United States Government Accountability Office

Report to the Committee on Science, Space, and Technology, House of Representatives

December 2014

POLAR WEATHER SATELLITES

NOAA Needs To Prepare for Near-term Data Gaps

On January 16, 2015, this report was reissued to include the Highlights page that was inadvertently missing from the previously posted report.

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NOAA Needs To Prepare for Near-term Data Gaps

Highlights

Highlights of GAO-15-47, a report to the Committee on Science, Space, and Technology, House of Representatives

Why GAO Did This Study

NOAA established the JPSS program in 2010 to replace aging polar satellites and provide critical environmental data used in forecasting weather and measuring variations in climate. However, GAO and NOAA have previously reported that a gap in satellite data between the current satellite and the next one is likely. Given the criticality of satellite data to weather forecasting, the likelihood of a significant satellite data gap, and the potential impact of a gap on the health and safety of the U.S. population and economy, GAO added this issue to its High Risk List in 2013.

GAO was asked to review the JPSS program. GAO's objectives were to (1) evaluate NOAA's progress on the JPSS satellite program with respect to cost, schedule, and mitigation of key risks; (2) identify the benefits and challenges of alternatives for polar satellite gap mitigation; and (3) assess NOAA's efforts to establish and implement a comprehensive contingency plan for potential gaps in polar satellite data. To do so, GAO analyzed program management status reports, milestone reviews, and risk data; examined polar gap contingency plans; and interviewed experts as well as agency and contractor officials.

What GAO Recommends

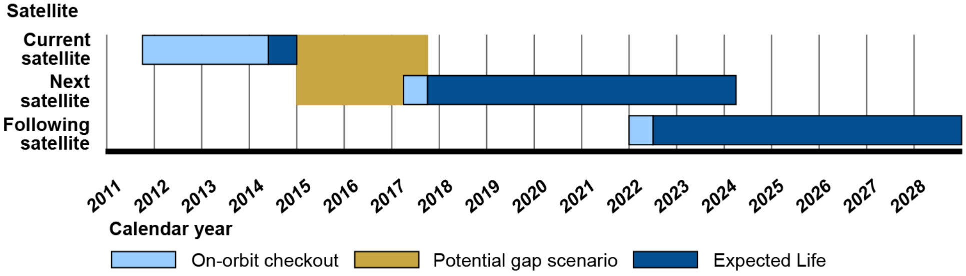
GAO is recommending NOAA track completion dates for risk mitigation activities, update its data gap assessment, address shortfalls in its contingency plan, prioritize mitigation projects most likely to address a gap, and report progress on all mitigation projects. NOAA concurred with GAO's recommendations and identified steps it is taking to implement them.

View GAO-15-47. For more information, contact Dave Powner at (202) 512-9286 or pownerd@gao.gov

What GAO Found

The Joint Polar Satellite System (JPSS) program has recently completed significant development activities and remains within its cost and schedule baselines; however, recent cost growth on key components is likely unsustainable and risks remain that could increase the potential for near-term satellite data gaps. For example, technical issues experienced while developing a key instrument have led to a very tight schedule. The National Oceanic and Atmospheric Administration (NOAA) is working to mitigate such risks, but is not tracking actual completion dates for its risk mitigation activities. In addition, while the program has reduced its estimate for a near-term satellite data gap in the afternoon orbit to only 3 months, its gap assessment was based on incomplete data (such as the increasing threat from space debris) and the agency has not updated its assessment to address these limitations. As shown below, a gap in satellite data may occur earlier and last longer than NOAA anticipates.

Timeline for a Potential Gap in Polar Satellite Data in the Afternoon Orbit



Source: GAO analysis based on NOAA and NASA data. | GAO-15-47

Experts within and outside of NOAA identified almost 40 alternatives for mitigating potential gaps in polar satellite data, which offer a variety of benefits and challenges. These alternatives include actions to prevent or limit a potential gap by providing JPSS-like capabilities, and actions that could reduce the impact of a potential gap by (a) extending and expanding the use of current data sources, (b) enhancing modeling and data assimilation,(c) developing new data sources, or (d) exploring opportunities with foreign and domestic partners. However, obstacles to the alternatives, such as the time required to develop new instruments, may restrict them from being available to address a near-term gap.

While multiple alternatives for mitigating a gap exist, NOAA's contingency plan focuses on a subset of these alternatives. NOAA has improved its contingency plan by identifying mitigation strategies and specific activities. However, the agency's plan has shortfalls such as not providing an assessment of available alternatives based on their cost and potential impacts. In addition, key projects affecting improvements to forecast models and assimilation of additional data sources have been delayed, but NOAA has not yet prioritized mitigation projects most likely to address a gap. Moreover, NOAA is not providing consistent or comprehensive reporting of its progress on all mitigation projects. Until NOAA addresses shortfalls in contingency planning, implements its most critical contingency activities before data gaps can occur in the near-term, and improves its progress monitoring, the agency will have less assurance that it is adequately prepared to deal with a gap in polar satellite coverage.

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Abbreviations

A-DCS	Advanced Data Collection System
ATMS	Advanced Technology Microwave Sounder
CERES	Cloud and Earth's Radiant Energy System
CrIS	Cross-Track Infrared Sounder
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
JPSS	Joint Polar Satellite System
Metop	Meteorological Operational (satellite)
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NWS	National Weather Service
S-NPP	Suomi National Polar-orbiting Partnership
OMPS	Ozone Mapping and Profiler Suite
POES	Polar-orbiting Operational Environmental Satellites
TSIS	Total and Spectral Solar Irradiance Sensor
VIIRS	Visible Infrared Imaging Radiometer Suite

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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December 16, 2014

The Honorable Lamar Smith
Chairman
The Honorable Eddie Bernice Johnson
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

In 2010, when the Executive Office of the President's Office of Science and Technology Policy announced the decision to disband the acquisition of polar-orbiting environmental satellites through a tri-agency program, the National Oceanic and Atmospheric Administration (NOAA) initiated its own satellite program with assistance from the National Aeronautics and Space Administration (NASA).[1] This new program, called the Joint Polar Satellite System (JPSS), includes three satellites, the first of which was successfully launched in October 2011. These satellites are to provide critical environmental data that are used in weather forecasting and in measuring variations in climate.

Due in part to delays associated with disbanding the prior program and initiating the new one, NOAA officials acknowledge that there could be a gap in satellite data before the next satellite is launched and operational. Because of the criticality of satellite data to weather forecasting, the likelihood of a significant satellite data gap, and the potential impact of a gap on the health and safety of the U.S. population and economy, GAO added this issue to its High Risk List in 2013.[2]

Given your interest in the progress NOAA has made, you asked us to review the JPSS program and the potential for satellite data gaps. Our objectives were to (1) evaluate NOAA's progress on the JPSS satellite program with respect to cost, schedule, and mitigation of key risks; (2) identify the benefits and challenges of alternatives for polar satellite gap

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[1] NOAA, NASA, and the Department of Defense were jointly responsible for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). While the disbanding of the program began in 2010, NPOESS was officially terminated in 2011.

[2] GAO, *High Risk Series: An Update*, GAO-13-283 (Washington, D.C.: February 2013).

mitigation; and (3) assess NOAA's efforts to establish and implement a comprehensive contingency plan for potential gaps in polar satellite data.

To evaluate NOAA's progress on the JPSS satellite program, we analyzed changes in cost and schedule for key program components and milestones since the program established its baseline in July 2013. We examined mitigation plans and status reports for risks presented to NOAA's program management since July 2013. We also analyzed the program's latest assessment of the potential for satellite data gaps. We assessed the reliability of cost and schedule data by interviewing program officials to determine their process for conducting accuracy checks, by examining multiple program and project status reports at different points in time, and by comparing reported dates to source schedule data. We determined that the data were sufficiently reliable for our reporting purposes. We attended program management council meetings and interviewed relevant NOAA and NASA officials to discuss JPSS development status, the reasons for cost and schedule changes, risk mitigation processes and action plans, and the program's gap assessment for polar afternoon satellites. To identify the benefits and challenges of alternatives for polar satellite gap mitigation, we reviewed existing literature and developed a list of alternatives, interviewed experts from organizations within and outside of NOAA, and summarized the key benefits and challenges that experts commonly identified.

To assess NOAA's efforts to establish and implement a comprehensive contingency plan for potential gaps in polar satellite data, we analyzed the extent to which NOAA's February 2014 polar satellite contingency plan addressed shortfalls that we previously identified by comparing a prior version of NOAA's plan to government and industry best practices.[3] We also reviewed project plans, progress reports, and other relevant documentation to evaluate the extent to which NOAA is making progress against its contingency plan. We interviewed relevant NOAA officials regarding changes reflected in the February 2014 contingency plan, oversight and reporting procedures, and implementation progress.

We conducted this performance audit from January 2014 to December 2014 in accordance with generally accepted government auditing

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[3] GAO, *Polar Weather Satellites: NOAA Identified Ways to Mitigate Data Gaps, But Contingency Plans and Schedules Require Further Attention*, GAO-13-676 (Washington, D.C.: Sept. 11, 2013).

standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. Additional details on our objectives, scope, and methodology are provided in appendix I.

Background

Since the 1960s, the United States has operated two separate operational polar-orbiting meteorological satellite systems: the Polar-orbiting Operational Environmental Satellite (POES) series, which is managed by NOAA, and the Defense Meteorological Satellite Program (DMSP), which is managed by the Air Force. These satellites obtain environmental data that are processed to provide graphical weather images and specialized weather products. These satellite data are also the predominant input to numerical weather prediction models, which are a primary tool for forecasting weather days in advance—including forecasting the path and intensity of hurricanes.[4] The weather products and models are used to predict the potential impact of severe weather so that communities and emergency managers can help prevent and mitigate its effects. Polar satellites also provide data used to monitor environmental phenomena, such as ozone depletion and drought conditions, as well as data sets that are used by researchers for a variety of studies such as climate monitoring.

Unlike geostationary satellites, which maintain a fixed position relative to the earth, polar-orbiting satellites constantly circle the earth in an almost north-south orbit, providing global coverage of conditions that affect the weather and climate. Each satellite makes about 14 orbits a day. As the earth rotates beneath it, each satellite views the entire earth's surface twice a day. Currently, a NOAA satellite (called the Suomi National Polar-orbiting Partnership, or S-NPP) and two operational DMSP satellites are positioned so that they cross the equator in the early morning, midmorning, and early afternoon. In addition, the government relies on a European satellite, called the Meteorological Operational (Metop)

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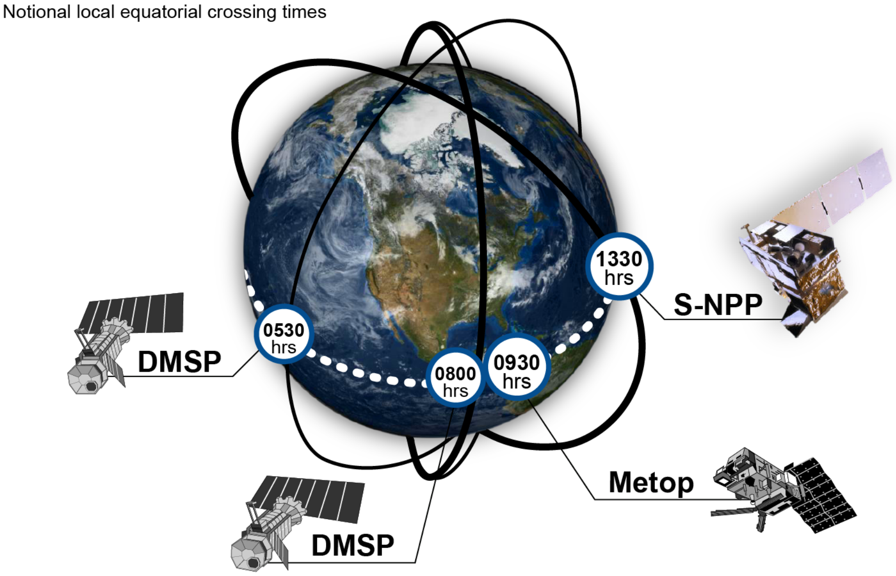
[4] According to NOAA, 80 percent of the data assimilated into its National Weather Service numerical weather prediction models that are used to produce weather forecasts three days and beyond comes from polar-orbiting satellites.

satellite, for satellite observations in the midmorning orbit.[5] In addition to the operational satellites, NOAA, the Air Force, and a European weather satellite organization maintain older satellites that still collect some data and are available to provide limited backup to the operational satellites should they degrade or fail. Figure 1 illustrates the current operational polar satellite constellation.

Figure 1: Configuration of Operational Polar Satellites



Sources: GAO, based on NPOESS Integrated Program Office, NOAA, and DOD data; NASA/Goddard Space Flight Center Scientific Visualization Studio (earth); S-NPP image provided courtesy of University of Wisconsin-Madison Space Science and Engineering Center. | GAO-15-47

Note: DMSP—Defense Meteorological Satellite Program, Metop—Meteorological Operational (satellite), and S-NPP—Suomi National Polar-orbiting Partnership.

Polar Satellite Data and Products

Polar satellites gather a broad range of data that are transformed into a variety of products. Satellite sensors observe different bands of radiation wavelengths, called channels, which are used for remotely determining

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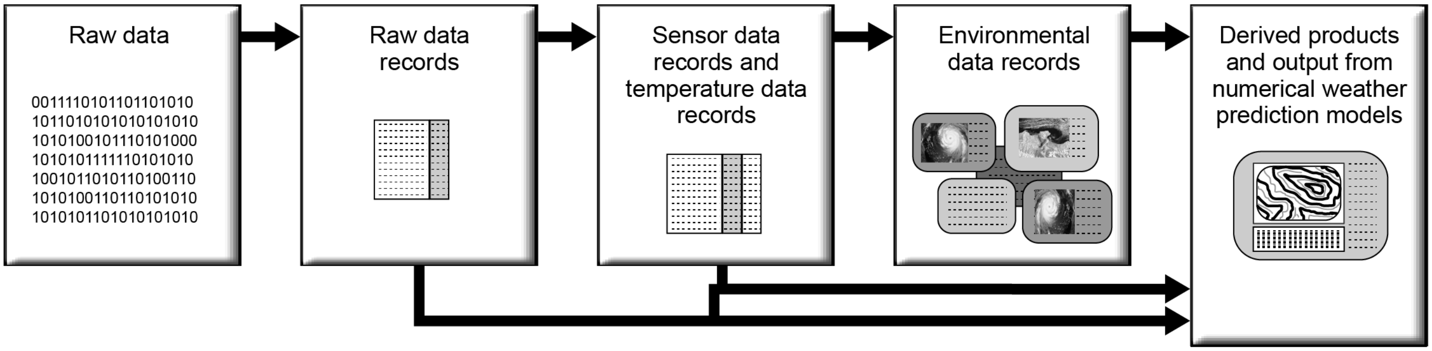
[5] The European Organisation for the Exploitation of Meteorological Satellites' Metop program is a series of three polar-orbiting satellites dedicated to operational meteorology. Metop satellites are planned to be flown sequentially over 14 years. The first of these satellites was launched in 2006, the second was launched in 2012, and the final satellite in the series is expected to launch in 2017.

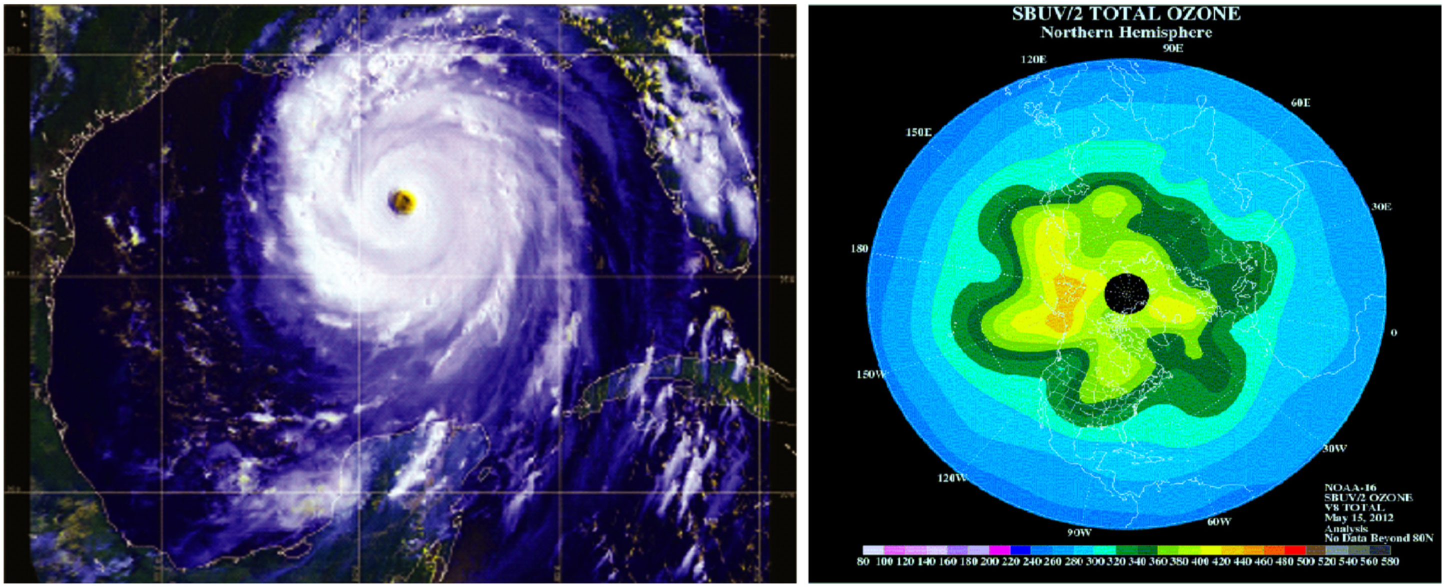
information about the earth’s atmosphere, land surface, oceans, and the space environment. When first received, satellite data are considered raw data. To make them usable, processing centers format the data so that they are time-sequenced and include earth-location and calibration information. After formatting, these data are called raw data records. The centers further process these raw data records into channel-specific data sets, called sensor data records and temperature data records. These data records are then used to derive weather and climate products called environmental data records. These environmental data records include a wide range of atmospheric products detailing cloud coverage, temperature, humidity, and ozone distribution; land surface products showing snow cover, vegetation, and land use; ocean products depicting sea surface temperatures, sea ice, and wave height; and characterizations of the space environment. Combinations of these data records (raw, sensor, temperature, and environmental data records) are also used to derive more sophisticated products, including outputs from numerical weather models and assessments of climate trends. Figure 2 is a simplified depiction of the various stages of satellite data processing, and figure 3 depicts examples of two different environmental products.

