197548
p. 4

N94-22340

EXTINCTION EFFICIENCIES FROM DDA CALCULATIONS SOLVED FOR FINITE CIRCULAR CYLINDERS AND DISKS

Withrow, J. R., and Cox, S. K.
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

July 13, 1993

1.0 Introduction

One of the most commonly noted uncertainties with respect to the modelling of cirrus clouds and their effect upon the planetary radiation balance is the disputed validity of the use of Mie scattering results as an approximation to the scattering results of the hexagonal plates and columns found in cirrus clouds. This approximation has historically been a kind of default, a result of the lack of an appropriate analytical solution of Maxwell's equations to particles other than infinite cylinders and spheroids. Recently, however, the use of such approximate techniques as the Discrete Dipole Approximation has made scattering solutions on such particles a computationally intensive but feasible possibility. In this study, the Discrete Dipole Approximation (DDA) developed by Flatau (1992) is used to find such solutions for homogeneous, circular cylinders and disks. This can serve to not only assess the validity of the current radiative transfer schemes which are available for the study of cirrus but also to extend the current approximation of equivalent spheres to an approximation of second order, homogeneous finite circular cylinders and disks. The results will be presented in the form of a single variable, the extinction efficiency, Q_{ext}.

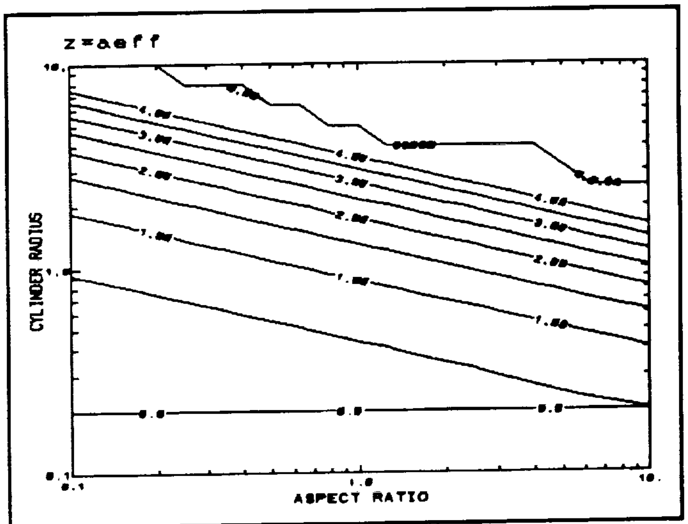

Figure 1. Lines of constant a_{eff}. Contour interval is .5.

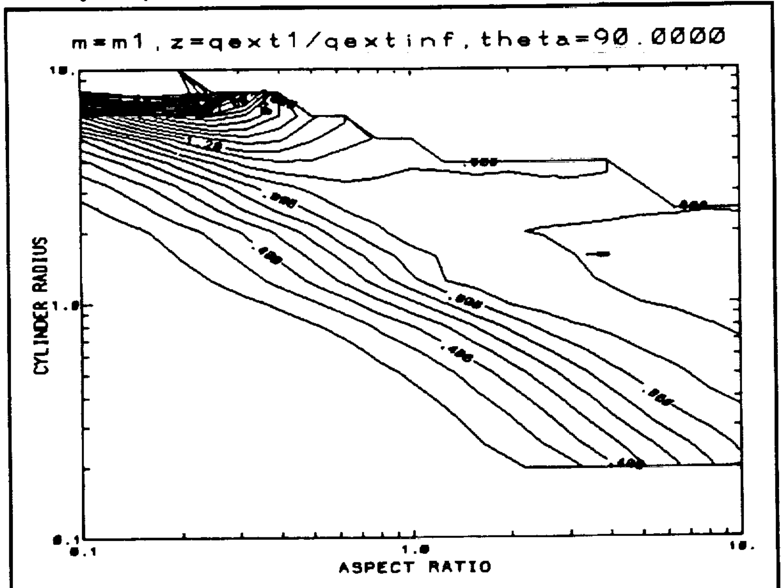

Figure 2. Ratio of Renormalized Q_{ext} values to Q_{ext} values of corresponding infinite cylinders. The contour interval is .1, m = 1.32 + 0i, and Θ=90.

