The influence of SST changes on the MJO variability

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Outline

- MJO Introduction
- The role of the SST in the MJO formation
- Modeling Results
- SST variability sensitivity experiments
- Conclusions

MJO Overview

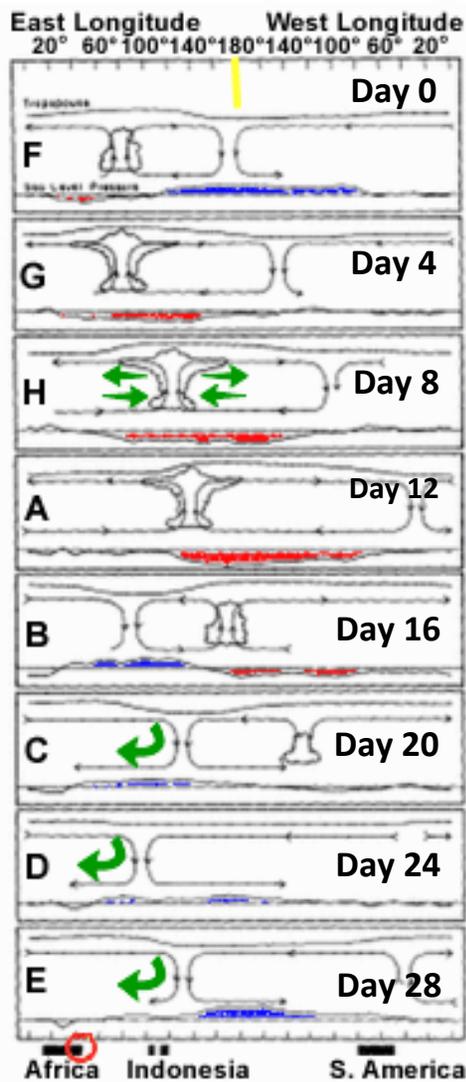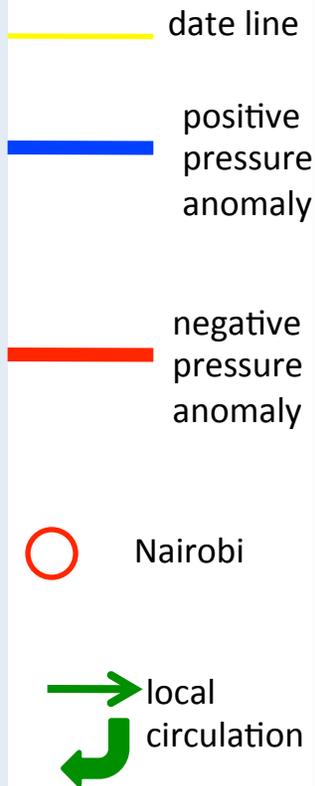Rolland Madden (left) and Paul Julian (right)

MJO life-cycle

East Longitude   West Longitude
20° 60°100°140°180°140°100° 60° 20°

date line

positive pressure anomaly

negative pressure anomaly

○ Nairobi

→ ⤷ local circulation

Day 0
Day 4
Day 8
Day 12
Day 16
Day 20
Day 24
Day 28

F G H A B C D E

Africa   Indonesia   S. America

Madden and Julian 1972

– Convection builds up in the Indian Ocean first, so this would be the initial time of an MJO

– Circulation cell east to the convection anomaly reaches only to the date line

– Circulation cell to the west has strong upper tropospheric easterlies

– Low pressure anomaly in the Indian Ocean propagates rapidly eastward

– A: Two symmetric circulations

– C: Weak convection but not coupled to the circulation

– E: High pressure at Canton is maximum

Adapted from:
http://www.meted.ucar.edu/climate/mjo/

What drives the MJO?

The 30–40 Day Oscillations Simulated in an "Aqua Planet" Model

By Yoshi-Yuki Hayashi and Akimasa Sumi

- SST distribution is symmetric about the equator and uniform in the zonal direction; derived from April temperature climatology
- Solar declination fixed at equinox; diurnal variation allowed

Findings
- "Spontaneous appearance of a collective motion of convective activity together with an east-west wavenumber one circulation resembling the observed 30-60 day oscillation in the atmosphere"
- "No moist processes result in the abrupt disintegration of the 30 day oscillation into Kelvin and Rossby waves. **Strong mode coupling between the equatorial free waves is required to maintain the 30-day oscillation**"
- " The 30-60 day oscillation in the atmosphere is the result of the intrinsic nature of the atmospheric circulation , although it is modified by the non-zonal distribution of SST"

What drives the MJO?

Origin of Low-Frequency (Intraseasonal) Oscillations in the Tropical Atmosphere.
Part I: Basic Theory

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(Manuscript received 12 March 1986, in final form 6 October 1986)

ABSTRACT

A theory of the origin of intraseasonal oscillations of the tropical atmosphere is presented and tested by simple model experiments. This study focuses on the validation of the basic theory against key features of the observed 40–50 day oscillation. It is shown that the observed eastward propagation of intraseasonal oscillation in the tropical atmosphere arises as an intrinsic mode of oscillation resulting from an interaction of convection and dynamics via the so-called "mobile" wave–CISK mechanism. Through this mechanism, the heat source feeds on the east–west asymmetry of forced equatorial waves. As a result, Kelvin waves are selectively amplified, which in turn causes the heat source to propagate eastward. This mechanism also prevents small-scale waves from immediate destabilization, contrary to the results of traditional wave–CISK theory. The "mobile" wave–CISK establishes a new dynamical equilibrium state between convection and the wind field to form a wave packet or collective motion with relatively fixed horizontal and vertical structure. Relative to the steady state solutions with stationary heat source, the new equilibrium state has suppressed Rossby-wave response to the west and enhanced Kelvin-wave response to the east of the propagating heat source.

Results also suggest that the periodicity of the oscillation is determined by the time taken for the Kelvin wave to complete one circuit around the globe in the equatorial region. The propagation speed (~19 m s⁻¹) of the model disturbance, which is about twice as fast as the observed, is found to coincide with the real part of the complex phase speed of the model's unstable normal mode modified by internal heating. The speed and the growth rate are dependent on the vertical structure of the heating profile and the static stability of the basic state. In addition to the eastward propagation, many observed features, such as pressure and wind distribution, amplitude modulation by SST, and dominance of low wavenumber response, are well simulated in the idealized experiments. The theory also predicts that the low-frequency disturbance should have a westward tilt with height. This is partially confirmed in real observation and in GCM simulations. While the basic theory appears to explain some fundamental features of the 40–50 day oscillation, large discrepancies still exist. The possibility of examining further detailed features of the oscillation in the present theoretical framework is also discussed.

MJO-SST Relationship in Observations

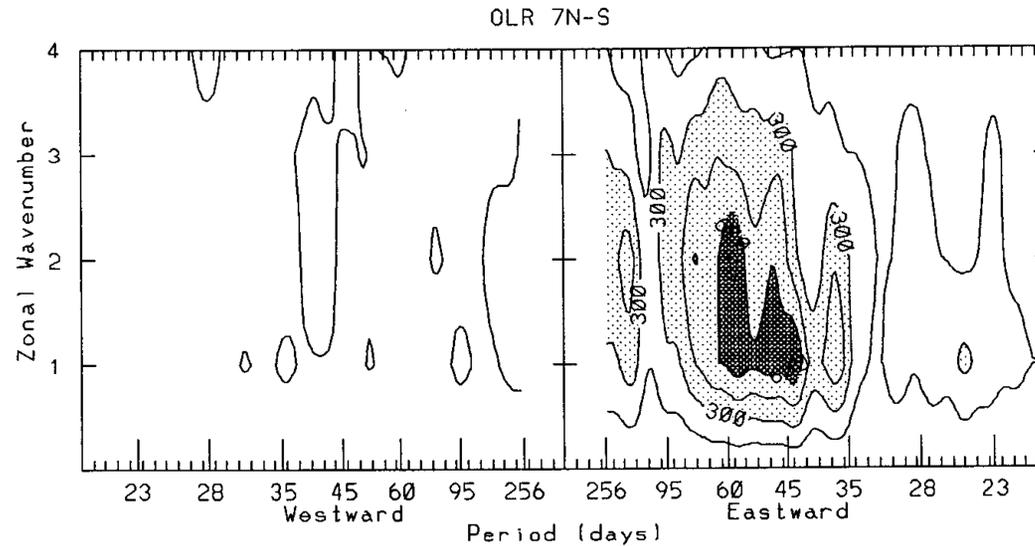Salby and Hendon, 1994; Hendon and Salby, 1994

OLR 7N-S

FIG. 5. Space–time spectrum of OLR averaged between 7°N and 7°S.

