RECENT ADVANCES IN TROPICAL METEOROLOGY*

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INDIA is meteorologically the best equipped country in the tropics. A fresh approach in Tropical Meteorology would necessarily be of great use to India.

The rain associated with the S.W. monsoon feeds literally most of the persons in Asia. It is a good starting point and most other problems of tropical meteorology can be made to depend on it. Apart from what one learns in Physical Geography, extensive work has appeared on the subject.[1] Up to 1925, the idea of the S.W. monsoon was that it was due to the penetration of the 'S.E. Trades' into the northern hemisphere under the influence of the vast summer low pressure area over Asia. Blanford, Hemraj, Simpson, Doraiswamy Iyer and Normand took this view. The Indian monsoon was statistically connected with the high pressure area over S. America. The transport of fresh air from there to India was assumed to take place along the geographically shortest path, *i.e.*, across extreme S. Africa and the 'roaring forties', then up along the 'S.E. Trades' almost up to the coast of E. Africa and then from the E. African coast to India across the Arabian Sea. As the idea is only implicit in papers by Hemraj, Walker and Doraiswamy Iyer, it was confirmed by consulting the last person. Meteorological observatories *were* maintained by the India Meteorological Department at Zanzibar and at Seychelles, showing thereby the importance attached to observations from these places rather than from places further east in the equatorial region. There was hardly any necessity to consider the monsoon in S.E. Asia. Doraiswamy Iyer[2] found much later that there was a great similarity in the summer rain over North Siam and over N.W. India as far as the statistical factors were concerned. The progressive delay in the dates of onset of the monsoon from the east to west did not disturb the earlier workers. The actual mechanism of the S.E. Trades crossing the equator was not definite; though epochs of high pressure in the S. hemisphere appear to have been pictured. For some reason after 1925, the idea of air crossing the equator receded into the background.

In the twenties of this century, the concept of air mass analysis was developed by Bjerknes and his school in Norway, and the idea captured Europe and America. The India Meteorological Department was equally enthusiastic to adopt newer methods of analysis. Roy and Roy (1930) looked into the question of air masses in the monsoon depressions in the Bay of Bengal. Their extent of observations was small. The methods adopted by them followed closely those used in extra-tropical latitudes. These imposed severe limitations on their conclusions. They found three air masses, *viz.*, (1) fresh monsoon air, (2) monsoon air desiccated and deflected by the hills in the N.E. angle of the Bay, or as sometimes designated as old monsoon air, and (3) dry continental air. Normand (1931) said that "the air mass concept was implicit" in the older workers in India. Wagner's[3] paper brought in a definite trend to the later thought. He utilised the upper air data which had considerably increased since Harwood. The picture of the S.W. monsoon was taken to be a vast stationary extra-tropical cyclone or a low pressure area after Bjerknes, *i.e.*, with two air masses. Air from south of the equator did not enter into the picture. Investigations on individual cyclonic storms or depressions in the Indian Seas were undertaken with mostly local data.[1] (Depressions and cyclonic storms are essentially similar and either of the terms will be used here to denote the conditions for both). Doraiswamy Iyer[4] extended the life of many of the depressions of the Bay of Bengal to the Far East with scanty available data. Ramanathan and Ramakrishnan on the one hand and Sur on the other tried to improve on Wagner's ideas with later data.[5] The main idea was that the fresh monsoon air was produced in the N. Indian Ocean.. The southern hemisphere was not generally brought in even for argument, else some space would have been devoted to it. In his contribution to the Indian Science Congress in 1938, Normand apparently kept on to his old view though explicit mention is lacking. Ramanathan and Ramakrishnan in 1938[6] were sceptic about the role of even 'southerly air' in the pre-monsoon cyclonic storms and the text was substantially the same in the reprint of 1943. A study of the monthly mean upper winds could hardly be expected to give clear enough indications of short-period discontinuous incursions of fresh monsoon air from south of the equator. The trajectories that were drawn across wide stretches, based purely on existing observations suffered under the serious disability of not always providing correct clues. Most of the workers tried, somehow, to reduce the tropical depressions into particular cases of extra-tropical depressions of the Norwegian school. It was thought that though at the surface, the structure did not resemble an extra-tropical depression, it should or would do so at a higher level in view of differences in the lapse-rates in the different air masses. Terms like 'upper air fronts' were coined. A scientific worker tries to take into account all the previous work known to him and puts an overall final picture. This is particularly so when mention has been made of the previous work and no statement is made that an alternative picture is being presented. The mere mention of certain terms in a vague way does not prevent the same terms being used by a later worker after giving a *specific* character to the terms or ideas. There should be no possibility of mixing up meanings. It is desirable to give the background of work which led to the ideas.

