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Role of equatorial Indian Ocean convection on the Indian summer monsoon

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सार – ग्रीष्मकालीन मॉनसून लाखों लोगों के साथ-साथ महाद्वीपीय भारत के जैव मंडल के लिए जीवन रेखा है। यह ताजा वर्षा जल से भूमि के जल स्रोतों की भरपाई करता है। इस अध्ययन में हमने अखिल भारतीय ग्रीष्मकालीन मॉनसून वर्षा और भूमध्यरेखीय हिंद महासागर के ऊपर वायुमंडलीय संवहनीय प्रक्रियाओं की आवृत्ति के संबंध के बारे में चर्चा की है। हमने भूमध्यरेखीय हिंद महासागर के ऊपर मॉनसून की विशिष्ट प्रकृति देखी है जो महाद्वीपीय भारत में ग्रीष्मकालीन मॉनसून वर्षा की भिन्नता को दर्शाता है। महाद्वीपीय भारत में मॉनसून की इस विशिष्ट प्रकृति में महत्वपूर्ण बदलाव सूखे मॉनसून और अच्छे मॉनसून के दौरान देखा जाता है। महाद्वीपीय भारत की वर्षा के साथ भूमध्यरेखीय हिंद महासागर (EIO) की संवहनीय प्रणालियों और उत्तरी हिंद महासागर (NIO) की सिनॉप्टिक प्रणालियों की भूमिका भी देखी गई है। मासिक सिग्नल के साथ अंतरा मौसमी अर्धसाप्ताहिक सिग्नल विलय और उच्च आयाम के संचयी सिग्नल के परिणामस्वरूप महाद्वीपीय भारत में खराब मॉनसून की स्थिति बनी। अर्धसाप्ताहिक और मासिक निजी सिग्नल की लगातार घटना के फलस्वरूप महाद्वीपीय भारत में मॉनसून वर्षा की अच्छी स्थिति बनी।

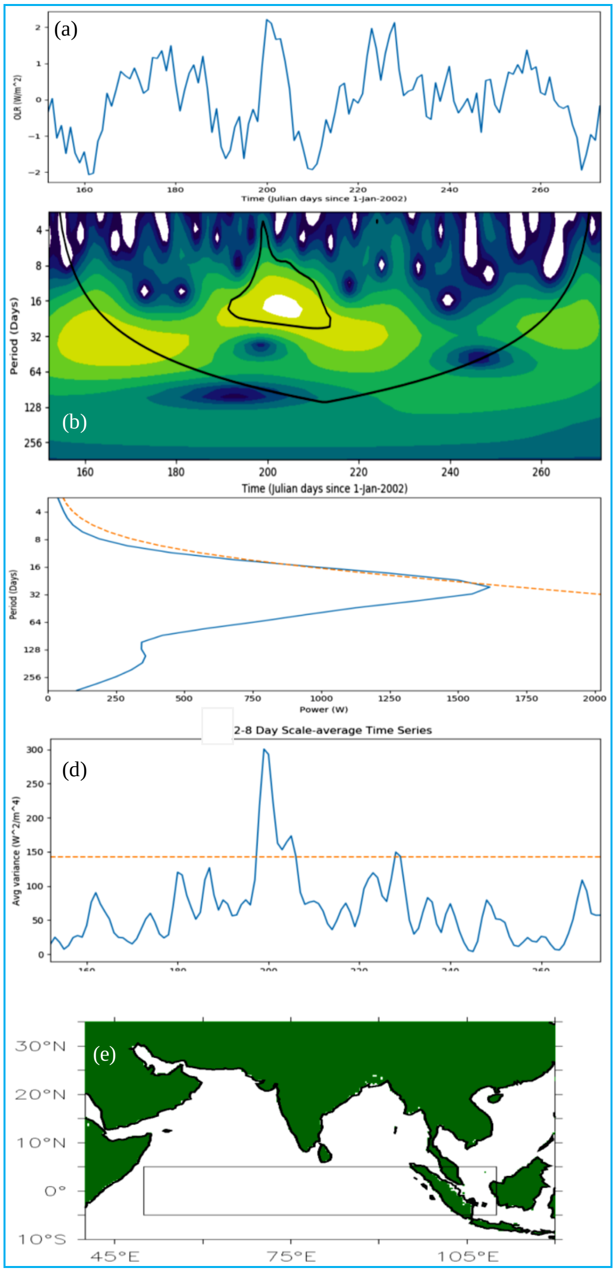
ABSTRACT. The Summer Monsoon is the life line of millions of people as well as for the biosphere of continental India. It replenishes the in-land water sources with fresh rain water. In this study we have discussed about the relation between the All India summer monsoon rainfall and the frequency of atmospheric convection processes over the equatorial Indian Ocean. We have noticed a signature of monsoon over equatorial Indian Ocean which reflecting the variation of summer monsoon rainfall over continental India. A significant change in the signature of monsoon is observed during a drought monsoon and a good monsoon over the continental India. It is also observed that the role of Equatorial Indian Ocean (EIO) convection and synoptic systems over Northern Indian Ocean (NIO) with the continental India rainfall. An intraseasonal biweekly signal merging with monthly signal and forming cumulative signal of high amplitude which results a poor monsoon condition over continental India. The consecutive occurrence of biweekly and monthly individual signals leading to a good monsoon rainfall condition over continental India.

