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ORIGINAL ARTICLE

Seasonal and Diurnal Variation of Mesoscale Convective Systems Over Southern Peninsular India as Observed by TRMM Satellite

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Abstract

Mesoscale Convective Systems (MCSs) contribute a large proportion of the earth's precipitation and hence their study is important from climatological point of view. In this paper, seasonal and diurnal variation of MCSs parameters over southern peninsular India has been studied. MCSs data over land for a period of 13 years (1998-2010) from Precipitation Measuring Mission (PMM) website of Utah University (www.trmm.chpc.utah.edu) have been utilized for this study. Distinct seasonal and diurnal variation of MCS parameters are observed over the study region. Number of occurrence and rainfall are maximum in June over southwest peninsular India and in October over southeast peninsular India. MCSs are found to be more severe during pre-monsoon and least severe during south-west monsoon. Their severity is found to be maximum in the month of May by virtue of highest median value of 20dBZ echo-top height (14.8 km) associated with highest median value of CAPE (1323 J/Kg). Convective fraction of rainfall is maximum in April and minimum in December. MCSs occurrence is found to be maximum in the late afternoon to evening and minimum in morning. They are found to be more intense during midday (10-14 hrs) and least intense during midnight (22-02 hrs). Diurnal cycle of convective fraction shows midday maximum and late night minimum.

Key words: Mesoscale Convective System, TRMM, Seasonal and Diurnal, Echo-Top Height, CAPE.

1. Introduction

Mesoscale Convective Systems (MCSs) are defined as "cloud systems that occur with an ensemble of thunderstorms and produces a contiguous precipitation area, with at least ~100 km or more in horizontal scale in one direction (Houze, 1982)". The overall cloud and precipitation pattern of MCSs may be round or linear and include weather system such as tropical cyclones, mesoscale convective complexes, squall lines among others. Majority of the MCSs are linear in shape as indicated by their eccentricity (Augustine *et al.,* 1989; Morel and Senesi, 2002; Sharma *et al.,* 2009). Mesoscale convective complexes (MCCs) are circular (eccentricity >0.7), but majority of the MCSs do not meet the MCCs criteria (Augustine *et al.*, 1989; Morel and Senesi, 2002). MCSs evolve over 3 to 6 hours and at some stage contain both convective and stratiform precipitation regions contributing a large proportion of the earth's precipitation (Houze, 1993). Across the tropics, stratiform precipitation accounts for 40% of the total rainfall, while it covers 73% of total raining area (Schumacher and Houze, 2003). They appear in many forms, ranging from a relatively disorganized mass of convective cells to a highly organized convective line and produce a large variety of hazardous weather (Fujita, 1978; Sharma *et al.*, 2009). The study of MCS by remote sensing is carried out in many spectral band such as visible, infrared and microwave, but the advantage of using microwave is that it penetrates through clouds and facilitates the study of internal structures of precipitating systems (Sharma *et al.*, 2009). In order to study tropical rainfall by facilitating remote sensing of MCS, the Tropical Rainfall Measuring Mission (TRMM) satellite which consists of precipitation radar (TRMM-PR) and microwave imager (TMI) was launched in 1997 (Kummerow *et al.*, 1998). Microwave sensors of

TRMM satellite give snapshot of precipitation systems roughly twice a day over a given area.

