9. Environmental Monitoring

Area Description

Environmental support for land, sea and air operations includes the day-to-day provision of space products and services to operational forces. These regional and local descriptors are key elements by which warfighters can use the natural or changing environment as part of their operational planning and execution. Thus, improved knowledge and prediction of the physical environment affecting the battlespace can be leveraged for mission success. Technological advances in Service and Defense Agency systems and techniques for global environmental characterization and prediction, and in their associated communications and data processing capabilities, are steadily improving the contributions of environmental monitoring services and products to the full spectrum of terrestrial military operations.

By comparison, space weather services and environmental characterization capabilities are relatively limited, but are expanding rapidly to keep pace with expanding space operations per se. A number of new technologies and operational capabilities are being deployed in the next few years to yield dramatic improvements in space weather monitoring and prediction and space environmental research. Many of these advances require routine access to space.

Environmental monitoring and the development of geospatial information for national security purposes rely on defense, civil and commercial space capabilities. The government both buys and provides space-generated terrestrial imagery and other information products, while customers for military space-generated information and services include such agencies as: the Departments of Agriculture (DOA), Commerce (DOC), Energy (DOE), Interior (DOI), and State (DOS); NASA; the Federal Aviation Administration (FAA) and Federal Communications Commission (FCC); the Arms Control and Disarmament, Environmental Protection, and U.S. Information Agencies (ACDA, EPA, and USIA); the National Science Foundation (NSF) and Smithsonian Institution; and a host of other civil and commercial organizations.

This mission area includes the traditional missions of Mapping, Charting, and Geodesy (MC&G). Within the DoD, the joint Defense Meteorological Satellite Program (DMSP), GPS, GEOSAT, NRO programs, National Imagery and Mapping Agency (NIMA) products and meteorology and oceanography (METOC) programs provide comprehensive weather, mapping, intelligence, and environmental surveillance, monitoring and forecasting support worldwide. Four space-reliant disciplines directly protect fighting forces and support facilities from adverse conditions and enable operational advantage by exploiting the physical environment to optimize the performance of platforms, sensors, and weapons. These disciplines — METOC, geospatial information and services, precise timing, and astrometry — provide an assessment of the impact of natural phenomena on weapon systems around the world and contribute to other functions (e.g., navigation, geolocation, flight safety, search and rescue) in the process.

Concurrently, as space-based capabilities become increasingly important to terrestrial operations, observing, understanding and predicting the naturally harsh space environment itself is becoming increasingly important to continued operations in all domains. This “space weather,” such as extremes of heat and cold, as well as radiation effects and collisions with space debris, can cause equipment failures and outages. Similarly, geomagnetic and ionospheric disturbances can disrupt even sophisticated wireless communications and navigation networks, interfere with global surveillance and information integration, and impede the proper functioning of sensors and networks that detect and track aircraft, missiles, and spacecraft.

From a technology-driver viewpoint, the needs are emerging as two-fold: on the one hand, space-based monitoring of the terrestrial environment requires ever more and more sophisticated space-based sensor systems and their associated processing and communications functions. (For example, the ability to observe and forecast atmospheric conditions with greater accuracy and timeliness, especially cloud cover and other obscurants over prospective target areas, would greatly support strike operations.) On the other hand, space-based systems (for all missions) need to monitor and be resistant to the effects of their own space environment. Even temporary outages (e.g., from geomagnetic or ionospheric effects) can jeopardize the assured information flow needed by military forces and by civil and commercial customers alike.

Mission Area Objectives

Advanced understanding of the environment from observation to prediction
Timely, high-quality real-time global weather data to operators
Three-dimensional (3D) characterization of ocean and land topography and the atmosphere
Global METOC and Earth remote monitoring (ERM) coverage
Differentiation of manufactured from natural phenomena and signatures, classification/identification, and timely change recognition
Improved capabilities to observe, model and forecast space environmental parameters
Earlier detection and assessment of space weather effects
Increased integration of space with terrestrial sensors E.g., unattended ground sensors (UGSs), unmanned aerial vehicles (UAVs)
Remote sensing of chemical effluents, fuel spills, atmospheric pollutants
Supporting Capabilities
Higher data rate on-board processing with faster refresh rates for METOC and ERM data sets
Improved spatial resolution of METOC and ERM data
Characterization of micrometeoroids and debris in orbits of military relevance
Exploitation of environmental impacts on sensors, weapons, systems, and platform performance
On-orbit monitoring of Van Allen Belt fluctuations
Detection and characterization of solar coronal events
Satellite laser and RF interference/vulnerability mitigation

Current Technology Initiatives *(Highlights of Current FYDP)*

Current projects address both the terrestrial environment, where most military operations will continue to take place, and the space environment, where increasing types and numbers of military functions will take place in the 21st century.

