The Interactions between the Summer Mean Monsoon and the Intraseasonal Oscillation in the Indian Monsoon Region

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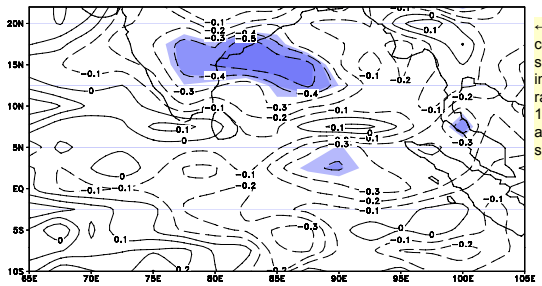
1.Introduction

The India monsoon experiences strong intraseasonal and interannual variations. However, what is the relationship between the summertime ISO intensity and the seasonal mean monsoon strength over the Indian monsoon region? It remains controversial. Physically, it is not clear how the ISO over the Indian monsoon region links to the strength of the summer mean monsoon. In this study we intend to examine the interactive nature of the ISO-mean Indian monsoon relationship and to understand the physical mechanism behind the observed relationship.

2.Results

2.1 Relationship between the ISO intensity and the seasonal mean monsoon rainfall over Indian summer monsoon region

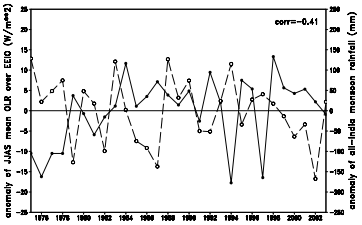


← Correlation coefficients between the summer time (JJAS) ISO intensity and all-India rainfall index for period 1975-2003. The shading areas exceed 95% significance level.

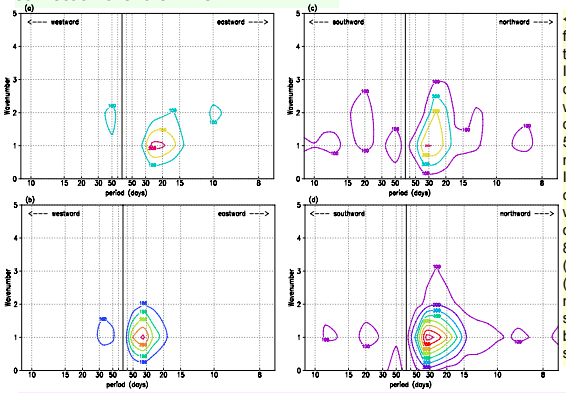
↑The simultaneous correlation between the summer ISO intensity and all-India rainfall index (AIRI) shows that it is a significant negative correlation over the Indian monsoon region from the central-eastern India to the western Bay of Bengal (BOB), also a negative correlation appears over the equatorial eastern Indian Ocean (EEIO). The result indicates that the interannual variation of the ISO intensity exhibits a strong out-of-phase relationship with the seasonal mean monsoon anomaly in JJAS, that is, a wet (dry) monsoon is associated with a weak (strong) ISO activity in situ.

2.2 Impact of the seasonal mean monsoon on ISO

An examination of the regression pattern between the summer mean OLR and AIRI reveals that it is a seesaw relationship between convective branches over the monsoon trough (15º-20ºN) and the EEIO. The largest negative correlation is located along the monsoon trough region, while a positive correlation is seen over the EEIO, especially over the region of (2.5˚S-2.5˚N, 90˚-100˚E). The correlation between the time series of AIRI and the seasonal mean (JJAS) OLR anomaly over EEIO for period of 1975-2003 is -0.41, indicating that a strong Indian summer monsoon is associated with suppressed convection over the EEIO. →



Time series of the all-India monsoon rainfall anomaly (dashed curve) and the seasonal mean OLR anomaly averaged over the region of (2.5˚S-2.5˚N, 90˚-100˚E) (solid curve) in JJAS for 1975-2003.



← The wavenumber-frequency spectra of the zonal propagating ISO mode (left panels, contour interval: 50 w²/m⁴) over the domain of 40ºE-180, 5ºS-5ºN and the meridional propagating ISO mode (right panels, contour interval: 100 w²/m⁴) over the domain of 10ºS-30ºN, 85º-95ºE for the wet (top panels) and dry (bottom panels) monsoon years. The spectrum analysis is based on the boreal summer OLR field.

The seasonal mean convection over EEIO may exhibit a large-scale control on ISO activity. The wavenumber-frequency analysis is performed in a limited zonal and meridional domain to demonstrate the dependence of ISO on the mean monsoon state. The composed spectrum analysis shows that during the wet (dry) Indian monsoon, eastward-propagating ISO variance along the equatorial IO and northward–propagating ISO variance over the BOB/northern IO are significantly reduced (enhanced), owing to the weakening (strengthening) of the convection over EEIO. The reduced (enhanced) northward propagation leads to the weakening (strengthening) of the intraseasonal variability over India. Thus, the change of the mean monsoon is crucial in determining the overall strength of ISO activity over IO and India.

