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# Impact of particle nonsphericity on the development and properties of aerosol models for East Asia

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## HIGHLIGHTS

- Impact of particle nonsphericity on the aerosol models clustering is studied.
- Aerosol models exhibit significant changes considering the shape information.
- Difference of aerosol models due to shape affects the aerosol remote sensing.

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## ABSTRACT

In this paper, the effects of aerosol nonsphericity information on the classification of aerosol models and the associated radiative properties over East Asia are investigated. The radiance measurements and inversions of the Aerosol Robotic Network (AERONET) are used. Four aerosol models over East Asia are obtained by adding the shape information to the clustering analysis. These four aerosols are identified on the basis of their optical properties. Compared to the results without sphericity parameter, adding the sphericity parameter in the clustering process contributes to the extraction of a strongly absorbing aerosol. Furthermore, the effect of the physical and optical properties of the aerosol on the top of atmospheric (TOA) total reflectance and polarized reflectance are investigated. The results indicate that the addition of the sphericity parameter in the clustering process leads to a change in the total reflectance by up to 16% and a change in the polarized reflectance by up to 100%.

## 1. Introduction

Aerosols play a significant role in climate change by directly interacting with atmospheric radiation and by indirectly modifying cloud optical properties and persistence. The uncertainty in quantifying the climatic impacts of aerosols continues to be greater than that of greenhouse gases (Solomon, 2007) due to the variety of sources, varying trends in aerosol loading and extreme heterogeneity in the spatial and temporal variability of their optical and microphysical properties (Morgan et al., 2006; Kaskaoutis et al., 2007). Reducing the uncertainties of aerosol radiative impacts requires integrated aerosol measurements and theoretical analysis to characterize various aerosol models and sources.

Various aerosol types have different effects on solar radiation (Kaskaoutis and Kambezidis, 2008) and on the sign and magnitude of the aerosol radiative forcing (Satheesh and Krishna Moorthy, 2005). For example, the presence of absorbing aerosols, such as black carbon, can change the sign of the forcing from negative to positive (Heintzenberg et al., 1997). Each aerosol model considers specific particle sizes and shapes and depends on sources, emission rates, transport, chemical reactions and removal mechanisms (Chin et al., 2002; Park, 2004). The scattering and absorption properties of different aerosol models are highly uncertain. To clarify the mechanisms of aerosol radiative forcing and to improve the accuracy of aerosol remote sensing retrieval, it is critical to use the proper aerosol models.

In recent years, a number of studies have been performed to categorize the aerosol models into global or regional scales based on ground and satellite observations. Compared to satellite remote sensing, ground-based aerosol observations provide wide angular and spectral measurements of solar and sky radiation and are best suited to continuously derive the detailed aerosol optical

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properties in key locations (Dubovik et al., 2002). Omar et al. (2005) developed global aerosol models via cluster analysis of approximately 250 Aerosol Robotic Network (AERONET) sites globally. Six significant clusters with distinct microphysical and optical properties are identified as desert dust, biomass burning, urban industrial pollution, rural background, polluted marine and dirty pollution. Qin et al. (2009) classified the Australian continental aerosol models via hierarchical cluster analysis of optical properties obtained from AERONET data at Australian aerosol ground stations over the last decade. Four classes are identified: aged smoke, fresh smoke, coarse dust and super-absorptive aerosols. Lee and Kim, 2010 developed type-specific aerosol models that include aerosol microphysics and optical properties. Although much attention has been paid to global and regional aerosol models and their corresponding microphysics and optical properties, information on particle shape effects in the development of aerosol models is still limited.

Tropospheric aerosols have a large variety of shapes. Analyses of laboratory measurements and in situ data using scanning electron microscopes reveal that the mineral dust and carbonaceous soot particles have complex morphologies, rather than homogeneous spheres (Adachi et al., 2007; Borghese et al., 1984). It has become universally recognized that the nonsphericity of particles has a profound effect on their scattering and absorption properties (Mishchenko, 2009). Particle nonsphericity has been considered in both aerosol particle modeling and remote sensing applications during the last two decades (Bohren and Singham, 1991; Cheng et al., 2010; Derimian et al., 2012; Feng et al., 2009; Ginoux, 2003; Yang et al., 2007). Dubovik et al. (2006) utilized the spheroid model to reproduce mineral dust light scattering matrices and retrieved detailed aerosol properties measured by AERONET ground-based sun/sky radiometers. The nonsphericity of aerosol particles (%sphericity) can be obtained as part of AERONET retrievals (Dubovik et al., 2006).

