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A Cut-off low at 500 hPa Geopotential Height and Rainfall Events over Iraq: Case Studies

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Abstract

A cut-off low is a closed low with a low value of geopotential height at the upper atmospheric levels that has been fully detached (cut-off) from the westerly flow and move independently. A cut-off low causes extreme rainfall events in the mid-latitudes regions. The main aim of this paper is to investigate the cut-off low at 500 hPa over Iraq from a synoptic point of view and the behavior of geopotential height at 500 hPa. To examine the association of the cut-off low at 500 hPa with rainfall events across Iraq, two case studies of heavy rainfall events from different times were conducted. The results showed that the cut-off low at 500 hPa with a low value of geopotential height will strengthen the low-pressure system at the surface, leading to a case of atmospheric instability over Iraq and a significant amount of rain will fall if the moisture is available.

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1. Introduction

A cut-off low is closed low at the upper level that has been fully cut off from the main westerly stream and flows independently [1]. Palmen (1949) and Palmer (1951) were the first to investigate the existence of a cut-off low with different thermodynamic parameters based on its formation area [2]. As a result of the deepening of a high-level trough, the cut-off low extends to the south of the mid-latitude westerly mean flow [3]. The cut-off low system is a baroclinic system known for its severe weather, which frequently results in heavy rainfall events [4]. For example, the unexampled rain events that occurred over Iraq on November 18-20, 2013 were produced by a cut-off low system, and the amount of rain that fell in Baghdad of (89.6mm) was reported [5].

In other regions of the world, the cut-off low is linked to extreme rainfall events which last for many days [6]. For example, unprecedented rain events in the western parts of Iran on 1 April 2019 were caused by a cut-off low where the amount of rain exceeded (100mm) [7]. In July 1998, a cut-off low system created a record flood in northern China, causing significant infrastructure damage and social and economic hardship [8]. A cut-off lows are responsible for 20% of floods in South Africa [9]. The southwest of South Africa got more than 500mm of rain in September 1968, due to a cut-off low stationed over the region [10]. In the United States, the cut-off low-pressure systems account for 2% to 32% of all annual precipitation [11].

Al Nassar et al. (2016) investigated the weather patterns that were connected with heavy rainfall occurrences in Iraq, looking at fifteen cases of them, and they found out that five of them are linked to cut-off lows [12]. AL Shouhani (2020) studied the cut-off low systems over Iraq according to their life cycle, she pointed out

that several dynamic factors influence the life of cut-off low [13]. Mastrantonas et al. (2020) pointed out that the weather patterns at 500hpa (cut-off lows and troughs) are strongly linked to heavy rainfall events in the Mediterranean region, and the effect is influenced by other factors such as local orography [14]. Oakey and Redmond (2014) looked at the cut-off lows in the northeast Pacific Ocean from 1948 to 2011 and discovered that they occured more frequently during ENSO positive phases [15].
According to Azizi and Rezaei (2021), a high frequency of cut-off lows over Iran was linked to El Nino, whereas a lower frequency was linked to La Nina [16]. Kouroutzoglou et al. (2012) investigated the vertical structure of extratropical cyclones in the Mediterranean region in non-summer seasons to understand the role of a disturbance at the upper level for the development of surface cyclones, they found that about 57% of cyclones extend to the 500 hPa [17].

This paper aims to study the connection between the cut-off low at 500 hPa geopotential height and rain events over Iraq from a synoptic point of view.

2. Material and Methods

Iraq is located in Southwest Asia, between (29° 5' and 37° 22' N) latitude and (38° 45' and 48° 45' E) longitude. It has a total area of (437072 km²). As seen from Fig. 1, it is bordered by Turkey to the north, Iran to the east, Kuwait, and Saudi Arabia to the south, while the west part of Iraq is shared with Jordan and Syria [18]. Iraq is regarded as a basin with steep mountains along its Turkish and Iranian borders. The desert areas in the west and southwest of Iraq make up almost 40% of the country's overall land area [19].

Figure 1: The location of Iraq and the neighboring countries.

The climate of Iraq is arid to semiarid, with an annual rainfall of about 213 mm that falls during non-summer seasons; there is a gradient in rainfall with a substantial portion of this rain falling in the northern region. The rainfall occurs between October and April [20]. the relative humidity in Iraq is low and ranged from 20.6% to 28.6% [21].

