An Overview of the Design and Development of the GOES R-Series Space Segment

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GOES-R Series Overview

Mission: Provide continuous imagery and atmospheric measurements of Earth’s Western Hemisphere and space weather monitoring.

- GOES-R is the newest generation of United States geostationary weather satellites
  - Provides the first update in sensor technology since the GOES-I launch in 1994
- Four satellites in the series: GOES-R, S, T and U
- Joint mission between NASA and NOAA
  - Continuing the successful partnership on weather satellite programs since the 1970s

<table>
<thead>
<tr>
<th>GOES-R Mission Key Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth observation from 68ºN to 68ºS latitude &amp; 150ºE to 2ºW longitude</td>
</tr>
<tr>
<td>Full Earth disk image every 15 minutes</td>
</tr>
<tr>
<td>Key Performance Parameter (KPP): Cloud and Moisture Imagery</td>
</tr>
<tr>
<td>Data Latency less than or equal to product refresh rate</td>
</tr>
<tr>
<td>34 atmospheric, land, ocean, space, and solar weather products</td>
</tr>
<tr>
<td>Replacement for failed spacecraft with on-orbit spare: 3 weeks</td>
</tr>
<tr>
<td>Mission availability for East and West stations: 0.80</td>
</tr>
<tr>
<td>Data outages &lt;=6 hours per year</td>
</tr>
<tr>
<td>7 day satellite autonomy</td>
</tr>
</tbody>
</table>
A History of GOES Weather Satellites

- **1975**: GOES 1-3
  - NOAA’s First GOES
  - Spin-stabilized

- **1980**: GOES 4-7
  - Vertical Profiling

- **1994**: GOES 8-12
  - 3-axis stabilized
  - Simultaneous imaging, sounding 100% of time

- **2006**: GOES 13, 14, 15
  - Simultaneous, independent imaging, sounding

- **2016**: GOES-R Series
  - Improved spectral, spatial and temporal resolution in imaging
  - Lightning mapping
  - Improved space weather monitoring
GOES-R Program Timeline

We are here

Implementation Start
Baseline Algorithm Delivery
GOES-R Instrument Deliveries
GOES-S ORR PSR
GOES-T ORR PSR
GOES-U ORR

Formulation Start
Spacecraft Core GS
GOES-R&S LV Start

GOES-R Operating Life
GOES-S Operating Life
GOES-T Operating Life
GOES-U Operating Life

1st Budget Estimate
L1 Req’ts Signed
SUVI SRR CDR
GLM KDP I SDR
SEISS PDR

GOES-R Architecture Overview

GOES-West 137°W

On-orbit Storage 105°W

GOES-East 75°W

NOAA Satellite Operations Facility, Suitland MD

Command and Data Acquisition Station, Wallops VA

Consolidated Backup, Fairmont WV
GOES-R Space Segment Overview

- Extreme Ultraviolet and X-Ray Irradiance Sensor (EXIS)
- Space Environment In Situ Suite (SEISS)
- Solar Ultraviolet Imager (SUVI)
- Magnetometer
- Geostationary Lightning Mapper (GLM)
- Advanced Baseline Imager (ABI)
Advanced Baseline Imager (ABI)

- Primary instrument in GOES-R series
- 16 channel imager
- Measures radiances in the visible and near-infrared wavelengths
- Improves upon current capabilities in spectral (3X), spatial (4X), and temporal resolution (5X)

