P3.24 EVALUATION OF MODERATE-RESOLUTION IMAGING SPECTRORADIOMETER (MODIS) SHORTWAVE INFRARED BANDS FOR OPTIMUM NIGHTTIME FOG DETECTION

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1. INTRODUCTION

A bi-spectral technique for nighttime detection of potentially hazardous low clouds and fog based on shortwave Infrared (SWIR) data near 4.0μm and longwave Infrared (LWIR) data near 11μm obtained from meteorological satellites has been in use for over two decades. Initially, the image products were derived from Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA polar-orbiting satellites (Eyre et al 1984), but have since migrated to geostationary satellites such as Geostationary Operational Environmental Satellite (GOES) (Ellrod 1995; Lee et al. 1997), and more recently, Meteosat Second Generation (MSG). The images provide excellent detection of low stratiform clouds, provided they are not obscured by higher cloud layers and are sufficiently thick to allow discrimination from the background scene. The detection technique is based on lower emissivity of water droplet clouds in the SWIR compared with LWIR wavelengths (Hunt 1973), leading to LWIR-SWIR brightness temperature differences (BTD) of ~2K or greater. The technique can only be used at night due to the solar contamination of the shortwave IR channel during daytime.

The recent availability of 1-km resolution IR data from the Moderate-resolution Imaging Spectroradiometer (MODIS) instrument on the experimental NASA Terra and Aqua spacecraft (launched in 1999 and 2002, respectively) provides the opportunity to evaluate a number of SWIR wavelengths simultaneously to determine their relative effectiveness in detecting low clouds at night. This paper describes the differences observed among MODIS SWIR channels for two cases of fog and stratus: one involving extensive fog in the Great Salt Lake Basin on the night of 19-20 December 2004, and the second for patchy valley fog and more extensive coastal stratus in the Middle Atlantic States on the night of 5-6 October 2005.

2. DATA AND PROCEDURES

MODIS features a total of 36 spectral bands, 20 visible and near-IR, 6 SWIR, and 10 LWIR (Schueler and Barnes 1998). The SWIR and LWIR channels have a spatial resolution of 1 km at nadir. Of the 6 shortwave IR bands, 2 have redundant spectral range but differ in noise characteristics due to broader thermal response in one of the channels. The MODIS fog images were compared with GOES images remapped to Lambert Conformal projection at 1 km scale. The GOES Imager channels used in the comparison were IR bands 2 (3.9μm) and 4 (10.7μm), which both have sub-point resolutions of 4 km. The characteristics of the IR channels used in this study (MODIS and GOES) are listed in Table 1.

The bi-spectral "fog product" was derived from the brightness temperature difference (BTD) of each MODIS SWIR band from LWIR Band 31 (11.0 μm), using the same contrast and background brightness settings for each image. A qualitative image comparison was then made, using the same cloud/no cloud threshold for all images.

3. EXAMPLES

3.1 *Case 1: 19-20 December 2004*

Late in the evening on 19 December 2004, dense fog and stratus covered the Great Salt Basin, including metropolitan Salt Lake City. The fog had persisted for more than two days under a surface and upper air high pressure ridge. A surface frontal system approaching during the night (Figure 1) likely resulted in some thickening of the fog as indicated by light snow at Salt Lake City by 1200 UTC. Data from a MODIS overpass at 0520 UTC

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were collected, and bi-spectral LWIR-SWIR images were compared with similar images from GOES IR data valid at 0515 UTC. Figure 2 shows a comparison of three MODIS bi-spectral image products with GOES. These images are color enhanced to show BTD values of ≥2K as yellow, while the black and blue areas represent cirrus. Among the MODIS IR products, the one derived from Band 20 (3.7μm) provided the strongest contrast along the edge of the stratus cloud deck, while Band 22 (3.9μm) was slightly less effective. Band 23 (4.0μm) was significantly worse in discriminating the fog from cloud-free regions, and had some noticeable false signals within the clear areas in the western portion of the image, likely a result of low-emissivity soils (Sutherland 1986) and possibly increased instrument noise.

3.2 *Case 2: 5-6 October 2005*

The second case involved patchy fog formation in Appalachian Mountain valleys of Pennsylvania and New York, and some coastal stratus on the night of 5-6 October 2005. The surface pressure map at 1200 UTC, 6 October 2005 (Figure 3) shows a ridge of high pressure over the Mid-Atlantic States in advance of a mid-latitude frontal system approaching from the central United States. Surface dew point temperatures were in the mid-50's to mid-60's F, ideal for radiation fog formation. The MODIS derived images at 0315 UTC (Figure 4) clearly showed valley fog forming in northern Pennsylvania and southern New York that was not detected by GOES (panel (a)) due to the latter's coarser spatial resolution. GOES was only able to observe the coastal stratus, mainly over New Jersey, along with a few patches elsewhere. With respect to channel selection, use of MODIS Band 20 (3.7μm) in the fog imagery was again slightly better than Band 22 (3.9μm), and significantly better than Band 23 (4.0μm). Band 24 (4.5μm – not shown) produced no useful information when differenced from Band 31.

