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Report to the Chairman, Subcommittee on Natural Resources, Agriculture Research, and Environment, Committee on Science and Technology
House of Representatives

March 1986

WEATHER SATELLITES

User Views on the Consequences of Eliminating a Civilian Polar Orbiter

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GAO

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Resources, Community, and
Economic Development Division

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March 7, 1986

The Honorable James H. Scheuer
Chairman, Subcommittee on Natural
Resources, Agriculture Research,
and Environment
Committee on Science and Technology
House of Representatives

Dear Mr. Chairman:

Your March 27, 1985, letter requested the General Accounting Office to examine various questions associated with eliminating one of the National Oceanic and Atmospheric Administration's (NOAA) two polar-orbiting weather satellites, as proposed by recent presidential budget submissions.

Your letter requested that we examine (1) how NOAA, the National Aeronautics and Space Administration (NASA), Department of Defense (DOD), and foreign countries use NOAA's polar-orbiting satellites; (2) how these users would be affected by the loss of one or both satellites; (3) the extent to which the two NOAA geostationary weather satellites or DOD's two weather satellites could compensate the National Weather Service for the loss of the polar orbiters; and (4) the likelihood and expected duration of the loss of all polar orbiter coverage if a one-polar-orbiter system were instituted.

We found that the polar orbiters are used by NOAA for weather forecasting, search and rescue operations, and other purposes; by NASA for climate research; by DOD as a supplement and backup to its own weather satellites; and by countries worldwide for weather forecasting and environmental data collection. Some users in NOAA and DOD reported to us that the elimination of one of NOAA's polar-orbiting weather satellites would harm their programs, but most users told us that they could continue their programs with one satellite. All users, however, said that the second satellite was important as a backup to the first and that the loss of all service would have serious consequences. The NOAA geostationary satellites and DOD's weather satellites could not adequately replace NOAA's polar orbiters, according to most users. In the past some of NOAA's polar-orbiting satellites have not been successfully launched, or their launches have been delayed, and some have failed early in orbit. A repetition of these problems in a one-satellite system could result in a loss of all services for several months or longer.

Background

NOAA operates two polar-orbiting weather satellites and two geostationary weather satellites. The polar-orbiting satellites circle the earth about 14 times a day to produce worldwide images of weather patterns and data on atmospheric and surface conditions. The geostationary satellites are in place over the equator, where they provide continuous images of weather patterns in the United States and surrounding areas. The polar orbiters are important to U.S. weather forecasting primarily for their data on atmospheric conditions; the geostationary satellites are especially valuable for tracking severe weather, like hurricanes.

The military services have their own two-polar-orbiter system referred to as the Defense Meteorological Satellite Program (DMSP). The NOAA and DMSP polar orbiters differ in (1) the sensors flown on the satellites, (2) the timing of orbits, and (3) the equipment needed to pick up the spacecrafts' signals. Because of these differences NOAA's polar orbiters provide some data and capabilities to military users that are not available with the current DMSP system.

The Administration has proposed the elimination of one of NOAA's two polar-orbiting weather satellites in the last five budgets submitted to the Congress (fiscal years 1983 through 1987). Congress has approved funds for a two-satellite system for the first four of these budgets and is currently considering the fifth. The budgets estimate that savings would result from cutting a polar orbiter by postponing the manufacture of satellites and reducing the frequency at which they would be launched.

NOAA's fiscal year 1987 budget submission to the Congress, which assumes yearly launches of replacement satellites in a two-satellite system and 18-month launch intervals in a one-satellite system, estimates that about $57 million would be saved in fiscal year 1987 and smaller amounts in subsequent years by switching to the single-orbiter system. The savings would be achieved by delaying the manufacture of replacement satellites.

NOAA has prepared a study entitled Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000 (April 1985) that suggests that the long-term savings achievable under a one-satellite system are small. The study concludes that to avoid extended gaps in service, i.e., periods in which no functioning satellites would be in orbit, NOAA would have to launch the same number of satellites whether it operated a one- or two-polar-orbiter system. This conclusion is based on historical data showing that many of NOAA's satellites have lasted longer than their design lives. Design lifetimes are engineering estimates of how long the satellites will be operational in space. The NOAA polar orbiters have 2-year design lives.

Because satellites sometimes function well beyond their design lives, with a two-orbiter system, NOAA is able to delay replacement launches. These delays are not anticipated in budget estimates of the costs of a two-satellite system, which, to allow for unexpected problems, are based on satellite launches at the end of design lives, with each of the two satellites expiring in alternate years and launches occurring every 12 months. In fact, since 1974 NOAA has launched satellites about once every 17 months, in part because recent satellites have lasted an average of 30 months rather than their 24-month design lives.

According to NOAA, extended satellite lives could not be taken advantage of in a one-satellite system. Launches would have to occur at 18-month intervals, regardless of the condition of the in-orbit satellite, to avoid service gaps.

The NOAA Optimum Management Strategies study estimated that a 1-satellite system, designed to allow quick call-up of a satellite to replace a polar orbiter that had malfunctioned in orbit, would require the construction and launch of 12 satellites over the next 15 years. According to the study, a 2-satellite system, which took advantage of extended satellite lives, would require 12 or 13 satellites, depending on the success of launches and in-orbit operation. (See app. I.)

Uses of NOAA's Polar-Orbiting Weather Satellites

We contacted users of NOAA's polar-orbiting weather satellites in NOAA, DOD, NASA, and international weather organizations. Their applications of satellite data are highlighted below.

- The National Weather Service uses data from NOAA's polar orbiters in its computer-driven forecast systems and for other purposes. The data are especially important for producing medium-range (3- to 10-day) weather forecasts. (See app. II.)
- The U.S. military services also use NOAA satellite data in their global weather forecast models and for various tactical purposes, such as scheduling troop movements and aircraft, ship, and submarine operations. (See app. III.)
- NOAA, the Air Force, and the Coast Guard participate in a search and rescue program using readings from NOAA's polar orbiters on the location of downed airplanes and ships in distress. (See app. IV.)

- NASA uses data from instruments flown on the NOAA polar orbiters to measure the radiation exchange between the earth and space (a determinant of climatic conditions) and the ozone content of the atmosphere. In addition, NASA uses the weather data supplied by the NOAA satellites in its climate studies. (See app. VI.)
- Several federal agencies, including NOAA and DOD, use environmental data relayed by the NOAA polar orbiters. The orbiters carry a system to relay collected data, on conditions such as ocean currents and sea ice, from sensors on earth back down to ground receiving stations. (See app. V.)
- NOAA's polar orbiters are also used worldwide for weather forecasting and resource assessment. More than 1,000 ground stations have been built in about 120 countries to receive weather images from the satellites. Countries with sophisticated forecast systems use the satellites' data on atmospheric conditions for medium-range weather forecasts. Other countries make more use of the satellites' imagery for general weather forecasting. According to officials of NOAA and the United Nations' World Meteorological Organization, some of the poorer countries rely almost exclusively on the NOAA polar orbiters for weather data. The Agency for International Development funds programs using the satellites' data to monitor drought conditions in the Sahel region of Africa and to give Bangladesh warnings of typhoons. (See app. VII.)

How the Elimination of One Polar Orbiter or the Loss of All Coverage Would Affect Users

Most users believed that the data produced by the satellite proposed for elimination are not essential to their programs. For example, the National Weather Service continues to produce medium-range weather forecasts during periods when, because of malfunctions, only one polar orbiter is operating. NASA researchers believed that their studies could continue with only one orbiter. Experts in the international uses of the satellites said that the loss of one satellite might reduce the accuracy of weather forecasts in some cases but would not be catastrophic. Users of the environmental data collection services provided by the polar orbiters said that their programs would not be severely damaged by the loss of one orbiter. (See app. II, V, VI, and VII.)

Some users, however, said that they made considerable use of the second satellite. For example, the Air Force informed us that the loss of a NOAA polar orbiter would critically affect some of its units that provide weather services to Army tactical operations in Europe. In addition, NOAA officials said that response to air and sea emergencies could be delayed by as much as several hours if one satellite were eliminated. (See app. III and IV.)

While not all users we interviewed had a strong operational need for a second polar orbiter, all users thought it was important as a backup to the first. The elimination of one satellite and a malfunction of the remaining satellite could result in a disruption of all service. Satellite users told us that the consequences of a loss of all NOAA polar-orbiting coverage would include (1) inability to produce weather forecasts for longer than a 5-day period, in the United States and overseas; (2) reduced weather services for military aviation, naval, submarine, and ground operations; (3) delayed response by search and rescue teams to air and sea emergencies; (4) the loss of data of major importance to some climate studies, such as NOAA's analysis of southern hemisphere climatic fluctuations that can cause major abnormalities in U.S. weather; and (5) the loss in some third world countries of their principal source of weather information. (See app. II through VII.)

Possible Service Gap in a One-Satellite System

The likelihood and duration of a loss of all polar-orbiting coverage in a one-satellite system would depend on

- the frequency of launch failures;
- the frequency of early satellite failures in orbit;
- the availability of launch pad, launch crew, and launch vehicle at the time of failure; and
- the availability of a satellite for launch at the time of failure.

The polar-orbiting satellite program has suffered launch failures, early in-orbit failures, and launch delays in the past. Depending on the manufacturing schedule chosen for a one-satellite system, a repetition of these problems could produce long disruptions in all polar-orbiting coverage.

Over the last 15 years, 3 of the 14 NOAA polar orbiters launched have not achieved orbit because of launch failure. Of the 11 satellites successfully launched, 2 have not reached their designed lives. Records are not available on the timeliness of all past launches; however, available records do disclose that two launches were delayed for several months because higher priority military uses preempted launch facilities.

The duration of a loss of all service in a one-satellite system, caused by a launch failure or early in-orbit failure, would depend on the manufacturing schedule for replacement satellites. According to NOAA budget officials, NOAA budgets proposing a one-satellite system have assumed that satellites would be produced on a schedule making them available for launch once every 18 months. NOAA officials estimate that this schedule could produce a service gap of more than a year if a launch failure occurred when no functioning satellite was in orbit. According to NOAA officials, the manufacturing schedule on which budget estimates for a one-satellite system are based might be shortened in practice, if funds were available. However, even if the rate of production were increased so that a replacement satellite were immediately available at the time of a launch or early in-orbit failure, NOAA officials said that the service gap would not be shorter than four months, the time needed to prepare launch facilities, launch vehicles, and the satellite itself for launch. (See app. VIII.)

Use of the Other NOAA or DOD Weather Satellites to Substitute for NOAA's Polar Orbiters

In addition to the polar-orbiting weather satellites, NOAA operates two geostationary weather satellites in orbit over the equator. These satellites have limited value as backups to the polar orbiters for most purposes.

According to Weather Service officials, the geostationary satellites do not produce sufficient data for medium-range weather forecasting. These satellites also cannot locate victims of air or sea emergencies for search and rescue operations and cannot satisfy the requirements of most organizations that use the polar orbiters' environmental data collection service. In addition, most foreign countries are outside the area viewed by the geostationary satellites.

The Department of Defense also operates two polar-orbiting weather satellites but their data are not available to other countries. National Weather Service officials believe that their forecasts would be less accurate if they were forced to rely exclusively on DOD satellites for polar-orbiting coverage. The officials said that the Weather Service could not produce medium-range forecasts using only DOD satellites because the data they produced on atmospheric conditions are not sufficient and their readings are not appropriately timed for Weather Service forecasts. The Defense Department satellites do not provide search and rescue or environmental data collection services. (See app. II, IV, VI, and VII.)

Objectives, Scope, and Methodology

The objectives of our review were to determine (1) how NOAA, NASA, DOD, and foreign countries use NOAA's polar-orbiting satellites; (2) how these users would be affected by the loss of one or both satellites; (3) the extent to which the NOAA geostationary weather satellites or DOD's weather satellites could compensate the National Weather Service for the loss of the polar orbiters; and (4) the likelihood and expected duration of the loss of all polar orbiter coverage if a one-polar-orbiter system were instituted.

