The United States Detailed National Report on Systematic Observations for Climate:

United States Global Climate Observing System (U.S.-GCOS) Program

Submitted to the Conference of the Parties to the United Nations Framework Convention on Climate Change

Compiled by the National Oceanic and Atmospheric Administration on Behalf of the United States Government

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Preface

Long-term, high-quality observations of the global environmental system are essential for defining the current state of the Earth's system, and its past history and variability. This task requires both space- and surface-based observation systems. The term "climate observations" can encompass a broad range of environmental observations. These include:

(1) Routine weather observations, which, collected over a long enough period, can be used to help describe the climatology of a region.
(2) Observations collected as part of research investigations to elucidate chemical, dynamical, biological, or radiative processes that contribute to maintaining climate patterns or to their variability.
(3) Highly precise, continuous observations of climate system variables collected for the express purpose of documenting long-term (decadal to centennial) change.
(4) Observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time to provide information on climate change for millennial and longer time scales.

Because this is the first government attempt to document all U.S. contributions to global climate observations, a wide net was cast to include information on observations that fall into each of these categories.

The sections of the report delineate climate monitoring from five distinct yet integrated areas: (1) *in-situ* atmospheric observations; (2) *in-situ* oceanographic observations; (3) *in-situ* terrestrial observations; (4) satellite based observations which by their nature cut across the atmospheric, oceanographic, and terrestrial domains; and (5) data and information management related to systematic observations.

The various federal agencies involved in climate observing, through space-based and ground-based activities, provide many of the required long-term observations. Space-based systems have the unique advantage of obtaining global spatial coverage, particularly over the vast expanses of the oceans, sparsely populated land areas (e.g., deserts, mountains, forests, and polar regions), and the mid and upper troposphere and stratosphere. They provide unique measurements of solar output, the Earth's radiation budget, vegetation cover, ocean biomass productivity, atmospheric ozone, stratospheric water vapor and aerosols, greenhouse gas distributions, sea level and ocean interior, ocean surface conditions and winds, weather, and tropical precipitation, among others.

Satellite observations alone are not sufficient; they require *in-situ* measurements for calibration and validation. *In-situ* observations are required for the measurement of parameters that cannot be estimated from space platforms (e.g., biodiversity, groundwater, carbon sequestration at the root zone, and subsurface ocean parameters). They also provide long time series of observations required for the detection and diagnosis of global change, such as surface temperature, precipitation and water resources, weather and other natural hazards, the emission or discharge of pollutants, and the impacts of multiple stresses on the environment due to human and natural causes. To meet the need for the documentation of global changes on a long-term basis, the U.S. integrates observations from both research and operational systems. The goal of the U.S.'s observation and monitoring program is to ensure a long-term, high-quality record of the state of the Earth system, its natural variability, and changes that occur. The U.S. will continue to support systematic observations in support of climate monitoring, and will provide reports of this nature in the future.

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Material for this report was developed by a U.S. interagency Global Climate Observing System (GCOS) coordination group comprised of representatives from the following federal agencies: (1) the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) and U.S. Forest Service (USFS); (2) three line offices of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA); (3) the U.S. Department of Energy's (DOE) Office of Science; (4) the U.S. Environmental Protection Agency (EPA); (5) the U.S. Department of the Interior's U.S. Geological Survey (USGS); (6) the National Aeronautics and Space Administration (NASA); (7) the U.S. Department of Transportation's Federal Aviation Administration; (8) the National Science Foundation (NSF); (9) the U.S. Naval Oceanographic Office; (10) the U.S. Army Corps of Engineers (USCOE); and (11) the U.S. Air Force. The report was coordinated with the U.S. Global Change Research Program.

This report was prepared as directed by United Nations Framework Convention on Climate Change (UNFCCC) Decision CP/1999/L.3, which requested all Annex I Parties to provide a detailed report on systematic observations in accordance with the UNFCCC reporting guidelines on global climate change observing systems adopted by UNFCCC Decision CP/1999/L.4. The principles of this report are based on climate observing requirements for observing networks, practices, and data management as agreed to internationally in "The Plan for the Global Climate Observing System (GCOS)," Version 1.0, May 1995 GCOS-14 (WMO/TD-No. 681).

NOAA wishes to express its great appreciation to the large group of individuals from many federal agencies for coming together and producing this very detailed and informative report characterizing the vital and diverse aspects of the U.S.'s global climate observing effort.

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Executive Summary

Since 1998, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have noted with concern the mounting evidence of a decline in the global observing capability and have urged Parties to undertake programs of systematic observations and to strengthen their capability in the collection, exchange, and utilization of environmental data and information. It has long been recognized that the range of global observations needed to understand and monitor Earth processes contributing to climate and to assess the impact of human activities cannot be satisfied by a single program, agency, or country. The U.S. supports the need to improve global observing systems for climate, and we join other Parties in submitting information on national plans and programs that contribute to the global capability. This report was prepared as directed by UNFCCC Decision CP/1999/L.3, which requested Annex I Parties to provide a detailed report on systematic observations in accordance with the UNFCCC reporting guidelines on global climate change observing systems adopted by the UNFCCC Decision CP/1999/L.4.

The U.S. actively supports the Global Climate Observing System (GCOS) through its participation in and support of the GCOS networks, and through its support of related climate observing activities. The U.S. recognizes that international cooperation both in data collection and sharing of information is essential to provide the climate information required by the UNFCCC.

With regard to capacity building, the initial climate report of the George W. Bush Administration noted that national and international bodies have "identified the building of a global observing system to monitor climate as being crucial to improving our understanding of the science of climate change. This system must include developing countries that have limited resources to make the necessary measurements." It further states that the U.S. will "provide resources to help build climate observation systems in developing countries throughout the world, and call upon other developed countries to provide matching funds for such an investment."

This report delineates climate monitoring in the U.S. in five distinct yet integrated areas: (1) *in-situ* atmospheric observations; (2) *in-situ* oceanographic observations; (3) *in-situ* terrestrial observations; (4) satellite based observations which by their nature cut across the atmospheric, oceanographic and terrestrial domains; and (5) data and information management related to systematic observations. The report attempts to include observation systems now known to be relevant, but is representative of the larger U.S. effort to observe environmental variables.

The U.S. actively participates in the GCOS Surface Network (GSN), the GCOS Upper Air Network (GUAN), and the Global Atmospheric Watch (GAW). The US supports 75 GSN stations, 20 GUAN stations, and 4 GAW stations. These stations are distributed geographically as prescribed in the GCOS and GAW network designs. The data (metadata and observations) from these stations are shared according to GCOS and GAW protocols. The GSN and GUAN stations are part of a larger network, which was developed for purposes other than climate monitoring. Nonetheless, the stations fully meet the GCOS requirements. In general, the National Oceanic and Atmospheric Administration (NOAA) operates most of the U.S. GCOS atmosphere-related networks.

There is no comprehensive system designed to observe climate change and climate variability in the U.S. Basically, sustained observing systems in the U.S., which provide continuing observations, provide data principally for non-climatic purposes, such as predicting weather, advising the public, and managing resources. In addition, there are research-observing systems that collect data for climate purposes, but they are often oriented toward gathering data for climate process studies or other research programs rather than climate monitoring. They are usually limited in their spatial and temporal extent. Because the U.S. climate record is based upon a combination of existing operational and research programs, it may not be "ideal" from a long-term climate monitoring perspective. Nevertheless, these observing systems collectively provide voluminous and significant information about the spatial and temporal variability of climate in the U.S. and contribute to the international climate observing effort as well. The detailed atmospheric section in the main body of the report examines *in-situ* climate monitoring involving systems from the surface, upper air, and atmospheric deposition domains.

Table 1. U.S. Participation in the Global Atmospheric Observing Systems

	GSN	GUAN	GAW	OTHER
How many stations are the responsibilities of the Party?	75	20	4	See Section I
How many of those are operating now?	75	20	4	See Section I
How many of those are operating to GCOS standards now?	75	20	4	See Section I
How many are expected to be operating in 2005?	75	21	4	See Section I
How many are providing data to international data centres now?	75	20	4	See Section I

The GCOS requirements for ocean observations are the same as the climate requirements for the Global Ocean Observing System (GOOS). Both are based on the Ocean Observing System Development Panel (OOSDP) Report, (OOSDP, 1995), which can be found at http://www-ocean.tamu.edu/OOSDP/FinalRept/t_of_c.html. The GOOS, like GCOS, is based on a number of *in-situ* and space-based observing components. The US contributes to all of these components. It supports surface and marine observations through 149 fixed buoys, over 500 surface drifting buoys, nearly 200 sub-surface floats, and over 1500 volunteer observing ships as part of the Integrated Global Ocean Observing System (IGOSS). It provides support for 244 sea-level tide gauges through the Global Sea Level Observing System (GLOSS). It currently provides satellite coverage of the global oceans for sea surface temperatures, surface elevation, ocean surface winds, sea ice, ocean color, and other variables of climate relevance. These satellite activities are coordinated internationally through the Committee on Earth Observation Satellites (CEOS).

Table 2. U.S. Participation in the Global Oceanographic Observing Systems[1]

	VOS	SOOP	Tide Gauges	Surface Drifters	Sub-Surface Floats	Moored Buoys	ASAP
For how many platforms is the Party responsible?	1557	51	244	~540/year	187	149*	<1
How many are providing data to international data centres?	1470	51	244	~800 (1½- 2 year lifetime)	187	149*	<1
How many are expected to be operating in 2005?	1470	51	244	~800	~1,000	~130*	<1

* Includes 5 mooring pairs along the equator in the Pacific, research moorings in the Arctic and Pacific, two time series sites, and an international collaborative program in the Atlantic.

- ASAP – Automated Shipboard Aerological Program
- SOOP – Ships of Opportunity
- VOS – Voluntary Observing Ships

Note: For Table 2, contributing to an international data centre is considered to be data available on the Global Telecommunications System (GTS) that is available to be downloaded from an ftp or other site either directly or via the Distributed Oceanographic Data System (DODS), as well as to world data centres.

For terrestrial observations, the requirements for climate observations were developed jointly between GCOS and the Global Terrestrial Observing System (GTOS) through the Terrestrial Observations Panel for Climate (TOPC); see GCOS/GTOS Plan for Terrestrial Climate-related Observations, version 2.0 June 1997, GCOS-32 (WMO/TD-No. 796). GCOS and GTOS, have identified permafrost thermal state and permafrost active layer as key variables for monitoring the state of the cyrosphere. GCOS approved the development of a globally comprehensive permafrost monitoring network to detect temporal changes in the solid earth component of the cryosphere. As such, the Global Terrestrial Network for Permafrost (GTN-P) is quite new and still very much in the developmental stage. The International Permafrost Association (IPA) has the responsibility for managing and implementing the GTN-P.

In the U.S., contributions to the GTN-P network are provided by the Department of the Interior and the NSF, through grants to various universities. All the U.S. GTN-P stations are located in Alaska. The active layer thickness is currently being monitored at 27 sites. Forty-eight boreholes exist in Alaska where permafrost thermal state can be determined. Of these, 4 are classified as *Surface* (0-10 m) sites, 1 is *Shallow* (10-25 m), 22 are *Intermediate Depth* (25-125 m), and 21 are *Deep Boreholes* (>125 m). U.S. contribution to the GTN-P network comes from short-term (3-5 year) research projects.

The U.S. operates a long-term "benchmark" glacier program to intensively monitor climate, glacier motion, glacier mass balance, glacier geometry, and stream runoff at a few select sites. The data collected are used to understand glacier-related hydrologic processes and improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change.

1 See also http://ioc.unesco.org/goos/act_pl.htm for details of ocean observation requirements.

The approach has been to establish long-term mass balance monitoring programs at three widely spaced glacier basins in the U.S. that clearly sample different climate-glacier-runoff regimes. The three glacier basins are South Cascade Glacier in Washington State, and Gulkana and Wolverine Glaciers in Alaska. Mass balance data are available beginning in 1959 for the South Cascade Glacier, and beginning in 1966 for the Gulkana and Wolverine Glaciers.

The AmeriFLUX network endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of CO_2, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global CO_2 budget, enable improved predictions of future concentrations of atmospheric CO_2, and enhance the understanding of carbon fluxes, Net Ecosystem Production (NEP), and carbon sequestration in the terrestrial biosphere.

The terrestrial section of the report examines *in-situ* climate monitoring and involves, in addition to the GTN-P, GTN-G, and AmeriFLUX programs, streamflow and surface water gaging, ground water monitoring, snow and soil monitoring, the U.S. paleoclimatology program, ecological observation networks, fire weather observation stations, as well as global, national, and regional land cover characterization. The U.S. contributes to all of these components, and supports 77 GTN-P sites, 3 GTN-G sites, and 52 Fluxnet sites.

Table 3. U.S. Participation in the Global Terrestrial Observing Systems

	GTN-P	GTN-G	FLUXNET AmeriFlux	Other
How many sites are the responsibilities of the Party?	77	3	52	See Section III
How many of those are operating now?	77	3	47	See Section III
How many are providing data to international data centres now?	77	3	24	See Section III
How many are expected to be operating in 2005?	80	0	50	See Section III

Space-based, remote sensing observations of the atmosphere-ocean-land system have evolved substantially since the early 1970’s when the first operational weather satellite systems were launched. Over the last decade satellites have proven their observational capabilities to accurately monitor nearly all aspects of the total Earth system on a global basis; a capability unmatched by ground-based systems that are limited to land areas and cover only about 30% of the planetary surface. Currently, satellite systems monitor the evolution and impact of the El-Nino, weather phenomena, natural hazards, and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal zones and algae blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and others. These various observations are used extensively in real-time decision-making and the strategic planning and management of industrial, economic, and natural resources. Examples include weather and climate forecasting, agriculture, transportation, energy and water resources management, urban planning, forestry, fisheries, and early warning systems for natural disasters and human health impacts.

Table 4. U.S. Environmental Satellite Program

	Polar Orbiting (Operational)	Geostationary (Operational)	Research (Systematic and Experimental Observations)
For how many platforms is the Party responsible?	2 – Landsat 2 – POES 2 – DMSP	2 – GOES	21 (See Section IV)
How many of those are operating now?	2 – Landsat 2 – POES 2 – DMSP	2 – GOES	21 (See Section IV)
How many are providing data to international data centres?	2 – Landsat 2 – POES 2- DMSP	2 - GOES	10 (See Section IV)
How many are expected to be operating in 2005?	1 – Landsat 1 – POES 2 – DMSP	2 - GOES	14 (See Section IV)

The GCOS planning process addressed satellite requirements for climate. In so doing, GCOS identified an extensive suite of variables that should be observed and monitored from space; see GCOS Plan for Space-based Observations, GCOS-14 (WMO/TD – No. 681). In addition, GCOS plans specified that instrument calibration and validation be performed to ensure that the resulting space-based observations meet climate requirements for accuracy, continuity, and low bias.

The current generation of U.S. research satellite instruments exceeds the GCOS requirements for the absolute calibration of sensors, something that was lacking in the early satellite platforms used for real-time operational purposes. Regarding historical satellite data, several of the data series from operational satellites have been re-processed using substantially improved retrieval algorithms and, therefore, provide good quality global data products for the purposes of GCOS and climate system variability and climate change research and applications. Improving the on-board capabilities for calibration on operational satellites will be one of the objectives considered in the development of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Prior to the launch of NPOESS in 2008, an NPOESS Preparatory Project (NPP) satellite will be launched in the 2005 timeframe as a bridge mission between the NASA Earth Observing Satellites (EOS) program and NPOESS. The mission of NPP is to demonstrate advanced technology for atmospheric sounding, providing ongoing observations about global change after EOS-Terra and EOS Aqua. It will supply data on atmospheric and sea surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. NPP will contribute to instrument risk reduction by offering early instrument and system level testing, lessons learned for design modifications in time to ensure NPOESS launch readiness, ground system risk reduction, early user evaluation of NPOESS data products, such as algorithms, and instrument verification, and opportunities for instrument calibration.

The satellite observations section of this report details a number of U.S. satellite operational and research missions in support of climate monitoring. The instruments on the Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), the series of Earth Observing Satellites (EOS), the Landsats 5 and 7, as well as the Total Ozone Mapping Spectrometer satellite and TOPEX/Poseidon satellite measuring sea surface height, winds, and waves form the basis of a robust national remote sensing program that fully supports the requirements of GCOS. Additional satellite missions in support of GCOS and described in the satellite observations section include: (1) the Active Cavity Radiometer Irradiance Monitor (ACRIM) for measuring solar irradiance; (2) EOS-Terra; (3) QuickSCAT; (4) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean productivity; (5) the Shuttle Radar Topography Mission (SRTM); (6) the Tropical Rainfall Measuring Mission (TRMM) for measuring rainfall, clouds, sea surface temperature, radiation, and lightning; and (7) QuickSCAT. In addition, a number of missions still to be launched are included in this group of environmental satellites.

The Defense Meteorological Satellite Program (DMSP) is a Department of Defense (DOD) program run by the Air Force Space and Missile Systems Center (SMC). The DMSP program designs, builds, launches, and maintains several near-polar orbiting, sun synchronous satellites, monitoring the meteorological, oceanographic, and solar-terrestrial physics environments. DMSP satellites are in a near-polar, sun synchronous orbit at an altitude of approximately 830 kilometers (km) above the earth. Each satellite crosses any point on the earth up to two times a day and has an orbital period of about 101 minutes, thus providing nearly complete global coverage of clouds every six hours.

The U.S. cooperates on an international basis with a number of coordinating bodies, including the Integrated Global Observing Strategy (IGOS). IGOS is a strategic planning process, uniting the major satellite and surface-based systems for global environmental observations of the atmosphere, oceans and land, in a framework for decisions and resource allocations by individual funding agencies. Its purview includes observations for climate, and the needs of multiple domains—the entirety of which no single Partner is able to address alone. It takes a strategic view across all Earth observing requirements, evaluates capabilities of current and planned observing systems, and has begun (at least among the space agencies) to obtain commitments for addressing the gaps. An IGOS Ocean Theme is in the implementation phase under leadership from GOOS. An analysis of requirements, gaps, and recommendations for priority observations is underway for integrated global carbon observations as well as integrated global atmospheric chemistry observations. Prospectively, similar analyses, recommendations, and commitments will likely be undertaken in the areas of the water cycle, geo-hazards, and coral reefs.

Operational weather satellites are internationally coordinated through the Coordination Group for Meteorological Satellites (CGMS), of which the World Meteorological Organization is a member and major beneficiary. CGMS has six satellite agency members. The primary body for policy and technical issues of common interest related to the whole spectrum of Earth observation satellite missions is the CEOS. CEOS has 22 space agency members, including both research and operational satellite agencies, with funding and program responsibilities for a satellite Earth observation program currently operating or in the later stages of system development. CEOS encourages compatibility among space-borne Earth observing systems through coordination in mission planning, promotion of full and non-discriminatory data access, setting of data product standards, and development of data products, services, applications, and policies.

Global environmental concerns are an overriding justification for the unrestricted international exchange of GCOS data and products for peaceful, non-commercial, global scientific and applications purposes. As such, GCOS developed an overarching data policy that endorses the full and open sharing and exchange of GCOS-relevant data and products for all GCOS users as a fundamental objective; these data and products should be provided at the lowest possible cost to GCOS users. The U.S. recognizes this and subscribes to GCOS' data policy.

Achieving the goals of the U.S. climate-observing program requires multidisciplinary analysis of data and information to an extent never before attempted. This includes the analysis of interlinked environmental changes that occur on multiple temporal and spatial scales, which is very challenging both technically and intellectually. For example, many types of satellite and *in-situ* observations at multiple scales need to be integrated with models and the results presented in understandable ways to all levels of the research community, decision makers, and the public. Additionally, very large volumes of data from a wide variety of sources and results from many different investigations need to be readily accessible to scientists and other stakeholders in usable forms that can be integrated.

Various U.S. agencies have engaged in extensive development of interagency data and information processes to address these needs, primarily through fostering better integration among U.S. Government data and discipline specific information. The Global Change Data and Information System (GCDIS) has been developed in response to this need and to facilitate data accessibility. GCDIS currently provides a gateway for discovery and information access among more than 70 federally funded sources of data, both governmental and academic. During the last decade, significant strides have been made in GCDIS' seamless connections between diverse data sets and sources, as well as its ability to search across the full complement of sources. The World Wide Web has facilitated this effort, however, important challenges remain.

The provision of data and information in forms needed for cross-disciplinary analyses and projections remain a challenge, even as the increasing focus of the U.S. agencies on investigating the impacts and consequences of change heightens the need for multidisciplinary research. Physical and biological data needs to be related to data on environmental conditions and socioeconomic trends originally compiled for other purposes. This is a particularly important challenge in addressing potential regional consequences of multiple stresses and determining the vulnerability of different resources and communities.

While a wide net has been cast to include information on each of the observing categories of this report, it is the position of the U.S. government (as evidenced by its active support of the 10 Principles of Climate Observations, and of the U.S. climate research community [National Research Council, 1999]), that high standards must be met if a particular set of observations is to serve the purpose of monitoring the climate system to detect long-term change. In general, the observing programs and resulting datasets described herein do not meet the ten "Climate Monitoring Principles" endorsed by the U.S. and UNFCCC. This shortfall stems from two main factors: 1) the principles were articulated only within the past decade (Karl et al. 1995), long after the initiation of most of our long-term observing systems; and 2) more recent observing programs typically do not have climate monitoring as their prime function.

It is hoped that the detailed information contained in this report will aid the GCOS Secretariat in the analysis of the state of global climate observing, as charged by the UNFCCC. The inclusion of this level of detail and the format of the supplementary tables for each section was developed, in concert with the GCOS Secretariat, at an informal meeting of GCOS national coordinators in Melbourne, Australia, in August 2000. This additional detail, while voluntary on the part of nations, should assist the secretariat in this endeavor. There are a number of overarching science questions dealing with how the Earth-Climate System is changing and what the consequences are for life on Earth. These questions are as follows:

- ***How is the global Earth-Climate system changing? (Variability-V)***
  - How are global precipitation, evaporation, and the cycling of water changing?
  - How is the global ocean circulation varying on interannual, decadal, and longer time scales?
  - How are global ecosystems changing?
  - How is stratospheric ozone changing as the abundance of ozone-destroying chemicals decreases and new substitutes increases?
  - What changes are occurring in the mass of the Earth's ice cover?

- ***What are the primary forcings of the Earth-Climate system? (Forcing-F)***
  - What trends in atmospheric constituents (including aerosols) and solar radiation are driving global climate?
  - What changes are occurring in global land cover and land use, and what are their causes?
  - How is the Earth's surface being transformed and how can such information be used to predict future climate changes?

- ***How does the Earth-Climate system respond to natural and human-induced changes? (Response-R)***
  - What are the effects of clouds and surface hydrologic processes on Earth's climate?
  - How do ecosystems respond to and affect global environmental change and the carbon cycle?
  - How can climate variations induce changes in the global ocean circulation?
  - How do stratospheric trace constituents respond to change in climate and atmospheric composition?
  - How is global sea level affected by climate change?
  - What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?

- ***What are the consequences of change in the Earth-Climate system for human civilization? (Consequences-C)***
  - How are variations in local weather, precipitation and water resources related to global climate variation?
  - What are the consequences of the interaction between climate and land cover and land use change in regard to the sustainability of ecosystems and economic productivity?
  - What are the consequences of climate and sea level changes and increased human activities on coastal regions?

- ***How well can we predict future changes to the Earth-Climate system? (Prediction-P)***
  - How well can weather forecast duration and reliability be improved by new in-situ and space-based observations, data assimilation, and modeling?
  - How well can transient climate variations be understood and predicted?
  - How well can long-term climatic trends be assessed or predicted?
  - How well can future atmospheric chemical impacts on ozone and climate be predicted?

The U.S.-GCOS effort is designed to aid in addressing these scientific questions, and contributes to all the international programs mentioned and their respective objectives. Following the UNFCCC reporting guidelines, adopted by COP-5, the U.S. contribution to GCOS regarding both in-situ and space-based observations are described in this report. Both operational and research systems are included in accord with the GCOS coordinators' guidance, elaborating on the UNFCCC guidelines.

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I. Atmospheric Observations

The United States actively participates in the Global Climate Observing System (GCOS) Surface Network (GSN), the GCOS Upper Air Network (GUAN), and the Global Atmospheric Watch (GAW). However, there is not a comprehensive system designed exclusively to observe climate variability in the U.S. As with other countries, most U.S. observing systems provide data for non-climatic purposes, such as predicting weather, advising farmers, and managing resources. The systems that collect data for climate purposes are oriented toward gathering data for climate process studies rather than climate monitoring, and are limited in their spatial and temporal extent. Because the U.S. climate record is based upon these existing operational and research programs, it is not “ideal” from a climate monitoring perspective. Nevertheless, these *in-situ* observing systems collectively provide tremendous information about the spatial and temporal variability of climate in the U.S.

Space-based remote sensing observations have played a critical role in support of atmospheric observations. Over the last decade, satellites have proven their observational capabilities to accurately monitor nearly all aspects of the total Earth system. This is a capability unmatched by surface based systems which are limited to land areas and cover only about 30% of the planetary surface. Currently, satellite systems monitor the evolution and impacts of the El Nino, weather phenomena, natural hazards, and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal zones and algae blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and others. While this section focuses on *in-situ* observing systems, a full picture of satellite observing can be found in section IV of this report.

A. GCOS Networks

1. GSN Stations

The U.S. has 75 GSN stations that collectively represent the temperature and precipitation variability of the country and its territories. Given that the U.S. accounts for less than two percent of the terrestrial surface, the U.S. component of the GSN is comparatively large (only the Russian Federation has more stations). Fifty-four GSN sites are in the conterminous U.S., 14 in Alaska, 2 in Hawaii, 2 in Antarctica, 1 in Puerto Rico, 1 in Guam, and 1 in American Samoa. All of these stations are currently operating, and should continue to operate through 2005. Ninety percent transmit their data in real-time via the Global Telecommunications System (GTS). The data and metadata for all stations are quality controlled by and archived at the World Data Center A for Meteorology (i.e., the U.S. NOAA National Climatic Data Center [NCDC]).

2. GUAN Stations

The U.S. has 20 GUAN stations that collect standard radiosonde data at standard observation times. Six stations are in the conterminous U.S., three in Alaska, one in Hawaii, two in Antarctica, one each in Puerto Rico, Guam, and American Samoa, and five others in areas such as Ascension Island in the South Atlantic, and Bermuda. All of these stations are currently operating and will continue to operate through 2005; the network is operated by NOAA’s

National Weather Service (NWS). The data and metadata for all stations are quality controlled by and archived at NCDC. The possibility exists for an additional GUAN station, in the central part of the U.S., to be added to the network by the year 2005.

3. GAW Stations

The U.S. has four GAW stations that collect atmospheric constituent data. The four stations: Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and the South Pole are currently operating and will continue to operate through 2005. The data and metadata for all stations are quality controlled by and archived at NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL).

B. Other Surface Networks

According to the 1999 National Research Council (NRC) report entitled, "Adequacy of Climate Observing Systems," the surface networks of the U.S. are only partially capable of delivering data suitable for detecting climate variations and changes on multi-decadal time scales. Surface temperature is adequate with respect to half of the 10 climate monitoring principles (data continuity/quality, integrated environmental assessment, complementary data, continuity of purpose, and data/metadata access). Snow cover and snow depth are adequate with regard to three of the principles (integrated environmental assessment, complementary data, and data/metadata access). Precipitation, wind, water vapor, and sea level pressure are adequate only in terms of one of the principles (continuity of purpose).

The two largest national-scale surface observing networks in the U.S. are the First Order Network and the Cooperative Observing Network. Many other networks exist at the regional, state, and local scale (e.g., the Oklahoma Mesonet), but are too numerous to discuss in this report.

1. First Order Network

The civilian surface observation network in the U.S. has undergone equipment modernization and management transition over the past ten years. The network of approximately 2100 observing locations, located mainly at airports, has been expanded in spatial and temporal density from previous decades. The network is comprised primarily of modernized automated weather observing systems. About 60 percent of the automated systems receive human augmentation or backup to enhance the data provided by the automated system.

Two major types of automated observing systems are deployed today: the Automated Surface Observing System (ASOS) (http://www.nws.noaa.gov/asos/) and the Automated Weather Observing System (AWOS). The sensor performance standards for both systems are identical, although the systems have varying degrees of difficulty in maintaining those standards. NOAA and the Federal Aviation Administration

ASOS Site in Haines, Alaska

(FAA) manage these automated civilian surface observation networks through a cooperative agreement.

The system's software algorithms and sensors are from different manufacturers. There are about 900 ASOS, 400 AWOS, and 650 non-federally owned AWOS comprising the surface-observing network. There are another 200 manually derived surface aviation observation stations at airports providing full-time 24 hour per day coverage or part time coverage observations. The network provides dissemination of data on at least an hourly basis for the following elements: 2-minute average wind speeds, sky condition (clouds to 12,000 feet and amount of coverage in octants), visibility to 10 statue miles, ambient air temperature, dew point temperature, pressure, and present weather (lightning data at a minimum). The ASOS also provides hourly precipitation accumulation amounts and a range of present weather elements. Some of the AWOS sites provide present weather and precipitation accumulation information. The staffed automated systems provide more detailed pressure, precipitation, present weather, and operationally significant remarks. While the network is located at airports to support the safe movement of aircraft, the data from the automated systems support climatological and meteorological applications for forecasts and warnings, modeling, research, and retrospective analysis.

The NWS currently has responsibility for certification of civilian weather observers in the U.S. and performs quality assurance routines on observations received through the NWS communications systems. The quality assurance of the observations is the responsibility of various NOAA groups, including the NWS Weather Forecast Offices (WFO), the National Center for Environmental Prediction (NCEP) and NCDC. NWS quality assurance includes regular maintenance and repairs by NWS electronics technicians for ASOS. FAA performs maintenance on the AWOS. Non-federal AWOS quality assurance is very limited.

The NOAA/NCDC is responsible for archiving the data for the surface observation network. NCDC archives the hourly and higher-resolution data from the ASOS stations and observational data from the AWOS stations that transmit data into the national communications networks. NCDC ensures the metadata received from network locations are made available digitally to customers. The NWS currently collects metadata from ASOS locations and relays the data to NCDC. NWS and NCDC are collaborating in an effort to modernize the digital reporting of metadata and station history files directly from the WFOs to NCDC. NWS is working to ensure metadata complies with national Federal Geographic Data Committee (FGDC) standards.

The surface observing network of 315 stations (formerly called First Order, or A stations, by the NWS) now possess ASOS. All of the stations have 30-year climate records, and approximately two-thirds of them contain some climatic elements extending back more than 50 years. Those stations have undergone minor relocations and several major equipment changes during the life of the stations. Documentation accompanies all of the equipment changes, and data continuity studies have been conducted to determine the effect of these changes on the temperature record. The results of those studies are also included in the station documentation. One of the data quality issues identified after the introduction of ASOS was in the area of precipitation measurement. The ASOS precipitation gauge routinely under-reports accumulations during freezing/frozen precipitation events. Initiatives are underway to deploy an all-weather precipitation gauge for the ASOS. Inadequate cloud cover measurements also impact the accuracy of ASOS records. The ASOS ceilometer reports only to 12,000 feet and in an automated mode reports clear skies if no clouds are reported below 12,000 feet. The NWS is working to improve the sensor and algorithm performance of the ASOS. In the next few years, the following sensor improvements for the ASOS are planned: an all-weather precipitation gauge, an improved dewpoint sensor, an ice-free wind sensor, an enhanced precipitation identifier, and a new central processing unit necessary to accommodate the sensor enhancements.

There will be continuing activities to field automated observing systems by the federal government, private industry, and local governments. The proliferation of these systems presents problems in the future for management and quality control. As the requests for access to the systems increase, the connectivity to national communication systems will increase.

The NWS has developed a climatic elements observation network comprising the 121 WFOs within the NWS to supplement the surface observing network. This network provides six hourly supplementary climatological data reports of the following elements: total cloud cover and synoptic cloud types, snowfall, water equivalency of snow on the ground, depth of snow on the ground, duration of sunshine (limited number of locations), six hourly precipitation accumulation amounts, and precipitation types and intensities. This is a new network located at newly built WFOs. As more experience with ASOS climate records is obtained, the quality and reliability of the data should increase with time, and long-term climatological records will begin to be established at these sites.

2. Cooperative Observing Network

The Cooperative Observing Network (Coop Network) is a nationwide weather and climate-monitoring network (http://www.nws.noaa.gov/om/coop/index.htm) that observes and reports weather information on a regular basis. It is an important component of the NWS data collection process and is vital to the national observing capability for monitoring temperature, precipitation, snowfall, and other significant weather events across the U.S.

The network was initially established at the end of the 19th century to serve agricultural needs, but due to the expansion of data applications over the past decades, the network data are now used across many disciplines ranging from management of water resources, and design and maintenance of infrastructure to predictions of crop yield and local weather forecasting. The data provided through this network are used for a myriad of important political and economic decisions by both government and the private sector. Because of its stability over time and the geographic density of its observations, the network is particularly well suited for monitoring and detecting local, regional, and nationwide climate variations and changes.

The Coop Network consists of thousands of volunteer citizens and institutions. Participants are provided with a set of simple weather instruments and observing instructions by the NWS, which manages the network under the Cooperative Observer Program (Coop Program). The observers provide basic weather data for their locations, usually on a daily basis. Within the Coop Network there are several types of stations. At the heart of the network are about 5,000 full “climatological” stations that measure daily maximum and minimum temperature, precipitation, snowfall, and temperature and snow depth. Many observers provide supplemental information, such as time of day when precipitation fell and other weather conditions, such as fog, freezing rain, thunder, hail, and damaging winds. These stations are called A stations by the NWS.

Over time, other types of stations have been added to the network. The Bureau of Reclamation and the U.S. Army Corps of Engineers (USCOE), which designs, builds, and operates many major water storage, river navigation, and flood control projects requires hydrologic data. As a result, a large number of “hydrologic” stations (also known as B stations) were added to the Coop Network, mostly during the 1940’s and 1950’s, many of which report only precipitation and/or river stages. Some stations are equipped with rain gauges to collect and record information on the intensity and duration of precipitation. The Coop Network also includes a small number of AC stations, which serve a variety of special purposes, such as research on, and forecasts of, frost in fruit growing areas and measurements of precipitation in remote areas. The total number of cooperative observer stations managed and maintained by the NWS is around 11,700. Of these stations, over 3,000 have been operational for 30 years or more. Currently the Coop Network is not participating in the GCOS Network due to the nature of the observation processes described. The U.S. has developed a list of recommended sites that will join the GCOS Network following station upgrades. These sites were identified for their length of service and quality of data. A Climate Reference Network (CRN) of 250 stations is being developed to aid in this area.

3. Observing Equipment

With a few exceptions, the instruments used by the cooperative observers have not changed significantly over the past century. Snowfall and snow depth are measured manually with rulers or stakes. Liquid precipitation is measured with two types of rain gauges:

- Non-recording gauges are standard 8-inch rain gauges that require the observer to go outside, take a visual measurement (using a dipstick) of the water level in the magnifier tube, and record the information on a paper form. About 90 percent of the stations that report precipitation use non-recording gauges.
- Recording gauges can be one of two types: the Belfort Fischer-Porter type or the Belfort Universal type. Recording gauges automatically weigh and record precipitation, using either a paper punch tape or paper analog chart. The Belfort Fischer-Porter gauges represent 1960’s technology.

Two basic types of instruments are used to measure temperature:

- Liquid-in-glass maximum/minimum thermometers require the observer to go outside to the radiation shelter (know as the cotton region shelter) that houses the thermometers, manually read the thermometer, record the observation on the appropriate paper form, and reset the thermometer. This type of thermometer is used at about 40 percent of the nearly 5,000 AA stations.
- Maximum-minimum temperature systems (MMTS) consist of electric thermistors in pole-mounted plastic radiation shelters and remote display units inside the observer’s home or workplace. MMTSs are powered by observer-provided electricity. Observations are recorded manually on paper.

Many observers at hydrological stations phone in their observations shortly after taking daily readings. Transmission of daily observations is mainly by voice. Observers at climatological stations make and record observations of significant weather events, which are recorded manually on official forms but are not routinely included in daily transmissions.

4. Data Assimilation and Quality Control

NCDC has the primary responsibility for processing and interpreting coop data and disseminating it to users. NCDC typically receives the data forms and paper tapes from NWS forecast offices two to four weeks after the end of the calendar month. Because these forms are sent by mail from 121 NWS forecast offices, NCDC does not receive them all at the same time. After varying amounts of review and preliminary quality control, NCDC prepares the forms and paper tapes for entry into an electronic database. More intensive quality control of the Coop data is performed after keying. Once all data have undergone full quality control processing, NCDC prepares various data products.

5. Metadata

The NWS has been modernizing the Coop Network metadata support, upgrading from the traditional and laborious process of entering data manually on complicated forms. The recently completed support software will provide much-improved access and quality control of the data. Many field offices have been equipped with hand-held global positioning system (GPS) receivers and digital cameras, important improvements to the management and oversight of the Coop Network.

6. Observation Problems

Time shifting – Monthly average temperatures in the U.S. are calculated using daily maximum and minimum temperatures for climatological purposes. The preferred measurement period is midnight-to-midnight. However, because readings by human observers at midnight are not feasible for a “volunteer” network, the vast majority of cooperative observers operate on a “climatological day” that does not correspond to the standard midnight-to-midnight calendar day. Since the end of the observation day varies from station to station, a non-climate time-of-observation bias is introduced into the calculated mean temperatures. Therefore, when a station changes its time of observation, an “apparent” climate change is introduced into the data set. Random changes have been made in the preferred observation time. For personal convenience, observers sometimes switch from a sunset-to-sunrise climatological day to a sunrise-to-sunrise schedule or the reverse.

Date shifting – A related problem is “date shifting,” the practice of entering data for a date other than when the observation was made, or combining daily totals. Some cooperative observers do not measure precipitation during the weekend. Instead, they include weekend precipitation in their Monday observation. This problem is difficult to identify because the monthly totals are consistent with those of nearby stations. Date shifting skews daily totals and can influence statistics on extreme events.

Missing observations – Another problem is dropped or missing observations. Sometimes observers get sick, take vacations, leave home for a weekend or longer, use improperly trained substitutes, forget to take an observation, record observations illegibly, or are too busy to take observations. Problems also occur frequently at institutional sites. Although these sites have around-the-clock staffing, their observers often have high turnover rates, and because of inadequate training, motivation, or management, they may not be dedicated to taking consistent observations.

7. Cooperative Network of the Future

The Coop Network will continue to rely on volunteer observers and will incorporate strategic upgrades that are feasible with current technology. The growing demand for accurate and timely cooperative data will determine the requirements for the modernization. In the design process the following questions are being considered: How many sites will be required? What other networks, if any should be incorporated? What variables should be measured? Which components should be automated? How often should data be sampled? How rapidly should data be made available to users? What tradeoffs of costs against quality and performance should be made? On what schedule should system design or redesign be implemented?

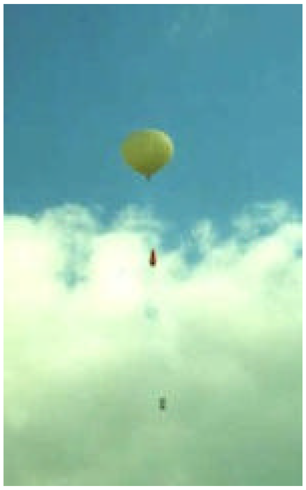
In addition to the 250-station CRN, NOAA proposes to embark on a coop modernization initiative for the larger population of cooperative stations beginning in the 2002 time frame. In preparation for this modernization and restructuring, the NWS has contracted for a spatial density study to determine an appropriate size for the Coop Network.

8. Climate Reference Network

The CRN (http://www.ncdc.noaa.gov/ol/climate/research/crn/index.html) will provide the nation a benchmark climate reference network and fulfill the nation's need for long-term high quality climate observations and records with minimal time-dependent biases affecting the interpretation of decadal to centennial climate variability and change. The full network will be limited to about 250 geographic locations (500 paired instrument suites, a primary site and a backup site) strategically selected to capture the representative climate regions of the nation. The number of quality observing instruments is limited and focused on a few climate significant parameters, specifically air temperature, precipitation, and humidity.

The primary goal of the CRN is to provide future long-term (50-100 years) high quality homogeneous observations of surface air temperature and precipitation that can be coupled to past long-term observations for the detection and attribution of present and future climate change. Fifty years from now the CRN will provide the requisite level of long-term high quality data that will, with the highest degree of confidence possible, support the answer to the question: How has the U.S. climate varied and changed over the past 50 years?

The U.S. CRN program complements the Coop Network and many other existing and proposed observing networks operated by NOAA and other federal, state, and local agencies, as well as private industry. The CRN Program has initiated contact with many other agencies (e.g., Drought Monitoring Program, USGS, USDA, USCOE, USGS, BLM, NWS, OFCM, DoD, DOE, and State networks) in coordinating additional "instruments of opportunity" and site selection to make an "optimal fit" with other network sites. There is a strong commitment to direct participation and involvement by the Regional Climate Centers (RCC) and State Climatologists (SC). Universities have already contacted the program and expressed interest in hosting CRN instrument sites and participating in related climate research activities.



C. Upper Air Network

The U.S. and other World Meteorological Organization (WMO) member countries maintain and manage an agreed-to network of observing locations that cumulatively form part of the Global Observing System of the World Weather Watch network. The synoptic rawinsonde observing programs of the U.S. and the other WMO member countries are designed to meet real-time operational needs for weather analysis and forecasting. These observations also provide a national and international data base of upper air observations for research and climatological purposes. From the standpoint of the 10 climate monitoring principles, the upper air network is probably adequate in only one respect: integrated environmental assessment.

1. Operations

The NOAA NWS, as the primary provider of upper air data for national and international data exchange, operates or supports the operation of a network of upper air weather observing stations in the contiguous U.S., Alaska, the Pacific Islands, and the Caribbean. At each station, a balloon-borne instrument called a radiosonde is sent aloft twice daily, at 0000 hours Universal Coordinated Time (UTC) and 1200 hours UTC, to measure atmospheric profiles of the temperature, moisture, pressure, and winds. The U.S. network of stations contributes more than ten percent of the global rawinsonde network. The primary responsibility for maintaining this network rests with the NWS. The network is augmented by observations made at military, National Aeronautics and Space Administration (NASA), DOE, and other installations. The NWS operated and supported network consists of 102 sites (Table S3). Ten of these sites in the Caribbean comprise the Cooperative Hurricane Upper Air Stations network. These sites are supported by the NWS through bi-lateral agreements with other nations.

The primary atmospheric variables collected from each rawinsonde location are pressure, temperature, relative humidity, wind speed, and wind direction. These variables are collected from surface to as high as 35 km and ranges out to 250 km from launch site to burst site.

2. Data Quality Assurance

Data quality assurance is carried out at several levels. At the station, the operator responds to data messages on data that are computer flagged. Data profiles are also reviewed and necessary editing accomplished before message generation and transmission over the GTS. NCEP performs the next level of quality control during the data ingest process and in comparisons with first guess fields. Data that are inconsistent with surrounding stations and/or the first guess field may be rejected. Data rejections can entail individual thermodynamic elements or wind elements in a sounding, for part or all of a sounding. Climatological data archives in a designated format are provided to NCDC. NCDC performs data quality checks on the climatic data set. Each archive data file has metadata information for the sounding, including location, time, date, latitude, longitude, radiosonde type, and balloon type. Data quality checks are adequate at the station level but could be improved through automation and the use of artificial intelligence.

3. Metadata

NCDC maintains extensive files of digital metadata, including station history information. The NWS archive data submitted monthly to NCDC have metadata information as a part of each data record. NWS supports the WMO with updates to the WMO Catalogue of Radiosondes and

Upper-Air Wind-Finding Systems in use for each site in the network. These data are also supplied to the national meteorological centers in the U.S., as well as to various international meteorological centers. NWS maintains current metadata on all stations.

4. Network Stability

The total number of stations in the NWS radiosonde network in the contiguous U.S. has remained relatively constant since the mid-1960's. However, from 1988 to 2000, 35 upper air sites were relocated as a part of the NWS modernization. In the late 1980's, the NWS changed from a single provider of radiosondes with a given sensor pack to multiple providers using different sensor packs. These changes have created discontinuities in the climatological records at sites employing different radiosondes.

5. Network Changes 2000 to 2005

Changes are not anticipated in the number of reporting stations by 2005. However, studies have been conducted with an eye toward reducing the radiosonde network and using aircraft measurements in areas where high volume aircraft traffic with sensor suites can enable provision of ascent, enroute, and descent temperature and relative humidity values. Over the period 2002 through 2005, the existing radiosonde network is scheduled for replacement with a new 1680 MHz-based ground system and the implementation of GPS radiosondes at all sites. The current vendors for the radiosondes will introduce new sensors that will in turn introduce data continuity issues.

6. Network History

The inability of kite and aircraft meteorographs to achieve high altitudes, operate in all weather, and provide data in real-time helped foster the development for the radio transmission of upper air data. In the late 1920's, scientists from many nations began suspending crude radio transmitters from free balloons and by the early 1930's the first radio-meteorographs or "radiosondes" were being flown. In 1937, the U.S. Weather Bureau established a domestic network of radiosonde stations that has continued to the present day.

World War II increased the need for upper air data and accelerated the development of radiosonde components and the growth of observational networks. Furthermore, advances were made in radio-direction finding or radio-theodolite technology that allowed the radiosonde to be tracked in flight so winds aloft could be obtained. Such observations became known as "rawinsonde" observations. Initially, radio-theodolites were adjusted by hand to track the in-flight radiosonde, but by the 1950's automated radiotheodolites (ART) were implemented, which are still used today. The early rawinsonde stations lacked computerized data processing systems, which resulted in a significant amount of manual labor and time needed to process and disseminate the upper air data. The observation process was generally a two-person effort. However, a third person was frequently involved for quality control, general oversight of procedures, and assistance during periods of difficult weather, ground system, or data analysis conditions.

A chronology of major observing/sensor changes in the U.S. rawinsonde network from 1943 to 1960 follows:

1943 Lithium chloride humidity element replaced hair hygrometer.

1943 Ceramic temperature element, operating on resistance principle, replaced glass tubes with electrolytic temperature elements.

1948 Began computing all relative humidity using saturation values with respect to water. Prior computations involved saturation with respect to ice for temperature below freezing.

1949 Smaller ceramic temperature element introduced to decrease instrument response time.

1950 Introduced correction to temperature data between 400 and 10 hPa for daytime soundings whenever solar elevation angle was equal to or greater than -2.5 degrees. Such corrections, which adjusted for radiation effects on the instrument, were discontinued with the introduction of white thermistors.

1957 Observation time changed from 0300 and 1500 UTC to 0000 and 1200 UTC.

1960 Introduced white-coated temperature elements.

To ease the workload required for taking a rawinsonde sounding, development of computerized reduction of rawinsonde data began during the late 1960's and early 1970's. By the 1980's, technological advances in telemetry and computers made rawinsonde observations more automated. This significantly reduced manual involvement in taking rawinsonde observations. In the mid-1980's the NWS made significant progress in automation. Through the use of station mini-computers and interfaces to automatically acquire flight data, data computations, coded message generation, and data transfer and storage functions could all be performed with minimal human intervention. The rawinsonde observation had become a one-person operation, with the time required for processing data reduced to less than one staff hour with improved data quality.

Parallel with the advances in computerized data processing came new techniques for determining winds aloft. Rawinsonde systems were developed to take advantage of radio-navigation aids (NAVAID) such as LORAN and Omega (note: Omega was discontinued in October 1997). NAVAID radiosondes contain electronics that receive radio signals from fixed, ground-based transmitter stations. The radiosonde then either retransmits the received signal to the ground subsystem or processes the received signals into velocity or position information and then transmits. Winds aloft are contained in or derived from this information. A chronology of major observing/sensor changes in the U.S. Rawinsonde Network for the period 1960 through 1986 is outlined below:

1960 Outrigger thermistor designed and implemented.

1965 Introduced carbon element relative humidity sensor. Began reporting low relative humidity (RH) measurements. Earlier practice with the lithium chloride sensor was not to report low values.

1969 Changed from completely manual system to a time-share computer system for calculating upper air data.

1972 Redesigned carbon hygristor ducts introduced to reduce insolation effects on instruments that were responsible for low biases in RH measurements for some daytime soundings.

1973 Introduced the current practice of considering measuring RH less than 20 percent and reporting all lower RH values as 19 percent.

1974 Introduced semi-automatic minicomputer-based system.

1980 New carbon hygristors introduced. RH transfer equation changed for the new sensor.

1985 Introduced fully automatic minicomputer-based system.

1986 GMD-5 System built by Space Data Division (SDD) introduced at five synoptic Air Force stations. The radiosonde was also changed to one built by SDD similar to the MSS radiosonde, which did not employ a pressure sensor to acquire pressure/heights but instead utilized a transponder.

