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Radiational structure of the atmosphere over the Indian seas during MONEX-77 and MONEX-79

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सार — मॉनेक्स 77 एवं मॉनेक्स 79 के दौरान सोवियत रूस के अनुसंधान जलपोतों से प्रेक्षित रेडियोसोन्दे प्रक्षेणों का उपयोग करके अरबसागर और बंगाल की खाड़ी के वायुमण्डल के विभिन्न स्तरों की विकिरण ऊष्मक/शीतलन दरों की गणना की गई है । संपूर्ण क्षोभमंडल में भूमध्यरेखा पर या उसके निकट मानसूनी वायु का अग्रगमन सामान्य शीतलन प्रदर्शित करता है, परन्तु भूमध्य रेखा को पार करने के बाद वही वायु कुछ दूर चलने के बाद ऊपरी क्षोभ मंडलीय स्तरों में विस्तृत ऊष्मक क्षेत्र दर्शाता है। दक्षिणपश्चिम मानसून के अग्रगमन के समय और मानसूनी पूर्व के चरण में भूमध्यरेखीय क्षेत्र की वायुराशि विभिन्न विकिरण अभिलक्षण प्रदर्शित करती हैं । प्रबल एवं दुर्बल मानसून के चरणों एवं अवदाब के क्षेत्र में, इसके बनने के कुछ दिन पहले समुद्र में वायुमंडल की विकिरणी संरचना के अभिलक्षणों का भी विवेचन किया गया है ।

ABSTRACT. Using the radiometersonde observations taken by USSR research vessels during MONEX-77 and MONEX-79, the radiational warming/cooling rates are computed for different atmospheric layers over both Arabian Sea and Bay of Bengal. The advancing monsoon air exhibits a general cooling at or near the equator in the entire troposphere but after crossing the equator the same air after moving some distance displays extensive region of warming in the upper tropospheric levels. The airmass over the equatorial region also displays different radiational characteristics during the pre-monsoon phase and at the time of the advance of the southwest monsoon. The characteristic features of the radiational structure of the atmosphere over the seas during strong and weak monsoon phases and in the field of a depression, a few days prior to its formation, have also been discussed.

1. Introduction

As a sequel to the IIOE (1963) and MONEX (1973) and as a prelude to the more ambitious MONEX-79, the Monsoon Experiment-1977 was conducted during the period May to August 1977. Five ships of the USSR Hydrometeorological Service took part in this study of southwest monsoon over Indian region and undertook extensive cruises over both Arabian Sea and Bay of Bengal. They also maintained quasi-stationary positions at different selected locations in these seas. The details of movements of these ships are given in Table 1(a).

Each of the ships normally took one radiometersonde observation at 18 GMT daily. The temperature, mixing ratio and radiation flux data are available in most of the cases upto or above 100 mb level, sometimes reaching 15 mb level. It is perhaps for the first time that the water vapour in the tropical stratosphere has been measured over Indian seas. Due to the lack of knowledge about the sensor used for such measurements, accuracy of the data, especially at very high levels, could not be assesed. However, no inconsistency within the data set has been detected and hence the accuracy of the data can be taken to be within reasonable limits.

During MONEX-79 another fleet of USSR research vessels undertook cruises over Indian seas and also maintained quasi-stationary positions at selected locations as given in Table 1(b). Two ships belonging to this fleet, namely, R. V. *Akademik Shirshov* and R. V. *Akademik Korolev* took one radiometersonde observation daily at 18 GMT. These flights recorded values of the same set of meteorological elements as recorded during MONEX-77 and reached, on the average, same pressure levels.

One Indian ship INS *Darshak* also took radiometersonde observations during the monsoon experiment 1979. However, the observations taken by this ship were few and far between and none of the flights reached the 100 mb level.

The radiation data obtained from the radiometersonde ascents have been used to calculate instant rates of warming/cooling of different layers, 50 mb thick, of the atmosphere as per I.S. circular (1972). Vertical cross-sections representing various cruises were prepared from these values of radiational warming/cooling of the layers and they were examined *vis-a-vis* the corresponding vertical sections of upper winds.

