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Evolution of the temperature and moisture fields over Arabian Sea from pre-onset to onset phase of the monsoon during 1979

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सार— मॉनेक्स 1979 की अवधि में अरबसागर में वायुयान और जलयान आँकड़ों का उपयोग करके मानसून के शुरू होने से पूर्व और शुरू होने की अवस्था के तापमान और नमी के क्षेत्रों में हुए खास-खास परिवर्तन का विवेचन किया गया है। अत्यधिक स्पष्ट परिवर्तन आपेक्षिक आर्द्रता के यामोत्तर अनुप्रस्थ समूहों में देखा गया। मध्य और पूर्व अरबसागर में 10° उ० के दक्षिण में मध्य क्षोभमंडल (750 मि० बार से ऊपर) में भूमध्यरेखीय क्षेत्र में मानसून के शुभारंभ के बाद उष्ण वायु नम वायु का स्थान ले लेती है। उत्तर पश्चिम अरबसागर के ऊपर का मध्य क्षोभमंडल, जो शुभारंभ से पूर्व प्रमुखतः शुष्क होता है, शुभारंभ के बाद बहुत ज्यादा आर्द्र हो जाता है। उत्तरी अरबसागर में बढ़ी हुई गति वाले ऊर्ध्वाधर परिसंचलन और मध्य अरबसागर और 10° उ० के दक्षिण में भूमध्यरेखीय अक्षांशों पर दक्षिणवर्ती प्रतिपूरक कम हुई गति परिकलित 'ω' क्षेत्र में देखी गई, जिससे उपरोक्त उष्णता का कारण स्पष्ट हो जाता है।

ABSTRACT. Prominent changes in the temperature and moisture fields over Arabian Sea from the pre-onset to onset phase of the monsoon during 1979 using aircraft and ship data have been discussed. The most revealing change was observed in the meridional cross sections of relative humidity. After the onset, dry air replaces moist air in the equatorial regions in the middle troposphere (above 750 mb) south of 10 deg. N over central and east Arabian Sea. Middle troposphere over northwest Arabian Sea, which is mainly dry before the onset, becomes highly humid after the onset. Vertical circulations with rising motion over north Arabian Sea and compensatory descending motion southward over central Arabian Sea and over equatorial latitudes to the south of 10 deg. N are observed in the computed ω field, which explain the above dryness.

1. Introduction

During 1979, onset of southwest monsoon over most part of the Arabian Sea and west coast of India was delayed by 10-12 days from the normal dates. It advanced upto latitude 5 deg. N in Arabian Sea on 7 June. Onset over Kerala took place after four days, *i.e.*, on 11 June as a feeble current. Further northward advance was in association with a low pressure system which formed over southeast Arabian Sea on 14 June and moving in a northerly direction concentrated into a depression on 17 June. Thereafter it took west-northwesterly course and crossed Arabian coast on 20 June near 20 deg. N. The northward advance of the monsoon was maintained as the depression formed over north Bay of Bengal on 23 June and moved in westnorthwesterly direction. Under the influence of these two systems monsoon advanced rather rapidly and covered Arabian Sea and Indian Peninsula within the course of ten days, *i.e.*, between 15 & 24 June.

During the Arabian Sea phase of the Monsoon Experiment 1979 (MONEX) an excellent coverage of upper air data was provided over Arabian Sea from the research aircraft flight missions and MONEX ships. These observations alongwith conventional upper air observations from land stations have been utilised to study the changes in the horizontal and vertical distribution of temperature and moisture which took place over Arabian Sea from pre-onset to the established phase of the southwest monsoon.

On 7 June the Inter Tropical Convergence Zone (ITCZ) was located around 6 deg. N and was quite well defined in the satellite cloud imagery between 65 deg. and 75 deg. E. On 27 June, after the monsoon was established, a well marked cyclonic circulation was centred over Gujarat and adjoining northeast Arabian Sea between 850 and 400 mb with an east-west trough running over north Arabian Sea. The data coverage during this period was very good. In view of availability of data and typicality of the synoptic situation as mentioned above, we have selected period 6-7 June and 27 June 1979 for the study of these two phases of pre-onset and onset of monsoon.

