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Study of Sutcliffe's Theory of Development in relation to Rainfall in Indian area

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ABSTRACT. Computation of Sutcliffe's development term over the Indian area in three synoptic situations during the SW monsoon season shows that, in spite of the various limitations in applying the theory to subtropical regions, the areas of heavy rain coincide with the areas of maximum development.

1. Introduction

Sawyer (1952) has made a study of rainfall over the British Isles and neighbourhood in two synoptic situations applying Sutcliffe's (1947) theory of development and shown that apart from the effect due to orographic lifting, other features of the rainfall distribution are in good agreement with those to be expected on the basis of this theory. The present paper attempts to apply this theory to some selected synoptic situations in the Indian area. It is seen that the agreement between the areas where the computations showed large 'development' and the areas where heavy rain occurred is good. This holds out fair promise that this method, in spite of the various limitations and approximations in the theory, may prove a useful additional tool for synoptic forecasters in this region also.

2. Method of evaluation

Sawyer and Matthewman (1951) have developed a technique for calculating div $\mathbf{V}'$ from the configuration of the contours of any two isobaric surfaces. Following their method div $\mathbf{V}'$ has been evaluated for three selected situations, between the pressure levels of 1000 and 700 mb. All the three cases relate to the monsoon season. The English workers have generally been computing relative divergence between 1000 and 500 mb; but for the present work 700 mb has been chosen as the upper level. At this level even in the monsoon season there are a fairly good number of pilot balloon winds which together with the height values at the radiosonde stations enable a fairly certain drawing of the contour lines on the constant pressure surface. Attempts with the 500-mb level showed that with the present network of radiosonde stations and the very few pilot balloon winds available at the level during monsoon there was much less certainty about the configuration of the contour lines. In view of the assumption of linear variation of divergence with pressure, there is no objection in choosing any suitable levels depending on the availability of data. Since most of the precipitation in the Indian monsoon season is believed to occur from levels below 10,000 – 15,000 ft as judged from the heights of tops of clouds etc reported by pilots of aircraft, the choice of 700 mb as the upper level for the evaluation of relative divergence may be further justified.

The grid lengths were chosen so that the multiplying factor $g^2/8l^2\,a^4$ (*vide* Sawyer and Matthewman's expression for $V'\dfrac{\partial\xi}{\partial s}=l\,\mathrm{div}\mathbf{V}'$) is equal to 10^{-2}. Different scales were constructed for each five degree interval of latitude. The values of the grid length, a, for different latitudes are given in Table 1.

TABLE 1

Latitude	30°	25°	20°	15°	10°
Grid-length (miles)	142	154	172	197	241

It may be mentioned here that Sawyer and Matthewman have mapped l div $\mathbf{V}'$, while in this paper div $\mathbf{V}'$ has been mapped.

In the latitudes covered by Sawyer and Matthewman's study variations in l being small the field of l div $\mathbf{V}'$ is fairly representative of div $\mathbf{V}'$ also. In the Indian area studied here variations in l are much greater and hence it was considered better to map div $\mathbf{V}'$ instead of l div $\mathbf{V}'$.

The 1000-mb constant pressure chart was constructed with the help of the sea level isobaric chart corrected for any difference in time between the hour of the chart and the time of the radiosonde ascents, the 3000 feet upper winds and the values of the 1000 mb height at the radiosonde stations. The 700-mb chart was constructed from the height values of that surface at the radiosonde stations and the available upper winds at 10,000 feet. Superposing the isopleths of 1000 mb height (h_{1000}) on the isopleths of 700 mb height (h_{700}) the values of $h_{700}+h_{1000}$ and $h_{700}-h_{1000}$ were calculated at the points of intersection and a sufficient number of other points. From these a fresh chart was constructed in which isopleths of $h_{700}+h_{1000}$ were superimposed on isopleths of $h_{700}-h_{1000}$. By using the transparent scales on this chart, l div $\mathbf{V}'$ was evaluated at a number of points as per Sawyer and Matthewman's technique and div $\mathbf{V}'$ obtained by dividing by the appropriate value of the Coriolis parameter, l. Isopleths of div $\mathbf{V}'$ were then drawn.

