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FUTURE POLAR ORBITING METEOROLOGICAL SATELLITE SYSTEMS

The USA discussed its future polar-orbiting meteorological satellite systems. NOAA addressed the current operational system and the planned launch schedule for NOAA-N'. Information was provided on the international polar-orbiting satellite program coordination between EUMETSAT and NOAA. The goal of this cooperation is to provide continuity of measurements from polar orbits, cost sharing, and improved forecast and monitoring capabilities through the introduction of new technologies. An agreement is in place between NOAA and EUMETSAT on the Initial Joint Polar-orbiting Operational Satellite System (IJPS). This program will include two series of independent but fully coordinated NOAA and EUMETSAT satellites, exchange of instruments and global data, cooperation in algorithm development, and plans for real-time direct broadcast.

The USA discussed the development and implementation plans for NPOESS. Beginning later this decade, NPOESS spacecraft will be launched into three orbital planes to provide significantly improved operational capabilities and benefits to satisfy the critical civil and national security requirements for space-based, remotely sensed environmental data. The advanced technology visible, infrared, and microwave imagers and sounders that are being developed for NPOESS will deliver higher spatial and temporal resolution atmospheric, oceanic, terrestrial, and solar-geophysical data enabling more accurate short-term weather forecasts, as well as serving the data continuity requirements for improved global climate change assessment and prediction. The NPOESS program is well along the path to creating a high performance, polar-orbiting satellite system that will be more responsive to user requirements, deliver more capability at less cost, and provide sustained, space-based measurements as a cornerstone of an Integrated Global Observing System. These activities represent a sound beginning for achieving the planned national and international operational satellite programs that will ensure continuous support to a variety of users well into the 21st century.

FUTURE POLAR ORBITING METEOROLOGICAL SATELLITE SYSTEMS

1. INTRODUCTION

Since 1960, polar-orbiting satellites have collected environmental data from space to support the preparation of informed short-term weather forecasts and warnings. The Polar-orbiting Operational Environmental Satellite (POES) system evolved from the experiences gained in space from ten experimental Television Infrared Observation Satellites (TIROS) and four generations of operational polar-orbiting satellites. Since 1978, the POES system has been operated with a two-satellite constellation in circular, near-polar, sun-synchronous orbits.

The POES program is managed by the National Environmental Satellite, Data, and Information Service (NESDIS) that is part of the National Oceanic and Atmospheric Administration (NOAA). During the 1980s, budgetary concerns guided program decision-makers to study convergence of the POES mission with the U.S. military's Defense Meteorological Satellite Program (DMSP) and investigate cooperative international programs to reduce overall costs for space-based observing systems. The results of these activities are now reflected in a Presidential Decision Directive and memorandums of agreement to implement new architectures for national and international polar-orbiting operational satellite systems by the end of the first decade in the 21st century. Until the new operational satellite systems are available, the current POES and DMSP programs will provide continuous satellite coverage from space to support user needs.

2. POLAR MISSION

The primary mission of the POES system is to provide daily global observations of weather patterns and environmental measurements of the Earth's atmosphere, its surface and cloud cover, and the proton and electron flux at satellite altitude; and to establish long-term data sets for climate monitoring and assessment and climate change predictions. Since the beginning of the POES program, environmental data and products acquired by its satellites have been provided to users around the globe.

The POES system comprises on-orbit remote-sensing satellites, and satellite command and control and data processing facilities. NOAA has in place a polar satellite program to replace current satellites as they reach the end of their operational life. This fifth-generation of POES Advanced TIROS-N (ATN) satellites are designated NOAA-K, -L, -M, -N, and –N'. NOAA-K, -L, and -M have been upgraded with new primary environmental instruments and will be followed by NOAA-N and N' that are being updated to a later instrument baseline. The major changes to the environmental instrument baseline for the NOAA-K, -L, and -M satellites, described below, include the AVHRR/3, the HIRS/3, and the AMSU-A and -B.

The current operational constellation includes NOAA-18 (NOAA-N) and NOAA-17 (NOAA-M). These satellites, with updated instruments, operate in an afternoon and morning orbit, respectively. To support the Polar mission, these satellites carry the following instruments:

- Advanced Very High Resolution Radiometer (AVHRR/3): Through modifications to the current AVHRR/2 instrument, a sixth channel has been added for near-IR data. This channel, referred to as 3A, will provide users with the ability to discriminate between clouds and snow and ice. It will be time shared with the previous channel 3, now referred to as 3B. Operationally, channel 3A will be active during the daytime part of each orbit and 3B will be active during the night time part of each orbit.
- High Resolution Infrared Sounder (HIRS/3- HIRS/4): The HIRS is an infrared sounder consisting of one visible, 12 long-wave IR, and 7 shortwave IR channels. The instantaneous field of view (IFOV) and ground sample distance (GSD) for the HIRS/3 (NOAA-17 through -17) are 20 km. The HIRS/4 flying on NOAA-18 (N' and Metop) has a 10 km IFOV with a 20 km GSD. This change was made to increase the number of clear (i.e., cloud free) observations taken by the HIRS instrument.
- Advanced Microwave Sounding Unit (AMSU-A and –B or MHS): The AMSU suite is a 20-channel scanning passive microwave radiometer. AMSU-A uses 15 channels to provide data for vertical temperature profiles and additional information on surface water and precipitation to enhance sounding measurements. AMSU-B, provided by the U.K. Meteorology Office (or MHS (Microwave Humidity Sounder) provided by EUMETSAT), is a five-channel microwave radiometer for measuring atmospheric water vapor. AMSU instruments will provide the capability for remote sensing of atmospheric and surface properties on a global basis, as well as improving the detection of precipitation and surface features such as ice and snow cover.
- Solar Backscatter-Ultraviolet Spectral Radiometer (SBUV): The SBUV provides estimates of the global ozone distribution by measuring back-scattered solar radiation in the ultraviolet Hartley-Huggins bands.
- Space Environment Monitor (SEM): The 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.
- Search and Rescue Satellite Aided Tracking System (SARSAT): The SARSAT receives distress signals from emergency beacons on international distress frequencies and retransmits them to local user terminals for action by appropriate government agencies.
- Advanced Data Collection System (A-DCS): The A-DCS (ARGOS) relays meteorological and other data transmitted from in-situ ground-based data collection platforms, including buoys, free floating balloons, and remote weather stations.

3. FUTURE PROGRAM PLANS

3.1 Follow-on POES Satellites

Instrument changes for NOAA-N and -N' include the HIRS/4 which provides 10 km field of view versus 20 km on the previous model, and the Microwave Humidity Sounder, provided by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), which will replace the AMSU-B.

NOAA-N, now designated NOAA-18, was successfully launched on May 20, 2005 into an afternoon orbit (i.e., 1400 Local Solar Time (LST) equatorial crossing time, ascending). NOAA-M, now designated NOAA-17, was successfully launched in June 2002 into a mid-morning orbit (i.e., 1000 LST equatorial crossing time, descending). The planning launch date for the remaining satellites in this series is:

NOAA-N’ 2007

NOAA will launch these satellites into afternoon polar orbits. European polar-orbiting satellites, as described below, will provide the data stream in the morning orbit.

On September 6, 2003, the NOAA-N’ spacecraft was involved in a serious accident at he spacecraft contractor’s plant. After many months of technical and programmatic assessments of the N’ damage and deliberations on alternatives to rebuilding or replacing this satellite, NOAA directed NASA to rebuild NOAA-N.’ On September 29, 2004, NASA modified the contract with the spacecraft contractor to rebuild NOAA-N’ with a scheduled launch date not later than December 31, 2007.

To provide the latest information on the specifics of these changes, NOAA has prepared a user guide for the new POES satellites. This information is available on the Internet at the following URL: http://www2.ncdc.noaa.gov/docs/klm/index.htm.

3.2 International Program Cooperation

In the 1980s, NOAA needed to balance the high cost of space systems and the growing need to provide a complete and accurate description of the atmosphere at regular intervals as input to numerical weather prediction and climate monitoring support systems. This led NOAA to enter into discussions and agreements at the international level with the European Organisation for the Exploitation of Meteorological Satellites. The goal of this cooperation is to provide continuity of measurements from operational satellites in polar orbits, cost sharing, and improved forecast and monitoring capabilities through the introduction of new technologies.

Building upon the POES program, an agreement is in place between NOAA and EUMETSAT on the Initial Joint Polar-orbiting Operational Satellite System (IJPS). This program will include two series of independent but fully coordinated NOAA and EUMETSAT satellites, exchange of instruments and global data, cooperation in algorithm development, and plans for real-time direct broadcast. Under terms of the IJPS agreement, NOAA will provide NOAA-N and NOAA-N’ satellites for flight in the afternoon orbit and EUMETSAT will provide Metop-1 and Metop-2 satellites for flight in the mid-morning orbit. These satellites will carry a common core of instruments that includes the AVHRR/3, HIRS/4, AMSU-A, A-DCS, SARSAT, SEM, and the Microwave Humidity Sounder (MHS). In addition, NOAA will fly a SBUV instrument on its satellites, while EUMETSAT’s additional payloads will include an infrared interferometer sounder, a scatterometer, an ozone instrument, and a Global Positioning System (GPS) occultation sounder.

Coordination on associated ground segments is also included in this agreement, which ensures the sharing of all mission data, blind-orbit data capture support, and telecommunications paths through each other's ground stations for back-up command and control functions. The first Metop satellite is currently planned for launch in 2006.

3.3 National Polar-orbiting Operational Environmental Satellite System

3.3.1 Introduction

Over the last nine years, the U.S. government has been merging the Nation's military and civil operational meteorological satellite programs into a single, integrated, end-to-end satellite system capable of satisfying both civil and national security requirements for space-based remotely sensed environmental data. The joint program formed in 1994 by a Presidential Decision Directive is the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The NPOESS program is expected to save $1.6 billion in acquisition and operational costs through the System Life Cycle of the program compared to the costs of continuing the previously planned upgrades to the separate DMSP and POES satellite systems within the Department of Defense (DoD) and NOAA.

Once operational later this decade, NPOESS will replace the current POES and DMSP systems, each with over a 40-year heritage of successful service. The POES and DMSP spacecraft have revolutionized the way in which we observe and predict the weather. With the development of NPOESS, we are evolving the existing "weather" satellites into an integrated environmental observing system by expanding our capabilities to observe, assess, and predict the total Earth system – ocean, atmosphere, land, and the space environment. Data from the advanced NPOESS sensors will enable more accurate short-term "nowcasts" and forecasts as well as serve data continuity requirements for improved global climate change assessment and prediction.

