The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA
International Atomic Energy Agency

1956-21

Targeted Training Activity: Seasonal Predictability in Tropical Regions to be followed by Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon

4 - 15 August 2008

Monsoon ISV and Indian Ocean mixed layer.

KLINGAMAN Nicholas Pappas
University of Reading, Department of Meteorology
2 Earley Gate. Whiteknights
P.O. Box 243
RG6 6BB Reading
UNITED KINGDOM

Walker INSTITUTE

The Intraseasonal Oscillation of the Indian Monsoon:

Air–Sea Interactions and the Potential for Predictability

Nicholas P. Klingaman
Hilary Weller, Julia Slingo, Peter Inness

Walker Institute for Climate System Research and
Department of Meteorology, University of Reading

11 August 2008
ICTP Workshop on Intraseasonal Variability

University of Reading

MARSHALL SCHOLARSHIPS

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Outline

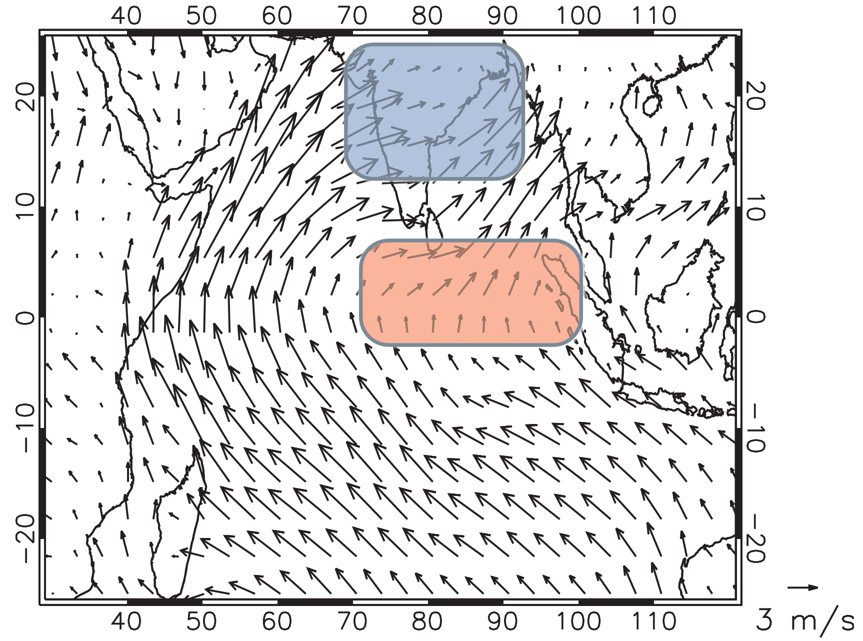
Walker INSTITUTE

- Introduction to the northward-propagating intraseasonal oscillation of the Indian monsoon.
- Motivation: Evidence for air–sea interactions in the intraseasonal oscillation.
- The importance of high-frequency sea-surface temperature variability to the intraseasonal oscillation.
- The intraseasonal oscillation in a regionally coupled GCM with a high-resolution mixed-layer ocean model.
- Conclusions and implications for predictability.

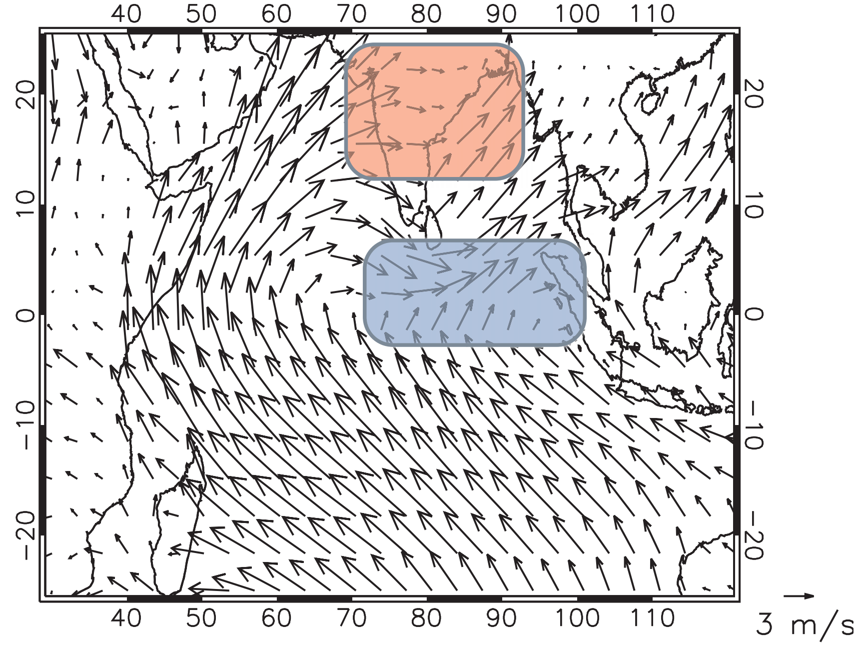
Introduction and Motivation

The Intraseasonal Oscillation

- Each monsoon season can be broken down into “active” and “break” events of enhanced and reduced rainfall over India, respectively.
- The opposite phase occurs over the equatorial Indian Ocean.



Example 10-m winds for an **active period** (ERA-40)

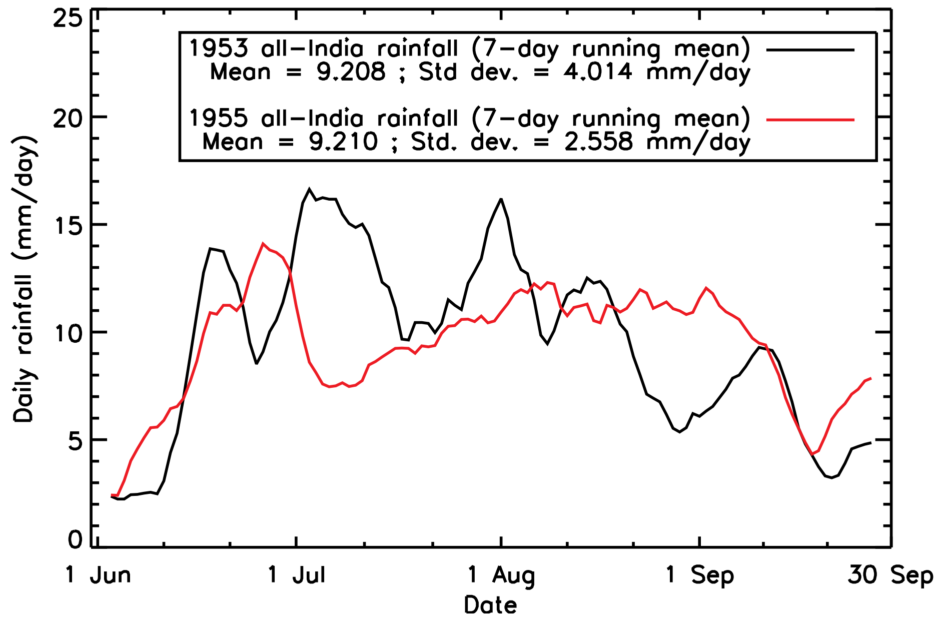


Example 10-m winds for a **break period** (ERA-40)

The Intraseasonal Oscillation

Walker INSTITUTE

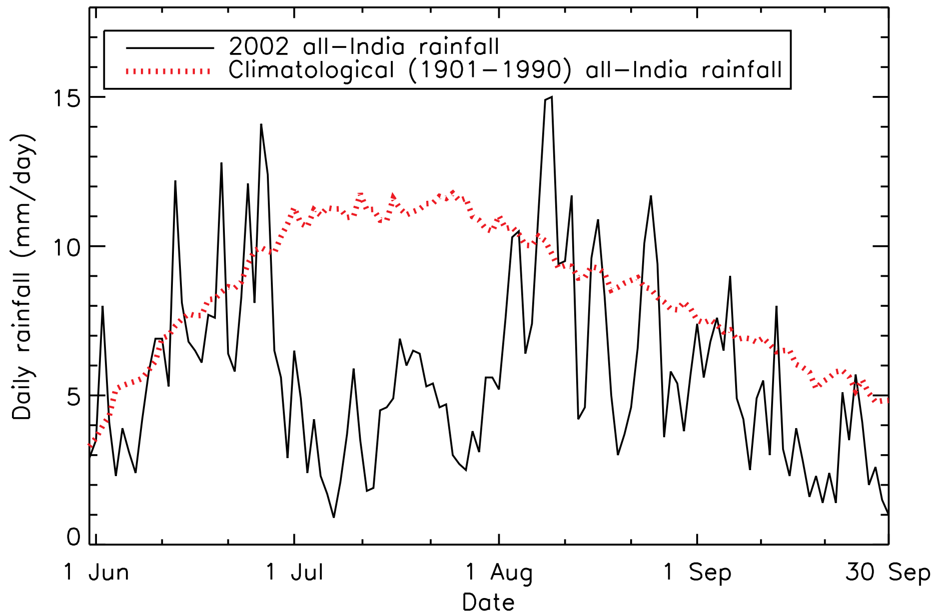
- The monsoon's intraseasonal variability is greater than its interannual variability.
  - ➡ Substantial or prolonged fluctuations can be as devastating (or more so) than deviations in the seasonal mean.
  - ➡ Webster and Hoyos (2004) estimated that successful forecasts on 14–21 day lead times could be a great boon to agriculture.



All-India rainfall (mm day^{-1}) and summary statistics for 1953 (black) and 1955 (red), years with similar means but very different variability.

The Intraseasonal Oscillation

- Because of the monsoon's low interannual variability, India's economy is finely tuned around the climatological rainfall.
  - ➡ Large deviations in the climatological seasonal-mean rainfall can be economically devastating.
  - ➡ The severely deficient 2002 monsoon season reduced India's GDP by about 3%.



2002 all-India rainfall (mm day^{-1}; black) and climatological all-India rainfall (1901–1990; red)

The Intraseasonal Oscillation

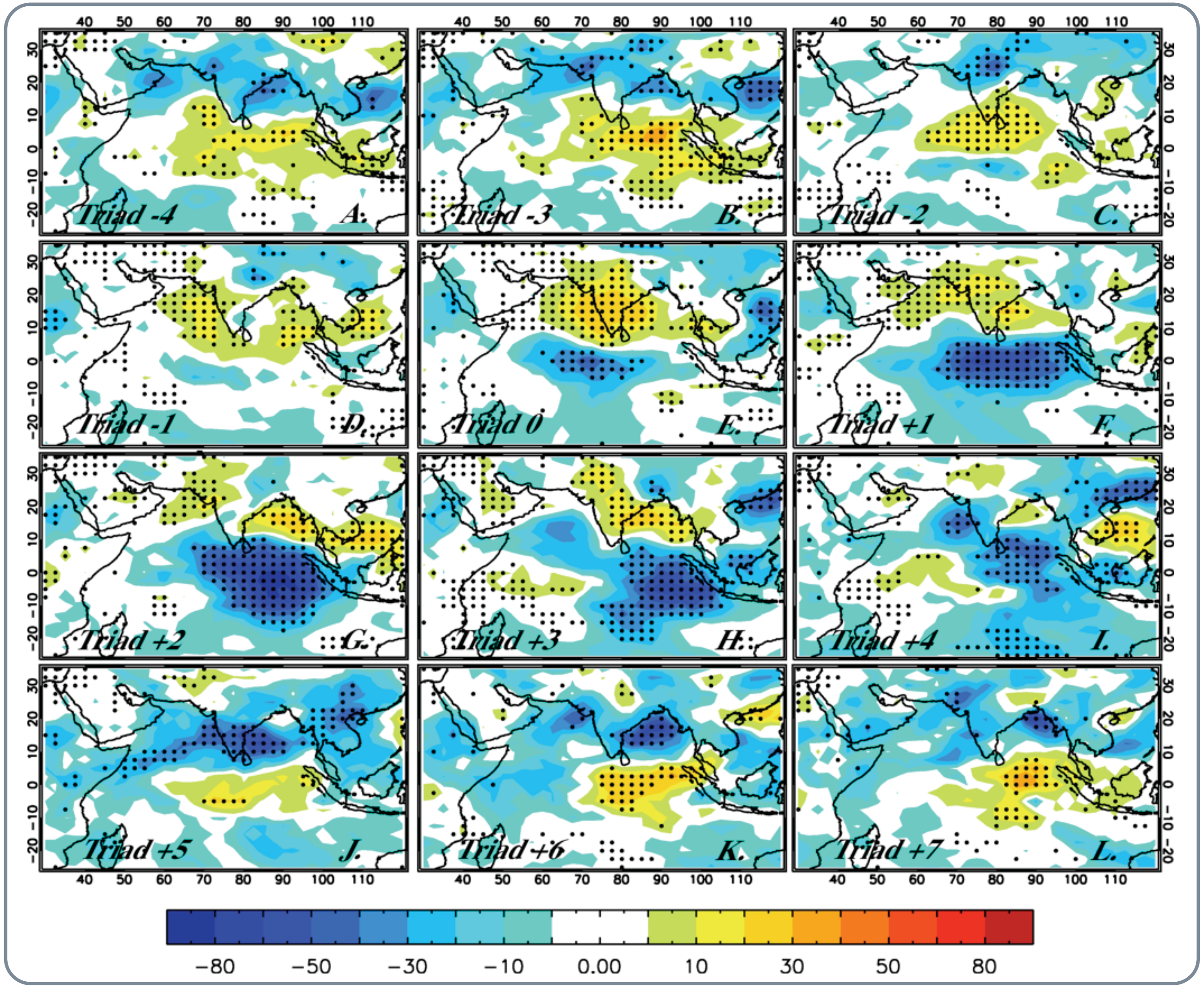
- Observed characteristics of the northward-propagating intraseasonal oscillation (NPISO).
  - ➡ Outgoing longwave radiation (OLR) over India exists in quadrature with OLR over the eastern equatorial Indian Ocean.
    (Krishnan et al., 2000; Vecchi and Harrison 2002)
  - ➡ Areas of enhanced or suppressed convection propagate northward from the eastern equatorial Indian Ocean to India with a speed of 1–2 m s^{-1}, giving the oscillation a period of 30–50 days.
    (Yasunari 1979; Gadgil and Srinivasan, 1990; Lawrence and Webster, 2002)
  - ➡ Most northward-propagating events are initiated by eastward-moving equatorial convection, although some grow *in situ*.
    (Wang and Rui, 1990; Webster, 1998; Lawrence and Webster, 2002)
  - ➡ Events are often attributed to Rossby waves generated by equatorial convection.
    (Wang and Rui, 1997; Kemball-Cook and Wang 2001; Annamalai and Slingo, 2001)
  - ➡ Events are associated with large (potential greater than 1°C) SST variations that are in quadrature with anomalous convection.
    (Bhat, 2001; Vecchi and Harrison, 2002; Klingaman et al., 2007)

Evidence for Air–Sea Interactions

Walker INSTITUTE

Triad-mean anomalies in OLR (W m^{-2}) for a composite intraseasonal break event constructed from NOAA/CIRES AVHRR observations.

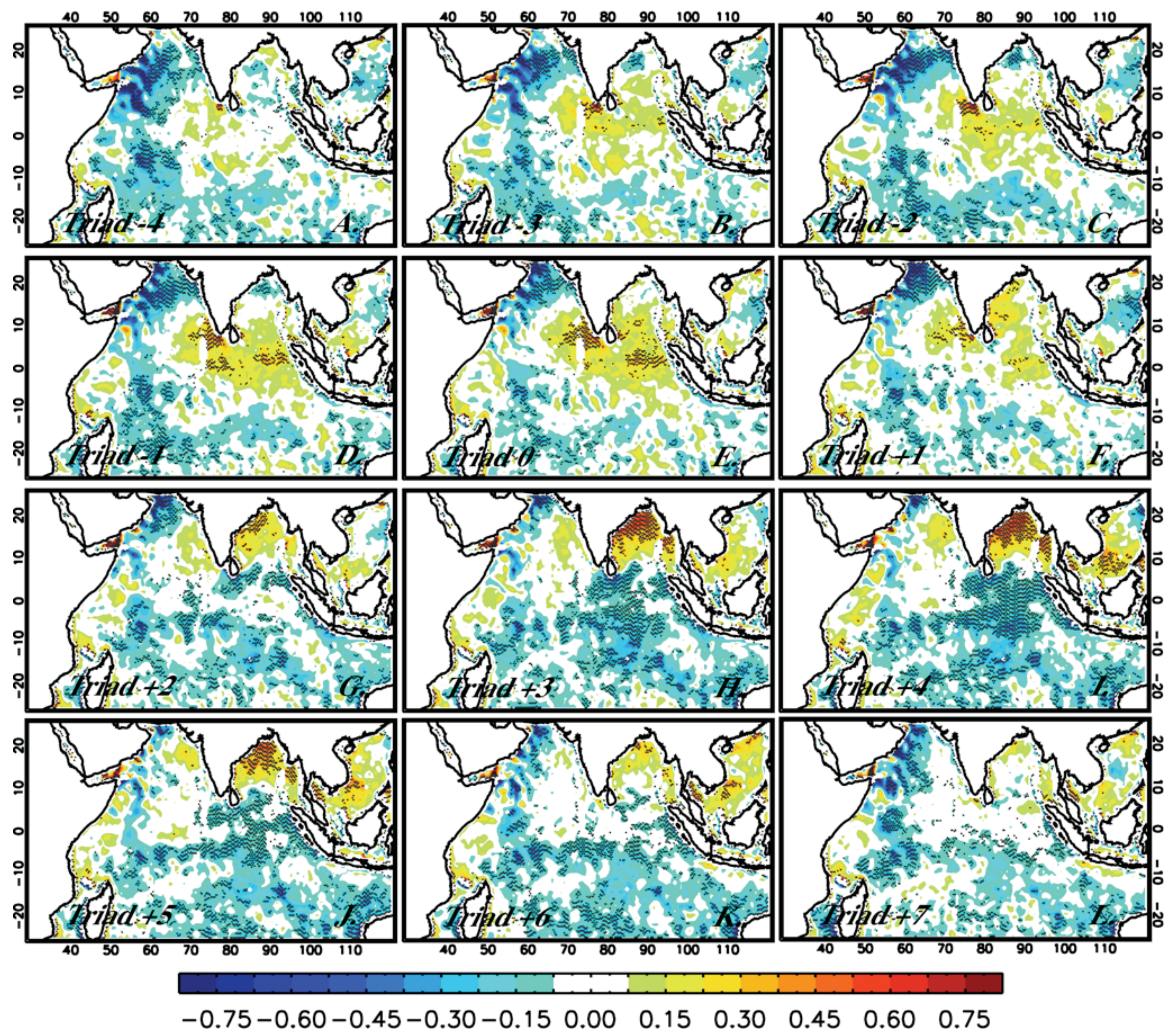
Filled circles show 95% confidence.



Evidence for Air–Sea Interactions

Triad-mean SST anomalies (°C) for the composite break event from the TRMM Microwave Imager (TMI).

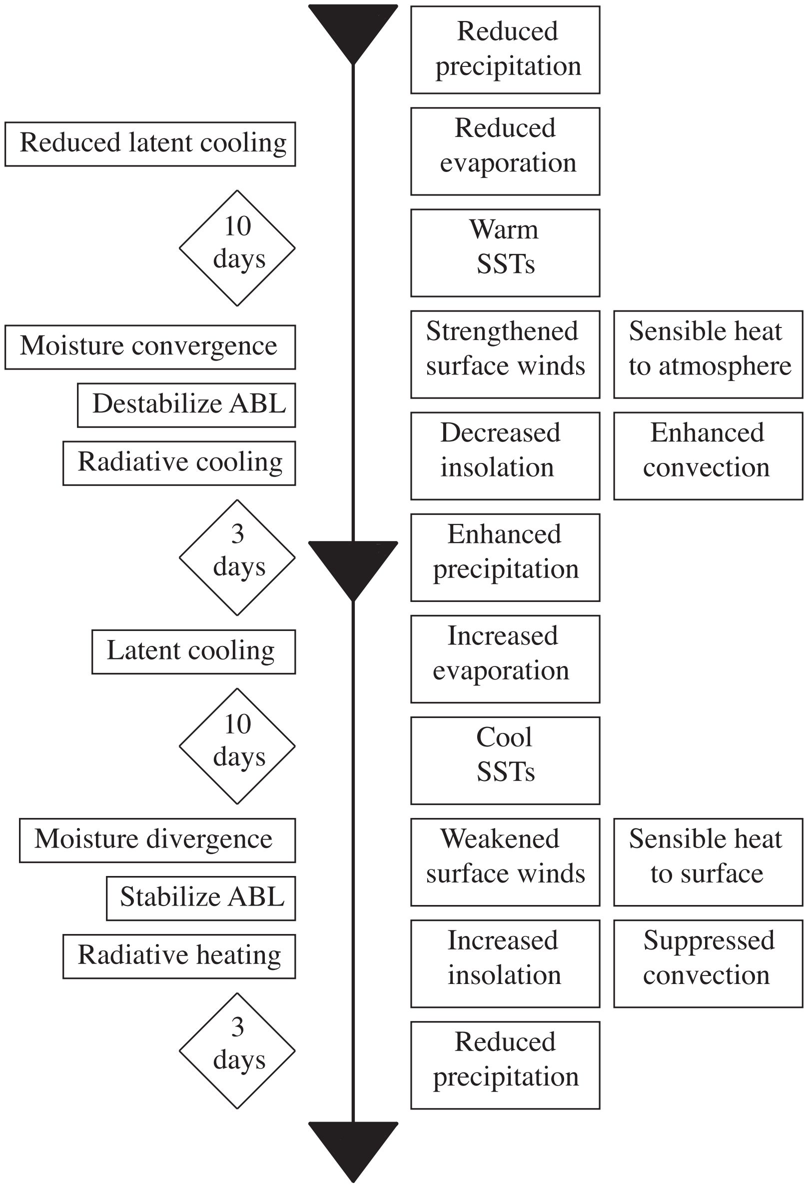
Filled circles indicate 95% confidence.



Evidence for Air–Sea Interactions

Walker INSTITUTE

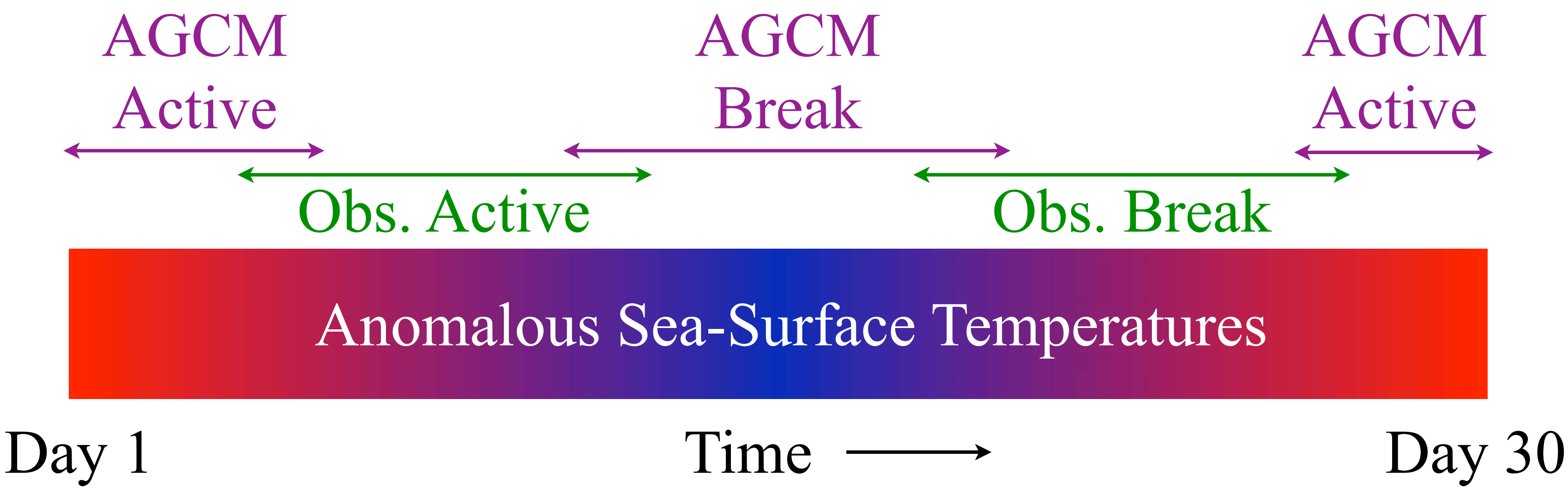
- Air–sea interactions may play a major role in determining the strength, period and propagation of the intraseasonal oscillation.
  - ➡ Convection acts as a negative feedback on SST anomalies via insolation and evaporation.
  - ➡ SST anomalies, in turn, act as a negative feedback on convection via boundary-layer stability.
  - ➡ Warming and cooling the sea surface represents the dominant temporal lag in the system.



The Importance of High-Frequency SST Variability

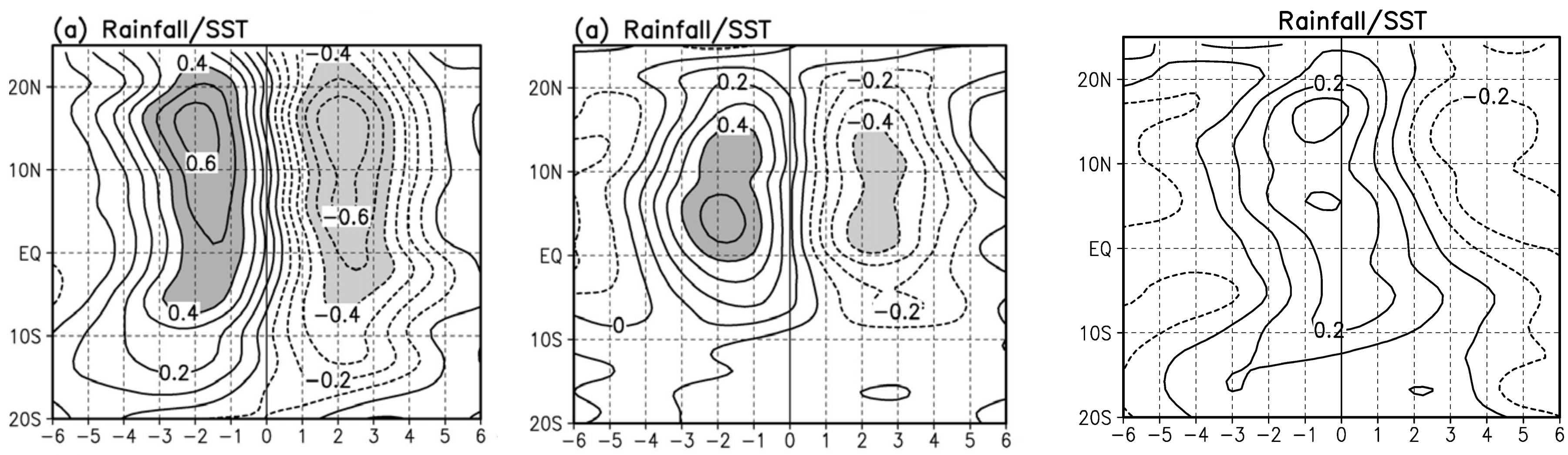
Quadrature and Coincidence

- Previous studies have found that atmosphere-only models (AGCMs) exhibit marked deficiencies when simulating the intraseasonal oscillation.
  - ➡ Lacking feedbacks from the atmosphere to the ocean surface, AGCMs too-readily initiate deep convection over the warmest SSTs.
  - ➡ Intraseasonal variability in AGCMs is substantially lower than variability in either coupled models or in observations.



Quadrature and Coincidence

Coupled GCM Observations (CMAP) Atmosphere-only GCM



Lag correlations between
longitude-averaged (65°-95°E)
rainfall and SST.

The time (horizontal) axis is in pentads.

Figures from Fu and Wang (2004)

Can AGCMs do better ...

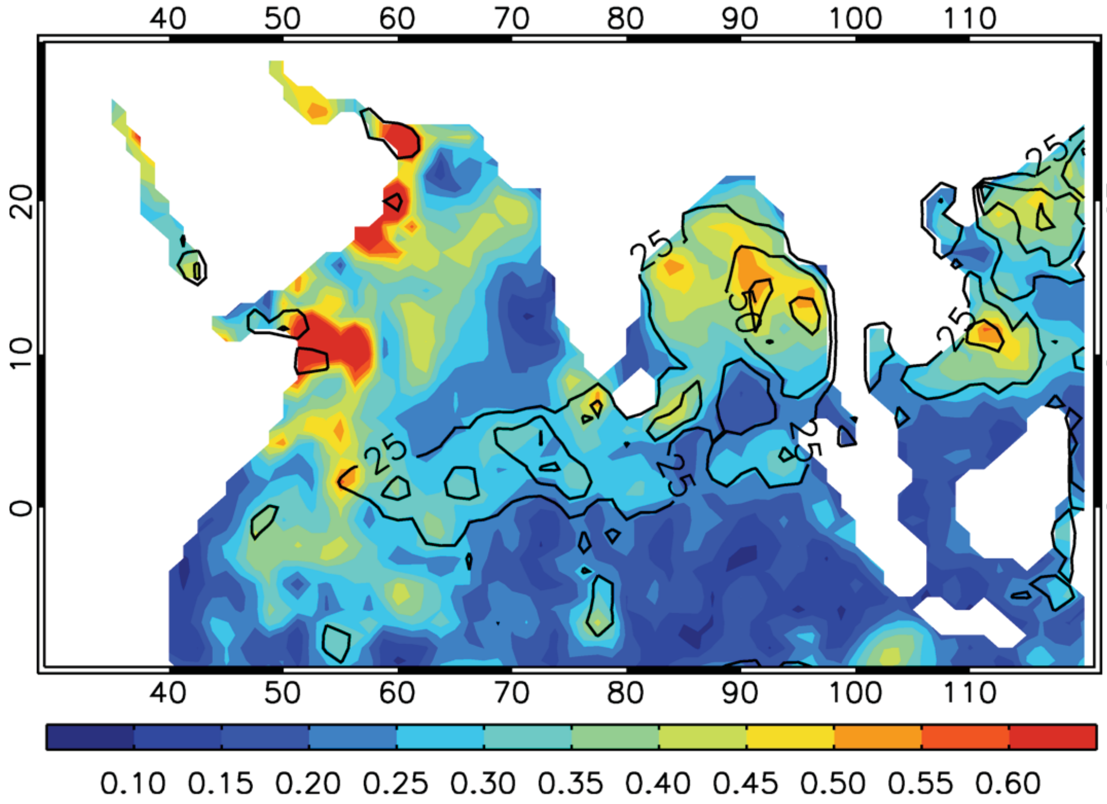
Walker INSTITUTE

- Previous studies have forced their AGCMs either:
  - ➡ With observed SSTs derived from satellite-based infrared sounders
    - ➡ Problem: Infrared sounders cannot reliably penetrate clouds, and so these SST datasets are not accurate in regions of substantial cloud cover.
  - ➡ With SSTs taken from previous coupled-model simulations
    - ➡ Problem: Most coupled models suffer from excessive thermal inertia in the upper ocean, due to coarse vertical resolution.
    - ➡ Problem: Most coupled models are coupled only once per day, and so neglect the diurnal cycle of fluxes and SSTs, both of which are considerable.
    - ➡ Bernie et al. (2005) demonstrated that a vertical resolution of 1 meter and three-hourly coupling was necessary to capture 95% of the intraseasonal variability of SST in the West Pacific.

... with the OSTIA SST dataset?

Walker INSTITUTE

- Assimilates data from microwave and infrared satellites, buoys, and ships.
- High resolution: 0.05° global at daily frequency.
- RMS error of 0.5°C and cold bias of 0.1°C at any one grid point.
- Available from February 2005.



Standard deviation in 30–50 day filtered OSTIA sea-surface temperatures for June–Sept. 2005

Objectives

- To ascertain whether when forced by high-frequency, accurate, observed SSTs, an atmosphere-only GCM can reproduce monsoon intraseasonal variability in-line with observations.
  - ➡ If we improve the variability of the SSTs, will the atmosphere respond by improving the variability of intraseasonal convection?
  - ➡ Comparisons of an intraseasonal variability in simulations forced by OSTIA SSTs to intraseasonal variability in observations.
- To estimate the impact of including high-frequency SST variability on the organization of intraseasonal convection.
  - ➡ If we provide high-frequency SSTs, will the atmosphere give better representations of intraseasonal convection?
  - ➡ Comparisons of simulations forced by the full, daily OSTIA dataset to simulations forced by OSTIA SSTs with high-frequency variability reduced.

Experiment Design

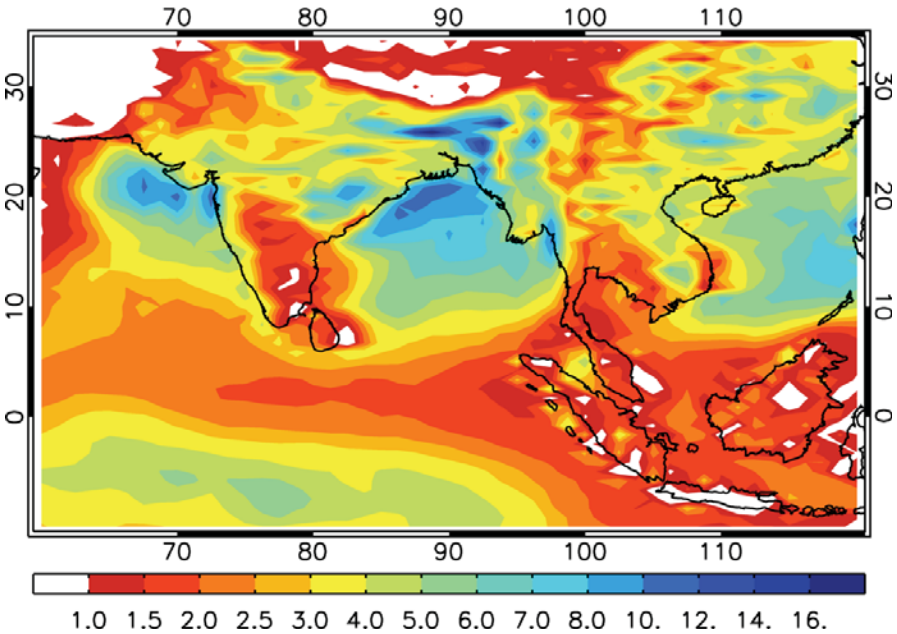
Ensemble	Daily	Five-Day	Monthly
SST Forcing	Daily data from OSTIA	Five-day means of OSTIA	30-day means of OSTIA
Model	Hadley Centre Atmospheric Model (HadAM3) version 4.5.1		
Number of Members	30 ensemble members		
Resolution	1.25° x 0.83° horizontal (N144) 30 vertical levels		
Length of Simulation	12 months using OSTIA data for February 2005–January 2006		

Intraseasonal Variability

Walker INSTITUTE

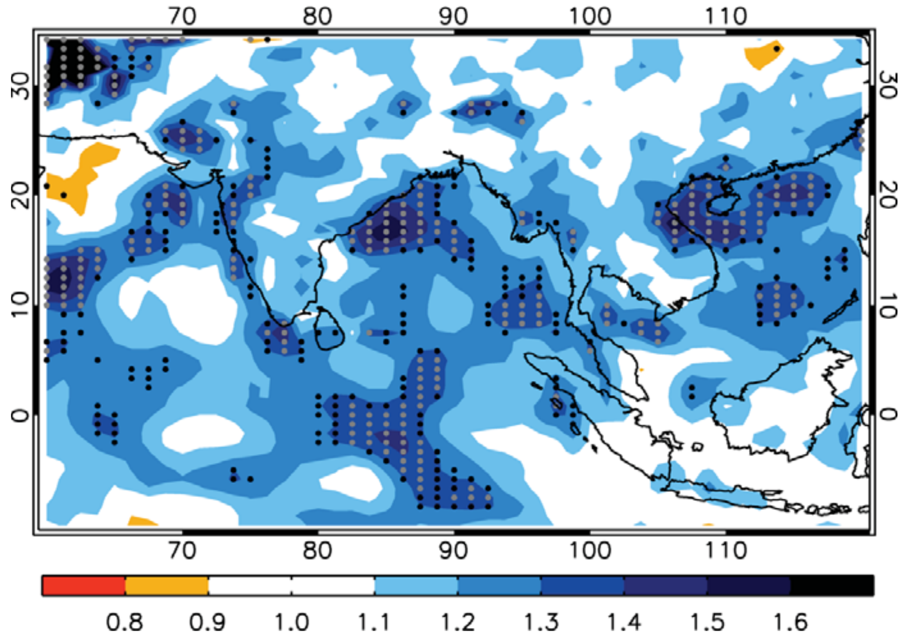
Additional intraseasonal variability in the Daily ensemble across the monsoon domain, particularly over the oceans.