3. Discussion of selected synoptic situations

The selection of the synoptic situations was guided by (*a*) there being well defined areas of heavy rain and of dry weather, (*b*) sufficient wind data being available for drawing of the height contours on the constant pressure surface with confidence and (*c*) the gradients on the thickness chart being well defined, as this has a large effect on evaluation of div $\mathbf{V}'$.

In order to check upon the accuracy of the method in practice, the computation was repeated independently for two situations starting from the basic data. It was seen that although individual values differed to some extent in the two trials, the areas of positive and negative values of div $\mathbf{V}'$ and their maxima remained practically the same. Thus while quantitatively the values of div $\mathbf{V}'$ and hence of the vertical velocity obtained in these evaluations may be subject to some change, the qualitative picture of the areas of development can be taken as fairly definite within a margin of about 50-100 miles.

The three situations studied were at (1) 0130 GMT on 22 September 1948, (2) 1430 GMT on 4 August 1953 and (3) 1430 GMT on 12 August 1953. These are described below—

Case 1 0130 GMT on 22 September 1948—At this time a depression from the Bay of Bengal lay over east Hyderabad with its centre near Hanamkonda. Fig. 1 (a) shows the isopleths of heights above m.s.l. of 1000 mb surface at 0130 GMT derived from the sea level isobars. The available winds at 3000 feet and the height values of the 1000 mb surface at the radiosonde stations are also shown. The time of surface observations was 0230 GMT while the pilot balloon and radiosonde ascents were taken at about 0130 GMT. Thus the three observations were almost synoptic. The isopleths of height of 700 mb surface are given in Fig. 1(b). A large number of wind observations are available for this occasion even at 10,000 feet so that the isopleths could be drawn with confidence. Fig. 1 (c) gives the isopleths of $h_{700}-h_{1000}$ superimposed on isopleths of $h_{700}+h_{1000}$. Fig. 1 (d) shows the distribution of div $\mathbf{V}'$ at 0130 GMT of 22nd. Fig. 1 (e) shows the rainfall which occurred during the 24 hours ending at 0230 GMT of 23rd with the isopleths of div $\mathbf{V}'$ from Fig. 1 (d) superposed. It is seen that the area of maximum development as indicated by Fig. 1 (d) coincides roughly with the region where heavy rain occurred subsequently. The area where most of the rain occurred also roughly corresponds to the area of positive values of div $\mathbf{V}'$, while there has been practically no rainfall in areas of markedly negative div $\mathbf{V}'$.

It is interesting to note that within the area of large positive development itself rainfall has been very much more along the west coast than on the leeward side of the ghats. This is no doubt due to the augmentation of the rainfall due to dynamical causes by the effect of orography But the concentration of very heavy rain along the west coast, only near area of maximum development shows that the additional effect of

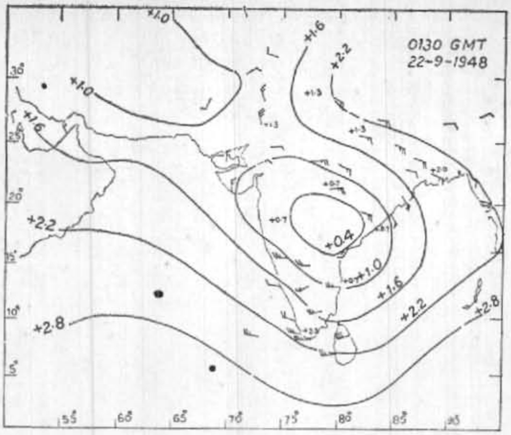

Fig. 1 (a). Isopleths of heights above m.s.l. of 1000-mb surface (unit : 100s of ft). Winds at 3000 ft are also shown

