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Studies on the movement of radioactive debris across the equator

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ABSTRACT. Short-lived fission products from the French tests of Polynesia (22°S) carried out during the summer period 1966-1971 have indicated a travel time of 15– 21 days to the west coast of India. It has also been noted that the levels of activity on the west coast of India are an order of magnitude higher than at other areas of the northern hemisphere. Comparison with the activity from the Chinese tests of northern hemisphere (40°N) shows that the levels on the west coast of India are comparable to other areas of the northern hemisphere. From these data it can be concluded that there is a heavy influx of air masses across the equator in the west Indian Ocean by way of the monsoon. An idea of the magnitude of this influx can be had by comparing the levels at Bombay and Thumba with those at Pretoria. It is also concluded from these studies that the source of the summer monsoon should be to the south of the equator.

1. Introduction

The source region of the Indian summer monsoon can be studied by the measurement of the radioactive debris released in nuclear weapon tests. As the classical view of the monsoon describes the low level current over India as the southeast trades of the southern hemisphere changing direction after crossing the equator, one can expect the radioactivity from nuclear tests in the southern hemisphere to cross-over to India by way of the monsoon (Vohra *et al.* 1958). There were U.K. tests in Maralinga, Australia, as early as 1957, but debris from these test could not be detected over India due to the absence of high capacity samplers and refined isotopic identification methods at that time. However, even before the advent of the recent French tests, trans-equatorial mixing had been noted from measurements on several trace substances. Junge (1962), after a detailed examination of the ozone data, attributed the differences in ozone variatons at Ahmedabad in comparison to the more northerly stations to the monsoon current with southern hemispheric air. He also drew attention in this connection, to the importance of investigations on inter-hemispheric mixing in the Indian Ocean region. On the basis of measurements carried out in India, the presence of the monsoon current with southern hemispheric air having lower levels of stratospheric fallout, was considered to be responsible for certain differences in the seasonal variation of Cs^{137} in peninsular India compared to that in the extreme northwest (Rangarajan *et al.* 1968).

During the past decade, several investigators have detected trace quantities of fission products from tropospheric fallout due to tests carried out in the other hemisphere (Collins 1961; Mc Naughton and Woodward 1961; Lockhart *et al.* 1961; Lambert 1963; Cambray *et al.* 1962,1966 Woodwards 1966; Van As and Basson 1968); However, these measurements were not related to specific regions of exchange or a particular mode of transport across the equator within the troposphere. Also, collection of half-monthly or monthly samples as in some of the above measurements, makes the calculation of travel times and paths difficult.

The French tests of Polynesia commencing from July 1966 released tropospheric fallout into the southern hemisphere which could be used in studying the movement of airmasses across the equator. The debris from 1968 series particularly, have been detected by several investigators in the northern hemisphere (Cambray *et al.* 1968; Gustafson *et al.* 1968; Thomas *et al.* 1969; Palmer 1969; Sotobayashi *et al.* 1969; Telegadas 1972).

The first really significant evidence of massive inter-hemispheric mixing of southern hemispheric air by way of the Indian summer monsoon was available in early August 1966 when a sharp increase in Zr^{95} levels were noted by us at Bombay. As the increase was too delayed to be due to the debris from the Chinese test of 14 May 1966, the increase was attributed to the travel of French test debris by way of the summer monsoon. This was repeatedly confirmed by measurement of radioactivity from the French