Daily ensemble



Standard deviation in 30–50 day filtered JJAS rainfall (mm day^{-1})

Daily / Monthly ensemble



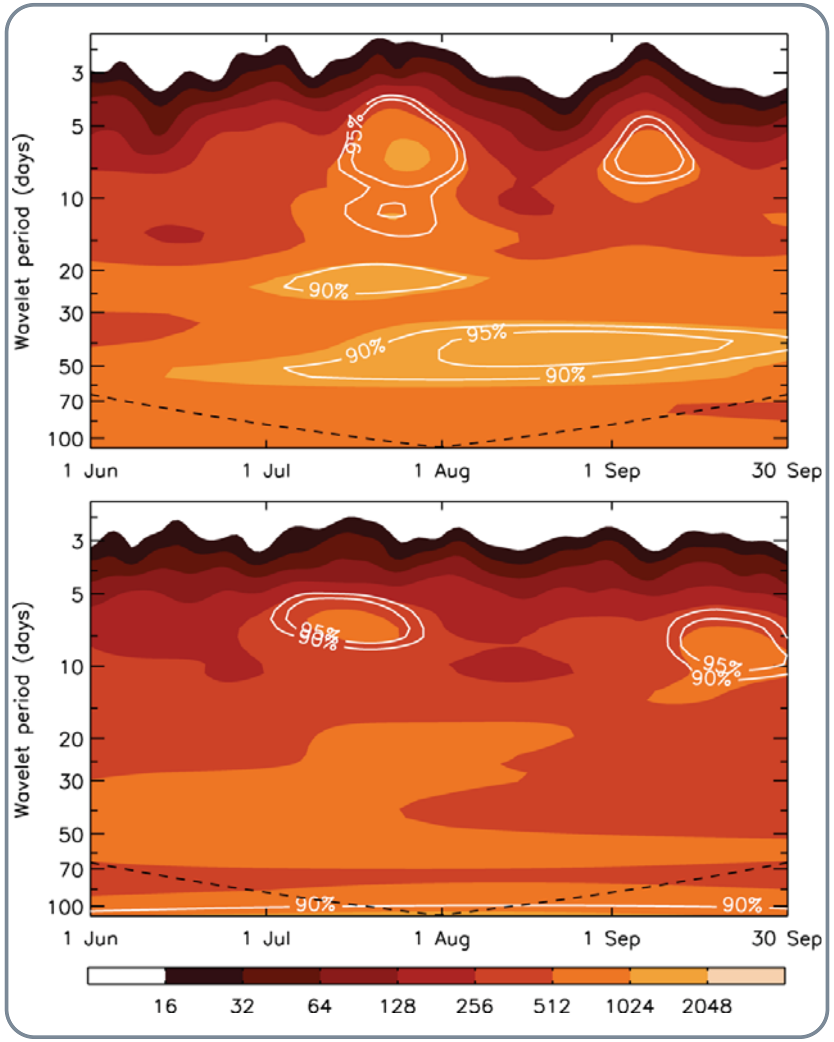
Ratio of standard deviation in 30–50 day filtered JJAS rainfall

Wavelet Transforms

Walker INSTITUTE

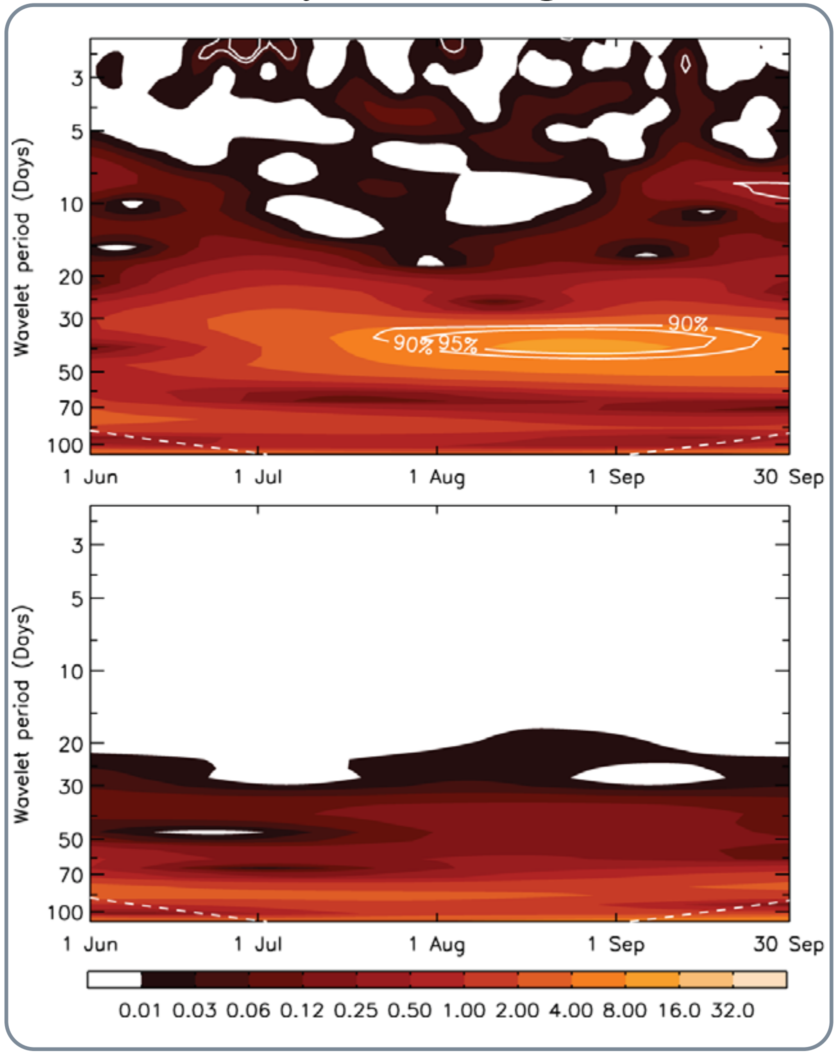
HadAM3 rainfall in Bay of Bengal

OSTIA SSTs in Bay of Bengal



Daily

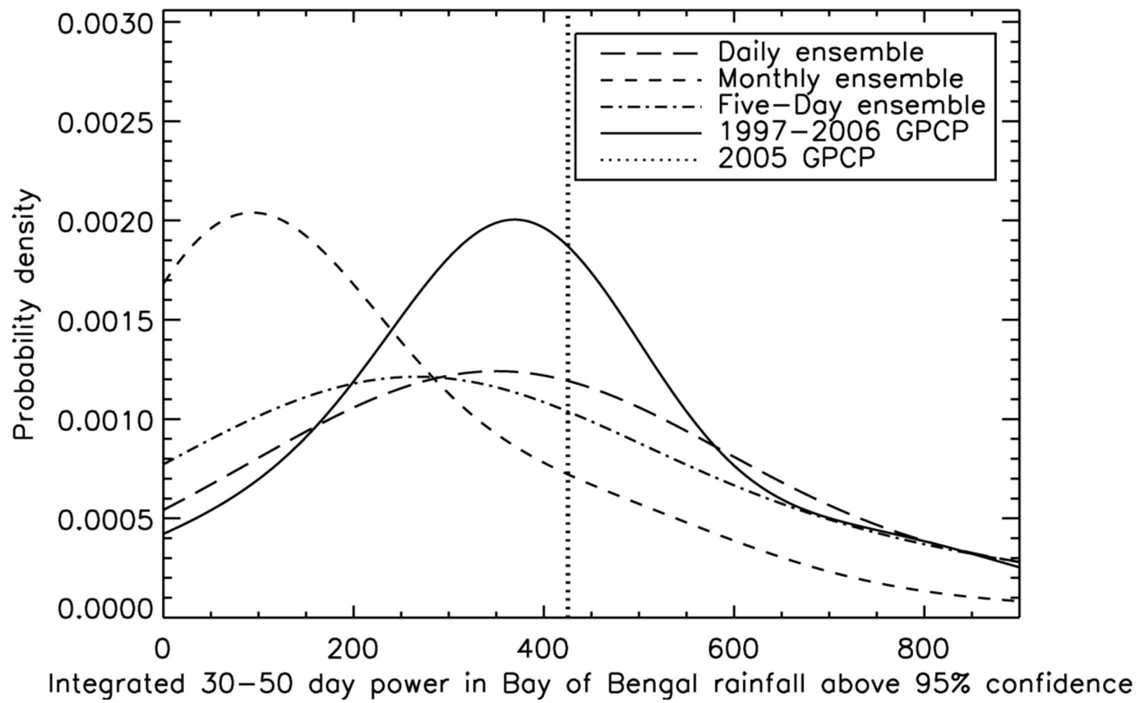
Monthly



Intraseasonal Power Metric

Walker INSTITUTE

- Quantifies the amount of statistically significant power in the 30–50 day band from the wavelet transform.
  - ➡ The Daily ensemble closely matches the GPCP analyses.
  - ➡ The Monthly ensemble contains little or no intraseasonal power.
  - ➡ The Five-Day ensemble is only slightly weaker than the Daily.

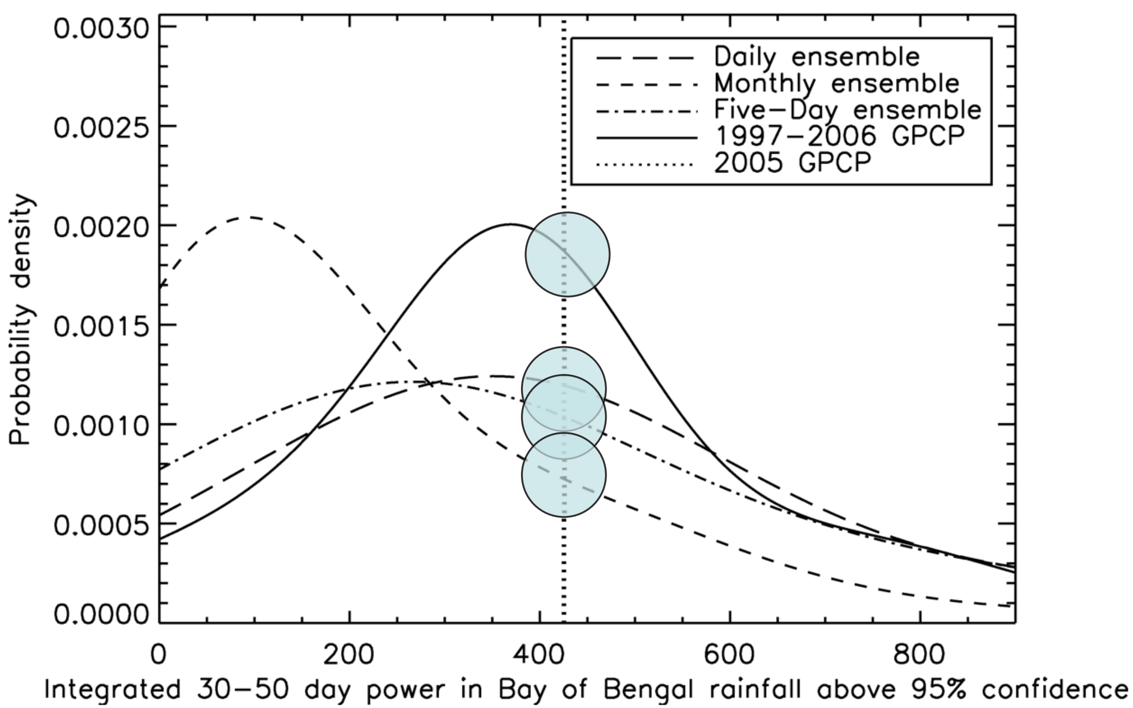


Probability-density function of the intraseasonal-power metric for all three ensembles, compared to high-resolution GPCP rainfall analyses.

Selection of "Observational Members"

Walker INSTITUTE

- To make a "fair" comparison between individual members of each ensemble, select members from each ensemble that have values of intraseasonal power closest to the value for the 2005 GPCP analyses.
  - ➡ Twice as likely to get a member with this power in the Daily ensemble as in the Monthly.

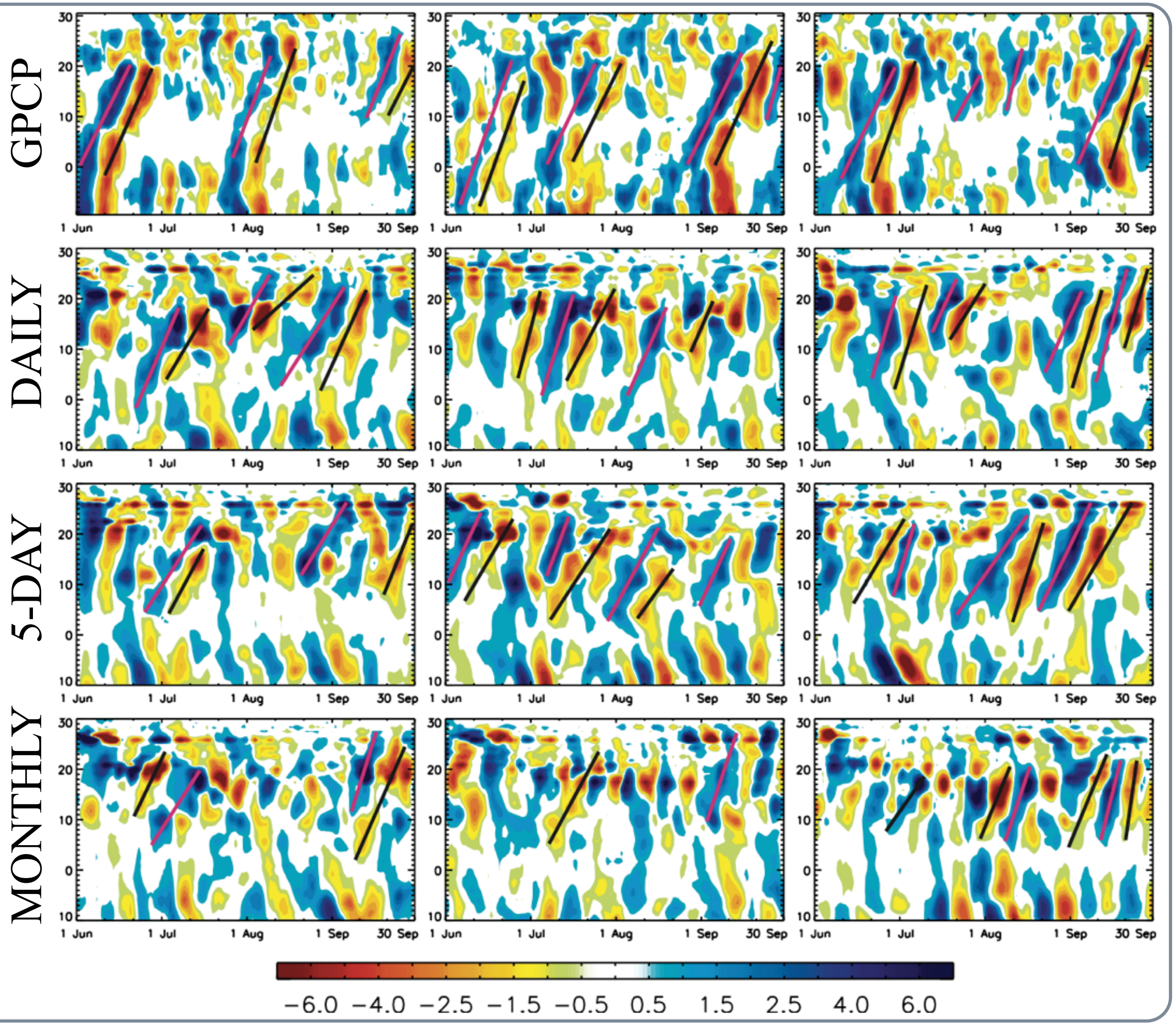


Probability-density function of the intraseasonal-power metric for all three ensembles, compared to high-resolution GPCP rainfall analyses.

Members vs. Observations

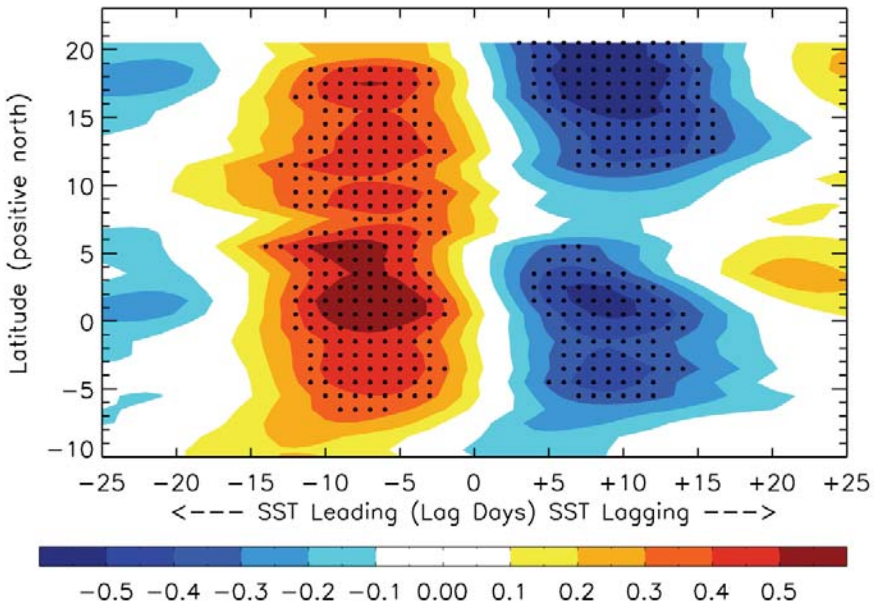
11-day centered linear trend in rainfall (mm day^{-2}), longitude-averaged over 80–90°E.

Pink (black) lines indicate the northward propagation of active (break) events.



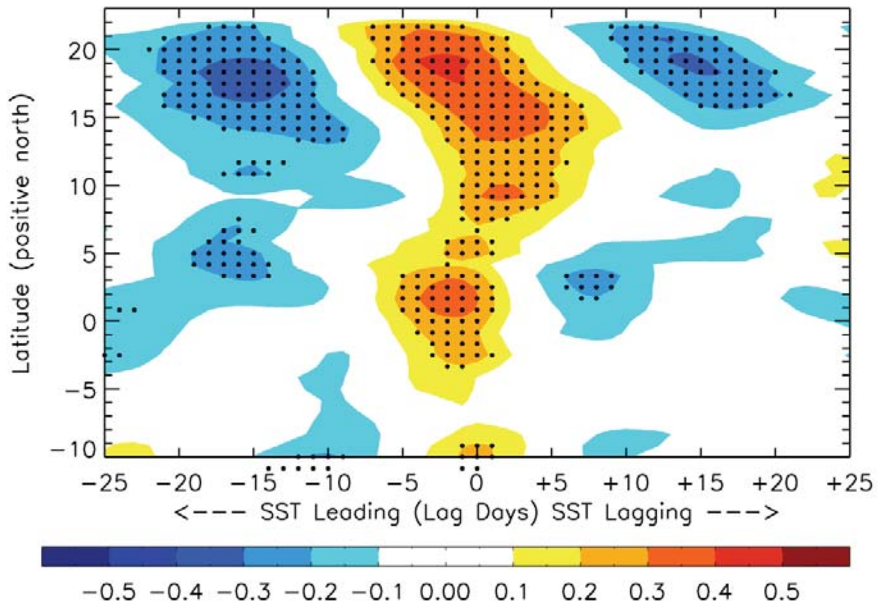
Quadrature vs. Coincidence

Observations



Lead–lag correlations between 11-day linear trends in GPCP rainfall and TMI SST. Data were first area-averaged over 80–90°E. Data from 1997–2006. Filled circles indicate 95% confidence.

HadAM3 Daily ensemble



Lead–lag correlations between 11-day linear trends in Daily-ensemble rainfall and daily OSTIA SST. Data were first area-averaged over 80–90°E. Filled circles indicate 95% confidence.

Conclusions

Walker INSTITUTE

- When forced by daily, observed SSTs containing appropriate intraseasonal variability, an atmosphere-only model can reproduce intraseasonal variability in-line with observations.
  - ➡ The Daily ensemble had a distribution of the intraseasonal-power metric consistent with that of the GPCP analyses.
  - ➡ The Five-Day ensemble had slightly less intraseasonal power.
  - ➡ Most of the Monthly ensemble members had either very low or no intraseasonal power.

- Sub-monthly SST variability plays a key role in organizing intraseasonal convection and directing its propagation.
  - ➡ The Daily and Five-Day ensembles showed northward-propagating events similar to those in GPCP analysis.
  - ➡ The Monthly ensemble members displayed little or no organization or northward propagation.

The Intraseasonal Oscillation in a Coupled Atmosphere–Mixed-Layer-Ocean Model

Objectives

- To develop an improved atmosphere–mixed-layer-ocean coupled model for simulating intraseasonal variability.
  - ➡ The model will have high vertical resolution in the ocean mixed-layer to avoid issues of high thermal inertia, which is common in existing coupled models.
  - ➡ The model will use depth-varying heat corrections to restore the model temperatures to climatology, thus avoiding biases in SSTs and sub-surface temperatures.
- To use this model to examine the effect on intraseasonal variability of including a high-resolution mixed-layer.
  - ➡ What is the impact of introducing atmosphere-to-ocean feedbacks?
  - ➡ What are the feedbacks between the ocean mixed layer and the intraseasonal oscillation? What is the magnitude and depth of the heat input (removal) by a break (active) event?

The KPP Mixed-Layer Model

Walker INSTITUTE

- Based on the K Profile Parameterization (Large et al., 1994).
- One-dimensional purely thermodynamic model with a three-dimensional "wrapper" to allow coupling to an AGCM.
- Low computational cost allows for high vertical resolution and diurnal coupling to the atmosphere.
  - ➡ 60 vertical levels within the 200-m model domain.
  - ➡ Stretched vertical grid places 39 levels in the top 50 m of the ocean.
  - ➡ One hour timestep and three-hourly coupling.
- Previously used to ...
  - ➡ Examine diurnal and intraseasonal SST variability using TOGA COARE data (Bernie et al., 2005).
  - ➡ Examine the impact of coupled feedbacks and improved SST variability on MJO forecasts (Woolnough et al., 2007).

Experiment Design

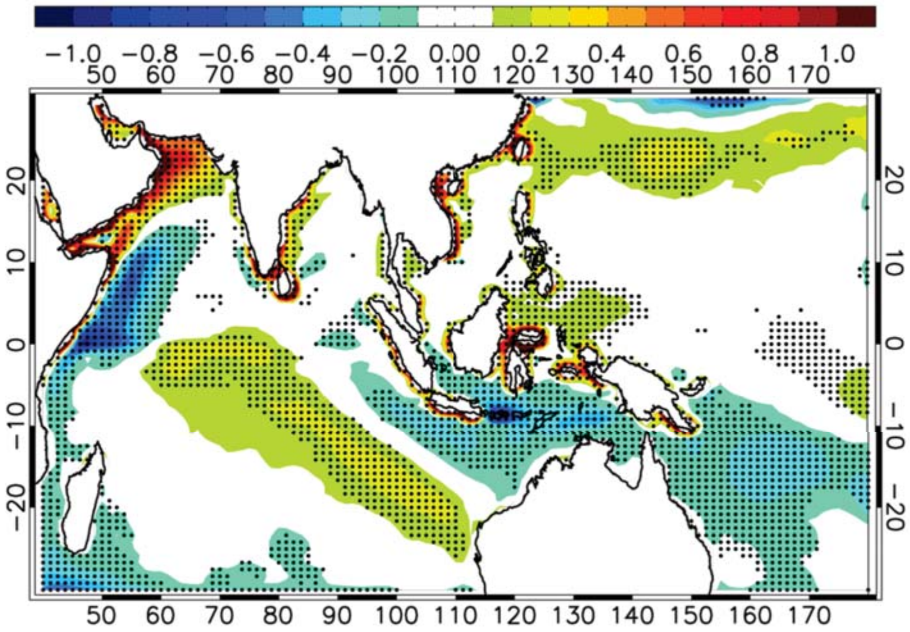
Walker INSTITUTE

30 HadKPP ensemble members
Integrated for 1 May–30 September with heat corrections.

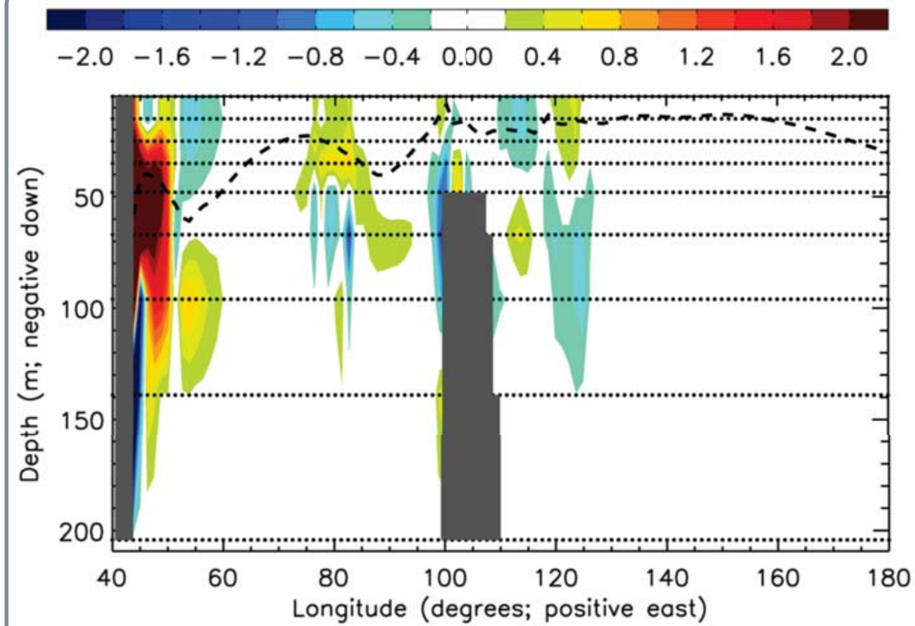
Model	HadAM3	KPP
Horizontal Resolution	N144 (1.25° x 0.83°)	N144 (1.25° x 0.83°)
Horizontal Domain	Global	20°–180°E 30°S–30°N
Vertical Resolution	30 levels (finer near surface)	60 levels (finer near surface)
Vertical Domain	Top at 10 hPa	Bottom at 200 m
Timestep	10 minutes	60 minutes
Initial conditions	May 1 atmospheres from Daily ensemble	Climatological May 1 FOAM temperatures and salinity

Mean SST with heat corrections

When run with depth-varying heat corrections, HadKPP has small temperature biases at the surface and throughout the model vertical domain. (Compare against an uncorrected drift of 3°C month^{-1})



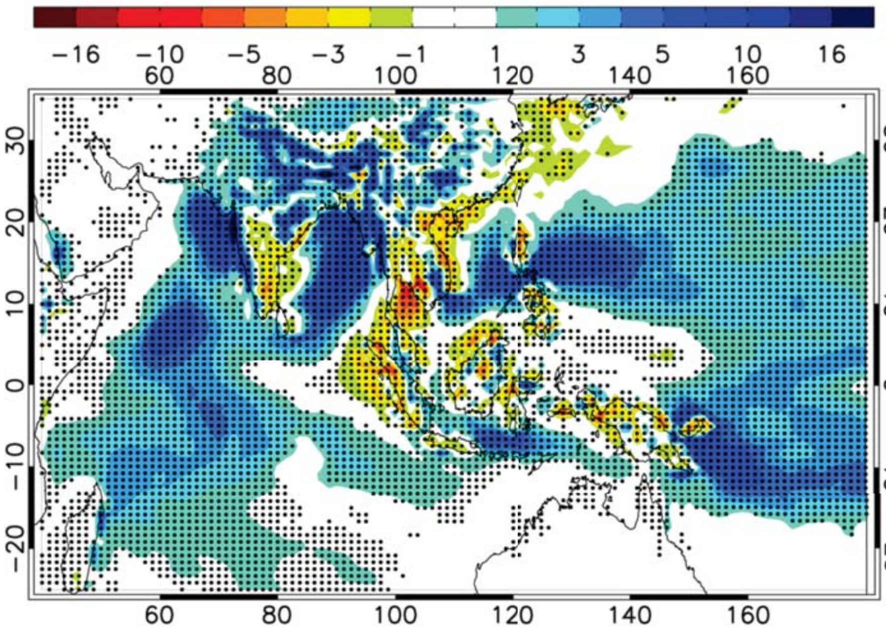
MJJAS-mean, ensemble-mean SST bias compared to the FOAM climatology



MJJAS-mean, ensemble-mean temperature bias, latitude averaged 0–10°N

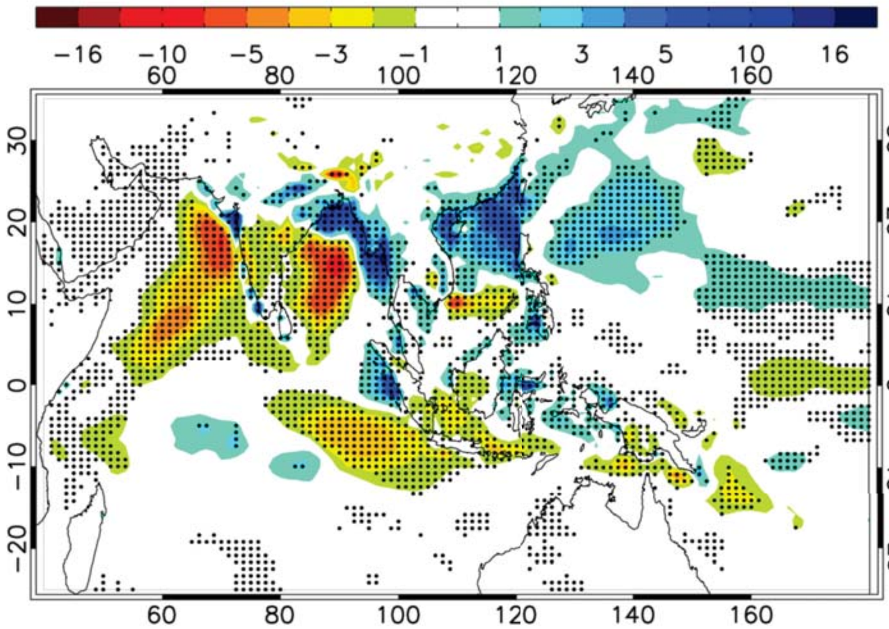
Mean rainfall

HadAM3 minus GPCP



Difference in MJJAS-mean rainfall rate (mm day^{-1}) for the HadAM3 Daily ensemble-mean minus the GPCP climatology (1997-2006).
Filled circles indicate statistical significance at the 1% level.

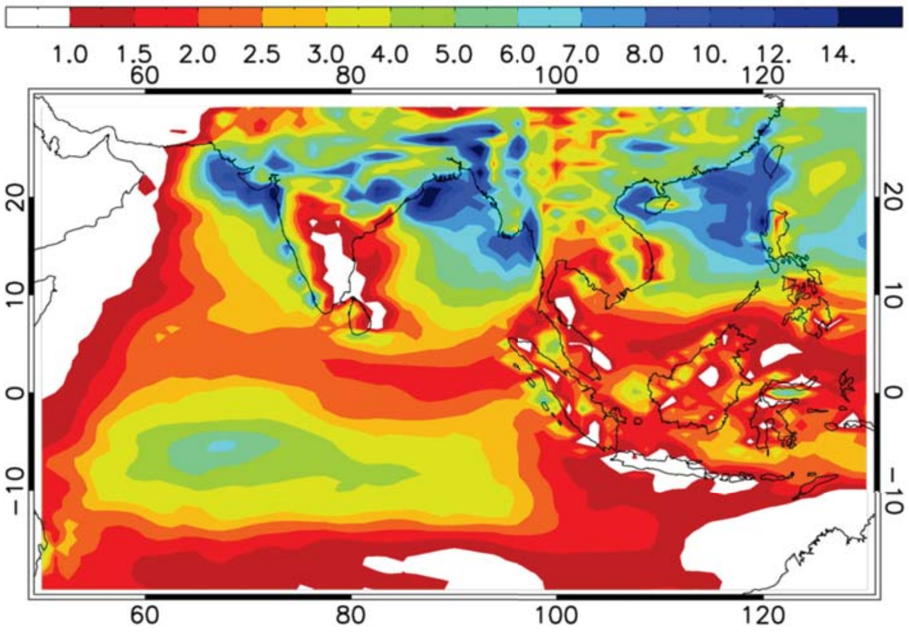
HadKPP minus HadAM3



Difference in MJJAS-mean rainfall rate (mm day^{-1}) for the HadKPP ensemble mean minus the HadAM3 Daily ensemble mean.
Filled circles indicate statistical significance at the 1% level.

