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Maximum cloud zone monitoring through INSAT Outgoing Long Wave Radiation (OLR) data

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सार – मौसम संबंधी उपग्रहों पर मौजूद स्कैनिंग रेडियोमीटर दृश्य और इन्फ्रा-रेड स्पेक्ट्रा के भीतर संकीर्ण गवाक्षों में विकिरणता को मापते हैं। उदाहरण के लिए, INSAT VHRR के मामले में ये गवाक्ष क्रमशः 0.55-0.75µ और 10.5-12.5µ हैं। ब्रॉड-बैंड बहिर्गामीदीर्घतरंग विकिरण और ग्रहीय अल्बेडो भौतिक और/या सांख्यिकीय एल्गोरिदम को लागू करके अप्रत्यक्ष रूप से ऐसी गवाक्ष माप से प्राप्त होते हैं। भूस्थिर उपग्रह (INSAT-3D/3R) संकीर्ण बैंड आधारित OLR प्रेक्षण सतह के तापमान परिवर्तन पर तात्कालिक प्रतिक्रिया का महत्वपूर्ण लाभ प्रदान करते हैं और भारतीय मॉनसून गतिविधि में महत्वपूर्ण भूमिका निभाते हैं।

यह दर्शाया गया है कि भारतीय ग्रीष्मकालीन मॉनसून (आईएसएम) के चरण, आरंभ से लेकर सक्रिय और वापसी तक, भूमध्यरेखीय बेल्ट के पास एक उच्चनिष्ठमेघ क्षेत्र (एमसीजेड) के विकास तथा क्षैतिज और उत्तर दोनों दिशाओं में इसके प्रसार से जुड़े हैं। आईएसएम के आरंभ, सक्रिय, ब्रेक अवधि के बीच परिवर्तन या दोलनों को रेखांशिक प्रवर्धनितमेघ बैंड दिनों, कमजोर या महीनों की आवधिकता के माध्यम से आसानी से मॉनिटर किया जा सकता है। निम्न दाब प्रणाली (एलपीएस) आदि जैसे मॉनसून घटक हर मॉनसून ऋतु में एमसीजेड को अलग तरह से प्रभावित करते हैं।

इस शोधपत्र में 2010 से 2017 के मॉनसून ऋतु के लिए ओएलआर डेटा को चार श्रेणियों 190-210/210-230/230-250/250-270 में वर्गीकृत किया गया था, जो कि तीन अक्षांशों (-5 °N - 10 °N, 10 °N - 25 °N और 25 °N - 35° N) पर अति प्रचण्ड, प्रचण्ड, मध्यम और कमजोर संवहन के सीमांकन के रूप में था।

यह पाया गया है कि यदि कमजोर ओएलआर की कालावधि समग्र मौसमी वर्षा से अधिक है तो यह वास्तविक से नकारात्मक विचलन दर्शाता है, हालांकि यह हमेशा सही नहीं होता है।

यह देखा गया है कि वर्ष 2010, 2011 और 2013 में मौसमी वर्षा प्रस्थान सकारात्मक है और ओएलआर डेटा यह भी दर्शाता है कि अति प्रचण्ड और प्रचण्ड संवहन की कालावधि की संख्या अन्य वर्षों की तुलना में अधिक है।

ECMWF रीएनालिसिस 5वीं पीढ़ी (ERA-5) मॉडल डेटा से प्राप्त 850 hPa मौसमी पवन गति विश्लेषण इस विचार का समर्थन करता है कि यदि प्रवाह प्रबल और व्यवस्थित है तो वर्षा भी उसी तरह से व्यवहार करती है।।

ABSTRACT. Scanning radiometers on-board the meteorological satellites measure the radiance in narrow windows within the visible and infra-red spectra. For example, in the case of the INSAT VHRR these windows are 0.55-0.75µ and 10.5-12.5µ respectively. The broad-band outgoing longwave radiation and the planetary albedo are derived indirectly from such window measurements by applying physical and/or statistical algorithms. Geostationary satellite (INSAT-3D/3R) narrowband based OLR observations offer the significant advantage of an instantaneous response to surface temperature changes and played an important role in Indian Monsoon activity.

It has been shown that Indian Summer Monsoon (ISM) phases starting from onset, active and withdrawal are associated with the development of a Maximum Cloud Zone (MCZ) near the equatorial belt and its propagation both horizontal and northward direction. The alterations or oscillations between onset, active, break periods of the ISM can easily be monitored through meridional propagating cloud bands days, weak or months periodicity. Monsoon elements like low pressure systems (LPS) *etc.* affects MCZ every monsoon season differently.

In this paper OLR data was grouped in four ranges 190-210/210-230/230-250/250-270 as demarcation of very severe, severe, moderate and weak convection at three ranges of latitudes (-5 °N – 10 °N, 10 °N-25 °N & 25 °N – 35 °N) for the monsoon seasons 2010 to 2017.

It is found that if the epochs of weak OLR are more than overall seasonal rainfall shows negative departure from actual, however it is not always true.

It is seen that years 2010, 2011 and 2013 have positive seasonal rainfall departure and OLR data also show that the number of epochs of very severe and severe convection are more frequent as compared to other years.

850 hPa seasonal wind speed analysis derived from ECMWF reanalysis 5th generation (ERA-5) model data support the idea that if the flow is strong and organized then rainfall also behave in the same manner.

Key words– Indian summer monsoon, OLR, Meridional propagation, active and break period, INSAT data, ECMWF reanalysis 5th generation (ERA-5) data.

