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On the use of convergence charts over the Indian Region*

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ABSTRACT. A summary has been made of the methods devised to delineate areas of convergence or divergence on weather charts. As a preliminary investigation, the wind component method has been used for a number of situations in monsoon and post monsoon months. An attempt has also been made to theoretically compute the rate of precipitation using vertical velocities obtained from convergence patterns.

1. Introduction

The quantitative use of convergence or divergence has formed the subject of considerable research in recent years. The usefulness of such an estimate lies in obtaining rates of vertical ascent and correlating it with other meteorological elements. The numerous methods so far developed admit of two broad classifications as set out below.

(i) *Thermodynamic methods*

These depend upon identifying an air mass by some property which remains invariant during its ascent or descent. Among those who have used, this technique, the works of Hewson[1], Graham[2], Panofsky[3], Petterssen[4] and others have received most attention. These methods generally involve drawing trajectories of air, which is a laborious and sometimes subjective process. The assumption of an adiabatic ascent or descent is also open to criticism.

(ii) *Kinematic methods*

Such methods depend upon measurements made from the wind field and application of the equation of continuity. A modified form of the same equation for an isobaric surface has also been recently indicated by Sheppard[5] and Van Ufforde.

Sawyer[6] and others have also used the wind field to compute changes in relative vorticity and thereby obtain the divergence using Rossby's vorticity theorem. Sawyer, however, used the geostrophic wind relation to obtain the vorticity and assumed that lines of equal vorticity moved with the geostrophic wind speed. This is not feasible within the tropics in the absence of a geostrophic balance.

In a recent paper Miller[7] indicated a method in which polynomials were fitted to the wind field and the divergence obtained by direct differentiation. The method, however, is only applicable over limited small areas where satisfactory functional forms could be fitted to the wind data.

2. The wind component method

As a preliminary investigation the wind component technique was used to obtain convergence patterns for different weather situations over India. The purpose of the investigation was to obtain the order of magnitude of convergence from synoptic charts and to see if it could explain individual cases of abnormal rainfall in monsoon and post monsoon months. The basis of the method adopted was as follows—

Treating the atmosphere as incompressible (density constant everywhere and always), the equation of continuity reduces to

$$\frac{\partial w}{\partial z} + \nabla_2 . \mathbf{V} = 0 \qquad (2.1)$$

On integrating the above through a layer of thickness δz,

$$w_2 - w_1 = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) . \delta z \qquad (2.2)$$

where w_2, w_1 are the vertical velocities at the top and bottom of a layer of thickness δz, and u, v are the easterly and northerly components of wind, which are assumed as constant with the layer.

*The present paper represents the results of a preliminary study of convergence. Subsequently further work has been done employing more accurate methods of evaluating convergence in different synoptic situations. These will be communicated at a later stage.

From winds recorded in the Indian Daily Weather Reports, isopleths of u, v were drawn. The gradients of u, v were next obtained in as large a number of places as possible. Finally, isopleths of $\triangle u/\triangle x$, $\triangle v/\triangle y$ were drawn from which the values of $(\triangle u/\triangle x + \triangle v/\triangle y)$ were obtained from different parts of the country. An estimate of horizontal convergence was thus obtained. The convergence was later expressed in terms of a vertical velocity by equation 2.2. This was done for three different levels in the atmosphere, 3000, 5000, and, wherever possible, 10,000 ft.

The method, as stated above, is subject to a few sources of error apart from personal errors. These are—

(i) *Neglect of the convergence of meridians*

If this be taken into account, then

$$\nabla_2 \cdot \mathbf{V} = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) - \frac{v}{R} \cdot \tan\phi \quad (2.3)$$

where, R = radius of the earth
ϕ = latitude.

Computation of the last term in the above equation showed that for all cases it was very small and could be neglected in comparison with the other terms.

