GOES Environmental Satellites

GOES-R series satellite, artist's rendering. Credit: Lockheed-Martin

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 ocean, 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 2016. After a successful launch and deployment, GOES-R will be designated GOES-16.

The new instruments and their data

Advanced Baseline Imager for GOES-R. Credit: ITT Exelis

Two of the GOES-R instruments point toward Earth.

- The Advanced Baseline Imager is the primary instrument on GOES-R for imaging Earth's weather, climate and environment.
- The Geostationary Lightning Mapper will detect and map total lightning (in-cloud and cloud-to-ground flashes).

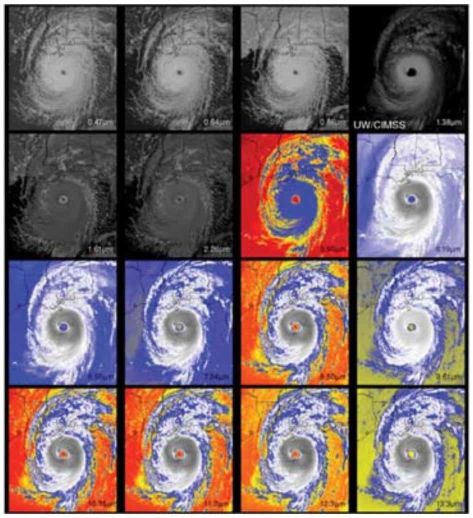
Two instruments point to the sun.

- The Solar Ultraviolet Imager will monitor solar X-ray flux with increased dynamic range, resolution and sensitivity.
- The Extreme Ultraviolet and X-ray Irradiance Sensors will monitor solar irradiance in the upper atmosphere.

Two in-situ instruments will monitor their own space environment.

- The Space Environment In-Situ Suite will monitor proton, electron and heavy ion fluxes at geosynchronous orbit and assess the risk of radiation posed to astronauts and high-altitude aircraft.
- The Magnetometer will monitor Earth's geomagnetic field, including geomagnetic storms and sub-storms.

The imager: From 16 notes, a symphony



The Advanced Baseline Imager separates energy into 16 spectral bands, allowing detailed differentiation among phenomena in the scene. Simulated Hurricane Katrina images from August 28, 2005. Credit: CIMSS

The **Advanced Baseline Imager** (ABI) will be able to view Earth in 16 different spectral bands. It is as if the imager has 16 different kinds of sunglasses, each one allowing only a certain wavelength—also called a band or channel—of light to come through. The imager detects two visible, four near-infrared and ten infrared bands. Each band is like a separate "color" of light, except that all but two of the 16 colors are invisible to human eyes.

The imager will be a huge advance over the current system, providing three times more differentiated spectral information, four times better spatial resolution and more than five times faster coverage of the same area. Forecasters will be able to use the higher resolution images to track the development of storms in their early stages.

A wide range of practical products will be generated from GOES-R imager data. These products apply to weather, oceans, land, climate and hazards (like fires, volcanoes, hurricanes and storms that spawn tornados). The GOES-R ABI will improve on every product provided by the current GOES imager and will introduce a host of new products for severe weather forecasting, fire and smoke monitoring, volcanic ash advisories and more.

In addition, several new products, such as hurricane intensity estimation and atmospheric visibility, will make use of the improved spectral, temporal and spatial resolution.

An independent study estimates that the monetary benefits to just five of the societal application sectors (aviation, energy, irrigated agriculture, recreational boating and tropical cyclones) will be at least $4.6 billion more than provided by the current system.

Summary of Advanced Baseline Imager's 16 spectral bands and sample uses

Six of the ABI bands are similar to the current GOES imager. Starting with the shorter wavelengths, these bands are useful for the following:

- Detecting daytime clouds, fog, insolation and winds.
- Detecting fog and low clouds at night, fire and hot spots, volcanic eruption and ash, and daytime snow and ice. This band is also useful for studying urban heat islands and for many other applications.
- Monitoring water vapor in the mid-troposphere.
- Measuring radiances for numerical weather prediction, imagery, land and sea surface temperature, cloud properties, rainfall rate and fire hot spots.
- Detecting low-level moisture, volcanic ash, dust, sea surface temperature and cloud particle size.
- Detecting clouds, assigning cloud-top drift motion vectors, providing high-cloud products to supplement surface-based observations, delineating tropopause and estimating cloud opacity.

