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An experiment with barotropic quasi-geostrophic model for the Indian region

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ABSTRACT. In spite of the well known limitations of quasi-geostrophic models in the tropics, an experiment with quasi-geostrophic barotropic model was made for the region of India and neighbourhood for each day of the 2-month period from 25 October to 24 December 1966. 24-hour forecast was compared with the actual chart realised next day. R.M.S. error of the forecast is presented. The error in forecast for the region 10°N to 20°N was of the order of 20 gpm.

1. Introduction

Actual weather cannot be forecasted with any simple model like a single level model. But single level models have been found useful in some regions, particularly those where advection through deep tropospheric layers plays a dominant role. It was, therefore, decided to test the performance of the simplest single level model with real data in the neighbourhood of India and watch the error in 24-hour forecast for a continuous period of about two months —

A simple dynamical model is the quasi-geostrophic barotropic model used by NMC in U.S.A. (Cressman 1960) and also by a few other National Met. Services. The equation for this model is—

$$\frac{\partial \zeta}{\partial t}+\mathbf{V}.\nabla\left(\zeta+f\right)-\frac{\mu}{\psi}\left(\zeta+f\right)\frac{\partial \psi}{\partial t}+\left(\frac{\partial \zeta}{\partial t}\right)_m=0 \qquad (1)$$

where,

ζ = Relative vorticity

$\mathbf{V}$ = Horizontal wind velocity at 500-mb level

f = Coriolis parameter

μ = Non-dimensional parameter

ψ = Stream function

$\overline{\psi}$ = Average value of ψ in the region.

The simplest model consists in taking only the first two terms on L.H.S. of equation (1). The third term includes divergence implicitly and also prevents the forward as well as backward movement of waves. This term has been found to be of practical usefulness in stopping the retrogression of middle latitude ultra-long wave in the atmosphere. The fourth term $(\partial\zeta/\partial t)_m$ represents creation of vorticity due to convergence forced by the terrain in the underlying layers. One can separately study the improvement or deterioration of forecast by inclusion or exclusion of different terms.

2. Experimental models

We have analysed the results of the experiments performed with the following two models —

$$\frac{\partial \zeta}{\partial t}+\mathbf{V}.\nabla\left(\zeta+f\right)=0 \qquad \text{Model (A)}$$

$$\frac{\partial \zeta}{\partial t}+\mathbf{V}.\nabla\left(\zeta+f\right)-\frac{\mu}{\psi}\left(\zeta+f\right)\frac{\partial \psi}{\partial t}=0 \qquad \text{Model (B)}$$

2.1. *Obtaining the stream function*

In both these models, we needed the stream-function ψ to calculate vorticity ζ and horizontal wind $\mathbf{V}$. There are various ways of obtaining stream function. The simplest, though not the best method of obtaining the stream function is by quasi-geostrophic approximation, using the geopotential field. This approximation is of doubtful validity in the tropical regions. Nevertheless, it needs experimentation with actual data to see how far such a crude approximation works or does not work in the neighbourhood of India. It also serves as a base or the crudest model with which other more realistic and progressively more sophisticated models could later be compared for the Indian region. With this in mind, we used quasi-geostrophic assumption to get stream function from the 500-mb contour field. For energetic consistency, a constant value of coriolis parameter in place of its actual variable value was used in this approximation.

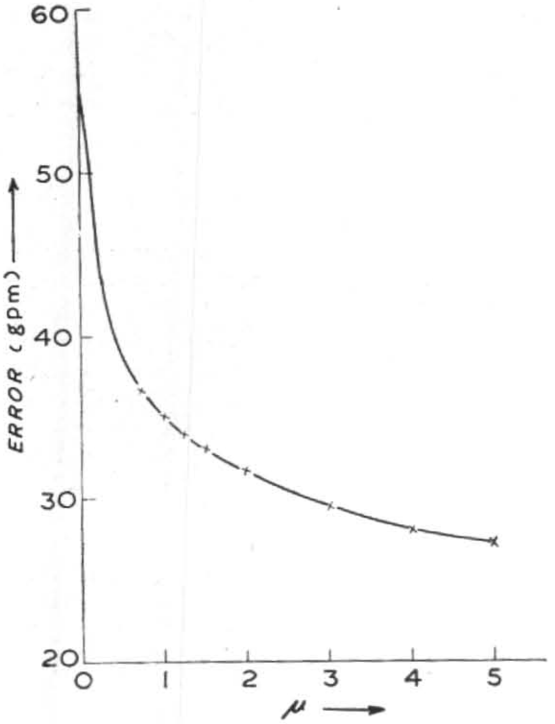

Fig. 1

2.2. *Real data*

We obtained hand-analysed 500-mb contour charts from the office of Dy. Director General of Observatories (Forecasting) daily for 2-month period from 25 October to 24 December 1966. The analysis was touched and modified slightly on a few days. There were a few days when data coverage was poor. Omitting such occasions of poor data, we could get 53 days' data for testing of the models.

