AD-A165 081 OPERATIONAL SATELLITE SUPPORT TO SCIENTIFIC PROGRAMS (U) NATIONAL ENVIRONMENTAL SATELLITE DATA AND INFORMATION SERVICE WASHINGTON DC H W YATES ET AL. MAR 85 1/1

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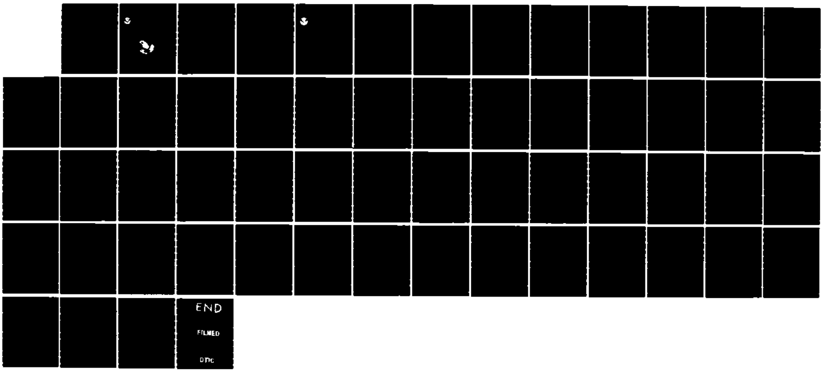

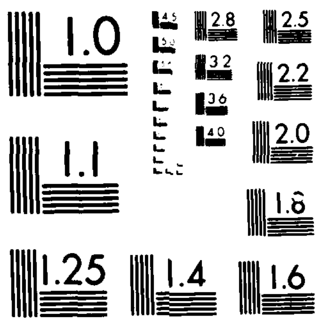

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ENVIROSAT–2000 Report

Operational Satellite Support to Scientific Programs

March 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

UNCLASSIFIED, UNLIMITED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A165 081

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified/unlimited	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for Public Release: Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: National Environmental Satellite, Data & Information Svc. — 6b. OFFICE SYMBOL (If applicable): Exl	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Washington, D.C. 20233	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: National Environmental Satellite, Data and Information Service — 8b. OFFICE SYMBOL (If applicable): Exl	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, D.C. 20233	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Operational Satellite Support to Scientific Programs

12. PERSONAL AUTHOR(S) Yates, H.W.; Cotter, D.J.; Ohring, G.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM ______ TO ______	8503	58

16. SUPPLEMENTARY NOTATION

An ENVIROSAT-2000 Report

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Environmental Satellites, Weather Satellites, National Science Programs, International Science Programs, Environmental Science, Satellite Observations, Remote Sensing

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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NOAA's operational satellites are serving the research community extensively. Research programs such as climate studies, ocean dynamics investigations, and global vegetation surveys benefit from the special characteristics of operational satellites. Among these characteristics are routine global coverage in many spectral intervals; reliability, resulting from a commitment to continue the service; speed in data access because of real-time applications; repeatability of measurements because of matched, calibrated instruments;

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified/unlimited
22a. NAME OF RESPONSIBLE INDIVIDUAL: Daniel J. Cotter	22b. TELEPHONE (Include Area Code): (301) 763-8078 — 22c. OFFICE SYMBOL: NESDIS E/SPD1

19. Abstract (cont.)

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In conclusion, this report shows that the need for operational satellites in science programs ranges from use as a complementary data source, such as for atmospheric temperature structure, to a unique observing tool, such as for global cloud cover, oceanic precipitation, radiation at the top of the atmosphere, and global observations of the cryosphere. For some of the programs cited in the report, satellite data are crucial for success; in some instances, NOAA's operational satellites make the programs possible.

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Operational Satellite Support to Scientific Programs

H. W. Yates, D. J. Cotter, G. Ohring

Washington, D.C.
March 1985

U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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OPERATIONAL SATELLITE SUPPORT TO SCIENTIFIC PROGRAMS

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I. INTRODUCTION

The emerging view of the scientific community is that it is important and possible to study Earth as a system, a task made practical by remote-sensing satellites. The purpose of this report is to examine the value of NOAA's operational satellites to Earth system studies. The contributions of NOAA satellites to past and current science programs are reviewed to determine the characteristics of this NOAA observing system that are important to the success of science and research efforts. Looking ahead to science programs that are in the preimplementation and conceptualization stages, this report provides NOAA and research program planners the opportunity to take better advantage of these characteristics. The report also suggests to these planners new areas for collaboration in the use of operational satellite data.

The aim of science is to understand the workings of the universe and the ways in which its components fit together. The Earth system, made more observable by satellites, offers an accessible laboratory in which basic discoveries can be made that apply to the wider world. These discoveries are worthy objectives in themselves and always lead to human benefits.

Concentrated scientific study of our environment--land, atmosphere, and oceans--is impelled by reasons other than intellectual curiosity. The evidence is overwhelming that civilization is placing dangerous and poorly understood stresses on Earth's capacity to sustain mankind. Every region exhibits nature in distress and every quadrant has human activities that are suspected of contributing to the damage. The problem is global. Geographic boundaries do not exist for natural phenomena. An urgent scientific challenge is to discover and understand the coupling processes that link these phenomena to each other. Science also must separate the natural trends from the perturbations induced by human activities and assess their long-term impact on the environment. The quality of life--and possibly even life itself--will depend upon our ability to plan and control our activities. This can be done intelligently only with a reasonable understanding of the physical forces at work, both natural and anthropogenic.

Technology now makes it possible to undertake studies of the Earth system with some confidence. Computers are available that can handle the volumes of data involved and the enormous demands of the numerical models. Today's communications systems allow data and results to flow between researchers and the operational community at the speeds and in the volumes required.

Science depends on measurements, and the technology of observations has kept pace. Contemporary instruments make it possible to obtain measurements with a coverage and accuracy unanticipated even a few years ago. Satellites are a unique and essential source of instrument data for global environmental studies. They provide a synoptic, global coverage of the Earth system not possible with local arrays of in situ or remote-sensing instruments; the resources to implement such a vast network will never be available. Further, satellites provide coverage that avoids the holes and gaps in the spatial distribution of data that are characteristic of most conventional observing systems. The radiosonde network, for example, was the only source of data on atmospheric temperature structure before operational NOAA satellite sounding instruments were introduced. The network has good coverage over the land masses of affluent North America, Europe, and parts of Asia, but has woefully inadequate coverage of the oceans and the less populated land masses that constitute the bulk of the globe.

Scientists the world over are planning and conducting research programs that depend on the presence of operational satellites for success. Many of these programs are global in scope, requiring detailed international planning and cooperation to achieve their aims. They involve data gathering periods that range from a few days or a season to years for climate research. They all provide for the collection of data by ground-based instruments, both to obtain unique information and to establish reference measurements for comparisons with satellite observations.

Past programs have demonstrated the essential and unique contributions of the operational satellites. The Global Atmospheric Research Program (GARP) and its component experiments of the late 1970's were among the first to test the influence of operational satellite systems on the results of large-scale science programs. The findings of the GARP data evaluations, which continue even today, are that satellites improve the large-scale representations of oceanic and atmospheric states and provide a basis for interpreting smaller scale events and observations. The planning for many new programs gives explicit recognition to this fact, as well as to recent and expected satellite improvements, by including NOAA satellite data as a valuable to indispensible component.

This report examines a number of important national and international science programs that depend on NOAA operational satellite data for success. These science programs also will benefit from the data provided by other U. S. operational satellite systems, such as the Defense Meteorological Satellite Program (DMSP) and Landsat, and from the data of operational satellite systems maintained by other nations. The research satellites of the United States and others will make important contributions too, adding new and specialized dimensions to the data sets available to science. This report, however, centers on NOAA's satellites and their role in science programs.

II. THE ROLE OF OPERATIONAL SATELLITES

Most pressing scientific questions about the Earth system are global in scope and long term in focus. This is especially true of questions that deal with climate. Scientists are observing biospheric conditions that they regard as unnatural--the rapid eutrophication of lakes, the loss of production on crop lands, the toxification of bays and seas, and changes in the ratios of atmospheric constitutents--and they ponder that these are signals of an artificial acceleration in climate change. Reputable scientists see in these events early threats to the continued habitability of the vulnerable regions of Earth, losses that could materialize even in the life spans of inhabitants of these regions.

The resolution of these questions rests on the ability of science to identify and gather the data that bear upon the problems. Accurate evaluations of environmental threats will be based upon the results of this effort. Operational satellites have unique characteristics and capabilities that make their role in this effort that of primary data collector.

The characteristics that make satellites so well suited to this role relate to coverage, reliability, timeliness, repeatability, and data handling.

Coverage. Each polar-orbiting satellite views the whole globe twice each day, while each geostationary satellite repeatedly observes the full disk of Earth in its view throughout the day. Beyond geography, satellite coverage also implies that on-board sensors observe conditions at the surface, in the intervening atmosphere, and at the spacecraft's altitude. These sensor observations are made with high precision in many spectral intervals and over a variety of energy level sensitivities. The volume of data collected is enormous by any standards and, when applied, the data describe existing conditions at a myriad of points and layers within the Earth system. Satellites observe where other measuring tools cannot be used or can be used only infrequently at great labor and expense. Harsh, hidden places are as accessible to satellites as are those that are close and comfortable. In addition to their own instruments, satellites provide for the collection and relay of in situ data from sensor platforms that are fixed or floating in remote areas. Their data collection and relay systems make it possible to track the details or dangers of distant happenings in a timely manner. Satisfying requirements for a global data base is the forte of remote-sensing satellites.

Reliability. Operational satellite systems are designed, planned, and managed to be dependable data sources. There is a national commitment to operate them into the predictable future with regularity and an absence of abrupt design changes that would impact on data users. When improvements are made, existing applications modes are protected. The hallmark of an operational satellite system is that failures result in a temporary reduction in data flow, not a catastrophic or long-lasting cessation.

Timeliness. Observations flow in a continuous broadcast stream from operational satellites, and stored data are offloaded during every passage over a ground control station. Stored data are processed, on line, to the user-product level within minutes of receipt at these ground stations, and are moved into accessible archives within hours or days. Real-time users obtain these data while their value is undiminished, and retrospective users may access the data in time frames that meet their needs.

