United States Air Force

Report to Congressional Committees

# Department of Defense Plan to Meet Joint Requirements Oversight Council Meteorological and Oceanographic Collection Requirements

August 2016

The estimated cost of this report or study for the Department of Defense is approximately $9,400 for the 2016 Fiscal Year. This includes $0 in expenses and $9,400 in DoD labor.

Public Law 113-291 Section 1612

# Introduction

This report is provided to the congressional defense committees as directed in Section 1612a of the National Defense Authorization Act for 2015.

*SEC. 1612. LIMITATIONS ON AVAILABILITY OF FUNDS FOR WEATHER SATELLITE FOLLOW-ON SYSTEM AND DEFENSE METEOROLOGICAL SATELLITE PROGRAM.*

*(a) WEATHER SATELLITE FOLLOW-ON SYSTEM.—*

*(1) LIMITATION.—Of the funds authorized to be appropriated by this Act or otherwise made available for fiscal year 2015 for research, development, test, and evaluation, Air Force, for the weather satellite follow-on system, not more than 50 percent may be obligated or expended until the date on which the Secretary of Defense submits to the congressional defense committees the plan under paragraph (2).*

*(2) PLAN REQUIRED.—The Secretary of Defense shall develop a plan to meet the meteorological and oceanographic collection requirements of the Joint Requirements Oversight Council, including the requirements of the combatant commands, the military departments, and the Defense Agencies (as defined in section 101(a)(11) of title 10, United States Code). The plan shall include the following:*

*(A) How the Secretary will use existing assets of the defense meteorological satellite program, including an identification of the extent to which requirements can be addressed by the Defense Meteorological Satellite program.*

*(B) How the Secretary will use other sources of data, such as civil, commercial satellite weather data, and international partnerships, to meet such requirements, and the extent to which requirements can be addressed by such sources of data.*

*(C) An explanation of the relevant risks, costs, and schedule.*

*(D) The requirements of the weather satellite follow-on system.*

## Executive Summary

In September 2014, the Joint Requirements Oversight Council (JROC) identified and prioritized 12 satellite-based weather observing (space-based environmental monitoring (SBEM)) sensing requirements and directed the Department of Defense (DoD) to develop a strategy to address them. The DoD-developed strategy relies on a combination of civil, international, and military assets to meet these requirements. The Defense Meteorological Satellite Program (DMSP) has been the primary US military program providing SBEM data since the 1960s. The DoD will continue to operate the constellation until it reaches end of mission life, projected to be in 2021.

The DoD's materiel contribution to the family of SBEM systems will address three requirements gaps (Ocean Surface Vector Winds, Tropical Cyclone Intensity, and Energetic Charged Particles). This program of record is referred to as the Weather System Follow-on (WSF). The remaining gaps will be addressed by space and ground-based capabilities provided by civil and international partners.

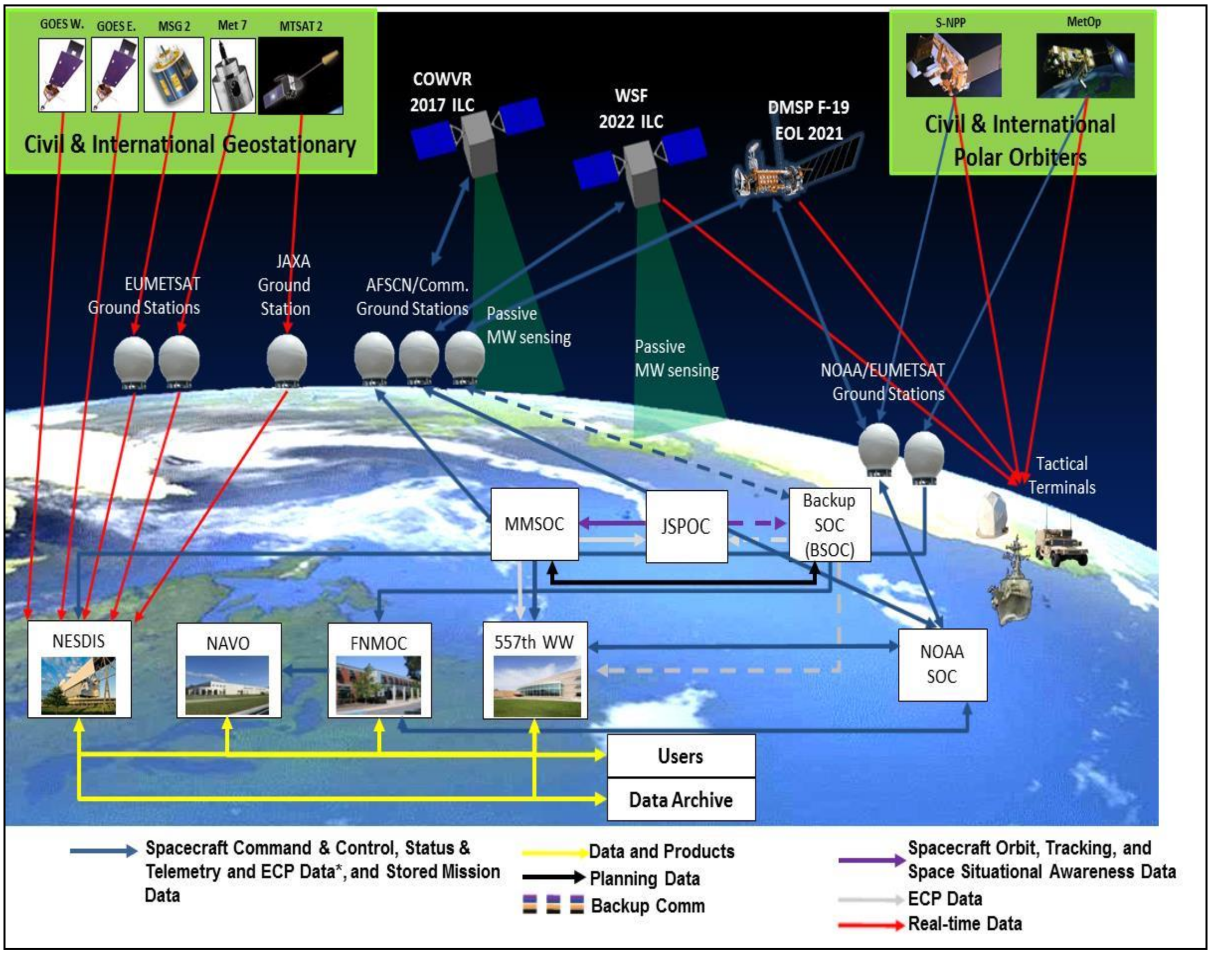
The Air Force strategy for addressing near-term Indian Ocean coverage utilizes a three-pronged approach. The first prong is a focused effort through the National Oceanic and Atmospheric Administration (NOAA) and the Department of Commerce (DoC) to engage internationally and fully exploit partner capability data. Secondly, DoD is working with NOAA to explore options to move a NOAA Geostationary Operational Environmental Satellite (GOES) to address cloud characterization and theater weather imagery over the Indian Ocean. Thirdly, the Air Force is exploring materiel solutions to address the cloud characterization and theater weather imagery gaps. In May 2016, the JROC endorsed this strategy and requested an update based on the recent loss of the ability to command DMSP-19. This update will be given to the JROC in September 2016.