MCSs are mainly continental and there is strong correlation between MCS triggering and orography as MCS occurrence is more frequent near mountains ranges (Morel and Sensei, 2002). Continental areas with low MCS are either associated with lack of strong diurnal heating during the warm season or lack of humidity at low levels and also lack of an efficient triggering source such as a mountain ridge (Augustine *et al.*, 1989). Large count of MCSs is associated with complex topography and higher convective available potential energy (CAPE) whereas less count of MCSs is associated with plain topography and low CAPE (Sharma *et al.,* 2012). The most significant number of MCSs occurs during the warm season and there is a sharp increase in number of convective systems when the warm season starts and sharp decrease when the warm season ends (Morel and Sensei, 2002). Diurnal cycle of MCSs shows maximum occurrence during the afternoon (Augustine *et al.,* 1989; Nesbitt *et al.,* 2000). MCSs over land are much more intense than over ocean (Nesbitt *et al.,* 2000; Sharma *et al.,* 2009). MCSs over land have a convective intensity peak in the late afternoon (Nesbitt and Zipser, 2003). Tropical continent shows strong spatial and seasonal variability in vertical structure of tropical precipitation in comparison to tropical ocean (Peterson and Rutledge, 2001). A lognormal distribution fits the observed storm height distributions quite well, and a strong correlation exists between mean rainfall rate and storm height (Short and Nakamura, 2000). Takayabu *et al*. (2002) studied convective and stratiform rain characteristics over the equatorial area (10°N–10°S). They reported that over ocean, both convective and stratiform rain vary almost synchronously with early-morning (03–06 LT) maximum, whereas over land convective rain has afternoon (15–18 LT) maximum and stratiform rain has a midnight (24–03 LT) maximum. Cecil *et al*. (2005) studied precipitation features (PFs) throughout the global tropics using 3-yr TRMM database. They reported that majority (97.6%) of the precipitation features are "weakest/smallest" without any detected lightning flash; lowest brightness temperature is 42 K as detected by 85GHz channel; largest precipitation feature covers 335000 km^2.

India is tropical country and receives a significant amount of rainfall from mesoscale convective systems. The rainfall over Indian region shows distinct spatial and temporal variability depending upon the topography, geographical location, seasonal pattern and nature of synoptic systems (Bhowmik *et al.,* 2008). Several climatological studies of convective systems over Indian region have been conducted. Gambheer and Bhat (2000) studied the life cycle characteristics including preferred regions of formation and dissipation, frequency of occurrence, life time, and propagation speed of deep cloud systems over the Indian region using *INSAT-1B* pixel data. Prominent diurnal variation with more deep cloud activity during the pre-dawn and early morning hours and enhanced precipitation during morning to early noon hours are observed over Indian region (Gambheer and Bhat, 2001). Heavy precipitation events associated with mesoscale convective systems occur over the west coast of India and part of northeast India due to orographic features (Dodla *et al.,* 2009; Kumar *et al*., 2014). During pre-monsoon (PM) period, many parts over India especially the eastern and northeastern parts of the country are affected by higher frequency of thunderstorms (Litta and Mohanty, 2008). Several studies on thunderstorm have been carried out over Indian region (Lal, 1990; Tyagi, 2007; Litta and Mohanty, 2008; Tyagi *et al.,* 2011). Jayakrishnan and Babu (2013) studied thunderstorm indices and thermodynamic parameters for identifying convective activity over southwest peninsular India during pre-monsoon season. Tornadoes are not common in India, however eastern India is vulnerable to tornadoes during PM months whereas there have been a few cases over northwest India (Litta *et al*., 2010). Uma *et al*. (2012) studied the evolution of MCSs over western peninsular India and observed that they occur frequently during the pre-monsoon season and originate over the land during early afternoon hours, propagate seawards and finally dissipate over the sea.

Mesoscale convective systems contribute a large proportion of earth precipitation (Houze, 1993) and also produce a large variety of hazardous weather (Fujita, 1978; Sharma *et al.,* 2009). Extreme weather and climate can have negative impact on society and ecosystems in many ways resulting into losses of human life, agricultural production and engineering structures (Bhatla and Tripathi, 2014). The southern peninsular India (8^0-16^0N, 73^0-80^0E) receives rainfall during PM (Mar-May), SWM (June-September) and NEM (Oct-Dec). Agricultural production and various development activities in India depend on monsoon rainfall. Geographically southern peninsular India is an ideal location for MCS triggering due to presence of mountain ranges and surrounding ocean. Thus study of MCSs over southern peninsular India is important from climatological point of view. Present work mainly focuses on temporal variability of selected parameters of MCSs. The main objectives of the present work are

- To study the seasonal and diurnal variation of bulk parameters (number of occurrence and rainfall) of MCSs over the study region.
- To study the seasonal and diurnal variation of intensity of MCSs and convective fraction of

rainfall from convective region of MCSs over the study region.

