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Dust-storm dynamics over Sistan region, Iran: Seasonality, transport characteristics and affected areas

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ABSTRACT

The present work examines the seasonality, dust-plume altitudinal variation and affected areas for dust storms originated from the Sistan region, southeastern Iran during the summer (June–September) months of the period 2001–2012 synthesizing local meteorological records, satellite observations (TOMS, OMI, METEOSAT, MODIS) and HYSPLIT forward trajectories. Dust-storm days (356 in total) are associated with visibility below 1 km at Zabol, Iran meteorological station with higher frequency and intensity in June and July. Monthly-mean composite maps of TOMS and OMI AI show high (>3–3.5) values over Sistan and nearby downwind areas. HYSPLIT forward-trajectory analysis at 500 m for air masses originated from Sistan on the dust-storm days shows that they usually follow an anti-clockwise transport direction at elevations usually below 2 km, initially moving southwards and then shifting to east-northeast when they are approaching the Arabian Sea coast. This is the result of the influence of the local topography and formation of thermal low-pressure systems over the arid lands. It is found that in few cases the dust storms from Sistan affect central/south Arabian Sea and India, while they control the aerosol loading over northernmost Arabian Sea. The Infrared Difference Dust Index (IDDI) images, which represent brightness temperature reduction due to dust presence over land, are used at specific periods of persistent dust storms over Sistan, confirming the main pathways of the dust plumes and illustrating the importance of the region as one of the most active dust sources in southwest Asia.

1. Introduction

Sand and dust storms are common phenomena over the global deserts and cause serious environmental, climatic, economic and human-health hazards (Goudie and Middleton, 2001; Ginoux et al., 2012; Goudie, 2014). Therefore, studying the desert-dust cycle (from entrainment to long-range transport and deposition) is critical for issues concerning climate change, weather, ecosystems, air quality and human health. The major dust sources over the globe are detected at topographical lows in arid regions with low annual precipitation (<200 mm) limited vegetation cover and alluvial sediments (Prospero et al., 2002; Schepanski et al., 2007, 2012; Ginoux et al., 2012). Monitoring of dust storms uses various techniques implementing ground-based observations, satellite remote sensing and integrate approaches (Shao et al., 2011; Akhlaq et al., 2012; Sorek-Hamer et al., 2013). The Arabian Peninsula and the Middle East region are responsible for the emissions of large quantities of dust, which are mainly transported over Arabian Sea (AS) with major intensity in June–August (Prasad and Singh, 2007; Prijith et al., 2013). The identification of the dust source regions and transport pathways in Middle East constitutes a real challenge (Rezazadeh et al., 2013) and, recently, has benefited from the development of the new Middle East Dust Index (MEDI) model (Karimi et al., 2012) and Global Dust Detection Index (GDDI) (Samadi et al., 2014).

Review studies (Prospero et al., 2002; Ginoux et al., 2012; Léon and Legrand, 2003) noted that ~65% of the southwest Asian arid terrain has potential to be a dust source. More specifically, the most effective areas are detected in the eastern and southern parts of Arabian Peninsula, the Oman desert, the Syria-Iraqi desert, the Aral and Turkmenistan basins to the north, and some closed inland areas of the Iranian plateau (i.e. Kavir and Lut deserts, Sistan Basin and Hamoun Jaz-Mourian Lake). All these areas are composed of alluvial silt and clay material or correspond to dry-bed lakes and abandoned agricultural areas. Although the Arabian, Iraqi and Thar

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deserts have been identified as major dust sources in south Asia (Middleton, 1986; Prospero et al., 2002; Maghrabi et al., 2011; Karimi et al., 2012), a small area (Sistan) that constitutes a topographically low-lying (~480 m above sea level, asl) basin with dried lakes (Hamoun) at the Iran-Afghanistan borders might also play a significant role. However, its role has not been studied so far, although it is well recognized as one of the windiest deserts in the world. Comprehensive studies in this region have only recently been published, examining dust sedimentation and characteristics (Rashki et al., 2012), the role of the local "Levar" wind in dust activity (Alizadeh Choobari et al., 2012, 2013), particulate matter (PM) concentrations and air quality (Rashki et al., 2013a), dust mineralogy and chemical composition (Rashki et al., 2013b), influence of dryness of the Hamoun lakes on dust exposure, local economy and ecosystems (Rashki et al., 2013c; Sharifikia, 2013). Furthermore, Esmaili and Tajrishy (2006) evaluate the dust sources in Iran via remote sensing (Aerosol Index records) and synoptic analysis highlighting Sistan and the southwestern part of Iran, covered by some marshes in the Khoozestan Province, as the major dust source regions of the country, while Alam et al. (2011) attributed the highest aerosol optical depth (AOD) over Karachi, Pakistan to influence by dust storms originated from Sistan. The arid central Iranian Plateau may also be a source of dust, especially during summer, when heat lows usually occur. The main sources of dust affecting western-central Iran are located in the Tigris-Euphrates Basin (Bayat et al., 2010; Masoumi et al., 2013).

