*Mausam*, (1991), **42**, 2, 205-210

551.551.8 : 551.501.777

# Precipitable water and its spectral analysis over eastern and western parts of India during Monex-1979

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(*Received 21 March 1990*)

**सार** — 50 मि० बार के उर्ध्वाधर अंतराल पर सतह से 300 मि० बार तक के मोनेक्स-79 आंकड़ों का प्रयोग करते हुए भारत के पूर्वी और पश्चिमी भागों में वर्षणीय जल का आकलन किया गया है। अवदाबों और चक्रवातों के परिप्रेक्ष्य में वर्षणीय जल के उतार-चढ़ावों का परीक्षण किया गया है। भंवर वर्षणीय जल का मानावलीय विश्लेषण किया गया है। विभिन्न स्तरों में आवर्तिता के उर्ध्वाधर परिवर्तनों का प्रेक्षण किया गया है।

ABSTRACT. Precipitable water over eastern and western parts of India have been computed using Monex-79 data from surface to 300 mb at a vertical interval of 50 mb. Fluctuations in precipitable water have been examined in relation to depressions and cyclones. The spectral analysis of eddy precipitable water was performed. Vertical variation of periodicity in different layers have been observed.

**Key words** — Eddy precipitable water, power spectrum analysis, null continuum, integrated layer, kinetic energy flux.

## 1. Introduction

The precipitable water or water vapour is the most important absorber of solar and terrestrial radiation in the atmosphere. It plays an important role in the energetics of the general circulation/monsoon circulation of the atmosphere. A knowledge of the quantity of precipitable water present at any moment in different layers of the atmosphere above any station is of fundamental importance in meteorological as well as hydrological studies. Several investigators in the past including Sikka and Mathur (1965), Saha and Bavadekar (1973, 1977), Bavadekar and Mooley (1978), Appa Rao (1985), Cadet (1986) have attempted to study the precipitable water over the Indian monsoon region.

In the present paper an attempt has been made to compute precipitable water over eastern and western parts of India using Monex-79 summer monsoon data. The results have been examined in relation to depressions and cyclones that formed over Bay of Bengal and Arabian Sea. Further existence of significant periodicities and its variation in the vertical up to 300 mb surface in three different layers was viewed through spectral analysis following Blackman and Tukey (1958).

## 2. Data and method of analysis

The daily aerological data for temperature and dew point temperature from surface to 300 mb at an interval of 50 mb obtained from the Monex-79 (May through August) set of data 00 GMT at Jodhpur, Ahmedabad, Santacruz, Goa, Mangalore, Trivandrum, Agartala, Calcutta, Bhubaneswar, Visakhapatnam, Madras and Port Blair have been used for computations of precipitable water. The expression for precipitable water (P.W.) in an atmospheric layer is :

$$\text{P.W.} = \frac{1}{g}\int_{p_o}^{p} q\, dp \qquad (1)$$

where, $q$ is the specific humidity and $g$ is the acceleration due to gravity; $p_o$ and $p$ refer to the pressure at bottom and top of layer. For practical purposes the expression for precipitable water may be approximated to :

$$\text{P.W.} = \frac{1}{g}\left[\, q_1 + q_2 + \ldots\ldots\ldots\ldots q_n \right] \triangle p \quad (2)$$

where, $\triangle p = (p_o - p)/n$ and $q_1, q_2, \ldots\ q_n$ are the mean specific humidities for '$n$' layer of pressure thickness $\triangle p$ taken as 50 mb. The specific humidity has been computed at each of the 16 levels in the vertical using Teten's formula on each day of available data from 1 May to 31 August 1979, 00 GMT. A spline interpolation technique is applied on computed specific humidity for missing dates in time domain as well as in the vertical for the purpose of spectral analysis. No extrapolation is being performed for such computations. Finally precipitable water computations have been broken in three layers over a column of unit square centimetre area.

Layer I — 300 mb to 500 mb surface,

Layer II — 500 mb to 700 mb surface,

Layer III — 700 mb to surface.

For the purpose of illustration, the computed precipitable water have been subdivided into 25 pentads from 1 May to 31 August 1979 (Last pentads includes only 3 days).

From the daily variations of the precipitable water in each of the three layers, the seasonal time mean precipitable water of each layer have been subtracted to get the eddy precipitable water. This eddy precipitable water has been subjected to power spectrum analysis.

