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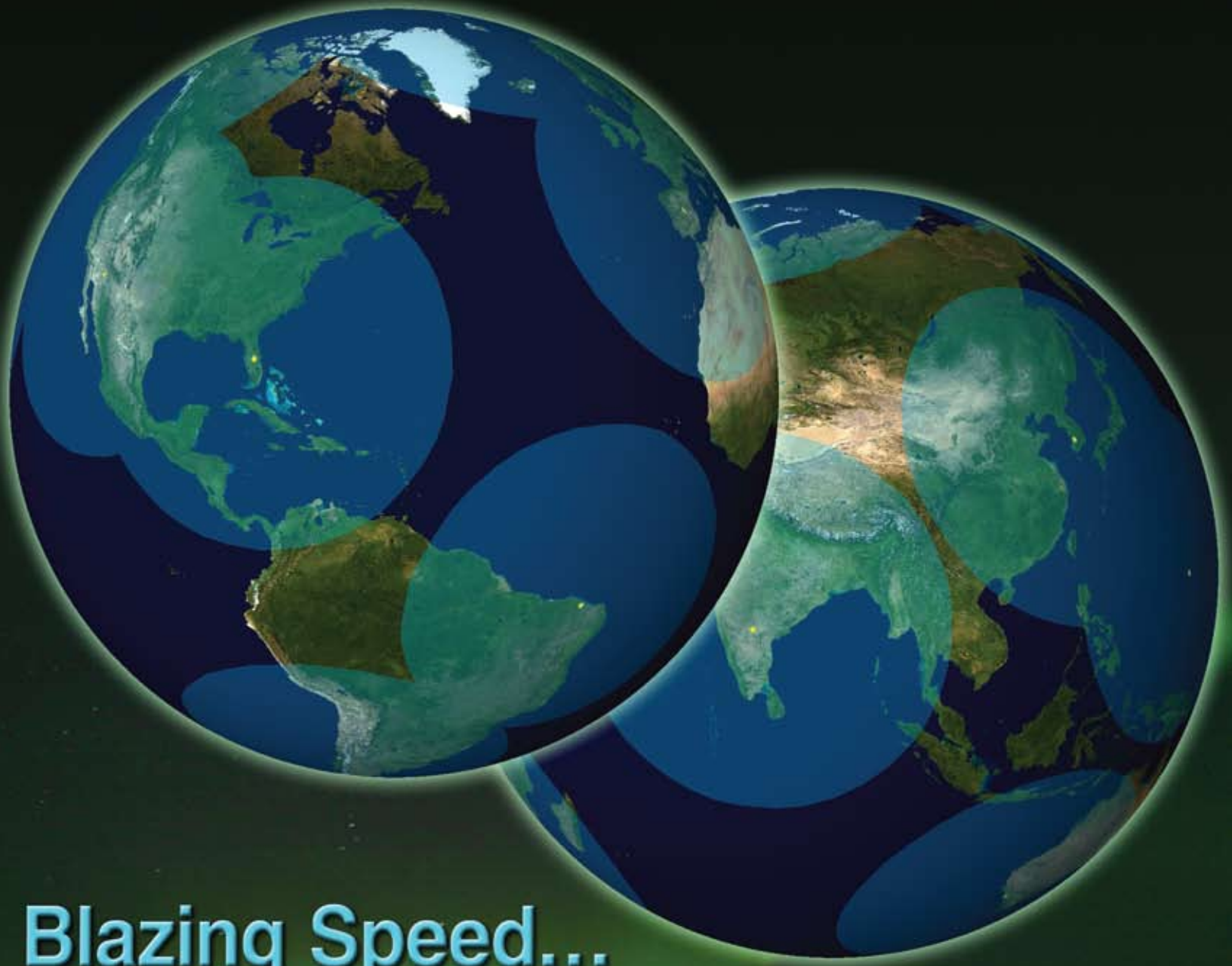

