Satellite Remote Sensing of Fog and Low Clouds

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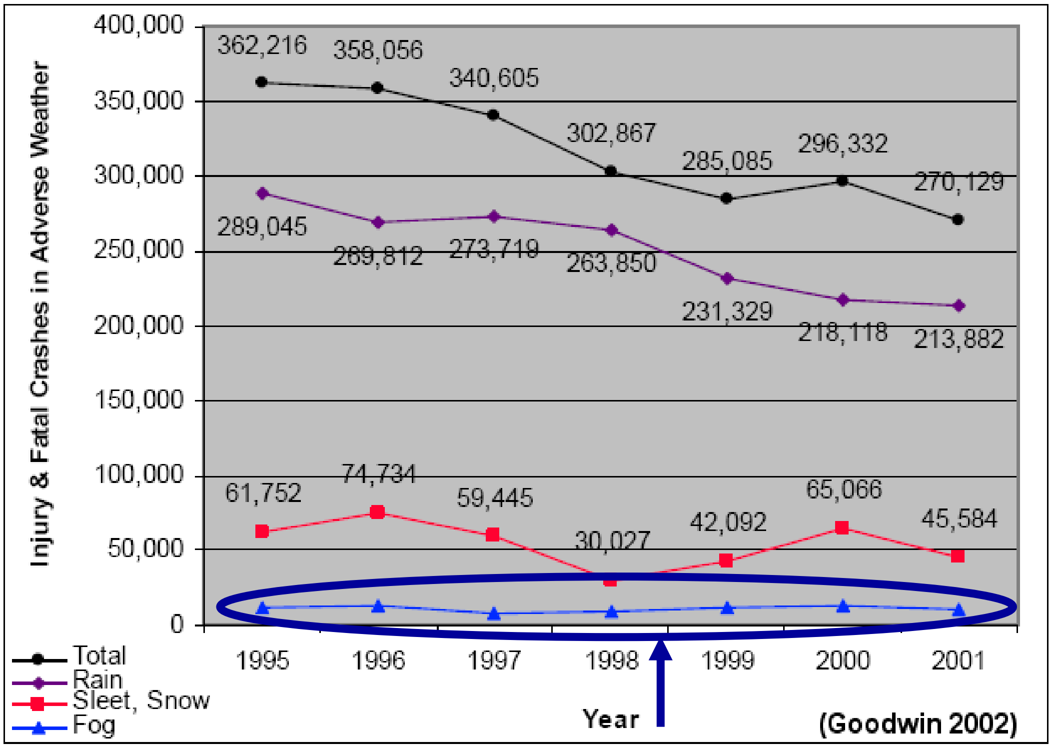
Fog and low ceilings are a major cause of airline delays, as well as aviation accidents and fatalities, especially for general aviation. Fog also has a significant impact on both land and maritime transportation. For example, in 2001 there were more than 670 highway fatalities in the United States due to accidents caused by dense fog (with visibilities of ¼ mile or less). The diagram in Figure 1 shows the trends of fatal and injury automobile accidents caused by different types of adverse weather. Unfortunately, while the number of these accidents due to rain has declined considerably during this period, the totals in snow and foggy conditions have not changed significantly.



Injury & Fatal Crashes in Adverse Weather by Year

Figure 1. *Automobile accident statistics from 1995-2001 for weather-related crashes (Goodwin 2002).*

Satellite remote sensing is an important tool in the detection and short range forecasting of fog and stratus, since the METAR network is often not sufficiently dense to show the true extent of the hazard or in some cases, to even detect its presence. This article will briefly describe the current methods used in satellite detection of fog, and provide a glimpse of improvements expected with future spacecraft.

