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Winds of Change: Environmental Monitoring for an Era of Peer Competition

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Key Points

Modern space-based environmental monitoring (SBEM) is essential to establish the weather information dominance necessary to empower successful combat operations.

The U.S. military's element of the current SBEM architecture, the Defense Meteorological Satellite Program (DMSP), is too brittle and old to ensure DOD's weather information dominance in future conflicts.

Multiple delays to a DMSP replacement over the past 20 years expose current U.S. forces to serious risk, as there are limited alternatives once the DMSP system reaches the end of its service life.

To ensure the SBEM mission does not fail, the Space Force must achieve its current strategy: fielding the Electro-Optical/Infrared Weather System (EWS) and Weather System Follow-on Microwave (WSF-M) programs to mature technologies and then transition to procuring an operational constellation with adequate numbers of systems.

SBEM partnerships are also critical to the SBEM Family of Systems (FoS), especially in the near term, because the DOD does not have enough capability currently on orbit to cover the necessary orbits and revisit rates.

A defined program of record based on mature technologies and current requirements is needed to secure support, funding, and resources to field the next generation of SBEM satellite constellations.

As the Department of the Air Force builds an architecture to support forces operating in a CJADC2 construct, Space Force should consider additional requirements for a more disaggregated SBEM architecture to provide more real-time weather data and greater resiliency with smaller, less expensive platforms.

Abstract

Throughout the history of conflict, those commanders who were able to harness weather insights have reaped strategic advantages. In contrast, those who neglected to properly account for weather conditions often fell victim to catastrophic campaign failures. Weather's importance in military operations will prove even more vital in an era where Combined Joint All-Domain Command and Control (CJADC2) transforms how missions are executed. Coordinating a highly networked force to facilitate real-time, dynamic, collaborative engagements demands robust environmental intelligence.

Despite the importance of weather data, the military environmental monitoring mission predominantly relies on a small number of satellites well past their design lives–the remains of the 60-year-old Defense Meteorological Satellite Program (DMSP). Multiple failed recapitalization efforts over the past 20 years fell short of yielding a viable operational capability and left the space-based environmental monitoring (SBEM) mission in a precarious state.

A brittle and aging DMSP architecture increases the odds of campaign failure. The current SBEM strategy to replace DMSP must be accelerated. This includes fielding the Electro-Optical/Infrared Weather System (EWS) and Weather System Follow-on Microwave (WSF-M). It also involves establishing a defined SBEM program of record as soon as possible to define the long-term vector necessary to sustain this mission. This includes defining the number of satellites needed to deliver the quality and quantity of weather data required for modern operations against a peer competitor.

The success of the SBEM strategy now hinges on a series of imperatives. Core mission capabilities provided by EWS and WSF-M must be fielded before the DMSP fails. Architecture requirements must grow to meet future mission needs—it must be adequately resilient and disaggregated; funding and resources must be assured and established in an SBEM program of record; and critical SBEM partnerships must be maintained to supplement the current DMSP architecture, which already lacks sufficient capability to cover necessary orbits and revisit rates to attain the weather information vital to all operations.

Introduction

The United States finds itself at an inflection point of needing a more effective, reliable, and resilient space-based weather capability. This mission is currently executed by a small number of aging satellites that are well past their design lives–a constellation known as the Defense Meteorological Satellite Program (DMSP). Over the last two decades, the Department of Defense (DOD) has started but never completed programs to replace these environmental monitoring satellites. Now that space is a defined warfighting domain, the imperative for a reset is even greater, considering the warfighter's need for greater capability, resilience, and assurance. This is especially true, given that the DOD plans for a Combined Joint All Domain Command and Control (CJADC2) construct of operations will demand near real-time weather data to facilitate more dynamic operational planning to allow forces to respond in shorter cycles to emerging threats. Commanders will struggle to meet mission objectives if DOD fails to meet warfighter demands with a modern set of environmental monitoring capabilities. Weather is a keystone military capability that requires focused modernization and investment that is both sufficient and consistent across time.

Multiple modern historical examples illustrate how superior—or inferior—weather information can impact mission success. Operation Eagle Claw, a 1980 special operations mission to rescue American hostages in Iran, stands as a prescient example of mission failure in an operating region sparse of high-fidelity space-based weather sensing and in-situ weather measurements across the operating region, as well as an understanding of unique regional weather features across the entire warfighting team. In short, the mission failed because of unforecast dust storms. Eight service members were killed, and the hostages remained captive for seven more months. The dramatic nature of this failure drove home the importance of environmental monitoring.

Weather: Maker and Breaker of Strategy

Anyone questioning the importance of weather need only look back across the span of military history to understand that it is one of the most critical make-or-break aspects of warfare. This is not true at just an operational level but a strategic level. To this point, in 1281, a powerful typhoon destroyed Kublai Khan's 4,400-ship invasion fleet off the coast of Kyushu, Japan. Strong winds and tides assured the success of the British strategy to destroy the Spanish Armada in 1588. Weather also proved Russia's salvation on two separate occasions separated by 100 years—helping defeat the invading forces of Napoleon and Nazi Germany. Furthermore, the Normandy invasion in WWII was delayed based on the analysis of an Army meteorologist. His forecast for a break in the poor weather was superior to the German weather analysis and resulted in achieving strategic surprise. In 2003, air operations planners used knowledge of poor weather trends to plan munitions loads using GPS-guided bombs to strike through the weather to decimate Iraqi forces in garrison. In a future peer conflict, superior weather intelligence could be the deciding factor—making space-based environmental sensing a top warfighting modernization priority.

In contrast, commanders appropriately used weather data in 2011 when they planned and executed the Osama bin Laden raid in Abbottabad, Pakistan. The mission was smartly delayed for 24 hours based on predictions in the targeted area for hazardous surface winds and thunderstorms. Not having this accurate and timely weather data might have yielded another disaster like Eagle Claw. It is not an exaggeration to state that environmental monitoring likely made the difference between success and failure in one of the highest-profile operations of the post-9/11 era.[1]

Today, the impact of weather in military operations is as pivotal as at any time in history, and it will continue to be as important in the future. According to Maj Gen Gregory Gagnon, Deputy Chief of Space Operations for Intelligence, U.S. Space Force, “Weather’s also important when you’re trying to forecast what the adversary’s going to do. War is hard and everything in war is hard and the weather always gets a vote. So it’s important on both sides of the equation.”[2]

Weather impacts all levels of warfare, from tactical to strategic. Environmental data plays an important part in closing kill chains to help get the right shooter to the right place at the right time to provide the right effect. This involves gathering and analyzing imagery and associated data, determining which sensors have the best line of sight, and selecting the correct weapon given the weather and environmental conditions. Concepts like CJADC2, which focuses on gathering tremendous volumes of data, and processing it into actionable information to effectively manage a broad array of battle assets in a dynamic, real-time fashion, are going to be highly reliant on weather data. Additionally, consider the benefits afforded to U.S. commanders that can anticipate an adversary’s decision calculus based on weather information—where forces are likely to move and what weapons they are likely to employ or not. The core of a CJADC2 strategy is to collect, process, and exploit information across all elements within the battlespace faster and more effectively than the adversary.

Today, effective environmental monitoring requires a broad range of sensors operating in the air, at sea, on land, and through space. Of these, the space domain is arguably the most crucial, given the unique ability of satellites on orbit to surveil and measure a vast expanse of territory both rapidly and concurrently from a vantage that terrestrial sensors cannot. This is especially important for military operations that are often executed in remote regions or where an adversary denies access. In terms of the scale and scope of the data gathered, space-based environmental monitoring (SBEM) satellites can secure the information needed to model weather patterns, cloud cover, surface wind speed and direction, wave heights, snow depth, soil moisture, and other critical weather information anywhere on the surface of the Earth.

The Defense Meteorological Satellite Program (DMSP)

Like many U.S. space systems, the DMSP began life in the early days of the Cold War space race as a classified program run by the National Reconnaissance Office (NRO). Per the Space Force program description:

“The main weather sensor on DMSP is an optical system, which provides continuous visual and infrared imagery of cloud cover over an area approximately 1,600 nautical miles wide. Complete global coverage of weather features is accomplished every 14 hours, providing essential data over data-sparse and data-denied areas.”

While it is referred to as a constellation, it is important to note that it comprises only two primary satellites in sun-synchronous low-earth polar orbits and ideally two backups, but it currently has no backups.

Source: DOD, DMSP Factsheet, 2023.

Despite general recognition of SBEM’s importance, the mission risks becoming a victim of its own success because individuals at all levels of the military enterprise often take it for granted. They expect immediate access to accurate and timely weather data and are unaware the function is reliant upon a declining set of aging DMSP satellites. Years of wear and tear on the DMSP satellites in orbit have taken their toll on the constellation, and it is now beyond its design life.

Furthermore, DMSP was designed and configured in an era where space was considered a peaceful operating domain. Satellites were engineered and built as large-scale, highly capable, multi-function systems. As such, a relatively small number of satellites sustained the entire SBEM mission. In an era where adversaries are increasingly contesting space operations, this design architecture fails to afford the resiliency required for modern operations. Losing one satellite, or 50 percent of the current operational constellation, would severely degrade what DMSP provides to the enterprise. A numerically larger, more disaggregated set of capabilities would help reduce this risk.

