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The Synoptic Characteristics, Causes, and Mechanisms of Kahlaa Tornado in Iraq on 14th April 2016

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Abstract:

In this study, an analysis of the synoptic characteristics, causes and mechanisms of Kahlaa tornado event was carried out. This tornado occurred on 10:30 UTC (1:30 pm Iraq Local Time) on 14 April 2016 to the north of Kahlaa town in Maysan governorate. We analyzed surface and upper charts, weather conditions, the damage indices, the dynamical features and the instability of the tornado. The analysis showed that there was a low pressure system which was an extension of the Monsoon low in addition to a supercell thunderstorm and a jet stream aloft. The cold trough and high relative vorticity at 500 hPa level, the humid warm wind blowing from the south and the dry cold wind from the north contributed to the initiation of the tornado. According to the damage amount, Kahlaa tornado can be classified as EF2 degree (considerable) on Enhanced Fujita scale. Three indices were calculated to estimate the instability of the tornado. The values of the convective available potential energy (CAPE), K-index, and lifted index were (≥2500 J/kg), (35.3 ^{o}C), and (-7), respectively. All these indices confirmed the instability required to form severe thunderstorm essential to tornado formation. Although the forecasting of tornadoes occurrence is difficult, there would be indications that may lead to expect of occurrence. These may include the availability of moisture, heat, and significant wind direction changes with altitude. However, the vital factors were the existence of high instability and a supercell thunderstorm.

Key words: Kahlaa, Synoptic, Thunderstorms, Tornado.

Introduction:

Tornadoes are the most destructive winds event created by nature. Sometimes they are strong enough to destroy most things in their path (1). The tornado is a tilting column of air touching the ground and hanging from a position under a deep thunderstorm base. Tornado is becoming visible when the water vapor condenses to droplets inside, or when the tornado uplifts debris and dust from the ground. The funnel shape of the hanging cloud is an indication of the tornado occurrence (2). Most of tornadoes occur in United States with more than 1000 tornados a year. It is very common that "Tornado Alley" in the central Great Plains is the area with higher frequency. However, research has identified evidence of a new spot in "Dixie Alley," which represents an eastward extension of "Tornado Alley" (3). On the other side of the Atlantic Ocean, it was estimated that at least 100 tornados occur each year in Europe. It is responsible for significant damages with impacts on many social activities, human health and economy (4,5). Most tornadoes rotate cyclonically. Tornadoes diameters are ranging from 100 m to about 600 m or more. Most tornadoes continue for minutes with a path of about 7 km but in very rare situations, tornadoes with hundreds of kilometers and duration of some hours have been recorded (6). Observing and forecasting tornadoes is a difficult task because it is very diverse in space and very short in lifetime. In addition, it is of small diameter that cannot be easily observed by satellites (7). The number of tornado occurrences around the world is variable but much related to the surface topography and distribution of land and sea (8). The possibility to generate tornadoes increases as the thunderstorm developed to a supercell cloud, which is a severe circulating cloud. However, not every supercell generates a tornado. In the same time, not every supercell generate tornado (9). Tornado may contain single vortex, but the most powerful tornadoes contain whirls inside, robust and smaller called suction vortices, which circulate around the center of the bigger tornado in anticlockwise direction (multi-vortex tornadoes) (10). Due to the strong pressure gradient in tornado, the wind speed may reach a maximum of 480 km per hour, which is a strong and destructive speed. In the late 1960's, Theodor Fujita suggested a scale to classify tornadoes owing to their rotational speed called Fujita Scale. The speed of tornadoes is estimated depending solely on the damage that produced by the tornado. In 2007, a new modified version of this scale was suggested, the Enhanced Fujita Scale (EF Scale). The new scale tried to give a wide range of criteria in determining the tornado speeds by using 28 damage indicators (6). There was a great deal of research focused on tornadoes on a global basis.

In Turkey, the country that located north of Iraq, 225 tornadoes were recorded in the last five years. This number is more than halve the total number experienced during two centuries. This increase was attributed to the climate changes impacts (11). Paul (2001) (12) in analyzed 304 tornado cases in France and showed that the regions of high occurrence of tornadoes are the northwestern and the southeastern of France. Most of the tornadoes there occur in spring and summer. Dotzek (2001) (13) implemented a study of tornadoes in Germany by using 517 cases starting from 1870. The study showed that the highest activity of tornadoes was in July and the lowest activity was from November to February mostly at afternoon and before sunset. Matsangouras et al. (2010) (14) studied a tornado case that happened in Greece in 12 February 2010 in an opened area. The Greek tornado happened afternoon and continued for 20 minutes and was of Class F2 in Fujita Scale. They analyzed the tornado synoptically by using the satellite images and radar soundings in addition to using the Weather Research and Forecasting model (WRF). Jagger et al. (2015) (15) presented a statistical climatological model to study the climate of tornadoes occurrence. It was found that the increase of population by half contributed to the increasing of the calls about the tornadoes occurrence by 13%. A survey, which was conducted in china for tropical cyclone tornadoes from 2006 to 2018, counted 64 cases with an average of five per year. The study determined that most tornadoes occur before and within 36 hours after the tropical cyclone passage (16).