In the 1990's, rawinsonde technology development continued through improved radiosonde sensors, data processing, and NAVAID systems. A primary advancement was the development of rawinsonde systems that use the GPS to determine winds aloft. Like other NAVAID systems, GPS radiosondes are equipped with a GPS receiver and associated electronics that transmit the GPS position information to the ground receiver from which winds are derived. NWS began the effort to replace the current ART ground systems and associated radiosondes with GPS-based systems.

Other advances in upper air observing technology included the development of operational remote observing systems such as wind profilers and the placement of temperature and water vapor sensors on commercial jet aircraft. Compared to rawinsondes, these systems are capable of providing more frequent upper air data, but with reduced vertical coverage and data resolution.

A chronology of major observing/sensor changes for 1988 through 1999 is outlined below:

1988-1989 MRS installed on 42 Navy ships and at six synoptic stations supported by the Navy. All use the Vaisala RS80 radiosonde.

1988-1990 SDD radiosonde introduced at 17 sites in the southwest U.S. and in Alaska. VIZ Type-B radiosonde introduced at remaining NWS supported sites. Last use of VIZ Type-A radiosonde which had been in use for 30 or more years.

1989-1990 MicroART system phased into network replacing the MiniART System. Algorithms and level selection methods were not changed in this system during the phase over to minimize problems with data continuity.

1989 First use of transponders to compute winds in NWS network in 12 years.

1990 Software modified to include the 925 hPa mandatory level per WMO request. Additional modifications pursued to eliminate relative humidity 20 percent, temperature -40 degree Celsius cutoffs, and changing the gravity constant per WMO recommendation.

1994-1995 SDD radiosondes phased out and replaced by Vaisala RS80-56H radiosondes at 17 sites in the southwest U.S. and in Alaska.

1997 On June 1, the NWS switched from the VIZ-B to the VIZ-B2 radiosonde at 57 upper air sites, in the conterminous U.S.

1998 On June 1, 1998, the NWS began use of the Vaisala RS80-57H radiosonde at 35 upper air stations. Use of VIZ radiosondes at these sites will be discontinued. Radiation corrections are applied to Vaisala temperature at the field site. The NWS uses the Vaisala radiation correction algorithm RSN93 for applying these corrections. The policy of not correcting data transmitted from the remaining VIZ radiosonde upper air sites will continue.

1999 On Microcomputer Automatic Radiotheodolite (MicroART) system software upgrades implemented at all upper air stations February 1. Features included:

- Automated addition of a WMO 41414 cloud data group to the upper air coded message.
- Allow for the recording of radiosonde temperatures colder than -90^{O}C.
- NWS upper air stations using the Sippican, Incorporated VIZ-B2 radiosonde implemented additional coefficients in the RH algorithm. NWS-supported stations in the Caribbean using this radiosonde also implemented these coefficients. The new coefficients improve the accuracy of RH measurements at high and low RH. Starting about October 15, 1999, NWS stations using the VIZ-B2 radiosonde began phasing over to radiosondes with the new coefficients. This activity was completed by December 1, 1999.

7. Other Upper Air Observation Systems

a. Next Generation Doppler Weather Radar (NEXRAD)

A U.S. national network of 158 NEXRADs (also known as the WSR-88D) provides essential information on the existence, location, and intensity of severe weather and precipitation (http://weather.noaa.gov/radar/national.html). NEXRAD makes conventional reflectivity observations and uses the "Doppler effect" to measure the motion of clear air and atmospheric phenomena within storms. The maximum range of NEXRAD is 230 km (125 nautical miles). Although NEXRAD is land-based, there is some radar coverage offshore, and the greatest offshore coverage is along the U.S. Atlantic and Gulf coasts. Doppler technology permits observation of the motion field of the air inside and around clouds. When sufficient reflectivity exists, the Doppler capability of the NEXRAD can be used to generate radial wind estimates at a limited number of altitudes within the atmospheric boundary layer. While these observations are limited to certain meteorological situations, they can, nonetheless enhance the composite wind set available for numerical weather processing over the continental U.S. However, there are potentially many other climate-related uses for NEXRAD data that involve more extensive study of precipitating weather systems and cloud-precipitation processes.

b. Tropospheric Wind Profilers

The NOAA Profiler Network (http://www-dd.fsl.noaa.gov/) is fully deployed at 31 locations throughout the central U.S. It provides hourly vertical profiles of the horizontal winds from .5 km to 16.4 km above ground level. Wind profilers are specifically designed to measure vertical profiles of horizontal wind speed and direction from near the surface to above the tropopause. The quality and value of these observations have been assessed and found to be important for a variety of meteorological uses. Radio-Acoustic Sounding Systems (RASS) operate with wind profilers at a dozen locations. These systems measure virtual temperature profiles in the lower atmosphere to about 12,000 feet.

c. Global Positioning System Integrated Precipitable Water (GPS-IPW)

GPS satellite radio signals are slowed as they pass through layers of the Earth's atmosphere, the ionosphere, and the neutral atmosphere. This slowing delays the arrival time of the transmitted signal from that expected if there were no intervening media. It is possible to correct for the ionospheric delay, which is frequency dependent, by using dual-frequency GPS receivers. The delays due to the neutral atmosphere, however, are not frequency dependent. They depend on the constituents of the atmosphere, which are a mixture of dry gasses and water vapor.

The purpose of NOAA's ground-based GPS-IPW project is to: (1) evaluate the engineering and scientific bases of surface-based GPS meteorology; (2) demonstrate the feasibility and utility of using surface-based GPS observations for improved weather forecasting, climate monitoring, and satellite sensor calibration/validation; and (3) transfer this observing system technology to operational use. The GPS-IPW demonstration network (http://oak.fsl.noaa.gov/gps.html) currently consists of 72 sites, grouped into three categories: NOAA wind profilers (35 sites), other NOAA sites (9 sites), and other agency sites (28 sites). Water vapor is one of the most significant constituents of the atmosphere since it is the means by which moisture and latent heat are transported to cause weather. Water vapor is also a greenhouse gas that plays a critical role in the global climate system. This role is not restricted to absorbing and radiating energy from the sun, but also includes the effect it has on the formation of clouds and aerosols, and the chemistry of the lower atmosphere. Despite its importance to atmospheric processes over a wide range of spatial and temporal scales, water vapor is one of the least understood and most poorly described components of the Earth's atmosphere.

d. Automated Aircraft Reporting Systems

A growing number of wind and temperature measurements from commercial aircraft are made available by several air carriers through the Aircraft Communications, Addressing and Reporting System (ACARS). These are provided, on a volunteer basis, to the Aircraft-to Satellite Data Relay (ASDAR). Currently, just over 50,000 observations are received each day, 46,000 of which are over the continental U.S. (http://acweb.fsl.noaa.gov/demo_java/). These data come from more than 500 aircraft. There are more data during the daytime than at night, but due to increased participation by some parcel-carrying airlines, nighttime coverage is substantial. For instance, over 16,000 observations are received between 0500 and 1400 hours UTC. About 20 ASDAR-equipped aircraft are operating globally, taking hundreds of en route observations per day.

D. Atmospheric Constituent Networks

1. Atmospheric Baseline Measurement Network

NOAA's CMDL monitors a broad range of atmospheric constituents capable of forcing change in the climate of the earth through modification of the atmospheric radiative environment and those that may cause depletion of the global ozone layer. Measurements are conducted in 20 states and 37 countries at facilities ranging from four manned, continuously operating CMDL Baseline Observatories (Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and South Pole) to a weekly collection of air samples in flasks at remote surface locations around the world (see map on Page 26). At the baseline observatories up to 250 different measurements (continuous-to-weekly) may be conducted. These include trace gas concentrations of carbon cycle and chlorofluorocarbon (CFC) species, aerosol physical and optical properties, ozone concentrations and profiles, solar radiation parameters, and meteorology. Mauna Loa Observatory is a Network for the Detection of Stratospheric Change (NDSC) site with a wide range of remote sensing instruments monitoring the status of the stratospheric ozone layer.

Continuous records of CO_2 concentrations from Mauna Loa and South Pole dating from 1957, and continuous solar radiation at Mauna Loa beginning in 1957, are available. Other continuous records start in the 1960's, and the Barrow and Samoa records date from the establishment of these stations in 1973. CMDL maintains the world standard for Dobson total column ozone measurements and the WMO standards for CO_2 and CO atmospheric trace gas measurements. CMDL prepares primary gas standards for CFC gas measurements and provides these to other global measurement programs. The radiation group of CMDL maintains the WMO Region Four solar beam reference standard. All other basic CMDL baseline measurements are traceable to primary or secondary standards. All regular CMDL data are available either through the CMDL home page http://www.cmdl.noaa.gov/ and/or at the relevant World Data Centers for the species of interest.

It is expected all the CMDL sampling programs and sites will be in operation for the next five years and the following list of planned expansions to the network will be implemented:

1. A baseline station on the West Coast of the U.S. to monitor the trans-Pacific flux of air pollution from Asia
2. UV radiation monitoring station in eastern Russia
3. Two new flask and aircraft profile monitoring sites in equatorial Africa
4. Three additional aircraft profile monitoring sites in the U.S.
5. Expanded shipborne atmospheric measurements off the east coast of Asia

2. Atmospheric Coordinated Observations and Research Network (ACORN)

NOAA's Air Resources Laboratory (ARL) is a long-time leading advocate of the principles of coordinated observations and research. This research philosophy is known by some as "integrated monitoring." ACORN represents a new approach to environmental research and prediction, in which measurements are not limited to tracking changes in the characteristics of some environmental systems, but are also matched with the requirements for specifically designed scientific studies of factors that lead to more sound explanations of the causes of those changes. From the aspect of climate and weather forecasting research, its objective is to improve forecasts by advancing our knowledge of the surface/atmospheric energy input and dissipation processes in the models. Coordinated observations and research implies a more focused coupling of measurements with theory to enhance the analysis and prediction research efforts being conducted by NOAA in compliance with its Strategic Plan. This in turn requires an effort to further utilize NOAA's long-term observing programs along the lines of a traditional scientific approach. It is through coordinated sets of observations, coupled with analytical investigations of cause-and-effect, that understanding can be improved at a more rapid pace, ultimately leading to more accurate prediction of future changes. The observations reveal the details of the true behavior of atmospheric phenomena and also provide for research on a continuous or nearly continuous basis, involving both NOAA's surface networks and satellites. The suite of NOAA observations constitutes a complementary subset of other national observational programs, such as those led by NASA, National Science Foundation (NSF), USDA, and DOE. However, the ARL surface networks are unique in that they cover much of the U.S. and obtain continuous data. It is the analysis and prediction aspects of the ACORN approach that constitute the heart of ongoing research. It is this aspect that differentiates ACORN from classical monitoring of status and trends.

Over the last two decades, ARL has organized a number of collaborative and interconnected monitoring networks, which together constitute an organized measurement and analysis approach to predict future changes in the coupling of the atmosphere-terrestrial biosphere system. This assembly of networks and research makes up the ACORN integrated monitoring network.

The components of ACORN start with the Integrated Surface Irradiance Study B (ISIS B) and end with the Atmospheric Integrated Research Monitoring Network (AIRMoN B). There are several sub-components of these arrays, such as (the ISIS level 2) the SURface RADiation network (SURFRAD B), but together the ARL monitoring system constitutes the nation's only truly integrated measurement system for permanent recording of past changes in the atmosphere-terrestrial system and for extrapolating the future trends. NOAA's satellite observations supply broader spatial coverage from the top of the atmosphere, but with less fine detail than the surface measurements. The two systems are complementary, each filling in scientific information voids where the other cannot.

The theme underlying ARL's network operations is the coupling of the earth's surface and the atmosphere. The magnitude and process of this coupling are quantified in terms of fluxes–rates of exchange of specific quantities such as heat, water, and various trace quantities like CO_2 and air pollutants. The driving force of the earth as a dynamic, life-supporting planet is radiation received from the sun. ARL's network operations therefore start with measurements of solar radiation received at the earth's surface.

There are four fundamental reasons the ACORN array is constructed in its present form. First, a basic tenet of integrated observing concepts is not all stations need to make every measurement with the sampling protocols necessary for every purpose. To do so would be prohibitively expensive. Therefore, ISIS (and all ARL network operations) is constructed as a nested network, with some stations using more advanced systems than others, but with a common set of fundamental observations shared by all. Second, the next generation of prognostic models will require observational data on the surface fluxes of heat, moisture, and momentum to benchmark the air-surface exchange formulations on which they rely and to serve as a basis for diagnosing model performance related to precipitation, evaporation, humidity, etc. Third, ARL scientists concur whole-heartedly with the current belief that satellites offer promise yet to be fully realized, but further believe in order to extend satellite observations, ground truth is critical. This attitude comes from direct experience with the use of ground-based observations to verify satellite observations of surface shortwave and ultraviolet (UV) irradiance, and just as importantly, the development of inversion algorithms to retrieve information on atmospheric properties. Moreover, the World Climate Research Program, in recognition of the importance of surface radiation for atmospheric research, has strongly emphasized the need for long term surface irradiance observations to validate satellite determinations of these quantities. ISIS and SURFRAD in particular offer a unique set of surface radiation observations for checking the calibrations and performance characteristics of satellite sensors. Fourth, and in some contexts most important, ARL endorses strongly the need for long-term observations at the surface where people and other living organisms are actually affected by the environmental characteristics of climate and are impacted by its change. Attributing changes in any property to greenhouse effects or to other climate change forcing factors requires candid examination of the roles of other influences. This necessarily mandates concurrent measurement of other variables, as is inherent in the overall philosophy of coordinated observations and research to which the ARL mission ascribes.

3. Integrated Surface Irradiance Study Network (Level 1)

The ISIS measures the incoming radiation from the sun, with emphasis on the direct beam, the radiation scattered and absorbed by the atmosphere and its constituents, and the components of radiation especially harmful to living organisms. ISIS therefore measures direct and global shortwave surface radiation, plus surface UV radiation in the biologically important broad wavelength band. The issues being addressed by ISIS relate to the solar radiation incident at the surface, for purposes such as the detection of changes in cloud cover, trends in atmospheric turbidity, and assessment of the change in UV radiation (which affects all exposed living organisms).

There are currently nine stations throughout the continental U.S. providing 15-minute data on one-second scans. The ISIS sites were established from March 1994 to August 1996 and are all expected to operate through 2005. A detailed description of ISIS and access to processed data from the ISIS Level 1 network can be found at http://www.atdd.noaa.gov/isis/isis_frame.htp. Hourly average data from all Level 1 sites are transmitted routinely to NCDC for archival, from where they are further submitted to the World Radiation Data Center in St. Petersburg, Russia. Quality assurance procedures are fully adequate with calibrations traceable to World Radiation Standards. Metadata are currently not available digitally; however, paper record conversion is currently underway. The UV components of this data set are routinely employed by NWS to benchmark the forecasts of UV Index, now operational.

The UV component of ISIS deserves special mention. Surface UV radiation remains difficult to measure. As a contribution to the national multi-agency UV monitoring program, ARL operates, as a collaborative venture with the National Institute of Standards and Technology (NIST), the national Central UV Calibration Facility. ARL also co-chairs (with NASA) the task team organized by the U.S. Global Change Research Program to coordinate the national UV measurement program.

ISIS is a limited refurbishment of nine SOLRAD Network stations with emphasis on data retrieval (data loggers) and timely QA/QC processing to provide high quality data. Some of the ISIS sites were relocated to coincide with the NWS modernization (moved from airport sites). Only the UVB sensors were added to the SOLRAD components. Sites with significant moves when relocated were in TN (~128 mi.), CA (~35 mi.), WA (~18 mi.), and WI (~7 mi.) with all other moves < 1 mi.

4. Surface Radiation Network (Level 2)

The motions of the lower atmosphere are largely governed by the rate of heat input at the surface. To obtain the necessary information and to help generate the understanding to interpret the relevant data, ARL operates a smaller subnetwork of ISIS where measurements are made of upwelling longwave and shortwave components of surface radiation as well as downwelling. From this perspective, the emission of thermal radiation (infrared) from the surface must be accounted for to obtain a complete measure of the radiant energy heating and cooling process. Therefore, this SURFRAD network; (see http://www.srrb.noaa.gov/surfrad/surfpage.htm) includes measurements of infrared radiation to the surface radiative flux suite. Since cloud cover is a crucial consideration, steps are currently being taken to augment SURFRAD stations with automated all-sky cloud cover sensors.

SURFRAD was established in 1993. Its primary objective is to support global change and related research with continuous measurements of the surface radiation budget, which includes upward- and downward-directed longwave and shortwave radiation. Measurements from SURFRAD are used for evaluating satellite-based estimates of surface radiation, and hydrologic, climate, and weather forecast models, as data for specialized research projects, and to monitor trends in parameters affecting Earth's climate. Specific variables collected by the network include downwelling global, direct, diffuse, and upwelling shortwave irradiance, downwelling and upwelling longwave irradiance, broadband UVB and photosynthetically active irradiance, air temperature, relative humidity, and wind speed and direction. Total sky images and cloud cover fraction are also measured. All radiation and meteorological instruments operate continuously and record three-minute averages. The total sky imagers sample the hemispheric sky once each minute during the daylight hours.

Six stations make up the SURFRAD network. All six stations measure the variables listed in the previous paragraph. The SURFRAD stations are at located near Bondville, IL (40.06°N, 88.37°W), at the Goodwin Creek Experimental Watershed near Batesville, MS (34.25°N, 89.87°W), on the Fort Peck Tribes Reservation near Poplar, Montana (48.31°N, 105.10°W), at Table Mountain near Boulder, Colorado (40.125°N, 105.237°W), at the Penn State Experimental Research Farm near State College, Pennsylvania (40.72°N, 77.93°W), and at Desert Rock, Nevada (36.626°N, 116.018°W). The first four stations were installed in 1995 at Bondville, IL, Fort Peck, Montana; Goodwin Creek, Mississippi; and Boulder, Colorado. Originally, these first four stations did not have the diffuse shortwave measurement, but by the end of 1996, a shaded pyranometer was added to the instrument suites. The stations at State College and Desert Rock were added in 1998. The total sky imagers were installed at all stations in 1999 and 2000. In 2000, the downwelling pyrgeometer at each station was moved from the main platform to the solar tracker, where its dome could be shaded according to Baseline Surface Radiation Network (BSRN) standards. This had a negligible effect on the downwelling infrared measurement record because the pyrgeometer has a built-in correction for errors caused by solar heating of the dome.

A seventh station may be added in West Virginia in 2001. From the beginning of the network to the present, ordinary thermopile pyranometers (Eppley model PSP) were used for the global, diffuse, and upwelling solar measurements. During the annual instrument exchanges in 2001, an Eppley model 8-48 pyranometer will replace the PSP for the diffuse solar measurement. This change will remove an erroneous negative offset (owing to the measurement surface artificially cooling to space) inherent to the Eppley PSP-type pyranometers. This offset may be as high as 10 Wm^{-2} at night. Its effect during the day is unknown but is probably smaller in magnitude than the nighttime error. This may affect the climate record by showing a slight artificial increase in downwelling solar irradiance when the component sum (direct + diffuse) is used for the global measurement.

5. Surface Energy Balance Network (Level 3)

ARL is actively establishing a network subset of full energy balance monitoring stations to complete the overall scheme of relevant observations. Stations currently operational are at Oak Ridge, Tennessee; Bondville, Illinois; and Fort Peck, Montana. Installations at Goodwin Creek, Mississippi; and Davis, West Virginia, are being planned.

The data from these stations are being used to test and develop improved mesoscale models, for weather forecasting purposes. The next generation of numerical forecast models will necessarily involve improved depictions of air-surface exchange, for which this array of surface stations will provide the requisite "ground truth."

6. The CO_2 Sequestration Network and AmeriFLUX (Level 4)

In addition to the eddy flux components of the surface heat balance, the augmented SURFRAD stations also measure fluxes of carbon dioxide. These measurements provide a direct quantification of the sequestering of atmospheric CO_2 in the terrestrial biosystem, and the water exchange data serve similarly in hydrological studies of the water balance of the atmosphere-biosphere system. These stations will contribute to the national ("AMERIFLUX") and international ("FLUXNET") networks now being set up to address the CO_2 air-surface exchange question on a wide-spread, internationally cooperative basis. FLUXNET and AMERIFLUX details are to be found at http://www.atdd.noaa.gov/climate.

7. AIRMoN-dry Network (Level 5)

The ability to measure some of the suite of air-surface exchange variables (radioactive and eddy fluxes) leads into one of the more extensive parts of the ARL coordinated observation program, the Atmospheric Integrated Research Monitoring Network (see http://www.arl.noaa.gov/research/programs/airmon.html). AIRMoN has been established to develop methodologies for monitoring the rates of deposition of air pollutants to natural landscapes. This deposition occurs in two forms–dry and wet. Dry deposition is the gravitational settling of particles and the turbulent exchange of trace gases (and particles too small to sediment in a turbulent atmosphere). Wet deposition is occasioned by precipitation. It entails the scavenging of pollutants by clouds and the washout of pollutants by raindrops falling from clouds. AIRMoN-dry is the dry deposition part of the overall AIRMoN program, described in detail at http://www.atdd.noaa.gov/airmon/airmon_frame.htm.

In AIRMoN-dry, measurements are made of the concentrations of selected pollutants in air, and of the atmospheric and surface variables that together control the efficiency associated with the turbulent exchange of these pollutants and their capture by the surface. The focus is on sulfur and nitrogen species, these being the key chemicals targeted by current U.S. federal regulations.

Methods for measuring dry deposition of airborne pollutants are not yet well developed. AIRMoN serves as the network in which new approaches are tested and site-specific requirements are addressed. For example, it is currently apparent that deposition in coastal and urban areas is an important issue; hence, it is expected that AIRMoN will move in related directions with a change in its site distribution. In accord with the driving principles of integrated monitoring, sites are selected where the data are most needed.

8. AIRMoN-wet Network (Level 6)

The wet deposition part of the overall AIRMoN program operates as a sub-network of the National Atmospheric Deposition Program (NADP; http://nadp.sws.uiuc.edu), the largest atmospheric deposition network in North America. In accord with the overall ARL monitoring philosophy, AIRMoN-wet is designed as a research sub-network of NADP, using more refined sampling protocols and exploring methodologies for accurately monitoring the deposition of quantities that NADP's existing protocols do not address well. A key chemical in this category is ammonium. For this reason, AIRMoN-wet stations are predominantly in coastal regions, since near the coasts nitrogen deposition is seen as a major issue and AIRMoN-wet best addresses this issue. A description can be found at http://www.arl.noaa.gov/research/programs/airmon-wet.html. Data access is through NADP, via http://nadp.sws.uiuc.edu/airmon/GetAMdata.asp.

Variables collected in the network include precipitation amount, sample volume, calcium concentration, magnesium concentration, potassium concentration, sodium concentration, ammonium concentration, nitrate concentration, chloride concentration, sulfate concentration, pH, and conductivity. Each station in the network collects all of the variables named above. The network consists of nine stations, most of which started after 1992, and six of which have at least 20 years of data. All stations are in the eastern U.S. Observation time is nominally 9 a.m. daily. Samples remain on the collector for no more than 24 hours. Current instrumentation at each station consists of an Aerochem Metrics 301 collector, Belfort 5-780 weighing rain gauge, NWS stick gauge, pH and conductivity meters, ion chromatographs, atomic absorption spectrophotometers, and automated colorimetric spectrophotometers. The data are quality assured via the Illinois State Water Survey. Digital metadata are available online at http://nadp.sws.uiuc.edu.

Some of the stations in the network were originally part of DOE's Multistate Atmospheric Power Production Pollution Study (MAP3S) program, which began in the mid-1970s. NOAA/ARL picked up funding for six of the original nine MAP3S stations in 1991 following a two-year period of extreme turmoil, and worked with the NADP to provide a research arm to the national precipitation chemistry monitoring program. As a result of NOAA's involvement, sampling protocols were changed from event (as defined by the field operator) to 24 hour. In addition, field and laboratory quality assurance was improved to mirror the program in place with the weekly NADP program. Major changes in communication and instrumentation are pending, to be made in accordance with budgets and decisions that will affect the entire NADP program. These changes should improve data quality, particularly for labile ions that are subject to degradation via biological activity. As with the metadata, all data are online at: http://nadp.sws.uiuc.edu. Data posting tends to run about six months behind the current date.

9. National Atmospheric Deposition Program National Trends Network

The NADP/ National Trends Network (NTN) is a nationwide network of precipitation monitoring sites. Managed by NOAA's ARL, the network is a cooperative effort between many different groups, including the State Agricultural Experiment Stations, U.S. Geological Survey, U.S. Department of Agriculture, and numerous other governmental and private entities. For a full list of contributors, see the collaborating agencies page on the NADP web site: http://nadp.sws.uiuc.edu.

The purpose of the network is to collect data on the chemistry of precipitation for monitoring of geographical and temporal long-term trends. At present, there are approximately 230 stations in the NADP/NTN program spanning the continental U.S., Alaska, Puerto Rico, and the Virgin Islands. Approximately 178 stations have 10 years of data, and 69 stations have 20 years or more. Digital metadata and a sampling history for each station can be found at http://nadp.sws.uiuc.edu.

Variables collected by all stations in the network include precipitation amount, sample volume, pH, conductivity, and concentrations of calcium, magnesium, potassium, sodium, ammonium, nitrate, chloride, and sulfate. Data are collected weekly according to strict clean-handling procedures. Observation time is nominally 9 a.m. each Tuesday morning. Samples remain on the collector for no more than seven days. Current instrumentation at each station includes an Aerochem Metrics model 301 collector, Belfort 5-780 weighing rain gauge, pH and conductivity meters, ion chromatographs, atomic absorption spectrophotometers, and automated colorimetric spectrophotometers. Collection methods have remained relatively constant over the years, though the shipping containers changed in 1992 following a lengthy process to address potential o-ring contamination from sample buckets (these problems posed no serious threat to data quality, except for samples collected in remote regions). Once collected, all data are quality assured by the Illinois State Water Survey on behalf of NOAA.

10. National Atmospheric Deposition Program/Mercury Deposition Network

The objective of the Mercury Deposition Network is to develop a national database of weekly concentrations of total mercury in precipitation and the seasonal and annual flux of total mercury in wet deposition. The data are used to develop information on spatial and seasonal trends in mercury deposited to surface waters, forested watersheds, and other sensitive receptors. The network is managed collectively by several state, federal, and private institutions. Additional information is available at http://nadp.sws.uiuc.edu.

The network consists of approximately 50 stations in the U.S. and Canada, 13 of which opened as early as 1995. Variables collected by all stations in the network include precipitation amount, sample volume, and total mercury (methyl mercury is also measured in some samples). The network uses standardized methods for collection and analyses. Weekly precipitation samples are collected in a modified Aerochem Metrics model 301. The “wet-side” sampling glassware is removed from the collector every Tuesday at about 9 a.m. and mailed to the Hg Analytical Laboratory at Frontier Geosciences in Seattle, Washington for analysis by cold vapor atomic fluorescence. Precipitation amount is measured using a Belfort 5-780 weighing gauge. Once collected, all data are quality assured by the Illinois State Water Survey on behalf of the various agencies involved in the network.

11. Interagency Monitoring of Protected Visual Environments Network (IMPROVE)

IMPROVE is a nationwide network of visibility monitoring sites managed by NOAA’s NWS. The network is a cooperative effort between many different groups and the state of Arizona. Its steering committee consists of the Environmental Protection Agency (EPA), National Park Service, USFS, Fish and Wildlife Service (FWS), and the Bureau of Land Management (BLM). The purpose of the network is to collect data required by law for federal visibility protection of specific National Parks and wilderness areas. At present there are approximately 107 stations in the IMPROVE program across the U.S. All stations in the network are expected to be in operation at least through the next decade, and because the network is intended to monitor trends through time, no changes are planned in the near future.

A number of visibility-related variables are collected in the network. Aerosol sampling and chemical speciation data (specifically, 24-hour duration samples and mass concentrations for PM 2.5 and PM 10 collected every Wednesday and Saturday) are available for all stations in the network, 20 as far back as 1987. Light extinction coefficients (1-hour average values continuously using long-path transmission measurements from Optec LPV-2 Transmissometers) are available for 15 locations, all since 1987. Light scattering coefficients (1-hour averages using ambient temperature Optic NGN-2 Nephelometers) are available for 8 sites, all since 1992.

Temperature and RH are collected using Rotronics instruments at 20 sites (15 since 1987 and 5 since 1992). Once collected, all data are quality assured by the NCDC and EPA's Office of Air Quality Planning and Standards. Quality control procedures are considered fully documented and adequate.

12. Atmospheric Radiation Measurement (ARM) Program

The ARM program (http://www.arm.gov) is a multi-laboratory, interagency program created in 1989 with funding from the U.S. DOE. The ARM program focuses on resolving the scientific uncertainties of the role of clouds on the Earth's radiation budget. ARM's goal is to improve the performance of general circulation models (GCM) used for climate research and prediction. These improved models will help scientists understand better the influences of human activities on the Earth's climate.

In pursuit of its goal, the ARM Program establishes and operates field research sites, called Cloud and Radiation Testbeds (CART – see Table 4), in several climatically significant locations, all of which are included in the international BSRN. Scientists collect and analyze data obtained over extended periods from large arrays of instruments to study the effects and interactions of sunlight, radiant energy, and clouds on temperature, weather, and climate.

12a. ARM Sites

Southern Great Plains (SGP)

The U.S. SGP CART site was the first field measurement site established by DOE's ARM program. The site consists of *in-situ* and remote-sensing instrument clusters arrayed across approximately 55,000 square miles in north-central Oklahoma and south-central Kansas. The 34-instrumented clusters are categorized as central, extended, intermediate, and boundary facilities. These facilities are designed to measure aerosols, upper air profiling, clouds, short and longwave radiation, surface meteorology, and surface eddy fluxes.

The central facility is located between Lamont and Billings, Oklahoma. The 160-acre complex, the most heavily instrumented facility, houses the site data system, and provides on-site investigator support. The site data system is linked to hundreds of individual instruments clustered across the 55,000 square mile CART site.

Deployment of the first instrumentation to the SGP site occurred in the spring of 1992, just 24 months after the program was approved. The site was dedicated in November 1992. Additional instrumentation and data processing capabilities have been incrementally added in the succeeding years.

Tropical Western Pacific (TWP)

The TWP locale is the second CART to be implemented by DOE's ARM Program. TWP began phased operations in 1996 at its first site on Manus Island. The second site on Nauru Island was established in 1998.

The TWP locale is the area roughly between 10^{o} N to 10^{o} S of the equator, from Indonesia to near Christmas Island. This region of the world plays a large role in the interannual variability observed in the global climate system. For instance, the El Nino/Southern Oscillation phenomenon has far reaching implications for weather patterns over much of the Northern

Hemisphere, and perhaps the entire planet. The TWP consistently has the warmest sea surface temperatures on the planet, referred to as the Pacific "warm pool." The warm pool supplies heat and moisture to the atmosphere above it, resulting in the formation of deep convective cloud systems that, in turn, produce high altitude cirrus clouds spreading out over much of the region. These cloud systems regulate the amount of solar energy reaching the surface of the earth and the amount of the earth's heat energy that can escape to space. Improved understanding of the interaction between clouds and incoming and outgoing energy will improve the general circulation models used for climate research.

North Slope of Alaska (NSA)

The NSA/Adjacent Arctic Ocean (AAO) CART site is providing data about cloud and radiative processes at high latitudes. These data are being used to refine models and parameterizations as they relate to the Arctic. The NSA/AAO site consists of two facilities, one at Barrow and the second in the vicinity of Atqasuk. The AAO site was probed by the Surface Heat Budget of the Arctic (SHEBA) experiment, a multi-agency program led by the NSF and the Office of Naval Research. SHEBA involved the deployment of an instrumented ice camp within the perennial Arctic Ocean ice pack that began in October 1997 and lasted for 12 months.

Data Availability

All data are available from ARM archive: http://www.archive.arm.gov/.

12b. ARM Instrumentation

A complete list of ARM instruments is available on http://www.arm.gov/docs/instruments.html. The ARM program focuses on data collection and research activities in six areas: 1) aerosols, 2) clouds, 3) longwave radiation, 4) shortwave radiation, 5) surface energy exchange (or flux), and 6) atmospheric state.

ARM data collection is continuous, and data are provided in near real-time. ARM also provides derived products through its value-added procedure (VAP). Many of the scientific needs of the ARM project are met through VAPs. Physical models using ARM instrument data as inputs are implemented as VAPs and help fill some of the unmet measurement needs of the program. A special class of VAPs, called quality measurement experiments, compares different data streams for consistency and allows for continuous assessment of the quality of the ARM data streams. These data streams may come from direct measurements, measurements derived from instrument observations via other VAPs, or model output also created by other VAPs.

The following table provides the climate measurement areas being conducted at the 3 sites:

Table 5. ARM Climate Measurement Categories

Radiometers	Clouds	Atmospheric Profiling	Surface Eddy Flux	Surface Meteorology
Atmospheric Emitted Radiance Interferometer	Belford Laser Ceilometer	Balloon-borne Sounding System	Eddy Correlation Systems	60-meter Meteorological Tower
Microwave Radiometer	Micropulse Lidar	Microwave Radiometer	Energy Balance Bowen Ratio (EBBR) Stations	ARCS* Meteorological Instruments (TWP & NSA only)
Sunphotometer	Millimeter - Wavelength Cloud Radar	Raman Lidar System	Infrared Thermometer (IRT)	Chilled Mirror (SGP only)
Multifilter Rotating Shadowband Radiometer	Microwave Radiometer	Wind Profilers (50 and 915 MHz)	Soil Water and Temperature Systems	60-meter tower: Temperature and Humidity Sensors (SGP only)
Pyrheliometers				
Pyrgeometers				40-meter tower and Nearby Sensors at Barrows, Alaska (NSA only)
Up- and Downwelling Radiometric Systems				Temperature, Humidity, Wind, and Pressure Sensors
Rotating Shadowband Spectrometer				

Atmospheric radiation and cloud stations (ARCS) were designed to provide long-term, basic climatological observations. An ARCS consists of an integrated instrument set that measures the surface radiation balance, surface meteorology, cloud properties, and some limited atmospheric quantities. In addition to the suite of scientific instruments, an ARCS contains data acquisition systems, monitoring and control systems, satellite communications, a backup electrical generator, and other support equipment. The ARCS is housed in five specially modified 20-foot sea containers. The ARCS system is self-contained and designed to operate semi-autonomously with a minimum of onsite support.

The ARCS data management system (DMS) controls the flow of data through the ARCS. Its primary functions are data collection, storage, and processing. A major requirement for the DMS is to minimize the loss of data. Consequently, redundancy is found throughout the system. The heart of the DMS is a pair of Sun workstations that back up each other. Each instrument also has a data storage buffer to further insure the preservation of data should the DMS be inoperative for a period of time. All of the ARCS data are written to magnetic tapes and periodically shipped back to the U.S. where they are processed further, quality assured, archived, and distributed to investigators. In addition, hourly statistics of the data are calculated, encoded in a compact form, and transmitted hourly to the U.S.. The hourly data are used by scientists and engineers responsible for operating the site in assessing the health and status of the instruments. These data are also useful in examining the general nature of the meteorological measurements being made. The hourly health and status information is transmitted via the Geostationary Operational Environmental Satellite (GOES) system.

The initial ARCS design uses a monitoring and control system (MACS) to monitor the environment inside the ARCS enclosures. Some of the parameters monitored are temperature and RH, whether the doors are open or closed, and power consumption. MACS also provides the capability to remotely turn the power on or off to individual systems and reboot computers. These capabilities are essential to the remote operations of an ARCS. A communication system provides the ability to issues commands to MACS to perform any of its functions. The system is also used to transmit unscheduled messages from on-site operators through a site data log or alarms triggered when environmental parameters fall outside an acceptable range. It utilizes the INMARSAT-C satellite system and can also serve as a backup for transmitting the hourly scientific data. Subsequent ARCS will use the INMARSAT-B satellite system.

Each ARCS enclosure has dual air conditioners with humidity control to maintain the required operating environment for the instruments, computers, and other equipment. Electrical power for the ARCS is normally supplied by local commercial power. A 50-kilowatt diesel generator serves as a backup. The generator system automatically starts when commercial power to the ARCS is interrupted and shuts down when the grid power resumes. It is capable of operating continuously should commercial power not be available. The generator's 700-gallon fuel capacity provides for about one month's run time before refueling.

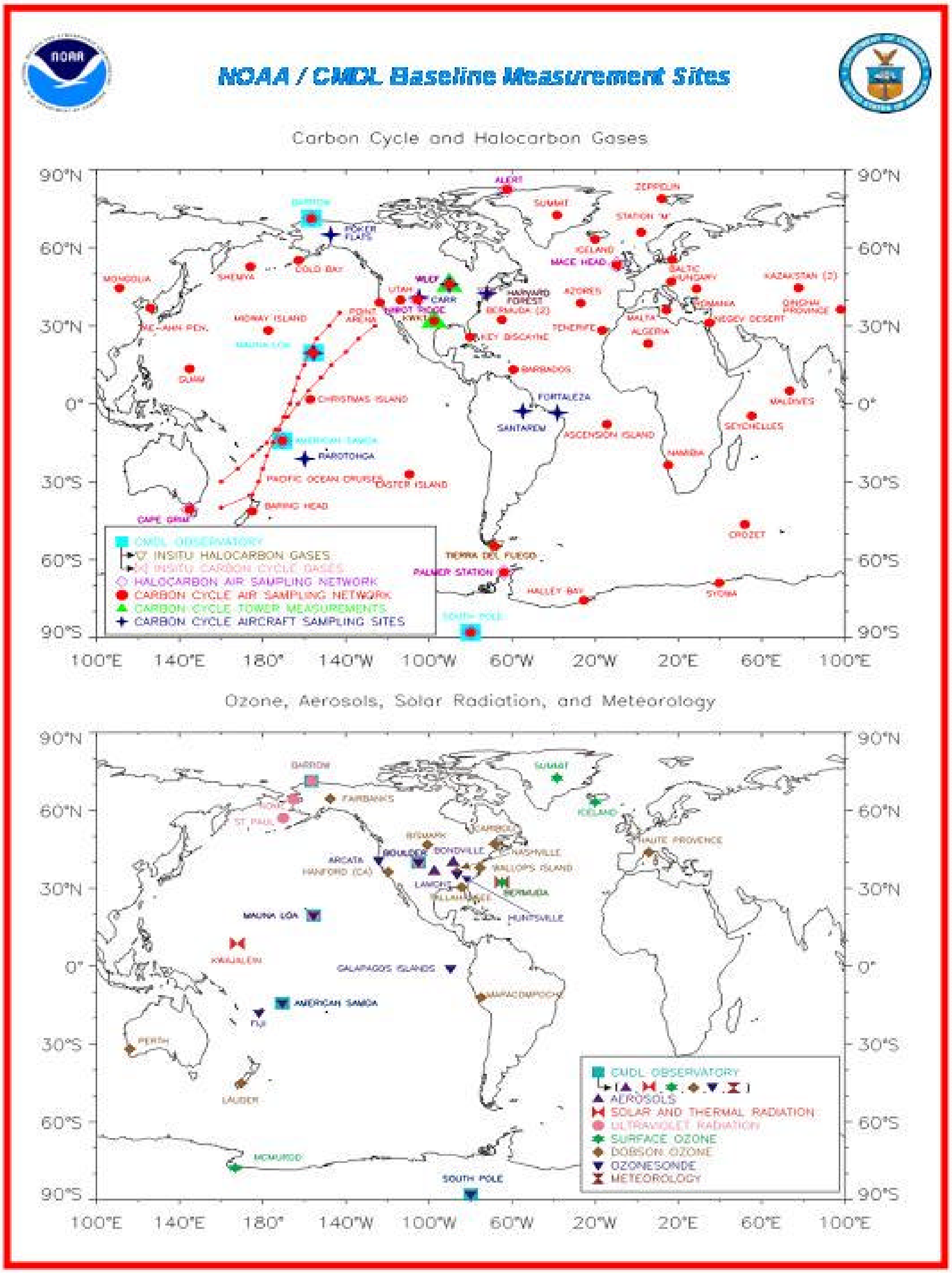

NOAA / CMDL Baseline Measurement Sites
Carbon Cycle and Halocarbon Gases
ALERT
ZEPPELIN
SUMMIT
STATION "M"
BARROW
POKER FLATS
ICELAND
MACE HEAD
BALTIC
HUNGARY
KAZAKSTAN (2)
MONGOLIA
SHEMYA
COLD BAY
UTAH
WLEF
CARR
HARVARD FOREST
AZORES
BERMUDA (2)
ROMANIA
QINGHAI PROVINCE
MIDWAY ISLAND
POINT ARENA
NIWOT RIDGE
WKT
NEGEV DESERT
TAE-AHN PEN.
MALTA
KEY BISCAYNE
TENERIFE
ALGERIA
MAUNA LOA
BARBADOS
GUAM
CHRISTMAS ISLAND
FORTALEZA
MALDIVES
SANTAREM
ASCENSION ISLAND
SEYCHELLES
AMERICAN SAMOA
RAROTONGA
NAMIBIA
PACIFIC OCEAN CRUISES
EASTER ISLAND
BARING HEAD
CAPE GRIM
CROZET
CMDL OBSERVATORY
INSITU HALOCARBON GASES
INSITU CARBON CYCLE GASES
HALOCARBON AIR SAMPLING NETWORK
CARBON CYCLE AIR SAMPLING NETWORK
CARBON CYCLE TOWER MEASUREMENTS
CARBON CYCLE AIRCRAFT SAMPLING SITES
TIERRA DEL FUEGO
PALMER STATION
HALLEY BAY
SYOWA
SOUTH POLE
90°N
60°N
30°N
0°
30°S
60°S
90°S
100°E
140°E
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
Ozone, Aerosols, Solar Radiation, and Meteorology
BARROW
SUMMIT
FAIRBANKS
ICELAND
NOME
ST PAUL
BISMARK
CARIBOU
HAUTE PROVENCE
BOULDER
BONDVILLE
NASHVILLE
ARCATA
HANFORD (CA)
WALLOPS ISLAND
LAMONT
TALLAHASSEE
BERMUDA
MAUNA LOA
HUNTSVILLE
KWAJALEIN
GALAPAGOS ISLANDS
MARCAPOMACOCHA
AMERICAN SAMOA
FIJI
PERTH
LAUDER
MCMURDO
SOUTH POLE
CMDL OBSERVATORY
AEROSOLS
SOLAR AND THERMAL RADIATION
ULTRAVIOLET RADIATION
SURFACE OZONE
DOBSON OZONE
OZONESONDE
METEOROLOGY

Table S1. National Climate Monitoring Systems for Land Surface (Meteorological) Observations

Systems	Climate Parameters (e.g. Temp, Precip, other)	Total # Stns	Appropriate for Characterizing National Climate?			Time Series # stations/platforms (# Data Digitized)			Are QC Procedures Adequate?			Metadata available? Total # Stations (% Digitized)	Continuity # expected operational in 2005
			Fully	Partly	No	>30y	>50y	>100y	Fully	Partly	No		
Stations Useful for National Climate Monitoring Purposes (Specify parameters observed)	Temperature	10,556		X		5,406	3,222	118		X		Yes TBD	~10,000
	Precipitation	17,700		X		7,995	4,915	144		X		Yes TBD	~17,000
	Snowfall	17,262		X		7,848	4,712	128		X		Yes TBD	~17,000
Stations Reporting Internationally	Temperature and Precipitation	510		X		230	204	128		X		Yes	~500
CLIMAT Reporting Stations	Temperature and Precipitation	188		X		160	150	85		X		Yes 188	~200
Reference Climate Stations	Temperature, Rel Humidity, Precipitation, Solar Radiation, and Wind Speed	250 *		X									~100-150

**** U.S. Climate Reference Network Still Under Development; Plans are to Deploy the System at 250 Unique Geographic Sites***

Table S2. Available Homogeneous Data Sets for Land Surface (Meteorological) Observations.

Data Set Name	Variable	# Stations or Grid Resolution	Describe Period	References
USHCN	Temp Precip	1221	1900-2000	http://www.ncdc.noaa.gov/ol/climate/research/ushcn/ushcn.html Easterling, D.R., and T.C. Peterson, 1995: A new method of detecting undocumented discontinuities in climatological time series, Int. J. of Climatol., 15, 369-377. Karl, T.R., C.N. Williams, Jr., P.J. Young, and W.M. Wendland, 1986: A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperature for the U.S., J. Climate Appl. Meteor., 25, 145-160. Karl, T.R., and C.W. Williams, Jr., 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities, J. Climate Appl. Meteor., 26, 1744-1763. Karl, T.R., H.F. Diaz, and G. Kukla, 1988: Urbanization: its detection and effect in the U.S. climate record, J. Climate, 1, 1099-1123. Karl, T.R., C.N. Williams, Jr., F.T. Quinlan, and T.A. Boden, 1990: U.S. Historical Climatology Network (HCN) Serial Temperature and Precipitation Data, Environmental Science Division, Publication No. 3404, Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, 389 pp. Peterson, T.C., and D.R. Easterling, 1994: Creation of homogeneous composite climatological reference series, Int. J. Climatol., 14, 671-680. Quayle, R.G., D.R. Easterling, T.R. Karl, and P.Y. Hughes, 1991: Effects of recent thermometer changes in the cooperative station network, Bull. Am. Meteorol. Soc., 72, 1718-1724.

Data Set Name	Variable	# Stations or Grid Resolution	Describe Period	References
GHCN, Version 2	*Precip*	*20,000*	*1697-Present*	*http://www.ncdc.noaa.gov/ol/climate/research/ghcn/ghcnoverview.html*
	Mean Monthly Maximum and Minimum temp data and mean temp	*~7,000*	*1697-Present*	*Peterson, Thomas C. and Russell S. Vose, 1997: An overview of the Global Historical Climatology Network temperature data base, Bulletin of the American Meteorological Society, 78, 2837-2849.* *Peterson, Thomas C., Russell S. Vose, Richard Schmoyer, and Vyachevslav Razuvaev, 1997: Quality control of monthly temperature data: The GHCN experience. International Journal of Climatology, submitted.* *Easterling, David R., Thomas C. Peterson, and Thomas R. Karl, 1996: On the development and use of homogenized climate data sets. Journal of Climate, 9, 1429-1434.* *Easterling, D.R. and T.C. Peterson, 1995: The effect of artificial discontinuities on recent trends in minimum and maximum temperatures. Atmospheric Research, 37, 19-26.* *Easterling, David R. and Thomas C. Peterson, 1995: A new method for detecting and adjusting for undocumented discontinuities in climatological time series. International Journal of Climatology, 15, 369-377.* *Peterson, Thomas C. and David R. Easterling, 1994: Creation of homogeneous composite climatological reference series. International Journal of Climatology, 14, 671-679.*

The Global Historical Climatology Network (GHCN) is jointly produced by the NCDC, the Carbon Dioxide Information Analysis Center/Oak Ridge National Laboratory/DOE, and Arizona State University.

Table S3. National Climate Monitoring Systems for Upper Air Observations (Meteorological)
Only active stations are included in the totals.

