Cloud Aspect Ratios Derived from Total Sky Imagers Data: Case Studies

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Introduction

The Atmospheric Radiation Measurement (ARM) Program operates total sky imagers (TSIs) to retrieve hemispherical sky cover. Previously, we have demonstrated a method to convert surface measurements of sky cover determined from TSI observations to the vertically projected cloud fraction (Kassianov et al. 2005). To perform the conversion successfully, the measurements of cloud cover must be highly sampled (at least 1-minute sampling) and performed for a limited (100°) field-of-view (FOV). As a result of our study (Kassianov et al. 2005), the ARM Program added 100° FOV retrievals from TSI observations. We suggest that a comparison between the 100° and 160° FOV retrievals can yield information on the cloud field effective aspect ratio (vertical over horizontal cloud size). The latter is a three-dimensional (3D) descriptive characteristic (e.g., Welch and Wielicki, 1985; Masunaga and Nakaima 2001). Up to now, the determination of this parameter has been limited to surface observations with narrow FOV (active remote sensing) (e.g., Clothiaux et al. 2000) and satellite observations (e.g., Chambers et al. 1997).

Measurement of the cloud field effective aspect ratio, γ, could be possible with both smaller FOV and larger FOV estimations of fractional sky cover: for small FOV, cloud bases are mostly observed; for large FOV, both cloud bases and sides can be seen (Figure 1).

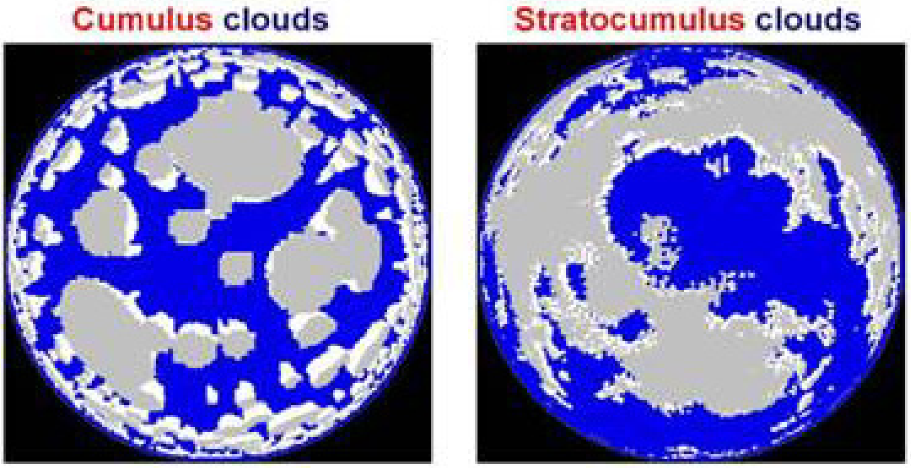

Figure 1. Computer realizations of hemispherical images generated by the stochastic models: cumulus (left) and stratocumulus (right) clouds; cloud bases (gray), sides (white).

Here, we demonstrate the research potential of TSI observations for deriving γ. We show retrievals of this parameter by using TSI observations (time series) of fair-weather cumulus clouds in Miami.

Approach

The TSIs provide time series of fractional sky cover (hemispherical), $N_{hemisph}$. We established a relationship between $N_{hemisph}$ and the nadir-view cloud fraction (or the vertically projected cloud fraction), N_{nadir}, (Kassianov et al. 2005) by application of a four-dimensional (three spatial and one temporal) cloud field provided by a Large Eddy Simulation model. This relationship has the form

$$N_{nadir}(\alpha) \approx N_{hemisph}(\alpha)\left(1-\gamma(0)\frac{\alpha}{\alpha_{\max}}\right) \tag{1}$$

where 2 α is the cone zenith angle α_{max} = 80°, $\gamma^{(0)}$ (for given FOV), = 80°, $\gamma^{(0)}$ is the cloud aspect ratio (for $\alpha = 0$; zenith-pointing observations, such as lidar or radar measurements); $\gamma(0) = H(0)/D(0)$, where $H(0)$ and $D(0)$ are the temporal mean of the vertical and horizontal cloud sizes, respectively. $N^{*}_{hemisph}{}^{(\alpha)}$ can be considered a corrected version of $N^{*}_{hemisph}{}^{(\alpha)}$.

Also, it was demonstrated that for the majority of cases, the 15-minutes averages of cloud fraction for 100° FOV ($2^{\alpha}{}_1$=100°) and 160° FOV ($2^{\alpha}{}_2$=160°) are comparable (Kassianov et al. 2005):

$$N_{nadir}(\alpha_1) \approx N_{nadir}(\alpha_2), \tag{2}$$

From Eqs. (1) and (2) follows that the cloud aspect ratio can be estimated as

$$\gamma(0) \approx \frac{N_{hemisp}(\alpha_1)-N_{hemisp}(\alpha_2)}{N_{hemisp}(\alpha_1)\beta_1 - N_{hemisp}(\alpha_2)\beta_2}, \tag{3}$$

where $\beta_i = \alpha_i / \alpha_{\max}$, $i = 1, 2$.

