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Vertical motion in the northern sector of two cyclones

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This note attempts to infer from radiosonde ascents the vertical motion in the northern sector of two fully developed cyclones, one in the Arabian Sea and the other in the Bay of Bengal.

2. The relevant portions of the tracks of the storms are given in Fig. 1. In the case of the Arabian Sea cyclone, the centre at 0800 IST of 20 November 1948 was about 340 miles southwest of Veraval at Lat. 18°N, Long. 66°E. The cyclone intensified further and became severe in the course of the next few hours. At the same time it started curving to the east and was centred at 0800 IST of the 21st at Lat. 19½°N, Long. 69°E about 130 miles southwest of Veraval. The radiosonde ascents at Veraval taken at 0200 GMT on the 20th, 21st and 22nd are shown in Figs. 2. (a), (b) and (c)

3. It will be seen that on the 20th, the lapse rate right upto 28,000 ft was nowhere far from the saturated adiabatic and there was no inversion or isothermal layer at any level except close to the ground ; but on the 21st, an isothermal layer appeared from 816 mb onwards upto the 700-mb level, beyond which level data are not available. Below 816 mb, however, dry adiabatic conditions developed in a layer extending downwards upto 905 mb.

Fig. 1

4. Very similar changes took place over Visakhapatnam between the evenings of 20 and 21 May 1952 when a severe cyclonic storm in the Bay of Bengal moved from about 330 miles south of that station (Lat. 13°N, Long. 83½°E) to about 260 miles south-southwest (Lat. 14½°N, Long. 81½°E). The radiosonde ascents at Visakhapatnam at 1500 GMT on the 20th, 21st and 22nd are reproduced in Figs. 3 (a), (b) and (c). The sounding of 20th showed that right upto 300 mb the lapse rate did not differ greatly from the saturated adiabatic, except between 710 and 680 mb, where it was superadiabatic. By the next day, a very nearly isothermal layer developed between 700 and 800 mb (temperature decrease being only 1·7°C), data above 700 mb being not available. The change became still more pronounced on the next day when the layer from 770 mb right upto 570 mb was nearly isothermal (except for a thin layer of nearly dry adiabatic lapse rate between 618 and 600 mb). There was also a layer with dry adiabatic lapse rate between 770 and 900 mb.

5. In both the cases described above, layers of marked stability developed over the stations located in the northern sector of the cyclones after or during recurvature. The resemblance between the sounding of 21 November 1948 at Veraval and that on 22 May 1952 at Visakhapatnam is striking in one more respect. Between 816 and 905 mb

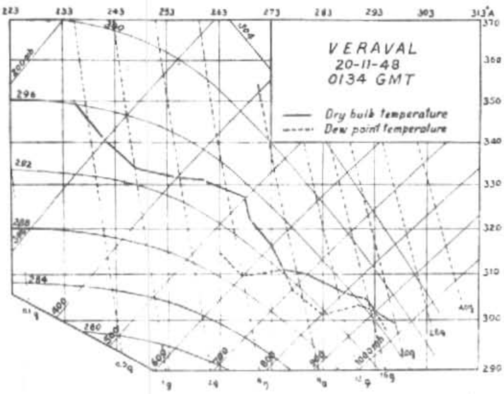

Fig. 2(a)

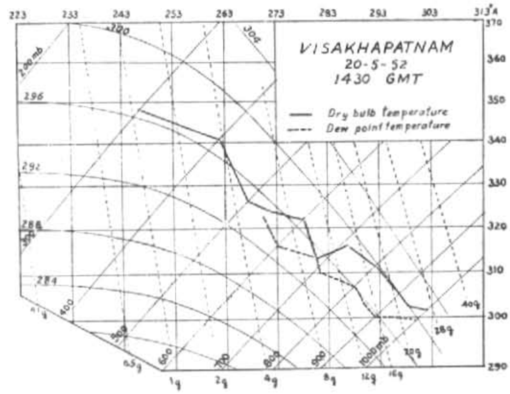

Fig 3(a)

