

GAO

Report to the Chairman, Subcommittee  
on Energy and Environment, Committee  
on Science, House of Representatives

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March 1997

# WEATHER SATELLITES

## Planning for the Geostationary Satellite Program Needs More Attention



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United States  
General Accounting Office  
Washington, D.C. 20548

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**Accounting and Information  
Management Division**

B-275996

March 13, 1997

The Honorable Ken Calvert  
Chairman  
Subcommittee on Energy and Environment  
Committee on Science  
House of Representatives

Dear Mr. Chairman:

This report responds to your predecessor's request that we review the National Oceanic and Atmospheric Administration's (NOAA) management of the Geostationary Operational Environmental Satellite (GOES) Program. Specifically, we were asked to assess (1) the agency's strategy for procuring satellites in the GOES continuation series, (2) what steps the agency should be taking now to prepare for the next generation series of satellites, and (3) whether the potential exists for improving the system and reducing costs in the long term. The report recommends that the NOAA Administrator take certain steps to improve the agency's planning for future systems.

We are sending copies of this report to the Ranking Minority Member of your Subcommittee; the Chairmen and Ranking Minority Members of the House Committee on Science; the Senate Committee on Commerce, Science, and Transportation; the House and Senate Committees on Appropriations; the House Committee on Government Reform and Oversight; and the Senate Committee on Governmental Affairs. We are also sending copies to the Secretary of Commerce and the Administrator of NOAA. Copies will also be made available to others upon request.

If you have any questions concerning this report, please call me at (202) 512-6240. Other major contributors are listed in appendix II.

Sincerely yours,

A handwritten signature in black ink, appearing to read 'J. Brock, Jr.', written in a cursive style.

Jack L. Brock, Jr.  
Director, Defense Information and  
Financial Management Systems

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# Executive Summary

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## Purpose

The National Oceanic and Atmospheric Administration (NOAA) is in the process of planning the procurement of new Geostationary Operational Environmental Satellites (GOES) to replace the current series of satellites, which will begin to reach the end of their useful lives in approximately 2002. NOAA plans to buy a continuation series of two to four satellites that will be very similar to the current series in their capabilities and operations to fill the potential gap in satellite coverage that could occur beginning in 2002. Beyond the potential gap in coverage, NOAA has not yet decided whether to continue procuring the same type of satellites or consider new designs for a next generation system.

In fiscal year 1998, NOAA plans to spend over \$240 million for development and operations costs associated with the GOES system. Given that the NOAA budget is expected to be constrained in the coming years, the Chairman of the House Committee on Science, Subcommittee on Energy and Environment, requested that GAO assess (1) the agency's strategy for procuring continuation series satellites, (2) what steps the agency should be taking now to prepare for the next generation series of satellites, and (3) whether the potential exists for improving the system and reducing costs in the long term.

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## Background

The GOES system, which has been operational since 1975, plays a critical role in weather forecasting. The continuous availability of GOES data is vital to the success of the National Weather Service's (NWS) approximately \$4.5 billion systems modernization program. GOES satellites are uniquely positioned to observe the development of hazardous weather, such as hurricanes and severe thunderstorms, and track their movement and intensity so that major losses of property and life can be reduced or avoided. GOES satellites have two primary meteorological instruments: an imager and a sounder. The imager collects digital images of portions of the earth's surface from radiation that is sensed at five different wavelengths. The sounder is mechanically similar but sensitive to a broader range of spectral wavelengths, which allows it to measure natural variables, such as temperature and humidity, at different levels of the atmosphere. NOAA's operational strategy calls for two GOES satellites to be active at all times—one satellite to observe the Atlantic Ocean and eastern half of the United States, and the other to observe the Pacific Ocean and the western part of the country. Two GOES satellites are currently in orbit—GOES-8 covering the east and GOES-9 in the west. These satellites were launched in 1994 and 1995, respectively.

Even though satellites in the GOES series have been operational for over 20 years, only one major design change has been implemented. The first generation design, used on GOES-1 through GOES-7, was developed experimentally by the National Aeronautics and Space Administration (NASA) and subsequently came to be relied upon for the operational system. The second generation, called GOES-Next, represents a complete redesign of the spacecraft and its instruments that allows for the collection of substantially more and better weather data. The GOES-Next series includes the two currently operational satellites, GOES-8 and GOES-9, plus three additional spacecraft that are in different stages of production. Development of this second generation experienced severe technical problems, cost overruns, and schedule delays. For example, NOAA's estimate of the overall development cost for GOES-Next grew from \$640 million in 1986 to \$2.0 billion in 1996. Also, a nearly 5-year schedule slip in the launch of the first GOES-Next satellite left NOAA at one point in real danger of temporarily losing geostationary satellite data coverage, although no gap in coverage ever actually occurred. GAO reported in 1991 that design complexity, inadequate management of the program by NOAA and NASA (NOAA's agent for the procurement), and poor contractor performance all contributed to the cost, schedule, and technical problems experienced by GOES-Next.<sup>1</sup> Although some technical problems remain, the first two of these satellites are now producing useful, high quality weather data daily.

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## Results in Brief

Based on the best available analysis, the potential for a gap in geostationary satellite coverage will be significant in the early years of the next century if procurement of new satellites does not begin soon. To prevent this problem, NOAA plans to competitively procure two to four continuation series spacecraft that will carry the same meteorological instruments as the current spacecraft and incorporate modest technical improvements. The satellites are planned for launch beginning in 2002. Given the importance of maintaining continuous geostationary weather coverage, NOAA's plans are reasonable. However, there are inherent difficulties in determining exactly when and how many of the continuation series spacecraft will be needed. Despite these difficulties, GAO identified several specific shortcomings in NOAA's spacecraft planning process that, if remedied, could improve planning in the future. They include unclear policies for replacing partially failed satellites and backing up launches.

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<sup>1</sup>Weather Satellites: Action Needed to Resolve Status of the U.S. Geostationary Satellite Program (GAO/NSIAD-91-252, July 1991), p. 3.

Also, NOAA has no formal program underway to develop a new spacecraft series to follow the continuation series. Based on the President's fiscal year 1998 budget, NOAA does not plan to begin a follow-on GOES program until fiscal year 2003 at the earliest. Given that the opportunity now exists to consider alternatives for a follow-on system, current usage of GOES data by weather forecasters suggests that a reexamination of the GOES satellite architecture is warranted. Although requirements have not been formally updated since the GOES-Next satellite series was developed, usage of GOES data has continued to evolve. The current satellite design hosts two meteorological instruments that are devoted to a range of capabilities, some of which are increasing in importance to weather forecasters and others of which remain largely experimental. Before a decision can be made about what kind of follow-on satellite system to build, an updated analysis of user needs must be completed.

Several new approaches and technologies for geostationary satellite meteorology have been suggested in recent years by government, academic, and industry experts. Some of these options may offer the potential for reducing system costs and improving performance in the long term. Examples include moving to an architecture of smaller satellites as well as incorporating various spacecraft and instrument technologies that were not available for the previous spacecraft generation. However, identifying and evaluating the full range of options will require thorough engineering analysis. In addition, past NOAA experience shows that developing new technologies is done most efficiently as a separate line of effort, outside of the operational satellite program. Such an effort would benefit from greater collaboration with NASA, whose expertise and support have, in the past, significantly contributed to the development of NOAA's weather satellite systems.

The longer that NOAA continues without actively considering other options for a future system, the more it risks having to procure additional continuation series satellites, because the availability date for a fully developed new satellite system will slip farther into the future. The potential advantages of advanced technologies and small satellite constellations as well as questions about changing user requirements suggest that alternatives to the present architecture should be seriously considered.

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## Principal Findings

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### Issues in NOAA's Planning to Ensure Continuous GOES Coverage

Based on the best available analysis, the potential for a gap in geostationary satellite weather coverage will be significant in the early years of the next century if procurement of new satellites does not begin soon. Although three satellites in the current series are still in production and scheduled for launch over the next 5 years, designing and producing an entirely new spacecraft would take much longer—approximately 10 years, according to aerospace experts. Accordingly, NOAA plans to procure a continuation series of at least two spacecraft that will carry the same meteorological instruments as the current spacecraft and incorporate only limited technical improvements. NOAA expects this approach to allow for development of the continuation series satellites within 5 years.

Calculating the quantity and need dates for the continuation series satellites is a complex process involving factors that cannot be precisely defined. Although NOAA has determined that it will need the first continuation series satellite in 2002, the actual date that a replacement satellite is launched may be different. A major risk for any satellite program is the chance that a spacecraft launch will fail, necessitating that future planned launches be moved up to try to compensate for the lost spacecraft. Unexpected component failures on operational satellites—such as GOES-8 and GOES-9 have recently experienced—can also advance the need dates for future satellites. Conversely, a string of successful launches and robust, long-lived satellites can significantly delay the need for new satellites. Once a change in needs is identified, scheduling a new launch may be constrained by the unavailability of flight-ready replacement spacecraft, launch vehicles and facilities, or funding to support a launch. Given these risks and uncertainties, NOAA's procurement strategy, which calls for two continuation series spacecraft to be built but includes separate options to build two additional spacecraft, provides a reasonable degree of flexibility to cope with unexpected schedule changes.

We identified several shortcomings in NOAA's spacecraft planning process that, if remedied, could lead to better planning in the future. First, the need for the continuation series arose because planning for a follow-on series has been repeatedly deferred since it was first attempted in 1989. Second, NOAA's official policy for replacing satellites that experience partial failures is unclear, increasing the uncertainty about when replacements will be

needed. Third, NOAA does not have a consistent policy for providing backup in the event of a launch failure. Timely initiation of follow-on planning combined with clearer, more consistent policies for replacing partially failed spacecraft and backing up launches would provide better assurance of meeting future needs with minimal risk.

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### NOAA Is Unprepared to Develop a Next Generation GOES System

In addition to procuring satellites to prevent a gap in coverage, NOAA needs to begin planning for a follow-on program of GOES satellites if it is to avoid continuing to procure additional continuation series satellites in the future. Although several preliminary efforts have been made to study the feasibility of making incremental enhancements to the current meteorological instrument designs, NOAA has no formal program underway to develop a follow-on series. Based on the President's fiscal year 1998 budget, NOAA does not plan to begin a follow-on GOES program until fiscal year 2003 at the earliest.

Current usage of GOES data by weather forecasters suggests that a reexamination of the GOES satellite architecture is warranted. Although requirements have not been formally updated since the GOES-Next satellite series was developed, usage of GOES data has continued to evolve. The current satellite design hosts two meteorological instruments that are devoted to a range of capabilities, some of which are increasing in importance to weather forecasters and others of which remain largely experimental. According to NOAA, limited experience with GOES-Next data makes it difficult to precisely determine which capabilities will be of most value to users in the future. Before a decision can be made about what kind of follow-on satellite system to build, an updated analysis of user needs must be completed.

Once user needs are determined and requirements established, a full range of potential architectural solutions needs to be identified and evaluated. Several new approaches and technologies for geostationary satellite meteorology have been suggested in recent years by government, academic, and industry experts. Some of these options may offer the potential for reducing system costs and improving performance in the long term. Examples include moving to an architecture of smaller satellites as well as incorporating various spacecraft and instrument technologies that were not available for the previous spacecraft generation. NOAA officials involved in GOES acquisition and development agree that these options need to be considered, given that the follow-on GOES program will be subject to cost constraints.



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Identifying and evaluating options will require thorough engineering analysis. In addition, past NOAA experience shows that developing new technologies is done most efficiently as a separate line of effort, outside of the operational satellite program. Such an effort would benefit from greater collaboration with NASA, whose expertise and support have, in the past, significantly contributed to the development of NOAA's weather satellite systems.

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## Matters for Congressional Consideration

Given that options may exist for NOAA to develop a significantly improved follow-on GOES system, the Congress may wish to closely examine the costs and benefits of different approaches for the timing, funding, and scope of the follow-on program. Further, the Congress may also wish to examine NASA's potential role in working with NOAA to support the needs of geostationary weather satellites within NASA's advanced spacecraft technology programs.

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## Recommendations

GAO recommends that the NOAA Administrator ensure that the National Environmental Satellite, Data, and Information Service (NESDIS) clarifies certain of its GOES planning policies. Further, GAO recommends that the Administrator prepare a formal analysis of the costs and benefits of several alternatives for the timing, funding, and scope of the follow-on program. This analysis should be provided to the Congress for its use in considering options for the future of the GOES program. Details of our recommendations are included in chapters 2 and 3.

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## Agency Comments and Our Evaluation

GAO requested comments on a draft of this report from the Secretary of Commerce. The Secretary provided written comments, which are discussed in chapters 2 and 3 and are reprinted in appendix I. The Secretary concurred with GAO's recommendation that certain of its GOES planning policies be clarified. However, the Secretary did not concur with GAO's recommendations that the NOAA Administrator reconsider the agency's decision to defer the follow-on program and prepare a formal analysis of options for such a program. The draft that GAO provided to Commerce was based on its fiscal year 1997 budget, which showed that a GOES follow-on program would begin in 2000. However, the fiscal year 1998 budget request, released since then, shows no follow-on program beginning through 2002. In discussions with GAO, NOAA officials confirmed that a follow-on program is currently not planned until 2003 at the earliest.

