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Prediction of a Break in Monsoon Conditions Over India Using a Nested Grid Hemispheric Model

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Prediction of a Break in Monsoon Conditions over India Using a Nested Grid Hemispheric Model[1]

by

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ABSTRACT

A two-way interacting nested grid hemispheric model is used to study the interaction between a mid-latitude wave in westerlies and monsoonal circulation over India and to investigate the development of Break in Monsoon conditions. The horizontal coordinates are those of a polar stereographic projection. The vertical coordinate is σ and the vertical layer structure is similar to the energy conserving structure derived by Arakawa. 'Elliassen' horizontal staggered grid and Lax-Wendroff time-difference schemes are used. This model is being developed and presently incorporates some physical processes including convective and nonconvective release of latent heat, surface friction and turbulent diffusion.

The initial state is derived from the NMC Global Hough Analysis (1970) on 00 GMT 22 July 1975. Truncation errors in the sigma-coordinate expression for the horizontal pressure force are large over the steep slopes. However, a 48-hr prediction from the dry version of the model (release of latent heat not included) shows that the model forecasts reasonably well the eastward movement of a mid-latitude wave across northern India and the Himalayas and the development of an anticyclonic flow over central India: features known to

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occur with the development of break in monsoon conditions. A 24-hr prediction with the inclusion of convective and non-convective release of latent heat predicts major areas of precipitation over northern India located close to the areas of large observed precipitation.

1. Introduction

The summer monsoonal circulation over India is characterized by the formation of a heat low over Pakistan in the lowest troposphere with the axis of the monsoon trough running from this low to head of the Bay of Bengal. In the middle troposphere, cyclonic circulation exists over central India. The most characteristic feature in the upper troposphere is a zone of strong easterlies over southern India with maximum winds near the 150 mb level. Tropical cyclonic circulations which form over the Bay of Bengal and generally move westwards along the axis of monsoon trough induce moderate to heavy rainfall over most of India.

Sometimes the monsoon-trough shifts close to the foothills of the Himalayas. The rainfall in such cases becomes very weak and scattered over most of India except over the foothills of the Himalayas. Flooding over north India occurs in rivers which originate in the Himalayas. This anomalous situation where drought conditions prevail over most of India and heavy rainfall over the Himalayan foothills, and which results in flooding of rivers over north India, is called Break in Monsoon. Such breaks sometimes last for a week or more in July and August.

Ramaswami (1958, 1962) showed that large changes occur in the middle troposphere over India in the break monsoon conditions. The troughs in the midlatitude westerlies, which normally lie to the north of the Himalayas, protrude southward over north India. In the diffluent regions to the east of these troughs, heavy rainfall occurs. In addition he pointed out that the high over Iran and Arabia also shifts southward in such cases and the associated ridge extends over central India. The cyclonic flow in the middle troposphere over central India is therefore replaced by anticyclonic flow which would inhibit precipitation.

One of the goals of Monex is to investigate the interaction of monsoon circulation with the global atmospheric circulations. For this purpose, JOC has recommended development of nested grid models incorporating steep orography. In this paper, a nested grid hemispheric model (Phillips, 1974) incorporating steep topography is briefly described. Preliminary results from this model to predict the protrusion of a wave in the midlatitude westerlies over north India and the development of a break in monsoon conditions are presented.

2. Brief description of the model

The two-way interacting nested grid hemispheric model uses polar stereographic projection. The vertical coordinate is $\sigma = (p_S - p)/(p_S - p_T)$, where p = pressure/1000 mb, p_S = p at the ground and p_T = pressure at the top of the model atmosphere. An eight-layer ($K = k_{max} = 8$, see Fig. 1) version of the model was used in this study. The two components (u,v) of the horizontal wind, the potential temperature (θ), the mixing ratio (q), and $\psi = gZ/c_p$, are defined in the layers and $\hat{\sigma} = d\sigma/dt$ is defined at the interfaces. Note that interface values are represented by $(\hat{\ })$. Here Z is the geopotential and c_p

is the specific heat. The vertical finite-difference structure follows the pattern suggested by Arakawa (1972).

Variables are staggered in the horizontal according to the pattern described by Phillips (1962), with the two-step time integration procedure also described therein.

