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Conditions over the equatorial area during the period of monsoon experiment (Monex) 1973

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ABSTRACT. The surface and upper air observations recorded by the two Russian ships, *viz., Okean* (EREI) and *Voekov* (UAAX) at different locations over the equator and by the observatories over Kenya during the monsoon experiment 1973, have been examined in detail to get an idea about the conditions over the equator during southwest monsoon. Comparative study of the observations over the equator at Long. 60° and 50°E and of observations recorded at Garissa and Nairobi during the period 27 May to 4 June and 24 June to 2 July, has been made and presented in this paper. The observations of the ship *Okean* over the equator on its cruise from about Long. 45·0°E to 70·0°E during the period from 16 to 22 June have also been critically examined.

The following salient features are revealed in this study :

(*a*) The southerly component in the wind direction and its depth increase as one moves west of Long. 60°E, southerly jet speed winds even being noticed near 40°E between about 850 and 700 mb.

(*b*) The high humidities are noticed in the western Indian Ocean west of 50°E upto about 500 mb, indicating considerable transport of moisture across the equator over this area.

(*c*) An area of maximum dryness in levels above about 850 mb is noticed near Long. 60°E compared to other longitudes to the east and west. The difluence at the western end (near 60°E) of the equatorial trough may also, to some extent, be responsible for relatively greater dryness at that longitude in levels above about 850 mb.

(*d*) The inversions or isothermal conditions seen in some of the tephigrams would not appear to be due to any mass subsidence over the equatorial area, but mainly due to the presence of distinct airmasses, as is evident from the variations of specific humidity values and the lapse rates.

(*e*) There would not appear presence of a deep layer of westerlies at all the longitudes over the equator.

(*f*) The upper level easterlies would appear to begin at lower heights over the eastern regions than over the western regions of the equator, the jet speeds occurring near about 150 mb.

(*g*) As a result of difference in circulation round 'highs' and 'lows' in the two hemispheres, it is difficult to trace systematic movements of pressure systems over the equator either from east to west or from west to east.

From the present study, it would appear that for a proper understanding of transport of air and moisture across the equator in the western Indian Ocean and the adjoining land areas, it is necessary to have rawin and radiosonde observations at intervals of about 1 degree between Long. 37° and 45°E. Such observations alone will enable us to understand the characteristics of southwest monsoon current over the Arabian Sea and predictions of its activity over the west coast of India in terms of rainfall.

1. Introduction

Due to sparse observations over the equatorial area between about 5°N and 5°S in the Indian Ocean, it has hitherto not been possible to draw firm conclusions about conditions obtaining therein the surface and upper levels. During the MONEX 1973 period, frequent observations were taken by the Russian ships *Voekov* and *Okean* over the equator between 45° and 70°E and also north and south of the equator, some of them being at the equator at 50° and 60°E respectively at a time for some days.

In a recent note, Ghosh and Godbole (1973) have discussed observations recorded by the Russian research vessel *Okean* during the period 27 May to 4 June 1973 and 4 to 7 June 1973 at the equator and 60° E and from the equator to about 14°S along 60°E respectively. They have stated that the sharp turning to the right of winds to the south of the equator and the associated discontinuity in the moisture field across the trough line, point to the existence of the westerlies as distinct from the trades, the westerlies prevailing in a deep layer from the surface to about 400 mb during the southwest monsoon season. According to them, the

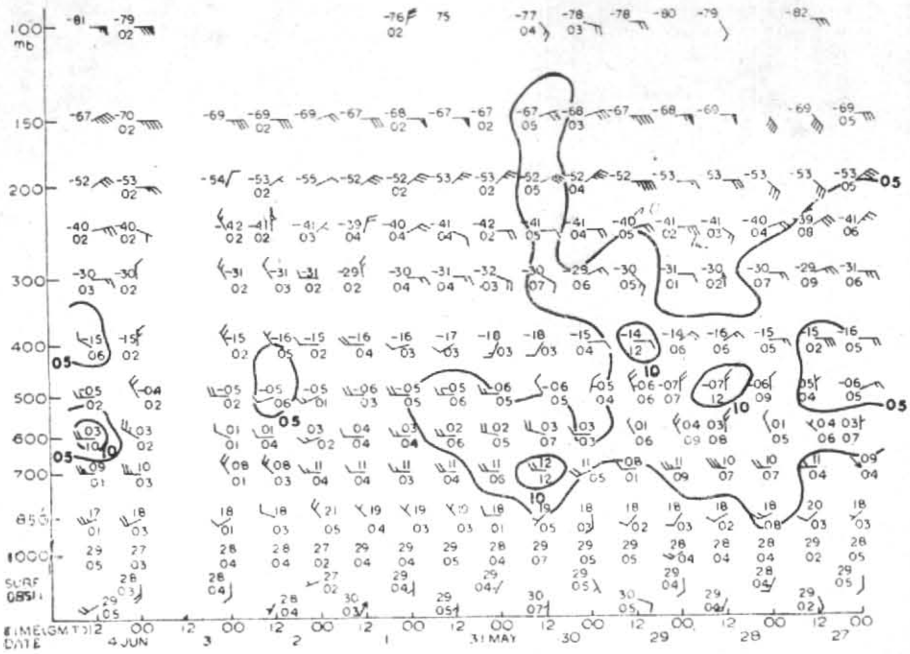


Fig. 1. Vertical time section for Ship *EREI* from 27 May to 4 June 1973 at Long. 60°E over the equator

southwest monsoon activity over India is due to the equatorial westerlies and *not* due to the southern hemispheric trades.

Jambunathan and Ramamurthy (1974) have stated that the equatorial westerlies in the middle troposphere have predominantly a zonal component and hence these westerlies to the north of the equator probably have their origin in the northern hemisphere itself, while those to the south of the equator have their origin in the southern hemisphere.

With a view to see how far the conclusions of Ghosh and Godbole (1973) over the equator and 60°E are valid during other periods of MONEX observations of the same ship over the same location as well as of the other vessel *Voekov* over the equator and 50°E and during the period when the vessel *Okean* moved along equator from near 45°E to 70°E, we are presenting in this paper the relevant observations. The data are also examined with a view to see how far they support various hypotheses proposed for circulation over the equatorial area in the Indian Ocean.

2. Discussion

2.1. *Conditions over the equatorial area during the period 27 May to 4 June 1973 at different longitudes*

The available data of winds, temperature and dew point depression of the two Russian ships and of Garissa and Nairobi have been plotted and are given in Figs. 1 to 4.

(*a*) *At Long. 60°E* (*Fig. 1*)

(*i*) No systematic large variations in day to day temperature are seen at different levels during the period.

(*ii*) There was a broad belt of relatively drier air between 700 and 300 mb on 28th and 29th, isolated pockets of drier air being seen at some levels on some days of the remaining period. There was also a zone of moist air between 500 and 300 mb on 27th. The dew point depression decreased in the easterly zone above about 300 mb.

(*iii*) Predominant westerly winds occur at 700 mb only during the period from 27th to 29th and in levels between 700 and 500 mb in the remaining period. The easterly winds prevailed generally above 400 mb, except for the period from 1st to 3rd when easterlies appeared above about 200 mb only. The winds at the surface were generally southerly to southwesterly over the entire period.

(*iv*) The jet speed winds in the easterlies occurred at 150 mb.

(*v*) Significant wind discontinuities in deep layers are not generally noticed.

