Department of Defense (DOD) Weather Satellites

Briefing to Congressional Defense Committees

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Introduction

- Meteorological and oceanographic data—also referred to as weather data—are key to providing information for the successful planning, execution, and sustainment of U.S. military operations. Some weather data are collected through space-based environmental monitoring (SBEM) satellites. The Department of Defense (DOD) uses data from its own satellites, such as the Defense Meteorological Satellite Program (DMSP), as well as from U.S. civil government and international partner satellites to provide weather information and forecasting.

Introduction *(continued)*

- As existing systems age, DOD is planning for follow-on systems to avoid gaps in critical capabilities. From February 2012 to September 2014, DOD conducted a requirements review and analysis of alternatives (AOA) for SBEM-related capabilities to identify potential solutions.[1] The AOA and subsequent decisions could affect stakeholders that use SBEM data, including the military services, the intelligence community, and U.S. civil agencies such as the National Oceanic and Atmospheric Administration (NOAA). With potential capability gaps starting as early as this year, it is important for DOD to make decisions in a timely manner, but based on informed analysis that considers stakeholders' input.

[1]An analysis of alternatives (AOA) is a key analysis in the DOD acquisition process that compares the operational effectiveness, suitability, and lifecycle costs of solutions to satisfy documented capability needs. This period includes the development of study guidance and a study plan for the AOA, and the Joint Requirement Oversight Council's review of the AOA.

Introduction *(continued)*

- The National Defense Authorization Act (NDAA) for Fiscal Year 2015 included a provision for GAO to review the SBEM AOA.[2]
- Senate Report No. 114-49 to accompany S. 1376, a bill for the NDAA for Fiscal Year 2016, included a provision for GAO to evaluate whether launching the final DMSP satellite, DMSP-20, was the most cost-effective solution for covering an expected SBEM data gap over the Indian Ocean. At the time, questions had been raised about whether to launch the satellite in light of concerns about its cost and utility given its age and military needs. In October 2015 GAO provided information in oral briefings to congressional committees regarding DOD's plans for DMSP-20. Since then, DOD has indicated it will not launch DMSP-20 due to lack of funding.

[2]Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Pub. L. No. 113-291 §1612(a)(3) (2014).

Objectives

This briefing addresses the following questions:

1) To what extent did the SBEM AOA address input from stakeholders and assess the range of alternatives for potential solutions?
2) To what extent has the AOA informed DOD's plans for providing SBEM capabilities?

Summary

GAO found:

1. The AOA team conducted a thorough assessment of some capabilities, despite pressures to complete the AOA in time to inform decision making for near-term needs. However, time constraints imposed limitations on the analysis of the military utility of certain critical capabilities, which affected the extent to which they were assessed in the range of alternatives. The AOA team also engaged with a broad range of DOD stakeholders, though some stakeholder concerns remained unaddressed in the AOA. In addition, DOD did not effectively coordinate with NOAA—the agency that, on a case by case basis, represents DOD's interests in international partnerships regarding SBEM data. This was partly due to a lack of a formal coordination and collaboration mechanism that identified roles and responsibilities for DOD and NOAA and facilitated input and discussion during the AOA. For example, NOAA was not involved in reviews of the AOA or regular discussions with study leadership, according to officials. DOD made an incorrect assumption about continued availability of international support, which we believe could have been avoided if coordination was more effective. Based on the incorrect assumption, DOD decided not to assess the two highest-priority capabilities more fully for potential DOD solutions in the range of alternatives.

Summary *(continued)*

GAO found:

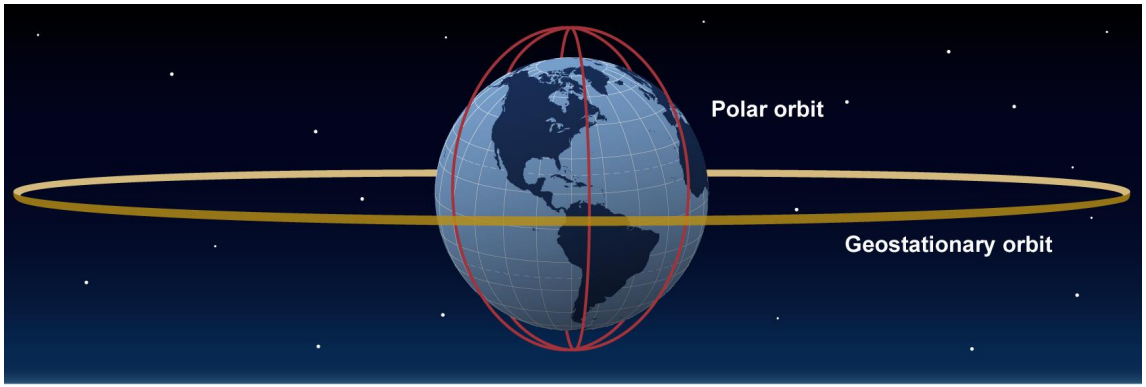
2) The AOA informed plans for providing a space-based solution for three capabilities with near-term needs. To address these needs, the Air Force is currently developing plans for a follow-on system and for hosting sensors on Air Force satellites. For most of the remaining nine capabilities assessed, the AOA determined that other assets could provide coverage, or that modeling development could help mitigate potential gaps. However, the AOA is less useful as a decision making tool for the two highest-priority capabilities for which it did not fully evaluate potential solutions. Outside of the AOA process, DOD is now examining options for meeting these two needs in the short term, including increased reliance on data from international partner satellites. Because DOD is still assessing those options, data on the most cost-effective approach are not yet available. Longer-term plans for providing the two highest-priority capabilities are undetermined. Given NOAA's role in coordinating with international partners to obtain SBEM data, and limited mechanisms for formal coordination and collaboration between DOD and NOAA that clarify roles and responsibilities and provide for mutual accountability, further assessments of options that rely on data from international partner satellites may be at risk of again using incomplete or incorrect information.

Background

Background: Satellites Providing SBEM Coverage

- Satellites carrying sensors that collect SBEM data primarily include:
  - Polar-orbiting satellites in low Earth orbit constantly circle the earth in an almost north-south orbit over the poles. Each successive orbital pass occurs at the same local time of day, such as early morning, mid-morning, and afternoon.[3] These satellites provide global high-resolution observations ideal for tactical weather support and long range numerical weather prediction.
  - Geostationary satellites maintain a fixed position relative to the earth, collecting data on a specific geographic region and providing real-time monitoring of developing weather conditions (see fig. 1).
- SBEM sensors collect data on a range of weather-related factors, such as cloud cover, winds, precipitation, atmospheric temperature, sea ice conditions, and space weather that may affect the accuracy and operability of other space-based signals.

