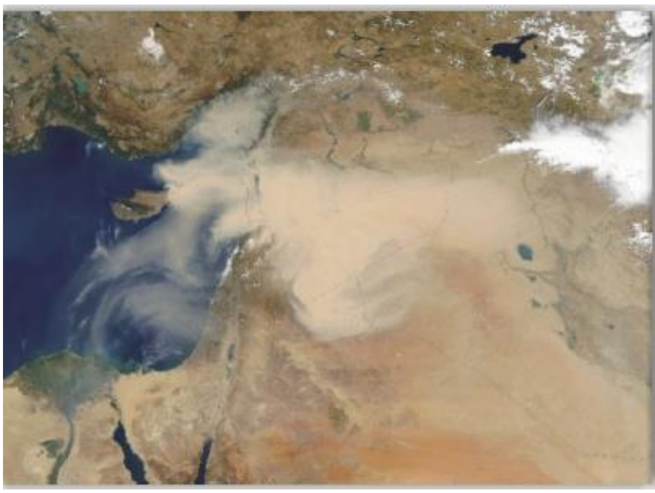
REPUBLIC OF TURKEY
The Ministry of Forestry and Water Affairs
Turkish State Meteorological Service



Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

Cihan DÜNDAR, A. Gökçen IŞIK, Kahraman OĞUZ

www.wdcc.mgm.gov.tr

ANALYSIS OF SAND AND DUST STORMS (SDS) BETWEEN THE YEARS 2003 AND 2016 IN THE MIDDLE EAST

INTRODUCTION

Mineral dust aerosols, the tiny soil particles suspended in the atmosphere, have a key role in the atmospheric radiation budget and hydrological cycle through their radiative and cloud condensation nucleus effects. Mineral dust aerosols are blown into the atmosphere mainly from arid and semi-arid regions where annual rainfall is extremely low and substantial amounts of alluvial sediment have been accumulated over long periods. They are subject to long-range transport of an intercontinental scale, including North African dust plumes over the Atlantic Ocean, summer dust plumes from the Arabian Peninsula over the Arabian Sea and Indian Ocean and spring dust plumes from East Asia over the Pacific Ocean. Mineral dust aerosols influence the climate system and cloud microphysics in multiple ways [1].

Furthermore, the Intergovernmental Panel on Climate Change (IPCC) accepts mineral dust as a very important component of atmospheric aerosols, one of the main climate variables. According to the IPCC's latest climate predictions, it is expected that sand and dust storms will be more intense as the frequency and severity of the drought has increased [5].

BAN Ki-Moon,
"Global Assessment of
Sand and Dust Storms,
UNEP, WMO, UNCCD (2016)".

There is considerable uncertainty about whether sand and dust storms are increasing in intensity and frequency and how much is due to human causes. There is also need for greater clarity on the role that climate change is playing and how changes in dust emissions due to land use and climate change may impact the atmosphere, climate and oceans in the future.

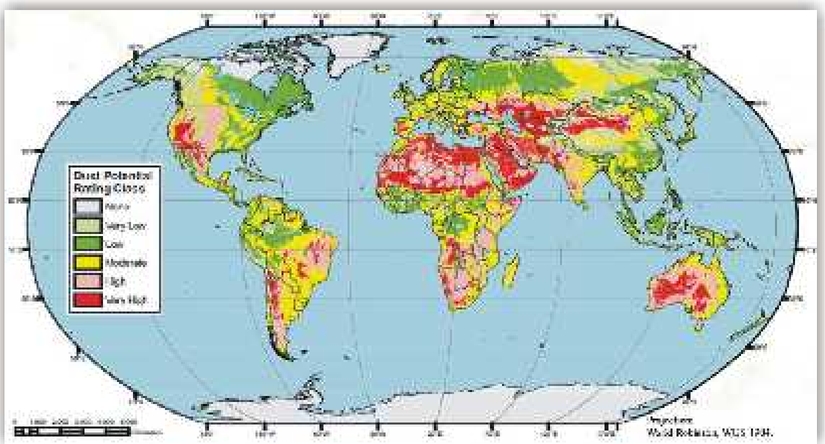


Figure 1. Global Dust Potential Map. Source: DTF (2013) [9]

Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

Approximately 1,000 Tg to 2,000 Tg (1-2 billion tons) of dust is emitted to the atmosphere from the deserts every year [8]. The most important sources of dust aerosols are located in the Northern Hemisphere, primarily over the Sahara and Sahel in North Africa, the Middle East, Central and South Asia respectively [1]. Potential areas for dust storms are illustrated on Figure 1. The annual amount of dust released from the Sahara into the atmosphere is about the half of dust released from all sources on Earth, while the dust released from the Sahara and Middle East regions is about 70% of global annual dust emissions. The annual amount of dust emitted from Arabian Peninsula (Middle East) to the atmosphere was estimated to 221 million tons [8].

Transport from North Africa to the Eastern Mediterranean occurs predominantly during spring and is commonly associated with the eastward passage of frontal low-pressure systems. Dust from sources in the Middle East is more typically transported to the Mediterranean in the fall[2].

Aerosol Optical Depth (AOD)

Aerosol Optical Depth (AOD) provides important information about the concentration, size distribution, and variability of aerosols (desert dust, sea salt, haze, and smoke particles) in the atmosphere. It is a dimensionless number related to the amount of aerosol distributed within the vertical column of atmosphere over the observation location. AOD provides a quantitative measure of the extinction of solar radiation due to aerosol scattering and absorption [4]. Heavy dust regions are defined by AOD higher than 0.3. Around deserts, AOD values are above 1.0 and usually below 3.0 [7].

April 27, 2005 - Al Asad Airbase, Iraq

Giovanni website provides a simple way to visualize, analyze, and access Earth science remote sensing data, particularly from satellites, without having to download the data. It includes data for aerosols, atmospheric chemistry, atmospheric temperature and moisture, and rainfall. It was developed by the Goddard Earth Sciences Data and Information Services Center (GES DISC).

Angstrom Exponent (AE)

$$\tau_{\lambda} = \tau_{\lambda_o} \left(\frac{\lambda}{\lambda_o}\right)^{-\alpha}$$

$$\alpha = Angstrom\ exponent$$

The Angstrom Exponent (AE) is an exponent that expresses the spectral dependence of aerosol optical thickness (τ) with the wavelength of incident light (λ). It provides additional information on the particle size, aerosol phase function and the relative magnitude of aerosol radiances at different wavelengths. AE (computed from τ measurements on two different wavelengths) can be used to find τ on another wavelength using the relation below:

Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

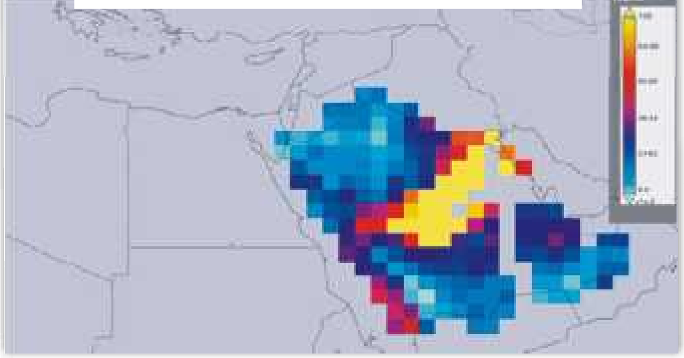
The Angstrom Exponent is a useful quantity to evaluate the particle size of atmospheric aerosols or clouds, and the wavelength dependence of the aerosol/cloud optical properties. It is inversely related to the average size of the particles in the aerosol: the smaller the particle size, the larger the Angstrom Exponent is. Therefore, low AE values indicate strong presence of coarse aerosols relating to the dust events.

SAND AND DUST STORMS (SDS) ANALYSIS

In literature, a well-defined methodology to investigate aerosol events does not exist. By using threshold values of AOD, several researchers tried to identify aerosol episodes. Gkikas et al (2009) investigated the aerosol events based on their frequency and intensity in the Mediterranean Basin for 7-year period (2000-2007) by using AOD data from MODIS (Moderate Resolution Imaging Spectroradiometer) [4].

