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SOURCE REGIONS OF DUST TRANSPORTED TO THE EASTERN MEDITERRANEAN

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ABSTRACT

During the years of 1992, 1993 and 1998, a total of 46 strong dust episodes occurred in the Eastern Mediterranean Basin. During dust episodes, and at normal conditions in order to compare dust and non-dust period, daily PM-10 aerosol samples were collected at Antalya, an eastern Mediterranean location. Although similar absolute concentrations of anthropogenic elements were observed during dust and non-dust periods, for crustal elements like Al, Sc, Fe, and rare earth elements concentrations during strong dust periods up to a factor of four higher concentrations were measured. The potential source contribution function (PSCF) has been used to study the source-receptor relationship for dust episodes. Important source regions for dust observed in the eastern Mediterranean accumulate in three general areas; 1) in western parts of North Africa covering Morocco and Algeria where big sand dunes of Erg Iguidi, Grand Erg Oriental, 2) in Libyan deserts and 3) Arabian deserts.

Key Words: Saharan Dust, Eastern Mediterranean Atmosphere, Multilayer PSCF

1. INTRODUCTION

Annually, 300 to 700 million tons of dust originated from Saharan Deserts are transported over short to long distances to the Atlantic (Carlson and Prospero, 1971; Moulin et al., 1998), Mediterranean Sea (Kubilay et al., 2000; Özsoy et al., 2001; Molinaroli and Ibba, 1995; Ganor and Mamane, 1982), southern Europe (Mattsson and Nihlen, 1996) as reported and discussed in many publications. It has been estimated that yearly amount of Saharan dust leaving North Africa in a northeasterly direction towards eastern Mediterranean is some 100 million tons (Ganor and Foner, 1996). This large quantity of dust transport has a significant impact on climatic processes, nutrient cycles, soil formation and sediment cycles.

Geographic locations from where dust originates in North Africa and Middle East are important in reducing uncertainties in the modeling of past and future climate as they have significant consequences particularly in climate change. Although source regions of dust in the atmosphere had been studied by various researchers using remote sensing (Brooks and Legrand, 2000), surface dust observations (Herrmann et al., 1999), backtrajectory analysis (Chiapello et al., 1997) and total ozone mapping spectrometer (TOMS) (Hsu et al., 1999; Washington et al., 2003). The exact source locations of dust observed in the Mediterranean are not well known, but data from Total Ozone Mapping Spectrometer (TOMS) suggest two major source areas: the Bodélé depression and an area covering eastern Mauritania, western Mali and southern Algeria (Goudine and Middleton, 2001). The Horn of Africa and Nubian Desert in southern Egypt and northern Sudan are also suggested as important source regions (Brooks and Legrand, 2000).

In this study, episodic behavior of dust transport to the eastern Mediterranean has been studied by measuring elemental concentrations of aerosols collected at rural location for the years 1992, 1993 and 1998. The potential source areas of dust were defined with Potential Source Contribution Function (PSCF) analysis by using chemical concentrations and backward air trajectories.

2. MATERIALS AND METHODS

2.1 Sampling and Analysis

A total of 789 daily high aerosol samples were collected from Antalya Air Quality Monitoring Station in the south part of Turkey (30.34 °E, 36.47 °N), in the northeast Mediterranean Sea during the years 1992, 1993 and 1998, using Andersen Model HV-100 High Volume Air Sampler equipped with a PM-10 pre-impactor. Further details on sampling and analytical procedures have been reported elsewhere (Güllü et al., 1998).

Approximately 300 samples collected in 1993 were analyzed by INAA and 490 samples collected in 1992 and 1998 were analyzed by AAS for trace elements. Samples were analyzed for Al, K, Na, Mg, Fe, Zn and Ca by flame and Pb, Cu, Cd, Ni, V and Cr by graphite furnace atomic absorption spectrometry using a Perkin Elmer, model 1100B atomic absorption spectrophotometer coupled to a Perkin Elmer HGA 700 electrothermal atomization system. Different parts of the same filters were also analyzed for an additional 30 – 40 elements by INAA, at the Massachusetts Institute of Technology (MIT), Nuclear Reactor Laboratory (thermal neutron flux: $1x10^{13}$ n cm^{-2} sec^{-1}), using the procedure developed by Olmez (1989).