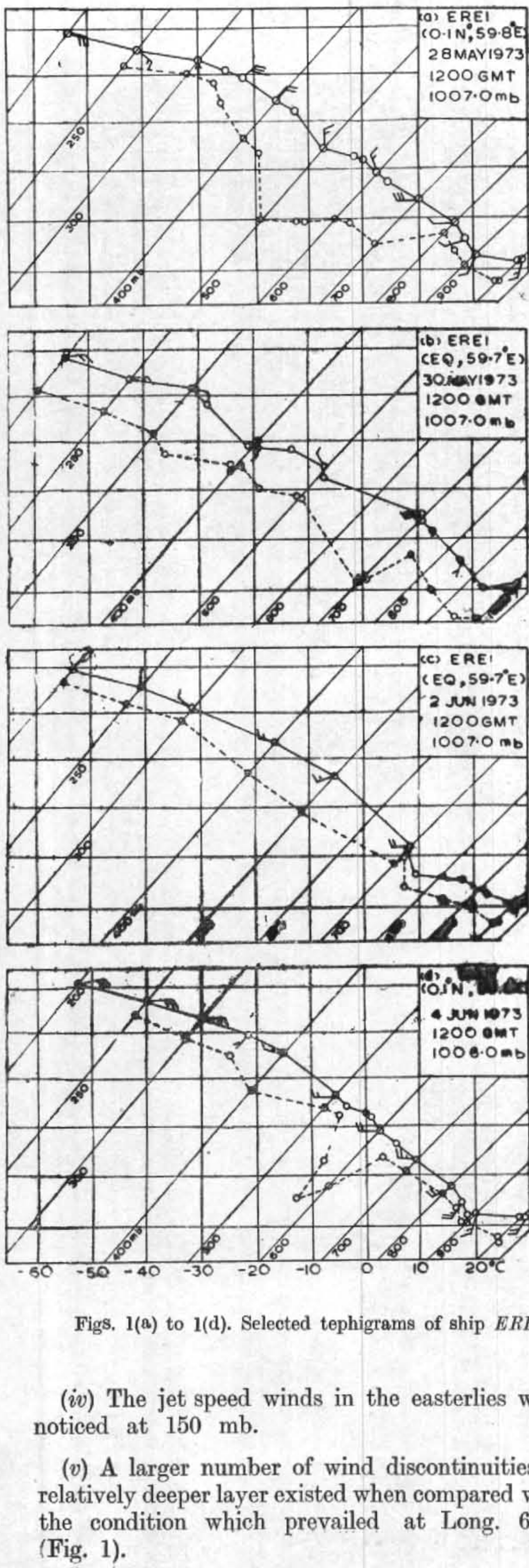
The tephigrams for selected days for the data given in Fig. 1 are reproduced in Figs. 1(a) to 1(d).

The 1200 GMT sounding of 28 May shows moist unstable layer of airmass upto 900 mb, a layer of moist air with saturation adiabat upto 800 mb, a saturation adiabat layer aloft with moisture decreasing with height upto 500 mb and then increasing gradually, the humidity being high above 330 mb.

The tephigram of 1200 GMT of 30 May indicates a relatively unstable layer upto 950 mb, above there being three shallow isothermal layers. The lapse rate is nearly saturation adiabatic upto about 700 mb and increases at higher levels, but being less than dry adiabatic. The moisture content of the air decreases gradually with height except in a shallow layer between 750 and 700 mb where a sharp fall is noticed.

Fig. 1(c) represents the sounding at 1200 GMT of 2 June and shows an unstable moist layer upto 750 mb, a moist near isothermal layer between 750 and 700 mb and nearly saturation adiabatic lapse rate above. A gradual decrease in moisture is seen from 700 mb upto 500 mb and a gradual increase further aloft. There is no sharp decrease of moisture at any level.

The 1200 GMT sounding of 4 June (Fig. 1d) shows a moist unstable layer upto 900 mb and an airmass with saturation adiabatic lapse rate above. There was a sharp decrease of moisture in the layer between 640 and 570 mb, a sharp increase from 570 to 530 mb, a gradual decrease from 500 to 400 mb and a gradual increase further above. The layer of airmass from 900 to 640 mb is moist.



Figs. 1(a) to 1(d). Selected tephigrams of ship *EREI*

(*b*) *At Long. 50°E* (*Fig. 2*)

(*i*) The day to day temperature changes at different levels were random, there being no systematic variation.

(*ii*) There were pockets of relatively drier air between 700 and 250 mb on 30 and 31 May and a broad belt of drier air between 700 and 250 mb on 3 and 4 June. However, a zone of moist air was seen between 700 and 250 mb on 27th and 28th. A general decrease of the dew point depression is noticed above 200 mb.

(*iii*) There were no marked zone of predominant westerlies. The winds at the surface were generally south to southwesterly, a marked increase in wind speeds being seen as compared to those at Long. 60°E. The level at which the easterlies appeared is as low as 400 mb during the earlier part of the period which gradually increased to about 200 mb towards the end of the period.

(*iv*) The jet speed winds in the easterlies were noticed at 150 mb.

(*v*) A larger number of wind discontinuities in relatively deeper layer existed when compared with the condition which prevailed at Long. 60°E (Fig. 1).

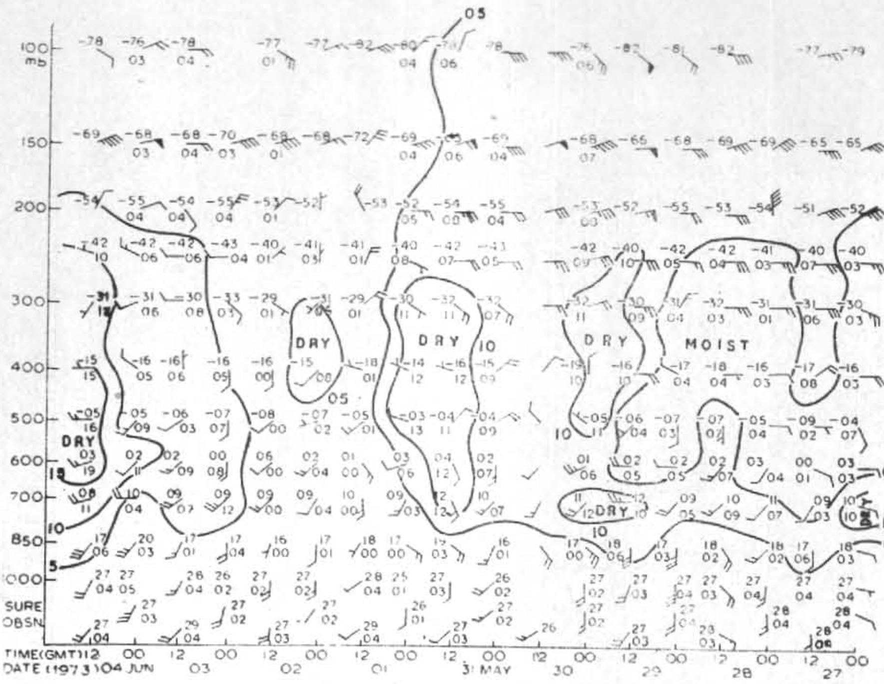


Fig. 2. Vertical time-section for ship *UAAX* from 27 May to 4 June 1973 at Long. 50°E over the equator

The tephigrams for selected days for the data given in Fig. 2 are reproduced in Figs. 2 (a)-2(d).

The sounding at 00 GMT of 30 May shows moist unstable layer upto 800 mb with a shallow inversion at that level. The layer was nearly saturation adiabatic above 800 mb except in the layers 700 to 600 mb and 500 to 400 mb where the lapse rate was nearly dry adiabatic, and an isothermal layer between 600 and 560 mb. Relatively dry air prevailed above 800 mb.

Fig. 2(b) gives the sounding data for 1200 GMT of 31 May. It is seen that the air is nearly saturation adiabatic at all levels except between 430 and 330 mb where it is nearly dry adiabatic. The air was moist upto 850 mb and drier aloft.

The sounding data of 1200 GMT of 2 June (Fig. 2c) indicated practically saturated air in all the levels. The lapse rate was dry adiabatic upto 900 mb and saturation adiabatic above except in the near isothermal layers from 710 to 690 mb and 580 to 540 mb, an inversion layer between 680 and 640 mb and a highly unstable layer between 540 and 500 mb. The reason for the highly unstable layer near about 500 mb is not clear.

