# Weather and Climate Observations 3

Many variables determine weather. For example, atmospheric pressure, temperature, and humidity at different altitudes affect the development and progress of storm systems, the amount of precipitation a region receives, and the number of cloudy days. Over time, these factors contribute to the climate on local, regional, and global scales. Throughout the day, sensors located on the land and oceans and in the atmosphere and space:

- take measurements of atmospheric temperature and humidity (essential to understanding weather systems and storm development);
- monitor atmospheric winds (providing critical information on weather patterns);
- take visible-light and infrared images of cloud formations and weather systems;
- monitor changes in solar radiation; and
- measure concentrations of important atmospheric constituents.

Data gathered by these sensors are essential to understanding weather and climate. Despite efforts to date, large gaps still exist in scientists' understanding of the detailed mechanisms of weather and climate and in their ability to predict how weather and climate will change, Climatologists would like more data on atmospheric chemistry and dynamics, the extent of clouds, winds at the oceans surfaces, and upper atmosphere winds. As the recent concern over the degradation of Earth's protective ozone layer demonstrates, human activities alter atmospheric chemical constituents and affect the structure and health of the atmosphere.

**Box 3-A-NOAA's Geostationary Satellite System**

The Geostationary Operational *Enviromnetal Satellites* (GOES) maintain orbital positions over the same Earth location along the equator at about 22,300 miles above Earth, giving them the ability to make nearlyconstant observations of weather patterns over and near the United States. GOES satellites provide both visible-light and infrared images of cloud patterns, as well as "soundings," or indirect measurements, of the temperature and humidity throughout the atmosphere. These data are essential for the operations of the National Weather Service-such data provide advance warning of emerging severe weather, as well as storm monitoring. The vantage point of GOES satellites allows for the observation of large-scale weather events, which is required for forecasting small-scale events. Data from GOES satellites may be received for free directly from the satellite by individuals or organizations possessing a relatively inexpensive receiver.

In order to supply complete coverage of the continental United States, Alaska, and Hawaii, the GOES geostationary satellite program requires two satellites, one nominally placed at 75° west longitude and one at 135° west longitude. The first SMS/GOES was placed in orbit in 1974. However, from 1984-1987 and from 1989 to the present time, as a result of sensor failures and a lackof replacements, only one GOES satellite has been available to provide coverage. GOES-7 is currently located at 112°west longitude, which provides important coverage for the eastern and central United States. Unfortunately, this single satellite is nearing the end of its "design life" and could fail at anytime, leaving the United States with no GOES satellite in orbit. The United States has borrowed a Meteosat satellite from Europe to cover the East Coast and serve as a backup should GOES-7 fail. Meteosat-3 is now positioned at 75° west longitude.

**SOURCE: National Oceanic and Atmosphere Administration and Office of Technology Assessment, 1993.**

By closing these data gaps, scientists hope to understand the forces that affect Earth's weather and determine its climate. They also hope to differentiate natural variability from anthropogenic changes in weather and climate.

Satellite sensors offer wide, repeatable coverage, long-term service, and the ability to monitor several aspects of weather and climate simultaneously. Data from satellites contribute to both short- and long-term weather prediction and modeling and enhance public safety. In the short run, images of weather systems, obtained primarily from satellites in geosynchronous orbit, allow forecasters to predict the probable paths of severe storms. Data collected by polar orbiting satellites concerning the atmosphere, land, and oceans, are invaluable for understanding and modeling atmospheric temperature, humidity, wind, and the extent and condition of global vegetation (plate 3).

## NOAA's OPERATIONAL ENVIRONMENTAL SATELLITE PROGRAMS

As noted earlier, NOAA operates two satellite systems to gather data concerning weather and climate in order to support the national economy and promote public safety.

### The GOES System

To provide complete U.S. coverage, NOAA normally maintains two GOES satellites in orbit (box 3-A). However, difficulties experienced in constructing the next series of GOES satellites, GOES-Next, and the lack of a backup for the current series, have left the United States dependent on a single satellite, GOES-7, the last in the current series. To maintain critical weather observations over the United States, NOAA has signed an agreement with ESA and Eumetsat (box 3-B), the European Organisation for the Exploitation of Meteorological Satellites,[1] to lend the United

[1] Eumetsat is an intergovernmental organization that operates meteorological satellites. Its satellite systems were developed and built by the European Space Agency.

