Aeolian Research 18 (2015) 83–97

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Meteorological regimes modulating dust outbreaks in southwest Asia: The role of pressure anomaly and Inter-Tropical Convergence Zone on the 1–3 July 2014 case

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ARTICLE INFO

Article history:
Received 25 March 2015
Revised 8 June 2015
Accepted 11 June 2015

Keywords:
Dust storm
Karakum desert
MSLP anomalies
Vertical dust distribution
ITCZ position
SW Asia

ABSTRACT

The present work examines the characteristics (source regions, pathways, vertical profiles) as well as the meteorological conditions and the role of the Inter-Tropical Convergence Zone (ITCZ) during a dust event on 1–3 July 2014 over southwest (SW) Asia. NCEP/NCAR reanalysis, meteorological and satellite remote sensing (MODIS, Meteosat, CALIPSO) observations are utilized. The major dust storm (AOD_{550} up to 1.5–2.0) was generated in the southern Karakum desert in Turkmenistan as a result of intense north winds (Levar), due to enhanced pressure gradient between the Caspian Sea and Hindu Kush Mountains. The dust storm was vertically extended up to 5 km over the arid terrain of SW Asia, as a consequence of the deep mixing layer and increased convection, while over northern Arabian Sea it was mixed with another dust plume coming from Arabia and marine aerosols due to strong monsoon winds within the boundary layer. The regional topography, variations in pressure, monsoon circulation and the position of the ITCZ play a decisive role on modulation of the wind field, dust-storm pathways and vertical distribution of dust. Enhanced knowledge of atmospheric circulation and processes responsible for dust export over SW Asia and Arabian Sea in linkage to the Levar wind and Indian summer monsoon is essential for improving dust forecasts and simulations over the region.

1. Introduction

The dust lifecycle is of high scientific interest for issues related to impacts on atmospheric chemistry, cloud microphysics, radiative forcing, hydrological cycle, ocean productivity, ecosystems, climate change and human health (Middleton and Goudie, 2001; Engelstaedter et al., 2006; Singh et al., 2008; Shao et al., 2011; Knippertz and Todd, 2012; Goudie, 2013, among many others). The regional/global meteorological and climatic factors are modulated by dust and, in turn, may influence dust emissions, transport and deposition rates (Schepanski et al., 2009; Basart et al., 2012; Pey et al., 2013; Fiedler et al., 2014; Salvador et al., 2014), thus leading to a strong linkage between synoptic/dynamic meteorology and dust life cycle (Mahowald et al., 2005; Washington and Todd, 2005; Todd et al., 2008; Bou Karam et al., 2010; Calastrini et al., 2012; Cavazos-Guerra and Todd, 2012; Marsham et al., 2014). Sand/dust storms are generated by soil erosion under surface winds, with velocity above a certain threshold, which is a function of meteorological (temperature, rainfall, evaporation) and edaphic (vegetation cover, soil composition, texture and moisture, roughness) characteristics (Marticorena et al., 1997; Engelstaedter et al., 2006; Bullard et al., 2011). Passive and active satellite remote sensing is an increasingly available technique for detection of dust sources, plume characteristics and transport pathways (Schepanski et al., 2007; Kahn et al., 2009; Baddock et al., 2009; Klüser and Schepanski, 2009; Israelevich et al., 2012; Mona et al., 2012; Shahraiyni et al., 2014) and strongly supports extensive field measurements over desert environments (Christopher et al., 2011; Todd et al., 2013).

Approximately 60–70% of the Iran, Afghanistan and southern Pakistan landscapes are arid, semi-arid areas that are prone to intense sand/dust storms under favorable edaphic and atmospheric conditions, i.e. dried soil, intense surface winds, thermal lows and enhanced convection (Alizadeh Choobari et al., 2014). The most active dust sources in southwest (SW) Asia are associated

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http://dx.doi.org/10.1016/j.aeolia.2015.06.006
1875-9637/

