JP1.19 EVALUATE THE EFFECT OF UPPER-LEVEL CIRRUS CLOUDS ON SATELLITE RETRIEVALS OF LOW-LEVEL CLOUD DROPLET EFFECTIVE RADIUS

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1. INTRODUCTION

The earth's radiation budget is sensitive to changes in the microphysical properties of low-level stratiform clouds. Their extensive coverage can significantly reduce the solar energy absorbed by the earth system. An estimate of reducing the global-mean droplet effective radius of these low-level clouds by ~2 μm while keeping the column liquid water constant would balance the warming due to a CO_2 doubling in the atmosphere (Slingo 1990). Accurate determination of the droplet effective radius of low-level clouds is hence essential in radiative transfer and climate modelling studies.

Satellite observations have been the primary source for routinely obtaining cloud droplet effective radius on large spatial scale. However, due to the ubiquitous presence of ice clouds that regularly cover ~20-30% of the globe, almost a third of the global cloud cover resides in upper-level clouds and, yet, half of this coverage is in the form of optically thin cirrus (Hartmann et al. 1992). These upper-level thin cirrus clouds may have a large impact on the emitted radiation and solar radiative transfer when absorption by ice crystal is significant. Distinguishing thin cirrus clouds from satellite measurements is especially challenging owing to the wide range of ice particle sizes and shapes and their various scattering and absorbing properties. The large spatial and temporal variability of cirrus emittances and optical thickness make cloud property retrieval an uneasy task. The task becomes even more difficult when the cirrus clouds are simultaneously overlaying with low-level water clouds. Despite the challenges, our capability of remote-sensing cloud properties from space can be enhanced with the NASA Moderate-Resolution Imaging Spectrometer (MODIS) satellite observations, which provide cloud images at 36 bands of high spectral resolutions located between 0.415-14.2 μm (King et al. 1992). In this preliminary study, the effects of thin cirrus clouds on satellite retrievals of low-level cloud droplet effective radius are evaluated by comparing between the retrievals with a correction of cirrus effect and those without the correction. The evaluations were made for the retrievals made at the MODIS 1.65, 2.15, and 3.75 μm. The existence of cirrus clouds was identified using MODIS 1.38-μm measurements. Such cirrus detection is impossible for the AVHRR satellite retrievals without 1.38-μm channel. The conventional threshold methods that are commonly applied to observations at visible and infrared channels for cloud type classification is not optimal for discriminating the contamination of upper-level thin ice clouds The evaluation focuses on the MODIS overcast pixels that were both covered by low-level cloud and contaminated by thin cirrus with an optical depth in the range of 0.2-0.5.

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2. RADIATIVE TRANSFER MODEL

Lookup tables of modelled reflectances and emissions were calculated for MODIS 0.63, 1.65, 2.15, 3.75, 11, and 1.38-μm channels by employing an adding-doubling radiative transfer model. The atmospheric column was divided into twelve vertical layers with cirrus cloud layer placed at 10 km. Low-level water-cloud layer were placed at five different altitudes from zero to 5 km. The Mie theory and lognormal droplet size distribution were adopted to calculate the water cloud optical properties for 18 droplet effective radius and 23 cloud optical depths. Atmospheric transmission and scattering properties were calculated using MODTRAN4 model. Lambertian reflection surface was assumed, but the cloud property retrievals were insensitive to the uncertainty in surface reflectance.

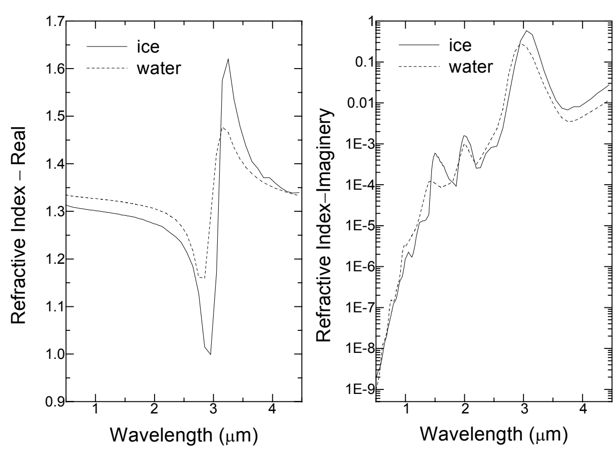

Fig. 1 The refractive indices of water and ice.

