Available online at www.sciencedirect.com
ScienceDirect
Global and Planetary Change 56 (2007) 297 – 310
GLOBAL AND PLANETARY CHANGE
www.elsevier.com/locate/gloplacha

Assessing uncertainties in dust emission in the Aral Sea region caused by meteorological fields predicted with a mesoscale model

Kremena Darmenova *, Irina N. Sokolik

School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA

Received 24 June 2005; accepted 19 July 2006
Available online 11 October 2006

Abstract

This study investigates how the choice of the planetary boundary layer (PBL) parameterization and dust emission scheme affects the prediction of dust entrainment simulated with a regional mesoscale model. For this analysis we consider a representative dust episode which occurred on April 2001 in the Aral Sea region. The meteorological fields were simulated using the PSU/NCAR MM5 modeling system considering two different boundary layer parameterizations. In each case, emitted dust fluxes were computed off-line by incorporating MM5 meteorological fields into the dust module DuMo. Several dust emission schemes with a prescribed erodible fraction and fixed threshold wind speed were the subject of our analysis. Implications to assessment of the anthropogenic fraction of dust emitted in the Aral region were investigated by conducting the full, half, and no lake modeling experiments.

Our results show that the discrepancies in dust fluxes between the two different PBLs are much higher compared to the discrepancy associated with the use of considered dust production schemes. Furthermore, the choice of the PBL affects the timing and duration of a modeled dust event. We demonstrate that different combinations of the PBL parameterization and wind- or friction velocity-driven dust emission schemes can result in up to about a 50% difference in predicted dust mass caused by the Aral Sea desiccation. We found that the drying-up of the Aral cannot only affect the dust emission by expanding the source area, but also by affecting atmospheric characteristics, especially winds. These competitive factors add further complexity to quantification of the anthropogenic dust fraction in the region.

Keywords: mineral dust; dust emission; planetary boundary layer; land use change; Aral Sea; mesoscale modeling

1. Introduction

The climate of Northern Eurasia has been undergoing major changes in the past century (Small et al., 2001). Growing evidence suggests that land-use/land-cover changes and increasing amounts of anthropogenic aerosols might be among the key drivers of observed climate change (IPCC, 2001). Among the main aerosol types, wind-blown mineral dust is strongly affected by human-induced land-cover and land-use changes. Desiccation of the Aral Sea, conversion of the steppe in Kazakhstan to cultivated lands in the 1950s, and severe desertification of northeast China resulting in the formation of new deserts are just a few examples of

* Corresponding author. Georgia Institute of Technology, School of Earth and Atmospheric Sciences, 311 Ferst Drive, Atlanta GA 30332, USA. Tel.: +1 404 894 1755; fax: +1 404 894 5638.

E-mail addresses: kdarmenova@eas.gatech.edu (K. Darmenova), isokolik@eas.gatech.edu (I.N. Sokolik).

0921-8181/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2006.07.024

land-use changes that occurred in Northern Eurasia and potentially led to increased dust loads (Orlovsky and Orlovsky, 2002; Xuan and Sokolik, 2002). The fraction of the dust load that originates from human-perturbed sources, called the anthropogenic dust, is of special interest in climate change studies because of the important diverse impacts that atmospheric dust can exert upon the Earth's systems. Despite its importance, quantification of anthropogenic dust and its impact upon the climate and environment remain highly uncertain (Sokolik et al., 2001; IPCC, 2001; Zender et al., 2004). One problem stems from challenges in distinguishing natural dust sources from anthropogenic ones (Sokolik and Toon, 1996; Tegen et al., 2004). Another problem is that recent studies that attempted to quantify the anthropogenic dust fraction mainly have been performed using global circulation models, GCMs, which rely upon many critical assumptions in treating dust processes (Zender et al., 2004). Given various problems in dust modeling with GCMs and the nature of spatiotemporal variability of dust events, it has been suggested that the use of the mesoscale atmospheric circulation models offers a number of advantages (e.g., Liu and Westphal, 2001). However, any mesoscale model relies on different parameterizations to handle the model physics at various levels of complexity. For instance, the PSU/NCAR Mesoscale Model (MM5) used in this study offers a wide range of physical parameterizations for representing clouds, radiation, land surface, and planetary boundary layer (PBL) processes. The latter two are especially important to modeling dust entrainment processes because they are controlled by both atmospheric characteristics (e.g., surface winds) as well as surface features (such as aerodynamic roughness length, vegetation, and soil moisture). Furthermore, several different dust emission schemes have been developed and used in the framework of the global and regional atmospheric dynamical models (Tegen and Fung, 1994; Marticorena and Bergametti, 1995; Ginoux et al., 2001; Gong et al., 2003; Zender et al., 2003). The dust emission schemes can be divided broadly into those formulated in terms of surface wind speed taken at 10 m, U_{10}, (U_{10}-driven schemes hereafter) and those expressed in terms of the surface friction velocity, u_*, (u_*-driven schemes hereafter). Although for a neutrally stable PBL, u_* and U_{10} can be related via a logarithmic wind profile and surface roughness, in general the relation between u_* and U_{10} and, hence, model-predicted dust fluxes would depend on the choice of a PBL parameterization as well as on a land model. Furthermore, several u_*-driven schemes exist in the literature that were derived under somewhat different physical assumptions (Shao, 2001). Therefore, it is important to understand the range of uncertainty in dust emission caused by model-dependent physics.

The goal of this paper is to investigate how the choice of model physics, especially the PBL parameterization and dust production scheme, affects the prediction of dust emission. We also explore implications to quantification of anthropogenic dust in Central Asia. Desiccation of the Aral is a perfect example of an anthropogenic dust source. Intensive irrigation from the rivers feeding the Aral in combination with the arid continental climate resulted in a drastic decrease of the lake water body over the last 50 yr. Since the 1960s the Aral Sea area decreased by half exposing about 42,000 km^2 of the highly erodible dried sea bed (Singer et al., 2003). In addition to forming an active dust source, it has been suggested that the Aral Sea desiccation has affected the air temperature and hydrological cycle in the region and hence contributed to climate change (Small et al., 2001). Improved assessments of anthropogenic dust is required to constrain the role of different individual factors as well as their coupled impacts in controlling climate change in this region.

Here we focus on the following questions: How does the choice of the PBL parameterization affect predictions of dust fluxes? For a given PBL, what are the differences between U_{10}-driven and u_*-driven dust fluxes? Are there any noticeable differences in dust fluxes calculated with different u_*-driven schemes? How does the choice of the PBL and dust emission scheme affect assessments of anthropogenic dust fluxes caused by the Aral Sea drying-up?

First, we describe an approach of this study in Section 2. Next, the results of modeling experiments with different dust emission schemes are presented and discussed in Section 3. Section 4 addresses the effects of PBL parameterizations. Then, in Section 5, we explore the uncertainties associated with the above factors in predicting anthropogenic dust fluxes caused by desiccation of the Aral Sea. A summary concludes the paper (Section 6).

2. Modeling approach

We consider a dust event occurring during 6–10 April 2001 that is representative of dust outbreaks in the region of interest. First, the MM5 model was run with different PBL parameterizations to simulate the meteorological fields. Then, emitted dust fluxes were computed by feeding meteorological fields into the dust module DuMo consisting of several dust emission schemes. The setup of the MM5 and DuMo models are described next.