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Prognosis of 500-mb surface by divergent barotropic model

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ABSTRACT. Forecasts of 500 mb surface by simple barotropic model which excludes divergence and ground contour effects, have been found to suffer from retrograde motion of ultra long waves. In this paper the effects of divergence term on the forecasts have been studied. It is shown that inclusion of the divergence term leads to an improvement in the 24-hr barotropic forecast for 500-mb level. It also produces a vastly improved 48 hours prognosis. Effects of the ground contour term are also discussed.

1. Introduction

Forecasting of 500 mb surface by numerical methods, using a simplified quasi-geostrophic barotropic model, has been done in India on a real time basis, for a period of one year. The details of this method are available in India. met. Dep. Sci. Rep. No. 112. Briefly, the method adopted was as follows.

The basic equation of the geostrophic model, in finite difference form, is given by —

$$\nabla^2 \frac{\partial z}{\partial t} - \mu^2 \frac{\partial z}{\partial t} = -\tfrac{1}{4} \mathbf{J}(z, \zeta+f) - \frac{\mu^2 m^2 g}{4 d^2 f} \mathbf{J}(z - z_g) \quad (1)$$

where ∇^2 and $\mathbf{J}$ are the Laplacian and Jacobian operators in the finite difference form. The other terms are :

- z — the contour heights of 500-mb level
- f — the coriolis parameter
- m — the map magnification factor
- ζ — the geostrophic vorticity
- g — acceleration due to gravity
- d — the mesh size of the grid utilised in numerical integration
- z_g — the ground contours

$$\mu^2 = \frac{d^2 A_0 f}{m^2 R T_0} \text{, where, } A_0/RT_0 \text{ is a constant.}$$

Datta *et al.* (1969) integrated the above equation numerically, by neglecting the 2nd and 4th terms, and obtained forecasts valid upto next 48 hours.

2. Inclusion of the divergence and ground contour terms

2.1. *Effects of divergence term*

It has been pointed out by many meteorologists, notably Cressman(1958), that the forecasts based on the simplified model, as mentioned above, suffer from the retrograde motion of ultra long waves. As a way out from this difficulty, it was suggested that the 2nd term in Eq. (1) which corresponds to the divergence term, be taken into account. Thus the notified equation neglecting the ground contour term, becomes —

$$(\nabla^2 - \mu^2) \frac{\partial z}{\partial t} = \tfrac{1}{4} \mathbf{J}(f+\zeta, z) \quad (2)$$

From the expression for μ^2 given above, it will be seen that, except for A_0/RT_0, all other factors are already known. Thus, in order to include the divergence term in our solution, it will be necessary to find the value of A_0/RT_0.

To determine the value of A_0/RT_0, an empirical approach has been adopted. We have used different values of A_0/RT_0 and numerically integrated Eq. (2), for obtaining 24 hr and 48-hr forecasts. As an alternate method, the whole of μ^2 has been treated as constant and solutions to Eq. (2) obtained. In the latter case, in effect, it is assumed that f and ζ remain constant throughout the area of integration, although it is realised that both these factors definitely undergo variations. However, this leads to simplifications in the computations, and as such was given a trial. Values of μ^2 were varied from 0·25 to 3·0 in steps of 0·25. The resulting forecasts were compared with those for which $\mu^2 = 0$

For $\mu^2 < 1{\cdot}0$ the results were similar to those with $\mu^2 = 0$. For $\mu^2 > 1{\cdot}5$, the results showed unwanted deformities in the shapes of lows and highs. For values in between, the results showed considerable improvements. However, to avoid the difficulty of having a constant μ^2 as mentioned in 2·1, it was decided to fix the value of A_0/RT_0 and let f and ζ vary in the expression for μ^2. Keeping in view the results obatined by putting μ^2=constant, A_0/RT_0 was given a value of $1{\cdot}25 \times 10^8$, so that the value of μ^2 continues to be within the limits 1·0 to 1·5. These results were found to be better than those with $\mu^2 = 0$ or μ^2=constant and are discussed in section 3.

2.2. The values of μ^2 obtained here, agree closely with values given by Cressman (1958) and Gambo *et al.* (1960). The values obtained by us, *viz.*, $\mu^2=1\cdot0$ to $1\cdot5$ are quite close to the ones suggested by Cressman ($\mu^2=0\cdot98$ to $1\cdot96$). With a value of $\mu^2>1\cdot25$, we could not find any significant improvement in the forecast.

It has been shown by Gambo (1960) that for $\mu^2=0\cdot98$ to $1\cdot96$, the divergence term becomes of comparable order in magnitude with the advection term, in Eq. (2). The insertion of the divergence term introduces considerable divergence or convergence effects in front of a trough or a ridge, on 500 mb surface. Thus, the trough or ridge weakens and flow pattern becomes flatter with passage of time. Thus observation of Gambo can be clearly observed in the 48-hr forecasts. When divergence term is not included, the troughs and ridges tend to magnify with passage of time. But with the divergence term included, this tendency is kept under control.

2.3. *Effects of ground contour term*

In addition to the modification introduced by the inclusion of the divergence term, efforts were made to include the effects of the ground contours as well. To achieve this, it is necessary to integrate Eq. (1), without any simplifications.

The ground contours over the area of integration were obtained from one degree ground contour smoothed map prepared at NHAC based on various atlases and Survey of India contours and from Bertoni *et al.* (1955). When these were introduced into Eq. (1) with $\mu^2=1\cdot25$, the integration tended to blow-up after two hours. However, convergence was produced and integration obtained upto 24-hr, by utilising time steps of 10 minutes instead of 1 hr. The solution for 24-hr showed small waves all over the integration area, which completely masked the basic flow pattern. Presumbly, this is caused by the steep contour gradient over the Himalayan area. In the course of integration, small amplitude waves develop over that area and finally obliterate the large scale pattern. Efforts are in progress to overcome this defect, by adopting methods suggested by Cressman (1960).

3. Discussion of results and conclusions

3.1. The area of integration is bounded by 0°N & 50°N and 25°E & 135°E. The grid distance is 380 km on a Mercator projection chart of $1{:}20\times10^6$ scale. The whole area is broken up into a mesh of 31×16 grid points and the values at those grid points are utilised for all computational work.

A number of smoothers were tried and finally the Canadian five-point smoother was found most suitable. This has been applied initially and thereafter at every 12-hourly intervals. The results indicate that this frequency of smoothing is satisfactory and sufficient.

Boundary conditions are similar to those employed by Datta *et al.* (1969).

3.2. *Case study*

The input data for this situation pertains to 500 mb contour values of 00 Z on 1 Nov. 71. The 24-hour barotropic forecast with $\mu^2=0$ and $\mu^2=1\cdot25$ are shown in Figs. 1(a) and 1(b) respectively. The actual 500 mb chart realised at 00 Z of 2 November 1971 is shown in Fig. 1(c). A comparison brings out the following salient features.

(*a*) The contour delineations over northern India are better represented when $\mu^2=1\cdot25$. Thus the 5800 gpm line forms a part of the high located east of Long. 62°E when $\mu^2=0$, which is not so in actual. Moreover it does not show any troughing north of Calcutta which is brought out when $\mu^2=1\cdot25$.

(*b*) North of 30°N both the charts show similar pattern, so that similar defects can be seen in both.

(*c*) Between 25° and 30°N, the trough between Srinagar and Delhi is better represented when $\mu^2=1\cdot25$.

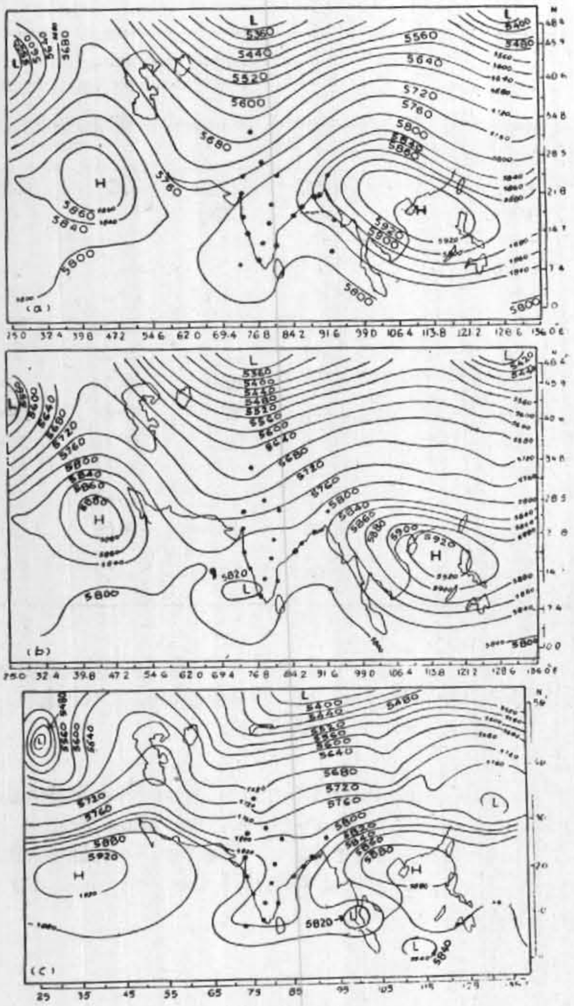
(*d*) Any new system which was not in the input data, like the 'low' east of Port Blair, as is to be expected in a barotropic (forecast) is missed in both forecasts.

Figs. 1(d), 1(e) and 1(f) show respectively the barotropic forecasts for 48-hr, with $\mu^2=0$, $\mu^2=1\cdot25$ and the actual realised on 3 November 1971.

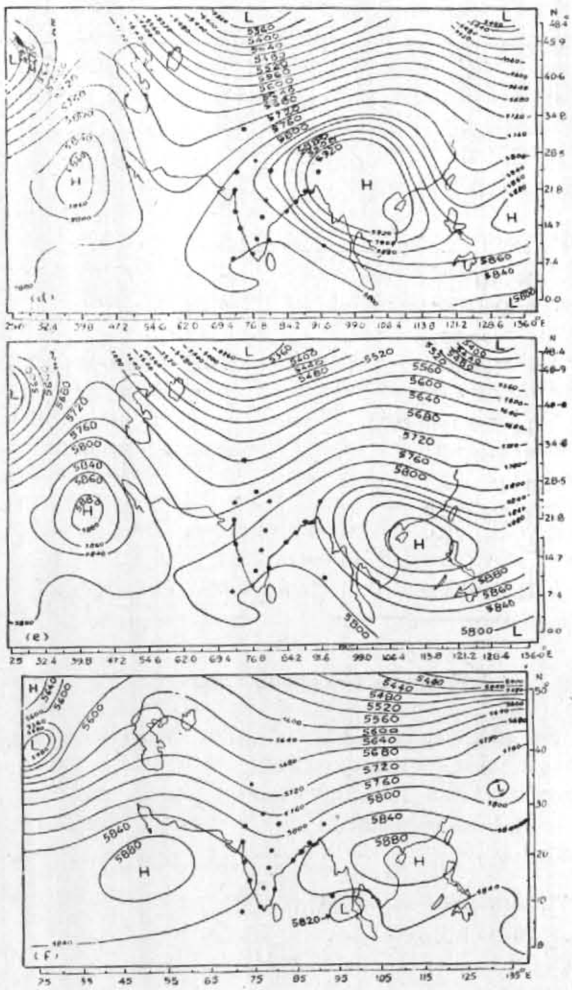
(*i*) As mentioned earlier, the amplitude of the troughs and ridges are very much exaggerated in the F/C with $\mu^2=0$. As examples, the troughs over West Pakistan and that between Long. 120° to 125°E may be seen. These are very much flatter with $\mu^2=1\cdot25$, more in keeping with the actual realised.

(*ii*) The high pressure system over Indo China is very much intesified when $\mu^2=0$. Thus the 5840 gpm line passes between Delhi and Lucknow, whereas actually it does not extend beyond Calcutta. This is shown very well in the F/C with $\mu^2=1\cdot25$.

(*iii*) The position of the trough east of Delhi is given wrongly by both forecasts. However, it is better in the case of $\mu^2=1\cdot25$.



Figs. 1 (a-c)



Figs. 1 (e-f)

3.3. A number of other case-studies have been made, but the charts are not being reproduced for reasons of economy. The correlation coefficients (C.C.) and root mean square errors (R.M.S.) for all the cases are given in Table 1. It will be seen from these values that for 24-hr forecasts, C.C. and R.M.S. have improved in every case. The 48-hr forecasts also become of acceptable order when the divergence term is included.

4. Conclusions

From the above case studies, the following important points are brought out.

(*i*) The modified barotropic model, which includes the divergence term also, produces better 24-hour prognosis compared to the model where this term is neglected. This is clearly brought out by the delineation of low and high pressure systems and the positioning of the different 500 mb contour lines. This is specially true for the areas south of Lat. 35°N.

(*ii*) The modified model produces vastly improved 48-hr prognosis compared to the unmodified model.

(*iii*) The modified model effectively controls the amplification of troughs and ridges, which otherwise, produces undesirable configurations in the un-modified model.

(*iv*) The rate of convergence in this model is much faster. As such, from the point of computer time economy also, this model is better than the earlier.

TABLE 1

Date	24-hour forecast				48-hour forecast			
	Without divergence term		With divergence term		Without divergence term		With divergence term	
	C.C.	R.M.S. (gpm)	C.C.	R.M.S. (gpm)	C.C.	R.M.S. (gpm)	C.C.	R.M.S. (gpm)
29 Sep 1971	0·90	15·85	0·96	11·58	—	—	—	—
8 Oct 1971	0·84	18·85	0·87	14·73	0·60	46·00	0·81	28·56
1 Nov 1971	0·85	22·48	0·92	18·95	0·29	51·61	0·83	28·19
8 Nov 1971	0·63	48·07	0·74	41·07	0·66	57·64	0·66	50·11
12 Nov 1971	0·35	37·72	0·52	33·68	0·33	63·93	0·71	33·83
14 Nov 1971 (12 Z)	0·63	34·22	0·73	23·31	0·64	78·92	0·66	29·87
3 Dec 1971	0·67	36·16	0·80	32·85	0·61	74·51	0·84	29·45
6 Dec 1971	0·70	39·57	0·71	26·93	0·68	73·79	0·75	25·05
8 Dec 1971	0·66	55·23	0·88	26·75	0·17	119·57	0·80	52·28
13 Dec 1971	0·84	37·78	0·92	16·98	0·29	99·49	0·64	29·02
Mean values	0·71	34·59	0·80	24·68	0·47	73·91	0·74	34·04

(*v*) Effect of the ground contours is to break up the basic flow pattern into small waves and does not produce usable forecasts. More experiements are needed to improve this effect.

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