Leaders have long understood the eventual capability gap the failing DMSP constellation represents, and they have outlined many potential solution paths. However, for various reasons, these modernization vectors were not executed. In the meantime, a series of collaborative decisions, such as interagency and international partnerships, have helped to deliver better global coverage as a part of a family-of-systems (FoS). However, given the rapid evolution of mission requirements, these improvised solutions will fall short of meeting mission demand. It is time for DOD to get serious about delivering a holistic, sustainable, and capable path forward, one that is purpose-built for the warfighter to fight and win the nation's wars.

Fortunately, a requirements-based plan does exist. In 2016, DOD harnessed the findings of a Joint Requirements Oversight Council (JROC) study to launch an SBEM recapitalization effort.[3] This study was based on mission gaps assessed via an Analysis of Alternatives (AOA) executed in the 2010s.[4] This collective effort led to the selection of two programs to meet modern space-based environmental sensing requirements: the Electro-Optical/Infrared Weather System (EWS) and Weather System Follow-on Microwave (WSF-M).

Electro-Optical/Infrared Weather Systems (EWS) and Weather Satellite Follow-on Microwave (WSF-M)

The EWS effort aims to demonstrate and mature technologies, thus reducing risks for a full operational constellation of small weather satellites that provide cloud characterization and theater weather imagery. These are the two highest priority requirements in the SBEM architecture. General Atomics Electromagnetic Systems is responsible for developing the EWS design.

The intent of the WSF-M program is to develop a next-generation operational environmental satellite system that addresses critical gaps identified in the current U.S. SBEM architecture: ocean surface vector wind measurements, tropical cyclone intensity, soil moisture, snow depth, and sea ice thickness. Ball Aerospace is responsible for developing the program.

These two satellite programs collectively satisfy the currently documented SBEM requirements, but greater capacity is likely needed to sustain the U.S. combat edge in future operations.

Sources: "GA-EMS Awarded Contract for USSF Weather Satellite Program Prototype," General Atomics press release, March 7, 2022; "Weather System Follow-On - Microwave," Ball Aerospace factsheet.

While this recapitalization effort is designed to provide better resiliency through far more modern, capable satellite systems, it is also important to recognize the risks that remain to achieve the desired SBEM architecture. Namely, the current plan initially fields demonstration satellites and will require additional satellites to deliver the quality and quantity of weather information necessary to meet evolving demands in a way that also prioritizes resilience. Larger constellations of a dozen or more of these systems are necessary to improve revisit rates and increase the delivery of near real-time weather data, as needed by today's warfighter. Sustaining more satellites in orbit also guards against an enemy potentially

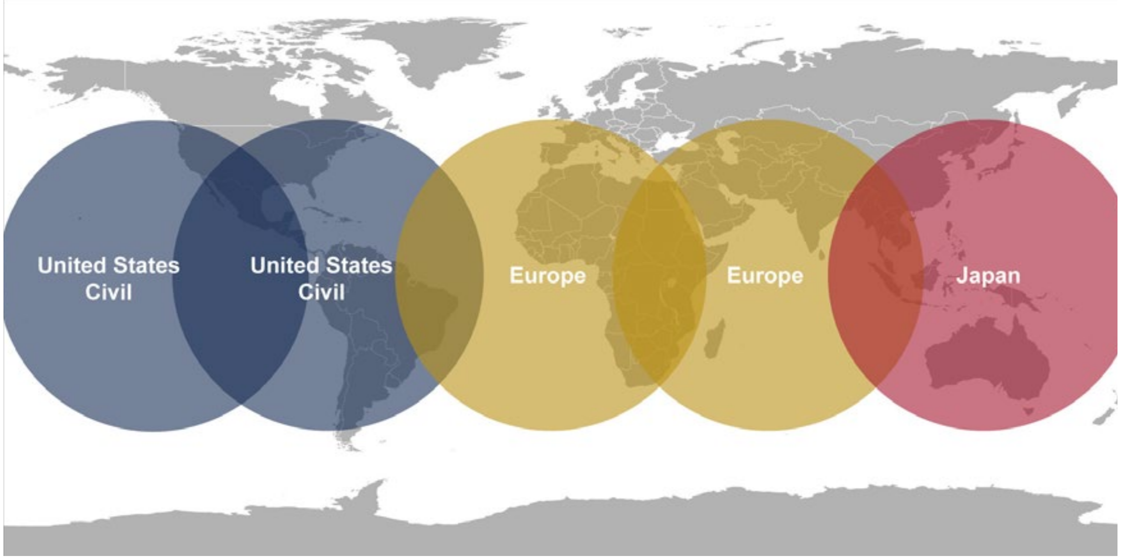


Figure 1: The DOD currently uses SBEM data from U.S. civil government, European, Japanese, and South Korean (not depicted) geostationary satellites to provide global environmental monitoring. These satellites cover latitudes up to 60 degrees north or south, depending on location. India, China, and Russia also employ geostationary satellites to collect weather data.

Source: "Department of Defense (DOD) Weather Satellites: Briefing to Congressional Defense Committees," Government Accountability Office (GAO), 2016, slide 12 (p. 22).

knocking out our SBEM capabilities with a limited number of attacks. To these points, it is important to highlight that the JROC study identified the core capabilities an SBEM architecture needs to deliver, but the plan for delivering these capabilities was established before concepts like CJADC2 were created. Space was still regarded as a relatively uncontested domain as well.

DOD and the Space Force can redress these shortcomings by capitalizing on the positive vector they are on with their current SBEM plan by factoring in these aspects when defining the operational SBEM architecture. A larger satellite constellation would help address both issues—providing more near real-time weather data and affording better resilience in the event any single satellite fails or is affected by adversary counterspace measures.

As the old-technology DMSP is already a degraded capability hanging by a thread, the urgency to move quickly cannot be understated—especially considering that the potential for peer conflict is the highest since the Cold War. DOD needs to express confidence in the Space Force's management of its demonstration phase of new SBEM capabilities and plan concurrently for the fielding of a follow-on defense-purposed constellation. Additionally, a consolidated SBEM program of record is needed to manage the demonstration efforts and define and field the multi-faceted operational architecture. It would signal the importance of the weather mission both within the Department of Defense and on Capitol Hill.

In the meantime, leaders are augmenting U.S. SBEM capabilities through a FoS approach by collaborating with other weather sensors on orbit via partnership with entities like the National Oceanic and Atmospheric Administration (NOAA) and allies. This measure provides necessary weather data in the interim, but it must not be mistaken as a full-on replacement for SBEM mission modernization.[5] A dedicated national security constellation of modern SBEM capabilities is essential to minimize the risks associated with relying on these partnerships during conflict when the data is needed the most. Gen Glen VanHerck, commander of U.S. Northern Command and NORAD, warns against dependence on sources of critical information that can be interrupted when most needed. “The thing we have to ask ourselves is, do we want to find ourselves where an individual or a business can impact national security by their perception or their political views? And we find ourselves in a situation where now they’re impacting our ability to conduct operations around the globe.”[6]

A smart, holistic solution demands that the Department of Defense, individual services and agencies, and Congress continue to ensure progress is delivered in a timely, responsive fashion. SBEM capabilities often fall below the budgetary cut line to offset higher priorities—a risk that exists today, given the 2023-enacted defense budget caps. Yet, tomorrow’s weather satellites will make the difference between success and failure in future missions. To this end, there are five specific imperatives that DoD must act on to sustain a weather decision advantage:

1. **Prevent any further delays of the DMSP replacement program.** Over the last two decades, the modernization program has fallen behind schedule, often due to budget concerns. The DMSP architecture is now on the precipice of system failure. Any further delays or budget cuts could see the capability sunset before a replacement is operationally deployed at a scale and scope required to meet full mission requirements.
2. **Build resiliency in the SBEM architecture.** Space is now recognized as a warfighting domain, with adversary nations clearly stating their willingness to disrupt and destroy U.S. space capabilities in the event of a conflict.[7] To mitigate the risks posed by this reality, DOD must embrace a disaggregated SBEM architecture to provide resiliency and offset risks associated with combat attrition through smaller, less expensive platforms.
3. **Continue to update SBEM architecture requirements to reflect the future CJADC2-related needs of the warfighter.** In order to build the SBEM satellite capacity that can meet the weather needs of the warfighter in 2023 and beyond, DOD will need to update its architecture requirements to increase coverage area and improve refresh rates. A constellation similar to the sensing footprint of DMSP requires a minimum of 12 satellites to gain a one-hour revisit period. Attrition reserve in orbit would be additive. Weather insights are fundamental to empowering smart force management decisions, a requirement that is growing given the increasingly dynamic, collaborative force employment concepts defense leaders seek to develop via efforts like CJADC2.
4. **Establish a long-term, stable SBEM program of record.** A defined program of record based on mature technologies will synchronize current requirements. This will help alleviate uncertainty in the SBEM architecture and focus funding to provide a full constellation of satellites, bringing the Space Force one step closer to delivering the operational SBEM capabilities warfighters need.
5. **Build and nurture partnerships.** While the U.S. military must be able to secure its own SBEM data necessary to execute missions organically, the risks are high that DMSP may experience mission failure before the next-generation SBEM solution is on orbit at the scale necessary to meet full operational demand. Accordingly, partnerships are critical to manage risk within the SBEM strategy, especially in the near term. The DOD partnership strategy must prioritize SBEM data assurance through reliable sources and data availability through all phases of conflict.