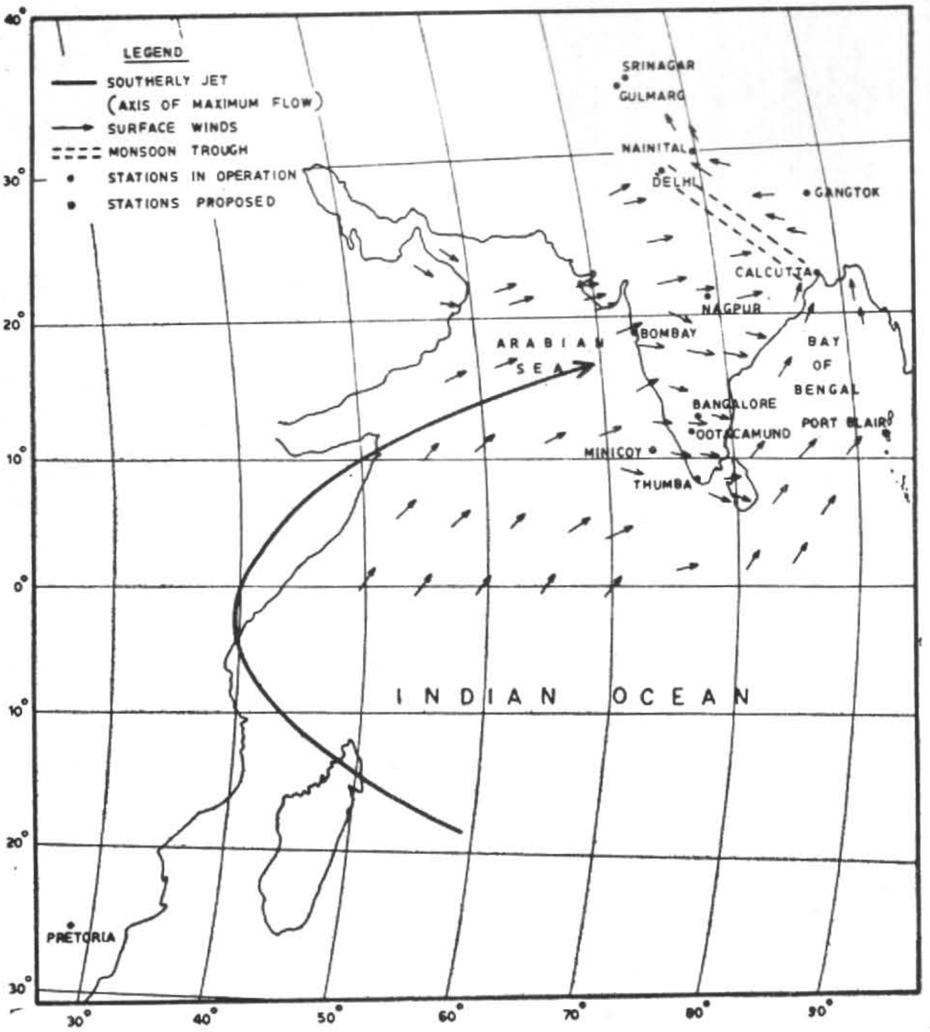


Fig. 1. Location of fallout monitoring stations in India and mean flow (0—1 km) during summer monsoon (July)

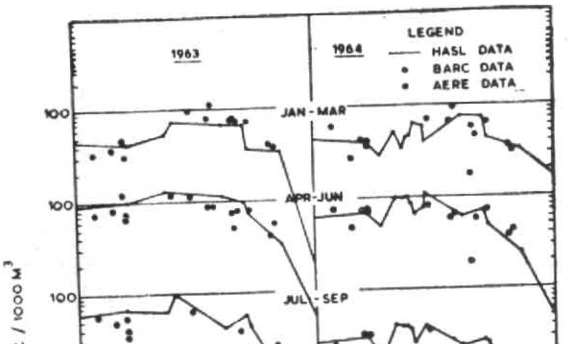


Fig. 2. Latitudinal variation of Cs^{137} in surface air (quaterly averages) during 1963 & 1964

TABLE 1

Dates of first detection of French nuclear test debris in aircraft swipe samples (Nandi-Sydney-Bombay flights)

Test date	First detection on
18 Jul 1966	22 Jul 1966
11 Sep 1966	22 Sep 1966
5 Jun 1967	14 Jun 1967
2 Jul 1967	5 Jul 1967
7 Jul 1968	17 Jul 1968
15 Jul 1968	7 Aug 1968
24 Aug 1968	4 Sep 1968
8 Sep 1968	18 Sep 1968
22 May 1970	30 May 1970
30 May 1970	17 Jun 1970
25 Jun 1970	8 Jul 1970
3 Jul 1970	11 July 1970
6 Aug 1970	26 Aug 1970
5 Jun 1971	16 Jun 1971

tests of 1967, 1968, 1970 and 1971. Most of these tests were during the summer period. A comparative study of the transport times and levels of activity between the French test series and the Chinese tests of the northern hemisphere