Blazing Speed... The NPOESS Ground System

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Speed Equals Efficiency

Delivering NPOESS Data on the Ground for Better Weather and Climate Forecasts and Environmental Monitoring

Dave Jones

How in the world can a satellite orbiting the Earth at more than 17,000 mph collect critical weather, climate, and environmental data from an altitude of 828 kilometers (514 miles) and deliver 95 percent of that data back to computers on the ground within 28 minutes of acquisition? It is an incredible feat that will be accomplished by a dedicated team of government and industry professionals involved with the Ground System for the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

Many talented scientists and engineers – *right now* – are hard at work building NPOESS, the most sophisticated Earth observing system in history. The tri-agency Integrated Program Office (IPO), comprised of the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD), and the National Aeronautics and Space Administration (NASA), is managing the development of NPOESS. NPOESS will replace heritage NOAA and DoD polar-orbiting operational environmental satellites that have provided successful service to the Nation for over 45 years. Northrop Grumman Space Technology (NGST) is the prime contractor responsible to the IPO for overall NPOESS system design and development, system engineering and integration, instrument acquisition, spacecraft assembly, and testing. When it comes to delivering the robust and speedy ground system needed to receive and deliver NPOESS data for processing into weather, climate, and environmental forecast models, Raytheon Intelligence and Information Systems, NGST's largest subcontractor and principal teammate, is providing the full NPOESS ground capability, from design and development through initial operations.

Weather information is essential for planning anything from an outdoor event to a military operation combating the war on terrorism. According to Brigadier General David L. Johnson, USAF (Retired), the U.S. Air Force Director of Weather from 2000 to 2003, input from the Combat Weather Team is a vital part of the mission planning process. "In the first three months of [the war on terrorism]," Johnson said, "15 percent of the targets ... and 30 percent of the weapons were changed as a result of what the weatherman said."

One of the fascinating designs of the NPOESS Ground System is just how many locations around the world will be used to collect data from NPOESS spacecraft in two different, sun-synchronous polar orbits (1330 local time ascending node, (LTAN) and 1730 LTAN). One of the key components to this innovative ground data collection system is called SafetyNet™ and will consist of 15 dedicated, unmanned, receive-only receptor sites, each with its own 4.06 meter diameter satellite dish and Ka-band (~26.7 GHz) communications equipment. The receptor sites will be connected through the AT&T world-wide, high-speed, highly-reliable commercial fiber optic communications network that will enable 95 percent of NPOESS data to be delivered and processed into Environmental Data Records (EDRs) at four U.S. data processing centers (Centrals) within 28 minutes of on-orbit measurement. This is approximately four times faster than the delivery rate of today's data links. The SafetyNet™ system can also be leveraged to accommodate other future satellite missions.

The four U.S. weather data-processing Centrals that will interface with and host the equipment for the NPOESS Interface Data Processing Segment (IDPS) are located at the NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland; the Air Force Weather Agency (AFWA) at Offutt Air Force Base, near Omaha, Nebraska; the Naval Oceanographic Office (NAVOCEANO) at Stennis Space Center in Mississippi; and the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California. The IDPS at each Central will process NPOESS Raw Data Records

Figure 1: Pictured here is an example of the antenna radome and equipment that is similar to what will be installed at NPOESS receptor sites. The antenna diameter is currently planned to be 4.06 meters.

(RDRs) into Sensor Data Records (SDRs) and EDRs, using auxiliary and ancillary data as necessary. Each Central will distribute processed data and products to civilian and military end users, as appropriate.

The 28-minute data latency (time from observation by the satellite to availability of processed EDRs) will lead to significant improvements in forecasts produced by numerical weather prediction (NWP) models by delivering data updates much earlier and more frequently than provided by today's satellites. This rapid information update cycle keeps models from building their forecasts on older data which introduces much more uncertainty. A steady stream of updates from NPOESS will feed into the NWP models that are run at NOAA's National Centers for Environmental Prediction (NCEP) for civilian applications and at AFWA, FNMOC and NAVOCEANO for military operations to provide more accurate and frequent mesoscale, regional, and global weather and environmental forecasts.

