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Reply

Validity of anomalous diffraction approximation in $m-\chi$ domain

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Abstract

In a recent paper, Liu et al. [Liu, C., Jonas, P.R., Saunders, C.P.R., 1996. Accuracy of the anomalous diffraction approximation to the light scattering by column-like ice crystals. Atmos. Res. 41, 63–69] reported that the anomalous diffraction approximation (ADA) accuracy is not sensitive to van de Hulst's condition $|m-1| \ll 1$, but is dependent on the size parameter χ. Videen and Chýlek [Videen, G., Chýlek, P., 1998. Anomalous diffraction approximation limits. Atmos. Res., this issue] pointed out that this result is at odds with previous research, and their results indicated that the accuracy of ADA is much dependent on the condition of $|m-1| \ll 1$. Some calculated results are presented here to provide further discussion of the ADA validity in the calculation of particle extinction and absorption efficiencies. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Anomalous diffraction approximation; Ice crystal; Extinction; Absorption

In the derivation of general particle extinction formula using anomalous diffraction approximation (ADA), van de Hulst (1981) pointed out that the condition $\chi \gg 1$ ($\chi = 2\pi r/\lambda$, r is particle radius and λ is the incident wavelength) means that the ray can be traced all through the particle, and the additional assumption that m is very close to 1 means that the ray suffers hardly any deviation at the two boundaries it crosses, so that it is virtually straight. These two assumptions are essential in theory, but they are hard to satisfy in reality. The error tolerance has to be carefully chosen for the ADA application. Based on these two assumptions, the extinction and absorption efficiencies for particles are derived and they are widely used in particle scattering property calculations (Farone and Robinson, 1968; Ackerman and Stephens, 1987; Chýlek and Videen, 1994). Liu et al. (1996) showed the insensitivity of the errors to the condition $|m-1| \ll 1$ when using ADA to calculate ice sphere extinction and absorption efficien-

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cies in wavelength ranging from 0.2 μm to 100 μm. Videen and Chýlek (1998) pointed out that this conclusion is at odds with a previous research. In order to carry out further discussion, the extinction and absorption efficiencies of ice spheres are calculated using ADA and Mie theory, respectively, for above wavelength range. The ice particle refractive indices are from Warren (1984). The error (e) can be defined as

$$e=\left|\frac{Q_{\mathrm{Mie}}-Q_{\mathrm{ADA}}}{Q_{\mathrm{Mie}}}\right|$$

where Q_{Mie} and Q_{ADA} may represent the extinction or absorption efficiencies calculated from Mie theory and ADA.

