

# PROXIMA

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this star before  
the end of the  
century?**

*Learn what it would take*

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# WEATHER SOUNDINGS



# A CHALLENGE TO THE STATUS QUO

*NASA, NOAA and their partners have spent decades and hundreds of millions of dollars making instruments to measure the temperature and moisture of the atmosphere from space. No one disputes that these sensors have improved our weather forecasts, but NOAA is suddenly listening to those who say there might be another way.*

**Ben Iannotta** explains.

**F**rom orbit, the sky around a patch of clouds looks the same in a photo whether it is cool, dry and stable or warm, moist and about to explode into a string of tornadoes or grow into a hurricane. The first photos of weather from space were handy, but what weather forecasters really wanted were the factors they couldn't see, chief among them the temperature and moisture content of the atmosphere at different altitudes. NASA, NOAA and experts from academia got busy figuring out how to collect Earth's radiation from orbit and parse it into spectral channels that could profile the atmosphere vertically.

Conventional wisdom holds that gathering these atmospheric soundings from orbit is such a complex task that it's a job best left to the government with the help of universities and the industry. The first NOAA sounder, called HIRS, short for High Resolution Infrared Radiation Sounder, was built that way and launched in 1978. Versions of HIRS remain NOAA's sounding workhorses, and in 2011, those workhorses were joined in orbit by an instrument called CrIS, short for Cross-track Infrared Sounder. CrIS is intended to be the first in a new breed of vastly more precise sounders that will ride on NOAA's polar-orbiting satellites. Researchers had been struggling since the early 1990s to get its technology into orbit.

Both instruments are highly complex. On HIRS, a mirror reflects radiation to a rotating wheel made of germanium sub-



**Cross-track Infrared Sounder:**

These sensors built by Harris Corp. measure the temperature and moisture content of the atmosphere by dividing incoming energy into 2,200 channels of wavelengths. The white cylinder partially visible in the center contains a scanning mirror.

strate, a metallic looking material that infrared wavelength can penetrate. The germanium is coated with materials to tune the wavelengths that can pass through. "It's actually quite a science to adjust the layers," explains physicist and sounding pioneer Hank Revercomb, director of the University of Wisconsin's Space Science and Engineering Center in Madison.

CrIS is even more exotic. A beam splitter divides a ray of light into two, and one beam strikes a fixed mirror, while the other strikes a moving mirror. The beams are then recombined to create a pattern called an interferogram. The resulting spectrum must be "unscrambled" inside the instrument by a mathematical process called a Fourier transform, and then on the ground an inverse Fourier transform is performed, Revercomb says.

CrIS is now delivering 2,200 channels of infrared wavelengths, which is 100 times more channels than HIRS. More channels means more moisture and temperature readings at more altitudes. Interestingly, CrIS was supposed to deliver 1,300 channels, but after CrIS arrived in

The GOES-East satellite captured this image (opposite page) of a Nor'easter developing over North Carolina's Outer Banks in 2015. The first in new series of Geostationary Operational Environmental Satellites, GOES-R, is scheduled for launch in October.

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orbit aboard the Suomi National Polar-orbiting Partnership (SNPP) satellite, the team adjusted onboard software to send more mid- and short-wave infrared bands.

“The data rate has increased slightly, but the SNPP has sufficient data rate margin,” says Harris Corp.’s Ron Glumb, who until last year was chief engineer for CrIS at the company’s Environmental Solutions facility in Fort Wayne, Indiana. NOAA seems pleased, and in January Harris received an additional \$316 million to its CrIS contract to deliver two more instruments.

Just as the CrIS technology is gaining momentum, however, members of Congress and NOAA are asking hard questions about the way ahead for atmospheric sounding. At issue is whether a simpler, commercial technology can supplement the sounding work planned for CrIS or even take over some of the duties. The outcome of these discussions and a NOAA pilot project that’s about to begin could have a big impact on some satellite and instrument builders. That’s because the

new technique requires collecting GPS signals with many small cubesats, rather than the 3,000-kilogram polar orbiters that are to carry the next CrIS instruments.

### Learning from Mars

All this discussion has been sparked by the advent of a technique called GPS-radio occultation, whose roots date to the Mariner 4 spacecraft’s flyby of Mars in 1965. In addition to taking the first photos of another planet from space, Mariner 4 flew behind Mars and sent radio signals back toward Earth with Mars blocking, or occulting, the view. Just as scientists expected, the signals that went by the periphery of Mars were bent as they passed through the Martian atmosphere.

Until then, “the density of the Martian atmosphere wasn’t known to within a factor of a thousand. That one measurement nailed it perfectly,” says Thomas Yunck, a former NASA research scientist at the agency’s Jet Propulsion Laboratory, and founder and chief technology officer of GeoOptics, a small company in Pasadena, California.

His firm is among those attempting to shake up the sounding world by applying the same basic principle used by Mariner 4. The company plans to test its concept in July by launching a single Pathfinder cubesat as a payload on a Soyuz rocket. That launch will be followed by four operational satellites on a Soyuz in November or December.