One of the Ka-band SafetyNet™ receptor sites will be located at Svalbard, Norway (cover background photo) and pictured below. The IPO, in cooperation with the Norwegian Space Centre (NSC), has already installed a X/S/L-band, 13-meter antenna at the Kongsberg Satellite Services (KSAT) Svalbard Satellite station (SvalSat) that will function as the primary Telemetry and Command (T&C) system for NPOESS when it launches in 2013. SvalSat will also provide T&C services and function as the primary X-band stored mission data downlink site for the NPOESS Preparatory Project (NPP), a joint mission between the IPO and NASA that will launch in 2010. While the SvalSat ground station located at 78° N experiences extremes in weather with lots of snow and ice, the location is perfect because antennas at this site will "see" the NPP and NPOESS spacecraft on every one of the passes that the satellites will make. Data from NPP and NPOESS will be transmitted from Svalbard within minutes to the U.S. Centrals via a fiber optic cable link that was completed in 2004 as a joint venture among the IPO, NASA, and the NSC. The new antenna and fiber optic link are already being used to bring down data from five to ten Coriolis/WindSat passes per day and deliver the data to users in a reliable and timely manner. Prior to the launch of the first NPOESS spacecraft (NPOESS-C1) in 2013, a Ka-band antenna system will be installed at SvalSat and integrated into the NPOESS SafetyNet™ system.

Because of its northern latitude location, Svalbard is also the single site from which the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) commands and receives all stored mission data from their Meteorological Operational spacecraft (Metop-A). Metop-A was launched in October 2006 to permanently replace NOAA's Polar-orbiting Operational Environmental Satellite (POES) in the mid-morning orbit as part of the NOAA/EUMETSAT Initial Joint Polar-orbiting Operational Satellite System (IJPS). IJPS will transition to the JPS once NPOESS launches and the joint constellation of NPOESS and Metop satellites assume their three orbits (0930 LTDN, 1330 LTAN, and 1730 LTAN). The NPOESS system will allow the international community to realize global coverage from advanced atmospheric imaging and sounding instruments with a data refresh rate of approximately four hours.

There are 15 locations around the world in the SafetyNet™ system that will function as data downlink sites for NPOESS. The SafetyNet™ receptor sites are shown in the map in Figure 3. Five sites are located on U.S. territory – Alaska, Arizona, Florida, Guam, and Hawaii. The other 10 SafetyNet™ receptor sites currently planned are located overseas – Antarctica, Australia, Brazil, Chile, India, New Zealand, Spain, South Africa, South Korea, and Svalbard. The geographic distribution of the SafetyNet™ receptor sites highlights an important international component of NPOESS. The location in Antarctica at McMurdo Station (~78°S) offers many of the same geographic advantages as the station at Svalbard.

The site at McMurdo Station will also "see" every NPOESS pass. Communications capabilities from Antarctica are already being upgraded to support NPOESS. In addition, 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. The 15 SafetyNet™ sites will be phased in between initial operational capability (IOC) at NPOESS-C1 launch in 2013 and full operational capability (FOC) at NPOESS-C2

Figure 2: The Svalbard Satellite station at Svalbard, Norway is an excellent location for downloading polar-orbiting satellite data because the satellites pass within range of the station on every orbit. Photo courtesy of Rolf Skatteboe, Kongsberg Satellite Services.

