

Dynamics of monsoon trough over northwest and adjoining westcentral Bay of Bengal

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सार – इस शोध-पत्र में बंगाल की खाड़ी के उत्तर-पश्चिम और समीपवर्ती पश्चिम मध्य में स्थित मानसून द्रोणी के पूर्वी छोर के इर्द-गिर्द के क्षेत्र में सतह और तापगतिकीय प्राचलों के दैनिक परिवर्तनों का अध्ययन किया गया है। बंगाल की खाड़ी के ऊपरी भाग, जहाँ दक्षिणी पश्चिमी मानसून के समय चक्रवात बनते हैं, में मानसून द्रोणी के सुदृढ़ होने/कमजोर पड़ने के निमित्त निदर्श अनुक्रम प्रस्तुत किया गया है। समुद्र पर मानसून द्रोणी की सक्रियता का चक्र चार दिनों का प्रतीत होता है। मानसून द्रोणी के सक्रियकरण के प्राथमिक प्रणोदन समुद्र सतह तापमान प्रतीत होते हैं। चरम एस.एस.टी. और न्यूनतम सतह दाब के बीच पश्चता 2 दिनों की प्रतीत होती है। चरम एस.एस.टी. और उड़ीसा की अधिक वर्षा के बीच पश्चता 4 दिनों की होती प्रतीत होती है।

ABSTRACT. Daily variations of surface and thermodynamical parameters in the vicinity of eastern end of the monsoon trough located over northwest and adjoining westcentral Bay of Bengal have been studied. A model sequence for the strengthening/weakening of the monsoon trough over head Bay of Bengal, which is the seat of cyclogenesis during southwest monsoon, has been proposed. Monsoon trough activity over the sea seems to possess a 4 day cycle. The primary forcing for the activation of monsoon trough appears to be the sea surface temperature (SST). The lag between peak SST and minimum surface pressure appears to be 2 days. The lag between peak SST and enhanced rainfall over Orissa seems to be 4 days.

Key words - SST, Monsoon trough, Cyclogenesis, Sea level pressure (SLP), Sensible heat flux, Latent heat flux, Zero degree isotherm.

1. Introduction

Monsoon trough is one of the important components of Indian summer monsoon. Its eastern end is located over the head Bay of Bengal which is the seat of cyclonic vorticity in the lower troposphere with deep moist convection. The significant part of monsoon rainfall over central India is associated with the intensity of monsoon trough.

The mechanism of the intensification and weakening of monsoon trough over Bay of Bengal is not fully understood due to lack of proper observational data from the sea areas. If the surface and upper air meteorological observations are available from the location of the eastern end of the monsoon trough over Bay of Bengal then the temporal variations of surface and upper air parameters could be utilised to define the conditions that precede active and weak phases of monsoon trough over the sea.

The studies on the intensification/weakening of monsoon trough and cyclogenesis over the north and adjoining central Bay of Bengal are very few, probably

due to very little surface and no upper air data from sea areas. Reliable surface and upper air meteorological data from Bay of Bengal have become available only after 1980's when the cruises of ocean research vessel (ORV) Sagar Kanya commenced. The main objective of the meteorological programme on board Sagar Kanya during its sixty sixth cruise (4 July to 12 August, 1991) was to collect meteorological data from the seat of monsoon trough over the Bay. The ship was stationed over northwest and adjoining westcentral Bay of Bengal for a period of eleven days from 12 to 22 July, 1991. Intensive surface and radiosonde observations were collected during the period which have been utilised here to study the dynamics of monsoon trough over the Bay of Bengal.

The convective activity over the sea is closely associated with sea-air interaction. Pyke (1965) has studied the role of sea-air interaction in the cyclogenesis. Warsh (1973) has studied the relationship between sea-air energy fluxes and the convective activity in the tropical Atlantic Ocean. Singh (1991) and Singh and Rajeevan (1991) found close relation between surface fluxes and the cyclogenesis over the Bay of Bengal.