<table>
<thead>
<tr>
<th>Band</th>
<th>Central Wavelength</th>
<th>SNR or NEdT</th>
<th>Pixel Size (at nadir)</th>
<th>Band Name/Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.47</td>
<td>300:1</td>
<td>1km</td>
<td>Blue</td>
</tr>
<tr>
<td>2</td>
<td>0.64</td>
<td>300:1</td>
<td>0.5km</td>
<td>Red</td>
</tr>
<tr>
<td>3</td>
<td>0.86</td>
<td>300:1</td>
<td>1km</td>
<td>Vegetation</td>
</tr>
<tr>
<td>4</td>
<td>1.38</td>
<td>300:1</td>
<td>2km</td>
<td>Cirrus</td>
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<tr>
<td>5</td>
<td>1.6</td>
<td>300:1</td>
<td>1km</td>
<td>Snow/ice</td>
</tr>
<tr>
<td>6</td>
<td>2.2</td>
<td>300:1</td>
<td>2km</td>
<td>Cloud Particle Size</td>
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<tr>
<td>7</td>
<td>3.9</td>
<td>0.1K</td>
<td>2km</td>
<td>Shortwave Window</td>
</tr>
<tr>
<td>8</td>
<td>6.2</td>
<td>0.1K</td>
<td>2km</td>
<td>Upper-Level Tropospheric Water Vapor</td>
</tr>
<tr>
<td>9</td>
<td>6.9</td>
<td>0.1K</td>
<td>2km</td>
<td>Mid-Level Tropospheric Water Vapor</td>
</tr>
<tr>
<td>10</td>
<td>7.3</td>
<td>0.1K</td>
<td>2km</td>
<td>Lower-level Water Vapor</td>
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<tr>
<td>11</td>
<td>8.4</td>
<td>0.1K</td>
<td>2km</td>
<td>Cloud-Top Phase</td>
</tr>
<tr>
<td>12</td>
<td>9.6</td>
<td>0.1K</td>
<td>2km</td>
<td>Ozone</td>
</tr>
<tr>
<td>13</td>
<td>10.3</td>
<td>0.1K</td>
<td>2km</td>
<td>Clean IR Longwave Window</td>
</tr>
<tr>
<td>14</td>
<td>11.2</td>
<td>0.1K</td>
<td>2km</td>
<td>IR Longwave Window</td>
</tr>
<tr>
<td>15</td>
<td>12.3</td>
<td>0.1K</td>
<td>2km</td>
<td>Dirty Longwave Window</td>
</tr>
<tr>
<td>16</td>
<td>13.3</td>
<td>0.3K</td>
<td>2km</td>
<td>CO2 longwave infrared</td>
</tr>
</tbody>
</table>

ABI at Harris Corp
GOES-R ABI Provides
3X More Spectral Information

GOES-N Series Imager

GOES-R Series ABI

Red

Blue

0.47 µm

0.64 µm

0.86 µm

1.38 µm

Red

Vegetation

Cirrus

1.61 µm

2.26 µm

3.9 µm

6.19 µm

Snow/Ice

Cloud Prt Size

SW Window

Up H2O Vapor

1.61 µm

6.92 µm

7.34 µm

8.5 µm

9.61 µm

LW Window

Cloud Top Phs

Lw H2O Vapor

Ozone

6.92 µm

10.35 µm

11.2 µm

12.3 µm

11.3 µm

LW Window

LW Window

LW Window

CO2

Courtesy: NOAA/NESDIS STAR, CIMSS and GOES-R Imagery Team
In 15 Minutes, GOES-N Imager can scan:
- Most (3/5) of a Full Disk Image

In 15 Minutes, GOES-R ABI can scan:
- 15 Mesoscale Images
- 3 CONUS Images
- 1 Full Disk Image

Courtesy Jun Li and Chian-Yi Liu (CIMSS). Water vapor Image. Data from AWG Proxy Teams.
Geostationary Lightning Mapper (GLM)

- GLM is a high speed CCD camera that detects ozone emissions at 777.4nm
- Detects total lightning activity across the Western Hemisphere: in cloud, cloud-to-cloud, and cloud-to-ground
  - Provides coverage over oceans and land
  - Complements today’s land based systems that only measures cloud to ground (~15% of the total lightning)
  - Improves forecaster situational awareness and confidence resulting in more accurate storm warnings (improved lead time, reduced false alarms) to save lives and property
Solar Ultraviolet Imager (SUVI)

- Continuously images the sun in 6 extreme ultraviolet wavelengths to characterize active region complexity
- Locates coronal holes, flares and coronal mass ejection source regions
- Thematic maps will be used to automate the identification and location of bright regions, flares and coronal hole boundaries in solar images
- Improves geomagnetic storm forecasting
Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS)