Strong aerosol events were observed frequently (14 aerosol events/year) in the western and central Mediterranean Basin while extreme events (AOD up to 5.0) occurred throughout the year systematically in the eastern Mediterranean Basin. Seasonally, while strong aerosol events in the western Mediterranean Basin occurred in summer and extreme events in the eastern part of the basin were observed in the spring season [4].

March 10, 2009 - Riyadh, Saudi Arabia



$$AOD_{Threshold} = \overline{AOD} + i \times \sigma_{AOD} \text{ with } i = 1,2,3,4 \quad (1)$$

$$\overline{AOD} + 2 \times \sigma_{AOD} \le AOD < \overline{AOD} - 4 \times \sigma_{AOD} \quad \text{strong aerosol case} \quad (2)$$

$$AOD \ge \overline{AOD} + 4 \times \sigma_{AOD} \quad \text{extreme aerosol case} \quad (3)$$

Methodology is based on calculating mean average AOD ($\overline{AOD}$)and standard deviation values (σ_{AOD}). Equation 1 above shows the calculation of threshold: adding 1, 2, 3 and 4 standard deviation (σ_{AOD}) to the mean AOD value. Equation 2 and equation 3 define the limit values for strong and extreme aerosol events [4].

Extreme aerosol events point out dust storms while strong aerosol events are linked to sea salt, biomass burning (forest fires), and anthropogenic activities [4].

Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

ANALYSIS

For the analysis between the years 2003 and 2016, domain covering Middle East (extending from 20° to 38° North and 36° to 64° East) is selected. Domain is divided into three subregions as Middle East North (ME-N), Middle East Centre (ME-C), and Middle East South (ME-S) for further analysis (Figure 2). To investigate average annual and monthly AOD and AE for the period 2003-2016, MODIS Aqua data is obtained from Giovanni website. (http://disc.sci.gsfc.nasa.gov/giovanni).

Figure 2. Study domain for the Middle East

RESULTS

In general, the AOD and AE parameters can be used to differentiate between coarse and fine particles of aerosols. Mean AOD of the period 2003-2016 (Figure 3) illustrates high AOD values reaching up to 0.5 over east of Saudi Arabia, Kuwait, Bahrain, Qatar, Iraq and Persian Gulf. Furthermore, to identify dust particles, low AE values are tracked on the plot of mean AOD of the period 2003-2016 (Figure 4). Low values are observed over Saudi Arabia, Iraq, Syria and lowest ones over Persian Gulf. Those areas with low AE and high AOD point out dust storms.