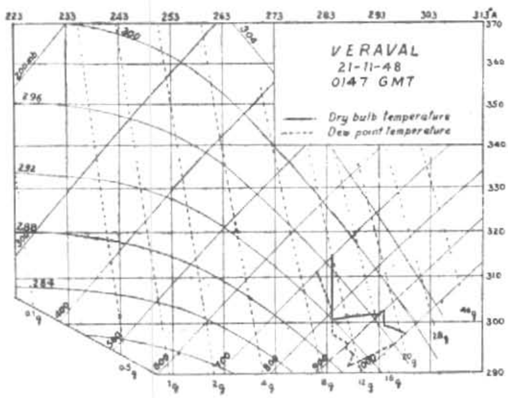

Fig. 2(b)

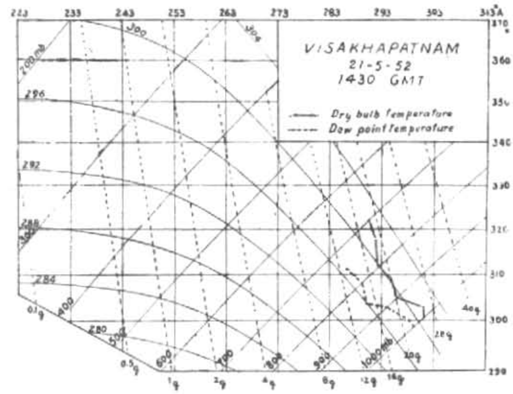

Fig. 3(b)

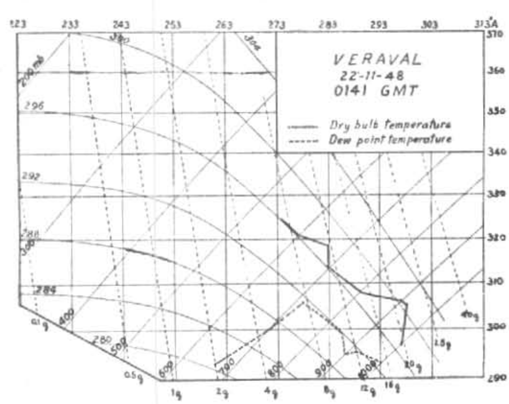

Fig. 2(c)

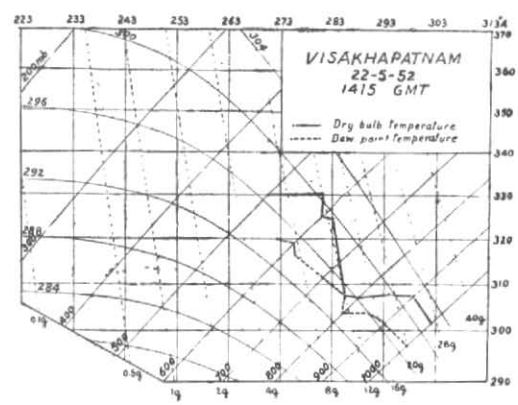

Fig. 3(c)

at Veraval and between 770 and 900 mb at Visakhapatnam there is an adiabatic layer with a very stable layer aloft ; the fall in temperature at the top of this dry adiabatic layer compared to the soundings of the previous day at Veraval and two days earlier at Visakhapatnam was 4°C and 5°C respectively. At 700-mb level the rise in temperature at Veraval from 20 to 21 November 1948 was 4°C and at Visakhapatnam from 20 to 21 May 1952 it was 6°C. In the curve of Visakhapatnam of 22 May 1952 which resembles better the curve of Veraval of 21 November 1948, the rise in temperature occurred above 700 mb, the maximum rise being at about 570 mb, of the order of 6°C (compared to 20th). It appears that the type of change which occurred over Veraval between 20 and 21 November 1948 was spread over two days, *i.e.*, between 20 and 22 May 1952 over Visakhapatnam.

6. From an examination of the upper level charts it appears that the rises in temperature are probably not due to advection. In the May 1952 cyclone, the temperature at 700-mb level at Visakhapatnam rose from 11·4°C on the 20th to 17·8°C on the 21st. On both these days no other station including Port Blair and Trivandrum recorded a temperature of more than 13·5°C. In the November 1948 cyclone, the temperature at 700 mb at Veraval rose from 7°C on the 20th to 11°C on the 21st. Considering the prevailing wind direction and speed at that level, the air over Veraval on the 21st should have been not more than 500 miles to the south or southwest of that station on the previous day. In this region the temperature on the 20th does not appear to have been more than 8°C. The changes have thus to be attributed to vertical motion and not to advection.