We obtained information on these issues through discussions with managers of the NOAA and DOD satellite systems and satellite users in NOAA, DOD, and NASA. We often had to rely on the judgment of meteorologists and progam managers in NOAA, DOD, NASA, and international weather agencies for assessments of the issues presented in this report. We discussed the international uses of the NOAA polar orbiters with officials of NOAA; NASA; the Agency for International Development; the European Centre for Medium Range Weather Forecasts, Reading, England; and the United Nation's World Meteorological Organization, Geneva, Switzerland. We also reviewed records of satellite uses in federal agencies and reviewed NOAA records and studies on (1) the performance of its satellites, (2) the capabilities of NOAA and DOD satellites, and (3) possible future designs for one- or two-satellite systems. (See app. I.)

Our analysis of the value of the second NOAA polar orbiter is based on (1) both DOD's and NOAA's operating separate polar-orbiting satellite systems using current technology and (2) the present state of international participation in the weather satellite program. We did not address alternative satellite systems being studied or proposed. For example, our discussion of the usefulness of the DMSP as a backup to NOAA's polar orbiters assumes the current DMSP design. DOD and NOAA are currently studying the possibility of developing common weather sensors. If this study results in DMSP data being of greater usefulness to NOAA, the value of the second civilian polar orbiter as a backup to the first may diminish. In addition, according to NOAA officials, several European countries have expressed interest in building, in the mid-1990's, a polar-orbiting space platform that could be used for weather sensors. This might reduce the reliance of the international community on the second NOAA satellite. In addition, proposals have been made over the years to converge the DOD and NOAA polar satellite systems into a single, national system. This report does not imply that a converged system is not feasible.

Our work, which was done between October 1985 and January 1986, was performed in accordance with generally accepted government auditing standards. The views of directly responsible officials were sought during our work and are incorporated in the report where appropriate. As agreed with your office, we did not request NOAA, NASA, or DOD to review and comment officially on a draft of this report.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from its date. At that time, we will send copies to appropriate congressional committees and executive agencies. Copies will also be made available to other parties upon request.

Sincerely yours,

J. Dexter Peach
Director

Contents

Abbreviations

AFGWC	Air Force Global Weather Central
ARGOS	a French government agency, Service ARGOS, that collects and distributes satellite-provided data
AWS	Air Weather Service
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DRO	Direct Read Out
ERBE	Earth Radiation Budget Experiment
FNOC	Fleet Numerical Oceanography Center
GAO	General Accounting Office
GOES	geostationary operational environmental satellite
ITOS	an early NOAA polar-orbiting satellite
NASA	National Aeronautics and Space Administration
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
RAF	Royal Air Force
SARSAT	Search and Rescue Satellite-Aided Tracking
TIROS	a type of NOAA polar-orbiting satellite
TOGA	Tropical Ocean and Global Atmosphere
USAFSO	U.S. Air Force Southern Air Division
USSOUTHCOM	U.S. Southern Command
WMO	World Meteorological Organization

Introduction

On March 27, 1985, the Chairman, Subcommittee on Natural Resources, Agriculture Research and Environment, House Committee on Science and Technology, requested GAO to review how much various federal agencies and foreign countries depend on the data produced by the National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting weather satellites. The request was made in response to proposals made in recent budgets submitted by the President to the Congress that one of these satellites be eliminated. NOAA currently seeks to maintain two polar-orbiting satellites in orbit.

The Chairman requested answers to the following questions:

- What uses do the National Weather Service (NWS), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) make of NOAA's polar-orbiting weather satellites?
- How do other countries use the data from these satellites?
- What impacts would the elimination of one polar orbiter have on these users?
- Under a single-orbiter scenario, what is the likelihood and the expected duration of the loss of all polar-orbiting coverage?
- How would users be affected by the loss of all coverage?
- How useful would data from NOAA's geostationary weather satellites or from DOD's weather satellites be to the NWS as a substitute for data from NOAA's polar-orbiting satellites?

This report provides the information we developed on each of these questions.

Organization and History of NOAA's Weather Satellite Program

Satellites have been used for observing weather since April 1, 1960, when the first meteorological satellite was launched. The weather satellites, which are operated by NOAA, produce images of weather patterns and numerical data on atmospheric and sea surface conditions for daily weather forecasts, storm warnings, and research. Over the years the system has evolved into a four-satellite configuration of two geostationary operational environmental satellites (GOES) and two polar-orbiting (NOAA) satellites. The GOES are in orbit over the equator where they provide continuous coverage of weather in the United States and parts of the Atlantic and Pacific oceans; the NOAA satellites circle the earth from pole to pole, providing global weather coverage. The GOES are especially valuable for tracking severe weather (such as hurricanes); the polar-orbiting satellites are useful for worldwide imagery and data for computer-driven weather forecast systems.

Operation, Management, and Procurement

NOAA is responsible for operating and managing the weather satellite system. NASA, under a 1973 agreement with NOAA, is responsible for procuring and launching the satellites. NOAA determines program requirements; obtains funding for establishing and operating its satellites; approves procurement plans; monitors system performance; and disseminates and archives data, forecasts, and analyses. NASA designs, engineers, and procures the weather satellites; procures launch vehicles; arranges for satellite launches; and monitors the satellites during their initial phases in orbit. NOAA reimburses NASA for its services.

Polar-Orbiting Satellites

NOAA's polar-orbiting satellites, the latest in a series that began in the early 1960's, circle the globe from pole to pole about 14 times daily. The satellites' orbits are arranged so that they are in a fixed position relative to the sun while the earth spins beneath them. They cross the equator at the same local time on each revolution. One satellite is timed to cross the equator on each revolution in the morning, the other in the afternoon. The afternoon satellite is considered more important to NWS, since its orbit is better timed for collecting data for weather forecasts.

The polar orbiters make measurements of temperature and humidity in the earth's atmosphere, surface temperature, cloud cover, and water-ice boundaries. The satellites can receive, process, and retransmit data from balloons, buoys, and other sources located anywhere on the earth's surface. Because of their globe-circling orbit, polar satellites are the principal source of environmental data for the 80 percent of the globe that is not covered by conventional data gathering, such as weather balloons. They broadcast weather information to about 120 countries worldwide. The U.S.S.R. is the only other nation that operates polar-orbiting weather satellites.

In fiscal year 1985, NOAA spent $109,785,000 to build and launch polar-orbiting weather satellites and procure ground station equipment to receive and process their signals. For fiscal year 1986, NOAA has been appropriated $86,454,000[1] to build and launch polar-orbiting weather satellites and procure ground station equipment.

[1] The original fiscal year 1986 appropriation was $90,350,000; however, this was reduced by $3,896,000 because of the requirements of the Balanced Budget and Emergency Deficit Control Act of 1985 (also referred to as the Gramm-Rudman-Hollings Budget Act).

Polar Orbiter Targeted for Elimination in the Past Five Budgets

The administration has proposed the elimination of one of NOAA's two polar-orbiting weather satellites in the last five budgets submitted to the Congress (fiscal years 1983 through 1987). Congress has approved funds for a two-satellite system for the first four of these budgets and is currently considering the fifth. The budgets estimate that savings would result from cutting a polar orbiter by delaying the production of satellites and reducing the frequency at which satellites would be launched. The budgets assume that in a two-orbiter system, satellites would be launched once a year and in a one-orbiter system, once every 18 months. Two-year operating lives are assumed for the satellites under either system. Under the one-orbiter system, described in the budget, a satellite would be launched 6 months before the end of the design life of the satellite it replaced, to provide some assurance against a gap in service resulting from an early in-orbit failure. Launches under a two-orbiter system are assumed in the budgets to occur at the end of the operating lives of the in-orbit satellites, with each satellite reaching the end of its design life in alternate years.

NOAA's fiscal year 1987 budget submission to the Congress, which assumes yearly launches in a two-satellite system and 18-month launch intervals in a one-satellite system, estimates that about $57 million would be saved in fiscal year 1987 and smaller amounts in subsequent years by switching to the single-orbiter system. The savings would be achieved by delaying the manufacture of replacement satellites.

NOAA has prepared a study entitled Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000 (April 1985) that suggests that the long-term savings achievable under a one-satellite system are small. The study concludes that to avoid extended gaps in service, i.e., periods in which no functioning satellites would be in orbit, NOAA would have to launch the same number of satellites whether it operated a one- or two-polar-orbiter system. This conclusion is based on historical data showing that many of NOAA's satellites have lasted longer than their design lives. Because satellites sometimes function well beyond their design lives, with a two-orbiter system, NOAA is able to delay replacement launches. These delays are not anticipated in budget estimates of the costs of a two-satellite system, which, to allow for unexpected problems, are based on satellite launches at the end of design lives, i.e. every 12 months. In fact, since 1974, NOAA has launched satellites about once every 17 months, in part because satellites of the current design have lasted an average of 30 months rather than their 24-month design lives.

According to NOAA, extended satellite lives could not be taken advantage of in a one-satellite system. Launches would have to occur at 18-month intervals, regardless of the condition of the in-orbit satellite, to avoid service gaps.

The NOAA Optimum Management Strategies study estimated that a one-satellite system, designed to allow quick call-up of a satellite to replace a polar orbiter that had malfunctioned in orbit, would require the construction and launch of 12 satellites over the next 15 years. According to the study, a two-satellite system, which took advantage of extended satellite lives, would require 12 or 13 satellites depending on the success of launches and in-orbit operation.

Defense Meteorological Satellite Program

The military services have had a polar-orbiting weather satellite program since the mid-1960's. The Defense Meteorological Satellite Program (DMSP) consists of two polar-orbiting satellites in early morning and late morning orbits. The DMSP's mission, according to an Air Force program description, is

"to provide, through all levels of conflict, consistent with the survivability of the supported forces, global visible and infrared cloud data and other specialized meteorological, oceanographic, and solar-geophysical data required to support worldwide DOD operations and high-priority programs."

The most important function of the DMSP satellites is to produce imagery, according to Air Force officials. NOAA regards the temperature data produced by its own polar orbiters as their chief product. Details on the capabilities and uses of the DMSP are discussed in appendix III.

When the NOAA polar-orbiting satellite program began, only one satellite was orbited at a time but it differed from today's satellites in that it was in a higher orbit with a broader field of view and accommodated more backup systems than the current satellites. In 1973, the Office of Management and Budget, to cut costs, directed NOAA to use for its polar orbiters the same satellite frame or "bus" as the Air Force used for its weather satellites. According to a NOAA official, since the Air Force bus was unable to accommodate backup sensors, NOAA started flying two polar orbiters at a time, with the second orbiter intended mainly as a backup to the first.

The weather-sensing instruments flown on NOAA satellites and the DMSP differ in important respects. The two agencies are presently studying the possibility of developing common sensors.

Geostationary Satellites

NOAA's goal is to maintain two fully operational GOES for continuous viewing of U.S. weather. These satellites orbit over the equator at the same rate that the earth turns so that they are always above the same spots on the earth's surface. If both GOES are in operating condition, one satellite orbits east of the United States to monitor North and South America and parts of the Atlantic Ocean. The other satellite orbits west of the United States and views North America and parts of the Pacific Ocean basin. The GOES carry imaging instruments that provide day and night pictures of clouds. Other instruments measure the earth's magnetic field and space radiation and relay weather and other environmental data from one ground location to another.

Because they provide a continuous view of weather, the satellites are especially valuable for detecting and tracking severe weather, such as hurricanes and local storms. They are also useful in detecting and tracking tropical cyclones, estimating rainfall amounts for flash flood warnings, and monitoring freezing surface temperatures for fruit frost predictions. Images from the GOES are broadcast to a NOAA-operated ground station, usually every 30 minutes. They provide the pictures of weather patterns seen on television weather broadcasts. Japan, India, and the European Space Agency (a consortium of 11 European countries) also operate geostationary weather satellites.