## Report

***(A) How the Secretary will use existing assets of the defense meteorological satellite program, including an identification of the extent to which requirements can be addressed by the Defense Meteorological Satellite program.***

Figure 1 provides a high-level depiction of the DoD SBEM architecture that includes both DoD owned/operated satellites as well as civil and international data sources. The assets of the DoD's meteorological satellite program include the DMSP and the WindSat payload onboard the Coriolis satellite. WindSat is operated by the U.S. Navy and is not part of the DMSP program of record.

**Figure 1.** DoD SBEM Architecture




**557th WW** - 557th Weather Wing
**AFSCN** - Air Force Satellite Control Network
**COWVR -** Compact Ocean Wind Vector Radiometer (ORS-6 payload)
**EUMETSAT** - European Organisation for the Exploitation of Meteorological Satellites
**FNMOC** - Fleet Numerical Meteorology and Oceanography Center
**GOES** - Geostationary Operational Environmental Satellite
**JAXA** - Japan Aerospace Exploration Agency
**JSPOC** - Joint Space Operations Center
**MMSOC** - Multi-Mission Satellite Operations Center
**MSG** - Meteosat Second Generation Satellite
**MW** - Microwave
**NAVO** - Naval Oceanographic Office
**NESDIS** - National Environmental Satellite, Data, and Information Service
**NOAA** - National Oceanic and Atmospheric Administration
**S-NPP** - Suomi National Polar-orbiting Partnership

In September 2014, the JROC identified and prioritized 12 satellite-based weather observing SBEM sensing requirements. These gaps are a subset of a larger number of space-based environmental monitoring gaps. This subset is comprised of the 12 parameters that if insufficiently met by space and ground-based systems may potentially lead to mission failure.[i] The overall approach to addressing SBEM gaps emphasizes addressing 11 of the 12 gaps specified in the JROCM 092-14. (The JROC determined auroral characterization is adequately addressed by a network of ground-based sensors.)

Of the 12 prioritized SBEM data collection gaps validated and prioritized in JROCM 092-14, "Review of Space-Based Environmental Monitoring Analysis of Alternatives Final Report Results" (dated September 3, 2014), DMSP cannot fully address any of them alone.

Defense Meteorological Satellite Program (DMSP)

The DMSP was initiated in 1961, and the first satellite launched in 1962. Each DMSP satellite operates in a 101-minute, sun-synchronous near-polar orbit at an altitude of 830 kilometers (km) above the surface of the earth. The DoD operates the DMSP in an early morning orbit – a mission requirement codified in the 2010 National Space Policy[ii], and it supports all DoD and U.S. intelligence community (IC) missions.

The current block, 5D-3, has seven sensors[iii]. These sensors can be grouped into three broad categories: visible and infrared imagery, microwave imager and sounder, and space weather. The primary mission sensor is the Operational Linescan System (OLS) which contributes to addressing SBEM gaps in cloud characterization and theater weather imagery.

The DMSP collects global visible and infrared cloud cover imagery and other critical air, land, sea, and space environmental data and disseminates it to DoD operational units and the IC. DMSP data are also furnished to U.S. civil agencies and to international allies through the Department of Commerce (DoC). DMSP produces visible and infrared cloud images and night-time lights (OLS); sea ice concentration, sea surface wind speed, temperature and moisture profiles (microwave imager and sounder); auroral boundaries (space weather sensors and OLS); and other useful data and products.

