ESKİŞEHİR TEKNİK ÜNİVERSİTESİ BİLİM VE TEKNOLOJİ DERGİSİ B- TEORİK BİLİMLER

Eskişehir Technical University Journal of Science and Technology B- Theoretical Sciences

2020, 8(1), pp. 61 - 72, DOI: 10.20290/estubtdb.543355

ANALYSIS OF DUST EVENT IN TURKMENISTAN AND ITS SOURCE REGIONS

Kahraman OĞUZ *

Research Department, Turkish State Meteorological Service, Ankara, Turkey

ABSTRACT

Dust transports cause significant increases in atmospheric concentration and surface PM10 particulate matter. In recent years, Asian countries have experienced dust transport frequently. Dust transport has a significant negative impact on human health, economy and environment. This study includes the analysis of a specific dust transport event occured on 27-29 May 2018 over Turkmenistan and its source regions and. Firstly, a general dust situation of Turkmenistan region has been studied by using MODIS AOD satellite data in the study. After, the meteorological conditions and the pathway of this dust transport event was examined. The preliminary analysis using synoptic analyzes and satellite data showed that the dust was transported from Uzbekistan and Kazakhstan. The transport was occured with northly winds and affected almost all regions of Turkmenistan on 27 May 2018. Observed AOD data in the region increased significantly during the event and took its maximum on 27 May 2018. The effect of this transport lasted until 30 May 2018 in Turkmenistan. The global CAMS dust model has estimated dust transport event even some overestimations. Finally, MSG/RGB satellite products were examined detailly in order to analyze the source regions of this dust transport. The analyzes indicated the main source region of this dust transport as Aral Sea.

Keywords: Dust event, Dust source regions, Turkmenistan, Dust model, Observed AOD

1. INTRODUCTION

Dust transports cause significant increases in atmospheric concentration and surface PM10 particulate matter. In recent years, there has been frequent dust transport events in Asia. In addition to the negative effects on human health, dust aerosols have direct and indirect effects on the climate. Dust aerosols reflect and absorb solar radiation that is known as direct effect on climate. Besides, dust aerosols can act as cloud condensation nuclei and change the cloud lifetime and droplet amount (Lohmann et al., 2005). In this way, dust aerosols trigger precipitation in low-level clouds (IPCC, 2007). Dust aerosols, an important source of iron, also affect the ocean biochemical cycle (Jickells et al., 2005). Dust aerosols are also an important nutrient source especially for oceans.

The main reasons of dust transport events are known as drought and desertification. The Intergovernmental Panel on Climate Change (IPCC) accepts dust aerosols as a crucial component of atmospheric aerosols which is one of the major climate variables. According to the current climate simulations of IPCC, dust transport is expected to be more intense with the increasing frequency and intensity of the drought incident (Dündar et al., 2013).

Dust aerosols are transferred into the atmosphere from arid and semi-arid areas by wind erosion. The amount of dust released into the atmosphere from the deserts is estimated to be approximately $5x10^8$ tons per year (Naruse et al., 1986). The dust resources in the world are mostly located in the Northern Hemisphere (especially in the Sahara desert), Middle East (Arabian deserts) and Southwest Asia (Goudie and Middleton, 2001). As in other arid regions, the frequency and impact of dust transport in the southwest Asian region is increasing day by day. Dust transport is a common phenomenon especially in the arid and semi-arid regions of Turkmenistan. The arid climate of the region, the

*Corresponding Author: koguz@mgm.gov.tr
Received: 22.03.2019 Published: 28.02.2020

presence of sandy and clayey desert in large areas, sparse vegetation and strong winds lead the formation of dust transport (Orlovsyk et al., 2005). The western part and the northern part of Turkmenistan and the Karakiya region of Kazakhstan are known as the main sources of dust in the region (Figure 1).

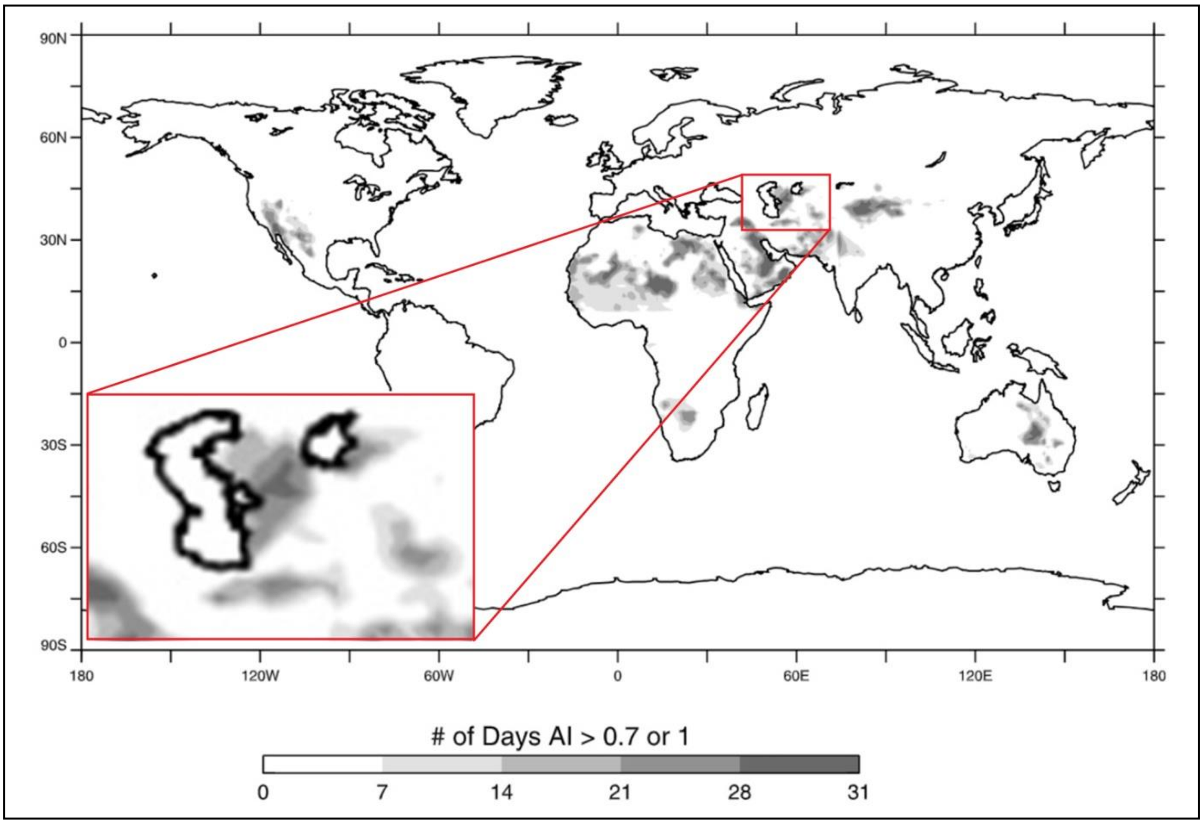

Figure 1. Global distribution of dust source regions (Prospero et al., 2002)