The u equation of motion is

(a) ½ time step

$$\frac{Du_k}{Dt} = - m\, c_p \left(\frac{\partial \psi_k}{\partial x} + \theta_k \frac{\partial \pi_k}{\partial x} \right)$$

$$+ \left(2\Omega \sin \text{H} + \frac{u_k y - v_k x}{2a^2} \right) v_k + \text{vertical diffusion} .$$

(b) Full time step

$$\frac{\partial H u_k}{\partial t} = - m^2 \left[\left(\frac{\partial}{\partial x} \frac{H u_k}{m} u_k \right) + \frac{\partial}{\partial y} \left(\frac{H v_k}{m} u_k \right) \right]$$

$$- \frac{H}{2\Delta_k} \left[\hat{\dot{\sigma}}_{k+1} \left(u_{k+1} + u_k \right) - \hat{\dot{\sigma}}_k \left(u_k + u_{k-1} \right) \right]$$

$$- m\, c_p \left\{ \frac{\partial}{\partial x} (H \psi_k) - \left[\psi_k + \theta_k \frac{\left(\hat{\hat{S}}_{k+1} \hat{\pi}_{k+1} - \hat{S}_k \hat{\pi}_k \right.}{\Delta_k} + \left. \pi_k \right) \right] \frac{\partial H}{\partial x} \right\}$$

$$+ \left[2\Omega \sin \text{H} + \frac{u_k y - v_k x}{2a^2} \right] H v_k + \text{vertical diffusion.}$$

and a similar equation for v.

The thermodynamic equation is:

(a) ½ time step

$$\frac{D\theta_k}{Dt} = \text{vertical diffusion} + \text{radiation} + \text{sensible heat}$$

(b) Full time step

$$\frac{\partial H\theta_k}{\partial t} = - m^2 \left[\frac{\partial}{\partial x}\left(\frac{Hu_k}{m} \theta_k\right) + \frac{\partial}{\partial y}\left(\frac{Hv_k}{m} \theta_k\right) \right]$$

$$- \frac{H}{2\Delta_k} \left[\hat{\dot{\sigma}}_{k+1}\left(\theta_{k+1} + \theta_k\right) - \hat{\dot{\sigma}}_k\left(\theta_k + \theta_{k-1}\right) \right]$$

$$+ \text{vertical diffusion} + \text{radiation} + \text{sensible heat} + \text{latent heat.}$$

The above equations together with equations of mixing ratio, continuity and hydrostatics are used for prediction.

Θ = latitude, λ = longitude

Ω = angular velocity of earth

m = map factor, a = radius of the earth

$(x, y) = (2a \cos\Theta/(1 + \sin\Theta))(\cos\lambda, \sin\lambda)$

$\hat{S}_k = 1 - \hat{\sigma}_k$, H = atmosphere thickness = $p_s - p_T$

$\hat{\pi} = (\hat{p}_k)^\kappa$, $\kappa = R/c_p$

$\pi_k = \left(\hat{p}_k\hat{\pi}_k - \hat{p}_{k+1} \hat{\pi}_{k+1}\right)/[(1 + \kappa)\left(\hat{p}_k - \hat{p}_{k+1}\right)]$

Notice that a Lagrangian advective scheme is used to predict the variables at the half time step. A detailed description of the model will be written up soon by Phillips.

3. Synoptic situation 22-26 July 1975

The weekly weather reports published by India Meteorological Department show that the monsoonal rainfal was either normal or in excess over India to the north of 22N in the week ending 23 July 1975. The rainfall was far below normal in the above region except near the foothills of the Himalayas in the week ending 30 July. The surface isobaric analysis published by the India Meteorological Department for 22, 24, and 26 July 1975 are shown in Fig. 2. These charts show a change from a nearly normal monsoon trough location (22 July) to a break in monsoon conditions (26 July). Notice that the isobars are oriented south to north in the normal monsoon situation (Fig. 2a) to the east of 80E and north of 20N. In contrast, the isobars run from west to east and a large north south pressure gradient exists in the break monsoon conditions (Fig. 2c). A very weak pressure gradient exists over north India during the intermediate day (Fig. 2b). These changes in the isobaric patterns imply that pressures fell over area north of 24N and east of 80E, and rose somewhat over central India during the above period (see Figs. 3a and 3b). The most pronounced pressure falls occurred close to the foot of the Himalayas east of 80E.

It is noted in section 1 that diffluent troughs in the westerlies protrude southward over north India when break in monsoon situations develop (Ramaswami 1958, 1962). If such a diffluent trough were to approach north India along 80E after 22 July, it could account for the observed pressure falls over north India. The position of a trough in westerlies at 500 mb over the Himalayan region indicated by the Global Hough objective analysis performed daily at NMC is shown in Fig. 4. It is evident that a trough in mid-latitude westerlies extends over north India just west of 80E after 24 July.

4. Numerical Results

In the Cartesian coordinates on a stereographic projection used in the model, there are 32.5 grid points between the pole and equator defining the coarse grid. The fine grid with twice the horizontal resolution is located over India and neighborhood.

a. Dry Model

The winds in the lower and the middle troposphere predicted by the dry version (release of latent heat not included) of the model are now presented. It was found that a large amplitude ($\sim$ 10 m sec^{-1}) quasi-stationary pattern in cross slope velocity develops in the lower troposphere in the region to the south of the Himalayas in the first 12 hours. Tests with a horizontally uniform resting standard atmosphere as initial data produced almost identical erroneous wind patterns and verify that these winds arise due to vertical truncation errors in the sigma coordinate expression for the horizontal pressure force. Although initially most severe at the tropopause level, by 12 hours, the outward propagation of an external gravity wave has left behind the quasi-stationary wind pattern referred to above. A vertical turbulent exchange coefficient proportional to the gradient of orography considerably reduced the amplitude of the quasi-stationary spurious waves without destroying flow patterns elsewhere. This is not viewed as a permanent solution to this well known problem, but was deemed justifiable here in order to test the basic meteorological hypothesis.

Streamline analyses[1] at layer one ($\sim$ 950 mb over the ocean) at the initial time (Fig. 5a) and t = 48 hr (Fig. 5b) show that the cyclonic circulation (weak surface depression) over northwest India is forecast to weaken. The easterlies over northwest India and southerlies over eastern India are replaced by westerlies. The predicted flow at 48 hrs therefore resembles a break in monsoon surface chart (Fig. 2b). The low over west

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[1]Wind barbs were plotted at all grid points on a microfilm output. Smoothed streamlines using these plots are presented here.

Pakiston is however not well predicted by the model. (Recall that surface heat flux and radiation are omitted in the current form of the model.)

The movement of the trough in the middle troposphere is also forecasted well by the model. For the purpose of showing this movement, the stream line analysis in layer 4 of our model (Fig. 6) is presented. This layer may be roughly taken to be at 600 mb over Indian region outside the Himalayas. The location of the trough and its extension southward at 48 hr (Fig. 6c) agrees fairly well with the observations (Fig. 4). Note that the anticyclonic circulation over India has shifted southwestwards and the ridge line is located at 48 hr farther to the south than at 0 hr.

b. Moist Model

The time integration was also carried out incorporating the convective (Kuo-type parameterization) and so-called large-scale release of latent heat. Regions of significant rainfall (1 cm or more) predicted by the model in 24 hours are shown in Fig. 7. These regions are located close to the regions of observed significant precipitation. In view of the fact that the initial state in the model is derived from a very coarse mesh (2.5° lat. x 2.5° long.) objective Hough analysis, the similarity between the observed and the predicted 24-hr rainfall regions is fair. The spurious gravity waves which originate in the regions of steep orographic gradients in the southern Himalayas do affect the solution over north India by 12 hrs and this partially accounts for larger rainfall amounts predicted by the model.

5. Remarks

The nested grid hemispheric model reasonably predicted the changes in the lower and the middle troposphere which occur during the transition from a normal monsoon situation to a break in monsoon conditions. In particular, the phase speed of the wave in westerlies and its southward extension over the Indian region is well predicted. Spurious large amplitude quasi-stationary pattern in cross slope velocity develops in the model over north India. These gravity waves are generated due to truncation errors in determining pressure forces in the regions of steep orographic gradients over the Himalayas. The magnitude of these cross slope velocities are considerably reduced by including a vertical exchange coefficient proportional to the gradient of orography at the lowest level. Further work is needed to be done to further reduce this problem, however.

