THE GOES-13 SCIENCE TEST

A Synopsis

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The *GOES-13* science test, which took place during December of 2006, was an opportunity for NOAA and other scientists to preview the capabilities of the latest U.S. geostationary operational satellite. Such science tests are a vital aspect of the checkout of each Geostationary Operational Environmental Satellite (GOES), and have been formalized as a part of post-launch testing for at least the last four GOES satellites. Results of the science test confirmed three major improvements expected from *GOES-13*: less loss of imagery during satellite eclipse periods, improved navigation, and lower instrument noise. There was also the discovery of a cold bias for one of the imager bands, an issue that continues to be investigated.

SCIENCE TEST BASICS. NOAA scientists are regularly involved in the checkout of GOES Imager and Sounder instruments. These science tests are part of the post-launch testing (PLT) administered by NASA for each satellite.

In the case of *GOES-13,* the PLT started shortly after launch of this GOES-N series satellite on 24 May 2006. After the end of the engineering tests, which take up most of the available PLT period, the science test started on 7 December and continued for 3 weeks. During that time, NOAA scientists were able to select among various predetermined operating modes for the satellite instruments, the 5-band imager, and the 19-band sounder. Others investigated the solar/space instrumentations. After those 3 weeks, *GOES-13* continued to transmit data until it was put into storage mode on 5 January 2007.

Goals of the science test included:

1) the investigation and quantification of *GOES-13* data, by comparison to previous GOES, as well as other satellites;
2) the generation of imager and sounder products from the *GOES-13* data stream, and their comparison to similar products created from previous GOES;
3) investigation of the impact of changes due to the new spacecraft bus that began with *GOES-13*; and,
4) the acquisition of nearly continuous high-resolution rapid-scan imagery, as part of risk reduction activities for the next-generation GOES-R series (starting in the 2015 time frame).

Science test data from *GOES-13* were collected at three locations: at NOAA/NESDIS in Camp Springs, Maryland [including the Office of Research and Applications (ORA) now known as Satellite Applications and Research (STAR), and the Office of Satellite Data Processing and Distribution (OSDPD)]; at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) in Madison, Wisconsin; and at the Cooperative Institute for Research in the Atmosphere (CIRA) in Fort Collins, Colorado. The science test investigations were conducted at the same locations using that data.

Various operating schedules for the imager and sounder were determined prior to the science test. Choices were made among those available schedules, depending on the weather situation, and to satisfy the need to collect many different types of data. The results of the *GOES-13* science test were collected and compiled into a NOAA technical report, which is available either online (http://rammb.cira.colostate.edu/projects/goes-n/NOAA_Tech_Report_NESDIS_125_GOES-13_Science_Test.pdf) or on compact disc, which can be obtained from the authors.

The following sections summarize the more important results from the *GOES-13* science test,

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Table 1. Summary of the noise (in K) for *GOES-8* through *GOES-13* imager bands. The specification (SPEC) noise levels are also listed.

Imager band	Central wave-length (μm)	*GOES-13*	*GOES-12*	*GOES-11*	*GOES-10*	*GOES-9*	*GOES-8*	SPEC
		(K @ 300 K, except band-3 @ 230 K)						
2	3.9	0.051	0.13	0.14	0.17	0.08	0.16	1.40
3	6.5/6.7	0.140	0.15	0.22	0.09	0.15	0.27	1.00
4	10.7	0.053	0.11	0.08	0.20	0.07	0.12	0.35
5	12.0	No band	No band	0.20	0.24	0.14	0.20	0.35
6	13.3	0.061	0.19	No band	No band	No band	No band	0.32

including reduced imager and sounder noise, improvements in image navigation and registration, expanded imaging operation during satellite eclipse periods, the bias discovered in imager band-6 data, and finally, examples of some of the image products generated from *GOES-13*.

REDUCED IMAGER AND SOUNDER NOISE. One of the more basic assessments for a satellite instrument is the noise level. That noise level is a measure of the precision of the measurements that can be obtained. Noise levels for the imager were estimated by statistical methods on a large collection of space-view imagery. The results were compared to similar calculations for the same instruments on previous GOES satellites, as well as to instrument specifications. The noise levels are summarized in Table 1.