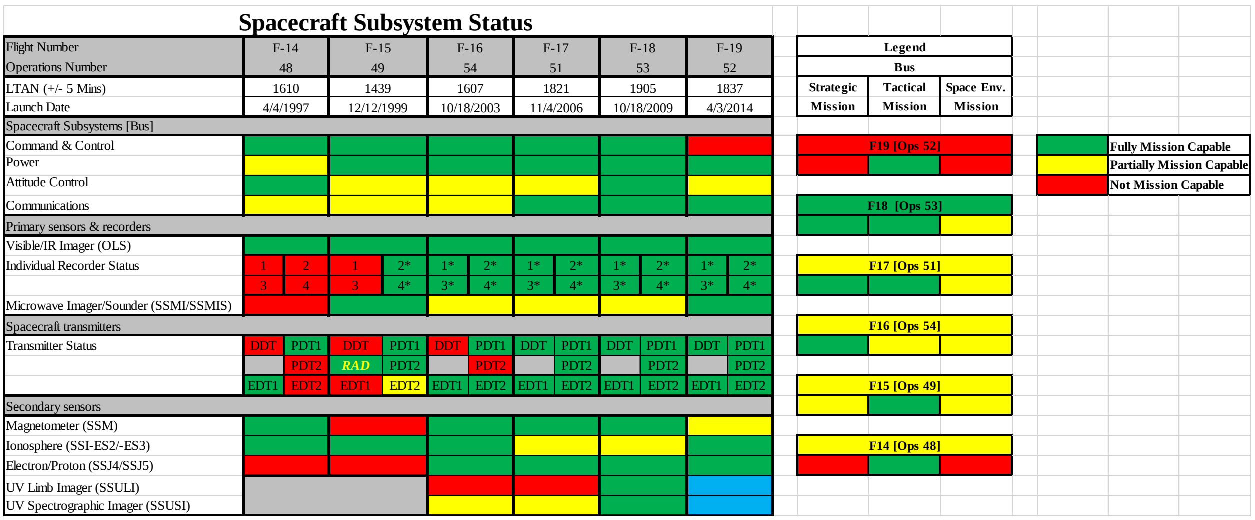
Of the DMSP satellites on orbit, two (DMSP-17 and -18) are fully mission capable – each has a fully functional OLS (primary mission sensor) and two independent recording devices. The recorded (stored) data are transmitted to a number of ground stations for dissemination to the DoD Weather Centrals (557th Weather Wing (557 WW); Fleet Numerical Meteorology and Oceanography Center (FNMOC); and Naval Oceanographic Office (NAVO)). The remaining satellites – DMSP-14, -15, -16 and -19 – are partially mission capable and provide data at varying degrees of degraded capability.

The DoD intends to operate on-orbit DMSP satellites until the constellation reaches end of mission life. DMSP projected end of mission life, based on historical performance:

| | | |
|---|---|---|
| DMSP-14: November 2016 | DMSP -16: July 2018 | DMSP -18: May 2021 |
| DMSP -15: June 2017 | DMSP -17: October 2019 | DMSP -19: Unknown |

Table 1 provides information on the status of the missions supported by DMSP. The "Strategic Mission" aids the IC in its mission to support the combatant commanders, as well as other missions; the "Tactical Mission" provides direct read-out to deployed forces as the satellite flies overhead; and the "Space Environment Mission" provides unique data to support DoD needs for characterization of the space environment. The strategic and space environment data are made available to DoD partners and the public at large. Although the OLS is fully mission capable on DMSP-14 and -15, the recorders are non-operational. Therefore, these satellites are partially mission capable for the strategic operations but fully mission capable for tactical operations. DMSP-19 no longer supports the strategic mission because of loss of command and control. The Air Force estimates that DMSP-19 will cease to support tactical operations sometime between 3Q 2016 and 2Q 2017.

**Table 1.** DMSP Subsystem and Mission Status as of May 2016



**Spacecraft Subsystem Status**

| Flight Number | F-14 | F-15 | F-16 | F-17 | F-18 | F-19 |
|---|---|---|---|---|---|---|
| Operations Number | 48 | 49 | 54 | 51 | 53 | 52 |
| LTAN (+/- 5 Mins) | 1610 | 1439 | 1607 | 1821 | 1905 | 1837 |
| Launch Date | 4/4/1997 | 12/12/1999 | 10/18/2003 | 11/4/2006 | 10/18/2009 | 4/3/2014 |
| Spacecraft Subsystems [Bus] | | | | | | |
| Command & Control | | | | | | |
| Power | | | | | | |
| Attitude Control | | | | | | |
| Communications | | | | | | |
| Primary sensors & recorders | | | | | | |
| Visible/IR Imager (OLS) | | | | | | |
| Individual Recorder Status | 1 2 | 1 2* | 1* 2* | 1* 2* | 1* 2* | 1* 2* |
| | 3 4 | 3 4* | 3* 4* | 3* 4* | 3* 4* | 3* 4* |
| Microwave Imager/Sounder (SSMI/SSMIS) | | | | | | |
| Spacecraft transmitters | | | | | | |
| Transmitter Status | DDT PDT1 | DDT PDT1 | DDT PDT1 | DDT PDT1 | DDT PDT1 | DDT PDT1 |
| | PDT2 | *RAD* PDT2 | PDT2 | PDT2 | PDT2 | PDT2 |
| | EDT1 EDT2 | EDT1 EDT2 | EDT1 EDT2 | EDT1 EDT2 | EDT1 EDT2 | EDT1 EDT2 |
| Secondary sensors | | | | | | |
| Magnetometer (SSM) | | | | | | |
| Ionosphere (SSI-ES2/-ES3) | | | | | | |
| Electron/Proton (SSJ4/SSJ5) | | | | | | |
| UV Limb Imager (SSULI) | | | | | | |
| UV Spectrographic Imager (SSUSI) | | | | | | |

| Legend | | |
|---|---|---|
| Bus | | |
| Strategic Mission | Tactical Mission | Space Env. Mission |
| F19 [Ops 52] | | |
| F18 [Ops 53] | | |
| F17 [Ops 51] | | |
| F16 [Ops 54] | | |
| F15 [Ops 49] | | |
| F14 [Ops 48] | | |

Fully Mission Capable
Partially Mission Capable
Not Mission Capable

The DMSP contribution to addressing the 12 SBEM gaps is summarized in Table 2.