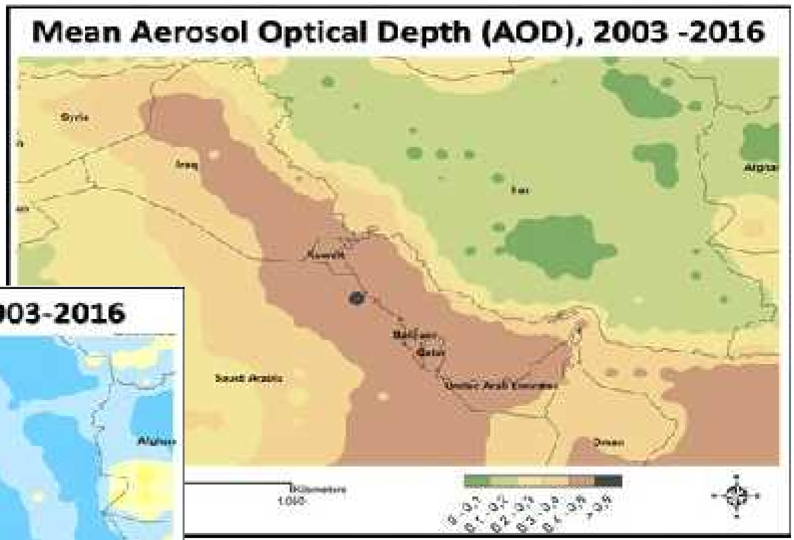


Figure 3. Mean AOD of the period 2003-2016 in the ME

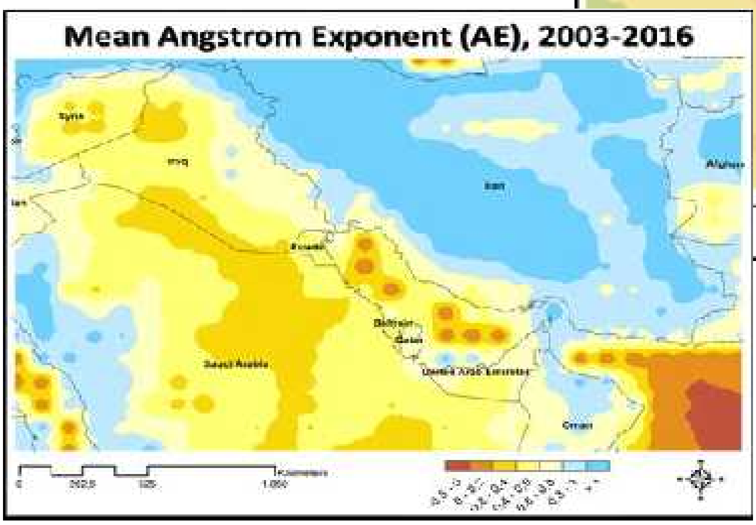


Figure 4. Mean AE of the period 2003-2016 in the Middle East

Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

February 22, 2008

Plots for latitude cross-section of AOD and AE averaged over Middle East region are prepared (Figure 5). Moving northward along 20-38N, AOD values decrease while AE values show an increase. In the southern part of the Middle East, this behavior can be closely related to more strong and frequent dust storms characterized by high AOD and low AE.

Average annual and monthly AOD graphs are plotted for three regions (Figure 5) to investigate the trends. Annual AOD values of the Central Middle East almost follow the averaged values of the Middle East Region as expected, while higher values of AOD are observed in the Southern ME.