Table 1 Single-scattering albedos (ω_0) and asymmetry parameters (g) for a water cloud model (front) with r_e = 10 μm and the cirrus model (rear).

λ (μm)	ω_0	g
0.63	1.00000/1.00000	0.8628/0.8458
1.65	0.99414/0.93823	0.84422/0.8742
2.15	0.97613/0.91056	0.8401/0.8904
3.75	0.89983/0.79240	0.7944/0.9003
11.0	0.47706/0.54167	0.9229/0.9574

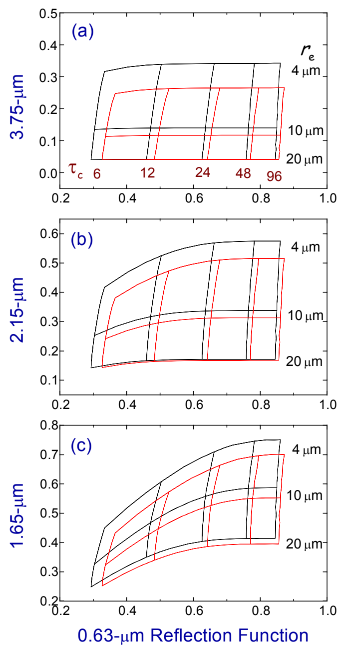

Fig. 2 Theoretical 3.75, 2.15, 1.65 and 0.63-μm reflectances for a low-level stratus cloud layer with (dashed) and without (solid) overlaying thin cirrus.

The cirrus optical properties were following the MODIS Algorithm Theoretical Basis Document (King et al. 1997). Figure 1 shows the refractive indices of real and imaginary parts for water and ice in the visible and near-infrared wavelengths (0.5-4.5 μm). The refractive indices are appreciably different between water and ice at wavelengths of 1.65, 2.15, and 3.75 μm. Notably, ice has a much larger absorption at 1.65 μm than does water as seen in Fig. 1b for the imaginary part of refractive indices. The extinction coefficients, single-scattering albedos and asymmetry parameters for the cirrus clouds are listed in Table 1.

Figure 2 shows the model-calculated reflectances at 0.63 μm (x-axis) versus (a) 3.75 μm, (b) 2.15 μm, and (c) 1.65 μm for low-level clouds with various cloud optical depths of 6, 12, 24, 48, and 96 and droplet effective radii of 4, 10, and 20 μm, respectively. Such reflectance sensitivities have been presented in many previous studies (e.g, Arking and Childs 1985; Nakajima and King 1990; Platnick and Twomey 1994; Han et al. 1994). Also plotted in the figure (dashed curves) is the similar reflectance except that they were calculated with an overlaying thin cirrus layer of cloud optical depth 0.5 at 10 km. The effects of the thin cirrus above the low-level water clouds are small at the 0.63-μm visible wavelength, but significantly reduce the reflectances at near-infrared wavelengths.

3. DATA ANALYSIS

The MODIS satellite observations on April 2, 2001 overpass the Oklahoma Southern Great Plain site of US/Department of Energy's Atmospheric Radiation Measurements Program (ARM) were analyzed to examine the effects of thin cirrus clouds on the retrievals of low-level cloud droplet effective radius. Figure 3 shows the satellite images constructed from MODIS 0.63, 1.38, 1.65, 3.75-μm observations for a 600 km x 500 km area. A low-level stratus cloud layers as observed by the ARM ground radar measurements covered large portion of the area, while some cirrus clouds were seen in the MODIS 1.38-μm images.