**Table 2.** JROC Validated and Prioritized Gaps

| Priority | Gap Designation and Description of DMSP Contribution |
|---|---|
| 1 | Cloud Characterization: As part of a family of systems of low earth orbiting (LEO) and geostationary (GEO) satellites, DMSP contributes to the World Wide Merged Cloud Analysis. This analysis incorporates cloud data from a family of meteorological satellite systems[iv] and is used to initialize cloud forecast models. |
| 2 | Theater Weather Imagery: As part of a 3-plane system following the 2010 National Space Policy with the NOAA and European polar orbiting satellites, it contributes to providing high latitude coverage. DMSP passes over high-latitude locations (north of 65° in the Northern |

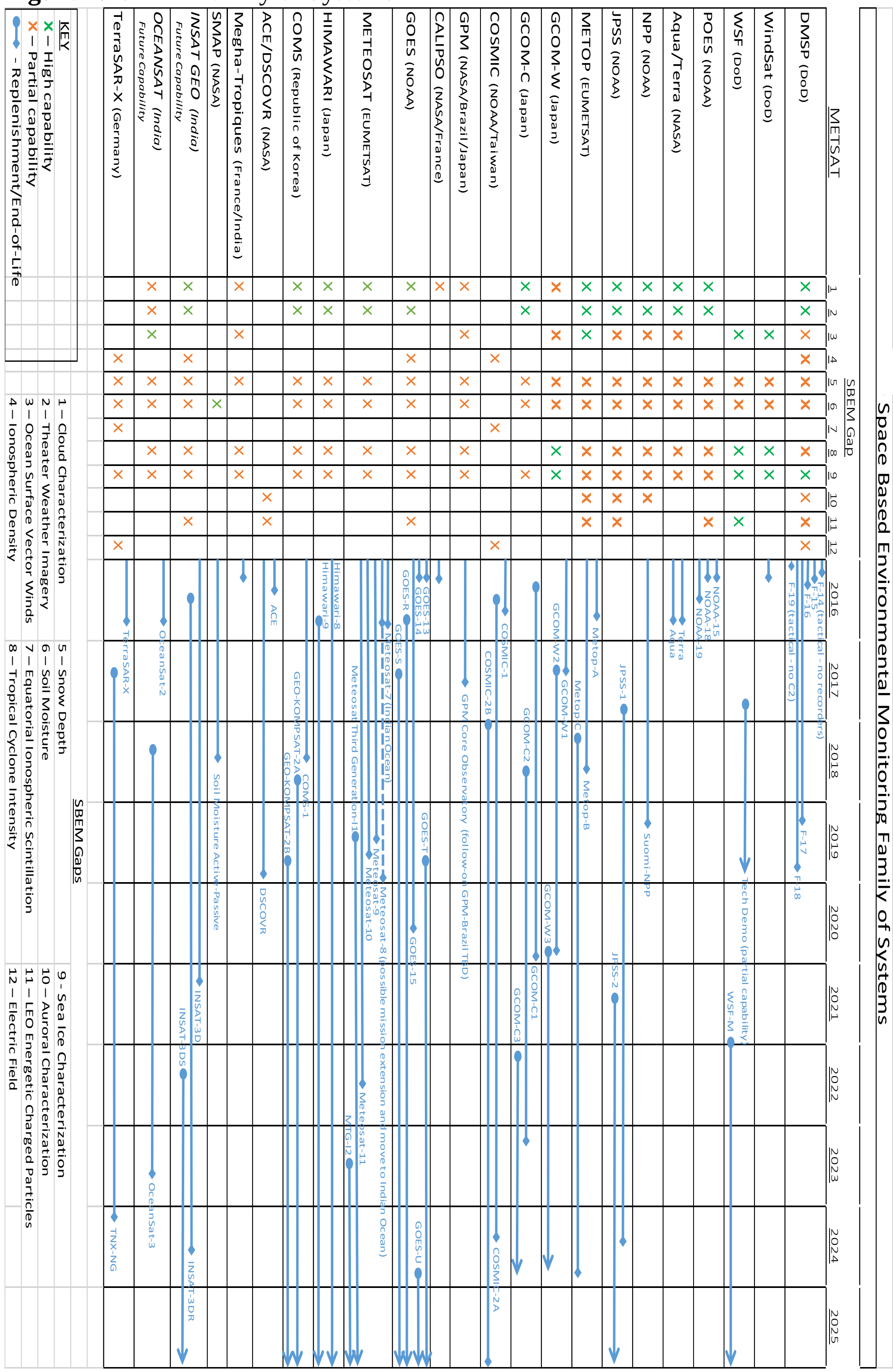
| | | |
|---|---|---|
| | | Hemisphere) several times per day, while it passes low latitude locations (South of 30° in the Northern Hemisphere) as little as twice per day. Thus while it contributes to addressing high latitude locations such as Canada and northern Russia because of its average revisit rate,[v] its contribution to addressing low latitude features varies based on phenomena. |
| 3 | | Ocean Surface Vector Winds (OSVW): While ocean surface vector winds are characterized by wind speed and wind direction; DMSP characterizes wind speed, not direction. |
| 4 | | Ionospheric Density: The JROC endorsed the conclusion of the Space Based Environmental Monitoring Analysis of Alternatives that space-based data provided minimal additional benefit when compared to ground-based data sources. No replacement capability is funded to mitigate the loss of these data when DMSP flies out. |
| 5 | | Snow Depth: DMSP contributes to addressing this gap by estimating the depth of recently accumulated dry snow. DMSP data can be used to estimate snow depth for minimum and maximum snow depths but does not have the capability needed to accurately estimate intermediate ranges of snow depth. |
| 6 | | Soil Moisture: DMSP minimally contributes to addressing this gap by making a wet/dry determination only. DMSP does not include the requisite sensor capability to measure soil moisture remotely. |
| 7 | | Equatorial Ionospheric Scintillation: Although DMSP sensors are able to measure scintillation, DMSP cannot address equatorial ionospheric scintillation since the satellite orbit is not optimized for this kind of data collection: DMSP altitude is too high and in a North-South orbit; DoD needs measurements at a lower altitude (about 200-350 kilometers) in a low inclination (about 20-25 degrees). The JROC endorsed the conclusion of the Space Based Environmental Monitoring Analysis of Alternatives that ground-based data-driven specification was sufficient to support this requirement. |