"Confinement of convective anomaly to the eastern hemisphere reflects comparatively **cold SST** east of the date line, reduced surface moisture, and a concomitant reduction of climatological convection. Anomalous convection amplifies over the **warmest equatorial waters** in the Indian Ocean and western Pacific, where the boundary layer is moisture laden."

January mean SST

July mean SST

Li and Wang., 1994
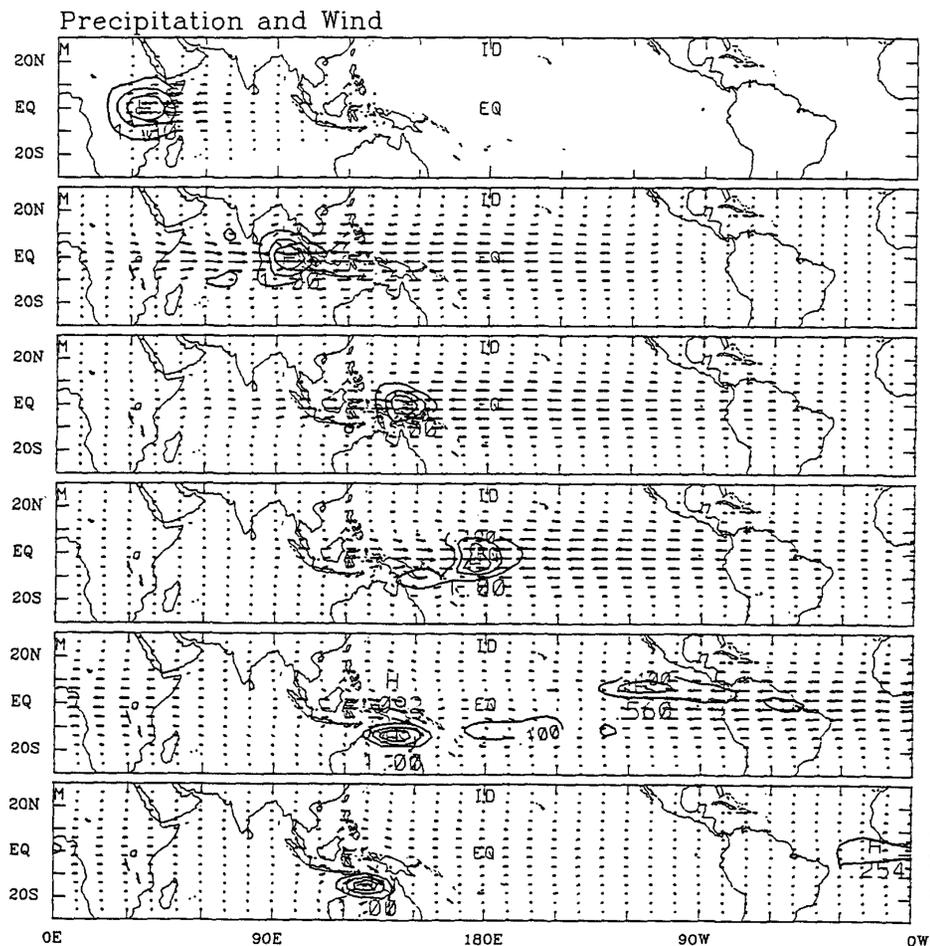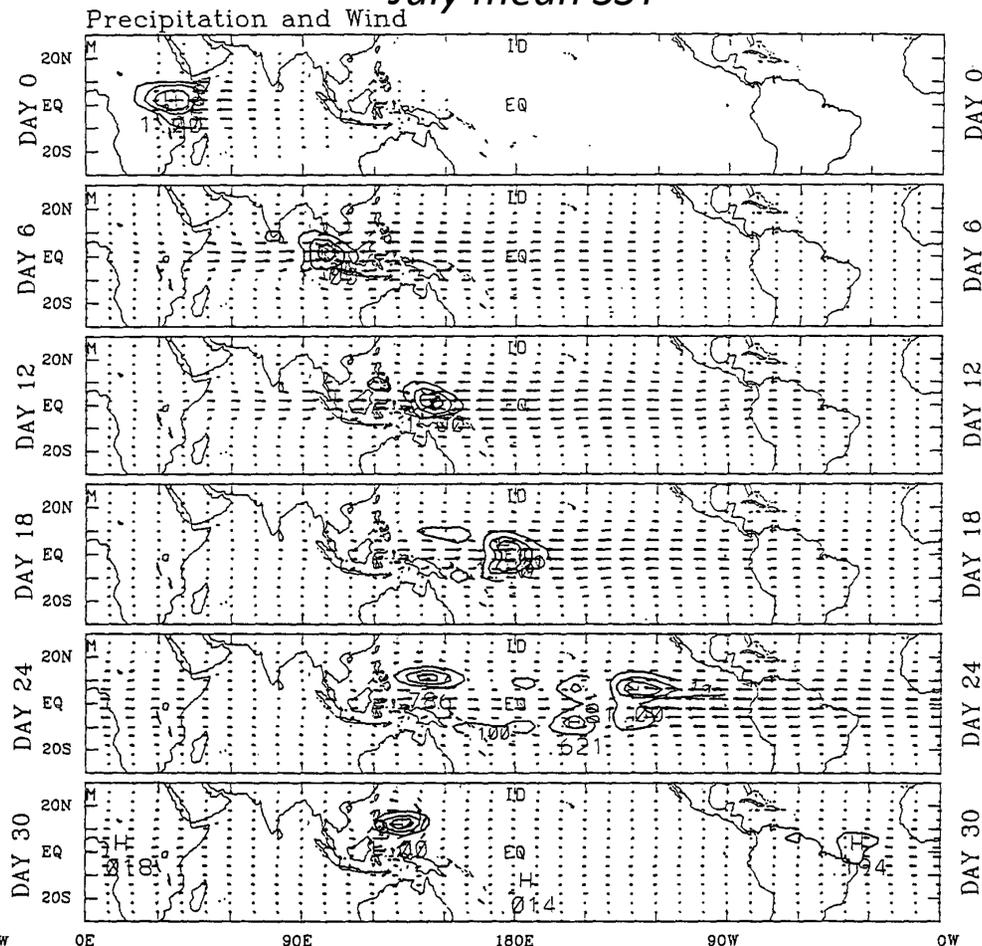
Observational Evidence

TOGA-CORE
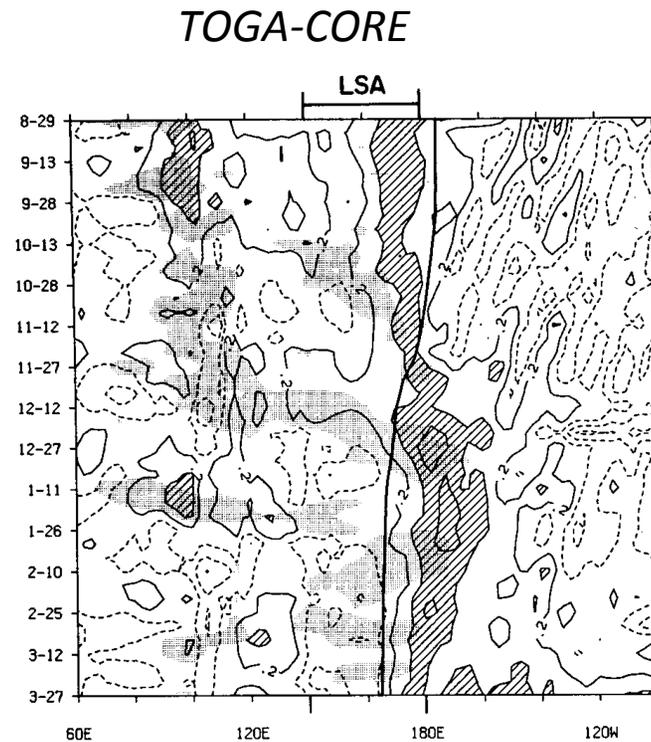
FIG. 9. Hovmöller diagram of pentad SSTA averaged between 5°S and 5°N for September 1992–March 1993, with vertical axis labels and LSA marked as in Fig. 8. Contour interval 0.4°C (±0.2°C, ±0.6°C, etc.; note the absence of a zero contour) with negative contours dashed and positive SSTA > 0.6°C hatched. Heavy solid line shows the easternmost extent of climatological SST ≥ 29°C. Light shading denotes OLR < 200 W m^{-2}, adapted from Fig. 8.

