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STUDY OF WEATHER PREDICTION USING BAROTROPIC VORTICITY MODEL

Hussain Abodi Nemah*, Ahmed S. Hassan and Jasem H. Kahdum

Department of Atmospheric Science, Collage of Science, Mustansiriyah University, Iraq.

Abstract

Numerical weather prediction (NWP) plays significant role on daily human life, agriculture, economy and disaster warning. The main aim of this study is to predict (24, 48, 72 and 96) hours ahead of forecast mid-latitude (500) hpa geopotential height by solution of barotropic vorticity equation. Inputted wind velocity was obtained from (ECMWF) for (500) hpa pressure level on one selected day for both winter and summer. The result shows that the model have good accuracy in predict low and high systems but there is a little shifting in determining systems location, And the model present same geopotential height gradient with pattern but it has a shifting from actual pattern. Also The model sensitivity test are carried out, which shows that efficient prediction is below horizontal wind value of (60 m/h), while vice versa for high wind lead to loss of predictability.

Key words : Weather forecasting, Barotropic model, Geopotential height, Middle east.

Introduction

Accuracy of forecasting model depend on many factors such as the knowledge of atmospheric weather condition from earlier time and efficiency of used mathematical way (Randall, 2004). The aim of study dynamical forecasting for weather prediction is to understanding future status of atmospheric circulation by the use of initial meteorological variable using mathematical order of magnitude on dynamical equations (Holton, 2004), another method of prediction use numerical modeling by ensemble prediction and find regions have potential predictability (Hassan, 2004). The study variables are horizontal wind component in two directions to run the model. The corresponding of dynamical equation with each others can produce good prediction for specific time period. Prediction process is not easy and require many factors to be in hand such as wide data base, huge storage capacity and high processor computer system and making the computational operations in exact required time. Barotropic vorticity model made high change in development of atmospheric predictions accuracy and led to possible forecasting for more than two days period (Kalnay, 2003). The source of data came from (ECMWF) for wind field over middle east region, and has converted to two arrays of zonal wind component and meridional wind component, where these arrays are combined and putted as input data to run the barotropic model to make four days forecasting. Study deal with (500) hpa level, and the period extend for winter and summer of 2017 year to show the behavior of brotropic model forecasting result in both winter and summer over middle east.

Historical review

Many studies and works have been made about numerical forecasting from a long time and then developed to become more accurate for produce good forecasting processes. for example the first attempted of prediction was done by Lewis Rechardson in 1922 on the first warld war which done by hand computation to make 24 hours forecasting but the results was poor because of high order of magnitudes leaded to unacceptable results (Anderson, 2000). after that Jacobs on 1968 made a prediction of geopotential height depending on non-divergent stream function (Jacobs, 1968), and then Buell on 1972 research for the relation between wind velocity and geopotential height by the use of differential equations (Buell, 1972). also Maurice 1976 study geopotential heights behavior on 500 hpa level to compare between winter and summer seasons (Maurice, 1976). Palmer on 1996 study the seasonal ensembles depending on obtaining nine

***Author for correspondence :** E-mail : Husain_abodi.atmsc @uomustansiriyah.edu.iq

ensembles for sea surface temperature variable form European center for medium range weather forecasting for the periods from 1986 to 1990 and compared between forecasted regions and also which one gives the best result (John, 1993).

Barotropic vorticity model

Barotropic model has a large interest in past decades because it used on making new successful numerical weather prediction, and this model is depend on equations for single pressure level. The barotropic atmosphere is defined us the atmosphere whose density is a function of pressure only, and the temperature is homogenous (Haltiner, 1980).

The study model depend on boison equation to make a finite difference calculations and it given by the following equation (1). (Krishnamurti, 1996).

$$\zeta = \nabla^2 \Psi \tag{1}$$

Where : (ζ) is the relative velocity.

(Ψ) is the stream function field.

This equation must be resolve to make forecasting of initial stream function by the use of finite difference method, and gives wind component to calculate relative vorticity and produce the following equation (2). (Krishnamurti, 1996)

$$\zeta_{m,n} = \frac{v(m+1,n) - v(m-1,n)}{2\Delta x} - \frac{u(m+1,n) - u(m-1,n)}{2\Delta x}$$

Finite difference term of horizontal laplacian corresponding with the difference between function value on middle point and mean value of the four nearing point. so if there is (M-1) × (N-1) of internal points, thus the result will produce (M-1) × (N-1) of equations which lead to determine $\psi_{m,n}$ for any array $\zeta_{m,n}$.

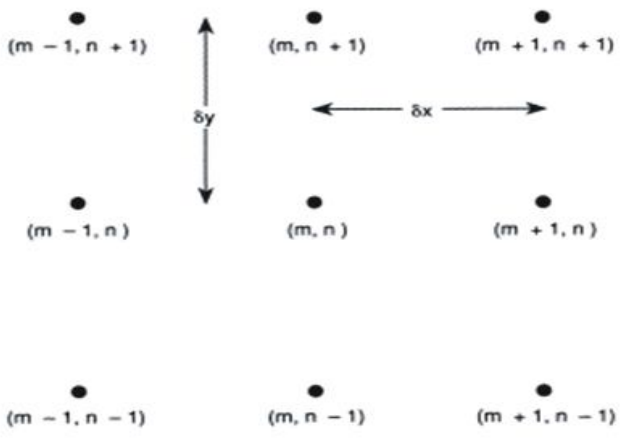

Diagram 1: Finite difference method.