Repeatability. Satellite data are collected by a small number of identical instruments, carefully matched on the ground and constantly calibrated and compared while in service. The variance in the relative values of the measurements is understood and corrected where possible and when needed by research users; absolute values are referenced to other instruments that are regarded as standards for the application at hand. Operational use does not demand perfect calibration in all cases, but more calibration could be provided if warranted by scientific objectives. Repeatability of satellite measurements is a unique feature in the context of global observing systems. Conventional systems, such as radiosonde networks for atmospheric temperatures, and buoys and bathythermographs for sea surface temperatures, employ thousands of expendable instruments manufactured by numerous United States and foreign producers. Of necessity, these inexpensive instruments are not uniform in their responses or readings, reducing their sensitivity to variances in the parameters they measure. This insensitivity ultimately appears as a kind of instrument noise in their data streams, masking small changes. Satellite sensors, built to higher standards and monitored for performance, can avoid this problem.

Data Handling. NOAA's operational satellites provide data that are required for immediate use in environmental analysis and forecasting. These data are processed, on line, from raw sensor readings to calibrated, geographically referenced data products during the minutes after receipt at central ground stations. In essentially parallel streams, the data products are entered onto the communication links servicing real-time users and the archive function. Products are both digital and analog, and are in formats that are agreed upon and traditional within the user community. The product processing methods are well described in the literature, and the products themselves carry interpretation keys. The data processing histories leading to these products are sufficiently well known to enable a reliable reconstruction of the scene as it was originally observed. Operational users and researchers alike receive data products that they can readily put to use.

III. SATELLITES AVAILABLE TO SUPPORT SCIENCE PROGRAMS

The National Oceanic and Atmospheric Administration (NOAA) manages the civil operational environmental satellite systems of the United States. These include the Polar-orbiting Operational Environmental Satellites (POES), the Geostationary Operational Environmental Satellites (GOES), and Landsat. The normal operational "fleet" of NOAA satellites consists of two POES, two GOES, and one Landsat. In addition, NOAA is responsible for aggregating Federal civil requirements for the data and services provided by non-NOAA environmental satellites, foreign and domestic, and arranging necessary procedures to meet these requirements. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) carries out the day-to-day management of these assignments. NESDIS operates the satellite systems; collects, processes, and distributes satellite products; and provides archive services. The United States has employed satellites dedicated to weather and environmental observations since 1960 and, under NOAA, has provided uninterrupted coverage by operational environmental satellites since 1966.

NOAA satellites will be available to meet the needs of science programs throughout the foreseeable future. Seven years or more are needed to plan and manufacture the first spacecraft of a given series, and a series usually remains in service for a decade or longer. Some improvements or additions may be included during the operational lifetime, but the basic capabilities of the series remain constant. These lead and service times apply to non-NOAA satellites as well, so science program planners have a rather clear view of the satellite capabilities that will be available during the coming decade.

This report centers on support to science programs by NOAA's operational satellites. Other spacecraft need special note, however, including those of the international array of geostationary satellites that are positioned over the equator to provide overlapping coverage between the polar regions. These satellites provide the essentially continuous observations required to detect and monitor changes with time scales of minutes or hours. During normal operations, NOAA maintains two geostationary satellites in orbit, one at 75° W. longitude, the other at 135° W. To complete the equatorial circle, the European Space Agency (ESA) has a geostationary satellite positioned at 0°, India has one at 74° E., and Japan maintains one at 140° E. Longstanding plans call for the U.S.S.R. to position a geostationary satellite at around 70° E.

Coordination among the operators of geostationary satellites is extensive. It is maintained to assure compatibility of data and services for the users and smooth system interactions for the operating agencies. All geostationary satellites provide visible and infrared images and systems that collect data from remote instrument platforms. Except for the Indian satellite, they all provide the rebroadcast of environmental products in facsimile format.

Among the non-NOAA polar-orbiting spacecraft of interest to science program planners are:

- The Navy Remote Ocean Sensing Satellite (N-ROSS), planned to be launched by the United States in 1990. Among its sensors will be an altimeter, a radar scatterometer, a multichannel microwave imager, and a low-frequency microwave radiometer.

- The ESA Remote Sensing (ERS-1) satellite, an ocean-observing spacecraft to be launched by the European Space Agency about 1989. It will carry an altimeter, a scatterometer, and a synthetic aperture radar. It will also test an experimental infrared sea surface temperature instrument called the Along Track Scanning Radiometer (ATSR).

- The Marine Observation Satellite (MOS-1), planned for launch by Japan about 1986. It will carry the Multispectral Electronic Self-Scanning Radiometer (MESSR), a radiometer for visible and thermal infrared observations, and a microwave scanning radiometer.

NOAA satellites that will contribute to science programs over the next dozen years will be both the polar-orbiting and geostationary types. The current series of polar-orbiting spacecraft will give way to an improved series very early in the 1990's. The next generation of geostationary satellites will be introduced late in this decade, about 1989. Highlights of these next-generation NOAA satellites are:

- Polar-orbiting. A 20-channel passive Advanced Microwave Sounding Unit (AMSU), one or two additional imager channels and, possibly, an Ocean Color Instrument (OCI).

- Geostationary. Separate imaging and sounding instruments, which will provide simultaneous data.

- Landsat. Continuation of the present government Landsat capabilities (as a commercial operation), under a contract with NOAA, including the introduction of 15 m panchromatic imagery.

The capabilities of current and planned NOAA satellites are given in Appendix A.

IV. BENEFITS OF OPERATIONAL SATELLITES TO SCIENCE PROGRAMS

The data and services provided by NOAA's operational satellites and the others that have been mentioned support operational users and the research community, both national and international. Numerous research satellites have served their purposes well and advanced science in their intended ways. Once the research purposes have been served, however, the observations are not continued. The usual case with a research satellite mission is that it is flown to prove the practicality of an instrument design, demonstrate an ability to make a certain type of observation, or explore the advantages of a data application concept. When these ends are attained the research phase is over, and it is up to interested users, researchers or otherwise, to develop the mechanisms for continuing their work with the new genre of data.

NOAA's operational satellites are designed to meet the requirements of users in the service community. These needs sometimes parallel the long-term requirements of the research community, differing from them in details that are accommodated to some extent in system designs. However, many research requirements are not met by the operational spacecraft, and the research community feels a need for a stronger voice in the planning stages. Researchers have unrestricted access to the products and services of NOAA's satellites. Many research programs require immediate or archived data providing long-duration coverage and continuity. These programs are the major beneficiaries of NOAA's satellite operations. Included among them are climate studies, ocean dynamics investigations, and global vegetation surveys. The following is NOAA's assessment of the disciplines that will benefit from satellites and the nature of some of the contributions satellites will make.

<u>Meteorology</u>

1. Inputs to Numerical Models

    a. Temperature soundings of the atmosphere with increased accuracy and greater global coverage from the Advanced Microwave Sounding Unit (AMSU).

    b. Sea surface temperatures, improved by coverage in cloudy areas, using the AMSU and microwave imagers.

    c. Surface wind fields from radar scatterometers.

    d. Water vapor profiles of the atmosphere at useful accuracy.

2. Severe Weather Prediction

    a. Cloud imagery of high temporal resolution, leading to a more accurate understanding of cloud dynamics.

    b. Intense convection observations, improved by better imagery and microwave radiometers.

    c. Flash flood forecasting from direct measure of precipitation, added to the current forecast inferred from cloud dynamics.

    d. Stability Index, a measure of convective potential derived from satellite data on the temperature and absolute humidity structure of the lower troposphere.

Climatology

1. Precipitation over the oceans from the AMSU. This thermodynamic mechanism transfers huge amounts of latent and sensible heat within the Earth system, but currently there is almost no data to measure its effects.

2. Earth Radiation Budget Experiment (ERBE) sensor measurements from the experimental NASA instrument on NOAA F and G, and from the additional channels on the geostationary and polar-orbiting imaging instruments. Since the energy from the sun provides virtually all the motivating power for the dynamic processes of the atmosphere, the ultimate understanding of meteorology will be based on a knowledge of how and where this energy is absorbed and dissipated. The radiation from the sun incident on the Earth is about 1.77×10^{17} W. Heat flow from the interior of the Earth through the surface is about 2.5×10^{13} W, and man's input from the burning of fossil fuels is about 6×10^{12} W. While these other sources may equal or exceed insolation in localized areas, globally they amount to only about 0.02 percent of that of the sun. It is evident from the magnitude of the solar input that if the radiation balance deviates from unity by any significant amount--i.e., the outflow does not equal the input--the result will be some very dramatic weather.

3. Global observations of sea surface temperature, clouds, soil moisture, snow and ice, albedo, and other parameters of climate models, improved both because new satellite sensors are being deployed and because the record of NOAA satellite observations is being lengthened with each passing year.

Oceanography

1. Improved global coverage of sea surface temperatures, using microwave channels.

2. Extent and condition of sea ice from microwave radiometers and synthetic aperture radars.

3. Significant wave heights from altimeters, scatterometers, and synthetic aperture radars.

4. Internal wave structure from synthetic aperture radars.

Hydrology

1. Precipitation over land from the AMSU and microwave radiometers.

2. Snow cover extent and condition (melting or hard) from infrared and microwave radiometers.

3. New, but limited, data on soil moisture from the AMSU and microwave radiometers.

4. Extent of inundated areas for flood damage assessment, improved by new channels and sharper channels on next-generation imaging instruments on NOAA's polar-orbiting and geosynchronous satellites.

Agriculture

Models for the prediction of commodity production are improved by the use of recently developed satellite data.

1. Vegetation index, a measure of the development and vigor of crops.
2. Precipitation, both episodic and time-averaged for separate segments of the growing cycle.
3. Maximum and minimum temperatures of the crop canopy, diurnally.
4. Insolation, or sunlight reaching the surface of the Earth.
5. Snow cover, a factor in winter kill of crops such as winter wheat.
6. Crop identification and acreage, from multispectral/multitemporal Landsat data.
7. Crop health, inferred from stress-related changes in spectral reflectance detected by Landsat when disease or insects infest crops.
8. Crop yield estimates, by combining Landsat and meteorological information.

Biology

1. Detection and monitoring, by Landsat, of the effects of algae blooms in lake waters.
2. Landsat mapping of coastal vegetation and the properties of tidal marshes, to assess wetland biomass and productivity.
3. Identification of the potential breeding grounds of African desert locusts by locating green-up areas after rainfalls, by Landsat and meteorological satellites.
4. Detection of changes in extent of forestation, especially tropical rain forests, using Landsat and meteorological satellites.

