CFSv2 MJO Simulation and Prediction

-Role of air-sea interaction and convection parameterization

Wanqiu Wang

Climate Prediction Center, NCEP/NWS/NOAA/DOC

with contributions from Meng-Pai Hung, Xuyang Ge, Jieshun Zhu, Ying Zhang, and Arun Kumar

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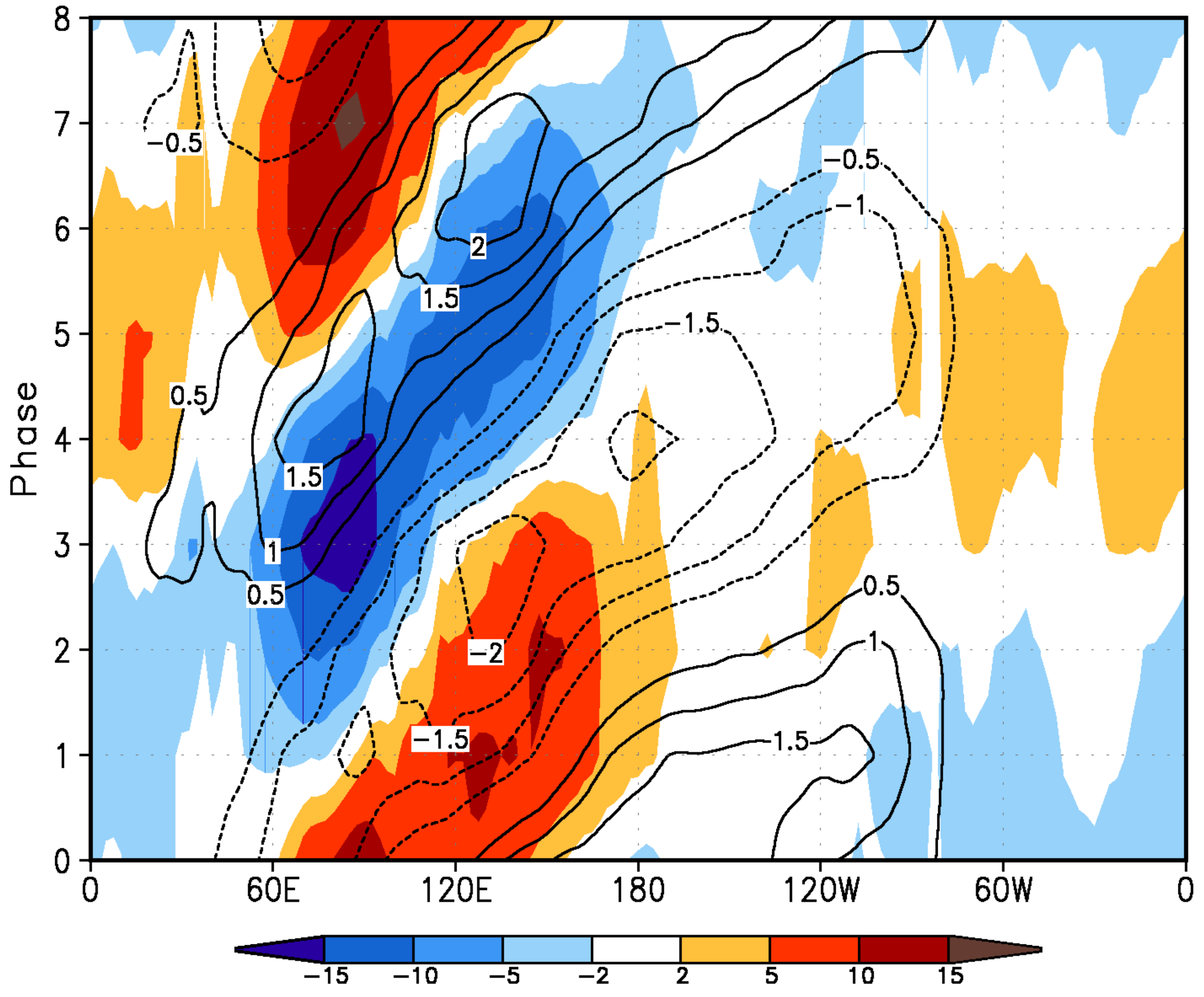
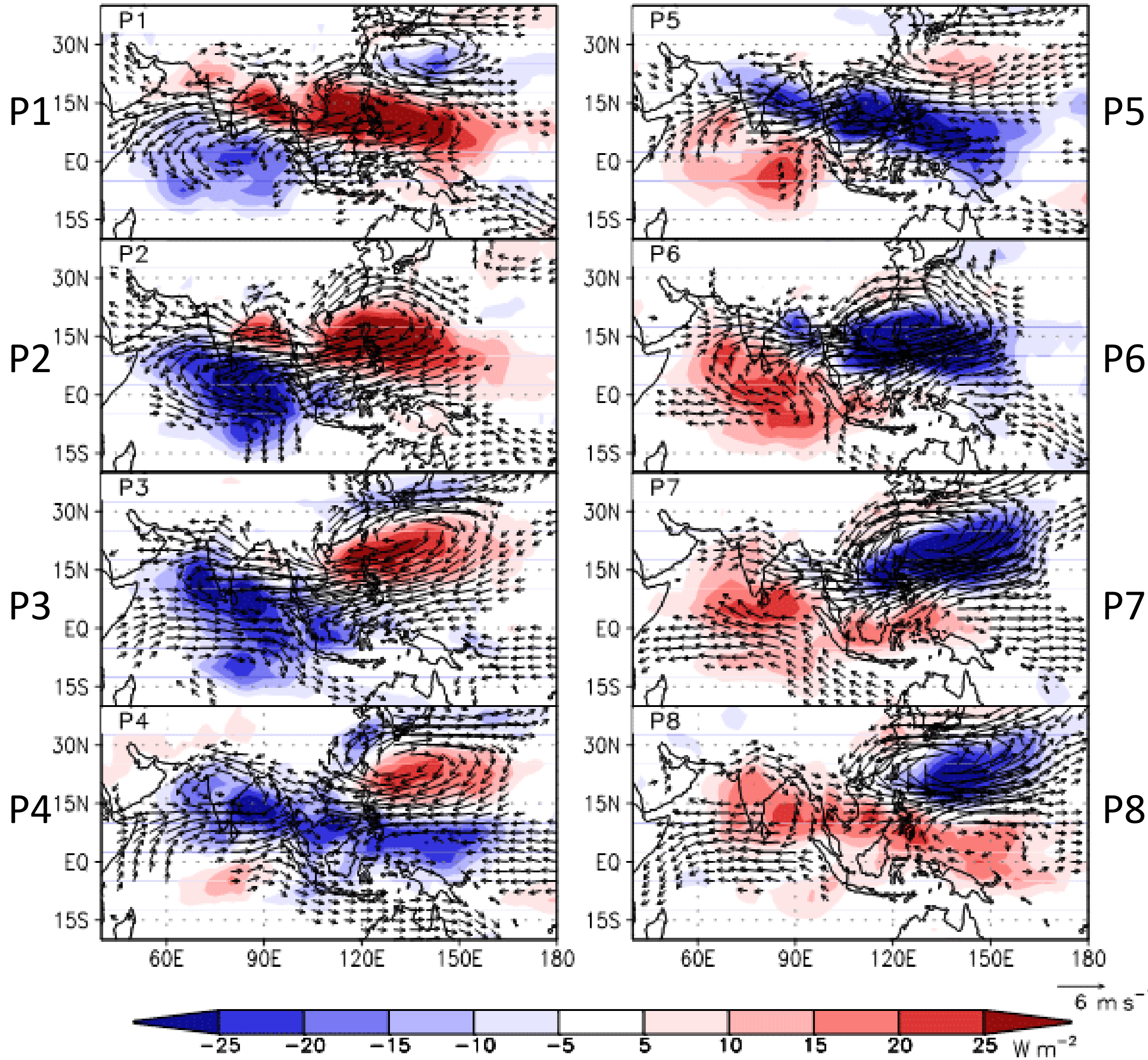
Madden-Julian Oscillation (MJO)



Shading: OLR
Contour: U850

Boreal Summer Intraseasonal Oscillation (BSISO)
Monsoon Intraseasonal Oscillation (MISO)

Shading: OLR
Vector: U/V850



Lee et al. (2013)

Importance of the MJO/MISO, and difficulties in their simulations and predictions

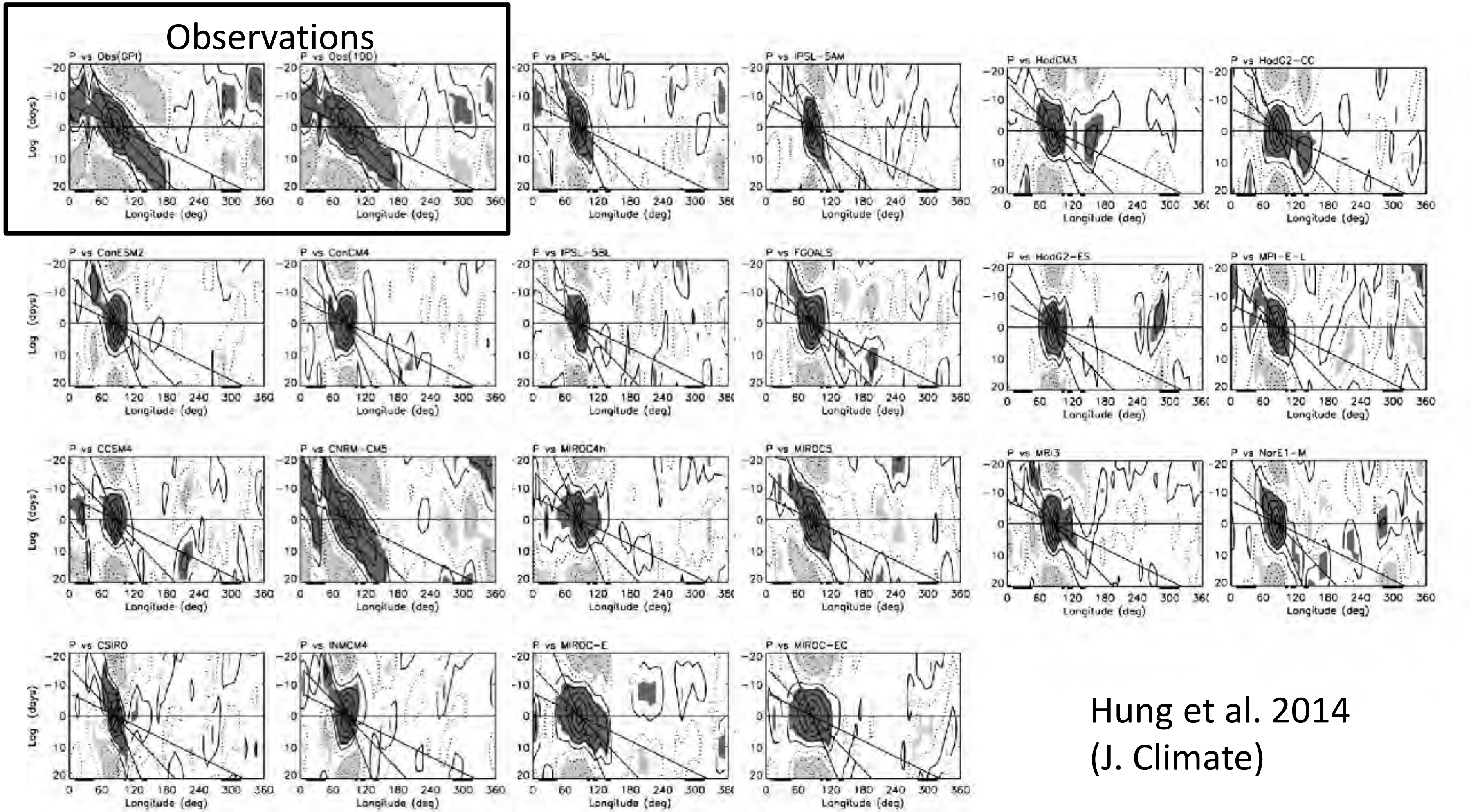
I. **MJO affects weather and climate over the globe at different time scales**, including the tropical cyclones, extratropical cyclone activity, Indian and Australian summer monsoons, North and South American climate, Arctic Oscillation, and El Nino Southern Oscillation

II. **MISO modulates regional weather climate** including tropical cyclones in Indian and western Pacific Oceans, and India and East Asia climate

III. **The MJO and MISO are predictability sources** for weather and climate systems

IV. **There are systematic errors in model simulations and predictions of MJO and MISO**. Models tend to produce standing oscillations and are unable to simulate the propagation across the Maritime Continent. The predictable length in most operational models is shorter than the estimated predictability (20 days or so versus 30 days or longer). The MJO in the prediction is generally too weak and propagate too slowly.

