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ENERGY CONVERSIONS DURING WEAK MONSOON

by

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Abstract

Using the quasi-geostrophic ω -equation (including friction and orography), the ω -field and energy conversions have been computed over the Indian region on a weak monsoon day, an active monsoon day and during mean July.

During mean July a meridional circulation with ascent over north India and descent to the south is seen. This cell is found to be direct, with conversion from zonal available potential energy into zonal kinetic energy. It is found that this conversion is small compared to the work done by the meridional circulation. The difference between these two arises from the larger pressure work or flux of potential energy at the boundaries.

The meridional cell is not seen on a weak monsoon day, when uniform descent is seen through out. The conversion from ZAPE into ZKE is also much less than during the mean. On the day of strong monsoon, however, the meridional cell is much more marked than in the mean and the associated energy conversion is also larger.

The Walker Circulation in the z-p plane, however, appears to be more marked during weak monsoon than during the mean.

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Energy Conversions during weak monsoon

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1. Introduction

Energy conversions in the mean monsoon have been studied by Keshavamurty (1971). The main energy conversion was found to be from zonal available potential energy into zonal kinetic energy by y-p overturnings in the mean meridional circulation. It may be worthwhile studuing this on an occasion of weak monsoon. We have computed quasi-geostrophic ω and energy conversions on a weak monsoon day and contrasted it with those in the mean monsoon and on a strong monsoon day.

2. Quasi-geostrophic ω -equation

The quasi-geostrophic ω -equation is

$$\sigma \nabla^2 \omega + f_0^2 \frac{\partial^2 \omega}{\partial p^2} = g \frac{\partial}{\partial p} J(z, \eta) - \frac{g^2}{f_0} \nabla^2 J\left(z, \frac{\partial z}{\partial p}\right) \cdot \cdot \quad (1)$$

where $\sigma = - \frac{\alpha}{\theta} \frac{\partial \theta}{\partial p}$

$$\eta = \frac{g}{f_0} \nabla z + f$$

The first term on the right hand side is the forcing due to vorticity advection and the second term is the forcing due to thermal advection. These forcings can be computed from a given height field.

We have solved this equation by relaxation. At the side wells and at the top, the boundary condition used is $\omega = 0$. At the bottom, we have used ω due to friction and orography.

We have used Charney and Eliassen's (1949) formula for frictional ω.

$$\omega_F = -g \rho \sqrt{\frac{K}{2f_0}} \sin 2\alpha \, (\zeta_{g_{1000}}) \quad \ldots\ldots \quad (2)$$

K = coefficient of eddy viscosity

α = angle of inflow

$\zeta_{g_{1000}}$ = geostrophic vorticity at 1000 mb.

The orographic ω was obtained by

$$\omega = - g \rho (\mathbf{V}_{g_{1000}} \cdot \nabla h) \quad \ldots\ldots \quad (3)$$

where h is the height of terrain above mean sea level taken from Berkofsky and Bortoni (1960).

Since the above ω -equation is linear, we can partition the ω due to different forcings and also sue to different boundary conditions.

3. Situations studied

We have computed quasi-geostrophic ω and energy conversions for mean monsoon (July), on a weak monsoon day i.e. 19 July 1963 and on a strong monsoon day i.e. 7 July 1963. Some contrasting features of these two monsoon situations have been studied by Raman et al (1965). Fig.1 shows 1000 mb analysis for 19 July 1963. It is seen that the monsoon trough has shifted to the foot, of the Himalayas on the weak monsoon day.

We have considered height data at 1000, 850, 700, 500, 300, 200 and 100 mb and have computed ω at 850, 700, 500, 300 and 200 mb.

The area for which computations are made is from 5°N to 22.5°N and 55°E to 95°E. A grid distance of 2½° was used.

4. Meridional Cell

We have averaged the ω (at each latitude and level) between the longitudes 55° and 95° E. Fig.2 shows the y-p section of zonally averaged ω for mean July. The mean meridional circulation with ascent over North India and descent to the south is seen. This meridional cell is also seen in the mean meridional winds (Fig.3). This meridional circulation was discussed by Koteswaram (1960) and Rao (1962). Fig.4 shows the y-p section of zonally averaged ω for 19 July 1963. It is seen that the monsoon cell is conspicuous by its absence on 19 July 1963 (weak monsoon). We have uniform descent throughout. Fig.5 shows such a section for 7 July 1963 (strong monsoon). It is seen that the monsoon meridional cell is stronger than the mean July cell.

The energy conversion in the meridional cell has also been computed.

5. Energy conversion in the meridional cell

This conversion from zonal available potential energy into zonal kinetic energy is given by

$$C(A_Z, K_Z) = - \int_{p_{100\,mb}}^{p_{1000}} \widetilde{[\omega]''[\alpha]''} \, \frac{dp}{g} \qquad \ldots\ldots (4)$$

where $\omega = \frac{dp}{dt}$

and $\alpha = - \frac{\partial \phi}{\partial p}$

The square bracket indicates zonal average, the tilde indicates area average and the double prime the deviation from the area average. The conversion from ZAPE into ZKE during mean July, on 19 July 1963 and on 7 July 1963 are indicated in Table 1.