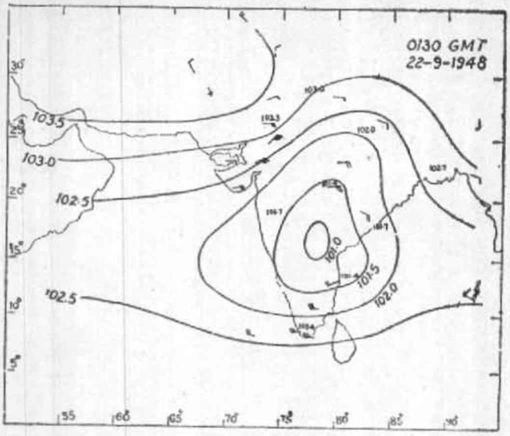

Fig. 1 (b). Isopleths of height of 700-mb surface (unit : 100s of ft). Winds at 10,000 ft are also shown

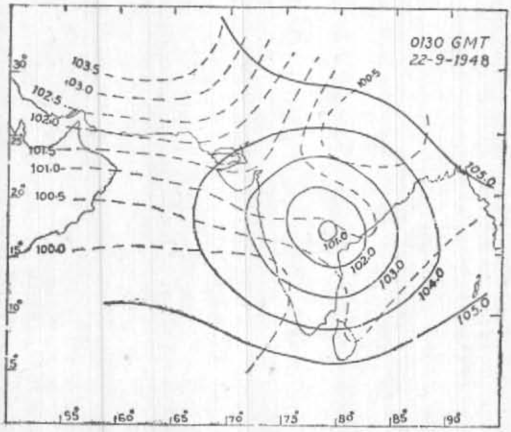

Fig. 1 (c). Isopleths of the sum (——) and difference (- - - -) of the height of 700 and 1000 mb surfaces (unit : 100s of ft)

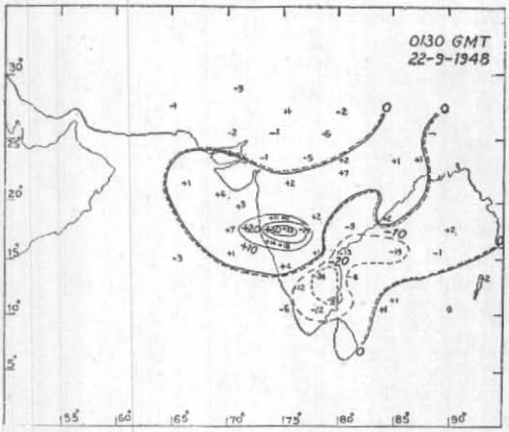

Fig. 1 (d). Isopleths of relative divergence (div V′) (unit : 10^{-2} hr^{-1})

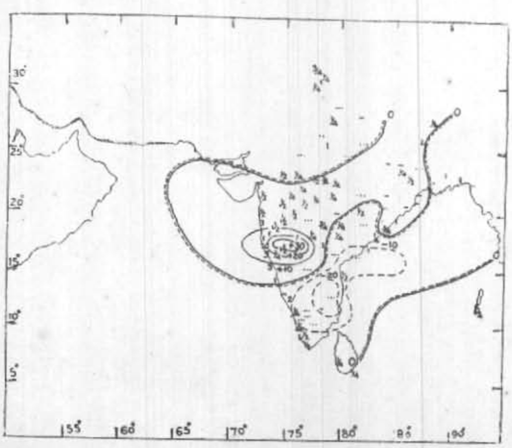

Fig. 1 (e). Rainfall during 24 hours ending at 0230 GMT on 23-9-1948 and isopleths of relative divergence at 0130 GMT on 22-9-1948

orography comes in only in regions where rainfall is to be expected from dynamical causes. Sawyer (1952) has come to a similar conclusion that "the orographic component occurs primarily within the rain areas already established by dynamical causes and augments the rainfall there".

