

GEOGRAPHICAL DISTRIBUTION AND GEOMORPHOLOGICAL CHARACTERISTICS OF MAJOR GLOBAL DUST SOURCE AREAS

VARGA, GYÖRGY –BRADÁK, BALÁZS –SZEBERÉNYI, JÓZSEF

Abstract

Satellite measurements provide useful information on mineral aerosol content of the atmosphere and on distribution of dust source regions. The NASA Total Ozone Mapping Spectrometer's (TOMS) and Ozone Monitoring Instrument's (OMI) Aerosol Index measurements (on board of different sun-synchronous satellites) have the longest (since November 1978) available global record with appropriate spatial (1×1.25 and 1×1 degree) and temporal (daily) resolution. The data-matrix was analysed by a self-developed mathematical-statistical MATLAB algorithm to attain information on situation and inter-annual and seasonal activity of major dust hot-spot areas. The compiled average aerosol maps show that the most important sources are situated mainly in the desert, semi-desert regions of North Africa, Middle East and Central Asia creating a more or less continuous area, called "Global Dust Belt". The frequency and magnitude of dust emission outside the dust belt is relatively low, and is concentrated in small distinct areas. In general, the temporal activity of source regions has an obvious seasonal pattern with a spring-summer maximum. Based on the systematic analyses of geographical distribution, it can be stated that major sources are associated to specific geomorphological environments. These can be connected to geomorphological depressions, ephemeral streams or wadi-systems and to alluvial fans. The fine-grained material of most of the sources was accumulated in some kind of fluvial or lacustrine environment with a certain Pleistocene pluvial history, which acts as a dust source area after the desiccation.

Keywords: dust storm; mineral dust; deflation; geomorphology

Introduction

Atmospheric particulate matter emission of arid and semiarid areas by dust storms is a special kind of (wind) erosion. The amount of deflated mineral particles, smaller than $62.5 \mu\text{m}$ in diameter can be set into the range of 1 to 3 billion of tons annually (TEGEN, I. et al. 1996; GINOUX, P.M. et al. 2001; ZENDER, C.S. et al. 2003). This huge amount of emitted dust can lead to severe land degradation of agricultural areas and has a negative impact on air quality (PYE, K. 1987; GOUDIE, A.S. – MIDDLETON, N.J. 2006; SHAO, Y. 2008). Beside, these primer evident effects, dust storms and atmospheric mineral dust have various direct and indirect climatic and other environmental effects (HARRISON, S.P. et al. 2001; KOHFELD, K.E. – TEGEN, I. 2007; MAHER, B.A. et al. 2010; PÓSFAL, M. – BUSECK, P.R. 2010; SHAO, Y. et al. 2011). The tiny wind-blown particles with various mineralogical compositions reflect, scatter and absorb the incoming shortwave (solar) and outgoing longwave (terrestrial) radiation. Mineral dust modifies cloud forming processes, changes the pH of precipitation, and has an effect on biogeochemical cycles of oceanic ecosystems. Beside the inorganic particulates, dust storms transport large amount of organic aerosols (fragments of plants and insects, pollen grains, bacteria, fungi etc.).

Aim of this paper is to discuss the geographic distribution of dust loading regions and provide new thoughts on the geomorphological characteristics of major dust source areas in a global context.

Methods

Major global dust source areas have been identified by satellite measurements of NASA’s Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) in the time period of 1979–2011. The applied Aerosol Index (AI) record has an appropriate temporal (daily) and spatial (TOMS: $1 \times 1.25^\circ$; OMI: $1 \times 1^\circ$) resolution, and it is a very useful tool to identify absorbing aerosol components of the atmosphere (HERMAN, J.R. et al. 1997; TORRES, O. et al. 1998). The Aerosol Index (AI), 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 AI is defined as

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

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, J.R. et al., 1997). Positive values of AI indicate absorbing aerosols (dust, smoke from biomass burning), while negative values represent sulphates or sea-salt particles. Because of our aims to identify and characterize major dust source regions, the positive values of the AI have been used, which can be connected almost exclusively to wind-blown dust in arid-semiarid regions (PROSPERO, J.M. et al. 2002). However, the AI is less sensitive to aerosols at a low altitude, source areas can be identified by their persistent nature on the long-term average maps. Mapping of dust source areas by AI measurements have attained by several previous studies, which have confirmed the suitability of these kind of satellite observations (PROSPERO, J.M. et al. 2002; WASHINGTON, R. et al. 2003; ENGELSTAEDTER, S. et al. 2006; GOUDIE, A.S. – MIDDLETON, N.J. 2006; VARGA, GY. 2012). In the course of our study, we have worked with the dust source database composed and discussed by VARGA, GY. 2012 (*Figure 1*).

