INTERNATIONAL JOURNAL OF
COASTAL, OFFSHORE & ENVIRONMENTAL ENGINEERING
IJCOE Vol.8/No. 1/winter 2023 (26-30)

Available online at: www. Ijcoe.org

A case study diagnosis of cyclogenesis over the Black Sea

Parvin Ghafarian

Faculty member, Iranian national institute for oceanography and atmospheric science; p.ghafarian@inio.ac.ir

ARTICLE INFO

Article History:
Received: 31 Dec. 2022
Accepted: 26 Feb. 2023

Keywords:
Cyclogenesis
Potential vorticity
NCEP/NCAR
Black Sea

ABSTRACT

In this study, cyclogenesis was investigated over the Black Sea from synoptic-dynamic view. While the Black Sea has an important role in precipitation of northwest of Iran, a system that is formed over the Black Sea was selected and it affected Iran on 14th and 15th March 2009 (40 mm precipitation has occurred in some stations). Using archived data of NCEP / NCAR, absolute and thermal vorticity advection in 500hPa level and potential vorticity at 325 degrees Kelvin level were calculated. Within the development process the cutoff low was formed over the Black Sea and the difference between directions of the upper-level cutoff low at 250hPa level and surface low represents a strong baroclinicity which in turn supports cyclogenesis. The results show that the absolute and thermal vorticity advection in mid-level and potential vorticity anomaly has a fundamental role in creating cyclogenesis. In such a way that the absolute vorticity advection gets 15 times larger (about $21 * 10^{-10} s^{-2}$), and cyclogenesis occurs when the mid-level trough axis is altered from northeast-southwest direction to northwest-southeast direction, and the polar jet will be combined with a subtropical jet. Also, a strong dependence of the cyclogenesis in initial stages occurs when a large upper level Potential Vorticity (PV) anomaly advected into a region where there is a meridional potential temperature gradient at low-level.

1. Introduction

The mid-level vorticity, thermal advection and vertical velocity play an important role on atmospheric systems development and decay. Sutcliffe [1] studied cyclones and anticyclones developments. He realized that cyclogenesis is associated with convergence in the low levels, and positive vorticity in the mid-level. Later Peterson [2] using the vorticity and thickness equations found that cyclonic development is dependent on thickness advection, vertical motion and diabatic heating fields. Carlson [3] defined that cyclonic development in the earth surface takes place in regions with baroclinicity and due to starting of thermal and vorticity advection in 500hPa. He also claimed that the cause of mid-level trough development is the positive absolute and thermal vorticity advections, which create a positive vorticity tendency. The seminal article by Hoskins et al [4] introduced a new approach for understanding and diagnosing atmospheric motions using potential vorticity (PV). PV diagnosis can be used to study all aspects of synoptic scale development. Ramalingeswara et al [5] study of cyclogenesis in PV framework shows that at later stages of cyclogenesis, an upper tropospheric PV anomaly development results in the growth of upstream and downstream positive PV anomalies over the cyclone. The large-scale lows and troughs evolving along the polar front jet seem to directly influence the cyclogenesis in the Mediterranean Sea [6-7]. In the presence of a cutoff structure the mass penetration from the middle latitudes has a decisive influence on precipitation [8-9]. The climatological studies [10] reveal the presence of three cyclogenetic regions in western, central and eastern Mediterranean. The eastern Mediterranean is in generally a weaker cyclogenetic region [11] in comparison with the cyclogenetic regions of the western Mediterranean.

Both western and eastern Black Sea coasts seem to be, almost permanently, two major cyclone paths. Sea–land contrast and associated low-level baroclinicity [12] may play an important role in their maintenance on the region. The relative vorticity advection and the potential vorticity anomaly triggered from the highest layers, in the maximum development phase, cause the cyclogenesis process in the Black Sea [13]. The aim of this study is to survey the cyclogenesis, especially from the vorticity viewpoint (relative vorticity, thermal vorticity and potentially vorticity) over the Black Sea and the following results by rainfall systems over northwest of Iran. Also, it can be useful for weather forecaster to diagnose the cyclogenesis in the study area. Thus, a cyclonic event crossing the region and affecting northwest parts of Iran on 14th and 15th March of 2009 with heavy precipitations or thunderstorms, is selected. Formation, intensification and routing of the system and some synoptical and dynamical quantities are analyzed. The data and methods of diagnosis are described in section 2, and an overview of the case study is provided in section 3. Sections 4 and 5 contain the discussion and conclusions.

2. Data and methods

In this study, reanalysis dataset produced by the US National Center for Environmental Prediction (NCEP) and the US National Centers for Atmospheric Research NCAR) has used [14]. 6-hourly global atmospheric data within a regular grid are used which has a special resolution of $2.5° \times 2.5°$ in latitude and longitude directions at 17 standard pressure levels from 1000hPa up to 10hPa.

Positive absolute and thermal vorticity advections in 500hPa level [15], and Ertel potential vorticity [16] are considered as cyclogenesis indices.

The research domain covers a horizontal regular network in an area between 0-to 80 degrees east in longitude and 10-to 60 degrees north in latitude. The following units are considered respectively for the absolute vorticity advections and the Ertel potential vorticity: $10^{-10}\mathrm{s}^{-2}$ and $10^{-6}\mathrm{m}^2\mathrm{s}^{-1}\mathrm{Kkg}^{-1}$.

3. Case study

In this study, a system which formed over the Black Sea and affected north-west area of Iran on 14th and 15th March of 2009 was considered. Satellite images related to the cyclonic event; show an expanded cloud region from the Black Sea to NW of Iran (Figure 1). 40 mm of accumulated rainfall within 24 hour were recorded in the Urmia synoptic station, a northwest province of Iran on 14th March of 2009, while climatic average recorded precipitation in the region in March is 52 mm. Thus, the system almost provided 77% of the regional long-term rainfall in March. Likewise, the system were accompanied with strong winds which resulted to raising dust particles during its eastward movement in the Ardebil region while losing its moisture content. In figures 2-5, the two stations representing their respective regions are shown with triangle and circle symbols.

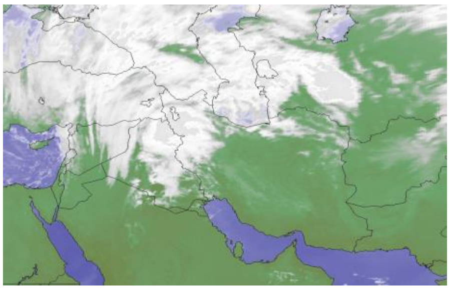

Figure 1. Satellite image of Meteosat-7 for 14th March 2009, 0000 UTC.

4. Results

Figures 2 (a, b, c, d) show the mean sea level pressure and Figure 2 (e, f, g, h) show geopotential height at 500hPa and polar jet for the period 12to 15March 2009. Pressure field at 0000UTC on 12th March 2009, shows a high pressure with 1020hPa iso-lines stretching towards from east of the Black Sea to southwest of Iran (Figure, 2a). Upper-level trough stretching from Europe to south of the Mediterranean Sea has a positive tilt on the same day. Likewise, zonal waves are passing from south of the Black Sea to east of Iran and intrusion of the polar jet is seen across the northern latitudes to the west Mediterranean Sea. A relatively zonal upper-level jet is placed between the Mediterranean region and the Aral Lake and a weak sub-tropical jet is passing from the lower latitudes (Figure, 2e). At 0000 UTC on 13th March 2009, upper-level trough has got entirely a meridional axis and expanded from the northwest of the Black Sea to the south of the Mediterranean Sea. At the same time, intrusion of the polar jet was continued more intensively from higher latitudes and got a cyclonic curvature from mid-Mediterranean to northeast of the Black Sea.