Before proceeding, a few definitions and distinctions must be given. The first concerns the normalization of the extinction efficiency for nonspherical particles. Usually, Q_{ext} is normalized according to the following equation:

$$Q_{ext} = \frac{C_{ext}}{\pi a_{eff}^2}$$

where C_{ext} is the extinction cross section and a_{eff} is the (effective)

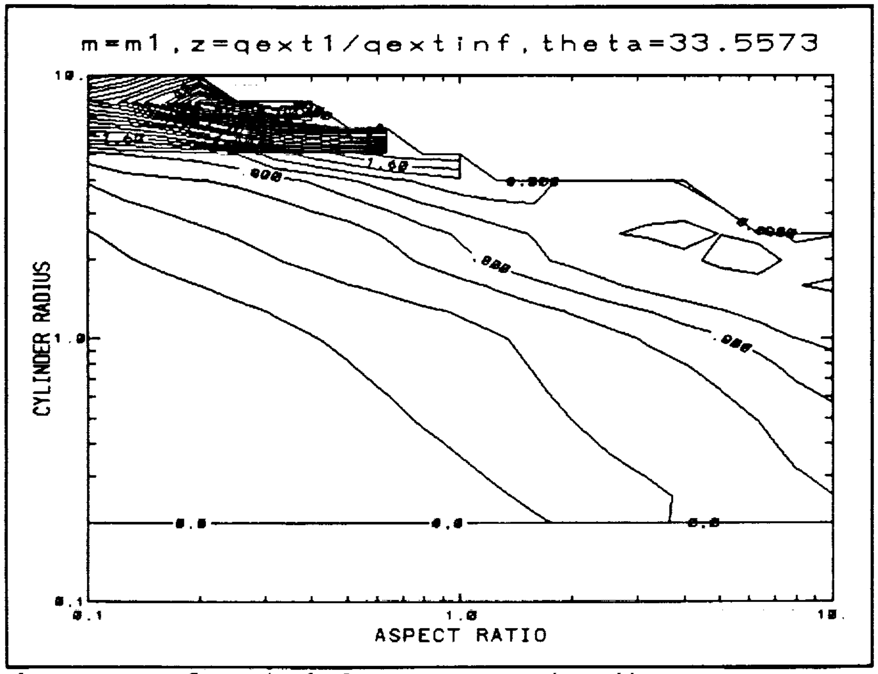

Figure 3. Same as figure 2 but for Θ=33.5573. Contour interval is .2.

