The central region is persistent in all samples but the fringes change from year to year. The largest variations occur in reflected and emitted radiation over South America and west of South America, but there are only weak maxima in the net radiation dispersion. These year to year differences show the negative correlation between emitted and reflected components, reciprocity, and damping out of the variation of the net radiation. The biggest dispersion of the net radiation occurs over the large continental deserts, the Sahara, S. Africa and Australia. There the reciprocity does not reduce the net variance. The large dispersion in both the reflected and emitted radiation complement each other amplifying the net year to year changes. The large dispersion in the North and Central Pacific appear primarily because of changes in the reflected component.

This dispersion can also be calculated for the variation of the zonal means. Figure 3-4 shows the time variation of the net radiation. One sees that the spring shows the largest variation.

These dispersions can also be interpreted as a measure of the uncertainty of the monthly mean. The standard error of the mean is about one half (four measurements of each month) of the dispersions. The real uncertainty is larger than this though, because of systematic errors.

Cloud climatology is a new project but useful cloud data exist, not only from current satellites, but from others no longer operating. Data are also being gathered around the world in a global cooperative project. A cloud climatology project must answer the questions: How many clouds are on our planet? What is their height distribution? And what is their variability? The available cloud data need to be coordinated and an algorithm designed to extract the necessary climate products.

We are trying to measure precipitation, but although some progress has been made, many problems remain. Questions still to be answered are precipitation frequency, intensity and amount. This climate information is extremely important to the wheat and corn belt, i.e. to world food production.

The use of satellite data, while necessary to maintain consistent global observations, requires in-situ measurements, best gathered by data collection and location platforms. These platforms, now in use and making data available, need to be incorporated more thoroughly into a COS. A wider distribution of DCLP's better coordinated with both geosynchronous and low earth orbiting satellites will provide the composite system necessary for worldwide, consistent climate data.

The conclusions of the three speakers on general climate observational needs are as follows. A composite system of at least three types of observation platforms (GEOS, LEOS, and DCLPS) is necessary to support global meteorological and hydrological observations. Extensive data on several climate parameters already exist but need to be focused. Unifying data processing and archiving procedures will help to accomplish this. Finally, although many experiments and operational instruments now exist that are providing useful climate data, more research instruments should be planned for future operational satellites.

TOPICAL PRESENTATIONS

Following the general speakers, several persons were invited to discuss specific topics in their areas of expertise. The topical presentations began with Dr. Salomonson of GSFC, on "Land, Hydrology, and Vegetation." Dr. Schmugge, also of GSFC, spoke later on "Soil Moisture." Because these two subjects are related, the two presentations together were summarized by Dr. Atlas.

Land Surface and Hydrological Processes

Land surface properties and hydrology clearly have visibly demonstrable effects on local weather and climate (e.g. lake and sea breezes, urban heat islands, valley winds, etc.). Recent satellite observations and mesoscale models have also demonstrated the importance of differential heating and soil moisture on the establishment of mesoscale circulations and moisture convergence and the initiation and evolution of clouds and convective storms. Indeed in subtropical regions where large scale forcing is weak, the daily weather repeats itself day after day and thus comprises "climate". Under many circumstances these effects can be demonstrated to occur over regional scales as large as 1000 km.

But the effects of land surface properties have equally important if less dramatic effects on larger scale weather and climate. Over the land, the atmosphere derives most of its heat and moisture from convective and radiative transports from the surface. Moreover, the vertical exchange of horizontal momentum depends critically upon the thermal stability and wind shear in the boundary layer, as is clearly evidenced by the intensification of winds and turbulence in the late morning hours and their decay in the evening. It is for these reasons that global circulation modellers have for some years given increasingly serious attention to realistic simulations of the evolution of the boundary layer and its parameterization in GCM models. It is also argued that because stored soil moisture, either from run-off or prior precipitation, has a long-time constant, it acts as a "memory" which can influence climate for weeks to months, almost certainly on regional and larger scales. This is due to the combined effect of the moisture on the thermal inertia of the surface, and thus on its ability to radiate and convect heat and to supply moisture to the atmosphere.

Indeed, numerical GCM experiments performed by Charney and others have demonstrated the dramatic effects that increases in surface albedo and decreases in soil moisture and evaporation have on decreasing regional precipitation. This led to the hypothesis of a bio-geophysical climate cycle in which overgrazing by cattle in semi-arid lands reduces vegetation and decreases soil moisture, thereby increasing albedo and reducing precipitation. This is a plausible mechanism to explain the extended drought in the Sahel between 1967 and 1972 and is supported by satellite observations of changing albedo both there and elsewhere; for example, across the political boundary between the Negev and Sinai deserts. Clearly, these combined processes constitute a rational hypothesis for desertification, a problem which is taking on increasing importance throughout the world.

Whether or not we can understand the interactions between the underlying land surface and the climate, it is of course clear that the vigor and extent of vegetation and crop production represents an important, sensitive integral index of regional climate which is also of great social and economic importance. It is in this regard among others that vegetation comprises a critical climate observational parameter. On the long climate time scales, an inventory of regional and global biomass is vital to the assessment of the CO_2 budget and to predictions of long term climatic change.

The importance of the hydrologic cycle in climate modeling derives from its control of the disposition of the sunlight (or solar radiation R_S) reaching the earth's surface and its partitioning into the heat flux in the soil H, evaporation LE, sensible heating of the atmosphere S, and thermal radiation terms from the surface R_{LW}.

$$R_S = S + H + LE + R_{LW}. \tag{2}$$

As shown elsewhere in this document and in recent literature, the feasibility of estimating the solar energy reaching the earth surface from space platform observations is quite promising; this is most fortunate since this is easily the largest term in the local surface heat budget.

If one integrates the heat flow into and out of the soil over an extended period the result is near zero, except for seasonal effects. It is true that the thermal conductivity, thermal diffusivity and heat capacity of a typical soil are strongly affected by its water content. Even so the net flow of heat into the soil over an extended period is again, except for seasonal effects, small so H is neglected.

While R_S and R_{LW} can be estimated quite well from space observations and the soil heat term can be set to near-zero for extended periods (day or days), the sensible heat(s) and latent heat terms remain. In micro-meteorological studies the Bowen ratio $B = \frac{LE}{S}$ is usually obtained by careful measurement of the vertical mixing ratio and temperature gradients in the constant flux layer. There is no way to obtain the Bowen ratio from space directly.

Worse yet, the Bowen ratio is temperature sensitive because the rate of increase of the vapor pressure with temperature increases sharply with temperature. The soil moisture not only represents the source of water substance, but its heat capacity, conductivity, and thermal diffusivity strongly affect the diurnal temperature range, which in turn steadily affects the Bowen ratio in a complex non-linear way depending on the surface wind.

Remote Sensing of Hydrological Parameters. In addition to surface albedo, the parameters which need to be observed and/or deduced are land cover (including surface water, snow and ice) vegetation, bare soil, rock classes, and their thermal inertia. Except for thermal inertia, determination of all these from space is clearly possible as has been shown by Landsat. Landsat has also made it possible to distinguish among several classes of vegetation (e.g. grassland, cropland, forest, and irrigated and non-irrigated fields).

While Landsat has a surface resolution of approximately 80m, recent experiments at NASA GSFC have shown that much, if not most, of the useful information is retained when the Landsat images are degraded to the 1 km resolution of TIROS-N, although 500m resolution would be preferable (See Figure 3-7 and 3-8). The loss in resolution is more than compensated by the more manageable data rate and appears to be quite adequate for climate studies. Unfortunately, the AVHRR data on TIROS-N, which is most appropriate for these measurements, is recorded on-board at a reduced resolution of 4 km due to limitations of the on-board processor and communications module. In the near term, the use of microprocessors on-board to process statistics of the high resolution data and to ratio various channels, would appear to provide a means of overcoming this restriction. In the longer term, increased communications bandwidth would be highly desirable.

The present AVHRR-2 has channels at 0.62, 0.90, 3.74, 10.8, and 12.0 μm. Ground based studies show the following additional information would be available from other channels:

(1) Plant water stress: from the reflectivity in the 1.55 - 1.75 μm band. (Note: the ratio of the radiance in this channel to that at 0.74 μm would also provide a capability to distinguish ice from water clouds). It is also worth noting that plant water

ORIGINAL PAGE
COLOR PHOTOGRAPH

Figure 3-7. A Color Composite Image (0.5-0.6, 0.6-0.7 , 0.8-1.1 μm) for 14 June 1978 over the Denver, CO Area

ORIGINAL PAGE
COLOR PHOTOGRAPH

Figure 3-8. Landsat Data Degraded to 1.1 km Resolution to Simulate TIROS-N AVHRR Spatial Resolution. The bands combined to form the color composite are the 0.5-0.6, 0.6-0.7, 0.8-1.1 µm data.

stress may turn out to be an excellent proxy for root zone soil moisture, which is not measurable by other means.

(2) Greenleaf area index: Ground studies show that the fractional area covered by green leaves in the field of view is directly proportional to the ratio of radiances in the 1.1 to 0.8 μm bands.

It should be noted that the observation of land surface properties and vegetation need not be made as frequently as the atmospheric measurements; except for plant water stress, these observations can be made at 5 to 7 day intervals. Of course, we must also determine how to average and/or summarize these data and use them parametrically on model grid scales of the order of 100 x 100 km.

Soil Moisture. There are a variety of candidate methods to measure and/or infer near surface soil moisture from space. These include (1) the use of the diurnal amplitude of the 11 μm IR radiance (once the thermal inertia of the dry soil is known); (2) radar back-scatter cross-section related to soil moisture; and (3) the microwave brightness at 20 cm wavelengths, which increases monotonically with decreasing soil moisture in the upper 2 to 5 cm of soil due to the decreasing dielectric constant of the water-soil mixture.

All these methods suffer from a variety of limitations. Method 1 (IR diurnal swing) is affected by the radiation (clouds, atmospheric or water vapor), and sensible and latent heat exchanges with the atmosphere, which in turn vary with atmospheric stability and atmospheric moisture and effective ventilation by the wind. Method 2 (radar) varies with surface roughness, orientation, and vegetation. Method 3 (20 cm radiometry) also varies with surface roughness and orientation, and with vegetation, but is less sensitive to these factors than the radar. Nevertheless, all factors considered, the latter approach appears to provide the greatest promise for estimating soil moisture in the upper few centimeters. At this stage, it is not expected to provide more than 3 or 4 classes of soil moisture. However, this is believed to be useful for climate monitoring and modeling.

Regardless of the remote sensing approach, all such measurements should be accompanied by the use of in-situ sensors to provide calibration "tie points" at a network of ground stations, and allow the space borne sensor to interpolate between them. Also, measurements of soil moisture should be used in conjunction with physical models to account for the vertical and horizontal transports.

Thermal Inertia and Soil Moisture. These two parameters are discussed together because soil moisture has a very strong effect on thermal inertia. The NASA Heat Capacity Mapping Mission (HCMM) was aimed at the mapping of geological features through their thermal inertia as measured by the diurnal swing of the IR temperature from successive passes at 1300 and 0200 local time. Some promising results are being obtained, but the measurements are complicated by transports of sensible and latent heat from ground to air and variable radiative and wind conditions between successive measurements spaced 13 hours apart. There have been several recent European papers which have described methods for extracting soil moisture and evapotranspiration using surface temperature data and a model for the soil water and heat fluxes. These approaches provide a basis for parameterizing the acquisition of evapotranspiration from surface temperature data.

For purposes of both mesoscale boundary layer forcing and climate, however, one does not require the 500 meter resolution of HCMM. Rather it seems entirely feasible to use the method of Vieillefosse and Favard ("CITHARE" Thermal Inertia and Humidity Cartography over Africa by Geostationary Satellite, XXIX Congress of the International Aeronautical Federation, October 1978). There they use the entire sequence of 24 1/2 hour interval observations of visible and IR radiances during the day. The visible data is used as a measure of the incoming solar radiation and surface heating, including effects of sloped surfaces, clouds, etc. The thermal inertia is then deduced either from the time lag between maximum heating and the peak outgoing IR radiation or the time derivative of the IR temperature after sunrise. Once the thermal inertia is known for the particular location (or measured through the seasonal cycle for vegetated areas), the changes in thermal inertia are related to soil moisture. The method holds considerable promise and is readily implemented with existing geosynchronous satellites. Indeed, this is the only technique which can now be applied with existing geosynchronous satellites and deserves high priority.

In the mid-term, further experimental aircraft trials of the 20 cm microwave radiometer and 5 to 6 cm radar warrant attention. The combined use of the radar and radiometer offers the possibility of improved measurements because the radar can account in part for surface roughness. Of course, the simultaneous use of visible and IR is useful for intercomparison, and for later use in space, for space-time interpolation between the orbiting microwave measurements. It goes without saying that one or more ground truth measurement systems should be used both for calibration of the space systems and maintenance of long term stability of the measurements.

In the long term, the use of 20 cm radiometry from an orbiting satellite will require an antenna of 10 to 15 m diameter thus yielding footprint diameters of order 10 to 15 km which would be useful for agricultural, hydrological, and climatological purposes. This would appear to be justifiable by the range of potential applications just mentioned, and more readily implemented if, for example, it were decided to use a large aperture antenna at shorter microwaves for active radar measurements of precipitation and/or other purposes such as sea surface wave conditions and wind stress.

Finally, it should be noted that soil moisture measurements by the 20 cm (or longer) wavelengths may be used as a proxy for antecedent precipitation overland, as has been shown by Schmugge with measurements from Skylab. Lacking a precipitation measurement radar, and recognizing that shorter wavelength radiometers suffer from highly variable background surface emissivity and temperature; 20 cm wavelength measurements may be the only other realistic means of estimating precipitation over land. In this regard, the concern about IR temperature measurement is that it is responsive to the moisture in the uppermost few millimeters and may be seriously affected by dew. However, the use of the thermal inertia method, involving time integrated measurements over an hour or more, overcomes this limitation. (The measurement of precipitation from space is discussed in another section.)

Evapotranspiration. Evapotranspiration is a difficult quantity to measure directly and cannot presently be measured at all from a remote platform. However, there are several possible ways to infer it from other measurements. The thermal inertia-soil moisture approach described above would appear to provide a possible solution since the time derivative and daily swing of IR temperature is affected by evaporation and, as mentioned earlier, has been used to obtain evapotranspiration when combined with a model. However, it would appear necessary to have an independent measure of soil moisture, as is possible with 20 cm radiometry, in order to separate out the evaporation term.

Over vegetated areas, measurements of plant water stress (described above) would provide additional information. Finally, it may be estimated as a residual from the surface hydrological budget.

As noted above, the microwave techniques sense soil moisture only in the upper centimeters; thus the all important root zone is missed. However, this upper layer is the most dynamic and difficult to model and the microwave observations will provide this important boundary condition in the models.

Brent showed, long ago, that the minimum surface temperature (more accurately, the soil cooling ratio due to long wave radiation loss from the surface) was a function of soil properties, including soil moisture. This technique has been shown by Diak and others to give excellent estimates of soil moisture in fallow soil, under clear, near calm, conditions. The night time cooling rate (and the relative heat loss) can both be observed from a geostationary satellite.

The situation over vegetated land is much more complicated. The canopy tends to thermally decouple the radiating surface from the soil heat sink (or source) while at the same time vastly increasing its coupling for moisture. Indeed, in vegetation the surface acts almost like a shallow sea. But stressed vegetation is, and canopy temperature can be, valuable parameters.

When plants are exposed to a heavy heat load, whether by ventilation or radiation, their stomata tend to close and through biological control, affect the Bowen ratio. Despite these complications, a heat budget approach for fallow land or heavily vegetated land will probably yield to an empirical approach if sufficiently limited as to soil type, slopes, etc. A much more complicated problem arises over marginal lands where one has fallow land and vegetation, usually under stress. In these areas long wavelength microwave systems which can penetrate the small amounts of vegetation present can yield important surface soil moisture data. There is now some evidence that the degree of stress can be estimated using observations from the so-called chlorophyll band of the near infrared spectrum. Additional tests of this nature should be encouraged as this approach appears to be the most promising area for obtaining estimates of stress, evaporation and sensible heat at the surface.

Hopefully, the look from space with its horizontal averaging, may help simplify the problem.

The hydrological working group recommends that this and other efforts along these lines be encouraged. At this time some measurement of soil moisture under lush or sparse vegetation does seem possible. A composite approach to this complex observation is necessary. Table 3-1 lists some of the composite observations that will be required in this empirical approach and how they may be obtained from spacecraft.

Table 3-1. Required Observations and Possible Measurement Systems

Parameter	Possible Measurement System
Albedo	Broad-band visible and near IR channels, e.g. HCMM.
Land Cover and Biomass Estimates	Landsat. TIROS-N visible and near IR channels.
Incident Solar Radiation	Repetitive cloud images from geosynchronous satellites.
Surface Temperature	Thermal IR from low earth orbit or geosynchronous satellites.
Thermal Inertia	From diurnal or sequential surface temperature observations.
Surface Soil Moisture	Active or passive microwave systems of the future.

