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A quantitative evaluation of the 3–8 July 2009 Shamal dust storm

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ABSTRACT

In this paper, a quantitative evaluation of the severe dust storm which occurred in the Middle East during 3–8 July 2009 is presented. The quantification is based on the numerical simulation using the WRF/Chem-D model which has been verified and calibrated for the Middle East region. It is found that, during the 3–8 July 2009 event, more than 9.67 Tg dust were emitted from the study area and the maximum simulated dust emission rate is 540 ($\mu g\,m^{-2}\,s^{-1}$). The west of Iraq, east of Syria and northwest of Jordan (Al-Nafud desert and western Euphrates alluvial plain) are found to be the most active areas of dust emission, contributing much to the dust emission from the Middle East region. In this study, more that 60% of dust particles were emitted from these areas and less than 10% were emitted from Iran dust sources. About 21% of the deposited dust was deposited in Iran land, while 79% in other parts of the study area. The dust load in the study area was estimated to be more than 0.3 $g\,m^{-2}$. The residence time of dust in the atmosphere was 6.2 days over the study area, 7.8 days over Iran and 6 days over other parts.

The simulation results exhibit that Iran contribution in emission rate in the study area is much lower than its contribution in dust deposition and residence time and the conclusion of this study can demonstrate the necessity of forming cooperation for suppressing the severe dust events.

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1. Introduction

Studies have shown that the Middle East region contributes to about 20% of the global total dust emission (Tanaka and Chiba, 2006), with the Tigris-Euphrates alluvial plain and Al-Nafud desert recognized as the main dust sources (Shao, 2008). In the Middle East, dust activity occurs all year long, but is generally weaker in winter than in summer (Shao, 2008). Summer dust storms in this region are mostly Shamal events. The weather system with an anticyclone over northern Africa – eastern Europe accompanied by a monsoon trough over Iraq and southern Iran provides a favorable condition for the Shamal dust storms.

The 3–8 July 2009 dust storm is one of the strongest dust storms which occurred in the past decade in the Middle East. The high dust concentration associated with this event resulted in serious human health problems in many countries in the Middle East and southwestern Asia. Residents of Baghdad described this storm as the worst one they have ever experienced (http://earthobservatory.nasa.gov/NaturalHazards). Also, the dust traveled eastward to Iran, and as a result, public services and state departments in Tehran were officially closed. The Iranian state broadcast ranked this event as the worst in three decades that the country had experienced (Hamidi et al., 2013). Therefore, for demonstrating the unpleasant effects of the dust events, quantitative evaluation of them can be beneficial and selecting the most severe one could be a good criterion for assessing the different aspects of these phenomena.

Synoptic analysis of the 3–8 July 2009 dust storm over the Tigris and Euphrates rivers alluvial plain dust sources shows that dust emission in this area was active during 3–5 July, but was much reduced in the days of 6–8 July. A zone of strong pressure gradient between a low pressure system over central-eastern Iran and a high pressure system over northern Africa was responsible for this Shamal dust storm, the dust emission from the Tigris and Euphrates alluvial plain, and the eastward dust transport (Hamidi et al., 2013). There are many investigations on this area, but no quantitative study was performed to estimate the dust emission (Abdi Vishkaee et al., 2011, 2012; Engelbrecht and Jayanty, 2013; Rezazadeh et al., 2013; Alam et al., 2014).

In recent years, a number of dust models have been used to simulate dust on regional and global scales (Hamidi and Kavianpour, 2013). While the models have the general capability of simulating dust events, there are large uncertainties in the results due to

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deficiencies in the host atmospheric models, dust schemes and input parameters. In this study, an improved dust model is used to simulate the dust event. The model was developed in the framework of WRF/Chem-D (Weather Research and Forecasting with the Chemistry and Dust Model) and has been successfully applied to dust simulations in Asia (Kang et al., 2011), the Middle East (Hamidi et al., 2013) and elsewhere. This model consists of several dust emission schemes supported by a GIS (Geographic Information System). It considers the soil salt effects on dust emission, necessary for studying dust in the Middle East. Previous studies have demonstrated that accurate estimate of dust emission from the Middle East cannot be achieved without considering the salt effect on dust emission (Hamidi et al., 2014).

While dust modeling effort has been recently made for the Middle East region, there are few quantitative dust budget estimates, in particular if the suppression of soil salt on dust emission is considered. In this work, WRF/Chem-D is used to simulate the 3–8 July 2009 Shamal dust storm, one of the most severe ever observed in the Middle East. The dust plumes of this event propagated to more than 10 countries and caused serious environmental concerns. So this kind of studies demonstrated that dust events can affect surrounding regions, even outside of the boundaries of the regions which are considered as the main source of dust emission. In some cases the effects of the dust storm on neighboring countries and regions are more significant than the producer one. The management of this kind of natural hazard needs suitable cooperation between all the countries that are affected by the dust events.

It can be concluded that however there are many research studies on the qualitative aspects of the dust events in the Middle East, this paper uses quantitative approach to assess different aspects of the following dust events. Providing accurate estimation of the dust emission and deposition rate and the dust residence time on many areas, can present a quantitative evaluation of dust particles emission, propagation and deposition in the Middle East region.

