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On the use of Tephigrams for forecasting Nor'westers

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ABSTRACT. The special radiosonde ascents made at Calcutta in May 1951 and the routine ascents of the same days have been discussed with a view to see how far one can successfully forecast the occurrence of nor'wester over Calcutta subsequently during the day on the basis of routine morning tephigram. It is found that the thermal structure often undergoes marked variations from morning to evening and that for accurate estimate of the instability as is likely to develop by evening, it is necessary to take due note of the synoptic charts and also of the changes in the upper air temperatures during preceding days over stations to the west as shown by radiosonde data.

1. Introduction

It is found from a study of the tephigrams of Calcutta during the premonsoon months that the mere existence or non-existence of a large amount of realisable latent instability in the morning is not always a sure indication of the occurrence or non-occurrence of nor'westers in the afternoon or night. The thermodynamical structure of the atmospheric column over the station as indicated by the 0830 IST ascent often gets modified later in the day as a result of advective temperature changes at higher levels in South Bengal. In May 1951 some special radiosonde ascents were made at Calcutta in the afternoon on four days. These ascents have been studied with reference to synoptic charts with a view to understand the changes in the morning tephigrams and in the weather conditions in the course of the day. The results of the study are presented in this paper.

2. Case 1 : 21 May 1951

On 21 May 1951 three radiosonde ascents were made at Calcutta. The 0830 IST ascent is plotted in Fig. 1 and it indicated the existence of latent instability with quite a large positive area. The sky was nearly overcast with *Sc* clouds at that time. The convective condensation level (CCL) was located at the 880-mb level and the temperature required to cause pronounced cumulus activity was found to be about 94°F (Berry, Bollay and Beers 1945). It is seen that nearly isothermal condition prevailed in a column of about 3300 ft thickness above the CCL and this condition was very unfavourable for the vertical growth of clouds through that column. Therefore, convective clouds were not likely to form when the surface temperature was 94°F. This isothermal condition could, however, be destroyed if the surface reached a temperature of 110°F. On the previous day the maximum temperature of Calcutta was only 94°F. The increase of dew-point temperature on the surface at 0830 IST and the inflow of moist current into Bengal at lower levels from the Bay suggested that the possibility of maximum temperature of Calcutta reaching up to 110°F on the day in question was very little. (In fact, the actual maximum temperature of Calcutta on that day was also 94°F). It was thus clear that the energy of the latent instability indicated in the 0830 IST tephigram was not realisable by insolation alone and that some more powerful trigger was necessary for the purpose.

With a dry adiabatically descending environment it has been shown that the ratio of the mass of the ascending currents to the mass of the descending currents cannot exceed the value C given by $C = (\gamma - \gamma_m) / (\gamma_d - \gamma)$ and hence the fractional cloud cover cannot exceed the value $C / (1 + C) = (\gamma - \gamma_m) / (\gamma_d - \gamma_m)$. Thus, when γ is close to γ_m convective clouds can occupy only a small portion of the sky and on the other hand when γ is close to γ_d the clouds can cover a considerable portion of the sky (Petterssen 1940). In Fig. 1 it is observed that the ratio $(\gamma - \gamma_m)/(\gamma_d - \gamma)$ remained nearly equal to one in the column between the 760 and the 585-mb levels and the column was thus favourable for the growth of *Cu* tops covering upto half the sky. The layer between the 585 and the 500-mb levels had a dry-adiabatic lapse rate and also contained the freezing level. One should, therefore, expect an explosive rise of the *Cu* tops through that layer and their transformation into *Cb* clouds. The layers above the 500-mb level were, however, absolutely stable.

On the night of 17 May 1951 a thermal low was located in west Rajasthan at 850, 700 and 500-mb levels and it moved into west Uttar Pradesh by the night of 19 May 1951. At Allahabad temperature decreased by 3°C at 850-mb level, by 4°C at 700-mb level and by 6°C at 500-mb level between the 18th and 19th evenings. This cold air flow was expected to spread subsequently to Bengal. The tephigram of the 20th evening did not indicate arrival over Calcutta of the cold air. One could expect that this incursion might occur during the next 24 hours and accentuate the instability conditions indicated by the morning tephigram of 21 May 1951.

At midday a well-marked upper air discontinuity developed up to 5000 ft roughly along the eastern border of Chota Nagpur and thunderstorm activities were expected to commence there in the afternoon. These thunderstorms were likely to provide a powerful trigger (Desai and Mull 1938, Desai 1950, Chatterjee and Sur 1938 and *Tech. Note* No. 10, 1944) at Calcutta towards the evening and conditions were thus favourable for the occurrence of nor'wester over Calcutta in the evening or night of that day.

A special ascent was taken at 1735 IST and is shown in Fig. 2. It is observed that the isothermal condition persisted in the layer between the 870 and the 800-mb levels and could not be wiped out by insolation. The temperatures decreased by 2 to 5°C in the layers between the 650 and 500-mb levels and super-adiabatic lapse rate developed between the 680 and the 580-mb levels; the instability conditions became more marked, supporting the inference drawn previously on the basis of the temperature changes which occurred over Allahabad about 36 hours earlier.

