Some aspects of the Arabian sea summer monsoon

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ABSTRACT

Some of the observed features of the Arabian sea summer monsoon, such as the formation of a low-level highspeed aircurrent, strengthening of the intertropical convergence zone over northeastern Arabian sea and formation of a secondary convergence zone over southeastern Arabian sea, changing patterns of cloud distributions and formation of double cloud bands over eastern Arabian sea and rainfall discontinuities along the west coast of India between July and August are discussed in relation to possible complex transformations of airmasses that cross the Arabian sea with a continually changing pattern of surface temperature during period May through August. It is hypothesised that following coastal upwelling in Somalia and Arabia during late May or early June, a wedge of cold water is advected across central Arabian sea by the southwestmonsoon current and that it is the feed-back effect of this advection upon the atmosphere that may be largely responsible for the observed monsoon features.

1. Introduction

The northern summer monsoon circulation over the Arabian sea forms part of a planetary-scale atmospheric circulation which is generated and maintained by a pressure distribution consisting of a continental heat low covering the entire land complex extending from Somalia to northern India and a high pressure area in the subtropical belt of the southern Indian ocean centered at latitude about 30° S. An average value during June of the lowest pressure in the continental heat low may be about 998 mb while that of the highest pressure in the sub-tropical ridge in the southern Indian ocean about 1026 mb. Forced by the prevailing pressure gradient air moves over the Arabian sea from a direction between south and west in the lowest levels, gradually veering with height due to horizontal temperature gradient and moving from a direction between north and east in the upper troposphere. At the surface of the Arabian sea, the southwest winds by their frictional stress drive the well-known ocean currents, viz., the Somali current and the southwest monsoon current.

Before the onset of the southwest monsoon over the Arabian sea, say during mid-May, the sea surface is warm with an average temperature of about 29°C near the coast of Somalia increasing northeastward to a value of about 31°C near the coasts of India, Pakistan and Iran. At this time, the surface winds near the coast of Somalia are light SSW (~4–7 m.p.s.) and there is no coastal upwelling. The Somali current flows as a narrow coastal current confined to within about 50 km of the coast and the cold south equatorial current is confined to latitudes south of about 2° S (Leetmaa, 1972). Sometime towards the end of May or beginning of June, however, there appears to be a major change in the situation the exact nature of which is not clear at present. But the following events would appear to take place: (i) the cool south equatorial current crosses the equator near the coast of Somalia and flows more or less parallel to the coast; (ii) the surface water temperature in the Somali coastal basin appears to drop by 1°C or 2°C; (iii) the surface winds along the Somali coast strengthens to about 10–15 m.p.s.; and (iv) the surface temperature in the Somali basin drops further, signifying, perhaps, beginning of coastal upwelling. Coastal upwelling also appears to occur about this time or slightly later along the coast of Arabia. After upwelling has proceeded for sometime, the water surface temperature near the coast of Somalia drops to very low values. For example, near Ras Mabber (Lat. 9° N, Long. 51° E), the surface temperature recorded

