Radon Daughter's Radioactivity Levels over the Arabian Sea as Indicators of Air Mass Mixing

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ABSTRACT

Measurements on radon daughter's activities over the Arabian Sea were carried out during the period 19 May to 9 July, 1973, under the joint Indo-USSR MONEX-73 project. The data were collected on board the ships of the Indian Navy cruising between 19–21°N within longitudes 60–73°E and the two USSR vessels *Okean* and *Prilive* cruising between latitudes 0–10°N and 10–18°N, respectively. The results show that there is a significant increase in radon daughter's activity at about 19–21°N, the average level being of the order of about 8 pCi m^{-3} as compared to 1–2 pCi m^{-3} at lower latitudes. This is explained, on the basis of synoptic charts and available sounding data, as being due to the normal wind and pressure pattern prevailing during the monsoon months which results in the transport of continental air from Arabia and Pakistan and its mixing with the maritime monsoon air mass of Southern Hemispheric origin. The significant increase in radon activity on some days of the cruise was mainly due either to the existence of disturbances like depressions, cyclonic storms, etc., over the north Arabian sea, or to the passage of western disturbances at relatively lower latitudes (along ~25°N) and their associated circulation patterns. These phenomena favor significant transport of continental air from the north and west. The mixing of this air mass with air masses of low radon concentrations results in increasing the average radon levels from 1 to 8 pCi m^{-3}.

1. Introduction

The variation in the concentrations of radon (^{222}Rn, half-life 3.8 days) and its short-lived daughters ^{218}Po (RaA, half-life 3.05 min), ^{214}Pb (RaB, half-life 26.8 min) and ^{214}Bi (RaC, half-life 19.7 min) over oceanic areas far from continents has been used by several investigators to study the nature of air masses arriving at any location (Lambert, 1963; Lambert *et al.*, 1970, 1972; Fontan *et al.*, 1963; Vilenskii *et al.*, 1967; Rama, 1970; Wilkniss *et al.*, 1974). The fairly long half-life of radon makes it a suitable tracer for such studies over vast areas of the ocean. The radon and daughter activity levels in the oceanic air are around 1 pCi per cubic meter of air (Lambert, 1963; Lambert *et al.*, 1972; Vilenskii, 1967; Rama, 1970; Rangarajan *et al.*, 1974a; Wilkniss *et al.*, 1974). The levels over land could vary from 20 to 400 pCi m^{-3} or more (Lambert *et al.*, 1970; Rangarajan *et al.*, 1974b). This large difference is due to the negligibly small emanation of radon over the oceans in comparison to land areas (Lambert *et al.*, 1972). Hence increase in radon activity levels over oceans would indicate the presence of air with a recent trajectory over land areas. This provides a method of detecting the presence of continental air at the location of interest.

During the MONEX-73 experiment carried out from 16 May 1973 to 9 July, 1973, radon daughter's activities at deck level were measured over the Arabian sea (Rangarajan *et al.*, 1974b). These measurements were carried out on the two USSR vessels *Okean* and *Prilive* which were on cruise during the whole period and on Indian Navy ships which carried out three sorties each of about 5 days duration. The results of these measurements along with the relevant synoptic charts were used for studying the mixing of maritime and continental air masses in the north Arabian sea. The measurements reported here are recorded simultaneously from three vessels and thus give a better idea of the radon behavior with reference to synoptic factors as compared to measurements on a single ship where the synoptic factors are bound to vary during the period of the cruise.

