The Influence of Spatial Resolution on the Inference of Ice Cloud Particle Morphological Parameters from Multi-angle Satellite Observations

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1. INTRODUCTION

In operational retrievals of ice cloud optical thickness and particle effective size, a satellite data product team selects specific particle shape and surface roughness parameters to define a representative model of their ice cloud. Previous studies show that such a selection can lead to systematic biases between products in the retrieved parameters (Yang et al., 2008; Zhang et al., 2009). Cloud models and observations must be consistent to achieve successful and reliable retrievals.

One aspect of the consistency is the directional distribution of the cloud reflectivity. Previous studies indicate that the application of surface roughness, which simulates imperfections of an ice particle in light scattering computation, brings simulations closer to the observations by multi-angle satellite sensors (Baran and C.-Labonnote, 2006; van Diedenhoven et al., 2012; Cole et al., 2014). However, the spatial resolution of multi-angle sensors differs (e.g. 275 m for the Multi-angle Imaging SpectroRadiometer (MISR) sensor; and 6 km for Polarization and Directionality of the Earth's Reflectance (POLDER) sensor), and the effects of spatial resolution on the consistency test have not been investigated. In this presentation, we demonstrate to what extent the spatial resolution of a sensor can affect the inference of the particle surface roughness parameter in a selected MISR data block.

2. METHODOLOGY

This study focuses on the inference of particle surface roughness. Variations in particle habit and aspect ratio of hexagonal column elements add further complexity, but they are not discussed.

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We select an aggregate of column particles as a representative shape of cloud particles and apply three different degrees of surface roughness, namely, smooth (σ^2=0), moderately rough (σ^2=0.03), and severely rough (σ^2=0.5). Three lookup tables of reflectivities as a function of solar zenith angle, satellite viewing zenith angle, relative azimuth angle, and cloud layer spherical albedo are computed with these degrees of surface roughness.

We compare spatial patterns of inferred particle surface roughness (smooth, moderately rough, severely rough) at different spatial resolutions using real or synthetic data. Real data from the MISR Level 1B radiance product is applied with a geometric correction, and only ice cloud pixels are processed to prevent contamination by water clouds. The collocated Moderate Resolution Imaging Spectroradiometer (MODIS) Level 2 Cloud product (Platnick et al. 2015) is used to obtain the cloud top height for the geometric correction and the cloud thermodynamic phase for the pixel selection.

From the lookup table and spatially averaged real or synthetic radiances, apparent spherical albedo values are computed. An apparent spherical albedo (ASA) is a proxy of the optical thickness, so ASA values from multiple viewing directions for a given pixel are supposed to be the same as long as the directional distribution of radiance in the lookup table is close to the observation. The degree of surface roughness that minimizes the intra-camera variance is, therefore, selected as the most representative surface roughness. The selection is recorded and the spatial resolution dependence is investigated.

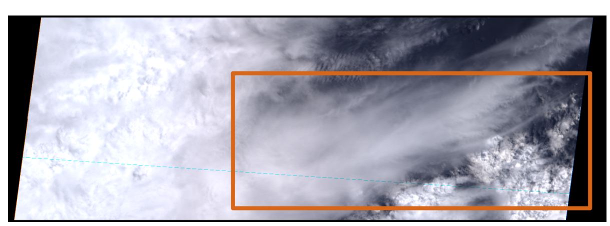

Fig. 1. The visible composite image of MISR block 99 in orbit 73111 over tropical Eastern Pacific. The area outlined by the orange box is depicted in Fig. 2.

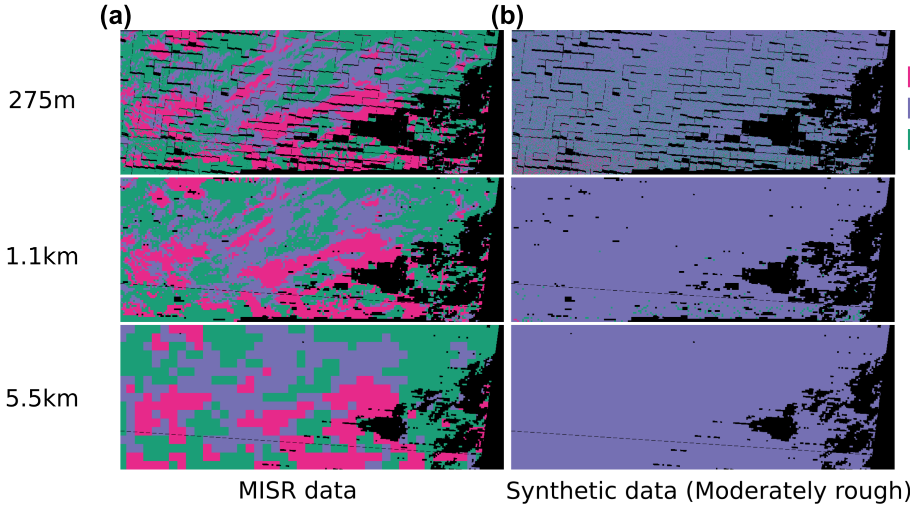

Fig. 2. Spatial pattern of inferred particle surface roughness. (a) based on original MISR reflectivity data in the area shown by the orange box in Fig. 1. (b) with synthetic reflectivities for moderate roughness substituted for the actual MISR data in the same ice cloud pixels, as described in the text.