After 0830 IST the cloud amount over Calcutta slowly decreased and the sky was only partly cloudy with *Sc* and *Cu* at midday and in the earlier part of the afternoon. Asansol reported thunderstorm at about 1600 IST and recorded ¼″ of rain. Volumes of *Cb* clouds began to develop over Calcutta towards the evening. The surface temperature commenced to fall rapidly at 1845 IST and decreased by 14°F between 1845 and 1910 IST. At 1900 IST the station experienced a squall from northwest which continued for about 30 minutes. The maximum speed of the squall was 64 mph and was attained at 1915 IST. There was also an associated rise of pressure by about 5 mb. Dum Dum which is situated at about 12 miles north-northeast of Alipore recorded a northwesterly squall of 54 mph at about 1845 IST. The nor'wester at Dum Dum was also presumably caused by the same mechanism. Almost all stations within 75 miles from Calcutta reported thunderstorm with precipitation that evening, the chief amounts of rainfall being 1″ at Midnapore, ½″ at Dum Dum and ¼″ each at Alipore, Saugor Island and Krishnagar.

The routine 2030 IST ascent was a short one and the significant changes in it were disappearance of the isothermal condition which existed between the 870 and the 800-mb levels in the previous ascent and the appearance of an inversion between the surface and the 900-mb level. The isothermal condition was obviously destroyed at the time of thunderstorm and the inversion above the ground level developed as a result of the combined effect of thunderstorm and night cooling of the surface layers.

It is thus seen in this case that (*i*) due to arrival of colder air above 650-mb level over Calcutta after 0830 IST latent instability conditions became more marked, (*ii*) insolation alone could not release the energy of latent instability and (*iii*) flow of cold air at the surface from thunderstorms