Childhood pneumonia events in Uzbekistan region are very high due to the dust transport in the region. Besides, 50% of all reported diseases are respiratory diseases in Turkmenistan. Children lung diseases are critical in Kazakhstan. Dust transport event usually begins at a wind speed of more than 7 m/s and has a strong relationship with soil structure, vegetation and drought (Indoitu et al., 2009). Dust aerosols are blended into the atmosphere with vertical directional air movement and can be transported hundreds of kilometers. Therefore, dust transport events are evaluated as a cross-border event. For this reason, the analysis and forecast of dust events have great importance both for the country where it is realized and for the neighboring countries.

Dust transports can be observed with MSG/RGB and MODIS-AOD satellite data, and can be forecasted with several dust forecast models. In this study, annual and seasonal AOD changes were investigated in order to demonstrate the dust situations of Turkmenistan region. Subsequently, the synoptic conditions of dust transport on 27 May 2018 were investigated. Products of ECMWF/CAMS dust transport forecast model are compared with satellite RGB images and the source regions of dust transport event are evaluated in detail.

2. MATERIAL AND METHODOLOGY

In this study, NCEP/NCAR reanalysis data, MODIS/Aqua satellite’s real-time products, HYSPLIT back trajectory model outputs, MSG/RGB satellite images and ECMWF-CAMS dust forecast model products have been used. Analysis of the occured dust transport on 27-29 May 2018 was carried out and the source regions were determined by using these numerical products.

2.1. NCEP/NCAR Reanalyses

NCEP / NCAR Reanalysis project uses the most advanced analysis / prediction system to perform data assimilation using data from 1948 to the present. These data are available 4 times daily and on average in the system. In addition, files containing variables derived from reanalysis and some other statistics are also present in the system (Kalnay et al., 1996). The system contains over 80 meteorological variables such as geopotantial height, temperature, relative humidity and wind at 17 pressure levels with resolution of 2.5 degree.

2.2. MODIS/Aqua Satellite

MODIS is an instrument with Terra and Aqua satellites. Terra's orbit around the earth is timed, so it moves north from South over the equator in the morning. Aqua goes northward on the equator in the afternoon. Terra MODIS and Aqua MODIS display the Earth's surface every 1 to 2 days, producing data at 36 spectral bands or wavelengths. These data provide information on global dynamics and processes on land, in the oceans and in the atmosphere (https://modis.gsfc.nasa.gov/about/).

The MODIS Aerosol product (AOD) used in this study indicates how much direct sunlight is prevented from reaching the ground by aerosol particles. In other words, AOD shows the distribution and density of aerosols in the atmospheric column. The AOD values are unitless and increase with rising amount of aerosol in the atmospheric column. This value refers to the dust predominantly in regions where the dust transport event is active. Giovani website designed by NASA was used in order to obtain the data and to illustrate.

2.3. HYSPLIT Model

HYSPLIT model is a system created to calculate the orbit of a simple air parcel. In this system, complex transport, distribution, chemical transformations and deposition simulations can also be performed. HYSPLIT model has become one of the most widely used models for atmospheric convection and sedimentation by experts working in atmospheric sciences. Backward trajectory analysis determines the trajectory of the air mass (https://www.arl.noaa.gov/hysplit/hysplit/). Backward trajectory analyzes are calculated by using the READY website (Rolph, 2012). The HYSPLIT model uses the data from the reanalysis product (Banacos and Ekster, 2010) or operational model studies (Moore et al., 2012) using the data of the wind and the v component, temperature, altitude and pressure at different atmospheric levels (Notaro et al., 2013).

2.4. MSG Satellite

MSG satellites are operated as two satellite systems, offering a fast scanning image for Europe, Africa and the Atlantic and Indian Ocean sections for 15 minutes and Europe for five minutes. The MSG satellite follows a quarter of the Earth and the atmosphere from a fixed position in the orbit of the Gulf of Equatorial Africa, 800 km above the Gulf of Guinea, 800 km above the Gulf of Guinea. It provides full world disc images and data for weather forecasting. Dust product is an RGB composite based on infrared channel data from the MSG satellite. It is designed to monitor the development and transport of dust storms both night and night. The dust consists of the data obtained from the combination of RGB, SEVIRI IR8.7, IR10.8 and IR12.0 channels. The channel combination and visualization parameters were chosen to maximize the visual contrast between the hot desert surface and the upper region of the dust particles (Lensky and Rosenfeld, 2008). Dust activity appears to be pink or purplish red in visuals (Solomos et al., 2017).

2.5. ECMWF-CAMS Dust Transport Forecast Model

The CAMS model, developed and operated by ECMWF, provides real-time analysis and global atmospheric composition estimates on a daily basis, including surface dust concentration and dust optical depth. The surface dust concentration provides information about the amount of dust on the surface, while the dust optical depth provides information about dust density in the atmospheric profile. CAMS dust model can provide good results for Turkmenistan and surrounding regions since it is a global model.

3. RESULTS

3.1. Aerosol (Dust) Evaluation for Turkmenistan Region

The annual and monthly AOD values from MODIS/Aqua satellite in the period of 2003-2017 for Turkmenistan are shown respectively in Figure 2 and Figure 3. It is clear that AOD values in the region show increasing trend and take its maximum value in 2008. After this date, AOD values show fluctuation until 2014 and decrease through 2017. Highest AOD values are seen especially in 2008, 2011 and 2014 years due to the high dust activity in the region (Figure 2).