These remote sensor observations should be augmented at calibration points with in-situ measurements of important parameters, for example, air temperature, wind speed, and vapor pressure. In between the tie points estimates of the surface air temperature and wind fields may be obtained interactively with the GCM's.

Oceans

Topical presentations on the subject of oceans were made by Dr. Bretherton of NCAR, and Dr. Mueller of GSFC, beginning with Dr. Bretherton, on an ocean climate monitoring system.

To a greater extent than is commonly realized, the climates of the oceans determine the climates of the Earth. Solar energy is absorbed and stored in regions during periods of the year, and later released, sometimes after transportation to other areas. This process causes changes in regional weather and climate. Therefore a system to measure and keep watch on climatically important aspects of the ocean is an important part of a climate observing system.

Objectives for a system to monitor the ocean climate are tentatively separated into short, intermediate and long range goals of, first, beginning a time series of selected near-surface indices such as sea level; followed by observing the heat budget of the upper layers on a regional basis; then beginning a time series of selected deep indices, and finally, planning to continue observations over many years.

The strategy to meet these objectives is to begin regional research programs concentrating on selected ocean areas which appear to be having the greatest effects on the Earth climate. While exploiting existing observation systems, new measurement systems should be developed, especially to monitor deep indices. Dr. Bretherton went on to discuss the measurement status of several climatically important ocean parameters, as listed in table 3-2.

Following Dr. Bretherton, a review was given of the status of the National Oceanic Spacecraft System (NOSS) by Dr. Mueller, the NOSS Project Scientist. NOSS is a joint program of NASA, NOAA, and DOD and is administered by a tri-agency committee. It has a scheduled 5-year mission based upon the use of two spacecraft. Each spacecraft will be 3-axis stabilized and

Table 3-2. Measurement Status of Climatically Important Ocean Parameters

	Existing Methodology	Status	Potential Developments	Needed Actions
HEAT STORAGE	XBT's from ships of opportunity	well developed; sampling problems in intense mesoscale eddies; need salinity in some regions; yields T(z)	correlate with SST: acoustic tomography	optimize retrieval of SST for climate indices; improve accuracy of SST measurements
NET RADIATION	parameterization From cloudiness, surface data	maybe OK; shows little interannual variability		rework parameterization in terms of satellite-derived measures of cloudiness; identify suitable baseline stations
FLUX OF SENSIBLE AND LATENT HEAT	parameterization from merchant ship meteorological observtions	sensible heat OK; latent heat flux larger with major interannual variability; parameterization formulae uncertain; humidity data suspect	index based on space observations of e.g. low level cloud structure; net atmospheric humidity budget; new humidity sensor for marine environment	explore potential developments
CUMULATIVE RAINFALL	a few atoll & weather ship rain gauges; microwave estimates of rainfall rate	Space observations give at best an index of required quantity		identify baseline stations for correlation anilyses
HORIZONTAL ADVECTION	not well developed		$\underline{H} = \rho C_P\left\{\underline{E}\,T_s + \int \underline{u}_G \cdot T(z)\,dz\right\}$ $\underline{H}$ can be calculated with reliable determination of: $\underline{E}$, Ekman flux derived from windstress T_s, sea surface temperature $\underline{U}_g$, geostrophic current derived from $\underline{U}$ at a reference level and T(z)	analysis of sampling & accuracy requirements, particularly on $\underline{U}$(Z.)

Table 3-2. Measurement Status of Climatically Important Ocean Parameters (cont.)

	Existing Methodology	Status	Potential Developments	Needed Actions
ENTRAINMENT FROM BELOW	not well developed		$H_e = \omega T$ estimate vertical velocity from wind stress T at bottom of seasonal thermocline, extend $\underline{U}g$ down to z_b.	
WIND STRESS	parameterization from merchant ship observations	parameterization OK except at high wind	scatterometer cloud drift winds	space-based instrumentation and data flow look good; need to secure uncontaminated Level 3 analyses and baseline surface observations for calibration
SEA LEVEL	Island stations	too few for inferences of currents except in special cases.	altimeter to be used For: basin scale general circulation (problems with geoid, tracking) basin scale time dependent currents in equational regions (problems with tracking and accuracy) statistics of mesoscale eddies	develop plans for NOSS tracking; TOPEX

Table 3-2. Measurement Status of Climatically Important Ocean Parameters (cont.)

	Existing Methodology	Status	Potential Developments	Needed Actions
DIRECT VELOCITY MEASUREMENTS	current meters SOFAR floats	unreliable near surface need tracking stations, near surface; give good velocity measurements	(expendable) pop-up drifters SST & color as tracers	explore potential for inexpensive position determination; develop techniques for automated pattern recognition of SST, color features, and derive time series of wave & eddy statistics; examine space-time structure of atmospheric precipitable water
	surface drifters	need calibration and interpretation; need to minimize wind drift and develop longlife sensors		

in sun-synchronous orbit, using the Global Positioning System for location. They will be launched by the Space Shuttle and use the Tracking and Data Relay Satellite System (TDRSS) for data transmission.

The objective of NOSS is to provide limited operational capability to obtain measurements of global sea surface parameters based on remote sensing from space. The system will be operational, generating products from four instruments within 80 minutes of acquisition, and will include a 25% research capability. The present NOSS sensors include a scatterometer, a radar altimeter, a Coastal Zone Color Scanner (CZCS), and a Large Antenna Multifrequency Microwave Radiometer (LAMMR). The only planned major development effort would be the LAMMR 4-meter antenna. Some modifications to this list are proposed by NASA to support the ICEX program. Data from these instruments are distributed to users as level II products; data from any research instruments are passed through as level 0 products. The two NOSS operational users, the U.S. Navy and NOAA, operate user processing centers. Other users must obtain data from one of these centers. This situation emphasizes the necessity of a research processing and analysis facility.

The NOSS configuration has not yet been determined in detail since the system is being procured by the A-109 procedure. An A-109 procurement specifies only functional requirements, giving bidders freedom to design the best system for accomplishing the desired functions. The schedule for NOSS has a 1986 launch target. A key point noted was that the algorithm scope will be frozen in October 1980. Further information regarding the NOSS program structure, data flow, instrument complement and schedule may be found in NOSS Project literature.

Cryospheric Climate Monitoring

Dr. Zwally of GSFC reported on cryospheric climate monitoring, specifically the Ice and Climate Experiment (ICEX). ICEX is a program of coordinated investigations of the ice and snow masses of the Earth. Principal scientific questions involve the roles of sea ice, ice sheets, and snow in climate processes. The sea ice extent is a sensitive indicator of regional and global climate, whereas the open water within the sea ice pack is the principal factor in cryospheric surface energy balance. These are observable from space, but greater ice concentration accuracy will be needed from the NOSS LAMMR. The stability of the major ice sheets and their dynamic mass balance is important both to climate consideration and to assess and detect the effects of potential CO_2 warming.

As a research project, the near-term goal of ICEX is to develop ice climate data sets using the Nimbus-5,6, and 7, Seasat, GOES-3, and Landsat. The data from these satellites should be processed, analyzed and made available to the scientific community. An important mid-range goal is the augmentation of NOSS for ICEX. In particular, a laser altimeter/ranger, an adaptive radar altimeter, and a LAMMR with a 91 GHz channel should be placed on NOSS. A longer range goal would lead to the capability of remotely sensing open water within ice packs with an imaging radar system with 25m resolution.

Earth Radiation Budget

Dr. Rao of NOAA reported on the current radiation budget data in NOAA archives. Earth atmosphere radiation budget parameters have been derived from the operational and experimental satellites for the last several years. The data were derived from various kinds of sensors and time periods and no long time continuity was maintained before 1974. With the launching of the NOAA series of polar orbiting operational satellites in 1974, radiation budget data have been derived routinely and archived. Rao then discussed the quality and limitations of these data.

The dynamics of the Earth-atmosphere system is determined by the energy input to the system and the distribution, transformation and storage in various forms. The radiation budget measurements made at the top of the atmosphere reflect the above processes. The upward flow of energy and the reflectance from the Earth-atmosphere system have large geographic and temporal variations and the same is true with the net radiation. In fact, the net radiation is the driving force for the atmospheric and oceanic circulation.

From June 1974, the operational NOAA and TIROS-N series of satellites have been providing observations to derive the radiation budget parameters. Gruber (1977) and Winston et. al. (1979) have given a full description about the derivation and discussion of these quantities. In short, the albedo is determined from the visible channel of the scanning radiometer in a narrow spectral interval (0.5 - 0.7 μm) by assuming that it is a good estimate of the full spectral reflectance (0.2 -4.0 μm) and that the reflectance is isotropic and independent of solar and satellite zenith angles and that there is no diurnal variation of the reflecting surface.

The outgoing longwave flux was computed from the radiance measurements in the narrow spectral window region (10 -12 μm) by using regression models. The model considers different model atmospheres (about 100) covering a broad range of temperature, moisture, and cloud conditions. The daily mean outgoing radiation is estimated by averaging the day and night observations.

The radiation budget parameters that are being currently archived by the Environmental Data and Information Service (EDIS) of NOAA are shown in table 3-3. They are available in hard copy form (maps, computer printouts, etc.) and on magnetic tapes. As pointed out earlier, the data were derived from various operational satellites and have certain limitations. The outgoing longwave radiation values in February 1978, were derived from a satellite which had equatorial crossing times of 0930 and 2130 local time; in February 1979, they had an equator crossing time of 0330 and 1530 local time; in February 1980, they had an equator crossing time of 0730 and 1930 local time. Thus, the three maps correspond to three different local times.

Table 3-3. Routinely Produced Radiation Budget Products

	DAILY[1]	MONTHLY[2]	SEASONAL[2]	ANNUAL[2]
AVAILABLE SOLAR ENERGY	*			
ALBEDO		X,O ✓	X,O ✓	X,O,✓
ABSORBED SOLAR RADIATION	*	X,O,✓	X,O,✓	X,O,✓
NIGHTTIME OUTGOING LONGWAVE RADIATION	*	X,✓	X,✓	X,✓
DAYTIME OUTGOING LONGWAVE RADIATION	*	X,✓	X,✓	X,✓
DAILY AVERAGE OUTGOING LONGWAVE RADIATION		X,O,✓	X,O,✓	X,O,✓
DAY MINUS NIGHT DIFFERENCE IN OUTGOING LONGWAVE RADIATION		X,✓	X,✓	X,✓
NET RADIATION		X,✓	X,✓	X,✓

* - AVAILABLE ON MAGNETIC TAPE IN BOTH THE 125 x 125 ARRAY AND THE 2.5° LATITUDE-LONGITUDE ARRA

X - DATA AT EVERY 2.5° LATITUDE-LONGITUDE, ON MAGNETIC TAPE AND IN TABULAR FORM.

O - PROFILES OF ZONAL AVERAGES AT EACH 2.5° LATITUDE FOR ENTIRE LATITUDE CIRCLE AND IN THREE 120° LONGITUDE SECTORS, 0° - 117.5°E, 120°E - 122.5°W & 120°W - 2.5°W; ALSO AVAILABLE IN TABULAR FORM.

✓ - GLOBAL MAPS PRODUCED: MERCATOR PROJECTION COVERING 60°N TO 60°S; POLAR STEREOGRAPHIC MAPS COVERING REGION: POLEWARD OF 50°N AND S.

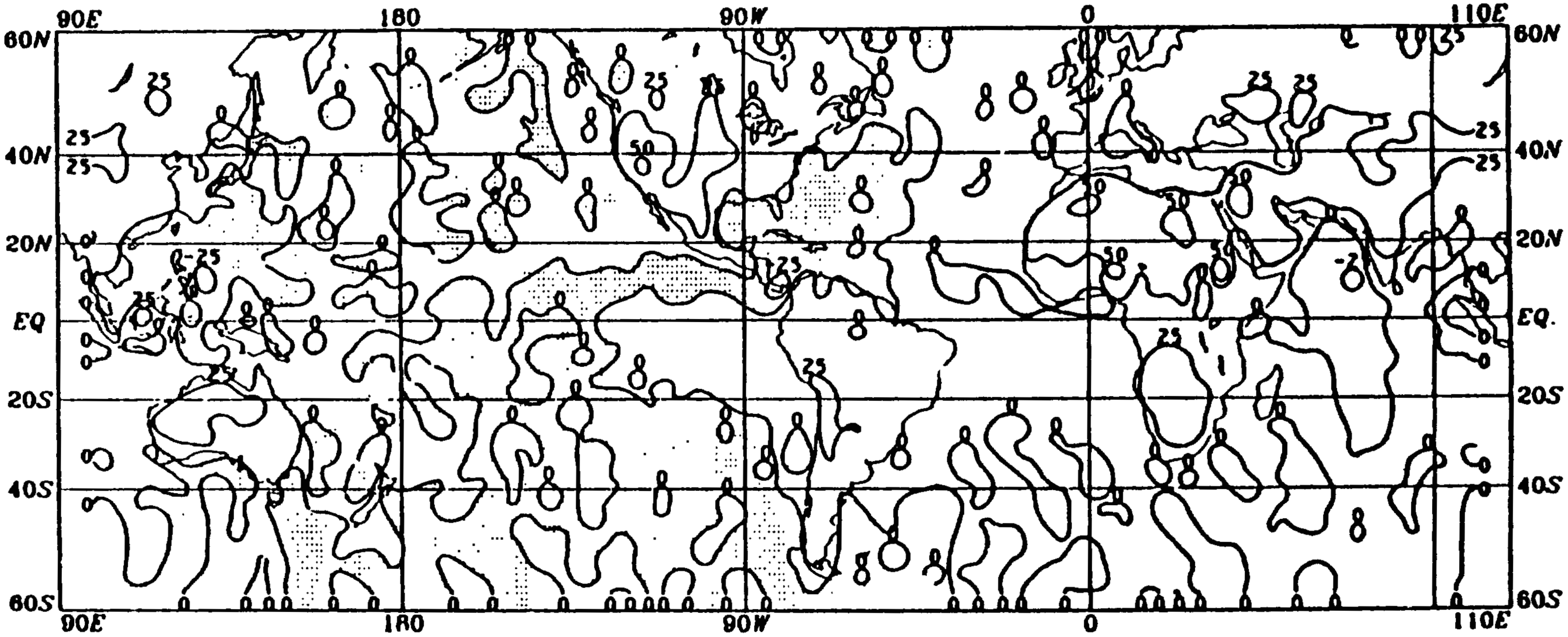
1 - REPRESENTS THE BASIC QUANTITIES WHICH ARE PRODUCED AND ARCHIVED ON MAGNETIC TAPE BY THE OFFICE OF OPERATIONS, NATIONAL ENVIRONMENTAL SATELLITE SERVICE.

2 - ROUTINELY PRODUCED BY THE METEOROLOGICAL SATELLITE LABORATORY, NATIONAL ENVIRONMENTAL SATELLITE SERVICE.

An examination of figure 3-9 shows various important features. For example, over the Sahara region, diurnal values greater than 50 Wm^{-2} are found in 1979 (0330 and 1530 local time). This clearly demonstrates that there is a strong diurnal change over the desert regions when viewed with a 0330 - 1530 equator crossing time (local) satellite.

In order to obtain true global estimates of the earth-atmosphere radiation budget it is essential to choose satellites with different orbits and times to provide adequate diurnal sampling. It is also essential to take into account the anisotropic character of the reflecting surfaces in calculating the reflectances and albedoes if accurate measurements are needed.

