J3.6 THE RETRIEVAL OF CLOUD PROPERTIES FOR PARTIALLY COVERED FIELDS OF VIEW

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1. INTRODUCTION

Almost without exception, current methods for retrieving cloud properties from satellite imagery data take a field of view to be overcast if it is found to have any measureable cloud signal. Otherwise, it is taken to be cloud-free. At the 1-2 km scale, about half the fields of view are either cloud-free or overcast, and thus satisfy this approximation. The other half contain broken clouds. Estimates of cloud properties such as cloud amount, visible optical depth, droplet effective radius, cloud altitude, etc. retrieved based on the assumption that the fields of view are overcast, when in fact they are only partially covered, will be biased. Furthermore, as the anisotropy of the radiances are nonlinearly related to physical properties such as optical depth and droplet radius, the radiative fluxes derived from the biased cloud properties will likewise be biased (Coakley and Kobayashi 1989). In order to estimate the possible biases, a retrieval scheme has been developed for obtaining the properties of clouds that only partially cover an imager field of view. The scheme is restricted to layered cloud systems for which clouds that fail to completely cover an imager's field of view are taken to be part of the same layer, and thus at the same altitude, as nearby clouds that completely fill the field of view. Properties of the clouds in the partly cloudy pixels are compared with those of the nearby clouds that completely cover the field of view. They are also compared with those derived assuming that the fields of view are overcast.

2. METHOD

The approach taken follows that suggested by Arking and Childs (1985). Extensive regions of single-layer, low-level clouds are identified using a scheme described by Coakley and Walsh (2002). The identification scheme distinguishes between fields of view that are 1) cloud-free, 2) overcast by clouds that form a readily identified layer, and 3) either partially cloud covered, or contain clouds that are parts of multiple cloud layers.

For regions that contain only a single cloud layer, the temperature associated with the layer, and thus, the layer altitude, is taken to be that of the overcast fields of view. For all pixels found to be partially cloud covered, the radiance at any wavelength is taken to be a weighted average of the cloud-free and overcast radiances within the field of view, as given by

$$I = (1 - A_C)I_S + A_C I_C \qquad (1)$$

with A_C the fractional cloud cover.

In this study, VIRS data (2-km resolution at nadir) from TRMM is used to retrieve cloud properties for ocean scenes. For the partly cloudy fields of view, a regional estimate of the layer altitude is derived from nearby overcast fields of view. The altitude of the clouds in the partially covered pixels is taken to be the same as the regional average. For each pixel, fractional cloud cover, the 0.64-µm cloud optical depth, and the droplet effective radius are then adjusted until radiances calculated for 0.64, 3.7, and 11 µm match those observed.

Not all fields of view identified as partially cloud covered admit a solution. If cloud amount is too small,or the clouds are too thin, it becomes impossible to derive realistic values of the cloud parameters from the observed radiances. Such fields of view have radiances that are near those of the cloud-free radiances but are not cloud-free. They are cloud contaminated, but the cloud cover and cloud opacity are too small to allow realistic solutions. Less than 10% of the fields of view fall in this category. In addition, some fields of view identified as partially cloud covered have radiative properties which suggest that cloud cover is essentially zero. Such fields of view can be taken as cloud-free. The inclusion of such fields of view has little impact on the distribution of cloud-free radiances derived for 50-250-km scale regions. Again less than 10% of the fields of view fall into this category. Likewise, some fields of view identified as partially cloud covered yield solutions that suggest overcast conditions, but with clouds at altitudes that differ from that derived for the layer from the nearby overcast fields of view. Again,

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such cases account for fewer than 10% of the fields of view.

For comparison, threshold retrievals were also obtained assuming that the partially covered fields of view were overcast. Pixels for which the fractional cloud cover was greater than 0.2 were taken to be overcast. Optical depths, droplet effective radii, and cloud altitudes were derived for these fields of view as if they were overcast.

3. RESULTS

The retrieval scheme was applied to VIRS observations for February and March 1998. The retrievals yielded over 250,000 50-km regions that contained single-layered cloud systems. If a region lacked overcast fields of view, the overcast fields of view within approximately 300 km of the region were used to derive the altitude of the cloud layer. For occasions in which regions were so heavily cloud covered that nearby cloud-free radiances could not be identified, cloud-free radiances observed on other days were used to characterize the radiative properties of the cloud-free background.

