551·515 : 551·577·37

Two spells of rainfall of unusually high intensity at Nagpur in June 1954

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During 1954 the first incursion of the monsoon current over Madhya Pradesh occurred on 17 June and within the first ten days of this date Nagpur experienced two severe thunderstorms associated with heavy downpour the aggregate recorded rainfall during which amounted to nearly a sixth of the total rainfall for the year (47·81 inches). A noteworthy feature of these two thunderstorms was the rather high intensity of the associated rainfall as brought out by the records of the syphon raingauge. A brief account of these two cases is given below.

(*a*) *Thunderstorm on the night of 21-22 June 1954*

The first and more intense of the two thunderstorms occurred on the night of 21-22 June. The severest phase of the thunderstorm was between 0130 and 0200 IST on 22 June 1954, slightly before the scheduled times of arrival of the night airmail services at Sonegaon airport. The relevant autographic charts are reproduced in Fig. 1. Unfortunately the recording mechanism of the raingauge failed a little before 0215 IST. Nevertheless, the chart brings out the high intensity of the thunderstorm rainfall which set in abruptly at 0130 IST. The total rainfall recorded by the ordinary raingauge during the 24 hours ending at 0830 IST of 22 June 1954 was 3·94 inches most of which fell between 0130 and 0230 hrs. Between 0130 and 0200 hours the intensity of the rainfall reached practically 1·6 inches in 15 minutes or 6·4 inches per hour. Examination of past records shows that this rainfall intensity has been reached only on one occasion (5 September 1951) since the installation of the self-recording raingauge at Nagpur in 1947.

(*b*) *Thunderstorm on the night of 26-27 June 1954*

After the severe thunderstorm on the night of 21-22 June, weather remained dry at Nagpur for the next four days. However, on the night of 26-27 June, a thunderstorm with heavy downpour again occurred the severity of which was only slightly less than that of the previous one. The relevant autographic charts are reproduced in Fig. 2. It will be seen that the peak activity of this storm was between 0300 and 0400 hours. The total rainfall recorded during the 24 hours ending at 0830 IST on 27 June 1954 was 3·61 inches most of which fell between 0300 and 0400 hours. The maximum intensity of rainfall in this case was 4·8 inches per hour between 0330 and 0400 hours. During the past eight years there have been only two occasions (19 June 1953 and 24 August 1952) when rainfall of this intensity has been recorded at Nagpur in addition to the instance mentioned under (*a*) above.

(*c*) *Rate of precipitation*

Both the instances referred to above were presumably associated with a high degree of atmospheric instability and vertical convection resulting therefrom. Assuming that the lowest layers of the atmosphere were saturated, it is of interest to calculate the vertical ascending velocity which would give rise to the observed intensity of precipitation.

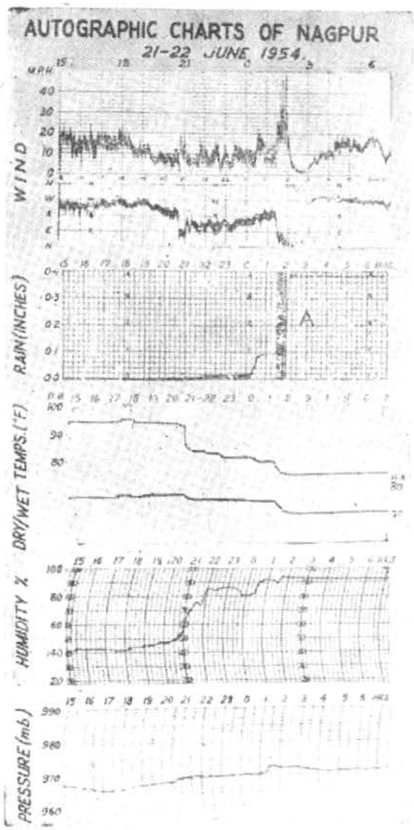
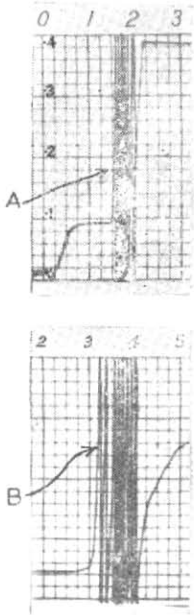

