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Inter-comparison of GOES and MODIS Imagery in the Analysis of Fog and Stratus

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1. INTRODUCTION

Advanced space-borne imagers such as the low earth-orbiting Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua and Terra spacecraft can be very useful for (1) validation of existing derived products from lower resolution instruments such as the Geostationary Operational Environmental Satellite (GOES) Imagers, and (2) assessing the capabilities of future polar (National Polar Orbiting Environmental Satellite Prototype, 2006) or geostationary (GOES Advanced Baseline Imager, 2013), which will have vastly improved multi-spectral sensors. The MODIS has 36 spectral bands with 1 km resolution infrared (IR) and 0.25-0.5 km visible and near-IR imagery. By comparison, the current GOES Imager has 4 IR channels (4 km resolution) and a visible band (1 km resolution).

One of the important applications of GOES data has been in the detection of fog and stratus clouds at night using two spectral bands centered near 3.9 µm and 10.7 µm. The Brightness Temperature Difference (BTD) in these two bands distinguishes stratus clouds consisting of water droplets versus cirrus clouds as well as cloud-free regions. While the presence of low visibilities due to fog must be implied from the satellite data, experienced analysts and forecasters are able to blend information from surface weather observations to make short term forecasts of conditions adverse to aviation operations. In order to evaluate any potential improvements offered by the MODIS data in supplementing GOES data in low cloud analysis, a comparison of the two platforms is needed. This paper describes how imagery and derived products from MODIS compared with those from GOES-8 and 10 for a case of orographic fog and stratus clouds during the night of 4-5 March 2001.

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2. DATA ANALYSIS TECHNIQUES

The derived product compared for both MODIS and GOES was based on the BTD between IR bands centered near 4 µm and 11 µm wavelengths (a.k.a. "Fog product"). A summary of these IR bands and their characteristics is described in Table 1. This approach to nighttime fog detection was first attempted in the United Kingdom using Advanced Very High Resolution Radiometer (AVHRR) data (Eyre et al 1984) and later with GOES imagery (Ellrod, 1995). The technique utilizes differences in radiative emissivity and transmissivity that occur for clouds of varying phase, versus cloud-free conditions (Hunt 1973). For stratus clouds, the BTD for 4 µm - 11 µm bands is typically -2 K or less. For stratus clouds consisting of large droplet sizes, this threshold may be slightly higher (Lee et al 1997). There may also be some false detection of stratus or fog caused by silicate soils (Sutherland 1986) such as those commonly observed in the southwestern United States.

The objectives of this work were to determine if there were any significant features appearing in the MODIS fog image that were not evident in GOES, and to compare the quality of features observed from both spacecraft. There are also plans to compare: (1) fog depth estimates based on the magnitude of BTD, and (2) a Low Cloud Base (LCB) product to show areas where ceilings below 1000 ft Above Ground Level are likely. The fog depth estimate is based on a relationship between the 4 µm - 11 µm BTD versus fog depth based on aircraft pilot reports and surface observations (Ellrod 1995). The Low Cloud Base product is estimated with the aid of both satellite IR cloud top temperatures and surface shelter temperatures to determine the likelihood of ceilings below 1000 feet (Ellrod 2002). These image products have been produced using GOES data.

3. CASE STUDY: 5 MARCH 2001

3.1 Description of the fog event

During the night of 4-5 March 2001, fog and stratus resulted in widespread low ceilings and visibilities over the High Plains from Kansas to eastern Montana. A ridge of high pressure at the surface extended from Manitoba province southward across the northern Plains states to north central Texas. On the west side of the ridge, light east to southeast flow resulted in upslope conditions in the northern High Plains, leading to the formation of extensive fog and stratus. Under the ridge axis, there was a deep snow pack over much of the region, which led to optimum radiational cooling. Surface temperatures in cloud-free areas fell to single digits F (-13 to -17 C), while temperatures in cloudy areas were held to the mid-teens F to middle 20's F (-3 to -8 C). The GOES-observed IR temperatures were in general agreement with surface and cloud top temperatures based on upper air soundings at Aberdeen, South Dakota and Glasgow, Montana at 1200 UTC (Figure 1). Due to minimal moisture however, the only radiation fog occurred in the James River Valley of South Dakota where cold air accumulated.