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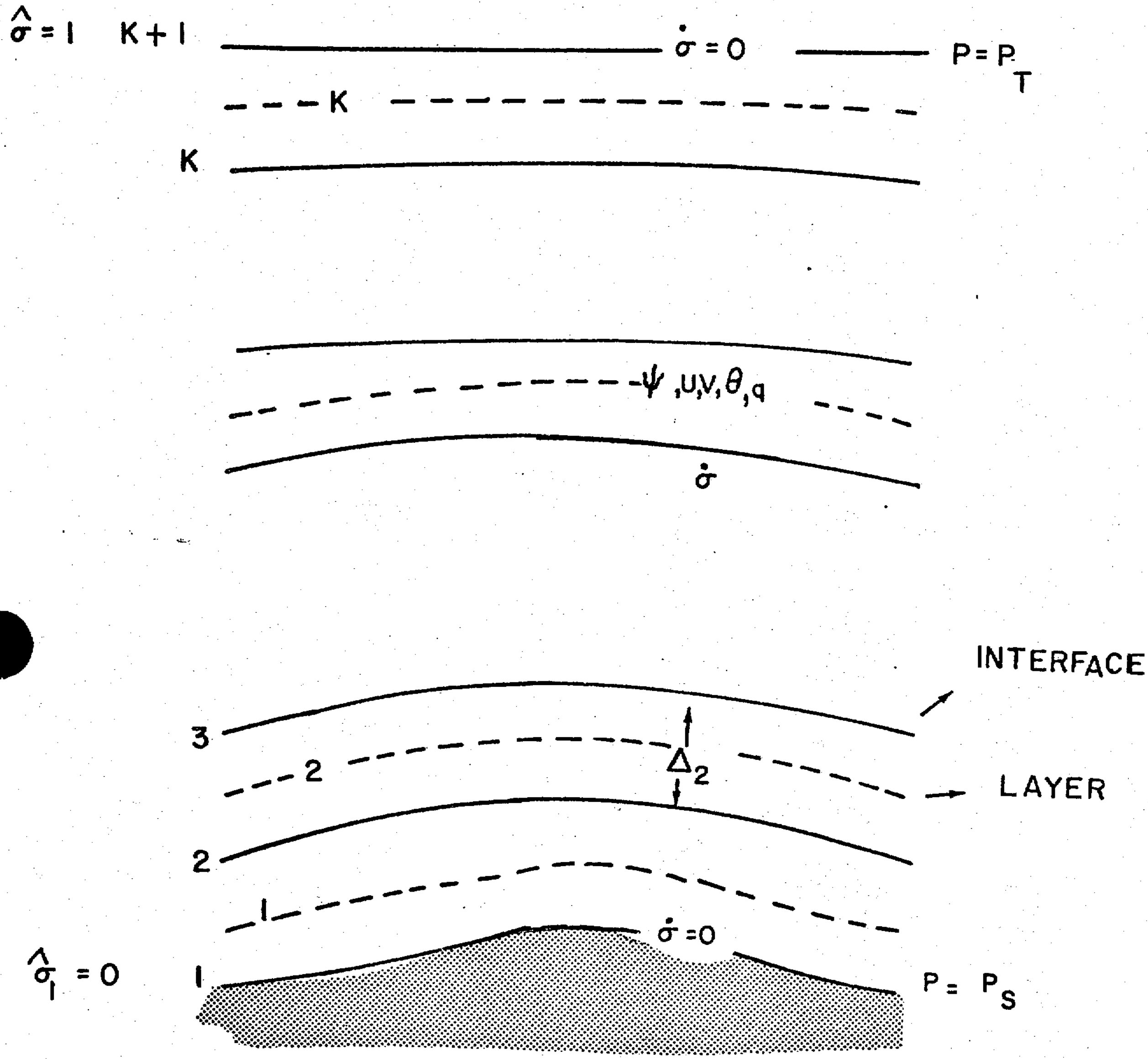
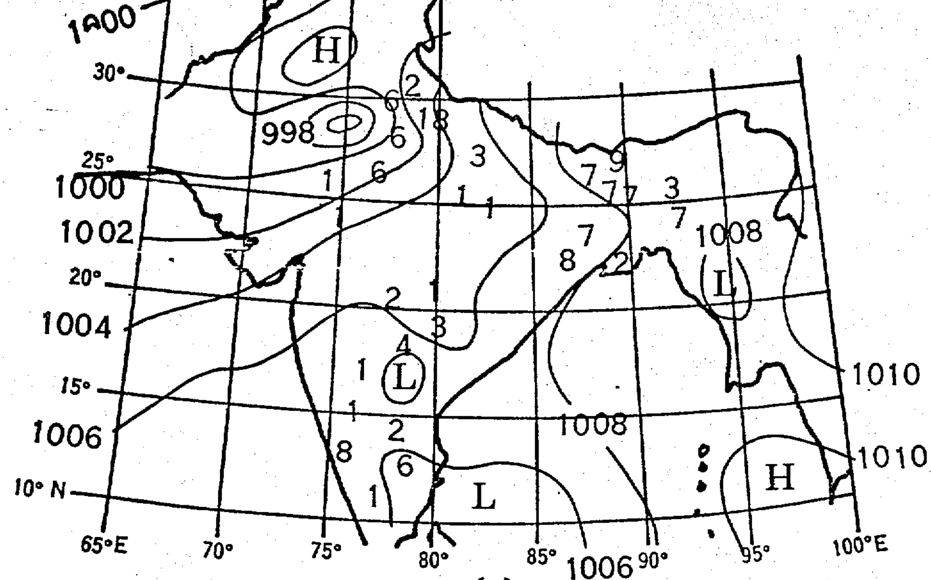