(ii) *Errors in wind speed*

Let, $\triangle u_2$, $\triangle u_1$ be errors in the easterly component of wind,
$\triangle v_2$, $\triangle v_1$ be errors in the northerly component of wind

$\therefore$ Error in divergence

$$=\left[\frac{\triangle u_2 - \triangle u_1}{\triangle x} + \frac{\triangle v_2 - \triangle v_1}{\triangle y}\right] \text{ approximately.}$$

As an extreme case we assume

$$\triangle u_2 = -\triangle u_1 = 5 \text{ knots}$$
$$\triangle v_2 = -\triangle v_1 = 5 \text{ knots}$$
$$\triangle x = \triangle y = 100 \text{ km}$$

$\therefore$ Error in divergence$=0.10$ m km^{-1}sec^{-1}
The error is of the same order as the divergence generally obtained. However, since that divergence was generally obtained from a large number of individual values, such extreme errors are likely to cancel out.

(iii) *Density variation*

The atmosphere was treated for all practical purposes to be incompressible, *i.e.*, the term for density variation was neglected in the equation of continuity. Now,

$$\frac{1}{\rho} \cdot \frac{d\rho}{dt} = w.10^{-6}. \sec^{-1} \text{ (approximately)} \quad (2.4)$$

The convergence generally obtained was of the order of 10^{-5} sec^{-1}, hence the error could be of the same order of magnitude only when w exceeded 10 cm sec^{-1}, which was not often. The retention of the term, therefore, could alter individual values of convergence but was unlikely to alter its order of magnitude. It was, therefore, considered sufficient for the present to neglect the term.

3. Results of preliminary investigation

Altogether nine synoptic situations (*vide* Table 1) in monsoon and post monsoon months were studied. The tentative results obtained could be summarised as follows—

(*i*) A rough agreement was observed between zones of convergence and areas of subsequent precipitation. There were a few occasions when the agreement was smudged because of rainfall due to orographic features. A striking agreement was observed between the precipitation on the night of 8 September 1946 and convergence patterns for the same situation (Figs. 1-3). Despite the fact that the wind field in such a situation could have been vitiated by the Western Ghats, it was interesting to note that most of the rain fell in the neighbourhood of a zone of convergence.

(*ii*) Convergence patterns were drawn for 3000, 5000 and, wherever possible, 10,000 ft. The patterns showed a tendency for zones of maximum convergence to be shifted northwards with height, but the result could not be claimed as conclusive.

(*iii*) This method gave a quantitative estimate of convergence which could not be obtained from the streamline pattern alone. In Figs. 4 and 5 this has been brought out for a situation on 2 February 1950, where a zone of convergence was obtained in northeast India which was not clearly shown by the streamline pattern.

(*iv*) The method involved the preparation of four different charts which tcok considers able time. It was, therefore, not feasible to use it as a routine practice.

TABLE 1

List of situations examined and maximum convergence associated with each situation

No	Date	Maximum convergence (in m km^{-1} sec^{-1}) 3000 ft	5000 ft	10,000 ft	Main Rainfall amounts	(inches)
1	8. 9.46	0.09	0.03 at Bombay	0.03	Bombay	8.5
2	22. 9.49	0.08	0.20 near Bombay and neighbourhood	—	Bombay Ahmednagar	14.1 14.4
3	21.11.48	0.06	0.04 in Gujarat	0.01	Bombay Veraval	3.9 1.3
4	3. 7.40	0.05	0.02 in Madhya Bharat	—	Saugor Hoshangabad	5.0 5.0
5	7. 7.45	0.06	0.01 in Madhya Bharat	—	Saugor Jabalpore	4.0 5.0
6	6. 7.48 7. 7.48	0.16	0.12 near Orissa Coast	—	Puri Gopalpur	3.0 2.0
7	3. 7.45	0.12	0.08 in Madhya Bharat	—	Bhopal Hoshangabad Jabalpur	4.6 3.1 2.0
8	22. 7.40	0.04	0.01 in Uttar Pradesh	—	Gorakhpur	5.0
9	2. 2.50	0.02	0.01	—	—	(c.f. Fig.5)