Geology

Landsat advantages to geology include:

1. Mapping soils and sediments for the identification of regions with agricultural potential.
2. Locating mineral deposits, based on the spectral characteristics of sites.
3. Locating seismically active areas, by detecting characteristic surface features.
4. Detecting areas suitable for petroleum exploration, because of the surface evidence of underground structural features.
5. Detecting the onset and rates of change of regional transitions, such as desertification or receding glaciers, by observing surface characteristics.

Fisheries

Measurement of sea surface temperatures, surface winds, and ocean color to improve the understanding of environmental processes influencing the recruitment, distribution, abundance, and harvests of fisheries resources.

Near-Space Environment

Continued monitoring of the radiative environment is conducted at low-orbit and geostationary altitudes by NOAA satellites. Electron, proton, alpha particle, and gamma radiation are measured, by all NOAA satellites, as a basis for forecasting their effects on communications, power distribution systems and, possibly, health. In addition, X-rays and the ambient magnetic field are measured at geosynchronous altitude.

V. INTERNATIONAL PROGRAMS OF THE WORLD METEOROLOGICAL ORGANIZATION (WMO) OF THE UNITED NATIONS

The World Meteorological Organization (WMO) is the recognized body for coordinating international cooperation relating to the atmosphere. These undertakings include operational activities, such as the World Weather Watch (WWW), and science and research activities, such as the World Climate Program (WCP).

The WCP is an ongoing activity of the WMO. It was established in 1979 and is projected to continue into the distant future. The objectives of the program are to aid nations in the applications of climate information, improve the present knowledge of climate, and provide the means to foresee and warn nations of potential man-made changes in climate that would be adverse to the well-being of humanity.

The WMO has the primary responsibility for the planning and execution of the program. The United States and the other member nations of the WMO participate in the planning for the WCP, commit resources, cooperate in the operational phases, and share results. Other international bodies, such as the United Nations Environment Program (UNEP), participate. International science associations also participate--specifically, the International Council of Scientific Unions (ICSU) and its member bodies, such as the International Union of Geodesy and Geophysics (IUGG) and the International Association of Meteorology and Atmospheric Physics (IAMAP).

The focus on global climate and its impacts causes the WCP to depend heavily on satellite data; satellites are the primary data source. Some subprograms, identified below, depend entirely on satellite data. NOAA's operational satellites are a main source of these data. Plans for the WCP are constructed to take best advantage of NOAA satellites in the meeting of program goals.

Discussed below are the four major components of the WCP:

- World Climate Data Program (WCDP)
- World Climate Applications Program (WCAP)
- World Climate Impact Studies Program (WCIP)
- World Climate Research Program (WCRP)

A. WORLD CLIMATE DATA PROGRAM (WCDP)

The objective of the WCDP is to improve the availability of climate data to other component programs of the WCP. The two basic approaches of the data program are to upgrade national climate data archives and the compilation of their inventories, and to improve international coordination for collecting, processing, archiving, and exchanging climate data.

NOAA's satellites are principal contributors to the climate data base. Processing satellite data to archive standards is a function of the ground segment of NOAA's satellite system. NOAA manages the national and international archives for ground-based and space-based geophysical data.

Satellite data are crucial to the World Climate Program. They are relied upon to provide a coverage and distribution that could not be provided by in situ sensors, even if resources were available to attempt such a network. A joint working group of experts, established by the WMO-WCP and the International Union of Geodesy and Geophysics, has been established to provide analyses and recommendations for this climate program. The major findings of this working group, as regards satellite data requirements, are shown in Appendix B.

The most important advantages of operational satellite data are:

- The data are truly global and, where required, are also synoptic (i.e., gathered several times a day).

- The data have excellent response to variance, having been derived from a single instrument (or a small number of identical instruments) rather than from a large number of different sensors such as the radiosonde network.

- The data have continuity and excellent temporal resolution--higher than required for some applications.

Some satellite data sets, such as atmospheric temperature structure, sea surface temperature, and snow cover, complement conventional sources. Other data sets are available only from the satellite. Among the latter are global cloud cover and type, precipitation over the ocean, radiation budget at the top of the atmosphere, and global stratospheric monitoring. More details are provided in the program discussions that follow.

B. WORLD CLIMATE APPLICATIONS PROGRAM (WCAP)

The WCAP promotes the use of knowledge of climate for applications to human activities. Priority areas within the WCAP are food and fiber production, combating desertification, energy resources management, and water resources management.

The satellite data needed for these applications are those that are identified as the satellite data requirements of the other component programs of the WCP, requirements that are shown in the appendices to this paper. A prime NOAA concern is that satellite applications data are delivered to investigators in the volumes, formats, and time frames required to achieve useful results. For local and regional applications that require the real-time accessing of satellite data, NOAA's satellites provide unrestricted, continuous, direct broadcasts of sensor data. Practitioners of less demanding applications may access the selected satellite data products distributed over international telecommunications circuits or provided in facsimile rebroadcasts by the geostationary environmental satellites operated by NOAA and others. Applications that are more retrospective in their needs are serviced from NOAA's archives.

C. WORLD CLIMATE IMPACT STUDIES PROGRAM (WCIP)

Lead responsibility for the WCIP is held by UNEP, with the WMO in a coordinating role. The WCIP has as its goal the formulation of policy alternatives that will reduce the unfavorable impacts of climate on or resulting from human activities. The WCIP focuses on assessing impacts from carbon dioxide-induced climate change, analyzing the vulnerability of food systems to climate variations and actions to reduce vulnerability, and broadening coordination between scientists of different disciplines in the context of climate impacts.

Data from operational satellites are indispensable ingredients in climate impact assessments. The characteristics of global coverage, frequent revisits, instrument calibration, and the like that are provided by satellites are essential in constructing the data base for the assessments. Operational satellites, such as NOAA's, add the key characteristic of long-duration coverage, without which climate trends cannot be detected. The global satellite data base in NOAA's archives now contributes more than two decades of measurements to the WCIP's needs, and it is being increased and improved daily.

As part of the WCIP, UNEP has initiated the International Satellite Land Surface Climatology Project (ISLSCP). This research program is designed to develop standardized methodologies for obtaining quantitative data concerning the Earth's surface from satellite radiance observations. The plan of the ISLSCP calls for these observations to be collected for a period of about 20 years, and to be used to improve climate modeling and monitoring. The land surface parameters to be observed are listed in Appendix C (ISLSCP, 1983).

D. WORLD CLIMATE RESEARCH PROGRAM (WCRP)

The WCRP has as its objectives the determination of the extent to which climate can be predicted and the extent of human influence on climate. The objectives encompass much research and technical work over a long period. To guide the efforts needed, the WMO and the International Council of Scientific Unions have established the Joint Scientific Committee, composed of internationally recognized experts in climate research, which is supported by the full-time Joint Planning Staff in Geneva.

The work strategy for the WCRP is to study processes significant in climate, develop physical-mathematical models of climate, and analyze the statistics of observed climate variables. In the area of observations, the WCRP's highest priority is for a consistent, relatively long time-series of global data describing the variability of the various components of the climate system--atmosphere, oceans, land surface, and cryosphere--and their interaction. For this reason, the WCRP relies heavily on operational satellite observing systems, but also will require new observing systems, such as experimental oceanographic satellites, for achieving expected results.

The Joint Scientific Committee has singled out for particular attention two controlling factors in climate, (1) the controlling effect of cloudiness on the radiation budget and (2) the effect of the oceans in the climate system. These two WCRP special research elements are addressed in the paragraphs that follow.

1. Cloud-Radiation Interaction. The complexity of feedback effects between clouds and radiation that are incoming or outgoing through the atmosphere represents a major stumbling block in climate prediction and understanding. Recognizing this and the inadequacy of available cloud climatologies, the WCRP initiated the International Satellite Cloud Climatology Project (ISCCP) (WCP 6, 1981). The objective of the ISCCP is to gather a five-year global data set of satellite radiances (visible and infrared) from the five geostationary satellites (operated by the United States, Japan, India, and the European Space Agency) and NOAA's polar-orbiting satellites. The satellite radiances will be averaged and sampled into reduced global data sets every three hours, and then will be transformed to cloud climatological statistics.

The observation program began in July 1983. Table 1 presents the data specifications for the project. As part of the ISCCP, national programs are planned to gather detailed observations on radiation and clouds for specific cloud types. In the United States, the First ISCCP Regional Experiment (FIRE) will concentrate on cirriform clouds and marine stratus, both of which have significant effects on the Earth's radiation budget and are poorly simulated in climate models (FIRE, 1983).

2. Ocean-Atmosphere Coupling. The controlling effect of the oceans on the climate system has been identified as another critical element of climate research. The Tropical Ocean Global Atmosphere (TOGA) research project is an international program consisting of observations and modeling research to advance the understanding of atmospheric and oceanic variations occurring over months to years. The motivation for the project stems from the growing evidence that global atmospheric circulation changes are correlated on interannual time scales with sea surface temperatures in the tropics. A 10-year program began Jan. 1, 1985. A list of required measurements is contained in Table 2 (CRC, 1983).

The World Ocean Circulation Experiment (WOCE) is designed to establish the scientific basis for climate prediction on time scales of several decades. Reliable quantitative models of the circulation of the oceans and the consequent transport of water mass, thermal energy, and salinity are prerequisites for prediction of climate changes on these time scales. Global ocean data are absolutely essential for testing and validating these models, and satellite data will be a crucial component. This requirement is stated in the following excerpt from the "Report of the Fifth Session of the Joint Scientific Committee," Hangzhou, China, March 12-17, 1984.

> An oceanographic satellite observing system (is required) including at least one altimetric satellite mission for measuring the ocean surface topography with appropriate accuracy and one satellite measuring the surface wind or wind stress for a minimum of three years during the WOCE intensive observing period. If any one of these two types of satellite observations were not available, the basis of the WOCE programme would need to be reconsidered. (Note: Emphasis added.)

The overall objectives of WOCE are:

- To collect the data necessary to develop and test ocean models useful for predicting climate change.

- To determine the representativeness of the specific WOCE data sets for the long-term behavior of the ocean, and to find methods for determining long-term changes in the ocean circulation.

