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# Satellite estimated water vapour in relation to Asian monsoon Circulation

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**सार** - वायुमंडल में विभिन्न आदान-प्रदान और वहन की प्रक्रियाओं में जल वाष्प महत्वपूर्ण भूमिका निभाती हैं। विभिन्न विश्वस्तरीय परिचालन निदर्शों में जल वाष्प के उपयोग के लिए उष्णकटिबंधों में इसकी विद्यमानता की जानकारी अत्यंत आवश्यक है। धरातल के विशाल महासागर प्रचुर नमी के स्रोत हैं। ये महासागर संघननी तापन और प्रच्छन्न उष्मा अभिवाह के माध्यम से वायुमंडल की उष्मागतिकी को निरंतर परिवर्तित करते रहते हैं। उष्ण कटिबंधों में, विशेषकर हिन्द महासागर में जल वाष्प अत्याधिक विषम प्रकृति की है। यह जल वाष्प उन प्राचलों में से एक है जो मानसून प्रवाह, अवदाब, चक्रवात आदि जैसी उष्णकटिबंधीय प्रणालियों के साथ मिलकर मेघ बनाते हैं। इस शोध-पत्र में हिन्द महासागर और भारतीय उपमहाद्वीप के आसपास के दक्षिणी पश्चिमी मानसून क्षेत्र को प्रभावित करने वाले जल वाष्प के संबंध में वाही तुल्यकाली और ध्रुवीय कक्षीय उपग्रहों से प्राप्त हुई विभिन्न सूचनाओं की समीक्षा की गई है।

जल वाष्प विस्तार का अध्ययन करने के लिए टाइरोस (TIROS) परिचालन उर्ध्वाधर ध्वनित्र टी.ओ.वी.एस. (TOVS) और इनसैट-2ई के जल वाष्प माध्यम से प्राप्त हुए तापमान और आर्द्रता के ऑकड़ों की जॉच की गई है। एशियाई दक्षिणी पश्चिमी (द.प.) मानसून के परिचालन को अभिलक्षित करने से संबंधित इनकी उपयोगिता पर इस शोध-पत्र में प्रकाश डाला गया है। केरल के समुद्र तट पर मानसून के प्रारम्भ होने से लगभग 8 से 10 दिन पूर्व पश्चिमी हिन्द महासागर में मध्य क्षोभमंडलीय आर्द्रता में वृद्धि (700-500 hPa) पाई गई है। NOAA/TOVS सतह तापमान और आर्द्रता का उपयोग मानक दाब स्तर पर आर्द्रता प्रोफाइल का पता लगाने के लिए किया गया है। इसका उपयोग प्रच्छन्न और संवेदी उष्मा अभिवाह की जानकारी प्राप्त करने के लिए भी किया गया है। SSM/I से प्राप्त कुल एकीकृत जल वाष्प का उपयोग भी प्रच्छन्न उष्मा अभिवाहों की जानकारी प्राप्त करने और एन.डब्ल्यू.पी. निदर्शों के अभिलक्षणों का पता लगाने के लिए किया गया है। हाल ही में, मानसून परिचालन लक्षणों मारीटरन के लिए इनसैट - 2ई जल वाष्प माध्यम का उपयोग किया गया है। नये डब्ल्यू वी. के माध्यम से विभिन्न वायु संहति के निवेशन को विशेषकर मानसून के प्रारम्भ और मानसून के धीमें पड़ने से संबंधित जल वाष्प को स्पष्ट रूप से देखा गया है।

**ABSTRACT .** Water vapour plays a crucial role in various exchange and transport processes in the atmosphere and its knowledge in the tropics is extremely important for input to various global circulation models. The vast oceans of earth's surface provide a large source of moisture and continuously modify the thermodynamics of the atmosphere through latent heat flux and condensational heating. In the tropics, especially in the Indian ocean the water vapour is highly heterogeneous in nature, and is one of the parameters which is responsible for cloud formation, associated with tropical systems like monsoon flows, depression, cyclones etc. The present paper reviews the various informations available from deferent geostationary and polar orbiting satellites about water vapour affecting the southwest monsoon region around the Indian Ocean and Indian subcontinent.

