JP4.4 RADIATIVE PROPERTIES OF OCEANIC BOUNDARY LAYER CLOUDS: SENSITIVITY TO CLOUD SCALE RESOLUTION

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1. INTRODUCTION

Millimiter radars have become very useful and reliable sources of information on cloud variability. Currently, much of this information has been obtained from 35-GHz cloud radar at 90-m vertical and 10-sec temporal resolution (e.g., *Clothiaux, et al*., 1999). It is possible to obtain finer cloud scale variability (30-m vertical and 2-sec temporal resolution) using 94-GHz cloud radar (e.g., *Kollias et a*l., 2001). In this study we evaluate the effect of cloud scale resolution on solar radiative transfer. Here we present an analysis of radiative calculations to determine whether the additional resolution has a significant impact on the mean radiative properties.

2. APPROACH

For our analysis we use observations of fair-weather cumulus observed by the University of Miami 94-GHz cloud radar (e.g., *Kollias et a*l., 2001). First, we obtain a two–dimensional set of extinction coefficient values with very high resolution (30-m vertical and 10-m horizontal resolution). Second, we degrade this resolution and obtain two additional sets of extinction coefficient values. We derive the first additional set from the original one by degrading the resolution in the horizontal direction only. We obtain the second additional set from the original one by degrading the resolution in the vertical direction only. Finally, these three sets (the original set and two additional ones) are used as inputs for solar radiative calculations using the Monte Carlo method. Then we compare the mean radiative properties.

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3. OPTICAL AND GEOMETRICAL PROPERTIES

To derive optical properties, we assume that the distribution of cloud droplets is described by a lognormal distribution with 10 μm effective radius and 0.35 logarithmic width (for all clouds). The radar reflectivity is then converted to cloud extinction coefficient values using this distribution (Fig. 1). The other optical properties (the scattering function and single scattering co-albedo) are obtained by Mie calculations for different wavelengths (visible and near-infrared spectral ranges). In section 4 we present the spectral radiative properties for a single wavelength (1.65 μm).

During these observations the wind speed at cumulus level was about 5 m/sec. To convert the temporal (2-sec) data to the spatial one, we specify the wind speed as 5 m/sec. Therefore, the spatial (horizontal) resolution of the radar data is 0.01km. Recall, the vertical resolution of the Miami 94-GHz cloud radar data is 0.03 km. The obtained set of the extinction coefficient $\sigma(i,k)$, $i = 1,\ldots,nx_0$ $k = 1,\ldots,nz_0$ has 10-m horizontal and 30-m vertical resolution ($\Delta x_0 = 0.01\,km$ and $\Delta z_0 = 0.03\,km$). Fig. 2a shows an example of a two-dimensional field (cross section of the extinction coefficient) obtained at very high resolution.

To estimate the effect of spatial resolution on the mean radiative properties, we obtain two additional sets of the extinction coefficient with coarse spatial scales. To do this we use values of the extinction coefficient σ over different scales in the horizontal (x) direction $\Delta x = nx\,\Delta x_0$, $nx = 1,\ldots,nx_0$, and in the vertical (z) direction $\Delta z = nz\,\Delta z_0$, $nz = 1,\ldots,nz_0$.

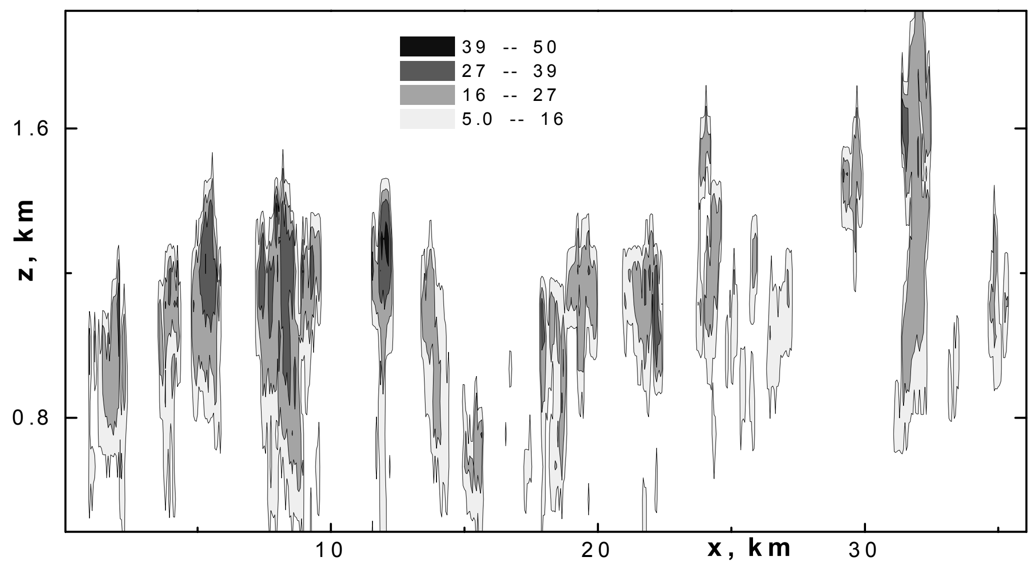

Figure 1. Cross section (the horizontal and vertical dimensions) of the extinction coefficient of cumulus clouds derived from ground-based radar measurements (high resolution Δx =0.05 km, and Δz =0.09 km).