Figure 1: Notional Example of Satellites in Polar and Geostationary Orbits



Source: GAO depiction of notional polar and geostationary orbits (data); Map Resources (map). | GAO-16-252R

[3]In addition to satellites in polar orbit, satellites in other low Earth orbits provide SBEM data to operational users.

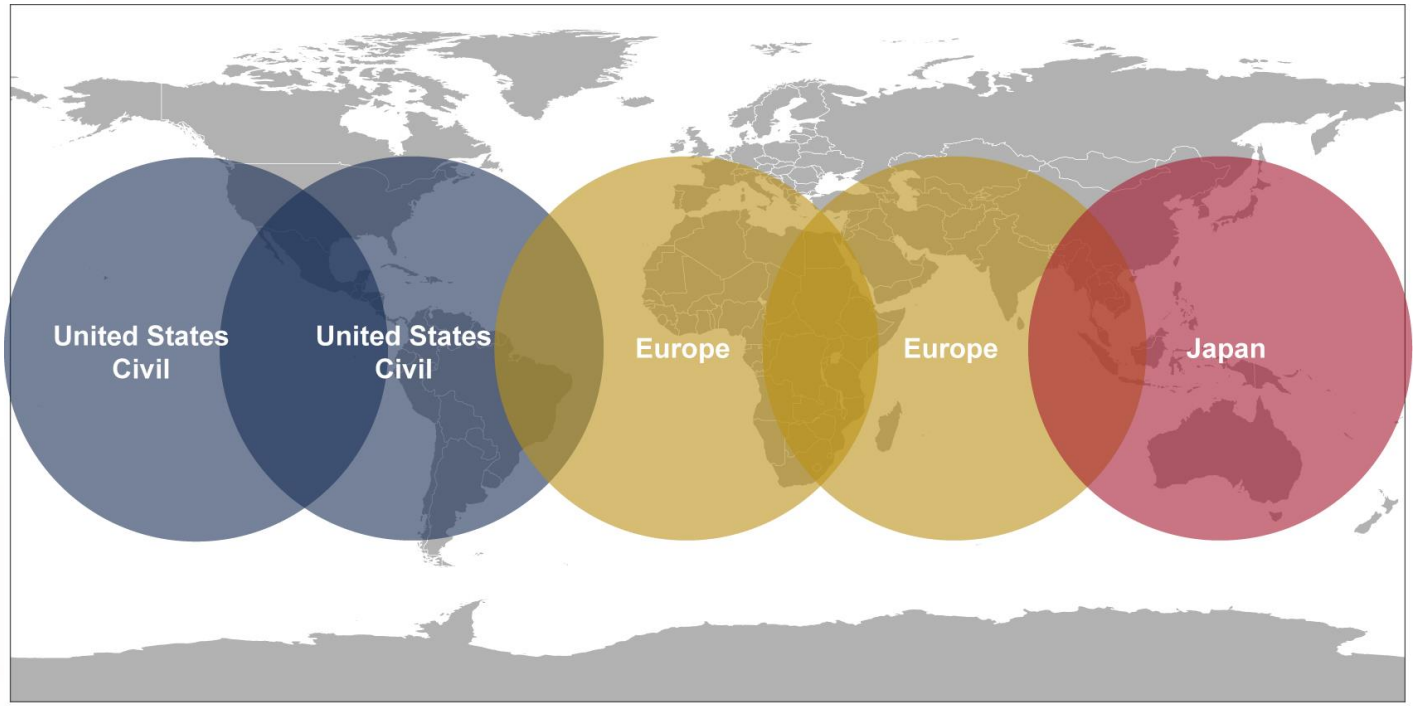
Background: Satellites Providing SBEM Coverage *(continued)*

- Since the 1960s, the United States has operated two separate meteorological polar-orbiting satellite systems:
  - DOD's DMSP—Currently crossing the equator in the early and mid-morning orbits.
  - NOAA's Polar-orbiting Operational Environmental Satellite (POES) and Suomi National Polar-orbiting Partnership satellite, the first in the Joint Polar Satellite System—Currently crossing the equator in the afternoon orbit.
  - The United States also relies on a European satellite, the Meteorological Operational satellite, currently crossing the equator in the mid-morning orbit.

Background: Satellites Providing SBEM Coverage *(continued)*

- Currently the DOD relies on SBEM data from geostationary satellites primarily provided by U.S. civil government, Europe, and Japan, each sharing data from a specific geographic region in order to provide global coverage (see fig. 2).[4] Such satellites provide high levels of effective coverage between 40 and 50 degrees north or south, depending on geographic location.

Figure 2: Geostationary Satellites Providing SBEM Coverage (Notional)



Source: GAO depiction of notional coverage of geostationary weather satellites; Map Resources (map). | GAO-16-252R

[4]In addition, DOD accesses data from a meteorological payload on a South Korean geostationary satellite. Indian, Chinese, and Russian geostationary satellites also collect weather data, but DOD does not currently use these sources.