The temperature and moisture data from TIROS operational vertical sounder (TOVS) and INSAT-2E water vapour channel are examined to study water vapour distribution. Their usefulness in characterizing the Asian south-west (SW) monsoon circulation is focused. The Western Indian ocean showed an increase in mid-tropospheric moisture (700-500hPa) over about 8 to 10 days prior to the onset over Kerala coast. NOAA/TOVS layer temperature and humidity is used to extrapolate the humidity profile at standard pressure levels. It is also used to compute latent and sensible heat flux. Total integrated water vapour from SSM/I is also used for estimating latent heat fluxes and for the diagnostics of NWP models. Recently, INSAT-2E water vapour channel was used to monitor the monsoon circiulation features. The new WV channel brought out clearly the feeding of various air masses, especially water vapour associated with monsoon onset and monsoon lows.

**Key words** – Tropospheric water vapour, Satellite observation, Southwest monsoon, TOVS.

## 1. Introduction

The Asian summer monsoon is one of the important summer circulation which affects the countries in the Indian & Asian subcontinent. In the past, several studies have been made in explaining different aspects of this circulation. The observational and theoretical attempts to understand the advancement of the monsoon from the equatorial Indian Ocean to the main continent (*viz.* Sikka & Gadgil, 1980, Krishnamurti *et al.*, 1981, Simon *et al.* 1995) is particularly of great interest.

Water vapour plays a crucial role in various exchange and transport processes in the atmosphere and its knowledge in the tropics is extremely important for input to various global circulation models. The vast oceans of our Earth's surface provide a large source of moisture and continuously modify the thermodynamics of the atmosphere through latent heat flux and condensational heating. The total precipitable water vapour (PW) in the atmosphere over the oceans is also useful parameter which indicates the dynamic state of the atmosphere (Prabhakara *et al.* 1982). The integrated water vapour plays an important role in the summer monsoon circulation/activity over the Indian Ocean, as its availability and transport into the Arabian sea affects the summer monsoon rainfall, and 60-80 % of the annual rainfall in most of the meteorological subdivisions.

In bringing the monsoon rains over India the cross equatorial flow of moisture as well as the evaporation over the north Indian Ocean and adjoining seas are known to be equally important (Saha and Bavadekar, 1973; Pisharoty, 1965; Cadet and Reverdin 1981a,b). These studies suggest that the atmospheric moisture variation studies are important for characterizing the onset of monsoon. Simon and Desai (1986, 1992) and Simon *et al.* (1995) and Cadet (1986) have recently studied the moisture variation and evaporation over the seas adjoining India as available from NOAA/TOVS satellite data.

The present paper summarises the information available from the different satellites about water vapour. Three significant sensor data are highlighted in this study. These are TOVS onboard NOAA satellites, VHRR onboard INSAT-2E and SSM/I onboard DMSP satellites. The review also describes the recent attempts in using this data for understanding role of water vapour in the atmosphere during the south-west monsoon season.

## 2. Water Vapour from TOVS onboard NOAA Satellites

The TIROS operational vertical sounder (TOVS) onboard the polar orbiting NOAA satellite has three infrared channels (8.3, 7.3 and 6.7 μm ) and has the capability of providing three-layer moisture data (Smith *et al.* 1979). These give precipitable water vapour in three different layers (*i.e.*, 1000-700, 700-500 and 500-300 hPa). Khalsa and Steiner 1988 have compared the various TOVS products with radiosonde measurements. They observed that TOVS water vapour estimates are within 15 % of in-situ data. The temperature and humidity profile data are now routinely available from National oceanic and atmospheric administration/National environmental satellite data & information services (NOAA-NESDIS). NOAA temperature sounding data from TOVS are available in 15 layers. The accuracy of these retrievals declines in the upper layers. The general problems of humidity assimilation for numerical weather