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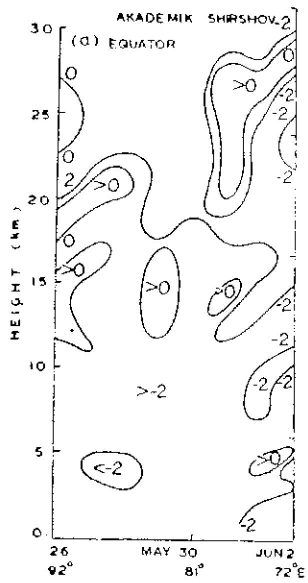


Fig. 1(a). Vertical time-section along equator during onset phase of monsoon in 1977 (Ship : *Akademik Shirshov*)

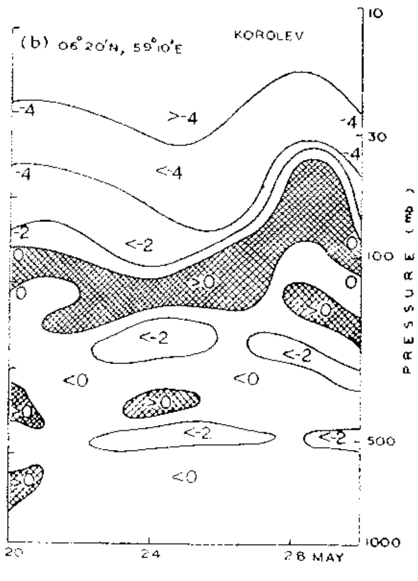


Fig. 1(b). Vertical time-section at 6°20′N, 59° 10′ E during onset phase of monsoon in 1979 (Ship : *Akademik Korolev*)

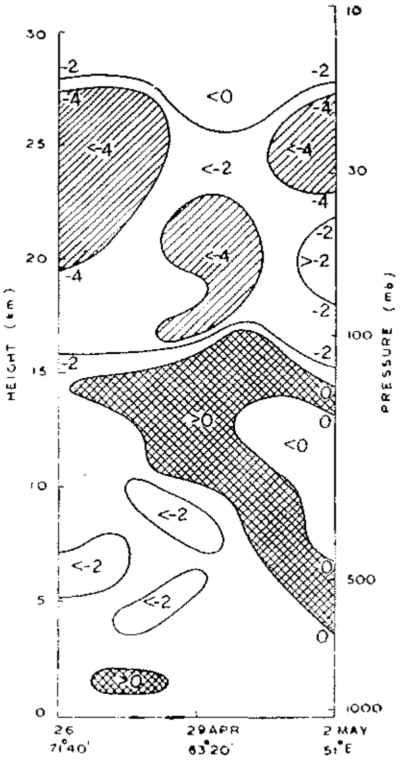


Fig. 2. Vertical time-section along equator during pre-monsoon of 1979 (Ship : *Akademik Shirshov*)

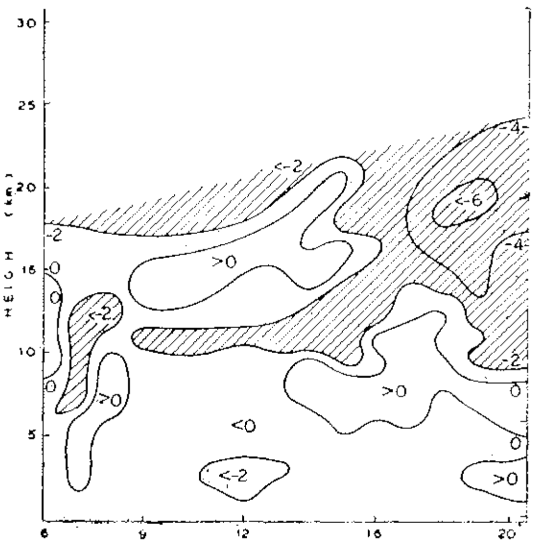


Fig. 3. Vertical time-section at 12° 30′N, 68°E during the strong monsoon phase in 1977 (Ship : *Akademik Shirshov*)