3.2 Image Analysis

The GOES-8 IR4 (10.7 µm) window image at 0400 UTC indicated extremely cold skin (ground) temperatures (-15 to -25 C) in cloud-free regions of eastern North and South Dakota, Minnesota and Iowa, with warmer temperatures (> -15 C) associated with the tops of stratus clouds in the western part of the area, and over parts of Minnesota to the east. The GOES IR2 - IR4 fog image (Figure 2) highlights the cloud covered area (yellow to orange) much better than the IR4 image, but exhibits considerable speckling due to the instrument noise in IR2 (3.9 µm). The noise is caused by the steep slope of the Planck radiance vs. temperature curve for cold temperatures (Hillger 2000). A GOES-10 fog image at 0500 UTC (not shown) exhibited less speckling as a result of the reduced instrument noise characteristics of this spacecraft (Hillger 2000).

A MODIS Band 31 image at 0455 UTC was quite similar to the GOES-8 IR image, although it revealed some fine scale terrain features that were not evident in GOES. A MODIS fog image, also at 0455 UTC (Figure 3) is significantly better in quality than both GOES versions, clearly showing the cloud boundaries, with no significant speckling in either the cloudy or cloud-free areas.

A MODIS fog image centered slightly farther south at 0455 UTC (Figure 4) clearly shows the location of the James River Valley fog that was rather indistinct in the GOES images. The surface observation at Huron, South Dakota (HON) slightly to the west of the IR fog band reported some visibility restriction, although there appeared to be no opaque fog layer present at the station.

In both MODIS fog images, there were undulations noted in the brightness temperature patterns of the stratus cloud tops over the western High Plains, possibly indicating the presence of gravity waves. These patterns were not seen in the GOES fog product. Also, subtle variations of temperature differences in the MODIS fog images were observed that could be due to: (1) overlying thin cirrus, (2) variations in fog thickness, (3) variations in prevalent cloud droplet sizes. Thin cirrus would reduce the BTD, leading to more yellow color in the images. Thicker fog would increase the BTD, while larger drop sizes reduce the BTD.

(More imagery for this case, including animations, can be found on the Internet at the following URL: ***http://cimss.ssec.wisc.edu/goes/misc/010305/010305.html***)

4. SUMMARY AND CONCLUSIONS

Comparisons of GOES and MODIS single band and derived fog images on the morning of 5 March 2001 indicated that there were some significant, fine scale features observable in the MODIS data not readily seen by GOES, such as better definition of a narrow band of fog in the James River Valley of South Dakota, although the overall area coverages were similar from both systems. A major difference was in the quality of the bi-spectral imagery, due to the very low instrument noise observed in the shortwave IR (4 µm) band from MODIS, and the resulting two-band fog product. Improved instrument noise was a major factor where fog was less extensive and surface temperatures were very cold, such as in the eastern portions of the Dakotas, Nebraska, and Minnesota.

5. REFERENCES

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Table 1.
Spectral Bands Used for Generating the Fog Images (MODIS vs GOES)

	Shortwave IR Band		**Longwave IR Band**	
Spacecraft	**Band# / λ(µm)**	**Resolution (km)**	**Band# / λ(µm)**	**Resolution (km)**
MODIS	22 / 3.96	1	31 / 11.03	1
GOES	2 / 3.90	4	4 / 10.7	4