The tephigram for 1200 GMT of 4 June (Fig. 2d) shows a moist unstable layer upto 900 mb with three near isothermal layers from 700 to 660 mb, 550 to 500 mb and 480 to 430 mb, with nearly saturation adiabatic lapse rate at other levels except in the layer between 660 and 550 mb where the lapse rate is nearly dry adiabatic and in the layer from 500 to 480 mb where the air is highly unstable. The air is dry above 900 mb.

(c) *At Garissa — Lat. 00° 29′S, Long. 39° 38′ E, height a.s.l. 128 m (Fig. 3)*

No temperature data are available and the upper wind data are also not available above 850 mb on all the days. It can be seen from the time section that the winds have a more southerly component at least upto 850 mb than at Long. 50°E (Fig. 2), the winds being particularly strong at 850 mb, there being even a 50 kt wind at 1200 GMT of 27th.

(d) *At Nairobi—Lat. 01° 18′S, Long. 36° 45′E (Fig. 4)*

The rawin and radiosonde data for Nairobi are given in Fig. 4; the humidity data being available only upto 500 mb. The height of the station above sea level is 1798 m.

(*i*) No significant change in day to day temperature variation is noticed.

(*ii*) With the limited data available for humidity observation, it can only be stated that the dew point depression increases with height from 700 to 500 mb.

(*iii*) There is no zone of predominant westerlies. The winds at 700 mb can be described as light variable.

(*iv*) The easterlies appear at 500 mb at the beginning of the period and at 150 mb towards the end. The jet speed winds do not occur generally below 150 mb.

(*v*) A few wind discontinuities are found which extend to deeper layers.

2.2. *Conditions over the equatorial area during the period 24 June to 2 July 1973 at different longitudes*

The data of winds, temperature and dew point depression of the same two Russian ships and of the same two land stations have been plotted and are given in Figs. 5 to 8 similar to Figs. 1 to 4.

(*a*) *At Long. 60°E (Fig. 5)*

(*i*) As in Fig. 1, the day to day temperature changes do not show any systematic variation.

(*ii*) Pockets of drier air are seen generally between 700 and 300 mb, except for the protrusion of moist air upto 500 mb, as indicated by 00 GMT observations of 24th and 26th. Moist air prevails above 300 mb and below 700 mb.

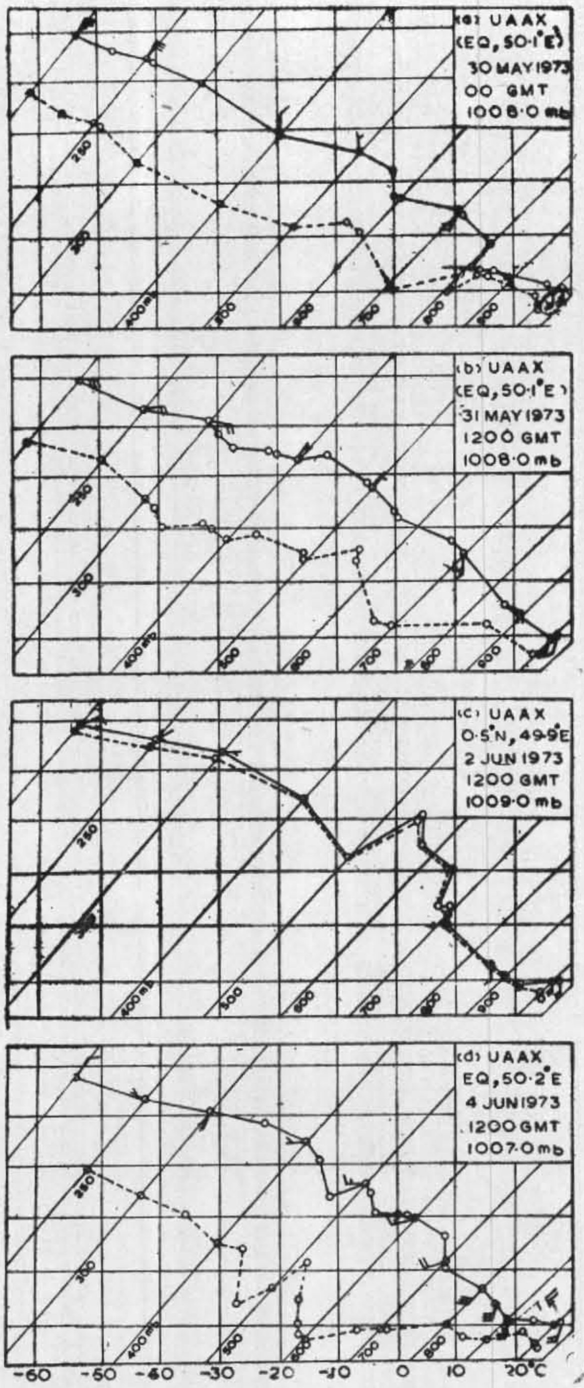
(*iii*) The westerlies are predominant only at 700 mb upto 27th and between levels 700 to 600 mb during the remaining period. The winds at the surface are southerly to southeasterly except for the observations on 24 June when the winds are light and on 1 and 2 July when the winds had some westerly component. The easterlies are seen from 250 mb onwards upto 29th and from 300 mb onwards during the remaining period under consideration.

(*iv*) The jet speed winds generally are seen at 150 mb.

(*v*) A few wind discontinuities are noticed, two of which extending to more deeper layers.

Figs. 5(a) to 5(d) give tephigrams for some selected days for the data given in Fig. 5.

The sounding of 00 GMT of 26 June shows an unstable layer upto 880 mb and generally saturation adiabat aloft except for the layer between 680 and 580 mb where the dry adiabatic lapse rate is prevailing. The moisture increases from the surface to 780 mb, decreases gradually upto about 640 mb, increases then to cent per cent humidity at 520 mb and gradually decreases with height above 500 mb.



Figs. 2(a) to 2(d). Selected tephigrams of ship *UAAX*

Fig. 5 (b) represents the tephigram of 00 GMT of 28 June, which shows unstable moist layer upto 830 mb, a moist isothermal layer between 830 and

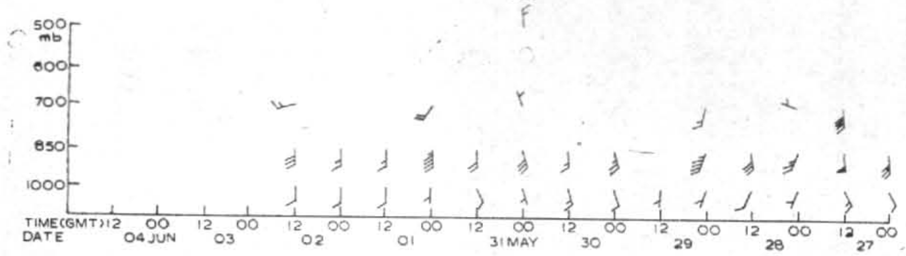


Fig. 3. Vertical time-section for Garissa (Lat. 00° 29′S, Long. 39°38′E, height a.s.l. 128 m) from 27 May to 4 June 1973