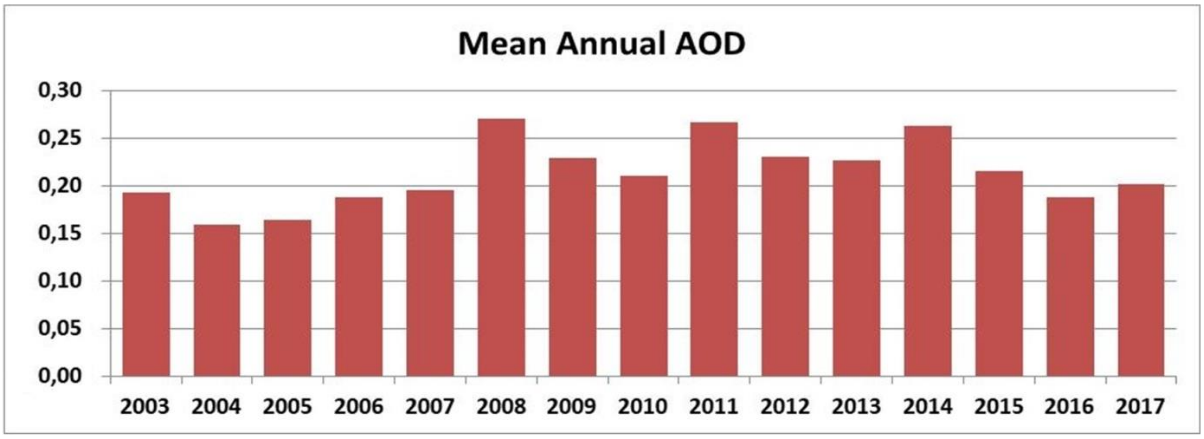

Figure 2. Mean annual AOD for Turkmenistan

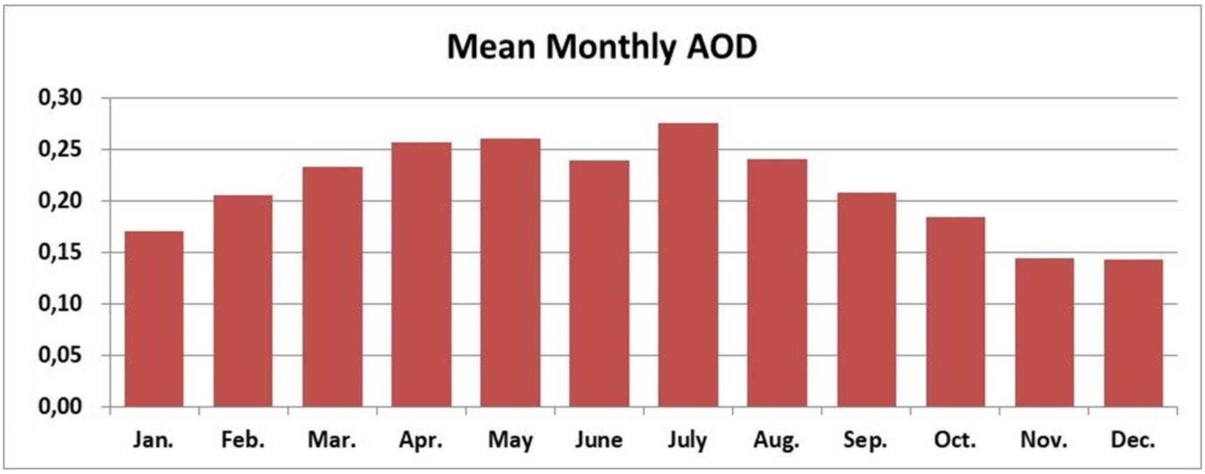

Figure 3. Mean monthly AOD for Turkmenistan

In addition, it is observed that monthly average AOD values increase between March and September (spring and summer seasons) with the increase of dust activity in Turkmenistan region. AOD values are quite low due to minimum dust activity in the region in winter season (Figure 3).

The spatial distribution of AOD data for 2003-2017 over Turkmenistan and its vicinity is shown in Figure 4. According to the AOD distribution map, the highest values (> 0.5) appear over Aral Sea. It is normal to see high AOD values due to high dust activity over Aral Sea, which is becoming more dense (Shen et al., 2018). It is also seen that the AOD values are still high over the region between the Aral Sea and the Caspian Sea (including the west of Turkmenistan) even not as much as in the Aral Sea. High values are related to the northly dust transports over the region and Aral Sea. The result is similar to the dust source regions shown in Figure 1.