Figure 2: Stages of Satellite Data Processing



Source: GAO analysis of NOAA information. | GAO-15-47

Figure 3: Examples of Environmental Products



Sources: NOAA's National Environmental Satellite Data and Information Service. | GAO-15-47

Note: The figure on the left is a Polar-orbiting Operational Environmental Satellite image of Hurricane Katrina in 2005; the figure on the right is an analysis of ozone concentration produced from Polar-orbiting Operational Environmental Satellite data.

The NPOESS Program: Inception, Challenges, and Termination

With the expectation that combining the POES and DMSP programs would reduce duplication and result in sizable cost savings, a May 1994 Presidential Decision Directive required NOAA and the Department of Defense (DOD) to converge the two satellite programs into a single one—the National Polar-orbiting Operational Environmental Satellite System (NPOESS)—that is capable of satisfying both civilian and military requirements.[6] The converged program, NPOESS, was considered critical to the nation's ability to maintain the continuity of data required for weather forecasting and global climate monitoring. NPOESS satellites were expected to replace the POES and DMSP satellites in the morning, midmorning, and afternoon orbits when they neared the end of their expected life spans.

To manage this program, DOD, NOAA, and the National Aeronautics and Space Administration (NASA) formed a tri-agency Integrated Program Office, with NOAA responsible for overall program management for the converged system and for satellite operations, the Air Force responsible for acquisition, and NASA responsible for facilitating the development and incorporation of new technologies into the converged system.

When the primary NPOESS contract was awarded in August 2002, the program was estimated to cost about $7 billion through 2018. It was to include the procurement and launch of 6 satellites over the life of the program, with each satellite hosting a subset of 13 instruments. The planned instruments included 11 environmental sensors and two systems supporting specific user services (see table 1). To reduce the risk involved in developing new technologies and to maintain climate data continuity, the program planned to launch the demonstration satellite in May 2006.[7] This satellite was intended to demonstrate the functionality of selected instruments that would later be included on the NPOESS satellites. The first NPOESS satellite was to be available for launch in March 2008.

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[6] Presidential Decision Directive NSTC-2, "Convergence of U.S. Polar-orbiting Operational Environmental Satellite Systems," May 5, 1994.

[7] Originally called the NPOESS Preparatory Project, in January 2012 the satellite's name was changed to the Suomi National Polar-orbiting Partnership satellite.

Table 1: Anticipated National Polar-orbiting Operational Environmental Satellite System (NPOESS) Instruments, as of July 2002

Instrument	Instrument type	Description
Advanced technology microwave sounder (ATMS)	Environmental sensor	Measures microwave energy released and scattered by the atmosphere; to be used in combination with the cross-track infrared sounder to produce daily global atmospheric temperature, humidity, and pressure profiles.
Aerosol polarimetry sensor	Environmental sensor	Retrieves specific aerosol (liquid droplets or solid particles suspended in the atmosphere, such as sea spray, smog, and smoke) and cloud measurements.
Conical microwave imager/sounder	Environmental sensor	Collects microwave images and data needed to measure rain rate, ocean surface wind speed and direction, amount of water in the clouds, and soil moisture, as well as temperature and humidity at different atmospheric levels.
Cross-track infrared sounder (CrIS)	Environmental sensor	Collects measurements of the infrared radiation emitted and scattered by the Earth and atmosphere to determine the vertical distribution of temperature, moisture, and pressure in the atmosphere.
Data collection system	System providing services to users	Collects environmental data from platforms around the world and delivers them to users worldwide.
Earth radiation budget sensor	Environmental sensor	Measures solar short-wave radiation and long-wave radiation released by the Earth back into space on a worldwide scale to enhance long-term climate studies.
Global positioning system occultation sensor	Environmental sensor	Measures the refraction of radio wave signals from the Global Positioning System and Russia's Global Navigation Satellite System to characterize the ionosphere and information related to the vertical distribution of temperature and moisture of the atmosphere.
Ozone mapper/profiler suite (OMPS)	Environmental sensor	Collects data needed to measure the amount and distribution of ozone in the Earth's atmosphere. Consists of two components (nadir and limb) that can be provided separately.
Radar altimeter	Environmental sensor	Measures variances in sea surface height/topography and ocean surface roughness, which are used to determine sea surface height, significant wave height, and ocean surface wind speed and to provide critical inputs to ocean forecasting and climate prediction models.
Search and rescue satellite-aided tracking (SARSAT) system	System providing services to users	A subsystem that detects and locates aviators, mariners, and land-based users in distress.
Space environmental sensor suite	Environmental sensor	Collects data to identify, reduce, and predict the effects of space weather on technological systems, including satellites and radio links.
Total and spectral solar irradiance sensor (TSIS)	Environmental sensor	Monitors and captures total and spectral solar irradiance data.
Visible infrared imaging radiometer suite (VIIRS)	Environmental sensor	Collects images and radiometric data used to provide information on the Earth's clouds, atmosphere, ocean, and land surfaces.

Source: GAO analysis of data from the former NPOESS Integrated Program Office. | GAO-15-47

In the years after the program was initiated, NPOESS encountered significant technical challenges in sensor development, program cost growth, and schedule delays. By November 2005, we estimated that the program's cost had grown to $10 billion, and the schedule for the first launch was delayed by almost 2 years.[8] These issues led to a 2006 decision to restructure the program, which reduced the program's functionality by decreasing the number of planned satellites from 6 to 4, and the number of instruments from 13 to 9. As part of the decision, officials decided to reduce the number of orbits from three (early morning, midmorning, and afternoon) to two (early morning and afternoon) and to rely solely on the European satellites for midmorning orbit data.

Even after the restructuring, however, the program continued to encounter technical issues in developing two sensors, significant tri-agency management challenges, schedule delays, and further cost increases. Because the schedule delays could lead to satellite data gaps, in March 2009, agency executives decided to use S-NPP as an operational satellite.[9] Later, faced with costs that were expected to reach about $15 billion and launch schedules that were delayed by over 5 years, the Executive Office of the President announced that NOAA and DOD would no longer jointly procure the NPOESS satellite system; instead, each agency would plan and acquire its own satellite system.[10] Specifically, NOAA would be responsible for the afternoon orbit and the observations planned for the first and third satellites and DOD would be responsible for the early morning orbit and the observations planned for the second and fourth satellites. The partnership with the European satellite agencies for the midmorning orbit was to continue as planned.

When this decision was announced, NOAA and NASA immediately began planning for a new satellite program in the afternoon orbit called JPSS. DOD began planning for a new satellite program in the morning orbit, called the Defense Weather Satellite System, but later decided to terminate the program and reassess its requirements, as directed by Congress.

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[8] GAO, *Polar-orbiting Operational Environmental Satellites: Technical Problems, Cost Increases, and Schedule Delays Trigger Need for Difficult Trade-off Decisions*, GAO-06-249T (Washington, D.C.: Nov. 16, 2005).

[9] Using S-NPP as an operational satellite means that the satellite's data will be used to provide climate and weather products.

[10] The announcement accompanied the release of the President's fiscal year 2011 budget request.

Overview of the JPSS Program

After the decision was made to disband the NPOESS program in 2010, NOAA began the JPSS satellite program. Key plans included:

- relying on NASA for system acquisition, engineering, and integration;
- completing, launching, and supporting S-NPP;
- acquiring and launching two satellites for the afternoon orbit, called JPSS-1 and JPSS-2;
- developing and integrating five sensors on the two satellites;
- finding alternative host satellites for selected instruments that would not be accommodated on the JPSS satellites, including the Total and Spectral Solar Irradiance Sensor (TSIS), the Advanced Data Collection System (A-DCS), and the Search and Rescue Satellite-Aided Tracking (SARSAT) system; and
- providing ground system support for S-NPP, JPSS, and the Defense Weather Satellite System; data communications for Metop and DMSP; and data processing for NOAA's use of microwave data from an international satellite.

In 2010, NOAA estimated that the life cycle costs of the JPSS program would be approximately $11.9 billion for a program lasting through fiscal year 2024, which included $2.9 billion in NOAA funds spent on NPOESS through fiscal year 2010.[11] Subsequently, the agency undertook a cost estimating exercise where it validated that the cost of the full set of JPSS functions from fiscal year 2012 through fiscal year 2028 would be $11.3 billion. After adding the agency's sunk costs, which had increased to $3.3 billion through fiscal year 2011, the program's life cycle cost estimate totaled $14.6 billion.[12] This amount was $2.7 billion higher than the $11.9 billion estimate for JPSS when NPOESS was disbanded in 2010.

In working with the Office of Management and Budget to establish the President's fiscal year 2013 budget request, NOAA officials agreed to cap the JPSS life cycle cost at $12.9 billion through 2028, to fund JPSS at roughly $900 million per year through 2017, and to merge funding for two climate sensors into the JPSS budget. Because this cap was $1.7 billion below the expected $14.6 billion life cycle cost of the full program, by October 2012, NOAA decided to remove selected elements from the

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[11] This figure does not include approximately $2.9 billion in sunk costs that DOD spent on NPOESS through fiscal year 2010.

[12] NOAA's $3.3 billion sunk costs included $2.9 billion through fiscal year 2010 and about $400 million in fiscal year 2011.

satellite program, such as the number of ground-based receptor stations (thus affecting the time that it takes for products to reach end users) and the number of interface data processing segments.

Subsequently, according to NOAA officials, the administration directed the agency to begin implementing additional changes in the program's scope and objectives in order to meet the agency's highest-priority needs for weather forecasting and reduce program costs from $12.9 billion to $11.3 billion. By April 2013, the program had decided to, among other things, transfer requirements for certain climate sensors to NASA, cancel one of two planned free-flyer missions, and transfer the remaining free-flyer mission to a new program within NOAA called the Solar Irradiance, Data, and Rescue (SIDAR) mission.[13] The program also reduced program costs by removing funding for 3 years of operations at the end of the JPSS mission; the program is now funded through 2025 even though the JPSS-2 satellite is expected to be operational until 2028.[14]

Table 2 compares the planned cost, schedule, and scope of NOAA's satellite programs at different points in time.

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[13] SIDAR is to accommodate the Total and Spectral Solar Irradiance Sensor, the Advanced Data Collection System, and the Search and Rescue Satellite-Aided Tracking system.

[14] This practice is not consistent with the common definition of a life cycle cost estimate. See *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs,* GAO-09-3SP (Washington, D.C., March 2009).

Table 2: Comparison of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the Joint Polar Satellite System (JPSS) Programs, at Different Points in Time

Key area	NPOESS after it was restructured (as of June 2006)	NPOESS prior to being disbanded (as of February 2010)	JPSS program (as of May 2010)	JPSS program (as of June 2012)	JPSS program (as of September 2013)
Life cycle	1995-2026	1995-2026	2010-2024	2010-2028	2010-2025
Estimated life cycle cost	$12.5 billion	$13.95+ billion[a]	$11.9 billion (which includes about $2.9 billion spent through fiscal year 2010 on NPOESS)	$12.9 billion (which includes about $3.3 billion spent through fiscal year 2011 on NPOESS and JPSS)	$11.3 billion (which includes about $4.3 billion spent through fiscal year 2012 on NPOESS and JPSS)
Number of satellites	4 (in addition to S-NPP)	4 (in addition to S-NPP)	2 (in addition to S-NPP)	2 (in addition to S-NPP)	2 (in addition to S-NPP)
Number of orbits	2 (early morning and afternoon; would rely on European satellites for midmorning orbit data)	2 (early morning and afternoon; would rely on European satellites for midmorning orbit data)	1 (afternoon orbit) (DOD and European satellites would provide early and midmorning orbits, respectively)	1 (afternoon orbit) (DOD and European satellites would provide early and midmorning orbits, respectively)	1 (afternoon orbit) (DOD and European satellites would provide early and midmorning orbits, respectively)
Launch schedule	S-NPP by Jan. 2010 First satellite (C1) by Jan. 2013 C2 by Jan. 2016 C3 by Jan. 2018 C4 by Jan. 2020	S-NPP no earlier than Sept. 2011 C1 by March 2014 C2 by May 2016 C3 by Jan. 2018 C4 by Jan. 2020	S-NPP—no earlier than Sept. 2011 JPSS-1 available in 2015 JPSS-2 available in 2018	S-NPP—successfully launched in Oct. 2011 JPSS-1 by March 2017 JPSS-2 by Dec. 2022	S-NPP—successfully launched in Oct. 2011 JPSS-1 by March 2017 JPSS-2 by Dec. 2021
Number of sensors	S-NPP: 4 sensors C1: 6 sensors C2: 2 sensors C3: 6 sensors C4: 2 sensors	S-NPP: 5 sensors C1: 7 sensors[b] C2: 2 sensors C3: 6 sensors C4: 2 sensors	S-NPP: 5 sensors JPSS-1 5 sensors[c] JPSS-2: 5 sensors	S-NPP: 5 sensors JPSS-1: 5 sensors JPSS-2: 5 sensors Free flyer-1 and-2: 1 sensor and 2 user services systems[d]	S-NPP: 5 sensors JPSS-1: 5 sensors JPSS-2: 5 sensors[e] No free flyers[f]

Source: GAO analysis of NOAA, DOD, and task force data. | GAO-15-47

[a] Although the program baseline was $13.95 billion in February 2010, we estimated in June 2009 that this cost could grow by about $1 billion. In addition, officials from the Executive Office of the President stated that they reviewed life cycle cost estimates from DOD and the NPOESS program office of $15.1 billion and $16.45 billion, respectively.

[b] In May 2008, the NPOESS Executive Committee approved an additional sensor—Total and Spectral Solar Irradiance Sensor—for the C1 satellite.

[c] The five sensors are the Advanced Technology Microwave Sounder, Clouds and the Earth's Radiant Energy System (CERES), Cross-Track Infrared Sounder, Ozone Mapping and Profiler Suite, and Visible Infrared Imaging Radiometer Suite. NOAA committed to finding an alternative spacecraft and launch accommodation for the Total and Spectral Solar Irradiance Sensor, the Advanced Data Collection System, and the Search and Rescue Satellite-Aided Tracking system.

[d] NOAA planned to launch two stand-alone satellites, called free flyer satellites, to accommodate the Total and Spectral Solar Irradiance Sensor, the Advanced Data Collection System, and the Search and Rescue Satellite-Aided Tracking system.

[e] In its fiscal year 2014 budget request, NOAA transferred responsibility for two sensors to NASA—the Radiation Budget Instrument (formerly known as CERES) and OMPS-L and plans to accommodate these sensors on the JPSS-2 satellite as long as they do not impact the likelihood of mission success.

[f] NOAA canceled Free flyer-1 and established Free flyer-2 as a new program outside the JPSS program. This new program, called the Solar Irradiance, Data, and Rescue (SIDAR) mission, is to accommodate the Total and Spectral Solar Irradiance Sensor, the Advanced Data Collection System, and the Search and Rescue Satellite-Aided Tracking system.

