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Loss of the 12.0 µm "Split Window" Band on GOES-M: Impacts on Volcanic Ash Detection

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1. INTRODUCTION

Beginning with the Geostationary Operational Environmental Satellite (GOES)-M spacecraft (successfully launched on 23 July 2001) through GOES-Q (scheduled launch in 2007), a 12.0 µm "Split Window" InfraRed (SWIR) band (4 km resolution) on the Imager will be replaced by a 13.3 µm CO_2 absorption band (8 km resolution). Table 1 summarizes the changes planned for the reconfigured GOES Imagers. A more detailed description of GOES-M, with an assessment of effects on many environmental parameters, is available in Schmit et al, (2001).

Brightness temperature differences (BTD) between the IR window bands at 10.7 µm (Band 4 on GOES) and 12.0 µm (Band 5) have been successfully used in tracking hazardous volcanic ash clouds since they first became available on GOES-8 in 1994. Negative values of the Band 4 minus Band 5 BTD are typical of volcanic ash, while positive values denote meteorological clouds (e.g. Prata, 1989). This Two-Band Split Window (TBSW) product from GOES-8 is relied upon heavily at the Washington Volcanic Ash Advisory Center (VAAC), which is responsible for operational hazard monitoring of a large, volcanically-active portion of the Caribbean, and Central and South America. Other North American VAACs (Anchorage, Montreal) also employ the TBSW from GOES, but to a lesser extent.

The purpose of this paper is to describe the possible impact of the loss of this IR channel on volcanic ash detection within the GOES field-of-view, and discuss alternative strategies to mitigate this loss. The latter comprise: (1) maximum utilization of all remaining GOES channels, and (2) exploitation of the global constellation of polar orbiting meteorological satellites, including the operational National Oceanic and Atmospheric Administration (NOAA) series, and research satellites launched by the National Aeronautics and Space Administration (NASA).

2. DATA AND PROCEDURES

In order to assess the effect of the GOES-M+ Imager channel reconfiguration on volcanic ash detection, GOES-8 Imager or Sounder data from several prior eruptions were analyzed to see how volcanic ash coverage would look with and without the use of the 12.0 µm IR band. The GOES-8 Sounder (see Menzel et al, 1998) has all IR bands currently on the Imager, plus the 13.3 µm band, although at a lower resolution (10 km). The analysis was completed using principle component image software developed by Hillger (1996) which displays unique information available from the input IR wavelengths. The best principle component depiction of the ash cloud for each event was compared to a subjective best estimate of the actual ash cloud coverage based on: (1) analysis of all available GOES data, including visible images, (2) the evolution of the volcanic cloud from its eruption to image time, and (3) VAAC advisories. In one case (26 December 1997) a concurrent Total Ozone Mapping Spectrometer (TOMS) Aerosol Index image was obtained as a source of independent ash coverage.

In addition to qualitative comparisons, a quantitative parameter, termed "false pixel rate" (FPR) was determined. The FPR describes the percentage of the total image area (expressed in pixels) comprised of "false ash" (based on the subjective "true" ash plume described above). This can be described as:

$$\mathbf{FPR = (T - A) / N} \qquad \mathbf{(1)}$$

where T is the total of ash plus false pixels, A is the number of "true" ash pixels, and N is the total number of pixels in the image scene.

The six cases analyzed are summarized in Table 2, which contains information on the volcano name, date, time(s), type of data evaluated (Imager versus Sounder) and relative strength of the eruption. Analysis of the 26 December 1997 Soufriere Hills eruption is not complete. Two cases (Lascar, 20 July 2000 and Guagua Pichincha, 5 October 1999) were evaluated at hourly intervals for several hours. For some events that utilized only Sounder data, only single time periods are available due to the relatively infrequent Sounder scanning of volcanically active regions (once every six hours for the Caribbean, one to three hours for the Gulf of Mexico, none over South America).

3. RESULTS

Preliminary results indicate that the loss of the SWIR band will result in an increase of mis-identified ("false") ash pixels which seem to vary diurnally. During the daytime, the increase in false pixel rate without SWIR will be minimal (~1-2%) due to the positive contribution of reflectance in the 3.9 µm shortwave IR band. At night, the false pixel rate increases by a factor of ~ 4, likely due to the loss of shortwave reflectance.

