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Sea and air temperatures distribution over the Arabian Sea during southwest monsoon, 1973

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ABSTRACT. Based on MONEX 1973 data, the sea surface and air temperatures in the troposphere over the Arabian Sea during spells of active and weak monsoon over India have been analysed.

The studies show that a cold area lies off Kerala coast and a cold tongue extends from off Somalia coast to central Arabian Sea in the lower troposphere during both the spells. Isotherms are parallel to the Arabian coastline with temperatures falling steeply seawards. Temperature gradient reverses at 500 mb over coastal Arabia during both the spells and over coastal Maharashtra during weak monsoon, but aloft the north to south temperature gradient with isotherms running east to west is maintained. There is no reversal of temperature gradient at any level over north Arabian Sea and Pakistan coast. The sea is warmer than the air during active monsoon off the west coast of India and colder than the air during weak monsoon. This feature is in some way associated with the development of a trough of low pressure off the west coast during active monsoon and a ridge during weak monsoon.

No significant difference in the temperature and moisture contents is observed between the two spells in the very low levels. The lower and middle troposphere, however, near the equator is generally cool and moist during weak monsoon while over the central and northern parts of the Arabian Sea, it is warmer and much drier than during active monsoon.

The veering and strengthening of the westerlies upto about 1·5 km a.s.l. resulting in the low level westerly jet appears to be mainly a frictional effect in the surface layers.

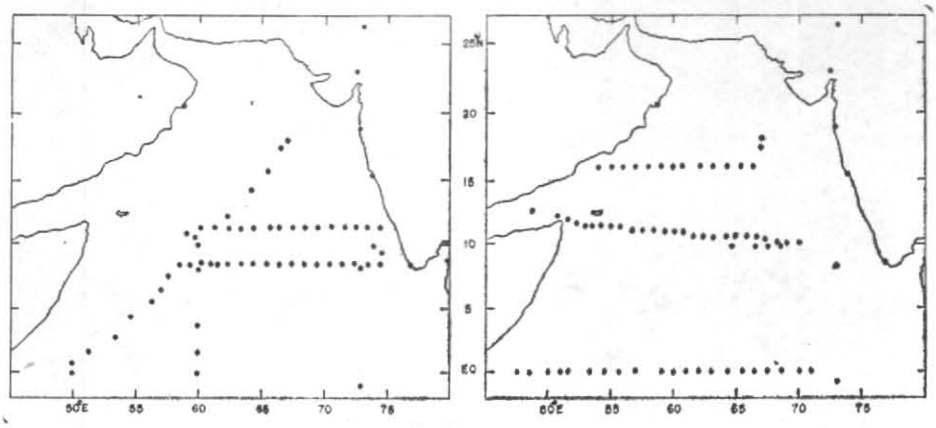
1. Introduction

In 1973, the southwest monsoon advanced over Kerala on 4 June and covered most of the Arabian Sea, the Peninsula, central and northeast India by 13 June. The monsoon did not advance further over the country during the rest of June, when there was a lull. Further, the monsoon during the later half of June was also weak over the Peninsula and the central parts of the country when the rainfall was less than 50 per cent of the normal.

The monsoon revived in the beginning of July and covered the entire country by the 6th. It was active during the first fortnight of July. The present study is concerned with the temperature distribution over the Arabian Sea from the surface upto 100 mb during the periods 19-25 June (representing a spell of weak monsoon) and 1-8 July (representing a spell of active monsoon). During the weak monsoon period, the axis of the seasonal trough was close to the foot of the Himalayas while during the active monsoon, it extended from Gujarat to the head Bay of Bengal with a well marked low over Gujarat and a depression moving from northwest Bay to north Madhya Pradesh.

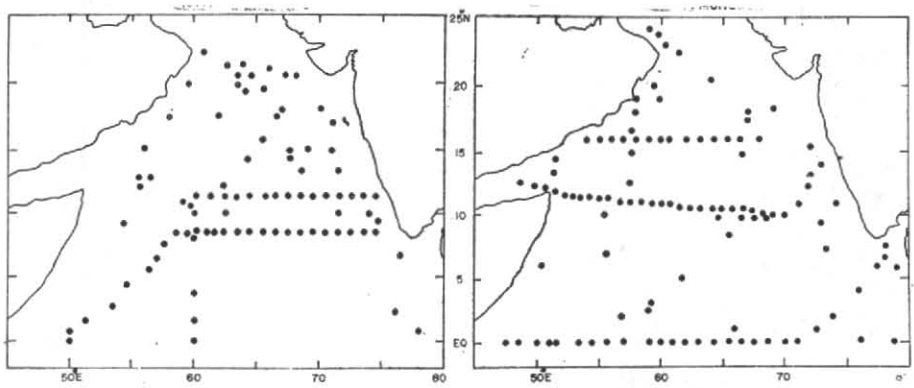
2. Data

In this study, radiosonde data provided by the four Russian ships (*Priliv, Voeykov, Okean* and *Shokalskiy*) which made extensive cruises in the Arabian Sea during the periods mentioned above have been utilised in addition to the radiosonde data from western India, Gan (41 350) and Masirah (40 564). No observations were available from west Arabian Sea during the active monsoon spell and from Somalia coast during both the spells. For a confident analysis of the temperature field over these areas, the dropsonde data of the IIOE period (1963) and the radiosonde data provided by the Russian ship *Shokalskiy* which was in west Arabian Sea during 7-11 June 1973, have been utilised. The period 7-11 June was also one of active monsoon in its advancing phase. Only the trend of the temperature distribution from these data has been taken into account for the analysis. Surface observations reported by all available ships over the Arabian Sea have been utilised for the analysis of air and sea surface temperatures. The data coverage for upper air observations in respect of the active and weak monsoon spells is shown in Fig. 1 (a) and for air and sea surface temperatures in Fig. 1 (b).



Active monsoon Weak monsoon

Fig. 1(a). Data coverage (upper air)



Active monsoon Weakmonsoon

Fig. 1(b). Data coverage (surface)

The total number of observations in the whole Arabian Sea during each spell was about 90 for surface and 50 for upper air observations. Each dot in the diagram represents one observation. It may be mentioned that the ships were stationary at 18°N, 67°E; 10°N, 60°E; Eq., 50° E and Eq., 60°E for some days during their cruises. The number of upper air observations available at Eq., 50° and Eq., 60°E, was 3 to 5 during each of the spells. At 18°N, 67°E and 10°N, 60°E, 6 to 8 observations were available during the active spell.

