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Interpretation of the U. S. A. *Oceanographer* sounding and radon data over the Arabian Sea during June 1967

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ABSTRACT. U.S.A. *Oceanographer* sounding and radon data during June 1967 have been discussed with reference to the synoptic charts. During the the period 14 to 21 June there was above the surface layer of maritime air, less moist air with nearly saturation adiabatic lapse from the south Arabian Sea side instead of the dry continental air from northeast Africa and Arabia. The *Oceanographer* soundings compare well with those at Bombay, if one keeps in mind the effect of the Ghats for the latter location. The radon data show that there was presence of the maritime air from across the equator, which had got mixed to some extent with continental air from northeast Africa and Arabia; the high radon values off Saurashtra-Konkan were *not* due to vertical mixing of the lower maritime air with the upper continental air.

1. Introduction

The U. S. A. Research Vessel *Oceanographer* had made a number of radiosonde ascents and collected temperature and humidity data during the period 14 to 21 June 1967 in the northeast Arabian Sea off the north Konkan-Saurashtra coast at the beginning of the southwest monsoon season. Rama (1969) has also given radon measurements for these days, and discussed them from the point of air masses present over the area. The *Oceanographer* soundings data show some marked differences from those collected over the area during the International Indian Ocean Expedition (IIOE) year 1963; it is proposed to discuss them along with Bombay soundings and Rama's radon data in this paper with reference to the main synoptic features.

2. Discussion

For the period 14 to 21 June 1967, the *Oceanographer* soundings are available for 00 GMT for five days, and at 06, 12 and 18 GMT for seven days for different locations off Konkan and Saurashtra. It is proposed to discuss only 12 GMT observations of 14 to 20 June with reference to the synoptic charts for drawing inferences about the air masses present over the area. For the 21st only 06 GMT data are available. Along with the *Oceanographer* data, similar data for Bombay (Santacruz) for 12 GMT of the 14 to 20 June (Figs. 1 to 7 respectively) and 00 and 12 GMT of 21st (Fig. 8) with *Oceanographer* data of 06 GMT have been considered to get a comparative idea. The *Oceanographer* locations on different days were within about 8° of Bombay, the extreme west position (18.47°N, 65.20°E) being on 18 June.

(*i*) *Radon data for 1 to 7 June 1967* — Rama has presented in his latest paper (1969) radon results over the Arabian Sea from the 1st to 6th June between about 7°N, 52°E and Goa (8 to 16 dpm/m^3) and on the 7th off the coast between Goa and Bombay (7-10 dpm/m^3). These results show presence over the area of radon-poor (1-4 dpm/m^3) air from across the equator slightly mixed with the radon-rich (80-160 dpm/m^3) continental air from northeast Africa and Arabia, although the monsoon in terms of rainfall did not appear over the coast till the 8th.

(*ii*) *Synoptic feature from 8 to 14 June 1967*— With the arrival of air from across the equator, a trough developed off Kerala on the 8th morning. Dry bulb and dew point temperatures at Minicoy and Trivandrum on the 8th evening, when compared with those on the 7th evening, showed that the air mass at those stations had changed and it was nearly saturated upto about 500 mb; on the 8th evening the dry bulb temperature had fallen upto 850 mb at Minicoy and upto 500 mb at Trivandrum. The trough moved northwestwards and rainfall also extended northwards on the coast upto Bombay by the 12th morning. At Bombay, from the 11th to 12th evening the temperature had decreased by 2-5°C and dew point increased by 3-8°C upto