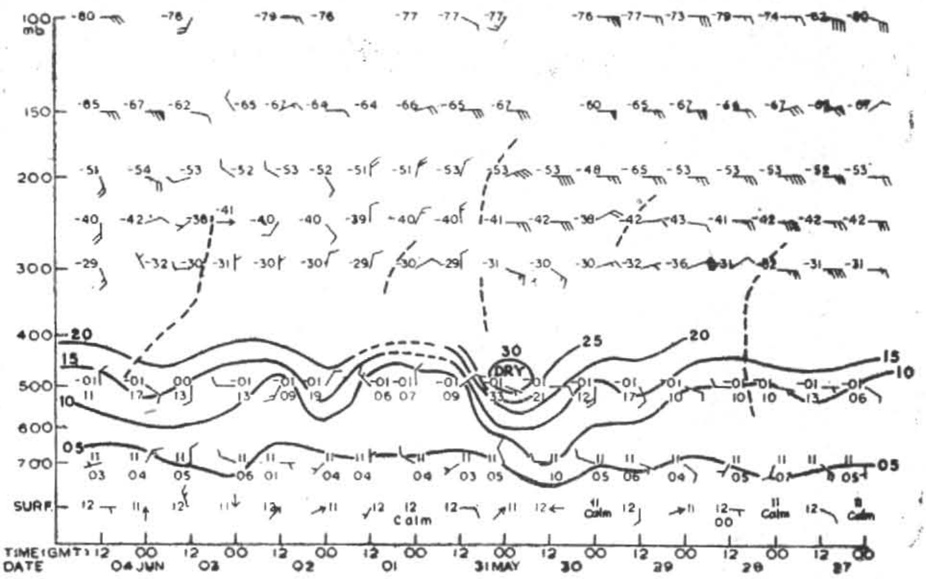


Fig. 4. Vertical time-section for Nairobi (Lat. 01° 18′S, Long. 36° 45′E, height a.s.l. 1798 m) from 27 May to 4 June 1973

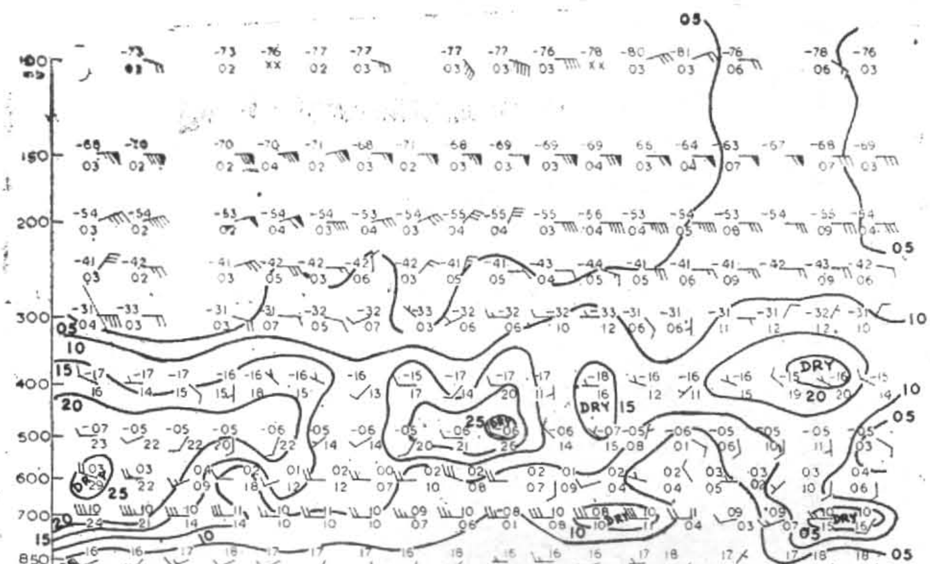


Fig. 5. Vertical time-section for ship *EREI* from 24 June to 2 July 1973 at Long. 60°E over the equator

800 mb, and nearly saturation adiabat upto 200 mb. A sharp decrease in humidity is seen between 700 and 430 mb followed by a sharp rise in humidity upto about 300 mb, the rise being gradual above.

It may be seen from the tephigram for 00 GMT of 29th (Fig. 5c) that the moist unstable layer prevails upto 820 mb. The layer above is nearly saturation adiabatic lapse, except for the two near isothermal layers between 700 and 670 mb and 570 to 550 mb separated by an unstable layer. Except for a rise in humidity between 700 and 670 mb, the humidity generally decreases with height upto 500 mb and increases gradually later.

The sounding for 1200 GMT of 2 July is given in Fig. 5(d), which shows an unstable moist layer upto 790 mb, a near dry isothermal layer between 800 and 700 mb, a dry layer with saturation adiabat between 700 and 620 mb, a dry unstable layer upto 500 mb, a near saturation adiabat upto 340 mb with the moisture showing a gradual increase, a moist isothermal layer between 340 and 320 mb, and a moist saturation adiabat aloft.

(*b*) *At Long. 50°E* (*Fig. 6*)

(*i*) No systematic day to day temperature changes have been noticed.

(*ii*) The zone of driest air is generally seen in the layers between about 700 mb and 300 mb except for the tongue of moist layer extending upto 600 mb seen from the observations of 25th and 26th. The dryness also extends to more height on those days. The moisture generally increased above 300 mb.

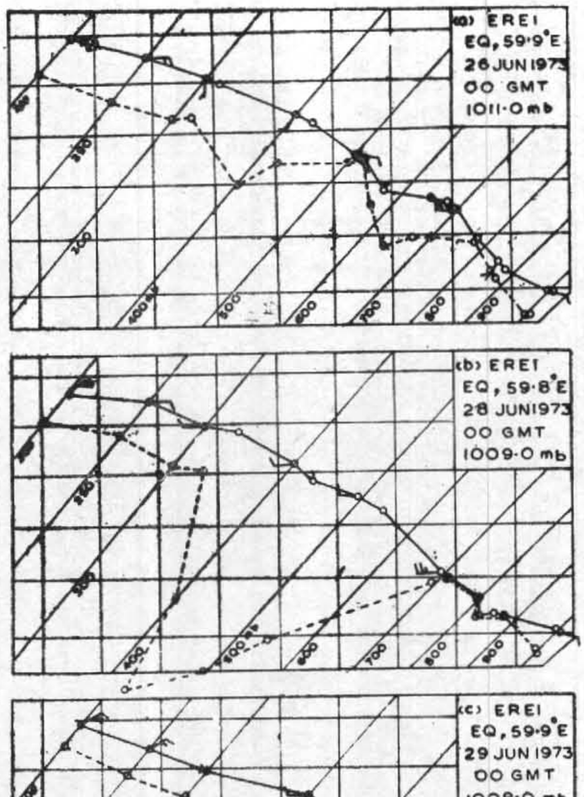
(*iii*) The westerlies are predominant only between 700 and 600 mb from 26 to 29 June and are seen only at 700 mb during the remaining days towards the end of the period. The westerlies seen at 700 mb are somewhat weaker than those seen at Long. 60°E. (Fig. 5). The winds at the surface are either southerly or southwesterly, the easterly component being practically absent on all days except at 1200 GMT of 27th. The zone of easterlies appears above 200 mb, a higher level as compared to the condition which existed at Long. 60°E.

(*iv*) The jet speed winds were generally seen at 150 mb.

(*v*) Wind discontinuities are also noticed, some extending to deeper layers.

The tephigrams on the sounding data of some selected days are given in Figs. 6 (a) to 6(c).