CMIP5 simulations: Rainfall lag correlation between anomaly (5°N-5°S average) with itself at (0°, 85°E)



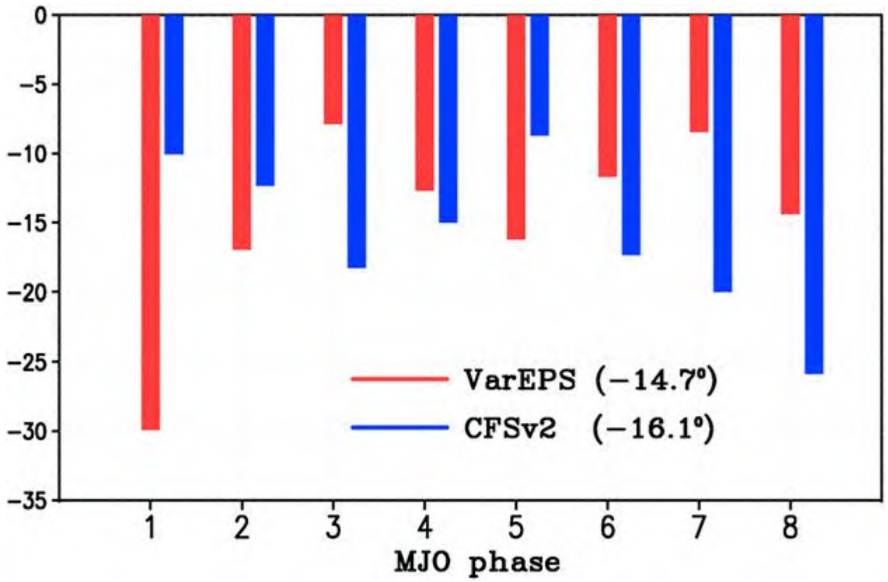
Hung et al. 2014
(J. Climate)

- Observations show clear eastward propagation
- Almost all models produced slowly propagating or stationary oscillations

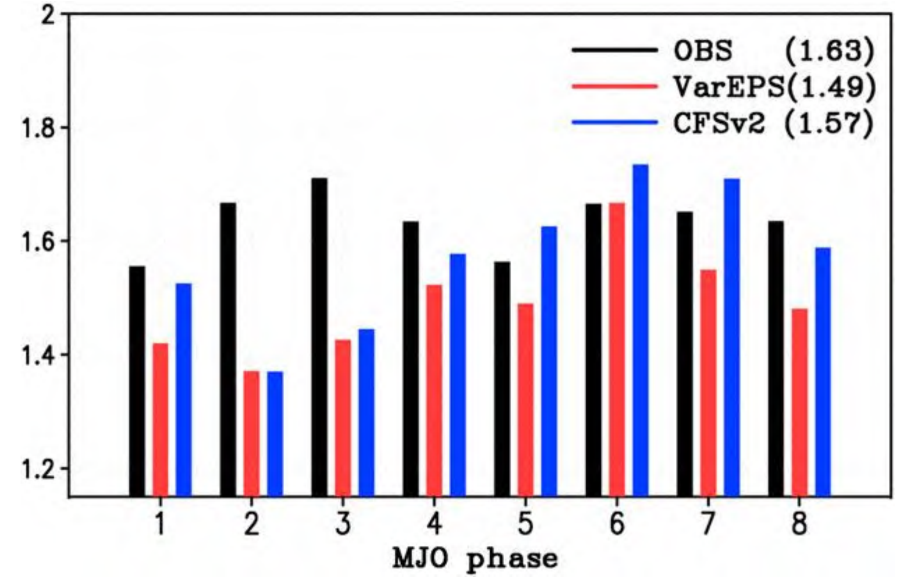
MJO predictions from ECMWF VarEPS and NCEP CFSv2

(Day 1 to day 25 average)

Phase angle error



Amplitude



Kim et al. 2014 (J. Climate)

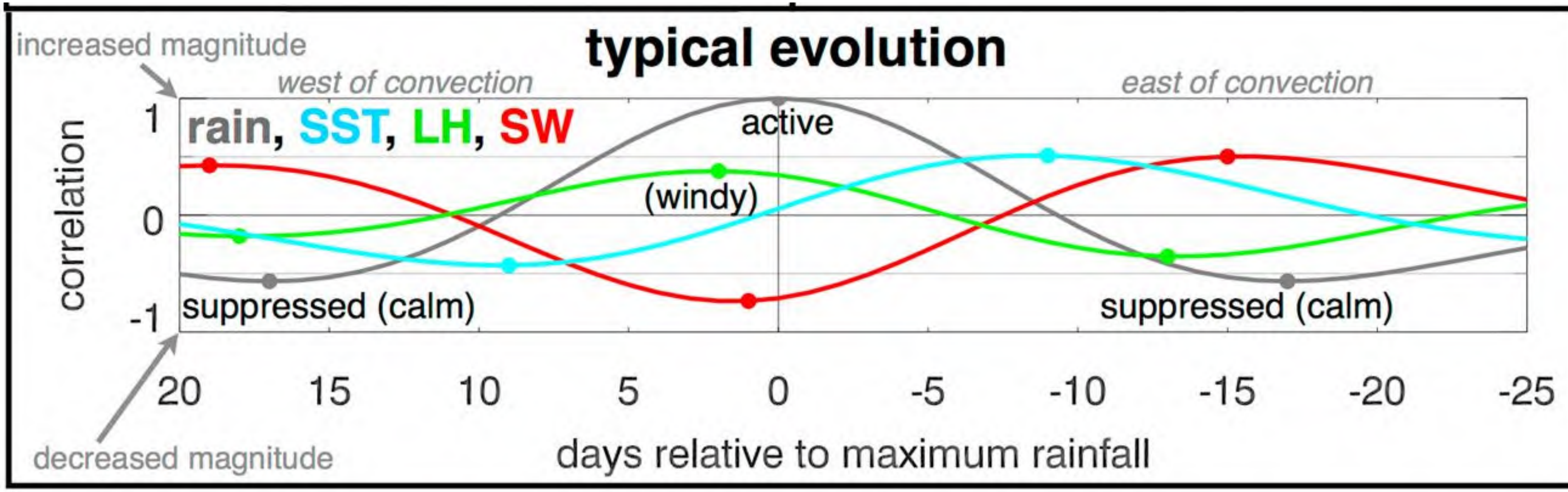
- Slower propagation
- Weaker amplitude

Factors affecting MJO/MISO simulations

I. **Atmospheric physics and configurations**
   1) Cumulus convection
   2) Shallow convection
   3) Cloud radiation
   4) Resolution
   5) Super-parameterization

II. **Air-sea interaction**
   1) Atmospheric response to SSTs
   2) Oceanic response to atmospheric variability
   3) Better simulations in coupled atmosphere-ocean models than atmosphere-only models

Relationships among fields associated with MJO



DeMott et al. (2015)

Questions to be addressed in this talk

I. How important is the accuracy of the underlying SST in the simulation of the observed MJO and MISO?

II. How does the accuracy of the simulated SST depend on the ocean model vertical resolution?

III. What are the impacts of SST diurnal cycle, intraseasonal variability and mean state?

IV. How important is the presence of the air-sea coupling?

V. How does the predictability depend on convection parameterization which also affects air-sea interaction?

Outline

I. Importance of the SST accuracy
   - Simulating the MJO/MISO with an *atmosphere-only* model

II. Importance of ocean vertical resolution
   - SST variability with an *ocean-only* model

III. Impact of SST diurnal and intraseasonal variations, and mean state
   - MISO simulations with *atmosphere-only* and *coupled* models

IV. Importance of the air-sea interaction
   - Simulating the MJO with a *coupled* model

V. Dependence of MJO predictability/prediction on convection
   - Perfect model predictability
   - Prediction skill dependence on convection scheme

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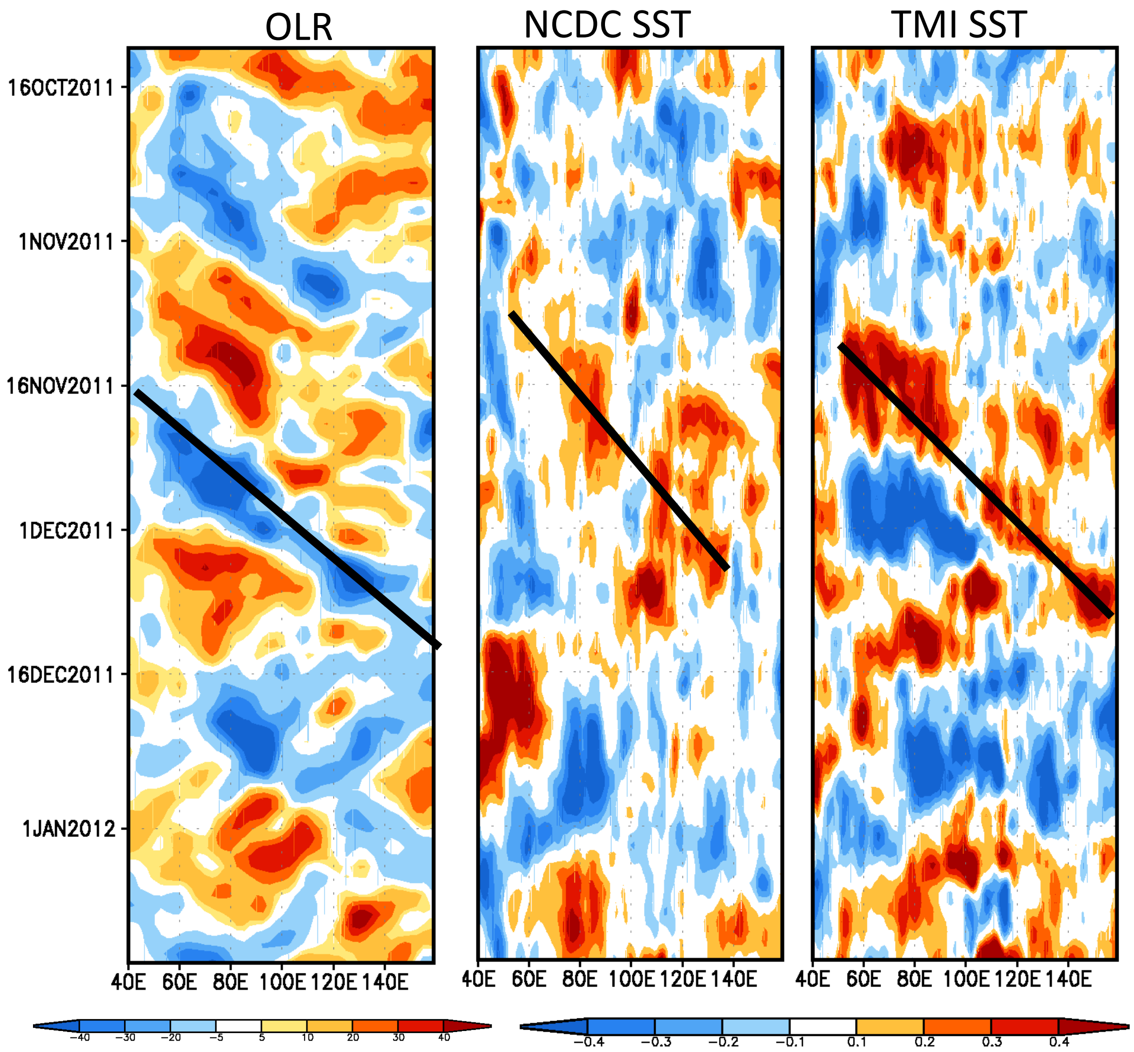
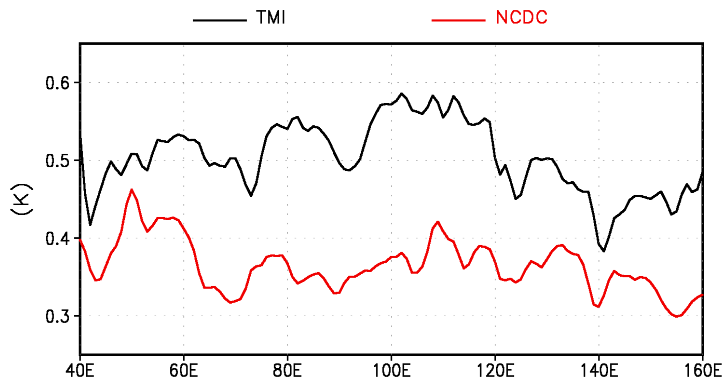
MJO events during DYNAMO IOP (1 Oct 2011 – 15 January 2012)