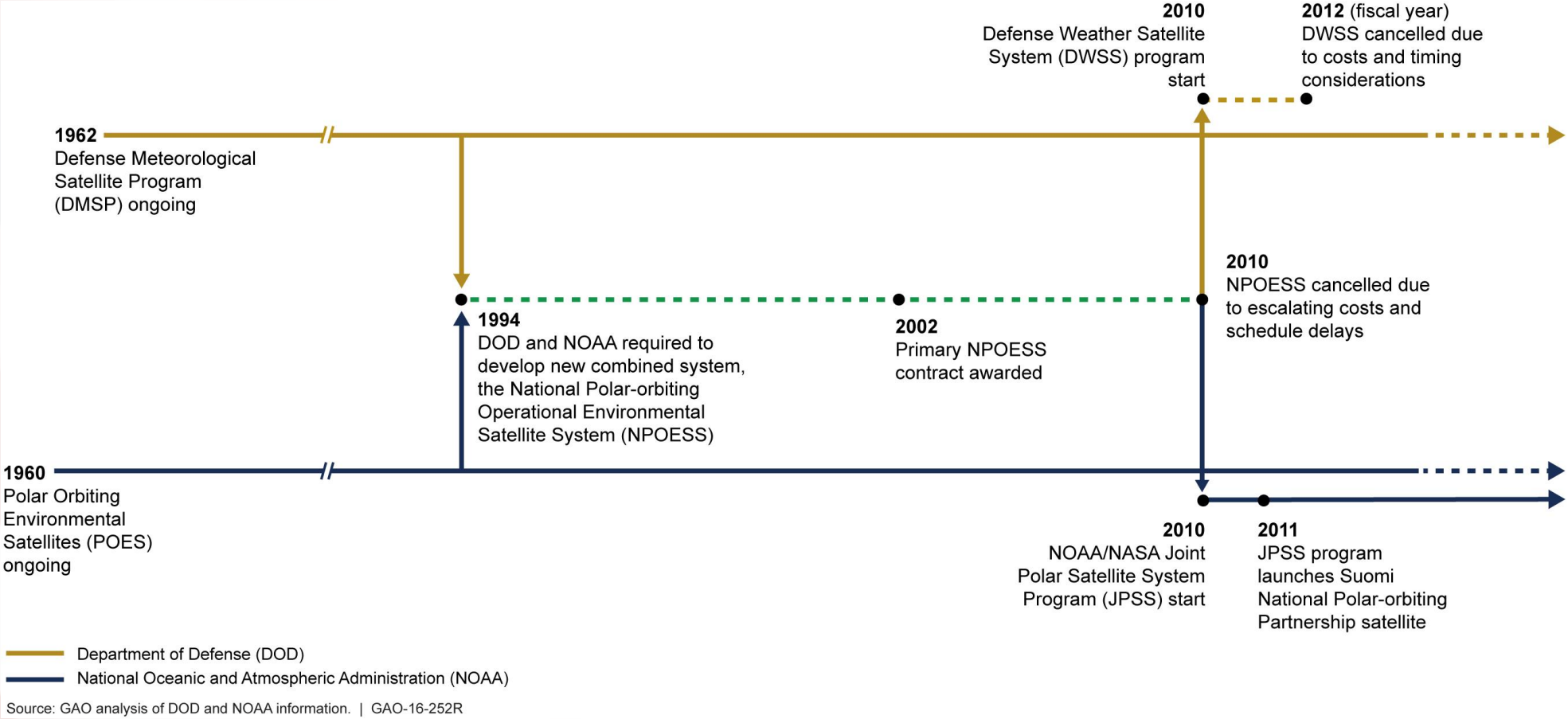
Background: History of DMSP Replacement Efforts

- DOD has been involved in two previous efforts to develop a replacement for DMSP, both of which were cancelled:
  - National Polar-orbiting Operational Environmental Satellite System (NPOESS)—Tri-agency program between DOD, NOAA, and the National Aeronautics and Space Administration to replace both DMSP and POES; started in 1997 and cancelled in 2010 due to escalating costs and schedule delays.[5] (see fig. 3)
  - Defense Weather Satellite System—DOD program intended to continue providing weather observations from the morning orbit following NPOESS cancellation; started in 2010 and cancelled in fiscal year 2012 because the program was considered early-to-need with unsustainable costs.

[5]DOD, through the Air Force, was responsible for the NPOESS acquisition, NOAA was responsible for overall program management and satellite operations, and the National Aeronautics and Space Administration was responsible for facilitating the development and incorporation of new technologies.

Background: History of DMSP Replacement Efforts *(continued)*

Figure 3: Time Line of Efforts to Replace DMSP



Source: GAO analysis of DOD and NOAA information. | GAO-16-252R

Background: SBEM Requirements Review and AOA

- Following the cancellation of the Defense Weather Satellite System, DOD conducted follow-on program activities.
  - In 2012, the Air Force analyzed almost 250 weather data collection parameters, or characteristics, from a 2009 initial capabilities document and determined that about 100 parameters required space-based sensing.
  - The Air Force then organized those parameters into three categories based on priority and ultimately identified12 potential gaps in capability that were mission critical, insufficiently met by existing and planned sources, and required space-based sensing capability. Officials representing the military services and the intelligence community jointly prioritized these 12 capabilities, which subsequently formed the list of capabilities that were to be assessed in the AOA.

Background: SBEM Requirements Review and AOA *(continued)*

- An AOA is a key analysis intended to support DOD's acquisition process. Specifically, an AOA is intended to inform a decision on the most cost effective solution for meeting validated capability requirements, and is to identify a wide range of solutions with a reasonable likelihood of providing the needed capability. Based on the preceding requirements review, the Air Force conducted an AOA from 2012-2013 in two phases.[6]
  - Phase 1 examined the 12 potential capability gaps to determine military utility—or operational benefit—and operational risk of each gap (see table 1).
  - Phase 2 assessed potential solutions for meeting the gaps, focusing on 3 of the capabilities identified in Phase 1 as potentially requiring a space-based solution.
- The Joint Requirements Oversight Council reviewed the AOA in September 2014 and supported the AOA's findings, including the determination that 3 of the 12 potential capability gaps could be considered for a DOD space-based solution.

[6]The Office of the Secretary of Defense, Cost Assessment and Program Evaluation (CAPE), was the approval authority for the AOA study and was responsible for developing study guidance, approving the study plan, providing study oversight, and reviewing the AOA for sufficiency.

