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THE EFFECTS OF MULTILAYER CLOUDS ON MODIS CLOUD EFFECTIVE RADIUS AND OPTICAL THICKNESS RETRIEVALS

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1. INTRODUCTION

The focus of our study is the observation of multilayer clouds by satellites. Specifically, we are concerned with how thin cirrus clouds overlying lower level water clouds affect the retrievals of cloud effective radius (r_e) and optical thickness (τ). Several multilayer cloud detection techniques have recently been proposed and developed for high spatial resolution imaging instruments such as AVHRR, VIIRS, and MODIS (e.g. Pavolonis and Heidinger, 2004; Nasiri and Baum, 2004).

While the potential for cloud property retrieval errors due to overlapping or multilayer clouds is frequently mentioned (e.g. Wielicki et al., 1995; Chung et al., 2000; Platnick et al., 2003), only a few studies have looked at the effects of overlapping clouds on particular retrieval schemes. Xiong et al. (2002) examine satellite cloud retrievals in the Arctic using AVHRR data. They model the specific situation in which a thin cirrus cloud with r_e = 30 μm and τ = 0.2 overlays a water cloud for which the r_e and τ are allowed to vary. Compared to the true water cloud effective radius, the retrieved r_e is larger by 35% to 50%. The retrieved τ is smaller by 70% to 80%, compared to the water cloud. A study by Dong et al. (2002) looks at stratus cloud retrievals from GOES, aircraft and ground-based retrievals. They estimate that contamination by a cirrus cloud with $\tau \sim$ 0.25 might increase stratus r_e retrievals by ~ 4% to 9%.

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There are two ways to approach a discussion regarding the effects of multilayer clouds on effective radius and optical thickness retrievals. The first approach is to look at the effect on the retrieval of cloud properties for individual pixels. This approach makes it possible to estimate the maximum possible retrieval errors and sensitivity to different cloud properties while providing a necessary background for understanding why these errors potentially occur. The second approach looks as the overall effects of multilayer clouds on all of the cloud retrievals for a set of pixels, such as a scene, a data elements, a day, or a geographic region. By considering a set of pixels, the frequency of occurrence of multilayer clouds is considered when judging the significance of their effects. This approach hinges on the effectiveness of the overlapping cloud detection scheme.

In this paper, we consider the effects overlapping clouds may have on a given MODIS pixel. First, the technique for detecting multilayer clouds is briefly introduced. Next, a sensitivity analysis discussing the effects of multilayer clouds on the cloud property retrieval scheme is presented. The consideration of scene, granule, and global overlapping cloud effects is reserved for the poster session.

2. MULTILEVEL CLOUD DETECTION

The multilevel cloud detection algorithm described by Nasiri and Baum (2004) is implemented in this study. The technique can be summarized as follows. A given block of 200 pixels by 200 pixels of MODIS data is separated into clear pixels and cloudy pixels using the operational MODIS cloud mask (Ackerman et al., 1998). The next step is to identify two groups of cloud pixels: pixels likely from single layer water clouds and pixels likely from single layer ice clouds. This cloud phase identification is made using the brightness temperature difference between 8.5 and 11.0 μm (e.g. Strabala et al., 1994; Baum et al., 2000b). From the 2.1 μm reflectance and 11 μm brightness temperatures of the single layer ice and single layer water pixels, a range can be inferred of 11 μm brightness temperatures and 2.1 μm reflectances within which overlapping clouds are expected to fall for the particular scene. This technique is applied sequentially to the entire MODIS image. A further refinement is to classify each pixel multiple times using different sets of cloud statistics by moving the 200 by 200 pixel array tile across the data granule. This allows a confidence assessment to be made regarding the likelihood that a given pixels contains overlapping clouds.

