

Introducing the GOES-M Imager

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Submitted to:

National Weather Association (NWA) *Digest*

August 22, 2001

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ABSTRACT

The next satellite in the operational GOES series, GOES-M, was launched on 23 July 2001. It achieved geostationary orbit on 12 August 2001, and hence is referred to as GOES-12. The Imager on GOES-12 has been modified from the previous four imagers in this series. One change is the addition of a spectral band centered at 13.3 μm . The GOES-12 Imager also includes a spectrally modified 6.5 μm band with an improved spatial resolution from 8 km to 4 km at the sub-satellite point. The addition of the 13.3 μm band comes at the expense of eliminating the 12 μm band on the GOES-12/N/O/P Imagers. A 12 μm band will remain available on the GOES-12 and beyond Sounders, although with coarser spatial and temporal resolutions and less geographic coverage than is available with the GOES Imagers. The 12 μm band will be re-introduced on the next series of Imagers, slated to begin with GOES-R in approximately 2010. The overall changes to the Imager will improve several satellite products, such as cloud properties and satellite-derived wind fields. In contrast, products that utilize the information provided by the 12 μm band to characterize low-level moisture and to differentiate between cloud types and volcanic ash may be degraded. In these cases, it may be necessary to rely upon data and products from a host of polar-orbiting satellites. This approach should be especially effective at higher latitudes due to more frequent coverage.

1. INTRODUCTION

The Geostationary Operational Environmental Satellite (GOES) Imager continues to be the backbone for observing clouds and other meteorological and surface parameters at high spatial and temporal resolutions. Quantitative products derived from the GOES Imager include, but are not limited to: estimates of wind fields, solar insolation, Total Precipitable Water (TPW), rainfall, hurricane location and intensity, and biomass burning (Velden et al., 1998 a and b; Goerss et al., 1998; Bosart et al., 2000; Diak et al., 1998; Hayden et al., 1996; Vicente et al., 1998; Prins et al., 1998). The current Imager obtains information from four infrared bands (Table 1) and one visible band (Menzel and Purdom, 1994). The next satellite in the operational GOES series is GOES-12, which was launched 23 July 2001. The GOES-12/N/O/P Imagers have been modified to add a band centered at 13.3 μm and improve north-south spatial resolution of a spectrally modified 6.5 μm band. The addition of the 13.3 μm band comes at the expense of eliminating the 12 μm band on the Imagers. Originally the loss of this band was scheduled for only one satellite. However, budgetary constraints did not allow for a six-channel imager. This resulted in the loss of the 12 μm band for all remaining platforms (GOES-12/N/O/P) in this series. The 12 μm band will be available on the next generation of Imagers, starting with GOES-R in approximately 2010 (Gurka and Dittburner, 2001).

The GOES-8 and GOES-12 Imager spectral response functions are shown in Fig. 1. The elimination of the 12 μm band and the addition of the 13.3 μm band can be seen, along with the change to the "water vapor" band. In general, the core mission of the

GOES Imager is accomplished by using time sequences of the infrared window and visible images. Hence this mission will not be affected by these instrument changes. Some products will be improved, while others may be degraded or not generated. The purpose of this paper is two-fold: to introduce the changes on the GOES-12 Imager instrument and to briefly highlight the affected products.

2. INSTRUMENT CHANGES

The GOES-12/N/O/P Imagers have been modified. This includes changing the "water vapor" band and adding a 13.3 μm band (at the expense of the 12 μm band) as discussed in the following sections.

2a. Changes to the "water vapor" 6.7 μm band

The current GOES Imager "water vapor" band 3 (6.7 μm) has many applications, ranging from estimating upper level moisture (Soden et al., 1993; Moody et al., 1999) to defining upper-level jetstreaks (Weldon et al., 1991). The GOES-M "water vapor" band is spectrally wider than the current 6.7 μm band. The spectral width covers the region from 5.77 to 7.33 μm with a center wavelength of 6.5 μm (Table 1). The water vapor spectral response function was made spectrally wider to improve the signal-to-noise ratio. This was needed to compensate for the smaller Field Of View (FOV) on GOES-M. The spectral shift will make it similar to the current European METEOSAT (METEOrological SATellite) band, which has a spectral width from 5.7 to 7.1 μm . The

next generation METEOSAT, to be launched in 2002, however, will have two water vapor bands centered at 6.2 and 7.3 μm (Schmetz et al., 1998; Woick et al., 1997). The next generation Advanced Baseline Imager (ABI) on GOES-R will also have two bands in this spectral region. Radiative transfer calculations for a standard atmosphere show that the GOES-M band 3 will be approximately 2 K warmer than the current Imager band 3 onboard GOES-8 (Fig. 2). This difference is consistent for a variety of atmospheres (not shown). The slight change can also be seen in Fig. 3 by comparing a current GOES Imager 6.7 μm image to a co-located image from METEOSAT. These remapped images are displayed at a longitude halfway between the two satellites. Exact comparisons cannot be made due to differences in atmospheric paths, spectral coverage and observation time. Even so, the images have a correlation coefficient of 0.92. The average METEOSAT brightness values are 3 K higher (239.14 K versus 236.16 K) for this scene. Thus, the GOES-M Imager band 3 can be used in place of band 3 on the GOES-8 for qualitative applications. Most quantitative applications should be unaffected if the correct spectral response function is used to account for this change.

