United States General Accounting Office

GAO

Testimony

Before the Subcommittee on Environment, Technology, and Standards, Committee on Science, House of Representatives

For Release on Delivery
Expected at
10:00 a.m. EDT
Wednesday,
July 24, 2002

POLAR-ORBITING ENVIRONMENTAL SATELLITES

Status, Plans, and Future Data Management Challenges

Statement of Linda D. Koontz
Director, Information Management Issues

GAO
Accountability * Integrity * Reliability

GAO-02-684T

Mr. Chairman and Members of the Subcommittee:

We appreciate the opportunity to join in today's hearing to discuss our work on the planned National Polar-orbiting Operational Environmental Satellite System (NPOESS). At your request, we will discuss our nation's current polar-orbiting weather satellite program, plans for NPOESS, and key challenges in managing future NPOESS data volumes.

In brief, today's polar-orbiting environmental satellite program is a complex infrastructure encompassing two satellite systems, supporting ground stations, and four central data processing centers that provide general weather information and specialized environmental products to a variety of users, including weather forecasters, military strategists, and the public. NPOESS is planned to merge the two satellite systems into a single state-of-the-art environment monitoring satellite system, at a significant cost savings. This new satellite system is expected to provide vast streams of data, far more than are currently handled by the four processing centers and weather information users.

To handle this increased volume of satellite data, the four processing centers will need to build up their respective infrastructures, and they will need to work to efficiently incorporate new data into their weather products and models. Because the NPOESS launch is several years in the future, agencies have time to plan for expanding their infrastructures and models so that they can handle the increased data volumes that NPOESS will provide. Each of the processing centers is planning activities to build its capacity to handle increased volumes of data, but more can be done to coordinate and focus these plans.

The approach we used to perform this work—our objectives, scope, and methodology—is provided in appendix I.

Polar Satellite Program Overview

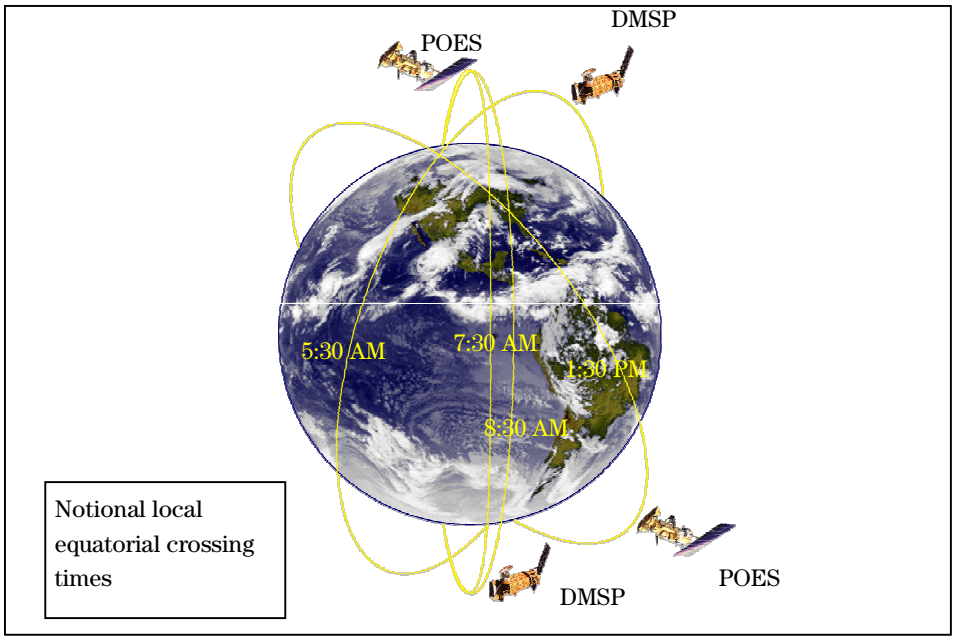
Since the 1960s, the United States has operated two separate polar-orbiting meteorological satellite systems. These systems are known as the Polar-orbiting Operational Environmental Satellites (POES), managed by the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS), and the Defense Meteorological Satellite Program (DMSP), managed by the Department of Defense (DOD). These satellites obtain environmental data that are processed to provide graphical weather images and specialized weather products, and that are the predominant input to numerical weather prediction models—all used by weather forecasters, the military,

and the public. Polar satellites also provide data used to monitor environmental phenomena, such as ozone depletion and drought conditions, as well as data sets that are used by researchers for a variety of studies, such as climate monitoring.

Polar Satellite Infrastructure

Unlike geostationary satellites, which maintain a fixed position above the earth, polar-orbiting satellites constantly circle the Earth in an almost north-south orbit, providing global coverage of conditions that affect the weather and climate. Each satellite makes about 14 orbits a day. As the earth rotates beneath it, each satellite views the entire earth's surface twice a day. Today, there are two operational POES satellites and two operational DMSP satellites that are positioned so that they can observe the earth in early morning, morning, and afternoon polar orbits. Together, they ensure that for any region of the earth, the data are generally no more than 6 hours old. Figure 1 illustrates the current operational polar satellite configuration. Besides the four operational satellites, there are five older satellites in orbit that still collect some data and are available to provide some limited backup to the operational satellites should they degrade or fail. In the future, both NOAA and DOD plan to continue to launch additional POES and DMSP satellites every few years, with final launches scheduled for 2008 and 2009, respectively.

Figure 1: Configuration of Operational Polar Satellites



Source: NPOESS Integrated Program Office.

Each of the polar satellites carries a suite of sensors designed to detect environmental data either reflected or emitted from the earth, the atmosphere, and space. The satellites store these data and then transmit the data to NOAA and Air Force ground stations when the satellites pass overhead. The ground stations then relay the data via communications satellites to the appropriate meteorological centers for processing.

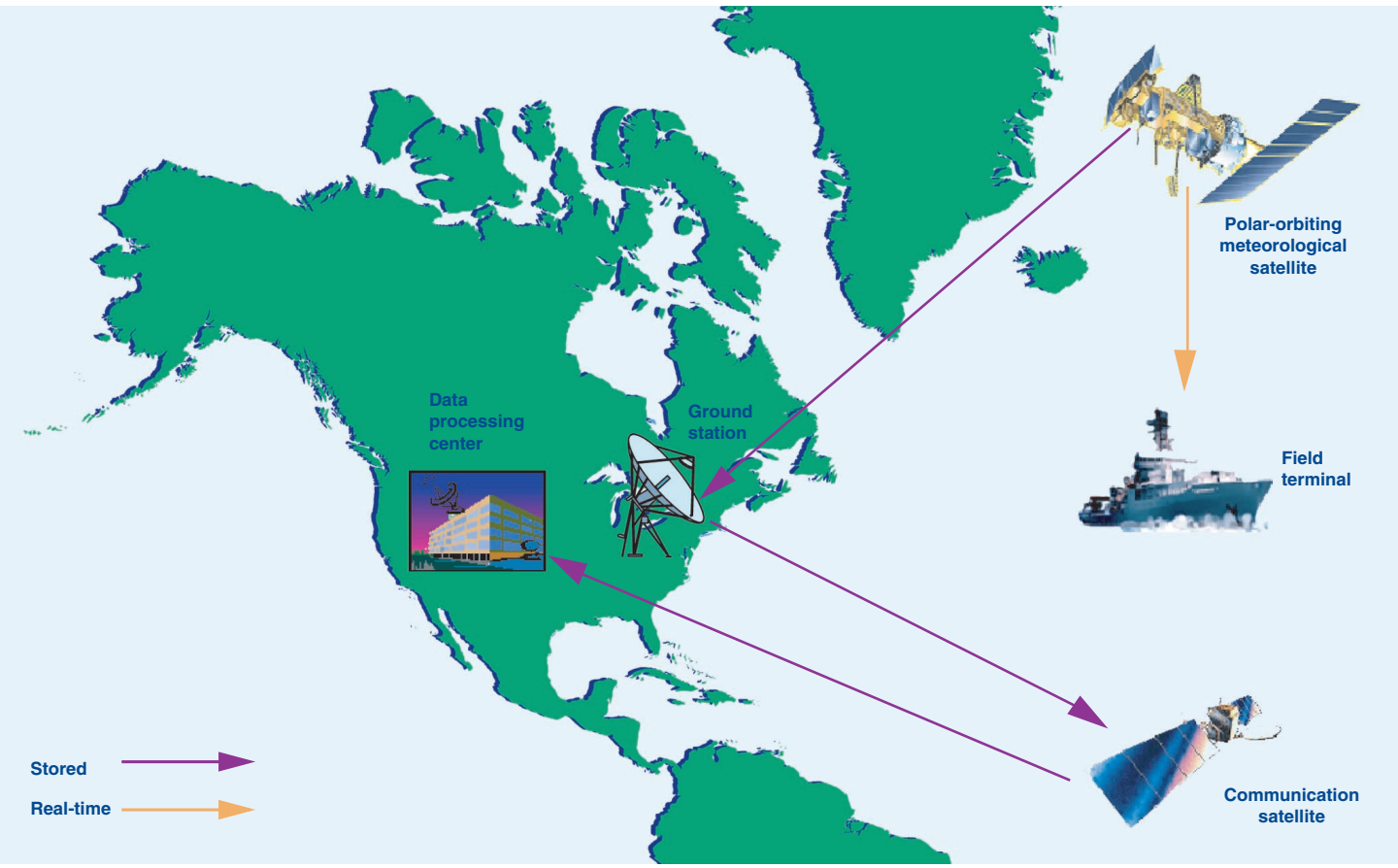
Under a shared processing agreement among the four processing centers—NESDIS,[1] the Air Force Weather Agency, Navy's Fleet Numerical Meteorology and Oceanography Center, and the Naval Oceanographic Office—different centers are responsible for producing and distributing different environmental data sets, specialized weather and oceanographic products, and weather prediction model outputs via a shared network. Each of the four processing centers is also responsible for distributing the

[1]Within NOAA, NESDIS processes the satellite data, and the National Centers for Environmental Prediction (NCEP), a component of NOAA's National Weather Service, runs the models. For simplicity, we refer to the combined NESDIS/NCEP processing center as the NESDIS processing center.

data to its respective users. For the DOD centers, the users include regional meteorology and oceanography centers as well as meteorology and oceanography staff on military bases. NESDIS forwards the data to the National Weather Service for distribution and use by forecasters. The processing centers also use the Internet to distribute data to the general public. NESDIS is responsible for the long-term archiving of data and derived products from POES and DMSP.