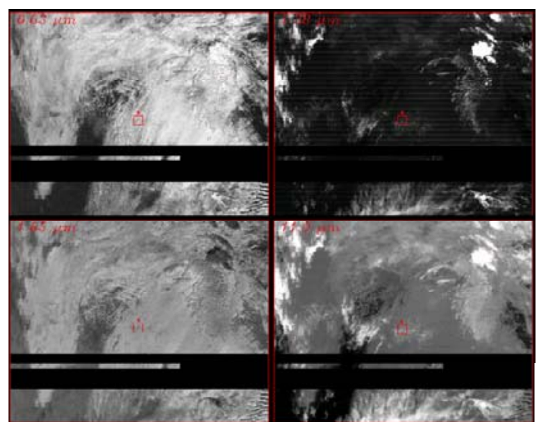

Fig. 3 MODIS images constructed from (a) 0.63-, (b) 1.65-, (c) 1.38-, and (d) 11-μm observations for a 600 km x 500 km region on April 2, 2001.

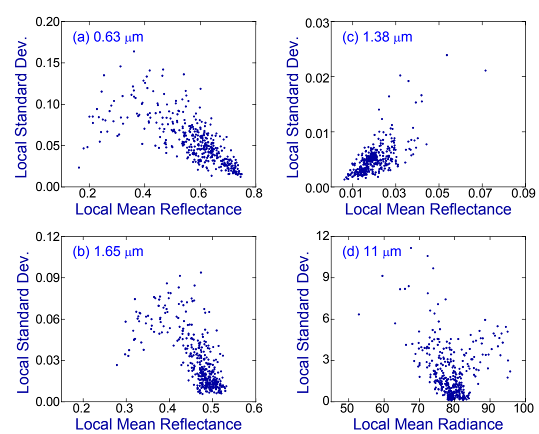

Fig. 4 Spatial coherence analyses of the MODIS 5 x 5 pixel arrays taken from a (100 km)^2 area from Fig. 3.

The MODIS pixels overcast with low-level stratus system were identified by the spatial coherence method (Coakley and Bretherton 1982). Figure 4 shows the spatial coherence analyses of the MODIS data extracted from Fig. 3 for 0.63, 1.38, 1.65, and 11-μm channels. The foot appeared in the scatter plots, for example, near 80 in Fig. 4d for the 11-μm emissions and near 0.5 in Fig. 4b for the 1.65-μm reflectances, was associated with a low-level stratus cloud layer. The pixels with 11-μm emissions colder than 80 and with large standard deviations were due to cirrus contaminations.

In this study, only the cirrus-contaminated pixels that had the thin cirrus cloud optical depth range between 0.2 and 0.5 were selected for data analyses. The selection criteria were based on the comparisons between the MODIS 1.38-μm reflectance measurements and model calculations. The MODIS 1.38 reflectances were approximately 0.02-0.08 for optical depths range 0.2-0.5, which depends on the incident and viewing geometry.

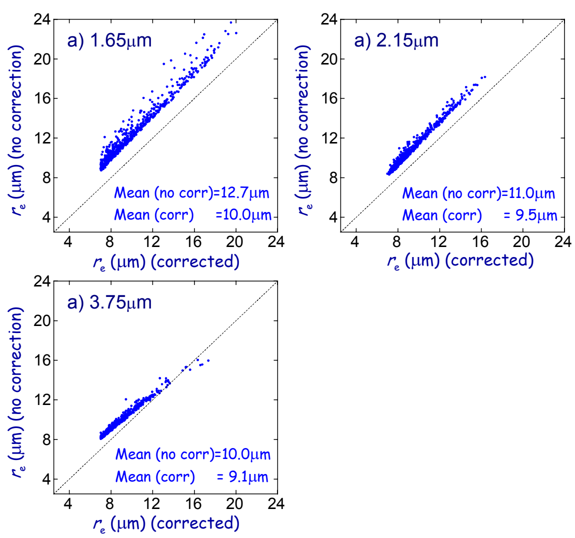

Fig. 5 Comparisons of MODIS-retrieved droplet effective radius with cirrus correction (x-axis) versus no cirrus correction (y-axis).

