NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'S (NOAA) – NEXT GENERATION GEOSTATIONARY SATELLITE (GOES R) IMPACT ON HAZARDS MANAGEMENT

Eric Miller * , Michael Madden , Blaine Nelson

1 INTRODUCTION

Geostationary Satellites satisfy National Weather Service (NWS) requirements for 24-hour observation of weather and the Earth's environment to support storm-scale weather forecasting by forecasters and numerical models. Currently, data are provided to users routinely from the Imager every 15 minutes and from the Sounder every hour throughout the day from each satellite. More rapid repetition is used when needed for severe weather events.

Limitations of this current GOES system are reviewed, as well as improvements expected with GOES R. Impacts to selected hazards (storms, fire detection, flooding and lightning) monitoring are addressed.

The GOES system goals are to:

- Maintain continuous, reliable operational environmental, and storm warning systems to protect life and property
- Monitor the earth's surface and space environmental and climate conditions
- Introduce improved atmospheric and oceanic observations and data dissemination capabilities (increased spatial, temporal and spectral resolution)
- Develop and provide new and improved applications and products for a wide range of federal agencies, state and local governments, and private users
- Maintain continuous and reliable operational environmental satellites to protect life and property.
- Monitor and predict changes in the Earth and space environment; conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs.

2 CURRENT GOES

The current GOES consists of two operational satellites covering the East and West portions of the Americas. The constellation consists of environmental sensors, auxiliary payload services and rebroadcast capabilities. GOES auxiliary payload services consist of Direct Communication Services (DCS), EMergency Weather Information Network (EMWIN), Low Rate Information Transfer (LRIT) and Search And Rescue Satellite Aided Tracking (SARSAT). Figure 1 depicts the current consolidated GOES architecture.

Corresponding author address: NOAA Satellite and Information Service, 1335 East West Highway, SSMC1 Station 5230, Silver Spring, MD 20910
(eric.miller, michael.madden, blaine nelson)@noaa.gov

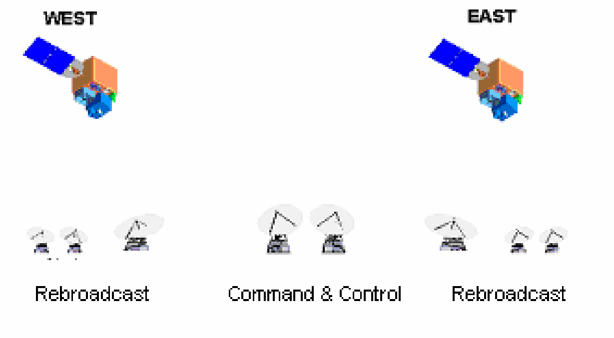

Figure 1 – Consolidated GOES Architecture

In the following sections, the limitations of GOES I-M and GOES N series systems are identified as a basis for why the GOES R system development is necessary. The shortcomings, covering both the space and ground segment, include: mission continuity; data losses; simultaneous hemispheric, synoptic, and mesoscale imaging; and data latency/timeliness.

2.1 Mission Continuity

Replacement satellites are required to sustain US geostationary capabilities and coverage beyond 2012. Expected mean mission duration for the GOES N-P series should support full mission availability through ~2018. GOES R must be launched 2012 to serve as on orbit replacement of GOES O. Currently available instrument capabilities are also inadequate to meet many of the emerging requirements, necessitating the development of new technologies.

2.2 Data Losses

With our current system, data losses occur for several hours each day during the weeks around the spring and fall equinox (eclipse). The reason is the viewing geometry of the current geostationary satellites, which allows sunlight impingement on the optical path of the sensing instruments. This direct sunlight may cause a degradation of the radiometric response accuracy and potential permanent damage to the Earth-viewing detectors. To avoid such damage, data is not sensed nor provided during these periods – termed the "keep out zones." The combined impact on the current GOES I-M and GOES N-P series is a 3 to 4 hour loss of data for 10 to 12 days before and after each eclipse

During these periods, there is significant loss of data for National Weather Service (NWS), which has the potential to impact critical forecasting and modeling operations. The spring eclipse and keep-out zone coincides with the beginning of the tornado season while the fall eclipse and keep-out zone coincides with the peak of the Atlantic Hurricane season (see figures 2 and 3).

