The Intraseasonal Fluctuation of Indian Summer Monsoon Rainfall and its Relation with Monsoon Intraseasonal Oscillation (MISO) and Madden Julian Oscillation (MJO)

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Research Article

Keywords: Intraseasonal oscillation, MISO, MJO, phase composite

DOI: https://doi.org/10.21203/rs.3.rs-432059/v1

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**Abstract**

The intra-seasonal fluctuations of Indian summer monsoon rainfall (ISM) are mainly controlled by northward propagating Monsoon Intra-seasonal Oscillation (MISO) and eastward propagating Madden Julian Oscillation (MJO). In the current study, we examine the relationship between the intra-seasonal fluctuations (active and break spells) of ISM with the phase propagation and amplitude of MISO and MJO. We notice that active spells generally occur during MISO phase 2–5 (MJO phase 3–6), and break spells mainly occur during MISO phase 6–8 (MJO phase 6–8 and 1). The association of active/break spells with MISO phases is more prominent than with MJO phases. We show the phase composite of unfiltered and regression based reconstructed rainfall for eight MISO and MJO phases, and the same is consistent with the earlier findings. We notice that the reconstructed field shows a systematic and well-organised northward propagation compared to the unfiltered field. Phase composite also indicates that there is a lead-lag relationship between MISO and MJO phases. MISO phase composite shows more robust northward propagation than the MJO phase composite. MISO reconstructed rainfall explained more percentage variance than MJO reconstructed rainfall with reference to 20–90 days filtered rainfall. It is found that long active (>7 days) predominantly occurs when either MISO or MJO, or both of them are active, and the associated signal is somewhere in between phase 2–5. A long break occurs when either one or both of them are feeble, or even though associated signals are strong, they are primarily located in phases 1, 6, 7 and 8.

**1. Introduction:**

In recent years much attention is being paid towards intraseasonal prediction as it fills the gap between synoptic weather scale and seasonal scale. The intraseasonal prediction has a wide range of applications over many sectors, such as agriculture, health, hydrology, and power (Pattanaik et al. 2019). Out of these different sectors, it has one of the most significant roles in the agricultural sector as the Indian economy is highly interlaced with agriculture. Although the majority of the rain occurs over the Indian mainland during June to September (JJAS), it has a sizeable spatio-temporal variability within the season. Skilful prediction of this intraseasonal variability could help in decision making in the agricultural sector, such as planting schedule, harvesting crop, fertiliser application, etc. (Meinke and Stone, 2005). The daily time series of standardised rainfall anomalies averaged over the core monsoon zone for Indian summer monsoon 2015 (JJAS) prominently show the intraseasonal fluctuations during the season (Refer Fig. 1). This fluctuations, i.e., above normal (below normal) rainfall activity over the core monsoon zone is known as the active (break) spell of the Indian summer monsoon (Annamalai and Slingo, 2001; Gadgil and Joseph, 2003; Rajeevan et al., 2010). Prediction of these active and break spells (occurrence of the spell and their duration and intensity) at the adequate lead time (at least 2–4 weeks lead) has immense socio-economic importance. The prediction of intraseasonal variability is related to several factors and the predictability primarily arises due to the low frequency oscillations during boreal summer. Many researchers (Goswami, 2005; Lawrence and Webster, 2002; Sikka and Gadgil, 1980; Yasunari, 1979) have reported that low frequency intraseasonal fluctuations over the Indian monsoon region are largely
controlled by two dominant modes of variability: (a) the convectively coupled, planetary scale, eastward propagating MJO (Hendon and Salby, 1994; Madden and Julian, 1994, 1972; Salby and Hendon, 1994) and (b) the northward propagating MISO (Lau and Chan, 1986; Sikka and Gadgil, 1980; Wang et al., 2005). These two are the most dominating modes of intraseasonal oscillation. MISO exists only during boreal summer whereas MJO exists round the year. Although MJO is weak during boreal summer (peaks in boreal winter; Hendon and Salby, 1994; Madden, 1986)), it still influences climate and weather phenomena throughout the year not only limited to the tropics but even in the sub-tropical region (Bond and Vecchi, 2003; Jones, 2000; Matthews, 2004; Mo and Higgins, 1998). During boreal summer, the eastward moving, MJO influences the active-break cycle of the Asian monsoon (Lawrence and Webster, 2002; Yasunari, 1979). However, many studies (Goswami, 2005; Sikka and Gadgil, 1980) have advocated that among different modes of intraseasonal oscillations, the active and break spells of Indian summer monsoon are significantly controlled by the northward propagating 30–60 day mode.