The case study in this paper is concerned with the tornado that happened in Kahlaa town, Maysan governorate, South of Iraq at 1:30 pm local Iraq time (10:30 am UTC) on 14 April 2016. There was no recorded case of a previous tornado in Iraq. Tornadoes, in general, may cause huge damage of buildings, fields, electric power towers, cars, and any other entities that come into its path. In our case, Kahlaa tornado causes destruction of some houses in the region of effect. This tornado also dropped down many high power towers and overturned some cars. This study is an attempt to investigate the causes of Kahlaa tornado and the geographical and meteorological conditions that led to such a phenomenon. Instability indices can be useful in determining the potential weather in forming the severe thunderstorms and tornado. One of the parameters describing atmospheric stability is CAPE. CAPE indicates the amount of energy available for convection (17):

The K index (KI) (Eq. 1) is particularly useful for identifying convective and heavy rain producing environments. Values exceeding 40 point out the best potential for thunderstorm with heavy rain (18):

$$K = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700}) \qquad 1$$

Where: T_{850} is the temperature at 850 hPa, T_{500} is the temperature at 500 hPa, T_{d850} is the dew point at 850 hPa, T_{700} is the temperature at 7oo hPa, T_{d700} is the dew point at 700 hPa.

Environments not characterized by high values of CAPE or vertical wind shear like the situation in Iraq receive less attention, but they can still support severe weather and tornadoes (19). The inclusion of the dew point depression term reflects the unique emphasis of K on assessing the vertical penetration of low-level moisture, thought to be essential for the formation of air mass storms (20). A value ≥ 30 °C is typically expected for severe thunderstorms (21). Lifted Index (Eq. 2) is presented by Galway (22) to be the temperature difference between the observed 500 hPa temperature and the assumed 500 hPa temperature of a mean parcel lifted from the boundary layer next to the ground.

$$Lifted\ Index\ LI = T_{500} - T_{p500} \qquad 2$$

Where LI < -9 refers to extremely unstable conditions, -9 ≤ LI ≤ -6 to very unstable and -6 ≤ LI ≤ -3 to moderately unstable (22).

Materials and Methods:

The tornado event was studied on many aspects: The weather conditions, which might contribute in tornado occurring. Also, its form and destruction, its synoptic, dynamical and thermodynamic properties.

Location and Data:

The tornado event occurred on 14 April 2016 at 13:30 local time to the north of Kahlaa town (47° E, 31° N), 20 km to the southeast of Amarah city in Maysan Governorate. The town center is relatively small with less than 5 km × 5 km area. The inhabitants of this town may reach about 85000 people. The town center surrounded by a flat area, mostly agricultural lands (Fig. 1). Houses there do not exceed 10 m in height.

To consider the case study of tornado, the routinely surface weather data was based on the datasets from the Iraqi Meteorological and Seismology Organization. The other data was acquired from the European Center of Moderate Weather Forecasting (ECMWF).

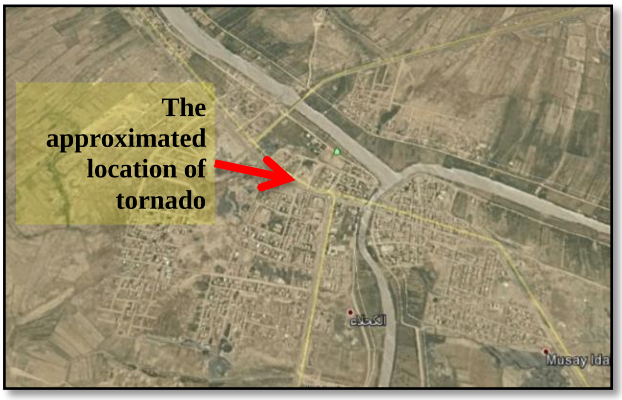

Figure 1. The approximated location of tornado

Weather Conditions during the Tornado Event:

The weather conditions for three days, before during and after the event were investigated. Visualization of wind speed, air temperature, and atmospheric surface pressure versus time are shown in Figs. 2-4.

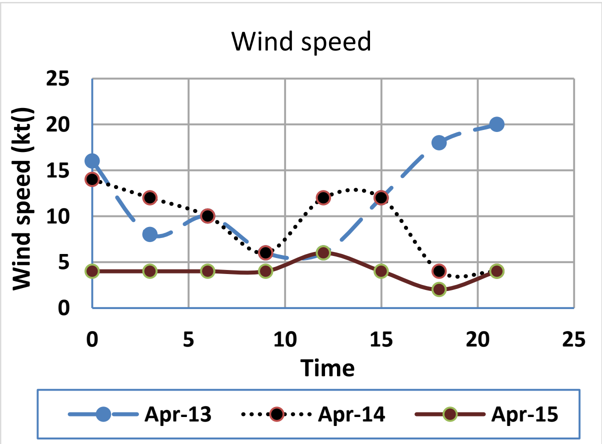

Figure 2. Diurnal wind speed in knots (1 kt = 0.514 m/s) of three days 13, 14, and 15 April 2016 of Amarah station

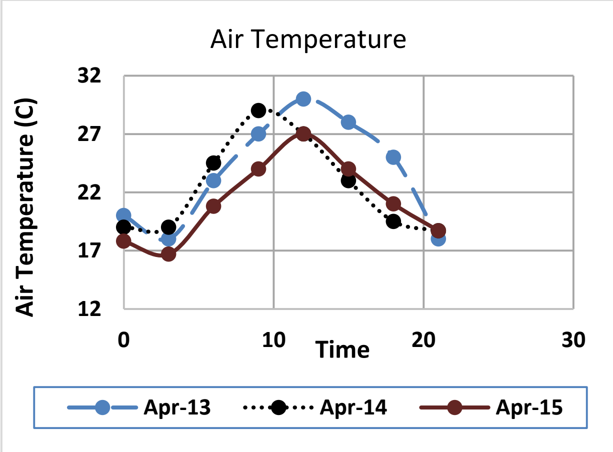

Figure 3. Diurnal air temperature of three days 13,14, and 15 April 2016 of Amarah station