> **“Every DOD operational mission begins with a weather briefing; either space weather, terrestrial weather, or both. The data required for DOD missions is often unique and necessitates 24/7 global ability to forecast weather in austere and denied environments.”**
>
> *-Gen David Thompson*

The time to field EWS and WSF-M and implement associated SBEM reforms is now. DMSP is well beyond design life expectations, and a follow-on capability is already late to need. The Space Force must urgently employ modern environmental monitoring technologies and satellite architectures to their fullest advantage. As Space Force moves ahead demonstrating new defense environmental sensing capabilities, DOD should lean into parallel planning of the eventual fielding of a defense-purposed constellation to tighten the timeline for getting capability to the warfighter. The urgency cannot be overstated.

A Fundamental Element of CJADC2 & Information Superiority

Environmental monitoring is an undeniable part of military operations and culture. In the regions U.S. forces will most likely need to operate in the future, like the Arctic and Western Pacific, crucial weather data from terrestrial sources is sparse, and SBEM will be a prime requirement to gain weather intelligence needed to fight and win. Every mission briefing begins with a weather update or weather forecast. Consider an aircrew getting ready to launch on a sortie: they need to know about wind speed, icing temperatures, lightning, cloud cover, visibility, sand/dust conditions, and severe weather precipitation. These factors impact when an aircraft can take off and land, what munitions might be employed, the types of sensors that will be more effective, and when and where aerial refueling operations can occur. They also affect essential supporting functions like search and rescue, plus intelligence, surveillance, and reconnaissance (ISR) activities. Maritime, land, and space launch operations have similar laundry lists of weather information requirements, and their success hinges on understanding weather conditions.

Operation Desert Storm in 1991 stands as an example of how weather drove targeting. During that time, the only precision weapons were laser-guided, and cloud cover would render them ineffective. The chief planner of that air campaign—then-Lt Col David A. Deptula—would begin every planning cycle with a weather forecast as that would determine where he could effectively use the laser-guided bombs carried by the F-117s.[8] A more recent historical example of weather information’s vital role in delivering a decision-making advantage is Operation Iraqi Freedom. As Chief of Space Operations, Gen Chance Saltzman described: “The ability of our U.S. commanders to keep track of a maneuvering Iraqi army through a sandstorm and then, when the sandstorm cleared, we started hitting it with precision munitions—this had a devastating effect on the army, both physically because we were hitting the army, but also mentally. They had no idea how we were able to track them through the weather through the night. And a lot of that, of course, was enabled by our space-based ISR capabilities and as well as the munitions that we employ with GPS precision.”[9] Thanks to weather intelligence, U.S. actors possessed a

“The Space Force space-based environmental monitoring capabilities provide key global terrestrial and space weather data for DOD to plan, execute, and assess daily mission operations”

-Lt Col Joe Maguadog, EWS Program Manager and Material Lead

decision advantage over the Iraqi forces that allowed them to know when and where to strike to best secure mission effects.

As the U.S. military prepares to face challenging peer threats, defense leaders continue to understand that victory in a future conflict will go to the side with information and decision superiority. That is the underlying thinking behind CJADC2—a “warfighting capability to sense, make sense, and act at all levels and phases of war, across all domains, and with partners, to deliver information advantage at the speed of relevance.” This concept of operations will see data collected from a broad array of sensors that will be processed into actionable information to empower highly effective, dynamic command and control of forces across a given theater. Near real-time weather data will be a critical part of this equation.

The scale of this sort of enterprise is far larger than its historical predecessors. No longer will requirements be based upon a 24-hour planning cycle. The new paradigm will increasingly focus on empowering decisions in the span of hours and minutes across an entire theater. That speed will increasingly demand near real-time weather data to empower effective dynamic force management. Commanders risk mission failure if they are compelled to rely on untimely, incomplete, or inaccurate data. Dynamic targeting is one example: weapon selection is often dictated by weather factors. Additionally, the types of assets brought together to rapidly collaborate on securing a given effect will depend on accurate weather information: aircraft may not be available from a given sector if they must transit through a violent pop-up thunderstorm.

Smart force management also extends beyond combat sorties. Protection of combat aircraft, infrastructure, and personnel requires high-fidelity weather analysis supported by space-based sensing that is refreshed rapidly. In 2018, a severe hurricane nearly destroyed an entire squadron of F-22s at Tyndall Air Force Base. A storm, not the enemy, almost eliminated 10 percent of the Air Force’s preeminent fighter inventory.

In most locations across the planet where U.S. forces will operate in war and peacetime, the dearth of environmental sensing limits decision-makers’ knowledge of current and short-term trends in weather and hinders their ability to conduct longer-term forecast modeling. A primary example is in the Indo-Pacific theater, where U.S. forces will need to transit long distances and deal with complex weather patterns in operations involving China. The lack of land and ocean-based sensors creates a data gap needed to support tactical operations, inform operational level planning, and protect warfighting systems and personnel.

Satellites can fill this gap in weather data-starved regions, enabling near real-time weather monitoring and providing improved initial conditions or a starting point required for weather modeling. Processing techniques allow for improved long-term forecasting.[10] Importantly, SBEM can provide data needed to make highly accurate short-term forecasts, known as nowcasting. Such capabilities will be key to modern combat operations and the migration to CJADC2 concepts by providing the highest efficiency for the configuration and employment of the joint force in a conflict in the Indo-Pacific region.

Weather data's impact, whether used to empower U.S. forces or to frustrate an adversary's forces, will also play a key role as U.S. commanders seek to actualize concepts like Agile Combat Employment (ACE)—a geographically dispersed operations plan. As RADM Ronald Piret states, "Our ability to know the current battlespace environment better than anyone is critical. … If we know what's going to happen in the environment sooner and farther out than our adversaries, then we can utilize our fleet and our joint forces to a greater extent."[11]

To meet these evolving demands, DOD and Space Force are considering how this will shape requirements for more satellites and their corresponding orbits to ensure sufficient revisit rates. Providing adequate, timely coverage for a region as large as the Indo-Pacific, which covers 52 percent of the earth's surface—is no small matter. There comes a point when the number of satellites and their orbits matter. Larger constellations are also important because they boost resilience in the event of an enemy attack. Adversaries, especially China and Russia, recognize the role assets in space play in providing the U.S. information advantage and are actively developing technologies to hold satellites at risk.[12] DOD seeks to mitigate this vulnerability by fielding larger numbers of smaller, low-Earth orbit (LEO) satellites to boost resiliency.[13] These factors must also apply to weather constellations.

Looking at these factors at a macro level, defense weather professionals understand their mission is critical. As 557th Weather Wing commander Colonel Patrick Williams explains: "Weather operations achieve U.S. decision advantage and imposes costs on U.S. adversaries. That's our goal; that's what we're trying to get after."[14] The mission statement of the 557th Wing echoes this sentiment in articulating the goal to "identify and create space in multiple areas to ensure friendly forces can operate with near impunity; predict adversarial behavior based on environmental conditions; [and] influence adversarial behavior." Empowering these weather professionals for success demands that DOD prioritize environmental monitoring capabilities, specifically the satellite architecture that underpins a weather information advantage.

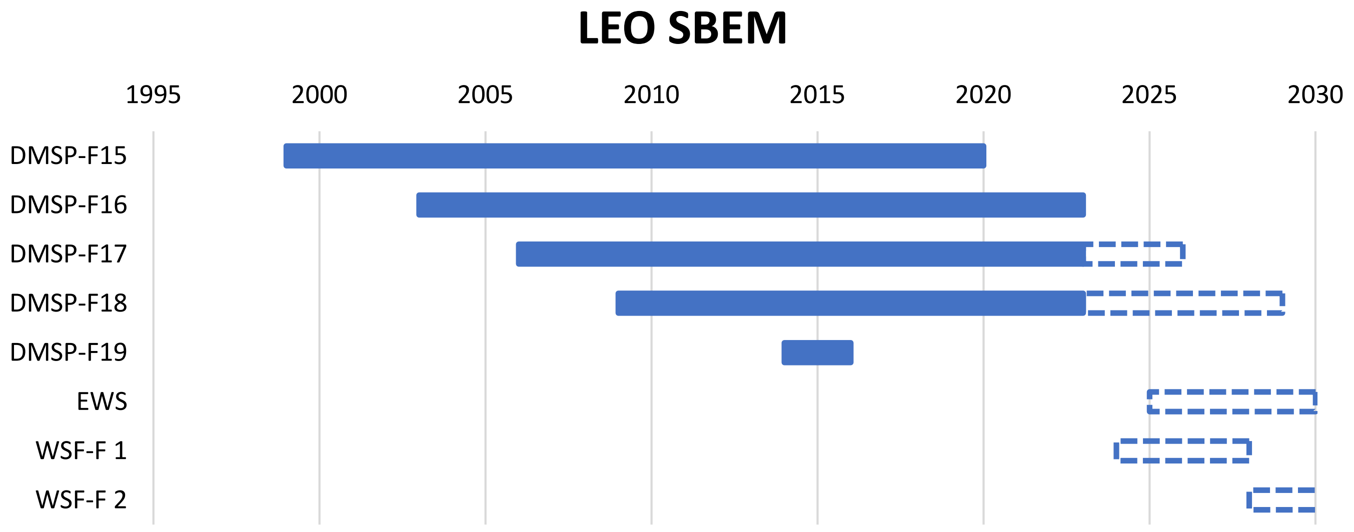


Figure 2: DMSP/EWS/WSF-M satellite expected life on orbit.