Figure 1 shows an example of results for a 500-km scale region that contains a single-layered system. The figure shows optical depths for the partly cloudy pixels as a function of fractional cloud cover for cloud cover fractions between 0.2 and 0.8. The optical depths prove relatively insensitive to the fractional cloud cover. Droplet effective radii, shown in Figure 2, are likewise insensitive to the fractional cloud cover. These results suggest that the linear weighting of radiances with fractional cloud cover, as done in (1), may properly account for the pixel-scale variability of radiances observed in satellite imagery data. Figure 3 shows the droplet effective radii and visible optical depths for overcast fields of view and Figure 4 shows these quantities for the partly cloudy fields of view within the 500-km scale region. For overcast fields of view, a slight increase in droplet radii with increasing optical depth is just detectable. Such an increase is consistent with the growth of droplet radius and optical depth with cloud thickness. Compared with clouds in the nearby overcast fields of view, those in the partly cloudy fields of view have smaller optical depths and smaller droplet radii. Clouds that cover an extensive area, equivalent to several pixels, are expected to be thicker than those which fail to cover a pixel. Such differences persist on average for all regions analyzed. This result suggests that the marked correlations between optical depths and droplet radii found, for example, by Han et al. (1998) may

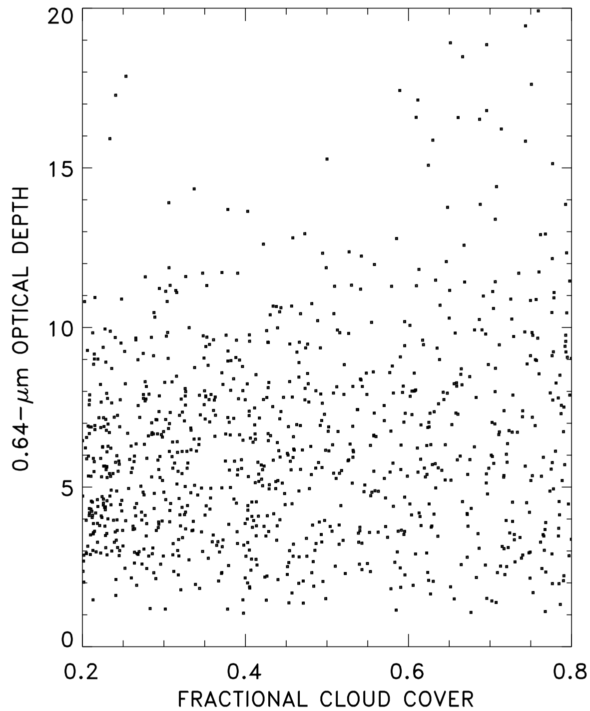

Figure 1. Fractional cloud cover and optical depth for partly cloudy 2-km pixels within a 500-km scale region that contains a single-layered cloud system

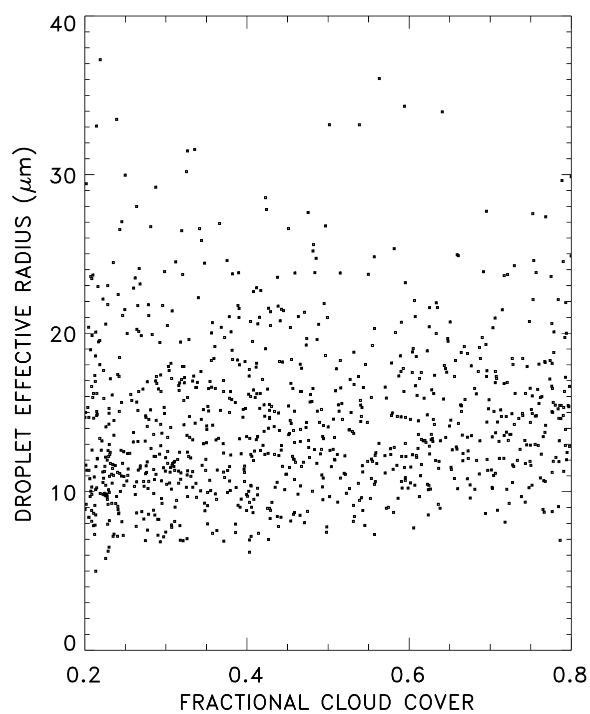

Figure 2. Same as Fig. 1 but for droplet effective radius.

