JP1.6 STATISTICS OF CUMULUS GEOMETRY FROM MISR DATA

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1. INTRODUCTION

Currently, most cloud retrieval schemes rely on spectral (e.g., microwave, visible, or IR) observations from near-vertically pointing remote sensors. The Multi-angle Imaging SpectroRadiometer (MISR), recently launched on the NASA Terra platform, provides high-resolution measurements of reflectance at nine different viewing angles. We have developed a new technique for retrieving cumulus vertical size (thickness) from *multi-angle* data and demonstrated that multi-angular MISR data can be used for measuring cloud geometry (e.g., *Kassianov et al*., 2002). Two dependences form the basis of this technique: (i) for fixed horizontal cloud distribution, the probability of clear line of sight is a decreasing function of zenith viewing angle and (ii) the rate of decrease of this probability depends on vertical cloud distribution. This paper presents recent analysis of two MISR overpasses at the Atmospheric Radiation Measurement (ARM) Tropical Western Pacific (TWP) site.

2. MULTI-ANGLE APPROACH

There are two basic steps of the suggested approach. *The first step* is the detection of cloud pixels. To separate cloud pixels from non-cloud ones, we used a new cloud analysis that relies on *angular* signatures of measured radiances. The output of this analysis is the horizontal distribution of cloud pixels (clouds). *The second step* is to obtain the vertical geometrical size of cloud pixels.

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Simple model, which converts the nadir radiance to the cloud vertical geometrical thickness, is applied. The values of cloud geometrical thickness were forced to agree with multi-angular MISR observations. These two steps are based on the directional cloud fraction.

2.1. *Directional Cloud Fraction*

Among the fundamental parameters describing the geometry of broken clouds is the directional cloud fraction, $N(\theta) = 1 - P_{clear}(\theta)$, where $P_{clear}(\theta)$ is the probability of a clear line of sight at zenith viewing angle θ. The directional cloud fraction $N(\theta)$ depends on the nadir-view cloud fraction N_{nadir}, the horizontal cloud distribution (e.g., random, clustered, or regular), and vertical cloud size variability. In the general, an empirical expression for $N(\theta)$ can be formulated based on field data or results of model simulations. For some cloud models, an analytical expression can be obtained in terms of cloud bulk geometrical parameters.

High-resolution (0.275 km) observations at nine viewing angles are available from the MISR, recently launched on the NASA Terra platform. These nine viewing angles $\boldsymbol{\theta} = \{\theta_i, i = 1, \ldots, 9\}$ are spread out along the flight path in the *forward* direction (*Df*, *Cf*, *Bf* and *Af* cameras), *aft* direction (*Da*, *Ca*, *Ba* and *Aa* cameras) and nadir direction (*An* camera) (Table 1). Since the MISR instrument measures reflectance in nine viewing directions, it seems reasonable to use all this information for cloud retrieval. To do that, we introduce an *average* cloud fraction N_{avr} defined as

$$N_{avr} = \frac{1}{n} \sum_{i=1}^{n} N(\theta_i), \ \mathrm{n=9} \qquad (1)$$

Table 1. The nine MISR cameras with corresponding look-angles θ (degree).

Number	Camera	Look-angle, θ
1	*Df*	70.5
2	*Cf*	60
3	*Bf*	45.6
4	*Af*	26.1
5	*An*	0
6	*Aa*	26.1
7	*Ba*	45.6
8	*Ca*	60
9	*Da*	70.5

Below we discuss how the directional cloud fraction, $N(\theta)$, can be retrieved from satellite data.

2.2. *Radiance Threshold*

Given a set of measured radiances at a single angle $I(\theta)$, a corresponding probability density function $pdf\,\{I(\theta)\}$ can readily be obtained that satisfies the normalization condition

$$\int_{I_{\min}(\theta)}^{I_{\max}(\theta)} pdf\{\, I(\theta)\,\}\, dI(\theta) = 1 \qquad (2)$$

where $I_{\min}(\theta)$ and $I_{\max}(\theta)$ are the minimum and maximum radiances, respectively.

One can define the directional cloud fraction $N_{obs}(\theta)$ as

$$N_{obs}(\theta) = \int_{I_0(\theta)}^{I_{\max}(\theta)} pdf\{\, I(\theta)\,\}\, dI(\theta) \qquad (3)$$

where $I_0(\theta)$ is a radiative threshold.

Here and below, the subscript "*obs*" on $N(\theta)$ and other variables indicates that they are obtained on the basis of equation (3). We emphasize that the threshold $I_0(\theta)$ depends on cloud geometrical and optical properties, atmospheric and surface parameters, and illumination conditions.

Presently, no reliable methods are available to select a threshold set $\mathbf{I}_0(\theta) = \{I_0(\theta_i),\, i = 1, \ldots, 9\}$ unambiguously; hence, the use of $N_{avr,\,obs}$ for cloud retrieval is not generally justified. Now we consider an alternative parameter

$$\Delta N = N_{avr} - N_{nadir} \qquad (4)$$

For a fixed horizontal distribution of cloud pixels, the parameter ΔN characterizes the relative influence of the vertical geometrical thickness *h* of cloud pixels on N_{avr}.

