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Fog at Santacruz Airport

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ABSTRACT. A study of fogs that occurred at Santacruz Airport during the period 1944 to 1951 has been made. It is found that while fog did not occur at all during certain years, as many as 7 fogs occurred in 1945 and 5 in 1951. Fog occurs mostly during the months of February and March. Synoptic situations associated with days of fog have been discussed and a method of forecasting fog has been indicated. A fog prediction diagram for Santacruz has been described and its usefulness tested with reference to actual data for the winter seasons of 1948 and 1950. A comparison has been made of fogs at Drigh Road Airport, Karachi and those at Santacruz.

1. Introduction

Fog occurs only on a few occasions during the late winter season at Santacruz Airport; however, when fog does occur, the serviceability of this international airport is impaired, sometimes even necessitating diversion of aircraft. It was, therefore, decided to study fogs at Santacruz with a view to find out conditions favourable for their formation.

2. Topographical features

To understand the formation of fog at Santacruz, it is necessary to consider its topographical features. Fig. 1 shows a sketch showing the location of Santacruz airfield in relation to the surroundings. The coastline of Arabian Sea is about 2 miles to the west. To the east, at a distance of 2 to 3 miles there are ranges of hills rising to about 670 feet. To the southeast and northeast, at distances of 5 to 6 miles there are hills that rise to about 1000 to 1500 feet. Again to the east, at a distance of about ten miles, hills rise to about 1300 feet. The waters of the Thana Creek and the Bombay Harbour lie at a distance of 4 to 5 miles from the airfield, covering all directions from east to southsoutheast and the intervening land is mainly flat and marshy. The estuary of river Mahim lies about 2 miles to the south of the airfield.

3. Observed facts about fog

3.1 *Available data*

Meteorological data for Santacruz are available from the year 1944 onwards. The data from 1944 to 1951 (up to the end of April) were examined to study the occurrence of fog. Besides fog as defined by International Convention, mist that reduced visibility to 1 mile or less, was also taken into account to enable a more exhaustive study to be made. In all, fog (with visibility 1 mile or less) occurred on 22 days during the 8 year period.

3.2 *Frequency of occurrence*

The frequency of occurrence varied widely from year to year. While no fog occurred during the years 1944 and 1948, as many as five days in 1951 and seven days in 1945

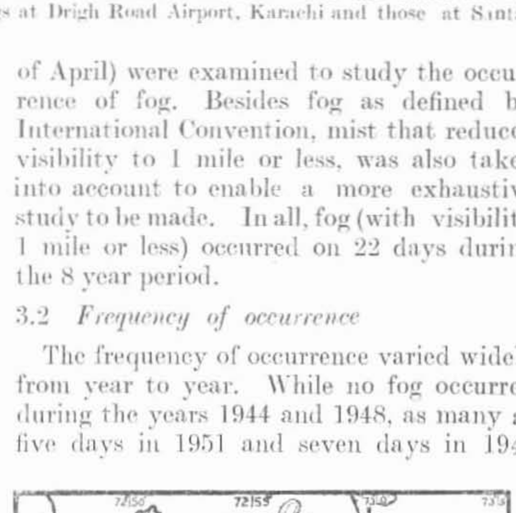

Fig. 1. Topography of Santacruz Airfield

had fog. Table 1 gives the number of fog days in each year.

TABLE 1

Year	No. of days of fog
1944	0
1945	7
1946	2
1947	2
1948	0
1949	4
1950	2
1951	5

The distribution of the above fogs by months is as shown in Table 2. It will be seen that February and March are the months with highest frequency. No fog has occurred during December and also during the period May to October. During the other months of the year, the frequency is small.

TABLE 2

Month	No. of days of fog
January	1
February	10
March	9
April	1
May to October	0
November	1
December	0

3.3 *Duration and intensity of fogs*

On two days the fog lasted for nearly four hours and was the thickest of all, with visibility as low as 10 yards. On two other days, the fog lasted for 2 to 3 hours, with visibility 50 to 200 yards. On 6 days the fog was of 1 to 2 hours duration with visibility 200 yards to ½ mile. On the remaining 12 days, the fog was of less than 1 hour duration with visibility ½ to 1 mile. It is seen that there is a close relationship between the duration of fog and the visibility. Table 3 illustrates this.

TABLE 3

Duration	Visibility: 10 yds or less	50-200 yds	200 yds-½ mile	½-1 mile
4 hours or more	2	..	..	..
2-3 hours	..	2	..	..
1-2 hours	..	..	6	..
Less than 1 hour	..	..	..	12

3.4 *Times of commencement and dissipation*

The two fogs of longest duration commenced by 0430 IST and dissipated one hour or more after sunrise. On three occasions fog commenced early between 0200 and 0400 IST and dissipated before sunrise. On most of the remaining occasions fog commenced during the one hour period preceding sunrise and dissipated by sunrise or soon after.