In October 1994, NOAA, DoD, and the National Aeronautics and Space Administration (NASA) created an Integrated Program Office (IPO), organizationally within NOAA, to develop, manage, acquire, and operate NPOESS. NOAA has overall responsibility for the converged system and is also responsible for satellite operations. NOAA is also the primary interface with the international and civil user communities. DoD is responsible for supporting the IPO for major systems acquisitions, including launch support. NASA has a primary responsibility for facilitating the development and incorporation of new cost effective technologies into the converged system.

The NPOESS development and acquisition plan is designed to make best use of production and existing POES and DMSP assets, to reduce risk on critical sensor payloads and algorithms, and to leverage civil, governmental, and international payload and spacecraft developments. The planned evolution from the current POES and DMSP programs to NPOESS will take place over the next six to ten years. Currently the U.S. is operating two primary POES and two primary DMSP satellites. With the planned launch in 2005 of EUMETSAT's first polar-orbiting Metop satellite, there will be one POES, one Metop, and two DMSP satellites in four orbital planes. The first launch of an NPOESS spacecraft is planned for November 2009 to begin replacing the last of the current POES and DMSP satellites. When NPOESS reaches full operational capability in 2013, spacecraft in all three orbital planes will provide global coverage with a data refresh rate of approximately four hours for most observations.

3.3.2 Requirements

The tri-agencies partners in the NPOESS program have agreed upon a fully defined set of integrated operational requirements that will meet the needs of the U.S. civil and military users for operational satellite data in the next decade. The military and civilian user communities jointly defined Environmental Data Records (EDRs), as well as the required performance characteristics for each of these data products. The established requirements for 55 (including active fires) atmospheric, oceanic, terrestrial, climatic, and solar-geophysical parameters are guiding the development of advanced technology visible, infrared, and microwave imagers and sounders that will provide enhanced capabilities to users and improve the accuracy and timeliness of observations. The data for the 55 NPOESS Environmental Data Records that will be collected by the NPOESS suite of instruments fully encompass the Earth science disciplines. The technical requirements for the complete set of 55 EDRs are fully described in the NPOESS Integrated Operational Requirements Document-II, dated 10 December 2001, that is available on-line at: **http://npoesslib.ipo.noaa.gov/Req_Doc/IORDII_011402.pdf**. When operational, NPOESS will truly be an “environmental observing system,” not just an advanced “weather” satellite.

Performance characteristics for each of the 55 EDRs were defined and bounded between threshold values that represent minimally acceptable performance for an attribute and objective levels that represent performance that would have significant added value to users. In many cases, threshold values were set to meet or exceed what can be achieved from instruments on current operational satellites (i.e., POES and DMSP). The specific attributes include horizontal (vertical) resolution, mapping accuracy, measurement range, measurement precision, measurement uncertainty, refresh rate, data latency, and geographic coverage. Long-term stability requirements have also been established for key parameters (e.g., atmospheric vertical temperature, sea surface temperature, sea surface winds) to ensure temporal consistency and continuity of data over the life of NPOESS that will support improved global climate change assessment and prediction. These stability requirements have necessarily influenced the design and performance of the advanced technology sensors that are being built for NPOESS, and are guiding the development of the calibration/validation activities that will extend throughout the life of the NPOESS program.

3.3.3 Instruments and System Development

In 1997, the IPO initiated a robust sensor risk reduction effort that was focused on early development of the critical sensor suites and algorithms necessary to support NPOESS. In August 2001, preliminary design efforts were completed for the last of five critical imaging/sounding instruments for NPOESS. Final design, prototype development, and fabrication of these instruments have begun, with delivery of the first flight units for four sensors scheduled for 2005. In 2000, the IPO initiated a program definition and risk reduction program to define the requirements for the NPOESS total system architecture, including space, ground processing, and command, control, and communications components, as well as to develop specifications for sensor/spacecraft integration. This phase of the early development program was concluded in August 2002 with the award of a single prime contract for Shared System Performance Responsibility to Northrop Grumman Space Technology (NGST) to accomplish the Acquisition and Operations (A&O) of NPOESS.

During A&O, the NGST, with its teammate Raytheon, will manage completion of development of the NPOESS sensor payloads; provide two satellite sensors and integration support to the joint IPO/NASA NPOESS Preparatory Project (NPP) mission; develop, deliver and support the Command, Control and Communication (C^3) and Interface Data Processing (IDP) segments; develop, integrate, and deploy the NPOESS space segment; integrate the NPOESS space segment with the launch support segment; develop and deploy the NPOESS support system; develop, deploy and support the software portion of the NPOESS field terminals; conduct a progressive integration, test and acceptance program; and operate and maintain NPOESS through Initial Operational Capability, including on-going calibration and validation activities. During the later Production phase, NGST will integrate and deploy additional satellites as needed through the program life. Northrop Grumman Space Technology will have responsibility for integrating, deploying, and operating NPOESS satellites in three orbital planes (1330, 1730, and 2130 LST equatorial ascending nodal crossing times) to meet the tri-agency requirements for NPOESS over the 10-year operational life of the program (2009-2019).

