Intraseasonal oscillation of total precipitable water over North Indian Ocean and its application in the diagnostic study of coastal rainfall

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[1] TRMM Microwave Imager (TMI) is reported to be a useful sensor to measure the atmospheric and oceanic parameters even in cloudy conditions. Vertically integrated specific humidity, Total Precipitable Water (TPW) retrieved from the water vapour absorption channel (22GHz.) along with 10m wind speed and rain rate derived from TMI is used to investigate the moisture variation over North Indian Ocean. Intraseasonal Oscillations (ISO) of TPW during the summer monsoon seasons 1998, 1999, and 2000 over North Indian Ocean is explored using wavelet analysis. The dominant waves in TPW during the monsoon periods and the differences in ISO over Arabian Sea and Bay of Bengal are investigated. The northward propagation of TPW anomaly and its coherence with the coastal rainfall is also studied. For the diagnostic study of heavy rainfall spells over the west coast, the intrusion of TPW over the North Arabian Sea is seen to be a useful tool. *INDEX TERMS:* 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; 3384 Meteorology and Atmospheric Dynamics: Waves and tides; 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504). **Citation:** Sajith, V., K. R. Santosh, and H. S. Ram Mohan, Intraseasonal oscillation of total precipitable water over North Indian Ocean and its application in the diagnostic study of coastal rainfall, *Geophys. Res. Lett.*, *30*(20), 2054, doi:10.1029/2003GL017635, 2003.

1. Introduction

[2] Intraseasonal Oscillations of atmospheric and oceanic parameters in the monsoon season contribute to the variability in summer rainfall over India. Since *Madden and Julian* [1971, 1972] recognized the eastward propagating planetary wave in the sea level pressure with largest amplitude in the near equatorial latitudes, many efforts have been made to explore the characteristics, origin and theoretical understanding of this oscillation. The wave traverses around the globe from west to east in a matter of roughly 30 to 60 days. *Zangvil* [1975] and *Yasunari* [1979] reported the existence of quasi 40-day cloudiness oscillation over the summer monsoon region. The evidence that intraseasonal oscillation (ISO) involves significant modulation of Sea Surface Temperature (SST) and turbulent fluxes at the air-sea interfaces in the tropical oceans came from 1979 MONEX [*Krishnamurti et al.*, 1988]. The oscillations with period 10–20 & and 30–50 days are active primarily over the Asian monsoon region and during boreal summer, this ISO shows complex space-time evolution. Besides the eastward propagating Madden-Julian Oscillation (MJO), the summer ISO of this region often exhibits northward propagation from equatorial latitudes [*Sikka and Gadgil*, 1980]. They found northward propagation in maximum cloud zone and many studies came to explore this ISO in other atmospheric and oceanic parameters, which are intimately related to the ‘‘active’ and ’’break’ cycles of the Indian monsoon. *Sengupta et al.* [2001] observed this oscillation in SST and wind speed derived from microwave imaging and in the surface heat flux over Bay of Bengal. *Simon et al.* [2001] used wavelet analysis from extended precipitation and atmospheric reanalysis datasets over southwestern India. *Cadet* [1986] studied the fluctuations of Precipitable Water over the Indian Ocean during 1979 in relation to the active and break monsoon conditions. Some useful applications of integrated columnar water vapour called Total Precipitable Water (TPW) have been reported by *Ferraro et al.* [1999]. TPW product in conjunction with wind speed was used by *Bhatia* [2000] for diagnosing areas of high moisture convergence over the oceans giving rise to heavy precipitation over coastal regions. He used TPW data derived from Special Sensor Microwave/Imager (SSM/I) as a prediction tool for the heavy coastal rainfall. TMI is similar to SSM/I except the lower frequency to derive SST. TPW derived from microwave imageries has applications in Asian monsoon studies mainly concerning with convection and its energy exchanges and the diagnostic forecasting of heavy rainfall events. In the present study, the ISO of TPW using TRMM Microwave Imager (TMI) retrieved data and its application in the diagnostic study of coastal rainfall during Indian monsoon period is attempted.

2. Data and Methodology

[3] TPW, which is vertically integrated specific humidity of the atmosphere, can be retrieved from microwave measurements near the centre of the weak water vapour 22GHz absorption line over oceans. For the present study, three day composite TPW and near surface wind speed retrieved from TMI brightness temperature, which has a spatial magnitude of $0.25^\circ \times 0.25^\circ$ has been used. Clouds and aerosols do not affect TMI products [*Wentz et al.*, 2000]. Rainfall over the west coast of India is taken from Indian Daily Weather Report (IDWR) for the monsoon periods of 1998, 1999, and 2000.