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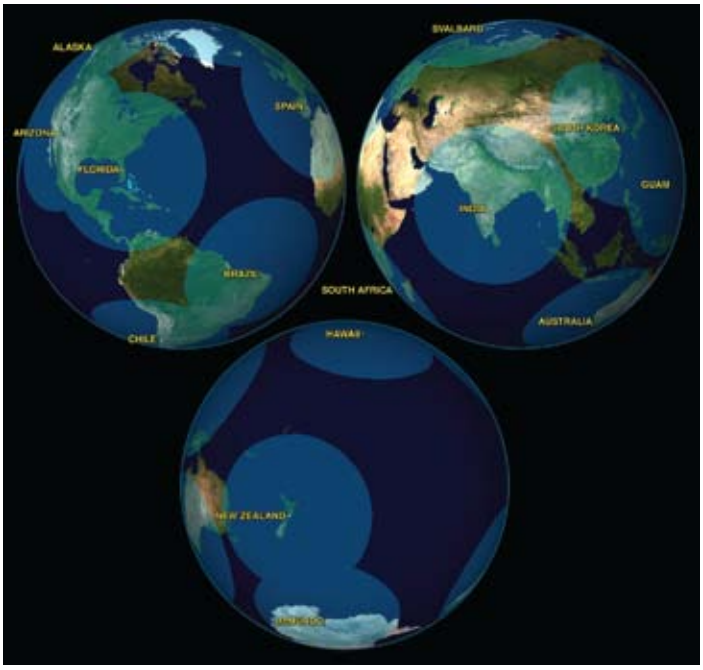

Figure 3: The 15 receptor sites around the world are what enable NPOESS data to be delivered so quickly.

launch in 2016. Although only about half of the 15 receptor sites will come on-line prior to the launch of NPOESS C1, the Svalbard location is now ready for operational testing when NPP launches in 2010.

NPP…The Mission

As soon as the NPOESS Preparatory Project (NPP) spacecraft launches, the first phase of NPOESS will begin and the ground system, developed on time and on budget, will get its first operational test. NPP will accomplish two key objectives: (1) reduce final development risks for NPOESS by providing on-orbit testing 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 Earth Observing System (EOS) Terra, Aqua, and Aura global imaging and sounding observations for NASA Earth Science research. NPP will not only provide the opportunity to test how primary NPOESS sensors will function on-orbit, it will offer the first "operational" test of how data acquired by state-of-the-art sensors will be received and distributed on the ground. While NPP will not employ the SafetyNet™ architecture for rapid delivery, it will download its global stored mission data through the Svalbard ground station that is now up and running.

NPP will demonstrate and validate new imaging and sounding technologies. Imaging technology will be improved so higher spatial and spectral resolution pictures can be taken of the Earth's environment, day or night, which will allow for more details to be seen. Improving the atmospheric sounding technology will allow considerably more information to be collected about the temperature and moisture content of the various layers of the atmosphere – the vertical distributions that describe and control what the environment is doing from near the ground to the top of the atmosphere – much more frequently each day. NPP will provide land and sea surface temperatures, atmospheric temperature and humidity soundings, information on land and ocean biological productivity, land surface types, snow and ice information, and cloud properties. Lessons learned from NPP will then be applied to NPOESS prior to launch, thereby further reducing risks to the program.

NPP will demonstrate the utility of improved imaging and sounding data in short-term weather "nowcasting" and forecasting and in other oceanic and terrestrial applications. The sensors on NPP will provide approximately 80 percent of the data rate assigned to all the sensors on NPOESS. This will be a significant step toward completing the data handling processes needed to accommodate even more data when NPOESS comes on-line. For climate researchers, NPP and NPOESS will be the sources for much satellite-derived climate data in the future. NPP and its associated ground system will collect and distribute remotely-sensed land, ocean, and atmospheric data and products to the meteorological and global climate change communities providing continuity of data as the responsibility for these measurements transitions from the existing NASA EOS Terra, Aqua, and Aura missions to NPOESS. Early access to and evaluation of data from NPP will ensure that data from NPOESS will be incorporated into NOAA and DoD operations soon after its availability.

Ground System Segments

The NPOESS Ground System has three key components that will ensure the timely and efficient delivery of NPOESS data once operational: Command, Control, and Communications

Figure 4: Raytheon IIS Senior Systems Engineers Joe Paciaroni (left) and Bill Sullivan (right) proudly pose with NPOESS logo at McMurdo Station Antarctica during the second NPOESS site survey in October 2005. McMurdo is an important SafetyNet™ receptor site for which preparation work has already begun and will be ready for operations by 2012. Photo courtesy Raytheon IIS.

