ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. (2015)
Published online in Wiley Online Library
(wileyonlinelibrary.com) **DOI:** 10.1002/asl.584

Royal Meteorological Society

Cyclone contribution to dust transport over the Mediterranean region

Emmanouil Flaounas,[1]* Vassiliki Kotroni,[1] Konstantinos Lagouvardos,[1] Stelios Kazadzis,[1,2] Antonis Gkikas[3] and Nikolaos Hatzianastassiou[4]

[1] *National Observatory of Athens, Greece*
[2] *Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Switzerland*
[3] *Earth Sciences Department, Barcelona Supercomputing Center, Spain*
[4] *Laboratory of Meteorology, Department of Physics, University of Ioannina, Greece*

**Correspondence to:*
E. Flaounas, National Observatory of Athens, Lofos Nymphon, Thissio, PO Box 20048, Athens 11810, Greece.
E-mail: flaounas@noa.gr

Received: 5 January 2015
Revised: 14 April 2015
Accepted: 17 April 2015

Abstract

This study addresses the question of cyclone contribution to dust transport events over the Mediterranean. For this reason, we tracked and associated all intense cyclones in the period 2005–2012 with satellite estimations of the aerosol optical depth, the aerosol index and the aerosol Ångström exponent. Results show that cyclones are related with up to 20% of the total dust events over the Mediterranean, especially affecting its eastern side. When considering only the extreme dust events, the cyclone contribution may reach 70%, highlighting cyclones as one of the main factors for extreme dust transport events in the region.

Keywords: **dust transport; Mediterranean cyclones; cyclones tracking**

1. Introduction

Understanding the atmospheric systems that cause dust transfer is crucial for the improvement of local air quality forecasting (Flaounas *et al.*, 2009) and for determining the contribution of certain weather systems in dust-related environmental and health risks. Moulin *et al.* (1998) and more recently Gkikas *et al.* (2014) and Varga *et al.* (2014) used satellite observations to analyze the climatological atmospheric conditions that cause dust transport over the Mediterranean. Their results showed that the dust transport events were constantly associated with cyclonic conditions over North Africa, especially in spring and summer periods, when North Africa cyclones are frequent (also known as Sharav cyclones; Engelstaedter *et al.*, 2006). Indeed, Fiedler *et al.* (2014) showed that 90% of dust uptake over the Saharan desert is due to depressions, such as the Saharan heat-low, while almost 25% of the total dust emissions in spring are due to cyclones occurring over North Africa.

Sharav cyclogenesis takes place mainly in spring, when the resulting cyclones are typically of weaker intensity, compared with the stronger winter and autumn Mediterranean cyclones (Hannachi *et al.*, 2011; Ammar *et al.*, 2014). Nevertheless, intense cyclones are known to be related to dust transport throughout the year in the region. For instance Bou Karam *et al.* (2010) analyzed a strong cyclogenesis case that occurred over the southern side of the Atlas Mountain in February 2007. The cyclone lasted 5 days, transferring large amounts of desert dust over the eastern and central Mediterranean, until its dissipation over the Middle East.

Several atmospheric factors might be responsible for dust emissions over North Africa, including local circulations, wind surges and larger scale depressions (Knippertz and Todd, 2012). Among these factors, cyclones present a particular interest due to their capacity to transport dust in large distances over the Mediterranean region (e.g. Bou Karam *et al.*, 2010; Fiedler *et al.*, 2014). The scientific literature currently suffers from the lack of a systematic study that shows the importance of the role of cyclones on dust transport in a climatological context. To this end, we apply a straight forward methodology associating cyclonic circulations of intense cyclones with dust presence over the Mediterranean basin. Thus, we aim at quantifying the cyclone contribution to dust transport events. Section 2. provides an explanation of the methodology and datasets used. Section 3. presents our results and finally Section 4. hosts the discussion and the conclusion of the results.