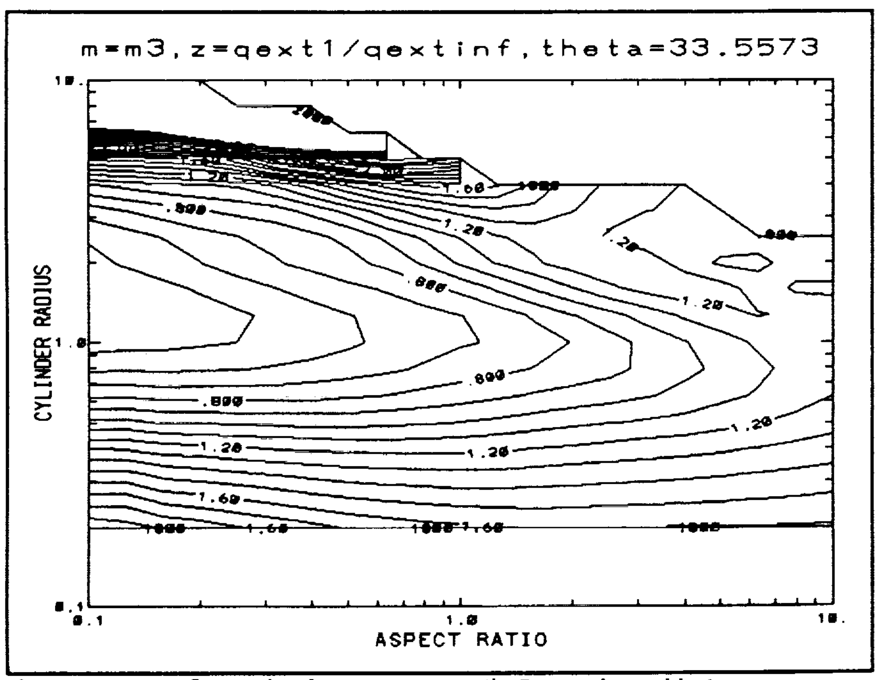

Figure 4. Same as figure 3 but for m = 1.32 + .05i. Contour interval is .1.

radius of the particle. This method is, of course, inappropriate for nonspherical particles and in the case of an infinite cylinder becomes inapplicable. For the infinite cylinder case, as defined in Bohren and Huffman (1983), the normalization becomes:

$$Q_{ext1} = \frac{C_{ext}}{2r_{cyl}L}$$

where r_{cyl} is the cylinder radius and L is the cylinder length. Of course, this represents a normalization with respect to actual cross sectional area (with perpendicular incidence) instead of an "effective" cross sectional area.

All of the graphs shown in the analysis section are contour plots in which results are expressed in terms of cylinder radius and aspect ratio, β, where:

$$\beta = \frac{L}{2r_{cyl}}$$

It should also be noted that in all cases the wavelength of the incident radiation is taken to be 2π and that results will be given for two common refractive indices of ice. Since:

$$r_{cyl} = \sqrt[3]{\frac{2}{3\beta}}a_{eff}$$

and all the axes are logarithmic, lines of constant a_{eff} will be linear with a slope of -1/3 (see Figure 1). Also, the top and bottom lines in Figure 1 reveal the region of the available data. These appear in all of the plots.

2.0 Analysis

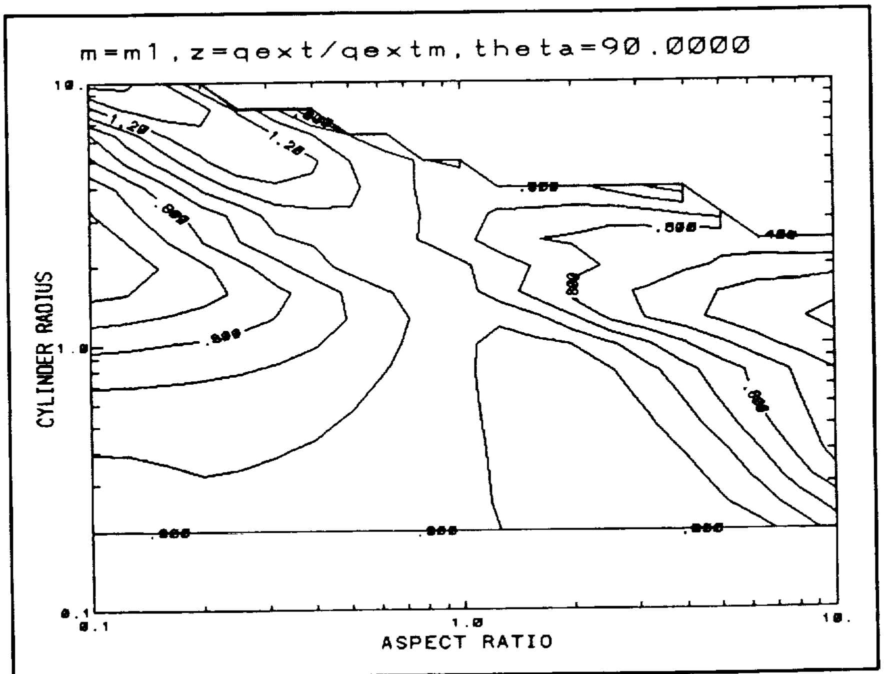

Figure 5. Ratio of Qext values to those of equivalent spheres (traditional normalization). The contour interval is .1, m = 1.32 + 0i, and Θ=90.

