Monsoon circulation induced variability in total column ozone over India

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The intra-seasonal variability of daily total column ozone (TCO) over 12 Indian stations has been studied. Total Ozone Mapping Spectrometer daily data from May to September for five years (1998–2002) have been utilized in the study. The power spectrum analysis of daily TCO data showed three dominant modes of period 3–8 days (synoptic), 10–20 days (quasi bi-weekly, qbw) and 30–60 days (Madden Julian Oscillation, MJO), similar to that found in the Indian Summer Monsoon Rainfall. Mean spatial distribution of the activities of these intra-seasonal modes in TCO variability over the Indian region has been studied. The spatial distribution of the synoptic mode shows the strongest activity over central India. The qbw mode shows strongest activity over northwest India. The MJO mode shows strongest activity over northern most and southern most parts of India.

THE total column ozone (TCO) variability is mainly dominated by annual cycle, quasi biennial oscillation (QBO), El Nino Southern Oscillation (ENSO) and solar cycle. Many researchers have documented the association between TCO and QBO. It is found[1–4] that TCO variability shows in-phase relation with QBO near the equator (≤ 15° lat.) and out-phase relation in the latitude region between 15 and 60°. ENSO-type variability in TCO in the tropical region has been shown[5]. A signature of solar cycle in TCO variability has also been suggested[6]. Londhe *et al.*[7] examined the association of monthly TCO over the Indian region with global parameters, viz. QBO and solar flux. Using these parameters, they developed multiple regression models for TCO variability over the Indian region.

The TCO variability on the seasonal timescale over India in the monsoon season is governed by large-scale convective motion forced by diabatic heating[8]. In this mechanism, divergence at the upper level and associated outflow of the mass due to convection leads to depletion of TCO over the Indian region. Hingane and Patil[9] analysed about fifteen years of monthly total ozone data in the light of associated meteorological processes in the tropical and subtropical regions of the northern hemisphere. They observed a well-marked trough in total ozone in July and August over the most humid part of the region, which comes under the influence of monsoon circulation. Indian Summer Monsoon Rainfall (ISMR) shows strong variability on intra-seasonal timescale, in addition to decadal and interannual timescales[10,11]. The dominant intra-seasonal modes found in ISMR are synoptic mode with 3–7 days period[12], quasi bi-weekly mode (qbw) with 10–20 days period[13,14] and Madden Julian Oscillation (MJO) with 30–40 days period[14–16].

Hartmann and Michelson[17] have pointed out the strongest activity of synoptic mode in ISMR over central India. They carried out spectral analysis of 70 years (1901–70) daily precipitation from 3700 stations in India and found significant spectral peaks with period 40–50 days, 5–7 days and 15 days. Murakami[18] reviewed the spectral analysis of the Indian monsoon and reported that at least two spectral peaks exist, one around 5 days and another around 15 days. The 5-day peak was associated with monsoon lows developing in the Bay of Bengal and propagating westward across India at about 20°N during summer season. The 15-day peak was attributed to variations in the strength of the monsoon itself.

This aspect forced us to search the signature of monsoon circulation in TCO variability over the Indian region. The association between TCO and monsoon circulation over the Indian region has been examined by searching three dominant intra-seasonal modes mentioned above in TCO variability. Spatial TCO variability based on three intra-seasonal modes is also explored in this communication.

The daily TCO data measured by Total Ozone Mapping Spectrometer (TOMS) on-board earth probe satellite for