The major elements of WOCE are:

- An ocean circulation modeling program that will be used to effect the synthesis and interpretation of the various WOCE data sets by applying realistic physical constraints in the possible behavior of the atmosphere-ocean system.

- An ocean satellite observing system that will provide all-weather sea surface temperatures, currents, eddies (from sea surface topography), surface wind, and wind stress.

TABLE 1. Data Specifications for the International Satellite Cloud Climatology Project

Parameters--Spatial and temporal averages and variances (or another statistical measure of the shape of the temporal distribution) are required for each of the following parameters.

Amounts	Precision (30-Day Averages)
Total cloud amount (fraction)*	± 0.03
Cirrus cloud amount (fraction)*	± 0.05
Middle cloud amount (fraction)	± 0.05
Low cloud amount (fraction)*	± 0.05
Deep convective cloud amount (fraction)	± 0.05
Heights	
Cirrus cloud top height (km)*	± 1.00
Middle-level cloud top height (km)	± 1.00
Low-level cloud top height (km)	± 0.50
Deep convective cloud top height (km)	± 1.00
Cloud Top Temperature (K) (for each cloud category)*	± 1.00
Cloud Optical Depth	
Cloud Size Distribution	
Average Narrow-Band Radiances (VIS and IR)*	

Spatial Averaging--The information is to be averaged over approximately 250 km by 250 km boxes.

Time Sampling--Every three hours, i.e., eight times a day, centered around the synoptic observation times.

Time Averaging--The global cloud climatology should consist of 30-day averages for each of the eight observing times per day.

Length of Time Series--Five years.

* Highest priority.

TABLE 2. Meteorological and Oceanographic Variables Required by the TOGA Program

Variable	Satellites	Research Ships	Ships of Opportunity	Buoys	Remote Stations
Sea level	Altimetry	Hydrography	XSTD*		Tide gauges
Ocean heat content		XBT**	XBT	Thermistor chains	
Ocean currents				Current meters	
Moisture flux	(Surface insolation)	Bulk method		Bulk method	
Wind stress	Scatterometer (cloud drift winds)	Wind	Wind	Wind	Wind
Sea surface temperature	Radiometry	XBT	Thermometry	Thermometry	Thermometry
Sea-level pressure			Barometry	Barometry	
Liquid water content, column total water vapor, and precipitation rate	Multispectral microwave radiometry				
Upper atmospheric flow	Cloud drift winds	Soundings			

* XSTD = Expendable salinity, temperature, depth probe.
**XBT = Expendable bathythermograph.

- Global hydrographic and chemical surveys that will measure temperature and salinity to determine heat fluxes and potential vorticity, and the distribution of specific tracers important for the WOCE objectives.

- A basin-scale ocean current velocity measurement program that will rely upon the development of subsurface drifting floats (of the type that could operate with infrequent data communications) and the use of remote acoustic sounding techniques.

The WOCE field phase is expected to be a five-year observing period to begin when the requisite data sources are operational. The ERS-1 and N-ROSS satellites are scheduled for launch between 1988 and 1990, and their availability will probably determine the beginning of the observing period. NASA's topography experiment (TOPEX) satellite, if approved, would also play a key role in WOCE.

A preliminary draft of the WCRP plan (WCRP, 1984) includes data requirements for climate research as listed in Tables 1-6 of Appendix D. The plan to provide these observations during 1988-94 is based on experimental satellite projects that either are being implemented or are in an advanced planning stage, as listed in Table 7 of Appendix D.

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VI. NATIONAL AND MULTINATIONAL PROGRAMS

Individually, nations establish science, research, and study programs to satisfy their needs for understanding and coping with environmental circumstances of concern to them. Often, two or more nations agree to undertake environmental programs together, to deal with questions that are regional in scope or because the participating nations share scientific or other interests in the questions being addressed. Operational satellites contribute to the success and practicality of most of these programs; for many of them, satellites are the essential or single data source.

Ongoing or planned national and multinational programs that depend on NOAA satellites for data are discussed in the segments that follow. Where overlap with other programs is present, the circumstances are noted.

A. STORMSCALE OPERATIONAL AND RESEARCH METEOROLOGY (STORM) PROGRAM

STORM will be a 10–15 year United States program consisting of three major phases: STORM-Central, -East, and -West. This program will seek further insight into storm-scale phenomena and will allow the development of advanced techniques for predicting and warning of severe weather. One portion of STORM will concentrate on the timely delivery of weather information to public and specialized users needing it most. The program will be based on a true partnership between its research and operational elements.

The United States is subject to a variety of severe and violent weather that is unusual when compared to the weather of other nations. Research into storms has been a tradition of United States scientists from the earliest days, because the impacts of severe weather are so evident here and because the opportunities for observations that lead to understandings are close at hand. The national satellite resources that are managed by NOAA provide today's scientists with a responsive tool for continuing the work on this unique domestic problem. The continent-scanning views of these satellites fits them well to the task of data gatherer, supporting a STORM program community that will include the Department of Commerce (NOAA), Department of Defense (Air Force, Army, and Navy), Department of the Interior (Bureau of Reclamation), Department of Transportation (Federal Aviation Administration), Environmental Protection Agency, National Aeronautics and Space Administration, and National Science Foundation (university participants and National Center for Atmospheric Research).

The initial phase of the program will be STORM-Central. It will examine weather events between the Rockies and the Mississippi River and between the Gulf of Mexico and the Canadian border. It will begin sometime after FY85 and will include an intensive field data collection program over a three-month period during the late spring and early summer. The initial research component of the program will include the investigation of the structure and behavior of mesoscale convective systems (MCSs) during their lifetimes, their means of initiation, their interactions with both smaller and larger scale phenomena, and their predictability.

The initial operational component will include tests and evaluations of a variety of forecasting and observing techniques for the improved prediction of the extreme weather impacts associated with MCSs, including heavy precipitation and severe weather. The program will include experimental forecasting, the deployment and testing of new composite observing systems, developing methods for improving data assimilation and presentation by such systems, and the assessment of the value of these systems for forecasting the effects and behavior of MCSs upon and within their environment. Of major importance to STORM-Central and its follow-on field exercises within the next 15 years will be the ready availability of rapid interval, high-resolution, and concurrent visible and infrared imagery and soundings from NOAA's GOES, as well as the Advanced Very High Resolution Radiometer (AVHRR) and, possibly, the microwave imagery from NOAA's polar-orbiting satellite systems.

B. GENESIS OF ATLANTIC LOWS EXPERIMENT (GALE)

The GALE program will be a joint venture of NASA (Goddard Laboratory for Atmospheric Sciences), NOAA, the National Center for Atmospheric Research (NCAR), and four universities--the University of Washington, the State University of New York-Albany, Drexel University, and North Carolina State University. Data for GALE will be collected between Jan. 15 and March 15, 1986. The primary objective is to study the genesis of cyclones in the coastal and offshore North Carolina-South Carolina region in order to better forecast these dangerous winter storms. The core objectives of the program are: (a) to describe the air flow, mass, and moisture fields during the evolution of east coast winter storms, with special emphasis on mesoscale processes; (b) to understand the physical mechanisms controlling the formation and rapid development of these storms; and (c) to develop and test numerical models to improve their prediction. Specific studies will examine the boundary layer momentum and energy fluxes from the Gulf Stream, the mesoscale structure of fronts, the role of orography, the physical and temporal changes in the structure of high- and low-level jet streaks, the mesoscale organization of precipitation on systems, the numerical simulation of east coast storms, and the use of GALE data in operational analysis and prediction models.

Canadian investigators will carry out a complementary program to study the same storms as they move into the maritime provinces of Canada. They are particularly concerned about predicting these storms because of the threat to offshore drilling in that area.

Satellite data in a variety of formats will be provided to GALE researchers. These data will be obtained from NOAA's polar-orbiting and geostationary satellites, as well as from Nimbus and Defense Meteorological Satellite Program (DMSP) spacecraft. Satellite data products will support many core objectives and specific tasks of GALE. For example, ozone maps, temperature and moisture profiles, and cloud vector winds will be developed from satellite data and provided to GALE investigators so that they can describe better the boundary layer, midtropospheric wind fields, and high- and low-level jet streaks.

Imagery will aid in locating synoptic-scale features and discerning the mesoscale organization of convective precipitation systems. Water vapor and temperature soundings will be used to help locate offshore frontal positions. Sea surface temperature data will be useful for surface heat flux estimates. Also, satellite data will be useful in developing conceptual predictive models and input for numerical models.

Real-time decision making is needed during GALE. The GALE forecast office will be provided with satellite products before the daily decision is made to begin, continue, or terminate an intensive operating plan (IOP). Full data sets of quality-controlled products will be made available to investigators. For operational needs, GOES is required to obtain visible and infrared imagery each half hour. Any soundings or cloud wind targets must be obtained in 12-minute specialized segments between these image scans. These specialized activities must be packaged in three-hour cycles, starting at 0000 GMT. During the GALE field season GOES scheduling, including rapid scans between images, must meet operational forecasting needs for the National Severe Storm Forecast Center at Kansas City, Missouri.

Finally, no soundings or other specialized activity can be scheduled during the daily satellite reprogramming cycle from 0300 to 1000 GMT. Daily GALE requirements must be communicated before this cycle.

Within these limits, the NOAA strategy proposed for use during GALE intense data collection periods is designed to:

- Allow as much wind vector computation as feasible during daylight hours.
- Furnish sounding information near times of scheduled three-hour balloon-borne observations.
- Schedule VAS soundings to supplement the fixed times of NOAA and DMSP soundings.

C. EASTERN PACIFIC OCEAN CLIMATE STUDY (EPOCS)

EPOCS is a NOAA Environmental Research Laboratory (ERL) program designed to investigate the circulation, currents, and air-sea interaction in the midlatitude Pacific Ocean. It has been going on for several years and is planned for continuation through the foreseeable future. Data from surface and space observing systems are applied to explain or develop theory. Computer modeling is applied as a tool for analysis and forecasting. Satellite sea surface temperature data, particularly with good temporal resolution (24 to 48 hours), is crucial. Conventional data--tropospheric soundings, cloud cover and distribution, and radiation balance--are important components and also are used to qualify satellite data.