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As stated in the report, GAO believes that continued deferral of the follow-on program is risky because it forgoes the opportunity to identify and develop a potentially more effective and economical architecture. Furthermore, the longer that NOAA continues without actively considering other options for a future system, the more it risks having to procure additional continuation series satellites, because the availability date for a fully developed new satellite system will slip farther into the future.

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# Contents

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<b>Executive Summary</b>		2
<b>Chapter 1</b>		12
<b>Introduction</b>	Background	12
	GOES Satellite Development History	14
	GOES-Next Development Problems	17
	Objectives, Scope, and Methodology	18
<b>Chapter 2</b>		21
<b>Issues in NOAA's</b>	NOAA's Strategy for Procuring the Continuation Series	22
<b>Planning to Ensure</b>	Difficulties in Determining When and How Many Continuation	24
<b>Continuous GOES</b>	Series Satellites Will Be Needed	
<b>Coverage</b>	Shortcomings in NOAA's Planning Process	27
	Conclusions	30
	Recommendations	30
	Agency Comments and Our Evaluation	30
<b>Chapter 3</b>		31
<b>NOAA Is Unprepared</b>	NOAA Has Studied Only Incremental Enhancements to the	32
<b>to Develop a Next</b>	Current Architecture	
<b>Generation GOES</b>	Uses of GOES Data Are Evolving	33
<b>System</b>	An Alternative Architecture Could Improve System Flexibility	36
	and Reduce Some Costs	
	Advanced Technology Could Improve Performance	37
	Choosing a Follow-on Design Approach Will Require Thorough	39
	Engineering Analysis	
	Collaborating With NASA Could Help NOAA Develop New	40
	Satellite Capabilities	
	Conclusions	43
	Matters for Congressional Consideration	43
	Recommendations	43
	Agency Comments and Our Evaluation	44
<b>Appendixes</b>	Appendix I: Comments From the Department of Commerce	46
	Appendix II: Major Contributors to This Report	55
<b>Related GAO Products</b>		56
<b>Figures</b>	Figure 1.1: GOES Satellite Coverage	13

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Figure 1.2: GOES 4-7 Satellite Design	15
Figure 1.3: GOES-Next Satellite Design	16
Figure 2.1: Planned GOES Launch Schedule	25

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**Abbreviations**

ATS	Applications Technology Satellite
AVHRR	Advanced Very High Resolution Radiometer
GAO	General Accounting Office
GATES	Geostationary Advanced Technology Environmental System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPS/MET	Global Positioning System/Meteorology
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSIP	Operational Satellite Improvement Program
TIROS	Television and Infrared Observational Satellite

# Introduction

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## Background

The GOES satellite system, which has been operational since 1975, plays a critical role in weather forecasting. The continuous availability of GOES data is vital to the success of NWS' approximately \$4.5 billion systems modernization program. GOES is one of two weather satellite systems operated by NOAA; the other is a system of polar-orbiting satellites.<sup>1</sup> Unlike the polar satellites, geostationary weather satellites are placed into a special orbit that allows them to continuously maintain the same view of the earth's surface.<sup>2</sup> Thus, they are uniquely positioned to observe the development of hazardous weather, such as hurricanes and severe thunderstorms, and track their movement and intensity so that major losses of property and life can be reduced or avoided. Further, the unique ability of geostationary satellites to provide broad, continuously updated coverage of atmospheric conditions over land as well as oceans is very important to NOAA's weather forecasting operations.<sup>3</sup>

NOAA's operating strategy calls for two GOES satellites to be active at all times—one satellite to observe the Atlantic Ocean and the eastern half of the U.S., and the other to observe the Pacific Ocean and the western part of the country. Figure 1.1 shows the coverage provided by two GOES satellites.

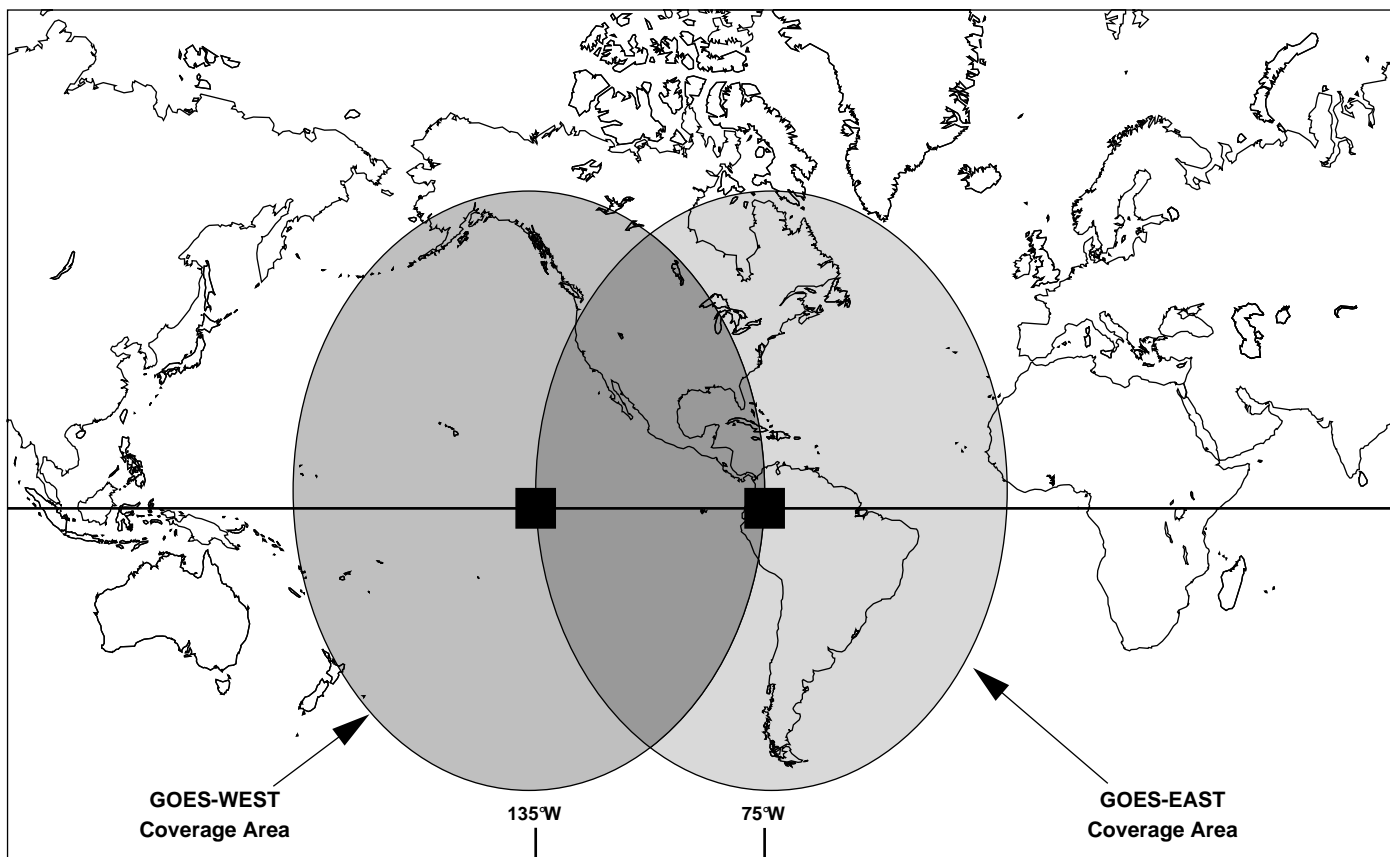
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<sup>1</sup>Polar satellites are launched on a roughly north-south trajectory that takes them over the polar regions of the earth. As the earth turns beneath them, polar satellites observe a different portion of the earth's surface during each orbit. Thus they can provide observations of the weather over any given location, such as the United States, only infrequently.

<sup>2</sup>Geostationary orbits are located approximately 22,300 miles out in space. In contrast, polar satellites orbit at an altitude of about 500 miles.

<sup>3</sup>GOES satellites carry out other secondary missions as well, such as monitoring conditions in the space environment around the earth, relaying data from remote surface-based instruments to NOAA's command and data acquisition stations, and relaying distress signals from aircraft or marine vessels to search and rescue ground stations.

Figure 1.1: GOES Satellite Coverage



Source: NOAA.

GOES satellites have two primary instruments for collecting weather data: an imager and a sounder. The imager is akin to a camera; it collects data in the form of digital images of the earth or some part of it, based on radiation that is sensed at five different spectral wavelengths or “channels,” including four in the infrared range and one that corresponds to visible light. Forecasters use animated sequences of imager data to track the development of various weather phenomena. The sounder is mechanically similar to the imager but receives data much more slowly and is sensitive to a broader range of spectral wavelengths. The sounder’s sensitivity to 19 different channels allows it to collect data on a number of

natural variables, such as temperature and humidity, and attribute those measurements to specific levels of the earth's atmosphere. The data from both the imager and sounder are relayed to a ground station at Wallops Island, Virginia, which processes the data to make them usable by weather forecasters. Then the data are retransmitted back up to the GOES satellites, which broadcast them to the weather forecasting community.

NOAA has never been directly responsible for the design and development of any of its meteorological satellites. Instead, the agency has relied on NASA's expertise in spacecraft design and development. After NOAA defines user requirements for its satellite systems, it turns them over to NASA to contract with industry to design and develop satellites that meet NOAA's needs. NASA launches and tests the satellites, which are subsequently turned over to NOAA to operate. Beginning in the 1970s, NASA had a formal ongoing program, called the Operational Satellite Improvement Program (OSIP), to develop and demonstrate experimental versions of advanced meteorological satellites and instruments. Successful designs from the OSIP program were often incorporated into NOAA's operational satellite systems. OSIP was terminated in 1981 due to budgetary constraints at NASA. However, NASA continues to act as the procurement agent for NOAA's weather satellites.

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## GOES Satellite Development History

Even though GOES satellites have been operational for over 20 years, only one major design change has been implemented. The first generation design was developed and operated experimentally by NASA in the 1960s and early 1970s and subsequently became the basis for the first operational satellites, GOES-1 through GOES-7. Figure 1.2 is an illustration of the first generation design. This series of satellites was "spin-stabilized," meaning that the satellites slowly spun while in orbit to maintain a stable position with respect to the earth. While these satellites operated effectively, they had technical limitations that NOAA wished to eventually overcome. The imager and the sounder on these satellites<sup>4</sup> shared the same telescopic viewing apparatus and could not collect data at the same time. Further, because the satellite was spinning, it had to collect data very slowly, capturing one narrow band of data each time that its field-of-view swung past the earth.<sup>5</sup> A complete set of sounding data, for example, took 2 to 3 hours to collect.

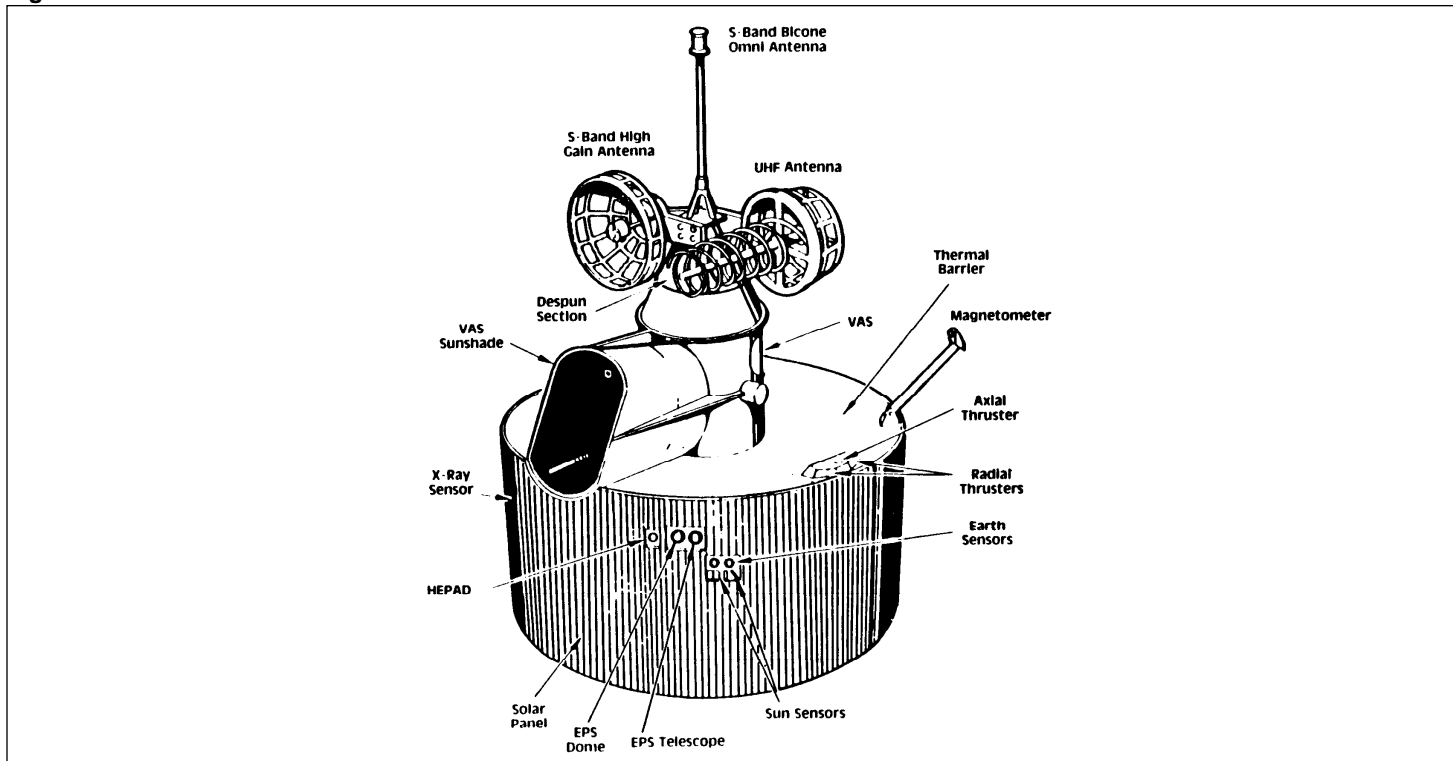
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<sup>4</sup>A sounder was first added to the existing satellite design as an experiment on GOES-4. Sounders have flown on all subsequent GOES satellites.

