MAUSAM, 50, 3 (July 1999), 251-256

551.510.52:551.511:551.553.21 (267. 64)

Thermodynamical characteristics of monsoon troposphere over the Bay of Bengal

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(Received 22 June 1998, Modified 4 February 1999)

सार — महासागर अनुसंधान पोत (ओ. आर. वी.), सागरकन्या द्वारा 8 जुलाई - 5 अगस्त, 1991 की अवधि में, एकत्रित किए गए रेडियो सौंदे आँकड़ों का उपयोग करते हुए, बंगाल की खाड़ी के विभिन्न क्षेत्रों में मानसून क्षोभमंडल, विशेषकर निम्न क्षोभमंडल की तापगतिक विशेषताओं का अध्ययन किया गया है। इनसे प्राप्त परिणामों से, जुलाई-अगस्त के महीनों के दौरान बंगाल की खाड़ी के मध्य में तथा दक्षिणी भाग के समीपवर्ती क्षेत्रों में 13.4° - 17.2° उ. और 84.5° – 90.0° पू. के मध्य में निम्न स्तरीय प्रतिलोमन की विद्यमानता का पता चलता है। बंगाल की खाड़ी के इस क्षेत्र में 850 हैक्टापास्कल तक निम्न क्षोभमंडल पूरी तरह से स्थिर प्रतीत होता है। पूर्णतया इसके विपरीत, 17.7° उ. के क्षेत्र में लिए गए किसी भी आरोहांक में कोई निम्न स्तरीय प्रतिलोमन दिखाई नहीं देता है। बंगाल की खाड़ी के उत्तर के निम्न क्षोभमंडल जहाँ मानसून ऋतु में अनुकूल सिनोप्टिक स्थितियों के अन्तर्गत संवहन बनते हैं, वे अस्थिर पाये गए हैं।

जुलाई में निम्न स्तरीय प्रतिलोमन का विस्तार दूर दक्षिण (लगभग 10.3° उ. तक) तक होता है किन्तु बंगाल की खाड़ी के दक्षिणी भागों में मानसून ऋतु के आगमन के साथ-साथ ये प्रतिलोमन विभाजित हो जाते हैं। बंगाल की खाड़ी के उत्तरी तथा मध्य भागों में अनेक आरोहांको से 0° के समीप के तल पर स्थिर स्तरों के होने का पता चलता है। बंगाल की खाड़ी के भूमध्यरेखा वाले 5°-10° उ. के बीच के भाग में, 400 हैक्टापास्कल और 850-800 हैक्टापास्कल तल के समीप स्थिर स्तर विद्यमान प्रतीत होते हैं। इन परिणामों से बंगाल की खाड़ी के मानसून ऋतु के संवहन के आंतरिक ढाँचे की जानकारी मिलती हैं।

ABSTRACT. Thermodynamical characteristics of monsoon troposphere, especially the lower troposphere, over different regions of Bay of Bengal has been studied utilising the radiosonde data collected by Ocean Research Vessel (ORV) Sagar Kanya during the period 8 July-5 August, 1991. The results reveal the existence of low level inversions over the central and adjoining parts of southern Bay of Bengal between 13.4°- 17.2°N and 84.5°- 90.0°E during July-August. The lower troposphere upto 850 hPa appears to be absolutely stable over this region of Bay of Bengal. In total contrast, none of the ascents taken over the region north of 17.7°N showed any low level inversion. The lower troposphere over the northern Bay of Bengal, where convection develops under favourable synoptic situations in monsoon, was found to be unstable.

In July the low level inversion appears to extend far south (upto about 10.3°N) but gets disintegrated over the southern parts of Bay of Bengal with the advance of season. Many ascents over the northern and central Bay of Bengal have shown the occurrence of stable layers near 0° level. In the equatorial Bay of Bengal between 5°-10°N stable layers appear to exist near 400 hPa level and near 850-800 hPa level. The results seem to provide an insight into the pattern of convection over the Bay of Bengal during monsoon.

Key words -- Inversion, Instability, Troposphere, Monsoon, Convection.

