Radiative Heating and Cloud Profiles associated with the Boreal Summer Intraseasonal Oscillation (BSISO) Based on CloudSat Observations

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Importance of the BSISO

- Intraseasonal oscillations in the tropics, most prominently the MJO and the boreal summer intraseasonal oscillation (BSISO) play a crucial role in shaping the tropical climate.
- The BSISO provides a primary source of monsoon-precipitation (PR) predictability.
  - BSISO is closely related to mean monsoon – stronger monsoon with fewer BSISOs
  - BSISO could also be the fundamental building block of interannual variability
- Skillful simulations of the BSISOs in weather/climate models are a key for improving summer monsoon rainfall predictability for the medium and extended periods.

Key Related Preceding Studies

BSISO-related cloud water, precipitation, and meridional circulation

Jiang, X., D.E. Waliser, J. Li, and C. Woods, 2011: Vertical cloud structure of the boreal summer intraseasonal variability based on CloudSat observations and ERA-Interim reanalysis. *Clim. Dyn.*, **36**, 2219-2332.

CloudSat-based radiative heating data

L'Ecuyer, T.S., N.B. Wood, T. Haladay, G.L. Stephens, and P.W. Stackhouse Jr., 2008: Impact of clouds on atmospheric heating based on the R04 CloudSat fluxes and heating rates data set. *J. Geophys. Res.*, **113**, D00A5.

Current Issues on BSISO studies

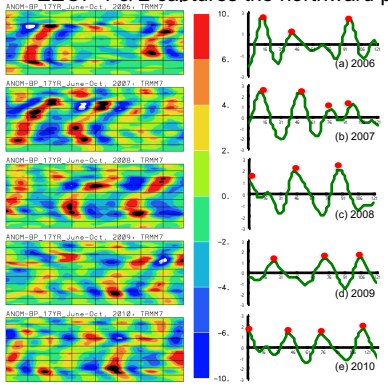
- Current GCMs show limited and widely-varying skill for simulating and forecasting the BSISO.
- Mechanisms and structures of the northward propagating BSISOs and their variability remain to be fully understood.

Experimental Outlines

- This study aims to find the profiles of the radiative heating and cloud condensates associated with the northward propagating BSISOs:
  - Jiang et al. (2011) found by analyzing the CloudSat data that the northward propagating BSISOs closely resemble typical MCSs.
  - Diabatic heating is closely related to the MCSs in their propagation and life cycle.
- Datasets at 1deg x 1deg resolutions:
  - CloudSat-based liquid- and ice- water contents (LWC & IWC) for five summers (Jun-Sep), 2006-10.
  - CloudSat-based longwave and shortwave radiative heating rates (QLW & QSW) for the 5 summers.
  - TRMM7 PR for 1998-2014, 20-70-day band-pass filtered.

Detect the northward moving BSISOs

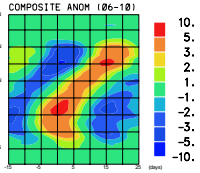
- EEOF analysis of the band-pass filtered TRMM data
  - 15S-30N, averaged over the 75E-95E (BoB) sector.
  - EEOF 1 & 2 captures the northward propagating BSISOs



Hovmoeller diagram of the filtered TRMM7 PR

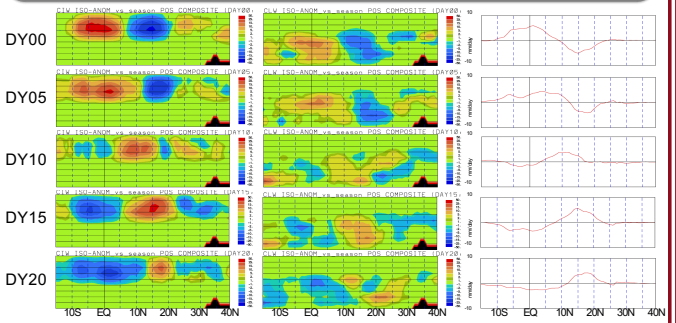
EEOF-1 time series

Based on the EEOF1 time series, 17 strong northward moving BSISO events are identified (red dots).



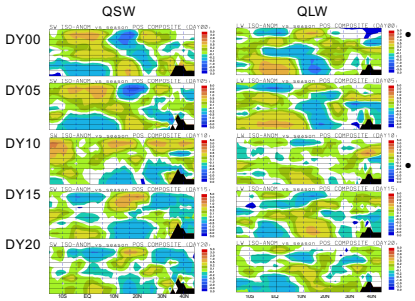
17-event composite Hovmoeller diagram

BSISO-composite ICW and LCW vs. Rainfall



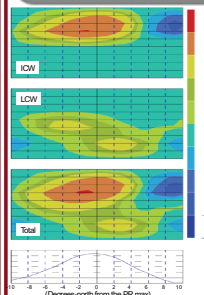
- The IWC and LWC anomalies propagate northward in conjunction with the northward movement of the PR maximum
- Vertical tilting of LWC is clear.
- Low-level LWC leads the precipitation maximum
- Upper-level IWC is approximately in-phase with the PR maximum

BSISO-composite Radiative Heating vs. Rainfall

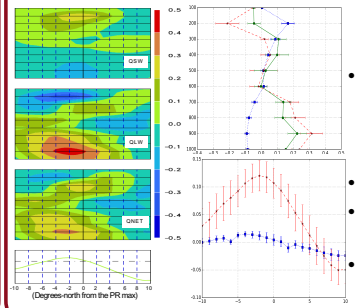


- Northward propagation of the radiative heating is highly synchronized with the northward movement of clouds the PR max.
- Near the PR max:
  - Upper- (Lower-) level SW heating (cooling).
  - Upper- (Lower-) level LW cooling (heating).

BSISO-composite Relative to Rainfall Maxima



- Enhanced upper-level ICW lags the PR max.
- Two LCW maxima: The low-level one leads the PR max (~2degs); the mid-level one at 550hPa lags the PR max (~3degs).
- Vertically-tilted cloud-water structure.
- The cloud water profile resembles an idealized tropical oceanic MCS with leading-line/trailing-stratiform structure.



- Enhanced ICW corresponds to upper-level positive QSW. The negative low-level QSW peak is due to shading by upper/mid-level clouds.
- QLW is generally positive in the troposphere except for the shallow layer near the top of the enhanced.
- QLW dominates QSW.
- Max QNET slightly lags PR max.
- QNET acts to enhance convection by providing additional MSE.

Summary

- During the northward propagation of the BSISO, cloud water and radiative heating is highly synchronized with the precipitation maximum.
- A marked vertical tilting is discerned in cloud liquid water content (LWC) with respect to the BSISO precipitation maximum.
- IWC variability is largely associated with deep convective clouds; LWC is mainly linked to non-precipitating Altocumulus and drizzling low-level Stratocumulus, indicating a pre-conditioning for the northward propagation of the BSISO.
- The LW heating dominates the SW heating: The net radiative heating cools at 200 hPa and heats below the 600hPa level.
- Overall, the radiative heating effects act to enhance convection by providing additional moist static energy to the convective system.

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