P5.59

FURTHER STUDY OF DERIVING SEA SURFACE TEMPERATURE FROM FUTURE GOES

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1. Introduction

On July 23, 2001, a new Geostationary Operational Environmental Satellite (GOES-M) was successfully launched into orbit, which will become GOES-12 once commissioned. For the Imager instrument on this and the following GOES satellites, the 12 µm channel has been replaced with a 13.3 µm channel. This poses challenges to both the correction of atmospheric absorption and the detection of clouds that are crucial to deriving sea surface temperature (SST) from GOES Imager. Following previous discussion (Wu and Menzel 2000), we further address these challenges in this poster.

2. Atmospheric Correction

Radiation from sea surface is subject to absorption by the overlaying atmosphere before it reaches a sensor on satellite. To accurately determine SST, the atmospheric absorption must be properly accounted for. Two approaches are often used simultaneously: selecting a spectral channel that is least affected by atmospheric absorption and correcting for the remaining absorption.

GOES Imager provides two “window” channels (at 3.9 and 11 µm) where atmospheric absorption is weak (Menzel and Purdom 1994). The atmosphere is often more transparent at 3.9 µm, however the reflected solar radiation at 3.9 µm is neither negligible nor well predictable. Therefore GOES SST is derived primarily from the 3.9 µm channel at night and from the 11 µm channel during day (Wu et al 1999).

To correct for the remaining atmospheric absorption in either window channels, a third channel is needed, typically at 12 µm, where atmospheric absorption is stronger than that at 11 µm channel (McMillin and Crosby 1984). These combinations of channels, the “split-window” of 11 and 12 µm during day and the “dual-window” of 3.9 and 11 or 12 µm (or “triple-window”) at night, have been used successfully for decades to derive SST from satellite measurements (McClain et al 1985).

Without the 12 µm channel on future GOES Imagers, atmospheric correction becomes difficult during day but remains virtually unchanged at night. Current focus is thus to ensure SST production at night from GOES-M and beyond while exploring new ways to retrieve SST during day. A regression algorithm is used to correct for atmospheric absorption. In the past, regression coefficients were derived from collocations of GOES Imager measurements and buoy SST. Alternatively, regression coefficients can also be derived from simulated GOES measurements. Using MODTRAN 3.5 and a set of 402 carefully selected cloud free radiosonde profiles that are representative of the world oceans, two algorithms were derived for GOES-M nighttime SST (see François et al 2001 for more details):

(A) $SST=(a+bS_\theta)T_{3.9} + (c+dS_\theta)(T_{3.9}-T_{11}) + eS_\theta + f$
(B) $SST=(a+bS_\theta)T_{11} + (c+dS_\theta)(T_{3.9}-T_{11}) + eS_\theta + f$

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where S_θ = sec(θ)-1, θ is satellite zenith angle, $T_{3.9}$ and T_{11} are brightness temperature in °C for the 3.9 and 11 µm channels, respectively, and coefficients are listed in Table 1. The residuals are 0.37°K for both algorithms, assuming noise of 0.12°K for 11 µm and 0.15°K for 3.9 µm band and error in mixing ratio profile is 1 g/cm^2.

Table 1. Coefficients for algorithms (A) & (B)

Alg.	A	b	C	D	E	F
(A)	1.024	0.008	0.139	0.095	2.239	1.747
(B)	1.024	0.008	1.164	0.103	2.239	1.747

3. Cloud Detection

As nighttime SST retrieval becomes more important for GOES-M and beyond, it is imperative to consider another aspect of nighttime SST retrieval, the detection of clouds.

Most clouds are bright in the visible spectrum, making them easily identifiable during day over the dark ocean as background. At night, thick high clouds stand out in infrared spectrum because they are cold. The emissivity of fog and low strata at 3.9 µm is lower than that at 11 µm so that T_{11}-$T_{3.9}$, normally positive because atmosphere is more transparent at 3.9 µm, becomes negative. Thin cirrus can be detected in two ways: its scattering property can cause large difference between T_{11} and T_{12}, and its 3-D distribution, often highly inhomogeneous, can cause large local variation in radiance. Finally, broken or partially filled cloud scenes are expected to significantly increase the $T_{3.9}$-T_{12} difference because $(dR/dT_b)_{3.9} > (dR/dT_b)_{12}$. Although there are more tests available at night, nighttime cloud detection has always been more difficult.