2.2 Trajectory Data

Five days-long, three dimensional isentropic back trajectories, arriving to the sampling point at the midtime of each sample, were computed by the publicly available operational model on the CRAY C90/UNICOS computer at the European Center for Medium Range Weather Forecast (ECMWF) Center. This model is similar to the method developed by Martin et al. (1987). The model uses analyzed zonal (u) and meridianal (v) wind field components; plus the vertical velocities available in the archives of the center (MARS) in the form of a special online database gridded every 12 hours (00:00, 12:00) for standard pressure levels. In order to run this model from a remote site, a request file which contains the place and date information were sent to the center. After that, a data matrix containing the information of the position of the air parcel in latitude and longitude at each hourly time step is sent back to the user. The data arriving for trajectories at three different barometric levels; 900, 850 and 700 hPa were obtained, and the end altitude of all three barometric level trajectories was used in the statistical analysis**.**

2.3 Multi-layer potential source contribution function

The geographic locations of the source regions of dust observed in the eastern Mediterranean are determined by an approach called the potential source contribution function (PSCF) which is originally developed by Ashbaugh et al. (1984). It has been applied in a series of studies over a variety of scales (Zeng and Hopke, 1989; Gao et al., 1993, 1994, 1996; Cheng et al., 1993). In this model, it is assumed that a species emitted within a grid cell is swept into the air parcel and transported to the receptor site without loss through diffusion, chemical transformation or atmospheric scavenging.

The PSCF of an element $\underline{x}$ in subregion $\underline{ij}$ is defined as a conditional probability:

$$PSCF_{x,ij} = \Sigma m_{ij} / \Sigma n_{ij}$$

Where $\underline{\Sigma n_{ij}}$ is the total number of trajectory segments in the $\underline{ij}$-th subregion from three different levels (700, 850 and 900 mb) during the whole study period, and $\underline{\Sigma m_{ij}}$ is the total number of "dust loaded" trajectory segments in the same $\underline{ij}$-th subregion during the same study period. Hence, high values of $PSCF_{x,ij}$ will pinpoint geographical regions that are likely to produce high concentration values of an element x at the receptor site if crossed by a trajectory. In this study, for the selection of "dust loaded" trajectory segments, we have used the predefined dust event sub data set.

In the PSCF analysis, a 120-h long 700, 850 and 900 mb arrival level back trajectories, corresponding to every sample collected in 1992, 1993 and 1998, were divided into 1-hr segments and these segments were counted in each subregion. Subregions are predefined as 1°x1° grids in the study area, which lies between 75°N latitude at north (north of Scandinavia), 15°N latitude at south (south of Algeria), 20°W longitude at west (west of UK) and 59°E longitude at east (east of Arabic Peninsula).

3. RESULTS AND DISCUSSION

3.1. General characteristics of data

In order to asses the impact of mineral dust on the composition of Eastern Mediterranean aerosols, the data set has been divided into 2 subsets; one corresponding to dust events and the other one corresponding to non dust samples. Samples that correspond to dust event were determined by using Al concentrations, TOMS data and backtrajectory information. Aluminum is widely used as a tracer for mineral dust in the Mediterranean region as it does not have any source other than crustal material in rural areas (Güllü et al., 1998; Kubilay and Saydam, 1995; Guerzoni et al., 1999). It is well documented that during Saharan Dust incursions to the Eastern Mediterranean region, crustal elemental concentrations like Al and Fe increase up to two-orders of magnitude. The baseline concentration of Al is approximately 100 ng m-3. However, during dust incursions this concentration varies between 300 and 6500 ng m-3. Consequently Al concentrations in dust-impacted samples should be high and this was set as the first criteria in selecting dust influenced samples. All the samples that had Al concentrations higher than twice the baseline concentrations were selected as samples potentially impacted by the mineral dust. As Al and Fe are markers for crustal material, they are not specific to Saharan Dust, to differentiate the dust episodes that originate from North Africa and Middle East, 5 days backward trajectory information were used. If either 850 and/or 700 MB level back trajectories originate or pass through North Africa and Arabian Peninsula and the sample Al concentration higher than twice the baseline concentration, that sample has identified as dust episode.

