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On the Cold Pools and their role in the development of Nor'westers over West Bengal and Eastern Pakistan

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1. In two recent notes Ramaswamy and Bose (1953a, 1953b) have put forward the view that "advection of colder air between 10,000 and 20,000 ft and possibly also between 20,000 and 30,000 ft appears to be the *final determining factor* in the outbreak of nor'westers, at least when they are widespread ". According to them in every one of the seven cases of nor'westers studied in the first note there was a cold pool or trough on the 700-500 mb thickness charts, 18-24 hours before the outbreak of nor'westers which tended to be maximum in the sector where thermal winds were from SSE and WSW. It is also stated that in some of these cases studied, there were few indications in the charts for sea level or upper levels below 10,000 ft to suggest the development of nor'westers.

2. In support of their arguments, Ramaswamy and Bose (1953a) have given upper wind charts for 2000 and 5000 ft for the morning of 14 April 1952 and the thickness chart for 700-500 mb with thermal winds for the evening of 13 April 1952 in Figs. 1, 2 and 3 respectively of their first note. The following points may be mentioned regarding this case—

(*i*) The day should not be classified as a typical day of nor'westers which usually travel from W or NW to E or SE. As stated by the authors themselves, on 13 April 1952 the thunderstorms travelled most unusually from the Gangetic West Bengal to Chota Nagpur, *i.e.*, from E to W.

(*ii*) It would appear that this case does not support their argument that the advection of cold air is the cause of nor'westers. Comparison of the radiosonde ascents shows that above 850 mb, temperatures rose at all levels upto 250 mb from 1500 GMT of 13 April to 0300 GMT of 14 April 1952; the rise was as much as 6 to 9°C above the 500-mb level. Below 850 mb there was slight fall in temperature. Thus, prior to the nor'westers which occurred on the 14th afternoon, temperatures were actually rising from 850 mb to 250 mb and not falling. There cannot be any objection to comparing the morning and evening ascents for finding the temperature changes above 800 mb since the *diurnal* variation is very small at these levels. In this connection it may be mentioned that Venkateswaran and Desai (1953) find from three ascents per day taken on fifteen days at Ahmedabad that the diurnal variation above 800 mb is less than 1°C.

3. From the surface and upper wind charts for the morning of 14 April 1952, it is seen that there was a wind discontinuity upto about 7000 ft [Ramaswamy and Bose have indicated this wind discontinuity in Figs. 1 and 2 of their note (1953a) although it is considered that its position should be more north towards Calcutta than that given by them]. One would, therefore, ordinarily expect thunderstorms to develop near this discontinuity as a result of convergence and insolation effects. The direction of the squalls was apparently determined by the surface and upper winds over Assam, East Pakistan and Gangetic West Bengal.

4. Ramaswamy and Bose (1953a) have quoted 2 and 11 March and 2 April 1953 as instances of dates when nor'westers did not develop, there being no cold pool or trough, even though the sea level and the upper air conditions were favourable

according to accepted ideas. It is felt that 2 April 1953 would not be considered as a typical nor'wester day judging the conditions as given in the sea level and upper winds (upto 10,000 ft) charts.

5. In order to test the validity of the theory advanced by Ramaswamy and Bose (1953a) regarding the usefulness of the presence of cold pools or troughs over Bengal and neighbourhood in forecasting nor'westers over the area during the next 18-24 hours we have prepared the thickness charts for 13 March, 1 May and 8 May 1953, between 700 and 500-mb levels for three important cases of nor'westers in the northeast India during 1953. It is noticed that the latter two cases have also been discussed by Ramaswamy and Bose (1953b) in their second note, which has been published after we had first submitted this note. In preparing the thickness charts the checked radiosonde and pilot-balloon data as published in the Indian Daily Weather Reports have been used. Wind shear for 0900 GMT pibals and 1500 GMT radar winds between 10,000 and 20,000 ft have been used. If the ascent did not reach 20,000 ft but reached upto 18,000 ft wind shear has been calculated between 10,000 and 18,000 ft. The 18,000 ft winds which are not published in the Indian Daily Weather Reports were obtained from the respective Regional Meteorological Offices.