Gutzler et al., 1994

Charge-Recharge MJO Theory
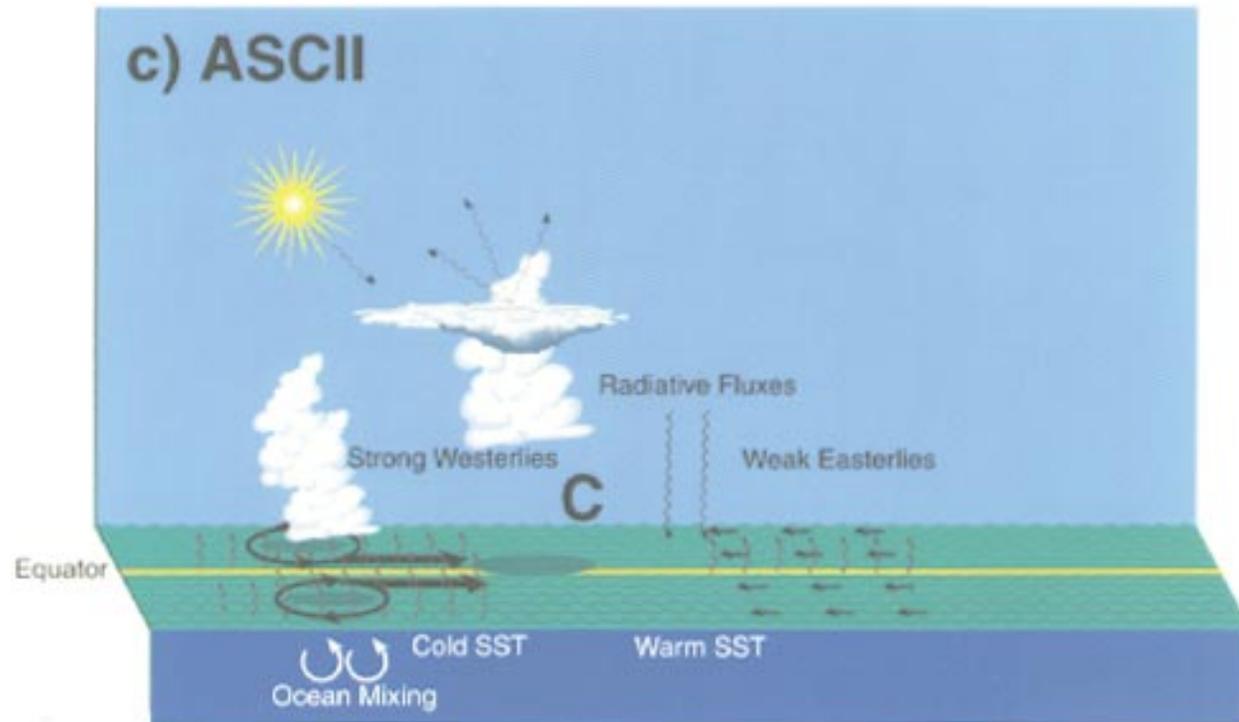
- Mutual interaction between the equatorial convection and SST
- Forcing of the Kelvin wave is provided by the SST distribution

Flatau et al., 1994

MJO-SST interaction

Nov 1987/May 1988
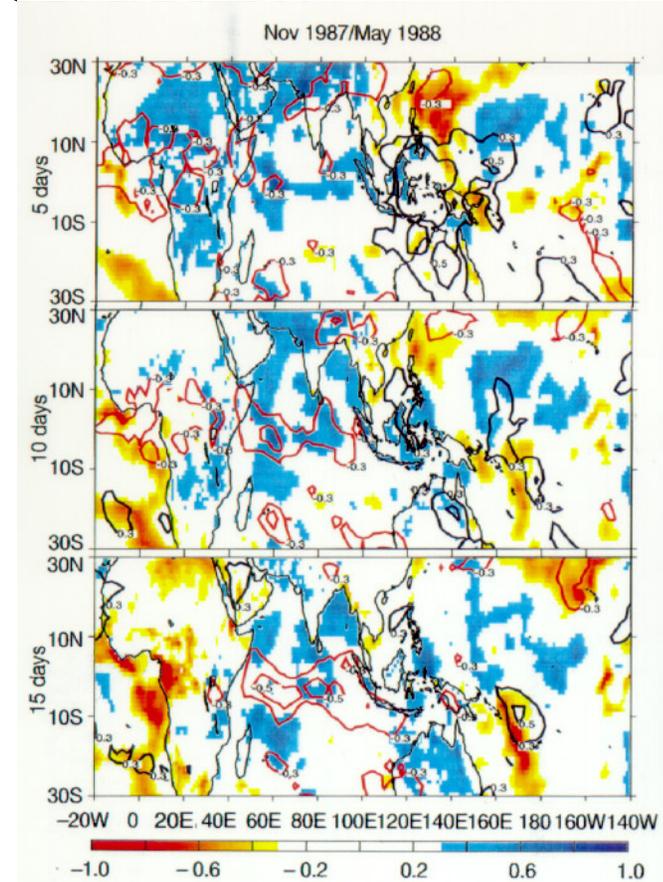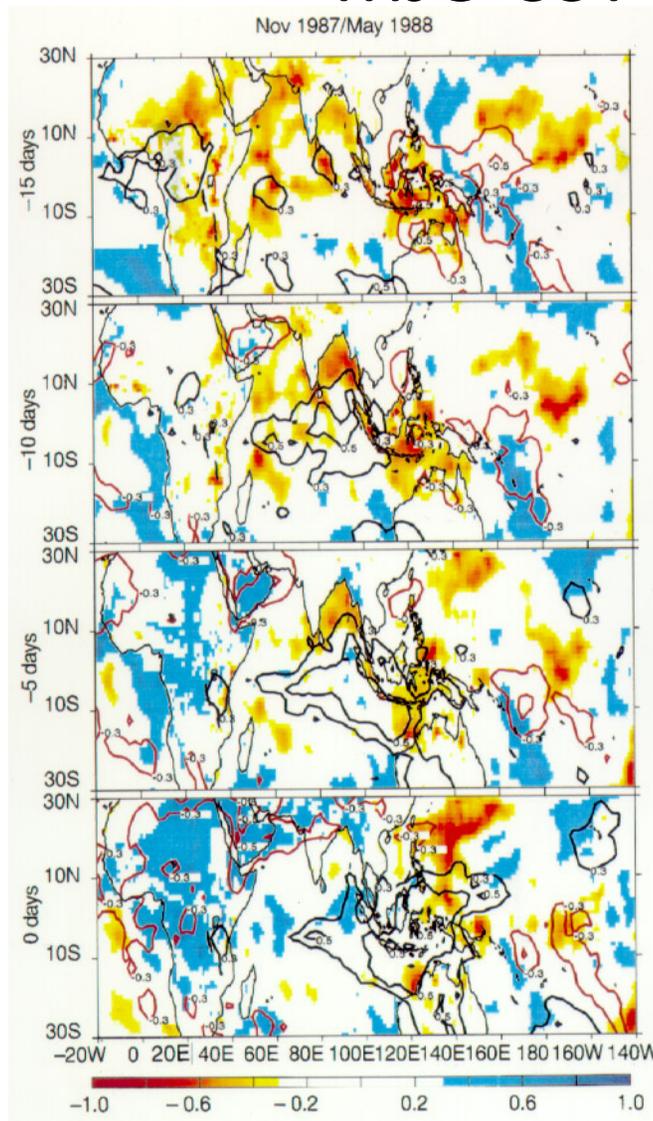
warm SST
suppressed convection