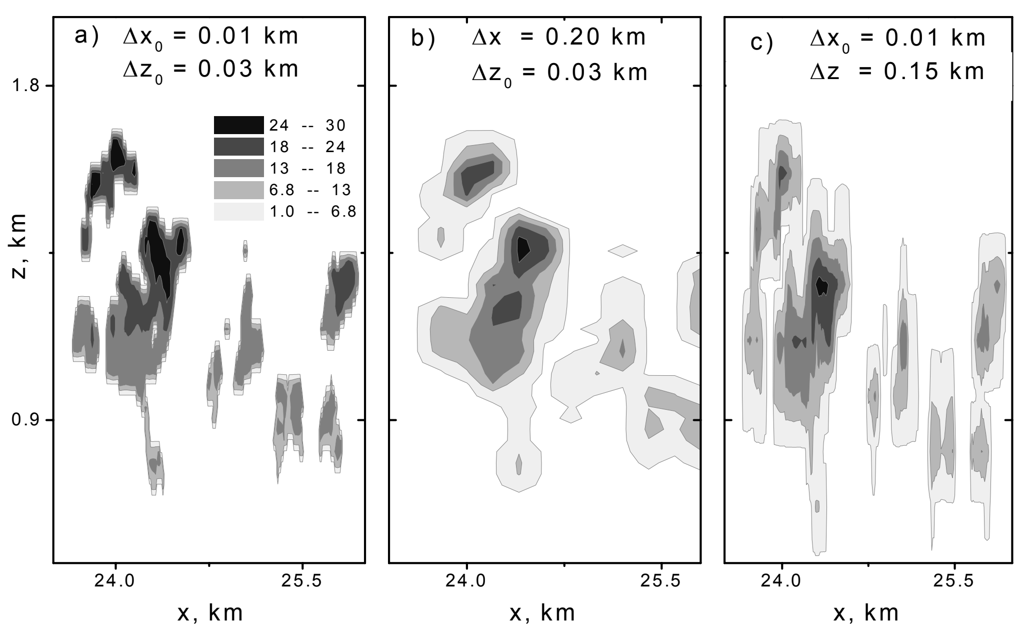

Figure 2. Cross section (the horizontal and vertical dimensions) of the extinction coefficient at (a) the very high resolution and (b,c) degraded resolution in (b) x-direction, and (c) z-direction.

- the *first* additional set is obtained by degrading the spatial resolution in the x-direction only (for each row with Δz_0 resolution)

$$\sigma(\Delta x, \Delta z_0) = \frac{1}{nx} \sum_{i=1}^{nx} \sigma(i, \Delta z_0) \qquad (1a)$$

- the *second* additional set is obtained by degrading the spatial resolution in the z-direction only (for each column with Δx_0 resolution)

$$\sigma(\Delta x_0, \Delta z) = \frac{1}{nz} \sum_{k=1}^{nz} \sigma(\Delta x_0, k) \qquad (1b)$$

We apply non-overlapping averaging and, therefore, the number of pixels is lowered by a factor *nx* (Eq. 1a) and *nz* (Eq. 1b). For example, if $nx = nx_0$ we will have only one pixel (for given vertical row) with the corresponding domain-averaging value of the extinction coefficient. Note that the domain-averaged (mean) optical depth is *the same* ($\tau_{mean} = 3.44$) for all sets considered here (the original set and two additional ones). Figs. 2 b,c show examples of cloud fields that correspond to these sets. To evaluate the effects associated with resolution effects, we use the relative differences

$$\delta F_x = [F(\Delta x, \Delta z_0) - F(\Delta x_0, \Delta z_0)] / F(\Delta x_0, \Delta z_0)$$

$$\delta F_z = [F(\Delta x_0, \Delta z) - F(\Delta x_0, \Delta z_0)] / F(\Delta x_0, \Delta z_0)$$

where *F* are optical, geometrical or radiative (section 4) properties obtained with different spatial resolution.

To separate cloudy pixels form clear-sky ones, we use a "perfect cloud detector" approach (e.g., *Di Girolamo and Davies*, 1997) for all sets. Note, we apply this approach to investigate the resolution effect only. According to this approach, a pixel is considered as cloudy pixel, if the extinction coefficient value for this pixel is distinct from zero (cloud threshold is scale-independent). Decreasing the horizontal resolution increases the nadir-view cloud fraction, N_{nadir} (Fig. 2b; Fig. 3). The opposite is true for the variance of optical depth (Fig. 3). Also, coarser resolution in the z-direction increases the vertical size of clouds (Fig. 2c; Fig. 4). Since the horizontal cloud size is fixed for the second set, the coarser resolution in z-direction increases the aspect ratio of clouds as well (Fig. 4).