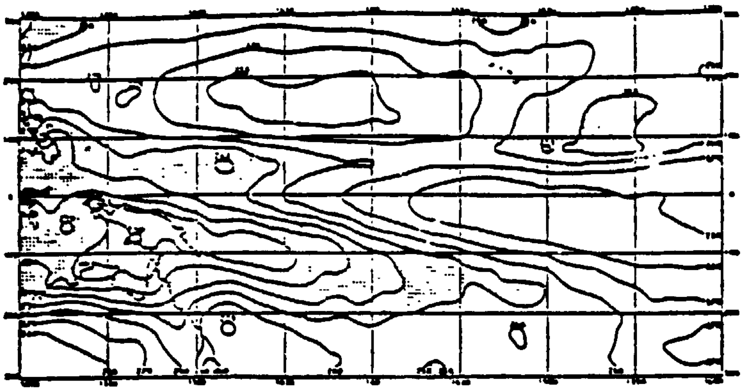
An additional presentation on the topic of earth radiation budget data was given by Dr. Winston, who spoke on the uses of operational radiation budget data in climate analysis. Several illustrations of analyses of the data are given. The first illustration (figure 3-10) shows fields of outgoing longwave radiation over the Pacific region for three Northern hemisphere winters (e.g., winter 1976 means December 1975 - February 1976). The eastward shift of lower values of outgoing radiation (more major cloudiness) and the retreat of the dry zone (high outgoing radiation) over the central equatorial Pacific are striking. The second illustration (figure 3-11) shows these events even more graphically in terms of the year-to-year differences in the winter-averaged longwave radiation. The third illustration (figure 3-12) shows the time variations in outgoing longwave radiation at two individual $2\frac{1}{2}^{0}$ x $2\frac{1}{2}^{0}$ grid points in the central Pacific. Note the general tendency toward lower values in longwave radiation starting in summer 1976 at 0^{0}, 180^{0} and by winter 1977 at 10^{0} S, 160^{0}W. Also note that these changes in radiation are related to weakening of the trade winds and to large-scale pressure differences in the Southern Hemisphere (i.e., the Southern Oscillation). The next illustration (figure 3-13) shows how these changes over the Pacific influence the complete zonally averaged radiation in tropical regions (note the lower outgoing radiation, or more cloudiness, in January 1977 and 1978 as compared with 1976). Also,



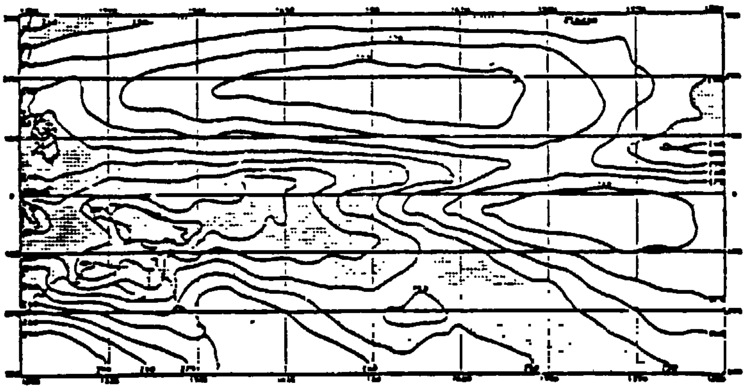
DIURNAL CHANGE OUTGOING LONGWAVE RADIATION (WM^{-2}) PRE

26 DAYS ENDING JUNE 30, 1979

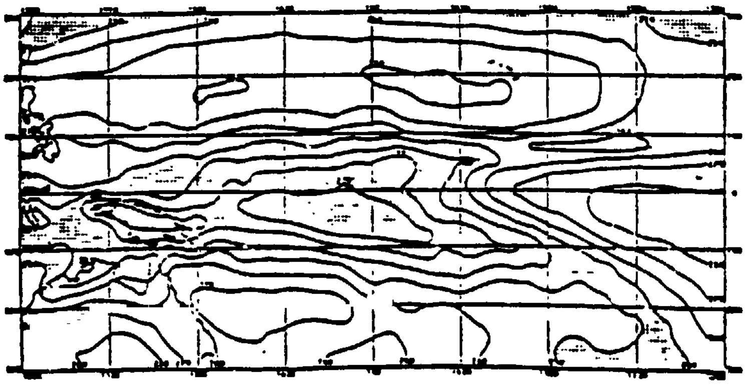
Figure 3-9. Diurnal Change (Outgoing Longwave Radiation) Viewed from a 0330-1530 Equator Crossing Time (Local) Satellite



OUTGOING LONGWAVE RADIATION (WM^{-2})
WINTER 1976



OUTGOING LONGWAVE RADIATION (WM^{-2})
WINTER 1977



OUTGOING LONGWAVE RADIATION (WM^{-2})
WINTER 1978

Figure 3-10. Outgoing Longwave Radiation Over the Pacific

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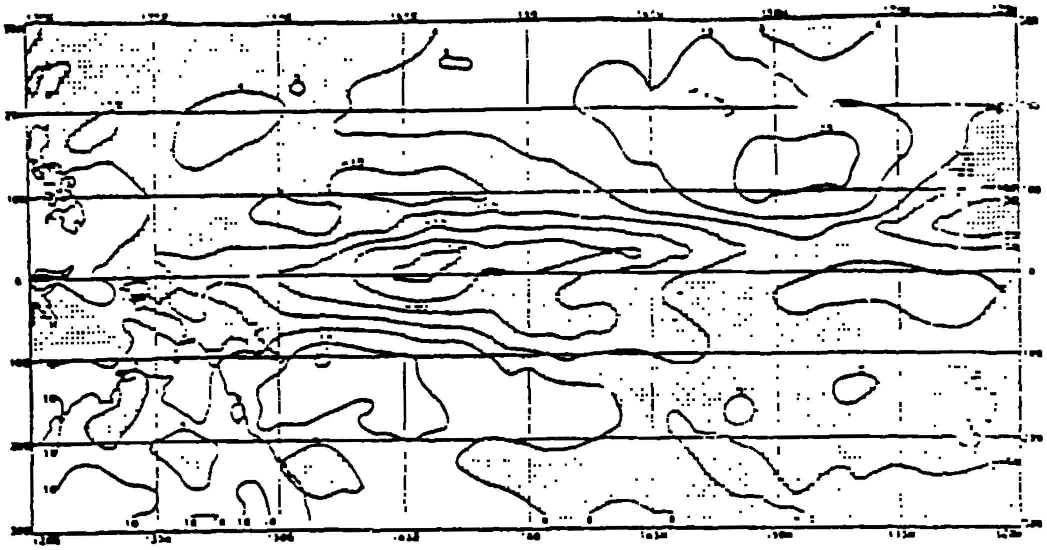
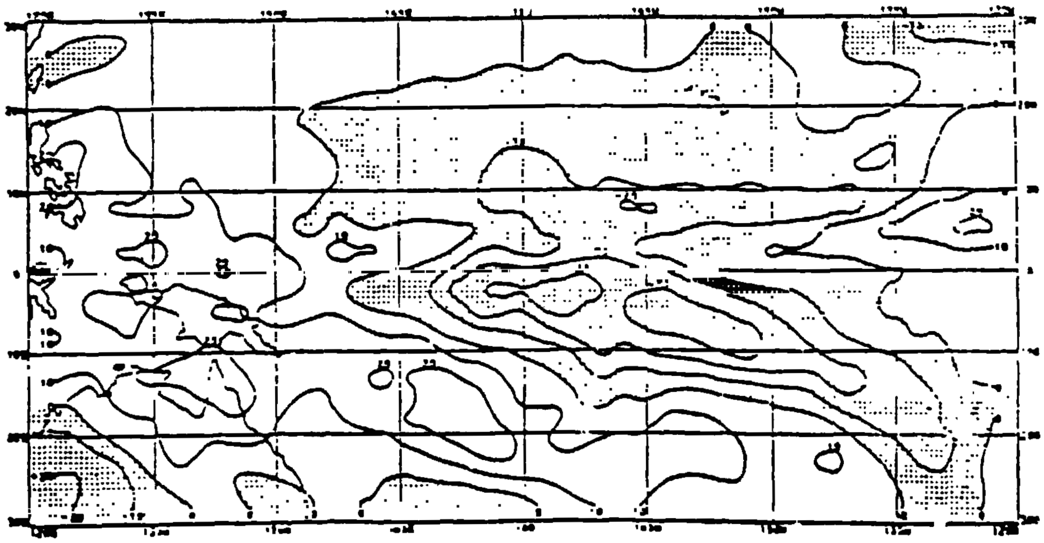


OUTGOING LONGWAVE RADIATION (WM^{-2})
DIFFERENCE WINTER 1977-1976



OUTGOING LONGWAVE RADIATION (WM^{-2})
DIFFERENCE WINTER 1978-1977

Figure 3-11. Year-to-Year Differences in the Winter-Averaged Longwave Radiation

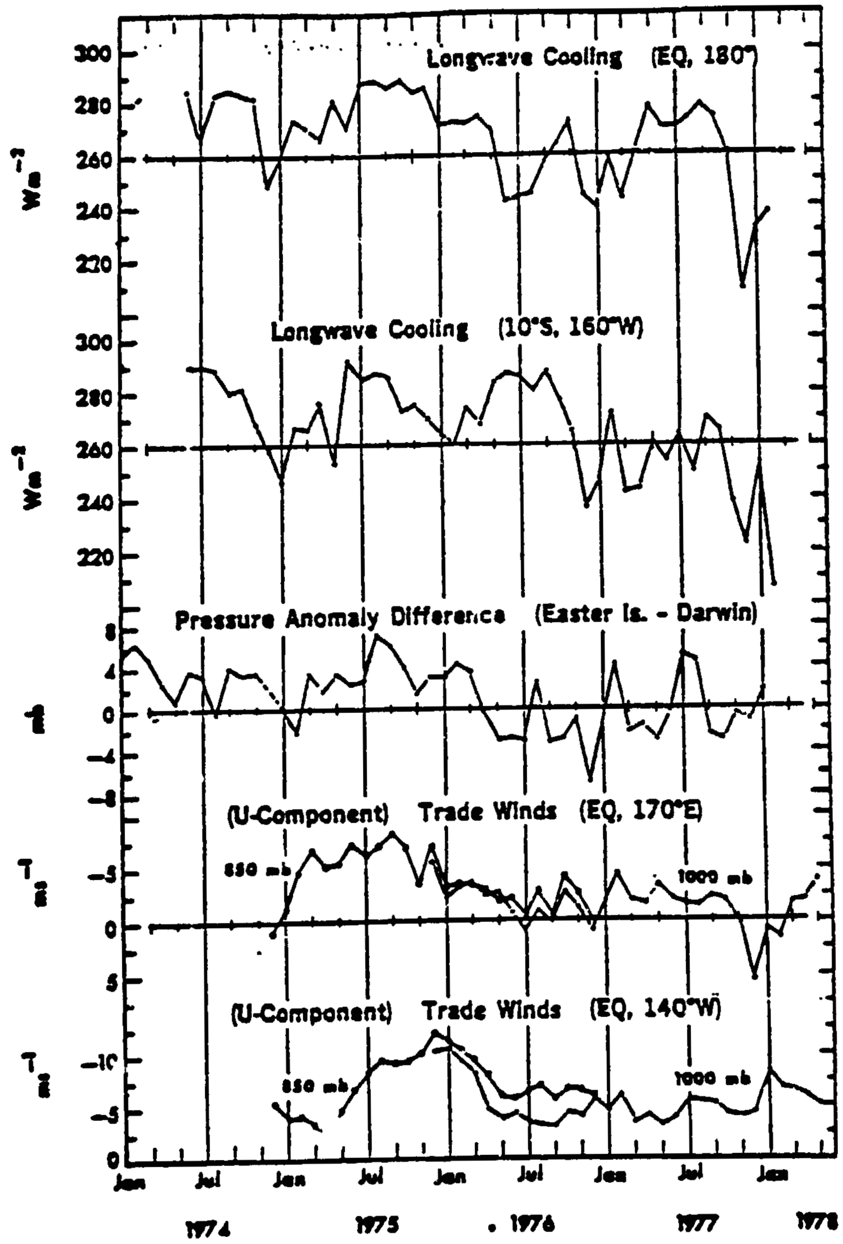


Figure 3-12. Time Variation in Outgoing Longwave Radiation At Two Individual Points in the Central Pacific

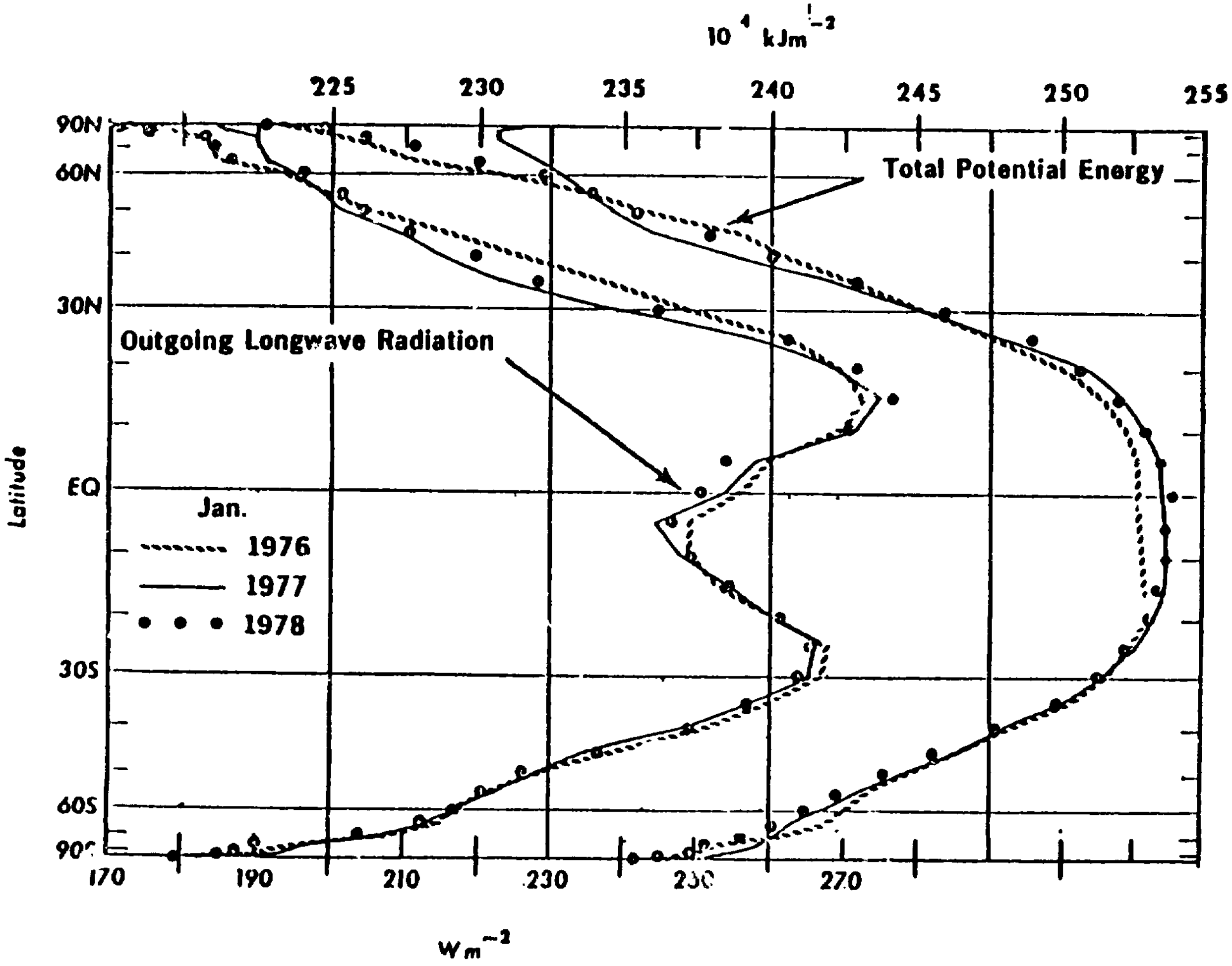


Figure 3-13. Outgoing Longwave Radiation over Central Pacific

note the differences in total potential energy, or mean tropospheric temperature, as obtained from NMC analyses. This shows higher temperatures over the tropics in 1977 and 1978 when cloudiness was greater, implying an enhanced Hadley circulation in these two years as compared with 1976.

The next illustration (figure 3-14) shows the kind of detail one can obtain with enlarged regional analyses of these data. In particular, this illustrates the changes in absorbed solar radiation over North America and vicinity between the summers of 1976 and 1977. In general there is a picture of generally less solar radiation (greater cloudiness) in summer 1977 over much of the United States and Canada, with generally more solar radiation (less cloudiness) along both east and west coasts (except off California).

The final illustration (figure 3-15) shows year-to-year differences in absorbed solar radiation over the eastern Pacific for a long sequence of seasons. Note that for four seasons in a row (in this figure winter is labeled with the year of each December, e.g., winter 1975 is December 1975-February 1976), there is a preponderance of positive changes in absorbed solar radiation. In the ensuing three seasons more negative changes set in, much of them in the regions of previous positive changes. Since most of these areas of changes are in regions of relatively high outgoing radiation where changes are small, these differences are mostly representative of substantial changes in low cloudiness and signify substantial differences in the solar radiation reaching the ocean surface.