<sup>5</sup>At a geostationary orbit, the earth would fill only 23 degrees (6 percent) of the satellite's 360 degree rotational view.



Figure 1.2: GOES 4-7 Satellite Design



Source: NASA.

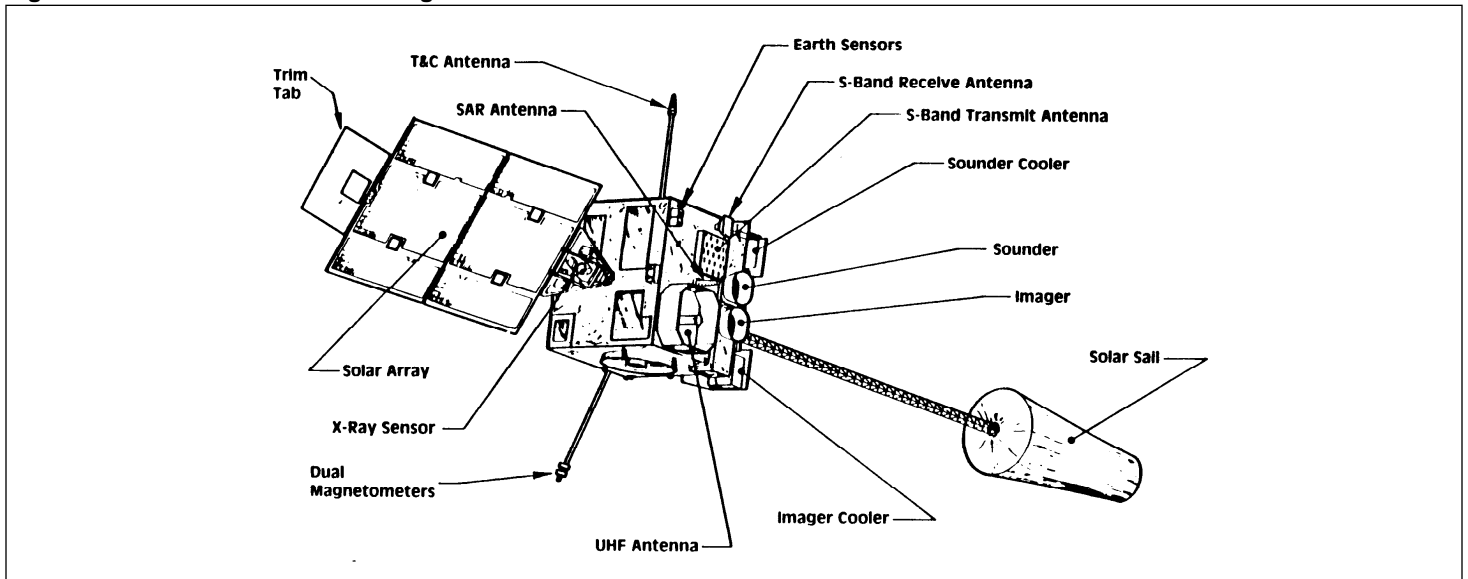
Legend:

- EPS - Electrical Power System
- HEPAD - High Energy Proton and Alpha Detector
- UHF - Ultra High Frequency
- VAS - Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder

In 1982, the National Weather Service (NWS) within NOAA sponsored a review of what new technologies were available and what additional missions could be performed by a new generation of geostationary satellites. The review was supported by NOAA's National Environmental Satellite, Data and Information Service (NESDIS) as well as by NASA's Goddard Space Flight Center and industry representatives. Based on input from these sources, requirements for a new generation spacecraft were developed.

The new spacecraft design, called GOES-Next, was a significant departure from the first generation GOES. For example, GOES-Next was to be “body-stabilized.” This meant that the satellite would hold a fixed position in orbit relative to the earth, allowing for continuous meteorological observations. Instead of maintaining stability by spinning, the satellite would preserve its fixed position by continuously making small adjustments in the rotation of internal momentum wheels or by firing small thrusters to compensate for drift. Further, the imager and sounder would be completely separate, so that they could function simultaneously and independently. These and other enhancements meant that the GOES-Next satellites would be able to collect significantly better quality data more quickly than the older series of satellites. However, the improvements would be made at the expense of a heavier and more complex spacecraft. Figure 1.3 is an illustration of the GOES-Next design.

Figure 1.3: GOES-Next Satellite Design



Source: NASA.

Legend:

SAR - Search and Rescue  
T&C - Telemetry and Command  
UHF - Ultra High Frequency

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## GOES-Next Development Problems

Although GOES-Next represented a complete redesign of NOAA's geostationary satellite system, satellite industry observers told us that the technical risks involved in developing GOES-Next appeared in the early 1980s to be manageable. Polar-orbiting meteorological spacecraft had already evolved from spin-stabilized to body-stabilized designs, and the GOES-Next builder, Ford Aerospace,<sup>6</sup> had already built a body-stabilized geostationary meteorological satellite for India. Furthermore, the instrument manufacturer, ITT Corporation, had proposed designs that were closely based on successful imagers and sounders it was building for NOAA's polar-orbiting satellites. On this basis, NOAA did not authorize and NASA did not require engineering analysis prior to GOES-Next development work.

Despite the spacecraft and instrument design heritage, the GOES-Next program experienced severe technical problems, massive cost overruns, and dangerous schedule delays. Technical issues that had seemed straightforward when the spacecraft design was being conceptualized proved to be substantially more difficult to implement. For example, the original design did not sufficiently take into consideration the harshness of geostationary orbit, which is subject to large daily temperature variations that can stress and warp ordinary materials. Accordingly, the scan mirrors on the instruments had to be completely redesigned using other materials. It was also discovered that it would be very difficult to establish the fine pointing necessary to meet requirements for accurately mapping the satellite's detailed images to their exact position on earth.<sup>7</sup>

These and other problems led to an increase of over 200 percent in NOAA's estimate of the overall development cost of the GOES-next program—from \$640 million in 1986 to \$2.0 billion in 1996. Also, the first launch of a GOES-next satellite, which had been planned for July 1989, did not occur until April 1994. This nearly 5-year schedule slip left NOAA in real danger of temporarily losing geostationary satellite data coverage. Fortunately, due to the exceptional robustness of the last remaining first-generation satellite, GOES-7, as well as the use of a borrowed European satellite, NOAA was able to avoid a gap in coverage. GAO reported in 1991 that design complexity, inadequate management of the program by NASA and NOAA, and poor contractor performance all contributed to the cost, schedule, and

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<sup>6</sup>Now called Space Systems/Loral.

<sup>7</sup>The process of establishing the satellite's exact position and maintaining it through a series of images continues to pose problems for NOAA even as the GOES-Next satellites have become operational.

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technical problems experienced by the GOES-next program.<sup>8</sup> Although some technical problems remain, the first two of these satellites, GOES-8 and GOES-9, are now producing useful, high quality weather data daily.

The GOES-Next contract with Space Systems/Loral is for five spacecraft, designated GOES-I through GOES-M.<sup>9</sup> Once the first two in the series, GOES-I and GOES-J, were successfully launched and placed in orbit, they were redesignated GOES-8 and GOES-9 respectively. The other three spacecraft in the GOES-Next series, GOES-K, GOES-L, and GOES-M, are in various stages of production. The GOES-K spacecraft has been completed and is scheduled for launch in April 1997. If GOES-8 and GOES-9 are still operational then, GOES-K will be stored at a central location in orbit and activated when either of its two predecessors fails. GOES-M and GOES-L are planned to be launched in 2000 and 2002, respectively. GOES-M, which has a stronger frame than the other satellites in the series, will be launched ahead of GOES-L in order to accommodate a new and heavier secondary instrument for measuring the space environment, called the Solar X-ray Imager.

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## Objectives, Scope, and Methodology

In February 1996, the House Committee on Science, Subcommittee on Energy and Environment, requested that we review NOAA's management of the GOES Program. On the basis of subsequent discussions with subcommittee staff, our specific objectives were to assess: (1) the agency's strategy for procuring continuation series satellites, (2) what steps the agency should be taking now to prepare for the next generation series of satellites, and (3) whether the potential exists for improving the system and reducing costs in the long term.

To meet our objectives, we reviewed NOAA and NASA documents regarding GOES historical background, current status, mission operations, spacecraft and instrument improvements, ground systems, future procurement strategies, and proposed technology infusion. We reviewed NASA documents regarding the GOES Project and proposed technology infusion. We reviewed NOAA cost and budget documents and NASA Program Operating Plans. In addition to discussing these issues with agency officials from NOAA and NASA, we met with a broad range of representatives from academia and industry. Staff also attended a 3-day conference on

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<sup>8</sup>Weather Satellites: Action Needed to Resolve Status of the U.S. Geostationary Satellite Program (GAO/NSIAD-91-252), July 24, 1991, p. 3.

<sup>9</sup>Weather satellites are given an alphabetic designation until they are launched; they are then assigned a number in the series.

“GOES-8 and Beyond,” sponsored by the International Society for Optical Engineering.

Specifically, with regard to the continuation series procurement strategy, we obtained and analyzed information from NOAA and NASA satellite acquisition officials. We discussed our analysis and obtained additional information from industry representatives of:

- Hughes Space and Communications Company, El Segundo, California;
- Lockheed Martin Corporation, Sunnyvale, California; and
- Space Systems/Loral, Palo Alto, California.

Regarding what steps the agency should be taking now to prepare for the next generation series of satellites, we obtained information from researchers and other officials at a range of NOAA and NASA facilities, including:

- NOAA System Acquisition Office, Silver Spring, Maryland;
- NOAA NESDIS GOES Program Office, Suitland, Maryland;
- NOAA NESDIS Cooperative Institute for Meteorological Satellite Studies, Madison, Wisconsin;
- NOAA NESDIS Cooperative Institute for Research in the Atmosphere, Ft. Collins, Colorado;
- NOAA NWS Headquarters, Silver Spring, Maryland;
- NOAA NWS Weather Forecast Offices in Sullivan, Wisconsin; Denver, Colorado; and Pueblo, Colorado;
- NOAA Forecast Systems Laboratory, Boulder, Colorado;
- NWS Cooperative Program for Operational Meteorology, Education, and Training, Boulder, Colorado; and
- NASA GOES Project Office, Goddard Space Flight Center, Greenbelt, Maryland.

Regarding the potential for improving the GOES system while reducing costs in the long run, we began by obtaining information from NOAA and NASA officials at the sites listed above. We analyzed this information and sought additional input from representatives of industry and academia, including:

- Aerospace Corporation, El Segundo, California;
- Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland;
- Ball Aerospace & Technologies Corporation, Boulder, Colorado;
- Hughes Space and Communications Company, El Segundo, California;

- Lockheed Martin Corporation, Sunnyvale, California;
- MITRE Corporation, McLean, Virginia;
- National Research Council, Washington, D.C.;
- Northrop Grumman Corporation, Baltimore, Maryland;
- Space Systems/Loral, Palo Alto, California;
- TRW Space and Electronics Group, Redondo Beach, California; and
- University Corporation for Atmospheric Research, Boulder, Colorado.

We were unable to perform a detailed audit of the cost of the continuation series and next generation satellites because cost information was unavailable. A budget figure of \$2.2 billion for a program to build four spacecraft had been estimated within NOAA for the fiscal year 1997 budget. However, during our audit, NOAA restructured the program and its procurement strategy on two different occasions, each of which resulted in different cost estimates. At the time we concluded our review, NOAA's System Acquisition Office, which will manage the continuation series procurement, did not have an official estimate for the overall cost of the program.

We conducted our review from March 1996 through February 1997, in accordance with generally accepted government auditing standards. We requested written comments on a draft of this report from the Secretary of Commerce. The Secretary provided us with written comments that are discussed in chapters 2 and 3 and are reprinted in appendix I.