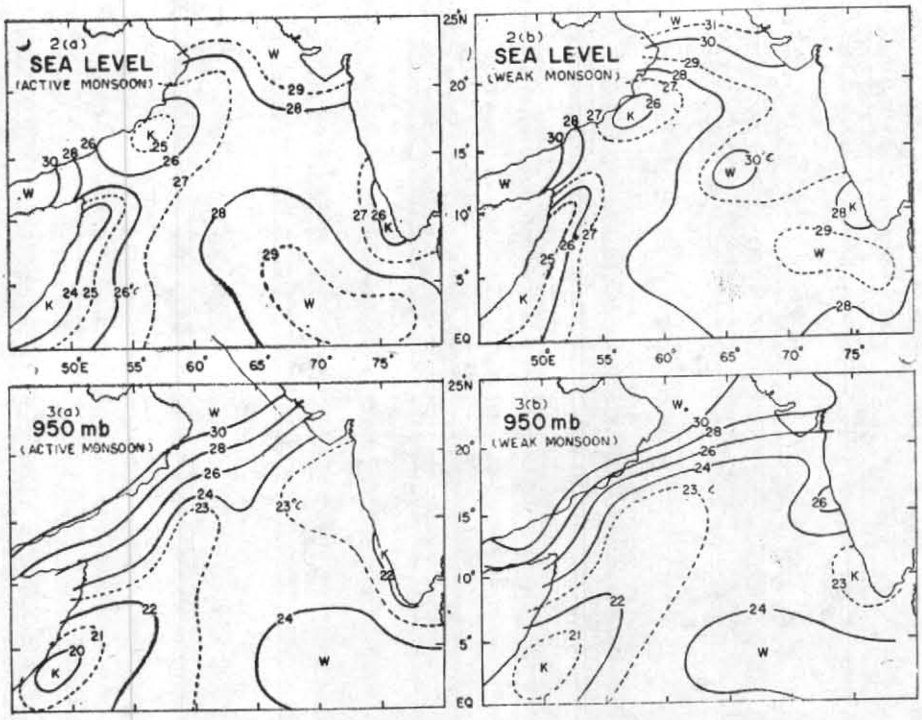
3. Analysis

Tephigrams were constructed for each radiosonde ascent made by the four Russian ships during these two spells. From these, temperature data (dry bulb) were extracted for every 50 mb interval upto 700 mb and for standard levels higher up upto 100 mb including 600 mb level. For each of the above levels one composite chart was prepared containing data for all the hours and for all days during the two spells. Over the sea area, data over 3°-4°longitude have been averaged and the mean value put in the centre of the longitudinal belt for the final analysis, giving due weightage to the more consistent values. Over the land area, the mean value for the stations in respect of each spell has been used.

In delineating the analysis, every attempt was made to secure uniformity and consistency with the limited data available over sea area. Considering the fact that even this much data was not available before MONEX 1973, it is felt that the present analysis may be regarded as more realistic in spite of the limitations mentioned above.

4. Description of results

4.1. *Dry bulb temperature at sea level* (Fig. 2) — The coldest areas are located off Somalia, east Saudi Arabia and Kerala coasts in both the active and weak monsoon spells, the coldest among them being off Somalia coast. The warmest areas are seen over the Gulf of Aden, extreme north Arabian Sea and southeast Arabian Sea. The temperatures during weak monsoon are about



Figs. 2 & 3. Isotherms(°C) at sea level and 950 mb level during active and weak monsoons

1°-2°C warmer over the east central Arabian Sea.

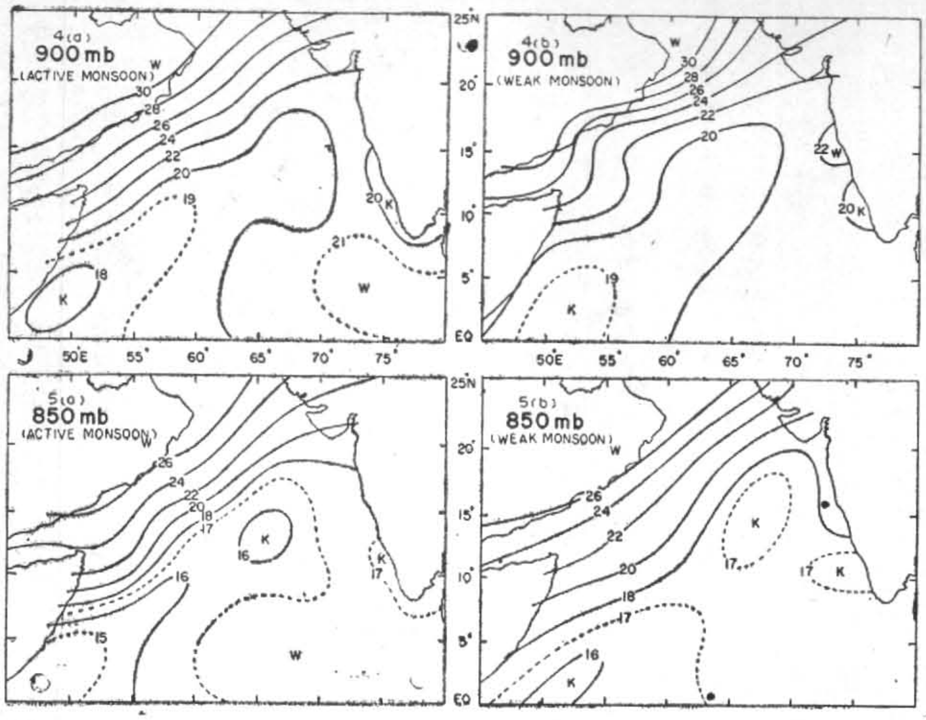
4.2. *950, 900 and 850 mb* (Figs. 3 to 5) — At these levels a steep temperature gradient of decreasing temperatures is observed over west Arabian Sea directed from northwest to southeast, the gradient being 8°-10°C over west central Arabian Sea. This gradient is slightly steeper in weak monsoon at 950 and 900 mb while at 850 mb it is steeper during active monsoon. A cold tongue extends from off Somalia coast northeastwards to west central Arabian Sea at 950 mb. The northern part of the cold air shifts southeastwards to east central Arabian Sea at 850 mb and the southern part persists more or less off Somalia coast upto 850 mb. The cold area off Kerala coast also persists at these levels. The warm area continues over southeast Arabian Sea. The temperatures at these levels are not significantly different during active and weak monsoon.

4.3. *800 mb* (Fig. 6) — In active monsoon, the NW-SE land-sea temperature gradient over west central Arabian Sea is slightly steeper than in weak monsoon and the cold area (14° C isotherm) over east central Arabian Sea is more extensive in active monsoon. The cold areas off Somalia and Kerala coasts persist in both the spells.

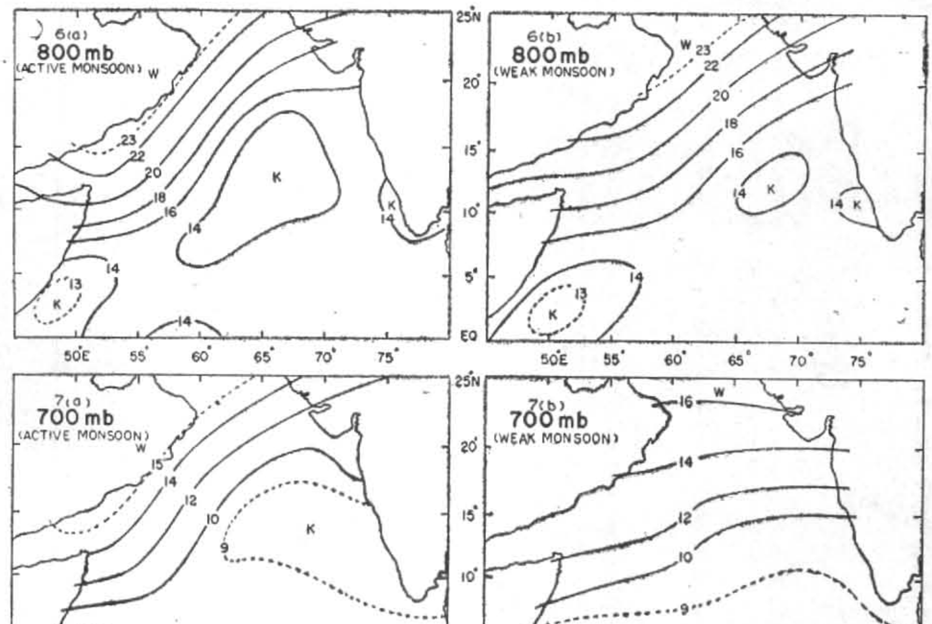
4.4. *700 mb* (Fig. 7) — The cold incursion extends from off Somalia coast to Kerala coast through east central Arabian Sea during active monsoon, while during weak monsoon it extends almost E-W from Somalia coast to Maldives. Steeper N-S temperature gradient is observed over east Arabian Sea in weak monsoon, the temperatures over northeast and adjoining east central Arabian Sea being higher by 2°-3°C as compared to active monsoon.