- To investigate the correlation of temporal variation of MCS parameters with selected thermodynamic parameters.

This paper consists of four sections. Section 2 describes the data and methodology, result and discussion are presented in section 3, while conclusion has been provided in section 4.

2. Data and Methodology

MCSs data over land within the study area (8^0-16^0N, 73^0-80^0E) for a period of 13 years (1998-2010) provided by Precipitation Measuring Mission (PMM) website of Utah University (www. trmm.chpc.utah.edu) has been utilized. Monthly rainfall data has been obtained from Global Precipitation Climatology Centre (GPCC). The convective available potential energy (CAPE) and convective inhibition energy (CINE) data are obtained from NCEP/NCAR data product (Kalnay *et al.*, 1996) provided by the NOAA/OAR/ESRL PSD in their Web site at http://www.esrl.noaa.gov/psd/*in*. The bulk and intensity parameters of MCS have been normalized with respect to their maximum values. To study the temporal variation of bulk parameters, the study region has been divided into southwest (8^0-16^0N, 73^0-77^0E) and southeast (8^0-16^0N, 77^0-80^0E) peninsular India. Diurnal variation of occurrence and frequency distribution of intensity parameters have been studied during pre-monsoon (March-May), southwest monsoon (June-September) and northeast monsoon (October-December).

3. Result and Discussion

The selected parameters of MCSs are bulk parameters, intensity parameters and convective fraction of rainfall from convective region of the precipitating system. The bulk parameters are studied in terms of MCS count and rainfall. The selected intensity parameters are vertical extent of the precipitating system in terms of echo-top height at 20 dBZ (ETH_{20dBZ}), ice scattering signature in terms of polarization corrected brightness temperature (PCT_{85GHz}) and rain intensity in terms of maximum near surface reflectivity (max. NSZ). A total of 955 MCSs were observed over the land within the study area (8^0-16^0N, 73^0-80^0E) based on the criteria proposed by Mohr and Zipser (1996) during 13 years period from 1998 to 2010, where southeast peninsular India accounts for 54.6% of total observed MCSs. The overall analysis is presented in three sections as seasonal and diurnal variation of (i) bulk parameters (ii) intensity parameters and (iii) convective fraction of rainfall from convective region of MCSs.

3.1. Seasonal and Diurnal Variation of Bulk Parameters

Occurrence of MCSs is highest during southwest monsoon (SWM) over both southwest and southeast peninsular India. The least occurrence of MCSs is observed during northeast monsoon (NEM) over southwest peninsular India and during pre-monsoon (PM) over southeast peninsular India. Maximum occurrence was found in 2005 and 2010 and minimum in 2003 with annual average of 75 ± 15. Over southwest peninsular India, occurrence of MCS and rainfall were maximum in June, whereas over southeast peninsular India these were maximum in October. Maximum monthly average rainfall was 295 mm (June) in southwest peninsular India and 226 mm (October) in the southeast peninsular India. Over the southern peninsular India as a whole, maximum occurrence of MCS was found in the month of October while maximum rainfall (243 mm) occurred in the month of September. The seasonal variation of normalized MCS count and rainfall over southwest, southeast and southern peninsular India are as shown in the Fig 1(a, b, c). Occurrence of MCS increases when warm season starts and decreases when warm season ends over the study area. Similar result has been reported by Morel and Sensei (2002) over Europe, a mid latitude region. Seasonal variation of CAPE shows sharp increase during PM from 762 J/Kg (Mar) to 1323 J/Kg (May). Table 1 shows monthly median value of thermodynamic parameters CAPE and CINE over southern peninsular India.

