THE NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS): IMPROVED CAPABILITIES FOR WEATHER FORECASTING AND ENVIRONMENTAL MONITORING

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ABSTRACT

In the next decade, weather forecasters, climate researchers, and decision-makers will rely on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) to meet many of their needs for remotely-sensed, Earth science data and information. NPOESS spacecraft will be launched into two orbital planes beginning in 2013 to provide significantly improved operational capabilities and benefits to satisfy critical civil and national security requirements for space-based, remotely sensed environmental data.

Index Terms— Satellites, Remote Sensing, Sensors

1. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA), Department of Defense (DoD), and National Aeronautics and Space Administration (NASA) are working with prime contractor Northrop Grumman Space Technology (NGST), principal teammate Raytheon, and instrument subcontractors to jointly develop and acquire the next-generation operational weather and environmental satellite system - the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NPOESS will replace NOAA's current Polar-orbiting Operational Environmental Satellites (POES) and DoD's Defense Meteorological Satellite Program (DMSP) spacecraft that have provided global data for weather forecasting and environmental monitoring for over 45 years. NPOESS will acquire and deliver critical Earth observation measurements to NOAA and DoD central processing facilities through an innovative global SafetyNet™ communications network of 15 unmanned ground stations that will provide significantly improved data latency. NPOESS will enable high-quality, space-based, remotely-sensed data to be used faster and more frequently in numerical weather prediction models for improved environmental forecasts and warnings. NPOESS will employ platforms and instruments that incorporate technological advances from NASA's Earth Observing System (EOS) satellites in an integrated mission serving the nation's civilian and military needs for space-based, remotely-sensed environmental data.

2. PROGRAM STATUS

The NPOESS program was significantly restructured in 2006 as a result of sensor development problems, cost growth, and schedule delays incurred in previous years. NPOESS will now consist of four spacecraft (C1 – C4) and associated sensors in two key orbital planes (1330 local time ascending node – LTAN and 1730 LTAN) to meet the operational needs of NOAA and DoD. The NPOESS program provides for the initial acquisition of two spacecraft (C-1 and C-2). The government may exercise its option under the existing contract with NGST in 2010 to procure two additional NPOESS satellites (C-3 and C-4).

As a precursor to NPOESS, the NPOESS Preparatory Project (NPP) is scheduled to be launched in 2010. The first operational NPOESS spacecraft (C-1) is now scheduled for launch in 2013. The last satellites (C-3 and C-4) in the two-orbit NPOESS constellation are expected to be operational into the 2023-2026 time period.

The first operational NPOESS spacecraft (C-1) is expected to be launched in 2013 into a sun-synchronous, afternoon polar orbit (1330 LTAN) at an altitude of 828 km to replace the last of NOAA's POES. Data collected from imaging and sounding instruments in this afternoon orbit are critical for global numerical weather prediction (NWP) models. The NPOESS C-2 satellite is being planned for launch in 2016 to replace the last of the DMSP spacecraft that currently occupy either an early morning (1730 LTAN) or mid-morning orbit to support military operations worldwide. Satellite imagery and atmospheric data from this orbit are critical to support DoD global NWP models and short-term local and regional forecasts that are used for tactical planning on the battlefield.

NOAA depends on data from the afternoon orbit (1330 LTAN) for critical input into global and regional weather forecast models. The afternoon NPOESS spacecraft will carry advanced technology visible, infrared, and microwave imagers and sounders to deliver higher spatial and temporal resolution data enabling more accurate short-term weather forecasts and severe storm warnings. The early morning orbit (1730 LTAN) will provide critical visible and microwave imagery for global cloud forecast models to support DoD's tactical decisions for air, sea, and ground operations. A mid-morning orbit (2130 LTAN) will be occupied by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Meteorological Operational (MetOp) spacecraft that carries advanced instruments similar to those that will fly on NPOESS. EUMETSAT successfully launched the first in the series of MetOp satellites in October 2006 to permanently replace NOAA POES in the mid-morning orbit as part of the NOAA/EUMETSAT Initial Joint Polar-orbiting Operational Satellite System (IJPS).

