SESSION VII

PREDICTION OF MONSOON

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Indian J. Met. Hydrol. Geophys. (1978), **29**, 1 & 2, 361-366

551.553.21 : 551.509.333 : 551.513.1

Numerical prediction experiments in the monsoon region

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ABSTRACT. An objective analysis/numerical prediction scheme, originally developed in the context of GATE, has been adapted to cover the monsoon region. The analysis scheme uses optimum interpolation to provide independently analysed winds and geopotential heights which are then mutually adjusted using a variational technique. Relative humidity is also objectively analysed. The prediction model is an 11-layer primitive equation model in sigma coordinates, applied on a 2° Lat./Long. grid and incorporating the main physical processes.

Results of integrations from some recent real data cases are to be presented and discussed.

1. The forecasting model

The model is a limited area version of an 11-layer global model which has been developed in recent years in the Dynamical Climatology branch of the UK Meteorological Office for research on medium range forecasting and general circulation studies (Saker 1975). A limited area tropical version of this 11-layer model was first produced to take advantage of the enhanced data available during the GARP (Global Atmospheric Research Programme) Atlantic Tropical Experiment (or GATE) in summer 1974 (Lyne, Rowntree, Temperton and Walker 1975). Subsequently this tropical model has been applied to other areas of the tropics, specifically to the Indian monsoon region.

The model is a primitive equation, finite difference model incorporating moisture and topography; the physical processes of radiation, convection and surface exchanges are also simulated. In the horizontal the basic variables of horizontal wind, temperature and specific humidity (and at the lower boundary, surface pressure) are represented on a 2° latitude/longitude grid with boundary rows along 35°N, 15°S, 13°E and 139°E (Fig. 1). The horizontal finite difference scheme is identical to that in the 5-layer hemispheric model of Corby, Gilchrist and Newson (1972). The vertical coordinate is $\sigma \equiv p/p_*$ where p is pressure and p_* is surface pressure. In the vertical there are 11 layers; the layer boundaries and nominal central values are given in Table 1. This vertical resolution is chosen to give :

(*i*) a higher resolution near the surface to give a reasonable representation of the temperature and humidity gradients needed for modelling the surface fluxes, of the boundary layer and of the inflow into tropical convective systems;

(*ii*) a vertical resolution of extratropical fronts consistent with the horizontal resolution;

(*iii*) a consistent resolution of the jet stream in the sense of (*ii*) and adequate representation of outflow from tropical convective systems;

(*iv*) one layer wholly in the stratosphere to provide a stable lid on tropospheric vertical motions.

Because the layers are of unequal mass the vertical finite difference scheme applied by Corby *et al.* (1972) is modified in order to maintain energy conservation. A leap frog time step ($\triangle t = 7\frac{1}{2}$ mins) is used, with time meaning at every time step to avoid time splitting. Lateral boundary conditions are required; grid point values on the boundary are held fixed throughout the forecast period; computed tendencies in the adjacent three rows are reduced according to their proximity to the boundary (Kesel and Winninghoff 1972). The tendencies calculated in the boundary row ($i=0$) and the three adjacent rows ($i=1, 2, 3$) are multiplied by S_i where $S_0=0$, $S_1=0{\cdot}3847$, $S_2=0{\cdot}7071$ and

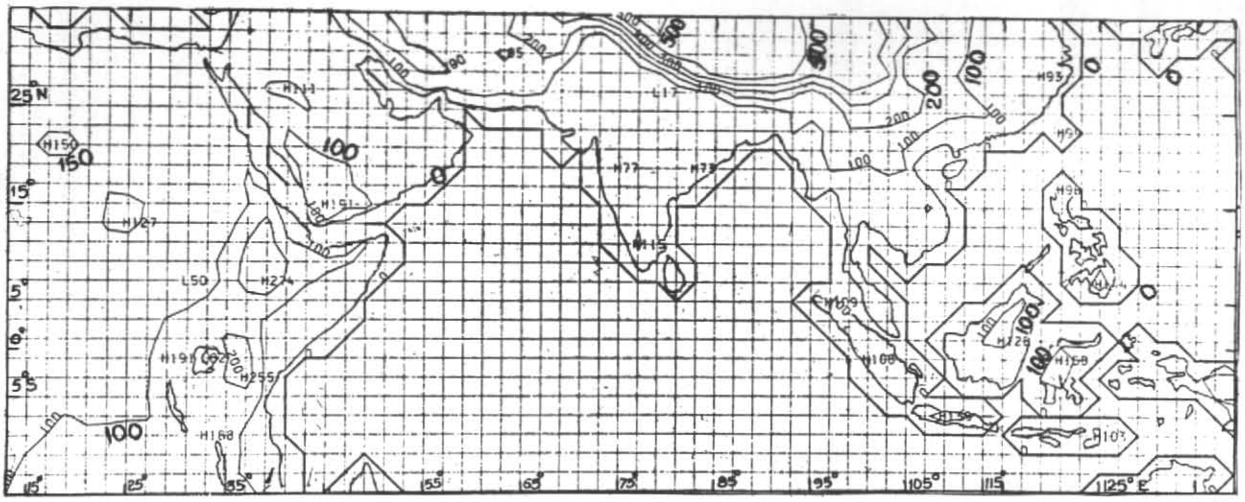

Fig. 1. Topography used in monsoon area

TABLE 1

Layer boundaries and nominal levels in σ co-ordinates

Layer number		11		10		9		8		7		6		5		4		3		2		1	
Boundaries	1		·975		·9		·79		·65		·51		·37		·27		·195		·125		·06		0
Nominal level		·9874		·9370		·8438		·7177		·5772		·4363		·3174		·2305		·1574		·0886		·0221	

$S_3=0{\cdot}9239$, the eoefficients being from a cosine curve. Computational smoothing is also required on the interior of the grid to preserve realistic fields. Instead of the non-linear diffusion used in Corby *et al.* (1972), a filter designed to remove 2 grid length waves is applied at 6-hour intervals in both meridional and zonal directions (Shapiro 1971). The maximum order of the filter is 8 (involving 17 grid points); as the lateral boundaries are approached the order of the filter is reduced progressively in the direction normal to the boundary, the order being the same as the row number. The order of the filter in the tangential direction is not changed. The fields filtered are PMSL (pressure at mean sea level), horizontal wind components, a linear combination of temperature T and potential temperature θ, $aT+(1-a)\,\theta$, and specific humidity q. The coefficients a are chosen to give zero vertical gradients of $aT+(1-a)\,\theta$ at each level for the mean tropical atmosphere during July, August and September (Oort and Rasmusson 1971). The application of the filter to this temperature function (and to PMSL rather than p_*) eliminates roughness which would be caused over mountains if the filter were applied directly to T, p_*. PMSL is related to p_* by the formula

$$\text{PMSL} = p_* \exp\left[\phi_*/R(T_{11}+\gamma\phi_*/2)\right]$$

where R is the gas constant, γ is a typical lapse rate for the mean tropical atmosphere (Oort and Rasmusson 1971), ϕ_* is the geopotential of the surface and T_{11} is the temperature of the lowest σ-layer.

1(a). *The boundary layer*

The approach adopted for modelling the boundary layer is very similar to that suggested by Clarke (1970). There are two parts to the formulation: (*a*) the surface fluxes and (*b*) the turbulent diffusion of properties through the boundary layer, assumed to occupy the three lowest layers. The surface fluxes of momentum, sensible heat and potential evaporation are expressed in terms of the wind at the lowest σ-level and the gradients of potential temperature and mixing ratio between the lowest σ-level and the surface. The formulation requires definition of a roughness length, taken as constant over land (10 cm) and dependent on wind stress over the sea.

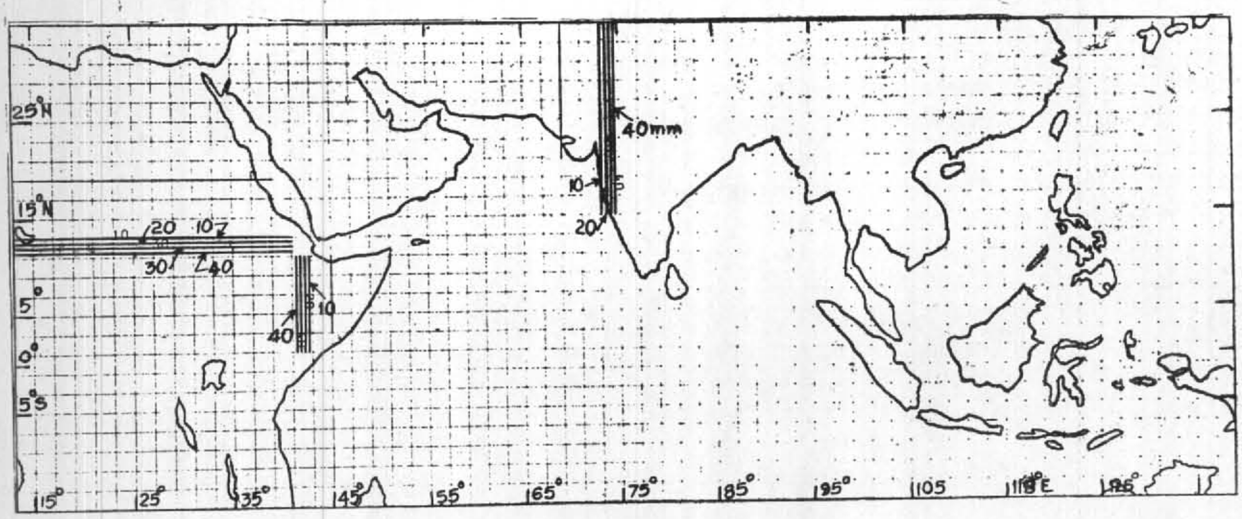

Fig. 2. Soil moisture content

The potential evaporation, E_p, is defined as the evaporation which would occur from a saturated surface for the given atmospheric conditions. To determine the actual evaporation, E, a formula which relates the ratio E/E_p to the soil moisture content (SMC) is used:

$$E = \begin{cases} E_p & \text{SMC} \geqslant 5 \text{ cm} \\ \dfrac{\text{SMC}}{5} E_p & \text{SMC} < 5 \text{ cm} \end{cases}$$

For SMC a fixed value of 5 cm is used for all land except North Africa, Saudi Arabia and the area to the east as far as the Thar desert. These areas have zero SMC, with a transition zone to the adjacent areas (Fig. 2). Evaporation is allowed to cool the surface (if land), the land being ascribed a thermal capacity equivalent to 5 cm of water. Sea surface temperatures are kept fixed throughout the integration.

To represent the turbulent diffusion of properties through the lowest three layers of the model a mixing length hypothesis is assumed with eddy diffusion coefficient K such that

$$K = l^2 \left| \frac{\partial V}{\partial z} \right|$$

The mixing lengths for momentum, heat and water vapour are assumed to be a function of stability and latitude as described by Clarke. However if layers are convectively unstable it is assumed that temperature and water vapour are mixed entirely by the convection scheme and the above mixing length approximation is not applied to these parameters in such conditions.

1(b). *Radiation*

The atmospheric radiative heating is $cS-R$ where S and R are mean daily solar heating and long wave cooling rates based on Dopplick (1970). S and R are functions of latitude and height; c is a diurnal variation coefficient which is zero at night but varies as a sine during the day and is scaled to give an average value of unity. The radiative heating to the surface is cH where H is the unreflected part of the total solar radiation received at the surface; the total solar radiation received is taken from Budyko (1963) and is dependent on both latitude and longitude. The albedo is assumed to range from ·28 (desert) to ·18 (non-desert), the surface condition being ascribed by reference to the SMC. The radiative output from the surface is $E_* s T_*^4$ where s is the Stefan constant, T_* the surface temperature of the model and E_* an effective surface emissivity dependent on climatological 850 mb specific humidity and cloudiness. The cloudiness data is obtained from IGY data mapped for the northern hemisphere by Lobanova (1967)and tabulated for the southern hemisphere by Kravcova (1968).