3.5 *Depth of fogs*

No direct measurements of the depth of fogs have been made. However, from debriefing reports of airline pilots, it can be surmised that the depth is of the order of 100 to 200 ft only. A pilot who flew over the airfield during the fog on 24 February 1951 reported that the visibility in the vertical direction was much better than in a slant direction.

4. Mode of formation

An examination of the synoptic charts and humidity at surface on fog days as well as days without fog shows that two conditions have to be satisfied for the occurrence of fog, *viz.*, (1) clear skies leading to full nocturnal radiation and (2) a pressure system that gives rise to a prolonged and slow advection of moist air from the sea in a shallow layer above the ground during the evening and the early part of the night. Such situations are described in Section 5. The slight turbulence that is necessary for the formation of fog is apparently brought about by a gentle katabatic flow from the hills to the east of the airfield. On days when land breeze of perceptible strength (Beaufort number 1 or more) develops, no fog is found to occur, even though the surface humidity is sufficiently high earlier in the night. This might be due to the land breeze bringing about too much turbulent mixing and also to the progressive replacement of moist air by drier air from the interior.

5. Synoptic situations associated with fog

A study of the synoptic situations associated with all the 22 cases of fog reveals that they fall mainly into two types as described below—

Type 1

When a relatively lower pressure exists to the north of Bombay and neighbourhood, the prevailing air flow is from west or northwest, causing an incursion of moisture from the Arabian Sea. Such situations are associated with passage of western disturbances or secondaries across north India. The fog on 24 February 1951 occurred under such a situation. In Figs. 2(a) and (b) are shown isobaric charts at 0830 IST and 2330 IST of 23 February 1951. The 1730 IST chart has not been shown, since at that hour the features of the pressure system are likely to be masked by the effects of insolation. The charts show the slow movement of a 'low' through Sind and adjoining Rajasthan and indicate the consequent incursion of moist air over Bombay. The variation in the dry bulb temperature and dew point at Santacruz during the 24-hour period preceding the fog is shown in Fig. 3. It will be seen that the rise of dew point from about noon to 2000 IST was about 12°F and this must have been brought about by the sea breeze. Later in the night there was a fall of about 5°F in the dew point till about 0300 IST—a trend that is a usual feature at Santacruz. This might be due to the mixing of the air brought by katabatic flow, besides the effect of diurnal variation with fall in dry bulb temperature[1]. However, after 0300 IST there was no further fall in dew point, presumably due to the slow incursion of moisture from the sea and the land breeze being arrested by the prevailing pressure gradient. On days without fog, further fall in dew points takes place even after 0300 IST.

By 0330 IST of 24th, a thin mist was noticeable over the airfield, which gradually developed into fog by 0455 IST. The visibility was at first about 500 yards but gradually it deteriorated to barely 10 yards. The fog was seen first forming to the east of Santacruz, gradually building up and spreading westwards. At Juhu airfield, about 2 miles to the westnorthwest of Santacruz, fog formed only at 0530 IST. This observation suggests that the katabatic flow from the hills provides the necessary turbulent mixing for the formation of fog.

Type 2

The other type of pressure distribution associated with fog is one in which the seasonal low in the southeast Arabian Sea is pulled up northwards into the East Central Arabian Sea under the influence of a western disturbance. Sometimes there may be even a shallow closed trough of low pressure off the Konkan coast. Under such situations an incursion of moist southerly air takes place over Bombay. The upper winds up to 2000 or 3000 ft become weak and have predominantly southerly component. The fog on 5 March 1951 occurred under such conditions. Figs. 4(a) and (b) show the isobaric chart at 0830 and 2330 IST of 4 March 1951. The variation in dry bulb and dew point temperatures at Santacruz during the 24-hour period preceding the fog is shown by the curves in Fig. 5. It is seen that from 0100 to 0330 IST there was a rise of 3°F in dew point due to incursion of moist air. Fog formed rather rapidly by 0200 IST. There were stratus clouds also covering half the sky from 0200 to 0300 IST. The fog dispersed at 0450 IST. Again at 0710 IST, a little after sunrise the fog formed and dissipated at 0805 IST. The formation of fog second time was probably due to the mixing of relatively colder air close to the ground with the overlying moist air as a result of turbulence set up with sunrise.