Pai et al. (2011) have studied the association of intraseasonal fluctuations (active/break) of ISMR with the phases of MJO using IMD high-resolution rainfall data and RMM indices of Wheeler and Hendon (2004). They commented that around 83% of the break spells are favoured during MJO phases 1, 2, 7 and 8, and about 70% of the active spells are set in during MJO phases 3–6. Mishra et al. (2017) have also reported similar findings to Pai et al. (2011). Marshall and Hendon (2015) have studied the relationship between the MJO phase and frequency of the active/break days of Australian summer Monsoon. They summarised that active episodes are much more frequent during MJO phases 5–7, and break phase are prevalent during MJO phases 8, 1, and 2 for Australian summer monsoon.

In the current study, we considered the two most dominant modes of intraseasonal oscillation (ISO), namely MJO and MISO, and tried to understand the relationship of Indian monsoon active/break with them. For MJO monitoring, we have used the PCs based on the Extended Empirical Orthogonal Functions (EEOF) analysis of combined fields (velocity potential, zonal wind at 200hPa and 850 hPa) as described in Dey et al. (2019). For monitoring northward propagating MISO, we have utilised the PCs based on Suhas et al. (2013).

2. Data And Methodology:

India Meteorological Department (IMD) gridded high resolution (0.25X0.25) rainfall data (Pai et al., 2014) over Indian land for the period 1998–2018 was used for this study. This data was initially developed up to the year 2010 and later extended for recent years. IMD-TRMM merged gridded rainfall datasets (Mitra et al., 2009) are also utilised wherever we require data beyond Indian land. For dynamical fields, the NCEP-NCAR reanalysis datasets (Kalnay et al., 1996) from 1998–2018 are used. Outgoing long-wave radiation (OLR) datasets from Advanced Very High Resolution Radiometers (AVHRR) aboard NOAA polar orbiting satellites (Liebmann and Smith, 1996) are also utilised for the same period.

2.1 Identification of Active and Break
To identify the active and break days of ISMR, we have calculated daily standardised rainfall anomaly averaged over the core monsoon zone (as proposed by Rajeevan et al. (2010)) based on the 1998 to 2018 period. Active (Break) is identified when the standardised rainfall anomaly averaged over the core monsoon zone is more than 0.9 (less than −0.9) for consecutive four days and the average anomaly over the region during the period crosses 1.2 (less than −1.2). The active and break identification is carried out from 10 June to 15 September because the delayed onset and early withdrawal of monsoon may lead to the misinterpretation of result (Joseph et al., 2009; Krishnan et al., 2000).

3. Results:

3.1. Active and break spell during 1998–2018:

In Table 1, we list the active (left column) and break (right column) spells during the period 1998 to 2018 as identified in the current study. It is evident from Table 1 that no active spell is identified during the years 2010 and 2017, and there are no break spells during the years 2003, 2010, 2011, 2013, and 2016. During the 21 years (1998–2018) study period, we have 34 active (29 break) spells and 193 active (194 break) days. These active and break spells have varying duration. The longest active spell with 17 days duration was identified during 25August – 10September 2011, and the longest break spell of 15 days duration was found during 03–17 July 2002.