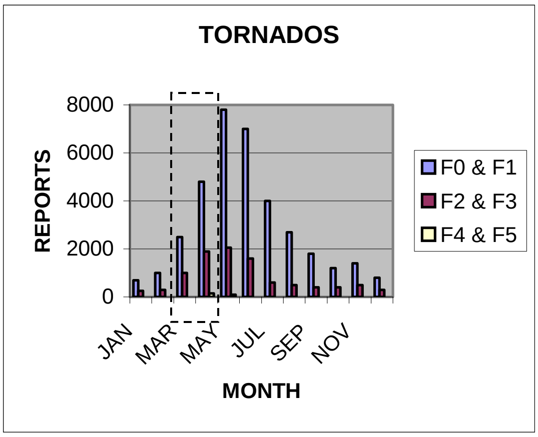

Figure 2. Tornado season and Spring Eclipse (dashed)

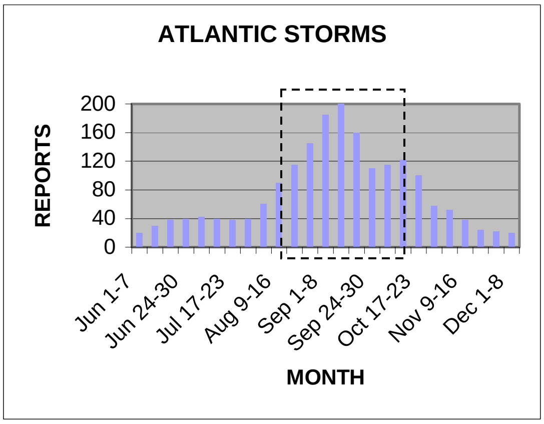

Figure 3. Hurricane season and Fall Eclipse (dashed).

Periodic spacecraft maneuvers are required to adjust the drift and orbit of the geostationary satellites and to counteract the gravitational forces from the sun and the moon. The time needed for the current GOES I-M satellites and the GOES N-P series to return to normal operations after such maneuvers may be up to 9 hours. This excessive delay is unacceptable for forecast and hazards management that require and depend upon timely satellite data input.

2.3 Simultaneous Hemispheric Imaging

The current GOES I-M and GOES N-P series cannot provide simultaneous Hemispheric (Full Disk), synoptic (CONUS Regional) and Mesoscale (Rapid-Scan) imaging. They are unable to provide Southern Hemispheric images during Rapid-Scan operations (invoked to support severe weather outbreaks) and cannot meet the temporal requirements for Full Disk and CONUS updates. Imaging and derived high-density wind products below the equator are also required during Mesoscale imaging. Simultaneous imaging is needed to support timely hazards response through our hemisphere.

2.4 Data Latency (Timeliness)

Product delivery must be done in near real-time to capture rapidly changing, relatively short-term events, (e.g., severe weather, thunderstorms, and flash floods). The usefulness (forecast value) of the current GOES imagery is greatly diminished if the images are not available for analysis by the forecaster before the start of the next image, i.e. in near real-time. Data latency sometimes exceeds two hours from the time measured until available for use at national forecasting centers. Reducing data latency will allow more timely and accurate warnings and forecasts.

3. GOES R IMPROVEMENTS

The GOES R system is planned to operate for a period of at least 14 years, providing a remote sensing capability to acquire and disseminate regional environmental imagery and specialized meteorological, climatic, terrestrial, oceanographic, solar-geophysical and other data to central processing centers and distributed direct users. GOES R will operate with improved latency, better full hemispheric coverage and during periods of eclipse. This section provides a description of the proposed system.

Key Performance Parameters (KPPs)

- GOES-R instruments must operate continuously during eclipse
- GOES-R must improve the temporal resolution of the imager over the full disk from 30 minutes to 15 minutes or less.
- GOES R must meet “simultaneous” global/synoptic/ mesoscale imaging needs by providing temporally interspersed images that meet the following schedule: 15-minute (or faster) full disk coverage, 5-minute CONUS coverage, and when commanded 30 second mesoscale coverage.
- GOES-R must improve spatial resolution of the imager in the infrared from 4 km to 2 km
- GOES-R sounding must improve the sounding coverage rate by factor of 4 compared to the current GOES-I and –N series sounders, accounting appropriately for any spatial resolution differences.
- GOES-R sounding must improve the rms temperature error from 2° K to 1° K over the region from 800 mb to 400 mb and rms relative humidity error from 20% to 11 % or smaller.