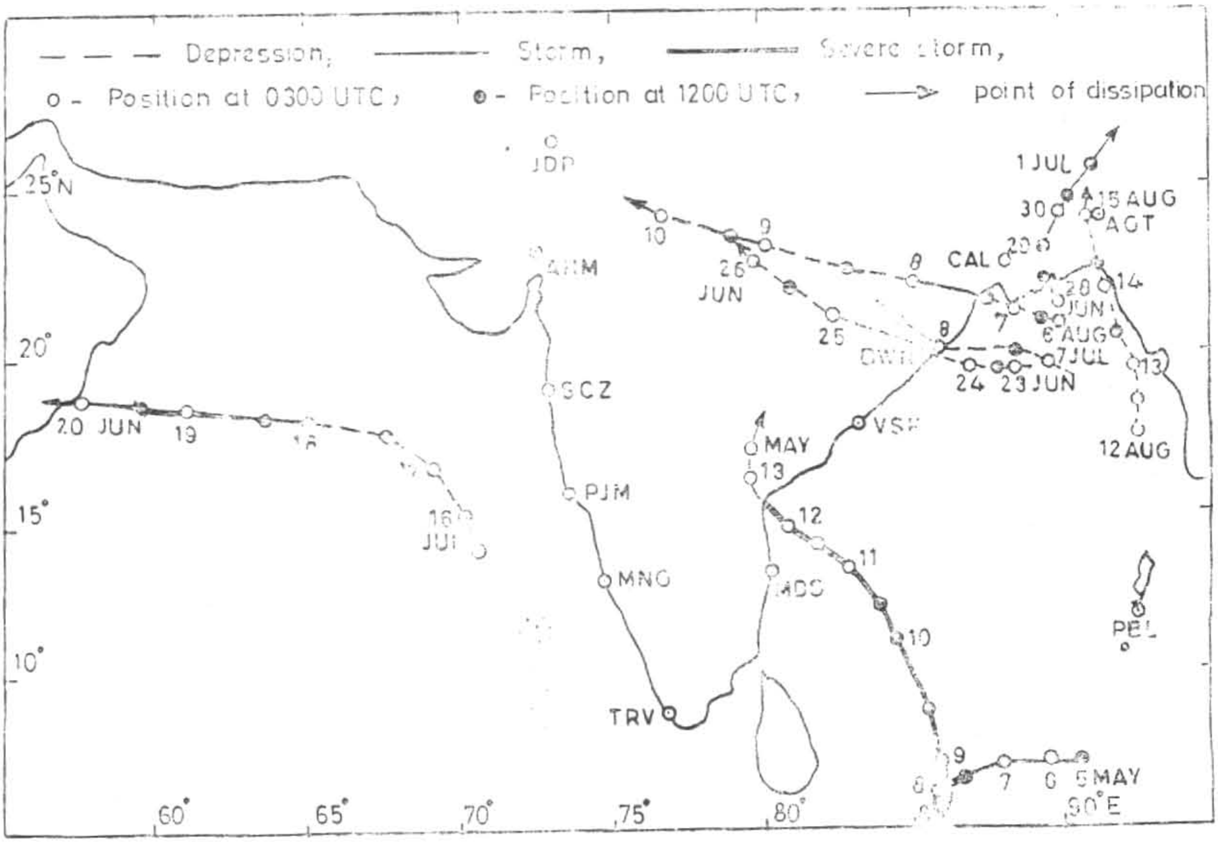



Fig. 1. Tracks of storms and depressions May to August 1979

The method of power spectrum analysis has been dealt with extensively by Blackman and Tukey (1958). The method followed here is mainly based on the formulation of Mitchell *et al.* (1966). The power spectrum has been computed for 1 May to 31 August 1979 for which $n=123$ and $m=14$. Here, $n$ is the total period in days and $m$ is the maximum lag. The smoothing of spectral estimates have been done by Hanning process. The null continuum and 95% confidence limit of the null continuum have also been computed.