3.2. Association of active and break days with MJO and MISO phase:

To examine the association of active and break days with the various phases of northward propagating MISO and eastward propagating MJO, we considered all active (193 days) and break (194 days) days during 1998–2018. We have computed Principal Components (PCs) of MISO, based on Suhas et al. (2013) and PCs of MJO based on Dey et al. (2019) during the study period. We plotted the scatter diagrams of MISO1 and MISO2 (Suhas et al., 2013) in phase space for all active days (Fig. 2a) and break days (Fig. 2b) during 1998–2018. The black circle of a unit radius in Fig. 2a and Fig. 2b delineates strong and weak MISO categories. The frequency of active and break days with the various phases of MISO are shown in Fig. 2c and Fig. 2d, respectively. During frequency computation, we have excluded points that fall inside the unit circle (that represents a weak MISO). Figure 2 indicates that the frequency of active (break) days is high during MISO phases 2–5 (6–8). Strong association/relation between active and break days with the MISO phase is apparent. Figure 3 is similar to Fig. 2 but for the PCs of MJO (based on Dey et al. (2019)). Figure 3 indicates that the frequency of active (break) days is high during MJO phases 3–6 (6-7-8-1). However, it is vital to note that, unlike the MISO case, the association/relation of active/break days with the various MJO phases is not very clear.

3.3. Composite of unfiltered rainfall anomalies for eight MISO and MJO phases:
Figure 4 shows the composite of daily unfiltered rainfall anomalies (mm/day) for eight MISO (Fig. 4a) and MJO (Fig. 4b) phases. It is evident from Fig. 4 that there is a phase lag in the MISO phase composite compared to the MJO phase composite. The phase 1 composite for MISO matches more or less with the phase 2 composite for MJO, and phase 2 composite for MISO matches with the phase 3 composite for MJO, and so on. Phase 1 composite of MISO (phase 2 composite for MJO) shows large negative anomalies over central India and the west coast of India. In contrast, positive anomalies are seen over the southeast and some parts of the northeast region of the country, which is the canonical structure of rainfall associated with break monsoon condition. In Phase 2 composite of MISO (Phase 3 for MJO), we can see the weakening of negative anomalies over the central India region and elongation of positive anomalies from southern parts towards the north. As we move from phase 3 towards phase 5 for MISO (phase 4–5 for MJO), the composite structure shows a systematic northward movement of rain band similar to that of active monsoon conditions (positive anomalies over core monsoon zone and negative anomalies over northeast and southeast part of India). The magnitude of rainfall anomalies is much stronger in the MISO phase composite than the MJO phase composite. Composite structure during phase 6–8 for MISO shows a sudden change in the pattern. Mainly negative anomalies prevail over most of the central India region, resembling the canonical structure of monsoon break. However, for MJO, we do not see such a sudden change in the rainfall pattern during phases 6–8, and changes are prominently seen during phase 1. Therefore, it could be contemplated that MJO phase 6–8 is the phase during which active to break transition happens, during this both active and break occur over Indian. The same is consistent with Fig. 3. In Fig. 5, we show the Hovmoller plot (phase vs latitude) of rainfall anomalies averaged over 65°-90°E for MISO (Fig. 5a) and MJO (Fig. 5b) composite. In the Hovmoller diagram, along the abscissa phase 5–8 (to the left of phase 1–8) and phase 1–4 (to the right of phase 1–8) are repeated for the display of continuity. Although the Hovmoller plot for MISO and MJO phase composite indicates a precise northward movement of the rain band, the signal is much more robust for MISO composite compared to MJO composite.