Figure 5: Mechanical assembly technicians work on the NPP spacecraft in the clean room at Ball Aerospace and Technologies Corp. in Boulder, CO in 2007. In this image, NPP has three instruments installed – ATMS (Advanced Technology Microwave Sounder), VIIRS-EDU (Visible/Infrared Imager Radiometer Suite – Engineering Development Unit) and CrIS-EDU (Cross-track Infrared Sounder-Engineering Development Unit). NPP is scheduled to be launched in 2010. Photo courtesy Ball Aerospace and Technologies Corp.

Segment (C3S), IDPS, and the Direct Readout Mission. The NPP mission will provide the opportunity to test a single point of data reception and the delivery of that data to two key data centrals, NSOF and AFWA.

The Command, Control, and Communications Segment (C3S)

The portion of the ground system responsible for collecting and distributing NPP and NPOESS data is the C3S. The C3S manages the overall satellite mission. This includes mission planning and resource scheduling, satellite command and control, active reception and accounting of mission data, enterprise management, anomaly resolution, system security, and reliable delivery of data to and from Centrals. These C3S tools give the support team keen insight, comprehensive operational oversight, detailed mission planning capability, full control of space and ground assets, continuous monitoring, and assessment of overall system performance. The central hub of the C3S is the NPOESS Mission Management Center (MMC) at the NSOF in Suitland, Maryland. An Alternate MMC (AMMC) will be located at the Raytheon facility in Aurora, Colorado to provide contingency support.

Equipment for the NPOESS C3S was installed in the MMC at NSOF in 2006/2007. In tests conducted in 2007, the C3S MMC at NSOF has already successfully commanded the NPP spacecraft that is being assembled at the Ball Aerospace and Technologies Corp. factory in Boulder, Colorado. The NPOESS C3S is so advanced and sophisticated especially with respect to modularity and scalability, that it can accommodate additional satellites and missions beyond NPP and NPOESS.

The Interface Data Processing Segment (IDPS)

The IDPS features high-speed, symmetric, multi-processing computers that will rapidly convert and process large streams of NPP and NPOESS RDRs (on the order of 8 Terabytes per day when NPOESS is fully operational) into 38 distinct EDRs at the four Centrals in the United States. To better appreciate the volume of data that this represents, consider that NPOESS will take less than 12 days to surpass the accumulated data volume from more than 45 years of operations of NOAA's POES spacecraft. NPOESS will replace the older POES satellites. The IDPS equipment for the NSOF is already installed and the equipment is scheduled for installation at AFWA in 2008 to serve the NPP mission. The IDPS equipment for NAVOCEANO and FNMOC will be installed in ~2012 to complete the full-up system for NPOESS operations.

The NPOESS EDRs encompass atmospheric, oceanic, terrestrial, climatic, and solar-geophysical parameters. They include cloud properties; atmospheric temperature, moisture, and ozone distributions; snow and ice cover; land temperature, vegetation, and use; and sea surface temperature and ocean surface winds; as well as energetic charged particles and auroral activity in the near-Earth space environment.

This wealth of information will enable numerous civilian and military users to improve their monitoring and prediction of changes in the weather, climate, oceans, and space environment. NPOESS products will be available to the scientific community to expand our knowledge of the environment. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) Data Centers will maintain the long-term archive of NPP and NPOESS data acquired from the IDPS at the NSOF. The worldwide user community, including decision makers and the public, will use NOAA's Comprehensive Large Array-data Stewardship System (CLASS) to access NPP and NPOESS data and higher-level products held by the NOAA Data Centers.