The GOES-M 6.5 μm band will also have a higher spatial resolution. This will be most apparent in the north-south direction (Table 2) where the resolution will change from approximately 8 km to 4 km at the sub-satellite point. The Sampled Subpoint Resolution (SSR) in km is the effective resolution, after considering the east-west over-sampling at nadir. The instantaneous geometric field of view (IGFOV) at the sub-satellite point for the GOES-M shortwave and longwave infrared window and water vapor bands is 4.0 km. On the GOES Imagers, the IGFOVs are over-sampled in the east/west

direction by a factor of 1.75 providing an effective resolution in the east-west direction of 2.3 km (Menzel and Purdom, 1994).

To demonstrate the improved spatial resolution that will be seen on the Advanced Weather Interactive Processing System (AWIPS) (Facundo, 2000), high spatial resolution (1 km) data from the MODerate-resolution Imaging Spectroradiometer (MODIS) onboard the Earth Observing System (EOS) Terra platform were used (Ackerman et al., 1998). A MODIS 6.7 μm image was averaged to both a 4 x 4 km and an 8 x 8 km box (Fig. 4). The existence of mountain waves is clearly seen in the higher resolution MODIS data in its early test period. On 7 April 2000, there was moderate-to-severe turbulence reported over Colorado.

2b. Addition of a 13.3 μm CO₂ band

The 13.3 μm band, referred to as the GOES Imager band 6, will allow for improved cloud height determinations. This band is similar, although with a broader spectral response function, to band 5 on the current GOES Sounder (Menzel et al., 1998) (Fig. 5). Forward radiative transfer calculations for a standard atmosphere show the GOES-M Imager 13.3 μm band will have a slightly higher mean brightness temperature than the Sounder band 5 (Fig. 6). This difference of approximately 1.5 K exists for other atmospheres as well (not shown).

The GOES-M 13.3 μm spatial resolution will be approximately 8 km in the north-south direction, as is the current 6.7 μm band for GOES-8 through GOES-11 (Table 2).

On the GOES-O/P Imagers, the north-south spatial resolution will be improved to 4 km for the 13.3 μm band. The east-west over-sampling will give an effective resolution in the east-west direction of approximately 2.3 km.

2c. Elimination of the 12 μm band

The addition of the 13.3 μm band results in the elimination of the 12 μm band on the GOES-M Imager. The 12 μm band is used for a number of different applications. The difference between the 11 and 12 μm brightness temperatures, known as the split window, helps detect dust, volcanic ash plumes, low-level moisture, and skin temperature and aids in distinguishing between cloud types and biomass burning aerosols (Ackerman, 1996; Ackerman et al., 1992; Moeller et al., 1996; Prata, 1989, Barton et al., 1992; Hayden et al., 1996; Prins et al., 1998). The impact on products due to these instrument changes are discussed in the following section.

3. IMPLICATIONS FOR GOES-M IMAGER PRODUCTS

Table 3 summarizes the expected changes to imagery and product quality due to instrument changes on the GOES-M Imager. One can see that most of the Imager data or products are not affected by these changes, although certain products will be improved or degraded. The following section describes how some individual products are affected.

3a. Cloud Products

Cloud products generated via the CO₂ absorption technique have been demonstrated from instruments on both geostationary and polar-orbiting platforms (Wylie and Wang, 1997; Schreiner et al., 1993; Wylie et al., 1994; Wylie and Menzel, 1999; Frey et al., 1999; Schreiner et al., 2001). Cloud products derived from the GOES Sounder have been used to initialize numerical models (Kim et al., 2000; Bayler et al., 2001). Improved products from the GOES-M Imager will include cloud top pressure, effective cloud amount and cloud top temperature. The effective cloud amount represents the optical thickness of the cloud. Figure 7 shows the Cloud Top Pressure (CTP) derived image using only spectral bands from the GOES Sounder that will be available on the GOES-M Imager. This image has been compared to one derived from the full set of Sounder bands used for deriving CTP. With a sample size of 3533, the bias (Sounder minus Imager derived CTP) was 20 hPa and the root mean square (rms) was 112 hPa.

With the addition of the 13.3 μm band on the GOES-M Imager, the Satellite Cloud Product (SCP) that complements the ground-based ASOS (Automated Surface Observing System) could be generated from the Imager rather than the Sounder (Schreiner et al., 1993). The SCP, based on GOES-M Imager data, would be available in a more timely fashion since the Imager coverage rate is much faster than the Sounder.

The loss of the 12 μm band will negatively impact the detection of low cloud. Currently, 11 minus 12 μm differences are used extensively to flag the presence of clouds. Without the 12 μm data, there will be more reliance on visible data during the day and 3.9 μm data during the night for cloud detection. The 13.3 μm data may also

help to mitigate the loss of the 12 μm band for cloud detection. Studies with actual GOES-12 data during the post-launch checkout will answer this question (Schreiner and Schmit, 2001).

3b. Sea Surface Temperature (SST)

The GOES platform allows frequent looks at a given area with the same viewing angle. This scanning feature is exploited to generate improved spatial and temporal coverage of Sea Surface Temperature (SST) from GOES (Wu et al., 1999). The GOES SST products have many applications, ranging from weather forecasting to fishery management (Seki et al., 2001). Currently a regression method is used to generate this product. At night, the shortwave window (3.9 μm) is used to help determine the SST field. The GOES-M Imager should be capable of retrieving SST fields at night. During the day, when solar reflections in the shortwave window mask the emitted signal, the 11 and 12 μm brightness temperatures are used in the retrieval of SST. In general, the generation of SST via the regression method, with sufficient precision, may not be possible without both of these channels. Efforts are underway in the NESDIS Office of Research and Applications to address the issue of day and night SST determinations using a radiative transfer model and ancillary atmospheric data from a Numerical Weather Prediction (NWP) analysis. SST products from the polar-orbiting satellites can also be used, especially if frequent updates are not needed.

