Western Region Technical Attachment
No. 95-25
October 24, 1995

DETECTING FOG AND MARINE STRATUS USING THE GOES-8 FOG PRODUCT

Danny Mercer - WRH - SSD, Salt Lake City, UT

Introduction

Marine stratus and fog frequently occur along the coastal regions of California, Oregon, and Washington. As warm air flows over upwelling cold water, a low-level inversion develops. Stratus and fog often form offshore at night, and as the land cools, the marine stratus and fog work their way inland (Kotsch, 1977). This poses problems for aviation and marine interests.

Determining the thickness of marine stratus and fog is an important key to improving the accuracy of forecasts for dissipation and movement. Since surface observations (SAOs) and pilot reports (PIREPs) are not always available, the GOES-8 fog product can be a useful tool in assessing marine stratus and fog movement and thickness.

This Technical Attachment has two goals:

(1) Explain the GOES-8 fog product and its advantages.

(2) Examine case studies in order to determine if the brightness values created by RAMSDIS (which processes imagery) can be reasonably correlated to specific fog depths.

The Fog Product

Prior to the use of the GOES-7 and GOES-8 fog product, a single IR window channel was used for nighttime fog detection. The success of this approach was limited, since a single IR channel has difficulty detecting small temperature differences between cloud top temperatures of the marine stratus and fog and the temperature of the underlying land/sea surface. The ability to detect small thermal differences is necessary to create good brightness contrast which is necessary for a usable fog image. The GOES-7 and GOES-8 fog product can detect the small temperature differences which provide the capability to distinguish between cloud and fog top temperatures and the land/sea temperatures.

The fog product is created by subtracting the temperature observed in channel 2 (3.9μm) from the temperature observed in channel 4 (11.2μm). The fog product takes advantage of emissivity differences between 3.9μm and 11.2μm channels and the sensitivity of the 3.9μm channel to small differences in emitted radiation of clouds composed of water droplets. This allows stratus and fog to be detectable during the nighttime hours which is critical for short-range forecasts. During the daytime hours, the 3.9μm channel should not be used to detect fog. This is because strong back scattering of sunlight by clouds in the 3.9μm channel overwhelms the contribution of the emitted radiation.

Although both GOES-7 and GOES-8 create their fog product by the same channel differences, the GOES-8 fog product has many advantages over the GOES-7 version. Perhaps the most important improvement has been the increased resolution. The GOES-8 fog product has a 4 km resolution compared to 8 km resolution in GOES-7. This is particularly useful in observing narrow bands of coastal and valley fog which are sometimes difficult to detect in the GOES-7 imagery. Also eddy circulations, which can determine the movement of marine stratus and fog, especially for the California coast, are better detected.

The fog product can also be used to estimate the depth of the marine stratus and fog layer. Before using the fog product to examine fog depth, it is important to understand the radiative properties of clouds and the correlation between emissivity differences and temperature differences. It has been observed that water clouds have a lower emissivity at the 3.9μm wavelength than at the 11μm wavelength. Therefore, stratus and fog radiate cooler at night in the 3.9μm wavelength than they do at the 11μm wavelength. Figure 1 shows how the difference in emissivity between the 3.9μm and 11.0μm wavelengths relates to the cloud thickness.