Material & Methods

As shown before the study deal with wind component in both zonal and meridional directions at (500) hpa pressure level because of its importance in forecasting process (Zheng, 2007), and the selected time was in both winter and summer seasons at two days over middle east region. Barotropic model runs to make its calculation for produce stream function as a part of program procedure and gives the relative vorticity from horizontal wind field, where it consist of three sub programs, the first one is called 'infield program ' which deal with input an actual values of wind field array, This array consist of (41) column and (48) raw of zonal and meridional wind components which obtained from 'ECMWF' and then dealing with given data by using of panoply program that provide a matrix of data covering selected area of study, after that manual re arranging of data has been done to make it compatible with infield program to be run and make calculations. The second step is done by operate the program end extracting output data of initial stream function to be used as input data of new program which called 'baro program' and then re run the program to calculate accumulative series needed for completing calculations and produce new output array to be used on third step. The third and final step use program called 'barout program' by modifying its script for needed forecasting time and make weather forecasting. After all that the result is given as array of three files of zonal, meridional and geopotential height values files and then opening it with new program called (surfer program) to get final results.

Results and Discussion

Analysis of forecasted geopotential height 500 hpa pattern

When putting the result in (surfer) program to plot maps, the results compared with actual plotted data until four days (after '96' hours at 5/1/2017 and 5/7/2017 in winter and summer respectively). The study result show that the efficiency of barotropic forecasting model on geopotential height can predict low and high pressure system perfectly but there is a shifting in the forecasted position, when compare fig. 1 which represent the output result of model after four days in winter season with fig. 2 that represent actual data at same day it found that the model show good prediction on determining high system where it gives maps showing the location of high system centered nearly to the north of middle east, and it found that the actual high pressure system is located to the north east of middle east. and when focus on low system it found that there is also a shifting in system location, but

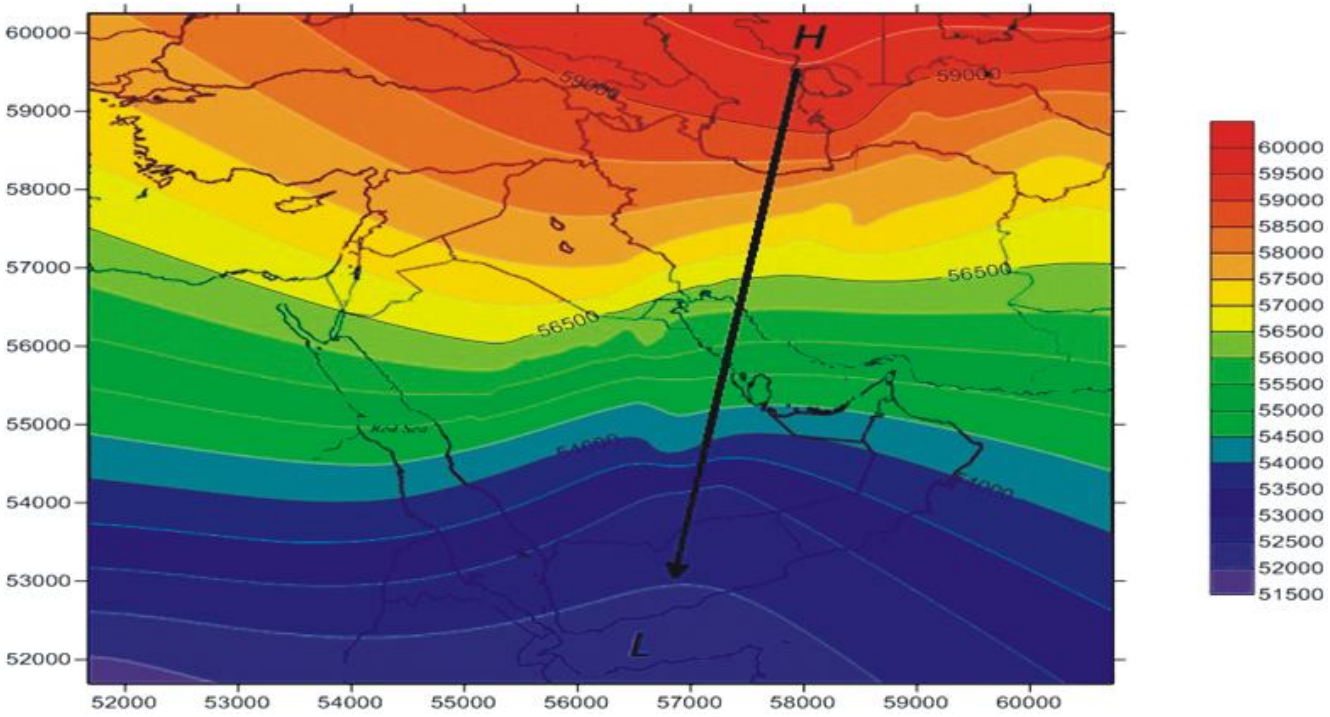

Fig. 1: Forecasted geopotential height contour on winter.