**3.4. Composite of unfiltered convection and circulation anomalies for eight MISO and MJO phases:**

In the last section, patterns of the rainfall anomalies for various MJO and MISO phases are discussed. Now we examine how these changes are linked with the low-level circulation and convection patterns. We show phase composites of OLR anomalies (shaded; W/m²) and wind at 850hPa anomalies (vector; m/s) for eight different MISO and MJO phases in Fig. 6a and Fig. 6b respectively. Like rainfall composite, here also we notice a lag in the MISO phase composite compared to the MJO phase composite. By and large, OLR and wind composite structures during phase 2–4 for MISO (phase 3–5 for MJO) looks like active monsoon condition whereas during phase 5–8, and 1 for MISO (phase 6–8, 1 and 2 for MJO) resemble like break monsoon condition. In Fig. 7, we show the Hovmoller diagram of the OLR anomalies (shaded; W/m²) and vorticity anomalies at 850 hPa (contour; positive solid and negative dashed; contour interval 1x10⁻⁶ s⁻¹) averaged over 65°-90°E for MISO and MJO composite. From Fig. 7, it may be noted that the centre of cyclonic (anticyclonic) vorticity at the low level is located to the north of negative (positive) OLR
anomalies for both MISO and MJO. This result is persistent with the previous study (Fig. 2.15a of Goswami (2005)) and confirms that both these intra-seasonal oscillations progress and sustain as a convectively coupled system.

### 3.5. MISO and MJO phase composite of the reconstructed field:

We use a regression based reconstruction technique for rebuilding the MISO/MJO filtered field. The leading pair of PCs are utilised to regress any variable to be reconstructed at every grid location. We regress the principal components (PCs) time series of MISO and MJO separately with a pool of past data of the required variables during the JJAS season. This way, we obtain the regression coefficients during JJAS season for any particular variable. These coefficients are then used for reconstructing any specific field \(X\) as follows:

\[
X(x, y, yr, t) = b_0(x, y, t) + b_1(x, y, t) \times PC1(yr, t) + b_2(x, y, t) \times PC2(yr, t) \tag{1}
\]

Where \(b_0, b_1, \) and \(b_2\) are the regression coefficients during the JJAS season and \(PC1\) and \(PC2\) are the pair of leading PCs of MISO/MJO.

In Fig. 8, we show the regression based reconstructed rainfall anomalies (mm/day) for eight phases of MISO (Fig. 8a) and MJO (Fig. 8b). Phase composite of the reconstructed rainfall looks more robust and organised compared to unfiltered composite. For MISO, the composite structure for phase 1, 7, and 8 looks like break composite, and that of phase 2–6 looks like active composite. In contrast for MJO, the composite for phase 1, 2 and 8 seems like break, and for phase 3–7 resembles active composite. The northward propagation of the rain band is very prominent. The magnitude of the MISO reconstructed field is much more robust compared to the MJO reconstructed field.

Figure 9 displays the Hovmoller plot (averaged over 65°-90°E) of reconstructed rainfall for MISO (Fig. 9a) and MJO (Fig. 9b). Phases are repeated for the ease of visualisation like Fig. 5. Figure 9 shows the relatively intense and organised northward propagation in the reconstructed field compared to the unfiltered field (refer to Fig. 5).

We plot phase composite of regression based reconstructed OLR anomalies (W/m²) and wind at 850hPa anomalies (m/s) for eight different MISO and MJO phases in Fig. 10a and Fig. 10b respectively. We notice active (break) like structure for phase 2–5 (remaining phase). In Fig. 11, we show the Hovmoller plot (averaged over 65°-90°E) of reconstructed OLR anomalies (shaded; W/m²) and vorticity anomalies at 850 hPa (contour; positive solid and negative dashed; contour interval 1x10^-6 s^-1) for MISO (Fig. 11a) and MJO (Fig. 11b).

In Fig. 12, we plot the percentage of variance explained by the MISO reconstructed rainfall, MJO reconstructed rainfall, and jointly by both the oscillations with respect to the 20–90 days Lanczos filtered
variance. The MISO reconstructed field explains much better percentage of variance and spatial extend compared to the MJO reconstructed field.

3.6. MJO and MISO during long active and break phase:

The active and break spells of relatively shorter duration (< 7 days) might be more related to synoptic-scale than the intraseasonal scale. Therefore, from the identified active and break spells (Table-1), we selected the spells with a minimum duration of seven days or more. We call them as long active or long break spells. We got eight (fourteen) such long active (break) spells during the study period. We have plotted MISO and MJO PCs in the phase space for those long active and long break spells, the same is shown in Fig. 13 and Fig. 14 respectively. It is clear from Fig. 13 that long active may occur when both MISO and MJO are strong, or either one of them is strong and associated signals are mainly somewhere in between phase 2–5. Figure 14 indicates that the long break may occur when either one or both of them are weak otherwise even though associated signals are strong; they are primarily located in phases 1, 6, 7 and 8.