According to equations (1) and (3), ΔN_{misr} is a function of nine parameters $I_0(\theta_i)$, $i = 1, \ldots, 9$. Therefore, a change to a *single* relative variable can be useful. Here this was done in the following way. To perform a calculation of $N_{misr}(\theta_i)$, bins $\Delta I(\theta_i) = [I_{\max}(\theta_i) - I_{\min}(\theta_i)]\,/\,M$ were selected. The parameter *M,* which will be referred to as the number of radiance bins, was set to be equal for all θ_i, $i = 1, \ldots, 9$. In this case, $I_0(\theta_i) = I_{\min}(\theta_i) + m \times \Delta I(\theta_i)$, $i = 1, \ldots, 9$ and ΔN_{obs} depends on just *one* relative variable (digital count) *m,* $m = 1, \ldots, M$.

Remember, the *h* retrieval algorithm proposed here consists of the following two basic steps: (i) the detection of cloud pixels and (ii) obtaining their vertical geometrical sizes. First, a relative value $m = m^*$ is determined, at which $\Delta N_{misr}(m^*)$ peaks. Then, an absolute threshold is selected for nadir radiance. This value $I_0^*(\theta_5) = I_{\min}(\theta_5) + \Delta I(\theta_5) \times m^*$ is then used for determining horizontal cloud distribution. Specifically, the condition $I(\theta_5) > I_0^*(\theta_5)$ is checked for each pixel. All pixels satisfying this condition are flagged as 100% cloud coverage, all other pixels are background (clear-sky). For each cloud pixel, the vertical cloud height was taken to be equal to $h_{\mathrm{mod}} = a + b\sqrt{I(\theta_5)}$ (artificial model). Finally, for the fixed horizontal distribution of clouds, the parameters of the chosen model (subscript "mod") are adjusted such that $\Delta N_{\mathrm{mod}} = \Delta N_{obs}(m^*)$.

3. MISR-DATA CLOUD RETRIEVAL

To perform the multi-angle retrieval of low cumulus clouds (single layer), we use available satellite observations at the ARM TWP site (Nauru island). Note, the MISR passes over Nauru once in nine days at ~22:54 UTC. Sixty-four available MISR overpasses from March 2000 to January 2002 are examined to determine appropriate overpasses with a well-defined single layer of low cumulus clouds (without cirrus cloud contamination) over Nauru and the surrounding area. We found that 14 overpasses met these requirements. Here we consider only two of these appropriate overpasses, one on 9 August, 2000 (scene 1) and one on 21 August, 2001(scene 2) (Fig. 1).

Figure 2 presents some results from the multi-angular retrieval. Let us start with the horizontal cloud statistics (Fig. 2a). Characteristic horizontal cloud dimension is one of the basic bulk cloud parameters. Both the effective cloud diameter (e.g., *Wielicki and Welch*, 1986) and the mean cloud chord length (e.g., *Malvagi et al.*, 1993) are frequently used as the characteristic horizontal cloud dimension. The effective cloud diameter of a cloud is defined as a circle of area equal to the area of this cloud (number of cloud pixels multiplied by the pixel area). The cloud chord length is defined as the distance between the trailing and leading edges of a cloud for a given direction. Note, these two horizontal characteristics are not necessarily the same. In contrast to the effective cloud diameter, the cloud chord length along the wind direction can be determined from ground-based zenith-pointing instruments (e.g., lidar, radar). Since in our analysis we compare the satellite-derived parameters with ground-based ones (e.g., *Kassianov et al.*, 2002), here we use the cloud chord length as the characteristic horizontal cloud size.

In spite of the fact that these two cloud fields look quiet different (Fig. 1b,d), the mean cloud chord, $\langle L_x \rangle$ (along x-direction), is relatively constant (Fig. 2a). The mean value $\langle L_x \rangle$~1 km is consistent with that of other investigators (e.g., *Wielicki and Welch*, 1986). Unlike the mean cloud chord, the variation coefficient (VC) of L_x depends substantially on the cloud sub-scene variability (Fig. 2a). Similar results were obtained for the cloud chord length L_y along y-direction (not shown). In general, the geometrically thick pixels have large nadir radiance, but for geometrically thin pixels, the reverse is true. Overall, clouds in sub-scene 2 are brighter than clouds in sub-scene 1 (Fig. 1b,d). Therefore, one can expect that the satellite-derived mean vertical size of cloud pixels will be larger for sub-scene 2. The results of cloud retrieval confirm this (Fig. 2b).

4. CONCLUSION

We have derived both the horizontal distribution of cloud pixels and their geometrical thickness for two MISR scenes from the angular variations of the satellite-measured radiances. We will perform further cloud retrievals over additional MISR scenes and test these retrievals with independent ground-based observations. Also, we plan to investigate the statistical relationship between the cloud horizontal and vertical size and integrate this information into useful parameterization.