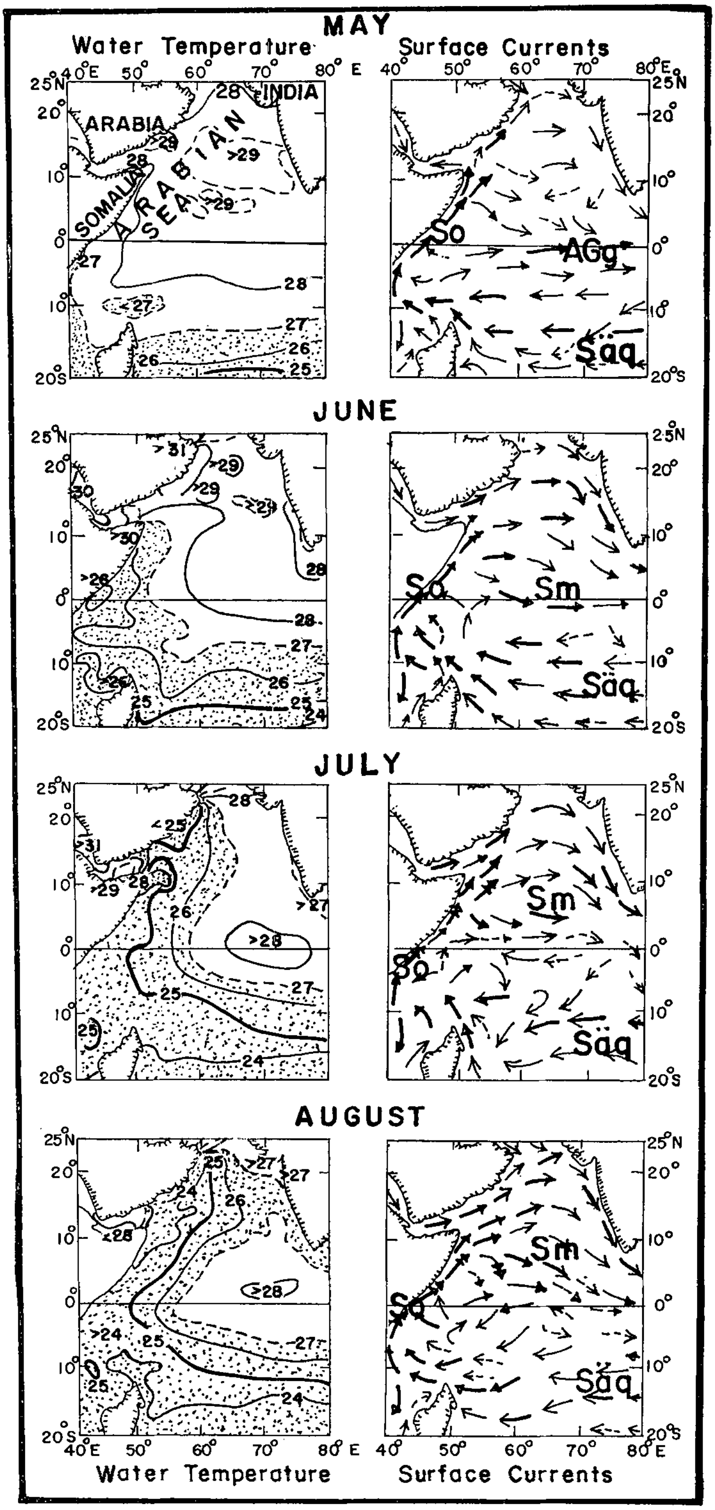

Fig. 1. Mean surface water temperature (°C) and currents (Sm/h) in the Arabian sea during May through August. The dominant surface currents shown are: AGg, Equatorial Countercurrent; So, Somali current; Sm, Southwest monsoon current; Säq, South equatorial current. The arrows have the following meanings: *Steadiness:* ⟶, Highly steady; ⟶, Moderately steady; ⇢, Unsteady. *Velocity:* ⟶, $\frac{1}{4}$ to $\frac{3}{4}$ Sm/h; ⟶, 1 to $1\frac{1}{2}$ Sm/h; ⟶▸▸, 2 Sm/h and above. Area with temperatures less than 27°C is stippled.

during Aug.–Sept. 1964 was below 14°C (Warren et al., 1966). There is support for such reports of low temperatures from satellite radiation data as well (Warnecke et al., 1971).

In a recent theory of the dynamic response of the Indian ocean to a pattern of wind-stress obtaining in equatorial Indian ocean after the onset of the westerly monsoon winds in the Arabian sea north of the equator, Lighthill (1969) visualises northward cross-equatorial flow of water along the western boundary of the equatorial Indian ocean where there are large regions of negative curl of wind stress and it is possible that the beginning of the movement of the south equatorial current into the Somali basin north of the equator towards end-May is part of the same process. The progressive lowering in the value of salinity in the Somali basin from May to June due to influx of fresh water carried by the South equatorial current appears to support this theory. After crossing the equator, the south equatorial current appears to merge with the Somali current and flow onward over the Arabian sea as the southwestmonsoon current.

There is evidence to suggest that the ocean currents that wash the shores of Somalia and Arabia serve to advect the upwelled cold water over the Arabian sea during period May through September. After upwelling has set in, the pattern of sea surface temperature changes, with the isotherms in the central Arabian sea gradually shifting eastward (Saha, 1970*a*). Fig. 1 shows the distributions of mean monthly sea surface temperature and surface currents in the Western Indian ocean during May through August (Deutsches Hydrographisches Institut, Hamburg, 1960). It shows, for example, that the 27°C isotherm which lies near a longitude of about 55° E along latitude 10° N during June advances to almost the west coast of India during August.

In the present paper it is proposed to study mainly the possible feed-back effects of the advection of cold water in the Arabian sea upon the atmospere, arising out of transformation of airmasses as they move over changing patterns of sea surface temperature. The meteorological phenomena that will receive particular attention are: (i) formation of low-level jet and wind maxima; (ii) strengthening of the intertropical convergence zone over northeastern Arabian sea and formation of a secondary convergence zone over southeastern Arabian sea; (iii) changing patterns of cloud distributions and formation of two broad bands of clouds over eastern Arabian sea; and (iv) rainfall discontinuities along the west coast of India between July and August.

2. Airmass transformations over the Arabian sea

Basically, there appear to be two major airmasses which enter into the circulation of the Arabian sea summer monsoon, one a hot, dry airmass of continental origin which enters the Arabian sea from a direction between west and south and the other a cool, moist airmass of maritime origin which after crossing the equator in the extreme Western Indian ocean enters the Arabian sea from the south (Findlater, 1969*a*; Saha, 1970*b*). Owing to interactions with the sea surface, both the airmasses get transformed in the lower layers as they move over the Arabian sea. In either case, although the interactions are highly complex, an approximate representation of temperature and specific humidity at a height Z after time t may be given by the well-known diffusion equations:

$$\frac{\partial T}{\partial t} = K_H \frac{\partial^2 T}{\partial z^2} \tag{1}$$

$$\frac{\partial q}{\partial t} = K_D \frac{\partial^2 q}{\partial z^2} \tag{2}$$

where T and q denote temperature and specific humidity respectively as functions of height Z and time t, and K_H and K_D the co-efficients of eddy diffusivity of heat and water vapour respectively as functions of Z and t.

Taylor (1915) (see also, Brunt, 1944) solves eq. (1) for a simple case in which a warm, continental airmass after moving over land with a uniform surface temperature T_0 enters a cool sea with uniform surface temperature T_1, assuming a constant co-efficient of eddy diffusivity of heat. He derives the following expression for temperature $T(Z, t)$ at height Z after time t;

$$T = T_0 - \beta z + (T_1 - T_0)\left\{1 - \frac{2}{\sqrt{\pi}} \int_0^{z/(4K_H t)^{1/2}} e^{-\mu^2} d\mu\right\} \tag{3}$$

Table 1. *Mean values of air temperature, TT(°C), and humidity-mixing-ratio, h.m.r. (g/kg), at surface and standard isobaric levels over Aden and Bombay during May through August, 1964*

Pressure level (mb)	Aden		Bombay	
	TT	h.m.r.	TT	h.m.r.
May 1964				
Surface	31.0	21.0	29.4	18.5
850	23.9	7.9	23.6	6.7
700	11.7	5.0	12.6	3.2
500	−6.2	1.2	−4.9	—
June 1964				
Surface	33.1	18.3	28.3	20.0
850	26.4	9.4	19.4	12.0
700	13.5	5.0	10.7	7.8
500	−7.9	1.5	−4.2	—
July 1964				
Surface	31.6	17.6	27.4	20.0
850	25.1	11.8	18.6	13.5
700	13.6	6.5	11.0	8.0
500	−7.0	2.7	−3.0	—
August 1964				
Surface	31.0	17.0	26.3	19.8
850	25.3	12.0	18.3	13.6
700	13.4	6.5	11.1	9.0
500	−7.4	2.7	−2.1	—

where β is the vertical lapse rate of temperature over the land, assumed constant.