In addition to the infrastructure supporting satellite data processing noted above, properly equipped field terminals that are within a direct line of sight of the satellites can receive real-time data directly from the polar-orbiting satellites. There are an estimated 150 such field terminals operated by the U.S. government, many by DOD. Field terminals can be taken into areas with little or no data communications infrastructure—such as on a battlefield or ship—and enable the receipt of weather data directly from the polar-orbiting satellites. These terminals have their own software and processing capability to decode and display a subset of the satellite data to the user. Figure 2 depicts a generic data relay pattern from the polar-orbiting satellites to the data processing centers and field terminals.

Figure 2: Generic Data Relay Pattern for the Polar Meteorological Satellite System



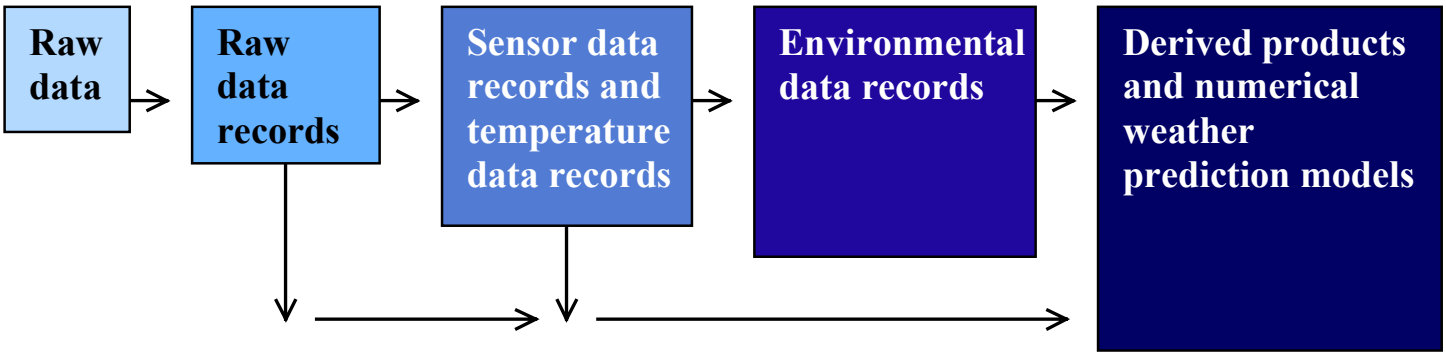
Polar Satellite Data, Products, and Uses

Polar satellites gather a broad range of data that are transformed into a variety of products for many different uses. Satellite sensors observe different bands of radiation wavelengths, called channels, which are used for remotely determining information about the earth's atmosphere, land surface, oceans, and the space environment. When first received, satellite data are considered raw data.[2] To make them usable, the processing centers format the data so that they are time-sequenced and include earth location and calibration information. After formatting, these data are

[2]NOAA uses different nomenclature for its data processing stages: raw data are known as level 0 data; raw data records are known as level 1a data; temperature data records and sensor data records are known as level 1b data; and environmental data records are known as level 2 data.

called raw data records. The centers further process these raw data records into channel-specific data sets, called sensor data records and temperature data records. These data records are then used to derive weather products called environmental data records (EDR). EDRs range from atmospheric products detailing cloud coverage, temperature, humidity, and ozone distribution; to land surface products showing snow cover, vegetation, and land use; to ocean products depicting sea surface temperatures, sea ice, and wave height; to characterizations of the space environment. Combinations of these data records (raw, sensor, temperature, and environmental data records) are also used to derive more sophisticated products, including outputs from numerical weather models and assessments of climate trends. Figure 3 is a simplified depiction of the various stages of data processing.

Figure 3: Satellite Data Processing Steps



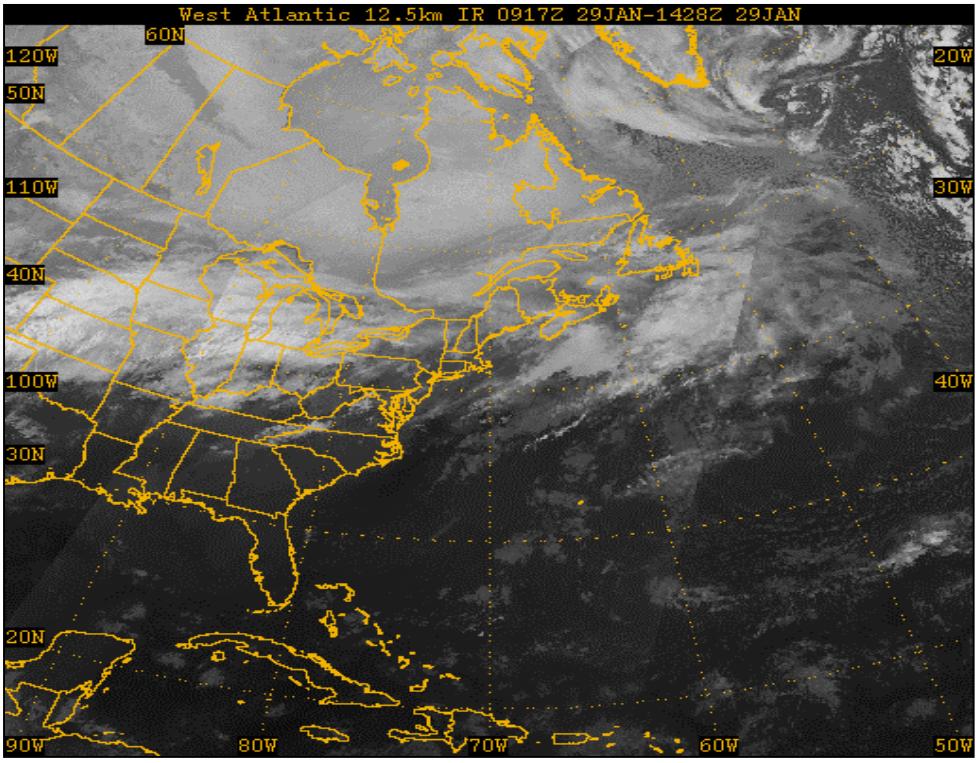
EDRs can be either images or quantitative data products. Image EDRs provide graphical depictions of the weather and are used to observe meteorological and oceanographic phenomena to track operationally significant events (such as tropical storms, volcanic ash,[3] and icebergs), and to provide quality assurance for weather prediction models.

The following figures present some polar-orbiting satellite images. Figure 4 is an image from a DMSP satellite showing an infrared picture taken over the west Atlantic Ocean. Figure 5 is a POES image of Hurricane Floyd, which struck the southern Atlantic coastline in 1999. Figure 6 is a polar-satellite image used to detect volcanic ash clouds, in particular the ash

[3]Volcanic ash presents a hazard to aviation because of its potential to damage engines.