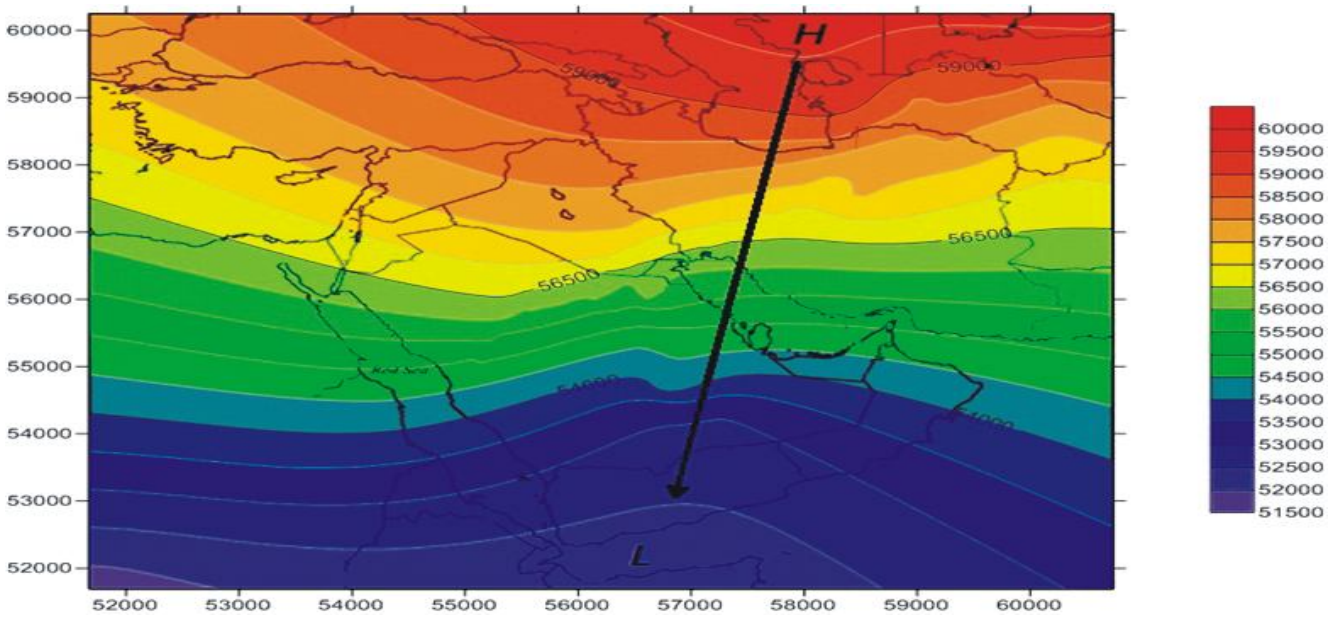

Fig. 2: Actual geopotential height contour on winter.

in spite of that it clearly shown that the center of high and low system is located on nearly same latitude. also when observing Fig. 1, 2 it clearly shows that the forecasted gradient line is little different from actual, where it directed to the south with small tilting in forecasting output while it directed to the south west in actual. The result also shows high perturbation of lines as compared with actual and this clearly shown in winter and summer, and the actual maps show more straight lines as compared with forecasting outputs. and also the geostrophic contour lines is parallel to the latitude lines.

When compare winter forecasting pattern with summer, the forecasted summer pattern on (5/7/2017) shows little difference with winter, because when compare the location of high and low system it clearly shown a good accuracy in forecasting location of systems and the gradient line is directed toward south west in both forecasted and actual pattern, see fig. 3, 4 which represent forecasted and actual geopotential height contour lines in summer season.