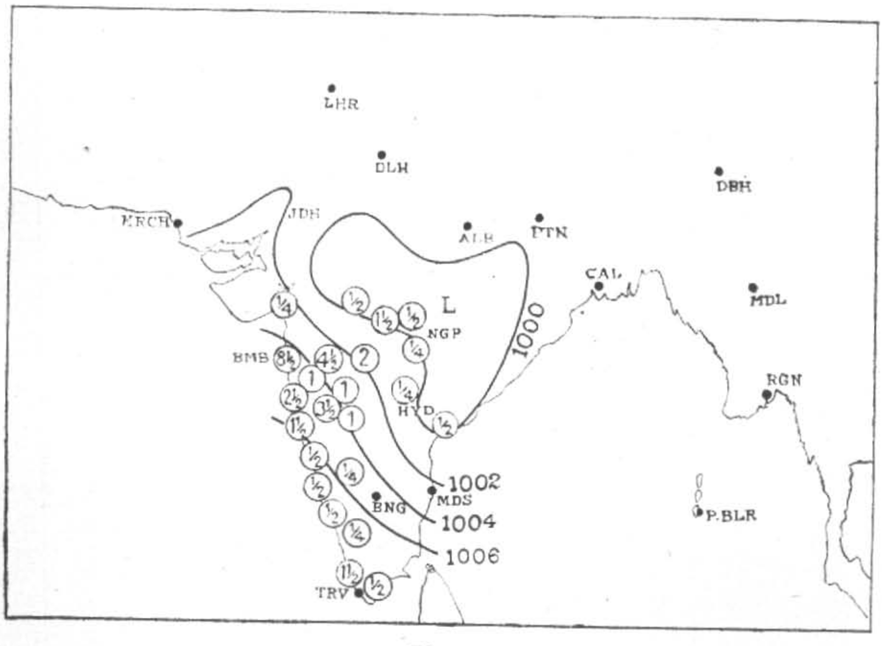

Fig. 1

Synoptic situation at 1700 IST on 8 September 1946 and precipitation recorded between that hour and 0800 IST on 9 September 1946

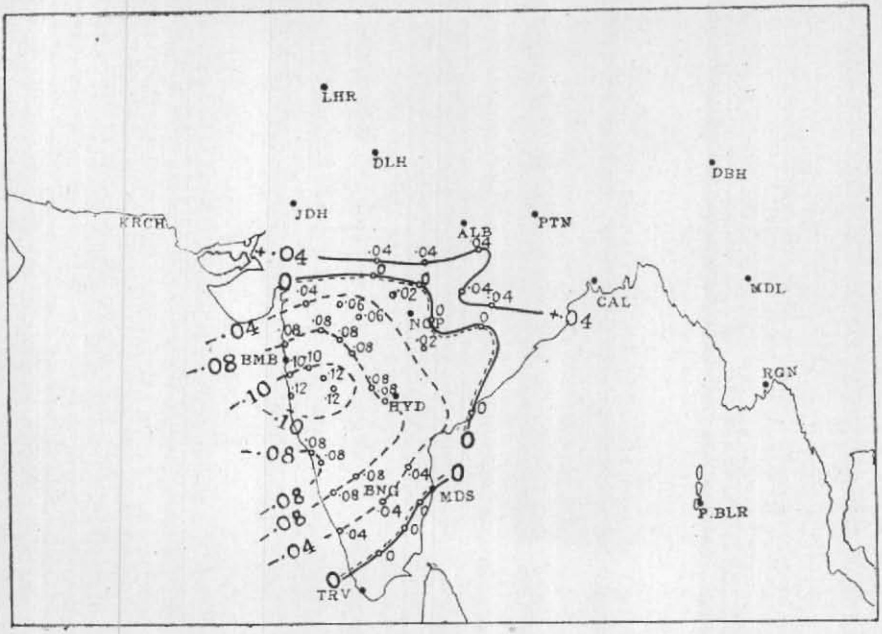

Fig. 2

Convergence Pattern for 3000 ft at 1600 IST on 8 September 1946 showing isopleths of $(\partial u/\partial x + \partial v/\partial y)$ in m km^{-1} sec^{-1}