Background: Table 1 – Capability Areas Assessed in the AOA

Capability Area and Priority Rank	Examples of Military Mission Areas	Current Partners	DOD Space-based Solution Potentially Required?
1. Cloud Characterization	Flying operations, mission planning, long range strikes	NOAA, Japan, Europe	No, but risk increases if civil and international data sources are unavailable.
2. Theater Weather Imagery	Military operations, resource protection, air refueling	NOAA, Japan, Europe	No, but risk increases if civil and international data sources are unavailable.
3. Ocean Surface Vector Winds	Resource protection, evacuation and ship maneuver operations	Europe	Yes, with change in minimal acceptable values for refresh rate and timeliness.[a]
4. Ionospheric Density	Communications, GPS guided systems, radar operations	Taiwan/NOAA	No, minimal contribution to increased military utility. Improved models have potential to increase the utility of data.
5. Snow Depth	Flood estimates, river gap crossing, ground maneuvers	Japan	No, assuming availability of and access to international capability. Limited contribution from space due to measurement uncertainty; may benefit from investment in algorithm development.
6. Soil moisture	Army off road mobility, land operations	Japan	No, assuming availability of and access to international capability. Limited contribution from space due to measurement uncertainty; may benefit from investment in algorithm development.
7. Equatorial Ionospheric Scintillation	Communications, GPS	Taiwan/NOAA	No, space-based solution adds minimal military utility if sufficient ground-based sensing is available.
8. Tropical Cyclone Intensity	Resource protection, evacuation and ship maneuver operations	Japan	Yes, with change in minimal acceptable value for refresh rate.
9. Sea Ice Characterization	Operational risk and safety for Arctic submarine and surface operations	Japan	No, with operational work-arounds.
10. Auroral Characterization	*No space-based auroral characterization information is currently used operationally.*		
11. Energetic Charged Particle Characterization	Satellite anomaly assessments and space protection	Europe	Yes, with change in minimal acceptable values for resolution, energy, and refresh rate.
12. Electric field	Space surveillance, missile defense radar operations, communication	Taiwan/NOAA	No, minimal contribution to increased military utility. Improved models have potential to increase the utility of data.

Source: GAO analysis of Department of Defense information. | GAO-16-252R

[a]A refresh rate is a performance measure of the frequency at which a sensor or multiple sensors can revisit a certain area of coverage.

Objective 1: AOA Was Thorough in Some Areas, but Limited Stakeholder Coordination Affected the Range of Alternatives Assessed

Objective 1: AOA Team Faced Time Constraints

- The AOA team faced pressures to complete the study in time to inform decision making for near-term needs.
  - Ideally, DOD could have conducted an AOA for SBEM capabilities when pursuing new acquisitions after the cancellation of NPOESS in 2010. Instead, in 2012 DOD initiated the AOA with the goal of having the results in time to plan for the fiscal year 2015 budget and to address near-term needs.
    - At start of the AOA in 2012, the gap for ocean surface vector wind was expected to begin as early as 2015. Other gaps, such as soil moisture and tropical cyclone intensity data, were estimated to begin as early as 2024 at the time.

Objective 1: Despite Time Constraints, AOA Included Thorough Analysis

- The AOA team generally conducted a thorough review of the military utility of capabilities in Phase 1. Specifically:
  - On a capability-by-capability basis, the team assessed the effectiveness of DOD providing, or not providing, a space-based solution.
  - The AOA team consulted with warfighter subject matter experts and assembled analytical working groups in key areas, including effectiveness analysis, technology and alternatives, and operational concepts. These working groups:
    - developed specific measures of performance, effectiveness, and outcomes for the relevant capabilities;
    - developed a set of architectural elements that could meet or contribute to needs for each capability;
    - defined the overarching operating concept for applying environmental monitoring to DOD operations; and
    - collaborated with one another in conducting their analyses.

Objective 1: Time Constraints Imposed Limitations on Analysis of Certain Capabilities

- However, pressures to complete the AOA study in time to inform decision making limited the military utility analysis of the two highest-priority capabilities—cloud characterization and theater weather imagery—in Phase 1 of the AOA.[7] This limitation affected the extent to which the capabilities were analyzed further for solutions in Phase 2. For example:
  - To assess the impact of various satellite and sensor configurations on forecast models for cloud characterization and theater weather imagery capabilities, the analysis used a limited weather data set, covering 7 days, due to the time required to generate and process data, according to DOD officials. This affected the degree to which operational risk could be assessed because the seasonal variability of weather conditions is not captured in a 1-week data set, according to officials.

[7]The analysis took approximately 10 months to complete, from October 2012 into July 2013, followed by 3 months to prepare the final AOA report, issued in October 2013.

GAO

Objective 1: Time Constraints Imposed Limitations on Analysis of Certain Capabilities *(continued)*

- Further, DOD officials stated that in some cases they would have preferred to test some capabilities in additional planning scenarios and vignettes to further assess their military utility, such as in additional regions, but were limited by time and resource constraints.
  - There is a no standard time frame for conducting an AOA, and DOD officials have stated that AOAs are always limited in time and resources. However, in prior work, we have concluded that conducting AOAs under compressed time frames in order to meet planned milestones or weapons system fielding dates can short-change a comprehensive assessment of risks and preclude effective cost, schedule, and performance trade-offs made before a program begins development.[8]

[8]GAO, *Defense Acquisitions: Many Analyses of Alternatives Have Not Provided a Robust Assessment of Weapon System Options*, GAO-09-665 (Washington, D.C.: Sept. 24, 2009).

Objective 1: AOA Team Engaged a Wide Range of DOD Stakeholders; Some Concerns Raised

- The AOA effort required engagement with a wide range of DOD stakeholders because of the broad applicability of space-based weather needs across the services.
  - While the AOA team effectively engaged with a broad range of DOD stakeholders, concerns were raised about the methodology used for assessing potential gaps in both AOA phases. For example:
    - The intelligence community had concerns related to how cloud characterization was assessed. For example, representatives stated certain measures used in the analysis did not effectively demonstrate the utility of cloud characterization in Phase 1, which contributed to a decision not to more fully assess the capability in Phase 2. The intelligence community ultimately agreed to the final AOA report because of plans at the time to launch DMSP-20, which would help satisfy its requirements in the short-term.

Objective 1: AOA Team Engaged a Wide Range of DOD Stakeholders; Some Concerns Raised *(continued)*

- The Navy had concerns that the vignettes used to assess minimum acceptable values for ocean surface vector wind and tropical cyclone intensity data collection did not capture the need for "nowcast" capability.[9] However, when provided additional time to assess the need further, the Navy was unable to provide quantitative analysis supporting this need.
- The Joint Chiefs of Staff and modeling experts were concerned with the importance of using global instead of regional models to assess capabilities. Specifically, while the AOA examined how regional meteorological models would be affected if data sources were unavailable, according to officials, it did not assess the impact on global models.

- Stakeholders had the opportunity to raise these concerns with the Air Force and CAPE. The Air Force and CAPE acknowledged these concerns during the AOA process, such as in Study Advisory Group meetings, and to some extent in the "Study Regrets" and "Lessons Learned" sections of the AOA report.[10] However, these concerns generally were not addressed further in the study because of time constraints, according to DOD officials.