Excessive dust loading over south Asia affects regional environment and climate, and modifies the biogeochemical cycles and radiative forcing of the atmosphere. Gautam et al. (2010) found significant effect of dust aerosols on the mid-tropospheric warming over the Indo-Gangetic Plains and Himalayan – Hindu Kush range and lowering of glacier's albedo due to dust deposition (Gautam et al., in press). Similar effects of dust originating from Middle East and southwest Asia on the acceleration of western-Himalayas glacier melting was mentioned by Prasad et al. (2009). Singh et al. (2008) found that the dust deposition over Arabian Sea may affect the chlorophyll blooming, influence the phytoplankton and cool the ocean surface. On the other hand, dust plumes can also affect weather by influencing the atmospheric thermal structure (Lemaître et al., 2010) suppressing cyclone activity (Dunion and Velden, 2004) and affecting cloud microphysics and hydrological cycle (Dipu et al., 2013). Except of the well-known pulmonary diseases and asthma (Bartzokas et al., 2004; Nastos et al., 2011), mineral dust has been suspected to be one of the most important health risk factors for allergies in elderly and young people, and contributes to meningitis in Sistan (Miri et al., 2007) and in west Africa (Martiny and Chiapello, 2013). These justify the importance of studying dust storms and regional climate, weather, air quality and human health in Middle East and southwest Asia.

The present work builds upon previous articles (Alizadeh Choobari et al., 2012; Rashki et al., 2012, 2013a,b,c, 2014; Sharifikia, 2013) examining the dust storms originating from the Sistan region, southeastern Iran. The current study focuses on analyzing the seasonal evolution of the dust storms, defined as the days with visibility < 1 km, in the summer months (June–September) during the years 2001–2012. Such long-term analysis of the occurrence of dust storms is still lacking over southwest Asia. Satellite observations (TOMS and OMI AI, METEOSAT, MODIS) were used to detect the dust-storm pathways and the affected areas in south Asia. Recently, Ekhtesasi and Gohari (2013) attempted to detect the areas affected by Sistan dust storms using satellite imagery under different wind speeds and advanced statistical data. However, the satellite imagery was limited at regional scale and, therefore, they did not examine the transport of dust over longer distances; an issue that is examined in the current work by analyzing the transport pathways and the altitudinal variation of 5-day forward air-mass trajectories via the HYSPLIT model. The results help predict the occurrence and pathways of the dust storms, enabling the warning for preventing local population of being affected and contribute to the atmospheric models describing the dust life cycle over southwest Asia.

2. Study region

Middleton (1986) highlighted the border areas between Iran, Pakistan and Afghanistan as the main dust source region in southwest Asia generating about 81 dust storms on annual basis, from which more than 30 were reported as being sourced over Sistan (see Fig. 1). The greatest dust activity in Sistan basin occurs near a system of ephemeral, marshy and shallow (<4 m depth) lakes (Hamouns) in the northern part of the basin surrounded by arid-rocky mountains to its north and west (Rashki et al., 2012). The Sistan/Hamoun lowlands are associated with drainage features, high rate of evaporation, sedimentation process and extensive salt deposits due to Helmand river inflow, making the lakes very vulnerable to be converted into dry lands during the hot-arid months of the year (June to September). The main characteristic in the Sistan region is the intense wind "Levar or 120-days wind" blowing from northern directions during the summer (June–September) period (Alizadeh Choobari et al., 2013) and enhances soil erosion and the weathering of sediments, making them good sources of fine-grained suspended dust often creating massive sand and dust storms over Sistan (Rashki et al., 2013c). Except of the serious effects on human health (PM_{10} concentrations usually above 1000 $\mu g\ m^{-3}$, Rashki et al., 2012), the dryness of the lakes and the associated dust storms create significant economic loss in the Sistan region (Sharifikia, 2013). Except of the above-mentioned studies, the meteorological and geomorphological features of Sistan and the significant role of the water-coverage in the Hamoun lake beds on dust activity, human health and ecosystems are highlighted in the United Nations Environment Programme (UNEP, 2006) report indicating the importance of the region in several environmental and atmospheric issues.

3. Methodology and datasets

The current work is initially based on the identification of dust-storm days during the summer months (June–September) over the period 2001–2012, as days with visibility <1 km at Zabol meteorological station (31.2°N, 61.3°E), located 10–20 km from the Hamoun dry-bed lakes (Fig. 1). The threshold of 1 km for the definition of dust storms is based on WMO (2005) classification and conventional usage in previous studies as well (Middleton, 1986; Engelstaedter et al., 2003; Mahowald et al., 2007; Rezazadeh et al., 2013). Focusing on the dust-storm days, various satellite observations and HYSPLIT forward trajectories have been used in order to examine the transport pathways of the dust plumes, the affected areas and the influence that the Sistan dust storms have over the Arabian Sea.

3.1. Satellite observations

The Aerosol Index (AI) values obtained via Earth Probe-TOMS (Total Ozone Mapping Spectrometer, version 8 algorithm) during the period 2001–2005 ($1° \times 1.25°$ spatial resolution) and the Aura-OMI (Ozone Monitoring Instrument) Level-2G (OMTO3, Version 003) at $0.25° \times 0.25°$ spatial resolution (period 2006–2012) were analyzed over south Asia during the dust-storm days. AI is a qualitative indicator of UV absorbing aerosols, such as smoke and mineral dust, and is especially suitable for detecting the pres-