ON THE DISTRIBUTION OF WEATHER OVER BENGAL ON ANY DAY DURING THE PREMONSOON SEASON AS RELATED TO THE POSITION AND MOVEMENT OF A BAROMETRIC TROUGH*

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ABSTRACT. Synoptic evidence is brought forward in support of a view that a relatively high proportion of the total weather over Bengal on any day during the premonsoon season is to be related to the position and movement of a quasi-stationary barometric trough that lies over the region in an approximately W-E direction in this season. The results of a graphical representation of the weather at Calcutta and the daily position of the trough line are discussed. Some physical characteristics of the trough and its behaviour with regard to formation of weather are discussed with the aid of aerological data of two stations, viz., Lalmonirhat and Barrackpore. It is concluded that the trough in space probably behaves as a quasi-stationary frontal surface and that its movement causes the weather that is observed. Theoretical position is reviewed and a tentative explanation of the latitudinal movement of the trough is offered. The possibility of forecasting the movement of the trough and the associated weather is discussed

1. INTRODUCTION

Norwesters or severe thundersqualls are important features of Bengal's weather during the premonsoon season from mid-March to May ; besides, during this period, there is, occasionally, weather due to western disturbances which cross the area eastward and also weather due to local heat convection. But if one takes stock of the total weather that occurs over the region over a reasonably long period, say a month, one is impressed by an appreciably large proportion of weather in the form of rain and thunderstorms which cannot be said to fall in any of the categories already cited. It is also noticed that this latter weather is not haphazardly distributed but would appear to show some kind of association and alignment with the position and movement of a quasi-stationary barometric trough (shown by a double line in figure 1) which lies over Bengal during this period in an approximately W-E direction as part of the seasonal low pressure over north and central India. In the present paper this probable association is investigated. Synoptic data of weather at Calcutta and the corresponding position of the trough line from day to day

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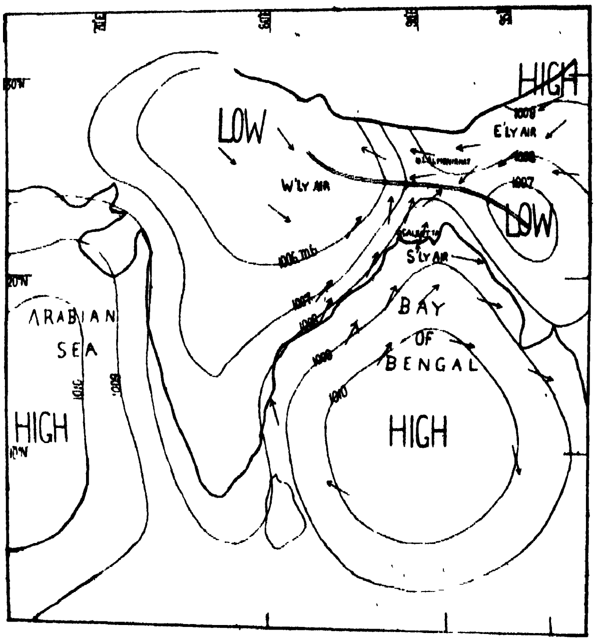

FIG. 1

Mean surface isobaric map, April. Arrows indicate mean wind directions. The double line represents the W-E barometric trough over Bengal.

during the months of April and May in four years 1942-43 and 1945-46 are presented in graphs and the results of this graphical repressentation are discussed in some detail. A high correlation being indicated, the properties and the role of the W-E barometric trough in the formation of the observed weather are discussed with the aid of synoptic and aerological data in sections 3 and 4. In section 5, the theory of movement of a barometric trough is briefly stated, and a possible explanation is offered of the movement of the W-E trough line. In section 6, the possibility of forecasting the movement the trough line is discussed.