# Issues in NOAA's Planning to Ensure Continuous GOES Coverage

Based on the best available analysis, the potential for a gap in geostationary satellite weather coverage will be significant in the early years of the next century if procurement of new satellites does not begin soon. Although three satellites in the current series are still in production and scheduled for launch over the next 5 years, designing and producing an entirely new spacecraft would take much longer—approximately 10 years, according to aerospace experts. Accordingly, NOAA plans to procure at least two “continuation series”<sup>1</sup> spacecraft that will carry the same meteorological instruments as the current spacecraft and incorporate only limited technical improvements. NOAA expects this approach to allow for development of the new spacecraft within 5 years.

Calculating the quantity and need dates for the continuation series is a complex process involving factors that cannot be precisely defined. Although NOAA has determined that it will need the first continuation series satellite in 2002, the actual date that a replacement satellite is launched may be different. According to NOAA officials, a major risk for any satellite program is the chance that a spacecraft launch will fail, necessitating that future planned launches be moved up to try to compensate for the lost spacecraft. Unexpected component failures on operational satellites—such as GOES-8 and GOES-9 have recently experienced—can also advance the need dates for future satellites. Conversely, a string of successful launches and robust, long-lived satellites can significantly delay the need for new satellites. Once a change in needs is identified, scheduling a new launch may be constrained by the unavailability of flight-ready replacement spacecraft, launch vehicles and facilities, or funding to support a launch. Given these risks and uncertainties, NOAA's procurement strategy, which calls for two continuation series spacecraft to be built but includes separate options to build two additional spacecraft, provides a reasonable degree of flexibility to cope with unexpected schedule changes.

We identified several shortcomings in NOAA's spacecraft planning process that, if remedied, could lead to better planning in the future. First, the need for the continuation series arose because planning for a follow-on series has been repeatedly deferred since it was first attempted in 1989. Second, NOAA's official policy for replacing satellites that experience partial failures is unclear, increasing the uncertainty about when replacements will be

<sup>1</sup>NOAA does not have an official name for this series of satellites. During our audit, NOAA officials originally referred to the series as “clones.” Later, after revising their procurement strategy, they referred to them as “gap fillers.” In comments on a draft of the report, the Department of Commerce objected to the use of the term “gap fillers.” Accordingly, we have adopted the phrase “continuation series” for our final report.

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needed. Third, NOAA does not have a consistent policy for providing backup in the event of a launch failure. More consistent policies for replacing partially failed spacecraft and backing up launches would provide better assurance of meeting future needs with minimal risk.

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## NOAA's Strategy for Procuring the Continuation Series

In order to procure continuation series spacecraft quickly, NOAA plans to minimize design changes from the current series. The same meteorological instruments as the current series will be used, and the spacecraft itself (called the spacecraft "bus") will be very similar. According to government and industry officials, limiting the amount of new design work should make an accelerated procurement feasible. NOAA, working through NASA, its procurement agent, has already negotiated a contract with the instrument manufacturer, ITT Corporation, to deliver up to four additional sets of GOES imagers and sounders to be flown on the continuation series satellites. NOAA and NASA also plan to soon issue a Request for Proposals for two to four spacecraft busses and expect several manufacturers to submit bids. In most cases, bids are likely to be based on modified versions of standard spacecraft busses that manufacturers have developed to satisfy commercial needs for geostationary communications satellites. NOAA and NASA plan to negotiate a firm fixed-price contract with the winner of the spacecraft bus competition.

Although the instruments on the continuation series spacecraft will be identical to those currently in use, the spacecraft busses will not. The current spacecraft bus, which was designed by Space Systems/Loral in the mid 1980s, has never been able to fully meet NOAA's original GOES-Next specifications for spacecraft pointing. Designing the spacecraft to point very precisely at the earth and maintain that precise orientation is important because it allows the data collected by the instruments, especially the imager, to be mapped very accurately to their exact location on the surface of the earth. Because the GOES-Next spacecraft has been unable to achieve the originally required precision, extra work routinely needs to be done by spacecraft operators to correct for errors in mapping GOES data to its proper position over the earth's surface. According to NASA and NOAA officials, improvements in pointing accuracy made in commercial spacecraft busses since the time that the GOES-Next design was finalized will better meet original GOES-Next specifications and are expected to be incorporated into the continuation series spacecraft.

Other, relatively minor improvements are expected in the spacecraft busses as well. For example, an improved power system, based on more



recent battery technology, should reduce certain brief observation gaps that occur periodically with the current design.

NOAA considered several other approaches before arriving at its current procurement strategy. Originally, NOAA intended to procure four or five additional "clones" of the current spacecraft from Loral on a sole-source basis. The clones would have been largely identical to the current spacecraft, using new parts only in cases where original parts were no longer available. However NASA and NOAA officials jointly concluded that the government would not be justified in avoiding a competitive procurement, and this strategy was dropped. NOAA then considered buying just one or two clones from Loral, to be followed by a competitive procurement for a continuation series. In September 1996, we reported that significant cost savings were not expected from the sole-source clone procurement and that requirements for a follow-on system had not been determined.<sup>2</sup> Because of concerns raised by ourselves and others, NOAA eventually also abandoned this second strategy.

NOAA's current strategy has advantages over earlier approaches that involved buying clones of the GOES-Next spacecraft. As discussed above, procuring a new spacecraft bus will allow NOAA to take advantage of technical improvements that have already been developed for commercial customers, such as greater pointing accuracy and a more capable power subsystem. In addition, use of a competitively awarded, firm fixed-price contract can be expected to help control or reduce costs.

While moving to a fully competitive procurement approach for the continuation series, NOAA is also planning to reserve the option to obtain an additional satellite in the current series in the event that one is needed before the first satellite in the continuation series can be completed. To do this, NOAA and NASA are negotiating a "warranty option" as an extension to the current contract with Space Systems/Loral. Under this arrangement, NASA will contract with Loral to procure necessary long-lead time parts so that it is ready to build an extra spacecraft of the current type, if such a spacecraft is needed due to (1) the premature failure of either GOES-8 or GOES-9, which were designed to last 5 years each, or (2) a launch failure of the GOES-K spacecraft in April 1997. Should either of these occur, NOAA plans to advance the launches of GOES-L and GOES-M and subsequently launch the warranty spacecraft to ensure continuity until the first continuation series spacecraft is available. NOAA and NASA will determine

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<sup>2</sup>NOAA Satellites (GAO/AIMD-96-141R, September 13, 1996).

by mid-1998 whether to exercise this warranty option and complete construction of the additional spacecraft.

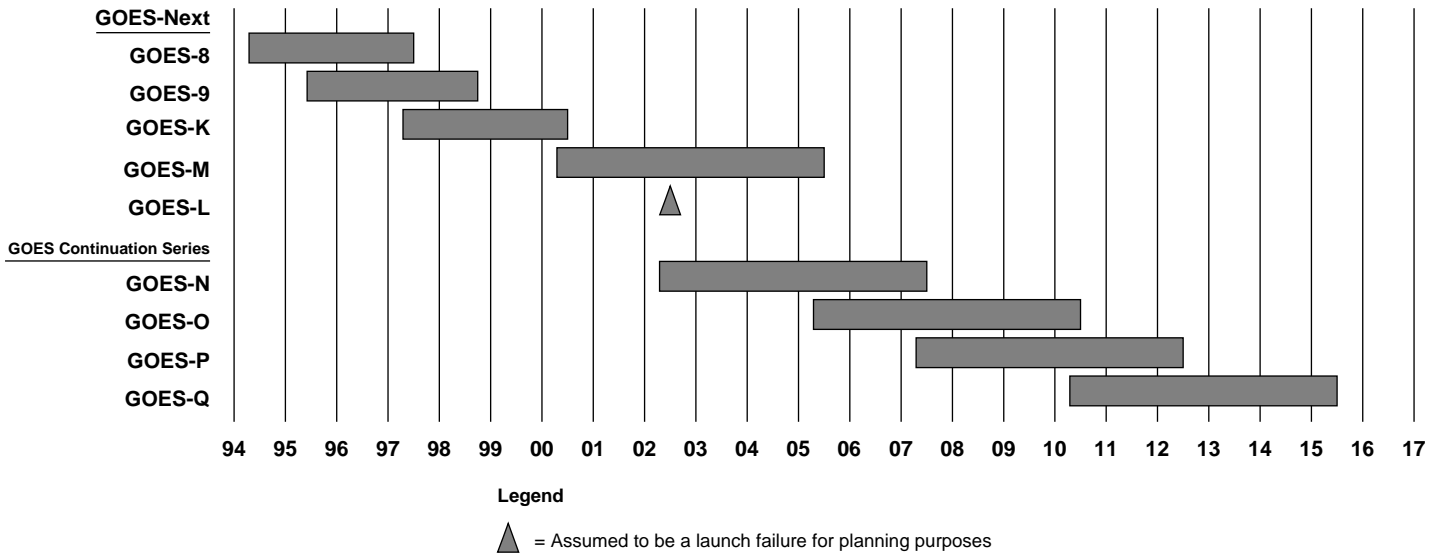
NOAA does not yet know what the continuation series will cost. A budget figure of \$2.2 billion for a program to build four spacecraft had been estimated within NOAA for the fiscal year 1997 budget. However, as discussed above, NOAA restructured the program and its procurement strategy on two different occasions, each of which resulted in different cost estimates. At the time we concluded our review, NOAA's System Acquisition Office, which will manage the continuation series procurement, did not have an official estimate for the overall cost of the program.

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## Difficulties in Determining When and How Many Continuation Series Satellites Will Be Needed

Calculating the quantity and need dates for the continuation series satellites is a complex process involving factors that cannot be precisely defined. Although NOAA has determined that it will need the first one in 2002, the actual date that a replacement satellite is launched may be different. Figure 2.1 shows NOAA's planned GOES launch schedule. A major risk for any satellite program is the chance that a spacecraft launch will fail, necessitating that future planned launches be moved up to try to compensate for the lost spacecraft. Unexpected component failures on operational satellites—such as GOES-8 and GOES-9 have recently experienced—can also advance the need dates for future satellites. Conversely, a string of successful launches and robust, long-lived satellites can significantly delay the need for new satellites. Once a change in needs is identified, scheduling a new launch may be constrained by the unavailability of flight-ready replacement spacecraft, launch vehicles and facilities, or funding to support a launch. Given these risks and uncertainties, NOAA's procurement strategy, which calls for two spacecraft to be built but includes separate options to build two additional spacecraft, provides a reasonable degree of flexibility to cope with unexpected schedule changes.

Figure 2.1: Planned GOES Launch Schedule



Source: NOAA.

The risk of launch failure is significant in any spacecraft program. NOAA and NASA officials have told us that a failure rate of one in five launches is a reasonable estimate for the GOES program. NOAA has factored this risk into its launch schedule by designating the GOES-L launch in 2002 as a “planned failure.” GOES-L will be the fifth and last in the current (GOES-Next) series. Because NOAA assumes for planning purposes that the GOES-L launch will fail, it is planning to have the next spacecraft (the first in the continuation series) ready for launch at the same time. NOAA officials told us that it is especially important to plan for the next spacecraft to be available at the same time as GOES-L is launched because it will be the first in a new series and may be vulnerable to schedule delays because of development problems. Conservatively scheduling its launch at the same time as GOES-L is one way to try to compensate for the risk of development delays. However, the success of other launches, especially the launch of GOES-K in April 1997, will also be of critical importance. If the GOES-K launch were to fail, NOAA could risk a gap in coverage between 1998 and 2000. NOAA GOES program officials told us that if this situation were to occur, they would

attempt to move up the GOES-L or GOES-M launches to reduce the length of the coverage gap.

Unexpected component failures are another source of risk to the launch schedule. GOES-8 and GOES-9, for example, are now expected to operate for only 3 years, due to several technical problems that were unforeseen when they were launched. The two satellites were launched in April 1994 and May 1995, respectively, and had been designed to last 5 years each. The most serious of the technical problems is a tendency of the motor windings within the satellites' meteorological instruments to break due to thermal stress.<sup>3</sup> Each of the satellite's two instruments has a primary and a backup motor winding. If both windings fail, the instrument cannot operate. The 3-year lifetime for GOES-8 and GOES-9 was determined in mid 1996 after one winding (out of a total of four) had already failed on each spacecraft. If the revised predictions for the lifetimes of GOES-8 and GOES-9 are accurate, NOAA runs the risk of having only one operational satellite (GOES-K, assuming it is successfully launched in April 1997) between 1998 and 2000. As described above for launch failures, if this situation were to occur, NOAA officials would attempt to move up the GOES-L or GOES-M launches to reduce the length of the coverage gap. They would also likely exercise the warranty option on the GOES-Next contract to ensure continuity until the first continuation series satellite were available.