Objectives, Scope, and Methodology

The objectives of our review were to determine (1) how NOAA, NASA, DOD, and foreign countries use NOAA's polar-orbiting satellites; (2) how these users would be affected by the loss of one or both satellites; (3) the extent to which the GOES or DOD's weather satellites could compensate the National Weather Service, a NOAA agency, for the loss of the polar orbiters, and (4) the likelihood and expected duration of the loss of all polar orbiter coverage if a one-polar-orbiter system were instituted.

We obtained information on NOAA's uses of the satellites through discussions with officials of three NOAA units—NWS; the National Environmental Satellite, Data, and Information Service; and the Office of Oceanic and Atmospheric Research. In NWS we talked to representatives of the National Meteorological Center, Camp Springs, Maryland, and the National Hurricane Center, Miami, Florida. We also spoke with and obtained documents from Department of Defense officials, including those at Air Force Global Weather Central, Offutt Air Force Base, Omaha, Nebraska; Fleet Numerical Oceanography Center, Monterey, California; Naval Eastern Oceanography Center, Norfolk, Virginia; the Navy-NOAA Joint Ice Center, Suitland, Maryland; the Naval Polar Oceanography Center, Suitland, Maryland; and the Office of the Oceanographer of the Navy, Washington, D.C. We also met with five present and two former Navy shipboard meteorologists to determine the uses made and importance of the NOAA polar orbiters on their operations. We coordinated our contacts with military users through the Chairman, Joint Environmental Satellite Coordinating Group, Pentagon, Washington, D.C. We also met with NASA headquarters and Goddard Space Flight Center officials who use the NOAA polar orbiters for research purposes.

To develop information on worldwide uses of the polar orbiters, we contacted officials of the National Environmental Satellite, Data, and Information Service responsible for international affairs; NWS's liaison to the World Meteorological Organization; a weather satellite specialist with the United Nations' World Meteorological Organization in Geneva, Switzerland; the Director of the European Centre for Medium Range Weather Forecasts, in Reading, England; and officials of NASA and the Agency for International Development responsible for international weather assistance programs.

We obtained information on the search and rescue services of the polar orbiters from officials of NOAA's SARSAT (Search and Rescue Satellite-Aided Tracking) Management Unit and on the data collection services provided through the satellites from a representative of Service ARGOS, a French government agency that operates the service.

We discussed the effects of eliminating a polar orbiter and a disruption of all service with each of the above officials. We often had to rely on the judgment of program managers in NOAA, DOD, NASA, and international weather agencies for assessments of this issue and other issues discussed in the report.

To obtain information on the likelihood and expected duration of a loss of all service under a one-orbiter system, we reviewed the history of launch failures and delays and the operating record of satellites in orbit. We developed most of our information on these subjects from officials of NOAA's National Environmental Satellite, Data, and Information Service and from the Air Force. We also obtained information on past satellite performance from an April 1985 NOAA study of the polar orbiters entitled Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000. We also discussed future launch and satellite production plans with NOAA and Air Force officials. To obtain information on the ability of the Air Force to meet its commitment to launch NOAA's polar orbiters, we contacted officials at the Air Force's Space Division, Los Angeles, California.

Our analysis of the value of the second NOAA polar orbiter is based on (1) both DOD's and NOAA's operating separate polar-orbiting satellite systems using current technology and (2) the present state of international participation in the weather satellite program. For example, our discussion of the usefulness of the DMSP as a backup to NOAA's polar orbiters assumes the current DMSP design. As indicated above, DOD and NOAA are currently studying the possibility of developing common weather sensors. If this study results in DMSP data being of greater usefulness to NOAA, the value of the second civilian polar orbiter as a backup to the first may diminish. In addition, according to NOAA officials, several European countries have expressed interest in building, in the mid-1990's, a polar-orbiting space platform that could be used for weather sensors. This might reduce the reliance of the international community on the second NOAA satellite. Further, proposals have been made over the years to converge the DOD and NOAA polar satellite systems into a single, national system. This report does not deal with this issue.

Our work, which was done between October 1985 and January 1986, was performed in accordance with generally accepted government auditing standards. The views of directly responsible officials were sought during our work and are incorporated in the report where appropriate. In accordance with our agreement, we did not request NOAA, NASA, or DOD to review and comment officially on a draft of this report.

National Weather Service Uses of NOAA Polar Orbiters

The National Weather Service (NWS) is an organizational unit under the National Oceanic and Atmospheric Administration (NOAA). Providing weather warnings and forecasts to the general public and other users is the principal NWS operation.

The NWS weather forecast system includes the following centers and offices:

- The National Meteorological Center (NMC), Camp Springs, Maryland, provides support to the entire organization. NMC prepares weather guidance in the short (up to 72 hours) and medium (up to 10 days) ranges to the other NWS offices. Most of NMC's guidance is in the form of regional, hemispheric, and global numerical weather analysis and prognoses. The center also prepares monthly and seasonal outlooks.
- The National Severe Storms Forecast Center, Kansas City, Missouri, issues tornado, severe thunderstorm, and severe local storm watches.
- The National Hurricane Center, Miami, Florida, issues advisories, watches, and warnings for hurricanes, other tropical storms, and associated coastal tides in the Atlantic, Carribean, and Gulf of Mexico.
- The 52 Weather Service Forecast Offices form the core of the field forecast operation. These offices are responsible for warnings and forecasts for states, large portions of states, and assigned zones. Weather Service Forecast Office zone forecasts are issued three times daily for a period up to 48 hours; a generalized statewide forecast is issued twice a day; and a more general extended 5-day forecast is issued daily.

National Meteorological Center Uses of Polar-Orbiting Satellites

NMC provides large-scale regional, hemispheric, and global forecasts based on the techniques of numerical weather prediction. This information is delivered to domestic and international users. The center also provides analyses and forecasts of marine weather and oceanographic conditions. In addition, the center provides monthly and seasonal outlooks and assessments of climatic conditions to users on a worldwide basis.

From NOAA's National Environmental Satellite, Data, and Information Service, NMC receives processed data on atmospheric temperature from the polar orbiters. NMC uses the temperature information in its short-term and medium-range forecast models. In fact, according to NMC officials, the orbit of NOAA's afternoon satellite is timed to pass over the northeastern Pacific Ocean to provide key sounding[1] and other data

[1] Readings of atmospheric temperature and moisture.

when needed for NMC's forecast models. A National Environmental Satellite, Data, and Information Service official told us that this region is especially important for U.S. weather since the clash of cold Siberian air and moist Pacific air creates turbulence in this area and influences air flows heading for the United States. This official pointed out that the satellites are the only source of data (except for limited data from transpacific airplanes) from this region.[2]

Other National Weather Service Uses of NOAA Polar Orbiters

The National Weather Service has a Satellite Field Service Station in Anchorage, Alaska, (collocated with the Anchorage Weather Service Forecast Office) which copies pictures from the polar orbiters. These pictures provide high resolution (1 kilometer) images day and night of cloud cover and, in cloudless areas, of ice and snow distribution. An official of the Anchorage office points out that because there are few conventional observing stations in the Arctic, these high resolution pictures are an important source of weather information.

We also found that the National Weather Service uses the sea surface temperature readings from the NOAA polar orbiters to (1) map the location of the Gulf Stream (such information is important for ship routing), (2) provide guidance to coastal weather forecast offices on differences in ocean temperature (which give indications to fishermen of where fish may be located), and (3) monitor sea surface temperature changes, especially in the tropical Pacific, that may affect long-range weather forecasts.

Impact on National Weather Service of the Loss of One Polar Orbiter

NMC officials have estimated that the reduction of the polar-orbiting satellite system from two satellites to one would cause only a small degradation in the accuracy of forecasts averaged over a season or a year. In such an average, the effect would likely be negligible in the northern hemisphere and probably be less than 10 percent in the southern hemisphere. A NOAA staff study explained that

> "there are occasions each year in the winter hemisphere when cyclones develop with unusual speed into intense major storms. When these developments occur over the oceans, there is a significantly greater likelihood that they will be inadequately observed with one satellite than with two, with adverse impact on weather forecasts in areas affected by these storms. These events do not occur frequently, and tend not to be noticeable in annual averages of forecast [accuracy]; but when they do

[2]The GOES does not produce soundings in this area.

occur, it is important to forecast them accurately. The impact of such missed forecasts would be felt mainly over the oceans and on the west coast of the U.S."

Impact of the Loss of All NOAA Polar Orbiter Coverage

According to NOAA documents the loss of all NOAA polar orbiter coverage would be immediate and disastrous on National Weather Service products. For example, forecasts for the oceans in the southern and northern hemispheres for even short periods in advance—a day or so—would be seriously degraded; the accuracy of medium-range forecasts—3-10 days over much of the United States— would be diminished to the point where weather forecasts beyond 5 days might not be of any value.

The Deputy Director, NMC, told us that with the loss of both polar orbiters, NMC would almost certainly stop making forecasts beyond 5 days and might stop making forecasts beyond 3 days. NMC officials explained that these medium-range forecasts are important not only to the general public but also (1) to utility companies for shifting fuel and planning loading needs and (2) to construction firms for planning work schedules. According to the Deputy Director, NMC, the use of data from the GOES or the DMSP satellites as a substitute for the loss of all NOAA polar-orbiting coverage would not enable medium-range forecasts to continue.

A NWS official informed us that the loss of all NOAA polar orbiter coverage would be critical to Alaskan weather forecasting. The unavailability of NOAA polar satellite data in Alaska would, according to a NOAA staff study, seriously degrade forecasts in an area of extremely hostile weather and could seriously impair business in one of the largest economic bases of the country.

Ability of GOES and DMSP to Substitute for Polar Orbiters

NMC officials told us that NOAA's geostationary satellites are not an acceptable substitute for the NOAA polar orbiters because

- they do not cover the whole earth;
- their temperature and humidity soundings are not as good;
- they provide soundings only in clear areas, not having microwave sounders; and
- they cannot provide soundings above about 45 degree latitude.

Furthermore, the next series of geostationary satellites will also be unable to substitute for the NOAA polar-orbiter soundings for the same reasons, according to NOAA officials.

The question of whether the DMSP satellite soundings can be used by the NMC in its weather forecast system is to be studied by NMC officials beginning in late spring 1986. A previous study of the DMSP sounder[3] has shown that although DMSP soundings are comparable at the 10,000 to 100,000 foot levels, the DMSP soundings are not as accurate at lower altitudes (below 10,000 feet).

The Deputy Director, NMC, said that the inaccuracy of the DMSP sounding data below 10,000 feet is important because it would not allow for an accurate capturing of the initial weather conditions needed for its weather forecasting systems and would result in degraded forecasts. In addition, the Deputy Director said that the orbits of the present DMSP satellites do not meet the timing requirements for NWS's weather forecasting systems.

An official at the Alaska Satellite Field Service Station, told us that the DMSP satellite imagery could be used as a temporary substitute should all polar orbiter coverage be lost. He stated that ice condition analyses would be somewhat degraded because the DMSP imager has fewer channels and is not as good as the NOAA polar orbiters for ice applications. The ice edge information is important to Alaskan fishermen and for resupply operations on the North Slope.

[3]Temperature Soundings from the DMSP Microwave Sounder, Norman C. Grody, Donald G. Grey, Charles S. Novak. Paper presented at proceedings of the Workshop on Advances in Remote Sensing Retrieval Methods held at Williamsburg, Virginia, October 30-November 2, 1984.

Department of Defense Uses Of NOAA Polar Orbiters

The military services are principal users of NOAA's polar-orbiting weather satellites. The military has its own two-polar-orbiter meteorological satellite system, the Defense Meteorological Satellite Program (DMSP), but it differs from the NOAA system in (1) the data collected, (2) the timing of orbits, and (3) the equipment needed to pick up the satellites' signals. As discussed below, these differences make the civilian satellites useful to DOD generally as a supplement to the DMSP data and to some military units as a primary data source.