Table 1: Monthly median value of thermodynamic parameters CAPE and CINE

Month	CAPE (J/Kg)	CINE (J/Kg)
January	17	71
February	450	53
March	762	38
April	1112	24
May	1323	27
June	525	52
July	286	65
August	401	61
September	682	38
October	743	39
November	604	54
December	241	76

At seasonal scale, occurrence of MCS shows a moderate correlation with CAPE ($CC = 0.45$) and CINE ($CC = -0.45$). Bhowmik *et al.* (2008) reported that in addition to strong thermodynamic environment, factors like strong wind circulation in the

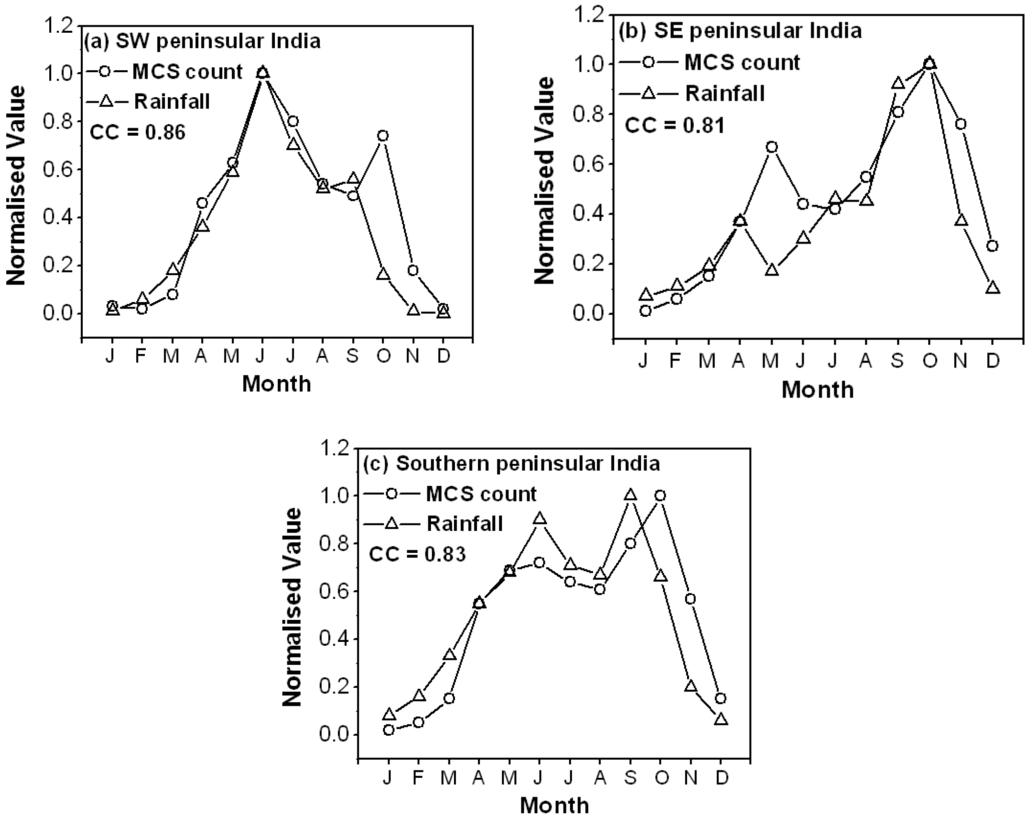

Fig 1: Seasonal Variation of bulk parameters (number of occurrence and rainfall) of MCSs over southern peninsular India during 1998-2010. (a) Southwest (SW) peninsular India (b) Southeast (SE) peninsular India (c) Southern peninsular India

Atmosphere plays an important role in occurrence of deep convective systems. During PM strong thermodynamic environment in terms of CAPE prevails in the atmosphere, but occurrence of MCSs reaches maximum during monsoon period, when CINE is less and the land sea contrast heating strengthens wind circulation in the atmosphere. Comparatively higher correlation coefficient (CC) between MCS count and rainfall is observed over southwest peninsular India (CC = 0.86) than over southeast peninsular India (CC = 0.81). The high correlation between MCS count and rainfall indicates the fact that a major portion of tropical rainfall is due to MCSs (Mohr *et al.,* 1999).