Estimates of radiation budget components have been made on a real-time basis from scanning radiometers on NOAA polar-orbiting satellites since June 1974 (except for a gap from March to December 1978). Although the data have deficiencies, some of which were pointed out by Dr. Rao, they represent a breakthrough for quantitative monitoring of certain climate

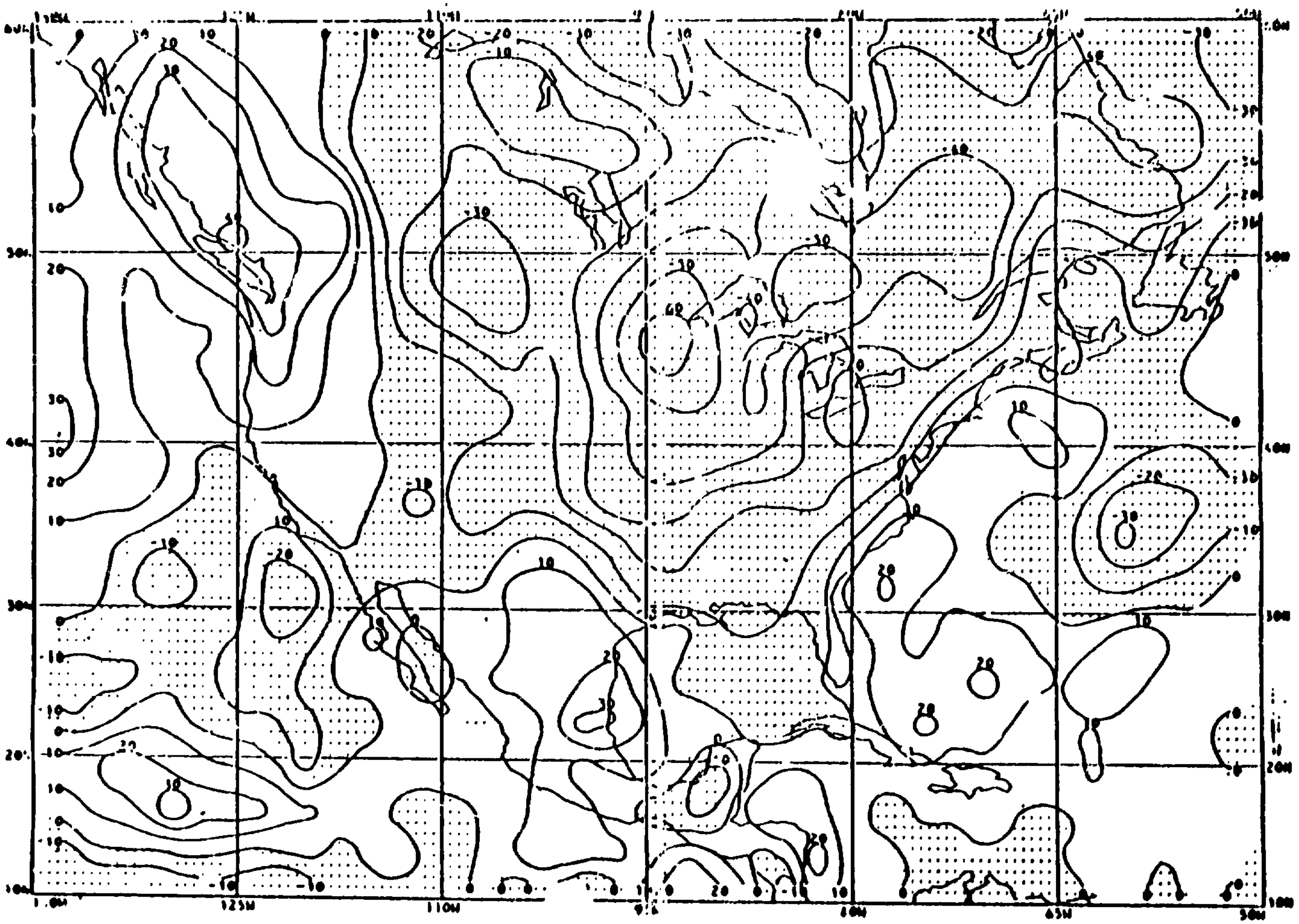


Figure 3-14. Absorbed Solar Radiation (WM^{-2}) over North America

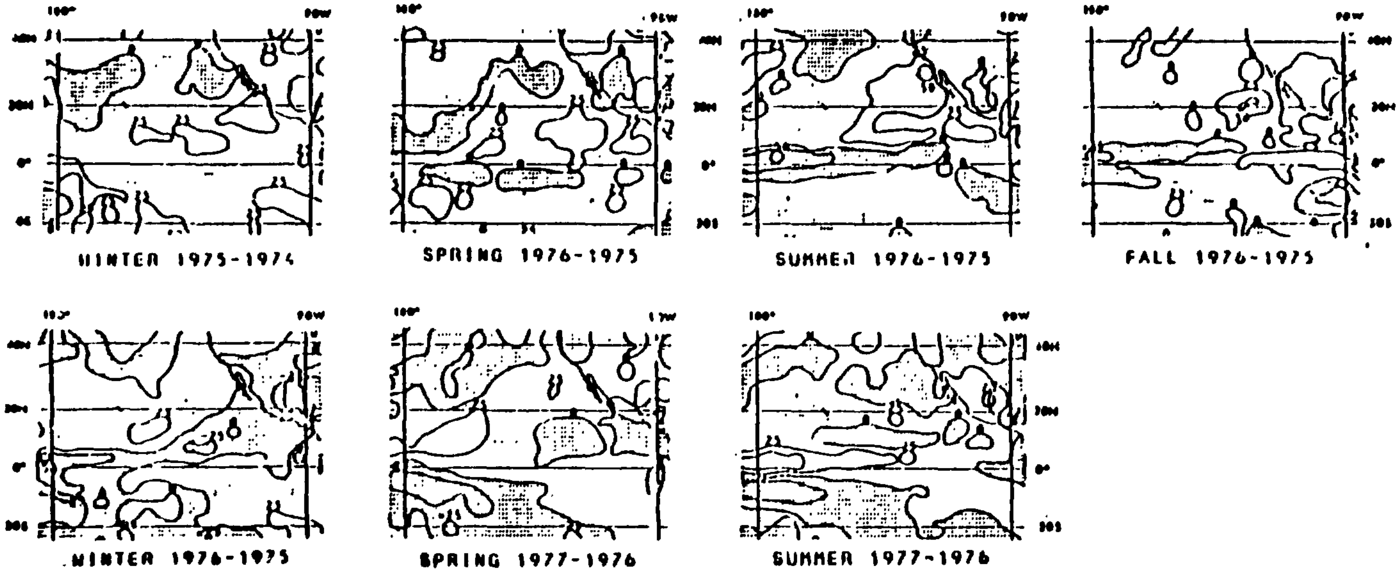

WINTER 1975-1974
SPRING 1976-1975
SUMMER 1976-1975
FALL 1976-1975
WINTER 1976-1975
SPRING 1977-1976
SUMMER 1977-1976

Figure 3-15. Absorbed Solar Radiation (WM^{-2}) Difference Year-to-Year fluctuations, particularly over vast areas of the Earth where such variations could barely be inferred previously. The principal uses of these data in climate analysis are as follows:

a. Real-time

(1) Maintenance of current awareness of regional fluctuations of components of radiative heating (outgoing longwave radiation and albedo) all over the globe at time scales of a few weeks to several years. Examination of fields of anomalies or year-to-year differences are of prime importance.

(2) Statistical long range prediction methods. As radiation budget data accumulate, it is expected that they will be used as predictors in statistical prediction methods for months and seasons. This use will ensure the follow-on of substantial diagnostic and statistical studies.

b. Diagnostic studies

(1) Examination of large-scale changes in tropical and extratropical cloudiness (and precipitation) largely through variations in outgoing longwave radiation. Some very large-scale interrelations (or teleconnections) have been revealed by these data over several years.

(2) Studies of variations in absorbed solar radiation over various portions of the globe for ocean, snow-ice regions, and land areas. The data have much potential for estimating surface radiative heating over large areas of the globe where estimates from other observations are not even possible.

Key Climate Parameters Difficult to Measure

Identified as key climate parameters were precipitation, soil moisture, the ocean boundary layer and winds. Each of these parameters is difficult to measure by remote sensing; yet consistent, global measurements are crucial to climate studies.

The first parameter to be discussed was precipitation, by Dr. Wilheit of GSFC. The most promising method of remotely sensing precipitation is by microwave radiometric measurements. However a number of problem areas still exist for passive microwave measurements, namely, beam filling, the thickness of the rain layer, atmospheric water vapor, the inadequacies of radiative transfer models, error analysis of the microwave method, surface measurements, and sampling.

Consequently ma y details need to be studied for the determination of rain over ocean and land. Current measurements give only yes/no indications of precipitation over land (3 mm) although some seasonal results of rain over ocean have been obtained from 1-2 cm measurements.

Dr. Wilheit made several recommendations regarding the microwave method, chief of which was the need for more realistic radiative transfer models. Also recommended was an intensive effort to interpret the DMSP/SSMI and expected NOSS/LAMMR data. A better error analysis and a more serious look at sampling problems are needed. Third, Wilheit recommended that a 91 GHz channel be included on LAMMR. He concluded his presentation with the recommendation for a research mission in the late 80's dedicated to precipitation.

Soil moisture was addressed earlier by Dr. Salomonson and Dr. Schmugge under the topic "Land Surface and Hydrological Processes."

Aspects of the ocean boundary layer, such as sea surface temperature and air-sea interactions, were discussed by Dr. Prabhakara and Dr Chahine.

Dr. Prabhakara expressed the need for improving the measurements involved in specifying the air-sea exchange interactions. In addition to the frequently discussed sea surface temperature (SST) parameter, these measurements would include: surface winds, since heat transfer and evaporation rates from the ocean are wind dependent; the height and variability of the boundary layer, since the activity of the interface exchange processes is expected to be correlated with boundary layer height; precipitable water vapor; and the air-sea temperature difference, which is important for determining the sensible and latent heat fluxes. He suggested the following experimental approaches to these parameter determinations: (1) simultaneous measurements of microwave and IR radiometers to help unscramble the surface temperature, wind, humidity and precipitable water vapor; (2) information on an AVHRR with split window channels and an 18-20 mm water vapor channel for improving SST determinations; (3) a relatively simple lidar system for determining the height of the boundary layer; and (4) improved ground truth determinations for all parameters.

Dr. Chahine discussed a proposed new instrument, the Advanced Moisture and Temperature Sounder (AMTS) for determining the SST. The AMTS utilizes a number of different narrow width channels including some in the 3.7 micron CO_2 band.

Because the atmosphere is not completely transparent even in the least absorbing regions of the terrestrial spectrum, the outgoing spectral radiance observed from space will be influenced not only by the sea-surface, but also by the composition and thermal structure of the atmosphere. The observed radiance will be further modified by the presence of hazes and clouds and by scattered solar radiation. It is therefore necessary to take all of these factors into account if accurate and reliable sea-surface temperatures are to be obtained.

The accuracy of current and planned infrared and microwave sea-surface temperature sounders is expected to be around 2K. The specific causes of this error vary from one sounder to the other but they are caused mainly by uncertainties about the variability of a number of geophysical parameters which modify the emitted sea-surface radiation along its path into space. In most cases the effects of instrument noise are relatively small and more manageable.

However, improvements of the absolute accuracy of sea-surface temperature to 1K can be obtained by:

a. Properly choosing from the 3.7 μm CO_2 window a set of "super window" channels with narrow band passes away from major water vapor absorption lines.

b. Simultaneous multispectral observations of the atmosphere and sea-surface in order to correct for most of the geophysical processes which affect the surface emission.

c. Development of a "quality control" algorithm capable of using information from the multispectral channels to identify those retrieved sea-surface temperature which have errors larger than a prescribed value, say 1 or 2K.

Development of a sounder capable of achieving the above requirements is now feasible. Sounding frequencies with narrow band passes are required in order to avoid contamination by major water vapor lines and achieve maximum frequency separation. The set of channels needed includes:

a. Three narrow band pass channels from the 3.7 μm region to account for sea-surface emissivity and reflectivity and to retrieve the sea-surface temperature.

b. Three long-wave channels from the 15 μm CO_2 band or preferably the 60 GHz O_2 line in the microwave region to correct for the effects of clouds and hazes.

c. A set of 4.3 μm CO_2 band channels to determine the temperature profile in the lower troposphere and a compatible set from the 15 μm CO_2 band to determine the rest of the temperature profile.

d. A set of 6.3 μm and 11 μm water vapor channels to optimize the corrections for water vapor effects.

The advantages of narrow band pass channels go far beyond just offering improved spectral purity by reducing channel contamination by water vapor lines and other minor atmospheric constituents, and achieving the necessary frequency separation between channels. Essentially they provide the basic concept for a new integrated atmospheric/surface sounder of the type illustrated in table 3-4.

Specifically by treating the atmospheric correction as an integral part of sea-surface sounding, we can achieve an accuracy in T_s of about 1K. The reverse is also true. In fact, accurate determination of surface temperature is essential for accurate determination of atmospheric temperature profiles, especially near the surface.

The availability of measurements obtained simultaneously in different parts of the spectrum will allow us to account for the effects of variability in surface emissivity, reflectivity and atmospheric thermal, radiative and compositional structures. The set of channels of table 3-5 can provide the necessary criteria for controlling the quality of T_s.

A design study conducted at JPL and GSFC has shown that such a sounder can be developed now. With a field of view of 10 x 10 km this sounder will be able to provide global data on a large number of air-sea interaction parameters of the type shown in table 3-5 such as:

a. Sea-surface temperature with an absolute accuracy of 1K and a relative accuracy of 0.5K.

b. Air-sea temperature difference with an accuracy of ±1K.

Table 3-4. Advanced Moisture and Temperature Sounder Narrow Spectral Bands

CHANNEL NUMBER	CENTER ν (cm^{-1})	WAVELENGTH λ (μm)	RESOLUTION $\Delta\nu$ (cm^{-1})	MAIN FUNCTION
1	606.95	16.476	0.50	
2	623.20	16.046	0.50	CLOUD FILTERING*
3	627.80	15.929	0.50	
4	634.30	15.765	0.50	
5	646.60	15.466	0.50	
6	654.35	15.282	0.50	TEMPERATURE PROFILE UPPER ATMOSPHERE
7	665.55	15.025	0.50	
8	666.85	14.996	0.50	
9	668.15	14.967	0.50	
10	669.45	14.938	0.50	
11	1041.00	9.606	1.00	OZONE
12	1203.00	8.313	1.00	
13	1231.80	8.118	1.00	H_2O WINDOW
14	1839.40	5.437	1.50	
15	1844.50	5.422	1.50	
16	1850.90	5.403	1.50	H_2O PROFILE
17	1889.57	5.292	1.50	
18	1930.10	5.181	1.50	
19	2384.00	4.195	2.00	
20	2386.10	4.191	2.00	TEMPERATURE PROFILE LOWER ATMOSPHERE
21	2388.20	4.187	2.00	
22	2390.20	4.184	2.00	
23	2392.35	4.180	2.00	
24	2394.50	4.176	2.00	
25	2424.00	4.25	2.50	AIR-SURFACE ΔT
26	2505.00	3.992	2.50	
27	2616.50	3.822	2.50	SURFACE TEMPERATURE
28	2686.00	3.723	2.50	

*60 GHz FREQUENCIES CAN BE SUBSTITUTED FOR CHANNELS 1-3

Table 3-5. Summary Assessment of Present Remote Sensing Capabilities for Air-Sea Interaction Studies

Parameter	Data	Accuracy	Spatial Resolution
1. Sea Surface Temperature	Available	2 K (absolute)	Adequate
2. Air-Sea Temperature Difference	Inadequate	TBD (± 1 K)	TBD*
3. Atmospheric Temperature Profiles	Available	2 K	Adequate
4. Humidity Profiles	Available	Factor of 2	TBD
5. Precipitable Water	Available	10-50%	TBD
6. Rainfall	Available	50%	TBD
7. Cloud Amount	Available	5-50%	Adequate
8. Cloud Top Height	Available	0.5-1 km	Adequate
9. Surface Salinity	Inadequate	0.5 ppt	TBD
10. Wind Speed	Available	1-3 m/s	TBD
11. Wind Vector	Available	0-15 deg	TBD
12. Surface Ocean Currents and Drifts	Available	1 m/s	TBD
13. Sea Level Height	Available	20-50 cm	TBD
14. Thermocline Depth	Not Available	TBD	TBD
15. Sea-Level Pressure	Not Available	TBD (2-3 mb)	200 km

*To Be Determined

Source: "Guidelines for Air-Sea Interaction Special Study: An Element of the NASA Climate Research Program," JPL Publication 80-8, Feb. 15, 1980.

c. Temperature profiles in the presence of up to three layers of broken clouds with an average rms accuracy of 1.5K at 8 distinct levels below 100 mb.

d. Total precipitable water vapor with an accuracy of 0.1 to 0.2 gr/cm^2 and relative humidity profiles with an average accuracy of 20 percent and up to 7 distinct levels between the surface and 200 mb.

e. The surface temperature of solid earth with an average absolute accuracy of 1.5K.

f. The fractional cover and height of multiple cloud layers (as seen from above) with an accuracy of ±0.05 and 0.25 km respectively.

g. The location of the tropopause to within ±0.5 km.

h. Total ozone loading of the atmosphere.

Upon the conclusion of Chahine's discussion, Dr. Melfi reported upon proposed techniques for measuring winds (table 3-6). He began by showing the requirements for wind determinations both for an operational (Fleet Numerical Weather Center) and a research (GLAS) numerical model. Typically the wind speed accuracies required were on the order of 1-2 meters/second, while the spatial scale and sampling frequency varied widely depending upon the data usage, the atmospheric region and the meteorological phenomena being considered.

The present status of remotely sensed wind measurement techniques was reviewed. The microwave techniques typically inferred the winds from a measured ocean surface property; lidar techniques utilized aerosol backscattering, while the laser heterodyne radiometer, the correlation spectrometer and the microwave limb sounder were sensitive to the Doppler shift of molecular emission lines and the laser/microwave active element is used to provide a frequency standard for the Doppler shift measurement. Other techniques mentioned included the clear-air radar, which relied on

Table 3-5. Summary of Wind Measurement Techniques, Principles and Applications

Instrumentation	Principle	Prime Application
Active Microwave Scatterometer	Sea-Surface Motion	Surface Winds
Scanning Multichannel Microwave Radiometer	Sea-Surface State	Surface Winds
Coherent Infrared LIDAR	Laser Doppler Shift - Aerosol Backscattering	Troposphere
Visible LIDAR	Laser Doppler Shift - Aerosol Backscattering	Stratosphere
Laser Heterodyne Radiometer	Doppler Shift - Molecular Emission Line	Stratosphere
Correlation Spectrometer	Doppler Shift - Molecular Emission Line	Stratosphere
Microwave Limb Sounder	Doppler Shift - Molecular Emission Line	Mesosphere
Clear-Air Radar (Ground Truth)	Refractive Index Variations	Troposphere-Ionosphere
Cloud Winds	Cloud Tracking	Troposphere

refractive index variations to infer air motion, and the cloud tracking technique which inferred wind speeds from cloud motions. The emphasis of this talk was on the coherent infrared lidar technique, the correlation spectrometer technique and the microwave limb sounder technique.