2. Datasets and methods

2.1. Cyclone tracking method

Cyclones are tracked during the 8-year period of 2005–2012. For this reason we applied the method developed by Flaounas *et al.* (2014), where cyclones centers and intensities are defined by the grid point and magnitude of relative vorticity local maxima at 850 hPa. Cyclones have been tracked using the 6-hourly 850 hPa relative vorticity fields of ERA-Interim in a standard horizontal grid spacing in longitude and latitude of $0.75° \times 0.75°$ (Dee and Uppala, 2009). Tracking has been performed within the region illustrated in Figure 1(a), where we retained only the systems that presented a life-time of at least 1 day (i.e. at least five track points) and maximum intensity of more than $8\times10^{-5}\ s^{-1}$. This intensity threshold has been previously used in Flaounas *et al.* (2013) and was shown to be adequate for discriminating the intense Mediterranean cyclones. In fact, the filters applied on lifetime and intensity provide a high degree of confidence that the tracked features correspond to cyclones in the sense of strong long lasting vortices. Consequently, our study identified 1055 cyclones for the whole 8-year period, evenly distributed over the period with about 130 cyclones per year. The latter is consistent with the results by Campins *et al.* (2011) who analyzed Mediterranean cyclones climatology and found about 100 intense cyclones per year.

Figure 2(a) presents the histogram of the maximum intensity for all tracked cyclones in terms of maximum relative vorticity. A sharp decrease is observed for approximately 90% of the cases within the range of $8\times10^{-5}\ s^{-1}$ to $12\times10^{-5}\ s^{-1}$, while the rest- and strongest cyclones- account for about 15 cyclones per year. The seasonal dependency of all tracked cyclones (Figure 2(b), gray line) comes in accordance with previous studies on intense Mediterranean cyclones climatology, presenting a pronounced maximum of occurrence in winter and a minimum in summer (e.g. Campins *et al.*, 2011; Flaounas *et al.*, 2013). Indeed, intense Mediterranean cyclogenesis mainly occurs in winter, when the intrusion of high tropospheric potential vorticity streamers is favored by the seasonal location of the polar jet (Chaboureau *et al.*, 2012; Flaounas *et al.*, 2015).

2.2. Satellite observations and dust events

In this analysis, Collection 051 Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua level 3 daily gridded data (MYD08_D3) is used provided at grid spacing of 1° × 1° in longitude and latitude. Additionally, the corresponding MODIS-Terra data (MOD08_D3) is used in cases where the Aqua retrievals are not available. MODIS instrument on board the Terra and Aqua satellites – with daytime equator crossing time at 1030 and 1330 UTC, respectively, and 2330 km viewing swath – provides almost daily global coverage for various aerosol optical properties including aerosol optical depth (AOD). The retrieval of MODIS aerosol data is performed by separate algorithms (e.g. Remer *et al.* (2005)), depending on the underlying surface type (land or ocean). Moreover, the MODIS Deep Blue product was also used, which enables the retrieval of aerosol optical properties over the bright Sahara desert surfaces through the Deep Blue (DB) algorithm (Hsu *et al.*, 2004). The accuracy of the AOD retrievals has been certificated based on evaluation analyses, both on a global or regional sca against the Aerosol Robotic Network (AERONET) sun photometer measurements (e.g. Remer *et al.*, 2008; Levy *et al.*, 2010; Shi *et al.*, 2013). It has been found that the performance of the retrieval algorithm of MODIS Collection 005 AOD is better over maritime ($\pm 0.03 \pm 0.05 \times \text{AOD}$) than continental ($\pm 0.05 \pm 0.15 \times \text{AOD}$) areas. From the MODIS database, we have used AOD at 550 nm and Ångström Exponent (AE) over land (470–660 nm) and ocean (550–865 nm), both derived by the Dark Target (DT) algorithm, while over deserts we have used AOD at 550 nm and AE (412–470 nm), both derived by the DB algorithm.

Absorption Aerosol Index (AI) data were taken from OMI-Aura (Ozone Monitoring Instrument) measurements (Torres *et al.*, 2007). This aerosol record is obtained at near-UV spectral wavelengths, with an uncertainty of ±0.1, provided on a daily basis, and it is a qualitative parameter associated with the presence of UV-absorbing aerosols (e.g. desert dust). The OMI-Aura and MODIS-Aqua observations are made at around the same time since Aura and Aqua satellites are flying in the A-Train constellation (http://atrain.nasa.gov/).