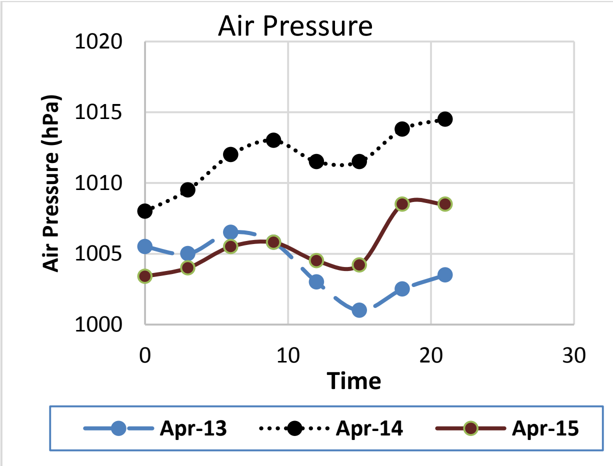

Figure 4. Diurnal air pressure of three days 13, 14, and 15 April 2016 of Amarah station

The Form and Destruction of the Tornado:

The photos, videos and witnesses from the site confirmed the following: The tornado event continued for about half an hour. It started at 1:30 pm Iraqi local time (10:30 am UTC) affecting the northern edge of the center of Kahlaa town.

Fortunately, the tornado did not cause casualties though it damaged some high power towers, houses, and cars. There was another funnel vortex hanging out of the cloud but did not reach the ground (Figs. 5-7).

Figure 5. The damage of houses on the path of the tornado

Figure 6. Kahlaa tornado lifts a huge amount of debris

Figure 7. Kahlaa tornado had two funnel vortices

The Synoptic Analysis of Weather:

To study the synoptic analysis of the weather, charts of temperature, surface air pressure, dew point were drawn for the times before and around the event. The dataset used to visualize the charts was extracted from the European Centre for Medium-Range Weather Forecasts (ECMWF) dataset. Figures. 8 and 9 show the surface air temperature on 13 and 14 April 2016. Figures. 10, 11 visualized the mean sea level pressure on 13 and 14 April 2016. For same period, the dew point temperature charts were drawn to look on the humidity Figs. 12 and 13.

