32ND SPACE SYMPOSIUM

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES – R SERIES (GOES-R) OVERVIEW AND STATUS

MICHAEL STRINGER
NOAA/NESDIS/GOES-R, michael.stringer@noaa.gov
GOES-R, Assistant System Program Director

ABSTRACT

NOAA's Geostationary Operational Environmental Satellites (GOES) are a mainstay of weather forecasts and environmental monitoring in the United States. The next generation of GOES satellites, known as the GOES-R Series, with a planned launch in 2016, will usher in a new era of continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring to provide critical atmospheric, hydrologic, oceanic, climatic, solar, and space data. The GOES-R Series' primary instrument, the Advanced Baseline Imager (ABI), will provide three times the spectral resolution and four times the spatial resolution, while scanning the Earth nearly five times faster than the current GOES. The GOES-R Series will also host a new instrument, the Geostationary Lightning Mapper (GLM) that is designed to continuously map in-cloud and cloud-to-ground lightning with a 8 km spatial resolution with near-uniform detection efficiency over the Western Hemisphere with a latency of less than 20 sec. It will provide information to improve severe storm monitoring and warnings and contribute to improved aircraft safety and efficient flight route planning. The GOES-R Series' space weather instruments will provide improved observations of the sun and space environment with more timely dissemination and early warning to a diverse user community. This paper will provide an overview and status update of the GOES-R Series Program and the forthcoming activities leading to an operational GOES-R system. The new instruments, improved spacecraft, and ground system will allow for a host of new environmental products and services, while improving most of the products and services that are currently provided. The new observations will contribute to dramatically improved weather, water, and space environmental services in the next decades, enhancing public safety and providing economic benefits to the U.S. and our international partners.

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES (GOES)

Since 1975, weather satellites stationed high above Earth's equator in geostationary orbit have provided nearly continuous imagery and data on atmospheric conditions and solar activity (space weather) affecting Earth. The data products of these Geostationary Operational Environmental Satellites (GOES) have led to improved weather and climate models, enabling more accurate and faster weather forecasting and better understanding of long-term climate. These satellites have even helped in the search and rescue of people in distress. To meet the nation's weather data needs, the GOES system requires two operational satellites and an on-orbit spare at all times. Two GOES satellites, one in the east and one in the west, maintain visual coverage of the entire nation and the adjacent oceans, where weather, especially storms, often originates. A single GOES cannot simultaneously monitor a hurricane in the Atlantic and a volcanic ash cloud in the Aleutian Islands. A backup GOES must be available on orbit in case one of the operational GOES fails. The National Oceanic and Atmospheric Administration (NOAA) operates GOES. The National Aeronautics and Space Administration (NASA) builds and launches them. Since the development and launch of the first of these geostationary operational satellites in 1974, these two organizations have pushed the technology to its current advanced state, as represented by the GOES-R series, the next generation of geostationary weather satellites.

GOES–R SERIES

The next series of GOES will be a giant leap forward in technology. It will offer more and different types of data products that will be more accurate, of higher resolution and greater quantity, and available faster than previous GOES. Although the current GOES provide critical weather information, future users will need even better information to forecast weather, manage ecosystems and monitor changing climate conditions. The user communities not only need improvements in instrument capabilities, but also are seeking new products and applications, along with faster data dissemination techniques and reduced product lag time. The GOES-R series of satellites is both important and beneficial to the nation's social welfare, scientific advancement and economic efficiency. Many sectors of society will receive direct and indirect benefits of GOES-R's enhanced data. GOES-R is scheduled for launch in October 2016. After a successful launch and deployment, GOES-R will be designated GOES-16. So what will GOES-R provide?