Using eq. (3), Taylor shows that the height Z to which the effect of surface change of temperature $(T_1 - T_0)$ extends in time t is given by the approximate relation, $Z^2 = 4\ K_H t$. Taylor also solves eq. (1) in the case in which the change of surface temperature is not sudden but occurs at a finite rate after leaving the coast, but the solution differs only slightly from eq. (3) and the relation, $Z^2 = 4\ K_H t$, is considered good enough for this case as well.

The problem of airmass transformation over the Arabian sea during the northern summer, however, appears to be much more complex than the simple case referred to above. Here, the complexity arises largely on account of the following:

(*a*) the sea surface temperature over the Arabian sea is far from being uniform with distance from the coast. Also, owing to movement of cold water from west to east across central Arabian sea, the surface temperature is continually evolving with time. However, the general distribution during the peak monsoon month of July is a relatively cold sea west of longitude about 60° E and a warm sea east of this longitude.

(*b*) the co-efficient of eddy diffusivity varies with thermal stability and height. Over the western Arabian sea where the surface air gets rapidly cooled, air is very stable and the value of K is likely to be low. However, over the eastern Arabian sea where the cooled surface air gets warmed again, there is continual destabliisation of the lower atmosphere and the value of K is likely to be high.

A reasonable theory of airmass transformation over the Arabian sea should, therefore, take into account a distribution of sea surface temperature which is constantly changing and evolving with time and a co-efficient of eddy diffusivity of heat, momentum and water vapour, which is functionally dependent upon height and stability and also distance from the shore.

Systematic measurements of vertical profiles of temperature and humidity over the sea areas which can reveal the degree of airmass transformation over the Arabian sea are lacking. However, the transformation is likely to be much greater in the case of the hot, dry continental airmass because of the larger value of the factor $(T_1 - T_0)$ in eq. (3). Over the hot deserts of Somalia and Arabia T_0 may have a value exceeding 50°C, whereas over the equatorial Western Indian ocean T_1 may have a value around 26°C, during June. Table 1 which represents the mean values of the air temperature and humidity-mixing-ratio at Aden and Bombay during May through August, 1964, shows in a general way that the airmass at Bombay which lies on the downwind side of the Arabian sea is definitely cooler and more humid during the SW monsoon than that at Aden which is taken to represent conditions in the dry, warm continental airmass before it enters the Arabian sea from the south-west.

Available observations suggest that the depth of the modified continental airmass which moves over the northwestern part of the Arabian sea varies only a little with distance from the shore over the western Arabian sea where the surface is cold and airmass stable but increases rapidly over the south-eastern Arabian sea where the surface temperatures are comparatively high. A strong low-level tempera-

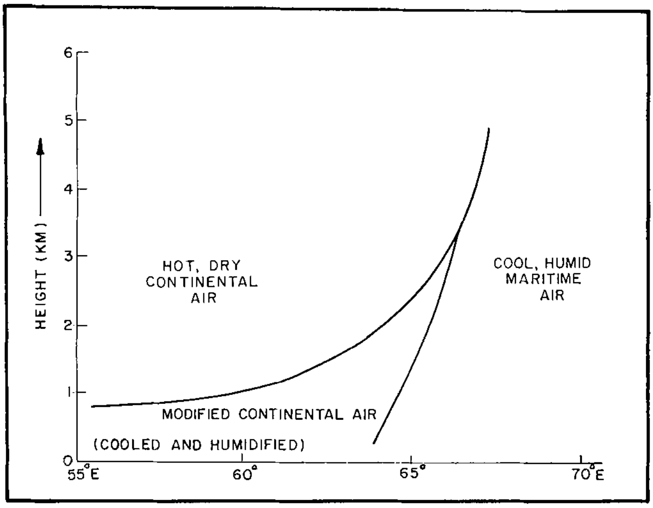

Fig. 2. Schematic diagram showing the relative dispositions of the hot, dry continental airmass, modified (cooled and humidified) continental airmass, and cool, humid maritime airmass in a vertical section through point 15° N, 60° E and normal to the coastline of Arabia, during the Southwest monsoon.

ture inversion which exists over the northwestern part of the sea is found to be weak and elevated over the south-eastern part (Bunker, 1965). A schematic diagram showing the relative dispositions of the different airmasses over the Arabian sea in a vertical section through point 15° N, 60° E and approximately normal to the coastline of Arabia during the southwest monsoon is presented in Fig. 2.