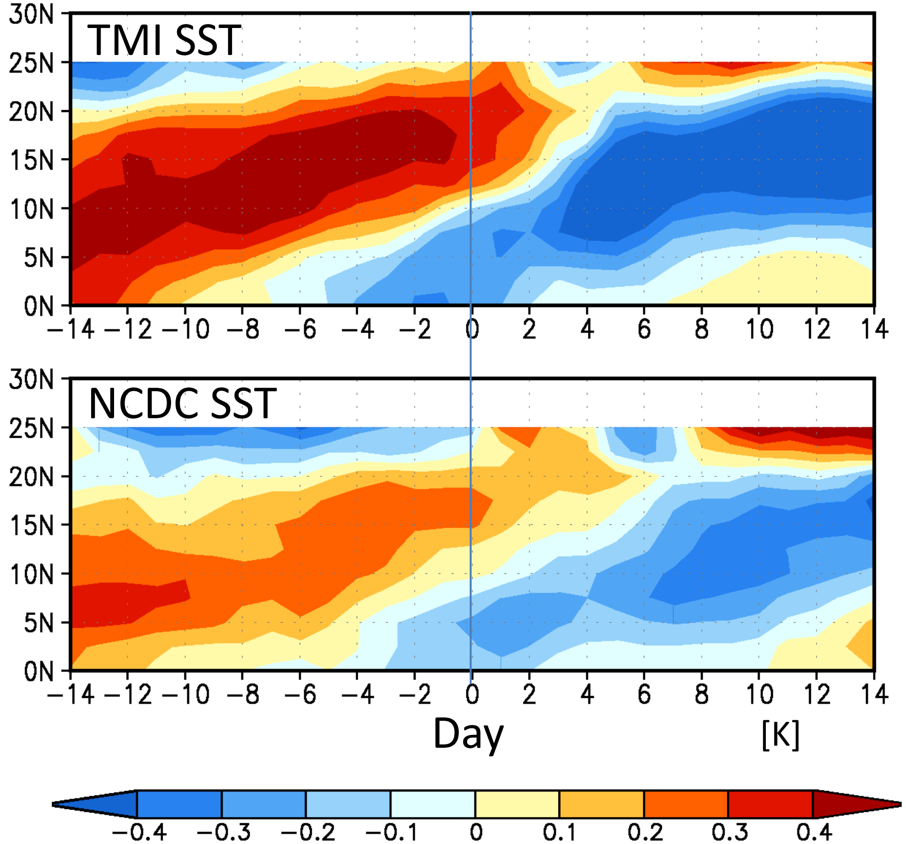
SST standard deviation

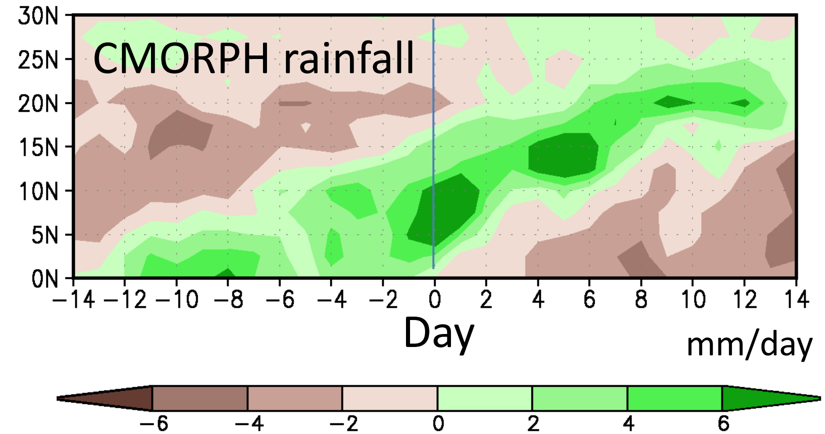


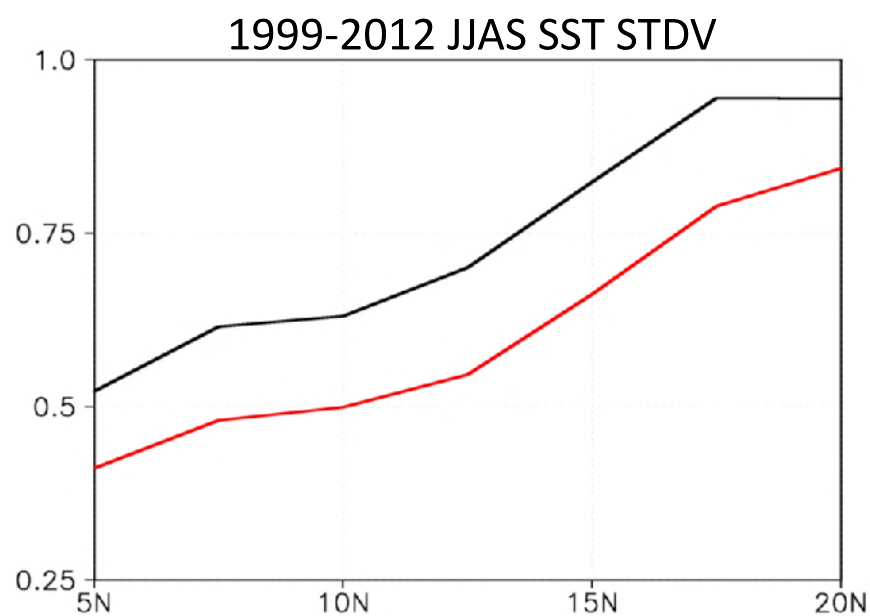
- Three MJO events
- Warm SST anomalies leads enhanced convection
- TMI SST is stronger by 0.1-0.2K

65°-95°E average anomalies of 7 MISO events during JJAS

(**Day 0:** 5°-10°N average rainfall at maximum)







- Warm SST leads convection
- On average, TMI SST anomalies stronger than NCDC by 0.1K or so.

Is an SST uncertainty of 0.1-0.15 K sufficient to cause the significant differences in the simulation or prediction of the intraseasonal oscillation?

Experiments to test Importance of the SST accuracy

1) Model

- Atmosphere-only GFS (T126/L64)

2) SSTs

- TMI (TRMM Microwave Imager)
- NCDC (National Climatic Data Center)
- Clim (NCDC 1982-2020 climatology)

3) Convection parameterizations

- SAS Simplified Arakawa Schubert (Pan&Wu 1995) used in operational CFSv2
- SAS2 Revised Simplified Arakawa Schubert (Han&Pan 2011) used in operational GFS
- RAS Relaxed Arakawa Schubert (Moorthi and Suarez (1999)

4) Forecast runs

- Initial conditions: CFSR
- Initial dates:
  - MJO experiments: Oct 2011 to 15 Jan 2012 (3 MJO events)
  - MISO experiments: 7 events during JJAS 2001 – 2009
- 31 target days

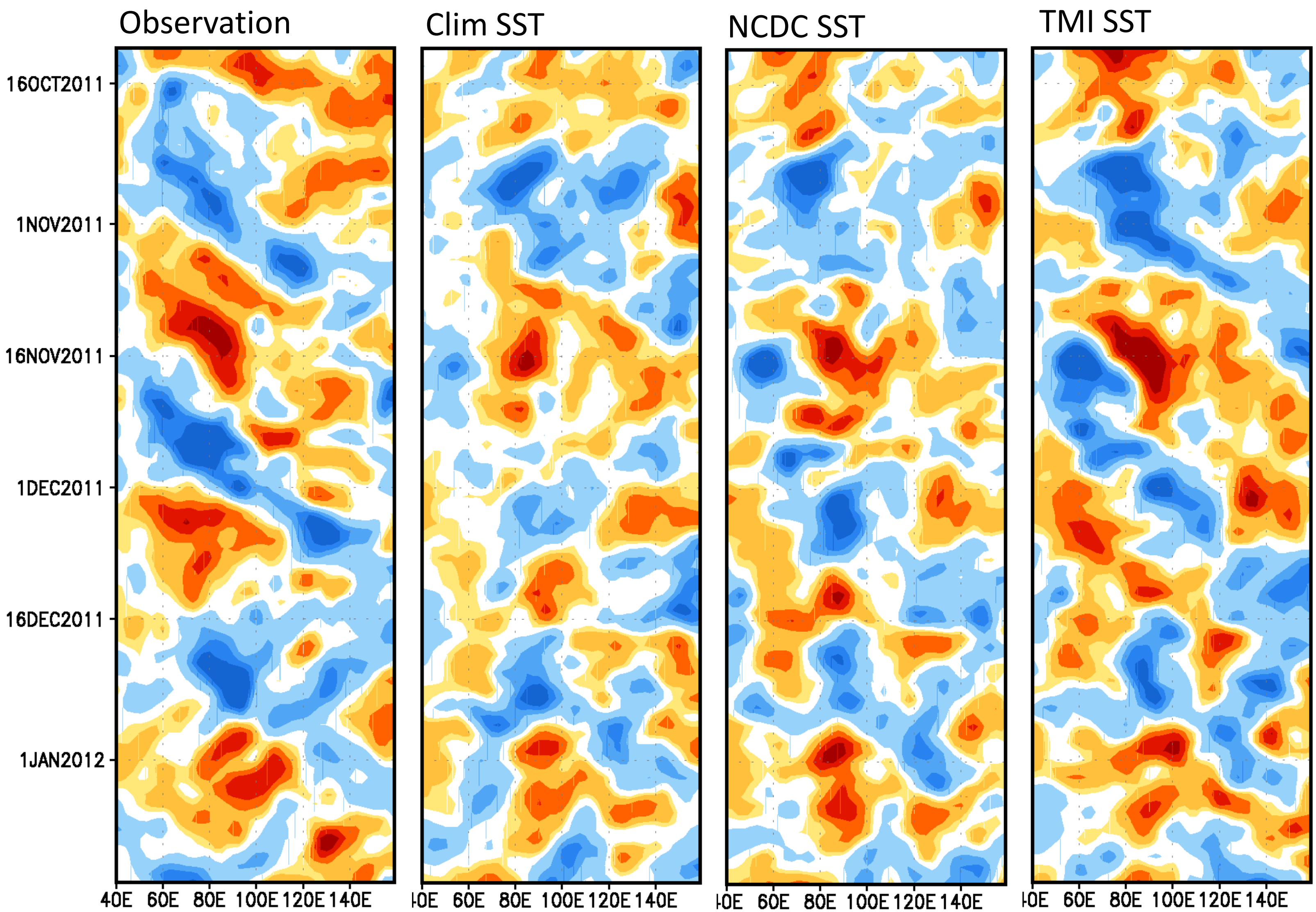
Boreal winter MJO simulations

DYNAMO IOP

MJO during DNAMO IOP: 10S-10N average OLR anomalies (Wm^{-2})