Ten of the ABI bands are new to GOES-R, allowing new products. Ordered from the shorter wavelength, visible-light bands to the near-infrared and infrared, these additional bands are useful for the following:

- Detecting aerosols and estimating visibility.
- Detecting aerosols and estimating vegetation health.
- Detecting very thin cirrus clouds.
- Discriminating between snow and cloud.
- Estimating aerosol and cloud particle size, assessing vegetation health, assessing and screening cloud properties, detecting hot spots, determining moisture and detecting snow.
- Two bands for detecting and tracking mid-tropospheric water vapor and detecting upper-level sulfur dioxide.
- Detecting volcanic dust clouds containing sulfuric acid aerosols and for estimating cloud phase.
- Monitoring atmospheric total-column ozone and upper-level dynamics.
- Deriving low-level moisture and cloud particle size.
- Monitoring air temperature, cloud heights and volumes.

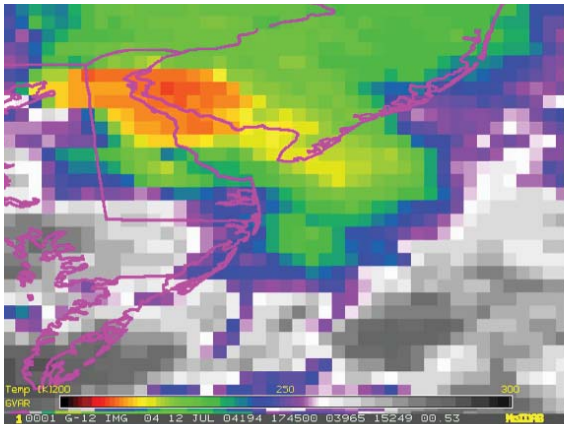
Each of these bands is often used in conjunction with other bands for generating products, such as the clear sky mask or aviation-related products.

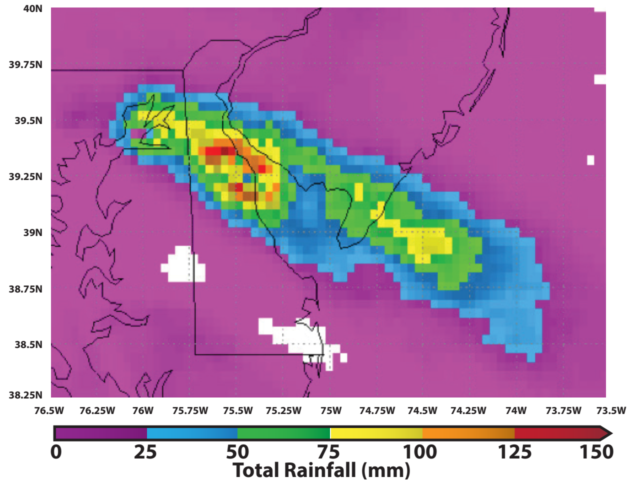
In developing each of the ABI's products, scientists develop an Algorithm Theoretical Basis Document. Data sets are selected to serve as proxy for the GOES-R imager data in order to validate and assess how well the algorithms perform. The theoretical basis documents for each product can be found at www.goes-r.gov.

Will it rain? Rainfall-related products

Satellites provide critical information about rainfall to supplement networks of ground-based radars and rain gauges.

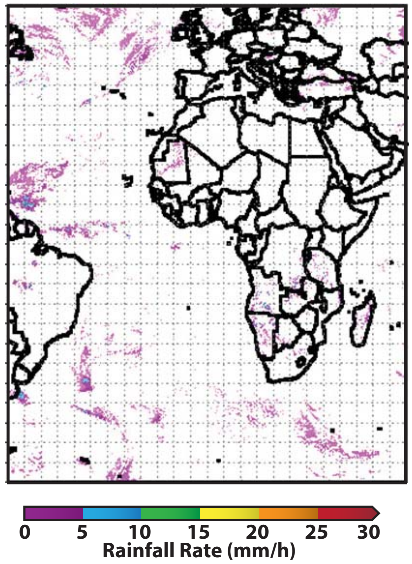
The GOES-R **Rainfall Rate** product from Advanced Baseline Imager data will estimate current rainfall rates over mountainous terrain and other areas where floods often originate, as well as ocean regions for monitoring incoming storms. It will provide twice the resolution (2 km vs. 4 km) of the current GOES imager. The advanced imager's near-infrared and infrared bands will account for cloud-top properties (whether water is in its gas, liquid or frozen state, as well as particle size) in deriving rainfall rates.