Direct Readout Mission

NPOESS will provide direct readout users, both fixed and mobile stations deployed aboard ships, at military installations, educational, scientific, and other government institutions, with the operational algorithms needed to generate data products from real-time broadcasts. NPOESS spacecraft will be able to simultaneously transmit real-time data directly to suitably equipped user terminals in two modes. In the High-Rate Data (HRD) mode (X-band frequencies), users will receive full data sets from NPOESS. In the Low-Rate Data (LRD) mode (L-band frequencies) users will be able to receive a subset of the full NPOESS data set. The operational algorithms will be available in advance of the NPOESS-C1 launch in 2013. NPOESS data will be continuously broadcast in real-time, making it available to combat units in the field, carrier battle groups, and any registered civil user of the NPOESS Direct Readout service. Weather warriors attached to these units will receive NPOESS imagery and data for their area of interest as the satellite passes overhead. As technology improves, "net-centric" solutions may allow deployed units to be tied into a larger infrastructure.

NPP will also broadcast real-time data in an X-band mode to users equipped with appropriate antennas and receivers and computer hardware and software. There are currently over 150 ground stations worldwide that are being used to

acquire real-time, Direct Broadcast (DB) data from the X-band downlinks on NASA's EOS Terra and Aqua satellites. These users who will also want to receive real-time data from NPP after it launches in 2010 will need the International Polar Orbiter Processing Package (IPOPP) that is being developed by the IPO through a collaborative arrangement with the Direct Readout Laboratory at NASA's Goddard Space Flight Center and the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin. IPOPP is the primary software processing package that will enable the DB community to process, visualize, and evaluate NPP and NPOESS Sensor and Environmental Data Records. IPOPP will be critical to the DB user community throughout the transition from EOS to NPOESS.

Timely Delivery

The capability of SafetyNet™ to reduce data latency (or speed up data delivery) is critical and is the key benefit of the ground system for NPOESS. Today, data collected by NOAA's POES are stored on board the aging fleet and delivered to a single ground antenna once per orbit. The current ground processing system adds another delay of up to two hours. In fact, the existing POES ground stations at Fairbanks, Alaska and Wallops Island, Virginia cannot "see" all 14 orbits per day and data from three "blind" POES orbits are processed considerably later in a delayed mode. Antennas at Svalbard are currently being used to receive data from the NOAA-18 "blind" orbits as part of IJPS. Notably, this "blind" orbit problem will not exist at all with the NPP and NPOESS ground systems that will rely on the site at Svalbard for one of the primary data downlinks. While not part of NPP, the NPOESS SafetyNet™ will use multiple sites around the world where data will be downloaded and delivered in some cases within 2 minutes of acquisition on orbit. This capability is unprecedented.

The reason it is important to deliver data so quickly seems obvious in today's world of quick decision making. "The faster the "better" concept applies here. The quicker that NPOESS data can be collected and delivered to the ground and into the weather and environmental forecasting computers at NCEP, AFWA, FNMOC, and NAVOCEANO, the faster numerical weather prediction models can produce more accurate forecast updates for decision makers.

According to Dr. Louis Uccellini, Director NOAA's National Centers for Environmental Prediction, "Lowering data latency rates ensures that we will be able to process NPOESS data quickly and deliver more timely, higher-resolution model forecasts to decision makers. We get as many kudos from having a 99.5% on-time delivery as we do for increasing accuracy. A decreased latency should provide a tremendous

Figure 6: The NOAA Satellite Operations Facility (NSOF) hosts the NPOESS Mission Management Center (MMC) and "Central" that will process and send NPP and NPOESS data to NOAA's NCEP for direct input into weather forecast models via the NPOESS interface known as the Interface Data Processing Segment (IDPS). The NSOF MCC is also the hub of the Command, Control and Communications Segment. Photo by StormCenter Communications, Inc.

Figure 7: The Direct Readout Mission will allow users in remote locations to access NPOESS data directly for rapid processing and environmental support for quick local assessments and decision making.

benefit to modelers as well as to users of model output such as the media," said Dr. Uccellini. "We listen to our customers when they say lost time in distributing model forecasts is a waste of resources."