It is most appropriate to begin the analysis with a look at the Q_{ext1} values. With the aforementioned renormalization we will be able to address the degree to which finite cylinders behave like infinite cylinders. Figures 2 through 4 display ratios of extinction efficiency for finite cylinders and infinite cylinders of the same radius. Here m_1 equals 1.32 + 0i and the angle of incidence (Θ) is expressed with respect to the cylinder axis. Note first that a "plateau" of infinite cylinder behavior is visible in Figure 2 in a region where r_{cyl} is between .4 and 3 and where β is between about .6 and 10, revealing that, in some cases at this incidence angle, the behavior of finite cylinders can approach that of their infinite counterparts very quickly, sometimes with aspect ratios as low as one or less. The region of this approach shows a strong but apparently monotonic dependence on r_{cyl}, appearing at lower values of β as r_{cyl} increases. There is also a dependence upon incidence angle, with the oblique incidence case showing a more complex approach to infinitum. Along these lines, resonance peaks are present near $r_{cyl}=2$, revealing most likely a Struve-function-type approach to infinitum instead of a purely monotonic approach. The peak found in the region of $r_{cyl}=10$ is very strong and is most strongly observed as θ approaches 0. More on this in a moment. Extending this to a case of strong absorption (m_3 = 1.32 + 0.05i), the same basic structure is observed in Figure 4, where it becomes apparent that the approach to infinitum and its dependence upon r_{cyl} is in fact not monotonic, but that in regions below r_{cyl} = 1.0 a strong dependence on r_{cyl} starts to become visible. A quick glance at figure 7 reveals this to be a region of mostly "Mie-type" behavior, which in the realm of extinction-per-unit-length apparently translates to a high dependence on r_{cyl} and a relatively low dependence on cylinder length.

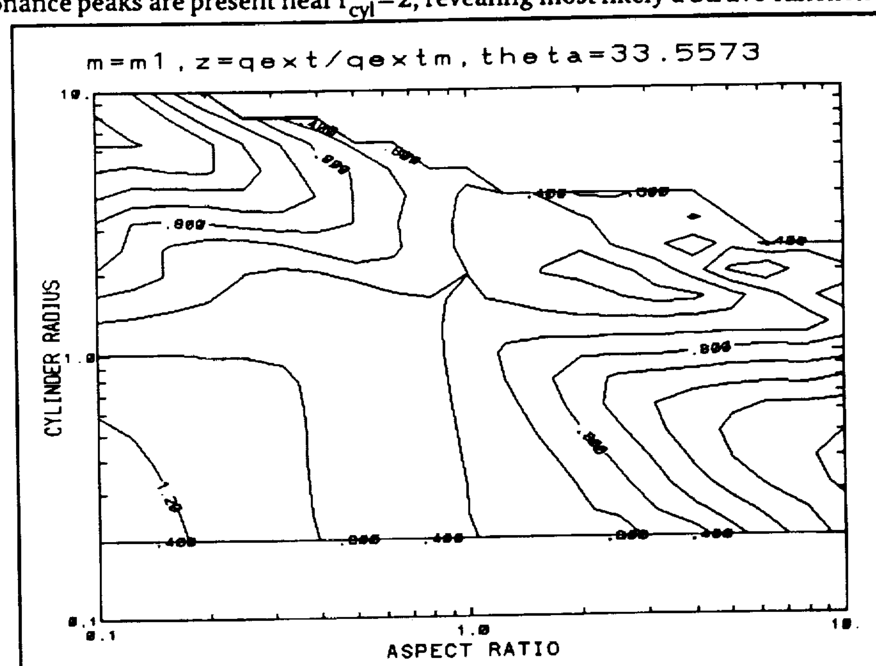

Figure 6. Same as figure 5 but for Θ=33.5573.