It may be mentioned that with some situations of type 1, fog also occurred at Veraval on the Saurashtra coast, about

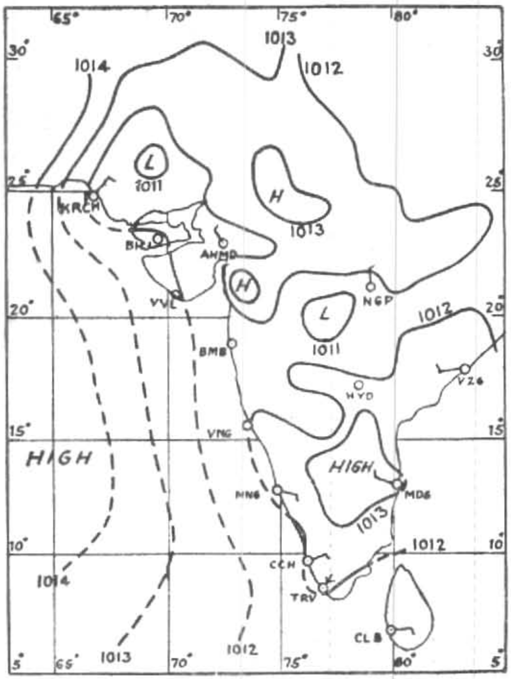

Fig. 2(a). Isobars at 0830 IST on 23 February 1951

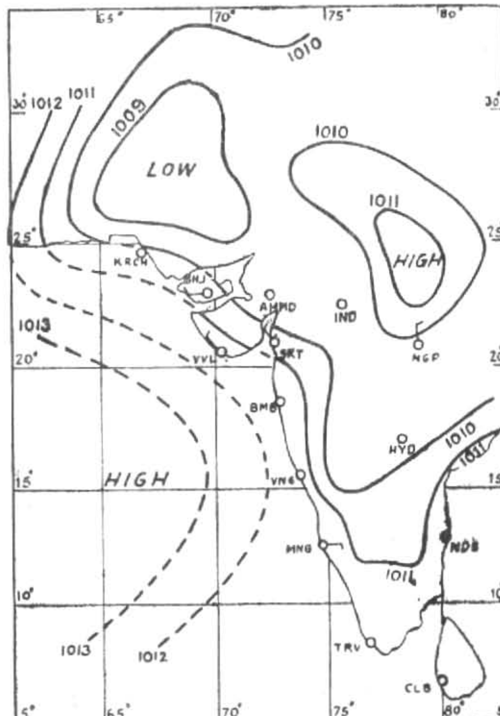

Fig. 2(b). Isobars at 2330 IST on 23 February 1951

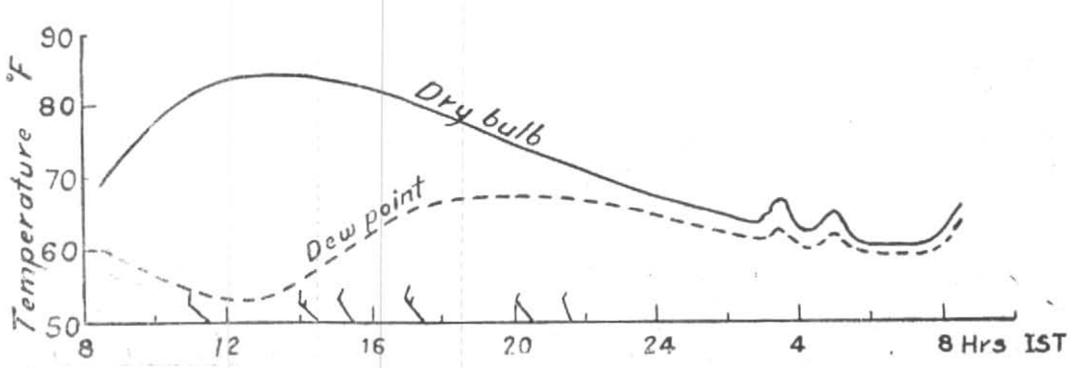

Fig. 3. Variation of dry bulb and dew point temperatures 23-24 February 1951

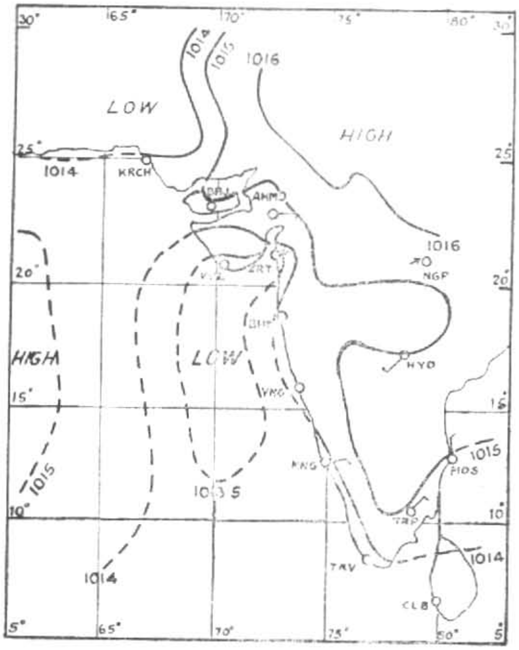

Fig. 4(a). Isobars at 0830 IST on 4 March 1951

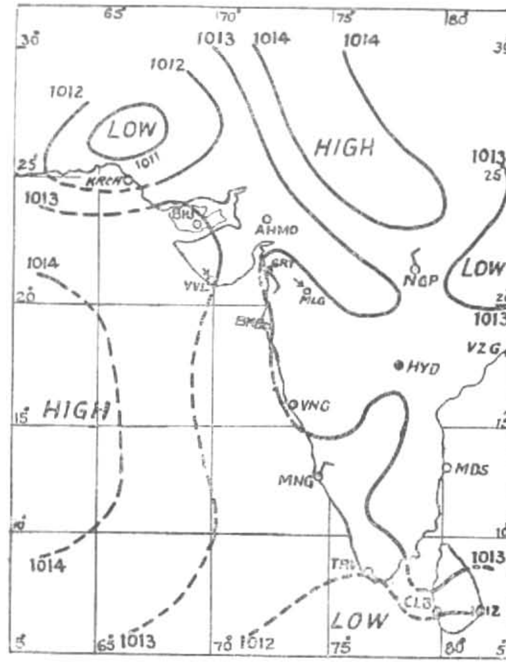

Fig. 4(b). Isobars at 2330 IST on 4 March 1951

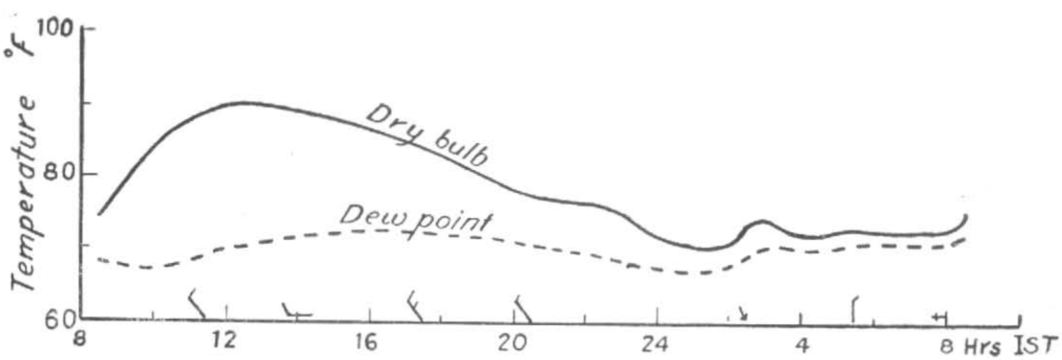

Fig. 5. Variation of dry bulb and dew point temperatures 4-5 March 1951

200 miles northwest of Bombay, a day earlier than at Santacruz.

Of the total of 22 fogs studied, 15 were of the type 1 and the remaining 7 of the type 2. In general, fogs of the type 1 were thicker and lasted longer than those of the type 2. Moreover, it was found that among the fogs of the type 1, those associated with 2330 IST isobars running west to east near Bombay were thicker and lasted longer than those associated with isobars running northwest to southeast or northnorthwest to southsoutheast.

Sometimes fog occurs on successive mornings. During the 8-year period there were 3 occasions when fog occurred on successive days at Santacruz. Such occasions of fogs on successive days were associated with synoptic situations that persisted without much change during a period of 24 to 48 hours.

6. Forecasting of Fog