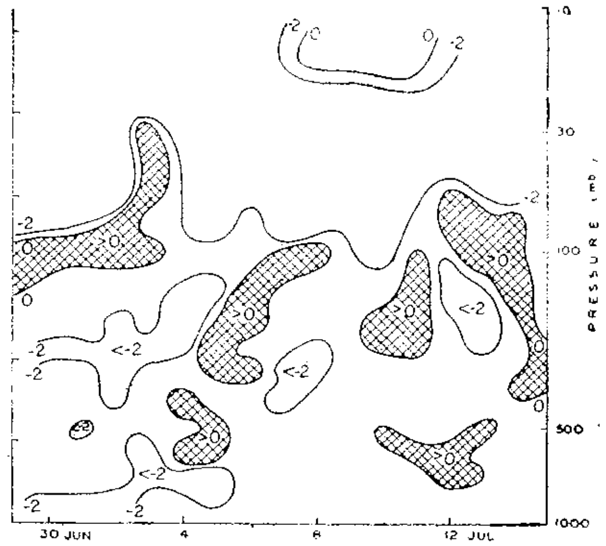


Fig. 4. Vertical time-section at 12° 38′N, 68°E during weak monsoon phase in 1977 (Ship : *Akademik Shirshov*)

TABLE 1 (a)

Location of ships during MONEX – 1977

Ships	26 May-2 Jun	6-20 Jun	29 Jun-16 Jul	23-31 Jul	7-11 Aug	12-18 Aug
Akademik Shirshov	Along equator, 92°E-72°E	12° 30′N, 68°E	12° 30′N, 68°E	Equator, 80°E	Along 91°E, 7°N-17°N	17°N, 91°E
Prilie	Along 2°N, 90°E-72°E	10° 30′N, 66°E	10° 30′N, 64°E	—	—	—
Priboy	Along equator, 88°E-70°E	12° 30′N, 64°E	12° 30′N, 64°E	1° 30′N, 78°E	—	19°N, 89°E
Okean	—	—	—	1° 30′N, 78°E	—	15°N, 87°E
Shokalsky	—	—	—	0° 30′N, 76°E	Along 87°E, 7° 30′N-17° 30′N	17° 30′N, 87°E

TABLE 1 (b)

Location of ships during MONEX-1979

	24 April-2 May	20-30 May	11-18 July
Akademik Shirshov	Along equator, 79°E-51°E	—	—
Akademik Korolev	—	16° 20′N, 91° 10′E	—

TABLE 2

Mean mixing ratio (gm/kg) at standard millibaric level during MONEX 1977

	Level (mb)													
	850	700	600	500	400	300	250	200	100	70	50	30	20	15
Akademik Shirshov (at equator)	11.88	7.20	4.66	2.63	1.36	.46	.21	.08	.003	.013	.03	.21	.96	1.72
Prilie at (2° N)	11.90	8.05	5.69	3.16	1.81	.71	.30	.10	.004	.015	.04	.30	1.12	2.60
Priboy (at equator)	11.83	7.52	5.39	2.90	1.30	.53	.26	.08	.003	.011	.03	.28	.92	1.52

2. Discussion

2.1. *Radiational structure*

For a quantitative estimation of radiational warming/cooling of a parcel of air, it is necessary to compute the outgoing and incoming radiational fluxes through the boundaries of the parcel taking into account the distributions of water vapour, carbon dioxide, ozone and particulate matter throughout the atmosphere, lapse rate of temperature in the vertical, horizontal temperature gradient, cloud cover etc. Evidently, the problem is too complicated to yield an exact solution in the absence of simplifying assumptions. Moller (1951) computed the average 24-hour local temperature changes, as a function of height, assuming water vapour as the only contributory factor in radiational exchanges. Based on the mean atmospheric sounding, his computation for an arbitrary cloudless tropical atmosphere shows cooling throughout the troposphere with a maximum around 12 km.

This mean picture obviously gets modified by the presence of clouds in the tropical atmosphere. The cloud tops act as strong emitter of long wave radiation and thus get cooled while the layers below become warm. In addition to cloud cover, radiational warming of an atmospheric layer can be produced by sharp changes in the vertical distribution of water vapour and/or lapse rate of temperature. In order to analyse the radiational structure of the atmosphere, isopleths of warming/cooling have been drawn at an interval of 2 ° K/day on the vertical cross-section which are discussed in the paragraphs to follow.

