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RESEARCH ARTICLE

Comparing Saharan track characteristics between the NCEP/NCAR, NCEP-DOE, and ECMWF (ERA40) Reanalyses

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Abstract

In this work three climatologies of the Saharan cyclones are created by applying the Melbourne tracking scheme on NCEP/NCAR (NCEP1), NCEP/DOE (NCEP2), and ECMWF (ERA40) for the period 1980-2001. We performed a comparison of the seasonal mean climatologies of the track characteristics of the Saharan cyclones. Generally, the track numbers in NCEP1 is greater than both NCEP2 and ERA40. NCEP2 tracks are more than ERA40 in all seasons except in winter.
The cyclogenesis patterns in NCEP2 and ERA40 show that the number of cyclones initiated over Egypt and Libya is less than in NCEP1 climatology in both winter and spring. Cyclone track climatologies show that in spring, the number of tracks decreases significantly over most of the Sahara in both ERA40 and NCEP2 compared with NCEP1. In autumn, the NCEP2 the Sahara tracks are shifted towards western Mediterranean.

INTRODUCTION

Saharan cyclones have a strong impact on local weather of the saharan and mediterranean countries. saharan cyclones bring dust to the saharan and mediterranean countries (e.g. tullet 1984; prezerakos 1985; alpert and ziv 1989; barkan et al. 2005; amiridis et al. 2005; birmili et al. 2008; vanderstraeten et al. 2008; schepanski et al. 2009; boukaram et al. 2010; prezerakos et al. 2010; barkan and alpert 2010). the sand transported with the saharan cyclone tracks also affects the global radiation budget. thus, changes in the dominant cyclone tracks, in their frequencies, or their characteristics may significantly affect the climate and particularly the sand storm activities.

Saharan cyclones were either ignored or studied in the context of mediterranean cyclones and so their unique characteristics were underestimated. only few works shed light on the nature and characteristics of the saharan cyclones; alpert et al. (1990), trigo et al. (1999), flocas et al. (2010). the only works that were dedicated totally to studying saharan cyclogenesis are hannachi et al. (2011) and ammar et al. (2014).

Cyclones climatologies are created by applying automatic tracking schemes which use different variables for the detection of cyclones; mean sea level pressure or geopotential height (Blender et al. 1997; Gulev et al. 2001; Wernli and Schwierz 2006), vorticity field (Sinclair, 1994), or a combination of both mean sea level pressure (or geopotential height) and vorticity (Murray and Simmonds, 1991).

Comparison between climatologies created from reanalysis datasets was mainly performed for the purpose of validating climate models with respect to cyclonic activities (Bengtsson et al., 2006; Bengtsson et al., 2009 and

Hodges et al., 2011). Examples of these studies are: HODGES ET AL. (2003, 2011), Hanson et al. (2004), Wang et al. (2006), Trigo (2006), Raible et al. (2007), Uotila, et al. (2009), and Allen et al., (2010).

The main aim of this study is to construct and compare three objective cyclone climatologies for the Saharan cyclones using NCEP/NCAR, NCEP/DOE, and ECMWF (ERA40). The goal of this study is to increase understanding of Saharan cyclones which have an important effect on the climate of the Saharan, the Mediterranean, and the whole globe.

This study will test the ability of the reanalysis datasets to represent the characteristics of the Saharan cyclones. Though the Saharan cyclones have smaller lifetimes and shorter extents than the Atlantic storms, there are a multitude of factors that contribute to their cyclogenesis and their development. This comparison should serve as a good test of the parameterizations of reanalysis datasets especially the dust accompanying their movement. This study will also test the success of the data assimilation schemes of the models producing the datasets involved in this study on the station-sparse Sahara.

Our cyclone climatologies were created with the aid of an automated semi-Lagrangian method; Melbourne University tracking scheme (Murray and Simmonds 1991; and Neu et al. 2013). This scheme has been used in studying cyclogenesis in the Mediterranean region (e.g., Nissen et al. 2010; Flocas et al. 2010; Kouroutzoglou et al. 2011) and in particular to Saharan cyclones (Ammar et al., 2014).

The comparison of the three datasets will involve the seasonal spatial distributions of track characteristics cyclogenesis, cyclolysis, and track density.

The paper is outlined as follows: After introducing the reanalysis datasets and the cyclone detection and tracking methods in section 2, we present the comparison of the reanalysis in Sec. 3. Sect. 4 summarizes the results of this study.

2. Data and methodology

2.1 Data

NCEP/NCAR reanalysis 1 (Kalnay et al., 1996, Kistler et al., 2001) is a publicly available set of gridded meteorological variables archived at 6-hours intervals starting in 1948 and continuing until present. The NCEP/NCAE reanalysis is denoted as NCEP1 in this study.

NCEP-DOE reanalysis 2 is an improved version of the NCEP re-analysis 1 model that fixed errors and updated parameterization of physical processes (Kanamitsu et al., 2002). It has a temporal coverage from January 1979 until present. The NCEP-DOE reanalysis-2 is denoted as NCEP2 in this study.

The third reanalysis is obtained from the European Centre for Median-Range Weather Forecasts; the (ERA-40) is available for the period 1957–2002 (Uppala et al. 2005).

All three reanalyzes have a spatial resolution of 2.5◦ degrees and a 6-hourly temporal resolution. Our analysis covers the period 1980-2001, which is the common period between the three reanalyzes.

In this study we are using three reanalyzes at a relatively low resolution. While SINCLAIR (1997) ARGUES THAT relatively coarse spatial resolution (2.50) could cause problems in the detection of cyclonic systems, Blender and Schubert (2000) have shown that a reduction in the spatial resolution can cause a reduction in the efficiency of the tracking by 15%. Pinto et al. (2005) and Bengtsson et al. (2009) found the datasets with resolutions of T42–T63 are capable of providing reasonable distributions. Hoskins and Hodges (2002) used a resolution of 2.80 and found it suitable for identifying synoptic scale features. Hodges et al. (2003) also suggested that, even very high resolution data (T255 spectral resolution) inadequately resolve extratropical cyclones.

Worthy to note that both Hannachi et al., (2011) and Ammar et al. (2014) used NCEP/NCAR dataset and found it suitable for detecting and tracking Saharan cyclones. The study area covered the region; 200W–500E AND 200N–500N.

2.2 Methodology

The cyclone identification and tracking was performed with the algorithm developed at Melbourne University, according to the Lagrangian perspective (the MS algorithm; Murray and Simmonds 1991; and Neu et al. 2013).

MS is a three-phase program that detects cyclones, tracks them from birth to decay, and then analyzes various statistics pertaining to these tracks. MS is a sophisticated method, which has proved to be a powerful tool in the study of cyclogenesis in different parts of the world. MS algorithm to study the regional climate variability and hazardous weather of the Mediterranean (e.g., Nissen et al. 2010; Flocas et al. 2010; Kouroutzoglou et al. 2011).

The initial step of the feature identification is a transformation of the gridded sea level pressure fields to a finer grid by a polar stereographic projection via bicubic spline interpolation. Pressure interpolation is necessary in order to allows cyclones to be located between the original data grid points (Pinto et al. 2005).