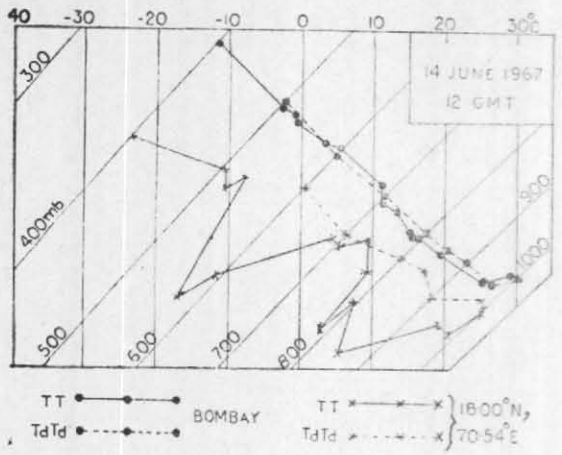

Fig. 1

TABLE 1

Pressure (mb)	Mean Jun temp.(°C) Aden	Bahrein	*Oceanographer* temp. (°C) on 14 Jun 1967
900	27·3	31·1	22·5
850	24·6	27·2	20·0
800	21·5	23·2	17·0
700	13·3	14·6	12·0
600	2·1	4·9	5·8
500	—8·0	—4·1	—3·0

about 630 mb, showing the presence of moist air on the 12th evening. On the 13th morning the trough moving northwestwards, extended off the Arabian coast between Muscat and Masirah island. Between the 12th and 13th evenings, the temperature at Bombay had further decreased by 1-3°C upto 500 mb and dew point increased by about the same amount upto about 600 mb, showing presence over the station of nearly saturated air mass. Light rain occurred on the west coast upto Dahanu between the 12th and 13th mornings.

(*iii*) *Synoptic features from 14 June 1967 and sounding data of Oceanographer and over Bombay and radon data over the Oceanographer locations* — At 00 GMT of the 14th a trough was present over the Arabian Sea with axis near 66°E at the surface in upper levels it could be located upto about 500 mb. From the WSW/W winds along the west coast from 0.6 to 1.5 km to the south of 19°N (Bombay), it appeared that the trough had not extended to the south of Bombay at those levels. At 2.1 km the westerlies were to the south of 15°N and the trough extended to that latitude. From 700 mb upwards, the trough extended further south.

Oceanographer and Bombay data for 12 GMT of 14 June are given in Fig. 1. The chief difference in the two ascents is the low humidity at 18°N, 70.54°E compared with Bombay except at the surface and between 740 and 680 mb. The temperature differences were small, but it should be noted that there was dry adiabatic lapse not only at Bombay upto 970 mb, but even over the sea upto 950 mb.

As the radiosonde ascents are for 12 GMT earlier flow pattern such as of 00 GMT may indicate likely trajectory of air. As seen from the charts, conditions similar to those at 00 GMT were persisting over the area even at 12 GMT. Around the trough in the Arabian Sea air from the west Arabian Sea could have come to the position of the *Oceanographer* at 18°N, 70.54°E in the lower troposphere, but not from northern India. These two sources only are considered on account of the relative dryness of the air over *Oceanographer* above about 950 mb.

In Table 1 are given the mean temperatures for June at Aden and Bahrein. Air from the Arabian Peninsula should normally have been much warmer as any cooling by travelling over the cooler Arabian Sea could not have extended beyond about 900 mb; an inversion would develop right from the surface but the air will still retain dryness as transport of moisture upwards from the sea surface could not be appreciable across the inversion in the light of the observations during IIOE period over the Arabian Sea (Desai 1966, 1968). Hence the air mass over the *Oceanogapher* area must have originated from the south Arabian Sea side.

There were thus deflected trades in the layer upto about 950 mb and air from the south Arabian Sea side above which had nearly moist adiabatic lapse and was colder upto about 650 mb than the air from the Arabian Peninsula side. The less moist air above the deflected trades had origin probably south of the equator. Such air mass stratification was also noticed during the IIOE year 1964 (Desai 1968), with or without an inversion between the lower moist and upper less moist air masses. As a result of the Ghats there was forced ascent of the moist air near Bombay which was responsible for higher humidity there than over the *Oceanographer* area about 300 miles