From the foregoing analysis of occasions with fog, it is to be expected that the pressure field is of considerable importance in the forecasting of fog at Santacruz. The advection of air from the sea within the frictional layer may be assumed to be roughly along the isobars and when the isollobaric gradient is weak, as is the case on most occasions near Bombay during the late winter period the isobars may be taken to represent the trajectory of the air. When considering the movement of air from the sea areas over the coastline the effect of friction may be considered small and the cross-isobar component of the wind may also be small.

The first step in the forecasting of fog is obviously to see if clear skies would prevail during the night. Apart from leading to full nocturnal radiation, clear skies also give rise to katabatic flow which is necessary for the formation of fog. It is also necessary that the surface wind should not have any easterly component and should not exceed about 3 to 4 mph during the latter half of the night. A wind stronger than this would lead to too much turbulent mixing. If the above conditions are likely to be fulfilled it has to be seen whether moist air is likely to advect over the place due to either of the two types of situations described already. For forecasting the pressure field expected to prevail during the latter part of the night, the 1730 IST chart is not found to be useful on account of the distortion produced in the prevailing circulation by the diurnal heating of the land. On the other hand, the 2330 IST chart has been found to be more useful, since by that hour the effects of insolation are no longer present. The disadvantage of having to issue a fog warning only a short period (4 to 6 hours) in advance of the occurrence of fog, will be more than offset by the greater chance of success in the forecasts, if they are based on the 2330 IST chart.

