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ENERGETICS OF MONSOON DISTURBANCES*

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ABSTRACT

The evidence for the growth of monsoon disturbances by the process of barotropic and baroclinic instabilities is examined. A new mechanism for the growth of tropical disturbances is proposed.

INTRODUCTION

THE DEVELOPMENT of monsoon depressions has been studied by Koteswaram and George (1958). The energetics of these disturbances has been studied by Keshavamurty (MS), Rao and Rajamani (1968) and Sreeramamurthy (1967). It is the object of the present paper to examine the evidence for the growth of monsoon disturbances by the known processes of barocilinic and barotropic instabilities.

SOURCES OF ENERGY FOR DISTURBANCES

Equation (1) shows the sources of energy for the growth of disturbances.

$$\frac{\partial K_E}{\partial t} = - \int \underbrace{[\omega^* \alpha^*]}_{A} \, dm - \int \underbrace{[u^* v^*]}_{B} \frac{\partial [u]}{\partial y} \, dm \qquad \ldots\ldots(1)$$

The main sources of energy for the growth of disturbances are (a) by conversion from the eddy available potential energy by x-p overturnings *i.e.* by the process of baroclinic instability (term A). (b) by conversion from zonal kinetic energy by the down-gradient transport of momentum by the eddies *i.e.* by the process of barotropic instability (term B).

Baroclinic growth

For the production of eddy available potential energy at the expense of zonal available potential energy the eddies have to transport sensible heat down the gradient. In the Indian monsoon the temperature gradient is from south to north. Therefore, for production of eddy available potential energy monsoon disturbances have to transport sensible heat from north to south.

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Koteswaram and George (1958) have shown that there is warm advection ahead of the depressions and cold advection in the rear. Keshavamurty (MS) has also discussed the southward sensible heat transport by monsoon depressions. Rao and Rajamani (1968) have been shown that monsoon disturbances convert zonal into eddy available potential energy. We shall further examine the evidence for this as follows :

For southward transport of sensible heat higher temperatures should be associated with northerlies and lower temperatures with southerlies i.e. $\overline{v'\tau'}$ at a station (under the influence of monsoon depressions) should be negative. We have split up $\overline{v'\tau'}$ at Nagpur into various periods. We computed the cospectra of the meridional component of wind and the 700-1000 mb thickness at Nagpur during the monsoon season of 1967. Keshavamurthy (1976) has analysed the periodicities corresponding to monsoon disturbances :

(i) monsoon depressions with a period of 20 days

(ii) monsoon lows with a period of 5.5 days and

(iii) middle and upper tropospheric lows or waves with a period of 7.5 days.

The cospectrum in the period 20 days corresponding to monsoon depressions is found to be negative showing that monsoon depressions transport sensible heat southwards. The cospectrum in the period 5.5 days is small and of indifferent sign (in the neighbouring frequencies) showing that the weak monsoon lows may not transport considerable sensible heat.

It can be shown (Murakami) that for baroclinic growth of perturbations upward motion should be in the region of warm advection or in the case of monsoon disturbances in the region of northerlies.

Synoptic evidence shows that most of the clouding (Keshavamurty, MS) and heavy rainfall (Pisharoty and Asnani, 1957) in association with monsoon depressions is in the western sector (southwestern to be more precise). This would show that there is ascent of warm air and descent of cold air in the x-p plane and conversion from eddy available potential energy into eddy kinetic energy and hence growth of the depression by the process of baroclinic instability.

Some theoretical studies (Keshavamurty, 1966 ; Sreeramamurthy, 1967), however, do not suggest that the monsoon field is favourable for the growth of disturbances by the process of baroclinic instability.

Barotropic instability

Let us now examine the evidence for the growth of disturbances by the process of barotropic instability. For growth by this mechanism monsoon disturbances should transport momentum from south to north (as $-\frac{\partial u}{\partial y}$ is positive in the monsoon field) *i.e.* at a station $\overline{u'v'}$ should be positive. We have split $\overline{u'v'}$ into periods. We have calculated the cospectura of u and v components of wind at a number of Indian stations during the monsoon season of 1967. Fig. 1 a and b show the field of the cospec-