| | |
|---|---|
| 8 | Tropical Cyclone Intensity (TCI): DMSP contributes to addressing this gap as part of a family of systems and meteorological techniques applied by forecasters. |
| 9 | Sea Ice Characterization: DMSP contributes to addressing this gap as part of a family of systems which includes buoys, models, and multiple low-earth orbiting satellites. |
| 10 | Auroral Characterization: DMSP contributes to addressing this gap; however, the JROC endorsed the conclusion of the Space Based Environmental Monitoring Analysis of Alternatives that no space-based auroral characterization data is currently used operationally and the data primarily supports engineering development of future space surveillance and missile defense radars. The JROC consequently determined auroral characterization is adequately addressed by ground-based data sources. |
| 11 | Energetic Charged Particles (ECP): Contributes to measuring the energy spectrum of low energy particles that cause the aurora. This information can aid in characterizing satellite anomalies possibly induced by space weather. |
| 12 | Electric Field: Although DMSP has a sensor that can measure electric field (E-field), it does not measure the E-field in a relevant location for a relevant operational model. The JROC endorsed the conclusion of the Space Based Environmental Monitoring Analysis of Alternatives that space-based data provided minimal additional benefit when compared to ground-based climatological sources. |

***(B) How the Secretary will use other sources of data, such as civil, commercial satellite weather data, and international partnerships, to meet such requirements, and the extent to which requirements can be addressed by such sources of data.***

The DoD is assessing how it might best use all of the applicable sources of data from civil and international partners. Figure 2 presents a list of members of the SBEM Family of Systems and relevant capabilities they provide. Though comprehensive, the list is not exhaustive. The highlighted capabilities are based on current and projected programs, not necessarily fully funded. Terrestrial and space weather modeling capabilities require further development to exploit some of the available data.

**Figure 2.** SBEM Family of Systems



<u>WindSat</u>

Launched in 2003, the WindSat is the primary payload on the Coriolis mission, jointly sponsored by the DoD Space Test Program and the U.S. Navy. The Coriolis satellite is in a 101-minute, sun-synchronous near-polar orbit at an altitude of 840 km above the surface of the earth. The WindSat was built with a design life of 3 years; it continues to operate nominally. The DoD plans to exploit the WindSat indefinitely – as long as it provides usable data.

The WindSat measures ocean surface wind vectors and sea ice, and it may contribute to soil moisture measurements as environmental models are improved. DoD forecasters also use microwave imagery and wind measurements from the WindSat to monitor tropical cyclone structure. The WindSat measurements over the ocean are input into numerical weather prediction models used by the DoD, the U.S. NOAA, and international partners.

<u>U.S. Civil Partnerships</u>

The DoD exchanges satellite-based weather data with the NOAA and with the national Aeronautics and Space Administration (NASA). This includes atmospheric and space weather data obtained from LEO polar-orbiting and geostationary satellites and used in analysis and forecasting models.

The DoD and DoC have enhanced their collaborative efforts and elevated the level and frequency of their interactions. In addition to existing joint working groups between the two departments, the Principal DoD Space Advisor Staff (PDSAS) is leading an effort with NOAA to coordinate expanded DoD use of U.S. civil assets, and the Deputy Assistant Secretary of Defense for Space Policy (OSD(P)) coordinates with them on international partnership advocacy. These interactions occur on a continuing basis to ensure pertinent weather information is available over the long term.

<u>International Partnerships</u>

The Secretary of Commerce, through the NOAA Administrator, manages international partnerships to sustain and enhance weather, climate, ocean, and coastal observation from space. The NOAA also advocates on behalf of the DoD in international (civil) meetings such as the World Meteorological Organization forums.

The DoD uses geostationary weather satellite data from international partners on a regional basis and LEO polar-orbiting data from DoD, civil, and international partners on a global basis.

The DoC, through the NOAA, has a long term cooperation agreement with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) to promote full, open and timely access to the EUMETSAT's SBEM systems. These systems include LEO polar-orbiting and geostationary satellites.

Since 1998, the EUMETSAT geostationary constellation has included coverage over the Indian Ocean on a "best effort" basis at 57 degrees East. Beginning in early 2017, the EUMETSAT will no longer provide this particular coverage over the Indian Ocean, but instead, they have begun to move a satellite to 41 degrees East. This satellite will be in place by mid-September 2016 and partially compensate for the resulting coverage gap. Based on dialog at the 44th plenary session of the Coordination Group for Meteorological Satellites, Russia will assume responsibility for geostationary weather satellite coverage over part of the Indian Ocean. Since U.S. law prohibits DoD reliance on weather satellite data provided by the Russian government, the DoD may be required either to fund a new satellite program or to fund the transfer of a NOAA geostationary satellite, when available.

Since 2002, NOAA has maintained agreements with the Japanese Meteorological Agency. These agreements benefit U.S. agencies by facilitating access to Japan's geostationary weather satellite (Himawari) data. NOAA also has agreements with the Japan Aerospace Exploration Agency (JAXA) for access to JAXA's Global Change Observation Mission (GCOM), a LEO polar-orbiting satellite.

The DoD accesses meteorological data from the Republic of Korea (ROK) Communication, Oceanographic, Meteorological Satellite for regional coverage.