### 3. Results and discussion

#### 3.1. *Vertical distribution of precipitable water*

The positions of different depressions/cyclones tracks are presented in Fig. 1. Besides that Table 1 summarises the duration of these depressions/cyclones in Bay of Bengal and Arabian Sea. The results of precipitable water in different pentads in all these three layers over those stations which are being directly influenced by a depression/cyclone have been presented in Table 2. Figs. 2 (a & b) show the vertical distributions of precipitable water in three layers in different pentads over eastern and western part of India. On the whole in the layer III precipitable water generally varies from 2 to 5 cm almost everywhere over eastern and western parts of India. In the layer II the amount gets reduced to one-fourth or one-fifth of the amount in layer III; whereas in layer I it amounts to only 5 to 10% of the value in layer III. There was a severe cyclonic storm at extremely low latitude in the Bay

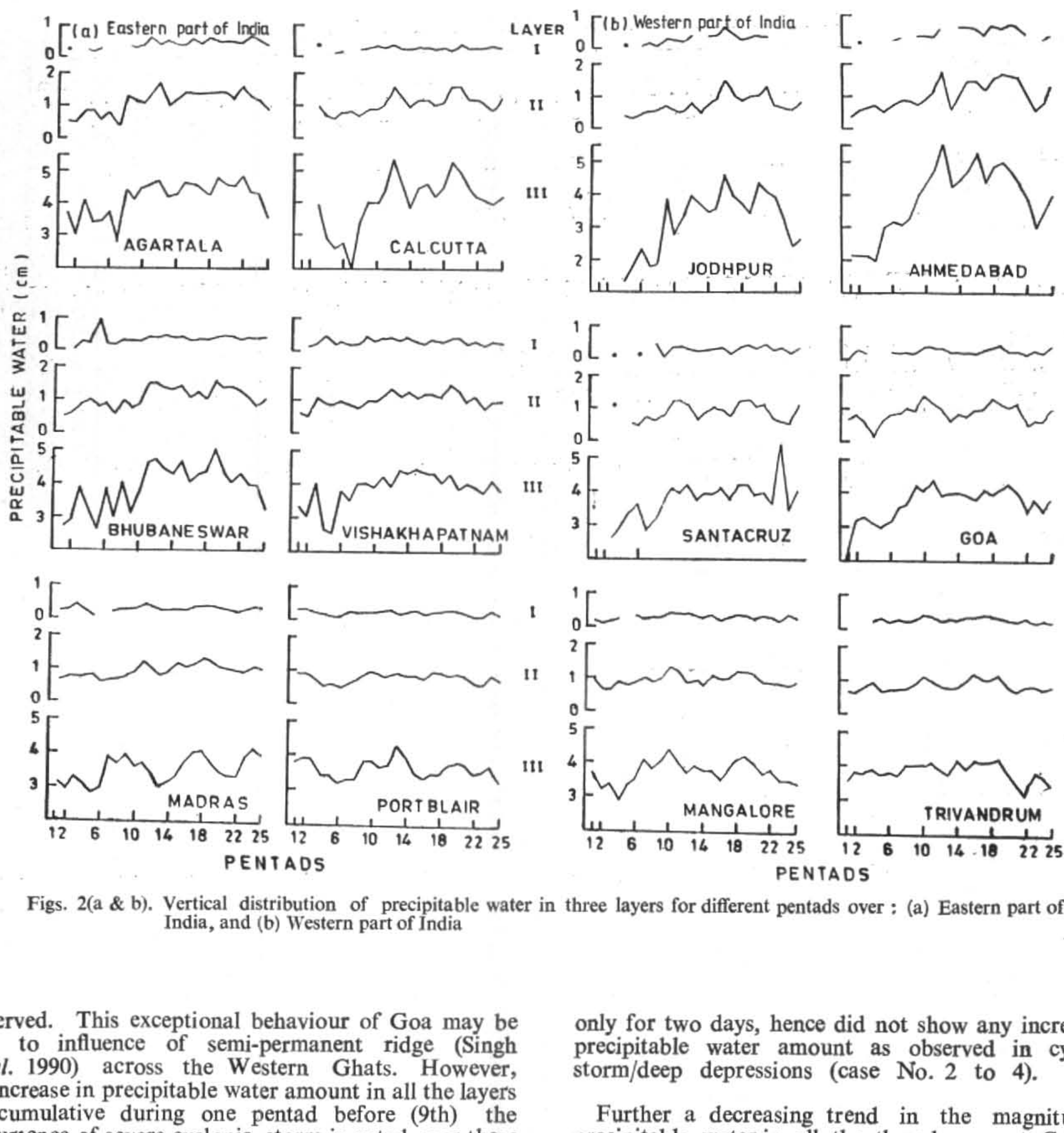
TABLE 1

Storms and depressions during Monex-79

| Case No. | Type of disturbance | Life period | Location |
|---|---|---|---|
| 1 | Severe cyclonic storm | 5-13 May | Bay of Bengal |
| 2 | Do. | 16-20 Jun | Arabian Sea |
| 3 | Deep depression | 23-26 Jun | Bay of Bengal |
| 4 | Do. | 28 Jun-1 Jul | Do. |
| 5 | Depression | 7-8 Jul | Do. |
| 6 | Severe cyclonic storm | 6-10 Aug | Do. |
| 7 | Depression | 12-15 Aug | Do. |