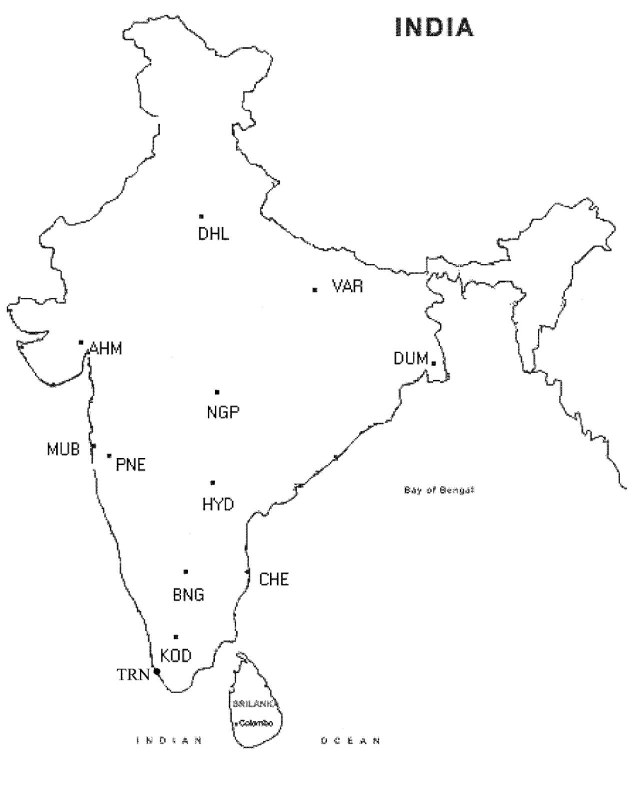

Figure 1. Map showing locations of 12 Indian stations. (see Table 1 for station names.)

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the period 1998–2002 have been collected for twelve Indian stations, (Figure 1), from the website http://jwocky.gfsc.nasa.gov/eptoms/EPTOMS_V7_Ovp.N. The data are continuous, however, there are few instances of missing data, for one or two days, which are filled by linear interpolation. Data were not available for the period 3–12 (10 days) in August 2002 for all stations. For this period, the daily averages of TCO computed from the remaining four years at each station have been used in the analysis. The data for each station are normalized by standard deviation for uniformity.

The intra-seasonal variability in TCO has been examined by subjecting the daily TCO data to power spectrum analysis based on Blackman and Tukey method[19]. The power spectrum analysis of daily TCO data for May through September for all twelve stations for five years shows three intra-seasonal modes, viz. synoptic (3–8 days), qbw (10–20 days) and MJO (30–60 days). Figure 2 represents the typical power spectrum of daily TCO for stations Varanasi, Hyderabad and Kodaikanal for selected years. Three intra-seasonal modes, viz. synoptic, qbw and MJO, which are significant at 95% level of significance, are clearly seen in the figure. These three modes of TCO variability have been tested for significance at 90 and 95% level. The mode which is significant at 90 or 95% level in a particular year, is documented in the Table 1 for 12 Indian stations. These three modes are observed at all stations for all the years with varying degrees of intensities. Though all the three modes are observed in every year, they are not significant at 90 or 95% level. The weekly/synoptic mode is found significant over the central parts of India. This mode is significant in 4 out of 5 years at Nagpur and Hyderabad. Low-pressure systems form over the Bay of Bengal and move westward, which may influence the TCO variability on synoptic timescale over this region. The qbw mode of TCO variability is found significant in 4 out of 5 years at New Delhi and Varanasi. It can be said that this mode is associated with the movement of the

Table 1. Level of significance for intra-seasonal modes at twelve Indian stations

		Year				
Station (code)	Mode	1998 (%)	1999 (%)	2000 (%)	2001 (%)	2002 (%)
Ahmedabad (AHM)	MJO	–	–	–	–	–
	QBW	–	–	90	95	90
	WEEK	–	95	–	95	95
Bangalore (BNG)	MJO	95	90	95	–	90
	QBW	95	–	95	90	–
	WEEK	95	–	–	95	95
Chennai (CHE)	MJO	–	90	95	–	–
	QBW	90	95	95	–	95
	WEEK	–	–	–	90	95
New Delhi (DHL)	MJO	–	90	90	–	–
	QBW	90	95	–	90	95
	WEEK	–	–	90	95	95
Kolkata (DUM)	MJO	–	90	90	–	–
	QBW	90	–	–	–	90
	WEEK	95	–	–	95	95
Hyderabad (HYD)	MJO	–	95	90	–	–
	QBW	–	–	–	–	95
	WEEK	95	–	90	95	95
Kodaikanal (KOD)	MJO	90	95	95	–	90
	QBW	90	–	–	95	90
	WEEK	–	90	–	95	95
Mumbai (MUM)	MJO	–	–	–	–	–
	QBW	–	–	–	95	95
	WEEK	–	–	–	95	95
Nagpur (NGP)	MJO	–	–	90	–	–
	QBW	–	–	95	–	90
	WEEK	90	90	–	95	95
Pune (PNE)	MJO	90	–	90	–	–
	QBW	–	–	–	95	95
	WEEK	–	90	–	95	95
Thiruvananthapuram (TRN)	MJO	–	95	–	–	–
	QBW	95	–	90	95	–
	WEEK	–	–	–	95	95
Varanasi (VAR)	MJO	90	–	–	–	90
	QBW	90	90	95	–	95
	WEEK	95	–	–	95	95