2. Experimental techniques

The system used for measuring short-lived radon daughters has already been described in detail elsewhere (Rangarajan *et al.*, 1974a, b). Briefly, it consists of a blower drawing air through a Hollingsworth and Vose H-70 filter of 2 inch diameter at flow rates of 50–100 liters per minute. The collected filter is counted

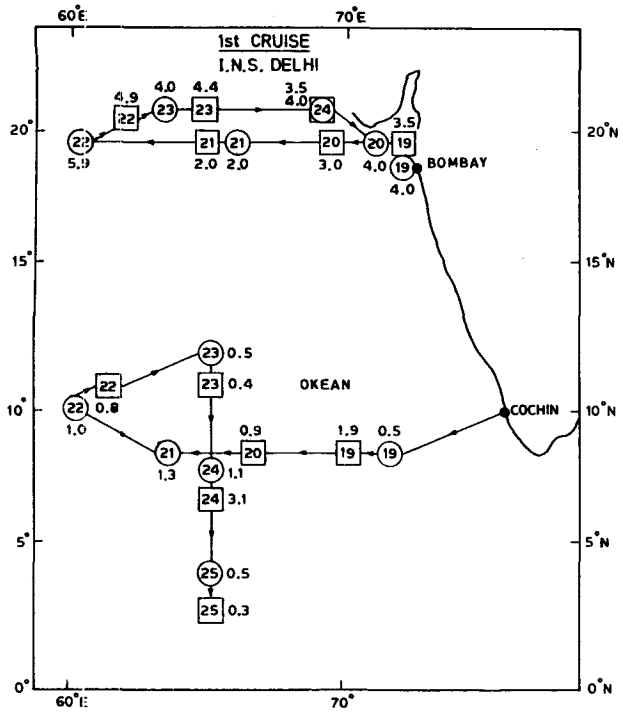

FIG. 1. Radon daughter's activity in the Arabian Sea region during the period 19–25 May 1973. Location of ships on dates (numbers inside) are indicated by circles (morning) and squares (afternoon). Activities (numbers by the side) are in picocuries per cubic meter of air.

in a ZnS scintillator for its alpha activity from which the radon daughter levels are estimated as described earlier (Rangarajan *et al.*, 1974b). The radon daughter's activities are likely to be an accurate index of radon levels as radon is generally in radioactive equilibrium with its daughters over the oceans (Lambert, 1963).

The cruises of the Indian Navy ships were between 19°N and 21°N while the *Prilive* and *Okean* operated between 10°N and 18°N and between 0° and 10°N, respectively. Since radon levels over equatorial regions are very low, the *Okean* results have counting errors of the order of 50–100% as compared to 10% and 50% for the Indian navy ship and *Prilive*, respectively. Hence the *Okean* data can only be taken as a general indicator of the order of activity prevailing in these regions.

3. Results

Figs. 1–3 give the daily radon daughter's activities and ship positions for the different cruises of the Indian Navy (IN) and USSR ships during the Monex-73 period. Figs. 4 and 5 give the complete cruise data for *Prilive* and *Okean*, respectively. The latitudinal variation of the average radon activity levels for the period 19 May to 9 July is shown in Fig. 6. For comparison, the averages of the values measured during June and July at the coastal stations of Bombay (19°N) and Thumba (8°N) are also included in the figure. The Bombay values refer to measurements carried out during the period 1968–72 while Thumba values are for the period 1971–72. (The results given in Fig. 6 are the averages for the complete cruises of each of the three ships). Table 1 gives the average radon daughter levels for the individual periods of the cruises along with the latitudinal and longitudinal spans of the IN and USSR vessels. Simultaneous measurements are available from all the three ships only during the period of the last cruise, no data being available from