Differences Between the Military and Civilian Polar-Orbiting Weather Satellite Systems

The primary DOD requirement is for imagery, while the primary civilian requirement is for vertical temperature profiles. Because of these differing primary requirements, some differences exist in the sensors flown on the civilian and military satellites. For example, both satellite systems have an imager, but according to Air Force officials, the DMSP imager, the Operational Linescan System, provides constant resolution over its total field of view, while the NOAA imager, although it is superior in some respects, does not provide images as clear at the edge of the field as it does at the center.

Both satellites carry sounders, that is, equipment to measure temperature through the various levels of the atmosphere. The DMSP has one sounder, a seven-channel microwave instrument capable of reading through clouds. NOAA has a three-sounder system, including a four-channel microwave sounder.[1] The NOAA sounder system provides better resolution than the DMSP sounder, that is, the DMSP gives one reading per 50 to 75 miles and sometimes as much as 150 miles and the NOAA sounder produces a reading for an area of less than 50 miles. The superior NOAA sounder resolution is important for some military users.

Although both the military and the civilian systems orbit their spacecraft at about the same altitude, differences exist in their orbit times. The DMSP equator-crossing times are currently both in the morning. The NOAA equatorial crossing times are fixed at 7:30 a.m. and 2:30 p.m. The DMSP times were selected to meet specific military needs. The NOAA orbits were chosen to provide timely inputs to numerical weather prediction models but are also advantageous to some military users.

A third difference between the two systems is the equipment needed to pick up the satellite signal. NOAA's satellites broadcast in the "clear,"

[1] NOAA's sounder system also includes a 20-channel High Resolution Infrared Radiation Sounder and a 3-channel Stratospheric Sounding Unit.

that is, any user worldwide who makes a small investment in an antenna can pick up the satellites' Automatic Picture Transmission. In contrast, the DMSP satellites broadcast an encrypted (or coded) signal. For security reasons, this signal can be picked up only by special, more expensive decoding receivers. We found that the easy accessibility to the NOAA satellites is not only beneficial to many civilian users worldwide but also to several military users.

The military services' weather forecast units depend on the DMSP and NOAA polar-orbiting satellites to provide data needed for the operation of complex numerical forecasting models run on supercomputers. The data from these satellites are also used to

- inform field commanders of local weather conditions, such as approaching storms, which may affect troop movements and weapon system operations;
- forecast and track typhoons, cyclones, hurricanes and other meteorological phenomena;
- identify cloud conditions for reconnaissance and refueling and for targeting;
- provide information needed to identify the location of ocean fronts and eddies;
- key data in antisubmarine warfare;
- provide ships and land bases with information on weather conditions, needed for flight operations; and
- determine the position and condition of sea ice for navigation and submarine operations.

The DOD's main meteorological activities are carried out by the U.S. Air Force's Air Weather Service and the U.S. Navy's Naval Oceanography Command. The following sections discuss (1) their uses of the NOAA satellites, (2) the impact on their operations if one NOAA polar orbiter were eliminated, and (3) the impact on their operations if both NOAA orbiters were out of service for an extended period.

Air Force—Uses of NOAA Polar Orbiters and Impacts of Their Loss

Air Force Uses of NOAA's Polar Orbiters

The Air Weather Service of the Military Airlift Command provides weather services to U.S. Air Force and U.S. Army units worldwide. Air Weather Service has just under 300 units, most of which are organized under six weather wings and one central processing facility—the Air Force Global Weather Central. The Air Weather Service has about 5,000 people worldwide and operates 160 base weather stations.

The central weather processing facility for the Air Force is Air Force Global Weather Central (AFGWC), located at Offutt Air Force Base, Nebraska. AFGWC provides direct support to military units in the form of (1) forecasts, flight plans, and other reports, (2) forecast guidance, and (3) warnings of severe weather. AFGWC employs over 700 scientists and technicans (military and civilian) and uses multiple computer systems.

Air Force Global Weather Central's Uses of NOAA Soundings

We were informed by AFGWC officials that they make extensive use of the soundings provided by the NOAA satellites. They are currently dependent on NOAA for about 75 percent of the temperature soundings used in their weather analysis.

AFGWC's Chief, Data Base Management, Forecasting Services Division, told us that AFGWC's new numerical weather analysis model, High Resolution Analysis System, needs satellite soundings to fill in data-sparse areas. For example, in the stratosphere, very little sounding data are available other than from satellites, and according to this official most of that which is available is unreliable. Therefore, they need the stability of a "single sensing system" to produce coherent observational input to the High Resolution Analysis System in the stratosphere. This official explained that the High Resolution Analysis System model will not provide reliable results in the stratosphere after 2 days without stratospheric satellite soundings. As a result, he said, AFGWC's ability to support high-altitude reconnaissance flights would be degraded. With two NOAA polar orbiters operating, AFGWC technicans receive approximately 14,000 soundings a day.

Furthermore, this official pointed out that AFGWC's numerical weather prediction models are initialized[2] using the analysis fields produced by the High Resolution Analysis System. Therefore, he said, AFGWC's weather support depends strongly on the quality of the analysis fields, which depend strongly on the NOAA soundings.

[2]Intialization refers to the process of determining what the weather conditions are at the start of the forecast period.

Air Force officials explained that around June 1987 they plan to increase their use of DMSP soundings. This will occur when AFGWC modifies one of its computer systems. Air Force officials were unable, however, to tell us what percentage of the soundings will be from either the DMSP or NOAA polar orbiters, when the computer upgrade is completed.

Air Force Global Weather Central's Uses of NOAA Imagery

AFGWC officials told us that NOAA imagery is used to supplement DMSP imagery. For example, AFGWC has three special Production Teams within the Forecasting Services Division that assist the Joint Typhoon Warning Center, in Guam, and the Alternate Joint Typhoon Warning Center, in Hawaii, in determining the location of tropical cyclones. An AFGWC official told us that the warning centers can request this support from "all available imagery," in which case storm locations will be determined from NOAA imagery as well as DMSP.

The Contingency Support Cell, Forecasting Services Division, AFGWC, uses the NOAA imagery to provide short-range forecasting for the Strategic Air Command and national and international contingencies.[3] It uses the afternoon NOAA polar orbiter to prepare forecasts and to verify them. Currently, NOAA imagery constitutes 25 percent of the Contingency Support Cell's supply of high-resolution weather satellite imagery.

Uses of NOAA Satellite Data by Air Force Field Units That Receive Both DMSP and NOAA Data

The Air Force also operates 12 DMSP tactical terminals, located throughout the world, which are used primarily to receive images from DMSP but which also receive the NOAA images. These tactical terminals were designed to provide a survivable source of real-time weather information (i.e. satellite imagery) to overseas commanders and other decision makers. According to Air Force documents, in the absence of peacetime sources of weather data, the DMSP tactical terminals can stand alone to provide essential information to support combat operations. These terminals are in vans, some of which are mobile and, in the event of a crisis, can be moved to the area of conflict.

The permanently staffed vans are currently carrying out missions in support of bases and activities in their areas of responsibility. After doing an analysis at our request of NOAA satellite use, Air Force Global Weather Central officials, reported to us that on average NOAA polar orbiters made up about 25 percent of the satellite images copied, per

[3]Contingencies, according to the Air Force are actual or potential crises any place in the world that do or could involve U.S. military, federal, or allied personnel.

day. However, as seen in table III.1, some sites depend on the NOAA satellites for over 40 percent of their images. Air Force officials told us that the particularly heavy use of the NOAA polar orbiters by the vans at Howard Air Force Base, Panama, and Royal Air Force Base, Croughton, England, was due to their extensive use of the afternoon NOAA satellite.

An October 18, 1985, Site Performance and Application Report from Howard Air Force Base for the period July 1 through September 30, 1985, stated:

> "Detachment 25 continues to use DMSP and NOAA data in support of weather briefings, forecasting, training, exercise support and overall weather support to USSOUTHCOM, USAFSO,[4] 24th Composite Wing and for inter-theater operations. Satellite imagery is a necessity for providing weather support in the data sparse region of Latin America."

[4]These are abbreviations for military units in the southern hemisphere: USSOUTHCOM—U.S. Southern Command, USAFSO—U.S. Air Force Southern Air Division.

Table III.1 DRO Sites' Percentage of All Weather Satellite Images Received From NOAA Polar Orbiters, October 1984-September 1985

Site-type/location	Percentage of images received from NOAA polar orbiters
Mark II-A sites[a]	
Hickam Air Force Base, Hawaii	28
Lajes Air Force Base, Azores	15
Clark Air Force Base, Philippines	20
Mark III sites[a]	
Ramstein Air Force Base, Federal	
Republic of Germany	15
Osan Air Base, Korea	22
Elmendorf Air Force Base, Alaska	10
Howard Air Force Base, Panama	43
Guam Joint Typhoon Warning Center	24
Kadenna Air Base, Okinawa	2
Site 12 (Classified)	N/A
Mark IV sites[a]	
Macdill Air Force Base, Florida	25
Royal Air Force Base, Croughton, England	57
Average all sites	25

[a]Mark II-A, III, and IV designations refer to various types of reception vans. The older model Mark II-A and III vans are larger "fixed" terminals. The newer Mark IV van is transportable by C-130 aircraft, and according to Air Force officials, it is more sophisticated and has greater capability for manipulating and enhancing meteorological satellite data.

Officials of the Air Weather Service told us that since DOD does not have an afternoon DMSP spacecraft, the afternoon NOAA satellite is important to all DMSP receiving sites. They explained that the afternoon NOAA satellite fills the data void during the afternoon hours and is essential for

- preparing forecasts, weather warnings, and meteorological watch advisories;
- briefing command/control agencies supporting aircraft and Army ground operations; and
- supporting the other military services and civilian agencies such as the Navy's Naval Oceanography Command Center in Rota, Spain, which prepares sea surface temperature analyses of the Mediterranean.

Air Weather Service officials also told us that the morning NOAA satellite is important to some DMSP sites. For example, they said that in the Pacific theater, the Joint Typhoon Warning Center, in Guam, and the alternate Joint Typhoon Warning Center, in Hawaii, depend on the morning NOAA data, collected by all the Pacific DMSP sites, to track and position tropical storms in the Pacific and Indian oceans. The Warning Center and its alternative routinely opt for data from the meteorological satellite whose orbit is in the best location in relation to a storm's position. According to Air Force officials, the NOAA data often fulfill this requirement and are therefore used just as much as DMSP data. In addition, the DMSP site in Hawaii supports the Central Pacific Hurricane Center to meet the same requirement.

Uses of NOAA Satellites by Air Force Units That Receive Only NOAA Data

Six Air Weather Service units throughout the world operate fixed stations receiving only the NOAA satellite signal and not the DMSP signal. (See table III.2.) According to the Air Force, NOAA data may be the only source of satellite data,[5] or of any data at some locations, for preparing forecasts, weather warnings, and meteorological watch advisories to support aircraft and Army ground operations. Table III.2 shows (1) where the Air Force's six fixed NOAA satellite receivers are located and (2) a summary of their use of the NOAA data.

Table III.2: Air Force Sites Receiving Only NOAA Satellite Signals and Basic Uses Made of NOAA Polar-Orbiting Satellites

Location	Uses made of polar satellite data
RAF Lakenheath, United Kingdom	Acquires data from both NOAA satellites for terminal and range forecast and for general weather monitoring.
RAF Mildenhall, United Kingdom	Acquires data from both NOAA satellites for strategic reconnaissance, Military Airlift Command transoceanic flight briefings, refueling forecast preparation, and general weather monitoring.
Florennes, Belgium	Acquires data from both NOAA satellites for Ground-Launched Cruise Missile mission control forecast preparation and for general weather monitoring.
Incirlik Air Base, Turkey	Acquires data from both NOAA satellites (only sources of satellite data) for flight briefings, preparation of weather advisories, and general weather monitoring.
Rhein-Main Air Base, Federal Republic of Germany	Acquires data from both NOAA satellites for terminal forecast preparation, Military Airlift Command transoceanic flight briefings, and general weather monitoring.
Shemya Air Base, Alaska	Acquires data from both NOAA satellites as sole source for providing weather support to reconnaissance operations.