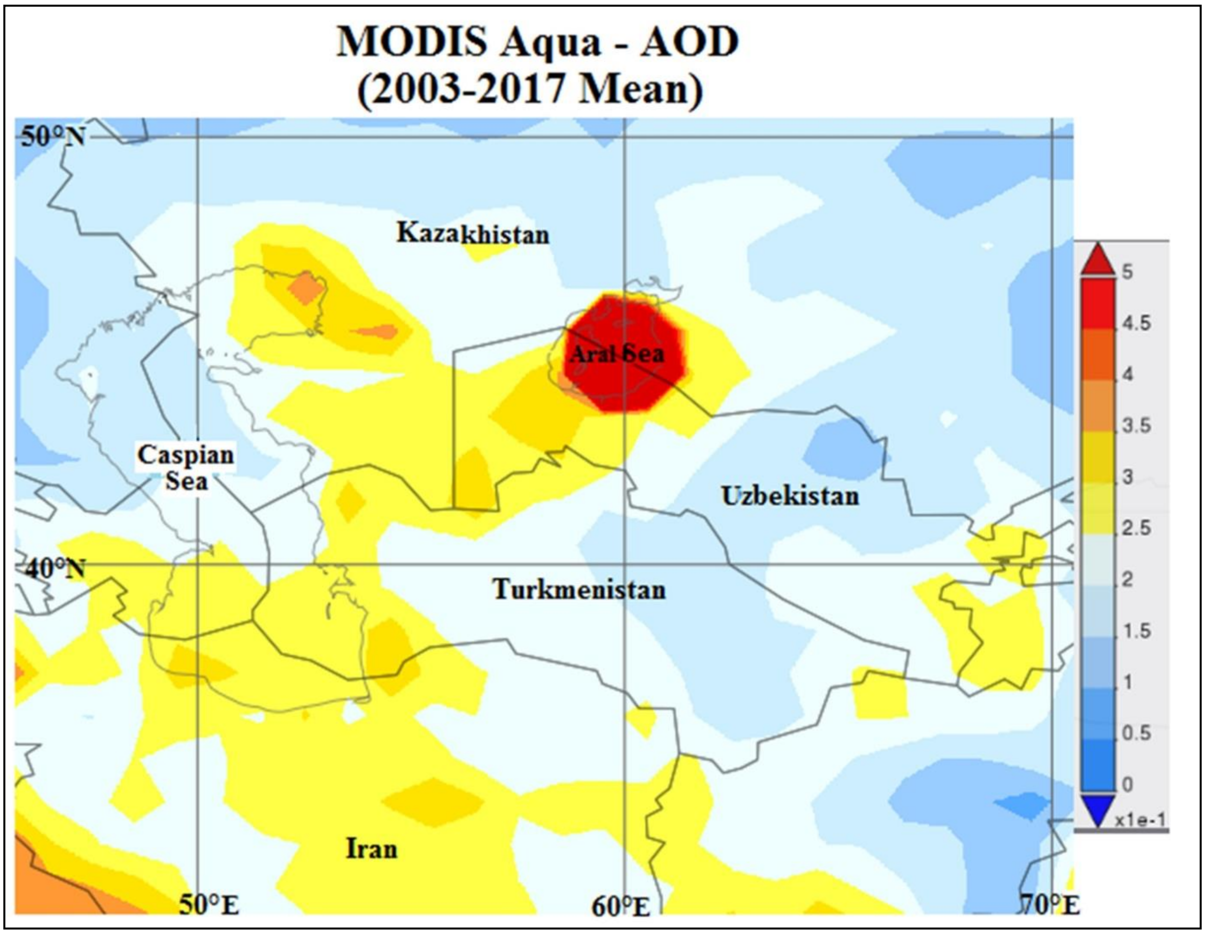

Figure 4. Spatial distribution of mean AOD for 2003 and 2017 years

Annual average of AOD values for Aral Sea is shown in Figure 5 in order to investigate the trend of this high values. According to the graph, a dramatic increase is occurred from 2003 to 2014 year. Although the values decrease after 2014, a serious increase stand out from 2003 to 2017 year. AOD value reach its maximum with the value of 0.98 in 2014 while it is 0.4 in 2003. AOD is measured as 0.78 in 2017. This result indicates that satellite AOD values was increased due to the increase of dust inclusion from the Aral Sea into the atmosphere.

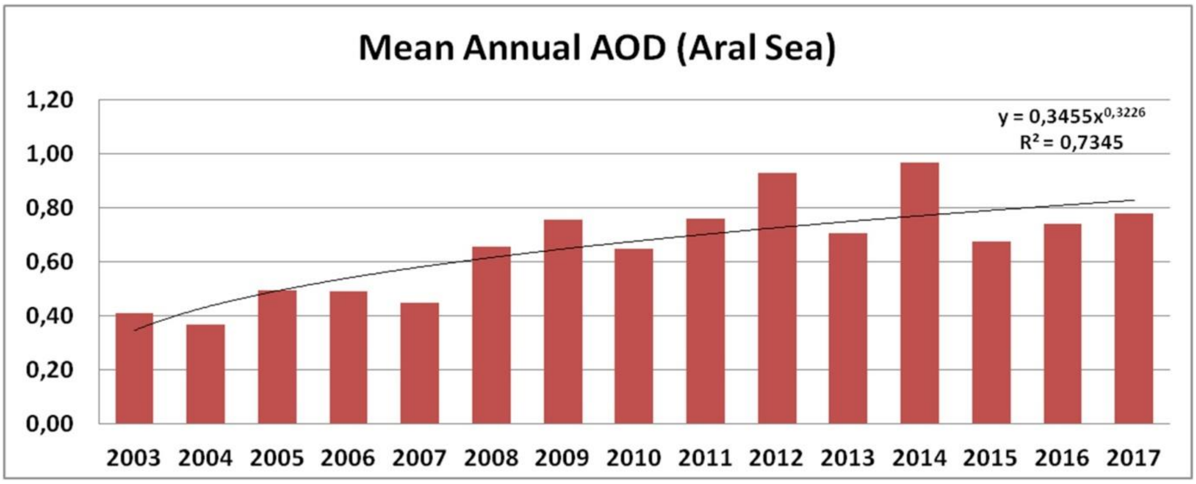

Figure 5. Mean annual AOD for Aral Sea

3.2. Analyses of Dust Transport Event dated on 26-29 May 2018

Dust transport is mainly controlled by meteorological conditions. The commence of dust emission, which is the first stage of dust transport, is directly related to wind speed. In addition, wind speed has an important role on the vertical and horizontal transportation of the dust from surface into the atmosphere. 850 hPa geopotential height (m) and wind speed (m/s) maps are presented in Figure 6 as well as satellite AOD maps. These maps show relationship between changing wind speeds and pressure center as well as AOD change. The 850 hPa maps show that Low Pressure Center, located over Kazakhstan and Uzbekistan on 26 May 2018, has moved eastward on 27 May 2018 and High Pressure Center replaced it. It is seen that the Low Pressure Center located over Pakistan and India has deepened on 28 May 2018. These conditions indicate that the movement of air parcel will be realized towards Turkmenistan from Kazakhstan. This movement that took place on 27 May 2018 showed its effect as increasing wind intensities. The wind intensities over Turkmenistan were around 4 m/s on 26 May 2018 and increased up to 8-10 m/s on 27 May 2018. This increase in wind velocity inherently triggered dust activity in the region.