The 11 minus 12 μm channel difference is also used for detection of thin cirrus cloud, which can contaminate the SST retrieval both day and night. The magnitude of

the product degradation due to the unavailability of this test is not known at this time, but will be addressed with GOES-M post-launch test data. It should be noted that the 13.3 μm band is useful in the detection of thin cirrus clouds (Wylie et al., 1994, Wylie and Wang, 1997; Schreiner et al., 2001). As listed in Table 2, band 6 will be at a coarser spatial resolution than the other IR bands on the GOES-M imager.

3c. Dust and Volcanic ash detection

The detection of volcanic ash plumes is important for aviation applications (Casadevall et al., 1992; Davies and Rose, 1998). Currently the GOES split window data are used, in part, for this purpose, especially at night and in the vicinity of water clouds when visible data are not available for detection and tracking of dust and ash plumes. The use of other bands on the GOES-M Imager, for example the 3.9 μm or the 13.3 μm band, may help in some instances. The correct band combinations could be determined via a principal component method (Hillger, 1996). Figure 8 shows an example of a volcanic ash cloud (from Mt. Cleveland in the Aleutian Islands) observed with various band combinations as a three-color composite from the MODIS instrument. These images were created by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) using Man computer Interactive Data Access System (McIDAS) software with an equal weighting in the three-color composite. The image on the left only includes bands on the current GOES Imager (11 minus 12 μm , 11 μm and 12 μm). The image on the right was created with bands available on the GOES-M Imager (11 minus 13.3 μm , 11 μm and 13.3 μm). This combination includes spectral bands that can be used to locate

volcanic ash plumes during the night. It is apparent that the loss of the 12 μm band will negatively impact the detection of volcanic ash plumes. Other researchers have come to this same conclusion (Hillger and Clark, 2001; Ellrod, 2001). This negative impact may be mitigated during daylight hours, however, due to the presence of solar reflectance in the 3.9 μm channel, and the availability of visible imagery. Studies are being done within the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) Office of Research and Applications to investigate whether the 13.3 μm data can help with the detection of volcanic ash plumes. Another option will be to rely on images and products from a host of polar-orbiting satellites. This will be especially effective poleward of 50 degrees.

3d. Low-level moisture, lifted index and skin temperature determinations

Given that most of the signal for the Imager Derived Product Images (DPI) comes from the split window difference (Hayden et al., 1996), the GOES-M Imager DPI will need to be replaced by those derived from the Sounder. This is the case for Total Precipitable Water (TPW), Lifted Index (LI) and the skin temperature product. While the Sounder DPI is limited in its spatial coverage and resolution, the Sounder DPI products have been shown to be an improvement over the Imager alone (Menzel et al., 1998). The Sounder DPI products are used by forecasters where available (Schrab, 2000) and are available on AWIPS. There are a few geographical regions that are covered by the Imager DPI, but not the Sounder DPI.

3e. Rainfall estimations

Rainfall estimation techniques that rely on only the infrared window, for example the auto-estimator (Vicente et al., 1998), will not be affected by changes to the GOES-M Imager. Multi-spectral algorithms, such as the GOES Multispectral Rainfall Algorithm (GMSRA) (Ba et al., 2001) will most likely not incur any major impact. This is due to a heavy reliance on the infrared window bands. The 12 μm data are currently used, in conjunction with the 11 μm data, to estimate the cloud top temperature (Wu et al., 1999). This temperature is used to compute the emitted portion of the 3.9 μm radiance. Some other technique will need to be employed to determine the cloud top temperature. Investigations will be performed to determine if GOES-12 Imager 13.3 μm data can be helpful in this regard.

3f. Satellite-derived wind fields

The tracking of atmospheric features (Velden et al., 1997) will be improved using the GOES-M Imager. The 13.3 μm data will provide better estimates of cloud height for the tracking of atmospheric motions. Currently, the height assignment is one of the greatest sources of error (Nieman et al., 1993). Improved cloud height estimates, especially for thin clouds, are possible with the 13.3 μm band via the CO_2 absorption technique (Schreiner et al., 1993). In addition, the improved spatial resolution of the water vapor band will allow better determination of cloud edges and moisture gradients. However, since the spectrally broader band 3 will sense radiation emitted from lower in

the atmosphere, low clouds may be tracked as opposed to water vapor gradients in very dry atmospheres. Data from the GOES-M post-launch test will be used to investigate the accuracy of the satellite-derived wind fields.

3g. Objective Dvorak technique

The Objective Dvorak Technique is used to monitor the strength of tropical cyclones and relies on the longwave infrared window band (Velden et al., 1998a). The changes to the GOES-M Imager should have no effect on this product.

3h. Biomass burning

In general, the detection of active fires (Prins et al., 1998) should not be affected by the changes to the GOES-M Imager because the primary bands used are the 3.9 μm and the 11 μm bands. However, the 12 μm data are used in the process of detecting cloud types, which will impact the determination of trends in fire activity. It will be more difficult to relate a change in the number of fires detected to the actual number of fires, since any reduction could be due to the presence of more cloud. The GOES smoke/aerosol detection algorithm relies on the 12 μm band and hence will be degraded. Investigations will determine the usefulness of the 13.3 μm band as a replacement.