Estimates of noise-equivalent winds versus altitude were provided. The wind error estimates of both the visible and the infrared lidar measurements increase monotonically with altitude. The infrared lidar system is estimated to provide accuracies of 2 m/sec, or better, at all altitudes below about 20 km, while the visible lidar system provides that accuracy only below about 8 km. The correlation spectrometer systems, shown in figure 3-16, provide a maximum accuracy of about 3m/sec at altitudes of about 35 km and about 62 km, with worse accuracies at altitudes off the specified altitudes. The microwave limb sounder is most accurate in the mesosphere with an accuracy of slightly over 2 m/sec at 85 km and a monotonically increasing error at lower altitudes. Further details of baseline parameters for coherent IR Lidar measurements (table 3-7) and accuracies were presented. Finally, a series of recommendations of research and development emphasis for wind techniques included: experimental verification of key geophysical and engineering assumptions involved in the infrared lidar approaches, troposphere wind measurements, the evaluation of a prototype correlation spectroscopy based instrument for stratospheric winds; and the evaluation of a Spacelab version of a microwave limb sounder for providing mesospheric winds.

Operational Meteorological Satellites

Dr. Yates and Dr. Miller from NOAA/National Environmental Satellite Service and Dr. Arking of GSFC spoke on stepwise improvements to the operational meteorological satellite system for climatic purposes.

Dr. Yates began this section with a discussion of the NOAA requirements for the ocean climate monitoring system. The desired accuracy, horizontal and

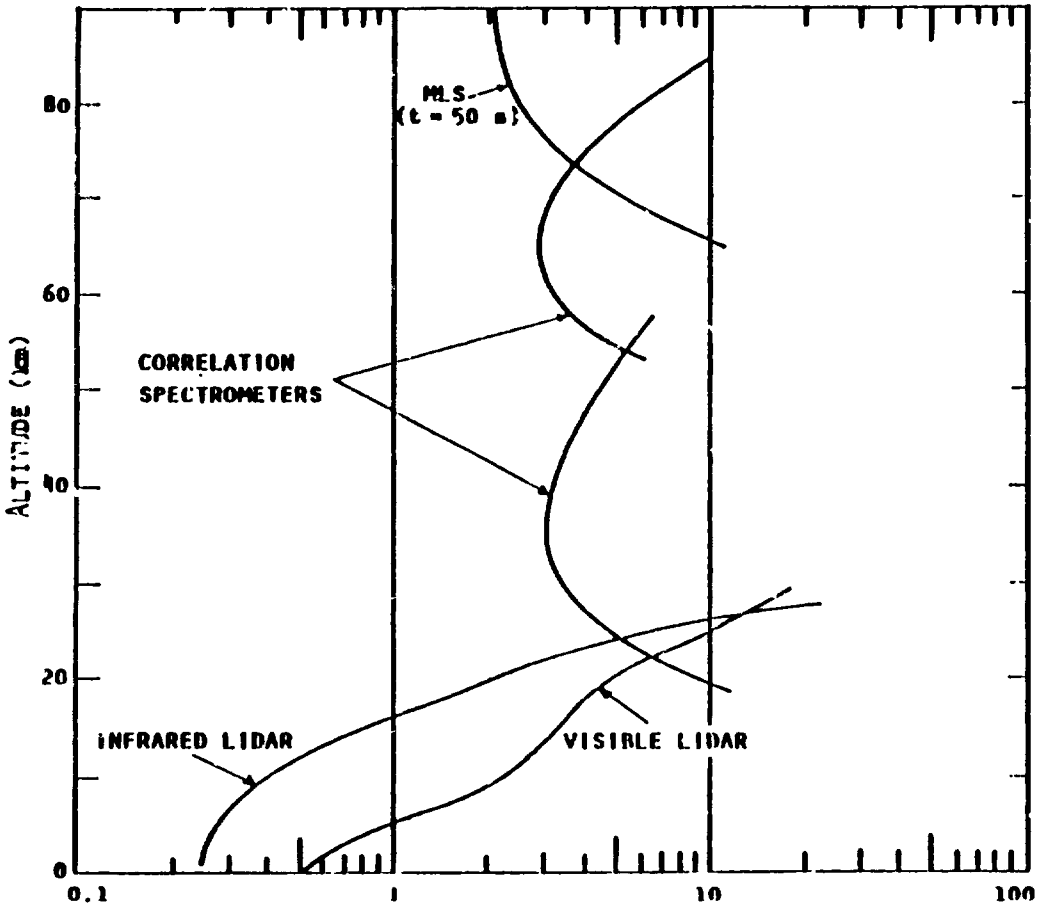


Figure 3-16. Wind Error vs. Altitude for Microwave Limb Sounder, Correlation Spectrometers, Infrared and Visible Lidar

Source: E.D. Hinkley; "Global Wind Workshop Summary Reports," NASA JPL and California Institute of Technology; Pasadena, California; November 15, 1979.

Table 3-7. Base Parameters for Coherent IR Lidar Simulation

	Shuttle	Free Flyer
Altitude (z) Nadir angle (Reach)	300 km 62° (600 km)	800 km 52° (1200 km)
Target Volume (300 km x 300 km x 1 km)	#2	
Wavelength (λ)	9.11 μm($^{12}C^{18}O_2$)	
Conical Scan Period	10 s	
Pulse Repetition Frequency (average)	8 Hz (variable)	
Efficiency (η)	10%	
Telescope Diameter (D)	1 m	
Pulse Energy (E_p)	10 J	
Pulse Duration (τ_p)	6.7 μs	
Long Term Pointing Error	50 μrad	
Short Term Pointing Error	2 μrad	
LO Jitter	50 kHz	
Atmospheric Model	M.L. Summer	M.L. Winter
Absorption	AFGL	
Backscatter	WPL (lognormal)	
Turbulence	Hufnagel with NOAA/WPL correction*	
Wind field	10 - .002 shr + 2D undisturbed, correlated	
Processor	Complex Covariance and Least Squares	

Source: R.M. Huffaker, Ed.; "Feasibility Study of Satellite-Borne Lidar Global Wind Monitoring System." NOAA Technical Memorandum ERL WPL-37; Wave Propulsion Laboratory; Boulder, Colorado; September 1978.

temporal resolution for each parameter, as listed in table 3-8 were discussed.

As part of this discussion, Dr. Yates made the following recommendations: 1) a U.S. data collection and location system should be developed and operated; 2) the operational system must be responsive to research needs; and 3) the Climate Project requires the administrative cooperation of Congress, Administration, OMB, and involved agencies.

Dr. Yates then reviewed the missions of NOAA H and I, their status and instrument complements. Launch for the two spacecraft is expected in April 1986 and April 1987. Both missions include these instruments: AVHRR, HIRS/2, MSU, SEM, SBUV, and Search and Rescue. NOAA H may also carry the SSU and DCS, while NOAA I may carry the AMSU and DCS.

Table 3-8. Preliminary Ocean Climate Monitoring Requirements

PARAMETER	ESTIMATED ACCURACY	APPROXIMATE HORIZONTAL RESOLUTION	APPROXIMATE TEMPORAL RESOLUTION
Sea Surface Temperature	1^{0}C (satellite) 0.2^{0}C (in situ)	50 km -	3 days 3 days
Upper Layer Heat Content	2 kcal/cm^{2} (0.2^{0}C)	200 km 200 km	1 month 1 month
Wind Stress	0.2 dynes/cm^{2}	200 km	5 days
Sea Level (Dynamic Topography)	2 cm	50 km	1 week
Currents			
Near Surface	2 cm/sec	Critical Areas Only	1 month
Subsurface	0.2 cm/sec	1000 km	1 year
Sea Ice Extent (% open water)	2%	50 km	3 days
Salinity	0.01 ppt	200 km	1 month

C - 2

Dr. Arking of the Climate and Radiation Branch, Goddard Laboratory for Atmospheric Sciences, GSFC, then discussed the possibilities of improvement in the operational meteorological satellite system based on the current TIROS-N series. A follow-on to the TIROS N operational meteorological satellite series will be needed, perhaps as early as 1984. Because of the time required to develop a new spacecraft, the initial satellites in the follow-on series, the NOAA H and I satellites, will be of the same basic design as the last ones in the current series, and a new spacecraft will not be available prior to NOAA J. The current satellite design places physical and power restrictions on the configuration of instruments. Arking's consideration of the scientific, technical, and operational factors leads to the following recommendations:

For NOAA H and I:

a. Add a sixth channel, at 1.6 μm, to the AVHRR/2 imaging radiometer, to be designated AVHRR/3, and to be used for snow/cloud discrimination and cloud classification.

b. To meet the 1984 readiness schedule, NOAA H should be identical to G except for replacing AVHRR/2 with /3; the payload would include SBUV and ERBI.

c. On NOAA I, same as H [illegible] replace the MSU and SSU with AMSU, compensating for the power deficit during later life of the satellite with reduced duty cycles on some instruments; this recommendation is preferable to the current idea of flying AMSU in place of ERBI.

For NOAA J and after:

d. Plan for a 10-12 channel imaging radiometer in place of the AVHRR; it would provide greater accuracy in sea surface temperature, measurement of cloud height and other cloud parameters, and observation of mid-tropospheric circulation patterns.

e. Deploy one or more of the new high spectral resolution sounders (e.g., AMTS and HIS) which provide greatly improved vertical resolution.

f. Experiment with an advanced earth radiation budget sensor, eventually to replace ERBI.

The TIROS N series of polar orbiting operational meteorological satellites began with the launch of TIROS N in October 1978, was followed by NOAA A (re-named NOAA 6 after launch), and will continue through NOAA G, a total of 8 satellites. The third in the series, NOAA B, was launched on May 29, 1980 but failed to achieve the required orbit and attitude control and is therefore a total failure. NOAA has reconsidered its need to immediately replace TIROS N (the objective of the NOAA B launch) and present plans call for continued use of NOAA 6 and TIROS N to meet the operational meteorological requirements. The nominal launch schedule for the remaining satellites, based upon the requirement for two operating satellites and their life expectancy is as follows:

NOAA C	April '81
NOAA D	April '82
NOAA E	April '83
NOAA F	April '84
NOAA G	April '85

On basis of the above schedule, replacement satellites are needed beginning in 1986. The follow-on requirements conveyed to NASA by NOAA can be summarized as follows:

a. Imaging. Maintain the radiometric imaging capability for cloud and surface features and for sea surface temperature mesurements, currently provided by AVHRR/1 (Advanced Very High Resolution Radiometer, version 1) on earlier satellites in the series and by AVHRR/2 on later satellites.

b. Sounding. Maintain the atmospheric sounding capability, currently provided by three sounders: HIRS/2 (High Resolution Infrared Radiometer Spectrometer, version 2), MSU (Microwave Sounding Unit), and SSU (Stratospheric Sounding Unit).

c. Energetic Particles. Continue energetic particle measurements along the satellite's orbit, currently provided by SEM (Space Environment Monitor).

d. Data Collection. Continue to collect data from balloons and remote platforms, currently provided by DCS (Data Collection System).

e. Ozone. Monitor the ozone by continuing measurements with the SBUV (Solar Backscatter UltraViolet) radiometer that will be deployed on NOAA F as an R&D experiment and on G as an operational instrument.

f. Earth Radiation Budget. Monitor the components of the earth radiation budget parameters by continuing measurements with ERBI (Earth Radiation Budget Instrument), which will be deployed on NOAA F and G as part of the NASA Earth Radiation Budget Experiment.

g. Search and Rescue. Continue deployment of SAR (Search and Rescue) system that will begin with NOAA E.

In addition to the above requirements, NOAA intends to gradually upgrade the capabilities of the satellite system and develop new capabilities to meet future requirements by conducting R&D experiments, jointly with NASA, utilizing improved and new sensors. This point will be further discussed below.

Improvements and New Sensors. At the present time there are no research satellites that could be used for testing and evaluating new sensors. But there is ongoing research in remote sensing leading to improvements in sensor design, which could provide the operational meteorological satellites with enhanced capabilities to meet current and future needs of the meteorological community.

It is intended that the TIROS N follow-on series be able to accommodate R&D missions with new sensors. There are three areas where improvements or new sensors, in various stages of development, should be considered for testing in the TIROS N follow-on series: (1) imaging; (2) atmospheric sounding; and (3) earth radiation budget monitoring.

a. Imaging. In imaging radiometers there is a near term improvement that can be achieved by addition of a sixth channel to the AVHRR/2 in the vicinity of 1.6 μm. This channel will add a capability of discriminating between snow and cloud cover. With the present AVHRR/2 snow and clouds are both highly reflecting in the visible and near IR channels, but at 1.6 μm the snow is dark (even darker than land surfaces and vegetation cover) while clouds are still bright. The 1.6 μm channel has the further capability of distinguishing between clouds consisting of liquid droplets and ice particles. An illustration of the 1.6 μm capability to discriminate snow, cirrus clouds, and cumulus clouds appears in figure 3-17 which is based upon aircraft measurements.

Other channels that could enhance the capability of the imaging radiometer to sense atmospheric and surface parameters are listed in table 3-9. However, only the 1.6 μm channel can be incorporated easily into the present design. Any of the others would require major redesign -- essentially, development of a new instrument. Therefore, it is recommended that the sixth channel be added, beginning with NOAA H and designated AVHRR/3, and the additional channels be considered

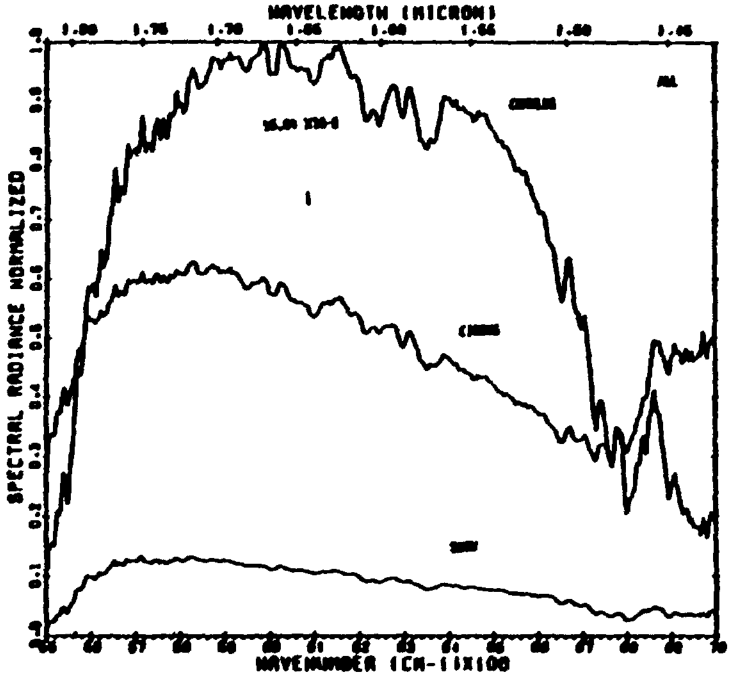


Figure 3-17. Spectral Radiance Normalized for All Incoming Radiation, Cumulus, Cirrus, and Snow. Valovcin (1978)

Table 3-9. Improvements in Visible/IR Imaging Radiometers

AVHRR/2

FOV: 1 KM

CHANNELS: .62, .90, 3.74, 10.8, 12.0 μM

PARAMETERS:		USEFUL INFORMATIONION:
CLOUD COVER AMOUNT		CLOUD TYPE, HEIGHT, THICKNESS
SNOW COVER		STORM TRACKS
ESTIMATES OF EARTH RADIATION BUDGET		CIRCULATION PATTERNS
SURFACE ALBEDO		
SEA SFC TEMPERATURE (1.0°C)		
VEGETATION COVER		
FLOOD BOUNDARIES		
AEROSOL OPTICAL THICKNESS		

AVHRR IMPROVEMENTS

ADDITIONAL CHANNELS:	ADDITIONAL PARAMETERS:
1.6 μM	CLOUD/SNOW DISCRIMINATION, CLOUD TOP PHASE (ICE VS. WATER)
4 μM	IMPROVED SEA SURFACE TEMPERATURE (0.5°C, NIGHT)
18 μM	TOTAL WATER VAPOR IN COLUMN
	IMPROVED SEA SURFACE TEMPERATURE (0.5°C DAY)
6.7 μM	UPPER TROPOSPHERIC WATER VAPOR
	CIRCULATION PATTERN IN CLEAR ATMOSPHERE
.75,.76 μM	CLOUD TOP HEIGHT

in the design of a new instrument to replace the AVHRR in the late 80's. A comparison of the three versions of the AVHRR is shown in table 3-10.

b. Atmospheric Sounding. Three instruments now provide the total sounding capability of the satellite. The HIRS/2 is a 20-channel instrument which utilizes channels in the thermal infrared portion of the spectrum to obtain information on surface temperature and atmospheric temperature and humidity profiles. The MSU has 4 channels in the 50-60 GHz portion of the microwave spectrum to sense tropospheric temperatures in the presence of clouds. The SSU has three channels in the center of the 15 μm CO_2 band to provide temperatures in the stratosphere (20-50 km).