The scheme searches the interpolated P field iteratively for centers of closed an open cells by first locating the grid points at which the pressure Laplacian (proportional to relative geostrophic vorticity) values are local maxima. These grid points are used as starting points to search for closed and open cell within a reasonable search radius from the local maxima. The point at which the pressure is a minimum among eight surrounding points is the center of a closed cell. If a closed cell is not found the scheme searches for a minimum of the pressure gradient as the center of an open cell.

In the tracking stage, the algorithm predicts a subsequent position and core pressure for each cyclone. The scheme uses a weighted combination of the cyclone's previous motion and a scaled steering velocity to predict the subsequent positions of the cyclones. The steering velocities are obtained geostrophically from the pressure data. Previous pressure tendency is used to predict the core pressure of the predicted cyclone. The probabilities of association between identified cyclones in the following time step, which are located in the vicinity of the predicted position, are examined and the most likely candidate is chosen as the next track element. This probability is a function of the distance between the centers of the predicted and the realized cyclones divided by some critical radius.

The particular nature of the Saharan cyclone forced us to change some of the instruction parameters of the tracking scheme:

Distance between cyclones: 3 degrees of latitude (deg. lat.).

Smoothing of the pressure field: 2 degrees.

Topography smoothing: no topography smoothing

Strength thresholds: 0.2 and 0.3 hPa/ $(\text{deg. lat.})^2$ for closed and open cyclones respectively.

Spurious cyclones: cyclones with central pressures larger than 1015 hPa are removed.

Track length: at least 1000 km.

Lifetime: at least 24 hours

Further details about the applicability of the Melbourne tracking scheme to finding and tracking Saharan cyclones can be found in Ammar et al. (2014).

3. Results

The comparison is done in this section by investigating the changes in the seasonal distributions of the track characteristics. The track characteristics include cyclogenesis, cyclolysis and track density.

Fig. 1 shows the number of tracks in every season for each dataset. Generally, the track numbers in NCEP1 is greater than either NCEP2 or ERA40. NCEP2 tracks are more than ERA40 in all seasons except in winter.

In Figs. 2-4, we will show the seasonal distribution of the track characteristic of the reference dataset NCEP1 along with the difference between the seasonal distribution for the same variable of the other two sets and the references datasets for the four seasons; winter (December-February), spring (March-May), summer (June-August) and autumn (September-November).

3.1 Cyclogenesis

Two main cyclogenesis centers are identified by Trigo et al. (1999), Alpert et al. (1991), Hannachi et al. (2011), and Ammar et al. (2014); the first over Algeria and the second over Eastern Libya and Western Egypt (Fig. 2a). In winter, NCEP2 climatology of the Saharan cyclogenesis shows a significant decrease over east Egypt, Libya and Chad with respect to the reference climatology of NCEP1 (Fig. 2b). A similar pattern is observed in ERA40 distribution. We believe that the change is mainly due to the weakening of the second cyclogenesis center over Libya and Egypt (Fig. 2c).

In spring, the NCEP1 cyclogenesis is stronger over Algeria (Fig. 2d). Little significant decrease in cyclogenesis is observed over Algeria and Egypt in both NCEP2 and ERA40 with respect to NCEP1 (Fig. 2e, f). This decrease is bigger over Egypt in the case of NCEP2.

In summer, the cyclogenesis center over Egypt weakens in NCEP1 and another center appears over South Western Sahara (Fig. 2g). In NCEP2 little insignificant increase is found over Libya and Egypt while the cyclogenesis decrease over Eastern Algeria and Western Sahara (Fig. 2h). Cyclogenesis decreases insignificantly over Libya and significantly over Morocco in ERA40 (Fig. 2i).

In autumn, the climatology of NCEP1 is similar pattern to spring but much weaker (Fig. 2j). Very similar and small differences are found in NCEP2 and ERA40. The decrease is significant only over Algeria in both NCEP2 and ERA40 (Fig. 2k, l).

3.2 Cyclolysis

The stronger cyclolysis centers are different from one season to another. In winter four centers are observed; Eastern Mediterranean, Central Mediterranean north of the Black sea and Egypt (Fig. 3a). In NCEP2 climatology of cyclolysis, the Eastern Mediterranean sink decreases significantly while in ERA40 the decrease is significant over the Black sea, Western Mediterranean and the Red Sea (Fig. 3b, c).

In spring, the cyclolysis centers are more intense over the Sahara and Eastern Mediterranean since the majority of cyclones develop tracks over the Sahara itself in NCEP1 (Fig. 3d). A Significant decrease in the cyclolysis is found over Egypt and Algeria in both NCEP2 and ERA40 climatologies (Fig. 3e, f).

In summer, a much weaker cyclolysis center is observed over south Western Sahara which results from the smaller number of cyclones over south Western Sahara. A much stronger center is found over Libya and Central Mediterranean (Fig. 3g). Very little change is found in both ERA40 and NCEP2 (Fig. 3h, i). A little significant increase shows over Central and South Western Sahara and another smaller decrease over Central Mediterranean are seen in ERA40.

In autumn, most of the Saharan cyclones decay over the Mediterranean Basin in NCEP1 (Fig. 3j). Little significant change is found in both datasets NCEP2 and ERA40 over Egypt and Libya (Fig. 3k, l).

3.3 Track density

In winter, the Saharan cyclones are mainly moving over the Sahara and Eastern Mediterranean in the reference climatology of NCEP1 (Fig. 4a). The Saharan tracks are decreasing significantly over small regions of the Sahara in both ERA40 and NCEP2 (Fig. 4b, c). In ERA40 a significant decrease is found over North West Black Sea and another significant increase is found further to the north.

In NCEP1, 60 % of the Saharan cyclones are found in spring with the majority over the Sahara (Fig. 4d). In both ERA40 and NCEP2 (Fig. 4f, e) the number of tracks decreases significantly over the Sahara while in NCEP2 (Fig. 4e) a significant positive increase is found over Morocco.

Summer Saharan tracks are generally shorter in NCEP1 (Fig. 4g) and they decrease significantly over Libya in ERA40 (Fig. 4i) and over Libya and Egypt in NCEP2 (Fig. 4h).

In autumn, the NCEP2 (Fig. 4k) climatology is marked with a shift in the tracks to west Mediterranean which explains the decrease over north Algeria and the increase over Western Mediterranean. Only a significant decrease is observed over North Algeria is found in ERA40 (Fig. 4l). Bothe data sets show a significant increase of the track density over Arabia.

3.4 Lifetimes

The percentages of the saharan tracks as function of lifetimes in days are displayed in the four seasons for the three reanalyzes are shown (Fig. 5).

In winter, the majority of Saharan detected lows (88% of NCEP1, 91% of NCEP2, and 86% of ERA40 cyclones) exist for four days or less. The average lifetimes are 2.7 days in NCEP1, 2.9 days in NCEP2, and 3.0 days in ERA40. Some of the ERA40 cyclones have 8 days lifetimes.

In spring, the lifetimes statistics are similar to winter. The majority of the tarcks in this season (91% of NCEP1, 87% of NCEP2, and 83% of ERA40) exist for four days or less. The average lifetimes are: 2.8 for NCEP1, 3.1 for NCEP2, and 3.2 for ERA40.