The operational weather forecasting and climate science communities have levied more rigorous requirements on space-based observations of the Earth's system. These requirements have significantly increased demands on performance of the instruments, spacecraft, and ground systems required to deliver NPOESS data, products, and information to end users. NPOESS instruments will observe significantly more phenomena simultaneously from space than its POES and DMSP predecessors. NPOESS will deliver more accurate measurements at higher spatial (horizontal and vertical) and temporal resolution to support operations and research. User demands for more real-time data from NPOESS are driving the space and ground-based architectures for data routing and retrieval that will dramatically shorten data latency (time from observation by the satellite to availability of processed EDRs). NPOESS will deliver data from its advanced technology visible, infrared, and microwave imagers and sounders at higher data rates with more frequent space-to-ground data communications. Most of the NPOESS sensors are considerably more complex and have data rates that are two orders of magnitude greater than the instruments carried on either DMSP or POES.

To support the converged civil and military requirements for space-based, remotely sensed environmental data, the NPOESS spacecraft (depending upon orbit) will carry the following sensor payloads:

- <u>Visible/Infrared Imager Radiometer Suite (VIIRS):</u> The VIIRS will combine the radiometric accuracy of the AVHRR/3 currently flown on the NOAA polar-orbiters with the high (0.65 km) spatial resolution of the Operational Linescan System flown on DMSP spacecraft. The VIIRS will have 22 channels grouped into the panchromatic day/night band, visible and near-infrared (IR), short and mid-wave IR, and long-wave IR, with additional spectral capabilities that can be used to determine ocean color. VIIRS spectral bands are characterized as either fine resolution or moderate resolution. Fine resolution bands will have horizontal sampling intervals (HSIs) of about 400 m to 800 m across the ~3000 km swath and moderate resolution bands will have HSIs of twice this size. VIIRS will provide measurements of sea surface temperature, atmospheric aerosols, snow cover, cloud cover, surface albedo, vegetation index, sea ice, and ocean color. VIIRS is expected to perform similarly to MODIS on NASA's Earth Observing System (EOS) Terra and Aqua missions in many of the spectral bands. VIIRS represents a significant step in transforming NASA's state-of-the-art research sensors into operational sensors to meet the needs of both the operational and research communities.

- Cross-track Infrared Sounder (CrIS): The CrIS is a Fourier Transform Spectrometer that uses a Michelson interferometeric sounder capable of sensing upwelling infrared radiances from 3 to 16 μm at very high spectral resolution (~1300 spectral channels) to determine the vertical atmospheric distribution of temperature, moisture, and pressure from the surface to the top of the atmosphere. The CrIS uses an array of 9 Fields of View (FOV), each 14 km in diameter and each spanning 3 IR bands. CrIS will provide data across a 2200 km swath that will be combined with data from passive microwave instruments to construct atmospheric temperature profiles at 1° K accuracy for 1 km layers in the troposphere and moisture profiles accurate to 15 percent for 2 km layers.
- Advanced Technology Microwave Sounder (ATMS): The ATMS is the next generation cross-track microwave sounder that will combine the capabilities of current generation microwave temperature sounders (AMSU-A) and microwave humidity sounders (AMSU-B/MHS/Humidity Sounder for Brazil (HSB)) that are flying or will be flown on NOAA's POES, NASA's EOS Aqua, and EUMETSAT's Metop spacecraft. The ATMS draws its heritage directly from AMSU-A/B, but with reduced volume, mass, and power. The ATMS has 22 microwave channels to provide temperature and moisture sounding capability in the 23/31, 50, 89,150, and 183 GHz spectral range.
- Conical-scanning Microwave Imager/Sounder (CMIS): The CMIS will combine the microwave imaging capabilities of Japan's Advanced Microwave Scanning Radiometer (AMSR) on NASA's EOS Aqua mission and the atmospheric sounding capabilities of the Special Sensor Microwave Imager/ Sounder (SSMI/S) on the remaining series of DMSP satellites, the first of which (DMSP F-16) was launched on 18 October 2003, with the polarimetric capabilities of the WindSat sensor on the Coriolis mission that was launched in January 2003. The CMIS uses a dual-primary rotating reflector with an aperture of ~2.2 m to make "all-weather" measurements across a large frequency range of 6 to 190 GHz. Polarization for selected imaging channels will be used to derive ocean surface wind vectors similar to what has previously been achieved with active scatterometers. CMIS data will be used to derive a variety of parameters, including all-weather sea surface temperature, surface wetness, precipitation, cloud liquid water, cloud base height, snow water equivalent, surface winds, atmospheric vertical moisture profile, and atmospheric vertical temperature profile.
- Ozone Mapping and Profiler Suite (OMPS): The OMPS will consist of a nadir scanning ozone mapper similar in functionality to NASA's Total Ozone Mapping Spectrometer (TOMS) and a limb scanning radiometer that will be able to provide ozone profiles with a vertical resolution of 3 km as compared to the present 7 to 10 km for the SBUV on POES.
- Global Positioning System Occultation Sensor (GPSOS): The GPSOS will be used operationally to make primary measurements of electron density and profiles in the ionosphere and secondary measurements of tropospheric temperature and humidity profiles.
- Space Environment Sensor Suite (SESS): SESS is the complement of sensors and algorithms used to measure the characteristics of: auroral boundary, auroral energy

deposition, auroral imagery, electric field, electron density profile, geomagnetic field, *in situ* plasma fluctuations, *in situ* plasma temperatures, ionospheric scintillation, neutral density profile, medium energy charged particles, energetic ions, and supra-thermal to auroral energy particles. The SESS will provide information about the space environment necessary to ensure reliable operations of current space-based and ground-based systems, to facilitate the analysis of system anomalies that are the result of space environmental effects, and to guide the design and efficient operations of future systems that may be affected by the space environment.

