Influence of Alignment on the Scattering Properties Atmospheric Mineral Dust

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Abstract

We carry out an investigation of the influence of particle alignment on the scattering properties of mineral dust layers. Our modelling indicates that in addition to modifying optical thickness, the alignment can significantly alter the scattering properties, including polarization. Influence of the alignment on remote sensing retrievals is also examined, and it is concluded that satellite and to a lesser extent sun photometry retrievals would be significantly affected.

1 Introduction

Mineral dust in the atmosphere exerts significant indirect influence on radiation by acting as a source of efficient nuclei for cloud formation, modifies both the shortwave and the longwave radiation, and is a major source of nutrients in the marine environment. There is also growing evidence that Saharan dust outbreaks may be reducing Atlantic hurricane activity. Consequently, much effort has been directed at the development of global-scale measurement of aerosol properties, including both satellite and ground-based instruments such as sun photometers and lidar [1,2].

Recent polarimetric observations of atmospheric Saharan dust have provided strong evidence for the presence of vertically aligned particles [3]. The observations, using a high-sensitivity astronomical polarimeter PlanetPol, which achieves fractional polarization sensitivities better than 10^{-6} with an absolute accuracy of about 1% [4], showed ~50 ppm excess of horizontal polarization of transmitted starlight in the presence of Saharan dust over La Palma, Canary Islands in May 2005. At present no other explanation exists for this measurement, despite extensive checks [3,5]. The alignment is thought to be due to a vertical electric field of the order of a kV/m, present probably because of dust charging. It was concluded that partial alignment of larger grains was likely to be a common feature of atmospheric mineral dust layers. For the observed case, shortwave optical thickness in the vertical direction was estimated to change by between 5 and 10% due to the alignment – a "Venetian blind effect". It was also suggested that the electric field associated with the alignment might modify dust transport by aiding the retention of larger particles within the dust layer [3].

Here we present the results of initial investigations of the influence of the postulated alignment on the scattering properties of mineral dust layers, starting with the case of the aerosol observed over La Palma. We investigate the angular dependence of scattering and the degree of linear polarization, and examine the potential impact on remote sensing retrievals of dust properties.

2 Scattering computations

Scattering calculations were done for prolate spheroids of aspect ratio 1.5. Dust size distributions and refractive index (1.46 – *i*0.006) were obtained for the dates of the dust event from the AERONET sun photometer in Santa Cruz Level 1.5 data (http://aeronet.gsfc.nasa.gov) using the spheroidal particle retrieval method of Dubovik et al. [2]. Additional screening was applied (number of measurements > 20, zenith angle between 25 and 77°). The size distributions were combined with size-dependent orientation distributions, calculated for various electric field strengths [3], to compute elements of the scattering matrix using the T-matrix program developed by Mishchenko [6]. Wavelength of 780 nm was used and vertical (zenith) incidence was assumed. Molecular scattering was not included.