1. Introduction

The Indian Summer Monsoon from June to September greatly influences the agriculture yield, economy, water resources, power generation and ecosystem and is known as the lifeline of India. Its behavior throughout the globe is different and the variations in monsoon rainfall affect life and economy of the country. The global land monsoon region, with the highest precipitation variability over land, affects two thirds of the world's population (Wang *et al*., 2012). Globally monsoon regions are divided into six sub-monsoon regions, North American, South American, North African, Asian and Australian monsoon regions (Wang & Ding, 2008) and connected to each other (Trenberth *et al*., 2000) to follow the mass conservation. During the monsoon warm and moist air blows from the southwest Indian Ocean towards India through the active Inter Tropical Convergence Zone (ITCZ) and India receives ~80% of total rainfall. The Maximum Cloud Zone (MCZ) is mostly confined with Indian longitudes (70-90 °E) and characterized by large seasonal excursions of MCZ (Sadler 1975). Due to the variation of MCZ seasonal transition as well as the fluctuations within the season vary from year to year. The observational data coverage initially was limited and therefore less attention was given to the changes of the rainfall over the monsoon region (Zhang & Zhou, 2011). The observational data gap issue has been addressed since the 1980s; the availability of satellite data has provided new opportunities for understanding the cloud and radiation characteristics over the global monsoon region. Considering the large impact of land monsoon precipitation changes on local social life and different cloud characteristics of land cloud from ocean cloud, this study mainly focuses on the cloud and radiation features over the global land monsoon region. In India, Satellite Meteorology Division of India Meteorological Department (IMD) used to receive the Satellite imageries (1972-1982) from NOAA and NASA meteorological satellites through Secondary Data Utilization Centre (SDUC) and images were printed on photographic paper for use in weather forecasting. Indian monsoon activity (active or break) is generally confined to the monsoon core zone, 18.0° N to 28.0° N and 65 °E to 88° E (Pai *et al*, 2016, Rajeevan *et al*., 2010). To study cloud seasonal variability, Outgoing Long Wave Radiation (OLR) retrieved from Kalpana-1 data for monsoon season (June to September) at 8.0 km horizontal resolution was analysed for the year 2010 to 2017. The MCZ mean position location in winter is south of the equator than its position shifts during monsoon season (20 °N) in association of seasonal excursions near equatorial trough (Sikka and Gadgiil, 1980, Sikka and dixit, 1972, Ramage, 1971 and Raghavan, 1973).

There are challenges in the retrieval of OLR initially and subsequently improved in algorithm as well as satellite payloads. The OLR data in broadband produces high quality data by directly observing a broadband range of 3 to 100 μm at the top of the atmosphere (Singh *et al*., 2007). The spectral bands available in INSAT satellites are not completely free from moisture contaminating, therefore moisture adjustment is essential and it is properly taken care by the algorithm development team of Space Application Centre, Indian Space Research Organisation (ISRO). Similar, situation was faced in the past with other geostationary satellite data developers. Atmospheric interference using differences in infrared and

WV channels and the difference in infrared channels are mainly used to calculate OLR using narrowband band data (Schmetz and Liu, 1988). On the other hand, geostationary narrowband based OLR observations offer the significant advantage of an instantaneous response to surface temperature changes (Ba *et al*., 2003). In the tropics, the OLR is largely modulated by cloudiness. In particular, it varies with the cloud top temperature, and consequently, low values of OLR indicate major convective systems [Schmetz and Liu, 1988].

It is known that, scanning radiometers on-board the meteorological satellites measure the radiance in narrow windows within the visible and infra-red spectra. For example, in the case of the INSAT VHRR these windows are 0.55-0.75µ and 10.5-12.5µ respectively. The broad-band outgoing longwave radiation and the planetary albedo are derived indirectly from such window measurements by applying physical and/or statistical algorithms. Further, the OLR data sets of different satellites are not strictly comparable because of differences in the filter response curves, radiometer calibration, instantaneous field of view of the sensor, observation times during the diurnal cycle, *etc*. (Kelkar, 1993). In other centers, OLR was routinely obtained from the 10-12 mm window on the operational National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellite beginning in 1974 [Gruber and Winston, 1978]. In the current scenario, IMD is operationally using the methodology adopted by Singh *et al*., 2007 in generating the OLR products and authors utilizes the optimum relationship between radiative transfer model calculated narrowband radiances and broadband flux were developed using Genetic algorithm, an advance empirical technique (GA).

Subsequent sections of this work are divided into data and methodology followed by results and discussion, concluding remarks and references. The northward propagation modes of OLR provide an idea of preparedness of convection and its periodicity. Therefore, it will help to understand the activity of southwest monsoon more realistically during its active and break phases. Close monitoring of these northward propagating modes helps to understand the variability of convection or even rainfall in core zones of monsoon, seasonally and within season. The fluctuations are not directly associated with local changes but they are also globally coordinated and tele connected by many processes and oscillations. Therefore, the present study is very thematic and important to get more insight into the mystery of southwest monsoon. Although rainfall and cloud developments have two different mechanisms which usually involve global as well as local interactions of land, ocean and atmosphere. Therefore, high resolution OLR datasets associated with rainfall and wind fields for active and break spells of Indian monsoon will be seen in future studies, In the past (Rajeevan *et al*., 2006) utilized the high resolution gridded rainfall data to study the active and break cycles of rainfall. During monsoon onset phase the value of OLR (< 200 W/m^2) was found to be favorable and taken as one of the parameters of operational objective criteria of India Meteorological Department in association with other parameters, pressure, upper wind and realized rainfall (Debnath *et al*., 2019).