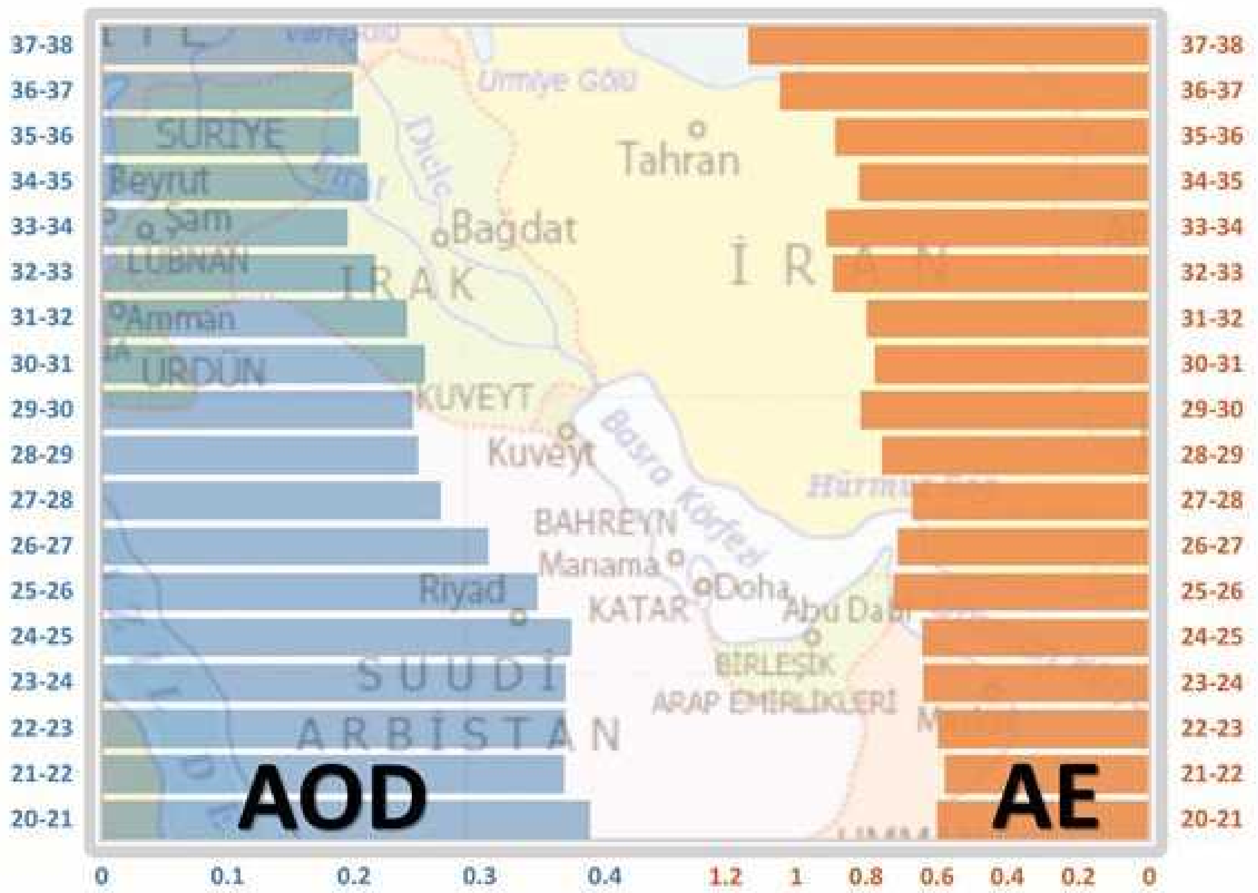


Figure 5. Latitude cross-section of AOD and AE averaged between 36°-64°E along 20°-38°N

Seasonal variation of AOD in the Central Middle East is similar to averaged AOD values of the Middle East which has a maximum in April. On the other hand, the Southern Middle East exhibits a different seasonal pattern with a maximum AOD value in July (Figure 6b). AOD values have a maximum in spring and low AOD values are observed during winter season for both Northern and Central ME.

SDS analysis of 2003-2016 has been carried out to estimate SDS number for each year for three regions and points out the 14 years trend of SDS. The number of strong and extreme aerosol events is calculated by the method explained in the methodology section. Extreme aerosol events indicate SDS [4].

In the southern region, high number of SDS occurs compared to the northern region throughout 14 years (Figure 7a). Between 2008 and 2012, annual average SDS number reaches values above 15 up to 40 in the southern region which has a peak value in 2011. Figure 7b illustrates the seasonal variability of SDS for those three subregions. High values of monthly dust events shift to summer when we move southward in the Middle East. Southern ME is affected by high number of dust events in July while Northern and Central ME have their peak values in spring.