In summer, the percentage of cyclones in NCEP1, and NCEP2 which don’t survive more than 4 days increases to 96% of NCEP1, 94% of NCEP2, and 85% of ERA40. In ERA40 cyclones have an average lifetime in creases to 3.4 days. The increase in the majority percentages mentioned above in NCEP1 and NCEP2 is natural because the tarcks in this season are short but the lower percentage in the case of ERA40 indicates a remarkable change in the tarcks’ characteristics.

In autumn, the ERA40 tracks have considerably longer lifetimes with only 73% cyclones live for four days or less. The average lifetime is 3.3 days.

3.5 Deepening

The percentage of Saharan tracks in categories of maximum deepening per 6 hours of the renalysis datasets (NCEP1, NCEP2, ERA40) for the four seasons are shown in Fig. 6.

In winter, maximum deepening of the cyclones of 3 hPa/6 hours or less happens in 73% of the caes in NCEP1, 77% of NCEP2, and 97% of ERA40. The average maximum deepening rate is 2.9 in NCEP1, 3.2 in NCEP2 and 2.7 in ERA40. Deepening rates of 5 hPa/6 hours happen only in 8 % of NCEP1, 23% of NCEP2 aand only 3% ERA40 tracks.

Spring deepening rates are generally higher than in winter, where in 87% of the cases has deepening rates less than or equal 4 hpa/6 hours in NCEP1, 78% in NCEP2 and 90% in ERA40. Deepening rates at or above 6 hPa/6 hours happen in 5% of NCEP1 tarcks, 4% of NCEP2, and 1% of ERA40 tracks. The average maximum deepening rate is 3.0 in NCEP1, 3.5 in NCEP2 and 3.0 in ERA40.

In summer, 87% of NCEP1 tracks has deepening rates less than or equal 4, while NCEP2 86 and ERA40 92. The average maximum deepenin rate is 3.0 in NCEP1, 3.2 in NCEP2 and 3.3 in ERA40.
In autumn, ~96% of the NCEP1 tracks donot wintness any deepeneing along their tracks by more than 4 hPa/6 hours. This percentage drops to 94% in NCEP2 and 92% in the case of ERA40.
Inspecting the lifetime distributions shows that, the pressure tendency show that NCEP1 and ERA40 are similar in winter, spring and autumn while NCEP1 and NCEP2 are similar in autumn.
Symmetrical distribtion of the pressure tendency around 2 hPa/6 hours in winter with a tail towards 7 hPa/6 hours. A more symmetric distribution is found in spring and summer around 3 hPa/6 hours. The peak of the distribution is flat with 2 and 3 hPa in autumn. Maximum deepening of 8 hPa/6hours is found in winter NCEP2.
Fig. 7 show the seasonal distribution of the positions at which the Saharan cyclones reach their minimal central pressures along the tracks.
In winter, cyclones raech their mimim central pressures over the Mediterranean and Black sea regions with the three datsets showing similar patterns. The pressure values are lower in NCEP1 (Fig. 7a) than in NCEP2 (Fig. 7b) or ERA40 (Fig. 7c). Deepening around Genoa is clearer in ERA40 than in both NCEP1 and NCEP2 datsets. Higher presure values are found in ERA40 and NCEP2 than NCEP1.
In spring, mimimm pressure are generally higher over the Sahara in NCEP1 (Fig. 7d). The Mediterraean pressures are lower in NCEP2 (Fig. 7e) than the other two datasets. The patterns are shifted to the west and south over the mediterraean in NCEP2 and ERA40 (Fig. 7f) compared with NCEP1.
In summer, the number of Saharan cyclones are generally lower than in winter or spring and most of their tarcks are confined to the Sahara itself. Minimum pressures are higher in NCEP1 (Fig. 7g) than NCEP2 (Fig. 7h) or ERA40 (Fig. 7i). The shift in the tarcks to Western mediterraean is clear in both NCEP2 and ERA40. The samll fractions of cyclones raeching Arabia and the Black Sea region is more in NCEP2 and ERA40.
In autumn, the Saharan cyclones raeching Western and Central mediterreanean deepen more in NCEP2 (Fig. 7k) and ERA40 (Fig. 7l) than in NCEP1 (Fig. 7j). The Genoa center is almost absent in ERA40 and deeper in NCEP2.

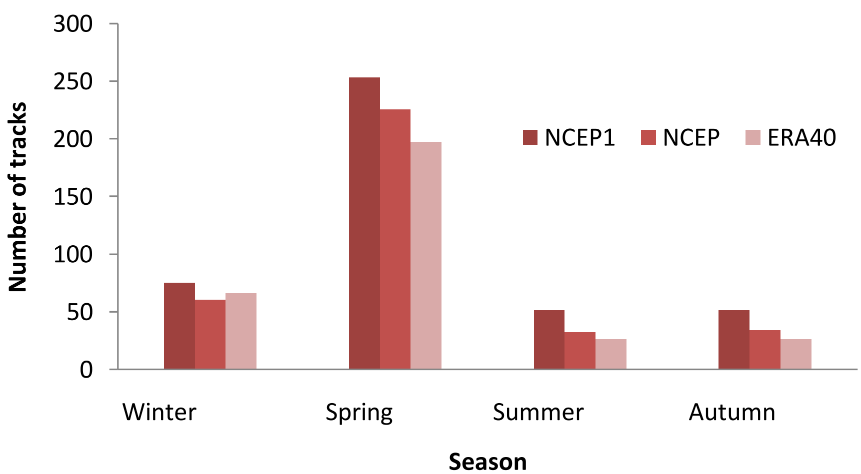


Fig. 1: The number of seasonal Saharan tracks for the three datasets for the period between 1980 and 2001.