3. EFFECTS OF MULTILAYER CLOUDS ON CLOUD PROPERTY RETRIEVALS

Retrievals of cloud properties such as optical thickness and effective radius are routinely made for most imaging satellite systems. A common retrieval method for the simultaneous retrieval of both r_e and τ, described by Nakajima and King (1990), utilizes two reflectance measurements. One measurement is made at a non-absorbing wavelength for which reflectance is mostly a function of optical thickness. The second measurement is made at a wavelength with ice and water absorption for which reflectance is mostly a function of particle size. The MODIS cloud property retrieval algorithm uses 0.65 μm as the non-absorbing wavelength over land and retrievals are made for three absorbing wavelengths, including 2.13 μm (Platnick et al., 2003).

An error analysis can be performed using radiative transfer modeling. The DISORT model (Tsay et al., 1990) is used to calculate top of the atmosphere radiances in the manner described by Nasiri et al. (2002). Water clouds single-scattering properties are calculated using Mie theory and a modified-gamma size distribution having an r_e ranging from 6 to 32 μm and an effective variance of 0.1. Ice cloud single-scattering properties are chosen to best correspond with those used in the operational MODIS retrievals (King et al., 1997; Baum et al., 2000a). Ice cloud r_e range from 6.7 to 58.9 μm.

In Figure 1, the error in water cloud retrievals is considered for the case of contamination by an upper level cirrus cloud with $\tau = 1$ and $r_e = 32$ μm. Errors, expressed as percent relative difference between the true and retrieved values, are shown as functions of true water cloud optical thickness and effective radius with contour interval of 10%. a) and b) show how these errors differ if the cloud is retrieved using water cloud or ice cloud libraries, respectively. Note that the r_e errors are smaller when the retrieval is performed assuming ice clouds, in this case. A different ice cloud τ or viewing geometry might change that, though. Errors for water cloud retrievals exceed –100% for $r_e < 15$ and $\tau < \sim 5$. The retrieved r_e is always larger than then the true r_e for this cirrus contamination case. Comparisons between c) and e) show that the error in retrieving total cloud column τ is much less than the error in retrieving just the underlying water cloud τ. Compared with the true optical thickness, the retrieved τ is larger when using water cloud libraries, and smaller when using ice cloud libraries.

The case of a lower level water cloud with $\tau = 5$ and $r_e = 10$ μm contaminating cirrus retrievals is considered in Figure 2. In a) and b), the percent relative difference between the true ice cloud r_e and the retrieved value is shown when the retrieval is performed using water and ice libraries respectively. Except when the overlying ice cloud r_e is very small, the retrieved r_e tends to be smaller than the true r_e, with similar errors whether the ice or water libraries are used. Note that in a) and c), when the ice cloud r_e is > 30 μm and the τ is > 3, the water cloud libraries do not yield retrieval values. In c) and d), the percent relative difference between total cloud column τ and the retrieved τ is shown. The water cloud libraries overestimate the cloud τ by up to 100%. The ice cloud libraries tend to underestimate the total cloud optical thickness, although the error becomes minimal for large ice cloud optical thicknesses, as one would expect. Retrieval errors for just the ice cloud τ tend to exceed several hundred percent and thus are not shown.

4. SUMMARY

While overlapping clouds occur frequently, their impact on the accuracy of cloud property retrievals has not been adequately established. Thin cirrus which overlies a lower level water cloud is the most problematic scenario for cloud property retrievals. The radiative transfer modeling shown here demonstrates that individual pixel retrieval errors could be quite large, on the order of –90% to +90% for effective radius retrievals. The potential errors are larger than many other established sources of uncertainty (e.g. Platnick and Valero, 1995). The next step is to apply an established multilayer cloud detection technique to global data and correlate the results with cloud property retrievals.

5. ACKNOWLEDGEMENTS

Some of the results presented here are part of the corresponding author's doctoral dissertation work and as such, have been funded by a NASA-GSFC Earth Sciences Directorate Suomi-Simpson Fellowship.