The NOAA and the DoD partner together with Taiwan in the combined development and operation of the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC).

The DoD Weather Centrals access both real-time and stored civil and international SBEM data. Real-time data is retrieved from some SBEM assets via direct readout either with tactical terminals (Mark IV-B, Air Force; AN/SMQ-11/AN/FMQ-17, Navy) overseas on land and at sea. Other DoD operational weather centers and deployed forces levy Defense Information Systems Agency networks to reach back to the DoD Weather Centrals for near-real time and less time critical data and products.

Commercial Data Opportunities

The US public law designation of civil government (NOAA) as the sole source for providing environmental data for public consumption under the 1870 Weather Service Organic Act (15 USC 313, as amended) has historically challenged potential commercial providers in developing a viable business case for entering the SBEM data market. A current example of a limited commercial data buy is the use of Canadian Radarsat data, purchased through the National Geospatial-Intelligence Agency from a Canadian commercial firm, for US Naval Ice Center analysis.

To support meeting its long term SBEM requirements, the Air Force released a request for information to industry soliciting its intent and ability to develop, launch, and operate space-based commercial services that could mitigate the SBEM gaps emphasized in this plan. The respondents indicated that they have proposals for sensors and constellations with the potential to satisfy a subset of the requirements.

The Air Force is evaluating the DoD SBEM enterprise to identify adjustments needed to accommodate integration of commercial data.

***(C) An explanation of the relevant risks, costs, and schedule.***

The DoD has determined that three of the gaps – OSVW, TCI, and ECP – require materiel solutions, while cloud characterization and theater weather imagery warrant continued evaluation for materiel solutions. Cloud characterization and theater weather imagery also benefit from partial reliance on partner capabilities. Non-materiel solutions are under evaluation for applicability to six of the seven remaining gaps – ionospheric density, snow depth, soil moisture, equatorial ionospheric scintillation, sea ice characterization, and electric field. The JROC determined auroral characterization is adequately addressed by a network of ground-based sensors, thus an SBEM solution is not needed.

The JROC and the Deputy's Management Action Group support advancement of a materiel option, including potential DoD and/or external partner options, for addressing cloud characterization and theater weather imagery while continuing to pursue non-materiel options. The JROC intends to convene in September 2016 to review updated options for meeting these gaps.

The Air Force will execute a two-phased acquisition approach for the WSF program to meet the remaining three JROC-validated materiel requirements for SBEM: OSVW, TCI, and ECP characterization. This program consists of two major segments: 1) a single-satellite constellation designed to address all three of these gaps; and 2) ECP sensors that will be integrated into all future Air Force space systems at pre-Milestone B in the acquisition process. The ECP sensors measure energetic particle radiation conditions at the satellite to support anomaly assessment and attribution.

For Phase 1, the Operationally Responsive Space (ORS) office is collaborating with the Space and Missile Systems Center Remote Sensing Systems Directorate (SMC/RS) to develop and launch a technology demonstration (designated ORS-6) focused on the OSVW. This effort leverages over $70M in prior investments in both the Compact Ocean Wind Vector Radiometer (COWVR) sensor and the ORS Modular Space Vehicle bus. ORS- 6 will demonstrate technology that has the potential to reduce the long term cost of meeting DoD SBEM requirements, while also potentially providing residual capability to support near term gaps, should the WindSat satellite reach end of life.

For Phase 2, the DoD plans to launch an operational WSF objective system to fully meet these latter three JROC-validated materiel requirements by 2022.

Furthermore, in addition to strengthening ties with civil and international partners to optimize use of non-DoD SBEM assets, the Air Force is exploring opportunities to expand the DoD’s use of commercial SBEM data services.

**Risks**

The DoD depends on civil and international partners to provide data supplementing DoD-owned and operated systems – DMSP and the Coriolis/WindSat satellites. The DoD is endeavoring to minimize future expenditures by increasing reliance on data available from civil and international sources in lieu of acquiring dedicated DoD-owned and operated SBEM systems.

An inherent trade-off in this cost-saving approach is the increased operational risk DoD incurs by relying on external entities for timely delivery of data needed to satisfy mission-critical requirements. These risks include volatility of some international partnerships; programmatic risk associated with relying on civil and international partners to maintain their proposed launch schedules; continued data access and assurance in data-limited and data-denied environments; and continued DoD access to environmental data during periods of heightened international conflict.

An intrinsic risk in fielding the single-satellite constellation to address OSVW and TCI is based on this satellite serving as part of a family of systems. A delay in replenishing any of the on-orbit assets addressing the OSVW or TCI gaps would result in loss of ability to meet the JROC-validated requirement for data refresh. This risk extends to all external dependencies for mitigation of any DoD SBEM gaps.

The future DoD SBEM architecture will increase dependence on civil and international partner data sources to satisfy requirements beyond those addressed by the WSF, a DoD LEO solution (if procured), and non-materiel solutions. Commercial solutions may also be integrated into the DoD architecture, if available. The DoD must also assess risks associated with data quality, cyber security, mission assurance, operations, and long-term viability of civil, international, and commercial data sources.

**Costs**

The DoD Weather Centrals ingest and process measurements from SBEM, airborne, mobile, and terrestrial meteorological and oceanographic sources and tailor weather analyses, forecasts, and alerts to support DoD operations.

The FY2017 President's Budget (PB) request, shown in Table 3, includes $5.4M for selective recapitalization of critical elements of the DMSP ground command and control system and $523M to support the development of WSF. A summary of the anticipated costs for the DoD owned and operated SBEM enterprise is provided in Table 4.