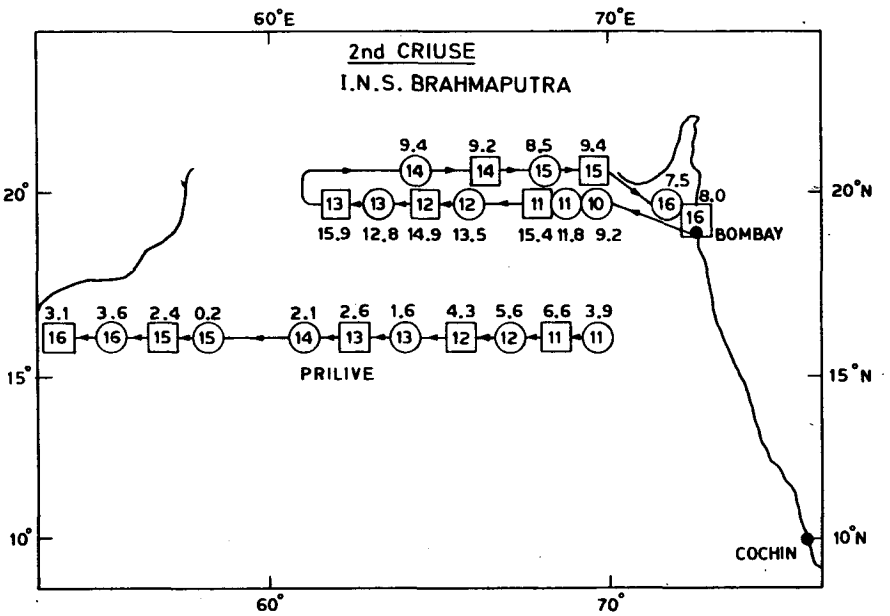

FIG. 2. As in Fig. 1 except for 10–16 June 1973.

TABLE 1. Average radon daughter's activities during the three cruises of the Indian Navy Ships*

Period 1973	Indian Navy Ships Location Latitude	Longitude	Average RaB activity	*Prilive* Location Latitude	Longitude	Average RaB activity	*Okean* Location Latitude	Longitude	Average RaB activity
19 May to 25 May	19°N to 20°N	73°E to 60°E	M 4.0 A 3.6				9°N to 12°N	75°E to 60°E	M 0.9 A 1.4
10 June to 16 June	19°N to 20°N	73°E to 61°E	M 10.6 A 11.7	16°N to 16°N	72°E to 53°E	M 2.8 A 3.8			
3 July to 8 July	19°N to 20°N	73°E to 62°E	M 10.1 A 10.9	18°N to 12°N	73°E to 62°E	M 1.6 A 1.8	0° to 9°N	60°E to 73°E	M 2.3 A 3.4
Average for the total period of the three cruises			M 8.2 A 8.8			M 2.2 A 2.7			M 1.5 A 2.2

M, Morning values; A, Afternoon values.
* Activity in picocuries per cubic meter of air.

Prilive for the first cruise and from *Okean* for the second. Table 1 also gives the total average values from all ships for the complete period of the three cruises of the IN ships. The clear increase in levels in the IN ship data over the values from *Prilive* and *Okean* is seen in all these data. The same trend is also indicated in the coastal data from Bombay and Thumba.

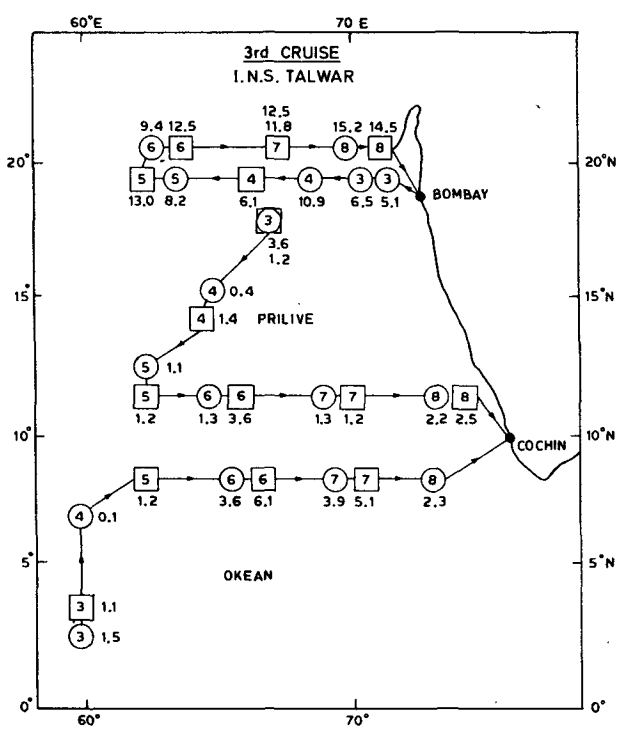

FIG. 3. As in Fig. 1 except for 3–8 July 1973.