- Improved hurricane track and intensity forecasts
- Increased thunderstorm and tornado warning lead time
- Improved aviation flight route planning
- Improved air quality warnings and alerts
- Better data for long-term climate variability studies
- Improved solar flare warnings for communications and navigation disruptions
- More accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft
- Better monitoring of space weather to improve geomagnetic storm forecasting

GOES-R SPACECRAFT

The GOES-R spacecraft bus is 3-axis stabilized and designed for 10 years of on-orbit operation preceded by up to 5 years of on-orbit storage. The spacecraft bus is being constructed by Lockheed Martin as the prime flight contractor and consists of a systems module and a core/propulsion module that are mated to create the bus. The

satellite will be able to operate through periodic station-keeping and momentum adjust maneuvers, which will allow for near-continuous instrument observations. Other notable performance elements include: vibration isolation for the Earth-pointed optical bench and high-speed spacecraft-to-instrument interfaces designed to maximize science data collection. The cumulative time that GOES-R science data collection (including imaging) will be interrupted due to all momentum management, station-keeping, and yaw flip maneuvers will be under 120 minutes/year. This is a nearly two orders of magnitude improvement compared to the current GOES satellites. The satellite driving requirements are:

- Spacecraft on-orbit life of 15 years with orbit East-West and North-South position maintained to within +/-0.1 degree
- Collect and transmit up to 100Mbps Instrument Payload data from each location continuously
- Continuous Rebroadcast function at L-Band up to 31 Mbps utilizing dual polarization
- Provide continuing services [Search and Rescue, Data System Collection, Emergency Manager's Weather Information Network (EMWIN)]

Spacecraft Specifications

Size	~5.5 meters (from launch vehicle interface to top of ABI)
Mass	Satellite (spacecraft and payloads) dry mass <2800kg
Power Capacity	>4000W at end-of-life (includes accounting for limited array degradation)

GOES-R INSTRUMENTS

There are three classifications of GOES-R instruments on the spacecraft; Nadir-pointing, Solar-pointing, and In-Situ. The Nadir or Earth pointing instruments are mounted on a highly stable, precision pointed Earth Pointing Platform (EPP) that is dynamically isolated from the rest of the spacecraft. The two instruments mounted on the EPP are the Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM). A Sun Pointing Platform (SPP) housed on the solar array yoke provides a stable platform that tracks the seasonal and daily movement of the sun relative to the spacecraft. There are two instruments mounted on the SPP the Solar Ultraviolet Imager (SUVI) and the Extreme Ultraviolet and X-Ray Irradiance Sensor EXIS). The Space Environment In Situ Suite (SEISS) and the Magnetometer provide localized measurements of particles and fields in geosynchronous orbit.

Advanced Baseline Imager (ABI)

The ABI is the primary instrument on GOES-R for imaging Earth's weather, oceans and environment. ABI will be able to view the Earth with 16 different spectral bands (compared to five on current GOES), including two visible channels, four near-infrared channels, and ten infrared channels. It will provide three times more spectral information, four times the spatial resolution, and more than five times faster temporal coverage than the current system. ABI will be a mission critical payload on GOES-R, providing more than 65 percent of all mission data products currently defined.

ABI is a multi-channel passive imaging radiometer designed to observe the western hemisphere and provide variable area imagery and radiometric information of Earth's surface, atmosphere and cloud cover. ABI will be used for a wide range of applications related to weather, oceans, land, climate, and hazards. The instrument has

two scan modes. It will have the ability to continuously take an image of the entire planet, or a full disk image, every five minutes. It also has an alternative, or flex mode, which will concurrently take a full disk image every 15 minutes, an image of the continental U.S. every five minutes, and smaller, more detailed images of areas where storm activity is present, as often as every 30 seconds. All the ABI bands will have on-orbit calibration.

ABI will be used for a wide range of applications related to weather, oceans, land, climate and hazards (fires, volcanoes, floods, hurricanes and storms that spawn tornadoes). ABI will improve every product from the current GOES imager and will introduce a host of new products. It will track and monitor cloud formation, atmospheric motion, convection, land surface temperature, ocean dynamics, flow of water, fire, smoke, volcanic ash plumes, aerosols and air quality, and vegetative health. ABI's data will enable meteorologists to pinpoint and track developing storms in much greater detail. Future products will also help the aviation industry with aircraft icing threat detection and turbulent flight condition predictions.