2. GRAPHICAL REPRESENTATION AND DISCUSSION OF SYNOPTIC DATA

To investigate a probable association of the weather of Bengal with the seasonal W-E trough line over the region in premonsoon season, synoptic data of weather at Calcutta and the position of the trough line at two main synoptic hours of 0230z (GMT) and 1130z (except in 1942 when the time of the morning data was 0800 hrs local mean time which corresponds to 0206z at Calcutta) on each day during the months of April and May of four years 1942-43 and 1945-46 were plotted in a series of graphs (figures 2-5). In these graphs a system of coordinates formed by Lat. 22½ degrees N (base line) and

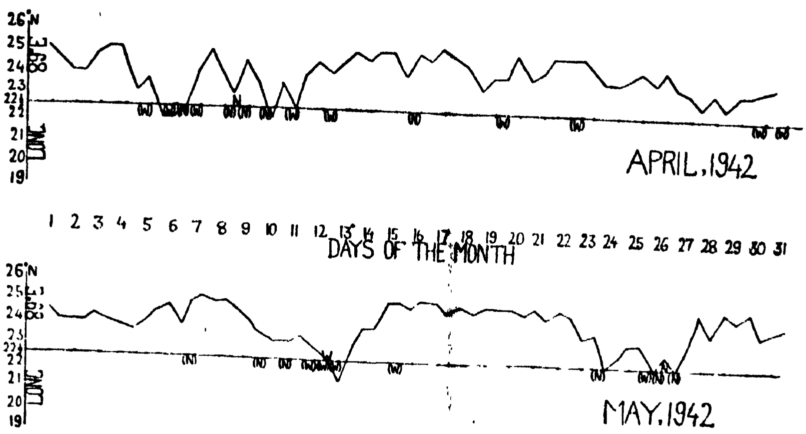

FIG. 2
Latitudinal movement graphs, April and May, 1942.

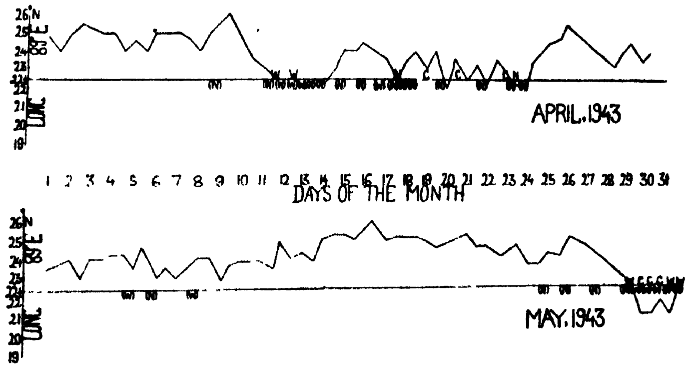

FIG. 3
Latitudinal movement graphs, April and May, 1943.

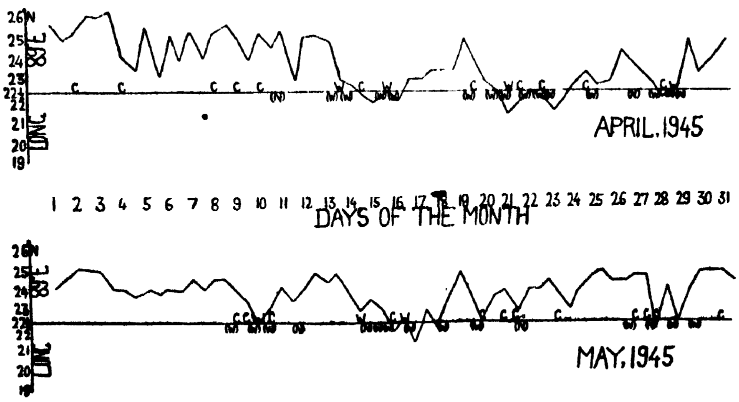

FIG. 4
Latitudinal movement graphs, April and May, 1945.