Lack of adequate upper-air observations prevents the boundary between the modified continental airmass and the maritime airmass over the Arabian sea to be accurately delineated. However, on the basis of some scanty observations which were available during the period of the International Indian Ocean Expedition (1963–65), a tentative boundary at 850 mb between the two airmasses during June–July, 1963 is shown in Fig. 3. It may be remarked that the warm, dry continental air-

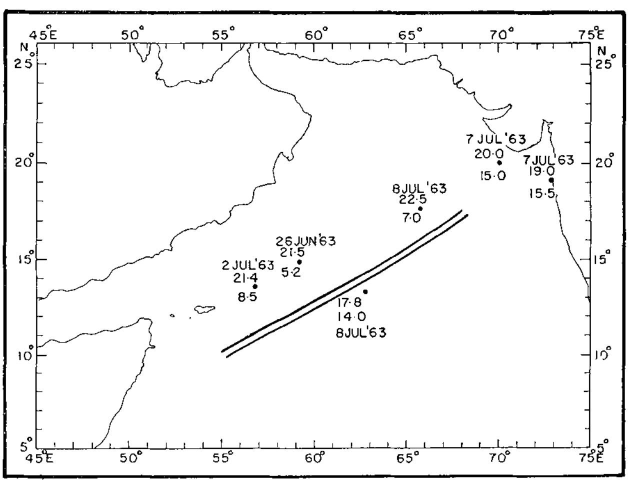

Fig. 3. A tentative boundary, indicated by double line, at 850 mb between warm, continental airmass and cool, maritime airmass over the Arabian sea during period late June to early July, 1963. At each plotted station, the upper figure gives the air temperature (°C) and the lower humidity-mixing-ratio (g/kg).

mass flowing from the west and lying to the north of the boundary, though considerably cooled and humidified at surface and in the lower layers, may retain some of the characteristics of the source region. This is suggested by high values of the radon content of the air, reported by Rama (1968).

3. The low-level jet and wind maxima

The formation of a low-level jet with maximum wind speed at a height of about 1.0 km a.s.l. over the western and central Arabian sea is of considerable interest. Bunker (1965) who studied the jet over Arabian sea with special aircraft and ships' data during the period of the International Indian ocean expedition finds that the maximum speed which is about 25 m.p.s. near the coast of Somalia decreases to about 15 m.p.s. near India. Observational evidence that the low-level jet over the Arabian sea is not an isolated or localised event but forms part of a major low-level aircurrent which originates in the southern Indian ocean near Mauritius and after crossing the equator near the coast of Somalia moves over the western and central Arabian sea as the southwest monsoon has been reported by Findlater (1969*b*). An important feature of the observations is that the low-level jet occurs not only over the coastal belts of East Africa and Somalia but also over open sea areas both north and south of the equator.

Bunker (loc. cit.) who offered an explanation of the low-level jet near the coast of Somalia states that the Somali jet is a thermal wind and the end result of complex interactions between the land, the sea and the atmosphere over the coastal region of Somalia. He states that the jet owes its origin to the strong pressure gradient between a ridge of high pressure that develops over the region of coastal upwelling and the axis of the trough of low pressure that extends into Somalia from the center of a deep low pressure over Arabia. He does not offer any explanation for the observed wind maxima over sea areas. According to Findlater (loc. cit.), the low-level jet over the Arabian sea may be associated with the intertropical convergence zone (ITCZ) over the region. This view runs into difficulty when it is realised that over many areas of the western Indian ocean where the low-level high-speed aircurrent is

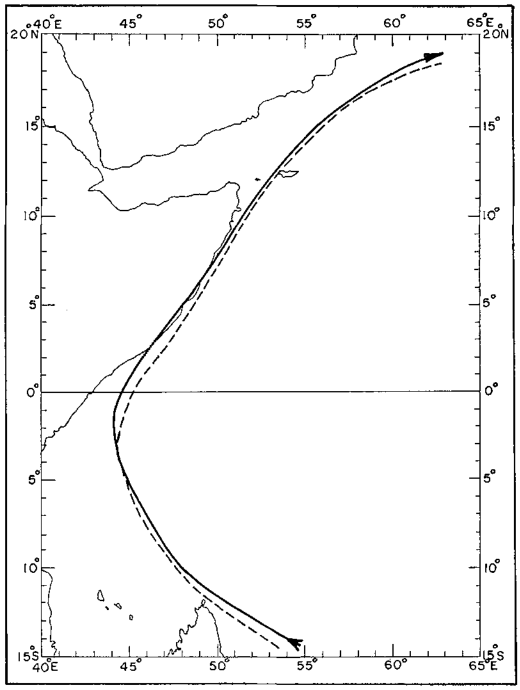

Fig. 4. Sketch showing the approximate path of the low-level-high speed aircurrent in relation to the axis of the minimum sea surface temperature in the Arabian sea during the SW monsoon.

observed, e.g. over southern Indian ocean, there is no ITCZ to be associated with the aircurrent. It, therefore, follows that the explanation for the low-level jet must be something else.

In a paper presented at the International symposium on the Indian ocean held at Cochin (India) in January, 1971, Saha & Suryanarayana (1972) noted that the path of the low-level high-speed aircurrent over the western Indian ocean during the northern summer was more or less coincident with the axis of the minimum sea surface temperature which runs from a point near the north coast of Malagasy to Coastal Somalia near the equator and then along the coast of Somalia to a northeasterly direction over the Arabian sea. Fig. 4 gives a sketch showing the approximate path of the low-level high-speed aircurrent in relation to the axis of the minimum sea surface temperature during the northern summer.