In our study we consider the presence of dust, when satellite retrievals present $\text{AE} < 0.7$ and $\text{AI} > 1$. More specifically, AE information can be used for separating coarse mode from fine mode particles. In past studies, Dubovik *et al.* (2002) have proposed a threshold of $\text{AE} < 0.9$ for the case of mineral dust particles, while for the Mediterranean region, Bryant *et al.* (2006) proposed a threshold of $\text{AE} < 0.6$ for dust cases. In order to discriminate sea salt from dust, we have used AI as an indicator of aerosol absorptivity. Herman *et al.* (1997) and Torres *et al.* (1998) have shown that negative values of AI indicate the presence of nonabsorbing aerosols (e.g. sea salt particles), whereas positive AI values (mostly >1) indicate absorbing aerosols (e.g. dust).

2.3. Attributing dust events to cyclones-related circulations

To be consistent with the MODIS observations, we take into account only the cyclone track points detected at 1200 UTC of each day. For these track points we plot all the wind streamlines at the 850 hPa level and we retain only the streamlines ending within 500 km around each cyclone center. The 500 km radius is taken here as the representative radius of intense Mediterranean cyclones, while cyclone circulation at the level of 850 hPa (approximately 1500 m above sea level) is consistent with the level of dust transport over the eastern Mediterranean (Griffin *et al.*, 2007).

As an example of our methodology, Figure 1(a) shows the streamlines associated with an intense dry cyclone (ending within the black circle of 500 km radius around the cyclone center) that caused a major dust outbreak in February 2007 over North Africa (Bou Karam *et al.*, 2010). Figure 1(b) shows the areas presenting dust ($\text{AE} < 0.7$ and $\text{AI} > 1$) and the domain's AOD at the timing of the cyclonic circulation, shown in Figure 1(a). In order to connect cyclonic circulation with dust transport, our method associates the 1° × 1° latitude–longitude grid points presenting dust (depicted

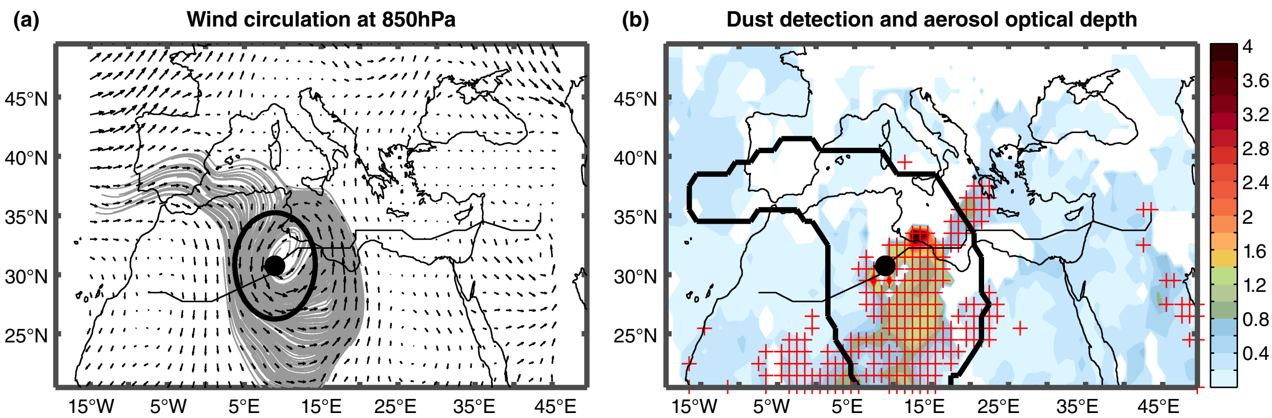

Figure 1. Methodology paradigm on associating dust transport with cyclones: the February 2007 case. (a) The cyclone track is represented by the thin black line, while the black dot depicts its location at the cyclone's mature stage at 1200 UTC, 22 February. Only wind streamlines (gray lines) ending within the 500 km radius around the cyclone center (thick black circle) are plotted. (b) The grid points presenting dust are depicted by red crosses (grid points presenting AE < 0.7 and AI > 1) and AOD is plotted in color. The black contour outlines the cyclonic circulation as defined by the streamlines shown in (a).