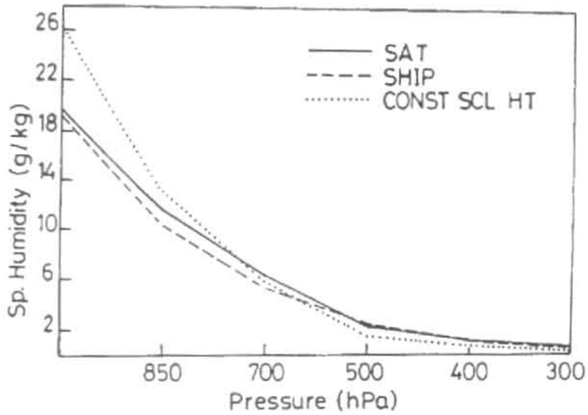


**Fig. 1.** Comparison of satellite derived humidity profile and radiosonde observed profile at equator and 55°E

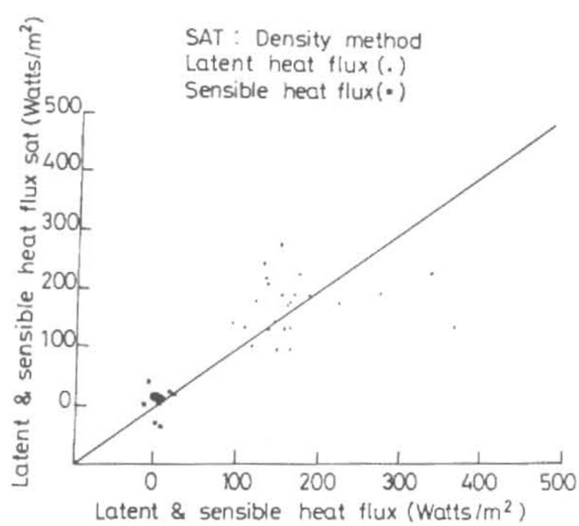


**Fig. 2.** Latent and sensible heat flux comparison (Satellite *versus* Ship), May, 1999

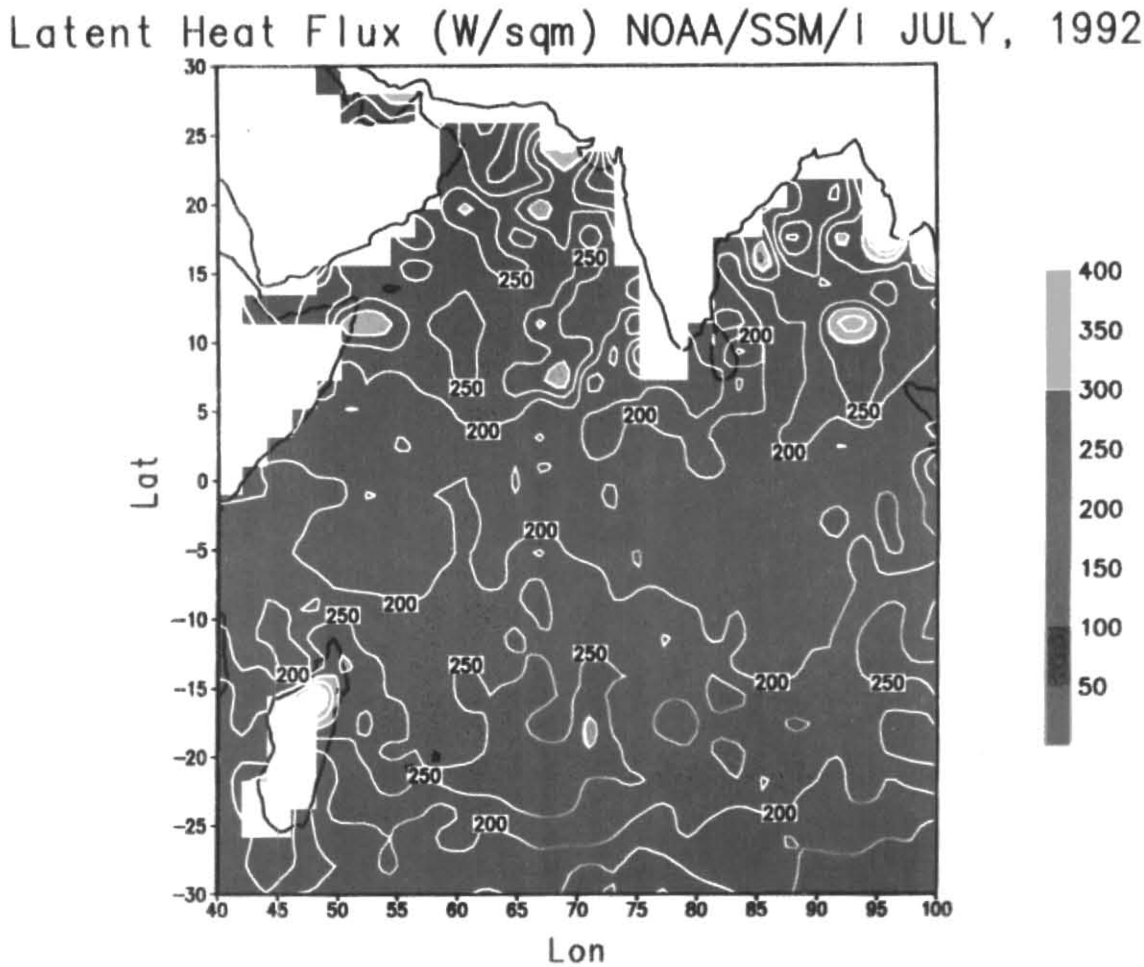


**Fig. 3.** Monthly averaged (July, 1992) latent heat flux (W/sq m) derived using SSM/I & NOAA/AVHRR data

prediction are well documented by Eyre, (1989) and Smith (1991).