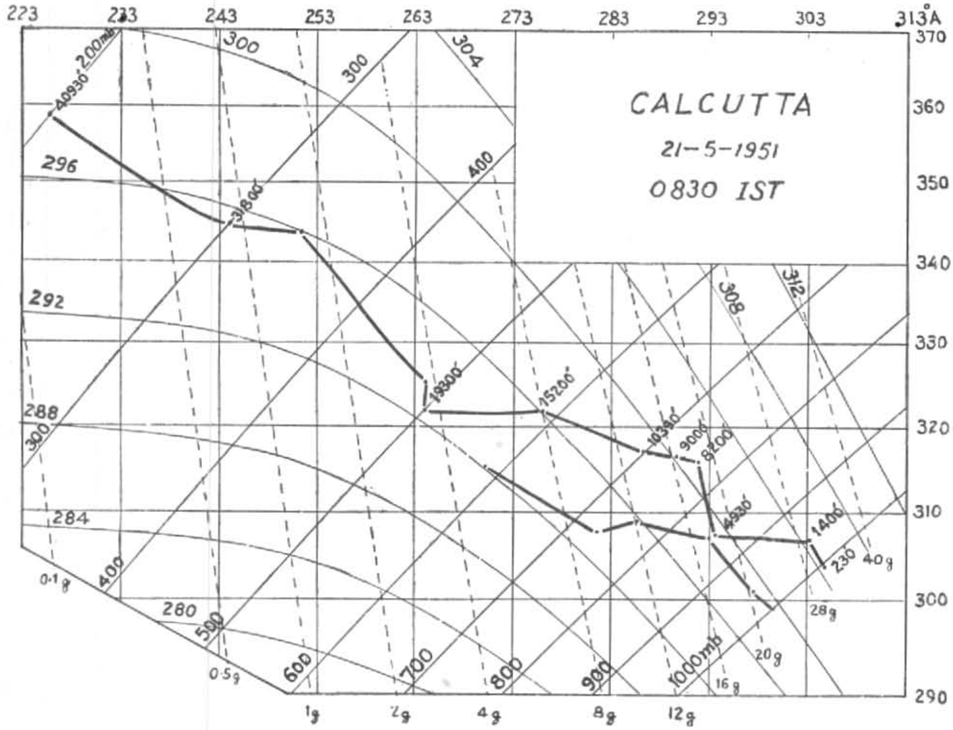


Fig. 1

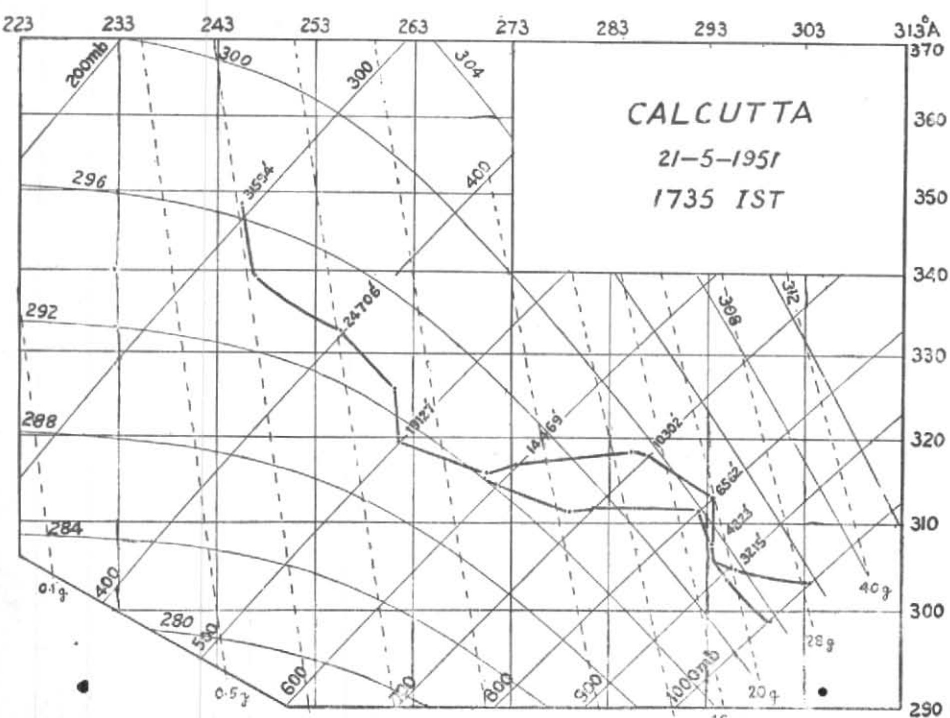


Fig. 2

Fig. 3

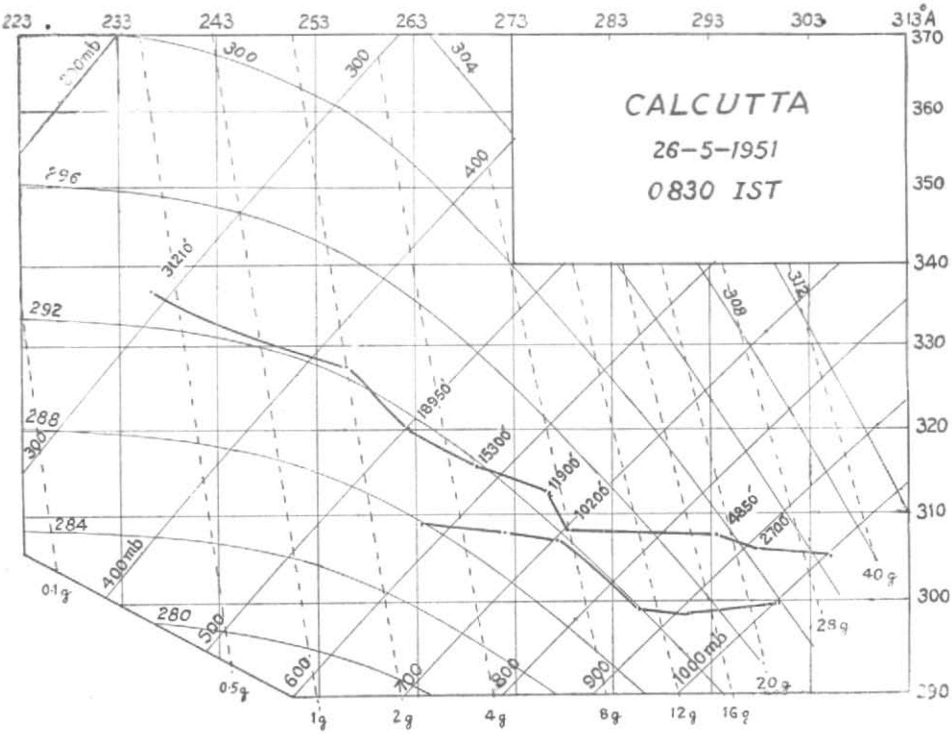
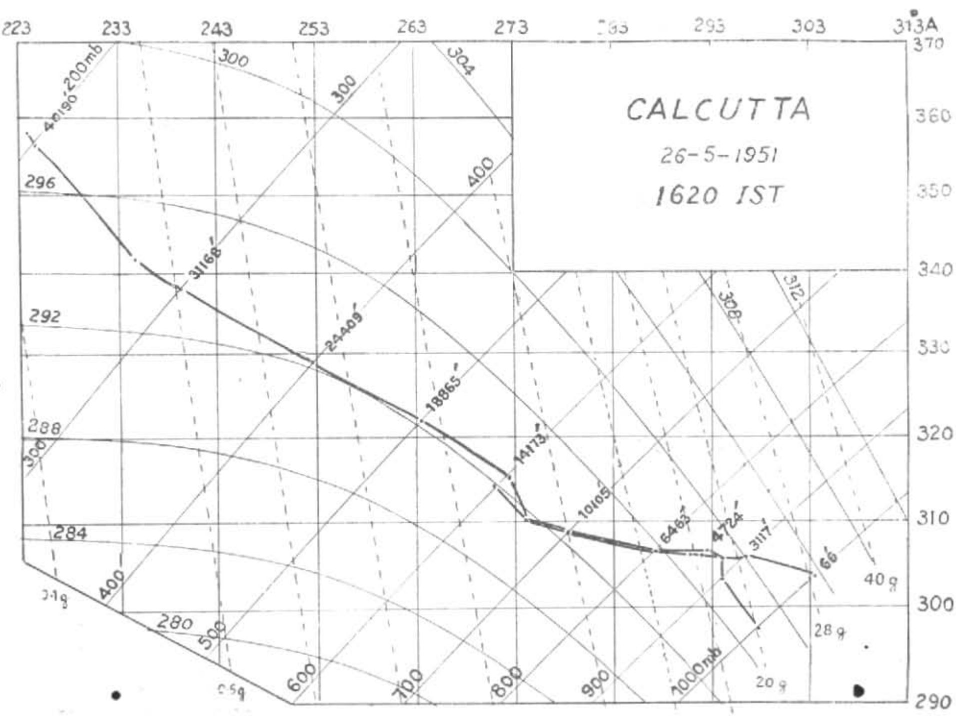