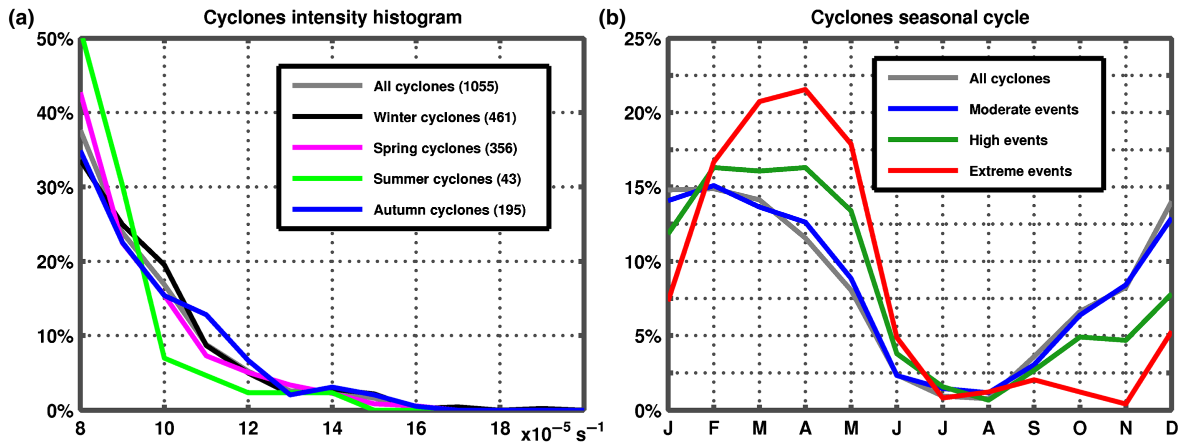

Figure 2. (a) Histogram of cyclones maximum intensity per season for the whole period of 2005–2012 (all cyclones present maximum intensity of more than $8 \times 10^{-5}\ s^{-1}$). Numbers in legend show the total number of cyclones tracked per season. (b) Seasonal cycle with respect to the annual total of (i) all detected cyclones (gray line), (ii) of all cyclones associated with dust events of moderate intensity (blue line), (iii) of all cyclones associated with high intensity (green line) and (iv) of all cyclones associated with extreme intensity (red line).

by red crosses in Figure 1(b)) with cyclone circulation within the overlapping area (depicted by the black contour in Figure 1(b)). The dust associated with these grid points is considered to have been transferred by the cyclone or more generally to be 'under the influence of the cyclone-induced circulation'. This procedure is repeated for all 1055 detected cyclones within the 8-year study period.

3. Results

Figure 3(a) shows the percentage of days that dust is observed over the broader Mediterranean. In accordance with Gkikas *et al.* (2013), the higher frequency of dust events is observed over North Africa, the Arabian Peninsula and the Atlas-Ahaggar plateau (centered at 22°N, 10°W). On the other hand, the Mediterranean Sea is affected by dust approximately in 5–10% of the total of days in our 8-year period. In order to quantify the cyclones contribution to the dust transport in the region we use the methodology described in Section 2.3. Figure 3(b), shows the total contribution of cyclones to dust transport events, defined at each grid point separately as the fraction of number of days when dust overlaps with cyclone-related streamlines, divided by the total number of days with dust. Results show that dust transport by intense cyclones is more frequent over the central and eastern Mediterranean (about 25–30%). Interestingly, the areas where cyclones-related dust transport contributes by more than 10% to the total of dust days match fairly well the Sharav cyclone tracks density (e.g. Hannachi *et al.*, 2011, their Figure 6), as also with the air masses trajectories which have caused major dust transport events over the eastern Mediterranean (Gkikas *et al.*, 2013).

