JP2.9 PROPERTIES OF CIRRUS OVERLAPPING CLOUDS AS DEDUCED FROM THE GOES-12 IMAGERY DATA

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1. INTRODUCTION

Understanding the impact of cirrus clouds on modifying both the solar reflected and terrestrial emitted radiations is crucial for climate studies. Unlike most boundary layer stratus and stratocumulus clouds that have a net cooling effect on the climate, high-level thin cirrus clouds can have a warming effect on our climate. Many research efforts have been devoted to retrieving cirrus cloud properties due to their ubiquitous presence. However, using satellite observations to detect and/or retrieve cirrus cloud properties faces two major challenges. First, they are often semitransparent at visible to infrared wavelengths; and secondly, they often occur over a lower cloud system. The overlapping of high-level cirrus and low-level stratus cloud poses a difficulty in determining the individual cloud top altitudes and optical properties, especially when the signals from cirrus clouds are overwhelmed by the signals of stratus clouds. Moreover, the operational satellite retrieval algorithms, which often assume only single layer cloud in the development of cloud retrieval techniques, cannot resolve the cloud overlapping situation properly.

The new geostationary satellites, starting with the Twelfth Geostationary Operational Environmental Satellite (GOES-12), are providing a new suite of imager bands that have replaced the conventional 12-μm channel with a 13.3-μm CO2 absorption channel. The replacement of the 13.3-μm channel allows for the application of a CO2-slicing retrieval technique (Chahine et al. 1974; Smith and Platt 1978), which is one of the important passive satellite methods for remote sensing the altitudes of mid to high-level clouds. Using the CO2-slicing technique is more effective in detecting semi-transparent cirrus clouds than using the conventional infrared-window method.

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This study attempts to use the GOES-12 imagery data to discriminate between the cirrus clouds that are overlapping low clouds and those single-layer cirrus that have no underlying low clouds. Individual layer properties of the GOES-12 retrieved cirrus and stratus cloud layers under situations when the two cloud types are overlapped are presented. The overlapping retrieval algorithm is a modified version of the method presented by Chang and Li (2005), which was applied to the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) satellite observations.

2. DATA AND METHODOLOGY

The GOES-12 satellite Imager is a five-channel (one visible at 0.65 μm and four infrared at 3.9, 6.7, 10.8, and 13.3 μm) imaging radiometer designed to sense spectral radiances reflected and emitted from sampled areas of the earth at approximately 5-km spatial resolution. The GOES satellites circle the Earth in a geosynchronous orbit, which means they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to hover continuously over one position on the surface and provide a constant vigil on cloud development. Prior to GOES-12, a 12-μm split-window channel is available, but it is no longer available on the GOES series after GOES-11.

Previous algorithms have been developed for determining cloud and radiation properties using the GOES data (e.g., Minnis and Smith 1998; Minnis et al. 1998; Minnis et al. 2005), for example, the Visible Infrared Solar-Infrared Split-window Technique (VISST), which retrieves cloud properties for cloudy pixels during daytime and the Solar-infrared Infrared Split-window Technique (SIST), which determines cloud properties for cloudy pixels at night. However, these techniques utilize the 12-μm split-window measurement. Owing to the loss of the 12-μm channel, development of new algorithms is required. This study applies the CO2-slicing technique to the channel pair of 11 and 13.3 μm as new features of GOES satellites after (and including) GOES 12.

Using the CO2-slicing cloud top properties retrieved from GOES 11-μm/13.3-μm pair, we apply the algorithm of

Chang and Li (2005) to detect the co-existence of overlapped cirrus and lower clouds and to retrieve their individual layer properties. In principle, the algorithm determines the cloud top pressure (Pc) and cloud top temperature (Tc) for the cirrus from the CO2-slicing retrieval and determines the Pc and Tc for the lower clouds from neighboring single-layer low clouds using the conventional infrared (IR) window technique. The algorithm then determines the cirrus cloud optical depth from the conversion of the cirrus cloud emissivity derived by the method of Minnis et al. (1990; 1993). The underlying low cloud optical depth is thus determined using an iterative two-layer cloud radiative transfer model by comparing both the visible and infrared window observations to the model calculations. More detailed description of the algorithm is addressed in Chang and Li (2005).

a)

b)