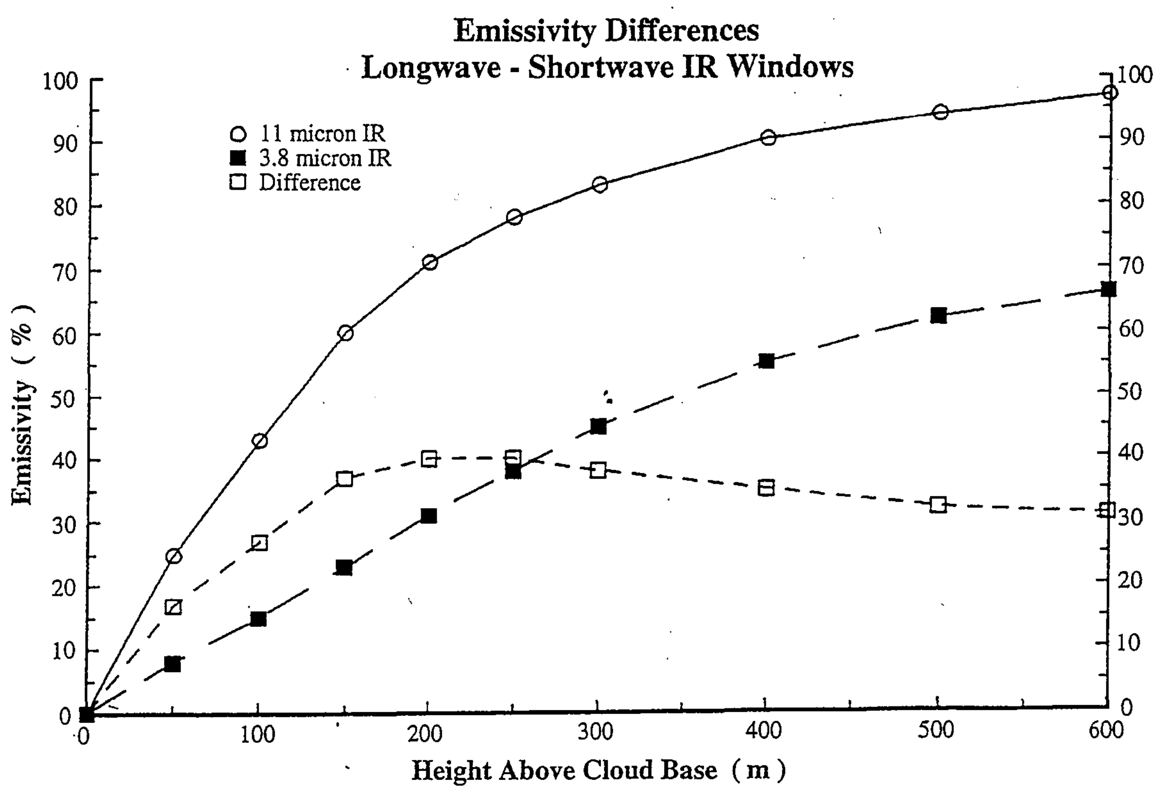

Figure 1. The variation of emissivity (%) in a stratocumulus cloud of water content 0.1gm-3 for increasing height above cloud base (m). Emissivities are shown for Longwave (LW) IR channel (11μm), the Shortwave (SW) channel (3.8μm) and the difference between the two. (from Hunt, 1973)

Notice that the emissivity rate in the 11μm wavelength increases faster than the 3.9μm until about 200 feet where the rates become constant. At this point the emissivity difference between the two wavelengths begins to level off, but the temperature difference between the two still increase.

Technique

RAMSDIS executes a program that converts the incoming digital data to brightness values which can be converted to specific temperatures. The command MINMAXF has been created which will display the brightness values and temperature difference between the two channels for any location in the imagery. The following is an example of what the MINMAXF command showed in Los Angeles on September 16, 1995.

maximum temperature difference: 6.10 DEG C
minimum temperature difference: 3.00 DEG C
average temperature difference: 4.95 DEG C

By using the relationship depicted in Fig. 2, the temperature difference can be used to determine the thickness of the fog. The large positive difference values in the above example indicates thick fog or stratus.

For this study, GOES-8 temperature differences created by RAMSDIS have been collected from several coastal sites, i.e., Los Angeles, San Diego and San Francisco. The fog thickness derived from GOES-8 was then compared to the PIREPs which included the fog and stratus thickness. Because the fog product is only available during the nighttime hours and most PIREPs are not available until sunrise, there were usually only a couple of direct comparisons which could be made, typically around sunrise. There was not sufficient data to create a statistically significant correlation of brightness values to fog and stratus depth. However, some preliminary analysis has been made for sites along the California coast using GOES-8 imagery, PIREPs and sounding data.

Algorithm

Since a best fit line of thickness vs. temperature difference for GOES-8 data is not yet complete, the data was compared to a best fit line for GOES-7 data. This comparison makes it possible to test the accuracy of the temperature differences.