For the dust episodes of year 1992, 1993 (till May 1993) and 1998, the selected sample dates were visually inspected with TOMS aerosol data. And for the year 1998, SeaWiFS (Sea-viewing Wide Field-of-view Sensor) satellite produce pictures of the Eastern Mediterranean region were also used to check the episodes if there were no cloud. Although comparison of the dust events with satellite pictures and TOMS data are not available for the whole period, as a general comparison proved useful.

By applying these criteria's, a total of 46 dust episodes covering 157 days out of 789 days were identified within the study period. This data set is used as dust set in all subsequent statistical treatment of data.

The backtrajectory, TOMS and SeaWIFS data for one of the dust episode is given as an example in Figure 1. This example is for the dust episode during 10 to 17 April 1998. This was one of the longest and strongest episodes observed during the study period. Aluminum concentrations varied between 560 to 1500 ng m-3. A strong dust pulse entering the Mediterranean from the Libyan coast is clearly visible in the satellite pictures.

3.2 Elemental characteristics of mineral dust

Table 1 summarizes the major element concentrations of mineral dust as sampled in the eastern Mediterranean, for comparison the average concentrations in the region during the rest of the period (non-dust), and the dust to non-dust ratio of the elements are also given.

Although major element compositions of soil material do not show substantial differences worldwide, minor and trace element content of different soil types could be useful in differentiating between different types of crustal material in atmosphere. When concentrations of elements in samples corresponding to dust episodes are compared with concentrations in non-dust samples, it has been observed that the overall mean of lithophilic elements are factors of 2.0 to 4.5 higher in episodic samples. As the episode samples were selected based on their litophile concentrations, the results are not surprising. However, all litophilic elements do not have the same ratio, while dust-to-nondust ratio of the elements e.g. Al, La, Ce, Sm, Lu, Sc, Yb, Gd, Th, Eu and Hf are around 4, the ratio is around 2 for the elements Rb, Fe, Tb, Cs, Nd, Dy, Co and Ti.