The thesis advanced in the present paper is that the observed low-level high-speed aircurrent over the Western Indian ocean may occur along the boundary between the cold ocean

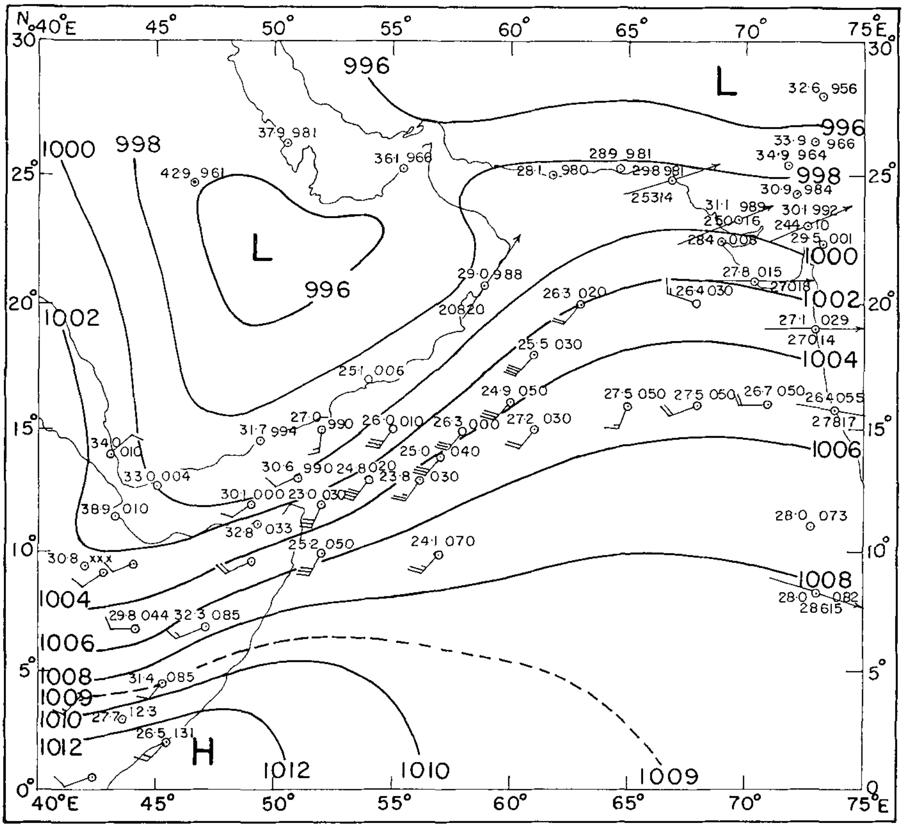

Fig. 5. Surface map, August, 1963, using conventional plotting symbols. Continuous lines are isobars (mb). *L* denotes low pressure and *H* high pressure. Long arrows at some stations give the winds at 900 m level.

current and its adjacent warm ocean because of the steep horizontal pressure gradient that develops locally across such a boundary in response to large temperature differences. A speed maximum occurs somewhat above the sea surface on account of the variation of the wind with height caused by the joint effects of surface friction and the thermal wind (Sheppard & Omar, 1952).

Detailed synoptic observations of temperature, pressure and wind at surface and in the upper air over western and central Arabian sea required to test the above-mentioned thesis are at present not available. However, during August 1963, as part of the IIOE, the research vessel *Atlantis II* took daily meteorological observations including upper-air Temps observations during its cruise over the Arabian sea. A composite chart showing the surface observations taken by *Atlantis II* along with mean values of the parameters over neighbouring land areas during August 1963 is presented in Fig. 5.

Fig. 6 which gives the distribution of air temperature, barometric pressure, and the wind speed at surface along a line passing through point 10° N, 55° E and approximately normal to the coastline of Arabia during August, 1963, as deduced from Fig. 5, appears to bring out clearly the relationship of the jet with surface temperature and pressure gradients. It should be emphasised that it is the local steep horizontal gradient of pressure across the boundary of the cold ocean current and not the pressure gradient between the cold sea and the neighbouring hot land, that is directly responsible for the observed jet.

Fig. 6 shows that for a horizontal temperature gradient of about 5°C/100 km between distances 250 km and 400 km from shore, the

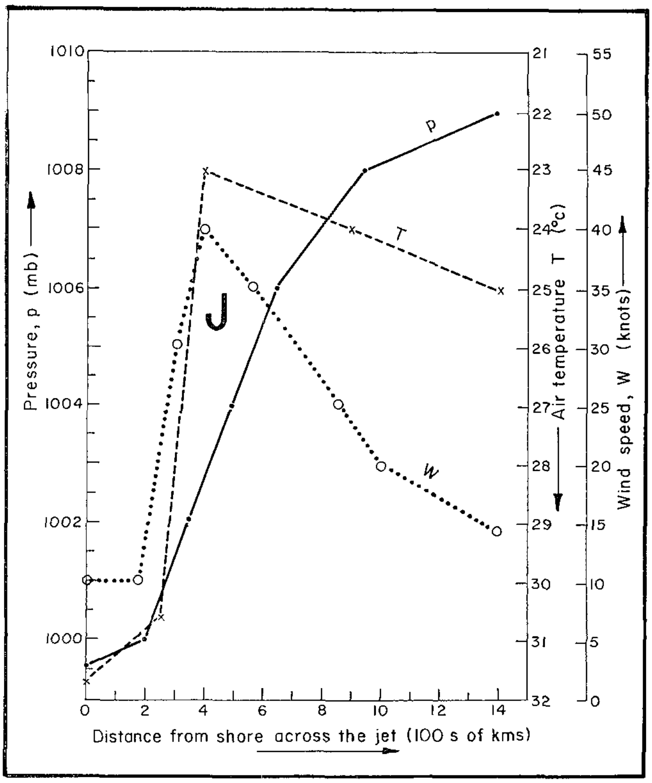

Fig. 6. Distribution of surface air temperature, barometric pressure, and wind speed along a line passing through the point 10° N, 55° E and approximately normal to the Arabian coastline during August, 1963, as deduced from Fig. 5.

observed horizontal pressure gradient is found to be about 1.25 mb/100 km. Assuming geostrophic approximation and a value of 1.20×10^{-3} g/cm^3 for air density and 3.10×10^{-5} sec^{-1} for the Coriolis parameter appropriate for a mean latitude of about 12.5° N, the geostrophic wind corresponding to the above-mentioned pressure gradient works out to be about 33 m.p.s. or 66 knots. As against this computed speed which is likely to be attained above the layer of surface friction, the observed maximum value of the windspeed at surface is about 40 knots (Fig. 5).