AUTOGRAPHIC CHARTS OF NAGPUR
21-22 JUNE 1954.
WIND
RAIN (INCHES)
A
DRY/WET TEMPS. (°F)
HUMIDITY %
PRESSURE (mb)

Fig. 1


A
B

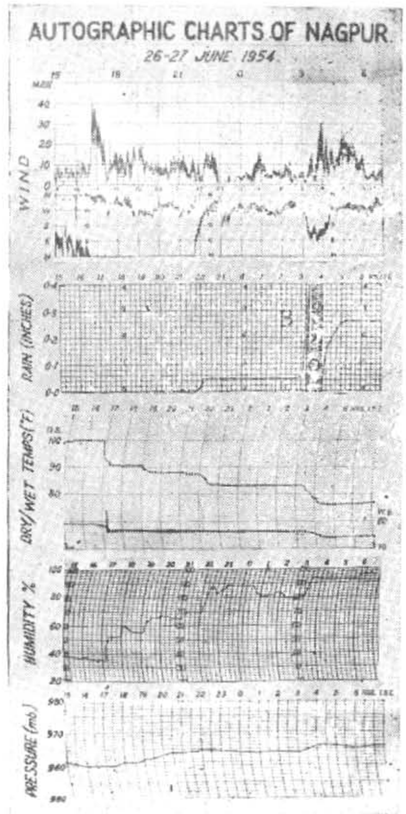

AUTOGRAPHIC CHARTS OF NAGPUR
26-27 JUNE 1954
WIND
RAIN (INCHES)
B
DRY/WET TEMPS (°F)
HUMIDITY %
PRESSURE (mb)

Fig. 2

The problem of calculating the rate of precipitation from ascending saturated air originally dealt with by Fulks (1935) has been discussed in the text-book *Dynamic Meteorology* by Holmboe and others (1945). Sil (1950) made numerical computations of the rate of precipitation in certain cases following this treatment. Bannon (1948) and Das (1951) have also discussed the same problem and made some numerical computations. It can be shown that the T-ϕ gram affords an extremely simple, rapid and sufficiently accurate method of evaluating the rate of precipitation from any atmospheric layer in which vertical ascent is taking place without the necessity of any additional tables of elaborate numerical computations.

Consider a vertical column of saturated air of 1 sq. cm cross-section. Let an element of this column 1 cm thick at the geopotential level ϕ be moved upwards through $d\phi$. Let ρ be the density of the element, w its water content and let dw grams of water be precipitated during the ascent. Remembering that the difference between the lapse rates of ascending saturated air (γ_s) and unsaturated (dry) air (γ_d) arises from the latent heat L liberated by the precipitated water we have the relation—

$$\rho c_p (\gamma_d - \gamma_s)\, d\phi = L\, dw \qquad (1)$$

where c_p = specific heat of the parcel of air. Hence we have for the rate of precipitation from the ascending element

$$\frac{dw}{dt} = \frac{\rho c_p}{L}(\gamma_d - \gamma_s)\frac{d\phi}{dt}$$

$$= \frac{\rho}{L}\left(1 - \frac{\gamma_s}{\gamma_d}\right)\frac{d\phi}{dt} \qquad (2)$$

This is Fulks' equation.