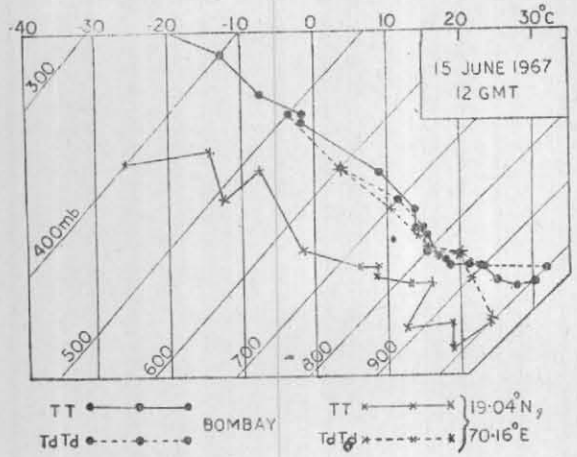

Fig. 2

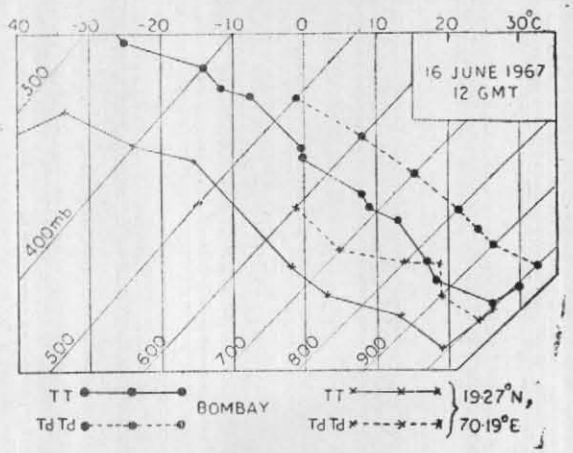

Fig. 3

westsouthwest; Bombay had 1 cm rain between the 13th and 14th mornings.

Isothermal layer with fall in humidity over *Oceanographer* area near 700 mb might be associated with subsidence in the less moist air, possibly due to divergence, there being a trough to its west as mentioned above.

Winds over the Konkan, Saurashtra and Kutch were mainly southerly at 850, 700 and 500 mb at 12 GMT of the 15th, thus showing the presence of a trough in the north and central Arabian Sea. The *Oceanographer* and Bombay data for 12 GMT of the 15th are given in Fig. 2. The remarks given for the 14th also apply broadly to the trajectory of the air on the 15th as well. Increase in humidity over the *Oceanographer* was possibly due to increase in cyclonic shear under the influence of the trough and, therefore, less divergence over the *Oceanographer* than on the previous day. High humidity over Bombay was due to the influence of the Ghats. In 24 hrs ending at 03 GMT of the 15th, widespread rain had fallen on the west coast south of 15°N; further north there was little rain. Nearly dry adiabatic lapse rates are noticed in lowest layers over the Bombay and *Oceanographer* areas. Bombay winds were northwesterly upto 900 mb at 12 GMT; over the *Oceanographer* area there were deflected trades upto about 950 mb as on the 14th. The meteorologist on board the *Oceanographer* has recorded that from the 13th to 15th June the monsoon was absent (presumably in terms of rainfall) over the area. This would show that although there were deflected trades in the surface layers, there was absence of any mechanism for considerable ascent of the moist air to give clouds and rain.