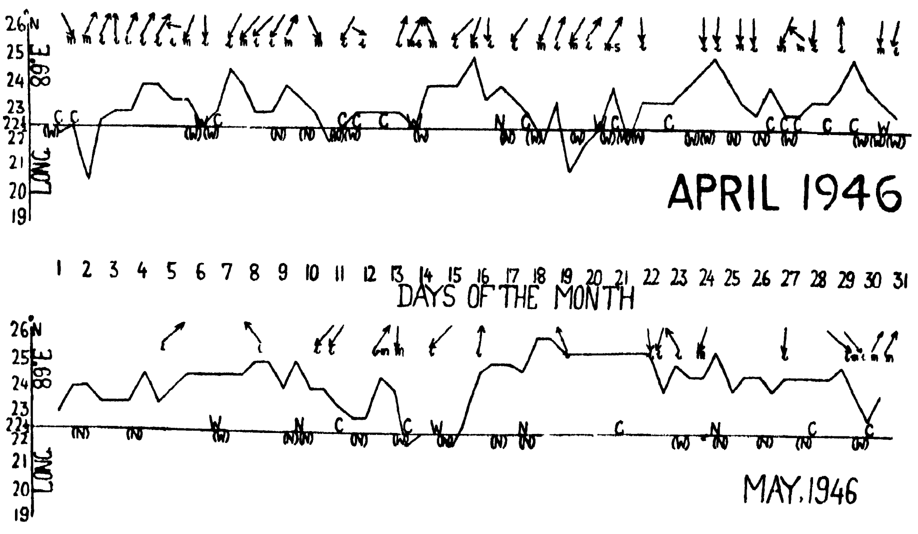

FIG. 5

Latitudinal movement graphs, April and May, 1946. The arrows at the top of each curve give direction of isallobaric winds (an arrow pointing downward indicates a N'ly isallobaric wind), the speed being given as *l*, *m*, or *s* according as these winds are light, moderate, or strong.

long. 89 degrees *E* (ordinate) was used to plot the position of the trough line and the corresponding weather at Calcutta which lies close to origin of the chosen system of coordinates. The position of the trough line was located with the aid of surface synoptic charts as well as winds-aloft charts for levels up to a height of 3,000-5,000 ft above M. S. L. and the surface position was marked on the ordinate at both the main synoptic hours of each day. On the base line the weather at Calcutta was noted in letter symbols. The symbols used were : *f* for fine, fair and fair to cloudy weather ; *c* for cloudy weather ; *N* for Norwester ; and *W* for rain or thunderstorm or both. For the sake of neatness, the symbol *f* was omitted from the graphs. The position on the base line immediately above or below a date-mark in the centre corresponds to 0230z, whereas, that halfway to the following date on its right corresponds to 1130z. The present weather was shown on the top of the base line, whereas, past weather was shown below it and in brackets. Past weather at 1130z was counted from 0230z of the same day but that at 0230z from 1130z of the previous day. Thus a thunderstorm at 1330z on a day would be taken as past weather at 0230z of the following day and placed symbolically below the base line between the present weather symbols of 1130z of the same day and that of 0230z of the following day and in brackets.

In figure 5 for the year 1946, the isallobaric components of surface winds as computed from the available 24-hours pressure-changes over the region were presented on the top of each curve. The significance of these wind components would be discussed in a later section. In deciding between a Norwester and any other thunderstorm the very severe character of the thundersquall associated with the former was the guiding consideration.

DISCUSSION

April, 1942 : figure 2. (*a*) Apart from four Norwesters and four cases of weather from local heat convection, there appears to be a close correlation between the weather at Calcutta and the position of the trough line. There were four days on which weather occurred at Calcutta when the W-E trough line lay on or in the vicinity of the city. With the trough line lying far away the weather over the city was generally fair or fine, apart from the occasional visitation of Norwesters or sporadic local air mass showers or thunderstorms. During the month the trough line lay most of the time north of the base line and approached the city close enough only three or four times and crossed it only on two occasions.

(*b*) The movement of the trough line would appear to be somewhat oscillatory. The northward movement of the trough line was interrupted by two successive Norwesters on the 8th and the 9th. But for this interruption, it may be argued, the crest position would have been reached on either of these days which would have given the oscillation a period of about 8 days. The maximum amplitude of oscillation was 3½ degrees of latitude (approx). The oscillation appeared to be rapid and marked in the first half of the month but rather slow and feeble in the latter half.

May, 1942 : figure 2. The close association of weather at Calcutta and the position of the trough line on or in the vicinity of the city is again indicated in this month, Though in the main the trough line lay north of the base line, it approached or crossed over the city three or four times and on all these occasions there was weather over the city. Weather was fair or fine on days when the trough line lay far away from the city except for Norwesters and local airmass showers which appeared to have no connection with the W-E trough line.

The movement curve would appear to be oscillatory in this month, but the period is not clearly defined. The flat nature of the curve from the 15th to 22nd is not understood. It may be that the trough did move appreciably during this period but the movement was difficult to follow because of the very weak intensity of the trough. The maximum amplitude of the oscilla-was 3 degrees of latitude.