To evaluate such a possibility, we performed TSI retrievals of fractional sky cover at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) site in Miami, Florida. These TSI retrievals were accompanied with coincident and collocated satellite observations. The multi-angle imaging spectroradiometer (MISR) orbit passes over the Miami site once in nine days at ~ 11:00 Local Standard Time (LST). We used the MISR observations to select the well-defined single layer of broken clouds occurred over the Miami site and in the area surrounding this site. Twenty-five available MISR overpasses of the site from January 2004 to June 2004 along with coincident ground-based measurements were examined. We selected four days with different cloud fields: February 16 (2004-0216), March 12 (2004-0312), March 26 (2004-0326), and April (2004-0420) (Figure 2).

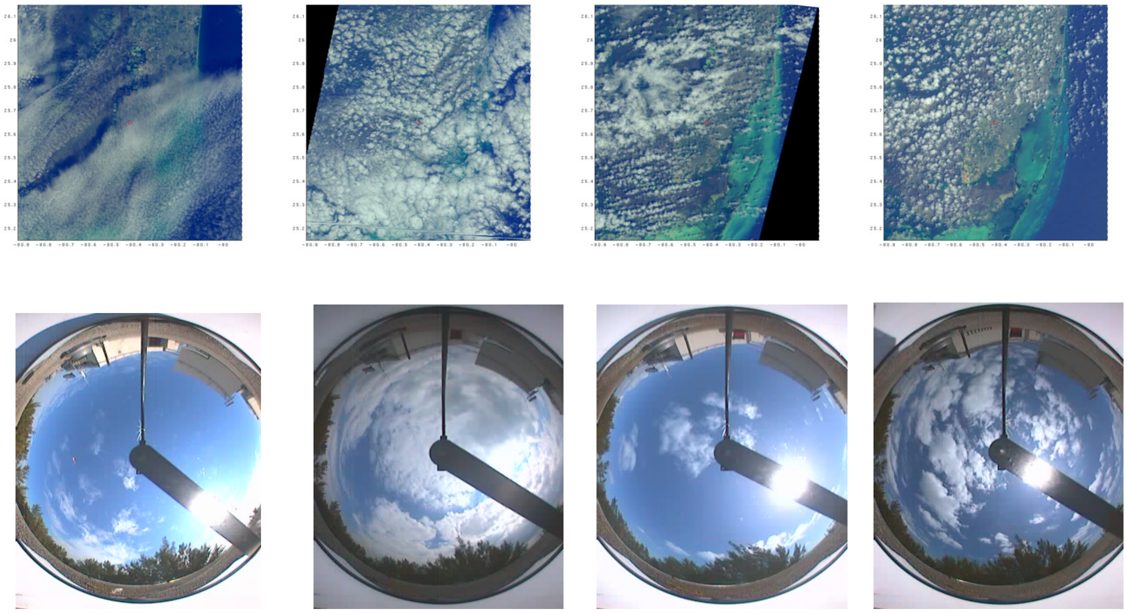

Figure 2. Instantaneous MISR images (top row) and corresponding TSI images at 11:00 LST (bottom row) for four cases 2004-0216, 2004-0312, 2004-0326, 2004-0420 (from left to right).

Results

The TSI observations at the RSMAS site had some viewing limitations. For example, a few instrumental containers are seen near the edge of TSI images (Figure 2). Due to these viewing limitations, $2^{\alpha}_{\max}$ was set as 150°. Thus, we obtained the fractional sky cover for 100° and 150° FOVs. Their temporal series are shown in Figure 3. On the average, the difference between $N_{hemisph}^{(150)}$ and $N_{hemisph}^{(100)}$ is positive (Figure 3), and it is mostly driven by the γ effects.

The temporal series were applied to calculated 15-minute averages of $N_{hemisph}^{(100)}$ and $N_{hemisph}^{(150)}$. Then we used these averages and Eq. (3) to estimate γ with 15-minutes temporal resolution (Figure 3). If $N_{hemisph}^{(100)}$ is less than 5% (e.g., image has just a few small clouds), we did not derive the cloud aspect ratio. The derived values of γ show considerable temporal variability (Figure 3). The latter is inversely proportional to variability of the fractional sky cover. The derived values of γ are within typical range (from 0.2 to 1) for marine cumulus/stratocumulus clouds (e.g., Benner and Curry 1998).