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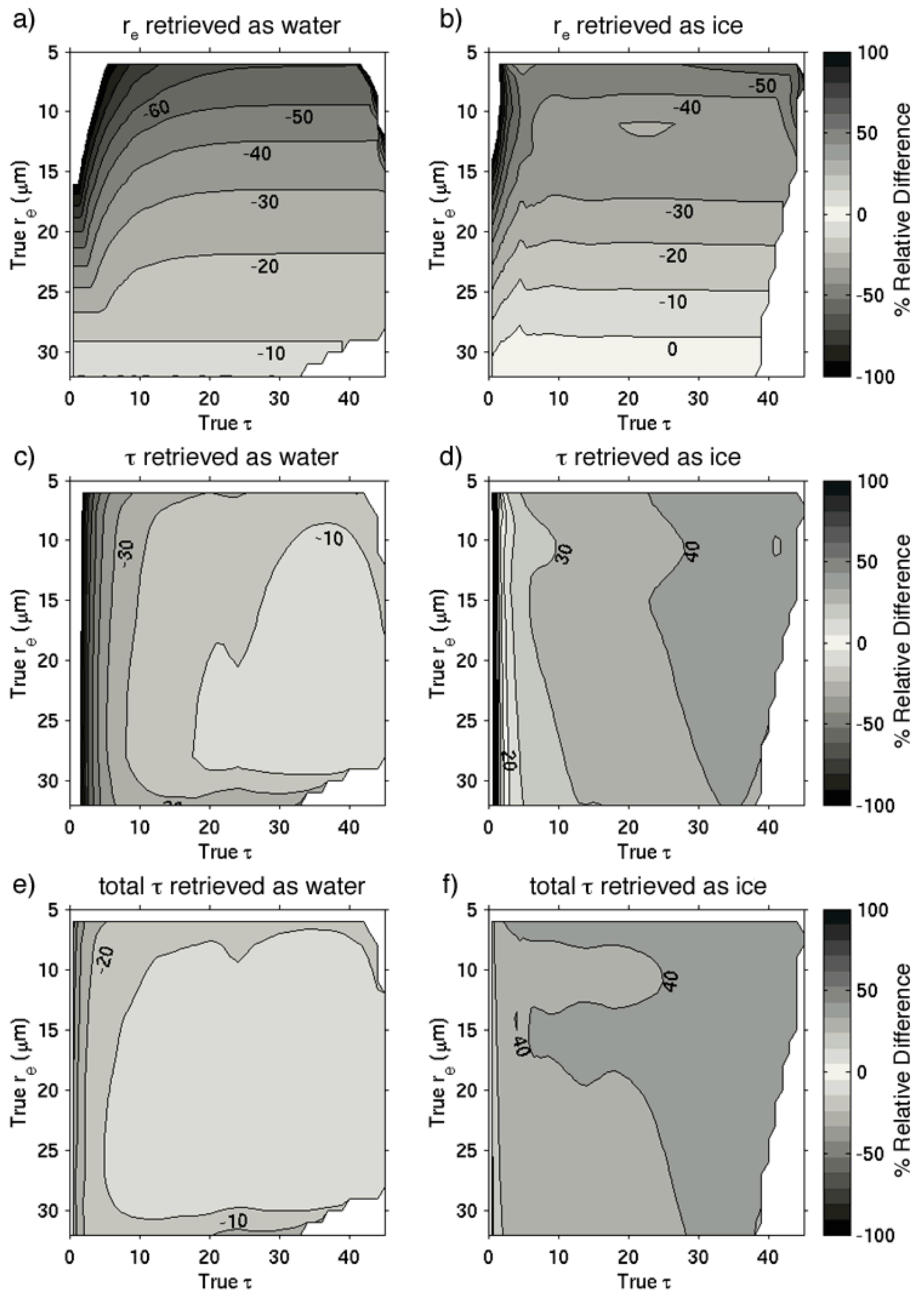

Figure 1: Percent relative difference between true water cloud *re* and *t* and retrieved values when the water cloud underlies thin cirrus with *t* = 1 and *re* = 32 *μ*m. a) and b) show *re* retrieval errors using lookup tables for water and ice, respectively. c) and d) show the error in water cloud *t* retrievals, while e) and f) consider the total column *t*. The contour interval is 10%.