3.1 Distributed Architecture

One of the possible differences with this next generation satellite is the distributed architecture concept. GOES R could benefit from a new more flexible distributed system architecture. Distributed architecture differs from the current consolidated architecture, as sensors, communications and services are deployed across numerous satellites. Distributed architecture would enable NOAA to realize the benefits of prolonged satellite life. Satellites equipped with one as opposed to two frontline sensors (ABI and HES) would have longer mean mission durations (MMDs) because fewer components allows for greater reliability. In addition, separating components (sensors, communications, and services) increases technology infusion flexibility and improves sparing strategy. In the event of a sensor failure or an infusion opportunity, NOAA would replace or upgrade only those affected components.

The optimal GOES R architecture is being evaluated by a twelve-month, industry led, architecture study. Options include varied communications alternatives. There are at least three alternative architectures for handling communications. Figure 4 depicts one example of the GOES R distributed architectures. The inclusion of alternative orbits, such as Mid Earth Orbit (MEO) for communications and services is also a consideration and would enable GOES R to support other missions and provides transition to NOAA's concept of a Global Observing System. Other options include dedicated communications satellites at GEO, or communications co-located with sensors.

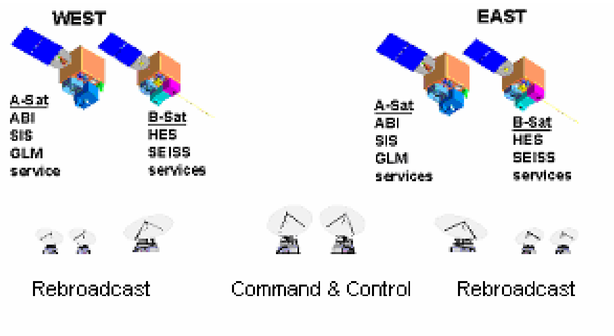

Figure 4. Distributed GOES R Architecture

GOES will continue to provide existing rebroadcast services. Federal, state and local agencies, academia, and industry, on a worldwide basis, will be able to access GOES R series real-time rebroadcast data. Collected and Processed instrument data is redistributed using GOES R. Broadcast capabilities of the GOES R series are currently under study. The issue of how to perpetuate the current policy of global broadcasting of all processed data has not been resolved. Ending the global broadcast from GOES would reduce the RF requirements and alter the satellite design, but would severely impact some receive only sites. Commercial communications satellites and the use of landlines are also being considered.

3.2 Sensor Improvements

3.2.1 Advanced Baseline Imager (ABI)

The Advanced Baseline Imager is a new state of the art, 16-channel imager covering 2 visible bands (0.47 µm & 0.64 µm) and 14 IR bands (0.86 µm to 13.3 µm). Spatial resolution is band dependent, 0.5 km at nadir for visible, 1.0 km for near IR, and 2.0 km for IR.

ABI will provide three imaging sectors; Full Disk (FD), CONUS, and Mesoscale. Full Disk includes the full Earth view from space. The CONUS sector covers a 5000-kilometer (km) x 3000 km area, and Mesoscale covers a 1000 km x 1000 km square at nadir. Figure 5 depicts ABI and HES coverage from GOES R constellations. *ABI coverage is shown as the outer ellipses and HES coverage is shown as circles.*

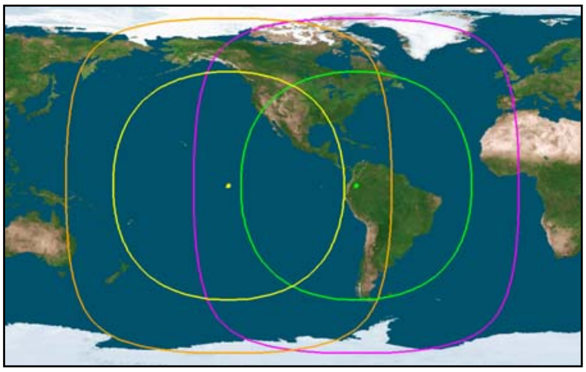

Figure 5. GOES R ABI and HES coverage

ABI has two imaging modes; Mode 3 and Mode 4. Mode 3 imaging can provide 1 Full Disk Image, 3 CONUS and 30 Mesoscale images, every 15 minutes. Mode 4 can provide 30 Mesoscale images every 15 minutes as well as a Full Disk every 5 minutes.