### Box 3-B—ESA and Eumetsat

The European Space Agency (ESA), a consortium of 13 member states,[1] has been in existence since 1975. ESA has developed and launched weather satellites and Earth remote sensing satellites. ESA has developed two experimental Meteosat spacecraft and an operational series of Meteosats. It is the primary agency responsible for developing remote sensing spacecraft in Europe and plays a major role in coordinating European remote sensing efforts. ESA develops and operates weather monitoring satellites on behalf of the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat).[2] Eumetsat is an intergovernmental organization, established by an international convention that states its primary objective:

> . . . to establish, maintain and exploit European systems of operational meteorological satellites, taking into account as far as possible the recommendations of the World Meteorological Organization.[3]

Some of the same issues that confront NASA and NOAA challenge ESA and Eumetsat. For example, Eumetsat has struggled to clarify its mission with regard to weather forecasting and research. ESA has recentiy decided to split its payloads between two different copies of a modular polar orbiting spacecraft, one in 1998 for scientific research and a second in 2000 for weather forecasting. Eumetsat heralds this decision, which has extended the organization's mission to environmental research, as leading to a dearer distinction between environmental experimentation and operational meteorology.[4]

1 Austria, Belgium, Denmark, Germany, France, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom; Canada and Finland are associate members.

2 Eumetsat has 16 members, including Finland, Greece, Portugal, Turkey, and the ESA members excluding Austria.

3 EUMETSAT Convention, Article 2, 1986.

4 "Eumetsat Likes Idea of Separate Polar Satellites," *Space News,* June 22, 1992, p. 23,

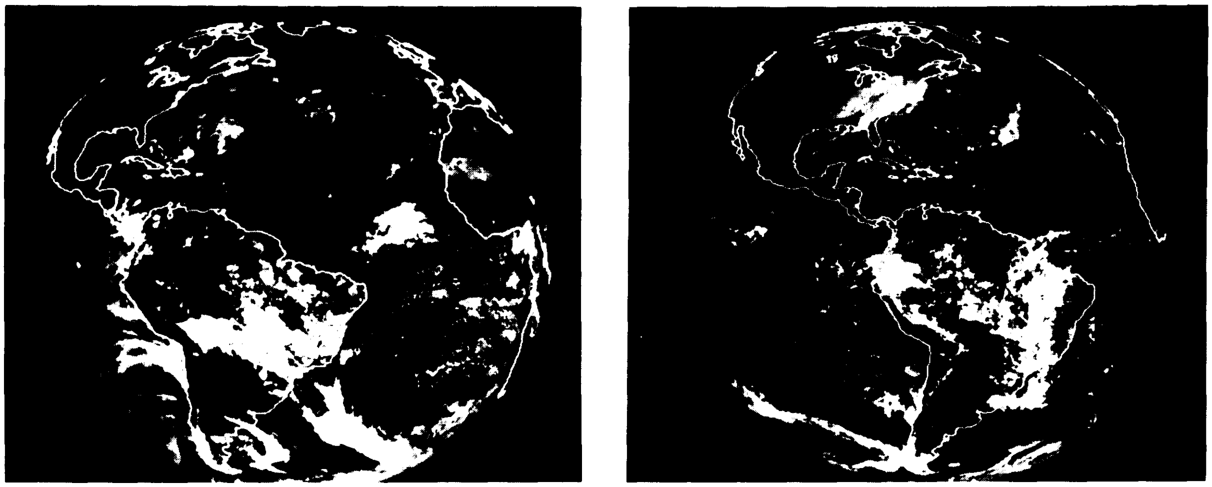
SOURCE: Office of Technology Assessment, 1993.

States Meteosat-3 to supplement observations from GOES-7 and to stand in should GOES-7 fail (figure 3-l). This arrangement illustrates the high level of international cooperation in meteorological remote sensing, which is carried out in other areas as well. Because **weather patterns move across national boundaries, international cooperation has been an important component in the collection of weather data. Governments need to cooperate with each other in order to follow weather patterns that transcend national boundaries.**

GOES-7 is currently operating well, but it and Meteosat-3 are about one year past their design lives. The first satellite in the series of GOES-Next satellites is scheduled for launch in spring 1994 (figure 3-2). The follow-on GOES-Next satellite has been plagued by technical and programmatic setbacks that, until the sumrner of 1992, led to major schedule slips and large cost overruns. Changes in management have resulted in controlled costs and good schedule success. However, until GOES-Next has been successfully launched and placed in operation, the United States faces the risk of losing weather information now provided by geosynchronous satellites.

During the early 1980s, in an effort to improve the satellite data available to the National Weather Service, NOAA funded and NASA developed new, more complex sensor and satellite designs for the GOES series. NOAA termed the new satellite series GOES-Next. GOES-Next will retain the existing visible imaging but also will provide higher resolution infrared imagery to enhance the prediction and monitoring of severe weather. A separate, continuously operating im-

Figure 3-1-Meteosat-3 Images of Earth



**These images were made before and after ESA moved Meteosat-3 westward from its earlier position near 500 west longitude to its current position at 75° west longitude. Meteosat 3, launched in 1988, served as Europe's operational satellite until June 1989, when it was placed in on-orbit storage. In August 1991 ESA reactivated the satellite and moved it from 0° west to 5@ west to supplement the U.S. GOES system. Beginning January 27, 1993, ESA moved the satellite 1° per day until it reached 75°, where the second image was taken.**

**SOURCE: National Oceanic Atmospheric Administration, European Space Agency, Eumetsat.**

proved atmospheric sounder[2] should allow for uninterrupted data on the atmosphere, contributing to improved storm prediction.