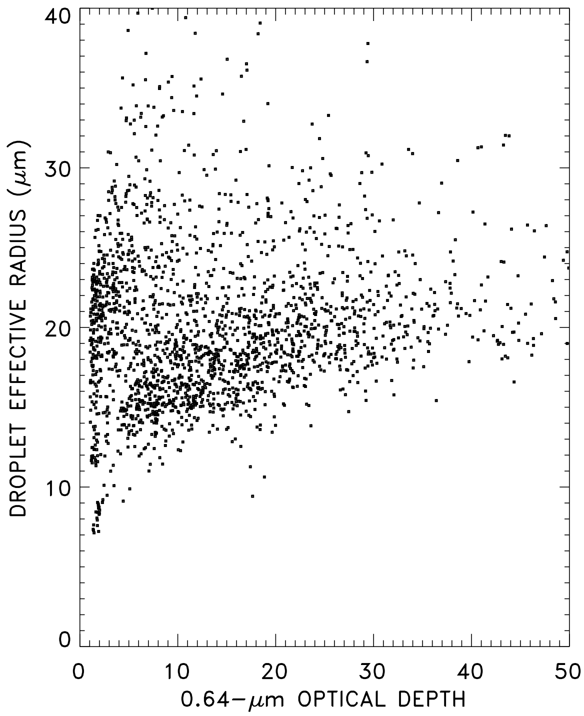

Figure 3. Optical depth and droplet effective radius for overcast 2-km pixels within the same 500-km region for which results are shown in Fig. 1.

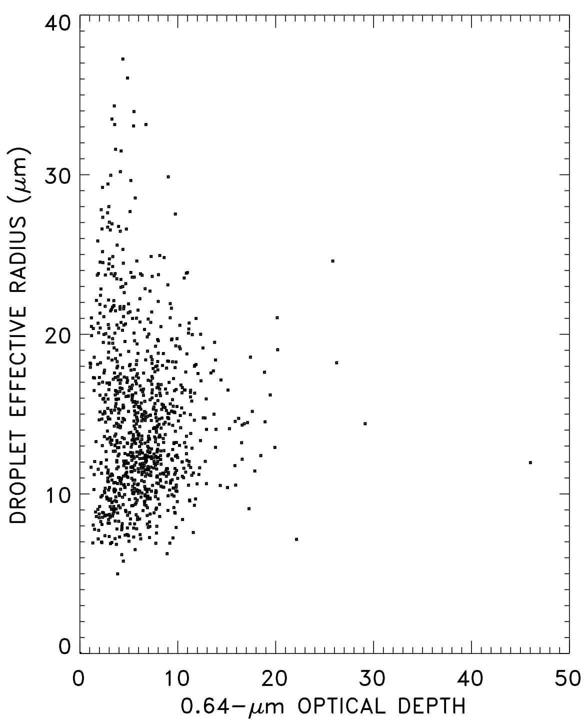

Figure 4. Same as Fig. 3 but for partly cloudy pixels.

simply reflect the consequence of mixing overcast and partly cloudy fields of view in the ISCCP threshold retrieval scheme.

Figure 5 shows optical depths derived using the partly cloudy retrieval scheme and those derived using a threshold, in which cloud contaminated fields of view are taken to be overcast. Each point in the figure represents an average for a 50-km scale region that contained a single-layer cloud system. The averages include all cloudy pixels, whether partly cloudy or overcast. Retrievals that allow for the fractional cloud cover yield clouds with larger optical depths but smaller droplet radii, as shown in Figure 6, than those that assume that the field of view is overcast. The cloud liquid water derived using the threshold retrieval is less than that for the partly cloudy retrieval and the altitude obtained assuming that the field of view is overcast falls below the altitude of the layer. For the threshold adopted here, the regional cloud cover is larger for the threshold retrieval but only by about 0.1 in cloud fraction as shown in Figure 7.

