ABNORMALLY HEAVY RAINFALL IN INDIA — TEMPERATURE INVERSIONS IN TROPICAL AIR MASSES

S. L. MALURKAR
(*Poona* 5)

THE frequency of heavy rain in 24 hours, in the course of nearly 30 years have been published.[1] Occasions when more than 10″ of rain fell in 24 hours have also been recorded.[2,3] The data are based on observations taken at nearly 3,000 provincial rain-gauge stations distributed over India. It is of interest even to attempt a tentative explanation of such rainfalls and their distribution. An analysis of 10″ or more in 24 hours, recorded over such a long period is hardly likely to lead to an easy solution, and becomes theoretically unwieldy. It is possible, however, to raise the limit of rain above which one has to consider. The places recording 15″ or more in 24 hours were noted on a large map of India (scale 1″ = 32 miles). The distribution of places where these abnormal amounts fell has a definite scatter leaving out of account some individual stations. The scatter could be broadly grouped under (*a*) East Gujarat near about the Gulf of Cambay, (*b*) South Assam near the Cachar Valley, to a lesser extent, (*c*) near the Circars and Coromandel Coasts, and finally, (*d*) the individual stations. It looked obvious that data in regions (*a*) and (*b*) would help, by analogy, to explain the instances under (*c*) and (*d*).

As the data refer to an extended series of years over fairly well-distributed rain gauge stations, the conclusions drawn from them *would be generally valid*.

East Gujarat is well north of the Western Ghats. The places that have had a record of heavy rain near the Ghats are Igatpuri (about 80 miles E.N.E. of Bombay) and Malcolmpeth (Satara District.). Some of the rainiest places in Mysore hardly touch 10″ in 24 hours. The average height of the Western Ghats decreases northwards. The rain, therefore, cannot be explained merely by Orography. Similarly, in N.E. India and Burma, one would have expected that the higher level stations along the Arakan Yomas, which are in the path of the monsoon winds, would show instances of very heavy rain as in South Assam. Kanpetlet (Lat. 21° 10′ N., Long. 93° 59′ E.; ht. 6,322 ft.) though considerably higher than Cherapunji (4,309 ft.) has not recorded even as heavy a rainfall.

The heavy rains at Cherapunji mostly occur when the monsoon over North India, *i.e.*, west of Cherapunji, is relatively weak.

Abnormally heavy rain occurs in and near East Gujarat associated with a depression to the east of the place. It is commonly observed that abnormally heavy rain occurs when a depression is almost filling up. When abnormally heavy rain fell in East Gujarat and S.E. Rajputana, the monsoon depression which had caused the abnormal rain did not travel much further west,[4] *i.e.*, the monsoon to the west of Gujarat and S.E. Rajputana would be weak. This shows the analogy in the case of South Assam.

For the formation of a tropical depression in the monsoon and non-monsoon months it is necessary to have three air masses:[5] (*a*) Em—Equatorial Maritime air which come from the other side of the equator—it can be made easily unstable and gives rise to thunderstorms; (*b*) Tr—a mixed Transitional air whose ultimate origins are the high pressure areas of the North Pacific and the North Asiatic continents. It flows along the displaced "N.E. Trades". Though this air is hot and moist and becomes more so in its travel in the S.W. monsoon due to its equator-ward motion, it gains in stability along its path (except perhaps when very near the equator and when about to cross to the other side); and (*c*) Tc—Tropical Continental air, a dry hot air.

A tropical depression fills up or recurves to a northeasterly direction when the supply of Em is cut off[6] and behaves like an extra-tropical depression with only two sectors. The extra-tropical disturbances are more or less active as the "N.E. Trades" feed into it or move away from it. The recurved tropical depression is an extreme case of the "N.E. Trades" feeding into an extra-tropical depression.[7]

