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Dust emission and transport over Iraq associated with the summer Shamal winds

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ABSTRACT

In this study, we investigate the diurnal evolution of the summer Shamal wind (a quasi-permanent low-level northwesterly wind feature) and its role in dust emission and transport over Iraq, using ground-based and space-borne observations together with a numerical simulation performed with the mesoscale model meso-NH. A 6-year dataset from the synoptic stations over Iraq allows establishing the prominence of the link between strong near surface winds and reduced visibility in the summer. The detailed processes at play during Shamal events are explored on the basis of a meso-NH simulation for a given, representative case study (25 June–3 July 2010). The Shamal exhibits an out-of-phase relationship between the surface wind and winds in the lower troposphere (typically 500 m above ground level), the maximum surface wind speeds being observed during the day while in altitude the maximum wind speeds are observed at night. The daytime near surface winds, at the origin of dust emission, are associated with the downward transfer of momentum from the nocturnal low-level jet to the surface due to turbulent mixing after solar heating commences each day. For the first time, an estimate of the dust load associated with summer Shamal events over Iraq has been made using aerosol optical depths derived from the Spinning Enhanced Visible and Infrared Imager, the Moderate Resolution Imaging Spectroradiometer, and the simulation. The dust load exhibits a large diurnal variability, with a daily minimum value of 1 Tg around 0600 UTC and a daily peak of 2.5 Tg or more around 1500 UTC, and is driven by the diurnal cycle of the near surface wind speed. The daily dust load peak associated with the summer Shamal over Iraq is in the same order of magnitude as those derived from simulations downstream of the Bodélé depression in Chad, known to be the world's largest dust source.

1. Introduction

While analyzing the dynamical processes responsible for dust emission over Iran and surrounding countries, as well as the subsequent transport of dust toward northwest Iran, Abdi Vishkaee et al. (2011, 2012) have shown the prevalent influence of Shamal winds for dust mobilization in both summer and winter. The "Shamal" names strong northwesterly winds blowing over Iraq and in the Persian Gulf area during the summer (June to September) and the winter (November to March) (Perrone, 1979). While the summer Shamal blows almost continuously, winter Shamal events occur two to three times per month between December and early March (Rao et al., 2001a).

The summer Shamal blowing over Iraq and the Persian Gulf exhibits an out-of-phase relationship between the surface wind and winds in the lower troposphere (typically 300–700 m above ground level, agl), the maximum surface wind speeds being observed during the day while, above, the maximum wind speeds are observed at night. This night-time feature is what we call nocturnal low-level jet (LLJ) (Membery, 1983). This Shamal-related LLJ is primarily a thermal phenomenon which has recently been analyzed by Giannakopoulou and Toumi (2011) using mesoscale simulations. They show that the Blackadar (1957) mechanism appears to be secondary to the heating in forcing the LLJ. It has been well established in other parts of the world, notably Africa, that dust emissions over potential source areas (e.g. Kok et al. (2012)) are

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related to surface wind speed maxima which occur in the hours after sunrise (e.g. the example of the Bodélé depression; Washington and Todd, 2005). The phase shift in the diurnal cycle of the LLJ and surface winds is associated with the downward transfer of momentum from the nocturnal LLJ to the surface due to turbulent mixing after solar heating commences each day (Todd et al., 2008).

Dust events associated with summer Shamal can reduce visibilities to a few hundred meters (e.g. Rao et al. (2001a), Abdi Vishkaee et al. (2011)). The link between the formation of the low level jet, maximum surface winds and reduced visibilities due to dust mobilization in Iraq and the northern Persian Gulf has been highlighted by Wilkerson (1991). A description of the major climatic controls, mesoscale synoptic features, and the influence of topography that lead to the formation of the summer Shamal, the low level jet and dust mobilization in the Persian Gulf region can be found in Walters and Sjoberg (1988). Moreover, dust mobilization in Iraq has broader impacts than the local ones and can affect the entire Arabian Peninsula (e.g. Notaro et al. (2013)). For instance, Notaro et al. (2015) has demonstrated that the long-term drought and increased dust emission from Iraq largely contributes to the recent increase in dust activity across the Arabian Peninsula. Also, dust from Iraq associated with summer Shamal winds largely regulates the interannual variability in summertime dust activity across Saudi Arabia (Yu et al., 2015).

The first objective of this paper is to analyze the impact of the diurnal evolution of the summer Shamal winds on the dust emissions and transport over Iraq, using data from existing synoptic stations, satellite observations including the newly available aerosol optical depth (AOD) product from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) over this region and a numerical simulation performed with the mesoscale model meso-NH. The second objective is to provide a quantitative estimate of dust emissions and concentrations over Iraq during such an event on the basis of the meso-NH simulation and satellite-derived AODs for a representative case study (25 June–3 July 2010).

