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Spatial and temporal variations of airborne dust fallout in Khorasan Razavi Province, Northeastern Iran

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ABSTRACT

Dust deposition rates depend mainly on the rate of dust supply, climatic conditions, and topography in the source and sink areas. The objective of this study was to investigate the role of these variables in the spatial and temporal variation of airborne dust fallout in Khorasan Razavi Province, Northeast Iran. Airborne dust samples were collected monthly from May 2014 to April 2015. Dust fallout rate was modelled as a function of air temperature, precipitation, relative humidity, wind velocity and distance from source regions. The lowest and highest rates of atmospheric dust fallout occurred in December and June, with average amounts of $9.97\ g\ m^{-2}$ and $20.96\ g\ m^{-2}$, respectively. The strongest winds were observed in June immediately following a relatively humid period (i.e., March–May) with considerably higher precipitation and lower evaporation. Spatial distributions showed that the highest dust fallout rates occurred in the southern and western parts of the province—areas adjoining the vast playas. During the spring and summer season, the distance from the nearest playa was a key factor that explained more of the variation in dust flux than climatic parameters. Both runoff by fresh sediment moved onto the surface of the playa and the formation of loose sediment on the surfaces of wet playas are mechanisms that can increase dust emissions. The lowest deposition rates were observed in the mountainous region in the north of the province likely due to higher precipitation, atmospheric humidity, and soil moisture. This work represents the first baseline dust data for Khorasan Razavi Province and may be useful in evaluating the effects of future land use and climate change on aeolian land surface processes.

1. Introduction

Airborne dust poses serious human health hazards and environmental risks in arid and semiarid regions (Griffin et al., 2001; Wiggs et al., 2003; Yu et al., 2012), where a lack of continuous vegetative cover makes surface sediments susceptible to wind erosion (Shao, 2008). In these areas, dust is generated by strong prevailing winds ($> 8\ m\ s^{-1}$) that erode sediment from the land surface (Engelstaedter et al., 2006; Xuan et al., 2004). This sediment is carried by these winds and ultimately accumulates on other parts of the landscape via dry or wet deposition or is carried off to other regions where it can have considerable influence over ecosystems (Groll et al., 2013; McTainsh, 1999). Most of this dust (> 80%) is emitted from natural surfaces (Chow et al., 1994), although anthropogenic dust emissions are considerable, especially in populous urban settings (Grobéty et al., 2010).

Various factors contribute to dust deflation and deposition and, thus, control the regional distribution of dust; these factors include surface roughness, vegetation cover, soil properties (e.g., moisture, texture, induration, structure and mineralogy) and topographic features (Engelstaedter et al., 2006; Hirmas et al., 2011; Reheis and Kihl, 1995; Reynolds et al., 2009; Xuan et al., 2004). Playas are susceptible to wind erosion making them arguably the most important sources for dust in arid regions (Cahill et al., 1996; Gill, 1996; Gill et al., 2002; Goudie and Middleton, 2006). Proximity to these landscape features likely controls the distribution of dust (e.g., Hirmas and Graham, 2011). For instance, Liu et al. (2011) studied the rate of airborne dust fallout in the Xinjiang region of China and found that dust fallout decreased with increasing distance from the source playa. This was attributed to increasing distance from the presence of recently deposited sediments and the formation of loose salt minerals on the playa surface which are susceptible

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to wind erosion following desiccation.

In recent years, many studies have been carried out on the temporal variability of dust to better understand aeolian and land surface processes (Engelbrecht and Jayanty, 2013; Flagg et al., 2014; Wang et al., 2009). For example, Groll et al. (2013) reported that peak dust rates in Central Asia between 2003 and 2010 occurred in February and June. They noted that the high dust deposition during the late winter months was likely due to the Siberian high-pressure system which affects regional weather patterns. Additionally, the highest deposition rate during late spring and early summer was related to seasonal warming of the Tibetan Plateau. Marx and McGowan (2005) reported that the highest rates of dust deposition along a 300-km section of the humid west coast of South Island, New Zealand, occurred in the summer due to the reduction in precipitation and abundance of winds capable of carrying airborne dust.

During the past decade, increasing awareness of the human health hazards posed by dust in Iran has spurred investigations documenting the deposition and source areas of the dust and identifying the regional atmospheric and land surface processes controlling dust transport. Hojati et al. (2012) investigated the characteristics of airborne dust along a topographic transect from Jandagh in the Kavir Desert to Kouhrang in the Zagros Mountains of western Iran and concluded that the rate of dust deposition was influenced by both elevation and climate. They also examined distance from the Kavir Desert as a factor affecting dust deposition and found it to be significant. Rashki et al. (2012) analyzed the characteristics of atmospheric airborne dust in the Sistan region in two locations near the Hamoon Lake in eastern Iran during the period between August 2009 and July 2012. The authors reported that the transfer of airborne dust depended mainly on the time of wind occurrence, wind speed and distance from the source. Similarly, Mahmoudi (2011), and Norouzi and Khademi (2015) in Isfahan Province and Jaafari and Khademi (2015) in Kerman Province found significant relationships between dust deposition rates and some climatic parameters such as wind speed, minimum and maximum temperature and average humidity.

