

## Inference of the moisture field over Arabian Sea during the monsoon of 1984 using INSAT-1B sea surface temperature data

C. L. AGNIHOTRI

Meteorological Office, New Delhi

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**सारा —** इस अध्ययन में समुद्र तल तापमान अनियमितताओं का प्रयोग करते हुए ग्रीष्म मानसून (मई-सितम्बर 1984) के आरम्भ में, सक्रिय और पीछे हटने के चरण के दौरान अरब महासागर में आर्द्रता के प्रभाव का मॉनिटरिंग किया गया। इस अध्ययन से पता चलता है कि मानसून के सामान्य आरम्भ से लगभग 20 दिन पूर्व आर्द्र वायु का प्रभाव दक्षिण प्रायद्वीप पहुंच गया था और वह प्रभाव मानसून के प्रारम्भ होने के बाद भी उससे 12-14 दिन पहले ही आगे-आगे चलता रहा। पीछे हटने की प्रक्रिया के दौरान यह देखा गया कि आर्द्र वायु उत्तरी अरब महासागर से सितम्बर माह के तीसरे सप्ताह पीछे हटनी आरम्भ हो गई थी और उसका स्थान शुष्क महाद्वीपीय वायुसंहति ने ले लिया जो कि आर्द्र वायु और मानसून को आगे दक्षिण की ओर लगातार धकेलती रही।

**ABSTRACT.** In this study moisture incursion in the Arabian Sea has been monitored during the onset, active and withdrawal phase of the summer monsoon (May-Sept 1984) using sea surface temperature anomalies. This study shows that tongue of moist air reached south Peninsula about 20 days ahead of the normal onset of monsoon and continued to be ahead by 12-14 day even after its setting. During the withdrawal phase it has been observed that moist air starts withdrawing from north Arabian Sea by third week of September replaced by dry continental air mass which continued to move southward pushing further south the moist air and the monsoon.

### 1. Introduction

The onset of Indian summer monsoon has been studied by many authors from various angles. Sutcliffe and Bannan (1954) have shown that onset of monsoon over Kerala occurs five to sixteen days after the first appearance of easterlies at 200 mb level at Aden. Ananthkrishnan and Ramakrishnan (1965) showed that variation is much more than that given by Sutcliffe. Koteswaram (1958, 1960) regards that the setting of easterly jet stream over south India coincides with the burst of monsoon. Rai Sarcar and Patil (1962) correlated the decrease of westerly component of 9.0 km wind in the month of April with early onset of summer monsoon. Jambunathan (1974) using satellite cloud pictures showed that during the onset of monsoon there is a northward movement of organised clouds from equator to 20°N. Other authors have studied the cross equatorial flow from southern hemisphere to the northern hemisphere and have established that the air of different origin crosses the equator and becomes southwest (SW) monsoon flow of the Arabian Sea. Simpson (1921) recognised that air from south of the equator is drawn into the southwest monsoon circulation. Findlater (1969) identified such feed from south of the equator into Indian southwest monsoon. From all these studies and from observations of the cross equatorial flow and other synoptic features as studied by different authors it is visualized that a tongue of moist air fully saturated with water vapour (monsoon air) appears sufficiently ahead of monsoon.