FIG. 1 VERTICAL STAGGERING OF VARABLES

2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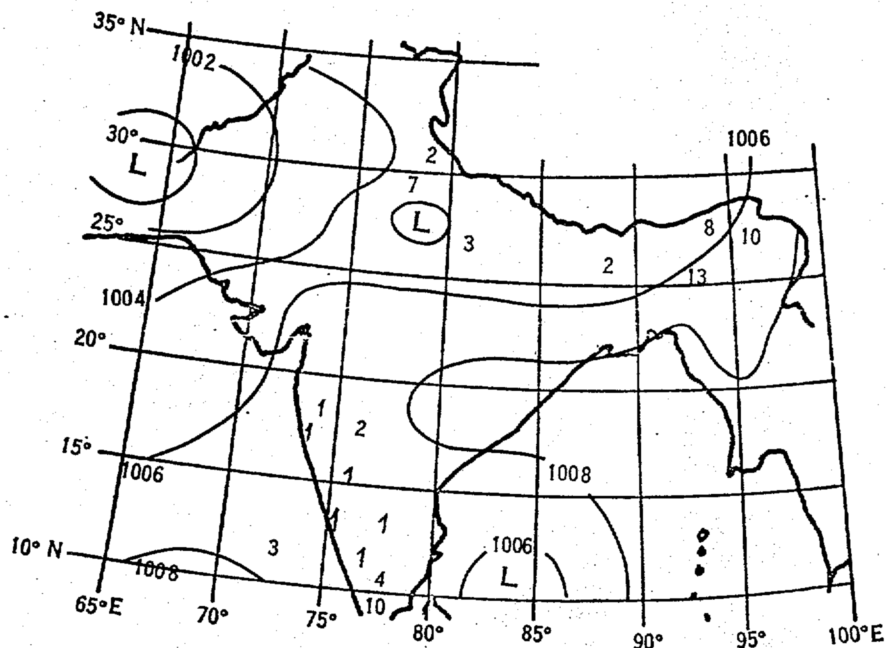
(a)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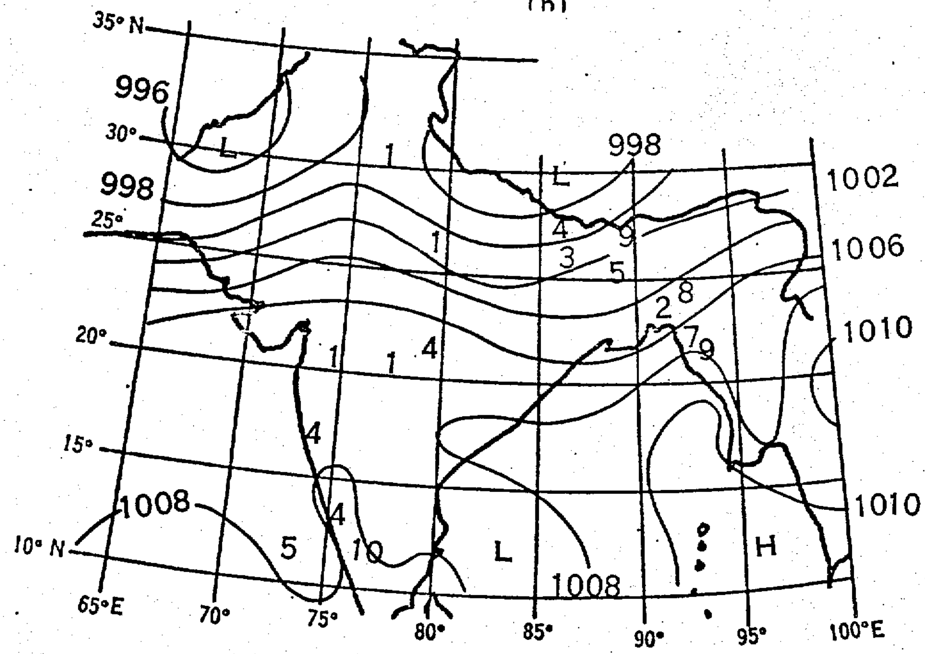
(b)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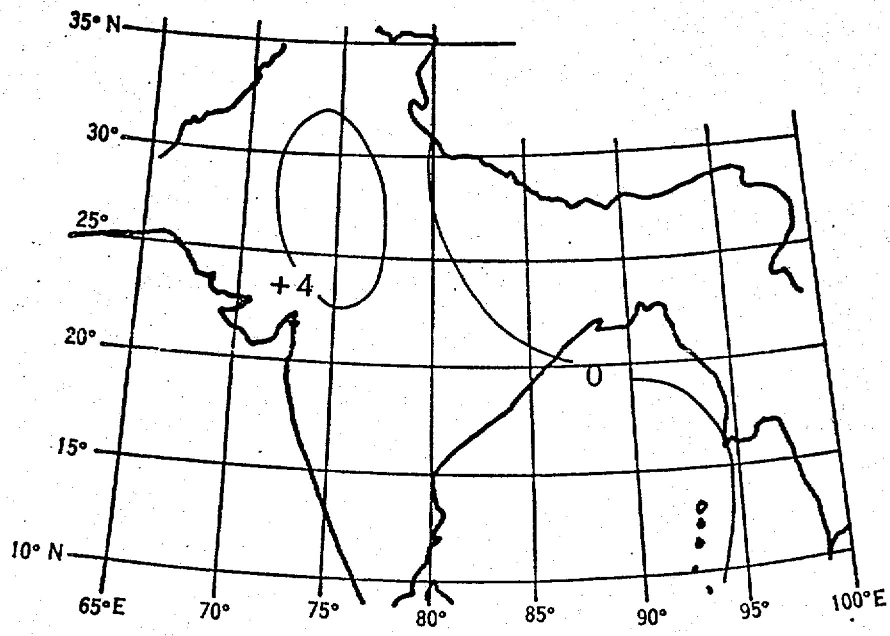
100°E