Fig. 6(a) gives the tephigram for 00 GMT of 25th and shows a moist unstable layer upto 970



Figs. 5 (a) to 5(d). Selected tephigrams of ship *EREI*

mb, a moist near saturation adiabat upto 650 mb except for a shallow moist unstable layer between 760 to 720 mb, a moist unstable layer upto 550 mb. Between 550 mb and 450 mb, an inversion layer and two shallow isothermal layers are seen, which

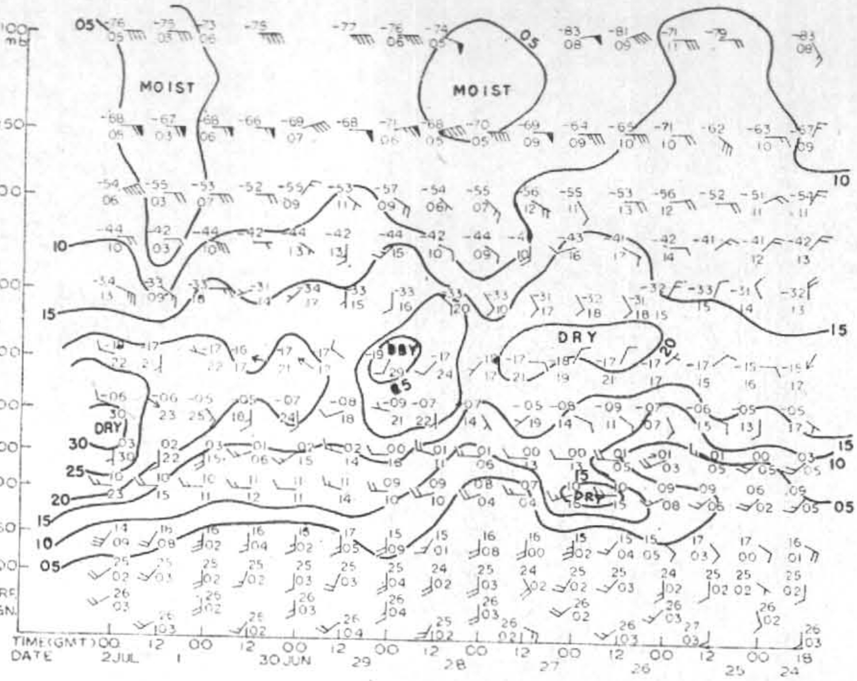


Fig. 6. Vertical time-section for ship *UAAX* from 24 June to 2 July 1973 at Long. 50°E over the equator

are separated by shallow unstable layers, the air being relatively drier. From 450 mb a dry unstable layer is noticed upto 270 mb, the lapse rate decreasing further alof

The data for 00 GMT of 29th (Fig. 6 b) shows a moist unstable layer upto 920 mb, the moisture generally decreasing with height aloft. Two isothermal layers are seen between 920 and 870 mb and 510 and 480 mb, together with an inversion layer between 820 and 800 mb. The lapse rate was generally saturation adiabatic above the isothermal layer near 500 mb, but more than saturation adiabatic in the layers separating the inversion and isothermal layers.

Fig. 6(c) gives the sounding for 00 GMT of 2 July, which represents a moist unstable layer upto 930 mb, the moisture decreasing gradually upto 600 mb and increasing gradually aloft. Except for the presence of a near isothermal layer between 800 and 700 mb and a shallow isothermal layer between 560 and 540 mb, the rest of the sounding has nearly saturation adiabatic lapse rate.

(c) *At Garissa* (*Fig.* 7)

Based on the available wind observation, it may be seen that the winds at the surface and 850 mb have a more southerly component as compared to the conditions prevailing at Long. 60° and 50°E. The winds at 850 mb are generally strong and on one day reached 50 kt.

(*d*) *At Nairobi* (*Fig. 8*)

Fig. 8 gives the rawin and radiosonde data during the period in question, the humidity observation being available only upto 500 mb as in Fig. 4.

(*i*) No significant day to day temperature variations were noticed above 250 mb on all days and in lower levels upto 250 mb during the period from 24 to 30 June. During the period of 1200 GMT of 30th and 00 GMT of 1st, a fall in dry bulb temperatures of 2, 7 and 3°, are noticed at surface, 700 and 500 mb respectively. The temperature values at 00 GMT of 2nd in these levels showed no significant change as compared to the corresponding values of 1st, but in the absence of 1200 GMT observation on both 1 and 2 July, no specific reason could be given for the significant fall in temperature mentioned above.

(*ii*) Due to limited observations available on humidity conditions, it can only be stated that the dew point depressions increase with height from 700 to 500 mb as in the case of Fig. 4, but the increase appears to be sharp on the last three days of the period under consideration.

(*iii*) No zone of predominant westerlies is seen. The winds at 700 mb show a greater easterly component in them. No definite regions of the easterly winds could be mentioned except that they occur at a very high level above 150 mb.

(*iv*) Jet speed winds are seen only at 100 mb.

(*v*) Wind discontinuities are generally seen between 700 and 300 mb, though some even extend to greater depths upto 150 or 100 mb.

2.3. *Conditions over the equator from 16 to 22 June 1973 at different longitudes*

The data of winds, temperature and dew point depression taken by the Russian ship *Okean* during its cruise from Long. 47.0°E to 70·0°E along the equator are given in Fig. 9. The salient features brought out in this figure are given below:

(*i*) A slight increase in surface temperature is generally seen at lower levels when the ship moved eastward. At higher levels, no definite systematic variations are noticed.

(*ii*) From 47·0°E to about 53°E, there was a layer of moist air upto 500/400 mb with relatively drier air aloft. Between 53° and 65°E, there was a deep layer of relatively drier air extending from about 850 to 300 mb, the maximum dryness being noticed near about Long. 60°E. Above 300 mb, the air is relatively moist. Further east the dryness decreases and is seen between 850 and 400 mb only, there being more moisture above and below it.

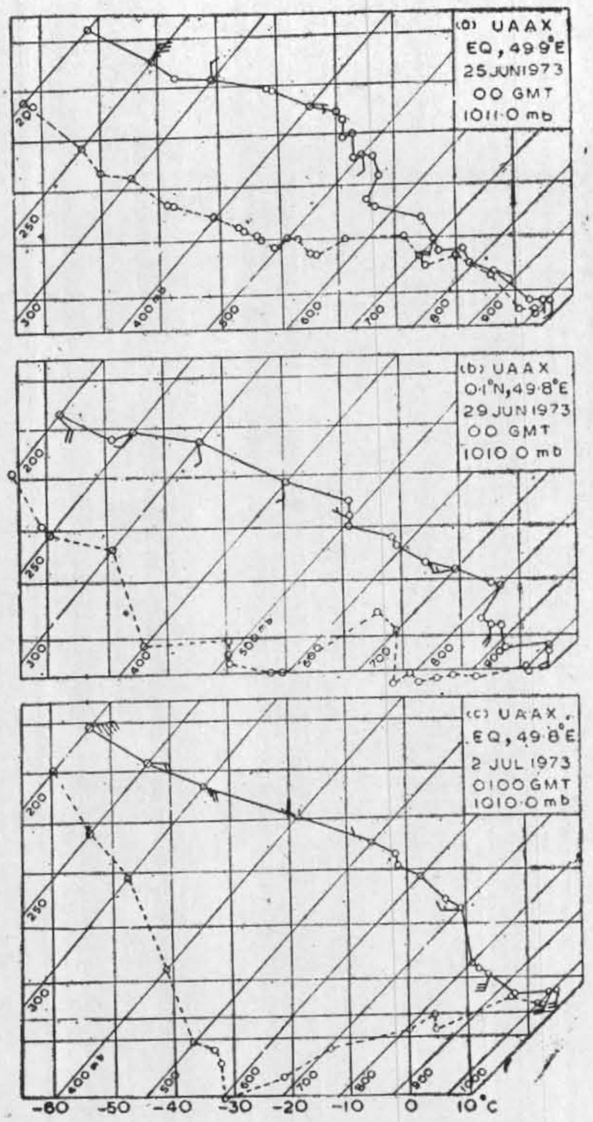
(*iii*) West of Long. 57°E, the winds upto 700 mb were generally stronger and had a larger southerly component when compared with winds at those levels further east. East of 56°E, the winds at 700 and 600 mb were generally westerly. The winds between 500 and 300 mb were of variable type. The easterly winds began at about 300 mb at Long. 70°E and at 150 mb at Long. 47·0°E, *i.e.*, the level of easterlies rose from east to west.

(*iv*) The jet speed winds generally occurred at 150 mb to the east of Long. 57°E on most of the days, no jet speed winds being noticed to the west of that longitude.

(*v*) Wind discontinuities are seen in some areas in shallow layers.

Figs. 9 (a) to 9 (c) represent the tephigrams of some typical days over the equator for the data given in Fig. 9.