Recent GAO Work Recommended Actions to Address Shortfalls in Establishing a Contingency Plan for Potential Polar Satellite Data Gaps

We previously reported that the polar satellite constellation—consisting of DOD, European, and NOAA satellites in the early morning, midmorning, and afternoon polar orbits—was becoming increasingly unreliable and that satellite data gaps in the morning or afternoon polar orbits would lead to less accurate and timely weather forecasting.[15] As a result, advanced warning of extreme events would be affected. Such extreme events could include hurricanes, storm surges, and floods. For example, the National Weather Service performed case studies to demonstrate how its forecasts would have been affected if there were no polar satellite data in the afternoon orbit, and noted that its forecasts for the “Snowmaggedon” winter storm that hit the Mid-Atlantic coast in February 2010 would have predicted a less intense storm further east, with about half of the precipitation at 3, 4, and 5 days before the event. Specifically, the models would have under-forecasted the amount of snow by at least 10 inches. Similarly, a European weather organization recently reported that forecasts of Hurricane Sandy’s track could have been hundreds of miles off without polar-orbiting satellites—rather than identifying the New Jersey landfall within 30 miles 4 days before landfall, the models would have shown the storm remaining at sea.[16]

In June 2012, we reported that the length of an afternoon polar satellite data gap could span from 17 months to 3 years or more under different scenarios.[17] Because the degradation in forecasts and warnings resulting from gaps in polar weather satellite data would place lives, property, and our nation’s critical infrastructure in danger, we added the potential gap in weather satellite data to our biennial High-Risk list in February 2013.[18] In that report, we noted that, while NOAA had established plans to address potential gaps in polar satellite data, those plans were only the beginning. We noted that NOAA must make difficult decisions about (1) whether and how to extend support for legacy satellite systems so that their data might

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[15] See, for example, GAO, *Polar-orbiting Environmental Satellites: Changing Requirements, Technical issues, and Looming Data Gaps Require Focused Attention*, GAO-12-604 (Washington, D.C., June 15, 2012); *High Risk Series: An Update*, GAO-13-283 (Washington, D.C.: February 2013); and GAO-13-676.

[16] The European Centre for Medium Range Weather Forecasts is an independent, intergovernmental organization supported by 34 European nations, providing global medium-to-extended range forecasts.

[17] GAO-12-604.

[18] GAO-13-283.

be available if needed, (2) how much time and resources to invest in improving satellite models so that they assimilate data from alternative sources, (3) whether to pursue international agreements for access to additional satellite systems and how best to resolve any security issues with the foreign data, (4) when and how to test the value and integration of alternative data sources, and (5) how these preliminary mitigation plans will be integrated with the agency's broader end-to-end plans for sustaining weather forecasting capabilities.

More recently, in September 2013 we reported that NOAA had identified multiple ways to help mitigate expected gaps in polar satellite data, but it had not yet developed and implemented a comprehensive contingency plan and its current mitigation plan had shortfalls when compared to government and industry best practices.[19] We recommended that NOAA establish a comprehensive contingency plan for potential satellite data gaps in the polar orbit that is consistent with contingency planning best practices. NOAA agreed with our recommendation and identified steps it planned to take to update its plan through July 2014.

JPSS is Meeting Cost and Schedule Baselines and Working to Mitigate Key Risks, but Potential Data Gaps Could Occur Sooner and Last Longer than Expected

While the JPSS program has recently completed significant development activities and remains within its cost and schedule baselines, risks remain that could increase the potential for near-term satellite data gaps in the afternoon orbit. For example, technical issues experienced during instrument development have led to reduced schedule margin and the ground system may not be ready in time for the next satellite launch. NOAA is working to mitigate these risks, but has not identified completion dates for key activities. Also, while the program has reduced its estimate for a near-term satellite data gap in the afternoon orbit, the assessment did not consider the potentially life-limiting impacts to S-NPP and other polar satellites due to an increasing threat from space debris. As a result, a gap in satellite data may occur earlier and last longer than NOAA anticipates.

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[19] GAO-13-676.

NOAA is Developing JPSS within Cost and Schedule Baselines, but Key Components Have Experienced Cost Growth and Milestone Delays

NOAA is currently developing JPSS within its cost and schedule baselines. In July 2013, NOAA formally established a cost baseline of $11.3 billion for the program through fiscal year 2025, launch dates of no later than March 2017 for JPSS-1 and December 2021 for JPSS-2, and completion dates for other important development milestones, such as the JPSS-1 critical design review and satellite integration and test review.

The JPSS cost baseline remains at $11.3 billion. NOAA currently estimates that the program's development, maintenance, and operations will cost $10.6 billion, meaning that it has about $700 million in reserve funding for unanticipated issues when compared to its cost baseline. In addition, the launch dates for the final two JPSS satellites remain on schedule since NOAA established the program's schedule baseline. JPSS-1 is still expected to launch no later than March 2017 and JPSS-2 is still expected to launch no later than December 2021. In addition, the program completed a major development milestone—the critical design review for the JPSS-1 mission—in April 2014. This is a significant accomplishment because the review affirms that the satellite design is appropriately mature to continue with development, and that the program is on track to meet mission requirements with appropriate margins and acceptable risk.

Key JPSS Components Have Experienced Cost Growth

While JPSS development is within its overall life cycle cost baseline, key JPSS components have experienced cost growth. Since July 2013, the total program cost estimate has increased by two percent, or $222 million. More than half of this increase is for three instruments. Specifically, since July 2013, the ATMS instrument's cost increased by 17 percent of its total, the CrIS instrument's cost estimate increased by 23 percent of its total, and the VIIRS instrument's cost estimate increased by 6 percent of its total. Table 3 compares cost estimates for JPSS program components since the program's key milestone review in July 2013.

Table 3: Changes in Cost Estimates for Joint Polar Satellite System Components between July 2013 and July 2014

JPSS program components	Program estimate ($M), as of July 2013	Program estimate ($M), as of July 2014	Difference ($M)	Percentage change
Flight segment	2,758	2,983	225	8%
Ground segment	1,318	1,274	-44	-3%
Program office (includes satellite operations and sustainment)	3,460	3,501	41	1%
Total:				
Total cost to complete (FY10-25)	7,537	7,759	222	3%
Legacy (enacted)	2,848	2,848	0	0%
Life cycle cost	10,385	10,607	222	2%

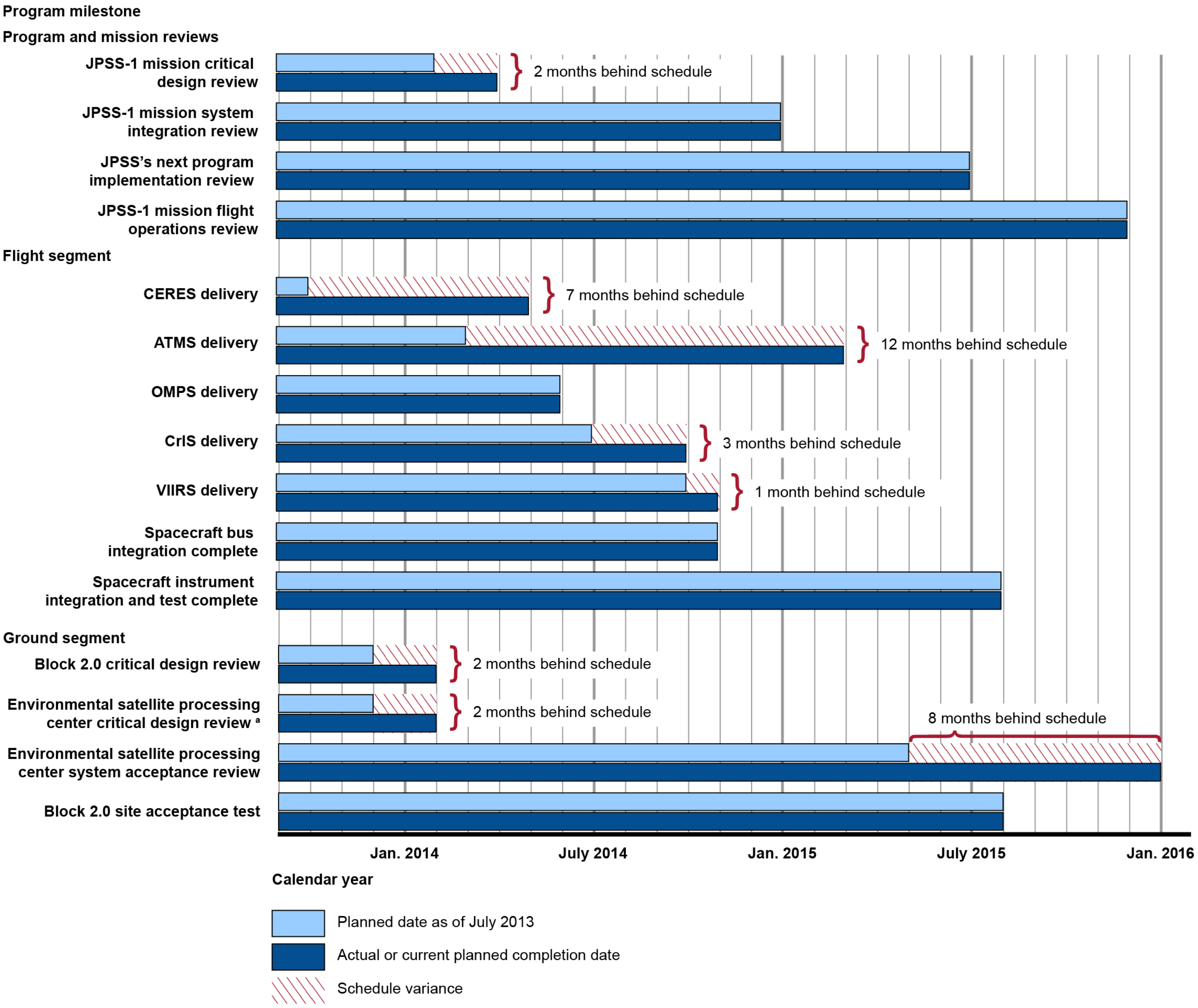
Source: GAO analysis of NOAA data. | GAO-15-47

Program officials cited multiple reasons for these cost increases, including technical issues identified with the CrIS instrument during environmental testing, the need for additional environmental testing dry runs and calibration effort for VIIRS, and the purchase of critical spare parts that are expected to help accelerate instrument development on the JPSS-2 satellite. While a 2 percent total cost increase for the program since July 2013 may appear to be relatively small given remaining reserves of roughly $700 million, the program cannot sustain this rate of growth over the long term. If JPSS costs were to continue to grow at the same rate of 2 percent of its life cycle cost estimate annually, the program could surpass its cost baseline by 2018 and end up costing $2 billion more than expected by 2025. Therefore, moving forward, it will be important for NOAA and NASA managers to aggressively monitor and control components that are threatening to exceed their expected costs.

Key JPSS Components Have Experienced Milestone Delays

While the JPSS-1 launch date has not yet been affected, key components have encountered milestone delays in development and testing. For example, since July 2013, the delivery of the ATMS instrument slipped by 12 months and the system acceptance review for the environmental satellite processing center slipped by 8 months. Figure 4 compares planned completion dates from the program’s key milestone review in July 2013 with actual or current planned completion dates for selected milestones.

Figure 4: Changes in Selected Joint Polar Satellite System (JPSS) Milestones since July 2013



Source: GAO analysis of NOAA data. | GAO-15-47

Note: CERES—Clouds and Earth's Radiant Energy System, ATMS—Advanced Technology Microwave Sounder, OMPS—Ozone Mapping and Profiler Suite, CrIS—Cross-Track Infrared Sounder, and VIIRS—Visible Infrared Imaging Radiometer Suite.

[a] The environmental satellite processing center critical design review milestone was for JPSS-supported components only.

Program officials provided multiple reasons for the schedule changes, including technical issues the ATMS instrument experienced during thermal vacuum testing, a schedule adjustment to align the environmental processing center site acceptance review with NOAA's geostationary satellite acquisition, and the October 2013 government shutdown. Officials explained that the government shutdown led the program to delay critical design reviews for ground system subcomponents that required government managers' participation, which subsequently caused delays to completion of the overall ground system critical design and the JPSS-1 mission critical design review.

These delays have caused a reduction in schedule margin prior to the JPSS-1 satellite integration and testing phase. Specifically, because of the technical issues experienced by ATMS, the instrument has now become the critical path for the entire JPSS-1 mission and only 1 month of schedule reserve remains until its expected delivery in March 2015.[20] While the program reports 6 months of schedule reserve remaining for the JPSS-1 mission through its launch readiness date, which exceeds NASA Goddard Space Flight Center development standards, with ATMS on the critical path, it will be important for NOAA and NASA managers to quickly resolve the instrument's technical issues before it becomes a more serious threat to the mission schedule and launch date.

JPSS is Addressing Key Risks, but Does Not Track Actual Completion Dates for Important Mitigation Activities

The JPSS program's risk management guidance calls for identifying risks and developing action plans for addressing the risks. These action plans are to include a list of steps to mitigate the risks and when those steps are to be completed. Further, sound risk management practices call for tracking actual completion dates against the planned schedule when implementing risk mitigation plans.[21]

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[20] The critical path is generally defined as the longest continuous sequence of activities in a schedule. As such, it defines the program's earliest completion date or minimum duration. If an activity on the critical path is delayed by a week, the program finish date will be delayed by a week unless the slip is successfully mitigated. Therefore, the critical path is most useful as a tool to help determine which activities deserve focus and, potentially, management help.

[21] See, for example, Software Engineering Institute, *CMMI® for Acquisition, Version 1.3* (Pittsburgh, Pa.: November 2010) and Project Management Institute, *A Guide to the Project Management Body of Knowledge* (PMBOK® Guide), Fifth Edition, (Newton Square, Pa.: 2013). "PMBOK" is a trademark of the Project Management Institute, Inc.

Since its key milestone review in July 2013, JPSS has identified approximately 40 key risks and has presented these during NOAA monthly program management council reviews. To mitigate these risks, the program has developed mitigation plans and started implementing those plans. Three key risks and efforts to mitigate them include:

- **JPSS-1 spacecraft vibration impacts:** Early tests showed that the spacecraft may not meet requirements associated with vibration testing, which could affect the instruments' performance. Program officials are taking steps to mitigate this risk, including working with instrument contractors to perform vibration analysis and testing and to address instances where performance does not meet specification.
- **Space debris environment:** NASA recently updated its assessment of the amount of orbital debris in the space environment to include expected increases in satellite launches and collisions between debris particles. Based on its most recent analysis, NASA identified an increased likelihood of a collision with space debris at the altitude where JPSS satellites operate. A collision with space debris could cause catastrophic damage to the satellites (see appendix II for additional information on the risks from space debris). NOAA and NASA regularly maneuver their spacecraft to avoid debris tracked by DOD's Space Surveillance Network (typically larger than 5 to 10 centimeters in size for the JPSS orbit); however, it is more difficult to address debris smaller than 5 centimeters. The JPSS program is taking steps to mitigate the risk for JPSS-1 from debris that is less than 2 centimeters, such as using shielding to protect propellant tanks, batteries, and other critical components. However, there is no shielding on S-NPP, which is currently in orbit. Further, the JPSS program currently has no way to protect the satellites from debris between 2 and 5 centimeters, as discussed later in this report.
- **ATMS amplifier issues may degrade instrument performance:** Problems with the ATMS instrument's amplifiers have been affecting the instrument's channels. NASA managers expressed a concern that the instrument could experience degraded performance in orbit. The program has traced several of the channel issues to intermediate frequency amplifiers that have been shown to have foreign object debris. In June 2014, the program initiated a mitigation plan to remove, test, clean, and rework all intermediate frequency amplifiers in the instrument.

While the program is developing mitigation plans and monitoring the execution of those plans for key risks, it has not tracked actual completion dates for the steps it is taking to address its key risks. Thus, it is not clear whether mitigation activities are being completed on, behind, or ahead of schedule. The program is not tracking actual completion dates because the program's risk management guidance does not require such tracking. While this is not required by the program's risk guidance, leading organizations including the Software Engineering Institute and Project Management Institute consider it a best practice because it allows for effective oversight. Until it tracks actual completion dates for key risk mitigation activities, NOAA will have less assurance that key risks that could affect JPSS's cost, launch schedule, and performance in orbit are being effectively mitigated.

NOAA Anticipates a 3-month Satellite Data Gap, but Other Scenarios Show Gaps that Occur Sooner and Last Longer than Expected

NOAA currently anticipates a shorter gap in satellite data than it previously estimated. In October 2013, the JPSS program office reported that a gap in between the S-NPP satellite and the JPSS-1 satellite could be as short as 3 months, which is 15 months less than NOAA estimated in 2012. This reduction is primarily due to factoring in a longer life for S-NPP because of its relatively strong performance since its launch, removing previous assumptions about satellite mechanisms (such as seals and bearings) wearing out, and reducing the expected length of the JPSS-1 satellite's on-orbit checkout phase. The program also reported that less-capable legacy satellites could provide backup data through 2019 to mitigate potential launch problems or premature instrument failures on the JPSS-1 satellite.

While it is encouraging that the program has concluded that a potential gap between S-NPP and JPSS-1 could be less than previously estimated, there are several reasons why this potential gap could occur sooner and last longer than NOAA currently anticipates.

- **Inconsistent launch date plans:** The program's analysis that JPSS-1 will be operational by June 2017 is inconsistent with NOAA's launch date commitment and the program's estimated checkout and calibration/validation period. Given that NOAA's external launch date commitment is no later than March 2017 and the program office estimates 6 months for on-orbit checkout and calibration/validation before the satellite data are operational, JPSS-1 would not be available until September 2017 or later, which increases the length of the potential gap from a minimum of 3 months to a minimum of 6 months.
- **Unproven predictions about the on-orbit checkout and validation phase:** The on-orbit checkout and calibration/validation phase could take longer than the program's estimated 6 months if there are issues with the instruments or ground systems. As a precedent, it has taken

the JPSS program more than 2 years to fully validate the highest priority data products from the S-NPP satellite.[22] In addition, if the program office's algorithm development team does not incorporate certain pre-launch updates into the ground system, additional algorithm work may be needed after the satellite launches, which could extend the validation time frame. Program officials noted that it took longer to validate data for S-NPP because it was the first satellite of the JPSS series. Program officials also stated that they are incorporating lessons learned from S-NPP's calibration and validation, such as improving communication between algorithm teams and operational users, and expect that algorithm work completed for S-NPP can be reused for JPSS-1 to shorten its validation phase.