1. Introduction

The knowledge about the spatio-temporal variability of upper air meteorological parameters over the Bay of Bengal during monsoon is rather fragmentary due to non-availability of routine upper air data from sea areas. The only source of upper air data from Bay of Bengal have been international experiments MONSOON-77 and MONEX-79. During these experiments limited data were collected by the Russian ships from the northern parts of Bay of Bengal (Gopalkrishna *et al.* 1988). The upper air meteorological data from different regions of Bay of Bengal were collected by ORV Sagar Kanya during the period 8 July-5 August 1991, which provided useful information about the thermal structure of monsoon troposphere over different parts of Bay of Bengal.

TABLE 1

Thermodynamical characteristics of monsoon troposphere over different regions of Bay of Bengal

Area over Bay of Bengal	Date (1991)	Time (UTC)	Latitude /Longitude	Inversion (hPa)	Stable layer (hPa)	0°level (hPa)	Temperature difference between surface and 850 hPa level (0°C)	Stability/Instability in the lower troposphere upto 850 hPa
Central and adjoining south Bay of Bengal area	12 Jul	0000	16.8°N / 90.0°E	1003-940	570- 500	496	5.5	Stable
	15 Jul	0000	17.0°N / 87.5°E	996.5-936	--	485	3.0	Stable
	22 Jul	0000	17.2°N / 86.1°E	1000.2-968	--	519	5.1	Stable
	22 Jul	1200	17.0°N / 85.5°E	999.6-883	540-500	525	1.3	Stable
	24 Jul	1200	14.7°N / 82.3°E	1001.3-949 (Isothermal)	--	536	6.2	Stable
12.4°-17.2°N	1 Aug	0000	12.8°N /81.9°E	1005.4-973 (Isothermal)	585-500	532	6.9	Stable
81.9°-90.0°E	2 Aug	0000	12.4°N / 84.5°E	1006-949	--	505	2.8	Stable
South Bay of Bengal area between	10 July	0000	10.3°N / 85.5°E	1005.6-956	--	504	3.8	Stable
	10 July	1200	11.8°N / 86.8°E	1004.7-951	--	570	6.8	Stable
10°-12.4°N	3 Aug	0000	12.0°N / 87.5°E	--	--	595	12.0	Unstable
	3 Aug	1200	11.8°N / 89.0°E	--	--	546	8.9	Unstable
North and adjoining Central Bay of Bengal area north of 17.2°N	12 Jul	1200	18.2°N / 90.0°E	--	--	576	10.8	Unstable
	13 Jul	0000	20.0°N / 90.0°E	--	--	534	12.6	Unstable
	13 Jul	1200	20.0°N / 89.0°E	--	--	526	10.6	Unstable
	14 Jul	0000	18.7°N / 89.0°E	500-491	--	537	9.6	Unstable
	15 Jul	1200	17.7°N / 87.0°E	--	535-500	564	11.7	Unstable
	17 Jul	0000	20.2°N / 88.3°E	--	545-500	545	11.2	Unstable
	18 Jul	1200	19.0°N / 88.0°E	--	560-500	535	14.0	Unstable
Equatorial region of Bay of Bengal south of 10°N	8 Jul	1200	5.5°N / 80.0°E	--	930-850 436-400	563	8.1	Unstable
	9 Jul	1200	8.5°N / 84.0°E	--	800-750 455-430	580	9.4	Unstable
	5 Aug	0000	10.0°N / 89.5°E	--	860-730	608	16.0	Unstable
	5 Aug	1200	9.2°N / 87.8°E	--	430-400	576	11.9	Unstable

TABLE 2

Details of synoptic systems forming over the Bay of Bengal during 8 July-5 August 1991

S. No.	Synoptic system	Period	Place of first location	Direction of movement	Place of dissipation	Remarks
1.	Well marked low pressure area	14th-19th	Northwest Bay and neighbourhood	Westnorthwesterly to westerly	Northwest Madhya Pradesh	Initially seen as a cyclonic circulation between 1.5 km and 7.6 km a.s.l. over the same area on 14 morning
2.	Low pressure area	21st-27th	North Bay	Westnorthwesterly	Northwest Madhya Pradesh and adjoining south Uttar Pradesh	Initially seen as a cyclonic circulation up to 7.6 km a.s.l.over the same area on 20th
3.	Deep depression	27th-31st	Northwest Bay	Westerly to westnorthwesterly	East Rajasthan and neighbourhood	Initially appeared as a cyclonic circulation up to 5.8 km a.s.l. over north and adjoining central Bay on 25th

The stability of lower atmosphere over the western Arabian Sea during monsoon has been well documented (Shukla, 1984, Cadet and Diehl, 1984; Ray and Bedi, 1985). There exists a strong low level inversion over the western and adjoining central Arabian Sea inhibiting the development of convection over that part of the Arabian Sea. The inversion disappears towards eastern Arabian Sea.