To a first approximation, the pressure field as seen in the 2330 IST chart may be assumed to prevail during the succeeding few hours. A detailed picture of the pressure field which is generally weak during the fog season may be obtained by drawing isobars every one or even half a millibar. As the barometric pressure can be read with great accuracy, the drawing of such close isobars even with the usual network of observatories will be justified. If the direction of isobars over Bombay is well defined and is from the sea to the land or from the south along the coastline, and if the relative humidity at 2330 IST is no less than about 70 per cent, fog can be predicted. It is found that when due to a low inland, say over north Deccan and adjoining areas, the isobars near Bombay run from north to south or northwest to southeast having little travel over the sea, no fog is found to form. This is presumably due to the air having very little travel over the sea. As an example of such a situation the 2330 IST chart of 3 March 1950 is shown in Fig. 6 ; there was no fog on this occasion.

When the pressure system is a combination of the types 1 and 2, a region of col develops, where there is no definite flow of air. If the col happens to be over Bombay or nearby, fog does not occur even with a humidity of over 70 per cent at 2330 IST. To illustrate an example of this type, the

2330 IST isobaric chart of 24 January 1950 is shown in Fig. 7. There was a 'low' over southwest Rajasthan and there was also the seasonal trough of low pressure extending into the East Central Arabian Sea. The resulting col was over Bombay and no fog occurred on the 25th morning, though the relative humidity at 2330 IST was 83 per cent.

The above criteria have been verified positively with reference to 21 out of the 22 cases of fog at Santacruz and negatively with reference to some of the days without fog during the late winter season. The one case when these criteria did not hold good was the fog on 3 March 1951. A brief description of this fog which formed rapidly during the latter part of the night even with a low humidity at 2330 IST may be of interest. In Figs. 8(a) and (b) are shown the isobaric charts for 0830 and 2330 IST of 2 March 1951. The trough of low pressure is seen extending as far northwards as the Gulf of Cambay. The lowest barometric pressure at 2330 IST was at Vengurla. On the 1730 IST chart (not shown here) a pressure departure low could be located along the Konkan coast, with the lowest barometric departure at Bombay. This confirms the existence of a feeble closed low pressure area off the Konkan coast. The relative humidity at 2330 IST was only 45 per cent at Santacruz.

By 0345 IST on 3 March 1951, fog set in rather abruptly to the accompaniment of a feeble southerly breeze. The breeze dropped down after some time and the fog thickened gradually with visibility about 200 yards. By 0515 IST, a feeble easterly wind set in and completely dispersed the fog in a short time. The variation in dry bulb and dew point temperatures at Santacruz during the 24 hour period preceding the formation of the fog is shown in Fig. 9. The rapid advection of moist air was presumably due to the northward movement of the low pressure. The rise in the dry bulb and dew points between 0515 and 0600 IST was associated with light easterly breeze as in the case of rise of both these elements between 0115 and 0200 IST; there being practically no wind before the setting in of the light easterly wind.