Key words – Summer monsoon, Equatorial Indian Ocean, convection, North Indian Ocean, Synoptic systems.

1. Introduction

As India is an agricultural country and farming is the occupation of its majority population, the summer monsoon rainfall research has the Mount Everest priority. The summer monsoon rainfall is the source of fresh water supply to the entire farming activities in India as well as in south Asian countries during June, July, August and September months (or JJAS season). The continental rainfall over India is highly influenced by (*i*) Movement and Position of ITCZ, (*ii*) Synoptic systems formed over the Northern Indian Ocean (NIO) and (*iii*) Equatorial Oscillations [Biweekly & monthly Maddan Julian Oscillations (MJO)]. In this present work the convection processes over equatorial Indian Ocean is analyzed to understand the relation with rainfall over the continental India on intra-seasonal scale. In this study, the Outgoing Long wave Radiation (OLR) is analyzed over a region 50° E to 110° E and 5° S to 5° N [Fig. 1(e)]. The intraseasonal oscillations (ISO) such as the eastward propagating Madden Julian Oscillations (MJOs) and the northward propagating monsoon Intraseasonal Oscillations (ISOs) with period in the range of 30 to 60 days are quite vigorous in the tropics. Both the MJOs as well as the monsoon ISOs are known to be driven by internal feedback between convection and dynamics (Ajaya Mohan and Goswami, 2003). A fresh elongated narrow band of convection formed close to the equator, grows rapidly in intensity and area and bringing about the monsoon onset over Kerala [Preenu *et al*. (2017)].

Goswami and Ajayamohan (2001) showed that the intraseasonal and interannual variability of the summer



Figs. 1(a-e). In this figure the wavelet spectrums are representing (a) OLR normalized by standard deviation (b) Wavelet Power Spectrum and (c) Global Wavelet Spectrum, where the dashed red line indicates the 95% significance level (d) Band averaged time series for 2-8 days, where the dashed red line indicates the 95% significance level and (e) the region of OLR analysis over the Equatorial Indian Ocean (top to bottom) respectively

monsoon are governed by a common mode of spatial variability. They further showed that strong (weak) monsoon is characterized by higher probability of occurrence of active (break) conditions. Indian summer monsoon is known to have vigorous ISOs having time scales between 10 and 90 days that arise essentially due to internal dynamics of the atmosphere (Yasunari, 1979, 1980; Sikka and Gadgil, 1980; Krishnamurti and Bhalme, 1976; Krishnamurti and Subrahmanyam, 1982).