Since fog over land develops primarily during the late-night and pre-dawn hours, infrared (IR) techniques are critical in observing fog formation, while visible imagery helps to monitor the extent and dissipation of fog after sunrise. Pattern recognition using single channel IR images was replaced by superior two-band methods following the launch of the advanced GOES I satellite in 1994. The temperature difference between 11µm and 4µm IR bands forms the basis for the technique, which is very effective for a wide range of temperature and surface conditions, provided the fog is sufficiently thick and extensive enough to be observed by the 4 km IR resolution GOES. Fog in narrow mountain valleys is often not observed by GOES for this reason. Higher-based stratus clouds may appear similar to fog or low stratus, and thus require some user experience for proper interpretation. A unique problem over desert areas due to the emission properties of silicate soils results in false fog signatures. In North America, this phenomenon is especially striking in the desert at the northern end of the Gulf of California in northwest Mexico, but appears elsewhere to a lesser in the Southwestern U. S. As soon as the sun rises, the 11μm - 4μm temperature difference reverses, and the low clouds are no longer distinguishable from other cloud types. Figure 2 shows how the temperature in the two IR channels varies across areas of fog in Oklahoma compared with cirrus-covered and cloud-free areas, with the single band and temperature difference images shown in the smaller panels at right. Note that there is little contrast in the 11μm IR channel, while the fog edge is clearly evident in the 4μm band image. Sometime the fog is evident at 11μm as a warmer (darker) region (often referred to as "black stratus") due to cloud top temperature that are warmer than surrounding clear regions.

