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Simulation of certain features of ITCZ over Indian sub-continent

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ABSTRACT. This study is an attempt to simulate certain features of pre-onset phase of summer monsoon circulation. The simulation experiment is based on Primitive Equation Barotropic Model written in flux form. The significant forcings considered during the experiment are heat source and sink in the two hemispheres. The experiment generates flow pattern very similar to conceptual flow pattern of early June discussed by Sud and Datta (1979). The similarity of the flow pattern in the simulated and actual/conceptual flow pattern is interesting and is discussed in this paper.

1. Introduction

The onset of the monsoon is a central problem for studying the behaviour of monsoon over India. One of the most important synoptic features which an Indian meteorologist looks for is the location and the intensity of the monsoon trough. Even after the onset phase, the location of the monsoon trough, especially during the absence of any monsoon depression, seems to play a very significant role in the distribution of rainfall. Specifically, question arises as to what is this monsoon trough and how it is related to Inter Tropical Convergence Zone (ITCZ) and the well known Equatorial Trough (ET). In particular the following questions were addressed by the planners of the monsoon experiment (MONEX 79):

(1) Does the ITCZ merely lose its identity in its equatorial position under the influence of the continentality (*viz.*, Continental Monsoon Trough)?

(2) What are the dynamical mechanisms that describe the replacement of an oceanic ITCZ by a continental monsoon trough? Furthermore, what is their relation to the onset?

Sud and Datta (1979) studied the relationship between ITCZ and Equatorial Trough during the onset phase of two contrasting monsoons for the years 1977 and 1978. To avoid confusion and for the purpose of uniformity of analysis they defined ET as a trough in pressure field and ITCZ as a zone where northerlies from northern hemisphere and southerlies from southern hemisphere converge. The study clearly brought out the contrasting structure of ET *vis-a-vis* ITCZ during the years. To understand this mechanism little more in detailed manner, the present study is an attempt to study the type of circulation which gets generated as a consequence of heat source and sink in the two hemispheres. The result of the simulation experiment which is based on Primitive Equation Barotropic Model, written in flux form is discussed in the present paper.

2. Description of the model

The model equations are based on the shallow-water equations on a β-plane.

In (x, y) coordinates, the equations for a shallow layer of fluid with a free surface are:

$$\frac{Du}{Dt} - fv + g\frac{\partial h'}{\partial x} = 0 \qquad (1)$$

$$\frac{Dv}{Dt} + fu + g\frac{\partial h'}{\partial y} = 0 \qquad (2)$$

$$\frac{D}{Dt}(h' - h_s) + (h' - h_s)\nabla \cdot \mathbf{V} = Q \qquad (3)$$

where h' is the height of the free surface, h_s is the height of the bottom topography and Q is the source/sink term.

Setting $h=h'-h_s$ and writing Eqns. (1)-(3) in the flux form, we obtain :

$$\frac{\partial}{\partial t}(hu)+\frac{\partial}{\partial x}(huu)+\frac{\partial}{\partial y}(huv)-fhv+$$

$$+hg\frac{\partial h}{\partial x}+gh\frac{\partial h_s}{\partial x}= \qquad (4)$$

$$\frac{\partial}{\partial t}(hv)+\frac{\partial}{\partial x}(huv)+\frac{\partial}{\partial y}(hvv)+fhu+$$

$$+hg\frac{\partial h}{\partial y}+gh\frac{\partial h_s}{\partial y}=0 \qquad (5)$$

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(hu)+\frac{\partial}{\partial y}(hv)=Q \qquad (6)$$

Writing Eqns. (4)-(6) in a standard second order finite difference form on an unstaggered grid, we get :

$$\delta_t\overline{hu}^t+\delta_x(\overline{hu}^x\,\overline{u}^x)+\delta_y(\overline{hv}^y\,\overline{u}^y)-fhv+$$

$$+gh\,\delta_x\overline{(h+h_s)}^x=0 \qquad (7)$$

$$\delta_t\overline{hv}^t+\delta_x(\overline{hu}^x\,\overline{v}^x)+\delta_y(\overline{hv}^y\,\overline{v}^y)+fhu+$$

$$+gh\delta_y\overline{(h+h_s)}^y=0 \qquad (8)$$

$$\delta_t\overline{h}^t+\delta_x(\overline{hu}^x)+\delta_y(\overline{hv}^y)=Q \qquad (9)$$