Although it is possible to move up scheduled launches, NOAA officials say that it is difficult to do so for several reasons. First, the spacecraft itself must be ready for launch at the earlier date, which may not be practical if integration and ground testing have not been completed well in advance of the previously anticipated launch date. Second, only a limited number of commercial launch opportunities (usually six) are available each year for the Atlas launch vehicle that GOES spacecraft are designed to use.<sup>4</sup> Most, if not all, of those launch opportunities are reserved far in advance. In order to move a launch forward, NOAA officials need to be able to find another scheduled launch that can be deferred and replaced by the GOES spacecraft. Third, it may be difficult to move a launch forward from one fiscal year to another because funding may not be available to support a launch. NOAA officials told us that a GOES launch costs approximately

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<sup>3</sup>Other technical problems have arisen as well. Some of GOES-8's electronic components have been damaged by electrostatic discharge, prompting the installation of additional shielding on the rest of the GOES-Next spacecraft. GOES-8 also experienced a failure within its attitude stabilization system, which is being compensated for through redundant components.

<sup>4</sup>NOAA's policy is to use commercial launch services wherever possible.

\$25 million (not including the cost of the Atlas IIA launch vehicle itself, which is approximately \$80 to 90 million).

Because of the many uncertainties in its planned launch schedule, NOAA has not made a final determination of how many satellites in the continuation series it will procure. The possibility of exercising the warranty option on the current GOES-Next contract, in addition to the chance that the existing satellites will last longer than 3 years and that none of the planned launches will fail, are all factors that could delay the need date for the first continuation series spacecraft, either singly or in combination. Conversely, NOAA's current predictions for satellite lifetimes and launch failures could hold true, in which case the first continuation series spacecraft would be needed in 2002.

The number of continuation series satellites needed also depends on when the potential for a coverage gap ends. The potential gap will end whenever the first of a new, follow-on series of satellites is available for deployment. As stated earlier, government and industry aerospace experts agree that it takes approximately 10 years to develop a new spacecraft system. If work were begun in 1998, the first spacecraft in a new GOES series would, therefore, be ready in about 2008 and could be launched as the GOES-Q spacecraft. (See figure 2.1.) Under this scenario, three continuation series satellites would be needed (GOES-N, -O, and -P). If satellites in the current series last longer than NOAA expects, or the expected launch failure does not occur, NOAA's schedule could easily slip one or two years for the later launches. In that situation, only two continuation series satellites might be needed.

NOAA's planned continuation series contract will be for two spacecraft with two separate options for one additional spacecraft each. Thus, as few as two or as many as four spacecraft may be procured through this contract. Given the uncertainties in the launch schedule, NOAA's flexible procurement strategy is reasonable.

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## Shortcomings in NOAA's Planning Process

We identified several shortcomings in NOAA's spacecraft planning process that, if remedied, could lead to better planning in the future. First, the need for the continuation series exists now only because planning for a follow-on series has been repeatedly deferred since it was first attempted in 1989. Second, NOAA's official policy for replacing satellites that experience partial failures is unclear, increasing the uncertainty about when replacements will be needed. Third, NOAA does not have a consistent

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policy for providing backup in the event of a launch failure. Timely initiation of follow-on planning combined with clearer, more consistent policies for replacing partially failed spacecraft and backing up launches would provide better assurance of meeting future needs with minimal risk.

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## Follow-on Planning Has Been Deferred

NOAA officials have recognized for many years that a follow-on program to GOES-Next would have to be started early in order to avoid facing a potential gap in coverage. In 1989, NOAA commissioned a working group to identify requirements for a follow-on system. A list of requirements was developed and turned over to NASA in May 1989 for an assessment of architectural options for a follow-on GOES program. Specifically, NOAA asked that NASA examine options for modifying the GOES-Next system to improve efficiency, reduce costs, and satisfy the new requirements. In response, NASA examined a range of three architectural options and presented its results in October 1990. NASA's final report indicated that the study had been very limited, both by resources<sup>5</sup> and by the restriction of only looking at modifications to the GOES-Next architecture. NASA recommended that a more thorough study be conducted and that development work be immediately begun on the more challenging technical features of its design options. However, no further resources were committed to this line of effort.

Since 1990, NOAA officials involved in the GOES program have made several attempts to initiate a follow-on program but have not received agency approval to move forward. An internal presentation delivered in March 1993 proposed studying a number of alternative approaches to the current GOES architecture, including flying low-cost weather cameras as secondary payloads on non-NOAA geostationary satellites. The presentation stressed the need to begin a formal study phase in fiscal year 1996 in order to have sufficient time to develop and implement a new architecture by 2008. Another presentation made in April 1995 also urged that engineering studies be conducted early in order to meet tight time frames. Both the 1993 and 1995 presentations assumed that several additional spacecraft in the GOES-Next series would be procured before the first follow-on satellite would be ready in 2008. Program officials told us that, faced with budget constraints, NOAA did not act on any of the recommendations of these studies.

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<sup>5</sup>NOAA and NASA estimates for the cost of a thorough study ranged from \$3 to \$6 million; however, NASA received only \$1.56 million to conduct the study.

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## Satellite Replacement Policy Is Unclear

NOAA's official policy for replacing partially failed satellites is unclear. The stated policy has been to launch and activate a replacement satellite if either of the two primary meteorological instruments (the imager or the sounder) fails on either of the two operational spacecraft. However, according to NASA and NOAA officials, it is not certain that a replacement would actually be launched in the event of a sounder failure, since sounder data is less critical than imager data. (Use of sounder data is discussed at greater length in chapter 3.) Also, no official criteria exist for launching a replacement satellite if other partial failures were to occur. For instance, a detector failure in a satellite's imager could reduce the number of channels that it uses to collect data. Such a reduction may or may not be cause to replace the satellite. NOAA officials told us that they prefer to exercise judgement on a case-by-case basis as specific failures occur. However, the lack of explicit criteria for replacement makes it more difficult to forecast how soon new satellites are most likely to be needed.

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## Launch Backup Policy Is Arbitrary

As discussed above, all spacecraft programs have to address the risk of launch failure. However, NOAA's approach of designating certain launches as "planned failures" and providing backup spacecraft for only those launches is arbitrary, because NOAA does not know in advance which launches will actually fail. In other words, the risk of a launch failure is no greater for the "planned failure" than for any of the other launches, which do not have specifically designated backups. Although NOAA's approach is effective in putting an extra spacecraft into the production stream to compensate for a launch failure, it is ineffective in providing backup for each launch. An alternative approach would be to schedule each launch to be backed up by the next spacecraft in the production stream. Such an approach would not require procurement of any additional spacecraft or launch vehicles and would enhance NOAA's ability to compensate for launch failures by planning to have spacecraft always available for backup launches.

According to NOAA satellite acquisition officials, the GOES program originally included the concept of maintaining an on-orbit spare in addition to the two operational satellites. The spare would be maintained in a central position and then moved either east or west to replace the first operational satellite that failed. As soon as possible after the on-orbit spare was activated, a new spare would be launched. If both GOES-8 and GOES-9 are still operating in April 1997 when GOES-K is launched, it will be put into on-orbit storage in the central location for up to 2 years. However, aside from this particular case, NOAA has not decided to move to this method of

backup. Among aerospace experts, on-orbit storage of satellites is controversial. Although the practice can reduce the risk of a break in satellite coverage, other risks are incurred in the process of storing a spacecraft in orbit that could reduce its capabilities once it is activated. For example, a satellite stored in orbit would be susceptible to the possibility of radiation damage that it would not face if it were stored on the ground. In our opinion, further analysis of this strategy is necessary before it is adopted on an ongoing basis.

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## Conclusions

Given the importance of maintaining continuous geostationary weather coverage, NOAA's decision to immediately begin procuring two to four continuation series spacecraft through a competitively bid, firm fixed-price contract is reasonable. The planned procurement has been designed to be flexible enough to deal with the uncertainties of determining exactly how many satellites to buy and when they need to be available. However, the continuation series became necessary because a follow-on program had been repeatedly deferred since 1989. Such a program must be initiated soon if the number of continuation series satellites is to be kept to a minimum. Clarifying official policies for replacing partially failed spacecraft and backing up planned launches could improve program planning for the future.

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## Recommendations

We recommend that the NOAA Administrator ensure that the National Environmental Satellite, Data, and Information Service (NESDIS) (1) clarifies official criteria for activating replacement spacecraft in the event of a failure of an operational GOES satellite or any of its instruments or subsystems and (2) reexamines the agency's strategy for anticipating possible launch failures and considers scheduling backups for all future launches.

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## Agency Comments and Our Evaluation

The Secretary of Commerce concurred with the recommendations that appear in this chapter but objected to our use of the term "gap filler" to refer to the GOES-N, O, P, and Q satellites in the draft report. Accordingly, we have used the term "continuation series" to refer to these satellites in the final report.



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# NOAA Is Unprepared to Develop a Next Generation GOES System

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In addition to procuring satellites to prevent a gap in coverage, NOAA needs to begin planning for a follow-on program of GOES satellites if it is to avoid continuing to procure additional continuation series spacecraft in the future. Although several preliminary efforts have been made to study the feasibility of making incremental enhancements to the current meteorological instrument designs, NOAA has no formal program underway to develop a follow-on series. Based on the President's fiscal year 1998 budget, NOAA does not plan to begin a follow-on GOES program until fiscal year 2003 at the earliest.

Current usage of GOES data by weather forecasters suggests that a reexamination of the GOES satellite architecture is warranted. Although requirements have not been formally updated since the GOES-Next satellite series was developed, usage of GOES data has continued to evolve. The current satellite design hosts two meteorological instruments that are devoted to a range of capabilities, some of which are increasing in importance to weather forecasters and others of which remain largely experimental. According to NOAA, limited experience with GOES-Next data makes it difficult to precisely determine which capabilities will be of most value to users in the future. Before a decision can be made about what kind of follow-on satellite system to build, an updated analysis of user needs is necessary.

Once user needs are determined and requirements established, a full range of potential architectural solutions needs to be identified and evaluated. Several new approaches and technologies for geostationary satellite meteorology have been suggested in recent years by government, academic, and industry experts. Some of these options may offer the potential for reducing system costs and improving performance in the long-term. Examples include moving to an architecture of smaller satellites as well as incorporating various spacecraft and instrument technologies that were not available for the previous spacecraft generation. NOAA officials involved in GOES acquisition and development agree that these options need to be considered, given that the follow-on GOES program will be subject to cost constraints.

Identifying and evaluating options will require thorough engineering analysis. In addition, past NOAA experience shows that developing new technologies is done most efficiently as a separate line of effort, outside of the operational satellite program. Such an effort would benefit from greater collaboration with NASA, whose expertise and support have, in the past, significantly contributed to the development of NOAA's weather

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satellite systems. NOAA and NASA are both likely to find it difficult to fund extensive engineering analysis or technology demonstration projects.

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## NOAA Has Studied Only Incremental Enhancements to the Current Architecture

Based on the President's fiscal year 1998 budget, NOAA does not plan to begin a follow-on GOES program until fiscal year 2003 at the earliest. Agency officials told us that, lacking a formal follow-on program, NOAA's primary ongoing efforts related to future planning for the GOES system are described in the GOES I-M Product Assurance Plan. Most of the plan addresses efforts to assess and improve the utilization of data from the current GOES satellites in order to maximize the return on the investment made in developing GOES-Next. The plan also discusses goals and potential capabilities for a follow-on system, concentrating on proposed incremental improvements to the current system, including enhancements to both the imager and sounder. The plan also suggests the need for additional instruments. However, none of these possible improvements has yet been funded for production.

In accordance with the plan, NOAA funded some research at the Massachusetts Institute of Technology's (MIT) Lincoln Laboratory and at ITT, the current manufacturer of the imager and sounder, to test potential incremental enhancements to both instruments. One possible enhancement would change the way the GOES sounder processes the radiance signal it receives from the earth, allowing that signal to be divided into a much greater number of discrete spectral bands. The larger number of bands would allow extrapolation of more information about the temperature, humidity, and pressure of the atmosphere over a given spot on the earth's surface. The device that would do this spectral separation, called an interferometer, was originally designed and demonstrated on aircraft flights in the mid 1980s. Although NOAA spent several million dollars for engineering studies of the interferometer at MIT Lincoln Laboratory and at ITT, it recently decided not to continue development of the device.

The second potential enhancement would change the configuration of the imager to speed up its operation. However, a faster imager would produce a larger data stream than the current space-to-ground communications system can handle. Because it would necessitate changes in other systems, this enhancement has also not been approved by NOAA.

The GOES I-M Assurance Plan also suggests the possible need for two new instruments, a lightning mapper and a microwave sounder, in the

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next-generation system. The lightning mapper could improve severe weather monitoring, while the microwave sounder would allow sounder data to be collected through cloud cover, which the current sounder cannot do. No engineering analysis has yet been done on the lightning mapper. NOAA commissioned a preliminary engineering study of the microwave sounder from MIT's Lincoln Laboratory, which is due in March 1997.

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## Uses of GOES Data Are Evolving

NOAA is not yet in a position to make decisions about what kind of follow-on satellite system to build because its future needs are not yet well understood. NOAA has not conducted a formal revision or update of user requirements since 1989. However, recent positive experience with GOES-8 and GOES-9 has led to increasing demands for imager data. Data from the GOES sounders, on the other hand, is in less demand because it has seen little operational use. Changing the follow-on GOES architecture to facilitate greater collection of imager data and deemphasize sounder data might better serve user needs.