April, 1943 : figure 3. During this month there were as many as 10 Norwesters of which 7 occurred between the 14th and 23rd. Outside this period, the correlation between the weather at Calcutta and the position of the trough line would appear to be high. The movement of the trough would appear to be oscillatory apart from the very marked distortion caused to it by the Norwesters over a fairly long spell. But for the effect of the Nowesters, a period of about 8 or 9 days would appear to be justifiable. The maximum amplitude of oscillation was 4 degrees of latitude.

May, 1943 : figure 3. Unlike April, only 3 Norwesters affected the city in May. None of these appeared to affect the trough line seriously. There were two days of local airmass showers or thunderstorms. Towards the end of the month, a depression formed in the NW corner of the Bay of Bengal and the W-E trough line moved rapidly southward crossing Calcutta on the 29th. It remained south till the 31st when it recrossed the base line on the return journey. But for this depression the trough line lay north of the base line all the time. It is clear that in this month the axis of oscillation of the curve had moved somewhat northward.

April, 1945 : figure 4. During the first two weeks of this month a number of western disturbances in almost occluded states passed over north Bengal and in the course of the eastward passage of these depressions the W-E trough line, which in most cases behaved as an overtaken warm front, moved eastward followed by a weak cold front. The position of the curve on many days in this period refers to that of the cold front on the ordinate and not to the W-E trough line. There is, of course, little justification for this deviation from the set procedure but it was made with the sole object of recording the effect of the movement of any other type of front across the long. 89 degrees E on weather at Calcutta when the W-E trough line position was not available. Apart from minor disturbances referred to above, the movement curve would appear to be oscillatory with a period of abou 7t or 8 days and an amplitude of 3½ degrees of latitude. During the month there were two days of Norwesters, one day of airmass thunderstorm, and eight or nine days of rain or thunderstorm which occurred when the W-E trough line lay on or near Calcutta. The passage of low pressure waves across north Bengal did not disturb the fair weather over the city apart from giving cloudiness on some days.

May, 1945 : figure 4. A very high correlation between the weather at Calcutta and the position of the W-E trough line is shown in this month. The extraneous influences were few, there being only four Norwesters of which only one affected the movement of the trough line appreciably on the 27th and four occasions of local airmass weather. In the first week of the month when the trough line lay far north of Calcutta, the weather over the city was uneventful but afterwards whenever it approached the city close enough or crossed it to the south, there was weather or appearance of thick massive clouds over the city. The oscillation of the trough movement appears to be fairly regular during this month and the period and amplitude of the oscillation would appear to be the same as in April.

April, 1946 : figure 5. The correlation of weather with the position of the trough line and the oscillation of the trough movement are very clearly evidenced in this month. There were five Norwesters, and eleven occasions of rain or thunderstorms. Of the latter, most occurred when the W-E trough line lay on or in the proximity of Calcutta. With the trough line lying far away from the city, the weather was generally fair or fine apart from occasional visitation of Norwesters or local showers. On the occasions when Norwesters occurred, the trough line position was well away from the city. The oscillation of the trough movement would appear to have a period of 7 or 8 days and maximum amplitude of 4 degrees of latitude.

May, 1946 : figure 5. The curve shows almost the same characteristics as in April. The following differences are, however, noted :

There were nine days of Norwesters in May. The trough line approached or crossed over to the south or north of Calcutta on fewer days in May than in April. This would give a smaller frequency and hence a longer period in May. The axis of oscillation of the trough appeared to be further north in May than in the previous month. Rain or thunderstorms occurred in Calcutta on the few occasions when the W-E trough line crossed over or approached the city. Norwesters appeared to occur, as a rule, in complete disregard of the position of the trough line.