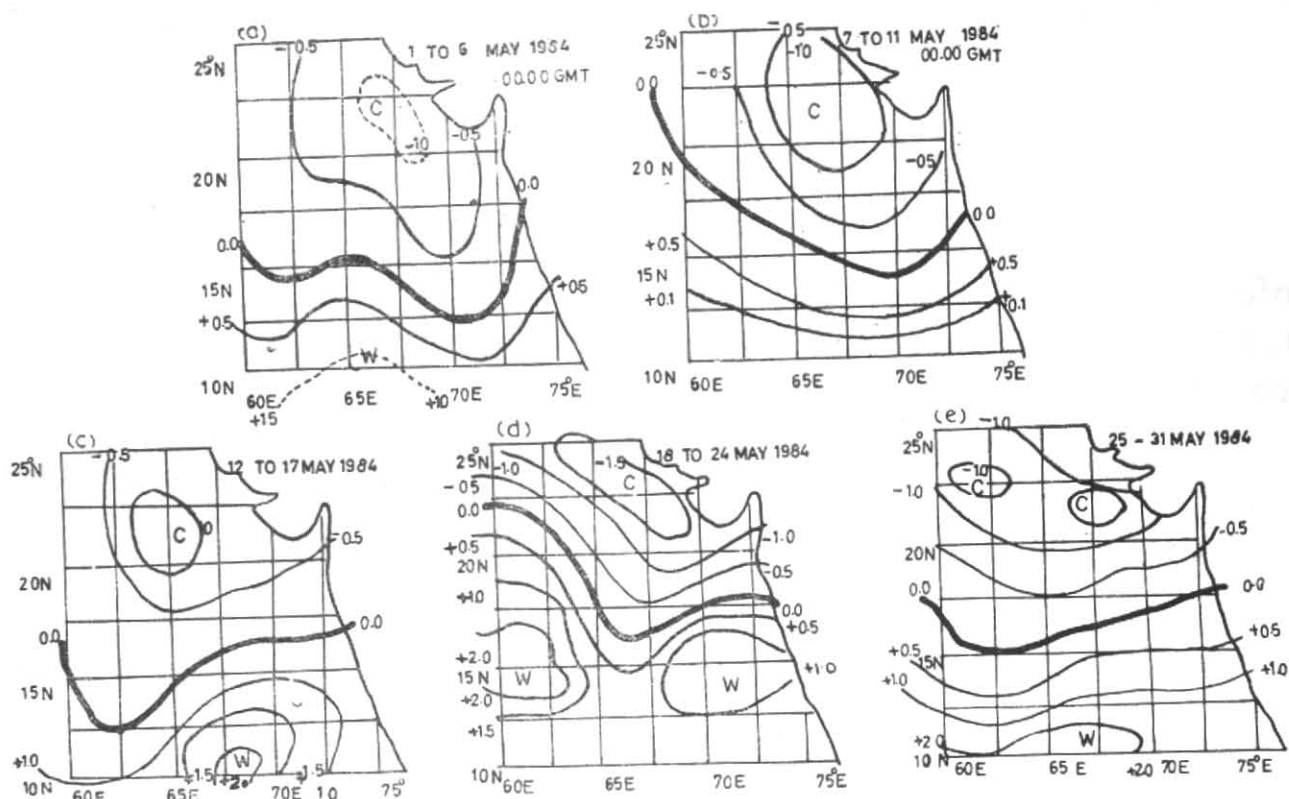
In this paper the author has attempted to identify this behaviour, and how much in advance such moist air can be detected before the actual arrival of monsoon. To study this behaviour the author has used uncorrected sea surface temperature (SST) derived from INSAT-1B data during the period of May to September 1984.

### 2. Data

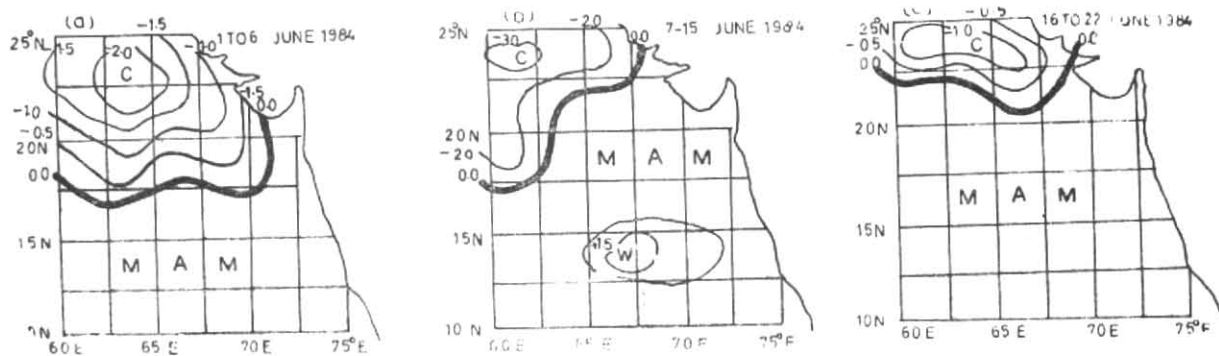
In the present study, INSAT derived uncorrected sea surface temperature (SST) over the Arabian Sea between 25°N & 10°N and 60°E & 75°E during the period May to September 1984 have been made use of. In this study only SST data of 0000 GMT was used, as early morning data is not subjected to any diurnal variation due to (1) heating and (2) mixing on account of strong wind.