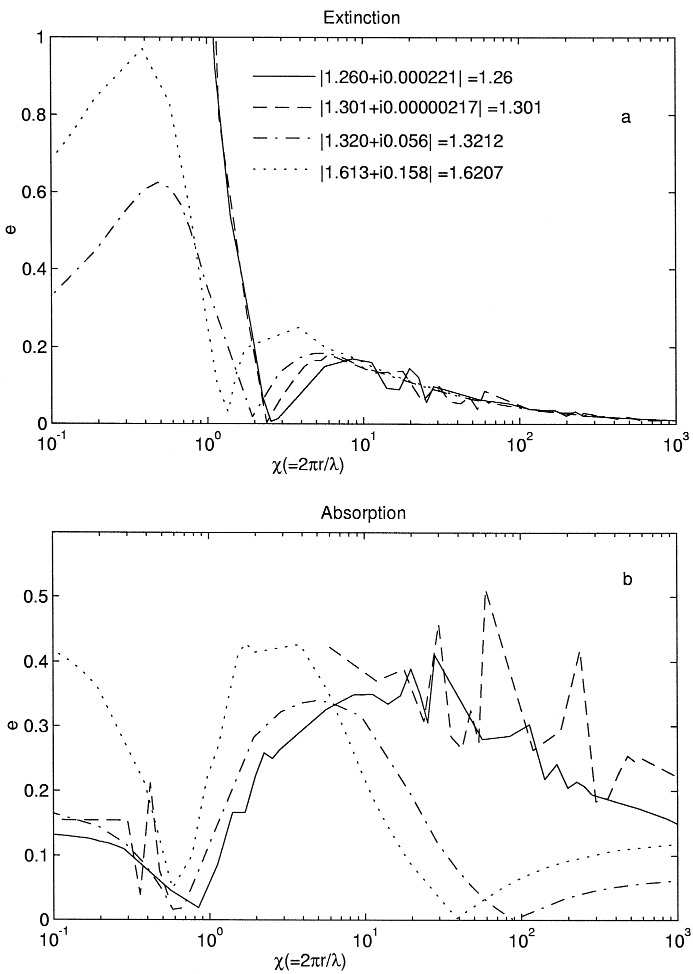

Fig. 1. Extinction and absorption error variations with particle size parameters for different particle refractive indices. (a) for extinction, (b) for absorption.

For the chosen particle refractive indices, the results of Videen and Chýlek (1998) indicated that the absorption error is sensitive to the soft sphere condition $|m-1| \ll 1$. Fig. 1 shows some results for different refractive indices. The absorption error shows different trends within different particle size parameter ranges. There is no consistent dependence on the soft sphere condition, and this will be further investigated in the following sections.

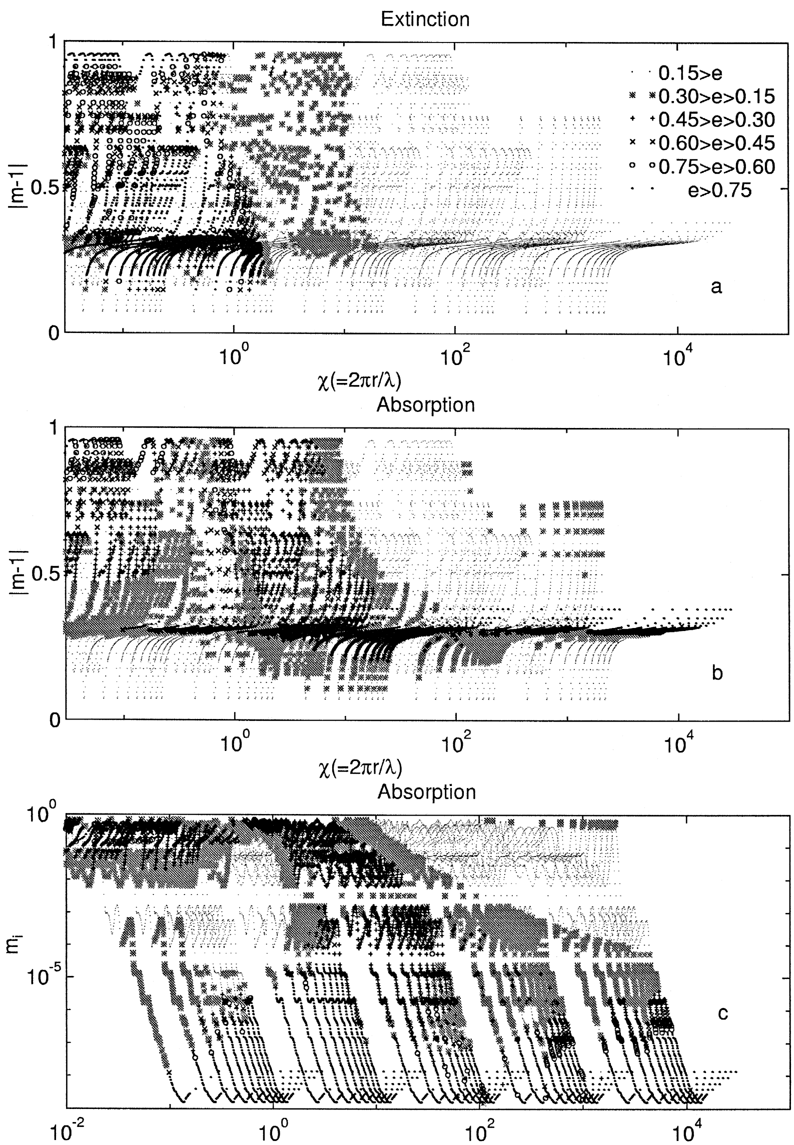

Fig. 2. Extinction and absorption error variations with particle refractive index and particle size parameter. (a) is for extinction, (b) and (c) are for absorption.