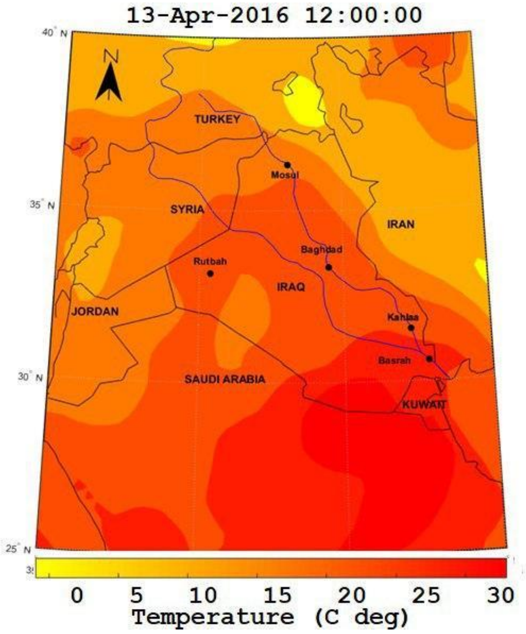

Figure 8. Surface air temperatures on 13 April 2016 at 12 UTC

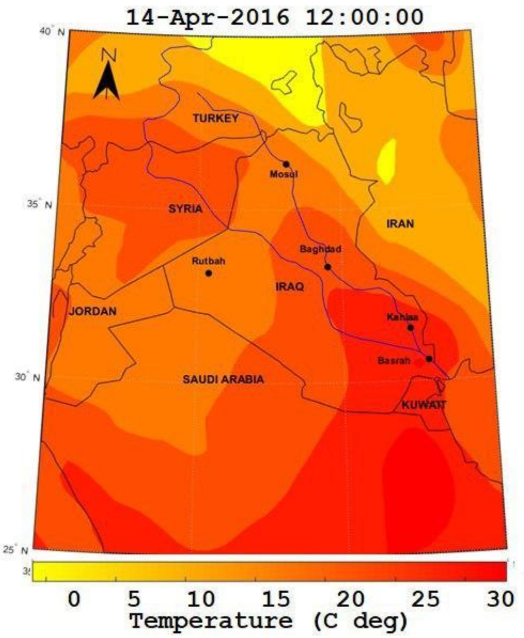

Figure 9. Surface air temperatures on 14 April 2016 at 12 UTC

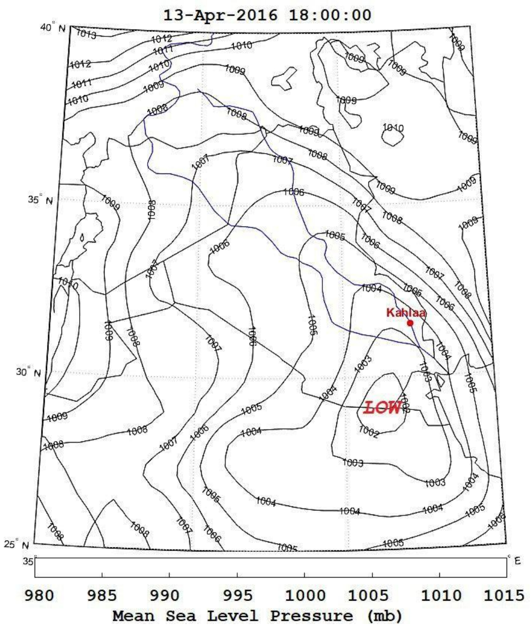

Figure 10. Mean sea level pressure (mb) on 13 April 2016 at 18 UTC

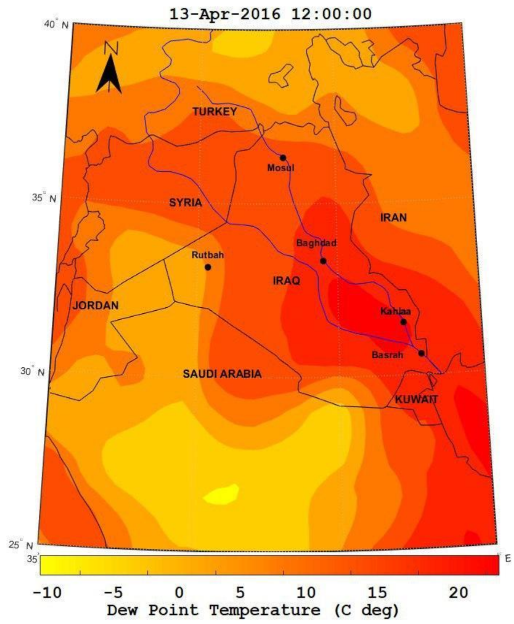

Figure 12. Dew point temperature (C deg) on 13 April 2016 at 12 UTC

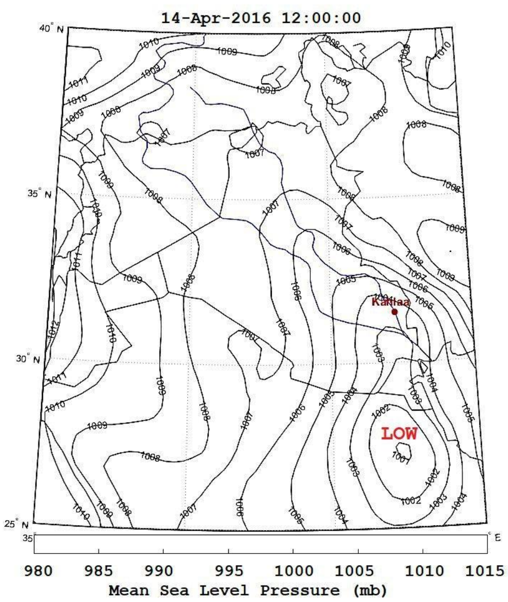

Figure 11. Mean sea level pressure (mb) on 14 April 2016 at 12 UTC

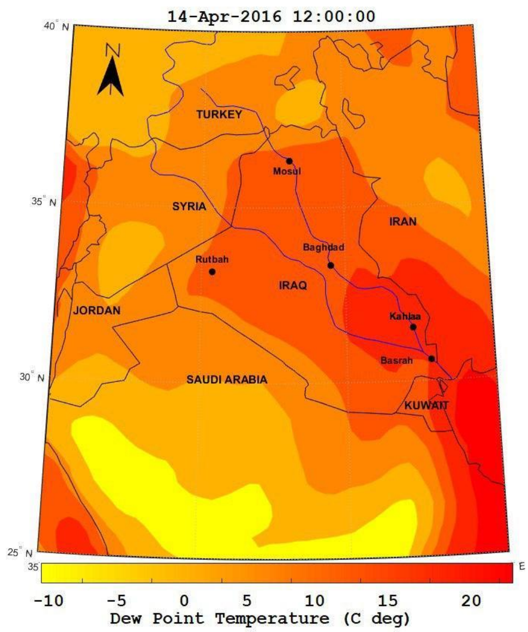

Figure 13. Dew point temperature (C deg) on 14 April 2016 at 12 UTC

The Dynamical and Stability Analysis of Weather:

To study the dynamical and instability situation, one should track the behavior of the geopotential heights for different levels in addition to the instability. Hence, the charts of pressure levels (850 hPa, 700 hPa, 500 hPa) were drawn. More emphasis was placed on 850 hPa level by taking the geopotential height, temperature, wind speed and relative humidity into account, Figs. 14-19. Also, the charts the relative vorticity (at 500 hPa), jet stream (at 200 hPa), and surface vertical wind were visualized, Figs. 20-21. To investigate the weather instability, the plots of the Convective