[5]Some units can receive imagery from other countries' geostationary satellites.

Impacts on Air Force Users of the Loss of One NOAA Polar Orbiter

Air Force Global Weather Central officials told us that the loss of one NOAA polar orbiter would result in no degradation in support to Global Weather Central, assuming that the remaining satellite has an operating sounder.

However, if the afternoon NOAA satellite were eliminated, the impact would be the loss of supplemental afternoon imagery. According to Air Force Global Weather officials, such a loss could have a critical impact on

- tropical storm detection and location fixes (Guam) and
- contingency forecasts issued by the Contingency Support Cell at Air Force Global Weather Central. These forecasts provide short-notice weather support to classified and unclassified missions or operations, such as disaster relief or rescue missions (e.g. Columbian volcanic eruptions) and for military operations (e.g. Granada invasion).

Air Force officials also told us that at sites equipped to receive both DMSP and NOAA data, (i.e. sites listed in table III.1)

(1) The elimination of the afternoon NOAA satellite would have "great impact" since the DOD does not have any afternoon DMSP spacecraft.

(2) The elimination of the morning NOAA satellite would cause significant impact on support of current operations in the Pacific theater and on support of worldwide operations if one or both of the DMSP spacecraft failed.

Furthermore, at the Air Force sites equipped to receive only the NOAA signal (see table III.2), Air Weather Service officials stated that the elimination of any NOAA polar orbiter (TIROS-N) would critically affect their mission support capabilities. These officials also noted in a December 13, 1985, letter to us explaining the impact of the loss of NOAA polar-orbiter coverage:

> "A significant point is that AWS [Air Weather Service] units currently have 3 portable [Air Force emphasis] non-DMSP DRO's (Direct Read Outs), with 23 more on order, which receive TIROS-N (but no DMSP) to support Army tactical operations in Europe. Loss of any TIROS-N would critically impact this tactical support."

The three portable Direct Read Outs are located in the Federal Republic of Germany at Heidelberg, Feucht City, and Pirmasens City.

Impact on Air Force Users of a Disruption of All NOAA Polar-Orbiting Coverage

We also asked Air Force officials to provide information on the impacts on their operations if all NOAA polar-orbiting coverage were lost. Air Force Global Weather Central officials stated that if their computer system is upgraded as planned by June 1987, to accept more DMSP sounding data, the loss of all NOAA data would not seriously affect most of their operations. They said, however, that the loss of all NOAA soundings would moderately degrade the accuracy of the products that are developed from their High Resolution Analysis System and Global Spectral Model, especially those products covering ocean and data-sparse areas.

More importantly, according to an Air Weather Service official, if one or both DMSP satellites could not provide soundings, the loss of NOAA soundings would significantly degrade product accuracy in data-sparse regions, since a very limited amount of data would be available for the data base that supports the High Resolution Analysis System. Such a situation did occur in the early 1980's when no DMSP spacecraft was operational. If it were not for NOAA data, the Air Force stated in a December 13, 1985, letter to us, its mission support would have been severely degraded. According to the Air Force letter, the morning NOAA polar orbiter currently complements the DMSP and would become the primary source of high-quality data in the event of a DMSP failure.

According to Air Force's December 13, 1985, letter, the 12 DMSP sites equipped to receive both the DMSP and NOAA signals would be seriously affected by the loss of the afternoon satellite images since DOD does not have an afternoon satellite. The letter also notes that the loss of the morning NOAA satellite would also cause significant impact on the Joint Typhoon Warning Center and the Alternate Joint Typhoon Warning Center's ability to locate tropical storms in the Pacific and Indian oceans.

The Air Force explained in its letter that at the non-DMSP Direct Read Out sites, the elimination of any NOAA polar orbiter would critically affect mission support capabilities. In fact, according to an Air Weather Service official, two sites (Incirlik, Turkey, and Shemya, Alaska) rely totally on NOAA satellites for their satellite imagery. These sites, the official said, would have to resort to conventional forecasting methods, i.e. local temperature, barometric pressure, humidity, and wind readings. He said, they would know little about incoming weather systems and their severity. This could hamper their base and flight operations, (e.g. reconnaissance and refueling). In fact, AFGWC officials said that at one of these sites (Shemya, Alaska), the crash of an Air Force transport plane in bad weather led to the installation of the NOAA satellite receiver.

Navy—Uses of NOAA Polar Orbiters and Impacts of Their Loss

Navy Uses of NOAA Polar Orbiters

Within the U.S. Navy, meteorological and oceanographic support is provided by the Naval Oceanographic and Meteorological Support System. The Support System is a collective title that includes environmental personnel and support assigned to various naval shore and afloat staffs; U.S. Marine Corps aviation weather units; test stations and ranges; shipboard weather offices; and activities of the Naval Oceanography Command.

Primary support for the Naval Oceanographic and Meteorological Support System is provided by activities and detachments reporting to the Naval Oceanography Command, Bay St. Louis, Mississippi. Shore field activities within the Naval Oceanography Command having meteorological responsibilities include the following:

- A primary environmental data processing center is located at the Fleet Numerical Oceanography Center, Monterey, California. Fleet Numerical is the Navy's equivalent to Air Force Global Weather Central. The center is the Navy's principal weather forecasting office and carries out several oceanographic-related analyses needed for antisubmarine warfare, including global sea surface temperature analyses. Each day it produces forecasts of weather and projected ocean thermal conditions that are relayed to the three regional oceanography centers for further dissemination.
- Three regional oceanography centers are located at the Naval Western Oceanography Center, Pearl Harbor, Hawaii; the Naval Eastern Oceanography Center, Norfolk, Virginia; and the Naval Polar Oceanography Center, Suitland, Maryland. They have been assigned broad geographical areas of responsibility for oceanographic and meteorological fleet support services and related matters. They utilize numerical products from Fleet Numerical to provide environmental broadcasts and tailored support in response to specific requests from the operating forces. The Naval Polar Oceanography Center also supports and operates a Navy-

NOAA Joint Ice Center that provides analyses and forecasts of sea ice conditions to the civilian community, as well as to DOD.

- Two Naval Oceanography Command Centers are located in Rota, Spain, and on the island of Guam. Both of these centers provide fleet environmental broadcast and tailored support in a manner similar to the regional centers. The Guam Command Center has the additional responsibility for the operation of a Joint Typhoon Warning Center with the Air Weather Service.
- Seven Naval Oceanography Command Facilities are located at Jacksonville, Florida; San Diego, California; Yokosuka, Japan; Cubi Point, Philippines; Keflavik, Iceland; Bermuda; and Bay St. Louis, Mississippi. The first six command facilities provide limited area local and aviation environmental forecast services. The seventh, in Bay St. Louis, Mississippi, is responsible for on-board training programs, Naval Reserve matters, and management of the Meteorological and Oceanographic Equipment Program.
- Forty-seven Naval Oceanography Command Detachments are located primarily at Naval Air Stations throughout the world.

The Navy also has 28 surface ships that have satellite reception capability. Eight ships can receive both the DMSP and NOAA polar orbiter signals, and the remaining 20 can receive only the NOAA polar orbiter or foreign countries' geostationary satellite signals, depending on their location at the time. They do not have the DMSP receiver because the reception equipment is very costly. An official from the Office of the Oceanographer of the Navy told us the Navy has plans to add new, less expensive DMSP receivers on 44 ships (including the 20 ships that now can receive only the NOAA signal) and 16 operational shore sites between July 1988 and June 1992.

Fleet Numerical Oceanography Center's Uses of Sea Surface Temperature Data

We were informed by an official within the Fleet Numerical Oceanography Center's (FNOC) Data Integration Department that the center makes extensive use of the multichannel readings of sea surface temperature provided by the NOAA polar orbiters. He pointed out that there are three sources for data on sea temperatures:

(1) sea surface temperature readings from ships,

(2) temperature depth profiles obtained by ships, and

(3) satellites.

The first two sources provide sparse data, while the satellites provide the majority of the information. The sea surface temperature information is used in FNOC's ocean thermal structure models. These models are developed to give ships forecasts of sonar performance, so that shipboard commanders can make tactical decisions, especially with respect to submarine warfare.

This official explained that the NOAA polar orbiter is preferred over the DMSP because it has several infrared channels, narrower bands, and better temperature accuracy. For example, the NOAA polar orbiters can produce temperature accuracies within a couple of degrees centigrade; and with some adjustments to the data, the accuracy level can be increased to 1 degree centigrade. In contrast, DMSP's temperature readings can be off by 5-10 degrees centigrade, he said.

Fleet Numerical Oceanography Center's Uses of NOAA Polar Orbiter's Atmospheric Soundings

A Fleet Numerical official explained that the NOAA polar orbiter has its greatest impact on FNOC's meteorological models. At present NOAA polar orbiter soundings make up about 75 to 80 percent of the soundings used in FNOC's numerical forecast models. They receive about 50,000 NOAA soundings a day.

According to a FNOC official, the soundings are used in the Navy Operational Global Atmospheric Prediction System and stratospheric models. The results from the stratospheric model are used in the Navy Operational Global Atmospheric Prediction System and FNOC's regional weather forecast models. The FNOC official noted that the stratospheric information is important to strategic missile operations.

Naval Eastern Oceanography Center's Uses of NOAA Polar Orbiters

The Naval Eastern Oceanography Center provides environmental support to the Department of the Navy and principal commands serviced by the center. This facility's basic operations are to provide

- broad area warnings of storms, high winds, high seas, high tides, and other destructive marine weather phenomena for naval users, primarily those in the Atlantic;
- identification of ocean fronts (e.g. the Gulf Stream);
- more specialized oceanographic and marine meteorological support to North Atlantic Treaty Organization forces;
- optimum ship-routing services on request to the Military Sealift Command, Navy contract ships, and Navy and Allied units in the Atlantic;
- route weather forecasts tailored for individual ships; and

- environmental services in support of naval aviation.

An oceanographer at this facility told us that he is dependent upon the NOAA polar orbiter's infrared imagery to show the temperature gradients in the ocean. These data are useful in sonar operations and enemy submarine detection.

According to officials at the Naval Eastern Oceanography Center, the polar orbiter data have also proved important for the Naval Eastern Oceanography Center's optimum ship-routing services. The NOAA polar orbiter enables them to identify where the Gulf Stream is located. They explained that using or avoiding the Gulf Stream can save large volumes of fuel on long voyages. Officials estimated that the government saved about $1,730,000 in fuel costs between 1981 and 1985 using Gulf Stream reports.

Naval Eastern Oceanography Center officials also stated that the NOAA polar orbiters are used in preparing forecasts of the "North Wall" effect, a weather phenomenon off the Virginia Coast. When cold dry air flows over the surface of the Gulf Stream, abnormally high winds and seas can be produced by the North Wall effect. This effect has proved to be disastrous to several naval vessels over the past 10 years.

Navy-NOAA Joint Ice Center's Use of NOAA Polar Orbiters

Another major U.S. Navy user of NOAA polar-orbiter data, using half of its imagery, is the Navy-NOAA Joint Ice Center, a subelement of the Naval Polar Oceanography Center, Suitland, Maryland. An official at the Ice Center told us that the center has three types of products (1) global, (2) regional, and (3) tailored.

- Global products are maps of the ice edge for both the Arctic and Antarctic regions. The center depends primarily on the NOAA satellite data, in addition to some on-site observations, and some reconnaissance flights (by the Canadians) to analyze ice concentrations, ice age, and ice hardness. The center is the only Ice Center in the world that produces a global product.
- Regional products are ice information for specific locations such as the Great Lakes or the North Slope of Alaska.
- Tailored products are specific products for Coast Guard ice breakers, research vessels, Arctic ice camps, and military resupply ships going to the Defense Early Warning Line and Greenland.