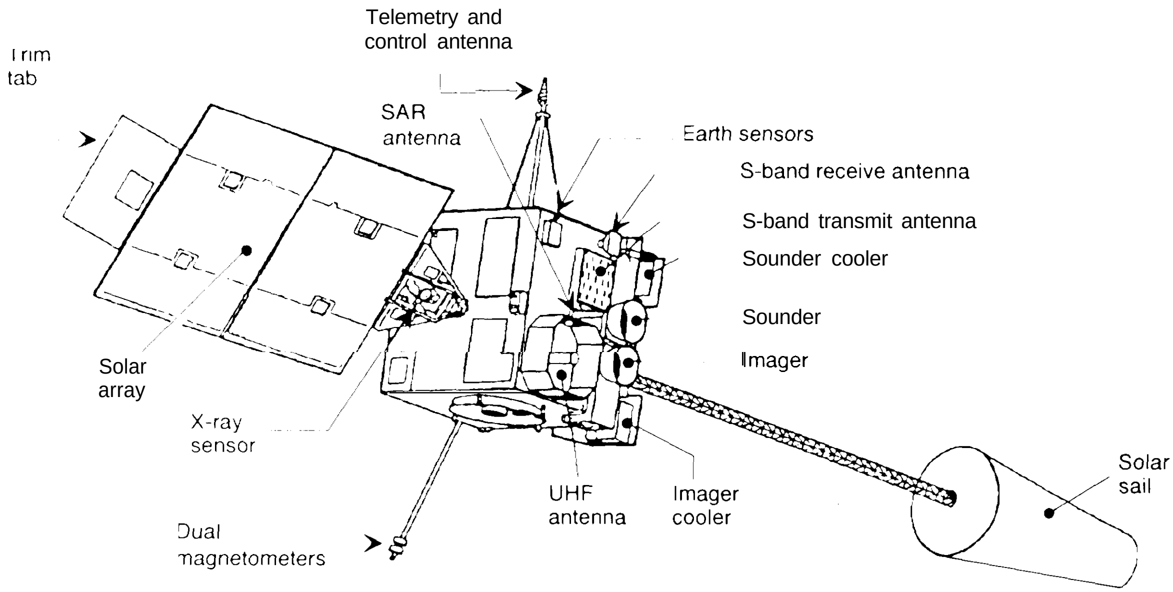
NOAA and NASA have a history of more than 30 years of cooperation on environmental satellites. NASA developed the frost TIROS polar orbiting satellite in 1960, and in 1974 it launched SMS-GOES, the precursor to NOAA's GOES system. Generally NOAA has relied on NASA to fund and develop new sensors, several of which NOAA adopted for its environmental satellites. A 1973 agreement between NASA and NOAA resulted in the Operational Satellite Improvement Program (OSIP) within NASA, which provided funding at the rate of some $15 million per year to support development of new sensors and other technologies to improve NOAA's operational satellites. In the 1970s, highly successful cooperation between NASA and NOAA resulted in the development of several sensors, including the Advanced Very High Resolution Radiometer (AVHRR) and the Total Ozone Mapping Spectrometer (TOMS).[3] During the early 1980s, in an attempt to cut its spending on satellite development, NASA eliminated spending on OSIP, leaving NOAA to fund development of GOES-Next, using NASA as the procurement agency. Problems with program management, unexpected technological challenges, and overly optimistic bids accepted from contractors have caused the development of GOES-Next to exceed its original estimated costs by over 150 percent (box 3-C).[4] If Congress wishes NASA to continue to engage **in research and development for NOAA's**

[2] A "sounder" is a sensor that provides data leading to estimates of temperature throughout the atmosphere.

[3] AVHRR and TOMS provide important data on weather, climate, and global change research. See Box 1-G below for descriptions of these sensors.

[4] Including launch costs, the GAO has calculated that the GOES-Next program, including development and construction of five satellites, will cost almost $1.8 billion, compared to its original estimate of $691 million.

Figure 3-2—Engineering Drawing of GOES-Next




**GOES-Next** is **the new generation of meteorological satellites developed for NOAA and built by Ford Aerospace. The satellite series features improved sounders and imagers, and will serve as the primary observation platform for NOAA after a much-delayed** 1994 **launch.**

**SOURCE: National Oceanic and Atmospheric Administration.**

**operational sensors and satellites, it could direct NASA to reinstate the OSIP budget line for sensor development and provide sufficient funds to support OSIP. In addition, Congress could direct NASA and NOAA to develop a more effective relationship for the development of new operational systems. Alternatively, Congress could fund NOAA sufficiently to allow NOAA to develop its own advanced sensors.** However, the latter option would require that NOAA develop sufficient expertise in satellite design and development to manage new development projects, which would likely cost more than directing NASA to take on the task again.

