Global and Planetary Change 100 (2013) 333–342

Contents lists available at SciVerse ScienceDirect

Global and Planetary Change

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

Analysis of Saharan dust intrusions into the Carpathian Basin (Central Europe) over the period of 1979–2011

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ARTICLE INFO

Article history:
Received 4 July 2012
Accepted 16 November 2012
Available online 24 November 2012

Keywords:
mineral dust
dust storm
meteorology
Sahara
Carpathian Basin

ABSTRACT

Aeolian dust particles and dust storms play substantial role in climatic and other environmental processes of the Earth system. The largest and most important dust source areas are situated in the Sahara, from where several hundred thousand tons of mineral dust is emitted each year and transported towards the European continent. Here we show that 130 Saharan dust events (SDEs) reached the atmosphere of the Carpathian Basin from 1979 to 2011 by using the NASA's daily TOMS Aerosol Index data, satellite images and backward trajectory calculations of NOAA HYSPLIT model. Monthly trends of dust events demonstrate that the main period of dust transportation is in the spring, with a secondary maximum in the summer (in July and August). This seasonal distribution match well the seasonality of Saharan dust emissions. However synoptic meteorological conditions govern primarily the occurrence of long-range dust transport towards Central Europe. Based on their different meteorological backgrounds (geopotential field, wind vector and meridional flow), SDEs were classified into three main types. By using composite mean maps of synoptic situations and backward trajectories, the possible source areas have also been identified for the different types of events. Finally, we provide a short discussion on how the African mineral dust could contribute to the local aeolian sedimentation of the Carpathian Basin during the Plio-Pleistocene.

1. Introduction

Dust storms and related atmospheric mineral particles have been in the focus of environmental and climatic studies for the last two decades (Stout et al., 2009). Previous investigations confirmed that windblown dust is an active component of the climate system, and can modify its elements via both direct and indirect effects (Harrison et al., 2001; Kohfeld and Tegen, 2007; Maher et al., 2010; Pósfai and Buseck, 2010). Dust particles affect the Earth's energy balance directly through absorption, scattering and reflection of incoming shortwave and outgoing longwave radiation or by changing the albedo of (bright) surfaces (e.g. Arimoto, 2001). Indirectly, by acting as cloud condensation nuclei, mineral particles have also an effect on atmospheric moisture balance (Rosenfeld et al., 2001; Sassen et al., 2003). Particles rich in Fe have major impact on iron-limited oceanic ecosystems, and thus, dust can influence the primary phytoplankton production and the carbon cycle through biogeochemical interactions (Ridgwell, 2002).

The global annual input of mineral dust deflated from arid-semiarid areas can be set in the range between 1 and 3 billion of tons (Tegen et al., 1996; Mahowald et al., 1999; Ginoux et al., 2001; Mahowald et al., 2006). Most important sources are situated in Saharan and Sahel regions, which are responsible for 50–70% of the global emission (Ginoux et al., 2001; Miller et al., 2004). Four main pathways of Saharan dust transport can be distinguished: (1) southward to Gulf of Guinea; (2) westward over the North Atlantic Ocean; (3) eastward to Middle East; and (4) northward to Europe (for more details, see Engelstaedter et al., 2006; Goudie and Middleton, 2006).

The several hundred thousand tons of dust derived from Saharan sources influence numerous constituents of European environmental systems (D'Almeida, 1986; Prospero, 1996). During heavy dust-outbreaks, atmospheric dust concentration often exceed PM_{10} standards of the European Union in Spain (Rodríguez et al., 2001), in Italy (Matassoni et al., 2011) and in Greece (Gerasopoulos et al., 2006), thereby affecting human health (Griffin et al., 2001). The strongly alkaline dust particles increase the pH of precipitation, thus reduce the frequency of acid rains (Roda et al., 1993; Rogora et al., 2004; Špoler Čanić et al., 2009). As proposed by Psenner (1999), permanent Saharan dust contributions to low-alkalinity European lakes prevented them to become acidic during the late twentieth century. The accumulated dust particles are even capable of modifying soil properties of a given region (Yaalon, 1997). As such, terra rossa soils in Portugal (Jahn et al., 1991), in Spain (Muhs et al., 2010), in Italy (Jackson et al., 1982), in Croatia

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http://dx.doi.org/10.1016/j.gloplacha.2012.11.007

(Durn et al., 1999), in Greece (MacLeod, 1980) and in Turkey (Atalay, 1997) have been shown to be an alteration product of local material and far-travelled African mineral dust.

Fine-grained particles lift to higher levels of the atmosphere and have a long atmospheric residence time up to a few weeks (Pye, 1987). Aeolian dust from North Africa can often be detected in Europe's high-latitude areas e.g. in British Isles (Wheeler, 1986), in Germany (Klein et al., 2010), in Scandinavia (Franzén et al., 1994; Barkan and Alpert, 2010) and even in our study area, the Carpathian Basin (CB) (Central Europe) (Borbély-Kiss et al., 2004; Koltay et al., 2006; Szoboszlai et al., 2009). Nowadays the CB is generally not regarded as a dusty place, except for episodic dust storms related to cold fronts invading the region at the beginning of the vegetation period in the early spring. Still, Central Europe is lying in the D1b zone of the "Saharan dust-fall map" of Stuut et al. (2009), implying that recent Saharan dust material can be incorporated into the soil system and may increase its fine silt content (Stuut et al., 2009). However, dust activity of the region was much more significant during the Plio–Pleistocene periods, as it is shown by thick aeolian dust deposits covering more than half of the area (e.g. Pécsi and Schweitzer, 1993; Kovács et al., 2008; Újvári et al., 2010; Kovács et al., 2011; Varga, 2011). It has been recognized that mineral dust particles of these aeolian sediments originate mainly from local sources (e.g. alluvial plains), and only the clay and fine-silt fractions may be linked to Saharan sources (Rózycki, 1991; Rousseau et al., 2007; Újvári et al., 2012), similarly to Italian loess deposits (Cremaschi, 1990a, 1990b).

