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Modeling of foehn-induced extreme local dust pollution in the Dead Sea valley

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Abstract

Using high-resolution COSMO-ART model simulations, a foehn phenomenon and foehn-induced effects on extreme local dust pollution on 22 March 2013 were analyzed over the Judean Mountains (~1000 m) and over the Dead Sea valley (-420 m). The model data were supplemented with in situ meteorological measurements from a chain of stations located across the mountain ridge. Hot foehn winds created a pronounced temperature inversion over the western part of the valley. Strong foehn winds activated local dust sources, while the foehn-induced pronounced temperature inversion trapped dust particles beneath the inversion. These trapped local dust particles contributed to maximum surface dust concentration but not to dust aerosol optical depth (AOD) in the western Dead Sea valley. By contrast, in the central and eastern Dead Sea valley, in the absence of temperature inversion, the ascending airflow lifted dust particles up to 2-km altitude, contributing to the maximum local dust AOD. Thus, it was because of the temperature inversion in the western Dead Sea valley that the maximum surface dust concentration did not coincide with the maximum AOD. This lack of coincidence indicates difficulties in using satellite-based AOD for initializing dust concentration within numerical forecast systems over a region with complex mountain terrain.

1 Introduction

The Dead Sea valley is a unique place because of its location at ~400 m below sea level. This deep valley is flanked by relatively high mountains of ~1000 m above sea level: by the Judean Mountains to the west and by the Moab Mountains to the east. High-resolution modeling is particularly important for this area with complex terrain, unsteady winds, and frequent intrusions of Saharan dust. This study focuses on extreme local dust pollution produced by strong foehn winds in the Dead Sea valley on March 22, 2013. We simulated this foehn phenomenon, as well as its effects on dust distribution, with a comprehensive online-coupled weather forecast model COSMO-ART (Vogel et al., 2009**.** Reasonable agreement was found between the simulated meteorological variables and the observations (Kishcha et al. 2016). The model also reproduced the spatiotemporal distribution of dust concentration, consistent with available measurements, in the Dead Sea valley and the surrounding areas (Kishcha et al. 2017). Our two major findings are: first, that strong foehn winds activated local dust sources, and second, that foehn-induced pronounced temperature inversion trapped dust particles beneath the inversion. These two factors caused measured extreme dust concentrations of ~7000 $\mu g\ m^{-3}$, which are two orders of magnitude higher than the annual mean surface dust concentration in the Dead Sea valley (Kishcha et al. 2016).

2 Method

To simulate the foehn-like phenomenon on March 22, 2013, and its effects on dust distribution over the Dead Sea valley, a comprehensive online-coupled weather forecast model COSMO-ART was used (Vogel et al., 2009, Kishcha et al., 2017). Dust productive areas in COSMO-ART are defined by soil properties (particle size distribution, residual soil moisture and surface roughness) and environmental conditions (friction velocity, soil moisture). A data set of soil properties by Marticorena et al. (1997) and Callot et al. (2000) covering the Sahara, the Sahel, the Arabian Peninsula and the Middle East was used in the model. The emission scheme of Vogel et al. (2006) combines the formulation of White (1979) for the horizontal saltation flux of soil particles with the parameterization of Shao and Lu (2000) for the threshold friction velocity of wind erosion.

3 Results and discussion

The obtained results on the foehn phenomenon and foehn-induced effects on observed extreme dust pollution in the Dead Sea valley are described in detail by Kishcha et al. (2016, 2017).

The foehn phenomenon in the Dead Sea valley. On March 22, 2013, an intensive low-pressure system over the Eastern Mediterranean created favorable conditions for dust transport from the Eastern Sahara into the Eastern Mediterranean. The following shift of this cyclone eastward was accompanied by strong west winds blowing across the ridge of the Judean Mountains towards the Dead Sea valley. As shown by Kishcha et al. (2016), both horizontal and vertical wind components significantly increased on the downwind side of the mountains, compared to the winds on the upwind side. Specifically, horizontal winds on the downwind side of the Judean Mts. were two times stronger than horizontal winds on the upwind side. The model showed that the increase in wind speed was accompanied by air heating in the valley and by air cooling on the top of the Judean Mts.

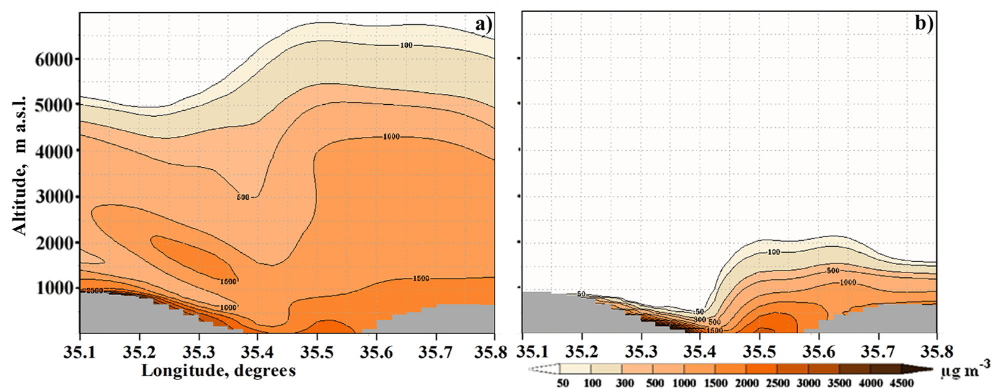

Figure 1. West-east cross-sections of modeled dust concentration for two model experiments: when (a) local dust sources in the valley were excluded, and when (b) only local dust sources in the valley were included.

