Characteristics of Thermal Wind over Iraq

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Abstract- Two fundamental wind systems in dynamical meteorology are the gradient wind that extends the geostrophic wind to curved trajectories and the thermal wind that describes the vertical change in the geostrophic wind in a baroclinic atmosphere. The aim of this work is to investigate the characteristics of thermal wind over Iraq and surrounding regions. NCEP long term monthly data of potential temperature at 850 hPa pressure level and meridinal wind component at 925 hPa and 700 hPa pressure levels for the northern hemisphere were used for calculating the LHS and RHS of the thermal wind equation. Quantities were averaged between the longitude limits of 30 to 50 ^{o}E within which Iraq is located. Analysis of the thermal wind equation suggests that thermal wind balance exists during all the time of the year for regions north of 45 ^{o}N latitude. In the mid-latitude region (between 20 and 45 ^{o}N) the balance holds only during winter time. A case study of heavy rain storm over southern Iraq was used to investigate the situation of thermal wind association with rainstorm. The results indicated a thermal wind situation could lead to a rapid convection that can help in forming a deep convective cloud. In such case, a heavy rain is likely to be expected at the ground surface. The results also showed that a strong south easterly wind existed on the southern part of Iraq, where the rain storm occurred. This wind pattern was caused by the occurrence of a deep low pressure system over northern part of the Kingdom of Saudi Arabia, just west of the core of rain region. As a result, more moist air was transported to the region which helped in producing the heavy rain event.

Index Terms- Thermal wind, Rainfall, Iraq

I. Introduction

Thermal wind is defined as the vertical shear of the geostrophic wind over a layer and it is directly proportional to the horizontal temperature (or thickness) gradient through the layer. The thermal wind can be used to diagnose the mean horizontal temperature advection within a layer of the atmosphere and therefore it is important for forecasting purposes [1] [2]. Many researchers studied the thermal wind, White and Staniforth (2008) [3] showed that the generalization of the thermal wind equation for the balanced zonal flow governed by the hydrostatic primitive equations. Truitt (2008) [4] used the thermal wind relationship to improved offshore and coastal forecasts of extratropical cyclone surface winds. Linden (2009) [5] studied nocturnal cool island and a thermal wind system. His results indicated that some important difference in processes determining the urban climate. Chkhetiani et al., (2013) [6] studied the generation of thermal wind over a nonuniformly heated wavy surface. They found that the horizontally periodic heating of such a surface can lead to a thermal wind effect. The aim of this research is to study the characteristics of the thermal wind over Iraq and surrounded regions by analyzing terms of the thermal wind equation. Real case study is also considered for investigating the synoptic situation associated with thermal wind.

II. Materials and Method

The thermal wind equation in pressure coordinates is given by [7]

$$\frac{\partial V}{\partial p} = \frac{R}{pf}\left(\frac{p}{p_o}\right)^{R/c_p} (\nabla\theta)_p$$

where V is the wind (in m/s), p is the pressure (in hPa), R is the gas constant of air (287.06 J/kg/K), f is the Coriolis parameter (in 1/s), p_o is the reference pressure, c_p is the specific heat capacity of air at a constant pressure ((1004 J/kg/K), and $\nabla\theta$ is the potential temperature (in C) of the parcel at constant pressure.

The zonal and meridional components of the thermal wind are given by

$$\frac{\partial u}{\partial p} = \frac{R}{pf}\left(\frac{p}{p_o}\right)^{R/c_p} \left(\frac{\partial \theta}{\partial y}\right)_p$$

$$\frac{\partial v}{\partial p} = \frac{R}{pf}\left(\frac{p}{p_o}\right)^{R/c_p} \left(\frac{\partial \theta}{\partial x}\right)_p$$

In order to illustrate the behavior of left hand right hand sides of the thermal wind equation requires data of the potential temperature at that level and data for wind filed components at higher and lower pressure levels of the given level. For that purpose, data from NCEP were used. For case study the data and weather maps used in this research were obtained from the National Oceanographic and Atmospheric Administration (NOAA) [8], the University of Wyoming, Laramie, Wyoming, USA [9], and the San Francisco State University, San Francisco, California, USA [10].