of Bengal during the period 5 to 13 May 1979 (case 1). During the second pentad the Port Blair has got largest precipitable vater amount. As the storm moved towards Madras, an increasing tendency is noted in precipitable water amount in all the three layers at Madras (pentad 3).

There was another severe cyclonic storm in the Arabian Sea during the period 16 June to 20 June (pentad 10). Its effect on precipitable water at Trivandrum, Mangalore, Goa, Santacruz, Ahmedabad and Jodhpur has been studied. Generally an increasing tendency in all the three layers during pentad 8 to 10th, except at Goa and Jodhpur over these stations, have been




Figs. 2(a & b). Vertical distribution of precipitable water in three layers for different pentads over : (a) Eastern part of India, and (b) Western part of India

observed. This exceptional behaviour of Goa may be due to influence of semi-permanent ridge (Singh *et al.* 1990) across the Western Ghats. However, an increase in precipitable water amount in all the layers or cumulative during one pentad before (9th) the occurrence of severe cyclonic storm is noted over these stations.

During the period 23 June to 8 July three depressions formed over the head Bay of Bengal. The effects of these depressions upon precipitable water amount at stations under influence in each case have been summarised in Table 2. In the case No. 3 pertaining to pentad 11, at Bhubaneswar, Calcutta and Agartala, we note an increased cumulative precipitable water of the vertical column in pentad 10 prior to occurrence of a deep depression. For case No. 4 (pentad 12) also, similar feature in pentad 11 prior to occurrence, is observed for above stations. This increase in magnitude of precipitable water in one pentad before occurrence is associated with the intensity and duration of the depressions forming over the regions. However, case No . 5 (pentad 14) is of very short duration, which lasted only for two days, hence did not show any increase in precipitable water amount as observed in cyclonic storm/deep depressions (case No. 2 to 4).

Further a decreasing trend in the magnitude of precipitable water in all the three layers at Calcutta, Bhubaneswar and Agartala from pentad 20-21 during the presence of cyclonic storm and depression (case No. 6 & 7) over the head Bay of Bengal, have been observed. However, they showed an increased amount of precipitable water in pentad 19 prior to the occurrence of cyclonic storm. The above decreasing tendency in precipitable water during pentad 20-21 in a vertical column is due to the cyclonic circulation associated with strong convection resulting into precipitation during active and mature stages of storm.

Thus, we conclude that a storm/deep depression over the Bay of Bengal/Arabian Sea results in an increased amount of precipitable water generally in all the three layers or cumulative depending upon its vertical penetration about one pentad before its occurrence over the surrounding stations.

TABLE 2

**Precipitable water content (cm) over different stations in different pentads**

| Stations | | Madras | | | Port Blair | | | Visakhapatnam | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pentads* | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Case No. 1 | Layer I | .18 | .21 | .37 | .33 | .31 | .23 | — | .14 | .25 |
| | Layer II | .61 | .73 | .74 | .93 | .90 | .76 | .63 | .53 | 1.1 |
| | Layer II | 3.1 | 2.98 | 3.27 | 3.81 | 3.94 | 3.87 | 3.3 | 3.0 | 3.98 |

| | | Trivandrum | | | Mangalore | | | Goa | | | Santacruz | | | Ahmedabad | | | Jodhpur | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pentads | | 8 | 9 | 10 | 8 | 9 | 10 | 8 | 9 | 10 | 8 | 9 | 10 | 8 | 9 | 10 | 8 | 9 | 10 |
| Case No. 2 | Layer I | .24 | .26 | .40 | .26 | .28 | .42 | .24 | .18 | .39 | .46 | .06 | .34 | — | .27 | .29 | .07 | .28 | — |
| | ,, II | .77 | .90 | 1.1 | .87 | .96 | 1.3 | 1.0 | 1.0 | 1.4 | .60 | .72 | 1.2 | .82 | .69 | .87 | .54 | .71 | .57 |
| | ,, III | 4.0 | 4.0 | 4.0 | 3.8 | 4.0 | 4.4 | 3.67 | 4.25 | 4.0 | 3.1 | 3.5 | 4.1 | 3.24 | 3.94 | 4.38 | 1.95 | 3.97 | 2.86 |

