## A possible new mechanism for northward propagation of boreal summer intraseasonal oscillations based on TRMM and MERRA reanalysis

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#### Introduction

During Boreal Summer, ISO shows a northward migration from Equatorial IO to about 30° N with 30-60 days periodicity.



Lag-Composite of GPCP Precipitation anomaly for BSISOs.

#### >Mechanisms:

- i. PBL sensible heat flux-atmosphere interaction (Webster, 1983).
- ii. Convection-thermal relaxation feedback (Goswami & Shukla, 1984).
- iii. Equatorial wave dynamics (Wang & Xie, 1997; Krishnan et al., 2000).
- iv. Vertical wind shear and moisture-convection feedback (*Jiang et al.,* 2004).
- But the complete understanding particularly, the interaction between large-scale circulation and convection is still elusive.
- In recent time, cloud observations are available based on remotesensing.

#### **Objectives**

What is the role of different cloud hydrometeors (e.g. cloud water, precipitable ice and cloud ice) on the northward propagation of BSISOs?

- Why does the vertical profile of diabatic heating (Q1) show a maximum in the middle troposphere?
- The space-time characteristics and the organization of the cloud hydrometeors and the vertical heating distribution during the northward propagation of BSISOs are also highlighted.

#### **Results: Methodology**



Identified 22 strong & 17 weak (1998-2008) BSISO cases based on precipitation index (PI) over central India (73°-85°E, 18°-28°N).

#### Strong :

PI>1.5 for consecutive 3 days or more Weak:

0.4<PI<1.0 for consecutive 3 days or more

Data: GPCP, TRMM 3B42, 3G68 rainfall TRMM 2A12 hydrometeors. TRMM diabatic heating MERRA reanalysis.

#### Results



Lag-Latitude plot for GPCP precipitation anomaly (mm day<sup>-1</sup>) averaged over 70°E-90°E for (a) strong and (b) weak BSISO cases. Red solid lines are drawn to indicate the propagation speed of the rainfall anomaly.

strong events are associated with the lower frequency of BSISO while the weak events are associated with the higher frequency component of BSISO



Lag composite of pressure-latitude profiles of anomalous TRMM cloud water (mg m<sup>-3</sup>, shaded) and cloud ice (mg m<sup>-3</sup>, contoured with minimum contour and contour interval of 0.15 mg m<sup>-3</sup>) over Indian region (70°E-90°E), based on composite analysis of 22 strong BSISO events during 1998-2008. At lower part corresponding 70°E-90°E averaged rainfall (mm day<sup>-1</sup>) from TRMM 3B42 are shown. The red (blue) shading denotes enhanced (reduced) rainfall activity. "Lag 0" represent the day on which maximum convection anomaly occurs over central India box.



Meridional-vertical structures of the northward propagating strong BSISO events for (a) vorticity (× 10<sup>-6</sup> s<sup>-1</sup>), (b) divergence (× 10<sup>-6</sup> s<sup>-1</sup>), (c) vertical velocity (× 10<sup>-2</sup> Pa s<sup>-1</sup>) (d) specific humidity (g kg<sup>-1</sup>) (e) horizontal moisture advection (W m<sup>-3</sup>) and (f) equivalent potential temperature ( $\theta_e$ , K) from MERRA Reanalysis. Horizontal axis represents the meridional distance (degree) with respect to maximum convection center (MCC). The +ve (-ve) value means to the north (south) of MCC.



Meridional-vertical structures of the northward propagating strong BSISO events for (a) cloud water (mg m<sup>-3</sup>, shaded with contours) and cloud ice (mg m<sup>-3</sup>, contours only with a contour interval of 0.25 mg m<sup>-3</sup>), (b) precipitable ice (mg m<sup>-3</sup>), (c) diabatic heating (K day<sup>-1</sup>) from *TRMM*, (d) diabatic heating (K day<sup>-1</sup>), (e) diabatic heating contribution from radiative and moist processes (K day<sup>-1</sup>), (f) vertical transport of heat by eddies (K day<sup>-1</sup>) (g) gradient of vertical transport of eddies (× 10<sup>-6</sup> K Pa<sup>-1</sup> day<sup>-1</sup>) from *MERRA* reanalysis and (h) convective (mm day<sup>-1</sup>, solid line) and stratiform rain (mm day<sup>-1</sup>, shade) from *TRMM* 3G68. Horizontal axis represents the meridional distance with respect to maximum convection center (MCC). The +ve (-ve) value means to the north (south) of MCC.



Meridional-vertical structures of the northward propagating Weak BSISO events for (a) vorticity (×  $10^{-6} \text{ s}^{-1}$ ), (b) divergence (×  $10^{-6} \text{ s}^{-1}$ ), (c) vertical velocity (×  $10^{-2} \text{ Pa s}^{-1}$ ) (d) specific humidity (g kg<sup>-1</sup>) (e) horizontal moisture advection (W m<sup>-3</sup>) and (f) equivalent potential temperature ( $\theta_{e}$ , K) from MERRA Reanalysis. Horizontal axis represents the meridional distance (degree) with respect to maximum convection center (MCC). The +ve (-ve) value means to the north (south) of MCC.



Meridional-vertical structures of the northward propagating weak BSISO events for (a) cloud water (mg m<sup>-3</sup>, shaded with contours) and cloud ice (mg m<sup>-3</sup>, contours only with a contour interval of 0.25 mg m<sup>-3</sup>), (b) precipitable ice (mg m<sup>-3</sup>), (c) diabatic heating (K day<sup>-1</sup>) from *TRMM*, (d) diabatic heating (K day<sup>-1</sup>), (e) diabatic heating contribution from radiative and moist processes (K day<sup>-1</sup>), (f) vertical transport of heat by eddies (K day<sup>-1</sup>) (g) gradient of vertical transport of eddies (× 10<sup>-6</sup> K Pa<sup>-1</sup> day<sup>-1</sup>) from *MERRA* reanalysis and (h) convective (mm day<sup>-1</sup>, solid line) and stratiform rain (mm day<sup>-1</sup>, shade) from *TRMM 3G68*. Horizontal axis represents the meridional distance with respect to maximum convection center (MCC). The +ve (-ve) value means to the north (south) of MCC.

#### Conclusion

 Cloud liquid water leads while cloud ice lags w.r.t. the centre of the convection.

 Lower level preconditioning is done by shallow cloud. It helps to grow the deeper convective cloud. Further, anvils (Ice phase) are generated from deep convective clouds.

• The heating maxima at the convection center further strengthen the deep convection.

 Diabatic Heating is transported by the sub-grid scale eddies in lower atmosphere and by strong vertical velocity in the free atmosphere.

• **Stratiform rain** mostly occurs at the south of the convection center.



Schematic diagram (a-c) for the cloud processes associated with the northward propagation of the BSISOs (figure not in scale). The proposed hypothesis on the mid-tropospheric heating maxima is shown in (a).

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# **THANK YOU**