A representative daytime example is shown by the histogram in Figure 1 for the Guagua Pichincha eruption. At 2015 UTC (~1.5 hr after eruption), the FPR is >5 times larger using the SWIR than without its use. Use of the SWIR is less effective shortly after the eruption, due to the opacity of the volcanic cloud caused by large ash particles and considerable condensed water droplets and/or ice. At the later times (2115 and 2215 UTC) the FPR is ~3%, comparable to that obtained from the best image with no SWIR contribution. The increase in the latter to ~5% by 2215 UTC is due to less contribution from solar reflectance as sunset approaches. The role of reflectance at shortwave IR wavelengths has been described by Schneider and Rose (1994) for analysis of Spurr volcano ash samples in Alaska. An image comparison at 2215 UTC is shown in Figure 2.

A nighttime example from the GOES Sounder was obtained for an ash cloud from Popocatepetl volcano in Mexico that drifted across eastern Mexico on the night of 23 January 2001. The FPR values for the image that all four IR bands (including SWIR) are ~5 times less than for one that uses only the other IR bands. The latter were determined using the Sounder equivalents to Imager bands 2, 3, 4 and 2, 3, 4, and 6, respectively (Band 6 will be the new 13.3 µm IR). Inclusion of data from the 13.3 µm band appears to provide a slight positive impact, allowing for better discrimination of ash from thin cirrus clouds. A scatter plot of the Sounder data at this time for equivalent Bands 4 minus 6 vs Band 4 temperature (Figure 3) indicated a significantly higher BTD for cirrus clouds than for ash.

Subjective evaluation indicated that most of the mis-identified ash is not contiguous with the "true" ash plume or cloud, however, suggesting that a human analyst can successfully track an ash plume or cloud, and provide a reasonably good estimate of its area. The capability to animate GOES imagery at 15 to 30 min intervals provides valuable continuity in this analysis. Any gain achieved from the 13.3 µm IR data will be offset somewhat by its lower resolution (8 km), until GOES-O in 2005 when it will improve to 4 km.

4. ALTERNATIVE DATA SOURCES

In addition to the GOES Imager, the GOES Sounder provides 18 IR bands at 10 km resolution. The Sounder has limited spatial and temporal coverage however (current GOES operational scanning areas and schedules may be viewed at: http://www.ssd.noaa.gov). Nevertheless, if dedicated to view volcanic regions more often, the Sounder can provide useful TBSW-based image products (Ellrod, 1998).

The 12 µm IR channel will continue to be available at 1 km resolution from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar spacecraft The Moderate Resolution Infrared Spectrometer (MODIS) on the NASA Earth Observation Satellites (Aqua and Terra) will also have this spectral band , along with 35 others, also at 1 km. The Chinese Fun Yueng (FY)-1C has also recently become available to the Anchorage VAAC to fill some data gaps at high latitudes. The polar satellite data can provide better quality images to supplement (or calibrate) ash products generated from GOES. Merging of concurrent GOES and POES images is also a possibility.

5. SUMMARY AND CONCLUSIONS

GOES Imager and Sounder data were evaluated to determine the possible effects of losing the 12 µm Split Window IR band, on GOES-M (12) through Q (a period of at least 6 years). Principle component images with and without the SWIR were compared subjectively, and objectively using a false alarm rate parameter. GOES Sounder data were also evaluated in a few instances to assess any potential contributions from the new 13.3 µm Imager band. During periods of daylight, there was little difference in the quality of IR detection without the SWIR, likely due to the reflectance peak of ash near 3.9 µm. At night, the ash detection capability appeared to be somewhat worse, due to more interference from non-ash features, such as clouds or surface features. The effects of this performance on aviation operations could be an occasional increase in the area of analyzed ash coverage to err on the side of safety, resulting in somewhat longer enroute diversions. The 13.3 µm IR band should be useful in distinguishing ash from cirrus clouds, but not from low level water droplet cloud systems. In summary, we will still be able to observe and track significant volcanic ash clouds in the GOES-M through Q era (2002-2008+), but with some degradation that will be most significant at night.