Despite the previous research in Iran, the role of landscape-scale and regional atmospheric processes on the distribution and concentration of modern dust is only poorly understood in Khorasan Razavi Province in northeastern Iran which covers approximately 7.8% of the country (Fig. 1). This is unfortunate since this province is unique in that it contains a combination of arid and hyper-arid climates, vast playas, and arid mountain ranges, is affected by significant changes in wind direction caused by the Sistan's 120-Day Winds period, and is home to approximately 6 million people making it the second most populous province in Iran (Statistical Centre of Iran, 2011; http://www.amar.org.ir). In addition, ~19.5% of the land area of Iran affected by wind erosion is located in this province (Range and Watershed Department of Khorasan Razavi; http://www.nr-khr.ir). Loess deposits in the southern City of Mashhad (Karimi et al., 2009) and on the eastern slopes of the Kopeh Dagh mountains (Karimi et al., 2014; Okhravi and Amini, 2001) as well as extensive areas of active and stabilized sand dunes are evidence of intense past and present wind activities in this province.

Given the intensity and seasonal direction of the winds coupled with the extreme relief in this region, we hypothesize that dust deposition in Khorasan Razavi is controlled by the interaction between these winds and the location of topographic features (e.g., mountain ranges or playas). In addition, we hypothesize that the nature of these interactions changes on a monthly or seasonal timescale corresponding to atmospheric features over the region.

Our objective was to test these hypotheses by investigating the spatial and temporal distribution of modern dust in Khorasan Razavi Province as well as its relationship to atmospheric properties and distance to probable sources (e.g., playas). Because this study represents the first published measurements of dust in this region of Iran, a secondary goal was to provide baseline dust data by which to evaluate future regional anthropogenic climate and land use effects on aeolian and land surface processes.

2. Materials and methods

2.1. Study area, geographical setting, and regional atmospheric processes

Khorasan Razavi Province is located between 56.2° and 61.5° E and 33.5° to 37.7° N in north-eastern Iran (Fig. 1). Elevations range from 235 m in Sarakhs plain near the border between Iran and Turkmenistan to 3211 m at Binaloud Mountain north of the City of Neyshabur (Fig. 1). Mean annual precipitation ranges from 116 mm in Khaf to 313 mm in Quchan and mean annual temperature ranges between 12.2 °C in Fariman and 18.2 °C in Sabzevar.

The Binaloud and Kopeh Dagh mountain ranges run parallel to each other and are separated by the Mashhad plain in the northern portion of Khorasan Razavi (Fig. 1). To the east, Sarakhs loess plain is located at the base of the Kopeh Dagh Mountains. The Chehel Tan is an east-west trending bow-like mountain range situated in the center of the study area and extends from the city of Torbat-e Heydariyh to Bardskan. Several extensive playas with clay flats, salt crusts and sand dunes are present immediately south of the Chehel Tan. Neogene gypsiferous and calcareous marls are distributed in the study area (Fig. 1).

Approximately 75% of the province is located within arid or semi-arid climates (Peel et al., 2007). Meteorological stations distributed throughout the province (Fig. 1) record multiple dust storms each year, with some stations reporting occasional frequencies of 50 or more storms occurring in a single year (Islamic Republic of Iran Meteorological Organization (IRIMO), 2013).

Khorasan Razavi is under the influence of three main air masses that cause major changes in weather conditions during the year. Southern migration of the Siberian high-pressure system causes polar continental air to interact with warm moist air originating from the Atlantic Ocean and Mediterranean Sea causing precipitation during the late fall to early spring. Warm dry air masses originating north of the Caspian Sea increase temperature and decrease humidity in the region and cause Sistan's 120-Days Winds period, which increases dust production and transport from late spring to mid-summer.

According to meteorological reports and satellite observations, most stormy days in Khorasan Razavi occur in the spring. Synoptic analysis of dust storms in the province show that in the warm period of the year (late spring and summer), a low-pressure center moves over the southern areas of Khorasan Razavi and Afghanistan while the Azores High expands toward the Black and Caspian Seas increasing the meridional pressure gradient and causing heavy winds and dust storms in the region (Lashkari and Keikhosravi, 2008).

2.2. Atmospheric data

Data on wind direction, wind speed, rainfall, humidity, and temperature during the sampling period (1 May 2014–30 April 2015) were obtained at 3-hour intervals from the Iranian Meteorological Organization from 11 weather stations distributed across Khorasan Razavi (Fig. 1). At nine of the stations (Gonabad, Kashmar, Khaf, Mashhad, Neyshabur, Sarakhs, Sabzevar, Torbat-e Jam, and Torbat-e Heidariyeh) dust storm events were recorded as either dust haze, raised dust, or dust storm. These stations were located near (< 10 km) the dust trap sites. Observations of dust storms were obtained from 1985 to 2015 to investigate long-term trends in dust flux within the province.

Atmospheric visibility as affected by dust was assessed using the World Meteorological Organization (WMO) coding system that is used to record and report the amount of dust in the atmosphere (Goudie and Middleton, 2006). To examine the spatial distribution of dust storms in Khorasan Razavi, seasonal and annual changes in the number of dust storms were analyzed using the Dust Storm Index (DSI). This index provides a measure of the frequency and intensity of wind erosion events following O'Loingsigh et al. (2014). It is calculated as: