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Contribution of the Middle Eastern dust source areas to PM_{10} levels in urban receptors: Case study of Tehran, Iran

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HIGHLIGHTS

- Modeled the Middle Eastern dust intrusions in 2009–2010 by HYSPLIT.
- Adjusted the model parameters including the threshold friction velocities.
- Potential origins of the Middle Eastern dust storm were identified.
- Contribution of the regional dust source areas to urban PM_{10} were determined.
- Deserts in Iraq and Syria were the main contributing dust sources to PM_{10} in Tehran.

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ABSTRACT

The origins and evolution of the Middle Eastern dust storms which frequently impact the residents of this arid region were studied. A methodology was adapted and developed to identify the desert regions of potential dust sources and determine their contributions to PM_{10} concentrations in the highly-populated receptor city of Tehran, Iran. Initially, the episodes of regional dust intrusion and the resulting amounts of increase in the particulate concentrations during these episodes were determined using a statistical analyzing methodology. The dust episodes were also inspected with the aerosol index information from the Ozone Monitoring Instrument (OMI). The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used as the main tool to determine the proportions of dust originating from different deserts during the dusty episodes of 2009–2010.

Daily 5-day back trajectories were obtained from the receptor stations during the dust outbreaks in order to find and confirm the location of potential sources. After the boundaries of the potential sources were determined by 5-day backward trajectories, this region was divided into different areas to quantify their contributions to the measured PM_{10} levels. The proximity between the measured and simulated data confirmed the ability of HYSPLIT in modeling the Middle Eastern dust intrusion and estimating the particulate concentration in the downwind receptor sites. Results showed that the deserts in Iraq and Syria are the main contributing dust sources which comprise more than 90% of the dust related PM_{10} concentrations in Tehran, during the studied dust episodes. The sources in northern Iraq and eastern Syria respectively represented 44% and 32% contributions on average.

1. Introduction

In the arid areas, dust storms release large amounts of particulate into the atmosphere every year, which could be transported to the downwind regions located hundreds of kilometers away (Fu et al., 2008). Dust storms can cause serious health problems such as lung irritation, allergic reactions, eye infections, meningitis and valley fever (Griffin and Kellogg, 2004; McKenna et al., 2008; Nieuwenhuijsen et al., 2007; Perez et al., 2012). Furthermore, mineral dust impacts the environment in many aspects including disturbance in the climate system, interrupting the balance of radiation, and adverse esthetic and visual effects (Tegen and Fung, 1994). This situation is particularly intense for the areas in the dust belt, which extends over North Africa, Middle East, Central and South Asia, and China (Chester et al., 1977; Mitsakou et al., 2008; Prospero et al., 2002).

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The development, evolution and transport path of mineral dust particles are affected by a complex system. A dust storm occurs when wind speed exceeds the threshold friction velocity and creates a suspended cloud of particles and carries it high into the air (Bagnold, 1941; Bréon et al., 2002; Stout, 2010). The threshold velocity of a region is affected by several parameters including the soil texture, humidity, vegetation, topography and particle diameter (Bréon et al., 2002; Fécan et al., 1999; Harris and Davidson, 2008; Marticorena et al., 1997). This cloud of suspended particles evolves and travels by various processes including advection, diffusion, turbulence, settlement and even chemical reactions. Hence, a proficient representation of a dust storm requires appropriate estimation of various parameters, particularly the threshold velocity, and proper simulation of aforementioned processes which define the dispersion and transformation of the dust particles.

Different approaches including satellite data processing, surface particulate monitoring, dust dispersion modeling and elemental tracers' analysis have been used to study the dust intrusions (Draxler et al., 2001; Engel-Cox et al., 2004; Liu et al., 2011; Schwikowski et al., 1995). Most of these studies have concentrated on finding the origins of the dust, and investigating the transportation of particulate dust storms. For instance, several researchers have processed Aerosol Index (AI) data from Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 satellite, and Aerosol Optical Depth (AOD) data from Moderate Resolution Imaging Spectroradiometer (MODIS) to locate potential origins of the dust storms and identify areas where dust mobilization is more frequent (Esmailli et al., 2006; Liu et al., 2011; Miller, 2003; Prospero et al., 2002; Qu et al., 2006). More advanced studies have used different dispersion modeling and back trajectory approaches as well as processing satellite data to investigate dust storm paths and origins. Among different modeling tools, the Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT) has been used for this purpose and has shown a superior potential (Draxler and Hess, 1998; Draxler and Rolph, 2012; Escudero et al., 2007a; Rodríguez et al., 2001; Querol et al., 2009). A few studies have been conducted to explore Mediterranean and North African dust storm origins and evolution using HYSPLIT as the main tool (Avila et al., 2007; Draxler et al., 2001; Escudero et al., 2005, 2006, 2011). However, most of these studies have shown that considerable uncertainties remain in these models of dust events. Hence, further investigations are required to improve the definition of the model's parameters and to enhance their accuracy.