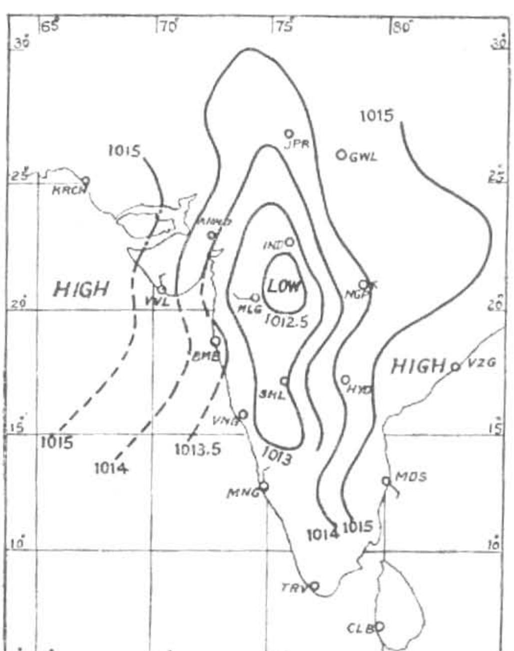

Fig. 6. Isobars at 2330 IST on 3 March 1950

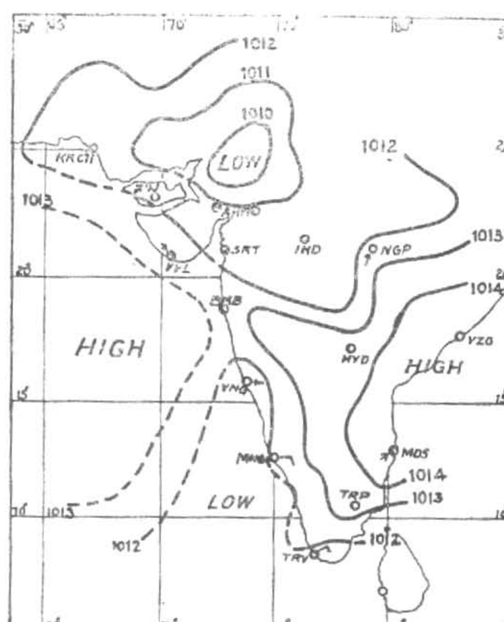

Fig. 7. Isobars at 2330 IST on 24 January 1950 showing a col over Bombay

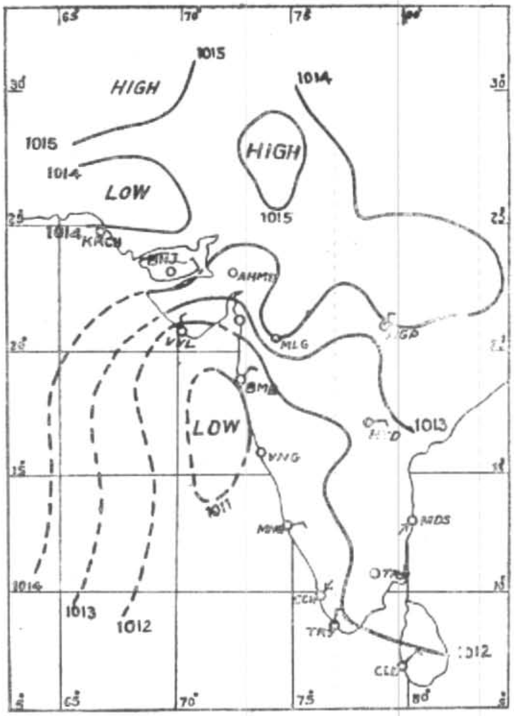

Fig. 8(a). Isobars at 0830 IST on 2 March 1951

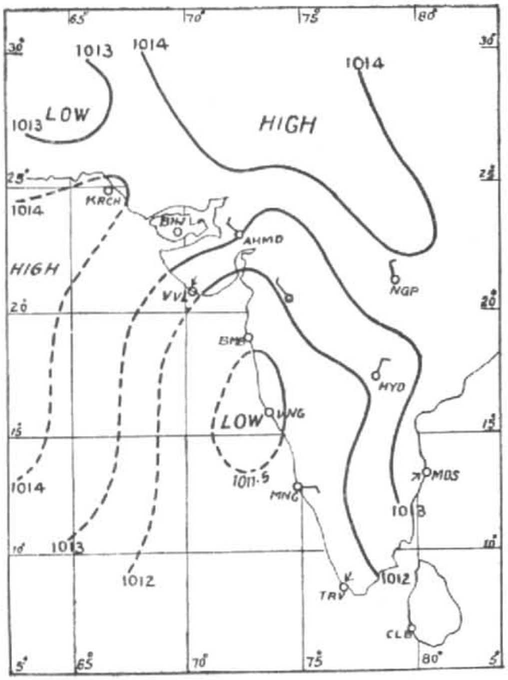

Fig. 8(b). Isobars at 2330 IST on 2 March 1951

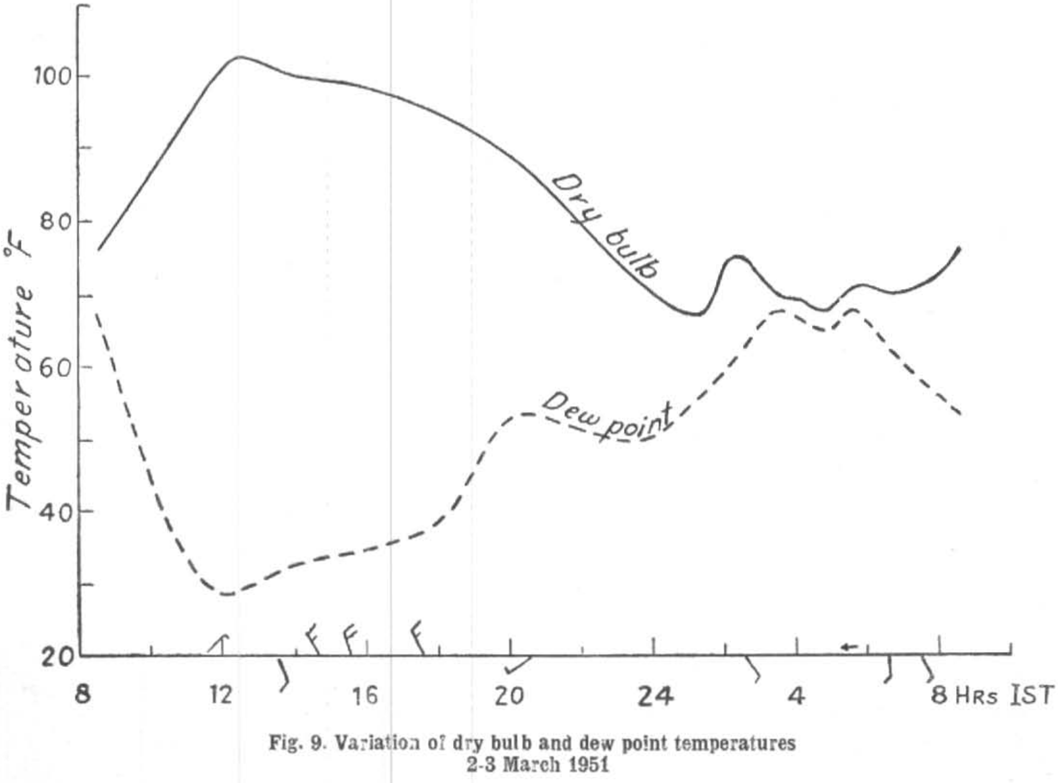

Fig. 9. Variation of dry bulb and dew point temperatures
2-3 March 1951

The rise in dry bulb and dew point at about 0315 and 0445 IST on 24 February 1951 (Fig. 3) and at about 0200 IST on 5 March 1951 (Fig. 5) was also probably due to the setting in of light easterly wind.

7. Fog prediction diagram for Santacruz

The results of the analysis given above can be fitted in with a fog prediction diagram (Fig. 10) to be used in conjunction with the 2330 IST chart or a chart of near about that hour. The centre of the circle represents a relative humidity of 50 per cent, and the spacing of the concentric circles correspond to 10 per cent increase in humidity. From the centre of the circle draw a radius vector, the direction of which in the sense towards the centre, is the same as that of the isobars over Bombay on the 2330 IST chart and the length of which corresponds to the relative humidity at that hour. If the end of the vector falls within the shaded portion of the circle, fog may be forecasted provided (1) clear skies are expected to continue throughout the night and (2) surface wind is not expected to be more than 3 to 4 mph during the latter part of the night and is not expected to have any easterly component. On the diagram, the end points of the vectors corresponding to conditions preceding 21 out of 22 fogs have been shown as large dots. In the case of three fogs that occurred during February 1949, the 0200 IST charts have been used, since during that period the 2330 IST synoptic charts were not prepared.

The fog prediction diagram described above, differs from the conventional diagrams used for radiation fogs. This is to be expected since for a coastal place like Santacruz advection of moist air is the important factor.

When a trough of low appears in the East Central Arabian Sea on the 2330 IST chart giving isobars running south to north over Bombay, the possibility of fog occurring will have to be taken into account even though the humidity may be low at that hour. On such occasions, frequent determinations of dew point are