As the supply of Em is cut off, when a depression is filling up, the abnormally heavy rain can only be assigned to Tr. Before the recurvature of the tropical depression, Tr has a slightly equator-ward motion and is gaining in stability at lower levels. Its moisture content and temperature are also increasing in the lower levels. As a result of this, a temperature inversion is set up in it which magnifies the stable nature of the air (*infra*). When the depression recurves, Tr becomes the moist and warm sector, and has a pole-ward movement. The hot moist stream which was gaining in stability (as shown by isothermal layers and temperature inversions) now develops latitudinal convergence and gets to be less stable in its N. or N.E. motion, the isothermal layers and temperature inversions get destroyed. The previous temperature inversion has helped in storing large energy. The effect of convergence or divergence with change in latitude is more marked nearer the equator than elsewhere. At the stage of recurvature of a tropical depression, a sort of front, extending from S.W. to N.E. with heavy rain along it develops in the depression.[8] The degree of abruptness with which Tr which till then had an equator-ward motion is *bent back* to a pole-ward direction determines the heaviness of the rain or to put it in other words, the change from stabilising to unstable conditions in the Tr is responsible for the heavy rain. The season and locality are necessary as the properties of Tr depend on them, *i.e.*, the amount of moisture and temperature the air has acquired before getting a pole-ward motion.[9]

The recurvature occurs due to a western disturbance moving in a more northerly latitude, and the rear of the latter provides the fresh Tc to the recurved depression and gives more contrast with Tr than before recurvature. The partition between Tc and Tr gets to be more marked.

During the S.W. monsoon months, the depressions form at the head of the Bay of Bengal and near Kathiawar.[10] The approximate positions of Tr should be to the N.E. of the places.[11] The Tc for depressions about Kathiawar would be from West Asia and adjoining regions of India. Tc for the depressions that form near the Gulf of Siam and Upper Burma would be from Upper India. The heavy rain in South Assam should, therefore, be due to the depressions that recurved over Siam and Upper Burma, and the mechanism should be similar to that which occurs in East Gujarat, *i.e.*, the bending back of Tr with the recurvature of a monsoon depression to the east of the place.

The above explains why a monsoon depression which remains stationary in the west United Provinces gives rise to heavy rain.[12] Under the influence of a western disturbance travelling far north and cutting off of fresh supply of Em, the Tr of the depression is given a northerly bend giving rise to heavy rain.

The heavy rain that falls along the Circars coast is due to the depressions from the Bay of Bengal. The depressions may themselves recurve and produce very heavy rain as in the first few days of June 1941. Due to distribution of land and sea, the other alternative would be the refraction of the trajectories of Tr to the north which would again be conducive to the production of heavy rain. It is well known that heavy rain falls very near the coast just about the time a depression moving in some westerly direction crosses the coast. After crossing the coast, if the depression tends to fill up, there is again a downpour of rain.

The question of *bending back of Tr towards the north coupled with a fresh supply of Tc giving rise to heavy rain* has been verified in a number of particular instances, and is being followed up. The abnormal amounts of rain that were recorded at Bombay on 10th September 1930 (22") and on 9th September 1946 (9") seem to have the same cause. In both cases a depression which was to the east of the place filled up about the same epoch.

The bending back of Tr shows as the wedges in the case of the western disturbances in winter and have been stressed elsewhere.[13] The weather only occurs, apart from orography, only where the air is ascending up the latitude.

The problem of heavy rain and its location is reduced to the following of the recurvature or filling up of a depression or the tracing of Tr carefully.

Temperature Inversions in Tropical Air Masses.—As rainfall is intimately connected with convection, a digression on this subject is called for. When an air stream is moving towards the north or south pole, there is latitudinal convergence or there is a tendency for upward convection in the air mass which is calculable. The upward convection would be indicated by a high lapse rate and an absence of a temperature inversion. When, however, the air has an equator-ward motion there is latitudinal divergence and the tendency is for the air to descend. The air stream is gaining in stability and is having slow subsidence (rapid subsidence cannot extend over a long period or area). The lapse rate tends to be below the adiabatic one. The stability of an air mass is, in fact, determined by its capacity to stop convection. This stability increases as the lapse rate decreases from the usual dry or wet adiabatic values. The lapse rate can become zero, *i.e.*, lead to isothermal layers or even become negative leading to temperature inversions. It follows that an equator-bound air stream would exhibit isothermal layers and even temperature inversions.

If the equator-ward moving air stream is passing over a large stretch of water or swampy land, due to its increasing temperature along its path, it would absorb moisture. As the amount of convection is small due to the small lapse rate, the moisture would be confined to lower levels of the stream: below the isothermal or inversion layer. Due to differential effect of radiation, the moisture in the lower levels would give rise to an inversion or sharpen it if one already existed.[14] The picking up of more moisture and temperature in the lower levels and the sharpening of the inversion level due to radiation and due to descent in the latitudes would be the character of an equator-ward moving stream near sea or swampy land. This may be expected to hold good unless the stream is very near the equator and about to cross it to the other side.