In order to analyze the dependency of the intensity of dust transport events to cyclones, we have assigned three classes of dust days intensities, using the ranges of 25–75%, 75–95% and 95–100% quantiles of AOD

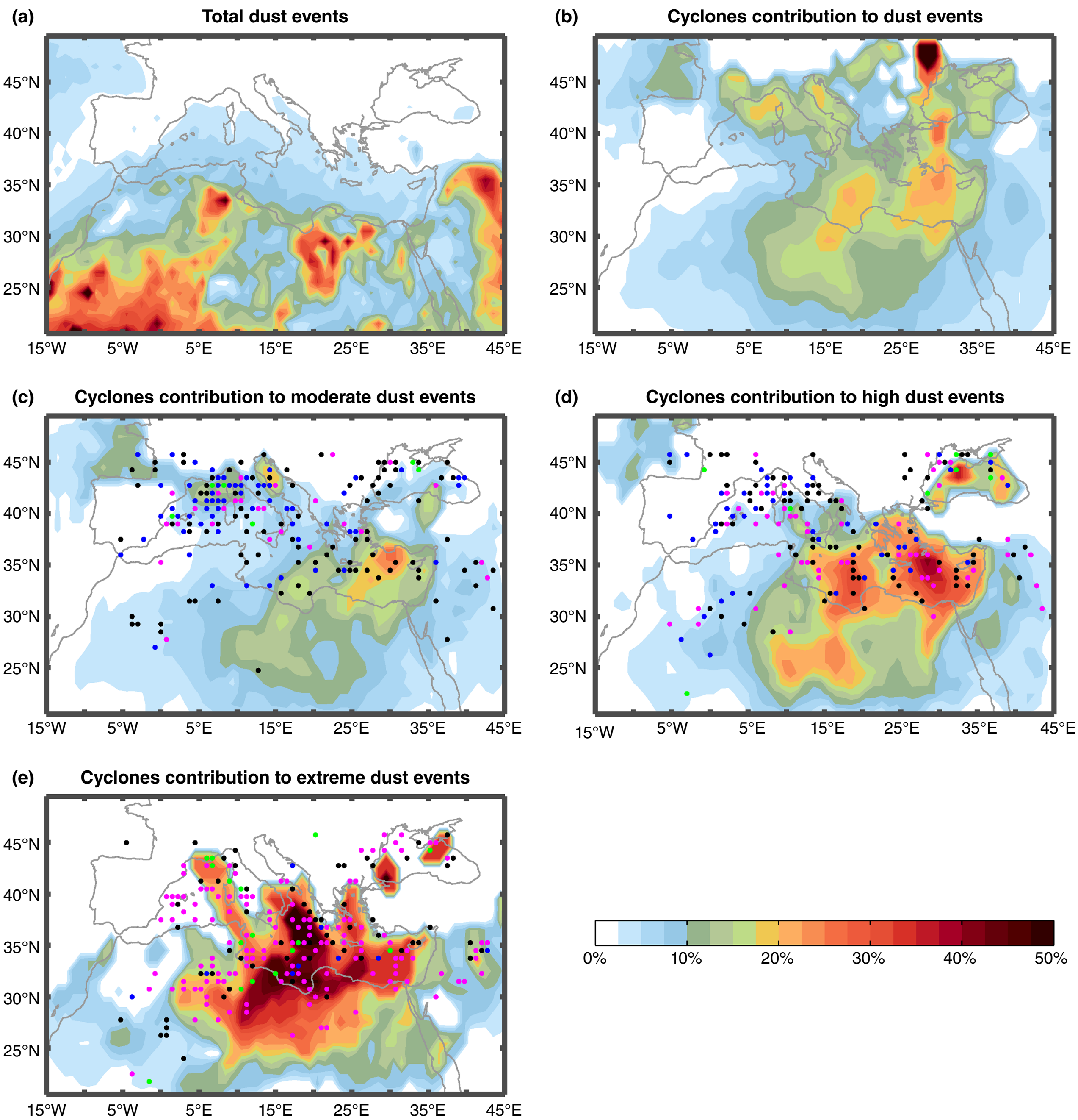

Figure 3. (a) Percentage of days with dust (grid points presenting AE < 0.7 and AI > 1) over the Mediterranean region for the whole 8-year period. (b) Percentage of dust days associated with cyclones. (c) Percentage of dust days of moderate intensity associated with cyclones. Dots represent cyclone locations contributing to dust days of moderate intensity (black dots denote winter cyclones, magenta dots denote spring cyclones, green dots denote summer cyclones and blue dots denote autumn cyclones). (d) As in (c), but for dust days of high intensity associated with cyclones. (e) As in (c), but for dust days of extreme intensity associated with cyclones.