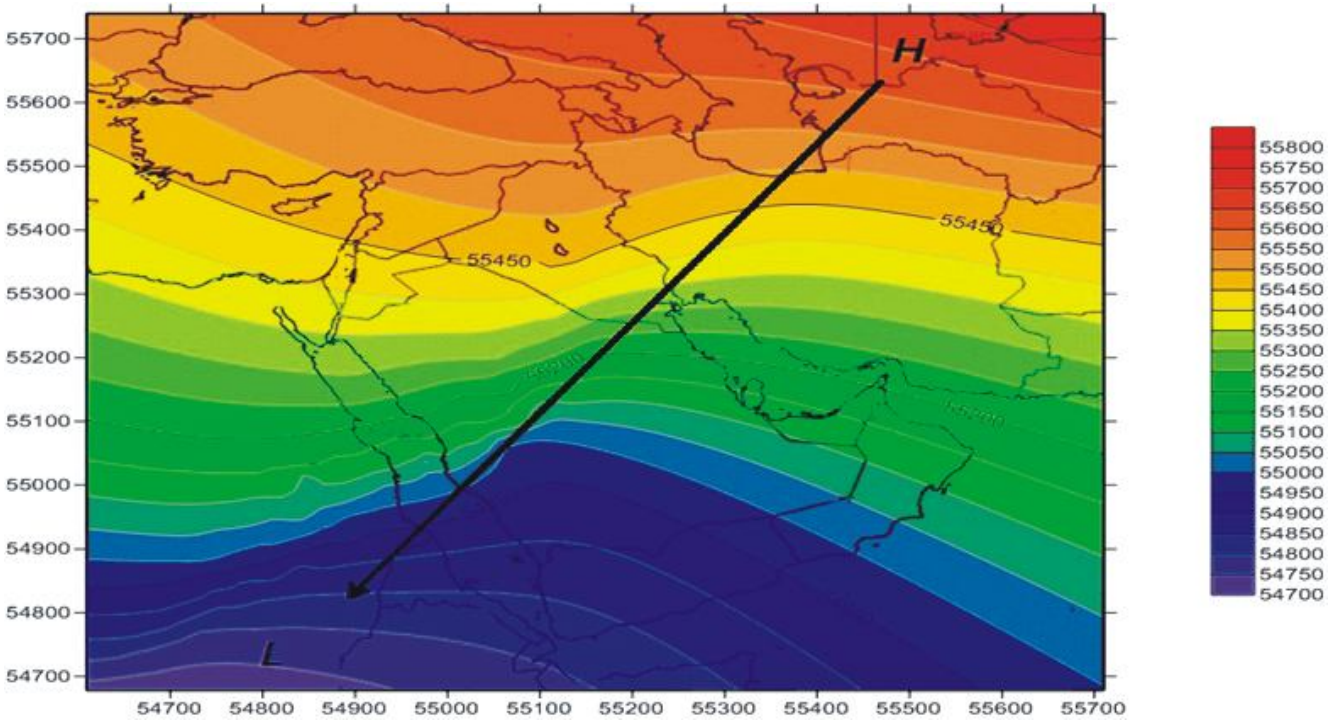

Fig. 3: Forecasted geopotential height contour on summer.

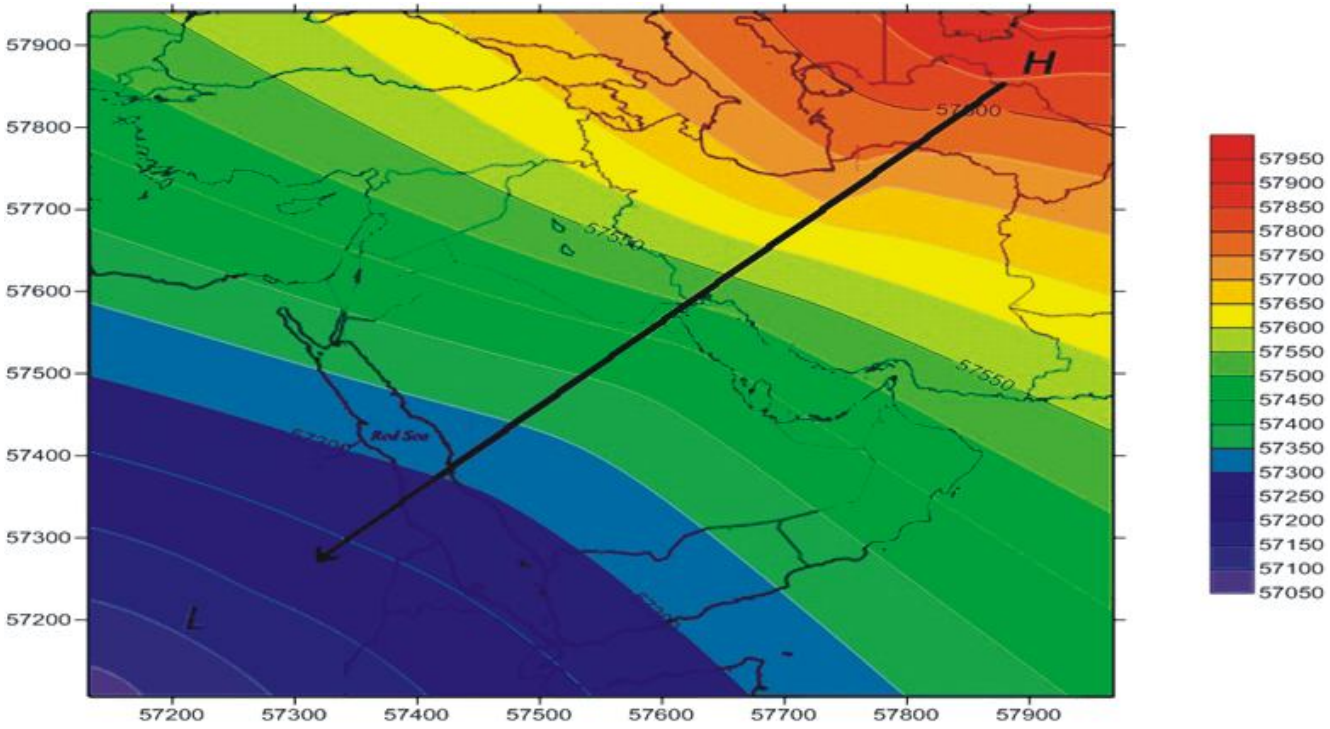

Fig. 4: Actual geopotential height contour on summer.

The following fig. 5, 6 shows a comparison between actuals and forecasting along four days of prediction separately and it shows clearly that all days have a shifting in low and high system location, and all result shows fluctuated lines in forecasted results. also forecasted geopotential height contour lines always nearly parallel to latitude lines, and pressure systems is more deeper than actual maps.