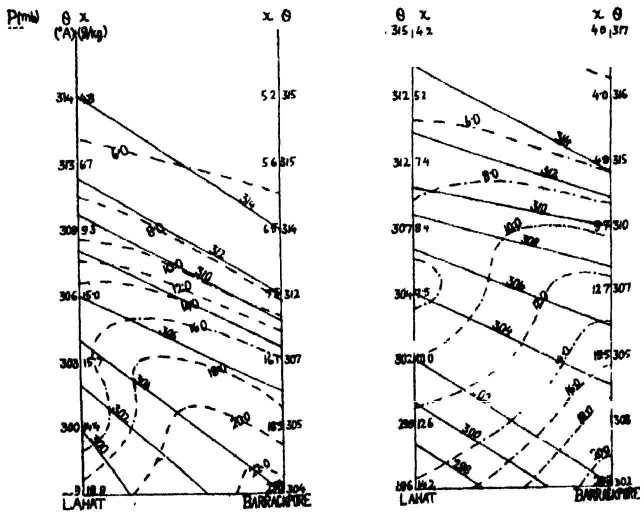

FIG. 6

Vertical distribution of potential temperatures (θ) and humidity mixing ratio (x) over Lahat and Barrackpore at 1300 G.M.T. on 8-5-45 and 15-5-45. Continuous lines represent potential temperature and dotted lines humidity mixing ratio.

3. SOME STUDIES OF THE PHYSICAL CHARACTERISTICS OF THE TROUGH LINE

It would be evident from the previous section that a close association exists between the weather at Calcutta and the position of the W-E trough

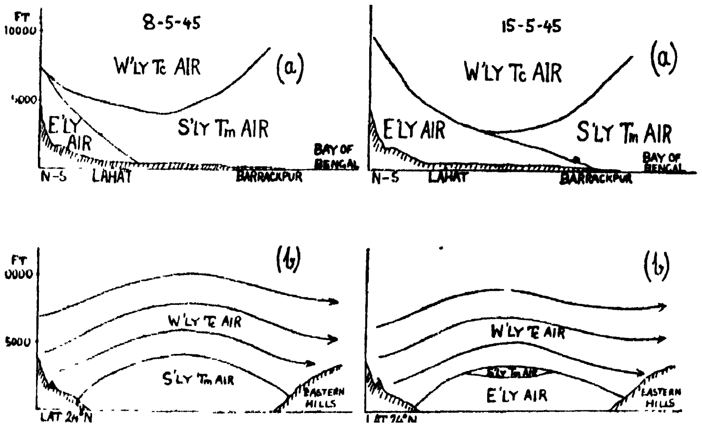

FIG. 7
Airmass crosssections (vertical). (a) N-S, along about long. 89°E; (b) E-W, along about 24°N.

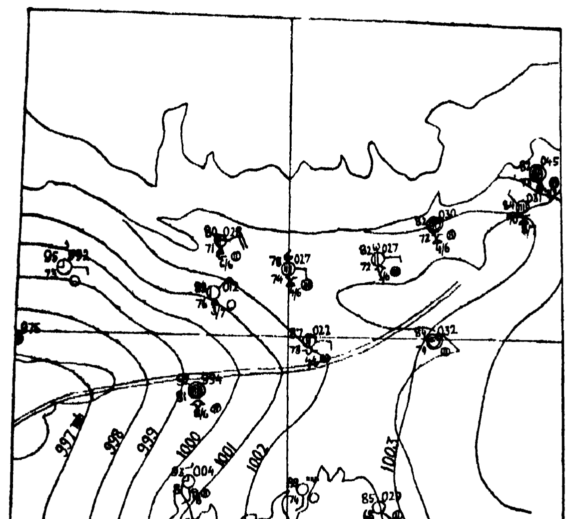

FIG. 8
Surface synoptic chart, 1130 G.M.T, 8-5-45.

line in the premonsoon season near the city. The manner in which the weather occurs would seem to suggest that the weather is caused by the activities of the trough line itself. This is, of course, subject to further investigation and it is attempted in the present section. The properties of the air north and south of the trough line would determine the physical characteristics and the ultimate behaviour of the trough line. In figure 1 it will be seen that the surface wind to the north of the trough is E/NE'ly whereas, that to the south is S/SW'ly. The mean geographical position of the trough is such that it will bring up from either side air of different tem-

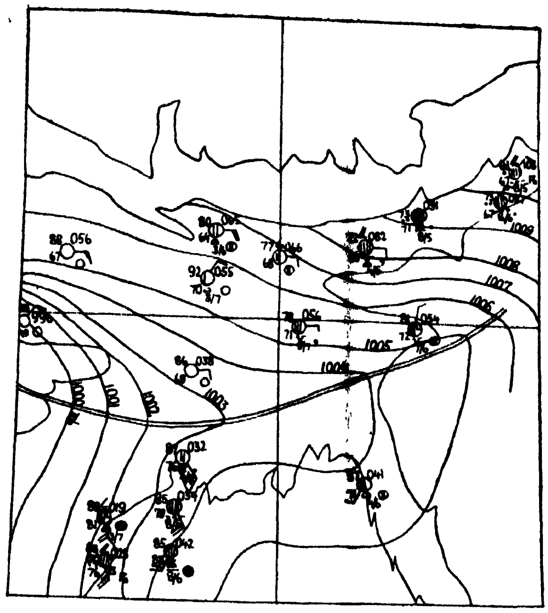

FIG. 9

Surface synoptic chart, 1130, G.M.T, 15-5-45.