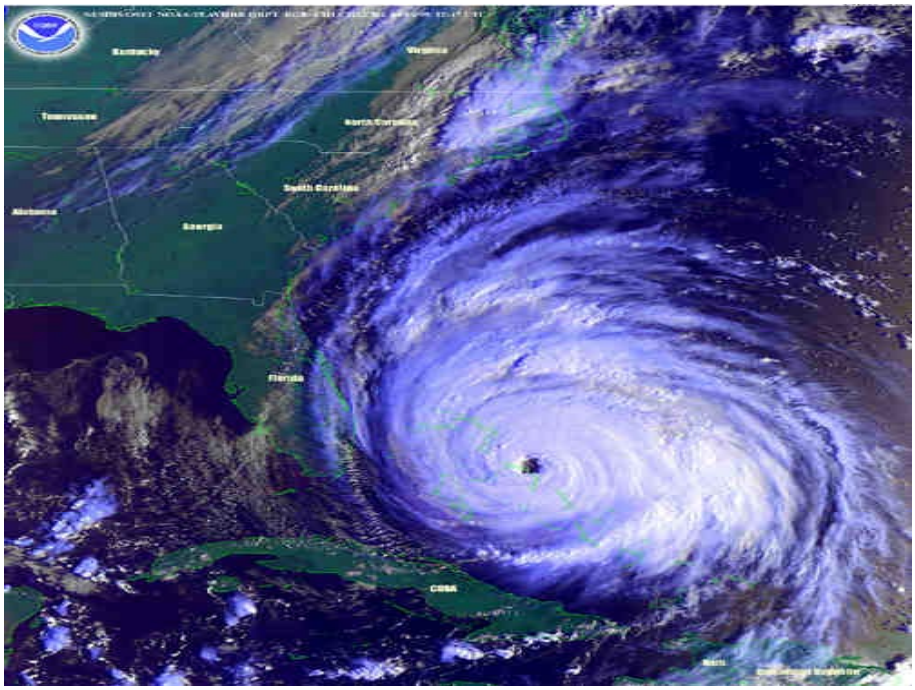
cloud resulting from the eruption of Mount Etna in 2001. Figure 7 shows the location of icebergs near Antarctica in February 2002.

Figure 4: DMSP Image of the West Atlantic Ocean



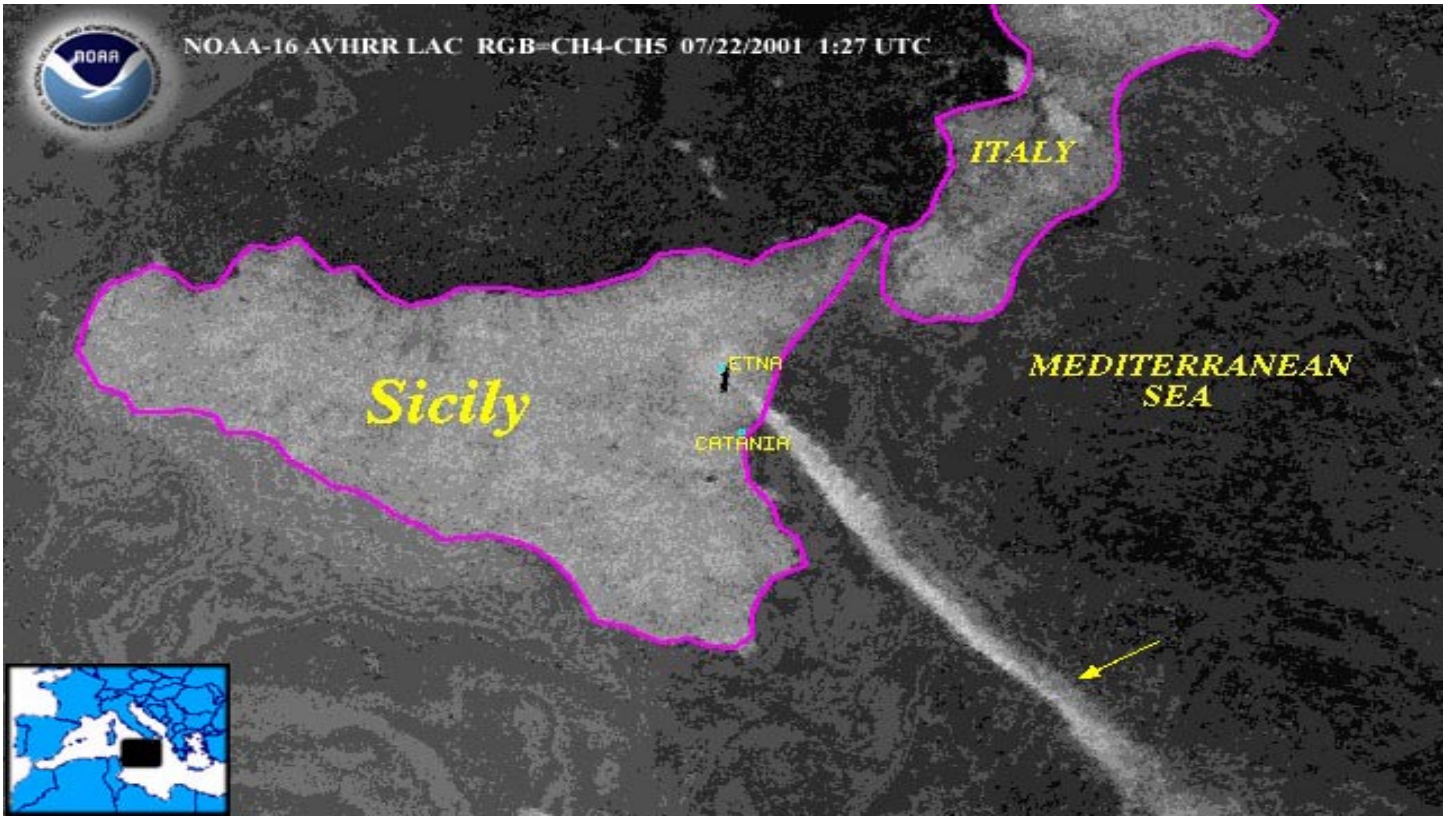
Source: Navy Fleet Numerical Meteorology and Oceanography Center.

Figure 5: POES Image of Hurricane Floyd in 1999



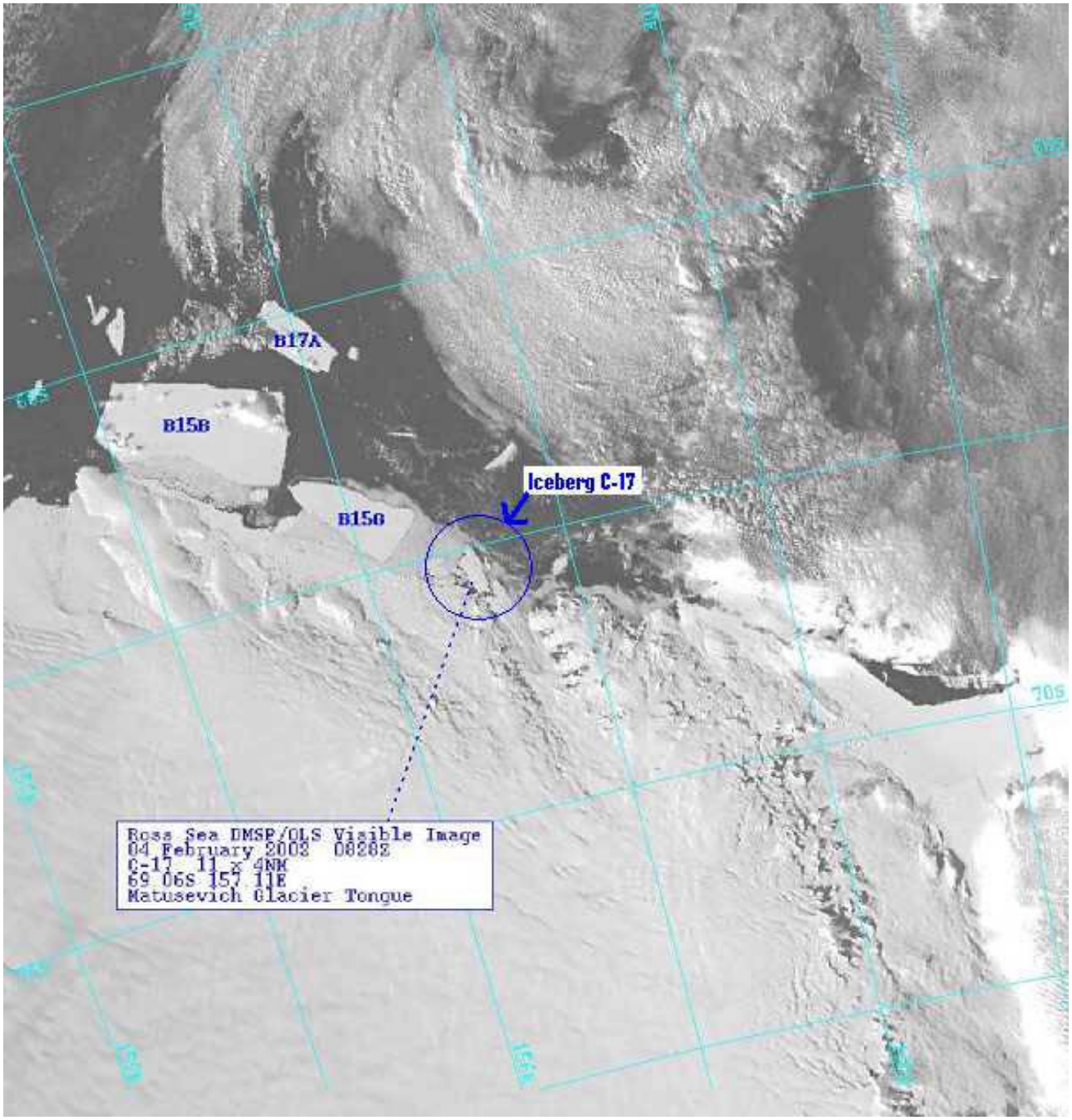
Source: NOAA.