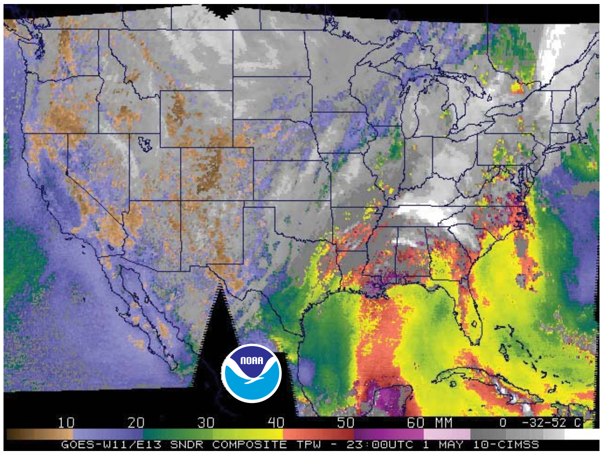
In the top image, cold (red) temperatures on infrared satellite imagery indicate deep, cold thunderstorm clouds with heavy rain. The bottom image is a simple schematic of Rainfall Rate estimation using the satellite imagery. Credit: NOAA/NESDIS/STAR

The **Rainfall Rate** product uses a statistical model to calibrate data from the visible and infrared portions of the spectrum against rainfall rate information from low-Earth-orbiting microwave observations. This method represents a step forward from the current-generation algorithm, which uses a "one size fits all" calibration for all regions and seasons.



Example of the Rainfall Rate product as generated by the GOES-R Rainfall Rate algorithm using Meteosat-8/SEVIRI (Spinning Enhanced Visible and Infrared Imager) data on January 7, 2005 12:45 UTC. Credit: NOAA/NESDIS/STAR

Total Precipitable Water is the amount of liquid water in a column of atmosphere from the surface to the top of the atmosphere. It is derived from atmospheric moisture profiles. Visualization of this product can reveal "atmospheric rivers." These are long, narrow filaments of moisture that can persist in the atmosphere for several days and can transport as much water as the Amazon River.



The Total Precipitable Water product will help to predict heavy rain events, such as that experienced by Nashville, Tennessee, in May 2010, when a plume of deep tropical moisture extended from the southern Gulf of Mexico northward into the Tennessee River Valley. Credit: NOAA/GOES-13

The improved accuracy and coverage of the rainfall products generated by ABI will lead to improved forecasting and warning of impending floods, reducing their economic cost and threat to human safety.

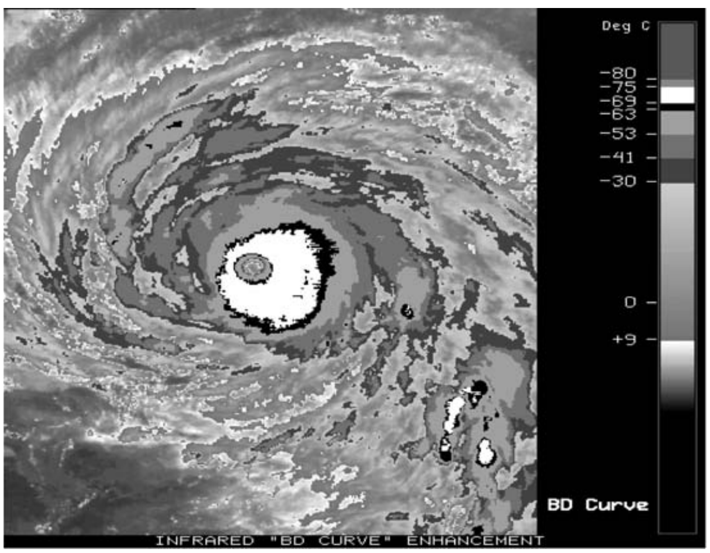
Should we evacuate? Severe storm warnings

Hurricanes

At NOAA's National Hurricane Center, the mission is to save lives, mitigate property loss and improve economic efficiency by issuing the best watches, warnings, forecasts and analyses of hazardous tropical weather, and by increasing understanding of these hazards.

Hurricane Katrina in 2005 was a powerful example of a devastating disaster that could have been much worse if not for the accurate and timely track forecasts and warnings issued by the National Hurricane Center. While hurricane track forecasts have generally improved over the past decade or two, less progress has been made with intensity forecasts.

The **Hurricane Intensity Estimate** product will produce real-time estimates of hurricane central pressure and maximum sustained winds using imagery from the GOES-R Advanced Baseline Imager.