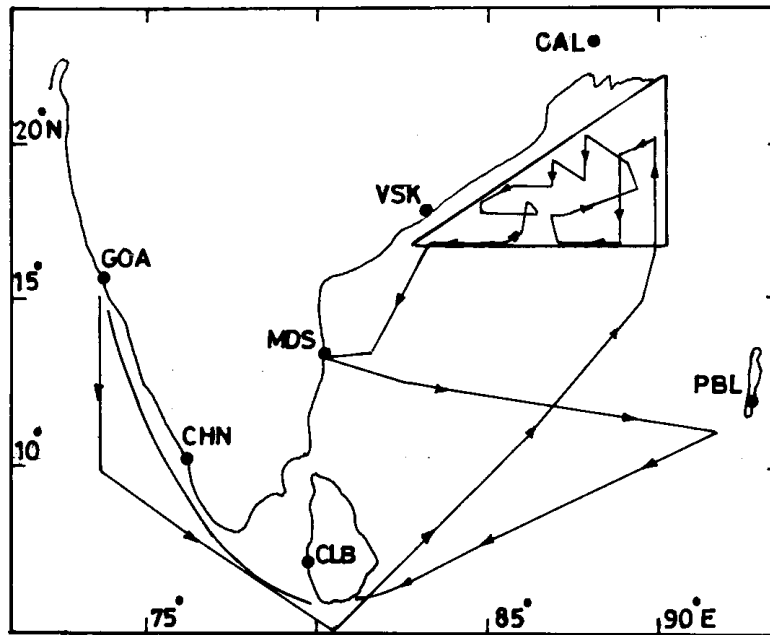


Fig. 1. Cruise track of ORV Sagar Kanya and area of observation over northwest and adjoining westcentral Bay of Bengal

Recently the role of SST in the genesis of tropical convection has been studied comprehensively by many investigators (Waliser *et al.*, 1993; Bhat *et al.*, 1996; Bhat, 2001 and Tompkins, 2001). The SST plays an important role in the genesis of warm pool over the southeastern Arabian Sea which triggers the onset of southwest monsoon (Shankar and Shetye, 1997; Rao and Sivakumar, 1999 and Shenoi *et al.*, 1999).

2. Data and methodology

The present study utilizes reliable surface and upper air meteorological data collected by professionals on board ORV Sagar Kanya during its 66th cruise which was undertaken to study the dynamics of monsoon trough and cyclogenesis over the Bay of Bengal. The surface data was recorded by the data logger in the meteorological lab which could record all meteorological parameters like sea level pressure, air temperature, wind speed and direction, humidity, SST etc. at frequent intervals. All parameters were displayed on the monitor of data logger every 10 minutes but data print outs were taken after 3 hours which was sufficient to study the daily variations. Similarly, upper air radiosonde ascents were taken by the meteorological team depending upon the weather situation.

Three hourly observations of SST and SLP have been used to compute daily means of these parameters

which have been utilised to study the daily variations. 1200 UTC radiosonde data have been used to study the daily variations of thermodynamical parameters. The area of observations over the northwest and adjoining westcentral Bay of Bengal has been depicted in Fig. 1.

Daily rainfall data of Orissa for corresponding period have been utilised to compute the daily percentage rainfall departures presented in Fig. 8.

3. Results and discussion

3.1. Synoptic features

During the stay of ORV Sagar Kanya over northwest and adjoining westcentral Bay of Bengal a low pressure area developed over there giving the opportunity to collect the observations from the field of the system. Special advisories were issued to Sagar Kanya to track the system. The system was seen as a cyclonic circulation over northwest Bay and adjoining coastal Orissa coast on 14th July, 1991 which became a low pressure area on 14th evening. On 15th evening the low pressure area intensified into a well marked low which persisted over northwest Bay and adjoining coastal Orissa till 16th. The well marked low moved northwestwards and was located over north Orissa and neighbourhood on 17th. The system moved further northwestwards and became unimportant by 19th. The surface and upper air meteorological