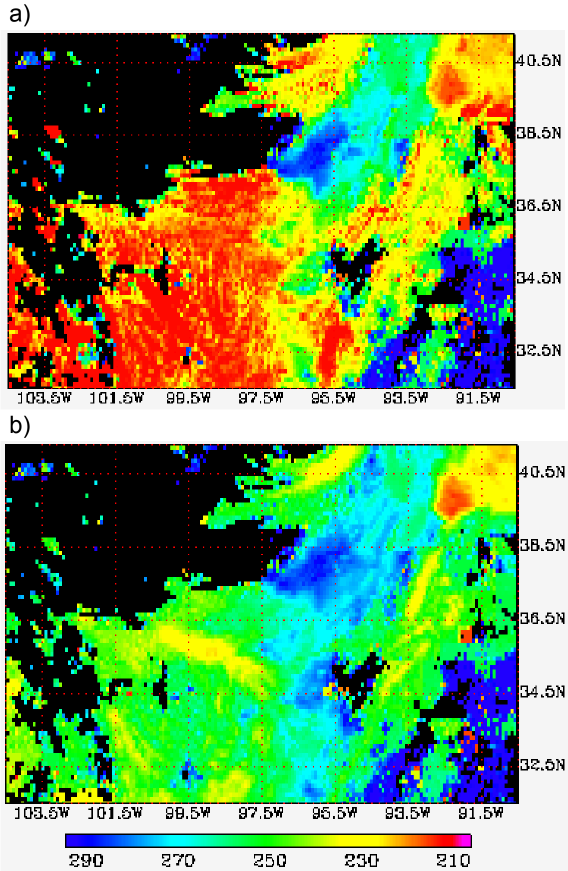

Fig. 1. Comparison of GOES-12 cloud top temperatures derived by a) CO2-slicing technique and b) VISST algorithm for May 18, 2005 (1915 UTC).

Figure 1 compares the cloud top temperatures retrieved by the CO2 slicing technique (1a) and by the VISST algorithm (1b) applied to the GOES-12 data observed on May 18, 2005, 1915 UTC, over Oklahoma. It is seen from the figure that over a large portion of the area the CO2 slicing retrieved Tc is much colder than the VISST retrieved Tc, which used a conventional IR retrieval technique. The differences between the two retrieved temperatures are due to the presence of thin cirrus clouds. The CO2 slicing Tc represents the uppermost cloud top temperature for the cirrus; whereas the VISST Tc represents a bulk IR cloud effective temperature, which is a mixture of the upper cirrus and lower stratus cloud temperatures. It is also seen that both the CO2-slicing Tc and VISST Tc can agree when there is only single-layer low cloud or when the high cloud is optically thick and nearly opaque. Fundamental information concerning the presence of overlapped clouds is further obtained by comparing the cirrus cloud optical depth retrieved from IR radiative transfer modeling with the total cloud optical depth retrieved from visible radiative transfer modeling. In case of the presence of single-layer cirrus cloud, both the IR and visible retrieved cloud optical depths agree; whereas in case of the presence of cirrus overlapping lower cloud, the visible retrieved cloud optical depth is larger than the IR retrieved cirrus cloud optical depth (Chang and Li 2005).

3. GOES-12 OVERLAP RETRIEVALS

Figure 2 shows the results of the single-layered and overlapped cloud mask derived by the CO2-slicing algorithm that is applied to the data shown in Fig. 1. The images cover a spatial region of 14° longitude by 10° latitude. The image constructed in Fig. 2a shows the multi-layer cloud mask, which consists of 12 different types of single-layer and overlapped cloud classification. These are described and listed in Table 1. Note that the cirrus overlapping clouds are denoted by the pink and yellow colors for their CO2-slicing Tc $<$ 440 mb and 500 mb $<$ Tc $\leq$ 440 mb, respectively.

Table 1 GOES-12 multilayer cloud classification for the color masks shown in Figure 2a.