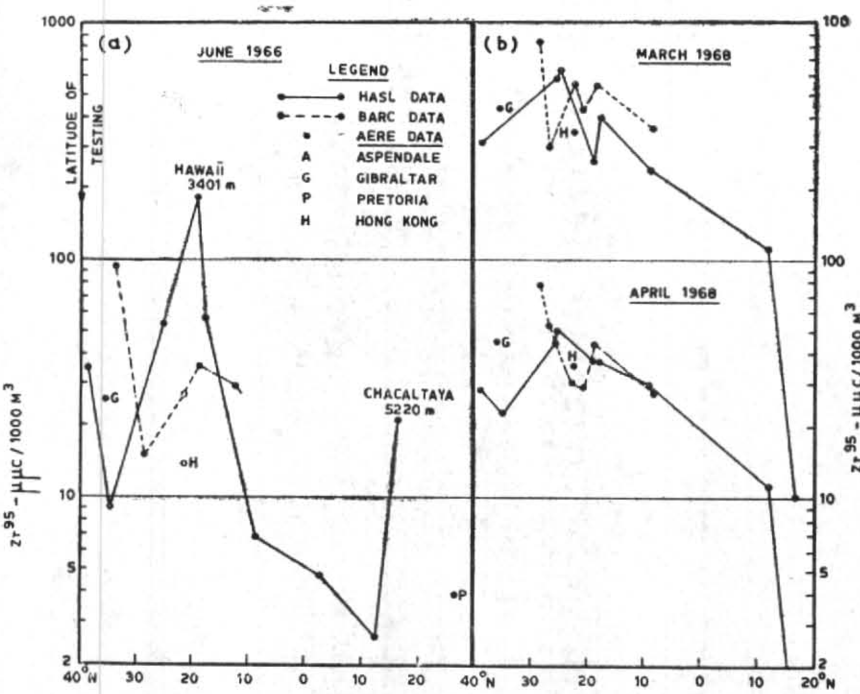


Fig. 3. Latitudinal variation of Zr^{95} in surface air during (a) June 1966, and (b) March & April 1968

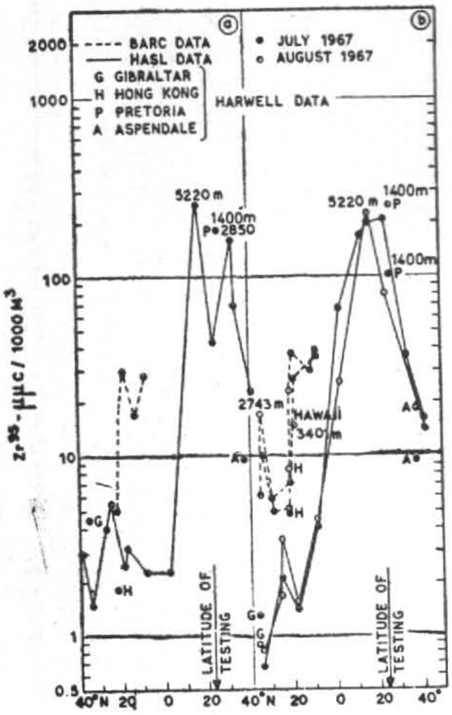
indicate massive transfer of southern hemispheric air to the west coast of India. It is important to stress here the relevance of the measurements carried out here as compared to other evidences of inter-hemispheric mixing mentioned above. The significantly higher levels on the two west coast stations compared to other global measurements of similar frequency, where available, made it possible to definitely conclude that the west coast was situated favourably to receive southern hemispheric debris and this could only be by the summer monsoon. A summary of these data is presented in this paper.

2. Observations

The data used in these studies are the concentrations of fission products, mostly Ba^{140} (half-life 12.8 days) and Zr^{95} (half-life 65 days). The use of short-lived fission products elimimate the interference from the background activity of stratospheric fallout. The activities are estimated by collecting the atmospheric particulates on efficient filters using a suitable suction device at the stations shown in Fig. 1. The activities are then estimated by gamma spectroscopic methods (Rangarajan *et al.* 1973). The sampling volume at Bombay and presently at Thumba (3000 m^3) are such that it is possible to measure Zr^{95} and Ba^{140} in daily or weekly collections. At other stations of the network sampling volumes are adequate only for monthly measurements.