| | | Bhubaneswar | | | | Calcutta | | | | Agartala | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pentads | | 9 | 10 | 11 | 12 | 9 | 10 | 11 | 12 | 9 | 10 | 11 | 12 |
| Case No. 3 & 4 | Layer I | .33 | .30 | .42 | .44 | .27 | .37 | .29 | .42 | .32 | .39 | .60 | .40 |
| | Layer II | .78 | .89 | 1.5 | 1.5 | .89 | .89 | 1.13 | 1.69 | 1.1 | 1.1 | 1.40 | 1.72 |
| | Layer III | 3.0 | 3.7 | 4.6 | 4.7 | 4.0 | 4.0 | 4.48 | 5.4 | 4.10 | 4.51 | 4.63 | 4.70 |

| | | Bhubaneswar | | Calcutta | | Agartala | |
|---|---|---|---|---|---|---|---|
| Pentads | | 13 | 14 | 13 | 14 | 13 | 14 |
| Case No. 5 | Layer I | .45 | .40 | .34 | .28 | .51 | .39 |
| | Layer II | 1.36 | 1.29 | 1.2 | .97 | 1.03 | 1.19 |
| | Layer III | 4.39 | 4.25 | 4.6 | 3.82 | 4.18 | 4.22 |

| | | Bhubaneswar | | | | Calcutta | | | | Agartala | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pentads | | 18 | 19 | 20 | 21 | 18 | 19 | 20 | 21 | 18 | 19 | 20 | 21 |
| Case No. 6 & 7 | Layer I | .33 | .41 | .46 | .47 | .33 | .23 | .47 | .29 | .59 | .52 | .48 | .45 |
| | Layer II | 1.07 | 1.55 | 1.38 | 1.41 | 1.1 | 1.6 | 1.6 | 1.2 | 1.42 | 1.40 | 1.42 | 1.19 |
| | Layer III | 4.34 | 5.0 | 4.25 | 4.09 | 4.8 | 5.3 | 5.0 | 4.5 | 4.22 | 4.79 | 4.55 | 4.53 |

*Pentad refers for five days mean and the number indicates that particular pentad from 1 May 1979 onwards.

(—) — Data missing.

### 3.2. *Spectral analysis*

Out of several charts of power spectra, it has been considered adequate to present only the chart for integrated layer (surface to 300 mb) at Agartala, Port Blair, Goa and Trivandrum in Fig. 3 for the purpose of illustration. Table 3 shows the vertical distribution of periodicity in eddy precipitable water over eastern and western parts of India in layer I, II and III as well as in integrated layer. The spectral peaks which did exceed or equalled the 95% confidence limit were considered to represent real oscillations in the precipitable water.

It has been observed that in layer I (300 mb-500 mb) no significant periodicity is present. However, the second layer (500 mb-700 mb) shows the presence of 4 to 4.6 days periodicity over selected stations namely Agartala, Madras, Goa and Mangalore, besides that a peak of 3.1 days at Port Blair was also observed but as this is significant below 95% confidence limit hence not taken into consideration. The third layer (700 mb-surface) shows the presence of a general periodicity of 2 to 3.5 days over whole of eastern and western parts of India except at Madras, Port Blair and Santacruz.

However, if we combine the whole of layer from surface to 300 mb as one layer, the vertically integrated