[4] TPW over Arabian Sea and Bay of Bengal is considered for the analysis. High frequencies are filtered out and time-latitude analysis of TPW anomalies has been done.

[5] For the periodicity study of TPW over North Indian Ocean and Indian west coast rainfall, wavelet transforms

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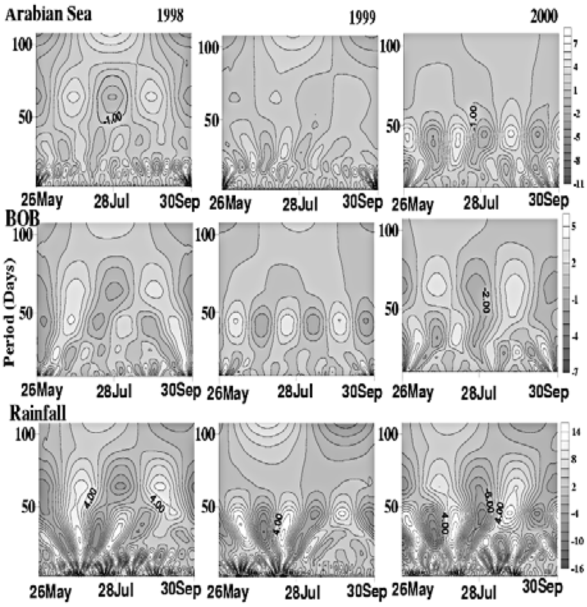

Figure 1. Wavelet analysis of TPW in Arabian Sea and BOB, and west coast rainfall during monsoon of 1998, 1999, and 2000. y-axis Period and x-axis Days.

(WT) method has been employed. It is an analysis tool well suited to study multiscale, non-stationary processes occurring over a finite spatial and temporal domain. By decomposing a time series in time- frequency space, one is able to determine both the dominant modes of variability and their variability in time. The Morlet wavelet used here is defined as the product of a complex exponent wave and a Gaussian envelope.

$$\Phi_0(\eta) = \pi - 1/4 e^{1/\omega_0 \eta} e^{-(1/2)\eta^2} \tag{1}$$

where Φ_0 is the wavelet value at non-dimensional time η, and ω_0 is the wave number. The ‘scaled wave’ is:

$$\phi\left[\frac{(n' - n)\partial t}{s}\right] = \left[\frac{\partial t}{s}\right]^{1/2} \phi_0 \left[\frac{(n' - n)\partial t}{s}\right] \tag{2}$$

where ‘s’ is the ‘dilation parameter’ used to change the scale, the factor of $s^{(-1/2)}$ is a normalization to keep total energy of the scaled wavelet constant [*Torrence and Compo*, 1998]. To determine significance levels for the spectrum an appropriate background spectrum is chosen as follows:

$$P = \frac{1 - \alpha^2}{1 + \alpha^2 - 2\cos(2\pi k/N)} \tag{3}$$

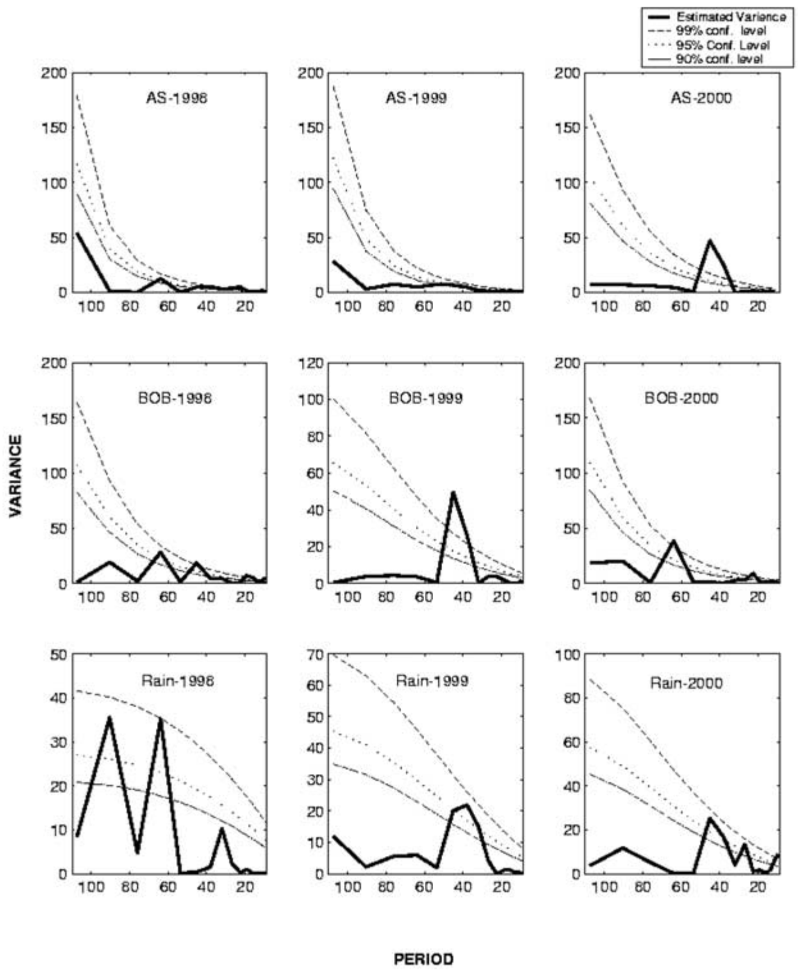

Figure 2. Significant test conducted for the wavelet analysis of TPW over Arabian Sea (AS) and BOB, and West Coast rainfall.

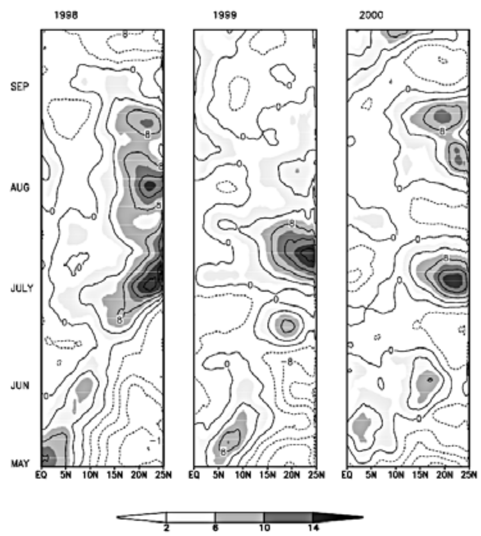

Figure 3. Time latitude analysis of high frequency filtered TPW anomaly for the summer monsoon periods of 1998, 1999, and 2000.

where k = 0. . ..n/2 is the frequency index and a is the lag-1 autocorrelation.

3. Intraseasonal Oscillation in TPW

[6] Wavelet analyses of TPW over Arabian Sea and Bay of Bengal (BOB) and rainfall over Indian west coast is given in Figure 1 for the three years 1998, 1999, and 2000. Significantly dominant periods of ISO in TPW over North Indian Ocean are determined by carrying out the significant test. A wide range of significant waves over Arabian Sea and BOB (Figure 2) has been observed in 1998. Over the Arabian Sea, periods less than 30-day are seen to be 99% significant. Over BOB 45.2 and 9.5 day periods are significant. The World Meteorological Organization has reported that 1997–98 witnessed the strongest El Nino of the century. Very high SST was reported globally that year and India had normal summer monsoon rainfall. In 1999, 10–20 day oscillation is seen to be 95% significant over Arabian Sea. BOB shows clear 30–50day oscillations. In 2000, Arabian Sea shows a clear 30–50 day oscillation and BOB shows 64 day and less-than-30-day significant oscillations. The difference in oscillations over Arabian Sea and BOB is notable. One of the main results from this analysis is the dominance of long period (64 day) oscillation in many cases as reported by *Simon et al.* [2001]. This period appears as a combination with a higher frequency oscillation (10–25 day). They reported significant 64-day wave in one third of the 90 years of rainfall data, and that it had a great role in the interannual variation of Indian summer monsoon.

[7] The oscillation of TPW over Arabian Sea and west coast rainfall is comparable. In 1998, 64-day oscillation is significant and the influence of TPW over Arabian Sea is well illustrated here. In 1999 and 2000 too, rainfall shows similar patterns of TPW over Arabian Sea.