	Mean July	19 July 1963 (weak monsoon)	7 July 1963 (Strong monsoon)
$C(A_z, K_z)$	+ 0.19 Watt/m^2	+ 0.06 Watt/m^2	0.57 Watt/m^2

Table 1. Conversion from ZAPE to ZKE

It is seen that the climatological meridional monsoon cell is direct (energy-producing). It is more marked on a day of strong monsoon and the rate of energy production is larger than in the mean. On a day of weak monsoon, this meridional cell is not seen and there is mostly descent throughout. The energy conversion is also much less.

6. Work done by the mean monsoon meridional circulation and conversion from ZAPE to ZKE.

The work done or the kinetic energy released by the mean meridionals Circulation in a longitudinal belt $\Delta\lambda$ per unit length of the meridian is

$$\left.\begin{aligned} &- a \cos\varphi\,\Delta\lambda \int_{p_{100\ mb}}^{p_{1000}} [\bar{v}]\,\frac{\partial[\phi]}{\partial y}\,\frac{dp}{g} \\ &= a \cos\varphi\,\Delta\lambda \int_{p_{100}}^{p_{1000}} [\bar{v}]\, f\, [\bar{u}_g]\,\frac{dp}{g} \\ &\backsimeq \frac{f_a \cos\varphi\,\Delta\lambda}{g} \int_{p_{100}}^{p_{1000}} [\bar{v}]\,[\bar{u}]\,dp \end{aligned}\right\} \quad \cdots\cdot (5)$$

assuming $\bar{u} \backsimeq \bar{u}_g$. The bar indicates time mean and the square bracket indicates average between longitudes λ and $\lambda+\Delta\lambda$. Keshavamurty (1968) estimated this energy release over the Indian monsoon region as 3 Watt/m^2.

However, we have seen that the conversion from zonal available potential energy into zonal kinetic energy by 'y-p' overturnings in the mean meridional circulation has been found to be 0.19 Watt/m^2 , which is on order of magnitude smaller than the work done by the mean meridional circulation. The difference between these two arises because we are considering a limited region and there are large fluxes at the boundary. Now the work done by the mean meridional circulation can be expanded as

$$-[v]\frac{\partial[\bar{\Phi}]}{\partial y} = -\left\{\frac{\partial}{\partial y}[\bar{v}][\bar{\Phi}] - [\bar{\Phi}]\frac{\partial[\bar{v}]}{\partial y}\right\}$$

$$= -\frac{\partial}{\partial y}[\bar{v}][\bar{\Phi}] + [\bar{\Phi}]\left\{\frac{\partial[\omega]}{\partial p} - \left[\frac{\partial\bar{u}}{\partial x}\right]\right\}$$

$$= -\frac{\partial}{\partial y}[\bar{v}][\bar{\Phi}] - [\Phi]\frac{\partial[\bar{\omega}]}{\partial p} - [\bar{\Phi}]\left(\frac{\bar{u}_2-\bar{u}_1}{\Delta x}\right)$$

$$= -\frac{\partial}{\partial y}[\bar{v}][\bar{\Phi}] - [\bar{\Phi}]\left(\frac{\bar{u}_2-\bar{u}_1}{\Delta x}\right)$$

$$-\left\{\frac{\partial}{\partial p}[\bar{\Phi}][\bar{\omega}] - [\bar{\omega}]\frac{\partial[\bar{\Phi}]}{\partial p}\right\}$$

$$\underset{\substack{\uparrow\\ \text{Work done by the}\\ \text{mean meridional}\\ \text{circulation}}}{-[\bar{v}]\frac{\partial[\bar{\Phi}]}{\partial y}} = \underbrace{\frac{\partial}{\partial y}[v][\Phi] - [\Phi]\left(\frac{\bar{u}_2-\bar{u}_1}{\Delta x}\right) - \frac{\partial}{\partial p}[\Phi][\bar{\omega}]}_{\substack{\uparrow\\ \text{Fluxes at the}\\ \text{boundary}}} \underbrace{-[\bar{\omega}][\bar{\alpha}]}_{\substack{\uparrow\\ \text{Conversion from}\\ \text{Z}_{\text{ape}}\text{ into ZKE}}} \qquad (6)$$

U_1 and U_2 refer to the zonal wind at the western and eastern boundaries and is the distance between the boundaries.

Out of the large energy release in the monsoon meridional circulation, only a small part is used in driving the local circulation.

A large part of this is used up in the work done at the boundaries or export of potential energy to the southern hemisphere and to Africa, mainly in the upper troposphere. This is evident from the mean 200 mb wind field July (Fig.6).