4.5. *600 mb* (Fig. 8) — During active monsoon, the cold area over east central Arabian Sea has shifted southwards at this level to southeast Arabian Sea and adjoining Lakshadweep. The cold tongue off Somalia coast persists. The isotherms over central and north Arabian Sea are oriented nearly E-W. During weak monsoon, the cold area continues to run E-W from Somalia to Maldives. The N-S temperature gradient at this level has weakened compared to that at 700 mb and a warm ridge has developed over east Arabian Sea roughly along 70° 72°E.

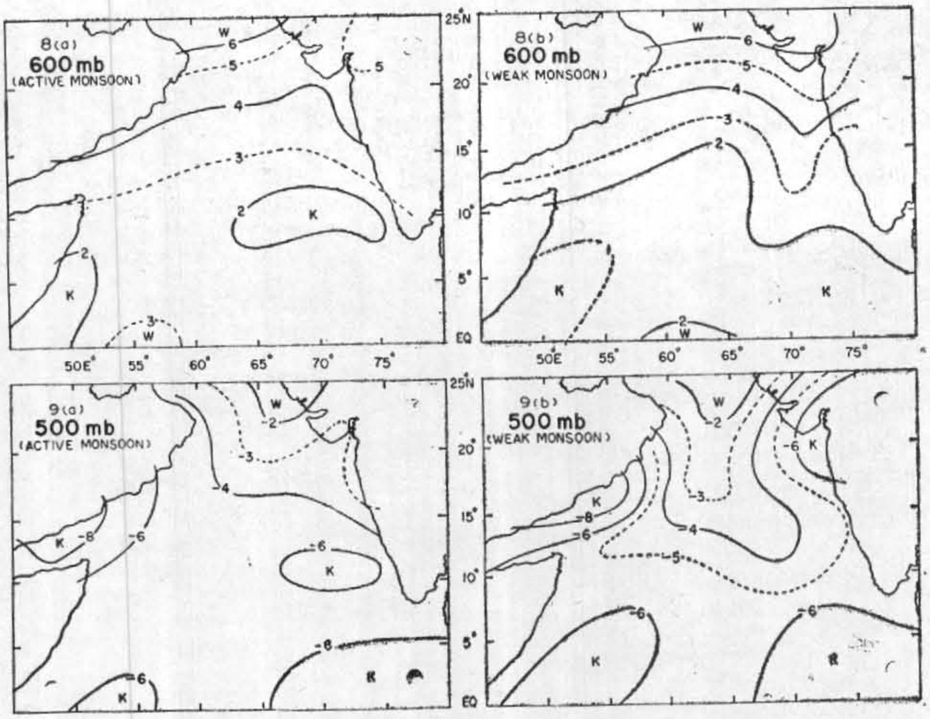
4.6. *500 mb* (Fig. 9) — In both the spells, the cold air is mainly confined between 5°N and equator. However, the cold area at 600 mb in active monsoon over southeast Arabian Sea and Lakshadweep persists at this level also during active monsoon. A cold area has also developed over the Gulf of Aden and neighbourhood during both the spells and over Maharashtra and adjoining Gujarat coasts during weak monsoon. The warm



Figs. 4 & 5. Isotherms (°C) at 900 and 850 mb levels during active and weak monsoons



Figs. 6 & 7. Isotherms (°C) at 800 and 700 mb levels during active and weak monsoons



Figs. 8 & 9. Isotherms (°C) at 600 and 500 mb levels during active and weak monsoons

ridge at 600 mb during weak monsoon is more pronounced at this level over north and central Arabian Sea.

4.7. *300 and 200 mb* (Figs. 10 and 11) — In both the spells the temperature gradient at these levels is from north to south without any significant difference in the gradient.

4.8. *150 mb* (Fig. 12) — The temperature gradient at this level over east Arabian Sea is slightly steeper in weak monsoon than in active monsoon.

4.9. *100 mb* (Fig. 13) — The temperature distribution at this level does not show any uniform gradient from north to south or the other way. Thermal lows and highs are located alternatively from north to south. This variation in the horizontal temperature gradient is due to this level being close to the tropopause and the reversal of temperature gradient occurring above the Easterly Jet Stream at 150 mb.

5. Tropopause

During both the spells, the tropopause surface slopes upwards from south to north (Fig. 14). Over the Arabian Sea, except the extreme eastern parts, the tropopause occurs at a lower altitude during active monsoon.

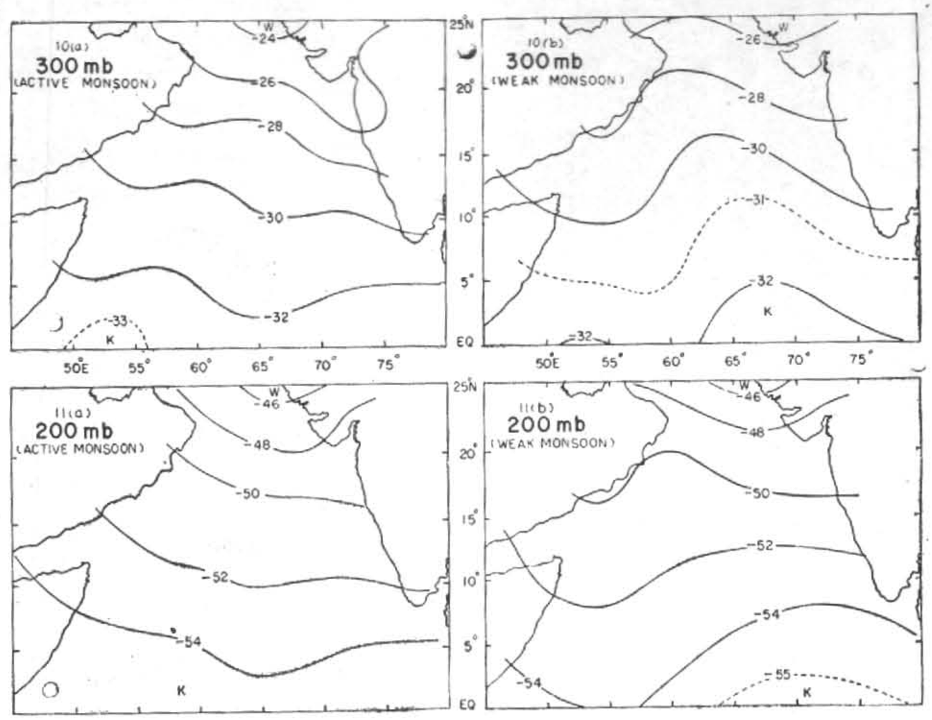
6. Vertical profile of temperature

Mean tephigrams for east and west Arabian Sea along 16°N, 10°N and equator for active and weak monsoon spells are depicted in Figs. 15 to 17. The salient features observed at these locations are as follows :