Figure 6 compares current GOES Full Disk coverage against GOES R Mode 4. Current GOES (I-P) provides a Full Disk every 30 minutes: GOES R will provide a Full Disk every 5 minutes under Scan Mode 4. GOES R will therefore provide six times the temporal coverage of current GOES.

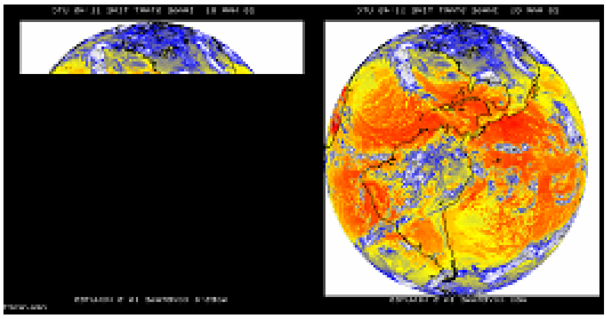

Figure 6. Five-Minute Coverage from GOES vs. GOES R

3.2.2 Hyperspectral Environmental Suite (HES)

The HES is a hyperspectral sounder and multi channel imager suite with three threshold tasks. HES will provide high-resolution Hemispheric Disk Soundings (DS) and Severe Weather Mesoscale (SW/M) soundings and Coastal Waters (CW) imaging. HES DS provides 10 km IR resolution from 3.7 µm to 15.4 µm with a one-hour refresh rate covering almost the full Earth disk with a 62° local zenith angle. Figure 5 illustrates the coverage expected with GOES HES.

SW/M will cover a 1000 x 1000 km square at a 4 km resolution for IR, as well as a single broadband visible channel for cloud detection. DS and SW/M may utilize the same IR and Visible focal planes. The total number of channels is still TBD, but expected to exceed 1500.

HES CW task will provide at least 14 channels coverage from 0.4 µm to 1.0 µm, with 300 meter or better visible resolution and a 3-hour refresh rate. CW has a goal resolution of 2 km for IR imagery. Coastal Waters are defined as the 400 km zone adjacent to CONUS, as well as waters surrounding Hawaii.

3.2.3 Solar Instrument Suite (SIS)

The SIS is comprised of several instruments (SXI, XRS, EUVS & Coronagraph) to monitor solar activity. The Solar X-ray Imager (SXI) is capable of operating in the soft X-ray to Extreme Ultra Violet (EUV) wavelength range. It provides full-disk solar images at high cadence around the clock, except for brief periods during orbital eclipse seasons. The X-ray Sensor will detect the beginning, duration, and magnitude of solar X-ray flares.

The Extreme UltraViolet Sensor (EUVS) will monitor the solar EUV flux in the 5 – 129 nm range. The Coronagraph solar imager is a pre-planned product improvement (P^3I) instrument for early detection of coronal mass ejections. Both the Solar X-ray Imager (SXI) and the coronagraph provide continuous images of the solar disk in X-ray and white light images of the solar corona, respectively

3.2.4 Space Environmental In Situ Suite (SEISS)

The SEISS monitors the near-Earth particle and electromagnetic environment. Instruments include a three-axis vector magnetometer and energetic particle sensors (EPS). SEISS is designed to provide real-time measurement of the charged particle environment, and the Earth's ambient magnetic field. EPS will measure proton, electron and alpha particle fluxes at GEO. All SEISS instruments shall be capable of operating and transmitting data during eclipses, and each instrument shall be capable of independent operation.

