National Aeronautics and
Space Administration

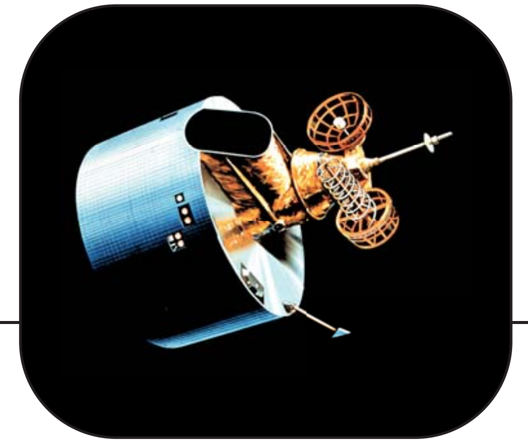
The History of GOES Weather Satellites

For almost 40 years, Geostationary Operational Environmental Satellites (GOES) have provided continuous imagery and data on atmospheric conditions and solar activity (space weather). They have even aided in the search and rescue of humans in distress. GOES' data products have led to more accurate and timely weather forecasts and better understanding of long-term climate. The National Aeronautics and Space Administration (NASA) builds and launches the GOES, and the National Oceanic and Atmospheric Administration (NOAA) operates them. Starting with the first GOES in 1974, the two organizations have worked together to push the technology to its current advanced state, as represented by the next generation weather satellite, GOES-R.

How have technology advances improved forecasting?

Launched 1975 - 1978: GOES A – C

GOES technology has come a long way since 1974. In the 1970s, the GOES provided data in only two dimensions—three if you consider time. There was no indication of cloud thickness, moisture content, temperature variation with altitude, or any other information in the vertical dimension. Weather forecasters looking at a satellite image couldn't really nail down the coordinates of the blurry blob that represented a storm, or clearly define its edges. Their forecast of affected regions could miss by a county or even a small state.



Launched 1980-1987: GOES D – H

In the 1980s, the capability was added to obtain vertical profiles of temperature and moisture throughout the atmosphere. This added dimension gave forecasters a more accurate picture of the intensity and extent of storms, allowed them to monitor rapidly changing events, and to predict fog, frost and freeze, dust storms, flash floods, and even the likelihood of tornadoes. However, as in the 70s, the imager and sounder still shared the same optics system. That meant the instruments had to take turns. Also, the satellites were still spin-stabilized, which meant that they were pointed toward Earth only about 10% of the time.

Launched 1994 - 2001: GOES I – M

It was GOES-I, launched in 1994, that brought real improvement in the resolution, quantity, and continuity of the data. Advances in two technologies were responsible: three-axis stabilization of the spacecraft and improved and separate optics for imaging and sounding. Three-axis stabilization meant that the imager and sounder could work simultaneously. Forecasters had much more accurate data with which to better pinpoint locations of storms and potentially dangerous weather events such as lightning and tornadoes. The satellites could temporarily suspend their routine scans of the hemisphere to concentrate on a small area of quickly evolving events to improve the short-term weather forecast for that area.

Launched 2006 - 2010: GOES N – P

GOES-N, O, and P further improved imager and sounder resolution with the Image Navigation and Registration subsystem, which uses geographic landmarks and star locations to better pinpoint the coordinates of intense storms, saving around $1million for every mile not requiring evacuation. Detector optics are improved. Because of better batteries and more available power, imaging is continous.

In development: GOES-R

The new R-series will have improvements in spacecraft and instrument technologies over the GOES currently serving. GOES-R will enable more timely and accurate weather forecasts, and improved support for observation of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development. For the first time, the GOES will include lightning detection, with continuous coverage of total lightning flash rate over land and water.

Why do we need weather satellites?

Meteorologists need sensors that are on the ground directly measuring local weather conditions, as well as in orbit high above Earth's atmosphere observing the "big picture" remotely. The United States has a network of ground stations for measuring surface and upper-air weather conditions at particular locations and times. However, this network leaves gaps in the information about the geographical extent of weather phenomena, their speed and direction of movement, and their duration. Satellite data are also needed to provide a complete and continuous picture of atmospheric conditions.

The Geostationary Operational Environmental Satellites (GOES) and supporting data processing centers provide timely environmental information to meteorologists and their audiences alike—graphically displaying the intensity, path, and size of storms. The impressive imagery of cloud cover, as the GOES view Earth from their very high orbits, is a staple of television weather forecasts. Forecasting the approach of severe storms for more than 35 years, the GOES are a cornerstone of weather observing and forecasting.

Why is a geostationary orbit needed?

Geostationary satellites rotate with Earth from west to east directly over the equator at an altitude of 35,800 km (22,300 statute miles). Because the satellite orbits in the same direction as Earth turns on its axis and matches the speed of Earth's rotation at the equator, the satellite always has the same view of Earth's surface. The U.S. has two Geostationary Operational Environmental Satellites (GOES) in service, one positioned to view the west coast and the Pacific Ocean and one to view the east coast and the Atlantic. Geostationary satellites are in position to maintain a constant vigil over nearly half the planet.

GOES is a collaborative mission of the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA). NASA designs, engineers, and procures the satellites and provides launch support. During these phases, a satellite has a letter designation (A, B, C, etc.). Once in orbit, NOAA takes over operation of the satellite, giving it a number designation. (GOES-D becomes GOES-4, for example.)

What exactly do the GOES detect?