As mentioned previously the barotropic forecasting model output is the value of wind speed and direction and also the value of geopotential height, So when combining maps of geopotential heights with wind field maps they can show good corresponding in output data, fig. (7a,b) shows wind direction toward gradient direction

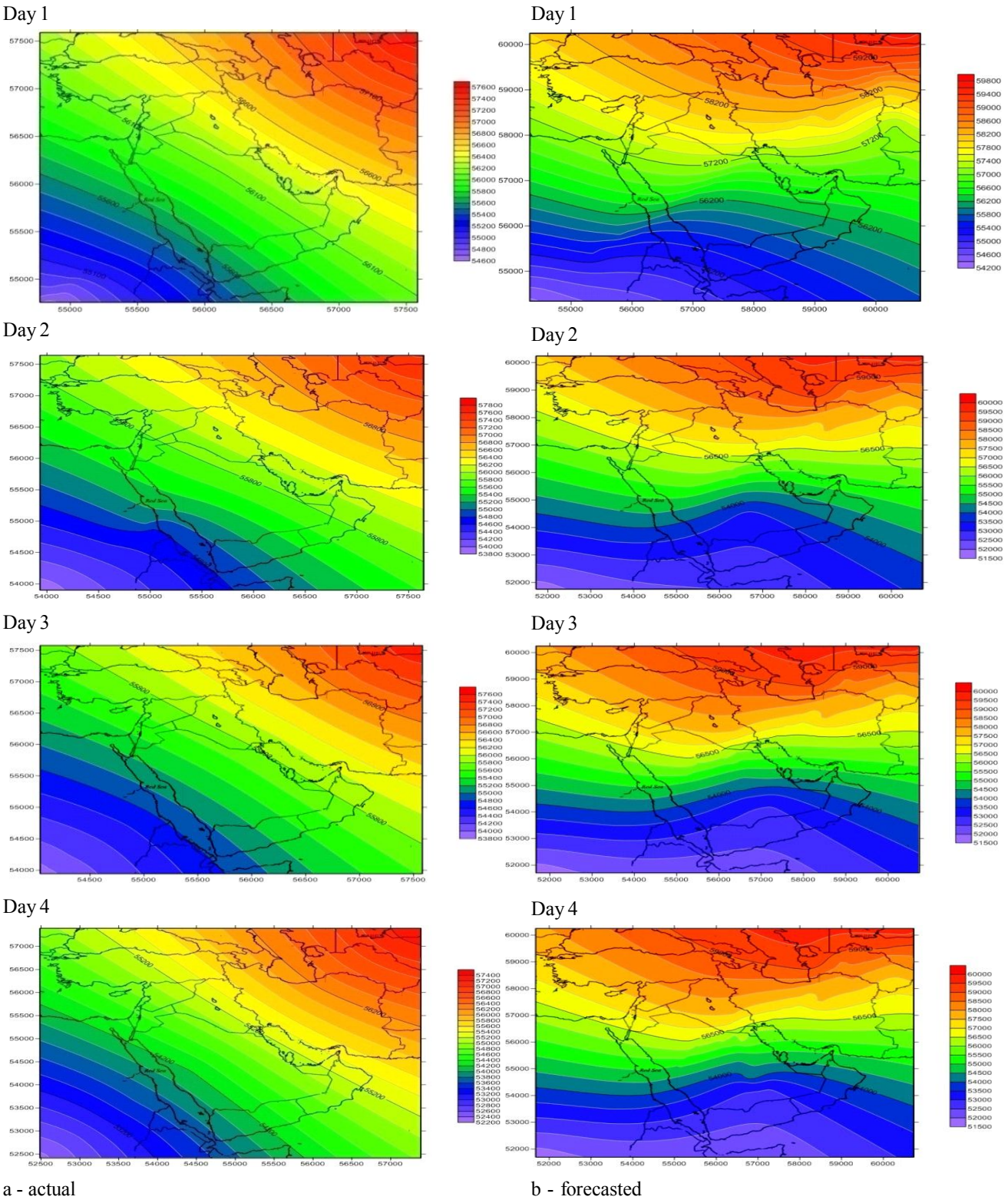

Fig. 5: Forecasted results vs actual along four days separately in winter season (a – actual, b - forecasted).

crossing geopotential heights lines, and this gives good indicate about model result, where the longest vectors mean the largest velocity values.

Resulted maps shows high predictability of convergence and divergence and it located near to the location of low and high system and there is a clear corresponding between wind direction and contour lines in winter correlated more than summer.

The forecasting result show also some point on grid have large anomaly values especially in summer but in

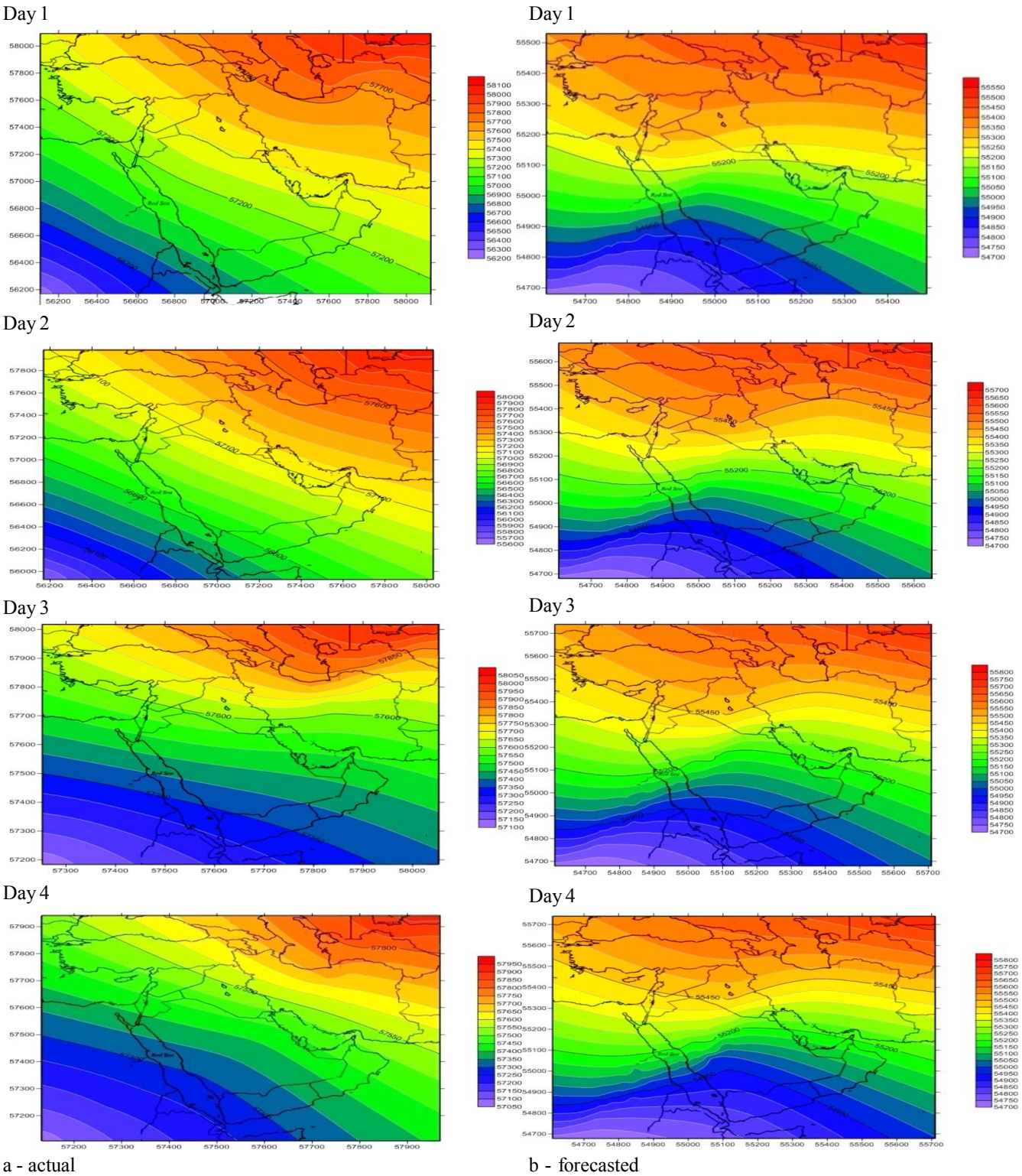

Fig. 6: Forecasted results vs actual along four days separately in summer season (a - actual, b - forecasted).

general for whole region it have good correlation with geopotential height contour lines.

Sensitivity of barotropic forecasting model

Consider that completing a simple program depending on linear equation and has a high importance to produce result that used by a company to calculate relation between capital and earning, so the program needs input values to make operations and this input must have a limit value because if the company increasing capital value higher than it recommended the earning will be lower and so the input capital value must be in acceptable range to make higher earns, so this system has a sensitivity to

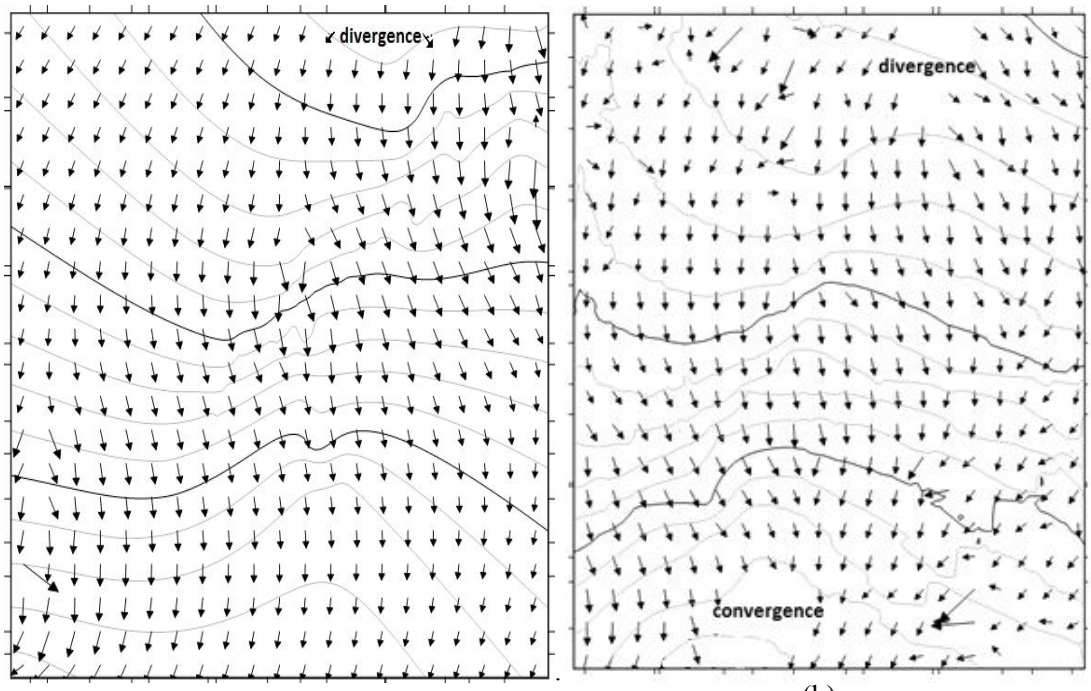

Fig. 7: Combined map of wind field and geopotential height contour (a) winter (b) summer.

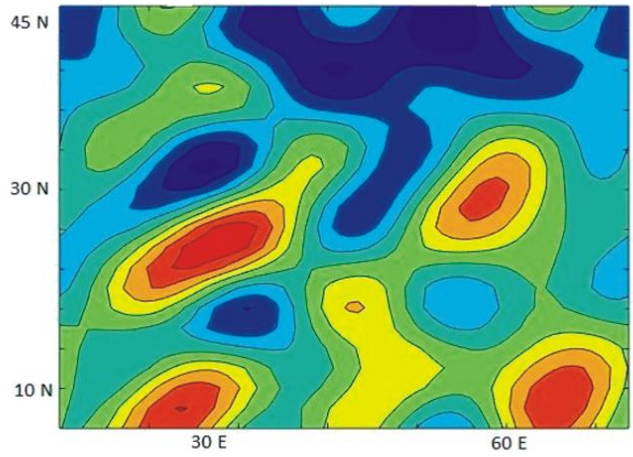

Fig. 8: Forecasted geopotential height pattern with value of wind velocity (10 m/h).

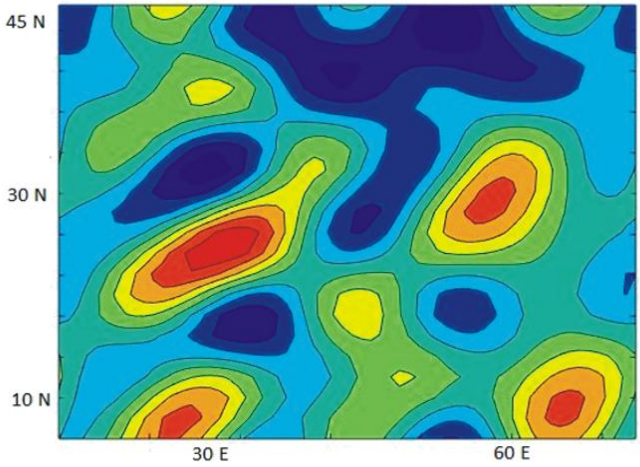

Fig. 9: Ideal geopotential height pattern produced by model.

input value of capital. Many studies test the sensitivity of its models to the value of corresponding variables so that knowing the range of input value of atmospheric model is very important for the sensitivity because it lead to inaccurate forecasting (Chinneck, 2006). The idea comes to test the maximum range value of wind speed that lead for produce acceptable prediction of geopotential height at (500) hpa level. and this method is very important because the problem is how much input values is accurate. The aim of any similar work is to know what type of input variable change is sensitive to the results and if we know that barotropic model depending on one type of input variable which is horizontal wind velocity so the study will test the maximum range of horizontal wind velocity that produce good prediction. The study used another model written in math lab language to make the sensitivity tests and it consist of more than one initial condition with different time ranges, it also can make forecasting process that exceed (48) hours to be reach (10000) days for climate studies, and each of different initial conditions has values differ from others, also the model has default result which shows the typical pattern over region. Our resent case study depend on weather and does not exceed (10) days. So after operate the model for (48) hours the modification has been made by changing horizontal wind speed values and test the accuracy of prediction with respect to increasing of wind velocity value until reaching values that is not available in this region at

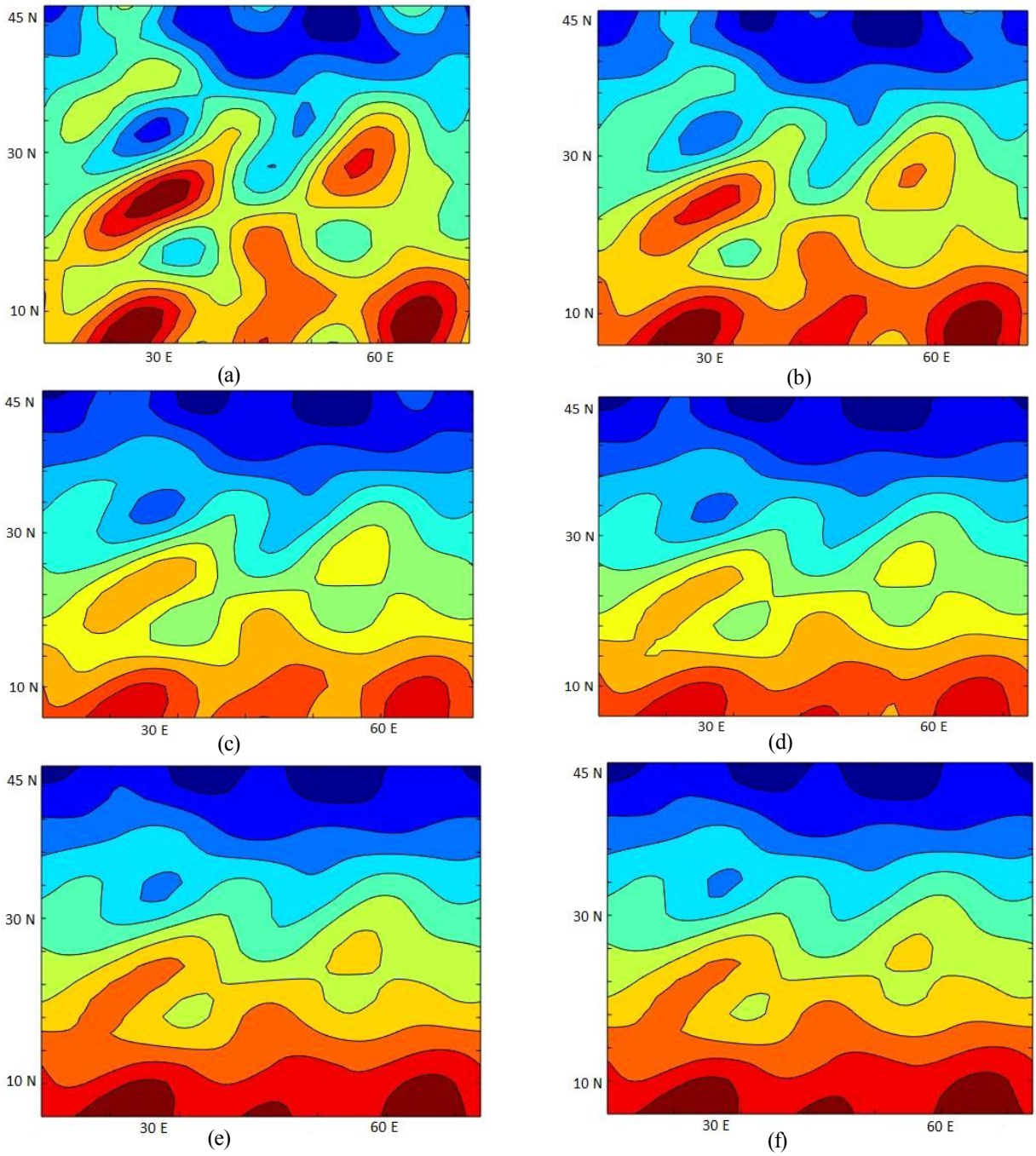

Fig. 10: Forecasting results with respect to slight change in wind velocity changes.

(500) hpa. the result shows that the model accuracy affected by wind velocity values and small fluctuation in velocity still gives good accuracy and it is clearly shown by comparing fig. 8 which represent geopotential height pattern at wind velocity (10 m/h) with fig. 9 of actual pattern, the resulted forecasting fig. show good arranged geopotential height pattern over middle east and that matches pattern on typical, and also the gradient of geopotential height contour lines in forecasted result is very similar to the typical and this indicate high forecasting accuracy.

By increasing velocity values on second state to (20 m/h) in fig. 10-a it can show a little corruption in geopotential height pattern, but it refer to acceptable accuracy when focusing on geopotential height pattern especially in the center of study region, the contour lines tend to be little straight because of homogenous values producing weak system and this is not as idealin fig. 9 but in spite of that it still gives good prediction until now.

By showing third tested value of wind velocity (40 m/h) in fig. 10-b it clearly shows high corruption of lines producing irregular curves and incorrect values of

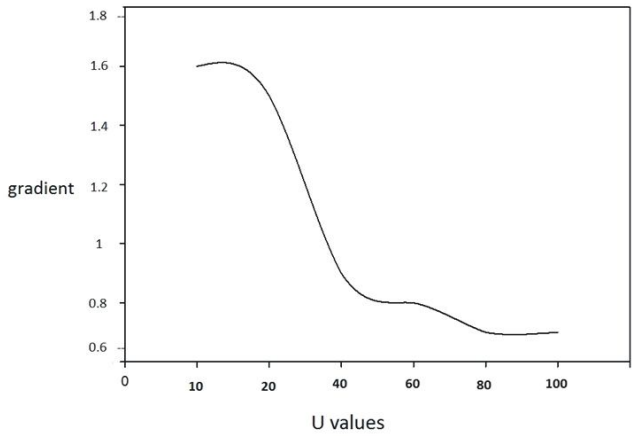

Diagram 2: Model result sensitivity to slight change on wind velocity .

geopotential heights, also the center of high system and low system become close together producing system decay in opposite with ideal, therefore it refer to bad prediction. Same thing is happen when gives wind velocity (60 m/h) on fig. 10-c) because it lead to less forecasting skill, and still very weak in cases of wind velocity (80 m/h), (90 m/h) and (100 m/h) where the system fail to produce good prediction at fig. 10-d, e, f). It is worth mention that all forecasted Fig. showing that high latitude from (30 N) and up gives better forecasted pattern.

From all above it can be concluded that model operating results is good at wind velocity range up to approximately (60 m/h) at (500) hpa level and increasing in input velocity value gives bad prediction, therefore a calculation have been made to get a diagram showing this relation, and this depend upon gradient of contour lines because the gradient value refer to the behavior of pressure system and this very important in locating high and low pressure systems. So the calculation was made by counting lines number upon the area of study "more in lines indicate more gradient ", and so the following diagram 2 shows the relation between wind velocity and the accuracy of prediction.

By showing above diagram we find that variable values of wind velocities and increasing of it lead to less forecasting accuracy activity until reaching minimum accuracy, therefore range of wind velocity is very important in forecasting process.

Conclusions

Forecasted geopotential height pattern is accurate in locating high and low systems but with shifted locations, also forecasted geopotential height lines is fluctuate more than actual and parallel to latitude lines, and Forecasting accuracy of barotropic vorticity model is sensitive to high change of horizontal wind input and gives good results until (60 m/h).

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