• EXIS has two sensors to measure solar radiation:
  ➢ Extreme Ultraviolet Sensor (EUVS): monitors solar variations that affect satellite drag, and ionospheric changes impacting communication and navigation operations
  ➢ X-Ray Sensor (XRS): detects the beginning, duration, and magnitude of solar X-ray flares
• Provides improved solar flare warnings for communications and navigation disruption
• Provides input to models predicting impacts on satellites, astronauts, and airline passengers on polar routes, and power grid performance

EXIS at the University of Colorado LASP
Space Environment in-Situ Sensor Suite (SEISS)

- SEISS consists of energetic particle sensors to monitor proton, electron, and alpha particle fluxes
- SEISS provides:
  - More accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft
  - Better monitoring of ionizing responsible for spacecraft charging
  - Improved warning of high flux events, mitigating damage to radio communication

SEISS at Assurance Technology Corp

1st SEISS Data Release
Magnetometer

- Consists of two sensors located on an 8 meter deployable boom structure that distances them from the magnetic signature of the spacecraft
  - Each sensor uses 3 flux gate magnetometers to measure the orthogonal vector components of the Earth’s mag field
- Magnetic field measurements provide information on the general level of geomagnetic activity, and enable detection of sudden storm commencements, substorms, & magnetopause crossings
GOES-R Communications Services

• **Search and Rescue Satellite Aided Tracking (SARSAT)**
  – All GOES-R satellites support the SARSAT system by relaying distress signals from 406 MHz emergency beacons

• **Information Network (HRIT/EMWIN)**
  – Delivers selected imagery, charts, other environmental data products, and text messages (NWS Watches and Warnings) to hemispheric users.
  – Combination of today’s LRIT (Low Rate Information Transmission) and Emergency Managers Weather Information Network services

• **Data Collection System (DCS)**
  – GOES-R spacecraft relay data transmissions for ~20,000 in-situ environmental data platforms from across the hemisphere

• **GOES Rebroadcast (GRB)**
  – GRB will contain the Level 1b data from each of the GOES-R Series instruments and is the GOES-R Series version of today’s GOES Variable format (GVAR)
GOES-R Spacecraft Overview

SEISS Cabinet houses 4 of 5 sensors

Earth Pointing Platform isolated from Spacecraft body to provide low jitter environment for ABI and GLM. Platform has star trackers and gyros to provide attitude information for instrument navigation.

Solar Pointing Platform on Solar Array Wing provides constant view of Sun for SUM & EXIS

Antenna Wing hosts communications services

Magnetometer & 5th SEISS sensor on +X panel not shown
GOES-R Spacecraft Design

- Customized Lockheed Martin A2100 spacecraft with upgrades to meet GOES-R requirements
  - Stable and accurate pointing achieved with:
    - Isolated Earth Pointing Platform
    - Isolated Reaction Wheels
    - Correction of spacecraft-induced torques with reaction wheel speed changes
    - Accurate attitude sensing with gyro, star tracker, and diagnostic accelerometers
  - No observing time lost to station keeping or momentum adjustment maneuvers
    - Low thrust rocket engines with correction of applied torques
  - Onboard orbit determination
    - 1st civilian use of GPS in geo orbit
  - High speed, error free data transmission
    - SpaceWire data bus
    - GOES-R Reliable Data Delivery Protocol
  - EMI compatibility with UHF payloads
    - Stringent EMI design and test methods