III. RESULTS AND DISCUSSION

NCEP long term monthly data of potential temperature at 850 hPa pressure level and meridinal wind component at 925 hPa and 700 hPa pressure levels for the northern hemisphere were used for calculating the LHS and RHS of the thermal wind equation. Quantities were averaged between the longitude limits of 30 to 50 ^{o}E within which Iraq is located. Figures 1 to 5 show the results of these calculations for March, June, September, and December months, which represent spring, summer, autumn, and winter seasons respectively. It is seen that in the equatorial region the potential temperature starts to increase sharply with increasing latitude during the months of June due to the fact that sun becomes perpendicular on the tropic of Cancer (23.5 ^{o}N) on June 23 (the summer solstice) and this increase becomes slower during the month of September. During December, the potential temperature decreases with latitude in the northern hemisphere because it receives less solar insolation during winter. At regions higher than about 20 ^{o}N zone, potential temperature decreases with increasing latitude during all the time of the year. Because of this behavior, the potential temperature gradient with respect to latitude is positive in the equatorial region and negative in regions from 20 ^{o}N to North Pole. The behavior of the vertical wind shear of the thermal wind equation is almost similar to that of the potential temperature gradient. The potential temperature side of the thermal wind equation tends to be relatively high in the equatorial region. This reflects the effect of Coriolis force, which is very small at that region. The results of the left and right hand sides residual of thermal wind equation suggests that thermal wind balance exists during all the time of the year for regions north of 45 ^{o}N latitude. In the mid-latitude region (between 20 and 45 ^{o}N) the balance holds only during wintertime. To investigate the synoptic situation of rainstorm over Iraq caused by thermal wind a case study of heavy rain events occurred over southern Iraq on 19 November 2013 was chosen for this purpose. Figure 6 shows a map of accumulated daily rain. It is obvious that the core of the storm occurred in south eastern part of the country with a rainfall rate of more than 50 mm/hr. Figure 7 shows the upper air sounding map for 19 November 2013 at 00Z for the nearby Iranian meteorological station (marked with red circle on Fig 6). The map indicates that there was a well mixed atmosphere in the levels from 950 to 650 hPa. The dew point curve (the left black curve) coincides with the temperature curve at 850 hPa level indicating the air parcel became saturated and cloud started to form. The confidence of the two curves continued up to the level just above the 650 hPa. This means that a deep convective cloud was formed on that producing the heavy rain at the earth surface. The map also indicates that there were a shift in the wind direction (as noted by the wind barbs on the right side of the map) at 850 hPa level. This suggest that a thermal wind balance existed on that level. Figure 8 illustrates the 300 hPa jet stream for the Northern Hemisphere. It seen that jet passes over the storm region, indicated by the red square. Thermal wind is always associated with the polar jet stream. Figure 9 shows the wind arrows composed on geopotential map for 925 and 850 hPa on 19 November 2013 at 00Z and 12Z. It is seen that a strong south easterly wind on the southern part of Iraq where the rain storm occurred. The maps indicate that the storm was caused by the deep low pressure system over northern part of the Kingdom of Saudi Arabia, just west of the core of rain region.

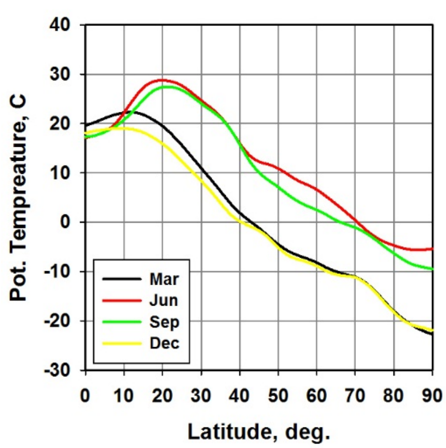

Figure 1: Potential temperature versus latitude for northern hemisphere on 19 November 2013.

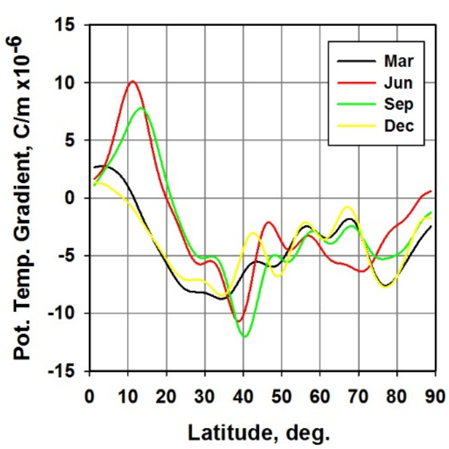

Figure 2: Potential temperature gradient versus latitude for northern hemisphere on 19 November 2013.

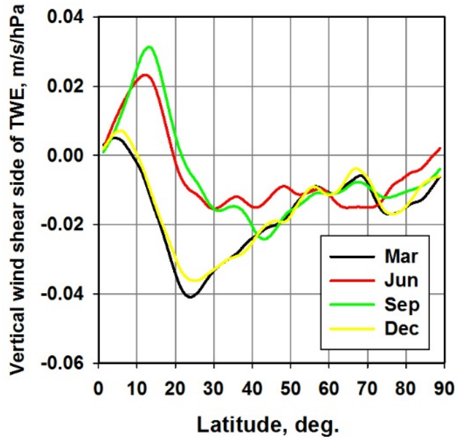

Figure 3: Vertical wind shear side of TWE for northern hemisphere on 19 November 2013.