2.3. *Area of forecast*

The area of analysis was Equator to 50°N, 20°E to 150°E.

The area of 24-hr forecast was 5°N to 45°N, 25°E to 145°E.

Grid distance was $2\frac{1}{2}$ degrees latitude and longitude on spherical earth surface.

2.4. *Some features of numerical integration*

2.4.1. *Sphericity of earth's surface*: Account was taken of varying grid length due to contraction of latitude circles and covergence of meridional lines on earth's spherical surface.

2.4.2. *Jacobian* : Arakawa's finite difference scheme for Jacobian was used to ensure energetic consistency and suppression of spurious error field.

2.4.3. *Smoothing* : Stream function obtained from geopotential field was smoothened as follows before starting time integration :

For getting smoothed value at (I, J), a weighting factor of 1/8 was given to the neighbouring grid points at $2\frac{1}{2}°$ distance and what remained from 1·0 after these weightings were given, was alloted to the point (I, J) . Thus at internal grid points, $\psi(I, J)$ was replaced by,

$$\tfrac{1}{2}\psi(I,J)+\tfrac{1}{8}\{\psi(I+1,J)+\psi(I,J+1)+ \\ +\psi(I-1,J)+\psi(I,J-1)\}.$$

At boundary points, $\psi(I, J)$ was replaced by,

$$\tfrac{5}{8}\psi(I,J)+\tfrac{1}{8}\{\psi(I,J+1)+\psi(I-1,J)+ \\ +\psi(I,J-1)\},$$ and so on.

2.4.4. *Boundary condition for integration*: The equation was first solved as Poisson equation in $\partial\psi/\partial t$, *i.e.*,

$$\nabla^2\left(\frac{\partial\psi}{\partial t}\right)=F$$

where, F is the forcing. The boundary values for $\partial\psi/\partial t$ were taken as $\partial\psi/\partial t=0$. Equation was solved by relaxation method. Since the boundaries were sufficiently far away from the area of our immediate interest, it was hoped that this boundary condition did not seriously interfere with the forecast in the region of our interest.

2.4.5. *Time step* : For integration with respect to time, we employed forward time differencing in first time step and centred time differencing in subsequent steps. Time step was taken as 1 hour. The forecast was for 24 hours.

2.4.6. *Computer facility* : The computational work was done with the help of CDC 3600 at the Tata Institute of Fundamental Research, Bombay.

3. Verification of forecasts

3.1. The forecasted stream function was reconverted into 500-mb contour field and compared with the analysed contour field next day. The error field was inspected for the entire area of forecast. The following features were observed :

(*a*) There was a persistent error pattern strongly correlated to the position of Himalayas and the Tibetan plateau, indicating that orography did play a dominant role at 500-mb level, north of 25°N.

(*b*) The introduction of divergence term with μ did improve the performance. The value of μ was progressively increased from 0 to 5. The error field was measured in terms of root-mean square value in the region of verification : 10°N to 35°N, 70°E to 95°E for various values of μ. Results are shown in Fig. 1. It will be seen that there was rapid improvement in forecast as μ increased from zero to 1. For larger values of μ, the improvement continued but at a progressively slower rate. At $\mu=5$, the error was 27 gpm.

3.2. It was found that if no integration were performed and instead 24-hour persistence was stipulated, *i.e.*, if it be stipulated that to-day's values would persist and re-appear tomorrow also, then the root mean square error in the forecast was found to be 26 gpm.

3.3. The individual errors decreased from higher to lower latitudes, becoming of the order of 20 gpm in the region 10°N to 20°N.

4. Discussion of results

(*i*) In the tropical latitudes, advection is important for the movement of troughs and ridges but non-advective or '*in situ*' changes also appear to be equally important so far as root mean square error method of verification is concerned. Other methods of forecast verification (*e.g.*, movement of troughs, ridges etc,) may perhaps yield more meaningful results.

(*ii*) For such a crude model as this, the error in forecast for the region 10°N to 20°N was of the order of 20 gpm. The analysis of 500-mb geopotential field itself and of its 24-hour changes are subject to errors of this magnitude. It is unlikely that more sophisticated models involving geopotentials would give performance of far superior quality in terms of root mean square error in the 500-mb geopotential field. In any case, the performance of more sophisticated multi-level models should be viewed against the performance of the crude and simple single level model outlined above.

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REFERENCE

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