Figure 6: POES Image of Volcanic Ash Cloud from Mt. Etna, Sicily, in 2001



Source: NOAA.

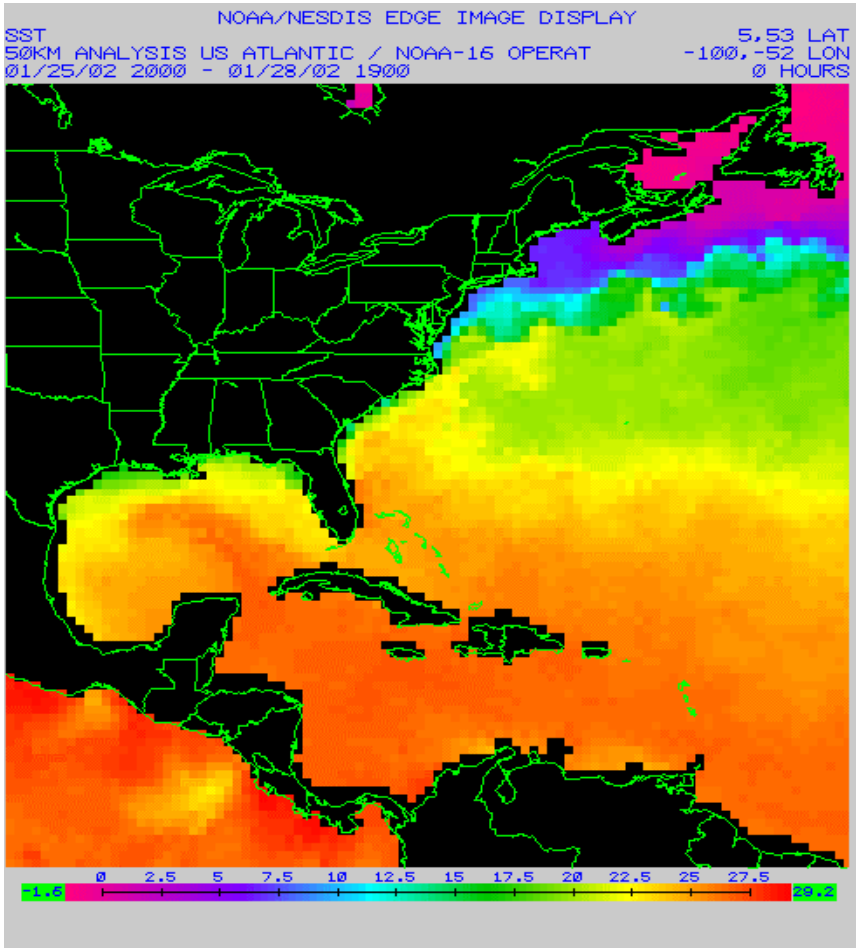
Figure 7: DMSP Image of Icebergs Near Antarctica



Source: Naval/National Ice Center.

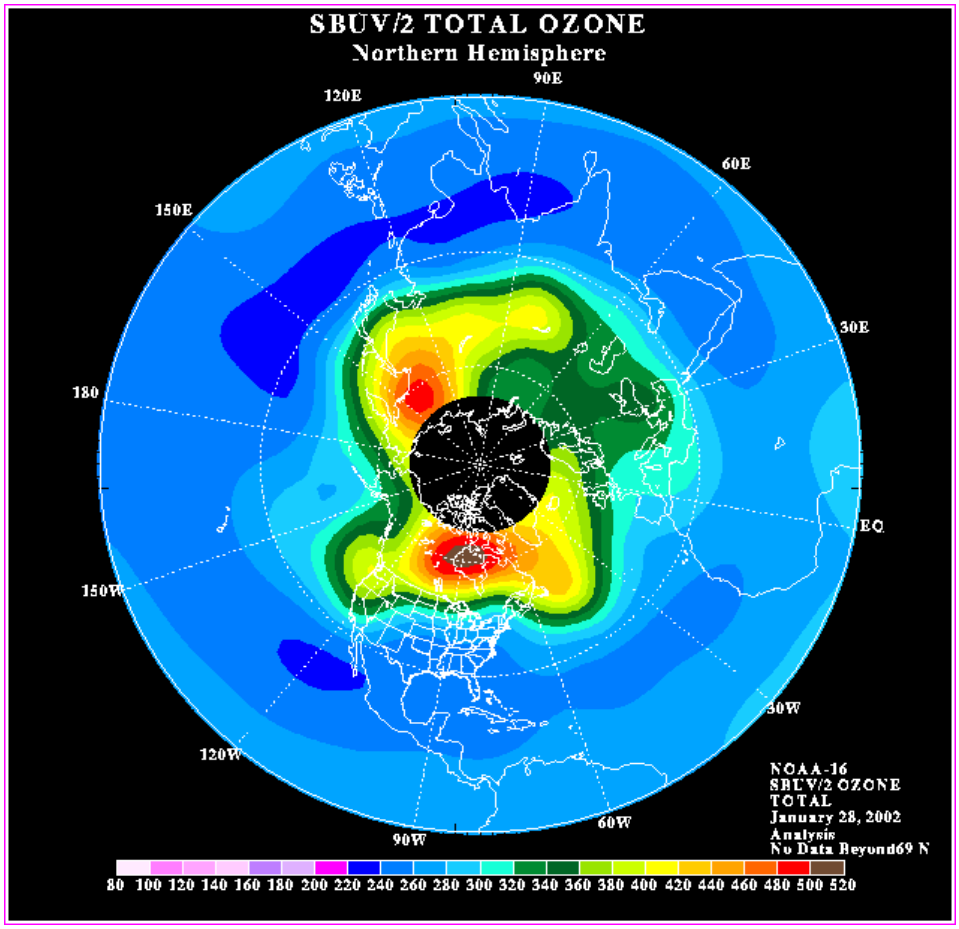
Quantitative EDRs are specialized weather products that can be used to assess the environment and climate or to derive other products. These EDRs can also be depicted graphically. Figures 8 and 9 are graphic depictions of quantitative data on sea surface temperature and ozone measurements, respectively. An example of a product that was derived from EDRs is provided in figure 10. This product shows how long a person could survive in the ocean—information used in military as well as search and rescue operations—and was based on sea surface temperature EDRs from polar-orbiting satellites.

Figure 8: Analysis of Sea Surface Temperatures from POES Satellite Data



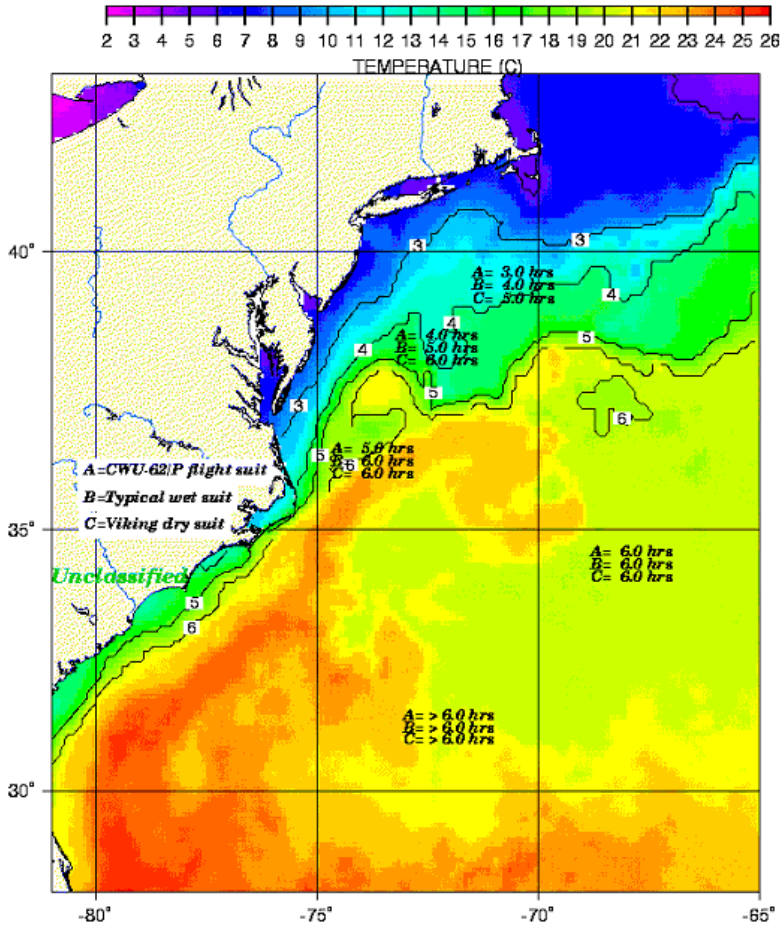
Source: NOAA/NESDIS.

Figure 9: Analysis of Ozone Concentration from POES Satellite Data



Source: NESDIS.

Figure 10: Analysis of Water Survivability off the Atlantic Seaboard, January 2002



Note: Contour lines with blocked numbers depict survival time, in hours, without a survival suit.

Source: Naval Oceanographic Office.