3. SENSORS

The afternoon NPOESS spacecraft will carry the following four primary instruments: Visible/Infrared Imager Radiometer Suite (VIIRS); Cross-track Infrared Sounder (CrIS); Advanced Technology Microwave Sounder (ATMS), Ozone Mapping and Profiler Suite (OMPS); as well as the Microwave Imager/Sounder (MIS – C3 only), Space Environment Monitor (SEM), Clouds and the Earth's Radiant Energy System (CERES – C1 only), and Total Solar Irradiance Sensor (TSIS – C1 only). Currently, the early-morning spacecraft will fly with a reduced complement of instruments: VIIRS and MIS (C2 and C4). Both early-morning and afternoon spacecraft will also be equipped with the Advanced Data Collection System (ADCS) and Search and Rescue Satellite Aided Tracking System (SARSAT). The current orbit manifest for the NPOESS and NPP sensor payloads is shown in Table I. Flight units for the primary instruments are nearing completion for integration onto the NPP spacecraft.

TABLE I
NPOESS AND NPP SENSORS BY ORBIT

Afternoon Orbit	Morning Orbit	NPP
VIIRS	VIIRS	VIIRS
CrIS		CrIS
ATMS		ATMS
MIS (C-3)	MIS	
OMPS (Nadir)		OMPS
SEM		
CERES (C-1)		CERES
TSIS (C-1)		
SARSAT	SARSAT	
A-DCS	A-DCS	

The 22-channel VIIRS will collect calibrated visible/infrared radiances to produce about 20 different Environmental Data Records (EDRs) including imagery, cloud and aerosol properties, albedo, land surface type, vegetation index, ocean color, and land and sea surface temperature to fulfill functions similar to what the Moderate Resolution Imaging Spectroradiometer (MODIS) does for NASA's EOS Terra and Aqua missions. VIIRS will provide complete daily global coverage over the visible, short/medium-infrared, and long-wave infrared spectrum at horizontal spatial resolutions of 370 m and 740 m at nadir. VIIRS will image at a near constant horizontal resolution across its ~3000 km swath (i.e., from 370 m at nadir to ~800 m at edge of scan) a significant improvement over NOAA's Advanced Very High Resolution Radiometer (AVHRR) and NASA's MODIS instruments. VIIRS also has a day/night band to detect low levels of visible-near infrared radiance at night from sources on or near the Earth's surface, such as low clouds and fog illuminated by moonlight, snow cover, and lightning flashes. VIIRS will produce low-light imagery at a higher horizontal resolution than the Operational Linescan System (OLS) on DMSP.

The VIIRS flight sensor for NPP is now undergoing final characterization and calibration. Instrument performance has been assessed by comparing VIIRS calibration and characterization Sensor Data Records (SDRs) to equivalent Level 1 products from MODIS. Predictions demonstrate that cloud products, land EDRs (land surface temperature, surface type, surface albedo, and vegetation index), and sea surface temperature (SST) from VIIRS will be equivalent in quality to products from MODIS [1], [2], [3]. However, aerosol EDRs and ocean color/chlorophyll products will be degraded with respect to MODIS performance due to cross-talk problems in the filter assemblies on the first VIIRS flight sensor [4], [5].

The Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) will provide vertical profiles of atmospheric temperature, humidity, and pressure from the surface to the top of the atmosphere. CrIS senses upwelled infrared radiances from 3 to 16 µm at very high spectral resolution (~1300 spectral channels) to determine the vertical atmospheric distribution of temperature and moisture from the surface to the top of the atmosphere across a swath width of 2200 km. CrIS will succeed the Atmospheric Infrared Sounder (AIRS) which is on NASA's EOS Aqua spacecraft and fly in a complementary orbit with the Infrared Atmospheric Sounding Interferometer (IASI) on the EUMETSAT MetOp satellites. ATMS has 22 microwave channels in the 23-183 GHz range to provide vertical temperature and moisture soundings. Data from CrIS and ATMS will be used to construct atmospheric temperature profiles at 1° K accuracy for 1 km layers and moisture profiles accurate to 15 percent for 2 km layers to approximate the accuracy of data obtained from radiosondes.

The tri-agency NPOESS Integrated Program Office (IPO) has defined a less complex passive microwave radiometer sensor and acquisition strategy to replace the Conical-scanning Microwave Imager/Sounder (CMIS) that was demanifested when the NPOESS program was restructured. The Microwave Imager/Sounder (MIS) will fly on NPOESS C2-C4 to perform key measurements including soil moisture and sea surface winds, as well as other environmental parameters including atmospheric temperature and moisture profiles, and integrated atmospheric moisture and precipitation. Details on MIS are provided in [6].