- **Exclusion of a key risk:** The program's gap assessment does not factor in the potential for satellite failures from space debris that are too small to be tracked and avoided. As an example of the potential impact that small debris can have on JPSS satellites, an initial risk assessment of JPSS-1's propellant tanks indicated that, without shielding, there was a 29 percent risk of failure over the mission's life time, which could be reduced to as little as 0.5 percent risk of failure with shielding. However, S-NPP does not have shielding to protect it from debris smaller than 2 centimeters. Moreover, like all satellites in this orbit, even if S-NPP had shielding, the program would have limited options on how to protect the satellite from debris between 2 and 5 centimeters. Thus, the S-NPP mission could end earlier than its 5-year design life, resulting in a gap period that occurs sooner and lasts longer than expected.

NOAA officials acknowledge that the gap assessment has several limitations and stated that they plan to update it. While it is a sound management practice to identify time frames for achieving objectives, the agency has not yet established a time frame for updating its assessment.[23] Until NOAA updates its gap assessment to include more accurate assumptions and key risks, such as the potential effect of space debris, the agency risks making decisions based on a limited understanding of the potential timing and length of a gap.

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[22] NOAA officials noted that while it has taken more than 2 years to fully validate certain high priority products for S-NPP, data from ATMS were used operationally 7 months after the satellite's launch. Further, NOAA officials believe that data from instruments with a history of operational use can occur within 4 months of launch if they have similar data quality.

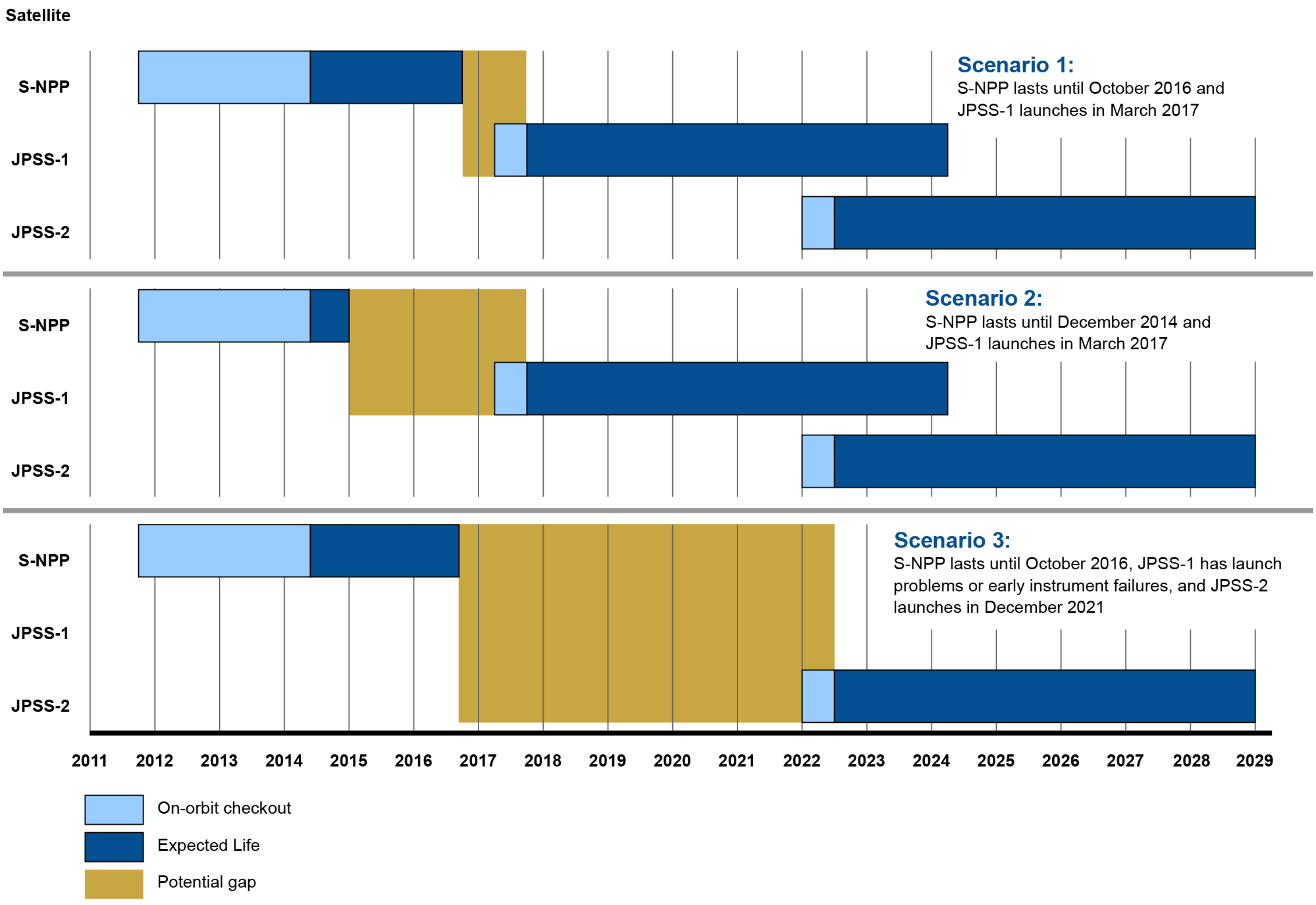
[23] Software Engineering Institute, *CMMI® for Acquisition, Version 1.3.*

Alternative Scenarios Depict a Longer Gap

While NOAA believes the gap between the time when the S-NPP satellite reaches the end of its life and the time when the JPSS-1 satellite is to be in orbit and operational could be as little as 3 months, we believe that there are other plausible scenarios where a gap could be substantially longer. Depending on different assumptions, a gap could span from 11 months to more than 3 years. In one scenario, S-NPP would last its full expected 5-year life (to October 2016), and JPSS-1 would launch as soon as possible (in March 2017) and undergo calibration/validation for 6 months as predicted by the JPSS program office (until September 2017). In that case, the data gap would extend 11 months.

In another scenario, S-NPP could fail this year as a result of impacts to the satellite from orbital debris. Assuming that the JPSS-1 launch occurred in March 2017 and the satellite data was certified for official use by September 2017, this gap would extend for 33 months. Of course, any problems with JPSS-1 development resulting in launch delays, launch problems, or delays in the planned 6-month calibration/validation period could extend the gap period. For example, another scenario could occur in which S-NPP lasts until October 2016 and JPSS-1 experiences launch problems or early instrument failures, resulting in a gap until JPSS-2 launches (in December 2021) and undergoes calibration/validation for at least 6 months (until June 2022). In that scenario, there could be a gap of 5 years and 8 months. Figure 5 depicts possible gap scenarios.

Figure 5: Potential Scenarios for a Gap in Polar Satellite Data in the Afternoon Orbit



Scenario 1:
S-NPP lasts until October 2016 and JPSS-1 launches in March 2017

Scenario 2:
S-NPP lasts until December 2014 and JPSS-1 launches in March 2017

Scenario 3:
S-NPP lasts until October 2016, JPSS-1 has launch problems or early instrument failures, and JPSS-2 launches in December 2021

Source: GAO analysis based on NOAA and NASA data. | GAO-15-47

Note: S-NPP—Suomi National Polar-orbiting Partnership, JPSS-1—Joint Polar Satellite System-1, and JPSS-2—Joint Polar Satellite System-2.

Multiple Alternatives Exist for Mitigating a Satellite Data Gap—Each with Benefits and Challenges—but They are Unlikely to Fully Address a Near-term Gap

NOAA and other experts in the weather satellite and modeling community have identified multiple alternatives for mitigating a potential gap in polar satellite data in the afternoon orbit. The alternatives can be separated into two general categories. The first category includes actions to prevent or limit a potential gap by providing JPSS-like capabilities. The second category includes actions that could reduce the impact of a potential gap by (a) extending and expanding the use of current data sources with capabilities similar to the JPSS program; (b) enhancing modeling and data assimilation; (c) developing new data sources; or (d) exploring opportunities with foreign and domestic partners. See table 4 for examples of alternatives within each of the categories.

Table 4: Key Alternatives for Mitigating a Potential Satellite Data Gap in the Afternoon Orbit

Gap mitigation categories and subcategories	Key alternatives
Prevent or limit a potential gap	• extend S-NPP mission life • ensure the timely and successful JPSS-1 launch • accelerate JPSS-2 launch readiness • establish a “gap filler” mission • establish the SIDAR mission
Reduce the impact of a potential gap	
• Extend and expand use of current data sources	• extend legacy satellites (POES, Aqua) • rely on DOD DMSP • rely on European Metop satellites • expand aircraft observations from domestic and international commercial flights • expand Global Positioning System radio occultation data • expand the use of direct readout imagery from satellites over Alaska • rely on NASA’s Aura satellite in the afternoon orbit • rely on NOAA’s geostationary satellites for data collection
• Enhance modeling and data assimilation	• enhance 4-dimensional data assimilation • accelerate global model research to operations • increase high-performance computing capacity for research and operations • enhance the blending of global models • add additional direct readout sites to reduce data latency
• Develop new sources	• develop geostationary satellite imagery-derived moisture profiles • develop atmospheric motion vectors (imagery-derived wind information) • develop cloud-impacted infrared and microwave soundings • develop doppler wind lidar • develop products from NASA’s Global Precipitation Measurement mission • implement targeted observations from unmanned aircraft

Gap mitigation categories and subcategories	Key alternatives
• Explore partnership opportunities	• explore accelerated procurement (sensors, satellites, and launch vehicles) • explore contracting for small satellites provided by industry • explore commercial data buys • explore hosted payloads • explore prototype-stage technologies • explore the use of data from China’s Feng-Yun 3 series • explore the use of Canada’s proposed Polar Communications and Weather mission • explore the use of European Sentinel satellites • explore the use of Japan’s Global Change Observation Mission – Water 2 and Water 3 satellites • explore the use of Japan’s Global Change Observation Mission for Climate satellite • explore the use of International Space Station as a host for instruments • explore the use of a French and Indian satellite in the early morning orbit • explore the use of Russian search and rescue capability in the early morning orbit • explore the use of proposed Canadian small satellite as SARSAT “gap filler”

Source: GAO analysis based on interviews with experts from weather satellite-related organizations. | GAO-15-47

Note: DOD—Department of Defense; DMSP—Defense Meteorological Satellite Program; JPSS-1—Joint Polar Satellite System-1; JPSS-2—Joint Polar Satellite System-2; Metop—Meteorological Operational (satellite); NASA—National Aeronautics and Space Administration; POES—Polar-orbiting Operational Environmental Satellites; NOAA—National Oceanic and Atmospheric Administration; SARSAT—Search and Rescue Satellite-Aided Tracking system; SIDAR—Solar Irradiance, Data, and Rescue; and S-NPP—Suomi National Polar-orbiting Partnership.

Alternatives for Preventing or Limiting a Satellite Data Gap Offer Benefits and Pose Challenges

There are several ways to reduce the likelihood of a potential gap by providing continuity for NOAA’s observational requirements in the afternoon polar orbit. These include:

- **S-NPP mission life extension:** This involves gathering lessons learned from long-lived NOAA and Goddard Space Flight Center missions that can be applied to S-NPP to prevent a near-term gap from occurring. It includes reviewing satellite monitoring and trending processes, identifying life-limiting items and consumables, assessing the status of residual risk and watch items, and ensuring the robustness of operations in response to on-orbit component failures.
- **Timely and successful JPSS-1 launch:** This involves taking the necessary steps to ensure the timely and successful launch of the JPSS-1 satellite. This includes keeping JPSS-1 within budget as well as continuing to aggressively manage the program’s progress towards its launch date.
- **JPSS-2 launch readiness acceleration:** This involves accelerating the development of the JPSS-2 satellite to reduce the likelihood of a potential gap should there be issues with the JPSS-1 satellite. It includes evaluating proposals and negotiating instrument contracts.

- **“Gap filler” mission:** Recommended by an independent review team, this alternative involves the potential implementation of “gap filler” satellites that would carry two key environmental instruments: ATMS and CrIS. The purpose of the satellites would be to bridge a gap in polar satellite data due to S-NPP failure, JPSS-1 launch failure, or JPSS-1 spacecraft failure.
- **SIDAR mission:** This alternative is intended to bridge the gap between satellites currently providing search and rescue, data collection, and solar irradiance capabilities in the afternoon polar orbit. It provides observations that were once part of the JPSS mission.

These alternatives have multiple benefits and challenges. Benefits include providing continuity for the S-NPP and JPSS-like observations. Challenges include the time it would take to develop the gap-filler instruments as well as the funding necessary to acquire them. Also, NOAA has not yet decided whether and how it will establish the SIDAR mission. Table 5 describes the key benefits and challenges commonly identified for alternatives that could reduce the likelihood of a potential afternoon polar data gap.

Table 5: Key Benefits and Challenges for Alternatives that Could Reduce the Likelihood of an Afternoon Polar Data Gap

Alternatives	Key benefits	Key challenges
S-NPP mission life extension	• Provides continuity of JPSS-like observations • Minimizes impact to users and operations	• Satellite may not last as long as expected
Timely and successful JPSS-1 launch	• Provides continuity of JPSS-like observations • Minimizes impact to users and operations	• JPSS-1 may not be technically and mechanically ready for launch
JPSS-2 launch readiness acceleration	• Provides continuity of JPSS-like observations • Reduces the gap if there was a JPSS-1 failure	• The spacecraft and instruments may not be available in time for an early launch • This option may require additional funding
“Gap filler” mission recommended by the National Environmental, Satellite, Data, and Information Service (NESDIS) Independent Review Team	• Provides continuity of JPSS-like observations (ATMS/CrIS) • Reduces the gap if there was a JPSS-1 failure	• The spacecraft and instruments may not be available in time for an early launch • This option would require funding
NOAA’s SIDAR mission	• Provides continuity of polar observations (TSIS, A-DCS, SARSAT)	• This option would require funding

Source: GAO analysis based on interviews with experts from weather satellite-related organizations. | GAO-15-47

Note: A-DCS—Advanced Data Collection System; ATMS—Advanced Technology Microwave Sounder; CrIS—Cross-Track Infrared Sounder; JPSS—Joint Polar Satellite System; JPSS-1—Joint Polar Satellite System-1; JPSS-2—Joint Polar Satellite System-2; NOAA—National Oceanic and Atmospheric Administration; SARSAT—Search and Rescue Satellite-Aided Tracking system; SIDAR—Solar Irradiance, Data, and Rescue; S-NPP—Suomi National Polar-orbiting Partnership; and TSIS—Total and Spectral Solar Irradiance Sensor.

Alternatives for Reducing the Impact of Satellite Data Gaps in the Afternoon Polar Orbit Offer Unique Benefits and Challenges

The alternatives that could reduce the impact of a potential afternoon polar data gap include both space-based and non-space-based mitigation options. This category of alternatives can be separated into the following subcategories: (a) extend and expand the use of current data sources; (b) enhance modeling and data assimilation; (c) develop new data sources; and (d) explore opportunities with foreign and domestic partners. The following provides more details on each of the subcategories.

- **Extend and expand the use of current data sources:** This includes alternatives for observations that are currently available and in use and that, if extended or expanded, might mitigate the impact of an afternoon polar data gap. For instance, extending the life of legacy satellites—such as POES and Aqua—could provide similar, but less capable, backup observations if there were a gap. Also, extending and expanding other current data sources that are already top contributors to numerical forecast models, such as aircraft observations from domestic and international commercial flights and Global Positioning System radio occultation measurements, could mitigate the impact of a gap by providing more observations. Additionally, continuing to rely on and improve NOAA's use of observations from other polar satellites outside the afternoon orbit, such as DOD's DMSP and European Metop satellites, could also help alleviate the impact of a gap in the afternoon polar orbit by providing similar environmental observations that occur at different times of the day.
- **Enhance modeling and data assimilation:** This includes alternatives that enhance the extraction of information from existing observed data, including data assimilation and modeling, increased operational computing capability, and multi-model ensemble products. Enhancing this back-end data processing could help mitigate the impact of a polar-orbiting satellite data loss in the afternoon orbit by making numerical forecast models more efficient and effective in processing data that continues to be received. For example, employing 4-dimensional data assimilation could improve the use of observations by using better quality assurance and higher resolution analysis. Also, accelerating the next-generation global forecast model from research into operations would mitigate forecasting skill loss by introducing more advanced modeling techniques and higher resolution. Additionally, blending global models could mitigate the impact of an afternoon gap in observations by adjusting the weights of the other global models used to influence the forecast to minimize the degradation in NOAA weather services. Finally, adding additional direct readout sites could make the remaining observations more useful by reducing data latency (the time it takes for data to reach the

forecast models) potentially allowing for more observations to be used in each model run.