Diurnal cycle of MCSs occurrence shows that diurnal variation is distinct during PM as well as SWM and NEM period. Diurnal variation of MCS occurrence over southern peninsular India is as shown in (Fig 2a-d). During PM, maximum occurrence is in evening (17-19 hrs) and minimum from midnight throughout the morning (00–10 hrs). Occurrence of MCSs is maximum in evening (18-21 hrs) during SWM and in late afternoon (15-17 hrs) during NEM, whereas it is minimum in the morning during both SWM and NEM. During SWM period maximum occurrence of MCSs is observed for longer duration (18-21 hrs) in comparison to PM and NEM period. Minimum occurrence shifts from 00-10 hrs during PM to morning hours during SWM and NEM. The diurnal variation MCSs occurrence is mono-model except during NEM over southeast peninsular India where it is bi-modal with maximum at midnight (01-02 hrs) and afternoon (14-15 hrs). Overall the southern peninsular India shows maximum occurrence in the late afternoon (16-18 hrs) and minimum in morning (8-10 hrs) as shown in Fig 2(d). This result shows that diurnal cycle of MCSs occurrence is strongly correlated with diurnal heating of low level of atmosphere. Similar observation was reported by Morel and Sensei (2002) in their study of climatology of MCS over Europe, where they reported that MCS triggering reaches its maximum around 2 pm whereas MCS dissipation reaches its peak around 7 pm.

3.2. Seasonal and Diurnal Variation of Intensity Parameters

The frequency distribution of ETH_{20dBZ},

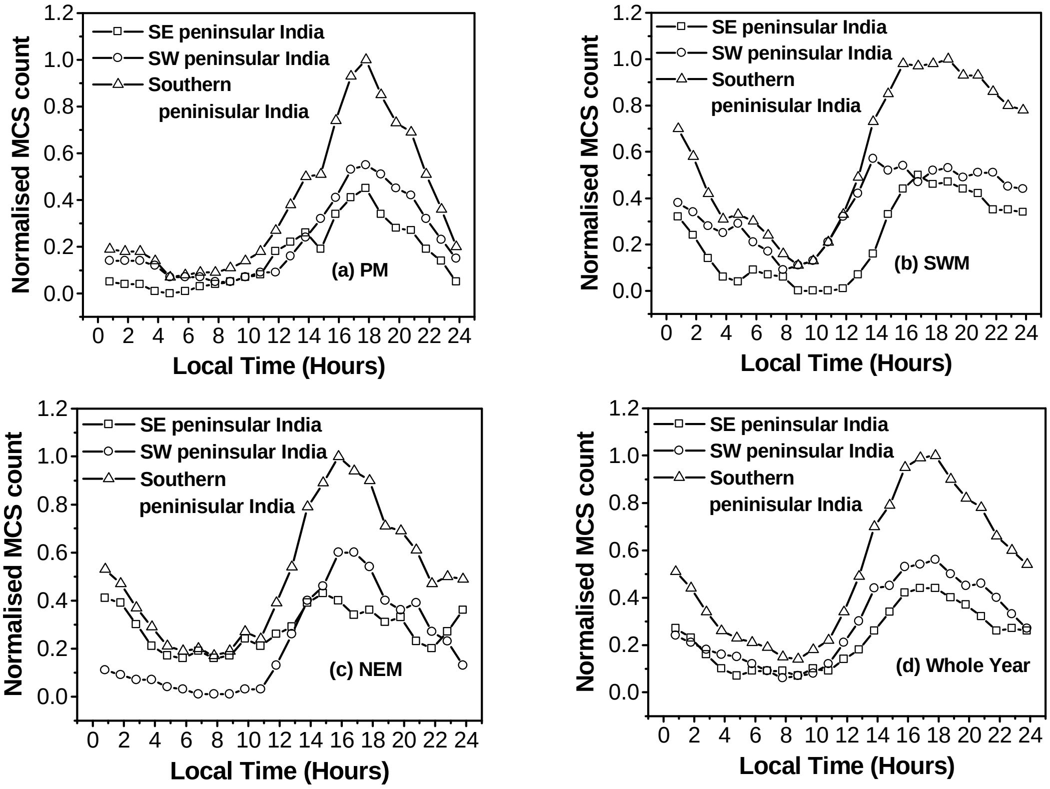

Fig. 2: Diurnal Variation of MCS occurrence over southern peninsular India during PM, SWM, NEM and whole Year. Moving average of 3 data has been considered.

minimum PCT_{85GHz} and maximum NSZ over the southern peninsular India are as shown in (Fig 3a-i) during PM, SWM and NEM. Significant variability in frequency of occurrence of various intensity parameters as well as seasonal variability is observed. The mean and standard deviation (SD) of selected intensity parameter during PM, SWM and NEM are presented in Table 2.