Case 2. 1430 GMT on 4 August 1953— A depression lay over north Madhya Pradesh with centre near Jabalpur. Fig. 2 (a) shows the isopleths of h_{700} and h_{1000}. The winds and height values at individual stations have been shown only for the 700-mb level. The radiosonde observations were at 1430 GMT while the pilot balloon winds used were those of 0900 GMT. In the construction of the 1000 mb chart the 1200 GMT sea level isobaric chart was used with a uniform correction for diurnal variation. Thus the various observations not being synoptic may have introduced some inaccuracies which were absent in the previous case where all the observations were very nearly synoptic. Fig. 2 (b) shows the isopleths of $h_{700}-h_{1000}$ and $h_{700}+h_{1000}$. Fig. 2 (c) shows the field of relative divergence at 1430 GMT of 4th and Fig. 2 (d) the rainfall which occurred up to the next morning, with the isopleths of relative divergence superposed. Again the agreement between the regions of expected and actual rainfall is fairly good. The rather high positive values of relative divergence over the extreme south of the peninsula are due to the small values of the Coriolis parameter at very low latitudes and so may not be significant.

Case 3. 1430 GMT on 12 August 1953— A depression lay in the northwest Bay of Bengal off the Orissa coast. As in the last case, Fig. 3 (a) gives the isopleth of h_{700} and h_{1000}, Fig. 3 (b) the isopleths of $h_{700}-h_{1000}$ and $h_{700}+h_{1000}$, Fig. 3(c) the field of div $\mathbf{V}'$ and Fig. 3 (d) the actual rainfall up to the morning of 13th with the isopleths of div $\mathbf{V}'$ superposed. Fig. 3 (d) shows a good agreement between the field of div $\mathbf{V}'$ and rainfall.

4. Validity of the assumptions and approximations made

The first point that arises in this connection is how far the geostrophic relation which has been assumed in the derivation can be taken as valid in the Indian latitudes. No definite answer to this has been reached by the workers in the field so far. The general experience of forecaster has, however, been that while the contours at the various levels are generally in conformity with the actual wind directions, the gradients of the contours are not in accordance with the geostrophic relation. Whatever may be the extent of the validity of the geostrophic assumption, the actual results obtained in the three cases studied would indicate that in practical working, calculation of div $\mathbf{V}'$ on geostrophic assumptions is useful.

Secondly the effect of vertical stability has been neglected in deriving the equation for relative divergence (Sutcliffe 1947). Sumner (1950) has shown that the effect of stability is to exert a damping effect on development. Bushby (1952) has calculated the vertical velocities neglecting and including the effect of stability for different synoptic situations and concluded that on an average stable stratification of the atmosphere reduces the vertical velocities to about a quarter of its value in neutral atmosphere. The damping depends on the departure of the actual lapse rate of temperature from the appropriate wet or dry bulb lapse rate depending on the state of saturation of the atmosphere. In the cases studied now, this departure was not large in the regions where heavy rainfall occurred as can be seen from Table 2 which gives the actual temperature difference between 900-mb and 700-mb levels and that along the wet adiabat.

TABLE 2

Date	Station	Actual temperature difference (°C)	Temperature difference on the wet adiabat (°C)
22-9-1948	Poona	10.0	8.5
4-8-1953	Nagpur	9.5	9.0
12-8-1953	Vizag	11.2	8.8

Thus the atmosphere in the region of maximum positive development was nearly neutral and the vertical velocities may not have been much affected by the stability factor in these cases.