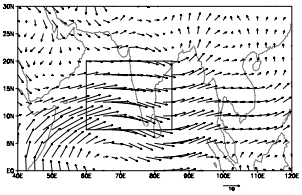
2.3 Feedback of the ISO to the mean monsoon

To depict the effect of the ISO on the mean monsoon, we calculate the seasonal mean zonal wind tendency induced by eddy momentum transport. The ISO contribution on the mean westerly tendency may be expressed as:

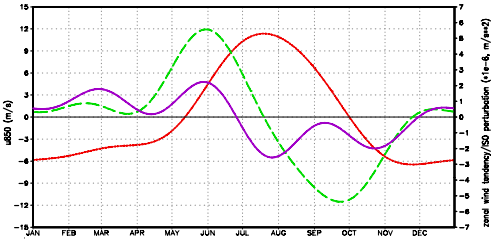
$$\frac{\partial \overline{u}}{\partial t} \propto -\frac{\partial \overline{u'v'}}{\partial y} - \frac{\partial \overline{u'u'}}{\partial x}$$

Where a bar represents annual cycle (annual and semi-annual harmonics) fields, and a prime denotes the ISO perturbation fields.

↓ Time series for 850hPa zonal wind (red line; left ordinate, unit: m/s), tendency of zonal wind (green line; right ordinate, unit: m/s²) and eddy momentum transport by the ISO perturbation (purple line; right ordinate, unit: m/s²) over the prevailing westerly region of (7.5˚-20˚N, 60˚-85˚E).

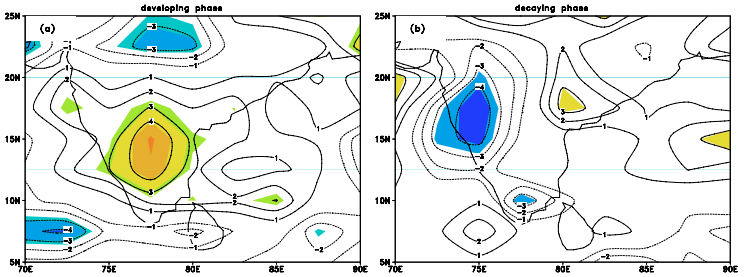


← Climatology 850hPa wind in summer (June-September) for 1975-2003.



The above figure shows that the ISO-induced nonlinear eddy momentum transport contributes to 40% of the observed zonal wind tendency during the monsoon onset period (June). This indicates that the ISO has a significant contribution to the establishment of the monsoon westerly during its developing stage. The correlation between the time series of the observed zonal wind tendency and the eddy momentum transport term throughout the entire annual cycle reaches 0.67, suggesting that the ISO perturbation not only plays an important role in the triggering and establishment of the monsoon westerlies, but also contribute to the wind tendency in other periods.

2.4 Contrast of ISO activity during the ENSO developing and decaying summers



↑ By examining the relationship between the ISO activity and ENSO, we note that while the simultaneous correlation between the summer ISO intensity over India and Nino 3.4 SSTA is insignificant, their relationship experiences a remarkable interannual variation and depends on the phase of ENSO. The above figures (a,b) illustrate the composite ISO intensity for the developing and decaying summers of ENSO (El Nino minus La Nina), respectively. Here the Nino3.4 SST anomalies are used to classify the El Nino or La Nina years for the period of 1975–2003, with the seasonal mean SSTA above 1 (less than 1) standard deviation as El Nino (La Nina) years. For the developing phase, there are four El Nino (1987, 1991, 1997, 2002) and four La Nina (1975, 1988, 1998, 1999) years; for the decaying phase, there are five El Nino (1983, 1987, 1992,1995, 1998) and five La Nina (1976, 1985, 1989, 1999, 2000) years. It is noted that a strengthened (weakened) ISO activity appears over India in the composite of the El Nino developing (decaying) summers. The opposite is true for the La Nina episodes.

3.Conclusions

It is found that there exists a strong out-of-phase relationship between the ISO intensity and the seasonal mean Indian monsoon anomalies during boreal summer.

The out-of-phase relationship is primarily attributed to the impact of the mean monsoon on ISO. A strong Indian monsoon leads to suppressed seasonal mean convection over EEIO, which causes the decrease of eastward and northward propagating ISO variances. The weakening of the northward propagating ISO further leads to the suppressed intraseasonal variability over the Indian monsoon region. ISO have a nonlinear impact on the mean monsoon in situ through the eddy momentum transport. The annual cycle of the Indian monsoon partially depends on the upscale feedback of ISO perturbations.

The relationship between the summer ISO intensity and the Nino3.4 SSTA experiences a marked interannual variation and depends on the phase of ENSO. The ISO intensity over India increase (decreases) during the ENSO developing (decaying) summers.