Systems Useful for National Climate Monitoring Purposes	*Total # Stns or platforms*	*Appropriate for Characterizing National Climate?*			*Time Series #stations/platforms (#Data Digitized)*				*Are QC Procedures Adequate?*			*Metadata available? Total # Stations (% Digitized)*	*Continuity? # expected operational in 2005*
		Fully	*Partly*	*No*	*>5y*	*>10y*	*>30y*	*>50y*	*Fully*	*Partly*	*No*		
Radiosonde stations	*299*		*Yes*		*86*	*69*	*66*	*55*		*X*		*Yes 102*	*~300*
Wind-only stations													
Stations reporting Internationally	*129*		*Yes*		*86*	*69*	*66*	*45*		*X*		*Yes 129*	*129*
CLIMAT TEMP reporting stations	*63*		*Yes*		*56*					*X*		*Yes 63*	*63*
ASAP stations	*See Section II*												
Profilers	*33*		*Yes*		*30*					*X*			*33*
Aircraft (land locations)													
*GPS **													
Others (e.g., satellite-based)	*See Section IV*		*Yes*										
Total Upper Air Network													

**** Under Development***

Table S4. Available Homogeneous Data Sets For Upper Air Observations (Meteorological)

Data Set Name	*Variable*	*# Stations or Grid Resolution*	*Describe Period*	*References*
None available				

Table S5. National Climate Monitoring Systems for Atmospheric Constituents (Source: Climate Monitoring and Diagnostics Laboratory)

Components	*Total # Stations or platforms*	*Appropriate for Characterizing National Climate?*			*Time Series #stations/platforms (#Data Digitized)*				*Are QC Procedures Adequate?*			*Metadata available? Total # Stations (% Digitized)*	*Continuity? # expected operational in 2005*
		Fully	*Partly*	*No*	*>10y*	*>20y*	*>30y*	*>50y*	*Fully*	*Partly*	*No*		
CO_2 Stations	*49[1]*	*X*			*25 25*	*22 22*	*2[1] 2*		*X*			*No 100%*	*>49*
Ozone (surface)	*5*	*X*			*1*	*4*			*X*			*No 100%*	*6*
Ozone (column)	*16[2]*	*X*			*2*	*5*	*9*		*X*			*No 100%*	*16*
Ozone (profile)	*8[3]*	*X*			*6*	*2*			*X*			*No 100%*	*10*
Atmospheric Water Vapor	*1[4]*	*X*				*1*			*X*			*No 100%*	*1*
Other Greenhouse Gases (e.g. CH_4)	*49*	*X*			*49*				*X*			*No 100%*	*~50*
Aerosol Measurements	*6*	*X*			*2*	*2*	*2*		*X*			*No 100%*	*7*
Halocarbons	*13*	*X*			*9*	*4*			*X*			*No 100%*	*>13*
Solar Radiation	*7*	*X*			*3*	*3*	*1*		*X*			*No 1005*	*7*

Table S6. Available Homogeneous Data Sets For Atmospheric Constituents

Data Set Name	Variable	# Stations or grid resolution	DescribePeriod	References
Carbon Cycle Gases; Carbon Dioxide Data	*CO_2*	*49 stations.*	*Data files begin in 1971 with the bulk beginning in the early 1980s.*	*CMDL: www.cmdl.noaa.gov and go to CO_2 data sets. CDIAC: http://cdiac.esd.ornl.gov and go to CO_2 data sets. WMO: http://gaw.kishou.go.jpand go to CMDL CO_2 data.*
Ozone Data	*Ozone*	*Up to 16 depending upon column or profile etc.*	*Some data files begin in 1962 with others in the 1980s.*	*CMDL: www.cmdl.noaa.gov and go to ozone data. WMO: http://exp-studies.tor.ec.gc.ca/e/WOUDC.htm and go to ozone data.*
Water Vapor	*Water Vapor*	*Two long-term sites and 18 sites of varying length.*	*Two long records, one beginning in 1964 and ending in 1980 and another beginning at a different location in 1980.*	*CMDL: www.cmdl.noaa.gov and go to water vapor data.*
Halocarbons, CFCs	*Other Greenhouse*	*Up to 13 global locations with the maximum number in later years.*	*Halocarbon Data begin in 1977 with CFC-11 and 12 and other halocarbon species beginning in the 1980s and 1990s.*	*CMDL: www.cmdl.noaa.gov and go to halocarbon data.*

Notes. [1.] The earliest continuous CO_2 data come from Mauna Loa and South Pole dating from 1957 in a program started by Scripps Institution Oceanography and later taken up by NOAA. Other continuous stations were added in 1974 (Barrow and Samoa) and flask sites (which comprise the majority of the sampling locations) at various times from 1957 to date. The flask samples also are used measure some other greenhouse gases and isotopes for a total of 6 gases in 2001.

[2.] NOAA/CMDL maintains 10 Dobson stations and is assisted in the operation of 6 others through cooperative agencies.

[3.] NOAA/CMDL maintains 4 long-term ozonesonde sites and has 4 sites set up for special projects with less than 4 years of data.

[4.] NOAA/CMDL maintains one permanent water vapour sonde site and has undertaken a number of measurements campaigns from a few months to a few years at 20 other sites. All data are available in the CMDL archives

II. Oceanographic Observations

The GCOS requirements for ocean observations are the same as the climate requirements for the Global Ocean Observing System (GOOS). Both are based on the Ocean Observing System Development Panel (OOSDP) Report, (OOSDP, 1995), which can be found at http://www-ocean.tamu.edu/OOSDP/FinalRept/t_of_c.html. The GOOS, like GCOS, is based on a number of *in-situ* and space-based observing components. The U.S. contributes to all of these components. Long-term, sustained, systematic observations are critical not only to developing an understanding of oceanic processes as they relate to climate and to predicting climate variability but there are many other applications of these data with significant societal benefit. In coastal waters, these observations meet the needs of managing living resources, preserving healthy ecosystems, and aiding marine operations, as well as putting climate changes in perspective for the coastal regions. They also provide a baseline to enable local observation systems of higher resolution to meet national objectives. Surface ocean data from the ocean observing system for climate will be assimilated into weather prediction models and improve weather forecasts. Thus, the cost, complexity, and scale of observations for climate need not be justified only by their benefits to climate monitoring, detection, and prediction; the same observations and many resulting products will produce other benefits in the short term.

A. Recent Developments

The U.S. government, both the Executive Branch (Administration) and the Legislative Branch (Congress), are increasingly cognizant of the need for sustained ocean observations and are supportive of strong U.S. involvement in its implementation. In 1997, the U.S. established the National Oceanographic Partnership Program (NOPP) (http://core.cast.msstate.edu/NOPPpg1.html) to coordinate and strengthen oceanographic efforts by identifying and carrying out partnerships among Federal agencies, academia, industry, and other members of the oceanographic scientific community in the areas of data, resources, education, and communication. The National Ocean Research Leadership Council (NORLC), comprised of the heads of 12 agencies with oceanographic programs and interests, oversees the activities of the NOPP.

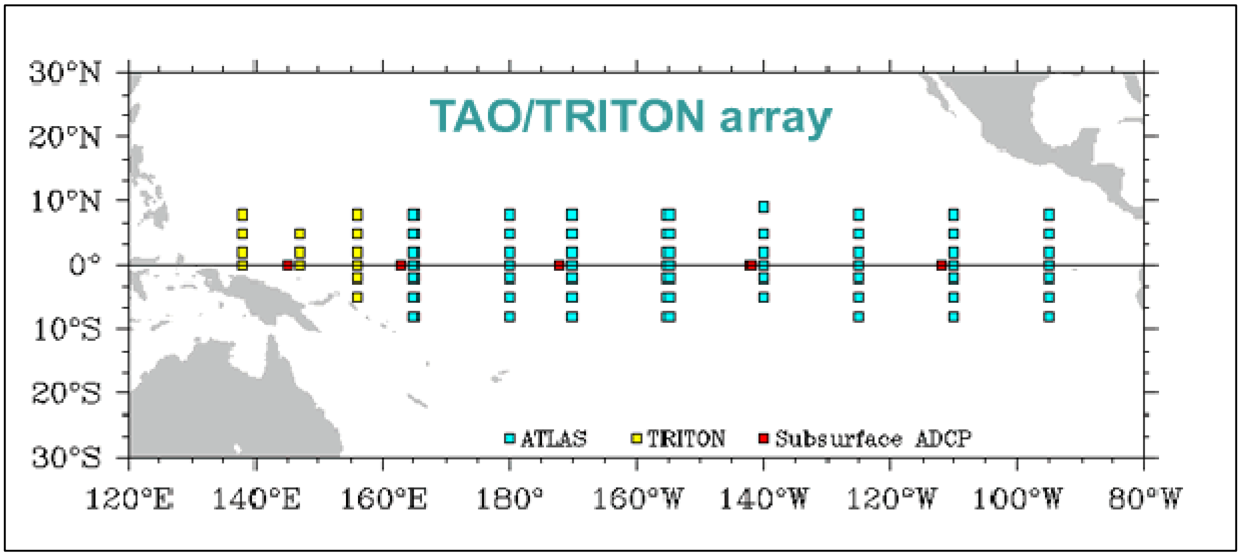
In August 1998, Congress requested the NORLC of NOPP to "propose a plan to achieve a truly integrated ocean observing system." In response to that request, the report "Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System” (http://core.cast.msstate.edu/NOPPobsplan.html), was prepared by a joint federal/non-federal task team. This document represented the first significant step by the U.S. oceanographic community toward the development of a comprehensive plan. This initial plan engaged the broader community consisting of NORLC member agencies, other government entities, academia, the private sector, non-governmental organizations, and the Congress in a community-wide discussion, concerning implementation. In so doing, the NORLC recognized that a number of issues would be topics for debate including: (1) how to manage the overall effort; how to achieve the integration of present and future systems, integrating both within and between the coastal and open ocean elements; and (2) how to develop an ocean-wide program with the international community; and how to identify objectives, requirements, and priorities.

The NORLC requested its advisory panel to accept responsibility for development of the next step toward a comprehensive plan, building on the initial report and the results of the community-wide debate. This resulted in the development of, "An Integrated Ocean Observing System: A Strategy for Implementing the First Steps of a U.S. Plan" (http://core.cast.msstate.edu/oceanobs.html), developed by a working group of experts. In October 2000, the NOPP established an interagency office for integrated, sustained ocean observations (Ocean U.S.) to implement this plan.

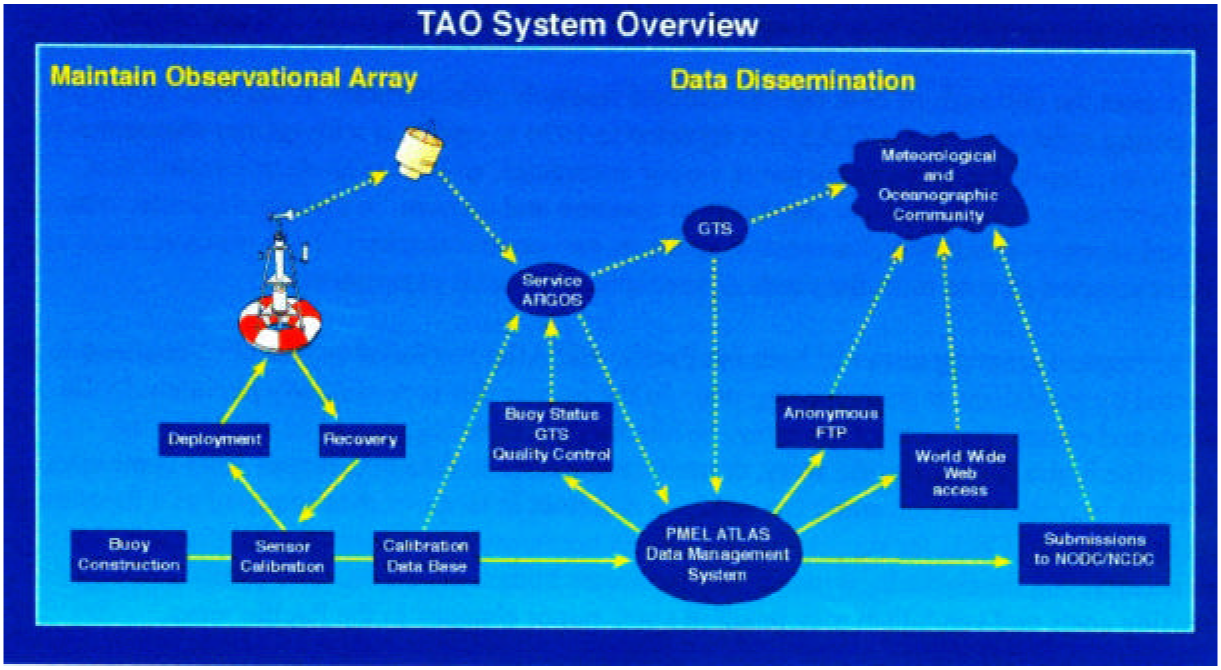
B. Fixed Mooring Observational Programs

1. TAO/TRITON

Begun in 1980, the Tropical Atmosphere-Ocean Triangle Trans Ocean Buoy Network (TAO/TRITON) array (http://www.pmel.noaa.gov/tao) (http://www.pmel of approximately 68 Autonomous Temperature Line Acquisition System (ATLAS)-type and current meter moorings in the Tropical Pacific Ocean, began telemetering oceanographic and meteorological data in real-time via the Argos satellite system. Development of the array was spurred by the 1982-1983 El Niño event, which was neither predicted nor detected until nearly its peak. That event highlighted the need for real-time data from the tropical Pacific for monitoring, prediction, and improved understanding of El Niño. The development of the ATLAS mooring permitted the implementation of the large-scale array present today. This low-cost deep ocean mooring was designed to measure surface meteorological and subsurface oceanic parameters, and to transmit all data to shore in real-time via satellite relay. The mooring was also designed to last one year in the water before needing to be recovered for maintenance. The full array was completed in December of 1994. During the years in which the array was under development, over 400 buoys were deployed on 83 cruises, using 17 different ships from 5 different countries (U.S.A, Japan, France, Taiwan, and Korea). Presently, the U.S. maintains the array from the west coast of the Americas to 165EE. Beginning in 1999, the moorings along 156EE, 147EE, and 137EE became part of the TRITON array maintained by the Japan Marine Science and Technology Center. Each mooring is visited twice a year requiring approximately 300 days of ship time to maintain the

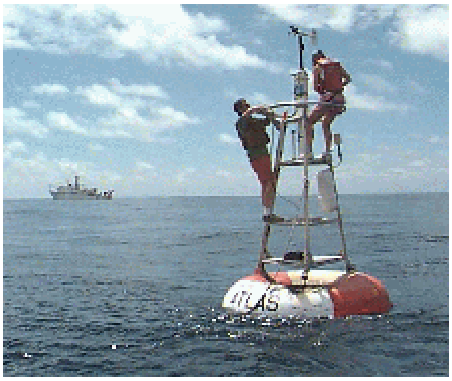


array along and east of 165EE, and approximately 90 additional days to maintain the western portion of the array.



The operationally supported measurements of the TAO/TRITON array consist of winds, sea surface temperature, RH, air temperature, and subsurface temperature at 10 depths in the upper 500 m. Five moorings along the equator also measure ocean velocity. Additional moorings and/or enhancements to the basic measurement suite are often incorporated to the operational array in support of research studies to understand specific physical processes not well measured by the existing network. Other measurements may be made for satellite or numerical model validation purposes. These research efforts are usually of limited duration and/or geographical scope, and done in collaboration with other institutions in the U.S. and abroad.

To meet the demands of both operational and research measurements in the TAO array, an engineering redesign of the ATLAS was initiated in 1994 to update it with greater measurement capabilities, improved ocean temperature sensor accuracies, and more modular construction. This Next Generation ATLAS has the capability to measure and transmit in real-time salinity, rain rate, long and shortwave radiation, barometric pressure, and ocean velocity. These measurements are made at selected sites to meet the needs of specialized research experiments.

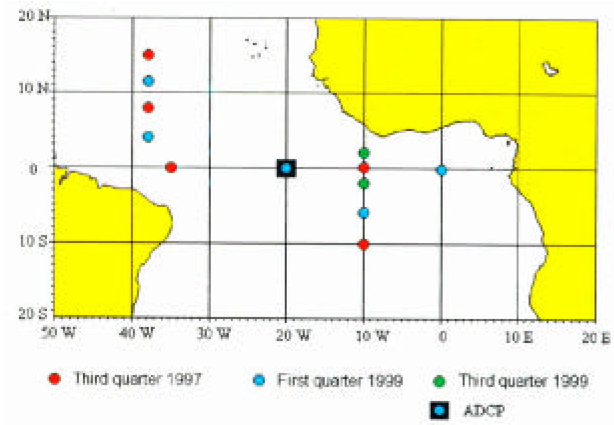


Servicing an ATLAS Mooring

The tropical mooring arrays in both the Pacific and Atlantic (following section) continue to be impacted by vandalism at an increasing rate. In the Pacific this is particularly prevalent in the western and eastern portions of the array. While funding is anticipated to be stable for the foreseeable future for the Pacific array, dramatic reductions in data return rates from some sites may result in those sites becoming too costly to maintain. Costs for supporting the vessels necessary to maintain the Pacific array have been accelerating dramatically without commensurate budget increases. The combination of increasing costs and vandalism may result in some minor changes in the Pacific array.

2. Pilot Research Moored Array in the Tropical Atlantic

The Pilot Research Moored Array in the Tropical Atlantic (PIRATA) is a collaborative effort by scientists from Brazil, France, and the U.S. to install and maintain an array of moored ATLAS buoys for monitoring the surface variables and upper ocean thermal structure at key locations in the tropical Atlantic (http://www.ifremer.fr/ird/pirata/piarataus.html). The measurements are transmitted via satellite (*e.g.* CLS-Argos) in real-time and are available to all interested users in the research or operational communities, and are implemented as a collaborative multinational effort. The data management protocols for PIRATA are similar to those for TAO.



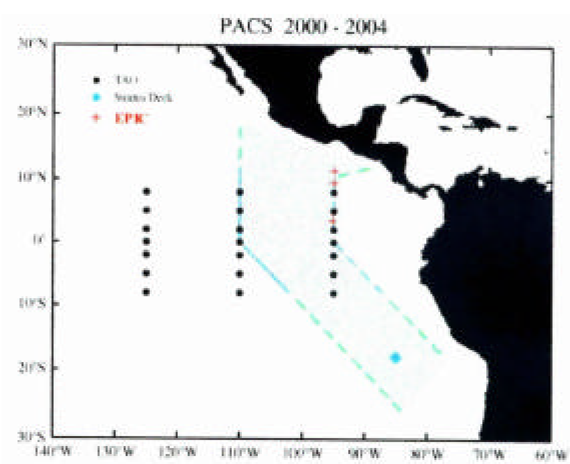
Tropical Atlantic Mooring Array

It is anticipated that these tropical Atlantic observations (http://www.ifremer.fr/ird/pirata/piarataus.html) will be maintained near their present levels for five years. As with the Pacific array, increasing vandalism is a serious problem for the tropical Atlantic array. This problem tends to be focused in the eastern portion of the array. The cost effectiveness of maintaining certain sites with low data return rates may result in configuration changes for the tropical Atlantic array.

3. Eastern Pacific Investigation of Climate Processes in the Coupled Ocean-Atmosphere System

Two observational programs being put in place for the Eastern Pacific Investigation of Climate (EPIC) in the Coupled Ocean-Atmosphere System program are intended to be sustained for approximately 4 years: 1) enhancements of the TAO Array along 95EW with ATLAS-type moorings at 3.5EN, 10EN, and 12EN; and 2) implementation of an IMET-type mooring in the stratus region off of South America at 85EW and 18ES or 20ES (http://www.atmos.washington.ede/gcg/EPIC).

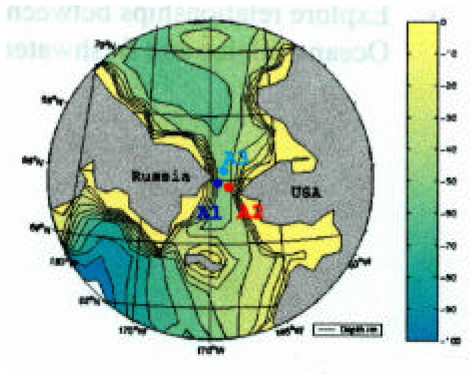
Improved Meteorological Instruments (IMET) was developed to meet the data quality requirements of the World Ocean Circulation Experiment (WOCE) (http://uop.whoi.edu/uophome/technotes.html). This system is now in use on several research ships and is available commercially. The modules are self-powered, self-recording, and communicate on a data bus.



Enhanced Mooring Array in the Eastern Tropical Pacific

The following modules are currently in routine use:

1. Barometric Pressure
2. Sea Surface Temperature
3. Relative Humidity/Air Temperature
4. Air Temperature (Static or Aspirated)
5. Wind Speed and Direction
6. Precipitation
7. Longwave Radiation (incoming
8. Shortwave Radiation (incoming)



Bering Strait Moorings

Custom modules have been designed for special applications such as:

1. Precipitation Temperature
2. Global Positioning System
3. ADCP Interface
4. ARGOS Satellite Telemetry

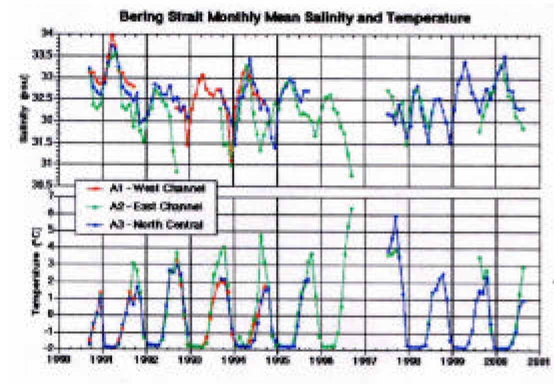
The IMET architecture is built around an addressable digital data bus. Each sensor is housed in a separate intelligent module that includes all of the sensor-specific functions and communicates with a central controller (PC, laptop, or any computer that has a serial port) via RS-485 in an ASCII protocol. The units are calibrated prior to an experiment and the calibration constants are stored in the module (EEPROM) so that all data is in calibrated engineering units. A post-experiment calibration is carried out to determine any drift (very small on most units). Should a module have to be changed during an experiment, the new module is plugged in and generates calibrated data. The concept permits adding multiple sensors of any type since each module is addressable. While averaging takes place within each module, the interrogation and storage of data are typically at a one-minute rate.

Ship and buoy IMET systems are integrated systems that have one central data logger and power supply as well as an interface to a satellite transmitter for real-time data recovery. VOS modules are designed for ease of carry-on installation on ships that cannot have permanently installed cables and central computers. The VOS units are self-powered (six months on eight D-cell batteries) and self-recording (on a four megabyte flash card, at the one-minute rate). The size of a VOS unit is about the same as an IMET unit.

4. Arctic

Moorings have been deployed in the Bering Strait since 1990 at two or more locations to monitor flow through the western (A1) and eastern (A2) channels of Bering Strait (http://psc.apl.washington.edu/HDL/Bstrait/bstrait.html). The moorings make long-term measurements of the variable inflow of Pacific waters to the Arctic Ocean through Bering Strait, together with the varying properties of those waters. The mooring A1 is in the Russian EEZ. In other years, a proxy site at A3 has monitored the western channel. This influx provides a key forcing for the Western Arctic shelf-slope-basin system, and the Pacific influence can be traced across the Arctic Ocean into the northern North Atlantic. A particularly important dynamical aspect of the Pacific presence in the Arctic Ocean is its contribution to stabilizing the upper ocean, thereby influencing ice thickness and Upper Ocean mixing.

Beginning in April 2001, bottom-moored instruments that sample from the surface to great depths over the 4000 m deep abyssal plain at the North Pole began to be maintained. Measurements include ice thickness and drift, water temperature and salinity, and current speed and direction. We anticipate other automated measurements being added in subsequent years, including concentrations of nutrients and a variety of other tracers. This moored time series station at the Pole has the following major objectives:



- Provide a platform for community-wide Eulerian measurements in the interior Arctic Ocean.
- Determine the statistics of both the ice drift and the planetary boundary layer in the upper ocean.
- Measure the low-frequency variability of the velocity field of the mixed layer and halocline, including the annual cycle and its inter-annual variability.
- Quantify the vertical and temporal scales of variability in the temperature and salinity fields, especially in the halocline and the Atlantic layer where many of the dramatic changes of the past decade have occurred.
- Assess the impact of large-scale changes in the circulation and properties of the Arctic Ocean in this region.
- Use the new measurements to increase the dynamical understanding of the interior Arctic Ocean and encourage improved modeling of this regime.
- Provide a long-term comparison base for earlier measurements in the region, including those incorporated into atlases.
- Measure Eulerian time series of sea ice drift and provide the quality-controlled, documented data sets to the arctic research community.
- Estimate the temporal variations of the sea ice thickness distribution, including its mean, modes, and open water fraction.
- In collaboration with other LTO participants, compare the observed variations in ice thickness with concurrent variations in the local ocean/atmosphere environment and with variations in the AO, NAO, and other indices of arctic change.
- Explore relationships between the observed variations in ice thickness in the central Arctic Ocean with ice and freshwater export through the Fram Strait.

C. Marine Observational Network of the National Weather Service

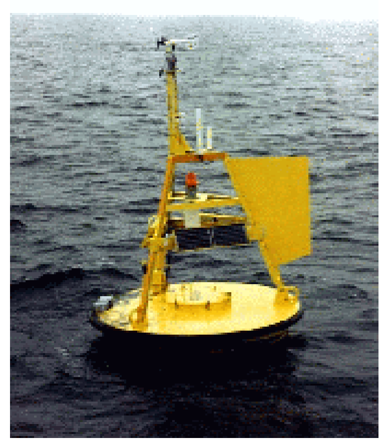
Globally, weather and marine forecasters in coastal nations require frequent, high-quality marine observations for assimilation into models and for diagnosing conditions before forecasts are prepared. During the 1960's, about 50 individual buoy programs were conducted by a variety of ocean-oriented agencies in the U.S. In 1967, a consolidated national data buoy system was created and placed under the U.S. Coast Guard. NOAA was formed in 1970 and the NOAA Data Buoy Office (NDBO) at Stennis Space Center, Mississippi, was created under its National Ocean Service (NOS). In 1982, the NDBO was renamed the National Data Buoy Center (NDBC) and was placed under NOAA's NWS.

The NDBC (http://www.ndbc.noaa.gov/) operates the Marine Observational Network (MON) for the NWS. The components of the MON are also programs within the WMO's Joint Commission for Oceanography and Marine Meteorology. Most of the assets that make up the network are defined as coastal, that is, they are within 50 miles of the coast. However, a few deep-water buoys lie beyond this distance. The oceanic components of the MON consist of:

- 69 moored buoys in the waters of the east, west, Alaskan and Gulf coasts, around Hawaii and in the Great Lakes.
- 55 stations of the Coastal-Marine Automated Network (C-MAN) along the east, west, Alaskan and Gulf coasts, the Great Lakes, and St. Lawrence Seaway.
- The VOS Program (discussed in the section on Voluntary and Ships of Opportunity).

Buoys are 3-, 10-, or 12-meter discus buoys or 6-meter Naval Oceanographic and Meteorological Automated Device (NOMAD) buoys. The majority falls in the 3-meter discus category. The C-MAN stations are on towers, piers, lighthouses, etc. Measured parameters include air temperature, sea level pressure, wind speed and direction, sea temperature at one meter, and certain wave characteristics (depending on particular location).

At a minimum, the moored buoy and C-MAN stations provide hourly observations of wind speed, direction, and gust; barometric pressure; and air temperature. In addition, all buoys, and some C-MAN stations, measure sea surface temperature and wave heights and periods. In general (exceptions will be presented) these data are transmitted hourly, via GOES to the NWS where gross quality control is preformed before being distributed on the GTS. Delayed mode quality control is performed by NDBC. Delayed mode data undergo more extensive quality control procedures and are available at higher resolution than the real-time data. Delayed mode data are available from the NDBC.



3 Meter Discus Buoy

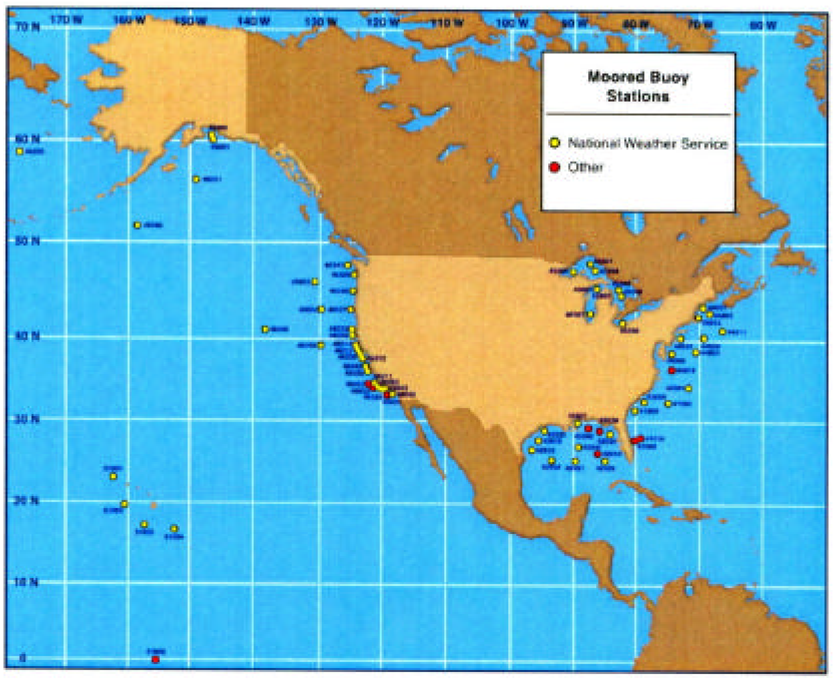
1. Moored Buoys

These buoys are deployed in the coastal and offshore waters from the western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific. NDBC's moored buoys measure and transmit barometric pressure; wind direction, speed, and gust; air and sea temperature; and wave energy spectra from which significant wave height, dominant wave period, and average wave period are derived. The direction of wave propagation is measured on many moored buoys (http://www.ndbc.noaa.gov/mooredbuoy.shtml).


6-Meter NOMAD Buoy

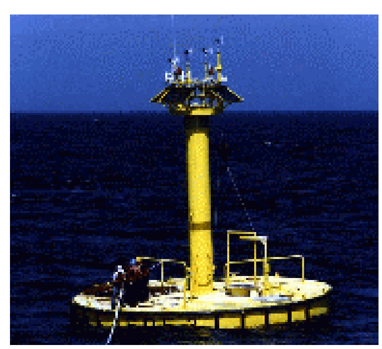
The fleet of moored buoys includes six types: 3-m, 10-m, and 12-m discus hulls; 6-m boat-shaped (NOMAD) hulls; and the newest two, the coastal buoy and the coastal oceanographic line-of-sight (COLOS) buoy. The choice of hull type used usually depends on its intended deployment location and measurement requirements.

The steel-hulled, 12-meter discus buoys are sturdier in rough weather than the smaller, steel-hulled 10-meter discus buoy, but are more costly to maintain. The 10-meter buoy has been known to capsize in certain environmental conditions and the overall motion of the buoy is more lively than that of the 12- meter buoy. Due to their size, the 10- and 12-meter buoys generally have to be towed to their appropriate locations. The aluminum-hulled, 3-meter discus is very cost-effective but does not offer long-term survivability that the larger discus hulls provide. The transportability of the 3-meter buoy is much improved over that of the larger discus buoys. Constructed of aluminum, it is less likely to corrode, and compass measurements are not affected.



National Weather Service Moored Buoy Locations

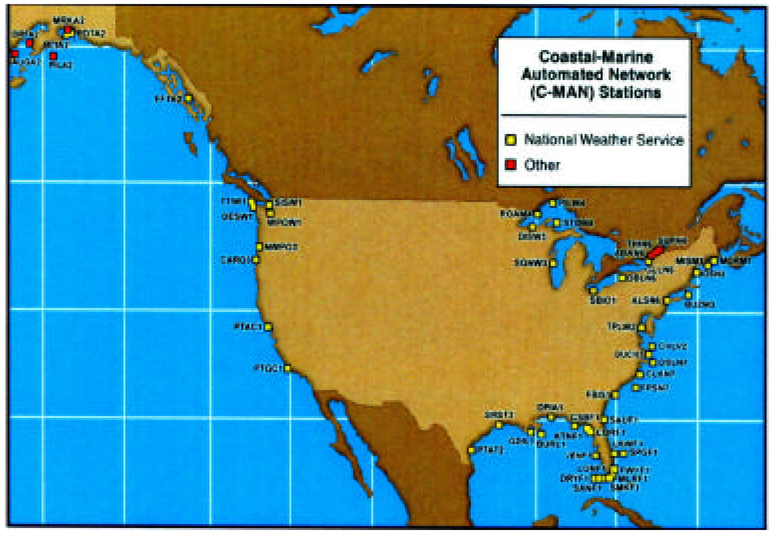
The 6-meter NOMAD buoy is an aluminum-hulled, boat-shaped buoy that provides relatively high cost effectiveness and excellent long-term survivability in severe seas. These buoys are highly directional and have a quick rotational response. There has been no known capsizing of 6-meter NOMAD hulls. The relatively small size of the NOMAD hulls allows for superb transportability. Like the 3-meter discus buoy, they are less likely to corrode and the magnetic effects on the compass are slight.


10-Meter Discus Buoy

2. Coastal-Marine Automated Network

The (C-MAN) was established in the early 1980's in response to a need to maintain meteorological observations in U.S. coastal areas (http://www.ndbc.noaa.gov/ cman.phtml). Approximately 60 stations have been installed on lighthouses, at capes and beaches, on near shore islands, and on offshore platforms.

Besides the baseline measurements of wind speed and direction, air temperature, and barometric pressure, measurements of RH, precipitation, visibility, solar radiation, sea water temperature and salinity, sea level, ocean currents at depth, underwater light intensity, and others can be made. To meet the need for more frequent real-time observations, data from several select C-MAN locations can be accessed by telephone with data being updated at 15-minute intervals. Three stations have data updated for telephone access every 5 minutes.

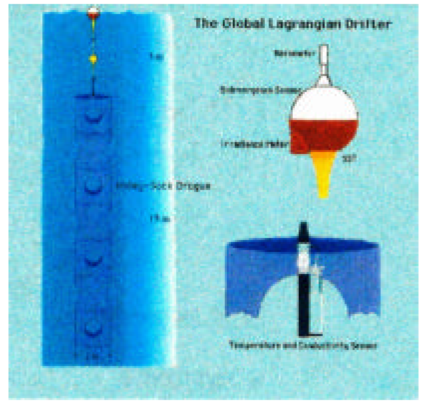


National Weather Service Coastal Marine Automated Network Station Locations

A few C-MAN stations located in Micronesia are at the fringe of, or lie outside, the GOES footprint. Data from these stations may be transmitted via either GOES or NOAA polar orbiting environmental satellites (POES), depending upon which provides better data relay capability. Arrangements have been made with the Japanese Meteorological Agency to transmit data from one western Pacific station through the Japanese geo-stationary meteorological satellite, referred to as GMS, via Tokyo to the NWS for processing and dissemination. Pictured is the C-MAN station located in Dry Tortugas, Florida, at 24.64E N, 82.86E W. The site elevation is 0.0 m above mean sea level; with the air temperature measured at 5.2 m above site elevation, the anemometer is at 5.7 m, and barometric pressure is measured at 4.5 m.

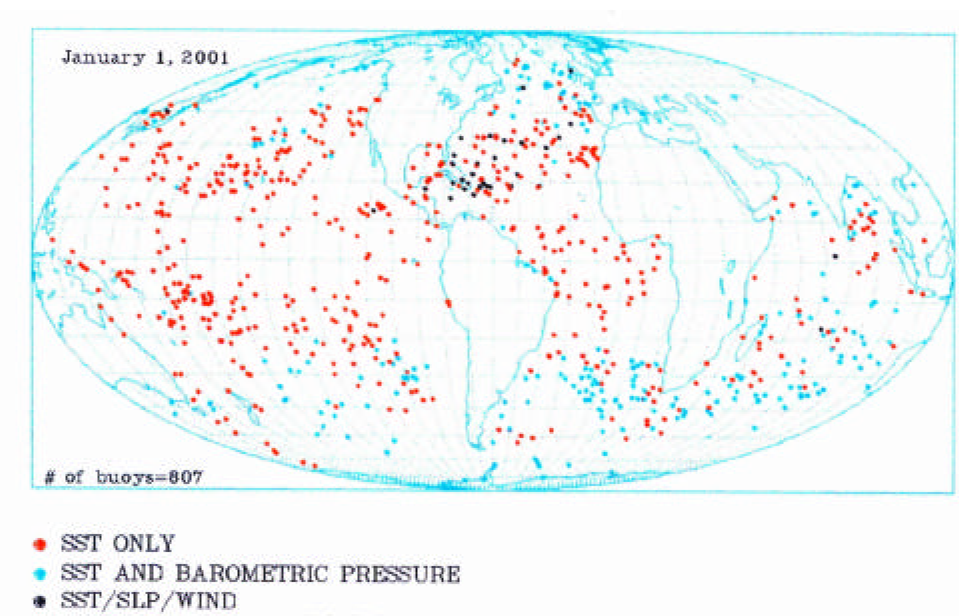
Dry Tortugas, Florida C-MAN Station

D. Drifting Buoy Program



1. Global Lagrangian Drifters

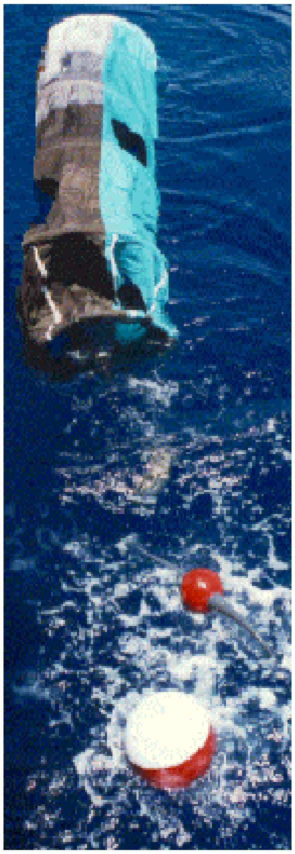
The objectives of this program are to assemble and provide uniform quality control of sea surface temperature (SST) and surface velocity measurements by maintaining an accurate and globally dense set of Argos-tracked Lagrangian drifters providing in-situ observations of sea-surface temperature (SST) and surface circulation. These measurements are obtained as part of an international program designed to make the data available in an effort to improve climate prediction. Climate prediction models require accurate estimates of SST to initialize their ocean component. Drifting buoys provide essential ground truth SST data for this purpose. These models also require validation by comparison with independent data sets. Surface velocity measurements are used for this validation.



U.S. Global Drifter Program, 1 January 2001

The U.S. presently deploys over 500 drifters annually in all three basins using the VOS Program, research vessels and U.S. Navy aircraft. These drifters are tracked daily via the ARGOS satellite system where their positions and sea surface temperatures (and sometimes other parameters) are processed and inserted onto the GTS for global distribution. Approximately 630,000 SSTs are collected annually via this program. Additionally, the U.S. performs the added function of a Data Acquisition Center (DAC) for the Global Drifter Program (GDP) (http://www.aoml.noaa. gov/phod/dac). The global drifter program is a participating member of the Intergovernmental Oceanographic Commission (IOC)/World Meteorological Organization (WMO), Data Buoy Cooperation Panel (DBCP).

Recently deployments of barometer drifters have taken place in the Southern Ocean, South Atlantic Ocean, and northwest Pacific Ocean. These instruments require careful monitoring to ensure that they are operating in good condition and that the data used in numerical weather prediction in near real-time by meteorological centers throughout the world, are being put to best advantage. The U.S. will continue to support the deployment of drifters equipped with barometers in key regions for numerical weather prediction as well as for sea surface temperature and velocity observations. Deployment of a significant number of drifters equipped with wind

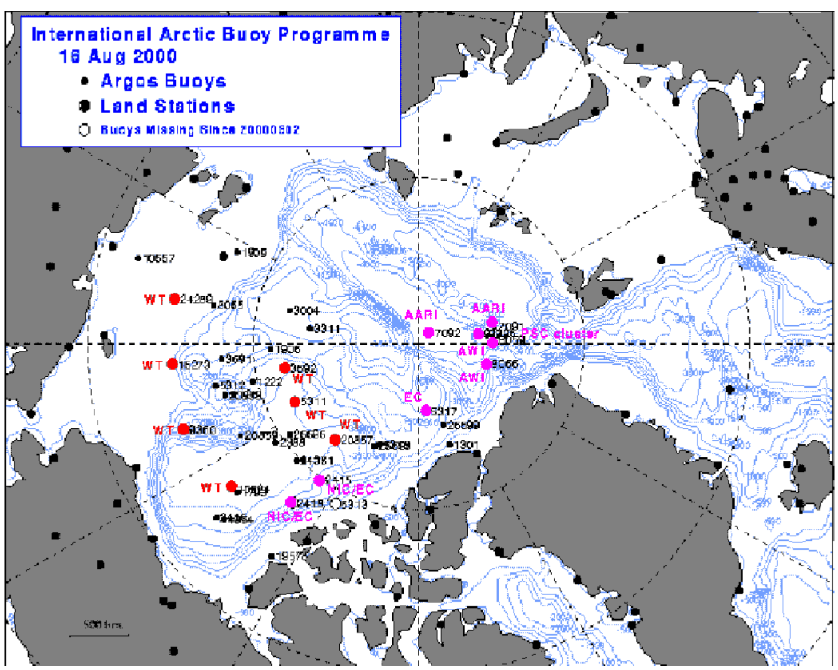


Lagrangian Drifter Being Deployed

monitoring capability is occurring, primarily in the tropical North Atlantic for hurricane prediction and monitoring purposes.

2. Arctic

The International Arctic Buoy Programme (IABP) is funded and managed by its participants, representing eight nations (Canada, France, Germany, Japan, Norway, Russia, United Kingdom, and the U.S.). Participants include operational and research agencies, meteorological and oceanographic institutes, and nongovernmental organizations. The IABP maintains a network of automatic data buoys (http://iabp.apl.washington.edu/buoys.html) in the Arctic Basin which monitors synoptic-scale fields of pressure, temperature, and ice motion to support real-time operations and meteorological and oceanographic research. Each nation collaborates in the centralized deployment of buoys. Funding, equipment, and services are provided by a number of U.S. agencies and organizations through the Polar Science Center at the University of Washington/Applied Physics Laboratory (http://iabp.apl.washington.edu/).



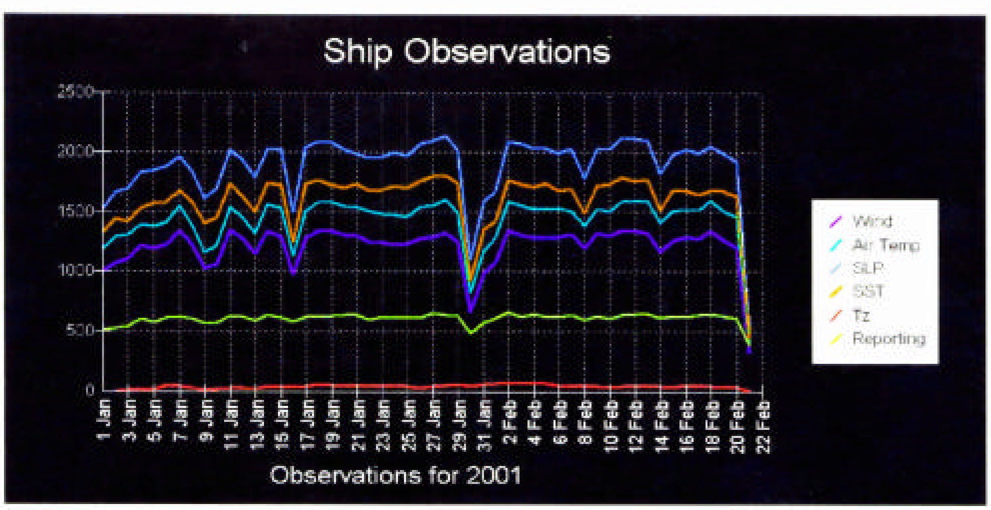
E. Voluntary and Ships of Opportunity

The WMO VOS is the international scheme by which ships plying the oceans and seas of the world are recruited by National Meteorological Services (NMS) for taking and transmitting meteorological observations. The contribution that VOS meteorological reports make to operational meteorology, marine meteorological services, and global climate studies is unique and irreplaceable. During the past few decades, the increasing recognition of the role of the oceans in the global climate system has placed even greater emphasis on marine meteorological and oceanographical observing systems.

One of the major continuing problems facing meteorology is the scarcity of data from vast areas of the world's oceans (the so-called 'data-sparse areas') in support of basic weather forecasting, provision of marine meteorological and oceanographic services, and climate analysis and research. While meteorological satellites help substantially to overcome these problems, data from more conventional platforms, in particular the voluntary observing ships, remain essential to provide ground truth for the satellite observations, and to provide important information which the satellites cannot observe. Tested instruments are supplied free of charge to the ship, and professionally installed, usually by a trained Port Meteorological Officer. The Officer provides advice on the technique of observing at sea, explains the use of the WMO SHIP code, and offers guidance on the transmission of the observations from the ship to shore. There are no charges to the ship for the transmission of these data. The instruments are professionally serviced, without charge to the ship or ship owner. The U.S. program operates over 1,500 vessels. As many observations as possible are transmitted in real-time and distributed on national and international circuits for operational uses such as weather prediction and ocean state estimation. All observations, those transmitted for operational uses and those whose transmission is delayed, are forwarded for use by the NCDC.

F. U.S. GOOS VOS Program

The U.S. GOOS VOS program presently operates a fleet of about 400 domestic and foreign commercial vessels, a subset of the global fleet. It also includes some research vessels. In



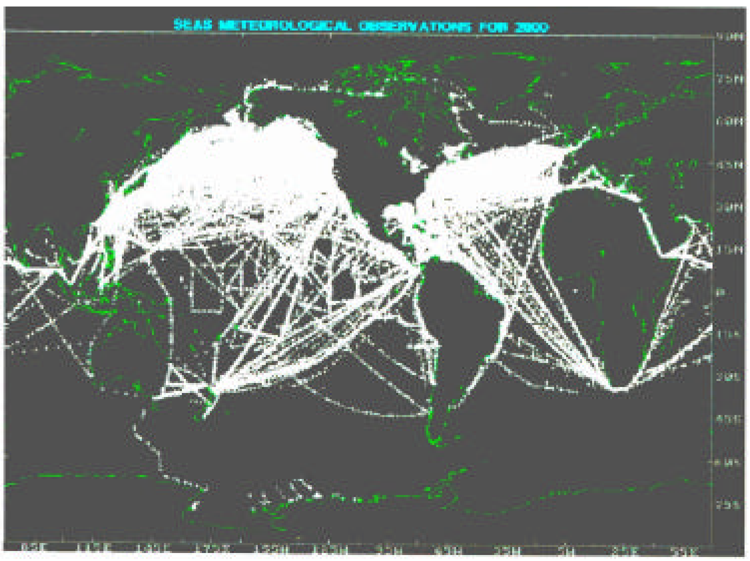
Meteorological and XBT Observations Received from Voluntary Observing Ships

addition to conducting sea surface meteorological observational programs, these ships are used to deploy sub surface eXpendable BathyThermographs (XBT), conduct underway shipboard ThermoSalinoGraph (TSG) and carbon dioxide (CO_2) measurement programs, and atmospheric observations. These vessels also deploy drifting buoys and highly instrumented profiling floats, and sometimes tow other instruments. In any given year this network provides the following approximate number of observations:

- 630,000 sea surface temperature observations from drifting buoys
- 110,000 meteorological observations
- 30,000 thermosalinograph observations
- 15,000 expendable bathythermograph observations

1. Shipboard Environmental (Data) Acquisition System (SEAS)

The SEAS program provides accurate meteorological and oceanographic data in real-time from ships at sea through the use of satellite data transmission techniques (http://www.dbcp.nos.noaa.gov/seas/met.html). This is a specific hardware/software package to ensure that meteorological and XBT observations are transmitted in real-time through either the GOES or INMARSAT C satellites for use in weather and climate forecasting and ocean state estimation and analyses. SEAS- equipped voluntary observing ships are responsible for more than 15,000 XBT (T_Z) observations and as many as 80,000 meteorological observations per year. Meteorological observations consist of wind speed, air temperature, sea-level pressure (SLP), and SST.



2. Expendable Bathythermograph Program

The XBT program (http://www.aoml.noaa.gov/phod/uot/) utilizes approximately 70 VOSs to monitor, on a monthly basis, 26 transects in all three ocean basins. It utilizes SEAS hardware/software to collect, quality control, and transmit in real-time subsurface oceanographic observations obtained using about 15,000 XBTs per year. The XBT is an expendable temperature probe that is manually launched from the bridge wings of commercial vessels approximately four times per day, along certain scientifically selected shipping lanes. The data transmitted via the wire link from the XBT probe is stored on the SEAS computer, where it is processed and formatted for satellite message transmission. The transmitted data is routed to a Center where it is further quality controlled,

XBT

SEAS

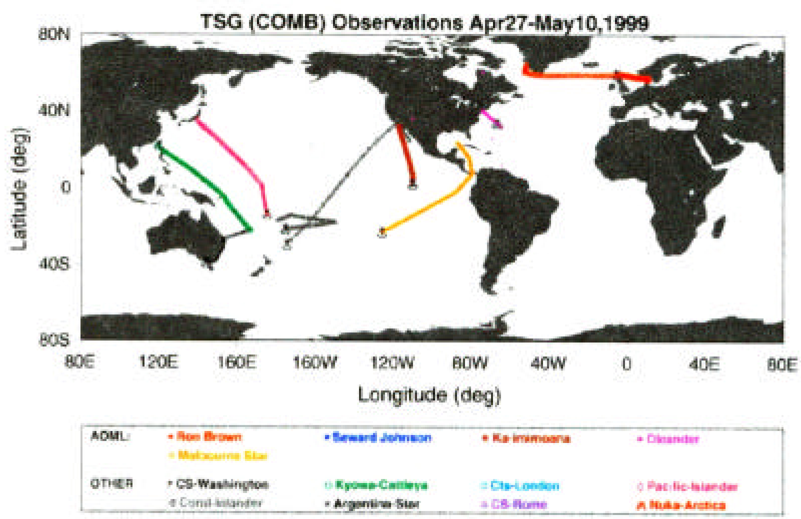
Automated XBT Launcher

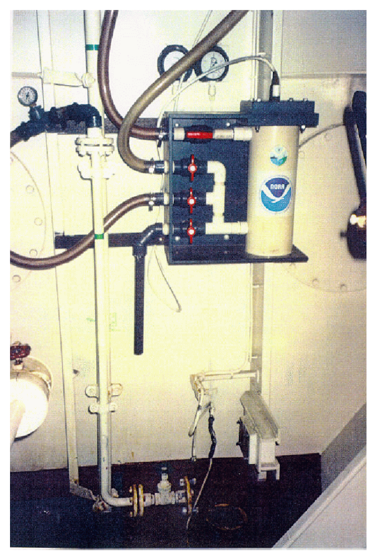
then placed onto the GTS for global distribution. NCEP uses the data for weather and climate forecasting as well as for seasonal, inter-annual, and decadal climate research. The XBT program is a participating member of the IOC/WMO Ship of Opportunity Program Implementation Panel (SOOPIP).