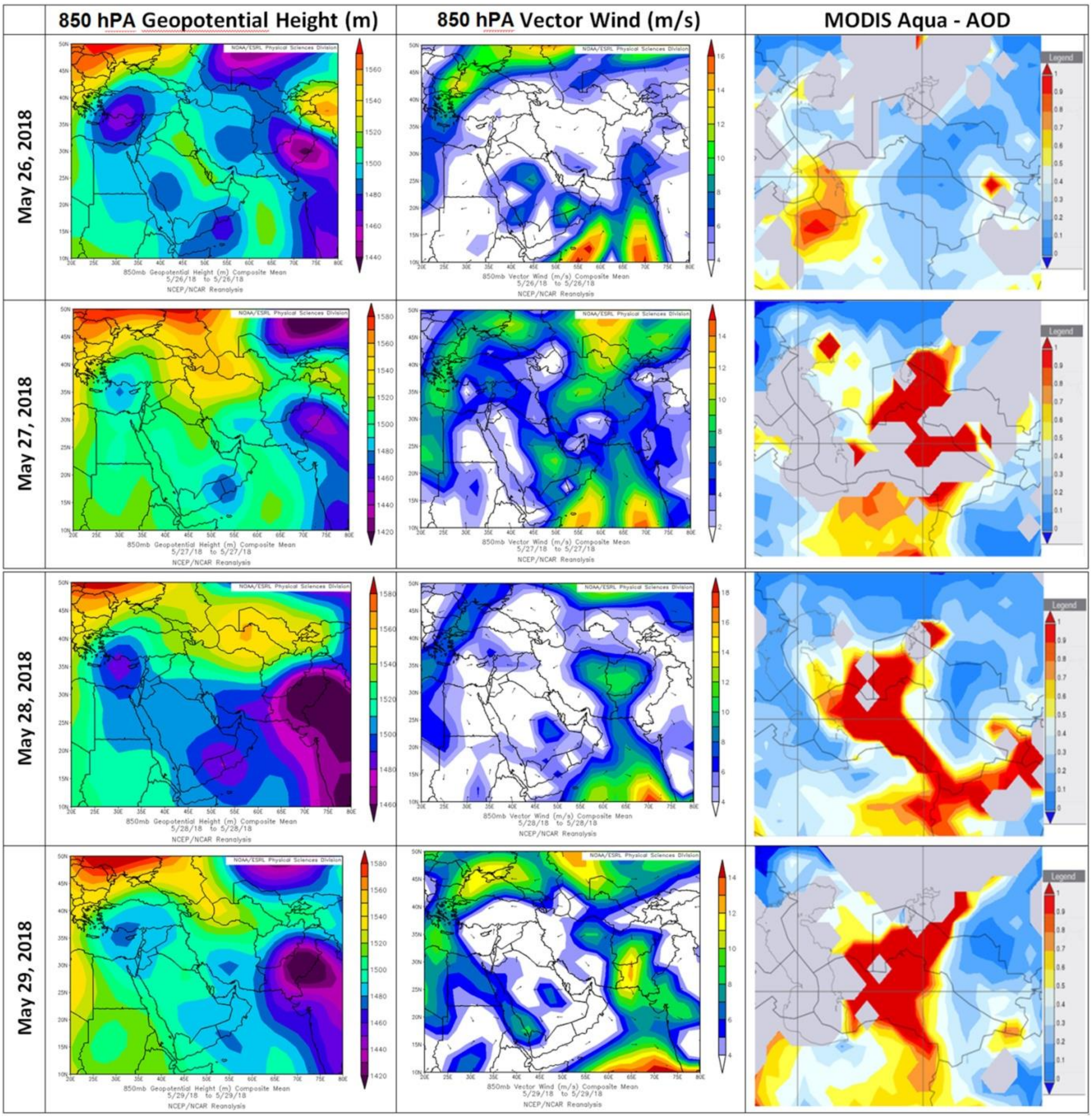

Figure 6. 850 hPa geopotential height (m), wind speed (m/s) and MODIS-Aqua AOD maps

The dramatic increase in AOD on 27 May 2018 also supports dust activity in the region. It is clear that the dust transport controlled by northernly winds affected almost all region of Turkmenistan. Even if wind intensities on Turkmenistan decreased on 28 and 29 May 2018, AOD values still conserved its high value which indicates proceeding dust acitivity in the atmosphere. Temporal variation of AOD for 25-31 May 2018 in Turkmenistan is shown in Figure 7. It is observed that the increasing AOD values received its maximum (~ 1.6) on 27 May 2018 and then decreased its severity slightly. However, it is clear that the high AOD values (~ 1) still continue after 28 May 2018 despite the decreases.

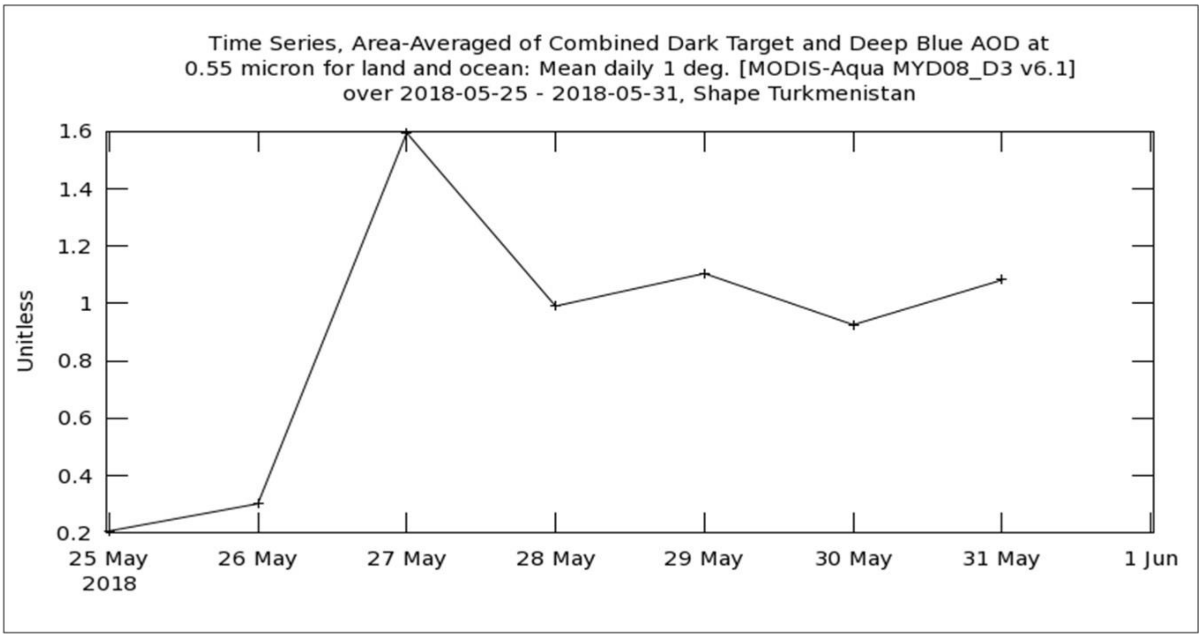

Figure 7. Temporal variation of AOD in Turkmenistan for 25-31 May 2018

The effects of the dust transport event are also seen in real-time satellite images (Figure 8 (a)). In addition to Turkmenistan, other countries like Kazakhstan and Uzbekistan are also affected by dust transport event. Dust transport reached to Turkmenistan from Uzbekistan and Kazakhstan on 27 May 2018. Real-time satellite images also show high intense of dust transport like in the satellite AOD maps. The dust transport event continued its effect until 30 May 2018.