- Aerosol Polarimetry Sensor (APS): The APS will measure along-track scene intensity as a function of wavelength and polarization to determine aerosol optical thickness, aerosol particle size, cloud particle size distribution, aerosol refractive index, and single scattering albedo and shape. The aerosol polarimeter will work in conjunction with and complement the VIIRS measurements of atmospheric aerosols.
- Earth Radiation Budget Sensor (ERBS): ERBS will provide data on the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface. The ERBS draws its heritage directly from NASA's Earth Radiation Budget Experiment (ERBE) instruments that were flown on NOAA-9 and NOAA-10 and from the Clouds and the Earth's Radiant Energy System (CERES) that is currently flying on NASA's Tropical Rainfall Measuring Mission (TRMM) that was launched in November 1997 and on the EOS Aqua mission that was launched in May 2002. NGST will procure ERBS as a leveraged payload for flight on the NPOESS spacecraft.
- Total Solar Irradiance Sensor (TSIS): The TSIS will measure variability in the sun's solar output, including total solar irradiance in the 200 to 300 nm and 1500 nm spectral ranges. The IPO currently plans to fly copies of the Total Irradiance Monitor (TIM) and Solar Irradiance Monitor (SIM), being developed for NASA by the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP). The two instruments together, termed TSIS, will be acquired by NGST as a leveraged payload for flight on the NPOESS spacecraft.
- Radar Altimeter (ALT): The IPO is planning to fly a dual frequency radar altimeter on the early-morning (0530 LST equatorial descending nodal crossing time) NPOESS satellite. The altimeter will measure sea surface topography, significant wave height, and wind speed. Altimetry measurements will be used to derive ocean circulation parameters to satisfy monitoring requirements for both operations and research purposes. The altimeter will be acquired as a leveraged payload for flight on the NPOESS spacecraft. We recognize that the near-polar, sun-synchronous orbit of the NPOESS spacecraft will not be ideal for replicating the series of long-term measurements of global and regional mean sea level change that have been initiated with the TOPEX/Poseidon and Jason missions. However, we do expect to be able to meet operational requirements for mapping mesoscale ocean variability. We are also working with our NOAA, NASA, and international partners to define a future constellation of altimeters to meet both real-time operational and long-term research requirements for measuring sea surface height.
- Search and Rescue Satellite Aided Tracking System (SARSAT): The SARSAT receives distress signals from emergency position indicating radio beacons (EPIRBs) on international distress frequencies and retransmits them to local user terminals for action by appropriate government agencies. The redesigned SARSAT subsystems on NPOESS will only support EPIRBs transmitting at 406 MHz.

- Advanced Data Collection System (A-DCS): The A-DCS (ARGOS) relays meteorological and other data transmitted from *in-situ* ground-based data collection platforms including buoys, free floating balloons, and remote weather stations. NPOESS will carry the upgraded ARGOS-3/4 data collection system that will provide two-way messaging capabilities for users to command and manage platform transmitters and sensors, as well as receive data efficiently from their platforms.

Fault tolerant designs for each of the instrument payloads will enable long mission life (up to 8 years storage and 7 years operation) to ensure mean mission durations exceeding five years for each of the NPOESS spacecraft over the operational life of the program (2009-2019).

Because the user-specified requirements for data refresh are different for the 55 environmental parameters, not all instrument payloads are required in each orbit. In addition, certain orbital characteristics (e.g., the terminator orbit is not conducive to certain measurements), as well as considerations of instrument field of view on the spacecraft have determined the payload configurations for each orbit. Data from multiple instruments will be required to derive certain parameters. In particular, "all-weather" requirements for selected EDRs will be met by combining near-simultaneous infrared (from VIIRS) and microwave (from CMIS) measurements to derive global and regional products (e.g., SST). The current orbit manifest for the NPOESS sensor payloads is as follows:

0530 (D)	0930 (D)	1330 (A)
VIIRS	VIIRS	VIIRS
CrIS		CrIS
ATMS		ATMS
CMIS	CMIS	CMIS
		OMPS
		GPSOS
TSIS		SESS
ALT	APS	ERBS
SARSAT	SARSAT	SARSAT
A-DCS		A-DCS

As a result of ongoing discussions between the USA and EUMETSAT, the CrIS and ATMS instruments that were manifested for the 0930 (descending) orbit (as originally proposed by NGST to meet U.S. user requirements for temperature and moisture sounding data in that orbit) have been shifted to the 0530 (descending) orbit. Instead, the USA (IPO) will rely on data from the Infrared Atmospheric Sounding Interferometer (IASI) and MHS on EUMETSAT's Metop satellite in the 0930 orbit to meet the requirements for temperature and moisture sounding data in this orbit.