The compiled average aerosol map shows that the most important sources are situated mainly in the desert, semi-desert regions of North Africa, Middle East and Central Asia creating a more or less continuous area, called “Global Dust Belt”. The frequency and magnitude of dust emission outside the dust belt is relatively low, and is concentrated in small distinct areas. In general, the temporal activity of source regions has an obvious seasonal pattern with a spring-summer maximum.

Dust storms at high latitude areas (e.g. in Alaska, Canadian Prairies or Iceland) from glacial outwash plains are also common; however TOMS and OMI AI measurements cannot represent well these sources, because of aerosol emission is restricted to the lower levels of the troposphere (HERMAN, J.R. et al. 1997).

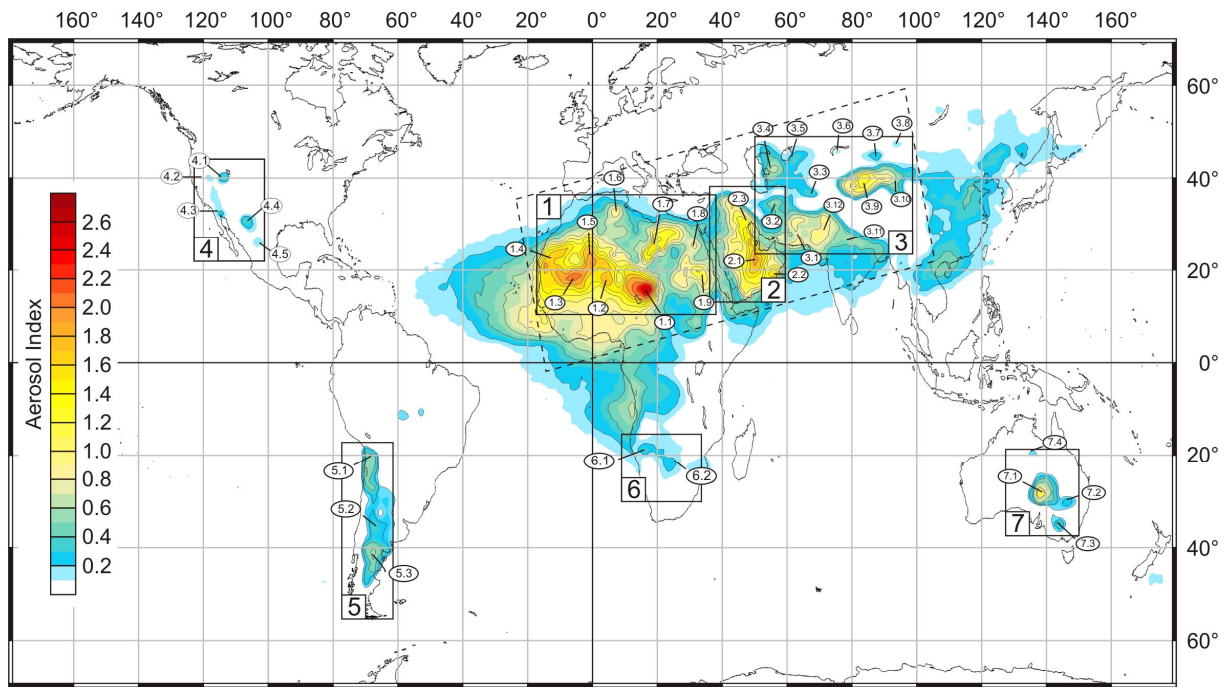


Figure 1 Global mean map of the measured daily Aerosol Index values and locations of the discussed major dust source domains (modified after VARGA, GY. 2012). The investigated dust hot-spots are the followings: **1. North Africa:** 1.1. Bodélé Depression; 1.2. Azawagh Structural Basin; 1.3. Taoudenni Basin; 1.4. W-Saharan sebkhas; 1.5. Tidikelt Depression; alluvial fans and wadis of W/NW-Ahaggar; 1.6. Chott Melrhir and Chott Jerid; 1.7. Cyrenaica és a Quattara Depression; 1.8. Western escarpments of River Nile; 1.9. Tokar Delta; **2. SW Asia:** 2.1. Salt flats and ephemeral streams of Jebel Tuwaiq; 2.2. Sabkha system of Jebel Dhoraf; 2.3. Floodplains deposits and marshlands of Tigris and Euphrates Basin; **3. Central Asia:** 3.1. Sistan (Seistan) Basin; 3.2. Dasht-e Kavir and Dasth-e Lut; 3.3. Fergana Basin; 3.4. Kara-Bogaz Gol; 3.5. Aral Sea; 3.6. Alluvial