- **Develop new data sources:** This includes alternatives that are hypothesized to have a positive impact on weather forecast models but need more time for development and testing before they are technically and operationally ready. For instance, data from geostationary satellite imagery-derived moisture profiles, atmospheric motion vectors (imagery-derived wind information), cloud-impacted infrared and microwave soundings, and doppler wind lidar could contribute to better forecast model performance and possibly reduce model dependence on existing data sources. Also, the targeted observations from manned and unmanned aircraft could provide a proving ground for performing demonstrations with new instruments that may mitigate the loss of polar satellite observations.
- **Explore partnership opportunities:** These alternatives focus on the partnership between NOAA and another party (i.e., commercial vendors, foreign government, NASA, DOD, and academia) to help mitigate a potential gap in the afternoon polar orbit. This includes alternatives such as accelerating the procurement of sensors, satellites, and launch vehicles; contracting for small satellites provided by industry; commercial data buys; hosted payloads; and prototype-stage technologies. Additionally, creating partnership agreements with foreign governments to potentially acquire data from satellites like China’s Feng-Yun 3 series, Canada’s proposed Polar Communications and Weather mission, and European Sentinel satellites could help reduce the impact of a potential gap by acquiring data that NOAA could use in weather forecast models, obtaining imagery in higher latitude and polar regions, or collecting data for processing environmental products.

There are key benefits and challenges associated with these alternatives. A key benefit is that some observations are already in use. For instance, aircraft observations and Global Positioning System radio occultation are already top contributors to numerical weather prediction models’ error reduction, and by extending and expanding their use, the models should become more resilient in the event of a gap. Also, the alternatives that enhance modeling and data assimilation could also make NOAA’s weather models more effective in dealing with a data gap. Key challenges involve timeliness. Because new data sources still need to be developed and tested, they may not be operational in time for a potential near-term gap. In addition, alternatives that require partnership agreements may not address a potential near-term gap due to data processing and data sharing concerns. Table 6 describes the key benefits and challenges commonly identified for alternatives that could reduce the impact of a potential gap.

Table 6: Key Benefits and Challenges for Alternatives that Could Reduce the Impact of an Afternoon Polar Data Gap

Subcategory	Key benefits	Key challenges
Extend and expand use of current data sources *Examples: extension of legacy satellites (POES, Aqua), DMSP, midmorning orbit data from European Metop satellites, aircraft observations from domestic and international commercial flights, and Global Positioning System radio occultation data.*	• Legacy satellites' observations, even though of lesser quality, could help partially mitigate the impact of potential gaps • Users are currently using and familiar with data sources • Global Positioning System radio occultation is an "anchor measurement" that improves the accuracy of other data sources in numerical weather prediction models • Aircraft observations and Global Positioning System radio occultation are top contributors to numerical weather prediction models' error reduction after polar microwave and infrared sounders	• Legacy polar sounders and imagers are not the same quality as ATMS, CrIS, and VIIRS • Legacy satellites may not be available when a gap occurs • Aircraft observations are limited by flight paths, which limit global and vertical coverage • Certain alternatives (i.e. DMSP, Metop) are not in the afternoon polar orbits
Enhance modeling and data assimilation *Examples: 4-dimensional data assimilation, accelerating global model research to operations, increasing high-performance computing capacity for research and operations, blending of global models, and adding additional direct readout sites to reduce data latency.*	• 4-dimensional data assimilation makes weather forecast models more robust with fewer observations • The next-generation global forecast model could improve NOAA's forecast skill with or without a gap • Other alternatives' development are enabled by additional research and operational high-performance computing	• Alternatives do not replace the need for observations • High-performance computing capacity for research and operations is in high demand • 4-D data assimilation and accelerating the next-generation global forecast model may not be operational in time for a potential gap before JPSS-1 launches
Develop new sources *Examples: geostationary satellite imagery-derived moisture profiles, atmospheric motion vectors (imagery-derived wind information), cloud-impacted infrared and microwave soundings, doppler wind lidar, and targeted observations from unmanned aircraft.*	• New data sources are promising in terms of mitigating the impact of data gaps by providing additional observations to the models • Non-NOAA weather organizations are already using certain data sources operationally	• New data sources can take one year or longer to transition to operations after the science is developed • Certain data sources' mitigation value may not prove to be worth implementing operationally • Unmanned aircraft may have difficulty targeting weather events as they develop (which is key for weather forecast model contribution)

Subcategory	Key benefits	Key challenges
Explore partnership opportunities *Examples: accelerated procurement (sensors, satellites, and launch vehicles), contracting for small satellites provided by industry, commercial data buys, hosted payloads, prototype-stage technologies, China's Feng-Yun 3 series, Canada's proposed Polar Communications and Weather mission, European Sentinel satellites, and various foreign satellites with search and rescue sensors.*	• Foreign satellites could provide more observations into models • Foreign satellites may offer instruments and capabilities that are comparable to JPSS program requirements • Commercially developed solutions may provide future or long-term options	• New foreign partnership agreements may not address a near-term gap • NOAA requires agreements related to open data sharing • Partnerships increase potential data security risks • New foreign partnership agreements increase reliance on foreign governments for observations • Commercial data buys and hosted payloads have limited options in the short-term • Foreign SARSAT and A-DCS capabilities do not cover the polar afternoon orbit

Source: GAO analysis based on interviews with experts from weather satellite-related organizations. | GAO-15-47

Note: A-DCS—Advanced Data Collection System; ATMS—Advanced Technology Microwave Sounder; CrIS—Cross-Track Infrared Sounder; DMSP—Defense Meteorological Satellite Program; JPSS—Joint Polar Satellite System; JPSS-1—Joint Polar Satellite System-1; Metop—Meteorological Operational (satellite); NOAA—National Oceanic and Atmospheric Administration; SARSAT—Search and Rescue Satellite-Aided Tracking system; and VIIRS—Visible Infrared Imaging Radiometer Suite.

Key Alternatives May Not be Available in Time to Address a Near-term Data Gap

While there are multiple alternatives available for preventing and reducing the impact of a gap, most of these options may not be available soon enough to address a near-term gap. In terms of preventing the potential gap, NOAA is currently doing what it can to extend the S-NPP mission life and to ensure the timely and successful JPSS-1 launch. However, the other alternatives for preventing a gap (including accelerating JPSS-2 launch readiness and acquiring a "gap filler" satellite) are not viable in the near-term because these instruments take years to develop and test. Additionally, NOAA is not currently funding the SIDAR mission.

Alternatives that extend and expand the use of current data sources are viable solutions to reduce the impact of a potential gap because users are familiar with and using the existing data sources. However, alternatives for enhancing modeling and data assimilation, developing new sources, and exploring partnership opportunities face challenges that may restrict them from reducing the impact of a potential near-term gap. For instance, it would take additional high-performance computing capacity to enhance modeling and data assimilation. Also, developing new data sources may take additional time to transition to operational use after the research is finished. In addition, NOAA would need to establish agreements about data sharing, data processing, and information security before embarking on new foreign partnership agreements, which may be subject to legal restrictions. Finally, while long-term commercial partnerships could address satellite data needs, these options will not likely be available in time to address a near-term gap.

While all of the alternatives have trade-offs, several alternatives may represent the best known options for reducing the impact of a gap:

- Extending legacy satellites like POES and Aqua, continuing to obtain data from European midmorning satellites, and ensuring legacy and European satellites' data quality remains acceptable would be a strong fallback strategy because forecasters and their models have been using these data operationally for years. Moreover, these alternatives could be important in the near-term when other options may not be available.
- Obtaining additional observations of radio occultation and commercial aircraft data are likely to provide more significant mitigation than other data sources because studies conducted by leading forecast modeling centers have validated that they are among the top contributors for reducing forecast errors.
- Advancing 4-dimensional data assimilation and the next generation global forecast model are likely to provide significant mitigation because they are expected to make more efficient use of data that are still available and produce improved techniques for evaluating data with each model run.
- Increasing high-performance computing capacity is likely to provide significant mitigation because it is the key factor for enabling greater resolution in existing and future models and it drives the pace of development for assimilation of new or additional data that could further improve NOAA's models.

As discussed in the next section, NOAA is currently pursuing all of these alternatives, although it has had mixed progress in implementing them.

NOAA Improved its Contingency Plan, but Delays May Limit The Effectiveness of Key Mitigation Activities and Oversight is Inconsistent

Government and industry best practices call for the development of contingency plans to maintain an organization’s essential functions in the case of an adverse event.[24] As a complement to risk mitigation, contingency planning includes strategies that attempt to reduce or control the impact of risks should they occur. These practices identified by, for example, the National Institute of Standards and Technology and the Software Engineering Institute, include key elements such as defining failure scenarios, identifying and selecting strategies to address failure scenarios, developing procedures and actions to implement the selected strategies, testing the plans, and involving affected stakeholders. These elements can be grouped into categories, including (1) identifying failure scenarios and impacts, (2) developing contingency plans, and (3) validating and implementing contingency plans (see table 7).

Table 7: Guidelines for Developing a Sound Contingency Plan

Category	Description of key activities
Identifying failure scenarios and impacts	Includes defining failure scenarios; conducting impact analyses that show the impact of failure scenarios; defining minimum acceptable levels of outputs and recovery time objectives; and establishing resumption priorities.
Developing contingency plans	Includes identifying alternative solutions to address failure scenarios; selecting contingency strategies from among alternatives based on costs, benefits, and impacts; defining actions, roles and responsibilities, triggers, and timelines for implementing contingency plans; developing “zero-day” procedures; ensuring that steps reflect priorities for resumption of products and recovery objectives; and obtaining review and approval of the contingency plan from designated officials.
Validating and implementing contingency plans	Includes identifying steps for testing contingency plans and conducting training exercises; preparing for and executing tests; validating test results for consistency against minimum performance levels; executing applicable actions for implementation of contingency strategies; communicating and coordinating with stakeholders to ensure that the strategies remain optimal for reducing potential impacts; and updating and maintaining contingency plans as warranted.

Source: GAO analysis of guidance documents from the National Institute of Standards and Technology, Software Engineering Institute, and GAO. | GAO-15-47

NOAA developed its original polar satellite gap contingency plan in October 2012. We reported in September 2013 that NOAA had not yet selected the strategies from its plan to be implemented or developed procedures and actions to implement the selected strategies.[25] Further,

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[24] See GAO, *Year 2000 Computing Crisis: Business Continuity and Contingency Planning*, GAO/AIMD-10.1.19 (Washington, D.C.: August 1998); National Institute of Standards and Technology, *Contingency Planning Guide for Federal Information Systems*, NIST 800-34 (May 2010); Software Engineering Institute, *CMMI® for Acquisition, Version 1.3* (Pittsburgh, Pa.: November 2010).

[25] GAO-13-676.

NOAA's initial plan had shortfalls when compared to government and industry best practices. NOAA agreed with our recommendation to establish a comprehensive contingency plan for potential satellite data gaps in the polar orbit that is consistent with contingency planning best practices.

In February 2014, NOAA updated its polar satellite gap contingency plan. NOAA's revised plan focuses on gap mitigation for weather services through activities in three primary categories: (1) understanding the probability and impacts of a gap, (2) preventing potential gaps, and (3) reducing the impact of potential gaps. The plan also includes actions for maintaining other important capabilities in the polar afternoon orbit, including continuing the total solar irradiance data record, continuing data collection, and continuing search and rescue support.

NOAA has made several notable improvements with its recent plan update. For example, NOAA has expanded its plan to include additional alternatives that experts identified. In addition, the plan accounts for additional gap scenarios such as the loss of early morning DMSP satellite data and midmorning European satellite data; integrates other alternatives that were identified from a prior study; identifies the mitigation strategies to be executed; and identifies specific activities with roles and responsibilities, triggers, and deadlines for implementing those strategies.

However, additional work remains for NOAA's contingency plan to fully address government and industry best practices for contingency planning. For example, NOAA's plan does not yet include an assessment of the available alternatives based on their cost and potential impacts and testing remains to be executed in order to validate that the agency has the optimal contingency plan. The following table describes previously identified weaknesses in NOAA's October 2012 contingency plan and the extent to which the agency has made progress in addressing the shortfalls in its latest plan.

Table 8: NOAA's Progress in Polar Satellite Contingency Planning

October 2012 contingency plan weaknesses	Description of progress in February 2014 plan
Category: Identifying failure scenarios and impacts	
The plan did not address certain scenarios such as the possibility of a loss of data from DOD and European partner satellites in morning orbits or a Japanese partner mission in the afternoon orbit.	Progress: Partially addressed The revised plan states that NOAA reviewed its analyses and available information and determined that there were no other options to DOD and European satellites in the morning orbits and the options in its current contingency plan will serve as mitigation against the potential loss of this data. NOAA also stated that it participated in the Air Force Space Command analysis of alternatives so that it is cognizant of DOD follow-on satellite plans and how they may affect NOAA's plans. However, the Air Force has not finalized its plans for a weather follow-on mission. Thus, NOAA does not yet have full knowledge about the probability of data availability or capabilities to be provided by future DOD polar satellites. The plan notes that the agency has had a memorandum of agreement in place with Japan since 2011 to obtain microwave imagery from its satellites. According to NOAA, the current Japanese satellite is expected to last until at least 2017 and two more missions are to provide continuity for this data through 2025. However, NOAA has also identified risks to Japan's ability to secure funding for these next two satellites with no comparable sensor to support 13 JPSS product requirements.
The plan did not include recovery time objectives for key data products.	Progress: Not addressed The plan states that future updates will provide information on recovery time objectives for key data products.
Category: Developing contingency plans	
The plan did not identify the contingency strategies NOAA selected to be implemented or establish procedures and actions to implement the selected strategies.	Progress: Partially addressed NOAA's revised plan identifies approximately 30 contingency strategies to be implemented in four categories: (1) understanding the probability and impacts of a gap; (2) preventing potential gaps; (3) reducing the impact of potential gaps; and (4) maintaining other capabilities. The plan includes procedures and actions to implement the selected strategies in each of these areas, such as conducting observing system experiments to replicate conditions during a gap period; installing additional high-performance computing capacity; extending mission life for the current polar satellite; and assimilating new observations on clouds, commercial aircraft, and other data.[a] However, the plan appears to be incomplete. NOAA has three ongoing gap mitigation projects that are not included in the polar satellite gap contingency plan. They are (1) S-NPP data processing and distribution; (2) the Hurricane Forecast Improvement Project; and (3) moving the Hurricane Forecast Improvement Project from research to operations. In addition, there are other alternatives identified by experts that are not included in NOAA's contingency plan. These include: (1) developing doppler wind lidar, (2) developing products from NASA's Global Precipitation Measurement mission, and (3) exploring the use of the International Space Station as a host for instruments.
The plan had not yet been integrated with other alternatives that were subsequently identified.	Progress: Fully addressed The revised plan integrates alternatives identified in NOAA's October 2012 plan with additional options identified in a subsequent study.
NOAA had not yet assessed its alternative strategies based on costs, benefits, and potential impacts.	Progress: Not addressed The plan does not provide details on NOAA's assessment of the available alternatives based on their costs, benefits, and potential impacts.

October 2012 contingency plan weaknesses	Description of progress in February 2014 plan
The plan did not identify options for preventing gaps from occurring.	Progress: Fully addressed The plan currently identifies mitigation steps being taken or to be taken to prevent gaps from occurring.
The plan did not identify opportunities for accelerating the calibration and validation phase—the time between launch and availability of operational products—for JPSS-1.	Progress: Partially addressed We reported in September 2013 that NOAA had experienced delays in validating key products for S-NPP. NOAA's revised plan states that the calibration and validation phase for JPSS-1 key performance parameter data (ATMS, CrIS, and VIIRS) will be 6 months. Program officials stated that they believe calibration times will be less for JPSS-1 due to the collection of S-NPP on-orbit data and their experience in calibrating and validating S-NPP instruments and data, including lessons learned. However, it has taken the program over 2 years to calibrate and validate S-NPP data and we have concerns as to whether calibration/validation can be completed in 6 months. According to NOAA, future plan updates are to provide an assessment of opportunities for further accelerating the calibration and validation phase on JPSS-1 and JPSS-2.
The plan did not always identify specific actions with defined roles and responsibilities, timelines, and triggers.	Progress: Partially addressed The plan identifies specific actions for mitigation strategies, general roles and responsibilities, line offices that are responsible for implementing specific actions, and triggers that are to result in actions or decisions when certain events occur. Among other scheduling best practices, an exposure draft of GAO's *Schedule Assessment Guide* states that durations should be reasonably short and meaningful and allow for discrete progress measurement.[b] However, the timelines in NOAA's plan do not provide for meaningful progress measurement because activity deadlines are long in duration—by fiscal year or longer—while other activities have no deadlines. GAO's *Schedule Assessment Guide* also states that activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. NOAA's plan does not clearly identify activities that need to be completed before other activities can begin, such as high performance computing upgrades that are required for observing system experiments and assimilation of new data sources. There is no integrated master schedule that identifies such linkages across NOAA's polar gap mitigation activities. Because deadlines are long in duration or do not exist for certain projects and there is no schedule integrating mitigation activities that are dependent upon each other, NOAA's ability to measure progress and ensure its planned activities remain on schedule is constrained.
Category: Validating and implementing contingency plans	
NOAA had not yet initiated efforts to validate or implement its gap mitigation plan.	Progress: Partially addressed NOAA has begun implementing its plan. Initial steps to acquire data, develop the science for new data, install technology and infrastructure upgrades, and hire subject matter experts are generally planned for fiscal year 2014 while validation activities are generally to be performed in fiscal year 2015 or later. However, completion dates for testing and validating the alternatives are not always defined. Until additional testing and validation activities are executed, NOAA will not have full knowledge regarding the potential impact of its planned contingency actions.