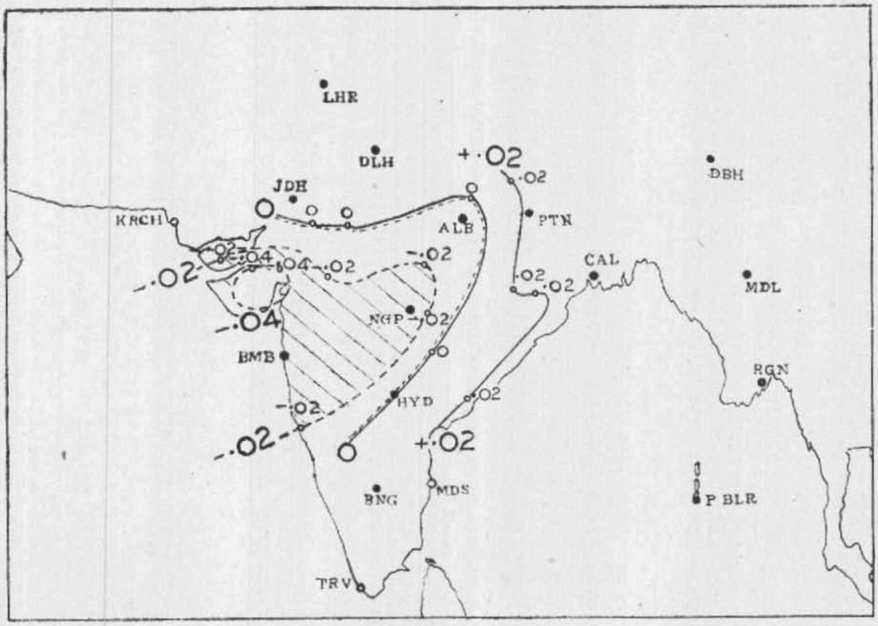

Fig. 3

Convergence Pattern for 5000 ft at 1600 IST on 8 September 1946 showing isopleths of $(\partial u/\partial x + \partial v/\partial y)$ in m km^{-1} sec^{-1}

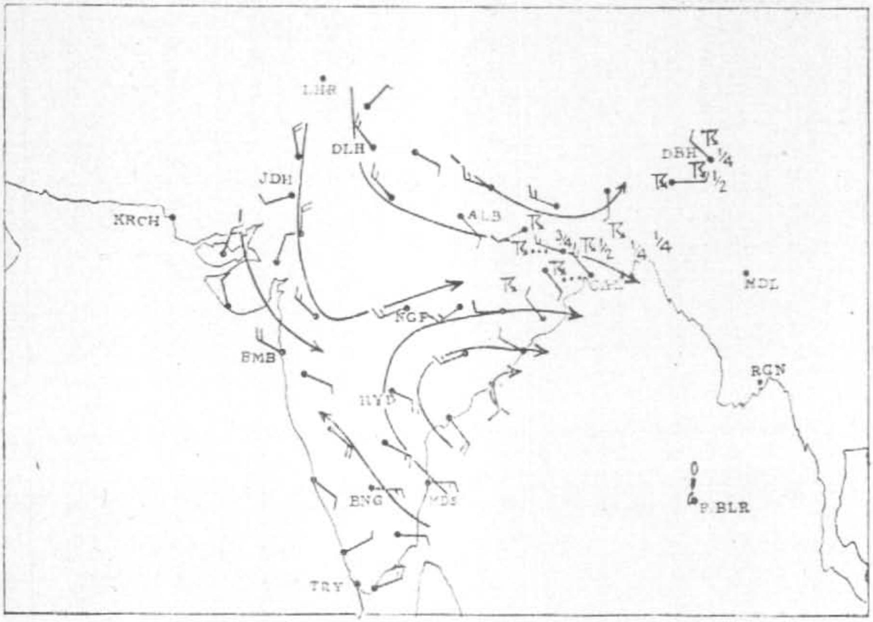

Fig. 4

Stream line chart for 3000 ft at 0700 IST on 2 February 1950 and past weather recorded at 0700 IST on 3 February 1950