By moving the aforementioned high pressure toward east, the low pressure extends from the southern latitudes to the Black Sea region, Figures (2b and 2c). At 0000UTC on March 14th, the upper-level trough axis acquired a negative tilt and a cutoff low was formed over west of the Black Sea. Investigation of the height field through different levels indicates expansion of the cutoff low from ground to tropopause level (250hPa), which presents a strong baroclinicity in the area, Figure (3). The Jet axis acquires a cyclonic curvature in south of the Black Sea, and also the sub-tropical jet were intensified and combined with the polar jet in south-east of the Black Sea. At this time cyclogenesis is formed meridionally from the north of the Black Sea to the southwest of Iran on the surface, which is beneath the polar jet exit region and it is shown with L sign in the Figures (2c) and (2g). The system had caused 40 mm of rainfall in northwest Iran. At 0000UTC 15th March 2009, the cutoff low continued its activity on the Black Sea and its eastern regions and the center of surface low moving toward east of the Caspian sea and the Aral lake, were deepened and the corresponding central pressure fell to 1000hPa with a 10hPa reduction in the central pressure. It seems that the Caspian Sea thermodynamic effect was the responsible factor for the weakening of the surface pressure. The cyclone moved a remarkable distance during the past 24 hours and the high latitudes polar jet was weakened and the cyclonic curvature was decreasing toward lending to more zonal currents. Due to strong winds (over 7.5 m/s) that were produced by the system passing from northwest Iran, there were some reports of rising dust in the region, Figures (2d) and (2h).

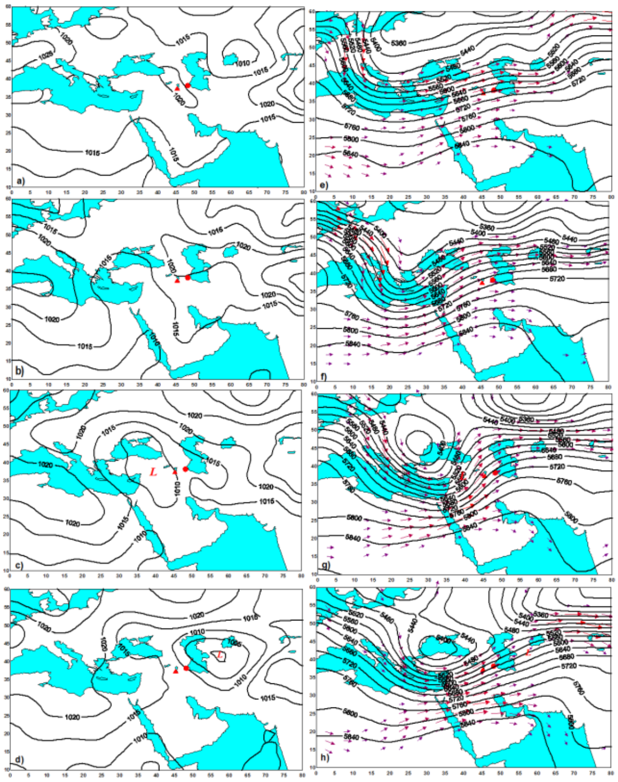

Figure 2. Left panels show sea level pressure (contours intervals is 5 hPa). Right panels show geopotential height at 500hPa (contours intervals is 40 m), and polar jet: (a,e) 12, (b,f) 13, (c,g) 14,(d,h) 15, March 2009, 0000 UTC.

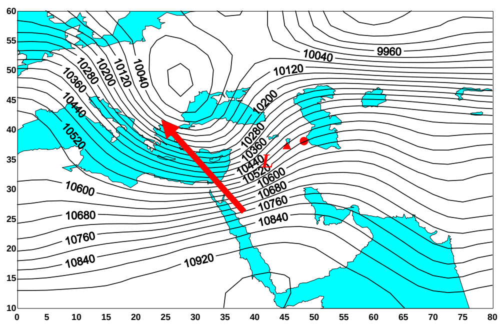

Figure 3. Geopotential height at 250hPa (contours intervals is 40 m), 0000 UTC, 14th March 2009. Red arrow shows the direction of trough axis from surface to the upper tropopause at 250hPa.