Source: GAO analysis of NOAA data. | GAO-15-47

[a] Observing system experiments provide objective assessments of existing observing systems' contributions to numerical weather forecasts while observing system simulation experiments provide objective assessments of the contributions to numerical weather forecasts from future potential observing systems.

[b] *GAO Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-12-120G (exposure draft) (Washington, D.C.: May 30, 2012).

NOAA's contingency plan and NOAA officials acknowledge several of these shortfalls, including the need to identify recovery time objectives, identify opportunities for further accelerating the calibration and validation phase for JPSS-1 and JPSS-2, update trigger points, and review options for testing and validating the plan. The plan and agency officials stated that these elements would be added to future updates that are to occur on a semiannual cycle. In addition, the NESDIS official responsible for updating and reporting on the status of NOAA's contingency plan stated that the plan did not include details on NOAA's assessment of the available alternatives based on their costs, benefits, and potential impacts because decisions on those alternatives were still being deliberated at the time of the last plan update. Also, a National Weather Service scientist who played a key role in selecting NOAA's gap mitigation strategies stated that, while the agency can make educated guesses about the potential impacts to numerical forecast systems for certain alternatives, scientists will not be able to validate the impact of these mitigation strategies until the strategies are ready for the implementation phase and are tested for their individual contributions in an operational forecast system. Based on current schedules, such testing is generally not expected to occur until fiscal year 2015 or later for National Weather Service gap mitigation strategies. Until NOAA fully addresses the elements identified above to improve its contingency plan, it may not be sufficiently prepared to mitigate potential gaps in polar satellite coverage.

NOAA Has Begun Implementing its Contingency Plan, but Key Activities Have Encountered Setbacks and Efforts to Monitor Progress Are Not Consistent or Comprehensive

While NOAA has started to implement its polar satellite gap contingency plan, it has experienced challenges in implementing key activities outlined in the plan. From the variety of alternatives noted earlier, NOAA has identified 21 mitigation projects that are to be implemented in order to address the potential for satellite data gaps in the afternoon polar orbit. These projects are supported primarily from the weather satellite data gap mitigation reserve fund from the Disaster Relief Appropriations Act, 2013. Table 9 summarizes the gap mitigation projects NOAA is implementing.

Table 9: Polar Gap Mitigation Projects Being Implemented by NOAA

Project	Budget ($M)	Original estimated completion	Key expected outcomes
Operational high-performance computing to accommodate data assimilation upgrades and observation enhancements	$18.6M	Dec 2014	• Increase horizontal resolution of the Global Forecast System (NOAA's primary forecast model) from 27 to 10 kilometers through 10-day forecasts • Make similar improvements to other models
POES/Metop data continuity	$17.4M	Aug 2015	• Ensure continuity of the key performance parameter measurements from Metop
Augmenting research high-performance computing resources and software engineering	$15.0M	Apr 2015	• Rebalance research and development capacity to approximately twice that of operations to support experimental runs of higher resolution, more complex models • Provide support for other gap mitigation activities
Hurricane Forecast Improvement Project	$10.1M	Mar 2015	• Improve numerical hurricane forecast system to reduce errors in track and intensity by 50% (20% in first 5 years) • Extend forecast skill beyond 7 days • Improve prediction of rapid intensification, reduce false alarms • Reduce overall preventable losses
Targeted observations for high impact events	$9.0M	Dec 2016	• Quantify the significance of unmanned observations to high impact weather prediction • Quantify the cost and operational benefit of unmanned observing technology for high impact weather prediction
Aircraft observations	$9.0M	Jan 2016	• Increase accuracy of numerical weather prediction for high impact events • Quantify the value of aircraft observations • Increase forecast skill performance by 1.0%
Hurricane Forecast Improvement Project: research to operations	$3.6M	Mar 2015	Same as Hurricane Forecast Improvement Project
Observing system simulation experiments	$3.3M	Dec 2015	• Develop the next generation global observing system simulation experiment system to replace the current obsolete system • Conduct preliminary observing system experiments and observing system simulation experiments in support of data gap mitigation
S-NPP data processing and distribution	$3.0M	Sep 2015	• Enable 24/7 data processing for S-NPP (currently 8 hours/5 days per week)
Geostationary data (GOES-R and international missions)	$2.7M	Nov 2015	• Provide new operational cloudiness product for users • Increase forecast skill performance by 0.25%
Assimilation of cloud-impacted radiances, quality control, observation error, and surface emissivity formulations	$2.5M	Nov 2015	• Increase the amount and spatial coverage of data assimilated for operations • Reduce the probability of a poor forecast • Increase forecast skill performance by 2.0%

Project	Budget ($M)	Original estimated completion	Key expected outcomes
Blends of global models	$2.0M	Dec 2015	• Provide improved verification product set for future use • Increase forecast skill by 1.0%
High-performance computing hardware augmentation for observing system simulation experiments	$2.0M	Dec 2015	• Accelerate research to operations activities with gap mitigation value • Support data denial experiments to assess numerical weather prediction impacts from potential data gaps • Support assessments of potential impact of future sensors on numerical weather prediction
Dual X/L band direct broadcast receipt sites	$1.7M	July 2016	• Install three new direct broadcast antennas at Monterey, California; Miami, Florida; and Puerto Rico • Reduce latency of sounder data from polar-orbiting satellites to less than 15 minutes • Provide direct broadcast users with satellite sounder products
Direct readout imagery from other satellites	$1.7M	Aug 2015	• Transform direct broadcast research system in Alaska to operational capability • Ensure reliable flow of satellite data to Alaska operations
Atmospheric motion vectors	$1.0M	Nov 2015	• Transfer atmospheric motion vector algorithms developed by the Navy and University of Wisconsin into NOAA operations • Increase forecast skill by 0.5%
High-performance computing software management and integration	$0.9M	Dec 2014	Same as operational high-performance computing project
Geostationary data (GOES-R and international)	$0.8M	Nov 2015	• Ensure Himawari-8 advanced imagery data are available to numerical weather prediction models
4-dimensional data assimilation	$0.8M	Nov 2015	• Improve use of observations by using better quality assurance and higher resolution • Increase computational efficiency and reduce code components • Increase forecast skill by 1.5%
Observing system experiments	$0.2M	Nov 2015	• Run regional experiments to replicate model conditions with no polar afternoon satellite data • Identify quantitative impact of data gap and latency on standard forecast scores
DMSP Special Sensor Microwave Imager/Sounder	$0.1M	Sep 2014	• Assimilate DMSP Special Sensor Microwave Imager/Sounder data into NOAA systems

Source: GAO analysis based on NOAA data. | GAO-15-47

Note: DMSP—Defense Meteorological Satellite Program, GOES-R—Geostationary Operational Environmental Satellite-R series, Metop—Meteorological Operational (satellite), NOAA—National Oceanic and Atmospheric Administration, POES—Polar-orbiting Operational Environmental Satellites, and S-NPP—Suomi National Polar-orbiting Partnership.

NOAA has demonstrated progress by implementing initial activities on these gap mitigation projects. The agency offices responsible for these projects have reported completing initial milestones such as defining statements of objectives, developing spending plans, obtaining funding, and getting the necessary workforce in place for execution. In addition, certain mitigation projects, such as the Hurricane Forecast Improvement Project and observing system experiments, have already begun. NOAA also completed a key upgrade to two supercomputers to be used for observing system simulation experiments.

However, NOAA has experienced delays in executing other key activities. For example:

- A planned upgrade to the National Weather Service's (NWS) operational high-performance computing was to occur by December 2014, but officials stated that the planned upgrade could be delayed by 12 months or longer to implement risk mitigation activities associated with the sale of a vendor's server business. This concern is expected to not only affect this individual project but has the potential to affect other NWS projects that were counting on having these additional computing resources in place in order to test and validate their actual impact on numerical weather prediction models prior to being implemented operationally. NWS officials stated that they are planning to partially address this issue by implementing an interim upgrade for operational high-performance computing in February 2015. The interim upgrade is expected to provide about half of the total planned computing capacity for planned enhancements to NWS weather model resolution and for testing and implementation of new data sources that are mature enough in their development. Officials reported that other data sources that require further development and further enhancements of model resolution will be supported by the full upgrade that is to be completed by July 2016.
- NOAA does not plan to complete observing system experiments that are to provide quantitative information regarding the anticipated degradation to NOAA's numerical weather prediction models from the absence of afternoon polar-orbiting satellite data until March 2016, which is 4 months later than planned. A contractor NOAA engaged in October 2012 to study alternatives for polar afternoon gap mitigation stressed the importance of conducting these experiments as soon as possible in order to facilitate informed decision making in choosing the best mitigation strategy. NOAA officials stated that a global observing system experiment has been completed that provides estimated quantitative impact from JPSS data, but regional experiments remain

to be completed. Thus, NOAA has been planning and may continue to implement gap mitigation measures over the next 2 years with limited information about the potential problem it is attempting to address. According to NWS progress reports, this project has been delayed in part because the computing resources the project received were 60 percent less than required.

- Multiple projects have been affected by a major shortfall in the availability of high-performance computing for research and development efforts during fiscal year 2014. According to a report by NOAA's high-performance computing working group, users' original request exceeded available resources by 256 percent due primarily to a spike in computing required to execute new and expanded gap mitigation efforts. The working group reported that it found a way to provide some allocation to all requesting parties but none of those parties received the allocation needed to meet their 2014 mission objectives.

Because a potential near-term data gap could occur sooner and last longer than expected, NOAA's ongoing gap mitigation efforts are becoming even more critical. According to Office of Management Budget guidance, projects that require extensive development work before they can be put into operation are inherently risky and should be prioritized by comparing their costs and outcomes to other projects within a portfolio.[26] Further, our previous work has found that projects should be prioritized when an agency is at risk of not meeting key deadlines and several strategies exist to accelerate schedules.[27]

However, the agency has not prioritized or accelerated activities most likely to address a gap because they have been focused on moving out on many different initiatives to see which ones will have the most impact. NOAA officials stated that further prioritization among mitigation activities was not warranted because the activities were fully funded and were not dependent on the completion of other activities. We disagree. There are dependencies among projects that would benefit from prioritization. For example, developing and utilizing new data sources is dependent on

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[26] Office of Management and Budget, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: Executive Office of the President, July 2014).

[27] See GAO, *2020 Census: Prioritized Information Technology Research and Testing is Needed for Census Design Decisions*, GAO-14-389 (Washington, D.C.: April 3, 2014); and GAO-12-120G.

improving the capacity of high-performance computing. While it makes sense to investigate multiple mitigation options, unless NOAA assesses the activities that have the most promise and accelerates those activities, it may not be sufficiently prepared to mitigate near-term data gaps.

Efforts to Monitor Progress of Contingency Planning Activities Are Not Consistent or Comprehensive

Three NOAA entities—NESDIS, NWS, and the Office of Oceanic and Atmospheric Research (OAR)—have primary responsibilities for implementing NOAA's February 2014 polar satellite gap contingency plan and associated mitigation activities. In order to provide oversight and monitor the budget, milestones, and performance of the agency's gap mitigation efforts, NOAA's contingency plan requires the officials responsible for contingency activities to provide monthly progress briefings to the assistant administrators for each of the three NOAA entities. Further, the plan requires them to provide quarterly progress briefings to NOAA's program management council.

While NOAA is providing some oversight of its many gap mitigation projects and activities, the agency's oversight efforts are not consistent or comprehensive. Specifically, NWS is providing the required monthly reporting on the status of its gap mitigation projects. However, NESDIS and OAR are not providing these reports. NOAA officials stated that monthly progress reporting was something that NWS did on its own and that in lieu of monthly reporting, OAR and NESDIS would provide quarterly reports on their respective mitigation projects. However, this is inconsistent with the requirement in NOAA's contingency plan. Until NOAA provides monthly reporting for all gap mitigation projects, the agency's oversight of these projects will be constrained.

In addition, responsible officials are providing quarterly progress briefings on 21 mitigation projects to NOAA's program management council. However, the responsible entities have not reported on 9 mitigation activities outlined in NOAA's contingency plan because they were not identified among the 21 mitigation projects. Examples of the 9 projects include expanding Global Positioning System radio occultation measurements; and projects related to continuing ozone, solar, search and rescue, and data collection capabilities. NOAA officials explained that selected projects are not being tracked the same as the 21 mitigation projects because they are funded under different appropriations. Because of the criticality of efforts to mitigate the potential gap and the need for oversight of these efforts, it is important for NOAA to monitor the progress being made on activities no matter their funding source.

Since these projects are not included in the monthly and quarterly progress reports that are required by NOAA's contingency plan, the extent to which they are being implemented and the extent to which they could effectively mitigate potential data gaps in the polar afternoon orbit may not be effectively monitored. Until NOAA improves the consistency and comprehensiveness of its progress monitoring, the agency's ability to ensure that the necessary progress is being made will be limited.

Conclusions

Facing an unprecedented gap in weather satellite data—which could have a devastating effect on the nation's economy and the safety of its population—NOAA is working to launch its next polar-orbiting environmental satellite as soon as possible. However, the JPSS program is facing risks and it has not yet tracked actual dates for completing activities in mitigating those risks. Further, the program revised its estimate of how long a gap could last down to 3 months, but this estimate was based on inconsistent and unproven assumptions and did not account for the risk that space debris pose to S-NPP's life expectancy. Until it does so, the program's ability to monitor progress in reducing significant risks and to understand the potential for a near-term gap will be limited.

Experts have identified multiple alternative ways to help mitigate the potential gap. These alternatives include taking steps to prevent and limit the gap as well as steps to reduce the impact of a gap once it occurs. While the alternatives promise increased robustness of the polar satellite infrastructure, key alternatives are not likely to be available in time should a near-term gap occur.

Taking these many alternatives into consideration, NOAA has improved its contingency plan and is moving forward to implement multiple mitigation projects. However, it has not yet addressed shortfalls such as providing key information about alternatives' costs and impacts, and establishing when testing of selected alternatives is to be completed. In addition, while the agency is moving forward on numerous initiatives, it has not prioritized them. NOAA has years of work remaining in order to fully implement and validate the data that the alternative sources offer, and it has already experienced persistent setbacks in completing mitigation efforts because of issues in obtaining sufficient computing resources. These factors make it more unlikely that NOAA will complete key mitigation activities before a gap occurs. Until NOAA prioritizes and accelerates mitigation activities with the greatest potential to reduce the impact of gap to weather forecasting, it may not be sufficiently prepared to mitigate near-term data gaps. Moreover, while NOAA is providing some oversight of its many gap mitigation projects and activities, the agency's oversight efforts are not consistent or comprehensive. Until NOAA demonstrates that it is making swift and effective progress in mitigating potential near-term gaps in polar satellite data and that it is effectively overseeing these important efforts, there will be a growing risk that degraded forecasts and warnings will lead to negative impacts on the health and safety of the U.S. population and economy.

Recommendations

Given the importance of reducing key risks to JPSS satellites we are making the following 5 recommendations to the Secretary of Commerce. Specifically, we recommend that the Secretary direct the Administrator of NOAA to

- track completion dates for all risk mitigation activities; and
- update the program's assessment of potential polar satellite data gaps to include more accurate assumptions about launch dates and the length of the data calibration period, as well as key risks such as the potential effect of space debris on JPSS and other polar satellites' expected lifetimes.

In addition, because NOAA has not fully implemented our prior recommendation to establish a comprehensive contingency plan for potential satellite data gaps in the polar orbit that is consistent with contingency planning best practices, we recommend that the Secretary direct the Administrator of NOAA to

- revise the polar satellite contingency plan to address the shortfalls noted in this report, such as identifying DOD's and Japan's plans to continue weather satellite observations, including recovery time objectives for key products, completing the contingency plan with selected strategies, identifying opportunities for accelerating calibration and validation of products, providing an assessment of available alternatives based on their costs and potential impacts, establishing a schedule with meaningful timelines and linkages among mitigation activities, and defining completion dates for testing and validating the alternatives.

Additionally, in order to enhance NOAA's preparedness for potential polar satellite data gaps in the near-term, we recommend that the Secretary direct the NOAA Administrator to direct the Assistant Administrators of NESDIS, NWS, and OAR to

- investigate ways to prioritize mitigation projects with the greatest potential benefit to weather forecasting in the event of a gap in JPSS satellite data and report recommendations to the NOAA program management council; and
- ensure that the relevant entities provide monthly and quarterly updates on the progress on all mitigation projects and activities during existing monthly and quarterly management meetings.

Agency Comments and Our Evaluation

We sought comments on a draft of our report from the Department of Commerce, the Department of Defense, and NASA. We received written comments from the Deputy Secretary of Commerce transmitting NOAA's comments. NOAA concurred with all five of our recommendations and identified steps that it is taking to implement them. It also provided technical comments, which we have incorporated into our report, as appropriate. In its technical comments, NOAA suggested we remove our discussion of a programmatic risk associated with a contractor's sale of its server business to a foreign company. NOAA's CIO stated that the terms of the sale ensured that this risk was addressed. We removed this risk from our report, but will continue to monitor the agencies' efforts to manage and oversee the maintenance of its servers. NOAA's comments are reprinted in appendix III.