Between the 15th and 16th mornings rainfall extended north of 15°N and there was widespread rain over the coast south of 18°N. At 12 GMT of the 16th the trough was present over the northwest Arabian Sea and the adjoining central Arabian Sea; winds over the Konkan and Saurashtra coasts were under the influence of the trough. The 12 GMT Bombay and *Oceanographer* data for the 16th are given in Fig. 3. It is seen that between the 15th (Fig. 2) and the 16th, there was considerable warming and decrease in humidity at Bombay; the same tendency was also noticed between 12 GMT of the 15th and 00 GMT of the 16th as seen from the Bombay data. Thus the warming and decrease in humidity changes started after 12 GMT of the 15th and not after 00 GMT of the 16th. Over the *Oceanographer* area, the temperature had somewhat fallen when compared with the previous day's location data; the causes of the same are not clear. The differences between the dry bulb and dew point over the *Oceanographer* are comparable with those over Bombay. Warming and lower humidity might be due to divergence over the area, there being a trough to the west. There was probably the same air mass over both the locations. According to reports *Oceanographer* had showers for the first time between 0300 and 0530 GMT of the 16th at a position slightly east of the 12 GMT position; lines of *Cb* extended WSW to ENE according to reports and cloud mass thickened 500-700 miles off shore and parallel to the west coast.

Between 03 GMT of the 16th and 17th widespread rain had fallen on the coast south of 20°N (Dahanu). Rainfall had considerably increased between 16° and 19·5°N; this increase in

rain was due to release of winds from the grip of the trough in the northwest and central Arabian Sea which had moved northwestwards. Bombay winds which were SSE to S'ly upto 700 mb at 12 GMT of the 16th, got westerly component in those levels by the next morning.

The trough at the surface did not move appreciably between 03 and 12 GMT of the 17th but had weakened; in the upper air there was a trough off north Konkan-south Saurashtra upto about 500 mb. The Bombay and *Oceanographer* data for 12 GMT of the 17th are given in Fig. 4, the former being about 4° east of the latter. Temperature fell and humidity became 80 to 100 per cent both at Bombay and over the *Oceanographer* location, and cyclonic shear besides Ghats' influence over Bombay was responsible for the same; from the *Oceanographer's* report it appeared that the vessel was near the northern boundary of the maritime air mass. The air mass over the area had come from the south and east central Arabian Sea and not from the west, *i.e.*, Arabia side.

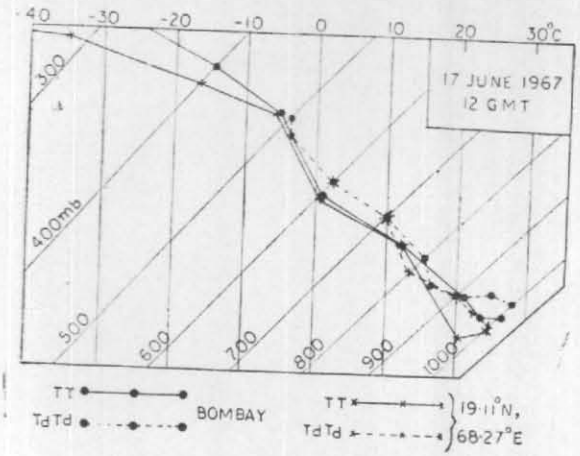

Fig. 4

By 03 GMT of the 18th, the trough had disappeared at the surface. Due to release of the winds and increase of westerly component, 2-9 cm of rain had fallen on the coast between 03 GMT of the 17th and 18th, there being 5 to 9 cm between 15° and 20°N (Panjim and Dahanu). Upper winds at Bombay and Veraval showed that at 12 GMT although there was no trough at the surface, there was a trough above at the entrance of and over the Gulf of Cambay. The Bombay and *Oceanographer* data for 12 GMT of the 18th are given in Fig. 5. Both Bombay and *Oceanographer* about 7° to the west had moist air. According to the *Oceanographer* weather diary the vessel although further west than on the previous day, was still near the northern boundary of the monsoon current; sea was rougher when compared with previous days and there was wind 18 to 24 kt with gusts to 30 kt in showers. This situation is typical of active monsoon conditions along the Konkan coast as judged from rainfall when there is moist air in all levels upto about 500 mb in the east, central and south Arabian Sea and there is no drier unstable air above the deflected trades as observed during the 1963 IIOE period.