perature and humidity, at least in the lower levels and in early summer months, to meet on the trough line. This means that both temperatures and dew points will be lower on the north of the trough line. This is exactly what is observed. During the months of March and April, the dew points on the north of the trough line are on an average 5-10°F lower than on the south. But surface observations may not always faithfully represent the airmass properties in space. Hence supplementary aerological data of two stations, Lalmonirhat (Lat. 25°55′N, long. 89°25′E) and Barrackpore (Lat. 22°34′N, long. 88°20′E) were computed and the results are presented in figure 6 which shows the upper-air distributions of potential temperature and humidity mixing ratio on two selected days, the 8th and the 15th May, 1945. The synoptic situations on these days are shown in figures 8 and 9. In Table I the equivalent potential temperatures on these days up to a level of 650 mbs are given for the two stations. It would seem to follow from these results that the airmass over Lahat (abbreviation of Lalmonirhat) which lies most often to the north of the trough line is definitely cooler and less humid than the airmass over Barrackpore. It would also seem to be established that the airmass contrast extends occasionally to a height of 3,000-5,000 feet above M.S.L. or even higher. With the overlying W'ly air which is warmer and drier than either of the lower airmasses, the special distribution of airmasses over Bengal during the months of April and May would look somewhat like that represented in figure 7 which gives (*a*) an approximately N-S vertical cross section through Lahat and Barrackpore, and (*b*) a W-E vertical cross section along Lat. 24°N on the dates mentioned. The relative disposition of the airmasses as shown in this figure is, however, to be regarded as tentative in the absence of further substantiating data. Aerological data from a closer network of radio sonde stations (R.S. stations) would be required for a more thorough and critical study.

TABLE I

Equivalent potential temperatures (θ_E) over Lahat and Barrackpore (Mean time of ascent-1300 G.M.T.).

Date	Station	1000 mb	950	900	850	800	750	700
8/5/45	Lahat	356	345	352	354	340	337	332
,,	Barrackpore	375	367	358	338	337	334	332
15/5/45	Lahat	339	338	333	328	334	336	327
,,	Barrackpore	365	363	355	348	343	333	331

The contrast between the airmasses on either side of the trough line would, however, seem to be wellestablished by the present study. The relative properties would lead to the formation of a sloping surface of discontinuity with cooler and less humid air on the north underlying warmer and more humid air on the south. An idea regarding the mean slope of the surface can be had from the position of the trough line at different heights above M.S.L. as found in winds-aloft charts. It is, therefore, concluded that the W-E trough in space probably functions as a frontal surface and that any weather that may form as a result of its movement should be amenable to frontological interpretation. This aspect of the question is examined in the following section.

MECHANISM OF WEATHER FORMATION AS A RESULT OF MOVEMENT OF THE TROUGH

The incidence of weather at Calcutta whenever the W-E barometric trough approached or crossed over the city as presented in section 2 would suggest that the weather was formed by the action of the trough itself. The conclusions drawn in section 3 would seem to support this view. During the premonsoon season a marked degree of latent and convective instability exists in the airmass over Bengal. Almost superadiabatic lapse rate of temperature in the overlying dry W'ly air is the chief cause of the instability of the season's atmosphere. When such a degree of instability occurs in the atmosphere, any agency which can lift the air sufficiently from the ground level may be instrumental in forming weather over Bengal.