Intraseasonal oscillation with period of about 15-30 days and 30-60 days are seen in the middle level and upper level water vapour over the East Arabian Sea (Simon *et al*., 2003). Low frequency (10-50 day) ISO of the South Asian summer monsoon are associated with episodes of large scale organised atmospheric convection, often marked by cloud bands moving northward over the warm northeast Indian Ocean and over land (Sikka and Gadgil, 1980; Webster *et al*., 1998). Over the tropical ocean, OLR is a proxy for convection. High values of OLR indicate clear skies whereas low OLR comes from high clouds with cold tops. Broadly, the low frequency variability of the monsoon atmosphere is an alternation between two phases a quiescent phase, when it is clear and calm and a convectively active phase, when it is cloudy and windy (Sengupta and Ravichandran, 2000). The poor predictability of the Indian summer monsoon (ISM) appears to be due to the fact that a large fraction of interannual variability (IAV) is governed by unpredictable ‘internal’ low frequency variations (Goswami and Xavier, 2005). The mean albedo over the south Bay of Bengal under clear, partly cloudy and overcast skies are found to be 0.05, 0.07 and 0.2 respectively (Gopala Reddy *et al*., 2003). (Sanikommu Sivareddy *et al*., 2015) Simulated zonal currents from DTS (DASCAT forcing) and QTS (QSCAT forcing) experiments are reasonably accurate in the eastern Equatorial Indian Ocean location of 90° E, 1.5° N. At the 90° E equator location, simulated zonal currents from QTS are much stronger than the observations during pre-monsoon and post-monsoon season.

In the present study attempts have been made to establish the relation between the intraseasonal oscillations over the equatorial Indian Ocean and continental rainfalls by analyzing the Fast Fourier Transform (FFT) signal of Outgoing Long wave Radiation (OLR) over Equatorial Indian Ocean region 50° E to 110° E and 5° S to 5° N [Fig. 1(e)]. The Morelet wavelet analysis also done for understanding the relation between frequency of Equatorial convection process to continental rainfall. The wavelet spectrum of OLR at Equatorial Indian Ocean during the year 2002 is given below.

2. Data

In this study the uninterrupted Outgoing Long Wave Radiation data for about 14 years (*i.e.*, from 2002 to 2015) is used to analyze the equatorial processes. The OLR data is freely available in website http://www.ncep.ncar.gov.in.