### 2.1. *Moisture Profiles from NOAA/TOVS Satellite Data*

Three layer water vapour content can be used to generate the atmospheric water vapour profile by combining it with temperature data. Simon and Desai (1986, 1992) suggested a model for calculating the scale height of water vapour from three broad layer humidity data. The humidity profile so obtained has been compared with the radiosonde observations (Simon *et al.*, 1995). The satellite estimated humidity compares well with the radiosonde observation. One such profile is shown in figure 1. There was improvement in the 850 hPa and 700 hPa levels specific humidity. It was seen that in 400 hPa and 300 hPa the % r.m.s. error significantly improved and was of the order of 20% and 21% (Simon *et al.*, 1995) respectively.

### 2.2. *NOAA/TOVS Satellite Data for Monsoon Onset Studies*

Analysing six years NOAA/TOVS humidity sounding data over Indian Ocean (Simon and Joshi 1994) it was found that the western Indian Ocean moisture in the middle (700-500 hPa), upper level (500-300 hPa) and scale height of water vapour are forerunner of the onset over south peninsular India (Kerala). The moisture and scale height of water vapour increased about 8 days prior to the onset over Kerala. The first signal leading to onset over Kerala is seen in the middle and upper levels rather than in the surface level. On examining the maintenance

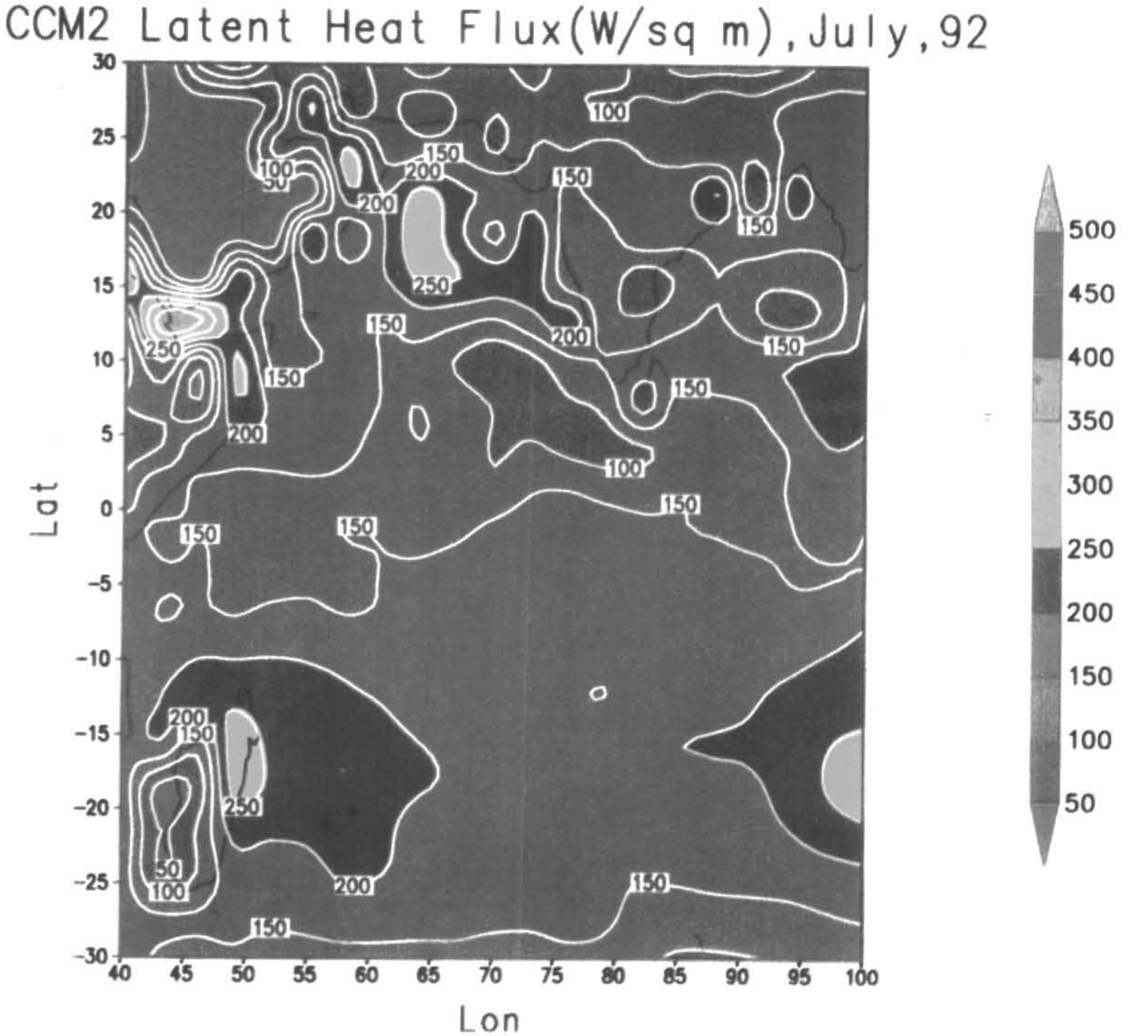