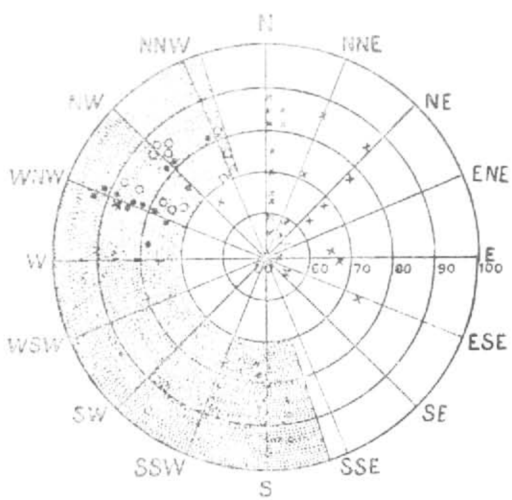

Fig. 10. Fog prediction diagram for santacruz

necessary. If there is a tendency for an appreciable increase of dew point, fog may be forecasted. The usefulness of the fog prediction diagram was tested by applying the 2330 IST data on all days during the months of February and March 1950. During this period there were 49 occasions when clear skies prevailed during the night and surface wind did not exceed 3 to 4 mph and did not have an easterly component. Out of these, 8 occasions were associated with col over or near Bombay and hence could be eliminated. On 27 occasions, the end point of the vector representing direction of isobar and the relative humidity fell outside the shaded area of the diagram, and these have been shown by crosses in Fig. 10. No fog occurred on these occasions. On 14 occasions, the end point of the vector fell within the shaded area. Actually, fog occurred only on one out of these occasions. An examination of the 2330 IST synoptic charts indicated that 12 out of the 13 occasions of apparent failure were associated with flow of air having a short sea travel only, as in Fig. 6. The end points of vectors corresponding to these 12 cases have been marked as unfilled circles. The cause for the non-occurrence of fog on the remaining one occasion (marked by an asterisk on the diagram) is not clear.

8. Fog prediction diagram applied for the year 1948

During the year 1948 there was no fog at all and hence it was decided to test the validity of the fog prediction diagram with respect to February and March conditions that year also. The 2330 IST synoptic charts were not being prepared during those days and hence the synoptic charts for the nearest available hour, *viz.*, the 0200 IST were used. In all, there were 43 occasions when clear skies prevailed and the surface winds without any easterly component were not more than 3 to 4 mph. Of these, 9 were associated with cols and hence could be eliminated. The direction of isobars on 4 occasions were not well marked and hence these cases were not taken into consideration. On 24 out of the remaining 30 occasions, the end point of the vector in the fog prediction diagram fell outside the shaded area. On 5 occasions it fell within the shaded area, but on those occasions the flow of air was having a short sea travel only as in Fig. 6. On the remaining one occasion, the end of the vector fell within the shaded area, but the cause for non-occurrence of fog is not understood.