Two new infrared sounders are under development which are aimed at significantly improving the vertical resolution of the sounding in the troposphere (from ~6 km to ~2.5 km). Both involve going to higher spectral resolution. One of them, the AMTS (Advanced Moisture and Temperature Sounder) uses discrete channels with spectral widths ranging from .5 to 2 cm^{-1}. The other, the HIS (High resolution Interferometer Spectrometer) is based upon a spectral measurement with 1 cm^{-1} resolution. A decision between these two approaches is pending a comparison study that is now taking place. A comparison of the key features of the new instruments with HIRS/2 is shown on table 3-11.

A third sounder under development is the AMSU (Advanced Microwave Sounding Unit), a 20-channel instrument which, in addition to the tropospheric temperature channels on the current MSU, has surface sensing channels, water vapor profiling channels, and high resolution stratospheric temperature channels. The AMSU will effectively replace both MSU and SSU on the current sounder group. Its key features are shown in table 3-12, in comparison with the MSU. This

Table 3-10. AVHRR Applications

DAYTIME	CHANNEL	NIGHTTIME			
MODERATE TO THICK CLOUD COVER SNOW AND ICE COVER	VISIBLE	-------------------	AVHRR/1	AVHRR/2	AVHRR/3
HYDROLOGY APPLICATIONS VEGETATION COVER	NEAR IR	-------------------			
CIRRUS CLOUD COVER DETECTION	3.7 μM	SEA SURFACE TEMPERATURES			
SEA SURFACE TEMPERATURES CLOUD HEIGHT	11 μM	CLOUD COVER HYDROLOGY APPLICATIONS			
WATER VAPOR CORRECTIONS TO 3.7 AND 11 μM CHANNELS	12 μM	WATER VAPOR CORRECTIONS TO 3.7 AND 11 μM CHANNELS			
CLOUD/SNOW DISCRIMINATION CLOUDTOP PHASE (ICE/WATER) PLANT STRESS	1.6 μM	---------------------			

Table 3-11. Improvement in Sounders

INFRARED
HIRS/2 FOV: 15 KM VERTICAL RESOLUTION: 5 KM NO. OF CHANNELS: 20 TECHNOLOGY: FILTER SPECTROMETER 20 CM^{-1} SPECTRAL RESOLUTION DETECTOR TEMPERATURE 105°K
AMTS FOV: 10 KM VERTICAL RESOLUTION: 2.5 KM NO. OF CHANNELS: 28 TECHNOLOGY: 0.5 TO 2.5 CM^{-1} SPECTRAL RESOLUTION GRATING SPECTROMETER DETECTOR TEMPERATURE 80°K
HIS FOV: 10 KM VERTICAL RESOLUTION: 2.5 KM TECHNOLOGY: 1CM^{-1} INTEFEROMETER (PARTIAL SCANNING)

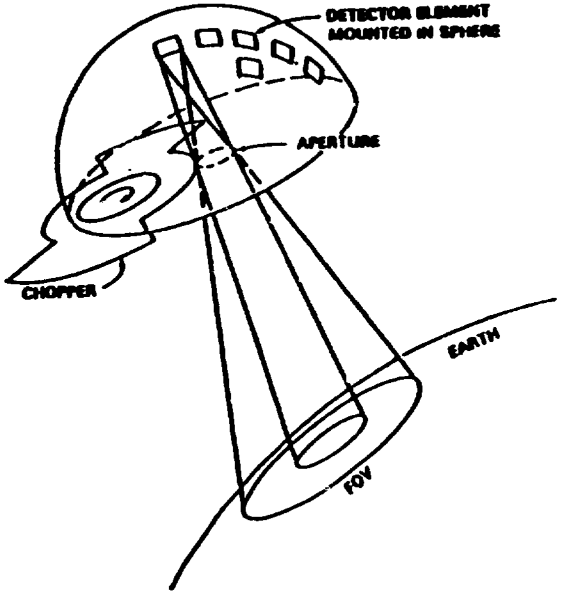
Table 3-12. Improvement in Sounders

MICROWAVE
MSU
FOV: 100 KM
CHANNELS: 4 IN 50-60 GHz BAND
PARAMETERS: TEMPERATURE PROFILES IN TROPSOPHERE
AMSU
CHANNELS (FOV): 18, 22, 31 GHz (50 KM) 11 IN 50-60 GHz BAND (50 KM) 94 GHz (20 KM) 4 IN 183 GHz BAND (20 KM)
PARAMETERS: TROPOSPHERIC TEMP AND HUMIDITY PROFILE HIGH RESOLUTION STRATOSPHERIC TEMP PROFILE ATMOSPHERIC WATER VAPOR (TOTAL) CLOUD LIQUID WATER PRECIP OVER OCEAN

instrument has already been selected by NOAA and NASA as an R&D experiment on NOAA H or I to be followed by operational use thereafter. Because of its size and required power, AMSU could not be mounted in addition to all of the required instruments. This point is considered below.

c. <u>Earth Radiation Budget Monitoring</u>. The earth radiation budget measurements that will come out of the ERBI instrument are based primarily upon wide field-of-view (WFOV) measurements to provide global budgets and narrow field-of-view (NFOV) measurements to provide geographic distribution. The NFOV measurements are made by radiometers which scan linearly across the downward hemisphere, mostly across the satellite track. Since the radiance emanating from any point on earth depends (sometimes strongly) on direction, a linear scan will develop a bias in that certain directions will be ignored. To compensate for the scan bias angular models are applied, based upon the earlier experiment on Nimbus 7 and on theoretical calculations. To the extent that the angular models do not adequately compensate for the bias, the residual error may be too large. Therefore, a new instrument is being developed, which senses uniformly within the downward hemisphere, completely avoiding any scan bias. It has the further advantage of being an array of fixed sensors and thus avoids mechanical scanning, which could limit the life of such instruments. This instrument is in an early developmental stage, but could become available in the mid-80's. The key features are shown on figure 3-18.

d. <u>Spacecraft Design Considerations and Launch Readiness</u>. The current spacecraft design limits our ability to meet the requirements as they evolve beyond the mid-80's. At some point a new spacecraft will be required to meet expanding requirements and to effectively utilize the shuttle launch capability. Initially, the follow-on series will begin with a spacecraft identical to NOAA G, which is of



LOW ORBITING POLAR SATELLITES

HEMISPHERICAL, FIXED-ARRAY SENSORS TO YIELD FULL ANGULAR DISTRIBUTION, 2 X DAILY PER SATELLITE.

GEOSYNCHRONOUS SATELLITES

EARTH RADIATION BUDGET CHANNELS TO MEASURE DIURNAL VARIATION AT FIXED VIEWING ANGLES.

DATA PROCESSING

SORT DATA ACCORDING TO TARGET AREA. AT EACH TARGET AREA, INTEGRATE POLAR SATELLITE MEASUREMENTS OVER VIEWING ANGLES TO GET FLUX AND THEN APPLY DIURNAL CORRECTION BASED UPON GEOSYNCHRONOUS MEASUREMENTS.

ADVANTAGES OVER EARLIER SYSTEMS

FIXED-ARRAY SENSORS PROVIDES HEMISPHERICAL SCAN WITHOUT MEHCANICAL MOTION -- HENCE, LONG LIFE.

WIDE AND NARROW FOV MEASUREMENTS ARE MADE SIMULTANEOUSLY USING THE SAME SENSOR ARRAY -- HENCE, GLOBALLY INTEGRATED ERB COMPONENTS ARE CONSISTENT WITH THE REGIONAL COMPONENTS.

DATA OVER THE ENTIRE HEMISPHERE OF VIEWING ANGLES AND OVER THE ENTIRE DIURNAL CYCLE MAKE DATA PROCESSING STRAIGHTFORWARD -- NO NEED TO ADOPT ANGULAR AND DIURNAL MODELS.

Figure 3-18. Advanced Earth Radiation Budget Monitoring System the ATN (Advanced TIROS N) design that makes its debut with NOAA E (in order to accommodate SAR).

Although the nominal launch schedule calls for the first satellite in the follow-on series (NOAA H) to be launched in 1986, NOAA has placed a requirement for it to be ready in 1984 to serve as backup for NOAA G and to allow for the possibility of one additional failure. Since a new spacecraft could not be ready prior to 1986 (according to estimates by the TIROS Project Office) it has more or less been decided that both NOAA H and I would continue with the ATN design, and a new spacecraft would not be introduced prior to NOAA J.

On the basis that the NOAA H and I satellites would continue with the ATN design, the TIROS Project Office conducted a study to determine what payload could be accommodated, taking into consideration the physical and electric power limitations of the spacecraft. The results of this study are contained in a memorandum entitled, "NOAA H and I Payloads", from Andrew McCulloch (TIROS Instrument Scientist) to the TIROS Deputy Project Manager/Technical, dated April 18, 1980.

The starting point of this study is the set of requirements listed above plus the desire to fly AMSU, it being the only instrument selected by NASA and NOAA for an R&D mission. It turned out that the spacecraft could not accommodate all of the required instruments plus AMSU. The key restriction was physical space to mount all of the instruments and provide the required unobstructed views of earth and space (for calibration). Insufficient power was another factor. A trade-off analysis was then carried out involving four instruments considered least important: AMSU, SAR, SBUV, and ERBI. The results are shown in table 3-13. There are six non-trivial options. The first is identical to NOAA G, which, of course, can be done. The second is the desired option of flying all four instruments, which cannot be done for the reasons mentioned above. The remaining options

Table 3-13. Instrument Trade-Off Analysis: NOAA H & I Options

NOAA H & I OPTIONS						
OPTION	AMSU	SAR	SBUV	ERBE	END-OF-LIFE PWR DEFICIT* (WATTS)	COMMENTS
1	NO	YES	YES	YES	NONE	IDENTICAL TO NOAA G
2	YES	YES	YES	YES	-84	INSUFFICIENT ROOM AND POWER ON S/C
3	YES	YES	NO	YES	-72	INSUFFICIENT ROOM ON S/C
4	YES	NO	YES	YES	-19	INSUFFICIENT ROOM ON S/C
5	YES	NO	NO	YES	-7	CAN BE DONE
6	YES	YES	YES	NO	-44	CAN BE DONE WITH POWER BUDGETING

*75 WATTS MORE POWER AVAILABLE AT BEGINNING-OF-LIFE consider keeping AMSU but dropping one or more of the others. It turns out that the only viable options involve deleting:

AMSU or [SAR + SBUV] or ERBI.

Although there will be a power deficit of as much as 44 watts at end-of-life with Option 6 (deletion of ERBI) it is not considered a problem because AMSU can be duty cycled, since it is an R&D instrument. Also, it is possible to turn off MSU and SSU and use AMSU for operational data if it is working properly.

The above considerations have led NOAA to decide on Option 1 for NOAA H and Option 6 for NOAA I (letter Spohn to Greenwood dated April 30, 1980). In effect, H would be identical to G and I would replace ERBI with AMSU.

If NOAA continues to fly two satellites operationally (one in afternoon and one in morning orbits) the deletion of ERBI from NOAA I would mean that when I is operational, earth radiation budget monitoring would be made from only one satellite. That would significantly restrict the diurnal coverage. It is difficult to estimate how seriously it would impair the earth radiation budget estimates because there is insufficient knowledge at this time concerning diurnal variability. To get the required diurnal coverage for the ERBE experiment it was decided to use three satellites: a morning orbit, afternoon orbit, and a non-sun-synchronous satellite that drifts through the diurnal cycle.

One of the options not considered above is deletion of MSU and SSU. This is viable option from the point of view of fitting the instruments on the spacecraft, although there may remain a small power deficit that could be eliminated with a reduced duty cycle for one or more instruments. The functions of the deleted instruments could be

> borne by AMSU, which will actually replace MSU and SSU on the subsequent satellites in the follow-on series.
>
> NOAA argues against deletion of MSU and SSU on the grounds that AMSU is an R&D instrument on which they cannot rely for operational data. They further argue that AMSU may slip in schedule and therefore they must be prepared to launch I without AMSU. Arking does not consider either of these arguments compelling. The distinction between operational and R&D instruments is simply a question of who pays for it, NASA or NOAA. By the time AMSU is launched on NOAA I, an identical instrument will have been built and integrated onto NOAA J without the MSU and SSU as backup. (It should be noted that J will be the backup to I and must be ready for launch within four months of I, if current policy continues.) On the second argument, concerning slip in AMSU schedule, one can protect against it by building the MSU and SSU as backup instruments, and when and if it becomes apparent that AMSU will not meet the schedule, then a decision could be made to fly MSU and SSU instead of AMSU.
>
> Arking concluded that earth radiation budget monitoring is sufficiently important that it not be deleted from I. The alternative, of deleting MSU and SSU, with the proviso stated above -- that they be prepared as backup if AMSU misses the schedule -- is strongly preferred.

Dr. Miller did not speak at the meeting, but he distributed an informal paper on operational meteorological satellites summarized here.

An operational meteorological satellite system has three primary objectives. The first is to view the global atmosphere regularly and reliably both day and night, providing direct readout of data to local ground stations. Such a satellite system should also regularly and reliably sound the global atmosphere to provide quantitative information for use in numerical weather prediction. Finally, weather features must be continuously viewed, the satellite system being supplemented by fixed and mobile platforms from which the satellites collect and relay meteorological data.

The remainder of Dr. Miller's presentation concerned the polar orbiting satellite subsystem namely the TIROS-N series of operational spacecraft. Figure 3-19 shows the system from data collection by the satellites to the ground stations and the user community.

The primary instrument system of TIROS-N includes the AVHRR, a data collection system, a space environmental monitor, and a TIROS operational vertical sounder, which in turn includes HIRS/2 and the stratospheric and mesopheric sounder units. This instrument complement gives the TIROS-N system the capabilities listed below:

a. Day and night image (AVHRR) information on cloud cover distribution, cloud top temperature, moisture patterns, and ice, snow and surface temperature. Provision of these data globally twice daily for central processing, to APT and HRPT stations.

b. Vertical temperature and moisture profiles of the atmosphere, provided globally, with continuous real-time transmission of radiance to local stations.

c. Collection of meteorological data from fixed and free-floating in-situ platforms.

d. Measurements of proton and electron flux density and total particulate energy deposition.

The capabilities of the data handling system are nearly as important to the user community as the data itself. The key concepts and systems for TIROS-N are level 1B processing, mapping and gridding, quantitative processing, determining soundings, external user support, data base and archiving. Level 1B processing gives calibrated and located data, which are used in

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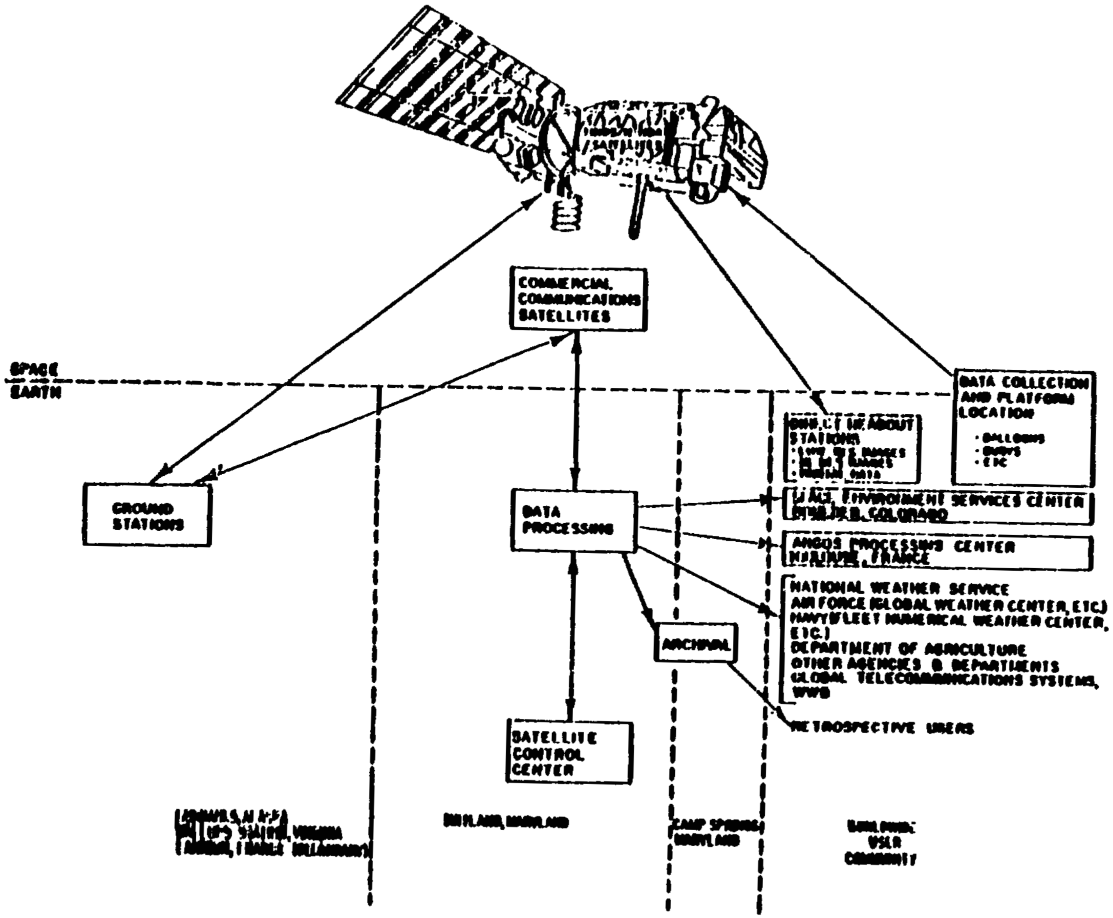

Figure 3-19. Polar Orbiting Satellite Subsystem

the gridding and mapping routines. The initial quantitative products will be as listed below:

INITIAL QUANTITATIVE PRODUCTS

a. Sounding

Tropospheric Layer Mean Temperature
Precipitable Water
Stratospheric Layer Mean Temperature
Tropopause Temperature
Clear Radiances
Total Ozone
Cloud Height and Amount

b. Sea Surface Temperature

Sea Surface Temperature 50GHz Resolution Observation
Global Objective Analysis (One Degree Grid)
Regional Scale Analysis (Five Degree Grid)
Climatic Scale Analysis (Five Degree Grid)
Monthly Mean Analysis

c. Heat Budget

Day/Night Longwave Flux
Reflected Energy
Available Solar Energy

The launch schedule for the TIROS-N system was presented (see Figure 3-20). The changes in the instrument complement for the advanced TIROS-N satellites are listed below:

ADVANCED TIROS-N

a. NOAA-E (1982?)