## ~ The POES System

**The** POES program (box 3-D), like the GOES program, employs a two-satellite system. One polar orbiter repeatedly crosses the equator at approximately 7:30 am local standard time (the ‘‘morning’ orbiter) and the other satellite crosses the equator at approximately 1:30 pm (the “afternoon’ orbiter). Although NOAA’s funding for the POES system has been highly constrained by tight NOAA budgets and by cost overruns of the GOES program, NOAA has nevertheless managed to keep two operating satellites in orbit at all times.[5] At the same time, it has actively sought international cooperation as a means of spreading the burden for providing important information to all countries of the world, and as a means of reducing U.S. costs.

For the future, NOAA is considering incorporating several of the instruments NASA has under development for the Earth Observing System in its operational satellites. For example, the Atmospheric Infrared Sounder (AIRS), planned as a

[5] In the 1980s, as a cost-cutting measure, the Reagan Administration regularly deleted funding for NOAA’s morning orbiter, but Congress re-appropriated the funding each year.

**Box 3-C Lessons learned From the GOES Experience**

The GOES system has been widely praised for its abilities to track both slow moving weather fronts and rapidly developing violent storms. GOES is credited with saving many lives since the first satellite was launched in 1975. For example, GOES images have contributed to improved early warning of violent storms, resulting in a global 50 percent decrease in storm-related deaths. Yet the development of the GOES follow-on, called GOES-Next, has met anything but calm weather. GOES-Next has been beset by management and technical problems that have resulted in a large cost overrun.[1]

NASA and NOAA have a long history of cooperation in developing spacecraft. An agreement between the two agencies, originaily signed in 1973, gives the Department of Commerce and NOAA responsibility for operating the environmental systems and requires NASA to fund development of new systems, and fund and manage research satellites. This NASA line item is known as the Operational Satellite Improvement Program, and was usually funded at an average level of about $15 million per year.[2] Prior to initiating GOES-Next development, this division of labor seemed to work well. NASA had developed the TIROS and Nimbus research satellites, which carry instruments that were eventually transferred to NOAA operational satellite systems. NASA and NOAA budgets and organizational structure were based to an extent on the agreed-upon division of responsibility.

NASA and NOAA cooperation became less effective over time. During the transition to the Reagan Administration in 1981, NASA faced cost overruns with ongoing programs and began to spend more of the available resources, including the line item that was used for NOAA development, on the Space Shuttle. In addition, the Reagan Administration was slow to appoint senior agency management in NASA. As internal pressures mounted, NASA decided not to fund development of NOAA operational sensors and spacecraft. With the concurrence of the Office of Management and Budget, NASA eliminated the budget line used to fund development of new sensors for NOAA systems.

The GOES satellites operating at the time had life expectancies that would carry the program through the late 1980s. NOM decided to build a GOES follow-on by 1989 that included a major design change. The system requirements led to a very sophisticated design. NOAA wanted to improve the sensor's visible and infrared resolution and to operate the sounder simultaneously with the imager. In responding to a GAO investigation of the GOES program, NASA officials agreed that NOAA's requirements would be hard to meet.[3] In an effort to shave

1 G~~~fi ~s o@i~II,w at a~~ $&O million; estimat~ tot~ costs are now over $1.7 biiiion, including iaunch costs, which shouid average neady $100 miiiion per iaunoh.

2 TMS figure was significantly higher durfng the eaffy 1970s.

3 U.S. - Acco@~ng ~~, '~at~ ~teliit~: Acth - to R~w ~atw of t~ U.S. Geostationary Satellite Program," Report to the Chairman, Committee on science, Space, and Technology, House of Representatives, July 1991.

high-resolution instrument that will provide temperature and humidity profiles through clouds, would be a candidate for use on future NOAA satellites.[6] However, NOAA will have to gain extensive experience with the NASA instruments and the data they provide in order to transfer them to operational use. NASA will also have to take into account the instrumental characteristics necessary for developing an operational sensor. NOAA is also investigating other new instruments to

6 AIRS will measure outgoing radiation and be able to determine land surface temperature. In addition, the sounder will be capable of determining cloud top height and effective cloud amount, as well as perform some ozone monitoring.

costs, NOAA eliminated the Phase B engineering review, an evacuation of satellite design and design changes.[4] What was not clear to NOAA program managers at the time was how great a departure from the original design was required. NOAA was confronted with the following in deciding how to replace the GOES-D satellite:

- NASA established a policy that future NOAA satellites should be designed to be launched by the Shuttle. The existing GOES design, optimized for launch on an expendable launch vehicle, was not. NASA's policy was subsequently revised after the Challenger disaster in 1986, but the new design (GOES-Next) had already been locked in.
- Several of the early GOES satellites had not demonstrated adequate reliability, failing earlier than expected. This forced a decision to advance the procurement schedule.[5]
- Since NOAA was traditionally an operational entity, it had little hope of receiving approval for satellite R&D funding, yet was pressed to proceed with a follow-on NASA procurement.
- Satellite manufacturers, though aware of the problems with the original GOES design, stated that providing simultaneous imaging and sounding could be incorporated with only modest risk. NOAA and NASA managers were skeptical of these claims, but they also needed to proceed quickly with the new design.
- A detailed interim engineering review for the GOES-Next plan was canceled for budget reasons. This review might have revealed some of the problems contained in the original design.[6]

These factors complicated the decision to proceed with the improvement to GOES, which became known as GOES-Next. The design change dictated by launch capabilities was unavoidable, given NASA's launch policy. NOAA proceeded with an ambitious effort that camouflaged some of the risk involved with developing GOES-Next. Nothing in the history of either of the contractors involved (Ford Aerospace[7] and ITT) indicated they were less than qualified for the task.