One of the strengths of the suggested retrieval is the ability to derive γ routinely from the surface observations. Since this simple retrieval is based on the model results (Kassianov et al. 2005), an assessment of its accuracy is required. To estimate the accuracy of the retrieval, we will perform a comparison of cloud aspect ratios derived from TSI data and other independent observations (e.g., surface radar and satellite data). Note that we have derived bulk geometrical properties of broken clouds from coincident and collocated radar and MISR data previously (e.g., Kassianov et al. 2003).

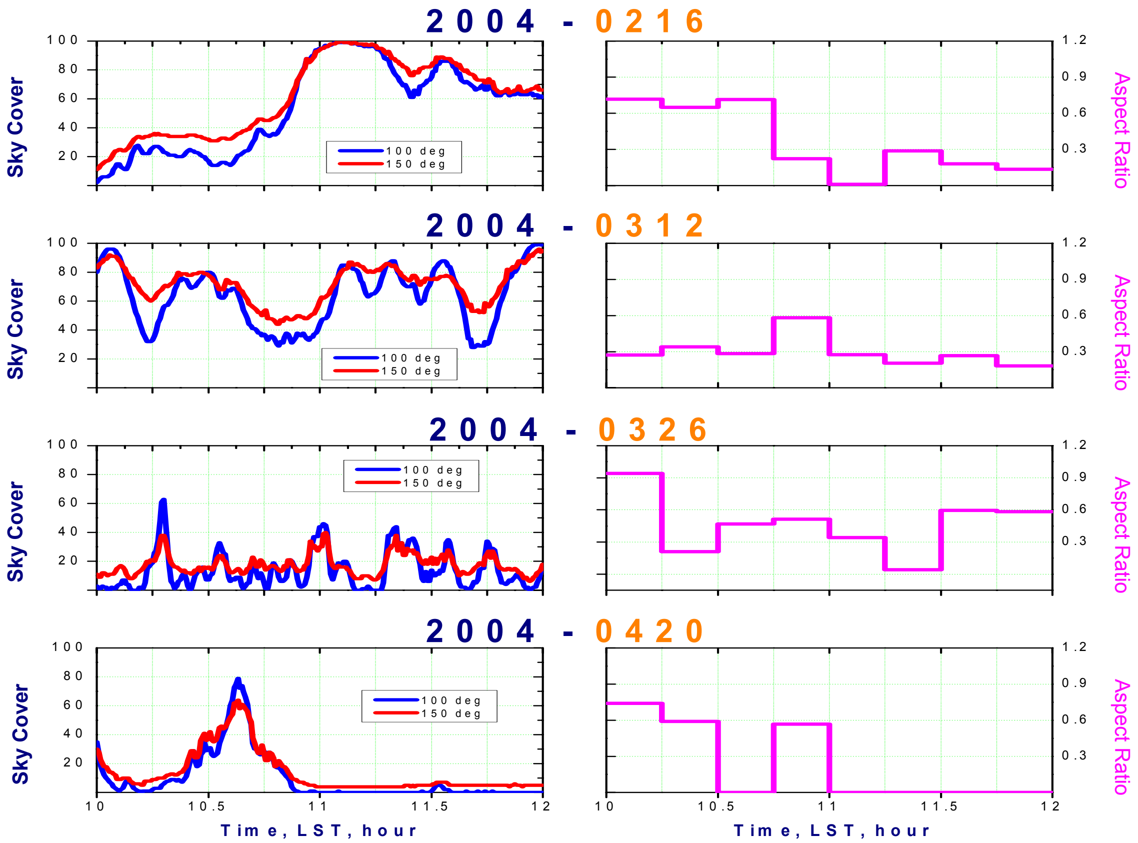

Figure 3. Fractional sky cover derived with high temporal (30-s) resolution (left column) and 15-minutes averaged derived corrective action report (right column) for 2004-0216, 2004-0312, 2004-0326, 2004-0420 (from top to bottom).

Summary

We suggest a new retrieval of the cloud aspect ratio from the high-resolution (1-minute) TSI observations and apply it to TSI datasets. The latter represent time series of the fractional sky cover obtained for 100° and 150° FOVs. The retrievals of the cloud aspect ratio were performed for different cloud fields (four cases) occurred in Miami. The derived 15-minute averages of the cloud aspect ratio are within the typical range for tropical cumulus clouds.

Through the TSI observations presented here, the potential for measuring the cloud aspect ratio is shown to be worthy of further work. Due to the simplicity of the suggested retrieval and wide deployment of TSIs, routine measurements of cloud aspect ratio could be possible on a global basis. Once the retrieval is tested thoroughly, it could demonstrate considerable use. To estimate the accuracy of the retrieval, we will perform a comparison of cloud aspect ratios derived from TSI data and other independent observations (e.g., surface radar and satellite data).

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