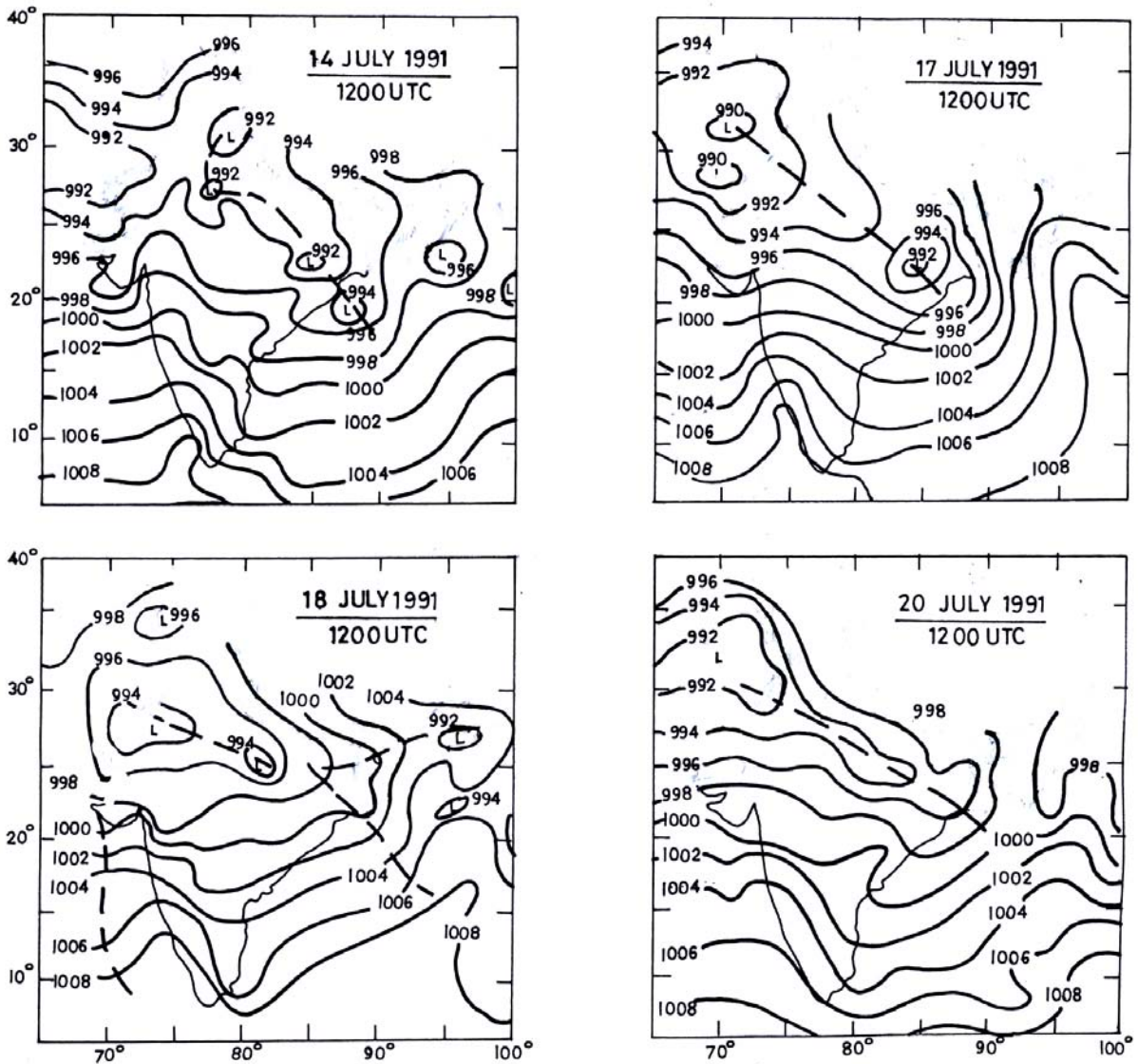


Fig. 2. Sea level chart showing the formation and movement of the low pressure system

observations collected by ORV Sagar Kanya during 13-19 July were extremely useful in the study of low pressure area and the intensification of monsoon trough over northwest Bay of Bengal. The sea level charts showing the formation and movement of the low pressure system have been depicted in Fig. 2.

3.2. Surface parameters

3.2.1. Sea surface temperature

The variations of daily mean SST over northwest and adjoining westcentral Bay of Bengal during the period

12-22 July have been presented in Fig. 3. Mean SST increased by 0.4°C from 12th to 13th, becoming 29.6°C and then decreased sharply to 27.9°C on 14th, the day when cyclonic circulation formed, showing that peak SST preceded the formation of the cyclonic circulation. The fall of SST by 1.7°C from 13th to 14th was probably due to increased evaporation on 14th as a result of formation of the circulation. This is reflected in the computed values of latent heat flux which increased from 75 to 120 Watt/m^2 between 13th and 14th. Fig. 8 shows that humidity at 500 hPa level increased from 56% to 78% between 13 and 14 which is again a manifestation of increased evaporation. During the analysis and processing of bulk