3i. Fog detection

The bispectral technique for fog detection (Ellrod et al., 1998) is based on the longwave minus shortwave IR window brightness temperatures. Hence it will not be affected by the changes on the GOES-M Imager.

3j. Aircraft icing

GOES imagery is used to generate an experimental product that highlights areas of supercooled water clouds that could produce aircraft icing (Ellrod, 1996). This product uses the split window (band 4 minus band 5) temperature difference of greater than 2 K to flag thin cirrus. The GOES-M Imager 13.3 μm band will be tested to determine its usefulness for cirrus detection.

4. GOES-M POST-LAUNCH CHECKOUT

The effect of instrument changes on the GOES re-broadcast signal format have been documented. For details, see the Operations Ground Equipment (OGE) Interface Specification (DRL 504-02 Part 1.) While no decision has been made at this time, it is possible that GOES-12 would be put into operational service before GOES-11. This may be due in part to the improved capabilities that GOES-M provides and also to use a new instrument onboard the GOES-M spacecraft, the Solar X-ray Imager (SXI). The SXI will provide images of the sun in the X-ray spectrum every minute (Bornmann et al., 1996; Hill et al., 2001). These data will be used in forecasting space weather. Its importance is magnified due to the recent solar activity maximum.

After the standard NASA GOES-12 instrument post-launch checkout, there will be a 5-week NOAA-led science test checkout phase. The highest priorities during the test will be acquisition of the new 13.3 μm data and the development and testing of current and new products. Hence, any remaining questions will be addressed on the transition of data from the GOES-8/11 to the GOES-12/P instruments.

5. SUMMARY

Several products from the GOES-M Imager will benefit from the inclusion of a band centered at 13.3 μm and the improved north-south spatial resolution of a spectrally modified 6.5 μm band. In order to accommodate the 13.3 μm band, the 12 μm band was eliminated on the GOES-M Imager. These changes to the Imager will allow some Imager products to be improved, while the quality of other products will be degraded or possibly the products will not be generated. Improved products include the Imager-based cloud information and satellite-derived motion vectors. For degraded products from the GOES-M Imager, more reliance may be placed on the coarser resolution Sounder products or it may be necessary to rely upon data and products from a host of polar-orbiting satellites. The latter approach will be especially effective at higher latitudes due to the more frequent coverage. Overall, the changes will not affect the core mission of the Imager because neither the longwave window nor visible band will be changed. The 12 μm band, along with a host of other bands, will be included on the next generation series of GOES Imagers, beginning with GOES-R in approximately 2010.

ACKNOWLEDGEMENTS

The authors would like to thank the following scientists from the CIMSS at the University of Wisconsin-Madison: Fred Wu for the SST section, Suzanne Wetzel Seemann and the entire MODIS team for the MODIS data, Scott Bachmeier for the mountain wave case, Mathew M. Gunshor for Figure 1, James P. Nelson III for programming support and Gail Bayler for a careful reading of the manuscript. Gary P. Ellrod, NESDIS/ORA, is thanked for many useful comments on the volcanic ash plume monitoring section. Eileen Maturi, NESDIS/ORA, is also thanked for input for the SST section. Robert J. Kuligowski, NESDIS/ORA is thanked for information on the GMSRA algorithm. Support for University of Wisconsin personnel came from NOAA/NESDIS grant NA07EC0676. The Spectral Response Functions were acquired via ITT.

WEB PAGES

GOES launch schedule and GVAR changes:

<http://www.osd.noaa.gov/sats/goeslaunch.htm>

<http://www.osd.noaa.gov>

GOES spectral response functions and GOES-M changes:

<http://www.oso.noaa.gov/goes/goescal.htm>

<http://www.oso.noaa.gov/goes/goes-calibration/change-channels.htm>

Forecast Products Development Team:

<http://orbit35i.nesdis.noaa.gov/arad/fpdt/>

Biomass Burning:

<http://cimss.ssec.wisc.edu/goes/burn/abba.html>

Tropical Cyclones:

<http://cimss.ssec.wisc.edu/tropic/tropic.html>

GOES Sounder 13.3 μm and cloud images:

<http://cimss.ssec.wisc.edu/goes/realtime/grtmain.html#gscb05>

<http://cimss.ssec.wisc.edu/goes/realtime/grtmain.html#ctop>

CIMSS GOES Gallery (07 April 2000; Mountain Wave case)

<http://cimss.ssec.wisc.edu/goes/misc/000407.html>

The SXI and space weather:

<http://www.sec.noaa.gov/sxi/>

MODIS:

<http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html>

METEOSAT:

<http://www.eumetsat.de/en/index.html>

Polar Orbiting Satellites:

<http://www.oso.noaa.gov/poes>

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Figure 3. A sample GOES-8 and METEOSAT “water vapor” image for 12 October 2000 at approximately 0900 UTC. Both images have been re-mapped to a Mercator projection. The temperature range between 255 and 225 K is enhanced. The region selected is centered at the mid-point longitude between the two satellites near the coast of South America. The METEOSAT image is darker representing brightness values that are approximately three K higher.

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TABLES

Table 1. GOES Imager spectral widths for GOES-8 (which are similar to GOES-9 through GOES-11) and GOES-M. The units of wavelength are μm ; the units for wavenumber are cm^{-1} . The current Meteosat bandwidth for the water vapor band is 5.7 to 7.1 μm .