Among the equator-ward moving tropical streams Tr is an important one. In the Pacific Ocean and in S.E. Asia it is moving over water or swampy land. Deppermann[15] has given the inversion in the "N.E. Trades" at 1·5 to 2·0 kms. The inversion that occurs over Bengal in the premonsoon months when the "N.E. Trades" have been displaced northwards to that latitude is given a simple explanation. Due to the frequency of monsoon depressions, the thermal structure over Bengal is disturbed, and the inversion is practically wiped out except during long 'breaks' in the monsoon. It is to be made clear that the wiping out is not solely due to the pole-ward moving Em or fresh monsoon air. The only thing this fresh air would do is to allow a parcel of it to pass through the inversion layer. But due to the cyclonic circulation, Tr, which is from the east and had an inversion, gets a slight northerly bend with a tendency to converge, and hence with a tendency for the wiping out of inversion. It is not possible to dynamically figure out the formation of inversions and their wiping out by advection of one or more air masses.[16,17] in the tropics without bringing in the latitudinal changes and radiation.

The inversions at Karachi are due to Tc flowing slightly equator-ward over the Persian Gulf and the North Arabian Sea during the monsoon months. Over lower Sind, the paucity of depressions and less chance of latitudinal convergence make the inversions more persistent about the height of 1·0 km. The deepening of the inversion layer as one moves from Mekran to Kutch also becomes understandable.

A reference to the radio-sonde observations of Addu-Attol, in the old Indian Daily Weather Reports, often shows isothermal layers, and, occasionally, temperature inversions during the northern summer. When the air is about to cross the equator, there is hardly any inversion.

The formation of a temperature inversion is very important as it allows sufficient moisture to accumulate without its being dissipated by convection or immediate thunderstorms. It conserves the moisture and the energy for later release if needed.[18] The inversion in Tr south of the equator, explains the shallow depth of the S.W. monsoon in the neighbourhood of the equator. The diurnal variation of temperature at Nuwara Eliya is nearly 12° F. even on a good monsoon day, showing that the hill station is not well within the monsoon stream. At Mahabaleswar the diurnal variation of temperature is sometimes as low as 2° F. The Mannar and Trichinopoly upper winds also show such variations. The depth of the S.W. monsoon increases with gain in latitude, partly due to sea travel and partly due to latitudinal convergence. Similarly the shallow layer of moisture of the N.E. monsoon in northern winter is explained by the Tr north of the equator having an inversion at about 1·5 kms. This air crosses to the southern hemisphere at intervals to feed the monsoon there. The radio-sonde and aeroplane ascents and the extreme dryness at the high hill stations in South India all show the existence of temperature inversions in the "N.E. Trades" in northern winter.

The data are being further studied.

1. *Memo. India Met. Dept.*, **23**, 413–520. 2. *Ibid.*, **21**, 1–110. 3. *Ibid.*, **25**, 109–43. 4. Malurkar, *Forecasting Weather In and Near India*: Printed in Bangalore, limited number, May 1945 (released Nov. 1945). 5. *Ibid.*, p. **34**, and p. 87. 6. Malurkar, *Curr. Sci.*, 1947, **16**, 14. 7. —, reference **4**, p. 139. 8. Normand, *Gerl. Beitr. z. Geophys.* 1931, **34**, 233. 9. Malurkar, reference **4**, p. 91. 10. *Ibid.*, p. 39. 11. Malurkar, *Curr. Sci.*, 1947, **16**, 148. 12. —, reference **4**, p. 48. 13. *Ibid.*, p. 110. 14. —, *Gerl. Beitr. z. Geophys.*, 1932, **37**, 415. 15. Deppermann, "Outlines of Philippine Frontology," Manila, 1936. 16. *Winter Rain in the United Provinces and Nor'westers in Bengal* (in press), and Chatterjee and Sur, *Memo. Ind. Met. Dept.*, **26**, 171. 17. References to Field in Chatterjee and Sur's paper in the above, and Hariharan, *Sc. Notes, Ind. Met. Dept.*, **5**, 41. 18. Malurkar, *Proc. Indian Ac. Sci.*, Sec. A, 1943, **18**, 26.