Day 12 forecast

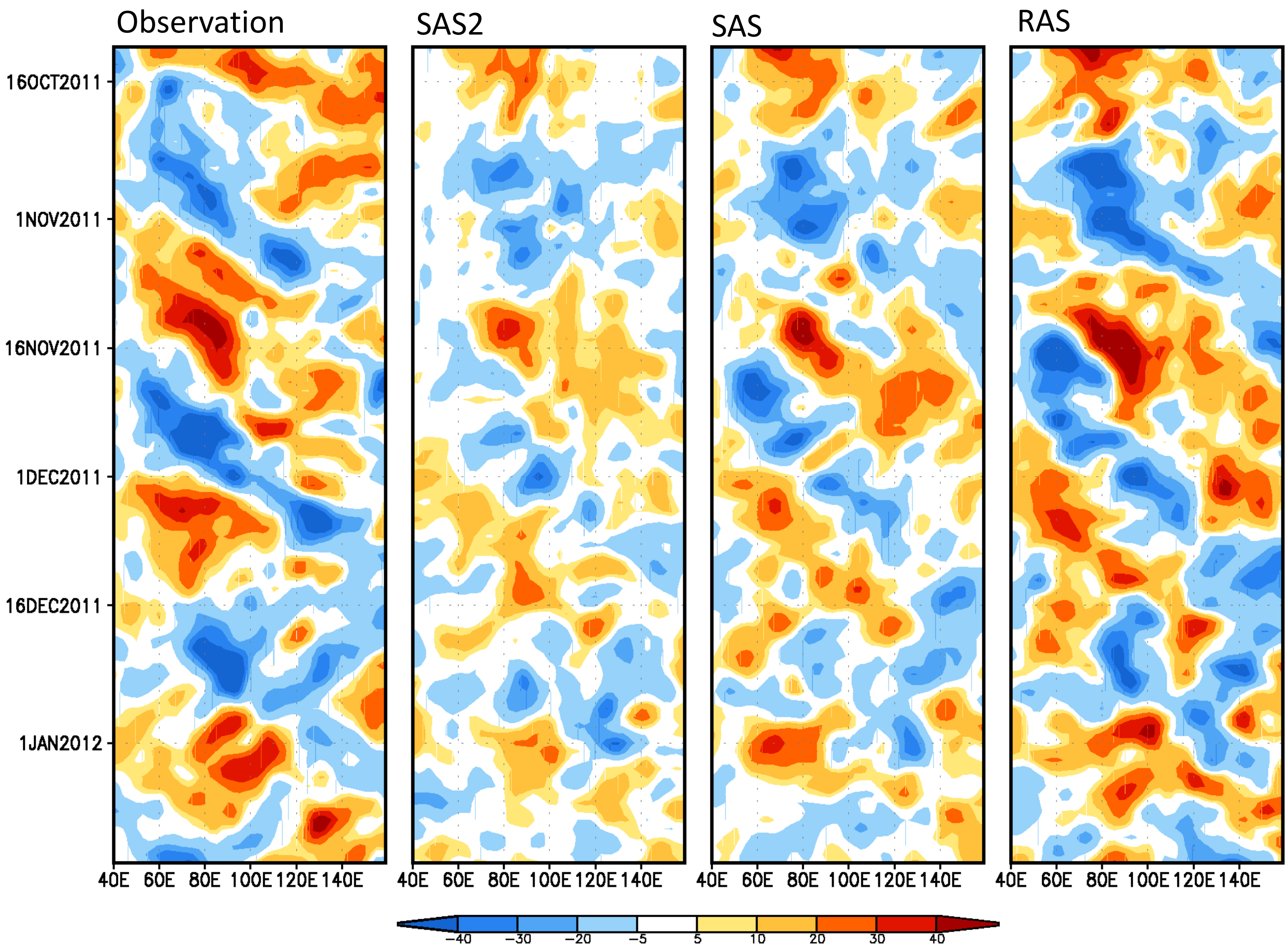
RAS convection scheme



MJO during DNAMO IOP: 10S-10N average OLR anomalies (Wm^{-2})

Day 12 forecast

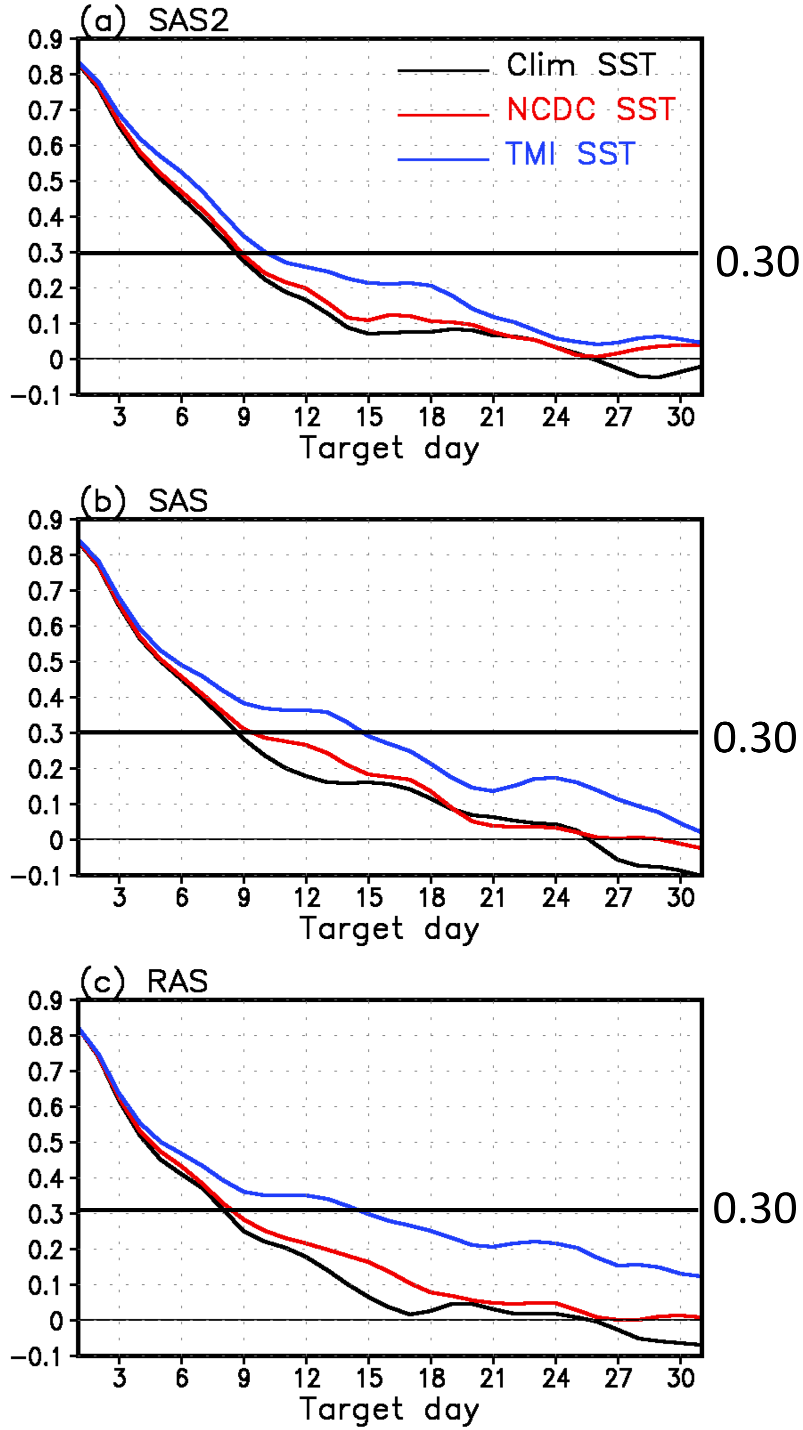
TMI SST



Correlation skill of 10S-10N/50E-150E OLR

During DYNAMO ISP

- Comparable skill for short lead (<5 days) for all SSTs and convection schemes
- At longer lead time, there is improvement when observed SSTs are used for all three convection schemes
- TMI SST results in much larger improvement than NCDC



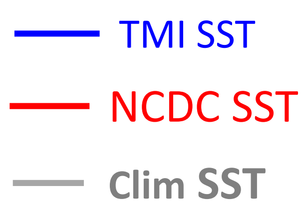
Boreal summer MISO simulations

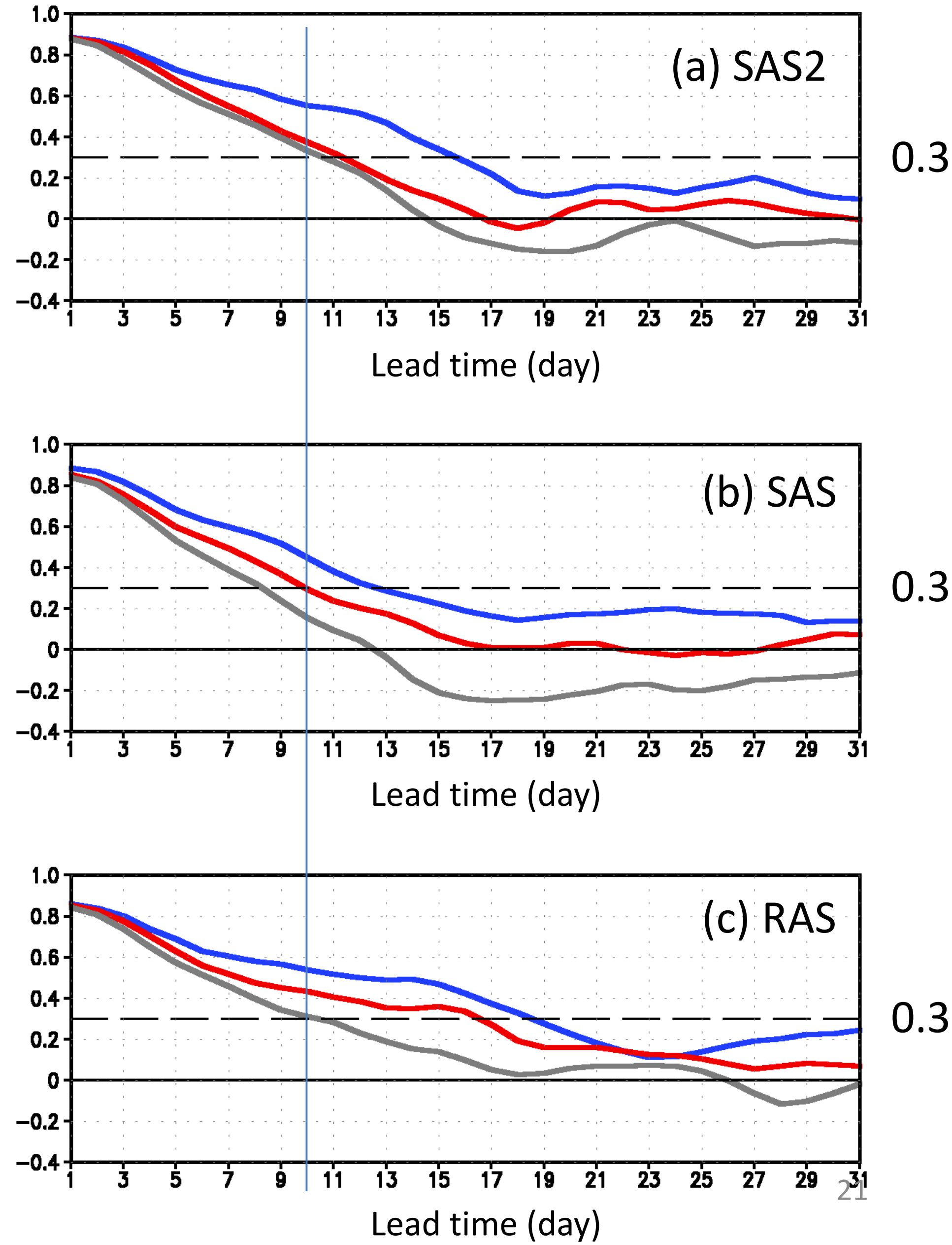
7 strong events

Case	Strong SST (Pr+SST)
1	Sep 9 – Oct 9, 2001
2	Jul 13 – Aug 12, 2004
3	Aug 20 – Sep 19, 2005
4	Aug 24 – Sep 23, 2006
5	Jun 6 – Jul 6, 2007
6	Oct 4 – Nov 3, 2008
7	Jun 20 – July 20, 2009

Correlation skill of 5°-20°N/65°-95°E rainfall

7 MISO events





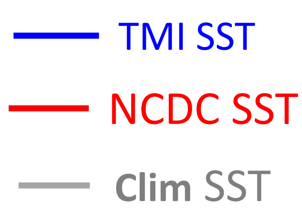
1. TMI SST results in larger improvement than NCDC, relative to the skill with Clm SST,

2. With the same SST, RAS scheme performs better than SAS and SAS2.

Correlation skill of BSISO index (Lee et al. 2013)

Correlation skill of BSISO index (Lee et al.)