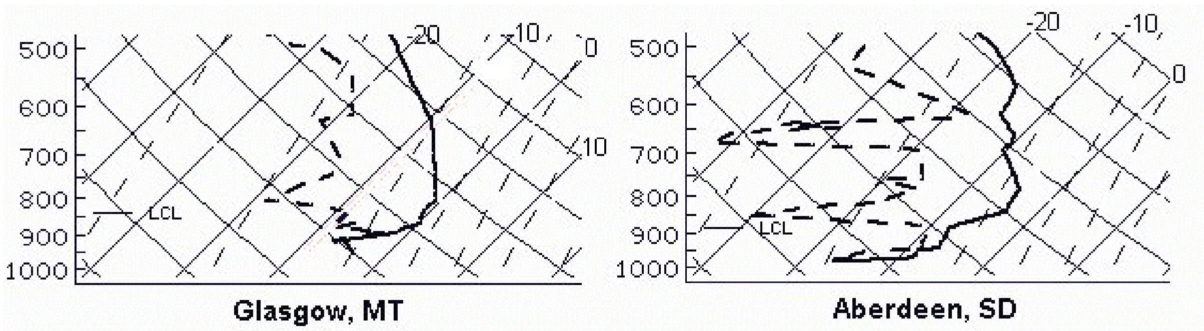

Figure 1. Upper air soundings at Glasgow, Montana (GGW) and Aberdeen, South Dakota (ABR) at 1200 UTC, 5 March 2001.

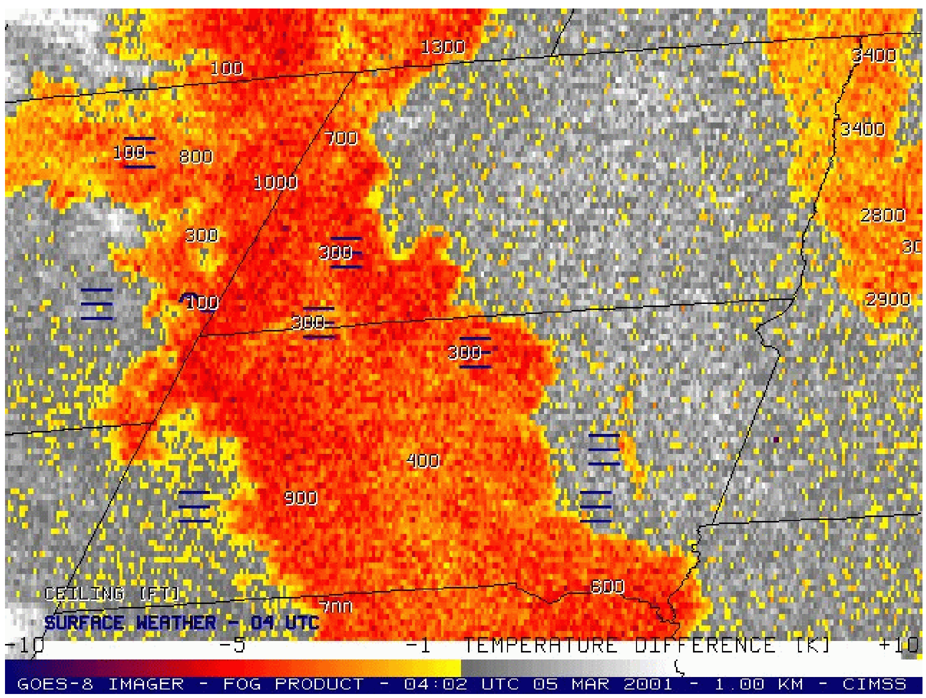

Figure 2. GOES-8 Band 2 - Band 4 fog image at 0400 UTC, 5 March 2001. Cloud ceiling heights (ft) and fog symbols at 0400 UTC are plotted. Temperature difference legend is at bottom.