GOES-R imagery will provide higher resolution of hurricane intensity indicators, such as temperature difference throughout the storm structure. *Credit: NOAA/NESDIS/STAR*

The improved performance and better resolution of the GOES-R imager will allow for better characterization of small hurricane eyes. The **Hurricane Intensity Estimate** will generate an intensity estimate analysis from the most current satellite image, as well as additional information about the intensity trend of the storm. Graphic illustrations and text listings of the hurricane intensity estimates will be distributed to users in real time.

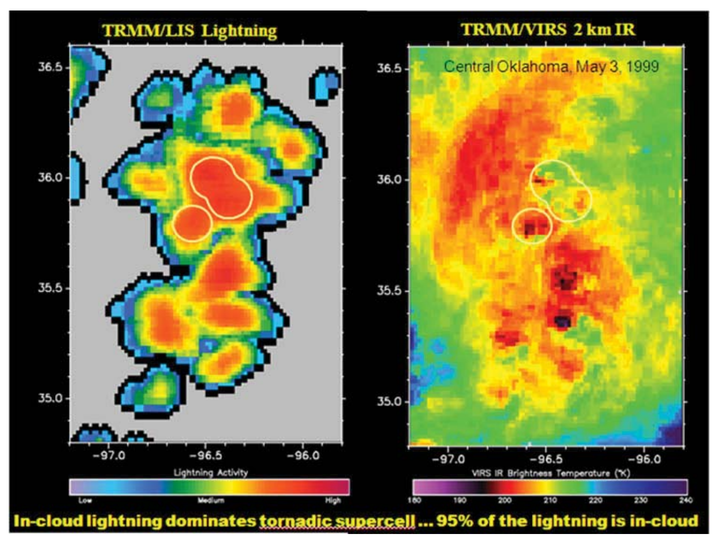
The advanced observational capabilities available from GOES-R will enable the National Hurricane Center to more accurately estimate hurricane intensity, leading to improved forecasts and extended forecast lead times.

Tornadoes

Because tornadoes are smaller than hurricanes, and the odds of a direct hit seem remote, people often do not heed the warnings. More precise warnings could save lives. GOES-R's advanced sensors for measuring key ingredients of severe weather, including winds, cloud growth and lightning, will help to fine-tune tornado warnings.

The **Cloud and Moisture Imagery** product will use all 16 spectral bands of the GOES-R ABI. The algorithms used in this product produce digital maps of clouds and moisture in the atmosphere based on measured reflectance within the visible bands and radiance within the infrared bands. These two values will be used to generate an array of forecast products that will help in monitoring and predicting all kinds of hazards, including tornados.

Studies show that a sudden increase in **Total Lightning Activity**—or flash rate—correlates with impending tornadoes and severe storms. The GOES-R Geostationary Lightning Mapper will take continuous day and night measurements of the frequent intra-cloud lightning that accompanies many severe storms, and will do so even when the high-level cirrus clouds atop mature thunderstorms may obscure the underlying convection from the imager. Thus, ABI and GLM will offer complementary and reinforcing sources of information on the intensity and life-cycle development of potentially severe storms.



These images are similar to what the GOES-R GLM and ABI would see. On the left is one minute of total lightning, mostly in-cloud lightning, as detected by the Lightning Imaging Sensor on the Tropical Rainfall Measuring Mission (TRMM) satellite. On the right is a 2-km infrared image from the Visible and Infrared Scanner on TRMM, which is the same resolution as the GOES-R imager. Both images were made from data taken during a May 3, 1999, tornado outbreak in Oklahoma

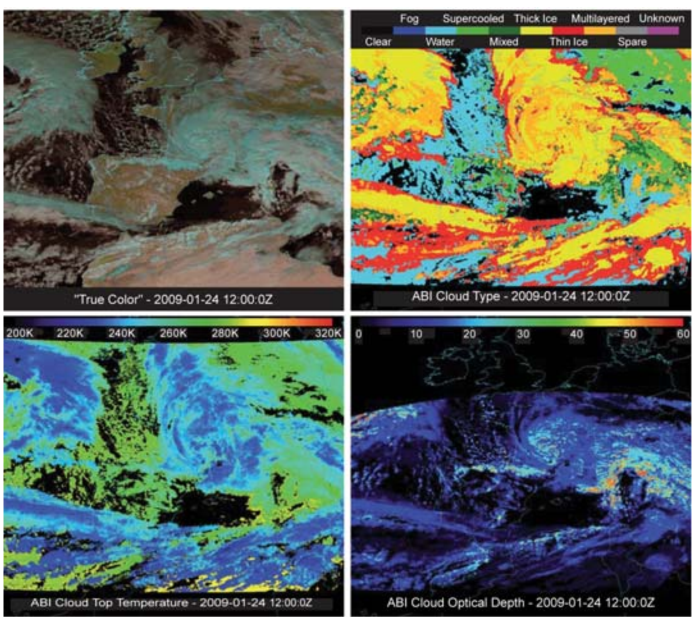
Is it safe to fly—or breathe? Clouds and aerosols