where,

$$(\overline{\ })_{i+\frac{1}{2}}=\tfrac{1}{2}[(\ )_i+(\ )_{i+1}]$$

$$\delta_x(\ )_{i+\frac{1}{2}}=\frac{1}{\Delta x}[(\ )_{i+1}-(\ )_i]$$

The set of Eqns. (7)-(9) have been solved by the usual centred differencing in time and space subject to the following initial conditions. :

$$u=v=0,\ h=\text{constant}=1.5\text{ km} \qquad (10)$$

The integration domain is centred on the equator and is 6000 km in the E-W as well as N-S directions. The grid length has been taken as 100 km in each directions.

Periodic boundary conditions have been considered in the E-W while no flux conditions are assumed at the north and south boundaries.

3. Forcings

3.1. *Heating effects*

An important forcing in the model is that due to a source/sink term. This forcing has been based on two considerations, *viz.*, (1) a region of outflow at 30°S representing the low-level divergence associated with the southern hemisphere high pressure belt and (2) a region of inflow at 30° N representing the low-level convergence of the monsoon trough. The source/sink term has been taken in the form :

$$Q=A\exp-\left(\frac{x-x_0}{a}\right)^2\left[\exp-\left(\frac{y+y_0}{b}\right)^2-\exp-\left(\frac{y-y_0}{b}\right)^2\right] \qquad (11)$$

where (x_0, y_0) are coordinates of the centre of an ellipse with major axis $2a$ = 1000 km and the minor axis $2b$ = 500 km. We have taken x_0 = 5000 km and y_0 = 2000 km. The constant $A\sim 0(10^{-2})$ which is equivalent to a heating rate of approximately 1°C per day.

3.2. *Topography*

Another important forcing which we propose to incorporate is the effect of topography. The significant topographic features being east African highland, topography of Western Ghats and Himalayas. As a first step we included an idealized topography of east African highland, the other regions are proposed to be included subsequently.

The idealized topography for east African highland has been taken in the form :

$$h_s=h_0F(x)G(y) \qquad (12)$$

when h_0 has been taken to be 1 km and $F(x)$, $G(y)$ are certain exponential functions. In a simplified form, the topography appears as a vertical wall between 10° S to 10° N and 40°E to 50° E.

4. Input

The model integration is initiated with uniform height of 1.5 km for free surface thereby starting with calm wind. The future variation in height and wind field is generated by the above two forcings, significant of these being heating function.

5. Results and discussion

Keeping the topography constant, we tried various experiments with different values of the constant A in the heating function (11), where $A=2\times10^{-2}$ generates within six hours of integration strong wind field, and with $A=0.5\times10^{-2}$, the generation is very slow, such that even after 24 hours of integration the wind field is only of the order of 1-2 m sec^{-1}. $A=1\times10^{-2}$ was found to be quite reasonable. Moreover it agrees with the order of heating over NE India during monsoon month (Das 1962).

After integration of 42 hours a more or less stable wind field gets established with maximum wind speed of 10 m sec^{-1}. The flow pattern is depicted in Fig. 1.