Besides, the trajectory analysis of the air mass reaching the Darvaza region of Turkmenistan on 27 May 2018 at 12UTC is shown in Figure 8 (b). Two different levels of air mass trajectory were investigated in orbit analysis. The results confirm that 10m and 500m air masses are transported from Kazakhstan and Uzbekistan through Darvaza region of Turkmenistan.

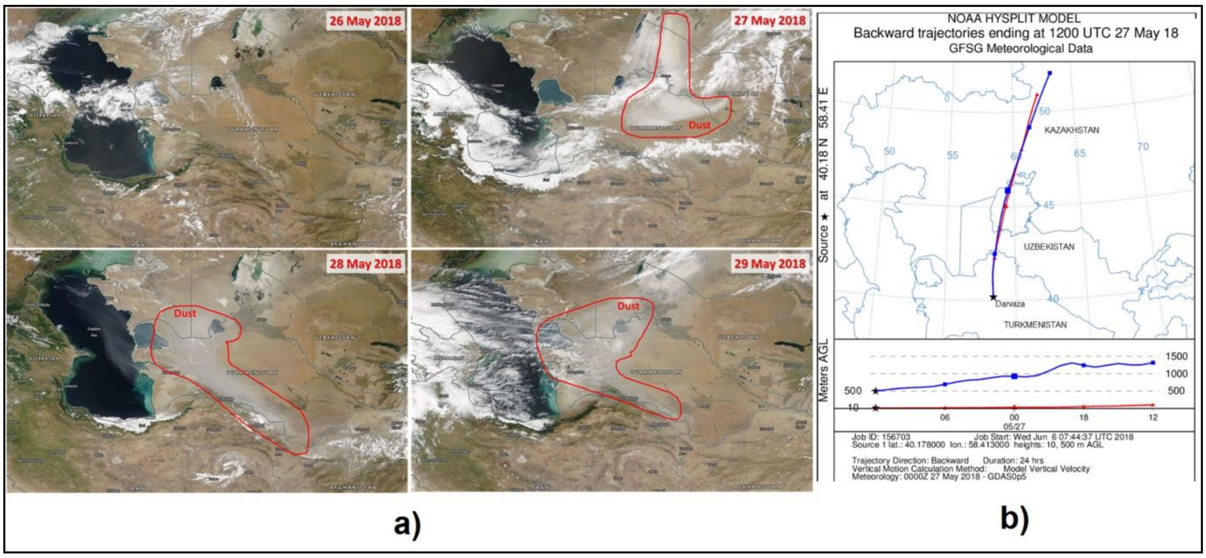

Figure 8. (a) Real time satellite images for 26-29 May 2018, (b) HYSPLIT backward trajectory analysis ended in Darvaza at 27 May 2018 - 12 UTC

