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The role of cloud-scale resolution on radiative properties of oceanic cumulus clouds

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Abstract

Both individual and combined effects of the horizontal and vertical variability of cumulus clouds on solar radiative transfer are investigated using a two-dimensional (x- and z-directions) cloud radar dataset. This high-resolution dataset of typical fair-weather marine cumulus is derived from ground-based 94 GHz cloud radar observations. The domain-averaged (along x-direction) radiative properties are computed by a Monte Carlo method. It is shown that (i) different cloud-scale resolutions can be used for accurate calculations of the mean absorption, upward and downward fluxes; (ii) the resolution effects can depend strongly on the solar zenith angle; and (iii) a few cloud statistics can be successfully applied for calculating the averaged radiative properties.

Keywords: Cloud scale resolution; Cloud radar dataset; Solar radiation

1. Introduction

The complex spatial and temporal variability of clouds impacts critically their radiative properties (e.g., [1–3]). For example, variability of stratus clouds at scales ranging from hundreds of meters to several kilometers reduces dramatically the domain-averaged albedo [2]. Similar

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results have been obtained for the mean albedo of cumulus clouds [3]. On the other hand, the mean albedo and reflected radiance (both visible and near-infrared spectral regions) of stratiform clouds are not sensitive to variations in optical depth on scales smaller than the photon mean free path ($\sim$ 30 m) [4].

Sensors deployed on the surface, in air, and in space have been used successfully to study cloud variability, (e.g., [5–8]). Combined and coincident observations from different instruments allow one to derive geometrical, optical and microphysical properties of clouds, which are important for climate-related studies. However, these sensors often have different spatial resolutions, and the question arises whether or not these observations resolve accurately the cloud structure that is essential for radiative transfer calculations. The resolution effects of satellite instruments (or their finite field of view) and associated errors on measurements of nadir reflectance and cloud properties have been examined (e.g., [9,10]). Different cloud fields (both simulated and inferred from satellite images) and different sensor resolutions (ranging from hundreds of meters to several kilometers) have been used. These studies demonstrate that errors associated with the effect of finite resolution (pixel size) can be substantial. The largest errors occur for coarse resolution and partly cloud scenes with relatively small clouds (where the ratio of average horizontal cloud size to pixel size is small). Note that all these results have been obtained for cloud fields that are inhomogeneous in the horizontal directions only.

While satellite observations provide a two-dimensional (2D) view of cloud spatial variability, they typically give no information on the vertical structure. Ground-based radars have been used to examine both the vertical and horizontal variability of clouds and their evolution (e.g., [11,12]). Currently, much of this cloud information has been obtained from a 35 GHz radar at 90 m vertical and 10 s temporal resolution [11]. Finer cloud scale variability (30 m vertical and 2 s temporal resolution) has been derived by using a 94 GHz cloud radar [13]. In this study, we use this high-resolution 94 GHz radar dataset to further evaluate the effect of cloud scale resolution on solar radiative transfer. In particular, we compare the effects of the horizontal and vertical resolutions both separately and combined on the solar radiative properties. We consider cloud fluctuations on scales comparable (and smaller) to the mean horizontal and vertical sizes of cumulus clouds.

2. Approach

For our analysis we use observations of fair-weather cumulus observed by the University of Miami 94 GHz cloud radar [13]. We begin by calculating a 2D set of extinction coefficient values from radar measurements at very high resolution (30 m vertical and 10 m horizontal resolution). We then degrade this resolution to obtain three additional sets of extinction coefficient values. We derive the first additional set from the original one by lowering the resolution in the horizontal direction only. We obtain the second additional set from the original one by reducing the resolution in the vertical direction only. We get the third set by degrading the resolution in both the horizontal and vertical directions. These four sets (the original set and three additional ones) are used as inputs for solar radiative calculations.