2. Temperature distribution over Arabian Sea before and after the onset of monsoon

Figs. 1 to 3 illustrate the analysis of temperature field at 850, 700 and 500 mb on 7 June and 27 June 1979. The charts reveal the following salient features.

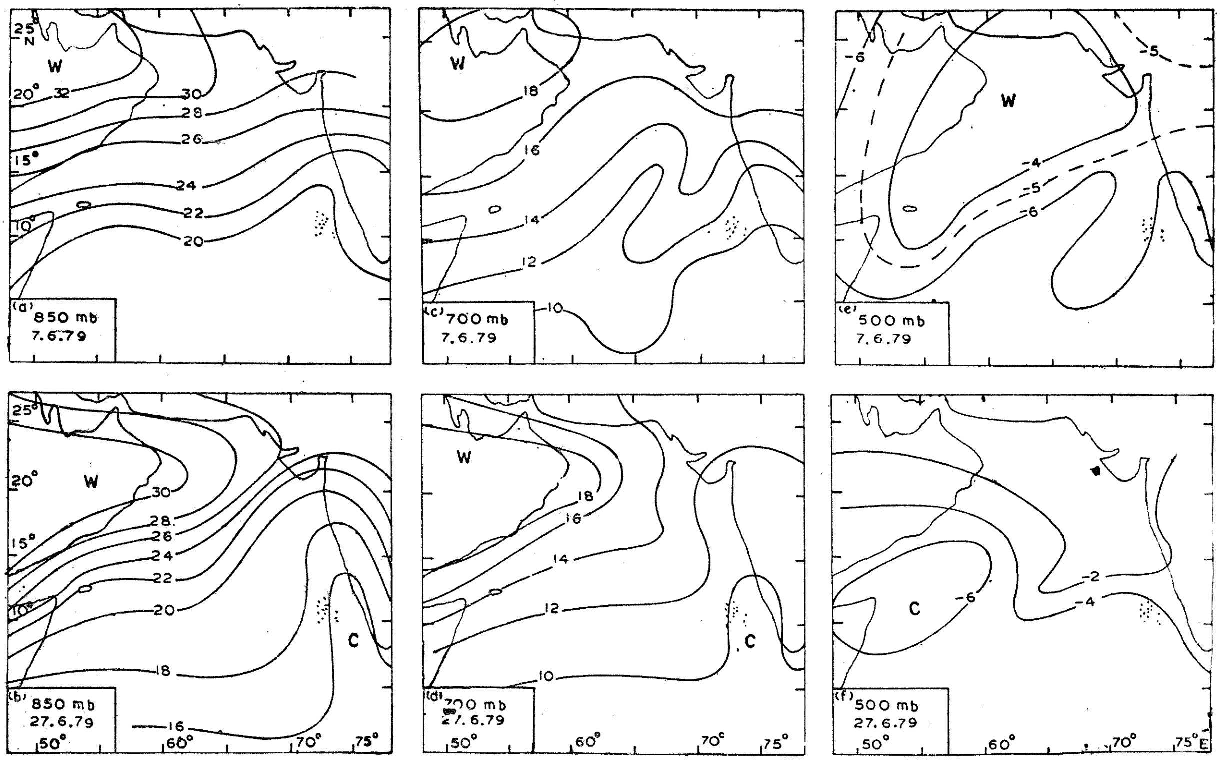

Fig. 1 Fig. 2 Fig. 3

Figs. 1-3. Temperature (°C) distribution at 850 mb (Fig. 1), 700 mb (Fig. 2) and 500 mb (Fig. 3) over Arabian Sea during the pre-onset and established phase of the monsoon in 1979

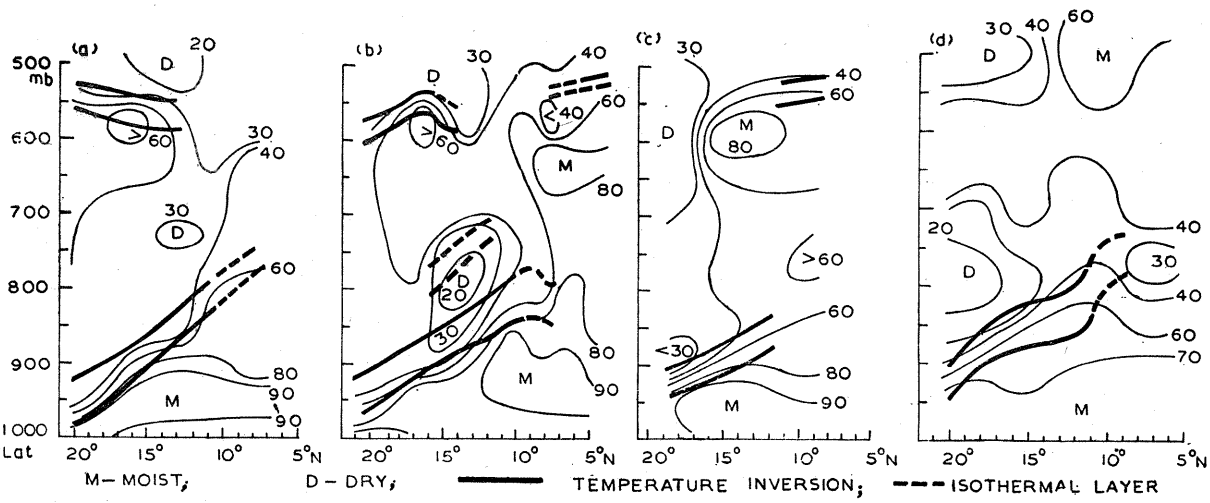

Fig. 4. Vertical cross-sections of relative humidity (%) during the pre-onset phase of the monsoon along the meridian of (a) 60° E on 7 June, (b) 65° E on 7 June, (c) 70° E on 6 June and (d) 75° E on 7 June 1979

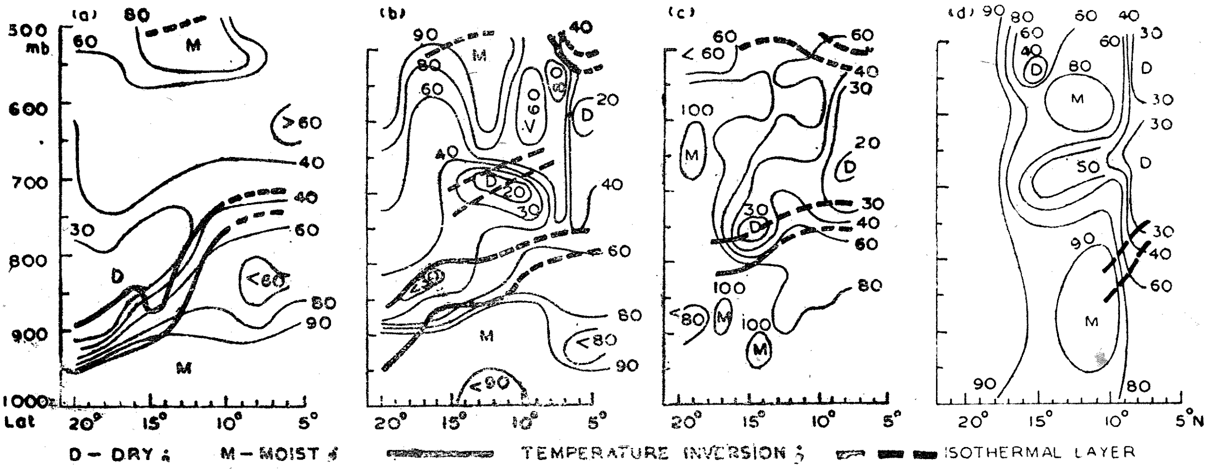

Fig. 5. Vertical cross-sections of relative humidity (%) during the established phase (27 June 1979) along the meridian of (a) 60° E, (b) 65° E, (c) 70° E and (d) 75° E

(a) *850 mb* — The dominating feature of the temperature distribution at 850 mb is the region of warmest temperature over Arabia and adjoining Persian Gulf area in both the phases. The temperature gradient is directed equatorward.