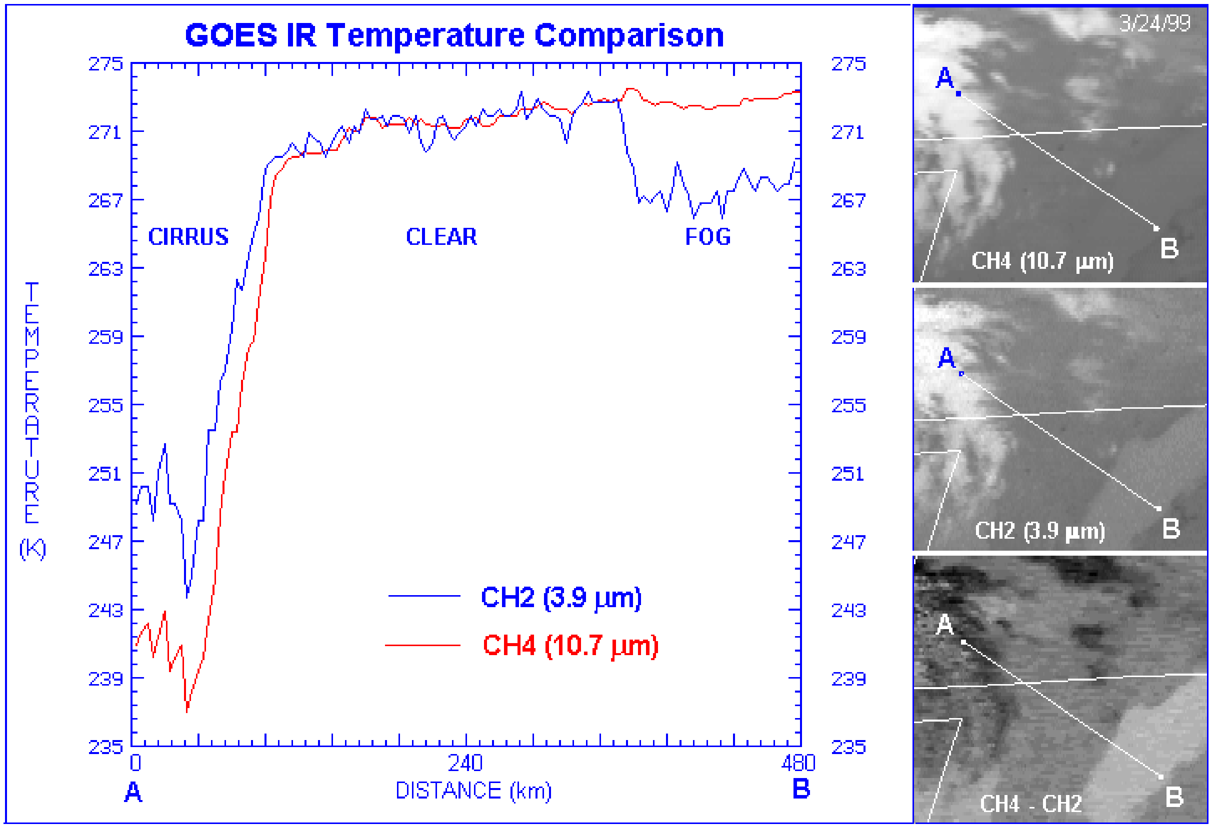


Figure 2. *Brightness temperature traces for GOES Channel 2 (blue, 3.9 μm) and Channel 4 (red, 10.7 μm) along the path A-B in the three images at right on 24 March 1999.*

The GOES two-channel IR fog image is available on the Advanced Weather Interactive Product System (AWIPS) at NWS offices. It can be identified as "11u – 4u" on the satellite image menu. The low cloud image cannot objectively distinguish fog and stratus clouds from higher based stratiform cloud layers. However, an improvement to the AWIPS fog product now shows areas where ceilings below 1,000 feet (and often fog) are likely. The Low Cloud Base (LCB) product, was implemented with Operational Build (OB)-8 in the fall of 2007. This product uses METAR surface temperatures as well as GOES cloud top temperatures to infer cloud base heights. Both types of images are also available on several web sites listed in the Appendix.