cold SST
enhanced convection

Sperber et al., 1997

MJO-SST Relationship during Dynamo

TMI
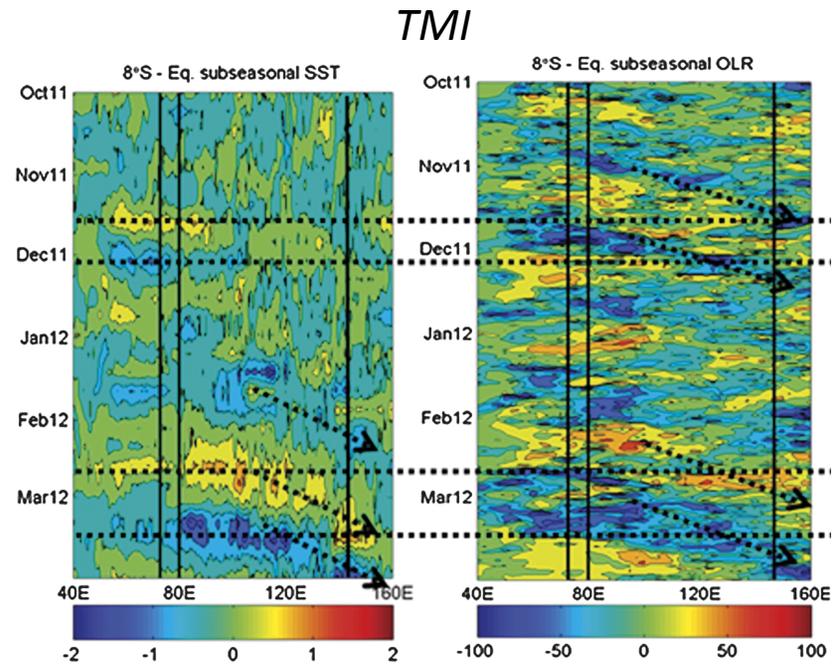
Fig. 19. Time-longitude diagrams of subseasonal variations of (left) SST (^{0}C), (right) OLR (Wm^{-2}). All variables are averaged between 8^0S and the equator, which where the DYNAMO latitudes. The vertical thick lines show the longitudinal location of the DYNAMO observing system and Manus. Diagonal lines indicate propagating features. Horizontal dashed lines allow for easier comparison of the timing of SST and OLR subseasonal variations.

Gottschalck et al., 2013

Modeling Studies
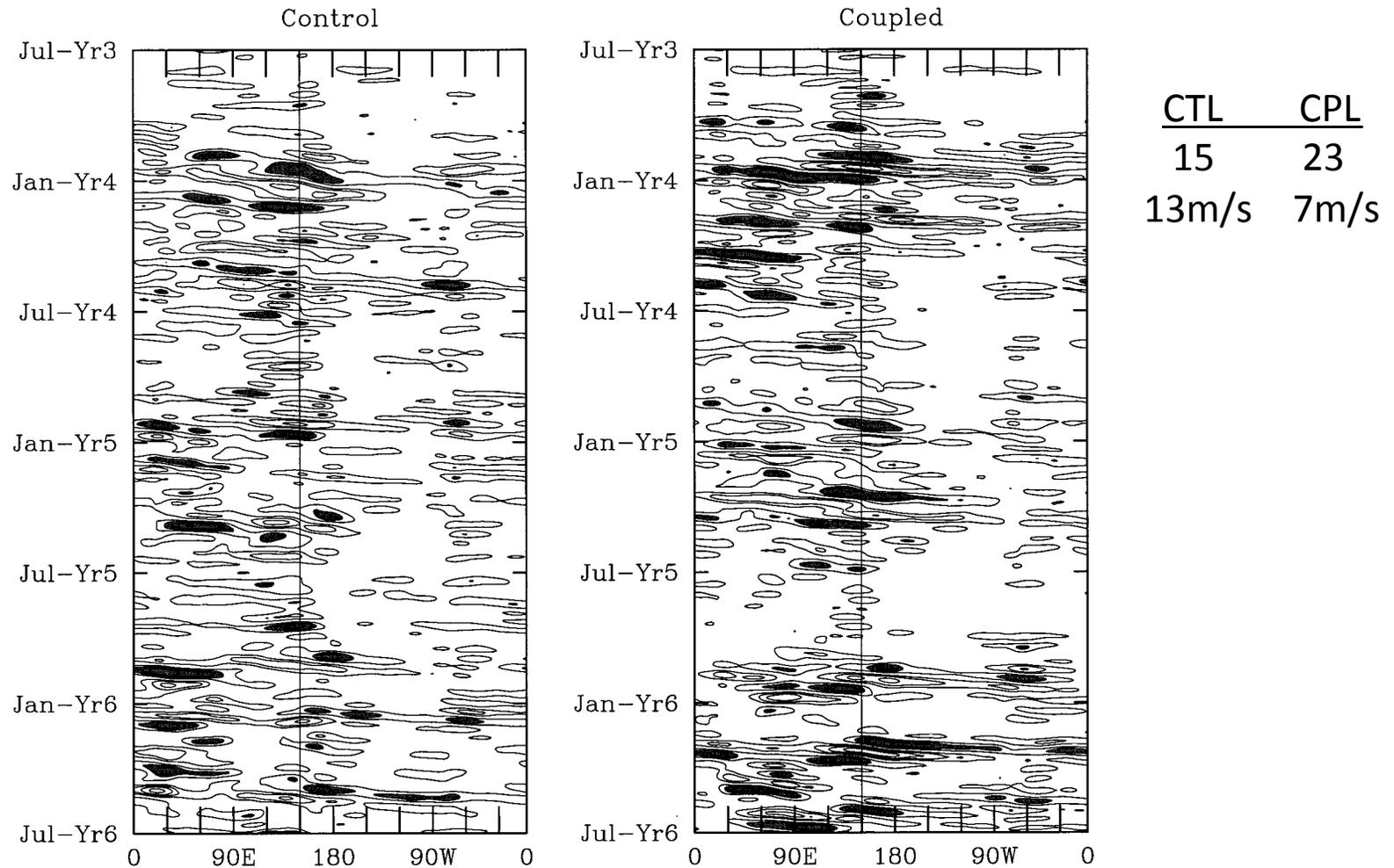
FIG. 3. Time–longitude diagrams of the equatorial (4°N–4°S) 20–100-day bandpassed 200-mb velocity potential for a selected 3-yr period of the CTL (left) and CPL (right) simulations. The -8×10^6 m²s⁻¹ contour is filled. The contour interval is 4×10^6 m² s⁻¹. The vertical line denotes the 150°E longitude line.

Waliser et al., 1999

CTL	CPL
15	23
13m/s	7m/s

Modeling Studies

Inness, Peter M., Julia M. Slingo, 2003: Simulation of the Madden–Julian Oscillation in a Coupled General Circulation Model. Part I: Comparison with Observations and an Atmosphere-Only GCM. *J. Climate*, **16**, 345–364.

"One impact of coupling this GCM to an interactive ocean is to improve the eastward propagation of convection across the Indian Ocean."

Sperber, K.R., S. Gualdi, S. Lugutke, V. Gayler, 2005: The Madden-Julian oscillation in ECHAM4 coupled and uncoupled general circulation models. *Clim*. *Dyn.*, **25**, 117–140.

"The coherence of the eastward propagation of MJO convection is sensitive to the ocean model to which ECHAM4 is coupled. "

Pegion, K. and B. P. Kirtman, 2008: The Impact of Air-Sea Interactions on the Simulation of Tropical Intraseasonal Variability. *J. Climate*, **21**, 6616 – 6635.

" … the overall intraseasonal variability of precipitation is reduced in the coupled simulation compared to the uncoupled simulation forced by daily SST. Additionally, air-sea coupling is responsible for differences in the simulation of the tropical intraseasonal oscillation between the coupled and uncoupled models, specifically in terms of organization and propagation in the western Pacific."

Benedict, J. J., D. A. Randall, 2011: Impacts of Idealized Air–Sea Coupling on Madden–Julian Oscillation Structure in the Superparameterized CAM. *J. Atmos. Sci.*, **68**, 1990–2008.

"The more realistic treatment of air–sea interactions in the coupled simulation improves many aspects of tropical convection on intraseasonal scales […] and propagation of the Madden–Julian oscillation (MJO)."