Mitchell Institute graphic based on data from the Observing Systems Capability Analysis and Review (OSCAR) Tool, World Meteorological Organization.

Figure 3: DMSP satellite graphic.

Source: U.S. Air Force/Lockheed Martin artist's concept.

SBEM Challenges & Future Requirements

The SBEM mission is currently conducted by the Cold War-era Defense Meteorological Satellite Program. Built as an exquisite, fully capable SBEM suite, each DMSP satellite hosts seven sensors. It covers a broad spectrum of weather sensing requirements. DMSP satellite sensors can "see" a wide range of environmental factors, from cloud cover to pollution. They collect information determining cloud type and height, land and surface water temperatures, and other surface condition data. They can even measure space environmental factors like charged particles and electromagnetic fields that affect military radars, communications, and satellite operations.[15]

However, this decades-old system is on its last legs. The DMSP has existed in various forms since the 1960s, and despite the constant demand for its services, there are currently no spares, sensor upgrades, or replenishment satellites in the Space Force inventory. The DOD has refreshed satellites as needed, but that backfill supply is now exhausted, with the last DMSP satellite launched in 2014. That means the enterprise is on a terminal trajectory with no backfills available, and it has exceeded its original design life. DMSP satellites now on orbit are deteriorating rapidly due to the combined realities of age and the harsh operating environment of the space domain.[16]

The DMSP and the Urgency to Modernize

DOD has long known that it needs to design and field a follow-on set of capabilities to replace DMSP. The warfighter is now depending on a family of systems that includes commercial and foreign sources. However, the DOD still needs to prioritize a dedicated SBEM capability to face a surge in threats and challenges around the world. Attempts to achieve this vision have involved a circuitous path of false starts and setbacks over the past 20 years that cannot be repeated as the U.S. military faces a surge in threats around the world. Notably, two weather satellite programs of record that could have addressed looming shortfalls were canceled without delivering operational capability: the National Polar Orbiting Environmental Satellite System (NPOESS) in 2010 and the Defense Weather Satellite System (DWSS) in 2012.

The NPOESS was a presidentially directed merger of NOAA's Polar Operational

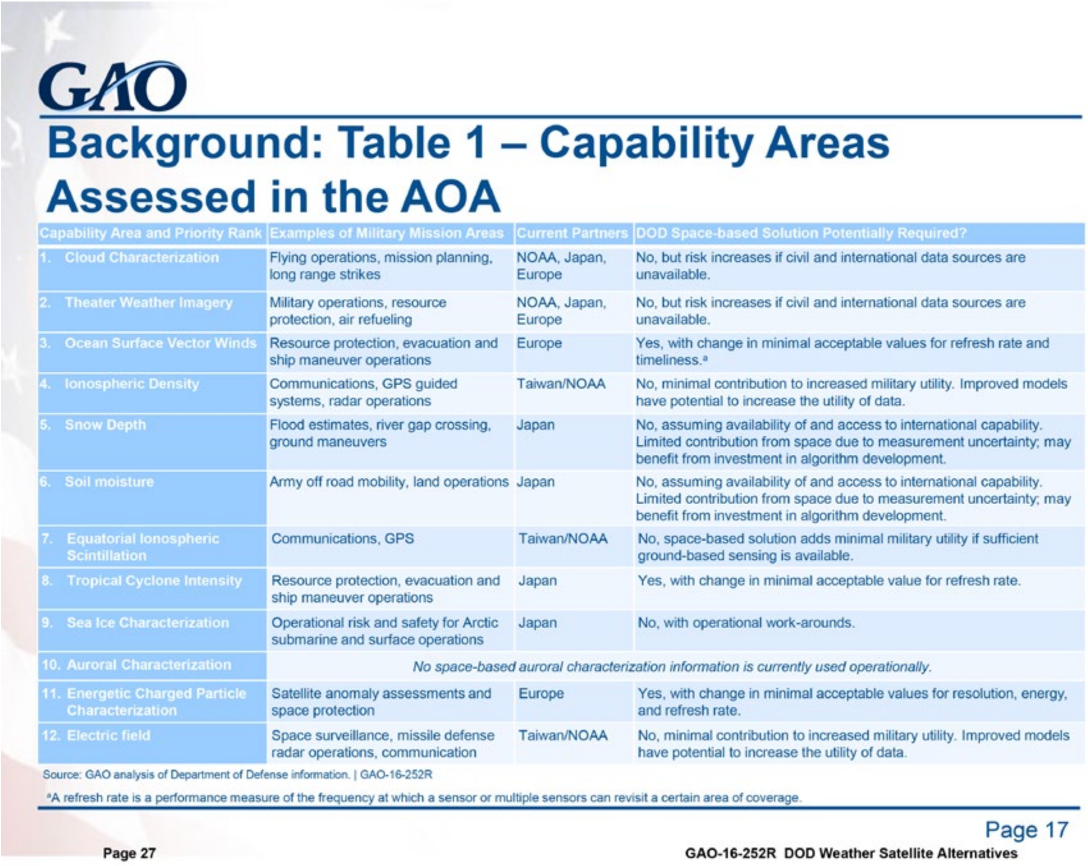
Environmental System (POES) with DOD's DMSP and NASA requirements. It became a program of record in 1994.[17] NPOESS aimed to combine the two satellite systems into a single state-of-the-art environmental monitoring satellite system. This was a critical effort to maintain the government-wide data continuity required for weather forecasting and global climate monitoring through 2020.[18] This merger was initially considered a cost-saving effort, but it ran into cost overruns exceeding 25 percent. This prompted three congressional reviews. Poor program performance ultimately led to its cancellation in 2010. Subsequently, two new programs emerged from this cancellation: the Joint Polar Satellite System, a NOAA/NASA partner program, and the DOD Defense Weather Satellite System (DWSS).

The DWSS program was primarily DOD's attempt to replace DMSP satellites. It capitalized on some of the design and sensor improvements of the NPOESS program, but it was short-lived.[19] Congress terminated the program in 2012 over concerns regarding cost and timelines. The Air Force sought to devise a new strategy using the remaining DMSP satellites, but Congress supported utilizing funding to establish new requirements and develop an entirely new system.[20]

While the decision-making involved was well-intentioned, these back-to-back failed mission modernization efforts weakened an already obsolescing national security weather enterprise, burning through time and resources while doing little to produce the operational capabilities necessary to meet demand. Knowing they needed to inject further service life into an already aged DMSP constellation, the Air Force launched a refurbished 1990s-constructed DMSP satellite in 2014. The positive impact of this band-aid solution was fleeting, with the satellite going offline in 2016 after a catastrophic power failure of the command-and-control system.[21] Lacking another DMSP satellite to launch, the Air Force reassigned its only remaining retired, on-orbit backup DMSP satellite to a primary system role to fill the gap and meet operational requirements.[22] It is a common practice to maintain retired satellites in orbit, but it is not common to bring them back into operation. This left an aging capability with no backup and still no potential replacement program.

After the cancellation of DWSS and even before the DMSP's catastrophic on-orbit failure, DOD recognized the potential risks to the mission and gaps in capabilities. It commissioned an SBEM requirements review and analysis of alternatives (AOA) study in 2012 to define options and the way ahead to replace DMSP. The purpose of this AOA was to plan for a future SBEM capability while focusing on being more cost-effective than previous canceled attempts. The outcome developed 12 capability needs and provided prioritization for their development. Importantly, this was years before space was acknowledged as a contested warfighting domain or before DOD was seriously planning for peer competition in the Western Pacific. Yet, with DMSP on a terminal trajectory and the potential for capability gaps only growing each year, DOD needed to make decisions promptly. The AOA was focused on providing for the nearest-term needs.[23]

The Air Force based its AOA review on a 2009 joint document regarding initial capabilities the service sought to satisfy via space-based sensing, from which it identified its 12 potential mission-critical capability gaps. The Air Force then carried out its two-phase AOA from 2012–2013. Phase 1 determined each gap's military utility, and Phase 2 identified potential solutions for meeting the gaps. The AOA resulted in a Joint Requirements Oversight Council study, in which these gaps became the justification for DOD's current plan to replace and significantly modernize defense-purposed environmental sensing from space. Most of these gap areas will remain important core data requirements for future operations:



GAO

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.