Fig. 4



to the northwest of Calcutta acted as a trigger for the release of energy of latent instability and development of nor'wester.

3. Case 2 : 26 May 1951

On 26 May 1951, five radiosonde ascents were taken at Calcutta. The 0830 IST ascent is plotted in Fig. 3. The sky was about half covered with *Sc* clouds at that time. The layer of instability extended up to 700-mb level and the positive area was quite large. It will be seen that only a small amount of external work was required to liberate the energy of instability. The CCL was located at the 820-mb level and the temperature required to cause pronounced cumulus activity was found to be about 95°F. On the previous day, the actual maximum temperature at Calcutta was 100°F and the synoptic charts did not indicate any appreciable change in it. (In fact the maximum temperature on that day was 99°F and was attained at about 1400 IST). Therefore, the energy of latent instability was realisable by insolation alone.

The thin layer between the 700 and the 650-mb levels was unfavourable for cloud development but it was convectively unstable. The column between the 650 and the 500-mb levels was favourable for the growth of *Cu* clouds covering up to half the sky. As this column also contained the freezing level, the *Cu* clouds were likely to transform themselves into *Cb* clouds with tops easily extending to 19,000 feet. Thus according to the 0830 IST tephigram conditions appeared to be favourable for the occurrence of nor'wester over Calcutta at about the time of maximum insolation.

It was, however, noticed that the temperature of Allahabad had steadily increased from —11°C to —8°C at the 500-mb level and from —1°C to 3°C at the 600-mb level during the period between 2030 IST of 22 May and 2030 IST of 24 May 1951. This fact and the upper winds observations of Allahabad and Calcutta suggested that the temperature would be increasing in the above levels over Calcutta during the day in question and hence the instability conditions present in the morning were likely to be less marked later. It will be seen from the 0830 IST tephigram (Fig. 3) that even a small rise of temperature in these levels would bring the lapse rate very close to γ_m in the column above 650-mb level. In the circumstances one should expect that sufficient amount of convective clouds would grow up to the 700-mb level and only a small amount might extend beyond that level. Hence nor'wester seemed unlikely over the station.

By midday the *Sc* clouds disappeared from the station and *Cu* appeared partly covering the sky and its amount was increasing. One special ascent was taken at 1500 IST and it showed that the instability conditions became somewhat less marked by then. The temperature slightly increased in the column between the 700 and the 500-mb levels as expected and the lapse rate in it became closer to γ_m. This ascent suggested that sufficient amount of convective clouds could grow only up to the 700-mb level.

At about 1500 IST thundery conditions* developed over the station and the sky gradually became overcast with large *Cu* and *Cb* clouds. Another ascent was taken at 1620 IST and it is shown in Fig. 4. It would appear from the tephigram that the balloon entered into a large cumulus cell with base at about 3700 ft and top at 12,000 ft. The temperature inside a cumulus cell at a particular level should be higher than that of the environment at the same level but it is found that the temperatures at 1620 IST were lower than those at 0830 IST and 1500 IST in the column between the 680 and the 650-mb levels. It is difficult to understand how *Cu* clouds could at all grow there. The extension of the *Cu* top beyond the 700-mb level was perhaps due to the force of inertia. It is further noticed that temperatures

*The term "thundery conditions" has been used here for occasions when large *Cu* or *Cb* developed over the station but there was no appreciable squall and no associated drop of temperature and rise of pressure slightly decreased at and below the 800-mb level at 1620 IST. This decrease was apparently due to the increased inflow of the Bay current over the station in the afternoon. The pilot-balloon charts of that day showed that the thickness of the Bay current was only 2000 ft at 0830 IST and extended up to 6000 ft by 1430 IST.