Terrestrially oriented technology programs continue to support space-based weather observation and forecasting, mapping, intelligence, environmental surveillance and forecasting, and both atmospheric and oceanic characterization operations worldwide. Their programs include DMSP, GPS, GEOSAT, specific NRO programs, NIMA products, and METOC functions. In addition, advanced monitoring systems include the developmental National Polar-orbiting Operational Environmental Satellite System (NPOESS), in which the Navy WindSat program is providing risk-reduction efforts for the:

- NPOESS Conical Microwave Imaging Sounder (CMIS) program
- Naval EarthMap Observer (NEMO)
- Indian Ocean METOC Imager (IOMI) program.

Space environmental monitoring and characterization projects include:

- The IOMI program to demonstrate critical sensor technologies for future civil and military weather systems that could greatly improve global weather forecasting by covering the broad Indian Ocean area
- A space weather S&T program of basic research through prototype development of operational sensors, models, and tailored products
- A program to provide real-time alerts and up to 1-hour forecasts of scintillation impacts to UHF SATCOM will be expanded from 4 to 10 sites and upgraded to include L-band scintillation warning for GPS navigation links

- Development of the Communication/Navigation Outage Forecast System (C/NOFS) sensor to provide GPS with 4-6 hour forecasts of scintillation outages
- Validation of a program currently used to specify global electron and neutral density profiles, plus upgrades to ground-based ionospheric sensors and algorithms to assimilate both ground- and space-based data into global electron and neutral density forecast models
- The Compact Environment Anomaly Sensor (CEASE), a small, lightweight, low-power sensor to provide satellite operators with alerts of space particle hazards to their satellites
- The Solar Mass Ejection Imager (SMEI) will detect and track coronal mass ejections (CMEs) all the way from the sun to Earth.

Selected project detail is tabulated in "Projected Applications," below.

Enabling Technologies *(Unconstrained)*

- Autonomous, adaptive, self-training algorithms for tasking, mission planning/ management, processing, exploitation, and dissemination
  - Real-time resource planning
- Improved sensors with 3D coverage, timely refresh rates, and improved accuracy
  - Acquisition, pointing and tracking,
- Increased sensor range and sensitivity technologies
  - Atmospheric, radiant and celestial background characterization, databases, modeling, and processing
- Advanced electro-optical (EO) technology (e.g., for long-dwell sensing)
- Hyperspectral sensing: improved low power, high capacity on-board processors
- Hyper- to ultra-spectral imagery (HSI USI) sensors (100s to 1000s of bands)
  - Exploitation of multiple-band IR sensor data
- Exploitation of evolving HSI/USI approaches
  - E.g., improved HSI/USI collection via focal plane arrays (FPAs)
- Visible and multispectral/hyperspectral and very short wavelength infrared (VSWIR) sensors/ imagers
  - Multi- to ultra-spectral detector materials, processes, and manufacturing
- Large FPA detector materials science and manufacturing
- Advanced small, high-capacity, space-qualified cryocoolers;
  - More efficient on-orbit storage of cryogenic hydrogen
  - More efficient infrared applications
  - Advanced regenerator/phase-change materials
- Space-based laser/lidar remote optical sensing
- Sensors to monitor the space environment and alert host spacecraft of natural hazards, man-made threats or anomalies
- Multi-point space weather measurements
- Real-time remote-sensing technologies to study ionospheric effects
  - E.g., scintillation of RF signals
- Advanced spatial resolution techniques
- Hyper resolution techniques
- Basic research leading to development/improvement of advanced sensor technologies and weather prediction models
- Advanced computing:
  - Hyper-performance hardware to run advanced, high-resolution models at to provide real-time data
  - Improved algorithms for speed, accuracy, and efficiency
- Reprogrammable radios and other electronics system components
- More efficient solar cells, batteries (chemically or thermally generated electricity, such as thermionic power generation and thermo-electric conversion)
  - E.g., lithium ion/polymer hybrid batteries
  - Affordable solar cell materials and manufacturing
- Radiation hardening and shielding of components
  - Radiation-resistant composites and associated materials
  - High-temperature and radiation-resistant electronic materials
  - Flash radiation-hardened digital memory (e.g., SiC)
- Isothermality technologies
- Advanced filters and limiters for satellite survivability
- Advanced effects phenomenology

Projected Applications

A wide range of applications exists; the following is a selection.