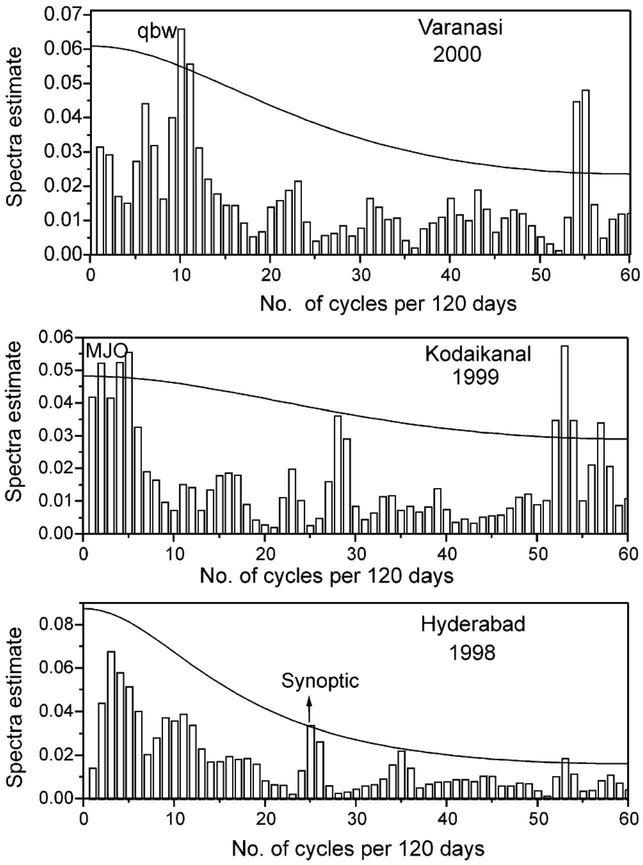

Figure 2. Power spectrum of daily TCO. Curved line represents 95% level of significance.