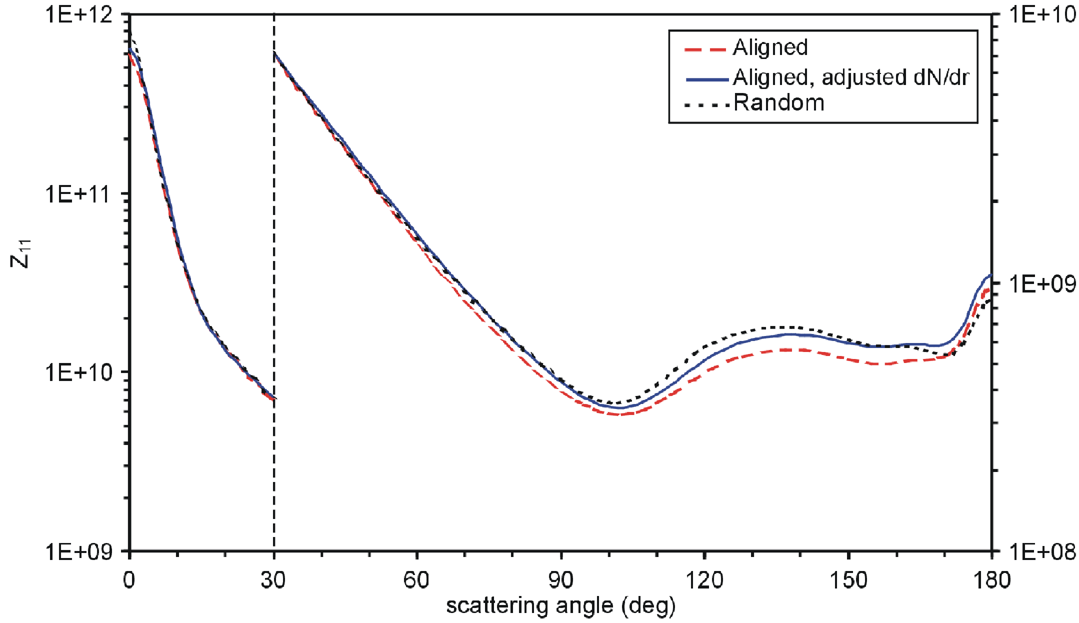

Fig. 1: Unnormalized phase functions computed for the AERONET size distribution on 4 May 2005, with (dashed line) and without the alignment (dotted line), and "aligned" phase function optimized to give best fit to the "random" (non-aligned) one by adjusting the distribution (solid line).

Figure 1 shows the phase function computed for the AERONET size distribution with and without the alignment. It can be seen that significant differences are present, mostly at larger angles. Thus partially aligned dust is estimated to scatter up to 27% less in the forward region, up to 20% less near 120°, and 10% more in backscattering, compared to non-aligned dust, during the La Palma episode. These differences may influence satellite retrievals for some viewing geometries, e.g MISR. However, most of the angular region where sun photometers operate was less strongly affected, with the exception of scattering angles towards 120°.

Since the AERONET size distribution was retrieved on the usual assumption of random alignment, we carried out a computational experiment to determine retrieval sensitivity to alignment. We computed a new phase function with the assumption of partial alignment (field strength of 1600 V/m) but with size distribution optimized to give best least squares fit between the new "partial alignement" and the old "random alignment" phase functions. While only imperfect fit could be obtained – see Figure 1 – the change in the size distribution was substantial. Both the coarse mode and the region centered on 100 nm radius were enhanced, while the mode near 400 nm radius was depleted – see Figure 2. Also, in this example the optical thickness was <0.3. Since the strength of the alignment is expected to increase with the amount of dust, and many dust episodes show higher thickness, the impact can be much greater.

Figure 3 shows the degree of linear polarization (DLP) computed for the AERONET size distribution with and without the alignment. Polarization changes due to alignment are seen to be significant, particularly at larger angles. A similar distribution optimization procedure was used to modify the DLP curves. However, in contrast to the phase function case, it was not possible to force the DLP for aligned dust to adopt a shape characteristic of the "random" DLP. This indicates that the DLP may provide a characteristic signature of alignment, although arguably not as unique as that of polarized extinction. This also suggests that mineral dust retrievals from satellite polarimeters like POLDER/PARASOL or GLORY-APS [1] may not become convergent unless alignment is assumed. In this context, it may be relevant that, qualitatively, the changes in the DLP caused by the alignment are similar in magnitude to those due the removal of a third of the size distribution by volume, for example [7]. Since it has been argued that retrieval algorithms based on radiance measurements alone cannot provide sufficient retrieval accuracy for aerosols [8], the existence of alignment could mean that the only available option is to combine alignment-based algorithms with polarimetry. However, it appears that the main obstacle at present is the lack of fast vector radiative transfer codes capable of including aligned particles. Such codes are increasingly used in astronomy, where speed of computation is of secondary importance [9,10] but are absent from atmospheric science.