The results in Table 1 indicate that *GOES-13* has reduced noise compared to *GOES-8* through *GOES-12*. A colder detector operating temperature is the main reason for the reduced noise. This is the result of a different location of the boom on the new spacecraft bus (Fig. 1). The new bus allows improvements to radiometrics, as well as to navigation and registration (to be discussed in the next section).

Noise levels for the sounder were also estimated statistically on space-view measurements, similar to those collected for the imager. For brevity, the sounder noise results will not be tabulated here, but can be summarized as a significant improvement in longwave sounder bands in particular, where instrument noise values are about half compared to the *GOES-12* sounder.

An analysis of image striping was undertaken as well for both the imager and sounder. The striping, although not set by specification, is a limiting factor in the quality of GOES imagery and data. Multiple detectors (two for most of the imager infrared bands, and four for the sounder bands) can lead to a striped image when the measurements from multiple detectors vary slightly.

There was potential for a reduction in detector-to-detector striping through an increased imager scan-mirror dwell time on the blackbody from 0.2 to 2 seconds. Although there was an expectation that striping might be reduced along with the lower noise found with *GOES-13* instruments, there was no improvement in measured striping for either the imager or sounder. These determinations were for early science-test data, so some improvement might be forthcoming after the striping is better characterized though long-term monitoring and feedback.

IMPROVED NAVIGATION AND REGISTRATION. There are improvements in both the navigation and registration on *GOES-13* due to the new spacecraft

Fig. 1. GOES-N, -O, -P series spacecraft. (Figure courtesy of NASA.)