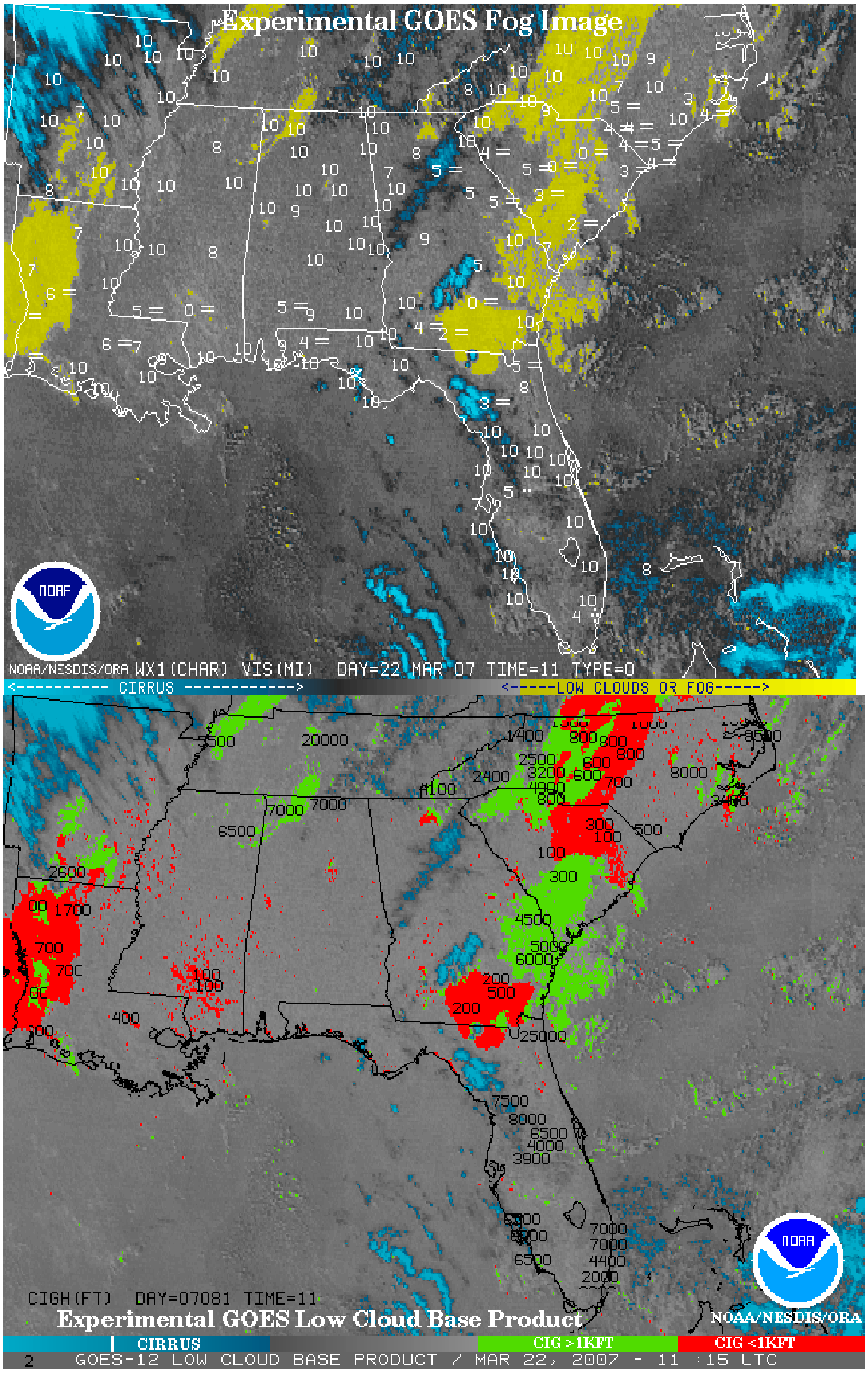


Figure 3. *GOES-12 low cloud image (top) and Low Cloud Base (LCB) product (bottom) at 1115 UTC, 22 March 2007, remapped to Lambert Conformal projection.*

The top panel in Figure 3 is a fog/low cloud image from the NESDIS web site at 1115 UTC, 22 March 2007 showing stratus and fog (with yellow color enhancement) over much of the South Atlantic states into north Florida and a small patch (barely discernible) in southern Mississippi with more extensive stratus in western Louisiana. The lower panel in Figure 3 is an example of the LCB product at the same time, showing estimated ceilings below 1000 ft (red) over much of the region (verifying METAR ceilings are superimposed). Cloud bases above 1000 ft are color coded green. METAR reports indicated that visibilities were less than one mile at many locations.

Similar IR channels available from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar-orbiting satellites and from the MODerate resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Earth Observation System (EOS) Aqua and Terra spacecraft provide superior quality images for fog detection due to their high spatial resolution (1 km) and high signal to noise ratio. However, due to infrequent sampling (6-hourly at mid-latitudes), the AVHRR and MODIS products are normally used to supplement the 15-minute interval GOES data over CONUS. AVHRR fog images can be found on the Web sites listed in the Appendix.

Prediction of fog clearing time is an important forecast problem that can be aided by pre-dawn estimates of fog thickness based on IR data. Fog thickness is proportional to brightness temperature difference in the two IR channels (for cloud layers <1 km thick) and the information is displayed by means of a color enhancement table (an example is shown in Figure 4). The products are available for several regions and selected metropolitan areas at the web sites listed in the Appendix.

After sunrise, the brightness difference between the fog and surrounding cloud-free areas can also help estimate dissipation time. Since fog often dissipates from the outer edges inward, the location of an airport relative to the edge of the fog bank helps determine approximate burnout time. Fog or stratus that overlies a cold surface such as snow, lake, or ocean water, tends to dissipate more slowly. Conversely, dry soil warms up faster than moist soil after sunrise, resulting in faster clearing of fog. In Figure 5, a thick patch of fog in southern Georgia (A) takes longer to dissipate than the thin patch in southern Mississippi (B). In the period from 1315 UTC to 1415 UTC, the eastern edge of the Georgia fog clears faster in the easterly flow, while the western edge remains nearly stationary. The stratus to the north is complicated by higher cloud layers, but the fog in south central South Carolina (C) persists at 1415 UTC. A GOES-12 visible animation from 1315 UTC to 1515 UTC shows the clearing trend during the morning.