Figures 4 (a, b, c, d) show the absolute vorticity advection (shaded), polar jet and geopotential height at 500hPa, (e, f, g, h) show the thermal vorticity advection (shaded), polar jet and geopotential height at 500hPa for the period 12 to 15 March 2009. Consideration of the absolute vorticity advection shows that there are three maximum centers of the quantity with the value of five units over the Black Sea, mid-Mediterranean, and Europe and in front of the trough region, at 0000 UTC on 12th March 2009, Figure (4a). At 0000 UTC, 13th March 2009, with intrusion of the polar jet toward the lower latitudes, absolute vorticity advection moves to the Mediterranean Sea and its isolated maximum centers became combined and placed in east of the trough axis so that its maximum value was placed in the southwest of the Black Sea with a directional expansion from northwest of the Black Sea to south of the Mediterranean (Figure 4b). At 0000 UTC 14th March 2009, the centered of maximum for this quantity with the amount of 21 units, was coincided with the center of cyclone while direction of the polar jet core up to its exit region had a negative tilt with the trough center and its direction is northwest-southeast and expands from the west of the Black Sea to the southwest boundaries of Iran. The same day, cutoff low has formed in the west of the Black Sea (Figure 4c). At 0000 UTC 15th March 2009, along with the zonal Jet, maximum center of this quantity with seven units is observed in the east of Mediterranean Sea (Figure 4d). Study of thermal vorticity advection shows that, at 0000 UTC12th March 2009, the maximum center of this quantity is in the west of the Black Sea and over the North Sea, Figure (4-e). At 0000 UTC 13th March 2009, with intrusion of the polar jet to the lower latitudes, thermal vorticity advection moved toward the lower latitudes. On this day, there are two maximum value centers in the north of Mediterranean Sea and east of trough, Figure (3f). At 0000 UTC 14th March 2009, with the cyclogenesis, thermal vorticity advection flux with northwest-southeast axis flew from northwest of the Black Sea to Saudi Arabia and the maximum center of this quantity got a value of 8 units in the northwest of the cyclone over the Black Sea, Figure (4g). At 0000 UTC 15th March 2009, the maximum center of this quantity with the amount of seven units is placed in the northeast of the Black Sea. Figure (4h).

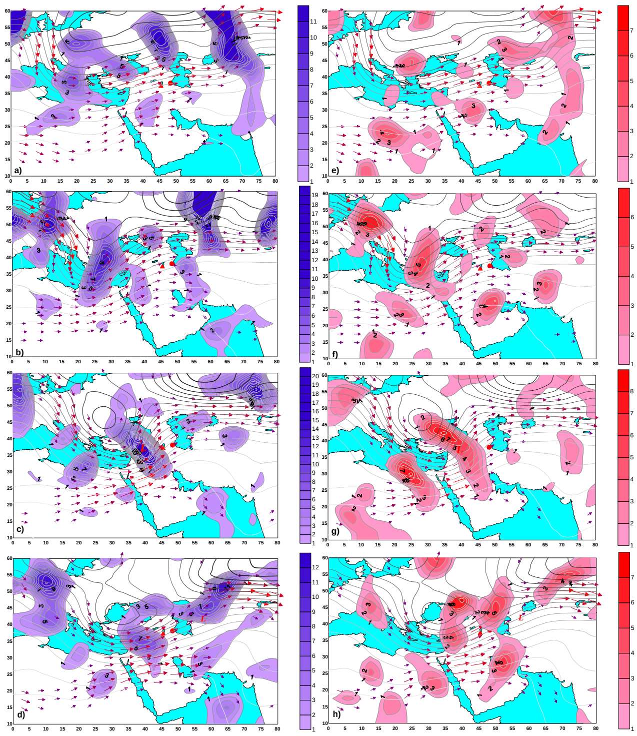

Figure4. Left panels show absolute vorticity advection at 500hPa (shading), geopotential height at 500hPa (contours), and polar jet. Right panels show thermal vorticity advection at 500hPa (shading), geopotential height at 500hPa (contours), and polar jet: (a, e) 12, (b, f) 13, (c, g) 14,(d, h) 15 , 00 UTC, March 2009.