Cloud basics

The Advanced Baseline Imager will provide data for improved cloud monitoring and interpretation products that will allow prompt and accurate estimates of cloud and thunderstorm properties. These products will improve storm forecast models and provide more accurate data for model validation than the data available from the current GOES.

The **Clear Sky Mask** quickly distinguishes between clear and cloudy pixels and will be used in many of the other ABI products. One example is for Numerical Weather Prediction.

Cloud Top Phase classifies the type of clouds in a given scene. Categories include clear (no cloud), fog, supercooled, mixed, thick ice, cirrus and overlapping, while cloud phases include ice, water and mixed phase. These products are particularly effective in establishing the maturity, convective intensity and life-cycle evolution of systems of clouds. This is also important to determine what types of clouds may be in the path of aircraft in order to avoid potentially dangerous locations that may be prone to icing.

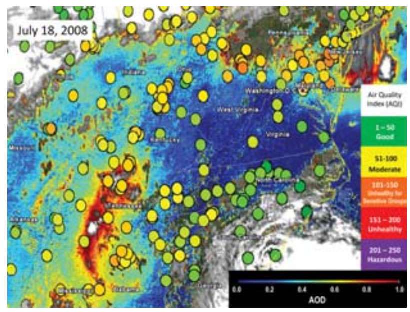


GOES-R simulated cloud product images using data from SEVIRI (Spinning Enhanced Visible and Infrared Imager) for a severe storm over France on January, 24, 2009. Credit: NOAA/NESDIS/ STAR

The **Cloud Top Height**, **Cloud Top Temperature**, and **Cloud Top Pressure** products indicate where the top of a cloud resides for a particular cloud-containing pixel. Cloud height information is used in weather prediction models and to forecast storm development. **Cloud Top Height** also contributes to aviation safety, enabling aircraft to be routed around towering thunderstorms and convective storm hazards.

Cloud optical and microphysical products include daytime and nighttime **Cloud Optical Depth** and **Cloud Particle Size Distribution**. These properties are important for climate research. For example, they provide information on how cloud effects feed back into Earth's radiation budget.

Aerosols



Values of Aerosol Optical Depth observed by GOES correlate well with EPA surface monitors (circles). GOES visible band observations were used to derive the Aerosol Optical Depth/Thickness. Credit: NOAA/NESDIS/ STAR

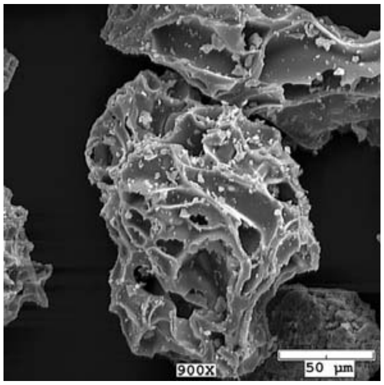
Aerosols (suspended particulate matter) are a key component of urban/industrial photochemical smog that leads to deteriorated air quality. They are also the primary pollutant in natural environmental disasters such as volcanic eruptions, dust outbreaks, biomass burning associated with agricultural land clearing and forest fires. Aerosols are detrimental to human health and the environment. High concentrations of aerosols, when inhaled, lead to upper respiratory diseases including asthma. They decrease visibility and lead to unsafe conditions for transportation. Aerosols are also a major influence on climate change. They affect the radiative balance of Earth, cooling or warming the atmosphere (depending on aerosol composition).

Aerosols scatter and absorb sunlight. When present in high concentrations, they are easily visible in satellite imagery. The **Aerosol Optical Depth** product is a measure of the atmospheric aerosol loading in a vertical column from the top of the atmosphere to Earth's surface. It is an effective stand-in for surface aerosol concentration measurements when aerosols are well-mixed and uniformly distributed in the lower atmosphere. By measuring **Aerosol Optical Depth** from the GOES-R imager, one can obtain information on surface aerosol concentrations to be used in air quality monitoring and forecasting applications. The **Aerosol Detection** product, on the other hand, is qualitative; it indicates the presence of aerosol (dust and/or smoke) in a given pixel and can be used to quickly identify the location of dust and smoke plumes.