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GAO-16-252R DOD Weather Satellite Alternatives

Figure 4: AOA assessment of capability areas and potential need for a space-based support systems.

Source: "Department of Defense (DOD) Weather Satellites: Briefing to Congressional Defense Committees," GAO, 2016, slide 17 (p. 27).

Priority 1: Cloud Characterization

Cloud characterization informs tactical weather forecasting and feeds key operational planning considerations. The employment of military aircraft is directly impacted by this capability. Which sensor package and weapons are selected for a sortie are dependent on understanding the cloud and storm forecasts. Knowing which areas of airspace to avoid for air refueling operations is also vital to operational planning. Clouds additionally impact the tracking of enemy missile forces and launch detection.[24]

Priority 2: Theater Weather Imagery (TWI)

TWI evaluates current weather conditions and forecasts future weather effects. It informs aircraft flight routes and maritime tracking operations and provides life-saving direction to combat search and rescue forces. This information will become essential as U.S. forces prepare to conduct military operations around and within contested environments where terrestrial weather sensors may be sparse or non-existent.[25]

Priority 3: Ocean Surface Vector Winds

Ocean surface vector winds are measured to provide wind speed data and direction. This is critical for naval access and asset protection. For example, carrier operations, amphibious warfare, and anti-submarine warfare rely on this environmental data to protect the force.[26]

Priority 4: Ionospheric Density

Current DMSP satellites measure charged particles in the Ionosphere and electromagnetic fields in space. These particles impact military communications and satellite operations by interfering with the satellite's signal to Earth. The JROC decided that space-based ionospheric density provided minimal benefit compared to other ground-based data sources, especially with improved modeling.

Priority 5: Snow Depth

DMSP satellites can currently estimate the depth of recently accumulated dry snow. However, the estimates are limited to the minimum and maximum snow depths and not the snow depth ranges, so there is a limited contribution from space-based capabilities.

Priority 6: Soil Moisture

DMSP contributes somewhat to soil moisture analysis, or determining how wet or dry the soil is, which is critical for off-road mobility, troop, and logistics movements.[27] The ability to determine not only the timing of movements but also the most effective route is a force employment imperative. It could potentially be used to, likewise, model likely adversary movements.

Priority 7: Equatorial Ionospheric Scintillation

Ionospheric irregularities that cause scintillation can affect satellite communication and navigation by impacting the signal strength and quality. Although DMSP satellite sensors can measure scintillation, or the distortion of radio signals in the atmosphere, ground-based sensors are optimized for this data collection.[28]

Priority 8: Tropical Cyclone Intensity

Satellite data and meteorological analysis techniques can measure cyclone structure and sustained wind speed. This is critical for military strategic positioning and resource protection.[29] This modeling must inform commanders as they implement the U.S. Air Force's Agile Combat Employment (ACE) concept. The JROC determined that this gap should likely have a space-based solution with a proper refresh rate to maximize effectiveness.

Priority 9: Sea Ice Characterization

Sea ice is constantly changing—pushed and pulled by winds and ocean currents, melting and freezing depending on the season. U.S. and allied access to the Arctic depends on this sea ice characterization. Multiple low-Earth orbit (LEO) satellites are critical components of the existing SBEM architecture for measuring sea ice thickness and providing actionable information for homeland security and economic activities in high latitudes.

Priority 10: Auroral Characterization

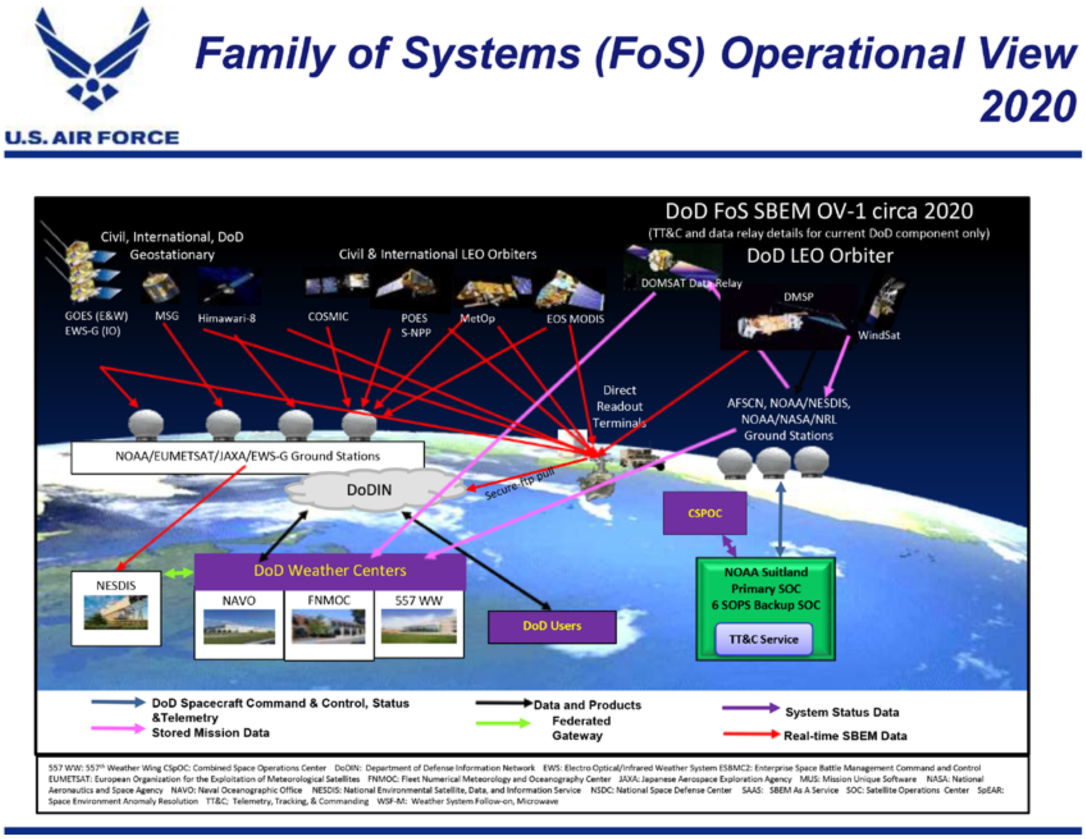
Although DMSP contributes to auroral characterization, no space-based auroral characterization data is used operationally. Therefore, the JROC decided this should not be part of a future follow-on system.[30]

Priority 11: LEO Energetic Charged Particle (ECP)

The ECP sensors observe the impact of geomagnetic disturbances on LEO satellites and monitor spacecraft safety and anomaly resolution.[31] The Earth's radiation belt consists of energetic particles which can potentially harm space assets. As the Space Force focuses on proliferated LEO orbits, this data will drive how spacecraft will be protected. The JROC determined, with changes in resolution, energy, and refresh rates, that this should be part of the requirement of future systems.

Priority 12: Electric Field

Current DMSP satellite sensors measure the electric field, but the data does not produce a useful operational model. Therefore, the JROC decided that a space-based sensor would provide minimal benefit to terrestrial sensors and sources for the electric field information.[32]

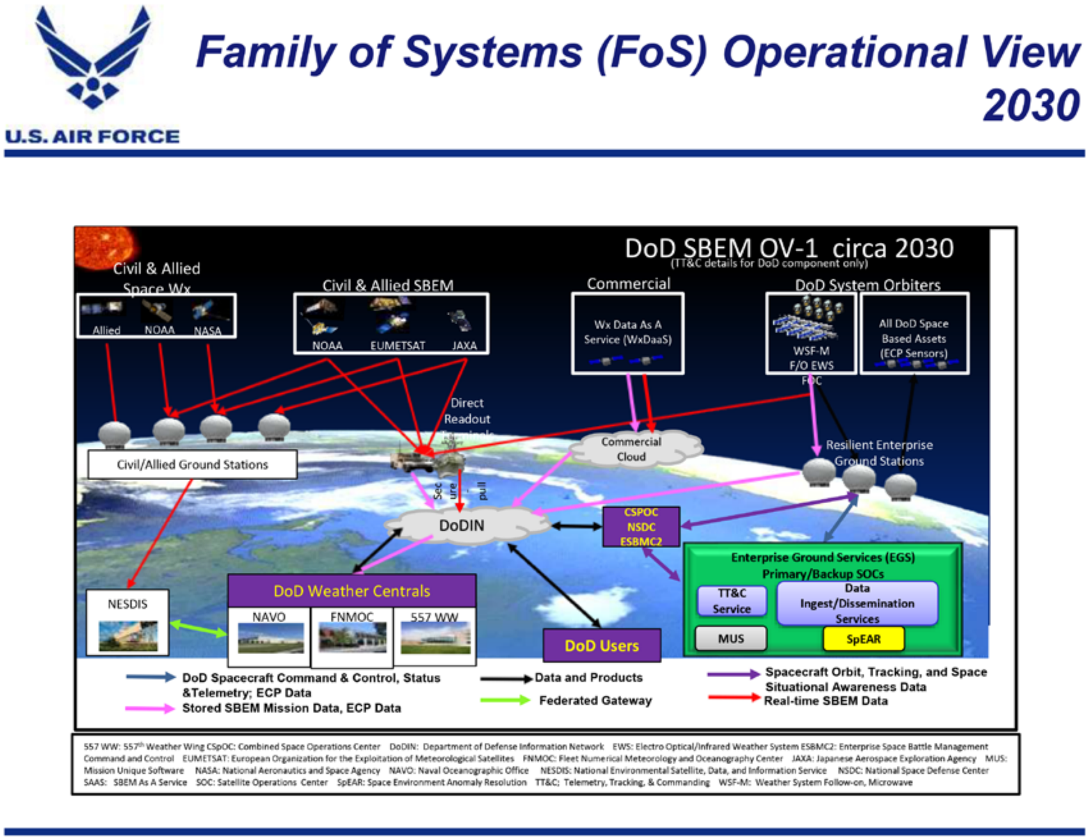


U.S. AIR FORCE

Family of Systems (FoS) Operational View 2020

DoD Spacecraft Command & Control, Status &Telemetry
Stored Mission Data
Data and Products
Federated Gateway
System Status Data
Real-time SBEM Data