Category	Project	Status	Agencies
Enhanced Atmospheric Characterization	• ***WindSat***	Experiment	Navy
	– Measure ocean surface wind speed and direction		
	– Provides risk reduction for NPOESS/CMIS		
	• ***Communication/Navigation Outage Forecasting System (C/NOFS)***	ACTD	Air Force
	– Equatorially orbiting satellite to warn of potential outages to GPS navigation and satellite comm links due to hazardous space environmental conditions		
	• Additional projects with sensors hosted on both operational and experimental spacecraft to measure and characterize the upper atmosphere	Development	Air Force Navy
Enhanced Oceanic Characterization	• ***Geodetic/Geophysical Satellite (GEOSAT) Follow-On (GFO) satellite***	Pre-operational calibration/ validation	Navy
	– Enhancements to ocean wave height and topographic measurements		
	• ***Radar Altimetry***	Development	Navy
	– Characterization of oceanographic thermohaline and geostrophic surface current structure		
	• Additional projects to characterize ocean surface	Development	Navy
Improved Space Characterization	• ***Compact Environmental Anomaly Sensor II (CEASE II)***	ACTD	Air Force, Navy
	– To demonstrate a small, low-power instrument resident on a host spacecraft to reduce anomaly resolution time and increase situational awareness		
	• ***Advanced Solar Telescope (AST)***	Proposed project	Nat'l Science Foundation
	– For solar disturbance monitoring		
	• ***Solar Mass Ejection Imager (SMEI) and space-based coronographs***	Experiment development	Air Force
	– Advance warning of coronal mass ejections (CMEs) and track their propagation from the Sun to Earth		
Advanced Environmental Monitoring Systems	• ***National Polar-orbiting Operational Environmental Satellite System (NPOESS)***	Engineering development	DOC-DoD-NASA
	– Passive microwave instruments will provide global oceanic and atmospheric data of direct operational relevance. Multiple primary sensors are planned		
	• ***Small satellite concepts***	Concepts	DARPA, Air Force
	– To provide sensors for global environmental data and space weather sensing		
	– Data acquisition using STRV-2c/d		BMDO
	• ***Naval EarthMap Observer (NEMO)***	Prototype development	Navy, DARPA, Industry
	– To collect broad-area HSI for Naval and Civil users		
	• ***Indian Ocean METOC Imager (IOMI)***	Development	Navy, NASA, NOAA
	– To demonstrate hyperspectral atmospheric characterization from GEO, using on-board high-performance processing and data compression		

Category	Project	Status	Agencies
Enhanced METOC Forecasting Models	• Projects to update the weather database, help exploit measurements, and develop predictive models	Research	Air Force, Navy
	• Projects to improve forecasting for the atmospheric, ionospheric and magnetospheric environments	Research	Air Force, Navy
Military-Civil Cooperative Activities	• Prediction of forest fires	Research	(Several)
	• Pacific Disaster Center functions	On-going	Fed agencies
	• Early detection of volcanic activity, both to mitigate effects and to support disaster relief	Research	(Several)

Opportunities for Partnering

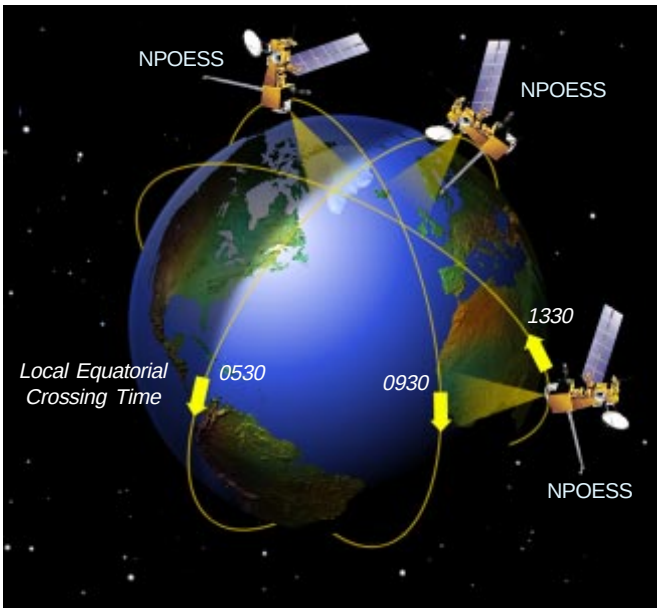
Partnerships and cooperative programs exist within the DoD and with other agencies. For example, NOAA, the Navy and Air Force cooperate on DMSP; the Joint Typhoon Warning Center also includes a broad range of military-civilian coordination. The Navy and NOAA continue to identify new areas for cooperation, such as operational numerical modeling, data exchange, risk-reduction efforts, and mutual backup among several agencies. Federal and commercial agencies use each other's R&D and missions of opportunity to obtain space environmental data.