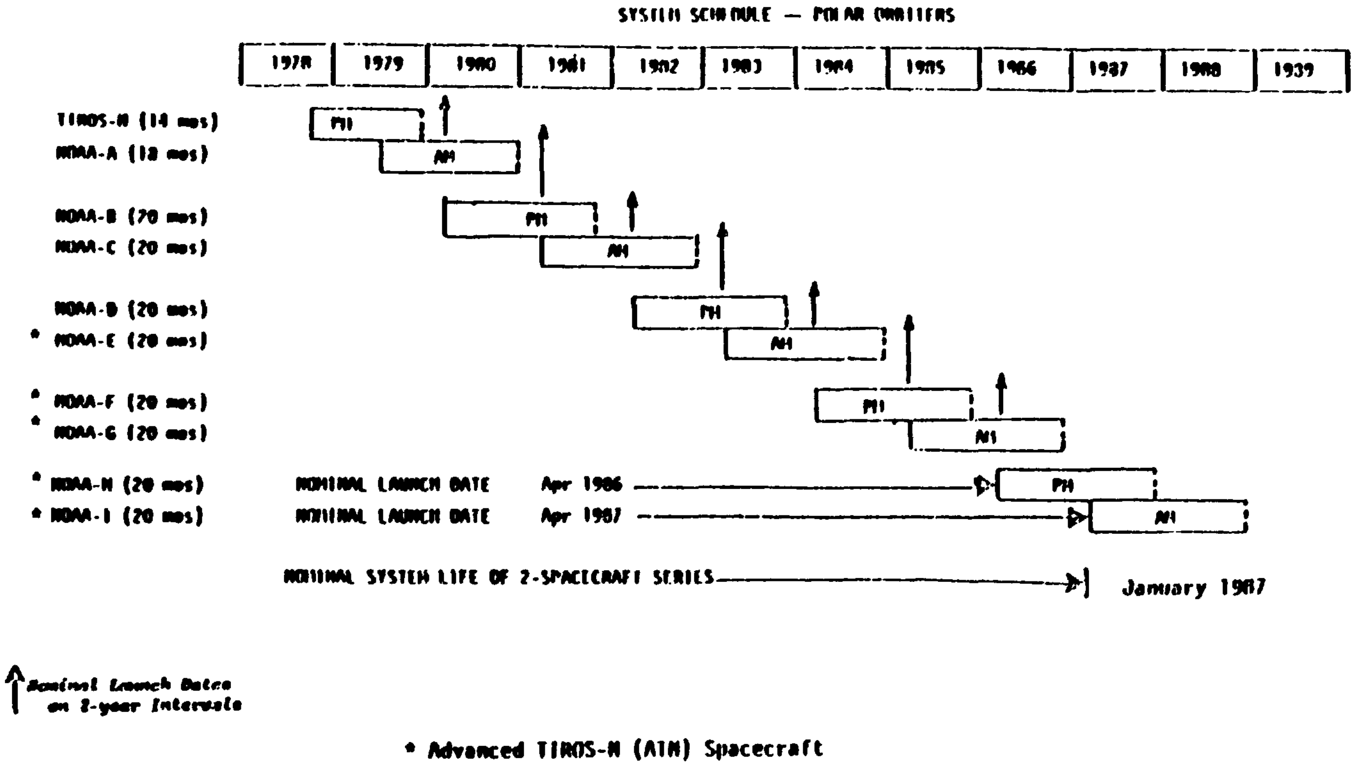

Figure 3-20. Launch Schedule for TIROS-N System

b. NOAA-F and -G (1984, 1985)

-- ADD SBUV: Ozone Monitor
-- ADD ERBE: Radiation Balance Experiment
-- Some HIRS/2 Improvements

c. NOAA-H (1986)

-- Same as NOAA-G Less ERBE

d. NOAA-I (1987)

-- Same as NOAA-H Plus Prototype AMSU
-- AMSU Replaces SSU and MSU

GENERAL CLIMATE OBSERVING SYSTEM OF THE 1990's

Dr. Atlas spoke on the concept of a global climate observing system (GCOS) to be implemented during the 1990's. He introduced his topic by surveying the major assumptions and considerations that went into this Global Climate Observing System (GCOS) concept and by referencing the major background documents implicit in this presentation. One major consideration was that the need for long-term (decades) sets of data made the data acquisition a quasi-operational problem. Taking this as a springboard, Atlas summarized the climatically relevant considerations from a prior paper "Visions of the Future Operational Meteorological Satellite System". This included a description of the need for, and the outlook for both Low Earth Orbiters (LEOS) and the Geosynchronous Earth Orbiters (GEOS) and networks of in-situ sensors. The meteorological and climatological data processing problems were touched on and the advantages and disadvantages of some aspects of the proposed GCOS were compared.

The goals of the climate program, especially as they affect the space-sensing portion include: (1) producing a long term global climatology of contributing boundary forcing parameters, and corresponding response variables, as a step in diagnosing, understanding and predicting climatic variations as well as initializing and validating models; (2) the monitoring of weather and climate as it applies to climate nowcasting and impact assessment, i.e., the effects on energy, food, water resources, etc; and (3) the monitoring for long term climatic changes such as the effects of CO_2 increase.

It is important that a target framework be set now for 1990's GCOS. Since there is no chance for a completely new, climate-dedicated observing system, it must evolve from existing and planned satellite systems (plus in-situ networks, etc.). Consequently, space systems being designed now will be building blocks of the GCOS. These building blocks will fit together only if they are designed to do so. Hence, a target framework is needed now to assure the creation of a solid framework for the next decade's GCOS. Finally, when one realizes that the climate research activity will cover decades, it is clear that it is a quasi-operational problem, and that the GCOS framework must be built around operational observing systems.

The points of departure for this GCOS concept include the documents and plans for various NASA and DoD satellites; the reports of the NASA climate special study workshops; the Atlas et al. EASCON paper, "Visions of the Future Operational Meteorological Satellite System"; the various instrument and/or system feasibility studies for precipitation, soil moisture, etc.; and the latest National Climate Program plans.

A GCOS has to reflect basic climate data considerations. As mentioned before, the data must cover a long time span with minimal gaps. It is also important that the climate measurements have no unknown systematic biases, although random errors are more tolerable, since the climatological datum will typically be an average of many measurements. In a similar vein, absolute measurement accuracy may not be as critical to climate measurements as long term precision. The requirement for precision, however obtained, will put a premium on absolute and transfer standards and calibration techniques, on instrument intercomparisons, on regular supporting ground truth measurements and on possible instrument recovery and recalibration after flight. While the coverage and repeatability provided by satellite-borne sensors is important for the climate program, determining some parameters may require that remote sensors be used in conjunction with in-situ ground networks or with drifting sensors (buoys, balloons) to provide the necessary data accuracy or precision. Finally, the need for adequate and timely data processing of climate parameters is well known.

Two types of satellite platforms are envisioned, the Low Earth Orbiters (LEOS) and the Geosynchronous Earth Orbiters (GEOS), as part of an integrated climate observing system. Eight LEOS are considered, each about 565 km altitude, and distributed into four polar orbit planes 45^{0} apart. Each orbit plane would contain two LEOS. Functionally, four LEOS would be mainly for NOAA/DoD meteorological and climate purposes, two for oceans and cryospheres, and two for NASA research. Also, the operational Landsat could be part of the low orbiting GCOS. The low orbits might allow shuttle retrieval and instrument recalibration with a consequent lower instrument lifetime costs, higher sensor resolution for a given aperture (this is particularly important for microwave instruments) and the possibility of usefully incorporating active sensors.

The GEOS platforms would provide full disk imaging at least every ½ hour with options for providing local and regional scale images with a correspondingly greater rapidity. It would also serve as a communication link from the LEOS and either directly or indirectly, from in-situ sensors. The GEOS would be directly useful in several cloud-related determinations; in inferring some climate parameters from time or space derivations, such as the surface heat capacity and its relation to soil moisture, and in studying local and regional climate and processes.

It was noted that some of the satellites in this scheme may be flown and operated by nations other than the United States.

The present outlook for LEOS assumes that the basic nature of operational meteorology and Landsat programs will be maintained. The present DMSP/NOAA LEOS series will extend at least through 1987 with new procurements required in the later 1980's. Then the NOAA, DMSP, operational Landsat and the NOSS programs may merge into an integrated operational system. A large shuttle-class operational bus for the 1990's may be available from the NOSS program, and may thereby dominate spacecraft configurations for a significant time afterward. There is no significant current effort on GEOS. The NASA 5 year plan shows a possible new start in FY 1984 with the earliest implementation occuring in 1988/1989. This outlook emphasizes the need for an overall strategy to achieve an integrated operational/research GCOS.

A recently completed convergence study on integrating the NOAA and DoD operational meteorological satellites suggested a constellation of sun-synchronous satellites in several orbital planes, in contrast to the polar-orbiting LEOS discussed above. Although three orbit planes were suggested for the present operational requirements, when a future merging of the operational Landsat and of NOSS with the meteorological satellites occurs, it is likely that the resulting system could evolve to an operation utilizing four symmetrically arranged orbit planes. This final result could be similar in spacing to that proposed for the GCOS. Also, future operational systems may employ an in-orbit spare resulting in two satellites in each orbit plane. Some trade-offs involved in two versus one satellite per orbit plane are shown in table 3-14.

One proposed data management system was described (see figure 3-21). For COSS purposes, the important thing to note is that the climate data management center is an integral part of the entire operational data system, and

Table 3-14, Tradeoffs - Two vs. One Satellite Per Orbit Plane

SWATH (DEGREES AT EQUATOR)	24	26	28	30
(ORBITS/DAY//PERIOD-MIN)	(15/96)			(12/120)
ALTITUDE (KILOMETERS)	550	950	1325	1680
MAXIMUM ZENITH ANGLE (FULL/HALF SWATH)	74.4/54.6	65.2/42.6	59.6/36.6	56.0/33.1
MAXIMUM SCAN ANGLE (FULL/HALF SWATH)	62.4/48.6	52.2/36.1	45.6/29.6	41.0/25.6
MAXIMUM FOOTPRINT RATIO (FULL/HALF SWATH)	10.2/2.8	4.6/1.8	3.2/1.5	2.7/1.4
NORMALIZED ALTITUDE/550 KM	1.0	1.73	2.41	3.05
NORMALIZED APERTURE AREA/550KM	1.0	2.99	5.81	9.30

ADVANTAGES OF TWO SATELLITES/ORBIT PLANE AT 550 KM

- GREATLY REDUCED SENSING APERATURE FOR A GIVEN RESOL
- REDUCED PROPULSION FOR SHUTTLE DEPLOYMENT AND RETRIEVAL
- DOUBLE COVERAGE FOR NADIR ONLY SENSORS
- ON-LINE REDUNDANCY (2 DAY GLOBAL COVERAGE)

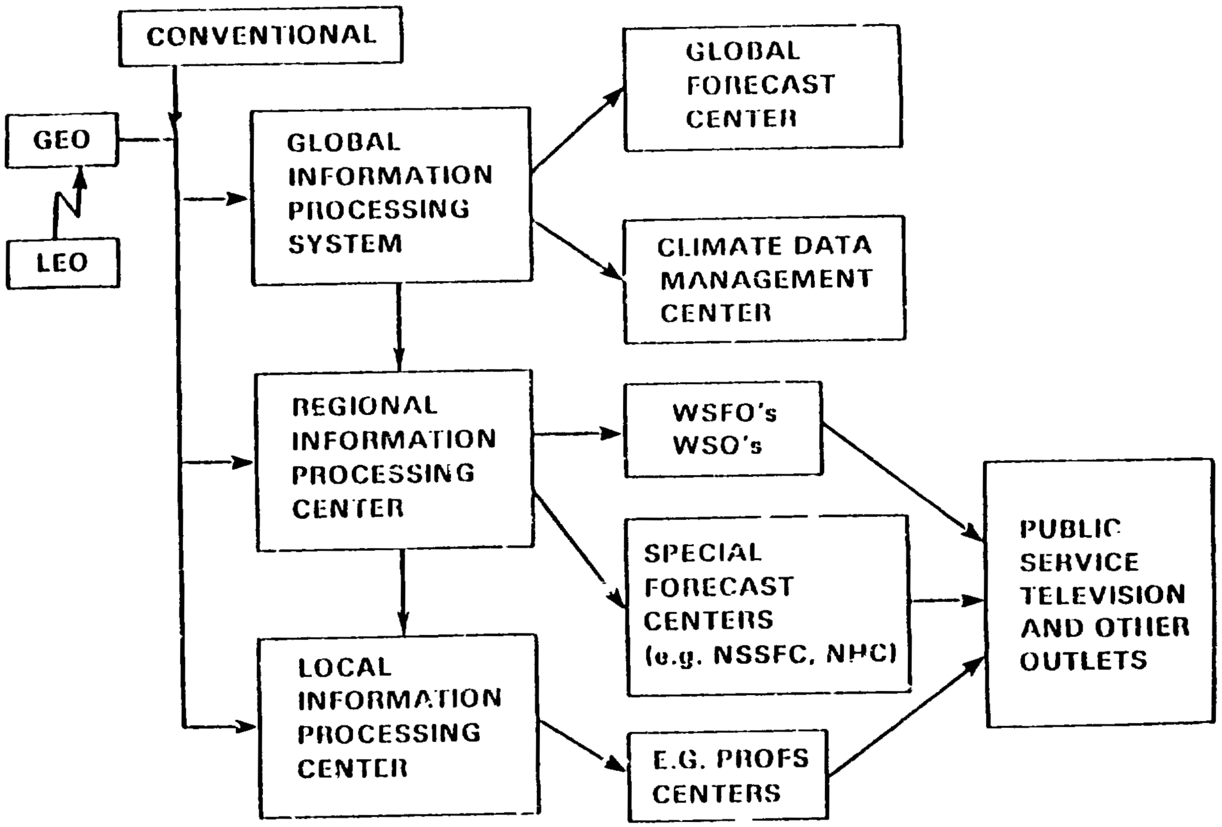

Figure 3-21. GCOS Data Management System

it would acquire its data at the same time as the global forecast center. This is essential to prevent large backlogs of data from piling up.

In conclusion, the GCOS must be combined with operational systems to the greatest extent possible. The candidate system presented shows a reasonable approach, meets the full spectrum of operational and climate needs and forms a framework for the future. Within this framework there are advantages and disadvantages to the symmetric, low orbit, 8 satellite system and several paths to be considered in an actual implementation. It is important to set the over-all GCOS framework now; otherwise the GCOS building blocks, which are the current and the planned satellites, will not fit into an integrated system.

REACTIVE PRESENTATIONS AND MODELLING NEEDS

At the evening session, Dr. Leith, Dr. Hansen, and Professor Gates were asked to give their initial reactions to the programs and recommendations made earlier.

Dr. Leith began by offering one definition of climate as being the statistical properties of the weather and emphasizing that it is the fluctuations of these statistical properties which are of primary interest.