per grid. Applying the same approach for deducing Figure 3(b), but taking into account only dust days within the three AOD classes, Figure 3(c)–(e) show the cyclone contribution to moderate, high and extreme dust events, respectively. For moderate dust transport events, the cyclone contribution is of the order of 10–20% of the total number of dust days, especially when centered in the eastern Mediterranean. On the other hand, when considering high and extreme dust transport events, the cyclone contribution rises significantly. Indeed, in the central and eastern Mediterranean Sea, cyclones are associated with 40–50% of the total number of high and extreme dust presence. In fact, this percentage might reach as much as 70% in certain areas. Based on this, the higher intensities of dust episodes in the central and eastern parts of the Mediterranean Sea (e.g. Gkikas *et al.*, 2013, their Figure 7) can be partly attributed to the increased contribution of intense cyclones to the transported dust loads.

In addition to the contribution of cyclones to dust transport, Figure 3(c)–(e) also show the locations and seasonality of the detected cyclones that contribute to moderate, high and extreme dust transport events, respectively. When considering moderate episodes, the contributing cyclone locations seem to be spread all over the Mediterranean irrespective to the season. On the other hand, as the dust events intensity increases, the cyclone locations tend to concentrate over the Mediterranean Sea and their timing of occurrence becomes more frequent in spring (Figure 3(d) and (e)). The latter is further explored in Figure 2(b), where we show the seasonal cycle of all detected cyclones and the seasonal cycle of the cyclones that contribute to moderate, high and extreme dust transport events. Clearly, the extreme dust transport events present their maximum percentage of occurrence during spring. It is also noteworthy that the monthly percentage of associated cyclones with dust transport events (moderate, high and extreme) reaches approximately 60% of the total number of tracked cyclones on average over the whole domain.

Our results suggest that the intense cyclones that occur in winter do not necessarily contribute to the most intense dust transport events (Figure 2). This is consistent with the fact that heavy precipitation is often associated with these systems and hence dust transport would be expected to present a sharp decrease due to aerosols wet removal through rainfall (e. g. Fiol *et al.*, 2005). On the other hand, such a concluding remark cannot be confirmed because the retrieval of AOD, AE and AI indices from satellite measurements is sensitive to cloud coverage. Consequently, the satellite observations that we used here suffer from missing values, especially when intense winter and autumn cyclones develop their characteristic comma shaped cloud coverage in the region. However, this is not expected to jeopardize the robustness of our results over North Africa, where the Sharav cyclones typically begin their lifetime as dry vortices.

4. Conclusion

In this study we objectively quantified the contribution of intense Mediterranean cyclones to the total dust transport events in the region. Our approach was based on satellite observations and atmospheric reanalysis in order to acquire realistic results, during an 8-year period (2005–2012). Our results showed that cyclones contribute through transport to approximately 10–25% of the total number of days with dust over the eastern Mediterranean. However, their contribution rises significantly when considering extreme dust transport events. Indeed, the cyclones we tracked were shown to be associated with as much as the 30–70% of the total number of extreme dust events over the central and eastern Mediterranean.

Our study highlights the importance of cyclones, as main contributors to extreme dust events in the Mediterranean region. Indeed, North Africa cyclogenesis may result to the uptake of heavy dust loads, trap them within the cyclones' mesoscale vortex and transport them over the Mediterranean basin causing major air quality events. A drawback of this study is the existence of clouds which prohibit measurements of the optical properties of dust within cloudy atmospheric systems. This is highly inconvenient, especially in winter when the strongest cyclones are expected to develop over the Mediterranean Sea. Quantifying dust transport within convection is further problematic due to the particles – clouds interactions (semi-direct, indirect effects). For this reason, future work will be devoted to the modeling analysis of heavy dust loads transport events by cyclones, aiming first to better understand the interaction processes between heavy atmospheric dust loads and microphysics, and also to evaluate dust impact on cyclones dynamics and thermodynamics.