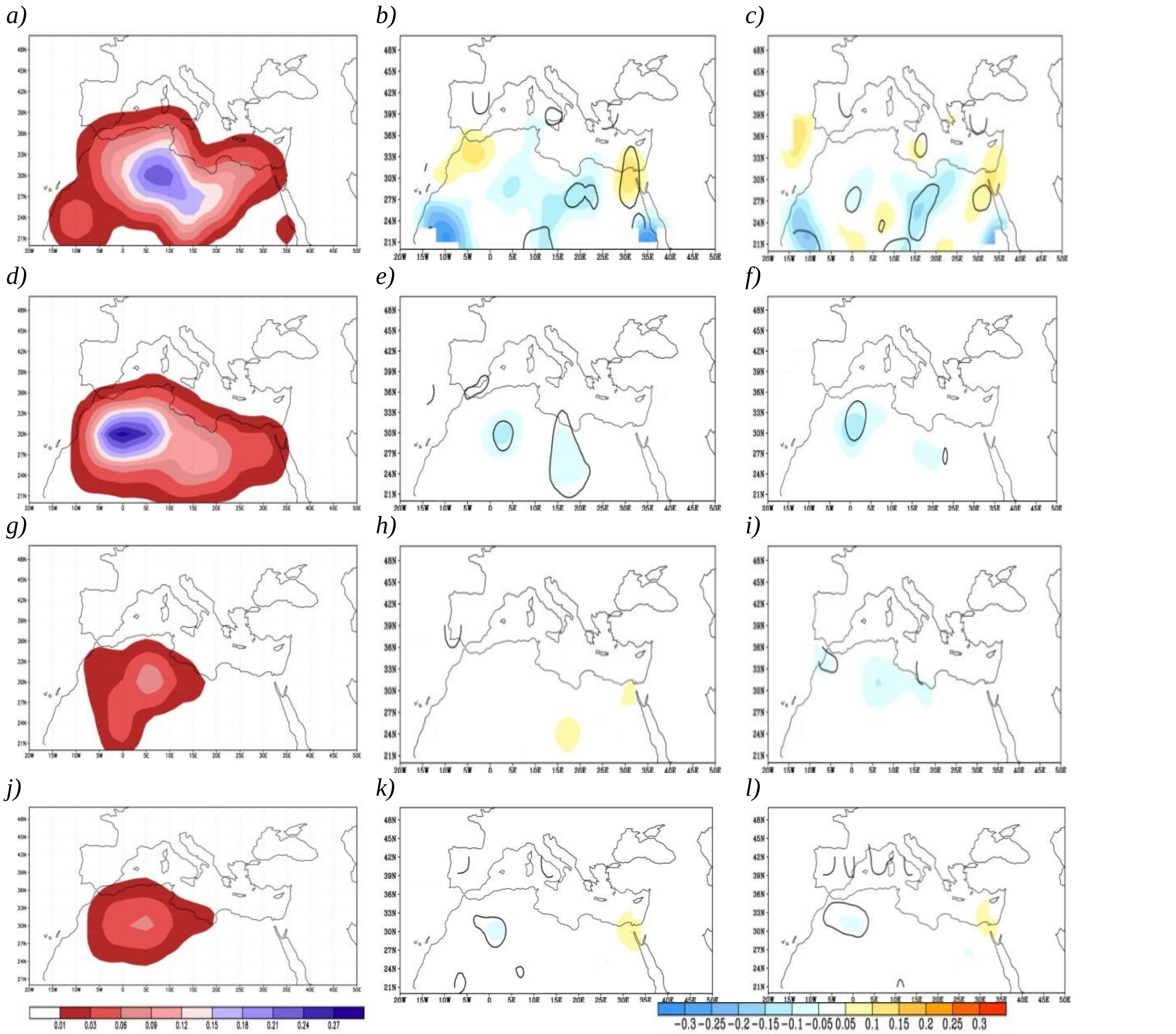


Fig. 2: NCEP1 seasonal distribution of the cyclogenesis for: a) winter, d) spring, g) summer, and j) autumn. The differences in cyclogenesis between NCEP2 and NCEP1 for the same seasons are in b, e, h, and k. The differences in cyclogenesis between ERA40 and NCEP1 in c, f, i, and l. The units are number of cyclones/ (deg.lat)^2. The contour denotes statistical significance at 95% level.

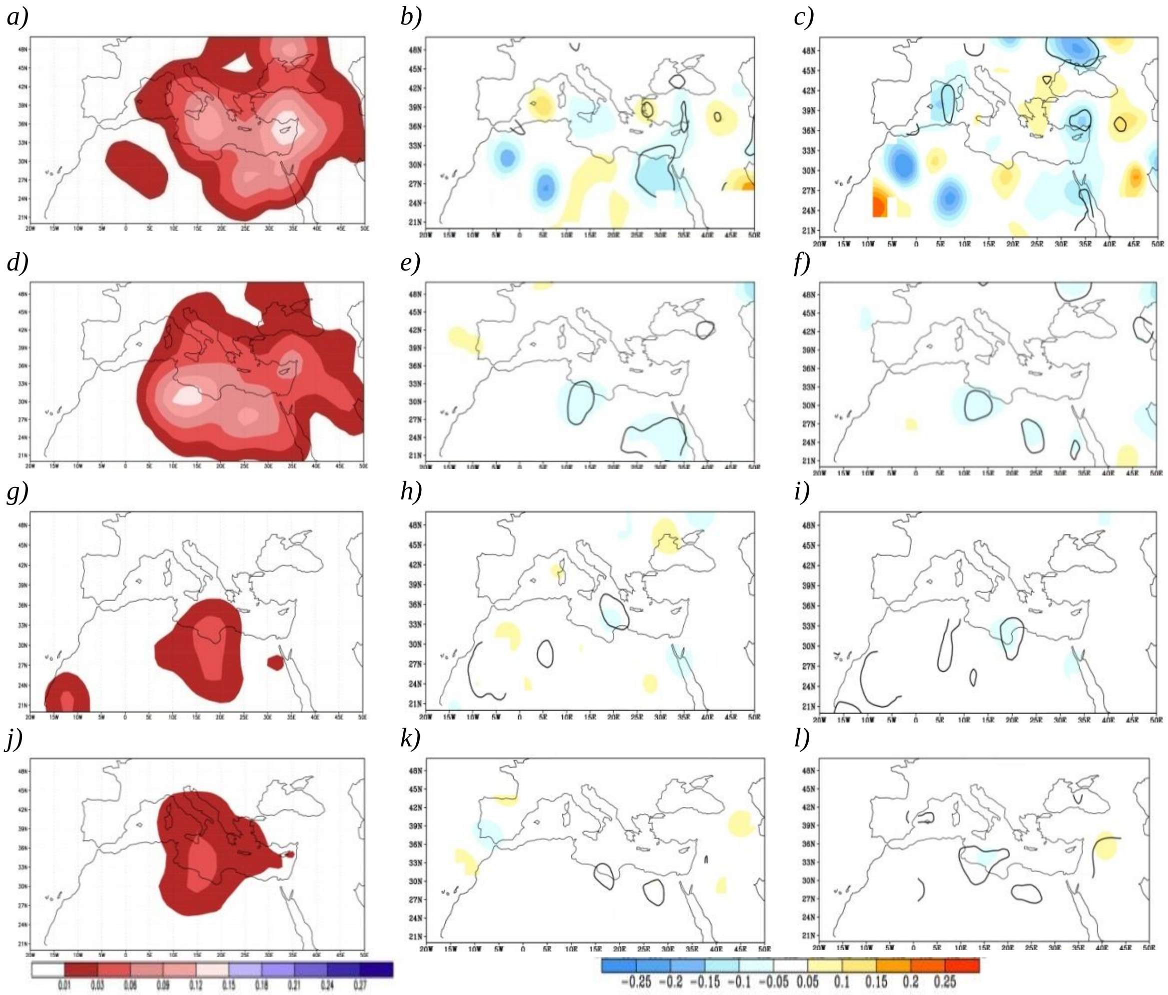
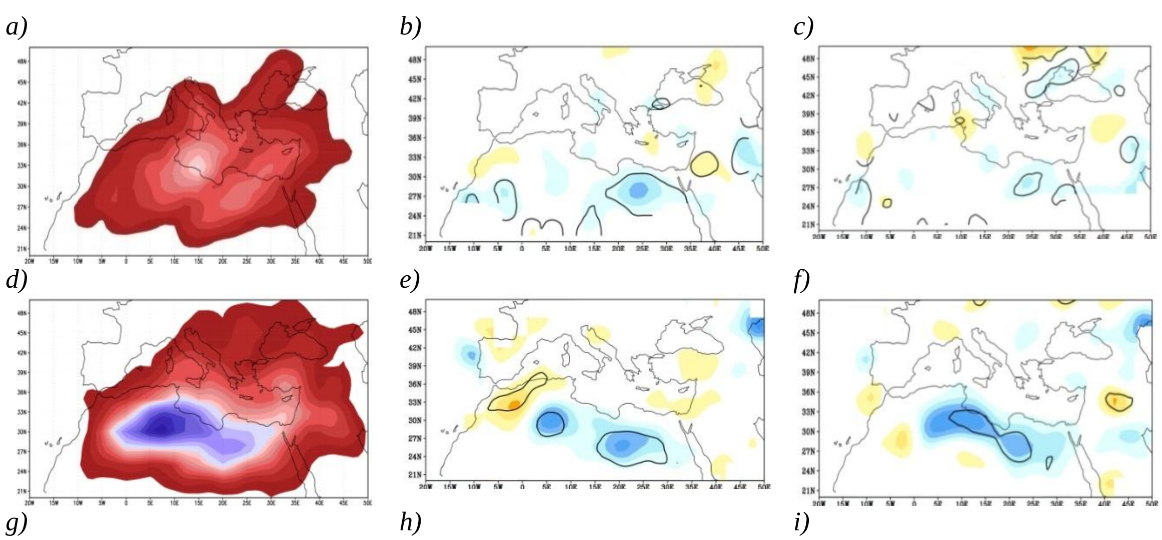