7 MISO events



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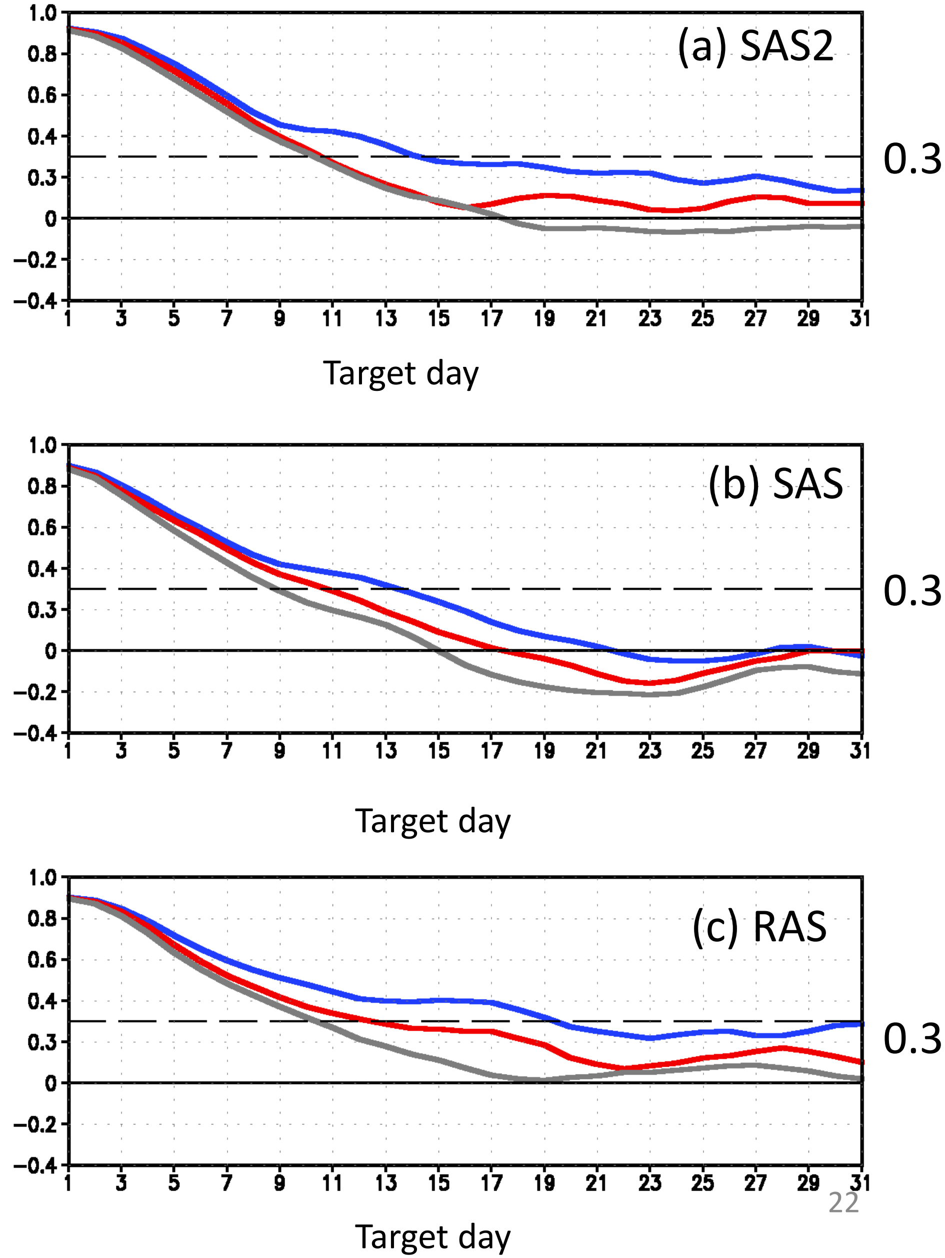

Part I Summary

1) Accurate SSTs are critical for the prediction of both MJO and MISO. This suggests that MJO and MISO simulations and predictions not only need coupled atmosphere-ocean models but also need improved modeling of upper ocean with realistic SST variability

2) Impact of SSTs depend on model physics. Among the three convection schemes tested, the RAS has better performance in capturing MJO and MISO variability.

Outline

I. Importance of the SST accuracy
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III. Impact of SST diurnal and intraseasonal variations, and mean state
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Why studying the impact of ocean vertical resolutions?

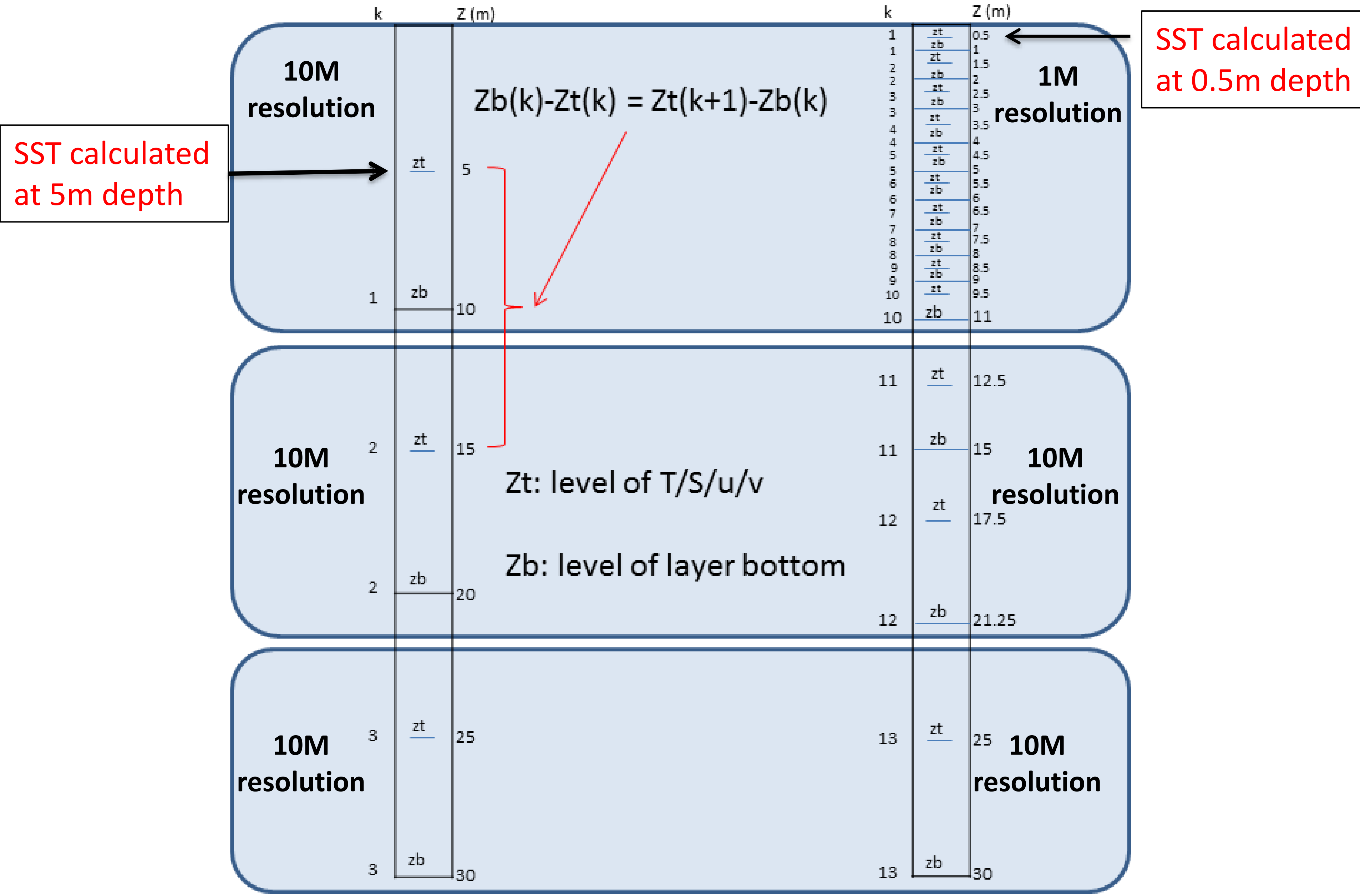
1) There have been studies showing that high (~1m) vertical resolution is required to represent the observed diurnal and intraseasonal SST variability (Bernie et al. 2005, 2007, 208; Woolnough et al. 2008), and Tseng et al. (2015)

2) Most of the current coupled climate models use a 10-meter vertical resolution for the upper ocean, and almost all models produced stationary or too-slowly propagating intraseasonal rainfall oscillations

Ocean vertical resolution in a subset of current CGCMs

CGCM	Ocean component	Vertical resolution	Reference
CFSv2	MOM	10 m	Saha (2014)
CanCM4	NCOM	10 m	Merryfield et al. (2013)
GloSea4	NEMO	10 m	(Shaffrey 2009; Arribas 2011)
ACCESS-CM	MOM4p1	10 m	Marsland et al. (2012).
CNRM-CM5.1	NEMO v3.2	10 m	Voldoire (2013)
MPI-ESM	MPIOM	10 m	Baehr et al., 2013
CCSM4	POP2	10 m	Gent (2011)
GFDL CM3	MOM4p1	10 m	Friffies (2011)
ECMWF Sys4	NEMO3.0	10 m	Molteni (2011); Mogensen(2011)

Ocean model resolution to be tested



Ocean vertical resolution experiments

1) **Model**
   - GFDL MOM5

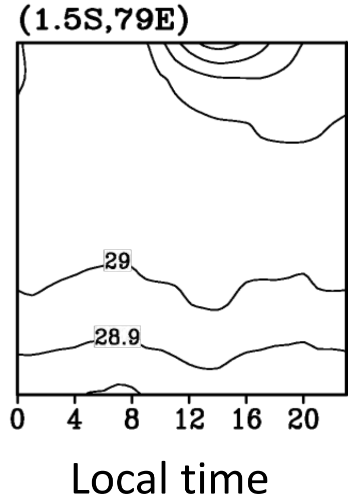
2) **Forcing fields** (hourly)
   - NCEP CFSR
   - NASA MERRA

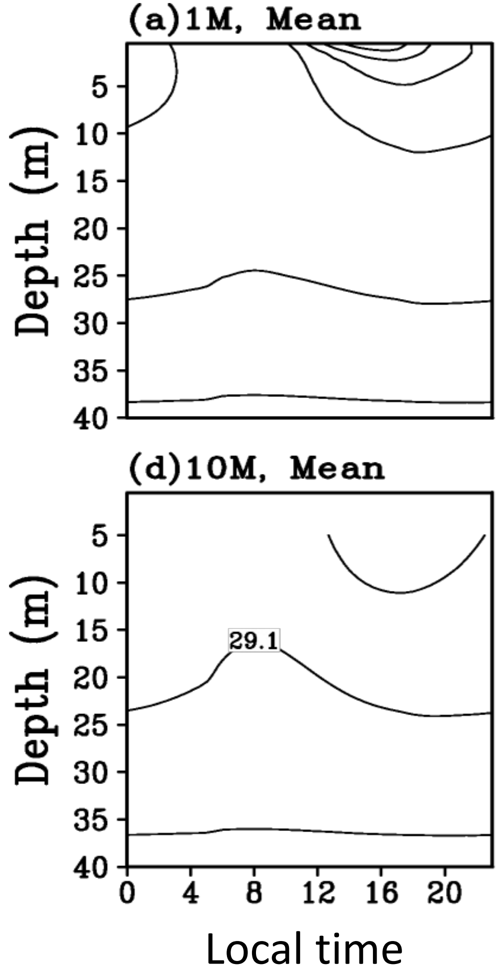
3) **Simulation period**
   - September 2011 to January 2012

4) **Experiments**
   1) 10M run: 10-meter vertical resolution for the 200 meter
   2) 1M run: 1-meter vertical resolution for upper 10 meters