Experimental design
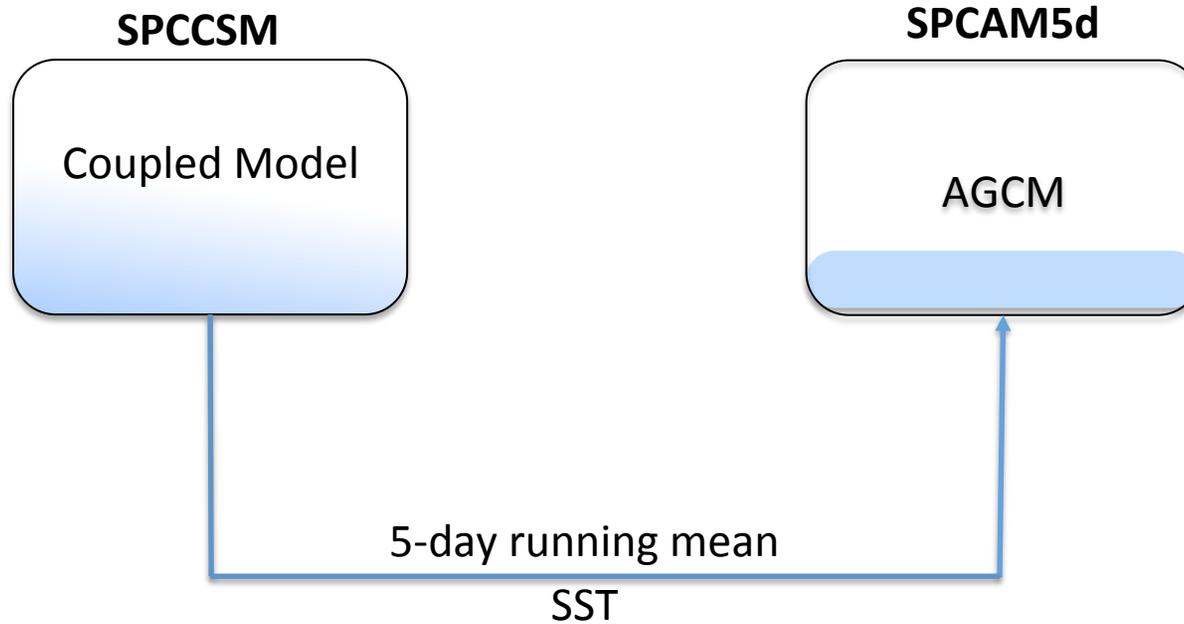
SPCCSM

SPCAM5d
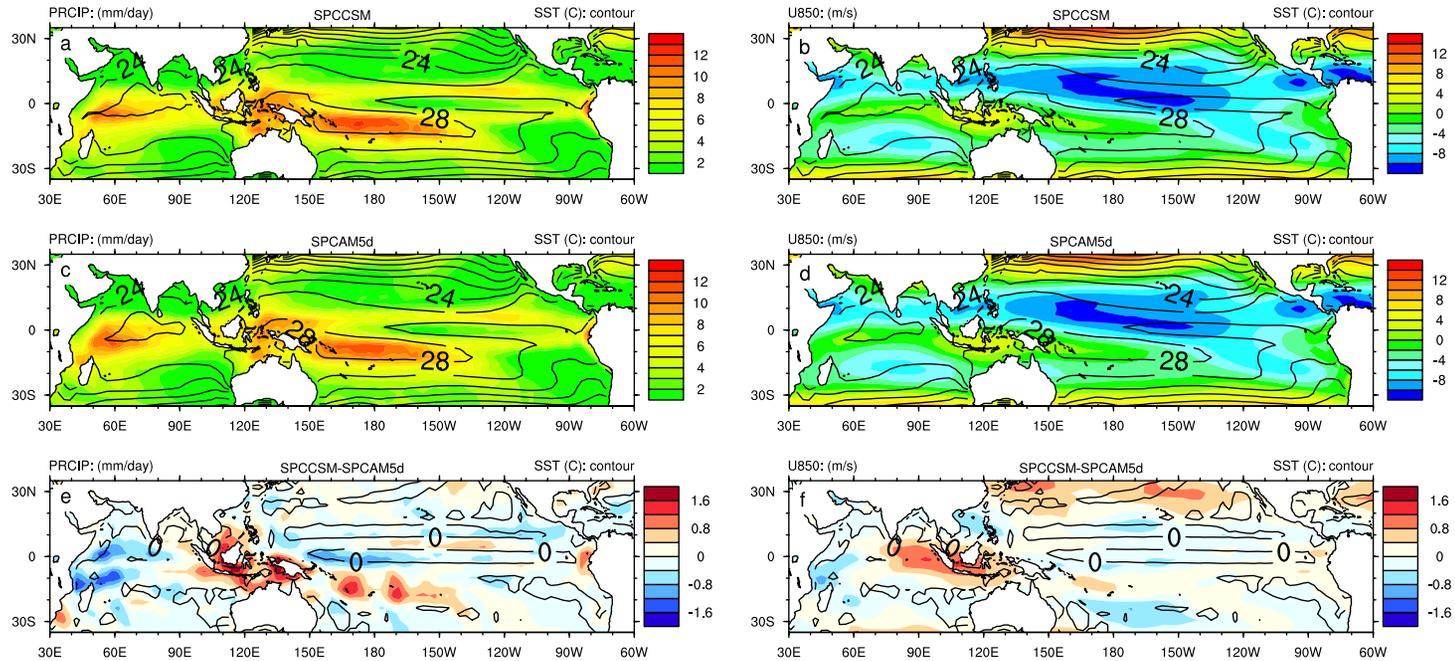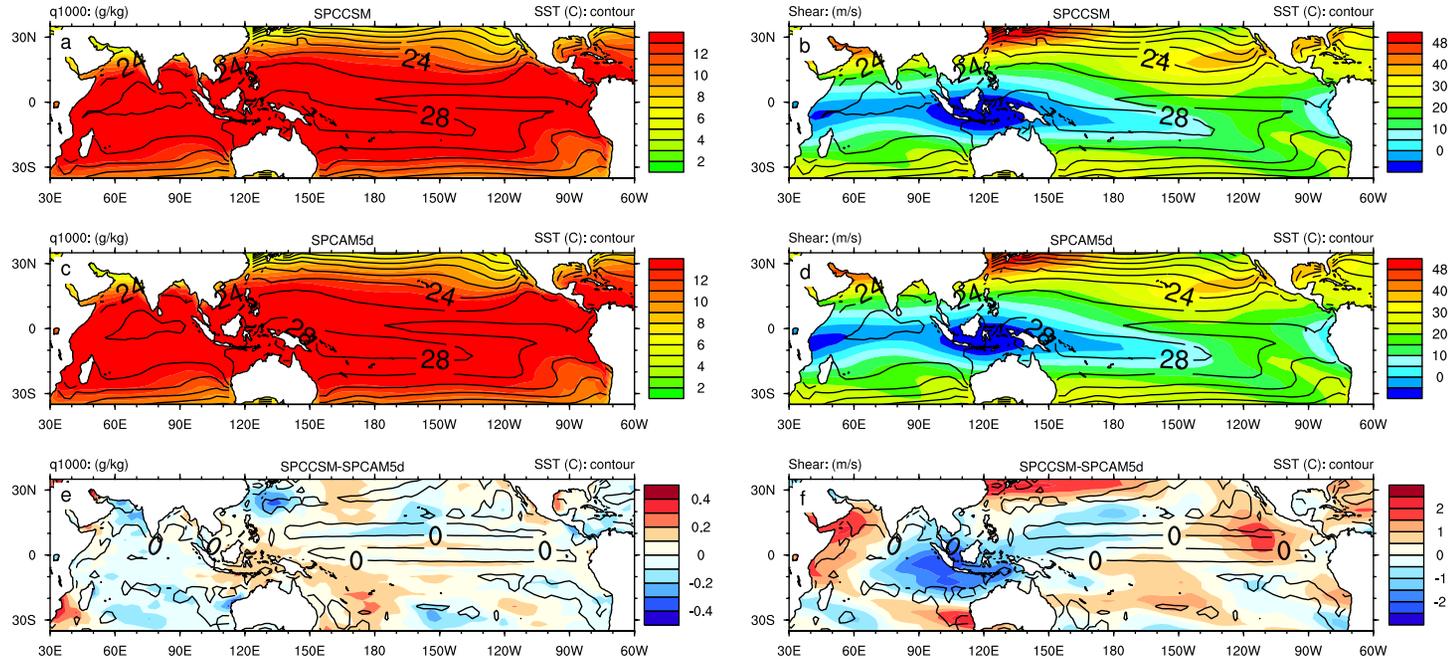
Coupled Model