6. REFERENCES

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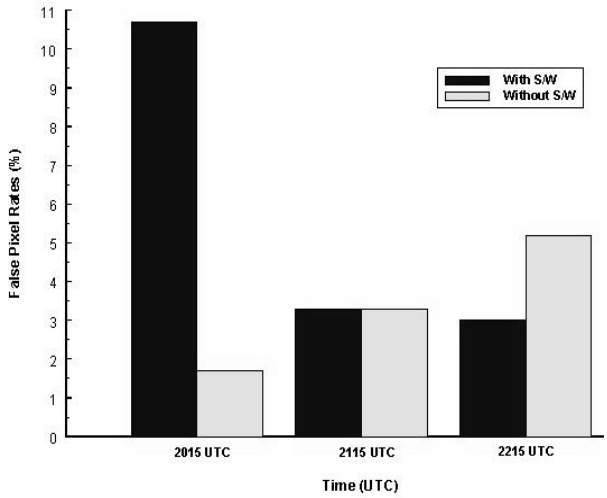

Figure 1. Histogram of False Pixel Rates (%) for Lascar eruption on 20 July 2000 with (black fill) and without (gray fill) the 12.0 µm IR band on the GOES Imager.

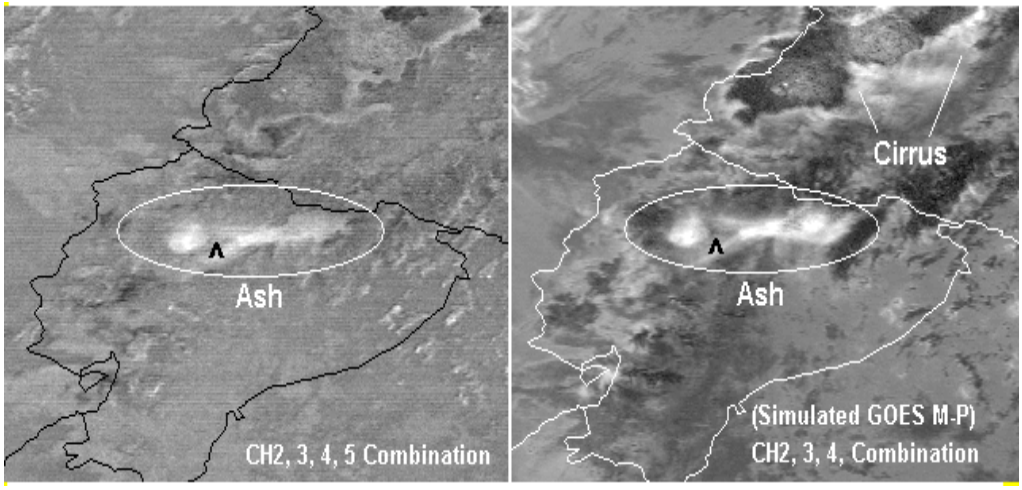

Figure 2. Comparison of ash cloud depiction from the GOES Imager on 5 October 1999 at 2215 UTC using all five IR bands, including 12 µm (left) versus only bands 2, 3, and 4 (right). The ash was produced by a moderate eruption of Guagua Pichincha volcano near Quito, Ecuador (shown by the ^) near 1945 UTC.

Table 1.
Imager Channel Configuration of GOES: Current vs GOES M-Q

	Current GOES (8-11)		GOES M-Q (2002-2008)		
Imager Band	**Wavelength (µm)**	**Resolution (km)**	**Wavelength (µm)**	**Resolution (km)**	**Description**
1	0.6	1	0.6	1	Daytime visible
2	3.9	4	3.9	4	Shortwave IR
3	6.7	8	6.7	**4**	Water Vapor
4	10.7	4	10.7	4	Window IR
5	12.0	4	**-**	**-**	Split Window
6	**-**	-	**13.3**	**8**	CO2 absorption