For spherical particles, ADA and Mie results depend upon both the particle size parameter χ and the particle refractive index m. In order to see the validity of ADA, similar to calculations of Farone and Robinson (1968) and Ackerman and Stephens (1987), the errors are investigated in $m-\chi$ domain. In the calculations, there are 371 wavelength data points covering wavelength range from 0.2 μm to 100 μm, and 46 particle size parameter data points covering χ values from 10^{-2} to 10^{4} which covers both Mie and optical regions. Due to large variation of ice refractive index within this

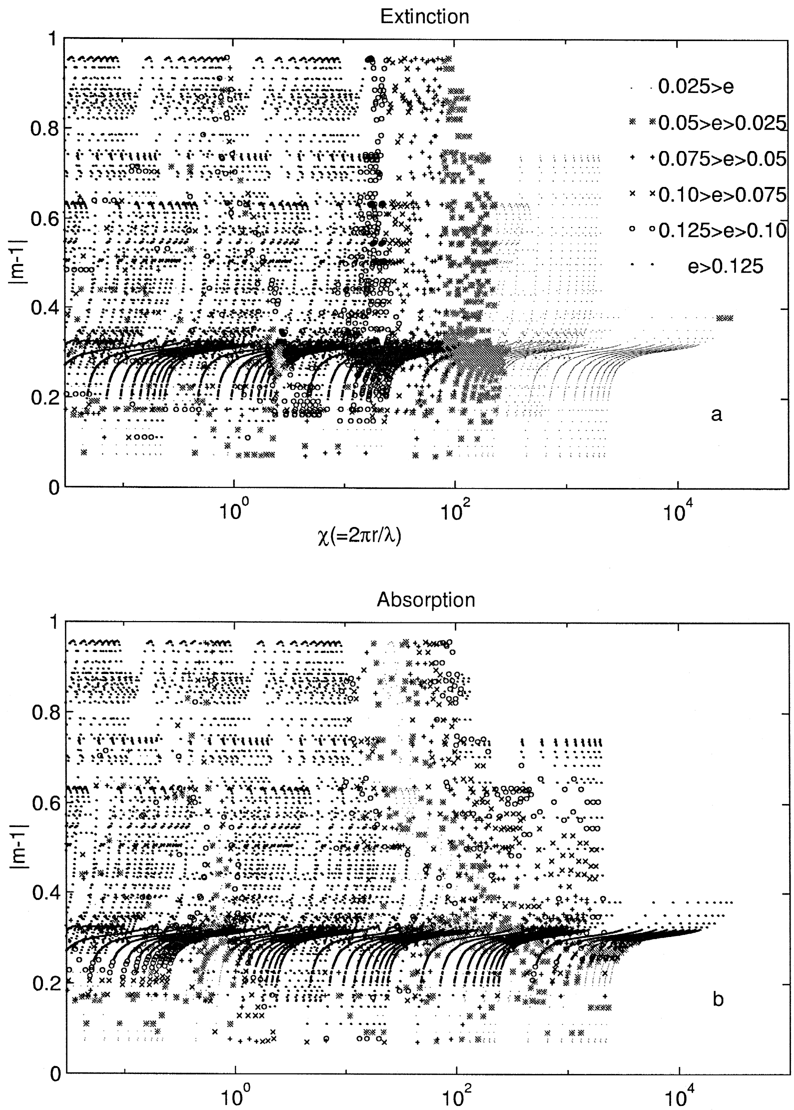

Fig. 3. As Fig. 2, but for small error divisions.

wavelength range, m values also cover large portions of the applied cases in the real world. Fig. 2 is the plot of errors which are divided into six regions. Panel (a) is the error of the extinction efficiency, it can be seen that when $\chi > 10$, the particle size parameter is near optical region, the error is $< 15\%$ throughout the whole m range, this case is explained by Videen and Chýlek (1998). When $10 > \chi > 1$ and $|m-1| > 0.25$, most of the errors are between 15–30%. The error is mixed in small χ region. Panel (b) is for the absorption, similar structures are found, but around $|m-1| = 0.3$ (from about 0.2 to 0.4), there is a band where the error is too large to be applied in real situation. Except for this band, for $\chi > 1$, the whole trend is that the error decreases as χ increases. Fig. 2a,b indicates that there are obvious band structures in χ direction, but there are no obvious band structures in $|m-1|$ direction. For $|m-1| < 0.2$, all