### 3. Description of INSAT-1B VHRR

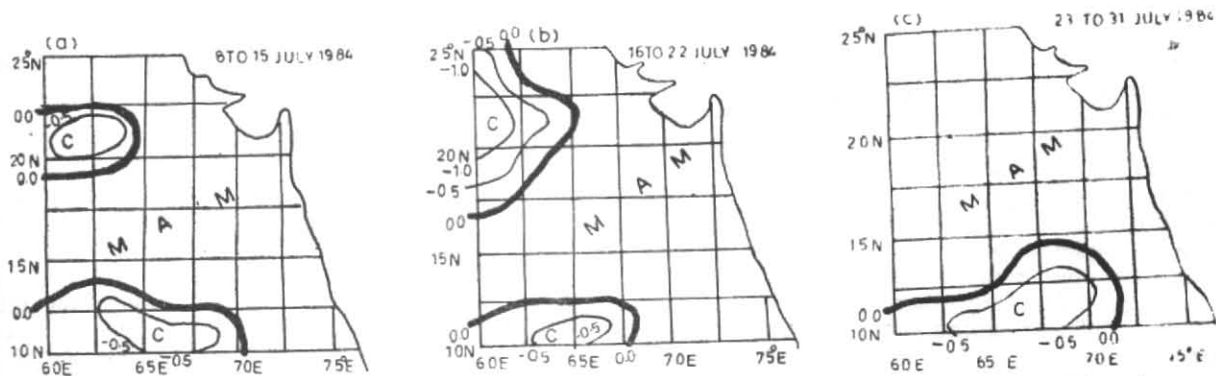
The Very High Resolution Radiometer (VHRR) on board geostationary satellite INSAT-1B which is located at 74°E over equator at a height of 36,000 km is a two channel radiometer, which measures the reflected and the thermal radiant intensity from the oceanic/earth surface in two wave bands (a) Visible (0.55 to 0.75  $\mu\text{m}$ ) and (b) Infrared (10.5 to 12.5  $\mu\text{m}$ ).



Figs. 1 (a-e). Weekly averaged SST anomaly contours for May 1984 showing areas of positive anomaly (W) and negative anomaly (C) and areas full of moist air mass (MAM)



Figs. 2 (a-c). Weekly averaged SST and anomaly contours (K) for June 1984 depicting positive anomaly (W) and negative anomaly (C) and areas full of moist air mass (MAM)



Figs. 3 (a-c). Weekly SST anomaly contours (K) for July 1984 showing areas of positive anomaly (W) and negative anomaly (C) and areas full of moist air mass (MAM)

#### 4. Analysis

The infrared (IR) channel is considered a high transmission window for the outgoing longwave radiations from oceanic earth surface. The near surface tropospheric absorption (attenuation) by atmospheric constituents like carbon dioxide, dust particles, aerosols, ozone and water vapour affects the outgoing surface radiant flux, as a result the sea surface temperature sensed by the satellite radiometer is several degrees lower than the actual surface temperature. Sea surface temperature and precipitable water in the atmosphere have also been studied by Prabhakara *et al.* (1982) by applying microwave technique to NOAA data.

Over the sea surface, the attenuation is mainly due to water vapour and the contribution by carbon dioxide, dust particles, aerosols in the near surface tropospheric layer is comparatively small which can be ignored. As such the lower temperature sensed over sea surface by the IR sensor is mainly due to the presence of water vapour, so the degree of SST deviation can be taken as a direct function of moisture content. In this study sub-area SST deviation from the area averaged SST (SST anomaly) has been considered as an indirect parameter to quantify the moisture content, as satellite derived SST products are more useful quantitatively.

To determine the SST anomaly (SSTA), the area under study (25°N-10°N, 60°E-75°E) has been divided into numbers of sub-areas of 2½ degree Lat./Long. grid. SST data in each sub-area has been averaged spatially over the periods of a week (SSTG). Likewise the whole area under consideration has been marked with averaged SST values and contaminated (C) values, where SST derivation is not possible due to clouds [Contamination (C) — An area is marked with 'C' value where more than 40% of all the image pixel in each sub-area of the visual cloud imagery is brighter than the specified visual threshold grey shade value]. The average of the SSTG data from various sub-areas have been considered as the average SST value for the whole area under study. SST anomalies (SSTA) have been computed for each sub-area for each week. Weekly charts for SSTA have been prepared for the period May to September 1984, and analysed to bring out relative patterns of negative and positive SST anomalies. SSTA contours for 0.0, ± 0.5, ± 1.0, ± 2.0 (K) etc. have been drawn to identify warm (positive) and cold (negative) anomaly areas.