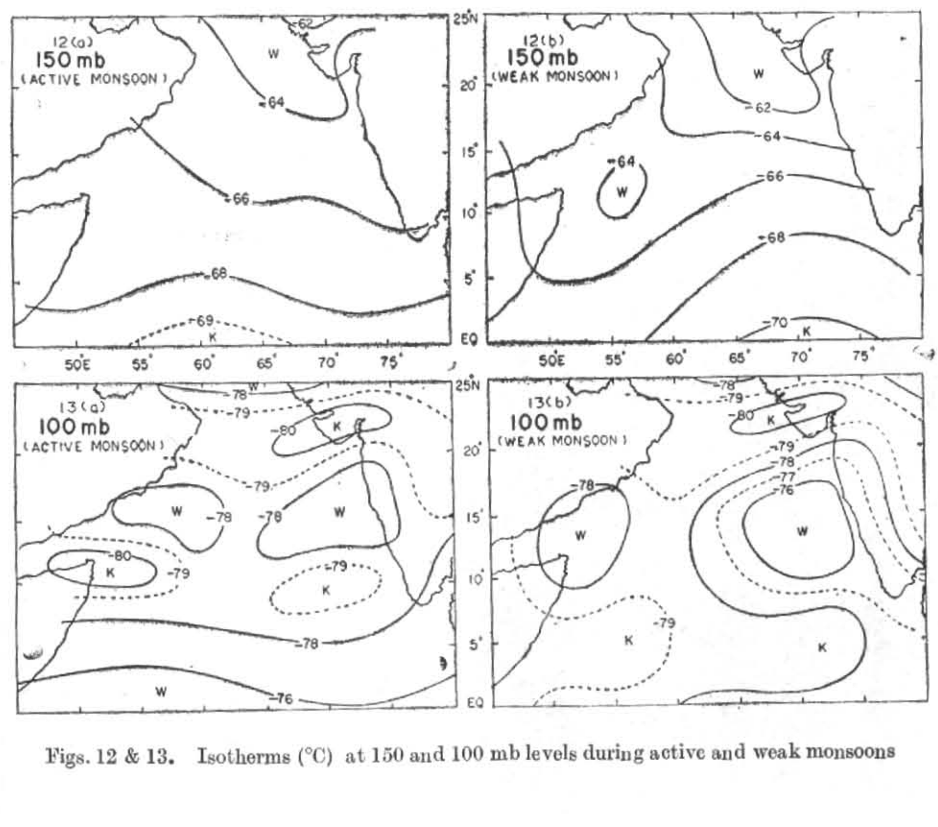
6.1. *16°N, 60°E* (Fig. 15 a) — During both the spells an isothermal layer occurs between 950 and 850 mb. However, in weak monsoon, another isothermal layer is seen in the middle troposphere between 550 and 500 mb. No appreciable difference in dry bulb temperature is noticed between the two spells over the entire troposphere. The lower and middle troposphere over the area is much drier during weak monsoon.

6.2. *16°N, 66°E* (Fig. 15 b) — No inversion/isothermal layer occurs during active monsoon. During weak monsoon an isothermal layer is seen between 900 and 800 mb. The isothermal layer in the middle troposphere noticed at 16°N, 60°E during weak monsoon persists over this area also but is less defined. Another important feature noticed is that the layer between 850 and 650 mb is warmer by 2°-3°C during weak monsoon. The troposphere above 850 mb is drier during weak monsoon.

6.3. *10°N, 60°E* (Fig. 16 a) — Dry bulb temperature is nearly the same in both the spells. An isothermal layer about 100 mb deep occurs



Figs. 10 & 11. Isotherms (°C) at 300 and 200 mb levels during active and weak monsoons



Figs. 12 & 13. Isotherms (°C) at 150 and 100 mb levels during active and weak monsoons

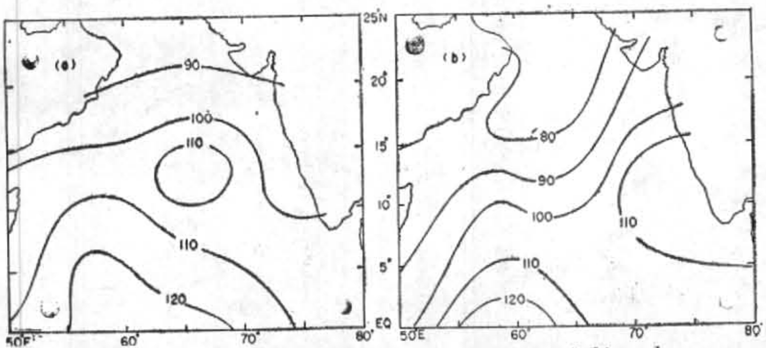


Fig. 14. Mean tropopause level (mb) during (a) active and (b) weak monsoon

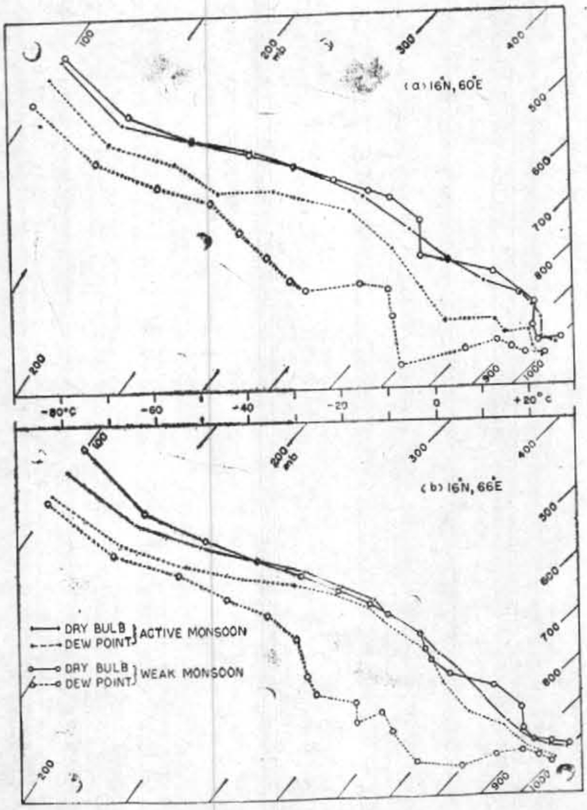


Fig. 15. Mean tephigrams during active and weak monsoons over (a) 16°N, 60°E and (b) 16°N, 66°E