D. SEASONAL EQUATORIAL ATLANTIC (SEQUAL) EXPERIMENT

SEQUAL is an ongoing National Science Foundation (NSF) study of the response of the equatorial Atlantic Ocean temperature and current fields to the seasonally varying surface winds. Winds are the principal driving force of the major ocean currents that, in turn, are frequently manifest in surface temperature structure. SEQUAL includes both a theoretical study to develop models and explain interactions, and an observation program to provide the data needed to validate the models and verify the theoretical hypotheses. NSF supports components of the program at the University of Washington, Columbia University (Lamont-Doherty Institute), the University of North Carolina, and the Woods Hole Oceanographic Institution. Scientists at the University of Paris, who have research ships operating off the equatorial west coast of Africa, are cooperating with the U.S. researchers in SEQUAL.

There was an intensive observation period in 1982 and 1983, and a second observation period is being planned for 1985-86. Satellites (AVHRR) have provided the sea surface temperature field that is used in conjunction with direct measurements from drifting buoys, ships, and moored arrays to determine the onset, extent, and duration of equatorial upwelling. The satellites provide the spatial overview and temporal continuity that allows single-point measurements to be evaluated.

The satellite measurements are continuous and have provided the long time-series type of data that are needed for assessment of interannual changes in the equatorial sea surface temperature distribution. Direct measurements tend to be discontinuous, and satellites fill these data gaps.

The satellite measurements have confirmed the existence of the 30-day oscillations of the South Equatorial Current in the Atlantic during 1983. Similar motions have been found in the Pacific Ocean since 1975, during non-El Nino years.

SEQUAL will benefit from the direct measurement of surface winds and wind stress from the ERS-1 and N-ROSS satellites later in this decade. The program will continue at a low level until these new data sources become available, then will enter a new intensive observation phase.

E. SATELLITE PRECIPITATION AND CLOUD EXPERIMENT (SPACE) AND MICROBURST AND SEVERE THUNDERSTORM (MIST) PROJECT

SPACE is a NASA study of the techniques for estimating precipitation by using satellite data to infer cloud dynamics. MIST is a NASA Huntsville program to study the dynamics of severe weather. The purpose of SPACE is to contribute to the understanding of precipitation processes associated with mesoscale and small convective systems and space sensor requirements for remote-sensing applications. The object of MIST is to investigate thunderstorm "downbursts" in a wet environment. The core field program for both experiments will take place in June and July, 1986, in the northern Alabama and western Tennessee area. A segment of SPACE will be activated in late April and May, 1986, to collect data during heavy rainfall episodes. During the core portion of SPACE and MIST in June and July, the use of the following special resources has been requested:

NOAA GOES satellite sounding and rapid scan	50 PAM II stations
NOAA TIROS AVHRR and TOVS	30 mesonet stations
NASA McIDAS interactive data system	Doppler radar (S&C bands)
NCAR CP1, CP3, and CP4 Doppler radars	LLP network (lightning)
3 to 12 rawinsonde systems in a meso-beta array	TVA rain gauge network
NASA Convair 990, U2, and ER2 aircraft	RADAP II/ICRADS data collection

F. EQUATORIAL MESOSCALE EXPERIMENT (EMEX), AUSTRALIAN MONSOON EXPERIMENT (AMEX), AND STRATOSPHERE-TROPOSPHERE EXCHANGE PROGRAM (STEP)

EMEX, AMEX, and STEP are three interrelated programs proposed for the Australian area in 1987. Satellite planning to support this effort is in its embryonic stages; TIROS and GOES-West may play a role.

EMEX is a NASA program that will investigate the diabatic heating mechanisms within tropical cloud clusters so as to define the effect of these cloud systems on the vertical profile of large-scale heating in the troposphere and at the tropopause. Data from the GARP Atlantic Tropical Experiment (GATE) and the Monsoon Experiment (MONEX) are becoming inadequate for further progress in this area because those experiments did not emphasize cloud-scale observations.

Critical needs for EMEX include one NOAA WP-3D aircraft (equipped with airborne Doppler radar, and cloud microphysical and radiation instrumentation) and the participation of NOAA scientists experienced in tropical field work and the use of the WP-3D aircraft in field research. The experiment will be conducted in January 1987 over northern Australia and southern Indonesia. It will coincide with two independent but complementary experiments, AMEX, aimed at defining the synoptic-scale structure of the northwest monsoon, and STEP, aimed at examining stratospheric-tropospheric interaction.

The AMEX program is a joint undertaking of NASA and the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. AMEX will document the synoptic-scale structure of the northwest monsoon over northern Australia and Indonesia in January 1987.

STEP is a NASA experiment that will employ U2/ER2 aircraft to observe the tropopause-lower stratospheric structure associated with cloud clusters. It will be conducted in the region of northern Australia and southern Indonesia in January 1987.

G. NATIONAL PROGRAM FOR STRATOSPHERIC OZONE MONITORING

The Federal Coordinator for Meteorological Services and Supporting Research developed and is coordinating the National Program for Stratospheric Ozone Monitoring following the directions of Public Law 95-95, Amendments to the Clean Air Act of 1977.

A purpose of PL95-95 is to provide a better understanding of the effects of human actions on the stratosphere. In order to assemble the data base needed to effect such an understanding, the plan calls for a combined ground-based and satellite monitoring program that will provide global coverage of the vertical distribution of stratospheric ozone and total ozone overburden.

The satellite component of the program is NOAA's TIROS satellite series, which launched the first operational instrument, SBUV/2, in December 1984. The series will extend late into the 1990's with the same instrument type. No other satellite program is planned that will be capable of providing the long-term monitoring information needed to help understand the state of the stratosphere.

H. UPPER ATMOSPHERE RESEARCH PROGRAM (UARP)

UARP is a NASA program of research, technology, and measurements of the Earth's upper atmosphere, particularly the stratosphere. The objectives of the UARP research are to understand the physics, chemistry, and transport processes of the upper atmosphere, and to accurately assess possible perturbations of the upper atmosphere caused by man's actions. Major activities will include determining the distribution of trace gases in the atmosphere, particularly those that have roles in the photochemistry of ozone, and observing global distributions of ozone and its vertical profile.

As part of this program, the NASA Upper Atmosphere Research Satellite (UARS) is planned to be launched in 1989. The complement of UARS instruments will make simultaneous measurements on a large number of stratospheric constituents and atmospheric parameters, in order to assemble an extensive data base for further atmospheric photochemical studies. Special interest will be centered on those constituents important in ozone photochemistry.

A major source of data needed to support the UARS mission and subsequent research will be the operational ozone measuring instruments--SBUV/2--on the TIROS satellites. These instruments will provide global distributions of vertical ozone profiles that will become part of the overall atmospheric data set. UARS will not obtain vertical ozone data through the backscattered ultraviolet technique but will rely on the NOAA operational satellites to supply this complementary data.

I. MARGINAL ICE ZONE EXPERIMENT (MIZEX) AND INTENSIFICATION OF CYCLONES EXPERIMENT (ICE)

MIZEX is a Navy study of meteorological forcing caused by air flow off ice shelves over water. Ice extent and condition, ice and sea surface temperature, and tropospheric temperature structure are required satellite inputs. Microwave data from the AMSU, and the synthetic aperture radar data from ERS-1 and (potentially) the U.S.S.R. Meteor, will be of crucial value.

On July 30, 1984, the first field operation, MIZEX '84, which sought to understand the environment of the Arctic in the Fram Strait area between northeast Greenland and Svalbard, Norway, was successfully completed. The culmination of more than five years of science planning and a continuation of MIZEX '83, this multinational Arctic research program utilized the resources and expertise of 10 nations. MIZEX '84 is the largest coordinated Arctic research program ever conducted and has the unique feature of an ad hoc management organization established by the scientists themselves, without any intergovernmental agreements, memoranda, or treaties. This scheme has proved to be efficient and effective for planning and conducting both MIZEX '83 and '84.

The MIZEX '84 Arctic research armada consisted of seven ships; eight remote-sensing, observational, and meteorological aircraft; and four helicopters, supporting a multidisciplinary team of more than 200 scientists and technicians, plus ship and aircraft crews. Scientists, equipment, and support came from Canada, Denmark, the Federal Republic of Germany, Finland, France, Ireland, Norway, Sweden, the United Kingdom, and the United States. Data from NOAA's polar-orbiting satellites were crucial for the large-scale mapping of the sea ice. Aircraft can probe and sample over ice-bound areas, but they are a prohibitively expensive means of the necessary large-scale mapping.

ICE is a United States Navy study of cyclogenesis in the Atlantic Ocean. The first field operations have not yet been fully planned, but satellite data--particularly sea surface temperatures on a regional scale--will be a prime requirement when the experiment gets underway in the near future. Convection is the primary driving force in cyclogenesis, and the energy for convection is derived from the sensible heat available in the surface waters. The ability to use the microwave channels of the AMSU instrument will be an important advantage toward obtaining sounding, precipitation, and surface data in the cloudy areas where cyclogenesis is present.

VII. PROGRAMS IN VIEW

The outlook for operational satellites as regards science programs is that their contributions will become greater and more crucial the closer we approach the end of this century. Years of analysis, planning, and resource gathering precede the implementations of major science programs. The program goals must be sharply defined, their expectations made reasonable, and their procedures firmly established for obtaining, protecting, and analyzing data before the commitment is undertaken.

Discussions are taking place now about science project concepts that will lead to formal science program planning later in the 1980's. Some of these programs will be underway in the 1990's. Two science programs that are in view and would depend on operational satellites for much or all of their success are discussed in the following pages. They have been selected from among the others that could be mentioned because of their satellite needs and the belief that ongoing discussions will lead to future implementations.

A. THE GLOBAL CHANGE PROGRAM (GCP)
Formerly the International Geosphere-Biosphere Program (IGBP)

Past developments and applications of satellite remote-sensing technology have tended to serve one or another of the benefiting disciplines--meteorology, hydrology, oceanography, the land sciences, and the like--without much planned crossover. These disciplines are interdependent; no one of them can be fully understood without a knowledge of how they interact. The land, sea, and air react together to determine our environment. Environmental scientists see that now is the appropriate time in the cycle of technological development to turn their attention to satellite instrument complements and analysis systems that recognize these interdependencies. Thus, future science program plans tend to be not only global in scope but interdisciplinary in context.

The National Academy of Sciences (NAS) of the United States and the International Council of Scientific Unions (ICSU) are in dialog about the Global Change Program (GCP). This dialog is an outgrowth of earlier NASA studies and assessments concerned with the implementation by the United States of the Global Habitability Program (GHP). As the huge scope of the GHP became evident, discussions of the topic broadened to include the mechanisms for international participation. In this wider context, the proposed activity was discussed under the title of International Geosphere-Biosphere Program (IGBP).