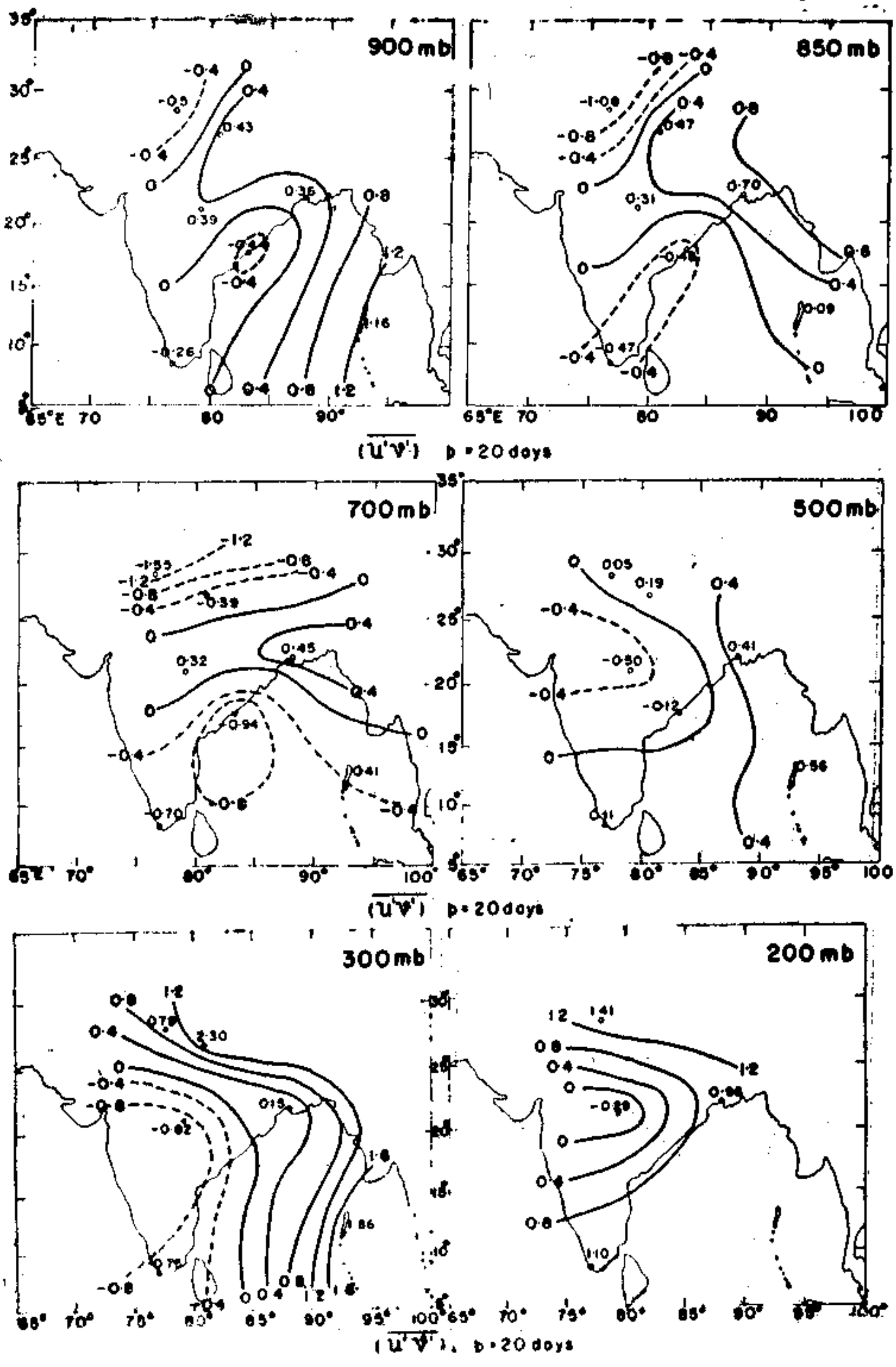
900 mb
850 mb
700 mb
500 mb
300 mb
200 mb
(U'V') p = 20 days
(U'V') p = 20 days
(U'V') p = 20 days