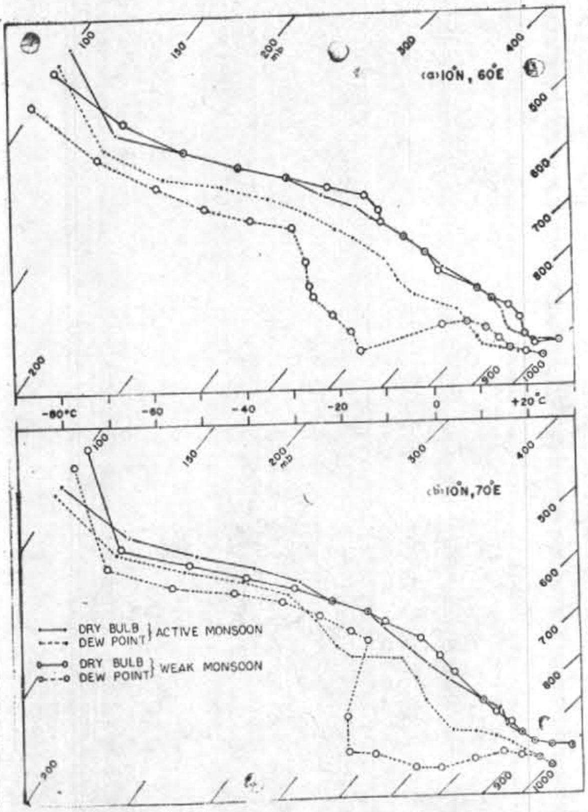


Fig. 16. Mean tephigrams during active and weak monsoons over (a) 10°N, 60°E and (b) 10°N, 70°E

around 850 mb in active and 900 mb in weak monsoon. Another isothermal layer is seen around 450 mb during weak monsoon. The layer between 750 and 350 mb is drier in weak monsoon.

6.4. *10°N, 70°E* (Fig. 16 b) — No inversion layer is seen in both the spells. The middle troposphere is slightly warmer and the upper troposphere slightly colder during weak monsoon. It is interesting to note that while the lower and middle troposphere is drier during weak monsoon, the upper troposphere is as moist as during active monsoon.

6.5. *Equator, 50°E* (Fig. 17 a) — An isothermal layer is seen between 850 and 750 mb during active monsoon, while during weak monsoon, it is confined to the layer 800 to 750 mb. It is also interesting to note that during active monsoon the middle troposphere is drier and the upper troposphere more moist as compared to weak monsoon. No appreciable difference is seen in the dry bulb temperature between the two spells.

6.6. *Equator, 60°E* (Fig. 17 b) — The low level inversion occurs between 800 and 700 mb in both the spells. The moisture characteristics in the

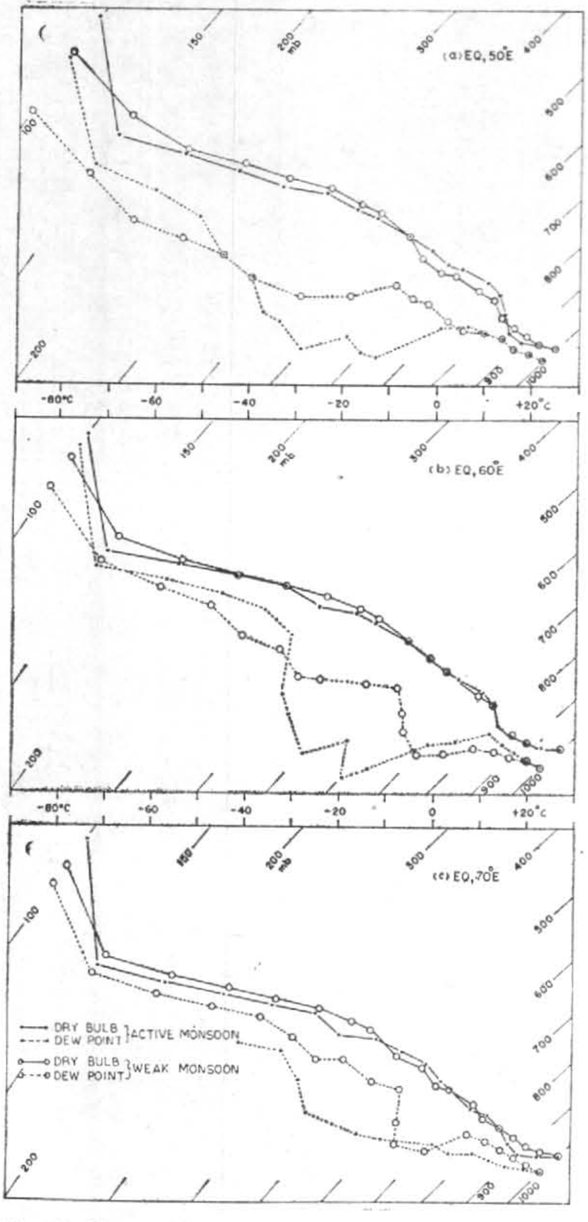


Fig. 17. Mean tephigrams during active and weak monsoons over (a) Eq., 50°E, (b) Eq., 60°E and (c) Eq., 70°E

middle and upper troposphere at this location are nearly similar to those seen at Eq., 50°E, although the upper troposphere is more moist at Eq., 60°E. Dry bulb temperatures do not show any difference between the two spells.

6.7. *Equator, 70°E* (Fig. 17 c) — Although there is no significant difference in dry bulb temperatures between the two spells, it is interesting to note that the troposphere in general is more moist during weak monsoon.

The vertical profile of moisture at the above three locations over the equator shows that during both active and weak monsoon, the air becomes generally drier in the middle and upper troposphere as we go westwards. This feature has also been brought out by Sikka and Mathur (1965).

7. Discussion

7.1. The temperature distribution described clearly brings out the effect of land-sea contrast over the Arabian Sea. The sea level air temperatures are obviously affected by the sea surface temperatures. Hence, the cold pools of air off Somalia, Arabia and Kerala coasts may be attributed to the upwelling ocean currents there. The warm air at the mouth of the Gulf of Aden and in the north Arabian Sea can similarly be attributed to the warm currents from the Red Sea and the Persian Gulf. Apart from these off-coast effects, the temperature of the air mass over most of the Arabian Sea is more or less uniform (28° to 29°C).

7.2. As we go upwards, the effects of the coastal upwelling are damped due to mixing of land air except above the Somalia coast and land-sea contrasts become more prominent. The land masses of Arabia and Pakistan are heated up and highest temperatures occur over these areas. Isotherms run parallel to these coasts and the temperature gradient represents the difference between the air mass properties of the warm continental and cool monsoon air. These conditions persist upto about 600 mb ($\approx 4 \cdot 5$ km asl). Over the open sea, the effect of the upwelling cold Somalia Ocean current also persists upto this level, while that of the other upwelling area off Arabia has been offset by the warm continental air flowing off the Arabian land mass. No such warm continental air flows above the Somali current, the air flow being cross-equatorial and maritime in this region upto about 700 mb. The temperature of the monsoon air mass over the Arabian Sea at 850 mb is 16° to 17°C and 8° to 9° C at 700 mb.