The Ozone Mapping and Profiler Suite (OMPS) on NPP will use nadir and limb scanning ultraviolet (UV) instruments to collect atmospheric total column and vertical profile ozone data and continue the daily global data produced by the current ozone monitoring systems, the Solar Backscatter Ultraviolet radiometer (SBUV)/2 and Total Ozone Mapping Spectrometer (TOMS), but with higher fidelity. The OMPS limb scanner is expected to provide vertical profiles of ozone concentrations for 3 to 5 km thicknesses of the atmosphere as compared to the 7 to 10 km thicknesses obtained from the SBUV/2 on NOAA POES. The OMPS on NPOESS C-1 may be a nadir sensor only.

The Space Environment Monitor (SEM) is a multi-channel, charged particle spectrometer that measures the population of the Earth's radiation belts and the particle precipitation phenomena resulting from solar activity. SEM is currently flown on NOAA's POES.

NPOESS is on track to deliver more than 35 essential measurements for operational weather and ocean nowcasting and forecasting, land use, and space weather while providing continuity of data for 14 of 26 essential climate variables. Although several NPOESS climate sensors were de-manifested as a result of restructuring in 2006, the NPOESS spacecraft is designed to handle the re-manifest of all de-manifested sensors, including climate monitoring sensors. In fact, as a result of recent tri-agency decisions, CERES was added to NPP and both CERES and TSIS will be flown on NPOESS C-1. NOAA and NASA are currently working on other options to meet requirements for long-term climate monitoring from space that may include NPOESS.

The Cloud and Earth Radiant Energy System (CERES) instrument consists of three broadband radiometers, covering the spectral regions from 0.3 to > 50 μm, which scan the Earth from limb to limb. CERES will provide measurements of the space and time distribution of the Earth's Radiation Budget (ERB) components. CERES will continue a nearly 30-year record of measurements of the Earth radiation budget by instruments on NASA spacecraft. Data from CERES will be used in conjunction with VIIRS to study changes in the Earth's energy balance and key changes in clouds and aerosols to determine the effect of changing clouds on the Earth's energy balance from space.

The Total Solar Irradiance Sensor (TSIS) will measure variability in the sun's solar output, including total solar irradiance. TSIS consists of two instruments: the Total Irradiance Monitor (TIM) that measures the total light coming from the sun at all wavelengths; and the Spectral Irradiance Monitor (SIM) that will measure how the light from the sun is distributed by wavelength. These measurements are needed to understand how solar radiation interacts with the Earth's surface and atmosphere. TSIS is an important climate sensor that will help maintain continuity of the climate data record for space-based solar irradiance measurements that now spans over three decades.

4. NPOESS PREPARATORY PROJECT

To ensure a successful transition from current research to future operations, the NPOESS IPO and NASA are partners in the NPP that is scheduled for launch in 2010 as a precursor to NPOESS. NPP will accomplish two key objectives: (1) reduce final development risks for NPOESS by providing on-orbit testing, calibration, and validation of sensors, algorithms, and ground-based operations and data processing systems prior to the launch of NPOESS-C1 in 2013; and (2) provide continuity of calibrated, validated, and geo-located NASA EOS Terra, Aqua, and Aura global imaging and sounding observations.

NPP will carry the four primary NPOESS sensors (VIIRS, CrIS, ATMS, and OMPS) and CERES to provide on-orbit testing and validation of sensors, algorithms, ground-based operations, and data processing and distribution systems prior to the launch of the first operational NPOESS satellite. The NPP satellite will be launched into the 1330 LTAN orbit to reduce the risk of a data gap between the last POES and the first NPOESS satellite. NOAA, DoD, and NASA will have real-time access to data from NPP for use and critical evaluation, ensuring that NPOESS products will be incorporated into operations soon after launch.

A key component of NPP is NASA's Science Data Segment (SDS). The SDS evaluates key NPP/NPOESS EDRs in the following discipline areas: oceans, land, ozone, atmospheric sounding, and atmospheric composition. The SDS will assess NPP EDR quality and performance, and test the suitability of EDRs for climate research. Details on the NPP SDS are provided in [7].