5) **Validation data**
   - DYNAMO observations
   - RAMA observations

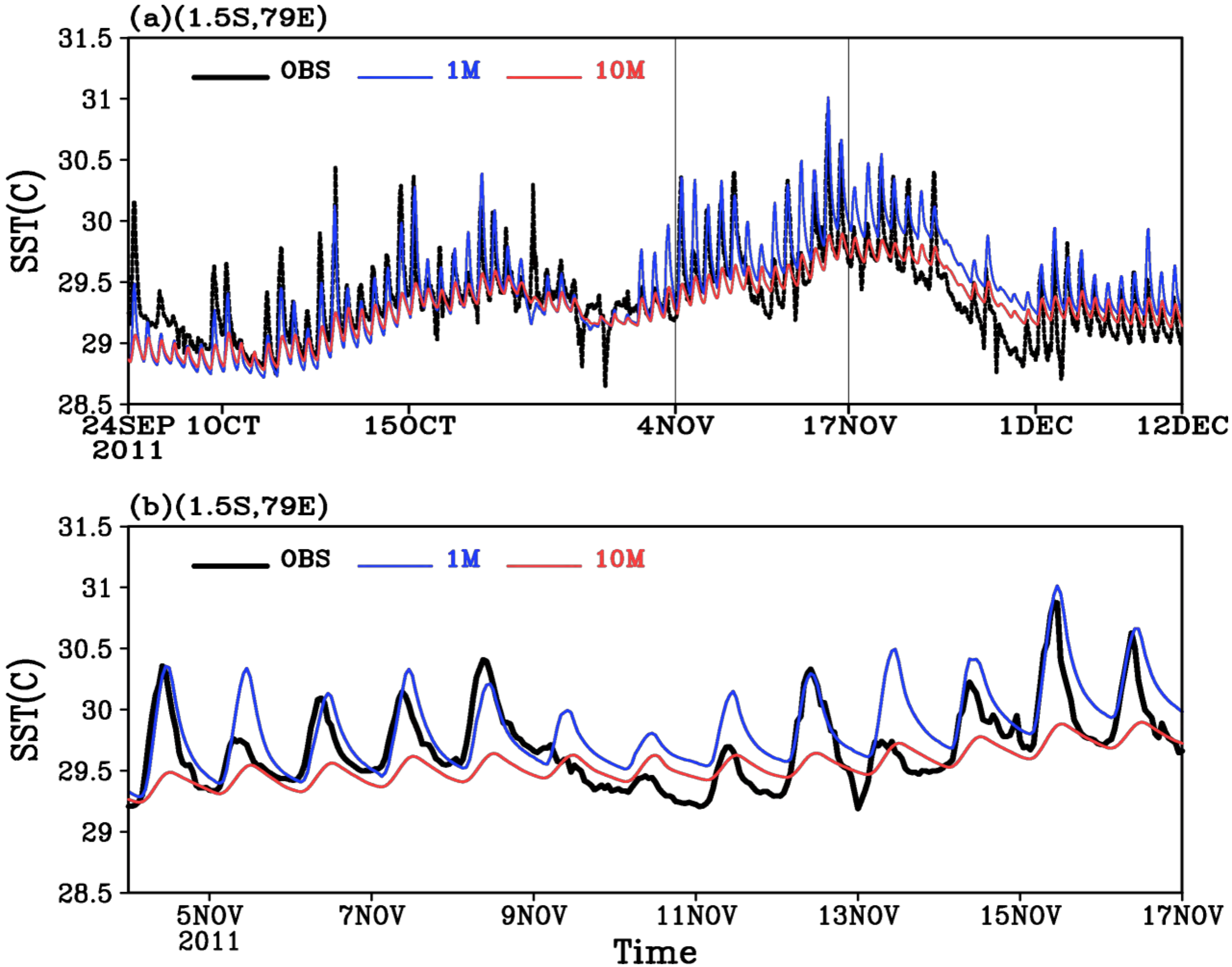
Average temperature diurnal cycle (1.5S, 79E)





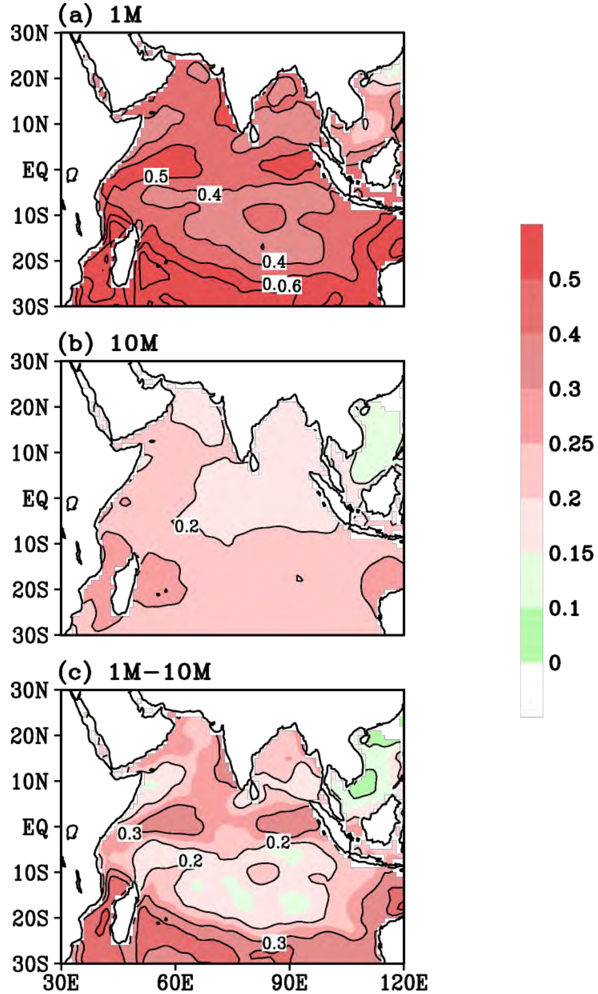
- Diurnal cycle realistic in 1M run and very weak in 10M run

SST evolution at (1.5S, 79E)

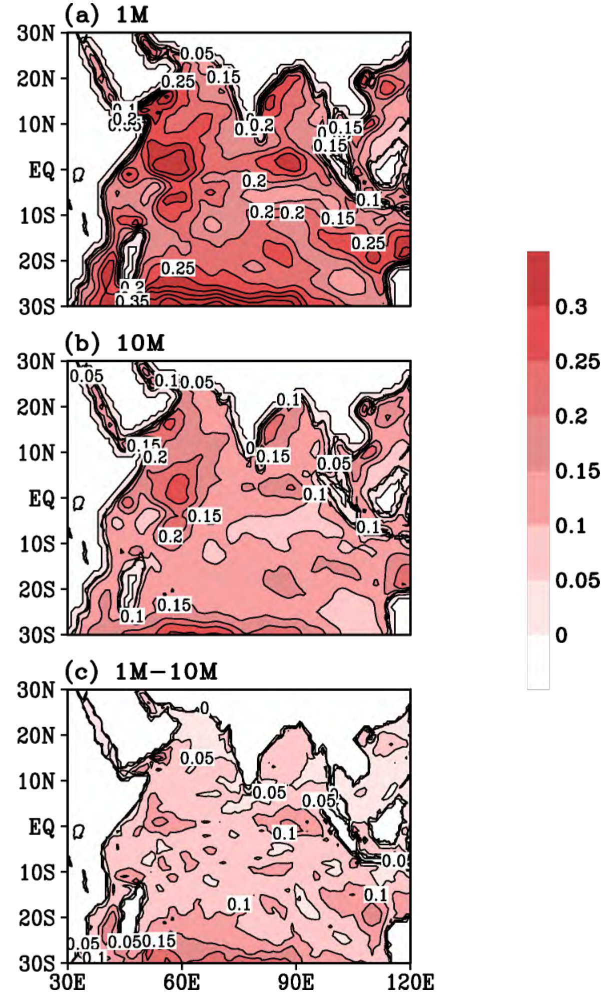


- Stronger diurnal cycle contributes to larger intraseasonal amplitude
- Diurnal cycle realistic in 1M run and very weak in 10M run

SST diurnal range

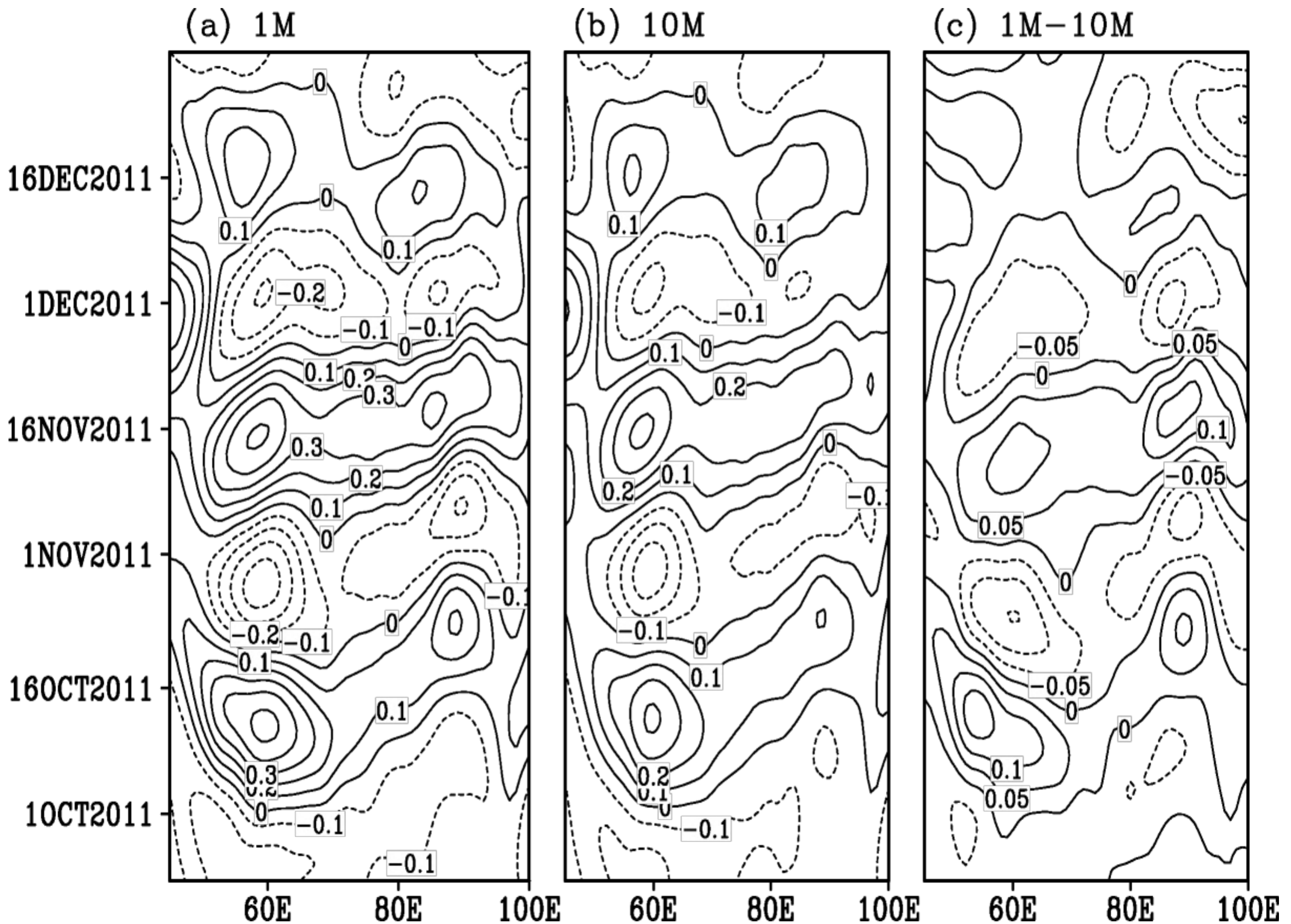


SST intraseasonal STDV



- Diurnal range in 1M run is 0.2-0.3K larger than in 10M run
- Intraseasonal STDV in 1M run is 0.1K larger than in 10M run

Intraseasonal SST evolution during DYNAMO ISP



- Stronger SST amplitude in 1M run
- In phase SST amplification

Part 2 Summary

1) The observed ocean temperature shows clear a diurnal cycle near the surface with a sharp vertical gradient in the upper 10 meters

2) Simulation with 1-m vertical resolution produced more realistic diurnal and intraseasonal variability, which is too weak in 10-m simulation

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Experiments to study impacts of SST diurnal cycle, SST intraseasonal variations, and SST mean state