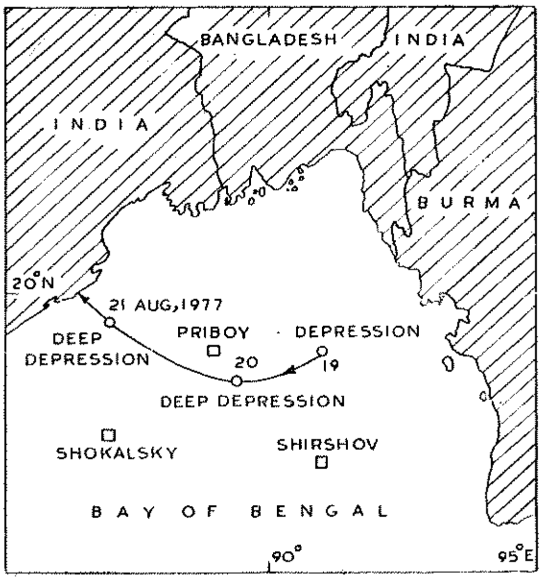
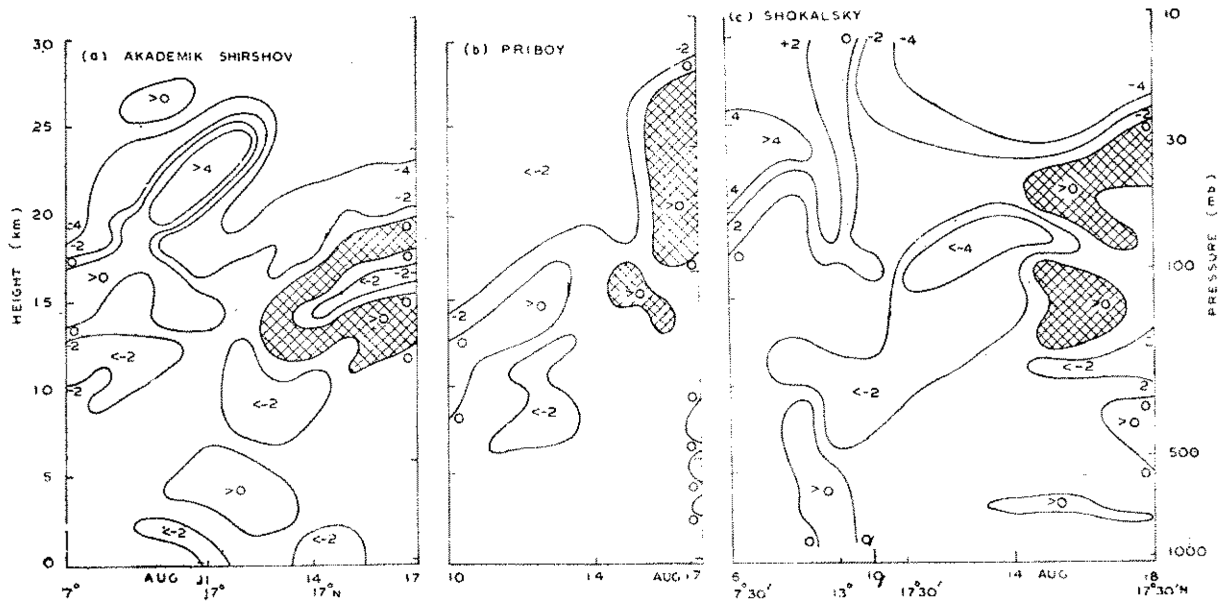


Fig. 5. Track of the Bay depression during 19-21 August 1977 and position of three ships as on 17 August 1977



Figs. 6(a-c). Vertical time-section at (a) 17°N, 91°E during 11-17 August 1977 (Ship : *Akademik Shirshov*), (b) 19°N, 89°E during 10-17 August 1977 (Ship : *Priboy*) & (c) 17° 30' N, 87°E during 11-18 August 1977 (Ship : *Shokalsky*)