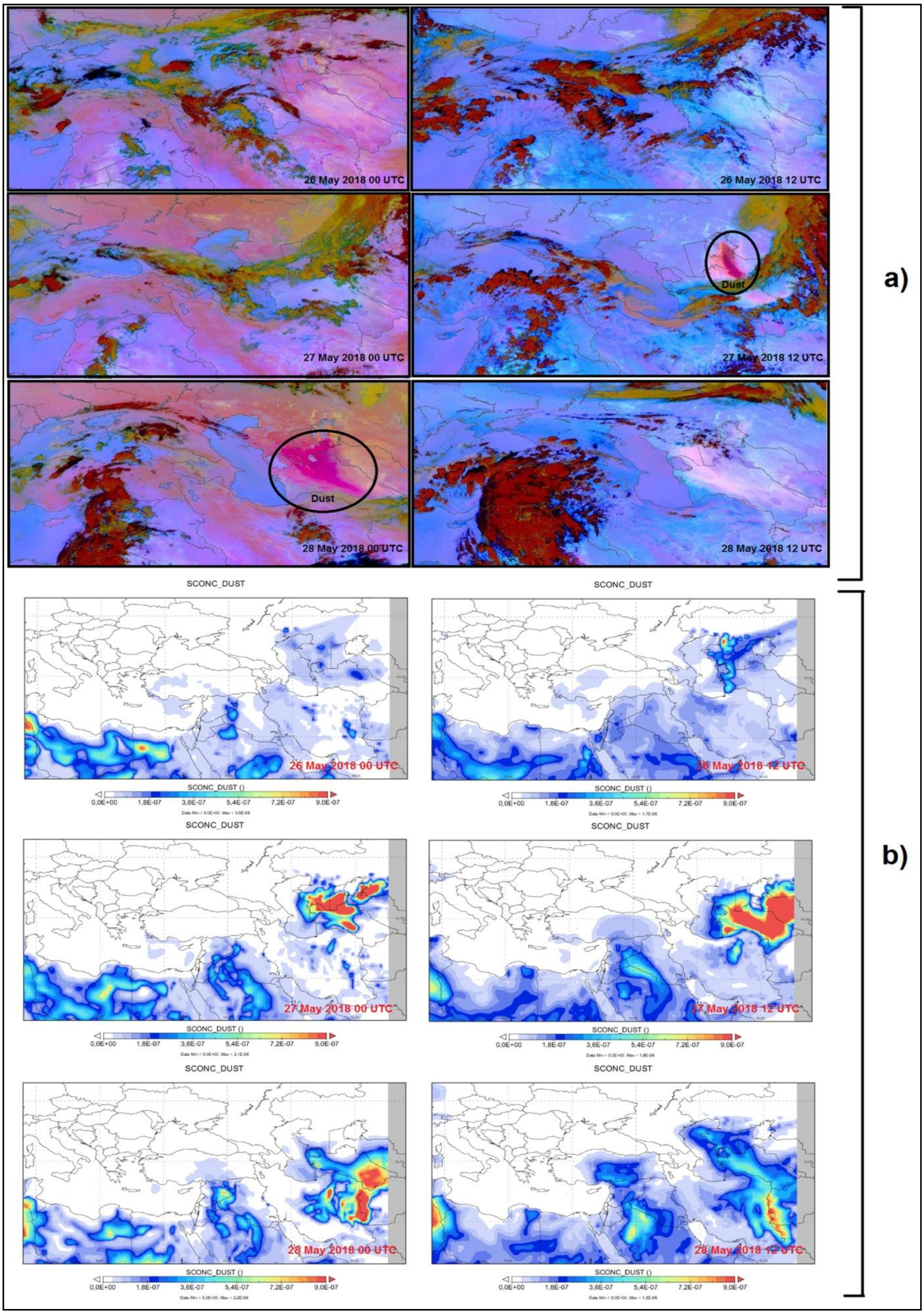

Figure 9. (a) MSG/RGB satellite images, (b) CAMS dust surfce concentration forecasts

In Figure 9 (a), the dust RGB products are shown for the dates of 26-28 May 2018. Dust is seen as dark pink colour in the maps. No dust event is seen on 26 May 2018. However, dust transport occurred on 27 May 2018 and continued until 28 May 2018 12UTC. Surface dust concentration forecasts of CAMS model for 26-28 May 2018 with 12 hour time intervals are shown in Figure 9 (b). According to CAMS model products, there is no significant dust transport in the region on 26 May 2018. However, a dust transport event started over Turkmenistan on 27 May 2018 and it increased the effect all day long according to CAMS model products. Forecasts show more than 9.10-7 kg/m3 (<900 μ/m3) surface dust concentration in the region. This amount is significantly higher than the EU PM10 air quality threshold (50 μ/m3). The effects of the dust event reduced on 28 May 2018, but still high surface dust concentration amounts continued in the region even if it is not as high as previous day.

More frequent time-lapsed RGB images are presented in order to identify the main source regions of the dust transport on 27 May 2018 in Figure 10. It is clear that a dust transport occured over the Aral Sea was proceeded towards Turkmenistan with the northern winds in the early times of 27 May 2018. It is noteworthy that the effect of the Aral Sea-borne dust event increased its effect during the evening of the same day. These results indicates the main source region of the dust transport event as the Aral lake located at the border of Kazakhstan and Uzbekistan.

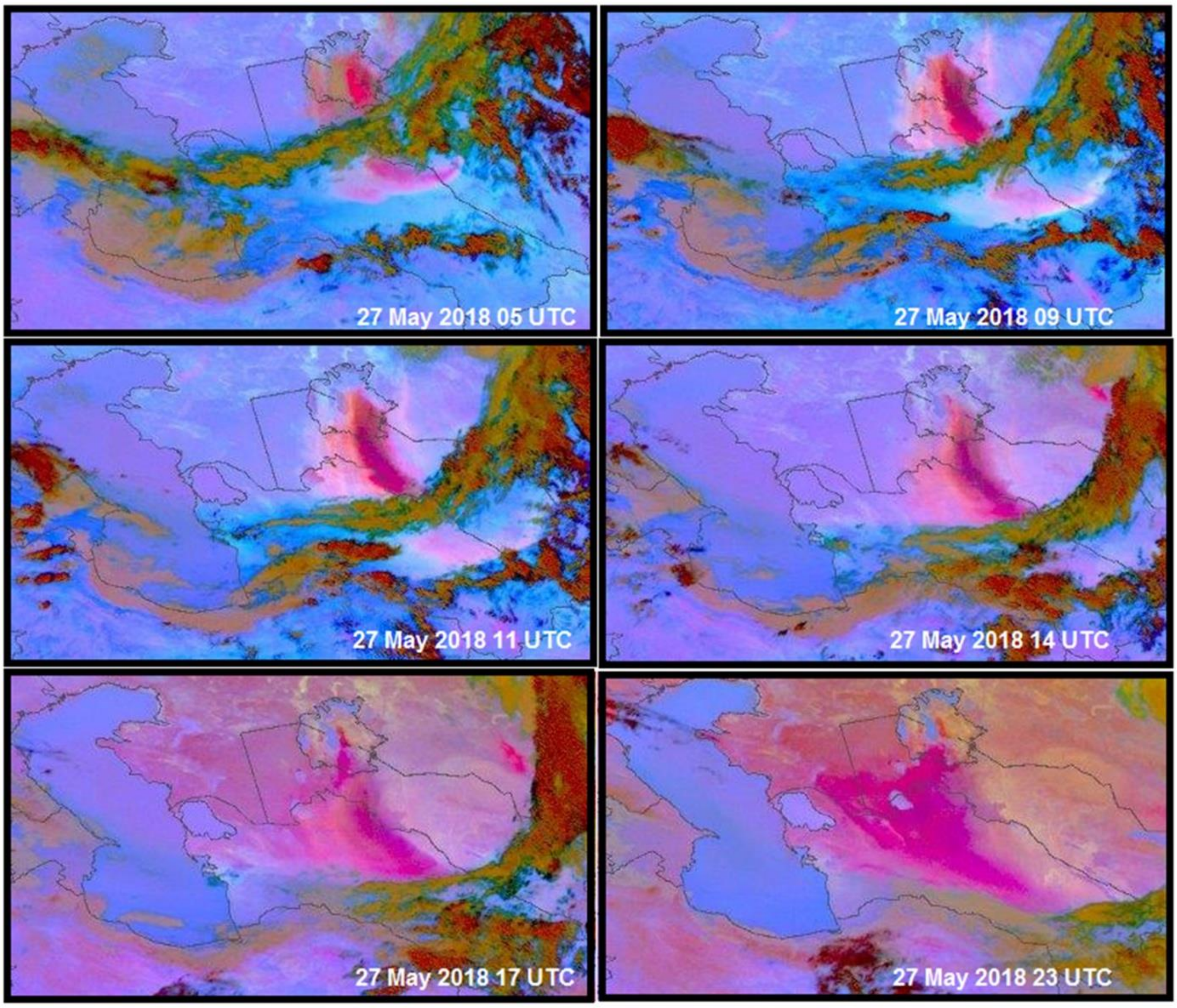

Figure 10. More frequent time-lapsed MSG-RGB dust images for 27 May 2018

4. CONCLUSIONS

Dust transport events, a natural phenomenon of arid and semi-arid regions, have important implications for Southwest Asia as well as North Africa and the Middle East regions. Southwest Asia region is often confronted with dust transport due to its arid nature. In this study, AOD distribution of the Turkmenistan region was investigated as well as the annual and monthly aerosol (dust) change by using MODIS-Aqua satellite. In addition, a strong dust transport event in Turkmenistan occured on 27 May 2018 was analyzed by using satellite and model forecast products. Besides, the source region of this dust event was determined in detail.