(c)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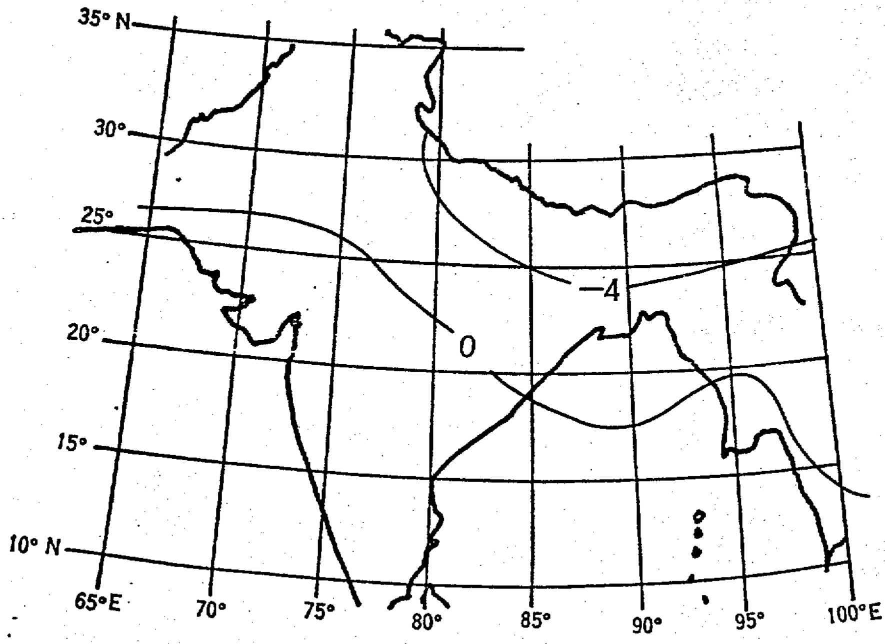
(a)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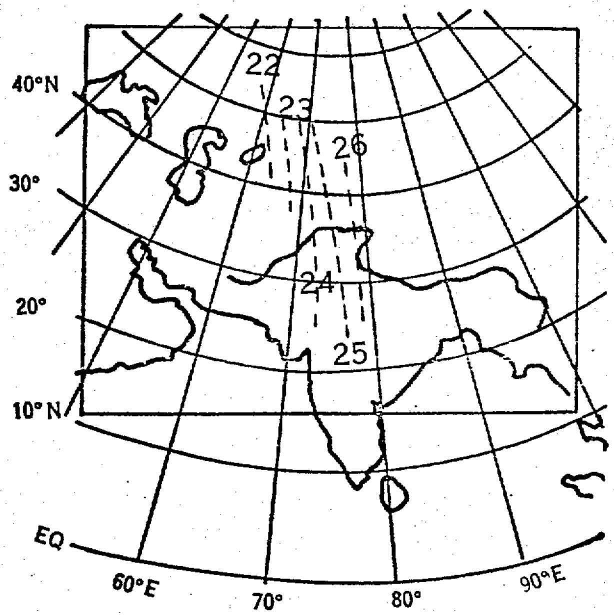
③