4. Summary And Conclusions:

In the current study, we analyse the relationship of active/break days of Indian summer monsoon with the phases of MISO and MJO. A strong relationship between active and break days with the MISO phase is seen (Fig. 2). The active (break) days mainly occur during MISO phase 2–5 (6–8) whereas the frequency of active (break) days is high during MJO phases 3–6 (6–8 and 1). However, the relationship between active and break days with the MJO phase is not quite prominent (Fig. 3). The MISO phase composite structure for unfiltered rainfall during the phase 2–5 shows systematic northward propagation (as we move from phase 2 towards phase 5) and resembles the canonical structure of active monsoon condition, and phase 6–8 resembles with break monsoon condition (Fig. 4a), consistent with Fig. 2. The MJO phase composite structure for unfiltered rainfall during phase 3–5 looks like the canonical structure of active monsoon condition, and during phase 6–8, active to break transition happens and phase 1 composite looks like break monsoon condition. Hovmoller plot of unfiltered rainfall for MISO and MJO phases show northward propagation; however, the signal is much strong for MISO compared to MJO (Fig. 5). The MISO and MJO phase composite for unfiltered low level circulation and convection anomalies are also consistent with the above findings, except there is a lag compared to rainfall phase composite. The hovmoller plot of low level vorticity and OLR anomalies show that the centre of cyclonic (anticyclonic) vorticity at low level is located to the north of negative (positive) OLR anomalies for both MISO and MJO (Fig. 7). This indicates that both the oscillations progress and sustain as a convectively coupled system. The MISO and MJO phase composite of the regression based reconstructed field also show similar features like unfiltered fields, but the signal is well organised. Spatial extent and percentage variance explained by MISO reconstructed rainfall with respect to 20–90 days filtered rainfall is much more compared to MJO reconstructed rainfall (Fig. 12). It is found that a long active (> 7 days) mainly occurs when both MISO and MJO are active or at-least one of them is active, and the associated signal is somewhere in between phase 2–5 (Fig. 13). On the other hand a long break occurs when either one or
both of them (MISO and MJO) are weak, even though associated signals are strong, they are primarily located in phases 1, 6, 7 and 8 (Fig. 14).

5. Declarations:

Competing interests:
The authors have no competing interests to declare.

Funding Statement:
This research is a part of a PhD work of A.D. carried out at Indian Institute of Tropical Meteorology (IITM) and did not receive any specific grant from any funding agencies.

Author’s Contribution:
A.K.S. and A.D. have conceived the idea of the study. A.D. has performed the analysis with significant help from A.K.S, S.J. and R.C. The first draft of the manuscript was written by A.D. and all the authors have contributed towards improving the manuscript.

Availability of data and material:
The datasets used in the present study are freely available: (i) IMD gridded rainfall dataset from http://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html (Pai et al., 2014). (ii) The NCEP-NCAR reanalysis datasets for dynamical fields from https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html (Kalnay et al., 1996). (iii) OLR datasets from https://psl.noaa.gov/data/gridded/data.interp_OLR.html (Liebmann and Smith, 1996).

Code availability:
Scripts and programming used for the analysis in the current study are available from the corresponding author upon reasonable request.

Ethics approval and Consent to participate
The authors confirm that this article is original research and has not been published previously in any journal.

Consent for publication:
The authors have agreed to submit this manuscript in its current form for publication in the journal.

Acknowledgements:
We express sincere gratitude to the Ministry of Earth Sciences (MoES), Govt. of India, for the full support of the research work carried out at the Indian Institute of Tropical Meteorology (IITM), Pune. We thank the India Meteorological Department (IMD), NCEP-NCAR, for providing data. We have used GrADS and Xmgrace for plotting graphs/figures. We thank the developers for providing the software packages free of cost.