Table 2.
Volcanic Eruption Cases Evaluated for GOES Ash Detection Capability

VOLCANO	DATE	TIMES	TYPE	INTENSITY
Soufriere Hills, Montserrat	29 Sep 97	1620 UTC	Sounder	Weak
Soufriere Hills, Montserrat	23 Sep 97	1520 UTC	Sounder	Weak
Popocatepetl, Mexico	23 Jan 01	0420 UTC	Sounder	Moderate
Guagua Pichincha, Ecuador	5 Oct 99	2015-2215 UTC	Imager	Moderate
Lascar, Chile	20 Jul 00	1539-1739 UTC	Imager	Moderate
Soufriere Hills, Montserrat	26 Dec 97	1520 UTC	Sounder	Strong

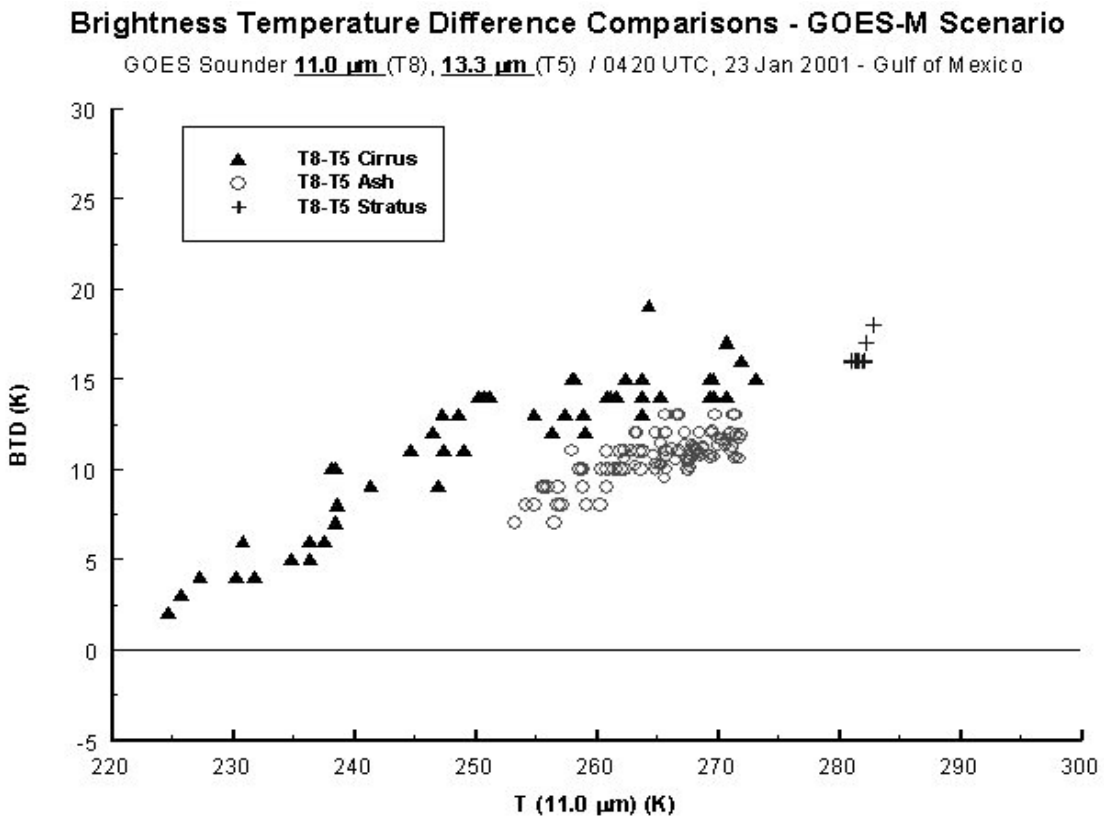

Figure 3. Scatter plot of GOES Sounder IR bands 8 - 5 BTD (equivalent to GOES-M Imager bands 4-6) versus Band 8 temperature (K) for volcanic ash (circles) and cirrus clouds (triangles) at 0420 UTC on 23 January 2001. Sounder bands 8 and 5 will be equivalent to GOES-M Imager bands 4 and 6, respectively.