557 WW: 557th Weather Wing CSpOC: Combined Space Operations Center DoDIN: Department of Defense Information Network EWS: Electro Optical/Infrared Weather System ESBMC2: Enterprise Space Battle Management Command and Control EUMETSAT: European Organization for the Exploitation of Meteorological Satellites FNMOC: Fleet Numerical Meteorology and Oceanography Center JAXA: Japanese Aerospace Exploration Agency MUS: Mission Unique Software NASA: National Aeronautics and Space Agency NAVO: Naval Oceanographic Office NESDIS: National Environmental Satellite, Data, and Information Service NSDC: National Space Defense Center SAAS: SBEM As A Service SOC: Satellite Operations Center SpEAR: Space Environment Anomaly Resolution TT&C; Telemetry, Tracking, & Commanding WSF-M: Weather System Follow-on, Microwave



U.S. AIR FORCE

Family of Systems (FoS) Operational View 2030

DoD Spacecraft Command & Control, Status &Telemetry; ECP Data
Stored SBEM Mission Data, ECP Data
Data and Products
Federated Gateway
Spacecraft Orbit, Tracking, and Space Situational Awareness Data
Real-time SBEM Data

557 WW: 557th Weather Wing CSpOC: Combined Space Operations Center DoDIN: Department of Defense Information Network EWS: Electro Optical/Infrared Weather System ESBMC2: Enterprise Space Battle Management Command and Control EUMETSAT: European Organization for the Exploitation of Meteorological Satellites FNMOC: Fleet Numerical Meteorology and Oceanography Center JAXA: Japanese Aerospace Exploration Agency MUS: Mission Unique Software NASA: National Aeronautics and Space Agency NAVO: Naval Oceanographic Office NESDIS: National Environmental Satellite, Data, and Information Service NSDC: National Space Defense Center SAAS: SBEM As A Service SOC: Satellite Operations Center SpEAR: Space Environment Anomaly Resolution TT&C; Telemetry, Tracking, & Commanding WSF-M: Weather System Follow-on, Microwave

Figure 5: The Department of the Air Force's Family of Systems concepts for 2020 versus 2030.

Source: Michael Farrar and Adam DeMarco, "Air Force Space-Based Environmental Monitoring (SBEM) Update," U.S. Air Force Directorate of Weather (AF/A3W) briefing, February 28, 2020, slides 3 and 9.

The Family of Systems Approach

The JROC's study focused on near-term fixes to gap-fill solutions that provide sensor capabilities and coverage to augment the DMSP architecture through partnerships until it can be replaced with a new organic system. The resulting strategy called for a family of systems approach, incorporating SBEM capabilities through a combination of DOD, National Oceanic and Atmospheric Administration (NOAA) civil systems, and international partners. The premise was simple: partner with other SBEM providers to share the burden of the weather architecture to keep costs low and help fill gaps in coverage with operational and available capabilities. While this is one common-sense way to build resiliency and keep partners close in peacetime, it should be an additive capability, not a primary one, for the simple reason that weather data from partners may not be assured or available during a conflict.

The need for the FoS model is currently driven by the reality that the existing DMSP architecture does not meet all requirements gaps and presents a risk of sudden and unpredictable system failure. The current FoS architecture consists of several satellites from allies and partners across different orbits, coupled with the legacy DMSP satellites. In LEO, weather data is provided by a combination of government and civil assets to deliver coverage during specific times of the day. These satellites are offset in their coverage times to provide updated weather information throughout the day with numerous satellite revisits. This architecture is vital because modeling and forecasting cannot be accomplished by one satellite in LEO. Additionally, NOAA provides weather data from geostationary orbit, allowing them to maintain their position over a specific region and maintain continuous coverage.

Leveraging Commercial Partnerships

Space Force recognizes that it can augment some of its space-based sensing capabilities with commercial services. Space Systems Command is already taking steps that respond to the demand for a new set of weather capabilities on orbit by taking advantage of commercial service offerings:

"SSC's pivot toward a more resilient, proliferated, hybrid architecture, one which exploits existing weather capabilities, buys commercially available technologies and services, and builds inherently more resilient disaggregated systems, ensures our warfighters retain the critical informational advantage provided by accurate and timely weather data."

While this is an important FoS capability, it is not a substitute for a DMSP replacement system, nor does it provide the necessary organic SBEM capabilities DOD requires.

Source: Space Systems Command Editorial Team, "Space Systems Command Space-Based Weather Data Forecast... Critical Informational Advantage for Joint Warfighters," *Milsat Magazine*, March 2023.

This FoS approach theoretically provides warfighters assured access to SBEM data. However, the strategy depends on shared security and agreements between the DOD, civil agencies (NOAA/NASA), and our allies.[33] Assured access to weather data demands more than partner relationships and an alignment of shared interests. This premise is not contentious in peacetime, but these relationships could be turbulent and portend undue risk during combat when weather data is most crucial. Reliance on a system without resilience and not under the control of an operational commander does not assure warfighting success. Additionally, if DMSP doesn't have an operational on-orbit replacement before its mission ends, it would leave an FoS without a DoD-controlled capability.

The Space Force is now responsible for providing these critical SBEM capabilities to feed models to support global military operations. They are moving toward a path

	Capability Area	System Addressing
1	Cloud Characterization	EWS
2	Theater Weather Imagery	EWS
3	Ocean Surface Vector Winds	WSF-M
4	Ionospheric Density	NOAA
5	Snow Depth	WSF-M
6	Soil Moisture	WSF-M
7	Equatorial Ionospheric Scintillation	Ground Sensors
8	Tropical Cyclone Intensity	WSF-M
9	Sea Ice Characterization	WSF-M
10	Auroral Characterization	Scientific use only
11	Energetic Charged Particle Characterization	WSF-M
12	Electric Field	NOAA

Table 1: Planned systems to address required capability areas.

Source: DOD Plan to Meet JROC Meteorological and Oceanographic Collection Requirements.

of balancing cost, performance, and schedule. This includes adding resiliency through proliferation and continuing to leverage commercial capabilities. This doesn't come without risk. In the near term, any slips in funding or launch will extend DMSP replacement, and this creates an environment ripe for a weather information disadvantage for the United States. These smaller proliferated satellites need to be matured and operational before DMSP reaches the end of life. DOD must shorten the path to a defense-purposed SBEM architecture by assuming some risk in the current phase of new technology demonstration. Lengthy sequential efforts for the eventual fielding of an SBEM constellation must be trimmed to address the urgency the warfighter faces during the current decade.

Defining the Path Forward

In 2016, the Air Force sent its plan for DOD to meet the requirements of the JROC study to Congress, which resulted in the decision to replace the monolithic Defense Meteorological Satellite Program with two separate disaggregated, small satellite constellations that contribute to the desired FoS model. These are the EO/IR Weather System (EWS) and the Weather System Follow-on Microwave (WSF-M) programs. The development of both remains driven by the gap areas identified in the 2012 AOA and 2014 JROC study.

DOD's path forward, as described in a 2019 Government Accountability Office report, highlights the need to address the identified weather mission gaps with some urgency:

> *(1) developing and implementing plans to acquire satellites as part of a family of systems to replace its aging legacy weather satellites, including awarding a contract for its Weather System Follow-on–Microwave program; (2) establishing plans to meet its highest-priority weather monitoring data collection needs that will not be covered by the Weather System Follow-on–Microwave program, including by acquiring and launching the Electro-Optical/Infrared Weather Systems satellite; and (3) monitoring the Weather System Follow-on-Microwave satellite program's progress toward addressing critical needs and assessing its operations and sustainment costs.*[34]

Replacing a single large system like the DMSP with multiple systems like EWS

Figure 6: Concept graphic of an EWS satellite on orbit.