A significant factor contributing to the development of intense convection over the north Bay of Bengal during monsoon appears to be highly unstable lower troposphere. The necessary buoyancy is provided by high sea surface temperature. Over the central Bay of Bengal the convection is very much subdued inspite of sufficiently high values of sea surface temperature (which is, of course, less than that

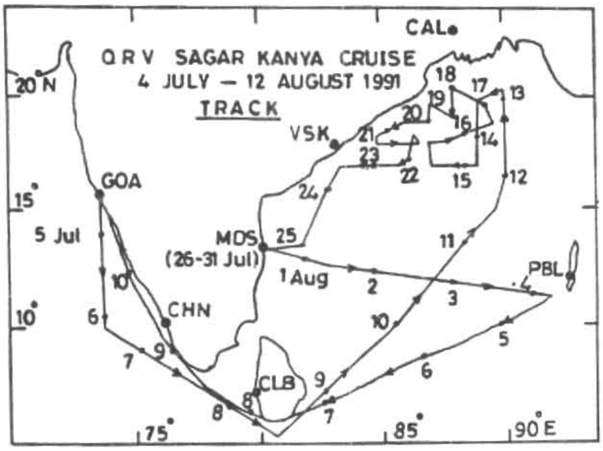

Fig.1. Track of ORV Sagar Kanya. Locations indicated pertain to 0000 UTC.

over the north Bay of Bengal). The main factor inhibiting convection over the central parts of Bay of Bengal appears to be the stability by prevailing in the lower troposphere.

Johnson *et al.* (1996) have reported common occurrence of stable layers of thickness of about 50-100 hPa near the freezing level over the tropical western Pacific. They have also reported the existence of stable layers near 800 hPa level over tropical Pacific and Atlantic. No such studies are available for the tropical Indian Ocean. However, Ananthakrishnan and Keshvamurthy (1974) have reported the occurrence of such stable layers over Bombay during the southwest monsoon.

2. Data used

Radiosonde data collected by ORV Sagar Kanya over the Bay of Bengal during the period 8 July to 5 August 1991 have been used. In all 42 ascents were taken during the entire period over different parts of Bay of Bengal. Generally two ascents were taken at 0000 and 1200 UTC. During intensive observation period additional ascents were also taken. All ascents have been processed and analysed. The track of ORV Sagar Kanya has been shown in Fig.1.

3. Results and discussion

Thermodynamical characteristics of the ascents taken over different parts of Bay of Bengal have been presented in Table 1. The ascents have been categorised into four groups, *viz*, those in the latitudinal belts 12.4°- 17.2°N, north of 17.2°N, 10°- 12.4°N and south of 10°N. The categorization is based on distinct characteristics observed in the temperature and moisture profiles after analysing the entire set of 43 ascents. The set of ascents have been chosen for each of above regions to high-light above distinct characteristics. Both type of ascents, *i.e.*, morning and evening (0000 and 1200 UTC) have been presented in order to eliminate diurnal biases.

3.1. *Low level inversions in temperature and moisture over the central and adjoining parts of south Bay of Bengal between 12.4°-17.2°N, 81.9°-90.0°E*

Out of seven ascents taken over the area 12.4°- 17.2°N, 81.9°- 90.0°E presented in Table 1, five have shown low level inversions in the layer from surface to 883 hPa. The ascent of 22 July (1200 UTC) shows maximum thickness of inversion, *i.e.*, 116.6 hPa. All the inversions have been observed in the longitudinal belt 84.5°-90°E.

Two ascents pertaining to western parts of central and adjoining south Bay of Bengal taken at 82.3°E and 81.9°E do not show occurrence of any low level inversion. However, these ascents do reveal isothermal layers between surface to 949 hPa and surface to 973 hPa respectively, showing that all seven ascents had strong stable layers upto about 1 km from the surface.

Table 1 also presents the temperature differences between surface and 850 hPa level. The differences range from 1.3° to 6.9°C, showing that lower troposphere upto 850 hPa over the central and adjoining parts of south Bay of Bengal is generally stable during July-August.