GOES-8 Imager Bandwidths

Ch	Wavelength	Central	Wavenumber
##	Range	Wavelength	Range
1	0.53 to 0.72	0.64	13812 to 19048
2	3.78 to 4.03	3.91	2482.2 to 2647.7
3	6.47 to 7.03	6.75	1421.8 to 1544.5
4	10.21 to 11.20	10.69	892.5 to 979.1
5	11.54 to 12.47	11.97	802.1 to 866.2

GOES-M Imager Bandwidths

Ch	Wavelength	Central	Wavenumber
##	Range	Wavelength	Range
1	0.53 to 0.77	0.65	12970 to 18939
2	3.76 to 4.03	3.90	2481.9 to 2656.4
3	5.77 to 7.33	6.48	1363.3 to 1733.4
4	10.23 to 11.24	10.71	889.7 to 977.1
-			
6	12.96 to 13.72	13.31	729.0 to 771.6

Table 2. GOES-8 and GOES-M Imager spatial characteristics. Detector Instantaneous Geometric Field Of View (IGFOV) or footprint is in km at the sub-satellite point. The Sampled Subpoint Resolution (SSR) is also in km and is a finer resolution due to over-sampling in the east-west direction. The spatial characteristics are listed as the east-west by north-south dimensions, respectively. The GOES-8 values are from Menzel and Purdom, 1994.

Ch	Descr.	GOES-8/11		GOES-M/P	
		IGFOV	SSR	IGFOV	SSR
1	Visible	1.0 x 1.0	0.57 x 1.0	1.0 x 1.0	0.57 x 1.0
2	SW window	4.0 x 4.0	2.3 x 4.0	4.0 x 4.0	2.3 x 4.0
3	water vapor	8.0 x 8.0	2.3 X 8.0	4.0 x 4.0	2.3 x 4.0
4	LW window	4.0 x 4.0	2.3 x 4.0	4.0 x 4.0	2.3 x 4.0
5	Split window	4.0 x 4.0	2.3 x 4.0	-	-
6	CO2	-	-	8.0 x 8.0	2.3 X 8.0

Table 3. The expected effects on products due to the instrument changes on the GOES-M Imager.

Product	Change	Comment
Cloud height products	Improved	Better height assignments
Satellite-derived winds	Improved	Better height assignments
Mid-level moisture gradients	Improved	Due to finer spatial resolution
“Water Vapor” Imagery	Slightly Improved	Change in spectral width
	Improved	Higher spatial resolution
Visible imagery	None	
Products from visible imagery (e.g. solar insolation)	None	
Infrared window imagery	None	
Products based only on IR window (e.g. auto-estimator)	None	
Rainfall based only on several bands	Slight Difference	
Shortwave window imagery	None	
Any products based only on shortwave Window	None	
Bispectral fog product	None	
Objective Dvorak technique	None	
Detection of active fires	None	
Aircraft icing	Unknown	Band 6 may be used for Cirrus detection
Sea Surface Temperatures	Unknown	Daytime products may not be possible
Dust, smoke and volcanic ash detection	Degraded	Affect more pronounced during the night
Detection of low cloud	Degraded	Affect more pronounced during the night
Low-level moisture and skin temperature determinations	Degraded	Rely on sounder or polar- orbiting data