The present paper is aimed at providing information on the frequency and seasonality of recent Saharan dust intrusions that can reach the CB atmosphere. Besides, our goal is to define the mean synoptic situations, typical transport pathways and source areas of this airborne mineral dust material.

2. Methods

2.1. Establishment of spatial and temporal changes of atmospheric dust using the TOMS Aerosol Index

Satellites represent the only data source with truly global coverage on most important dust source areas and their emissions. For this study the Total Ozone Mapping Spectrometer's (TOMS) aerosol data were employed to estimate atmospheric dust amount. The TOMS aerosol index, as defined by the NASA/GSFC Ozone Processing Team, is a measure of how much the wavelength dependence of backscattered UV radiation from an atmosphere containing aerosols (Mie scattering, Rayleigh scattering, and absorption) differs from that of a pure molecular atmosphere (pure Rayleigh scattering). Quantitatively, the aerosol index AI is defined as

$$AI = 100\log_{10}\left(\frac{I_{360}^{\mathrm{meas}}}{I_{360}^{\mathrm{calc}}}\right), \qquad (1)$$

where I_{360}^{meas} is the measured 360 nm TOMS radiance, and I_{360}^{calc} is the calculated 360 nm TOMS radiance for a Rayleigh atmosphere (Herman et al., 1997). The TOMS sensors (on board of different sun-synchronous NASA satellites) have the longest available global record (since 1978 November) with appropriate spatial (1×1.25 degree) and temporal (daily) resolution (Herman et al., 1997; Torres et al., 1998).

Analyses of daily data-matrices were performed in MathWorks' MATLAB (R2007b) environment, while kriging of maps was processed in Golden Software SURFER 8 (Fig. 1). The fractional data of 1993 and 1996 (caused by satellite failure), the periods with calibration problems of 2001–2004 (Kiss et al., 2007) and 2010–2011, and the four-yearly leap days (due to the matrix-operations) were excluded from the long-term mean mapping analyses (Table 1). Some few dates have not been either available within other periods, so these were replaced by mean values of previous days.

2.2. Identification of Saharan dust events (SDE) over the Carpathian Basin

The daily TOMS AI values of the investigation area (45°–48.5°N, 16°–23°E) were standardized following the work of Barkan et al. (2005):

$$\mathrm{AI}_{\mathrm{st}} = \frac{(\mathrm{AI}-\mathrm{AI}_{\mathrm{mean}})}{\sigma_{\mathrm{AI}}}, \qquad (2)$$

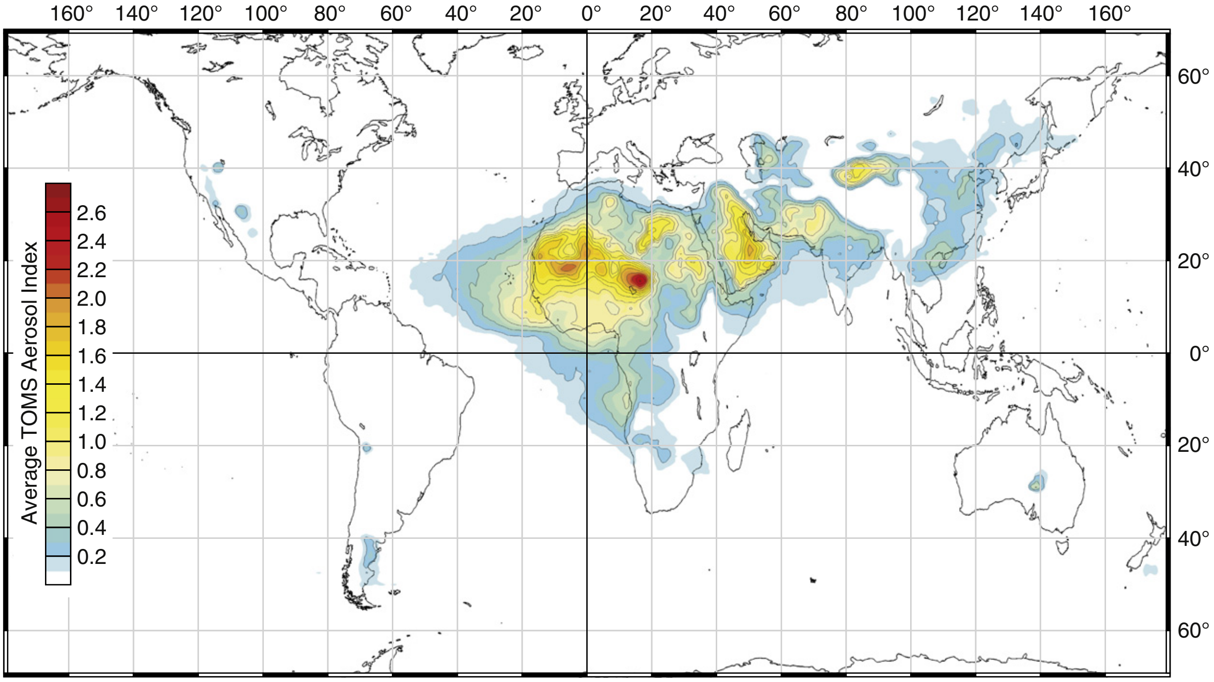

Fig. 1. Mean global TOMS AI map of the investigated 23 full years from 1979 to 2009.