2.1.1. *Radiational characteristics of the advancing monsoon air*

The vertical section depicted in Fig. 1(a) represents the radiational balance of the atmosphere between 92 deg. E and 70 deg. E, at and near equator for the period 26 May to 2 June 1977. Since, in 1977, the southwest monsoon advanced into south Kerala by 30 May the sections shown in Fig. 1(a) may be assumed to represent the radiational characteristics of the advancing monsoon air at the equator. A common feature reflected in the vertical sections at the equator is a general cooling of the troposphere with isolated regions of weak warming in the layer between 10 & 15 km. The radiational characteristics of the advancing monsoon air undergo significant changes after crossing the equator. While the region of cooling in the lower troposphere shrinks, a wide region of warming appears in the upper troposphere extending into the lower stratosphere upto about 20 km with a marked gradient in cooling in the layer just aloft. A comparison of mixing ratios at different levels (Table 2), as recorded by the three ships, shows that the advancing monsoon air picks up greater moisture in the layer between 700 mb and 200 mb and in the layer aloft 20 mb just after crossing the equator. This, perhaps, accounts for the existence of the extensive warm region in the upper troposphere and lower stratosphere upto 20 km.

In 1979, the southwest monsoon had set in over Andaman Seas and adjoining Bay on 25 May. Hence, the vertical cross-section 1(b) representing the quasi-stationary position of R. V. *Akademik Korolev* at the location 6 deg. 20′ N and 59 deg. 10′ E during the period 20 to 30 May, may be assumed to reflect the radiational characteristics of the advancing monsoon airmass in 1979. In this case also an extensive region of radiational warming appears in the upper troposphere and lower stratosphere with a layer of strong cooling aloft.

2.1.2. *Some contrasting features of radiational structure of airmasses over equator before and after the advance of the southwest monsoon*

The time section in Fig. 2 represents the radiational structure of the atmosphere over the equator during the period 24 April to 2 May and reflects the radiational characteristics of the airmass over the equator prior to the advance of monsoonal airmass. Although, only one set of radiometer sonde observations of pre-monsoon airmass is available in 1979 and none in 1977, some differences are noticed between the radiational characteristics of the pre-monsoon airmass and that of the monsoonal airmass. After the onset of southwest monsoon over India, the airmass over equator is characterised by radiational cooling throughout the troposphere with only isolated pockets of weak warming while prior to the onset of monsoon the airmass over equator is characterised by an extensive region of radiational warming in the upper and the middle troposphere. In the stratosphere, the monsoonal airmass, in general, undergoes radiational cooling at a rate comparable to or slightly faster than the rate of cooling in the troposphere. In contrast, the airmass over equator, prior to the onset of southwest monsoon over India, experiences strong radiational cooling in the layer between 100 mb and 20 mb with strong gradients in the rate of radiational warming/cooling near both the top and the bottom boundaries of this layer. This difference between the radiational characteristics of the advancing monsoonal airmass and that of the pre-monsoon airmass over equator, if confirmed by subsequent observations, may prove useful in determining the exact period when the monsoonal airmass from southern hemisphere crosses the equator.

2.1.3. *Radiational characteristics during strong monsoon epochs*

The period 6 June to 21 June 1977 represents strong monsoon conditions with a depression over Arabian Sea centred near 16 deg. N and 70 deg. E on 9th. The depression then moved northwestwards and intensified into a storm on 10th and subsequently moved westwards. A vertical cross-section of radiational warming/cooling of atmosphere during this period is shown in the section in Fig. 3.

The regions of warming in the middle of troposphere, as seen in the section, are due to the presence of clouds. The appearance of extensive regions of strong cooling around 200 mb (shown by hatching) with a few extending beyond 100 mb is associated with tops of *Cb* clouds. From the data collected from meteorological reconnaissance flights and schedule civil flights operated by jet aircraft, Deshpande (1964) has shown that tops of *Cb* clouds during the southwest monsoon season (June to September) in the Indian region are found most frequently between 38,000 ft and 47,000 ft and sometimes they even shoot upto 60,000 ft. The appearance of strong cooling layers at these heights in section 3 corroborates the above findings and further points out that over the Indian seas also, specially over the Arabian Sea, the *Cb* tops can reach even a height of 20 km (more than 60,000 ft) during a spell of active monsoon.