Case Studies

GOES-8 imagery for cases of fog and low stratus along the west coast have been archived from July-September of 1995 to current. The SAOs and PIREPs from California, Oregon, and Washington were also collected for this period. The more interesting cases have been examined to obtain some preliminary results on the accuracy of the temperature differences. A fog example from Oakland, CA is provided which was typical of the cases studied.

On September 12, 1995, a PIREP from Oakland, CA at 1300Z reports a marine stratus thickness of 1500 feet. An analysis of sounding data shortly before that time indicated a similar stratus depth of 1466 feet. The GOES-8 imagery clearly defined the fog and stratus along the coast as seen in Fig. 3. By using the MINMAXF command, an average temperature difference of 4.68°C was estimated. By looking at Fig. 2, the GOES-8 temperature difference corresponds to a thickness of 1,500 feet. Comparisons made from Vandenberg AFB and San Diego where also made for this fog episode. The temperature differences estimated for these two sites were similar to the Oakland approximation.

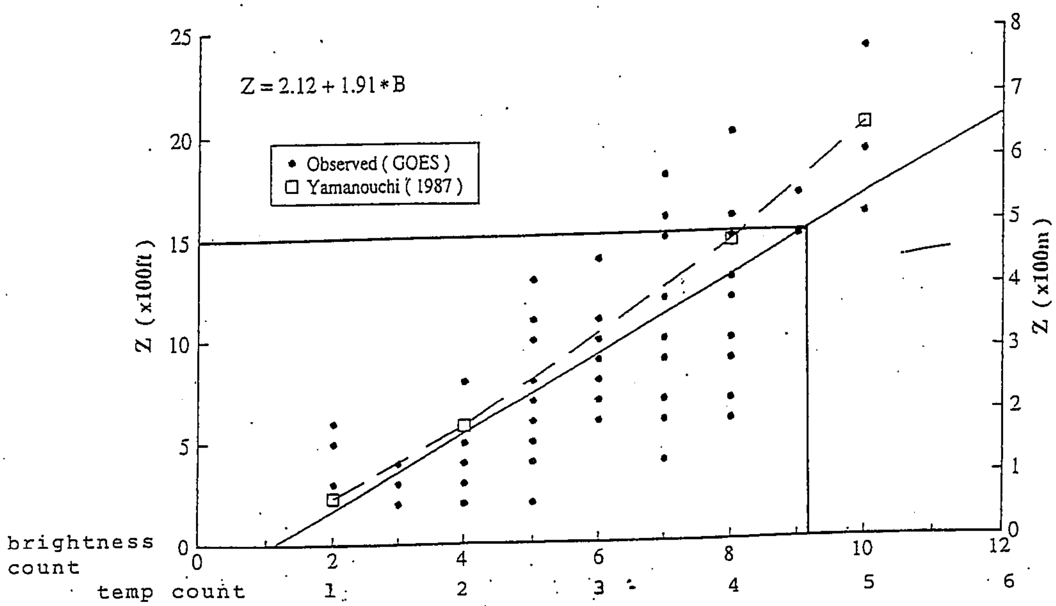

Figure 2. Fog depth (ft and m) versus brightness differences (counts) between GOES IR CH12 (3.9μm) and CH8 (11μm). A least-squares regression line of best fit and its equation are shown. One count is ≈0.5°K. Data from Yamanouchi, et al., (1987) are shown for comparison.

Conclusion

Although a statistically significant correlation of fog and stratus thickness to the temperature difference is not yet complete, it does appear from initial comparisons that a reasonable estimation can be made. Perhaps most impressive has been the improvement in observations of fog and stratus movement and structure. Due to the improved 4 km resolution of GOES-8, narrow bands of valley fog can now be seen in detail which was not possible with the older GOES-7 imagery (see Fig. 3). Also, the progression of coastal eddies can now be better determined.

References

Ellrod, E., 1994: Detection and Analysis of Fog at Night Using GOES Multispectral Infrared Imagery. NOAA Technical Report NESDIS 75.