1(c). *Convection*

The parameterisation of convective processes is designed to represent the effects of deep penetrative convection characteristic of tropical systems (Lyne and Rowntree 1976). The scheme is based on the concept of the parcel theory, modified to provide a treatment of entrainment and detrainment and has been developed in the context of the GATE model (Lyne *et al.* 1975). Considering an ensemble of buoyant plumes of different radii, temperatures and humidities, these characteristics determine their entrainment rates and hence their upward extent. The less buoyant plumes terminate and detrain through lack of buoyancy at a lower level than more buoyant plumes which may, in favourable conditions, reach the heights accessible to an undilute parcel. In the parameterisation scheme rather than attempting to treat plumes of different characteristics separately the mean characteristics of the ensemble are considered. These characteristics are modified by an entrainment rate which decreases with height as the mean plume radius is assumed to increase and by detrainment of air from less buoyant plumes as they die; since this detrainment is at environment buoyancy it enhances the positive mean buoyancy of the ensemble. Any liquid water produced by condensation is rained out, but evaporation of this condensed water in the adjacent lower layer is permitted. The environment is modified by removal of entrained air, addition of detrained air, the compensating subsidence and the evaporation of precipitation falling from above. The scheme requires the specification of several parameters, which give the method flexibility and which through experimentation allows improvements to be made. The main parameters are the initial ensemble size, the rates of entrainment and detrainment, the initial temperature excess of the parcel over the environment, and the degree of evaporation permitted to precipitation falling through lower layers.

2. The analysis method

The objective analyses of geopotential height and wind data are performed basically independently, using optimum interpolation techniques, and then a mutual adjustment is made to the independently analysed fields to bring them towards a compatible balanced state. Analyses are performed at 12 different pressure levels (Jones 1976a, 1976b). Experiments over the monsoon area to date have used data received operationally in Bracknell *via* the Global Trunk Circuit.

The optimum interpolation method uses the previous day's forcast as a first-guess background field.

$$\overset{I}{h}_g = \overset{B}{h}_g + \sum_{i=1}^{\text{obs}} p_i\,(\overset{0}{h}_i - \overset{B}{h}_i)$$

where,

$\overset{I}{h}_g$ = analysed field,

$\overset{B}{h}_g$ = background field,

$\overset{0}{h}_i$ = observed value at observation location and

$\overset{B}{h}_i$ = background value at observation location

and summation is taken over the number of observations used (usually 8). The scheme is optimum in the sense that the weights p_i ascribed to each observation are such that the error in the analysis is minimised over a large number of analyses. To be able to choose the p_i accordingly it is required to know :

(*a*) The accuracies of the background fields

(*b*) the spatial correlations of background errors

(*c*) the accuracies of the differing types of observation (radiosonde, aireps, SIRS etc).

Specification of (*a*) and (*b*) has been made based on experiments conducted with the GATE version of the model. From these experiments the accuracies of the background fields are specified at every grid point and analysed level and the spatial correlations of background errors at each analysis level expressed as correlation functions dependent only on distance (*i.e.*, isotropy has been assumed for the background errors of both height and wind). The correlation function are largely based on data from the GATE ship arrays; it was found that only in that part of the GATE area there was sufficient proximity, frequency and reliability of data to allow satisfactory spatial correlations to be computed. These prediction statistics are, therefore, based on a particular region of the tropics, samples at a particular time of year. In the case of the correlations they are associated with a particular type of disturbance, namely the easterly waves which passed through the ship arrays. It is recognised that the application of these structure functions may not be appropriate to the monsoon area case studies.

The adjustment process applied after the optimum interpolation analysis is based on the Variational Adjustment Technique (Sasaki 1970). Having obtained grid point analyses of height and wind, a new set of balanced heights are first derived by applying the reverse balance equation to the wind field. The reverse balance height field will differ from the analysed height field, perhaps by a few decametres. Adjustments are then made to the analysed fields of height and wind in such a way that any departures from the balanced state that they possess tend towards a geostrophic balance. The way the adjustments act is such that the original wind field is almost exactly preserved in equatorial region; the absolute value of geopotential heights are close to their original values; and the gradients of height are changed towards the gradients of height implied in the reverse balance height field. The general effect of this adjustment process in experiments to date has been small. The analysis of relative humidity is performed in the same way as in the operational analysis used in the Central Forecasting Office, Bracknell except that analyses are performed directly on σ-levels ready for use in the forecasting model. The scheme is basically a successive correction method (Atkins 1974) using non-isotropic weighting functions to preserve well defined zones of humidity gradient as identified in the first guess field, which is again taken from the previous forecast.