Table 2: Mean and SD of MCS intensity parameters during PM, SWM and NEM

Season	ETH_{20dBZ} (km)		PCT_{85GHz} (K)		Max. NSZ (dBZ)	
	Mean	SD	Mean	SD	Mean	SD
PM	13.98	2.45	149	42	13.98	2.45
SWM	11.63	2.45	179	35	11.63	2.45
NEM	12.69	2.34	167	35	12.69	2.34

MCSs are found to be more severe during PM and least severe during SWM in terms of vertical extent ETH_{20dBZ} and ice scattering signature PCT_{85GHz}. Maximum occurrence of ETH_{20dBZ} corresponds to 15-16 km, 9-10 km and 12-13 km during PM, SWM and NEM respectively. The highest frequency of occurrence of minimum PCT_{85GHz} corresponds to 125-150 K, 200-225 K and 175-200 K during PM, SWM and NEM respectively. The highest frequency of occurrence of maximum NSZ corresponds to 50-55 dBZ during PM and 45-50 dBZ during monsoon. Monthly median value of vertical extent ETH_{20dBZ} which is a proxy for rain height (Sharma *et al*., 2012) is found to be maximum (14.8 km) in May and minimum (10.20 km) in July. At seasonal scale MCS intensity (ETH_{20dBZ}) is highly correlated with thermodynamic parameters CAPE ($CC = 0.8$) and CINE ($CC = -0.8$). During PM the atmosphere is highly unstable because of surface warming and high temperature prevailing at lower levels (Litta and Mohanty, 2008; Bhowmik *et al.,* 2008). Monthly median value of PCT_{85GHz} is found to be minimum (143 K) in April and maximum (192 K) in June. The maximum and minimum of monthly median value of max. NSZ which is a proxy for rain intensity are found in April (51 dBZ) and in June (48 dBZ) respectively. Seasonal variation of these intensity parameters of MCSs is as shown in Fig 4. At seasonal scale the correlation between ETH_{20dBZ} and PCT_{85GHz} is found-