7. According to Riehl (1950), in the rain area of cyclones, the ascent curve follows the saturated adiabat from the lifting condensation level and is warmer than the undisturbed tropical atmosphere. Further, the air ascending just around the eye has a higher potential temperature and mixing ratio than the air further outside even in the rain area. Hence ascent curves in the innermost parts of the rain area will be warmer than in the outer portions, which in itself is warmer than the undisturbed current. The question arises whether the rise in temperature at upper levels at these stations can be due to such ascent of air, particularly as the rise in temperature is associated with an increase in mixing ratio. If such were the case, the temperatures in the subsequent soundings cannot be greater than the temperature shown by the saturated adiabat through the mean wet bulb temperature at the surface. Considering all the soundings in question, there is definite evidence of temperatures having exceeded this. Besides, dry adiabatic lapse rates as found between 570 and 500 mb and 600 and 618 mb in the sounding at Visakhapatnam on 22 May 1952 cannot occur by such saturated adiabatic ascent. The lapse rate distribution seen between 500 and 770 mb on 22 May 1952 at Visakhapatnam corresponds to the characteristics of subsided air mass (Petterssen and others 1947). In the upper portion of the subsiding column there is horizontal convergence and vertical stretching leading to a dry adiabatic lapse rate between 500 and 570 mb. In the lower portion of the column there is horizontal divergence and vertical shrinking leading to increased stability between 570 and 770 mb. The sounding at Veraval on 21 November 1948 and that at Visakhapatnam on 21 May 1952 also show the stable layers of the lower portion of the subsiding column. These soundings have not reached sufficient heights to show up the characteristics of the upper portion of the subsiding column. However, the increase in mixing ratio on these days suggests that subsidence had not taken place in the air originally over these stations but in air which had earlier ascended in the rain area.

8. In the dry adiabatic layers between 815 and 905 mb on 21 November 1948 at Veraval and between 770 and 900 mb at Visakhapatnam on 22 May 1952 the air is reaching saturation at the top of the layers. This together with the dry adiabatic lapse

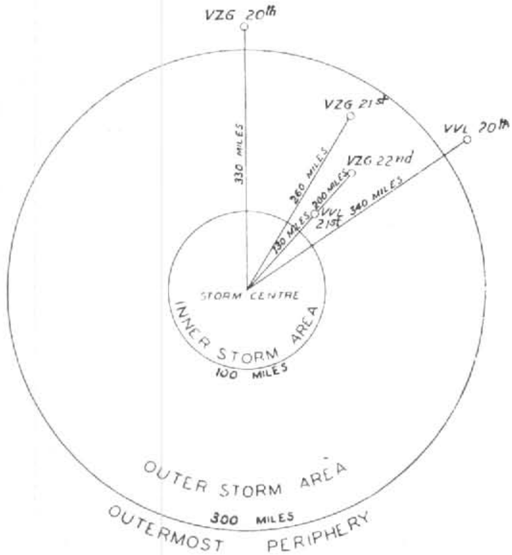

Fig. 4

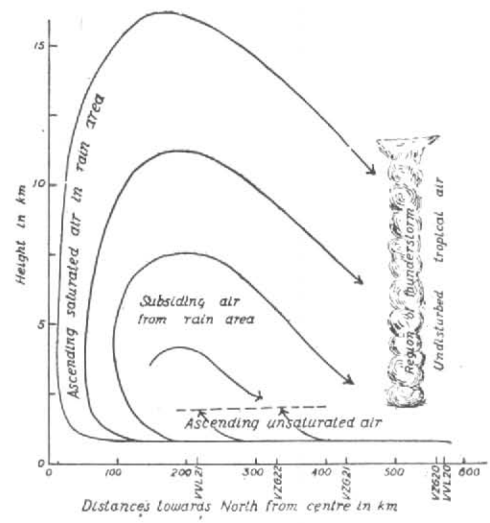

Fig. 5. Schematic diagram of vertical motion in north sector of the two cyclones

rate would suggest ascent of unsaturated air in these layers. No such characteristic is noticed in the curve of 21 May 1952 at Visakhapatnam.