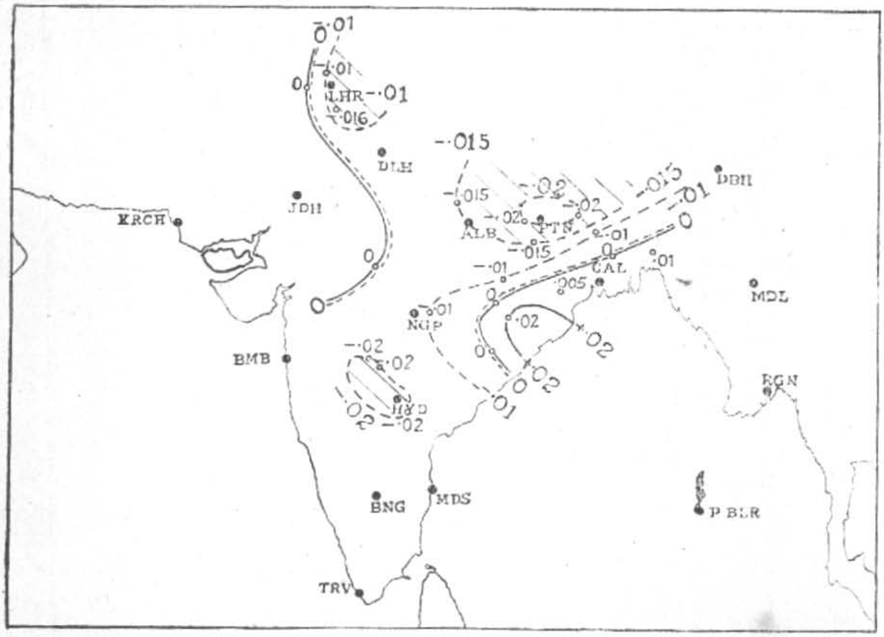

Fig. 5

Convergence Pattern for 3000 ft at 0700 IST on 2 February 1950 showing isopleths of $(\partial u/\partial x + \partial v/\partial y)$ in m km^{-1} sec^{-1}

4. The rate of precipitation

An attempt was made to compute the rate of precipitation from vertical velocities at 3000, 5000 and 10,000 ft levels. In this we followed a method similar to that developed by Fulks[8].

We consider $(1+x)$ gm of saturated air, where x denotes the saturation mixing ratio. When allowed to ascend through a height δz, the precipitation released $= -\frac{dx}{dz}.\delta z$ *gm.*

Hence, the precipitation released by the ascent of 1 gm of saturated air

$$= -\frac{1}{1+x}\cdot\frac{dx}{dz}.\delta z \ gm.$$

If the rate of ascent be w cm sec^{-1} then the rate of precipitation released by the ascent of unit mass saturated air

$$= -w\left(\frac{1}{1+x}\cdot\frac{dx}{dz}\right) gm.\ sec^{-1}$$

We consider next a column of unit area and thickness $\triangle h$.

The mass of moist air in such a column $=\rho m.\triangle h.\ gm.$

Hence, the rate of precipitation from the ascent of such a column at the rate of w *cm* sec^{-1}

$$= \triangle h\ \rho m.w\left(\frac{1}{1+x}\cdot\frac{dx}{dz}\right) cm.\ sec^{-1} \qquad (4.1)$$

where, ρm=density of saturated air.

Let $Q=\frac{1}{1+x}\cdot\frac{dx}{dz}$

Since, $x=\varepsilon\cdot\frac{e}{p-e}$ $\quad[\ \varepsilon=0.6221]$

$$\therefore\ \frac{dx}{dz}=\varepsilon\cdot\frac{e}{p}\left[\frac{1}{e}\cdot\frac{de}{dz}-\frac{1}{p}\cdot\frac{dp}{dz}\right]$$

approximately,

and $\frac{de}{dz}=\Gamma_s\cdot\frac{de}{dT}$

where, Γ_s is the saturated adiabatic lapse rate. Fulks determined de/dt using vapour pressures over water, as given in Smithsonian Tables. As a first approximation the simpler Clausius—Clapeyron equation was used by us.

Thus, we have,

$$Q=\frac{\varepsilon.e}{p}\left[\frac{1}{e}\cdot\frac{de}{dT}\cdot\Gamma_s\ \ \frac{g}{RT}\right]$$

$$=\frac{\varepsilon.e}{p}\left[\frac{Lx}{AR'T^2}\cdot\Gamma_s+\frac{g}{RT}\right]$$

Since, $R'=\dfrac{R}{1-\frac{3}{8}\cdot\frac{e}{p}}$

where, R′=gas constant for water vapour
R=gas constant for dry air

$$Q=\frac{\varepsilon.e}{p}\cdot\frac{1}{RT}\left[\frac{L}{AT}\left(1-\frac{3}{8}\cdot\frac{e}{p}\right).\frac{\varepsilon.e}{p}\cdot\Gamma_s+g\right] \qquad (4.2)$$

where, $e=$ water vapour pressure in mb
$p=$ pressure in mb
$L=$ latent heat of condensation
$=(595-0.5t^oC)$ cal/gm
$\frac{1}{A}=J=4.19\times10^7$
$g=$ 981 cm sec^{-2}

The values of Q obtained for different temperatures and pressures are shown in Table 2.