Fig. 4. Monthly averged (July, 1992) latent heat flux (W/sq m) using CCM2 model

of onset vortex, Krishnamurti *et al.* (1981) has shown that the energy of the horizontal shear flow plays a dominant role. They also suggested that this barotropic instability is triggered by gradual descent of mid-tropospheric cyclone to lower levels. The moisture variation around onset time is showing more or less similar behaviour.

The amplitude of the middle level moisture over western Indian ocean had a phase lag of 8-10 days when compared to the maximum pentad rainfall over Kerala Coast. Analysing NOAA/TOVS temperature data Joshi *et al.* (1989, 1990) saw similar peaking of upper tropospheric temperature over heat low regions prior to onset and also its utility for seasonal monsoon rainfall prediction. The explanation for the moisture changes prior to onset would require more theoretical investigations. However, for the present it appears that the TOVS data would be useful for monitoring the onset of the South-West monsoon over India.

### 2.3. *Flux for Monsoon Studies*

On the basis of specific humidity at surface from NOAA/TOVS satellite data, and a special procedure to derive planetary wind shear information and surface level winds from cloud motion vectors from geostationary satellites, the fluxes can be computed. During MONEX-79 a large number of ship observations were available. The latent heat and sensible heat fluxes were determined using both the satellite data and the *in-situ* data by