In 1933-34, I had tried to study the equatorial circulation with the newly started pilot balloon observatories in Br. E. Africa. The observatories were within a few degrees of the equator and were, I thought, suitable for a study of transport of air across the equator. In north-

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ern summer, large southerly components could be found up to about 1·5 to 2·0 kms. at these places. The data from the Malayan Peninsula and from the Far East were also used. Unfortunately other duties prevented me from following up the ideas. While forecasting at Karachi (1938-42), I was distressed like most novices, at the large mass of disjointed facts apart from a few well-known ones. Among them were: "A western disturbance would, often, have passed away over Iraq according to prevalent ideas. But yet, Bahrein continued to record southeasterly or southerly winds and Bushire continued to record low pressure values and the value used to be very often corrected. During the summer, in the Persian Gulf region, instead of the usual "Col" pattern, a hexagonal pattern with three low pressure areas alternating with three high pressure areas existed almost daily. Simple ideas of axes could not be applied. The hexagonal pattern and the stationary type of the S.W. monsoon were apparently connected. There was hardly any detectable disturbance over Iraq; on the evening of 16h February 1939, the upper winds at about 2·0 kms. were 180° apart at Bahrein and Sharjah. Later a ship reported a southerly wind off Oman. The subsequent fortnight of bad weather with its air accidents were difficult to explain cogently. B. N. Banerji had given the idea of a secondary western disturbance. The fact that every western disturbance had to be divided up into a series of separate circulations, each of which could be supposed to have its own identity and evolution, was not on record. Fresh problems were posed when the observations from Iraq were cut off in 1940 due to disturbances there. By an analytical method of mixing up of cause and effect, the criteria for the production of dust-rising winds were determined. Sen's vortex method of weather forecasting appeared after 1942.[1] After I came to Poona in May 1942, the ideas that were represented on the charts did not agree with what I had gathered at Karachi for the same region. The security reasons prevented access to work elsewhere. Deppermann's pre-war work was available only at the end of 1946. Pendall's charts came slowly in batches after August 1943. Apart from this, observations from familiar places like Burma and Sumatra and from the ships were cut off and those from Russian Turkestan, new to us, obtained. In between Russian Turkestan and the frontiers of India the area was unrepresented. The maximum use had to be made of the data without waiting for the 'collection of statistics' or 'climatology'. *Ad hoc* methods were not in place. Fresh data would trickle in at any time and newer demands were made by the weather clients. It was very necessary to formulate some method of tackling the problem, and in a colloquium at Poona in January 1943, the "Basis of Tropical Meteorology" was given.[7]

The drawing of isobars or other isopleths in the tropics was the first problem. They had to belong to a non-intersecting family of curves. The pressure and wind at each place gave three quantities which went to solve the equations determining the members of the family. This advantage could not be sacrificed on the plea of uncertainty of observations or of their significance. Rules were formulated so that fairly reproducible curves could be drawn.

In the tropics, the disturbances are mostly diffuse. They have to be split up into individual circulations and followed step by step. The principle of minimum action was applied to the motion of depressions, which should have a preference to cross coast near the river deltas, valleys and to move in between the corridors of two high pressure areas. The idea of latitudinal convergence was applied to both streams and disturbances. A depression that had an *apparent* equator-ward travel and showed a *deepening* was definitely taken as composed of two depressions. The main depression moved as usual, polewards and a secondary depression had developed on the more equatorial side. The western disturbances and the typhoons that crossed over into the Indian area furnished the evidence for this concept.