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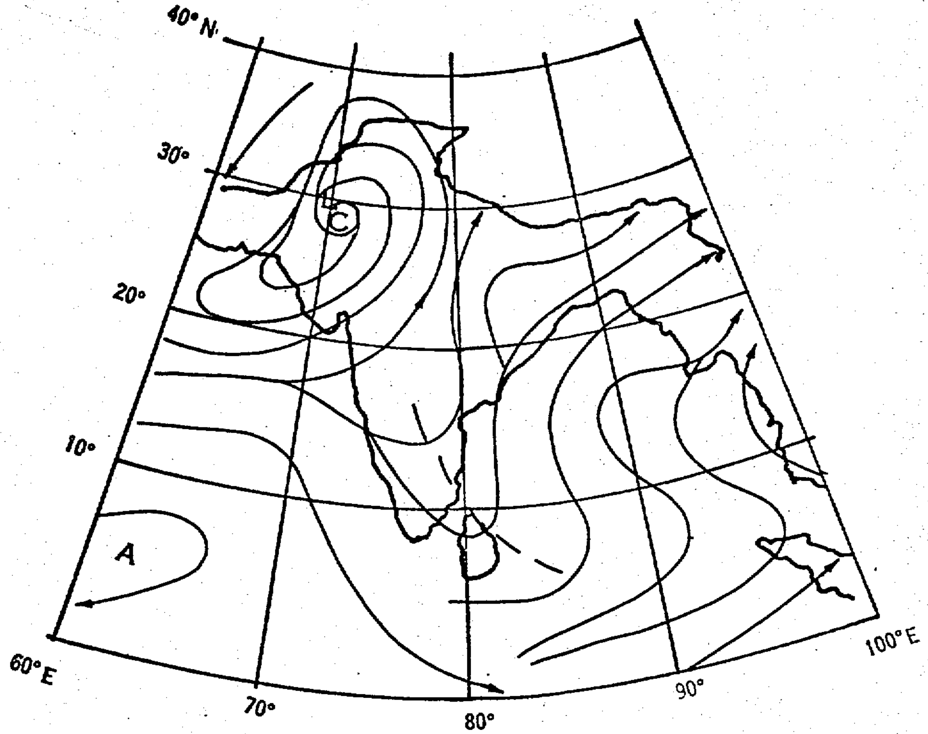
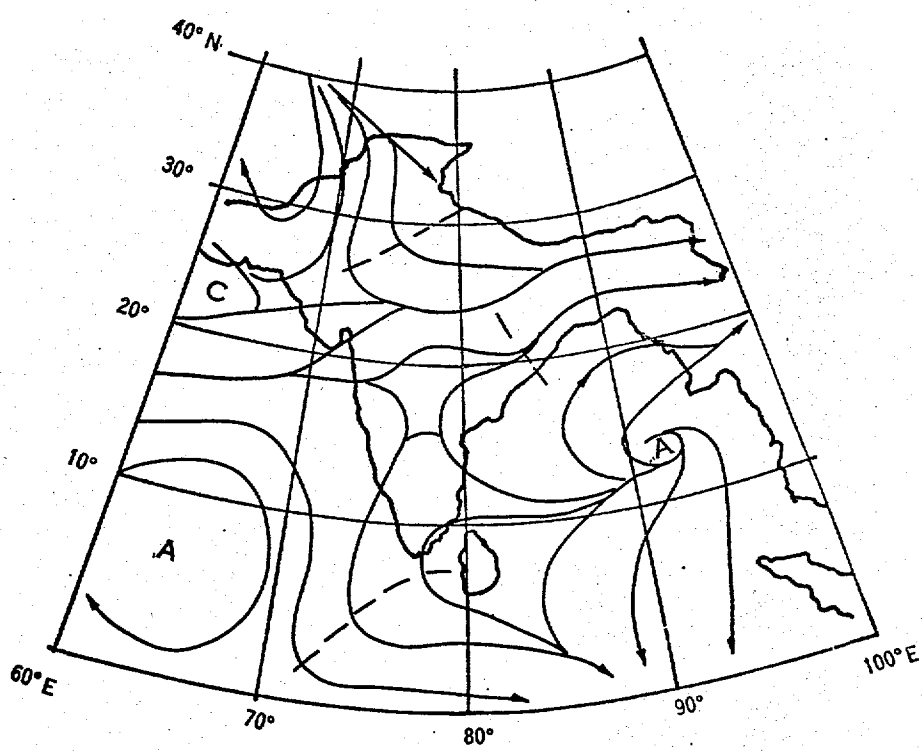