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## Official User Requirements Have Not Been Updated

Current GOES user requirements were established in 1983 and have not been formally revised since 1989. In 1994, just after the launch of the first of the GOES-next satellites, a NWS draft document identified potential requirements for a next-generation GOES system. However, this document was never finalized because NOAA officials wanted to wait for the chance to evaluate the utility of the enhanced data from GOES-next satellites before specifying requirements for future systems. To this end, an assessment group was formed and a strategy for evaluating GOES-next data was developed. Although assessment results for the first year have now been collected from users, NWS officials estimate that it will take from 2 to 3 more years to complete the study because of delays in the implementation of the NWS' new Advanced Weather Interactive Processing System, which is needed by forecasters to properly display GOES-next data, and because many forecasters have not yet been trained in how to make best use of the enhanced data.<sup>1</sup>

NOAA has undertaken several other activities that could help in defining requirements for a follow-on series. For example, in developing the GOES I-M Product Assurance Plan, NOAA researchers suggested possible needs for future spacecraft capabilities. Also, a 2-day conference held in 1994

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<sup>1</sup>For a further discussion of the Advanced Weather Interactive Processing System, see *Weather Forecasting: NWS Has Not Demonstrated That New Processing System Will Improve Mission Effectiveness* (GAO/AIMD-96-29), February 29, 1996.

invited experts from NOAA's research and operations community to consider future requirements for GOES. However, because NOAA has neither given formal programmatic endorsement to establishing future GOES requirements nor set aside resources to conduct this activity, requirements for the follow-on series remain undefined.

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### Requirements for Imager and Sounder Data Appear To Be Changing

Although the full range of GOES-Next capabilities is still not available to all local weather forecasters, many have access to at least some enhanced GOES-Next products, processed from data collected by the imager. Several significant new uses of GOES imager data have already been developed. For example, imager data have been used in combination with Doppler radar data to enhance winter snowstorm forecasting in the Great Lakes region, allowing local forecast offices to closely monitor the development, orientation, and movement of "lake effect" snow bands, formed when relatively cold air sweeps across the warmer Great Lakes. Forecasters have also discovered that combining data from two of the imager's infrared channels allows them to detect fog at night, a new capability that had not been planned when the imager was designed. This capability has helped forecasters in the West give advance warning to airports of the likelihood of early morning fog that could affect the startup of flight operations.

According to NOAA and NASA officials, many forecasters would also like to see an increased availability of "rapid scan" images of severe weather activity, such as thunderstorms and hurricanes. Rapid scan images are collected at short time intervals—every few minutes—so that a rapidly evolving storm can be carefully monitored and its direction and severity predicted. Since accurate prediction of severe weather is a critical activity for the NWS, there is high demand for rapid scan data when severe weather develops. However, GOES imagers cannot simultaneously produce rapidly updated imagery of storm activity within the continental United States and also collect a full set of data from the rest of the western hemisphere, which is important for routine weather forecasting. The conflicting demands for close-up (or "mesoscale") views of severe storms and broad (or "synoptic") views of hemispheric weather patterns are difficult to resolve. As a result, NOAA researchers see a coming need for significantly more data than the current GOES-Next imager can produce.

In contrast, usage of GOES-Next sounder data has not progressed as rapidly and remains largely experimental. Although sounder data from polar satellites is routinely used in preparing near-term weather forecasts,

geostationary sounder data were never used on a daily basis in the numerical prediction models that provide the basic guidance to NWS forecasters until very recently.<sup>2</sup> The sounder on GOES-4 through GOES-7 was very slow and could not be used at the same time as the imager. As a result, sounder data were used only for special experiments. With the advent of GOES-8 in 1994, continuous geostationary sounder data has been available for the first time. However, as stated above, these data are available mainly to researchers. Most weather forecasters have had no direct exposure to GOES sounder data.

NOAA researchers are investigating a number of promising uses for GOES sounder data. For example, studies performed at the University of Wisconsin have shown that precipitation forecasts and hurricane landfall predictions can be improved by using temperature and moisture data from the sounder in conjunction with the imager data that is traditionally used for such predictions. Although key NOAA officials believe sounder data will grow in importance in the future, the degree of added value that the sounder could contribute to NWS' prediction models has been difficult to determine. Some researchers believe the data could significantly improve forecasts, while others believe the improvement would be only marginal. Meteorologists at the National Centers for Environmental Prediction, which run the prediction models that guide NWS forecasters, had been hesitant to put the sounder data into operational use until they completed their own evaluations. However, they now plan to begin incorporating GOES sounder data into their standard prediction models by the middle of 1997.

Given that experience with this data has been limited, it is difficult to determine how valuable sounder data may be in the future. In contrast, the well-defined utility of imager data for critical forecasting activities and the need for additional imager data suggest that the mix of instruments to be flown on future GOES satellites should be re-examined. An architecture that would facilitate a greater collection of imager data and deemphasize sounder data might better serve user needs. A formal update of user requirements is needed before the potential advantages of alternative architectures can be fully assessed.

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<sup>2</sup>Beginning in February 1997, measurements of precipitable water from the GOES sounder have been included in the input to the numerical prediction models.

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## An Alternative Architecture Could Improve System Flexibility and Reduce Some Costs

According to GOES program officials, current GOES satellites are more expensive to launch and operate than the earlier generation of satellites. When NOAA developed the current generation, it moved from a relatively small and easy to operate spacecraft to one that is larger and much more complex. The newer satellites require a more expensive launch vehicle because they are larger and heavier than the first generation satellites. Furthermore, more extensive ground support is required to keep the spacecraft operating. These factors contribute to increased costs.

Aerospace experts in industry and academia have identified a variety of options for attempting to reduce the costs of weather satellite systems such as GOES. For example, a number of studies have been done of alternative architectures based on smaller satellites carrying fewer instruments, which would have the potential to reduce launch and production costs. In the case of GOES, an architecture based on smaller satellites carrying one critical meteorological instrument instead of two could be considered. According to a recent study supported by NASA and the Department of Defense, cost reduction occurs predominantly, although not entirely, in small spacecraft, which tend to be inherently simpler and cost less than large spacecraft.<sup>3</sup> Further, a smaller spacecraft would not need as large a launch vehicle as the current GOES system uses. Currently, GOES satellites are launched on Atlas IIA vehicles, which cost \$80 to \$90 million each. Smaller satellites could be designed to use Delta vehicles, for example, which currently cost \$45 to \$50 million apiece, or perhaps an even smaller vehicle. While the actual cost of launching a smaller GOES satellite 10 or more years from now cannot be determined, it is likely to continue to be cheaper than the launch cost for a large satellite.

A recent study by the Applied Physics Laboratory of Johns Hopkins University shows that a small spacecraft architecture can increase the flexibility of the system to respond to failures and, in doing so, potentially reduce costs relative to an architecture based on larger satellites. For example, in the GOES system, failure of an instrument or a critical subsystem on one of the current spacecraft would likely necessitate the launch of a replacement, even though the original spacecraft might still retain some capabilities. If a smaller satellite architecture were used, in which each spacecraft would have only one primary meteorological instrument, the failure of an instrument would not affect the operations of the instruments flying on other spacecraft. Similarly, the failure of a critical subsystem, such as the communications or power subsystems,

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<sup>3</sup>James R. Wertz and Wiley J. Larson, eds., *Reducing Space Mission Cost* (Microcosm Press, Torrance, CA: 1996), p. 10.

would only affect one instrument instead of two. Thus the overall robustness of the system would be enhanced.

Based on discussions with NOAA, NASA, and academic experts, it appears that a smaller satellite architecture could also provide greater flexibility in the deployment of meteorological instruments. Currently, imagers and sounders are always deployed in pairs (one set per satellite) so that an operational constellation of a pair of instruments in both the east and west locations can be maintained. Flying the instruments on separate spacecraft would allow greater flexibility to position individual instruments in orbital locations where they are most needed and to change the locations of specific instruments in the event of a spacecraft failure or other emergency. It could also allow deployment of differing numbers of imagers and sounders to meet changing user needs.

Making a decision about this or any other alternative architecture is not a simple task. Clearly, there are drawbacks to the small satellite architecture as well as advantages. Using such an architecture could require significantly more spacecraft launches, for example, even though the launch vehicles used would be smaller. The increased launch workload would have to be manageable by available launch facilities and ground crews. Ground operations, though possibly simplified for each spacecraft, would have to handle a larger total number of spacecraft. Also, the secondary instruments currently flown on GOES satellites would have to be accounted for, either within the new architecture or on other satellite systems. In reaching a decision on an architecture for a follow-on system, NOAA will need to carefully weigh these factors against the potential benefits of moving to small satellites.

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## Advanced Technology Could Improve Performance

Technological advances have been made in recent years that strongly suggest that more efficient and effective instruments and spacecraft could be designed today to replace the current GOES series, which was designed in the early 1980s and uses 1970s technology in its meteorological instruments.

While the planned continuation series satellites will incorporate some improvements to the design of the spacecraft bus to improve pointing and power management, further improvements could be made with a new spacecraft design. In a recent evaluation of the state of spacecraft technology, the National Research Council identified a number of new technologies that could contribute to smaller spacecraft that are cheaper

to build and operate. For example, greater operational autonomy could be built into the spacecraft's control systems, allowing them to carry out orbit determination and station-keeping with less intensive involvement of ground controllers. High-density computers and memory devices combined with advanced software techniques could enable extensive on-board data processing and screening, reducing the amount of data to be transmitted to earth. Such data processing advances could be of critical importance in compensating for the increased data volumes that would likely be produced by more advanced meteorological instruments.<sup>4</sup>

According to NASA and aerospace industry experts, significant advances have been made in sensor technology, which, if incorporated, could result in faster meteorological instruments that could produce significantly higher resolution data. Specifically, technological advances now allow for placing a much larger array of more sensitive optoelectronic detectors inside the instruments, thus producing higher resolution data more quickly. In 1996, NASA's Goddard Space Flight Center proposed developing and flying an experimental satellite to be called the Geostationary Advanced Technology Environmental System (GATES) that would demonstrate this technology, known as focal plane arrays. Other proposals for advanced geostationary weather imagers have also been made in recent years, based on focal plane array technology. For example, the MITRE Corporation prepared a report in 1993 that assessed the development of an advanced focal plane array imager that could fly as a secondary payload on a commercial communications satellite. MITRE concluded in its study that such an imager would be feasible and would offer improved resolution and radiometric performance.<sup>5</sup> MIT's Lincoln Laboratory also completed a conceptual design study of an advanced imager. The study found that it would be feasible to exploit advanced technologies, such as focal plane arrays, to resolve the conflict in forecasters' need for simultaneous close-up and broad views.

A focused effort would be needed to develop focal plane array technology for possible use in the GOES system. According to an analysis by the Aerospace Corporation, although focal plane arrays are now considered the state of the art in infrared sensor technology, they are generally designed for highly specialized purposes and can be expensive to produce.<sup>6</sup>

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<sup>4</sup>National Research Council, Aeronautics and Space Engineering Board, Technology For Small Spacecraft (National Academy Press, Washington, DC: 1994).

<sup>5</sup>A.S Cherdak, et al., Imaging From Nondedicated Satellites (The MITRE Corporation, McLean, VA: 1993), p. 6-1.

<sup>6</sup>The Aerospace Corporation, Infrared Systems and Technology: Executive Summary (undated).



A necessary enabling technology for focal plane array sensors is active cooling, which has advanced to the point that it is being considered for use in operational systems, according to aerospace experts. However, further development and testing is still needed to demonstrate that active coolers can remain reliable over long lifetimes.

As another example, work underway by the University Corporation for Atmospheric Research shows that small, low earth orbiting satellites equipped with special receivers can use Global Positioning System (GPS) signals to measure temperature and humidity in the atmosphere. Preliminary results indicate that this system, called GPS/MET (Meteorology), may provide superior vertical resolution in the lower atmosphere compared to the GOES sounder. Further development and expansion of this system could reduce the need for potentially expensive improvements to the GOES sounder to improve its accuracy.

NOAA officials involved in GOES acquisition and development agree that new approaches and technologies need to be considered, given that the follow-on GOES program will be subject to cost constraints. In public presentations, NOAA officials have stressed the importance of looking at new ways of doing the GOES mission, including flying smaller GOES satellites or constellations of small satellites carrying different instruments. However, NOAA has not yet conducted any in-depth analysis of alternative approaches.

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## Choosing a Follow-on Design Approach Will Require Thorough Engineering Analysis

If revised user requirements suggest that a new GOES architecture may be needed, thorough engineering analysis of a range of design options will then be necessary. Past experience in developing NASA spacecraft, such as the Hubble Space Telescope and the Gamma Ray Observatory, shows a clear correlation between the amount of resources focused on the early phases of a project, which include concept definition and engineering trade studies, and the ability of that project to meet its cost and schedule commitments.