To investigate the association of 500 hPa geopotential height with rainfall events over Iraq, two case studies of heavy rainfall events were conducted. The weather chart for this study was taken from the National Oceanic and Atmospheric Administration (NOAA) (https://psl.noaa.gov/data/composites/day/), which has a large collection of archived maps from around the world. The chosen chart covers the domain of latitudes 10°N to 50°N and longitudes 10°E to 60°E; the geopotential height at 500 hPa chart was selected to identify the weather patterns at the upper level, the sea level pressure charts, which illustrate weather systems at the surface, the relative humidity at the surface, surface vector winds, omega at 850 mb, and temperature at 500 mb. The satellite image was obtained from the National Aeronautics and Space Administration (NASA) (https://wvs.earthdata.nasa.gov/). The amount of rain for this study was obtained from the Iraqi Meteorological Organization and Seismology. The threshold of rainfall intensity is classified as shown in the Table 1 [22].

Table 1: Illustrates the rainfall intensity.

Rainfall intensity	Rate (mm/day)
Trace	0.1-0.9
Very light rain	1-2.49
Light rain	2.5-7.49
Moderate rainfall	7.5-35.49
Heavy rainfall	35.5-65.49
Severe rainfall	More than 65.5

3. Results and discussion

3.1 Synoptic Analysis (23-25 December 2012).

The period (23-25/12/2012) was characterized by unsettled weather over Iraq where heavy rainfall events occurred.

On 23 December 2012, the 500 mb geopotential height map illustrated a cut-off low over the southern Mediterranean (30-35N) latitudes, while there was a ridge extending from lower latitudes towards the Arabian Peninsula and Iraq as shown in Fig.2(a). At the surface, the sea level pressure map shows a low-pressure system over the Mediterranean region known as Mediterranean low pressure, while a high-pressure system over central Asia, Iran, Turkey, and Iraq as illustrated in Fig.2(b). The wind was easterly with a speed of about (3-6m/s) over Iraq (Fig.2(c)), the relative humidity varied between (45% to 65%) in the middle and southern parts of Iraq while in the northern parts of Iraq the relative humidity was more than 70% (Fig.2(d)), a cold advection was associated with cut-off low in the Mediterranean region (Fig.2(f)). The weather in Iraq was clear to partly cloudy.

On the next day, the cut-off low moved eastward and affected the northern red sea as illustrated in Fig.3 (a), this led to intensifying low pressure from the red sea which represents the extension of Sudanese low pressure and merged with Mediterranean low pressure to form one system and covered the Arabian peninsula Jordan, and southern parts of Iraq, while the middle and northern parts of Iraq were under the influence of the high-pressure as depicted in Fig.3(b). The surface wind map indicates south easterly wind with cyclonic flow covering a wide area, Fig.3(c), the relative humidity fluctuated between (40% to 80%) over Iraq, Fig.3(d), the negative value of omega at 850 hPa can be observed in the western parts of Iraq, Fig.3(e). The weather in Iraq was partly cloudy to cloudy with little to moderate rain in the southern region of Iraq, where the amount of rain that fell in Nasiriya was about (10.1 mm) and Amara station reported (10.6 mm).