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7. Tables:
Table 1: Active and break spells during 1998-2018

| Year  | Active Spells   | Year  | Break Spells   |
|-------|----------------|-------|----------------|
| 1998  | 11SEP-15SEP    | 1998  | 20JUL-27JUL    |
| 1999  | 18JUN-23JUN    | 1999  | 30JUN-06JUL    |
| 1999  | 10SEP-15SEP    | 1999  | 12AUG-16AUG    |
| 2000  | 17JUL-20JUL    | 2000  | 01AUG-08AUG    |
| 2001  | 10JUN-18JUN    | 2001  | 10SEP-13SEP    |
| 2001  | 09JUL-12JUL    | 2001  | 26AUG-30AUG    |
| 2002  | 24JUN-27JUN    | 2001  | 06SEP-11SEP    |
| 2003  | 24JUL-28JUL    | 2002  | 03JUL-17JUL    |
| 2004  | 12JUN-17JUN    | 2002  | 21JUL-31JUL    |
| 2004  | 10AUG-13AUG    | 2004  | 20JUN-26JUN    |
| 2005  | 25JUN-03JUL    | 2004  | 19JUL-23JUL    |
| 2005  | 09SEP-15SEP    | 2004  | 26AUG-03SEP    |
| 2006  | 03JUL-06JUL    | 2005  | 08AUG-14AUG    |
| 2006  | 27JUL-30JUL    | 2005  | 25AUG-02SEP    |
| 2006  | 02AUG-09AUG    | 2006  | 16JUN-20JUN    |
| 2007  | 29JUN-03JUL    | 2006  | 17JUL-23JUL    |
| 2007  | 05JUL-09JUL    | 2007  | 16JUL-23JUL    |
| 2007  | 06AUG-09AUG    | 2009  | 17JUN-20JUN    |
| 2008  | 10JUN-13JUN    | 2009  | 28JUL-10AUG    |
| 2008  | 09AUG-12AUG    | 2012  | 27JUN-30JUN    |
| 2008  | 10SEP-13SEP    | 2014  | 15AUG-21AUG    |
| 2009  | 13JUL-16JUL    | 2015  | 03JUL-07JUL    |
| 2009  | 20JUL-23JUL    | 2015  | 20AUG-26AUG    |
| 2011  | 20JUN-23JUN    | 2015  | 03SEP-07SEP    |
| 2011  | 25AUG-10SEP    | 2017  | 06JUL-09JUL    |
| 2012  | 03SEP-07SEP    | 2017  | 01AUG-04AUG    |
| 2013  | 10JUN-17JUN    | 2018  | 27JUL-30JUL    |
| 2013  | 17AUG-23AUG    | 2018  | 03AUG-06AUG    |
| 2014  | 19JUL-23JUL    | 2018  | 10SEP-15SEP    |
| 2014  | 31AUG-04SEP    |       |                |
| 2015  | 19JUN-25JUN    |       |                |
| 2015  | 25JUL-29JUL    |       |                |
| 2016  | 09JUL-13JUL    |       |                |
| 2018  | 15JUL-18JUL    |       |                |

Figures
Figure 1

Time series of daily standardized rainfall anomalies over core monsoon zone region during the Indian summer monsoon of 2015.
Figure 2

Scatter diagram of MISO1 and MISO2 for all (a) active days (b) break days during 1998-2018. Black circle has unit radius. (c) Frequency of active days with MISO phase and (d) Frequency of break days with MISO phase. During frequency computation we have excluded points which fall inside the unit circle.
Figure 3

Same as Fig. 2 but for the PCs of MJO.
Figure 4

Phase composite of rainfall anomaly (mm/day) for eight (a) MISO and (b) MJO phases during 10th June-15th September (period 1998–2018).
Figure 5

Hovmoller plot of rainfall anomaly (averaged over 650-900E) for (a) MISO and (b) MJO, obtained from Fig.4a and Fig.4b respectively. Phase 5-8 (to the left of phase 1-8) and phase 1-4 (to the right of phase 1-8) are repeated in the Hovmoller diagram for the display of continuity.
Figure 6