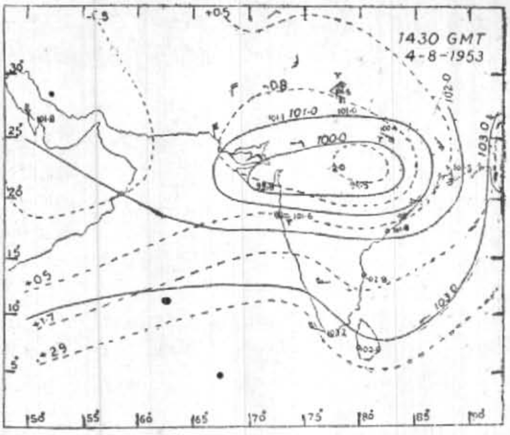

Fig. 2(a). Isopleths of heights of 700 mb (——) and 1000 mb (- - - -) surfaces (unit : 100s of feet). 700-mb height values and winds at 10,000 ft are also plotted. Those marked 'r' are 1500 GMT radar winds, rest 0900 GMT pilot balloon winds. 700-mb height value at Nagpur from 0400 GMT ascent

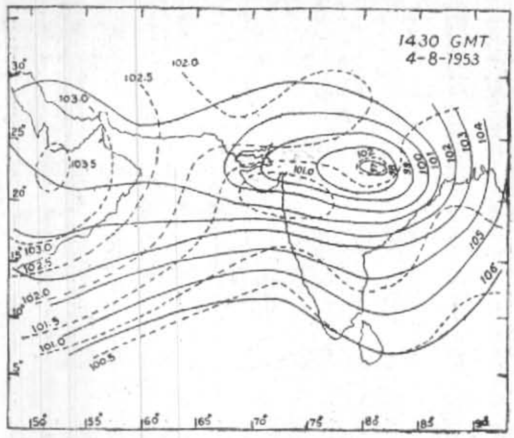

Fig. 2 (b). Isopleths of the sum (——) and difference (- - - -) of the height of 700 mb and 1000 mb surfaces (unit : 100s of ft)

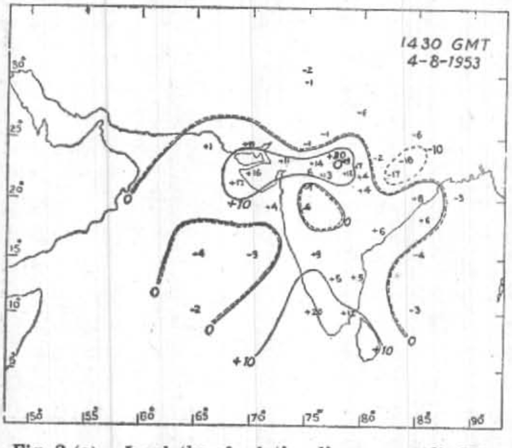

Fig. 2 (c). Isopleths of relative divergence (div V′) unit : $10^{-2}hr^{-1}$

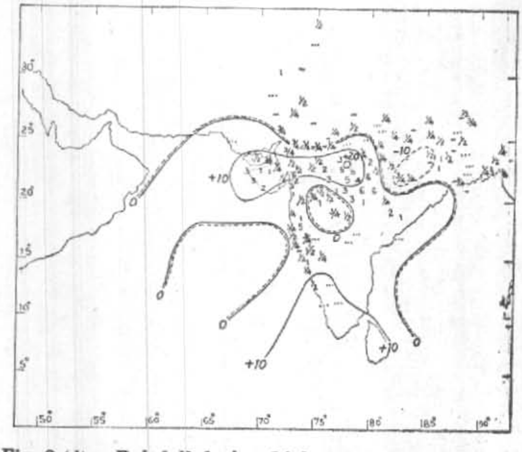

Fig. 2 (d). Rainfall during 24 hours ending at 0300 GMT of 5-8-1953 and isopleths of relative divergence at 1430 GMT of 4-8-1953

Further, Bushby (1952) has concluded that the inclusion of the vertical stability term does not alter the positions of the main maxima and minima of vertical velocity and the technique usually employed, *viz.*, neglecting the effects of vertical stability is adequate enough to show important regions of maximum vertical motion.

5. Conclusion

This study of three synoptic situations shows that the development evaluated on the basis of Sutcliffe's theory is related to rainfall even over Indian area and its computation gives useful indication in locating areas of likely heavy rain. Except for slight displacements of 50-100 miles of the areas of maximum development due to small inaccuracies in the drawing of the various charts, the process of inferring the areas of heavy rain is not liable to subjective factors, which is a great advantage.