FIGURES

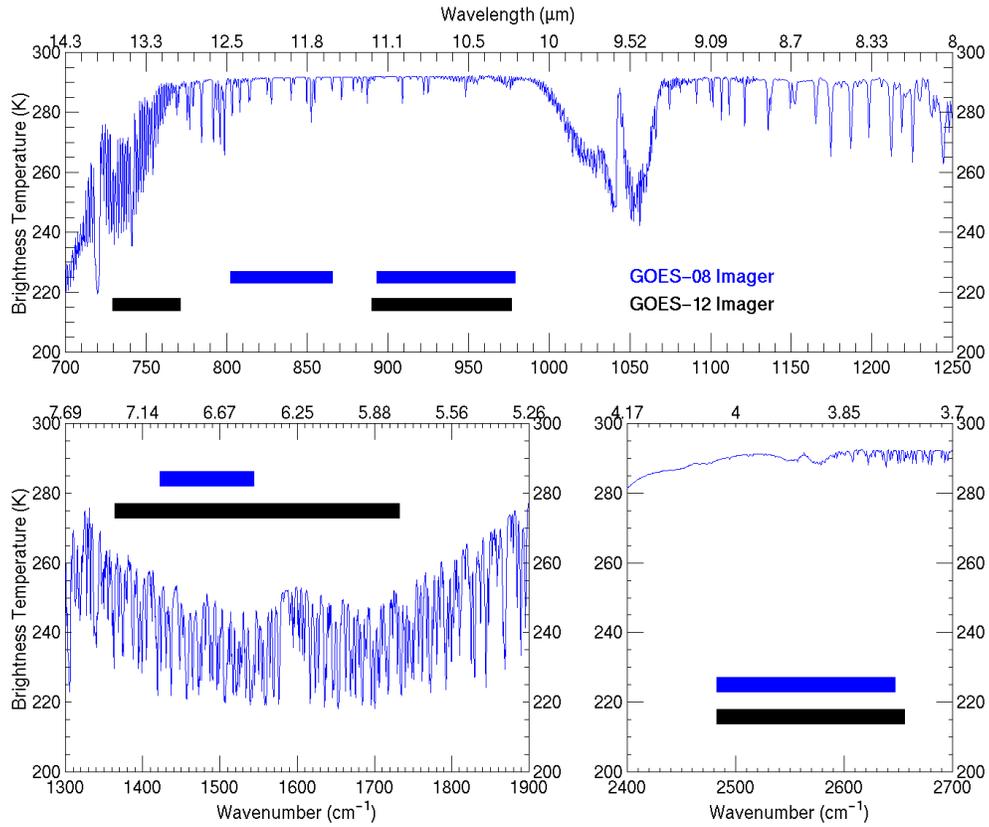


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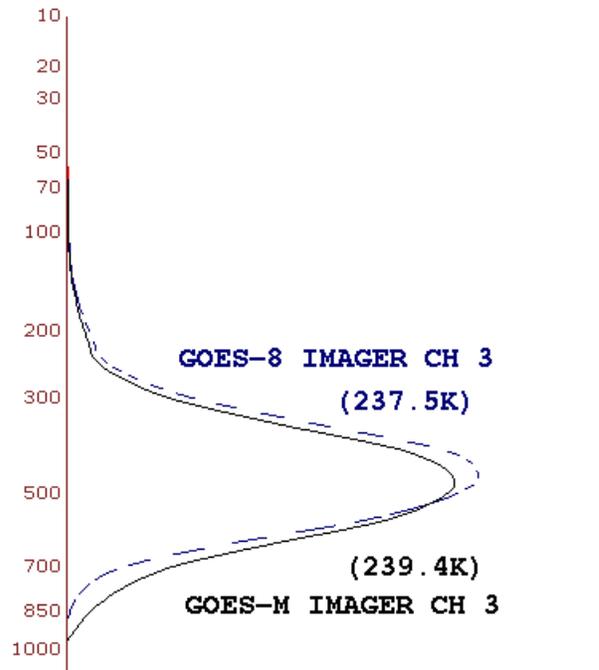


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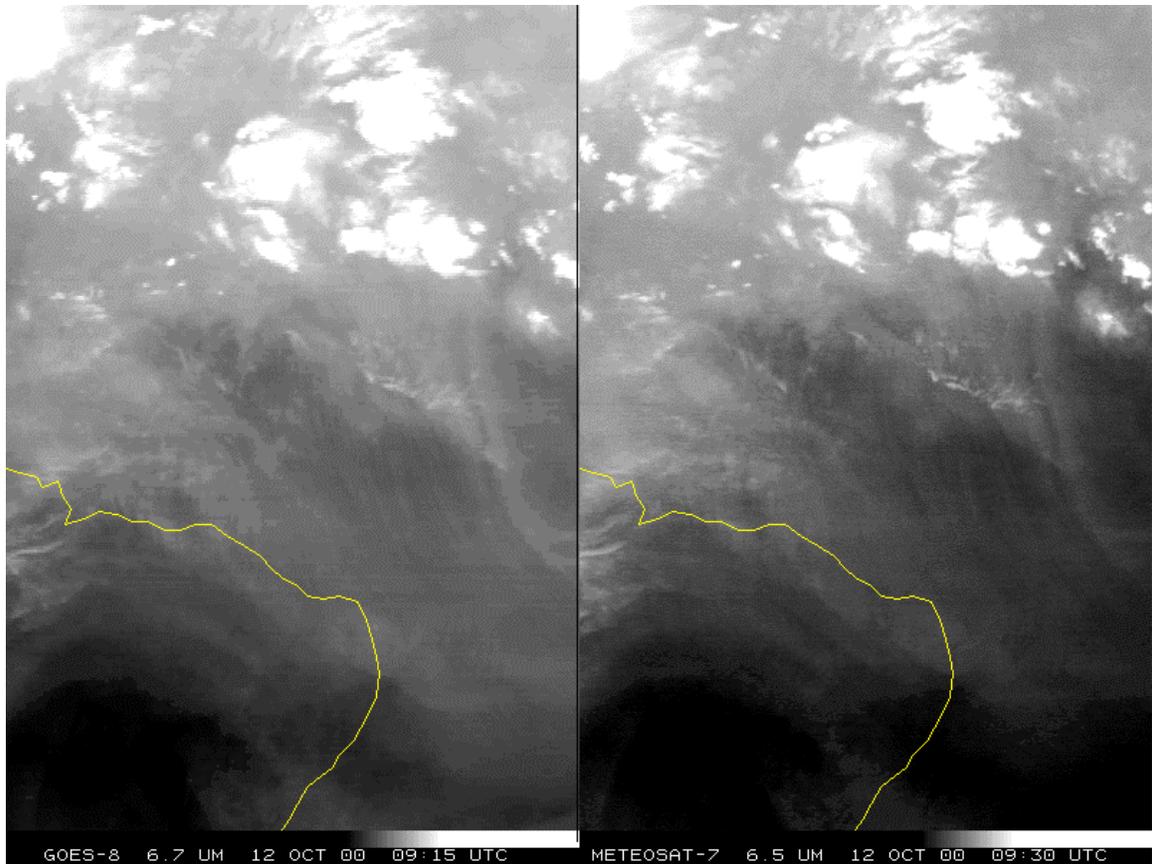