During the pre-onset period the isotherms have a zonal orientation generally, with a nearly uniform north-south temperature gradient of about 0.7 deg. C/degree latitude between 8 deg. N and 20 deg. N. After the monsoon had established, the orientation of isotherms changed from east-west to northeast-southwest, the effect being more pronounced east of 60 deg. E. As an instance, the latitudinal northward shift in the position of 20 deg. C isotherm along 70 deg. E (east Arabian Sea) is as much as 8 deg. of latitude from about 12 deg. N on 7 June to 20 deg. N on 27 June. On the other hand the same isotherm along 50 deg. E meridian (on the east African coast), shifted little. This change in the orientation of isotherms and their northward shift in the eastern parts of the Arabian Sea, however, signifies the spread of the cold monsoon air mass from southwest to northeast Arabian Sea from the pre-onset to the onset phase of the monsoon. A marked increase in the temperature gradient also developed between 20 deg. and 30 deg. isotherms whereas a flat temperature field existed equatorward of the 20 deg. isotherm during both the phases.

A poleward bulge in the 20 deg. C isotherm over the region of Arabian Sea islands was noticed (Fig. 1) on 7 June. This bulge is perhaps indicative of the northward intrusion of the monsoon air over the area. The tongue of cold air extended northward along the west coast and became more prominent after the onset.

The northward march of isotherms over east Arabian Sea, appearance of cold tongue along the west coast and a flat temperature field south of about 10 deg. N are thus the most significant features associated with the advancing monsoon current.

(b) *700 mb* — The warmest region continues to be over Arabia and adjoining Persian Gulf in both the phases. The north-south temperature gradient is a little weaker (0.6 deg. C/Lat.) as compared to 850 mb. The temperature gradient along the west coast weakened and the cold tongue is not as marked as at 850 mb after the onset (Fig. 2).

(c) *500 mb* — The region of the warmest temperature lies over north and west Arabian Sea and adjacent land area. There was a general warming by about 2 deg. C from 7 to 27 June over most parts of the Arabian Sea except over western part where a region of colder temperature appears after the onset (Fig. 3).

3. Meridional-vertical cross sections of temperature and relative humidity

The vertical cross sections of temperature and relative humidity were prepared from 5 deg. N to 20 deg. N along 60 deg., 65 deg., 70 deg. and 75 deg. E. The cross sections of relative humidity are presented in Figs. 4 & 5. The outstanding features of the temperature cross sections, *viz.*, the inversion layers have been superimposed on the humidity cross sections for a better appreciation of the two parameters which are inter-related. The cross sections reveal the following salient features :

Pre-onset phase

It will be seen from the cross section of 7 June along 60 deg. E (Fig. 4) that a pronounced low-level inversion exists with its base, lowest and close to the surface over northwest Arabian Sea. The base of the inversion rises considerably equatorward to above 800 mb as it approaches the northern boundary of the monsoon air (the ITCZ was quite active between 5 deg. and 7 deg. N Lat. on 7 June). It also rises slowly eastward by about 50 mb from 60 deg. to 75 deg. E (Fig. 4). The inversion is non-existent in the vicinity of the ITCZ.