7. Circulation in the x-p plane

Das (1962) deduced the mean ω -field in the Indian region and found a region of strong ascent over Northeast India and a region of descent over NW India - Pakistan. Keshavamurty (1970) estimated the associated energy conversion and found that this circulation in the x-p plane is indirect i.e. that there might be conversion from standing eddy kinetic energy into standing eddy available potential energy. Fig. 7 shows the East West Walker circulation along 15 N during mean July. Its maximum intensity is however likely to be further north. Krishnamurti (1971) located this East-West Walker circulation by computing the non-divergent wind component at 200 mb. Pisharoty (1972) drew attention to the importance of this circulation and postulated an eastward shift of this Walker circulation during periods of drought.

We have estimated the conversion from eddy available potential energy into eddy kinetic energy on these two days of strong and weak monsoon. They are shown in Table 2.

	7 July 1963 (Strong monsoon)	19 July 1963 (Weak monsoon)
$C\ (A_E\ ,\ K_E\ )$	-0.08 Watt/m^2	0.12 Watt/m^2

Table 2. Conversion from EAPE to EKE

It is seen that there is conversion from eddy available potential energy into eddy kinetic energy on the weak monsoon day and surprisingly from eddy kinetic energy into eddy available potential energy on the day of strong monsoon.

from eddy kinetic energy into eddy available potential energy on the day of strong monsoon.

8. Discussion

It was seen in the earlier section that the mean meridional circulation is direct and there is conversion from ZAPE into ZKE by y-p overturnings in this cell. It was also seen that this cell is more marked during strong monsoon and the associated energy conversion is also larger in magnitude. During weak monsoon, this meridional cell is weaker than normal and the associated energy conversion is also less.

The north-south distribution of diabatic heating (resulting from the heating of Asian land-mass in contrast to the ocean to the south, the heating of the Himalayas and the release of latent heat over north India) drives this monsoon meridional cell. We can speculates as to why this cell is less marked during weak monsoon. One reason can be less-marked north-south temperature contrast. Keshavamurty et.al. (1972) found that the north-south temperature gradient during the drought month of August 1965 is weaker than during the normal monsoon month of August 1967. They also found that during periods of drought southerly components develop in the upper troposphere over peninsular India in place of the normal northerly components supporting weakening of the meridional circulation during these periods. Keshavamurty et.al. (1972) found that the upper atmosphere over north India is cooler during periods of drought. This may be due to advection of cold air from mid-latitudes or due to less

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release of latent heat.

Regarding the East-West Walker circulation, the situation appears to be quite the reverse. This circulation is possibly more marked and energy producing during periods of weak monsoon or drought than during periods of normal or active monsoon. This hypothesis is supported by the rainfall distribution during breaks in the monsoon (Ramamurthy, 1969). The rainfall during breaks is above normal over northeast India, and is below normal over northwest India.

The above two modes i.e. the meridional and the zonal modes of the monsoon have been discussed by Ramage (1972).

9. Conclusion

The final picture that emerges is that during weak monsoon or drought the monsoon meridional cell is weaker than normal, but the East-West Walker cell is stronger than normal. We have to investigate further as to what are the general circulation features like the abnormalities of quasi-stationary planetary waves and other such features that might influence these two circulations.

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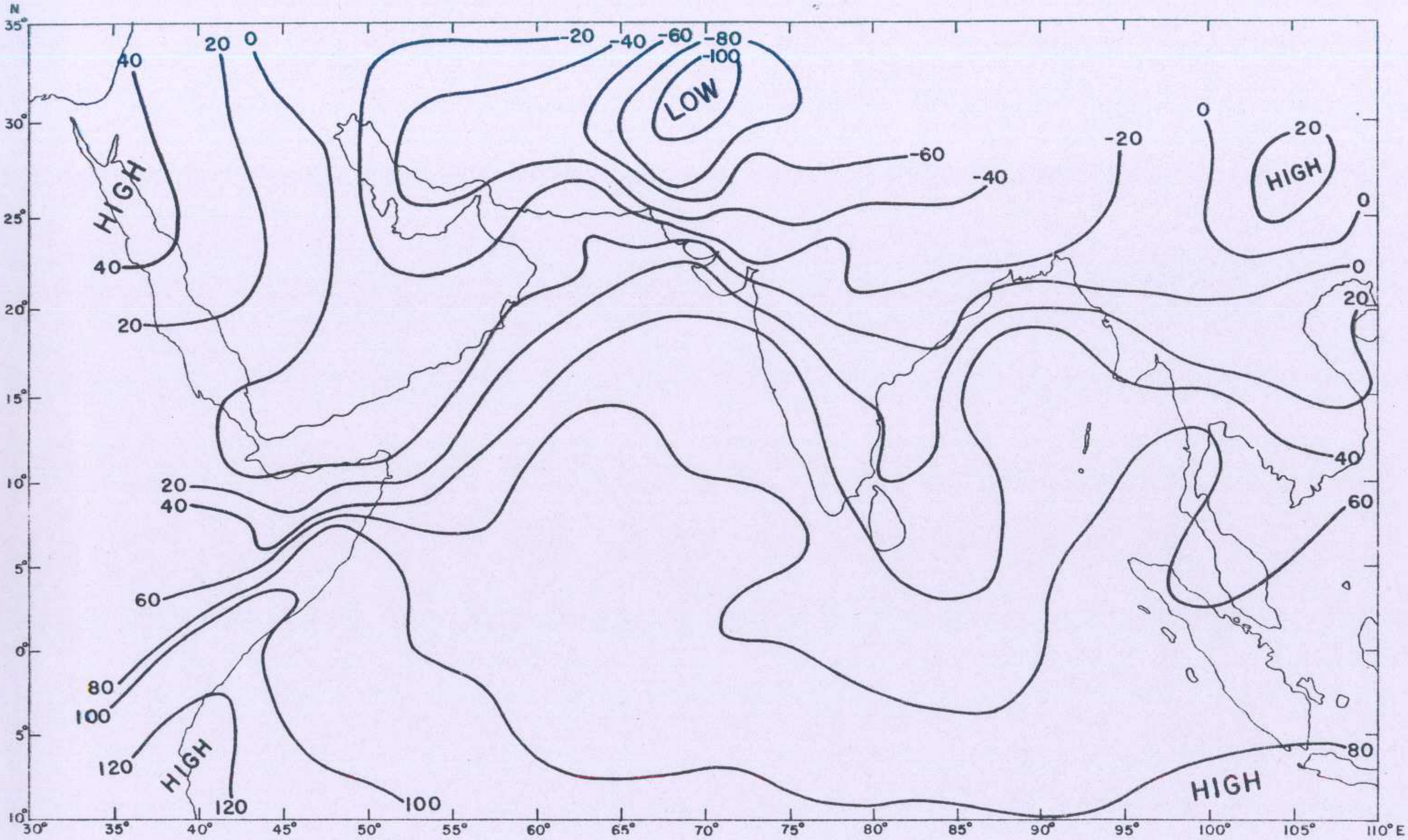

FIG. I . 1000 MB HEIGHT FIELD (GPM). 19-7-63.

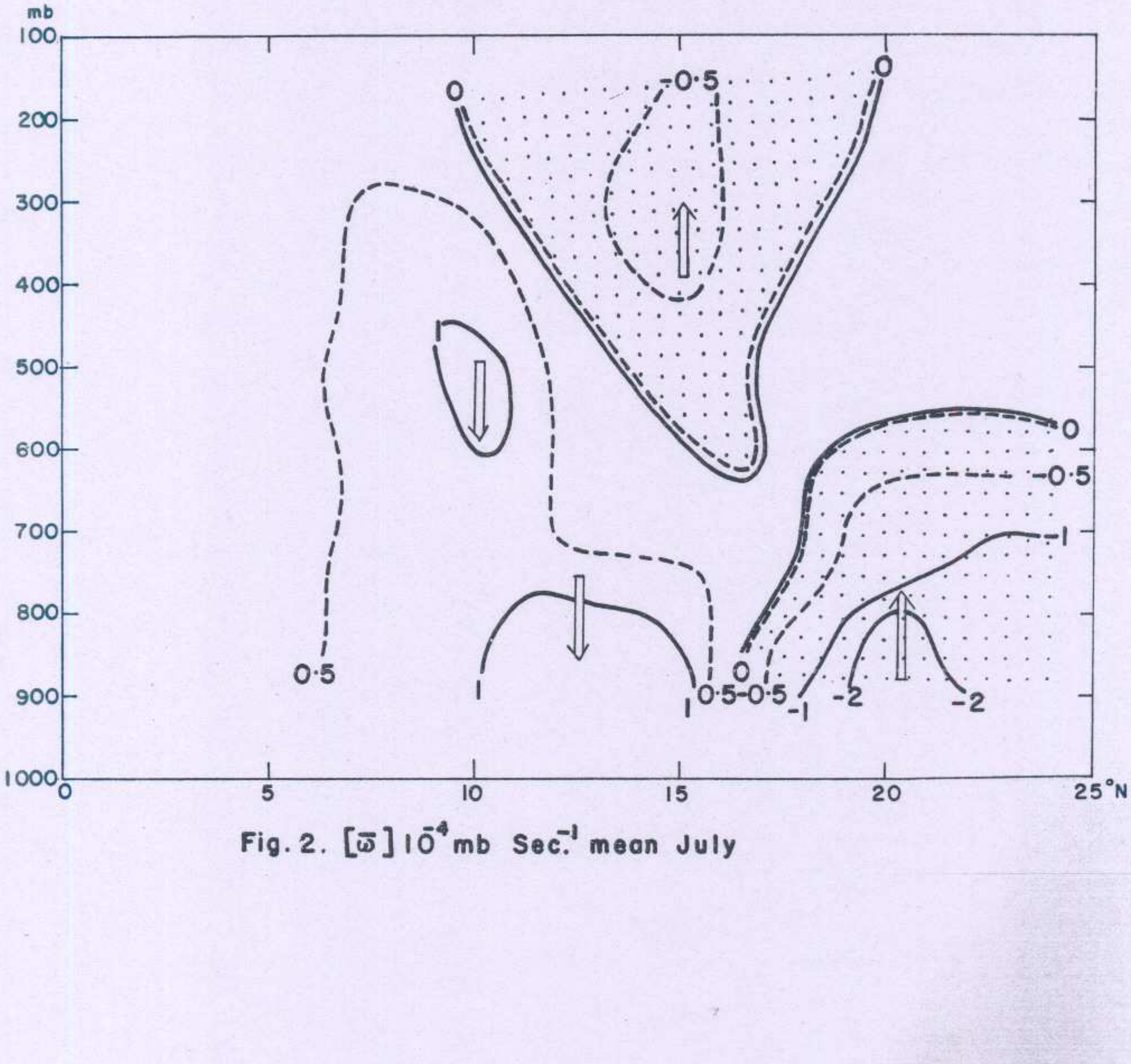

Fig. 2. $[\bar{\omega}]\ 10^{-4}$ mb Sec.$^{-1}$ mean July

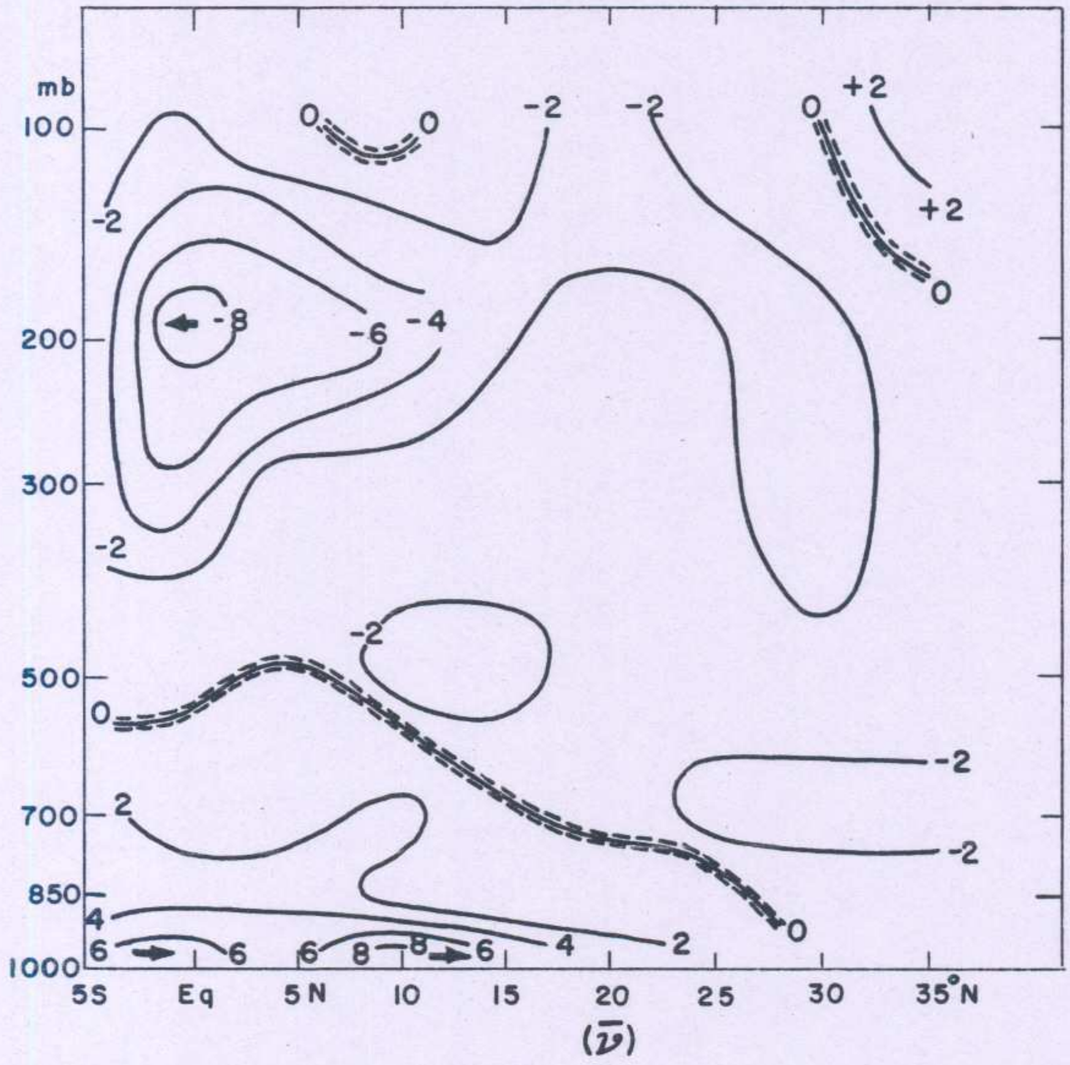

Fig. 3. Mean v-component for July averaged between 50E & 100E (in kt)

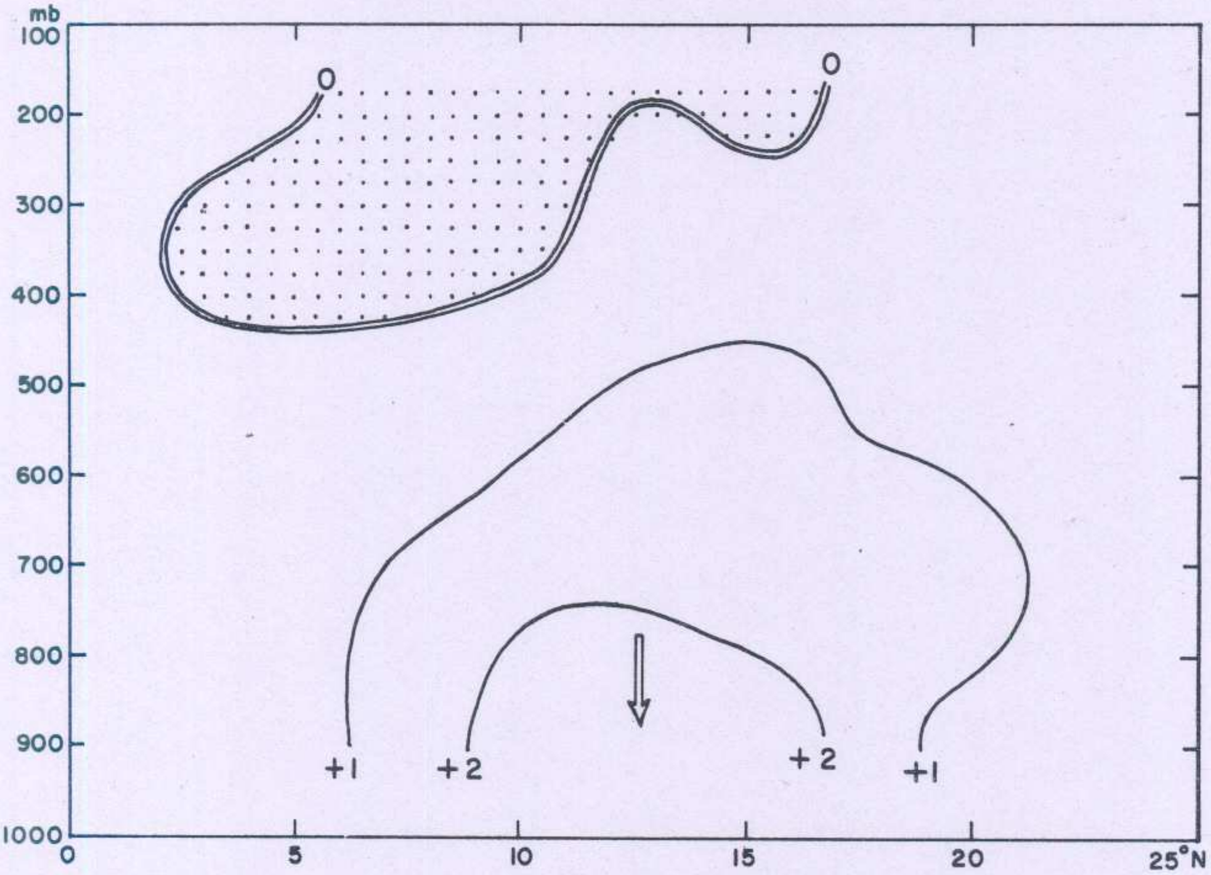

Fig. 4. [ω] 10^{-4}mb Sec.$^{-1}$ 19 July 1963.