On October 17, 2014 an audit liaison for the Department of Defense provided an email stating that the department did not have comments on the report's findings or recommendations. The liaison also provided technical comments, which we have incorporated into our report.

On October 22, 2014 an audit liaison for NASA provided an email stating that the agency would provide any input it might have to NOAA for inclusion in NOAA's comments.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of this letter. We are sending copies of this report to interested congressional committees, the Secretary of Commerce, the Administrator of NASA, the Secretary of Defense, the Director of the Office of Management and Budget, and other interested parties. In addition, this report will be available on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions on the matters discussed in this report, please contact me at (202) 512-9286 or at pownerd@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix IV.

David A. Powner

David A. Powner
Director, Information Technology
Management Issues

Appendix I: Objectives, Scope, and Methodology

Our objectives were to (1) evaluate NOAA's progress on the JPSS satellite program with respect to cost, schedule, and mitigation of key risks; (2) identify the benefits and challenges of alternatives for polar satellite gap mitigation; and (3) assess NOAA's efforts to establish and implement a comprehensive contingency plan for potential gaps in polar satellite data.

To evaluate NOAA's progress on the JPSS satellite program with respect to cost, schedule, and mitigation of key risks, we assessed to what extent the program was (1) meeting expected costs for key program components; (2) meeting expected schedules for key program milestones; and (3) effectively mitigating key program risks through implementation of action plans and assessing the potential for gaps in polar afternoon satellite data. A more detailed description of our activities in each of these areas follows.

- **Cost:** We reviewed documentation from the program's key milestone review in July 2013 and program management council briefings to identify baseline and estimated costs for key JPSS program components as of July 2013. We reviewed monthly program status reports through July 2014 and compared them to the program's prior cost estimates to identify any changes in estimated costs and to determine the reasons why development costs had increased or decreased. We assessed the reliability of the cost estimates by interviewing program officials to determine the process the program used to formulate the cost estimates and to conduct accuracy checks on data presented in program status reports. We determined that the cost data were sufficiently reliable for our reporting purposes. We also interviewed program officials to discuss JPSS development status and reasons for changes in costs.
- **Schedule:** We reviewed documentation from the program's key milestone review in July 2013, including the program's integrated master schedule developed for this review, to select program milestones representing key near-term development and identify baseline and estimated completion dates for those milestones as of July 2013. We reviewed documentation prepared for the JPSS-1 mission critical design review and monthly program status reports and compared them to expected completion dates to actual/estimated completion dates as of July 2014 for the selected milestones. We reviewed monthly program status reports to identify reasons why milestone dates may have changed. We assessed the reliability of reported milestone dates by examining multiple program and project status reports at different points in time for consistent reporting of

dates or explanations of any changes and compared reported dates to source schedule data. We determined that the milestone data were sufficiently reliable for our reporting purposes. We also interviewed agency officials to review our selection of milestones and to determine additional rationale for changes in milestone schedules.

- **Risk:** We reviewed documentation from the program's key milestone review in July 2013 to identify top program risks. We reviewed program monthly status reports through July 2014 to track the status of these and other top program risks presented monthly to the NOAA program management council. We reviewed monthly program status reports, documentation on risk mitigation action plans, risk management board meeting minutes, and JPSS project risk registers to assess (a) whether the program had developed a mitigation plan with specific actions to address the risk; (b) whether the program tracked the status of mitigation plan implementation; (c) the extent to which the mitigation plan was implemented on schedule; and (d) the extent to which the program reduced the risk's likelihood and consequence. We also evaluated whether the program tracked actual completion dates for mitigation steps against the planned schedule, as recommended by leading organizations.[1] We obtained an October 2013 briefing and detailed report with the JPSS program's assessment on the potential for a gap in polar satellite data and assessed key assumptions from this study. We compared the results of the study with prior GAO reports and briefings from NASA's Orbital Debris Program Office on future projections of orbital debris risk to determine scenarios that could result in polar satellite gaps. We interviewed the program's risk manager and other relevant program officials to discuss the program's risk mitigation processes, the status of risk mitigation action plans, and the program's assessment of potential gaps in the polar afternoon orbit.

To identify benefits and challenges of alternatives for polar satellite gap mitigation, we reviewed existing literature discussing alternatives for polar satellite gap mitigation and developed a list of alternatives that have been recently identified for NOAA to consider. We interviewed experts from 15 different organizations within and outside of NOAA—including NOAA organizations with key responsibilities for gap mitigation efforts, NOAA

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[1] See, for example, Software Engineering Institute, *CMMI® for Acquisition, Version 1.3* (Pittsburgh, Pa.: November 2010) and Project Management Institute, *A Guide to the Project Management Body of Knowledge* (PMBOK® Guide), Fifth Edition, (Newton Square, Pa: 2013). "PMBOK" is a trademark of the Project Management Institute, Inc.

weather forecast offices, international weather forecast organizations, Department of Defense weather forecast organizations, industry associations and contractors, and research organizations related to weather forecasting and modeling—to gather input on benefits and challenges associated with the list of alternatives.[2] We categorized the list of alternatives based on the capabilities they were expected to provide and summarized the key benefits and challenges that experts commonly identified for the alternatives.

To assess NOAA's efforts to establish a comprehensive contingency plan for potential gaps in polar satellite data, we reviewed NOAA's February 2014 polar satellite gap contingency plan and compared it against contingency planning best practices as well as shortfalls we previously identified in NOAA's October 2012 contingency plan. We compared elements of the plan against best practices developed from leading government and industry sources such as the National Institute of Standards and Technology, the Software Engineering Institute's Capability Maturity Model® Integration, and our prior report.[3] In order to assess NOAA's efforts to implement a comprehensive contingency plan for potential gaps in polar satellite data, we reviewed NOAA's February 2014 contingency plan, progress reports for relevant projects, and relevant project plans and proposals to identify the set of projects NOAA has been implementing and the planned schedule and outcomes of those projects. We evaluated project status reports to determine the extent to which NOAA has reported on and tracked the progress of its polar gap mitigation projects and the extent to which NOAA has been meeting each project's planned schedule and outcomes. We also evaluated the extent

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[2] The NOAA organizations include the National Centers for Environmental Prediction's Environmental Modeling Center and National Hurricane Center; the National Weather Service's Alaska Weather Forecast Offices (Anchorage and Fairbanks); the Office of Atmospheric Research's Atlantic Oceanographic and Meteorological Laboratory and Earth System Research Laboratory; the Office of the Chief Information Officer; and the National Environmental, Satellite, Data and Information Service's Integrated Product Team (which includes representatives from the JPSS Program Office and Office of Satellite and Product Operations). The international weather organizations include the United Kingdom Meteorological Office and the European Centre for Medium-range Weather Forecasts. The DOD entities include the Air Force Weather Agency and the Fleet Numerical Meteorology and Oceanography Center. The industry and contracting organizations include the University Corporation for Atmospheric Research and the Alliance for Earth Observations. The research organizations include NASA's Global Modeling and Assimilation Office and Jet Propulsion Laboratory.

[3] GAO-13-676.

to which NOAA had prioritized its mitigation projects by comparing them to best practices identified by the Office of Management and Budget and from prior GAO reports.[4] We interviewed relevant NOAA and JPSS program officials regarding changes reflected in the February 2014 contingency plan, oversight and reporting procedures for gap mitigation projects, and implementation progress for gap mitigation projects.

We performed our work at NASA and NOAA offices in the Miami, Florida, Boulder, Colorado, and Washington, D.C. area. We conducted this performance audit from January to December 2014 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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[4] Office of Management and Budget, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: Executive Office of the President, July 2014); GAO, *2020 Census: Prioritized Information Technology Research and Testing is Needed for Census Design Decisions*, GAO-14-389 (Washington, D.C.: April 3, 2014); and GAO-12-120G.

Appendix II: Space Debris Pose a Catastrophic Risk to Spacecraft

Experts estimate that more than 100 million man-made objects larger than 1 millimeter are orbiting the earth. These objects—space debris—include whole and fragmentary parts of rocket bodies and other discarded equipment from space missions. According to NASA's Orbital Debris Program Office, over 500,000 of these objects (those 1 centimeter and larger) pose a threat to current and future satellites because they can cause catastrophic damage upon impact.[1]

NASA and DOD share responsibility for determining the amount of space debris at various sizes and altitudes. DOD uses its Space Surveillance Network, which is comprised of radars and electro-optical sensors around the world, to track and catalog objects as small as 5 centimeters in diameter. While smaller debris cannot be tracked, NASA's Orbital Debris Program Office estimates the amount of smaller debris using ground-based radars and visual inspections of spacecraft that have returned from orbit. It also develops and maintains models of the space debris environment at different altitudes. NASA currently estimates that in low-earth orbit the debris populations are approximately 22,000 objects larger than 10 centimeters; approximately 500,000 objects between 1 and 10 centimeters in diameter; and roughly 100 million particles between 1 millimeter and 1 centimeter.

Due to the high impact speed in space (approximately 10 kilometers per second, or 22,369 miles per hour), even debris that is less than 1 centimeter can cause catastrophic damage to a spacecraft.[2] As an example, space debris as small as 0.3 centimeters could have the same effect as a bowling ball traveling at 60 miles per hour. As debris size increases, so does the potential impact to spacecraft. For example, debris as small as 1 centimeter can have the same effect as a 400 pound safe traveling at 60 miles per hour, debris that is 5 centimeters has energy similar to being hit by a bus, and debris that is 10 centimeters has energy similar to a large bomb. The following figure illustrates the potential effects of various sizes of space debris.

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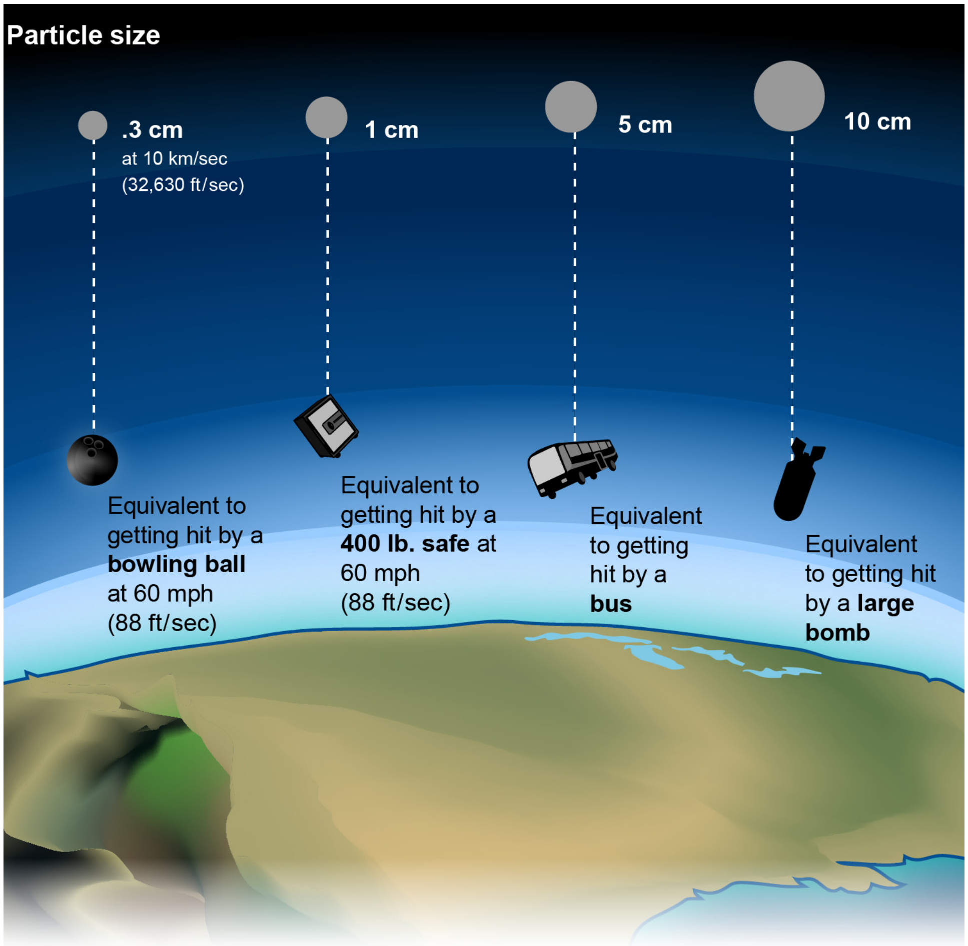
[1] According to a NASA expert who conducts hypervelocity impact testing, space debris less than 1 centimeter can cause serious damage to satellites, possibly resulting in mission termination. The impacting particle size causing failure is a function of satellite design and shielding. Particle sizes from 1 to 5 millimeters typically cause failure of important satellite hardware such as propellant tanks.

[2] GAO, *Space Program: Space Debris a Potential Threat to Space Station and Shuttle*, GAO/IMTEC-90-18 (Washington, D.C.: April 6, 1990).

Figure 6: Potential Effects of Space Debris at Various Sizes



Source: Report on Orbital Debris, by Interagency Group (Space), National Security Council, February 1989, and data used with permission of The Aerospace Corporation. | GAO-15-47

Options for mitigating the impacts of space debris differ depending on the size of the debris. For debris 5 to 10 centimeters and larger that are typically tracked and cataloged, spacecraft operators can perform collision avoidance maneuvers. For debris that is less than 2 centimeters, shielding can generally provide protection to critical components. However, there are limitations to adding shielding, such as the amount of weight that it adds to the spacecraft and the inability of shielding to protect from debris larger than 2 centimeters.[3] Because debris less than 5 centimeters is not tracked and protective shielding is generally limited to debris 2 centimeters and smaller, there is no mitigation for debris in this size range other than reorienting the spacecraft or flying the spacecraft at altitudes with less debris. However, this may not be an option for certain missions like JPSS that requires a specific spacecraft orientation in a polar sun-synchronous orbit at an altitude of 824 kilometers.

JPSS Satellites' Orbit Has an Elevated Risk from Space Debris

Space debris experts from NASA's Orbital Debris Program Office believe that the danger of collisions to satellites at altitudes similar to JPSS is compounded by estimates that the amount of space debris will increase as worldwide spacecraft launch rates increase and collisions between debris particles create more debris. In particular, experts are concerned about increases in space debris that is larger than 2 centimeters for which shielding options are limited and less than 5 centimeters for which collision avoidance maneuvers cannot be conducted because the debris are not actively tracked and cataloged. Figure 7 illustrates NASA's projection of the amount of space debris that is 0.3 centimeters and larger at JPSS satellites' altitude through 2035.

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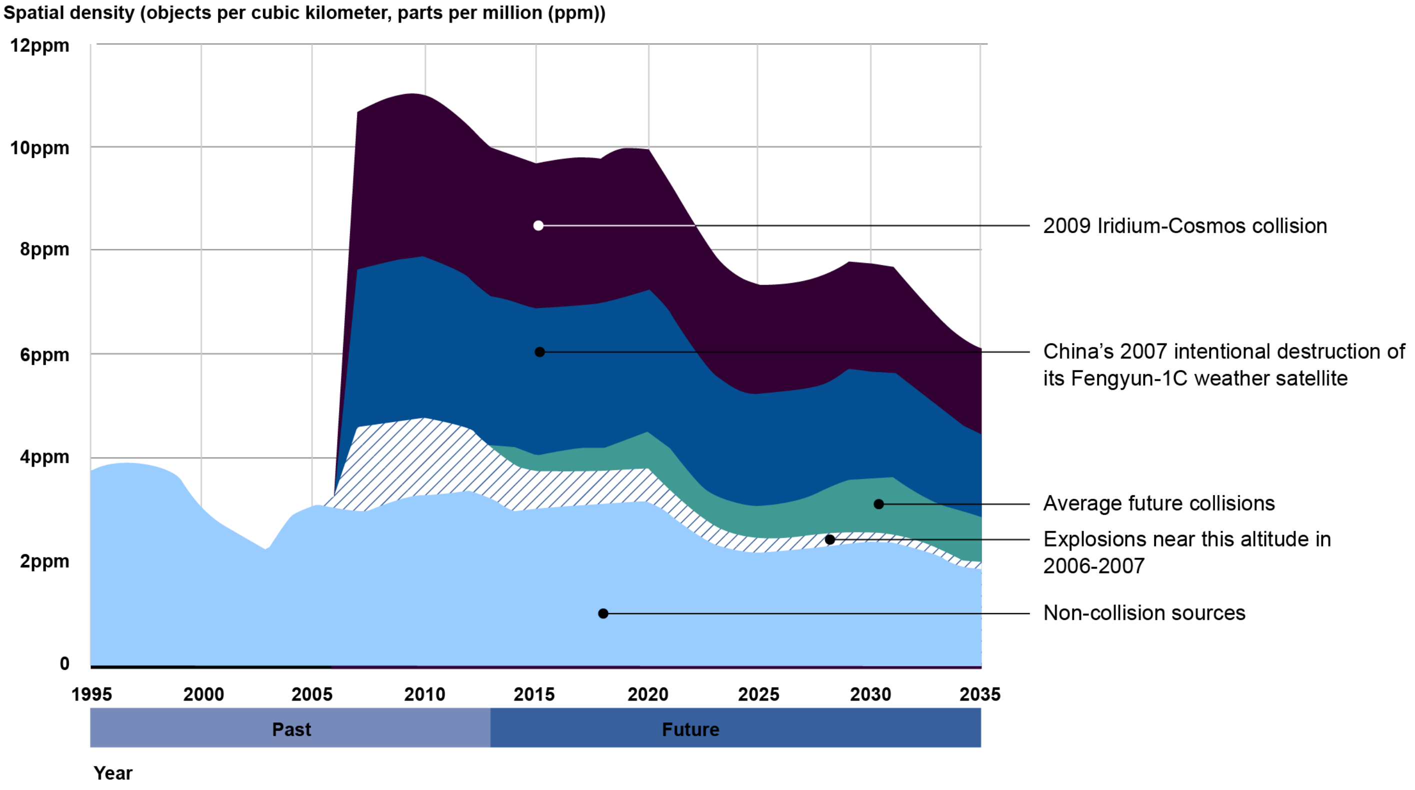
[3] According to the program manager of NASA's Orbital Debris Program Office, most robotic spacecraft are not shielded against debris as large as 1 centimeter because shielding for debris of this size requires both weight and volume that is typically not available.