Acknowledgements

This publication was supported by the European Union Seventh Framework Programme (FP7-REGPOT-2012-2013-1), in the framework of the project BEYOND, under Grant Agreement No. 316210 (BEYOND – Building Capacity for a Centre of Excellence for EO-based monitoring of Natural Disasters). This work also contributes to the HyMeX program (HYdrological cycle in The Mediterranean Experiment). We acknowledge the MODIS mission scientists and associated NASA personnel for the production of the data used in this research effort, as also ECMWF for making reanalyses available.

References

Ammar K, El-Metwally M, Almazroui M, Wahab MMA. 2014. A climatological analysis of Saharan cyclones. *Climate Dynamics* **43**: 483–501, doi: 10.1007/s00382-013-2025-0.

Bou Karam D, Flamant C, Cuesta J, Pelon J, Williams E. 2010. Dust emission and transport associated with a Saharan depression: February 2007 case. *Journal of Geophysical Research* **115**: D00H27, doi: 10.1029/2009JD012390.

Bryant C, Eleftheriadis K, Smolik J, Zdimal V, Mihalopoulos N, Colbeck I. 2006. Optical properties of aerosols over the Eastern Mediterranean. *Atmospheric Environment* **40**: 6229–6244.

Campins J, Genovés A, Picornell MA, Jansà A. 2011. Climatology of Mediterranean cyclones using the ERA-40 dataset. *International Journal of Climatology* **31**: 1596–1614, doi: 10.1002/joc.2183.

Chaboureau JP, Pantillon F, Lambert D, Richard E, Claud C. 2012. Tropical transition of a Mediterranean storm by jet crossing. *Quarterly Journal of the Royal Meteorological Society* **138**(664): 596–611.

Dee DP, Uppala S. 2009. Variational bias correction of satellite radiance data in the ERA-Interim reanalysis. *Quarterly Journal of the Royal Meteorological Society* **135**: 1830–1841.

Dubovik O, Holber B, Eck TF, Smirnov A, Kaufman YJ, King MD, Tanre D, Slutsker I. 2002. Variability of absorption and optical properties of key aerosol types observed in worldwide locations. *Journal of the Atmospheric Sciences* **59**: 590–608.

Engelstaedter S, Tegen I, Washington R. 2006. North African dust emissions and transport. *Earth Science Reviews* **79**: 73–100.

Fiedler S, Schepanski K, Knippertz P, Heinold B, Tegen I. 2014. How important are atmospheric depressions and mobile cyclones for emitting mineral dust aerosol in North Africa? *Atmospheric Chemistry and Physics* **14**: 8983–9000, doi: 10.5194/acp-14-8983-2014.

Fiol LA, Fornos JJ, Gelabert B, Guijarro JA. 2005. Dust rains in Mallorca (Western Mediterranean): their occurrence and role in some recent geological processes. *Catena* **63**(1): 64–84.

Flaounas E, Coll I, Armengaud A, Schmechtig C. 2009. The representation of dust transport and missing urban sources as major issues for the simulation of PM episodes in a Mediterranean area. *Atmospheric Chemistry and Physics* **9**: 8091–8101, doi: 10.5194/acp-9-8091-2009.

Flaounas E, Drobinski P, Bastin S. 2013. Dynamical downscaling of IPSL-CM5 CMIP5 historical simulations over the Mediterranean: benefits on the representation of regional surface winds and cyclogenesis. *Climate Dynamics* **40**: 2497–2513, doi: 10.1007/s00382-012-1606-7.

Flaounas E, Kotroni V, Lagouvardos K, Flaounas I. 2014. CycloTRACK (v1.0) – tracking winter extratropical cyclones based on relative vorticity: sensitivity to data filtering and other relevant parameters. *Geoscientific Model Development* **7**: 1841–1853, doi: 10.5194/gmd-7-1841-2014.

Flaounas E, Raveh-Rubin S, Wernli H, Drobinski P, Bastin S. 2015. The dynamical structure of intense Mediterranean cyclones. *Climate Dynamics* **44**: 2411–2427, doi: 10.1007/s00382-014-2330-2.

Gkikas A, Hatzianastassiou N, Mihalopoulos N, Katsoulis V, Kazadzis S, Pey J, Querol X, Torres O. 2013. The regime of intense desert dust episodes in the Mediterranean based on contemporary satellite observations and ground measurements. *Atmospheric Chemistry and Physics* **13**: 12135–12154, doi: 10.5194/acp-13-12135-2013.

