

RETRIEVAL OF AEROSOL MICROPHYSICAL PROPERTIES FROM THE AERONET
PHOTO-POLARIMETRIC MEASUREMENTS

by

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Atmospheric aerosols play a crucial role in the global climate change. They affect earth energy budget directly by scattering and absorbing solar and terrestrial radiation, and indirectly through altering the cloud formation, lifetime, and radiative properties [Haywood and Boucher, 2000; Ramanathan *et al.*, 2001]. However, quantification of these effects in the current climate models is fraught with uncertainties. The global average of aerosol effective radiative forcing were estimated to range from -0.1 to -1.9 Wm^{-2} with the best estimate of -0.9 Wm^{-2} [Boucher *et al.*, 2013], indicating that the cooling effects of aerosol might counteract the warming effects of $1.82 \pm 0.19 \text{ Wm}^{-2}$ caused by the increase of carbon dioxide since the industrial revolution [Myhre *et al.*, 2013]. The climate effects of aerosol particles depend on their geographical distribution, optical properties, and efficiency as cloud condensation nuclei and ice nuclei. Key quantities pertain to the aerosol optical and cloud-forming properties include particle size distribution (PSD), chemical composition, mixing state, and morphology [Boucher *et al.*, 2013]. While the daily aerosol optical depth (AOD) can be well measured from current satellite and ground-based remote sensing instrumentations [e.g., Holben *et al.*, 1998; Kaufman *et al.*, 2002], the accurate quantification of aerosol ERF is in no small part hindered by our limited knowledge about the aerosol PSD and refractive index (describing chemical composition and mixing state).

To fully understand the role of aerosol particles in the global climate change, further development in observations along with retrieval algorithms for these aerosol microphysical properties from different platforms are thus highly needed [*Mishchenko et al.*, 2004], and the focus of this two-part series study is the characterization of aerosol properties from ground-based passive remote sensing.

1.1.1 Previous studies on aerosol microphysical retrievals

There have been continuous efforts in determining aerosol microphysical properties from ground-based measurements of direct and/or diffuse solar radiation since *Ångström* [1929] first suggested an empirical relationship between the spectral dependency of extinction coefficients and the size of aerosol particles. Over thirty years later, *Curcio* [1961] inferred the aerosol PSD from the spectral particulate extinction coefficients in the visible and near-infrared regions. Soon with the effective numerical inversion technique developed by *Phillips* [1962] and *Twomey* [1963] specifically for error-involved optimization, a number of studies explored the use of either spectral attenuations or scattered radiances (in a small range of scattering angles) to determine the aerosol PSD [*Twomey and Howell*, 1967; *Yamamoto and Tanaka*, 1969; *Dave*, 1971; *Grassl*, 1971; *Herman et al.*, 1971; *King et al.*, 1978]. *Shaw* [1979] and *Nakajima et al.* [1983] were among the first studies that have combined optical scattering measurements with spectral extinctions to recover particle size spectrum. *Kaufman et al.* [1994] suggested useful information contained in the sky radiances of larger scattering angles to retrieve the aerosol scattering phase function and PSD. The first operational retrieval algorithm for aerosol microphysical properties was introduced by *Nakajima et al.* [1996], when the multi-band automatic sun- and sky-scanning radiometer was deployed in the AErosol RObotic NETwork, or the AERONET [*Holben et al.*, 1998]. All of above mentioned methods treated aerosol particles as homogeneous

spheres and with refractive index assumed a priori, even though the refractive index can highly impact the optical, especially the scattering characteristics [*Hansen and Travis*, 1974]. *Tanaka et al.* [1982, 1983] developed an inversion library method to estimate the complex refractive index and PSD simultaneously from measurements of scattered radiances polarized in the perpendicular and parallel directions. Another concept for determining refractive index from both direct and diffuse angular radiances was developed by *Wendisch and Von Hoyningen-Huene* [1994] and *Yamasoe et al.* [1998], which were based on the fact that sensitivities of scattered radiances to the PSD and those to the refractive index are dominated on different scattering-angular regions. The current AERONET operational inversion algorithm was developed by *Dubovik and King* [2000], which has heritage from algorithms developed by *King et al.* [1978] and *Nakajima et al.* [1983, 1996] but was implemented for simultaneous retrieval of particle size distribution and complex refractive index with sophisticated inclusion of multiple a priori constraints. *Dubovik et al.* [2002, 2006] further implemented the spheroids in the particle shape consideration for desert dust in the retrieval, and added fractional volume of non-spherical particles to the inversion products.

1.1.2 The AERONET measurements

With over 400 locations around the world, most AERONET sites are equipped with an automatic sun and sky scanning spectral radiometer, or the CIMEL-318 type SunPhotometer, to measure direct and diffuse solar radiation in various atmospheric window channels [*Holben et al.*, 1998]. Direct sun radiances at various atmospheric window channels from the ultra-violet (UV) to near infrared are used to infer the spectral AODs with the Beer-Lambert-Bouguer Law [*Holben et al.*, 1998; *Smirnov et al.*, 2000].

1.1.3 Challenges and opportunities

1.2 Objectives

1.3 Organization

CHAPTER 2

MODEL DEVELOPMENTS

2.1 Introduction

The radiation fields—radiance and the state of polarization—measured by the remote sensing instruments are the outcome of the interactions of solar radiation with various physical processes including the absorption and scattering by atmospheric molecules, aerosols and clouds, as well the reflection and absorption by underlying surface. The radiance and polarization of light at

2.2 The UNL-VRM

2.2.1 Surface representations

2.2.2 Molecular scattering and absorption

2.2.3 Aerosol single scattering

2.2.4 Radiative transfer

2.2.5 Capability of calculating Jacobians

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3.4.2.2 Refractive indices

3.4.2.3 Single scattering albedo

To be filled ...

3.5 Sensitivity of retrieval error to AOD and fmf

To be filled ...

3.6 Summary

To be filled ...

CHAPTER 4

INVERSION ALGORITHM

4.1 General sturcture

Basic formulation of inverse problem; sturcture of the algorithm.

4.2 Combine a priori and smoothness constraints

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APPENDIX A

ABBREVIATIONS AND ACRONYMS

APPENDIX B

SYMBOLS

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LIST OF PUBLICATIONS

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