The paper is organized as follows: In section 2, the datasets utilized in this study are introduced. Section 3 gives an overview of the dust sources in Iraq. In Section 4 we show evidence of the link between strong Shamal winds and low surface visibility using a 6-year dataset of SYNOP stations in Iraq and Iran. Section 5 details the case study and give an estimate of the dust loads associated with Shamal-induced dust emissions based on space-borne observations and meso-NH numerical simulation. Section 6 provides a summary and conclusions.

2. Data

2.1. Regional networks

We use meteorological measurements provided by stations in Balad, Mosul and Tallil (Iraq) as well as Abadan (Iran) (see Fig. 1 and Table 1, available from http://weather.uwyo.edu/) for the period 2005–2010. These stations report 3-hourly surface data including pressure, temperature, humidity, and wind speed and direction. The visibility observations in Iraq are taken by observers looking at landmarks (also see Abdi Vishkaee et al. (2012) for further discussion on this). In this paper, dust storms are considered to be associated with visibility values of 3.5 km or less, as in Liu et al. (2007) and Walker et al. (2009) for the same region. For a given station, this threshold value on visibility allows to account for both strong dust events occurring near dust source regions in Iraq (characterized by visibilities less than 1 km, Middleton (1986b)) and events resulting from long-range transports (for which visibilities are in the range 2–9 km, e.g. Mahowald et al. (2007)). In the case of propagating dust storms, the arrival of airborne dust at a given site is generally associated with a significant decrease in visibility and increase in wind speed.

2.2. Space-borne observations

The distribution of dust aerosols at regional scale (mobilization and transport) is described using three satellite products. The Moderate Resolution Imaging Spectroradiometer (MODIS) fields of AOD are obtained from the MODIS/AQUA MYD08 (collection D3.051) daily level 3 products. Two AOD products at 550 nm are used: the AOD processed with deep blue algorithm (Hsu et al., 2004) over desert surfaces and the standard product processed over dark surfaces. Both are available from the Giovanni Web portal (http://disc.sci.gsfc.nasa.gov/giovanni). We use the level 3, gridded ($1^\circ \times 1^\circ$) daily products, representative of the aerosol load around 1:30am/pm equator crossing time. Sayer et al. (2013) and Banks et al. (2013) have shown that AODs derived from Deep Blue AQUA collection 6 data compared well with AERONET (generally within 20–25%) over the Sahara and the Arabian Peninsula. The uncertainty estimate for MODIS Deep blue Collection is in the order of ±0.2 as detailed in Sayer et al., 2013.

In this paper, satellite observations of dust over Iraq have been made, for the first time, using SEVIRI in geostationary orbit aboard Meteosat-9 (Schmetz et al., 2002) above 0°N/0°E. SEVIRI provides observations every 15 min in 11 channels in the visible and infared. At nadir, the spatial sampling rate is 3 km, over Iraq this increases to ~5.5 km. Iraq is towards the limb of SEVIRI's field-of-view, so over much of the country the viewing zenith angles are greater than 60°. SEVIRI AOD retrievals over desert and arid regions (Brindley and Russell, 2009; Banks and Brindley, 2013) are attempted where the solar and viewing zenith angles are less than 70°, so over Iraq the last measurements each day are made at 1400 UTC. Dust AOD retrievals are made in a three-stage process, starting by screening pixels as being dusty and/or cloudy (Derrien and Le Gléau, 2005). The next step is to calculate a 'pristine-sky' (Brindley, 2007) value of the brightness temperature at 10.8 μm ($T_{B108dfe}$) for each timeslot, and hence to calculate the instantaneous variation ΔT_{B108} from the pristine-sky values. Adjustments are made to account for variability in the column water vapour and skin temperature, which will also impact on the observed brightness temperature. Finally, the AOD at 550 nm at the pixel-scale is derived using a simulated relationship between $\Delta T_{B108}/\Delta T_{B134}$ and AOD (Brindley and Russell, 2009). Validation against AERONET measurements from six sites over a three-year period indicates that root-mean-square differences vary from 0.19 to 0.46 (Banks and Brindley, 2013). Banks et al., 2013 estimated the uncertainty associated with SEVIRI AODs retrievals over the study area to be on the order of ±0.1.

Finally, the vertical distribution of the aerosols is documented over the Persian Gulf region using the space-borne Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) (Winker et al., 2007) on board the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. CALIOP-derived profiles of particle extinction coefficient (at 532 nm) are obtained from our own calculation (using level 1B version 3.01 data) as that by Cuesta et al. (2009), with a vertical resolution of 60 m and a horizontal resolution of roughly 12 km. We expect the uncertainty on the extinction coefficient and on the AOD to be on the order of 30% (and may be greater for AOD greater than 2), accounting for an uncertainty of 20% on both the backscatter-to-extinction ratio and the multiple scattering coefficients. Data from two daytime overpasses are used to analyze the case: on 30 June 2010 and on 2 July 2010. The data is available through the ICARE Web portal (http://www.icare.univ-lille1.fr).