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The Unreasonable Effectiveness of Mimicking Measured Infrared Extinction by Hexagonal Ice Crystals With Mie Ice Spheres

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SUMMARY

An armada of infrared[1-2] and other remote sensing equipment have been developed and deployed to characterize clouds from the ground, from airplanes, and from satellites. Perhaps someday we will be able to trust this equipment to provide all the information we need about clouds - we no longer will have to fly through them and directly record particle statistics - but first, we must properly invert cloud radiative signatures to obtain particle information. To invert, obvious common thought has been that we must have proper numerical models for the single scattering properties of generally nonspherical cloud particles. We have been using a cloud box in the laboratory to measure radiative properties of spherical water[3] and hexagonal ice particles[4] in a controlled environment where clouds can be well characterized. Our first spectral extinction measurements (2-18 μm) were performed on ice clouds grown near water saturation at a variety of temperatures so that a wide range of particle morphologies from nearly equi-axed columns to sector plates were observed.[4] Then we measured spectral extinction by water clouds so we could learn how to invert, using Lorenz-Mie theory, the extinction spectra to obtain particle size spectra, with the larger goal in mind of eventually retrieving ice particle size spectra using the discrete dipole approximation.[3] We decided to first apply the inversion based on the Lorenz-Mie theory for ice spheres to the measured ice spectra (mostly so we could grin and giggle at the anticipated poor results), and found much to our surprise that the retrieved IR spectra matched the measurements even better than the water cloud results! Though the retrieved ice sphere size spectra are qualitatively in accord with the measured results, we have not yet found a proper principle to guide us in converting from the geometry of a hexagonal ice crystal to the geometry of a sphere. Ok, so the Mie model seems to work for mimicking the infrared spectral extinction by ice crystals, but are the inverted size spectra reasonable and useful? Come to the talk and find out.

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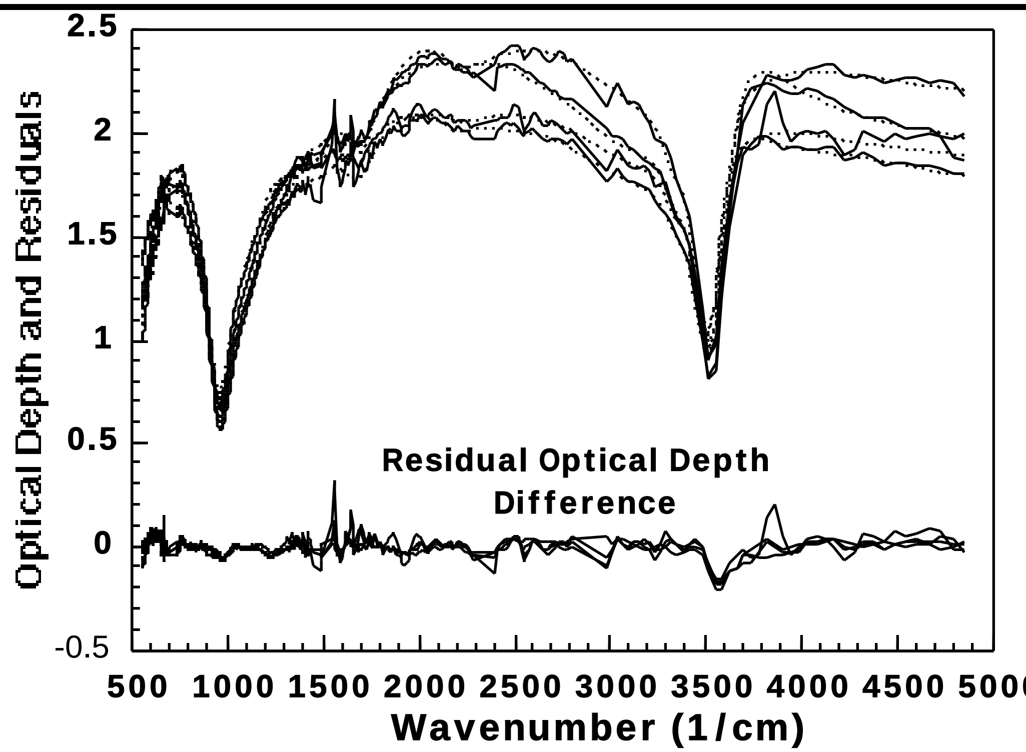

Figure 1. Measured (solid) and modeled-by-Mie-theory (dashed) spectral extinction by ice particles. Measurements are from Fig. 11 of Ref. 4. Residual optical depth is the difference between measured and modeled spectra.