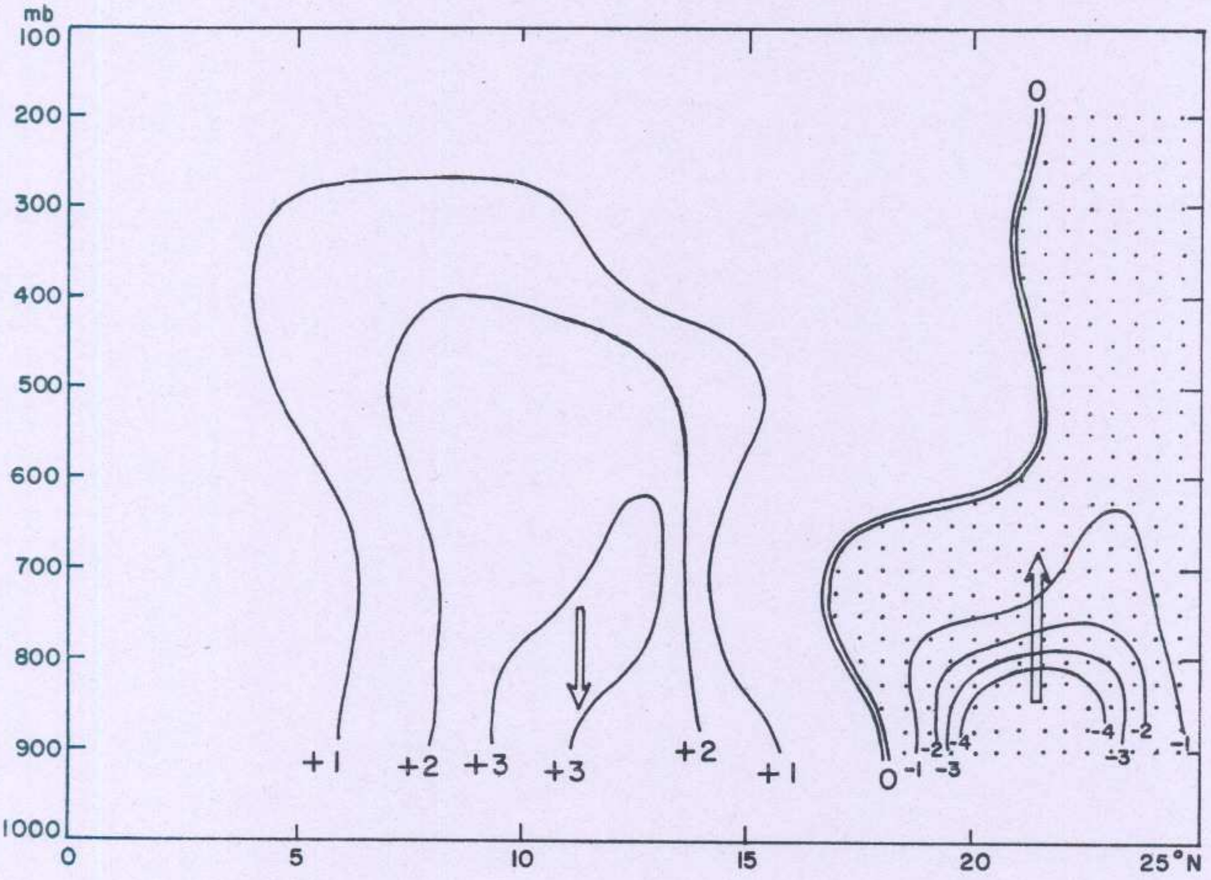

Fig. 5. [ω] 10^{-4} mb Sec.$^{-1}$ 7 July 1963.