Geostationary weather satellites work by sensing electromagnetic radiation to indicate the presence of clouds, water vapor, and surface features. Unlike ground-based radar systems and some other types of satellites, these satellites do not send energy waves into the atmosphere and analyze returning signals. Rather, the GOES work by passively sensing energy. The GOES sense visible (reflected sunlight) and infrared (for example, heat energy), from Earth's surface, clouds, and atmosphere. The Earth and atmosphere emit infrared energy 24 hours a day, and satellites can sense this energy continuously. In contrast, visible imagery is available only during daylight hours when sunlight is reflected.

How do the GOES detect this energy?

The instruments on the GOES that measure electromagnetic energy are called **radiometers**. GOES has two kinds of radiometers: imagers and sounders.

- **Imagers**: GOES have two types of imagers: One measures the amount of visible light from the sun that Earth's surface or clouds reflect back to space. The second measures the infrared energy that Earth's surface and clouds radiate back to space. Because the GOES can sense infrared radiation, they can operate at night.
- **Sounders**: Sounder is short for Vertical Atmospheric Sounder. "Sounder" is from the French "sonder," which means to probe or measure. Sounders measure infrared radiation. Sounders enable satellites to "see" the atmosphere in 3-D. They provide vertical profiles of temperature, pressure, water vapor and trace gases such as carbon dioxide that are critical to Earth's climate.

How are the detectors tuned to Earth?

Most visible light passes right through the atmosphere, but not so much through clouds. Clouds reflect some of the visible light back to space. How much depends upon the thickness and height of the cloud. Earth's surface absorbs the visible light energy, gets warmer, and re-radiates the energy as infrared radiation. Clouds also absorb some of the visible light energy, as well as the infrared energy re-radiated from Earth.

Satellite sensors are particularly sensitive to those wavelengths of infrared energy re-radiated up through the atmosphere to space. Scientists can measure the height, temperature, moisture content (and more) of nearly every feature of Earth's atmosphere, ocean, and land surface, with and without vegetation.

Any other roles for GOES?

GOES provides an important search and rescue function used to detect signals transmitted from emergency beacons on aircraft and maritime vessels or carried by individuals in distress. These emergency beacon transmitters provide a way of signaling for help when all other means of communication have failed. Beginning with GOES-I, a dedicated Search and Rescue Satellite-Aided Tracking (SARSAT) transponder has flown on each of the GOES. These transponders provide constant coverage to immediately receive and relay a 406-MHz beacon alert to ground stations on Earth. The signal is then routed to a Mission Control Center for processing and to determine the location of the alert. In turn, the Mission Control Center notifies the Rescue Coordination Center that is nearest the alert, which initiates the search and rescue response. SARSAT is part of the international Cospas-Sarsat program, which provides a global network to detect and locate emergency signals anywhere in the world. SARSAT's goal is to help take the "search" out of search and rescue. Since the program's founding in 1982, it has been has been credited with helping to save thousands of lives in the United States and around the world.

Beginning with GOES-N, a Solar X-ray Imager is carried on each satellite. This sophisticated instrument detects solar flares, coronal mass ejections, and other solar disturbances that affect the "space weather" near Earth. Such events can adversely affect satellites, astronauts, and power grids. Early warning enables safety measures that help protect people and equipment.

What's in the future?

The next generation GOES-R series currently under development will be a giant leap forward in the technology, in terms of accuracy, resolution, quantity, speed, and types of data products available. Although the current GOES system provides critical weather information, improvements over the current capabilities are required to meet future users' needs for enhanced observations, improved weather forecasting, ecosystems management, and monitoring changing climatic conditions. The user community is not only looking for improvements in instrument capabilities, but also seeks new products and applications, along with faster data dissemination techniques and reduced product lag time.

Not your father's GOES . . .

GOES-R will have six major instruments. Where the imager on the current GOES N – P series detects 5 spectral bands (wavelengths of light), GOES-R's Advanced Baseline Imager will distinguish 16 separate spectral bands, or wavelengths, of visible, near-infrared, and infrared light. Every product now produced from the GOES N – P series imager will be improved due to data from the new GOES-R imager. In addition, several new products, such as vegetative health and atmospheric visibility, will be possible because of the imager's improved resolution. The increased number of wavelengths covered will alone or in combination with other information provide many of the products provided by the sounder on the current GOES. GOES-R will also carry a lightning mapper, and a suite of instruments for monitoring solar activity and Earth's magnetosphere.

Image credits:
Tornado image: Justin Hobson
Lightning: U.S. Air Force photo by Edward Aspera Jr.
Super cell: Matthieu Pron
Hurricane: NASA/NOAA
GOES-R Spacecraft: Lockheed Martin

Who will benefit?

Some of the new products from GOES-R data that will benefit a wide range of sectors of society are:

Aviation:

- Warnings of conditions conducive to dangerous ice buildup on aircraft wings in flight
- Warnings of conditions likely to produce bursts of severe turbulence above thunderstorm clouds
- Warnings of volcanic ash plumes, which can severely damage aircraft engines

Human Populations:

- Tracking and estimating intensity of hurricanes and other severe storms, with increasing accuracy and forecast lead times, allowing more time for necessary evacuation and leading to less unnecessary evacuation
- Short-term heavy rainfall, probability of rainfall, and flood hazard forecasting. Help identify flash flood and landslide risks
- Accurate imaging of flooded areas
- Detection and real-time monitoring of wild fires to help firefighters and emergency managers in charge of evacuations

Agriculture:

- Health of crops and other vegetation

Climate trends:

- Ozone total
- Ice and snow cover (and depth)
- Cloud properties
- Ocean currents
- Atmospheric visibility