Mask	Description
0	Clear
1	Single low ($680 \leq Pc$, $\tau < 3.6$)
2	Single low ($680 \leq Pc$, $3.6 \leq \tau < 23$)
3	Single low ($680 \leq Pc$, $23 \leq \tau$)
4	Single mid ($440 \leq Pc < 680$, $\tau < 3.6$)
5	Single mid ($440 \leq Pc < 680$, $3.6 \leq \tau < 23$)
6	Single mid ($440 \leq Pc < 680$, $23 \leq \tau$)
7	Mid cirrus overlap low ($440 \leq Pc < 500$)
8	High cirrus overlap low ($Pc < 440$)
9	Single cirrus ($Pc < 440$, $\tau < 3.6$)
10	Single high ($Pc < 440$, $3.6 \leq \tau < 23$)
11	Single high ($Pc < 440$, $23 \leq \tau$)

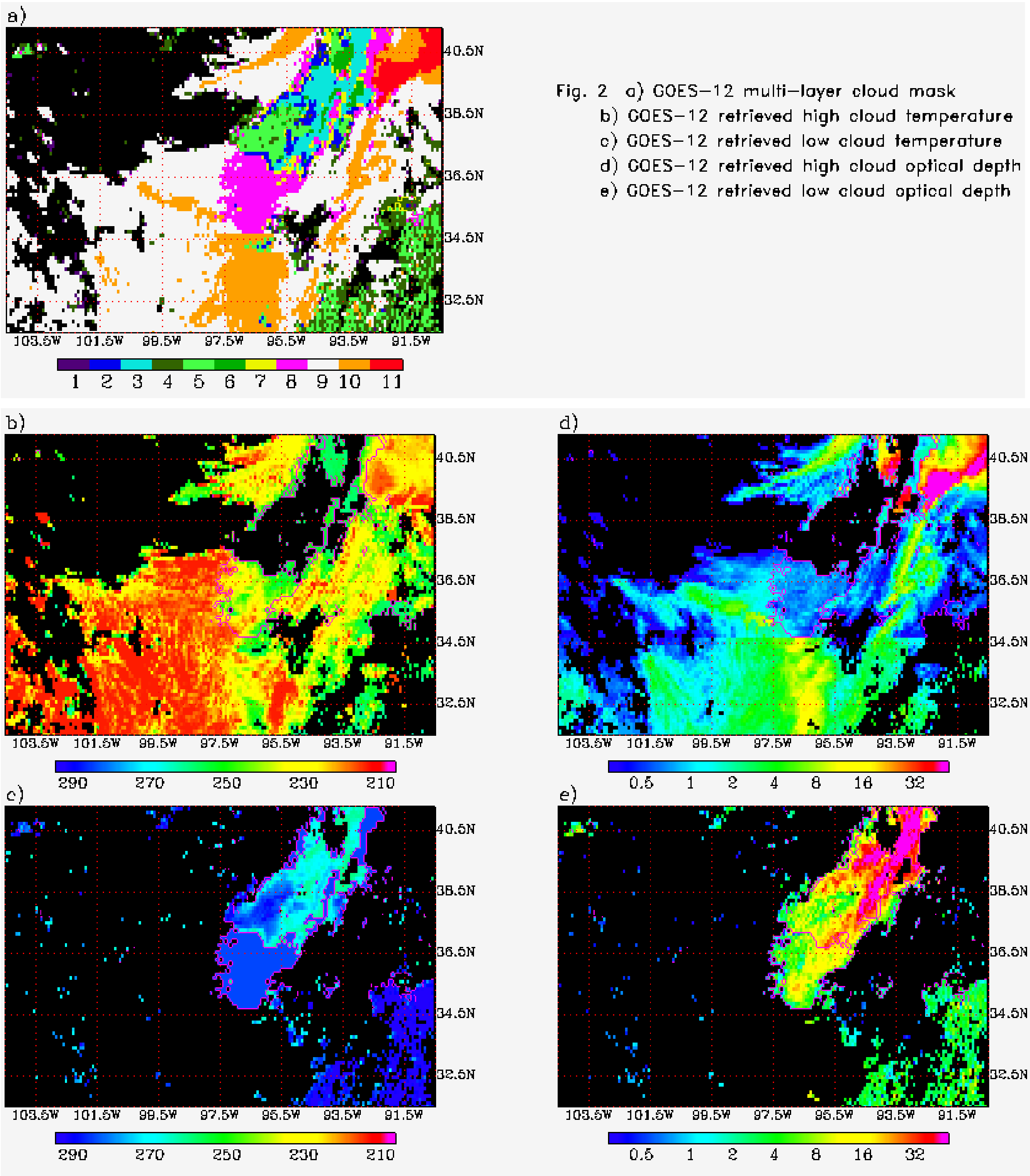

Fig. 2 a) GOES−12 multi−layer cloud mask
b) GOES−12 retrieved high cloud temperature
c) GOES−12 retrieved low cloud temperature
d) GOES−12 retrieved high cloud optical depth
e) GOES−12 retrieved low cloud optical depth