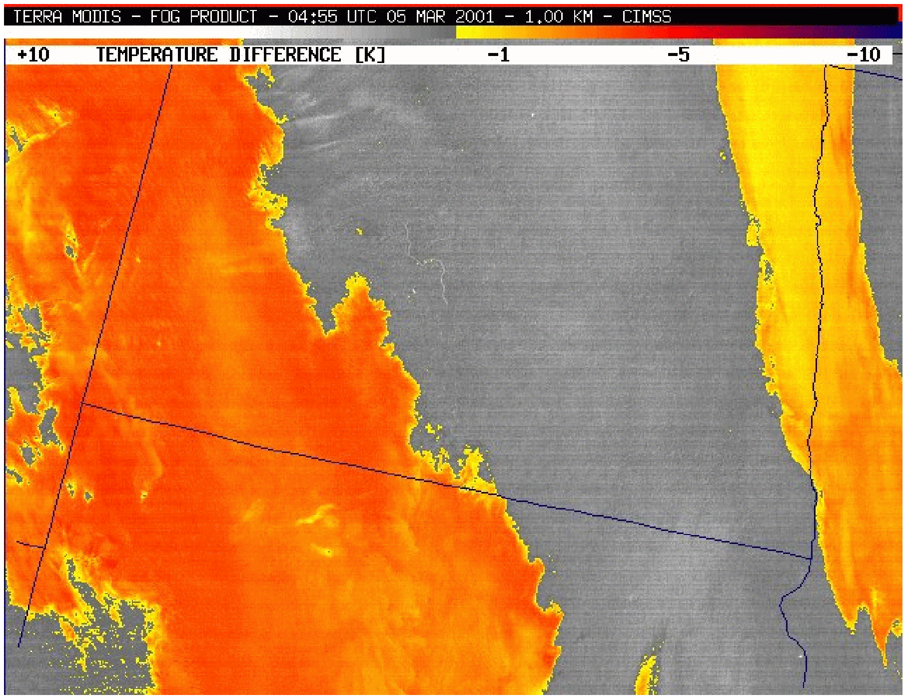

Figure 3. MODIS fog image (Band 22 - Band 31) at 0455 UTC, 5 March 2001. Temperature difference legend at top.

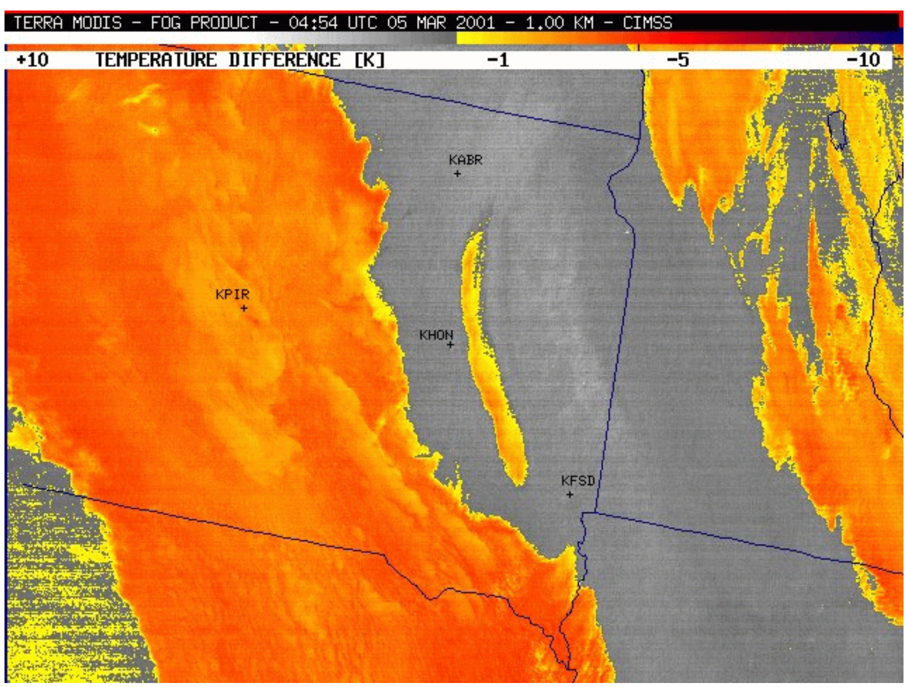

Figure 4. MODIS Band 22 - Band 31 fog image at 0455 UTC, 5 March 2001 for southern portion of area.