The effect of a limited obstruction like a mountain or a high pressure ridge in the path of a depression of the same or bigger order of dimension was next considered. A secondary depression can often be induced on the other side of the obstruction even though the original one was deflected away polewards.

The principle of 'confusion or mixing up of cause and effect' was necessary in a continuous and uncontrollable process or series of experiments. The principle of superposition follows logically for a resynthesis of meteorological phenomena.

While it is hardly possible to write down the concrete steps in any but extremely general steps, yet the definite method of approach was a step forward. Obviously, any theory so formulated must lead to further verifiable results without an overloading of *ad hoc* assumptions. There must be an essential rational structure in tropical meteorology. The ideas were verified in a few typical cases. When they were found correct, newer logical consequences were deduced for further verification and in turn for further deductions. Due to inherent observational difficulties, it was realised that not all stages of argument could be verified. If, however, there was a definite contradiction in the course of the work, all assumptions were re-examined and suitably modified. The starting point was the ideas actually prevalent. This method saved time and gave the much needed results. When draft "Notes on Forecasting Weather Over India and the Neighbourhood" had to be written up in January 1943, the method allowed me to write up the book continuously (in a few weeks), as a series of connected facts. Any other method would have involved formidable work and inordinate delay. Soon after the observations from the Indian Ocean were charted (May 1943), the essentials of tropical depressions and of monsoon could be grasped.

The surface gradients of the measured elements in the tropics are small compared with their corresponding values in the temperate zones. If an attempt at air mass analysis has to be made distinctly and unmistakably, the tracing in space and time has to be from a far enough region from an actual depression. The sequence of meteorological phenomena is an important guide in following the air streams.

Mauritius used to send telegrams about cyclonic storms in the S.W. Indian Ocean in the non-monsoon months up to the end of 1942. The concurrent weather over India was noted. The old ships' logs near the equator were also consulted. The weather near the equator was found to be significantly related a few days before the detection of formation of cyclonic storms on either side of the equator. Fresh monsoon air crossed the equator only at intervals and under only specified conditions. A definite time sequence was found and could be used for medium range weather forecasting.

In my experience the heat waves at Agra (1935-37) and at Karachi (1938-42) were followed by unsettled weather in the Bay of Bengal or in the Arabian Sea respectively. The time sequence was detectable.

Roy and Roy's idea of "deflected and desiccated monsoon air" was highly localised in space and time. It could not be used for a monsoon depression in the N.E. Arabian Sea. It could not be applied to even the depressions in the Bay of Bengal in the non-monsoon months. Often, the sequence of weather did not permit the time lag required for the monsoon air to get deflected. The potential wet bulb temperature of this 'deflected' air was greater than that of the fresh monsoon air so that the idea of desiccation is invalid. The application of this deflected and desiccated air, elsewhere in the tropics, was out of question. Sen and Puri's observations were confined practically to India and Burma. Little attempt was made to trace the air masses even by implication to high pressure areas. Deppermann found, sometimes, on the N.E. side of the typhoons a warm sector near the Philippines. His background of analysis is similar to that employed for extra-tropical depressions. My method of detection of this third air mass was based on a study of carefully drawn isobars, streamlines and on the sequence of weather. It came from the east and its temperature and humidity changed considerably with season and locality.

The monsoon depression and tropical cyclonic storms with a westward travel had the same structure and involved the incursion of three and only three air masses: (1) Fresh monsoon air or Equatorial Maritime air (Em) from the other side of the equator; (2) Far Eastern Transitional air (Tr) and (3) Dry Continental air (Tc and occasional Pc). The chief features of the three air masses are:

Equatorial Maritime Air (Em).—During the S.W. monsoon and in the pre- and post-monsoon months, fresh maritime air crosses the equator from the south at intervals depending on other specific meteorological conditions. The actual time taken to cross the equator is very small. There is a good interval of a few days before the next crossing can take place at or near the same locality. The word 'pulse' of monsoon was employed to indicate the discontinuous and short-period crossing of air from the southern hemisphere. The character of the air mass undergoes considerable change during its travel. It starts from one of the high pressure cells in the southern hemisphere as almost dry continental air (Tc). In its westward travel, it gradually picks up moisture and additions of dry air from further south. Later, due to its moisture content, it can be recognised as giving rise to shallow low pressure areas. Its vertical height is not more than 2 kms. It moves in an almost W. or W.N.W.-ly direction. The air at this stage corresponds to the Far Eastern Transitional or Mixed air (Tr) described later. As there is an equator-ward component in the motion of the shallow low pressure area, the air cannot be made easily unstable. It picks up considerable amount of moisture and temperature when moving over large water surfaces in the tropics. Being southern winter, the moisture content would be large only in the lower layers. Mid-air temperature inversions would be found at about 1·5 kms. As the shallow low pressure area or 'pulse' approaches the equator, the moisture content increases appreciably. When just about to cross and certainly after crossing the equator, the air would have accumulated a large amount of energy and the temperature inversion disappears. The equator acts as a sort of selective barrier which is not impassable. After crossing the equator and moving northwards, the air undergoes convergence due to pole-ward travel. *The air at this stage is Em.* It can be made easily unstable. Thunderstorms occur all along its path and the weather over the sea would be squally. The diurnal variation of temperature in its mass is small, hardly 2° to 3° F. The sea-level temperature is just under 80° F. In its northward travel, due to latitudinal convergence and due to its passing over the sea the vertical thickness of moisture increases and the energy is easily releasable. It acts as a 'source' among the tropical air masses.

Far Eastern Transitional or Mixed Air (Tr).—This is a mixture of Tropical Maritime air (Tm) and Tropical Continental air (Tc) in varying proportions depending on the locality and season. In the Pacific Ocean, there may be even a mixture of Em. In winter, over land area, there may also be Polar Continental air (Pc). The air comes to India from the same side of the equator as the depression; the ultimate origin of Tm is the high pressure area over the N. Pacific Ocean; and the high over N. Asia supplies Tc and in winter even some Pc. Tr flows along the 'N.E. Trades' in winter. In summer, it flows along the displaced 'N.E. Trades', displaced because of the vast low prssure area over Asia. Part of the air has an equator-ward travel and tends to develop stability in its mass and, as mentioned by Braak long ago, mid-air temperature inversions. Once the temperature inversion has developed, it is not sensibly affected by the slow drifting of air northwards round the anticyclonic cells. If the mid-air inversion is wiped out by rapid latitudinal convergence, bad weather and very heavy rain can result. Ordinarily it does not release energy, though it is hotter than Em in summer, both as regards the dry and wet bulb potential temperatures; and it passes very near the temperature and pressure equators. In the hills of N.E. India, it may produce some weather due to orography and due to any convergence. The word 'Transitional' is apt as the air undergoes all the stages in the transformation from Tc to Em in its travel from one of the high pressure cells upto its crossing the equator to the other side.

Tropical Land Air or Continental Air (Tc).—For India, it has mostly a land origin from lands in W. Asia. It can be described as Tc with an occasional mixture of Pc. Its humidity is small and it shows a large diurnal variation of temperature on the ground. It brings in unusually hot or unusually cold days over the regions where it passes. For depressions in E. Bay of Bengal or E. Arabian Sea it would be mixed with Tm or Tcm. It is unnecessary to have a separate classification: Equatorial Continental air (Ec), for hot dry air.

With an extensive weather chart, the various air masses can be separated and studied. In the case of the S. hemisphere, an obvious interchange of words 'north to south' and *vice versa* in the above has to be carried out. The ideas are applicable to any part of the tropics.