Without the 12 µm channel, the T_{11}-T_{12} test for thin cirrus can no longer be made. The $T_{3.9}$-T_{12} test for partial/broken cloud can be replaced by a $T_{3.9}$-T_{11} test. Since the varying atmospheric water vapor loading can alter the $T_{3.9}$-T_{11} difference in clear scene, a measure of that loading is needed to establish the threshold for the partial/broken cloud test. Although T_{11} was used by some authors (Saunders and Kriebel 1988 and, more recently, Závody et al 2000), we have been using T_{11}-T_{12} as a measure of total water vapor in an atmospheric column to avoid mistakes in regions where SST is high but atmosphere is relatively dry. Without the 12 µm channel, it will be more difficult to set the threshold properly. Note that the detection of broken/partial clouds at night is complicated anyway, especially for a field of view (FOV) partially filled with strata.

The addition of the 13.3 channel should enhance cloud detection at night. According to the radiative transfer theory, T_{13} for a clear FOV is cooler than T_{11} by about 20K, varying with lapse rate and water vapor profile, because of CO_2 absorption at 13.3 µm. For a cloud contaminated FOV, the T_{11}-T_{13} difference will be reduced, depending on the height, optical thickness, and fractional coverage of the cloud. In the limit, the difference approaches to zero when the FOV is filled with sufficiently high and thick clouds.

We tested this theory with MODIS data that has all the current and future GOES Imager channels (Fig. 1). From an image taken during daytime, we first detect clouds with visible channel as a reference (upper panel). Two experiments follow to detect cloud without the visible channel, one with T_{11} only (middle panel) and one with T_{11} and T_{13} (lower panels). T_{11} alone can detect most of the clouds, but the last few percent of cloudy pixels are the most difficult to identify without losing a lot of clear pixels. In that context, T_{13} is very helpful. The results of using T_{11} and T_{12} are similar to that using T_{11} alone (not shown). We could not use $T_{3.9}$ for this image because of solar contamination. Preliminary results at night suggest that T_{11}-T_{13} is as effective as $T_{3.9}$ for detecting low clouds but more effective for detecting other type of clouds, including the broken/partial clouds. Overall, it seems that for nighttime cloud detection, the 13.3 µm channel is more useful that the 12 µm channel.

4. Summary

The current GOES SST algorithm is reviewed to assess the impact of losing the 12 µm channel from GOES-M and beyond. Although atmospheric correction will be difficult during day, it remains the same at night. Regression coefficients for two nighttime SST retrieval algorithms have been derived from simulated GOES-M measurements. On the other hand, this shifted emphasis on nighttime SST prompted an examination of nighttime cloud detection since it has been a challenge in nighttime SST retrieval. It was found that the addition of the 13.3 μm channel would be very helpful to ensure high quality of nighttime SST production.

5. References

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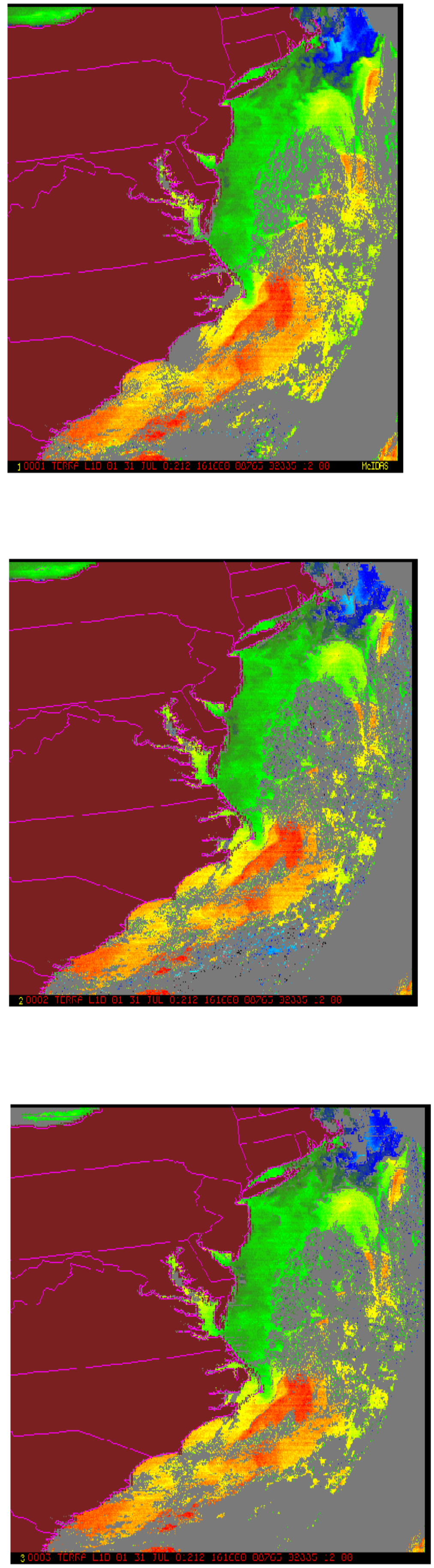

Figure 1: Cloud detection with visible (upper), T_{11} only (middle), and both T_{11} and T_{13} (lower).