The experience with GOES-Next highlights the problems of interagency cooperation within the U.S. government. When NASA stopped funding development of operational satellites, agency responsibilities were no longer dear. Funding authority for development of future operational satellites needs to be clarified.

4 Eric J. Lerner, "Goes-Next Goes Astray," *Aerospace America*, May 1992.

5 The early GOES satellites (D-H) were plagued with the same problem—a small component that was essential to determining the direction of the field of view of the VAS sensor prematurely failed. The problem was eventually overcome, but not before NOAA was faced with an early replacement for two of its operational satellites.

6 Lerner, op. cit., footnote 15.

7 Now part of Loral Corporation.

SOURCE: Office of Technology Assessment, 1993.

improve the quality of its POES data collection.[7] Over the years, NOAA has established an enormous base of international data "customers" who depend on the delivery of data of consistent standards and familiar formats. It therefore carefully considers any changes to the format and eschews technical or financial risks to its operations.

The United States historically has transmitted data form the polar metsats at no cost to thousands of U.S. and international users, who collect data using inexpensive Automatic Picture Transmission (APT) recorders or High Resolution Picture Transmission (HRPT) recorders as the satellite passes over. Some 120 governments and thousands of other users around the world benefit from

[7] For example, NOAA and Eumetsat are supporting research on the Interferometer Temperature Sounder (ITS) by the University of Wisconsin and Hughes Santa Barbara Research.

## Box 3-D-NOAA's Polar-Orbiting Operational Environmental Satellite System

The POES satellites follow orbits that pass dose to the north and south poles as Earth rotates beneath them. They orbit at about 840 kilometers altitude, providing continuous, global coverage of the state of Earth's atmosphere, including essential parameters such as atmospheric temperature, humidity, cloud cover, ozone concentration, and Earth's energy budget, as well as important surface data such as sea ice and sea surface temperature, and snow and ice coverage. All current and near-future POES satellites carry five primary instruments:

1. *The Advanced Very High Resolution Radiornefer/2 (AVHRR/2)* determines aloud cover and Earth's surface temperature. This scanning radiometer uses five detectors to create surface images in five spectral bands, allowing multispectral analysis of vegetation, clouds, lakes, shorelines, snow, and ice.
2. The *High Resolution Infrared Radiation Sounder (HIRS/2). HIRS/2* measures energy emitted by the atmosphere in 19 spectral bands in the infrared region of the spectrum, and 1 spectral band at the far red end of the visible spectrum. HIRS data are used to estimate temperature in a vertical column of the atmosphere to 40 km above the surface. Data from this instrument can also be used to estimate pressure, water vapor, precipitable water, and ozone in a vertical column of the atmosphere.
3. The *Microwave Sounding Unit (MSU)* detects energy in the troposphere in four areas of the microwave region of the spectrum. These data are used to estimate atmospheric temperature in a vertical column up to 100 km high. Because MSU data are not seriously affected by clouds, they are used in conjunction with HIRS/2 to remove measurement ambiguity when clouds are present.
4. The *Space Environment Monitor (SEM)* is a multichannel charged-particle spectrometer that measures the flux density, energy spectrum, and total energy deposition of solar protons, alpha particles, and electrons. These data provide estimates of the energy deposited by solar particles in the upper atmosphere, and a "solar warning system" on the influence of solar fluctuations on the Earth system.
5. The *ARGOS Data Collection System (DCS)* consists of approximately 2,000 platforms (buoys, free-floating balloons, remote weather stations, and even animal collars) that transmit temperature, pressure, and altitude data to the POES satellite. The onboard DCS instrument tracks the frequency and timing of each incoming signal, and retransmits these data to a central processing facility. The system is able to determine transmitter location rather accurately.

Other instruments do not fly on every POES mission. Instruments in this category include:

The *Stratospheric Sounding Unit (SSU),* a three channel instrument, has flown on all NOAA POES satellites except for NOAA-1 2. It measures the intensity of electromagnetic radiation emitted from carbon dioxide at the top of the atmosphere, providing scientists with the necessary data to estimate temperatures through the stratosphere. The SSU is used in conjunction with HIRS/2 and MSU as part of the TIROS Operational Vertical Sounder System.