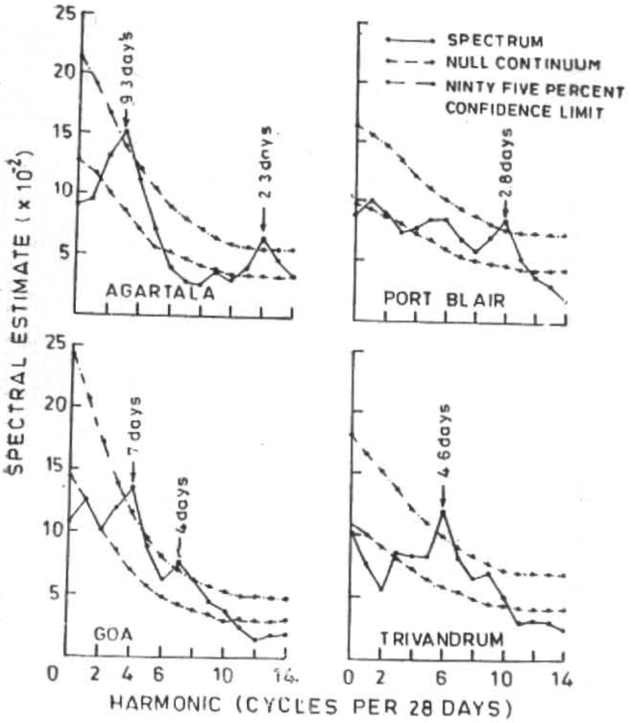



Fig. 3. Power spectra of eddy precipitable water for integrated layer over selected stations

TABLE 3

**Periods (days) at which spectral values are significant at 95% confidence level or more in different layers**

| Station | Layer I (300 to 500 mb) | Layer II (500 to 700 mb) | Layer III (700 to surface) | Integrated layer (Surface to 300 mb) |
|---|---|---|---|---|
| Agartala | — | 4.6 | 2.3 | 2.3 & 9.3 |
| Calcutta | × | × | × | × |
| Bhubaneswar | — | × | 3.5 | 3.5 |
| Visakhapatnam | — | × | 2.5 | 2.5* & 4.6* |
| Madras | — | 4.3 | × | 3.5 |
| Port Blair | × | 3.1* | × | 2.8 |
| Jodhpur | — | — | 2.1 | 4.6* |
| Ahmedabad | — | — | 3.1 | 2.5 |
| Santacruz | × | × | × | × |
| Goa | — | 4 | 3.1 | 7 & 4 |
| Mangalore | — | 4 | 3.5 | 4.6 |
| Trivandrum | × | × | 3.1 | 4.6 |

(—) — Not computed due to lack of data,
(×) — No significant periodicity is present,
(*) — Peaks below but close to 95% confidence limit.

precipitable water shows a presence of general periodicity of 2.5 to 5 days except at Calcutta and Santacruz. Besides that there is unusual peak of 7 and 9 days in integrated layer at Goa and Agartala respectively. Mishra (1972) observed the westward propagating planetary pressure wave of 4-5 days period in the tropics. The 5-day periodicity in different meteorological parameters has already been confirmed by several investigators including Ananthakrishnan and Keshavamurty (1970) in pressure and wind field, Bhalme and Parasnis (1975) in wind field, Murakami (1976) in rainfall, wind and pressure fields and Zangvil (1975) in cloudiness over tropical Indian Ocean. It is most prominent in northern India and is related to the frequency of monsoon lows travelling from Bay of Bengal to northern India. Singh *et al.* (1988) observed 3-7 day periodicity over arid and semi-arid regions of northwest India in vertical mean heat, momentum and kinetic energy fluxes.

Thus in precipitable water we may consider the dominance of 4-5 days periodicity in middle troposphere due to westward propagating modes as well as due to the travelling lows of monsoon depressions whereas 2-3.5 days periodicity in the lower troposphere may be due to fluctuations in local circulation/local weather phenomena over the regions of its occurrence. Cadet (1986) observed a 10-12 days periodicity in precipitable water and meridional wind field and inferred that these fluctuations appear to be associated with westward propagating mode north of equator. Thus 7 days periodicity in integrated layer at Goa and 9 day at Agartala may be linked to a westward propagating mode north of equator. As 1979 was an abnormal monsoon year, these values may not be very representative of average monsoon conditions but still they throw much light on this area of research. The noted periodicities in the range of 2 to 3.5 days and 4-5 days are in agreement with periodicities noted in the monsoon system by many earlier studies.

#### 4. Conclusions

(*i*) An increased amount in precipitable water content in either of the three layers of cumulative in a vertical column is observed one pentad before the occurrence of cyclonic storm/deep depression over the region of of its influence.

(*ii*) No significant periodicity is observed in precipitable water in upper troposphere (500 mb to 300 mb).

(*iii*) A periodicity of around 4-5 day is substantiated in precipitable water over Agartala, Madras, Goa and Mangalore in middle troposphere (700 mb to 500 mb).

(*iv*) A periodicity of 2-3.5 days is observed over whole of eastern and western parts of India except at Madras, Port Blair and Santacruz in lower troposphere (surface to 700 mb).

*Acknowledgement*

One of authors (JBS) wishes to express his thanks to the U. G. C., New Delhi for the award of senior research fellowship.

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