4. Discussion of synoptic features and radon levels

The synoptic features responsible for the increase in radon levels at 20°N during the three periods will now be described. Since radon decreases rapidly with height, the increase in radon activity will be discussed in terms of advective effects only, neglecting vertical mixing.

a. 19–25 May 1973

The weather was seasonal over the Arabian Sea except for the advancement of the southwest monsoon over the south Arabian Sea under the influence of an upper air cyclonic circulation over the southwest peninsula and adjoining Lakshadweep area. The low radon values recorded on the *Okean* indicate the presence of monsoon air which is maritime and of Southern Hemispheric origin. The IN ship data show higher radon values due to the presence of continental air as shown by the prevailing isobaric pattern (Fig. 7).

b. 10–16 June 1973

A cyclonic storm lay over the northwest Arabian Sea near 22.0°N, 63.0°E on the morning of the 10th; 24 h later it was centered near 22.0°N, 62.0°E (Fig. 8). It then moved southwest but weakened into a depression and was centered at about 250 km east of Masirah on the morning of the 12th, and dissipated off the Oman coast on the 13th. The IN ship *Brahmaputra* was cruising in the rear of the cyclonic storm over the west Arabian Sea. The general isobaric pattern prevailing over the Arabian Sea during this period suggested a marked transport of continental air from Arabia and mixing with monsoon air. The mixed air mass might have been transported to the rear of the storm field

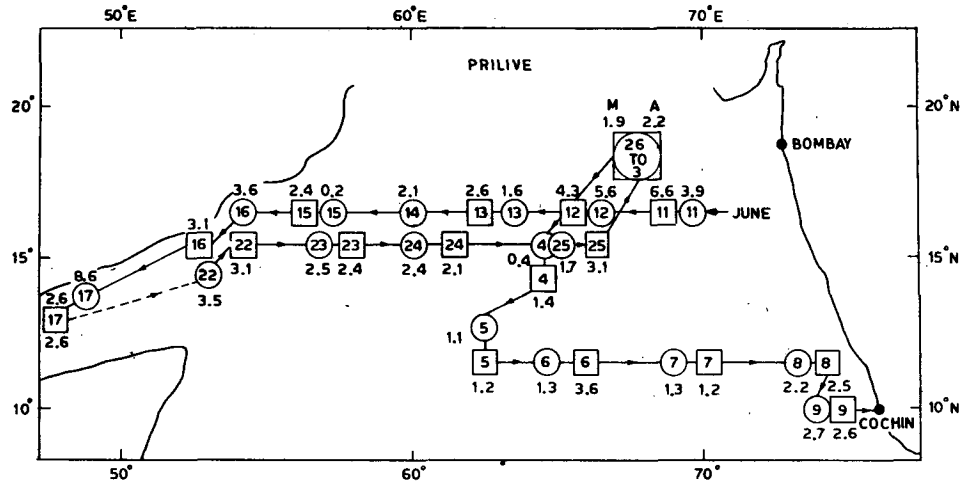

FIG. 4. As in Fig. 1 except for 11 June–9 July 1973. Measurements on *Prilive*. (Average values given for 26 June–3 July when ship was stationary at 18°N, 67°E.)

and hence is probably responsible for the high values of radon (12–15 pCi m^{-3}) recorded during the period 12–13 June near 20°N (Fig. 2). The radon values recorded on board *Prilive* along latitude 16°N are also somewhat high because of the mixing of the continental air with the monsoon air of maritime type.

On the return journey of the naval ship along latitude 20°N, radon values continued to remain fairly high (~9 pCi m^{-3}). During this period an active western disturbance moved across Punjab and steep pressure gradients continued to prevail over Gujarat State (northwest India) and the adjoining sea area until the end of the cruise period (Fig. 9). The significant transport of continental air from Arabia due to this pressure pattern and its probable mixing with the monsoon air already present over this area may be responsible for the high radon values.

c. 3–8 July 1973

In the trough of low pressure that lay off the North Maharashtra-South Gujarat coast, a low pressure area