Nor'westers on the night of 13 March 1953

6. Widespread nor'westers occurred over Assam, northern portions of West Bengal and adjoining parts of Bihar and East Pakistan on the night of 13 March 1953. A Pak Orient Airways Convair plane crashed 80 miles off Dacca on this night probably due to the thunderstorm activity. The thickness chart prepared with 0900 GMT pibals and 1500 GMT radar and radiosonde data of 13 March 1953 is shown in Fig. 1. Rainfall between 1200 GMT of 13th and 0300 GMT of 14th are also shown in this figure, as also the weather remarks during the same period over the area to the north of 15°N and east of 80°E. Weather that occurred between 1200 and 1500 GMT of 13th is marked inside circles. The idea in marking rainfall amounts and weather remarks besides thunderstorms is that in this season rainfall in northeast India is almost always associated with thunderstorms either over the station or nearby. So we may take that besides those stations which have recorded thunderstorms, stations which have had any rain were also affected by nearby thunderstorms. Available data would suggest that over northeast India the thickness lines were practically straight with no indication of a cold pool or trough. Though Ramaswamy and Bose consider the thickness chart of 18-24 hours prior to the nor'westers as of forecasting significance, there is no reason to think that the thickness charts nearer to the time of occurrence of thunderstorms should not show the same characteristics, if not to a more pronounced extent. Actually even thickness chart of the data of 12th (Fig. 2) does not suggest any cold pool or trough.

Nor'westers of 2 May 1953

7. The thickness chart for the evening of 1 May 1953 is shown in Fig. 3. The chart for 30 April 1953 also is shown in Fig. 4. In Fig. 3 rainfall during the twentyfour hours ending 0300 GMT of 3 May 1953 and weather remarks during that period are also marked over the area to the north of 15°N and east of 80°E. Weather remarks pertaining to the period between 0300 and 1200 GMT of 2nd are marked inside circles. The cold trough over Rajasthan and neighbourhood on the 30th moved over to the East Uttar Pradesh and was extending southwards upto the southeast Madhya Pradesh. On the 30th, from the NE shear wind at Dibrugarh, it appears that there was a cold pool over Upper Burma and adjoining regions of Assam. This had definitely moved away by the 1st and thickness at Shillong rose from 8858 ft to 9055 ft and there was a thickness high over Assam and East Pakistan.

8. The axis of the only cold trough near northeast India on the 1st was along 82°E. From the weather elements plotted in Fig. 3, it will be seen that there were only a few thunderstorms from 82°E to 85°E, *i.e.*,

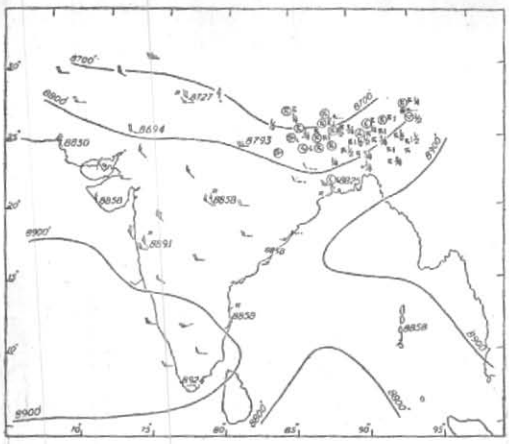

Fig. 1 (13 March 1953)

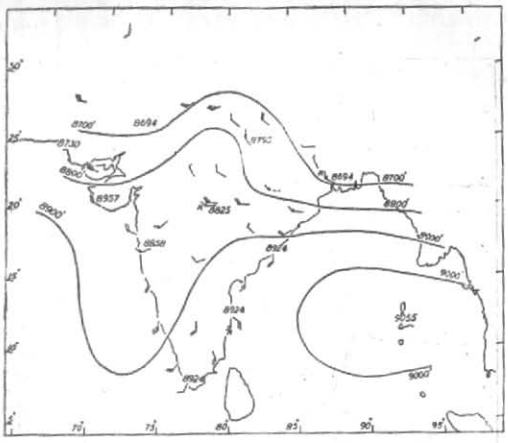

Fig. 2 (12 March 1953)

Figs. 1-2. Thickness between 500 and 700 mb based on (i) Radiosonde data of 1500 GMT, (ii) Wind shear between 10,000 and 18/20,000 ft from pilot balloon winds of 0900 GMT and (iii) Wind shear between 10,000 and 20,000 ft from radar winds of 1500 GMT (indicated as R). Wind shear between 10,000 and 18,000 ft indicated by broken lines

In Fig. 1, rainfall and weather remarks between 1200 GMT of 13 and 0300 GMT of 14 March 1953 are shown within area north of 15° N and east of 80° E. Weather before 1500 GMT is enclosed in circle

within three degrees to the east of the axis ; this is, however, the area where according to Ramaswamy and Bose (1953a) the maximum number of thunderstorms should have occurred. There were considerable number of thunderstorms further to the east right upto Assam which area was under the influence of a thickness high. On account of the SE shear wind over Gopalpur and WNW shear wind over Calcutta, the intervening region where thunderstorms had occurred has to be regarded as under a thickness high.