By any title--and new ones are bound to emerge--the GCP is seen as a research effort aimed at obtaining a truly comprehensive, cross-disciplinary, quantitative understanding of the complicated terrestrial "machine," the functions and interaction of its various parts, and the knowledge of the major geographical and biological processes that drive its cyclical pulses.

The goal of the GCP, as it is now defined, is to develop a knowledge base through a sharply focused aggregate of research efforts that share a global view of the Earth system and emphasize the interrelationships among all segments of that system. These research efforts would assess trends and anticipate natural and anthropogenic changes that have time domains of 50 to 100 years. Extensive knowledge and great skill in applying that knowledge are needed to attempt Earth system forecasts of this magnitude. The data base upon which the research efforts will rest must be extremely accurate and complete--a factor having profound implications for the satellite observing systems that are expected to provide the preponderance of data base input.

Two concurrent modes of research experiments will be required to meet the goals of this program. One will be to detect the rates of change that are currently present in the component parts of the Earth system. The shorter the observing period available to do this, the more precise and detailed the measurements must be. The other experiment mode will be to use the program's data base and new, elegant numerical models to reconstruct the major natural changes that have taken place. Using these "natural laboratory" conditions to confirm the accuracy of the models and the applicability of the data base will provide the confidence for applying these models as predictors of the future.

The GCP concept will likely be initiated as a formal international program during this decade. One of the main purposes of the program will be to further develop the use of space techniques for observing the Earth system and detecting the changes that occur within it. Agencies like NOAA, which operate Earth-observing satellite systems and assure the availability and quality of the data obtained from satellites, will be willing partners in this program.

B. THE SPACE ENVIRONMENT OF EARTH—THE SOLAR ACTIVITY SPACEBORNE PATROL (SASP) CONCEPT

Solar input is the primary fuel of the Earth system. Along with solar light and heat there are other components of this input, such as energetic particles, X-rays, and magnetic torques. These components are responsible for spectacular displays of aurorae and influence the use of electronic technology. Insufficient observational data on these solar phenomena exist to explain the cause and effect relationships linking the Earth system to these less apparent energy streams.

Operational satellites provide the opportunity for the routine, direct measurement of solar particle and magnetic forces at polar-orbiting and geostationary altitudes. The monitoring instruments now on all NOAA spacecraft sample a broad range of energetic particles. The geosynchronous satellites are equipped to measure X-rays and the ambient magnetic field. Although these operational spacecraft provide valuable space environment information, they furnish only a small fraction of the information that is needed by operational and research interests dealing with the challenges of this science area.

Over the coming years, NOAA's operational satellites will become more completely instrumented to respond to the requirements of the science community concerned with space environment matters. The Space Environment Laboratory (SEL) of NOAA's Environmental Research Laboratories (ERL) has proposed a program of 11 operational satellite instruments to serve as a partial and preliminary guide for discussions and planning. The instruments proposed by SEL are for real-time service applications, but would contribute to research ends by providing reliable, long-duration coverage.

This collection of instruments, referred to collectively as the Solar Activity Spaceborne Patrol (SASP), is described in Appendix E. A brief list of pertinent references follows.

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VIII. SUMMARY

This report provides a perspective on the value of NOAA's operational satellites to science programs. The discussions have focused on programs with requirements that are matched to the capabilities of NOAA's operational satellites, including reliable acquisition of long-duration data sets, adequate data distribution on appropriate space and time grids, repeatability of measurement, timeliness of data deliveries, continuity of services to permit long-range program planning, routine archiving, and accessible data bases for researchers.

The contributions of NOAA's operational satellite systems to scientific programs are many. The programs, in most cases, could not achieve the anticipated results without data provided by NOAA's satellite systems. Both the regional and global data bases provided by these satellites are essential to the successful completion of many national and international scientific programs. The research community, in planning for Earth science programs, specifies dependence on NOAA's operational satellites and, in some major cases, explicitly recognizes that NOAA's satellites make the programs possible.

APPENDIX A

CURRENT AND PLANNED NOAA SATELLITES

NOAA's Polar-Orbiting Operational Environmental Satellites (POES)

The current POES series has spacecraft in sun-synchronous polar orbits at 833 and 870 km. Imaging, surface temperatures, and cloud mapping are provided by a 5-channel visible and infrared radiometer with 1.1 km resolution. Three instruments provide atmospheric sounding data: a 20-channel high-resolution infrared sounder, a 3-channel selective absorption sensor to determine weighting functions at 15 micrometer wavelengths, and a 4-channel Dicke microwave radiometer instrument. Additionally, these satellites monitor solar particle flux at the spacecraft and provide for the collection and relay of data from fixed and moving automatic sensor platforms. Satellite sensor data are broadcast continuously for intercept by any ground station within range.

The next POES series will include the Advanced Microwave Sounding Unit (AMSU), which will replace the 3-channel infrared absorption and 4-channel Dicke microwave sounding instruments now in use. The AMSU will provide 15 channels of coverage in the 20-90 GHz range and 5 channels in the 90-184 GHz range. It will add new capabilities for atmospheric humidity measurements, distinguishing sea ice, and gathering information about snow thickness and soil moisture. AMSU will make soundings more accurate and will permit sounding through clouds over areas with active weather patterns. The current imager will be improved by adding one or two new channels and sharpening others; some channel changes also are planned for the high-resolution infrared sounder. A major planned sensor addition is the Ocean Color Instrument, which probably will be introduced on an early spacecraft in this series. The other functions and services of the series will remain as they are currently.

NOAA's Geostationary Operational Environmental Satellites (GOES)

The current GOES series provides imaging and sounding data via a single instrument. A visible channel (0.55 to 0.75 micrometers) and 12 IR channels (from 3.9 to 15.0 micrometers) are provided. Subpoint resolution is 1 km in the visible and 7 or 14 km in the IR, determined by detector selection. The single optical system of the instrument precludes its simultaneous operation in both the imaging and sounding modes. GOES are equipped to monitor the flux of solar X-rays, alpha particles, protons, and electrons at the spacecraft. They are provided with data collection systems for the relay of information from automatic sensor platforms. Sensor data are broadcast continuously for receipt by ground stations. A GOES service is the retransmission of meteorological charts and other environmental information, including satellite imagery, in facsimile format.

The next GOES series will provide separate imaging and sounding instruments, so that these functions can occur simultaneously. More imaging and sounding channels will be included. The other capabilities and services of the current series will be continued.

NOAA's Land Remote-Sensing Satellites (Landsat)

Current Landsat spacecraft provide Earth-imaging through two separate instruments. One, the Multi-Spectral Scanner (MSS), is a four-channel instrument that provides visible and infrared data at 80 m subpoint resolution. The other, the Thematic Mapper (TM), is a seven-channel visible and infrared spectrometer that provides data at 30 m resolution, except for 120 m resolution in the thermal infrared band. Two spacecraft of the current series are in orbit, Landsats 4 and 5. The orbit is sun-synchronous at 705 km, providing a 16-day repeat cycle for revisits to the same Earth scene. Direct data broadcasts are provided to non-Federal ground stations, which pay a data access fee and enter into formal agreements covering the receipt and distribution of Landsat data.

The Landsat system is being commercialized. Under the expected conditions of commercialization, the U.S. government will continue services from Landsats 4 and 5 through their design lifetimes (probably mid-1987) by contracting with a private company for the day-to-day operation of the system. The same company also will be responsible for the marketing of Landsat data. The company will continue service beyond Landsat 5 by launching an improved Landsat 6 in late 1988. Landsat 6 will provide a TM-class instrument and an MSS emulator to convert TM data to MSS format. The new satellite also will provide a panchromatic imager with 15 m subpoint resolution. A five-year lifetime is projected for Landsat 6. Landsat 7 probably will replace it in orbit in late 1992.

APPENDIX B

WCP SATELLITE-OBSERVABLE CLIMATE VARIABLES NEEDED FOR REGIONAL AND GLOBAL SCALES
(Preliminary Consolidation of Requirements)[1]

(see footnotes for details)

Category	Climate Research[2]	Climate Applications[3]	Obtainable From (observing system)	Desired/Minimum Useful Accuracy (based on 1 sigma)	Space Resol.[4] (grid size)	Time Resol.[4]
A. BASIC ATMOSPHERIC STRUCTURE AND WEATHER VARIABLES						
Temperature	V,M,P	A,W,E,C,T,H	Radiosondes, satellite soundings	1 °C/2 °C	500 km (100-200 mb)	12-24 h
Surface temperature (screen temperature)	V,M,P	A,W,E,C,T,H	Conventional thermistor shelters, satellites	0.2 °C/1 °C		
Pressure	V,M,P	H	Stations, balloons, satellite soundings	1 mb/3 mb	500 km	12-24 h
Wind velocity	V,M,P	A,W,E,C,T,H,O	Rawinsondes, pilot balloons, stations, drifting clouds (satellite), commercial aircraft, mobile ships	1/3 m/s	500 km (100-200 mb)	12-24 h
Humidity (and related variables)	V,M,P	A,W,E,C,H	Rawinsondes, stations, satellite soundings	7%/30%	500 km (200-300 mb)	12-24 h
Sea-surface temperature[5] (skin temperature)	V,M,P	E,O	Ship data and in situ measurements, satellite measurements	0.2 °C/1 °C	30-150 km	3 d V: 5-10 d M: 30 d