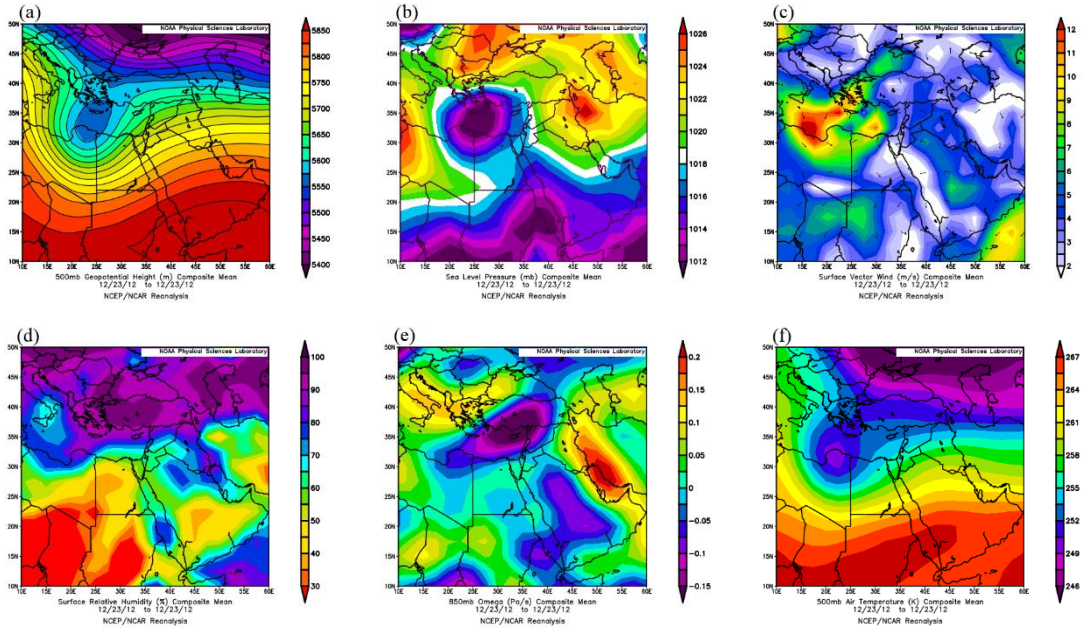

Figure 2: The weather chart for 23 December 2012, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega (pa/s), and (f) temperature (k) at 500 mb.

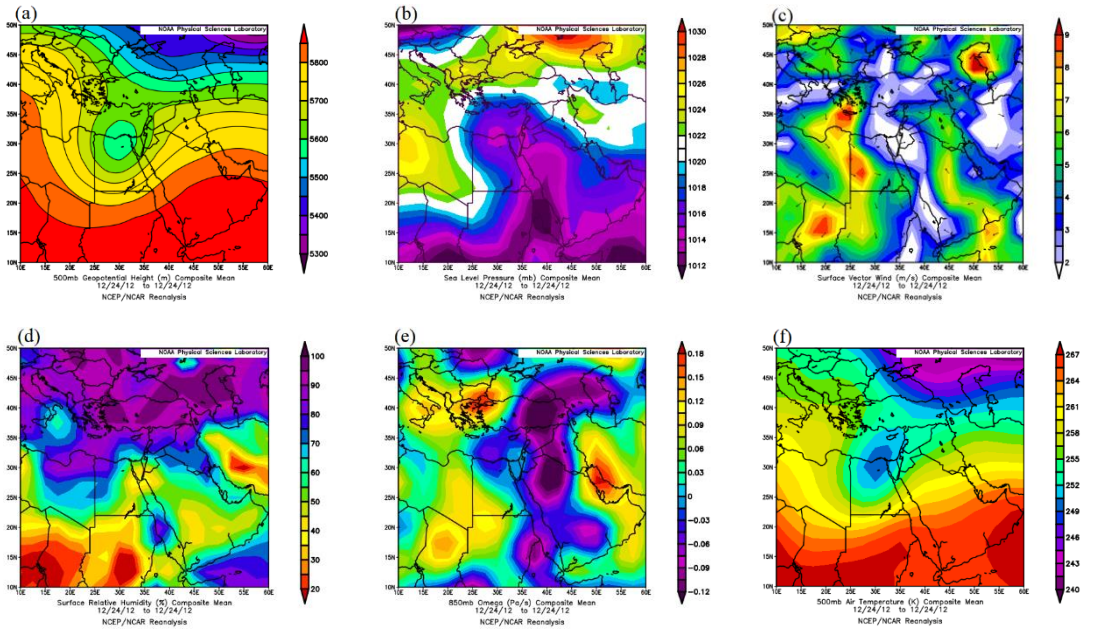

Figure 3: The weather chart for 24 December 2012, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega (pa/s), and (f) temperature (k) at 500 mb.

On 25 December 2012, the cut-off low moved southeastward as shown in Fig.4(a), the low pressure deepened as shown in Fig.4(b), the wind was southeasterly in the southern parts of Iraq and turns northwesterly in the western parts of Iraq, the relative humidity reached more than 85% across Iraq, Fig.4(d), a negative value of omega at 850 hPa about (-0.06 pa/s) indicated upward motion in the middle and southern parts of Iraq, Fig.4(e). Moderate to heavy amounts of rain fell in the middle and southern parts of Iraq, while scanty rain fell in the northern parts. Baghdad station

reported heavy rainfall (67.5 mm), in Nasiriya station the amount of rain was (29 mm), Basra station (23.8), and Najaf station (18.2), while the amount of rain that fell in the Kirkuk station was about (1.9 mm). Fig.5 illustrates the satellite images that show cloud over Iraq during the period (23-25 December 2012).