NASA has a standard project model that it generally uses for planning spacecraft development. The NASA model calls for a six-phase life cycle, the first three phases of which are all dedicated to ensuring that the proposed project is well defined, feasible, and will likely meet requirements. The first phase, called the Pre-Phase A or Advanced Studies phase, is intended to produce a broad spectrum of ideas and alternatives from which new projects can be selected. Possible system architectures

are defined in this phase, and initial cost, schedule, and risk estimates are developed. The second phase, Phase A or Preliminary Analysis, determines the feasibility and desirability of a suggested new system by demonstrating that a credible, feasible design exists after considering alternative design concepts by conducting feasibility and risk studies. The third phase, Phase B or Definition, aims to define the project in enough detail to establish an initial baseline capable of meeting mission needs. During this phase, system functional and performance requirements along with architectures and designs become firm as engineers conduct trade studies of design options for the various systems and subsystems that make up the spacecraft. These trade studies are conducted iteratively in an effort to seek out cost-effective designs.

According to NASA, it is generally accepted that cost overruns in the later development phases of a spacecraft project are caused by inadequate attention to the early phases of mission design. This principle was borne out in the GOES-Next development experience, which suffered an over 200 percent cost increase<sup>7</sup> and serious schedule slippages. Because development risks were thought to be well understood and manageable, NOAA did not authorize and NASA did not require that engineering analysis be done prior to GOES-Next development work. However, as discussed in chapter 1, a number of technical problems arose that were expensive and time-consuming to fix. In addition, some of NOAA's performance requirements for the spacecraft, such as the pointing requirement mentioned in chapter 2, had to be relaxed because the planned spacecraft could not meet them. If a more thorough engineering analysis of the proposed design had been conducted early on, these problems likely could have been identified and resolved more cheaply and expeditiously.

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## Collaborating With NASA Could Help NOAA Develop New Satellite Capabilities

NOAA faces several significant obstacles in developing a new architecture for its geostationary satellite system. Most significantly, as numerous industry and government aerospace experts told us, it is difficult and expensive to develop new satellite capabilities within the constraints of an operational program such as NOAA's. Research and development are more effectively conducted separately, with proven results incorporated into the operational program afterwards. Originally, all of NOAA's satellites and meteorological instruments were developed experimentally by NASA and subsequently adopted for operational use by NOAA. However, NASA canceled its formal weather satellite research program in 1981 and is now

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<sup>7</sup>This figure is based on the change in NOAA's official cost estimate for the overall development of GOES-Next, which increased from \$640 million in 1986 to \$2.0 billion in 1996.

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reluctant to fund technology demonstration projects that will primarily benefit NOAA.

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## NASA Supported Weather Satellite Technology Development in the Past

NASA originally developed prototypes of both the GOES system and NOAA's polar-orbiting weather satellite system, using its own funding. The first experimental satellite dedicated to meteorological observations, called the Television and Infrared Observational Satellite 1 (TIROS 1), was launched by NASA in 1960. Nine more experimental TIROS satellites were launched between 1960 and 1965. These experimental satellites gave NASA the opportunity to test a number of significant technological features that since have become standard on meteorological satellites, such as including a transmitter that would allow weather stations around the world to receive data from the satellite when it is overhead. These early satellites also gave the U.S. weather forecasting community the opportunity to experiment with the data transmitted back from the satellites to determine its best uses. The first geostationary meteorological observations were made by NASA's Applications Technology Satellites (ATS 1 through 3), launched in 1966 and 1967. As with the early TIROS polar satellites, the ATS satellites gave NASA and NOAA the opportunity to gain experience in operating meteorological satellites in geostationary orbits and analyzing their observations on an experimental basis.

In 1973, NASA and NOAA formalized their successful ongoing relationship by establishing the Operational Satellite Improvement Program (OSIP) at NASA. Through the OSIP program, NASA continued to fund the development of the Nimbus series of experimental polar-orbiting weather satellites. Derivatives of many of the meteorological instruments developed for the Nimbus program are now being operated on NOAA's polar-orbiting satellites. For example, the High Resolution Infrared Radiometer which flew on Nimbus 1 in 1964 was a progenitor of the Advanced Very High Resolution Radiometer (AVHRR) that currently flies on NOAA polar-orbiting satellites. The AVHRR, in turn, was the basis for the design of the current GOES imager. Despite the success of OSIP, NASA canceled the program in 1981 because of budgetary pressures.

NASA's elimination of OSIP left NOAA without the engineering support required to design, develop, and test new spacecraft and instrument technologies before incorporating them into the agency's operational satellite systems. According to NASA and NOAA officials, many of the technical problems that plagued GOES-Next development could have been

addressed and resolved more efficiently and less expensively within the context of a smaller, experimental precursor program, such as OSIP.

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### NASA Development Activities Could Once Again Support NOAA Needs

Although OSIP no longer exists as an ongoing program to improve weather satellites, NASA has several avenues within its existing programmatic structure for undertaking research and demonstration projects related to advanced weather satellites. However, no such projects are currently being funded.

As mentioned above, NASA's Goddard Space Flight Center proposed developing and flying its experimental GATES satellite in 1996. Although it would lack a sounder and other secondary GOES instruments, GATES would feature a much faster and more efficient imager that would take advantage of advanced focal plane array technology to include more channels and offer higher resolution than the current GOES imager. If successful, GATES could demonstrate the feasibility of addressing user needs for more imager data from a small satellite platform. However, only preliminary design work for the GATES system has been completed to date.

Further opportunities for collaboration may exist within NASA's New Millennium or Earth System Science Pathfinder programs. The New Millennium Program is a NASA effort to develop and validate revolutionary technologies that will enable the construction of highly capable and agile spacecraft in the 21st century. The program has already committed to the development of an advanced land imager, which will be its first earth science mission. A geostationary weather monitoring mission is also under consideration, along with a number of other possibilities, but no commitment has yet been made. While the New Millennium program is focused on space technology, the Earth System Science Pathfinder program is a similar effort aimed at furthering earth science. An advanced geostationary weather monitoring mission could also fit within its mission.

NOAA officials also recognize that development of a new generation of instruments and spacecraft would benefit from greater collaboration with NASA. NOAA recently agreed to modest participation, at a rate of \$1 million per year, in NASA's GATES project, which in February 1997 became part of a new Advanced Geostationary Studies program. However, NOAA has generally been reluctant to provide funding to NASA to support new research efforts, believing that they should be NASA's responsibility. NOAA did not previously provide funding for NASA's OSIP program.

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## Conclusions

NOAA faces a difficult decision in determining how and when to proceed with development of a next generation GOES system. Because of budget constraints, NOAA has decided not to begin planning for a follow-on system until after fiscal year 2002. While delaying the start of a follow-on GOES program saves funds in the near term, it also incurs a significant measure of risk, in that NOAA, as a result, may have to procure more of the continuation series type of satellite farther into the future, delaying the opportunity to adopt an improved design. Indeed, the continuation series is now necessary because the start of a follow-on program has been delayed repeatedly since 1989.

Deferring development of a follow-on GOES satellite system is risky because it forgoes consideration of two kinds of potential benefits. First, a follow-on system could provide the opportunity to design a system architecture that is more flexible, less costly, and better able to meet users' needs. Second, a follow-on system could incorporate advanced technologies that could lead to improvements in weather forecasts in the future. We believe that these potential benefits are significant and that a decision on when and how to develop the follow-on generation is one that should be carefully considered.

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## Matters for Congressional Consideration

Given that options may exist for NOAA to develop a significantly improved follow-on GOES system, the Congress may wish to closely examine the costs and benefits of different approaches for the timing, funding, and scope of the follow-on program. Further, the Congress may also wish to examine NASA's potential role in working with NOAA to support the needs of geostationary weather satellites within NASA's advanced spacecraft technology programs.

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## Recommendations

We recommend that the Administrator of the National Oceanic and Atmospheric Administration prepare a formal analysis of the costs and benefits of several alternatives for the timing, funding, and scope of the follow-on program, including the possibility of starting the program as early as fiscal year 1998 and the potential need to fund some types of technology development apart from the operational satellite program. This analysis should be provided to the Congress for its use in considering options for the future of the GOES program.

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## Agency Comments and Our Evaluation

The Secretary of Commerce did not concur with our recommendations to reconsider NOAA's decision to defer the follow-on program and to prepare a formal analysis of options for such a program. The draft that we provided to Commerce for comment was based on the fiscal year 1997 budget, which showed that a follow-on program would begin in 2000. However, the fiscal year 1998 budget request, released since then, shows no follow-on program beginning through 2002. In discussions with us, NOAA officials confirmed that a follow-on program is not being planned until 2003 at the earliest.

Commerce did provide information on four small research efforts that it has recently funded or that are currently underway to examine advanced technology and alternative architectures for potential adoption in the future. Two of these were initiated in February 1997, as we were completing our review. They include the Advanced Geostationary Studies program being supported by both NOAA and NASA and the contract with the Jet Propulsion Laboratory to develop design concepts for an advanced imager. The other two items mentioned by Commerce in its comments are an Aerospace Corporation study of possible future architectures, begun in late 1996, and support from MIT's Lincoln Laboratory for several items, including the Aerospace architecture study, the advanced imager work, and a geostationary microwave sounder study.

We believe that these are valuable activities and have included references to them where appropriate in the report. However, they do not obviate our overall concerns about planning for the future of the GOES program. Activities such as these are useful but do not represent a commitment to exploring all options and developing a new generation of satellites. The fiscal year 1998 NOAA budget request does not allow for either a follow-on program to formally begin until 2003 at the earliest or for enhanced instruments to be flown on the continuation series. Therefore, NOAA's ability to take action based on the results of these studies is questionable. Other studies funded by NOAA, such as the work on advanced sounders and imagers that is mentioned in our report, have not led to any operational implementation.

We believe that continued deferral of the follow-on program is risky because it forgoes the opportunity to identify and develop a potentially more effective and economical architecture. Furthermore, the longer that NOAA continues without actively considering other options for a future system, the more it risks having to procure additional continuation series

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**Chapter 3**  
**NOAA Is Unprepared to Develop a Next**  
**Generation GOES System**

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satellites, because the availability date for a fully developed new satellite system will slip farther into the future.

# Comments From the Department of Commerce

Note: GAO comments supplementing those in the report text appear at the end of this appendix.



**THE SECRETARY OF COMMERCE**  
Washington, D.C. 20230

MAR - 4 1997


Mr. Gene L. Dodaro  
Assistant Comptroller General  
Accounting and Information Management Division  
United States General Accounting Office  
Washington, D.C. 20548

Dear Mr. Dodaro:

Enclosed is a copy of the Department of Commerce's comments on the General Accounting Office's Draft Report: WEATHER SATELLITES: Planning for the Geostationary Operational Satellite Program Needs More Attention (GAO/AIMD-97-37).

These comments were prepared in accordance with the Office of Management and Budget Circular A-50.

Sincerely,

  
William M. Daley

Enclosure



U.S. DEPARTMENT OF COMMERCE  
COMMENTS ON GAO DRAFT REPORT ENTITLED

"WEATHER SATELLITES: Planning for the Geostationary Operational  
Environmental Satellite Program Needs More Attention"

GAO/AIMD-97-37  
February 10, 1997

**Appendix I  
Comments From the Department of  
Commerce**

COMMENTS:

The National Oceanic and Atmospheric Administration (NOAA) has reviewed the findings and recommendations of the General Accounting Office (GAO) draft report "WEATHER SATELLITES," Planning for the Geostationary Operational Environmental Satellite Program Needs More Attention," February 1997, GAO/AIMD-97-37, to the Chairman, Subcommittee on Energy and Environment, House Committee on Science.

We have the following comments to make regarding the specific portions of the report cited below:

Now on p. 4.

**Page 3. 3rd paragraph, relative to the GAO view that NOAA has no follow-on program to develop a new spacecraft series to follow the gap fillers, as well as the comment that NOAA does not plan to begin funding a follow-on Geostationary Operational Environmental Satellite (GOES) program until FY 2000.**

See comment 1.

GAO uses the term "gap filler" to refer to the GOES N,O,P and Q series. The GOES N through Q series was not designed as a gap filler, and this terminology should not be used. NOAA believes it should be recognized that the GOES N-Q series is designed to be compliant with the existing specifications, dating from 1983, with some allowance for growth. NOAA also believes that analyses of requirements and technology should continue as on-going efforts. These efforts are presently underway.

See comment 2.

NOAA believes that early concept development designs will benefit from having more than one simultaneous study effort running parallel. For this reason, NOAA and the National Aeronautics and Space Administration (NASA), in February 1997, also invested in a joint Advanced Geostationary Studies (AGS) program which will focus on risk reduction studies and design proof-of-concept demonstration flights of potential future technologies applicable to the GOES mission. This effort, cofunded by NOAA and NASA, will examine concepts for up-to-date imagers, sounders (infrared and microwave), the GOES constellation, lightning mappers, ground systems, and other technologies for possible technology infusion into the GOES program.