[9]Because ocean surface vector wind and tropical cyclone intensity measurements can change dramatically within a few hours, frequent measurements are required to maintain accurate "nowcasts," which provide data on current weather conditions.
[10]The Study Advisory Group for the SBEM AOA was chaired by CAPE and included representatives from the Undersecretary of Defense for Acquisition, Technology and Logistics and other offices under the Office of the Secretary of Defense, the Joint Chiefs of Staff, U.S. Strategic Command, the military services, and the intelligence community.

Objective 1: Limited Engagement with NOAA Contributed to an Incorrect Assumption

- Ineffective coordination with NOAA contributed to an incorrect assumption and affected which alternatives the AOA team fully assessed in Phase 2.
  - DOD did not have a formal coordination and collaboration mechanism that specified roles and responsibilities for DOD and NOAA for the AOA.
    - The Air Force's AOA Handbook advises AOA leads to identify appropriate stakeholders and how they will be involved in the study and review process, including vetting the results of the final analysis.[11] The handbook also advises AOA leads to identify potential areas of risk pertinent to the study, such as a lack of stakeholder participation. NOAA is generally the signatory to international agreements on space-based weather monitoring data sharing and represents DOD's interests with international partners on a case-by-case basis, such as for the Joint Polar System. As such, NOAA has a stake in analysis of, and decisions about, the use of data from international satellites.

[11]Office of Aerospace Studies, Air Force Materiel Command OAS/A9, *Analysis of Alternatives (AOA) Handbook: A Practical Guide to Analyses of Alternatives*, (Kirtland Air Force Base, N. Mex: July 2010).

Objective 1: Limited Engagement with NOAA Contributed to an Incorrect Assumption *(continued)*

- NOAA was not involved in reviews of the AOA or regular discussions with the AOA study leadership, according to NOAA officials, and did not provide formal input during the AOA study period. Three NOAA staff participated in a working group; however, one of the participants noted that he received emails but did not participate in meetings or regular dialogue throughout the AOA.

- Without effectively coordinating with NOAA during the AOA, DOD made an assumption that current capabilities with partner organizations would continue. This included the expectation that a European satellite providing coverage over the Indian Ocean, Meteosat-7, would be replaced.

Objective 1: Limited Engagement with NOAA Contributed to an Incorrect Assumption *(continued)*

- DOD established this assumption—which was based on historical precedent—during the requirements review. DOD carried this assumption forward into the AOA without adequately assessing the risk that European coverage might not continue.
  - NOAA officials, who work closely with international partners, had an understanding of the plans for European satellites at the time. While DOD made some efforts to communicate with NOAA representatives, such as through a discussion with a senior technical advisor, these efforts did not result in DOD determining the full risks of assuming that Meteosat-7 would be replaced.
  - In addition, during the time of the AOA study, publicly available reports from an international coordination group indicated uncertainty about extended Meteosat coverage over the Indian Ocean.[12] The reports stated that such coverage was not guaranteed and that the European agency had not committed to providing coverage in the long term.

[12]The Coordination Group for Meteorological Satellites has a range of international member organizations, including NOAA and the European agency responsible for the Meteosat satellites, EUMETSAT. The group meets about once a year and coordinates satellite systems to support operational weather monitoring and forecasting. Coordination Group for Meteorological Satellites, *Report of the 41st Meeting of the Coordination Group for Meteorological Satellites* (Tsukuba, Japan: July 8-12, 2013); *EUMETSAT's Plans for Indian Ocean Coverage Beyond 2013,* CGMS-41 EUM-WP-15 v1a (July 2, 2013); and *Report of the 40th Meeting of the Coordination Group for Meteorological Satellites* (Lugano, Switzerland: Nov. 5-8, 2012).

Objective 1: Limited Engagement with NOAA Contributed to an Incorrect Assumption *(continued)*

- The AOA study guidance directed the study team to conduct a comprehensive assessment of existing and planned future international partner capabilities—including Meteosat systems—and the likelihood of availability of such capabilities.
  - CAPE's assessment of the AOA stated the study team could not adequately assess the future state of affairs with regard to civil and/or international partners and therefore did not attempt to quantify the risk.
  - Despite the study team's inability to quantify the risk, as well as a statement by the European agency's Director of Operations that a decision to replace Meteosat-7 had not been made and would hinge on several outstanding factors documented in the AOA report, the final AOA report deemed the likelihood of the gap not being filled as low, based on historical trends. The AOA report also noted that the consequence of not filling the gap could be significant.
- DOD officials stated that assumptions must be made for the purpose of conducting analysis, and that decisions based on the AOA results are dependent on the risk tolerance of the decision makers.
- While making assumptions is a necessary step in scoping an AOA study, understanding the true risk of an assumption about the reliability of partner satellites is critical for those making decisions based on the SBEM AOA, particularly if decision makers are asked to use their risk tolerance to inform their decision on a DOD investment.

Objective 1: Range of Alternatives Primarily Focused on a Subset of Capabilities

- The analysis of military utility in Phase 1 informed the range of alternatives to be assessed in Phase 2. Based on the Phase 1 analysis, the AOA team determined that all but 1 of the 12 capabilities demonstrated military utility.[13] Within the remaining 11 capabilities, the team determined:
  - 8 capabilities had limited space-based utility, would be sufficiently provided by climatology and/or ground-based capabilities, or would be sufficiently provided by U.S. civil government and international partner satellites; and
  - 3 capabilities could be provided by a DOD space-based solution.
- With approval from the Study Advisory Group, the AOA team identified a total of ten alternatives to assess in Phase 2.[14]

[13]The analysts determined that no space-based auroral characterization data were being used operationally and therefore excluded the capability from further analysis.
[14]The AOA included four principal alternatives, with six excursions under the second principal alternative, for a total of ten.

Objective 1: Range of Alternatives Primarily Focused on a Subset of Capabilities *(continued)*

- The team determined that the three capabilities that potentially justified a DOD solution—1) ocean surface vector wind, (2) tropical cyclone intensity, and (3) energetic charged particles—would be fully assessed in Phase 2. The team assessed various ways to provide these three capabilities in seven alternatives.[15]
  - Within the scope of these three capabilities, the AOA team duly evaluated a broad range of options in Phase 2. For example, the team evaluated disaggregated options with sensors on separate and/or host satellites; miniaturized satellites called CubeSats; providing no capabilities or a subset of the three capabilities; and satellites in different orbits.
  - In prior work, based on an assessment of over 20 programs that conducted AOAs, we found that programs that considered a broad range of alternatives tended to have better cost and schedule outcomes than programs that examined a limited range of alternatives.[16]

[15]These three capabilities were assessed under one principal alternative, with six excursions, for a total of seven alternatives.
[16]GAO-09-665.