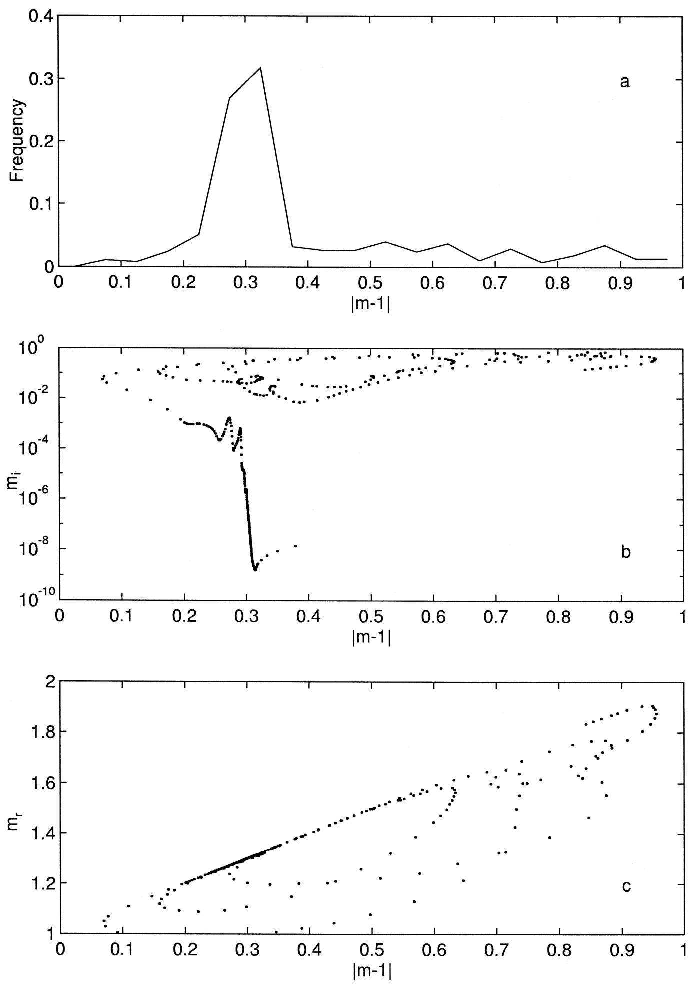

Fig. 4. (a) Is the frequency of $|m-1|$ values; (b) is the m_i variation with $|m-1|$, and (c) is for m_r.

extinction errors are less than 15%, and for $|m-1|<0.1$, all absorption errors are less than 15%.

Because the real (m_r) and imaginary (m_i) parts of the particle refractive index have different effect on the position of error regions, the absorption error variations with χ and m_i are plotted in panel (c) of Fig. 2. For large m_i and large χ, due to strong absorption, the absorption efficiency is near 1, so the error is small. For large χ, there is a tilted band structure in m_i direction. It is noticed that there is a large error region when $m_i < 10^{-7}$, and this area is independent of the particle size parameter.

Fig. 3 is the fine structure of Fig. 2, errors are divided into six bands, as shown in the figure legend. For extinction (panel a), the band structures along χ direction are very obvious, but there are no clear structures along the $|m-1|$ direction. For absorption's case, the large error region around $|m-1|=0.3$ is the main feature. The error band structure is tilted.

For further investigation of the m effect on the error, the frequency distribution of $|m-1|$ values is plotted in panel (a) of Fig. 4. It can be seen that most of the data points are populated around $|m-1|=0.3$. Panel (b) shows that m_i varies dramatically in this region while m_r in panel (c) is nearly constant. Compared with Fig. 2, it is found that the large error region around $|m-1|=0.3$ in absorption efficiency is mainly due to small m_i values.

From our analysis, it is clear that the ADA error is consistent sensitive to particle size parameter χ, rather than $|m-1|$ values in the $m-\chi$ domain considered in our analysis. The imaginary part plays an important role in the determination of the error region. Of course, this is only for limited cases, when the entire wavelength range is used and a different error tolerance is chosen, we may see more structures.

Acknowledgements

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