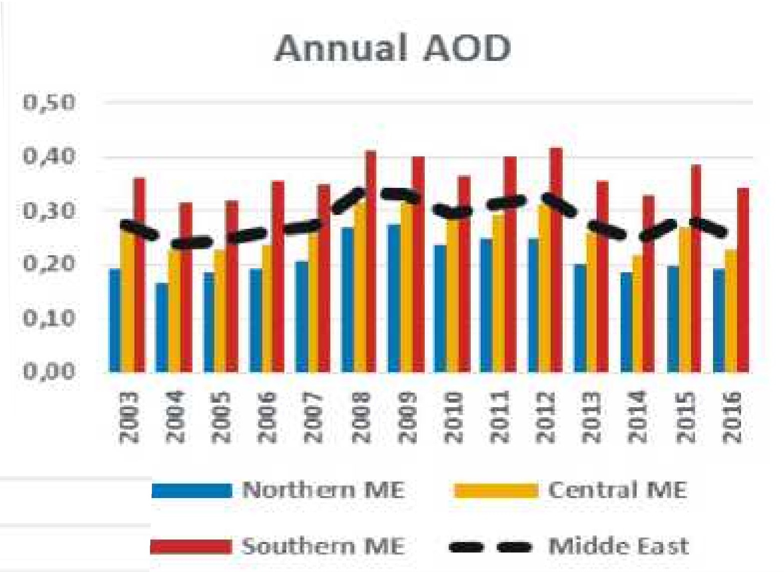


Figure 6. (a). Average annual AOD

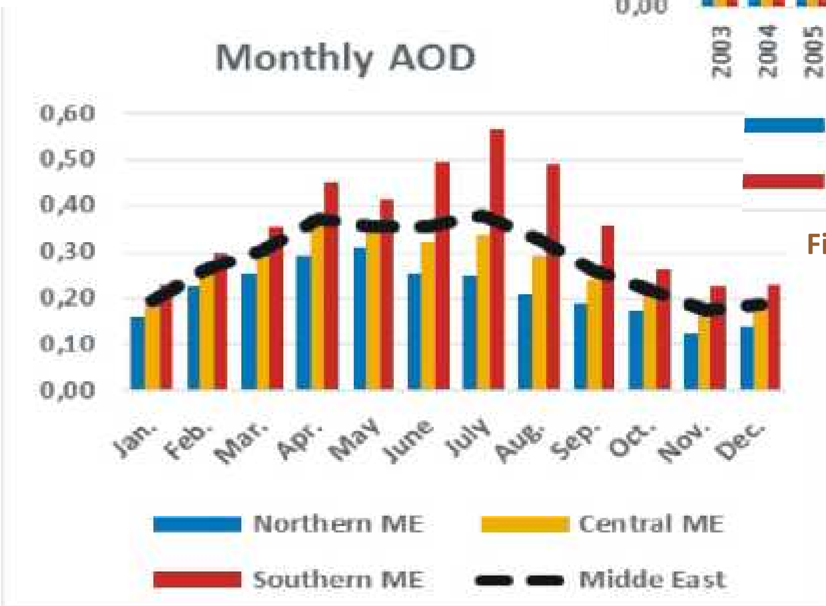


Figure 6. (b). Average monthly AOD

Analysis of Sand and Dust Storms (SDS) between the years 2003 and 2016 in the Middle East

CONCLUSION

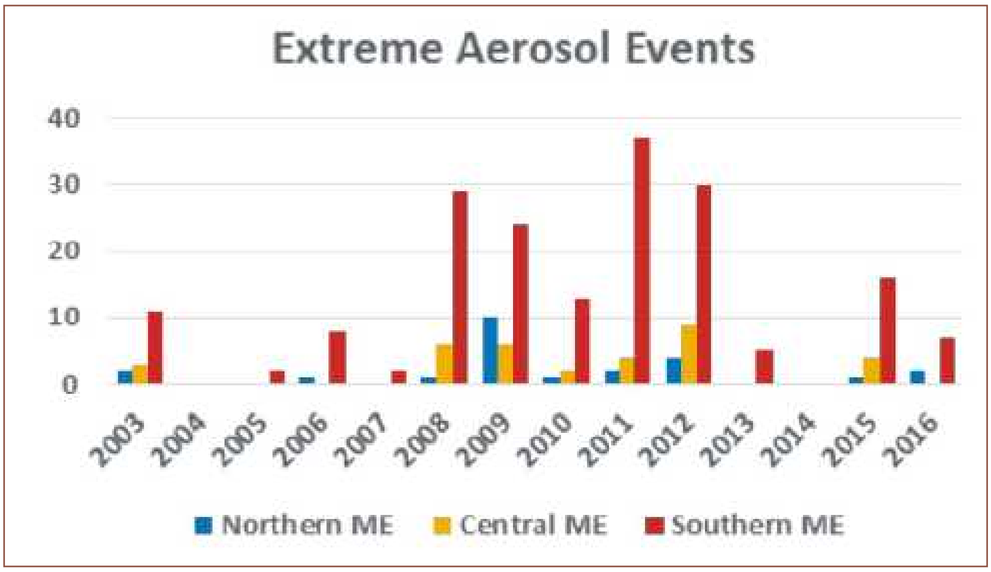


Figure 7. (a). Annual extreme events

Spatial and temporal analyses of the Middle East (extending from 20° to 38° North and 36° to 64° East) between the years 2003 and 2016 are performed with three subregions: Northern Middle East, Central Middle East and Southern Middle East. Moving southward along 20-38N latitudes, there is a significant increase in AOD values, accompanied by a decrease in AE values (coarse particles) in the same direction. It concludes that throughout 14 years, more strong and frequent dust storms are observed in the Southern Middle East which also shows different seasonal SDS characteristics.

To sum up, for the last years (2013-2016), annual mean AOD and the number of SDS are comparably lower than the other periods while the values are the highest between 2008 and 2012.