The *Solar Backscatter Ultraviolet Radiometer/2 (SBUV/2)* measures concentrations of ozone at various levels in the atmosphere, and total ozone concentration. This is achieved by measuring the spectral radiance of solar ultraviolet radiation "backscattered" from the ozone absorption band in the atmosphere, while also measuring the direct solar spectral irradiance. The SBUV is flown on POES PM orbiters only.

The *Search and Rescue Satellite Aided TrackingSystern (SARSATorS&R)kxates* signals from emergency location transponders onboard ships and aircraft in distress, and relays these data to ground receiving stations, which analyze them and transmit information to rescue teams in the area.

The Earth *Radiation Budget Experiment (ERBE)* was flown only on NOAA-9 and NOAA-10. **This research instrument consists of a medium and** wide field-of-view nonscanning radiometer, operating in four channels that view the Earth and one channel that views the sun, and a narrow field-of-view scanning radiometer with three channels that scan the Earth from horizon to horizon. ERBE measures the monthly average radiation budget on regional to global scales, and determines the average daily variations in the radiation budget.

NOAA currently has four POES satellites in orbit. NOAA-11 and NOAA-12, launched in September 1988 and May 1991, respectively, are operational, while NOAA-9 and NOAA-10, launched in 1984 and 1986, are essentially in a stand-by mode. However, the ERBE instrument on NOAA-9 continues to return limited data on the Earth's radiation budget, and the SBUV/2 instrument on NOAA-10 continues to return useful information on ozone concentration in the atmosphere. NOAA plans to upgrade several of the POES instruments in the near future. The SSU and MSU will be replaced with the Advanced Microwave Sounding Units (aboard NOAA K-M), AVHRR **will gain an additional channel, and the** ARGOS system will have expanded capacity. NOAA is planning additional improvements (in the latter part of the 1990s) to AVHRR, HIRS, and AMSU and expects to add a Total Ozone Mapping Spectrometer (TOMS) to the platform.

**NOTE: The SSU is contributed by the United Kingdom; ARGOS is a contribution of the Freneh Space Ageney CNES; and the SARSAT instrument is a joint project of Canada and France.**

**SOURCE: Office of Technology Assessment, 1993.**

this service.[8] In return, through the World Meteorological Organization,[9] many of these users provide the United States with local ground-based and radiosonde[10] data, which are essential to understanding large-scale weather patterns and climate. Some countries contribute directly to U.S. programs by supplying satellite instruments. Over the last few years, France has supplied the ARGOS onboard data collection receiver, and, with Canada, the SARSAT location system for the POES satellites; the United Kingdom has supplied the SSU.

Negotiations are currently underway between NOAA, representing the United States, and ESA and Eumetsat for Europe to assume responsibility for morning-crossing operational meteorological data on the European METOP polar platform. originally, Europe had planned to fly a large polar orbiting platform called POEM (Polar Orbit Earth Observation Mission), planned for launch in 1998. It would have included both research instruments and operational monitoring instruments. However, in order to reduce technical and financial risk, ESA and Eumetsat decided in late 1992 to split up the platform and place the operational and climate monitoring instruments on the Eumetsat METOP platform and the upper atmosphere, ocean, and ice research instruments on the ENVISAT platform.[11] The United States will also fly an improved AVHRR and an Advanced Microwave Sounding Unit (AMSU) on METOP- 1, which is planned for launch in

8 The reception and analysis of data from these and the GOES satellites have become important instructional tools in schools throughout the world.

9 See U.S. Congress, Office of Technology Assessment, OTA-ISC-239, *International Cooperation and Competition in Civilian Space Activities* (Washington, DC: U.S. Government Printing Office, 1985), ch. 3.

10 Instruments carried by satellites or weather balloons that measure and transmit temperature, humidity and pressure data.

11 The minutes of the ESA Ministerium of November, 1992, state:

(1) the Envisat-1 mission planned for launch in 1998, which will be mainly dedicated to understanding and monitoring the environment and to providing radar data as a continuation of the data provided by ERS 2.

(2) the Metop-1 mission planned for launch in2000, which will provide operational meteorological observations to be carried out taking into account the requirements expressed by the Eumetsat Council and in accordance with the terms of an Agreement to be concluded with Eumetsat.

## Box 3-E–DoD's Defense Meteorological Satellite Program

Since the mid 1960s, the Defense Meteorological Satellite Program (DMSP) has provided military commanders with accurate and up-to-date weather information. It began after DoD argued for a satellite to provide reliable and unique weather data in support of U.S. troops involved in exercises or stationed in remote locations that lack other sources of weather information.

Each current DMSP block 5D-2 satellite flies in a polar orbit at an altitude of 632 km (530 miles), and views the entire globe twice per day. The satellites use optical and infrared sensors, which cover aground swath of just under 3,000 km:

The Operational *Linescan System (OLS),* **a visible** and infrared imager that monitors aloud cover, has three spectral bands. OLS operates at high spatial resolution (.6km) about 25 percent of the time.

TheMicrowave Imager(a radiometer used for determining soil moisture, precipitation, and ice cover) has four **channels,** and a spatial resolution of 25-50 km.