Geostationary Lightning Mapper (GLM)

The GLM is a single-channel, near-infrared optical transient detector that can detect the momentary changes in an optical scene, indicating the presence of lightning. GLM will measure total lightning activity continuously over the Americas and adjacent ocean regions with near uniform spatial resolution of approximately 10 km. GLM will provide early predictions of intensifying storms and severe weather events. It will also provide data for long-term climate studies. The instrument will aid forecasting of weather events that could affect aviation safety and efficiency. GLM is unique both in how it operates and in the information it collects. While ground-based sensors only provide cloud-to-ground lightning coverage, GLM provides total lightning activity detection with both cloud-to-ground and cloud-to-cloud coverage. Also, ground-based systems can only provide coverage over land. GLM will identify growing, active and potentially destructive thunderstorms in areas over both land and oceans.

The instrument will collect information such as the frequency and location of lightning events to detect the intensification of thunderstorms and tropical cyclones, which are often accompanied by increased lightning activity. Research and testing has demonstrated the GLM potential for improvement in tornado warning lead time and false alarm rate reduction. It is anticipated that GLM data will have immediate applications to aviation weather services, climatological studies, and severe thunderstorm forecasts and warnings. Data from the instrument will also be used to produce a long term database to track decadal changes in lightning activity. This is important due to lightning's role in maintaining the Earth-atmosphere electrical balance.

Solar Ultraviolet Imager (SUVI)

The SUVI is a telescope that monitors the Sun in the extreme ultraviolet wavelength range. By observing the Sun, SUVI will be able to compile full disk solar images around the clock. It replaces the current GOES Solar X-ray Imager (SXI) instrument and represents a change in both spectral coverage and spatial resolution over SXI. SUVI will observe and characterize complex active regions of the Sun, solar flares, and the eruptions of solar filaments which may give rise to coronal mass ejections. Depending on the size and the trajectory of solar eruptions, the possible effects to near-Earth space and Earth's magnetosphere, referred to as space weather, can cause geomagnetic storms which disrupt power utilities, communication and navigation systems, and may cause radiation damage to orbiting satellites and the International Space Station. SUVI observations of solar flares and solar eruptions will provide an early warning of possible impacts to Earth's space environment and enable better forecasting of potentially disruptive events on the ground.

SUVI will be located on the Sun Pointing Platform (SPP) which is located on the solar array yoke. The SPP will provide a stable foundation and track the daily and seasonal movement of the Sun which is critical to the success of SUVI.

Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)

The EXIS on the GOES-R series satellites are critical to understanding and monitoring solar irradiance in the upper atmosphere, that is, the power and effect of the Sun's electromagnetic radiation per unit of area. EXIS will be able to detect solar flares that could interrupt communications and reduce navigational accuracy, affecting satellites, high altitude airlines and power grids on Earth.

On board the EXIS are two main sensors, the Extreme Ultraviolet Sensor (EUVS) and the X-Ray Sensor (XRS), which will help scientists monitor activity on the Sun. EXIS will reside on the Sun Pointing Platform mounted in the yoke of the solar array. The instrument also includes the EUVS/XRS Electrical Box (EXEB) and the Sun Positioning Sensor (SPS) subsystems.

NOAA requires the real-time monitoring of the solar irradiance variability that controls the variability of the terrestrial upper atmosphere (ionosphere and thermosphere). This requirement supports NOAA's space weather operations and is implemented with XRS and EUVS.

XRS monitors solar flares and helps predict solar proton events that can penetrate Earth's magnetic field. The XRS is important in monitoring x-ray input into the Earth's upper atmosphere and alerts scientists to x-ray flares that are strong enough to cause radio blackouts and aide in space weather predictions. (This is different from the SUVI instrument which monitors solar flares via images on the x-ray spectrum.) With the completion of GOES-R, the EXIS will provide more information on solar flares and include a more complete and detailed report of solar variability than is currently available.

The EUVS will measure changes in the solar extreme ultraviolet irradiance which drive upper atmospheric variability on all time scales. EUV radiation has major impacts on the ionosphere. An excess can result in radio blackouts of terrestrial high frequency communications at low latitudes. EUV flares also deposit large amounts of energy in Earth's upper atmosphere (thermosphere) causing it to expand into Low Earth Orbiting satellites, causing increased atmospheric drag and reduce the lifetime of satellites by degrading items such as solar panels.

The NOAA Space Weather Prediction Center will rely on the products from the EXIS to issue warnings of radio blackouts. This will aid preserving ground-based radio communications and navigation systems.