3.3.4 Early System Testing

Early flight-testing of instruments is a critical part of the NPOESS program to reduce development risk and to demonstrate and validate global imaging and sounding instruments, algorithms, and pre-operational ground processing and distribution systems prior to the first NPOESS launch in late 2009. The joint DoD/IPO Coriolis/WindSat mission was launched in January 2003 to provide a space-based test and demonstration of passive microwave polarimetric techniques to derive measurements of ocean surface wind speed and direction. Preliminary results from the first ten months of on-orbit operations of WindSat have demonstrated excellent radiometric functionality and improved spatial resolution over the Special Sensor Microwave Imager (SSM/I) on DMSP. Recent test images produced for the complete Stokes Vector from the vertically, horizontally, and circularly polarized data demonstrate that space-based passive polarimetry will measure wind direction successfully. This planned three-year mission continues the development of improved microwave measurement capabilities from the Special Sensor Microwave Imager and Sounder (SSMI/S) on the remaining DMSP spacecraft**,** the first of which (DMSP F-16) was launched on 18 October 2003, to CMIS on NPOESS.

The joint IPO/NASA NPOESS Preparatory Project (NPP), that will be launched in October 2006, will carry four of the critical NPOESS sensors (VIIRS, CrIS, OMPS, and the NASA-developed ATMS) to provide on-orbit testing and validation of sensors, algorithms, and ground-based operations and data processing systems while the current operational POES and DMSP and the NASA EOS research satellite systems are still in place. Although NPP will be launched after the expected lifetime of NASA's Terra mission (December 2005), it will be in orbit well in advance of the expected lifetimes of Aqua (April 2008) and Aura (January 2010). In addition to ATMS, NASA is providing the NPP spacecraft that is being built by Ball Aerospace and Technologies Corporation, as well as the launch vehicle. The IPO is responsible for the VIIRS, CrIS, and OMPS instruments, NPP spacecraft operations, and ground processing systems.

The IPO, in cooperation with the Norwegian Space Centre (NSC) has installed a 13-meter antenna at Svalbard, Norway as the primary data downlink site for global stored mission data from NPP. Global stored mission data from NPP will be broadcast at X-band frequencies (8212.5 MHz) using a bandwidth of 375 MHz at a data rate of 300 Mbps. In addition to the stored data, NPP will broadcast real-time data at X-band frequencies (in the 7750-7850 MHz band using a carrier frequency of 7812 MHZ at a data rate of 15 Mbps) to users equipped with appropriate field terminals. The Svalbard site will be ready for NPP ground system readiness in December 2004. The IPO and NSC signed a cooperative agreement in April 2003 to install two fiber-optic cables from Norway to Svalbard. This fiber-optic link that is now in place will serve as the primary data routing path for NPP. Subsequent to the NPP mission, the Svalbard site and the high-speed fiber-optic link will serve as a primary site for NPOESS telemetry and command and as one node in a globally-distributed ground data communications system for NPOESS.

The NPP mission will provide operational agencies early access to the next generation of operational sensors, thereby greatly reducing the risks incurred during the transition from POES and DMSP to NPOESS. Early system-level integration and testing will provide "lessons learned" and allow for any required modifications in time to support readiness for the first NPOESS launch. Development risk for the NPOESS ground system is being reduced through early delivery and testing of the NPP ground system (a subset of the NPOESS architecture). Extensive pre-launch and on-orbit calibration and validation of instruments on NPP and early user evaluation of NPOESS data products will allow for modifications to algorithms prior to the first NPOESS launch in 2009. NPP will demonstrate the utility of the improved imaging and radiometric data in short-term weather “nowcasting” and forecasting and in other oceanic and terrestrial applications, such as harmful algal blooms, volcanic ash, and wildfire detection.

In addition to serving as a valuable risk reduction and prototyping mission for the IPO and users of NPOESS data, NPP will provide continuity of the calibrated, validated, and geo-located NASA EOS Terra and Aqua systematic global imaging and sounding observations for NASA Earth Science research. With a five-year design lifetime, NPP will provide a “bridge” from NASA’s EOS research missions (Terra, Aqua, and Aura) to the operational NPOESS mission. NPP will extend the series of key measurements in support of long-term monitoring of climate change and of global biological productivity.

3.3.5 Operations

The current operational concept for NPOESS consists of a constellation of spacecraft flying at an altitude of 833 km in three sun-synchronous (98.7 degree inclination) orbital planes with equatorial ascending nodal crossing times of 1330, 1730, and 2130 local solar time, respectively. NPOESS spacecraft are being designed for precise orbit control to maintain altitude, nodal crossing times to within +10 minutes throughout the mission lifetime, and repeat ground tracks to +1 km (repeat cycles of ~17 days) for certain measurements (e.g., sea surface height). The afternoon (1330 ascending) spacecraft will carry a full complement of instruments. The early-morning (0530 descending) and mid-morning (0930 descending) NPOESS spacecraft will carry reduced complements of instruments, including VIIRS and CMIS that are required to meet the stringent U.S. horizontal resolution and data refresh (four hours) requirements for “all-weather” imaging (visible/infrared and microwave) and ocean surface wind field mapping in these orbits.