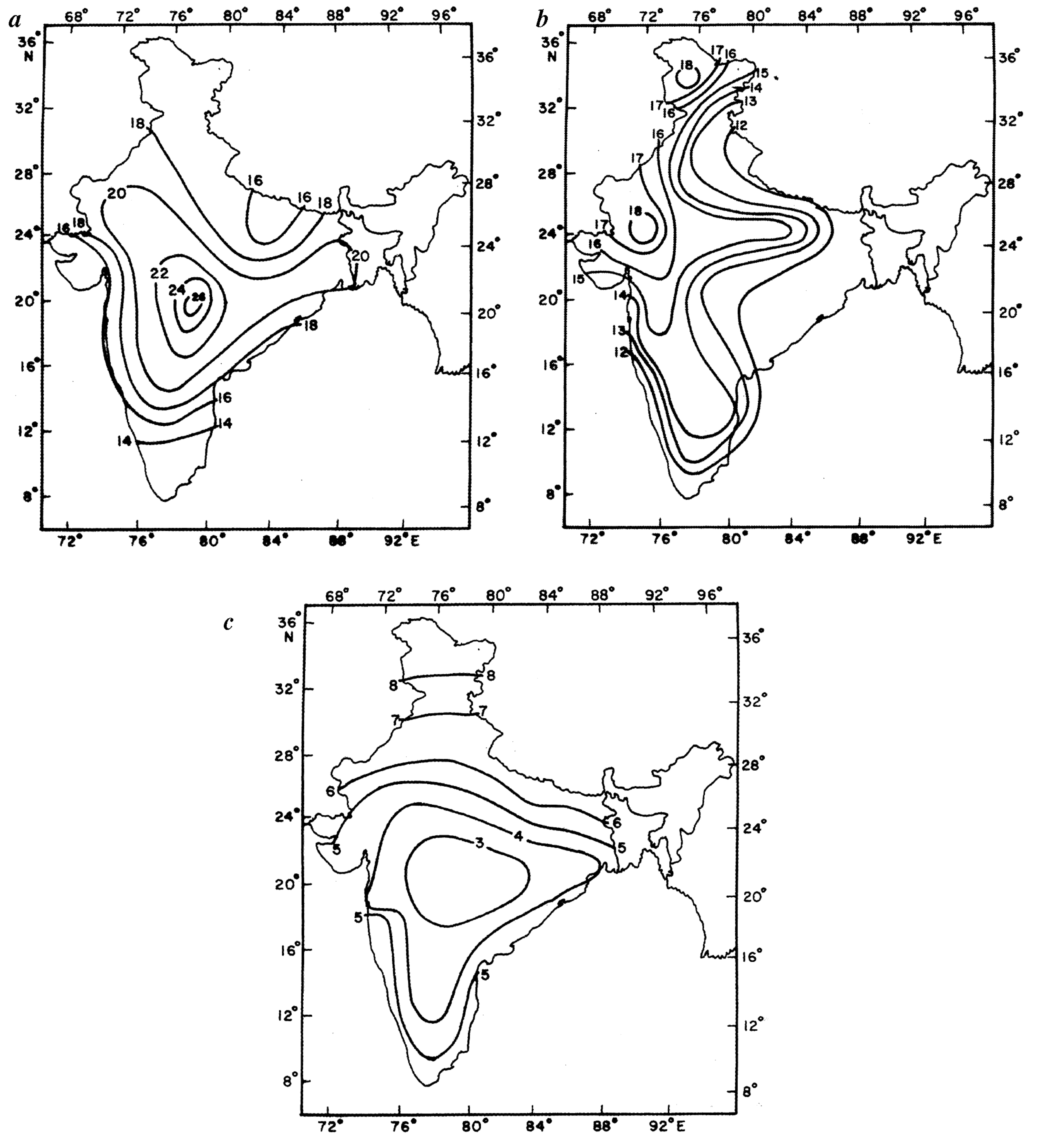

Figure 3. ***a***, Spatial distribution of mean activity (%) of synoptic mode (3–8 days) in TCO over India. Analysis is based on 5 years (1998–2002) of daily TCO data; ***b***, Same as (***a***) but for quasi bi-weekly mode (10–20 days); same as (***a***), but for MJO (30–60 days).

monsoon trough and the weather phenomena over and around the monsoon trough region.

The MJO mode of TCO variability is found significant in 4 years at Bangalore, while it is significant in 3 years at Kodaikanal out of 5 years. Thus MJO mode is significant over southern India. Chowdhury *et al.*[11] reported the stronger activity of the MJO mode in ISMR over southern India. They studied the spatial and temporal variations of different frequency modes of the southwest monsoon rainfall over India. Daily normal rainfall data (1901–1970) and those of the individual years during the period 1978–83 for 220 Indian stations are subjected to harmonic analysis. They revealed the presence of 30–60-day periodicities as a predominant mode over central peninsula of India. Similar feature was also reported by Yasunari[14–16]. The northward propagation of precipitation anomalies with recurrence period of 40 days was reported by Singh and Kriplani[20,21].

Thus, the variability in daily TCO and ISMR as discussed above suggests close association between the two at a first look. This association has been further examined by studying mean spatial distribution of the activity of the modes in TCO variability over the Indian region. The mean percentage variance (for 5 years data) contributed by the three modes to total variance has been taken into account to study the spatial distribution.

Figure 3 *a* shows the spatial distribution of mean activity of the synoptic mode. The activity is strongest over central India (mean percentage variance is 28) and decreases both southward (mean percentage variance is 14) and northward (mean percentage variance is 17). The variation in the activity in the east-west direction is small. The spatial distribution of qbw activity (Figure 3 *b*) shows maximum (mean percentage variance is 18) over northwest India, and has equally strong gradients in the eastward and southward directions (mean percentage variances are 12). The spatial distribution of MJO (Figure 3 *c*) is quite different from the other two modes. Here the minimum activity is found over central India (mean percentage variance is 3) and maximum activity over (i) northernmost part of India (mean percentage variance is 8) (ii) southernmost part of India (mean percentage variance is 5). The strongest activity of this mode over southern India is clearly associated with the revival of the continental Tropical Convergence Zone (TCZ) by northward propagation of the oceanic TCZ about one month after the culmination of the onset phase of the monsoon[22]. However, stronger activity of this mode over the northern part of India is yet to be investigated. Thus the spatial distribution of the activities of intra-seasonal TCO modes over India is qualitatively in agreement with the spatial distribution of the activities of the intra-seasonal ISMR modes.

The daily TCO variability over the Indian region shows three dominant modes, viz. synoptic (3–8 days period), qbw (10–20 days period) and MJO (30–60 days period) analogues to dominant modes found in the daily summer monsoon rainfall. The mean spatial distribution of the activity of modes in TCO variability over the Indian region revealed that (i) synoptic mode shows the strongest activity over central India; (ii) qbw mode shows strongest activity over northwest India and (iii) MJO mode shows strongest activity over northernmost and southernmost parts of India.

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