with closed topographic-low basins surrounded by mountains, i.e. Dasht-e Kavir and Dasht-e Lut deserts in Iran, Margo and Registan deserts in SW Afghanistan, as well as with ephemeral dry-bed lakes, like Hamouns in Sistan (east Iran), Jaz-Mourian lake at the southern edge of Dasht-e Lut, Hamoun-e Mashkel in western Pakistan and valleys along the coastal Makran Mountains (Goudie and Middleton, 2006, Fig. 1). SW Asia usually suffers from intense sand and dust storms during the summer period that cause serious environmental, climatic, economical and human-health hazards (Rashki et al., 2012, 2013a; Sharifikia, 2013). The knowledge of the dust-source regions, dust-plume pathways and the atmospheric circulation patterns that are associated with sand/dust storms is of great importance for issuing sufficient and timely warnings to the public (Akhlaq et al., 2012). Although dust storms over SW Asia mostly originate from the Sistan basin (Middleton, 1986a; Rezazadeh et al., 2013), under specific circumstances the region is under the influence of extensive dust storms originating from Karakum desert in southern Turkmenistan. Karakum desert is responsible for ~62 dusty days per year (Orlovsky et al., 2005; Goudie and Middleton, 2006), although lower number of dust storms was reported by Middleton (1986b), that mostly affect the northeastern part of Iran along to Afghanistan borders, as well as the SW Pakistan and to a lesser extent the central and northwestern Iran (Masoumi et al., 2013).

During the last decades dust storms have increased in both frequency and intensity over southeastern Iran (Rashki et al., 2012) due to land use/land cover changes and decrease in soil productivity, leading the farmlands to be more abandoned and subject to natural desertification and erosion processes (Sharifikia, 2013). Recent studies (Alizadeh Choobari et al., 2013; Hamidi et al., 2013; Rashki et al., 2013b; Kaskaoutis et al., 2015) have shown that the dust activity over the region is a function of several parameters, such as regional and synoptic meteorology, topography, rainfall and lake's water coverage, soil moisture, surface wind and low-level jet (LLJ), boundary-layer dynamics and convective activity. Najafi et al. (2013) analyzed the influence of atmospheric circulation patterns on dust storms over Iraqi plains and Arabian Peninsula, while Mohalfi et al. (1998) reported a strengthening of the Saudi Arabian heat low due to dust-aerosol radiative heating. Jish Prakash et al. (2014) examined the atmospheric circulation and radiative impact of dust over the Arabian Peninsula during the intense dust storm of 18–20 March 2012, while similar studies have been performed by Maghrabi et al. (2011) and Saeed et al. (2013) for severe dust events. On the other hand, significant dust outflow from SW Asia and Arabia towards north Arabian Sea has been detected by satellite remote sensing (Prijith et al., 2013; Jish Prakash et al., 2014; Kaskaoutis et al., 2014), which may impact the atmospheric dynamics over south Asia and the summer monsoon rainfall (Solmon et al., 2015).

The present work examines the atmospheric circulation patterns over central/south Asia that are associated with continental dust export from southern Turkmenistan to Pakistan, Indus basin and northern Arabian Sea during 1–3 July 2014. Specific importance is given to the role of the anomalies in mean sea-level pressure (MSLP) and Inter-Tropical Convergence Zone (ITCZ) on modulating the dust emission, pathway, vertical distribution and long-range transport.

2. Data set

2.1. Meteorological dataset

Ground-based meteorological data from 10 stations, i.e. Mashhad [36.32°N, 59.6°E, 990 m], Sarakhs [36.32°N, 61.08°E, 235 m], Torbat e Jam [35.15°N, 60.35°E, 928 m], Khaaf [34.58°N, 60.15°E, 998 m], Nehbandan [31.53°N, 60.03°E, 1211 m], Zabol [31.2°N, 61.3°E, 490 m], Zahak [30.9°N, 61.68°E, 495 m], Zahedan [29.5°N, 60.9°E, 1370 m], Mirjave [29.01°N, 61.45°E, 894 m] and Saravan [27.33°N, 62.33°E, 1195]) along the eastern part of Iran (Fig. 1) have been analyzed during the dust-storm period, as well as during pre- and post-dust days. The meteorological data consist of air temperature at 2 m above ground level (agl), local atmospheric pressure, relative humidity (RH) at 2 m agl, wind speed and direction at 10 m agl and visibility (vis) corresponding to 3-h observations during the period 26 June–7 July 2014.

Atmospheric circulation patterns of MSLP, geopotential heights at 850 hPa (Z850) and 700 hPa (Z700), as well as wind vectors and meridional winds at 850 hPa are obtained from the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis project (Kalnay et al., 1996). The study of the NCEP/NCAR maps focuses on the daily composite means and the anomalies from the mean climatology (1981–2010) during the dust-storm period (1–3 July 2014). The maps cover the region 45° to 100°E and 5° to 50°N with 2.5° × 2.5° spatial resolution.

2.2. Satellite observations

MODIS imagery and aerosol retrievals have been used to identify the dust plume origin, transport pathway and affected areas.

Fig. 1. Locations of the 10 meteorological stations in eastern Iran. The main dust-source regions are shown in yellow, while the mountainous ranges in brown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)