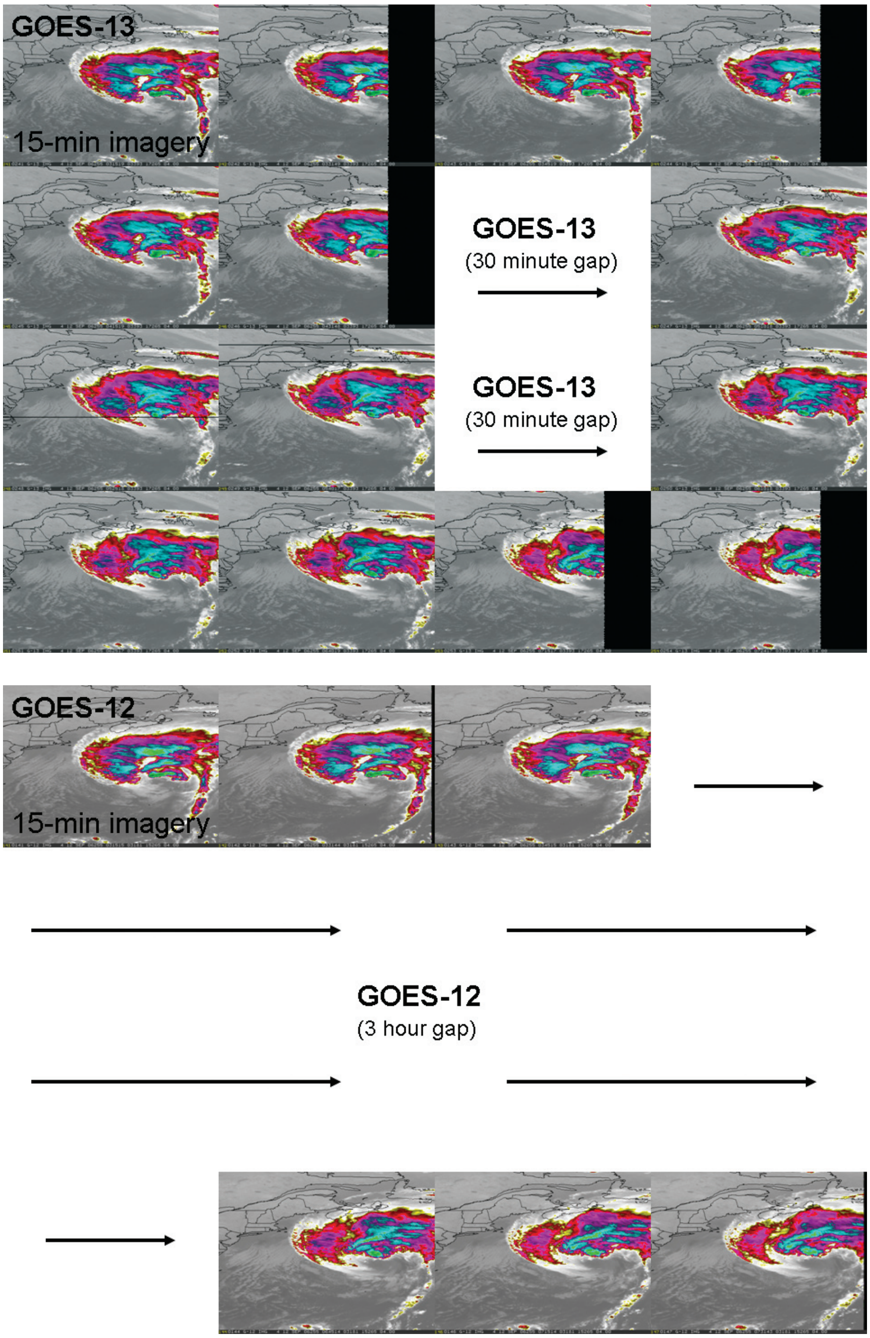

Fig. 2. Sequences of images from 12 Sep 2006 comparing *GOES-13* (top) to *GOES-12* (bottom) through eclipse. Rather than one long gap while the Sun is either within view on each side of the Earth or behind the Earth, there are two shorter gaps when the Sun is within view on each side of the Earth.

bus and the use of improved onboard sensors for the determination of spacecraft orientation. As a result, the navigation accuracy (at nadir) improved from 4–6 km with current/operational imager data to less than 2 km with those on *GOES-13*.

For example, the improved image navigation and image-to-image coregistration for *GOES-13* is vital to the successful automated production of atmospheric motion vectors at small time intervals between images. Any registration/navigational shifting between images will result in correlation tracking failures and/or significantly reduced vector quality.

Loops of imagery from *GOES-13*, when compared to similar images from *GOES-12*, are good indicators of the improved navigation and registration. Unfortunately, those loops cannot be shown in a static publication. Examples are posted on the *GOES-13* science test Web site (URL given in the reference section).

EXPANDED OPERATION DURING SATELLITE ECLIPSE. *GOES-13* has an increased potential to operate its instruments during satellite eclipse periods. Eclipse periods occur when the satellite passes into the shadow of the Earth, a biannual event, lasting several hours a night for about 6 weeks during both spring and fall. During this time, the satellite's solar panels do not receive the energy needed to power the satellite. The outage for a given day varies, from as little as 1 hour to as much as 2.5 hours. By using larger spacecraft batteries to supply data through eclipse periods, the GOES-N/O/P system addresses one of the major limitations of the current GOES series. Other outage periods include "Keep Out Zones" (KOZ), when there is a possibility that the Sun, when in view on either side of the Earth, can contaminate imagery by being within the field of view (FOV) of the instruments.

A sequence of 15-minute images from 12 September 2006 comparing *GOES-13* to *GOES-12* shows the effect of the eclipse (Fig. 2). Rather than one long gap while the Sun is either within view on each side of the Earth or behind the Earth, there are two shorter gaps only when the Sun is within view on each side of the Earth.

Table 2. Comparison of *GOES-13* imager to Atmospheric InfraRed Sounder (AIRS). The bias is the mean of the absolute values of the differences.