<table>
<thead>
<tr>
<th>Key GOES-R Space Segment Performance Parameters</th>
<th>Requirement</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pointing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitude Knowledge - Diurnal</td>
<td>45μrad 3σ</td>
<td>26μrad 3σ</td>
</tr>
<tr>
<td>Attitude Integrated Rate Error provided to ABI - 1 Sec</td>
<td>1μrad 3σ X,Y, 1.5μ 3σ Z</td>
<td>0.8μrad 3σ</td>
</tr>
<tr>
<td>Attitude Integrated Rate Error provided to ABI - 30 Sec</td>
<td>2μrad 3σ X,Y, 2.5μ 3σ Z</td>
<td>&lt;1.0μrad 3σ</td>
</tr>
<tr>
<td>Attitude Integrated Rate Error provided to ABI - 300 Sec</td>
<td>7μrad 3σ per axis</td>
<td>&lt;=1.8μrad 3σ</td>
</tr>
<tr>
<td>Attitude Integrated Rate Error provided to ABI - 900 Sec</td>
<td>18.5μrad 3σ per axis</td>
<td>&lt;=2.7μrad 3σ</td>
</tr>
<tr>
<td><strong>Orbit Knowledge</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Track Position</td>
<td>75m 3σ</td>
<td>13m 3σ</td>
</tr>
<tr>
<td>Cross-Track Position</td>
<td>75m 3σ</td>
<td>7.3m 3σ</td>
</tr>
<tr>
<td>Radial Position</td>
<td>100m 3σ</td>
<td>20m 3σ</td>
</tr>
<tr>
<td>Velocity</td>
<td>6 cm/sec 3σ</td>
<td>0.85 cm/sec 3σ</td>
</tr>
<tr>
<td><strong>Navigation Accuracy</strong></td>
<td>ABI</td>
<td></td>
</tr>
<tr>
<td>GLM</td>
<td>28μrad (1km at nadir) 3σ</td>
<td>20μrad 3σ</td>
</tr>
<tr>
<td>EMI (for SAR and DCPR) in UHF band</td>
<td>-12 dBμV/m</td>
<td>-24 dBμV/m</td>
</tr>
<tr>
<td>Raw Data Transmission</td>
<td>Transmit Data Rate</td>
<td>120Mbps</td>
</tr>
<tr>
<td>Raw Data Link Margin</td>
<td>3dB</td>
<td>9dB</td>
</tr>
<tr>
<td>Availability</td>
<td>Lost observation time</td>
<td>&lt;120 min per year</td>
</tr>
<tr>
<td>Fuel Lifetime</td>
<td>For on-orbit storage + operations</td>
<td>15 years</td>
</tr>
</tbody>
</table>

- EMI compatibility with UHF payloads
  - Stringent EMI design and test methods
GOES-R Techniques for Stable Pointing

Reaction Wheels Isolation to Minimize Disturbances Transmitted to Spacecraft

Earth Pointing Platform Isolated to Minimize Disturbances to ABI & GLM

Reaction Wheels not Isolated

Reaction Wheels Isolated

Without Torque Compensation

With Torque Compensation

Spacecraft Body Rates during ABI Scanning, before and after Enabling Torque Compensation
GOES-16 Imagery

ABI 1st Light, January 7, 2017
RGB using 0.47um, 0.64um, 0.86um
First ABI Public Release

GOES-16 vs GOES-13 on January 15, 2017
Full Disk Imagery Increased
From 8X to 96X per Day

GOES-R every 15 minutes

GOES-N every 3 hours

Courtesy Dan Lindsey, Colorado State University/CIRA
ABI Tracks Wild Fires

3.9 um (hotspots)
0.47 um (smoke plumes)

Courtesy Bill Line, National Weather Service
ABI 3.9um Channel Sees Atlas V Launch
ABI Band 13 Infrared Imagery
Severe Weather in Eastern U.S.
GLM Lightning Detected during Severe Weather in Eastern U.S.

GLM lightning superimposed on GLM background
SUVI 304Å Channel

Courtesy
Lockheed Martin
Hurricane Harvey Strikes Texas Coast
Lightning in Hurricane Harvey

ABI 0.47um Imagery with GLM lightning groups

Courtesy UW CIMSS
GOES-S Satellite at Lockheed Martin
Many thanks to the GOES-R Team!

Check out the latest GOES-16 Imagery at:
www.goes-r.gov
Twitter.com: #GOES16
http://cimss.ssec.wisc.edu/goes/blog/
http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/