The Joint Ice Center's primary purpose is to support shipping, both military and civilian. In addition to the activities mentioned above, the center supports classified submarine activities in the Arctic and Antarctic areas. Furthermore, according to an Ice Center official, private contractors take the Ice Center's unclassified ice analyses and reformat it for sale to civilian shipping concerns.

Shipboard Uses of NOAA Polar Orbiters

According to an official at the Office of the Oceanographer of the Navy, the Navy is heavily dependent on the NOAA polar orbiter for its shipboard weather forecasting activities. Currently, 28 ships have some type of satellite receiving capability; however, only 8 have the DMSP receiver. This situation is expected to change. Beginning in July 1988 the Navy plans to phase in new types of terminals capable of receiving both DMSP and NOAA signals on about 44 ships. This phase-in operation is to be completed by June 1992.

In November 1985 we interviewed five shipboard meteorologists with experience on ships with and without the DMSP receiver. We also obtained information from two former shipboard meteorologists, one of whom now works for the Oceanographer of the Navy. They told us that they used the NOAA polar orbiter data to assist in making effective decisions on flight and ship movement operations. The satellites gave them up-to-date information on the position of existing fronts and weather systems that enabled them to forecast visibility, ceilings, wind, and precipitation.

Impact on Navy Users of the Loss of One NOAA Polar Orbiter

By a memorandum to us dated December 17, 1985, the Deputy Oceanographer of the Navy provided us a November 22, 1985, message from the Commander, Naval Oceanography Command, Bay St. Louis, Mississippi. That message informed us of the impact on the Navy's meteorological and oceanography activities of the loss of one or both NOAA polar orbiters.

In general, the Navy stated that the elimination of the morning NOAA polar orbiter would affect

- ships' ability to provide flight briefings;
- some fleet units' (i.e. selected Naval Oceanography Commands) ability to provide tactical weather forecasts at sea;
- the Joint Typhoon Warning Center's ability to determine the position of tropical storms;

- naval units' ability to forecast high latitude, fast-moving storms that must be monitored more frequently than every 12 hours; and
- naval units' ability to analyze and interpret medium scale weather systems in dynamic areas such as the Mediterranean.

An official at the Fleet Numerical Oceanography Center said that if one NOAA polar orbiter were eliminated, it would reduce the number of sea surface temperature observations 50 percent and this would have a significant impact on their forecasting operations. More importantly he said with only one NOAA polar orbiter in place, an increased likelihood would exist that from time-to-time all coverage will be lost because of instrument or satellite failure. He explained this would result in a complete loss of data that would have a very major impact.

The FNOC official explained that neither DMSP nor the Navy Remote Ocean Sensing System satellite (scheduled for launch in 1990) would serve as a complete substitute for NOAA's polar orbiters. He explained that it is important to remember that the mission of the DMSP satellite is to look for weather features, i.e. clouds, while the NOAA polar orbiter was designed with a more multi-use concept. He pointed out that the DMSP was never designed to look at ocean thermal structure.

This official also stated that the Navy Remote Ocean Sensing System will supplement, not replace, the NOAA polar orbiter. He explained that the Navy Remote Ocean Sensing System's sea surface temperature measurements will be of different parts of the spectrum from those of NOAA's polar orbiters. Furthermore, the resolution in the Navy's satellite will not be as great as that in the present NOAA polar orbiters. An official from the Office of the Oceanographer of the Navy said that since the NOAA polar orbiters are designed to measure atmospheric parameters and the Navy Remote Ocean Sensing System satellite is designed to measure oceanographic parameters, the combination of data from these systems will provide a comprehensive data set.

An official at the Naval Eastern Oceanography Center stated that it uses the afternoon satellite the most for its ocean front analysis work. The loss of the afternoon satellite would decrease the timeliness and amount of imagery received. As a result, on average they would be down to only two orbits or two visits per area, per day (instead of four).

Both DMSP and the NOAA orbiters tape record weather data for later transmission. The capacity of these tape recorders is limited. Officials of the Navy-NOAA Joint Ice Center told us that they could not use the DMSP tape recorder since it is fully committed to other DOD needs and that they compete for time on the NOAA orbiters' tape with civilian agencies and commercial groups. They said that if one of the NOAA orbiters were eliminated they would lose recorder time and data needed to make accurate ice reports.

A Navy official at the Joint Ice Center pointed out that the ice zone is cloudy 60 to 80 percent of the time and that the loss of any satellite coverage is critical. They sometimes do not receive good imagery because the lighting over ice is poor. Thus they need both satellites to give them several comparisons of the same area.

Navy officials told us that for those ships that can pick up both the DMSP and civilian satellites, the impact of the loss of one NOAA polar orbiter would not be severe. They said that such a loss, however, would degrade the ships' ability to monitor severe weather in their vicinity. The shipboard meteorologists we interviewed told us that they considered the NOAA polar orbiter to be important, even to those ships that have the DMSP receiver, primarily because NOAA's afternoon satellite provides an important data source. One former shipboard meteorologist told us of an incident where the NOAA afternoon satellite enabled him to locate and thus avoid a large storm that could have caused major aircraft damage.

Navy officials pointed out that for ships that can pick up only the NOAA signal, the loss of one NOAA polar orbiter would reduce the available polar orbit satellite data by 50 percent. According to the Navy this would have a significant impact if the ship were operating outside geostationary satellite coverage, i.e. the Indian Ocean. Many of the shipboard meteorologists we interviewed pointed out that the NOAA satellite receiver sometimes goes down and that as a result they do not always receive every NOAA polar orbiter pass. Therefore if NOAA were to cut back to one polar orbiter, their satellite coverage would be reduced to even less than 50 percent.

Impact on Navy Users of the Loss of Both NOAA Polar Orbiters

As previously indicated, the Deputy Oceanographer of the Navy provided us a November 22, 1985, message from the Commander, Naval Oceanography Command, listing the impacts on the Navy's meteorological and oceanographic activities of the loss of one or both NOAA polar orbiters. In general, a loss of both NOAA satellites would affect

- oceanography centers' ability to depict ocean thermal features and

- some Navy Oceanography Commands' ability to meet military aviation support requirements.

Furthermore, according to the November 22, 1985, message from the Commander, Naval Oceanography Command, the Joint Typhoon Warning Center in Guam considers the afternoon NOAA polar orbiter to be a "unique and valuable source of cyclone position information which would be sorely missed."

An official at FNOC stated that the impact of the loss of both NOAA polar orbiters on FNOC's sea surface temperature analyses would constitute a very major impact.

The oceanographer at the Naval Eastern Oceanography Center told us that if all NOAA polar orbiter coverage were lost, in regard to their ability to make ocean frontal and eddy analyses, he would have to "close shop." He explained that the DMSP imagery that they receive from FNOC is not of sufficient detail or quality to complete his ocean frontal analyses. He explained that he is able to locate ocean frontal changes within 5 nautical miles using the NOAA data but the DMSP imagery permits them to do analyses of only 10 to 15 or 10 to 20 nautical miles. According to the Naval Eastern Oceanography Center's oceanographer, this difference is critical because the DMSP variance is beyond the tactical range of their sonar systems.

The worst effects of a loss of both NOAA satellites would be on the 20 ships that can receive only the NOAA polar orbiter signal. According to Navy officials this impact would be severe. It would eliminate any satellite capability for ships when operating outside geostationary satellite coverage (e.g. in high latitudes or in the Indian Ocean.)

As for those ships that have both receivers (i.e. DMSP and civilian), Navy officials stated that the loss of both NOAA satellites would severely degrade those units' ability to depict ocean thermal features (ocean fronts and eddies) that are critical in sonar operations in support of antisubmarine warfare. The Navy officials stated that DMSP satellites can be used in oceanographic applications, but the primary sensor, the Operational Linescan System, is designed for meteorological (cloud) imagery. Furthermore, according to the Navy officials, the NOAA polar orbiter has an excellent ability to depict ocean thermal features.

In summary, the Commander, Naval Oceanography Command, stated that the loss of one or both NOAA polar orbiters is "unacceptable" to the Navy, at least for the next several years.

Satellite-Aided Search and Rescue Program

Since March 1983 NOAA's polar-orbiting weather satellites have carried a system to help locate victims of air and sea accidents and other people in need of emergency assistance. This satellite-aided search and rescue program is called SARSAT. Two satellites orbited by the U.S.S.R. also carry search and rescue systems.[1] Emergency transmitters on ships and planes broadcast signals to either country's satellites, which relay them to ground stations located in five countries. In the United States three stations pick up the satellites' signals. These stations transmit the location of the emergency signal to the U.S. Mission Control Center at Scott Air Force Base, Illinois. The Control Center alerts the Coast Guard of emergencies on water and the Air Force of emergencies on land. Two passes of the satellites over the emergency signal are normally needed to locate it with enough precision to begin search and rescue operations. According to NOAA officials, more than 500 lives have been saved through 1985 as a result of the joint U.S.-U.S.S.R. program, most of them in the United States.

In a 1984 memorandum of understanding with the U.S.S.R., France, and Canada, the United States agreed to keep two search and rescue satellites in orbit through 1990.

Effect of Eliminating One NOAA Polar Orbiter on Search and Rescue Efforts

According to a Coast Guard official, the faster that accident victims are located and rescued, the greater their chance of survival. Eliminating one polar-orbiting weather satellite, without replacing it with a search and rescue receiver on another satellite, would increase the time needed to detect distress signals. The increase, according to the Program Manager of the SARSAT Management Unit, would depend on the location of the signal on the earth and the position of the remaining satellites in orbit when the emergency transmitter was activated. The following factors influence how often a distress signal would be detected:

- The broadcast ranges of the satellites can overlap on successive orbits. A distress signal located in the area of overlap would be read by a satellite on each pass.
- The orbits of the satellites converge at the poles. Distress signals at the higher latitudes are received more often than those at the equator.
- The orbits of the U.S. and U.S.S.R. satellites are different, so that the interval between when the two countries' satellites pass over a point on the earth varies.

[1] As of January 1986, a search and rescue device on a third U.S.S.R. satellite was partially operational.

The SARSAT Program Manager measured the increase in signal detection times, resulting from the elimination of NOAA's morning polar orbiter, for a randomly selected day (June 28, 1985), which, he said, would give representative data. The Program Manager's calculations, presented in table IV.1, show the time elapsing between satellite passes at the intersection of 100 degrees west longitude with the equator (a point in the eastern Pacific) and 30, 45, and 60 degrees north latitude (points in continental North America).

Table IV.1 shows that possible increases in response times to an emergency from eliminating a search and rescue satellite differ from a few minutes to several hours. The increases tend to be smaller nearer the pole where more satellite readings are taken.

Table IV.1: Time (In Hours and Minutes) **Elapsing Between Satellite Search and Rescue Readings at 100°W Longitude**

Equator		30°N latitude		45°N latitude		60°N latitude	
Four satellites	**Three satellites**	**Four satellites**	**Three satellites**	**Four satellites**	**Three satellites**	**Four satellites**	**Three satellites**
2:43	[a]	2:43		1:02		1:03	
1:40		1:40		1:41		1:40	
2:47	7:10	2:47	7:10	1:40		1:41	
1:55	1:55	1:46	1:46	2:47	7:10	2:47	7:11
1:30	1:30	1:30	1:30	1:44	1:44	1:45	1:45
49	49	22	22	1:32	1:32	1:34	1:34
1:06	1:06	1:23	1:23	14	14	13	13
3:14		16	16	03	03	1:29	1:29
1:39		2:39		1:27	1:27	20	20
3:14	8:07	1:41		08	08	1:20	1:20
1:19	1:19	1:27	5:47	2:39		05	05
21	21	1:46	1:46	1:41		53	
1:25	1:25	1:29	1:29	1:26	5:46	39	1:32
17	17	38	38	13		17	17
4:12		1:08	1:08	1:34	1:47	24	24
3:37	7:49	33	33	36	36	21	
		2:34		53	53	39	1:00
		1:40		46	46	47	47
		3:36	7:50	59	59	13	
				45	45	38	51
				2:31		36	36
				1:42		19	19
				3:35	7:48	06	
						38	44
						45	45
						14	
						02	16
						40	40
						49	49
						06	
						47	53
						52	52
						01	01
						1:39	
						1:40	
						1:53	5:12

[a]Blank slot indicates that a reading would not occur because of satellite elimination.