9. Forecasting of fog with the aid of upper winds

The question naturally arises whether the advection of moist air in the lowest levels could not be forecasted from upper winds up to 2000 or 3000 ft. Upper winds, no doubt give a better and more objective representation of air flow than the direction of isobars, but unfortunately the present hours of pibal ascents in India are not quite convenient from point of view of forecasting fog. The 1430 IST pibal winds up to 2000 ft, particularly at coastal stations would be considerably influenced by the diurnal heating of land and hence cannot be relied on. The next pibal ascent at 0230 IST provides data for forecasting fog at too late an hour. The most suitable hour for pibal ascent would be 2030 IST. A pibal ascent at 2030 IST at Santacruz would be a valuable aid to supplement the data available from the 2330 IST surface chart.

To see whether the 1430 IST pibal winds could be of any forecasting value, a qualitative comparison was made between the lower portions (upto 1 km) of trajectories of 1430 IST pibals and those of the succeeding 0230 IST pibals for Juhu airfield for the months of February and March 1951, there being no pibal station on the Santacruz airfield. There were 5 days of fog at Santacruz and 3 days at Juhu during this period. No definite relationship could be found between the change in winds from 1430 to 0230 IST on fog days vis-a-vis days without fog. When the proposed pibal observatory at Santacruz starts functioning it may be possible to establish better conclusions regarding the utility of pibals for forecasting fog.

10. Forecasting of fog from 1730 IST synoptic data

If a forecast for fog has to be issued in advance based on 1730 IST synoptic charts, the following points will be found useful. With situations of type 1: (*a*) the 1430 IST upper winds up to 3000 ft should have a more westerly component than usual, and (*b*) the surface dew points at Bombay should show an appreciable increase since the previous day. With situations of type 2: (*a*) 1430 IST upper winds up to 3000 ft should show a predominantly southerly component, and (*b*) when a shallow low pressure area exists off the coast, surface winds at 1730 IST at coastal stations do not blow from northwest as on normal days but in a southwesterly or westerly direction. The wind should also be appreciably weaker than usual. Positive dew point changes at Bombay and stations to the south give a good indication of incursion of moist southerly air.

11. Fog at Juhu Airfield

It was found that fog did not occur at Juhu airfield on all the days when Santacruz had fog. On most situations of type 1, particularly when isobars over Bombay run west to east, or westnorthwest to eastsoutheast, fog is seen to form to the east of Santacruz and to drift later from Santacruz to Juhu. On most situations of type 2 only one of the two places is affected by fog.

12. Comparison of fogs at Karachi and Santacruz

Mull, Desai and Sircar[2] have made a detailed study of temperature and humidity changes associated with the development, persistence and dispersal of fogs at Drigh Road, Karachi, during March 1931. Out of the 7 fog studied by them, 4 were of the radiation type and 3 of the advection type. The latter type appears to be mostly associated with incursion of moist air in the warm sector of western disturbances and bears some similarity to fogs at Santacruz, particularly those of type 1. The sequence of processes in both cases is in the following order: (1) incursion of moist air during the evening and early part of the night (2) nocturnal radiation during the night leading to cooling of the air to very near the dew point and (3) katabatic flow from the neighbouring hills bringing about the necessary turbulent mixing for the formation of the fog. At Drigh Road, Karachi, the Kohistan hills which are situated at a distance of 10 to 20 miles to the west and northwest, presumably give rise to the katabatic flow. At both Santacruz and Karachi the drift of fog is generally along the direction of katabatic flow. The variation of mean temperature and dew point for the 7 March fogs at Karachi is shown by the curves in Fig. 11. These curves are generally similar to the curves in Fig. 3 showing variation of temperature and dew point preceding a fog in February of type 1.

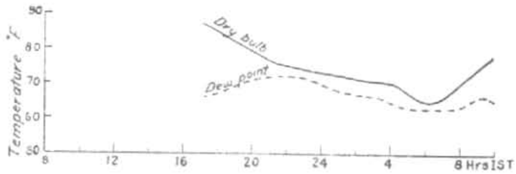

Fig. 11. Variation of mean temperature and dew point for 7 fog days during March at Karachi

13. Acknowledgements

The author wishes to record his grateful thanks to Dr. B. N. Desai, for suggestions and guidance during the course of this investigation. He also wishes to thank Mr. Y. P. Rao for some helpful suggestions.

REFERENCES

1. Petterssen, S., *Weather Analysis and Forecasting*, pp. 17-18 (1940).

2. Mull, S., Desai, B. N. and Sircar, S. P., *Ind. met. Dep. Mem.*, **29**, Pt. 1, pp. 50-53 (1942).