4. SUMMARY OF RESULTS

Analysis of bi-spectral images from MODIS using three different SWIR bands revealed that the shortest SWIR channel (Band 20 centered near 3.7μm) provided the best nighttime low cloud detection (based on contrast of the cloud edge) and lowest false detection (caused by certain soil types and instrument noise). The 3.9μm channel (Band 21) was a close second in quality, while the longer wavelengths (Band 23, 4.0μm and Band 24, 4.5μm) produced the worst fog detection, perhaps due to weak water vapor absorption, and the proximity of Band 24 to a strong CO_2 absorption band centered near 4.3μm.

5. IMPLICATIONS FOR CURRENT AND FUTURE SPACECRAFT

The Advanced Very High Resolution Radiometer (AVHRR), currently on NOAA polar-orbiting satellites, and the Visible Infrared Imager/Radiometer Suite (VIIRS) instruments planned for National Polar-orbiting Operational Environmental Satellite System (NPOESS) to be launched by late 2008 will both have a 3.7μm SWIR band, and thus can provide the best possible nighttime fog detection. Although the future Geostationary Operational Environmental Satellite (GOES) Advanced Baseline Imager (ABI) SWIR (proposed to be a 3.9μm channel) will provide good low cloud detection, minor tuning of the central wavelength would result in some improvement, although effects on other products (e.g., wildfire detection) must be also be considered. Further evaluations of optimal shortwave bands for fog detection such as described here could lead to improved safety and efficiency for the aviation industry, as well as for surface transportation.

6. REFERENCES

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7. DISCLAIMER

The contents of this extended abstract are solely the opinions of the author and do not constitute a statement of policy, decision, or position of the United States Government.

TABLE 1.
MODIS/GOES Channels Evaluated for Fog Detection

Spacecraft	Instrument	Band #	Wavelength (μm)	Resolution (km)
Terra	MODIS	20	3.750	1
“	“	22	3.959	1
“	“	23	4.050	1
“	“	24	4.466	1
“	“	31	11.030	1
GOES	Imager	2	3.90	4
“	“	4	10.70	4

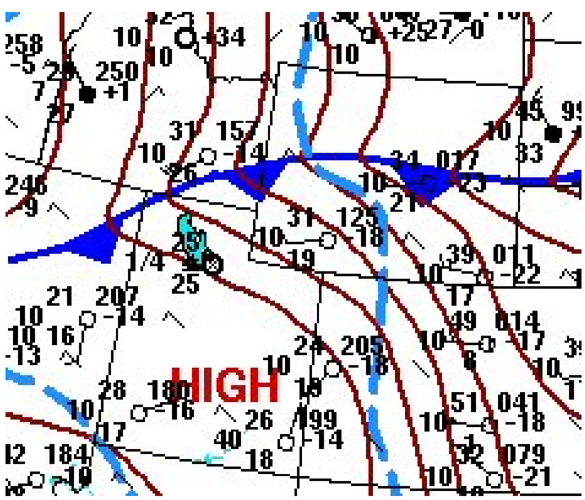

Figure 1. *Surface map and station plot at 1200 UTC, 20 December 2004 (from NCEP Web site: http://www.hpc.ncep.noaa.gov/dailywxmap/frame.html). Visibility is reduced to ¼ mile in light snow and fog at Salt Lake City.*