Space Environment In-Situ Suite (SEISS)

The SEISS is comprised of four sensors that will monitor proton, electron, and heavy ion fluxes at geosynchronous orbit. The information provided by SEISS is critical for assessing the electrostatic discharge (ESD) risk and radiation hazard to astronauts and satellites. In addition to hazard assessment, the information from SEISS can be used to warn of high flux events, mitigating any damage to radio communication.

The SEISS instrument suite consists of: the Energetic Heavy Ion Sensor (EHIS), the Magnetospheric Particle Sensors - High and Low (MPS-HI and MPS-LO), and the Solar and Galactic Proton Sensor (SGPS). The instrument suite also

includes the Data Processing Unit (DPU). Data from SEISS will drive solar radiation storm portion of NOAA space weather scales and other alerts and warnings and will improve energetic particle forecasts.

Magnetometer (MAG)

The MAG will provide measurements of the space environment magnetic field that controls charged particle dynamics in the outer region of the magnetosphere. These particles can be dangerous to spacecraft and human spaceflight. The geomagnetic field measurements are important for providing alerts and warnings to many customers, including satellite operators and power utilities. GOES Magnetometer data are also important in research, being among the most widely used spacecraft data by the national and international research communities. The GOES-R Magnetometer products will be an integral part of the NOAA space weather operations, providing information on the general level of geomagnetic activity and permitting detection of sudden magnetic storms. In addition, measurements will be used to validate large-scale space environment models that are used in operations. The MAG requirements are similar to the tri-axial fluxgates that have previously flown. GOES-R requires measurements of three components of the geomagnetic field with a resolution of 0.016 nT and response frequency of 2.5 Hz.

GOES-R UNIQUE PAYLOAD SERVICES (UPS)

The GOES-R Unique Payload Services suite consists of transponder payloads providing communications relay services in addition to the primary GOES mission data. The UPS suite consists of the Data Collection System (DCS), the High Rate information Transmission / Emergency Managers Weather Information Network (HRIT/EMWIN), GOES Rebroadcast (GRB), and the Search and Rescue Satellite Aided Tracking (SARSAT) System.

GOES Rebroadcast (GRB)

GOES Rebroadcast is the primary space relay of Level 1b products and will replace the GOES VARiable (GVAR) service. GRB will provide full resolution, calibrated, navigated, near-real-time direct broadcast data. The content of the data distributed via GRB service is envisioned to be the full set of Level 1b products from all instruments onboard the GOES-R series spacecraft. This concept for GRB is based on analysis that a dual-pole circularly polarized L-band link of 12 MHz bandwidth may support up to a 31-Mbps data rate – enough to include all ABI channels in a lossless compressed format as well as data from GLM, SUVI, EXIS, SEISS, and MAG.

Data Collection System (DCS)

The Data Collection System is a satellite relay system used to collect information from Earth-based data collection platforms that transmit in-situ environmental sensor data, such as stream or river flow, tide-levels, weather conditions, etc. The transmissions can occur on predefined frequencies and schedules, in response to thresholds in sensed conditions, or in response to interrogation signals. The transponder on board the GOES satellite detects this signal and then rebroadcasts it so that it can be picked up by other ground-based equipment. Federal, state and local agencies then monitor the environment through the transmission of observations from these surface-based data collection platforms. The platforms can be placed in remote locations and left to operate with minimal human intervention. The Data Collection System thus allows for more frequent and more geographically complete environmental monitoring. In the GOES-R era, the number of user-platform channels will expand from 266 to 433. There will also be a frequency change from 1696 MHz to 1679 MHz, which will require replacement of users' Low Noise Block (LNB) feed. Direct Readout Ground Station (DRGS) manufacturers have

been informed of this change. Data transmission rates in the GOES-R era will be 300 bps and 1200 bps. There will be no change to the data access policy.

Emergency Managers Weather Information Network (EMWIN)

The Emergency Managers Weather Information Network (EMWIN) is a direct service that provides users with weather forecasts, warnings, graphics, and other information directly from the National Weather Service (NWS) in near real time. The GOES EMWIN relay service is one of a suite of methods to obtain these data and display the products on the user's personal computer. The HRIT service provides broadcast of low-resolution GOES satellite imagery data and selected products to remotely located user HRIT Terminals.