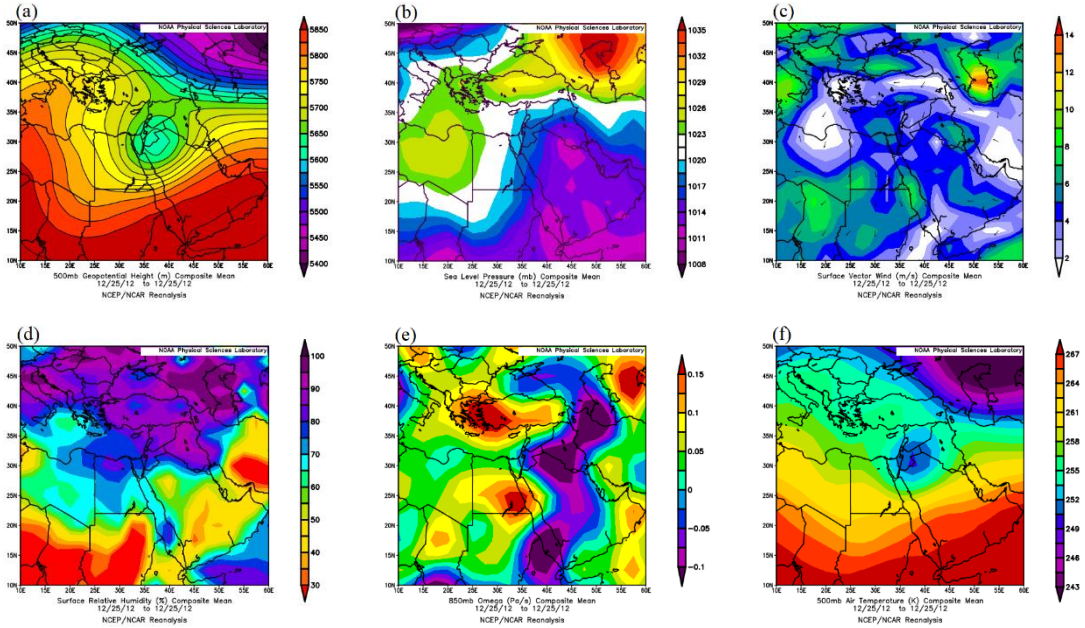

Figure 4: The weather chart for 25 December 2012, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega (pa/s), and (f) temperature (k) at 500 mb.

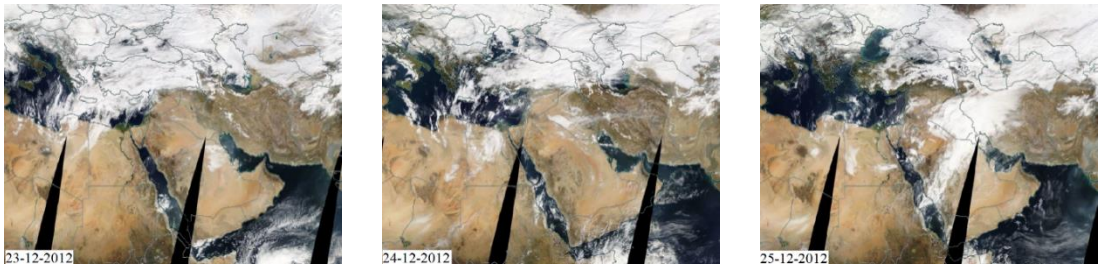

Figure 5: The satellite images illustrate the cloud over Iraq during the period (23-25 December 2012).

3.2 Synoptic Analysis (3-5 November 2018)

The period (3-5/11/2018) was marked by atmospheric instability over Iraq, with a cut-off affecting the weather in Iraq and caused unstable weather. The value of geopotential height at 500 hpa has dropped during this period. This case represents a case of cyclogenesis in the midlatitude where the upper pattern influences the low pressure at the surface.