Available Potential Energy (CAPE) were drawn, as well, Figs. 23-24

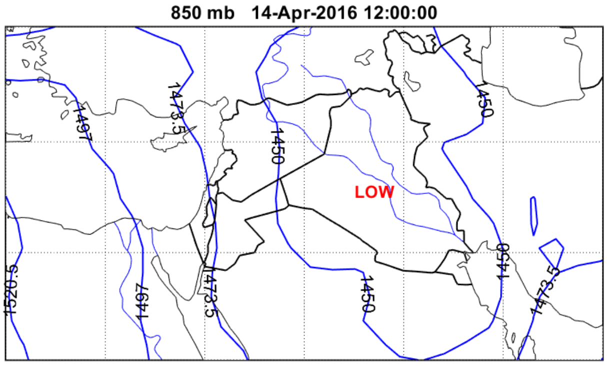

Figure 14. 850 hPa chart on 14 April at 12 UTC

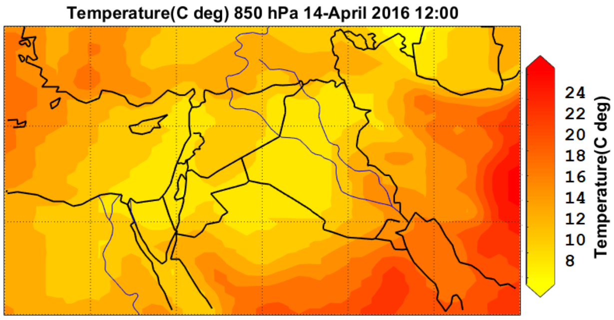

Figure 15. Temperature (C deg) at the level of 850 hPa on 14 April 2016 at 12 UTC

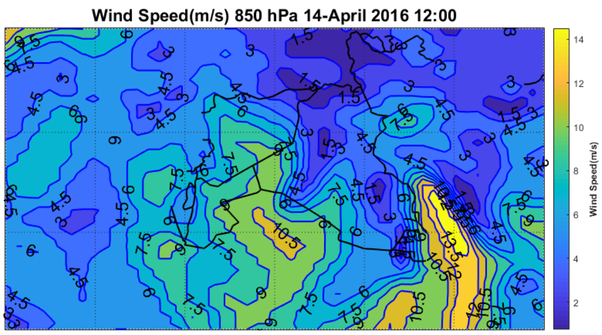

Figure 16. Wind speed (m/s) at the level of 850 hPa on 14 April 2016 at 12 UTC

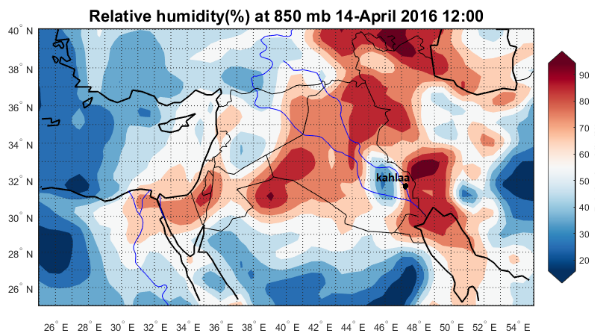

Figure 17. Relative humidity (%) at the level of 850 hPa on 14 April 2016 at 12 UTC

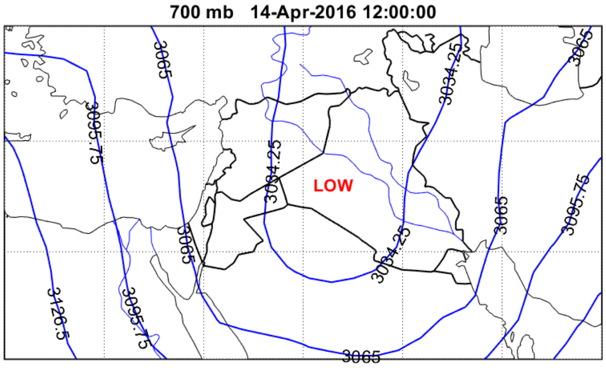

Figure 18. 700 hPa chart (geopotential height contours) on 14 April at 12 UTC

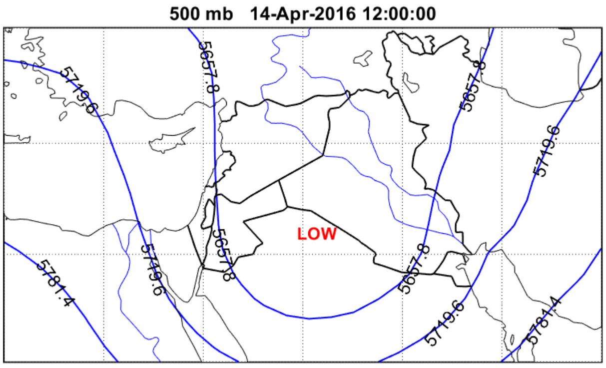

Figure 19. 500 hPa chart (geopotential height contours) on 14 April at 12 UTC

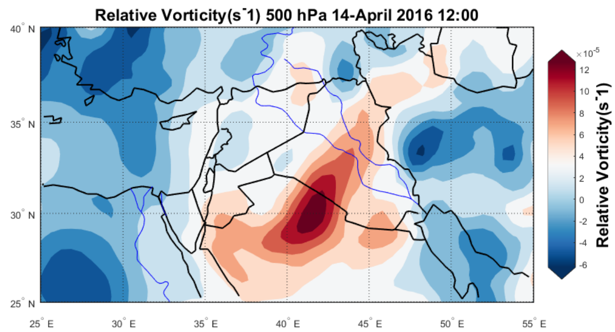

Figure 20. Relative vorticity (sec^{-1}) at 500 hPa chart on 14 April at 12 UTC (The dark red spot refers to more than 12 ×10^{-5} s^{-1} value of relative vorticity)