Fig. 3: as in Fig. 2 but for cyclolysis. The same units as in cyclogenesis (Fig. 2)



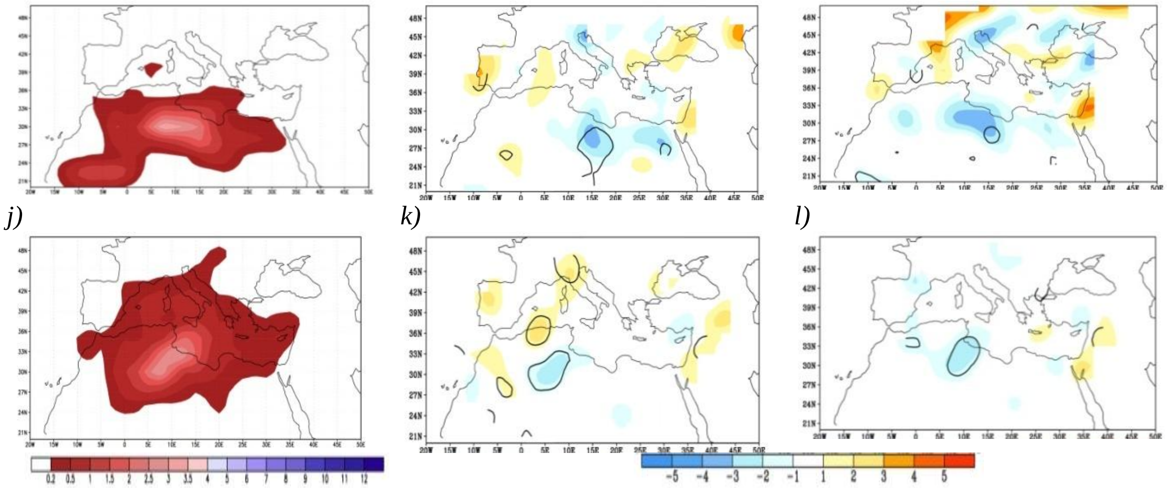


Fig. 4: as in Fig. 2 but for track density. The units are number of tracks/ (deg.lat) ^{2}

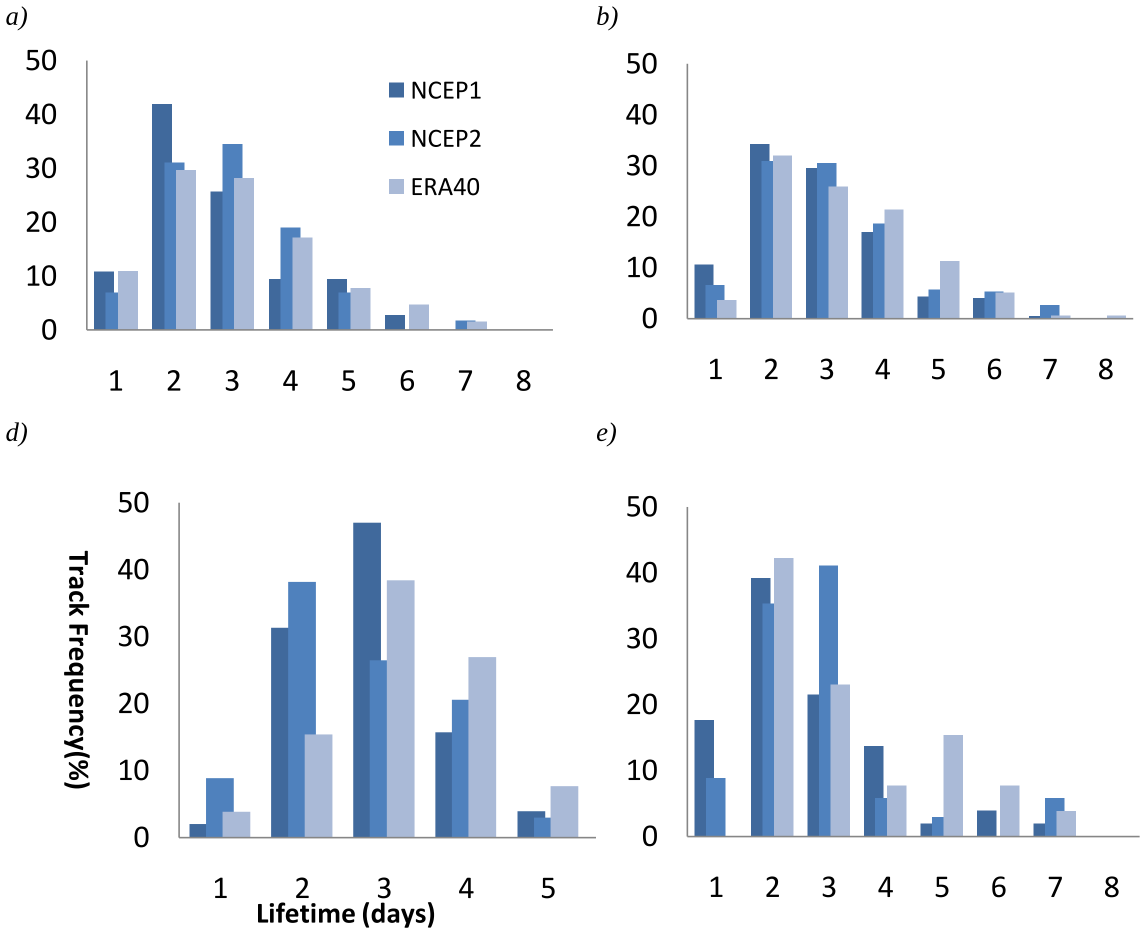


Fig. 5: the percentage of tracks in life time categories(days) of NCEP1, NCEP2, ERA40 for a) winter, b)spring), c) summer, and d)autumn.