9. Ramaswamy and Bose (1953b) in their drawing of thickness chart for 1 May 1953 have placed the East Uttar Pradesh cold trough in the same position as we have done. But they have rejected the Shillong thickness value as too high and with the aid of Dibrugarh shear wind (NE-5 kts) placed a cold pool over East Assam. The reason given for rejecting Shillong thickness is that it was too high compared to the previous and following days. This is too weak an argument. Both due to the stronger winds and larger temperature gradients at upper levels, changes in temperature and thickness at upper levels are more rapid than at the ground and consequently meteorologists are feeling the need for more than one radiosonde ascent per day. In such a situation to reject the thickness value as being too high compared to previous and following days would mean to lay down the rate at which upper level temperatures should change. In the Indian Daily Weather Reports Dibrugarh winds are published upto 7000 ft only.

10. In this case upper air temperatures were generally falling over Calcutta prior to the occurrence of nor'wester, the fall being marked above 600 mb which would appear to fit with the hypothesis of Ramaswamy and Bose (1953a) about cold air advection. But on the thickness chart the nor'westers over northeast India occurred in a region of thickness high and *not* a cold pool. In passing, it may be mentioned that on 2nd afternoon a B. O. A. C. jet aircraft—Comet crashed near Calcutta being caught in a nor'wester.

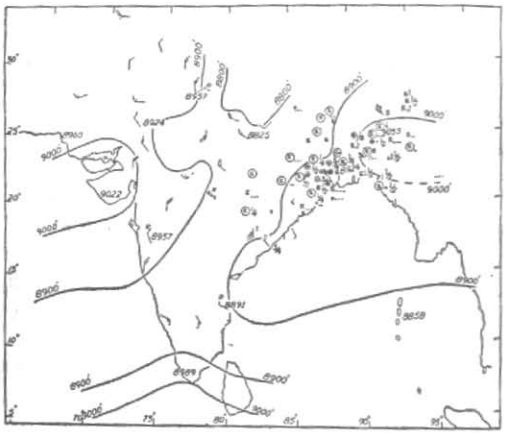

Fig. 3 (1 May 1953)

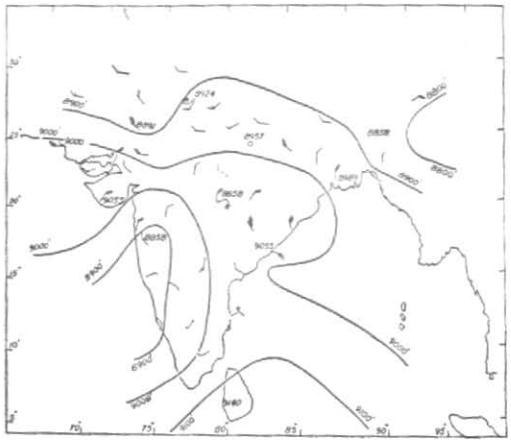

Fig. 4 (30 April 1953)

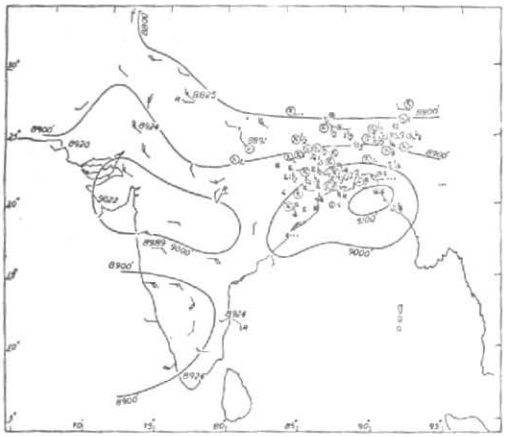

Fig. 5 (8 May 1953)

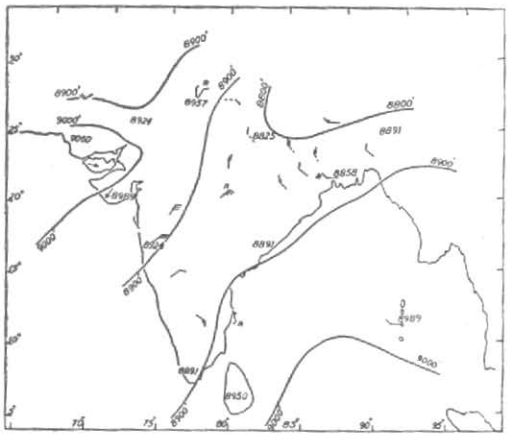

Fig. 6 (7 May 1953)

Figs. 3-6. Thickness between 500 and 700 mb based on (i) Radiosonde data of 1500 GMT, (ii) Wind shear between 10,000 and 18/20,000 ft from pilot balloon winds of 0900 GMT and (iii) Wind shear between 10,000 and 20,000 ft from radar winds of 1500 GMT (indicated as R). Wind shear between 10,000 and 18,000 ft indicated by broken lines

In Figs. 3 and 5, rainfall and weather remarks during 24 hours ending 0300 GMT of 3 May and 10 May 1953 respectively over the area north of 15 N and east of 80° E are also marked. Weather between 0300 and 1200 GMT of 2 May and 9 May is enclosed in circle

Nor'westers of 9 May 1953

11. This was a day of fairly widespread thunderstorm activity over northeast India. The thickness chart for 8 May is shown in Fig. 5. It shows a thickness high between longitudes 83° and 95°E and latitudes 18° and 24°N. To the north, thickness lines were running practically straight. There was another thickness high between longitudes 70° and 81°E and latitudes 24° and 18°N. Between these two thickness high regions there is a narrow col. As will be seen considerable thunderstorm activity took place over northeast India in the region of the thickness high or straight thickness lines.