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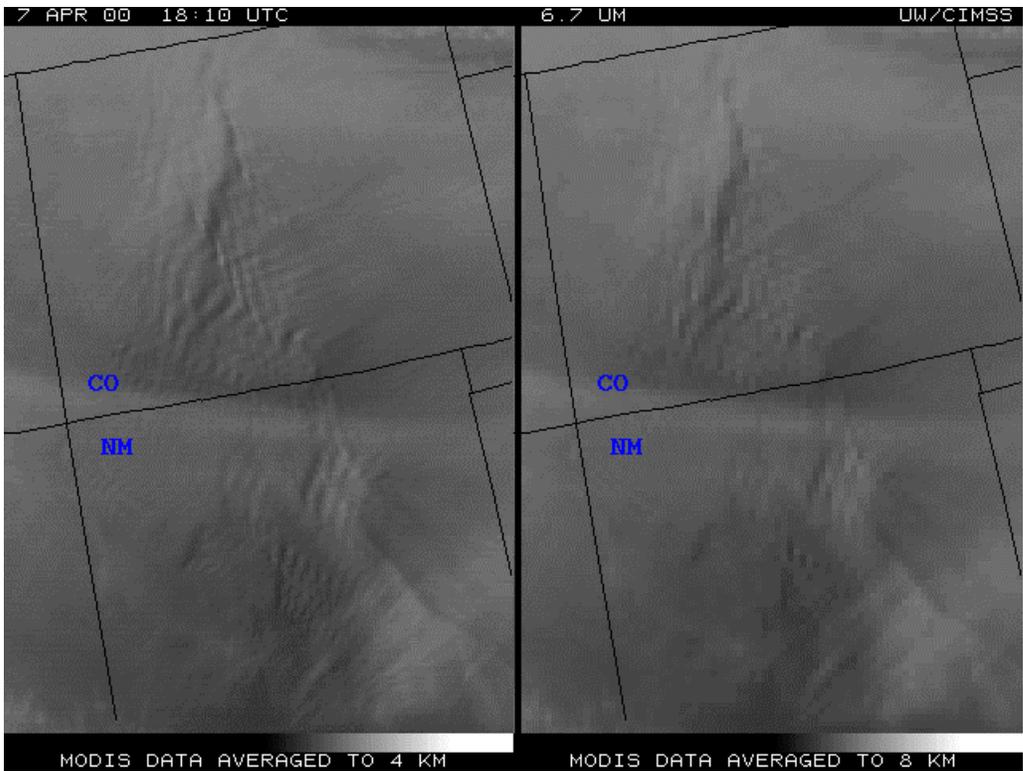


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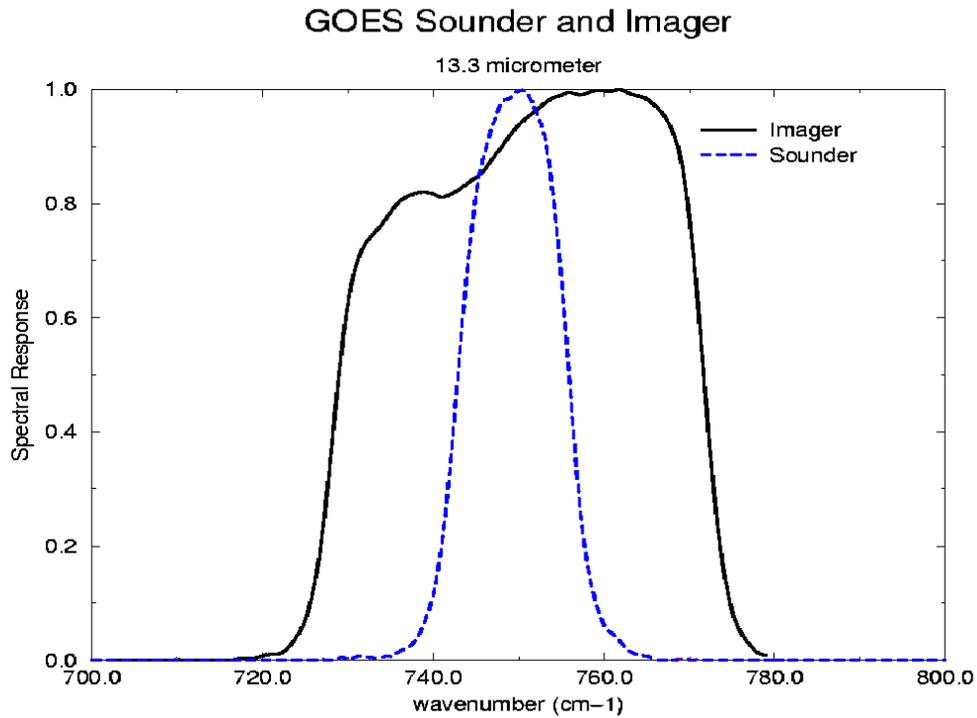


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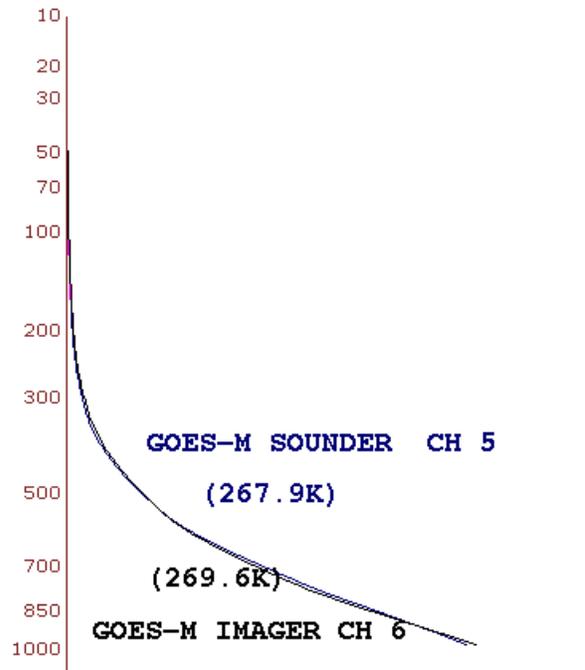