[8] After filtering higher frequencies (below 10 days) TPW anomalies from TMI averaged over Arabian Sea (60°–72°E) are analysed (Figure 3). The time series from equator to 24°N shows clearly the intraseasonal oscillations of TPW. Northward movement of moisture is seen in all years. The high values of positive anomaly of TPW (high moisture intrusion) is mainly seen over northeast Arabian Sea and can be treated as a standing mode oscillation form June to August end (1998 is an exception), but from the Figure 5, it is evident that TPW intrusion has a northward movement from 14°N to the northeastern Arabian Sea along the west coast of India. The variation in moisture propagation upto date of onset of monsoon and thereafter is well portrayed in this analysis. In the onset phase, the TPW does not intrude into the northern Arabian Sea beyond 18°N. The influence of desert winds from Arabia decay only after the onset when the Low Level Jet strengthens and moves northward.

4. Diagnostic Study of Coastal Rainfall Using TMI TPW

[9] The TPW over northeast Arabian Sea where the moisture intrusion occurs, the TMI derived rain rate over that area and Indian west coast rainfall during monsoons of 1998, 99 and 2000 are plotted in a time series (Figure 4). The correlation between columnar moisture and coastal rainfall is clearly observed here. The piling up of TPW well before the starting of a heavy rainfall spell over Indian west coast region is also evident. TMI derived rain rate is also responding to the high moisture piling over the north Arabian Sea. The variation of surface wind speed and TPW over Arabian Sea during the 4 days prior to the commencement of heavy coastal rainfall spells has been analysed for

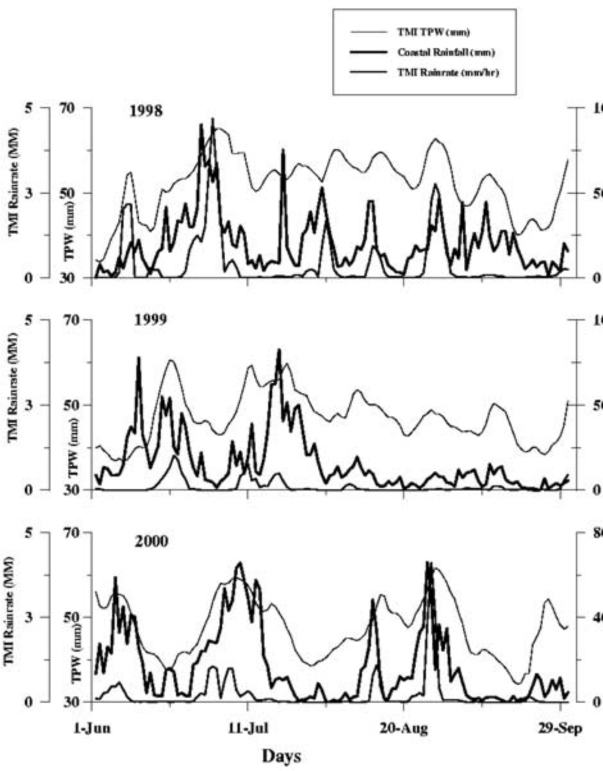

Figure 4. Time series analysis of North Arabian Sea TPW, Oceanic Rainrate both from TMI and Indian West Coast rainfall.

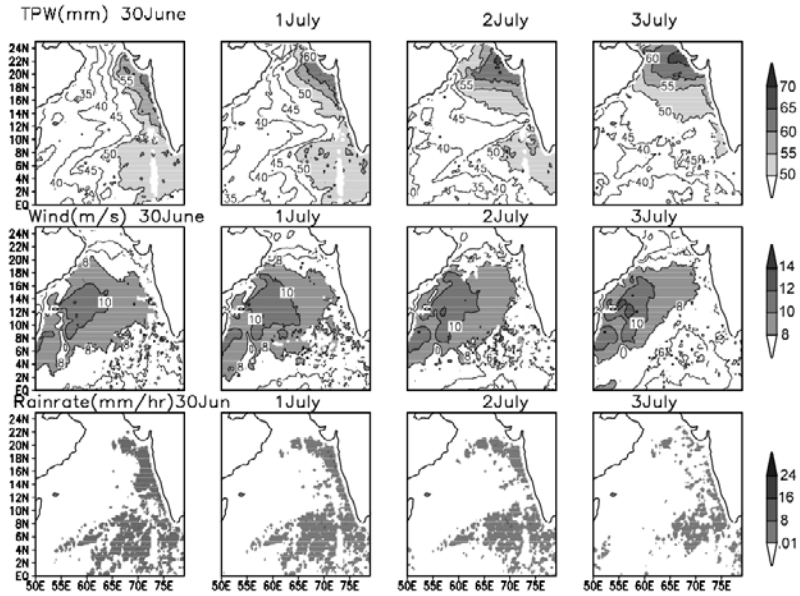

Figure 5. TPW, Surface Windspeed and Rainrate derived from TMI over Arabian sea from 30 Jun 2000 to 3 Jul 2000.