The planning launch dates for the NPOESS series of spacecraft are as follows:

NPOESS-C1	November	2009	0930 (D)
NPOESS-C2	June	2011	1330 (A)
NPOESS-C3	June	2013	0530 (D)
NPOESS-C4	November	2015	0930 (D)
NPOESS-C5	January	2018	1330 (A)
NPOESS-C6		~2019	0530 (D)

The IPO plans to continue cooperation with EUMETSAT for a Joint Polar System (JPS). During the transition to a future international polar satellite program, an NPOESS spacecraft and EUMETSAT’s Metop-3 satellite will occupy the mid-morning orbit (0930) and provide complementary data from the advanced sounding and imaging instruments on each satellite. Use of data from EUMETSAT’s Metop satellite will increase the global coverage and refresh rate of the U.S. polar satellite system. In addition, the European meteorological community will receive valuable data from instruments on both the Metop and NPOESS series of satellites. Shared operation of NPOESS ground systems at the NSC Svalbard site with EUMETSAT is also under consideration.

3.3.6 Ground Systems

<u>Global Data</u>

To meet U.S. user-validated requirements for 55 geophysical parameters, including specific DoD and NOAA user requirements for data latency, the NPOESS C^3 segment will deliver global Stored Mission Data (SMD) to four U.S. Operational Processing Centers (Centrals) for processing and distribution. These Centrals are: NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) and National Centers for Environmental Prediction (NCEP); the Air Force Weather Agency (AFWA); Fleet Numerical Meteorology and Oceanography Center (FNMOC); and the Naval Oceanographic Office (NAVOCEANO). Global SMD will be down-linked to 15 globally-distributed, low-cost, unmanned ground stations at Ka-band frequencies (25500-27000 MHz with a carrier frequency of 25.65 GHz, using a bandwidth of 300 MHz, transmitting at a data rate of 150 Mbps) that will be tied to Centrals via commercial fiber-optic networks. This innovative NGST/Raytheon SafetyNet (patent pending) ground system will deliver 75% of the SMD (daily average) to Centrals within 15 minutes and 95% of the data (daily average) within 26 minutes from the time of on-orbit collection. SMD will be the complete, full resolution data set containing all sensor data and auxiliary data necessary to generate all NPOESS Environmental Data Records (EDRs) at the Centrals. Each Central will be equipped with an IDP segment consisting of the necessary data ingest and computational hardware/software to process NPOESS Raw Data Records (RDR) into EDRs, using auxiliary and ancillary data as necessary. Intermediate-level satellite instrument Sensor Data Records (SDRs) will be produced as RDRs are processed into EDRs. The SDRs contain the counts and calibration data at geo-located points. RDRs will also be provided by the IDP for archive and validation purposes. These data products will be available through the Centrals' IDP as retrievable data records.

NPOESS data, including RDRs, SDRs, EDRs, stored raw mission data, stored and real-time telemetry, and stored data from the A-DCS, will be distributed through the data routing and retrieval component of the NPOESS C^3 segment to the four U.S. Centrals and to the two NPOESS mission management/control centers. The primary NPOESS Mission Management Center (MMC) will be located at the NOAA Satellite Operations Facility in Suitland, Maryland. An alternate MMC will be located at Schriever Air Force Base, Colorado. The Centrals' IDP will provide sufficient temporary storage capacity (i.e., storage capacity for multiple passes – minimum of 24 hour storage) to store the RDRs/SDRs/EDRs and ancillary data for immediate use in the Centrals' higher-level product applications. NOAA's NESDIS will maintain the long-term archive of NPOESS data. NESDIS will also be responsible for providing the worldwide user community access to near real-time processed NPOESS data and higher-level products via the NESDIS Central Environmental Satellite Computer System (CEMSCS) servers, as well as access to archived NPOESS data via other distributed servers at the three NESDIS Data Centers.

Direct Broadcast Services

In addition to the space-to-ground transmission of SMD, NPOESS will simultaneously broadcast two continuous real-time data streams, at high and low rates, to suitably equipped field terminals worldwide. These direct broadcast/real-time field terminals will be capable of processing NPOESS RDRs into EDRs by using IDP software appropriate for the type of field terminal. NGST is developing the IDP software that will run on the high-end computer systems at each of the Centrals, as well as the scalable IDP software that will run on the field terminals, including commercial-off-the-shelf systems. The IPO will distribute the nonproprietary IDP field terminal software, software changes, and program updates to field terminal users worldwide.

The NPOESS High Rate Data (HRD) broadcast will be a complete, full resolution data set containing all sensor data and auxiliary/ancillary data necessary to generate all NPOESS EDRs (except some Earth Radiation EDRs) and is intended to support users at fixed, regional hubs. The HRD broadcast will be transmitted at X-band frequencies in the 7750-7850 MHz band (carrier frequencies of 7812 MHZ and 7830 MHZ), at a data rate of 20 Mbps, and will require a bandwidth of 30.8 MHz, with a tracking, receive antenna aperture not to exceed 2.0 meters in diameter.