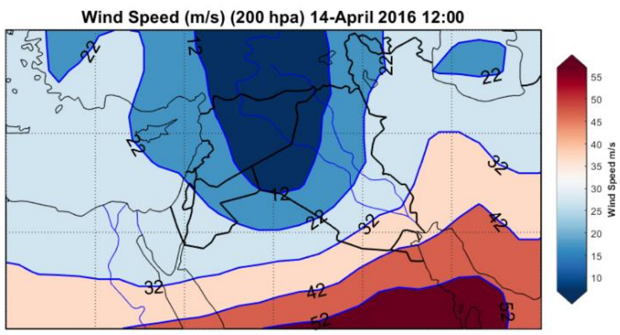

Figure 21. The wind speed chart at the level of 200 hPa on 14 April at 12 UTC featuring the jet stream to the south of Iraq (wind speeds greater than 40 m/s)

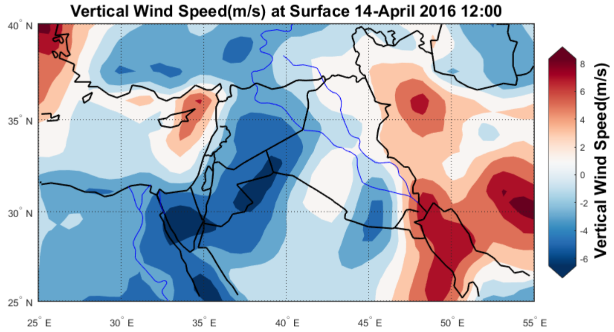

Figure 22. The surface vertical wind speed chart (m/s) on 14 April at 12 UTC

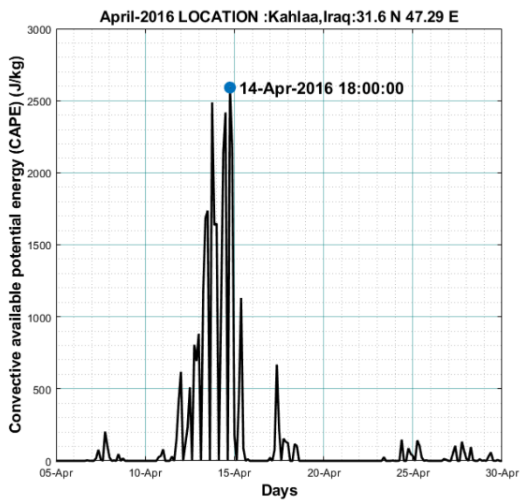

Figure 23. Plot of development of CAPE for the period from 5 to 30 April. There was a significant increase on 14 April 2016.

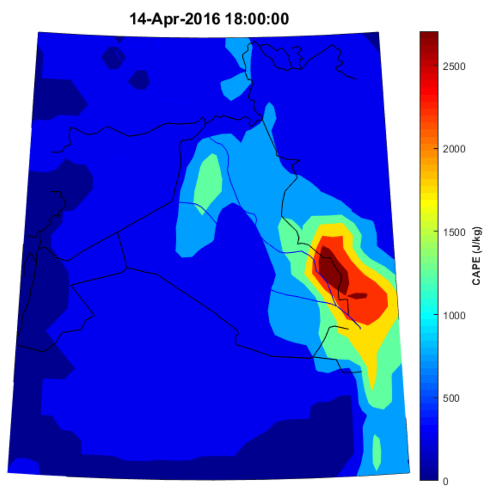

Figure 24. Chart The darker red spot is the region of high CAPE at the day 14 of April 2016 enclosing Kahlaa region

Results and Discussion:

Weather Conditions during Tornado Event:

Spring in Iraq is a season with a significant quantity of rain. The humidity and heat impose convection process and large cumuliform clouds. Looking at the observations of the day of tornado (April 14, 2016) in addition to the day before and after for Amarah city shows occasional thunderstorms. The meteorological station of Amarah city is the nearest station to Kahlaa city. Most of the clouds during these days were stratocumulus and altostratus with significant amounts of cumulonimbus (Cb).

The plots of wind speed, air temperature, and air pressure, Figs 2-4 do not show a specific trend at the time of tornado event, namely 1:30 pm local time (10:30 am UTC) on April 14.

Unfortunately, Kahlaa city does not have meteorological station and hence the data of Amarah station, which located at tens of kilometers apart, did not reveal the exact meteorological situation at Kahlaa.

Damage Class:

According to its damages (See Figs 5-7), Kahlaa tornado can be described as considerable on Enhanced Fujita scale (EF2). It is with a wind speed of 100 knots, the one that uproots large trees and causes destruction of weak structures (7).

The Synoptic Analysis:

Charts of air temperature, Figs 8, 9 showed an increase at the day of tornado and revealed that the hottest span on Kahlaa city was on 14 April, the day of tornado. Charts of mean sea level pressure, Figs 10, 11 show a low-pressure system (Monsoon) extended from the south to the north of Iraq. Humidity was high in the region as it is clear in charts of dew point temperature, Figs 12, 13. The thunderstorm was not frontal but of air mass type.