Figures 5 through 7 show ratios of traditionally normalized Q_{ext} values with respect to those of equivalent spheres. Here, in the same region around $r_{cyl}=10$, efficiencies which are much less than that of spheres are observed. A quick glance at figure 1 reveals that the $r_{cyl}=10$ resonance displayed in figures 2 through 4 occurs in a region in which a_{eff} is close to 4, where the Mie extinction profiles reach a maximum. Apparently the strong resonances in figures 2 through 4 are due to the disks behaving to some extent as Mie particles, behavior which translates into a large amount of extinction per unit length in the case of thin disks. In contrast, however, the peaks near $r_{cyl}=2$ are reiterated here, revealing that neither spherical nor infinite cylinder theory can explain their existence, and that they are most likely resonances associated with characteristic distances in the particle. What is most observable is a large degree of remarkable agreement between finite cylinders and spheres for a large range of aspect ratios, cylinder radii, incidence angles, and refractive indices. As would be expected, the region of agreement is centered around $\beta=1$ and improves slightly with the addition of absorption.

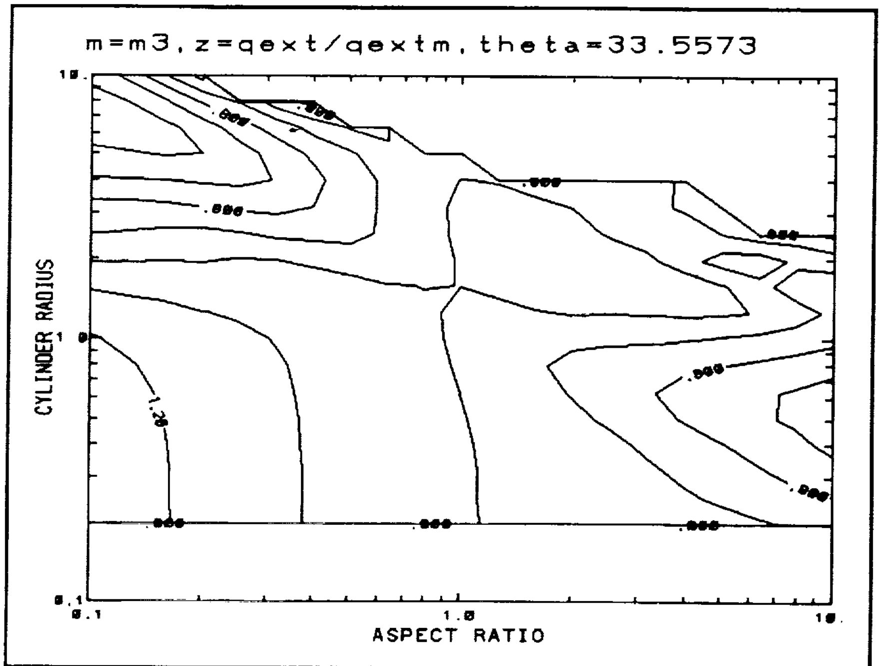

Figure 7. Same as figure 6, but for m=1.32 + .05i.

3.0 Conclusion

The agreement of extinction efficiencies between finite cylinders and spheres is remarkable especially at aspect ratios close to 1. This agreement subsides as β increases and the particle begins to behave like an infinite cylinder. This agreement also subsides as β becomes much less than 1. This agreement region shows a high sensitivity to incidence angle and a weak dependence on absorption. Infinite cylinder behavior is observed for nonabsorbing cylinders at normal incidence in some cases even when β is less than 1, but this agreement becomes more complex as incidence angles become oblique.

Acknowledgements

This research has been supported by The Office of Naval Research under Contract No. NOOO14-91-J-1422, P00002, National Aeronautics and Space Administration under Grant NAG 1-1146, and The Department of Energy, Contract No. DE-FG02-90ER60970. Acknowledgement is also made to the National Center for Atmospheric Research, which is sponsored by the National Science Foundation, for the computing time used in this research.

References

Bohren, C. F., and Huffman, D. R., Absorption and Scattering of Light by Small Particles, Wiley & Sons, 1983.

Flatau, P. J., Scattering by Irregular Particles in Anomalous Diffraction and Discrete Dipole Approximations, Colorado State University, Department of Atmospheric Science Paper Number 517, 140 pp.