**Table 3.** DoD Investment Funding Programmed ($M) for SBEM Systems (FY17 PB)

| SBEM System | FY17 | FY18 | FY19 | FY20 | FY21 | FYDP |
|---|---:|---:|---:|---:|---:|---:|
| DMSP | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 5.4 |
| Weather System Follow-on | 119.0 | 151.7 | 153.3 | 61.9 | 36.9 | 522.8 |
| Total | 120.0 | 152.8 | 154.4 | 63.0 | 38.0 | 528.2 |

**Table 4.** Current annual expenditures ($M) for the acquisition and processing of data from Defense Meteorological Satellite Program (DMSP) and other SBEM data sources

| Service | Cost ($M) FY15 |
|---|---:|
| Department of the Navy | 19.2 |
| Department of the Air Force | 10.6 |
| Total | 29.8 |

The future DoD SBEM architecture will increase dependence on civil and international partner data sources to satisfy requirements beyond those addressed above. Commercial solutions may also be integrated into the DoD architecture, if available. Costs for these approaches are being evaluated and will be added to the budget when appropriate.

## Schedule

To satisfy the immediate requirements for OSVW and TCI, the Air Force plans to launch a technology demonstration satellite acquired under the Operationally Responsive Space Office in 2017. The first operational satellite under the WSF program will launch in 2022, and the second is projected for initial launch capability in 2027.

The WSF program will develop and flight-certify the ECP sensors and transition it to industry for cost-effective production of the units. Funding for deployment of these sensors and the associated ground processing will be provided by the individual satellite program accounts. The first ECP sensors are expected fly on an Air Force satellite in 2021 or 2022.

The DoD upgrades its Weather Central architecture to ingest and process data from additional international partner systems to meet each service's unique meteorology and oceanography requirements. The DoD's schedule of modifications for ground processing of these external sources is outlined in Table 5. These modifications are subject to budget considerations.

**Table 5.** Schedule for Upgrading DoD Weather Centrals to Ingest and Process METOC Data from Additional Civil and International SBEM Satellites (Systems in gray are planned but not programmed as of this report. Acronyms are listed in Appendix C.)

| Weather Central | FY17 | FY18 | FY19 | FY20 | FY21 |
|---|---|---|---|---|---|
| FNMOC<br>NAVO | COWVR<br>GCOM-C1<br>GOES-R<br>Himawari<br>ICESat-2<br>Jason 3<br>JPSS-1<br>Meteosat-8<br>Sentinel-1B | GCOM-W2<br>GEO<br>KOMPSAT<br>Metop-C | GCOM-C2<br>GOES-S<br>Meteosat-11 | Sentinel-6<br>SWOT | GCOM-W3<br>GOES-T<br>JPSS-2<br>MTG-I<br>Metop-SG-A1 |

| | | | | | |
|---|---|---|---|---|---|
| | Sentinel-3A/B | | | | |
| 557th WW | Oceansat-2/3<br>Meteosat-8<br>INSAT-3D<br>ASCAT<br>GOES-R/S/T<br>Himawari<br>COSMIC-2A/2B<br>GCOM-W2<br>JPSS-1<br>Metop-C<br>TSX-NG<br>MTG-I | GCOM-W3<br>EPS-SG-A | JPSS-2<br>MTG-S | EPS-SG-B | MTG-I |

***(D) Requirements of the Weather Satellite Follow-on System***

The Weather Satellite Follow-on program materiel solution currently emphasizes meeting requirements associated with OSVW, TCI, and ECP. The threshold performance values for the three WSF requirements are listed in Table 6.

**Table 6.** WSF Threshold Performance Values

| Capability Requirement | Description | Metric | Threshold Value |
|---|---|---|---|
| OSVW | Coverage | Area (PACOM AOR) | Globally over oceans |
| | Resolution | Horizontal cell size | 30 km |
| | Refresh | Average time between sensor collects at the storm center location +100km in all directions from the center | 22 hours (6 hours from a Family of Systems) |
| | Timeliness | Average time from when data is collected to the time it is received at the DoD Weather Central (min) | 2 hours, at least 95% of the time, except for latency associated with USN afloat operations and USMC tactical users. When a WSF satellite is in line-of-sight, the threshold is 15 minutes, 95% of the time. |
| | Accuracy | Speed and Direction | ≤ 1.5 m/s (speed) & ≤ 20 degrees (direction) for speeds between 5-10 m/s<br>≤ 2.5 m/s (speed) & ≤ 15 degrees (direction) for speeds between 11-25 m/s |
| TCI | Coverage | Area (PACOM AOR) | Globally over oceans |
| | Resolution | Horizontal cell size | 15 km |
| | Refresh | Average time between sensor collects at the storm center location +100km in all directions from the center | 22 hours (6 hours from a Family of Systems) |

| Capability Requirement | Description | Metric | Threshold Value |
|---|---|---|---|
| | Timeliness | Average time from when data is collected to the time it is received at the DoD Weather Central (min) | 2 hours, at least 95% of the time, except for latency associated with USN afloat operations and USMC tactical users. When a WSF satellite is in line-of-sight, the threshold is 15 minutes, 95% of the time. |
| ECP Characterization | Coverage | Altitude | Global |
| | Sample Rate | Time between sensor collects | 10 sec |
| | Type | Energy Level | >1 KeV |
| | Timeliness | Average time from when data is collected to the time it is received at the DoD Weather Central (min) and for host operators, the time it is received at the host's ground site | 2 hours |

## Conclusion

In September 2014, the JROC identified and prioritized 12 satellite-based weather observing (SBEM) sensing requirements. According to the JROC, failure to sufficiently meet these requirements by space- and ground-based systems may potentially lead to mission failure.[vi] These 12 requirements are drawn from a larger collection of satellite-based sensing requirements generally characterized as capability gaps. This report describes the DoD's plan to address this subset of 12 SBEM gaps.