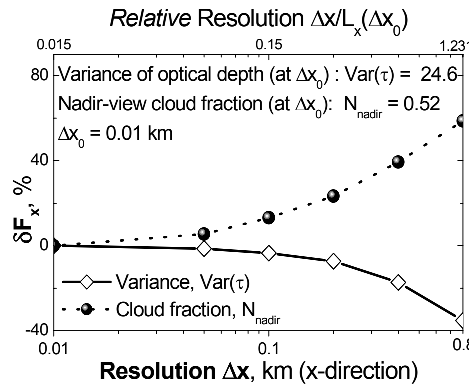

Figure 3. The relative differences of the variance of optical depth and nadir-view cloud fraction as functions of the spatial resolution in x-direction. The scale converting the spatial resolution to the relative spatial resolution is given at the top of the figure ($L_x(\Delta x_0)$=0.65 km is the mean cloud horizontal size at Δx_0 resolution).

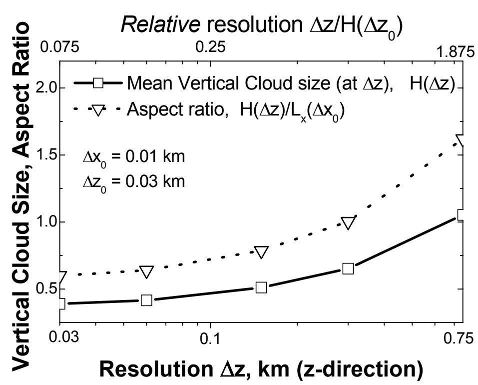

Figure 4. The same as Figure 3, but for z-direction ($H(\Delta z_0)$=0.40 km is the mean cloud vertical size at Δz_0 resolution).

4. RADIATIVE PROPERTIES

We use the Monte Carlo method to calculate the spectral (1.65 μm) domain-averaging radiative fluxes and absorption by water droplets. We assume that the solar zenith angle is equal to 60.

For fixed the mean optical depth, τ_{mean}, the mean albedo of inhomogeneous clouds increases as the variance of the optical depth $Var(\tau)$ is reduced (e.g., *Cahalan et al*., 1994). Degrading the horizontal resolution decreases the variance $Var(\tau)$ (Fig. 2) and does not change τ_{mean}. As a result, degrading the horizontal resolution increases the mean albedo (Fig. 5a).

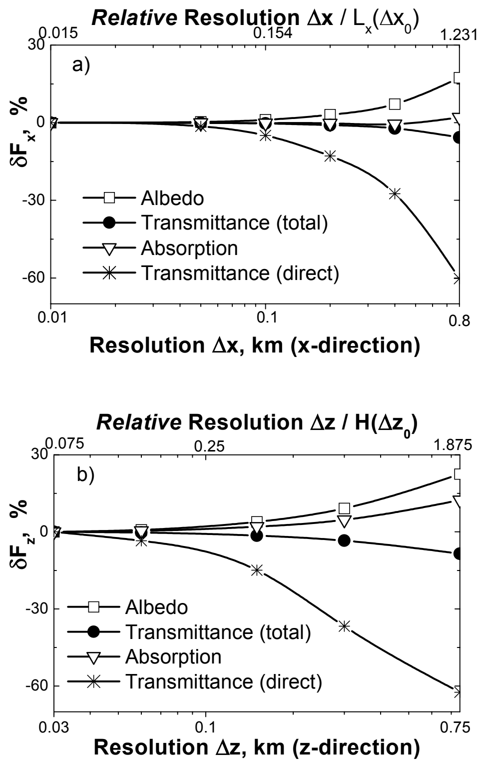

Figure 5. Relative differences of the mean radiative properties as functions of (a) the horizontal resolution (x-direction) and (b) the vertical resolution (z-direction).

For fixed the nadir-view cloud fraction, N_{nadir}, the mean albedo of inhomogeneous clouds increases as the cloud aspect ratio is extended (e.g., *Welch and Wielicki*, 1985). Degrading the vertical resolution enhances the cloud aspect ratio (Fig. 4) and does not change N_{nadir}. As a result, degrading the vertical resolution increases the mean albedo (Fig. 5b). One can see from Figure 5 that the spatial resolution should be an order of magnitude smaller than the characteristic cloud size ($\Delta x \sim 0.1 L_x$ and $\Delta z \sim 0.1 H$) for accurate (~5%) calculations of the mean fluxes. Compared to the mean albedo, the mean absorption is less sensitive to the spatial resolution effects (Fig. 5).

5. CONCLUSION

For given the mean optical depth τ_{mean}, degrading of the horizontal and vertical resolution affect the domain-averaged radiative properties (e.g., the mean albedo) in a similar manner. The mean radiative properties depend weakly on small-scale ($\Delta x \sim 0.1 L_x$ and $\Delta z \sim 0.1 H$) variations of the extinction coefficient.

ACKNOWLEDGMENTS

This work was supported by the Office of Biological and Environmental Research of the U.S. Department of Energy as part of the Atmospheric Radiation Measurement Program.

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