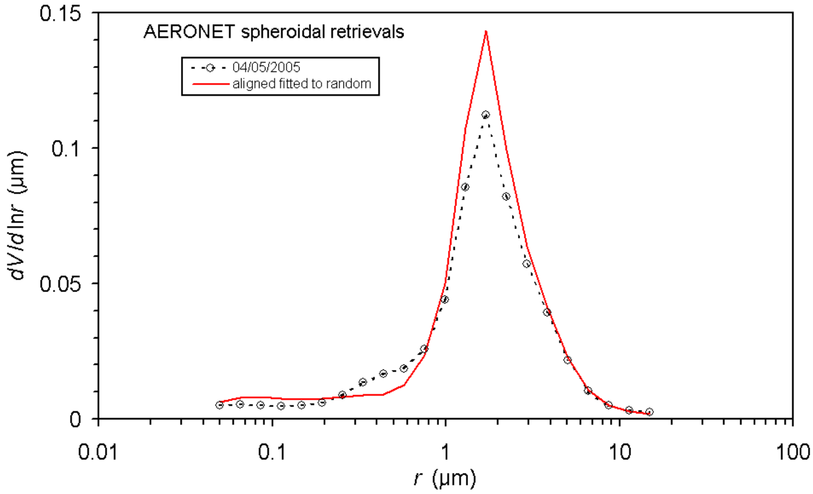

Fig. 2: AERONET size distribution for the La Palma dust on 4 May 2005 (dotted line with circles), and distribution optimized so that the "aligned particle" phase function computed from it gave best fit to the "random" (non-aligned) phase function for the original size distribution (solid line) – Fig. 2.

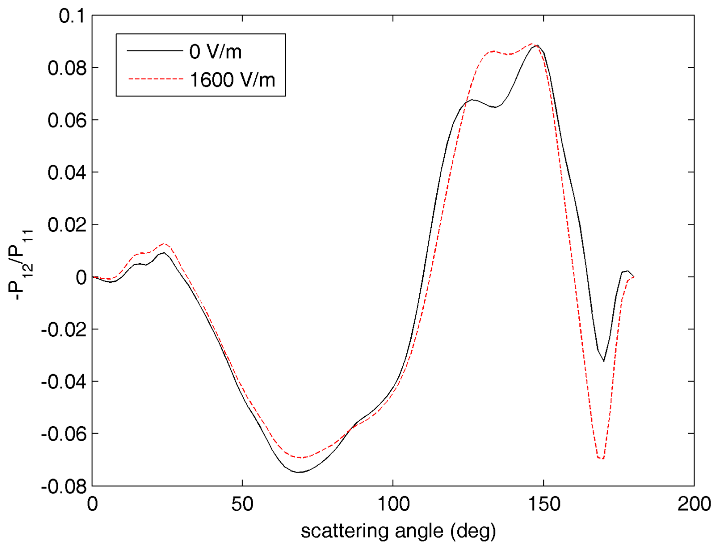

Fig. 3: Degree of linear polarization (DLP) computed for the AERONET size distribution without (0 V/m field, solid line) and with (1600 V/m field, dashed line) the alignment.

3 Conclusions

Polarimetry of transmitted starlight, showing ~50 ppm excess of horizontal polarization in the presence of

Saharan dust, indicates the presence of vertically aligned particles in the atmosphere. Significance of the alignment from the point of view of scattering properties can be summarised as follows:

- Change in optical thickness, particularly for zenith (vertical) incidence;
- Change in phase function - may affect satellite retrievals and to a smaller extent sun photometers;
- Change in polarization - may affect polarimeters, e.g. POLDER/PARASOL and GLORY-APS [1].

Consequently, if the alignment is shown to be widespread, future remote sensing retrieval algorithms for mineral dust, most notably those applied to polarimetry [8], may have to be capable of handling aligned particles.

These conclusions apply to retrievals for sun at the zenith. Also, for these preliminary studies prolate spheroids have been used, while it has been demonstrated that mixtures of prolate and oblate spheroids improve the quality of mineral retrievals from sun photometers [2]. Furthermore, a single-scattering model has been applied, in the absence of fast radiative transfer codes capable of dealing with aligned particles and polarization. Future modelling studies should address these shortcomings. Likewise, further polarimetric measurements, ideally accompanied by measurements of electrical properties and lidar sounding, are needed to answer questions concerning the precise origin, magnitude and extent of the phenomenon investigated here.

Acknowledgments

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