7.3. There is a significant change in the isotherm patterns at 500 mb and above where they tend to assume an E-W orientation. This is achieved by the sharp fall in temperature over coastal Arabia where the coldest air (—8°C) is located at 500 mb. Due to dry adiabatic lapse rate over Arabia, the reversal of temperature gradient between the monsoon and continental air masses takes place there at this level. No such change is seen over Pakistan coast and adjoining north Arabian Sea, where the highest temperature of —2°C occurs at this level. The normal temperatures at 500 mb (WMO 1965) are : Karachi —1·6°C (June) & —1·1°C (July), and Aden —8·0°C (June) & —7·8°C (July).

7.4. Above 500 mb a latitudinal uniformity of temperatures is maintained in the strong easterly currents and temperature decreases north to south with the highest value occurring over the heated Tibetan Plateau and lowest over the equatorial regions.

7.5. It should be mentioned that except over Arabia there is no reversal of temperature gradient at any of the levels below 100 mb as pointed by Koteswaram (1958). Ramanathan and Banerjee (1931) first postulated a reversal in the temperature gradient with height between the cold monsoon air and the hot continental air over northwest India. They assumed that since the lapse rate in the dry continental air will be higher compared to the moist adiabatic lapse rate of the monsoon air, there should be some level above 2 km where the temperature of the dry air would be less than that of the moist air. Koteswaram (1958) pointed out that such a reversal is untenable in a wind regime in which westerlies decrease with height in the lower troposphere and easterlies increase with height in the upper troposphere. He also pointed out that there should be a temperature gradient with warm air to the north and cold air to the south throughout the troposphere in the summer monsoon regime upto the easterly jet stream level at 150 mb. Desai (1972) has been emphasising the earlier concept of the reversal of the temperture gradient between the two air masses and its possible synoptic significance. The MONEX 1973 observations do not indicate any such reversal except over coastal Arabia at 500 mb during active and weak monsoon and confirm that a uniform southward decreasing temperature gradient exists over the Arabian Sea and adjoining Indian sub-continent upto 150 mb.

7.6. The question arises why the dry air over Pakistan and adjoining north Arabian Sea does not exhibit the same characteristics as the dry air over coastal Arabia which cools at near dry adiabatic lapse rate resulting in the reversal of temperature gradient at 500 mb. One plausible explanation is that the dry air over this area (northwest India, Pakistan and adjoining Arabian Sea) maintains higher temperatures due to subsidence (Das 1962).

7.7. Another interesting feature observed at this level (500 mb) is that during weak monsoon a cold area (temp of —6°C) is located over Maharashtra and adjoining Gujarat coasts (Fig. 9). This reversal of temperature gradient over Maharashtra coast at this level is also due to the dry continental air from north cooling at near dry adiabatic lapse rate over this area in the same manner as over coastal Arabia. Such a feature is not observed over coastal Maharashtra during active monsoon where the temperature is of the order of -3° C only (Fig. 9). The higher temperature is due to the air there being moist and cooling at near saturated adiabatic lapse rate. It is moist during active monsoon because of the incursion of the moist monsoon air over that area (westerlies over Maharashtra and deflected easterlies over Gujarat). During weak monsoon, this moist air is replaced by dry continental air from the north. It is also seen that in between the two cold areas over coastal Arabia and coastal Maharashtra, a warm ridge protrudes from Mekran coast to central Arabian Sea during weak monsoon (Fig. 9). Over this ridge also the air is of continental origin (from the north) and is as dry as over coastal Arabia and coastal Maharashtra. Why does not the air over this area cool at the same rate as over the other two areas? We are of the opinion that the cooling of the dry air over this area at near dry adiabatic lapse rate is retarded possibly due to subsidence extending from Pakistan and north Arabian Sea into central Arabian Sea also during weak monsoon.

7.8. We have also noticed that the temperatures over the central Arabian Sea, particularly the eastern parts, are 2°-3°C higher during weak monsoon than in active spell in the layer 800-600 mb. This seems to be due to the extension of the warm dry continental air into this area. The low level inversion observed over this area during weak monsoon is perhaps due to this air mass.

7.9. Another significant feature noticed is the increase in the moisture in the middle troposphere over the low latitudes near the equator during weak monsoon, and its corresponding decrease during active spell. It was pointed out by Koteswaram (1950) that during monsoon 'breaks' low pressure areas move from east to west in low latitudes causing precipitation over south India. These lows will contribute to the increase in the moisture content over the low latitudes of the Arabian Sea by pumping up moisture from the surface to the middle troposphere in the cloud clusters during weak monsoon. The relative dryness in the middle troposphere over the equator during active monsoon is due to the absence of such low pressure systems and the associated vertical motion.

8. Low level westerly maximum over west central Arabian Sea

8.1. An analysis of the wind field over the Arabian Sea by the authors (1974) using MONEX

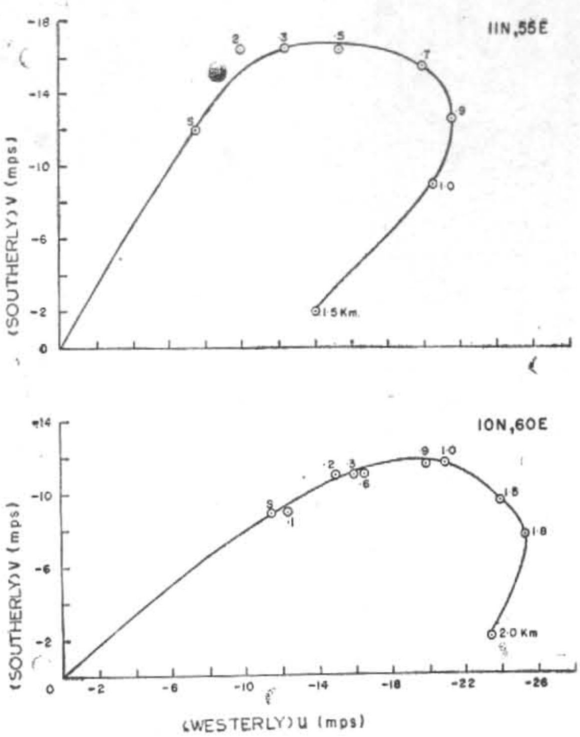


Fig. 18. Wind hodographs

1973 data, has revealed that the low level westerlies veer with height and attain a mean maximum speed of 50-55 kt over west central Arabian Sea, the maximum occurring at about 900 mb near 12°N, 58°E during active monsoon and further west, *viz.*, at 11°N, 55°E at about 950 mb during weak monsoon. Bunker (1965) also found that the low level westerly maximum was located near 11°N, 58°E and it occurred near about 1000 m (900 mb) based on IIOE data. According to him, the strong southwesterlies are caused by a steep south to north pressure gradient set up due to a ridge of high pressure along the east African coast (caused by cold waters off Somalia coast which cool the atmosphere above them and thereby increase the pressure) and a trough of low pressure extending from Arabia down into Ethiopia. The explanation of the strong southwesterlies as a result of strong pressure gradient is understandable. However, his theory for explaining the westerly maximum occurring at about 1000 m near 11°N, 58°E as a result of thermal wind does not appear to be borne out by facts. A qualitative explanation of this feature is attempted in the following paragraphs.