An intervention facility exists whereby analysis can be repeated after subjective assessment.

Vertical interpolation is performed to convert the analysed winds and heights to pressure levels to winds and temperatures on σ-levels ready for the forecast.

3. Dynamic initialisation

The analysis scheme is followed by a dynamic initialisation process (Temperton 1976). The purpose of this is to reduce high frequency waves which could otherwise develop in the forecasting model. The process is dynamic in the sense that the process involves repeated application of the model's prediction equations from time zero, first to advance one forward timestep and then return one backward time step, followed by a linear combination of the latest values and the values at the end of the previous iteration. A wave of frequency w is damped by a factor $1-2\,w^2\triangle t^2$ by one cycle of this scheme so that high frequency models are selectively damped. Experiment shows that by applying the scheme for the equivalent of 6 hours of model time, external gravity waves are successfully removed.

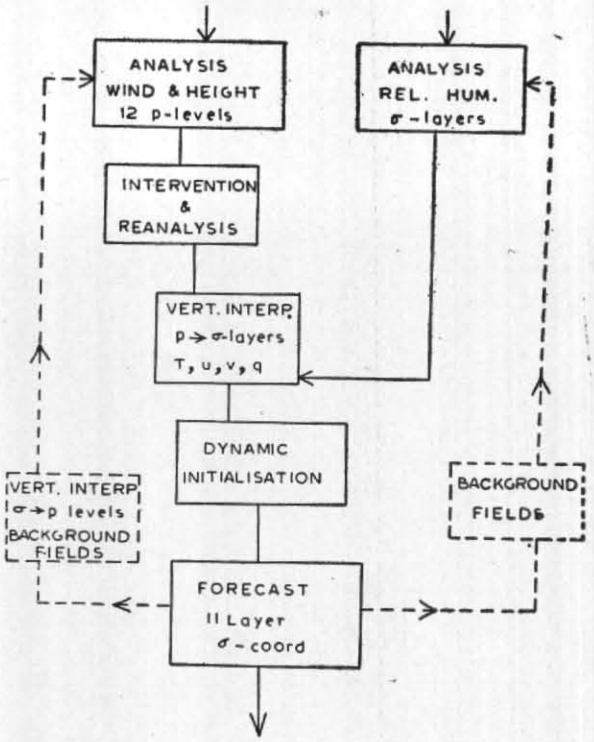

Fig. 3

During the initialization all sources and sinks of energy (including latent heat release) are ignored.

One extra effect is, however, incorporated : at the end of each cycle a convective adjustment is applied to the temperature fields, to prevent the generation of vertical instabilities by the initialization.

The overall forcasting cycle is summarised in Fig. 3. It is this scheme, described in the foregoing paragraphs, which has been used for short range prediction experiments in the monsoon region. Results of integrations from some recent real data cases will be presented and discussed.

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DISCUSSION

Abdul Latif Huneidi : Did you take into consideration the almost daily torrential rain which takes place in Oman interior ?

Author : The scale of the feature to which you refer is probably too small to be represented correctly in the model. However, there is some evidence of a localized maximum of rainfall in some of the forecasts in the region referred to.

J.B. Topaz : What are boundary conditions in your regional monsoon model? Your problem in the northern boundary may not be due all to topography. It could be due to improper boundary condition. At our centre we think that boundary conditions are very important in regional models and that they should be obtained from a global model.

Author : The boundary conditions are held fixed at their initial (analysed) state throughout the integration. It is possible that the problem south of the Himalayas is associated with the boundary conditions, though the point in question is five grid away from the boundary. Boundary conditions of the type referred to by you may well improve the integration but were not available for the forecasts described.