XBT Probe

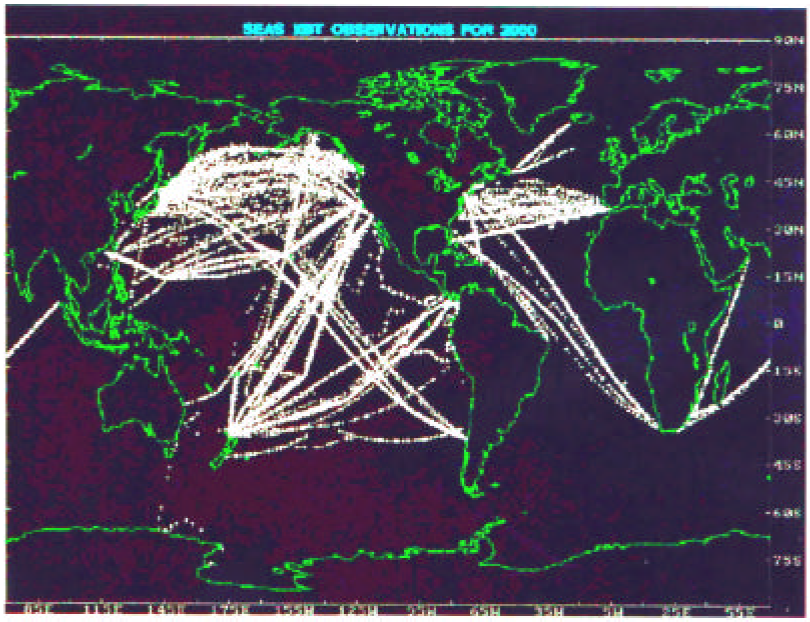
3. Thermosalinograph (TSG)

A project has been developed to evaluate and implement TSG technology on VOS (http://www.aoml.noaa.gov/goos/goos-developing.html and http://www.aoml.noaa.gov/ goos/techtsg.html). The TSG determines sea surface temperature and conductivity from underway vessels through a stainless steel assembly mounted near the ship's seawater intake. The system also employs other devices such as sensors for dissolved oxygen and fluorescence. High-resolution data, along with the vessel's location from a GPS receiver, are recorded and archived for research purposes. A subset of these data is transmitted every 3 hours via the GOES. Water samples used to verify the TSG data are taken by the vessel's crew twice daily. TSGs have been operational on research vessels for a number of years; however, it has only been over the past two years that a Sea-Bird TSG has been operating on the VOS OLEANDER (Newark, N.J. to Bermuda) and more recently on the VOS SKAGAFOSS (Newfoundland to Iceland).



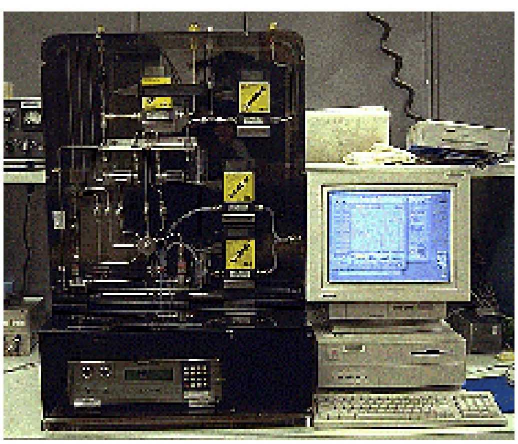


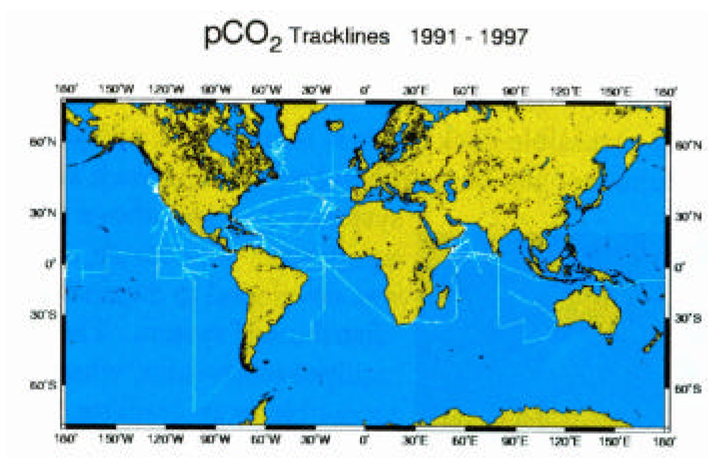
Shipboard Thermosalinograph and Observations



4. Carbon Dioxide

The air-sea Flux (F) of CO_2 is commonly determined from the gas transfer velocity (k) multiplied by the partial pressure difference (pCO_2) across the air-water interface: $F= kpCO_2$. By measuring pCO_2 with automated systems on ships of opportunity, a global flux map can be produced. Beginning in 1991, a semi-automated system was deployed on research vessels (three vessels today) measuring the pCO_2 in air and water on all cruises in order to fill critical voids in the global data set of pCO_2 measurements. The area of concentrated deployment has been the equatorial Pacific, where seasonal snapshots of surface water CO_2 levels have been obtained in concert with the TAO array (http://www.aoml.noaa.gov/ocd/oaces/co2/).

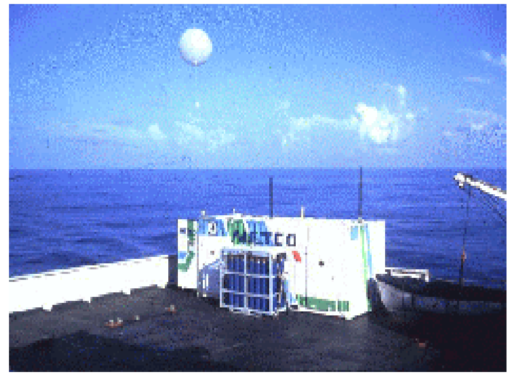




Underway pCO_2 Monitoring

5. Automated Shipboard Aerological Program (ASAP)

The ASAP in its present form began in the mid-1980s. It involves the generation of upper air profile data from data-sparse ocean areas using automated sounding systems carried on board merchant ships plying regular ocean routes. The profile data are all made available in real-time



Radiosonde Launch from an ASAP Container

on the GTS, for use by operational centers. The original ASAP system was developed as a modular "containerized" unit, which could be quickly installed or removed from a ship. The system is completely housed within a specially modified, standard 20-foot shipping container. This includes all of the necessary electronics and antennas, a balloon launching system, stowage for consumable supplies such as helium balloons and sondes, and adequate operator workspace. It requires only to be connected to the ship's power and secured to a suitable deck space. Several NMSs operate ASAP units. The program is coordinated through the ASAP panel, a component of the JCOMM Ship Observations Team. Most of the soundings are presently from the North Atlantic and North West Pacific Oceans, but the program is also expanding into other ocean basins. The U.S. presently collaborates in the maintenance of one around-the-world ASAP vessel.

The containerized ASAP has definite advantages in today's flexible shipping environment because it can easily accommodate abrupt changes in shipping routes by simply moving to another ship more suitable for ASAP operations. It becomes apparent, however, that the number of potential ships of opportunity, able to carry such a system, is limited. Substantial non-obstructed and easily accessible deck space is required. In addition, costs over and above the required maintenance of the electronic equipment are incurred by maintenance of the container and its peripheral equipment such as air conditioners and mechanical launching systems. As a result, an alternative “distributed” system configuration, was developed to expand the versatility of the ASAP concept. The distributed system is essentially limited to the required electronics installed in existing ship's spaces accessible to an operator, usually on the bridge or close by. Consumable supplies are stored in appropriate on-board space, and manual or remote launching techniques may be employed. Two U.S. research vessels (NOAA ships *Ronald H. Brown and Ka’imimoana*) have distributed systems installed on board. These vessels conduct routine upper air observations that contribute to the overall ASAP observational program as much as possible. The tropical Pacific is an area of vital importance for these observations. The *Ka’imimoana* supports the TAO array and, thus, can routinely provide upper air profiles from this region.

Radiosonde Launch from a Distributed ASAP System

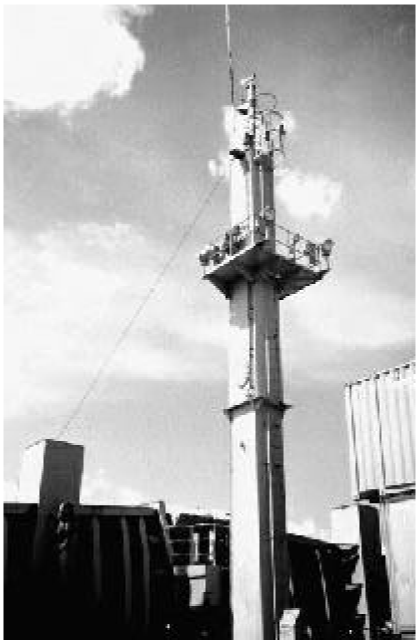
6. Improved Meteorology

In planning for WOCE, it was recognized that moored buoys and ships would provide especially attractive platforms from which to make accurate in-situ measurements of the basic surface meteorological observable parameters required to investigate the air-sea fluxes of momentum, heat, and mass. The Woods Hole Oceanographic Institution was funded to evaluate and choose sensors capable of meeting the WOCE goals and to develop the IMET system as a flexible data collection system. The IMET technology has evolved into new modules designed for use on VOS ships. These new VOS-IMET modules are self-powered, self-recording, stand-alone units.

Currently installed sensor modules include the full flux suite consisting of wind speed and direction, RH and air temperature, barometric pressure, precipitation, shortwave radiation, longwave radiation, and SST (http://uop.whoi.edu/uophome/asimet/asimet.html#instrumentation).

IMET System on the Bow of a Research Vessel

The U.S. VOSs are sold and change routes on a very regular basis. This has severe implications in that it is not feasible to run cables for system installations and it is normally not possible to obtain useable electrical power close to sensor mounting locations. One special problem is getting SST data from inside the hull of the ship at the waterline up to the rest of the modules. An acoustic modem that uses the ship's steel hull at the acoustic path for 20-baud data has recently been developed. The measurement system for a VOS therefore must be self-powered, self-recording, and able to communicate data to the bridge area for both ship use and satellite transmission. This means that the VOS climate observing system uses nearly the same components as a buoy climate observing system. It is expected that the prototype climate observing system currently being tested on VOS will be available from commercial sources as an operational system. This commercial system will provide the same data quality and data time resolution as modules used previously to establish a better understanding of climate processes. This system or its components can provide the same performance from buoys and smaller ships.



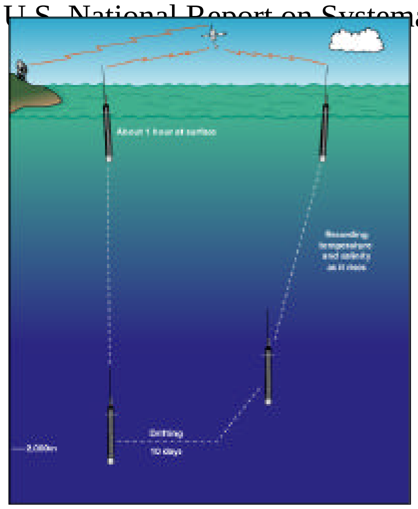
IMET on a Commercial Vessel

G. Floats

Deployment of the broad-scale global array of free-drifting, profiling floats, known as Argo, began in 2000. The planned array of 3,000 floats distributed over the oceans at 3-degree spacing will measure the temperature and salinity of the upper 2,000 m of the ocean, providing continuous monitoring of the state of the ocean. It is expected that global coverage will be initially achieved in 2004 and fully completed in 2005. The U.S. plans call for supporting one-third of the global array.

A Profiling Float

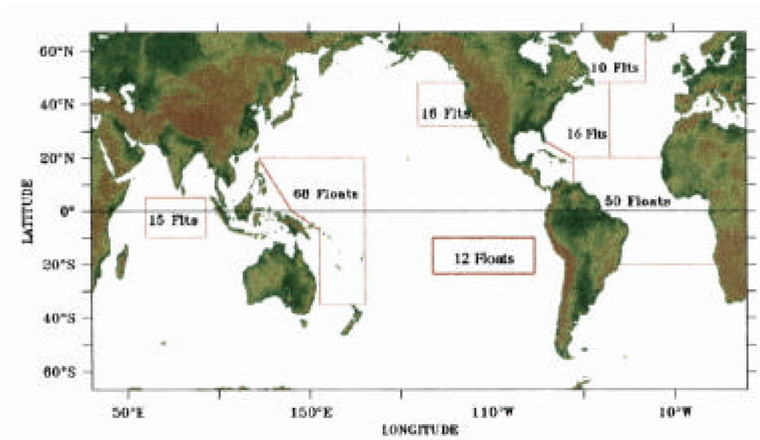
Floats are capable of cycling from the surface to 2,000 m and have an expected lifetime of 4 to 5 years. Present plans are for a 10-day duty cycle, providing some 100,000 profiles annually when the array is complete. Argo data will be publicly available in near real-time via the GTS, and in scientifically quality-controlled form with a few months



A Typical Operating Cycle for a Profiling Float

delay. Conceptually, Argo builds on the existing upper-ocean temperature observing networks, extending their spatial and temporal coverage, depth range and accuracy, and enhancing them through addition of salinity and velocity measurements. For the first time, the physical state of the upper ocean will be systematically measured and assimilated in near real-time.

Argo objectives fall into several categories. Argo will provide a quantitative description of the evolving state of the upper ocean and patterns of ocean climate variability. The data will enhance the value of the Jason altimeter through measurement of subsurface vertical structure (temperature and salinity) of the oceans. It will also measure velocity at the parking depth of the instruments, and provide sufficient coverage and resolution for interpretation of altimetric sea surface height variability. Argo data will be used to initialize ocean and coupled forecast models, data assimilation, and dynamical model testing. A primary focus of Argo is seasonal-to-decadal climate variability and predictability, but a wide range of applications for high-quality global ocean analyses is anticipated.



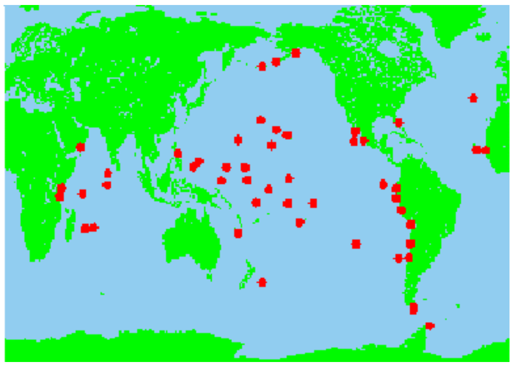
Planned U.S. Profiling Float Deployments in 2001 and Early 2002

The initial design of the Argo network is based on experience from the present upper ocean thermal observing system, on knowledge of variability gained from the TOPEX/Poseidon altimeter, and on estimated requirements for climate and high-resolution ocean models. The design emphasizes the need to integrate Argo within the overall framework of the global ocean observing system. The U.S. has funded the acquisition, deployment, and data management of 187 floats to be deployed in the 2001/2002 period as part of the sustained global array. All floats will have the same parking depth of 1000 meters. This is the deepest common level to date, and has the greatest likelihood for obtaining a common velocity field and accurate velocity information. The floats will have varying profiling depths between 1,000 and 2,000 meters depending on the location and float type. The present U.S. program will support the acquisition and deployment of approximately 150 to 160 floats annually and the operations of a global array of 600 floats. Plans call for increasing this deployment to around 270 floats annually and maintaining an array of 1,000 floats.

Tide Gauge Station

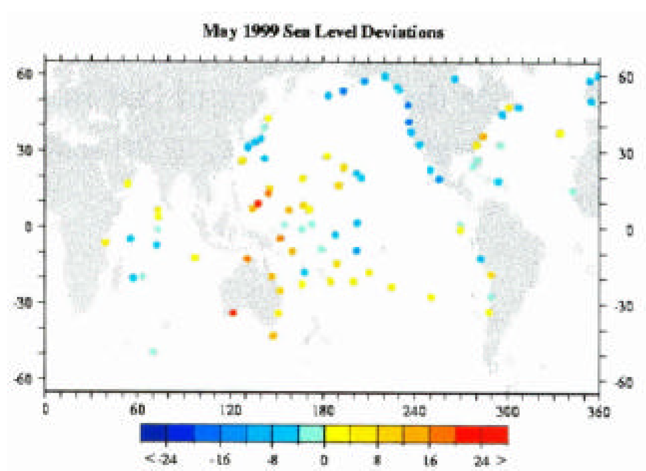
H. In-Situ Sea Level

Observations of in-situ sea level in the U.S. are centered at the University of Hawaii Sea Level Center (UHSLC), a research facility within the School of Ocean and Earth Science and Technology (SOEST), University of Hawaii. The UHSLC began in the 1970's as the Pacific Sea Level Network. In the mid-1980's the Tropical Ocean Global Atmosphere (TOGA) Sea Level Center (TSLC) and the IGOSS Sea Level Project in the Pacific were added and the network was expanded to the Indian Ocean. In the early 1990's the WOCE center was established. The program has three distinct activities: the Indo-Pacific Sea Level Network (IPSLN), the IGOSS (Integrated Global Ocean Services System) Sea Level Project in the Pacific (ISLP-Pac), and the UHSLC research databases. The principle mission of the UHSLC is to support climate research by collecting, processing, distributing, and analyzing in-situ tide gauge data from around the world. The program supports the JASON program in the development of in-situ tide gauge/GPS stations for monitoring the temporal drift of satellite altimeters. The UHSLC also hosts the Joint Archive for Sea Level (JASL), a collaborative effort with the National Oceanographic Data Center (NODC). The USHLC provides three on-line databases: the research quality data, the WOCE "fast delivery" data, and the ISLP-Pac map data.

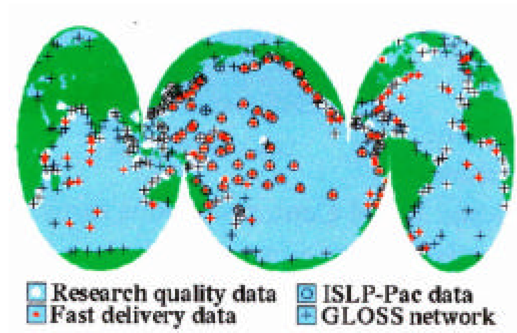


Indo-Pacific Sea Level Network

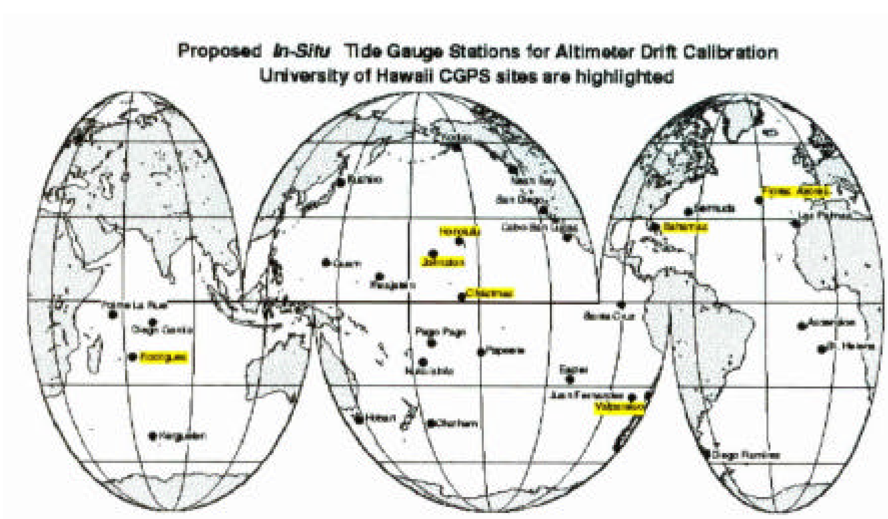
The IPSLN is an observational network of sea level gauges, most with satellite data telemetry, located throughout the tropical portions of the Indian and Pacific Oceans. It is presently the largest open ocean sea level network in the world that is operated by a single group. Its purpose is to create and maintain an effective sea level observing system in the tropical portions of the Indian and Pacific Oceans. Station selection has been guided by the needs of ephemeral programs, such as TOGA or WOCE, as well as the needs of the Global Sea-Level Observing System (GLOSS). Presently just over 300 sites have been designated as GLOSS sites; nearly all of the IPSLN stations fall into this category. The ISLP-Pac produces and distributes, within five weeks of the end of each month, maps of Pacific Ocean sea surface topography variations. This activity was an early, and very successful, example of operational oceanography. Products include monthly maps of Pacific sea level deviations from the long-term mean and maps of sea level anomalies from the long-term seasonal cycle corrected for atmospheric pressure anomalies. The ISLP-Pac also produces quarterly updates of an index of the tropical Pacific upper layer volume and annual updates of indices of the ridge-trough system and equatorial currents for the Pacific Ocean. As part of the ISLP-Pac, the UHSLC operates a Specialized Oceanographic Centre (SOC) that produces monthly sea surface topography maps and quarterly diagnostic time



series for the Pacific Ocean. The UHSLC presently distributes these products through the Internet and by mail to users, including several national agencies that reproduce them and further distribute them. These products are also submitted, along with a text description, to the IGOSS Products Bulletin. Approximately five weeks after the end of a month, hundreds of users throughout the world receive an analysis of the state of the Pacific Ocean sea surface topography for that month. All of the UHSLC data and products are available on the Internet (http://uhslc.soest.hawaii.edu/), and on CD-ROM.



The UHSLC databases are the result of work started by the TSLC and WOCE centers. The research quality database currently includes 330 sites with 3923 station-years of quality assured data. The "fast delivery" database currently includes 125 stations, 105 of which are located at GLOSS sites. Sea level data from a globally distributed set of stations is processed and made available to users within three months of data collection. All of these data are available on the Internet. For 82 “fast delivery” stations, the existing time series has been extended back to 1985 in order to link Geosat altimetric data with the present TOPEX/Poseidon data. The UHSLC and NODC collaborate to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level data from selected stations around the world. In the past year, the UHSLC increased its JASL holdings to 7477 station-years of hourly quality assured data. The JASL set now includes 4326 station years of data at 180 GLOSS sites. Of the 101 GLOSS stations presently operating on islands, data for 93 of them have been obtained by the UHSLC. Though the lag from collection to public dissemination is typically a few years, the August 1999 submission of the JASL data to the world Data Center-A for Oceanography included 146 series that contained data through the year 1998.



Recent work emphasizes the importance of the tide gauge network for satellite altimeter calibration. In support of satellite altimeter calibration and validation, the UHSLC is installing co-located GPS (CGPS) systems at various tide gauge stations. The co-location of GPS and tide gauge stations at select sites is progressing, with the sixth and seventh installed this year.

The National Water Level Observation Program is managed by NOAA’s Center for Oceanographic Products and Services Division (CO-OPS) (http://www.co-ops.nos.noaa.gov/). Its primary mission is to provide basic tidal datums to determine U.S. coastal marine boundaries and to support nautical chart work. It also provides support for NOAA's tsunami and storm surge warning programs, climate monitoring, coastal processes, and tectonic research. The program's operational component is the National Water Level Observation Network (NWLON). The NWLON consists of approximately 190 water level measurement stations distributed along U.S. coasts, in the Great Lakes and connecting channels, and in the U.S. territories and possessions. One hundred forty stations are considered "long-term control" and "primary" stations. These have been in operation at least 19 years, are still in continuous operation, and transmit data in near real-time, i.e., every three hours. In addition to these near real-time records, the program's online archives include historical data from secondary and tertiary stations, i.e., those with record lengths from 18 years to a few weeks.

National Water Level Observation Network Station Key West, Florida

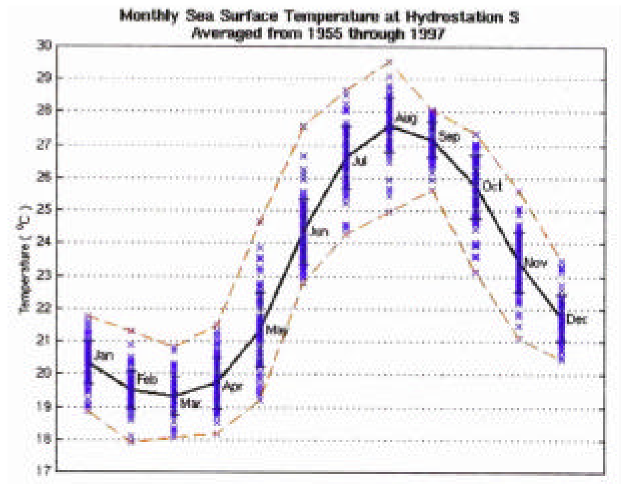
Using the NWLON, CO-OPS collects, processes, and analyzes the water level and ancillary data and produces standard time series and water level datum products. The benchmark information that controls the horizontal and vertical position of each tide station is also part of the program's on-line archives (http://www.co-ops.nos.noaa.gov/data_res.html). The program is currently upgrading its water level measurement equipment from mechanical and electromechanical to a fully integrated, state-of-the-art electronic data collection, processing, and dissemination system called the Next Generation Water Level Measurement System (NGWLMS). Most stations will consist of a primary data collection platform with a self- calibrating acoustic ranging sensor. Ancillary data, such as wind velocity, barometric pressure, air and water temperature, conductivity, and RH, can also be accommodated. Data are transmitted every three hours via GOES to CO-OPS computers for quality control, analysis, and dissemination. More that seventy five percent of the NWLON stations have been equipped with NGWLMS (http://www.co-ops.nos.noaa.gov/data_res.html).

I. Time Series

In 1988, JGOFS (Joint Global Ocean Flux Study) (http://www1.whoi.edu/jgofs.html) initiated two time-series measurement programs at Bermuda and Hawaii. The objectives of the time-series program are to provide well-sampled seasonal resolution of biogeochemical variability at a limited number of ocean observatories, provide support and background measurements for process-oriented research, as well as test and validate observations for biogeochemical models. The records now span a period greater than 10 years, with well over 100 successful cruises at each site and permanent moorings in place to assess ocean variability in the oligotrophic ocean.

1. Bermuda Atlantic Time Series

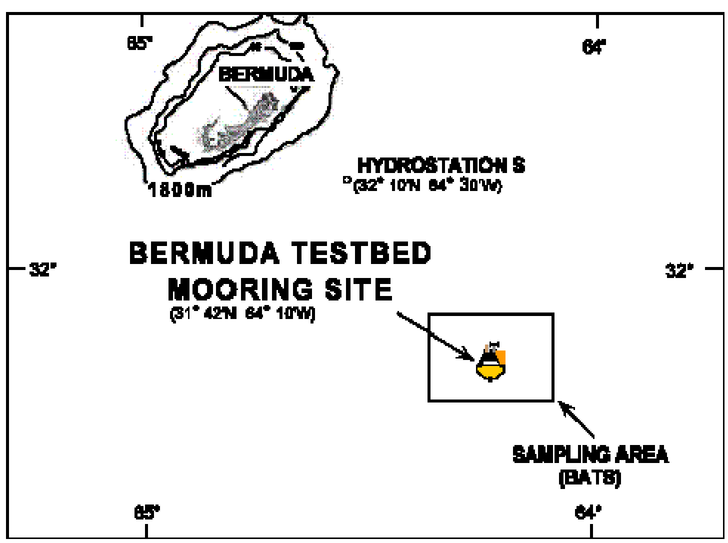
The Bermuda Atlantic Time Series (BATS) builds on a program begun in 1954 with the establishment of "Hydrostation S" by Henry Stommel. Hydrostation S is located 12 nautical miles southeast of Bermuda at 32º 10' N, 64º 30' W and has been occupied biweekly nearly continuously since 1954 (http://www.bbsr.edu/ cintoo/hydrostation_s/hydrostation_s.html). The data from Hydrostation "S" are primarily physical consisting of temperature, salinity, and dissolved oxygen measurements.



Bermuda Testbed Mooring

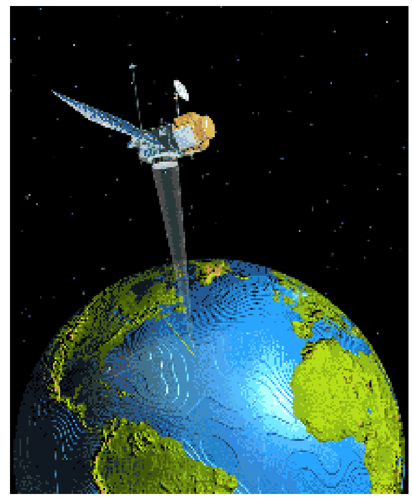
BATS (http://www.bbsr.edu/ cintoo/bats/bats.html) encompasses three major in-situ programs: Hydrostation S, the ocean flux project, and the Bermuda testbed mooring (BTM). The BATS station is located approximately 80 km SE of Bermuda (31E 50' N, 64E 10' W). In addition to major monthly cruises, cruises of shorter duration are conducted to document the yearly overturn and bloom period. Standard JGOFS core measurements (with the exception of zooplankton) are made by researchers at the Bermuda Biological Station. Cruise results are initially sent to the U.S. JGOFS office at Woods Hole; they are then forwarded to the U.S. NODC where they are available to the community as a whole. BATS was originally planned to last 10 years (until 1997) but now funds have been assigned to carry out activities indefinitely.

The BTM (http://www.opl.ucsb.edu/btm.html) has been deployed since June 1994 and provides the oceanographic community with a deep-water platform for developing, testing, calibration, and intercomparison of instruments that can obtain long-term data sets. Instruments are being used to collect meteorological and spectral radiometric measurements from a buoy tower. Subsurface measurements include: currents, temperature, conductivity, several inherent and apparent optical properties, pCO_2, ^{14}C primary productivity, nitrate, and trace element concentrations. Data have been sent to shore and to a nearby



ship using a new inductive-link telemetry system. The high temporal resolution, long-term data collected from the mooring provide important information concerning episodic and periodic processes ranging in scale from minutes to years. For example, short nitrate pulses or injections and associated biological events have been observed in the mooring data sets but cannot be resolved in the shipboard data set. Evaluation of undersampling and aliasing effects characteristic of infrequent sampling (i.e., monthly or often less frequently) are also enabled with these data sets. Ground truthing of satellite data is another important component of the program.

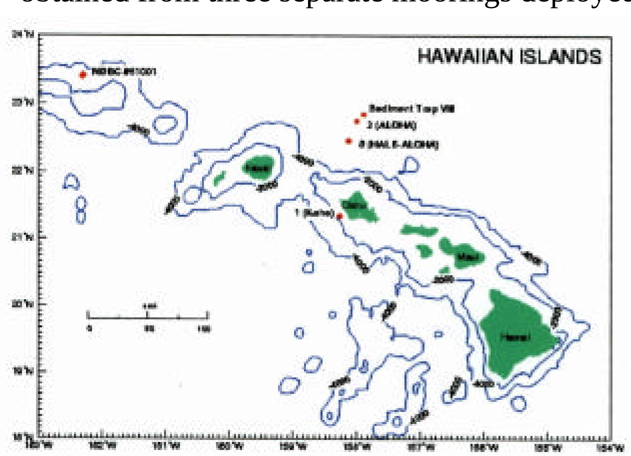
International efforts to develop global scale ocean and climate observation systems will be aided by coordination of and access to existing observational and modeling efforts. With this in mind, the Sargasso Sea Ocean Observatory (S_2O_2) is being formed to coordinate and enhance the contributions of the many marine biological, biogeochemical, hydrographic, and atmospheric studies conducted in time series mode in and above the western North Atlantic. The S_2O_2 comprises several ongoing ocean and atmospheric observation and modeling programs, which are in turn managed by several institutions. Primary objectives of S_2O_2 will be to maintain the vigor of the local time series programs and to provide a fluid and timely data stream to the international community of ocean and climate scientists (http://www.bbsr.edu/Labs/hanselllab/s2o2/s2o2mainpage.html).



TOPEX/Poseidon Satellite Over the Earth

2. HOT Series

The benchmark study site for the Hawaii Ocean Time (HOT) - series is station ALOHA (at 22E 45' N, 158E W) in the subtropical North Pacific gyre (http://hahana. soest.hawaii.edu/hot/hotjgofs.html). Core physical, chemical, and biological measurements are obtained on monthly intervals during research cruises of approximately four days' duration. Higher frequency measurements of dynamic height, particle flux, and a comprehensive suite of physical and chemical and bio-optical parameters are obtained from three separate moorings deployed near this site. Data collected as part of the HOT program are publicly available via the World Wide Web (WWW). The basic HOT measurement program will continue until at least mid-2001. In addition to the JGOFS observational program, the physical oceanographic measurements contribute to the objectives of the World Climate Research Programme (WCRP) Climate Variability and Predictability (CLIVAR) Programme by providing information on interannual to decadal variability of the North Pacific Ocean (http://www.soest.hawaii.edu/HOT_WOCE/).

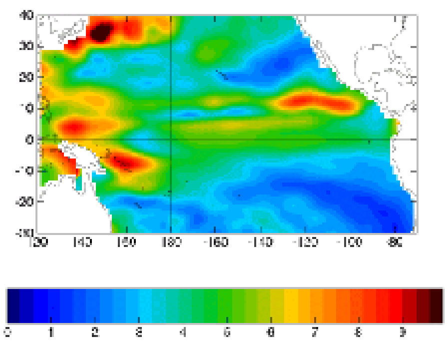


J. Remote Sensing Systems

Note: This is also covered in Section IV on Remote Sensing; it is included here given the unique nature of oceanographic remote sensing systems and their close relationship to oceanographic in-situ systems.

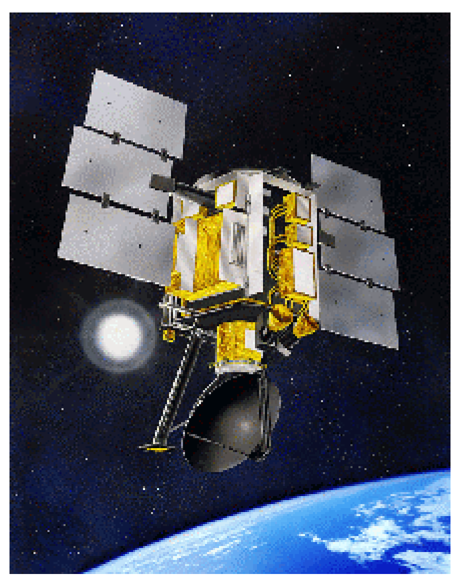
1. Altimetry

Launched into Earth orbit in August 1992, TOPEX/Poseidon is a partnership between the U.S and France to monitor global ocean circulation, discover the ties between the oceans and atmosphere, and improve global climate predictions. The TOPEX/Poseidon (http://topex-www.jpl.nasa.gov/discover/ discover.html) satellite measures global sea level with unparalleled accuracy. NASA provided the satellite bus and five instruments with their associated ground elements. NASA's Jet Propulsion Laboratory is responsible for project management and operates the satellite through NASA's Tracking and Data Relay Satellite System. The French Space Agency, Centre National d'Etudes Spatiales (CNES), furnished two instruments with their associated ground elements and a dedicated launch on a Ariane 42P rocket. Both CNES and NASA provide precision orbit determination and process and distribute data to 38 science investigators from nine nations, as well as other interested scientists.



TOPEX RMS Sea Level (cm) 1993-1996

From its orbit 1,336 kilometers above the Earth's surface, TOPEX/Poseidon measures sea level along the same path every 10 days using the dual frequency altimeter developed by NASA and the CNES single frequency solid-state altimeter. This information is used to relate changes in ocean currents with atmospheric and climate patterns. Measurements from NASA's microwave radiometer provide estimates of the total water-vapor content in the atmosphere, which is used to correct errors in the altimeter measurements. These combined measurements allow scientists to chart the height of the seas across ocean basins to an accuracy of less than 10 centimeters.

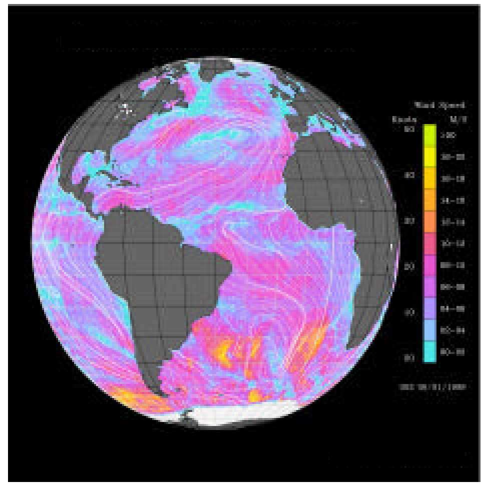


SeaWinds QuikSCAT Spacecraft

Three independent techniques determine the satellite altitude within 10 centimeters of accuracy. NASA's laser retro-reflector array is used with a network of 10 to 15-satellite laser ranging stations to provide the baseline tracking data for precision orbit determination and calibration of the radar altimeter bias. The DORIS system provides an alternate set of tracking data using microwave Doppler techniques. The system is composed of an on-board receiver and a network of 40 to 50 ground transmitting stations, providing all-weather, global tracking of the satellite. A GPS demonstration receiver provides precise, continuous tracking of the spacecraft. TOPEX/Poseidon's three-year prime mission ended in Fall, 1995 and is now in its extended observational phase. Its first follow-on mission, Jason-1, will continue this program of long-term observations of ocean circulation from space into the next century.

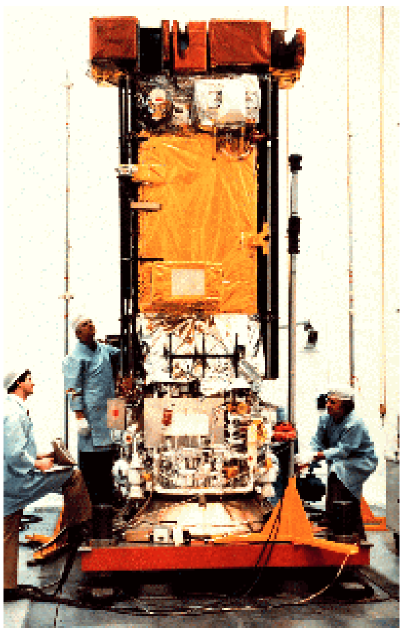
2. Sea Surface Winds

The sea winds instrument on QuikSCAT mission is a "quick recovery" mission to fill the gap created by the loss of data from the NASA scatterometer (NSCAT), when the satellite it was flying on lost power in June 1997. QuikSCAT was launched on June 19, 1999, in a south-southwesterly direction to achieve a sun-synchronous orbit, 803 kilometers, 98.6E inclination (http://winds.jpl.nasa.gov/missions/quikscat/quikindex.html). The designed mission life is 2 years (3 years for consumables).



Ocean Surface Winds by QuikSCAT, August 1, 1999

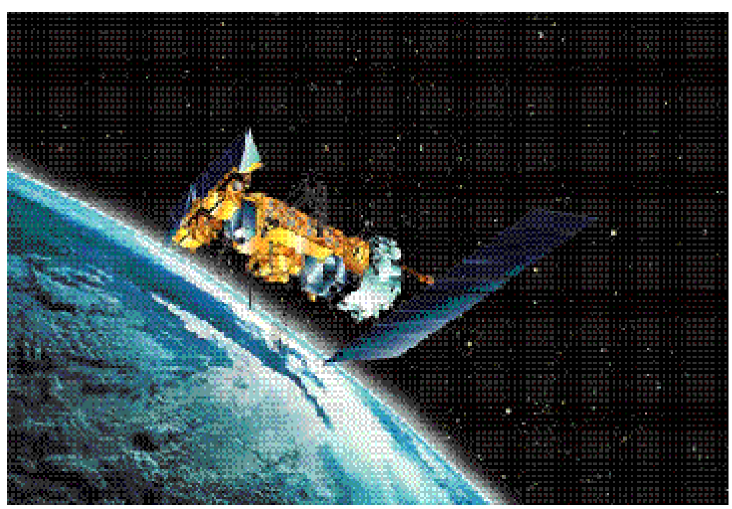
The sea winds instrument is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans. It uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions on Earth's surface. The instrument collects data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band, making approximately 400,000 measurements and covering 90% of Earth's surface every day. The instrument provides wind speed measurements between 3 to 20 meters/second, with an accuracy of 2 meters/second; and direction, with an accuracy of 20 degrees. Wind vector resolution is 25 kilometers. In addition to its mission to acquire all-weather, high-resolution measurements of near-surface winds over the global oceans, sea winds also provides information on daily/seasonal sea ice edge movement and Arctic/Antarctic ice pack changes.



Readying a TIROS-N for Launch

High-quality research data products produced at NASA's Jet Propulsion Laboratory are distributed to the science community within two weeks of receipt (http://podaac.jpl.nasa.gov). Operational data products produced by NOAA for the international meteorological community are distributed within three hours of data collection.

The NPOESS (see SST - NPOESS) will carry ocean wind instruments

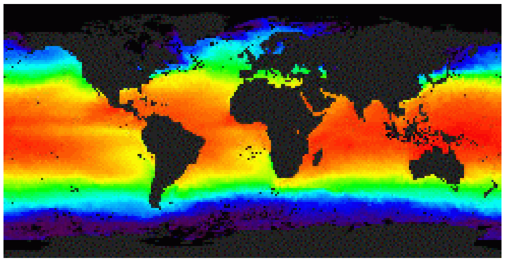


Polar Orbiting Satellite Over the Earth

beginning in 2010. Studies are presently underway to determine the configuration of the NPOESS wind sensing system (http://www.ipo.noaa.gov/ windsat.html). It is probable that other ocean wind instruments will be available between QuikSCAT and NPOESS.

3. Sea Surface Temperature

Initial efforts at mapping SST were conducted using data from NASA's Nimbus series of satellites. The world's first meteorological satellite, a polar-orbiting satellite named TIROS (Television Infrared Observations Satellite), was launched in 1960. Between 1960 and 1978, twenty-four polar orbiting meteorological satellites in the TIROS series were launched. The four-channel Advanced Very High Resolution Radiometer (AVHRR), flown on NOAA's TIROS-N (N representing the next generation of operational satellites) weather satellites beginning in1978 (NOAA-6) greatly increased the accuracy of SST measurements. The radiometer provides views in four different parts of the electromagnetic visible and infrared spectrum. Still greater increases in accuracy were achieved when a fifth channel was added to the AVHRR instrument flown on NOAA-7 in 1981 and on subsequent NOAA satellites. The fifth channel improved the measurement of SST by providing corrections for atmospheric water vapor that otherwise would have interfered with the temperature measurements.



Satellite Derived Sea Surface Temperature Distribution

In March 1983, the first of the Advanced TIROS-N (or ATN) satellites, designated as NOAA-8 was launched. These satellites are physically larger and have more power than their predecessors, and can accommodate more equipment. NOAA continues to operate the ATN series of satellites today with improved instruments (http://www.oso.noaa.gov/poes/index.htm). The current configuration includes NOAA-14, launched in December 1994; NOAA-15, launched in May 1998; and NOAA-16 launched in September 2000. NOAA-15 is the first in a series of five satellites with improved imaging and sounding capabilities that will operate over the next decade. This series is NOAA-K (15), NOAA-L (16), NOAA-M, NOAA-N, and NOAA-N'. The latest AVHRR (AVHRR/3) instrument, a six-channel instrument, is carried on NOAA-16.

4. National Polar orbiting Operational Environmental Satellite System (NPOESS)

In May 1994, the U.S. decided to merge the nation's military and civil operational meteorological satellite systems into a single, national system capable of satisfying both civil and national security requirements for space-based remotely sensed environmental data. The joint program formed is the NPOESS (http://www. ipo.noaa.gov/). NPOESS is a convergence of the nation’s two operational weather satellite systems - NOAA's Polar-orbiting Operational Environmental Satellite (POES) (http://poes2.gsfc.nasa.gov/), and the DoD’s Defense Meteorological Satellite Program (DMSP). In October 1994, NOAA, DoD, and NASA created an Integrated Program Office (IPO) that will develop, manage, acquire, and operate the NPOESS system. The IPO concept provides each of the participating agencies with lead responsibility for one of three primary functional areas. NOAA has overall responsibility for the converged system and is responsible for satellite operations. NOAA is also the primary interface with the international and civil user communities. The DoD is responsible to support the IPO for major systems acquisitions, including launch support, while NASA has the primary responsibility for facilitating the development and incorporation of new cost-effective technologies into the converged system. The first converged NPOESS satellite is expected to be available for launch in the latter half of the decade, approximately 2008, depending on when the remaining POES and DMSP program satellite assets are exhausted. Present plans call for the program to run until 2018.

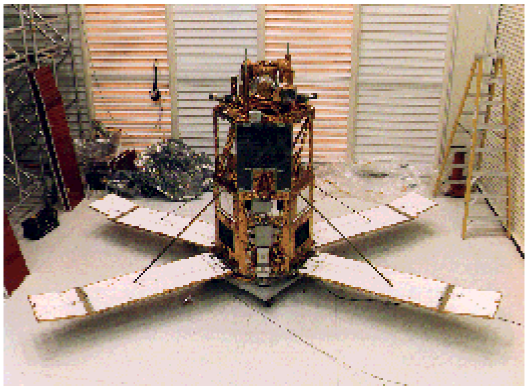
The Visible/Infrared Imager Radiometer Suite (VIIRS) on NPOESS (http://npoesslib.ipo.noaa.gov/S_viirs.htm) will collect visible/infrared imagery and radiometric data, including sea surface temperature and ocean color. The VIIRS combines the radiometric accuracy of the AVHRR currently flown on the NOAA polar orbiters with the high spatial resolution (0.65 kilometer) of the operational line-scan system (OLS) flown on DMSP. The VIIRS thus provides the capabilities to produce higher resolution and more accurate measurements of sea surface temperature than currently available from the AVHRR instrument on POES, as well as an operational capability for ocean color observations and a variety of derived ocean color products.

5. Ocean Color

For most regions of the world, the color of the ocean is determined primarily by the abundance of phytoplankton and their associated photosynthetic pigments. As the concentration of phytoplankton pigments increases, ocean color shifts from blue to green. Taking advantage of this change, NASA developed the Coastal Zone Color Scanner (CZCS) that was launched on the Nimbus-7 satellite in October 1978. During its 7 1/2 year lifetime (October 1978 - June 1986), CZCS acquired nearly 68,000 images, each covering up to 2 million square kilometers of ocean surface (http://daac.gsfc.nasa.gov/DATASETDOCS/czcsdataset.html).

The CZCS was a multi-spectral line scanner devoted principally to measurements of ocean color. It had six spectral bands (channels). Four channels were devoted to ocean color, each having a 20 nanometer band width centered at 443, 520, 550, and 670 nanometers. These are referred to as channels 1 through 4, respectively. Channel 5 sensed reflected solar radiance and had a 100-nanometer bandwidth centered at 750 nanometers and a dynamic range more suited to land. Channel 6 operated in the 10.5 to 12.5 micrometer region and sensed emitted thermal radiance for derivation of equivalent black body temperature. The CZCS level 1, 2, and 3 data products are available from the Goddard Space Flight Center Distributed Active Archive Center (DAAC).

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (http://seawifs.gsfc.nasa.gov/SEAWIFS.html) is a follow-on sensor to the CZCS to study ocean productivity and interactions between the ocean ecosystems and the atmosphere. The SeaStar satellite carrying the SeaWiFS was placed in an initial parking orbit of 278 kilometers using an aircraft/rocket launch procedure. Once the systems were tested, the satellite's orbit was slowly raised through a series of very short rocket firings over a 30-day period until it reached its operational altitude of 705 kilometers. On September 4, 1997, the SeaWiFS instrument was turned on.