The Dynamical and Instability Analysis:

The dynamical situation can be analyzed in this manner: at the surface, there was a warm humid air from the south east caused by the effect of monsoon. At the level of 850 hPa, there was a wedge of warm humid wind veered slightly with a significant wind speed blowing from the southeast, Figs 14-17. At 700 hPa level Fig 18, the trough axis was passing in the mid-width of the Arabian Peninsula. The wind became southerly with cold dry air. At 500 hPa level, the wind became southwesterly with a high value of relative vorticity Figs 19, 20. The cold trough causes the warm air near the surface to ascend by the buoyancy process. The high relative vorticity (greater than 10^{-4} s^{-1}) at the level of 500 hPa strengthened the convergence at the surface and thus increased the speed of upward winds. The subtropical jet stream, which was passing to south of Iraq Fig 21 strengthened the tornado by enhancing the upper level divergence. This successive turning of wind with height caused a spinning effect, which contributed to the tornado formation. The chart of vertical wind speed shows a significant value of the ascending wind at the surface, greater than 6 m/s, which was much greater than the usual speed that is about 1 m/s (See Fig 22). This mechanism summed by the high instability in the region supported the chances to build up the huge cell of thunderstorm. Study of the Convective Available Potential Energy (CAPE) is of importance in investigating tornado occurrence. The deep convection is caused by the strong instability of air and it is vital in thunderstorm and tornado formation. Figs 23, 24 show the high values of CAPE on the day of tornado occurrence in the region of Kahlaa. CAPE index suggested that the layer was mostly unstable and developed a deep convection with a value of more than 2500 J/kg. This value is higher than those of the tornadoes that occurred in other places such as in Czech Republic (Average from 500 J/kg to 900 J/kg) (23)

Also, the K-index value in the region was calculated by using eq.1 to be 35.3 ^{o}C. This value suggests numerous activity of thunderstorms. In a study in Greece for a total number of 34 ^{o}C significant tornadoes, showed that the mean value of K-index is 31.5 and the maximum value is 40 ^{o}C (24). Hence, Kahlaa tornado corresponds to an average value of significant tornadoes.

The lifted index was calculated by using eq.2 for the time of the tornado, it was -7 which is a negative value and refers to very instable condition.

The above synoptic regime and the atmospheric environment: Convective storm, the low level moisture, the vertical wind shear (the change of wind speed and direction with altitude), CAPE and lifted index was taken into account in many studies as effective factors in the process of tornado genesis (6 ,25)

In the end, it can be said that despite the difficulty of predicting the location, time, intensity and horizontal path of a tornado, there would be indications that may lead to an increase in the expectation of occurrence. This may include the availability of moisture and heat with significant wind direction changes with altitude. The vital factors are the existence of high instability and a supercell thunderstorm. These factors were also confirmed by many research works (26- 28)

Conclusions:

The study of the tornado event in Kahlaa shows that the tornado is formed in very instable conditions. It is initiated within the effect of the low pressure system (Monsoon) with sufficient heat and humidity. The turning of wind with height played an important role in offering the spinning effect of the tornado. It was found that the tornado was of EF2 degree, which is called “considerable” on Enhanced Fujita Scale. Many factors affect the instability of the air in the region of the tornado. The high relative vorticity, jet stream, and surface vertical wind. This instability is confirmed by the instability indices such as CAPE index, K-index, and LI index with values of 2500 J/kg, 35.3 ^{o}C, and -7, respectively. These values suggest that the layer is mostly unstable and developed a deep convection and a numerous activity of thunderstorm.

Despite the difficulty in predicting the location, time, intensity and horizontal path of a tornado, there would be indications that may lead to an increase in the expectation of occurrence. This may include the availability of moisture and heat with significant wind direction changes with altitude. The vital factors are the existence of high instability and a supercell thunderstorm.

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Authors’ declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in Mustansiriyah University.

References:

1. Caldera HJ, Wirasinghe SC, Zanzotto L. Severity scale for tornadoes. Nat Hazards. 2018 Feb 1; 909(3): 1051–1086.
2. Wallace JM, Hobbs PV. Atmospheric Science: An Introductory Survey. Elsevier; 2006 Mar 24. 483p.
3. Gensini VA, Brooks HE. Spatial trends in United States tornado frequency. Clim Atmos Sci, 2018 Oct 17; 38:1-5.
4. Antonescu B, Bell A. Tornadoes in Romania. Mon Weather Rev, 2015; 143: 689-701.
5. Andrei S, Andrei MD, Hustiu M, Cheval S, Antonescu B. Tornadoes in Romania-from forecasting and warning to understanding public’s response and expectations. Atmosphere, 2020; 11: 2-26.