But should we fly through that? Tracking volcanic ash

Augustine Volcano, Alaska. Image courtesy of U.S. Geological Survey. Image creator: Game McGimsey

Scanning electron microscope image of volcanic ash particles. Credit: Pavel Izbekov and Jill Shipman, Alaska Volcano Observatory/University of Alaska Fairbanks, Geophysical Institute



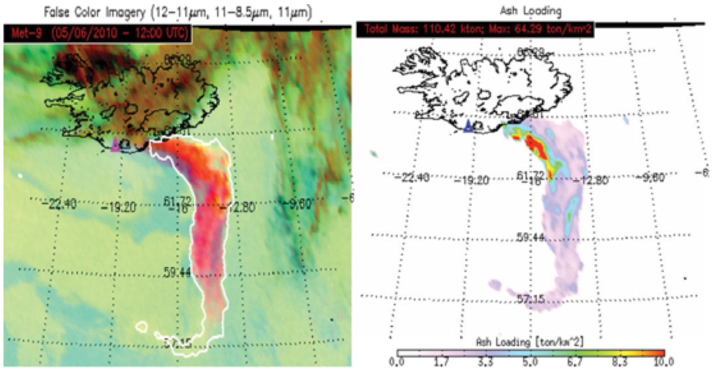
On average, more than 50 volcanic eruptions occur each year, many of which are within or downwind of the region viewed by the GOES satellites. Volcanic ash particles are like very fine particles of jagged broken glass, and airborne volcanic ash can cause significant aviation, health, infrastructure and economic damage. To minimize risk, it is important to monitor volcanic regions and promptly identify ash clouds.

Volcanic ash plumes at flight altitude are especially dangerous. They are often either invisible to the pilot or just look like another cloud. When ingested into aircraft engines, volcanic ash can lead to engine damage or failure. For example, in December 1989, a 747 jetliner carrying 231 passengers encountered an ash cloud during an eruption of the Mount Redoubt volcano, located southwest of Anchorage, Alaska. Within 60 seconds of encountering the heavy ash cloud, all four engines of the aircraft stalled. Fortunately, the pilot was able to restart the engines, narrowly avoiding a crash.

This KLM passenger jet engine has been damaged by volcanic ash.

The **Volcanic Ash Detection** product from GOES-R's Advanced Baseline Imager is customized for this aviation need.

Using five spectral bands of the GOES-R ABI, the **Volcanic Ash Detection** product will reveal the height and mass loading properties of any pixel found to contain volcanic ash. It will provide estimates of ash cloud coverage, height, mass and particle size, which are necessary to issue Significant Meteorological Information (SIGMET) advisories for aircraft and accurately forecast the dispersion of ash clouds.



Volcanic Ash Detection product (left) as indicated by white contour overlaid on false color Meteosat-9/SEVIRI (Spinning Enhanced Visible and Infrared Imager) image. The associated ash loading retrievals are also shown (right). Credit: NOAA/NESDIS/STAR

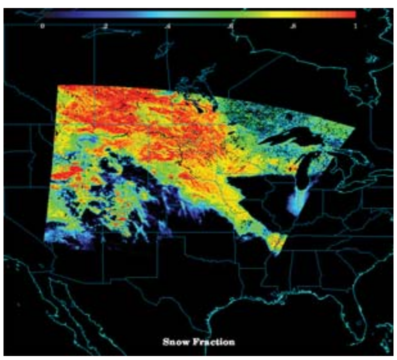
The advanced spectral, spatial and temporal resolution of the GOES-R imager will be used to generate a complete set of volcanic cloud detection and monitoring products, resulting in improved air and ground safety as well as economic savings. The GOES-R products will also be used to improve the modeling of volcanic ash clouds, which will allow for more accurate ash cloud dispersion and ash fall forecasts.

The big picture on the ground

The GOES-R series satellites will provide nearly continuous imagery of Earth's Western Hemisphere. It will not only be the primary tool for detecting and tracking hurricanes and severe weather, but will also provide new and improved applications and products for fulfilling NOAA's other missions with respect to water, climate, commerce and ecosystems.