Kotsch, W., 1977: Forewarning and Formation of Fog. *Weather for the Mariner.* United States Naval Institute, p. 183-191.

fog. This is because strong back scattering of sunlight by clouds in the 3.9μm channel overwhelms the contribution of the emitted radiation.

Although both GOES-7 and GOES-8 create their fog product by the same channel differences, the GOES-8 fog product has many advantages over the GOES-7 version. Perhaps the most important improvement has been the increased resolution. The GOES-8 fog product has a 4 km resolution compared to 8 km resolution in GOES-7. This is particularly useful in observing narrow bands of coastal and valley fog which are sometimes difficult to detect in the GOES-7 imagery. Also eddy circulations, which can determine the movement of marine stratus and fog, especially for the California coast, are better detected.

The fog product can also be used to estimate the depth of the marine stratus and fog layer. Before using the fog product to examine fog depth, it is important to understand the radiative properties of clouds and the correlation between emissivity differences and temperature differences. It has been observed that water clouds have a lower emissivity at the 3.9μm wavelength than at the 11μm wavelength. Therefore, stratus and fog radiate cooler at night in the 3.9μm wavelength than they do at the 11μm wavelength. Figure 1 shows how the difference in emissivity between the 3.9μm and 11.0μm wavelengths relates to the cloud thickness.

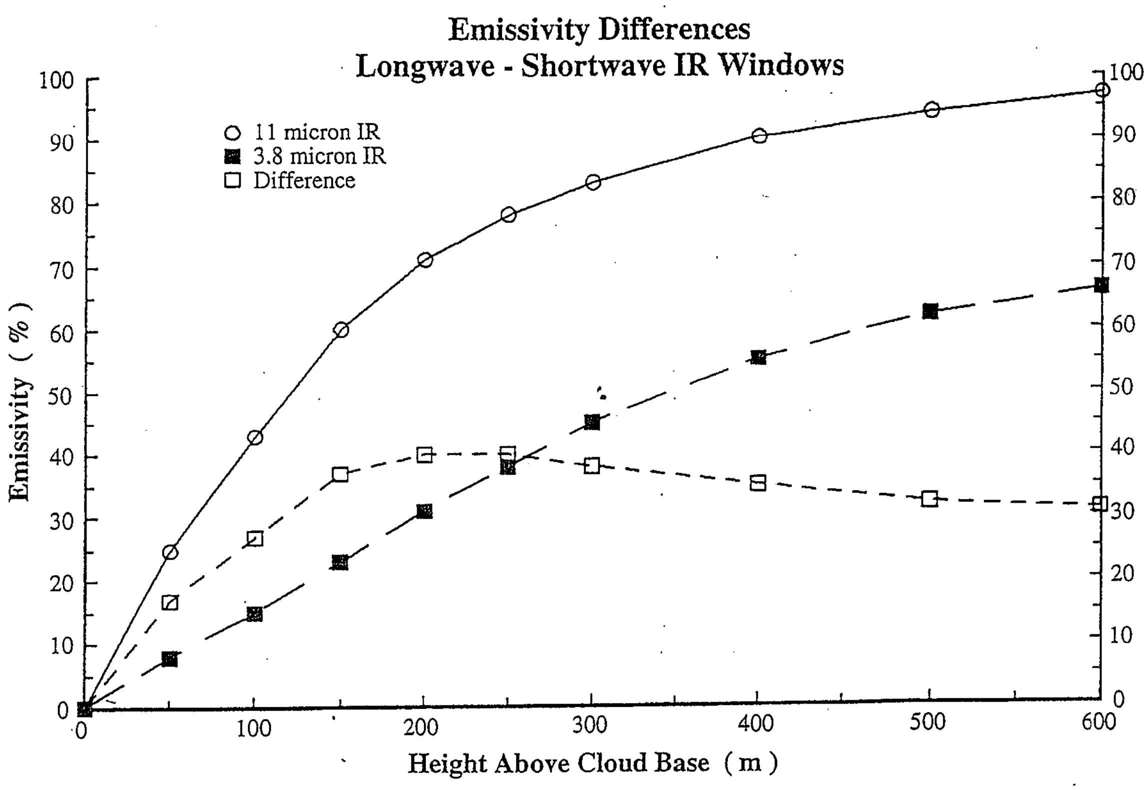

Figure 1. The variation of emissivity (%) in a stratocumulus cloud of water content 0.1gm-3 for increasing height above cloud base (m). Emissivities are shown for Longwave (LW) IR channel (11μm), the Shortwave (SW) channel (3.8μm) and the difference between the two. (from Hunt, 1973)