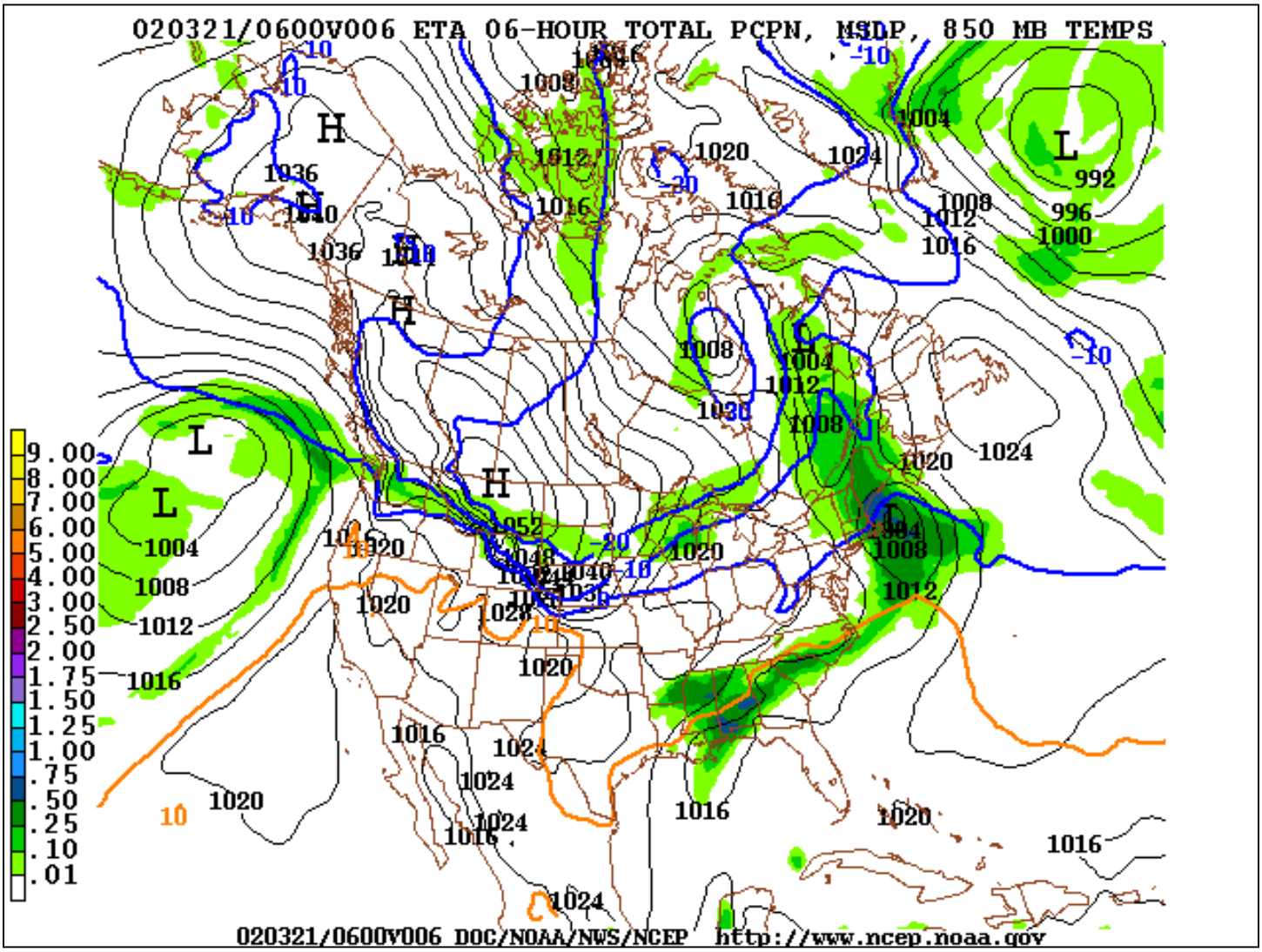
Another use of quantitative satellite data is in numerical weather prediction models. Based predominantly on observations from polar-orbiting satellites and supplemented by data from other sources such as geostationary satellites, radar, weather balloons, and surface observing systems, numerical weather prediction models are used to help forecast atmospheric, land, and ocean conditions hours, days, weeks, and months into the future. These models require quantitative satellite data to update their analysis of weather and to produce new forecasts. Table 1 contains

examples of models run by the processing centers. Figure 11 depicts the output of one common model.

Table 1: Common Numerical Weather Prediction Models Used by Processing Centers

Model	Purpose	Processing center
Global Forecast System	Global weather forecasts	NESDIS/NCEP
Eta Model	Regional weather forecasts	NESDIS/NCEP
Mesoscale Model 5	Regional forecasts	Air Force Weather Agency
Advect Cloud Model	Global cloud forecast and analysis	Air Force Weather Agency
Navy Operational Global Atmospheric Prediction System	Global weather forecasts	Navy Fleet Numerical Meteorology and Oceanography Center
Coupled Oceanographic and Atmospheric Mesoscale Prediction System	Regional weather forecasts	Navy Fleet Numerical Meteorology and Oceanography Center
Wave Model	Regional oceanographic forecasts	Naval Oceanographic Office

Figure 11: Model Output Depicting a 6-Hour Precipitation Forecast



Source: NCEP.

All this information—satellite data, imagery, derived products, and model output—is used in mapping and monitoring changes in weather, climate, the ocean, and the environment. These data and products are provided to weather forecasters for use in issuing weather forecasts and warnings to the public and to support our nation's aviation, agriculture, and maritime communities. Also, weather data and products are used by climatologists and meteorologists to monitor the environment. Within the military, these data and products allow military planners and tactical users to focus on

anticipating and exploiting atmospheric and space environmental conditions. For example, Air Force Weather Agency officials told us that accurate wind and temperature forecasts are critical to any decision to launch an aircraft that will need mid-flight refueling. In addition to these operational uses of satellite data, there is also a substantial need for polar satellite data for research. According to experts in climate research, the research community requires long-term, consistent sets of satellite data collected sequentially, usually at fixed intervals of time, in order to study many critical climate processes. Some examples of research topics include long-term trends in temperature, precipitation, and snow cover.

The National Polar-Orbiting Operational Environmental Satellite System

Given the expectation that converging the POES and DMSP programs would reduce duplication and result in sizable cost savings, a May 1994 presidential decision directive required NOAA and DOD to converge the two satellite programs into a single satellite program capable of satisfying both civilian and military requirements. The converged program is called the National Polar-orbiting Operational Environmental Satellite System (NPOESS), and it is considered critical to the United States' ability to maintain the continuity of data required for weather forecasting and global climate monitoring. To manage this program, DOD, NOAA, and the National Aeronautics and Space Administration (NASA) have formed a tri-agency integrated program office, located within NOAA.

Within the program office, each agency has the lead on certain activities. NOAA has overall responsibility for the converged system, as well as satellite operations; DOD has the lead on the acquisition; and NASA has primary responsibility for facilitating the development and incorporation of new technologies into the converged system. NOAA and DOD share the costs of funding NPOESS, while NASA funds specific technology projects and studies.

NPOESS Overview

NPOESS is a major system acquisition estimated to cost $6.5 billion over the 24-year period from the inception of the program in 1995 through 2018. The program is to provide satellite development, satellite launch and operation, and integrated data processing. These deliverables are grouped into four main categories: (1) the launch segment, which includes the launch vehicle and supporting equipment, (2) the space segment, which includes the satellites and sensors, (3) the interface data processing segment, which includes the data processing system to be located at the four processing centers, and (4) the command, control, and

communications segment, which includes the equipment and services needed to support satellite operations.

NPOESS will be a launch-on-demand system, and satellites must be available to back up the planned launches of the final POES and DMSP satellites. The first NPOESS satellite—designated C1—is scheduled for delivery in 2008 and is to be available to back up the planned launch of the final POES satellite in 2008. If C1 is not needed to back up the final POES, it will be launched in April 2009. The second NPOESS satellite is to be available to back up the planned launch of the final DMSP satellite in late 2009, or if not needed as a backup, it is to be launched in 2011. Subsequent launches are expected to occur approximately every 2 years through 2018.

Program acquisition plans call for the procurement and launch of six NPOESS satellites over the life of the program and the integration of 13 instruments, including 11 environmental sensors and 2 subsystems. Together, the sensors are to receive and transmit data on atmospheric, cloud cover, environmental, climate, oceanographic, and solar-geophysical observations. The subsystems are to support nonenvironmental search and rescue efforts, as well as environmental data collection activities. According to the integrated program office, 8 of NPOESS's 13 instruments involve new technology development, whereas 5 others are based on existing technologies. The planned instruments and the state of technology on each are listed in table 2.