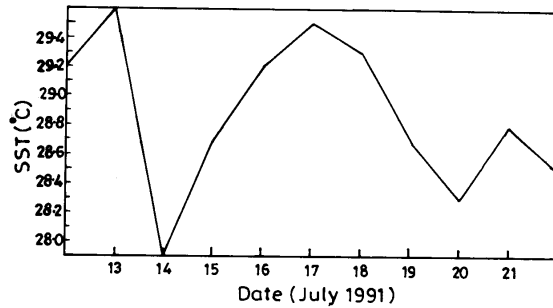


Fig. 3. Variation of SST

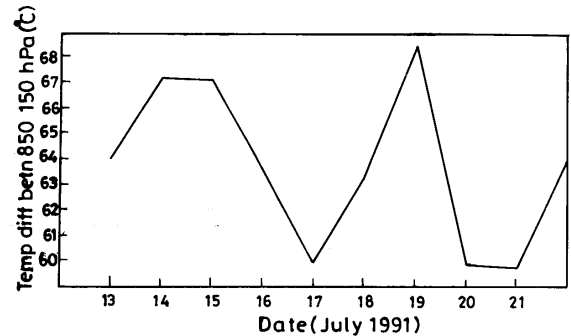


Fig. 5. Variation of the temperature difference between 850-150 hPa

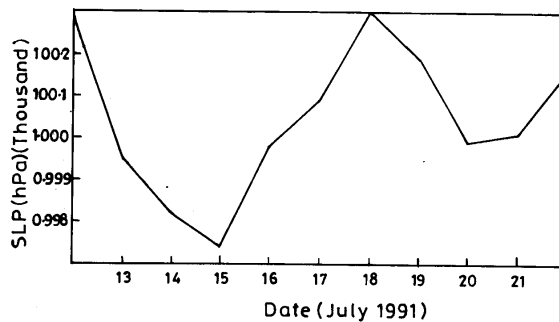


Fig. 4. Variation of SLP

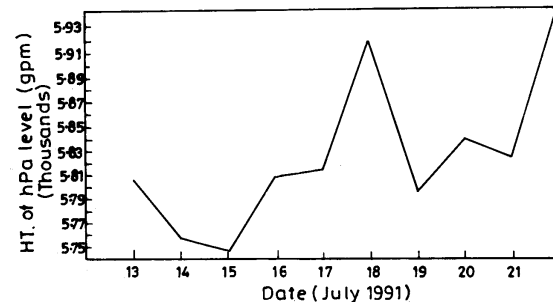


Fig. 6. Variation of the height of 500 hPa level

oceanographic data the author has invariably noticed that higher SSTs generally prevail before enhanced evaporation rate and fall sharply thereafter. Thus the cause-and-effect relationship between SST and evaporation on smaller time scales appears to be pretty clear. Higher SSTs cause higher evaporation rate whereas higher evaporation rate causes lower SSTs. Thus there appears to be an in-built mechanism in the SST fluctuations over the sea. The computed values of latent heat flux, as mentioned above reveal this aspect.

Fig. 3 shows that SSTs registered an increasing trend from 14th to 17th, peaking on 17th to 29.5° C. Another peak was noticed on 21st. Thus a 4 day cycle appears to exist in the SST fluctuations. A 4-5 day cycle is also seen in the humidity fluctuations at 500 hPa level (Fig. 8).

3.2.2. Sea level pressure

SLP variations show remarkable relationship with SST fluctuations (Fig. 4). Minimum surface pressure of 997.4 hPa was observed on 15th July. This obviously coincided with the intensification of low pressure area to the well marked low. Another minima of 999.9 hPa was observed on 20th exhibiting a 5 day cycle in SLP variation over the northwest Bay of Bengal.

Most interesting aspect of SST and SLP variations is that there is a lag of 2-3 days between SST maxima and SLP minima. Thus there appears no doubt that SST is the main forcing for the pressure fluctuations over the head Bay of Bengal during SW monsoon. If the SSTs are monitored on daily basis over the north Bay of Bengal, then the intensification or weakening of monsoon trough and the possible development of monsoon systems could be predicted with reasonable degree of accuracy atleast 48 hr in advance.