Objective 1: AOA Team Assessed Alternatives for Other Capabilities to a Limited Extent

- The AOA team determined the remaining eight capabilities with military utility would undergo an abbreviated assessment in Phase 2.
  - One of the ten alternatives, referred to as the baseline, assessed ways to mitigate all capabilities by relying only on non-DOD assets; that is, U.S. civil government, commercial, and international partner assets.
  - Two of the ten alternatives sought to address all capabilities—one by leveraging alternative data sources as a more cost-effective approach to mitigate potential gaps, and another designed to meet all minimum performance requirements.

Objective 1: AOA Team Assessed Alternatives for Other Capabilities to a Limited Extent *(continued)*

- Importantly, the AOA did not assess alternatives for providing cloud characterization and theater weather imagery—deemed the highest-priority capabilities—at the level of detail at which it assessed alternatives for ocean surface vector wind, tropical cyclone intensity, and energetic charged particles. As noted above, the analysis assumed U.S. civil government and international partner assets, such as Europe's Meteosat, would continue to provide the necessary support, despite indications at the time that continued Meteosat coverage was uncertain.

Objective 1: Range of Alternatives Included Limited Assessment of Key Aspects of Space Systems

- Within the range of alternatives assessed, the analysis considered other key aspects of space systems, including resiliency and ground segment impacts, to a limited extent.
  - DOD has recently emphasized the importance of considering resiliency—the ability of a system to support the functions necessary for mission success in spite of hostile action or adverse conditions—for military space systems. The AOA included a limited resiliency analysis, but resiliency was not used to compare alternatives.[17]
  - The AOA focused on the space segment and did not analyze alternative ground segment components. However, the study team considered implications and impacts to the ground segment and determined these would need to be assessed more thoroughly once DOD decides on a solution. In prior work, we recommended DOD comprehensively examine the full range of issues related to moving to a new approach, such as disaggregation, which include the impacts to ground and other interconnected systems.[18] At the time, DOD concurred with our recommendation.

[17]At the time of the AOA, "resiliency" was not yet defined across DOD. The analysis focused on the need to protect DOD systems from adversary attack and the potential to affect DOD capabilities if assets such as satellites were unavailable, according to officials.

[18]GAO, *DOD Space Systems: Additional Knowledge Would Better Support Decisions about Disaggregating Large* Satellites, GAO-15-7 (Washington, D.C.: Oct. 30, 2014).

Objective 2: AOA Informed Plans for Some Capabilities, but Is Less Useful as a Decision Making Tool for Two Critical Capabilities

Objective 2: AOA Informed Some Solutions for Meeting Capability Gaps; DOD Is Assessing Solutions for Other Gaps Outside of the AOA Process

- The AOA provided useful analysis of potential DOD space-based solutions for 3 of the 11 capabilities determined to have military utility. DOD is proceeding with plans to provide 3 capabilities that were fully assessed in the AOA.
- For the remaining 8 capabilities, the AOA determined other assets—such as ground-based and U.S. civil government and international partner satellites—could provide sufficient coverage or modeling development could help mitigate the gaps. Consequently, the AOA is less useful for informing plans for 2 of the highest-priority capabilities. DOD is now re-assessing solutions for these capabilities outside of the AOA process.

Objective 2: AOA Provided Useful Analysis for Plans for Some Capabilities

- Given an increasingly constrained budget environment, with the SBEM AOA, DOD took a relatively new approach to considering ways to provide capabilities in Phase 2.
  - Specifically, DOD considered what was really needed operationally and options for leveraging other sources of space-based weather data instead of planning to provide all capabilities on its own.
  - The AOA also identified non-space based solutions for meeting capabilities, including the development of algorithms to more effectively process existing data.
  - In addition, DOD conducted the analysis without identifying a preferred solution before the AOA, avoiding a flaw we have found in past AOAs.[19]

[19]In prior work, we found that some AOAs were limited because program sponsors had decided on a preferred solution prior to the AOA. GAO-09-665.

Objective 2: Plans for the Weather System Follow-on (WSF)

- Based on the AOA's focus on evaluating solutions for three capabilities—(1) ocean surface vector wind, (2) tropical cyclone intensity, and (3) energetic charged particles—DOD is developing plans to meet those needs with space-based solutions, though some may not be available in time to avoid short-term gaps, as discussed further below.
- The Weather System Follow-on (WSF) is intended to provide the first two capabilities, ocean surface vector wind and tropical cyclone intensity, in a morning polar orbit. According to officials, plans, which are in development, include:

Objective 2: Plans for WSF *(continued)*

- Step 1: A technology demonstration using the Jet Propulsion Laboratory's Compact Ocean Wind Vector Radiometer, with a planned launch in 2017 and a 3-year design life. The demonstration plans to use a currently available payload to partially address the ocean surface vector wind and tropical cyclone intensity requirements.[20] The Air Force plans to use Operationally Responsive Space acquisition principles, according to officials, in order to streamline decision making and reduce the acquisition time line.[21]
- Step 2: The WSF objective system, planned for launch in 2022, is envisioned as a single polar-orbiting satellite with a replacement satellite every 5-7 years, providing capabilities until around 2040.

[20]Satellites carry one or more payloads, which contain the technology to provide certain capabilities, such as a microwave sensor to collect data on wind speed.
[21]The Joint Operationally Responsive Space Office was established in 2007 to plan and prepare for the rapid deployment of space capabilities to meet urgent warfighter needs. According to the ORS Office, because it is a technology demonstration, the project does not require an acquisition strategy. Instead, the Air Force Program Executive Officer for Space is the milestone decision authority and approved the demonstration in February 2016.