3.2.5 GOES Lightning Mapper (GLM)

The GLM shall continuously map the intensity, frequency and location of lightning discharges over both hemispheres and CONUS. A GLM with high spatial resolution and detection efficiency will be an invaluable tool in severe storms forecasting. GLM can detect storm formulation and determine maturity/severity over both land and oceans. Threshold hemisphere horizontal resolution shall be 10 km (with a objective of 1 km). The mapper will image 500 frames per second and capable of detecting in excess of 50 lightning strikes per second. The GLM should detect lightning strikes lasting longer than 1 microsecond (ms). The mapping accuracy should be 1 km (goal: 100 meter). The measurements would be disseminated in real time (within 1 minute) and could thus be related on a continuous basis to other observable data, such as radar returns, cloud images, and other meteorological variables.

4.0 HAZARDS MONITORING

The increased resolutions of GOES R (spatial, spectral and temporal) will benefit hazards management and environmental monitoring. The increased resolution and continual near time imaging of GOES R will improve response to hazard related events, such as hurricanes, floods and fires. GOES R increased resolution will enable more accurate location determinations and increased latency means earlier hazards detection. The increased temporal resolution provides more looks at the area of interest.

The Advanced Baseline Imager (ABI) will provide better smoke, plume, and fire detection. Figure 7 illustrates the fire and smoke detection capabilities using current GOES. Figure 8 denotes the improved plume detection expected with GOES R, using 0.5 km resolution from EOS MODIS as an example. GOES R will provide similar resolutions from GEO that LEO orbiting satellites provide today.

In addition to increased spatial resolution, ABI will have additional imaging bands to enable improved detection of smoke, volcanic ash, and aerosols. Figure 9 illustrates some volcanic ash detection improvements expected due to the additional of five new ABI channels covering 8.5 to 12.3 µm.

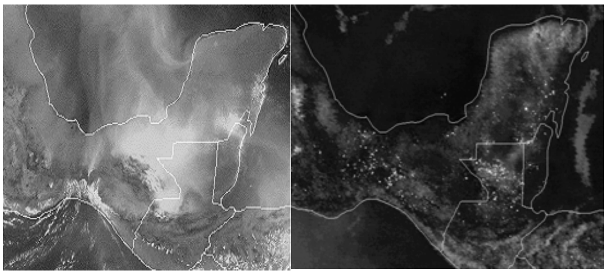

Figure 7. Visible and IR Fire Detection

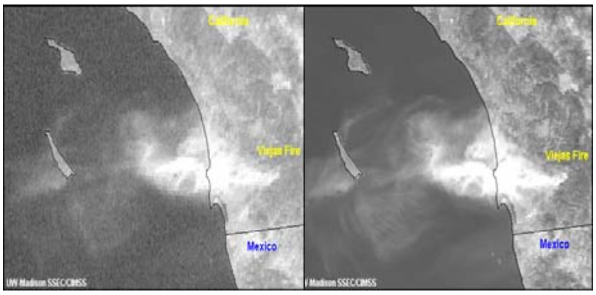

Figure 8. Smoke Plumes From GOES vs. GOES R

Improved data latency and faster scan rates will also provide increased storm detection and warnings. Increased warnings will benefit hazards response and hazards management. GOES R will provide day/night cloud and moisture imagery every 5 minutes with 5 minute data latency rates. Mesoscale refresh rates and data latency will both be 30 seconds. These rates represent six-fold increase in temporal resolution. The increased GOES R spatial resolution will also improve analysis of storm and moisture formations. Figure 10 illustrates the improvements in hurricane detection expected with GOES R.

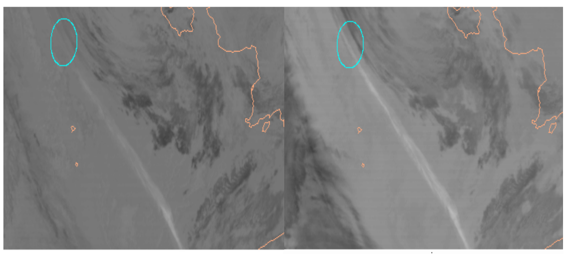

Figure 9. Volcanic ash detection (8.5 and 12.3 µm)

Hyperspectal sounding and imaging will benefit airborne disease tracking by measuring atmospheric inversions, cloud properties, land/sea surface properties and moisture gradients. HES will improve water vapor depiction by identifying small-scale features vertically and horizontally. HES will likewise characterize the complete life cycle of clouds, as well as distinguish between ice and water clouds.