TABLE 2

Values of $Q\times10^8$ (C. G. S. Units)

T°A	Pressure in mb				
	950	850	750	650	550
300	2.72	2.87			
290	1.61	1.76	1.92		
280		0.90	1.02	1.18	
270			0.52	0.60	0.71

By choosing the appropriate value of Q from the above table and using equation 4.1, the rate of precipitation was computed for different layers of the atmosphere whose vertical rates of ascent were obtained from convergence charts. The results for a number of stations at 1600 IST on 8 September 1946 are shown in Table 3.

TABLE 3

		Station			
		Bombay	Poona	Ratnagiri	Ahmednagar
Convergence at top of layer ($m\ km^{-1} sec^{-1}$)	1.	0.09	0.12	0.12	0.10
	2.	0.03	0.03	0.03	0.03
	3.	0.03	0.03	0.03	0.03
$\overline{W_o}$ ($cm\ sec^{-1}$)	1.	4.1	5.5	5.5	4.5
	2.	9.2	11.9	11.9	10.0
	3.	12.4	15.1	15.1	13.2
Computed precipitation ($cm\ hr^{-1}$)	1.	0.04	0.05	0.05	0.04
	2.	0.05	0.06	0.06	0.05
	3.	0.13	0.15	0.15	0.13
Total		0.22	0.26	0.26	0.22
Precipitation computed by Bannon's method ($cm\ hr^{-1}$)	1.	0.04	0.05	0.05	0.04
	2.	0.06	0.06	0.06	0.06
	3.	0.16	0.18	0.18	0.16
Total		0.26	0.29	0.29	0.26
Precipitation recorded in next 15 hrs		8.5 in or 21.6 cm	1.0 in or 2.5 cm	2.5 in or 6.4 cm	4.5 in or 11.4 cm

Key

Layer 1 = 0—3000 ft

Layer 2 = 3000—5000 ft

Layer 3 = 5000—10,000 ft

$\overline{W_o}$ = mean vertical velocity of layer

The results obtained by this method were also compared with computations made on the basis of a slightly different method devised by Bannon[9]. Bannon considered the ascent of unit volume of saturated air and obtained an expression for the rate of precipitation measured at the ground. In Bannon's notation, the rate of precipitation

$$= \overline{w} \int_{z_1}^{z_2} I.dz$$

where, $\overline{w}$ = average upward velocity of layer considered,

$$I = \Gamma_s \left(\frac{r}{T} + \frac{\partial r}{\partial T} \right) - \frac{gr}{RT}$$

r = water vapour content of 1 cc of saturated air.

Bannon also computed $\partial r/\partial T$ from values of r in Smithsonian Tables. The results of the comparison as seen in Table 3 show that only small differences result if we use the simpler Clausius-Clapeyron equation.

In constructing Table 3 the height of an individual station was not taken into account. This may introduce slight inaccuracy in the case of Poona which is at a height of 1800 ft above sea level but since we were mainly concerned with the order of precipitation this refinement was considered unnecessary.

It is seen from Table 3 that if the air over Bombay had been ascending upto 10,000 ft at the rate shown by the convergence charts the rainfall, purely due to convergence, would have been lesser than that actually recorded. In fact, even if the air remained saturated from 10,000 to 20,000 ft and ascended at the rate 12 cm sec^{-1} the total rate of precipitation would only be of the order of 0.5 cm hr^{-1}. Hence the rainfall recorded in the next fifteen hours would only be of the order of 7.5 cm, whereas about 22 cm was recorded. From the above, it appears safe to conclude that the abnormally heavy rain recorded at Bombay could not have been due to convergence alone.

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