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Toward Direct Uses of Satellite Cloudy Radiances in NWP Models. Part III: Sensitivity study of cloud particle size and shape on Stokes vector

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1. INTRODUCTION

The cloud microphysics parameters such as the effective radius of the cloud particles and the cloud water contents have the important impact on the radiation budget and the climate change. The shape of cloud particles plays also a role in the climate change. Liou and Ou (1989) have shown the regardless of the shape of the ice cloud particle it may result in the different statement on the climate change. Using one-dimensional cloud and climate model, Liou and Ou (1989) found that the surface temperature would increase 0.4 K if one applies the spherical rather than the column/plate particle for the ice cloud. The uncertainty of 0.4 K for the surface temperature is comparable to the effect of greenhouse gases on the climate change. Furthermore, clouds directly affect satellite-based remote sensing of the Earth in the visible and infrared domain. An improved characterization of their optical properties is a key issue in improving the quality of products based on data from future spaceborne imaging instruments.

The cloud liquid water over Oceans can be derived from AMSU and SSM/I microwave sensors (Weng and Grody, 1994). The cloud mask can be obtained from AVHRR and MODIS data (Heidinger et al., 2002). Preliminary results (Heidinger and Liu, 2001) show that the effective radius of the cloud particles and the cloud water content may be derived from AVHRR data or from a combined AVHRR and AMSU data set. However, the retrieval accuracy of the cloud parameters over land is affected by the large variability of the topography and the surface emissivity. The polarized sensor like POLDER has demonstrated new capabilities to derive the optical properties of aerosols and clouds. There are growing needs to study the sensitivity of cloud particle size and shape on Stokes vector and to utilize the sensitivity in the retrievals. In particular, the upcoming sensor, AEROSOL POLARIMETRY SENSOR (APS), of U.S. National polar-orbiting Environmental Satellite System (NPOESS) will have Stokes vector measurements from blue to near infrared bands for multiple viewing directions. The multi-angle and multi-spectral Stokes vectors provide unique signatures for studying the particle size and shape of clouds.

There are advantages using the Polarimetric measurements to study the cloud microphysics parameters. The polarization may separate the signature from cloud from the surface since the land surface is generally un-polarized. The third and the fourth Stokes components may reveal the shape of the cloud particles. The fourth component can further separate the scattering of clouds from the molecular scattering since the Rayleigh scattering doesn't make any contribution to the fourth Stokes component. In this paper, we study the sensitivity of particle size and the shape of the particles of clouds on the scattering functions.

2. SCATTERING FUNCTION

The polarization signature is mainly contributed by the surface and the atmosphere. Over up-polarized surface, the polarization is resulted from the scattering of the aerosols and clouds. The scattering depends on the scattering matrix (Weng and Liu, 2002).

The optical depth, single scattering albedo, and the scattering phase matrix are the function of the refractive indices, the size distribution, the shape, and the orientation of the scatters. To simplify the problem, we use the random distribution for the orientation and the single particle size. Ray trace method of Macke and Mishchenko (1996) is applied because of the large Mie size parameter of clouds in the visible regime.

For the randomly-oriented scatter the scattering matrix **S** can be written as (Mishchenko, 2000):

$$\mathbf{S} = \begin{bmatrix} P_{11}(\Theta) & P_{12}(\Theta) & 0 & 0 \\ P_{12}(\Theta) & P_{22}(\Theta) & 0 & 0 \\ 0 & 0 & P_{33}(\Theta) & P_{34}(\Theta) \\ 0 & 0 & -P_{34}(\Theta) & P_{44}(\Theta) \end{bmatrix} \quad (1)$$