It may be remarked that average sea surface temperature over central and adjoining parts of south Bay of Bengal during the period under consideration was 28.7°C, which is sufficient for generating necessary buoyancy at the sea-air interface. Thus the stability in the lower troposphere over that part of the Bay of Bengal seems to play a role in inhibiting intense convection. This becomes more apparent when we consider the synoptic situations prevailing over the Bay of Bengal presented in Table 2. Unfortunately, we could not track the deep depression that developed during the disembarkment period of the ship at Madras from 26-31 July.

A cyclonic circulation developed over northwest Bay off Orissa coast on 14 July 1991 which became a low pressure area on 14th evening. On 15th evening the low pressure area concentrated into a well marked low and persisted over the NW Bay upto 16th and subsequently moved westnorthwestward. The monsoon was active over NW Bay and adjoining areas. Table 1 shows that the ascent taken on 15th (0000 UTC) over the location 17.0°N, 87.5°E had a low level inversion between 996.5- 936 hPa. The ascent was taken only about 150 km south of well marked low pressure area over the northwest Bay. Similarly, the ascent taken on 12th (0000 UTC) at 16.8°N, 90.0°E prior to the formation of low also showed a low level inversion between 1003-940 hPa. Thus, the intensification of mon-

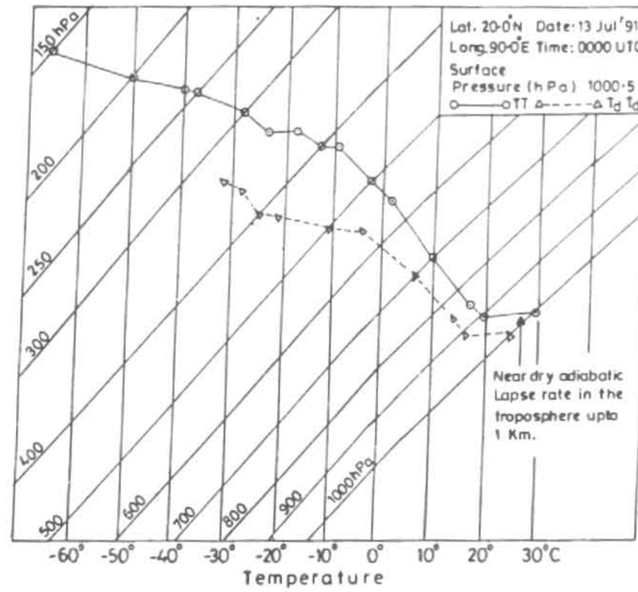

Fig.2. T-ϕ gram showing low level inversions in temperature and moisture over northern parts of south Bay of Bengal.

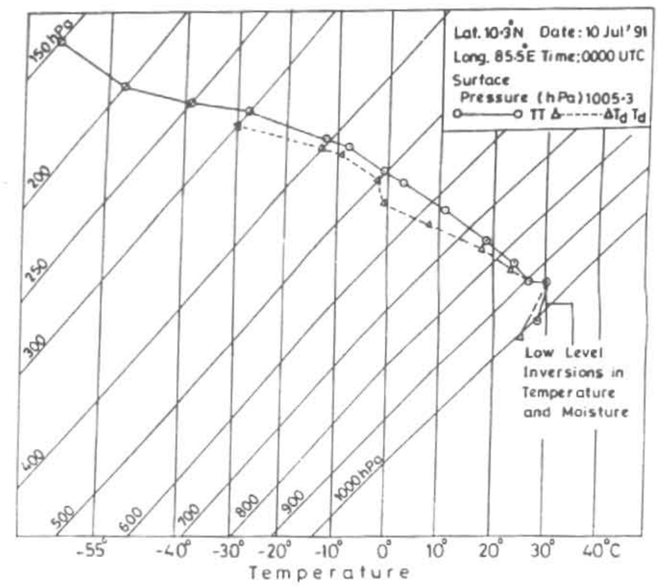

Fig.3. T-ϕ gram showing near dry adiabatic lapse rate in the lower troposphere upto 1 km over the north Bay of Bengal.

soon trough in association with the formation of low over the NW Bay did not alter the stability prevailing over the central Bay in the lower troposphere. Similar feature was observed during the period of the low pressure that formed on 21st. Thus the lower tropospheric stability seems to be a regular feature over the part of central Bay under discussion.