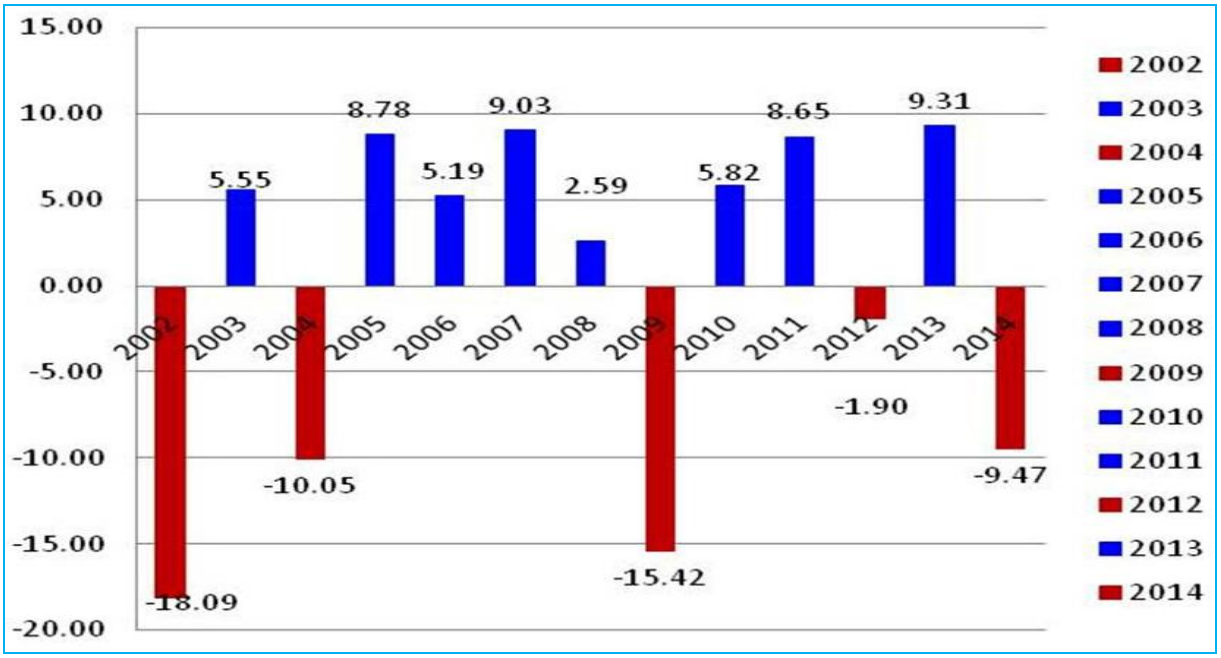


Fig. 2. The All India summer monsoon season (Jun-Sep) rainfall anomalies from year 2002 to 2014

TABLE 1

The Julian day of the each JJAS season and the corresponding synoptic systems are listed in the table. In 5th, 6th, 7th and 8th columns D-Depression, DD - Deep depression, CS - Cyclonic storm, SCS - Severe Cyclonic Storm, VSCS - Very Sever Cyclonic Storm and LD - Land depression/Deep depression A - Arabian Sea, B - Bay of Bengal, W(1, 2, 3, 4, 5) - week of the month respectively

S. No.	JJAS Julian Days			LPS during JJAS season			
	Year	1-Jun	30-Sep	June	July	August	September
1.	2002	152	273	-	-	-	-
2.	2003	517	638	-	DD(B)	D(B)	-
3.	2004	883	1004	DD(A-w2), DD(B-w3)	-	-	LD(w3)
4.	2005	1248	1369	D(A-w4), LD(w4)	DD(B-w4)	-	D(B-w3), D(A-w3), CS(B-w3)
5.	2006	1613	1734	-	DD(B-w1)	DD(B-w1), D(B-w2), D(B-w3), D(B-w5)	D(B-w1), LD(w4), SCS(A-w4),D(B-w5)
6.	2007	1978	2099	SCS(A-w1), CS(B-w4), DD(B-w5)	DD(B-w1 &w2)	DD(B-w1)	D(B-w4)
7.	2008	2344	2465	D(A-w1), D(B-w3)	-	LD(w2)	DD(B-w3)
8.	2009	2709	2830	D(A-w4), D(A-w4)	DD(b-w3)	-	DD(B-w1)
9.	2010	3074	3195	VSCS(A-w1)	-	-	-
10.	2011	3439	3560	D(A-w2), DD(B-w3 & w4)	LD(w4)	-	D(B-w4)
11.	2012	3805	3926	-	-	-	-
12.	2013	4170	4291	-	D(B-w5)	LD(w3 & w4)	-
13.	2014	4535	4656	CS(A-w2)	LD(w3 & w4)	LD(w1)	-
14.	2015	4900	5021	CS(A-w2), D(B-w3), DD(A-w4)	LD(w2), CS (JA-B-w4,5,1), LD (w4 & w5)	LD(w1)	LD(w3)

