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A rare case of haboob in Tehran: Observational and numerical study

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ABSTRACT

A great dust storm occurred in Tehran on 2 June 2014 and caused severe damage to properties and involved loss of human life. From the visual evidence available, it can be regarded as a case of haboob. As a lower latitude phenomenon, its occurrence in Tehran was unprecedented in the last 50 years.
This paper aims to present a detailed analysis of the weather conditions, the pathways by which dust particles were ingested by the haboob, as well as the impact of the urban boundary layer on the intensity and propagation of the dust storm. Using numerical simulation carried out by the WRF-Chem model and various observational techniques, the coupling of a low-level small-scale deformation field with a lower-tropospheric cold pool produced by precipitating mid-tropospheric clouds is identified as the main process involved in shaping this rare dust storm.

1. Introduction

Dust storms are important sources of global atmospheric aerosol particles (Westphal et al., 1987; Prospero, 1999) and dust is the most abundant aerosol species in the atmosphere, with global emission estimates ranging from 1000 to 3000 $Tg(yr)^{-1}$ (Houghton et al., 2001). A notable example is the dust storm produced by precipitating convective clouds over regions where surface particles are easily lifted by the wind. Observational studies have found large concentrations of dust within convectively active regions (Levin et al. 1996; DeMott et al., 2003; Jensen et al., 2004; Twohy et al., 2009). Further, observational (Marsham et al., 2008b, 2013) and modeling studies (Heinold et al., 2013) suggest that a large fraction of dust emission over the Sahara in summer is due to convective dust storms. These mesoscale dust storms are better known as "haboob" (e.g., Sutton, 1925; Lawson, 1971; Membery, 1985; Roberts and Knippertz, 2012). Haboobs occur most often across the major deserts of Southwest Asia, Africa (Knippertz et al., 2007; Williams et al., 2009), and Australia (Mctainsh et al., 2005). They are characterized by a sharp fall in temperature, a sudden strong wind often followed by rain, fluctuation in air pressure and rise of relative humidity (Sutton, 1931).

Haboobs occur when downdrafts from convective storms reach the ground and spread out. The cold air spreading away from its parent storm is known as convectively-generated cold pool (Flamant et al., 2007; Cuesta et al., 2010; Marsham et al., 2008a, b, 2013; Garcia-Carreras et al., 2013; Roberts and Knippertz, 2014), and when it flows over a surface with easily-lifted material, the gust front blows up dust from surface into a wall that forms the leading edge of a haboob. A cold pool generated by the initial storm propagating in a sheared environment will have an enhanced gust-front height. Sutton (1925) suggests an average height of 1 and 2 km for these dust walls. However, only a few studies have presented the lifting of dust by the cold pool in order to understand its impacts on parent convection (Tulet et al., 2010; Van den Heever et al., 2006, 2011; Zubler et al., 2011). Hales (1975) used satellite and radar data, along with ground measurements from synoptic stations, to produce detailed explanations of a severe case of desert thunderstorm in the southwest of the US. This was carried out despite the fact that in satellite observations dust is often masked by the convective clouds (Heinold et al., 2013; Kocha et al., 2013). A general lack of observations of the haboob environment prior to its formation, during its life span and after its demise inhibits full understanding of the haboob process especially in the Middle East where severe haboobs cause significant damage every year. Forecasting convection under conditions of weak synoptic-scale forcing (e.g., Jankov and Gallus, 2004) and unavailability of high spatial resolution information characterizing the environmental state in this region, make it difficult to resolve the small-scale circulations and sharp gradients associated with the haboobs. Furthermore, most operational models lack convective dust storms (Marsham et al., 2011; Garcia-Carreras et al., 2013), since they do not explicitly resolve convection and rely on parameterization schemes. Also the sensitivity to initial condition of numerical weather prediction simulations (Birch et al., 2013; Schepanski et al., 2015) make the model outputs more uncertain than what is required for the accurate representation of convective dust storms.

A great dust storm occurred in Tehran on 2 June 2014 and caused severe damage to properties and involved loss of human life. From the visual evidence available from this phenomenon (Fig. 1) and other

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Fig. 1. An image of the dust storm in Tehran on 2 June 2014.
(Photo is taken from IRNA news website. www.irna.ir).

evidences presented in the current study, it can be regarded as a case of haboob. The goal of this paper is to gain a better understanding of the weather conditions and the pathways by which dust particles were ingested by haboob and to study the urban effect on intensity and propagation of the dust storm. The WRF-Chem model is used for the numerical simulation of this haboob. Some issues of the simulation are very

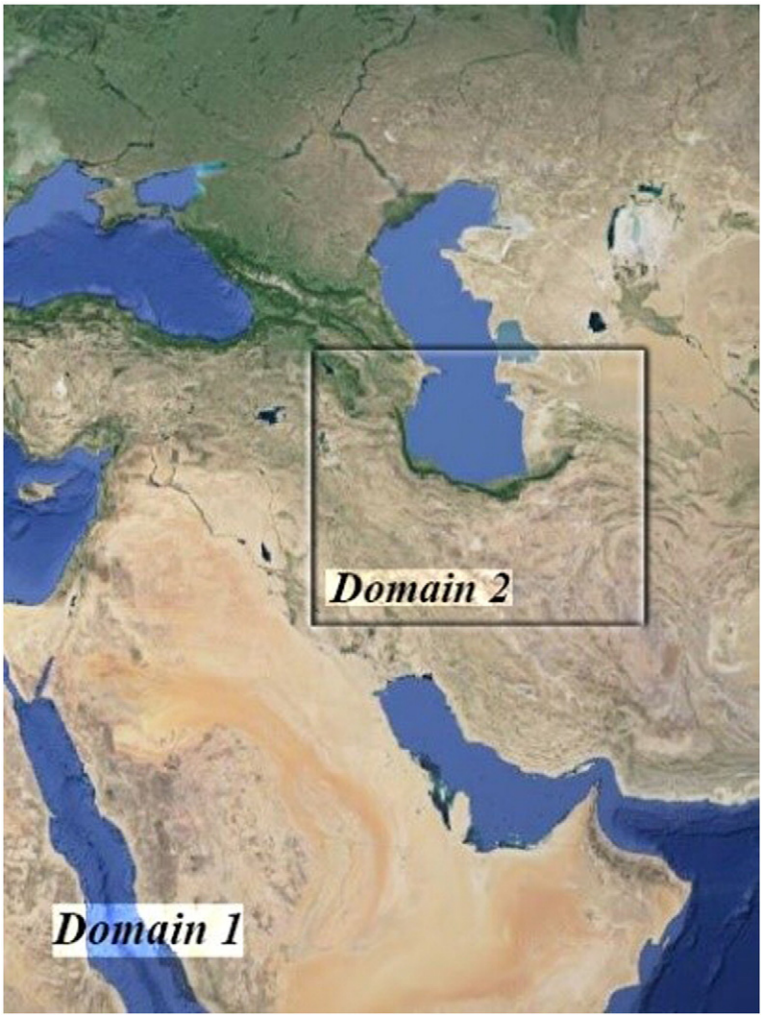

Fig. 2. Model domains with 30 and 10 km resolutions.