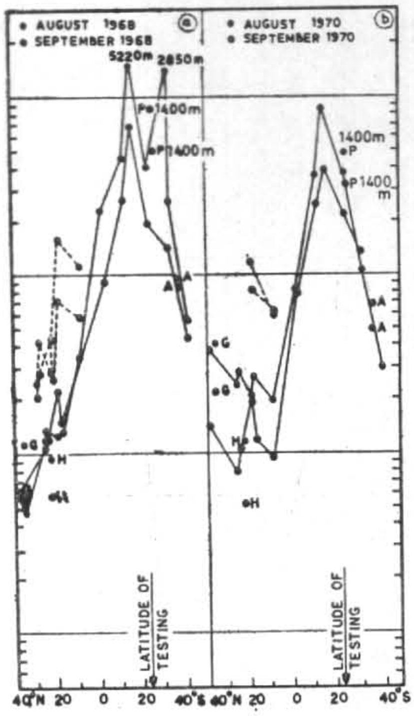
As a preliminary for the comparisons to follow Figs. 2 and 3 show the variations in radioactivity from stratospheric fallout and fallout from the Chinese tests of the northern hemisphere. Here our data has been compared with the global measurements carried out by U. S. and U. K. Generally, close agreement is noted in Fig. 2 between the levels in Indian stations and the values at the other stations. However, there is a slight reduction in levels in the Indian stations compared to the U. S. data during the period July-August. This was attributed to the prevalence of monsoon carrying southern hemispheric air which had less stratospheric fallout at that time (1963-64). In other meridians there was no such intrusion of southern hemispheric air (Rangarajan *et al.* 1968).

Fig. 3(b) gives Zr^{95} of stratospheric origin a few months prior to the commencement of the French tests. Again there is a close agreement between measurements carried out by various laboratories, the values differing by less than ± 50 per cent along any latitude. Fig. 3(a) shows that in the case of the Chinese test, inspite of a rather wide scatter in the data, the Indian values show agreement with other meridians (*see* also Fig. 7). Thus the data presented in Figs. 2 and 3 indicate the difference between a stratospheric and a tropospheric source, both in the northern hemisphere in contrast to the variation of a source in the southern hemisphere as illustrated in the following figures.



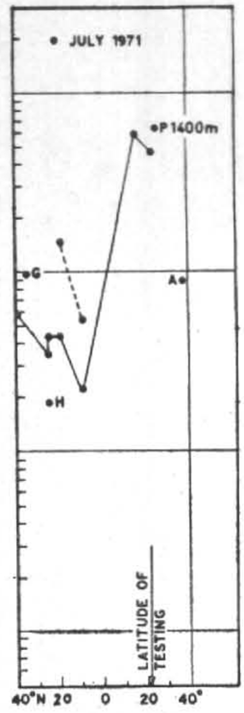
(a) Aug 1966 (b) Jul-Aug 1967

Fig. 4



(a) Aug-Sep 1968 (b) Aug-Sep 1970

Fig. 5



July 1971

Fig. 6

Latitudinal variation of Zr^{95} activity in surface air

Figs. 4-6 give the monthly concentrations of Zr^{95} at various stations all over the world after the several French test series of 1966-1971. Fig. 7 gives similar data for Ba^{140}. Figs. 8 and 9 give the variation in concentrations of Ba^{140} against days after explosion for the Chinese test of December 1967 and the French test of 1968, 1970 and 1971. The U. S. Health and Safety Laboratory does not report Ba^{140} data but some data from BNWL, USA (Thomas *et al.* 1969) are included in Fig. 8.

The basic features described above are also evident if ratios of selected pairs of isotopes, *viz.*, Ba^{140}/Zr^{95} or Zr^{95}/Cs^{137} are examined rather than individual concentrations (Rangarajan *et al.* 1968, 1970; Gopalakrishnan 1972). While considering ratios, possible errors due to difference in inter-laboratory calibrations, sampling errors, etc are likely to be reduced.

The data presented in the above figures bring out the following : (*a*) the levels of activity are significantly higher (upto an order of magnitude) at the Indian stations on the west coast (Bombay and Thumba) compared to other stations in the northern hemisphere (Figs. 4-7). This is evident in Fig. 7 in the large difference in activity between Bombay and Hong Kong at similar latitudes. For a northern hemispheric source there is agreement among all the stations; (*b*) the debris from the French test reach Bombay and Thumba in about 16-22 days while it takes much longer for other stations (Fig. 8 and 9) in the northern hemisphere. Again, a comparison with the Chinese test data (Fig. 8) shows little difference in travel times to Bombay or Hong Kong. These features can be related to the meteorology of the Indian Ocean area.