For Figs. 2b-2e, they are constructed for b) the high cloud top temperature (Pc < 500 mb), c) the low cloud top temperature (Pc ≥ 500 mb), d) the high cloud optical depth (Pc < 500 mb), and e) the low cloud optical depth (Pc ≥ 500 mb). It is noted that the low cloud top temperature and low cloud optical depth shown in Figs. 2c and 2e include both the cirrus-overlapped low clouds and those being single-layer low. The pink contour lines shown in Figs. 2b-2e delineate the boundary between the single-layer and overlapped clouds identified by the overlapped retrieval algorithm. This multi-layer case is verified by the ground-based active remote sensing of the Atmospheric Radiation Measurement program. It is found that the GOES-12 retrieved cirrus cloud top height is lower than the ground-based measurement at (36.6°N, 97.5°W). Validation for the retrieved cirrus and low cloud optical depths is more difficult because cirrus optical depth is much smaller than the dominant lower water cloud optical depth for ground-based remote sensing. Some in situ aircraft observations in addition to microwave liquid water path measurements will be required for more extensive verification of the overlap retrievals in future work.

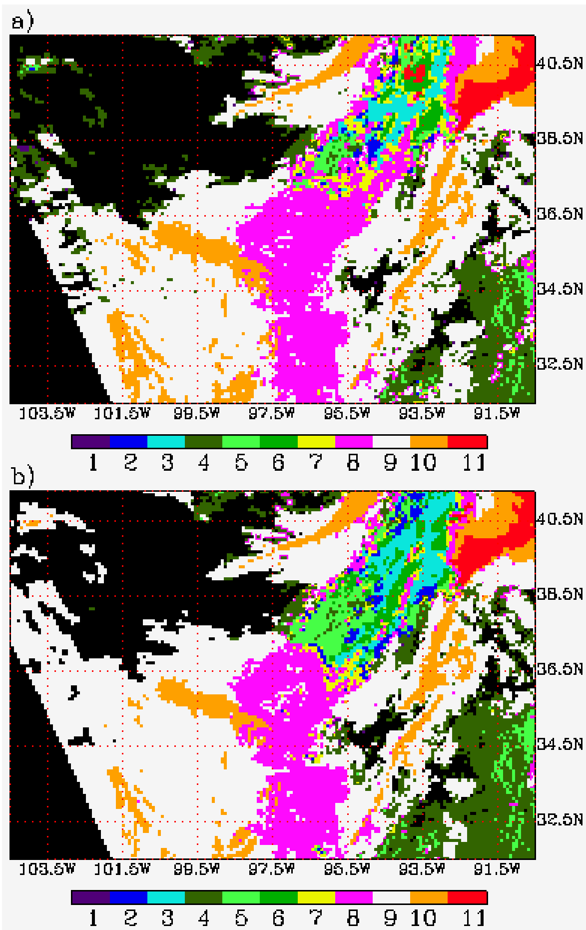

Fig. 3. MODIS multilayer cloud masks derived from a) all available CO2-slicing channels and b) only the 11-µm/13.3-µm channel pair. Data are obtained for May 18, 2005 1910 UTC.

4. COMPARISON WITH MODIS RETRIEVALS

Figure 3 compares the MODIS derived multi-layer cloud mask for the same area. There are slight time differences between the GOES-12 observing time (1915 UTC) and the MODIS overpass (1910 UTC Aqua). Since the MODIS instrument has a few more CO2 slicing channels including 13.3, 13.6, 13.9, and 14.2 µm, it is useful to compare the GOES-12 multilayer mask (Fig. 2a) with the MODIS multilayer mask derived using all available MODIS CO2-slicing channels (as shown in Fig. 3a) and that derived using only the 11-µm/13.3-µm channel pair (as shown in Fig. 3b).

It is seen that the general features of the three multilayer cloud masks are similar. However, GOES-12 (Fig. 2a) displays less cirrus cloud and less cirrus-overlapping-low cloud amounts than the MODIS CO2-slicing results. Nonetheless, the results derived from application of the limited two channels from GOES-12 are encouraging. Future work will include more sensitivity studies that are needed to quantify the deficiency of using only the 11-µm/13.3-µm pair and the discrepancies compared to using more channels as in MODIS.

5. ACKNOWLEDGEMENTS

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