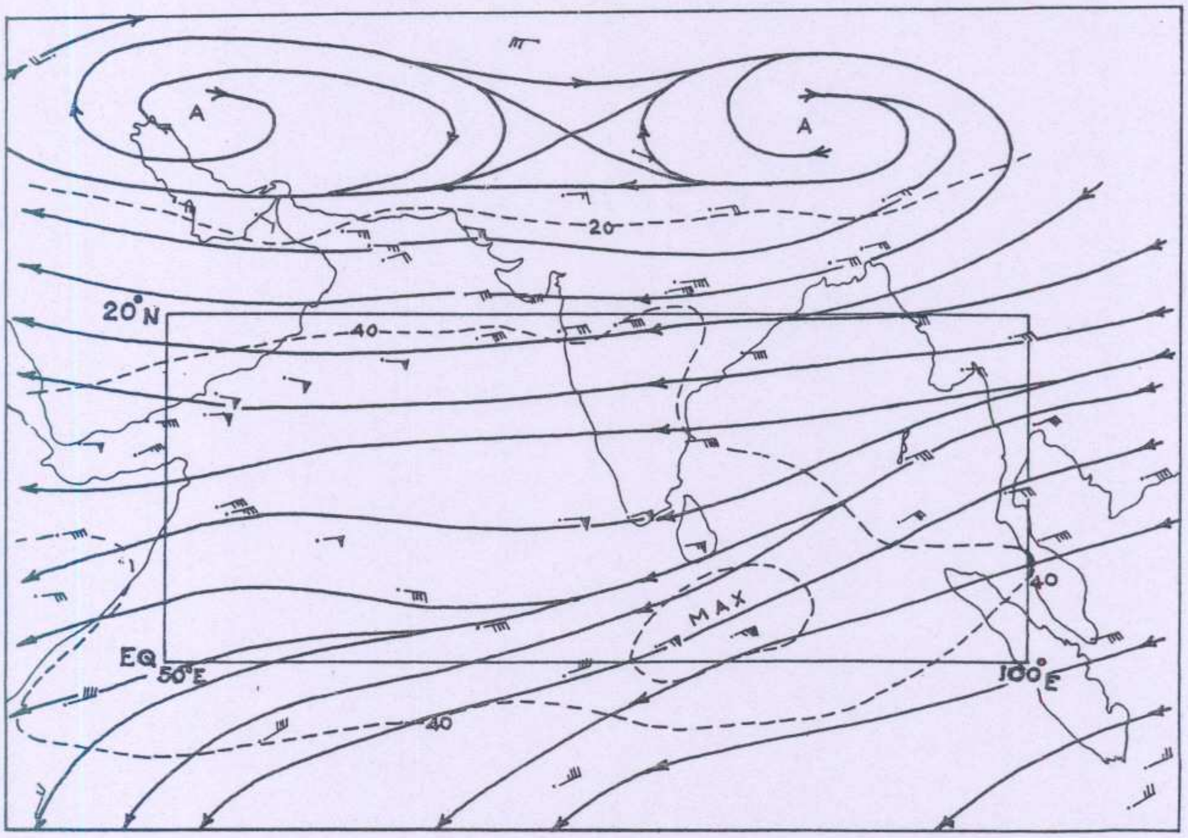

FIG. 6. MEAN-WIND CHART FOR JULY, 200 mb, SOLID LINE, STREAM-LINE, DASHED LINE, ISOTACH

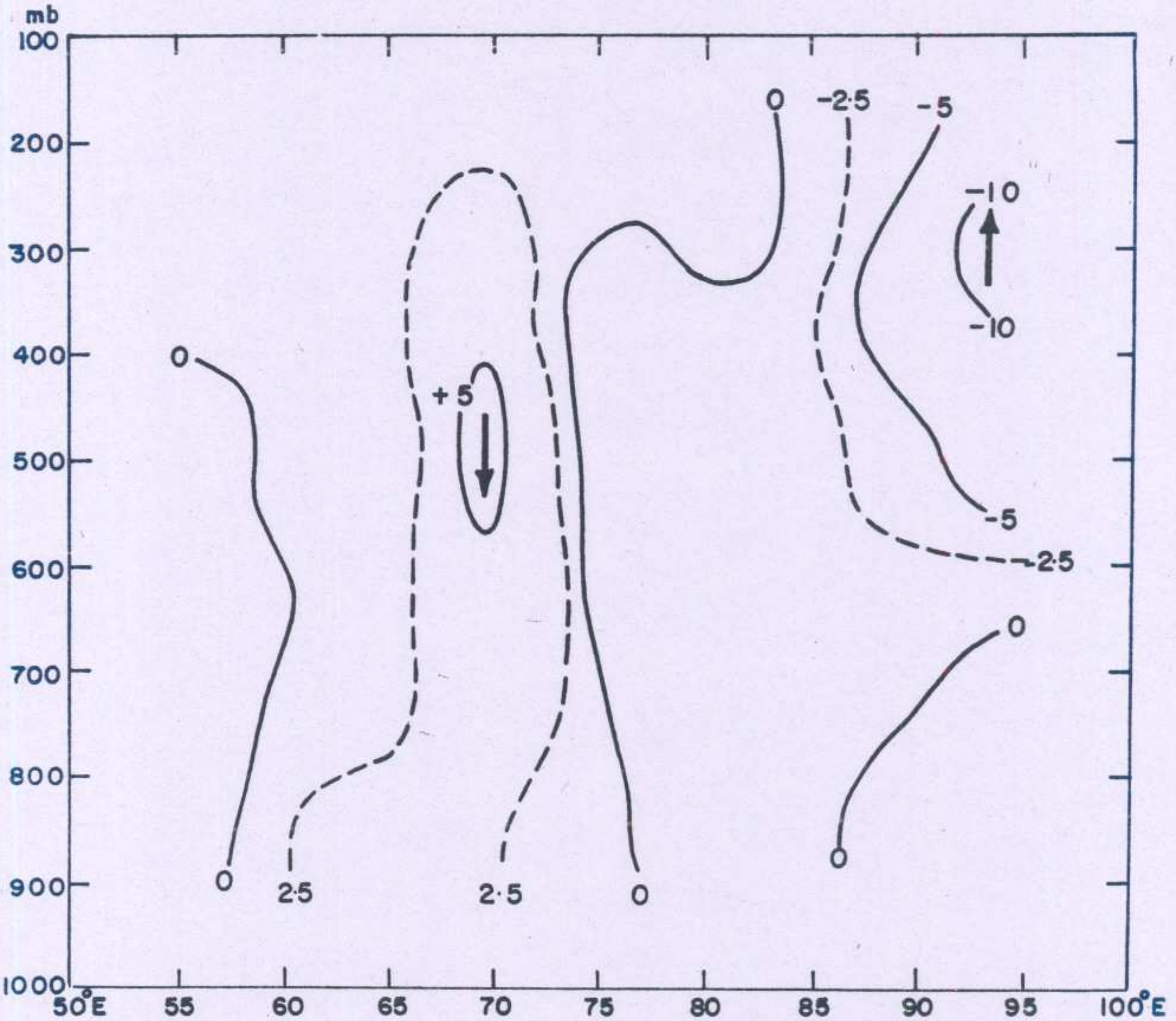

Fig. 7. ω (10^{-4}mb sec^{-1}) Mean July At 15°N