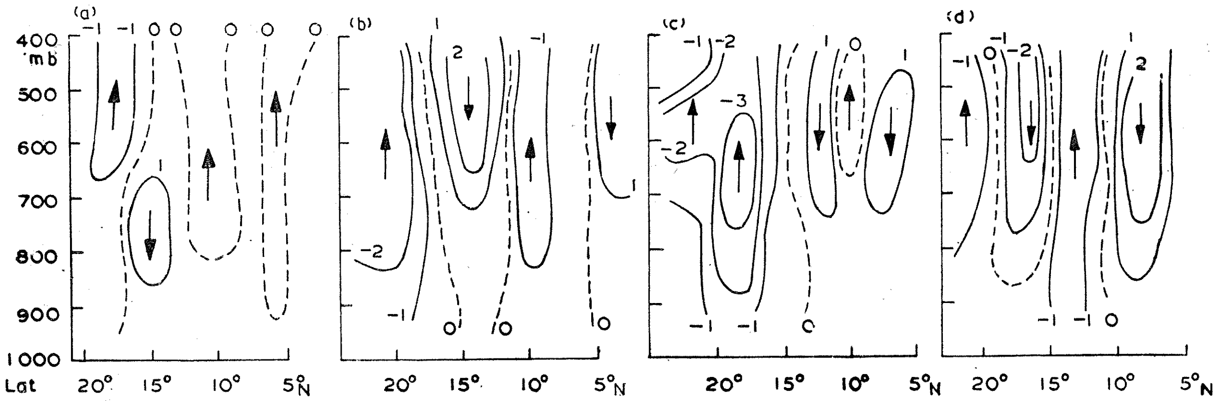

Fig. 6. Cross-section of vertical velocity (10^{-3} mb/sec) along (a) 60°, (b) 65°, (c) 70° and (d) 75° E on 27 June 1979

Over the north and west Arabian Sea the surface moist layer (with relative humidity exceeding 60%) is very shallow and is immediately capped by a strong temperature inversion. Pockets of extremely dry air with relative humidity 20-30% lie above the inversion. The depth of the moist layer increases both eastward and southward. The increase, however, is more rapid towards the south particularly over the west and central Arabian Sea. Interestingly, the depth of the surface moist layer along 75 deg. E is again shallow in the equatorial region, where it is confined to only below about 900 mb and is overlain by a layer of dry air between 850 and 700 mb.

A shallow inversion layer is also evident around 600 mb level over the north Arabian Sea, north of about 15 deg. N latitude with extremely dry air prevailing above.

Established phase

The depth of the surface moist layer over the north and west Arabian Sea shows a little increase from the pre-onset phase with a strong low-level temperature inversion still persisting in the region (Fig. 5). A significant increase in the moist layer is, however, observed over the east Arabian Sea. Such an increase in the moisture (precipitable water) is also observed by Rao *et al.* (1980). Along 70 deg. E Long., the low-level inversion is lifted to about 800 mb with the advance of monsoon air and extends further south. The inversion is absent further east along 75 deg. E. A shallow stable layer, however, appears at about 800 mb south of 10 deg. N along this meridian. In the moisture field the most revealing change from the pre-onset to the established phase of the monsoon occurs in the equatorial latitudes south of about 10 deg. N over the central and east Arabian Sea, where the air becomes extremely dry. Moist air replaces dry air of the pre-onset phase in the middle troposphere over north Arabian Sea.

4. Discussion

From the foregoing it is evident that systematic changes occur in the moisture regime in lower and middle troposphere as the monsoon advances. The equatorial troposphere becoming dry after the onset of monsoon is the most interesting aspect of these changes. The presence of dry air in the equatorial latitudes after the onset of monsoon seems to be a persistent feature which results in the striking abnormality — the lack of cloudiness in this region in the southwest monsoon period. One can perhaps link up this phenomenon with the vertical motion fields of the ITCZ and its movement northward as the monsoon advances. The structure of ITCZ has been studied in detail during the preceding few years by Estoque (1975) over the central regions of tropical north Atlantic and north Pacific Oceans on the basis of observations collected during Atlantic Trade Wind Experiment (ATEX) and Line Island Experiment (LIE), Godbole and Ghosh (1975) from ISMEX-73 data over north Indian Ocean, and Estoque and Douglas (1978) over the GATE area of Atlantic. From these studies it emerges that ITCZ is associated with warm and dry air some distance away on either side of its location. Estoque has proposed a model for the synoptic scale structure of the ITCZ over mid-oceanic regions of Atlantic and Pacific. According to his model the ITCZ system forms a vertical circulation cell with rising motion taking place in the central convergence zone and compensatory descending motion in the vicinity on both sides of the ascending core, resulting in warming and drying of the air. The

TABLE 1

Monthly and seasonal rainfall (cm) during June to September

	Jun	Jul	Aug	Sep	Seasonal
Calicut	87.1	86.0	40.5	21.5	235.1
Trivandrum	33.1	21.5	16.4	12.3	83.3

synoptic aspects of ITCZ and Equatorial Trough have also been studied by Datta *et al.* (1981) for pre-onset and onset phases of the monsoon.