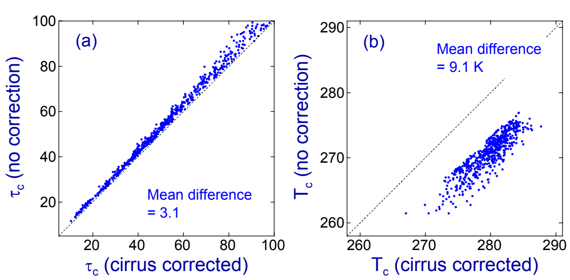

Fig. 6 Comparisons of MODIS-retrieved (a) cloud optical depth and (b) cloud top temperature with cirrus correction (x-axis) versus no cirrus correction (y-axis).

4. RESULTS

Figure 5 shows the comparisons of the retrieved cloud droplet effective radius with a correction of the thin cirrus and without the correction. The effects of thin cirrus contaminations were found the largest with the 1.65-μm retrievals as seen in Fig. 5a. The mean droplet effective radius reduced from 12.7 μm to 10.0 μm when accounting for the cirrus effects. For 2.15-μm retrievals, the mean radius reduced from 11.0 μm to 9.5 μm. The effects were smallest with 3.75-μm retrievals, which can be attributed to the counteract effect in subtracting the emission parts of the 3.75-μm measurements. In the 3.75-μm retrieval, it is required that the removal of the unwanted emission from the measured radiance. Such removal relies on the accurate retrieval of cloud emission temperature from 11-μm channels. However, when a pixel is contaminated by upper-level thin cirrus, the 11-μm retrieved cloud top temperature will be significantly colder than the low-level cloud temperature. As a result, the subtraction of the 3.75-μm emission contribution is underestimated and then leads to an overestimation in 3.75-μm reflectance, which offsets the reduction by thin cirrus.

Figure 6 shows the effects of thin cirrus contaminations on the retrievals of cloud optical depth (Fig. 6a) and cloud top temperature (Fig. 6b). As shown in Fig. 6b, the 11-μm retrieved cloud temperatures were much colder with no correction for the cirrus effect. The mean cloud temperature is 270.6 K for no correction, which is 9.1 K colder than the mean cloud temperature of 279.7 K with the correction. The effect on cloud optical depth retrieval is less significant because both the ice and water do not absorb in the visible wavelengths.

5. CONCLUSION

Water and ice are non-absorbing and so transparent in the visible wavelengths of the spectrum. They begin to absorb appreciably in the near-infrared spectrum, in particularly at 1.65, 2.15, and 3.75 μm. As the spectral reflectances at these near-infrared wavelengths differ between water and ice clouds, the retrieval of low-level cloud droplet effective radius requires meticulous classifications of cloud type. As thresholds are commonly applied to satellite observations at visible and infrared channels for cloud type classification, the method is subject to the contamination of upper-level thin cirrus clouds that reside above the low-level thick water clouds. While such thin cirrus clouds have weak effects on cloud optical depth retrievals, their influence on the retrievals of cloud droplet effective radius and emission temperature may be rather significant. As satellite measurements are dictated primarily by cloud particles encountered first, high-level thin cirrus containing mostly large ice crystals will absorb significant solar reflectances. The contamination of thin cirrus can cause overestimation in satellite retrievals of droplet effective radius when the pixels were assumed overcast by low-level water clouds. The overestimation was found most significant in 1.65-μm retrievals (Δr_e > 2.5 μm) as compared to 2.15- and 3.75-μm. The upper-level thin cirrus may have the offset effects on 3.75 μm when dealing with both reflected and emitted radiances in the satellite measurements.

6. ACKNOWLEDMENTS

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