4. Strengthening of the ITCZ and formation af a secondary convergence zone

(a) *Strengthening of the ITCZ over northeastern Arabian sea*

It is now well-established (Sawyer, 1947; Thompson, 1965) that the intertropical convergence zone associated with the continental heat low over Asia and Africa during the northern summer lies along a sloping surface of discontinuity separating the warm, continental airmass with easterly flow to the north from the cool, maritime airmass with westerly flow to the south and that the belt of cloudiness and precipitation associated with the ITCZ is situated a few degrees of latitude equatorward of the surface position of the trough of the heat low. Sawyer who studied the ITCZ over northwestern India found in a specific case during August, 1945 that while the surface position of the ITCZ lay along a mean latitude of about 28° N, the associated belt of cloudiness and precipitation lay between Karachi (25° N, 67° E) and Poona (18.5° N, 73.8° E). Observations show that the ITCZ over northeastern Arabian sea is rather weak and inactive during June, but becomes strong and active during July and August when cold water advected by the southwestmonsoon ocean current advances towards India.

Table 2. *Differences of temperature (°C) and zonal wind component (m/sec) between Jodhpur and Bombay (Jodhpur–Bombay) at surface, 850, 700, and 300 mb during period May through October*

ΔT is temperature difference; Δu is difference of zonal wind component

	Surface		850 mb		700 mb		500 mb		300 mb	
	ΔT	Δu	ΔT	Δu	ΔT	Δu	ΔT	Δu	ΔT	Δu
May	+5.6	−0.70	+4.0	+3.61	+0.3	+4.06	−2.3	+7.62	−2.0	+12.62
June	+5.9	−0.97	+6.3	−1.39	+2.7	−2.60	−0.5	+0.51	+0.7	+ 8.81
July	+4.8	−2.90	+4.9	−7.50	+2.9	−9.46	+1.1	−3.80	+2.6	+ 3.57
August	+3.2	−2.77	+4.1	−5.94	+2.4	−6.32	+0.6	−2.23	+1.6	+ 4.35
September	+3.1	−1.71	+3.6	−2.03	+1.1	−2.86	0	+0.72	+0.6	+ 8.05
October	+0.8	−1.61	0	+3.54	−1.1	+4.57	−2.1	+6.55	−1.6	+15.10

Since the intensity of the ITCZ is, *inter alia*, dependent upon the horizontal meridional gradients of temperature and wind across the sloping surface of discontinuity, it appears likely that an increase in the gradient of temperature caused by increased cooling of the atmospheric boundary layer over the Arabian sea through its effect upon the gradient of wind would lead to increased positive relative vorticity and, hence, strengthening of the ITCZ over northeastern Arabian sea. A stronger north–south horizontal temperature gradient across the ITCZ may result from a net cooling of the lower tropospheric airmass lying to the south of the zone over the northeastern Arabian sea as a result of its complex interactions with the underlying cold sea surface. During June, cold water advection in the Arabian sea is confined to its western part and may have little feed-back effect upon the atmospheric temperatures over northeastern Arabian sea. However, during the following two months when cold water extends over a large part of the Arabian sea, its feed-back effect upon the atmosphere in lowering its temperatures may be considerable.

Reliable meteorological observations over the Arabian sea to test the above hypothesis are practically non-existent. However, upper air data in the form of monthly long-term averages at stations lying near a vertical section along 73° E meridian which passes near the west coast of India have recently been presented by Ramage & Raman (1972) and are also available from the records of the India Meteorological Department. Table 2, taken from the latter source, gives the value of the differences of temperature and zonal wind components between Jodhpur (26°18′ N, 73°01′ E) and Bombay (19°07′ N, 72°51′ E) at surface, 850, 700, 500 and 300 mb during period May through October. If the data presented in Table 2 are any indication of conditions over northeastern Arabian sea, they do seem to suggest that the horizontal meridional gradients of temperature and zonal wind component especially at mid-tropospheric levels of 700 and 500 mb are distinctly stronger during July and August than during June or any of the other months. While interpreting the data presented in Table 2, the effects of the equatorward slope of the surface of discontinuity must be borne in mind. The seasonal changes of temperature must also be considered. In spite of the cooling over the northeastern Arabian sea, the horizontal temperature gradient up to 850 mb decreases since the air temperature over the land decreases more from June to July and August than the sea temperature. For example, Jodhpur air temperature drops 3.5°C while the air temperature over the sea drops only 1° to 2°C. It appears likely that the local intensification of the ITCZ at mid-tropospheric levels over the northeastern Arabian sea leads to the genesis of a mid-tropospheric cyclone described by Miller & Keshavamurthy (1965).