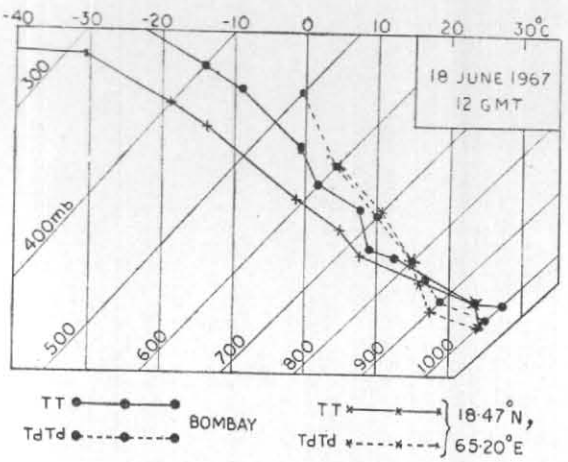

Fig. 5

Between 03 GMT of the 18th and 19th there was 1-8 cm rain between Calicut and Dahanu and 10 cm at Veraval. Heavy rain of 5 to 10 cm between Bombay and Veraval was due to the presence of the trough over the Gulf of Cambay area mentioned for the 18th evening. Ships' reports indicated a more southerly component developing in the winds and their strength decreasing in the Arabian Sea east of about 65°E. At 12 GMT of the 19th there was a trough over the Arabian Sea

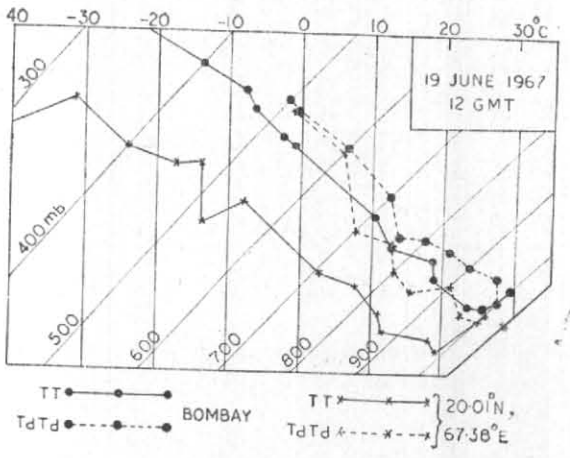

Fig. 6

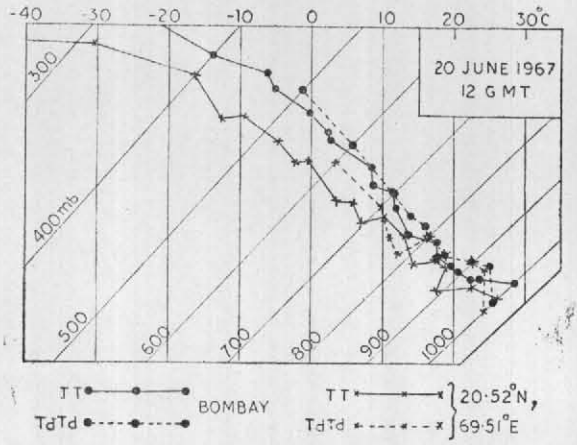

Fig. 7

north of 15°N; this was also shown by mainly easterly winds at Karachi and Jiwani at 850 and 700 mb; the trough at 500 mb was to the south of the 700 mb position. Winds at Masirah and Salalah were mainly northerly from 850 to 500 mb. The data of *Oceanographer* and Bombay for 12 GMT of the 19th are given in Fig. 6. Both *Oceanographer* and Bombay were in the same air mass, but relative humidity decreased considerably more over the former than the latter. *Oceanographer* was near the western end of the trough but not in the continental air as the lapse rate was near saturation adiabatic; Bombay was near the eastern end towards the Ghats. Temperatures rose over Bombay upto 600 mb when compared with those on the previous day because although between the 18th and 19th mornings Bombay had 8 cm (Dahanu 6 cm) rain there was practically no rain there (Dahanu 1 cm) between the 19th and 20th mornings; Bombay would also be near the divergence area in the moist air.