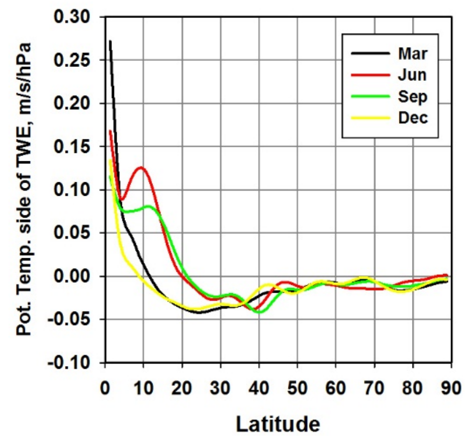

Figure 4: Potential temperature gradient side of TWE versus latitude for northern hemisphere on 19 November 2013.

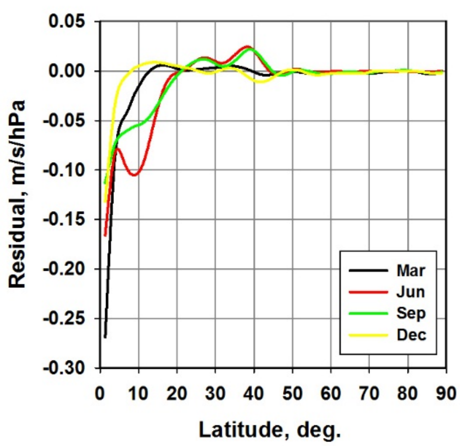

Figure 5: Potential temperature gradient side of TWE versus latitude for northern hemisphere on 19 November 2013.

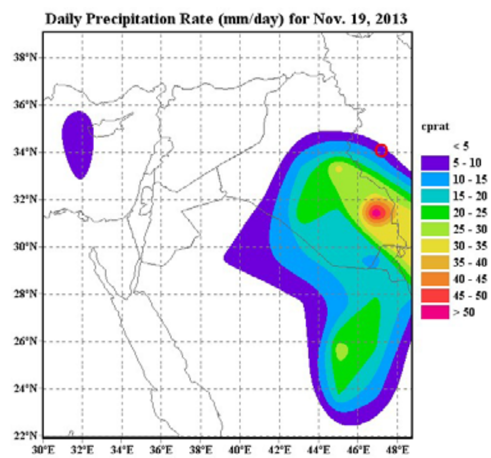

Figure 6: Daily precipitaion for 19 Novemebr 2013 over Iraq.

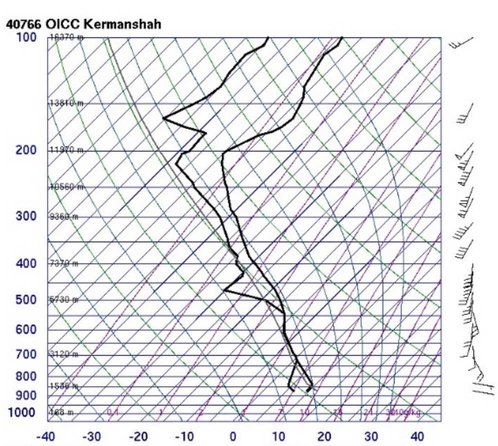

Figure 7: Upper air sounding for Kermanshah city at

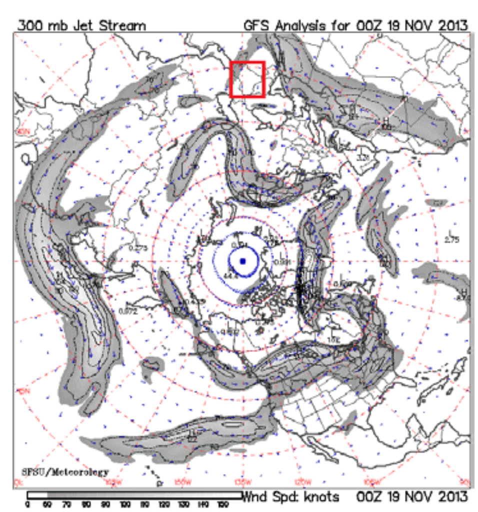

Figure 8: 300 hPa jet stream over the northern

00Z 19 November 2013. hemisphere.