AGCM

5-day running mean
SST

Boreal Winter Mean State
November-April

The Role of the SST
in the MJO
formation

Modeling Results

SST variability
sensitivity
experiments

Conclusions

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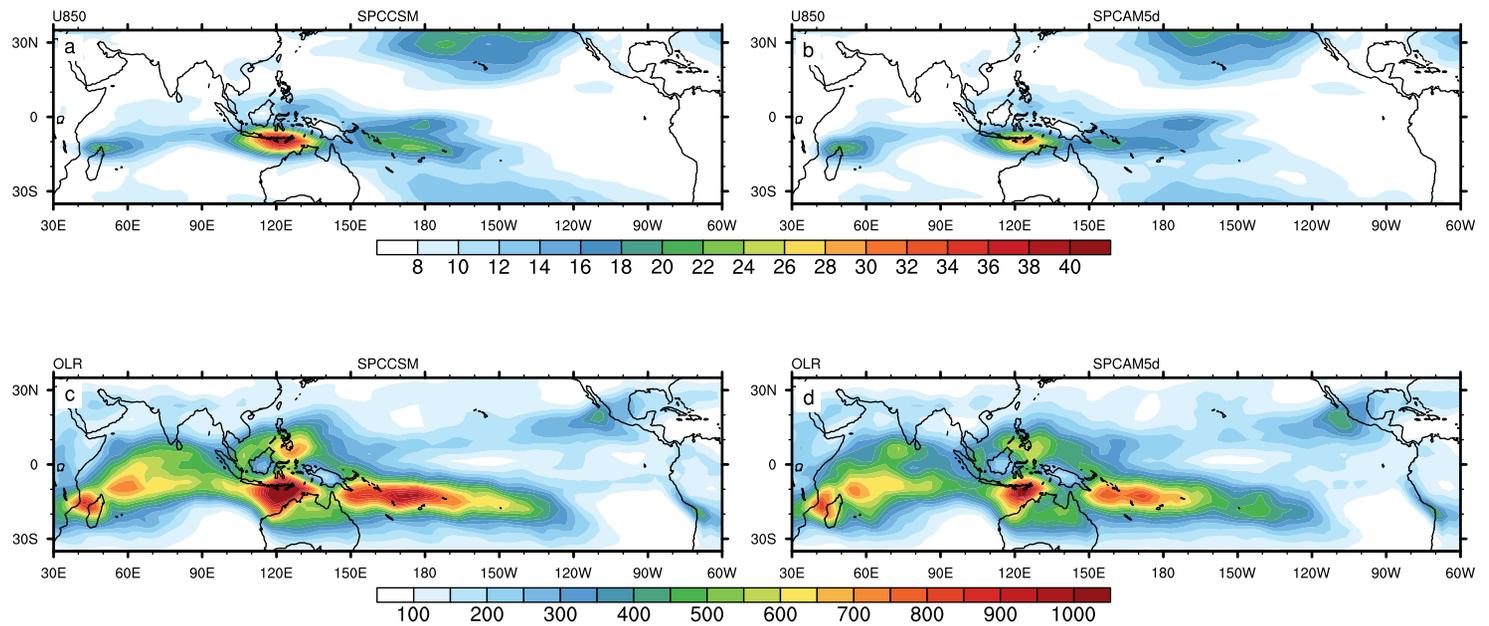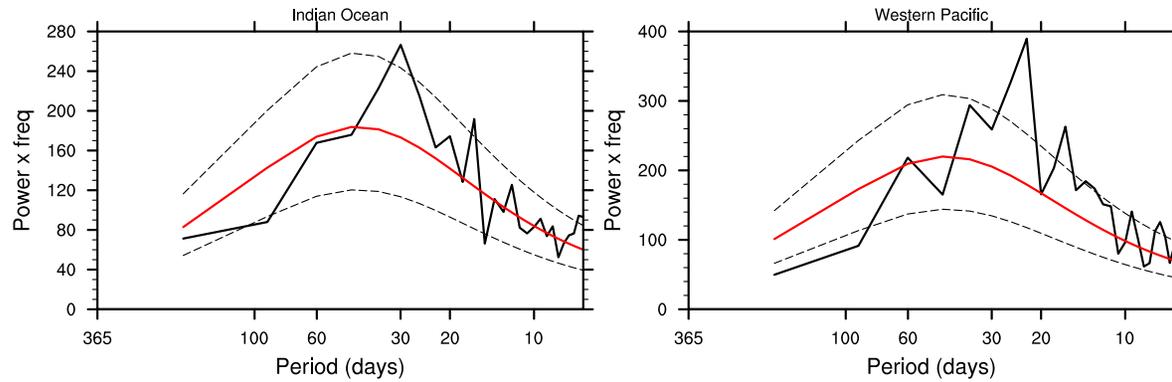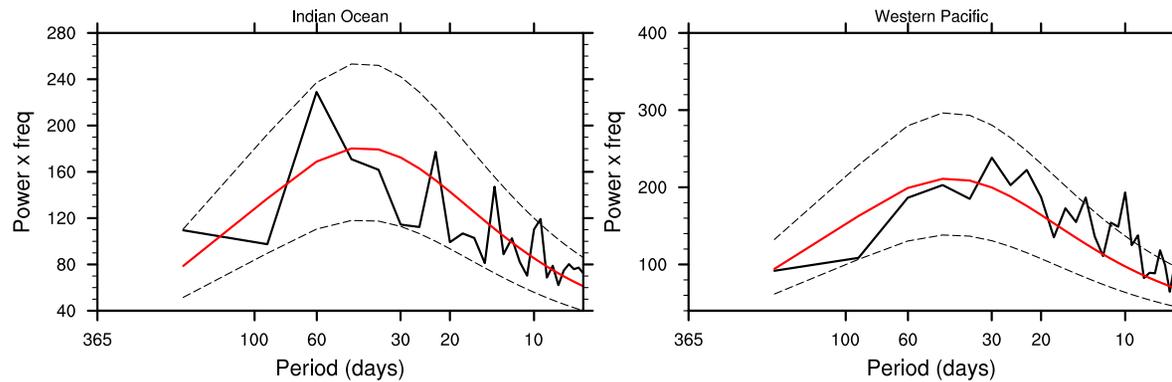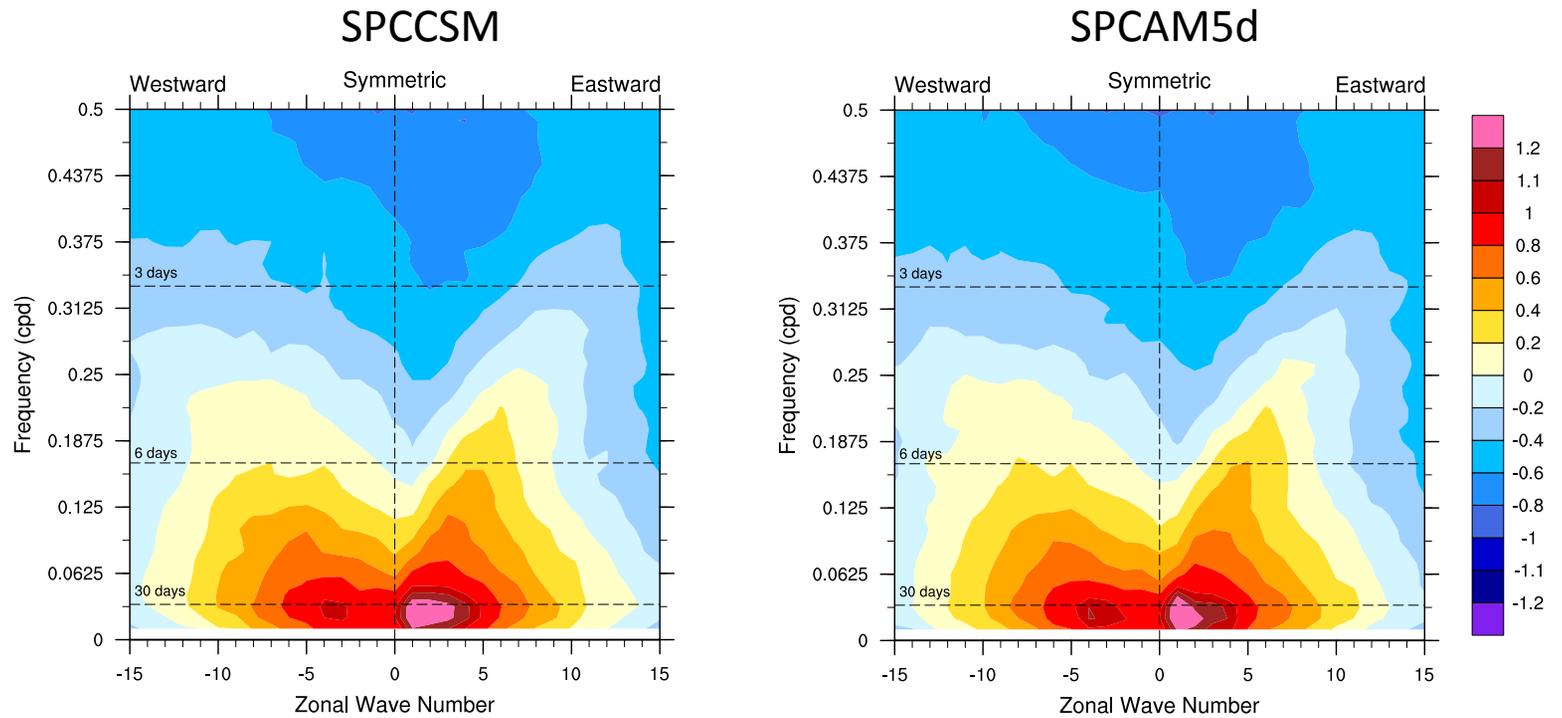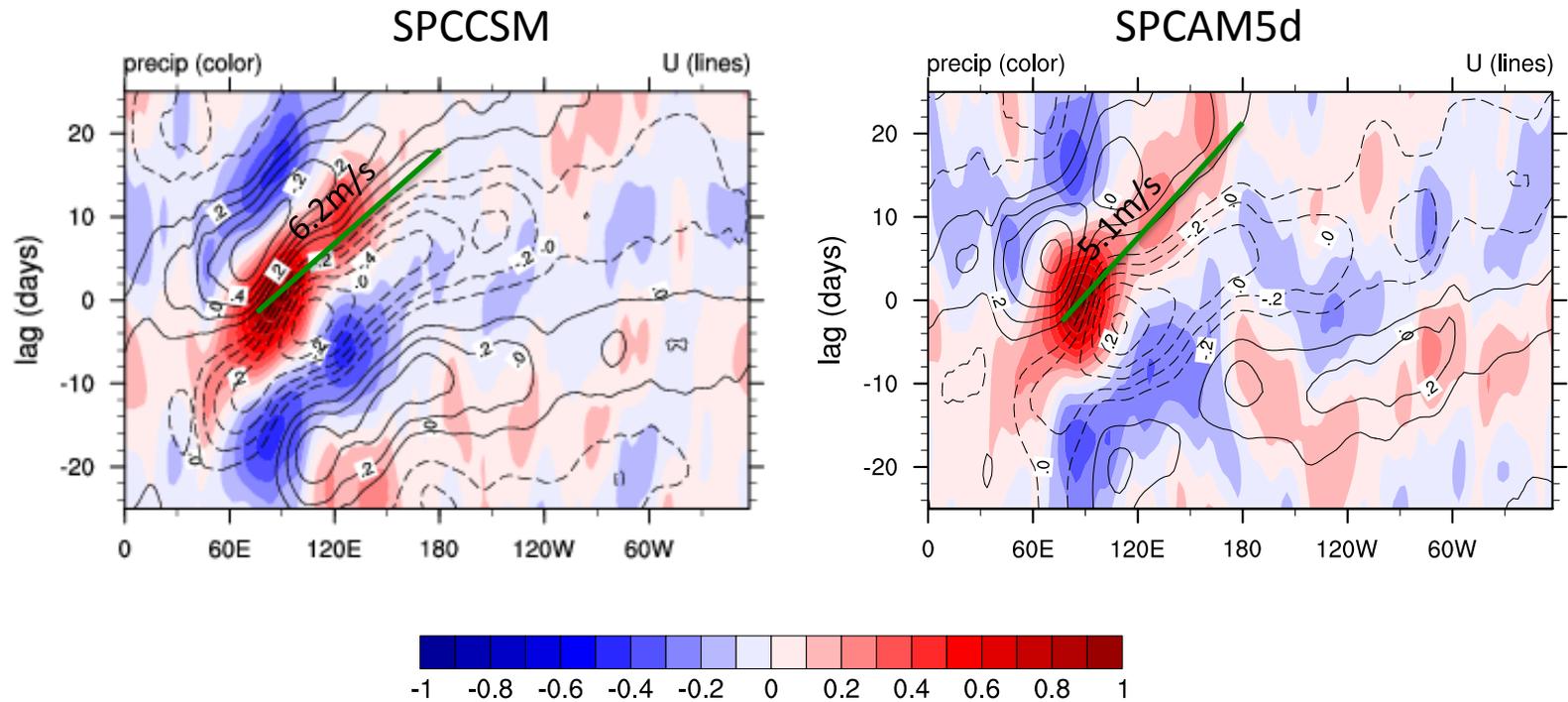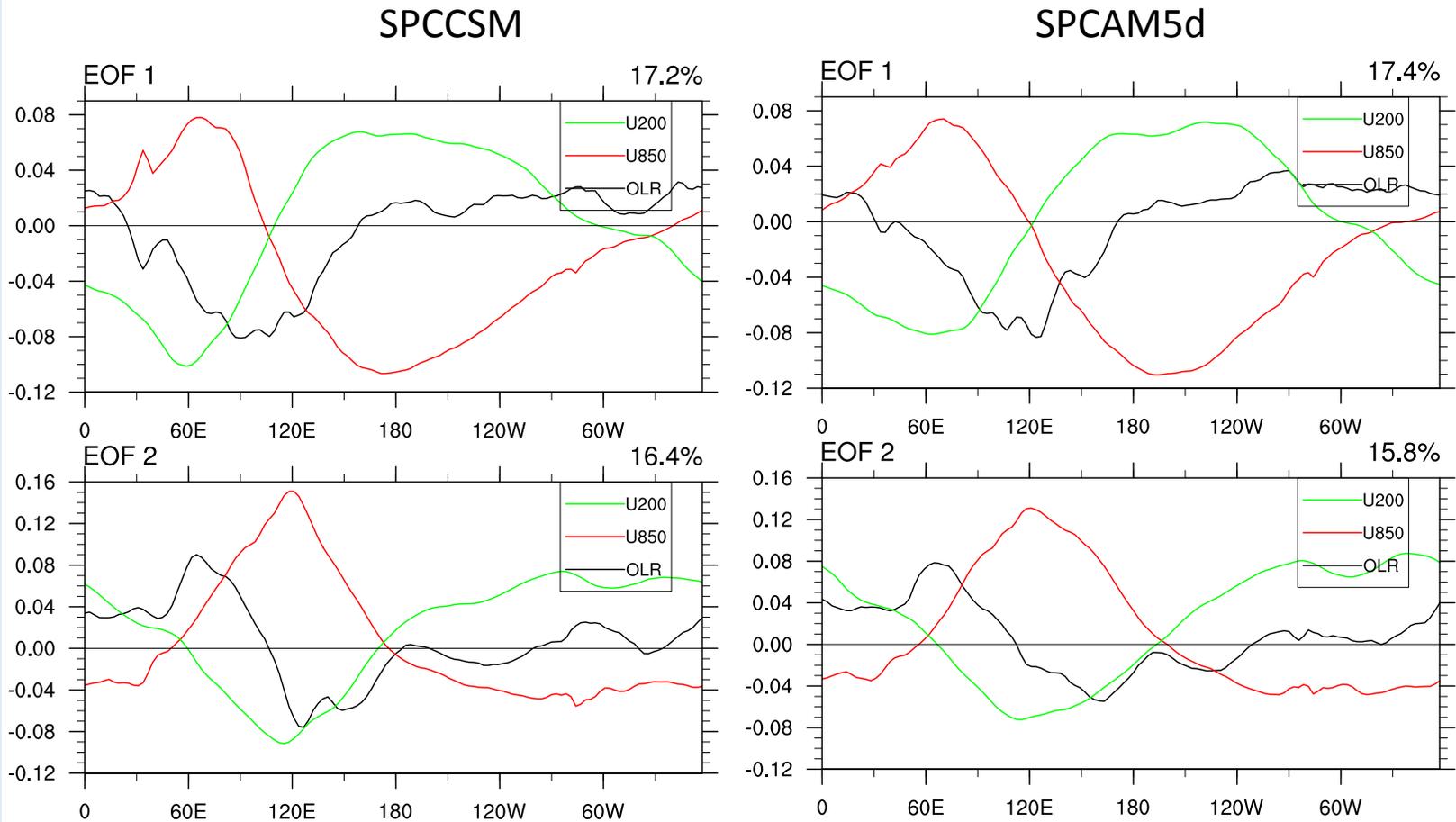
Conclusions