SeaStar Satellite Carrying SeaWiFS

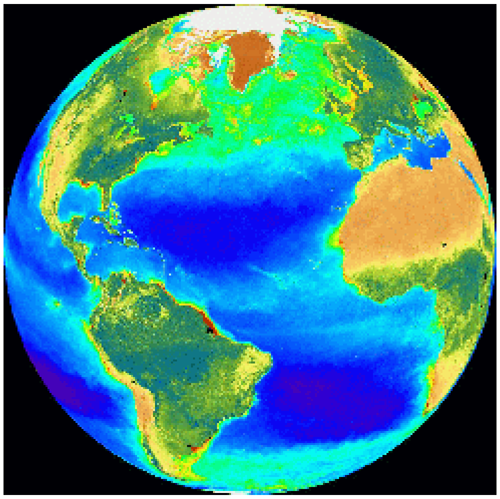


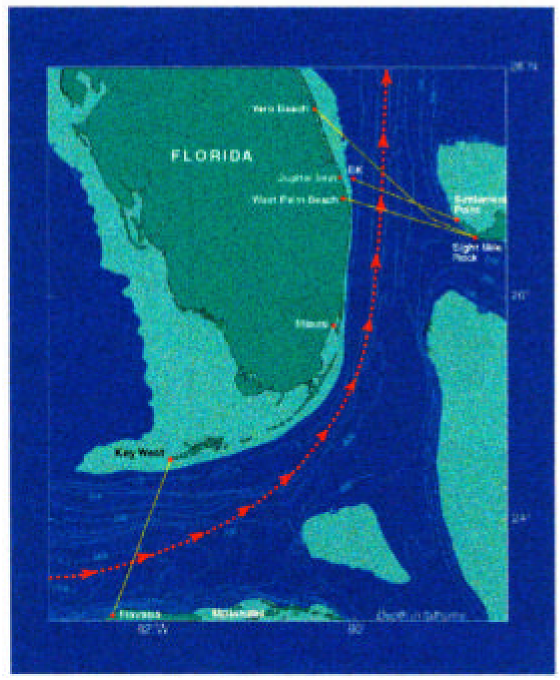
Image of the Global Biosphere (September 97 - August 98) Atlantic Projection

The purposes of SeaWiFS data are to examine oceanic factors that affect global change and to assess the oceans' role in the global carbon cycle, as well as other biogeochemical cycles, through a comprehensive research program. Coupled ocean-atmosphere models indicate that changes in phytoplankton community structure and the resulting elemental interactions can drastically affect the rate of CO_2 increase in the atmosphere. Moreover, ocean biogeochemistry and circulation interact over a large range of temporal and spatial scales. This coupling between large and small scales leads to the fundamental sampling requirement of global scale, long time series (decades) at moderate temporal and spatial scales (days and kilometers). The NPOESS will continue to monitor ocean color globally.

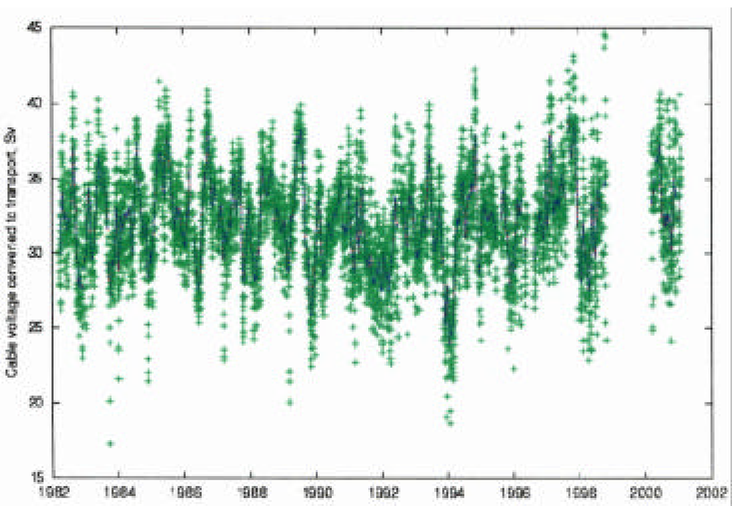
K. Miscellaneous

1. Current Transport from Voltage Measurements

The motion of an ocean current through the earth's magnetic field creates a cross-stream voltage proportional to the transport of a mass of water. The data are used in models of the ocean circulation to evaluate numerical models being developed for climate studies. Such voltage measurements are being made in several other locations by a number of different researchers in the Pacific and Atlantic Oceans, and are in the planning stages for other cables. Motion-induced voltages were used to monitor the flow of the Florida current from 1982 to 1991 by the use of an out-of-service cable spanning the Florida Current at 27E N between Jupiter Inlet, Florida, and Settlement Point, Grand Bahama Island. Voltage measurements between West Palm Beach, Florida, and Eight Mile Rock, Grand Bahama Island, observed since 1985 (except for a brief period in 1999-2000) using an in-service cable, are now being used to continue



Undersea Cables Used to Monitor the Flow of the Florida Current



Daily (Green) and Mean (Blue) Transport of the Florida Current

these measurements of the Florida current transport. The voltage-derived transports are compared with transport derived from profiling at 27E N that provides the calibration factor to convert voltage to transport (http://www.pmel.noaa.gov/wbcurrents/cabletransport.html).

A CREWS Platform

2. Coral Reef Observations

Coral reefs are in serious decline globally, especially those near shallow shelves and dense populations. It has been estimated that 10 percent of the earth's coral reefs have already been seriously degraded and a much greater percentage is threatened. If allowed to continue, this decline is likely to lead to the loss of most of the world's reef resources during the next century. NOAA's Coral Health and Monitoring Program (CHAMP) provides facilities for researchers and laypersons to witness, act upon and learn about threats to the health of all coral reefs. The Global Coral Reef Monitoring Network (GCRMN) has been established to address these problems. Its major product will be the facilitation of networks of people trained to look closely at coral reefs and to monitor their progress over time.

The U.S. is developing a Coral Reef Early Warning System (CREWS) as part of the GCRMN. CREW is a combination of observing systems for near real-time monitoring of oceanographic and atmospheric conditions and software/ communications to acquire and transmit the data in near real-time for processing and dissemination. CREWS interfaces with existing systems such as NWS' C-MAN stations and augments those systems when necessary. The CREWS atmospheric observations are barometric pressure, wind speed and direction, wind gust, and air temperature. Oceanographic observations are photosynthetically active radiation, temperature, salinity, fluorometry, transmissometry, and tides. New instrumentation under development includes UV-B radiation, pCO_2, and nutrients. In addition to six sites in the Florida Keys, a new site is being implemented at Lee Stocking Island in the Bahama Islands. Sites are proposed for St. John's in the U.S. Virgin Islands, Puerto Rico, and American Samoa.

Lee Stocking Island, Bahamas

3. Trans-Pacific Profiler Network

The development of a set of baseline climate observations, calibrations, and model initialization and validation has been severely hampered by the lack of baseline atmospheric observations over the oceans. There is a serious lack of information on the distribution of key surface parameters, such as rainfall, as well as upper air parameters. The Trans-Pacific Profiler Network (http://www.al.noaa.gov/WWWHD/pubdocs/ElNino.html) comprises vertically directed Doppler radars, called wind profilers, located on six remote island sites spanning the tropical Pacific Ocean. The instruments use "clear air" atmospheric echoes to measure a "profile" of both horizontal winds and vertical motions, at heights from the surface to 5-15 kilometers (depending on the frequency of the instrument). In addition to the wind profile, information about precipitation and atmospheric turbulence is obtained.

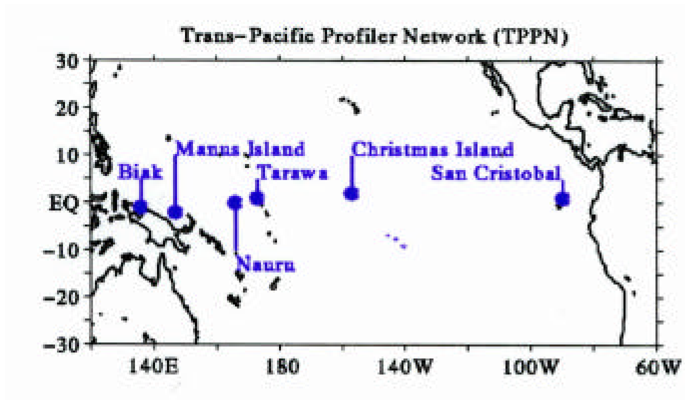


Table S7. National Climate Monitoring Systems for Oceanographic Observations.

Network Component	Total # Stations	Appropriate for Characterizing National/Regional Climate?			Time Series #stations/platforms (#Data Digitized)			Are QC Procedures Adequate?			Metadata available? Total # Stations (%Digitized)	Continuity # expected operational in 2005
		Fully	Partly	No	30y	50y	100y	Fully	Partly	No		
Sea Level e.g., Tide gauges	244	X						X				244
SST (e.g., Moored Buoys, Drifting Buoys)	~642		X					X				~640
Meteorological Obs (e.g., Temp, Precip, Pressure)	1,478		X						X			~1,478
Sub-Surface Profiles (e.g., moorings, floats, stations, as of 2001)	260	X						X				~1,000
Ocean Circulation												
Carbon Fluxes (e.g., ships and moorings) Continuous Shipboard Observations (# of legs of cruises)	114	X						X				Not Applicable
Energy Fluxes	1		X					X				0

Table S8. Available Homogeneous Data Sets for Oceanographic Observations.

Integrated Data Sets Name and Brief Description	Variable	Platforms and/or grid resolution	Describe Period	References
WORLD OCEAN ATLAS 1998 FIGURES	*Temperature, salinity, oxygen, nutrients, and chlorophyll.*			http://www.nodc.noaa.gov/OC5/WOA98F/open_1st.html
WOCE Global Data Version 2.0 2000		*Summaries* *Acoustic Doppler Current Profilers* *Bathymetry* *Current Meters* *Drifting Buoys* *Floats* *Hydrography* *Satellite Observations* *Sea Level* *Surface Meteorology* *Upper Ocean Thermal Data*	*1990-1998*	http://www.cms.udel.edu/woce/
World Ocean Database 1998	*Expands on World Ocean Atlas 1994 (WOA94) by including the additional variables nitrite, pH, alkalinity, chlorophyll, and plankton, as well as all available metadata and meteorology.*			http://www.nodc.noaa.gov/OC5/pr_wodv2.html
World Ocean Atlas 1994	*In-situ temperature, salinity, oxygen, phosphate, nitrate, and silicate.*	*The series contains the objectively analyzed one-degree latitude-longitude mean fields for each of the measured parameters, and two derived parameters (Apparent Oxygen Utilization and Oxygen Saturation), and five-degree square statistics of standard level values.*		http://www.nodc.noaa.gov/OC5/woadet.html
Oceanographic Station Profile Time Series	*Temperature, salinity, density, and nutrients.*	*27 North Pacific sections; 56 North Atlantic sections; sections along coastal California from the California Cooperative Fisheries Investigations (CALCOFI); 19 sections from other ocean regions; and data from the 10 Ocean Weather Stations.*		http://www.nodc.noaa.gov/General/CDR-detdesc/time-series.html

Integrated Data Sets Name and Brief Description	Variable	Platforms and/or grid resolution	Describe Period	References
Global Ocean Temperature and Salinity Profiles	*Temperature, salinity.*	*Two CD-ROMs contains global ocean temperature and salinity profiles derived from six major NODC archive files:* *(1) Oceanographic Station Data,* *(2) CTD/STD Data,* *(3) Expendable Bathythermograph Data,* *(4) Mechanical Bathythermograph Data,* *(5) Radio Message Bathythermograph Data, and* *(6) Selected Level Bathythermograph Data.* *1.62 million profiles from the Atlantic and Indian Oceans; 1.57 million profiles from the Pacific Ocean*	*1900-1990*	http://www.nodc.noaa.gov/General/CDR-detdesc/gots_cds.html
Atlas of Surface Marine Data 1994	*Wind, air and sea surface temperature, sea level pressure, humidity, and present weather.*	*Voluntary Observing Fleet. Observations included in this historical collection have also been taken by various military ships, ocean weather ships, light ships, research vessels, buoys, and bathythermographs.*	*1945-1989*	http://www.nodc.noaa.gov/OC5/asmdesm.html
Geosat Global Wind/Wave Data		*Global wind/wave data derived from altimeter data*	*March 31, 1985 through September 30, 1986*	http://www.nodc.noaa.gov/General/CDR-detdesc/geosatww.html
Ocean Current Drifter Data		*Ship and Subsurface Float*	*1972-1992*	http://www.nodc.noaa.gov/General/CDR-detdesc/ocurdesc.html
Sea Level Data				http://www.nodc.noaa.gov/General/CDR-detdesc/sealevel_cd.html
Comprehensive Ocean-Atmosphere Data Set (COADS)	*Sea surface temperature, wind, cloudiness, air temperature, sea level pressure, relative humidity*	*Individual observations (surface marine reports from ships, buoys, etc.) monthly summary statistics for 2° latitude x 2° longitude boxes (and for 1°x1° boxes since 1960)*	*1784-1997*	http://www.cdc.noaa.gov/coads/products.html

Integrated Data Sets Name and Brief Description	Variable	Platforms and/or grid resolution	Describe Period	References
Carbon Dioxide Information Analysis Center (CDIAC)	*CO_2-related parameters (TCO_2, pCO_2, alkalinity, and pH), salinity, and the concentrations of dissolved oxygen and macro-nutrients along constant seawater density surfaces.*	*An effort to measure the global spatial and temporal distributions of $T(CO_2)$ and other related parameters. Goals of the survey are to estimate the meridional transport of inorganic carbon in a manner analogous to the oceanic heat transport, and to build a data base suitable for carbon cycle modeling and the estimation of anthropogenic CO_2 increase in the oceans. The CO_2 survey is taking advantage of the sampling opportunities provided by the WOCE Hydrographic Program and JGOFS cruises.*	*1990-1998*	http://cdiac.esd.ornl.gov/oceans/home.html
Ocean Atmosphere Carbon Exchange Study	*Partial pressure of CO_2 in the surface ocean and overlying atmosphere, and total dissolved inorganic CO_2 (DIC) in the surface and deep ocean water masses.*	*Investigations of processes controlling air-sea exchange of carbon dioxide, as well as the rate and direction of that exchange throughout the major basins of the world oceans. Core components of this effort are (1) process studies conducted cooperatively with JGOFS pilot studies, (2) "long lines" occupied on approximately five year intervals along WOCE lines, and (3) continuous underway sampling from research vessels.*	*1986-Present*	http://ingrid.ldgo.columbia.edu/SOURCES/.LDEO/.Takahashi http://www.aoml.noaa.gov/ocd/oaces/co2/ http://www.pmel.noaa.gov/co2/co2-home.html
Joint Archive for Sea Level	*Hourly sea level heights*	*JASL prepares scientifically valid data sets of hourly, daily, and monthly values which are submitted annually to international data banks and are made readily available in a more timely fashion through the Internet.. As of November 2000, 474 series with 8216 series-years of quality-assured data. The objective is to assemble a scientifically valid, well-documented archive of hourly, daily, and monthly sea level values in standardized formats.*	*Generally 1970-Present with a few sites going back to 1930.*	http://ilikai.soest.hawaii.edu/UHSLC/jasldr00/manual.html

III. Terrestrial Observations

A. Status of the National Terrestrial Portion of the GCOS Program

The requirements for terrestrial climate observations were developed jointly between GCOS and the Global Terrestrial Observing System (GTOS) through the Terrestrial Observations Panel for Climate (TOPC); reference GCOS publication 32. As with atmospheric and oceanographic observations, terrestrial observing is also highly dependent on the importance of satellite observations, and again, while this section focuses on *in-situ* observing systems, a full picture of satellite observing can be found in section IV of this report.

1. U.S. Component of the Global Terrestrial Network for Permafrost

The GCOS and the GTOS have identified the permafrost thermal state and the permafrost active layer as key variables for monitoring the state of the cyrosphere. Changes in permafrost temperature and active layer thickness frequently reflect changes in surface climate over time, and therefore serve as useful indicators of climate change. The GCOS steering committee recently (February 1999) approved the development of a globally comprehensive permafrost monitoring network to detect temporal changes in the solid earth component of the cryosphere. As such, the Global Terrestrial Network for Permafrost (GTN-P) is quite new and still very much in the developmental stage. The International Permafrost Association (IPA) has taken the responsibility for managing and implementing the GTN-P (see http://www.geodata.soton.ac.uk/ipa).

The GTN-P network has two primary observational components: the active layer (i.e. the surface layer that freezes and thaws annually) and the thermal state of the underlying permafrost. Despite its youth, parts of the GTN-P are already in place through nationally and regionally funded programs. The active layer is monitored by a network of stations (Circumpolar Active Layer Monitoring network, CALM) involving 12 countries. These stations provide an important component of the GTN-P. In addition, borehole temperature measurements used to characterize the thermal state of permafrost, have been made for years under various national and regional programs. The GTN-P serves to organize this work into an international monitoring effort.

In the U.S., the GTN-P network is funded primarily by the NSF and the Department of the Interior (DOI). This is accomplished through grants to various universities. The DOI contribution results from a collaboration between the USGS, the BLM, and the FWS (the USGS is the lead agency). The U.S. Forest Service also has two sites. All of the U.S. GTN-P stations are located in Alaska.

Active layer thickness is currently being monitored at 27 sites in Alaska. Many of these instrumented sites also monitor soil temperature (at several depths), soil moisture, snow depth, and air temperature. Sixteen of the active layer sites are co-located with boreholes where the permafrost thermal state can be monitored. All sites are appropriate for characterizing national climate. The first of the GTN-P active layer monitoring stations were installed in 1991. Station data are provided annually to the University of Cincinnati, where active layer data management for the Northern Hemisphere occurs. Summary data are then made available via the Internet (http://www.geography.uc.edu/CALM).

Forty-eight boreholes exist in Alaska where permafrost thermal state can be determined. Of these, 4 are classified as *Surface* (0-10 m) sites, 1 is *Shallow* (10-25 m), 22 are *Intermediate Depth* (25-125 m), and 21 are *Deep Boreholes* (>125 m). The frequency of measurement varies greatly according to the total depth of the boreholes. The Geological Survey of Canada is providing the international data management for the GTN-P borehole temperature monitoring (permafrost thermal state) program and maintains the GTN-P web site (http://sts.gsc.nrcan.gc.ca/gtnp/index.html). GTN-P data, both active layer and permafrost thermal state, will subsequently be archived at the National Snow and Ice Data Center (Boulder, CO) as part of IPA's Global Geocryological Database.

One issue concerning the U.S. contribution to the GTN-P network is that all funding currently comes from short-term (3-5 yr) research projects. All sites require logistical support and funding for equipment maintenance and upgrades if they are to continue to operate. More substantial, long-term commitments are needed if the GTN-P is to be a viable long-term monitoring network. While the current network should be expanded to include the sub-arctic and high elevation sites in the contiguous U.S. (where changes are expected to happen more quickly), and to identifying sites in the Antarctic, the current federal budget plan for fiscal year 2002 does not accommodate that expansion.

2. U.S. Component of the Global Terrestrial Network for Glaciers (GTN-G)

The USGS operates a long-term "benchmark" glacier program to intensively monitor climate, glacier motion, glacier mass balance, glacier geometry, and stream runoff at a few select sites. The data collected are used to understand glacier-related hydrologic processes and improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change.

The approach has been to establish long-term mass balance monitoring programs at three widely spaced glacier basins in the U.S. that clearly sample different climate-glacier-runoff regimes. The three glacier basins are South Cascade Glacier in Washington State, and Gulkana and Wolverine Glaciers in Alaska. Mass balance data are available beginning in 1959 for the South Cascade Glacier, and beginning in 1966 for the Gulkana and Wolverine Glaciers. Additional information and data for the benchmark glaciers is available at http://ak.water.usgs.gov/glaciology/.

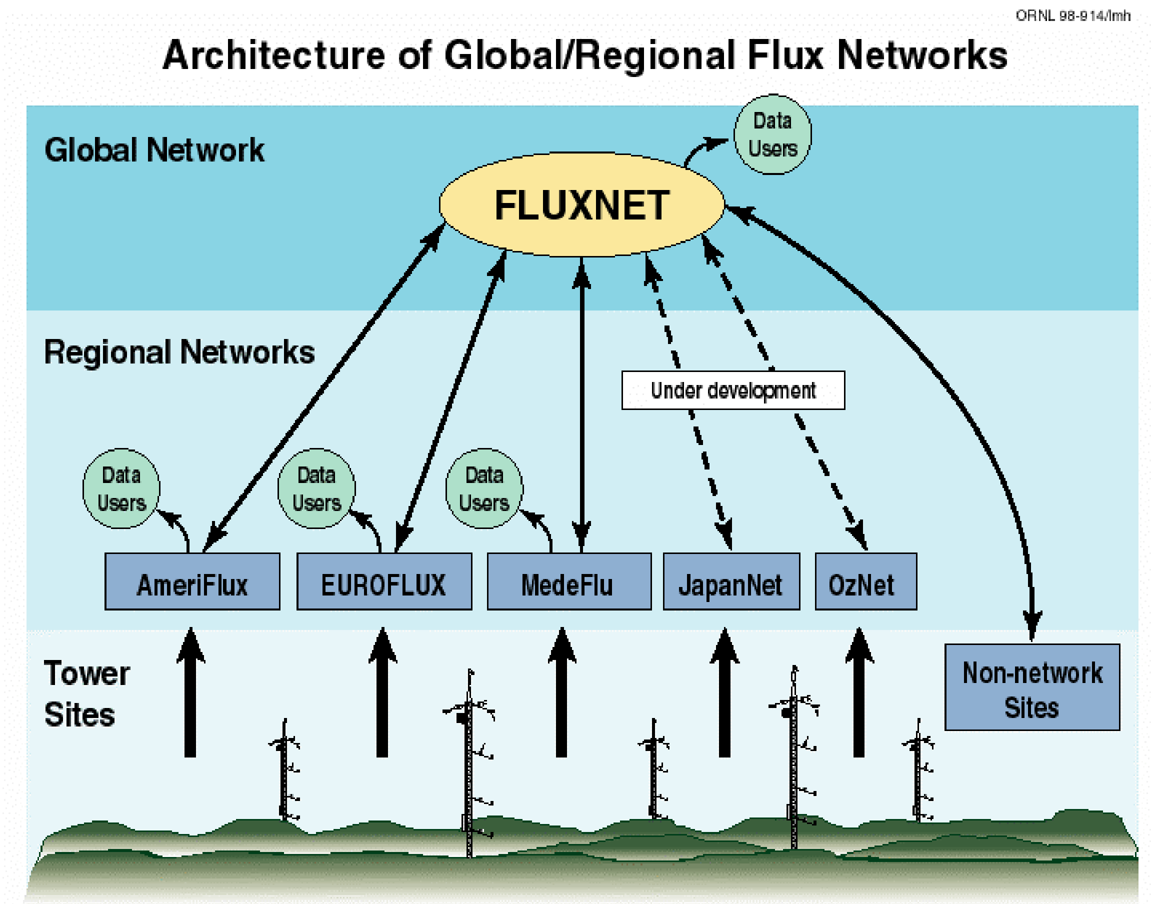
3. U.S. Component of the Global Terrestrial Network for Carbon (FLUXNET - AmeriFlux)

The U.S. DOE's Global Terrestrial Network for Carbon (FLUXNET - AmeriFlux) network (http://cdiac.esd.ornl.gov/programs/ameriflux/) generally endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of CO_2, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global CO_2 budget, enable improved predictions of future concentrations of atmospheric CO_2, and enhance the understanding of carbon fluxes, Net Ecosystem Production (NEP), and carbon sequestration in the terrestrial biosphere. Other major sponsors of the Ameriflux network include NOAA, USFS, NASA, NSF, DOD, and USGS.

The AmeriFlux data archive at the Carbon Dioxide Information Analysis Center (CDIAC) offers two types of AmeriFlux data. Preliminary data are contributed by AmeriFlux principal investigators (PI). The file formats and contents are unchanged from their original submission state. Any descriptive files provided are those furnished by the site PIs. The values provided in these preliminary files have been scrutinized by the PIs but are subject to change. Users are required to communicate with the contributing PIs before performing data analyses and are reminded that data used for publication are subject to AmeriFlux FAIR USE rules.

Preliminary AmeriFlux data sent to CDIAC are checked, processed into a consistent data format, and documented by CDIAC before release as a final data set. Again, users are required to interact with the contributing PIs before publishing any results based on final AmeriFlux data and reminded that data used for publication are subject to AmeriFlux Fair Use rules. This includes informing the appropriate Principal Investigator of how site data is being used and of any associated publication plans.

The AmeriFlux network is included in and coordinated with the worldwide FLUXNET CO_2 flux measurements.



4. Streamflow and Surface Water Gaging

The USGS operates a network of about 6,760 streamgaging stations at which continuous records of water level (stage) and streamflow (discharge) are obtained. The USGS compiles, analyzes, and publishes data for these stations annually. In addition, the USGS publishes furnished data for about 630 streamgaging stations operated by other Federal, state, and local agencies. These 7,400 stations have a mean record length of 39 years, with a maximum record length of 126 years. Historical streamflow data for all of the streamgaging stations and real-time data for about 5,350 stations that are equipped with telemetry can be retrieved from the Internet at http://water.usgs.gov/nwis.

Most of the streamgaging stations in the USGS network are not useful for analyzing changes in climate because the stations are affected by human influences, such as diversions, dam regulations, and urban land uses. A group of 1,659 stations, named the Hydro-Climatic Data Network (HCDN), was identified and data was compiled for the stations for use in studies of climate change. The HCDN stations are described and data for them can be obtained from the WWW at http://wwwrvares.er.usgs.gov/hcdn_cdrom/1st_page.html. Periods of data collection spanned 44 years on average for the HCDN stations in 1988, when the data were compiled. Data began as early as 1874. Since 1988, however, 444 of the original 1,659 HCDN stations have ceased operating, primarily because of lack of funding.

Concern about losses to its streamgaging network has prompted the USGS and its partners to develop the National Streamflow Information Program (NSIP). Information on NSIP can be obtained at http://water.usgs.gov/nsip/. The NSIP plan would increase the level of streamflow information available for National needs, improve the way streamgaging stations are funded and located, and develop new ways to collect, store, and distribute streamflow information. Those streamgaging stations providing data that meet Federal needs, such as analyses of climate change, would be funded entirely through Federal appropriations under the NSIP plan rather than funded in cooperation with other agencies, as is the current practice. During the previous two fiscal years, the USGS has received increased appropriations that were used to begin implementing the NSIP.

The USCOE uses data from 8,810 gaging stations that produce about 150,000 pieces of data daily. This represents the bulk of surface water data collected and/or used by DOD within the USA. About 85 percent of the data are recorded hourly and telemetered in real-time. Each station measures from one to twelve parameters. A site commonly measures precipitation, temperature, and stream water levels, but may include evaporation, wind speed, barometric pressure and water quality parameters.

Unlike most agencies, the primary purpose of USCOE gages is tied to its civil works mission of planning, constructing, and operating water projects. In addition to projects owned by the USCOE, during floods the USCOE takes control all federal flood control storage regardless of project ownership. Also, it performs emergency activities wherever needed. USCOE responsibilities include about 600 USCOE dams, reservoirs, pump stations and local protection projects, 108 non-USCOE flood control reservoirs, and 8,500 miles of federal levees and channel diversions or modifications. Emergency activities include flood fighting and technical assistance, providing materials, and temporary construction. Because the gaging stations are related to projects, their locations are not evenly distributed, but grouped by river basins to meet project data needs.

Significant flood damage reduction benefits are derived from the project regulation via data from the gauging system. Over the past ten years (1991-2000) the USCOE prevented an average of $20.8 billion in damages annually. In addition, with flood reduction projects in operation the number of flood-related lives lost has dramatically fallen. The year 1980 marked the completion of most large flood reduction projects. Despite major flooding in 1983, 1986, 1993 and 1997, the ten-year average of flood-related fatalities has dropped from 176 deaths in 1981 to 89 in 2000. Although flood reduction projects are not the only factor impacting this statistic, they significantly contribute to the reduction. The benefits of flood control projects regulated by the gaging system are available at http://www.usace.army.mil/inet/functions/.

All USCOE data is available for climate change analysis. Even though streamgaging data are affected by river regulation, coefficient data from historic records and the USCOE river model can reconstruct natural river flows. USCOE computer models also use the data to forecast future river and streamflow levels. Regulators use forecasts to fine-tune discharge amounts from dams to optimize flood reduction and to improve environmental conditions. Data and forecasts are archived and shared with multiple agencies. NOAA/NWS uses 100 percent of SCOE data in its models. The USGS archives much of the streamflow data. Other federal, state and local agencies mutually share their data with the USCOE.

5. Hydromet System

The Bureau of Reclamation’s (BR) Hydromet system is a data collection and distribution system that supports the BR's mission of water resource management. Hydromet data collection supports reservoir and water project operations, water management, and water supply forecasting for BR's multipurpose reservoir systems in a number of basins including the Columbia and Snake River basins. Water uses supported by the Hydromet system include flood control, irrigation, power generation, water quality, water conservation, fish and wildlife management, research, and recreation. The Hydromet database provides an excellent source of information for water management planning activities.

Hydromet consists of approximately 400 unstaffed data collection platforms located at dams, streams and mountain areas in the Pacific Northwest and Great Plains. The system also collects data from approximately 1100 similar stations maintained by other organizations. These stations typically collect data in 15- or 60-minute increments, and then transmit collected data every 4 hours via the GOES satellite network. Data indicating abnormal conditions can be transmitted more frequently on special satellite channels. Data are received at a central downlink site in Boise, Idaho, as well as at NASA’s facility in Wallops Island, Virginia.

Other sources of Hydromet data include radio-controlled stations that can be interrogated at any time and instrument readings manually entered into the computer system. The relatively short-range radio-controlled sites are commonly found near large water projects where bi-directional control systems or time-critical data are important. Data from the radio sites are transmitted to the central Boise site via the Internet.

Data collection platforms carry a variety of environmental sensors that monitor conditions such as water level, gate position, temperature, precipitation, water and barometric pressure, dissolved gas content, solar radiation, evaporation, wind speed and direction. Many data collection platforms are a result of cooperative agreements between the Bureau of Reclamation and other organizations. Hydromet station information and data are available at: http://www.gp.usbr.gov/www/hydromet.htm and http://mac1.pn.usbr.gov/hydromet/mcf_list.html.

6. Ground Water Monitoring Wells

The USGS operates a national network of 150 ground-water monitoring wells for use in climate change studies. Explanation of the network and a list of stations are provided on the WWW at http://water.usgs.gov/ogw/CBR.html. The wells have a mean record length of 32 years, with a maximum record length of 83 years. Historical water levels for all of the wells and real-time data for 27 wells that are equipped with telemetry can be retrieved at http://water.usgs.gov/nwis.

7. *Manual Snow Courses*

The USDA's Natural Resources Conservation Service (NRCS) operates a manual network of 1205 snow courses located in the western U.S., including Alaska. Some snow courses have more than 90 years of record, and many have at least 30 years. The manual snow course network is a transect made up of 5 to 50 measurement points measured using a federal snow sampler. The distance between each sample point is consistent, with most being 5 to 50 feet apart. Most manual snow courses have 5 to 10 sample points. Manual snow courses are typically measured on a monthly basis from January through May. Snow depth, water content, and snow density are averaged for each snow course. Nearly 900 additional snow courses have from 1 to 60 years of historical record but have now been discontinued. Of the 1205 operational courses, approximately 50% of the available metadata have been digitized and are available upon request.

8. SNOwpack TELemetry (SNOTEL)

The SNOTEL system began operation by NRCS in the late 1970’s. It is designed to provide near real-time snowpack information. The SNOTEL system operates in the western U.S. and Alaska. It uses meteor burst communication technology to obtain remote site information and deliver it to the National Water and Climate Center (NWCC) central computer system. Once the data are ingested into the NWCC computer system, they are made available to users in a variety of ways. SNOTEL collects, at a minimum, daily Snow Water Equivalent (SWE), accumulated water year precipitation, current, maximum, minimum, and average daily air temperature at all sites. About 15% of the SNOTEL system has additional sensors, measuring wind speed and direction, soil moisture and temperature, and other elements. At present, 200 of the 665 operational SNOTEL stations have nearly 25 years of record. Daily time increment SNOTEL data are thoroughly quality controlled, while hourly data receive a much lower level of quality control. Approximately 50% of the total potential metadata for all SNOTEL stations has been digitized and can be made available upon request. Details of station moves, instrumentation changes, location information, and other metadata are less likely to be available, at least not in a readily accessible format. Information about the SNOTEL network, and access to the data, is available by clicking on "snow" at the NWCC homepage: http://www.wcc.nrcs.usda.gov/.

9. Airborne, Satellite, and Modeled Snow Cover Data

NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC) provides remotely sensed and modeled products and data sets to support the NWS Hydrologic Services Program for the U.S. The NOHRSC generates satellite-derived a real extent of snow cover observations, and makes airborne snow water equivalent measurements over large regions of the country.

The NOHRSC satellite remote sensing program uses NOAA GOES and AVHRR data. Data ingest and pre-processing steps are performed automatically, including data calibration and orbital navigation, image alignment with surface features, solar normalization of visible data, and cloud detection (Carroll, et al., 2000). Manual image analysis is used to classify snow cover from image data. The image-processing environment incorporates a variety of geospatial data sets to facilitate the image classification process. The principal product is a daily map of areal extent of snow and cloud cover for the continental U.S. Additionally, the NOHRSC maintains an Airborne Gamma Radiation Snow Survey Program to make near real-time snow water equivalent measurements over a network of 1,900 flight lines covering portions of 29 states and 7 Canadian provinces (Carroll, 1985). The ability to make reliable airborne gamma radiation snow water equivalent measurements is based on the fact that natural terrestrial gamma radiation is emitted from the potassium, uranium, and thorium radioisotopes in the upper 20 cm of soil. The radiation is sensed from a low-flying aircraft flying 150 m above the ground. Water mass in the snow cover attenuates, or blocks, the terrestrial radiation signal. Consequently, the difference between terrestrial radiation measurements made over bare ground and over snow-covered ground can be used to estimate the mean areal snow water equivalent over the approximately 2-3 km^2 flight line with a root mean square error of less than one cm.

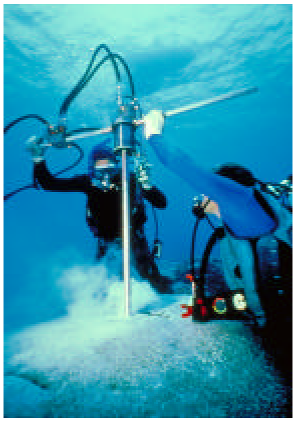
Satellite-derived snow- and cloud-cover products are used in conjunction with airborne and ground-based observations of snow water equivalence to perform analyses of the spatial distribution of snow water equivalent. Daily maps of snow water equivalence are generated using available ground-based and airborne snow water equivalent data sets. Additionally, regional snow water equivalent maps for the central and eastern U.S. are produced following each NOHRSC airborne snow survey mission. Alphanumeric summaries of these maps are provided, in near real-time, to operational hydrologic forecasters in NWS field offices to support river, flood, and water supply forecasting. Lastly, the NOHRSC routinely generates daily surface temperature, cumulative freezing and thawing degree-day, and snow depth (from cooperative observer data) products for the coterminous U.S. Temporal composites of satellite-derived areal extent of snow cover and cooperative observer snow depth products are generated each week. Information about NOHRSC and its data products is available at http://www.nohrsc.nws.gov/.

Additionally, the office ingests a wide variety of near real-time, ground-based hydrometeorological data sets along with real-time, numerical weather prediction (NWP) model data sets for the country. NWP model output data sets are used to force a physically-based, snow-modeling, and snow-data-assimilation system. The ground-based, airborne, and satellite snow cover observations will soon be assimilated, in near real-time, into the gridded fields generated by the snow accumulation and ablation model. Snow model products include a variety of alphanumeric and gridded representations of the snow pack state variables. A distributed, energy-and-mass-balance snow model and data assimilation system has been developed and implemented at the NOHRSC to augment basic hydrologic analysis. The purpose of the Snow Data Assimilation System (SNODAS) is to provide a physically consistent framework for integrating the wide variety of snow data that is available at various times. SNODAS includes: (1) data ingest and downscaling procedures; (2) a spatially distributed energy-and-mass-balance snow model that is run once each day, for the previous 24-hour period and for a 12-hour forecast period, at high spatial (1 km) and temporal (1 hr) resolutions; and (3) data assimilation and updating procedures. The snow model is driven by downscaled analysis and forecast fields from a mesoscale, NWP model, surface weather observations, satellite-derived solar radiation data, and radar-derived precipitation data. The snow model states can be updated using satellite, airborne, and ground-based snow observations. The model is cast in an assimilation framework and serves to organize various snow observations and to track the evolution of the snow pack between observations. SNODAS permits more frequent and timely product generation–near real-time model analyses and forecasts–and provides several new products, including maps of modeled snow characteristics such as snow ripeness, melt rates, and sublimation losses.

10. Soil Climate Analysis Network (SCAN)

Currently, NRCS operates the Soil Climate Analysis Network (SCAN), which has data sites across the U.S., including Puerto Rico. Most of the SCAN sites have been funded by sources outside NRCS. SCAN will focus on agricultural areas of the U.S. If SCAN were fully funded, it would allow for 1,000 new sites and integrate an additional 1,000 existing cooperator sites to form the basis for the network. The typical SCAN station reports precipitation, air temperature, and maximum, minimum, average hourly and average twenty-four hour temperature information. They also measure solar radiation, relative humidity, wind speed and direction, soil moisture and temperature down to 40 inches deep. All basic SCAN data are available via the NRCS web page http://www.nrcs.usda.gov/. Approximately 10 of the 44 operational SCAN stations have nearly 20 years of record. Daily time increment SCAN data are thoroughly quality controlled, while hourly data receive a much lower level of quality control. Approximately 50% of the total potential metadata for all SCAN stations has been digitized and can be made available upon request. Details of station moves, instrumentation changes, detailed location information, and other metadata are less likely to be available–at least not in a readily available format.

11. Paleoclimatology

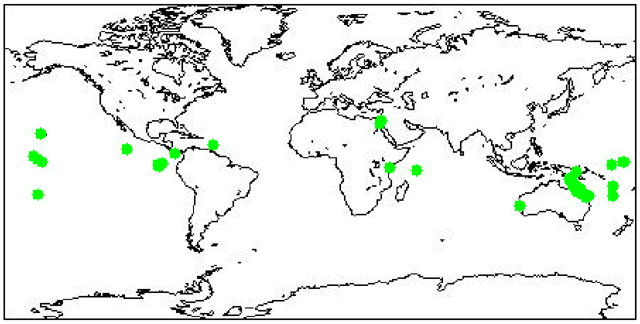


Extracting Coral Core with a Hydraulic Drill

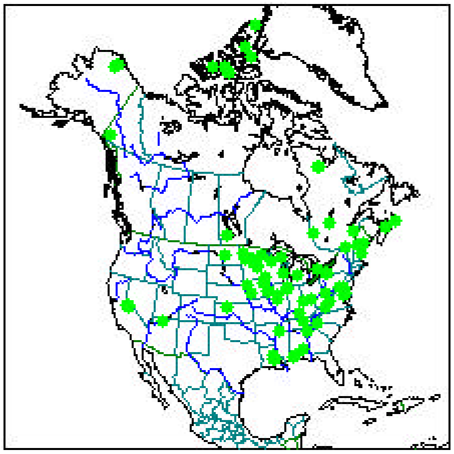
Unlike instrumental data, the paleoclimate data in Table S10 come from a variety of sources. Each source represents a "proxy" for climatic conditions that are derived from these biological or environmental data. Temperature measurements in deep boreholes provide a direct signal of past temperatures at the surface. Using mathematical inversion techniques, temperature records at decadal to millennial scales can be computed. Geochemical analyses of coral skeletons provide seasonal to annual scale records of past temperature, rainfall, cloudiness, and environmental factors. Growth rings and inclusions in the skeleton can yield additional annual records of climate. Flora and fauna change in their distributions as they experience changes in climate. These lower time-resolution data can be dated radiometrically with high precision, but response times of the organisms must be factored in as well. This applies to faunal records, plant macrofossils, and pollen. Records from paleolimnological and paleoceanographic sources provide annually dated records in some locales and decadal scale records in others. However, the abundance of biota in lakes and oceans can change rapidly (within a season) in response to climate signals, thus avoiding problems of response time. These can provide records as to temperature, rainfall, wind, upwelling, and other environmental changes. Trees respond to climate and change their ring growth patterns at sub-seasonal time scales. These annually resolved records provide air temperature, precipitation and other environmental data that have been critical in regional to global reconstructions of temperature and drought and can provide information as detailed as mean annual streamflow.

Table S11 provides data on reconstructions of either large-scale climate indices or gridded climatic data. Each source of proxy data has its own advantages and disadvantages. Most reconstructions use a multi-proxy approach, mathematically building climate fields from spatially distributed networks of data from multiple data types. This effort is not without its difficulties, and the reconstructions are becoming better each year. The data sources in Table S11 include the best reconstructions and data sets of pre-instrumental climate available today. These reconstructions and the proxy data in Table S10 can be found at the NOAA Paleoclimatology Program website at http://www.ngdc.noaa.gov/paleo.

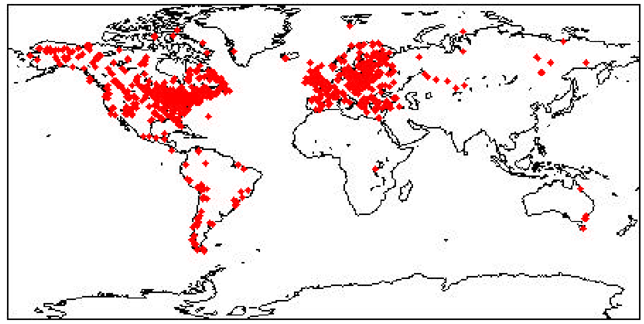
The following figures depict various paleoclimatology programs documented in Table S10.



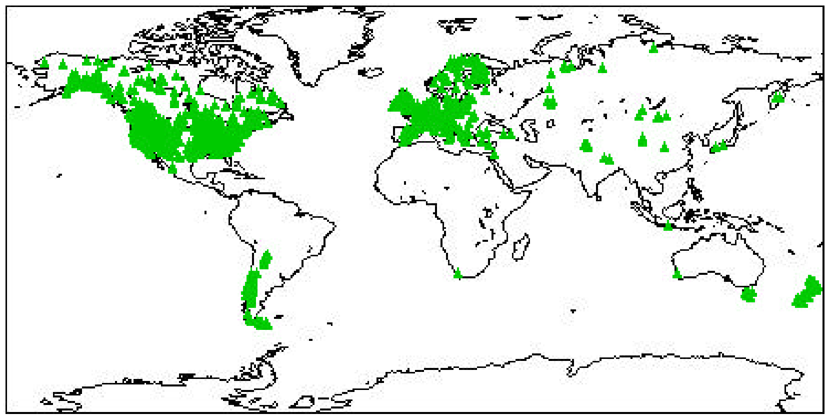
Coral Data at 1 U.S. Site and 61 Global Sites



Plant Microfossil Data at 42 U.S. Sites



Pollen Data at 474 U.S. Sites and 1424 Global Sites



Tree Ring Data at 1029 U.S. Sites and 1854 Global Sites

12. Ecological Observation Networks

a. Fire Inventory and Analysis Program

The Fire Inventory and Analysis (FIA) Program of the USFS has been monitoring and reporting on status, condition, and trends in the nation's forests for over 70 years (http://fia.fs.fed.us). FIA inventories provide a basic suite of vegetative data across all forested landscapes measured in a consistent and compatible manner on a systematic national grid. FIA collects, analyzes, and reports information on the status and trends of America's forests. These include how much forest exists, where it exists, who owns it, and how it is changing, as well as how the trees and other forest vegetation are growing and how much has died or has been removed in recent years. This information is combined with related data on insects, diseases, and other types of forest damages and stressors to assess the health condition and potential future risks to forests.

Data collection is based upon double sampling for stratification. FIA has 3 phases: (1) remotely sensed data interpretation, known as Phase 1; (2) general field data collection through plot visits, known as Phase 2; and (3) detailed health and vitality measures on a subset of the phase 2 plots, known as Phase 3. Phase 1 provides primary information on the extent and distribution of forest cover. Phase 1 uses remote sensing in a combination of aerial photography, 30-meter TM imagery, and AVHRR imagery to determine forest areas to be selected for Phase 2 field data collection. Field visits confirm data and interpretations made from the remotely sensed data and provide additional data not observable from Phase 1, some 300 different variables. There are approximately 125,000 forested, Phase 2, sample plots across the U.S., roughly one for every 6,000 acres of forest. Tree measurements on Phase 2 plots include species, diameter breast height

(dbh), and total height, as well as more detailed measurements of status and vigor. On a subset of the Phase 2 plots, measures related to forest ecosystem function, condition, and health are collected. The current measurements include crown condition, soil erosion potential, soil chemical analyses, lichen communities, ozone bioindicator plants, vegetation structure, and down woody debris. Forest inventory data is the basis for monitoring changes in carbon stocks over intervals of 5-10 years. The high sampling intensity allows detailed description of some of the causes of observed carbon stock changes, such as the effects of vegetation growth, mortality, and harvesting. Field information from phase 3 may be used to confirm indicator findings of Long-term Ecological Research LTER research (see section 11b below) on a broader scale.

Consistency is maintained through a nationwide forest survey field manual that specifies a core set of definitions, accuracy requirements, measurement standards, and reporting requirements. The current national standards provide an accuracy of ±3-5 percent per million acres (approximately ±1-2% per million hectares) of forested land and ±5-7 percent per billion cubic feet (approximately ± 3-4% per 100 million cubic meters) of volume or biomass. FIA fact sheets, statistics, online databases, and a map of U.S. forest distributions are available at http://fia.fs.fed.us.

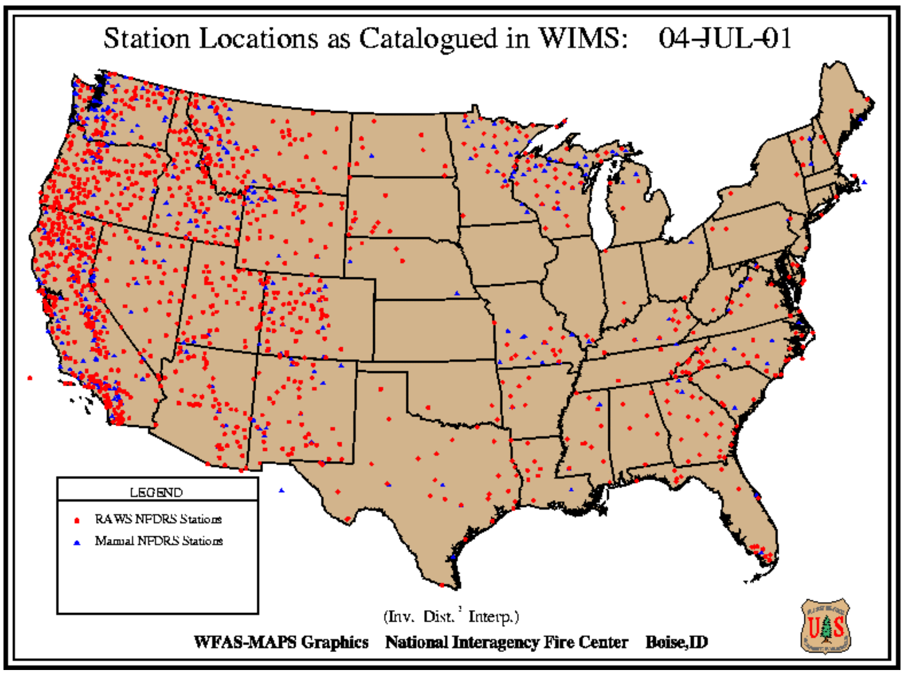
b. LTER Network

Twenty-four research sites and a Network Office make up the U.S. Long-term Ecological Research (LTER) network (http://lternet.edu/data). Focusing on fundamental ecological research, each LTER site is supported by an individual grant from the NSF, with significant support from USGS, USFWS, NOAA, EPA, USDA, and numerous universities and other partners. The LTER sites are found in forest, desert, prairie, alpine, coastal and marine environments. The research topics addressed at sites are similarly varied, with research on ecological succession, disturbance, landscape ecology, elemental cycling, trophic structure, biodiversity, organic matter and primary productivity ongoing at each site. The sites also differ in their degree of centralization, with researchers from up to 15 universities at a single site.

The types of data collected and used at LTER sites are highly variable. Satellite images, scanned aerial photos, and output from spatially explicit models fall at the high-end of size, with an individual image requiring over 300 MB of disk space. At the other end of the spectrum are types of data, such as deep soil cores where a small number of samples are subjected to a large number of different tests. NSF's proposed National Ecological Observatory Network (NEON) will establish 10 observatories located around the country that will serve as national research platforms for integrated studies in field biology. Each observatory will provide state-of-the-art infrastructure to support interdisciplinary, integrated research. Collectively, the network of 10 observatories will allow scientists to conduct comprehensive, continental-scale experiments on ecological systems. Each NEON observatory will include site-based experimental infrastructure; natural history archive facilities; and facilities for biological, physical and data analyses; see http://www.mpcer.nau.edu/neon/ for more details.