An important point has to be stressed. The three air streams may be in juxtaposition very near the tropical depression. But earlier to the formation of, and further away from the location of the depression, between every two infeeding streams there is a sort of stagnant air which can at best be described as 'mixed'. The larger circulation due to the tropical depressions may affect the 'mixed' air. If the latter is moist enough, in the 'larger' field of circulation of the depression there would be precipitation whenever there is convergence due to latitude or otherwise. It is possible to mistake this 'mixed' air as the main moist stream of the depression and follow it. One of the most important areas where the 'mixed' air occurs near India is in Central and East Arabian Sea. The West Arabian Sea has Tc from Africa. Before the formation of a monsoon depression at the head of the Bay of Bengal, the track of thunderstorms is from the S.E. Madras to Orissa coast. But with the formation of a monsoon depression in the N.W. angle of the Bay of Bengal, places like Poona get continuous rain. The west coast may get rain as far north as Dahanu, north of Bombay. Within a very short time after the Bay depression has crossed coast, sometimes as short as half an hour, the rain stops at Poona and often even along the N. Konkan coast. Rain along the west coast of India and the rain at Poona are *not followed*, after a definite number of days by a depression at the head of the Bay of Bengal. It appears that the rain along the west coast and at Poona must be due to convergence in the 'mixed' air due to the larger circulation of the Bay depression and perhaps orography. The rain near Gulbarga, Bangalore or Kodaikanal when there are depressions at corresponding latitudes in the Bay must have similar explanation. Pisharoty[8] found the distance between two convergent areas due to change in latitude of an air stream applying Holmboe's theory. The distance from Poona to the head of the Bay of Bengal was of the right order. If the 'mixed' air in the Arabian Sea is not moist enough or if the amount of convergence is insufficient, rain may not fall along the west coast with a depression at the head of the Bay. It is easy to explain the temperature structure of the air stream on the rainy days and the simultaneous onset of the monsoon rain throughout the west coast. The type of rain associated with a depression in the N.E. angle of the Arabian Sea has much more of a creep along the west coast. The other 'mixed' air which needs to be taken into account is the Tr which has approached the equator, which is deflected back due to some reason and which undergoes sufficient latitudinal convergence. Its property would be very similar to Em. A plea may be put forward that the bent-back Tr from the equatorial regions or the 'mixed' air from the Arabian Sea may sometimes be the monsoon feeds of a tropical depression. The over-all sequence of weather phenomena and the reaction of weather in the northern tropics when there is a tropical depression south of the equator in the same longitudinal sector are strong arguments against the plea.

It was found that after a tropical depression recurved eastwards, it had only two sectors and had only two air masses.[9] The air masses could be designated as Tm or Tcm and Tc with an occasional mixture of Pc. The depression resembled the extra-tropical ones. When Em was absent, the depression had an eastward motion. A rigorous convention can be established that a depression is strictly tropical when all the three air masses including Em are present and has, therefore, a westward movement. The depression is to all purposes extra-tropical in structure when only two air masses are involved and has an eastward tendency of motion. Before the actual change of directions takes place the previous momentum of the depression as an entity should be taken into account. Nearer the equator, after a depression has recurved eastwards, it may again get an infeed of Em and once more move westwards. This occurs sometimes and makes a depression change its course unexpectedly from some N.E.-ly direction to some N.W.-ly direction in the Indian area.

Low pressure areas or diffuse disturbances, however, travel in either direction according to the motion of the 6 km. winds in the 'source' sector.

The western disturbance could be split up into simpler circulations or secondary low pressure areas. Each of these had a distinct and evolution.[10] Each of them moved in a well-ordered way almost E.N.E.-wards. The weather at a place was a resultant of the effects of the simple lows. The seasonal low pressure area in winter is south of the equator and modifies the secondary lows of the western disturbance particularly in the more southerly latitudes of the northern hemisphere. The strength of the westerly winds at higher levels decreases as the equator is approached. Each secondary low pressure area of the western disturbance travels slower and extends vertically to a lesser height than its immediate northern primary. Outside the coast of the Persian Gulf and Oman, there were hardly any series of observations. This and the slower travel of the more southerly secondary depressions gave a faulty impression of S.E.-ly travel of western disturbances in the Gulf. The detailed analysis is consistent with known facts.