The W-E barometric trough in space would seem to be capable of acting as such an agency. Its movement would lift the warm and moist air of the S'lies to a higher level and cause cloud, rain and thunderstorms. The intensity of the weather to develop would depend on the strength and the degree of convergence of the interacting airstreams and hence may be different at different points along the trough line. Observations appear to show that the number of thunderstorms that are formed is somewhat greater when the trough moves southward than when it moves in the opposite direction. This is, of course, subject to further confirmation. It may be that the wedge action of the relatively cool and less humid, air on the north is responsible for the apparent discrepancy but, in presenting this view it is considered necessary to stress that the weather that forms on the W-E trough seldom has the pattern and sequence of weather that is found on a pure frontal surface of the cold front or the warm front type connected with a travelling depression of the middle latitudes. In actual fact, it appears to conform more closely to the weather that is observed on a quasi-stationary frontal surface. We may, however, note here an important distinction between this weather and the Norwester of Bengal. Observations seem to indicate that apart from the greater severity of the Norwester as a thundersquall it has no genetical relation with the W-E trough. A Norwester may originate anywhere near the hills of Chotanagpur (Type-A Norwesters), southern slopes of the Himalayas (Type-B Norwesters), and the Khasi hills of Assam (Type-C Norwesters) (*Vide* "Norwesters of Bengal," 1944) and move to some southerly direction. There is, however, an effect which is noticeable when the Norwester moves. It distorts and sometimes completely breaks through the W-E trough line but as would be evident from the data presented in section 2 this disturbance is only short-lived and the trough regains its normal position and characteristic as soon as the Norwester dies out.

It is interesting to observe on any day the movement of the W-E trough line over a station. A bank of thick cloud and rain and thunderstorm oriented more or less in a W-E direction approaches the station. Just when the cloud moves over, there is a wind-shift. This change is usually attended with gusts but light squall is not rare. The wind speed may reach 30/40 knots if the trough happens to be a deep one. If the trough is weak, there may be simply a bank of cloud that moves over. In any case, the cloudiness and weather that forms appear to move in a narrow latitudinal belt in alignment with the position of the trough line.

The position of the trough may, therefore, be regarded as a deciding factor in the distribution of weather over Bengal on any day. When it lies over extreme south Bengal, weather deteriorates over that region while it becomes fine and clear in the north and *vice versa*. Roy (1938), in a paper on the distribution of rainfall over south Bengal during the premonsoon season found a high correlation between the frequency of rainy days over the region and the existence of a higher barometric pressure at Berhampore (Lat. 24° 05′N, long. 88° 15′E) than at Calcutta. As a corollary to the same investigation he concluded that the favourable condition of higher barometric pressure at Berhampore than at Calcutta indicates the probable presence of dry and somewhat cooler air of land origin to the north of deltaic Bengal at some upper level, if not actually on the ground level, and perhaps also its movement towards deltaic Bengal. The present investigation would appear to lend support to the conclusion reached by Roy in that a higher baromteric pressure at Berhampore than at Calcutta is only feasible when the W-E barometric trough line lies over extreme south Bengal. The probable presence and the southward movement of land air suspected by him also appear to be confirmed. But the evidence brought forward in the present study would seem to indicate that rainfall and weather over Bengal at any instant during the premonsoon season are not haphazardly distributed but occur in a narrow latitudinal belt somewhat in alignment with the W-E trough line. It is this regularity in the distribution of the observed weather that would appear to have been specially brought out by the present investigation.

5. THEORY OF MOVEMENT OF A TROUGH AND A POSSIBLE EXPLANATION OF THE MOVEMENT OF THE W-E TROUGH

Pettersson (1940) gives for the movement of a trough line the following expressions :

$$C = -\frac{\partial^2 p/(\partial x \partial t)}{\partial^2 p/\partial x^2} \qquad \dots \quad (1)$$

$$A = \frac{\partial^3 p/(\partial x \partial t^2) + 2C\partial^3 p/(\partial x^2 \partial t)}{\partial^2 p/\partial x^2} \qquad \dots \quad (2)$$

where C denotes the velocity of the trough line along the x-axis drawn normal to the trough line in the horizontal plane; A, the the acceleration along the x-axis, and

$\partial^2 p/(\partial x \partial t)$ = the increase in the barometric tendency $\partial p/\partial t$ per unit length along the x-axis,

$\partial^2 p/\partial x^2$ = the increase in the pressure gradient $\partial p/\partial x$ per unit length along the x-axis,

$\partial^3 p/(\partial t^2 \partial x)$ = the slope of the $\partial^2 p/\partial t^2$ profile along the x-axis, and

$\partial^3 p/(\partial x^2 \partial t)$ = the curvature of the tendency profile along the x-axis.