Category	Climate Research[2]	Climate Applications[3]	Obtainable From (observing system)	Desired/Minimum Useful Accuracy (based on 1 sigma)	Space Resol.[4] (grid size)	Time Resol.[4]
Precipitation[5]	V,M	A,W,E,C,T,H	Stations, radar, satellites	10% or 2 mm per wk	250-500 km	12-24 h
Precipitation over ocean	V		Radar, ships, satellites	10% or 2 mm per wk	250-500 km	V: 5-15 d
Clouds	V	A,W,E,T,H,O	Observers, satellites		250-500 km (1 km vertical)	1 d 5-15 d
			B. OCEAN VARIABLES			
Sea-surface temperature	V,M,P	E,O	Ship and in situ measurements, satellites	See (A)	See (A)	See (A)
Wind stress	V		Scatterometer, ships	0.1/0.3 dyn/cm^2	200 km	1 wk (5-10 d)
Sea level (to determine currents)	V,M		Altimetry, tide gauges	1/10 cm	20-200 km	1 wk (5-10 d)
			C. LAND, HYDROLOGY, AND VEGETATION[6]			
Plant water stress		A,W	Local observations (satellites?)	4 levels/2 levels	250 km	1 wk (5-10 d)
Vegetation cover and land use		A,C,H,W	Reports, satellites	Not defined	250 km	1 mo/1 yr
Surface albedo	V		Satellite data	.02 (mo)/.04	250 km	3 d
			D. RADIATION BUDGET			
Planetary radiation budget components (albedo, emission)	V,M		Satellite radiometers	10/25 W/m^2 emission 0.02/0.05 albedo	500 km	15-30 d
Equator - pole gradients	M		Satellite radiometers	2/4 W/m^2	1000 km	30 d

Category	Climate Research[2]	Climate Applications[3]	Obtainable From (observing system)	Desired/Minimum Useful Accuracy (based on 1 sigma)	Space Resol.[4] (grid size)	Time Resol.[4]
Solar constant (total solar flux)	M		Satellites	1-5 W/m^2		1 d, 1 mo, variable[5]
Solar UV flux	M,P		Satellites	10%/50 A interval		1 d
Surface albedo	V,M	E,W	Satellites	0.02/0.05	250 km	5-15 d variable[5]
Surface radiation[6]	V,P	A,W,E,C	Combination of satellite and ground-based measurements	10/25 W/m^2	500 km	1 wk (5-10 d)
Net solar at surface	V,P	A,W,E,C	Combination of satellite and ground-based measurements	1-3%		1 wk (5-10 d)
Net IR at surface	V,P	A,W,E,C	Combination of satellite and ground-based measurements	1-3%		1 wk (5-10 d)
Land and ice surface temperature	V	A,W,E,C,T	Satellites (if cloud free), direct measurement	1 °C/2 °C	250 km	1 d
			E. CRYOSPHERE VARIABLES			
Snow (% coverage)	V,M	A,W,E,C,T	Satellites, surface observations	3% (mo)/5%	250 km	3 d
Snow (water content)	V	A,W	Satellites, surface observations	.5 cm equiv. water depth/1 cm	250 km	1 wk (5-10 d)
Elevation of continental ice sheet	M		Satellite altimetry direct observations	10 cm/1 m	2-200 km	1-10 yr
Sea ice (% open water)	V,M	T,O	Satellites, surface observations	3%	250 km	1 wk
Ice sheet boundary	M		Satellites, surface observations	1 km/5 km		1-10 yr[5]

Category	Climate Research[2]	Climate Applications[3]	Obtainable From (observing system)	Desired/Minimum Useful Accuracy (based on 1 sigma)	Space Resol.[4] (grid size)	Time Resol.[4]
Sea ice boundary	M		Satellites, surface observations	20 km/50 km		1 wk
Drift of sea ice	P		Satellites, surface observations	2/5 km/d	400 km	1-5 d
Sea ice melting	P		Satellites	Not defined	50 km	5 d
Sea ice thickness (first year, multiyear)	V,M	T,O	Satellites, direct observations	10-20 cm	250 km	1 mo
			F. ATMOSPHERIC COMPOSITION			
Stratospheric aerosol	M		Satellite limb soundings, direct sampling	.002/.01 optical depth at a reference wavelength	250 km N-S 1000 km E-W (3 km vert)	1 mo
Tropospheric aerosol	M	E,H	Direct, radiation measurements at ground, satellites	.005/.02 optical depth at a reference wavelength	500 km N-S (3 km vert)	1 mo
Ozone	V,M,P	A	Satellite soundings, ozone sondes, Dobson spectrometers	.005 (mo)/.02 total 10% at altitude	250 km N-S 1000 km E-W (3 km vert)	1 d
Stratospheric H_2O	V		Direct measurements, satellite soundings	.5 ppm/.5 ppm	250 km N-S 1000 km E-W (3 km vert)	1 mo
N_2O			Direct measurements, satellites	.01 ppm/.03 ppm		1 yr
CO_2	V,M	A	Direct measurements, satellites	.5 ppm/10 ppm		1 yr
			G. SOLAR EFFECTS			
Alpha particles			Satellites	not defined		1 d

1 Extracted from Report of the World Climate Program Data Management Meeting, WMO--WCP 17, Geneva, 1981.

2 WCRP data classification -

V: Data needed for the verification and evaluation of climate models

M: Data needed for the long-term monitoring of slowly varying elements of the atmosphere-ocean-cryosphere-land system, including external forcing factors that may induce climate trends

P: Data for the studies of specific processes and parameterization

Note: Certain data types not classified as V, M, or P are also needed for climate diagnostics and other basic studies.

3 Applications -

A: Agriculture/food	T: Transportation
W: Water resources	O: Offshore fisheries
E: Energy (solar and wind)	H: Health
C: Construction	

Space/time resolutions are applications dependent. Resolutions as specified do not necessarily apply.

4 Space/time resolutions based on large-scale climate research and applications considerations.

5 Space or time resolutions vary depending on location and purpose.

6 All related variables/parameters for applications purposes are not included here.

APPENDIX C

ISLSCP SATELLITE OBSERVATION REQUIREMENTS
(Land-Surface Parameters for Monitoring and Modeling)

Parameter	Spatial Scale	Temporal Scale	Time Period	Accuracy	Precision	Comments
A. GLOBAL CLIMATE MODELING AND MONITORING						
Vegetation	250 km x 250 km	3 monthly	1 year	? ± 0.05	?	% of major land cover/type
Dry soil albedo	250 km x 250 km	Annual average	3 years	± 0.05	± 0.02	Dry soil reference to be used to predict other soil albedo
Total surface albedo	250 km x 250 km	Monthly	1-3 years	± 0.05	± 0.02	Cf. JSC recommendations
Surface IR emittance	250 km x 250 km	Annual average	?	± 0.02	± 0.01	Probably changes with major land cover type
B. VALIDATION OF GLOBAL DATA SETS						
Day and night (3 hours) surface temperatures	250 km x 250 km	Monthly	1 year	± 1 °C	?	Diurnal range also required
Noon time surface solar radiation intensity	250 km x 250 km	Monthly	? 1 year	± 25 Wm^{-2}	± 10 Wm^{-2}	
Surface soil moisture	250 km x 250 km	Monthly	? 1 year			5 categories, wet to dry 0-10 cm depth
Rainfall index	250 km x 250 km	?	?	?	?	Current monitoring by NOAA satellite provides between ± 10% and ± 25%

Parameter	Spatial Scale	Temporal Scale	Time Period	Accuracy	Precision	Comments
Snow area and depth	250 km x 250 km	Monthly/weekly	1 year	?	?	Microwave useful
Net radiation at noon evaporation	250 km x 250 km	Daily/weekly	1 year	± 10 Wm^{-2} ± 10-20%		Alternative to soil moisture
C. MESOSCALE CLIMATIC MODELING AND MONITORING						
Terrain (elevation/slope)	↑ Scale suggested 10 km-30 km ↓	Fixed	↑ Could vary from diurnal on selected days to weekly throughout the year ↓	± 5-10%	?	Doubt that mesoscale models run longer than 1 week without being nested to GCM because of changing boundaries; therefore, time scale should be at least daily
Major land cover types		Weekly		± 10%	?	
% cover of vegetation		Weekly		± 10%	?	Roughness related to vegetation height (z_0 - 0.13 h) and impossible to measure otherwise; has to be linked to vegetation height
Roughness length		Weekly		± 10%	?	
D. VALIDATION OF MESOSCALE DATA SETS						
Albedo (total)		Weekly	↑ Could vary ↓	± 0.01- ± 0.03	± 0.02	Should albedo accuracy also be scaled in relative terms?
Vegetation height		Weekly		± 5-10%	?	Also soil structure for moisture (maximum available water reserve)
Leaf area index	Scale suggested 10 km-30 km	Weekly		± 0.5%	?	

Parameter	Spatial Scale	Temporal Scale	Time Period	Accuracy	Precision	Comments
Emissivity variables	↓	Weekly, monthly	↓	± 0.02 - ± 0.01		In general, most of these are pretty well fixed in urban or forest context, but are variable in crop situations or in semiarid areas with intermittent rains
Soil structure	↓	Seasonal	↓	± 10%, with full cover only ± 50%		
Surface temperature	5 km x 5 km	Monthly	1 month/1 year	± 0.5°		↑
Evaporation	5 km x 5 km	Monthly	1 month/1 year	± 10-20%		Also need soil moisture and surface wind velocity
Global and net radiation	5 km x 5 km	Monthly	1 month/1 year	± 10 Wm^{-2}		
Rainfall	5 km x 5 km	Daily	1 month/1 year	0.1 mm day^{-1}		↓

E. ADDITIONAL PARAMETERS FOR CLIMATE IMPACT MONITORING

Parameter	Spatial Scale	Temporal Scale	Time Period	Accuracy	Precision	Comments
Length of vegetation growing period	250 km x 250 km < 50 km for pilot studies	Weekly	Continuous	± 0.05	± 0.02	↑ The two parameters could be joined under "vegetation cover"
Change in vegetation type or % cover	250 km x 250 km < 50 km for pilot studies	?	Continuous	± 0.05	± 0.02	↓
Soil moisture change and variability	Pilot study 10 km	Weekly	Year	?	?	---

Parameter	Spatial Scale	Temporal Scale	Time Period	Accuracy	Precision	Comments
Soil erosion	A few km	2 per day	Continuous	?	?	Only for regions at risk.
1) wind: dust/sand storms		day/week	5 years	?	0.1 km x 0.1 km	Could be observed with geostationary satellites.
2) water: inland water areas	50 km	Monthly	5 years	?	?	Could sediment dust loading rivers be monitored? As an indicator of water erosion?
permafrost areas	50 km	Monthly	5 years	?	?	