(a)



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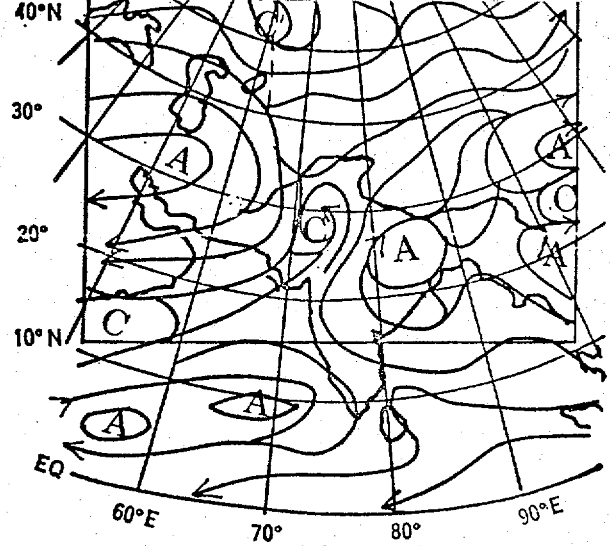
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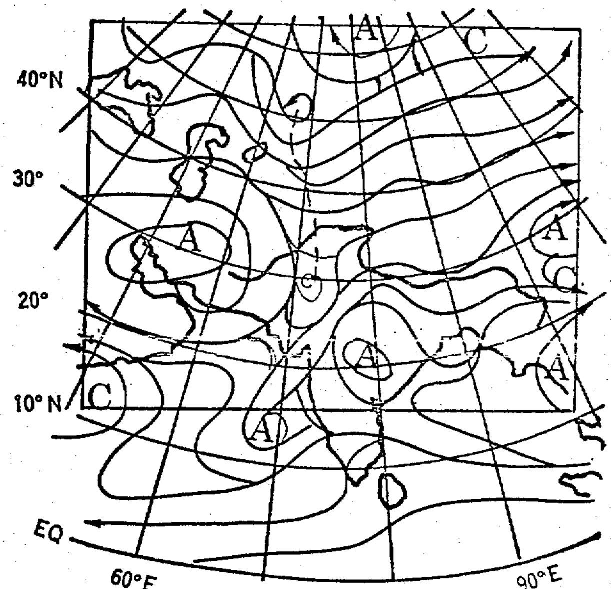
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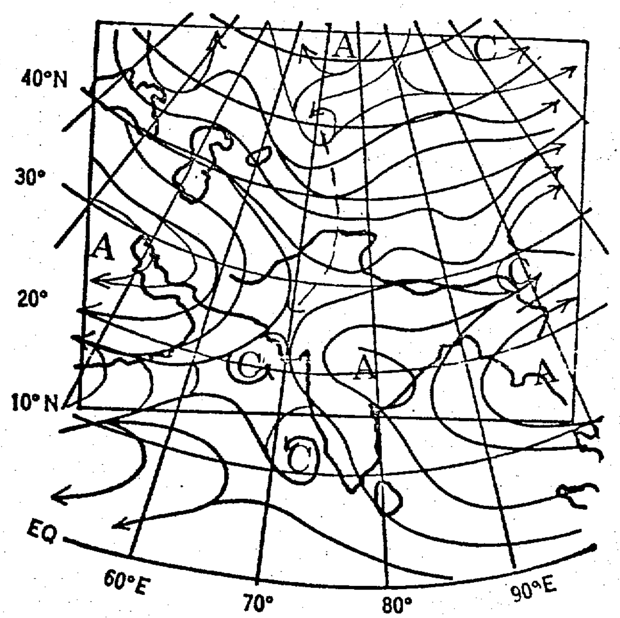
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(c)

b

(7)

(7)