SST anomaly (SSTA) = areas average SST (SST) — Sub-areas average SST (SSTG)

$$SSTA = (SST - SSTG)$$

SSTA can be positive (warm) as well as negative (cold) depending upon whether the SST is greater or lesser than SSTG. SSTA will be positive when the absorption (water vapour) cover a particular sub-area is more as compared to the absorption of the area, resulting in a net decrease of radiant flux or the sensed temperature (SSTG). Therefore, one can conclude that the sub-area which has positive anomaly will be more moist and area with negative anomaly will be less moist (dry) with respect to the average moisture of the area, *i.e.*, more positive anomalies means a higher degree of moisture content, neglecting the contribution of other sources (aerosols, dust particles) which is of significant

value in the lower troposphere. The line separating (0.0 contour) the dry and moist area can be considered as the upper limit upto which moisture tongue has advanced into the Arabian Sea.

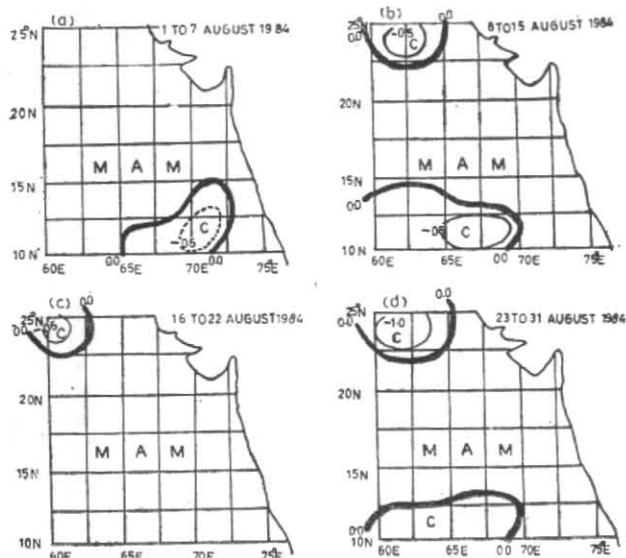
#### 5. Discussion

Figs. 1 (a-e) show weekly SSTA charts for May 1984. These charts have been analysed to identify the area with positive (warm) and negative (cold) anomalies. The 0.0 SSTA contour has been shown in thick line which separates the dry air mass from the moist air. The study of these charts shows that moist air tongue from southwesterly direction starts appearing in south Peninsula area as early as first week of May and established by second week, which gradually moved north-westward as well as extended towards west, pushing the dry air mass to N/NW-ward. A strong positive anomaly (+2°K) has also been observed around 11°N/67°E with a tendency to move NW-ward during 12-17 May (Fig. 1c). Synoptically a low pressure area has been observed at (0000 GMT) of 20 May around 10°-14°N/65°-70°E which may be as a consequence of the movement of strong (positive anomaly) moisture cell. The analysed SSTA weekly charts for June 1984 have been shown in Figs. 2(a-c). These charts show the further northward movement of moisture limit (0.0 contour). Fig. 2(b) shows how the dry air mass has been compressed further into NW corner by the upcoming moist air tongue.