On 3 November 2018, the 500 hPa geopotential height map, Fig.6(a), depicted a closed low with a low value of geopotential height as well known as the cut-off low, this cut-off low propagated from Europe and was situated over Turkey, Syria, Jordan, Iraq, and northern parts of Saudi Arabia, with the lowest value of geopotential height in its core about (5710 m) over Turkey and Syria, while there was a high value of geopotential height over the western Mediterranean and Iran. On the surface, there was a low-pressure system over Sudan and Saudi Arabia, and there was a high-

pressure system over central Asia while over Iraq there was a relatively high-pressure, Fig.6(b). The wind over Iraq was south-easterly, Fig.6(c), and the relative humidity fluctuated between (25%-40%) while in the southwest of Iraq was about 60%, Fig.6(d). The weather in Iraq was partly cloudy to cloudy as shown in Fig.7, with little rain across some parts of Iraq.

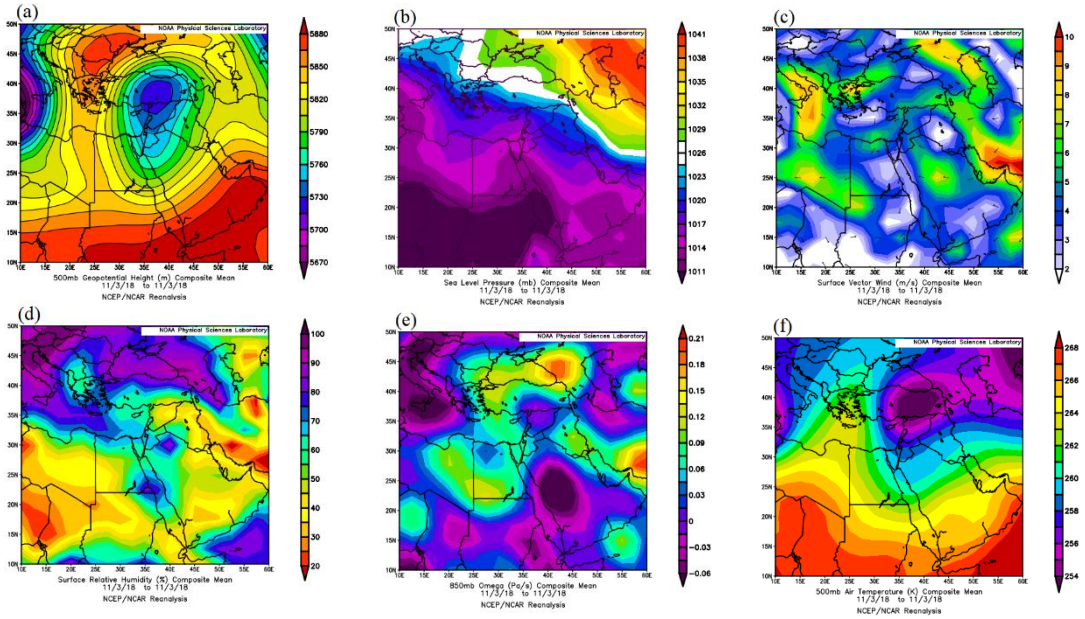

Figure 6: The weather chart for 3 November 2018, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega (pa/s), and (f) temperature (k) at 500 mb.

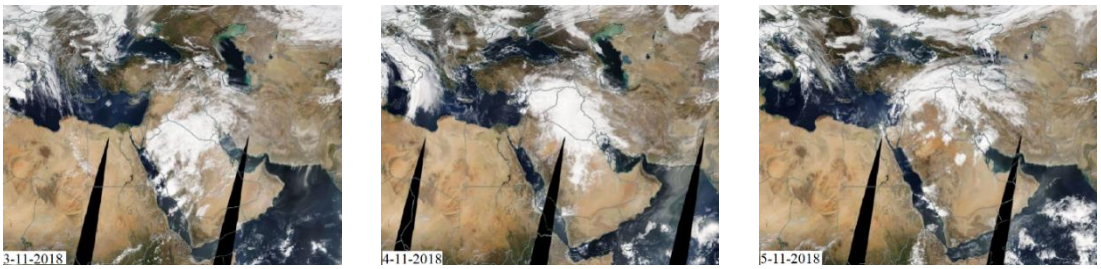

Figure 7: The satellite images illustrate the cloud over Iraq during the period (3-5 November 2018).