External partnerships also include the DOC-DoD-NASA collaboration on NPOESS, which allows significant opportunities to transition Air Force and Naval space technologies and models into operations. NPOESS's six primary sensors will cover wide electromagnetic and operational applications ranges to meet evolving military needs. Meanwhile, the Navy's Windsat will provide risk reduction for the NPOESS Conical Microwave Imager Sounder (CMIS), a DMSP microwave suite follow-on that will use passive microwave radiometry.

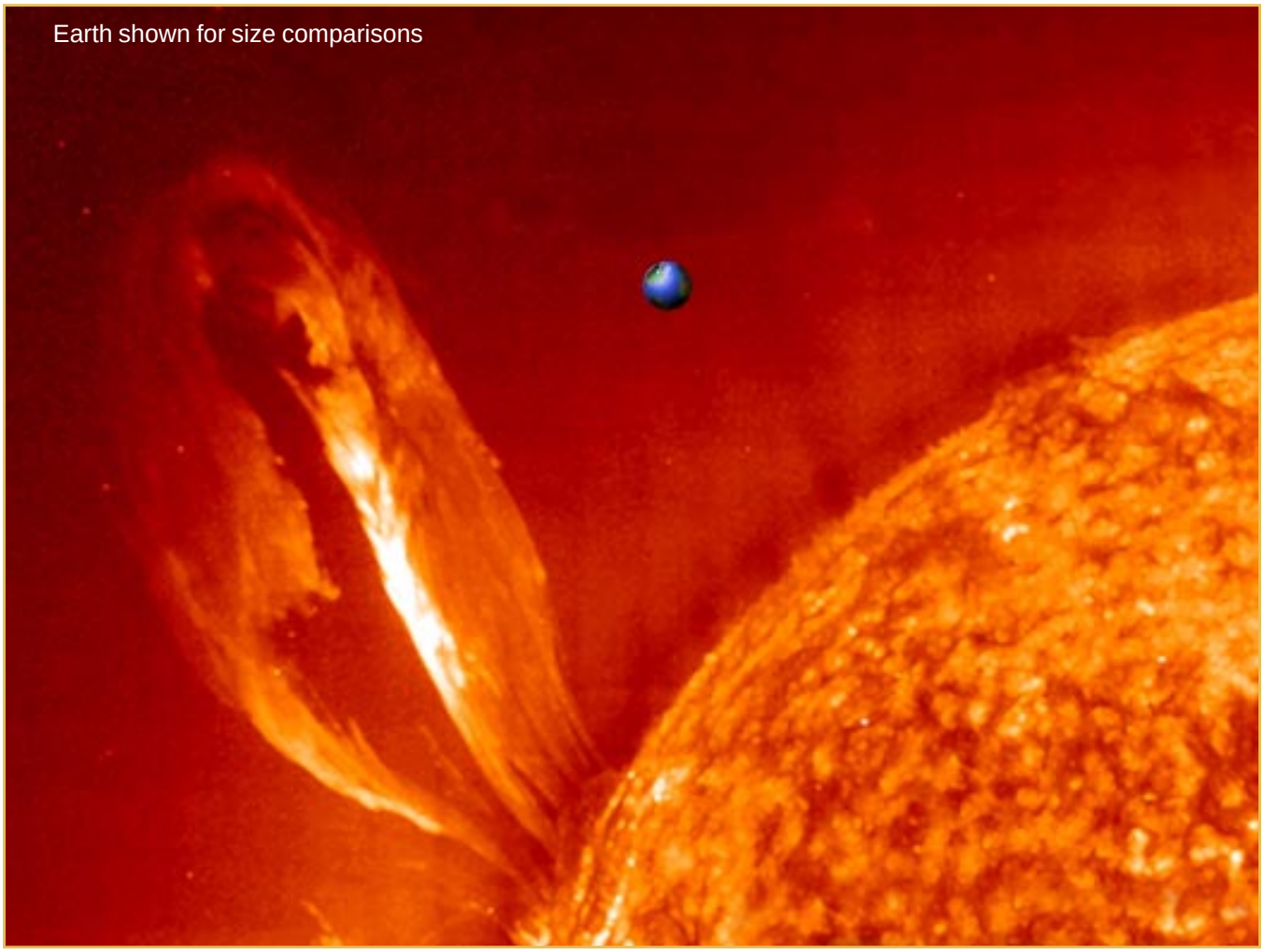
The Navy is partnering with NASA to combine its IOMI program with NASA's Geostationary Imaging Fourier Transform Spectrometer (GIFTS) program to demonstrate hyperspectral atmospheric characterization from geosynchronous orbit. The IOMI/GIFTS project will demonstrate critical sensor technologies for future civil and military weather systems, with the potential to greatly improve global weather forecasting. The project will include direct data downlink to the fleet and data distribution to the Navy Fleet Numerical Meteorological Oceanographic Center, NOAA, NASA, and the world meteorological community.