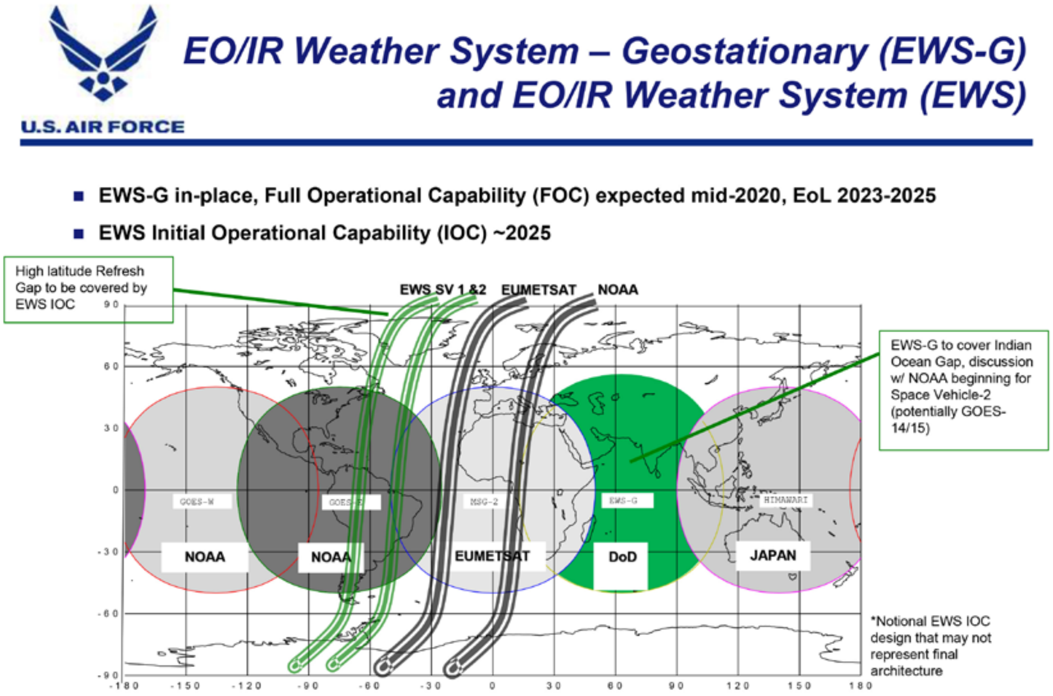
Source: Graphic courtesy of General Atomics Electromagnetic Systems.

and WSF-M operating in their respective constellations can offer numerous benefits. This approach improves the architecture's resilience by distributing its functions across multiple satellites—a crucial factor considering adversaries have displayed capabilities to hold assets on orbit at risk. Smaller satellites also allow for more rapid technology updates on orbit and progressive constellation modernization, ultimately enhancing U.S. force lethality by increasing revisit rates and ensuring a resilient architecture to reduce mission risk. This is the type of capability that must be matured and operational to ensure no mission loss or information disadvantage. Projected launches in 2024–2025 must be achieved, especially when coupled with DMSP end-of-life projections, to maintain the vital operational weather information the joint force requires for success.

Electro-Optical/Infrared Weather System (EWS) program

The EWS addresses two major SBEM requirements: cloud characterization and theater weather imagery. By using advanced technology to observe various weather obstructions like heavy cloud cover, EWS plays a pivotal role in weather monitoring.[35]

EWS cloud characterization sensor capabilities are imperative to supporting flying operations, from understanding sensor visibility to determining icing conditions on aircraft wings. Characterizing cloud cover is also foundational to understanding missile warning timelines as well as providing timely missile warning to fielded forces, allies, and partners. These capabilities will provide U.S. and allied forces with the needed information to conduct current and future forecasting to maximize



U.S. AIR FORCE

EO/IR Weather System – Geostationary (EWS-G) and EO/IR Weather System (EWS)

- **EWS-G in-place, Full Operational Capability (FOC) expected mid-2020, EoL 2023-2025**
- **EWS Initial Operational Capability (IOC) ~2025**

High latitude Refresh Gap to be covered by EWS IOC

EWS-G to cover Indian Ocean Gap, discussion w/ NOAA beginning for Space Vehicle-2 (potentially GOES-14/15)

*Notional EWS IOC design that may not represent final architecture

Figure 7: A DOD depiction of a fielded, operational EWS capability that covers gaps in the FoS.

Farrar and DeMarco, "Air Force Space-Based Environmental Monitoring (SBEM) Update," AF/A3W briefing, February 28, 2020, slide 6.

operational success. This information will inform critical combat functions such as flight routes, combat search and rescue, maritime surface tracking efforts, enemy missile observation, and intelligence collection.

EWS Program Progress

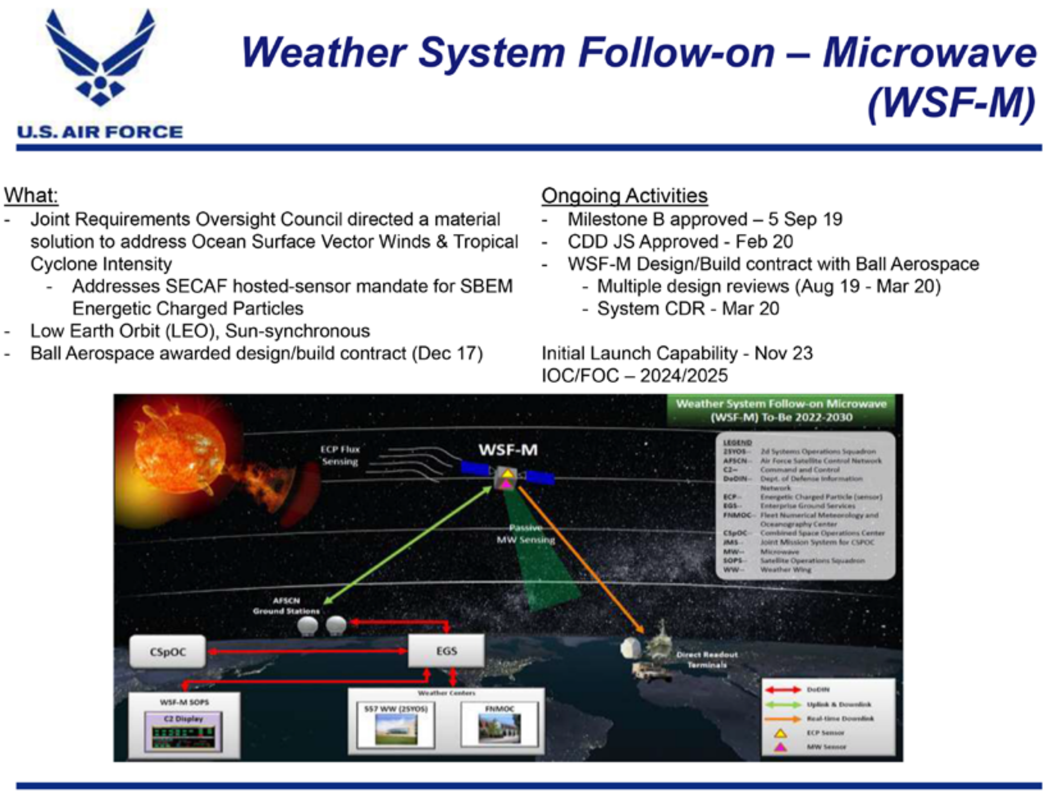
General Atomics is currently developing an EWS prototype design set to launch in 2025. According to Lt Col Joseph Maguadog, the materiel leader and program manager for EWS at SSC, "The idea is to build EWS satellites using existing sensors developed by … General Atomics," and that the designs "are promising and are the basis for the government furnished sensor." Maguadog confirmed in June 2023 that SSC has made no decisions yet on the number of satellites it will need to acquire or an acquisition timeline. The transition to an operational constellation must be resolved to ensure warfighter needs are met.

Source: Sandra Erwin, "Space Force exploring options to build weather monitoring constellation," *Space News*, June 1, 2023.

EWS support for theater weather imagery directly affects the ability to understand weather conditions in a specific geographic region, often austere and unsupported by terrestrial weather sensors. Colonel Brian Denaro, Space Systems Command's Space Sensing Program Executive Officer, stated, "EWS continues to blaze the trail on numerous space acquisition tenants. The program is building smaller satellites while minimizing non-recurring engineering."[36] Given the age of DMSP, the criticality of EWS to satisfy the two highest SBEM priorities can't be overstated.

Weather System Follow-on Microwave (WSF-M) program

WSF-M will operate from a low Earth orbit, using a next-generation passive microwave imager to collect terrestrial weather information and space environment observations. This single satellite will address six SBEM gaps. WSF-M is projected to launch in late 2023 and become operational by mid-2024. A second WSF-M



U.S. AIR FORCE

Weather System Follow-on – Microwave (WSF-M)

What:
- Joint Requirements Oversight Council directed a material solution to address Ocean Surface Vector Winds & Tropical Cyclone Intensity
  - Addresses SECAF hosted-sensor mandate for SBEM Energetic Charged Particles
- Low Earth Orbit (LEO), Sun-synchronous
- Ball Aerospace awarded design/build contract (Dec 17)

Ongoing Activities
- Milestone B approved – 5 Sep 19
- CDD JS Approved - Feb 20
- WSF-M Design/Build contract with Ball Aerospace
  - Multiple design reviews (Aug 19 - Mar 20)
  - System CDR - Mar 20

Initial Launch Capability - Nov 23
IOC/FOC – 2024/2025

Figure 8: A DOD depiction of a fielded, operational WSF-M capability.