Table 2: Expected NPOESS Instruments

Instrument name	Description	State of technology
Advanced technology microwave sounder	This sensor is to measure microwave energy released and scattered by the atmosphere, and is to be used with infrared sounding data from NPOESS' cross-track infrared sounder to produce daily global atmospheric temperature, humidity, and pressure profiles.	New
Aerosol polarimetry sensor	This sensor is to retrieve specific aerosol (liquid droplets or solid particles suspended in the atmosphere, such as sea spray, smog, and smoke) and cloud measurements.	New
Conical microwave imager/sounder	This sensor is to collect microwave images and data needed to measure rain rate, ocean surface wind speed and direction, amount of water in the clouds, and soil moisture, as well as temperature and humidity at different atmospheric levels.	New
Cross-track infrared sounder	This sensor is to collect measurements of the Earth's radiation to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere.	New
Data collection system	This system collects environmental data from platforms around the world and delivers them to users worldwide.	Existing
Earth radiation budget sensor	This sensor measures solar short-wave radiation and long-wave radiation released by the Earth back into space on a worldwide scale to enhance long-term climate studies.	Existing

Instrument name	Description	State of technology
Global positioning system occultation sensor	This sensor is to measure the refraction of radio wave signals from the Global Positioning System and Russia's Global Navigation Satellite System to characterize the ionosphere.	New
Ozone mapper/profiler suite	This sensor is to collect data needed to measure the amount and distribution of ozone in the Earth's atmosphere.	New
Radar altimeter	This sensor measures variances in sea surface height/topography and ocean surface roughness, which are used to determine sea surface height, significant wave height, and ocean surface wind speed and to provide critical inputs to ocean forecasting and climate prediction models.	Existing
Search and rescue satellite aided tracking system	This system detects and locates aviators, mariners, and land-based users in distress.	Existing
Space environmental sensor suite	This suite of sensors is to collect data to identify, reduce, and predict the effects of space weather on technological systems, including satellites and radio links.	New
Total solar irradiance sensor	This sensor monitors and captures total and spectral solar irradiance data.	Existing
Visible/infrared imager radiometer suite	This sensor is to collect images and radiometric data used to provide information on the Earth's clouds, atmosphere, ocean, and land surfaces.	New

Unlike the current polar satellite program, in which the four centers use different approaches to process raw data into the environmental data records that they are responsible for, NPOESS' integrated data processing system ~~to~~ be located at the four centers—is expected to provide a standard system to produce these data sets and products. The four processing centers will continue to use these data sets to produce other derived products, as well as for input to their numerical prediction models.

NPOESS is planned to produce 55 environmental data records (EDRs), including atmospheric vertical temperature profile, sea surface temperature, cloud base height, ocean wave characteristics, and ozone profile. Some of these EDRs are comparable to existing products, whereas others are new. The user community designated six of these data products—supported by four sensors[4]—as key EDRs, and noted that failure to provide them would cause the system to be reevaluated or the program to be terminated.

Acquisition Strategy

The NPOESS acquisition program consists of three key phases: the concept and technology development phase, which lasted from roughly 1995 to early 1997; the program definition and risk reduction phase, which began in early 1997 and is ongoing now; and the engineering and

[4]The four sensors supporting key EDRs are (1) the advanced technology microwave sounder, (2) the conical microwave imager/sounder, (3) the cross-track infrared sounder, and (4) the visible/infrared imager radiometer suite.

manufacturing development and production phase, which is expected to begin next month and continue through the life of the program. The concept and technology development phase began with the decision to converge the POES and DMSP satellites and included early planning for the NPOESS acquisition. This phase included the successful convergence of the command and control of existing DMSP and POES satellites at NOAA's satellite operations center.

The program definition and risk reduction phase involves both system-level and sensor-level initiatives. At the system level, the program office awarded contracts to two competing prime contractors—Lockheed Martin and TRW—to prepare for NPOESS system performance responsibility. These contractors are developing unique approaches to meeting requirements, designing system architectures, and developing initiatives to reduce sensor development and integration risks. These contractors will compete for the development and production contract. At the sensor level, the program office awarded contracts to develop five sensors.[5] These sensors are in varying stages of development. This phase will end when the development and production contract is awarded. At that point, the winning contractor will assume responsibility for managing continued sensor development.

The final phase, engineering and manufacturing development and production, is expected to begin next month when the development and production contract is awarded. The program office issued a request for proposals for the contract in February 2002 and is currently evaluating proposals, with an expectation of awarding the contract by the end of August 2002. The winning contractor will assume system performance responsibility for the overall program. This responsibility includes all aspects of design, development, integration, assembly, test and evaluation, operations, and on-orbit support.

Risk Reduction Activities

In May 1997, the integrated program office assessed the technical, schedule, and cost risks of key elements of the NPOESS program, including (1) the launch segment, (2) the space segment, (3) the interface data processing segment, (4) the command, control, and communications

[5]The five sensors include (1) the conical microwave imager/sounder, (2) the cross-track infrared sounder, (3) the global positioning system occultation sensor, (4) the ozone mapper/profiler suite, and (5) the visible/infrared imager radiometer suite.

segment, and (5) the overall system integration. As a result of this assessment, the program office determined that three elements had high risk components: the interface data processing segment, the space segment, and the overall system integration segment. Specifically, the interface data processing segment and overall system integration were assessed as high risk in all three areas (technical, cost, and schedule), whereas the space segment was assessed to be high risk in the technical and cost areas, and moderate risk in the schedule area. The launch segment and the command, control, and communications segment were determined to present low or moderate risks. The program office expects to reduce its high risk components to low and moderate risks by the time the development and production contract is awarded, and to have all risk levels reduced to low before the first launch. Table 3 displays the results of the 1997 risk assessment as well as the program office's projections for those risks by August 2002 and by first launch.

Table 3: Actual Risk Levels in 1997 and Projected Risk Levels by August 2002 and by First Launch

	Actual risk levels in May 1997			Projected risk levels by August 2002			Projected risk levels by first launch (2008-2009)		
Area assessed	Technical	Schedule	Cost	Technical	Schedule	Cost	Technical	Schedule	Cost
System integration	H	H	H	M	M	L	L	L	L
Launch segment	L	L	M	L	L	L	L	L	L
Space segment	H	M	H	L	M	L	L	L	L
Interface data processing segment	H	H	H	M	L	L	L	L	L
Command, control, and communications segment	L	L	L	L	L	L	L	L	L

Source: NOAA/Integrated Program Office.

In order to meet its goals of reducing program risks, the program office developed and implemented an integrated risk reduction program that includes nine initiatives. While individual initiatives may address one or more identified risks, the program office anticipated that the combination of these nine projects would address the risk to overall system integration. The nine projects are as follows:

- **Deferred development:** To reduce program risk, the program office deferred development of 21 EDR requirements either because the technology needed to implement the requirements did not exist or because the requirement was too costly. For example, the requirement for measuring ocean salinity was deferred until the technology needed to take these measurements has been demonstrated in space. If feasible, the

program office plans to implement these requirements later as program enhancements.

- **Early sensor development:** Because environmental sensors have historically taken 8 years to develop, development of six of the eight sensors with more advanced technologies was initiated early. In the late 1990s, the program office awarded contracts for the development, analysis, simulation, and prototype fabrication of five of these sensors.[6] In addition, NASA awarded a contract for the early development of one other sensor.[7] Responsibility for delivering these sensors will be transferred from the program office and NASA to the winning development and production contractor. According to program office officials, these sensors should be delivered at least 2 years before the earliest expected NPOESS launch because of these early development efforts.

- **Building on existing sensor technologies:** In order to minimize risks, the program office used existing sensor technologies as a starting point from which to build new sensors and also plans to use some existing sensors on NPOESS. For example, the new cross-track infrared sounder sensor grew from technology used on the POES high-resolution infrared sounder and on the atmospheric infrared sounder carried on NASA's Earth Observing System/Aqua satellite. Also, NPOESS' data collection system is based on the data collection system already flying on another satellite and, according to program officials, will likely be available largely "off the shelf." Program office officials reported that building on existing sensors should enable them to obtain half of the NPOESS sensors and almost half of the required 55 EDRs while reducing the risk of integrating new technology into the program.

- **Ground demonstrations:** To reduce the risk to the data processing segment, the program office had both of the program definition and risk reduction contractors conduct four ground-based demonstrations of hardware and software components of the data processing system. Because of work done during the program definition and risk reduction

[6]The five program office–developed sensors are (1) the cross-track infrared sounder (2) the conical microwave imager/sounder, (3) the global positioning system occultation sensor, (4) the ozone mapper/profiler suite, and (5) the visible/infrared imager radiometer suite.

[7]NASA is developing the advanced technology microwave sounder sensor.

contract phase, the program office expects the interface data processing segment to be relatively mature before contract award.

- **Internal government studies:** To reduce the risks in integrating the NPOESS space and interface data processing segments, over the past 5 years, the integrated program office has overseen risk reduction studies performed by over 30 major scientific organizations, including government laboratories, major universities, and institutes. These studies include observing system simulation experiments and data assimilation studies, which involve simulating a future sensor and then identifying ways to incorporate the new data into products and models. For example, the studies were used to assess the impact of advanced sounders similar to those on NPOESS and the impact of NPOESS-like data on forecasts and end user products.

- **Aircraft flights:** Since 1997, the integrated program office has used aircraft flights to demonstrate satellite sensors and to deliver early data to its users so that they can begin to work with the data. For example, in 2001, the NPOESS airborne sounder testbed project began using NASA aircraft to provide an environment in which instruments could be tested under conditions that simulate space.

- **Operational algorithm teams:** The integrated program office established five operational algorithm teams to serve as scientific advisory groups. The teams, made up of representatives from government and federally funded research and development centers, worked with the program office for 5 years to oversee the development and refinement of various algorithms that NPOESS will use. They will continue to work with the development and production contractor to refine the data processing algorithms.