Imager band	Mean difference (K)	Bias (K)	Standard deviation of differences (K)
2 (3.9 μm)	0.2	0.4	0.6
3 (6.5 μm)	–0.4	0.4	0.3
4 (10.7 μm)	–0.1	0.4	0.4
6 (13.3 μm)	–2.4	2.4	0.6

With the new capability of acquiring data during KOZ comes the risk of allowing images contaminated with energy from the Sun. Of course, an image with artificial brightness temperature excursions may affect products. To determine how much good data can be acquired, while at the same time minimizing the amount of bad data, many scans were conducted during the eclipse period, prior to—but as part of—the science test. It was found that all the imager bands can be contaminated during these KOZ time periods, with the visible and shortwave bands most affected. The bottom line is that while more imagery can be acquired during KOZ—even some images with potential contamination—only the unaffected imagery/data should be used for product generation.

UNRESOLVED BIAS IN IMAGER BAND-6. To determine if biases were present, data were collected during the science test near the *GOES-13* subsatellite point from the high-spectral-resolution Atmospheric InfraRed Sounder (AIRS) on NASA's polar-orbiting Aqua satellite. *GOES-13* imager data were collected within 30 minutes of polar-orbiter overpass time. During the checkout period, there were 19 comparisons between *GOES-13* and AIRS. The results are presented in Table 2. The mean brightness temperature difference for these comparisons shows that *GOES-13* is well calibrated based on the accuracy of AIRS measurements and that it compares favorably with similar results from operational *GOES-12* and *GOES-11* (not shown). Imager-to-imager radiance comparisons for most bands showed fair agreement. The exception is *GOES-13* imager band-6 at 13.3 μm, which presented a considerable cold bias. Based on feedback from the science test, this issue is being investigated further to see if the bias is due to unknowns in the spectral response measurements or some other factor.

PRODUCT GENERATION FROM *GOES-13*. A number of products were generated with data from the *GOES-13* instruments and then compared to products generated from other satellites or ground-based measurements. Products derived from the sounder were total precipitable water (TPW), lifted index (LI), cloud products, and atmospheric motion vectors (AMVs). The products derived from the imager were cloud products, AMVs, clear-sky brightness temperature (CSBT), sea surface temperature (SST), and fire detection.

Total precipitable water retrievals (displayed in the form of an image) for *GOES-12* and *GOES-13* sounders are presented in Fig. 3 over the same area at approximately the same time (13 December 2006). These retrievals are generated for each clear radiance FOV. Radiosonde measurements of TPW are plotted on top of the images. Qualitatively, there is good agreement between the *GOES-12* and *GOES-13* TPW retrievals that, in turn, compare reasonably well with the reported radiosonde measurements of TPW. When comparing measurements from two satellites, one must consider the different satellite orbital locations; even precisely colocated fields of view are seen through different atmospheric paths.

Figure 4 shows a spatially thinned sample of AMVs from all five imager bands from *GOES-12* (left) and *GOES-13* (right) for one case. The vectors have been thinned to enhance viewing. Qualitatively, the results appear quite similar in this example, which is representative of all the cases. This is supported by an objective statistical comparison with RAOB data (not shown).

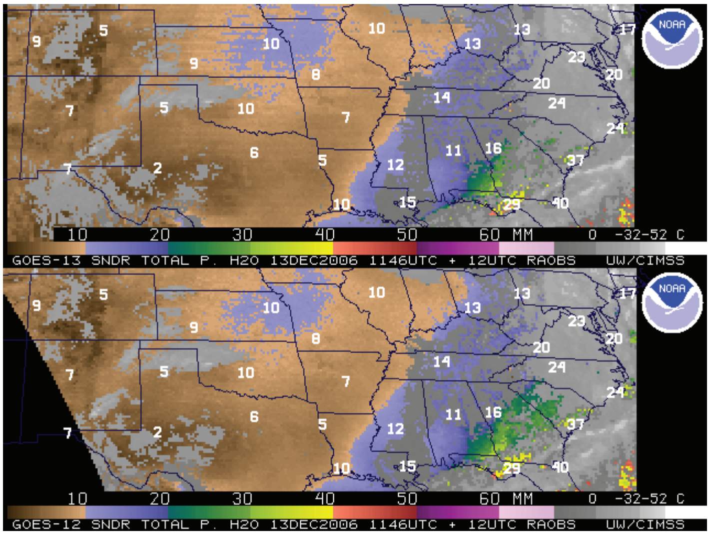

Fig. 3. *GOES-13* (top panel) and *GOES-12* (lower panel) retrieved total precipitable water (TPW) (mm) from the sounder displayed as an image. The data are from 1146 UTC on 13 December 2006. Measurements from radiosondes are overlaid as white text; cloudy FOVs are denoted as shades of gray. (Figure courtesy of J. Nelson.)