The Microwave *Temperature Sounder,* used for vertical temperature sensing, has seven channels.

The Microwave *Water Vapor Sounder,* used for determining humidity through the atmosphere, has five channels and spatial resolution between 40 and 120 km.

The satellites are capable of storing up to 2 days' worth **of data before** downloading to ground stations located at Fairchild AFB, Washington, and Kaena Point, Hawaii. There are currently two of the block 5D-2 satellites in operation, and anew block upgrade is currently in development. The bus, the structural element of the satellite that carries and powers the sensors, is similar to the bus used for the TIROS satellites.

Since 1975, the Navy, Air Force, and NOM have coordinated data processing efforts and exchanged meteorological data through a shared processing network. Each of the processing centers has a particular expertise: NOM for atmospheric soundings; Navy for sea surface measurements and altimetry; and Air Force for visible and infrared mapped imagery and aloud imagery. The focus on each area of expertise is designed to limit duplication and ensure cooperation. NOAA's National Environmental Satellite, Data, and Information Service archives the data processed by all three organizations.

SOURCE: U.S. Department of Defense, 1993.

2000. This will reduce U.S. costs of providing data from the second polar orbiter, which is an important first step in saving U.S. costs for the entire polar satellite system. It may also enable the United States and Europe to provide more accurate coverage of weather and climate.

In the early part of the next century, Europe plans to provide nearly half of the polar-orbiter program. NOAA expects the cooperative polar metsat program to lead to nearly identical U.S. and European instruments, spacecraft, instrument interfaces, standard communication procedures, and data transmission standards. This is essential to reduce problems of integrating instruments and to assure that international partners can use each other's data with a minimum of complication. The program will include some moderate enhancement of instrument capabilities and the addition of a TOMS to maintain the capability to monitor atmospheric ozone.

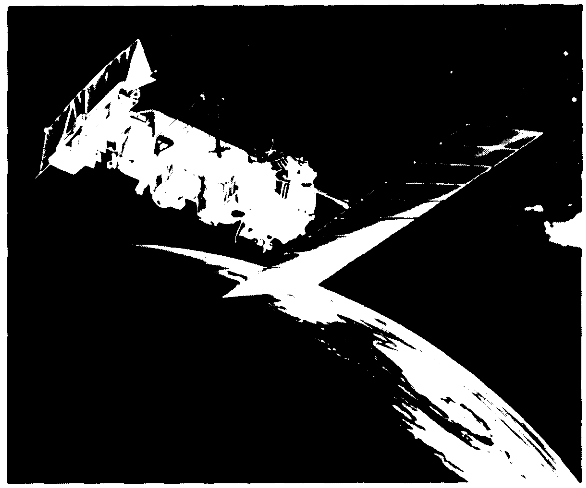
This cooperative structure should enable the United States and Europe to supply polar orbiter data to the rest of the world. Eventually the two partners might wish to embark on a broader cooperative effort including other countries, which would reduce U.S. and European costs and give greater likelihood to a widely accepted international data standard. For example, Russia operates a polar-orbiting meteorological satellite, Meteor-3, which already carries a TOMS instrument supplied by NOAA. Both the United States and Russia would likely benefit from closer cooperation on Earth observation satellite systems.

A more broadly based organization, including for example, Russia, China, and India, could also lead to a more capable system of polar orbiters. As noted earlier, the United States and other spacefaring nations have organized the Committee on Earth Observations from Space (CEOS) in order to encourage development of complementary and compatible Earth observation systems (and data), and to address issues of common interest across the spectrum of Earth observation satellite missions.[12] Chapter 8, International Cooperation and Competition, discusses these and other cooperative arrangements in more detail.

## DEFENSE METEOROLOGICAL SATELLITE PROGRAM

DoD maintains an independent meteorological system, the Defense Meteorological Satellite Program (DMSP), managed by the Air Force Space Command (box 3-E). DMSP (figure 3-3) uses a satellite platform very similar to the NOAA POES platform and operates in near-polar orbit, but carries somewhat different instruments. Among other data, DMSP provides visible and infrared ground images, measurements of soil and atmospheric temperature and moisture content, location and intensity of aurora (for radar and communications), and measurements of sea state and wind fields for naval operations. The military also uses three-dimensional cloud data from DMSP in computer models used in operational planning. The phenomena observed by DMSP are similar to those of interest to civilian weather forecasters, but several of the data requirements, such as wind speed at the oceans' surface, are of crucial interest to the military.