4. SUMMARY AND FUTURE WORK

Cloud fraction, optical depth, droplet radius, cloud liquid water, and cloud altitude are all biased to varying degrees. The biases in cloud fraction

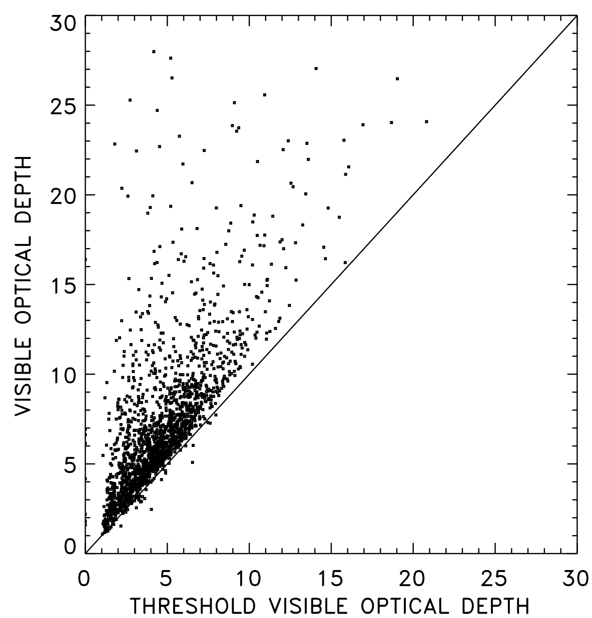

Figure 5. Optical depths derived using threshold and partly cloudy retrievals. Each point is an average of cloud properties for all cloudy pixels, both partly cloudy and overcast, within a 50-km region.

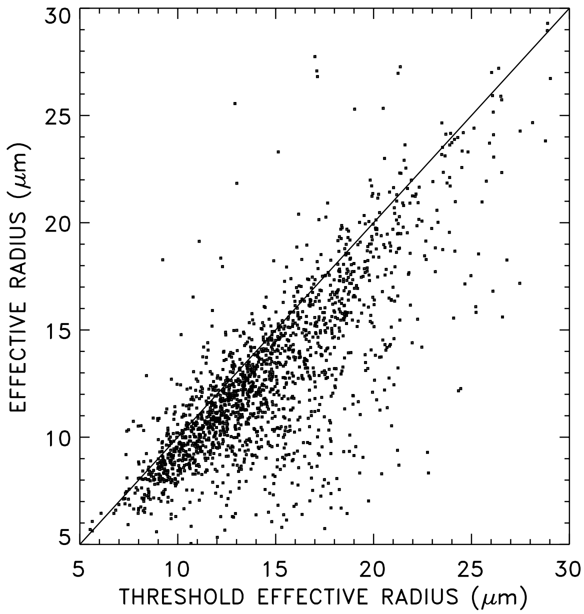

Figure 6. Same as Fig. 5 but for droplet effective radii.

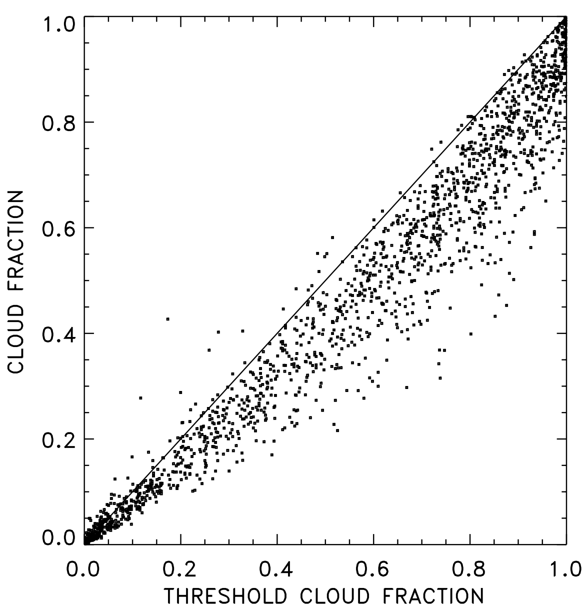

Figure 7. Same as Fig. 5, but for fractional cloud cover.

and optical depth should lead to biases in the top of the atmosphere and surface radiative fluxes, but realistic magnitudes for the biases remain to be derived. In addition, the cloud properties retrieved for the partly cloudy pixels are subject to uncertainties in the cloud-free radiances and cloud altitude which themselves are subject to uncertainties as single values are assumed for the region being analyzed. Finally, if the partly cloudy scheme presented here has merit, the retrieved products should be insensitive to the spatial resolution of the observations. In other words, degrading the fields of view from 2 to 4-km pixels should yield no changes in regional cloud cover, droplet radii or cloud liquid water.

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