9. From these considerations it appears that the soundings of 20 November 1948 at Veraval and 20 May 1952 at Visakhapatnam represented tropical atmosphere which was probably not being subject to conspicuous vertical displacement. The sounding of 21 November 1948 at Veraval suggests that there was an ascent of unsaturated air upto 816-mb level, above which there was a descent of air from the rain area. At Visakhapatnam, the sounding of 21 May 1952 shows no conspicuous vertical displacement upto 800 mb, above which level there has been a descent of air. The next day's sounding at Visakhapatnam indicates ascent of unsaturated air upto 770 mb with a descent of air from the rain area above this level.

10. The relative distances of the two stations from the storm centres on the dates in question are shown in Fig. 4. In Fig. 1 of his paper, Riehl (1950) has given a schematic outline of the vertical circulation in the area away from the eye of a mature hurricane upto a distance of 200 km. The soundings discussed in this note correspond to distances of more than 200 km from the centre of storm. Attempt has been made in Fig. 5 to combine Riehl's cross-section of vertical circulation upto 200 km with that deduced here for further distances. It will be seen that outside the rain area at distances between 200 and 400 km unsaturated air is ascending only upto about 2 km, while aloft, air is subsiding from the inner rain area. At about a distance of 400 km the ascent of the unsaturated air is ceasing, though the descent of air above 2 km still continues, probably upto a distance of about 500 km. From the diagram it will be clear that the magnitude of descent will be greater at larger distances from centre. This is supported by the fact that the temperature at 700 mb on 21 May 1952 at Visakhapatnam (representing conditions at about 430 km from the centre) is higher than the temperature at the same level on the next day (representing conditions at about 330 km from the centre).

11. At the times of the radiosonde data studied here the cyclone had either just commenced recurving or was slowing down

as a preliminary to recurving. However, it is not possible to conclude that the descent of air in the northern sector was in any way associated with the recurvature until more evidence is gathered. The soundings of Madras between 20 and 22 May 1952 do not show any evidence of subsidence as revealed by Visakhapatnam soundings. Madras was then located in the W to S sector of the cyclone at distances between about 130 and 220 miles from the centre. In the case of the November 1948 cyclone, Poona which was about 500 miles to the east of the cyclone on the 20th and 150 miles to the southeast on the 22nd did not also show any changes similar to those which occurred at Veraval. Arakawa (1950) has recorded that there is marked descent of air 100 to 200 km in the rear of a typhoon centre, which he explains as an isollobaric divergent motion due to the isollobaric high in the rear of the typhoon. On 21 and 22 May 1952 Madras was in the rear of the cyclone but the soundings did not show descent of air. It may be mentioned here that Hughes (1952) has found from the mean low level wind structure of tropical storms that horizontal divergence of air commences at a distance of 150 to 200 miles in the forward portion of tropical cyclones while to the rear upto much greater distances no divergence is noticed. In a general way this fits in with the changes observed at Veraval, Visakhapatnam and Madras.

12. At Veraval there was a thunderstorm between the soundings of 20 and 21 November 1948 with rainfall of about two inches. At Visakhapatnam there were thunderstorms between the soundings of 20 and 21 May 1952 with rainfall of one and half inches. In both the cases the thunderstorms have occurred between the times of the sounding in 'undisturbed air' and the sounding in subsiding air in the outer storm area. It is tentatively suggested that the occurrence of thunderstorms is a characteristic of this transition zone, though the exact mechanism is not clear.

13. The descent of air in the outskirts of the cyclone leading to temperatures higher than in the rain area should create unfavourable solenoid field for the maintenance of the cyclone. No conclusion can, however, be drawn as to the effect of this process on the life-cycle of the storm since the magnitude of the energy-producing processes in the rain area of these cyclones is not known.

14. I would like to thank Dr. B. N. Desai, Director, Regional Meteorological Centre, Bombay, for his guidance and encouragement. My thanks are also due to Mr. Y. P. Rao, Meteorologist, for helpful discussion.

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