Search and Rescue Satellite Aided Tracking (SARSAT)

As an integral part of the international search and rescue satellite program called COSPAS-SARSAT, NOAA operates the SARSAT System to detect and locate mariners, aviators, and other recreational users in distress almost anywhere in the world at any time and in almost any condition. This system uses a network of satellites to quickly detect and locate distress signals from emergency beacons onboard aircraft, vessels, and from handheld personal locator beacons called PLBs. The SARSAT transponder that will be carried onboard the GOES-R satellite will provide the capability to immediately detect distress signals from emergency beacons and relay them to ground stations - called Local User Terminals. In turn, this signal is routed to a SARSAT Mission Control Center and then sent to a Rescue Coordination Center which dispatches a search and rescue team to the location of the distress.

GOES-R continues the legacy Geostationary SAR (GEOSAR) function of the SARSAT system onboard NOAA's GOES satellites which has contributed to the rescue of thousands of individuals in distress. The SARSAT transponder will be modified slightly for GOES-R by being able to operate with a lower uplink power (32 dBm) enabling GOES-R to detect weaker signal beacons. The below statitics are from http://www.sarsat.noaa.gov/:

Total Rescues in Calendar Year 2015 in the United States: 250

- Rescues at sea: 138 people rescued in 46 incidents
- Aviation rescues: 21 people rescued in 11 incidents
- Terrestrial PLB rescues: 91 people rescued in 65 incidents
- Worldwide – Over 39,000+ people rescued (since 1982)
- United States – 7,769 People Rescued *(since 1982)*

Ground Segment (GS)

The GS is critical to the GOES-R mission. NOAA, through our prime ground contractor Harris, is developing a state-of-the-art ground system that will receive data from the GOES-R spacecraft and generate real-time data products. This is accomplished via a core set of functional elements, a new antenna system and a product access component. The GOES-R series satellites will produce 3.5 terabytes of data per day, as compared to only 90 gigabytes of data per day for current geostationary and polar-orbiting satellites combined.

The GOES-R Core GS consists of two primary locations that will receive data from the GOES-R series satellites: NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland, and Wallops Command and Data Acquisition

Station (WCDAS) in Wallops, Virginia. A third operations facility in Fairmont, West Virginia, will serve as the Consolidated Backup (CBU). NSOF will house the majority of GOES-R mission operations and product staff. Four 9.1-meter antennas at NSOF were upgraded for compatibility with GOES-R. These upgraded antennas will maintain compatibility with existing GOES satellites and will operate continuously for the life of the GOES-R series satellites.

WCDAS will be the primary site for space-to-ground communications. Some data will be processed at WCDAS to produce GOES Rebroadcast (GRB) data for satellite uplink. WCDAS will also provide uplink to the satellites to support certain Unique Payload Services, which consist of transponder payloads providing communications relay services in addition to the primary GOES mission data. Three new 16.4-meter antennas at WCDAS are designed to operate during a Category 2 hurricane with sustained winds of 110 mph and gusts of up to 150 mph. These antennas are compatible with existing GOES satellites and will operate continuously for the life of the GOES-R series.

The GOES-R GS will receive the raw data from GOES-R series spacecraft and generate Level 1b and Level 2+ products. The GS will also make these products available to users in a timely manner consistent with the GOES-R latency requirements. Level 1b data from each instrument and Level 2+ data from the Geostationary Lightning Mapper (GLM) will be distributed to direct readout users with antenna receives by means of spacecraft relay as GOES Rebroadcast (GRB). Level 1b products and Level 2+ products will be provided to the Product Distribution & Access (PDA) System for users including the Data Archive centers (CLASS). The tables below define the data levels and the GOES-R delivered products and their respective data levels.