(b) *Formation of a secondary convergence zone over southeastern Arabian sea*

An important effect of the lowering of air temperature over a wide belt of latitudes in the Central Arabian sea, say between 10° N and 16° N, is strengthening of the westerly winds with height up to mid-tropospheric levels due

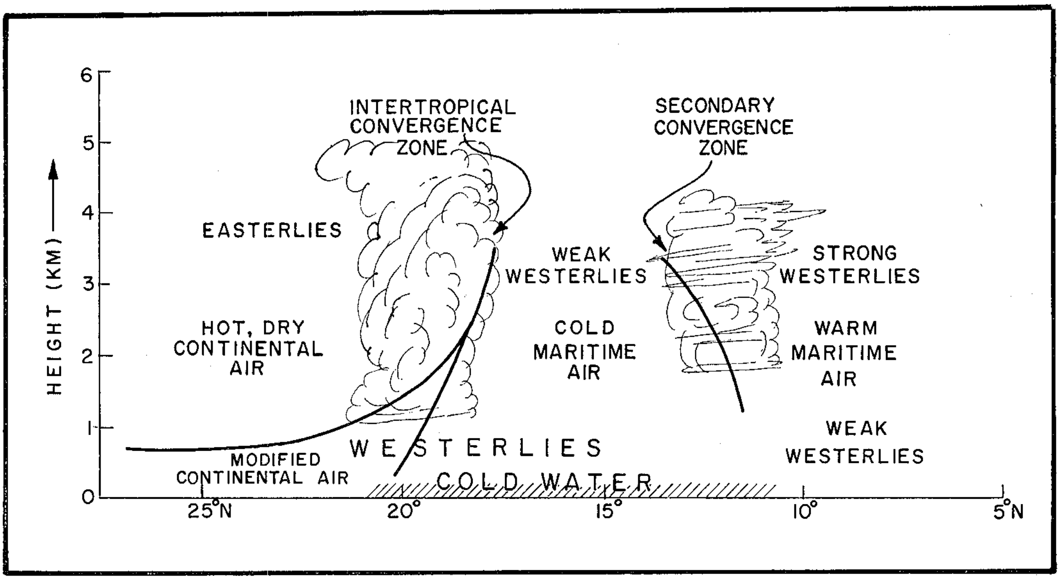

Fig. 7. Schematic diagram showing the locations of the intertropical convergence zone over northeastern Arabian sea and a secondary convergence zone over southeastern Arabian sea in a vertical meridional section near the west coast of India. Approximate relative positions of cold surface water (hatched area), airmasses and wind systems are indicated.

to thermal wind effect over the southeastern Arabian sea and adjoining southern Indian peninsula south of about 10° N. The existence of a belt of strong westerlies in the altitude range of 1.5 to 3.0 km a.s.l. over extreme southern India has been shown by Joseph & Raman (1966). Thus although a horizontal anticyclonic wind shear may exist at low levels over southeastern Arabian sea, an appreciable cyclonic wind shear and positive relative vorticity characteristic of a zone of convergence may develop in the upper layers of the lower troposphere over the area. However, since the horizontal temperature gradient across the zone is likely to be small, the convergence zone is generally weak.

Fig. 7 gives a schematic diagram showing the locations of the ITCZ over the northeastern Arabian sea and a secondary convergence zone over the southeastern Arabian sea, in relation to a wedge of cold water and a dome of cold airmass over Central Arabian sea, in a vertical meridional section near the west coast of India.

5. Changing patterns of cloud distribution and formation of cloud bands

Complex ocean–atmosphere interaction leading to conditions favourable for cloud-free and cloudy regions over the Arabian sea during the northern summer has been qualitatively discussed by Saha (1971). In general, the western Arabian sea (west of about 60° E) where the ocean surface is cold is clear of clouds. Clouds develop over the eastern Arabian sea which is comparatively warm. However, the distribution and structure of clouds that develop over the eastern Arabian sea vary from month to month. These characteristic variations are well depicted in Fig. 8*a–d* which show the relative cloud cover during May through August, 1967–70, based on photographic signals from meteorological satellites, as presented in a global atlas by Miller & Feddes (1971).

Fig. 8 shows that during May, there is very little clouding over the Arabian sea although the sea surface is quite warm with temperatures ranging from 29°C to 31°C. During June, when intense upwelling has set in along the coasts of Somalia and Arabia and cold water is being advected by the SW monsoon current towards India, the western Arabian sea is clear of clouds but there is considerable amount of clouding over the eastern Arabian sea which continues to be warm. During July, cold water is advected further towards India and the advection is clearly shown by the cloud-free region in the middle Arabian sea in the photo-