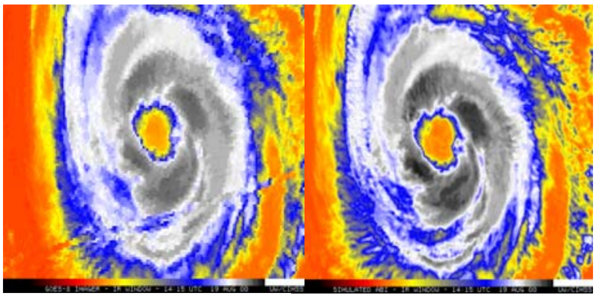

Figure 10. Hurricane Coverage From GOES vs. GOES R

The large number of HES hyperspectral channels will enable near real time trace analysis of chemical and biological hazards at 4 km and 10 km resolutions. HES soundings will detect and characterize a variety of gases, such as sulfuric dioxide, carbon and carbon monoxides.

The HES Coastal Waters Imager will enable high resolution monitoring of flooding, floating debris, spills and tide conditions, such as Harmful Algae Blooms (aka red tides). The 300 m spatial resolution and hourly revisit time of Coastal Waters Imager will enable near real time monitoring of coastal hazards.

The GOES Lightning Mapper will enable improved tracking of storms and lightning hazards by real time monitoring of the location and frequency of lightning strikes. Ground based Lightning tracking only detect cloud to ground strikes. The GOES Lightning Mapper will improve safety and save lives by detecting intra cloud, inter cloud and cloud to ground strikes.

The combination of GOES R ABI, HES and G&LM will benefit hazards management on various levels. In addition to storms, hurricanes, floods, spills, and lightning, GOES R will improve the following hazards related products.

GOES Product Improvements

- Hydrologic forecasts and water resources management
- Short-term and mesoscale forecast
- Ocean surface and internal structures forecasts
- Medium range forecast outlook (out to fifteen days)
- Solar and space environmental forecasts
- Aviation forecasts (domestic, military, and international)
- Ice conditions forecasts
- Seasonal and inter-annual climate forecasts
- Decadal-scale monitoring of climate variability
- Environmental air quality monitoring and emergency response
- Long-term global environmental change assessment
- Nowcasting capabilities

5. CONCLUSION

The GOES R system will transition from and begin replacing the GOES N series beginning circa 2012. Based on new architecture concepts and system designs, the GOES R series will continue to meet and exceed GOES mission goals. GOES R will improve data latency and eliminate existing problems with simultaneous mesoscale/hemispheric coverage and data loses during eclipses.

Sensor improvements will enable more timely land, atmospheric and ocean forecasts. The increase in GOES R latency and revisit times will improve forecasts and climate/hydrology monitoring.

The inclusion of a GLM will provide continuous lightning detection over land and water. Storm severity, maturity and advanced warning will be improved by the ability to track lightning intensity, frequency and location from space.

In addition to day/night weather coverage, GOES R will have the added benefit of monitoring hazardous spills, floods and forest fires. The ability of GOES R to monitor aerosols, dust, and suspended matter will benefit hazard management and improve homeland security. For additional information, please visit NOAA's GOES R webpage at http://www.osd.noaa.gov/goes_R/index.htm.

6. REFERENCES

Consolidated Observations Requirements List (CORL), Version 0.1, June 2002

Mission Requirements Document, -1A Draft, (MRD1), NOAA GOES Program Office, July 2003

NESDIS, A Strategic Approach for the New Millennium, 2001

NESDIS Mission Observations Requirements List (MORL), Version 0.1, June 2002

NOAA NESDIS Satellite Data Processing Center, Comprehensive Large Array-data Steward-ship System (CLASS) Archive and Access Requirements, July 20, 2001

Program Requirement Document – 1 Final Draft, NOAA, (PRD1), June 2003

7. ACKNOWLEDGEMENTS

MODIS Images courtesy of UW Madison, SSEC/CIMSS. GOES 8 and GOES 10 imagery courtesy of NOAA.