Objective 2: Plans for WSF *(continued)*

- Because WindSat, the only SBEM sensor that fully meets DOD's ocean surface vector wind capability needs, may reach end-of-life as early as this year, a gap in providing full capabilities is likely to occur until the objective system is launched.
- The Space and Missile Systems Center is preparing an acquisition strategy for the objective system, and expects to present the strategy to the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics in early 2016. However, the NDAA for Fiscal Year 2016 limits the availability of funds for the WSF program until DOD presents a plan to Congress for meeting cloud characterization and theater weather imagery requirements and makes certain certifications to the congressional defense committees.[22]

- To address the third capability, the Air Force plans to host energetic charged particle sensors on all of its satellites for programs that are in the pre-system development phase. Planned dates of implementation are expected to vary across programs, but DOD estimates to begin implementation around 2022.

[22]Specifically, not more than 50 percent of funds authorized to be appropriated by the NDAA or otherwise made available for fiscal year 2016 for research, development, test, and evaluation AF, for the WSF may be obligated or expended until DOD provides a briefing on the plan to the Congressional defense committees, and the Chairman of the Joint Chiefs of Staff certifies to the committees that the plan will meet DOD's requirements and will not negatively affect the combatant command commanders. Pub. L. No. 114-92 §1615 (2015).

Objective 2: AOA Is Less Useful as a Decision Making Tool for Two Critical Capabilities

- The AOA is less useful for informing plans for two critical needs.
  - Currently, DOD faces a near-term need for cloud characterization and theater weather imagery capabilities over the Indian Ocean given the estimated end of life of the European's Meteosat-7 in 2017.[23] DOD did not fully assess potential alternative solutions to meet these capability needs within the AOA process.
  - Instead, outside of the AOA process, DOD is now examining solutions to meet cloud characterization and theater weather imagery capabilities in the short term. As shown in table 2, options being considered, either alone or combined, that would partially replace Meteosat-7 coverage include:
    - Continuing to rely on DMSP coverage, along with other polar-orbiting satellites from NOAA and Europe, through the end of life for DMSP-19.
    - Using data from a European satellite, Meteosat-8—moved over Eastern Europe, which would partially cover the Indian Ocean region—and begin using data from Indian geostationary satellites.

[23]Officials have noted that without Meteosat-7, DOD can still meet the minimum requirement of a 4-hour refresh rate using the combination of existing polar-orbiting satellites: DMSP, NOAA's Joint Polar Satellite System, and Europe's Meteorological Operational satellite. However, these will not consistently provide the 30-minute refresh Meteosat-7 currently offers.

Objective 2: Short-Term Space-Based Options for Cloud Characterization and Theater Weather Imagery

Table 2: Potential Short-Term Options for Providing Cloud Characterization and Theater Weather Imagery Over the Indian Ocean

Program/Satellite (Owner)[a]	Period of Coverage	Steps Required	Potential Limitations
Defense Meteorological Satellite Program [DMSP] **(Department of Defense [DOD])**	Present to 2020	Continue supporting DMSP satellites in orbit, combined with continued use of U.S. civil government and European polar-orbiting satellites	Will not meet refresh rate currently provided by Metoesat-7; only provides partial geographic coverage of the region.
Meteosat-8 **(European Organisation for the Exploitation of Meteorological Satellites [EUMETSAT])**	2016 to 2020	EUMETSAT decision to move Meteosat-8 further east , which would partially cover the Indian Ocean Implement minimal changes to data downlink	Availability depends on EUMETSAT determination (expected in June 2016) that Meteosat-8 is no longer needed in its current position; only provides partial geographic coverage of the region.
INSAT **(Indian Space Research Organisation)**	2017 (estimated) to undetermined (potential for longer-term support)[b]	Secure approval from Indian government Establish and maintain operational data link	Further development of reliable data delivery may be needed; only provides partial geographic coverage of the region.

Source: GAO analysis of DOD, National Oceanic and Atmospheric Administration, and international organization information. | GAO-16-252R

[a]DOD has also inquired with NOAA about moving a Geostationary Operational Environmental Satellite over the Indian Ocean to provide support for geostationary coverage. While technically feasible, potential limitations would need to be addressed, including ensuring availability of a satellite as a spare and funding to cover costs associated with operations and construction of a ground system.
[b]INSAT-3D was launched in 2013 with a 7-year mission life. The Indian Space Research Organisation has plans to build and launch additional INSAT satellites.

Objective 2: Short-Term Space-Based Options for Cloud Characterization and Theater Weather Imagery *(continued)*

- The options noted above in table 2 are short-term solutions.
  - For example, continuing to rely on the DMSP satellites already in orbit is to provide coverage until 2020, based on the estimated lifespan of the final satellite in orbit, DMSP-19.
    - At the time of the AOA, DOD expected to launch DMSP-20, which would have extended coverage until 2023-2027, depending on when the satellite was launched. DOD and intelligence community officials we interviewed emphasized the importance of launching DMSP-20 to provide continued coverage for military and intelligence community needs.
    - However, due to lack of funding for DMSP-20, the Air Force moved to terminate activities for the satellite in December 2015.[24] The termination cannot be reversed because of payload contamination once maintenance activities for DMSP-20 are shut down, according to officials.

[24]The Explanatory Statement of the Consolidated Appropriations Act, 2016, Pub. L. No. 114-113 (2015) provided for a $89,351,000 reduction of the DMSP fiscal year 2016 budget request and a rescission of $50,000,000 from the fiscal year 2015 procurement funds for DMSP. [161 Cong. Rec. H9693 at H9928 (Dec. 17, 2015)] Prior to the termination, officials estimated the costs to integrate, store (including maintaining contractor support), and launch DMSP-20 at over $400 million. DOD officials said the program will continue to sustain DMSP satellites in orbit.

Objective 2: Longer-Term Plans Undetermined

- Longer-term plans for providing cloud characterization and theater weather imagery over the Indian Ocean are not yet determined.
  - The Joint Requirements Oversight Council directed the Air Force to address cloud characterization and theater weather imagery parameters and mitigation strategies in the capabilities development document for WSF.[25] The Air Force is currently examining options. Depending on the risk tolerance of decision makers, officials stated these could include:
    - Relying on U.S. civil government and international partners;
    - Hosting a sensor on a satellite; or
    - Building a new DOD satellite.

[25]According to some officials, related efforts include the review and re-assessment of assumptions in the AOA.