The sounding of 1200 GMT of 17 June at Long. 51·4°E (Fig. 9 a) represents the characteristic sounding in moist layer upto 400 mb and relatively drier air aloft. There were unstable layers between surface and 850 mb, between 700 and 600 mb and between 550 and 500 mb; in the remaining layers upto 400 mb the lapse rate was nearly saturation adiabatic, there being nearly isothermal layer between 600 and 550 mb. Above 400 mb, there was a relatively drier layer with nearly saturation



Figs. 6(a) to 6(c). Selected tephigrams of ship *UAAX*

adiabatic lapse rate. The tephigram does not give any evidence of subsidence.

Fig. 9 (b) gives conditions at 0100 GMT of 20 June 1973 at Long. 61·0°E. The layer was moist upto 800 mb and above about 350 mb, the air being relatively drier in the intervening layer. Except for an inversion between 770 and 750 mb and near isothermal conditions between 510 and 470 mb, the lapse rate at all levels was between dry and moist adiabatic. The variations in the values of specific humidities seen above the inversion or near isothermal layer do not justify subsidence occurring in those levels.

The sounding of 1200 GMT of 22 June 1973 at Long. 70°E (Fig. 9 c) shows moist unstable layer

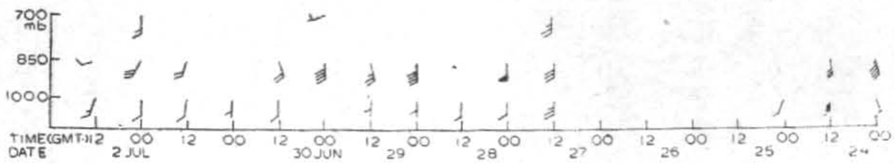


Fig. 7. Vertical time-section for Garissa from 24 June to 2 July 1973

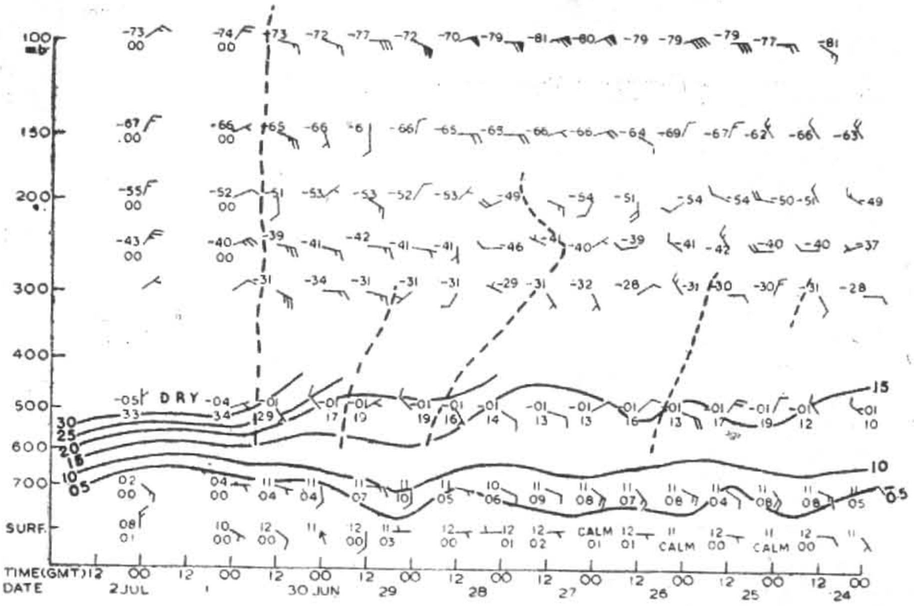


Fig. 8. Vertical time-section for Nairobi from 24 June to 2 July 1973

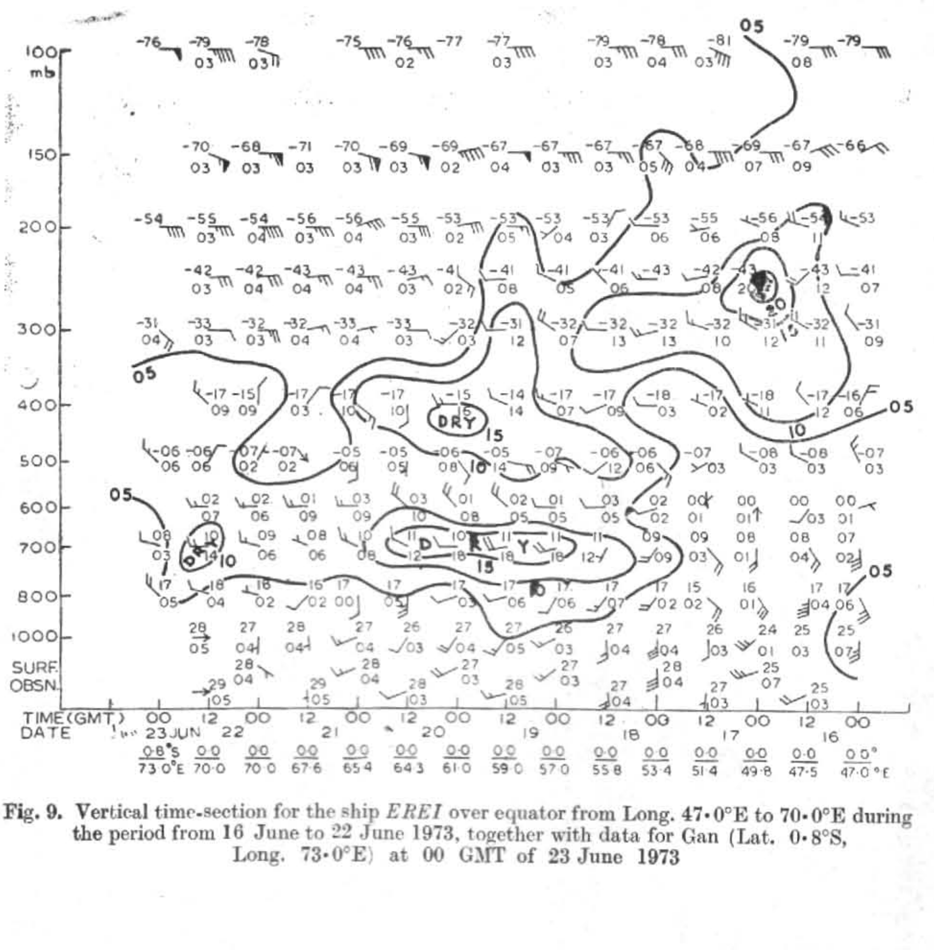
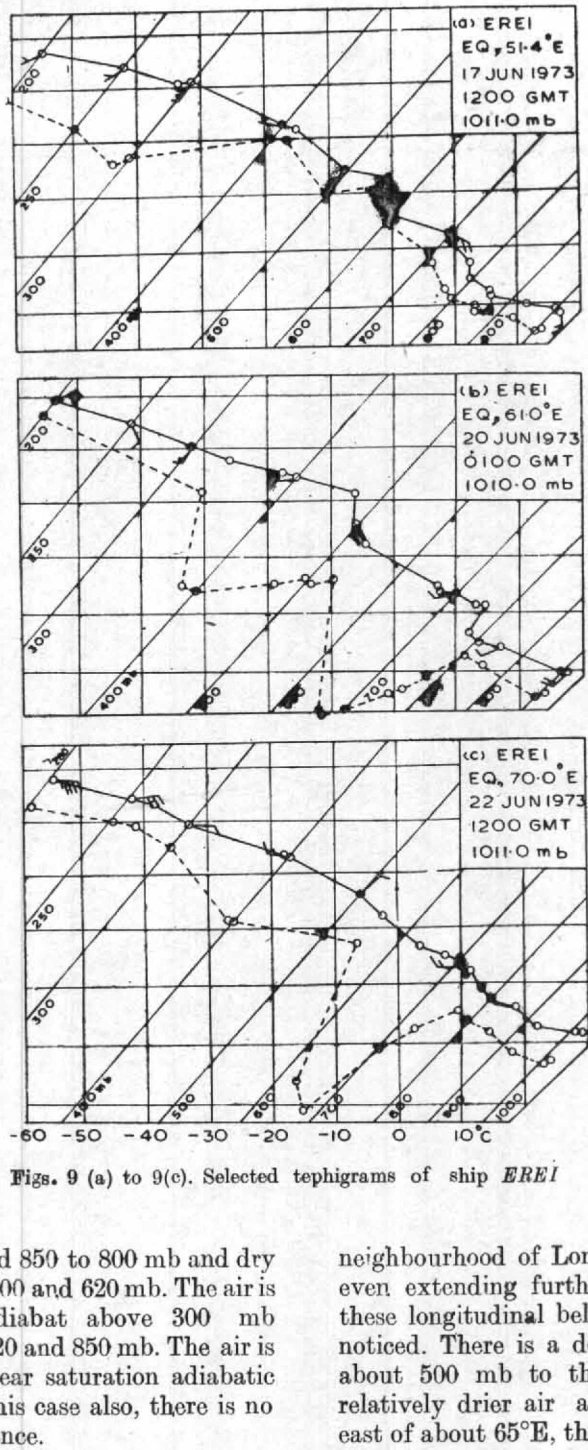