During the course of the work, a very fundamental result was found regarding the weather in one hemisphere when there is simultaneously a tropical depression in the other in a small sector of longitude. It was found that two tropical depressions, both moving in a westward direction, could not for long coexist on either side of the equator when the longitudinal separation was small, about 10°. In winter, the existence of a similar tropical depression in the S. Indian Ocean gave dry weather over N.W. and Central India even if western disturbances passed over India. During the S.W. monsoon, a 'break' occurs if a monsoon 'pulse' does not cross into the Indian region and moves away westwards or if no 'pulse' appears south of the equator. The first would happen if there be a tropical depression in the S. Indian Ocean. The southern depression may give rain in the extreme south Peninsula within about 12° of the equator. It follows that whatever be the season, outside 10° or 12° of the equator, the weather over a greater portion of India would be generally dry if there be a tropical depression in the S. Indian Ocean. Though tentative dynamical reasons were given to account for the effects,[10] the facts have been verified. In general it follows that the weather would mostly be dry in a latitudinal belt between 12° and 30° of the equator and a longitudinal sector of

(b) one of the tropical depressions may fill up and the other may continue on its westward journey;

(c) one of the tropical depressions may recurve under the influence of an extra-tropical depression and the other tropical depression may continue its westward journey;

(d) Both the tropical depressions may recurve after they have moved away from the equator under the influence of extra-tropical depressions or their secondaries.

The strength of the easterlies at 6 kms. near the equator is smaller than the strength of the westerlies away from the equator. Under similar conditions, an extra-tropical depression moves much faster than a tropical depression. As a rule, the rate of latitudinal shift is also similar. Hence, a recurved tropical depression must normally be more severe than it was before recurvature. If, however, under category

EVOLUTION OF A TROPICAL CYCLONIC STORM

(Idealised diagram of air mass partitions on successive days.)