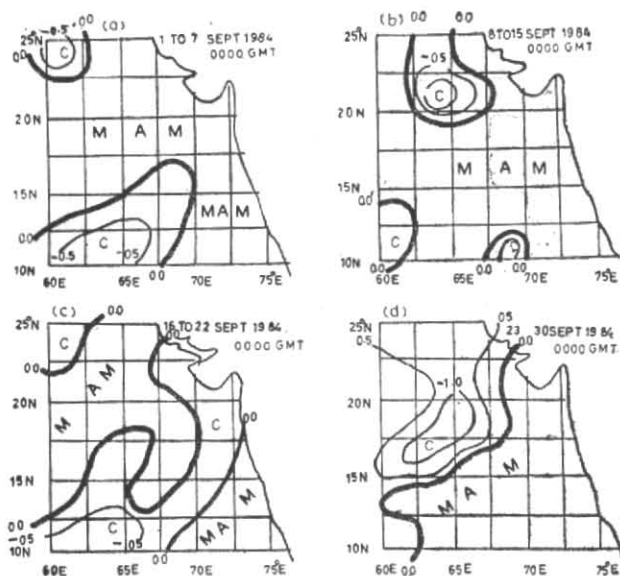
Figs. 3. (a-c) show analysed weekly charts for the month of July 1984. These charts show the whole areas under the influence of strong moist air as monsoon has fully established, except two negative (cold) anomalies areas around 20°-22°N/61.5°-65° E and 10°-15°N/60°-70°E where a dry air mass is expected. Fig. 3(c) shows negative (cold) anomaly area around 10°-13°N/60°-70° E, the other appeared to have moved very fast and emerged with the continental dry air mass. Figs. 4 (a-d) show the analysed weekly charts for August 1984. These charts show that the negative (cold) anomaly area around 10°-14°N/65°-70° E of previous month also persisted throughout the month of August and continued to September extending northeastward. Another negative (cold) anomaly area appeared in second week of August around 20°-25°N/60°-65°E which showed extension towards southeast with passage of time. The appearance of negative anomaly around 20° - 25°N/ 60° - 65°E (dry area) gives an indication for the withdrawal of monsoon, as continental dry air will push southward the moist air mass and, thus, will establish on opposite air mass flow.

Weekly analysed charts for September 1984 have been shown in Figs. 5(a-d). It is seen from Fig. 5(c) how two negative (cold) anomaly areas observed during the month of August merged into one negative anomaly zone compressing the moist air in between. As a result a tongue of dry continental air mass gets into the prevailing moist air area from northeasterly direction, thereby cutting the supply of the moist air from the south and affecting the monsoon activity. Fig. 5 (d) brings out clearly the southward movement of dry air mass pushing further south the limit of the moist air, and the withdrawal limit of the monsoon.





Figs. 4 (a-d). Weekly SST anomaly contours (K) for August 1984 showing areas of positive anomaly (W) and negative anomaly (C) & areas full of moist air mass (MAM)



Figs. 5 (a-d). Weekly SST anomaly contours (K) for September 1984 showing areas of positive anomaly (W) and negative anomaly (C) and areas full of moist air mass (MAM)

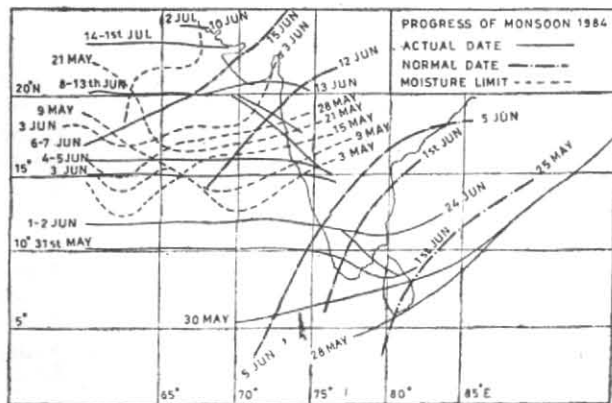


Fig. 6

Fig. 6: shows the northern limit of the monsoon during 1984, normal dates of monsoon and the moisture limit based on the analysis of SST anomalies. The study of the actual monsoon limit as observed (NHAC, New Delhi record) during 1984 and the moisture limit as computed above, indicates that the moisture limit is about 20 days ahead in the onset phase of summer monsoon over south 'Peninsula,' India and about 12 days over the central Arabian Sea when the monsoon has fully established during the month of June. The actual monsoon limit shows a zonal pattern while moisture limit shows a SW'y orientation.

## 6. Conclusion

(a) The moisture limit appeared about 20 days in advance to the actual onset of summer monsoon over south Peninsula, India and maintained a 10-day lead to the actual date over the central Arabian Sea. This result shows that INSAT-1B SST data can be of potential use in the prediction of the onset and progression of the Indian summer monsoon.

(b) The orientation of the moist tongue is SW to NE upto central Arabian Sea.

(c) Dry continental air mass showed appearance over Gulf of Oman in the second week of August which moved eastward and formed a dry continental air tongue which engulfed the moist air mass of Arabian Sea resulting in setting an opposite air mass circulation and withdrawal of summer monsoon by third week of September 1984.

In the absence of any actual observation of moisture field over the oceanic area, this technique may be helpful to identify the moisture limit and to forecast the likely dates of onset and withdrawal of Indian summer monsoon.

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