Snow cover

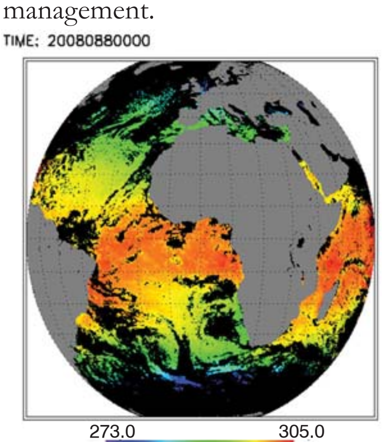
The **Snow Cover** product uses GOES-R Advanced Baseline Imager spectral information in the visible and near-visible wavelengths to estimate fractional snow cover per pixel, as well as grain size and the snow albedo of that fractional snow cover. This product will be assimilated into NOAA's snow product model. It will also be used in hydrologic forecasts and warnings, including river and flood forecasts, as well as water management, snowpack monitoring and analysis, and climate studies.



Example of the Snow Cover product as generated by the GOES-R snow fraction algorithm using MODIS data. Credit: NOAA/NESDIS/STAR

Sea surface temperature

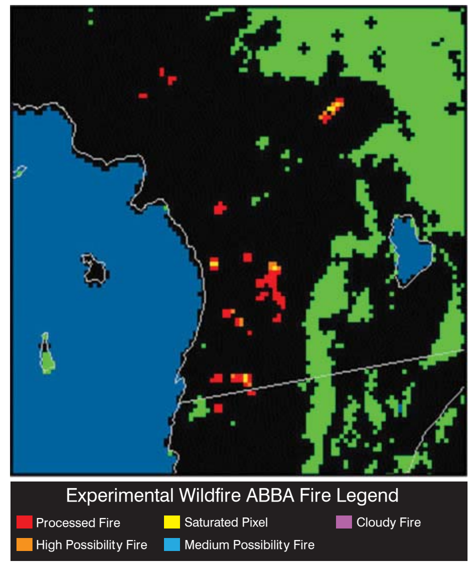
GOES-R will give forecasters a **Sea Surface Temperature** for each cloud-free pixel over water identified by the GOES-R ABI. Sea surface temperature data are useful for climate monitoring and forecasting, seasonal forecasting, operational weather and ocean forecasting, military and defense operations, validating or forcing ocean and atmospheric models, tracking of sea turtles, coral bleach warnings and assessment, tourism, and commercial fisheries management.



Proxy of product generated by the GOES-R Sea Surface Temperature algorithm using SEVIRI (Spinning Enhanced Visible and Infrared Imager) data. Credit: NOAA/NESDIS/STAR

What's burning?

Fires produce a heat signature detectable by satellites even when the fires represent a small fraction of the pixel. Compared to the current GOES imager, the GOES-R ABI will be able to detect this heat signature with improved temperature, temporal and spatial resolution. It will thus detect smaller fires and provide a more accurate estimate of the intensity of large fires. GOES-R will advance the ability of hazards and air quality monitoring communities to detect fires and their properties.



Example of the GOES-R Fire/Hot Spot Characterization product using simulated GOES-R ABI data over Southern California at 1825 UTC on October 23, 2007. Credit: NOAA/NESDIS/STAR

Search and rescue

GOES-R will carry a dedicated Search and Rescue Satellite Aided Tracking (SARSAT) transponder to detect signals transmitted from emergency beacons on aircraft, maritime vessels or individuals in distress. The transponder provides constant coverage to immediately receive and relay a 406-MHz emergency beacon alert to ground stations called Local User Terminals. GOES-R continues the legacy Geostationary SAR (GEOSAR) function of the SARSAT system carried on NOAA's GOES satellites since GOES-I. SARSAT has contributed to the rescue of thousands of individuals in distress in the United States and around the

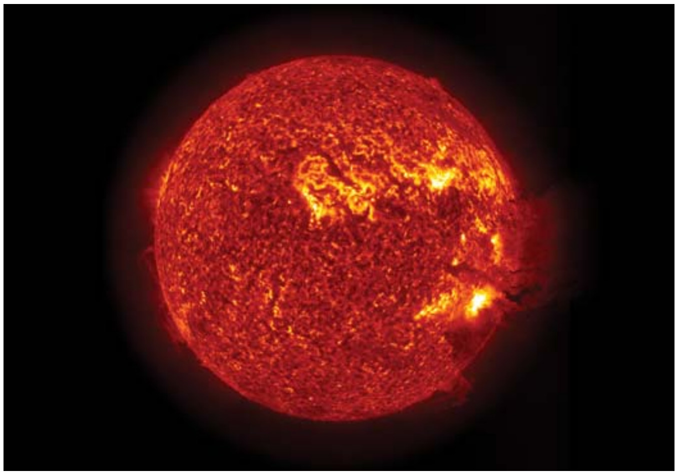
Credit: Jack Kamen, U.S. Coast Guard art gallery

Space weather and solar monitoring

GOES-R will also carry a number of solar and space monitoring instruments that will provide significantly improved images and detection of approaching space weather hazards. These space storms endanger billions of dollars worth of commercial and government satellite systems by causing power surges in sensitive electronics that can affect system performance, end the life of the satellite, or even threaten the lives of astronauts who may be working outside the protection of the International Space Station hull. These storms also affect ground-based power grids.