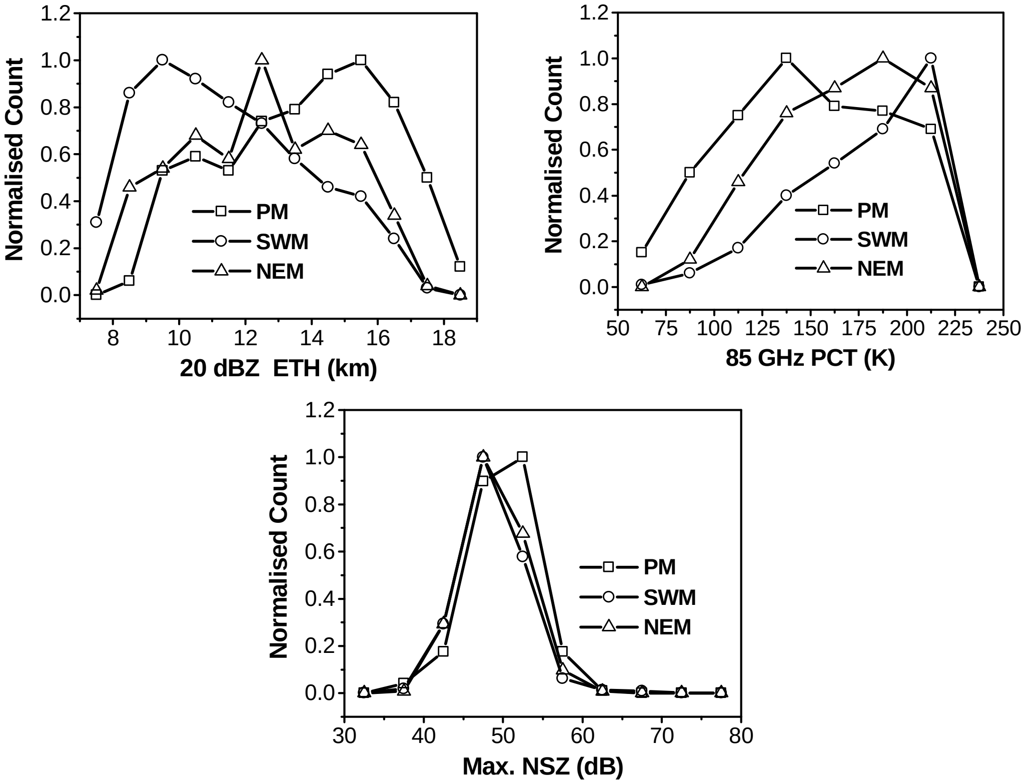

Fig 3: Frequency distribution of ETH_{20dBZ}, PCT_{85GHz} and max. NSZ over southern peninsular India during PM, SWM and NEM

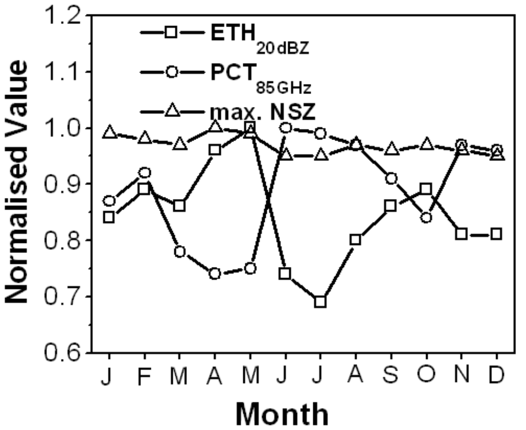

Fig 4: Seasonal Variation of intensity parameters of MCSs over southern peninsular India during 1998-2010.

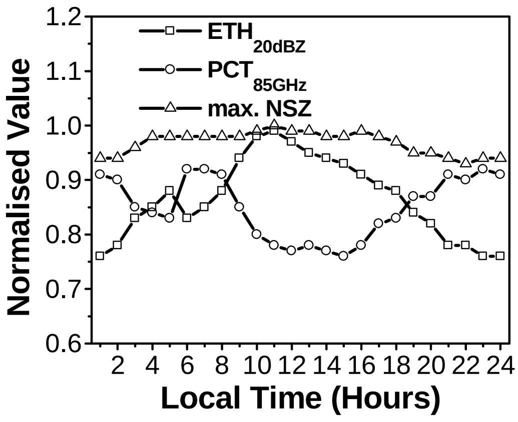

Fig. 5: Diurnal variation of ETH_{20dBZ}, PCT_{85GHz} and NSZ over southern peninsular India

to be -0.86 and that between ETH_{20dBZ} and NSZ is 0.77. The correlation between PCT_{85GHz} and NSZ is -0.77 at seasonal scale.

Diurnal cycle of selected intensity parameters shows that MCSs are more intense during midday (10-14 hrs) and least intense during midnight (22-02 hrs) by virtue of ETH_{20dBZ} and PCT_{85GHz}. Diurnal variation of these parameters is as shown in the Fig 5. Median value of ETH_{20dBZ} is maximum (14 km) during 10-11 hrs and minimum (10 km) during 0-1 hrs. Median value of PCT_{85GHz} is minimum (153 K) during 15-16 hrs and maximum (210 K) during 7-8 hrs whereas -