For military operations, processing of NPOESS data can mean the difference between launching aircraft off a carrier now or waiting 6 hours. It could mean turning a fleet to avoid a developing storm system in the middle of the ocean, which could cost millions of dollars or continuing through the weather system that is forecast to weaken. Satellites provide an unprecedented and unique source of information for military operations. From support of ground troops to weapons deployment and the need to make rapid tactical decisions, Earth observation data are invaluable to our Nation's global military mission. Polar-orbiting and geostationary satellites both play an important role, particularly in combat situations.

Ready for Launch

The Ground System Segments are very successful components of NPP and NPOESS. Both the C3S and IDPS have been delivered on schedule and within budget. For NPP, the ground segments have already undergone compatibility tests which have proven that the data-delivery and satellite-commanding capabilities work very well. Further testing and fine-tuning will ensure readiness of the ground segments for the NPP launch in 2010. Both NPP and NPOESS will be operated and sustained for the government by a Northrup Grumman led Operations and Support team.

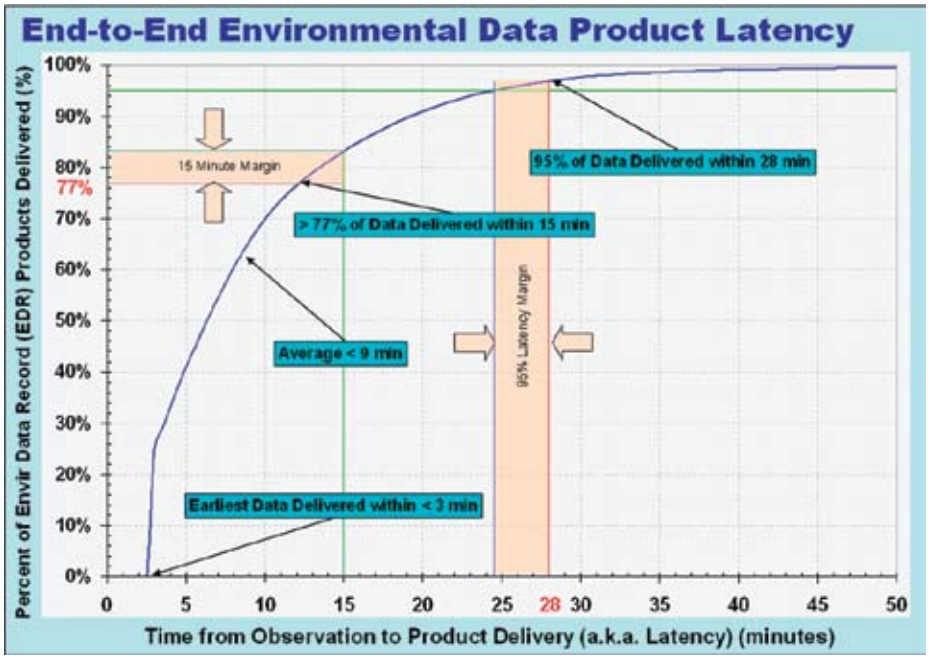

Figure 8: NPOESS EDR Processing Timeline – End-to-End EDR Latency to illustrate expected delivery times from 2-3 minutes for earliest data to 95% of data within 28 minutes

Contributors

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About the Author

Dave Jones is founder, president & CEO of StormCenter Communications, Inc. (www.stormcenter.com) in Ellicott City, MD. StormCenter focuses on "Raising the Environmental IQ of America™" through innovative technologies and programs in partnership with public and private organizations across the nation. He is also a director on the board of the Foundation for Earth Science, a 501 (c) 3 corporation in Northern Virginia. Dave can be reached via dave@stormcenter.com.

At Northrop Grumman, the progress we make daily on NPOESS is crucial to bringing this next generation of low earth orbiting environmental satellites into service. NPOESS' state-of-the-art technology will deliver more accurate information in minutes, rather than hours, enabling decision makers to act quickly reducing potential loss of human life and property. In partnership with the Department of Commerce, the Department of Defense and NASA, the Northrop Grumman team is committed to developing a highly reliable national weather forecasting capability that saves lives and protects our economic well-being.

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