13. Fire Weather Observations Remote Automated Weather Stations

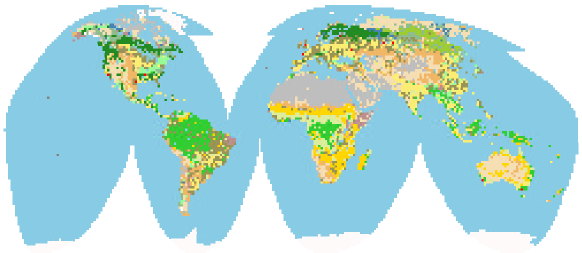
Remote Automated Weather Stations (RAWS) are weather stations set up on tripods, and are an important input to the USFS' Weather Information Management System (WIMS). Approximately 1150 RAWS sites (depicted in red below) are strategically positioned throughout the U.S. Sensors on every RAWS unit are calibrated annually. RAWS sensors monitor: (1) wind speed and direction; (2) wind gusts; (3) precipitation; (4) air temperature; (5) relative humidity; and (6) fuel moisture. RAWS units collect, store, and forward data hourly, via the GOES satellite to a computer system located at the National Interagency Fire Center in Boise, Idaho. RAWS are often located in isolated areas accessible only by all-terrain vehicles, helicopters, snowmobiles, or backpacking trails. Fire managers use RAWS weather data to predict fire behavior and monitor fuels. Resource managers also use RAWS to monitor environmental conditions and air quality. Some RAWS units are used as early-alert warning systems for floods, mudslides, or hazardous material levels. RAWS station information and data are available at: http://raws.boi.noaa.gov/rawsidx.html and http://raws.boi.noaa.gov/rawsobs.html.



14. Global, National, and Regional Land Cover Characterization

The USGS began the Land Cover Characterization Program (LCCP) in 1995 to develop land cover and other land characterization databases to address national and international requirements that were becoming increasingly sophisticated and diverse. To meet these requirements, USGS develops multiscale land cover characteristics databases used by scientists, resource managers, planners, and educators (Global and National Land Cover Characterization), and contributes to the understanding of the patterns, characteristics, and dynamics of land cover across the Nation and the Earth (Urban Dynamics and Land Cover Trends). The program also conducts research to improve the utility and efficiency of large-area land cover characterization and land cover characteristics databases.

a) Global Land Cover Characterization: The initial goal to develop a global 1-km land cover characteristics database was achieved in 1997. Current efforts focus on revising the database utilizing input from users around the world.



Global Land Cover Characterization Database

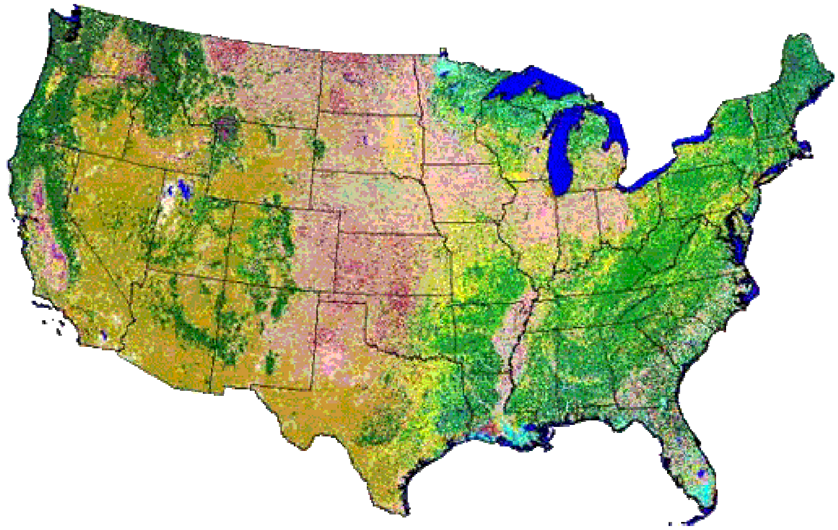
The USGS, the University of Nebraska-Lincoln, and the European Commission's Joint Research Centre generated the initial 1-km resolution Global Land Cover Characteristics database using 1-km NOAA AVHRR data from April 1992 through March 1993. This was done on a continent-by-continent basis using standard map projections and 1-km nominal spatial resolution; each continental database contains unique elements based on the geographic aspects of the specific continent. The continental databases are combined to make seven global data sets, each representing a different landscape based on a particular classification legend.

Two versions of the Global Land Cover Characteristics database are now available (http://edcdaac.usgs.gov/glcc/glcc.html). The first version (Version 1.2) was released to the public in November 1997. It was produced as an International Geosphere-Biosphere Program Data and Information System (IGBP-DIS) initiative lead by the Land Cover Working Group and has been subjected to a formal accuracy assessment (the IGBP DISCover classification). Many users of the land cover data set provided suggestions for additions and improvements that have been incorporated into Version 2.0. A formal accuracy assessment has not yet been conducted for this version.

This effort is part of the NASA Earth Observing System Pathfinder Program; funding was provided by the USGS, NASA, EPA, NOAA, USFS, and the United Nations Environment Program. IGBP-DIS has adopted the database to satisfy its requirement for a global 1-km land cover data set. Unless protected by copyrights or trade secret agreements, all data used or generated during the course of the project (source, interpretations, attributes, and derived data) are distributed through the USGS EROS Data Center Distributed Active Archive Center (DAAC) for land processes data.

b) National Land Cover Characterization: The USGS has also led an effort to produce a U.S. National Land Cover Data set (NLCD) based on 30-meter Landsat Thematic Mapper data (http://landcover.usgs.gov/nationallandcover.html). The National Land Cover Characterization project began in 1995 using Landsat-5 data from the interagency Multi-Resolution Land Characterization (MRLC) Consortium Image Database assembled by the partners (USGS, EPA, NOAA, and USFS). The National Land Cover Dataset 1992 (NLCD 92) contains 21 USGS Anderson land cover classes in a nationally consistent 30-meter spatial resolution raster format. Land cover mapping for the conterminous U.S. was completed in September 2000. In addition to Landsat data, developers of NLCD 92 used a variety of supporting information, including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label each land cover type. An accuracy assessment was performed and the results are posted on the web site. The NLCD is being used for a wide variety of national and regional applications, including watershed management, environmental inventories, transportation modeling, fire risk assessment, and land management.

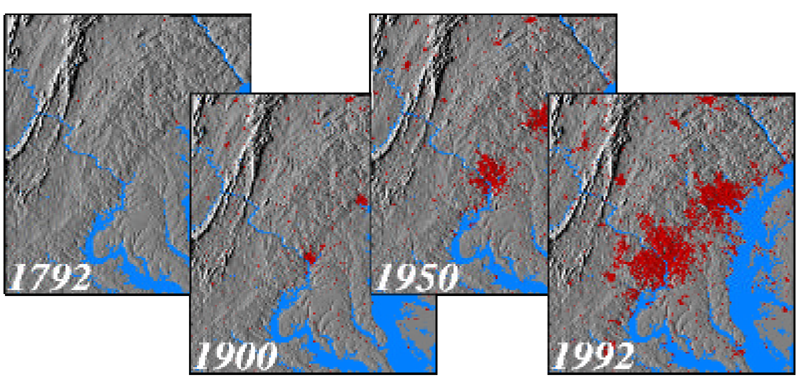
Based on the growing need for land-cover and other geospatial data within the Federal Government and the success of the MRLC Consortium, the Partners agreed to fund a Landsat-7 Image Database. These data are being used to develop a second-generation national land-cover product, the National Land Cover Database 2000 (NLCD 2000). This land cover mapping effort will be developed using a database approach, which provides flexibility in developing a suite of independent data layers that provide more flexibility in applying the database to relevant applications.



National Land Cover Dataset 1992

c) Urban Dynamics and Land Cover Trends: USGS is mapping and documenting landscape transformations that result from the growth of metropolitan regions. Using historical maps and Landsat satellite data, urban land use databases are being assembled and used to analyze the effects of urbanization and to model growth and land use change under various growth scenarios (http://edcdgs9.cr.usgs.gov/urban/).

Projects are underway in several U.S. metropolitan regions: Washington, D.C.-Baltimore, Philadelphia, New York, Chicago, Milwaukee, Portland, Vancouver, San Francisco, and Las Vegas. Additional work is being done in the Detroit River corridor, California's Central Valley, the Front Range corridor of Colorado, South Florida, and in the Middle Rio Grande Basin in New Mexico. The Urban Dynamics Program is a joint activity between the USGS and the University of California, Santa Barbara. Other partners have been included in specific areas. For example, the Washington-Baltimore study was supported by the University of Maryland-Baltimore County, NASA, the Census Bureau, Library of Congress, Smithsonian Institution, and the Maryland Historic Trust.



Urban Area Growth (in red) for the Washington DC-Baltimore MD Area Between 1792 and 1992 (background is a shaded relief image)

The Urban Dynamics program provides temporal land use databases, analyses of land use change, and landscape change predictions. Databases for study sites contain digital maps of urban extent, transportation routes, water features, and other significant land uses compatible for use in geographic information systems. Digital animations are available to help visualize the temporal patterns inherent in the data. A land use change model and documentation are also available. Interpretive papers and maps based on the data and models are published in a variety of formats.

USGS and EPA are collaborating through the Land Cover Trends Project (LCTP) to document the rates, causes, and consequences of land use and land cover change for the conterminous U.S. for the 1972-2000 period. A scientific understanding of the rates of change, the driving forces of change, and the associated impacts of change is needed to resolve national policy questions associated with issues such as carbon budgets and carbon credits. Fundamental questions that must be addressed include: (1) what are the overall rates of land cover change, and what are the rates of change by sector (i.e., what are the rates of conversion from agricultural to urban land cover); and (2) how do the rates of change vary locally, regionally, and temporally?

The LCTP has developed a comprehensive methodology for using sampling and change analysis techniques and Landsat MSS and TM data for measuring land cover change in 85 U.S. landscape ecoregions. The goals are to: (1) estimate the types, rates, and temporal variability of change for each ecoregion; (2) document regional driving forces and consequences of change; and (3) prepare a national synthesis of land cover change. Datasets representing these activities are being developed.

B. International Data Exchange

The National Snow and Ice Data Center (NSIDC) at the University of Colorado had published a number of data sets made available through the U.S.-Russia Bilateral Data Exchange Working Group VIII. These historical baseline data sets include fresh water ice data (river freeze-up events at 50 stations in northern Russia dating back to 1917 from the State Hydrological Institute, St. Petersburg, Russia), soil temperature data (about 140 station records digitized at the Soil Institute, RAS, Pushchino), and snow cover (snow depth and snow water equivalent data from 1345 stations from the Institute of Geography, Moscow). In 1998, NSIDC also published a CD-ROM providing a global synthesis of permafrost distribution in space and time (Circumpolar Active-Layer Permafrost System Version 1.0). The 1998 CD-ROM contains 40 data sets of active layer, borehole temperature profiles, and rock glaciers from representative sites throughout the world.

The Arctic Climatology Project Arctic Meteorology and Climate Atlas on CD-ROM was published in 2000 by the NSIDC with Russian partners at the Arctic and Antarctic Research Institute, St. Petersburg, and with partners at the University of Washington. The atlas contains previously unavailable Russian synoptic meteorology data material as well as a glossary of meteorological terms in English and Russian. Development of the atlas was funded by NOAA and the Environmental Working Group (EWG). EWG was established in 1995 under the framework of the U.S.-Russian Joint Commission on Economic and Technological Cooperation.

The Lake Ice Analysis Group (LIAG), an international ad hoc group of scientists, contributed to the Global Lake and River Ice Phenology Database published in 2001 by NSIDC. The data set contains freeze and breakup dates for 747 lakes and rivers. Four hundred twenty-eight water bodies have records longer than 19 years (287 in North America and 141 in Eurasia); 170 exceeded 50 years; and 28 exceeded 100 years.

Table S9. National Climate Monitoring Systems for Terrestrial Observations

Systems useful for national climate monitoring	Total # stations	Appropriate for Characterizing National Climate?			Time Series #Stations/platforms (#Data Digitized)			Are QC procedures adequate?			Metadata available? Total # Stations (%Digitized)	Continuity? # Expected operational in 2005
		Fully	Partly	No	>30y	>50y	>100y	Fully	Partly	No		
River Discharge (Streamflow Gages)	USGS: 7,388	1,166	~ 1,500		3,822	2,398	32	6,760	630		7,038	7,500
	USCOE: 3,491	1,074	~1,500		1,842	784	17	2,976	300		2,500	3,500
Ground Water Storage (e.g., Boreholes)	150	150			60	25		150			150	150
Snow												
Manual Snow Courses	1205	1205			600	50	0	1205			1205 (50%)	1205
SNOTEL	665	665			0	0	0		665		665 (50%)	670
Glaciers	3	3			3			3				
Permafrost , Active Layer Thickness												
DOI	8	Yes			0	0	0	Yes			8	~10
NSF	19	Yes			0	0	0	Yes			19	~20
USFS	2	Yes			2	0	0	Yes			2	~2
Total	29				2	0	0				29	~30
Permafrost, Thermal State+	SU SH IB DB+ Total											
DOI	0 0 0 21 21	Yes			0	0	0	Yes			21	21
NSF	4 1 22 0 27	Yes			0	0	0	Yes			27	27
Total	4 1 22 21 48				0	0	0				48	48
Ice												
FluxNet-AmeriFlux	47		Yes		<10 yrs				Yes		Yes , 24 stations 100% digitized	50 stations
Radiation												
Soil												
SCAN	44	44			0	0	0		44		44(50%)	50
Water Level – Tidal	84 - USCOE	84			42	32	10	76	8		36	80

+Permafrost thermal state is determined by periodically measuring temperatures in geophysical boreholes. Boreholes are classified according to their depth: SU (Surface 0-10m), SH (Shallow 10-125 m), DB (Deep>125m)

Table S10. National Climate Monitoring Systems for Ecological Observations

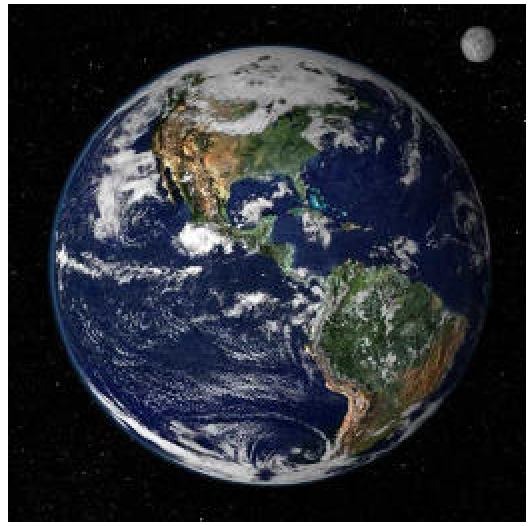
Systems useful for national climate monitoring	*Total # stations*	*Appropriate for Characterizing National Climate?*			*Time Series #stations/platforms (#Data Digitized)*				*Are QC Procedures Adequate?*			*Metadata available? Total # Stations (%Digitized)*	*Continuity? # Expected operational in 2005*
		Fully	*Partly*	*No*	*>30y*	*>50y*	*>100 y*	*>300y*	*Fully*	*Partly*	*No*		
Phenological	*No Data*												
Biomass Change	*11*		*11*		*11*				*Yes*			*11*	*11*
Vegetation Type	*24*		*24*		*24*				*Yes*			*24*	*24*
Land Cover	*24*		*24*		*24*				*Yes*			*24*	*24*
Fire Weather (RAWS)	*1150*		*1150*						*Yes*			*1150*	*>1150*
Land Use Change	*No Data*												
Paleoclimatic Data, US													
Borehole Data	133	133						133				133	
Corals	1		1										
Fauna	219		219					219				219	
Paleolimnology	9	9						9				9	
Paleoceanography	19	19											
Plant Macrofossils	37	37						37				37	
Pollen	474	474						474				474	
Tree Ring	1029	1010	19				329	700				1029	
Other Paleo Data	0												
Total U.S. Paleo	**1921**	**1682**	**239**				**329**	**1572**	**Yes**			**1901**	**NA**
Paleoclimatic Data, non-US													
Borehole Data	483	483						483				483	
Corals	61	56	5			9	38	9	61			61	
Fauna	1	1						1				1	
Ice Cores	23	23						23				23	
Insecta	7	7						7					
Paleolimnology	6	6						6				6	
Paleoceanography	1100	1100						1100				1100	
Plant Macrofossils	42	42						42				42	
Pollen	950	950						950				950	
Tree Ring	825	800	25				450	375				825	
Other Paleo Data	5	5						5				5	
Total non-US Paleo	**3465**	**3435**	**30**				**460**	**2995**	**Yes**			**3458**	**NA**

Table S11. Available Homogeneous Data Sets for Sustained Terrestrial and Ecological Observations.

Data Set Name	Variable	# Stations or Grid Resolution	Describe Period	References
Paleoclimatic Data Sets, US Tree-ring Reconstructed Palmer Drought Severity Index	PDSI	388 chronologies, 155 grid points, 2x3° grid	1700-1978	http://www.ngdc.noaa.gov/paleo/usclient2.html Cook et al. 1999. Journal of Climate, 12:1145-1162.
Paleoclimatic Data Sets, Global Mann et al. 1998 Temperatures	Reconstructed Annual Average Temperature	5x5° grid	1730-1980	http://www.ngdc.noaa.gov/paleo/pubs/mann1998/frames.htm Mann et al. 1998, Nature 392:779-787.
	Reconstructed Annual Average Temperature	N. Hemisphere Avg.	1400-1980	
	Reconstructed Mean Temperature within NINO3	8 gridpoints within NINO3 box	1650-1980	
Jones et al. 1998 Temperatures	Reconstructed Annual Average Temperature	2 (N. And S. Hemisphere averages)	1000-1991	ftp://ftp.ngdc.noaa.gov/paleo/contributions_by_author/jones1998/ Jones et al. 1998, The Holocene 8:455-471.
Overpeck et al. 1997 Arctic Temperatures	Reconstructed Air Temperature	29 sites	1600-1990	http://www.ngdc.noaa.gov/paleo/sciencepub/front.htm Overpeck et al. 1997 Science 278:1251-1256.
Mann et al. 2000 Temperatures	Reconstructed Annual Average, Boreal Summer, Boreal Winter Temperature	5x5° grid	1730-1980	http://www.ngdc.noaa.gov/paleo/ei/ei_cover.html Mann et al. 2000 Earth Interactions, 4-4, 1-29, 2000.
Net Primary Productivity Database	Biomass production	11 sites	1975-1998	http://intranet.lternet.edu/cgi-bin/anpp.pl Alan K. Knapp and Melinda D. Smith

IV. Satellite and Remote Sensing Observations

A. Objectives



True Color Image of North and South America Combining NASA MODIS Data (land surface) and NOAA GOES Data (clouds)

Space-based remote sensing observations of the atmosphere-ocean-land system have evolved substantially since the early 1970’s when the first operational weather satellite systems were launched. Over the last decade satellites have proven their observational capabilities to accurately monitor nearly all aspects of the total Earth system on a global basis. This is a capability unmatched by surface based systems which are limited to land areas covering only about 30% of the planetary surface. Currently, satellite systems monitor the evolution and impacts of the El Nino, weather phenomena, natural hazards, and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal zones and algae blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and others. These various observations are used extensively in real-time decision-making and the strategic planning and management of industrial, economic, and natural resources. Examples include weather and climate forecasting, agriculture, transportation, energy and water resource management, urban planning, forestry, fisheries, and early warning systems for natural disasters and human health impacts.

The current generation of satellite instruments exceeds the GCOS requirements for the absolute calibration of sensors, something that was lacking in the early satellite platforms used for real-time operational purposes. However, several of the data series from these operational satellites have been re-processed using substantially improved retrieval algorithms and, therefore, provide high quality global data products for the purposes of GCOS, climate system variability, and climate change research and applications. It is underscored, however, that satellite observations cannot measure all parameters of the Earth system. Also needed are surface-based, and in-situ observing systems for the calibration and validation of satellite-derived geophysical, chemical, and biospheric parameters. Thus, the future evolution of global climate observing is seen as one that calls for an integrated approach or strategy involving both space-based systems and surface-based in-situ observing networks.

All satellite systems carry instruments that sense electromagnetic radiation in spectral bands that are related, via retrieval algorithms, to some property of the Earth’s atmosphere, ocean, or land surface. The precise technology used, spectral discrimination, number of channels, and view angles differ, but they possess common objectives in terms to what they are designed to “see” from the standpoint of applications and research. Most satellites carry passive sensors, which detect the natural radiation reflected or emitted by an object. Increasingly, however, new generation satellites carry active sensors such as synthetic aperture radar, microwave radar, and laser scatterometers.

In recent years, there have been well-articulated moves towards the establishment of an IGOS. IGOS[2] is a strategic planning process, uniting the major satellite and surface-based systems for global environmental observations of the atmosphere, oceans, and land, in a framework for decisions and resource allocations by individual funding agencies. Its purview includes not only observations for climate, but also the needs of multiple domains, the entirety of which no single Partner is able to address alone. It takes a strategic view across all Earth observing requirements, evaluates capabilities of current and planned observing systems, and has begun (at least among the space agencies) to obtain commitments for addressing the gaps. GCOS is in fact a major contributor to the IGOS-Partnership.

Operational weather satellites are internationally coordinated through the Coordination Group for Meteorological Satellites (CGMS) of which the WMO is a member and a major beneficiary. CGMS has six satellite agency members. The primary body for policy and technical issues of common interest related to the whole spectrum of Earth observation satellite missions is the Committee on Earth Observation Satellites (CEOS). CEOS has 22 space agency members, including both research and operational satellite agencies, with funding and program responsibilities for a satellite Earth observation program currently operating or in the later stages of system development. U.S. members of CEOS are NASA, NOAA, and USGS. CEOS encourages complementarity and compatibility among space-borne Earth observing systems through coordination in mission planning, promotion of full and non-discriminatory data access, setting of data product standards, and development of compatible data products, services, applications, and policies. Multidisciplinary programs such as the IGBP and the WCRP, among others, rely on data from both operational and research satellite systems. Several international observing system programs have also been established in recent years that endeavor to coordinate both satellite and in-situ measurements to meet the requirements of operational and research applications objectives. These include the GCOS; the GOOS; and the GTOS. The lead agencies for their coordination are, respectively, the WMO in Geneva, Switzerland, the IOC in Paris, France, and the Food and Agricultural Organization (FAO) in Rome, Italy.

In the context of the evolution of GCOS and the IGOS, there is a convergence between research and operational requirements, despite an apparent divergence in the past. As the "prediction" time-window is broadened beyond weather time scales (days to a week) to include (quasi-operationally) seasonal-to-interannual (e.g., El-Nino), and decadal (e.g., climate change and impacts) time scales, a substantially larger number of components and processes of the Earth system need to be observed and modeled. And, they need to be observed on a global basis. Such a need may be construed as a driving requirement for the improvement of operational observing systems, and also for the transition of research to operational platforms. Global-scale observations would, by definition of the land/ocean distribution, be heavily dependent on space-based systems. Of course, space-based systems would benefit from improved in-situ observational coverage. Furthermore, better observations of sub-surface parameters such as soil moisture, ocean sub-surface T/S profiles, and continental/ocean snow/ice depth/thickness are

[2]The IGOS Partners include the GCOS, GOOS, and GTOS Secretariats; the FAO, ICSU, IOC-UNESCO, UNEP, and WMO; Committee on Earth Observation Satellites (which includes national and regional government agencies with an Earth observing satellite system); research programs (IGBP and the WCRP); and IGFA for Global Change Research.)

required. Accurate, high-resolution tropospheric (and ocean surface) winds on a global basis would be important to improve weather forecasts (especially hurricanes/typhoons). Atmospheric T/H and surface hydrological parameters, atmospheric chemistry/constituents, ocean circulation, and others would be essential to address climate variability/change questions and environmental resource management issues. The monitoring of water resources (water cycle), ecosystems (and carbon cycle/budgets), snow/ice, and others are important categories in which observations are needed to improve prediction models and address impacts and resilience/vulnerability assessments. These questions and issues have gone well beyond the strictly research domain. They are now coming from policy-makers and the general public. Consequently, they are becoming, de-facto, operational needs (though currently, quasi-operational) even if some of them may happen to reside within the research framework at this time.

In accord with the evolutionary Earth-system observational concepts mentioned above, it is considered important to adopt planning strategies that orient global observational programs toward answering key scientific and management questions. It becomes equally important for such objectives to be integrated with parallel efforts to deliver the requisite data, analysis, and information products needed by the scientific community as well as operational managers and policy makers.

B. Implementation Status of Satellite Series and Platforms

Several U.S. agencies have been and are involved in the development, management, and operation of satellite observing systems. In general, satellite observing systems may be categorized as “operational” systems or “research” and “experimental” systems. Measurements taken by operational systems are likely to be continuous and maintained for an indefinite period of time. Typically, they also refer to observations required for a variety of real-time or near-real-time operational applications. Due to their long-term continuity, they contribute substantially to climate research, even if their data quality requirements have historically been less stringent than those required by research. Research or experimental satellite systems are likely to be new technological developments that measure a host of new parameters needed for research studies on the complex processes of the Earth-climate system Due to the nature of the time scales involved in climate system processes, some research satellite systems are designed to provide “systematic” measurements of select key parameters for a substantial period of time. Generally, systematic observing systems also aim for measurement continuity, but their implementation plans may not provide for instantaneous in-orbit replacements in case of premature sensor or spacecraft failure. Another sub-category of research or experimental satellites is exploratory, i.e. missions that can yield new scientific breakthroughs. Such exploratory satellite observing systems are often one-time missions that have the potential to deliver conclusive scientific results addressing a very tightly focused set of scientific objectives. These missions are also important to climate research and GCOS. A particular challenge arises when the systematic observations obtained in a research-oriented program have proven to be useful or essential to operational applications. That is, there is a need for mechanisms to facilitate the transition of the specialized or enhanced technologies used in research platforms to operational observing systems. In the U.S. for example, there is a coordinated effort to ensure the continuity of the measurements made by the research-based Earth Observing System (EOS) satellite series, and future operational environmental satellites.

This section provides summaries, in tabular form, of U.S. satellite observing series contributing to GCOS. Tables 6-8, found at the end of this section, are briefly described below.

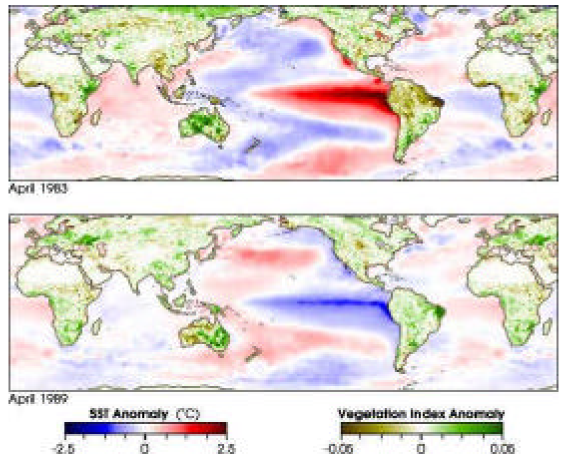
Table 6 summarizes the U.S. satellite series and/or platforms that contribute to GCOS. The table responds to the UNFCCC guidelines for data exchange, barriers to data exchange, international participation, and applications to capacity building. Information is also summarized on the availability of data and data sets. In general, all U.S. satellite data relevant to GCOS are extensively documented in the Global Change Master Directory (GCMD) coordinated by the interagency USGCRP. Table 6 identifies the major agencies responsible for the satellite series and the primary centers that distribute data. Comprehensive details on these and other data centers, and data set descriptions, are available from the GCMD, which can be accessed on the Internet. The search engine for obtaining details on each satellite platform or instrument is built into the GCMD. Likewise, information may be retrieved by parameter, application, or scientific theme through a plain-language query. For satellites that are not yet launched, information on instruments, launch schedules, data processing, and mission objectives is provided on the web site.

Table 7 provides information on the types of observations obtainable from the U.S. satellite systems contributing to GCOS, typical space/time resolutions, the continuity of the satellite series (and data), and the degree to which processed/derived data sets comply with GCOS climate monitoring principles, as identified by the COP-UNFCCC. Only those satellites (and satellite series) that either have historical data continuity or are currently operational, are included in this table. Satellites that have not yet been launched, but have been approved (i.e., future approved missions), are described in Table 6.

Table 8 summarizes the status of the potential for the transition of research satellite remote sensing instruments to operational systems. The five sub-tables are cross-mapped against the five major scientific themes identified earlier as scientific questions that need to be addressed, namely: Variability (“V”), Forcing (“F”), Response (R”), Consequences (“C”), and Prediction (“P). In Table 8, the number following a letter such as “V2” refers to the bullet number corresponding to a particular scientific question. While substantial international cooperative efforts are necessary for the development and implementation of next-generation operational observing systems, such an activity is seen as a key element for the further advancement of an optimum, operational, global observing system for GCOS that would also support the objectives of the Integrated Global Observing Strategy promulgated by the CEOS and the WMO-GOS.

C. Operational U.S. Satellite Observing Systems

1. Polar Operational Environmental Satellites (POES)



NOAA AVHRR False Scale Image of SST and Vegetation Anomaly

The first meteorological satellite observations of the Earth began with the launch, by NASA, of the first Television and Infrared (IR) Observation Satellite (TIROS-I) on April 1, 1960 to demonstrate the feasibility of observing the Earth's cloud cover and weather by means of slow-scan television cameras in an Earth-orbiting, spin stabilized satellite. TIROS-II was launched on November 23, 1960, to demonstrate, in addition to the wide- and narrow- angle television cameras, an experimental 5-channel scanning IR radiometer and a 2-channel non-scanning IR device. They measured the thermal energy of the Earth's surface and atmosphere to provide data on the planet's heat balance and add a new dimension to the understanding of weather. A series of these TIROS satellites, developed by NASA and operated by NOAA, were launched throughout the 1960s. A 2-channel Scanning Radiometer (SR) was launched on a NOAA satellite in June 1974 and lasted until February 1978. One channel was in the visible part of the spectrum, while the other channel was in the thermal infrared window. The first operational Earth Radiation Budget measurements were made by the SR. Beginning with TIROS-N, in 1978, an AVHRR sensor was carried on board NOAA's POES. The NOAA/TIROS POES continuously orbits the Earth from North to South Pole (hence the name polar orbiting) at an altitude of approximately 830 to 870 km.

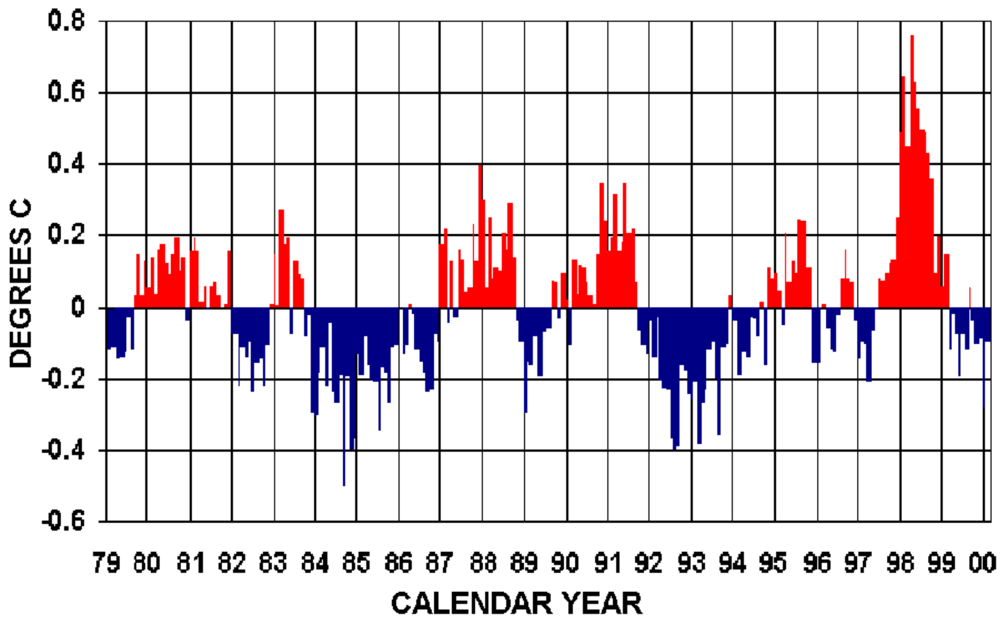
POES data has been crucial in depicting global distributions of a number of important climate parameters such as ozone, aerosols, outgoing long-wave radiation, Microwave Sounding Unit (MSU) temperature times series, snow cover, and water vapor. The NOAA/POES series currently carry scanning radiometers as imaging and radiometric devices and sounders to obtain information on the vertical profiles of selected parameters. Key instrument packages include:

- The AVHRR, currently, a 5-channel, cross-track scanning instrument, providing image and radiometric data in the visible, near-infrared, and far infrared portions of the spectrum, is used to observe clouds, land-water boundaries, snow and ice, water vapor, temperature of clouds, land and sea surface temperature, aerosols, and the Normalized Difference Vegetation Index (NDVI) as an indicator of green biomass.

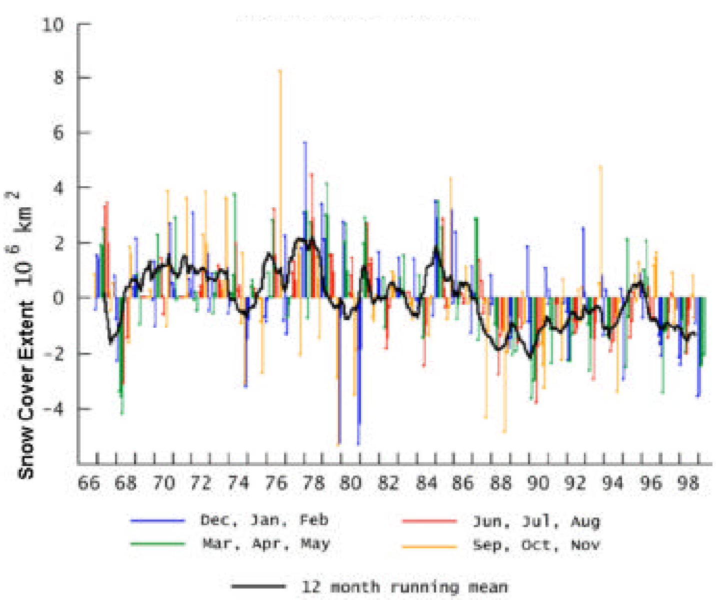
- The TIROS Operational Vertical Sounder (TOVS), a three-part TIROS system is used to measure temperature profiles of the Earth's atmosphere from the surface to about 10 millibars, water content of the Earth's atmosphere, and total column ozone content of the atmosphere. The TOVS system comprises three separate sensors: (1) the High Resolution Infrared Sounder (HIRS), a 20 channel, step-scanned visible and infrared spectrometer used to produce tropospheric temperature profiles; (2) the Stratospheric Sounding Unit (SSU), a 3-channel, pulse modulated, step-scanned, far-infrared spectrometer used to produce temperature profiles of the stratosphere; and (3) the Advanced MSU (AMSU-A and AMSU-B), a 4-channel, step-scanned spectrometer with a response in the 60-GHz oxygen band, used to produce temperature profiles in the atmosphere in the presence of clouds.

- A Solar Backscatter Ultraviolet (SBUV) system for ozone measurements (added to TOVS starting with the NOAA-9 spacecraft). It also carries a space environment monitor to measure energetic particles emitted by the Sun.

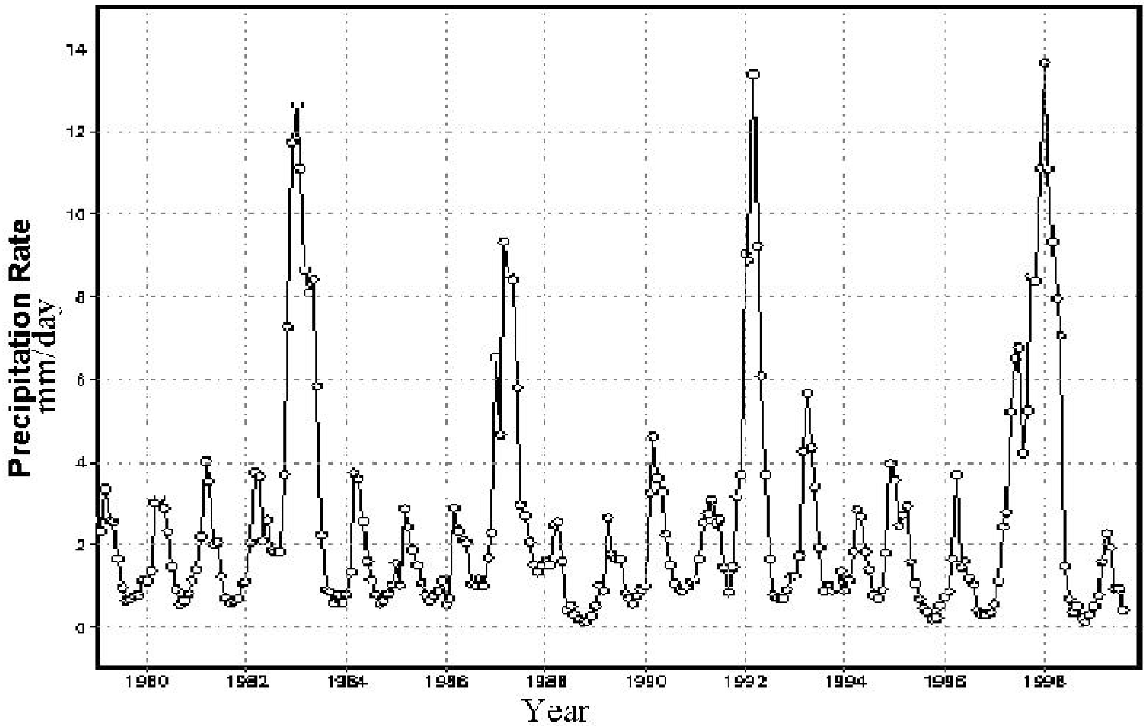
A few prime examples of climate related data sets produced as a result of POES data include the following that deal with temperature anomalies, snow cover, and precipitation.



Global Tropospheric Temperature Anomalies, January 1979 - February 2000 (Christy et al., 2000)



Northern Hemisphere Snow Cover Anomaly (Robinson, 2000)



Precipitation (5N-5S, 170W-120W), 1979-1998 (Gruber, 2000)

2. Defense Meteorological Satellite Program

The Defense Meteorological Satellite Program (DMSP) is a DOD program run by the Air Force Space and Missile Systems Center (SMC). The DMSP program designs, builds, launches, and maintains several near-polar orbiting, sun synchronous satellites monitoring the meteorological, oceanographic, and solar-terrestrial physics environments. DMSP satellites are in a near-polar, sun synchronous orbit at an altitude of approximately 830 km above the earth. Each satellite crosses any point on the earth up to two times a day and has an orbital period of about 101 minutes thus providing nearly complete global coverage of clouds every six hours.

Each DMSP satellite monitors the atmospheric, oceanographic and solar-geophysical environment of the Earth. The visible and infrared sensors collect images of global cloud distribution across a 3,000 km swath during both daytime and nighttime conditions. The coverage of the microwave imager and sounders are one-half the visible and infrared sensors coverage, thus they cover the polar regions above 60 degrees on a twice daily basis but the equatorial region on a daily basis. The space environmental sensors record along track plasma densities, velocities, composition and drifts. DMSP satellites have been operational since 1976. The Operational Linescan System (OLS) on-board the DMPS Block 5D-1 and 5D-2 series, includes two telescopes and a photo-multiplier tube. Visible and infrared imagery from the OLS instruments is used to monitor the global distribution of clouds and cloud-top temperatures twice daily, during day and night. The archive data sets contain imagery from low-resolution (2.7 km) global coverage and high resolution (0.55 km) regional coverage. Nighttime visible data are obtained from the photo-multiplier tube designed to produce cloud imagery by moonlight. In addition to cloud information, OLS data are being used for a variety of studies and applications such as land surface fires, natural gas flaring, urban lights leading to information on natural fires, biomass burning, power failures and population density.

The Special Sensor Microwave/Imager (SSM/I) instrument has been flown on the DMSP weather satellites since June 1987. It is a well calibrated passive microwave radiometer particularly well suited for measuring hydrological cycle parameters under all-weather conditions. These include measurements of snow cover, frozen ground, land classification, sea ice, wind speed over the oceans, cloud liquid water and water vapor, and rainfall. The SSM/I instrument series (six instruments have been flown, with a seventh scheduled for a future flight) will continue before being replaced by its successor SSM/IS which is a combined passive microwave imager and sounder. The SSM/I itself is a successor to the earlier Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) developed and launched by NASA in 1978 and providing data through 1987. The combined SSM/I-SMMR data time series exceeds 20 years and provides an invaluable, albeit unanticipated, all-weather data set for GCOS and global change studies.

3. NPOESS

The NPOESS program, scheduled to begin around 2008, provides continuity to the NOAA-POES series and the DoD series of polar-orbiting, operational, environmental satellite systems. Building on new technologies the program is designed to create a new system supporting long-term data for environmental monitoring and global change assessments. NPOESS merges DoD and NOAA meteorological satellite systems into a single national asset. Currently, the first phase of NPOESS is planned to extend through 2018. The satellite series will carry an enhanced suite of instruments incorporating new technologies from NOAA, DoD, and NASA. A tri-agency effort established an NPOESS Integrated Program Office (IPO) to develop, acquire, manage, and operate the next generation of polar-orbiting, operational, environmental satellites.

The NPOESS mission is to provide an Operational remote sensing capability to acquire and receive in real-time at field terminals, and to acquire, store and disseminate to processing centers, global and regional environmental imagery and specialized Meteorological, Climatic, Terrestrial, Oceanographic and Solar-Geophysical and other data in support of Civilian and National Security missions.

To achieve this mission, NPOESS has undertaken a far-reaching program of sensor development and satellite transition to provide complete coverage of meteorological conditions for civil, military, and scientific purposes while cutting operational costs dramatically. The program will adapt existing technology and develop new sensors. To accomplish this, NPOESS satellites in two orbital planes will replace the two-satellite constellations, DMSP and POES, respectively. A satellite of the European Meteorological Satellite Organization (EUMETSAT), METOP will provide data in the mid-morning third orbital plane, jointly establishing a coordinated, three-orbit constellation. NPOESS and EUMETSAT will share data from their polar-orbiting satellites. The sensors onboard NPOESS will collect and disseminate data about Earth's oceans, atmosphere, land, climate, and space environment. NPOESS will include the following new sensors under development:

- VIIRS—Visible/Infrared Imager/Radiometer Suite. Collects visible and infrared radiometric data of the Earth's atmosphere, ocean, and land surfaces. Data types include atmospheric, clouds, Earth radiation budget, land/water surfaces, sea surface temperature, ocean color, and low light imagery.
- CMIS—Conical scanning Microwave Imager and Sounder for clouds, sea surface winds, atmospheric temperature and moisture profiles, all-weather land/water surfaces, hurricanes, and rainfall. Collects global microwave radiometry and sounding data to produce microwave imagery and other meteorological and oceanographic data.
- CrIS—Cross-track Infrared Sounder for atmospheric profiles. Measures the Earth's atmospheric radiation to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere.
- ATMS—Advanced Technology Microwave Sounder. In conjunction with CrIS, ATMS will take global observations of temperature, moisture and pressure profiles at high temporal resolution on a daily basis.
- GPSOS—Global Positioning System Occultation Sensor. Measures the refraction of microwave signals from the GPS and Russia's Global Navigation Satellite System (GLONASS) to characterize the ionosphere. Primary instrument for electron density profiles. Secondary measurements for Tropospheric temperature and humidity profiles.
- OMPS—Ozone Mapping and Profiler Suite. Collects data to permit the calculation of the vertical and horizontal distribution of ozone in the Earth's atmosphere.
- SESS—Space Environment Sensor Suite for magnetic fields, electron, and aurora. Measures neutral and charged particles, electron and magnetic fields, and optical signatures of aurora sensors being developed by other agencies.
- ALT—Radar ALTIMETER. ALT maps the topography (heights) of the ocean surface with respect to the geoid and determines ocean wave characteristics.
- ERB—Earth Radiation Budget Sensor. ERB measures major components of the Earth’s radiation budget and atmospheric radiation from the top of the stratosphere to the surface.
- TSIS—Total Solar Irradiance Sensor. TSIS is a broad-banded Total Solar Irradiance monitor plus two narrow bands to monitor the highly variable, active regions of the sun in the ultraviolet and near-infrared spectral regions.
- CAPS—Cloud and Aerosol Polarimeter Sensor. CAPS will measure cloud and aerosol properties such as aerosol and cloud particle size distributions, aerosol indices of refraction and scattering albedos.
- DCS—Data Collection System. DCS will continue the heritage to collect environmental data from autonomous platforms and will deliver these data to users worldwide.
- SARSAT—Search and Rescue System. SARSAT will continue the heritage to provide free-of-charge distress alert and location for maritime, aviation and land users in distress.

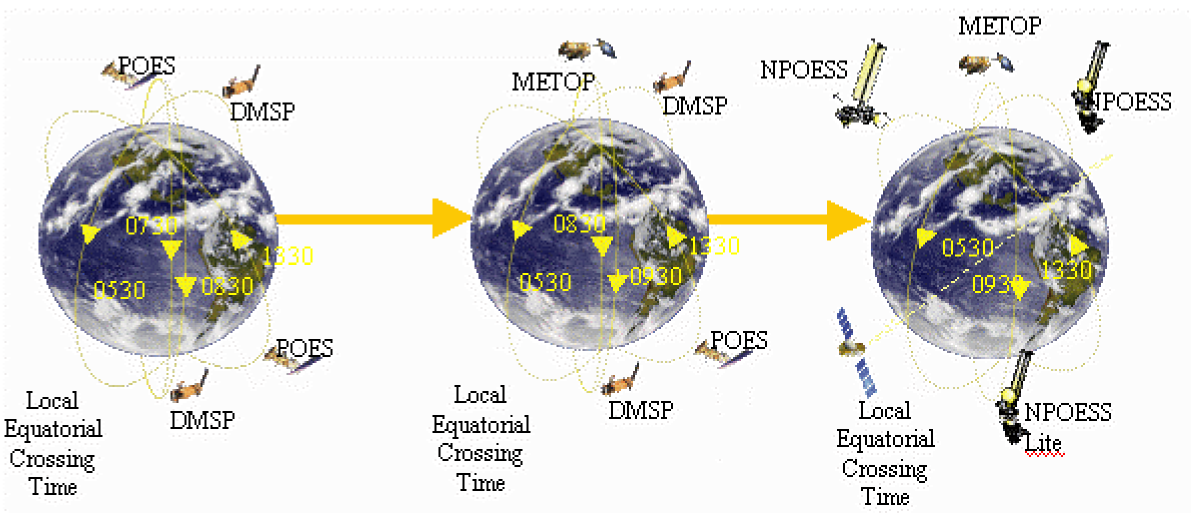
4. NPOESS Preparatory Project (NPP)

Prior to the launch of NPOESS in 2008, an NPP satellite will be launched in the 2005 timeframe as a bridge mission to provide continuity for selected key observations between the EOS series of satellites (Terra and Aqua) and NPOESS. The VIIRS, CrlS, and ATMS sensors are currently under development for the NPP mission to demonstrate advanced technology for atmospheric temperature and humidity soundings, sea surface temperatures, land and ocean biological productivity, and cloud and aerosol properties, among others. They will provide continuing observations for global change after Terra and Aqua.

The primary mission of NPP is to demonstrate advanced technology for atmospheric sounding and imaging, giving continuing observations about global change after EOS-Terra and EOS Aqua. It is an instrument risk reduction project for the following NPOESS sensors under development: VIIRS, CrIS, and ATMS. It will supply data on atmospheric and sea surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. NPP will contribute to instrument risk reduction by offering early instrument and system level testing, lessons learned for design modifications in time to ensure NPOESS launch readiness, ground system risk reduction, early user evaluation of NPOESS data products, such as algorithms, and instrument verification, and opportunities for instrument calibration. Additional information on NPOESS is available at http://www.ipo.noaa.gov/. The NPP and NPOESS programs will lead to the evolution of the U.S. polar satellite observation program as follows:

Evolution

U.S. civil and defense programs, working in partnership with EUMETSAT, will ensure improved global coverage and long-term continuity of observations at a loweer cost!