- **WindSat/Coriolis demonstration:** WindSat/Coriolis is a demonstration satellite, planned for launch in 2003, to test critical new ocean surface wind-observing science and technology that will be used in the NPOESS conical microwave imager/sounder sensor. This demonstration project will also help validate the technology needed to support various EDRs.

- **NPOESS preparatory project:** This is a planned demonstration satellite to be launched in early 2006, 2 to 3 years before the first NPOESS satellite launch. It is scheduled to host three critical NPOESS sensors (the visible/infrared imager radiometer suite, the cross-track infrared sounder, and the advanced technology microwave sounder), and it will provide the program office and processing centers an early opportunity to work with

the sensors, ground control, and data processing systems. This satellite is expected to demonstrate about half of the NPOESS EDRs and about 80 percent of its data processing load.

Data Management Challenges and Plans to Address Them

NPOESS is expected to produce a massive increase in the volume of data sent to the four processing centers, which presents considerable data management challenges. Whereas current polar satellites produce approximately 10 gigabytes of data per day, NPOESS is expected to provide 10 times that amount. When combined with increased data from other sources—other satellites, radar, and ground sensors—this increase in satellite data presents immense challenges to the centers' infrastructures for processing the data and to their scientific capability to use these additional data effectively in weather products and models.

The four processing centers and the integrated program office are well aware of these data management challenges and are planning to address them. Specifically, each of the four centers is planning to build its capacity to handle increased data volumes, and both the centers and the program office are working to improve their ability to assimilate new satellite data in their products. Because the NPOESS launch is several years in the future, agencies have time to build up their respective infrastructures and models so that they can handle increased data volumes. However, more can be done to coordinate and further define these efforts.

Infrastructure Challenges and Plans to Address Them

The expected increase in satellite data from NPOESS presents a considerable challenge to the processing centers' infrastructures for obtaining, processing, distributing, and storing satellite data. All four of the central processing centers reported that their current infrastructures would require changes in order to support expected NPOESS data streams. In fact, two centers reported that their current infrastructures could not support any of the NPOESS EDRs that they expect to use; another center reported that its infrastructure could not support 82 percent of the EDRs it expects to use; and the fourth center reported that its infrastructure could not support 27 percent of the EDRs that it will use.

As for specific shortcomings, officials at the processing centers reported that they need to increase the computational power of the supercomputers that will process the data records, upgrade the communication systems used to transmit the data, and/or increase the storage capacity of the systems used to archive the data. For example, National Weather Service officials told us that current supercomputers could not process the vast

amount of satellite data NPOESS will generate within required timeframes to produce forecasts, because even today they are encountering computer capacity constraints. Specifically, the target usage rate for effectively processing modeling data is 50 percent of computing capacity. Officials told us that the average current usage rate is 70 percent of capacity, and usage often peaks well above this rate. As another example of an infrastructure challenge, officials at the Navy's Fleet Numerical Meteorology and Oceanography Center reported that even with recent upgrades to their local data storage capacity, their current infrastructure could not likely support NPOESS increased data volumes.

To handle these increased data volumes, the four processing centers have begun high-level planning to transform their respective satellite data processing infrastructures. Understandably, the centers have not yet begun detailed planning for operational and technology change in the 2008-2009 timeframe because there are too many unknowns for them to do so reliably. For example, the architectural characteristics of the NPOESS system will not be known until sometime after the development and production contract is awarded later this year. Also, as stated by center officials, technology changes so quickly that it is difficult to predict technology options 6 to 7 years from now.

Although the centers are not yet building their infrastructures specifically to support NPOESS, officials told us that they are currently working to upgrade their infrastructures to support current and future data streams. For example, NOAA plans to increase the processing capacity of its supercomputers to handle the increased volume of satellite data expected over the next several years. In addition, the Air Force Weather Agency is in the process of upgrading its information technology infrastructure to increase the capacity of its computer and communications systems.

The processing centers recognize the infrastructure challenges they face, and each is planning or initiating upgrades to improve its data management capacity to meet immediate challenges. Once the NPOESS development and production contract is awarded and the system design is determined, it is imperative that the four processing centers adjust and further define their future architectures to address this design, and identify the steps they need to take to reach that future goal. All of the centers have expressed their intentions to do so.

Data Utilization Challenges and Plans to Address Them

The increased data volumes from NPOESS pose a challenge to those seeking to use these data in operational weather models and products. These models and products are heavily dependent on satellite data, but experts in the weather modeling community acknowledge that satellite data are not always used effectively because the science needed to understand and use the data is sometimes immature. For example, forecasters do not yet know how to use microwave data from areas covered in ice or under heavy precipitation in their weather prediction models. Experts reported that it often takes years of study and scientific advances to effectively assimilate new satellite data into weather models and to derive new weather products. While there is some debate as to how long it takes to develop the science to put new data in models, in 2000, the National Research Council reported that it generally takes 2 to 5 years of simulations and analyses before a satellite launch for data from new sensors to be effectively incorporated into weather models.[8] They noted that if this work does not occur, there is a gap of several years during which data are collected but not used efficiently in models. Defense and civilian modeling officials reiterated the value of advance assimilation studies by citing an example in which such studies performed before a new sensor was launched allowed modelers to use the data only 10 months after launch.

The processing centers acknowledge that much needs to be done for them to be able to incorporate NPOESS data into operational products. Officials at the processing centers reported that they should be able to use some EDRs after only minor changes to their data processing algorithms and models, because these products are expected to be comparable to current products. Other EDRs, however, involve new data and will require major scientific advances in order to be used. That is, the centers will not be able to use these data until they conduct new scientific investigations and determine how to best use the data in their derived products and models. In fact, the three centers that are the heaviest planned users of NPOESS EDRs reported that about 45 percent of the EDRs they plan to use would require major advances in science in order to be utilized. For example, NESDIS stated that it would take major science changes to be able to utilize all six of the key EDRs, including atmospheric vertical temperature profile, soil moisture, and sea surface winds. Table 4 lists the number of EDRs each of the processing centers plans to use and each center's views

[8]National Research Council, *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death* (2000).

of how many of those EDRs require major science changes. Appendix II identifies the EDRs that the centers reported as requiring major scientific advancements.

Table 4: Processing Centers' Views of the Usability of Planned NPOESS Products

Processing center	Number of NPOESS EDRs each center plans to use	Number of NPOESS EDRs requiring major scientific changes
NESDIS	55	26
Air Force Weather Agency	38	16
Navy Fleet Numerical Meteorology and Oceanography Center	38	16
Naval Oceanographic Office	15	1

Effective and efficient use of satellite data in weather products, warnings, and forecasts is critical to maximizing our national investment in new satellites. A committee representing the four processing centers noted that expedited incorporation of new satellite data into weather models is a key metric for measuring NPOESS' success. Given that understanding, the processing centers and the integrated program office have various efforts under way and planned to address challenges in effectively using new NPOESS data. Key initiatives include the following:

- **Joint Center for Satellite Data Assimilation:** In July 2001, NOAA and NASA formed a joint organization to accelerate the rate at which satellite data are put into operational use. While the center is currently focused on assimilating data from existing satellites, joint center scientists plan to undertake projects to accelerate the assimilation of future satellite data, including NPOESS data, into weather prediction models. The joint center received $750,000 in its fiscal year 2002 budget and requested $3.4 million for fiscal year 2003. In a November 2001 letter to the processing centers, the integrated program office offered to help fund the joint center efforts to assimilate NPOESS data if the DOD processing centers were to join the joint center. The processing centers have discussed this option, but DOD has not yet made a final decision.

- **Processing centers' assimilation projects:** Two of the three military processing centers, the Air Force Weather Agency and the Navy Fleet Numerical Meteorology and Oceanography Center, have developed programs to improve assimilation of high-resolution satellite data into their models. They have also developed a program that is designed to improve their models so that they will be able to use data from the NPOESS preparatory project, when they become available.

- **Other government-sponsored studies:** As noted in its risk reduction efforts, the integrated program office has funded studies—both simulations and data assimilation studies—to prepare for the NPOESS data. Since fiscal year 1995, the program office has reportedly spent more than $3 million on satellite data assimilation experiments and projects to develop techniques for processing satellite data. For example, the program office funded NOAA to develop methods to begin processing and assimilating sounding data from the advanced infrared sounder on a NASA satellite. This effort was expected to pave the way for processing and assimilating data from two sensors that will fly on the NPOESS preparatory project in early 2006 and on NPOESS in the 2008 to 2009 timeframe.

Centers Have Time to Meet Challenges, but More Coordination and Definition of Plans Are Warranted

Between now and the first NPOESS satellite launch, the four processing centers and the integrated program office have time to meet the challenges in effectively using NPOESS data, but more can be done to coordinate and define these efforts. The four centers' views on their ability to use NPOESS EDRs in their models and products highlighted that the centers are not always consistent on whether an NPOESS data product requires major scientific advancements or not. Specifically, the centers' views differ on over 30 EDRs. For example, in the case of one key EDR—atmospheric vertical temperature profile—one center states that it will require only minor software changes to use these data; another center states that it will require a major advancement in science to use the data; and a third states that it will not require a science change, but instead will require an upgrade to its supporting infrastructure. Appendix II lists the processing centers' views of which EDRs require major scientific advancements in order to be used.