The scattering matrix for the spherical scatter has:

$$P_{11}(\Theta) = P_{22}(\Theta) , \quad (2)$$

and

$$P_{33}(\Theta) = P_{44}(\Theta) . \quad (3)$$

Therefore, the elements of the scattering matrix for the spherical and non-spherical particles are distinguishable. Figure 1 displays the normalized P_{22} at a wavelength of 0.865 micrometer for an ice sphere and ice circular cylinder of the ratio of the length to radius of 2. The volume-equivalent radius is 20 micrometer. It can be seen from Figure 1 that the backscatter part, which contributes to the satellite measurement, is distinguishable for the spherical and non-spherical scatters. The difference of the element

P_{11} of the scattering matrix for the intensity is also obvious for the sphere and circular cylinder (see Figure 2), but negligible for the spherical scatters of different radius (see red and green lines in Figure 2). The off-diagonal element P_{12} for the polarization is also sensitive to the shape, but small sensitivity for the particle size (see Figure 3). The sensitivity depends strongly on the sun and viewing directions. Large sensitivities around 90° and 180° are found. The diagonal element P_{33} for the third component of the Stokes vector shows the remarkable difference for the shape of the scatter (see Figure 4).

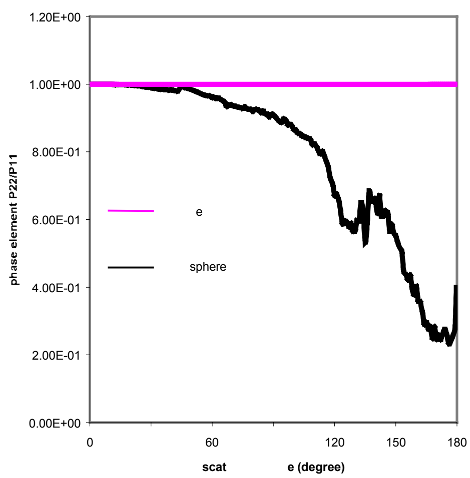

Fig. 1: Normalized element P_{22} *of the scattering matrix for the spherical and circular cylinder scatters.*

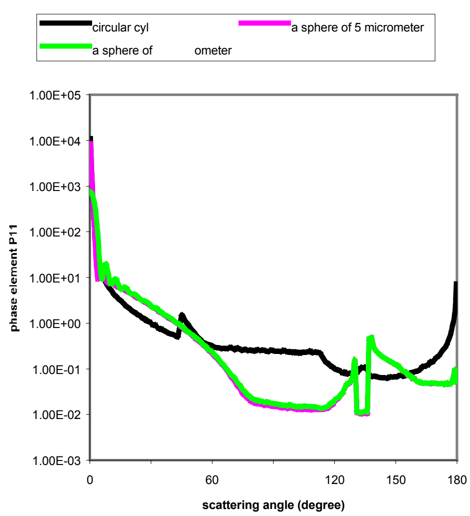

Fig. 2: Same as Figure 1, but the element P_{11} *for the intensity.*

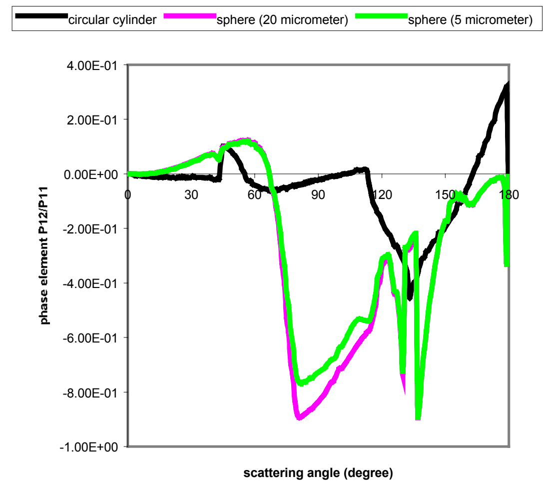

Fig. 3: The normalized off-diagonal element P_{12} for the polarization.