acteristics of the instruments on GOES-O will be computed and compared with those obtained from previous GOES. Super rapid-scan (30-second) imagery, which is not available during normal satellite operations, will also be acquired for storm growth studies, in conjunction with both radar and lightning data. The finer spatial resolution of the 13.3-μm GOES-O imager will also be investigated. In addition, image products need to be generated and tested from each GOES so that there is no gap in product availability when there is a switch to a new satellite—an event that sometimes is required with little notice, possibly years later. For example, *GOES-11* began its operational use approximately 5 years after its initial checkout.

Currently, *GOES-13* is in on-orbit storage mode, since there are two GOES covering the eastern and western United States. Plus, *GOES-10* is operating over the Southern Hemisphere. GOES-O will likely be placed in storage as well, if there is no immediate need for its operational use. The lifetimes for GOES have been much longer than specified. For example, *GOES-10* was launched in April 1997, with a 5-year life expectancy, yet at the time of this writing is still operating at 60°W longitude. With only one more GOES, GOES-P, yet to be launched after GOES-O in the current spacecraft series, there will be no more launches of GOES until the next-generation GOES-R, which is expected to launch in the 2015 time frame.

THE GOES-O SCIENCE TEST IS NEXT.

Science tests have evolved into an official part of GOES checkout. With the launch of GOES-O currently expected in early 2009, the science test for that satellite will likely be in mid-2009. Many of the tests accomplished for *GOES-13* will be repeated for GOES-O. For example, the noise and striping char-

Scientists wishing to be involved in the GOES-O science test should contact the authors. The proposed test schedules for GOES-O will again be determined before the satellite is launched. The preoperational science test data from GOES-O will be scrutinized, and an official report will be produced similar to the one for *GOES-13*.

General information about the *GOES-13* NOAA/

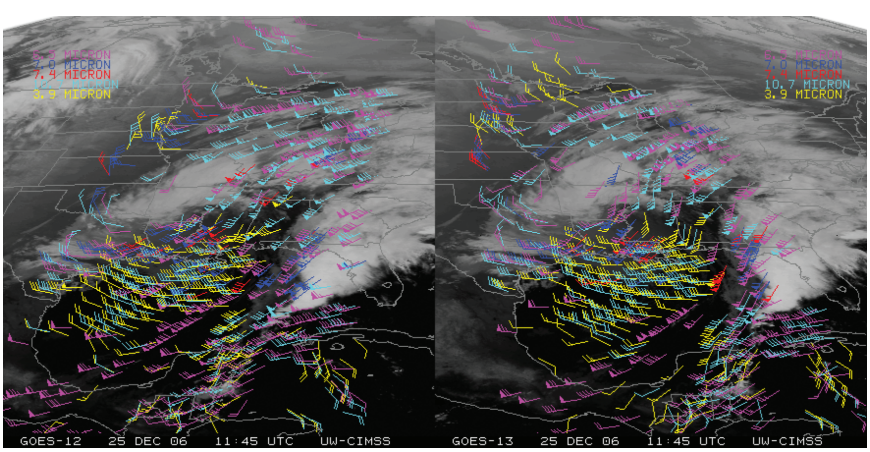

Fig. 4. *GOES-12* (left) and *GOES-13* (right) atmospheric motion vectors (AMVs) for 25 December 2006 plotted over band-4 (10.7 μm) images. The color coding differentiates the satellite bands used in AMV derivation. Note that the viewing angles are different. Also, not all AMVs are shown for clarity of display. (Figure courtesy of D. Stettner.)

Science Post Launch Test is available online: http://rammb.cira.colostate.edu/projects/goes-n.

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FOR FURTHER READING

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