Another ascent was taken at 1725 IST when thundery conditions decreased over the station. There was a general increase of the temperatures and decrease of the lapse rate in the entire air column up to 400-mb level and this suggested that conditions were gradually becoming stabler. The routine ascent at 2030 IST indicated further stability. The temperature increased by 2 to 6°C since 1620 IST in the layers between the 850 and the 650-mb levels and this appreciable rise was besides due to arrival of warmer air from the west also perhaps partly due to subsidence after cumulus activity which was mainly confined to these layers. At night the *Cu* and *Cb* clouds disappeared from the station and the sky was only lightly covered with alto clouds.

Thunder was first heard at Calcutta at about 1500 IST but there was no noteworthy squall over the station and also no drop in temperature and no sudden rise in pressure. The absence of both squall and drop in surface temperature might be due to causes similar to those mentioned by Desai and Mull (1938). Dum Dum experienced a dry thunderstorm accompanied by a gust of 40 mph from northwest at about 1600 IST. None of the reporting stations within 75 miles of Calcutta registered any measurable precipitation on that day except Midnapore and Krishnagar although some of them reported dry thunderstorms.

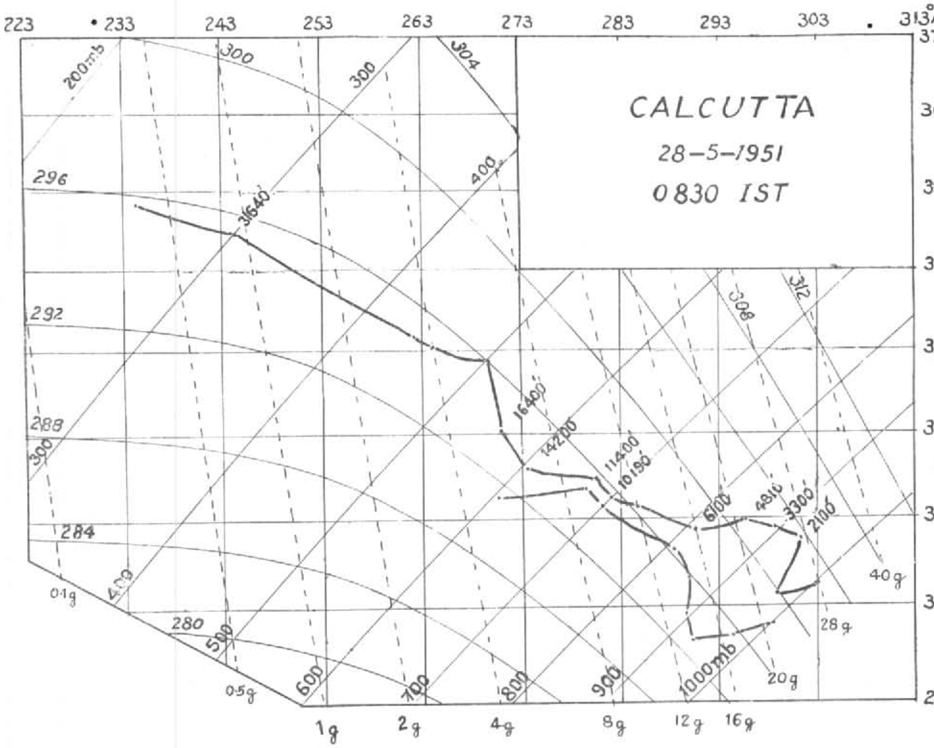
Thus in this case, although there was sufficient latent instability in the morning and insolation alone could release the energy of instability and cause nor'wester, the arrival of warmer air above 850-mb level in the course of the day decreased the instability conditions over the station and as a result only thundery conditions developed there, insolation having acted as trigger.

4. Case 3 : 28 May 1951

In the morning of 28 May 1951 the sky of Calcutta was partly covered with *Sc* and *Ac* clouds. The 0830 IST ascent is plotted in Fig. 5. It is seen that although the layer of instability extended up to 650-mb level, appreciable energy could be realised only from a thin layer above the surface. The column between the 600 and the 500-mb levels was absolutely stable and hence no *Cu* tops were likely to penetrate it. Thus the 0830 IST tephigram was not indicative of thunderstorm but conditions were favourable for the development of sufficient amount of large *Cu* with tops extending up to about 14,200 ft at the time of maximum insolation. It was noticed that the temperature of Allahabad had steadily increased from 25° to 28°C at the 850-mb level, from 10° to 14°C at the 700-mb level and from −8° to −5°C at the 500-mb level during the period between 2030 IST of 24 May and 2030 IST of 26 May 1951. The upper winds between Allahabad and Calcutta indicated the possibility of arrival over Calcutta of the warmer air during the course of 28 May 1951 and, therefore, the instability conditions indicated by the morning ascent were likely to be less marked later in the day.

