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Forecasting over the monsoon area by a semi-implicit semi-Lagrangian regional primitive equation model

A. K. BOHRA

Meteorological Office, New Delhi

सार – प्राचलीकृत रूप में विभिन्न भौतिक प्रक्रियाओं के समावेशन के साथ क्षेत्रीय पूर्वग समीकरण निदर्श का वर्णन किया गया है। 16 जून 1979 को अरब सागर में मानसून तूफान की प्रागुक्ति के लिए भारतीय मानसून में इस निदर्श का अनुप्रयोग किया गया है। प्रागुक्त परीक्षण से प्राप्त परिणामों पर विचार विमर्श किया गया है।

ABSTRACT. A regional primitive equation model, with the incorporation of different physical processes in parameterised form, is described. The model is applied over the Indian monsoon area for predicting a monsoon storm in the Arabian Sea on 16 June 1979. The results of the prediction experiment are discussed.

1. Introduction

The southwest monsoon is the most dominant phenomena in determining the weather conditions over southeast Asia and adjoining regions. Attempts are being made to predict the different aspects of monsoon (such as onset, rainfall, movement of monsoon depression etc) on short and medium range time scales utilizing various global and regional models (Krishnamurti *et al.* 1983 a, Bohra *et al.* 1986, Singh *et al.* 1988, etc). In this paper, a short range forecast experiment is conducted over the region (30° S - 50° N and 30° E - 150° E) which includes the monsoon region. A semi-implicit, semi-Lagrangian regional primitive equation model is used to conduct this experiment.

2. The model

The model is described in detail by Bohra *et al.* (1986). We describe here only a few salient points.

2.1. *Structure*

Keeping in view the intended use of the model for monsoon prediction, it has been cast on a regular latitude/longitude grid with 2×2 resolution. Its horizontal domain is 30° S to 50° N and 30° E to 150° E. Sigma coordinate system has been used in the vertical to account for the high orography of the region. The present version has 10 levels in the vertical. The top of the model is at $\sigma = 0.1$ and bottom level is at the earth's surface. The model includes envelope orography normalized to a peak height of 3 km. Arakawa-A grid is used in the horizontal. The variables are staggered in the vertical as shown in Fig. 1. The model domain as well as the resolution is flexible and can be changed, if required.

2.2. *Dynamic formulation*

The usual momentum equations, thermodynamic equation, mass continuity equation and the moisture continuity equation written in the Lagrangian form constitute the prognostic equations of the model.

2.3. *Initialization scheme*

A dynamic normal mode initialization scheme, similar to one proposed and used by Sugi (1986) in FSU global model, has been used. In this scheme a balanced state is obtained by forward-backward integration of linear part of the model equations. During the integration of the linear part, the non-linear part is kept constant. The change in the non-linear terms due to linear integration is considered iteratively as in the non-linear normal mode initialization. This scheme does not require explicit computation of the free normal modes, but condition of initialization is similar to Machenhauer (1977) scheme. A selective damping scheme due to Okamura is used for forward-backward integration.

2.4. *Parameterization of physical processes*

The parameterization of the following physical processes are included in this model :

(*i*) Dry convective adjustment,

(*ii*) Deep cumulus convection,

(*iii*) Shallow convection,

(*iv*) Large-scale non-convective heating,

(*v*) Surface fluxes of momentum, moisture and heat,

(*vi*) Planetary boundary layer,

(*vii*) Radiation including the cloud feedback and diurnal processes,

(*viii*) Energy balance at the earth's surface and

(*ix*) Empirical estimate of ground wetness.

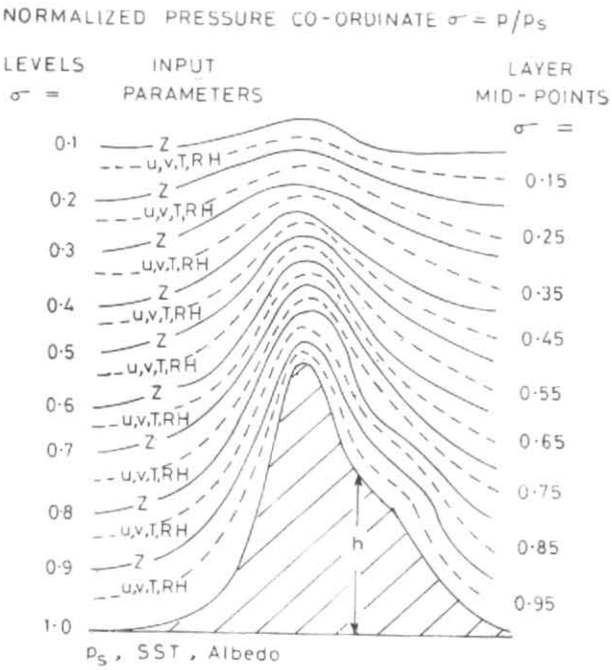

Fig. 1. Vertical discretization of the model

Besides these, effects of envelope orography are also accounted for.

2.4.1. *Dry convective adjustment*

Wherever the lapse rate becomes superadiabatic, a dry convective adjustment is made by changing the temperatures of the unstable layer under the constraint that the total dry static energy in the vertical remains constant.

2.4.2. *Deep cumulus convection*

A modified Kuo scheme (Krishnamurti *et al.* 1983 b) is used. In this, parameterization is posed as a two-parameter problem : a moistening parameter "*b*" and a mesoscale convergence parameter "η". These parameters are determined from a statistical regression analysis structured to GATE data sets. The scheme is invoked when the atmosphere is conditionally unstable and there is net convergence of moisture in the lower levels. The regression coefficients based on the GATE data give under-estimate of heating and rainfall.

2.4.3. *Shallow convection*

The ECMWF experience has shown that the inclusion of shallow convection in the model enhances the diabatic heating through latent heat release. A simple diffusive form for the parameterization of the shallow convection has been included in our model. It is invoked over conditionally unstable undisturbed situations (defined as rainfall $<$ 5 mm/day) *via* a diffusion theory.

2.4.4. *Large-scale non-convective heating*

For upward motion with a stable stratification in the atmosphere, large-scale condensation heating above the lifting condensation level is invoked disregarding lateral diffusion, vertical eddy diffusion and other forms of heating.

2.4.5. *Surface fluxes*

Surface fluxes of momentum, sensible heat and moisture due to turbulent eddy motion within the planetary boundary layer and the surface layer have been considered. Similarity analysis approach has been used for specification of these fluxes. A distinction between the oceanic and land areas has been made on the basis of surface albedo. It has been ensured that these fluxes are compatible with those involed in surface energy balance with radiative fluxes over land areas.

2.4.6. *Planetary boundary layer*

Normalized vertical distribution of surface fluxes of momentum, sensible heat and moisture are constructed on the GATE observations for undisturbed and disturbed planetary boundary layer. These are used in the planetary boundary layer parameterization.

2.4.7. *Radiation*

The radiation parameterization scheme of the model includes parameterization of both the short and the long wave radiation. The absorption and scattering of short wave radiation by atmosphere, clouds and ground and reflection from ground are considered. The radiation scheme utilizes the emissivity tabulations for the calculation of infrared radiative transfer. It utilizes absorptivity function (which is a function of path length and has somewhat different form for the absorbed and scattered radiation) for the definition of solar radiation. It contains a fairly complete heat balance at the earth's surface for the land areas. Other features of the scheme include calculation of zenith angle which allows for seasonal and diurnal changes. The cloud cover at various levels are estimated on the basis of model relative humidity values. The radiation scheme is an interactive one, and permits examination of cloud feedback radiative processes.

3. A forecast experiment

During the onset phase of southwest monsoon 1979 a low pressure area developed over the east Arabian Sea on 15 June and moved in a northerly and then northnorthwesterly direction ultimately developing into a cyclonic storm by the morning of 18 June. Later it moved westnorthwestward till it struck Saudi Arabian coast on 20 June. Under its influence the southwest monsoon strengthened and advanced over the country. The wind field south of the storm was monsoonal.

The model was integrated up to 48 hours for the data sequence of 00 GMT FGGE data of 13 June 1979 to 18 June 1979. For this experiment, we have used the input data set provided by the regional optimum interpolation scheme of objective analysis. For this experiment, the OI scheme has used only the synop and upper air data to simulate a real time situation. It uses climatology as the first guess. Results of both, the analysis scheme as well as the model, are being monitored. The model has been updated a few times based upon the experiments. The preliminary results presented here are, however, based on the originally adapted version.