8.2. A land to sea temperature gradient prevails in the area of the maximum wind at 950 and 900 mb and is directed from northwest to southeast (Figs. 3 and 4). This temperature gradient should weaken the southwesterlies upwards from surface to 1·0 km asl. However, the southwesterlies are observed to strengthen and veer from surface to 1·0 km asl. As the observed temperature gradient over the area of the maximum wind cannot contribute to an increase in the wind speed with height, the maximum occurring at 900 mb can only be the result of friction in the lower levels. But for friction, the pressure gradient at the surface level would itself have given rise to much stronger southwesterlies than what is observed. If the temperature gradient was absent and friction alone was effective in these layers, then the observed variation of the wind with height should conform to the theoretical Ekman spiral assuming that the other conditions required for deriving the Ekman spiral are satisfied. Even with the temperature gradient, the applicability of the thermal wind equation is doubtful at such low latitudes.

8.3. The observed variation of the mean wind with height at 11°N, 55°E and 10°N, 60°E (near the region of the maximum wind) are depicted in Fig. 18. It is interesting to see that the wind hodograph resembles the theoretical Ekman spiral with a slightly higher meridional component. This would suggest that the observed variation of the wind with height in the lower levels is therefore mainly due to the effect of friction, the thermal gradient in that area probably contributing to the observed deviation from the theoretical Ekman spiral.

8.4. To see whether the pressure gradient at the mean level of the maximum wind (900 mb) would itself contribute to the maximum wind observed, contour analysis for 900 mb level for the weak monsoon spell was done (Fig. 19). This spell was chosen because observations from ship *Priliv* and *Shokalskiy* were available from west central Arabian Sea. Assuming the wind at this level and over this area to be geostrophic, the wind speed computed from the contour gradient comes out to be about 20 mps which agrees well with the observed mean maximum wind of 20-25 mps at this level. The observed mean contour gradient over this area is therefore sufficient to produce a mean maximum wind of 20-25 mps at 900 mb.

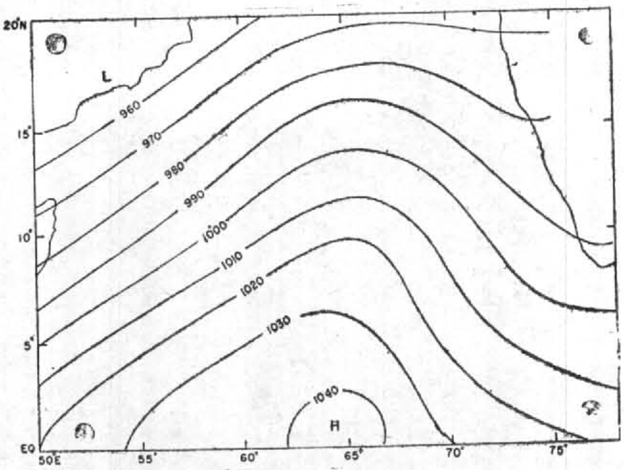


Fig. 19. Mean contours (gpm) at 900 mb level

9. Mean thickness pattern and shear winds

9.1. The mean thickness between 850 and 500 mb (Fig. 20) varies from 4350 to 4420 gpm over the entire Arabian Sea during active and weak monsoon spells. During weak monsoon, the thickness is greater over east central and southeast Arabian Sea suggesting that the air over that area is warmer in this layer compared to active monsoon. This agrees well with the observed temperature distribution at the mean layer (about 700 mb). During both the spells the thickness pattern closely resembles the isotherm pattern in this layer.

9.2. Fig. 21 shows the shear winds between 500 and 850 mb. The shear winds were computed for each $2\frac{1}{2}°$ grid over the Arabian Sea from the wind analysis presented in an earlier paper (Jambunathan & Ramamurthy 1974). These are stronger during active monsoon over west central Arabian Sea which agrees with the observed thickness gradient (Fig. 20) over that area. The low in the shear wind field is centred around 5°N, 67°E during active monsoon and is displaced towards the equator during weak monsoon. During both the spells, the shear winds follow the thickness lines north of about 10°N but further south, they do not conform to the thickness pattern.

10. Sea surface temperature

The sea surface temperature distribution (Fig. 22) over the Arabian Sea is nearly similar to the distribution of air temperature at sea level during both the spells, the coldest sea surface temperature occurring off north Somalia coast. The sea surface over the entire Arabian Sea is, in general, slightly warmer during weak monsoon. However, a significant difference between the two spells is seen off Karnataka-Maharashtra coasts where the sea is warmer by 1°-2° C during weak monsoon. The sea surface temperature distribution obtained from this study is more or less similar to that obtained by Sastry and D'Souza (1970) and that depicted in the monthly mean sea surface temperature charts for June and July published by Ramage *et al.* (1972) and by the Naval Oceanographic Office, USA (1968).

11. Difference between air and sea surface temperatures

Fig. 23 shows isopleths of air *minus* sea surface temperatures during the two spells. While over the west Arabian Sea, the isopleth patterns do not significantly differ, the east Arabian Sea exhibits considerable difference between the two spells. The sea surface over east Arabian Sea is warmer than the air during active monsoon, being 1°-2° C off Kerala-Karnataka coasts. During weak monsoon, the sea surface over east Arabian Sea is colder than the air, being 1°-1·5° C over its central parts. Development of a shallow trough of low pressure off the west coast of India, particularly off Karnataka-Kerala coasts, is a common feature during active monsoon conditions over India, while during weak monsoon, the trough is generally not seen but a ridge develops in that area very often. During the active monsoon spell from 1-8 July 1973, the off-shore trough was present on most of the days. However, during the weak monsoon spell (19-25 June 1973), this trough was absent and a ridge had developed over the east central Arabian Sea off the west coast. The sea which is warmer than the air off the west coast during the active monsoon spell would facilitate transport of moisture and sensible heat to the lowest layers of the atmosphere, while during weak monsoon, the sea being colder than the air off the west coast