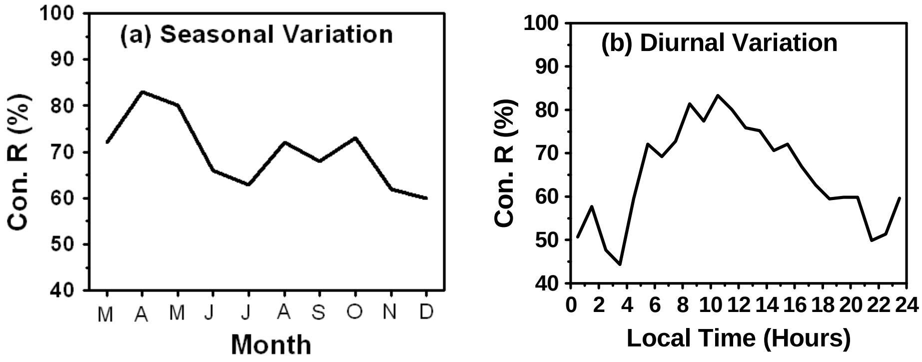

Fig. 6: Temporal variation of median value of convective fraction (Con. R %) of rainfall from the convective region of the precipitation system (a) seasonal and (b) diurnal.

median value of max. NSZ is found to be maximum (50 dBZ) during 10-11 hrs and minimum (47 dBZ) during 02-03 hrs. At diurnal scale the correlation coefficient between ETH_{20dBZ} and PCT_{85GHz} is found to be -0.84 and that between ETH_{20dBZ} and NSZ is 0.72. The correlation coefficient between PCT_{85GHz} and NSZ is -0.49 at diurnal scale.

3.3. Seasonal and Diurnal Variation of Convective Fraction of Rainfall

Convective fraction is the percentage of rainfall from the convective region of the precipitation system. Distinct seasonal and diurnal variation of the convective fraction of rainfall from MCSs has been observed over the study region as shown in (Fig 6a-b). Convective rain production depends on strength of convection, whereas stratiform rain production is not very dependent on the strength of convection (Schumacher and Houze, 2003). The median value of convective fraction of rainfall from MCSs is found to be maximum (81%) during PM and minimum (67%) during SWM, whereas that during NEM it is found to 69%. Similar result was reported by Schumacher and Houze (2003) in their study of stratiform precipitation across the tropics using three years TRMM data base. They reported that stratiform rain fraction is low in the season before monsoon and high during the monsoon season. Diurnal cycle of convective fraction shows high value in day time with maximum during 10-11 hrs and low value in night time with minimum during 03-04 hrs. The correlation coefficient (CC) between ETH_{20dBZ} and convective fraction (Con. R%) is 0.82 and 0.73 at seasonal and diurnal scale respectively. This indicates that convective fraction is strongly correlated with convective intensity of the precipitating systems.

4. Conclusions

Tropical rainfall measuring mission (TRMM) provides an opportunity to study the climatology of MCSs by providing a large database. In this study, temporal variation of MCS parameters at seasonal and diurnal scale is considered over southern peninsular India using 13 years (1998-2010) TRMM database. Seasonal and diurnal variations of MCS parameters are distinct over southern peninsular India. The main conclusions of this study are:

- MCS occurrence over southern peninsular India increases in the beginning of warm season and decreases at the end of the warm season. Seasonal variation of MCS occurrence can be attributed to favorable thermodynamic environment in addition to local condition like land-sea contrast heating which strengthens wind circulation in the atmosphere during monsoon period.
- Both southwest and southeast peninsular India observes strong diurnal variation of occurrence of MCSs during PM as well as SWM. During NEM the southwest peninsular India observes strong diurnal variation whereas the southeast peninsular India observes semi diurnal variation of occurrence. Diurnal cycle of MCSs occurrence is strongly correlated with diurnal heating of low level of atmosphere.
- MCSs are found to be more severe during PM and least severe during SWM. More severe MCS is found to be associated with high CAPE value at seasonal scale. MCSs are more intense during midday and least intense during midnight which can be correlated with diurnal cycle of heating of the low level of atmosphere.
- Convective fraction of rainfall from MCSs is more before monsoon period and decreases during monsoon period. Diurnal cycle of convective fraction shows midday maximum and

late night minimum. Temporal variation of convective fraction of rainfall is strongly correlated with convective intensity of precipitating systems.

In this study temporal variation of MCS parameters and their correlation with thermodynamic conditions in terms of CAPE and CINE are investigated. A detailed study of MCS considering various thermodynamic parameters and local dynamic condition like horizontal wind shear is planned to carry out in future which may be helpful for better understanding of the MCS climatology over the southern peninsular India.

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