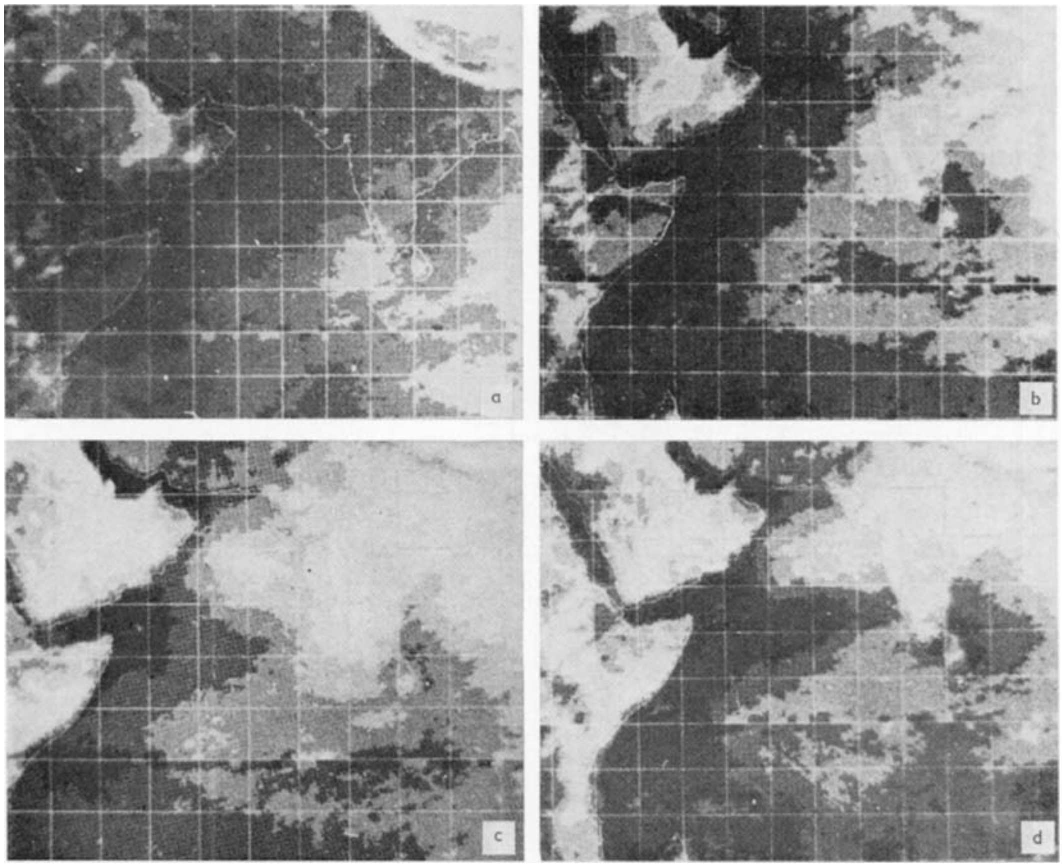

Fig. 8. Maps showing the relative cloud cover during May through August, 1967–70 based on photographic signals from meteorological satellites, as presented in a global atlas by Miller & Feddes (1971): (*a*) May; (*b*) June; (*c*) July; and (*d*) August.

graph for this month in Fig. 8*c*. A prominent cloud band appears over the northeastern part of the Arabian sea along latitude about 20° N during this month. Also, as the cold water cuts through the heart of the Arabian sea, one can see evidence of a second convergence zone appearing over the southeastern Arabian sea. The above processes are enhanced during August when the cold water advection registers its maximum eastward advance (Fig. 8*d*). Two broad bands of clouds appear over the eastern Arabian sea, the mean position of the northern band continuing to be along latitude about 20° N as mentioned earlier while that of the southern band being along latitude about 10° N. Both the cloud bands weaken or disappear during September when water temperatures in eastern Arabian sea begin rising except in a narrow coastal belt near Kerala where some local upwelling occurs.

6. Rainfall discontinuities along the west coast of India

Measurements of precipitation over oceanic areas are generally scarce. Even IIOE records are deficient in this respect and we have few authentic measurements of precipitation over the Arabian sea. We have, of course, the island stations at Minicoy and Amini Dibi and a number of recording stations along the west coast of India. Ananthakrishnan & Pathan (1971) who studied the space-time distribution of pentad rainfall at different stations along the west coast of India as well as at Arabian sea Islands find that sometime about the middle of August there is a spectacular decrease in the amount of pentad rainfall at a number of stations. Mooley (1971) adopting the criterion of quartiles for defining marked climatological discontinuity, e.g. lower quartile of rainfall distribution for a month being more than the upper quartile of rainfall distribution for the next month, finds marked rainfall discontinuity, i.e., decrease from July to August at Vengurla, Mangalore and Cochin on the west coast in the latitude belt 10°–16° N. No such marked discontinuity was found at Bombay in the north and Trivandrum and Minicoy in the south. Aminidivi at 11° N appeared to be an exception in that it did not show any marked discontinuity. Since cold water by its interaction with air inhibits cloud growth and precipitation and since such water advected by the southwest-monsoon current makes its farthest eastward advance towards the west coast of India during August, it appears likely that there should be rainfall discontinuity of the kind observed between July and August at stations approached by cold water, i.e., those lying between latitudes about 10° N and 16° N along the west coast. A possible physical relationship between the observed variation in the west coast rainfall between July and August and the advection of cold water across Central Arabian sea towards India was suggested earlier by Saha (1970*a*).

7. Conclusions

The hypothesis that is advanced in the present paper is that formation of a number of atmospheric phenomena such as low-level high-speed aircurrents, double convergence zones and associated cloud bands and rainfall discontinuity in the Arabian sea during the northern summer may arise as feed-back effects of the sea with complex distributions of surface temperature upon the overlying atmosphere. Advection of a broad wedge of cold water from the coastal basins of Somalia and Arabia towards India by the SW monsoon current during June through August may play a dominant role in this interaction. However, the tentative character of the ideas advanced and conclusions drawn in the present paper in the absence of detailed meteorological and oceanographic observations must be emphasised. It may be hoped that the proposed monsoon experiment (MONEX) over the Arabian sea to be conducted as part of the First GARP Global Experiment during 1977 will throw further light on the problem.

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НЕКОТОРЫЕ АСПЕКТЫ ЛЕТНЕГО МУССОНА В РАЙОНЕ АРАВИЙСКОГО МОРЯ

Обсуждаются некоторые наблюдаемые особенности летнего муссона Аравийского моря, такие как образование сильных течений воздуха на низких уровнях, усиление внутритропической зоны конвергенции над северовосточной частью Аравийского моря и образование вторичных зон конвергенции над юго-восточной частью, изменение в распределении облаков и формирование двойных облачных полос над восточной частью Аравийского моря, формирование резких изменений в распределении осадков вдоль западного берега Индии с июля по август. Все эти вопросы обсуждаются в связи с возможной комплексной трансформацией воздушных масс, пересекающих Аравийское море, при непрерывно меняющемся поле температуры поверхности в период с мая по август. Выдвигается гипотеза, что вслед за подъемом глубинных вод у берегов Сомали и Аравийского п-ва в конце мая или начале июня, слой холодной воды переносится через центральную часть Аравийского моря юго-западным муссонным течением и что именно обратный эффект этой адвекции на атмосферу ответственен за наблюдаемые особенности муссона.