On the next day, the cut-off low deepened and penetrated southerly to about 20N, Fig.8(a), the value of geopotential height decreased to reach about (5650 m) in its core over most parts of Iraq, meanwhile, there was a high value of geopotential height at the same latitude over Iran of about (5800 m). The decrease in the value of geopotential height when compared to other location at the same latitude was a sign of unstable weather over the area that has a low value of geopotential height. The penetration of cut-off low to lower latitude transformed the Sudanese low-pressure to active low pressure that moved northward and affected the Arabian peninsula, Jordan, Syria, and Iraq, Fig.8(b), the southeasterly wind transported moist and warm air towards Iraq, Fig.8(c),which led to an increase in the relative humidity which exceeded 80% in most parts of Iraq except the southeasterly parts of Iraq, the relative humidity was about 40% Fig.8(d), while cut-off low advect cold air at the upper, Fig.8(f), the presence of humid warm air at the surface and cold air at the upper led to destabilizing the atmosphere, where the omega value indicates high ascending motion,

as shown in Fig.8(e). The weather in Iraq was cloudy as illustrated in Fig.7 with rainfall across most parts of Iraq, the amount of rain that fell at Tikrit station was (50.6 mm), while the amount of rain over Baghdad station was (38.4 mm).

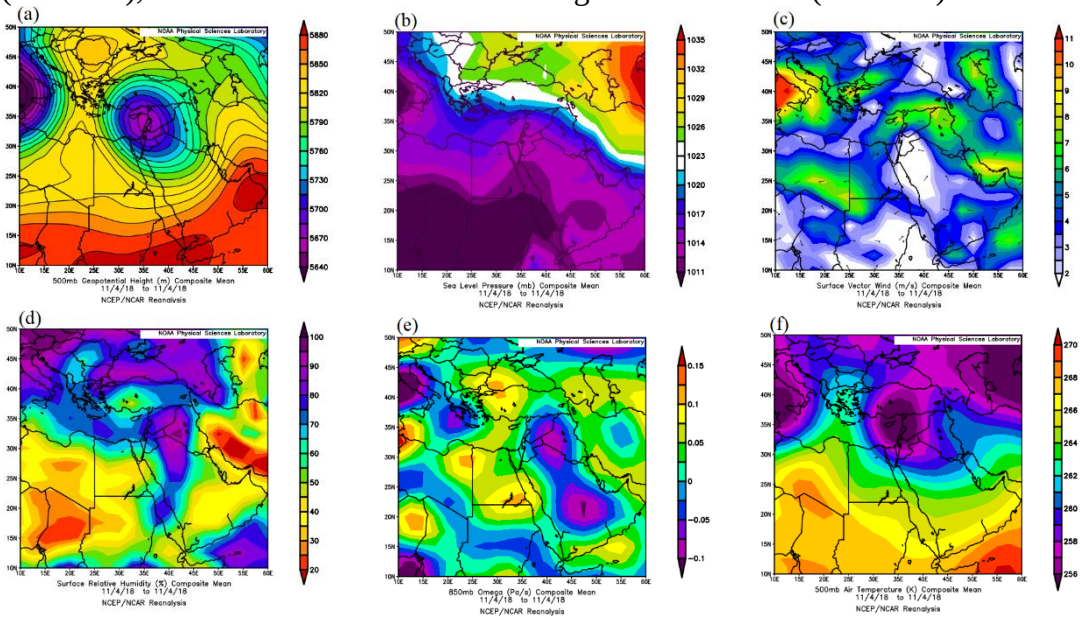

Figure 8: The weather chart for 4 November 2018, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega (pa/s), and (f) temperature (K) at 500 mb.

On 5 November 2018, the cut-off low moved eastward, Fig.9(a), the southeasterly wind, Fig.9(c), continued to push humidity, where it fluctuated between 60% to 90%, Fig.9(d), and the weather was partly cloudy to cloudy with rainfall that intensity fluctuated across Iraq, the amount of rain that fell on Nasiriya station was (35.7 mm) and Kirkuk station was (23.8 mm).