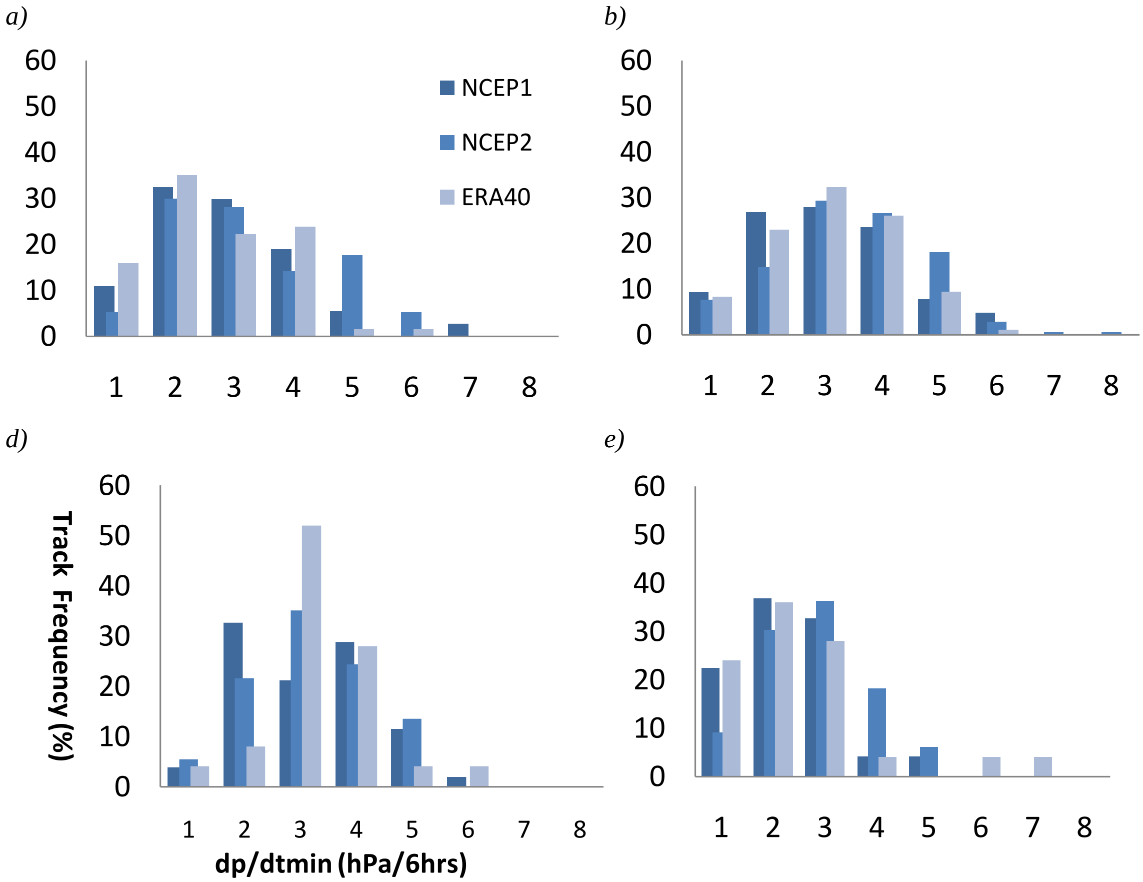
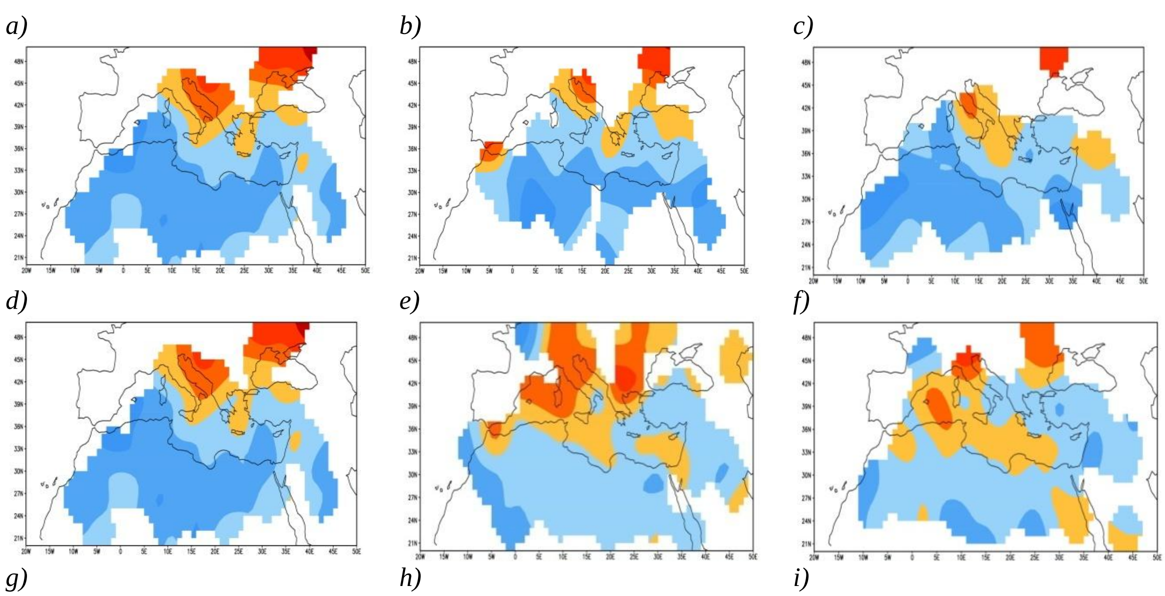


Fig. 6: the percentage of tracks in categories of maximum deepening per 6 hours of NCEP1, NCEP2, ERA40 for a) winter, b)spring), c) summer, and d)autumn.