APPENDIX D

WORLD OCEAN CIRCULATION EXPERIMENT (WOCE) REQUIREMENTS

TABLE D-1. Data Required for Detection of Climate Change

Parameter	Horizontal Resolution	Time Resolution	Accuracy (rms)
Mean surface air temperature over land and oceans	Global	Seasonal	0.1 K
Mean sea surface temperature		Seasonal	0.1 K
Mean sea level		1 year	1 cm
Mean extent of sea ice		1 year	50 km on location of the ice margin

TABLE D-2. Data Required for Validating Climate Models and Diagnostic Studies

Parameter	Horizontal (Vertical) Resolution	Time Resolution	Accuracy (rms)
Temperature	500 km (100-200 mbar)	1 day	1 K
Wind velocity	500 km (100-200 mbar)	1 day	1-3 m/s
Surface pressure	500 km	1 day	1-3 mbar
Total precipitation	As provided by the basic synoptic networks	1 day	As provided by the basic synoptic networks
Total precipitable water in the air column	500 km	1 day	2 kg/m^2

TABLE D-3. Data Required for Ocean Variability

Parameter	Horizontal Resolution	Time Resolution	Accuracy (rms)
Sea surface temperature	5° x 5°*	1 month	0.5 K
Wind stress on the surface	5° x 5°*	1 month	0.01 N/m^2**
Surface wind velocity (direction)	5° x 5°*	1 month	0.5 to 1 m/s (20°)
Mean sea level	***	***	2-5 cm

* Horizontal resolution is meant to indicate the spatial scale consistent with the specified accuracy, i.e., the result of averaging over a 2×10^4 km^2 area. A square shape (about 5° x 5°) is preferred for grid elements in the extratropics, while elongated boxes (about 2° latitude by 10° longitude) are preferred in the central region of the tropical oceans. A finer resolution (2° x 2°) is needed for describing the sea surface temperature field near ocean boundaries, even if the accuracy must be correspondingly reduced.

** Tropical ocean currents may be sensitive to even smaller changes of the wind stress under light to moderate wind conditions.

*** The determination of the mean sea surface topography is the end result of a complex procedure involving many different corrections, merging with tracking and geodetic data, and multidimensional analysis, which must be optimized for individual problems. Accordingly, the specified accuracy depends upon the nature of the problem being addressed, such as:

- 3 cm altitude accuracy for 3-month mean energy spectrum of ocean eddies in a 10° x 10° box
- Variable extratropical ocean currents, 5 cm for each 5° x 5° box and 3-month average
- Variable tropical ocean currents, 5 cm for each 2° latitude x 10° longitude box and 1-month average
- Mean flow, 2 cm for each 2° latitude x 5° longitude box, averaged over the duration of the mission

TABLE D-4. Data Required for Hydrological Processes

Parameter	Horizontal Resolution	Time Resolution	Accuracy (rms)
Area-averaged mean precipitation	2° x 2°	1 month	1 cm/mo or 10% of monthly total precipitation*
Total precipitable water in the air	2° x 2°	1 week	0.5 cm
Run-off from river basins	About 2° x 2°	1 month	**
Extent of snow	2° x 2°	1 week	

* When precipitation exceeds 10 cm in one month.

** Consistent with or better than the accuracy requirement for mean precipitation.

TABLE D-5. Data Required for Sea Ice

Parameter	Horizontal Resolution	Time Resolution	Accuracy (rms)
Ice concentration (including position of the ice edge)	50 km	3 days	5-10%
Ice thickness	*		
Ice velocity	500 km	3 days	0.02 ms^{-1}
Wind stress	500 km	1 day	0.05 Nm^{-2}
Surface air temperature	500 km	1 day	1 °C

* Not feasible with adequate space and time sampling density by available methods.

TABLE D-6. Data Required for Radiative Processes

Parameter	Horizontal Resolution	Time Resolution	Accuracy (rms)
Total incident solar flux	Global	1 year	1 W/m^2
Planetary net radiation budget (visible and IR)	*	1 month	1-10 W/m^2*
Net radiation at the surface	2° x 2°	1 month	10 W/m^2
Insolation at the surface	2° x 2°	1 month	5 W/m^2
Surface albedo	2° x 2°	1 month	0.03

* Accuracy depending on the spatial resolution. Estimations for the most advanced space instrumentation (ERBE project) are:

Global domain:	1-3 W/m^2
1000 km wide zonal belt:	5 W/m^2
500 x 500 km area:	10 W/m^2

TABLE D-7. Required Satellites

Satellite Mission	Instrument Package	Target Launching Date
	1988-92 PERIOD	
TOPEX (U.S.)	Altimeter	Tentative
ERS-1 (Europe)	Imaging radar Wind scatterometer Altimeter IR radiometer (ATSR)	1988
N-ROSS (U.S.)	Wind scatterometer Altimeter Imaging microwave radiometer Low-frequency microwave	1990
NOAA series (U.S.)	IR radiometer	ongoing
	1992-94 PERIOD	
TOPEX (U.S.)	Altimeter	Tentative
MOS-2 (Japan)	Wind scatterometer Altimeter Visible and IR radiometer	Tentative
ERS-2 (Europe)	Imaging radar Wind scatterometer Altimeter IR radiometer (ATSR)	Tentative
Radarsat (Canada)	Imaging radar Wind scatterometer	Tentative
Next generation operational polar environmental satellite series (U.S.)	Tentative	Tentative

APPENDIX E

NOAA SPACE ENVIRONMENT LABORATORY RECOMMENDATIONS FOR OPERATIONAL SATELLITE INSTRUMENTS
(Solar Activity Spaceborne Patrol)

Instrument Purpose	Service Requirement	Phenomena Addressed	Technical Solution (geostationary or polar S/C)
Solar monitoring by X-ray imager	Geomagnetic storms, energetic particles, neutral atmosphere expansion predictions	Flares, mass ejections, X-ray coronal holes, magnetic field configuration at the sun	Soft X-ray imager (geostationary)
Geosynchronous in situ monitoring	Define the space environment at geosynchronous orbit	Ambient plasma, magnetic field, energetic particle parameters	Plasma and magnetic field probes; energetic proton, ion, and electron flux meters and spectrometers; simple magnetometers (geostationary)
Mass ejection monitoring	Geomagnetic storms, neutral atmosphere expansion predictions	Coronal mass ejections in transit to Earth at 1/3 the distance	Coronagraph viewing the outer corona or HELIOS-type photometer (geostationary)
Polar region in situ monitoring	Define the space environment at polar-orbiting altitudes	Energetic particle parameters, pitch angles, precipitating energies	Energetic proton, ion, and electron flux meters and spectrometers; simple magnetometers (polar)
Satellite radio beacon signal monitoring	Space-to-ground radio communication predictions	Ionospheric total electron content and irregularities	VHF/SHF transmitters in space, ground receiver network (geostationary)
Polar particle precipitation monitoring	Predict radiation hazards for polar space flight, D-region propagation anomalies	Solar particle impact in polar regions	In situ particle measurements (polar)
Chromospheric monitoring	Upgrade current monitors for added reliability, economy	Solar chromospheric features and events	H-alpha and UV imager, X-ray and UV full-disk photometer, radio telescope (geostationary)
Solar vector magnetographics	Geomagnetic storms, energetic particles, neutral atmosphere expansion predictions	Three-component solar magnetic fields and associated stresses at one atmospheric height	Vector magnetograph (geostationary)

Instrument Purpose	Service Requirement	Phenomena Addressed	Technical Solution (geostationary or polar S/C)
Particle acceleration monitoring	Energetic particle predictions	Gamma-ray production in flares	Gamma-ray full-disk monitor (geostationary)
Ionosphere upper atmosphere polar disturbances monitoring	Neutral atmosphere expansion, auroral/ionospheric propagation effects	Particle energy, electrical energy input over polar regions	X-ray, UV, and VIS imaging; electric field measurements in situ (polar, 5000 km height)
Monitoring the interplanetary scintillation of pulsars	Geomagnetic storms, neutral atmosphere expansion predictions	High-speed solar wind streams, mass ejections (1 to 2 days before Earth encounters)	Long-baseline radio interferometers on two spacecraft (geostationary)

APPENDIX F

GLOSSARY OF ACRONYMS

AMEX	Australian Monsoon Experiment
AMSU	Advanced Microwave Sounding Unit
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CCOPE	Cooperatiave Convective Precipitation Experiment
CSIRO	Commonwealth Scientific and Industrial Research Organization
DMSP	Defense Meteorological Satellite Program
EMEX	Equatorial Mesoscale Experiment
EPOCS	Eastern Pacific Ocean Climate Study
ERBE	Earth Radiation Budget Experiment
ERL	Environmental Research Laboratories
ERS	ESA Remote Sensing Satellite
ESA	European Space Agency
FIRE	First ISCCP Regional Experiment
GALE	Genesis of Atlantic LOWS Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCP	Global Change Program
GHP	Global Habitability Program
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
IAMAP	International Association of Meteorology and Atmospheric Physics

ICE	Intensification of Cyclones Experiment
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IOP	Intensive Operating Plan
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
IUGG	International Union of Geodesy and Geophysics
Landsat	Land Remote-Sensing Satellite
McIDAS	Man-computer Interactive Data Access System
MCS	Mesoscale Convective System
MESSR	Multispectral Electronic Self-Scanning Radiometer
MIST	Microburst and Severe Thunderstorm Project
MIZEX	Marginal Ice Zone Experiment
MONEX	Monsoon Experiment
MOS	Marine Observation Satellite
MSS	Multi-Spectral Scanner
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
N-ROSS	Navy Remote Ocean Sensing System
NSF	National Science Foundation
OCI	Ocean Color Instrument
PAM	Portable Automatic Mesonet
POES	Polar-orbiting Operational Environmental Satellite
SASP	Solar Activity Spaceborne Patrol

SBUV	Solar Backscatter Ultraviolet Instrument
SEL	Space Environment Laboratory
SEQUAL	Seasonal Equatorial Atlantic Experiment
SESAME	Severe Environmental Storms and Mesoscale Experiment
SPACE	Satellite Precipitation and Cloud Experiment
SSM/I	Special Sensor Microwave/Imager
SST	Sea Surface Temperature
STEP	Stratosphere-Troposphere Exchange Program
STORM	Stormscale Operational and Research Meteorology
TIROS	Television and Infrared Observation Satellite
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
TOPEX	Topography Experiment Satellite
TOVS	TIROS Operational Vertical Sounder
TVA	Tennessee Valley Authority
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UNEP	United Nations Environment Program
VAS	Visible Atmosphere Sounder
WCAP	World Climate Applications Program
WCDP	World Climate Data Program
WCIP	World Climate Impact Studies Program
WCP	World Climate Program
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch

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