6. Ahrens CD, Henson R. Essentials of meteorology: An invitation to the atmosphere. 8th ed., Brooks Cole; 2017. 509p.
7. Ahrens CD, Henson R. Meteorology today: An introduction to weather, climate, and the environment. 11th ed., Cengage Learning; 2016. 640p.
8. Potter TD, Colman BR. Handbook of weather, climate, and water. USA: Wiley-Interscience; 2003. 973p.
9. Aguado E, Burt JE. Understanding weather and climate. 6th ed., Prentice Hall; 2012. 576p.
10. Lutgens FK, Tabuck EJ. The atmosphere: An introduction to meteorology. 12th ed., Pearson; 2013. 506p.
11. Demircan M, Arabac H, Soydam M, Eroglu H. Trends of tornado disasters in Turkey in context of climate change. Mesut Demircan1, Hüseyin Arabacı1, Murat Soydam1, Hikmet Eroğlu1.350-355.
12. Paul F. A Developing inventory of tornadoes in France. Atmos Res. 2001; 56: 269-280.
13. Dotzek N. Tornadoes in Germany. Atmos Res. 2001; 56: 233-251.
14 Matsangouras IT, Nastos PT, Pytharoulis I. Synoptic-mesoscale analysis and numerical modeling of a tornado event on 12 February 2010 in northern Greece. Adv Sci Res. 2011; 6: 187-194.
15. Jagger TH, Elsner JB, Widen HM. A statistical model for regional tornado climate studies. PLoS ONE. 2015; 10: 1-21.
16. Bai L, Meng Z, Sueki K, Chen G, Zhou R. Climatology of tropical cyclone tornadoes in China from 2006 to 2018, Sci China Earth Sci. 2020; 63: 37-51.
17. Ziarani MR, Bookhagen B, Schmidt T, Wickert J, de la Torre A, Hierro R. Using convective available potential energy (CAPE) and dew-point temperature to characterize rainfall-extreme events in the Southcentral Andes. Atmosphere. 2019; 10: 1-22.
18. Sfica L, Apostol L, Vasilica I. Instability indices as predictors of atmospheric lightning - Moldova region: Study case. 15th International Multidisciplinary Scientific Geo Conference SGEM 2015, Conference Proceedings- Hydrology and Water Resources. 2015; 387-394.
19. Barrett BS, Marin JC, Jacques-Coper M. A multiscale analysis of the tornadoes of 30–31 May 2019 in south-central Chile. Atmos Res. 2020 May 15;236:104811.
20. Peppler RA. A review of static stability indices and related thermodynamic parameters. Illinois State Water Survey; 1988.
21. Gottlieb RJ. Analysis of stability indices for severe thunderstorms in the Northeastern United States. USA: Cornell University; 2009.
22. Galway JG. The lifted index as a predictor of latent instability. Bull Amer Met Soc. 1956 Dec; 37(10):528-529.
23. Brazdil R, Chroma K, Pucik T, Cernoch Z, Dobrovolny P, Dolak L, Kotyza O, Reznickova L, Taszarek. The climatology of significant tornadoes in the Czech Republic. Atmosphere. 2020; 11:1-22.
24. Sioutas M, Chrisodoulou M, Chatzi E, Doe R. Significant tornado occurrences and their meteorological environments in Greece. Conference proceedings, 14th International Conference on Meteorology, Climatology and Atmospheric Physics, October 15-17, 2018, Alexandroupolis, Greece. 2018: 70-75.
25. Leitão P, Pinto P. Tornadoes in Portugal: An Overview. Atmosphere. 2020 Jul;11(7):679.
26. Bosart LF, Seimon A, LaPenta KD, Dickinson MJ. Supercell tornadogenesis over complex terrain: The Great Barrington, Massachusetts, tornado on 29 May 1995. Weather Forecast. 2006 Dec;21(6):897-922.
27. Schoen JM, Ashley WS. A climatology of fatal convective wind events by storm type. Weather Forecast. 2011 Feb;26(1):109-21.
28. Miglietta MM, Mazon J, Rotunno R. Numerical simulations of a tornadic supercell over the Mediterranean. Weather Forecast. 2017, 32; 1209-1226.

الخصائص الساينوبتيكية وأسباب وميكانيكيات إعصار الكحلاء في العراق في 14 نيسان 2016

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الخلاصة:

في هذه الدراسة، تم عمل تحليل للخصائص الساينوبتيكية والأسباب والميكانيكيات لحدث اعصار الكحلاء. هذا الاعصار حدث عند الساعة العاشرة والنصف بالتوقيت العالمي (الواحدة والنصف ظهراً بالتوقيت المحلي) في الرابع عشر من شهر نيسان 2016 في شمال مدينة الكحلاء في محافظة ميسان. قمنا بتحليل الخرائط الطقسية السطحية والعليا والظروف الجوية وادلة الضرر والصفات الديناميكية وعدم الاستقرارية لإعصار الكحلاء. التحليل أظهر وجود نظام منخفض ضغطي الذي هو امتداد لمنخفض المونسون بالإضافة الى زوبعة رعدية فائقة وتيار نفاث في الاعلى. ساهم كل من التقعر البارد وقيمة الدردورية النسبية العالية عند مستوى 500 هكتوباسكال والرياح الرطبة الدافئة الهابة من جهة الجنوب والهواء البارد الجاف من جهة الشمال في نشوء اعصار الكحلاء. حسب مقدار الضرر، يمكن تصنيف إعصار الكحلاء بانه من الدرجة EF2 (مُعتبر) طبقاً الى مقياس فوجيتا المحسن. تم حساب ثلاث ادلة لغرض تخمين عدم الاستقرارية للإعصار. كانت قيمة دليل الطاقة الجهدية الحملية المتوفرة (كيب) ودليل K ودليل الرفع هي (أكبر من 2500 جول/ كغم)، (35.5 درجة سيليزية)، و (-7)، على التوالي. جميع هذه الأدلة اكدت عدم الاستقرارية المطلوبة لتشكيل الزوبعة الرعدية الشديدة الضرورية لتشكيل الاعصار. وبالرغم من ان عملية التنبؤ بالإعصار هي عملية صعبة، الا ان هناك مؤشرات يمكن ان تقود الى توقع الحدوث. وهذه المؤشرات تتضمن توفر الرطوبة والحرارة وتغيرات ملموسة في اتجاهات الرياح مع الارتفاع. على اية حال، ان العوامل المهمة كانت وجود عدم استقرارية عالية وزوبعة رعدية فائقة.

الكلمات المفتاحية: الكحلاء، ساينوبتيكية، زوابع رعدية، تورنادو.