deposits of Balkhas-Alakol Basin; 3.7. Junggar Basin; 3.8. Uvs Lake Basin; 3.9. Tarim Basin; 3.10. Salt flat of Lop Nor and Quaidam Basin; 3.12. Thar; **4. North America:** 4.1. Salt flats at Great Salt Lake; 4.2. Smoke Creek and Black Rock Deserts; 4.3. Playa system of Salton Sink; 4.4. Chihuahuan Desert; 4.5. Bolsón de Mapimi; **5. South America:** 5.1. Salar de Uyuni (and other salt lakes/salars of the Altiplano); 5.2. Eastern slopes of Southern Andes; 5.3. Patagonia; **6. South Africa:** 6.1. Etosha Pan; 6.2. Makgadikgadi Depression; **7. Australia:** 7.1. Lake Eyre Basin; 7.2. Floodplain deposits and salt swamps along River Darling (e.g. Caryapundy); 7.3. Floodplain deposits and salt swamps along River Murray; 7.4. Barkly Tableland.

Geomorphological characteristics of dust source regions within the “Global Dust Belt”

The largest and most intense mineral dust sources can be connected to *large geomorphological depressions previously flooded by Pleistocene lakes*, like Bodélé Depression (1.1. on *Figure 1*) (remnant of ancient Lake Megachad) and Taoudenni Basin (1.3. on *Figure 1*) (remnant of Lake Araouane). The thick, fine-grained ancient lakebed deposits (diatomite, salt) and sparse vegetation (due to climatic and pedological reasons) make these places vulnerable to deflation. The bombardment energy of saltating sand-sized particles from nearby lying sand seas enhance the intensity of wind erosion by disrupting the hardened surface of lacustrine deposits. In the Bodélé, another geomorphological effect enhances the wind erosion, where the prevailing northeastern dry trade wind (Harmattan) is strengthened by the *channelling effect* of the Tibesti and Ennedi Mountains (*Figure 2*).