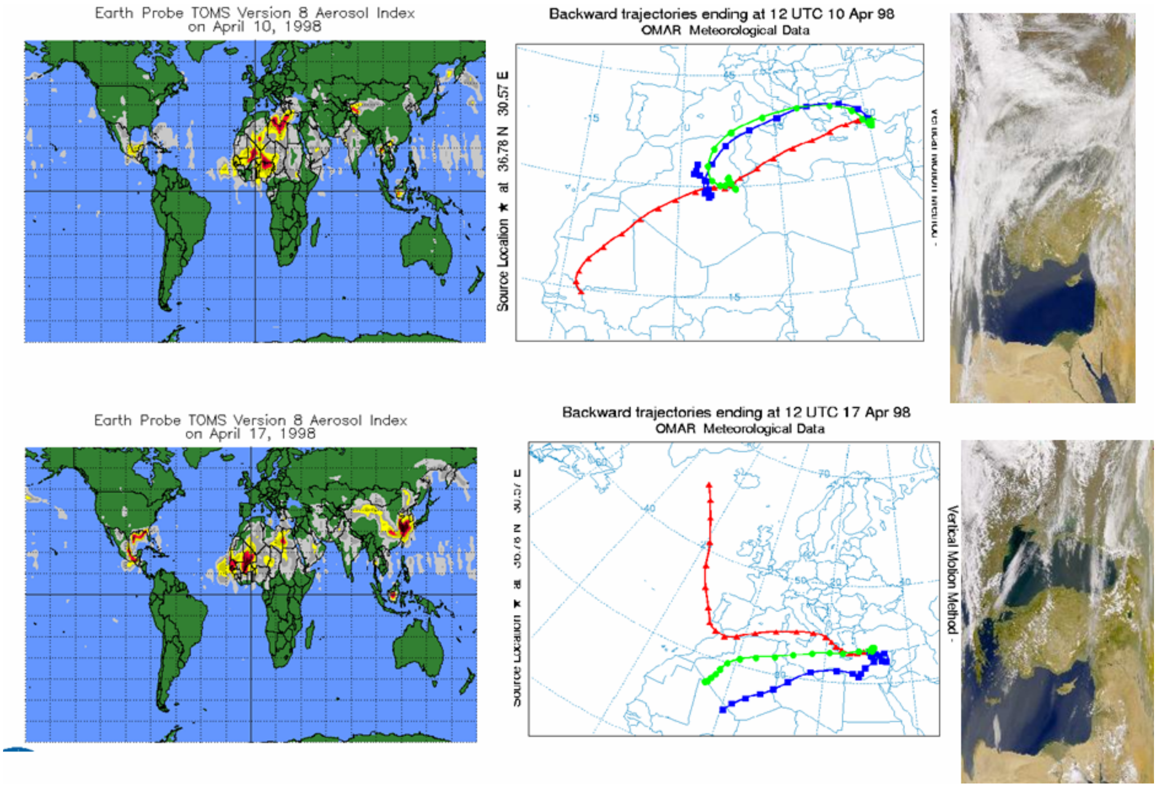

Figure 1. The TOMS Aerosol Index, backtrajectory and SeaWIFS data are given for the episode observed during 10-17 April 1998.

3.3. Source regions of dust in the eastern Mediterranean region

The geographic locations of the source regions of dust observed in the Eastern Mediterranean are determined by multilayer potential source contribution function. The dust data set are assumed to be “polluted”. The 900, 850 and 700 MB level PSCF values for Al are depicted in Figure 2. Important source regions for dust observed in the eastern Mediterranean appears to accumulate in three general areas. One of these regions is located in western part of North Africa covering Morocco and Algeria. In these areas there are big sand dunes of Erg Iguidi, Grand Erg Oriental which is called as sand sea and Dra desert in Morocco. These regions are frequently cited in the dust studies performed in the western Mediterranean. Also TOMS studies indicated that Aerosol Index in the central Algeria and eastern Mauritania varies between 6 – 20, suggesting high dust re-suspension in this region. High PSCF values calculated in these areas indicate that some of the dust observed in the eastern Mediterranean is transported from Western Sahara.

Table 1. Median concentrations of elements in dust and non-dust samples

	Dust Samples (n=157)	EF_{dust}	Background Concentrations (n=632)	$EF_{nondust}$	Dust/Non Dust Ratio
Na	1232	36,37	922	249,44	1,34
Mg	557	1,99	267	9,47	2,09
Al	995	1,00	237	1,00	4,20
Cl	1283	160,59	1042	1575,91	1,23
K	507	1,98	223	4,88	2,27
Ca	3097	0,66	1711	2,23	1,81
Sc	0,20	0,60	0,043	0,63	4,64
Ti	62	0,16	22	0,23	2,84
V	4,37	0,45	1,82	1,20	2,41
Cr	4,39	0,87	3,05	3,38	1,44
Mn	15,99	0,65	6,53	1,25	2,45
Fe	753	0,33	221	0,40	3,40
Co	0,34	0,69	0,11	2,81	2,98
Ni	3,59	1,71	2,00	4,91	1,79
Zn	16,23	8,67	9,52	14,46	1,70
As	1,27	8,06	1,24	89,47	1,02
Se	0,36	6,33	0,22	27,43	1,66
Br	15,44	83,39	13,47	749,18	1,15
Rb	1,59	2,34	0,50	4,30	3,20
Mo	0,25	5,72	0,21	79,77	1,18
Sb	0,35	21,26	0,30	133,54	1,18
Cs	0,13	2,78	0,06	7,74	2,22
La	0,65	1,17	0,15	1,29	4,25
Ce	1,27	1,35	0,29	1,56	4,35
Nd	0,70	2,18	0,30	8,79	2,34
Sm	0,096	1,14	0,021	1,12	4,42
Eu	0,020	1,26	0,005	1,38	4,05
Tb	0,010	1,15	0,002	1,37	3,70
Dy	0,083	0,18	0,030	0,48	2,68
Yb	0,038	1,17	0,008	1,14	4,71
Lu	0,006	0,90	0,001	0,89	4,43
Hf	0,049	1,41	0,012	1,30	4,02
Hg	0,021	79,10	0,037	889,87	0,58
Pb	22	22,90	18	149,98	1,25
Th	0,17	1,25	0,04	1,47	4,17

The second source region appears in the southeastern part of Libya and Negec desert in Egypt. This region is also found to have Aerosol Index values between 9 and 15 and suggested to be an important dust source in the previous studies (Goudie and Middleton, 2001). This source region identified by the PSCF also agrees with satellite pictures of 1998. Most of the dust episodes in 1998 were transported to eastern Mediterranean off the Libyan coast, which is in agreement with this second region found in PSCF calculations.