6. Acknowledgement

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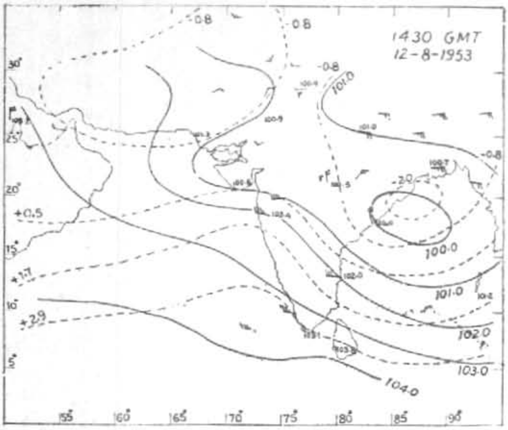

Fig. 3 (a). Isopleths of heights of 700 mb (——) and 1000 mb (- - - -) surfaces. (unit : 100s of ft). 700 mb height values and winds at 10,000 ft are also shown. Those marked 'r' are 1500 GMT radar winds, rest 0900 GMT pilot balloon winds

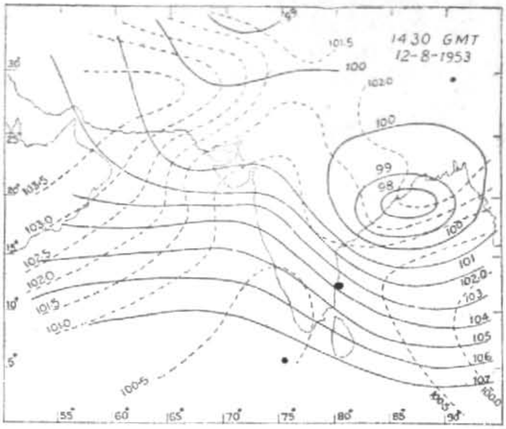

Fig. 3 (b). Isopleths of the sum(——) and difference (- - - -) of the height of 700 and 1000 mb surfaces (unit 100s of ft)

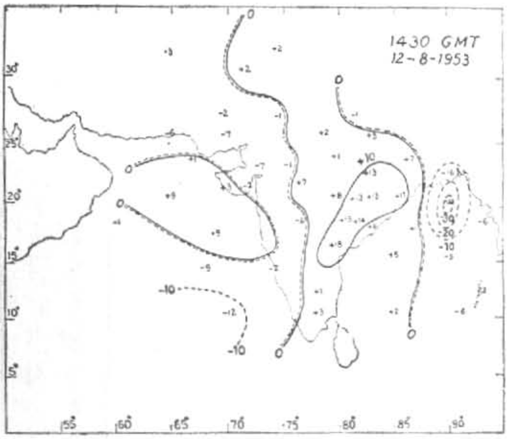

Fig. 3 (c). Isopleths of relative divergence (div V′) (unit : 10^{-2} hr^{-1})

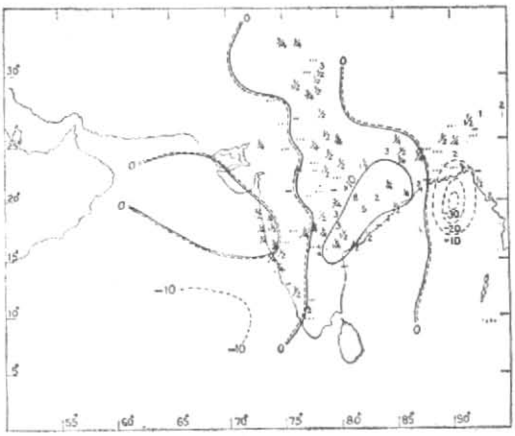

Fig. 3 (d). Rainfall during 24 hours ending at 03C0 GMT of 13-8-1953 and isopleths of relative divergence at 1430 GMT of 12-8-1953

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