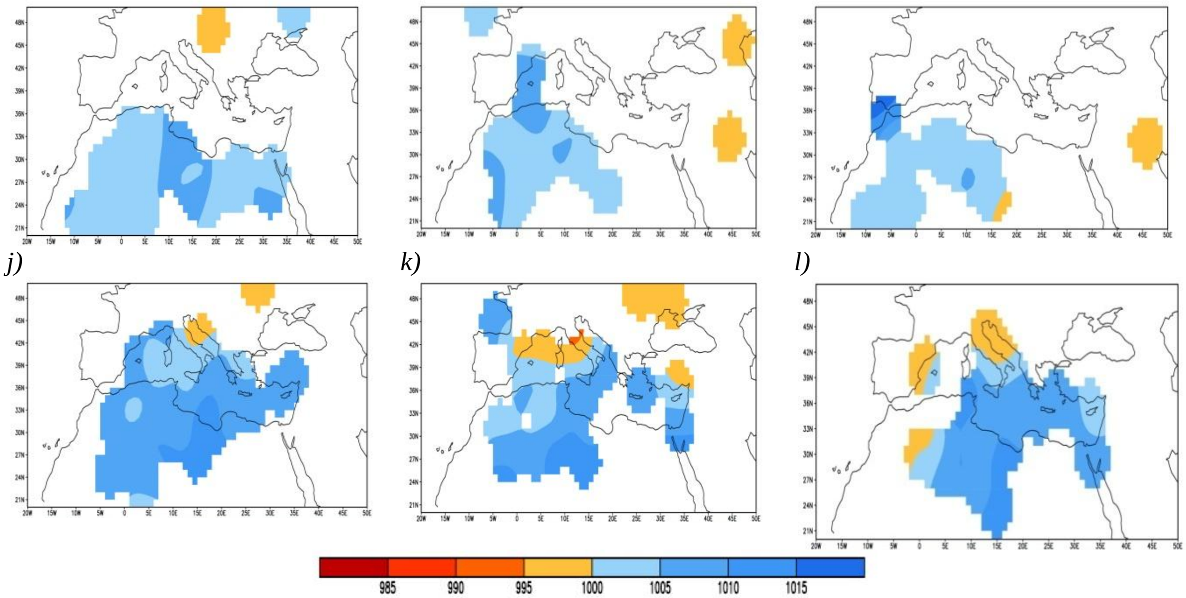


Fig. 7: the seasonal distribution of the deepest points along the tracks in winter (top row), spring (second row), c) summer (third row) and d) autumn (bottom row) for NCEP1 (left column), NCEP2 (center column) and ERA40 (right column). The units are in hPa.

Table1: Linear trends of the track clusters per decade for the period 1980-2001 for the three datasets: NCEP1, NCEP2, and ERA40. The underlined values are 90% significant according to the t-test.

Track cluster	NCEP1	NCEP2	ERA40
AT-EM	-0.012	-0.008	0.000
AT-WM	-0.002	-0.004	-0.005
AT-AT	-0.005	-0.004	0.004
AT-LE	-0.006	0.000	-0.008
LE-EM	0.001	-0.004	-0.001
LE-LE	-0.014	-0.003	-0.002
LE-AR	-0.002	-0.004	-0.001

Table 2: Correlations between corresponding times series of the track clusters in reanalysis datasets. Correlations values marked with a "*" are 90% significant, "**" 95% significant, and "***" 98% significant.

Track cluster	NCEP1-NCEP2	NCEP2-ERA40	NCEP1-ERA40
AT-EM	0.73***	0.27	0.49***
AT-WM	0.17	0.29	0.49***
AT-AT	0.39*	0.20	0.32
AT-LE	0.58***	0.21	0.40*
LE-EM	0.45**	0.48**	0.61***
LE-LE	0.32	0.43**	0.30
LE-AR	0.38*	0.50***	0.27

4. Summary and Conclusions

In this work three climatologies of the Saharan cyclones are created by applying the Melbourne tracking scheme on NCEP1, NCEP2, and ERA40 for the common period 1980-2001. Our analysis is based on the comparison between the seasonal means of the track characteristics of the Saharan cyclones. The track characteristics include cyclogenesis, cyclolysis and track density.

Generally, the track numbers in NCEP1 is greater than either NCEP2 or ERA40. NCEP2 tracks are more than ERA40 in all seasons except in winter.

It was found that the cyclogenesis patterns in NCEP2 and ERA40 show that the center over Libya and Egypt is weaker compared with NCEP1 datasets in both winter and spring. In summer, cyclogenesis decreases in both datasets (NCEP2, ERA40) over Algeria. In winter, NCEP2 climatology shows that Eastern Mediterranean sink decreases significantly while in ERA40 the decrease is significant over the Black sea, Western Mediterranean and the Red Sea. In spring, a significant decrease in the cyclolysis is found over Egypt and Algeria in both NCEP2 and ERA40 climatologies. Cyclone track climatologies show that in spring, the number of tracks decreases significantly over most of the Sahara in both ERA40 and NCEP2 compared with NCEP1. In autumn, the NCEP2 track climatology is marked with a shift in the tracks to western Mediterranean.

Similar lifetimes statistics are found for winter and spring. The majority of Saharan detected cyclones in these two seasons (~ 90% of NCEP1, ~90% of NCEP2, and ~85% of ERA40 cyclones) exist for four days or less. The average lifetimes ranges from 2.7 days in NCEP1 to 3.0 days in ERA40. In summer, only 73% of ERA40 tracks exist for 4 days or less, the remaining percentage is remarkably high since the tracks in this season are short. In autumn, the ERA40 tracks have considerably longer lifetimes than NCEP1, and NCEP2.

In winter, deepening is stronger in Both NCEP1, NCEP2, than in ERA40. Spring deepening rates are generally higher than in winter with an average maximum deepening rate is 3.0 in NCEP1, 3.5 in NCEP2 and 3.0 in ERA40. In summer, maximum deepening rates are similar in all three datsets. The average maximum deepenin rate is 3.0 in NCEP1, 3.2 in NCEP2 and 3.3 in ERA40. In autumn, around 95% of the tracks in all three datsets don not deepen by more than 4 hPa/6 hours. Inspecting the pressure tendency show that NCEP1 and ERA40 are similar in winter, spring and autumn while NCEP1 and NCEP2 are similar in autumn.

The seasonal distribution of the positions of the mimimu pressure along the tarcks shows that in winter cyclones reach their mimim central pressures over the Mediterranean and Black sea regions with the three datsets showing similar patterns. In spring, mimimm pressures are generally higher over the Sahara in NCEP1. The Mediterraean pressures are lower in NCEP2 than the other two datasets. The patterns are shifted to the west and south over the mediterraeaen in NCEP2 and ERA40 compared with NCEP1 due to the shift in the tracks. In summer, minimum pressures are higher in NCEP1 than NCEP2 and ERA40. In autumn, the Saharan cyclones reaching western and central mediterreanean deepen more in NCEP2 and ERA40 than in NCEP1. The Genoa center is almost absent in ERA40 and deeper in NCEP2.

References

Allen, J. T., Pezza, A. B., and Black, M. T. (2010): Explosive Cyclogenesis: A Global Climatology Comparing Multiple Reanalyses. J Clim 23:6468-6484. DOI: 10.1175/2010JCLI3437.1

Alpert, P., and Ziv, B. (1989): The Sharav cyclone: Observations and some theoretical considerations. J Geophys Res 94: 18495–18514. doi: 10.1029/JD094iD15p18495

Alpert, P., Neeman, B. U., and Shay-El, Y. (1990): Intermonthly variability of cyclone tracks in the Mediterranean. J Clim 3: 1474–1478

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

Amiridis, V., Balis, D., S., Kazadzis, S., Bais, A., Giannakaki, E., Papayannis, A., and Zerefos, C., (2005): Four-year aerosol observations with a Raman Lidar at Thessaloniki, Greece, in the framework of European Aerosol Research Lidar Network (EARLINET). J Geophys Res 110: (D21). doi: 10.1029/2005JD006190

Barkan, J., and Alpert, P., (2010): Synoptic analysis of a rare event of Saharan dust reaching the Arctic region. Weather 65:208–211. doi:10.1002/wea.503

Barkan, J., Alpert, P., Kutiel, H., and Kishcha, P. (2005): Synoptics of dust transportation days from Africa toward Italy and central Europe. J Geophys Res 110:D07208. doi:10.1029/2004JD005222

Blender, R., Fraedrich, K., and Lunkeit, F. (1997): Identification of cyclone track regimes in North Atlantic. Q J R Meteorol Soc 123:727–741