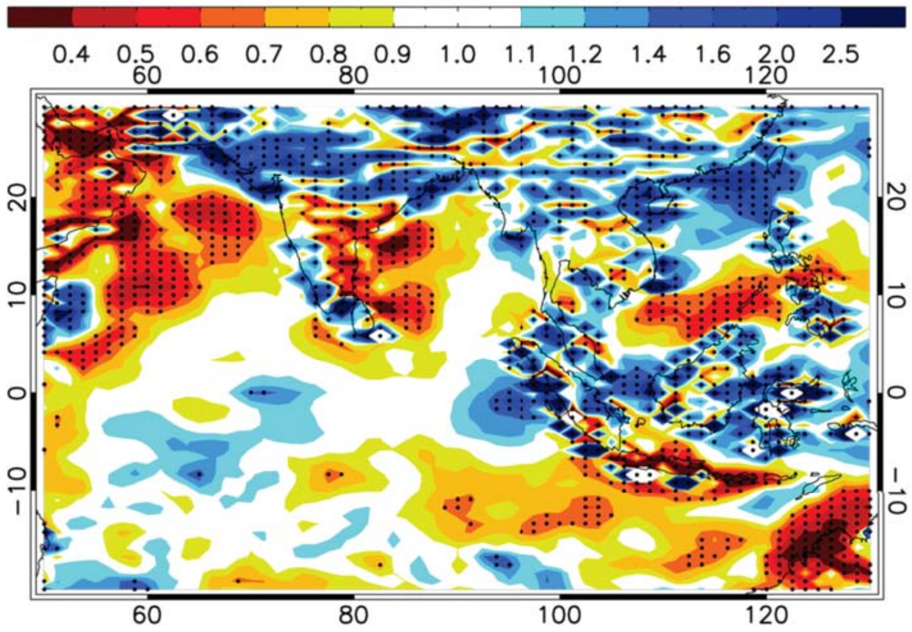
Intraseasonal Variability

HadKPP



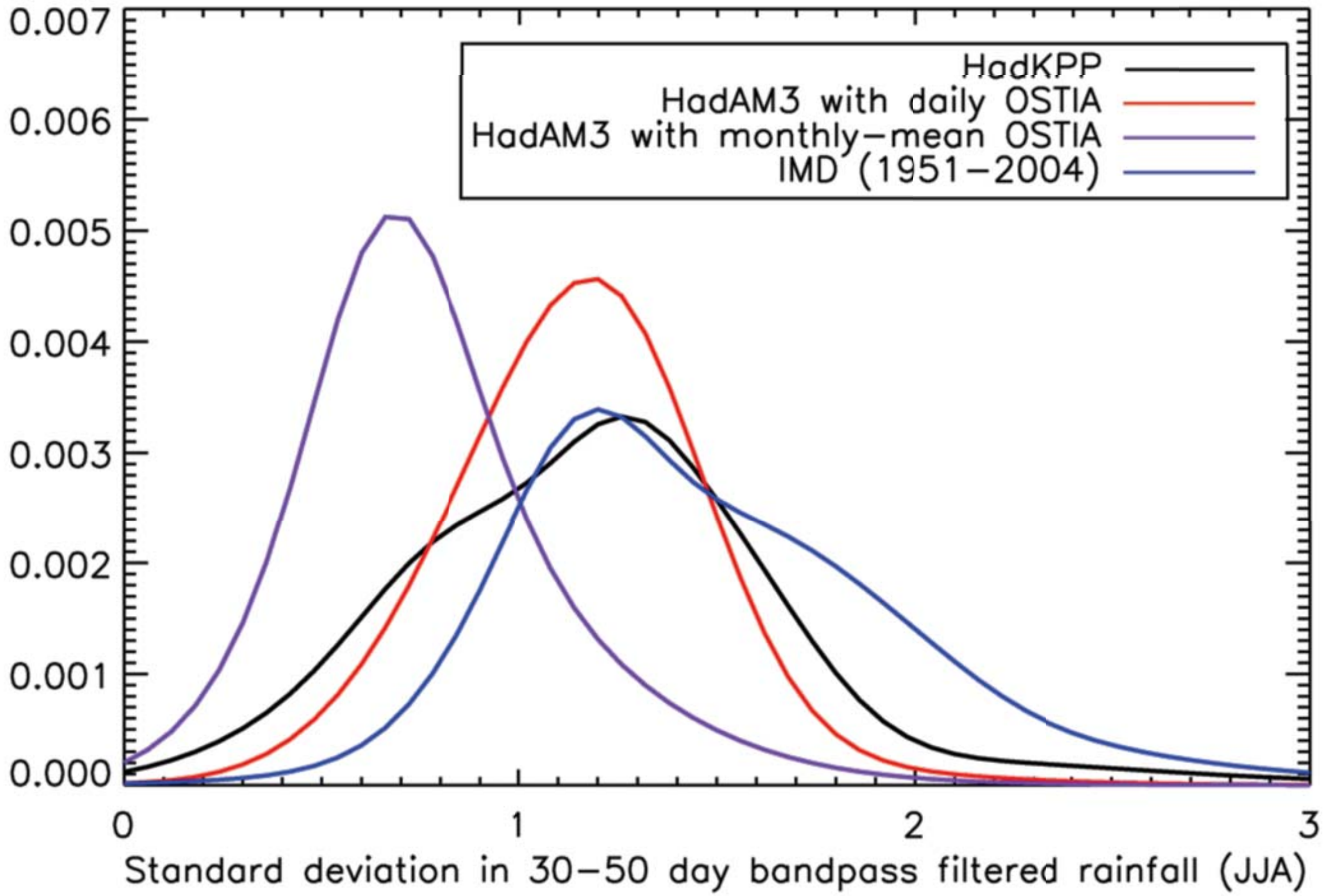
Ensemble-mean standard deviation in 30–50 day filtered June–August rainfall.

HadKPP divided by HadAM3



Ratio of ensemble-mean standard deviation in 30–50 day filtered June–August rainfall for HadKPP divided by HadAM3.

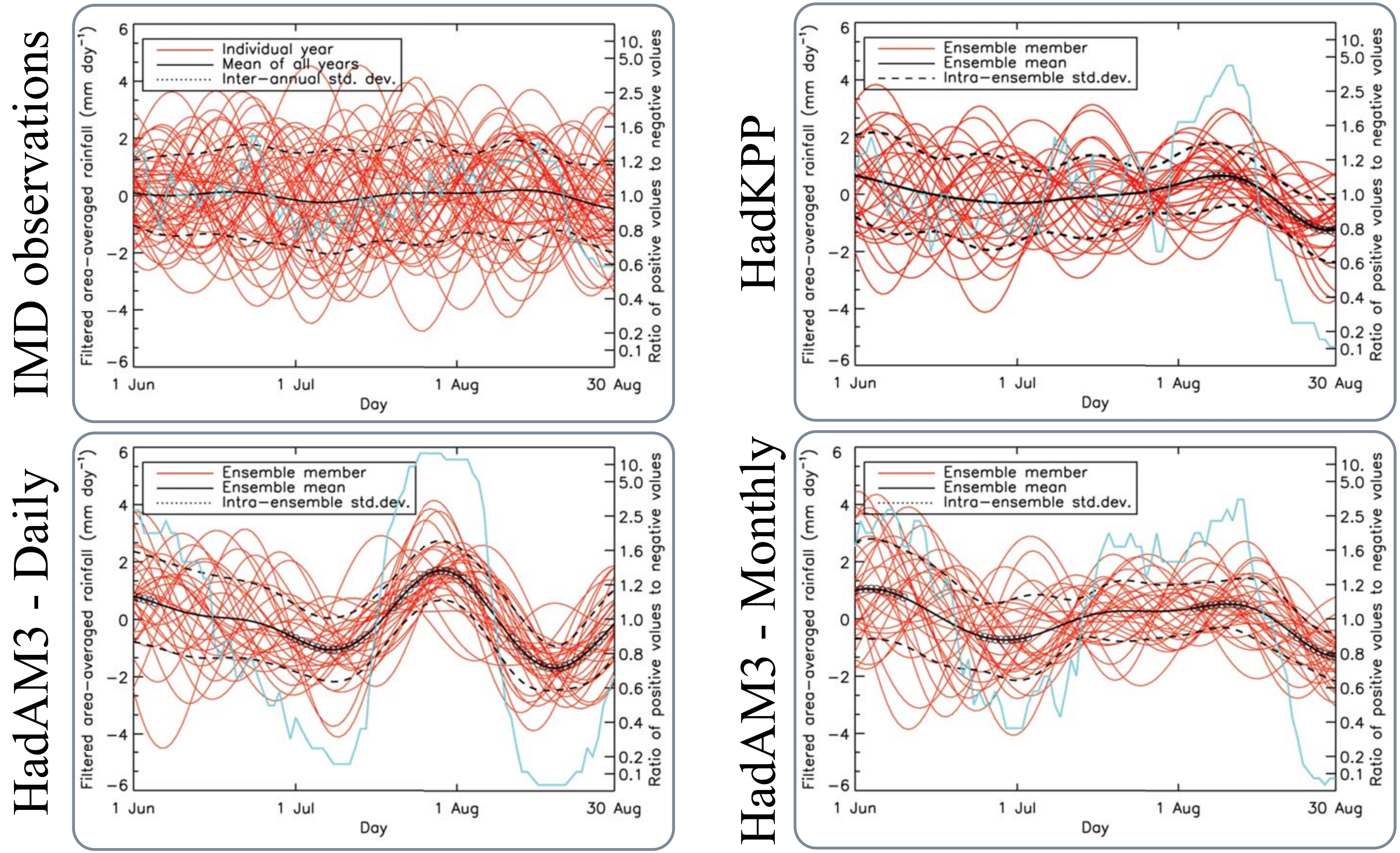
Intraseasonal Variability



Probability-distribution function of the standard deviation in 30–50 day bandpass filtered rainfall that was first area-averaged over land points over India.

Intraseasonal Variability

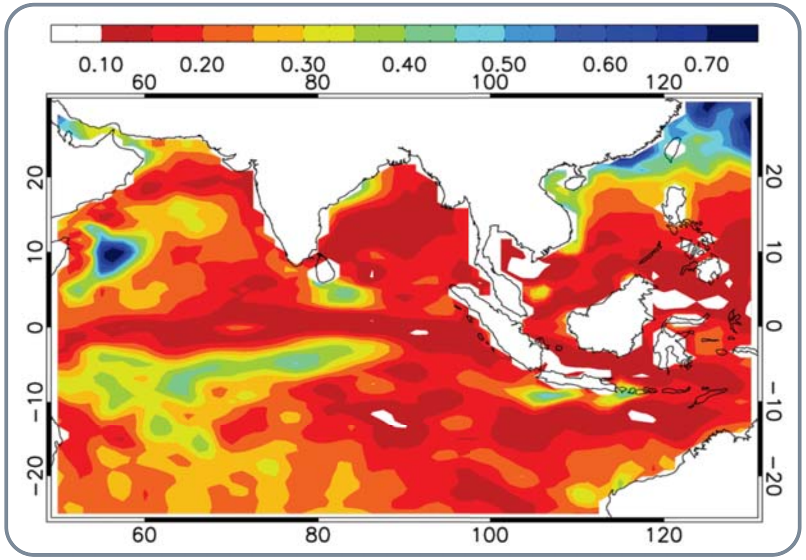
Walker INSTITUTE

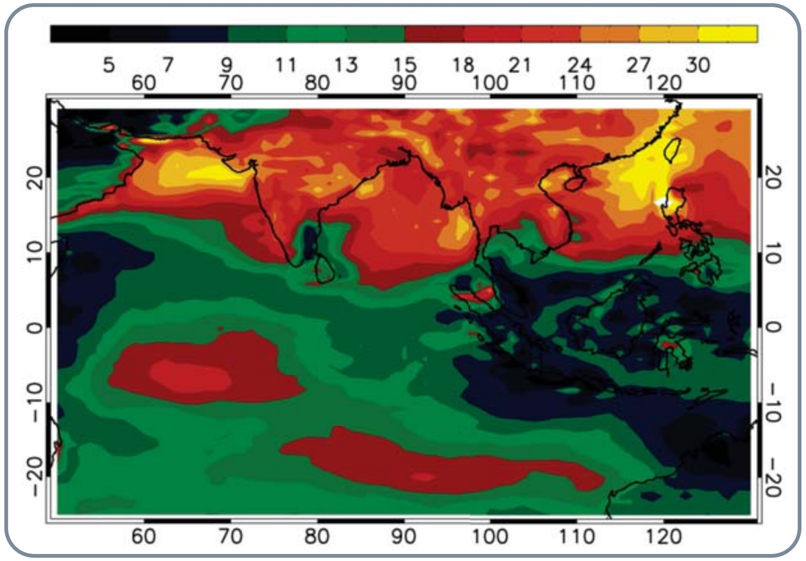


Intraseasonal Variability

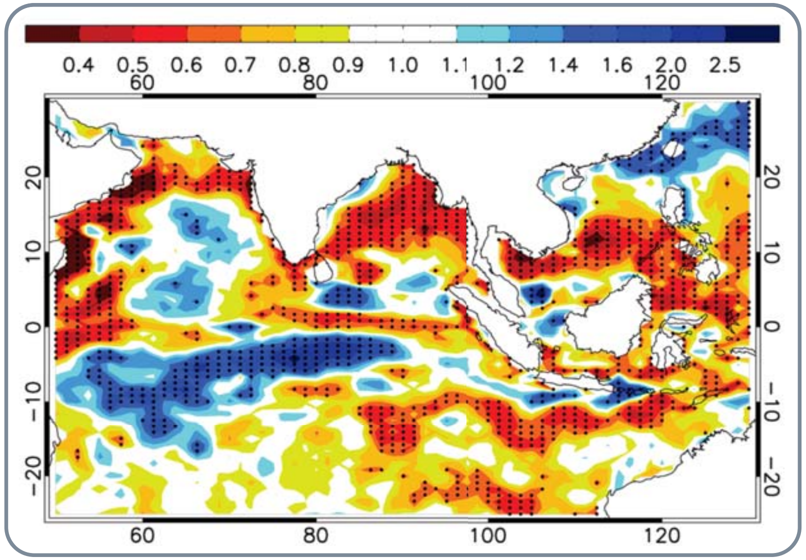
SST

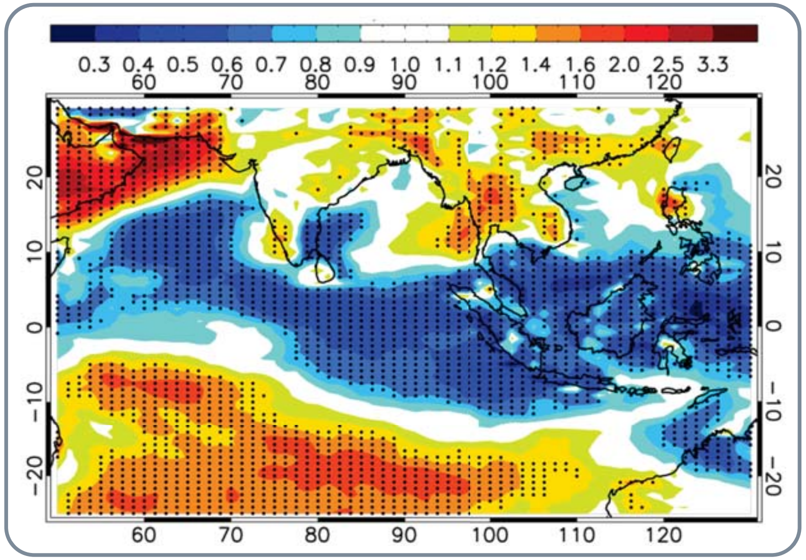
Net surface solar





HadKPP std. dev. of 30–50 day filtered quantity



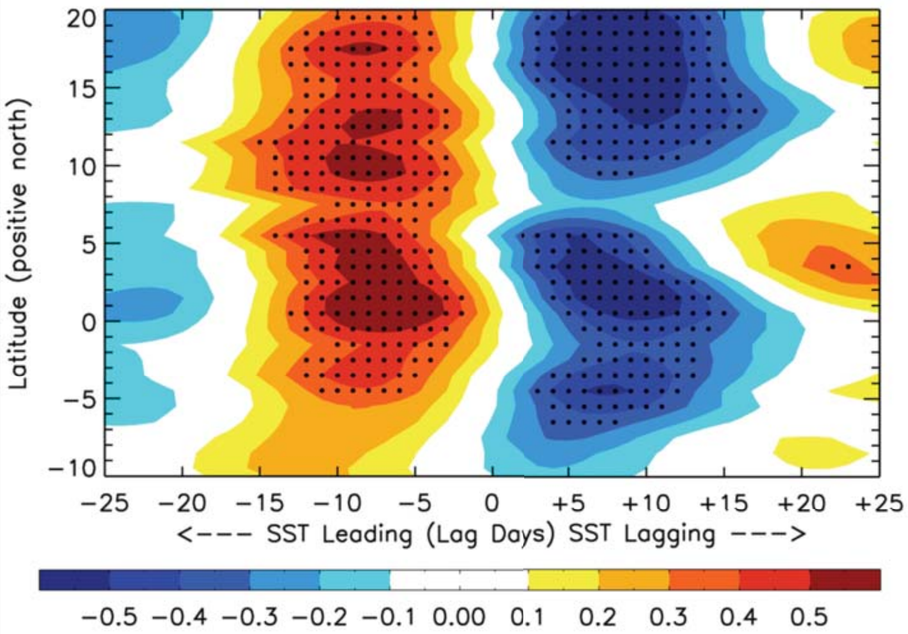


Ratio of HadKPP std. dev. to std. dev. from (left) TMI (right) ERA

Quadrature and Coincidence

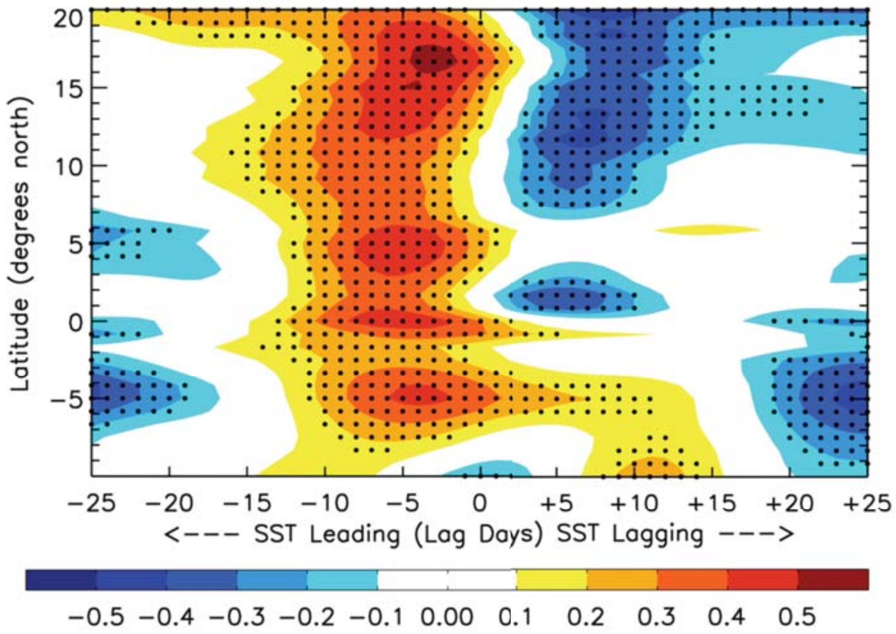
Walker INSTITUTE

GPCP/TMI



Lead–lag correlations between 11-day linear trends in GPCP rainfall and TMI SST. Data were first area-averaged over 80–90°E. Filled circles indicate 95% confidence.

HadKPP



Lead–lag correlations between 11-day linear trends in HadKPP rainfall and SST. Data were first area-averaged over 80–90°E. Filled circles indicate 95% confidence.