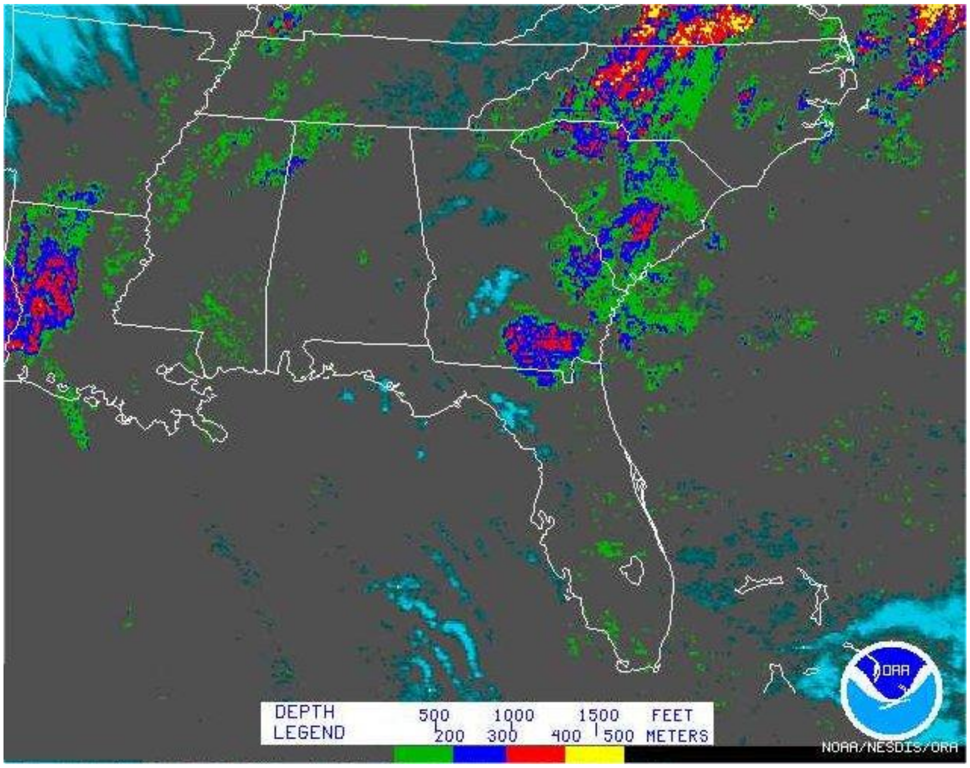


Figure 4. *GOES-12 fog image at the same time as Figure 3 with a color enhancement that shows approximate depth (x100m).*