12. Ramaswamy and Bose (1953b) in their drawing have placed a thickness low to the west of Calcutta. The thickness value of Calcutta did not fit in with such a drawing and hence they corrected the thickness of Calcutta from the observed value of 9020 ft to a more convenient value of 8830 ft. The reasons for such correction as made out by them are " to maintain continuity with previous day's pattern, to avoid unjustifiable crowding of thickness lines to the west of the cold pool, to fit in the westerly thermal wind over Chittagong and SSE thermal wind over Calcutta and to avoid undue deviation from the normal thickness pattern in North Bay of Bengal where the normal partial thermal winds are between SSW and WSW in May ". The thickness pattern for 7 May 1953 is reproduced in Fig. 6. It is very clear that continuity considerations are not violated between our drawing of 7th and 8th. There is also no crowding of thickness lines in our drawing of 8th. The westerly thermal wind fits at Chittagong which is to the north of the thermal high and SSE wind at Calcutta fits with its position in the western half of the thermal high. We do not consider necessary that the thermal winds over the Bay should be SSW and WSW on all days since that is the normal pattern and that if the values of any particular day do not fit in with such a pattern, the values should be corrected. The practice in constructing the configuration of both constant pressure charts and the thickness charts is to obtain a pattern consistent with the height or thickness values at the radiosonde stations and the winds. Only such radiosonde data as do not fit with such a test should be rejected.

13. It is hence felt that there is no justification to correct Calcutta thickness value by 200 ft and place a cold pool to the west of Calcutta as has been done by Ramaswamy and Bose (1953b). The thunderstorms have generally occurred in a region of straight thickness lines or in a thickness high which does not support the hypothesis of Ramaswamy and Bose. The upper air temperatures at Calcutta were rising before the thunderstorm as seen from the radiosonde ascents of 1600 GMT of 8 May and 0300 GMT of 9 May 1953 against any idea of cold air advection.

14. In the second note Ramaswamy and Bose (1953b) have drawn thickness lines at intervals of 50 ft. This would not appear justified by the accuracy of the radiosonde data. It can be shown that thickness h between two pressure levels p_1 and p_2 is related to the mean temperature T_m by the equation,

$$h = \frac{R}{g} T_m \log \frac{p_1}{p_2}$$

An error of $\triangle T_m$ in the mean temperature causes an error $\triangle h$ in the thickness which is given by

$$\triangle h = \frac{R}{g} \triangle T_m \log \frac{p_1}{p_2}$$

Between 700 and 500 mb levels, 2°C error in mean temperature makes $\triangle h$=65 ft. As it is doubtful if the accuracy of radiosonde temperatures is more than 2°C, the closest interval at which thickness lines may be drawn appears to be 100 ft.

15. E. J. Sumner (1952), who made a statistical and synoptic study of the cold pools over Europe studied only cold pools with two or more closed thickness lines drawn at intervals of 200 ft. He remarks

that " at the other extreme a minute and ephemeral pocket of cold air contained within one closed thickness line (the presence of which may depend on the interval at which the lines are usually drawn, and may in fact be drawn arbitrarily owing to observational shortage) is of slight interest." Owing to weaker thermal gradients over India, it may be justified to draw thickness lines at smaller intervals than 200 ft adopted by Sumner, but drawing lines at 50 ft and basing conclusions on cold pools with only one closed line of 50 ft interval is of doubtful scientific validity.

16. The preceding cases show that temperatures were sometimes falling and sometimes rising before the occurrence of nor'westers. Thunderstorms were also not confined to the areas of cold pools or troughs alone, widespread storms having occurred in regions of thermal high or straight thickness lines. It is hence felt that the conclusion of Ramaswamy and Bose (1953a) that the final determining factor in the outbreak of nor'westers is the advection of colder air at upper levels cannot be accepted as generally true and so also their claim that the thunderstorms are mostly in areas of thermal lows or troughs with greater frequency in the eastern portions of such systems. We do not contend that upper level thermal patterns have no effect on the occurrence of nor'westers ; but Ramaswamy and Bose have to put forward better evidence before their claims can be accepted.

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