The *Sc* and *Ac* clouds disappeared from the station shortly after 0830 IST and the sky remained variable with *Ci* and *Cs* clouds for the rest of the day. A special ascent was taken at 1800 IST and is shown in Fig. 6. It is noticed that as anticipated the temperature of Calcutta increased by 3°C at the 800-mb level, by 4°C at the 700-mb level, by 6°C at the 600-mb level and by 2°C at the 500-mb level while the mixing ratio decreased by 3 to 6 grams between the 850 and the 600-mb levels and owing to these changes practically stable condition prevailed over the station.

The midday and the afternoon pilot-balloon charts showed the development of an upper air discontinuity up to 3000 ft across the eastern parts of Chota Nagpur and in association with this, widespread thundershowers occurred in Chota Nagpur


CALCUTTA
28–5–1951
0830 IST
223
233
243
253
263
273
283
293
303
313°A
370
360
350
340
330
320
310
300
290
200mb
300
400
500
600
700
800
900
1000mb
296
292
288
284
280
304
308
312
0·1g
0·5g
1g
2g
4g
8g
12g
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40g
31640
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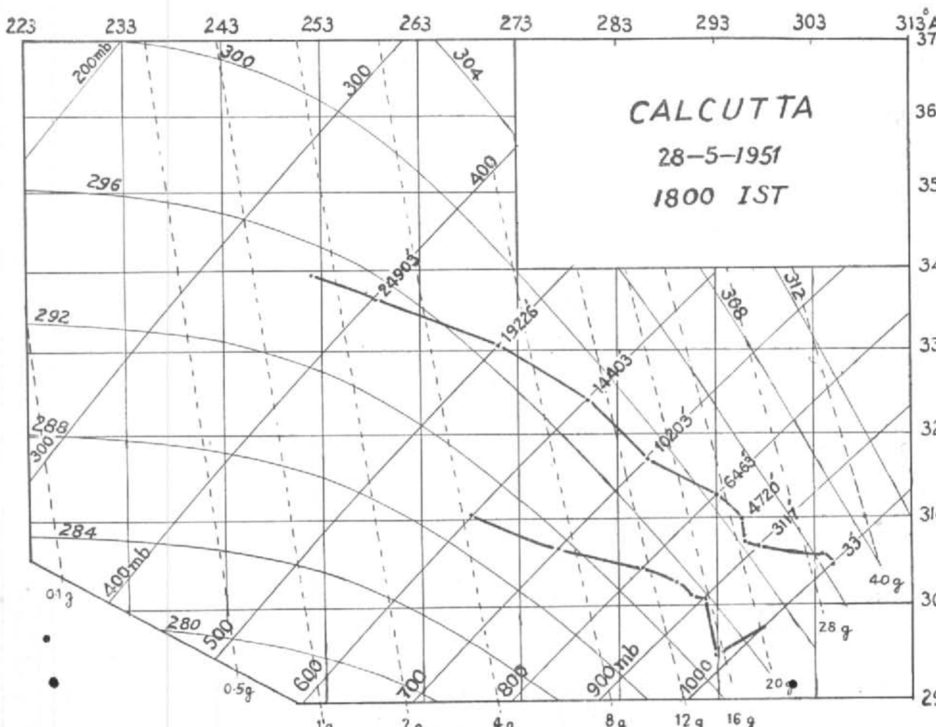
14200
11400
10190
6100
4810
3300
2100

Fig. 5


CALCUTTA
28–5–1951
1800 IST
223
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313°A
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320
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Fig. 6