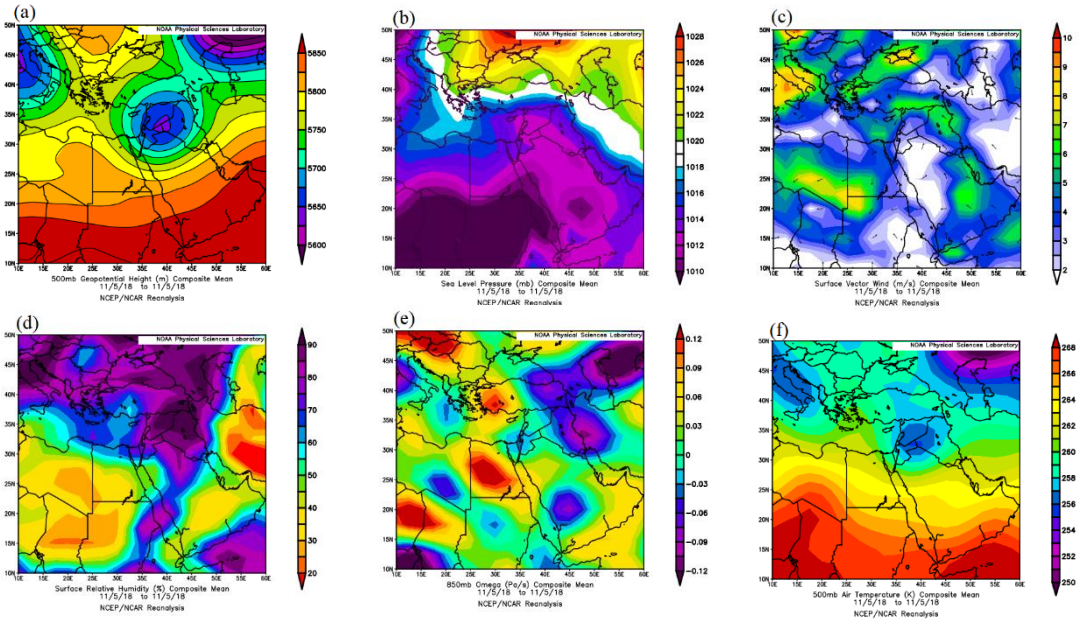

Figure 9: The weather chart for 5 November 2018, (a) 500 mb geopotential height (m), (b) sea level pressure (mb), (c) surface wind (m/s), (d) surface relative humidity (%), (e) 850 mb omega(pa/s), and (f) temperature(k) at 500 mb.

4. Conclusions

Iraq's weather like the mid-latitude countries is strongly connected to the weather pattern at the upper level. A cut-off low is a major weather pattern that causes active weather over Iraq and may lead to extreme rainfall amount. The results revealed that a cut-off low is associated with a decrease in the value of geopotential height, when propagates from Europe towards the eastern Mediterranean, it intensifies the low-pressure system at the surface and causes instability, which leads to significant rainfall events if humidity is present.

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Conflict of interest

Authors declare that they have no conflict of interest.

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منخفض القطع عند الارتفاع الجهدي في ال 500 هكتوباسكال وهطول الامطار على العراق: دراسة حالات

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الخلاصة

منخفض القطع هو منخفض مغلق مع قيمة منخفضة للارتفاع الجهدي عند مستوى الغلاف الجوي العلوي الذي تم فصله عن التدفق الغربي ويتحرك بشكل مستقل. منخفض القطع يسبب هطول امطار غزيرة في مناطق العروض الوسطى. الهدف الرئيسي من

هذا البحث هو التحقق من منخفض القطع في مستوى 500 هكتوباسكال فوق العراق من وجهة نظر ساينوبتيكية وسلوك الارتفاع الجهدي عند مستوى500 هكتوباسكال. للتحقق من ارتباط منخفض القطع عند 500 هيكتوباسكال مع أحداث هطول الأمطار فوق العراق تم إجراء دراستي حالة لأحداث هطول الأمطار الغزيرة في جميع أنحاء العراق. أظهرت النتائج أن منخفض القطع عند 500 هكتو باسكال مع قيمة منخفضة للارتفاع الجهدي يعزز الضغط المنخفض على السطح، مما يؤدي إلى حالة من عدم الاستقرار فوق العراق وهطول أمطار غزيرة في حالة توفر الرطوبة.