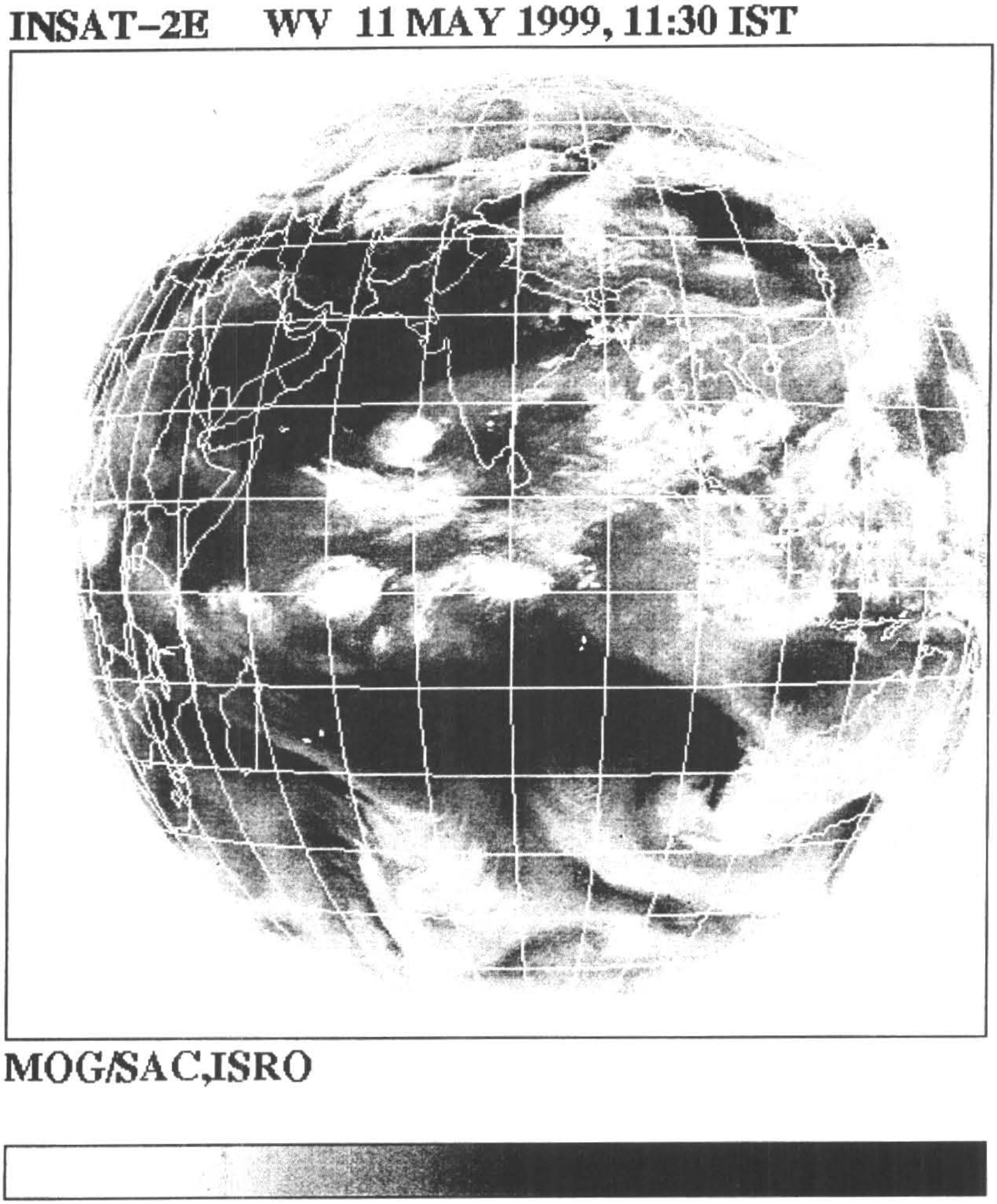


**Fig. 5.** Water vapour imagery (6.7μm) using INSAT-2E VHRR data for 11 May, 1999

applying bulk aerodynamic parameterisation scheme (Simon and Desai, 1986). The comparison is shown in Fig.2. We find that satellite determined estimates are within 30% of the in-situ observations.

The flux peaking around June indicates a marked monsoon onset signal over Western Arabian Sea (Somali region). The latent heat flux shows a maximum value of 250 $Wm^{-2}$ during the onset phase over this region.