In the Dead Sea valley, on 22 March, the air became warmer because of the adiabatic downward movement along the lee side of the Judean Mts. The temperature difference between the valley and the top of the Judean Mts. exceeded 16°C. The significant air heating in the valley was accompanied by a considerable decrease in relative humidity from 40% to ~20%. The air-cooling on the top of the Judean Mts. was accompanied by an increase in relative humidity exceeded 90%. This suggests a possibility of some light rainfall. Available radar measurements of rainfall rate supported these model results providing observational evidence of light rainfall amounts on the upwind side of the Judean Mts. (Kishcha et al., 2016). The adiabatic heating by the downward foehn winds in the valley caused the upward airflow there. All the above-mentioned facts are indicative of the presence of a foehn phenomenon in the Dead Sea valley. Thus, the foehn phenomenon could be significant even over the relatively low Judean Mountains of approximately 1-km height.

Foehn effects on dust. two model experiments were conducted in order to determine separately the contribution of local dust sources to the dust distribution over the Dead Sea valley and that of remote dust sources (Fig. 1). In the first experiment local dust sources in the valley were excluded, while in the second experiment only local dust sources in the valley were included. Being transported by west winds from the upwind side of the Judean Mts., the remote dust was mainly responsible for the vertical dust distribution up to 7 km height over the Dead Sea valley (Fig. 1a). The local dust sources in the valley were mainly responsible for the extreme near-surface dust concentration and only slightly contributed to dust concentration at high altitude (Fig. 1b).

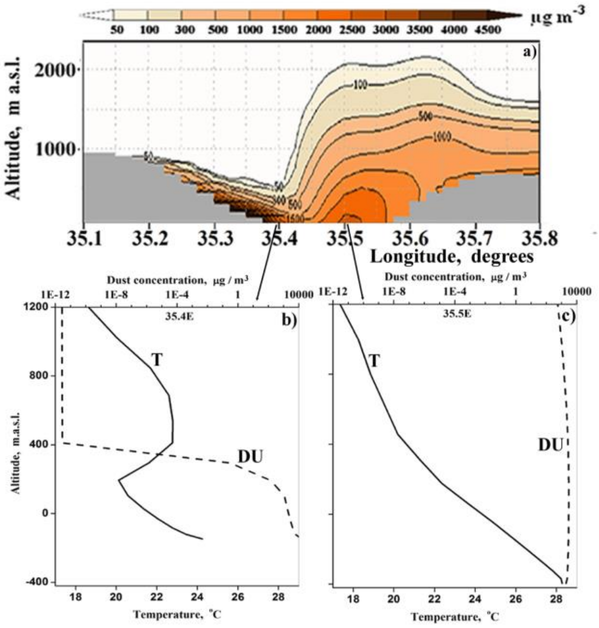

Figure 2. a – vertical distribution of modeled dust concentration from local sources within west-east cross-section over the Dead Sea valley at 31.6°N. b – modeled vertical profiles of temperature (T) and dust concentration (DU) at longitude 35.4°E of maximal surface dust concentration (elevation -157 m). c – the same as in b but for longitude 35.5°E of maximal dust AOD (elevation -405 m).

Being associated with the foehn-like phenomenon, the strong horizontal winds on the downwind side of the Judean Mts. were capable of activating local dust sources, contributing to the strong maximum in surface dust concentration in the western the Dead Sea valley (Fig. 2a). The model shows that, in the western Dead Sea valley, dust was located near the surface, while, in the central and eastern Dead Sea valley, dust particles were lifted up to two kilometers altitude. Such vertical distribution was determined by a foehn-induced pronounced temperature inversion in the western Dead Sea valley (Fig. 2b). This temperature inversion trapped dust particles beneath the inversion. This led to the extremely high near-surface dust concentration in the western Dead Sea valley (Fig. 2b). By contrast, in the central and eastern Dead Sea valley there was no temperature inversion (Fig. 2c). In the absence of temperature inversion, the ascending airflow lifted local dust particles up to 2-km altitude (Fig. 2a), contributing to the maximum local dust aerosol optical depth (AOD). As discussed by Kishcha et al. (2016), it was because of the temperature inversion, that maximum surface dust concentration (located in the western Dead Sea valley) did not coincide with the maximum dust AOD (located in the central Dead Sea valley). This is one of the specific effects of the foehn phenomenon on local dust pollution in the Dead Sea valley.

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