The NPOESS Low Rate Data (LRD) broadcast will be a subset of the full NPOESS sensor data set and is intended for U.S. and worldwide users of field terminals (land and ship-based, fixed and mobile environmental data receivers operated by DoD users and surface receivers operated by other U.S. government agencies, worldwide weather services, and other international users). Some data compression (lossy or lossless) may be employed for the LRD link. The LRD L-band broadcast will provide data at a rate of about 4.0 Mbps (nominally 3.88 Mbps) at 1706 MHz, using a bandwidth of 8 MHz, with full Consultative Committee for Space Data Systems (CCSDS) convolutional coding, Viterbi decoding, and Reed Solomon encoding/decoding into a tracking receive antenna aperture not to exceed 1.0 meter diameter. The LRD parameters (frequency, bandwidth, data rate, and data content) have been selected to satisfy U.S. requirements for low-rate, real-time direct broadcast, as well as be closely compatible with (but not identical to) the broadcast parameters for the Advanced High Resolution Picture Transmission (AHRPT) format that has been accepted and approved by the Coordinating Group on Meteorological Satellites (CGMS) and will be used on the EUMETSAT Metop spacecraft. The LRD broadcast will include data required to satisfy the U.S. user-specified, eight highest priority EDRs for real-time broadcast: imagery (from VIIRS) at 800 m HSI from at least one visible and one infrared channel and nighttime imagery at 2.7 km HSI from the day/night band; atmospheric vertical temperature and moisture profiles (from CrIS, ATMS, and CMIS); global sea surface winds (from CMIS); cloud base height, cloud cover/layers; pressure (surface/profile), and sea surface temperature. Fifteen additional lower priority EDRs will also be included in the LRD broadcast. Future communications capabilities (e.g., rebroadcast of processed imagery/data and delivery via the Internet or “commercial” services) may allow other-than-direct satellite-to-ground data transmission to follow-on field terminal systems.

Data Availability

Data from NPOESS satellites will be provided to users in accordance with U.S. policy, as reflected in the guiding principles of the 1994 Presidential Decision Directive (PDD) that created NPOESS. NPOESS will assure access to operational environmental data to meet civil and national security requirements and international obligations. The PDD also directs that, “The United States will ensure its ability to selectively deny critical environmental data to an adversary during crisis or war yet ensure the use of such data by [the] U.S. and [its Allies].”

NPOESS data will be broadcast without encryption during normal operations for access by Centrals and field terminal users worldwide. The international community will have free and open access to all data from NPOESS satellites. All users will be able to acquire the data and will not need any additional decryption equipment to receive and process data in real-time via the direct broadcast services.

However, to meet U.S. policy requirements for selective data denial, NPOESS will be capable of encrypting selected mission data in all satellite links, excluding the SARSAT and A-DCS real-time downlinks. If the IPO is directed to implement selective data denial, NPOESS will be switched to a Selective Data Encryption (SDE) mode. NPOESS encryption commanding will be selectable by: downlink (HRD, LRD, SMD); area (global or specific geographic regions); instrument suite or mission data type; and ground facility or end user identifier. During SDE, authorized users of registered real-time field terminals in the U.S. and international communities will have the capability to automatically decrypt the NPOESS data downlinks using Advance Encryption Standard (AES) decryption equipment in the field terminal systems. The IPO is responsible for authorizing, registering, and controlling decryption keys for all field terminals and will provide the necessary decryption software and keys to authorized/registered users. Field terminals that are not registered and authorized by the IPO will not be able to decrypt and process NPOESS data until the system is switched back to normal operations. While NPOESS is in the SDE mode, Centrals will continue to receive and process NPOESS global SMD that will be available to the worldwide user community in non-real-time.

4. SUMMARY

Plans and programs are in place to provide continuous polar-orbiting satellite coverage well into the 21st century. In the near-term, key milestones highlight the significant progress that has been made towards implementing these plans: the successful launches of NOAA-N (NOAA-18) in 2005, the decision to rebuild NOAA-N'; continued development and production of the Metop spacecraft and ground systems in preparation for launch in 2006; and the completion of the NPOESS concept definition phase with the award of the NPOESS Acquisition and Operations contract in 2002. The IPO, in cooperation with the POES and DMSP program offices, is also studying additional potential cost effective approaches to maximize user satisfaction during the transition to NPOESS, while guaranteeing continued uninterrupted satellite data services. For example, the new antenna at the NSC Svalbard site could be used to support POES, thereby eliminating the blind orbits in the existing POES ground system. The advanced technology visible, infrared, and microwave imagers and sounders that will fly on NPOESS will deliver higher spatial and temporal resolution oceanic, atmospheric, terrestrial, climatic, and solar-geophysical data, enabling more accurate short-term weather forecasts and severe storm warnings. The improved accuracy in atmospheric temperature and humidity soundings from these instruments, in combination with other observations expected to become available over the next ten years, will enable the current 3- to 5-day short-term weather forecasts to be improved from 70 to 80 percent to better than 90 percent and to be extended to 5 to 7 days with 80-percent accuracy. NPOESS will help us "take the pulse of Planet Earth" by providing continuity of critical data for monitoring, understanding, and predicting climate change and assessing the impacts of climate change on seasonal and longer time scales. These activities represent a sound beginning for achieving the planned national and international operational satellite programs that will ensure continuous support to a variety of users well into the 21st century.