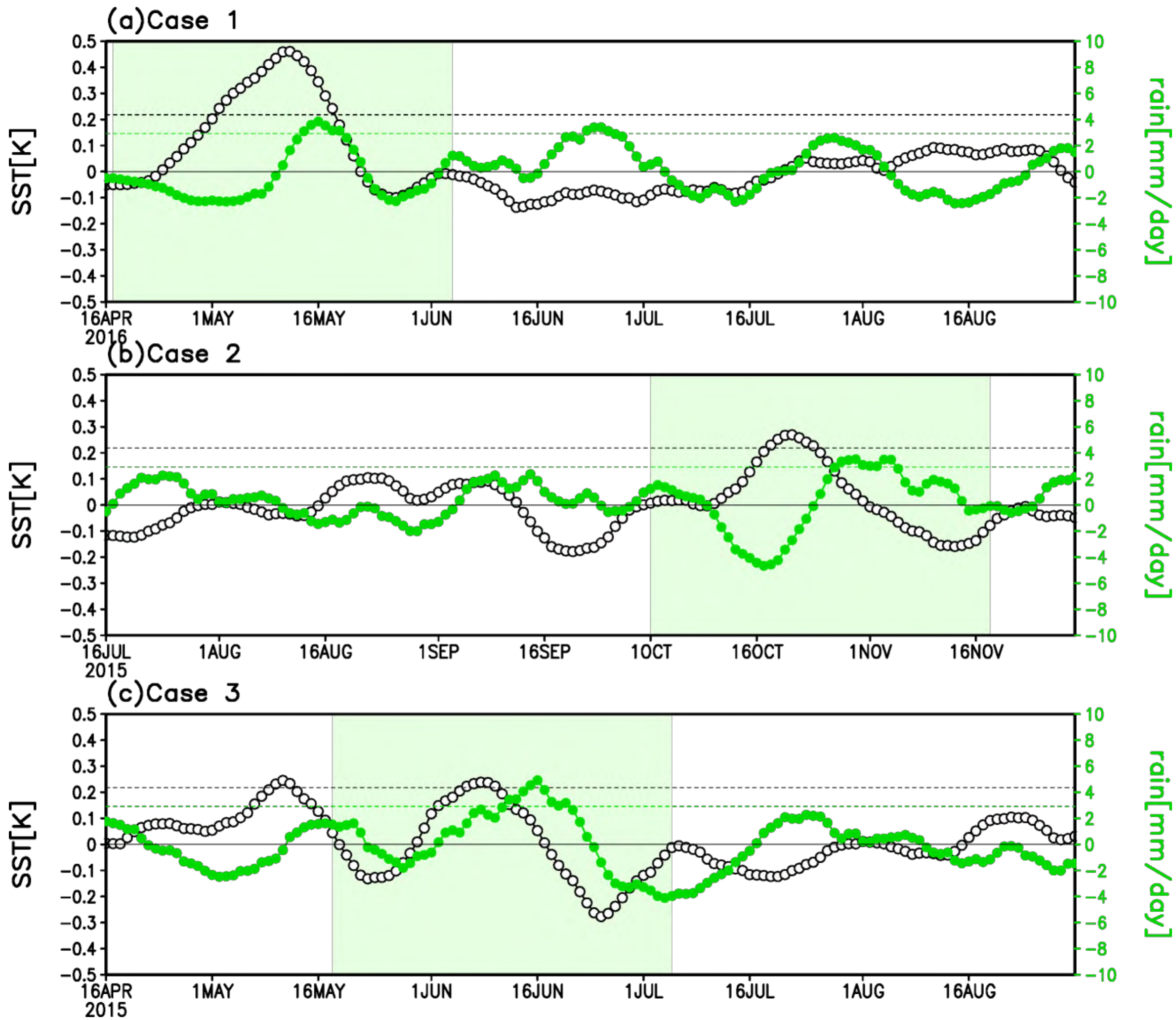
1) Models

- Atmosphere-only GFS
- Coupled GFS/MOM5 (CFSm5)

2) **Experiments** (impacts of SST diurnal cycle, SST intraseasonal variations, and SST mean state)

	Experiments	SST variability	SST forcing
GFS	SSThly	Hourly	Hourly OSTIA SST
	SSTdly	Daily	Daily OSTIA SST
	SSTssn	Seasonal	Daily OSTIA SST without intraseasonal variation
	SSTssnh	Warmer Seasonal	Daily OSTIA SST without intraseasonal variation + 1K in the tropical Indian Ocean
	SSTssnl	Cooler Seasonal	Daily OSTIA SST without intraseasonal variation - 1K in the tropical Indian Ocean
CFSm5	CFSm501	1m vertical resolution in the upper ocean in MOM5	
	CFSm510	10m vertical resolution in the upper ocean in MOM5	

3). Events for MISO experiments



Selection of events:
Amplitude of both SST and rainfall anomalies > 1 STDV

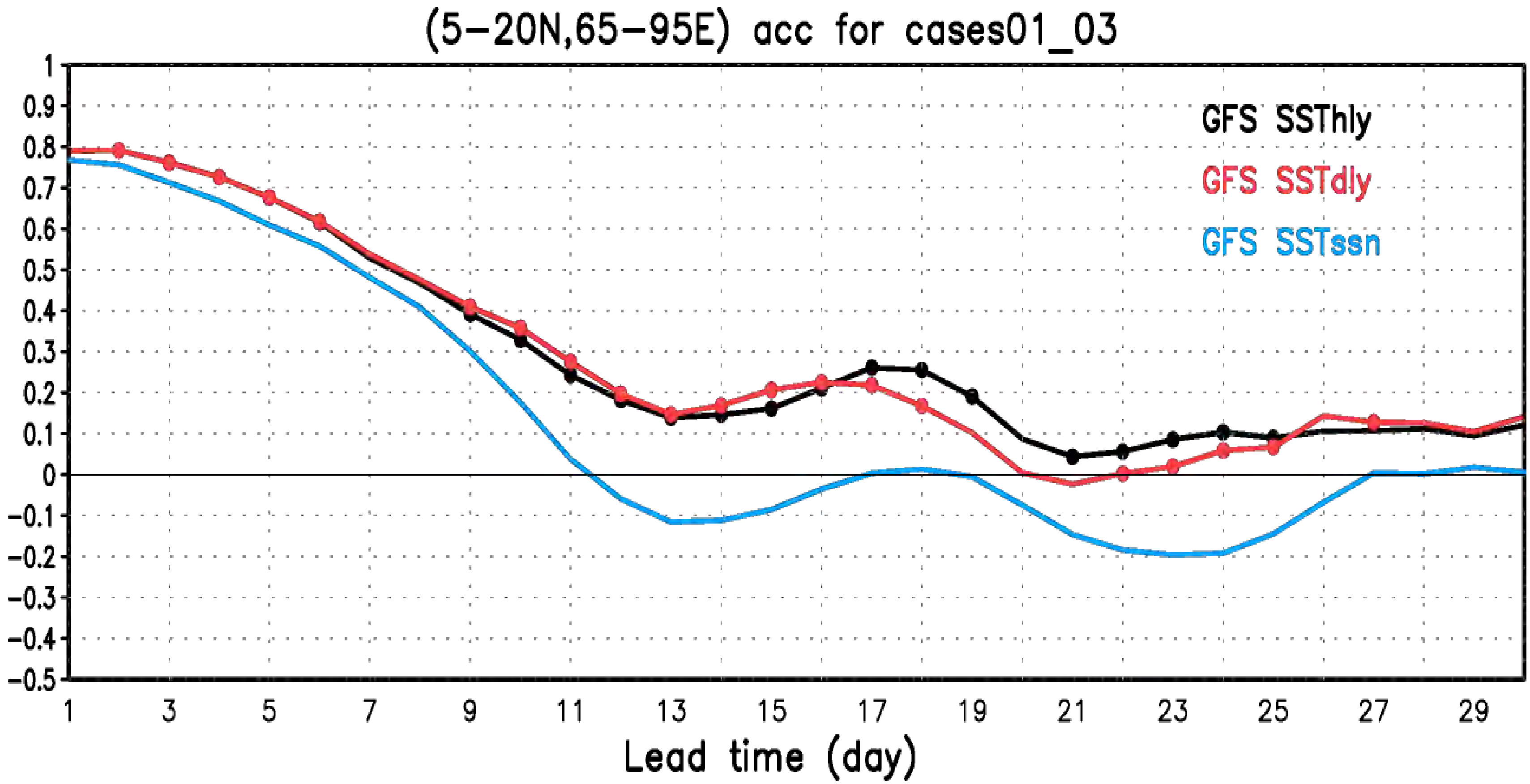
4). Forecasts

i) Four initialized forecasts each day

ii) 30-day target period

Atmosphere-only **MISO** experiments

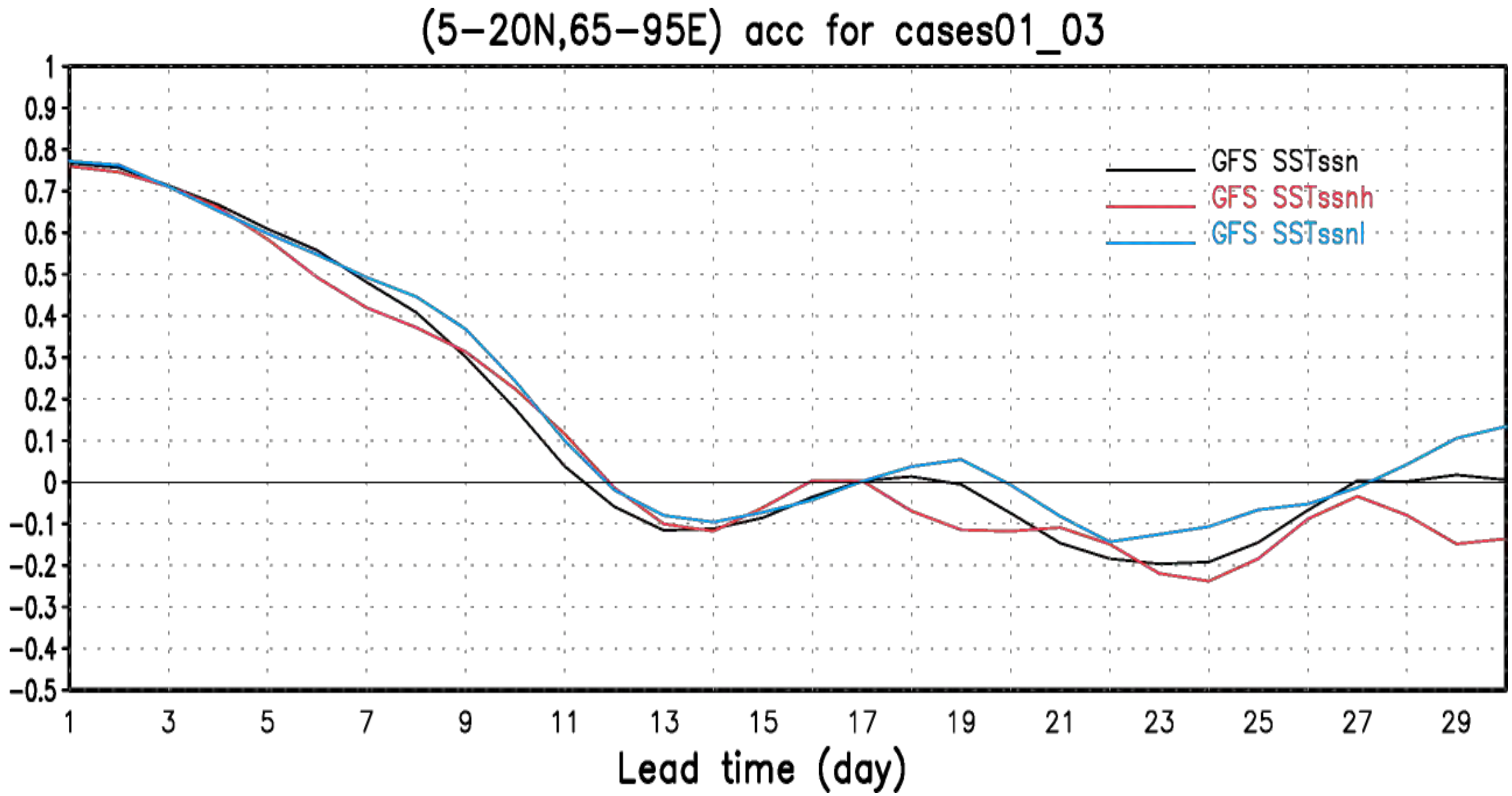
Rainfall anomaly correlation



- Inclusion of SST intraseasonal variations improves MISO prediction skill
- SST diurnal cycle itself does not result contribute to prediction skill