The variable which best defines the slowly evolving state of the atmosphere for dynamic purposes is the quasi-geostrophic geopotential vorticity. A rule of thumb for relating an error in a wind observation to an error in the temperature observation is to make them roughly equivalent in the weight they carry in determining this quantity. For cyclonic scales 1K error in temperature is roughly equivalent to an error in wind of 2 m/sec. Wind information becomes more useful than temperature as one moves toward the tropics, and toward smaller scales. Wind information at 2 m/sec error carries information which is equal to or better than temperature information at 1K everywhere except for the very largest scales of the ocean and atmosphere. Lidar may provide wind observations on the order of a

0.5 m/sec equivalent to a temperature of ½K to ¼K. Present temperature sounding schemes are running around 2-3K.

There are a number of areas which show up in every description of climate programs. There are two principal areas of concern that have been discussed for several years.

One of them has to do with cloud radiation interaction and the importance of possible feedback mechanisms relating clouds and temperature changes. The feedback mechanisms will modify the sensitivity of the climate system to any kind of external forcing such as changing CO_2 amounts. Modelling meteorologists have been trying to form some judgement about their confidence in the results which are coming out of their model sensitivity studies, which are directed toward estimating the sensitivity of the real atmosphere in response to such things as CO_2 doubling.

The complicated interactions between clouds and radiation fields have become a hot topic recently. In order to understand these phenomena, the first necessary step is the appropriate observation. As we know, the internationally organized cloud climatology project has been formed to define clouds in terms of the infrared radiated properties from the top of the clouds and cloud albedo. The climate system is very sensitive to very high and very low clouds. Middle cloud IR and visible radiation effects tend to compensate. Research on the marine boundary layer status would be useful.

The next big topic which has also been discussed for some years, in connection with the climate system is the ocean-climate connection. The ocean serves as a kind of regulator for climate. People recognize the importance of the ocean as a heat transport mechanism in the overall energy budget for the Earth because of the fact that the sizeable part of the heat exported from the equatorial regions toward the poles is being transported not by the atmosphere, but by the ocean.

One of the increasing interests in the climate community is the land-surface connection and its impact on climate. There have been many discussions on its physics, which heavily involves the energy balance of the Earth's surface evaporation, evapotranspiration, and effective vegetation soil moisture, etc. Some of the points seriously considered:

a. Numerical experiments have shown regional climates to be impacted by albedo and soil moisture.

b. Evidence exists that indicates regional climates are affected by the continental boundary layers.

c. It may be conjectured that quasi-independent regional climates may make up the climate as a whole.

d. The hydrological cycle is a very important part of the energy cycle. The atmosphere is a steam engine rather than a heat engine. Latent heat release measurements are needed.

e. Soil moisture variations have time scales ranging from weeks to months.

Other climate factors to be considered in the Earth climate are:

a. CO_2 cycle, and other important trace gas cycles.

b. Solar-terrestrial interaction may be significant on scales greater than a century.

A composite climate observing system, as proposed by Dr. Atlas and others, seems to be an appropriate approach to solve the sophisticated climate problems in the late 80's and early 90's.

As a beginning, we must extract every bit of information from the existing data bank by developing software to learn how to use the available data sets. It is also worthwhile to use a General Circulation Model to simulate the satellite observing system if a set of data orbit information, desired sampling frequency, etc. are given. The information resulting from this simulation would be useful for studies of the composite climate observing system.

The next speaker was Dr. Hansen of the Goddard Institute of Space Studies. After having listened to the day's presentations, he suggested three areas of priority activity. The first thing to be done is to coordinate the existing and planned data and improve their useability. This is mainly a software job that would define and implement on-line data reduction and compaction schemes, especially for visible and infrared satellite imagery, to provide good Level II data sets. Such software activity is particularly relevant to cloud data sets, precipitation, snow cover, ice cover, and so forth. The different data sets should be coordinated and documented to assure the compatibility of imaging on different satellites and finally, climate data needs should be factored into the observing and processing systems of other programs.

A second area of activity is to improve current measurements of such parameters as were discussed in the section "Key climate parameters difficult to measure."

The third priority, Dr. Hansen continued, would be such new business as the improvement of current measurement capability, the enhancement for climate studies of the payloads on planned satellites, and the definition of new candidate satellite observing systems.

The last speaker was Professor Gates from Oregon State University, whose remarks are summarized below.

In the background of current research on the problem on climate are two general questions: Do we understand the mechanics of a changing climate?, and Do we know whether the Earth's climate is predictable or not? The only responsible answer to both of these questions at the present time is no.

The importance of finding a better answer for the management of man's future resources, however, fully justifies the vigorous theoretical, diagnostic and observational climate research programs now underway in a variety of quarters.

It is widely recognized that the climate is a complex system, consisting of interacting atmospheric, oceanic, cryospheric, land surface and biotic components over a wide range of space and time scales. Although we understand the physical nature of each component reasonably well, we have very little knowledge of the system's coupled dynamics, and virtually no knowledge of the processes governing the system's long-term variations. Climate models have illuminated the role of several important feedback mechanisms, such as that between surface temperature and albedo, and models have been widely used in the study of the equilibrium climate's sensitivity to major changes in the atmospheric boundary conditions, such as changes of ocean surface temperature, ice-sheet distribution or atmospheric CO_2 concentration. Climate models, however, have not yet succeeded in simulating a specific time-dependent change of climate, such as a forecast of the climate of a specific season or year. The diagnostic study of observed data suggests that a large portion of such climate changes are the result of essentially random and therefore unpredictable fluctuations of the atmosphere. Much of current climate research is thus aimed at the identification of the potentially-predictable portion of climate change, which may turn out to be small but nevertheless of great value.

Basic to all climate research, however, are our observations of the structure and behavior of the actual climate. Our knowledge of even primary climatic variables such as wind, cloudiness and precipitation is inadequate over much of the Earth, while other processes both within and without the climate system go completely unobserved. A sustained and systematic global climate observing system is thus an obviously essential element of any comprehensive climate research program. The uniquely global coverage of satellite-based observing systems, moreover, strongly suggests that they will provide and increasingly large share of the data necessary for our future understanding of the structure and predictability of climate.

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APPENDIX A. AGENDA AND PARTICIPANTS

APPENDIX A. AGENDA

1st Climate Observing System Workshop
February 21-22, 1980--Goddard Space Flight Center
(Building 21, Room 183)

		Lead Speakers
Start 8:30 a.m. February 21 - Introductory Remarks -		
8:40	Suggestions for the formulation of an observing system development strategy consistent with the National Climate Plan	Edward Epstein (NCPO)
9:10	Philosophy and key elements of an evolutionary program for the development and use of a climate observing system.	Verner Suomi (U. of Wisc.)
9:55	Coffee	
10:05	Exploiting existing operational and research satellites for climate purposes	Tom Vonder Haar (Colo. St. Univ.)
10:50	Land, hydrology, and vegetation	Vincent Salomonson (GSFC)
12:00-1:00	Lunch	
1:00	First cut of an oceans climate monitoring system	Francis Bretherton (NCAR)
1:45	National Oceanographic Satellite System as it relates to ocean climate monitoring	Jim Mueller (GSFC)
2:00	Cryospheric climate monitoring	Jay Zwally (GSFC)
2:25	Coffee	
2:35	Stepwise improvements to the operational meteorological satellite system for climatic purposes	Harold Yates (NOAA/NESS) Al Arking (GSFC) Don Miller (NOAA/NESS)
3:15	Uses of Operational Radiation Budget Data in Climate Analysis	Jay Winston (NOAA/NWS)

AGENDA (cont.)

3:30	Status Report on Operational Radiation Budget Data Sets	P.K. Rao (NOAA/NESS)
3:45	Key climate parameters difficult to measure (12 minutes each speaker plus 5 minute discussion)	
	a. Precipitation	Tom Wilheit (GSFC)
	b. Soil Moisture	Tom Schmugge (GSFC)
	c. Ocean boundary layer, S.S.T. and Air-Sea Interactions	M. Chahine (JPL) C. Prabhakara (GSFC)
	d. Winds	Harvey Melfi (GFSC/ Earth Observations Systems Division)
4:50	Toward a Global Climate Observing System of the 1990's	David Atlas (GSFC)
5:30	Open Discussion	
5:45	Social	
6:15-7:30	Dinner	
7:30	Initial reactions --Are we on track?	Cecil Leith (NCAR) James Hansen (GISS) Larry Gates (Oregon St. Univ.)
	OPEN DISCUSSION	
9:30	Recess	

<u>February 22</u>

8:30-11:00	Divide into working groups to prepare summary findings and initial recommendations; identify subjects which need further study

AGENDA (cont.)

11:00- 12:00	Presentation and discussion of summaries
12:15- 1:15	Lunch
1:15- 3:00	Identify problems, formulate study plan and task assignments for follow-up activity
3:00	Adjourn

WORKSHOP ATTENDANCE

Participants, Ex-Officio Members, and Attendees

Dr. David Atlas (Chairman)
NASA/GLAS

Dr. Herb Jacobowitz
NOAA/NESS

Dr. W. Larry Gates
Oregon St. Univ.

**Mr. M.L. Garbacz
NASA/RET

Dr. Robert A. Schiffer
NASA HQ

*Dr. Stan Wilson
NASA HQ

Dr. J. Susskind
NASA/GLAS

Dr. Edward S. Epstein
NCPO

*Dr. Ichtiaque Rasool
NASA HQ

Dr. P.K. Rao
NOAA/NESS

Dr. Cecil Leith
NCAR

Dr. C. Prabhakara
NASA/GLAS

Dr. E. M. Rasmusson
NOAA/CAC

Dr. M.T. Chahine
JPL

Dr. Larry Stowe
NOAA/NESS

Dr. J. W. Siry
NASA/GSFC

**Dr. Edward A. Wolff
NASA/GSFC

Dr. K.H. Bergman
NSF

Mr. William R. Bandeen
NASA/GSFC

Dr. Jim Gatlin
NASA/GSFC

Mr. A. Gruber
NOAA/NESS

Prof. Tom Vonder Haar
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Dr. Albert Arking
NASA/GSFC

Dr. Lewis D. Kaplan
NASA/GSFC

Prof. Vern Suomi
Univ. of Wisconsin

Mr. Otto W. Thiele
NASA/GSFC

***Ex-Officio Members**
**Other Attendees

*Dr. S. G. Tilford
NASA HQ

Mr. Fred Flatow
NASA/GSFC

*Mr. John Theon
NASA HQ

Mr. Charles R. Laughlin
NASA/GSFC

Dr. Fritz Vonbun
NASA/GSFC

Dr. Harold Yates
NOAA/NESS

Dr. Jagadish Shukla
NASA/GSFC

Dr. Milton Halem
NASA/GSFC

Dr. Francis Bretherton
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**Dr. John Stanford
NASA/GLAS

Dr. James Coakley
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Mr. E.F. Harrison
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Dr. James Hansen
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Dr. Jay S. Winston
NOAA/NWS

Dr. Vincent V. Salomonson
NASA/GSFC

Dr. Jay Zwally
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Dr. Joe Otterman
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Mr. Marvin S. Maxwell
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**Dr. James Sparkman
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Dr. Tom Wilheit
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Lieut. Col. Walter Meyer
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**Dr. James C. Shiue
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APPENDIX B. CLIMATE SOURCE DOCUMENTS

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Below are listed documents, not previously referenced in this report, which are of general interest as background sources for climate research.

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APPENDIX C. ABBREVIATIONS AND ACRONYMS

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ACR	Active Cavity Radiometer
ADS	Applications Data Service
AEM	Atmosphere Explorer Mission
AIT	Advanced Information Transmission
ALT	Radar Altimeter
AMSU	Advanced Microwave Sounding Unit
AMTS	Advanced Moisture and Temperature Sounder $\lambda/\Delta\lambda \sim 1200$
APT	Automatic Picture Transmission
ARC	Ames Research Center (NASA)
AVHRR	Advanced Very High Resolution Radiometer
AVHRR-3	Advanced Very High Resolution Radiometer With Added Channels (e.g., 6.7 μm, 18 μm, or 1.6 μ m, etc.)
AVHRR-X	A version of AVHRR with a "split" IR window channel
AXET	Atmospheric X-Ray Emission Telescope
CCT	Computer Compatible Tape
CFM	Clorofluoromethane
COSS	Climate Observing System Study
CZCS	Coastal Zone Color Scanner
DCP	Data Collection Platform
DCPLS	Data Collection and Platform Location System
DCR (TROP)	Differential Correlation Radiometer (Troposphere)
DMSP	Defense Meteorological Satellite Program
DNSPRB	DOC-NASA Satellite Program Review Board
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOMSAT	Domestic Communications Satellite

DST	Data Systems Test (GARP Test Data)
EPOCS	Equatorial Pacific Ocean Climate Studies (NOAA)
ERB	Earth Radiation Budget
ERBE	Earth Radiation Budget Experiment
ERBI	Earth Radiation Budget Instrument
ERL	Environmental Research Laboratories (NOAA)
ESMR	Electrically Scanning Microwave Radiometer
GAMETAG	Global Atmospheric Measurement of Tropospheric Aerosols and Gases
GARP	Global Atmospheric Research Program
GCM	General Circulation Model
GEO	Geostationary Earth Orbiter
GISS	Goddard Institute for Space Studies
GLAS	Goddard Laboratory for Atmospheric Sciences
GPS	Global Positioning System
GRAVE	Global Research on Atmospheric Volcanic Emissions
GSFC	Goddard Space Flight Center
GOES	Geostationary Operational Environmental Satellite
HALOE (STRAT)	Halogen Occulation Experiment (Stratosphere)
HCMM	Heat Capacity Mapping Mission
HDDT	High Density Data Tape
HDT	High Density Tape
HIRS	High Resolution IR Sounder
HRMI	High Resolution Microwave Imager
HRPT	High Resolution Picture Transmission
IBM	International Business Machines
ICEX	Ice and Climate Experiment
IR	Infrared
IRIS	Infrared Interferometer Spectrometer
JPL	Jet Propulsion Laboratory
JSC	Joint WMO/ICSU Scientific Committee
LACATE	Lims with Azimuth Scan
LAMMR	Large Antenna Multifrequency Microwave Radiometer

LANDSAT-TM	Land Satellite Thematic Mapper
LaRC	Langley Research Center
LAS	Laser Absorption Spectrometer
LBMR	L-Band (21 CM Microwave Radiometer)
LEO	Low Earth Orbiter
LIDAR	Light Detection and Ranging
LIDAR (PRESS)	Lidar Pressure Sounder
LIDAR (T&H)	Lidar Temperature and Moisture Sounder
LIDAR (TROP AEROSOLS)	Lidar Aerosol Sensor (Troposphere)
LIDAR (WIND)	Lidar Wind Sensor (Clear Skies)
LIMS	Limb Infrared Monitor of the Stratosphere
MRVM	Medium Resolution Vegetation Mapper
MSS	Multispectral Scanner
MSU	Microwave Sounding Unit
M.W.	Microwave
NASA	National Aeronautics and Space Administration
NAVSAT	Navigation Satellite (Existing System)
NCAR	National Center for Atmospheric Research
NCP	National Climate Program
NESS	National Environmental Satellite Service
NOAA	National Oceanic and Atmospheric Adminstration
NORPAX	North Pacific Experiment
NOSS	National Oceanic Satellite System
NSF	National Science Foundation
OBLIS	Ocean Boundary Layer IR Sensor (Dr. C. Prabhakara Concept)
OGCM	Ocean General Circulation Model
OLS-2	Operational Line Scanner (DMSP)
OSS	Office of Space Sciences
PRECIP RADAR	Precipitation Radar
RTP	Research Test Platform
SAGE	Stratosphere Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar

SBUV (POLAR)	SBUV With Polarization Measuring Capability
SBUV	Solar Backscatter Ultraviolet (Monochromator)
SCAT	Radar Scatterometer
SCLERA	Santa Catalina Laboratory for Experimental Relativity Through Astronomy
SDM	Statistical-Dynamical Model
SEA	Science and Education (Dept. of Agriculture) Research Stations
SEASAT	Sea Satellite
SMMR	Scanning Multichannel Microwave Radiometer
SMM	Solar Maximum Mission
SP	Special Publication
SR	Scanning Radiometer
SRI	Stanford Research Institute
SSH-3	IR Interferometer (Temp. and Moisture Sounder) (DMSP)
SSM-A	Advanced Microwave Radiometer and Scatterometer (DMSP)
SMM-I	Microwave Imager (Precip. Sea Ice, Sea SFC Wind) (DMSP)
SMM-T2	Microwave Temp and Moisture Sounder) (DMSP)
S.S.T.	Sea Surface Temperature
SSV	Multispectral Coherent Lidar (DMSP)
SSW	Coherent Pulse Doppler Lidar (DMSP)
TIROS	Television and Infrared Operational Satellite
SYSTEMS-80-X	Planning Concept for Follow-on TIROS-N and GOES Operational Satellites
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
UARS	Upper Atmosphere Research Satellite
VISSR	Visible and Infrared Spin Scan Radiometer
μWAVE	Microwave
WMO	World Meteorological Organization
WSIR	Wide Swath Imaging Radar