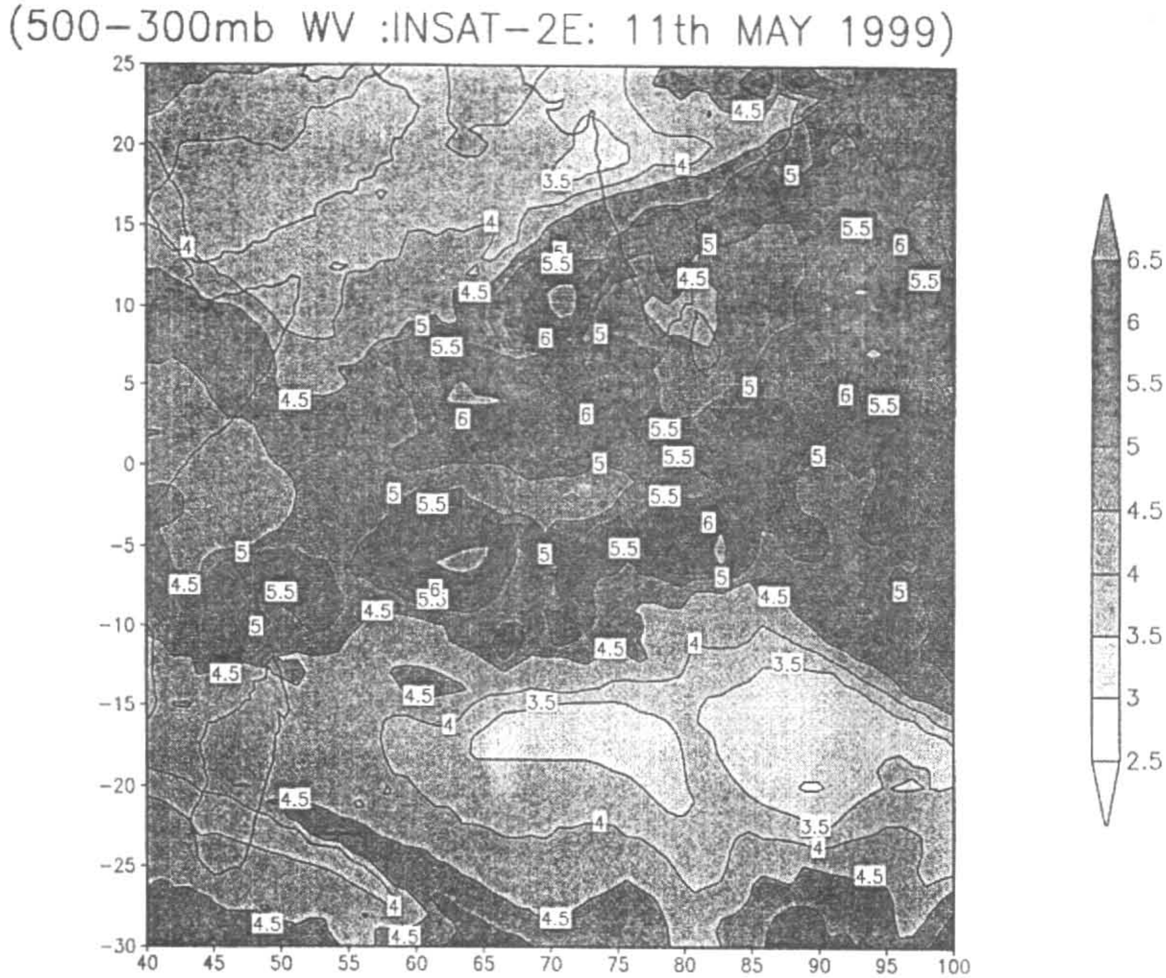


**Fig. 6.** Total precipitable water vapour content (500-300 hPa) in (mm) derived using INSAT-2E VHRR Water vapour imagery

After the onset, perhaps as a result of increased relative humidity and cloudiness, evaporative flux from the ocean decreases sharply (50 $Wm^{-2}$). The sensible heat flux is order of 15 $Wm^{-2}$ before the onset and falling to −15 $Wm^{-2}$.

## 3. Water Vapour from SSM/I Onboard DMSP Satellites

The total precipitable water vapour, wind speed and cloud liquid water content can also be obtained by SSM/I (Special Sensor Microwave Imager) brightness temperature data (Wentz, 1988). The SSM/I determined water vapour has added advantage of accuracy over cloudy region in comparison to TOVS estimation. The SSM/I is a microwave radiometer system flown on DMSP satellites to measure microwave emission coming from Earth and the intervening atmosphere. Dual-polarization measurements are taken at 19.35, 37.0, 85.5 GHz, and only vertical polarization is observed at 22.235 GHz has been used for deriving geophysical parameters over the ocean using SSM/I brightness temperature data (Wentz, 1988).

Recently efforts have been made by Liu *et al.* (1991), Basu *et al.* (1995) to derive humidity profiles over oceans using a combination of SSM/I derived precipitable profiles over oceans using a combination of SSM/I derived precipitable water and empirical orthogonal functions of past radiosonde profiles.

### 3.1. *Satellite estimates of Evaporative Fluxes for Extended range Numerical weather Prediction*

Liu (1984) suggested a procedure for estimating surface humidity from total precipitable water vapour for monthly averaged values. In association with SST and surface wind the above methodology can be used for estimating monthly mean evaporative fluxes (Nair *et al.*, 1995). Evaporative flux obtained from satellite data can be used as a diagnostic tool for extended range forecast. Monthly mean latent heat fluxes were computed for July 1992 using the data of SSM/I and NOAA/AVHRR over the ocean, through the bulk aerodynamic parameterisation schemes (Fig.3). The satellite based estimates indicate that regions of high latent heat fluxes occur over the Head Bay of Bengal region with values of the order of 350-400 $Wm^{-2}$. In comparison the monthly mean latent heat fluxes computed using CCM2 (Community Climate Model/version 2) for the same region (Fig.4) are of the order of 150-200 $Wm^{-2}$ only. Higher latent heat flux indicated in satellite estimation is also corroborated by the total precipitable water vapour from SSM/I data over the Head Bay of Bengal region – of the order of 70 mm and the rain rate of the order of 2 mm/hr. The model simulated evaporative fluxes over Head Bay of Bengal, is thus an under estimation by 100 %.