Another spell of strong monsoon occurred in 1977 during the last week of July. The radiation characteristics of the atmosphere in the equatorial region during this phase can be inferred from the data collected 24 and 31 July. The radiational structure during this period has some similarity with that shown under Fig. 3 also representing strong monsoon phase but in the south Arabian Sea. A general cooling throughout the troposphere with isolated patches of warming is the main feature of these two sections.

In the year 1979, monsoon was active over the central and eastern parts of India and weak over the Peninsula during the period 11 to 18 July. During this period the ship *Akademik Korolev* maintained a quasi-stationary position at 16 deg 10′ N and 91 deg. 10′ E in the Bay of Bengal and the data obtained by it may be assumed to represent the radiational characteristics of one of the strong monsoon phases of 1979. On comparison with other vertical sections, representing strong monsoon phase, an almost identical picture of cooling throughout the troposphere with isolated patches of radiational warming is revealed in this case also.

2.1.4. *Radiational characteristics during a weak monsoon phase*

The section in Fig. 4 represents the radiational budget of the atmosphere over the Arabian Sea during the first half of July. During the end of this period weak monsoon conditions established over India starting on 13th and prevailing upto 22nd. An interesting feature, present in all the three sections, is a region of warming which first appears in the lower stratosphere and progressively descends to upper and even middle troposphere (shown by cross-hatching in the figures). The exact nature of this warming cannot be established without a quantitative study but a plausible reason may be the readjustment that takes place in the water vapour field in association with the weak monsoon conditions. The remaining regions of warming/cooling in the troposphere are due to clouds; the region of strong cooling corresponding to the cumulonimbus or towering cumulus tops. Warming occurs either inside the cloud due to enhanced absorption of long wave radiation or just above the cloud top due to strong incoming radiation from the cloud tops. A comparison of the radiation structure representing a strong monsoon phase in the last week of July with those shown in Fig. 4 representing a weak monsoon phase in early July does not reveal any striking difference in the additional warming/cooling pattern of the troposphere indicating that the change over from a weak monsoon to a strong monsoon phase does not radically change the radiational budget of this part of the atmosphere.

2.1.5. *Radiational characteristics in the field of a depression prior to its formation*

A depression formed over northeast Bay of Bengal with its centre near 18 deg. N, 91 deg. E at 0300 GMT on 19 August. It intensified into a deep depression on 20th and then moved westnorthwestwards across Orissa coast. The track of the depression and the position of the ship as on 17 August are shown in Fig. 5. Radiometersonde observations from ships are not, unfortunately, available beyond 17 August.

The set of sections presented in Figs. 6(a-c) represents the pattern of radiational warming/cooling in the field of the depression, a few days prior to its formation. It is interesting to note that 2 to 3 days before the formation of the depression, warming appeared in the lower stratospheric and upper tropospheric layers of the atmosphere in the depression field and these have been cross-hatched in the figures. The presence of regions of strong cooling both below and above these warm layers suggests that the warming in these layers might have been due to the net radiation fluxes received through both top and bottom boundaries.

3. Conclusions

The study attempts to project the radiational warming/cooling patterns associated with different phases of the Indian southwest monsoon 1977 and 1979 and also with broad synoptic systems without taking into account the fluctuations in CO_2, O_3 and aerosols. It is found that :

(a) During the southwest monsoon, radiational cooling generally occurs throughout the troposphere with scattered regions of warming which are mostly on account of extensive and thick clouds, usually *Cb* or towering *Cu*.

(b) Warmings in the stratosphere generally take place due to fluctuations in the moisture field especially prior to the onset of weak monsoon conditions in the country.

(c) The advancing monsoon air exhibits slightly different radiational characteristics on crossing the equator.

(d) The airmass of the equatorial region in the pre-monsoon period (April-May) shows a radiational structure quite distinct from that of the advancing monsoonal air.

(e) The cooling observed in the topmost tropospheric and stratospheric levels over the south Arabian Sea during a spell of active monsoon suggests that even in the sea the *Cb* tops can attain a height of 20 km in such active spell.

(f) The vertical time sections of upper winds were also examined *vis-a-vis* the sections showing radiational warming/cooling. The upperwinds do not seem to have any significant effect on the radiational budget of the atmosphere. It is, perhaps, the vertical moisture distribution and readjustments thereof that contribute most of the radiational warming/cooling in the atmospheric layers.

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