Intraseasonal Variability
November-April

20-100 day BPF variance

Intraseasonal Variability
November-April

MJO Simulation

SPCCSM

SPCAM5d

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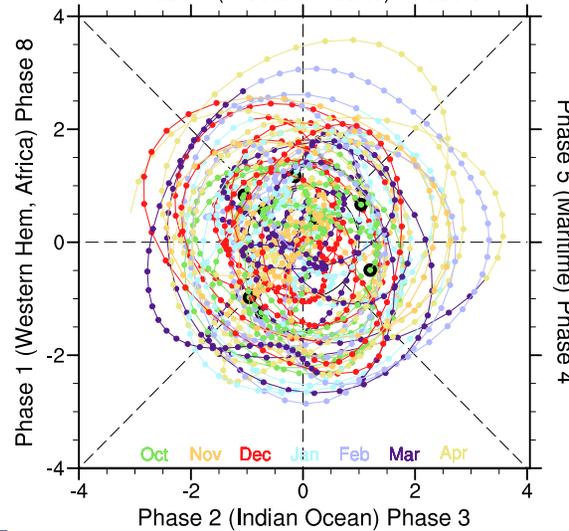
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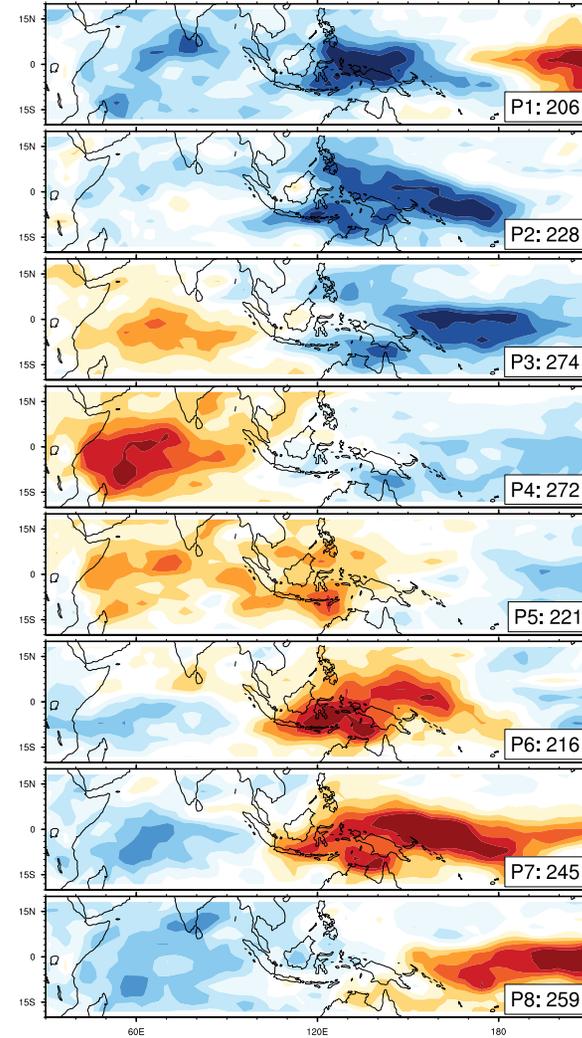
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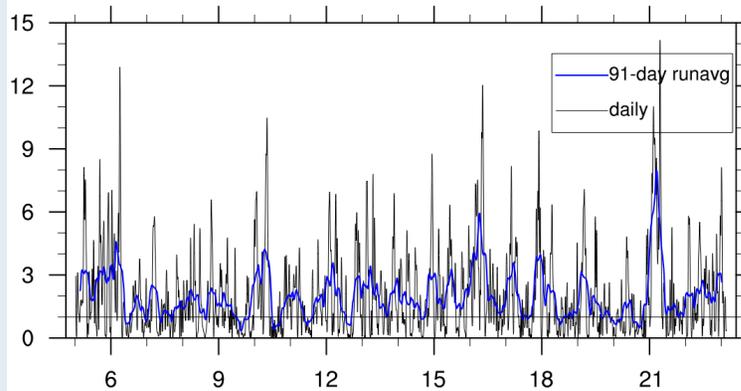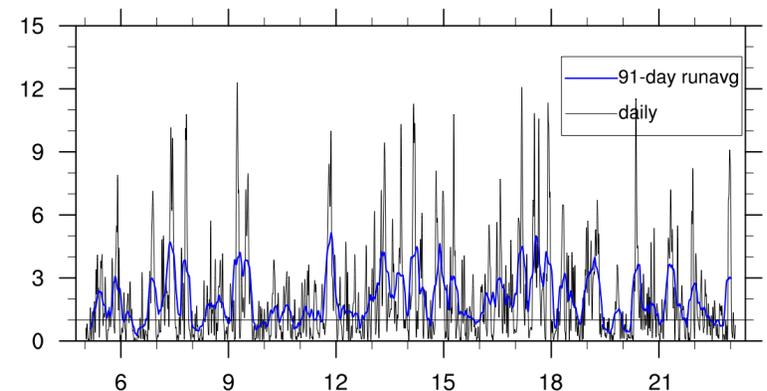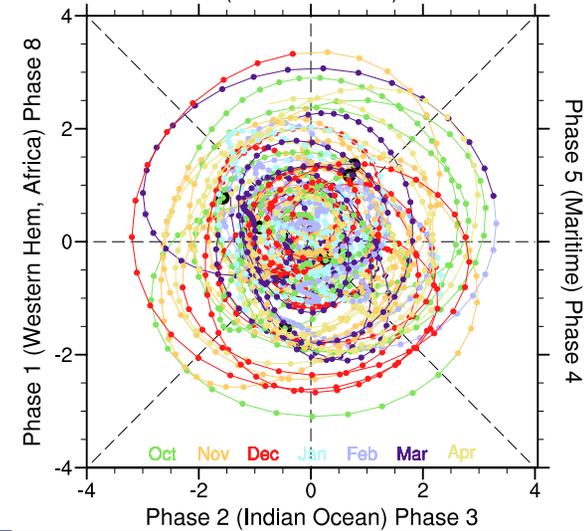
SPCCSM
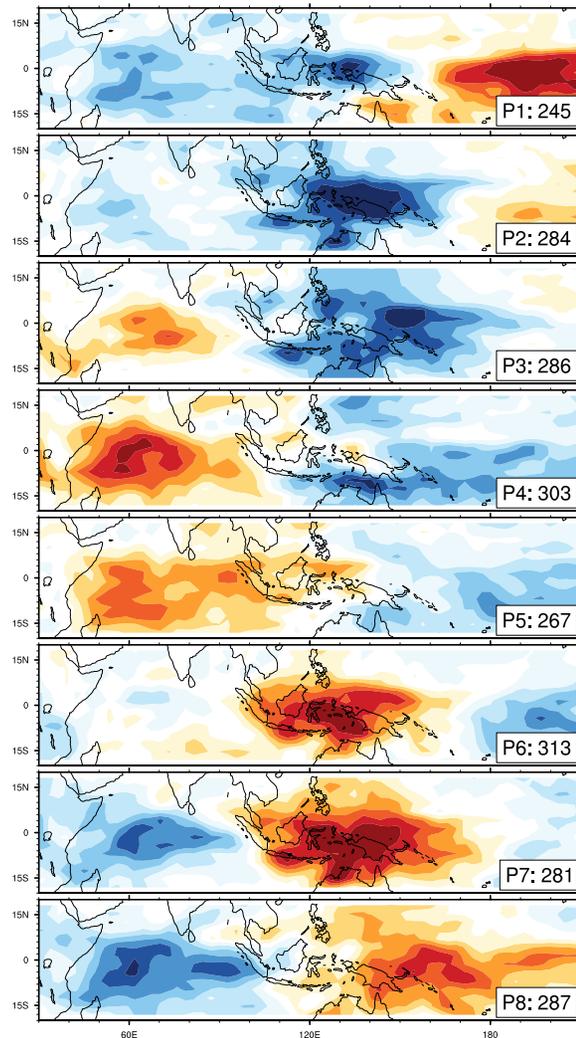
SPCAM5d

Lower troposphere wind shear

SPCCSM   SPCAM5d

Summary

The SST variability on the 5-day timescale:
- enhances the intraseasonal variability of the tropical atmosphere
- controls the coupling between the dynamics and convection associated with the MJO
- plays a significant role in the organization of the eastward propagating convection

Possible mechanisms through which the 5-day variability in the SST exerts an influence on the organization of convection on the MJO spatio-temporal scales:
- moisture transport
- the wind shear of the lower troposphere.