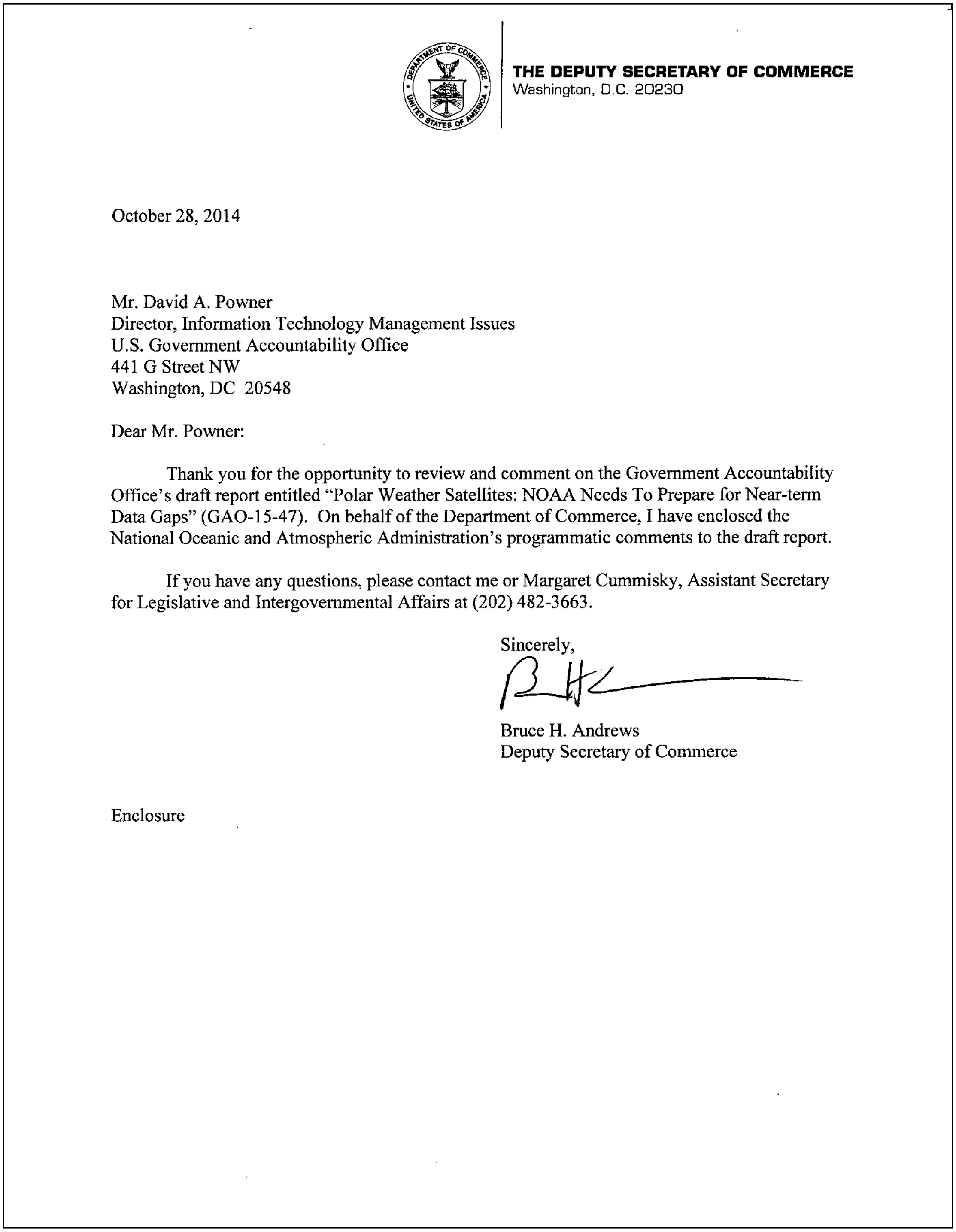
Figure 7: Projected Space Debris at JPSS Satellites' Altitude



Source: NASA Orbital Debris Program Office. | GAO-15-47

Note: Spatial density represents the effective number of spacecraft and other objects as a function of altitude. In this figure, spatial density represents the number of objects larger than 0.3 centimeters at an altitude of 825 kilometers.

Appendix III: Comments from the Department of Commerce



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

October 28, 2014

Mr. David A. Powner
Director, Information Technology Management Issues
U.S. Government Accountability Office
441 G Street NW
Washington, DC 20548

Dear Mr. Powner:

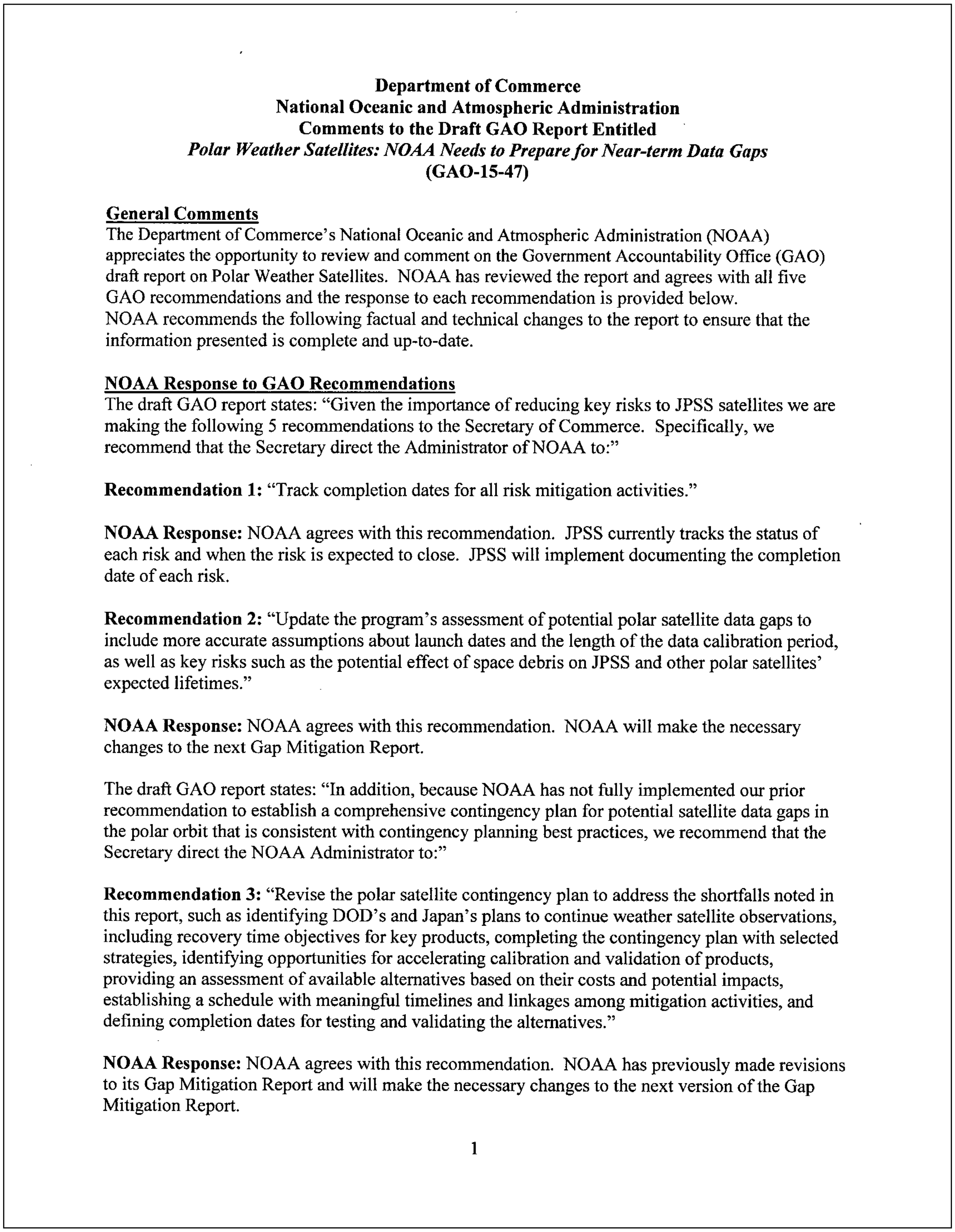
Thank you for the opportunity to review and comment on the Government Accountability Office's draft report entitled "Polar Weather Satellites: NOAA Needs To Prepare for Near-term Data Gaps" (GAO-15-47). On behalf of the Department of Commerce, I have enclosed the National Oceanic and Atmospheric Administration's programmatic comments to the draft report.

If you have any questions, please contact me or Margaret Cummisky, Assistant Secretary for Legislative and Intergovernmental Affairs at (202) 482-3663.

Sincerely,

Bruce H. Andrews
Deputy Secretary of Commerce

Enclosure



Department of Commerce
National Oceanic and Atmospheric Administration
Comments to the Draft GAO Report Entitled
Polar Weather Satellites: NOAA Needs to Prepare for Near-term Data Gaps
(GAO-15-47)

General Comments

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) appreciates the opportunity to review and comment on the Government Accountability Office (GAO) draft report on Polar Weather Satellites. NOAA has reviewed the report and agrees with all five GAO recommendations and the response to each recommendation is provided below.
NOAA recommends the following factual and technical changes to the report to ensure that the information presented is complete and up-to-date.

NOAA Response to GAO Recommendations

The draft GAO report states: "Given the importance of reducing key risks to JPSS satellites we are making the following 5 recommendations to the Secretary of Commerce. Specifically, we recommend that the Secretary direct the Administrator of NOAA to:"

Recommendation 1: "Track completion dates for all risk mitigation activities."

NOAA Response: NOAA agrees with this recommendation. JPSS currently tracks the status of each risk and when the risk is expected to close. JPSS will implement documenting the completion date of each risk.

Recommendation 2: "Update the program's assessment of potential polar satellite data gaps to include more accurate assumptions about launch dates and the length of the data calibration period, as well as key risks such as the potential effect of space debris on JPSS and other polar satellites' expected lifetimes."

NOAA Response: NOAA agrees with this recommendation. NOAA will make the necessary changes to the next Gap Mitigation Report.

The draft GAO report states: "In addition, because NOAA has not fully implemented our prior recommendation to establish a comprehensive contingency plan for potential satellite data gaps in the polar orbit that is consistent with contingency planning best practices, we recommend that the Secretary direct the NOAA Administrator to:"

Recommendation 3: "Revise the polar satellite contingency plan to address the shortfalls noted in this report, such as identifying DOD's and Japan's plans to continue weather satellite observations, including recovery time objectives for key products, completing the contingency plan with selected strategies, identifying opportunities for accelerating calibration and validation of products, providing an assessment of available alternatives based on their costs and potential impacts, establishing a schedule with meaningful timelines and linkages among mitigation activities, and defining completion dates for testing and validating the alternatives."

NOAA Response: NOAA agrees with this recommendation. NOAA has previously made revisions to its Gap Mitigation Report and will make the necessary changes to the next version of the Gap Mitigation Report.

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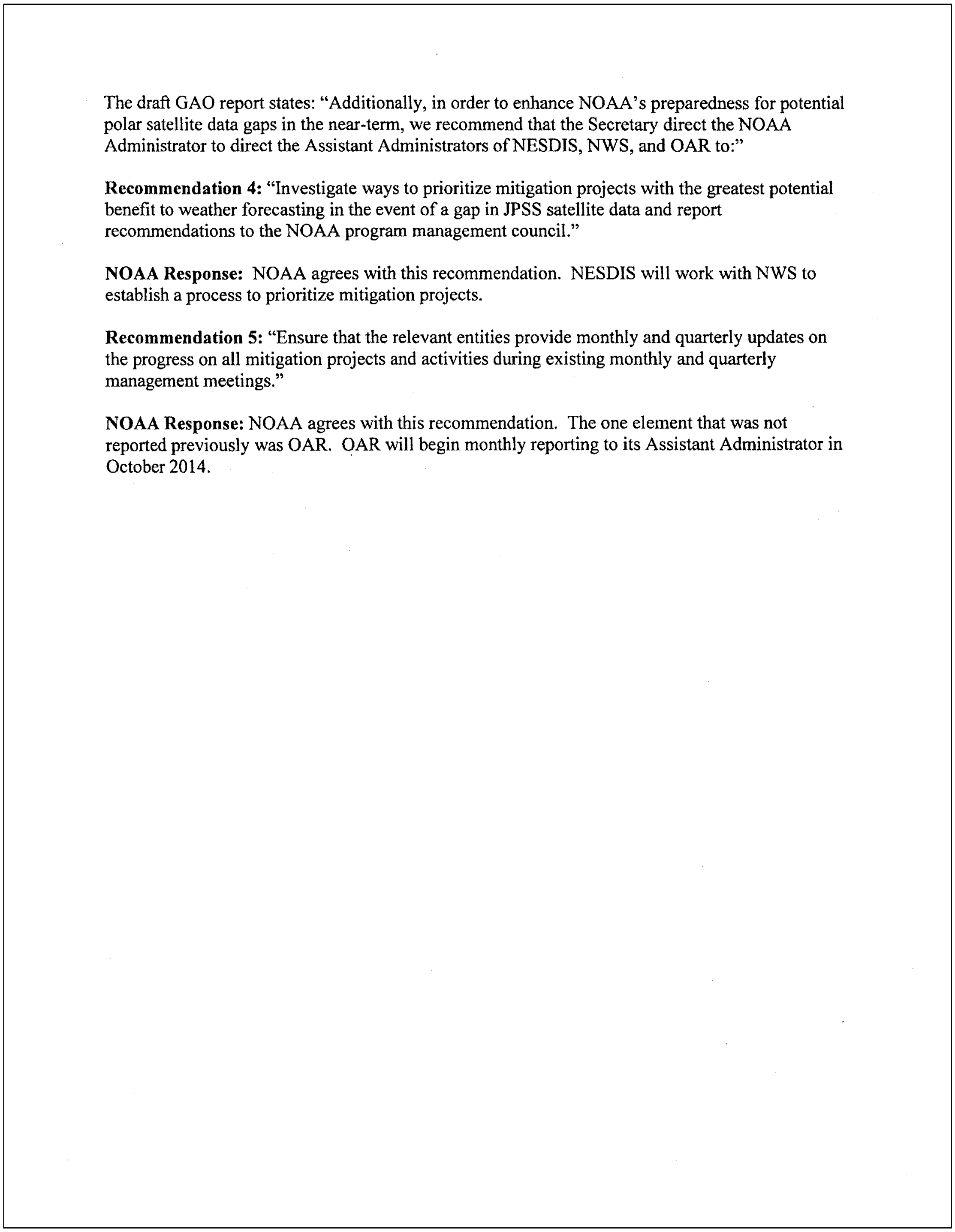

The draft GAO report states: "Additionally, in order to enhance NOAA's preparedness for potential polar satellite data gaps in the near-term, we recommend that the Secretary direct the NOAA Administrator to direct the Assistant Administrators of NESDIS, NWS, and OAR to:"

Recommendation 4: "Investigate ways to prioritize mitigation projects with the greatest potential benefit to weather forecasting in the event of a gap in JPSS satellite data and report recommendations to the NOAA program management council."

NOAA Response: NOAA agrees with this recommendation. NESDIS will work with NWS to establish a process to prioritize mitigation projects.

Recommendation 5: "Ensure that the relevant entities provide monthly and quarterly updates on the progress on all mitigation projects and activities during existing monthly and quarterly management meetings."

NOAA Response: NOAA agrees with this recommendation. The one element that was not reported previously was OAR. OAR will begin monthly reporting to its Assistant Administrator in October 2014.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

David A. Powner (202) 512-9286 or pownerd@gao.gov.

Staff Acknowledgments

In addition to the contact named above, Colleen Phillips (Assistant Director), Nancy Glover, Franklin Jackson, Joshua Leiling, Kate Sharkey, and Shawn Ward made key contributions to this report.

(311403)

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