Composite Events

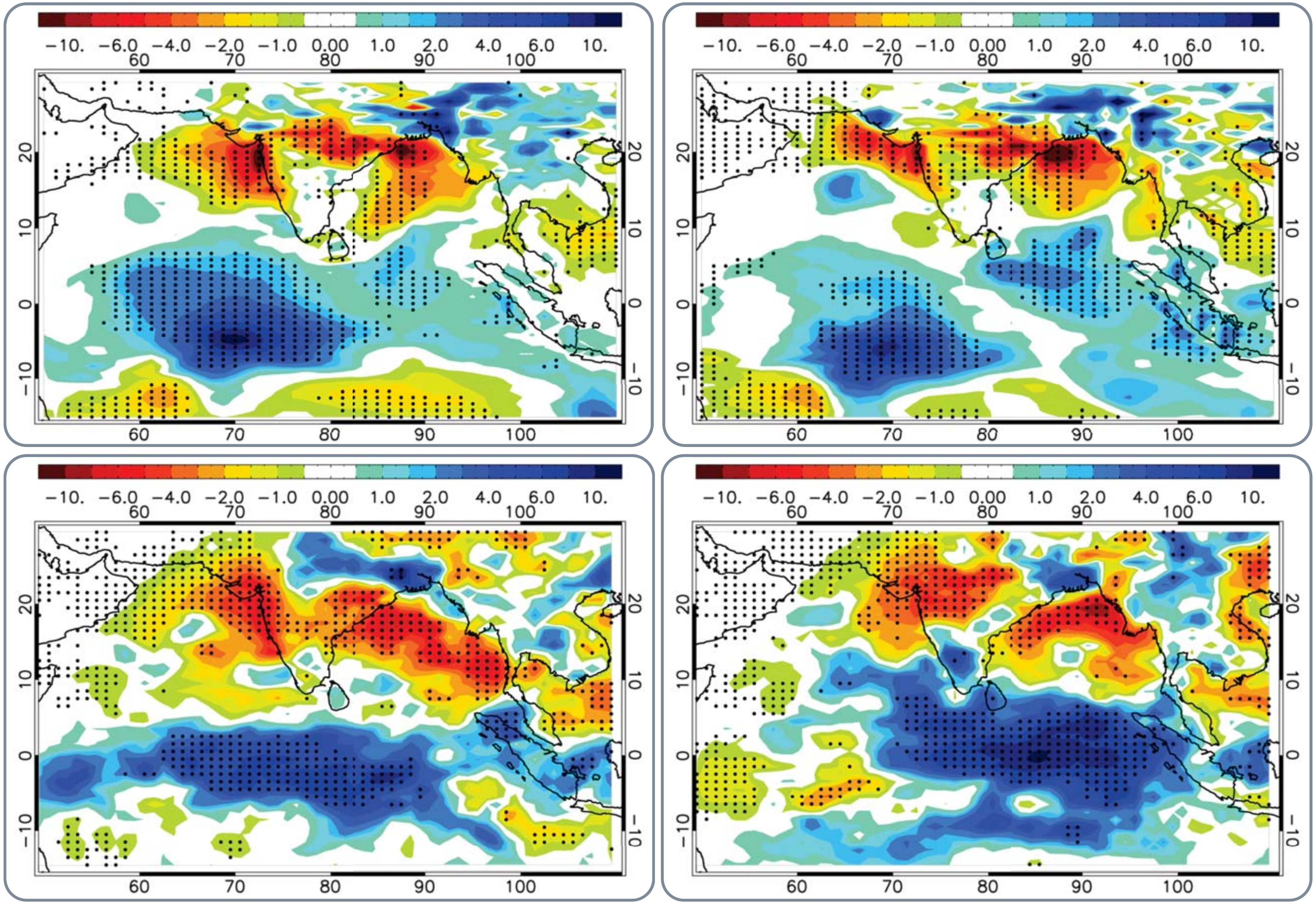
- For each ensemble member or year, area-average rainfall in two boxes:
  - ➡ 15°-25°N, 70°-90°E (land points) and 10°S-5°N, 60°-90°E (ocean points)
- Take the 11-day linear trend in the area-averaged rainfall.
- Subtract the trend in the ocean box from that in the land box.
- When this index is above (below) its mean plus (minus) one standard deviation for five consecutive days or more, the period is an active (break) event.

Composite	Event Type	Number of Events	Mean Length	Std. dev. of length
HadKPP	Active	33	8.0 days	2.5 days
	Break	39	8.4 days	3.5 days
Observations (10 years)	Active	15	8.1 days	1.6 days
	Break	14	8.6 days	2.6 days

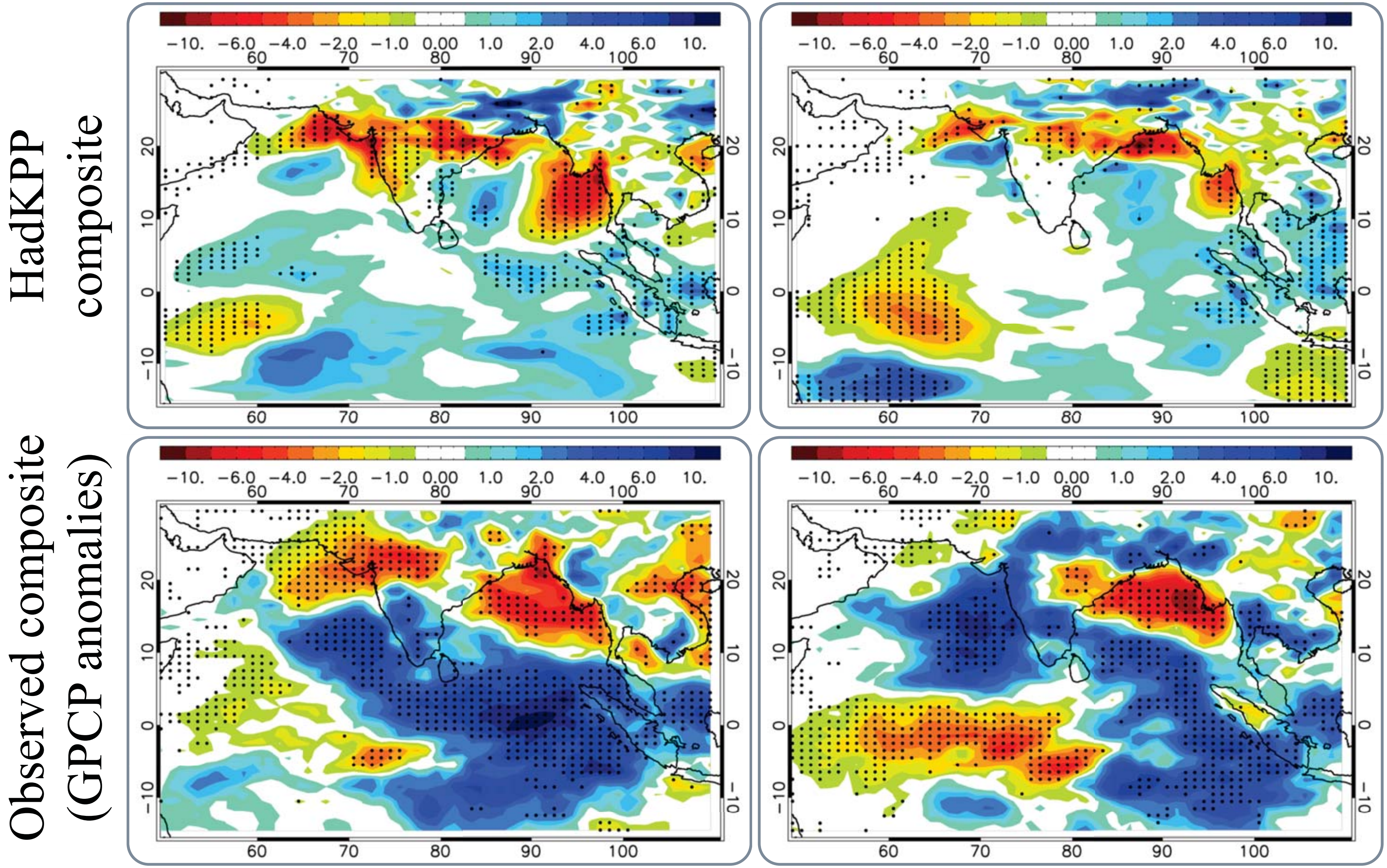
Composite Active Event - Rainfall

HadKPP composite

Observed composite (GPCP anomalies)



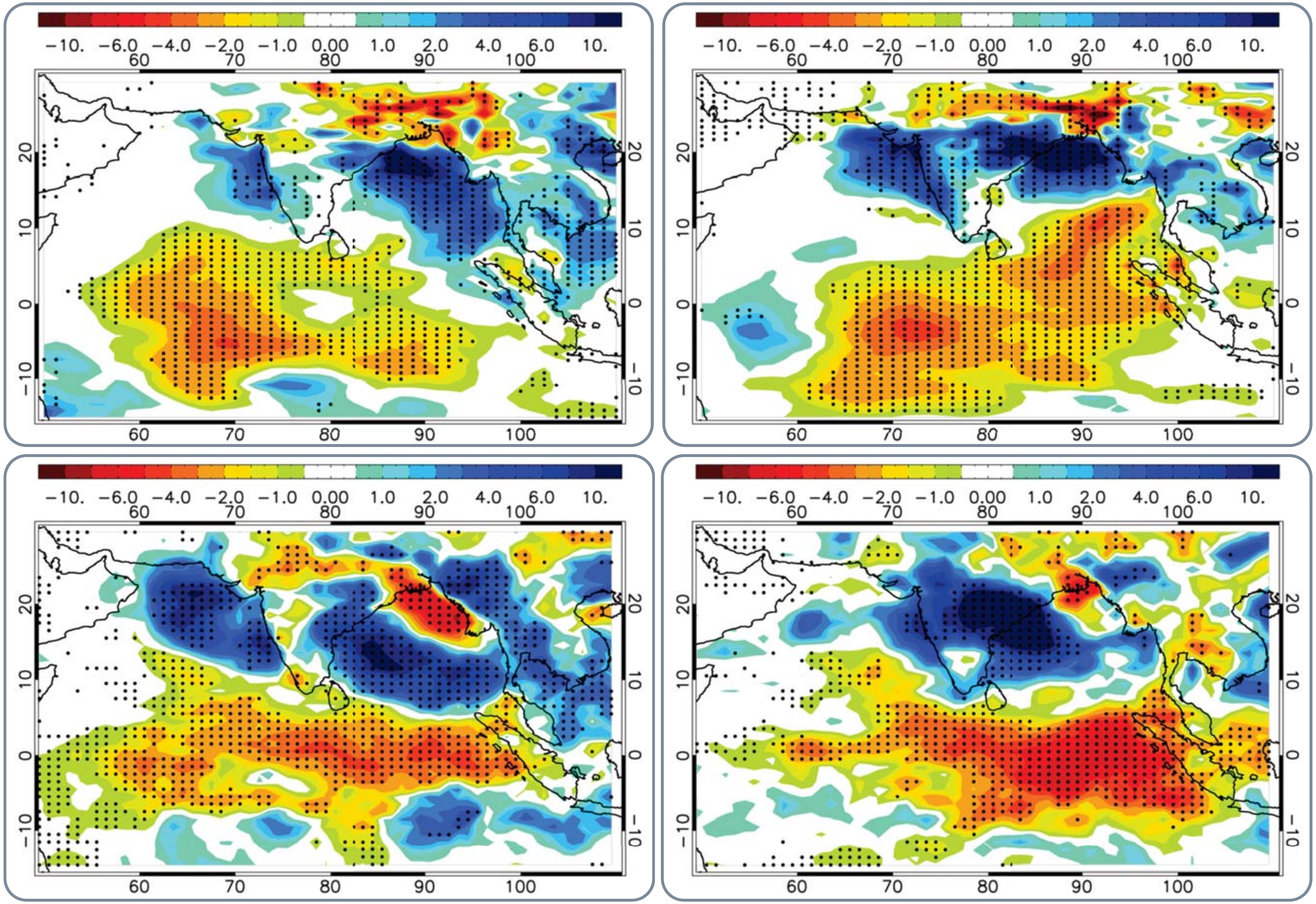
Composite Active Event - Rainfall



Composite Active Event - Rainfall

HadKPP composite

Observed composite (GPCP anomalies)

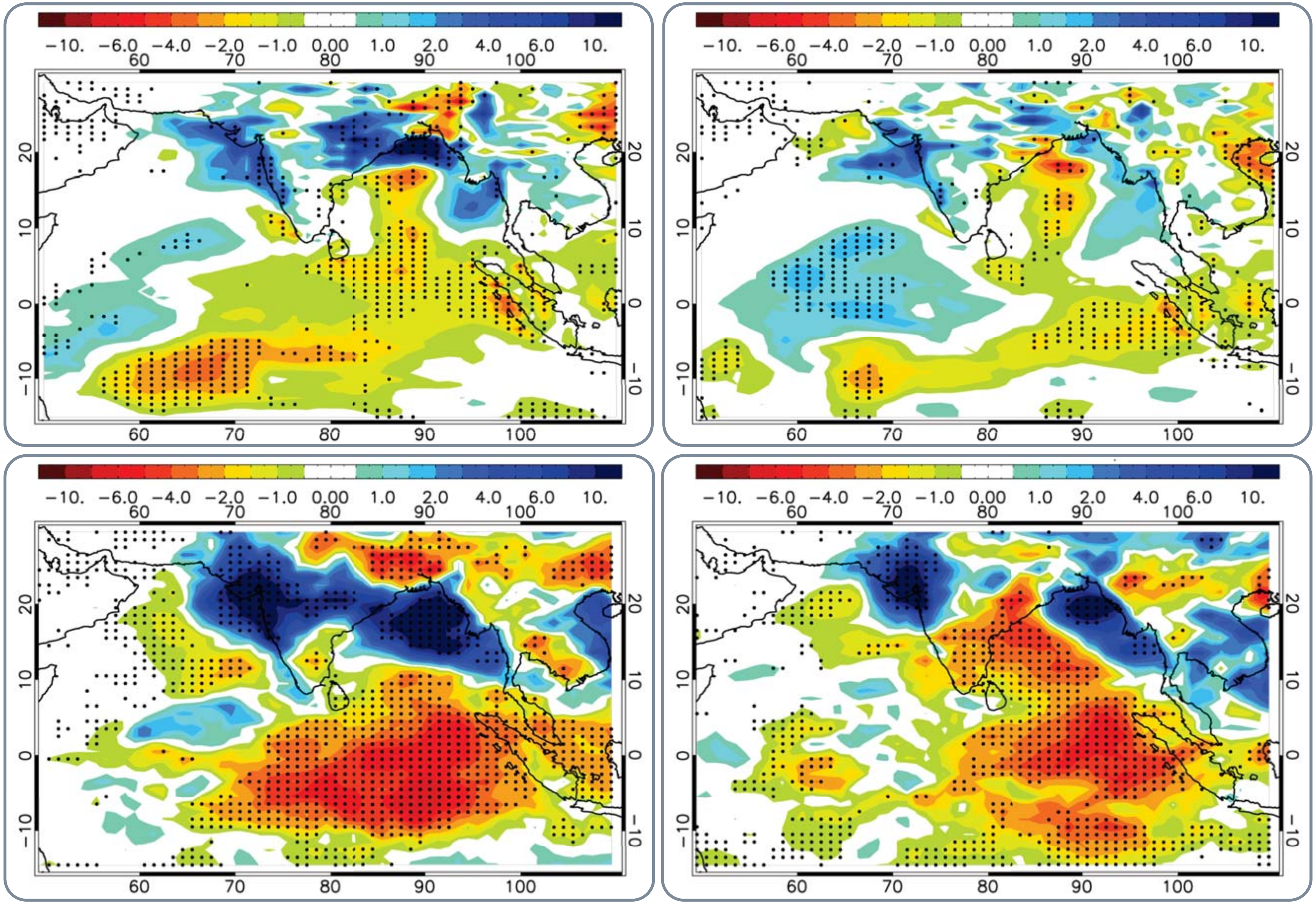


Composite Active Event - Rainfall

Walker INSTITUTE

HadKPP composite

Observed composite (GPCP anomalies)

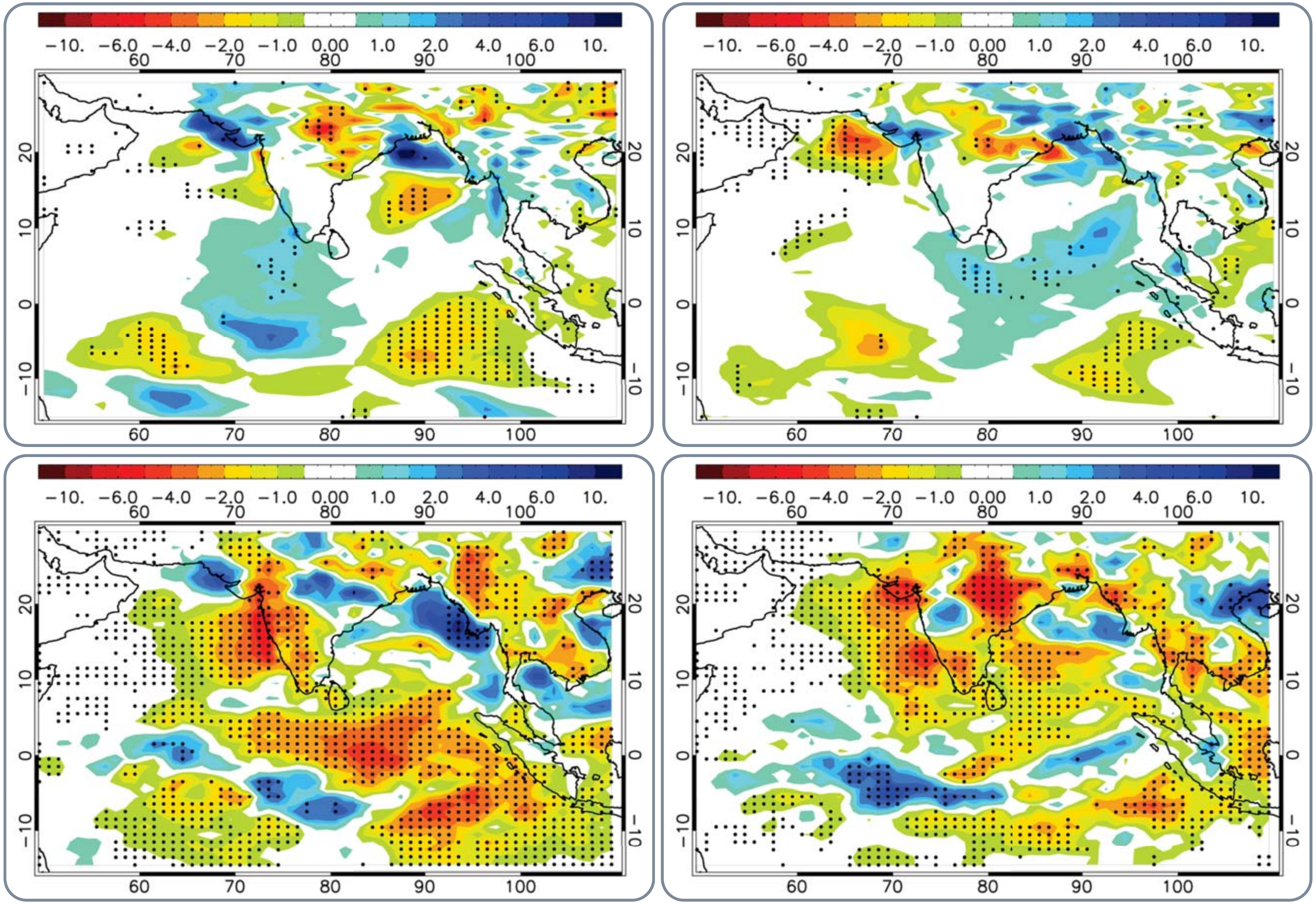


Composite Active Event - Rainfall

Walker INSTITUTE

HadKPP composite

Observed composite (GPCP anomalies)