Satellite AOD data showed an increase through 2008 year due to the increase in dust activity in Turkmenistan. Some fluctuations is observed between 2008 and 2014. However, AOD data showed decreasing trend after 2014 year. This indicates a slight decrease in dust activity towards 2017 year in the region. In addition, it is found that dust activity occurs mostly in spring and summer seasons in Turkmenistan. Observed AOD data shows high AOD values between March and September months compared to other months. Winter season shows the lowest AOD values which indicates low dust activity in the region. Besides, highest AOD values in the region are found over the Aral Sea due to spatial variation of AOD. Temporal variation of AOD for Aral Sea generally shows increasing trend from 2003 to 2017.

Regarding the actual dust transport, it was clear that dust incident in Turkmenistan on 27 May 2018 started with high wind intensities and affected almost all regions of Turkmenistan throughout the day. Dust activity continued until 30 May 2018 in the region. The effect of this dust event was evident in MODIS-Aqua, MSG/RGB and CAMS model products. The back trajectory analysis showed that the air mass was moved from Kazakhistan and Uzbekistan through Turkmenistan. In addition, detailed analyzes with RGB products showed that the dust event on the Aral Sea started in the early hours of 27 May 2018 and moved directly through central regions of Turkmenistan with the northernly winds. The results clearly shows the main source region of this dust event as the Aral Sea.

The CAMS global dust forecast model showed the high surface dust concentration on 27 May 2018. However, it was seen that the model forecasted the effects of this dust transport more than actual. Therefore, high resolution dust modeling with a regional model can provide better results to represent the dust activity in the region.

ACKNOWLEDGEMENTS

I am very gratefull to NASA, EUMETSAT, NOAA and ECMWF to provide dust related satellite data, synoptic charts and dust forecast products. I also thank to Mr. Cihan Dündar from Turkish State Meteorological Service to help for visualization processes of some charts.

REFERENCES

[1] Banacos PC and Ekster ML. The association of the elevated mixed layer with significant severe weather events in the Northeast United States. Wea. Forecasting 2010; 25:1082-1102.

[2] Dündar C, Oğuz K and Güllü G. Evaluation of Sand and Dust Storms (SDS) over Eastern Mediterranean Basin. 10. National Conference on Environmental Engineering; 12-14 September 2013; Hacettepe University, Ankara, Turkey.

[3] Goudie AS and Middleton NJ. Saharan dust storms: nature and consequences. Earth-Science Reviews 2001; 56; 179–204.

[4] Indoitu R, Orlovsky L and Orlovsky N. Dust storms in Central Asia: spatial and temporal variations. J Arid Environ 2012; 85; 62–70.

[5] IPCC 2007 Summary for policymakers in Climate Change 2007: the Physical Science Basis; Cambridge University Press, New York, NY, USA.

[6] Jickells TD, An ZS, Andersen KK, Baker AR, Bergametti G, Brooks N, Cao JJ, Boyd PW, Duce RA, Hunter KA, Kawahata H, Kubilay N, laRoche J, Liss PS, Mahowald N, Prospero JM, Ridgwell AJ, Tegen I and Torres R. Global iron connections between desert dust, ocean biogeochemistry, and climate. Science 2005; 308; 5718 67–71.

[7] Kalnay et al. The NCEP/NCAR 40-year reanalysis Project. Bull. Amer. Meteor. Soc. 1996; 77; 437-470.

[8] Lensky IM and Rosenfeld D. Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAPSAT). Atmos. Chem. Phys. 2008; 8; 6739–6753.

[8] Lohmann U and Feichter J Global indirect aerosol effects: a review. Atmospheric Chemistry and Physics 2005; 5 3; 715–737.

[9] Moore BJ, Neiman PJ, Ralph FM and Barthold F. Physical processes associated with heavy flooding rainfall in Nashville, Tennessee, and vicinity during 1–2 May 2010: The role of an atmospheric river andmesoscale convective systems. Mon. Weather Rev. 2012; 140; 358–378.

[10] Naruse T, Sakai H and Inoue K. Aeolian dust origin of fine quartz in selected soils. Japan Quat Res (Tokyo) 1986; 24; 295–300.

[11] Notaro M, Alkolibi F, Fadda E, and Bakhrjy F. Trajectory analysis of Saudi Arabian dust storms. J. Geophys. Res. Atmos. 2013; 118; 6028–6043.

[12] Orlovsky L, Orlovsky N and Durdyev A. Dust storms in Turkmenistan. Journal of Arid Environments 2005; 60; 83–97.

[13] Prospero JM, Ginoux P, Torres O, Nicholson S, Gill TE. Environmental characterization of global sources of atmospheric soil dust derived from the NIMBUS&TOMS absorbing aerosol product. Rev. Geophys. 2002; 40; 1 2-1-2-31.

[14] Rolph GD 2012 Real-time Environmental Applications and DisplaysYstem (READY) website (http://ready.arl.noaa.gov); NOAA AirResources Laboratory, Silver Spring, MD.

[15] Solomos S, Ansmann A, Mamouri RE, Binietoglou I, Patlakas P, Marinou E and Amiridis V. Remote sensing and modelling analysis of the extreme dust storm hitting the Middle East and eastern Mediterranean in September 2015. Atmos. Chem. Phys. 2017; 17; 4063-4079.

[16] Shen H, Abuduwaili J, Ma L and Samat A. Remote sensing-based land surface change identification and prediction in the Aral Sea bed, Central Asia. International Journal of Environmental Science and Technology 2018; 1-16.

[17] https://www.arl.noaa.gov/hysplit/hysplit/

[18] https://modis.gsfc.nasa.gov/about/