Based on current operational practices, many of the 12 prioritized gaps may continue to be partially addressed by a family of LEO polar orbiting weather satellites and GEO weather satellites. This family of systems is comprised of DoD, U.S. civil, and international partner satellites. Other gaps may be mitigated by changes in tactics, techniques, or procedures. The DoD is exploring both alternatives.

The Deputy's Management Action Group recently directed the DoD to pursue all options for filling cloud characterization and theater weather imagery gaps by leveraging civil and international partnerships and to refine organic DoD options in case partner solutions do not develop.

The DoD has developed this plan – contingent on funding, availability of civil and international partner data, and commercial industry capability – to address its three highest priority SBEM gaps with materiel solutions (e.g., new programs of record). Two other gaps, of lower priority but without suitable alternatives – tropical cyclone intensity and energetic charged particles - will also be addressed by materiel solutions. The DoD is evaluating non-materiel options for resolving the remaining gaps. The conclusions of this assessment will be presented to the JROC in September 2016.

## Acronyms and Abbreviations

**ACE** – Advanced Composition Explorer
**ASCAT** – Advanced Scatterometer
**CALIPSO** – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
**COMS** – Communication, Oceanographic, Meteorological Satellite
**COSMIC** – Constellation Observing System for Meteorology, Ionosphere, and Climate
**COWVR** – Compact Ocean Wind Vector Radiometer
**DMSP** – Defense Meteorological Satellite Program
**DoC** – Department of Commerce
**DSCOVR** – Deep Space Climate Observatory
**ECP** – energetic charged particle
**EPS** – EUMETSAT Polar System
**EUMETSAT** – European Organisation for the Exploitation of Meteorological Satellites
**FNMOC** – Fleet Numerical Oceanography Center
**GCOM-C** – Global Change Observation Mission – Climate
**GCOM-W** – Global Change Observation Mission – Water
**GEO** – geosynchronous earth orbit (also referred to as geostationary)
**GOES** – Geostationary Operational Environmental Satellite
**GPM** – Global Precipitation Measurement
**IC** – intelligence community
**ICESat** – Ice, Cloud and land Elevation Satellite
**INSAT** – Indian National Satellite
**JAXA** – Japan Aerospace Exploration Agency
**JPSS** – Joint Polar Satellite System
**JROC** – Joint Requirements Oversight Council
**JROCM** – JROC Memorandum
**km** – kilometer
**KOMPSAT** – Korea Multi-Purpose Satellite
**LEO** – low earth orbit
**METEOSAT** – Meteorological Satellite (Meteosat)
**METOC** – meteorological and oceanographic
**METOP** – Meteorological operational satellite (Metop)
**MTG** – Meteosat Third Generation
**MTG-I** – MTG Imaging Satellite
**MTG-S** – MTG Sounding Satellite
**NASA** – National Aeronautics and Space Administration
**NOAA** – National Oceanic and Atmospheric Administration
**NPP** – National Polar-orbiting Partnership
**OCEANSAT** –Oceansat (no breakout)
**OLS** – operational linescan system
**ORS** – Operationally Responsive Space
**OSD(P)** – Office of the Secretary of Defense (Policy)
**OSVW** – ocean surface vector winds
**PB** – President's Budget

**PDSAS** – Principal DoD Space Advisor Staff
**POES** – Polar-orbiting Operational Environmental Satellite
**ROK** – Republic of Korea
**SBEM** – space based environmental monitoring
**SMAP** – Soil Moisture Active Passive
**SWOT** – Surface Water and Ocean Topography
**TCI** – tropical cyclone intensity
**TerraSAR** – TerraSAR (no breakout; SAR: synthetic aperture radar)
**TSX** – TerraSAR-X
**WSF** – Weather System Follow-on (also known as Weather Satellite Follow-on)
**WW** – Weather Wing

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## Endnotes

[i] JROCM 091-12, "DoD Meteorological and Oceanographic Collection Requirements"

[ii] "The Secretary of Commerce, through the NOAA Administrator, the Secretary of Defense, through the Secretary of the Air Force, and the NASA Administrator shall work together and with their international partners to ensure uninterrupted, operational polar-orbiting environmental satellite observations. The Secretary of Defense shall be responsible for the morning orbit, and the Secretary of Commerce shall be responsible for the afternoon orbit. The departments shall continue to partner in developing and fielding a shared ground system, with the coordinated programs operated by NOAA. Further, the departments shall ensure the continued full sharing of data from all systems." (https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf)

[iii] The seven DMSP sensors are

- OLS: Operational Linescan System (This is the primary mission sensor.)
- SSMI/S: Special Sensor Microwave Imager & Sounder
- SSULI: Special Sensor Ultraviolet Limb Imager
- SSUSI: Special Sensor Ultraviolet Spectrographic Imager
- SSIES: Special Sensor Ionospheric Plasma Drift/Scintillation Monitor
- SSJ: Precipitation Electron/Proton Spectrometer
- SSM: Special Sensor Magnetometer

[iv] While DMSP and other polar orbiting systems at low earth orbit provide relatively frequent coverage at high latitudes because of their orbital periods, altitudes, and number of orbital planes (three), they offer relatively insignificant contributions at low latitudes compared to persistent, frequent (approximately 30-minute refresh) weather imagery provided by geostationary platforms. Geostationary weather satellites, on the other hand, offer little benefit at high latitudes due to foreshortening: distortion of cloud imagery due to the effects of viewing it over a distant horizon relative to the equator.

[v] The average refresh rate between 50° - 60° latitude is about 90-150 minutes. The LEO polar-orbiting satellite refresh above the "Arctic" circle (66N) is more frequent.

[vi] JROCM 091-12, "DoD Meteorological and Oceanographic Collection Requirements"