3.2. *Low Level inversion over south Bay of Bengal between 10°-12.4°N*

Tephigram of ascent taken on 10 July, 1991 (0000 UTC) over the south Bay of Bengal at 10.3°N, 85.5°E is presented in Fig.2. Sharp inversions in temperature and moisture are observed between surface and 956 hPa. Table 1 shows the low level inversion in the same day's ascent of 1200 UTC also. However, the ascents taken on 3 August do not show any low level inversion over above mentioned region of the south Bay of Bengal. These ascents were taken in the absence of any synoptic disturbance over the Bay. It would not be fair to draw any definite conclusions regarding the disappearance of low level inversion in August on the basis of the meagre data set.

3.3. *Non occurrence of any low level inversion and prevalence of instability over the northern Bay of Bengal (north of 17.7°N)*

It is evident from Fig.1 that north Bay of Bengal was intensive observation area during ORV Sagar Kanya's cruise. In all 17 ascents were taken over the area north of 17.7°N. It is remarkable that none of the ascents showed any low level inversion in the lower troposphere upto 1km. 7 ascents have been presented in Table 1.

The lower troposphere upto 850 hPa was unstable over the north Bay of Bengal during the period under study in total contrast to the thermal structure observed over the central and adjoining south Bay of Bengal between 12.4°-17.2°N. Table 1 shows that the temperature differences between surface and 850 hPa were ranging from 9.6°C to 14.0°C over the north Bay of Bengal. Tephigram presented in Fig.3 shows near dry adiabatic lapse rate between surface and 900 hPa at the location 20.0°N, 90.0°E. Thus it appears that the highly unstable lower troposphere is the major determining factor for the development of intense convection and cyclogenesis over the north Bay of Bengal supported, of course, by the relatively high sea surface temperature. It may be pointed out that the average sea surface temperature at the locations of above ascents over the north Bay of Bengal was 29.3°C.

Tables 1 and 2 show that the ascents taken over the north Bay on 12th, 13th and 18th July did not coincide with any low pressure area whereas the ascents on 14-17 July were taken when the low pressure area was present over the north Bay. The lower troposphere was highly unstable during this period of active monsoon conditions. The ascents taken on 19th and 20th July also showed instability in the lower troposphere but the degree of instability was less than that observed during the earlier period.

3.4. *Stable layers near freezing level over the northern and central Bay of Bengal*

Johnson *et al.* (1996) have reported stable layers near the freezing level over the tropical western Pacific Ocean. All the ascents over Bay of Bengal were critically examined to identify the stable layers in the vicinity of zero degree

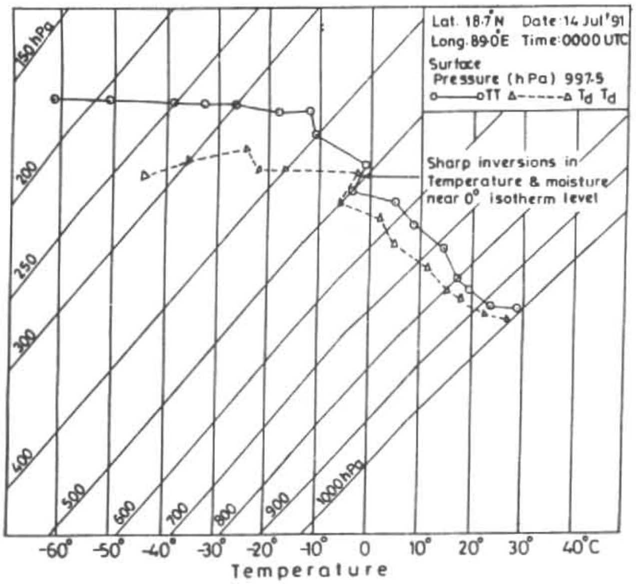

Fig.4. T-ϕ gram showing sharp inversions in temperature and moisture near 0° isotherm level over north Bay of Bengal