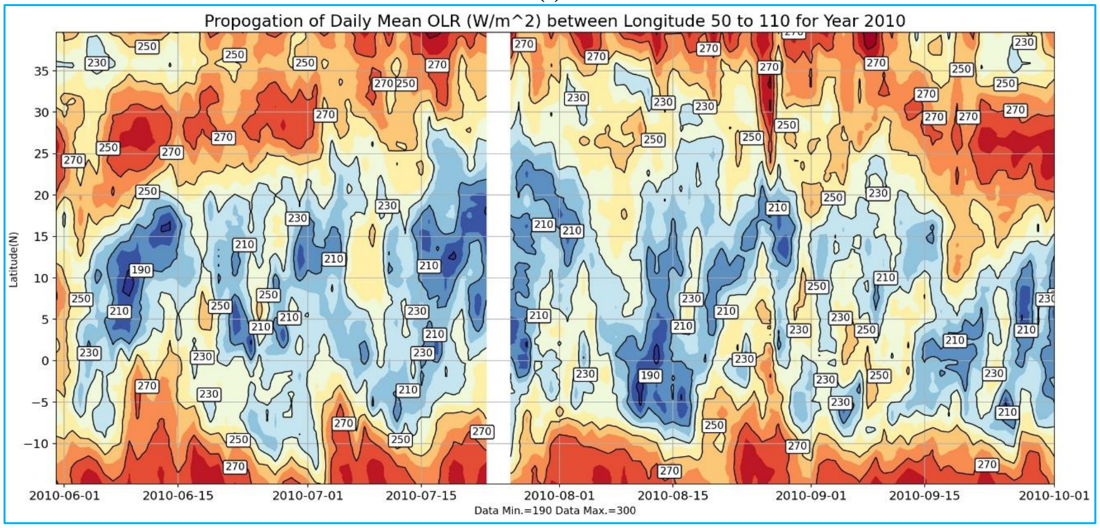
2. Data and methodology

INSAT derived OLR data sets have been taken from India Meteorological Department (IMD), Lodi Road, New Delhi. The high resolution OLR data sets of 0.25° × 0.25° resolution for the year 2010 to 2012 have been taken from Indian Institute of Tropical Meteorology (IITM) website (Mahakur *et al*., 2013). Similar gridded data sets have been generated for the period 2013 - 2017 over extended Indian domain (50° E – 110° E, 15° S - 40° N) at IMD. The data set generation has already taken care of equinox time passes and geo-location adjustment with respect to satellite zenith angle (up to 70 degree). Other supporting documents and monsoon reports prepared jointly by IMD and IITM were utilized to study the past monsoon behaviour in this study. 850 hPa seasonal winds flow of 25 × 25 km (m/sec) were generated from ECMWF reanalysis 5thgeneration (ERA-5) data sets.

3. Results and discussions

Outgoing Longwave Radiation is a proxy of convection but not directly related to rainfall or precipitation. Lower values of OLR are indicative of cloudiness and -30 °C to -50 °C, -50 °C to -70 °C and -70 °C with varying spatial coverage represents low, medium and intense convection respectively (Goyal *et al*., 2016). INSAT based cloud top temperature decides the strength of convection. The stronger the convection is, the lower the value of OLR. Therefore, OLR can reveal the intensity of convective activity to some extent. OLR is known as the energy radiating from the earth to external space as infrared radiation. In view of relative homogeneity of the underlying surfaces in low-latitude and mid-latitude zones, the value of OLR is mainly determined by the cloud coverage and its spread. This feedback has been taken into consideration by the ISRO team in recent operational OLR algorithms at IMD. OLR has a close relationship with earth-atmosphere radiation budget (WU, *et al*.; Zhang *et al*., 2016). It mainly depends on the temperature profile (the cloud in the cloudy sky or the underlying surfaces in the clear sky) (Zhang *et al*., 2017). During monsoon season, in a cloudy sky, OLR usually depends on the cloud top temperature

(a)


Propogation of Daily Mean OLR (W/m^2) between Longitude 50 to 110 for Year 2010
Latitude(N)
2010-06-01
2010-06-15
2010-07-01
2010-07-15
2010-08-01
2010-08-15
2010-09-01
2010-09-15
2010-10-01
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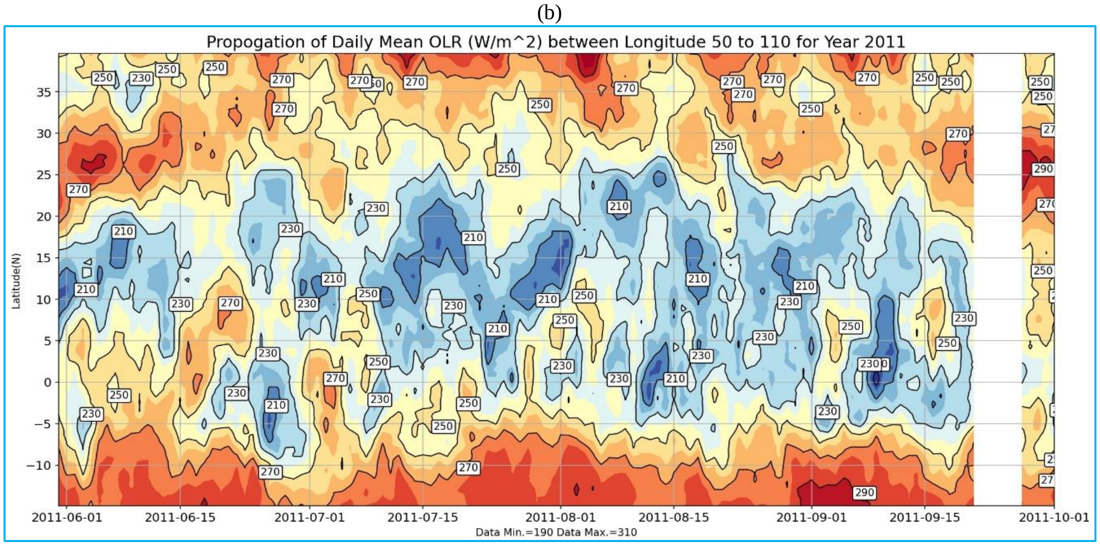
(b)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Latitude(N)
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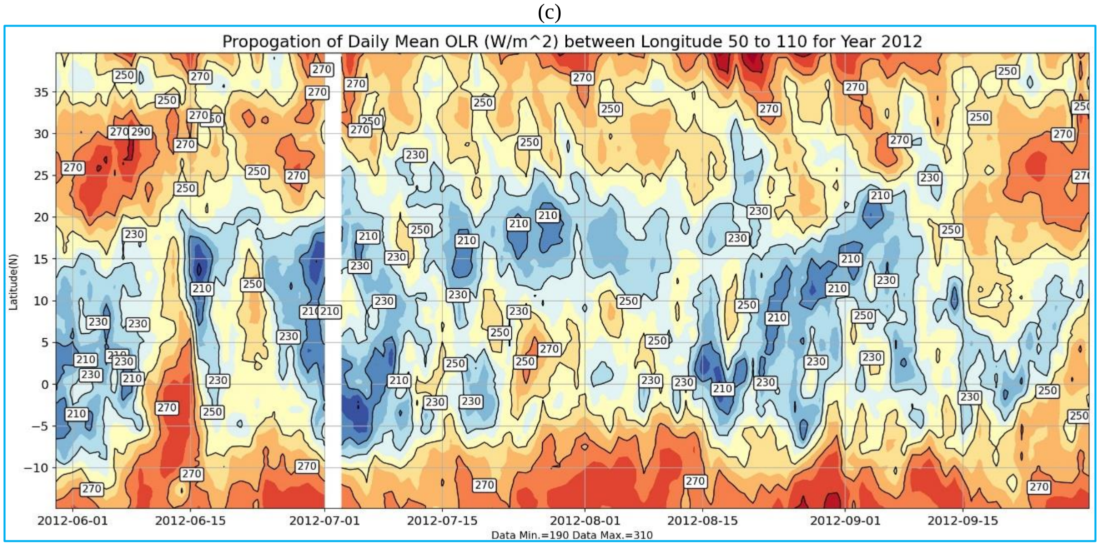
2011-06-15
2011-07-01
2011-07-15
2011-08-01
2011-08-15
2011-09-01
2011-09-15
2011-10-01
Data Min.=190 Data Max.=310

(c)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Latitude(N)
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2012-06-15
2012-07-01
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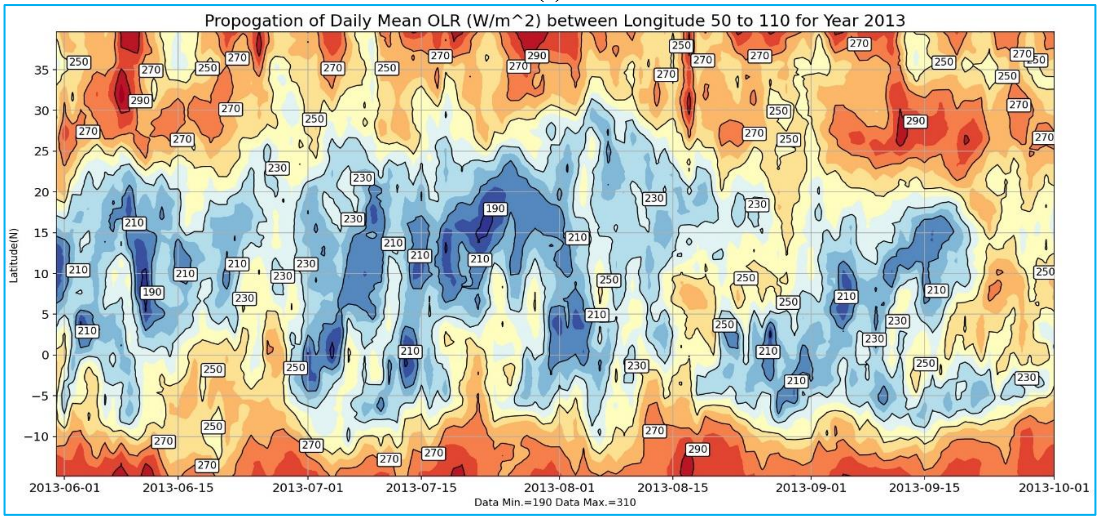
2012-08-15
2012-09-01
2012-09-15
Data Min.=190 Data Max.=310

(d)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2013-06-15
2013-07-01
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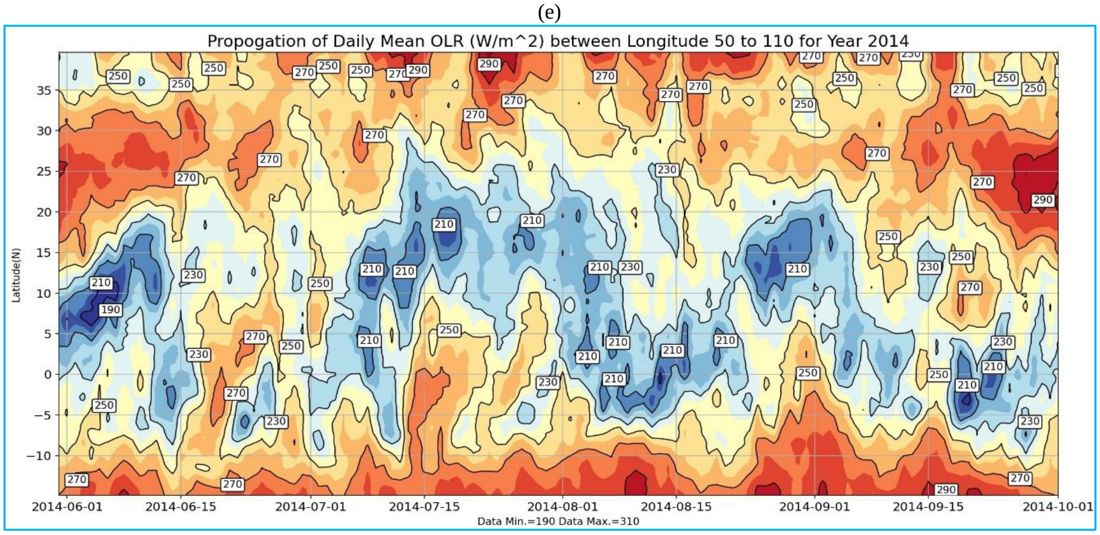
2013-09-01
2013-09-15
2013-10-01
Data Min.=190 Data Max.=310

(e)


Propogation of Daily Mean OLR (W/m^2) between Longitude 50 to 110 for Year 2014
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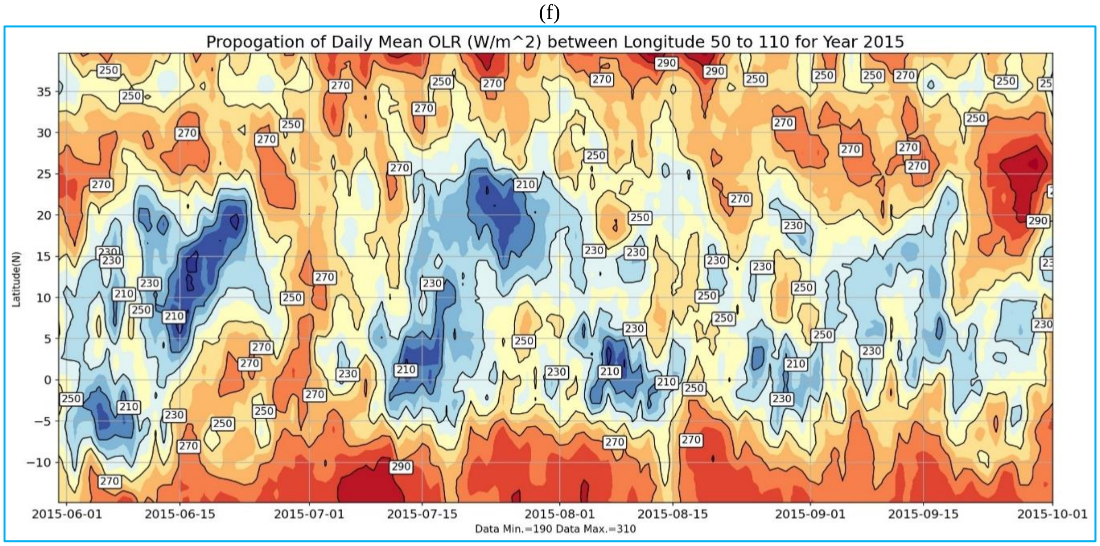
Data Min.=190 Data Max.=310