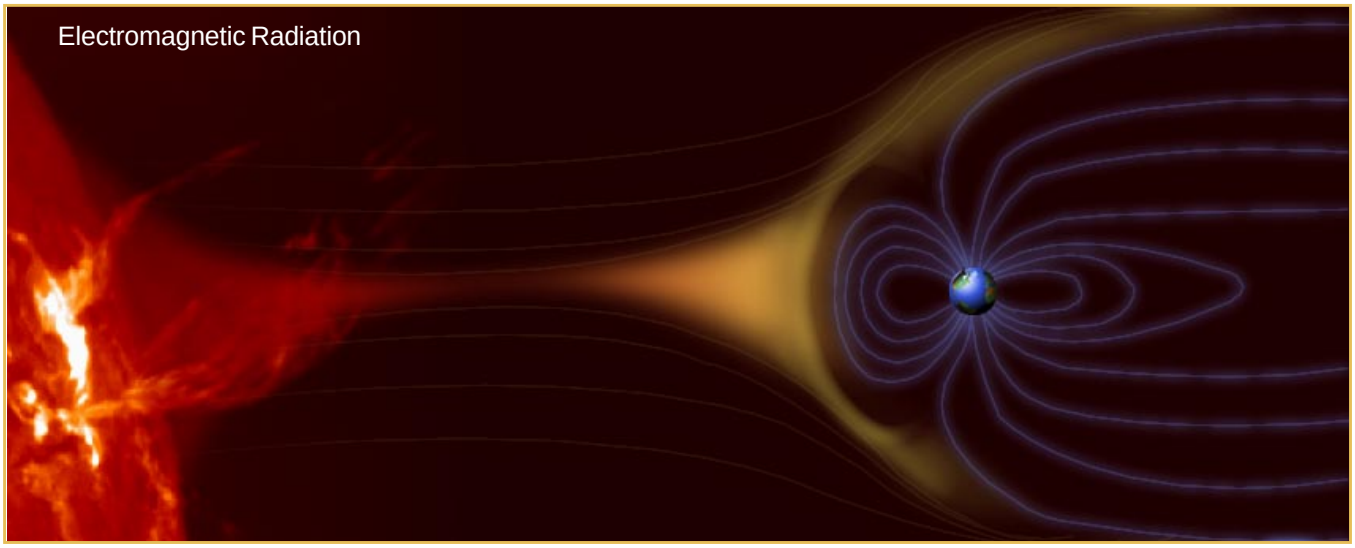
BMDO is cooperating with the Air Force, NASA, the UK and the European Space Agency (ESA) over measurement of Van Allen Belt fluctuations and the testing of radiation resistance of key electronic components. BMDO and NASA/JPL are measuring the micrometeoroid and debris environment in low- to mid-altitude orbits.

Further, unclassified Service-produced data is made available to NOAA for public distribution. Service partnerships with the NSF, NOAA and NASA currently exist in the National Space Weather Program. Finally, new NASA and Navy initiatives in space weather and space S&T research will allow the DoD to test new space sensing technologies and participate in continuous solar and Earth environmental monitoring.



National Polar-orbiting Operational Environmental Satellite System (NPOESS) Constellation





Space Weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. **Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids,** leading to a variety of socio-economic losses.

National Space Weather Program
Strategic Plan, August 1995