It is evident that all relative maxima in SST and all relative minima in SLP would not lead to the development of a monsoon system (low or depression) over the Head Bay. A case in point is the SST maxima on 17 July and SLP minima on 20 July when no system developed. This, however does not undermine the importance of these extrema. The intensification of eastern end of monsoon trough itself is important for the rainfall over coastal Orissa and West Bengal.

Computed values of sensible heat flux showed significant variations which were almost parallel to SLP variations. The value of this parameter rose from 2.1-38.7 Watt/m² between the period 13-15 July. The sensible heat flux maxima coincided with SLP minima on 15th. The

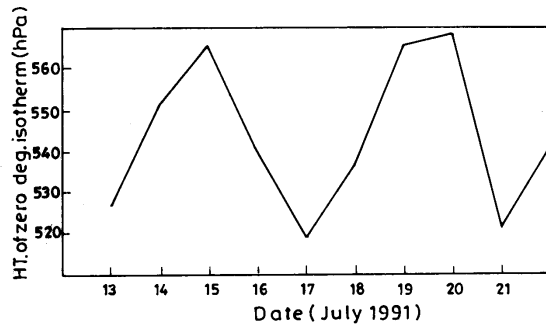


Fig. 7. Variation of the height of zero degree isotherm

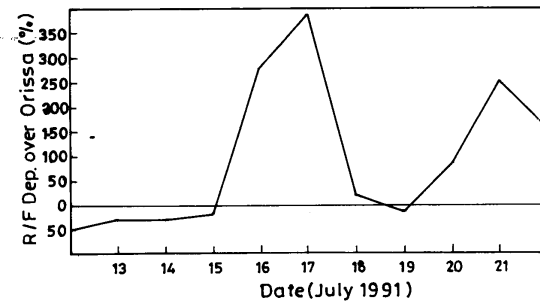


Fig. 9. Rainfall departure over Orissa

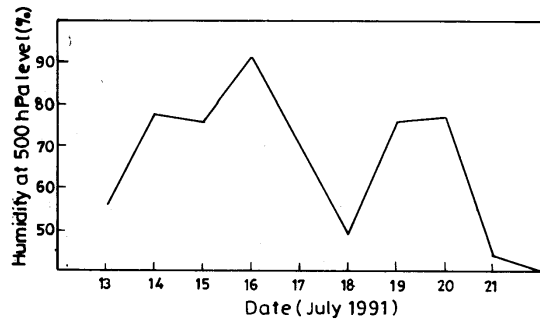


Fig. 8. Variation of the humidity at 500 hPa level

increasing tendency of sensible heat flux appears to be an indication of intensification of monsoon trough over the north Bay of Bengal.

It would be important to establish the threshold values of SST over the head Bay of Bengal leading to the formation of monsoon lows and depressions. This, however can not be done using the data from the field of only one system. It is desirable to have surface and upper air data from the fields of at least 4-5 monsoon lows and depressions. Another problem is that even if the threshold values of SST and SLP for the development of monsoon systems are established, the daily monitoring of these parameters is not possible throughout the monsoon with the help of conventional ships' observations. Thus crucial meteorological parameter like SST needs to be monitored over the head Bay on a daily basis with the help of buoys/satellites in order to predict the possible intensification and weakening of the monsoon trough and the development of monsoon systems.

3.3. Upper air parameters

Daily variations of the thermodynamical parameters like temperature difference (δT) between 850-150 hPa, height of 500 hPa level, height of zero degree isotherm

and humidity at 500 hPa level over the northwest and adjoining westcentral Bay of Bengal have been shown in Figs. 5-8. The temperature difference between 850-150 hPa has been presented in Fig. 5. As expected the temperature difference fluctuations show close relation with the SST fluctuations. The δT maxima on 14th/15th and 19th follow SST maxima on 13 and 17, thus showing a lag of 1-2 days. The δT variation shows a cycle of 5 days analogous to the SLP variation (Fig. 4). The peak δT was observed a day before the lowest SLP. Thus both the SST and the temperature difference in the troposphere appear to have indications of possible intensification and weakening of monsoon trough. Peak SST is followed by peak temperature difference between 850-150 hPa, which is followed by lowest SLP with the interval of one day each.

