ADJOINT INVERSION OF ATMOSPHERIC DUST SOURCES FROM MULTI-SENSOR SATELLITE OBSERVATIONS

by

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University of Nebraska, 2015

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Abstract to be filled ...

DEDICATION

To my parents, wife, sons, and friends for providing the unwavering encouragement and support that allowed me to accomplish my goal.

ACKNOWLEDGMENTS

Arma virumque cano, Troiae qui primus ab oris Italiam, fato profugus, Laviniaque venit litora, multum ille et terris iactatus et alto vi superum saevae memorem Iunonis ob iram; multa quoque et bello passus, dum conderet urbem, inferretque deos Latio, genus unde Latinum, Albanique patres, atque altae moenia Romae.

GRANT INFORMATION

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

1.1.1 Impacts of Atmospheric Dust Aerosol

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 (ERF) were estimated to range from -0.1 to -1.9 Wm2 with the best estimate of -0.9 Wm2 [Boucher et al., 2013], indicating that the cooling effects of aerosol might counteract the warming effects of 1.820.19 Wm2 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 (CCN). 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

[2] have investigated ...

1.2 Objectives

1.3 Organization of This Dissertation

CHAPTER 2

MODELING OF ATMOSPHERIC DUST

2.1 Modeling of Dust Emission

2.1.1 Development of the Wind Speed Distribution

In order to incorporate the variability of wind speed due to the subgrid scale circulations, we introduce a probability density function (PDF) of the wind speed within each grid box. The dust emission is computed according to the fraction of the PDF that exceeds the threshold value:

$$E_d = \int_{u_{*t}}^{\infty} E(u_*)p(u_*)du_*. \tag{2.1}$$

Where $E(u_*)$ is the emission as a function of the surface wind friction velocity, and $p(u_*)$ is the PDF of u_* within the grid box.

The PDF for surface wind speeds can be represented by a Weibull distribution [Justus et al., 1978] and has been used in recent studies [e.g., Grini and Zender, 2004; Grini et al., 2005; Ridley et al., 2013] to charaterize the subgrid dust emissions. The PDF of a Weibull random variable x is described by a shape factor k and a scale factor c:

$$p(x;c,k) = \frac{k}{c}(x/c)^{k-1}\exp\left[-(x/c)^k\right], \text{ for } x > 0. \tag{2.2}$$

One of the advantages in using the Weibull PDF is that it is analytically integrable with the cumulative distribution function:

$$P(x \leq x_1; c, k) = 1 - \exp\left[-(x/c)^k\right]. \tag{2.3}$$

Based on above cumulative function, we cut off wind speeds with a minimum and a maximum wind speed to retain the central 95% of the wind PDF. As a result, the lower and upper limits of wind speed are respectively:

$$x_l = c\,[\ln 0.975]^{-k} \tag{2.4}$$

$$x_u = c\,[\ln 0.025]^{-k} \tag{2.5}$$

Parameters k and c can be estimated from the statistical mean $\bar{x}$ and variance σ^2 (of x), since they are related to $\bar{x}$ and σ^2:

$$\bar{x} = c\Gamma(1+1/k) \tag{2.6}$$

$$\sigma^2 = c^2\left[\Gamma(1+2/k) - \Gamma^2(1+1/k)\right] \tag{2.7}$$

Where $\Gamma()$ is a gamma function. According to Justus et al. [1978], k and c can be best estimated by:

$$k = (\sigma/\bar{x})^{-1.086} \tag{2.8}$$

$$c = \bar{x}\,[\Gamma(1+1/k)]^{-1} \tag{2.9}$$

Thus, the only parameter that must be supplied beyound the mean wind speed is the variance (σ^2) of subgrid wind speeds within the grid box. Cakmur et al [2004] calculated the σ^2 by incorporating information from the parameterizations of the planetary boundary layer along with dry and moist convection. Here, we follow Grini and Zender [2004] and Grini et al [2005] that assumed an approximation of k based on Justus et al. [1978]:

$$k = 0.94u_*^{\frac{1}{2}} \tag{2.10}$$

Finally, the dust emission flux is calculated by

$$E_d = A_m S' \left(\sum_{i=1}^{3} M_{i,j}\right) \frac{c_q}{0.95} \int_{u_{*t}}^{u_{*u}} u_*^b \left(1 - \frac{u_{*t}}{u_*}\right) \left(1 + \frac{u_{*t}}{u_*}\right)^2 p(u_*) du_*. \tag{2.11}$$

Where u_{*u} is the upper limit of wind speed determined by equation 2.5.

2.2 Modeling of Dust Transport and Deposition

CHAPTER 3

ADJOINT MODELING DEVELOPMENT

3.1 GEOS-Chem Adjoint

3.2 Implement Adjoint of DEAD

According to the physical processes described in the section xxx, the total vertical mass flux of dust into transport bin j is

$$E_{d,j} = \begin{cases} A_m S' c_q u_*^b \left(1 - \frac{u_{*t}}{u_*}\right)\left(1 + \frac{u_{*t}}{u_*}\right)^2 \sum_{i=1}^{3} M_{i,j} & \text{if } u_* \geq u_{*t}, \\ 0 & \text{if } u_* < u_{*t}. \end{cases} \tag{3.1}$$

Where $S' = S\alpha$, c_q is the constant ($= \frac{c_s \rho_a ir}{g}$), and b is the exponential order, which is 3 in White [1979].

Here we implement the adjoint calculation for three parameters, i.e., S', b, and u_{*t}. This implementation reqiures the partial derivatives of $E_{d,j}$ with respect to these parameters (when $u_* \geq u_{*t}$):

$$\frac{\partial E_{d,j}}{\partial S'} = \frac{E_{d,j}}{S'}, \tag{3.2}$$

$$\frac{\partial E_{d,j}}{\partial b} = E_{d,j} \ln u_*, \tag{3.3}$$

$$\frac{\partial E_{d,j}}{\partial u_{*t}} = C_j \left[\frac{1}{u_*} - \frac{2u_{*t}}{u_*^2} + \frac{3u_{*t}^2}{u_*^3} \right]. \tag{3.4}$$

Where C_j represents $A_m S' c_q u_*^b \sum_{i=1}^{3} M_{i,j}$.

CHAPTER 4

SOME TABLES AND FIGURES

First	Last
Ned	Hummel
Ned	Hummel
Ned	Hummel

Table 4.1: Arma virumque cano, Troiae qui primus ab oris Italiam, fato profugus, Laviniaque venit litora, multum ille et terris iactatus et alto vi superum saevae memorem Iunonis ob iram

✓ Foo
✓ Foo
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Table 4.2: Arma virumque cano, Troiae qui primus ab oris Italiam, fato profugus, Laviniaque venit litora, multum ille et terris iactatus et alto vi superum saevae memorem Iunonis ob iram

Figure 4.1: Arma virumque cano, Troiae qui primus ab oris Italiam, fato profugus, Laviniaque venit litora, multum ille et terris iactatus et alto vi superum saevae memorem Iunonis ob iram

CHAPTER 5

SOME MATH

This is a triviality, but we include it for completeness.

$$\int_0^\infty f(x)\,dx = \begin{cases} 1 & \text{if } f = \delta, \\ 0 & \text{if } f = 0. \end{cases} \tag{5.1}$$

Here is an aligned set of equations.

$$f(x) = f(x) \cdot 1 \tag{5.2}$$

$$= f(x) \cdot (2-1) \tag{5.3}$$

$$= f(x) \tag{5.4}$$

The clever step is (5.3).

APPENDIX A

TESTING, 1, 2, 3, . . .

This has been a test of the thesis typesetting system. Had this been an actual thesis, this would have been preceded by an actual thesis.

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