On September 12, 1995, a PIREP from Oakland, CA at 1300Z reports a marine stratus thickness of 1500 feet. An analysis of sounding data shortly before that time indicated a similar stratus depth of 1466 feet. The GOES-8 imagery clearly defined the fog and stratus along the coast as seen in Fig. 3. By using the MINMAXF command, an average temperature difference of 4.68°C was estimated. By looking at Fig. 2, the GOES-8 temperature difference corresponds to a thickness of 1,500 feet. Comparisons made from Vandenberg AFB and San Diego where also made for this fog episode. The temperature differences estimated for these two sites were similar to the Oakland approximation.

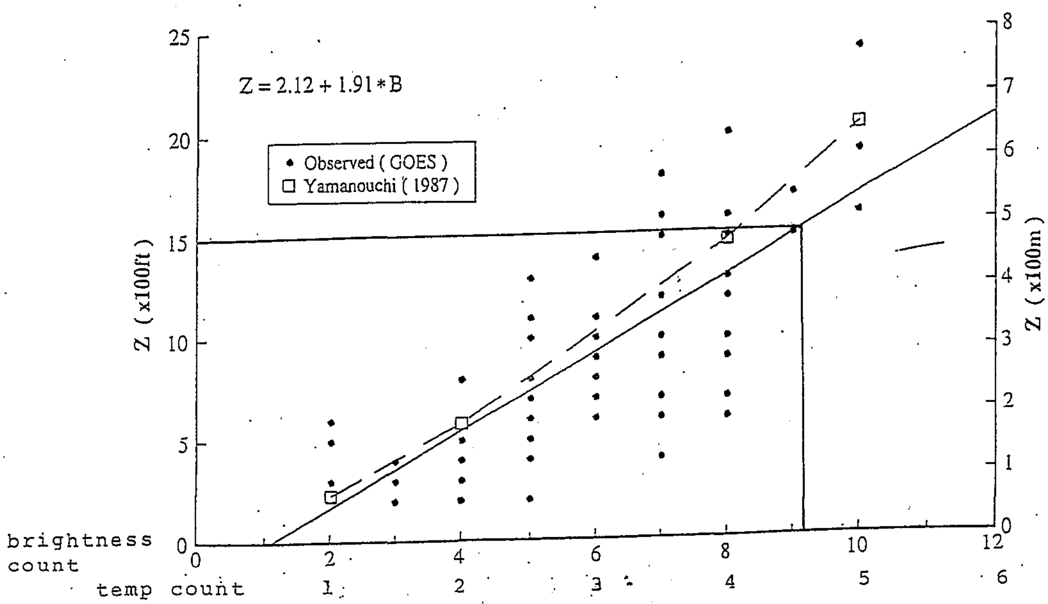

Figure 2. Fog depth (ft and m) versus brightness differences (counts) between GOES IR CH12 (3.9µm) and CH8 (11µm). A least-squares regression line of best fit and its equation are shown. One count is ≈0.5° K. Data from Yamanouchi, et al., (1987) are shown for comparison.

Conclusion

Although a statistically significant correlation of fog and stratus thickness to the temperature difference is not yet complete, it does appear from initial comparisons that a reasonable estimation can be made. Perhaps most impressive has been the improvement in observations of fog and stratus movement and structure. Due to the improved 4 km resolution of GOES-8, narrow bands of valley fog can now be seen in detail which was not possible with the older GOES-7 imagery (see Fig. 3). Also, the progression of coastal eddies can now be better determined.

References

Ellrod, E., 1994: Detection and Analysis of Fog at Night Using GOES Multispectral Infrared Imagery. NOAA Technical Report NESDIS 75.

Kotsch, W., 1977: Forewarning and Formation of Fog. *Weather for the Mariner.* United States Naval Institute, p. 183-191.