all the rainfall epochs in the three years. The heavy rainfall event from July 4th to July 8th 2000 is illustrated here (Figure 5) as a case study. High TPW values greater than 65 mm occurs 48 to 24 hours before the commencement of the active spell as TPW intrusion advances north along the coast from about 6 days earlier and reaches north Arabian Sea in a box 18°N to 22°N and 65°E to72°E. Wind speed over central Arabian Sea is 10 to 14 m/s where as in the northern latitudes it is 6–8 m/s and brings out moisture convergence. TMI derived rain rate over the Arabian Sea is seen to decrease when the rainfall over land is picking up intensity. During the periods of low rainfall, the TPW values were lower and restricted to central Arabian Sea. Coherence is observed in the day to day variation in TPW intrusion and rainfall in the coastal stations.

5. Summary and Conclusion

[10] The dominant modes of ISO in TPW over Arabian Sea and BOB are clearly shown using wavelet analysis and the differences in ISO over Arabian Sea and BOB are noted. The 64-day oscillation which was reported by *Simon et al.* [2001] and the waves with periods shorter than 30 days are seen to be significantly dominant. The correlation of TPW over Arabian Sea and the west coast rainfall is illustrated. Even the less significant waves in TPW contribute to the ISO of coastal rainfall. It is observed that TPW greater than 65 mm intrudes in to the northeastern Arabian Sea at least one day before the commencement of heavy rainfall spells.

[11] **Acknowledgments.** We thank Frank Wentz of Remote Sensing Systems CA, USA for making the TMI data available on their site ftp://ftp.ssmi.com.

References

Bhatia, R. C., Use of SSM/I derived products for diagnostic studies of heavy rainfall events over coastal area of India, in *TROPMET 2000*, pp. 281–285, Indian Met. Soc., CUSAT, Cochin-16, 2000.

Cadet, C., Fluctuations of precipitable water over the Indian ocean during the 1979 summer monsoon., *Tellus*, *38A*, 170–177, 1986.

Ferraro, R. R., S. J. Kusselson, and M. Colton, An introduction to passive microwave remote sensing and its applications to meteorological analysis and forcasting, *National Weather Digest*, *22*, 11–23, 1999.

Krishnamurti, T. N., D. K. Oosterhof, and A. Mehta, Air-sea interaction on the time-scale of 30–50 days, *Jn. Atm. Sci*, *45*, 1304–1322, 1988.

Madden, R., and P. Julian, Detection of 40–50 day oscillation in the zonal wind in tropical Pacific, *Jn. Atm. Sci.*, *28*, 702–708, 1971.

Madden, R., and P. Julian, Description of global circulation cells in the tropics with 40–50 day period, *Jn. Atm. Sci*, *29*, 1109–1123, 1972.

Sengupta, D., B. N. Goswami, and R. Senan, Coherent intraseasonal oscillations of ocean and atmosphere during the Aian summer monsoon, *GRL*, *28*, 2033–2036, 2001.

Sikka, D. R., and S. Gadgil, On the maximum cloud zone and the ITCZ over Indian longitudes during the Asian summer monsoon, *Mon. Wea. Rev.*, *108*, 1840–1853, 1980.

Simon, A., G. N. Venu, and P. V. Joseph, Intra-seasonal oscillation in Kerala rainfall, in *TROPMET*, pp. 166–173, Indian Met. Soc., Colaba, Mumbai, 2001.

Torrence, C., and P. Compo, A practical guide to wavelet analysis., *Bull. American. Met. Soc.*, *79-1*, 61–78, 1998.

Wentz, F. J., C. Gentemann, D. Smith, and D. Chelton, Satellite measurements of sea surface temperature through clouds., *Science*, *288*, 847–850, 2000.

Yasunari, T., Cloudiness fluctuation associated with the Northern Hemisphere summer monsoon., *Jn. Met. Soc. Jp.*, *75*, 227–242, 1979.

Zangvil, A., Temporal and spatial behavior of large-scale disturbance in tropical cloudiness deduced from satellite brightness data., *Mon. Wea. Rev.*, *103*, 904–920, 1975.

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