Same as Fig.4 but for OLR anomaly (shaded; W/m²) and wind at 850 hPa anomaly (vector; m/sec).
Figure 7

Same as Fig. 5 but for OLR anomaly (shaded; W/m²) and vorticity anomaly at 850 hPa (contour, positive solid and negative dashed, contour interval 1x10⁻⁶ s⁻¹).
Figure 8

Phase composite of rainfall anomaly (mm/day) for (a) MISO reconstructed field for eight MISO phases (b) MJO reconstructed field for eight MJO phases during 10th June-15th September (period 1998–2018).
Figure 9

Hovmoller plot of rainfall anomaly (averaged over 650-900E.) for (a) MISO reconstructed field and (b) MJO reconstructed field, obtained from Fig.8a and Fig.8b respectively. Phases are repeated like Fig.5.
Figure 10

Same as Fig.8 but for OLR anomaly (shaded; W/m²) and wind at 850 hPa anomaly (vector; m/sec).
Figure 11

Same as Fig.9 but for OLR anomaly (shaded; W/m²) and vorticity anomaly at 850 hPa (contour, positive solid and negative dashed, contour interval 1x10⁻⁶ s⁻¹).
percentage variance explained by the reconstructed field of (a) MISO (b) MJO and (c) MISO and MJO jointly with respect to the 20–90 day Lanczos filtered rainfall variance during 1998-2013 JJAS seasons.
| Duration of active spells | MISO | MJO | Duration of active spells | MISO | MJO |
|--------------------------|------|-----|--------------------------|------|-----|
| 10-18 JUN 2001          | ![MISO Plot](image1) | ![MJO Plot](image2) | 25AUG-10 SEP 2011 | ![MISO Plot](image3) | ![MJO Plot](image4) |
| 25JUN-05 JUL 2005        | ![MISO Plot](image5) | ![MJO Plot](image6) | 10-17 JUN 2013    | ![MISO Plot](image7) | ![MJO Plot](image8) |
| 09-15 SEP 2005           | ![MISO Plot](image9) | ![MJO Plot](image10) | 17-23 AUG 2013    | ![MISO Plot](image11) | ![MJO Plot](image12) |
| 02-09 AUG 2006           | ![MISO Plot](image13) | ![MJO Plot](image14) | 19-25 JUN 2015    | ![MISO Plot](image15) | ![MJO Plot](image16) |

**Figure 13**

Phase Space plot of MISO and MJO PCs during long active spells
| Duration of break spells | MISO | MJO | Duration of break spells | MISO | MJO |
|--------------------------|------|-----|--------------------------|------|-----|
| 20-27 JUL 1998          | ![MISO](image1) | ![MJO](image2) | 08-14 Aug 2005          | ![MISO](image3) | ![MJO](image4) |
| 30 JUN - 06 JUL 1999    | ![MISO](image5) | ![MJO](image6) | 25 AUG - 02 SEP 2005    | ![MISO](image7) | ![MJO](image8) |
| 01-08 Aug 2000          | ![MISO](image9) | ![MJO](image10) | 17-23 JUL 2007          | ![MISO](image11) | ![MJO](image12) |
| 03-17 JUL 2002          | ![MISO](image13) | ![MJO](image14) | 16-23 JUL 2008          | ![MISO](image15) | ![MJO](image16) |
| 21-31 JUL 2002          | ![MISO](image17) | ![MJO](image18) | 28 JUL - 10 AUG 2009    | ![MISO](image19) | ![MJO](image20) |
| 20-26 JUN 2004          | ![MISO](image21) | ![MJO](image22) | 15-21 AUG 2014          | ![MISO](image23) | ![MJO](image24) |
| 26 Aug - 03 SEP 2004    | ![MISO](image25) | ![MJO](image26) | 20-26 AUG 2015          | ![MISO](image27) | ![MJO](image28) |

**Figure 14**

Phase Space plot of MISO and MJO PCs during long break spells.