3. Discussion

The data discussed above can be explained on the basis of the 'Somali' jet which crosses the equator near the African coast and arrives as westerly winds on the west coast of India. The jet velocities are maximum at about 40°E, maximum speeds of 50 to 100 kt occurring intermittently in the layer 600 to 2400 m (Findlater 1969 a). These jet streams have been connected with the jet off the coast of Somalia and the low level westerly jet stream over India to form a wind system bringing in air of southern hemispheric origin over India in significant quantities (Rao and Desai 1969). The approximate path of this jet is indicated in Fig. 1. Saha (1970) from

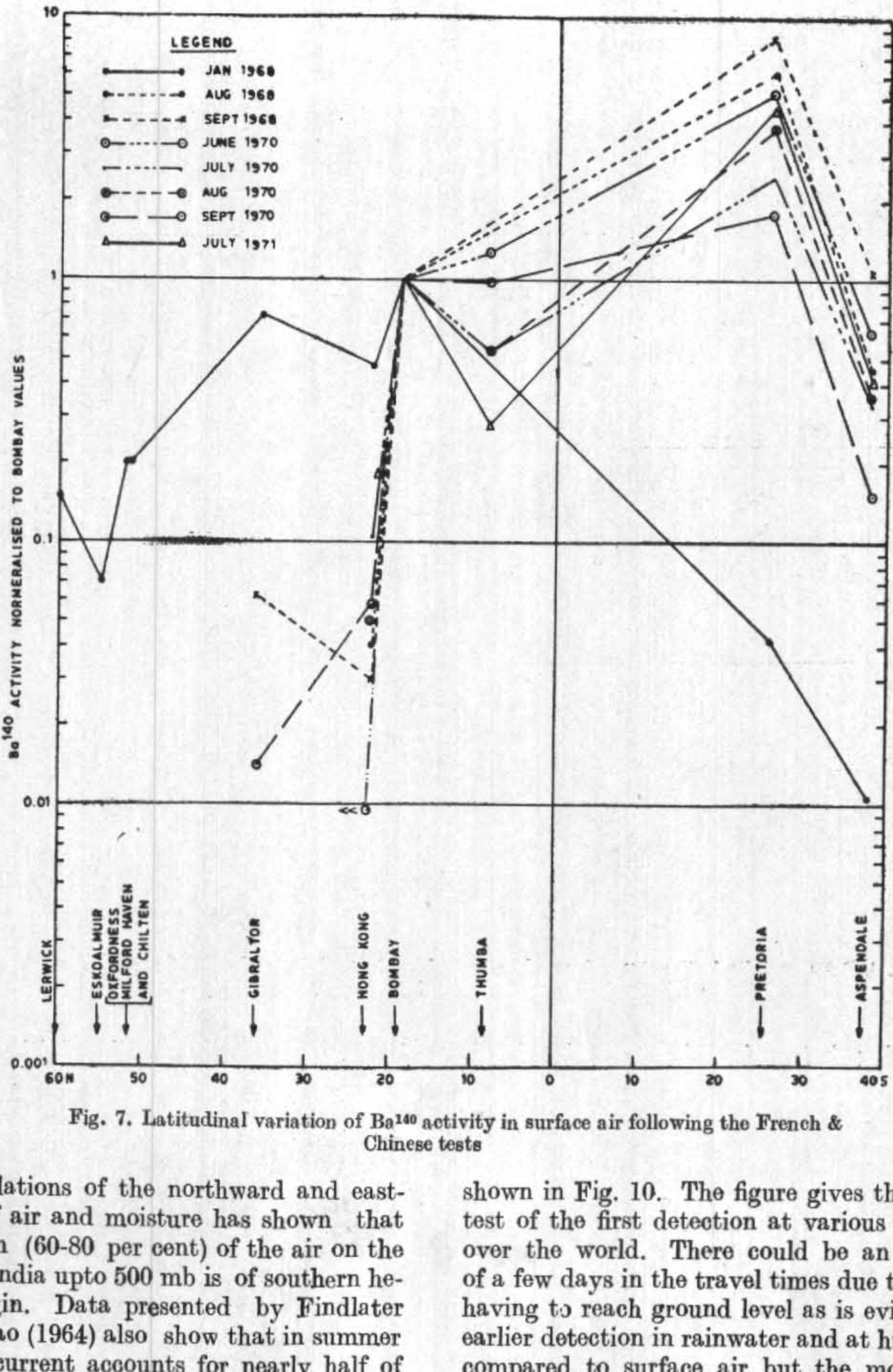


Fig. 7. Latitudinal variation of Ba^{140} activity in surface air following the French & Chinese tests