Figure 1 shows an example of the use of Mie theory to model the measured spectral extinction by hexagonal ice crystals. Different curves correspond to different times during the roughly 7 minute cloud growth and decay life cycle. Cloud particles were mostly hollow column crystals. All of the other spectral extinction measurements reported in Ref. 4 have been similarly modeled. The particle size spectral retrieval algorithm described in Ref. 3 has been used to obtain this degree of agreement between measured and modeled spectral extinction. Figure 2 shows the retrieved size spectra from use of the Mie theory algorithm and also the maximum dimension of the measured crystals. The minimum detectable crystal size at the time of the measurements was around 7 μm, and was perhaps limited by the collection efficiency of the impaction plate. Suppose for a moment that the measured and modeled size spectra were perfectly accurate and precise. Is there a meaningful transformation that could be applied to the measured size spectrum to obtain the modeled spectrum (or vica versa)? We are working on this issue. Rest assured that our future spectral extinction and size spectra measurements will strive for maximum dynamic range. The size spectra observed in laboratory measurements are similar to those sometimes occuring at the top of cirrus clouds, to ice fog, and to contrail cirrus.

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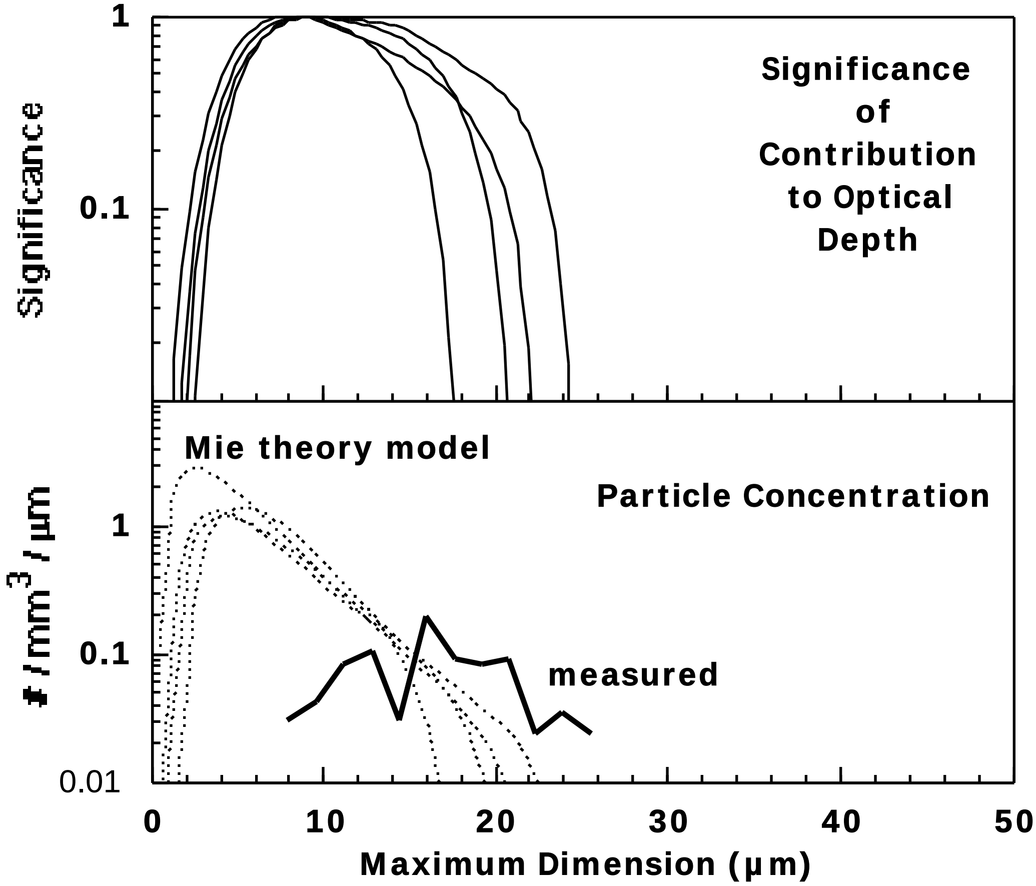

Figure 2. Lower panel shows the measured crystal maximum dimension along the C-axis of the hexagonal columns that were observed (thick solid) and retrieved size spectra from use of Mie theory (dashed). The significance of the contribution to optical depth from various portions of the retrieved size spectra is shown in the upper panel.

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