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REFERENCES

Kassianov, E., T. Ackerman, R. Marchand, and M. Ovtchinnikov, 2002: Satellite multi-angle cumulus geometry retrieval, *J. Geophys. Res.* (in review).

Wielicki, B., and R. Welch, 1986: Cumulus cloud properties derived using Landsat satellite data, *J. Appl. Meteorol.*, **25**, 261-276.

Malvagi F., R. Byrne, G. Pomraning, and R. Somerville, 1993: Stochastic radiative transfer in a partially cloudy atmosphere. *J. Atmos. Sci.*, **50**: 2146-2158.

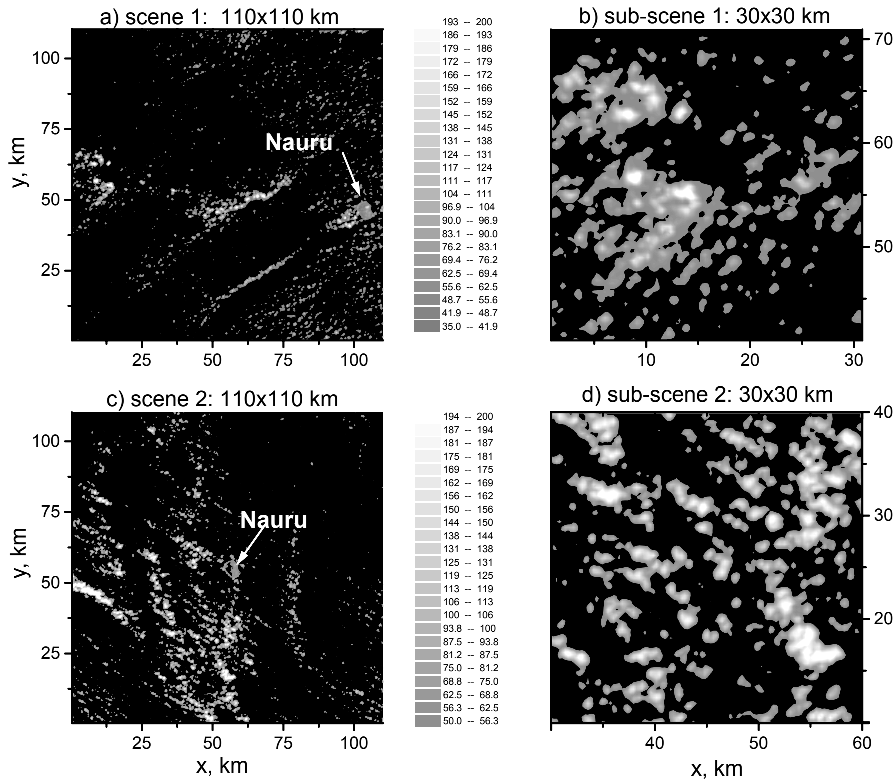

Figure 1. Cumulus clouds from MISR (nadir radiance) in 110x110 km^2 (a,c) and 30x30 km^2 (b,d) regions surrounding and near ARM TWP site: 9 August, 2000 (a,b) and 21 August, 2001 (c,d).

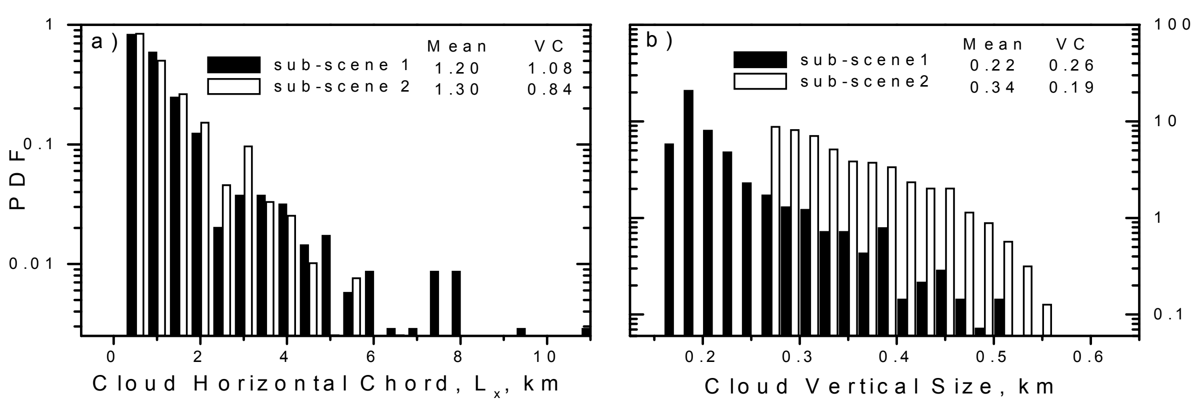

Figure 2. Probability density functions (PDF) of satellite-derived cloud geometrical properties for two considered (Fig.1b, d) sub-scenes: (a) cloud horizontal chord L_x (x-direction) and (b) cloud vertical size. Corresponding values of the mean and variation coefficient (VC) are shown.