Finally this study can be helpful to providing suitable information for the countries which are influenced by dust events and demonstrate them the necessity of forming a cooperation and agreement for controlling and suppressing severe dust storms.

The paper is organized as follows: In Section 2, the numerical simulation details of this study including model description and input parameters are introduced. Section 3 provides the model validation and the result of simulation including dust emission, deposition and residence time and a discussion on the results. Section 4 consists of a summary and conclusion of the study.

2. Numerical simulation

2.1. Model description

WRF/Chem-D used in this study couples the Weather Research and Forecasting with the Chemistry and Dust Model. The WRF/Chem-D modeling system, follows the same structure as the WRF model by consisting of these major programs: The WRF Pre-Processing System (WPS), WRF-Var, WRF solver including chemistry and Post-processing and visualization tools. The WRF/Chem-D model makes uses of several modules for dust emission, transport and deposition and is supported by dust-related input parameter datasets. WRF/Chem-D applies three different dust emission schemes, including the MB (Marticorena and Bergametti, 1995), LS (Lu and Shao, 1999) and S04 (Shao, 2004) scheme and provides the opportunity for choosing one of the mentioned schemes for simulation of a dust event.

Kang et al. (2011) estimated the rate of dust emission using the three dust emission schemes for an Asian dust event and conducted sensitivity tests to evaluate the performance of each dust emission scheme. They found that the simulated spatial dust distributions using the three schemes matched well with the Ozone Monitoring Instrument (OMI) Aerosol Index (AI) data, but the estimated amount of dust emission differed substantially. The estimated total dust emission by use of the MB scheme is generally higher than those by use of the LS and S04 schemes and the results of the S04 scheme appeared to match best the observations. Hamidi et al. (2014) showed that the S04 scheme leads to proper results in modeling the dust events in the Middle East. Hence, the S04 scheme is selected in this study.

The S04 scheme considers three dust emission mechanisms, namely, aerodynamic entrainment, saltation bombardment (or sand blasting) and aggregates disintegration (or self-abrasion). The scheme estimates the threshold friction velocity of wind erosion, intensity of sand drift, and dust emission rate for each particle size groups. This model uses four dust bins to calculate emission, transport and deposition and to present the outputs, i.e. 1.95–2.5, 2.5–5, 5–10 and 10–20 µm. The emission rate for each dust bin is estimated by:

$$\tilde{F}(d_i, d_s) = c_y \eta_{fi}[(1-\gamma) + \gamma\sigma_p](1+\sigma_m)\frac{gQ}{u_*^2}$$

where $\tilde{F}(d_i, d_s)$ is the dust emission rate for the ith dust bin (dust particle size group) generated by the saltation particles of size d_s and η_{fi} is the mass fraction of the ith dust bin (calculated from full u_{*t} y dispersed particle-size analysis). Q is the saltation flux of the sand grains with the size d_s, which can be calculated using the White (1979) model for a given d_s. Also, g is the acceleration due to gravity and γ is a weighting function which can be described as $\gamma = e^{-k(u_* - u_{*t})^n}$ where u_* is friction velocity, is a threshold friction velocity, and, k and n are empirical parameters (set to 1 and 3 in this study, respectively). In the case of weak erosion, $u_* \sim u_{*t}$, $\gamma \to 1$ and for strong erosion, $u_* \gg u_{*t}$, $\gamma \to 0$. Also, $\sigma_p = p_m(d)/p_f(d)$, where $p_f(d)$ and $p_m(d)$ are respectively the fully and minimally dispersed particle size distributions. The dimensionless coefficient c_y is found to fall between 10^{-5} and 5×10^{-5}. It has been suggested as a general guidance to set $c_y \approx 5 \times 10^{-5}$ and $P \approx 1000–5000$ Pa for loose sandy soils, and $c_y \approx 10^{-5}$ and $P \approx 30{,}000–50{,}000$ Pa for clay soils (Shao, 2008). Finally, the saltation bombardment efficiency σ_m is calculated by:

$$\sigma_m = 12u_*^2\frac{\rho_b}{P}\left(1 + 14u_*\sqrt{\frac{\rho_b}{P}}\right)$$

where P is the plastic pressure of the soil and ρ_b is the soil bulk density (~1000 kg m^{-3}). Using the above described equations the dust emission rate for the ith dust bin can be calculated by:

$$\hat{F}(d_i) = \int_{d_1}^{d_2} F(d_i, d)\delta d$$

where d_1 and d_2 are the lower and upper boundaries of saltation particles sizes. The total dust emission rate, F, can be calculated by:

$$F = \sum_{i=1}^{I}\hat{F}(d_i)$$

One of the most important factors for estimating dust emission is the threshold friction velocity (u_{*t}), defined as the minimum friction velocity for the initiation of soil particle movement. This quantity strongly depends on surface conditions and mineral characteristic of the soil, such as soil moisture, surface roughness and soil-salt concentration. These parameters are usually heterogeneous in space and vary slowly in time, and are considered in the scheme by modifying the u_{*t} as follows;

$$u_{*t}(d_s, w, \lambda, s_c, \ldots) = u_{*t0}(d_s)f_w(w)f_\lambda(\lambda)f_{sc}(s_c)\ldots$$

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