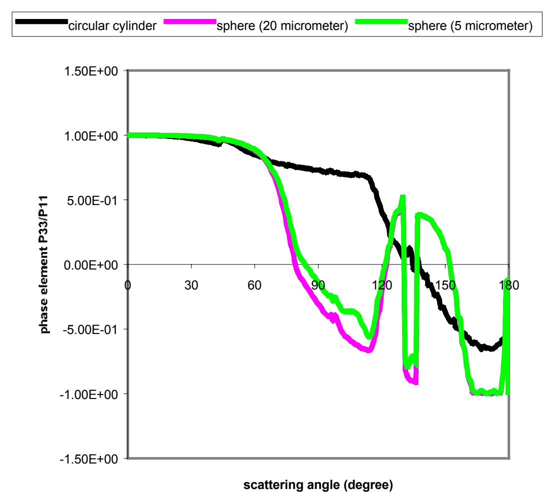

Fig. 4: The normalized diagonal element P_{33} for the third component of the Stokes vector.

3. DISCUSSION

It has shown that scattering matrix elements are sensitive to the particle shape. The particle shape can also modify the extinction efficiency and the absorption efficiency even for the particle having the same cloud water content and the same volume-equivalent radius. The effect of modified optical properties due to the particle shape is crucial for the climate study. The elements of the scattering matrix for the polarization may be different for the spherical particles of different radii for certain sun-view conditions. Therefore, the Polarimetric sensor is demanded for the study of the optical thickness, particle size, and the particle shape. The multi-looking sensor can provide the maximum sensitivities for the study. The Polarimetric sensor is especially interesting for the retrieval of the aerosol properties and to improve the ocean color products. Figure 5 displays the degree of linear polarization for a typical case (maritime aerosol) and a stressing case (dust aerosol) and US standard atmosphere. It is clear that the polarization signature is very helpful to identify the typical and the stressing aerosols.

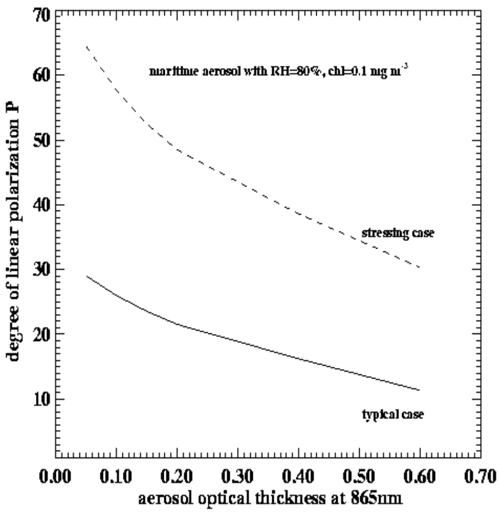

Fig. 5: Variation of the degree of polarization for maritime aerosol (typical case) and the dust aerosol (stressing case).

References

Heidinger, A., V. Rao Anne, and C. Dean, 2000: Using MODIS to Estimate Cloud Contamination of AVHRR Data Record, *J. Atmos. Sci*., **19**, 586-601

Heidinger, A., and Q. Liu, 2001: Validation of a global cloud liquid water product from AVHRR, 484-487, 11th Conference on satellite meteorology and oceanography, American Meteorological Society.

Liou, KN, and S. Ou, 1989: The role of cloud microphysical processes in climate: An assessment from a one-dimensional perspective. *J. Geophys. Res*., **94**,8599-8607

Mishchenko, M., J. W. Hovenier, and L. D. Travis, 2000: Light Scattering by Nonspherical Particles, Edited by Michael I. Mishchenko, Joachim W. Hovenier, and Larry D. Travis, Academic Press, San Diego.

Weng, F., and Q. Liu, 2003: Toward Direct Uses of Satellite Cloudy Radiances in NWP Models. Part I: Forward and Adjoint Models, 12th Conference on satellite meteorology and oceanography, American Meteorological Society.

Weng, F., N. C. Grody, 1994: Retrieval of cloud liquid water using the Special Sensor Microwave/Imager. *J. Geophys. Res*., **99**, 25535-25551.