While there may be valid reasons for some of these differences—such as the centers' differing uses for these EDRs or their varying customers' needs—the centers have not yet compared their differing views or identified opportunities for learning from other centers' expertise. Agency officials generally agreed that such coordination would be valuable and stated their intentions to coordinate.

In addition to coordinating on EDRs determined to pose scientific challenges, it will be important for the centers to identify what needs to be done to meet these major science challenges and to define their plans for doing so. However, the centers have not yet determined what actions are needed to effectively incorporate NPOESS EDRs in their respective models and derived products. Further, they have not yet established plans

for addressing the specific EDRs that require major scientific advancements. Agency officials agreed that such planning is necessary and stated that they will likely accelerate these efforts after the development and production contract is awarded.

Clearly, there are opportunities for the processing centers to coordinate their particular concerns, learn from other centers' approaches, and define their plans for addressing challenges in using EDRs. Given the years it takes to effectively incorporate new satellite data into operational products, it is critical that such coordination and detailed planning occur so that NPOESS data can be effectively used.

In summary, today's polar-orbiting weather satellite program is essential to a variety of civilian and military operations, ranging from weather warnings and forecasts to specialized weather products. NPOESS is expected to merge today's two separate satellite systems into a single state-of-the-art weather and environmental monitoring satellite system to support all users. This new satellite system is expected to provide vast streams of data, far more than are currently handled by the four central processing centers. To prepare for these increased data volumes, the four data processing centers must address key data management challenges—including building up their respective infrastructures and working to be able to efficiently incorporate new data in their derived weather products and models. Because the NPOESS launch date is still several years in the future, the four processing centers and the integrated program office have time to continue to develop, define, and implement their plans to address key data management challenges.

Each of the processing centers is planning activities to build its capacity to handle increased volumes of data, but more can be done to coordinate and define these plans—including sharing information on what is needed in order for the centers to use particular weather products and developing a plan to address these scientific issues. Unless more is done to coordinate and define these plans, the centers could risk delays in using NPOESS data in operational weather products and forecasts.

This concludes my statement. I would be pleased to respond to any questions that you or other members of the Subcommittee may have at this time.

Contact and Acknowledgments

If you have any questions regarding this testimony, please contact Linda Koontz at (202) 512-6240 or by E-mail at koontzl@gao.gov. Individuals making key contributions to this testimony include Ronald Famous, Richard Hung, Tammi Nguyen, Colleen Phillips, Angela Watson, and Glenda Wright.

Appendix I: Objectives, Scope, and Methodology

The objectives of our review were to (1) provide an overview of our nation's polar-orbiting weather satellite program, (2) identify plans for the NPOESS program, and (3) identify key challenges in managing future NPOESS data volumes and the four processing centers' plans to address them.

To provide an overview of the nation's polar-orbiting weather satellite system, we reviewed NOAA and DOD documents and Web sites that describe the purpose and origin of the polar satellite program and the current POES and DMSP satellites' supporting infrastructures. We assessed the polar satellite infrastructure to understand the relationships among the satellites, ground control stations, and satellite data processing centers. We also reviewed documents and interviewed officials at the integrated program office and four processing centers to identify the processes for transforming raw satellite data into derived weather products and weather prediction models.

To identify plans for the NPOESS program, we obtained and reviewed documents that describe the program's origin and purpose, and interviewed integrated program office officials to determine the program's background, status, and plans. We assessed the NPOESS acquisition strategy and program risk reduction efforts to understand how the program office plans to manage the acquisition and mitigate the risks to successful NPOESS implementation. We reviewed descriptions of each of the NPOESS sensors and assessed NPOESS program requirement documents to determine the types of products that NPOESS will produce and how these products will be used.

To assess NPOESS data management challenges, we reviewed documents from the program office and the four processing centers and discussed challenges with DOD and NOAA officials. We assessed descriptions of each center's current and planned polar satellite infrastructure to identify plans for infrastructure growth. We also identified each processing centers' views on which NPOESS products will require infrastructure changes or scientific advancements in order to be used. We analyzed this information to determine whether the centers face challenges in their ability to process NPOESS data and their scientific capability to assimilate NPOESS data into their weather prediction models. We reviewed documents that describe NOAA, DOD, and integrated program office efforts to address the challenges that we identified, and we evaluated current and planned efforts to address those challenges. We interviewed program office and processing center officials to discuss these documents and their plans to address NPOESS data management challenges.

We obtained comments from NOAA and DOD officials on the facts contained in this statement. These officials generally agreed with the facts as presented and provided some technical corrections, which we have incorporated. We performed our work at the NPOESS Integrated Program Office, located at NOAA headquarters in Silver Spring, Maryland; the NESDIS Central Satellite Data Processing Center in Suitland, Maryland; the NCEP Environmental Modeling Center in Camp Springs, Maryland; the Air Force Weather Agency at Offutt Air Force Base in Omaha, Nebraska; the Fleet Numerical Meteorology and Oceanography Center in Monterey, California; and the Naval Oceanographic Office at Stennis Space Center in Bay St. Louis, Mississippi. Our work was performed between October 2001 and July 2002 in accordance with generally accepted government auditing standards.

Appendix II: Processing Centers' Views of Which NPOESS EDRs Require Major Scientific Advancements

		Processing center view			
Data category	**Environmental data record**	**Air Force Weather Agency**	**Fleet Numerical Meteorology and Oceanography Center**	**Naval Oceanographic Office**	**NESDIS/ NCEP[b]**
Key	Atmospheric vertical moisture profile	No	No	–[a]	Yes/No
	Atmospheric vertical temperature profile	No	No	–	Yes/No
	Imagery	No	No	No	Yes/No
	Sea surface temperature	No	No	Yes	Yes/No
	Sea surface winds	No	No	No	Yes/No
	Soil moisture	No	No	No	Yes
Atmosphere	Aerosol optical thickness	Yes	No	No	No/Yes
	Aerosol particle size	Yes	No	–	Yes
	Aerosol refractive index	–	No	–	Yes
	Outgoing long–wave radiation	–	No	–	No
	Ozone total column/profile	–	No	–	No
	Precipitable water	–	No	No	No
	Precipitation type/rate	No	Yes	–	Yes
	Pressure (surface/profile)	No	No	–	Yes/No
	Suspended matter	Yes	No	–	Yes
	Total water content	No	Yes	–	Yes
Cloud	Cloud base height	Yes	Yes	–	Yes
	Cloud cover/layers	Yes	No	No	Yes
	Cloud effective particle size	Yes	Yes	–	Yes
	Cloud ice water path	–	Yes	–	No/Yes
	Cloud liquid water	Yes	Yes	–	No/Yes
	Cloud optical thickness	–	Yes	–	Yes
	Cloud particle size/distribution	–	Yes	–	Yes
	Cloud top height	Yes	Yes	–	No/Yes
	Cloud top pressure	–	Yes	–	No/Yes
	Cloud top temperature	Yes	Yes	–	No/Yes
Earth radiation budget	Albedo	No	No	–	No
	Downward long–wave radiance	–	No	–	Yes
	Downward short–wave radiance	–	No	–	Yes
Land	Land surface temperature	No	Yes	–	Yes
	Snow cover/depth	No	No	No	No/Yes
	Surface type	No	Yes	No	No
	Vegetation index	No	Yes	No	No
Ocean/water	Ice surface temperature	–	No	–	Yes
	Net heat flux	–	–	–	Yes
	Net solar radiation	–	–	–	Yes
	Ocean color/chlorophyll	–	–	No	No
	Ocean wave characteristics	Yes	No	No	Yes
	Sea ice characteristics	–	No	–	Yes/No
	Sea surface height/topography	Yes	Yes	No	No
	Surface wind stress	–	Yes	–	Yes

Data category	Environmental data record	Processing center view			
		Air Force Weather Agency	Fleet Numerical Meteorology and Oceanography Center	Naval Oceanographic Office	NESDIS/ NCEP[b]
Space environment	Auroral boundary	No	–	–	No
	Auroral energy deposition	No	–	–	No
	Auroral imagery	No	–	–	No
	Electric fields	Yes	–	–	No/Yes
	Electron density profile	Yes	–	No	No/Yes
	Energetic ions	No	–	–	No
	Geomagnetic field	No	–	–	No
	In-situ plasma fluctuations	Yes	–	–	No/Yes
	In-situ plasma temperature	No	–	–	No
	Ionospheric scintillation	Yes	–	No	No
	Neutral density profile	Yes	–	–	No/Yes
	Medium energy charged particles	No	–	–	No
	Solar irradiance	–	–	–	No
	Suprathermal/auroral particles	No	–	–	No
	Total yes	**16**	**16**	**1**	**26/30**
	Total no	**22**	**22**	**14**	**29/25**
	Total –[a]	**17**	**17**	**40**	**0**

[a]A dash indicates that a center does not plan to use the EDR.

[b]Where noted, NESDIS and NCEP offered different views because of each entity's different products.