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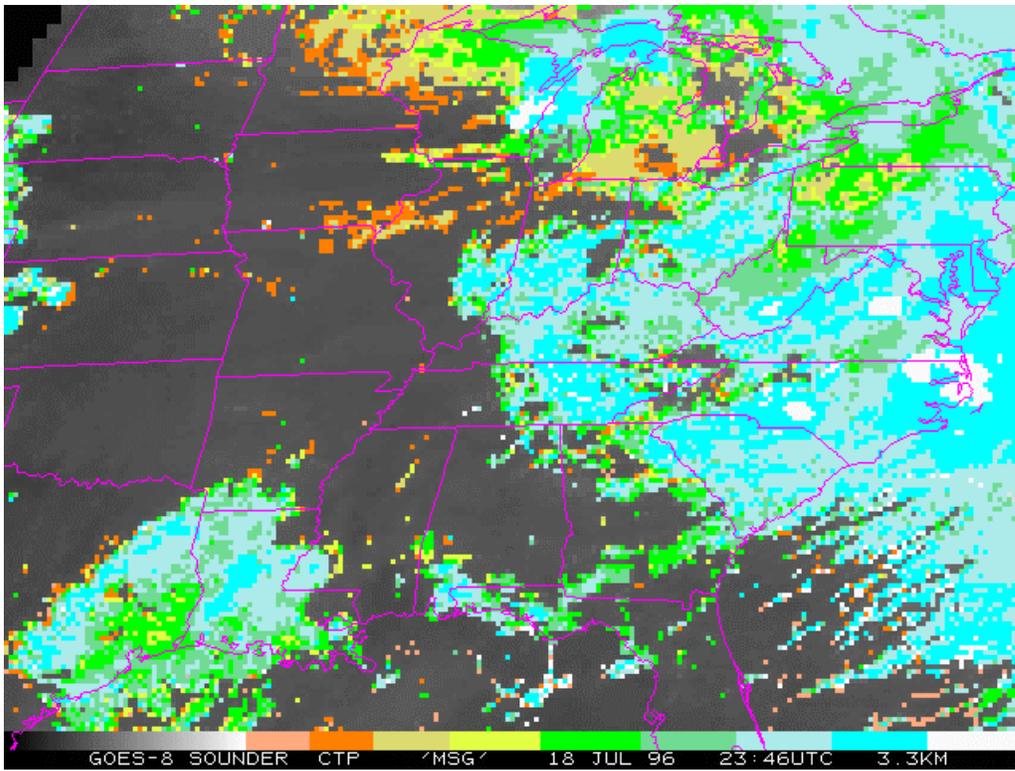


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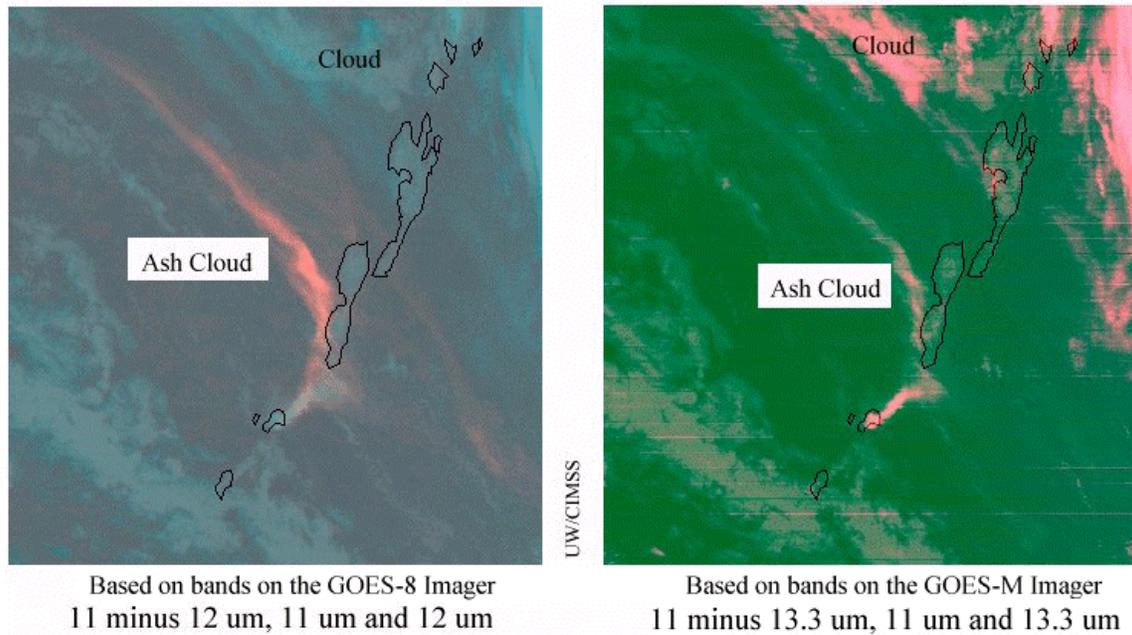


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