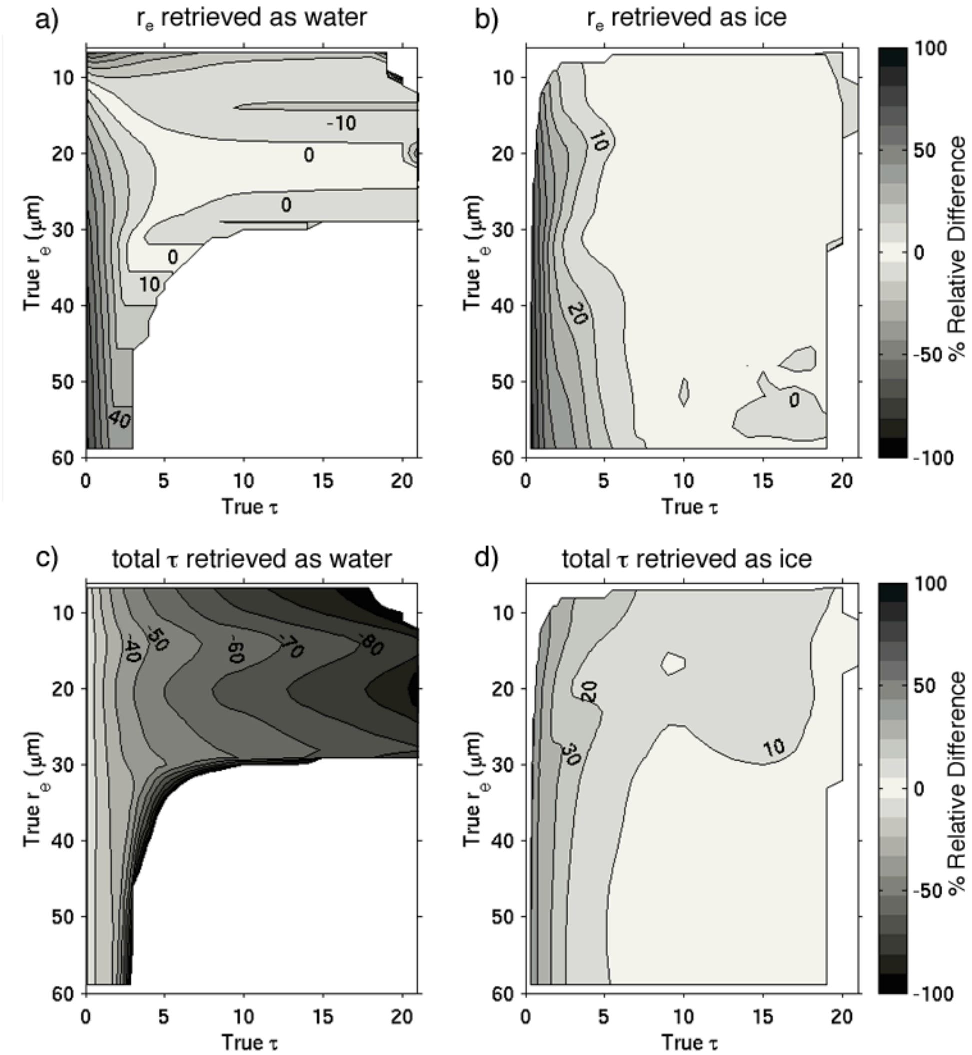

Figure 2: Percent relative difference between true cloud r_e and τ and retrieved values when the ice cloud overlies a water cloud with τ = 5 and r_e = 10 μm. a) and b) show r_e retrieval errors using lookup tables for water and ice, respectively. c) and d) show the error in total cloud column τ retrievals. (Errors in ice cloud τ retrievals, in general, greatly exceed 100% and are not shown here.) The contour interval is 10%.