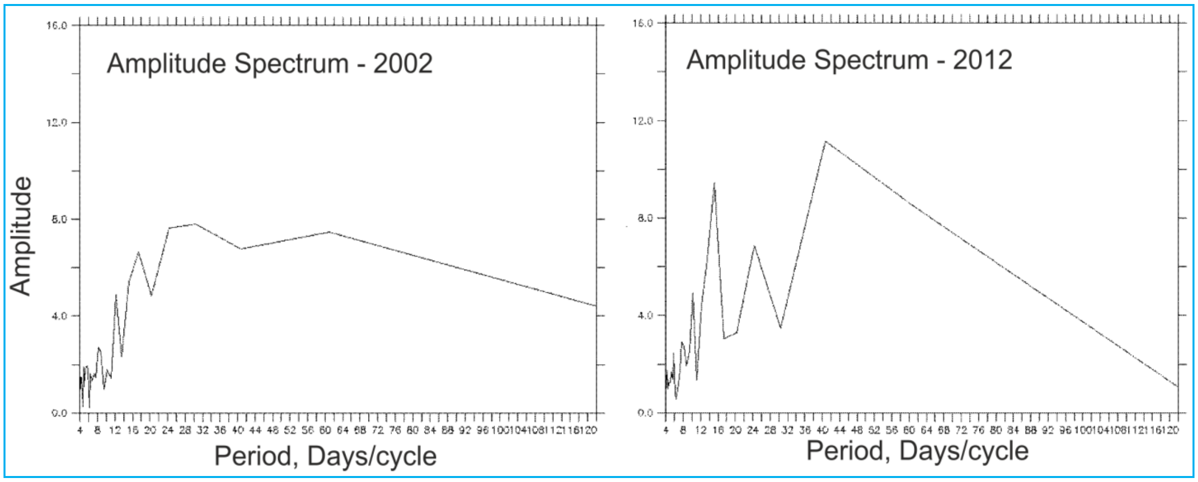


Fig. 3. The FFT signal of Equatorial Indian ocean convection signals of JJAS season for two monsoon years 2002 (left) and 2012 (right) are shown

Rainfall over the continental India is taken from the Indian Meteorological Department (IMD) developed high resolution 0.25° × 0.25° gridded data set (Pai *et al*., 2010). The Details of Julian days of each season and the corresponding synoptic systems over North Indian Ocean are shown in the Table 1.

3. Results and discussion

In this present work the Equatorial convection processes over Indian Ocean was analyzed for about 14 years (*i.e*., from 2002 to 2015). The Indian summer monsoon rainfall is also analyzed for the 13 years (*i.e*., from 2002 to 2014 JJAS seasons) period to find the influence of equatorial convection on summer monsoon rainfall. The All India summer monsoon rainfall anomalies for year 2002 to 2014 are taken using the 13 years JJAS rainfall average. Out off 13 years there are 5 years with negative anomalies and the remaining years with positive anomalies. From the anomaly analysis it is clear that there is a poor monsoon rainfall occurred during the year 2002, 2004, 2009 and 2014 (Fig. 2).

The Fast Fourier Transform signal of OLR over the region 50° E to 110° E and 5° S to 5° N during summer monsoon season (JJAS) of 14 years revealed that, the weekly biweekly and monthly signals have a crucial role in the continental rainfall. The FFT signals of active monsoon seasons at Equator are in the amplitude of 2-10 and their duration over equator are very less, such as in the year 2011, 2012 and 2013 (Fig. 3). Whereas in a break monsoon year the FFT signals are strong at equator and having a prolong duration with cumulative amplitude or absence of signal is observed such as in the year 2015, 2009 and 2002 (Fig. 3).

The sequence of biweekly signals has significant role in the JJAS continental rainfall. The wavelet power spectrum reveled the importance of biweekly signals their sequence and duration over equator. The wavelet power spectrum of 2012 shows the sequence of biweekly signals over Equatorial Indian Ocean (EIO). The short duration monthly convection signals (MJO) over equator are also provide good amount of rainfall over continental India. The year 2012 is an active monsoon year without any synoptic disturbances in the North Indian Ocean (NIO). The rainfall over continental India during JJAS season is mainly due to ISO or synoptic systems over NIO. The Absence of synoptic systems during the JJAS season itself proving that the rainfall is due to convection over EIO. The thunderstorms are minor scale systems and their contribution in the JJAS season ISM rainfall is minimal. Hence the rainfall can be considered as the result of pure Intraseasonal Oscillations (ISO). Generally the synoptic disturbances over NIO act as complimentary rainfall systems for continental India. Most of the severe cyclones are forming over the Upper Ocean Heat Content range between 40-80 kj/cm^2 in the Bay of Bengal (Maneesha *et al*., 2015). It is found that variations in heat flux play an important role in SST cooling over the central and eastern equatorial Indian Ocean, Bay of Bengal and part of Arabian Sea from late winter to early summer during the decay phase of La Nina (Bhavani *et al*., 2017). Under a La Niña regime, the convective activity and low-level cyclonic vorticity associated with MJO phases 2-6 are very strong in the Bay of Bengal (BOB) compared to the an El Niño regime (Girishkumar and Ravichandran, 2012). The relatively higher heat content within the higher Effective Oceanic Layer region would help in the deep-convection and affects the Outgoing Long wave Radiation (Murty *et al*., 2002). The strong high energetic and long lasting signals over EIO are leads to monsoon break situation like year 2015 (Fig. 4).