3. RESULTS AND DISCUSSION

The particle roughness is inferred from one block of MISR data (block 99 of orbit 73111) over the tropical Eastern Pacific. Figure 1 shows the visible composite from the MISR nadir-viewing camera.

The inferred particle surface roughness patterns for the orange box in Fig. 1 are shown in the left panels of Fig. 2, where the top panel has the original 275 m resolution and the middle and bottom panels have reflectivities averaged in 4×4 or 20×20 pixel blocks to simulate instruments with 1.1 km and 5.5 km resolution.

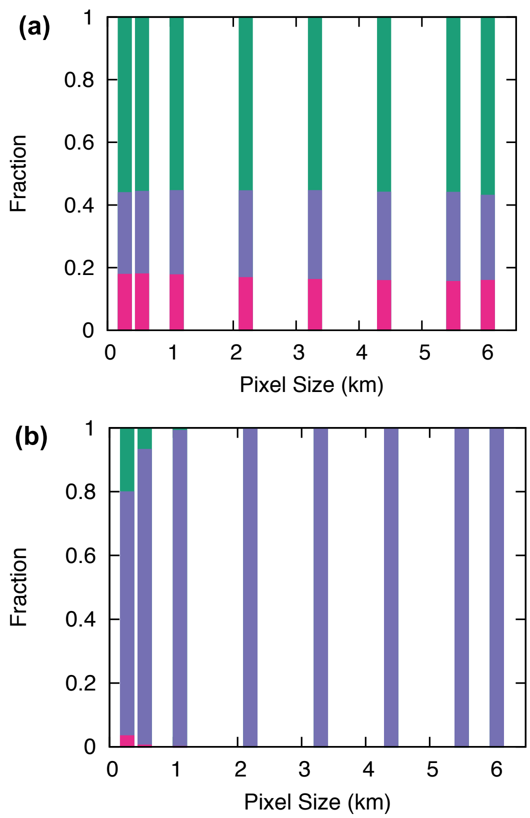

Fig. 3. (a) The fractions of pixels that are best described by each particle model. (b) Same as (a) but with the synthetic data.

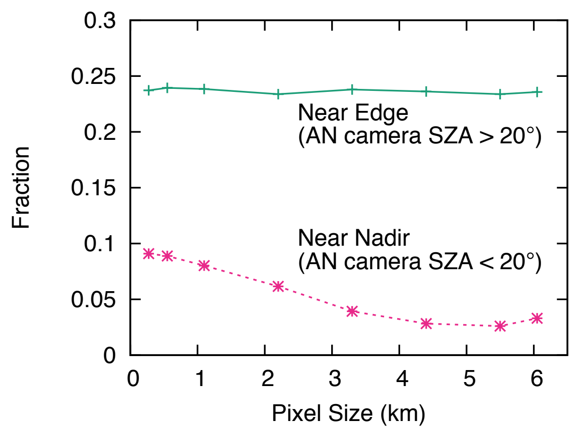

Fig. 4. The fractions of pixels that are best described by the smooth particle model, stratified by the solar zenith angle of the nadir-viewing (AN) camera.

Inferred cloud particle surface roughness is consistent throughout the spatial averaging scale. Optically thick ice clouds appear to be best modeled as smooth particles.

The result from the entire block from Fig. 1 is presented in Fig. 3 (a) in terms of fractions of pixels. The figure also shows no significant spatial resolution dependence. The fraction of pixels that are best explained by the smooth particle model is shown in Fig. 4, stratified by the viewing zenith angle of the nadir-viewing camera. Although it is not evident in Fig. 3 (a), there is weak spatial resolution dependence near the satellite ground track. Further study is in progress to infer the global distribution of surface roughness as well as to identify the cause of this localized resolution dependence.

The same surface roughness inference is repeated with synthetic data to assess the effect of radiometric noise. The synthetic data is generated from the geometry data in the MISR product and the radiance lookup table for a moderately roughened particle with 1% of radiometric noise being superimposed. The results (Fig. 2 (b) and Fig. 3 (b)) indicate that the error in the inference could reach as much as 20% when the spatial averaging scale is less than 1 km, but the inference converges to the true value at large spatial averaging scales.

4. SUMMARY

In this study, the inference of ice cloud particle roughness parameter is conducted with a block of MISR multi-angle radiometric data. The results show a consistent spatial pattern throughout different scales of spatial averaging from 275 m to 6 km, and no significant resolution dependence is found except near the satellite ground track. It is currently under investigation if this result holds in different locations and time periods. The sensitivity test with 1% of radiometric noise indicates that the noise can disturb the inference of surface roughness parameter at high resolution. At 275 m resolution, the false inference rate can reach up to 20%.

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