Fig. 7

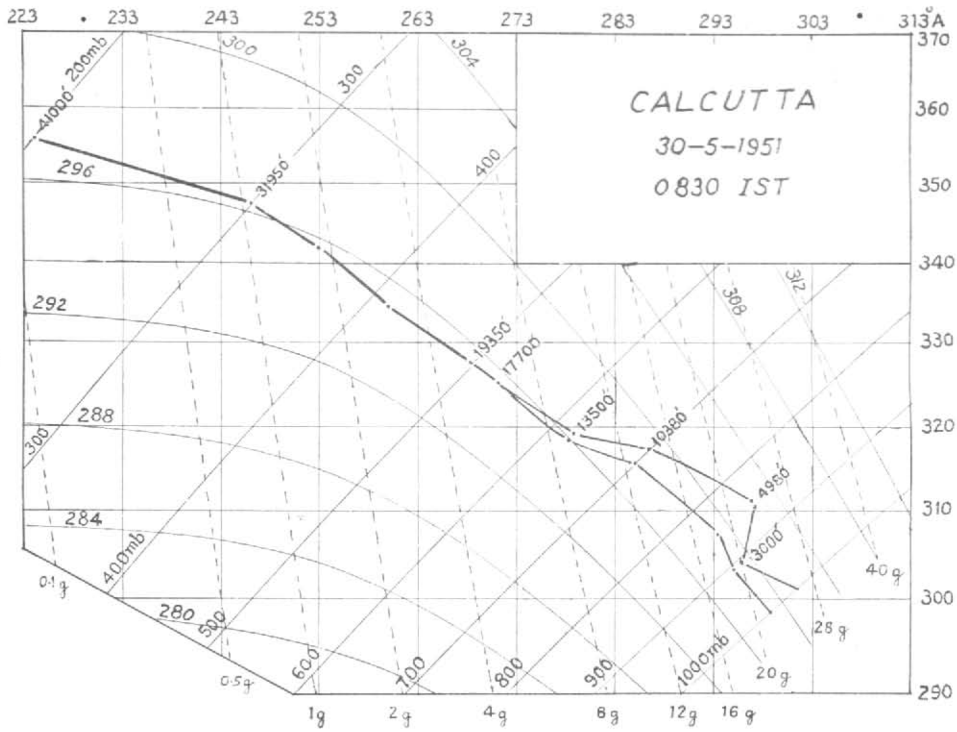
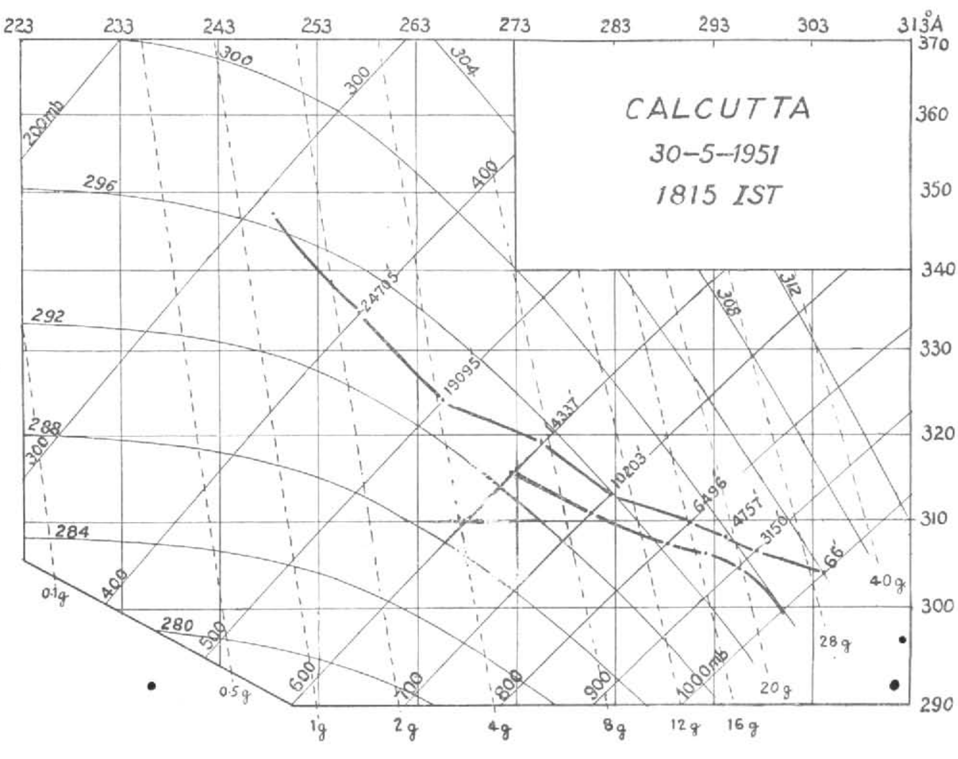


Fig. 8



and in the adjoining region of southwest Bengal in the late afternoon, Asansol and Jamshedpur having recorded ¼″ and ½″ of rain respectively. The routine 2030 IST ascent showed that the vertical distribution of temperature over Calcutta was appreciably affected by these thundershowers; the air which prevailed over Calcutta in the higher levels at 2030 IST was cooler and more humid than that at 1800 IST. It is seen that the temperature at Calcutta decreased by 2°C at the 700-mb level, by 3°C at the 600-mb level and by 5°C at the 500-mb level since 1800 IST. The moisture content also increased in the lower levels due to the continuous inflow of wet current from the Bay upto about the 850-mb level. The decrease of temperature in the higher levels and the general increase of moisture in the atmosphere resulted in the development of latent instability of the real type over the station. After dusk Midnapore reported thundershower with about 1″ of rain. In the earlier part of the night *Cb* and *As* developed over Calcutta and there was a thunderstorm with slight precipitation. Dum Dum did not report any thunderstorm but *Cb* clouds developed there at night.

In this case also as in case 2, the arrival of warmer air in the higher levels from the west decreased the latent instability conditions noticed in the morning but later due to the arrival of colder air in these levels from the west in association with thunderstorm activity over Chota Nagpur and surrounding areas latent instability conditions were again established and thundery conditions developed. These later changes after 1800 IST are of the type mentioned by Roy (1950). The cold air from adjoining thunderstorms to the west spread over Calcutta at the surface and acted as a trigger.