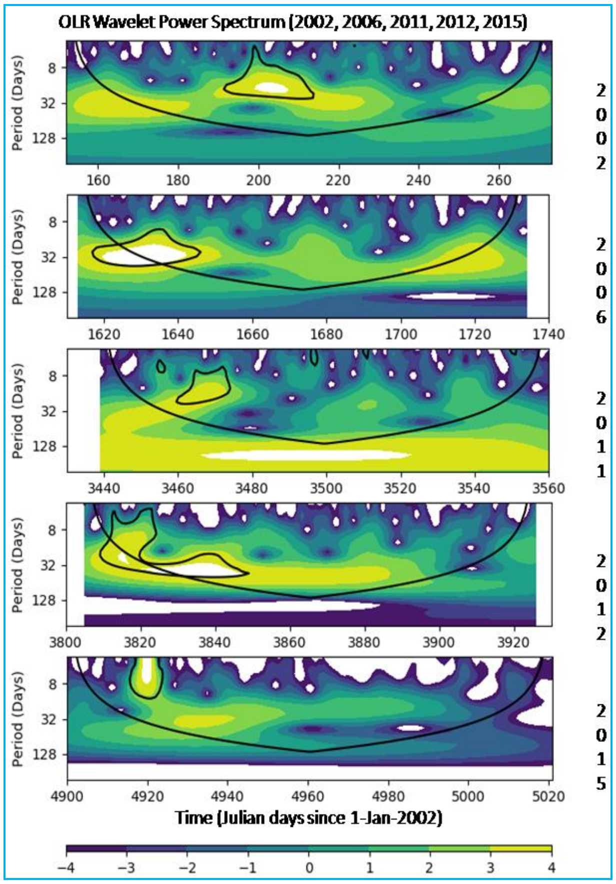


Fig. 4. The Wavelet Power Spectrum of 2002, 2006, 2011, 2012 and 2015 are shown. The dark black line indicates the 95% significance level

The Absence of both the EIO signals and synoptic systems over NIO/Indian Land will leads to monsoon break and results drought such as year 2002. Over lapping of EIO convection signals (biweekly and MJO) and synoptic systems over NIO/Indian land will leads to excess of rainfall and results floods. Thus, the summer monsoon rainfall over the continental India is the result of North ward propagation of convection oscillation over the EIO and Low pressure systems over Indian land/NIO. The role of weekly oscillation signals over EIO is needed to be analyzed with some enhanced methods in order to understand the monsoon rainfall in detail over the continental India.

4. Conclusions

The biweekly and monthly convection signals over EIO with a short life time and amplitude of 2-10 and in a regular sequence will give continuous and good amount of rainfall over continental India like year 2012. The absence/long lasting of signals with cumulative amplitudes over EIO will lead to reduction of rainfall over continental India and it is frequently complimented by the synoptic system over the NIO/Indian land and mitigates the reduction. The absence of both signals over EIO and synoptic systems over NIO/Indian land will lead to reduction of rainfall and results drought situation over Indian Land. The over lapping of convection signals over EIO and synoptic systems over NIO/Indian land leads to heavy rainfall over continental India and causes floods.

List of all Acronyms

NIO	Northern Indian Ocean
MJO	Madden-Julian Oscillation
OLR	Outgoing Long-wave Radiation
ISO	Intra Seasonal Oscillation
ISM	Indian Summer Monsoon
DTS	DASCAT forcing
QTS	QSCAT forcing
FFT	Fast Fourier Transform
JJAS	June-September period (4months)
LPS	Low Pressure System
D	Depression
DD	Deep Depression
LD	Land Depression
CS	Cyclonic Storm
SCS	Sever Cyclonic Storm
VSCS	Very Severe Cyclonic Storm
IMD	Indian Meteorological Department
EIO	Equatorial Indian Ocean
SST	Sea Surface Temperature
BOB	Bay of Bengal

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