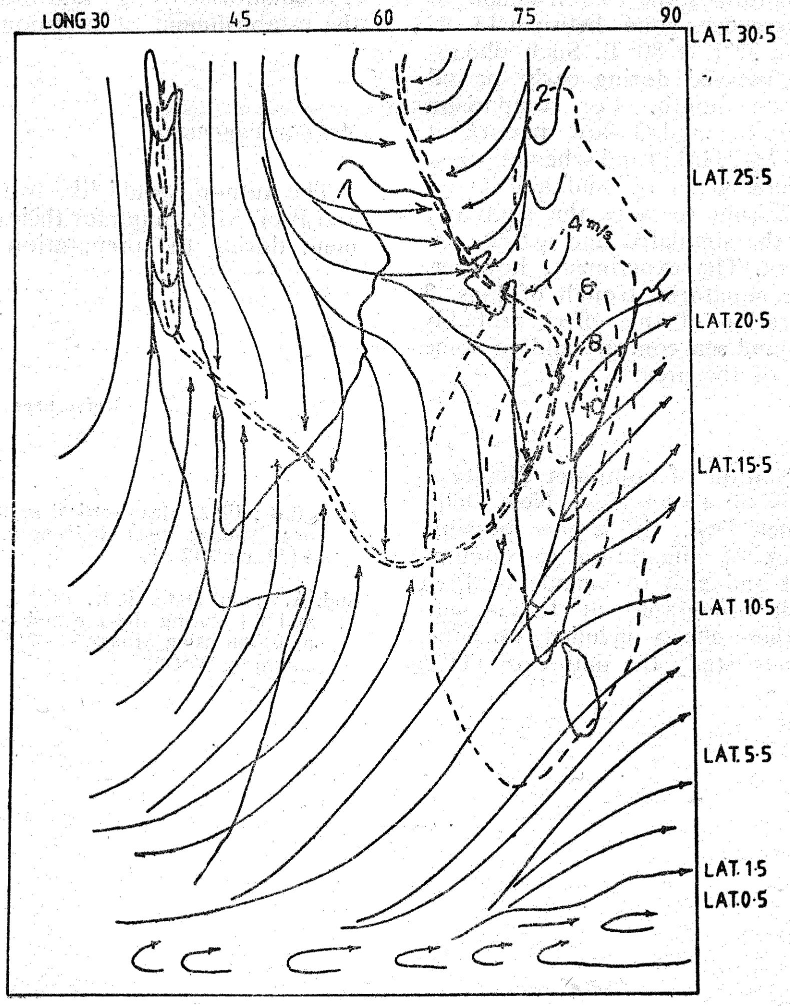

Fig. 1

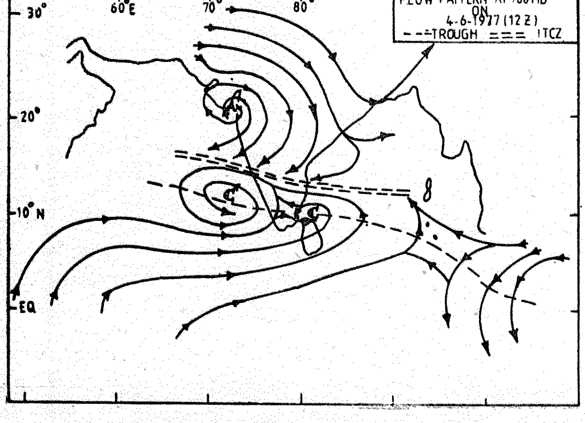

Fig. 2

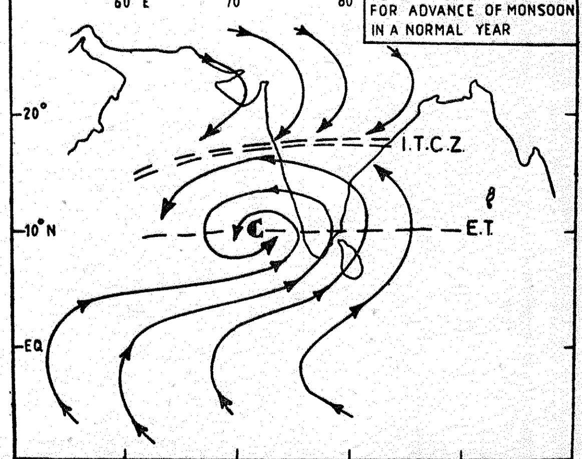

Fig. 3

The significant feature is the establishment of well marked convergence zone between 13° N & 28°N and between 37°E & 80° E. Such phenomenon has been observed during early period of summer monsoon month. For comparison we reproduce in Figs. 2 and 3 flow pattern at 700 mb on 4 June 1977 (12 GMT) and schematic flow pattern of early June given by Sud and Datta (1979). It is interesting to note the similarity of flow pattern in the simulated and actual/conceptual flow pattern. The experiment, however, could not generate equatorial trough of Figs. 2 and 3. The generation of this effect probably needs addition of land/sea contrast and to some extent topography of the area.

6. Future work

With the augmentation of computer facility at the Indian Institute of Technology, New Delhi as well as India met. Dep., it is now possible to extend our area of integration to circumpolar tropical belt and also to include land/sea contrast alongwith topography of Indian subcontinent. With these effects included, we hope, it will be possible to study the nature of ITCZ and equatorial trough and their relationship with the establishment of monsoon trough.

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