Objective 2: Collaboration with NOAA on International Partner Capabilities

- Limited mechanisms for formal coordination and collaboration between DOD and NOAA increase the possibility that, going forward, DOD assesses potential solutions involving international satellite capabilities without fully understanding the risks.
    - Changing circumstances in a partner country may lead to changes in related plans. For example, since the AOA was completed, according to NOAA, changes in program priorities and budget constraints have led Japan to reconsider its decision to develop a follow-on for GCOM-W, a satellite that supports DOD's snow depth, soil moisture, and tropical cyclone intensity capabilities.
    - Effective coordination and collaboration between DOD and NOAA would help to ensure DOD is informed about such changes as it plans for ways to provide capabilities in the future.

Objective 2: Collaboration with NOAA on International Partner Capabilities *(continued)*

- NOAA and DOD officials have indicated that formal coordination and collaboration are key to ensuring DOD's interests are represented with international partners. In addition, in prior work we concluded that unclear agency roles and responsibilities can pose a challenge to interagency collaboration.[26]
- Since the conclusion of the AOA study period in the fall of 2013, DOD and NOAA officials state they have increased their communication by discussing ways to leverage data from international partner satellites in the near term. DOD and NOAA have also discussed establishing more formal mechanisms of coordination and collaboration, such as a memorandum of understanding (MOU).
  - Our body of work on interagency collaboration has shown that establishing formal collaborative mechanisms and documenting agreements can help provide clarity about roles and responsibilities and support mutual accountability.[27]

[26]GAO, *Interagency Collaboration: Implications of a Common Alignment of World Regions among Select Federal* Agencies, GAO-11-776R (Washington, D.C.: July 11, 2011).
[27]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms,* GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

Objective 2: Collaboration with NOAA on International Partner Capabilities *(continued)*

- One potential vehicle for formalizing coordination and collaboration between DOD and NOAA is the recently re-established Committee for Operational Environmental Satellites, led by NOAA's Office of the Federal Coordinator for Meteorology.
  - The committee is intended to help achieve interagency coordination in the planning for and use of operational environmental satellites. DOD representatives have participated in quarterly meetings, according to officials.
  - While the committee does not necessarily focus on international partner issues, one proposed objective of the committee is to establish a dialogue with other groups, including international organizations. Further, DOD officials have stated that the committee is one way DOD can connect with NOAA's international affairs officials.

Scope and Methodology

We obtained information from DOD officials at:

- Office of the Secretary of Defense:
  - Cost Assessment and Program Evaluation, Washington, D.C.
- Office of the Undersecretary of Defense:
  - Acquisition, Technology and Logistics, Washington, D.C.
  - Intelligence, Washington, D.C.
  - Policy, Washington, D.C.
- Joint Chiefs of Staff:
  - Directorate of Force Structure, Resource, and Assessment, Washington, D.C.
  - Directorate of Intelligence, Washington, D.C.
- Army:
  - Deputy Chief of Staff, Washington, D.C.
- Navy:
  - Chief of Naval Operations, Washington, D.C.
  - Naval Research Laboratory, Washington, D.C.
- Air Force:
  - Office of the Assistant Secretary of the Air Force, Acquisition, Washington, D.C.
  - Office of the Assistant Secretary of the Air Force, Space / DOD Executive Agent for Space Staff, Washington, D.C.
  - Air Staff, Operations, Plans and Requirements, Washington, D.C.
  - Air Staff, Strategic Plans and Programs, Washington, D.C.
  - Air Combat Command, 557th Weather Wing, Offutt Air Force Base, Neb.
  - Air Force Space Command, Peterson Air Force Base, Colo.
  - Space and Missile Systems Center, Remote Sensing Systems Directorate, Los Angeles Air Force Base, Calif.
  - Operationally Responsive Space Office, Kirtland Air Force Base, N. Mex.

Scope and Methodology *(continued)*

We obtained information from joint intelligence community officials at:

- National Geospatial-Intelligence Agency, Springfield, Va.
- National Reconnaissance Office, Chantilly, Va.

We obtained information from U.S. civil government officials at:

- National Aeronautics and Space Administration, Washington, D.C.
- National Oceanic and Atmospheric Administration:
  - Office of the Federal Coordinator for Meteorology, Silver Spring, Md.
  - National Environmental Satellite, Data, and Information Service, Silver Spring, Md.
  - National Weather Service, Silver Spring, Md.

We obtained information from industry officials at:

- Atmospheric and Space Technology Research Associates (ASTRA)
- Ball Aerospace and Technologies Corp.
- Exelis Inc. (as acquired by Harris Corporation)
- Lockheed Martin Space Systems
- Orbital ATK

Scope and Methodology *(continued)*

- To determine the extent to which the SBEM AOA addressed input from stakeholders and assessed the range of alternatives for potential solutions:
  - We reviewed relevant DOD and GAO documents to develop an understanding of the requirements and guidance for conducting an AOA. Specifically, we reviewed the DOD Instruction 5000.02, the Office of Aerospace Studies Analysis of Alternatives Handbook, the SBEM AOA guidance and study plan, and prior GAO work on conducting early acquisition activities and government leadership and communication for cross-cutting issues to identify assessment criteria.[28]
  - We reviewed the AOA documents and interviewed officials involved in conducting and reviewing the AOA to understand how the AOA was developed.

[28]DOD Instruction 5000.02, "Operation of the Defense Acquisition System" (Jan. 7, 2015).

Scope and Methodology *(continued)*

- We interviewed users and providers of DOD SBEM data (stakeholders)—officials from the military services, the intelligence community, and U.S. civil agencies—to gain their perspectives on how stakeholder views were incorporated into the AOA. We also interviewed industry officials to obtain their perspectives on ways to effectively assess options for providing SBEM capabilities, including stakeholders that should be involved.

- To determine the extent to which the AOA informed plans for providing SBEM capabilities:
  - We reviewed documents and interviewed DOD officials about plans and decision making processes for providing future SBEM capabilities in order to understand decisions made following the AOA.
  - We reviewed documents and interviewed NOAA officials about activities of the international SBEM community (including partners) to understand the potential effects on DOD plans.

Scope and Methodology *(continued)*

- We interviewed DOD officials and other stakeholders about potential alternatives, if any, to launching DMSP-20 in order to provide coverage over the expected Indian Ocean gap.
  - Because DOD is still assessing options, data on the most cost-effective approach are not yet available. Instead, we obtained information about the viability of implementing potential options and the extent to which they are expected to provide the necessary coverage, and related rough order of magnitude cost estimates, as available.