Fig. 6 shows that the lowest height of 500 hPa level on 15th and 19th almost coincided with the lowest SLPs on 15th and 20th. Similarly Fig. 7 shows that the lowest height of zero degree isotherm on 15th and 20th which were 565 hPa and 568 hPa respectively, exactly coincided with the lowest SLPs. Thus the intensification of monsoon trough over north Bay appears to coincide with lowest heights of 500 hPa level and zero degree isotherm.

Humidity variation at 500 hPa level is shown in Fig. 8 which shows two relative maxima on 16th and 20th with values 91% and 77% respectively. Thus the lag between minimum SLP and maximum humidity at 500 hPa appears to be 0-1 day.

3.4. A model sequence for strengthening and weakening of monsoon trough over the head Bay of Bengal

Fig. 10 depicts a proposed model for the dynamics of monsoon trough over the head Bay of Bengal. The model shows a 4 day cycle for the intensification of eastern end of the monsoon trough over the north Bay. +1 indicates

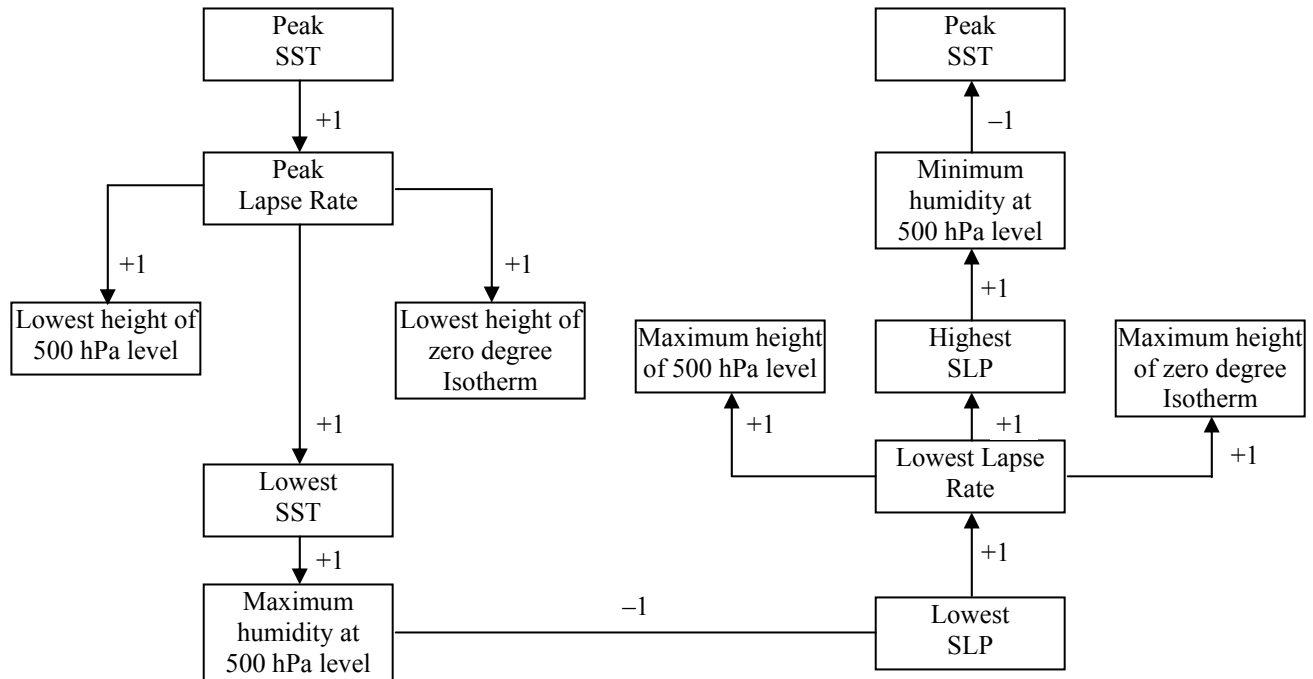


Fig. 10. A model sequence for strengthening/weakening of monsoon trough over the head Bay of Bengal

that the event follows with a lag of 1 day. Similarly, -1 implies that the event occurs 1 day before. The proposed model is based upon the observed variations of different surface and upper air parameters discussed in the foregoing sections. Two important parameters having predictive informations are SST and the lapse rate in the troposphere. Two parameters, viz, heights of 500 hPa level and zero degree isotherm appear to fluctuate with the sea level pressure, thus having little predictive value. The humidity at 500 hPa level appears to be the effect of intensification/weakening of the monsoon trough. Needless to mention, the SLP has been taken as the measure of intensity of the monsoon trough.