Today (2001)

4-Orbit System
- 2 U.S. Military
- 2 U.S. Civilian

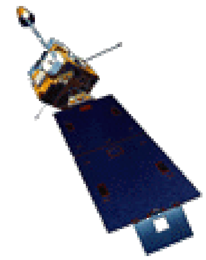
Tomorrow (2005)

4-Orbit System
- 2 U.S. Military
- 1 U.S. Civilian
- 1 EUMETSAT/METOP

Future (2013)

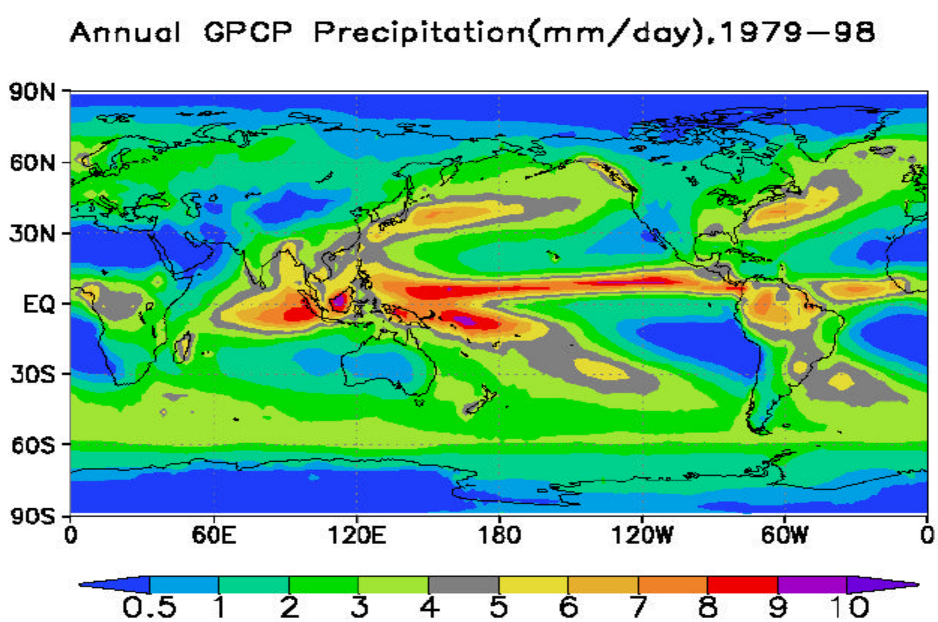
3-Orbit System
- 2 U.S. Converged
- 1 U.S. "Lite"
- 1 EUMETSAT/METOP
- Specialized Satellites

5. Geostationary Operational Environmental Satellites (GOES)



Geostationary satellites observe the Earth from above the equator and maintain their position relative to the Earth at an altitude of 35,790 km or 22,240 miles. The satellite travels around the Earth in the same direction as the rotation of the Earth with an orbital period equal to that of the rotation of the Earth (23 hours, 56 minutes, 04.09 seconds). The U.S. GOES satellites, developed by NASA and operated by NOAA, are positioned around 75 degrees west and 135 degrees west. A worldwide network of operational geostationary meteorological satellites provides visible and infrared images of the Earth's surface and atmosphere on a global basis. The satellite systems include the GOES (USA), METEOSAT (launched by the European Space Agency, and operated by the European Meteorological Satellite Organization-EUMETSAT), the Japanese Geostationary Meteorological Satellite (GMS), and the geostationary satellites operated by India and China.

Operational geostationary satellites have made a considerable contribution to data products for climate. Among them are snow cover, surface insolation, clouds and precipitation and of course vertical moisture and temperature profiles. Clouds and precipitation make extensive use of the worldwide operational geostationary satellites. The former is through the International Satellite Cloud Climatology Project (ISCCP), and the latter through the Global Precipitation Climatology Project (GPCP). The GPCP data is composed of merged POES, geostationary, and gauge data to provide a global map of monthly mean precipitation. The satellite data portion of the GPCP data set specifically consists of geostationary IR from GOES, GMS, Meteosat, NOAA polar orbiting IR data, and DMSP microwave data. The following figure shows the annual mean precipitation for the period 1979 through 1998 and demonstrates the usefulness of GOES data to producing climate data sets.

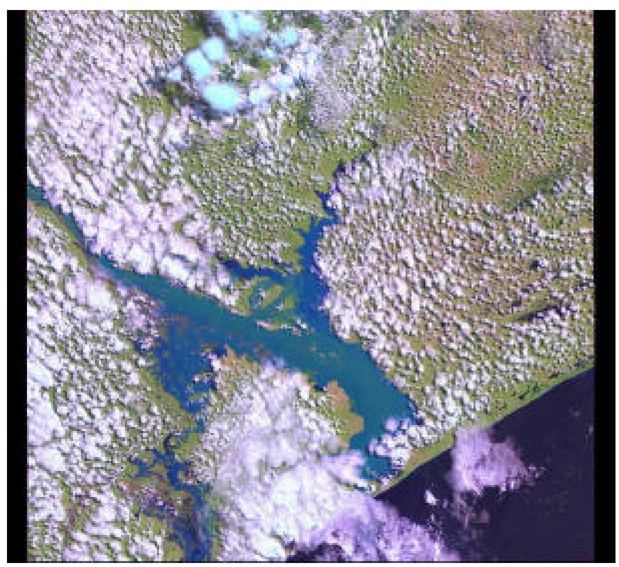


The NOAA-GOES carries three major sensor systems:

- A multi-spectral, five-channel, imaging instrument capable of simultaneously sweeping one visible and four infrared channels in a North-to-South swath across an east-to-west path, providing full disk imagery once every 30 minutes.
- A sounder with more spectral bands than the imager, to produce high quality profiles of temperature and moisture, surface and cloud temperatures, and ozone distribution, capable of stepping one visible and eight infrared channels in a north-to-south swath across an east-to-west path. The most recent GOES-11 satellite has a sounder with a 19-channel discrete filter radiometer.
- The Space Environment Monitor (SEM) to measure the condition of the Earth's magnetic field, solar activity and radiation around the spacecraft.

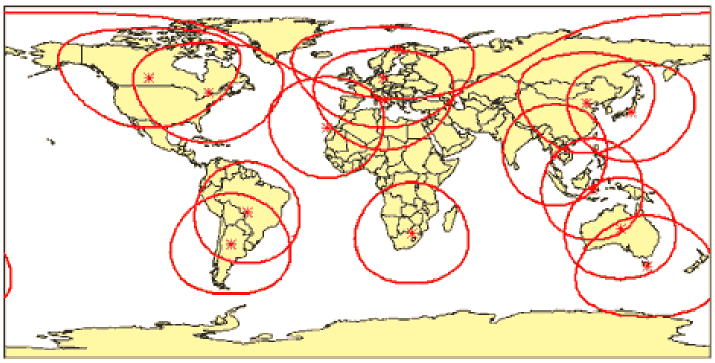
GOES-M, an advanced environmental satellite equipped with instruments to monitor Earth's weather and a telescope for detecting solar storms, was launched on July 23, 2001, by NASA for NOAA. Following scheduled apogee motor firings and adjustment maneuvers, the spacecraft was placed in a geosynchronous orbit, 35,790 km above the Earth's equator, at 90 degrees West longitude. As with other GOES satellites, GOES-M will be renamed and will be commissioned by NOAA as GOES-12. Currently, GOES-M provides a fully capable spacecraft in on-orbit storage that can be activated on short notice to assure continuity of service from the current two-spacecraft operational constellation. GOES-M is also the first GOES satellite equipped with a Solar X-ray Imager (SXI) instrument that will be used to aid in forecasting Earth's space weather due to solar activity. The SXI will gather full and detailed data of the sun's atmosphere each minute. The data will be used to forecast the intensity and speed of solar disturbances that could destroy satellite electronics, disrupt long-distance radio communications, or surge power grids.

6. Landsat



Landsat 7 Image of Severe Flooding of the Mozambique Coastline, March 2000

Landsat is a series of satellites designed to gather data on the Earth's resources for application to global change research, land cover classification, geological and mineralogical exploration, crop and forest assessment, and cartography. Landsat-1 was developed and launched by NASA in 1972 following the early success of NASA's TIROS and Nimbus series, to expand the possibilities for Earth remote sensing from space. This was in response not only to geologists and biologists, but also a broad community of scientists, natural resource managers, and engineers. The Multi-Spectral Scanner (MSS) proved to be so valuable that a version of it has been flown on each of the first five Landsat missions. With the 1982 launch of Landsat-4, the Thematic Mapper (TM) was introduced. The TM was a significant improvement over the MSS, providing greater spatial resolution in the visible and near-infrared regions (30 m vs. 80 m), and three additional spectral bands. Landsat-5, launched in 1984, continues to provide coverage well beyond its design lifetime, and is operated by the USGS. Landsat-6 failed to reach orbit in 1993. Landsat-7, which is also operated by the USGS, was launched by NASA on April 15, 1999, in sun-synchronous orbit (705 km) to provide continuity and enhanced coverage to characterize, monitor, manage, explore, and observe the continental Earth's surface. Landsat-7's payload consists of the Enhanced Thematic Mapper Plus (ETM+). New features on Landsat-7 include a panchromatic band with 15-meter spatial resolution, a thermal infrared channel with 60-meter resolution, both high and low gain, on-board radiometric calibration, and a solid-state tape recorder to collect imagery outside the range of ground stations. The tape recorder has a capacity of 380 gigabytes (100 scenes). ETM+ provides continuity with the Thematic Mapper that flew on Landsat-4 and Landsat-5 and assures worldwide coverage as defined in a Long Term Acquisition Plan (LTAP). All Landsat data captured by the U.S. since 1972 are archived, managed, and distributed by the USGS Earth Resources Observation Systems (EROS) Data Center (EDC).



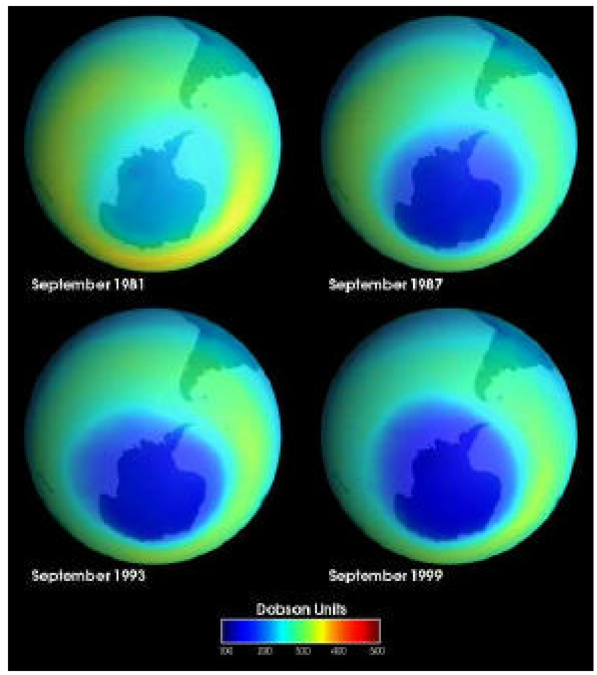
Location and Area Coverage of U.S. and International Landsat 7 Ground Stations

D. Research and Experimental Satellites

1. ACRIM-III

The Active Cavity Radiometer Irradiance Monitor (ACRIM-III), a small satellite-dedicated mission, called ACRIMSAT, launched in December 1999, continues the series of satellite data monitoring solar irradiance. ACRIM-III instrument is a miniaturized version of the technology flown successfully on SMM, Spacelab-1, and Atlas missions. Surveillance of radiation received from the sun began with instruments on board Nimbus-7 in 1978, which continued through early 1993, providing the longest data set currently available for solar measurements. The unambiguous evidence of variability in total solar irradiance (TSI) was first obtained from the highly precise ACRIM instrument on the SMM in 1980. The satellite is spin stabilized with the instrument's solar viewing axis aligned with the sun within 0.25º using magnetic torquers. The sun is a variable star, and luminosity has been found to vary by about 0.1% over a solar cycle in phase with the level of solar magnetic activity. Sustained change in total solar irradiance (TSI), as small as a few tenths of one percent per century, could be a primary cause for significant climate change. A precision TSI database, with resolution adequate to correlate centuries of systematic TSI variation to climate change, must be compiled from the results of many flight experiments. With a nominal lifetime of 5 years per experiment, their contiguous results must be related with the maximum precision accessible to current technology, on the order of 10 ppm. This far exceeds the capabilities of current "ambient temperature" flight instrumentation to define the "absolute uncertainty" of the TSI (>1000 ppm) and even that of cryogenic instrumentation currently under development (>100 ppm). Modeling TSI using ground-based observations of proxy solar emission features is orders of magnitude less precise. The single approach capable of providing the required precision for the long-term TSI database using current measurement technology employs an “overlap strategy” in which successive ambient temperature TSI satellite experiments (each with a nominal lifetime of 5 years) are compared in flight, transferring their operational precision to the database. The current generation of ambient temperature ACRIM flight instrumentation has demonstrated a capability of providing annual precision of approximately 5 ppm of TSI. A second phase ACRIM instrument is planned for launch in late 2001. It will combine the TSI database maintenance function with a new technology designed to develop a prototype instrument for both total and limited spectral solar monitoring on an operational basis in the NPOESS program. The Total Solar Irradiance Mission (TSIM), planned for launch in 2002, will carry a combination of solar radiometer and spectrophotometer instruments to measure: total (full spectrum) solar irradiance with absolute accuracy of 0.1% or better, and relative precision of 2×10^{-5} per year; and solar radiation spectrum in the range 200 nm (ultraviolet) to 2500 nm (short-wave infrared) with absolute accuracy of 2% or better and relative precision of 2×10^{-4} per year.

2. TOMS



TOMS Images Depicting the Progressive Depletion of Ozone Over Antarctica from 1981-1999

The Total Ozone Mapping Spectrometer (TOMS) instrument, which measures atmospheric total column ozone, has flown on various spacecraft since 1978. It has been the mainstay of international efforts by the WMO, the United Nations Environment Program (UNEP), and other agencies to monitor Antarctic, Arctic, and global ozone depletion in support of the Montreal Protocol on ozone depletion. NASA flew the first TOMS instrument on-board the Nimbus-7 satellite in 1978. It operated for almost 15 years (until May 1993). A second TOMS was flown aboard the Meteor-3 (Russia) satellite, which operated from August 1991 to December 1994. A third TOMS was flown aboard the ADEOS-I (Japan) satellite operating from August 1996 to June 1997. A fourth TOMS was launched on board an Earth probe mission in July 1996 and remains operational. The gap in TOMS coverage (December 1994 – July 1996) has been filled by SBUV/2 (on NOAA-11) data and European Global Ozone Monitoring Experiment (GOME) data. QuikTOMS is scheduled for launch in June 2001 to bridge any possible gaps in data continuity before ADEOS-II (Japan) is launched with a TOMS instrument. Stratospheric ozone and aerosol profile data have mainly been obtained from the Stratospheric Aerosol and Gas Experiment (SAGE) program. SAGE-type instruments (SAM-II, SAGE-I, SAGE-II) have been flown since 1978. SAGE-III which takes advantage of both solar and lunar occultation is scheduled to be launched on board the Meteor 3M-1 (Russia).

3. UARS

Launched by NASA in September 1991, the Upper Atmospheric Research Satellite (UARS) was the first satellite dedicated to increasing our understanding of the chemistry and dynamics of the Earth's stratosphere and mesosphere. UARS measures atmospheric ozone depletion chemistry, trace gases, water vapor, winds, and solar variations. It confirmed the role of CFCs in ozone depletion and clarified chemical processes that cause the Antarctic ozone hole. UARS made the first measurements of key stratospheric gases chlorine nitrate ($CLONO_2$), chlorine monoxide (CLO), hydrogen fluoride (HF), hydrogen chloride (HCL), and dinitrogen pentoxide (N_2O_5). These measurements along with the measurements of nitric oxide (NO), nitrogen dioxide (NO_2), and nitric acid (HNO_3) provide a comprehensive picture of stratospheric photochemical processes involved in ozone depletion. UARS provided the first comprehensive mapping of volcanic aerosol layers and documented the slow increase in aerosol amounts following the eruption of Mt. Pinatubo in the Philippines. The satellite also gave us the first global picture of atmospheric tides, a clearer understanding of solar ultraviolet radiation (UV) variations, insight into the relationship between upper tropospheric water vapor and climate, and multiyear information on the transport of trace gases into the stratosphere. UARS was designed to make observations of the upper atmosphere for 18 months. More than 7 years after launch, UARS continued to make observations with 8 of 10 instruments and continues to collect data. The UARS measures the following parameters with associated instrumentation. These include: (1) Chemistry: Cryogenic Limb Array Etalon Spectrometer (CLAES), Halogen Occultation Experiment (HALOE), Improved Stratospheric and Mesospheric Sounder (ISAMS), Microwave Limb Sounder (MLS); (2) Wind Measurements: High Resolution Doppler Imager (HRDI), Wind Imaging Interferometer (WINDII); (3) Solar Measurements: Active Cavity Radiometer Irradiance Monitor (ACRIM II), Solar/Stellar Irradiance Comparison Experiment (SOLSTICE), Solar Ultraviolet Spectral Irradiance Monitor (SUSIM); and (4) Energetic Particle Measurements: Particle Environment Monitor (PEM).

The EOS-Aura satellite (previously CHEM–see full description in section H-7) is scheduled for the 2003-2008 timeframe, and builds on the heritage of measurements initiated by the still active UARS. Aura will also carry a totally new, high spectral resolution (~0.025 cm^{-1}) Tropospheric Emission Spectrometer (TES), that will allow vertically resolved measurements of ozone and trace gas constituents.

4. TOPEX/Poseidon

Jointly developed by NASA and CNES (France), the TOPEX/Poseidon (Ocean Topography Experiment) carrying dual and single frequency altimeters was launched in August 1992 to accurately measure the altitude of the satellite above the sea surface, sea surface wind speed and wave energy. The dual-frequency altimeter corrects for ionospheric effects. A GPS receiver is one of the three systems used to precisely track the satellite orbit. A laser retroreflector, used with ground-based lasers, measures satellite position and verifies the satellite altimeter's height measurements. A microwave radiometer measures atmospheric water vapor content and is used to correct altimeter measurements for pulse delay caused by water vapor. Sea surface height is measured to within 4.3 cms. The triple tracking system determines the satellite's location to within 2.8 cms. The distance between the ocean surface and the satellite is measured with an accuracy of 3.2 cms. The follow-on to TOPEX/Poseidon is Jason-1, scheduled for launch in Fall 2001.

5. SeaWiFS

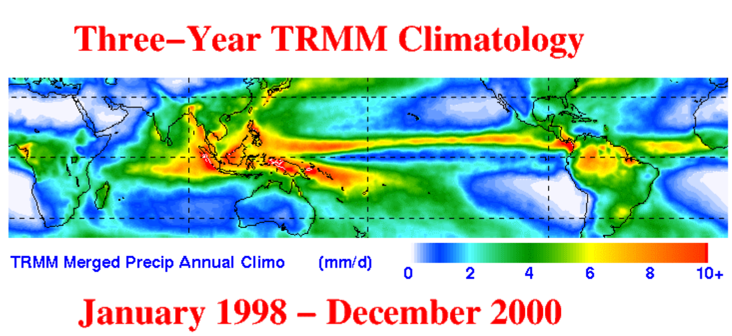
SeaWiFS was launched in August 1994, and resumed the measurement of ocean color (phytoplankton) made from 1978 to 1986 by the CZCS satellite. Aerosols directly affect the radiative transfer in the atmosphere, and therefore, the radiation received by a satellite from the surface of the Earth (land and ocean). When surface or near-surface signals are received from sensor-measured radiances at satellite altitude, the atmospheric effect must be removed. This atmospheric correction removes more than 90% of the observed radiance at visible wavelengths measured at the top of the atmosphere. The SeaWiFS satellite's atmospheric correction algorithm uses radiances measured at two near-infrared wavelengths, 765 nm and 865 nm, at which the ocean appears black due to strong absorption by water to estimate the aerosol optical properties and extrapolate them into the visible spectrum. This enables SeaWiFS to measure global ocean color and ocean bio-optical properties. Aerosol optical properties, particularly optical depth or thickness, is an important byproduct of the SeaWiFS atmospheric correction.

E. Recently Launched "Next" Generation Research Satellites and Instruments

Substantially improved satellite instruments have been under development for the past five or ten years. They address several of the deficiencies found in the older technologies used even in the current generation of operational satellites. They typically have a broader spectral range, better spectral resolution, more flexibility in terms of view angles, and much better spatial resolutions. Importantly, they have the best possible on-board calibration systems. The sections that follow describe some next-generation satellite instruments, several of which have already been recently launched.

1. Tropical Rainfall Measuring Mission (TRMM)

Tropical Rainfall Measuring Mission (TRMM)



In November 1997, the TRMM was launched as a collaborative venture between NASA and the National Space Development Agency (NASDA) of Japan. It measures rainfall, clouds, sea surface temperature, radiation, and lightening using five instruments: the first space-borne precipitation radar (PR), the TRMM Microwave Imager (TMI), a Visible and Infrared Scanner (VIRS), a Cloud and Earth Radiant Energy System (CERES), and a Lightning Imaging Sensor (LIS). The precipitation radar and microwave radiometer measure the vertical distribution of precipitation over the tropics between +/- 35° in latitude, from the surface to about 20 km: horizontal resolution: 4 km; swath width: 220 km. Rain rates down to about 0.7 mm/hour can be detected. TRMM will reduce the uncertainty in global tropical rainfall estimates to about 10%, an 80% improvement over the current uncertainty of about 50%. The TMI has a full suite of channels ranging from 10.7 GHz to 85 GHz and is the first satellite sensor capable of accurately measuring SST through clouds. When rain is not present, attenuation at 10.7 GHz is small and 97% of the sea surface radiation reaches the top of the atmosphere. The high frequency channels (19 to 37 GHz) can precisely estimate the 3% attenuation due to oxygen, water vapor, and clouds. The 37-GHz channels are very sensitive to rain and are used to determine when rain is in the radiometer's field of view. At frequencies below about 12 GHz, microwaves penetrate clouds with little attenuation providing a clear view of the sea surface under all weather conditions except rain. At these frequencies aerosols have no effect. The first satellite microwave radiometers operating at such low frequencies were successfully demonstrated on Nimbus-7 and Seasat in 1978, but they were limited by poor calibration systems. The VIRS senses radiation in five spectral regions ranging from the visible to infrared (0.63 to 12 µm). It serves as a rainfall indicator and a transfer standard between TRMM measurements and those made routinely on the operational POES and GOES satellites.

2. NASA-Shuttle Radar Topography Mission

NASA's-Shuttle Radar Topography Mission (SRTM) radar system was flown on board Space Shuttle Endeavor on February 11, 2000. Its mission was to gather high resolution topographic data over approximately 80% of the land surfaces of the Earth, creating the first-ever, near global data set of land elevations. To acquire topographic (elevation) data the SRTM payload was outfitted with two radar antennas, one in the shuttle payload bay, and the other on the end of a 60m mast extended from the payload once the shuttle was in orbit. While various preliminary images and maps have already been released, the full calibration of the SRTM was completed in early 2001, and production processing is scheduled to begin in late 2001.

3. NASA's EOS Satellite Series

NASA's EOS is a series of polar orbiting and mid-inclination satellites specifically developed to monitor nearly all aspects of the Earth system with unprecedented calibration, accuracy, spectral discrimination, and spatial resolution. The first major satellite of the EOS-series began in 1999 with the launch of EOS-Terra. It had a sun-synchronous polar orbit, descending southward across the equator in the morning. The second, to be launched in 2001 will be EOS-Aqua in a sun-synchronous polar orbit ascending northward across the equator in the afternoon. This will be followed in later years by EOS-Aura. The key instrument developed to fly on Terra and Aqua is the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS will continue to take measurements in spectral regions that have been and are currently being measured by other satellites, or "heritage" instruments. Therefore, MODIS will extend the time series of data sets taken by such instruments as AVHRR, used for meteorology and monitoring sea surface temperature, sea ice, and vegetation; and the CZCS used to monitor ocean biomass and ocean circulation patterns.

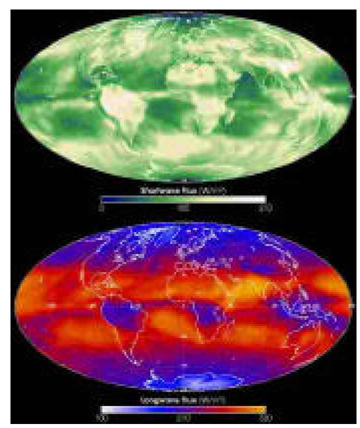
The EOS satellite sensors have unprecedented on-board calibration systems, enabling a characterization of their performance throughout the lifetime of each satellite's mission; and the correction of errors introduced into the data due to system degradation. Calibration is a set of operations or processes used to determine the relationship between satellite instrument output (i.e., digital counts) and corresponding known values of a standard, expressed in Systeme Internationale (SI) units. Pre-flight calibration and characterization includes radiometric and geometric calibration. Radiometric calibration involves determining the relationship between instrument output and radiant input while the instrument views a calibrated radiant source. For the solar spectrum (400 to 2500 nm), the calibrated radiant source is an integrating sphere which has been calibrated using standards. For thermal infrared (above 2500 nm) the calibrated source is a variable temperature blackbody. Pre-flight geometric calibration involves the determination of the detailed spatial response of each instrument band with respect to the nominal instrument telescope pointing direction. Geometric calibration is necessary for converting the instrument radiometric data into images with known relationships to observed Earth targets. Instruments will also be radiometrically and geometrically calibrated on orbit using solar diffusers, blackbodies, space viewports, and, in the case of MODIS, a monochromatic source known as the spectroradiometric calibration assembly. The moon will also be used by EOS and other satellite instruments as a common, stable, on-orbit radiance reference target. The accuracy and precision of Earth remote sensing data sets produced by different instruments are achieved only by the consistent use of common on-orbit calibration sources and measurement methodologies. EOS-Terra will perform an on-orbit, pitch-based, calibration attitude maneuver to enable the instruments to view deep space and the moon. The deep space view provides CERES and ASTER an accurate determination of the DC offsets in their thermal bands, and it provides MODIS the opportunity to characterize the dependence of the thermal infrared reflectance on the angle of incidence of the scan mirror. The same pitch-based maneuver also provides EOS instruments the opportunity to view the Moon at a lunar phase of 22º. The moon affords the ability to monitor radiometric responsivity and stability in the visible, near-infrared, and shortwave infrared wavelengths, among others. Validation of satellite measurements is carried out through various means such as cross-comparing the satellite measurements with aircraft observations.

F. Specific EOS-Terra Research Instruments

1. EOS-Terra

With an AM equatorial crossing, EOS-Terra was launched on December 18, 1999, by NASA. Terra houses five instruments for simultaneous, geolocated measurements and for the intercomparison of new measurement techniques. For example, the MODIS detailed internal calibrations will be used, through simultaneous geolocated measurements, to help in the calibration of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The MODIS and ASTER high-resolution multi-channel observations of clouds will be used by the Clouds and the Earths Radiant Energy System’s (CERES) low resolution radiative flux measurements, and by the Measurement of Pollution in the Troposphere (MOPITT) instrument to determine the location, distribution and properties of clouds. The Multi-angle Imaging Spectrometer’s (MISR) multi-angle measurements will determine the angular reflectance properties of land surface features, aerosols, and clouds, all of which will be used in the data analysis of MODIS, ASTER and CERES. Vegetation properties will be derived from both MODIS and MISR data. Aerosol properties will be measured by MODIS using its wide spectral range and 1-2 day single view coverage, and also independently by MISR using its multi-angle data, narrow spectral range, and 2-9 day coverage. Water vapor will be derived independently from MODIS measurements of reflected near-infrared sunlight and emitted terrestrial infrared radiation. Emitted smoke particles from biomass burnings and forest fires will be observed by MISR and MODIS, and emitted trace gases (carbon monoxide and methane) observed by MOPITT. Terra will provide, for the first time, simultaneous measurements of clouds, aerosols, atmospheric trace gases, land and ocean surface properties, and Earth radiation budget parameters. The first CERES instrument was flown on TRMM and will also provide continuity to Earth Radiation Budget Experiment (ERBE) and pre-ERBE Earth radiation budget measurements. ASTER, developed and built by the Ministry of International Trade and Industry (MITI) in Japan, has 14 spectral bands in the visible, near-infrared, shortwave infrared and thermal infrared wavelengths, and spatial resolutions ranging from about 15 to 90 meters. MISR, a new instrument, views the Earth in four color bands (blue: 446 nm; green: 558 nm; red: 672 nm; and near-infrared: 866 nm) and from nine view angles with nine cameras pointed in different directions. MODIS views the Earth every 1-2 days making observations in 36 co-registered spectral bands at moderate resolution (250 m to 1 km). MOPITT, developed by the University of Toronto, Canada, employs gas correlation spectroscopy to measure upwelling and reflected radiation in three absorption bands of CO and CH_4. EOS-Terra instruments are described in the following sections. With a development time of approximately 10 years, the EOS series of NASA's flagship satellites represents an unprecedented effort in space-based remote sensing of the Earth system as a whole, and meets and exceeds the requirements of GCOS and the climate monitoring principles identified by UNFCCC/COP-5. These satellites are likely to be the main stay of Earth science research for the next decade. It is noteworthy that NASA's EOS has involved a large number of partnerships between NASA and the space agencies of many different countries. The enterprise represents a significant achievement in international collaboration.

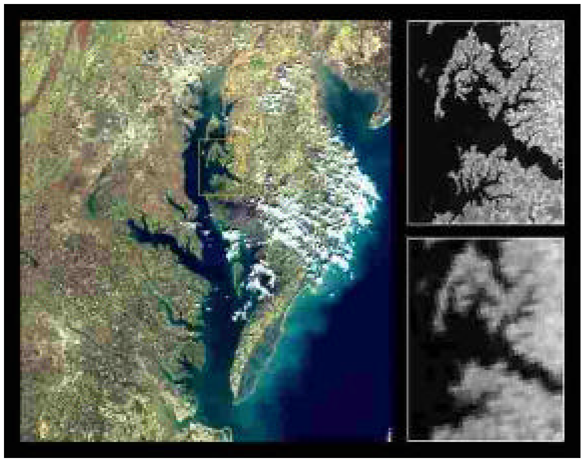
2. EOS-Terra/CERES



Terra-CERES Monthly Global Longwave and Shortwave Radiation

CERES is based on NASA's Earth Radiation Budget Experiment (ERBE), which used three satellites to provide global energy budget measurements from 1984 to 1990. The first CERES instrument was flown on TRMM. CERES will provide continuity to ERBE and pre-ERBE measurements. It is a broadband scanning thermistor bolometer package with extremely high radiometric measurement precision and accuracy. Terra/CERES will carry two identical instruments; one will operate in a cross-track mode and the other in a biaxial scan mode. The cross-track mode will essentially continue the measurements of the ERBE and TRMM missions, while the biaxial mode will provide new angular flux information that will improve the accuracy of angular models used to derive the Earth's radiation balance. Each CERES instrument has three channels–a shortwave channel for measuring reflected sunlight, a longwave channel for measuring Earth emitted thermal radiation in the 8-12 µm "window" region, and a total channel for total radiation. On-board calibration hardware includes a solar diffuser, a tungsten lamp system with a stability monitor, and a pair of black-body sources. Cold space and internal calibration looks are performed during each normal Earth scan. Both CERES scanners operate continuously throughout the day and night portions of an orbit. In the cross-track scan mode, calibration occurs biweekly. In the biaxial mode, calibrations also occur biweekly, and sun avoidance short scans occur twice per orbit. CERES will be used to study cloud radiative forcings and feedbacks, develop an observational baseline for clear-sky radiative fluxes, determine radiant input to atmospheric and oceanic energetics models, validate general circulation models, and enhance extended-range weather predictions.

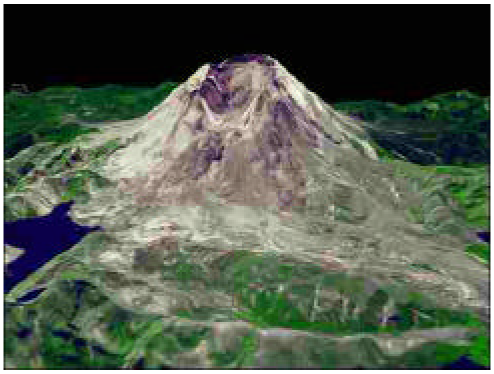
3. EOS-Terra/MODIS



Terra/MODIS True Color Image of the Chesapeake Bay, March 2000

MODIS views the entire Earth's surface every 1-2 days, making observations in 36 co-registered spectral bands at moderate resolution (0.25 – 1 km). MODIS is a whiskbroom scanning imaging radiometer consisting of a cross-track scan mirror, collecting optics, and a set of linear arrays with spectral interference filters located in four focal planes. With a viewing swath width of 2330 km (the field of view sweeps +/- 55º cross-track), MODIS will provide high radiometric resolution images of daylight-reflected solar radiation and day/night thermal emissions over all regions of the globe. Spatial resolution varies from 250 m to 1 km at nadir: 250 m (2 bands), 500 m (5 bands), 1000 m (29 bands) at nadir. The broad spectral coverage of the instrument (0.4 – 14.4 µm) is divided into 36 bands of various bandwidths optimized for imaging specific surface and atmospheric features: 21 bands within 0.4 to 3.0 µm; 15 within 3 to 14.5 µm. Polarization sensitivity: 2% from 0.43 µm to 2.2 µm and +/- 45º scan. Absolute irradiance accuracy: 5% for <3 µm and 1% for >3µm. The observational requirements also lead to a need for very high radiometric sensitivity, precise spectral band and geometric registration, and high calibration accuracy and precision. The MODIS instrument has one of the most comprehensive onboard calibration subsystems ever flown on a remote sensing instrument. Calibration hardware includes a solar diffuser stability monitor, a spectroradiometric calibration assembly, a plate-type black body, and a space view port.

4. EOS-Terra/ASTER



Terra/ASTER Image of Mount St. Helens Volcano, Washington State, August 2000

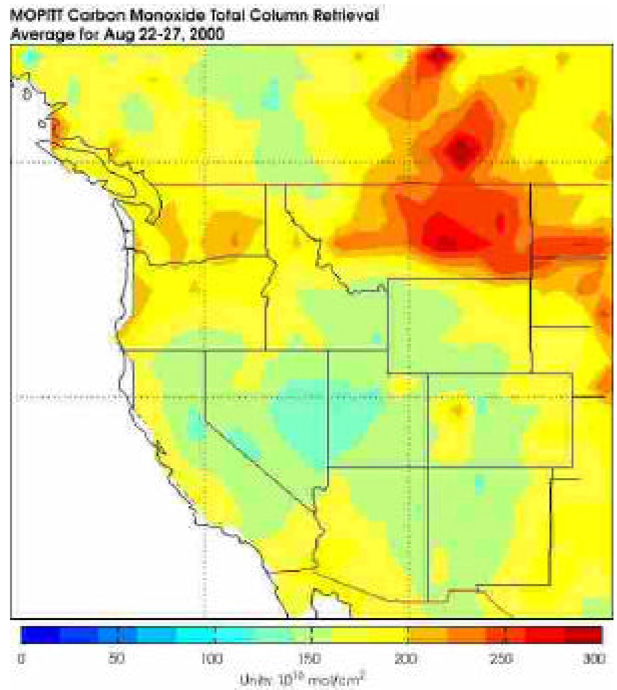
Developed and built by MITI-Japan, ASTER has a broad spectral coverage and high spectral resolution with 14 spectral bands covering visible and near-infrared (VNIR), shortwave-infrared (SWIR) and thermal infrared (TIR) wavelengths. Spatial resolution is high ranging from about 15 to 90 meters. Spectral separation is accomplished through discrete bandpass filters and dichroics. The VNIR subsystem operates in three VNIR bands, with 15 m resolution and 60 km swath width. It consists of two telescopes, one that looks backward (along track) and one that looks at nadir, which together produce same-orbit stereo images. The telescope pair is pointable cross-track over a +/- 24º angle to increase the revisit frequency of any given Earth location. Light from either of two on-board halogen lamps will be used periodically for calibration. The SWIR subsystem operates in six SWIR channels, with a 30 m resolution and 60 km swath width. It contains a mirror that can point +/- 8.54º from nadir to allow coverage of any point over the spacecraft's 16-day cycle. The mirror is used periodically to direct light from either of two on-board calibration lamps into the subsystem's fixed aspheric refracting telescope. The TIR subsystem operates in five TIR channels with 90 m resolution and 60 km swath width. It contains a scan mirror used for both scanning and pointing up to +/- 8.54 degrees from nadir. As with the SWIR, this mirror is also used periodically to view the on-board blackbody for calibration. Light from the TIR scan mirror is reflected into a Newtonian catadioptric telescope system with an aspheric primary mirror and lens for aberration correction. ASTER instruments operate for a limited time during the day and night portions of an orbit. The full configuration (all bands plus stereo) collects data for an average of 8 minutes per orbit. Reduced configurations (limited bands, different gains, etc.) can be implemented as requested by investigators. ASTER is the highest spatial resolution instrument on EOS-Terra and the only one that does not acquire data continuously. Monitoring application products include active volcanoes, crops and crop stress, cloud morphology and physical properties, wetlands evaluations, thermal pollution, coral reef degradation, and surface heat balance.

5. EOS-Terra/MISR

MISR Image of James Bay Canada Showing Contrast Between Summer (left) and Winter (Right), August 2000 and January 2001

MISR is a new instrument on board EOS-Terra, which will view the Earth in four color bands (446 nm–blue, 558 nm–green, 672 nm–red, and 866 nm–near-infrared) and from nine view angles with nine cameras pointed in different directions. Spatial resolution is about 275 meters to 1.1 km, with swaths of 360 km. The nine angles are: 70.5, 60.0, 45.6, and 26.1 degrees in the forward and aft directions, and 0.0 degrees. MISR is the first instrument to carry sensors making simultaneous observations at different angles from the same platform. Different combinations of look angles and spectral band are optimized to meet different scientific objectives. Over a period of 7 minutes, a 360 km wide swath of the Earth comes into view at all nine angles. Highly accurate absolute and relative radiometric calibration is achieved on-board using deployable solar diffuser plates and several types of photodiodes. On-board calibration is complemented by in-situ field instruments (such as PARABOLA-III), which automatically scan the sky and ground at many different angles, and multi-angle aircraft cameras (AirMISR). Global coverage is acquired every nine days at the equator. MISR will monitor the monthly, seasonal, and long-term trends in the amount and type of atmospheric aerosol particles (natural and human produced); amount, type, and heights of clouds; and the distribution of land surface cover, including vegetation canopy structure.

6. EOS-Terra/MOPITT



MOPITT, developed by the University of Toronto, Canada, is a scanning radiometer employing gas correlation spectroscopy to measure upwelling and reflected infrared radiance in three absorption bands of carbon monoxide and methane. The instrument modulates sample gas density by changing the length or the pressure of the gas sample in the optical path of the instrument, with detectors at 2.3, 2.4, and 4.7 µm. CO concentrations are obtained using pressure and length modulation with three independent pieces of information represented by values on seven pressure levels as well as CO and CH_4 columns. Spatial resolution: 22 km at nadir. Swath width: 640 km. MOPITT operates continuously, providing data on both day and night portions of an orbit. Calibration using on-board blackbodies and a space look occurs monthly and provides calibration at an elevated blackbody temperature. MOPITT data will be used to measure and model CO and CH_4 in the troposphere; obtain CO profiles with a resolution of 22 km horizontally and 3 km vertically, with an accuracy of 10%; measure the CH_4 column in the troposphere with a resolution of 22 km and a precision of better than 1%; and generate global maps of CO and CH_4 distribution, providing increased knowledge of tropospheric chemistry. Heritage: AVHRR, HIRS, Landsat TM, Nimbus-7 Color Scanner.

G. Future (Approved) NASA Research Satellites

1. QuiKTOMS

QuiKTOMS, scheduled for launch in Summer 2001 will measure the atmospheric ozone column and provide continuity to TOMS measurements. (See TOMS for description.)

2. Jason-1

Scheduled for launch in Fall 2001, Jason-1 (France), with the Poseidon-2/JMR/DORIS instrument package, will provide sea surface height (sea level), sea surface wave height, sea surface winds, and ocean surface circulation parameters. Poseidon-2 is the key instrument measuring sea surface heights, with DORIS providing precise orbit determination, and JMR providing range correction. Jason-1 will provide continuity to TOPEX/Poseidon (Joint US-France).

3. EOS-Aqua

Scheduled for launch in Fall 2001, Aqua will monitor the Earth system at a PM equatorial crossing time, complementing EOS-Terra (AM crossing). The instrument suite on board Aqua includes: MODIS (also on Terra), CERES (also on Terra), The Advanced Scanning Microwave Radiometer (ASMR-E, with Japan), Atmospheric Infrared Sounder (AIRS), AMSU-A, and HSB. MODIS and CERES on Aqua provide complementary and higher diurnal time resolution with the identical instruments on Terra (AM crossing). AIRS will fly on Aqua with two operational microwave sounders, the Advanced Microwave Sounding Unit (AMSU) and Humidity Sounder for Brazil (HSB). The AMSU and the HSB measurements will be analyzed jointly with AIRS to filter out the effects of clouds from the IR data in order to derive clear column air temperature profiles with very high vertical resolution and accuracy, plus high accuracy sea surface temperatures. The HSB microwave radiometer is being developed by Brazil.

4. SeaWinds

Scheduled for launch in November 2001, SeaWinds will measure surface winds and wind stress over the ocean surface. SeaWinds builds on the heritage of the NASA Scatterometer (NSCAT) instrument flown aboard the Japanese ADEOS-I in 1996-1997. For continuity, NASA flew QuickScat in June 1999 and will also fly the instrument on board ADEOS-II (Japan) to further improve and test the active scatterometer technique. Concurrently, the U.S. Navy is preparing an experimental satellite mission (CORIOLIS) to test the passive microwave polarimetry-radiometer technique for vector wind finding applications. NSCAT will be flown on ADEOS-II (Japan) when launched.

5. EOS-ICESat

Scheduled for launch in December 2001, the first precision altimetry mission of the Ice, Cloud and Land Elevation Satellite (EOS-ICESat) will carry the Geoscience Laser Altimetry System (GLAS) and a GPS orbit determination system, to measure along-track ice sheet and land topography to an absolute accuracy of 10 cm or better, and within a footprint of 70 m or less. The mission will also provide cloud profile information with reduced vertical information. A repeat mission, focused on the primary science goal of measuring changes in the topography and mass balance of polar ice sheets is under planning for the 2010 time frame.

6. Solar Radiation and Climate Experiment

Scheduled for launch in July 2002, the Solar Radiation and Climate Experiment (SORCE) will provide daily measurements of Total Solar Irradiance (TSI), and spectral solar irradiance between 1 nm and 2000 nm, incorporating absolute sensors, in-flight calibration, and, in the case of the UV observations, comparisons to bright early-type stars. (Also see description under ACRIM-III).

7. EOS-Aura

Scheduled for launch in June 2003, EOS-Aura (previously EOS-CHEM) will comprehensively measure atmospheric chemical composition, building on the heritage of the still active UARS, and SAGE. Aura will make the first global measurements of tropospheric chemistry. Instruments include the microwave limb sounder (MLS), and the High Resolution Dynamic Limb Sounder (HIRDLS). MLS measures lower stratospheric temperature and concentrations of H_2O, O_3, ClO, BrO, HCl, OH, HNO_3, HCN, and N_2O for their effects on (and diagnosis of) ozone depletion, transformation of greenhouse gases, and radiative forcing of climate change. HRDLS is an infrared limb sounder to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature; concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $CLONO_2$; aerosols; and polar stratospheric clouds and cloud tops. CHEM will also carry a totally new, high spectral resolution (~0.025 cm^{-1}) Tropospheric Emission Spectrometer (TES), which will allow vertically resolved measurements of ozone and trace gas constituents. Data continuity for GCOS research purposes is provided by similar instruments which are also on-board by UARS.

H. Future (Approved) Experimental Satellites

1. Gravity Recovery and Climate Experiment (GRACE)

The observational goals of the GRACE are achieved by making accurate measurements of the inter-satellite range between two co-planar, low altitude polar orbiting satellites, using a microwave tracking system. In addition, each satellite will carry geodetic quality GPS receivers and high accuracy accelerometers to enable accurate orbit determination, spatial registration of gravity data, and the estimation of gravity field models. The differential influence of the gravity field is manifest as a difference in the orbit motion of the center of gravity of the GRACE satellite. The distance change, and hence the gravity field variations, must be inferred from the phase change measurements made between the spacecraft antenna phase centers on the two satellites using the K-band ranging instrument. In essence, the two satellites themselves become the instrument.

2. CloudSAT

CloudSAT will use advanced radar to “slice” through clouds to see their vertical structure, providing a completely new observational capability from space. Current satellites can only image the uppermost layers of clouds. CloudSAT will be one of the first satellites to study clouds on a global basis and look at their structure, composition and effects. Instruments include a 94-GHz Cloud Profiling Radar (CPR), and a Profiling Oxygen A-Band Spectrometer/Visible Imager (PABSI). The satellite will be launched (scheduled: May 2003) into a 705 km sun-synchronous orbit, and fly in formation with EOS-Aqua and PICASSO-CENA.

3. Vegetation Canopy Lidar (VCL)

The VCL carries a Multi-Bream Laser Altimeter (MBLA) for the characterization of the three-dimensional structure of the Earth’s surface, including the vegetation canopy heights and the vertical distribution of intercepted surfaces such as leaves and branches. The VCL/MBLA is an active lidar remote sensing system consisting of a five-beam instrument with a 25 m contiguous along-track resolution. The five beams are in circular configuration 8 km across, and each beam traces a separate ground track spaced 2 km apart, eventually producing 2 km coverage between 67ºN and 67ºS.

4. PICASSO-CENA

PICASSO-CENA, with a scheduled launch date of August 2004, will fly a 3-channel lidar with a suite of passive instruments in formation with EOS-Terra to obtain coincident observations of radiative fluxes and atmospheric state. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects. Instruments include: a 2-wavelength (532 nm and 1064 nm) polarization-sensitive lidar, a high spectral resolution (0.5 cm – 1 cm) A-band spectrometer, an imaging infrared radiometer, and a high-resolution wide field camera.

5. Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)

The GPS/MET (Ware et al., 1996) project demonstrated atmospheric and ionospheric limb sounding from low-earth-orbit (LEO) with high vertical resolution, high accuracy, and global coverage. Based on the scientific results of GPS/MET, a follow-on project for weather, climate, and space weather observations and research is currently being implemented. COSMIC will launch six LEO satellites in FY 2004. Each of these spacecraft will carry three science payloads: (1) GPS receiver, (2) Tiny Ionospheric Photometer (TIP), and (3) Triband Beacon Transmitters (TBB). Each of the satellites will continuously track the signals transmitted by 12 or more of the 24 GPS radio beacons. Each COSMIC satellite can retrieve about 500 daily profiles of key ionospheric and atmospheric properties from the tracked GPS radio-signals as they are occulted behind the Earth limb. The constellation will provide frequent global snapshots of the atmosphere and ionosphere with about 3,000 daily soundings down to about 1000 m from the surface. TIP will measure electron densities at the peak of the F2 layer along the satellite track. TBB transmissions will be received on the ground for high-resolution ionospheric tomography. COSMIC orbits and GPS tracking data also promise to benefit geodetic studies. COSMIC is a joint U.S.–Taiwan project, and is sponsored in the U.S. by the NSF, NASA, DOD, and NOAA.

Information on the above missions is summarized in Table 6, together with all other satellite missions supporting or contributing to GCOS.