(f)


Propogation of Daily Mean OLR (W/m^2) between Longitude 50 to 110 for Year 2015
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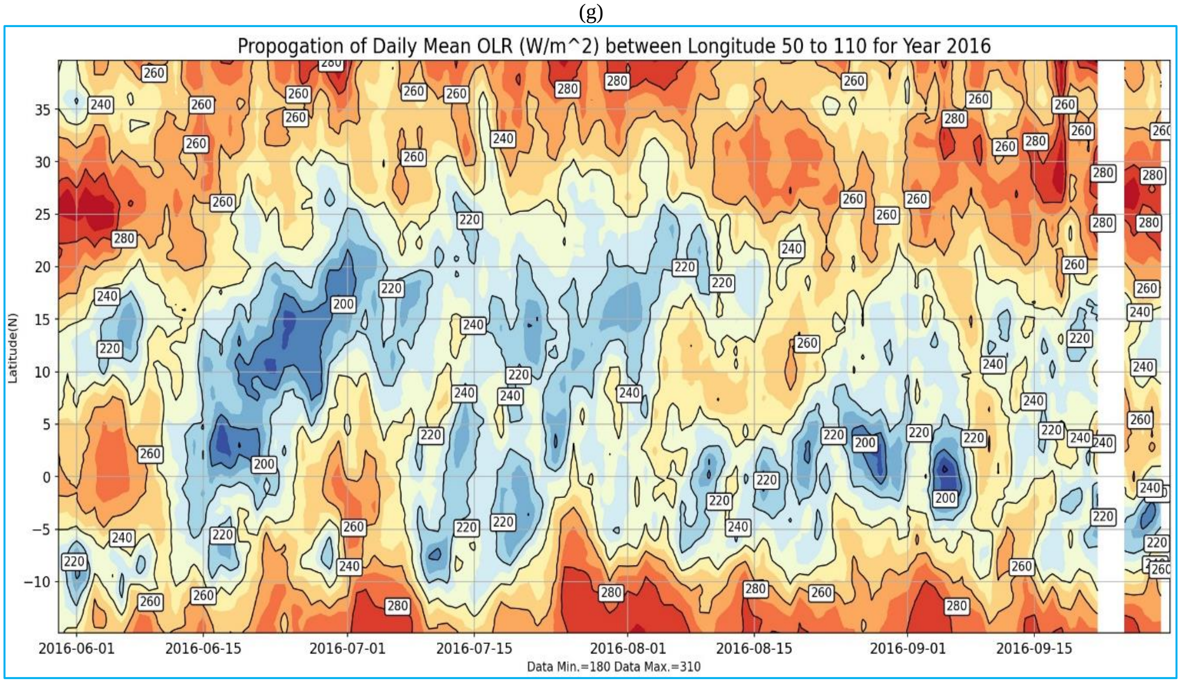
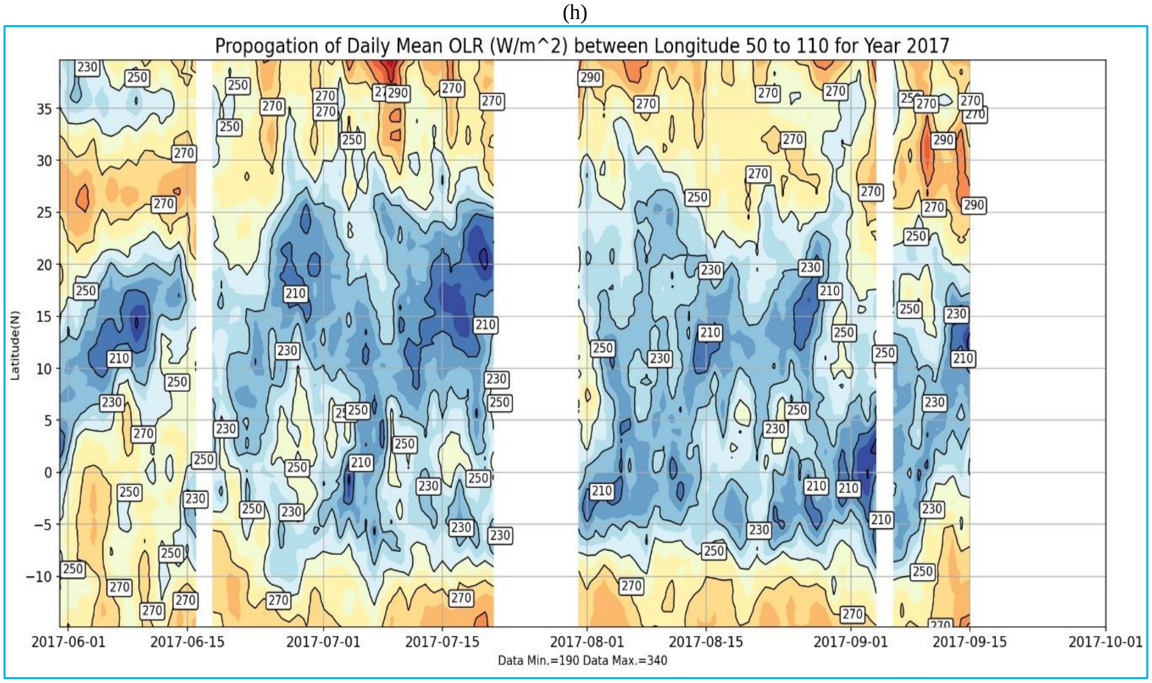
2015-09-01
2015-09-15
2015-10-01
Data Min.=190 Data Max.=310