The Middle East region has been described as a major dust source in several previous studies (Ginoux et al., 2012; Littmann, 1991; Middleton, 1986); however, limited work has focused on the Middle Eastern dust storms evolutions. One of these studies includes the attempt to estimate the soil roughness in the areas including Kuwait, Iraq, Syria, Saudi Arabia, the Emirates and Oman (Draxler et al., 2001). Also, a few studies were conducted to find dust sources in the Middle Eastern region (Ginoux et al., 2012; Prospero et al., 2002). Nonetheless, the dust storm evolution in the Middle East region has not been sufficiently explored, and the contribution of the dust storms to the observed Particulate Matter (PM) levels in the receptor cities has not been investigated.

Iran, like most other countries in the Middle East, is affected by multiple dust storms each year, especially in the western and central regions, including where the highly-populated capital city of Tehran is located (Shahsavani et al., 2011, 2012). Inhabitants in Tehran are generally exposed to high levels of urban background PM due to the large number of anthropogenic sources and the unique geographic characteristics of a city surrounded by a high altitude mountain chain on its boundary, downstream of the prevailing wind (Arhami et al., 2013; Atash, 2007; Halek et al., 2010; Madanipour, 2006; Sabetghadam et al., 2012). The particles from the dust storms are also being added to this high urban background level resulting in significantly elevated PM concentrations and reduced visibilities during the dust intrusion episodes (Vishkaee et al., 2011). Despite the significance of these phenomena, there is not sufficient information available about dominant dust origins and their contribution in particulate levels in Tehran.

In this paper, the dust storm origins and evolution which affect Tehran have been studied and the contribution of each dust origin to the measured PM_{10} levels has been determined. Initially the episodes of regional dust intrusion during the study period of 2009–2010 and the resulting amounts of increase in the particulate concentration during these episodes were determined. A methodology was developed for this purpose by means of statistical analyses of the recorded pollutant levels at the ambient monitoring stations. The occurrence of regional dust events was corroborated by inspecting AI data from the Ozone Monitoring Instrument (OMI) using a threshold index of 0.7. HYSPLIT was used as the main tool to model the dispersion and the route of dust particles. The model parameters including the threshold friction velocities have been adjusted and calibrated. The potential origins of dust storms were determined using back trajectory modeling. Finally, the contributions of different deserts in the region to the measured PM_{10} at Tehran's stations were estimated using the model simulation of dust contributed from each of the source regions. Results of this study can be used to improve decision-making and in determining more effective control strategies to deal with the dust intrusion crisis in the region.

2. Methodology

2.1. Dust episodes and their impact on PM_{10} levels

The hourly pollutant concentrations during 2009–2010 were extracted from the recorded data at 8 urban stations throughout the city of Tehran operated by Air Quality Control Company. Days affected by regional dust events (called "dusty days" from now on) were separated as described subsequently by applying a statistical analyzing procedure to the pollutant concentrations along with using satellite imagery. In several studies (e.g. Escudero et al., 2007b), just a threshold for PM_{10} concentration (e.g. 100 $\mu g/m^3$) was used to separate "dusty days" from other days (called "regular days" from now on). However, in Tehran other phenomena besides regional dust storms, such as inversion and stable weather conditions, could also cause high particulate levels. The difference between pollutant behavior in the days influenced by a regional dust storm and days of stable atmospheric/inversion conditions were used to separate these two events. During the dust storms the particulate matter levels are expected to substantially increase without a substantial increase in gaseous pollutant levels including Carbon Monoxide (CO), which is mainly formed from primary combustion, particularly in vehicle engines. On the other hand, during stable atmospheric/inversion conditions, there is expected to be a substantial increase in both particulate and gaseous pollutants including CO levels. In order to find the dusty days, the periods of substantially high PM_{10} levels (i.e. the daily levels were at least one standard deviation higher than average) were selected. Among the selected time frames, the periods for which daily CO levels were not more than one standard deviation above the average were retained for analysis. The AI maps from OMI for the selected periods were inspected both visually, and quantitatively using an AI threshold value of 0.7 to ensure the occurrence of regional dust events. The AI threshold of 0.7 is in the range of 0.6–1 which was suggested by previous studies to identify the regional dust events (Hsu et al., 1999; Prospero et al., 2002). The outcomes did not vary much by choosing a different threshold value in this range, since generally the AI values