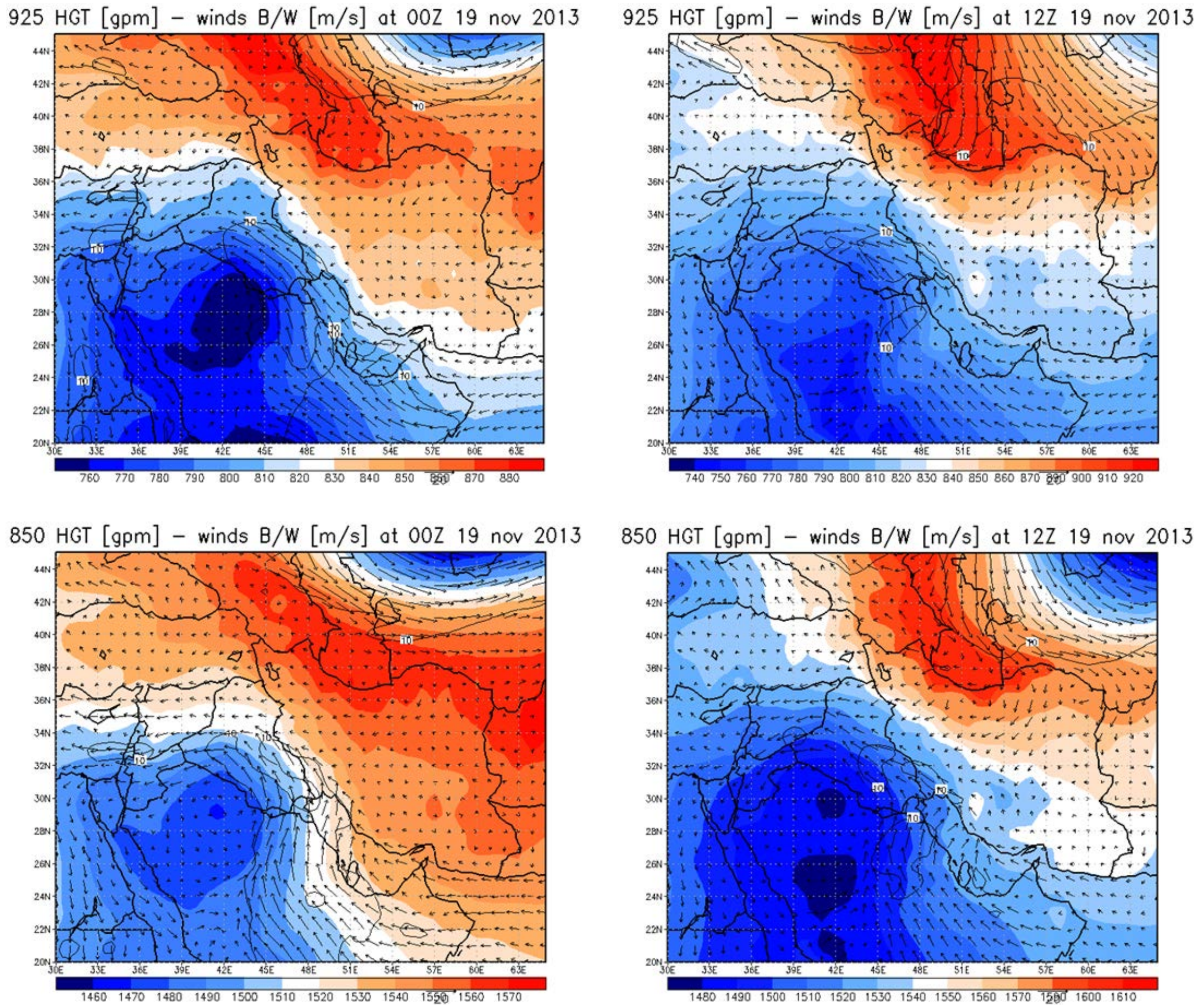

Figure 9: Wind arrows composed on geopotential height maps at 00Z and 12Z 19 Nov 2013 for pressure levels of 925 hPa (upper plots) and 850 hPa (lower plots).

IV. Conclusion

This research is an attempt to study the characteristics of thermal wind over Iraq and surrounding regions. Calculations of terms of thermal wind equation based on monthly data indicated for regions north of 45 ^{o}N latitude thermal wind balance exists during all the time of the year but the mid-latitude region the balance holds only during wintertime. Local case study of heavy rain event associated with the existence of thermal wind at 850 hPa level showed that thermal wind led to the formation of deep convective cloud which produced heavy rain at the ground surface.

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[10] http://squall.sfsu.edu/crws/jetstream.html

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