The trough mentioned for the 19th evening, had intensified and moved somewhat northwestwards and lay over the north Arabian Sea and the adjoining central Arabian Sea on the 20th. Between the 19th and 20th the monsoon had been strong over Saurashtra and south Gujarat and moderate on the west coast between Calicut and Dahanu. The *Oceanographer* (off Veraval) and Bombay data for 12 GMT of the 20th given in Fig. 7 show increased moisture and there is general agreement between the two ascents.

Between the 20th and 21st mornings 2 to 9 cm rain had fallen on the coast between Calicut and Dwarka. The trough, probably a depression, in the north Arabian Sea had moved somewhat northwestwards and lay off Muscat-Masirah in the northwest Arabian Sea. After the 19th winds over the Arabian coast backed to N to NW and the continental air from the Arabian Peninsula began to flow over the west Arabian Sea above the surface layers. From the 06 GMT *Oceanographer* data and 00 and 12 GMT Bombay data for the 21st given in Fig. 8, it is seen that there was a similar trend about decrease in humidity above 800 mb both over the *Oceanographer* location for 06 GMT and at Bombay for 12 GMT. The decrease in humidity since the previous day was due to decrease in cyclonic shear of winds, the disturbance having moved away. It is, however, unlikely that the air over both the locations was continental air from Arabia, which was probably only to their west to northwest as seen from flow patterns for 12 GMT of the 21st; air over *Oceanographer* had nearly saturation adiabatic lapse above 900 mb.

Rama's (1969) radon results for the period 13 to 22 June 1967 over the *Oceanographer* locations off Saurashtra-Konkan at deck-level showed that the radon content varied from 16-41dpm/m^3. Considering these results with reference to the synoptic charts and the above discussion they would show presence at deck-level of the maritime air from across the equator *mixed horizontally* with the continental air from west and north Arabian Sea side in varying proportions over the area. Rama's conclusion that higher radon values were due to *vertical mixing* of the lower maritime air with the upper drier continental air is *not* tenable as above the maritime or deflected trades air mass there was less moist air with nearly saturation adiabatic lapse, having its origin in the south Arabian Sea or even further south (Rao and Desai 1970).

It will not be out of place to mention here that Rama (1970) has given in Fig. 1 of his paper mean values of radon concentration in different five-degree squares over the Arabian Sea and the equatorial western Indian Ocean based on observations during July-August-September given in