The presence of extremely dry air in the middle levels over the equatorial region of east Arabian Sea and also over the central Arabian Sea after the full onset of monsoon suggest the existence of large scale sinking motion in these areas. A quantitative assessment of the vertical motion field (ω) over the Arabian Sea has been made by computing vertical velocities (ω) with the help of kinematic method from the upper air data of 27 June 1979. Fig. 6 shows the vertical cross section of 'ω' along 60 deg., 65 deg., 70 deg. and 75 deg. E.

It may be seen that downward motion occurs in the middle levels over central Arabian Sea east of 65 deg. E. Over east Arabian Sea strong descending motion is also observed in the middle levels over the equatorial region to the south of 10 deg. N along 75 deg. E, where extreme dryness extends through a deep layer. Another feature of interest is that upward motion occurs over the whole of north Arabian Sea, with stronger upward motion occurring over northeast Arabian Sea (at 65 deg. and 70 deg. E) particularly in the middle levels. The strong upward motion over north Arabian Sea is apparently associated with the well marked mid-tropospheric low, the east-west trough over north Arabian Sea and neighbourhood. Compensating downward motions of nearly equal magnitude are observed immediately to the south of the trough, with maximum occurring along 75 deg. E. This pattern of ascending motion in the trough region and the compensatory descending motion south of it agrees well with the model of ITCZ described earlier by Estoque (1975), Godbole & Ghosh (1975), and Estoque & Douglas (1978). The assessment of vertical motion field in this study is, however, based on single day's data. Detailed study with more extensive data is in progress.

It may be of interest to mention that the rainfall decreases on the west coast south of about 14 deg. N inspite of greater heights of the Ghats (Rao & Desai 1974), and abruptly to south of about 10 deg. N as would be apparent from the comparison of monthly and seasonal monsoon rainfall of Calicut (11 deg. 5'N, 75 deg. 47'E) and Trivandrum (08 deg. 29'N, 76 deg. 57' E) on the west coast of Indian Peninsula is shown in Table 1.

The abrupt decrease of rainfall south of 10 deg. N as reflected in the rainfall data of Trivandrum may perhaps be due to the sinking motion stated above which thus appears to be a climatological feature. This phenomenon may also account for no significant variations observed by Mukherji (1962) in the amount of precipitable water before and after the onset of monsoon. Rao and Desai (1974) have attributed the decrease of rainfall over southern west coast to the lower level divergence and the absence of drier air above the moist current over the area. The present study, however, shows that dry air of subsidence origin is present above the lower moist monsoon air in this area. The subsidence might restrict the growth of clouds and occurrence of rainfall to the south of 10 deg. N.

5. Concluding remarks

The study brings out the following important features in the evolution of temperature and moisture fields from the pre-onset to the established phase of the monsoon.

The most significant change in the temperature field occurs at 850 mb where orientation of isotherms changes from east-west in the pre-onset phase to northeast-southwest, east of 60 deg. E in the established phase and northward march of the isotherms over the east Arabian Sea, signifying the spread of monsoon air from southwest to northeast Arabian Sea.

Analysis of meridional cross sections of relative humidity over Arabian Sea, has shown a significant change in the moisture distribution from the pre-onset to the established phase of the monsoon. Dry air replaces moist air in the equatorial region in the middle troposphere (above 750 mb) south of 10 deg. N over central and east Arabian Sea. Middle troposphere over northwest Arabian Sea, which is mainly dry before the onset, becomes highly humid after the onset. Vertical circulations with large scale rising motion are seen to occur over north Arabian Sea. Compensatory descending motion southward over central Arabian Sea and over equatorial latitudes to the south of 10 deg. N is proposed to account for the observed dryness in the middle levels of central Arabian Sea and equatorial region after the monsoon is established.

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