Fig. 1 A

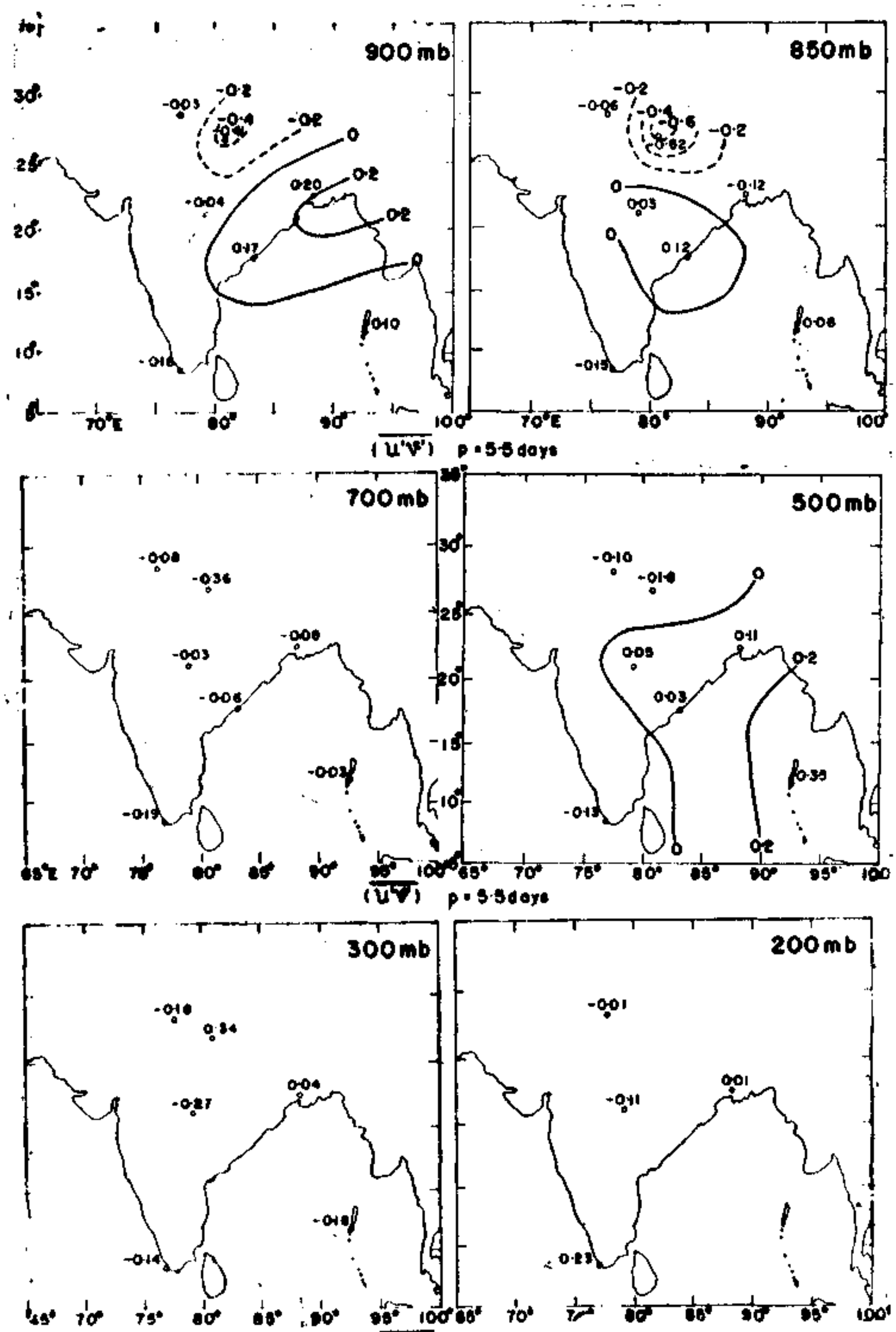
900 mb
850 mb
(u'v') p = 5·5 days
700 mb
500 mb
(u'v') p = 5·5 days
300 mb
200 mb
(u'v'), p = 5·5 days

Fig. 1 B

trum in the Indian region at standard levels in the periods (i) 20 days corresponding to monsoon depression (ii) 5.5 days corresponding to monsoon lows. It is seen that the period 20 days in the lower troposphere $\overline{u'v'}$ is positive over Bay of Bengal, Central India and eastern parts of North India, showing that monsoon depressions can derive energy from zonal motion and grow by the process of barotropic instability. However the cospectrum in the period 5.5 days corresponding to monsoon lows is smaller or even negative. The possibility of their growth by this mechanism is less.

A New Mechanism for the Growth of Monsoon Disturbances

Let us consider the equation for the balance of transient kinetic energy

$$\frac{\partial K'}{\partial t} = \text{Influx}$$

$$- \int \overline{u'v'} \left(\frac{\partial \bar{u}}{\partial y} \underset{\substack{\uparrow \\ A}}{+} \frac{\partial \bar{v}}{\partial x} \right) dm - \int \left(\overline{u'^2} \frac{\partial \bar{u}}{\partial x} \underset{\substack{\uparrow \\ B}}{+} \overline{v'^2} \frac{\partial \bar{v}}{\partial y} \right) dm$$

$$- \underset{\substack{\uparrow \\ C}}{\int \overline{\mathbb{V}' \cdot \nabla \phi'}} \, dm + \underset{\substack{\uparrow \\ D}}{\int \overline{\mathbb{V}' \cdot \mathbb{F}'}} \, dm \qquad \ldots\ldots(2)$$

Term A shows the growth of disturbance kinetic energy by processes similar to barotropic instability and term C by baroclinic instability. Term D shows the dissipation by friction. Let us now look at term B. In this term $\overline{u'^2}$ and $\overline{v'^2}$ are positive. Therefore this term will be positive if $\frac{\partial \bar{u}}{\partial x}$ and $\frac{\partial \bar{v}}{\partial y}$ are negative. These are divergence terms and generally small in the free atmosphere. But let us consider the friction layer. In the friction layer there will be frictional convergence in regions of cyclonic vorticity. The region of the monsoon trough is a region of cyclonic vorticity and hence there is frictional convergence. Therefore term B will always contribute to growth of disturbance kinetic energy. I have called this growth by the name 'barotropic instability of the second kind' (BISK). This is distinct from conditional instability of the second kind which requires cumulus convection.

Conclusion

(i) Evidence is produced to show that monsoon depressions can grow both by the processes of baroclinic and barotropic instabilities.

(ii) A new mechanism for the growth of monsoon disturbances is proposed.

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