In late 1996, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) initiated a task at the Aerospace Corporation to examine NOAA's geostationary orbit architectures for new future GOES series. Aerospace Corporation is a Federally Funded Research and Development Center (FFRDC), with a primary support role to the Department of Defense (DOD) and its space program. This study is to look at architectures for future GOES satellite series for the year 2006 time period and beyond. We consider this study to be a pre-Phase A study of future GOES

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**Appendix I  
Comments From the Department of  
Commerce**

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architectures, and a start of future studies. It will look at the role of small geostationary satellites, if any, and the role of smaller main GOES spacecraft buses for NOAA. This study will examine ways of reducing or containing future GOES costs through smaller spacecraft buses that can be accommodated on less expensive launch rockets than the presently used Atlas Centaur, such as the Delta and expected new launch vehicles such as the Evolved Expendable Launch Vehicle (EELV), and to longer spacecraft and sensor lifetimes. Preliminary Aerospace results identify that more launch options should be available for NOAA GOES in the future, particularly with respect to the potential for cost savings from smaller GOES satellites in the architectures. The Aerospace study will also examine the new advanced spacecraft technologies of today and the early post year 2000 era with respect to improved performance, reduced weight and reduced cost. With respect to small satellites, it will, in particular, examine cost savings offered by small satellites in geostationary orbit.

Concurrently with the Aerospace Corporation study, NESDIS initiated in February 1997, a new contract with the Jet Propulsion Laboratory (JPL) to develop design concepts for an advanced new generation imager for NOAA's satellites to follow the GOES N through Q satellite series. JPL is an aerospace-based FFRDC with a principal support role to NASA. This is NESDIS' second such advanced new generation imager study. We consider this to be a pre-Phase A study, a very important one, necessary to support any future initiatives to develop a new GOES imager, and to support the pre-Phase A new satellite series GOES architecture study at the Aerospace Corporation. The JPL new imager design is a necessary input to the Aerospace Corporation's efforts to size future GOES satellites, particularly with respect to planning how to save or contain costs. JPL is the leader of NASA's New Millennium Program (NMP) which is a program directed to identify newly available technologies that can improve performance, reduce cost, and reduce weight. JPL is also a leader in sensor development for interplanetary space vehicles.

The Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL), a third FFRDC, under contract to NOAA, is supporting the future GOES satellite architecture pre-Phase A work at the Aerospace Corporation, and the new advanced GOES imager work at JPL. MIT/LL had in 1995 submitted a pre-Phase A type of imager design proposal with NOAA to the NASA NMP for an advanced GOES imager. As a member of the NMP, MIT/LL along with other NMP members developed for NMP a design concept for a next generation NOAA satellite series GOES imager. The February 1997 JPL imager study for NOAA is to build and expand upon this earlier MIT/LL advanced imager work. MIT/LL is supporting the Aerospace Corporation future GOES architecture study through its assessments of future GOES sensors (microwave, sounder, lightning mapper).

**Appendix I  
Comments From the Department of  
Commerce**

Now on p. 5.

**Page 4, last paragraph, last three lines:** An important factor is not mentioned that severely constrains GOES launch scheduling. This factor is the requirement for the GOES program to use commercial launch services. At the present time, NOAA must compete with other launch customers for an extremely limited number of launch slots. In particular, today's launch manifests are typically booked up between 12 to 18 months into the future. If GOES would need a launch slot rapidly, it would face the challenge of either negotiating with a launch slot holder to swap dates (at potentially costly equitable adjustment amounts), or deciding whether NOAA's launch priority should be exercised (and pay the political penalty of having the Commerce Department in a position of not fostering a competitive launch industry).

See comment 3.

**Page 5, first full paragraph, 6th line:** GAO indicates NOAA does not have a consistent policy for providing backup in the event of launch failure. In fact, the present policy is to ensure a spacecraft and launch vehicle are available for a launch as early as one year after the previous planned launch.

Now on p. 11.

**Page 8, acronym list:** Add commas: NESDIS is the National Environmental Satellite, Data, and Information Service.

Now on p. 14.

**Page 10, first full paragraph:** The opening few words should be changed to: NOAA is not directly responsible for the design..."

Now on p. 23.

**Page 16, first paragraph:** Change the three references to NOAA to "NOAA/NASA."

Now on p. 24.

**Page 16, last paragraph:** The second sentence should read "Originally, NOAA intended to procure three or four additional..." The sentence starting on line 5 should be "However, NASA and NOAA officials jointly concluded that the Government..."

Now on p. 24.

**Page 17, second full paragraph:** Change the two references to "NOAA" in lines 4 and 5 to "NOAA/NASA."

See comment 4.

**Page 18, last paragraph, five lines from the bottom:** Change the sentence to: "The 3-year lifetime for GOES-8 and GOES-9 was determined in 1993 based on GOES lifetime historical data, when NOAA and NASA were developing strategic plans for the next series of satellites. In mid-1996, with the second motor winding failure, this assumption was reaffirmed."

Now on p. 28.

**Page 19, first full paragraph:** Change the last sentence to "NOAA officials told us that a GOES launch costs approximately \$25 million." Note that for GOES I-M, five total launch services costs (launch services include the launch vehicle itself and costs to perform the launch) \$525 million.

**Appendix I  
Comments From the Department of  
Commerce**

Now on p. 26.

**Following page 19, Figure 2.1:** Change the footnote to read "= assumed to be a launch failure for planning purposes."

Now on p. 30.

**Page 21, first full paragraph:** The third sentence suggests that it is not certain that a replacement would be launched in the event of a sounder failure. While this is in principle correct, it should be noted that the sounder data are becoming increasingly important. On February 6, 1997, sounder precipitable water data became a fully-operational input to numerical models. Further, in response to requirements from numerical modelers and field forecasters, high-density wind vectors are being made available on a regular basis for testing and operational use with full implementation targeted for late 1997. Also, the North American Observing System experiments will be demonstrating the utility of GOES sounder direct radiance assimilation starting in June 1997. At least one user is using the high-density winds on a fully-operational basis to make numerical forecasts over vast ocean regions. Ever increasing demands requiring sounder measurements make it more and more likely that a replacement satellite will be launched in the event of a sounder failure.

Now on p. 34.

**Page 24, last paragraph, relative to geostationary microwave and lightning mapper sensors.**

See comment 2.

NESDIS and NOAA's Systems Acquisition Office (SAO) initiated a study in September 1995, that is a pre-Phase A study on microwave sensor needs and feasibility for application to present GOES and future new generation satellites series. A draft report of that geostationary microwave study is to be available by the summer of 1997 from MIT/LL. Professor David Staelin of MIT was tasked by NOAA to form and chair a science and technology team to evaluate NOAA's geostationary science needs and the technology feasibility of the microwave sounder instrument. Professor Staelin is considered among the world's leading experts on microwave, in particular space-based microwave. This NOAA-formed team, through its work over the last year and a half, has significantly advanced the state of existing geostationary microwave sensor technology and science knowledge. It also found that it is now technically feasible to incorporate a microwave sounder onto GOES satellites. In particular, cost variables directed at optimizing costs and science needs are being explored by the team. This report will be a principal document for future GOES microwave program actions.

NESDIS is well aware of the work that NASA's Marshall Space Flight Center (MSFC) has done on space-based lightning mapper sensor (LMS) development, and has followed it closely. With respect to the LMS technology, NESDIS, with MIT/LL assistance, has evaluated the technologies associated with the MSFC designs and concepts and considers it to be readily available for a GOES spacecraft. With respect to lightning mapper technology, NOAA, for the new series, wants to look at technologies to reduce cost

**Appendix I  
Comments From the Department of  
Commerce**

and minimize weight and size with respect to what NASA/MSFC has done. MIT/LL, in support of NESDIS, developed in 1996 and is currently working on a number of technology and concept design ideas relative to lowering future geostationary lightning mapper sensor cost, weight, and size parameters. We expect a report from MIT/LL by this summer identifying these technology ideas. We are also aware of the need to examine the operational science benefits and need for a geostationary lightning mapper sensor within the NWS modernized weather system.

Now on p. 35.

**Page 25, first full paragraph, last sentence:** The GOES sounder is becoming an instrument in greater and greater demand. In addition, there are rising requests for sounding data at a much greater number of layers in the atmosphere. These requirements point to the need for upgrading the sounder from a 19 position filter wheel design to an interferometer type instrument capable of hundreds of levels instead of nineteen. Also see our comments provided in reference to page 21, first full paragraph.

Now on p. 36.

**Page 26, second paragraph:** The sentence beginning on line six should be corrected to indicate that "However, GOES imagers cannot... a full set of data from the southern half of the western hemisphere..." Required operational coverage for the northern hemisphere is not jeopardized by rapid scan scenarios. Only during internationally-agreed-upon full disks (every 3 hours) is the Northern Hemisphere missed during rapid scans.

Now on p. 37.

**Page 27, first full paragraph:** See earlier comments regarding importance of the sounder.

Now on p. 31.

**RECOMMENDATIONS, Page 22:** GAO recommends that the NOAA Administrator ensure that the National Environmental Satellite, Data, and Information Service (NESDIS):

**Recommendation (1):** Clarifies official criteria for activating replacement spacecraft in the event of a failure of an operational GOES satellite or any of its instruments or subsystems.

**RESPONSE (1):**

NOAA concurs and is already examining the replacement policy for GOES spacecraft. NOAA will document by the end of CY 1997 the process of deciding when to activate an in-orbit spare.

**Recommendation (2):** Reexamines the agency's strategy for anticipating possible launch failures and considers scheduling backups for all future launches.

**RESPONSE (2):**

NOAA concurs and is already examining its strategy, and will include a discussion of this in the replacement policy document referenced in Recommendation 1.

**Appendix I  
Comments From the Department of  
Commerce**

Now on p. 45.

See comment 5.

RECOMMENDATIONS, Page 34: GAO recommends that the NOAA Administrator:

Recommendation (3): Reconsider the Agency's decision to defer the follow-on GOES program until FY 2000.

RESPONSE (3):

NOAA does not concur. NOAA believes that in order to begin a GOES follow-on program, among other considerations, requirements need to be documented, and available technology to meet these requirements needs to be examined as to feasibility, cost, etc. We do not see these planning ingredients as being available before FY 2000. NOAA will develop a road-map document to guide the follow-on program by the end of CY 1998. As an additional step, we are making small investments in modeling studies, advanced spacecraft and instrumentation to position ourselves for an FY 2000 start.

For FY 1997 and FY 1998, NOAA will continue its recently initiated pre-Phase A studies on the future satellite series new sensors and spacecraft architectures with FFRDC's and NASA.

Recommendation (4): Prepare a formal analysis for consideration by the congress of the costs and benefits of several alternatives for the timing, funding, and scope of the follow-on program, including the possibility of starting the program in FY 1998 and the potential need to fund some types of technology development apart from the operational program.

RESPONSE (4):

NOAA does not concur with the recommendation to study the possibility of starting the follow-on program in FY 1998. NOAA is studying the various facets of the program now and is prepared to perform a formal analysis however, because of the complexity inherent in a thorough requirements study, we will not be in a position to start a formal follow-on program in FY 1998. As noted in our response to Recommendation 3, NOAA is making some small investment in technology now.

## GAO Comments

1. NOAA does not have an official name for this series of satellites. During our audit, NOAA officials originally referred to the series as “clones.” Later, after revising their procurement strategy, they referred to them as “gap fillers,” the term we used in our draft report. We have adopted the phrase “continuation series” for our final report.

2. Discussed in “Agency Comments and Our Evaluation” section of chapter 3.

3. In the report, we point out that NOAA’s launch backup policy is arbitrary. (See chapter 2.) All spacecraft programs have to address the risk of launch failure. However, NOAA’s approach of designating certain launches as “planned failures” and providing backup spacecraft for only those launches is arbitrary, because NOAA does not know in advance which launches will actually fail. In other words, the risk of a launch failure is no greater for the “planned failure” than for any of the other launches, which do not have specifically designated backups. Although NOAA’s approach is effective in putting an extra spacecraft into the production stream to compensate for a launch failure, it is ineffective in providing backup for each launch. An alternative approach would be to schedule each launch to be backed up by the next spacecraft in the production stream. Such an approach would not require procurement of any additional spacecraft or launch vehicles and would enhance NOAA’s ability to compensate for launch failures by planning to have spacecraft always available for backup launches.

4. When we began our review in March 1996, we received documentation from NOAA indicating that the GOES-9 spacecraft was expected to last a full 5 years. After technical problems developed on GOES-8 and GOES-9, NOAA officials reduced their estimate of the expected lifetime of GOES-9 to 3 years.

5. In the final report, we have combined the intent of the two recommendations that appeared at the end of chapter 3 in the draft report. The draft that we provided to Commerce was based on its fiscal year 1997 budget, which showed that a GOES follow-on program would begin in 2000. However, the fiscal year 1998 budget request, released since then, shows no follow-on program beginning through 2002. In discussions with us, NOAA officials confirmed that a follow-on program is currently not planned until 2003 at the earliest. Therefore, our final report focuses on the need for NOAA to prepare a formal analysis of the costs and benefits of alternatives for the timing, funding, and scope of the follow-on program.



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# Related GAO Products

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NOAA Satellites ([GAO/AIMD-96-141R](#), September 13, 1996).

Weather Forecasting: NWS Has Not Demonstrated That New Processing System Will Improve Mission Effectiveness ([GAO/AIMD-96-29](#), February 29, 1996).

Weather Satellites: Action Needed to Resolve Status of the U.S. Geostationary Satellite Program ([GAO/NSIAD-91-252](#), July 24, 1991).

Weather Satellites: Cost Growth and Development Delays Jeopardize U.S. Forecasting Ability ([GAO/NSIAD-89-169](#), June 30, 1989).

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