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Note on the equivalent barotropic level in the Indian tropical regions

Y. RAMANATHAN

Institute of Tropical Meteorology, Poona

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ABSTRACT. Parameters computed for the winter and summer monsoons from the mean 1963 and 1964 radiosonde data for the International Indian Ocean Expedition period for Indian stations show (*i*) the equivalent barotropic level appears to be around 400 mb in the winter and (*ii*) no such level seems to exist in the troposphere during summer monsoon.

1. Introduction

Charney (1949) established a correspondence between the motions of the three dimensional real atmosphere and those of a ficticious "equivalent barotropic atmosphere". By this he sought to simplify the forecasting problem of the three dimensional real atmosphere into a two dimensional single isobaric level problem.

If $\vec{V}(p)$ is the wind at an observational point and $\vec{V}_m$ is the mean wind for the atmosphere at that point, $\vec{V}(p) = \vec{A}(p)\,\vec{V}_m$ in this formulation. The isobaric level (p^*) corresponding to the wind $\vec{V}^* = \bar{A}^2(p)\,\vec{V}_m$ is the equivalent barotropic level.

The parameter $\bar{A}^2(p) = 1{\cdot}25$ in the middle latitudes where it is a matter of experience that this equivalent barotropic level is nearly a level surface around 500 mb (Charney 1949). This also roughly coincides with the so called level of non-divergence.

2. Discussion for the Indian region

While a single type of basic current, namely, the increase of westerlies with height almost always predominates in the middle latitudes, the basic currents in the Indian tropical stations vary from season to season. Figs. 1 and 2 represent the winter and summer monsoon seasonal profiles of the zonal components of typical Indian stations respectively.

(a) *Winter profiles* — In Fig. 1 the profiles of the Indian radiosonde stations located north of 10°N show generally an increase of westerlies with height from surface to 200 mb. Also the increase of westerlies are in varying degrees depending on latitude as can be seen from Fig. 1 in the profiles of New Delhi (Lat. 28° 35'), Allahabad (Lat. 25° 27'), Bombay (Lat. 19° 07'), Visakhapatnam (Lat. 17° 43') and Madras (Lat. 13° 04'). As in the middle latitudes, there is a general increase of westerlies with height and so that $A(p)$ values which determine the equivalent barotropic level are generally positive (Table 1) in all stations at all levels. $\bar{A}^2(p)$ vary between 1 and 2 except at Madras 1963 (3·3) where the basic current is twin structured with easterlies in the lower levels and westerlies in the upper levels, and is thus different. The equivalent barotropic level varies from 300 mb to 400 mb except at Madras (1964) where it is 480 mb close to the mid-level of the atmosphere.

Charney (1947) has reported the results of various workers on the level of non-divergence for wind profiles with westerlies increasing with height. The level varies from 600 mb to 350 mb depending upon the height of the tropopause and the wind profile. The choice of 400 mb which is around the so called level of non-divergence, as the equivalent barotropic level is therefore reasonable.

(b) *Summer monsoon profiles* — A characteristic of the basic current in summer monsoon is the striking contrast between lower and upper atmosphere. Equatorial westerlies associated with the summer monsoon circulation in the lower levels are overlain by easterlies. A finite transition zone separates these contrasting regimes between 600 mb and 400 mb with individual variation depending on latitude and longitude.

$A(p)$ values in the lower layers are opposite in sign to those of the higher layers unlike in winter. But $\bar{A}^2(p)$ values are all positive and very large for all stations (Table 2). This gives an