## 4. Water Vapour from MSMR Onboard IRS-P4 Satellite

Indian Space Research Organisation (ISRO), under its Remote Sensing program has designed, developed and launched Oceansat-I satellite (IRS-P4) mainly for ocean and atmosphere related applications. The satellite launched on 26$^{th}$ May 1999 carries onboard two sensors namel;y Ocean Color Monitor (OCM) and Multi-frequency Scanning Microwave Radiometer (MSMR). The MSMR is a microwave sensor operating in 6.6, 10.8, 18 and 21 GHz in both horizontal and vertical polarization and is used to measure geophysical parameters related to ocean such as SST, wind speed, total integrated water vapour over the oceans and liquid water content in clouds.

MSMR can only provide total water vapour data. Some of the earlier used methodologies such as EOF technique can be used to estimate profile. MSMR offers unique opportunity for estimating the heat fluxes as well as the parameters like SST, sea surface winds and water vapour from the same satellite platform.

## 5. Mid-Tropospheric Water Vapour from INSAT-2E

Starting with Meteosat nearly two decades ago the geostationary meteorological satellites also have water vapour channel. This channel was recently introduced in INSAT series satellites. The VHRR on board INSAT-2E spacecraft will provide imaging capability in water vapour channel (5.7-7.1 μm) in addition to the visible and thermal IR bands with a ground resolution at the sub-satellite point of 2 km x 2 km in the visible and 8 km × 8 km in the WV & TIR bands. This geostationary satellite is located over 83.5°E. The important specifications are given in Table 1.

**TABLE 1**

**INSAT-2E VHRR (Specifications)**

| Sensors | Spectral Band (μm) | Resolution (km) |
|---|---|---|
| Visible | 0.55-0.75 | 2 x 2 |
| Infra Red | 10.5-12.5 | 8 x 8 |
| Water Vapour | 5.7-7.1 | 8 x 8 |

### 5.1. *Water Vapour Imagery from INSAT-2E*

The water vapour image is basically an absorption pattern in 6.7 micron region of the radiation emitted by earth surface. The advantage of the water vapour imagery is that it shows the continuous inflow of moisture, as it form part of the same air mass, which otherwise appear detached in the visible and IR images. The water vapour imagery over Indian region for May 11, 1999 is shown in Fig. 5. The cloudy regions do not show any additional feature in the water vapour picture except the high moisture region near clouds. The drier mid tropospheric regions in the northern Arabian sea particularly around the coast of Saudi Arabia, the northern parts of Indian mainland and the southern Indian ocean are clearly seen in the imagery. The water vapour patterns also align along the direction of mid troposphere flow. These water vapour images can be used for estimating the mid troposphere winds in addition to hitherto available cloud motion vectors. In association with CMV's these winds now provide information at three important levels in the atmosphere.

### 5.2. *Mid-Tropospheric Moisture Content*

6.4μm channel radiance can be utilised for computing the quantitative estimation of mid-tropospheric moisture content. Water vapour radiances in these channel were earlier used to study the mid-tropospheric circulations (Narayanan *et al.* (1989). The weighting function in this channel peaks around 400 hPa in the tropics. Similar channel is available in HIRS sensor onboard NOAA/TOVS. This channel is used for estimating the moisture profile. For selected few days we received the NOAA/TOVS data at Ahmedabad Earth Station (AES). This TOVS data was processed to compute the humidity profile using the TOVS Processing package. A regression between the brightness temperature of 6.7 micron and the 500-300 hPa layer moisture was obtained. This regression was used to estimate the mid level moisture content from INSAT-2E (Simon *et al.* 1999). Fig. 6 shows the mid-tropospheric moisture content from INSAT-2E for May 11, 1999. The onset of monsoon took place on 25th May and the increased moisture content in the Indian mainland and adjoining sea is seen from the estimated moisture distribution. The high water vapour content near a big cloud mass in the Arabian sea, finally intensified into tropical cyclone. The estimation procedure is in the process of improvement. The procedure adopted by us gives moisture content over oceanic region only.

## 6. Conclusions

Different sensors onboard meteorological satellites now provide the precipitable water vapour information over monsoon circulation regime. The total water vapour as well as the profile could be estimated from daily to the monthly time scales. These informations are vital inputs to the numerical model attempting to understand the different monsoon features. The total water vapour data is also useful diagnostic tool for these studies.

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