The displacement, S, of the trough in time, t, is given by

$$S = Ct + \tfrac{1}{2}At^2 \qquad \dots \quad (3)$$

In equation (2), the terms in the numerator are usually small, whereas, $\partial^2 p/\partial x^2$ may vary within wide limits. Hence in a rough qualitative estimation of the displacement the factor A may be neglected. Writing equation (1) in the form

$$C = \frac{-I}{\partial^2 p / \partial x^2} \qquad \dots (4)$$

where $-I$ is the isallobaric gradient, we note that the movement of the trough line occurs along an isallobaric gradient, *i.e.*, in the direction from the centre of an isallobaric 'high' to the centre of an isallobaric 'low' and that the rate of movement is directly proportional to the magnitude of this gradient. $\partial^2 p / \partial x^2$ is always positive for a barometric trough and its value must be computed in a quantitative study of the speed of a trough line. In the present study the exact speed of the movement was not calculated. The direction of movement being always down the isallobaric gradient a qualitative estimate of the speed was made from an examination of the isallobaric distribution and intensity of the pressure trough over the region.

An analysis of the 24-hour pressure change charts at 0230z and 1130z during April and May in 1946 appeared to support the above theoretical expressions for the movement of the W-E trough line. Isallobaric wind components (Petterssen, 1940) were estimated from the charts and expressed as light, moderate, or strong according as the isallobaric gradient was weak, moderate, or steep. In figure 5 the isallobaric winds are presented at the tops of the movement curves, the direction of the wind being shown by the conventional arrow and the speed expressed as *l*, *m*, or *s* according as it was light, moderate, or strong. Estimation of the isallobaric wind in the case of weak isallobaric gradients was a difficult problem. A second difficulty arose when there were a number of isallobaric 'highs' and 'lows' on the chart. In the present investigation isallobaric winds were estimated in all cases of pronounced pressure tendency 'highs' and 'lows' and the resultant isallobaric winds were estimated in some cases. In the remaining cases in which the gradient was weak or there was an unduly large number of 'highs' and 'lows' the estimation was either dropped or the wind was expressed as light variable.

It would be seen from the foregoing analysis that the movement of the trough is vitally related to the pressure changes that occur on either side of the trough line. Figure 1 shows the normal position of the trough between the subtropical high pressure cell over north Assam and western China and the high pressure cell over the Bay of Bengal. It is plausible to hold that the pressure changes that occur on either side are vitally related to the growth or decay of these high pressure cells. However, it is the relative pressure change that moves the trough. In the course of the present investigation it was observed that the trough line moved southward whenever the northern high pressure cell intensified relative to the southern high pressure cell and vice versa for movement in the opposite direction.

6. POSSIBILITY OF FORECASTING THE MOVEMENT OF THE TROUGH AND ASSOCIATED WEATHER

Thus the history of the movement of the barometric trough is indissolubly bound up with that of the intensification or dissipation of one system of high pressure relative to the other. It is the relative change that matters and not the individual changes. This fact, coupled with probable existence of periodicity in the movement of the trough line, points to the possibility of forecasting its movement on any day. For this purpose the isallobaric gradient and the phase of the periodic movement will have to be determined with sufficient accuracy. It is also to be borne in mind that extraneous factors, such as the Norwester or the western disturbance, may interfere with the movement of the trough, although temporarily, and that these factors should be duly considered and their effects assessed in order to obtain the resultant movement of the trough. Another factor which must be taken into consideration in a full analysis is a diurnal oscillation of the trough brought about by temperature differences between land and sea. An examination of the movement curves presented in section 2 reveals a slight northward movement in most afternoons and southward movement in mornings. These small scale diurnal oscillations are superimposed on the main latitudinal oscillation of the trough line. The resultant movement of the trough at any instant, therefore, will depend upon the amplitude and phase relations of both these oscillations. But the effect of the diurnal oscillation is not sought to be discussed in any detail in the present paper. In the course of the investigation it was realised that pressure change charts for a period much shorter than 24 hours are necessary to reveal the micro-structure of the changes that occur in the isallobaric gradient over any period. This will involve predetermination of normal diurnal oscillation of pressure at a number of stations at intervals of, say, 3 or 6 hours.

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