While working at JPL in 1988, Yunck wrote a research proposal outlining the concept he’s now trying to turn into a viable business. The proposal noted that Earth’s atmosphere bends GPS microwave signals. An instrument properly placed in orbit could receive those signals each time a GPS satellite rises or sets behind the curve of the Earth in occultation. Temperature, moisture, pressure and density could be deduced from the degree of signal bending. The technique was dubbed GPS-radio occultation or GPS-RO.

Each GPS signal received by an orbiting cubesat is called an occultation, and GeoOptics hopes to convince NOAA to buy a license to receive 100,000 of them a day and feed them into numerical weather forecasting models. The company faces competition from PlanetIQ of Boulder, Colorado, which plans to launch its first

## Planning ahead

*NOAA managers and weather scientists must wrestle with more than the here-and-now questions about atmospheric soundings. They know they must chart a long-term course for weather satellites and their instruments, so that the right budget and policy decisions can be made now.*

*NOAA has assembled a Space Platform Requirements Working Group to consider the kinds and numbers of satellites that should provide weather data in 2030 and beyond. The team will look at what should come after the four Joint Polar Satellite System (JPSS) spacecraft that are slated to carry the Cross-track Infrared Sounder instruments and the next four Geostationary Operational Environmental Satellites (GOES), the first of which, the Lockheed Martin-built GOES-R, is scheduled for launch in October. NOAA says all options will be entertained. That includes a possible role for privately operated weather satellites and the possibility of shifting the agency’s strategy away from 3,000-kilogram satellites like JPSS and GOES-R to numerous, small spacecraft, an approach that satellite experts call disaggregation. “Disaggregation is ONE among the many options being considered by the architecture study team,” NOAA cautions in an email to me.*

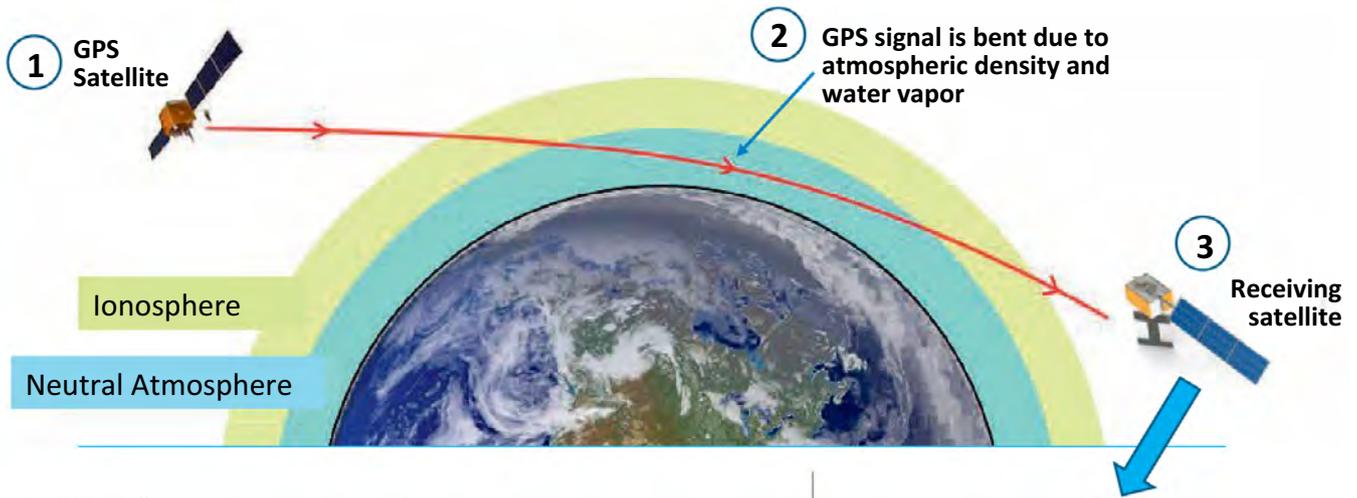
*The topic of weather satellites and sensors also will be addressed in the next Decadal Survey of Earth Science and Applications from Space, which is to be published in July 2017 by the National Academies of Sciences, Engineering and Medicine. The decadal surveys give scientists and technologists an opportunity to recommend spending priorities. The new survey will cover the 10 years starting Oct. 1, 2017.*

**Ben Iannotta**



# How GPS aids weather forecasters

From the vantage point of space, a GPS satellite will periodically rise or set behind Earth's horizon. During these occultations, the radio signals that are normally received on the ground pass through the atmosphere and into space, where they can be collected by orbiting sensors. By measuring how far the atmosphere bends the signals, weather forecasters can deduce moisture and temperature. This graphic from PlanetIQ, one of the companies looking to turn GPS-radio occultation into a business, describes the process.