rigorous calculations of the northward and eastward fluxes of air and moisture has shown that a large fraction (60-80 per cent) of the air on the west coast of India upto 500 mb is of southern hemispheric origin. Data presented by Findlater (1969b) and Rao (1964) also show that in summer the monsoon current accounts for nearly half of the air estimated to be transported into the northern hemisphere across the whole equator at lower levels. The fission product data presented here is thus in full agreement with the recent meteorological studies and is the result of the special conditions of the west Indian Ocean which give rise to inter-hemispheric mixing with jet velocities. The path of the French test debris to the Indian ocean can be predominantly by the westerly winds (Saha 1970). The transport of debris at higher latitudes by westerly winds is shown in Fig. 10. The figure gives the days after test of the first detection at various locations all over the world. There could be an uncertainty of a few days in the travel times due to the debris having to reach ground level as is evident by the earlier detection in rainwater and at high latitudes compared to surface air but the movements as indicated by the figure is mainly westerly. Inspite of this an easterly path cannot be completely ruled out as shown by data in Table 1 (*see* p. 392) which gives dates of detection of French debris in 'Swipe sample' collections from Air India commercial aircraft flying from Nandi to Bombay (Mishra 1973). The date of detection for some tests, *viz.*, 2 July 1967, 22 May 1970, 3 July 1970 is too early for the debris to have reached to Nandi-Bombay path by westerly winds and an easterly movement is indicated.

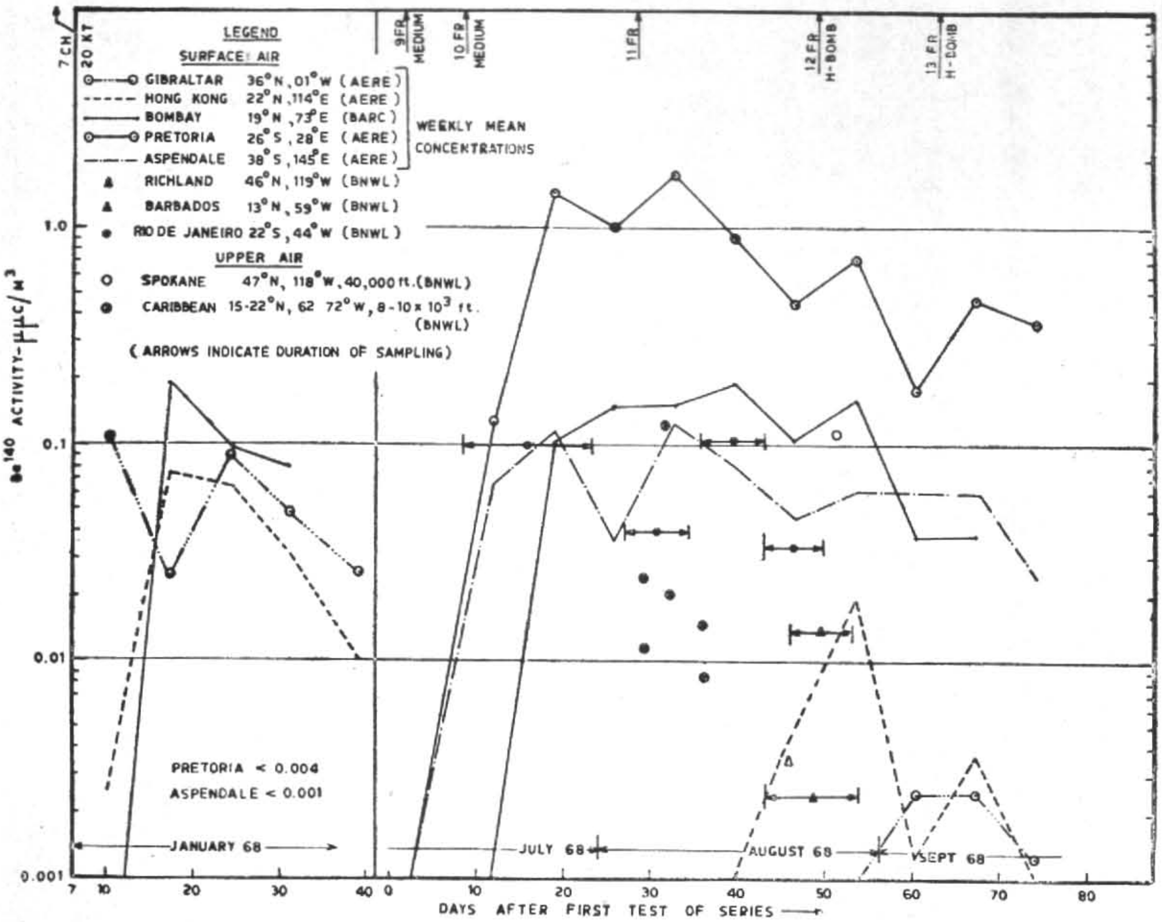


Fig. 8. Ba^{140} activity in the atmosphere after the Chinese test of December 1967 and the French tests of 1968 (sampling laboratories are indicated in the legend)