5. GROUND SYSTEMS

NPOESS will be an end-to-end system to acquire, process, and deliver meteorological, oceanographic, terrestrial, climatological, and solar-geophysical observations of the Earth, atmosphere, and space to NOAA and DoD central processing facilities through an innovative global SafetyNet™ communications network of 15 unmanned ground stations that will provide significantly improved data latency over current systems. The NPOESS ground system architecture is expected to deliver 95% of the data within 28 minutes from the time of collection. NPOESS spacecraft will also simultaneously broadcast real-time data at X-band and L-band frequencies to suitably equipped ground stations.

A ground station has already been installed for NPP and is operating at the Svalbard Satellite station (SvalSat) in Svalbard, Norway. SvalSat will function as the primary Telemetry and Command system for both NPP and NPOESS. Data from all 14 daily NPP satellite passes will be relayed via fiber-optic cable from SvalSat to the U.S. in minutes, thereby improving data latency compared to the legacy POES and DMSP systems. NPP will also support real-time Direct Broadcast (DB) services via an X-band downlink.

Key components of the NPP and NPOESS command, control, and communications system have already been installed and have passed preliminary tests at SvalSat and at NOAA's Satellite Operations Facility. Communications capabilities from Antarctica are being upgraded to support NPOESS. NOAA and EUMETSAT are currently exploring opportunities to receive MetOp data from an Antarctic ground station, thereby substantially improving data latency in the mid-morning orbit. Installation and testing of the NPOESS Integrated Data Processing system at NOAA and DoD facilities will continue throughout 2008. In the future, NPOESS and MetOp will provide essential real-time data to the international community to support weather forecasting, as well as continuity of critical data for monitoring, understanding, and predicting climate change.

6. APPLICATIONS AND TRAINING

The visible and near-infrared channels on VIIRS will be used to generate high resolution cloud imagery, sea ice, aerosols, vegetation, and land surface type products. The short- to long-wave infrared channels will provide data to derive cloud properties (cloud type, cloud particle size, cloud top height, cloud top temperature), snow cover, sea surface temperature, and fires. Multi-channel algorithms will combine visible and infrared data to generate measurements such as albedo that is important in measuring and understanding the Earth's energy balance. These multi-spectral capabilities will allow users to accurately detect phenomena such as volcanic ash plumes and discriminate low clouds from fog that may significantly impact aircraft operations.

Higher (spatial, temporal, and spectral) resolution and more accurate sounding data from CrIS and ATMS will support continuing advances in data assimilation systems and NWP models to improve short- to medium-range weather forecasts. Assimilation of high-spectral resolution radiance data from AIRS into NWP models at NOAA's National Centers for Environmental Prediction (NCEP) has already resulted in a several hour increase in forecast skill/range at five to six days in both northern and southern hemispheres, a significant improvement that normally takes several years to accomplish [8]. CrIS will produce operational sounding data comparable to AIRS. VIIRS will deliver high resolution, radiometrically accurate data on surface albedo, land surface type, sea surface temperature, snow cover, and ice extent for ingesting into global and regional models. OMPS will profile ozone vertically in 3 km layers to provide better specification of stratospheric ozone that is now being used as a tracer in global NWP models.

Even as data from NASA's MODIS and AIRS instruments are being used to support current operations, weather forecasters and other users of remote sensing data are being prepared to exploit NPP and NPOESS data as soon as these new systems launch. Over the past six years, the Cooperative Program for Operational Meteorology, Education and Training (COMET) has focused its satellite training on the capabilities, applications, and relevance of NPP and NPOESS to operational weather forecasters and other user communities. A complementary training effort is hosted by Naval Research Laboratory (NRL) in Monterey, California on their NRL/NPOESS Next Generation Weather Satellite Demonstration Project (NexSat) website. NexSat uses real-time imagery from current operational (e.g, POES and DMSP) and research (e.g., NASA's EOS Terra and Aqua) satellites to highlight the expected capabilities of comparable sensors on the future NPP and NPOESS [9]. The goal of these efforts is to ensure that forecasters and other users will be prepared to use data and products from NPP and NPOESS on Day 1 of operations.

7. SUMMARY

The NPOESS architecture will enable high-quality, space-based, remotely-sensed data to be used faster and more frequently in numerical weather prediction models for improved environmental forecasts and warnings. As a key component of the Global Earth Observation System of Systems (GEOSS), NPOESS data will contribute to the "Nine Societal Benefits Areas." NPOESS will provide essential real-time data to the international community to support weather forecasting, as well as continuity of critical data for monitoring, understanding, and predicting climate change and assessing the impacts of climate change on seasonal and longer time scales.

8. REFERENCES

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