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RADIATIVE FORCING BY MINERAL DUST

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1. INTRODUCTION

Mineral dust plays an important role in the radiative and chemical balance of the atmosphere in and downwind of arid regions. Dust tends to heat the atmosphere and cool the surface, effects which can lead to regional circulation changes (Alpert et al., 1998; Miller and Tegen, 1998). Two of the great challenges in global modeling of mineral dust are representing sub-gridscale mobilization processes realistically at typical GCM resolutions of order 100 km. While our understanding of the mechanisms of dust production at small scales continues to improve (e.g., Marticorena and Bergametti, 1995; Shao et al., 1996), the quantification of the resulting global radiative forcing of dust is complicated by the large uncertainties in the optical properties of the dust (e.g., Sokolik and Toon, 1999). Subject to these limitations, we have developed a prognostic model of mineral dust atmospheric lifecycle and radiative effects for climate studies. In this abstract we describe the design of the global mineral dust model and discuss some of the outstanding problems in determining the radiative forcing of mineral dust.

2. MODEL

The global mineral dust model contains relatively detailed representations of dust mobilization and deposition processes. The mobilization scheme uses the friction speed u_* and the threshold friction speed for saltation u_{*t} to predict the horizontal mass flux of saltating particles as in White (1979). We assume saltation initiates when $u_* > u_{*t}(D = 75\ \mu\text{m})$. The saltation flux is converted to a vertical mass flux of suspended dust using the soil texture-dependent relationship of Marticorena and Bergametti (1995).

Soil moisture affects u_{*t} by increasing interparticle cohesive forces. We account for this using the soil texture-dependent relationship of Fécan et al. (1999). Soil moisture and vegetation are provided by the NCAR Land Surface Model (LSM) (Bonan, 1996). Soil texture is obtained from the IGBP-DIS soil dataset (Scholes et al., 1999).

Once mobilized, the suspended dust is assumed to reside in the multi-modal "background" size distribution proposed by D'Almeida (1987), as modified by Schulz et al. (1998). This source distribution is mapped into a number of bins for transport. Transport bins are contiguous in particle size, and each bin is an independently configurable truncated lognormal distribution. Thus one bin may be used to represent the transport mode alone, or many bins may be employed to approach a continuous representation of the size distribution.

The treatment of dry deposition uses the resistance method as outlined by Seinfeld and Pandis (1997). Aerodynamic resistance depends upon atmospheric stability, momentum roughness length, and friction velocity. The 10 m wind speed determines the roughness length over ocean (Large and Pond, 1981). Roughness lengths over land depend on snow cover, but are otherwise time-invariant (Bonan, 1996). Quasi-laminar layer resistance depends upon the Stokes and Schmidt numbers of the particles. Gravitational settling depends on particle size, and air viscosity. Appropriate corrections to the Stokes velocity are applied to particles with Reynolds numbers > 0.1.

Currently wet deposition is treated with a simple scavenging ratio method similar to Tegen and Fung (1994). The removal of dust is proportional to the mixing ratio of dust, the mixing ratio of rain, and the fractional cloud cover. Evaporating rain releases scavenged dust in proportion to the evaporation rate.

Regionally varying mineral dust composition and transport history introduce significant uncertainties to the problem of modeling mineral dust radiative forcing (e.g., Sokolik and Toon, 1999). Optical properties of long-range transported Saharan mineral dust are employed globally in our model (Volz, 1973; Patterson, 1981).

This mineral dust model has been embedded in the NCAR Community Climate Model (CCM), where climate sensitivity and radiative forcing s-

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tudies are performed, and in the NCAR Model for Atmospheric Chemistry and Transport (MATCH), where mineral dust events are driven by NCEP meteorological analyses. We will examine the characteristics of mineral dust loading and radiative forcing in and downwind of the Saharan and Arabian desert regions. We will focus on the role of dust in ameliorating current biases between the observed and modeled radiation budget.

3. OUTSTANDING PROBLEMS

Global studies of mineral dust radiative forcing allow us to assess the extent to which mineral dust may mitigate or exacerbate climate change caused by radiatively active atmospheric constituents. To reduce current uncertainties in the direct and indirect radiative forcing of mineral dust, many difficult challenges must be overcome. Economic means must be found to account for the effects of dust mineral composition, hygroscopicity, and interactions with soluble aerosols in large scale, coupled atmospheric models. Improved land surface properties (e.g., Scholes, 1999) and optical properties (e.g., Sokolik and Toon, 1999) and are essential to this. Condensing these data into computational forms which do not overburden coupled climate system models remains a significant challenge.

Comparison of predicted radiative forcing to satellite-measured radiances and fluxes is extremely useful for exposing the successes and shortcomings of mineral dust models. However, most global aerosol models do not allow for heterogeneous aerosol combinations (e.g., sulfate coated dust), and thus tend to overestimate aerosol optical depths even when the mass of individual species may be correctly predicted. Addressing this problem requires, in addition to model improvements, coordinated field programs to identify and calibrate the contributions of individual aerosol types to long term satellite observations. Thus modelers must integrate mineral dust with all relevant aerosols, and begin to attempt closure studies with data from field programs such as AERONET, INDOEX, and SAFARI.

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