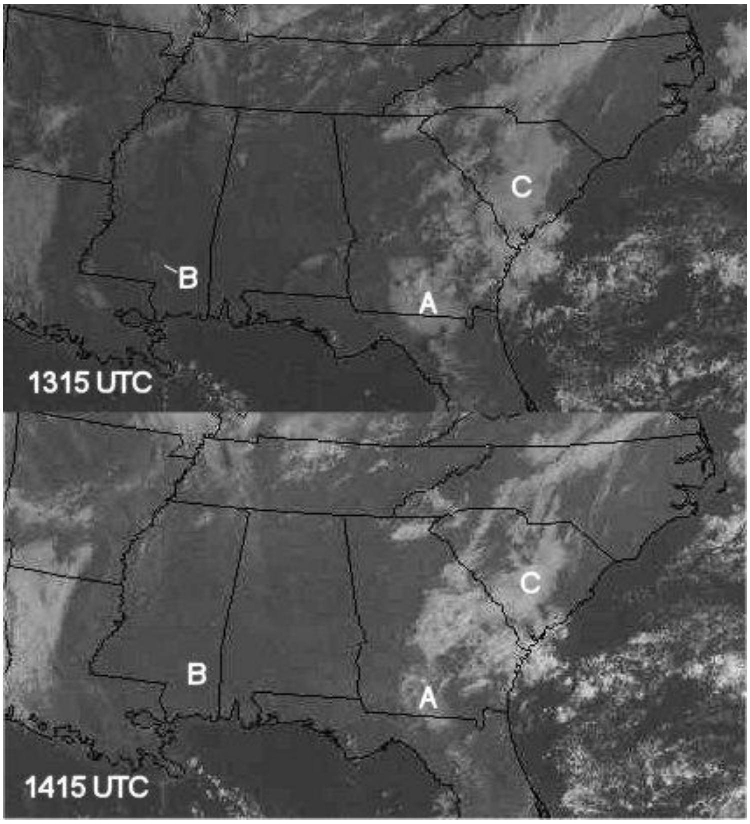
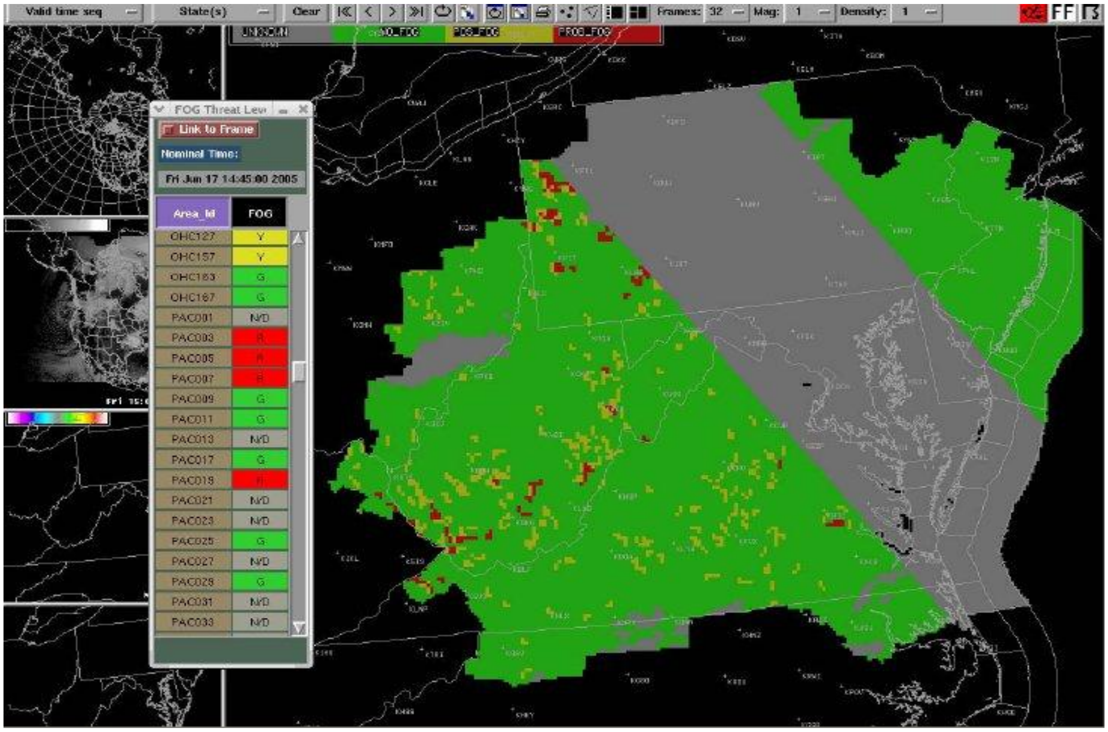


Figure 5. *GOES-12 Visible images at 1315 UTC and 1415 UTC, 22 March 2007. See text for explanation of features.*

A satellite-based tool for detecting both marine and continental fog, known as the "Fog Monitor," has been available on AWIPS since 2005. At coastal stations, the Fog Monitor was originally part of the SAFESEAS line of products. It provides the likelihood of fog (expressed as low, medium and high risk) at any location within a WFO warning area both day and night. Figure 6 shows an AWIPS screen capture of the Fog Monitor product for the Sterling, Virginia WFO area at 0945 UTC, 17 June 2005. Yellow areas indicate that fog is possible, while red shows that fog is likely. The gray area denotes missing data due to twilight periods in which neither nighttime nor daytime algorithms are successful. It is possible to list the fog threat for various forecast zones in a table, as shown on the left side of the figure. Technical notes describing the rationale behind the Fog Monitor and details on the AWIPS product are available from the NWS (See Appendix).