Farrar and DeMarco, "Air Force Space-Based Environmental Monitoring (SBEM) Update," AF/A3W briefing, February 28, 2020, slide 9.

satellite is planned for launch in 2028 to replace the first one. WSF-M will support meteorologists in generating the weather products necessary for daily global mission planning and operations.

Its sensors fulfill the requirements for one of the 12 gaps by providing the ocean surface wind speed and direction measurements needed to support naval maneuver operations and aircraft takeoff and recovery. Additionally, it will provide tropical cyclone intensity measurements and predictions, enabling critical warnings to impacted areas and informing military operations likely to be affected by extreme weather conditions. WSF-M will use state-of-the-art algorithms to measure snow depth, soil moisture, sea ice thickness, and sea ice characterization. Finally, WSF-M addresses gaps in characterizing energized charged particles by taking measurements to determine space weather impacts on satellites and limit disruptions to HF communications and SATCOM.[37]

A combination of EWS and WSF-M addresses the existing military capability needs. However, since these capability gap areas originated from the JROC study before CJADC2 and the drive to increase resilience became a priority, additional requirements may also exist. The DOD should build from the JROC study to continue to grow and mature the architecture requirements for evolving capability, capacity, and resilience requirements.

Modernization of SBEM to gain what the Warfighter Needs

The JROC's study validates the core capability requirements that EWS and WSF-M plan to deliver, but it does not account for the scale and scope of architecture needed to provide that data near real-time in a modern threat environment. The imperative to achieve U.S. decision advantage and impose costs on U.S. adversaries will rely heavily on assured space-based weather sensing in a constellation sufficiently sized to meet today's warfighter needs.

Figure 9: Concept graphic of an WSF-M system on orbit.

Source: Graphic courtesy of Ball Aerospace.

Following a CJADC2 strategy, U.S. forces aim to collect more near real-time weather and environmental information so that they can make decisions based on that information to achieve effects before an adversary can, constituting a weather decision advantage. Achieving a satellite architecture that can deliver this weather decision advantage requires additional consideration about its necessary size and orbits. Speaking to the growing air and missile threats to the U.S. homeland that track through Arctic approaches and the challenges of Arctic air defense operations, Gen Glen VanHerck emphasizes the relevance of weather to his missions at U.S. Northern Command and NORAD: "To defend our homeland, we must be able to operate in the Arctic, and that requires domain awareness, which also is the weather aspect of that."[38] Greater Chinese and Russian threats to U.S. space assets also suggest the DOD and Space Force should reexamine the sizing of the SBEM constellation to include an on-orbit factor to account for attrition.

Currently, the two operational DMSP satellites provide coverage, which yields up to a 10.5-hour lag in its refresh rate. Three satellites are needed to meet the JROC requirement of a four-hour refresh rate. However, both configurations are insufficient for warfighter needs today and especially in the future as the services migrate to CJADC2 operational concepts. Describing the conditions required to operate out of the Alaskan Arctic region, Lt Gen David Nahom, commander of Alaskan Air Command and 11th Air Force, explained the heroic efforts of the aircrews that responded to China's surveillance balloons:

> *In January, in Alaska, in the middle of a blizzard, we had F-35s taken off 30 minutes before a blizzard hit with no idea how they're getting home. You had tankers taking off in the middle of a fight. You had snowplow drivers working around the clock trying to keep the runways clear. You had HH-60 Air Force rescue guys flying through the valleys of the Brooks Range at night in NDGs in a snowstorm… It is absolutely on our mind and how we predict it [weather].*[39]

The reality is warfighter demands will be closer to one-hour refresh rates with highly accurate short-term forecasts. This will require a bare minimum of 12 satellites to satisfy the dynamic, high-tempo operations both in the harsh environment of the Northern Tier or in a CJADC2 environment.[40]

A very salient consideration needs to be factored into an eventual SBEM architecture. The JROC's study was conducted under the working assumption that existing sensors would not be denied or compromised. This was premised on a benign space environment. An SBEM architecture for future conflicts should account for the greater resiliency and assuredness likely required to operate in the contested space and other domains.

Recommendations

The Space Force has shown a commitment to fielding new SBEM capabilities, and while this progress is noteworthy and should be commended, additional progress is required to assure the future success of this mission:

1. Congress must protect DMSP replacement efforts. The NDAA should fence EWS and WSF-M for defense requirements only and avoid repeating the past delays, complexities, and dysfunctions involved with merging many government agency requirements into an interagency program in the name of efficiency. Certainly, environmental data from defense-dedicated programs should be appropriately shared. However, the U.S. military is facing the potential for peer conflict without the assurance of weather data support it needs to maximize its ability to project power and employ effectively. Non-defense needs should not delay or sub-optimize the rapid replacement of space-based environmental monitoring that underpins weather support to the warfighter.
2. The U.S. Space Force must continue to develop a resilient SBEM architecture. Adversaries have clearly articulated their intent and demonstrated their ability to disrupt and destroy U.S. space capabilities. To mitigate this risk, the Space Force must continue to embrace a disaggregated SBEM architecture to provide resiliency with smaller, less expensive platforms to offset the loss of one or two systems. The current weather strategy distributes the sensor capabilities from DMSP to EWS for EO/IR and WSF-M for microwave. Pending their successful launch and demonstration, they could be the first increment of a resilient, assured SBEM capability. A constellation similar to the sensing footprint of DMSP requires a

minimum of 12 satellites to gain a one-hour revisit period; attrition reserves in orbit would be additive.

3. The U.S. Space Force must continue to develop SBEM requirements to reflect the current and emerging needs of the warfighter. EWS and WSF-M meet the current requirements established in the 2012 AOA and subsequent JROC study, but the Space Force must continue to update requirements that incorporate combatant commanders' future needs. The U.S. military faces threats from a peer adversary and is developing CJADC2 as the future warfighting concept. This drives new warfighting requirements beyond those identified in the AOA and will be imperative for future success in conflict. The DOD must continue to update its architecture requirements to ensure the provided capabilities meet the needs of the warfighter in 2023 and beyond. Additional satellites are likely part of the solution to boost refresh rates and afford enhanced resiliency.
4. The U.S. Space Force needs a stable, long-term program of record for SBEM. Lacking a defined program of record creates uncertainty in the SBEM architecture. The space-based environmental monitoring enterprise would benefit from a long-term, stable program of record with requisite defined funding to provide a full constellation of satellites. This program of record should be based on mature technologies and current requirements for future developments. The singular EWS and WSF-M satellites currently under contract will provide capability, but rapidly transitioning to fielding the operational constellation within an established program will provide stability and a resilient architecture in line with warfighter requirements.
5. Nurturing partnerships is imperative to our weather strategy. Partnerships are critical to the SBEM strategy, especially in the near term, because the DOD does not have enough capability currently on orbit or programmed to cover necessary orbits and revisit rates. Until the DOD delivers the SBEM constellation of satellites envisioned in their family of systems concept, the U.S. cannot generate the SBEM data it needs without a combination of allied, partner, civil, DoD, and commercial capabilities. The DOD partnership strategy must prioritize SBEM data assurance through reliable sources and data availability through all phases of conflict.

Conclusion

SBEM satellites are critical to warfighting operations. They help provide the decision advantage commanders must have for success in a CJADC2 world. A combatant commander's requirements to enable the right asset at the right time and with the right tools will be underpinned by weather data. This is imperative as the United States prepares for a possible conflict with a peer adversary. These same adversaries have already demonstrated capabilities to hold SBEM assets on orbit at risk; this modernization cannot wait. Weather decision advantage is wholly dependent upon a new set of space-based environmental monitoring technologies—and the investment required to underwrite this crucial capability.

The current SBEM enterprise faces the risk of collapse based on the impending DMSP end-of-life and the unhurried schedule for its replacement. Much of the time desired to field these new technologies and investments has run out; the uncertainty of DMSP's life expectancy and volatile defense budgets have eroded any buffer. Grasping the seriousness of the situation, the time to field EWS and WSF-M and enact SBEM enterprise reforms is now. ✪

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24 DOD Plan to Meet JROC Meteorological and Oceanographic Collection Requirements.

25 DOD Plan to Meet JROC Meteorological and Oceanographic Collection Requirements.

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34 GAO, *High-Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas* (Washington, DC: GAO, March 2019).

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39 Lt Gen David Nahom in, “Guarding the Northern Tier: Domain Awareness and Air Superiority in the Arctic,” p. 11.

40 The minimum constellation in an polar orbital configuration similar to DMSP to gain a one hour revisit time of any area of priority operational interest is 12 satellites (two daily orbits), not including an on-orbit attrition factor for adversary counterspace action.

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