In response to proposals to eliminate one of the polar orbiters, NASA commissioned the Johns Hopkins University Applied Physics Laboratory to study the costs and time required to build and launch a dedicated search and rescue satellite. The study, issued in May 1985, estimated that the first of these satellites could be built in about 2.5 years for about $27.7 million. A second dedicated search and rescue satellite was estimated to cost about $15.2 million. A NOAA official told us that it would cost about $8.8 million to launch each of these satellites.

Effect of a Gap in All Polar-Orbiting Coverage on Search and Rescue Efforts

Loss of all service from the polar orbiters would extend search and rescue response times beyond those listed in table IV.1 for a three-satellite system. The United States would be dependent on the U.S.S.R. satellites for emergency signal detection from space. NOAA officials expect, however, that the search and rescue devices on the polar orbiters will have longer operating lives than the weather sensors carried on these satellites. Therefore, unless a satellite were totally disabled, search and rescue service could continue while a satellite to replace the malfunctioning weather sensors was being readied for launch.

Search and Rescue Service From the Geostationary Weather Satellites

The current geostationary weather satellites do not carry search and rescue equipment. However, the next of these satellites to be launched will test the usefulness of the geostationary satellites for search and rescue operations. The geostationary satellites, unlike the polar orbiters, will monitor distress signals continuously within their fixed field of view. However, these satellites will be capable of receiving signals only in a frequency recently set aside for emergencies and that uses a transmitter that is not yet commercially available. The geostationary satellites will also not be able to determine the location of an emergency unless the emergency transmitter broadcasts this information. According to the SARSAT Program Manager, it is expected that only the largest commercial ships and planes will have transmitters with this capability.

In addition, the geostationary satellites will not be able to detect distress signals above 70 degrees north or south latitude and cannot detect signals blocked by an obstacle. For example, the geostationary satellites could not read a signal from a plane crashed on the side of a mountain facing away from them.

Use of DMSP as a Substitute for the NOAA Polar Orbiters

According to the Chairman of DOD's Joint Environmental Satellite Coordinating Group, DOD is unable to place a search and rescue system on its weather satellites without removing DOD sensors, which it is unwilling to do.

Other Data Collection Services Performed by the Polar-Orbiting Weather Satellites

In addition to the weather sensors and search and rescue system, NOAA's polar-orbiting weather satellites carry a system to relay environmental data collected by sensors on the earth back down to ground receiving stations. This data collection service is provided by the French space agency's Service ARGOS, which builds the systems on board the satellites and operates a data processing center in Toulouse, France.

The ARGOS data collection system has about 2,000 users in 20 countries. The U.S. government is the largest single user, accounting for almost 40 percent of the system's broadcast time. Users deploy a variety of measuring and transmitting devices to collect and broadcast data to the satellites. Buoys are used for reporting on ocean conditions; instruments carried by balloons can be used for reporting on atmospheric conditions.

Applications of the ARGOS system include

- Meteorology—measurement of weather conditions with buoys, balloons, and land-based stations;
- Oceanography—measurement of sea surface and subsurface temperatures, ocean swells and waves, and acoustic studies;
- Glaciology—study of polar currents and buoy and iceberg trajectories, and avalanche risk forecasts;
- Biology—tracking of dolphins, basking sharks, turtles, whales, and polar bears;
- Hydrology—management of hydrologic networks, water survey and supply, and assessment of water resources;
- Geology—monitoring and prediction of earthquakes and volcanic eruptions, study of the thermal inertia of soil types; and
- Offshore—measurement of environmental control factors for oil spill tracking, pollution studies, ocean climate studies, and mooring failure monitoring.

According to NOAA officials the principal federal users of the ARGOS data collection system include

- NOAA itself, which uses ARGOS for meteorological observations, climate studies, studying ocean currents and other ocean parameters, assessment of fish stocks, tracking hurricanes, and other purposes;
- the Navy, which uses the system for monitoring ice conditions, studying ocean currents, observing ocean weather, and doing acoustical ocean research;
- the Department of the Interior, which attaches transmitters to animals to study their migratory patterns; and

- the National Science Foundation, which uses platforms for ocean and Antarctic weather research and for studying seal behavior.

Effect of Eliminating One NOAA Polar Orbiter on ARGOS Users

We discussed how the loss of one polar orbiter would affect ARGOS users with the U.S. representative of Service ARGOS; with a NOAA official who coordinates federal government users of ARGOS; and with officials of the National Weather Service and NOAA's Office of Oceanic and Atmospheric Research. These officials believed that the second polar orbiter's principal value was as a backup to the first. None knew of users whose programs would be severely damaged by the loss of one orbiter.

Effect of a Gap in All Polar-Orbiting Coverage on ARGOS Users

According to Service ARGOS and NOAA officials, a total disruption of all ARGOS service would have very serious consequences on users. The U.S. representative said that not only would users lose all data during the service interruption but the value of much research data collected by ARGOS would be reduced or destroyed. According to the U.S. representative, scientists who do ocean or atmospheric research depend on continuous data to spot trends. A service gap might destroy much of the value of the data collected before or after the gap.

NOAA participates in an international effort called the Tropical Ocean and Global Atmosphere (TOGA) project to study and eventually to predict climatic variations in the southern hemisphere. These variations produce the so-called "El Nino" effect (an ocean-warming phenomenon), which in 1982-83 caused drought and violent weather in many countries and affected U.S. weather as far north as Alaska. According to NOAA officials the TOGA project will cost more than $200 million over its 10-year life, with the United States paying about $100 million. Much of the data TOGA collects come from about 50 buoys that transmit information on sea surface and atmospheric conditions to the ARGOS system on board the polar orbiters. The Director of the U.S. TOGA Project Office, a unit in NOAA's Office of Oceanic and Atmospheric Research, told us that the maintenance of one functioning polar orbiter in orbit at all times was critical to the success of the TOGA project.

Data Collection Services From the Geostationary Weather Satellites

The geostationary weather satellites also provide data collection services but cannot determine the location of transmitters. Therefore, these satellites are not adequate substitutes for the polar orbiters for any applications in which it is essential to know the position of a moving transmitter. According to the U.S. representative of Service ARGOS, about 80 percent of transmitters broadcasting to the polar orbiters (for example, drifting buoys used for ocean studies or transmitters attached to animals) are moveable, and their locations must be known for the data collected to have value. In addition, according to the U.S. representative, the geostationary weather satellites cannot receive transmissions from the higher latitudes and so are not useful for sea ice monitoring, an important ARGOS application.

Use of DMSP as a Substitute for the NOAA Polar Orbiters

The DOD weather satellites do not provide ARGOS-type data collection services.

NASA Uses of the Polar-Orbiting Weather Satellites

NASA depends on NOAA's polar-orbiting weather satellites to carry out some of its research activities. For example, the Earth Radiation Budget Experiment (ERBE) sensor, a NASA instrument first flown on NOAA-9, is used to study how and where solar energy is absorbed and dissipated from the earth. In addition, the Solar Backscatter Ultraviolet instrument, also flown on NOAA-9, is used by NASA to study atmospheric ozone levels. Moreover NASA uses data from the polar orbiters in its climatic study activities.

We contacted several NASA officials to determine their use of the polar orbiters and the impacts of the loss of one or both of the polar orbiters on the outcome of their research and/or experiments. In general, NASA officials said that while two satellites are preferred, primarily using the second satellite as a backup, the experiments would not fail if only one satellite were in orbit.

Earth Radiation Budget Experiment

NASA has lead responsibility for a multiagency study of solar and earth radiation. The earth's radiation budget, which is the central element of this research, describes the energy balance that exists between the sun, earth, and space. The geographical and temporal imbalance in this key relationship governs the state and changes of regional climate. Earth radiation budget data acquired for the ERBE, which began in 1984, are collected in part from satellites, including

- a NASA-dedicated Earth Radiation Budget Experiment satellite (launched in October 1984),
- NOAA-9 (launched in December 1984), and
- NOAA-G (to be launched in March 1986).

According to the NASA official responsible for the ERBE project, the experiment is already in operation; and when NOAA-G is in orbit, they will merge the information from the third satellite. NASA plans to receive the data from the third satellite for several years and run the experiment through 1988 or 1989.

Impact of Loss of One or Both NOAA Polar Orbiters on the Earth Radiation Budget Experiment

The manager of NASA's Climate Research Program told us that if one of the NOAA polar orbiters were eliminated, ERBE's results would be degraded but it would not be a failure. However, the manager said that if both NOAA polar orbiters were lost, the experiment would be ruined. This official pointed out that the Earth Radiation Budget Experiment will be largely completed before a one-orbiter system could be instituted.

Solar Backscatter Ultraviolet Sensor Used by NASA to Collect Ozone Data

Another NASA instrument flown on NOAA's polar orbiters is the Solar Backscatter Ultraviolet Sensor. The instrument was flown on NOAA-9 in December 1984. According to a NASA official, the general goal of the project is to establish whether the ozone content of the atmosphere is changing. The instrument will also be flown on NOAA-G, -H, and -I.

According to a NASA official, any shift by NOAA to one polar orbiter will have little impact on this project, since one instrument continuously in orbit is all that is needed. If both NOAA polar orbiters were lost, the continuity of data collected by the program would be broken.

Overall Importance of NOAA Polar Orbiters to NASA Climate Work

We interviewed the Chief, Atmospheric Dynamics and Radiation Branch, and the manager of NASA's Climate Research Program to determine the impact of the loss of one or both polar orbiters on NASA's climate work.

The Chief, Atmospheric Dynamics and Radiation Branch, stated that if they lost both polar orbiters they would be severely affected. Although in North America there are enough radiosondes[1] for coverage, without the polar orbiters, vast ocean areas would be without data. As a result, NASA would be forced to replace missing satellite data with estimated data in its models. He said this would be unsatisfactory and throw them back 10 to 15 years in their observation of the atmosphere.

According to these officials the elimination of one polar orbiter would

- reduce opportunities to fly research sensors and
- cause a loss of data on variations in weather conditions occurring within a day.

Officials said that in recent years, because of the end of an earlier series of satellites (Nimbus), opportunities to fly their own research sensors have been reduced. Space shuttle experiments, they said, can test only whether something works or calibrate it. The space shuttle experiments do not last long enough to gather long-term data.

One NASA official pointed out that NASA's research sensors are secondary in importance to NOAA, compared to NOAA's own weather sensors. NOAA does not replace a satellite with working weather sensors just because a NASA research sensor fails. The official stated that a one-satellite system would therefore leave NASA especially vulnerable to service disruptions.

[1] Airborne devices, usually attached to balloons, that radio meteorological data to the ground.

One NASA official pointed out that since research sensors are of secondary importance to NOAA, a cutback to one polar orbiter would make matters worse. For example, if an experimental sensor failed, NOAA would not launch a new spacecraft.

Officials said that NOAA's polar orbiters are well suited to climate studies because they can provide several readings daily of the same location on the earth's surface. Such multiple daily observations are important, they said, to climate research. Officials said also that loss of service from both of NOAA's polar orbiters would leave them without sufficient data to run their climatic models.

International Uses of the Polar-Orbiting Weather Satellites

NOAA's polar-orbiting weather satellites are used worldwide for weather forecasting and environmental data collection. More than 1,000 ground stations have been built in about 120 countries to receive weather images from the polar orbiters. According to officials of NOAA and the United Nations' World Meteorological Organization, some third world countries rely entirely on the polar orbiters for weather information. About 16 countries receive the polar orbiters' numerical data in addition to the satellites' images for use in their weather forecast models. Information from the satellites is also distributed worldwide through the World Meteorological Organization. The United States does not charge foreign users for the satellites' data.