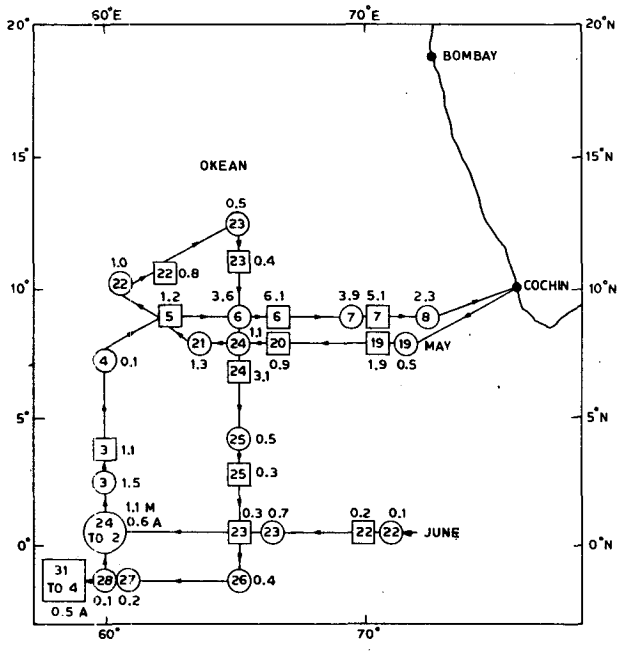

FIG. 5. As in Fig. 1 except for 19 May–9 July 1973. Average values given for 24 June–3 July when ship was stationary at 0°, 60° E. (No data for the period 5 June–21 June.)

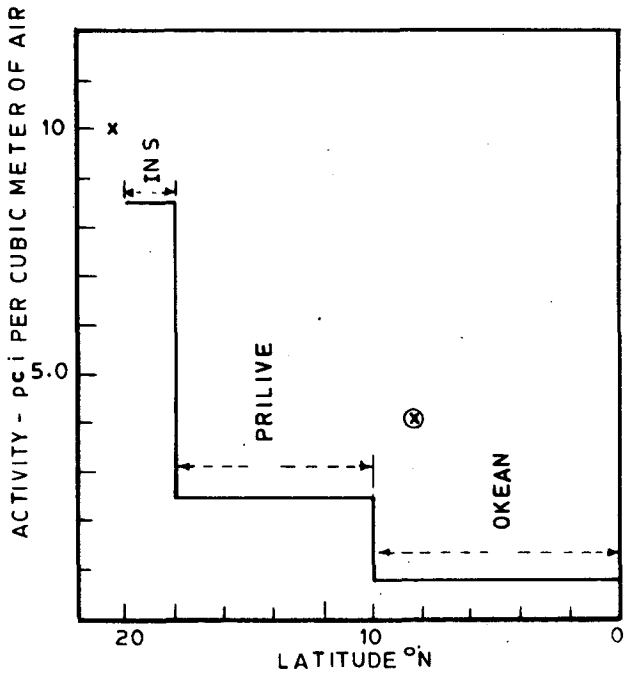

FIG. 6. Average radon daughter's activities in the Arabian Sea as measured by Indian Navy (IN) and U.S.S.R. ships (*Prilive* and *Okean*) during MONEX-73, and at Bombay (×) and Thumba (⊗).

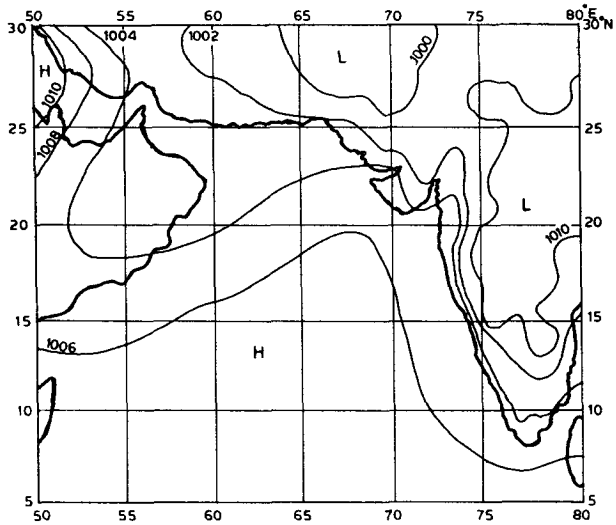

FIG. 7. Weather chart at 1200 GMT 20 May 1973.