Figure 5 (a, b, c, d) show the evolution of the PV field on the 325 degrees Kelvin isentropic surface, potential temperature at 850hPa and polar jet. The study of potential vorticity on a fixed temperature surface, 325 degrees Kelvin level, shows that the maximum anomaly, PV was observed at 0000 UTC 12th March 2009 in the north of the Mediterranean Sea. Contours of PV are zonal and accompanied the jet flow, Figure (5a). At 0000 UTC 13th March 2009, the maximum PV anomaly in the west of the Black Sea is observed and is meridional. On this day, potential temperature anomaly is seen in 850hPa level, Figure (5b). At 0000 14th March 2009, the maximum PV anomaly in the west of the Black Sea (northwest of cyclone's position) is seen simultaneously with the occurrence of cyclogenesis in the southern of the Black Sea. On this day, the maximum potential temperature anomaly occurs at 850hPa level and warm air and cold air were located in east and west of the cyclone respectively. At 0000 UTC 15th March 2009, the PV anomaly located in the center of the Black Sea, is weakened and direction of contours are altered from meridional to zonal and potential temperature anomaly were reduced, Figure (5c).

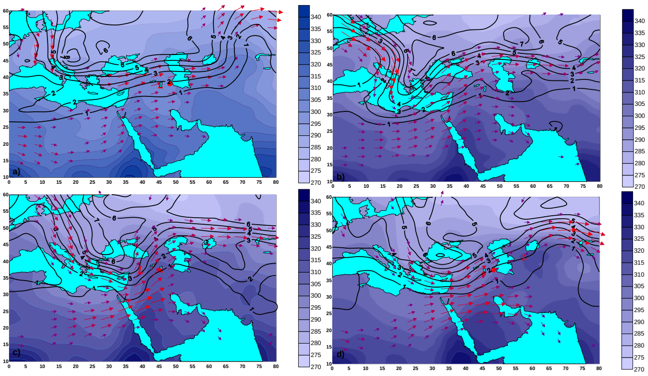

Figure 5. Potential vorticity distribution on the 325 K isentropic surface (PV, bold contours in pvu), potential temperature at 850hPa (shading in K), and polar jet .a: 12, b: 13, c: 14 and d: 15, 0000 UTC, March 2009.

5. Conclusions

cyclogenesis mechanism in the mid-latitude is very different from the cyclone that forms in the subtropical regions [17-18]. In this research the structure of the cyclogenesis over the Black Sea during 12-15 March 2009 was investigated within a synoptic and dynamic framework. Evidence for the importance of effects by developments at 500hPa level, especially in the early stages of rapid cyclogenesis, are manifested by changes in orientation of the trough axis from northeast-southwest (positive) to northwest-southeast (negative). Within the development process the cutoff low was formed over the Black Sea and the difference between directions of the upper-level cutoff low at 250hPa level and surface low represents a strong baroclinicity which in turn supports cyclogenesis. Intrusion of the polar jet from upper latitudes and combination with the subtropical jet along with a cyclonic curvature in the east of the Black Sea produces the cyclogenesis in the exit region of the combined jet stream. Study of quantities of absolute and thermal vorticity advections in, 500hPa level by actual and thermal wind and surface pressure height shows that the maximum values of dynamic parameters is in front of the mid-level trough and that is mainly because of polar jet displacement toward lower latitudes. In the cyclogenesis stage, they are placed on the exit area of the jet current. The difference is that the maximum absolute vorticity advection was in center of the cyclone and the maximum thermal vorticity advection was over the Black Sea and northwest of cyclone. Also at the cyclogenesis stage, absolute vorticity advection has increased 15 units compared to a similar time on the previous day and its value has reached to a large amount, $21 * 10^{-10} s^{-2}$ and the thermal vorticity advection has increased from 5 to 7. Since the development (decay) of the mid-level trough causes strengthening (weakening) pressure systems by convergence (divergence) of the horizontal wind in the lower levels and create an upward (down ward) motion, these two quantities indirectly affect strengthening and development of the Black Sea trough. A strong dependence of the cyclogenesis in initial stages occurs when a large upper level PV anomaly advected into a region where there is a meridional potential temperature gradient at low-level. Maximum PV anomaly in cyclogenesis stage is located in the west of the Black Sea and warm air advection is observed in the east of the cyclone (east of the Black Sea) and cold air advection in the west of it. Finally, for a better understanding of the physical and dynamic process of cyclogenesis over the Black Sea, we need to use the numerical model to evaluate air-sea interaction effects.