- GOES-7 fog product imagery along the western U.S. coast

September 12, 1995 12:31pm

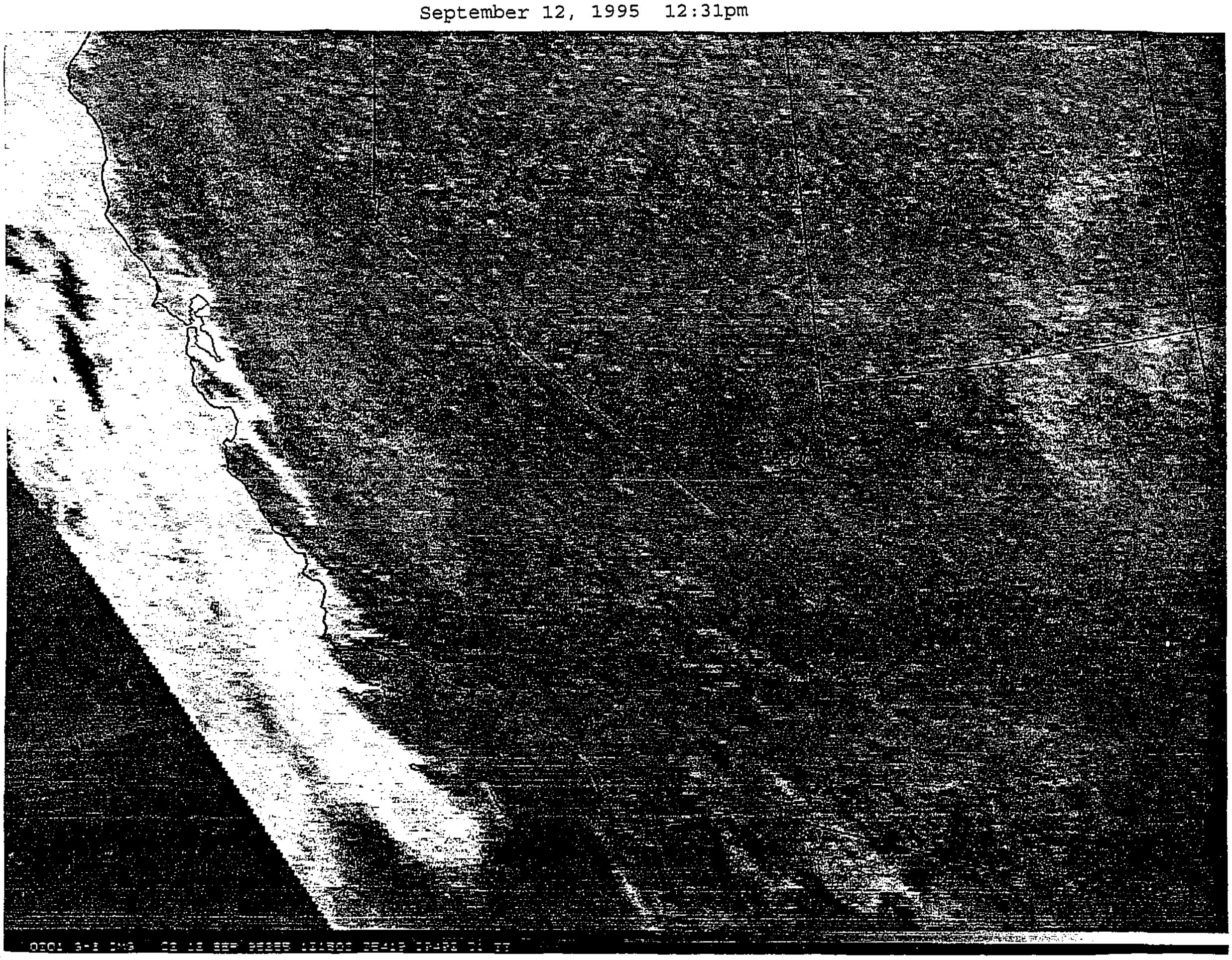

Fig. 3

- GOES-8 fog product imagery along the western U.S. coast

September 12, 1995 12:15pm