Fig. 9. Vertical time-section for the ship *EREI* over equator from Long. 47·0°E to 70·0°E during the period from 16 June to 22 June 1973, together with data for Gan (Lat. 0·8°S, Long. 73·0°E) at 00 GMT of 23 June 1973



Figs. 9 (a) to 9(c). Selected tephigrams of ship *EREI*

from surface to 920 mb and 850 to 800 mb and dry unstable layer between 700 and 620 mb. The air is moist with saturation adiabat above 300 mb and in the layer between 920 and 850 mb. The air is relatively drier and has near saturation adiabatic lapse at other levels. In this case also, there is no clear evidence of subsidence.

The noteworthy points brought out in Sections 2.1, 2.2 and 2.3 can be summarised as under:

(*a*) No systematic large variations in temperatures are seen at the same locations on different days.

(*b*) The zone of relatively drier air is generally found between about 700 and 300 mb in the neighbourhood of Long. 60°E, the same at times even extending further west; at other levels in these longitudinal belt an increase in moisture is noticed. There is a deep layer of moist air upto about 500 mb to the west of Long. 50°E and relatively drier air aloft upto 300 mb. To the east of about 65°E, the air is relatively more moist than to the west.

(*c*) There is no deep layer of westerlies in all the cases.

(*d*) The southerly component of the winds increases as one proceeds west of Long. 53°E.

(*e*) The layer of esterlies is lower in the eastern areas than to the west.

TABLE 1

Okean **(EREI)—15 and 16 June 1973**

Pressure level (mb)	15 Jun, 00 GMT At 2·9°S, 45·8°E		15 Jun, 08 GMT At 1·5°S, 45·5°E		16 Jun, 06 GMT At 0·0, 47·0°E		16 Jun, 12 GMT At 0·0, 47·5°E	
	TT TT—TdTd	DDD FF	TT TT—TdTd	DDD FF	TT TT—TdTd	DDD FF	TT TT—TdTd	DDD FF
100	—81 17	095 22	—78 02	110 38	—79 —	085 29	—79 08	085 28
150	—69 09	235 16	—66 02	265 20	—66 —	055 19	—67 09	070 30
200	—54 09	265 28	—52 02	335 16	—53 —	300 15	—53 11	290 18
250	—44 09	290 40	—40 02	100 08	—41 07	280 12	—43 12	230 18
300	—31 15	285 36	—29 02	170 06	—31 09	310 12	—32 11	295 11
400	—16 04	296 38	—16 01	200 20	—16 06	025 14	—15 12	340 10
500	—07 04	215 12	—05 00	180 28	—07 03	345 14	—08 03	300 10
700	08 09	150 12	08 00	145 24	07 02	170 25	08 04	165 22
850	17 01	135 32	16 00	170 36	17 06	165 25	17 04	180 28
1000	25 03	140 32	24 01	160 20	25 07	180 25	25 03	230 22

(*f*) The jet speed winds are seen near about 150 mb in all the cases.

(*g*) The tephigrams show that there is generally a moist unstable air in lower levels and moist stable layer above about 300 mb. In the intervening levels, there is relatively dry air with nearly saturation adiabatic lapse.

(*h*) On days when inversion or near isothermal layers are noticed, the lapse rate and the specific humidity variation above them would incline one to the view that there might not be any subsidence. Thus, the less moist air with saturation adiabatic lapse consists of a distinct airmass.

(*i*) No distinct wind discontinuities in deep layer moving east or westwards are noticed over the equatorial area. This is not surprising if one remembers the fact that the circulation of air around highs and lows is opposite to the north and south of the equator.

The statement of Ghosh and Godbole (1973) that there is a deep layer of westerlies over the equator is generally not supported by the present results. Pant (1974) has considered the presence of inversion over the equatorial area as evidence of subsidence. But as stated above, the lapse rate and humidity variations in the relatively dry layer above the inversions or isothermal layers do not support the view put forward by Pant.

The zone of relatively dry air between about 700 and 300 mb noticed in Figs. 5, 6 and 9, is to be expected in view of the fact that the relative humidity is high at the surface as well as above 200 mb. As a result of such relative humidity distribution, one may expect an increase in the dew point depression from surface upwards and also from about 200 mb downwards, the zone of maximum dew point depression being near about 500 mb.

In the discussion of the tephigrams at different positions over the equator, it has been shown that there is generally a moist unstable layer in the lower levels, a less moist layer with saturation adiabatic lapse upto about 300 mb, and the humidity increasing with height above 300 mb. This will show that in the layer between about 700 and 300 mb, the air is relatively drier. It is seen from the charts of Ramage and Raman (1972) that above about 850 mb and particularly at 700 mb, there is air from the Atlantic side which has moved across South Africa turned northwards around Madagascar area following the prevailing pressure pattern. The sounding of Dar-es-Salaam, reproduced by Findlater (1969 a) in Fig. 8 of his paper also shows a layer of less moisture with nearly saturation adiabat above the reflected trades, which sometimes even may extend upto about 4·5 km, there being an inversion and still drier air aloft. These observations would generally support the zone of relatively greater dryness round about 500 mb. The examination of available Dar-es-Salaam data during the MONEX period would also support the presence of relatively drier air near about 500/400 mb. Further observations, however, are considered necessary to identify the exact nature of the airmass between about 700 and 300 mb over the equatorial area in the western Indian Ocean and neighbourhood.

Table 1 gives data of the Russian research vessel *Okean* for two days. Although there is a difference of about one day between the observations of 0800 GMT of 15th and 0600 GMT of 16th and the observation at 0800 GMT of 15th is 1·5° to the south of the equator, it is clear that winds at lower levels are generally southerly and strong, the height of the southerly winds increasing westwards. The dew point depression decreases as one moves west.

3. Origin of the equatorial westerlies

According to Ghosh and Godbole (1973), the equatorial westerlies consitute a distinct air mass, they being drier than the trades in the southern hemisphere. The westerlies are drier than both the trades of the southern hemisphere and of the deflected trades of the northern hemisphere.

It is well known that there is a trough just to the south of the equator to the east of about 60°E and which extends upto about 500 mb. As a result, there will be a turning of winds at the western end —southeasterly winds veering to westerly winds. Due to difluence near 60°E on account of the equatorial trough, the westerlies might be drier than the trades or the deflected trades.

To the west of about 60°E, the air which crosses equator will also move eastwards near it and westerly winds might be found even further west of 60°E near 700 mb.

In the layers upto about 800 mb, there is apparently no marked difference, the dew point depression being small.