For purposes of calculation using the T-ϕ gram we may divide the atmosphere into layers of say 100-mb thickness and assume that the conditions corresponding to the midpoint of the layer are representative for that layer. If $\triangle h$ cm is the thickness of one such layer, then the rate of precipitation ($\triangle P$) from that layer is given by—

$$\triangle P = \frac{\rho}{L}\left(1 - \frac{\gamma_s}{\gamma_d}\right)\frac{d\phi}{dt}\cdot\triangle h$$

$\rho.\triangle h$ = mass of air in the 100-mb thickness layer $= 10^5/g$ gm. Hence the rate of precipitation in grams per second from the layer of 100-mb thickness is given by—

$$\triangle P = \frac{10^5}{L}\left(1 - \frac{\gamma_s}{\gamma_d}\right)\frac{dz}{dt} \qquad (3)$$

where $\frac{dz}{dt}$ = rate of ascent in cm sec^{-1}

The value of L for 0°C is $2\cdot5\times10^{10}$ ergs/gm. With a sufficient degree of accuracy for the present problem we may neglect the variation of L with temperature and assume the above value. We then get for the rate of precipitation in grams per second from a saturated layer of 100-mb thickness, in which vertical ascent is taking place at the rate of 1 cm per second

$$\triangle P = 4\times10^{-6}\left(1 - \frac{\gamma_s}{\gamma_d}\right) \qquad (4)$$

The rate of precipitation in inches per hour from a saturated layer of 100-mb thickness ascending with a velocity of 1 km hr^{-1} can be calculated as:

$$\triangle P = 0\cdot1576\left(1 - \frac{\gamma_s}{\gamma_d}\right) \qquad (5)$$

When we are concerned with several layers each of 100-mb thickness the total rate of precipitation in inches per hour for an ascending velocity of 1 km hr^{-1} is given by—

$$P = 0\cdot1576\ \Sigma\left(1 - \frac{\gamma_s}{\gamma_d}\right) \qquad (6)$$

The value of γ_s/γ_d for any layer can be easily obtained from the T-ϕ gram. It is given by the ratio of the difference of temperature between the top and bottom of a saturation adiabat passing through the midpoint of the layer to the corresponding difference of temperature for a dry adiabat.

As an example let us consider a saturated atmosphere having a saturated adiabatic lapse rate and a surface temperature of 25°C at the 1000-mb level. (The surface condition is practically the same as that which obtained in the two cases mentioned above). The total quantity of precipitable water in this column is about 3·2 inches and practically the whole of this is contained between 1000 and 200-mb levels*. Using the T-ϕ gram the following values for successive 100-mb layers are readily calculated—

Layer (mb)	ΔP (in/hr)	(gm/100 gm of dry air)
1000—900	0·11	1·90
900—800	0·10	1·65
800—700	0·09	1·45
700—600	0·09	1·20
600—500	0·08	0·90
500—400	0·08	0·60
400—300	0·06	0·30
300—200	0·03	0·07
Total: (1000—200)	0·64	8·07 (=3·2 inches of precipitable water)

The last column gives the humidity mixing ratio corresponding to the midpoint of the layer expressed in grams of water per 100 grams of air and hence gives the precipitable water in grams in each layer for all practical purposes.

It is seen that an ascending velocity of 1 km hr^{-1} throughout the column from 1000 to 200 mb will give a rate of precipitation of 0·64 in. hr^{-1}. A vertical velocity of 10 km hr^{-1} throughout the column will be required to account for the observed rate of 6·4 in. hr^{-1} on 22 June 1954.

It is interesting to see that the rainfall contributions of the different layers decrease less rapidly with height than their total water content. The layer 400-300 mb for instance gives over half the contribution of the bottom-most layer although its total water content is less than a sixth of that of the 1000-900 mb layer.

Bannon (1948) has discussed the problem of estimation of large scale vertical currents in the atmosphere from measurements of the rate of rainfall. The T-ϕ gram method explained in the present note gives practically the same results as those arrived at by Bannon by more elaborate mathematical computation for the rate of precipitation.

In an interesting paper entitled "World's Greatest Observed Point Rainfalls", Jennings (1950) has given a table in which are listed some of the highest observed rainfall intensities. According to this the highest observed rainfall intensity is 0·65 inches in 1 minute. Such high intensities which naturally can only be of very short duration are exceptional.

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*See *Compendium of Meteorology* (1951), pp. 1035-36