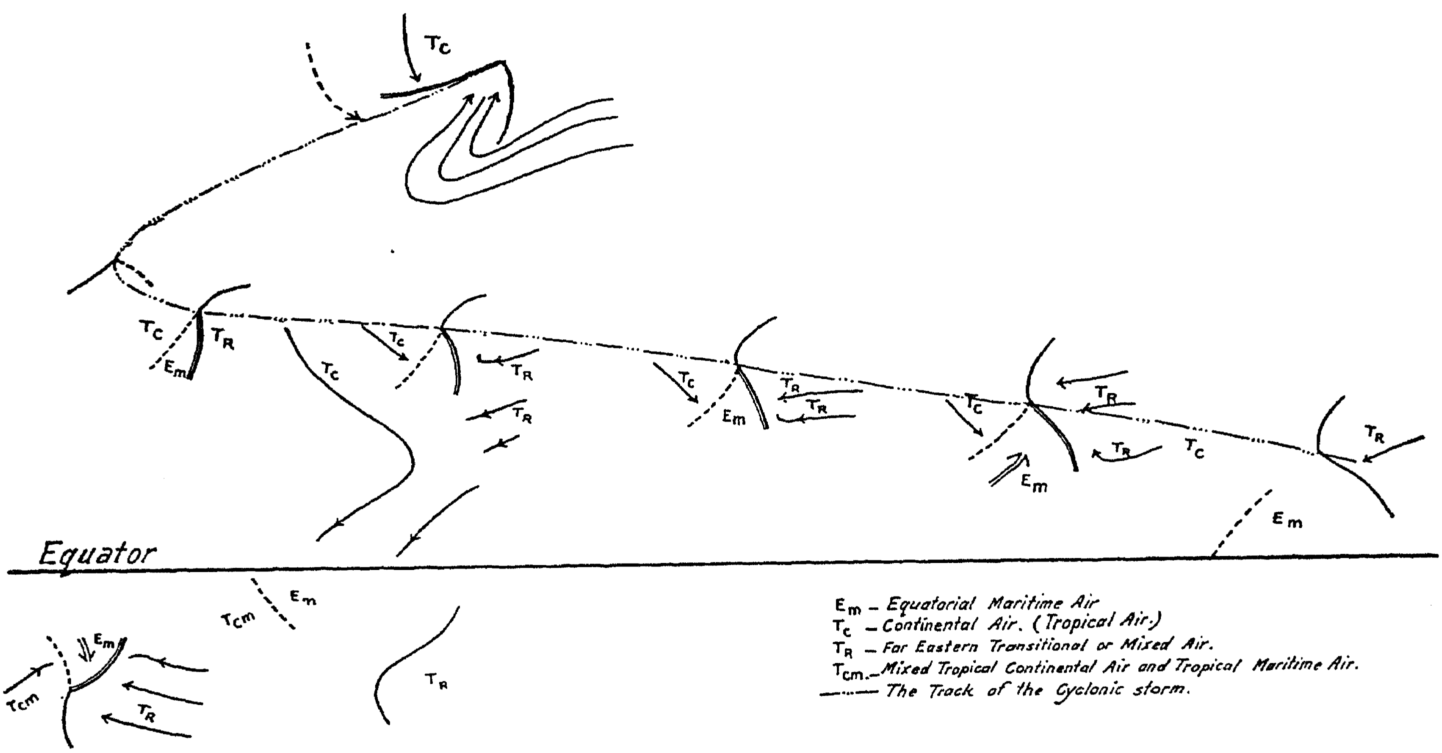

FIG. 1

15° to 20°, whenever there is a tropical depression in the other hemisphere moving in a westward direction. This rule can be used with benefit over the Pacific Ocean and over Australia. As a counterpart, when the 'Trades' fed into an extra-tropical depression, the latter would be more active than usual. A recurved tropical cyclonic storm is an extreme case of this.[10]

As two tropical depressions cannot co-exist for long on either side of the equator within a small longitudinal sector, four distinct possibilities can occur:

(a) Both the tropical depressions may fill up, particulary if they are fairly near the equator;

(c) there is a tropical depression on the other side of the equator, the recurved tropical depression does not get to be severe soon after recurvature. The problem is similar to a western disturbance with a tropical depression on the other side of the equator. After the separation between the recurved depression and the westward moving tropical depression has become large enough in longitude, the former, if it still exists, has a chance of getting severe (see idealised figure).

More popular conclusions would be the partial explanations of "Why is a major portion of India dry in winter?", "Why is Australia drier than India?" and of the distribution of arid zones on either side of the equator. The development of high pressure belts, during the winter, may also be explained.

The application to medium-long range forecasting on a synoptic basis is implicit in the above. The most important air mass Em was traced from the northern side of the high pressure area in S. America. Its travel south of the equator to the north of the seasonal high pressure belt was modified by several meteorological conditions till it finally moved into the N. Indian Ocean. A good climatic chart showed what the factors would be and these provided the long-sought for physical explanation of centres of action determined statistically by Walker. To further verify the ideas, the analogous case of the southern monsoon was traced from the southern side of the winter high pressure area over N. America and the modifying factors found. Rain in N.W. India being adversely affected by southern depression, it should be negatively correlated with the southern monsoon and hence with the high pressure on the south-west side of the winter N. American high after a definite time lag. With data extending over 75 years, the value of the correlation coefficient was $-0{\cdot}38$: a significant value.[11] This factor had not been used earlier and hence was a critical one. The role of Tc and of Tr in medium-range forecasting was also determined. The method of analysis of a western disturbance and the differential rates of travel and evolution of the secondaries, when Tr fed into them or away from them, were directly usable.

The question of 'heat' and 'frontal' thunderstorms was tackled. In the case of 'frontal' thunderstorms, there is an appreciable fall in the wet bulb temperature. With the help of analysed western disturbances, where the secondary travels slower and extends to a lesser vertical height than its northern primary, a simple explanation of the fall in the wet bulb temperature could be given without invoking the descent of air from 4 to 6 kms. Heat thunderstorms were looked into. Taking account of the daily variations in the high pressure belts in upper air at about 2 kms. on either side of the equator, the thunderstorms that occur on the pole-ward side of the belt are of 'frontal' type and those that occur in the equatorial side of 'heat' type.[12] Tornadoes that sometimes accompany 'frontal' thunderstorms cannot, therefore, occur in the tropics.

The application of the above methods have been helpful in understanding tropical weather in a rational way, and many problems can be explained satisfactorily.