Table 6. Satellite Series/Systems, Responsible Agencies, Data Exchange/Availability, Applications
All U.S. Satellites contributing to GCOS

Satellite Platform/ Series	Implement. Time Frame	Responsible Agencies	Participa-tion/Use in other Programs	Data Exchange	Barriers to Data Exch.	Applications	Internat'nl. Participat'n	Data Center(s) (Observed data and derived data products)
NOAA/POES- 2 sat. system Continuity: Indefinite: (NPP, NPOESS)	1978-present Design life: 5 years (per satellite) NPP: 2005 NPOESS: Launch-2008	NOAA (& NASA, DOD for NPP, NPOESS) International Partners	All	Open	None	Operational Weather Forecasting; El-Nino Prediction; Climate Monitoring/Prediction; Ozone monitoring; Resource management; Environmental monitoring; Solar flux; Volcanoes	Extensive Open to all countries	NOAA (NESDIS, NCDC); WMO/WMC's Data availability info: http://www.saa.noaa.gov/
NOAA/GOES- 2 sat. system Continuity: Indefinite	1979-present Design life: 5 years (per satellite)	NOAA NASA for R & D	All	Open	None	Operational weather forecasting; Climate monitoring and prediction; Resource management applications; Space environment	Extensive Open to all countries	NOAA/NESDIS WMO/WMC's Data availability info: http://www.goes.noaa.gov/
DOD/DMSP- multi-satellites Continuity: Indefinite	1976-present Design life: 3 years (per satellite)	DOD NOAA for operations	All	Open	None	Operational weather forecasting; All weather Ocean/Land surface monitoring;	Open to participating countries	NOAA (NESDIS, NSIDC, NCDC) Data availability info: http://www.ngdc.noaa.gov/dmsp/dmsp.html
Landsat 5&7 Continuity: Landsat Data Continuity Mission (LDCM)	1972-present Landsat-7: Launch: April 1999. Design life: 5 years	NASA USGS	All	Open	None	Resource management Land surf. Characterization Land use/cover mapping, monitoring; Mineral surveying; global change research	Network of International Ground Stations	USGS/EDC Data availability info: http://landsat7.usgs.gov
ACRIM (III) ACRIMSAT Continuity: NPP, NPOESS)	1978-present ACRIMSAT: Launch: Dec 1999. Design life: 5 years	NASA	Solar-Terrestrial; Climate Change	Open	None	Solar-Terrestrial interactions; Solar monitoring; Climate variability and climate change monitoring and prediction	Open to all countries	NASA/LARC Data availability info: http://gcmd.gsfc.nasa.gov
UARS Continuity: EOS-Aura	1991-present Design life: 3 years	NASA International Partners	All	Open	None	Ozone depletion, atmospheric chemistry, climate monitoring/prediction, solar radiation	Open to all countries	NASA/LARC Data availability info: http://gcmd.gsfc.nasa.gov

Satellite Platform/ Series	Implement. Time Frame	Responsible Agencies	Participa-tion/Use in other Programs	Data Exchange	Barriers to Data Exch.	Applications	Internat'nl. Participat'n	Data Center(s) (Observed data and derived data products)
TOMS Continuity: QuickTOMS, ADEOS-II	1978-present QuickTOMS: Fall 2001. Design life: 5 years;	NASA NASDA	Ozone; Global change	Open	None	Ozone depletion; climate modeling and climate change prediction	Open to all countries	NASA/GSFC, NASDA Data availability info: http://gcmd.gsfc.nasa.gov
TOPEX/ Poseidon Continuity: Jason-1	Aug 1992-present Design life: 5 years Jason-1 scheduled: Fall 2001	NASA/CNES	Atmosphere; Ocean	Open	None	Weather forecasting; Ocean surface winds, sea level and state monitoring; El-Nino prediction; Geodesy/gravity	Open to all countries	NASA (JPL, GSFC) CNES Data availability info: http://gcmd.gsfc.nasa.gov
SeaWiFS Continuity: EOS-Terra/Aqua	Aug 1994-present Design life: 5 years	NASA (Through data buy)	All	Open	None	Carbon cycle, vegetation, ocean biomass, atmospheric aerosols; fisheries, natural resources management	Open to participating countries	NASA/GSFC Data availability info: http://gcmd.gsfc.nasa.gov
TRMM Continuity: GPM (TBD)	Nov 1997-present Design Life: 3 years	NASA NASDA	All	Open	None	Weather forecasting, Tropical Rainfall, El-Nino monitoring & prediction; climate monitoring & prediction; water cycle and water resources	Open to all countries	NASA/GSFC NASDA Data availability info: http://gcmd.gsfc.nasa.gov
SRTM (Shuttle Radar Topo. Miss.) Continuity/Repeat: TBD	Mission: Feb 2000 (Calibrated data–early 2001)	NASA DoD USGS	All	Open	None	Near-Global high resolution data base of Earth's topography	Open to all countries	NASA/JPL DoD/NIMA USGS/EDC Data availability info: http://www.earth.nasa.gov/missions/index.html
EOS-Terra [MODIS, CERES, ASTER, MISR, MOPITT) Continuity: TBD	Dec 1999-present Design life: 6 years	NASA with International partners	All	Open	None	Weather and climate system monitoring and prediction; atmosphere/ocean/land/cryo; natural resources monitoring; El-Nino monitoring/prediction; Carbon cycle & vegetation/ocean biomass; Water and Energy cycles; Aerosols and radiation budget	Open to all countries	NASA (GSFC, LARC) USGS/EROS International partners Data availability info: http://gcmd.gsfc.nasa.gov

Satellite Platform/ Series	Implement. Time Frame	Responsible Agencies	Participa-tion/Use in other Programs	Data Exchange	Barriers to Data Exch.	Applications	Internat'nl. Participat'n	Data Center(s) (Observed data and derived data products)
EO-1 (First New Millennium mission) Continuity TBD.	Dec 2000-present Design life: 3 years	NASA	All	Open	None	Similar to Landsat-7 (See Landsat)	Open to all participating countries	NASA USGS/EDC Data availability info: http://gcmd.gsfc.nasa.gov
EOS-Aqua (pm) (MODIS, CERES, AMSR-E, AIRS, AMSU-A, HSB) Continuity: TBD	Scheduled: Fall 2001 Design Life: 6 years	NASA with international partners	All	Open	None	Weather and climate system monitoring and prediction; atmosphere-ocean-land-cryo interaction; natural resources management; carbon, water and energy cycles; aerosols and radiation budget	Open to all countries	NASA/GSFC National & International partners Data availability info: http://www.earth.nasa.gov/missions/index.html
EOS-Aura (MLS, HIRDLS, TES) Continuity: TBD	Scheduled: July 2003 Design Life: 5 yrs	NASA	Ozone, Trace gases, Atmos. Chemistry	Open	None	Montreal Protocol; Framework Convention on Climate Change; Climate monitoring, modeling and prediction	Open to all countries	NASA (LARC, GSFC) National & International partners Data availability info: http://www.earth.nasa.gov/missions/index.html
Jason-1 (Poseidon-2/JMR/DORIS instrument package) Continuity for TOPEX/ Poseidon	Scheduled: Fall 2001 Design life: 3 years	NASA/CNES (Contributing agencies: NOAA EUMETSAT)	Atmos/ Ocean	Open	None	Sea surface winds, state, level; El-Nino monitoring & prediction; fisheries; ocean circulation	Open to all countries	NASA/GSFC CNES NOAA, EUMETSAT Data availability info: http://www.earth.nasa.gov/missions/index.html
SeaWinds (NASCAT) Continuity: ADEOS-II	Scheduled: Nov 2001; Quick-SCAT: 6/1999 Design Life: 3 years	NASA NASDA	Atmos/ Ocean	Open	None	Weather forecasting; Oceanography; El-Nino prediction; Climate modeling/prediction	Open to all countries	NASA/GSFC NASDA Data availability info: http://www.earth.nasa.gov/missions/index.html

Satellite Platform/ Series	Implement. Time Frame	Responsible Agencies	Participa-tion/Use in other Programs	Data Exchange	Barriers to Data Exch.	Applications	Internat'nl. Participat'n	Data Center(s) (Observed data and derived data products)
EOS-IceSAT (GLAS) Continuity: TBD (possible repeat mission in 2010)	Scheduled: Dec 2001 Design Life: 3 years	NASA	Ice, and Land elevation/ topograph y	Open	None	Ice sheet mass balance; Climate system monitoring, modeling and prediction	Open to all countries	NASA (WFF, GSFC) Data availability info: http://www.earth.nasa.gov/ missions/index.html
SORCE (TIM, SOLSTICE, SIM, XUV) Continuity: See ACRIM-III, NPOESS	Scheduled: July 2002 Design Life: 5 years	NASA	Solar & solar-terrestrial interaction	Open	None	Solar irradiance and variability	Open to all countries	NASA/GSFC Data availability info: http://www.earth.nasa.gov/ missions/index.html
Approved satellites: (ESSP-VCL; GRACE; PICASSO-CENA; Cloudsat)	Scheduled: 2001-2004 Design Life: Various (3-5 years)	NASA with International partners	Various	Open	None	Various	Open to all countries	NASA International partners Data availability info: http://www.earth.nasa.gov/ missions/index.html
ESSP-GRACE. Continuity: TBD	Scheduled Nov. 2001 Design life: 5 years	NASA DLR (Germany)	Earth Syst. Gravity field	Open	None	Ocean surface currents, ocean heat transport, Mass balance of Ice sheets, Changes in Storage of water/snow on continents	Open to all countries	NASA/JPL Data availability info: http://www.earth.nasa.gov/ missions/index.html
ESSP-CloudSat. Continuity: TBD	Scheduled May 2003 Design life: 3 years	NASA	All	Open	None	Vertical Profile of clouds, Cloud base/top, optical depth, atmospheric heating rate, cloud water, ice, particle size, precipitation, Vis/IR radiances, cloud-climate feedback, effect of aerosols on clouds	Open to all countries	NASA/GSFC Data availability info: http://www.earth.nasa.go v/missions/index.html
ESSP-VCL. Continuity: TBD	Scheduled: TBD (Aug 2003) Design life: 3 years)	NASA	Atm/Land Surf/Veg	Open	None	Land cover/vegetation structure, climate, topography,	Open to all countries	NASA/GSFC USGS/EROS Data availability info: http://www.earth.nasa.gov/ missions/index.html

Satellite Platform/ Series	Implement. Time Frame	Responsible Agencies	Participa-tion/Use in other Programs	Data Exchange	Barriers to Data Exch.	Applications	Internat'nl. Participat'n	Data Center(s) (Observed data and derived data products)
ESSP-PICASSO-CENA. Continuity: TBD	Scheduled: Aug 2004 Design life: 5 years	NASA CNES	All	Open	None	Clouds and aerosols vertical distributions, optical depth, albedo, emissivity, particle size; surface and atmospheric radiative fluxes	Open to all countries	NASA/LARC CNES Data availability info: http://www.earth.nasa.gov/missions/index.html
NPP (NPOESS Preparatory Project)	Scheduled: Dec 2005	NOAA, DoD, NASA; EUMETSAT/ METOP	All	Open	None	Demonstrate advanced technology. Bridge between EOS-Terra/Aqua and NPOESS	Extensive Open to all countries	NOAA/NESDIS Data availability info: http://www.ipo.noaa.gov/sat_evolu.html
NPOESS Continuity: indefinite	Scheduled: 2008 Design life: 5 years per satellite	NOAA, DoD, NASA; EUMETSAT/ METOP	All	Open	None	Operational Weather Forecasting; El-Nino/Climate Monitoring & Prediction; Ozone monitoring; Resource management; Environmental monitoring; Solar flux; Volcanoes; Aerosols;	Extensive Open to all countries	NOAA/NESDIS Data availability info: http://www.ipo.noaa.gov/

Table 7. Satellite Series, Observations, Series Duration/Continuity, Compliance with GCOS Principles
(Excluded: Satellites not yet launched. For these satellites, see Table 6)

Satellite Series & Compliance With GCOS Principles	Coverage & Space Resolution	Time Resol.	Atmosph.	Atmos. Comp/ Chem	Land Surface/ Terrestrial	Ocean	Cryos.	Series Duration & Continuity
NOAA/POES (two) (Vis, IR, Microwave) Most recent: NOAA-16 Compliance: Good for reprocessed data	Global 1-4 km Orbit: 870 km	2/day am & pm	Temp, moisture, clouds, weather, radiation	Ozone	Temp, vegetation (NDVI), snow, ice	Temp, land-water boundaries, precipitation (index)	Snow, ice	1978-present, 2 satellite system. Continuity: NPP, NPOESS
NOAA/GOES (two) (Vis & IR) Most Recent: GOES-11 Compliance: Good for reprocessed data	Regional. Locations: 75W and 135W Orbit: 35,790 km	Full disc every 30 min	Temp, moisture, Clouds, weather, cloud tracked winds	Ozone	Temperature	Temperature, precipitation (index)	Snow, ice	1979-present, 2 Satellite system Continuity: Indefinite
DOD/DMSP (Vis, IR, Microwave) Most recent: DMSP-14 Compliance: Good for reprocessed data	Global: 2.7 km Regional: 0.55 km	2/day	Clouds, Cloud water, temperature, moisture	N/A	Temperature, snow cover, frozen ground, rainfall, fires	Temperature, sea ice, wind speed, rainfall	Snow cover, sea ice	1976-present, 5 satellite system Continuity: NPP, NPOESS
NASA/USGS-Landsat (Vis, Near-IR, IR). Most recent: Landsat-7 Compliance: Very good	Global 15 m – 80 m Orbit: Sun Synchronous; Altitude: 705 km; Inclination: 98º; Period: 98.9 min	16-day each satellite (8-day repeat with Landsat 5&7)	Secondary	N/A	Land surface properties/characterization, land use, land cover, vegetation, soils, minerals, water bodies	Land-ocean boundaries, inland seas/water bodies	Snow cover, ice	1972-present Continuity: Indefinite (TBD)
NASA/ACRIM –III (ACRIMSAT: Dec. 99). Heritage: ACRIM-I on SMM; ACRIM-II on UARS Compliance: Very good	Global (Solar) 5 ppm of TSI. Spin stabilized to within 0.25º Orbit: 685 km	N/A	N/A (Solar)	N/A (Solar)	N/A (Solar)	N/A (Solar)	N/A (Solar)	1978- present. Continuity: Indefinite (TBD)

Satellite Series & Compliance With GCOS Principles	Coverage & Space Resolution	Time Resol.	Atmosph.	Atmos. Comp/ Chem	Land Surface/ Terrestrial	Ocean	Cryos.	Series Duration & Continuity
NASA/UARS UV, Vis, IR, Microwave - Compliance: Very good	Orbit altitude: 600 km Resolutions: various for different instruments	1 day	Stratosphere/ mesosphere: Temperature, moisture, winds, energetic particles Also: solar observations	Aerosols, Ozone depletion chemist: CLONO2, CLO, HF, HCL, NO2, N2O5, NO HNO3, others	N/A	N/A	N/A	1991-present. Continuity: EOS-Aura (Launch: June 2003)
NASA/TOMS (Total Ozone Mapping Spectrometer) Heritage: TOMS Compliance: Very good	Global 42 km at sub-satellite point Orbit: 800 km; Cross-track: 2300 km	1 day	N/A	Ozone & SO2 Smoke Smog	N/A	N/A	N/A	1978-present Continuity: QuikTOMS (Launch: Fall 2001), ADEOS-II
NASA/CNES-TOPEX/Poseidon (Laser altimeter, Microwave radiometer) Compliance: Very good	Global Sea surface height to within 4.3 cm. Satellite location to within 2.8 cm	1 day; Repeat cycle: 10 days for global sea level fields	Water vapor content	N/A	N/A	Sea surface height, sea surface wind speed and wave energy	N/A	1992-present Continuity: Jason-1 (Launch: Fall 2001)
NASA-SeaWiFS (W/Commercial partners). Heritage: CZCS (Vis. Near-IR, IR) Compliance: Very good	Global	1 day	Water vapor	Aerosols-optical properties & optical depth	Land vegetation cover	Ocean bio-optical properties, ocean biomass	Secondary	1994-present Continuity: EOS-Terra/Aqua. Historical data: 1978-1986 CZCS
NASA-TRMM (with NASDA/Japan) (Active precipitation radar, Microwave, Vis, IR) Compliance: Excellent	Global belt: +/- 35º N/S Horiz. Resolution: 4 km; swath width: 220 km Rain rates down to 0.7 mm/hr	Instantaneous for local; climatology for global precip.	Temperature, water vapor, clouds, radiation, lightening	Aerosols	Tropical precipitation (vertical distribution).	Sea surface temperature (all weather and thru' clouds)		1997-present. Continuity: GPM (TBD)

Satellite Series & Compliance With GCOS Principles	Coverage & Space Resolution	Time Resol.	Atmosph.	Atmos. Comp/ Chem	Land Surface/ Terrestrial	Ocean	Cryos.	Series Duration & Continuity
NASA/EOS-Terra-CERES (Also flown on TRMM) (SW, LW, Total radiation, Vis, IR). On-board calibration. Compliance: Excellent	Global 15m – Orbit: Polar, 705 km; Inclination: 98.2º; Descending node: 10.30 am; Period: 98.88 min	1 day	Clouds, Earth's radiation budget, cloud radiative forcing/ feedback	N/A	Clear sky radiative fluxes	Clear sky radiative fluxes	Clear sky radiative fluxes	1999-present Continuity: 6 yr Life duration of Satellite. Future: TBD. Historical: NASA/ERBE (1984-1990); TRMM: since 1997.
NASA/EOS-Terra-MODIS (Vis & IR w/high spectral discrimination). On board calibration. Compliance: Excellent	Global Resolution: 250 m to 1.0 km Orbit: Polar, 705 km; Inclination: 98.2º; Descending node: 10.30 am; Period: 98.88 min	1 day	Clouds, water vapor, temperature	Aerosols	Temperature, land surface cover, vegetation, fires	Surface temperature, ocean color (sediment, phytoplankton), primary productivity	Snow cover, Ice cover	1999-present Continuity: 6 yr Life duration of instrument. Future: TBD
NASA/EOS-Terra-ASTER (w/MITI-Japan) (Vis., Near IR, SW-IR, Thermal-IR). On-board calibration. Compliance: Excellent	Global 15m to 90 m 60 km swath Orbit: Polar, 705 km; Inclination: 98.2º; Descending node: 10.30 am; Period: 98.88 min	Non-continuous (Full configuration data for 8 min per orbit. Reduced configuration data–on demand)	Cloud morphology, cloud properties	Aerosols/Volcanic eruptions	Surface temperature and emissivity, Surface digital elevation, surface composition and vegetation,	Sea ice and polar ice	Sea ice and polar ice	1999-present. Continuity: 6 yr Life duration of instrument. Future: TBD

Satellite Series & Compliance With GCOS Principles	Coverage & Space Resolution	Time Resol.	Atmosph.	Atmos. Comp/ Chem	Land Surface/ Terrestrial	Ocean	Cryos.	Series Duration & Continuity
NASA/EOS-Terra-MOPITT (w/ Canada) (Scanning radiometer using gas correlation IR spectroscopy) On-board calibration. Compliance: Excellent	Global Resolution: 22 km; Swath: 640 km Orbit: Polar, 705 km; Inclination: 98.2º; Descending node: 10.30 am; Period: 98.88 min	Day and night		CO, Methane (CH_4),	N/A	N/A	N/A	1999-present Continuity: 6 yr Life duration of instrument. Future: EOS-Aura or TBD

Table 8. Status of the Potential for the Transition of Research Satellite Remote Sensing Instruments to Operational Systems

NOTE: Under "Parameter/Question", the notation in parenthesis "( )" refers to the Science Questions in Section 1 of this Chapter on satellite systems. V = Variations; F = Forcings; R = Response; C = Consequences; P = Prediction. Example: V1 denotes bullet #1 under Science Question referring to Variations and Trends.

NOTE: The parameters identified in the Tables are those for which systematic measurements are considered necessary. Not included are several other satellite observations, needed for research, that may not be required on a continual, systematic basis, and/or those not yet being considered for near future operational systems.

Table 8a. Key Observations for Identifying Earth-Climate System Variations and Trends.

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Atmospheric Temperature (V1)	Passive Sounding	Radiosondes (NOAA, WWW, NASA, NDSC)	Excellent	NPOESS requirement	EUMETSAT Coordination
	Active Sounding (GPS)	Global GPS network	Full demonstration needed	NPOESS requirement	EUMETSAT Coordination
Atmospheric Water Vapor (V1)	Passive Sounding	Radiosondes, Ly-α, µwave (NASA, NOAA, WWW)	Satisfactory	NPOESS requirement	EUMETSAT Coordination
Global Precipitation (V1)	Requires 6-8 satellite constellation for time resolution	Rain gauges, weather radar (NOAA, WWW)	Demonstrated by TRMM and passive µwave imagers	TBD; only passive µwave currently planned	Excellent – several needed
Soil Moisture (V1)	Requires relatively low (L-band) µwave frequency	Neutron probes, Lysimeters (USDA, USGS, FAO)	Very large real or synthetic antenna to be demonstrated	Highly desired; subject to operational viability	Likely with European Space Agency
Ocean Surface Topography (V2)	Prefer non-polar orbit to avoid tidal aliasing	Tide gauges (Global Geodetic Network)	Demonstrated Development needed for denser coverage	Included on one NPOESS sat. but polar orbit is problematic	Continuation of current partnerships likely
Ocean Surface Winds (V2)	Active µwave technique preferred	Ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and Seawinds	NPOESS need nominally fulfilled by passive sensor	Seawinds and follow-on cooperation with Japan
Sea Surface Temperature (V2)	Both IR and microwave needed for all-weather observation	Ships, buoys (NOAA, WWW)	Excellent	NPOESS requirement	EUMETSAT Coordination
Sea Ice Extent (V2)	Microwave radiometry needed for all-weather measurements	Ships, airborne reconnaissance (Navy, USCG, NOAA)	Excellent	NPOESS requirement	NASDA cooperation
Terrestrial Primary Productivity (V3)	1 km or better resolution needed	Crop, forest inventory. (USDA, FAO, LTER (NSF), GTOS	Excellent	NPOESS requirement	EUMETSAT Coordination

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Marine Primary Productivity (V3)	Very precise inter-calibration is essential	NASA-SIMBIOS time series studies	Demonstrated	Partially provided by NPOESS	Cooperation with Japan, Europe possible
Total Column Ozone (V4)	High long-term accuracy needed for trend studies	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)	Excellent	NPOESS requirement	EUMETSAT Coordination
Ozone Vertical Profile (V4)	Good vertical resolution needed near tropopause	Ozonesondes, lidar, µwave , IR, (NASA, NOAA)	Excellent	NPOESS requirement	Coordination potential exists
Ice Surface Topography (V5)	Excellent vertical resolution and accuracy needed for mass balance studies	GPS (NASA, NSF)	ICEsat lidar altimetry demonstration pending	Not currently an operational requirement	Coordination with European radar altimetry satellite

Table 8b. Key Observational Requirements for Determining Primary Forcings on Earth-Climate System

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-Situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Total Solar Irradiance (F1)	High absolute accuracy, overlap of successive records required	global surface networks (BSRN, WRDC, SURFRAD)	Excellent	NPOESS requirement	Possible
Solar UV Irradiance (F1)	Need for spectral resolution and good radiometric accuracy	USGCRP UV network, NDSC (multi-agency)	Excellent	NPOESS measurement planned	Strong history of cooperation
Stratospheric Aerosol Distribution (F1)	Good vertical resolution and large dynamic range required	Lidar, backscatter-sondes (NASA, NOAA, NSF)	Excellent	NPOESS meas. possible but resolution is problematic	Possible
Total Aerosol Amount (F1)	Global coverage over ocean and land needed	AERONET, USDA network, NOAA/BSRN, DOE/ARM	Excellent	NPOESS requirement	Possible
Aerosol Properties (F1)	Need in-situ and ground-based measurements	AERONET, NOAA/CMDL, airborne aerosol spectrometers	Further development needed for space measure.	NPOESS requirement	Possible, important for ground-based measurements
Sfc. Trace Gas Concentration (F1)	Ground-based measurements fulfill requirements	NASA AGAGE, NOAA flask network and CO_2 meas.	Need simpler instruments with better time resolution	NOAA flask sampling network, NASA AGAGE	Helps support ground network
Volcanic Gas & Ash Emissions (F1)	Global observation of ash and gas plumes	In-situ optical calibration	Further progress needed to characterize tropospheric constituents	Significant on account of impact on aviation	Possible
Fire Occurrences (F2)	Global observation of infrared and vis/near-ir; hyperspectral for fuel load	Aeronet (NASA), burn scar inven. (USFS, int’l.), In-situ optical calibration	Excellent	NPOESS EDR application	NPOESS EDR application
Trace Gas Sources (F2)	CO_2 column mapping is greatest priority	Flask network (NOAA), Ameriflux (DOE, USDA, NASA), FluxNet	Technical developments needed for exploratory mission	Unlikely	TBD
Land Cover/ Land Use Inventories (F2)	High spatial resolution required (few tens of meters)	Land Cover Maps (USGS), Veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Government/commercial partnership possible	Possible with U.S. industry
Surface Stress and Deformation (F2)	Special focus on active earthquake and volcanic regions	Regional GPS networks, geological observations	Excellent	Joint support of ground arrays by local agencies	Multi-national support for ground arrays

Table 8c. Special Observational Requirements for Response and Feedback Process Studies

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Cloud System Structure (R1)	Multispectral visible and IR radiometry	Radiosondes, lidar (NASA, NOAA, FAA)	Excellent	NOAA & NPOESS requirement	EUMETSAT and Japan's ADEOS/GLI
Cloud Particle Properties and Distribution (R1)	Active sensor to resolve three-dimensional structure	None	Demonstration of cloud radar and lidar pending	Desirable; subject to operational viability	DOD is contributing to Cloudsat project
Earth radiation Budget (R1)	Broadband radiometry	None	Excellent	Planned on NPOESS	Possible
Soil Moisture (R1)	Spatial resolution and ability to penetrate vegetation are the issues	Neutron probes, lysimeters (USDA, USGS, FAO)	Approaching readiness (done from aircraft)	Highly desired; subject to operational viability	Likely with European Space Agency
Snow Cover & Accumulation (R1)	Need to assess snow depth or water equivalent quantitatively	Snow transects (NOAA/NWS)	Awaiting demonstration	NPOESS requirement for snow cover	Possible
Freeze-Thaw Transition (R1)	Need to assess in all cloud and vegetation conditions	Not a routine measurement	Awaiting demonstration	Desired; subject to operational viability	Possible
Biomass (R2)	Based on resolving canopy vertical structure; requires active lidar sensor	Crop/Timber yield (USDA, DOI), carbon database (DOE)	Demonstration pending (VCL)	TBD	Possible
Marine Productivity in Coastal regions (R2)	High spatial and temporal resolutions needed to resolve specific events	NASA-SIMBIOS; Coastal bio-optics (NOAA, EPA)	Excellent	Possible NPOESS derived product	International product inter-comparison
Carbon Sources and Sinks (R2)	CO_2, CH_4 column mapping is most promising approach;	Flask network (NOAA), Ameriflux/Flux Net (DOE, USDA, NASA)	Experimental technique needs further development	Unlikely	Possible
Sea Surface Salinity (R3)	Very high radiometric precision needed for passive µwave observation	Ships and moored/drifting buoys (NOAA/NSF)	Approaching readiness (done from aircraft)	Unfulfilled NPOESS requirement	Likely with European Space Agency
Sea Ice Thickness (R3)	Significance of ice freeboard observations remains to be established	Moored buoys (ONR)	High spatial resolution radar; development needed	Desirable, subject to operational viability	Possible with international/ commercial partners
Atmospheric Properties in Tropopause Region (R4)	Need ozone, water vapor, temperature at high vertical resolution	Sondes (WWW, NOAA)	Limb viewing sensors not yet demonstrated	TBD	Interest exists
Polar ice sheet velocity (R5)	Synthetic aperture radar interferometry; high latitude coverage (polar orbit) needed	GPS (NASA, NSF)	Demonstrated	Government/commercial partnership possible	Possible

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Tropospheric Ozone and Precursors (R6)	Need excellent vertical resolution through entire troposphere, implies active lidar sensor	Airborne in-situ for DC-8, R-2, WB-57	Experimental technique, needs further develop.	TBD	Interest exists
Global Precipitation (C1)	Requires Constellation for Good Time Resolution	Rain gauges, weather radar (NOAA, WWW)	Demonstrated via TRMM	TBD; only passive µwave currently planned	Excellent – several needed
Ocean Surface Winds (C1)	Active µwave technique	Ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and SeaWinds	NPOESS need nominally fulfilled by passive sensor	Seawinds cooperation with Japan; EUMETSAT
	Passive µwave radiometry/polarimetry probably sufficient for meteorological applications		Windsat/Coriolis demonstration funded by DOD, USN, NPOESS	NPOESS requirement	Possible
Meteorological Properties Around Storms (C1)	Requires vertical profiling from a geostationary platform	Radiosondes (NOAA, WWW)	Demonstration planned with GIFTS	May become operational GOES sensor if successfully demonstrated	Possible
Lightning Rate (C1)	Requires geostationary implementation for temporal resolution	Sferics	Demonstrated by OTD and LIS	Could be implemented on future GOES	Possible
River Stage Height/ Discharge Rate (C1)	Requires high precision, vertical resolution, and frequent sampling	River gauges (USGS)	Capability demonstrated by TOPEX/Poseidon	TBD	TBD
Primary Productivity (C2)	1 km or better resolution needed	NASA-SIMBIOS, GOOS, GTOS, crop, forest inventories (USDA, FAO), LTER (NSF)	Excellent	NPOESS requirement	EUMETSAT coordination
Land Cover / Land Use Change (C2)	High spatial resolution (few meters) crucial	Land cover maps (USGS), veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Government/commercial partnership possible	Possible with U.S. industry
Coastal Region Properties and Productivity (C3)	Multispectral radiometry at high spatial and temporal resolution from GEO	Coastal observations (NOAA, EPA)	Excellent	Could be implemented on future GOES	Possible

Table 8d. Special Observational Requirements for Prediction and Assessments

Parameter/ Question	Satellite Instrument Implementation Detail	Corresponding In-situ Measurement Systems	Technical Readiness of Satellite Instrument(s)	Operational Potential	Partnership Potential
Tropospheric Winds (P1)	Active Doppler lidar remote sensing	Rawinsondes (NOAA, WWW)	Technical developments, demonstration needed	Very high, when demonstrated	Commercial data purchase possible
Ocean Surface Winds (P1)	Active µwave technique	Ships, buoys (NOAA. WWW)	Demonstrated by NSCAT & SeaWinds	NPOESS requirement nominally fulfilled by passive sensor	Seawinds cooperation with Japan; EUMETSAT data acquisition
	Passive µwave radiometry/polarimetry		Windsat/Coriolis demonstration funded by DOD, USN, NPOESS	NPOESS requirement	Possible
Global Precipitation (P1)	Requires Constellation for Good Time Resolution	Rain gauges, weather radar (NOAA, WWW)	Demonstrated via TRMM	TBD; only passive µwave currently planned	Excellent – several needed
Freeze-Thaw Transition (P1)	Need to assess in all cloud and vegetation conditions	Not a routine measurement	Awaiting demonstration	Desired; subject to operational viability	Possible
Lightning Rate (P1)	Requires geostationary implementation for temporal resolution	Sferics	Demonstrated by OTD and LIS	Could be implemented on future GOES	Possible
Soil Moisture (P1, P2)	Spatial resolution and ability to penetrate vegetation are crucial	Neutron probes, lysimeters (USDA, USGS, FAO)	Approaching readiness (done from aircraft)	Highly desired, subject to operational. viability	Possible
Sea Surface Temperature (P2)	Both IR and µwave observations needed for all-weather measurement	Ships, buoys (NOAA, WWW)	Excellent	NPOESS requirement	EUMETSAT coordination
Sea Level Height (P2)	Prefer non-polar orbit to avoid tidal aliasing	Tide gauges; Global Geodetic Network for reference frame	Demonstrated	Included on one NPOESS satellite, polar orbit is problematic	Continuation of past partnership likely
Deep Ocean Circulation (P3)	Requires *in-situ* oceanographic observations	Ships and ARGO floats (NOAA, NSF)	WOCE, GODAE research projects provide initial data base	Operational Global Ocean Observing System is being envisaged	Multi-agency, international cooperation is anticipated
Total Column Ozone (P4)	High long-term accuracy needed for trend studies	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)	Excellent	NPOESS requirement	EUMETSAT coordination
Trends in Carbon sources and sinks (P5)	CO_2 and CH_4 column mapping is most promising approach	Flask network (NOAA), Ameriflux/FluxNet (DOE, USDA, NASA)	Experimental technique; needs further development	Unlikely	Possible
Land Cover/Land use Change (P5)	High spatial resolution (few meters) crucial	Land cover maps (USGS), Veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Commercial data purchase likely	Possible with U.S. industry

V. Data and Information Management Related to GCOS

Achieving the goals of the U.S. climate-observing program will require multidisciplinary analysis of data and information to an extent never before attempted. This includes the analysis of interlinked environmental changes that occur on multiple temporal and spatial scales, which is very challenging both technically and intellectually. For example, many types of satellite and in-situ observations at multiple scales need to be integrated with models and the results presented in understandable ways to all levels of the research community, decision makers, and the public. Additionally, very large volumes of data from a wide variety of sources and results from many different investigations need to be readily accessible to scientists and other stakeholders in usable forms.

Various U.S. agencies have engaged in extensive development of interagency data and information processes to address these needs, primarily through fostering better integration among U.S. Government data and information centers that have traditionally developed along disciplinary lines to serve specific scientific and operational communities. Included has been the development of the Global Change Data and Information System (GCDIS) in response to the need to coordinate among the disparate data centers and systems in the participating agencies and to facilitate making data readily available to users. GCDIS currently provides a gateway for discovery and information access among more than 70 federally funded sources of data, both governmental and academic. During the last decade, significant strides have been made in GCDIS's seamless connections between diverse data sets and sources as well its ability to search across the full complement of sources. The Internet has facilitated immeasurably this coordinated effort. However, important challenges remain. A number of U.S. Government agencies are involved in climatological data management activities, and links to these can be found at http://www.ofcm.gov/Climate/climate.htm, a site maintained by the U.S. Office of the Federal Coordinator for Meteorology.

The provision of data and information in forms needed for cross-disciplinary analysis and projection remain a challenge even as the increasing focus of U.S. agencies on investigating the impacts and consequences of change heightens the need for multidisciplinary research. Physical and biological data will need to be related to data on environmental conditions and socioeconomic trends originally compiled by agencies and groups primarily for purposes other than global change research. This is a particularly important challenge in addressing potential regional consequences of multiple stresses and determining the vulnerability of different resources and communities.

Similarly, the need to effectively link global observation data activities supported by the U.S. and its international partners is increasing. Further, observational data on individual variables must be combined into long-term, integrated measures of environmental changes. Both need to be coupled with modeling efforts at multiple scales to provide the synergy necessary to understand the relationships between complex variables, such as the relationships between air and water quality and human health.

The data centers in Federal agencies, which are the repositories of both USGCRP and external data and information, are experiencing either flat or declining budgets while their workload from data and user volume is increasing. During the past five years, the volume of data at Federal centers has increased by two- to six-fold, and this growth rate is expected to increase at even higher rates in the next decade. As examples, NASA's Earth Science data holdings increased by a factor of six from 1994 to 1999, and the total amount of data then doubled between 1999 and 2000. NOAA’s data center holdings are expected to increase by ten-fold in the next decade.

Over the past decade the meteorological community has witnessed an ever-increasing demand for current and historical data related to extreme weather and climate events. Such data are necessary for seasonal and interannual climate prediction as well as for climate research, monitoring of climate variability, and detection of climate change. The importance of these activities has been recognized on numerous occasions by governments at various meetings, in particular by the Intergovernmental Panel on Climate Change (IPCC) and by the Conference of the Parties to the UNFCCC. In response to these requirements from the climatological community, the GCOS program, established in 1992, developed the GSN, which consists of 989 meteorological surface reporting stations from 50 member states of the WMO (http://www.wmo.ch).

NCDC is responsible for building a permanent data base of GSN daily and monthly data submissions, along with the appropriate station metadata history, and for providing free and open user access to this information via the Internet. This site contains all of the historical daily and monthly CLIMAT-formatted GSN data received at NCDC from 250 of these surface stations in 28 nations. As more data are received they will be integrated into the system and made available for use. The visitor may view data in both textual and graphical form and, through the use of copy and paste, can download subsets of the database to their own system for later use and analysis. As new station information is made available to NCDC, the GSN database will be updated and information will be posted on their web site at http://lwf.ncdc.noaa.gov/servlets/gsn.

The Global Observing System Information Center (GOSIC) web site located at http://oceanic.cms.udel.edu/gos/ is a data and information management facility established by the Joint Data and Information Management Panel (JDIMP) of the GCOS program. The JDIMP no longer exists, but a GOSIC advisory group has taken its place to guide the requirements for the GOSIC. This site provides additional information on the observing requirements, operational data systems, and the access procedures for finding and obtaining data and products of the G^3OS. The G^3OS consists of GCOS, GOOS, and the GTOS. The University of Delaware, with funding and support from NOAA, currently operates GOSIC. The GOSIC is going through a new 3-year developmental effort that will be followed by a 2-year transition period to an operational agency.

Through the EOS Data and Information Systems (EOSDIS), Earth science data products are provided routinely to end-users within five days of receipt or production of the requested data product. These products comprise data from currently operating space assets, including: precipitation measurements and observations of tropical storms from TRMM, ocean productivity measurements from the SeaWiFS, detection of ocean surface height changes used to predict El Niño occurrence and strength from TOPEX/Poseidon, and sea-ice motion and Antarctic mapping from Canada’s RADARSAT. The data also include measurements of stratospheric trace chemicals from the UARS, Antarctic ozone hole measurements from the TOMS, land use and land cover data from heritage Landsat missions, and measurements of incoming solar radiation and outgoing radiation from the Earth by the ERBE. Similar arrangements are in place to meet the anticipated demand for data products from EOS-Terra, EOS-Aqua, and other satellite missions.

A wide net has been cast to include information on observations falling into each of the observing categories of this report. The U.S. Government and the U.S. climate research community support the 10 Climate Monitoring Principles of observations. High standards must be met if a particular set of observations is to truly serve the purpose of monitoring the climate system to detect long-term change. In general, the observing programs and resulting datasets described herein do not meet the ten "Climate Monitoring Principles" endorsed by the U.S. and, indeed, by the UNFCCC. This shortfall stems from two main factors: 1) the principles were articulated only within the past decade (Karl et al. 1995), long after the initiation of most of our long-term observing systems; and 2) more recent observing programs, in general, do not have climate monitoring as their prime function.

The U.S. is beginning to develop climate-monitoring systems that more fully incorporate the climate monitoring principles. For example, a climate reference network for surface meteorological data is currently being implemented. Beyond these incipient observations, only our trace gas monitoring efforts have yielded long-term homogeneous observations of the climate system. Here we use the term homogeneous to refer to a data set with sufficient continuity and quality that it can be used, without adjustments, for detection of long-term change.

This does not mean that other climate observations are not potentially useful for such detection studies. Several examples exist of data products based on originally inhomogeneous records that, by careful scrutiny, winnowing of bad data, and, in some cases, adjustment of parts of the record to remove artificial signals, have been made into more useful climate records. The global surface temperature datasets are a prime example. Thus, we can draw a distinction between originally homogeneous observations, which can be used without adjustment, and 'homogenized' data products, which are the result of research activities to improve otherwise inhomogeneous data. In both cases, however, it cannot be assumed that a set of observations is sufficiently homogeneous for analysis of long-term change without actually attempting such analysis. The scientific publication and peer review process provides a means for identifying homogeneous or homogenized datasets. Therefore, the supplementary tables in the report list homogenous and homogenized datasets, with relevant references to the scientific literature in which their homogeneity has been documented.

The U.S. hopes that the documentation of our current climate-related observations in this report will provide a basis for improved global climate observing systems that directly address the climate monitoring principles, which are key to detection of long-term climate change.

The 10 Climate Monitoring Principles are as follows:

- The impact of new systems or changes to existing systems should be assessed prior to implementation.
- A suitable period of overlap of new and old observing systems should be required.
- The results of calibration, validation and data homogeneity assessments and assessments of algorithm changes should be treated with the same care as data.
- A capability to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information should be ensured.

- Consideration of environmental climate-monitoring products and assessments, such as Intergovernmental Panel on Climate Change (IPCC) assessments, should be integrated into national, regional and global observing priorities.
- Uninterrupted station operations and observing systems should be maintained.
- A high priority should be given to additional observations in data-poor regions and regions sensitive to change.
- Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.
- The carefully planned conversion of research observing systems to long-term operations should be promoted.
- Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.

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ACRONYMS

AAO	Adjacent Arctic Ocean
ACARS	Aircraft Communications, Addressing, and Reporting System
ACORN	Atmospheric Coordinated Observations and Research Network
ACRIM	Active Cavity Radiometer Irradiance Monitor
AIRMoN	Atmospheric Integrated Research Monitoring Network
AIRS	Atmospheric Infrared Sounder
AMSU	Advanced Microwave Sounding Unit
AO	Arctic Oscillation
ARCS	Atmospheric Radiation and Cloud Stations
ARL	Air Resources Laboratory
ARM	Atmospheric Radiation Measurement
ART	Automated Radiotheodolite
ASAP	Automated Shipboard Aerological Program
ASDAR	Aircraft-to-Satellite Data Relay
ASMR	Advanced Scanning Microwave Radiometer
ASOS	Automated Surface Observing System
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS	Autonomous Temperature Line Acquisition System
ATMS	Advanced Technology Microwave Sounder
ATN	Advanced TIROS-N
AWOS	Automated Weather Observing System
AVHRR	Advanced Very High Resolution Radiometer
BATS	Bermuda Atlantic Time Series
BLM	Bureau of Land Management
BR	Bureau of Reclamation
BSRN	Baseline Surface Radiation Network
BTM	Bermuda Testbed Mooring
C-MAN	Coastal-Marine Automated Network
CALM	Circumpolar Active Layer Monitoring
CART	Cloud and Radiation Testbed
CDC	Climate Diagnostics Center

CDIAC	Carbon Dioxide Information Analysis Center
CDR	Climate Data Record
CERES	Clouds and the Earth's Radiant Energy System
CEOS	Committee on Earth Observation Satellites
CES	Committee on Earth Studies
CFC	Chlorofluorocarbon
CGMS	Coordination Group for Meteorological Satellites
CHAMP	Coral Health and Monitoring Program
CLAES	Cryogenic Limb Array Etalon Spectrometer
CLIVAR	Climate Variability and Predictability Proramme
CMDL	Climate Monitoring and Diagnostic Laboratory
CMIS	Conical Microwave Imager/Sounder
CNES	Centre National de'Etudes Spatiales
CO_2	Carbon Dioxide
CO-OPS	Center for Oceanographic Products and Services Division
COOP	Cooperative Observing Network
COP	Conference of the Parties
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CREWS	Coral Reef Early Warning System
CrIS	Cross-track Infrared Sounder
CRN	Climate Reference Network
CZCS	Coastal Zone Color Scanner
DAC	Data Acquisition Center
DAAC	Distributed Active Archive Center
DMS	Data Management System
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DODS	Distributed Oceanographic Data System
DOE	Department of Energy
DOI	Department of the Interior
EDC	EROS Data Center

EDR	Environmental Data Record
EEZ	Exclusive Economic Zone
EOS	Earth Observing Satellite
EOSDIS	Earth Observing Satellite Data and Information Systems
EPA	Environmental Protection Agency
EPIC	Eastern Pacific Investigation of Climate Processes
ERBE	Earth Radiation Budget Experiment
EROS	Earth Resources Observations Systems
ETM	Enhanced Thematic Mapper
EUMETSAT	European Meteorological Satellite Organization
EWG	Environmental Working Group
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization
FIA	Fire Inventory and Analysis
FWS	Fish and Wildlife Service
G^3OS	Three Global Observing Systems (GCOS, GOOS, and GTOS)
GAW	Global Atmosphere Watch
GCM	General (or Global) Circulation Model
GCMD	Global Change Master Directory
GCDIS	Global Change Data and Information System
GCOS	Global Climate Observing System
GCRMN	Global Coral Reef Monitoring Network
GDP	Global Drifter Program
GHCN	Global Historical Climatological Network
GLOSS	Global Sea Level Observing System
GMS	Geostationary Meteorological Satellite (Japanese)
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
GOOS	Global Ocean Observing System
GOSIC	Global Observing System Information Center
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning Satellite

GPSOS	GPS Occultation
GRACE	Gravity Recovery and Climate Experiment
GSN	GCOS Surface Network
GTN-G	Global Terrestrial Network for Glaciers
GTN-P	Global Terrestrial Network for Permafrost
GTOS	Global Terrestrial Observing System
GTS	Global Telecommunications System
GUAN	GCOS Upper Air Network
HALOE	Halogen Occultation Experiment
HCDN	Hydro-Climatic Data Network
HIRDLS	High Resolution Dynamic Limb Sounder
HIRS	High Resolution Infrared Sensor
HRDI	High Resolution Doppler Imager
HOTS	Hawaii Ocean Time Series
HSB	Humidity Sounder for Brazil
IABP	International Arctic Buoy Program
ICES	Ice Cloud and Land Elevation Satellite
IGBP	International Geosphere-Biosphere Program
IGBP-DIS	International Geosphere-Biosphere Program Data and Information System
IGFA	International Group of Funding Agencies for Global Change Research
IGOS	International Global Observing Strategy
IGOSS	Integrated Global Ocean Services System
IMET	Improved Meteorological instruments
IMPROVE	Interagency Monitoring of Protected Visual Environments Network
IOC	International Oceanographic Commission
IORD	Integrated Operational Requirements Document
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change
IPO	Integrated Program Office
IPSLN	Indo-Pacific Sea Level Network
IPW	Integrated Precipitable Water
ISAMS	Improved Stratospheric and Mesopheric Sounder

ISCCP	International Satellite Cloud Climatology Project
ISIS	Integrated Surface Irradiance Study
ISLP-Pac	IGOSS Sea Level Project in the Pacific
JASL	Joint Archive for Sea Level
JDIMP	Joint Data and Information Management Panel
JGOFS	Joint Global Ocean Flux Study
LCCP	Land Cover Characterization Program
LCTP	Land Cover Trends Project
LDCM	Landsat Data Continuity Mission
LEO	Low Earth Orbit
LIAG	Lake Ice Analysis Group
LTAP	Long Term Acquisition Plan
LTER	Long Term Ecological Research
MACS	Monitoring and Control System
MAP3S	Multistate Atmospheric Power Production Pollution Study
MBLA	Multi-Beam Laser Altimeter
METOP	Mid-morning Orbital Plane Satellite
MISR	Multi-angle Imaging Spectrometer
MLS	Microwave Limb Sounder
MISR	Multi-angle Imaging SpectroRadiometer
MITI	Japan's Ministry of International Trade and Industry
MMTS	Maximum-Minimum Temperature Systems
MODIS	Moderate Resolution Imaging Spectroradiometer
MON	Marine Observational Network
MOPITT	Measurement of Pollution in the Troposphere
MRLC	Multi-Resolution Land Characterization
MSS	Multi-Spectral Scanner
MSU	Microwave Sounding Unit
NADP	National Atmospheric Deposition Program
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NAVAID	Navigational Aid

NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDBC	National Data Buoy Center
NDBO	NOAA Data Buoy Office
NDSC	Network for the Detection of Stratospheric Change
NDVI	Normalized Difference Vegetation Index
NEON	National Ecological Observation Network
NEP	Net Ecosystem Production
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar
NGWLMS	Next Generation Water Level Measurement System
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Dataset
NMS	National Meteorological Services
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOHRSC	National Operational Hydrologic Remote Sensing Center
NOMAD	Naval Oceanographic and Meteorological Automated Device
NOPP	National Oceanographic Partnership Program
NORLC	National Ocean Research Leadership Council
NOS	National Ocean Service
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NSA	North Slope of Alaska
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSIP	National Streamflow Information Program
NTN	National Trends Network

NWCC	National Water and Climate Center
NWLON	National Water Level Observation Network
NWP	Numerical Weather Processing
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OFCM	Office of the Federal Coordinator for Meteorology
OGP	Office of Global Programs
OLS	Operational Linescan System
OMPS	Ozone Mapping and Profiler Suite
OOSDP	Ocean Observing System Development Panel
QME	Quality Measurement Experiment
PEM	Particle Environment Monitor
PI	Principal Investigator
PIRATA	Pilot Research Moored Array in the Tropical Atlantic
POES	Polar Orbiting Environmental Satellite
RASS	Radio-Acoustic Sounding System
RAWS	Remote Automated Weather Stations
RCC	Regional Climate Centers
RH	Relative Humidity
S_2O_2	Sargasso Sea Ocean Observatory
SAB	Science Advisory Board
SAGE	Stratospheric Aerosol and Gas Experiment
SBUV	Solar Backscatter Ultraviolet
SC	State Climatologist
SCAN	Soil Climate Analysis Network
SDD	Space Data Division
SEAS	Shipboard Environmental (data) Acquisition System
SeaWiFS	Sea-viewing Wide-Field-of-view Sensor
SEM	Space Environment Monitor
SESS	Space Environment Sensor Suite
SGP	Southern Great Plains
SHEBA	Surface Heat Budget of the Arctic

SLP	Sea-Level Pressure
SMM	Solar Maximum Mission
SMMR	Scanning Multichannel Microwave Radiometer
SNODAS	Snow Data Assimilation System
SNOTEL	Snowpack Telemetry System
SOC	Specialized Oceanographic Centre
SOEST	School of Ocean and Earth Science and Technology
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SOOP	Ships of Opportunity
SORCE	Solar Radiation and Climate Experiment
SR	Scanning Radiometer
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit
SURFRAD	Surface Radiation Network
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SWIR	Shortwave-Infrared
SXI	Solar X-Ray Imager
TAO	Tropical Atmosphere Ocean
TBB	Triband Beacon Transmitters
TES	Tropospheric Emission Spectrometer
TIP	Tiny Ionospheric Photometer
TIR	Thermal-Infrared
TIROS	Television Infrared Observations Satellite
TIROS-N	Next Generation TIROS
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOVS	Tiros Operational Vehicle Sounder
TRITON	Triangle Trans Ocean Buoy Network
TRMM	Tropical Rainfall Measuring Mission

TSI	Total Solar Irradiance
TSLC	TOGA Sea Level Center
TSG	ThermoSalinoGraph
TSIS	Total Solar Irradiance Sensor
TWP	Tropical Western Pacific
UARS	Upper Atmosphere Research Satellite
UHSLC	University of Hawaii Sea Level Center
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USCOE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
USHCN	United States Historical Climatology Network
UTC	Universal Coordinated Time
VCL	Vegetation Canopy Lidar
UV	Ultraviolet
VAP	Value Added Procedure
VIIRS	Visible Infrared Imager Radiometer Suite
VNIR	Visible and Near-Infrared
VOS	Voluntary Observing Ship
WCRP	World Climate Research Program
WFO	Weather Forecast Office
WIMS	Weather Information Management System
WMO	World Meteorological Organization
WOA	World Ocean Atlas
WOCE	World Ocean Circulation Experiment
WSR-88D	Weather Surveillance Radar - Doppler
WWW	World Wide Web
XBT	eXpendable Bathy Thermograph