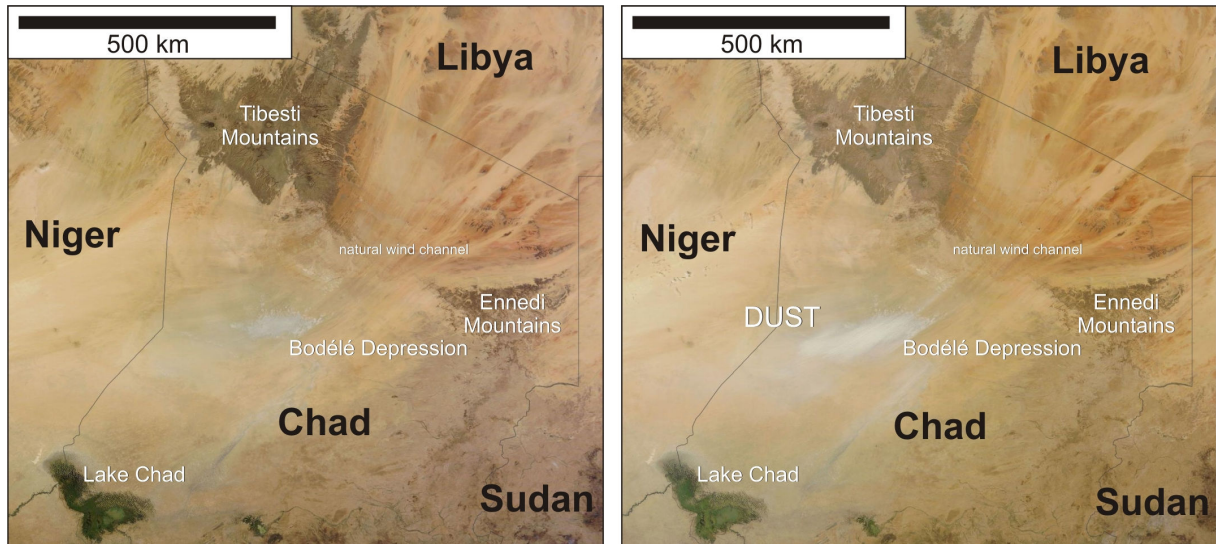


Figure 2 NASA MODIS Satellite images of Bodélé Depression on a “clear” (1 January, 2014) and a dusty day (6 February, 2014). Image source: <https://earthdata.nasa.gov/labs/worldview/>

Seasonally flooded, *ephemeral salt and dry lakes* (chotts, sebkhas) represent another (very similar to previous) geomorphological environment suitable for severe dust emission episodes. These, mainly isolated, relatively small dust hot-spots can be found in lowlands, often surrounded by mountainous areas (source areas of water in spring from thawing). A typical example is the “Chott Region” in North Africa, south of the Tell Atlas. Chott Melrhir and Chott Jerid (1.6. on *Figure 1*) are salt lakes, with changing shores and are dry for much of the year. Strong winds associated with Sharav cyclones transporting huge amount of mineral dust from the lakebed towards the Mediterranean (ALPERT, P. –ZIV, B. 1989). Sand bombardment (particles from Grand Erg Oriental) plays also important role during the initial stage of wind erosion.

As the above mentioned examples show, water plays substantial role in transportation and storage of silt-sized particles. It is increasingly true in the case of *alluvial fans and wadi-systems of mountainous areas*, which are also important source regions. The fine-grained mineral material is transported from the higher areas by ephemeral streams, seasonal flash floods or by mass-movements. The western and north-western slopes of Ahaggar and the long narrow band of dust sources at the eastern slopes of gentle hills running parallel to Atlantic coast in Western Sahara are good representatives of this kind of geomorphological environment.

Especially in “High Asia”, *endorheic basins* are major sources of mineral dust. Sistan, Junggar or Uvs Lake Basins (3.1., 3.7. and 3.8. on *Figure 1*) are closed intermountain basins (with own internal drainage system) fed with clay- and silt-sized material by alluvial fans and wadis. Salt swamps, marshes and shallow lakes (hamouns, kavirs) occupy the central part of the basins with fine-grained deposits accumulated in them. In general, katabatic winds from the higher areas are responsible for intense deflation episodes. The largest and most persistent dust source area of Asia is situated also in an intermountain basin; the huge sand sea of Taklimakan desert located in the Tarim Basin (3.9. on *Figure 1*) and is bounded by the Himalayan Plateau, Hindu Kush and Tien Shan. At marginal areas of the sandy desert areas extensive ephemeral drainage systems, seasonal lakes and alluvial fans can be identified.

Dust source areas bordering rivers can be characterized by different kind of geomorphological features. For instance, in the Tigris-Euphrates Basin (2.3. on *Figure 1*) desiccated *floodplain* deposits and *extensive marshlands* of the two rivers provide the source material of deflated fine-grained dust (*Figure 3*). From the Tokar Delta (1.9. on *Figure 1*)

huge quantities of dust can be transported into the direction of Red Sea from the alluvial deposits of silt-laden Baraka River.