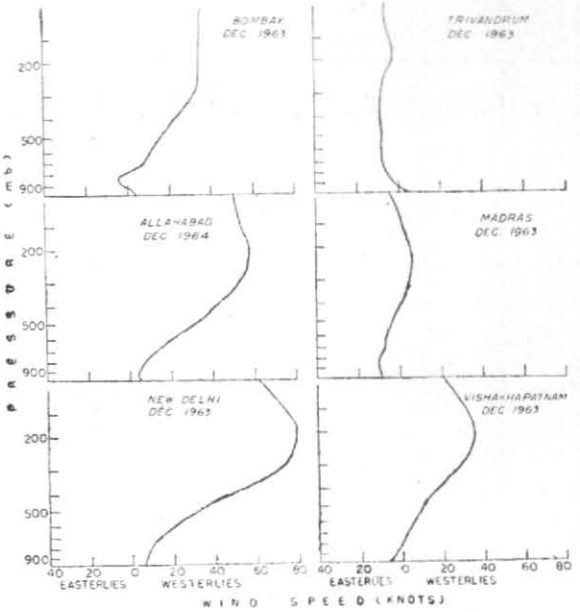

Fig. 1

Zonal wind profiles in **winter**

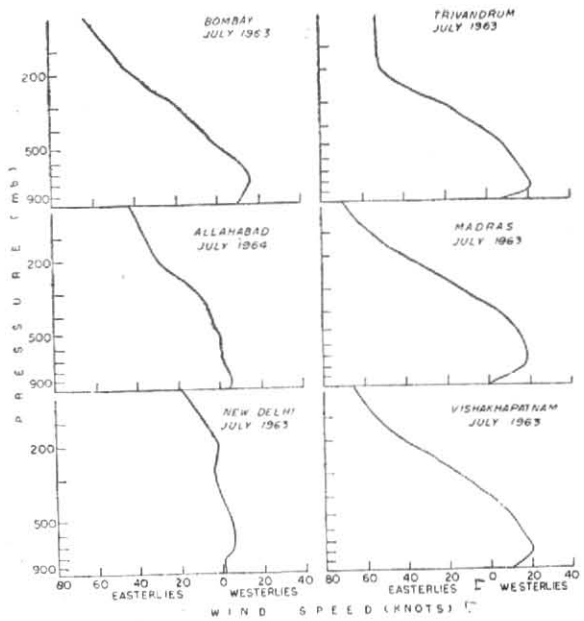

Fig 2

Zonal wind profiles in **summer**

TABLE 1

$A(p)$ values at typical stations (1963)

Station	Pressure level (mb)						
	Surface	850	700	500	300	200	100
				SUMMER			
Bombay	—1·5	—2·2	—2·2	—0·1	2·6	5·7	9·0
Visakhapatnam	—2·5	—4·7	—4·4	—2·6	3·9	10·3	16·0
Madras	—0·1	—3·1	—3·9	—2·7	2·7	8·2	15·0
Nagpur	—0·5	—1·5	—0·8	0·2	1·8	4·6	7·0
				WINTER			
Bombay	0·3	—0·3	0·5	0·9	2·1	2·3	2·3
Visakhapatnam	—0·6	—0·1	0·2	0·8	2·5	3·0	1·7
Madras	2·3	3·1	2·2	1·1	—1·4	—1·4	1·0
New Delhi	—0·1	0·1	0·5	0·9	1·8	2·5	1·7

TABLE 2

$\bar{A}^2$ (p) values

	Allahabad	Nagpur	Bombay	Calcutta	Visakhapatnam	Madras	Trivandrum
				SUMMER			
1963	—	7·5	13·5	5·9	48·0	38·4	25·2
1964	5·6	9·3	—	6·5	9·5	7·7	12·3
				WINTER			
1963	—		1·9	1·6	2·2	3·3	1·3
1964	1·5	1·9		1·6	—	1·2	—

TABLE 3

p^* (mb) equivalent barotropic level

	Allahabad	Nagpur	Bombay	Calcutta	Visakhapatnam	Madras	Trivandrum
				SUMMER			
			Above 100 mb in all the stations for 1963, 1964, 1967				
				WINTER			
1963	—	—	335	360	320	320	340
1964	390	340	—	360	—	480	
1967	—	440	400	—	300	—	—

TABLE 4

Level p (mb) of non-divergence in summer

	Allahabad	Nagpur	Bombay	Calcutta	Visakhapatnam	Madras	Nagpur
1963	550	480	490	510	440	400	480

unrealistic equivalent barotropic level (p^*) beyond the troposphere (Table 3). However, the zonal wind profiles show that there is a particular level in each profile where the wind becomes zero in the transition layer from westerlies to easterlies aloft. Since this is fairly a level surface around 500 mb (Table 4) this transition layer may therefore contain a level of non-divergence. Though it is feasible to consider 500 mb as a level of non-divergence, since this level is not the equivalent barotropic level, the actual motion of the atmosphere at this particular level in summer monsoon cannot approximate the horizontal motion of an equivalent barotropic atmosphere.

3. Conclusion

An equivalent barotropic atmosphere can be defined in the winter in the Indian tropical regions whose motions correspond to those of the real baroclinic atmosphere, at a particular level — 400 mb. No such level seems to exist in the troposphere in the summer monsoon, and there seems to be no basis for the application of an equivalent barotropic model at any level in the troposphere in the summer monsoon in the Indian tropical regions.

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