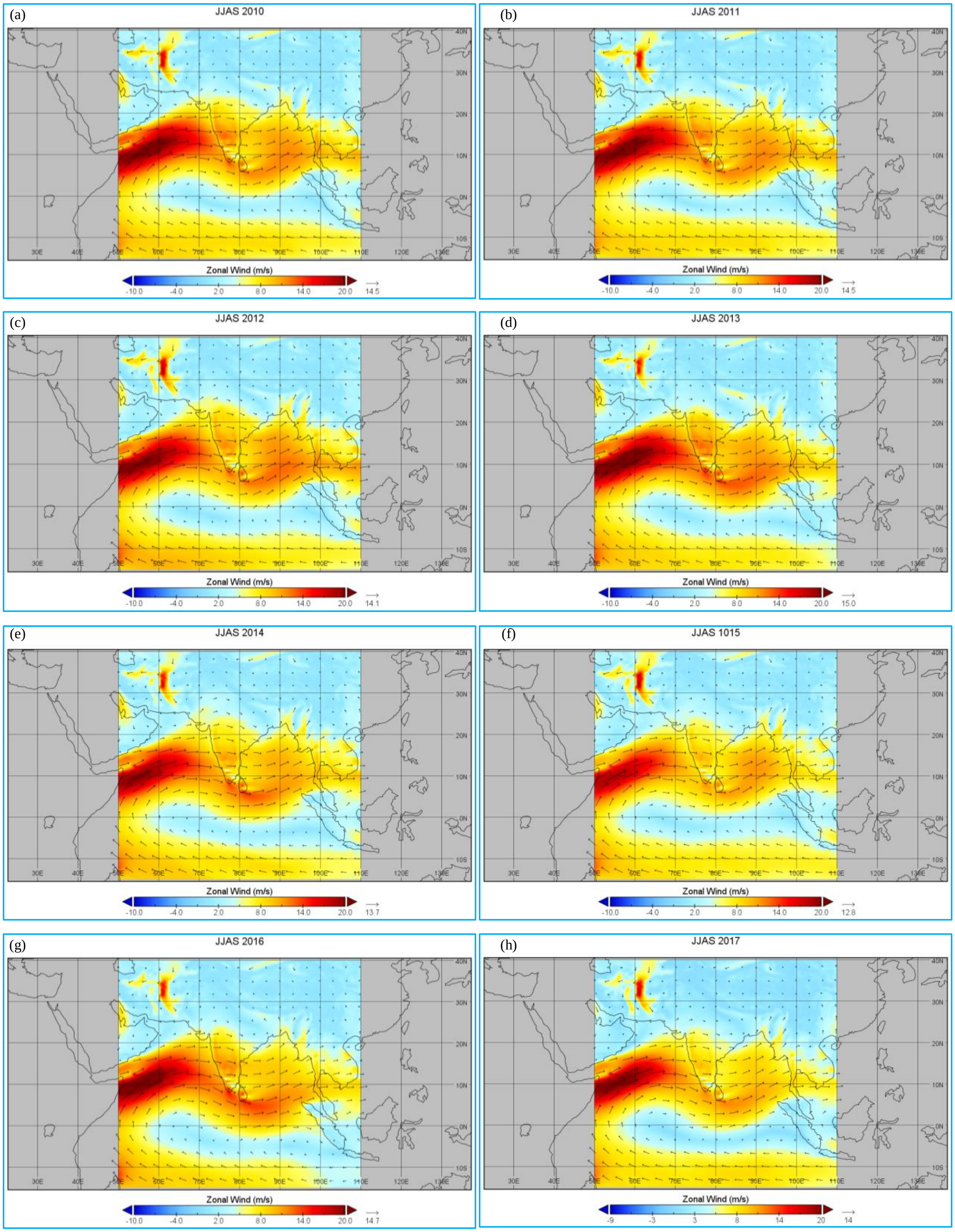
(g)



(h)



Figs. 1(a-h). (a) Daily OLR progression series of monsoon season (June to September) for the year - 2010 (b) same as (a) for the year 2011 (c) same as (a) for the year 2012 (d) same as (a) for the year 2013 (e) same as (a) for the year 2014 (f) same as (a) for the year 2015 (g) same as (a) for the year 2016 (h) same as (a) for the year 2017



Figs. 2(a-h). (a) ERA-5 850 hPa seasonal mean wind flow (JJAS) for the year 2010 (b) same for the year 2011 (c) same for the year 2012 (d) same for the year 2013 (e) same for the year 2014 (f) same for the year 2015 (g) same for the year 2016 (h) same for the year 2017

TABLE 1(a)

Onset date of Monsoon (2010 to 2017)

Year	Actual Onset Date	Forecast Onset Date
2010	31st May	30th May
2011	29th May	31st May
2012	5th June	1st June
2013	1st June	3rd June
2014	6th June	5th June
2015	5th June	5th June
2016	8th June	7th June
2017	30st May	1st June

Press Information Bureau report, Ministry of Earth Sciences (MoES) (https://pib.gov.in/newsite/PrintRelease.aspx?relid=121749).

TABLE 1(b)

The seasonal rainfall statistics (2010-2017)

Year	Rainfall (mm)	% Departure
2010	911.1	3 %
2011	901.3	2 %
2012	823.9	-7%
2013	937.4	6%
2014	781.7	-12%
2015	765.8	-14%
2016	864.4	-3%
2017	887.5	-5%

Source: Envi Stats India-2018, Ministry of Statistics and Program Implementation-2018.

and cloudiness and is spatially modulated with the changes in cloud top temperature. In general, 2010 was the warmest year since 1901 with mean temperature was +0.53 °C above normal and the rainfall for the country as a whole was normal with actual 121.5 cm against Long Period Average (LPA) 119.7 cm. Seasonal rainfall during the south west monsoon season was 102 % of its LPA of 89 cm against the normal contribution of 75 % of the total rainfall of the country.