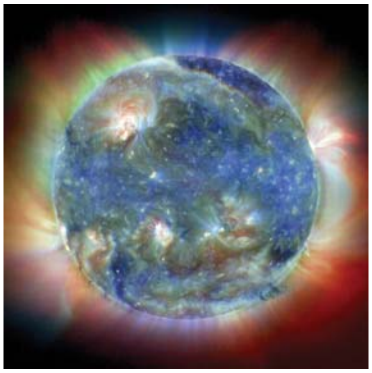
Geomagnetic storms caused by energetic streams of particles and fields that originate from the sun affect Earth's magnetic field, interact with the long wires of the power grid, and cause electrical currents to flow in the grid. These currents cause imbalances in electrical equipment, reducing performance and leading to dangerous overheating. With warning, power grid operators can modify their operations to counteract the effects of space weather and thereby maintain adequate power for customers, as well as maintain reserve capacity. With these solar and space monitoring instruments on the GOES-R series, NOAA's Space Weather Prediction Center will be able to significantly improve space weather forecasts for government and commercial satellite operators and for the communications and power generation industries.

Forecasting space weather



Solar Dynamics Observatory image in extreme ultraviolet shows solar flare with coronal mass ejection. Credit: NASA Science Visualization Studio

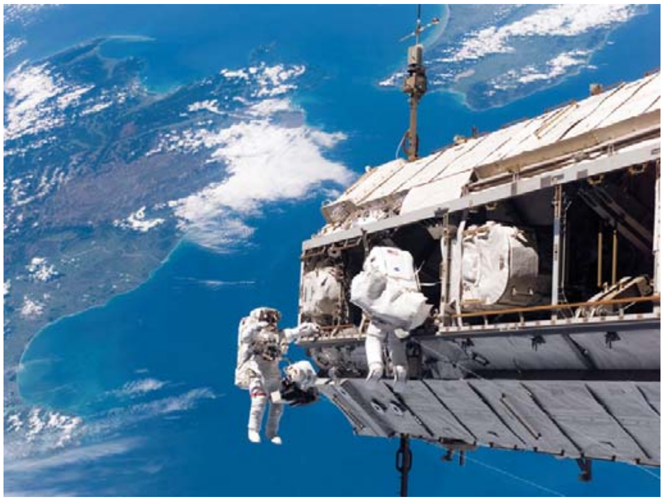
The **Solar Ultraviolet Imager** (SUVI) on GOES-R is a telescope that observes the sun in the extreme ultraviolet wavelength range. SUVI will observe active regions of the sun in order to detect solar flares and the warning signs of coronal mass ejections. Depending on the size and trajectory of solar eruptions, the energetic particles may affect Earth's environment in space, with concomitant destructive results. SUVI observations will provide an early warning of such impacts to the Earth environment. SUVI will replace the current GOES Solar X-ray Imager instrument and will produce multi-band "color" images at the same rate as the current X-ray imager produces single-band images.



Simulated GOES-R Solar Ultraviolet Imager image. This one is from the Solar and Heliophysics Observatory Extreme Ultraviolet Imaging Telescope. Credit: SOHO EIT, a joint NASA/ESA program; and Steve Hill/NOAA SWPC

Monitoring the magnetosphere

The **Space Environment In-Situ Suite** (SEISS) on GOES-R will monitor the proton, electron and heavy ion fluxes in the magnetosphere at geosynchronous orbit (~35,000 km, above the equator). The information provided by SEISS is critical for assessing the radiation hazard to astronauts and satellites. In addition to hazard assessment, the information from this suite of instruments can be used to warn of high flux events, mitigating any damage to radio communication. This data will determine the solar radiation storm portion of NOAA's space weather scales that describe the severity of geomagnetic storms, solar radiation storms and radio blackouts.



Astronauts working outside the International Space Station are especially vulnerable to radiation from solar storms. Credit: NASA