With the population increase, industrialization and demands for energy, the aerosol load in East Asia is gradually increasing and having significant impacts on the continuation of solar dimming (Badarinath et al., 2010). In East Asia, aerosols vary greatly in composition, shape and size and have a significant effect on the atmospheric radiation budget. Although much attention has been paid to this issue, information on the aerosol properties and their spatial and temporal variation is still limited. Thus, a systematic study is required to clarify the particle shape effect on the optical properties of different aerosol models and to improve our knowledge of East Asia aerosol radiation effects.

In this paper, the effects of aerosol shape on the development of aerosol models over East Asia are studied via cluster analysis. The optical and microphysical properties of aerosols are obtained from radiance measurements and inversion data at 19 AERONET stations. To quantify the shape effect on the properties of various aerosol models, the corresponding optical properties of clustering results without the shape parameter are presented for comparison.

In section 2, the AERONET site distribution and methodology of aerosol classification are briefly introduced. The clustering results and aerosol nonsphericity parameter in relation to the optical properties of various aerosol classes are presented in section 3. The aerosol particle shape impact on the TOA total/polarized reflectance is provided in section 4. In this section, the method used by Cheng et al. (2010) is referred to investigate the sensitivity of TOA total reflectance and polarized reflectance to different aerosol models.

## 2. Clustering classification

### 2.1. Data selection

Measurements of sun and sky radiances observed in the solar almucantar at the AERONET network (Holben et al., 1998) are used to estimate detailed aerosol properties (e.g., the aerosol size distribution, the complex refractive index, the single scattering albedo (SSA), the sphericity, the phase function and absorption properties). The latest retrievals scheme (Dubovik et al., 2006) assumes that the aerosol is a mixture of spherical and non-spherical aerosol components and estimates the fraction that is non-spherical. The modeling is performed using kernel lookup tables of quadrature coefficients employed in the numerical integration of spheroid optical properties over size and shape (see the work of Dubovik et al., 2006). The AERONET data are provided as three categories; cloud-screened and quality-assured “Level 2 Inversion All Points” data are used in this paper.

The locations of the AERONET sites are shown in Table 1. According to Omar et al. (2005), unique aerosol models are identified by parameters that represent aerosol size and absorption. However, as the aerosol particle shape is important in climate studies and in remote sensing of the environment (Gobbi et al., 2002; Kahnert et al., 2007), there is sufficient motivation to consider the degree of non-sphericity of the aerosols. Thus, the following parameters that comprise the optical and physical properties retrieved from AERONET inversion algorithms are chosen in the clustering analysis:

**Table 1**
AERONET site distribution.

| Country | Site name | Lon/Lat | Observation Period | Number of records |
|---|---|---|---|---|
| China | Beijing | 116.38/39.98 | 2001.3−2012.8 | 2280 |
| | Cheng-Kung_Univ | 120.22/23.00 | 2002.3−2012.3 | 1154 |
| | EPA-NCU | 121.19/24.97 | 2006.7−2011.12 | 798 |
| | Hefei | 117.16/31.91 | 2005.11−2008.11 | 175 |
| | Hong_Kong_Polyu | 114.18/22.30 | 2005.11−2011.10 | 240 |
| | Hong_Kong_Hok_Tsui | 114.26/22.21 | 2007.11−2010.7 | 338 |
| | Lulin | 120.87/23.47 | 2007.3−2011.11 | 175 |
| | NCU_Taiwan | 121.19/24.97 | 1998.4−2012.5 | 704 |
| | Taihu | 120.22/31.42 | 2005.9−2012.10 | 1716 |
| | XiangHe | 116.96/39.75 | 2001.3−2001.4;<br>2004.9−2012.5 | 2282 |
| | Xinglong | 117.58/40.37 | 2006.2−2008.5;<br>2010.8−2012.5 | 363 |
| | Yulin | 109.72/38.28 | 2001.4−2002.10 | 173 |
| Japan | Noto | 137.14/37.33 | 2001.4−2010.12 | 553 |
| | Osaka | 135.59/34.65 | 2001.11−2011.11 | 1051 |
| | Shirahama | 135.36/33.69 | 2000.10−2010.11 | 3807 |
| Korea | Anmyon | 126.33/36.54 | 1999.10−2007.11 | 1541 |
| | Gosan_SNU | 126.16/33.29 | 2001.4−2011.6 | 673 |
| | Gwangju_GIST | 126.84/35.23 | 2004.2−2011.11 | 818 |
| | Seoul_SNU | 126.95/37.46 | 2000.11−2003.2 | 252 |