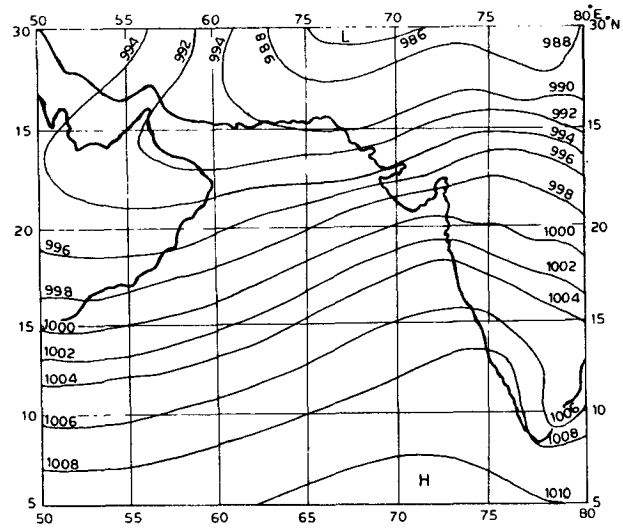

FIG. 9. Weather chart at 0300 GMT 15 June 1973.

developed over south Gujarat and the east central Arabian sea on the 6th. It concentrated into a depression on the morning of the 7th and was centered near 20.5°N, 70.5°E. It lay over Saurasotra and the adjoining northeast Arabian sea 24 h later (Fig. 10). Moving northwest it weakened into a low pressure area over Kutch on the morning of the 9th. Hence the radon values were relatively high from 6–8 July when the IN ship was on its return cruise along 20°N. These pressure patterns resulted in a large-scale transport of continental air from northwest India and Pakistan which mixed with the monsoon air.

The radon values were also fairly high on some days during the earlier part of the same cruise. It may be seen from the normal isobaric pattern for the month of July published by the India Meteorological Department (Fig. 11) that the mixing of the continental air from Arabia and the monsoon air from the Southern Hemisphere occurs off the Arabian coast and the mixed air mass is being transported toward the north and east Arabian sea by the prevailing strong southwesterlies, resulting in the high radon values mentioned above.

5. Conclusions

The radon daughter's activity levels presented here appear to show that up to about 18°N there is no significant increase in activity above the equatorial values. It is only at 20°N and above that some admixture of air with higher radon levels generally seems to take place, a result which is due either to the seasonal

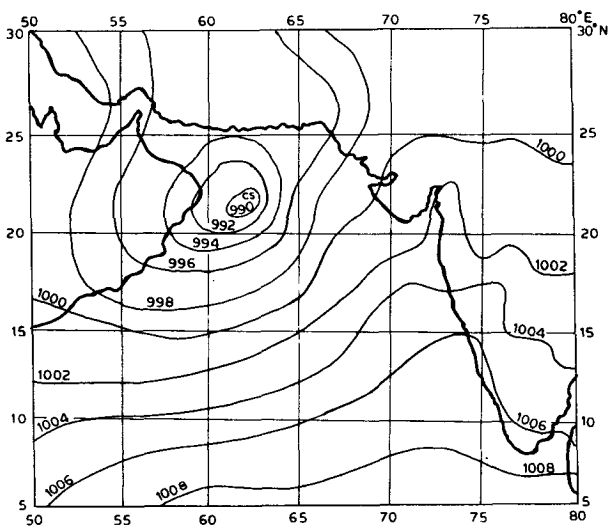

FIG. 8. Weather chart at 0300 GMT 11 June 1973.