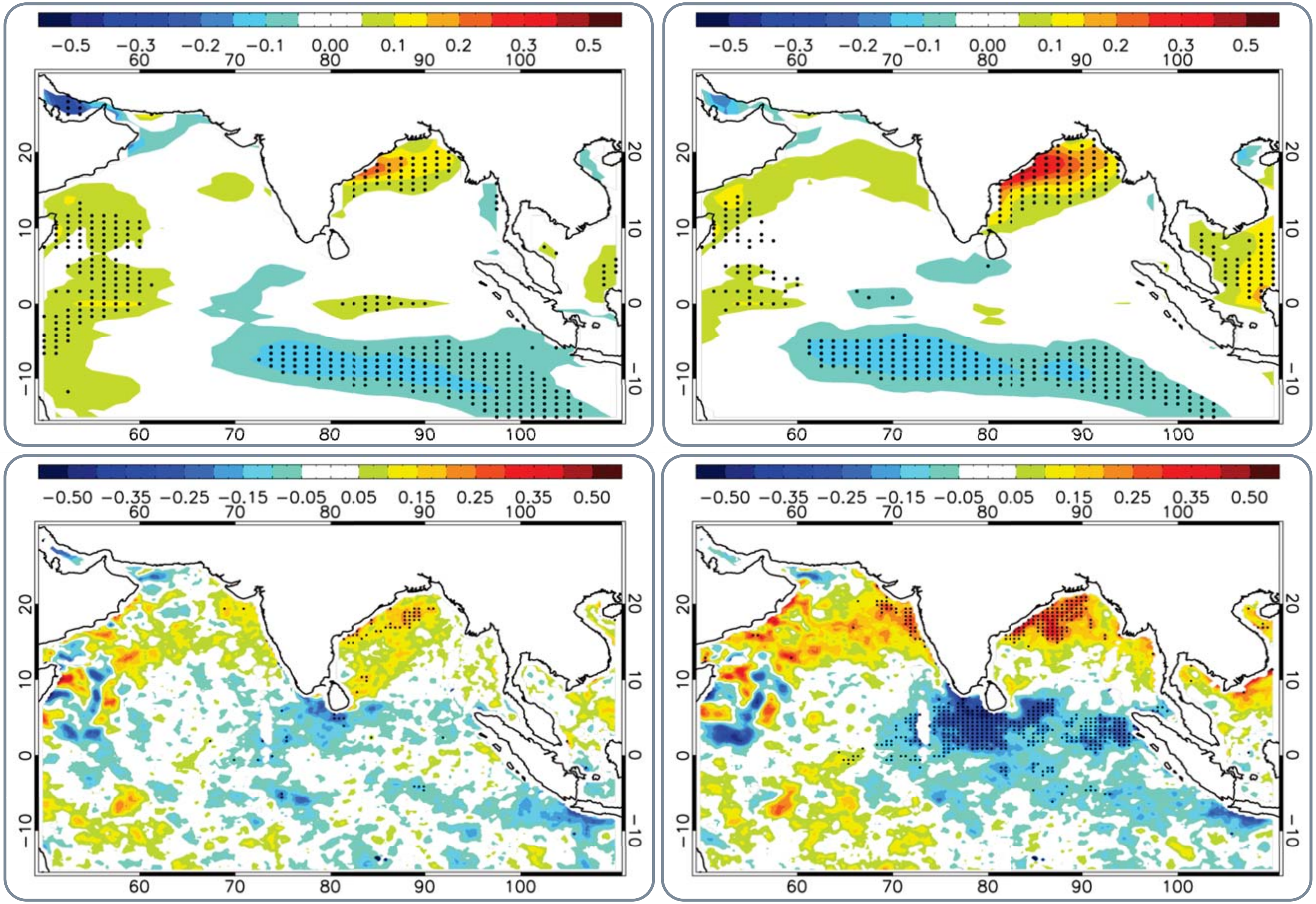


Composite Active Event - SST

Walker INSTITUTE

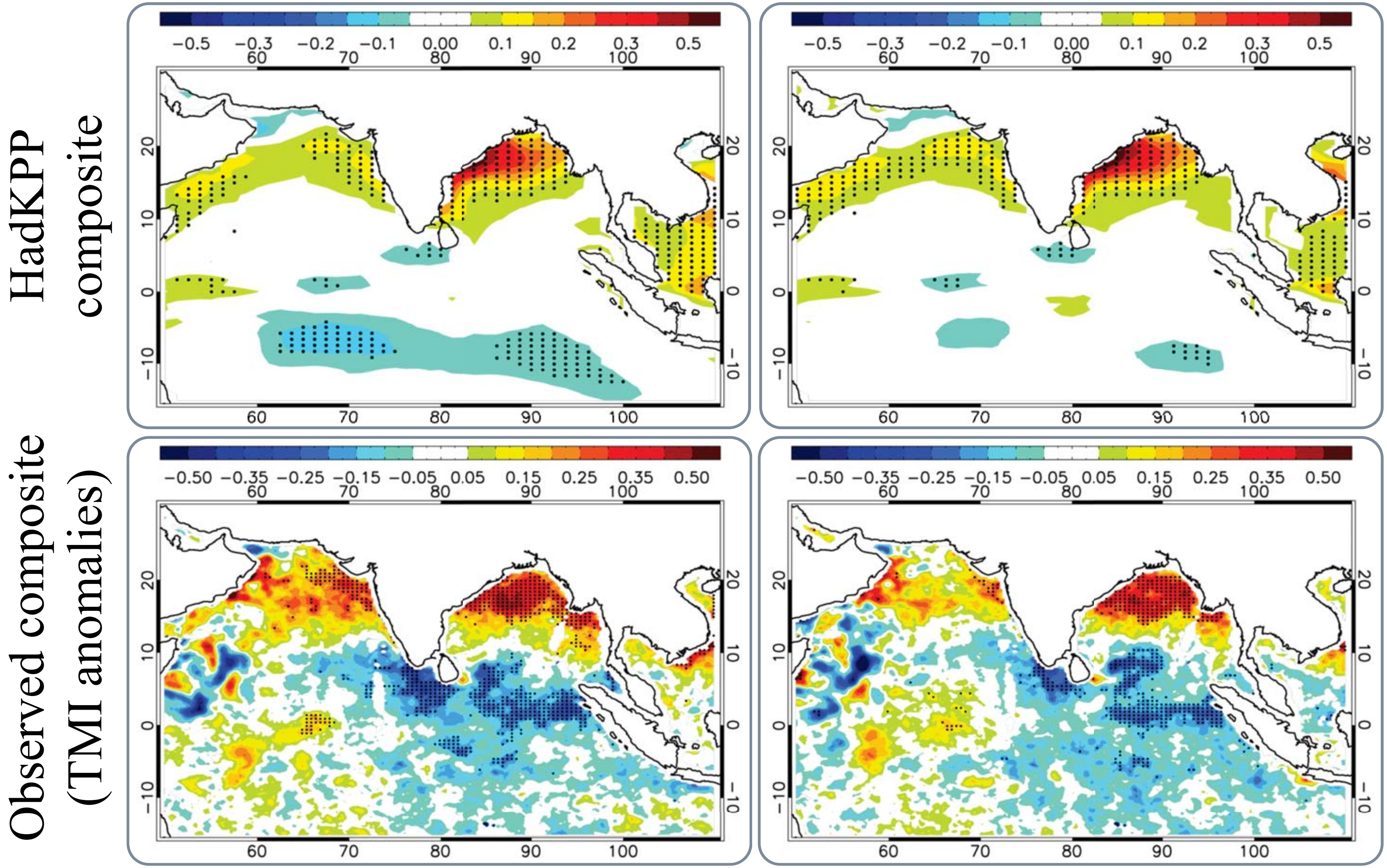
HadKPP composite

Observed composite (TMI anomalies)



Composite Active Event - SST

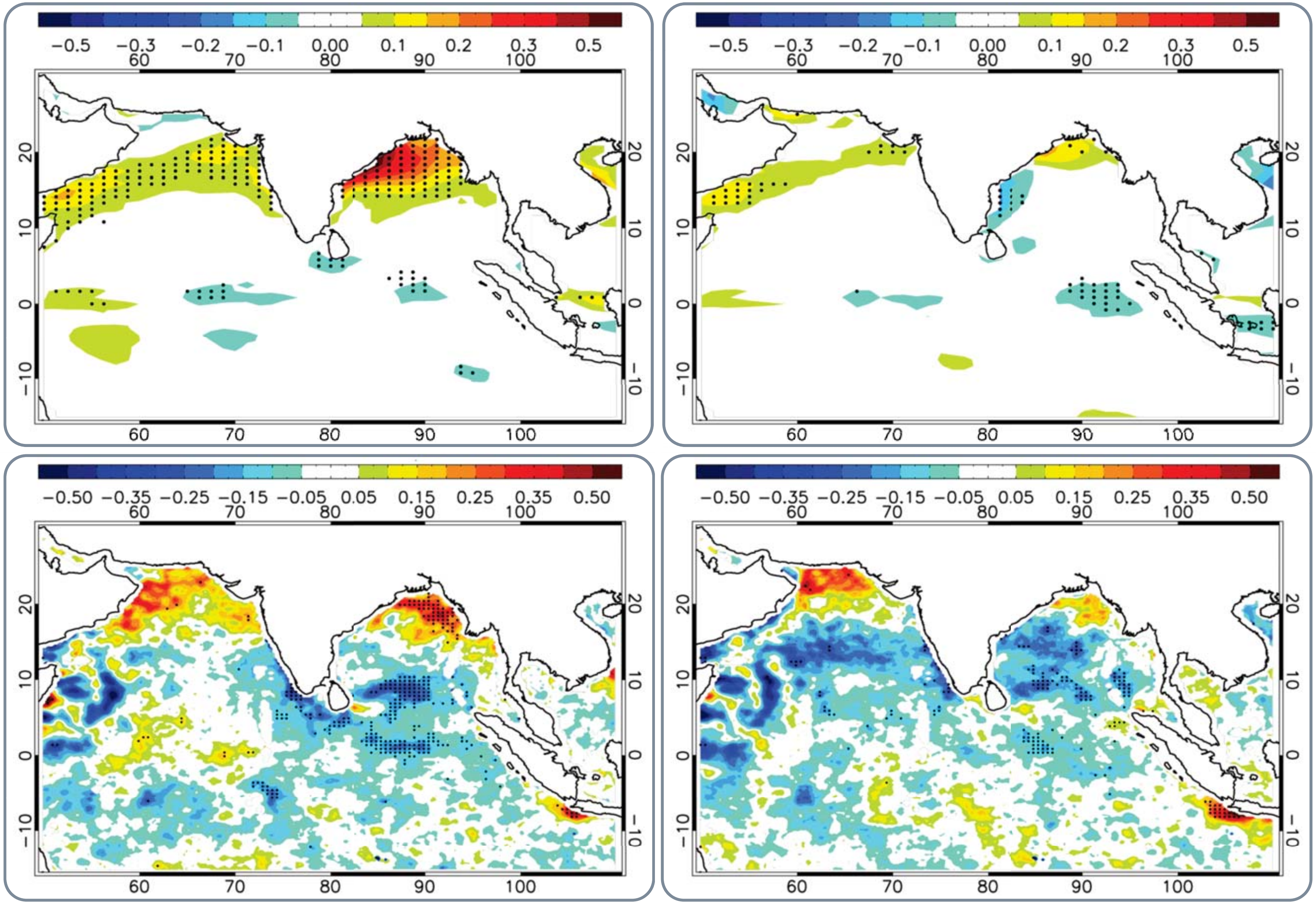
Walker INSTITUTE



Composite Active Event - SST

HadKPP composite

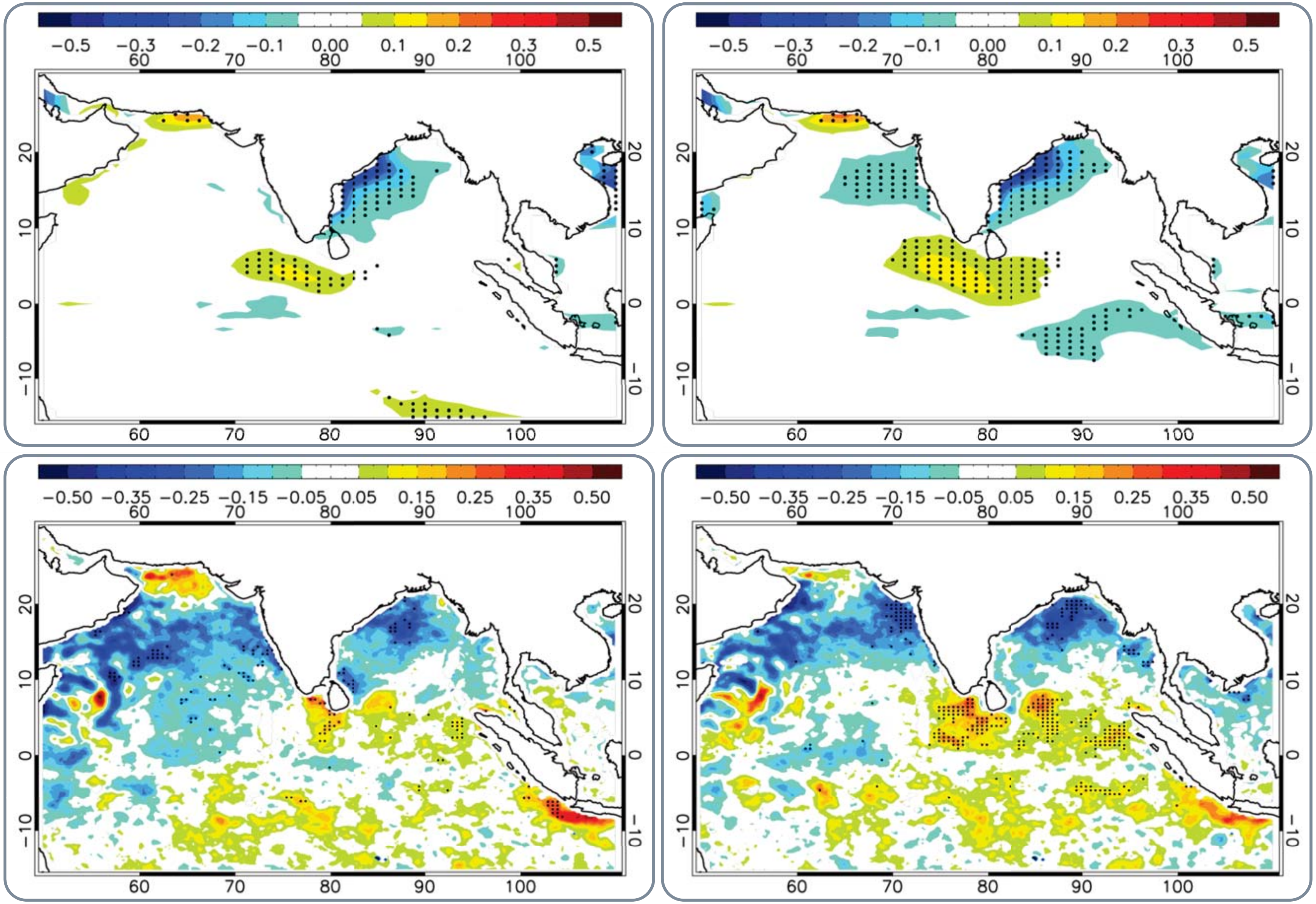
Observed composite (TMI anomalies)