6. References

[1] Sutcliffe, R.C., (1938), *On Development in the Field of Barometric Pressure*, Q.J. Roy. Meteorl., Soc., 64, p. 495-509.

[2] Petterssen , S., (1956), *Weather Analysis and Forecasting*, Vol II, Weather and weather system, McGraw Hill, Book Company, New York, p. 266.

[3] Carlson,T.N, (1991) *Mid-Latitude Weather System*.University Press,cambridge.

[4] Hoskins, B.J., Mcintyre, M.E. and Robertson, A. W., (1985) *On the Use Significance of Isentropic Potential-Vorticity Maps*, Q.J., Roy. Meteorol. Soc., 111, p. 877-946.

[5] Ramalingeswara, S., K. Muni Krishna., O. S. R. U. Bhanu Kumar, (2009) *Study of Tropical Cyclone "Fanoos" Using MM5 Model- A Case Study*. Nat. Hazards Earth Syst. Sci., 9, p. 43–51.

[6] Flocas H. A. and Karacostas, T. S. , (1996) *Cyclogenesis over the Aegean Sea: Identifications and synoptic categories*, Meteor. Appl., 3, p. 53–61.

[7] Trigo, I. F., Bigg, G. R., Davies, T. D, (2002) *Climatology of cyclogenesis mechanisms in the Mediterranean*, Mon.Wea. Rev., 130,549–569.

[8] Alpert, P., Reisin, T., (1986) *An early winter polar air mass penetration to the eastern Mediterranean*, Mon. Wea. Rev., 114, p. 1411–1418.

[9] Alpert, P., Neeman, B. U., Shay-El, Y., (1990) *Climatological analysis of Mediterranean cyclones using ECMWF data*, Tellus, 42A,p. 65– 77.

[10] Maheras, P., Flocas, H. A., Patrikas, I., Anagnostopoulou, Chr., (2001) *A 40 year objective climatology of surface cyclones in the Mediterranean region: spatial and temporal istribution*, Int. J. Climatol., 21, p. 109–130.

[11] Radinovic, D. , (1965) *Cyclonic activity in Yugoslavia and surrounding areas*, Arch. Meteorol. Geophys. Bioklim, 14(A), p. 391–408.

[12] Hoskins, B.J. and Valdes, P.J.(1990) *On the existance of Storm-Tracks*. J. of the Atm.Sciences. Vol.47, No.15, p.1854-64.

[13] Georgescu, F., S. Tascu, M. Caian, D. Banciu., (2009) A severe blizzard event in Romania – a case study. Nat. Hazards Earth Syst. Sci., 9, p. 623–634.

[14] Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., (1996) The NCEP/NCAR 40-year reanalysis project. Bulletin of the American meteorological Society, 77(3), p.437-472.

[15] Holton, J. R., (1992) *An introduction to dynamic Meteorology*, Academic Press Inc., San Diego, USA.

[16] Nielson-Gammon, J. W., and D.A. Gold, (2008) *Potential Vorticity Diagnosis in the Quasigeostrophic and Nonlinear Balance System*. J. Atmos. Sci., 65, p. 172-188.

[17] Pegahfar, N., Gharaylou, M., (2018) Sensitivity of an Axi-Symmetric Tropical Cyclone Model to Two External Parameters. International Journal of Coastal, Offshore And Environmental Engineering, 3(3), p. 41-51.

[18] Hajivalie, F., Arabzadeh, A., (2017). A 3D Numerical Study of Cyclone Gonu Waves Impact on Ramin Port. International Journal of Coastal, Offshore And Environmental Engineering., 2(1), p. 33-41.