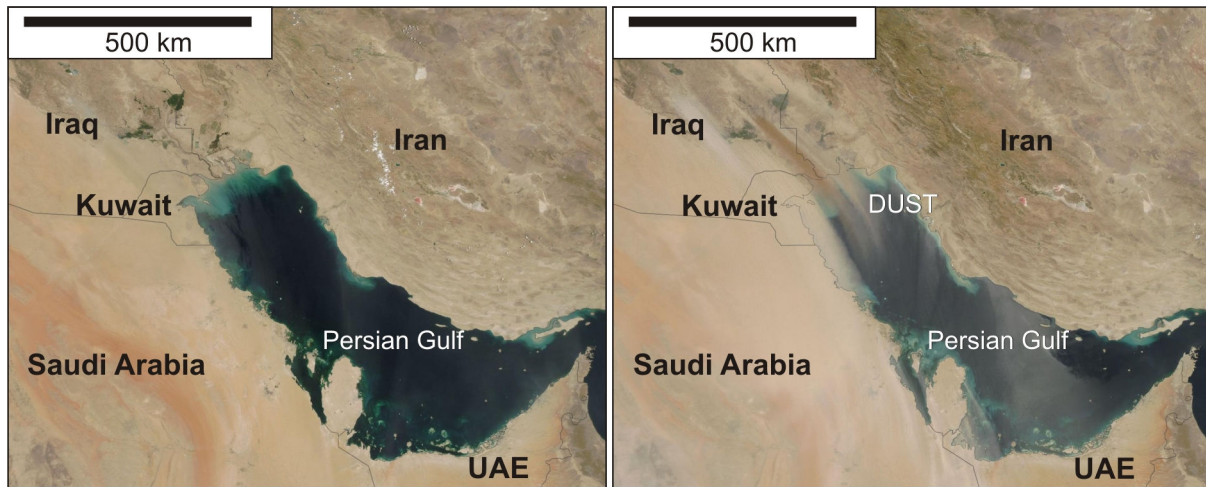


Figure 3 NASA MODIS Satellite images of Persian Gulf on a “clear” (7 June, 2013) and a dusty day (2 June, 2013). Image source: <https://earthdata.nasa.gov/labs/worldview/>

Anthropogenic factors could also enhance the dust activity by unreasonable constructions of irrigation channels or other irresponsible agricultural activities. Kara-Bogaz Gol (3.4. on *Figure 1*), the ancient gulf of Caspian Sea was dried out as a consequence of embankment construction; and now it is an intense dust source region. Aerosol measurements show, that the dried out deltas of Amu and Syr Darya rivers and the exposed lakebed of shrinking Aral Sea (3.5. on *Figure 1*) became important emitters of mineral dust due to man-made reasons.

Geomorphological characteristics of dust source regions outside the “Global Dust Belt”

Outside the “Dust Belt”, small, distinct source areas are responsible for dust emission, and have only a minor contribution to the global dust budget, however their various effects can have relevant impact on local (or sometimes regional) environmental processes. These, mainly seasonally active hot-spots can be connected to specific climatic and geomorphological environments similar to those discussed above.

In North America (SW part of United States and northern Mexico), several isolated sources are situated in the internal drainage systems of intermountain highland basins (sub-basins of Great Basin and Mexican Altiplano). The surface of the closed basins is covered by salt flats, playas, shallow lakes and deep alluvial deposits of fans. Generally, the salty deposits of the endorheic basins are remains of past moister climatic regimes; for instance the Tule and Sevier Dry Lakes are remnants of pluvial Lake Boneville, while alkali deposits of Smoke Creek and Black Rock Deserts (4.2. on *Figure 1*) were formed after the desiccation of Pleistocene Lake Lahontan.

General characteristics of South American sources are determined by the Andes. Many isolated hot-spots are associated with the salt flats (salars) located in the internal drainage system of high plateau region of Altiplano (5.1. on *Figure 1*); and have a Pleistocene pluvial origin. Alluvial sediments of piedmont areas and Pleistocene loess and loess-like deposits are source material of dust storms at the eastern slopes of Southern Andes, deflated by katabatic winds.

In South Africa, two isolated source areas can be distinguished (Etosha Pan (6.1. on *Figure 1*) and Makgadikgadi Depression (6.2. on *Figure 1*)). Both of them are located in

geomorphological depressions, are seasonally flooded by ephemeral rivers, and are remnants of large pluvial lakes.

The largest dust source area outside the “Global Dust Belt” is located in Australia. The huge playa system of Lake Eyre (7.1. on *Figure 1*) is fed by ephemeral rivers, streams and creeks. Other minor sources are related to floodplains and salt swamps of Murray and Darling Rivers and their seasonal tributaries (7.2. and 7.3. on *Figure 1*).

Conclusion

Based on the systematic analyses of geographical distribution, it can be stated that major dust sources are associated with specific geomorphological environments. These can be connected to geomorphological depressions (e.g. remnants of ancient lakebeds, salt or dry lakes, intermountain basins and lowlands), ephemeral streams or wadi-systems and flanks of high mountains (alluvial fans). The fine-grained material of most of the sources was accumulated in some kind of Pleistocene fluvial or lacustrine environment. Accordingly, it is important to note, that dust storms and deflational episodes are related to arid and semiarid environments (or droughts), however water plays substantial role in formation, transportation and storage of fine-grained particles.

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