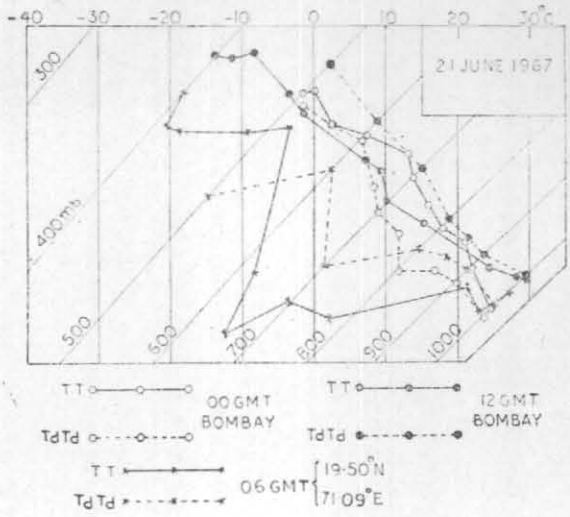

Fig. 8

Rama's two earlier papers (1968, 1969). If mean values for each five-degree square from June values given in Fig. 1 of his paper (1969) are computed and compared with the mean value in the same five-degree square for July-August-September (Rama 1970), it is seen that they are higher than the former in four and lower in two cases. For two five-degree squares between Longs. 70° and 75° E and Lats. 20° and 25°N and 10° and 15° N there are no mean values in Rama's Fig. 1 (1970) for July-August-September; mean values of 34 and 10 dpm/m³ respectively for the same squares are, however, available for June. Further, the June mean values in five-degree squares between Lats. 15° and 20°N and Longs. 65° and 70°E and 70° and 75° E are 17 and 18 dpm/m³ respectively for July-August-September and 25 and 11 dpm/m³ respectively for June; thus Rama's conclusion in his paper (1970) that radon concentration *increases* towards the west coast is *not* supported by his June results; Desai (1969) has discussed the conditions under which higher values of radon concentration might be observed near the west coast of the Peninsula than further west. Again for the five-degree squares between Lats. 10° and 15°N and Longs. 65° and 70°E and 70° and 75°E the radon concentration values are 18 dpm/m³ and 'no data' respectively for July-August-September and 11 and 10 dpm/m³ respectively for June, thus showing decrease in radon concentrations towards the coast during June. In addition for different five-degree squares whether for July-August-September or June the total number of observations available for computation of the mean value are quite different and the difference between the lowest and highest values of radon concentration in each square is generally not small. Under the circumstances, it would appear that the mean values of radon concentration for each five-degree square whether for June or June to September or July to September *cannot* be meaningfully utilised either for indentifying air masses or for determining the the percentage of different air mass by comparing them with actual values on any particular day for the same area. The actual radon concentration values have to be interpreted with reference to the prevailing synoptic conditions and the trajectory followed previously by the air mass present over any area (Desai 1969, Rao and Desai 1970).

The following conclusions can be drawn from the above discussion of the data for *Oceanographer* locations and Bombay :

(*a*) The south Arabian Sea air mass had nearly saturated adiabatic lapse rate but had not very high humidity. This air is carried over to east Arabian Sea under favourable conditions.

(*b*) When the south Arabian Sea air mass is subjected to cyclonic shear over a wide area, its humidity increases ; its temperature is lower than that of the air mass it replaces due to its origin being in more southerly latitudes.

(*c*) As much of the monsoon rainfall is from cumulus and there are gaps between clouds where there might be even gentle subsidence, wide variation in air mass characteristics may be noticed based on the area sampled.

(*d*) Continental air from Arabia or Pakistan did not reach the east and central Arabian Sea to the east of 65° E.

(*e*) High radon values from the 13th to 22nd June off Saurashtra-Konkan were due to the fact that the radon-poor deflected trades air had got mixed to some extent with the continental air from northeast Africa and Arabia. There was no drier continental air in the upper levels as the soundings showed presence of less moist air with nearly saturation adiabatic lapse.

3. Concluding remarks

It will be clear from the above discussions that the *Oceanographer* period data confirm the ideas prevailing prior to 1963, *i.e.*, the depth of the moist current over the east and south Arabian Sea was about 6.0 km; the air had unstable lapse in the surface layers and moist adiabatic lapse above with or without an inversion between the two air masses. Some of the data collected in 1964 during the IIOE period also showed similar conditions (Desai 1968) although not so pronounced. The data collected during 1963 showed presence of drier air with unstable lapse above the deflected trades 1.0 to 1.5 km deep with an inversion between the two air masses and little rain to the west of 65°E; the inversion weakened, its base got raised and depth decreased and cloudiness and rain increased as one approached the west coast south of 20° N and over the west coast, there was no inversion and the depth of the moist current became about 6.0 km, there being *Cu* and *Cb* clouds and considerable precipitation over the coast and the Western Ghats (Desai 1966, 1967, 1968). Fig. 14 of Findlater (1969) would also show possibility of presence of drier unstable air above the lower layer of deflected trades over the west and north Arabian Sea. It would appear that interpretation of radon results is not easy as pure air masses ordinarily do not exist over the Arabian Sea, and to utilise deck-level results to get idea about air masses present in the upper levels is not justified as soundings may not support the same as in the present case.

Acknowledgement

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