According to NOAA estimates, foreign countries have spent about $200 million on building ground stations to receive and use the polar orbiters' signals.

Some foreign countries have used the polar orbiters for monitoring environmental conditions in addition to weather. For example,

- Finland has inventoried forests using the satellites' imagery.
- The forestry services of Canada and Australia used the satellites' images for forest fire surveillance.
- China uses the satellites' data to determine temperature patterns in the ocean, which help fishermen find fish.

Effect on International Users of Eliminating One NOAA Polar Orbiter

We discussed how weather forecasting in foreign countries would be affected by the elimination of one of NOAA's polar orbiters with officials of NOAA, the Agency for International Development, NASA, the World Meteorological Organization, and the European Centre for Medium Range Weather Forecasts. The Agency for International Development funds a NOAA program to monitor drought conditions in the Sahel region of Africa and a NASA program to give Bangladesh warnings of typhoons. Both programs make use of the polar orbiters. The European Centre, in Reading, England, is funded by several European countries to make global forecasts of weather 4 to 10 days in advance. The Centre's Director said that it makes extensive use of the NOAA polar-orbiting satellites.

Officials of the above organizations generally believed that the principal value of the second polar orbiter was as a backup to the first. However, World Meteorological Organization, Agency for International Development, and European Centre officials said that the loss of one orbiter could increase the time needed for forecasters to spot the development of major storms.

Effect on International Users of a Gap in All Polar-Orbiting Coverage

All officials we interviewed who were involved with the uses of the polar orbiters overseas, said that the loss of all service would have very serious consequences. For example,

- The Director of the European Centre for Medium Range Weather Forecasts said that it would be unable to issue forecasts.
- A weather satellite specialist with the World Meteorological Organization said that the effect on foreign countries in general would be similar—inability to make medium-range forecasts. He also said that countries that lack much data on weather conditions outside their borders (e.g. island countries) would be especially hard hit by the disruption of all service, as would poorer countries that rely almost exclusively on the orbiters for weather data.
- A NASA official in charge of a program to help Bangladesh predict typhoons said that the loss of both polar orbiters could have grave consequences. The orbiters' weather data and the data they relay through the ARGOS system from buoys in the Bay of Bengal are the principal means of alerting Bangladesh of approaching typhoons. In 1971, a severe typhoon, which hit the coast without warning, killed over 500,000 people in that country. In May 1985 another massive storm hit Bangladesh. The death toll, which was estimated at 20,000, would have been much higher, according to NASA officials, if the typhoon had not been detected by a polar orbiter.
- NOAA's Assessement and Information Services Center produces periodic reports on crop conditions in the Sahel region of Africa. These reports can provide early warnings of drought and crop failure. The Director of the center told us that the reports would not be possible without the polar-orbiting data.

Ability of the GOES to Substitute for the Polar Orbiters Internationally

The GOES have a limited field of view and do not observe weather conditions in most foreign countries. In addition, they do not measure weather parameters with the same accuracy as the polar orbiters.

Use of DMSP as a Substitute for the Polar Orbiters Internationally

The DMSP signal is encrypted and not available to other countries.

Likelihood and Expected Duration of the Loss of All Polar-Orbiting Coverage Under a Single-Orbiter Scenario

In a one-polar-orbiter system as proposed by the administration, a replacement satellite would be launched every 18 months. The satellites would have 2-year design lives. The likelihood and duration of a loss of all polar-orbiting coverage in this one-satellite system would depend on

1) the frequency of launch failures; 2) the frequency of early satellite failures in orbit; 3) the availability of launch pad, launch crew, and launch vehicle at the time of failure; and 4) the availability of a satellite for launch at the time of failure.

The polar-orbiting satellite program has suffered launch failures, early in-orbit failures, and launch delays in the past. Depending on the manufacturing schedule chosen for a one-satellite system, a repetition of these problems could produce long disruptions in all polar-orbiting coverage. An April 1985 NOAA study of the polar orbiters entitled Optimum Management Strategies for the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000 concluded that

"...in the one-satellite ... system [with replacement satellites not available before their scheduled launch date], there probably will be data gaps up to 30 percent of the time over the next 15 years. Individual periods when no satellite data will be available are likely to be 6 to 24 months[1] long."

Launch Vehicle Failures

Over the last 15 years, 3 of the 14 polar-orbiting weather satellites launched have not achieved orbit because of launch failure. (See table VIII.1.) The first eight of these launches, which resulted in two failures, were by Delta rockets; the last six launches were by Atlas rockets.

[1]Assumes that a premature failure in orbit after a year is followed by a launch failure.

Table VIII.1: Launch History of NOAA's Polar-Orbiting Satellites

Satellite	Launch Date	Launch Failure
TIROS-M[a]	01/23/70	
NOAA-1	12/11/70	
ITOS-B	10/21/71	Yes
NOAA-2	10/15/72	
ITOS-E	07/16/73	Yes
NOAA-3	11/06/73	
NOAA-4	11/15/74	
NOAA-5	07/29/76	
TIROS-N[b]	10/13/78	
NOAA-6	06/27/79	
NOAA-B	05/29/80	Yes
NOAA-7	06/23/81	
NOAA-8	03/28/83	
NOAA-9	12/12/84	

Source: GAO-derived, based on information in National Oceanic and Atmospheric Administration report Optimum Management Strategies For the NOAA Polar-orbiting Operational Environmental Satellites, 1985-2000, Volume 1, April 1985, pp. 4 and 18.

[a]TIROS-M thru NOAA-5, satellites in single-orbiter system, were launched on Delta boosters.

[b]TIROS-N thru NOAA-9 were launched on Atlas E/F boosters.

NOAA plans to launch its next four polar orbiters (NOAA-G to -J) on Atlas rockets, which according to Air Force officials, have a 90-percent launch success rate. NOAA-K, -L, and -M, planned for launch beginning in about 1991, will be launched either by a refurbished Air Force rocket, the Titan-II, which does not have a track record, or by the shuttle, which has not yet attempted the launch of a satellite into polar orbit.

Premature Satellite Failures in Orbit

Of the 11 polar-orbiting weather satellites successfully launched in the last 15 years, 2 have not reached their design lives, while 8 have exceeded their design lives. The eleventh, NOAA-9, was launched in December 1984 and is still fully operational.

NOAA-6 thru -9 are especially significant as indicators of future performance, since they have a design similar to the satellites NOAA plans to operate through the mid-1990's. Each of these satellites had a 2-year design life. NOAA-6 was fully operational for 51 months and is still partially working. NOAA-7 was used for 44 months. NOAA-8 functioned fully for 15 months before instrument failure.[2] Of the three satellites of the current generation with histories as long as their 2-year design lives, two exceeded lifetime expectations, and one failed early.

Availability of Launch Facility, Crew, and Vehicle

The length of a gap in service resulting from a launch failure or premature in-orbit failure in a single-orbiter system depends in part on how quickly another launch could be arranged. Under a 1977 agreement, the Air Force promised to launch NOAA's polar-orbiting satellites within 120 days of a launch request, allowing time to prepare the satellite, launch vehicles, and pad for launch operations.[3] The Air Force has indicated that it would extend this agreement to cover launches on the Titan-II rockets. NASA has also promised NOAA to launch within 120 days if NOAA uses the shuttle for NOAA-K, -L, and -M. Some NOAA officials are skeptical about NASA's ability to provide 120-day launch service by shuttle because of its more inflexible launch schedule. Furthermore, a DOD official stated that NOAA's competition with classified program launches on the shuttle would make it difficult for NOAA to get launches on demand.

History of Air Force Success in Meeting 120-Day Launch Commitment

Neither NOAA nor the Air Force maintains complete records showing whether launches were accomplished within 120 days of request for all satellites of the current generation. However, officials of both agencies told us that there had been no significant delays in the launch of TIROS-N, or NOAA-A, -B, and -C.[4] The launch of NOAA-E was delayed 9 months, because of the Air Force's need to support DOD priority missions. According to a NOAA official, while the Air Force failed to meet its 120-day commitment, the delay did not have serious consequences because a failed sensor on the satellite NOAA-E was scheduled to replace began operating again. The launch of NOAA-F was delayed about 2 1/2 months because of equipment and weather problems. The launch of NOAA-G has been delayed 7 months.

Delayed Launch of NOAA-G

According to a NOAA official, on January 24, 1985, NOAA asked the Air Force to launch NOAA-G in the August/September 1985 timeframe. At a working group meeting in February 1985, NOAA acquiesced to an Air

[2]Some of the satellite functions were restored for a 6-month period following the initial failure. The satellite is currently completely inoperable.

[3]According to NOAA officials, 30 additional days, or 150 days, would be needed to set up a launch following a launch failure.

[4]NOAA-B did not achieve orbit but was launched on schedule. NOAA-D was never launched.

Force request that the launch be delayed about 2 months until November 1985. This delay was requested in order for the Air Force to launch a navigation satellite in August 1985. However, technical problems developed with this satellite causing its launch to slip to late September 1985 and the launch of NOAA-G to be delayed another 2 months until January 1986.

Air Force and NOAA indicate that NOAA went back to the Air Force and informally asked it to consider using double shifts at the launch pad to bring NOAA's launch date back to a date no later than December 1985. During July 1985 NOAA learned that the requirement to launch a classified payload would not permit second shift personnel to be made available for its use. Further, NOAA learned that because of this classified mission and a probable launch pad conflict, the NOAA-G launch would slip to March 1986. One of the problems was that the booster contractor was unable to support both missions. It was determined that if the Air Force delayed the classified mission 3 weeks, NOAA could launch in December. However, the Air Force official responsible for the classified mission vetoed this option.

A NOAA official explained that the NASA-Air Force launch agreement provides that in the event of priority conflicts, such as this, the signers of the agreement would be notified for resolution. NOAA's Deputy Administrator sent a letter on August 30, 1985, to the Air Force Under Secretary requesting that he resolve the conflict and meet the intent of the 120-day agreement. The NOAA Deputy Administrator stated in his letter

> "we feel very strongly that the [United States Air Force] should stand behind their commitment to our program."

The Deputy Administrator pointed out that NOAA's meteorological satellite program is structured heavily around the provision of atmospheric temperature profiles for the National Weather Service.

Nevertheless the Air Force decided that the NOAA-G launch be delayed until March 1986. The decision memorandum pointed out that while NOAA's current "on-orbit satellite capacity" is capable of meeting NOAA's operational requirements, the same statement could not be made about the classified satellite.

The Air Force Under Secretary assured NOAA's Deputy Administrator that should NOAA's sole existing sounder instrument fail, he would take all possible actions to accommodate an immediate launch of NOAA-G.

Availability of a Satellite

The schedule chosen for the manufacture of satellites could greatly affect the duration of a service break in a one-satellite system. According to NOAA budget officials, past budgets proposing a one-satellite system have assumed that satellites would be produced on a schedule making them available for launch once every 18 months. In the event of the premature failure of a satellite, in orbit or because of a launch failure, an extended gap in service could develop under this manufacturing schedule. According to the Chief, Ocean and Atmosphere Systems Group, NOAA, the worst case—a launch failure during a period in which no functioning satellites were in orbit—could open up a service gap of about a year and a half—18 months to build and launch a replacement, plus a month to put it into operating condition in orbit. The disruption of service could be reduced by accelerating the production of a replacement satellite but at an increase in contract costs. According to this official it is not possible to predict in advance how much time could be gained, since the degree of acceleration would depend on the availability of staff at the contractor's plant at the time. This official also estimated that under the best of circumstances, the 18-month manufacturing and launch schedule might be shortened to 12 months.

The Chief, Ocean and Atmosphere Systems Group, NOAA, emphasized that the manufacturing schedule for a one-polar satellite system had not been worked out in detail and that the actual schedule adopted could provide for the faster production of satellites, depending on the funding available and the actual costs of manufacture at the time. At best, however, he did not foresee a system that could launch a replacement for an early in-orbit failure sooner than 4 months after the failure or 5 months after a launch failure.

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