Throughout the year-2010, the north Indian Ocean witnessed the formation of eight cyclonic disturbances (depression & above) which was far below the normal of 13 disturbances. However, five cyclones formed during 2010 which is the first such year after 1998 when six cyclones formed. There was no depression during monsoon season. Fig. 1(a) of OLR data series derived from Kalpana-1 satellite data shows distribution of convection or cloudiness throughout the year - 2010. It is seen from the figure that even in the beginning of June, 2010 the northward convection building up between (10° N to 20° N) was not so prominent; it may be attributed to the fact that country faced almost dry winter and dry summer season with more number of warmer days than normal. Therefore, Intertropical Convergence Zone (ITCZ) activities were not so active as seen from the higher values of the OLR in Fig. 1(a).

For the year of 2011 the OLR distribution is shown in Fig. 1 (b). The entire monsoon season of the year 2011 witnessed 4 depressions and 10 Low Pressure Area formed and withdrawal were delayed 3 weeks & commenced on 23rd September, 2011 from west Rajasthan. Year 2011 was a good monsoon year and this was shown northward evolution of convection in daily OLR values in Fig. 1(b). It is seen from the comparison of Figs. 1(a&b) that overall distribution of OLR during the year 2011 (or region of MCZ) was more organised as compared to the year 2010. The ITCZ was active almost throughout the year 2011 and it was clearly depicted as having low OLR values near the equatorial belt (5 °N to 5 °S).

4. Normal feature of monsoon

It is well known that the south west monsoon season is associated with the seasonal reversal of wind pattern. Based on the known fact the normal date of monsoon onset over Kerala is 1st June and then it continues to cover the entire country from south to north and from east to west. Once arrived in Kerala, it also covers parts of its adjacent states like Tamil Nadu and Rayalaseema and also some parts from northeastern states like Tripura, Nagaland, Manipur and Mizoram. By 5th June, monsoon covers parts of Karnataka, Andhra Pradesh and reaches to south Maharashtra and entire north east India. Monsoon advances up to Mumbai along with regions from West Bengal, Sikkim, Assam, Meghalaya and most parts of Arunachal Pradesh around 10th June. It covers further north and northwest parts of the country (parts of Gujarat and Kutch, Madhya Pradesh, Bihar and east Uttar Pradesh) by 15th June. On 1st July, monsoon advancement takes place over most parts of east Rajasthan, Punjab,

TABLE 1(c)

OLR distribution

Year	OLR range (watt/m^2)	Latitude range	June	July	August	September	Total
2010	190-210/210-230/230-250/250-270	-5° N -10° N	1/1/2/3/1=8	0/2/2/1=5	1/2/2/2=7	0/4/2/0=6	26
	190-210/210-230/230-250/250-270	10° N-25° N	1/1/1/0=3	0/0/1/0=1	2/1/2/0=5	0/4/1/1=6	15
	190-210/210-230/230-250/250-270	25° N - 35° N	0/1/1/1=3	0/0/1/0=1	1/1/1/1=4	0/1//1/0=2	10
2011	190-210/210-230/230-250/250-270	-5° N-10° N	0/1/2/1=4	0/1/3/1=5	0/1/4/3=8	0/5/2/1=8	25
	190-210/210-230/230-250/250-270	10° N - 25° N	2/0/0/0/=2	2/2/1/0=5	4/2/1/0/=7	1/1/2/0=4	18
	190-210/210-230/230-250/250-270	25° N-35° N	0/0/1/0=1	0/0/1/1=2	0/0/0/1=1	0/0/1/0=1	5
2012	190-210/210-230/230-250/250-270	-5° N-10° N	0/4/2/0=6	0/2/3/1=6	0/2/2/1=5	0/3/3/1=7	24
	190-210/210-230/230-250/250-270	10° N-25° N	0/2/1/0=3	0/3/2/1=6	0/2/3/2=7	0/3/1/0=6	22
	190-210/210-230/230-250/250-270	25° N-35° N	0/0/0/1=1	0/0/0/1=1	0/1/1/0=2	0/1/0/0=1	5
2013	190-210/210-230/230-250/250-270	-5° N-10° N	1/3/2/1=7	3/2/1/1=7	0/3/2/1=6	0/4/3/1=8	28
	190-210/210-230/230-250/250-270	10° N-25° N	0/2/1/0=3	1/2/1/0=4	0/2/3/0=5	0/2/2/0=4	16
	190-210/210-230/230-250/250-270	25° N-35° N	0/0/0/1=1	0/0/1/0=1	0/0/2/1=3	0/0/0/0=0	5
2014	190-210/210-230/230-250/250-270	-5° N-10° N	2/2/1/0=5	1/2/1/1=5	0/5/1/0=6	0/1/2/1=4	20
	190-210/210-230/230-250/250-270	10° N-25° N	0/2/1/0=3	0/4/0/1=5	0/2/0/1=3	0/2/1/0=4	15
	190-220/210-230/230-250/250-270	25° N-35° N	0/0/0/1=1	0/0/0/1=1	0/0/1/1=2	0/1/1/0=2	6
2015	190-210/210-230/230-250/250-270	-5° N-10° N	0/2/3/2=7	1/1/0/0=2	2/3/1/2=8	0/1/1/0=2	19
	190-210/210-230/230-250/250-270	10° N-25° N	0/1/2/2=5	0/0/1/0=1	2/3/1/1=7	0/2/0/0=2	15
	190-220/210-230/230-250/250-270	25° N-35° N	0/0/0/1=1	0/0/1/0=1	1/1/0/0=2	1/1//1/0=3	7
2016	190-210/210-230/230-250/250-270	-5° N-10° N	1/2/2/0=5	0/2/1/0=3	0/2/2/0=4	0/4/2/1=6	19
	190-210/210-230/230-250/250-270	10° N - 25° N	0/1/1/0=2	0/3/1/0=4	0/4/1/0=5	0/1/2/0=3	14
	190-210/210-230/230-250/250-270	25° N-35° N	0/0/0/1=1	0/0/2/0=2	0/2/2/0=4	0/0/0/1=1	8
2017	190-210/210-230/230-250/250-270	-5° N-10° N	0/3/1/1=5	1/3/1/0=5	0/2/3/0=5	0/3/1/2=6	21
	190-210/210-230/230-250/250-270	10° N-25° N	0/2/2/0=4	0/3/1/0=4	0/3/2/0=5	0/3/1/0=4	15
	190-210/210-230/230-250/250-270	25° N-35° N	0/0/0/2=2	0/0/2/1=3	0/2/2/1=5	0/0/0/2=2	12