Nominal Time: Fri Jun 17 14:45:00 2005

Area_Id	FOG
OHC127	Y
OHC157	Y
OHC163	G
OHC167	G
PAC001	N/D
PAC003	R
PAC005	R
PAC007	R
PAC009	G
PAC011	G
PAC013	N/D
PAC017	G
PAC019	R
PAC021	N/D
PAC023	N/D
PAC025	G
PAC027	N/D
PAC029	G
PAC031	N/D
PAC033	N/D

***Figure 6**. Example of AWIPS Fog Monitor image at 0945 UTC , 17 June 2005.*

Looking into the future, the GOES-R Advanced Baseline Imager will provide the capability for markedly improved fog detection due to increased resolution in the IR (2 km) and Visible (0.5 km) channels, and routine 5-minute coverage over CONUS. GOES-R is planned for launch in 2015. Figure 7 compares a simulated GOES-R fog image derived from NASA MODIS data with GOES-10 for dense fog in the Salt Lake Basin at 0515 UTC, 20 December 2004. The images are remapped to a Mercator projection at 2 km scale.

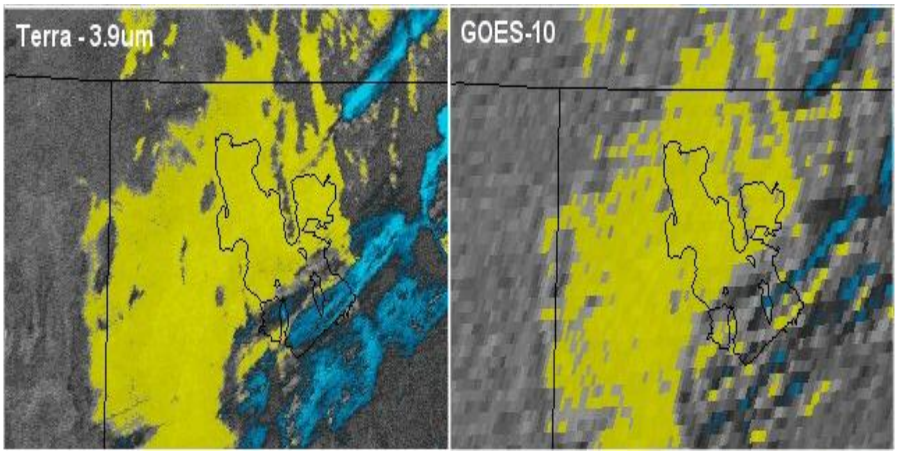


***Figure 7** . Comparison of a simulated GOES-R fog/low cloud image based on IR data from NASA Terra (left) and a GOES-10 image (right) at 0515 UTC, 20 December 2004.*

Appendix: Additional Internet Resources

Current GOES nighttime fog images:
http://www.star.nesdis.noaa.gov/smcd/opdb/aviation/fog.html (NESDIS Applications and Research)
http://www.nrlmry.navy.mil/NEXSAT.html (Naval Research Laboratory – Monterey)
http://www.wrh.noaa.gov/satellite/ (NWS Western Region)
http://weather.msfc.nasa.gov/sport/ (NASA Marshall Space Flight Center)

Current AVHRR fog imagery:
http://www.star.nesdis.noaa.gov/smcd/opdb/aviation/fog.html (NESDIS Applications and Research)
http://www.nrlmry.navy.mil/NEXSAT.html (Naval Research Laboratory – Monterey)

Fog depth estimates:
http://www.star.nesdis.noaa.gov/smcd/opdb/aviation/fog.html (NESDIS Applications and Research)
http://weather.msfc.nasa.gov/sport/ (NASA Marshall Space Flight Center)

Information on the AWIPS Fog Monitor:
http://www.nws.noaa.gov/mdl/fog_monitor/Fog_Technote.pdf
http://www.nws.noaa.gov/mdl/fog_monitor/docs/FogMonitor_UGOB6.pdf

Tutorials on fog from COMET:
http://www.meted.ucar.edu/topics_fog.php or
http://www.meted.ucar.edu/topics_aviation.php

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