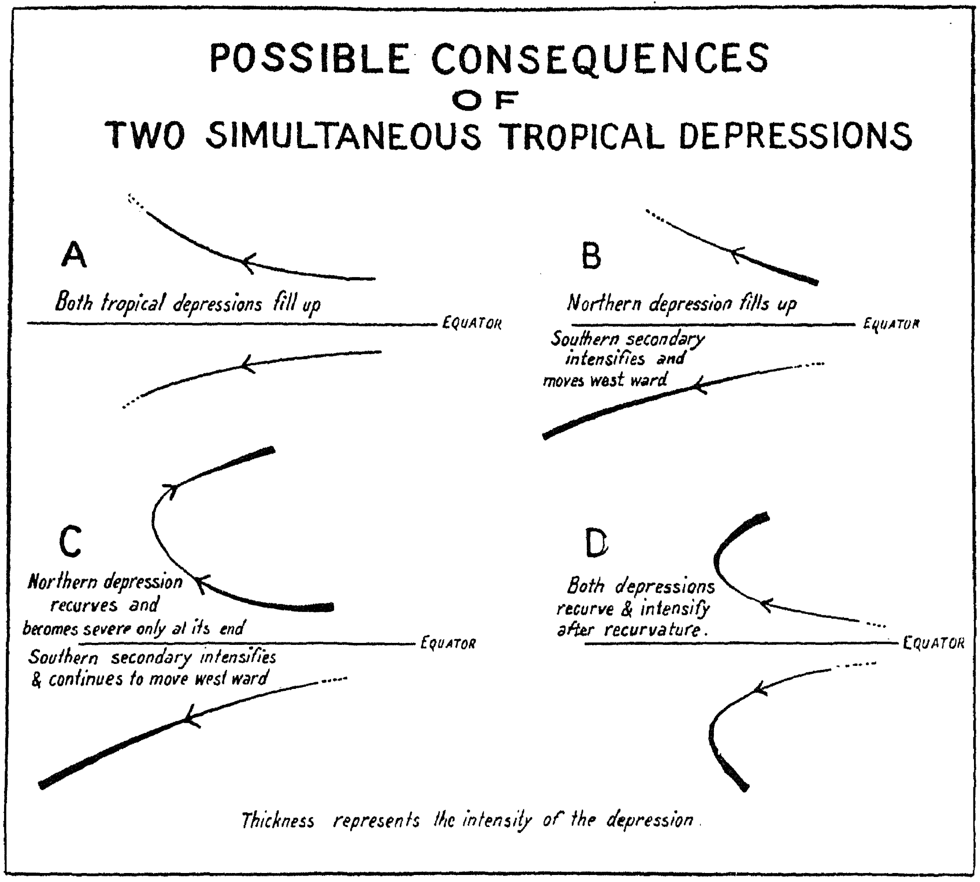

Fig. 2

1. The references are found in *Curr. Sci.*, 1947, **16**, 177, and Hemraj, *The Imperial Gazetteer of India*, 1907, **1**, 3. Doraiswamy Iyer, see below. 2. Doraiswamy Iyer, 'Rainfall in Siam, *Sci.' Notes Ind. Met. Dept.*, 1931, **4**, 69. 3. Wagner, *Gerl. Beitr. z. Geophys.*, 1931, **30**, 196. 4. Doraiswamy Iyer, *Mem. Ind. Met. Dept.*, **26**, 93. 5. Ramanathan and Ramakrishnan., *Mem. Ind. Met. Dept.*, 1932, **26**, 13 and Sur *ibid.* 37. 6. Ramanathan and Ramakrishnan, *ibid.*, 1938, **189** (reprinted text, 1943), 7. Malurkar, *Proc. Ind. Acad., Sci., Bangalore.*, 1947, **25**, 297. 8 Pisharoty, announced in *Symposium Nat. Inst. Sci. (India)*, Sept 1946. 9. Malurkar, *Curr. Sci.*, 1947. **16**, 14. 10. Malurkar., *ibid.*, **139**. 11. Malurkar, *ibid.*, 77. 12. Malurkar, "Winter Rain in the United Provinces and Norwesters in Bengal;" Malurkar, "Mechanisms of Thunderstorms in the Tropics" (MSS. unprinted yet).

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