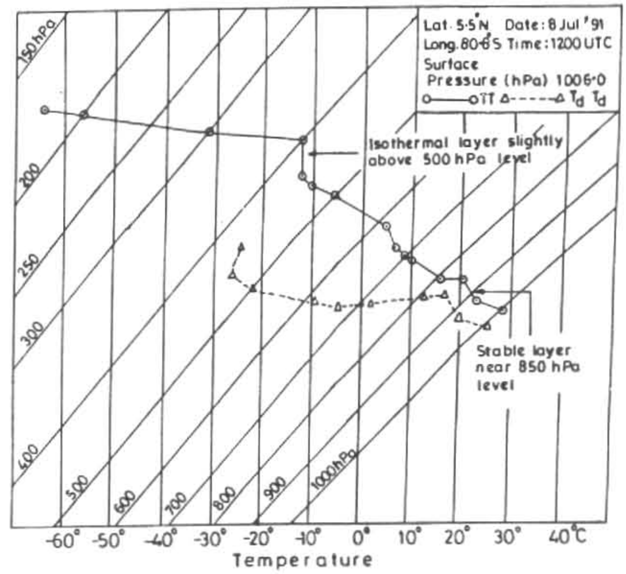

Fig.5. T-ϕ gram showing stable layers near 850 hPa and 500 hPa level over the equatorial parts of Bay of Bengal.

isotherm level. None of the ascents taken over the south Bay of Bengal south of 12.8°N revealed the existence of any stable layer near the freezing level. However, about 50 % of the ascents taken over the northern and central Bay of Bengal north of 12.8° showed the existence of stable layers near 0° isotherm level. Table 1 shows that average thickness of these stable layers was 49 hPa. This in good agreement with the thickness of such stable layers over the western Pacific reported by Johnson *et al.* (1996). Tephigram of such an ascent at 18.7°N, 89.0°E is presented in Fig.4. The strong stable layer could be seen near 500 hPa level. The freezing level in this case was 537 hPa.

Johnson *et al.* (1996) have provided convincing physical reasons for the occurrence of such stable layers near 0° isotherm level over the tropical oceans. Such stable layers are presumably associated with the direct effects of melting in the vicinity of 0° isotherm level within precipitation systems or immediately following there decay. Once generated, the inversions/stable layers may persist for periods up to a day or longer if vertical mixing or radiation does not quickly destroy them. Above mechanism for formation of stable layers near 0° isotherm level seems to hold good also over the area of continued precipitation especially near the eastern end of monsoon trough over the Bay of Bengal.

3.5. *Stable layers over the equatorial regions of Bay of Bengal south of 10°N*

Two types of stable layers were observed over the equatorial regions, *viz*, in lower troposphere between 850-800 hPa levels and in middle troposphere near 400 hPa level (much above the freezing level). Thermodynamical characteristic of some such layers could be seen in Table 1. As reported by Johnson *et al.* (1996) the occurrence of stable layers near 850-800 hPa level is a common phenomenon in the tropical regions. They have associated it with the convergence zone. It is interesting to note that such stable layers over the Bay of Bengal were observed only in equatorial regions and not over the northern or central parts of Bay of Bengal. This may perhaps be due to convergence zone associated with northern hemispherical equatorial trough seen over sourthern part of the Bay of Bengal.

The stable layers observed over 400 hPa level over the equatorial regions of Bay of Bengal appear to be very interesting. Table 1 shows that the thickness of these layers varied from 25-36 hPa. These layers are observed much above the freezing level. Tephigram of an ascent taken at 5.5°N and 80.8°E showing stable layers near 850 hPa and 400 hPa levels has been presented in Fig.5.

4. Conclusions

(*i*) Most of the ascents taken over the central and adjoining parts of south Bay of Bengal between 12.4°-17.2°N during July-August, 1991 revealed the occurrence of low level inversions of varying thickness from 40- 100 hPa in the boundary layer showing strong stability in the lower troposphere upto about 850 hPa level.

(*ii*) None of the ascents taken over the northern Bay of Bengal during this period showed the existence of any low level inversion or isothermal layer in the lower troposphere. The lower troposphere upto 850 hPa was found generally unstable during July-August.

(*iii*) About 50 % of ascents taken over the northern and adjoining central Bay of Bengal north of 12.8°N during this period showed the occurrence of stable layers near the freezing level. These stable layers seem to be associated with melting in the vicinity of 0° isotherm level occurring over areas of continued precipitation.

(*iv*) In the equatorial regions of the Bay of Bengal south of 10°N stable layers were found in the lower troposphere near 850-800 hPa level and above middle troposphere near 400 hPa level.

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