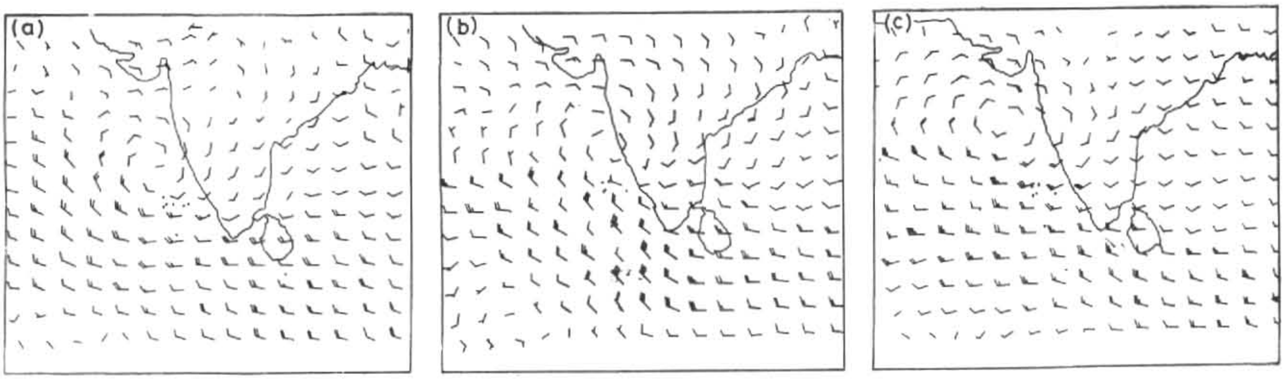

Fig. 2(a). Initial wind field at 850 hPa, 00 GMT of 16 June 1979

Fig. 2(b). 24-hr forecast wind field at 850 hPa, 00 GMT of 17 June 1979

Fig. 2(c). Realized wind field at 850 hPa, 00 GMT of 17 June 1979

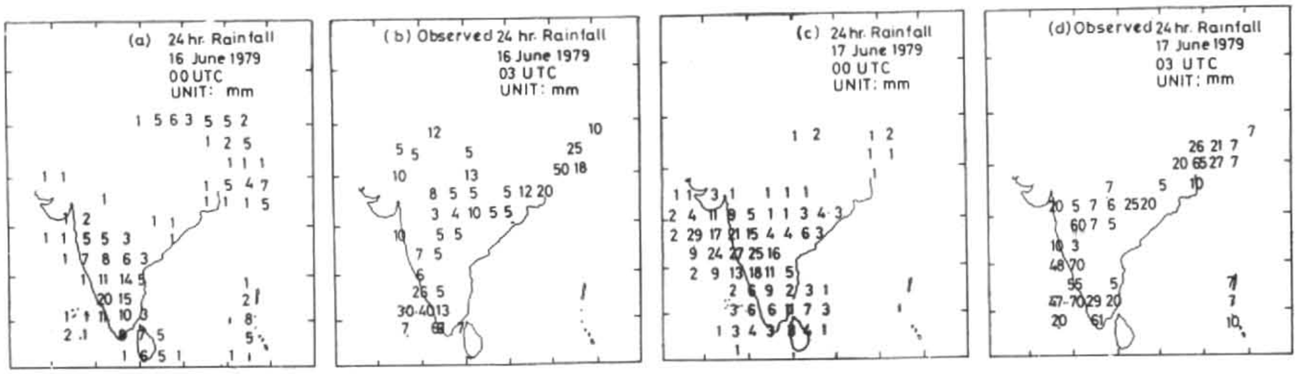

Fig. 3(a). Predicted 24-hr precipitation, 00 GMT of 16 June 1979

Fig. 3(b). Realized 24-hr precipitation, 03 GMT of 16 June 1979

Fig. 3(c). Predicted 24-hr precipitation, 00 GMT of 17 June 1979

Fig. 3(d). Realized 24-hr precipitation, 03 GMT of 17 June 1979

3.1. *Data*

The regional analysis scheme povides the zonal and meridional components of wind, temperature and geopotential heights at ten levels, shown in Fig. 1. The relative humidity values are provided at the lower seven levels. The model requires fields of u, v, z, relative humidity, vertical velocity parameter ($\dot{\sigma}$) and log of surface pressure (log P_s) at all horizontal grid points. The $\dot{\sigma}$ and z are required at the interfaces of the layers and u, v, relative humidity are required at the middle of the layers.

The fields provided by the ROI scheme are initialized onto the model grid by interpolation taking geopotential heights as linear functions of natural log of pressure.

For verification of the predicted rainfall, grid point averages are derived from the observed rainfall plotted on NHAC charts. The total rainfall falling within a 2×2 square is divided by the number of observations to get simple average. The value of a point falling on the boundary is halved and included in the adjoining squares.

3.2. *Results*

The model integrations are stable up to 48 hours for each day of the sequence.

The Figs. 2(a)-2(c) give the initial wind field for 16 June, 24-hour forecast valid for 17 June and realized wind field on 17 June. All the figures are for 850 hPa and all refer to 00 GMT. It is seen that the forecast shows slower movement of the system and the predicted position is much to the southeast of the actual.

For possible explanation, the initial humidity fields and the vertical velocity fields were examined. It is seen that the vertical velocity field, in general and in the area of the system, is very weak. The relative humidity values of 80 to 100 per cent are confined to isolated patches over a very small area. Besides, the orography in these experiments had been scaled down to a peak height of 3 km, thereby reducing the height of the Western Ghats greately. These, combined with the fact that the analysis scheme uses climatology as the first guess resulting in higher values of humidity near the coast where the observed values are available, appear to be partial reasons for the predicted error. Krishnamurti *et al.* (1984) has pointed out that inadequate moisture field or erroneous humidity field could lead to a wrong equilibrium of fields, particularly in the rain area, affecting the dynamic circulation.

It has been seen from examination of predictions for all days of the sequence that if a circulation is present in the initial field, it is maintained up to 24 hours after which not only the system becomes shallower but the wind strengths also get reduced. In fact, predicted monsoon flow in this experiment is much weaker than the observed.

As shown in the Fig. 3, the 24-hour predicted precipitation fields show that the area of the rainfall agrees reasonably well with the observed grid point averages. However, the predicted precipitation values are much underestimated. The lower orography and the resolution used in this experiment are not adequate for predicting the rainfall close to the coast. A higher resolution, better orography representation and improved humidity analysis are required. In another case of a depression over Bay of Bengal in September 1985, predicted rainfall estimates are much closer to the observed using the same convection scheme but the NMC analysis.

Acknowledgements

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