Blender, R., and Schubert M. (2000): Cyclone tracking in different spatial and temporal resolutions. Mon Wea Rev 128:377–384

Bengtsson, L., Hodges, K. I., and Roeckner, E. (2006): Storm track and climate change. J Clim 19: 3518–3543
Bengtsson, L., Hodges, K. I., and Keenlyside, N. (2009): Will extratropical storms intensify in a warmer climate? J Clim 22:2276–2301.
Birmili, W., and Coauthors (2008): A case of extreme particulate matter concentrations over Central Europe caused by dust emitted over the southern Ukraine. Atmos Chem Phys 8:997–1016
BouKaram, D., Flamant, C., Cuesta, J., Pelon, J., and Williams, E. (2010): Dust emission and transport associated with a Saharan depression: February 2007 case. J Geophys Res 115:D00H27. Doi: 10.1029/2009JD012390
Flocas, H. A., Simmonds, I., Kouroutzoglou, J., and Keay K. (2010): On cyclonic tracks over the eastern Mediterranean. J Clim 23:5243–5257
Gulev, S. K., Zolina, O., and Grigoriev, S. (2001): Extratropical cyclone variability in the Northern Hemisphere winter from NCEP/NCAR reanalysis data. Clim Dyn 17:795–809.
Hannachi, A., Awad, A., and Ammar, K. (2011): Climatology and classification of spring Saharan cyclone tracks. Clim Dyn 37:473–491.doi:10.1007/s00382-010-0941-9
Hanson, C. E., Palutikof, J. P., and Davies, T. D. (2004): Objective cyclone climatologies of the North Atlantic – a comparison between the ECMWF and NCEP Reanalyses. Clim Dyn 22: 757–769. DOI 10.1007/s00382-004-0415-z
Hodges, K. I., Hoskins, B. J., Boyle, J., and Thorncroft, C. (2003): A comparison of recent reanalysis datasets using objective feature tracking: storm tracks and tropical easterly waves. Mon Wea Rev 131:2012–2037. doi:10.1175/1520-0493(2003)131<2012:ACORRD>2.0.CO;2
Hodges, K. I., Lee, R. W., and Bengtsson, L. (2011): A comparison of extra-tropical cyclones in recent reanalyses; ERA-Interim, NASA MERRA, NCEP CFSR and JRA-25. J Clim 24 (18): 4888-4906. ISSN 1520-0442 doi: 10.1175/2011JCLI4097.1
Hoskins, B. J., and Hodges, K. I. (2002): New perspectives on the northern hemisphere winter storm tracks. J Atmos Sci 59:1041–1061
Kalnay, E., and Coauthors (1996): The NCEP/NCAR40-year reanalysis project. Bull Am Meteorol Soc 77:437–471
Kistler, R., and Coauthors (2001): The NCEP/NCAR 50-year reanalyses: monthly CD-ROM and documentation. Bull Am Meteorol Soc 82:247–267
Kanamitsu, M., Ebisuzaki, W., Woollen, J., Yang, S-K., Hnilo, J. J., Fiorino, M., and Potter, G. L. (2002): NCEP-DEO AMIP-II Reanalysis (R-2) Bul of the Atmos Met Soc, 728:1631-1643
Kouroutzoglou, J., Flocas, H. A., Keay, K., Simmonds, I., and Hatzakia, M. (2011): Climatological aspects of explosive cyclones in the Mediterranean. Int J Climatol 31:1785–1802. doi:10.1002/joc.2203
Murray, R. J., and Simmonds, I. (1991): A numerical scheme for tracking cyclone centers from digital data. Part I: development of and operation of the scheme. Aust Meteorol Mag 39:155–166
Neu, U., and Coauthors (2013): IMILAST: a community effort to intercompare extratropical cyclone detection and tracking algorithms. Bull Am Meteorol Soc 94:529–547. doi:10.1175/BAMS-D-11-00154
Nissen, K. M., Leckebusch, G. C., Pinto, J. G., Renggli, D., Ulbrich, S., and Ulbrich U. (2010): Cyclones causing wind storms in the Mediterranean: characteristics, trends and links to large-scale patterns. Nat Hazards Earth Syst Sci 10: 1379–1391
Pinto, J. G., Spangeh, T., Ulbrich, U., Speth, P. (2005): Sensitivities of cyclone detection and tracking algorithm: individual tracks and climatology. Meteorol Z 14:823–838
Prezerakos, N. G. (1985): The North West African depressions affecting the Balkans. J Clim 5:643–654
Prezerakos, N. G., Paliatsos, A. G., and Koukouletsos, K. V. (2010): Diagnosis of the relationship between dust storms over the Sahara desert and dust deposit or colored rain in the South Balkans. Adv Met Art 760546. doi:10.1155/2010/760546
Raible, C. C., Della-Marta, P. M., Schwierz, C., Wernli, H., and Blender, R. (2007): A Comparison of Detection and Tracking Methods and Different Reanalyses. Mon Wea Rev 136:880-897 DOI: 10.1175/2007MWR2143.1
Schepanski, K., Tegen, I., Todd, M. C., Heinold, B., Bo¨nisch, G., Laurent, B., and Macke, A. (2009): Meteorological processes forcing Saharan dust emission inferred from MSG-SEVIRI observations of sub-daily dust source activation and numerical models. J Geophys Res114:D10201. doi:10.1029/2008JD010325
Sinclair, M. R. (1994): An objective cyclone climatology for the Southern Hemisphere. Mon Weather Rev 123:1601–1619
Sinclair, M. R. (1997): Objective identification of cyclones and their circulation intensity, and climatology. Wea Forecasting 12:595–612.
Trigo, I. F., Davies, T. D., and Bigg, G. R. (1999): Objective climatology of cyclones in the Mediterranean region. J Clim 12:1685–1696
Trigo, I. F. (2006): Climatology and interannual variability of storm-tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses. Clim Dyn 26: 127–143. DOI 10.1007/s00382-005-0065-9

Tullet, M. T. (1984): Saharan dust-fall in Northern Ireland. Weather 39:151–152
Uotila, P., Pezza, A. B., Cassano, J. J., Keay, K., and Lynch, A. H. (2009): A comparison of low pressure system statistics derived from a high-resolution NWP output and three reanalysis products over the Southern Ocean. J Geophys Res 114, D17105. doi:10.1029/2008JD011583.
Uppala, S. M., and Coauthors (2005): The ERA-40 re-analysis. Quart J Roy Meteor Soc 131:2961–3012.
Vanderstraeten, P., Lenelle, Y., Meurrens, A., Carati, D., Brenig, L., Delcloo, A., Offer, Z. Y., and Zaady, E. (2008): Dust storm originates from Sahara covering Western Europe: A case study. Atmos Environ 42 21 2008: 5489–5493
Wang, X. L., Swail, V. R., and Zwiers, F. W. (2006): Climatology and changes of Extratropical Cyclone Activity: Comparison of ERA-40 with NCEP–NCAR Reanalysis for 1958–2001. J Clim 19:3145-3166
Wernli, H., and Schwierz, C. (2006): Surface cyclones in the ERA-40 data-set (1958-2001). Part I: Novel identification method and global climatology. J Atmos Sci 63: 2468-2507