The cause-and-effect relations need to be used alongwith the observations of different parameters. The most significant feature of the variations of different surface and upper air parameters is that almost all of them exhibit a 4-5 day cycle with certain lag. It may be pointed out that average period of stay of the eastern end of monsoon trough along foothills as well as average duration of monsoon breaks are also about 4-5 days. It may also be pointed out that it is the eastern end of the monsoon trough that is more dynamic. Thus the key to medium range forecasting of monsoon rainfall over central parts of India appears to lie over the north Bay of Bengal.

It is remarkable that surface and thermodynamical parameters over the sea have exhibited similar cycle with some lags. Hanawa (1991) has reported that SST fluctuations were highly correlated with 500 hPa height variations over the north Pacific. Unfortunately, similar studies relating SST to upper air parameters over the Indian Seas do not exist.

3.5. Rainfall variability over Orissa

Daily rainfall variability over Orissa during the period 12-22 July, 1991 has been presented in Fig. 9. It is interesting to observe two peaks in the rainfall variations, i.e., on 17th and 21st. The first peak on 17th coincides with the well marked low that moved northwestwards from northwest Bay and was located over north Orissa and neighbourhood on that day. The second peak on 21st appears to be associated with the intensification of eastern end of the monsoon trough on 18th. The lag between lowest surface pressure over the north Bay and enhanced rainfall over Orissa appears to be 2-3 days (Figs. 4 and 9). Thus it seems that good rainfall over the coastal regions of India close to northwest Bay is mainly dependent upon the intensity of the eastern end of the monsoon trough. It is not surprising that there have been monsoons without a single monsoons depression but the rainfall over Orissa has been normal.

The important factor for good rainfall activity over Orissa appears to be the frequent intensification of the monsoon trough over the northwest Bay of Bengal even without crossing the threshold intensity for producing the monsoon depressions or well marked lows. It is evident from Fig. 9 that enhanced rainfall activity over Orissa during the period 20-22 July was almost comparable to the rainfall activity during 16-18 July when a well marked low moved over the state. It may be pointed out that no synoptic system affected Orissa during 20-22 July. Thus rainfall over Orissa during monsoon appear to be related with the SST and SLP over northwest Bay of Bengal and thus to the intensity of the eastern end of the monsoon trough rather with the frequency of monsoon lows or depressions. When monsoon trough becomes very intense cyclogenesis occurs producing more rainfall for short durations. However, frequent activation of monsoon trough even without monsoon depressions can produce normal/excess rainfall over Orissa.

Even the experiments like MONEX have emphasised more over the data collection from the Arabian Sea. It would be fascinating to investigate how the head Bay of Bengal is able to sustain such high values of SST at the peak of SW monsoon which cools other parts of the Indian seas substantially.

Even though the crucial surface and upper air data from the northwest Bay were available only for a short duration the variations exhibited by different parameters and their relationships with each other appear to be remarkable which surely give an insight into the dynamics of monsoon trough over the head Bay of Bengal.

The sea level pressure analysis depicted in Fig. 2 validates, to some extent, the pressure fluctuation in the proposed sequence model for a short duration. A few more similar cruises of ORV Sagar Kanya over the north Bay of Bengal may perhaps confirm the proposed sequence of events for the intensification/weakening of the eastern end of the monsoon trough.

4. Conclusions

The study has brought out the following :

- (i) Monsoon trough activity over the northwest and adjoining westcentral Bay of Bengal appears to possess a 4 day cycle.
- (ii) The primary forcing for the activation of the eastern end of the monsoon trough over head Bay of Bengal appears to be the sea surface temperature.

(iii) The time lag between the peak sea surface temperature and the minimum sea level pressure appears to be 2 days.

(iv) Heights of 500 hPa level and zero degree isotherm appear to fluctuate with the sea level pressure.

(v) The time lag between peak sea surface temperature over the northwest Bay and enhanced rainfall over Orissa appears to be 4 days.

(vi) The model sequence for the intensification and weakening of the eastern end of the monsoon trough proposed here shows that the sea surface temperature and the temperature profile in the troposphere over the north Bay of Bengal may provide predictive indications of possible intensification/weakening of the monsoon trough over the sea.

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