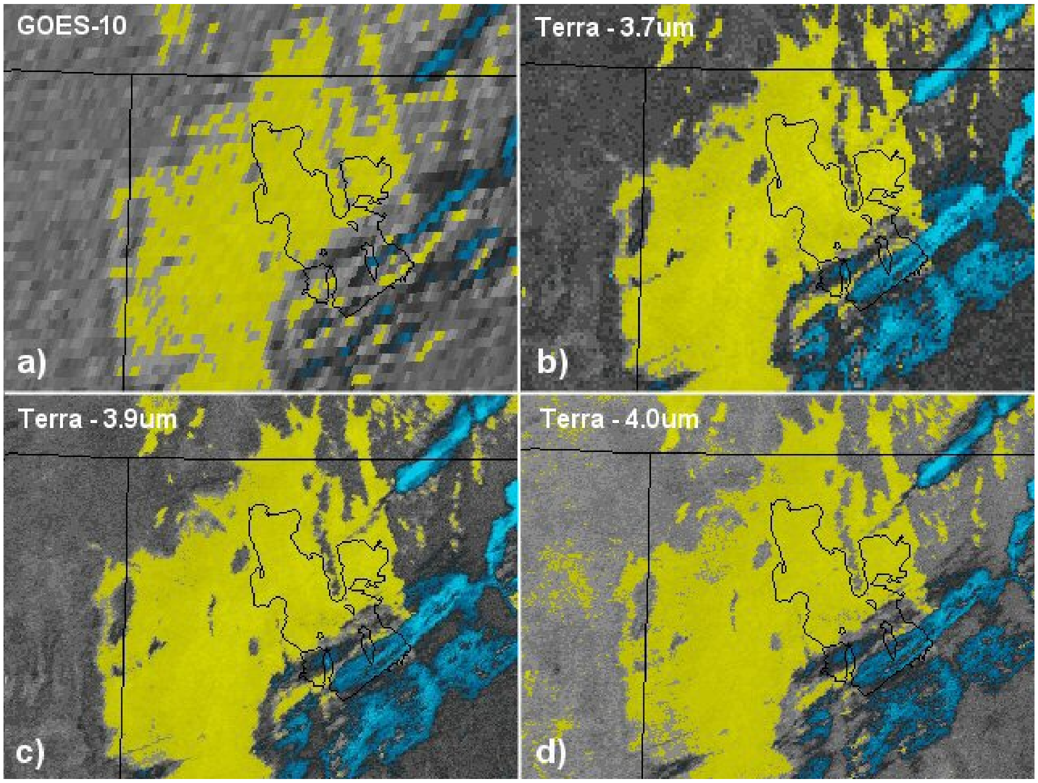

Figure 2. *Comparison of GOES IR fog image (Band 4-Band2) at 0515 UTC, 20 December 2004 (a) with Terra MODIS images derived from Band 20 (b), Band 22 (c) and Band 23 (d) at 0520 UTC, 20 December 2004. Yellow areas represent BTD values of 2K or greater. Blue indicates thick cirrus clouds.*

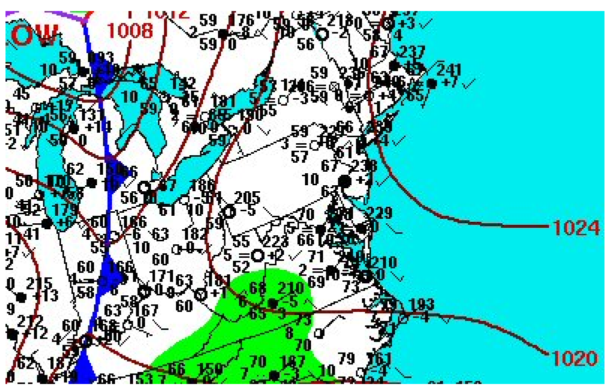

Figure 3. *Surface map and station plot at 1200 UTC 6 October 2005 (from NCEP web site: http://www.hpc.ncep.noaa.gov/dailywxmap/frame.html).*

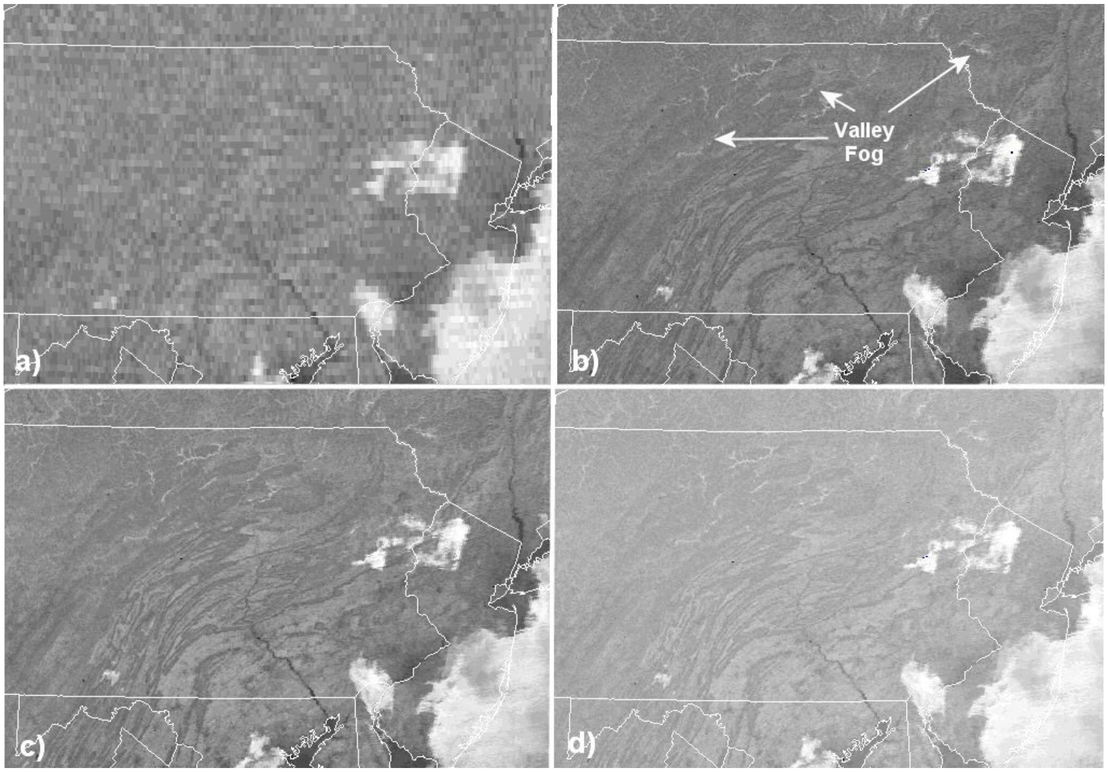

Figure 4. *Same as Figure 2, except at 0315 UTC 6 October 2005 and without color enhancement.*