Data Levels

Level 0	Unprocessed instrument data at full resolution
Level 1b	Level 0 data with radiometric and geometric correction applied to produce parameters in physical units
Level 2+	Derived environmental variables with comparable to Level 1 spatial and temporal resolution

GOES-R Delivered Products

Product	**Product Data Level**
Radiances	L1b
Solar Imagery: EUV	L1b
Energetic Heavy Ions	L1b
Magnetospheric Electrons and Protons: Low Energy	L1b
Magnetospheric Electrons and Protons: Medium and High Energy	L1b
Solar and Galactic Protons	L1b
Geomagnetic Field	L1b
Solar Flux: EUV	L1b
Solar Flux: X-Ray	L1b
Lightning Det: Events, Groups, Flashes	L2+
Cloud and Moisture Imagery (KPP)	L2+

Aerosol Detection (including Smoke & Dust)	L2+
Aerosol Optical Depth	L2+
Volcanic Ash: Detection & Height	L2+
Cloud Optical Depth	L2+
Cloud Particle Size Distribution	L2+
Cloud Top Phase	L2+
Cloud Top Height	L2+
Rainfall Rate / QPE	L2+
Legacy Vertical Moisture Profile	L2+
Legacy Vertical Temperature Profile	L2+
Derived Stability Indices	L2+
Total Precipitable Water	L2+
Clear Sky Masks	L2+
Downward Shortwave Rad.: Surface	L2+
Fire / Hot Spot Characterization	L2+
Land Surface (Skin) Temperature	L2+
Sea Surface Temperature (skin)	L2+
Reflected Shortwave Rad.: TOA	L2+
Snow Cover	L2+
Derived Motion Winds	L2+
Hurricane Intensity	L2+
Cloud Top Pressure	L2+
Cloud Top Temperature	L2+

GOES-R PROGRESS

The GOES-R spacecraft has been completed with all instruments integrated. The GOES-R spacecraft has completed Thermal Vacuum (TV), vibrations, and launch vehicle match mate testing. The satellite and ground system have completed numerous testing events including:

- End-to-End (ETE) tests validate the telemetry and command interface between the satellite and the operational ground system
- Data Operations Exercises (DOEs) demonstrate the readiness of the ground system and operations personnel to produce and distribute product data to external users
- Ground Readiness Exercises (GREs) validate the full ground system functionality in an operational context

The ground system hardware and software has been fully delivered and checked out at WCDAS, CBU, and NSOF. All four of the antennas at the NSOF have been upgraded and 5 of the 6 new 16-meter antennas have been completed and are ready for operations. The spacecraft still needs to undergo acoustics and electromagnetic interference (EMI) testing before being shipped to Kennedy Spaceflight Center (KSC) for launch in mid-October 2016.

GOES-R LAUNCH VEHICLE OVERVIEW

The Launch Vehicle that will place the GOES-R and GOES-S satellites into geosynchronous orbit will be an Atlas V 541 Expendable Launch Vehicle (ELV). The term expendable launch vehicle means each vehicle is only used once. The three numbers in the 541 designation signify a payload fairing, or nose cone, that is approximately 5 meters (16.4 feet) in diameter; four solid-rocket boosters fastened alongside the central common core booster; and a one-engine Centaur upper stage.

A launch vehicle is chosen based on how much mass the vehicle can lift into space. A two-stage Atlas V 541 launch vehicle was selected for the GOES-R and S launches because it has the right liftoff capability for the heavy weight requirements. The GOES-R and GOES-S spacecraft will launch in 2016 and 2018, respectively, aboard Atlas V 541 rockets from Space Launch Complex-41 at Cape Canaveral Air Force Station, Florida.

GOES-S PROGRESS

All the GOES-S instruments have been delivered and are ready for integration. The EXIS and SUVI have been installed on the SSP. The Systems Integration Review for GOES-S was completed on the 3rd of December 2015 and the systems and core/propulsion modules were mated on the 21st of December 2015. Progress continues on GOES-S however it is currently slowed because GOES-R is the number one priority. Current plans for GOES-S put it's launch in 2018 but the exact launch slot is still to be determined.

ADDITIONAL INFORMATION

More detailed information including videos, factsheets, quarterly newsletters, etc. can be found at **www.goes-r.gov** you can also follow our progress on twitter **@NOAASatellites** or Facebook https://www.facebook.com/GOESRsatellite or find photos on flickr at **https://www.flickr.com/photos/noaasatellites/sets/** and find videos on our YouTube channel at **https://www.youtube.com/playlist?list=PLY6u3ZR91o24FazYzKeZ3TcGMS-piUBho**