The third source region of mineral dust for the eastern Mediterranean region appears in the Middle East region. Idso (1976) recognized Arabia as one of five world regions where dust storm generation is especially intense. The TOMS data indicate that the Middle East especially Ad Dahna erg region of eastern and central Saudi Arabia is an important area of dust-storm activity (Washington et al., 2003).

Although the identified source regions in this study agrees fairly well with the source regions reported in the literature with different methodology. However, PSCF analysis did not indicate the Bodele Depression, which is the known dust source area (with aerosol index values of 30). The reason for this inconsistency between literature and our assessment is probably due to the lenght of trajectories used in this study. The trajectories were 5 days long in this study, and most of the backtrajectories didnot extend beyond southern borders of Algeria into Chad, where Bodele Depression is located.

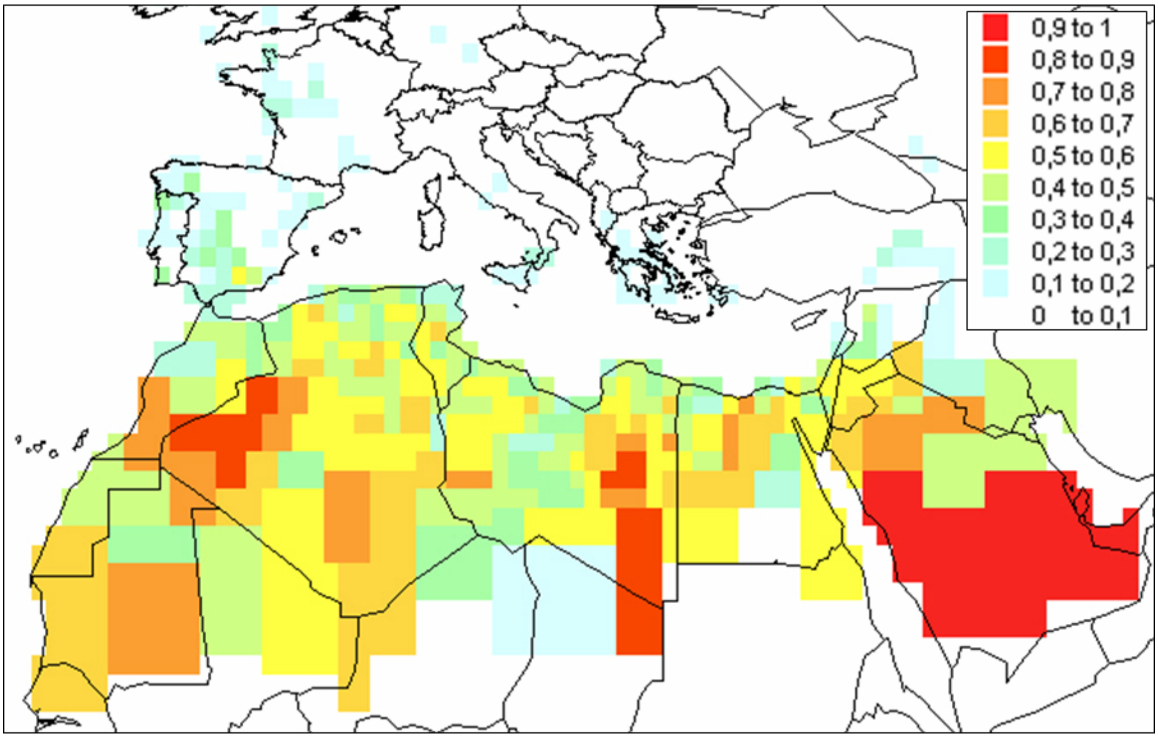

Figure 2. PSCF for eastern Mediterranean during 1992, 1993 and 1998

4. CONCLUSIONS

A source-receptor model has been used to identify potential source areas of mineral dust reaching eastern Mediterranean region. During the study period (the years 1992, 1993 and 1998) the strongest potential source areas are identified as western parts of north Africa covering Morocco and Algeria where big sand dunes of Erg

Iguidi, Grand Erg Oriental, Libyan deserts and Arabian deserts. Our findings are in excellent agreement with the recent independent analysis of Washington et al., (2003) etc.

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