5. Case 4 : 30 May 1951

In the morning and forenoon of 30 May 1951 the sky of Calcutta was moderately clouded mainly with *As*. The 0830 IST ascent is shown in Fig. 7. It is seen that there was only slight latent instability, the positive area being rather small. The lapse rate was nearly moist-adiabatic above 13,500 ft and, therefore, only a little amount of *Cu* cloud could extend beyond that level. The lapse rate between the 850 and the 625-mb levels was, however, favourable for the growth of sufficient amount of *Cu* clouds. Therefore the 0830 IST ascent was indicative of only large *Cu* clouds, provided a suitable powerful trigger was available.

On 28 May 1951, a western disturbance had moved across west Uttar Pradesh and in its rear cold air was flowing eastwards in the higher levels. During 24 hours from 2030 IST of 28 May 1951 the temperature of Allahabad decreased by 2°C at the 850 and the 700-mb levels and by 7°C at the 500-mb level. This fact and the upper air circulation between Calcutta and Allahabad indicated that the temperature of Calcutta might commence falling at these higher levels during the course of 30 May 1951. Thus the instability conditions indicated in the 0830 IST tephigram were likely to become more marked in the afternoon or evening.

A special ascent was taken at 1815 IST and is shown in Fig. 8. As expected, the temperature decreased with the advection of colder air from west by about 3°C throughout the column from the 850-mb level to the 500-mb level. The decrease of temperature at the 850-mb level due to the advection of colder air and the increase of temperature at the 900-mb level due to insolation wiped out the inversion which existed in the layer between the 910-mb and the 850-mb levels at 0830 IST. The positive area also became larger. It is seen that the lapse rate was closer to γ_m in the column between the 700 and the 500-mb levels. Conditions were favourable for the growth of sufficient amount of *Cu* clouds; the tops would, however, extend upto the 700-mb level unless a powerful trigger lifted air sufficiently as to make it easy to realise energy of latent instability. The advection of cold air in this case could not make the conditions favourable for the occurrence of nor'wester over Calcutta, as the temperature decreased by about the same amount (3°C) at 850, 700, 600 and 500-mb levels with the result that there was no material change in the lapse rate above 850-mb level. If changes above 850-mb level over Calcutta were of the same order as those observed over Allahabad, instability would have considerably increased. It is, however, not clear why Calcutta had not more decrease in temperature at 500-mb level than at 850-mb level as noticed at Allahabad between 28 and 29 May 1951.

Large *Cu* and *Cb* clouds developed over Calcutta towards the evening, covering more than half the sky but no thunder was heard. Also, none of the stations within 75 miles of Calcutta reported any thunderstorm on that day.

The routine 2030 IST ascent showed an increase of temperature by 2 to 3°C in the layers between the 900 and the 700-mb levels with little change between the 600 and the 500-mb levels since 1815 IST. The increase of temperature between the 900-mb and the 700-mb levels might have been due to subsidence after cumulus activity which was mainly confined between these two levels. The appearance of a moist-adiabatic lapse rate at 2030 IST in the column from the surface to the 900-mb level and again between the 850 and 800-mb levels made the conditions unfavourable for the growth of *Cu* clouds at night. It is seen from the weather diary that the *Cu* and *Cb* clouds disappeared from the station at night and sky became clear.

In this case as in the first case, latent instability increased in the course of the day due to the advection of colder air in the higher levels from the west in the rear of a western disturbance but no nor'wester occurred ; only large *Cu* and *Cb* clouds developed over the station. Nor'wester would have occurred if a suitable powerful trigger in the form of arrival of cold air from thunderstorms to the west of Calcutta had become available for the release of energy of latent instability. Although Asansol got dry thunderstorm and Hazaribagh thunderstorm with a few cents of rain, cold air flow in sufficient depth did not apparently develop from those thunderstorm cells as to give powerful trigger and nor'wester over Calcutta ; other stations over southwest Bengal also did not get any nor'wester presumably due to same reasons.

6. Conclusion

It would thus appear from the four cases discussed in the paper that the upper air temperatures over Calcutta are affected during the course of the day by the advection of colder or warmer air from northwest India and the trend of temperature changes in the higher levels over Allahabad during the preceding days are often found to be helpful for correct anticipation of the changes in the instability conditions over Calcutta that are likely to occur after 0830 IST ascent. On some occasions, however, the changes over Calcutta caused by the progress of nor'westers from Chota Nagpur may undo the effect (if warmer air has arrived from the west) or increase the effect (if colder air has spread from west) of the advective changes. It has, however, to be understood that producing or increasing the latent instability conditions over Calcutta alone is not sufficient to cause nor'westers. Triggers in the form of insolation (as mentioned in case 2) or flow of cold air from adjoining thunderstorms (as mentioned in cases 1 and 3) or movement of cold fronts (no such case has been found in the present study) have to be operative for the release of energy of latent instability and production of nor'wester.

7. Acknowledgement

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