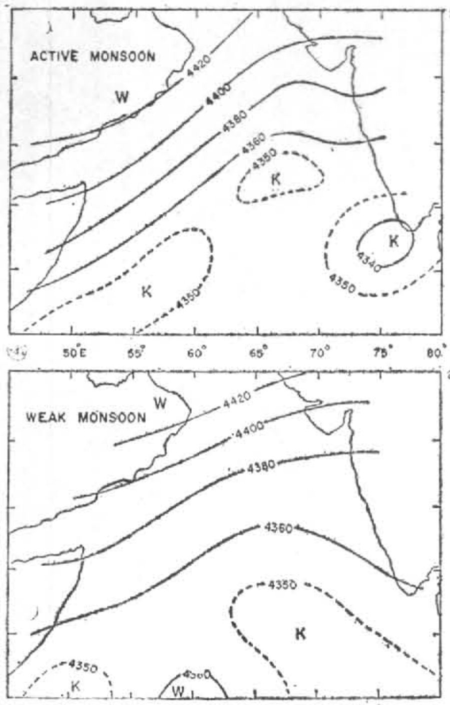


Fig. 20. Mean thickness (gpm) 850-500 mb

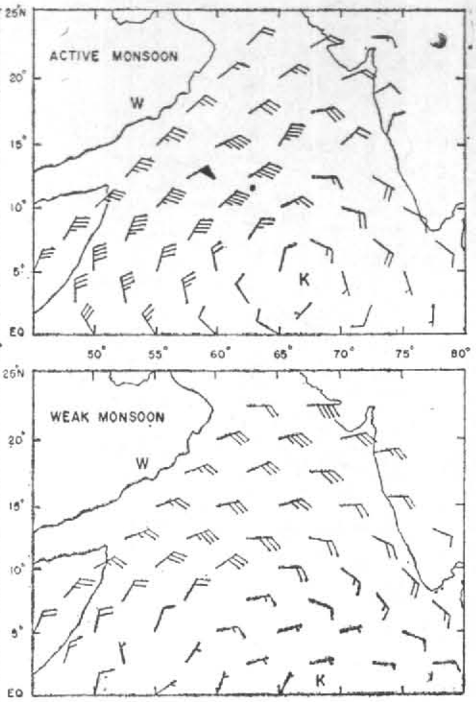
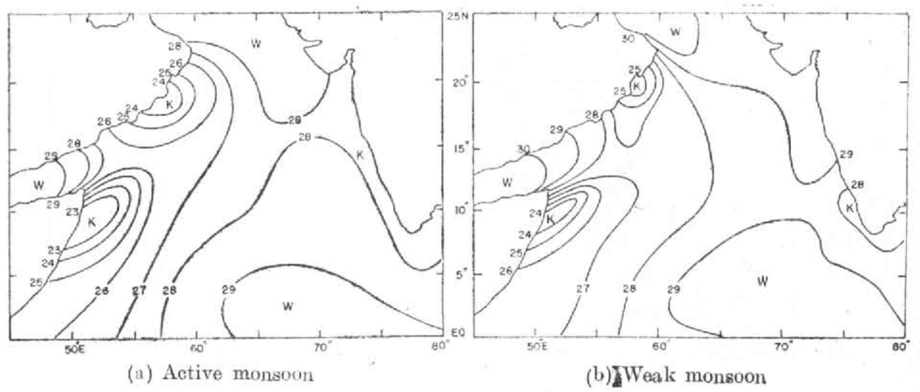
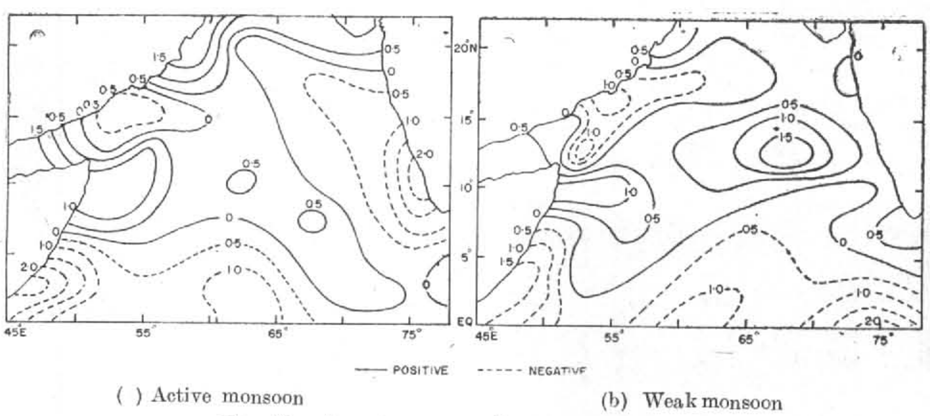


Fig. 21. Mean shear winds 500-850 mb



(a) Active monsoon (b) Weak monsoon

Fig. 22. Sea surface temperatures (°C)



( ) Active monsoon (b) Weak monsoon

Fig. 23. Air *minus* sea surface temperatures (°C)

would facilitate a reverse process, cooling the lowest layers of the atmosphere. It is possible that this feature may, in some way, contribute to the development of the trough and ridge off the west coast during active and weak monsoon respectively, although the exact mechanism is not clear and requires further study. It is also interesting to note that the sea is warmer than the air by as much as 1°-2° C over the equatorial region near Maldives during weak monsoon, while during active monsoon, there is hardly any difference between the air and sea surface temperatures over this area. It may be mentioned that during the weak monsoon spell, the heaviest clouding over the Arabian Sea was confined to the equatorial region near Maldives as evinced from the satellite pictures during this period.

12. Diurnal variation of air and sea surface temperatures at fixed locations over the Arabian Sea

The four Russian ships remained stationary for some days at 18°N, 67°E; 10°N, 60°E; Eq., 50°E and Eq., 60°E where they recorded hourly surface observations. The hourly values of air and sea surface temperatures recorded by them at the above locations have been utilised to get an idea of the diurnal variation of these two elements over the sea area. The analysis shows that the diurnal variation of air temperature over the Arabian Sea is about 1°C while that of the sea surface temperature is hardly 0·5°C generally under cloudy sky conditions.

Rangarajan and Srivastava (1965) have also found that diurnal variation of sea surface temperature over the Arabian Sea in different months during IIOE period ranged between 0·4° and 0·8°C.

13. Conclusions

13.1. The sea and air temperatures are lowest off Somalia, Arabia and Kerala coasts and highest over the Gulf of Aden, north and east Arabian Sea during both active and weak monsoon spells. They are slightly higher during weak monsoon.

13.2. During active monsoon the sea surface is warmer than the air over east Arabian Sea, particularly off Kerala-Karnataka coasts. During weak monsoon, the east Arabian Sea is colder than the air, particularly over its central parts. This feature appears to be in some way associated with the development of a trough of low pressure off the west coast of India during active monsoon and a ridge over the same area during weak monsoon.

13.3. The diurnal variation of air temperature over the Arabian Sea is about 1°C while that of the sea surface temperature is hardly 0·5°C generally, under cloudy sky conditions.

13.4. During active and weak monsoon, a cold area lies off Kerala coast and a cold tongue extends from Somalia coast to central Arabian Sea in the lower troposphere.

13.5. Isotherms run parallel to the Arabian coast and a steep temperature gradient directed seawards prevails in the lower troposphere upto 600 mb over the Arabian Sea during spells of active and week monsoon.

13.6. At 500 mb, there is a reversal of temperature gradient, with the coldest air (–8°C) over coastal Arabia. No such reversal takes place over coastal Pakistan and north Arabian Sea and the air is warmest over these areas at all levels upto 150 mb. Isotherms assume an E-W orientation above 500 mb.

13.7. There is generally no significant difference in the dry bulb temperature in the troposphere over the Arabian Sea between active and weak monsoon spells. However, during weak monsoon spells, the east central Arabian Sea is warmer by 2°-3°C between 850 and 650 mb.

13.8. Over the entire west Arabian Sea, low level inversion is observed during both active and weak monsoon. Over the east central Arabian Sea it is seen only during weak monsoon. The low level inversion occurs at a lower level over the west Arabian Sea. A similar feature was also brought out by Sikka and Mathur (1965) using the dropsonde data over the Arabian Sea during the IIOE period.

13.9. Another inversion occurs in the middle troposphere during weak monsoon only, particularly over the central Arabian Sea.

13.10. The lapse rate in the layer within a few hundred metres above the sea surface is dry adiabatic.

13.11. The surface of the tropopause over the Arabian Sea slopes upwards from south to north during both the spells.

13.12. The middle troposphere over the equatorial region is more moist during weak monsoon.

13.13. The veering and strengthening of the westerlies upto about 1·5 km asl, particularly over west Arabian Sea appears to be mainly due to friction.

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