1. GPS satellite transmits a radio signal.
2. The signal is bent as it passes through the atmosphere.
3. The frequency of the signal shifts due to the Doppler effect, and the bending angle can be calculated from this shift.
4. The bending angles are fed into numerical weather models to refine estimates of temperature, pressure and water vapor, as well as electron density in the ionosphere.

**4**  
**Output:** Temperature, pressure, water vapor and electron density by altitude; similar to weather balloon

PlanetIQ

two cubesats in early 2017, and Spire of San Francisco, Glasgow, Scotland, and Singapore, which has four operational satellites up and plans to deliver 100,000 occultations a day by next year.

The potential value of GPS-RO is well known to forecasters at the National Weather Service because of work by the University Corporation for Atmospheric Research in Boulder and partners in Taiwan. In 2006, UCAR and Taiwan launched six COSMIC satellites (short for Constellation Observing System for Meteorology, Ionosphere, and Climate). A year later, forecasters began incorporating occultations into their numerical weather models. These occultations have proved valuable, but there aren't enough COSMIC satellites or occultations for the readings to have a large impact.

"The long and the short is we can make use of more radio occultation data," says the National Weather Service's Jim Yoe, the chief administrative officer for the Joint Center for Satellite Data Assimilation.

## Pilot project

A GPS-RO sensor is a GPS receiver that's been souped up to survive in space. Yunck says his company's version costs about \$100,000 apiece. When construction of the cubesat and a ride to orbit are factored in, the total rises to about \$1.5 million. The trick to making GPS-RO viable as a business will be to launch many of those satellites to deliver thousands of occultations a day. Each occultation provides highly accurate readings and excellent vertical resolution, but a single occultation covers only a narrow portion of the atmosphere hori-

zontally. A CrIS instrument, by contrast, costs about \$150 million but it scans from side to side, or cross track, as it orbits and covers about 2,200 kilometers. For severe-weather forecasting, a geostationary sounder would be much more useful because of its even broader view and its ability to watch the same features evolve, says the University of Wisconsin's Revercomb.

"The GPS-RO will never do that unless you darken the sky with [them or] something," he says.

That's pretty much what the commercial startups hope to do, but first things first. NOAA is preparing to invite the commercial companies to compete to have their weather observations assessed by the National Weather Service under a commercial weather data pilot project. The goal will be "to see how well those measurements meet NOAA's observing requirements," the agency says in written responses. NOAA plans to provide a report to Congress in 2017 with its initial findings.

The pilot was not NOAA's idea. Last year, U.S. Reps. James Bridenstine and Frank Lucas, two Oklahoma Republicans, wrote authorization language proposing a \$9 million commercial data pilot. The language didn't become law, but Bridenstine worked with colleagues to include \$3 million for a commercial pilot in the omnibus appropriation bill for 2016.

NOAA appears to be warming to the idea. "NOAA has been laying the groundwork for this effort since the day the omnibus appropriation was enacted," the agency says. In February, the agency surprised some observers by requesting an additional \$5 million in the president's budget to continue the pilot in 2017.

Even so, Bridenstine hopes to see Congress pass authorization language this year that would spell out the intent of Congress for the pilot and require NOAA to follow it.

### Trust

The pilot project will look at the technical aspects of GPS-RO, but the business model behind commercial services could prove to be the bigger sticking point. What if a commercial supplier goes out of business or a licensing or price dispute erupts? Can forecasters trust that the data will always be there?

"You don't want somebody to have to pay a bundle because they want to know if they're going to be hit by a tornado. This is a difficult political, sociological process here," Revercomb says.

Proponents of commercial data say NOAA can make sure that won't happen by negotiating wisely. Yunck of GeoOptics says it's just like NOAA purchasing a software license for a certain number of users.

"If they want to give the data away to the world, then we have a worldwide license price, which saves us the trouble of having to sell to everybody," he says. "We're not breaking ground here."

NOAA may have unwittingly created the bureaucratic and political opening for this proposed new way of doing business. The satellite that carries the first CrIS instrument, the SNPP, was launched in 2011, five years late, due in part to problems with development of its sensors. The satellite was originally intended to be an experimental pathfinder for a new constellation of spacecraft, but in 2009 slow development of NOAA's next polar-orbiting satellites prompted managers to declare it operational.

CrIS soundings today are fed into weather forecasting models. Members of Congress and the Government Accountability Office have been worried that Suomi NPP might not last until the first of four planned Joint Polar Satellite System spacecraft is launched. That's supposed to happen in early 2017.

Given this history, Bridenstine chafes at the argument that the private sector can't be trusted to meet weather data needs. He is among those concerned about a gap.

"Reliance on government satellites is not a guarantee of data availability," he says in a statement relayed by his staff. "Several companies are already seeking to partner with NOAA and, should the government send the signal that they are open to these data sources, there will undoubtedly be more."

Of course, all the discussions and politics could prove to be moot if the startups can get their GPS-RO constellations operating with broad enough coverage. "Once the data is out there and available, people are going to use it. The users don't care. They just want data," Yunck says. ▲