Gkikas A, Houssos EE, Lolis CJ, Bartzokas A, Mihalopoulos N, Hatzianastassiou N. 2014. Atmospheric circulation evolution related to desert dust episodes over the Mediterranean. *Quarterly Journal of the Royal Meteorological Society*, doi: 10.1002/qj.2466.

Griffin DW, Kubilay N, Kocak M, Gray MA, Borden TC, Shinn EA. 2007. Airborne desert dust and aeromicrobiology over the Turkish Mediterranean coastline. *Atmospheric Environment* **41**: 4050–4062, doi: 10.1016/j.atmosenv.2007.01.023.

Hannachi A, Awad A, Ammar K. 2011. Climatology and classification of Spring Saharan cyclone tracks. *Climate Dynamics* **37**: 473–491.

Herman JR, Bhartia PK, Torres O, Hsu NC, Seftor CJ, Celarier E. 1997. Global distribution of UV-absorbing aerosols from Nimbus-7/TOMS data. *Journal of Geophysical Research* **102**: 16911–16923.

Hsu NC, Tsay S-C, King MD, Herman JR. 2004. Aerosol properties over bright-reflecting source regions. *IEEE Transactions on Geoscience and Remote Sensing* **42**(3): 557–569, doi: 10.1109/TGRS.2004.824067.

Knippertz P, Todd MC. 2012. Mineral dust aerosols over the Sahara: meteorological controls on emission and transport and implications for modeling. *Reviews of Geophysics* **50**: RG1007, doi: 10.1029/2011RG000362.

Levy RC, Remer LA, Kleidman RG, Mattoo S, Ichoku C, Kahn R, Eck TF. 2010. Global evaluation of the Collection 5 MODIS dark-target aerosol products over land. *Atmospheric Chemistry and Physics* **10**: 10399–10420, doi: 10.5194/acp-10-10399-2010.

Moulin C, Lambert CE, Dayan U, Masson V, Ramonet M, Bousquet P, Legrand M, Balkanski YJ, Guelle W, Marticorena B, Bergametti G, Dulac F. 1998. Satellite climatology of African dust transport in the Mediterranean atmosphere. *Journal of Geophysical Research* **103**: 13137–13144.

Remer LA, Kaufman YJ, Tanré D, Mattoo S, Chu DA, Martins JV, Li RR, Ichoku C, Levy RC, Kleidman RG, Eck TF, Vermote E, Holben BN. 2005. The MODIS aerosol algorithm, products and validation. *Journal of the Atmospheric Sciences* **62**: 947–973.

Remer LA, Kleidman RG, Levy RC, Kaufman YJ, Tanré D, Mattoo S, Martins JV, Ichoku C, Koren I, Yu H, Holben BN. 2008. Global aerosol climatology from the MODIS satellite sensors. *Journal of Geophysical Research-Atmospheres* **113**: D14S07, doi: 10.1029/2007JD009661.

Shi Y, Zhang J, Reid JS, Hyer EJ, Hsu NC. 2013. Critical evaluation of the MODIS Deep Blue aerosol optical depth product for data assimilation over North Africa. *Atmospheric Measurement Techniques* **6**: 949–969, doi: 10.5194/amt-6-949-2013.

Torres O, Bhartia PK, Herman JR, Ahmad Z. 1998. Derivation of aerosol properties from satellite measurements of backscattered ultraviolet radiation. Theoretical Basis, *Journal of Geophysical Research* **103**: 17099–17110.

Torres O, Tanskanen A, Veihelman B, Ahn C, Braak R, Bhartia PK, Veefkind P, Levelt P. 2007. Aerosols and surface UV products from OMI observations: an overview. *Journal of Geophysical Research* **112**: D24S47, doi: 10.1029/2007JD008809.

Varga G, Újvári G, Kovács J. 2014. Spatiotemporal patterns of Saharan dust outbreaks in the Mediterranean Basin. *Aeolian Research* **15**: 151–160, doi: 10.1016/j.aeolia.2014.06.005.