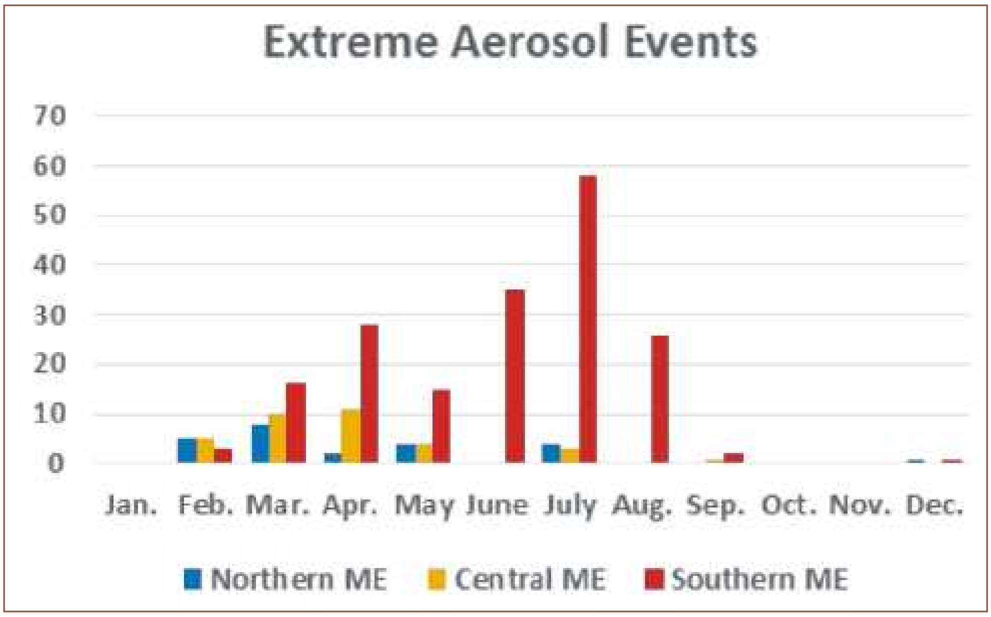


Figure 7.(b). Monthly extreme events

REFERENCES

[1] O. Alizadeh Choobari, P. Zawar-Reza, A. Sturman, The global distribution of mineral dust and its impacts on the climate system: A review, Atmospheric Research 138 (2014) 152–165.

[2] N. J. Middleton and A. S. Goudie, Saharan Dust: Sources and Trajectories, Transactions of the Institute of British Geographers Vol. 26, No. 2 (2001), pp. 165-181.

[3] Dündar C., Oğuz K., Öz N., Güllü G., Aerosol Optik Derinliği Verilerinin Türkiye İçin Alansal ve Zamansal Değişimlerinin İncelenmesi, VII. Atmosfer Bilimleri Sempozyumu, 28-30 Nisan 2015, İstanbul Teknik Üniversitesi, Istanbul (in Turkish).

[4] Gkikas, A., Hatzianastassiou, N., and Mihalopoulos, N.: Aerosol events in the broader Mediterranean basin based on 7-year (2000–2007) MODIS C005 data, Ann. Geophys., 27, 3509– 3522, doi:10.5194/angeo-27-3509-2009, 2009.

[5] IPCC: Climate Change 2013: The Physical Science Basis; 5th Assessment Report, Cambridge University Press, Cambridge and New York, 2014.

[6] Martínez Avellaneda N., Serra N., Stammer D., Minnett P.J. (2010) Response of the eastern subtropical Atlantic SST to Saharan dust: a modeling and observational study. J Geophys Res 115:C08015. doi:10.1029/2009 Jc005692

[7] NASA, National Aeronautics and Space Administration, Science Mission Directorate. NP- 2005-8-709-GSFC.

[8] Tanaka, T. Y., & Chiba, M. (2006). A numerical study of the contributions of dust source regions to the global dust budget. Global and Planetary Change, 52(1), 88-104.

[9] UNEP, WMO, UNCCD (2016). Global Assessment of Sand and Dust Storms. United Nations Environment Programme, Nairobi.