Haryana, Delhi, Uttarakhand, west Uttar Pradesh, and Jammu and Kashmir. Climatologically, the southwest monsoon covers the entire country (remaining parts of northwest India) by 15th July (Pai *et al.*, 2020). The 850 hPa monsoon season mean wind pattern (m/sec) from ERA-5 data set of 25 × 25 km resolution data sets are generated and shown in the Figs. 2 (a-h). The onset and actual rainfall departure statistics are given in the Tables 1(a&b) respectively. The onset was forecasted based on the IMD objective criteria and progress was monitored based on the observed rainfall as per the existing observational network. Therefore an attempt was made to understand the convection surges evolved, progressed or dissipated meridionally with the help of OLR data. It is because moist winds from the surrounding seas increase the humidity in the atmosphere. Both the temperature and humidity influence the cloud formation over the monsoon region. The proxy of convection OLR represents convective activity, which is the basis for cloud formation.

In Fig. 1(c), Kalpana-1 OLR propagation mode shows slightly different behaviour as compared to years 2010, 2011 and during the month of June, 2012 the OLR values were slightly higher (5° N to 20° N) till mid of July accept one or two monsoon surges at the end of July. Low OLR values can be considered as proxy of MCZ development and at the end of July Fig. 1(c) with a periodicity of about 30 days of this new monsoon surge and which is the crucial period for agriculture (sowing).

To calculate the contribution OLR in deep convective and non-deep convective of westward propagation in ITCZ region based on the threshold (205 watt/m^2) suggested by Gu and Zhang, 2002, thresholds especially in Indian domain we need to take larger data sets of different years in future. The differences of periodicity in the evolution of convection throughout the year in different seasons may be attributed to the occurrence of different types of weather systems in each season. Work is in progress to make such thresholds for the south west monsoon season over the Indian region. In this work we have analysed northward propagation of OLR modes and every monsoon season has a different periodicity of epochs.

For monitoring the northward propagation of convention OLR data (watt/m^2) was grouped in four ranges 190-210/210-230/230-250/250-270 as demarcation of very severe, severe, moderate and weak convection at three ranges of latitudes (-5° N - 10° N, 10° N- 25° N & 25° N- 35° N) for the monsoon seasons 2010 - 2017 [Table 1 (c)]. In Tables 1(a&b) the monsoon onset dates and overall seasonal rainfall departure is given for examining the nature of the monsoon season. We know from the data that the years 2010, 2011 and 2013 were normal monsoons. Current OLR analysis shows that the number of epochs of very severe and severe convection have 18, 14 & 22 respectively. Hence, depending on the epochs of each month of monsoon season year to year northward convection propagation was different.

It is found that if the epochs' weak OLR are more (in 2014-19 epochs, 2015-8 epochs, 2014-7 epochs) than overall seasonal rainfall shows negative departure from actual, however it is not always true. It is because the rainfall occurrences are a complex process and depend on the interactions of other monsoon elements. 850 hPa seasonal wind speed analysis derived from ERA-5 model data support the idea that if the flow is strong and organized then rainfall also behaves in the same manner. During the year 2015 the areal extent and distribution of Arabian Sea branch mean wind flow was not as strong as other years' monsoon flow [Fig. 2(f)].

5. Concluding remarks

Spatial distribution of OLR shows that lower values of OLR are indicative of strong convection and therefore OLR propagation modes with time provide a broad view of time series of convection distribution. Monsoon is a global phenomenon and its dynamics is coupled with convection & cloud evolution, growth and decay mechanism. Therefore, current study can only reveal the idea of convection movement with time at different years of monsoon season. Its assimilation in regional as well as climate models definitely improve the predictive understanding of convection coupling of land and atmosphere. INSAT OLR captures well about MCZ development and therefore the variability (intra-seasonal and inter-annual) which can further help for planning and managing water resources, agriculture and disaster management for societal benefit. Daily Operational generation of these products will improve operational forecast and prediction skill of the forecasters. GuGuojun and Zhang Chidong, 2002, used OLR threshold of 205 watt/m^2 to distinguish deep convective clouds from non-deep clouds and he decomposed ITCZ into 5 components to study the convective propagation of clouds and contains about 40-50 % total cloud signals in the ITCZ. Therefore, ITCZ weak and strong activeness depends on the westward and eastward zonal movement of clouds present in ITCZ. Figs. 1(b-h) comprises the distribution of daily mean OLR and their northward propagation which consists of trails of deep convective and weak convective clouds in the ITCZ domain throughout the year. It has been observed that 2010, 2011, and 2012 have different convective signals in the (5° N to 20° N) domain. Year 2011 has more weak convective strength (> 205 watt/m^2) signals during pre-monsoon season as compared to 2010 & 2012. Similarly, monsoon season for all the three years has an association of weak and strong trails of convection depending on the threshold (205 watt/$m^{2)}$. From Fig. 1(b), the strong signals are easily captured in the horizontal distribution of OLR of different years.

It is found that weak OLR are more than seasonal rainfall departure is negative than normal. Similarly, if very severe and severe epochs are present in more numbers then rainfall departure of the season was found positive. It means that MCZ was more organized in normal or excess rainfall monsoon years as compared to deficient monsoon years. 850 hPa seasonal wind speed analysis derived from ECMWF reanalysis 5th generation (ERA-5) model data support the idea that if the flow is strong and organized then rainfall also behave in the same manner.

The MCZ evolution, propagation and dissipation will be different mesoscale convective systems, synoptic scale systems, cyclone development, monsoon lows, monsoon depressions *etc*, and their periodicity and northward as well as horizontal spread. Differences can be seen clearly in Figs. 1&2 (a-h). Another reason for varying periodicities of OLR propagation/amplification modes linked with the interaction of other monsoon elements, like low level jet, Tibetan High, Mascarenes High, Cross equatorial flow and dry and moist static stability and their cooperative interaction with lower troposphere over India. In this work this type of interaction was not studied. This wave-like pattern of OLR is not continuous and depends on the complex interaction of ocean, land and atmosphere and it is seen in Figs. 1& 2(a-h) as higher values of OLR or different colour shades.

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