The equatorial westerlies do not extend in the Arabian Sea to the north of about 8°N to the west of about 60°E; they enter into the monsoon circulation only in the southeast Arabian Sea and the south and southeast Bay, their contribution to the monsoon activity over India being much smaller than that of the deflected trades which move to the west coast of the Peninsula across the Arabian Sea after crossing the equator to the west of about 60°E. As such, the statement of Ghosh and Godbole (1973) that equatorial westerlies are responsible for the activity of the southwest monsoon over India cannot be accepted.

In a recent paper Godbole and Ghosh (1975) have stated that the westerlies to the north of the equator are more moist than those to its south. It is not difficult to understand the difference in view of the origin of the westerlies discussed above.

The statement of Jambunathan and Ramamurthy (1974) that the westerlies to the north of the equator have their origin in the northern hemisphere and the westerlies to the south of the equator have their origin in the southern hemisphere would not also appear correct in view of what has been stated above.

4. Bearing of the results on the transport of air and moisture across equator

It will be relevant to refer here to the computations made by various workers about transport of air and water vapour across equator and examine the bearing of the MONEX data on the same which are given in Table 2.

On comparing values of water vapour, it is seen that the value of Pisharoty is half of that of Saha. This difference is due to the fact that Saha considered Seychelles aerological data and ship's data for the middle and western sectors of the equatorial section, while Pisharoty used data of Nairobi and Dar-es-Salaam as discussed by

TABLE 2

Transport of water vapour and air across equator

Author	Area considered	Transport of water vapour (Metric tons/ day × 10^{10})	Transport of air (metric tons/day × 10^{12})
Pisharoty (1965)	Between 42° and 75°E and layer surface to 450 mb	2·2 July 1964	—
Saha (1970)	Same belt and depth as taken by Pisharoty	4·43 July 1964	5·02 July 1964
Findlater (1969b)	Belt between 35° and 75°E in the lower troposphere	—	7·63 July mean
Godbole and Ghosh (1975)	Belt between 55° and 65°E and depth surface to 500 mb	1·5 23-28 May 1973	—

Desai and Rao (1971). Godbole and Ghosh's value is lowest because it is for the section 55° to 65°E, where there is definite evidence of dryness above about 800 mb due to difluence at the western end of the equatorial trough as discussed earlier; further, this value is for the last week of May when monsoon current had not reached the west of the Peninsula and the monsoon circulation had not well established over India.

Findlater's value of air transport is about one and a half times that of Saha because, as discussed by Desai and Rao (1971), winds between 42° and 45°E would be stronger as seen from Findlater's data (1969 a, 1972) than those at Seychelles whose data have been utilised by Saha, and, therefore, the vertical cross-section in his Figs. 2 and 3 for the western sector would require modifications; such modifications would make Saha's value of air transport nearer to that of Findlater. The same considerations would also mean increase in the value of 4·4 of water vapour transport of Saha across equator and thus bring it practically near to the value of 5·8 of Pisharoty (1965) across 75°E between equator and 25°N, *i.e.*, most, if not all, of the water vapour reaching the west coast of India would be from across the equator although some moisture would certainly be added over the Arabian Sea as the cold monsoon air moves over warmer areas.

Pisharoty (1967) has stated that the mean flow of air in the equatorial belt from 80° to 100°E *corresponds to* a southerly wind of 6-8 kt and from 40° to 60°E of a southerly wind of 2-4 kt; the flux from the south in the belt between 60° and 80°E was relatively negligible. As the transport of air across equator between 40° and 60°E was comparatively small, Pisharoty concluded that greater attention to the northern hemisphere phenomena was necessary for understanding the pulsations of the Arabian Sea branch of the monsoon. Pisharoty had used data of Nairobi near 37°E, of Seychelles near 55°E and of Gan near 73°E in his computations for the equatorial belt between 40° and 80°E. It is, however, seen from Findlater's papers (1969 a and b, 1972), that the flow of air across equator between 37° and 45°E is considerable and thus use of data of Nairobi (height 1798 m a.s.l.) and of Seychelles by Pisharoty for his computations of flux across the equatorial belt between 40° and 60°E would not appear correct, and his conclusions are, therefore, untenable and misleading.

It would appear from the foregoing discussions that for a proper understanding of the air and water vapour transport across equator, one should have data between 37° and 45°E across which belt bulk of the transport takes place as seen from Findlater's data (1969 a, b). During the MONEX period, however, no observations were taken over the equatorial area over the ocean west of 45°E by the Russian ships, nor were arrangements made for getting aerological data of selected stations in the area from East Africa and Island observatories. It is hoped that in any future planning for MONEX or any other programme, such shortcomings would not be allowed to occur, thus making interpretation of data easy; absence of data from the said areas would make some (Pisharoty 1965, 1967) believe that much of the moisture was added by evaporation over the Arabian Sea without realising that the winds over the Arabian coast could not explain the presence of jet speed winds over the Arabian Sea noticed during

MONEX period. Further, as a result of the low level airmass inversion over the west and north Arabian Sea due to warm continental air spreading over the cold maritime air, appreciable moisture cannot be added by evaporation over the Arabian Sea, although the cold moist air from the southern hemisphere could pick up some moisture while travelling north and northeastwards over warmer areas.

The jet current over the Arabian Sea is embedded in the monsoon current which crosses equator to the west of 60°E, bulk of the monsoon air flowing between 38° and 42°E.

5. MONEX data and circulation models proposed for the area

According to Koteswaram (1958), the air which rises in the monsoon trough in the lower levels is joined up with the air rising over the Tibetan plateau and the same flows out northwards and southwards. The latter branch flows equatorwards and sinks in the equatorial region and constitutes the return flow of surface westerlies which picks up copious moisture during northward travel over the warmer sea surface.

From the MONEX data, it is clear that there is no mass subsidence of air over the equator between about 45° and 70°E. The directions above 300 mb as well as between about 800 and 500 mb would not support mass sinking motion from levels above 300 mb over the equatorial area in spite of northerly component in the easterly winds at some locations at 300 mb level and above.

Frost and Stephenson (1964) have stated that their 200 mb level charts showed that between Indonesia and 60°E there was strong trans-equatorial flow from eastnortheast. The fact that the flow in July at the surface is 180° out of phase with the flow at 200 mb would suggest, according to them, a simple circulation model with a sink more or less fixed over the Indian Ocean at the equator at about 60°E. As stated by Desai (1967), observations over Gan upto about 600 mb at least did not show that there might be subsidence near 70°E at the equator. The present data also show that there is no mass subsidence of air over the equator between about 45° and 70°E.

Bjerknes (1969) has postulated a zonal equatorial cell with limb of ascending air over Indonesia and of sinking air off Africa. From the data in Figs. 2, 6 and 9, it would appear that there was no evidence of sinking of air off Africa.

The MONEX data do not thus support Bjerknes' postulate of the zonal cell over the equatorial Indian Ocean.

6. Concluding remarks

From discussion of the MONEX 1973 data over equator in the Indian Ocean, it would appear that there is no subsidence over the equatorial area of air which has ascended in the Indian monsoon trough and over Tibet.

The westerly winds in the equatorial area east of about 60°E have not their origin in the Arabian land mass at any level; they would appear to originate in the southern hemisphere. Higher humidity both to the west and east of the area around 60°E in levels above about 800 mb would definitely rule out connection between conditions over there and further east and west. The flow over the Arabian Sea is from the southern hemisphere crossing equator to the west of about 60°E, and it is not primarily of northern hemisphere origin, as contemplated by Pisharoty (1965, 1967). Interpretations of computations of moisture content along any meridian over the Arabian Sea with reference to the flow of moisture across equator will lead to misleading conclusions unless one traces the trajectory of the western air over the Arabian Sea. The data of MONEX 1973 show that the southwest monsoon current over the Arabian Sea has its origin in the southern hemisphere in conformity with the earlier ideas and what we have learnt in text books of Geography, bulk of the moisture being from across the equator, only some moisture being added by evaporation over the Arabian Sea as the cold moist monsoon air from the southern hemisphere moves north and northeastwards over warmer areas.

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