An interesting feature in this connection is a sharp fall in activity between 20°-25°N in the Indian network. It was pointed out earlier (Rangarajan *et al.* 1970) that this coincides approximately with the monsoon trough. The trough moves north and south depending on the monsoon conditions. During the 'breaks' in monsoon, the trough lies at the foot of the Himalayas, while during strong monsoon conditions it is more towards the south. South of the trough line we have the Arabian Sea branch of the monsoon which is a continuation of the jet stream mentioned earlier. To the north, the Bay current is present, consisting mainly of the Arabian Sea branch which enters the Bay after crossing the land masses and turns north westwards and also the current which enters the Bay directly, across the equator east of 60°E. It was mentioned before (Rangarajan *et al.* 1970) that east of about 60°E transfer is small, the velocities at Gan (0° N, 73°E) being a few knots, as compared to the velocities at Garissa (0°N, 40°E) of about 30 kt (Findlater 1969a). This implies less feed through of radioactive debris to the Bay current directly. In addition, the Arabian Sea branch component may be reduced in activity due to washout by the monsoonal rains and by vertical mixing. The depth of the Arabian Sea monsoon current is only 1·0-1.5 km with an inversion above in many cases (Desai 1967). The depth increases to about 6 km only near the coastal regions and over the continent while the depth of the Bay branch is about 6 km. These factors could make for greater dilution of the activity in the Bay current. Therefore, stations north of the trough line generally getting the Bay current are likely to get much less activity compared to stations which are directly in the path of the Arabian Sea branch particularly those on the west coast like Bombay and Thumba. This point can probably be settled if data from the proposed station at Port Blair is available (*see* Fig. 1).

The extent of interhemispheric mixing at other meridians can now be taken up for consideration. The levels of activity from the French tests of 1968 were significantly higher than from the