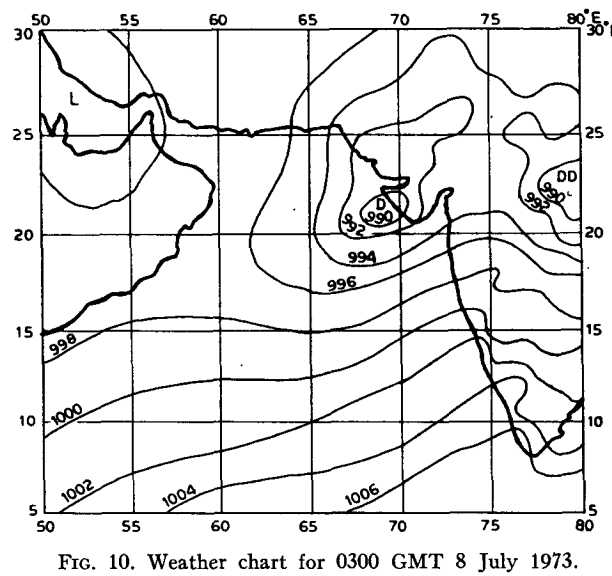

FIG. 10. Weather chart for 0300 GMT 8 July 1973. (D: depression, DD: deep depression).

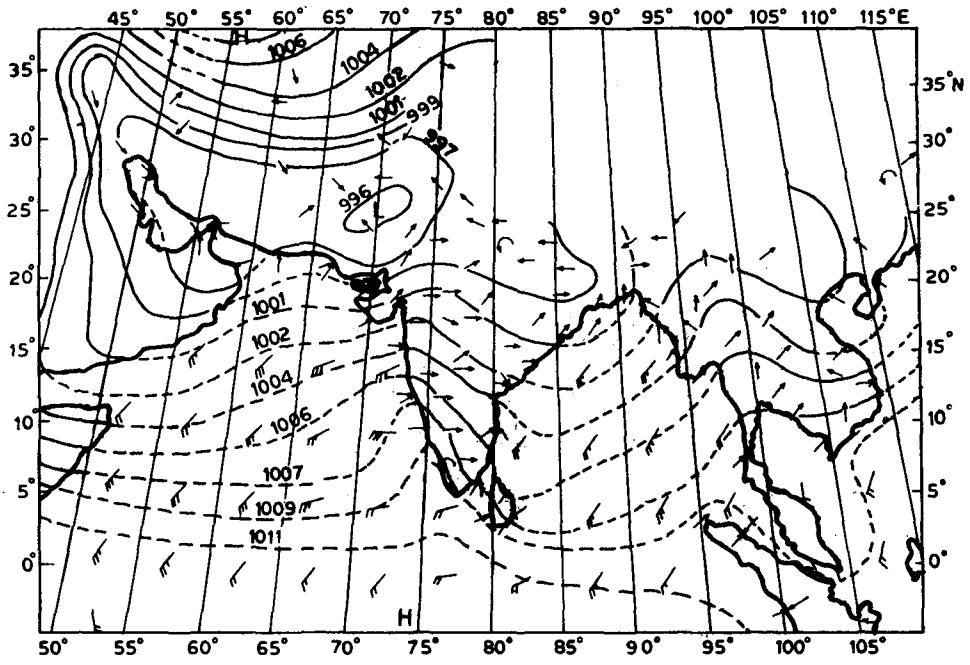

FIG. 11. Mean pressure and prevailing wind during the month of July.

pressure and associated wind pattern (Figs. 7 and 11) or to the existence of cyclonic storms or depressions over the north Arabian sea (Figs. 8, 10) and the traverse of western disturbances at relatively lower latitudes (Fig. 9). All these result in higher radon levels. This appears to confirm the fission product and other data (Gopalakrishnan *et al.*, 1972; Rao *et al.*, 1970; Rangarajan *et al.*, 1975) regarding the significant presence of Southern Hemisphere air during monsoon, at least up to 20°N. The component of continental air up to 18°N seems to be only about 20–30% of that prevailing north of this latitude. Also, the low levels of radon at equatorial latitudes (Fig. 5) rule out the possibility of the "equatorial westerlies" having a continental (African) source (Godbole *et al.*, 1975). These are likely to be the southeast trades moving eastward or northeastward after crossing the equator.

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