Figure 3-3-Artist's Rendition of the Defense Meteorological Satellite, DMSP Block 5D-2



DMSP, **operated by the Air Force, gathers meteorological data for military and civilian use. The military services and NOAA operate a joint data center to coordinate data processing and distribution.**

**SOURCE: U.S. Department of Defense.**

Are two polar-orbiting satellite systems required? Critics of the policy of maintaining separate polar-orbiting systems argue that the United States cannot afford both systems.[13] DoD and NOAA counter that each satellite system serves a unique mission. The NOAA satellites routinely provide data to thousands of U.S. and international users. DMSP serves a variety of specialized military needs and provides valuable microwave data to the civilian community. For example, often the United States has troops involved in exercises or stationed in remote locations that would not have other sources of weather information. DoD and NOAA regularly exchange meteorological data. NOAA benefits from DMSP data, and DoD also routinely uses data from NOAA. Yet DoD's needs for both training and operations can be unique. DoD

12 Committee on Earth Observations Satellites, *The Relevance of Satellite Missions to the Study of the Global Environment,* UNCED Conference, Rio de Janeiro, 1992, p 2.

13 In 1987 the General Accounting Office released a study arguing that the United States could achieve savings by eliminating duplication of environmental satellite systems. See U. S. Congress, General Accounting Office, NSIAD 87-107, ''U.S. Weather Satellites: Achieving Economies of Scale' {Washington, DC: U.S. Government Printing Office, 1987).

requires a reliable source for global weather forecasting, a function it argues is not duplicated within NOAA. Military analysts fear that civilian satellite systems, which are not under DoD control, would be unable to deliver crucial weather information to their users in time. DoD also wants to have a domestic data source insulated from international politics because data from another country's satellites might not always be made available. Finally, differences in the priorities of instruments result in differing replacement criteria for satellites when an instrument fails. For NOAA the sounder on its POES has the greatest priority. The DMSP imager holds the highest priority for the DoD. For these reasons, DoD claims a distinct need for its own meteorological system.

Congress may wish to revisit the question of **the possible consolidation of DMSP and the NOAA polar orbiting system as it searches for ways to reduce the Federal deficit.** Such a study should include a detailed analysis of the benefits and drawbacks of consolidating civilian and military sensor packages in one system, and the ability of a combined system to serve military needs in time of crisis. It should also look for innovative ways for NOAA and DoD to continue to work in partnership to carry out the missions of both agencies.

## NON-U.S. ENVIRONMENTAL SATELLITE SYSTEMS

### ESA/Eumetsat Meteosat

The first European Meteosat satellite was launched by ESA in 1977. Eumetsat took over overall responsibility for the Meteosat system from ESA in January 1987. The first spacecraft of the Meteosat Operational Programme (MOP-1) was launched in March 1989. MOP-3 is now being prepared for launch in late 1993. It has a 7-year design life. ESA has developed the MOP satellites on behalf of Eumetsat.

The Meteosat/MOP spacecraft design, instrumentation, and operation are similar to the current U.S. NOAA GOES spacecraft. The spin-stabilized spacecraft carry:

1. a visible-infrared radiometer to provide high-quality day/night cloud cover data and to collect radiance temperatures of the Earth's atmosphere; and
2. a meteorological data collection system to disseminate image data to user stations, to collect data from various Earth-based platforms and to relay data from polar-orbiting satellites.

Meteosat spacecraft are in position to survey the whole of Europe, as well as Africa, the Middle East, and the Atlantic Ocean. They relay images and data to a Meteosat Operations Control Centre within ESA'S Space Operations Control Centre in Darmstadt, Germany. A Meteorological Information Extraction Centre, located within the Meteosat control center, distributes the satellite data to various users.

### Japanese Geostationary Meteorological Satellite

The Japanese space agency, NASDA, developed the Geostationary Meteorological Satellites 1-4, which were launched in 1977, 1981, 1984, and 1989. GMS-5 is projected for a 1995 launch.[14] The GMS satellites are manufactured by Hughes Space and Communications Group and the Japanese corporation NEC, and draw heavily on Hughes' U.S. experiences with GOES. The Japan Meteorological Agency operates the third and fourth satellites, collecting data from the systems' radiometers (visible and infrared sensors), and space environment monitors.

[14] GMS-5 is currently in storage at Hughes Space and Communications Group, awaiting an H-II launch vehicle, which is still under development.

## Commonwealth of Independent States

The former Soviet Union assembled an integrated network of meteorological, land, and ocean sensing systems that have served a wide variety of military and civilian purposes. Now essentially controlled by the Russian Republic, these satellites represent one of the most capable array of remote sensing systems deployed in the world. The CIS operates eight different space platforms (including the Mir space station) that provide remotely sensed data.[15]

The CIS Meteor environmental satellite system consists of two or more polar orbiters, each of which lasts only a relatively short time in orbit. Each Meteor satellite provides data roughly similar to the NOAA POES satellites. Meteor satellites carry both visible-light and infrared radiometers, and an instrument for monitoring the flux of high energy radiation from space. Data from these instruments lead to information about the global distribution of clouds and snow and ice cover, global radiation temperature of the surface, cloud-top heights, and vertical distribution of temperature. The data can be received around the world by the same APT stations that receive data from the U.S. polar orbiters.

15 See Nicholas L. Johnson, *The Soviet Year in Space* 1990 (Colorado Springs, CO: Teledyne Brow-n Engineering, 1991), pp. 59-70.