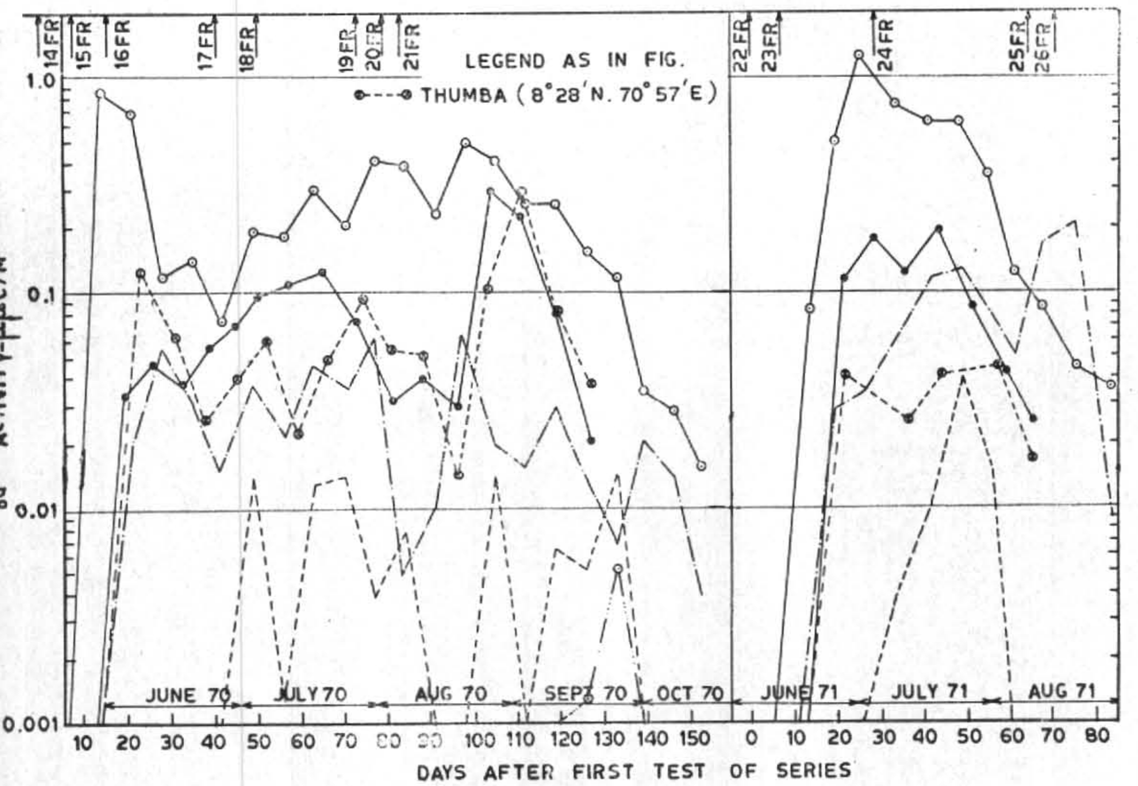


Fig. 9. Ba^{140} activity in surface air after the French tests of 1970 & 1971

previous tests (Figs. 4 and 5) and consequently they have been detected in several parts of the northern hemisphere as mentioned earlier. Wash-out of activity by monsoon over India is not likely to deposit all the activity in the air mass as French test debris have been detected as far north as Srinagar (34° N) which lies beyond the active monsoon regions (Figs. 4 and 5). The ultimate path of the air masses rising as they approach the trough is to be carried along by the westerly winds at higher latitudes and the easterly jet at the lower latitudes. In this way activity can be carried to other meridians.

On the other hand, cross-equatorial currents can exist in other meridians also. Thomas *et al.* (1969) present evidence for an upper tropospheric transport of debris as far north as Spokane (47°N), Washington (Fig. 8). Comparison of these levels with the values at Bombay (Fig. 8) indicates that the intrusions are much less as compared to that by way of the southwest monsoon, and therefore, it is difficult to determine the path of debris to these various locations.

The data discussed above refer to the summer period. During winter, conditions are reversed and an upper tropospheric path is a possibility for crossing into the northern hemisphere. How effective this is, cannot be determined at present due

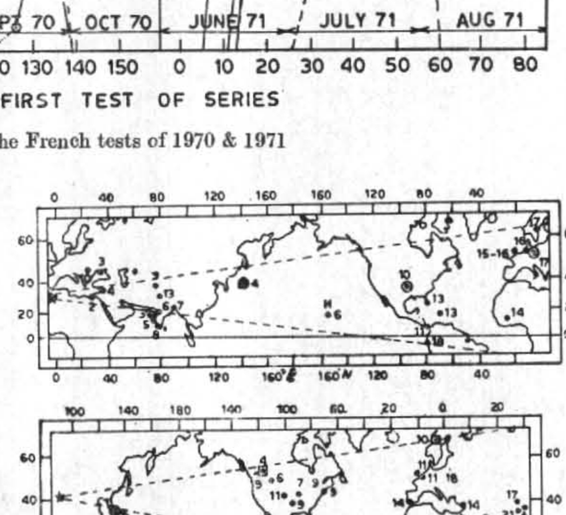


Fig. 10. Travel times (days) of tropospheric fallout from (a) French test of 13 Feb 1960, (b) Chinese test of 14 May 1965 & (c) French test series commencing from 8 Jul 1968.
* Test site ⊙ Rain water data, ● Surface and ☐ Upper air data, and H—high altitude station.

to the absence of tracer data and relevant meteorological measurements in the Indian Ocean. Transport into the southern hemisphere can however, take place (during northern winter) by way of the northeast monsoon. Findlater's data (Findlater 1969b) shows a a shallow current of about 1500 m height with a weak southerly circulation above. Most of the flow to the south seems to be concentrated near the African coast. Tentative calculations by Rao (1964) and Findlater (1969b) indicate that while in summer the monsoon current accounts for nearly half of the air estimated to be transported into the northern hemisphere across the whole equator, the value during winter for transport into the southern hemisphere is about a ninth of the total. Thus there may be significant differences in the transport of aerosols during winter and summer to the other hemisphere. This could explain the fact that in January 1968, Ba^{140} activity from the Chinese test of December 1967 at Pretoria was only a few per cent of that of Bombay (Fig. 8).

The powerful cross-equatorial currents of the Indian Ocean will lead to significant differences in several problems connected with the atmosphere and biosphere in this region compared to other areas. Only two examples will be mentioned briefly.

Goat's thyroids collected at Tarapur, seventy miles north of Bombay were found to contain significant amount of I-131 following the French test series (Bhat *et al.* 1969). The levels were comparable to those following the Chinese tests. I-131 from the French tests in animal thyroid have not been reported elsewhere in the northern hemisphere.

Secondly, low values and wide fluctuations in the atmospheric electrical conductivity have been noted over the south Indian Ocean. This has been atrributed to the cross-equatorial transport of airborne pollution from the land masses to the north (Cobb and Wells 1970). More extensive investigations will undoubtedly reveal several other significant interhemispheric effects in the Indian Ocean region.

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