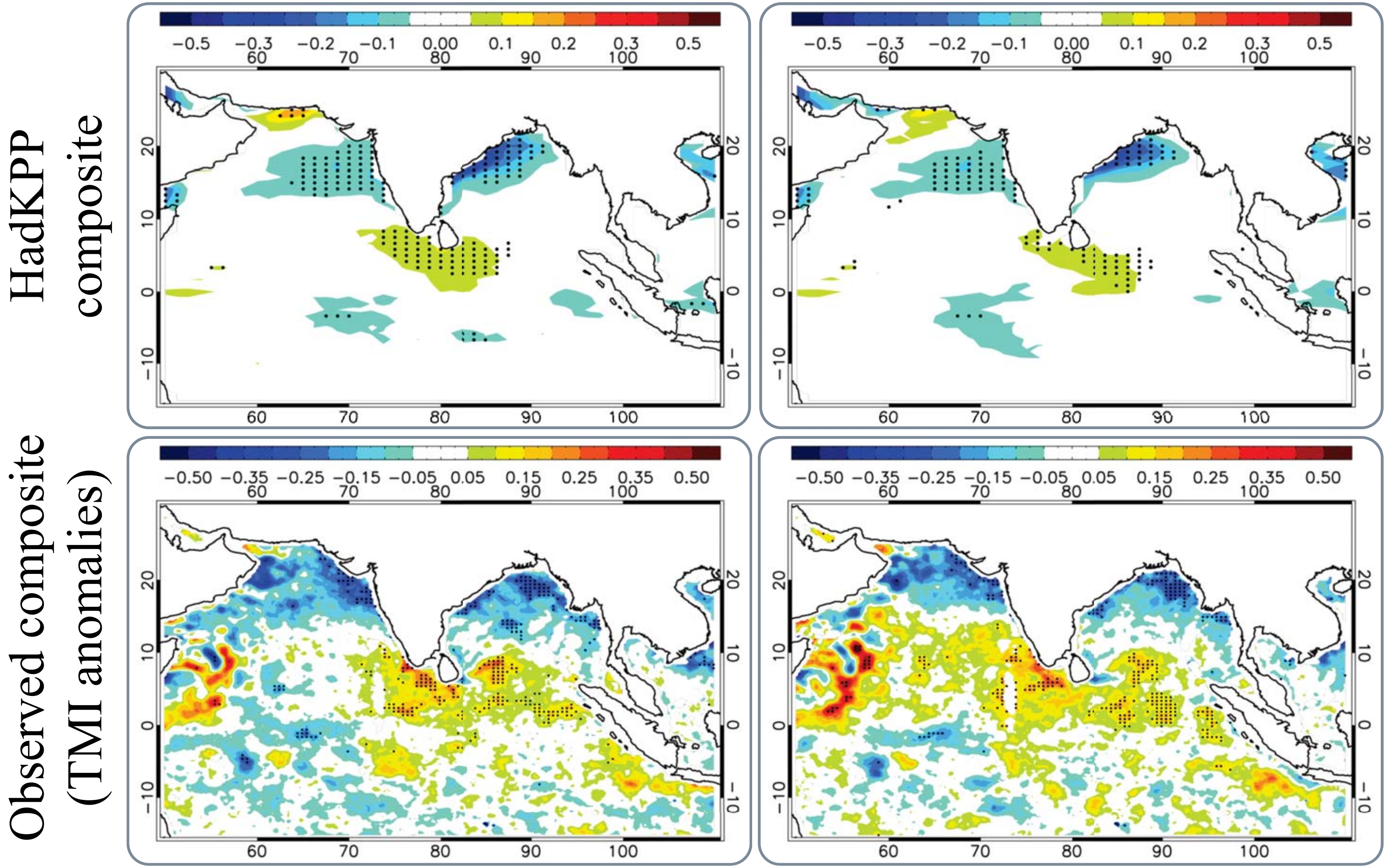
Composite Active Event - SST

HadKPP composite

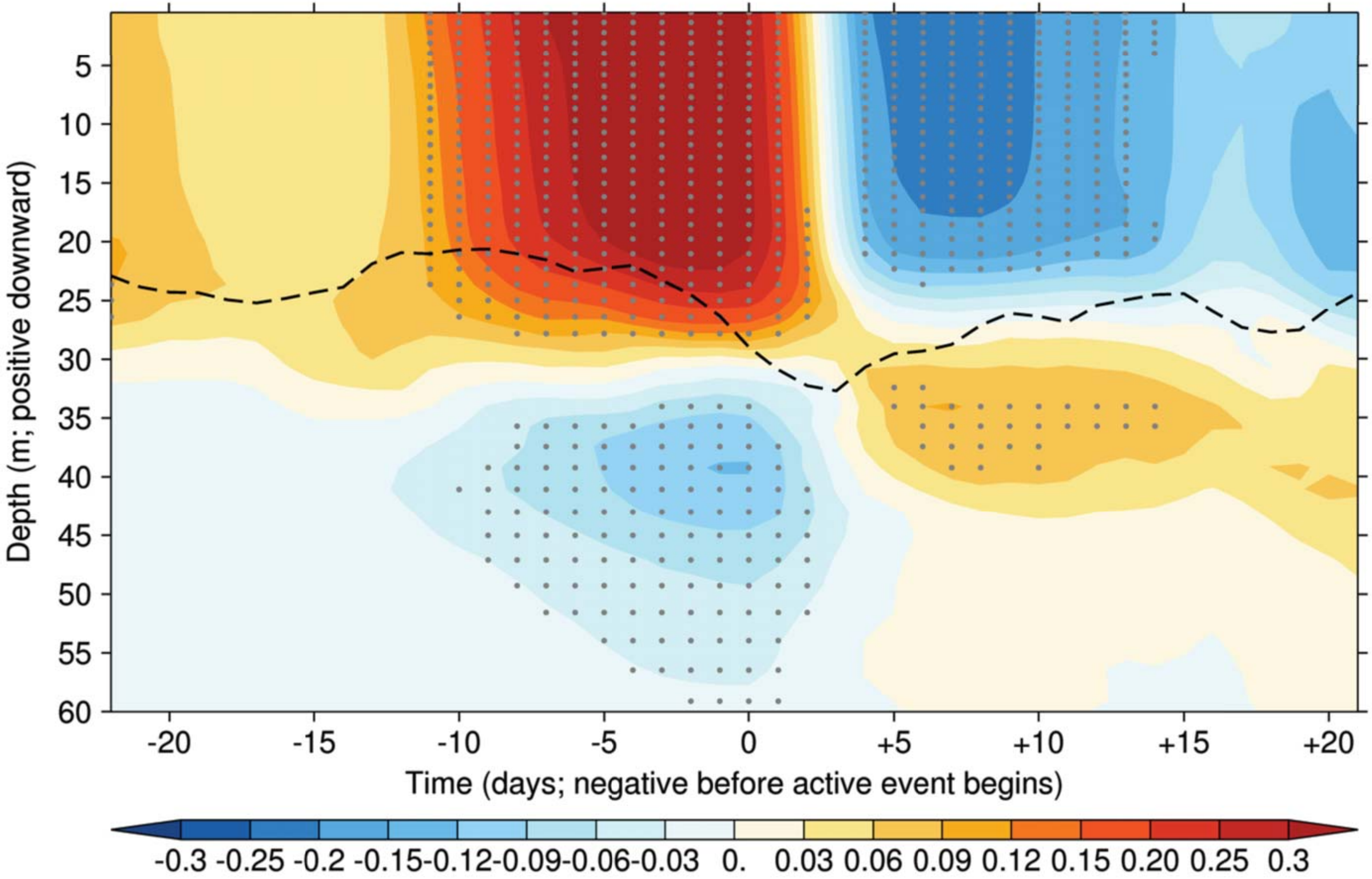
Observed composite (TMI anomalies)



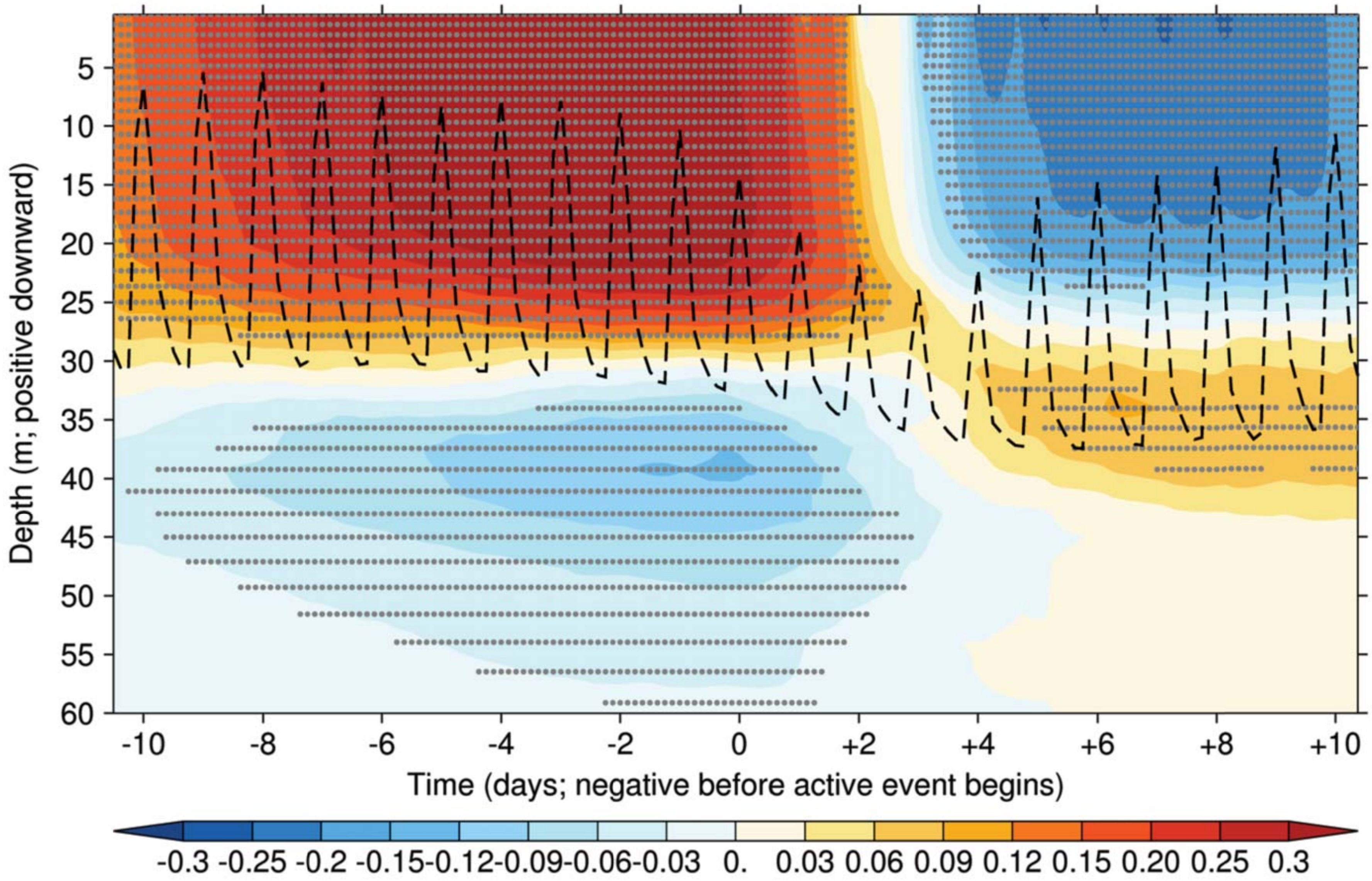
Composite Active Event - SST



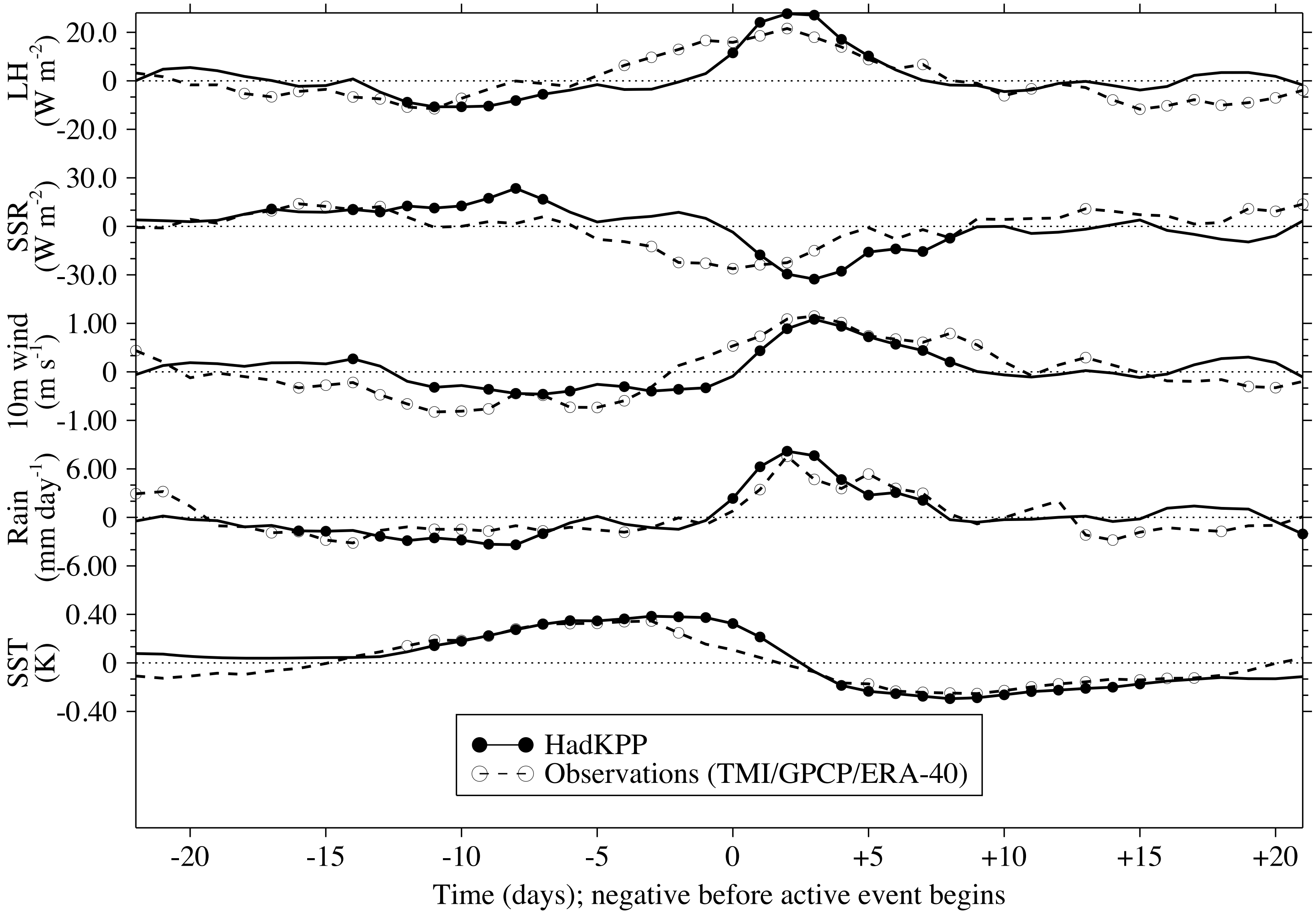
Composite Active Event - Mixed Layer and Diurnal Cycle



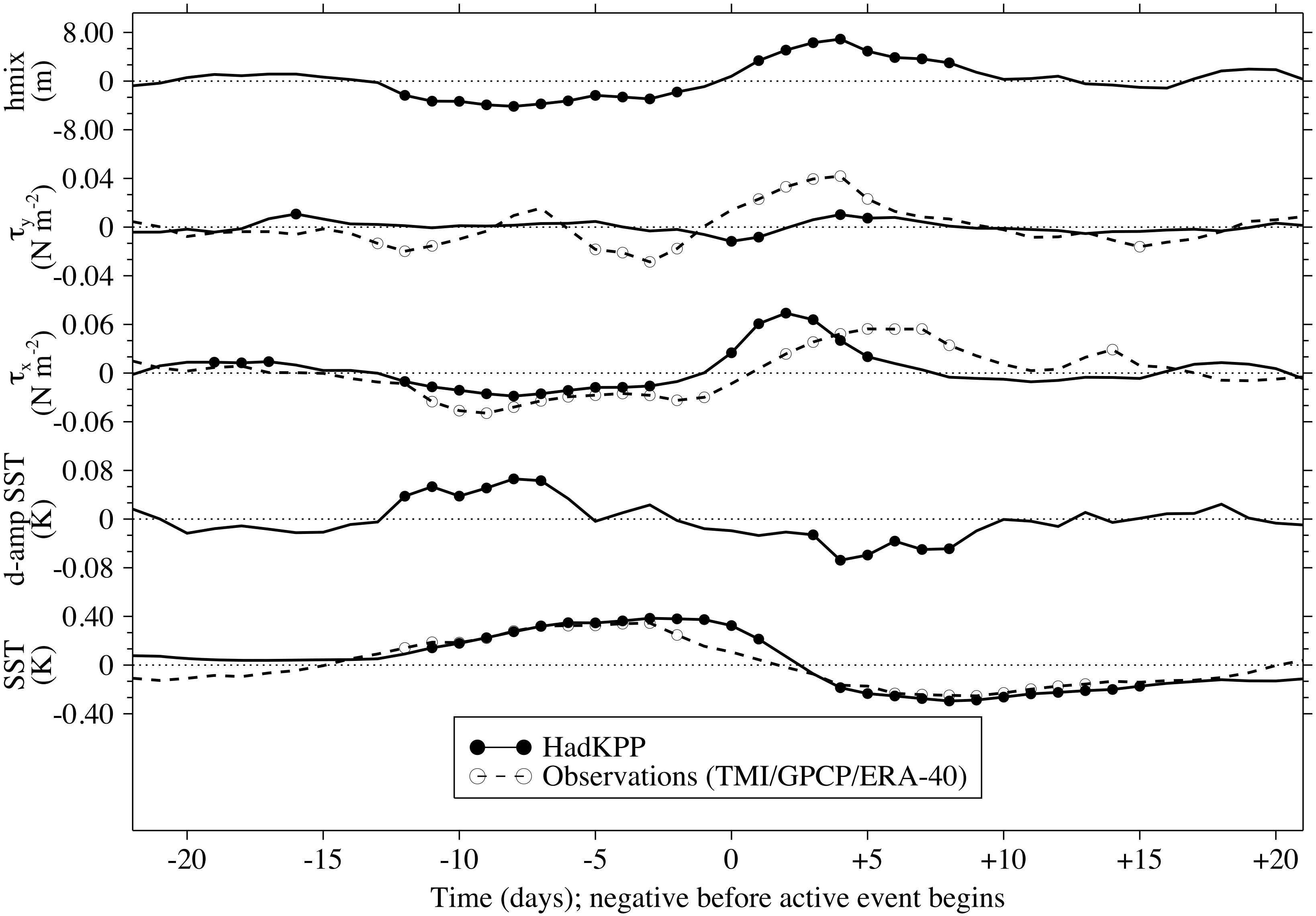
Composite Active Event - Mixed Layer and Diurnal Cycle



Composite Active Event - Time Series of Anomalies



Composite Active Event - Time Series of Anomalies



Conclusions

Walker INSTITUTE

- We have demonstrated that HadKPP can be used in experiments concerning the predictability of intraseasonal variability.
  - ➡ HadKPP has a fine vertical resolution and diurnal coupling.
  - ➡ The addition of atmosphere-to-ocean feedbacks corrects the erroneous coincident SST–rainfall phase relationship in HadAM3.
  - ➡ The HadKPP ensemble members contain variability in intraseasonal rainfall that is in-line with IMD observations.
  - ➡ HadKPP composite events are similar to the observed composite in rainfall and SST, except for in the eastern equatorial Indian Ocean, where errors are likely due to low intraseasonal variability in surface fluxes from HadAM3.
  - ➡ In regions where the surface forcing is sufficient, KPP reproduces the temporal evolution of TMI SST anomalies during the composite active event.
- Forecast models must include an interactive ocean if the lead time is longer than the persistence time scale of SST anomalies.