Atmosphere-only **MISO** experiments

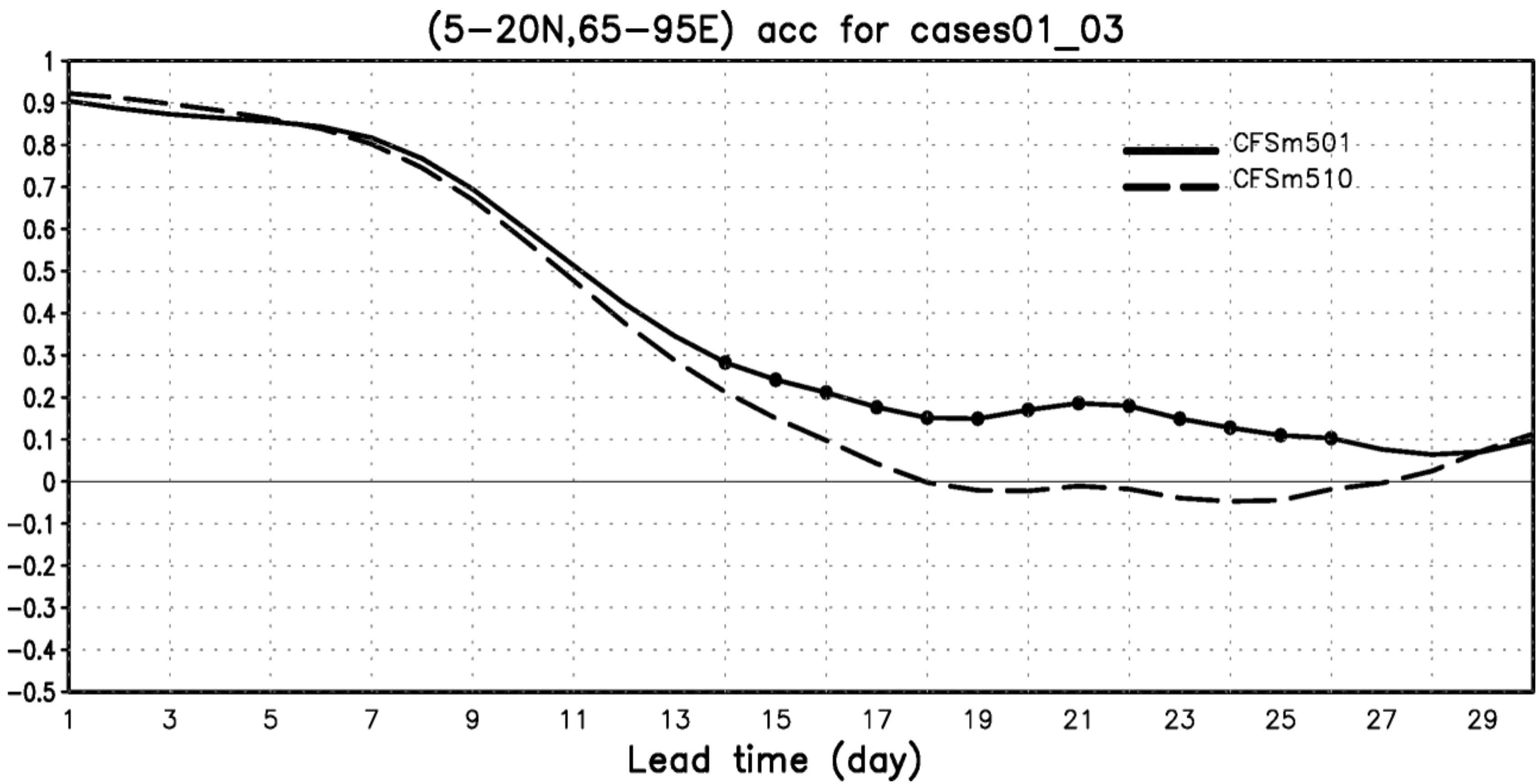
Rainfall anomaly correlation



- Change of SST mean state does not have any significant impact

Coupled model **MISO** experiments

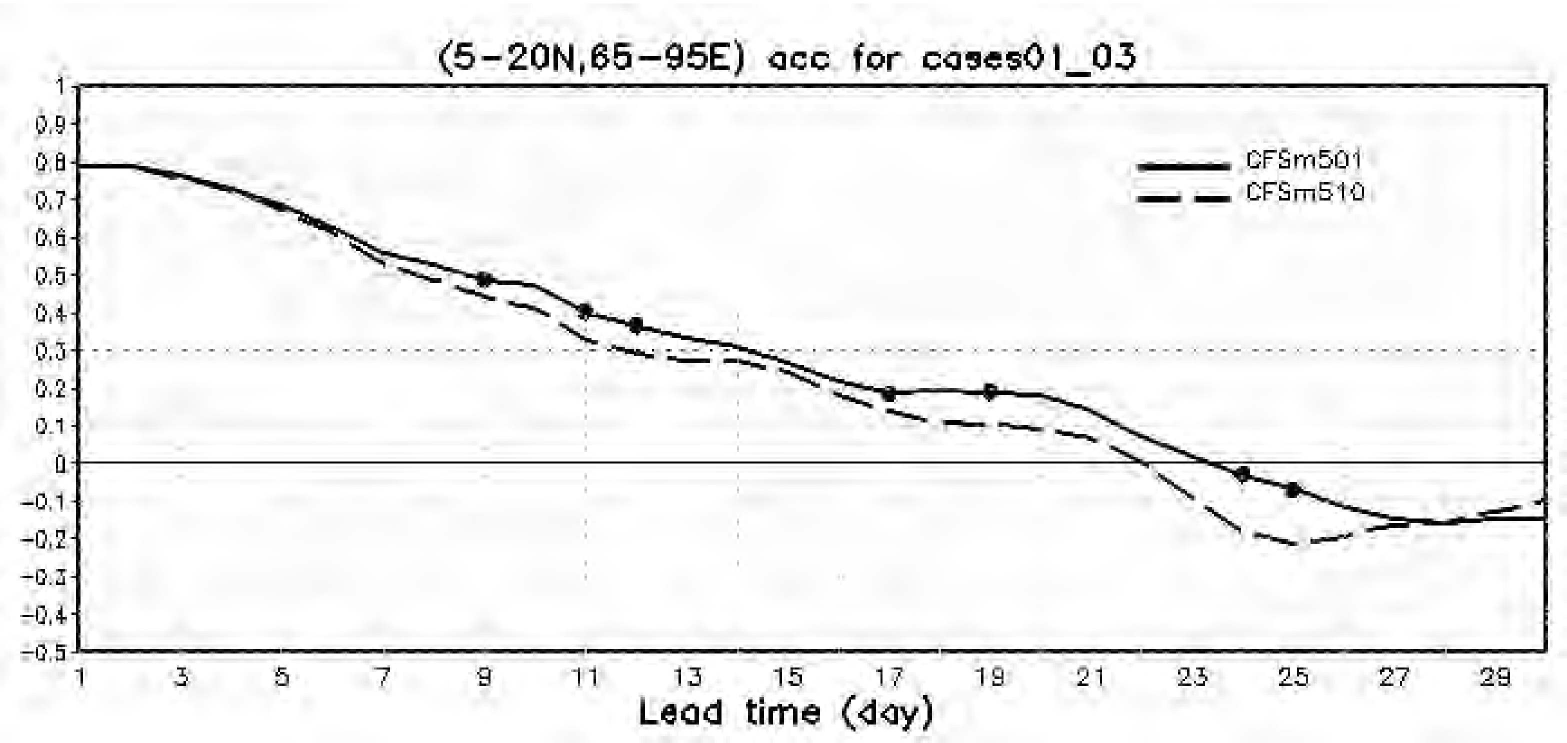
SST anomaly correlation



- Use of higher vertical resolution in the upper ocean (CFSm01) improves MISO prediction

Coupled model **MISO** experiments

Rainfall anomaly correlation



- Use of higher vertical resolution in the upper ocean (CFSm01) improves MISO prediction

Part 3 Summary

1) Consistent SST intraseasonal variations contribute to the representation of MISO.

2) Presence of diurnal cycle itself is not critical for MISO prediction, although it is necessary in a coupled model to improve the prediction of SST intraseasonal variations.

3) Use of higher upper ocean vertical resolution leads to an improved SST and MISO rainfall prediction.

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- How important is the presence of the air-sea interaction when the mean state of SST is the same?

- What is the role of convection parameterization in maintaining consistent SST variability through its impact on surface fluxes?

Coupled model experiments

1) Model

- CFSv2 (GFS T126/MOM4 0.25°X0.5°)
- CFSv2L (GFS T62/MOM4 0.33°X1°)

Ocean vertical resolution is 10m

2) Convection parameterizations

- SAS (Simplified Arakawa Schubert (Pan&Wu 1995))
- RAS (Relaxed Arakawa Schubert (Moorthi and Suarez (1999))

3) Experiments (20 years from 25 year runs)

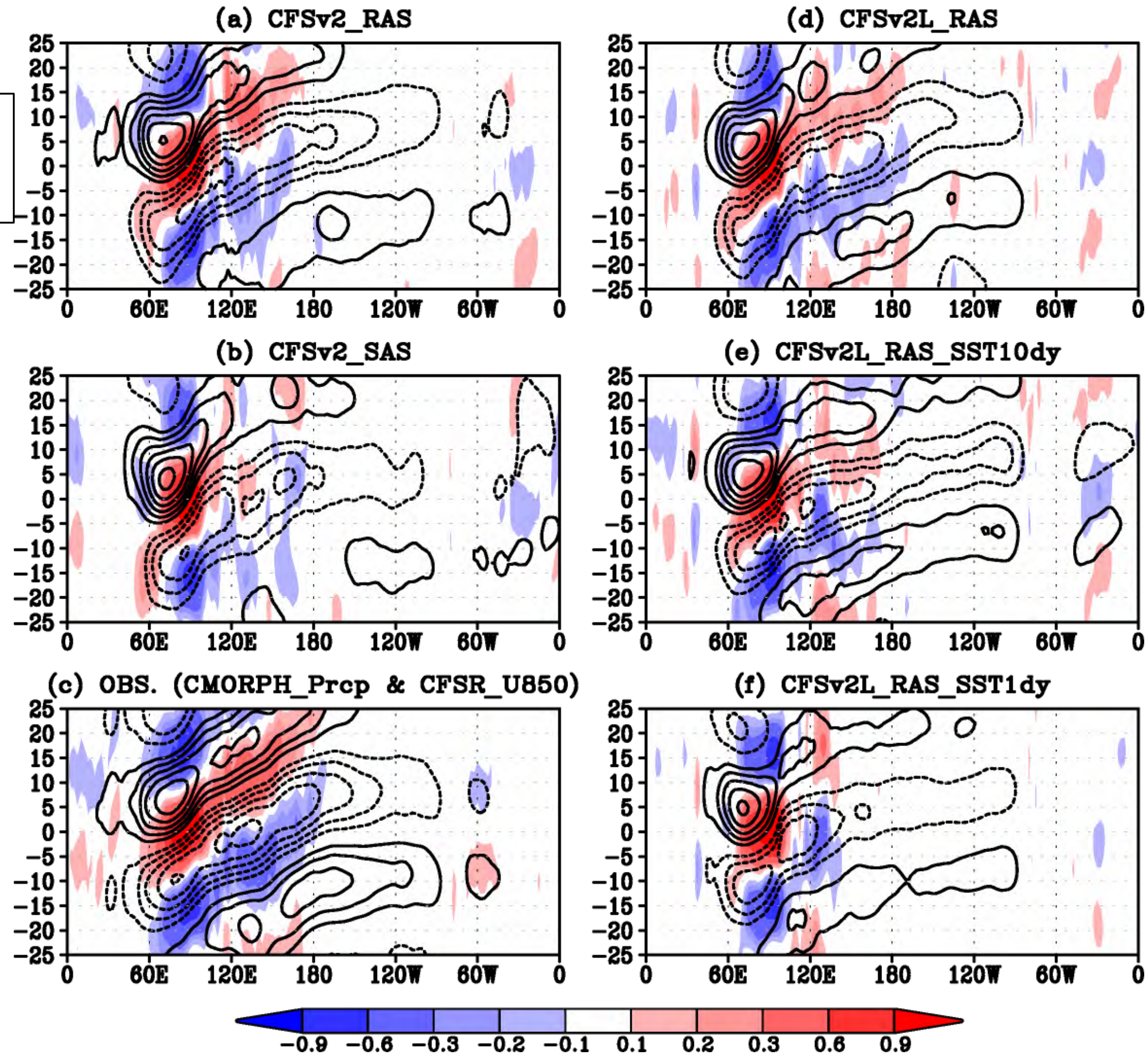
Experiments	Model	Convection	SST nudging	
CFSv2_SAS	CFSv2	SAS	No	Full coupling
CFSv2_RAS	CFSv2	RAS	No	
CFSv2L_RAS	CFSv2L	RAS	No	
CFSv2L_RAS_SST1dy	CFSv2L	RAS	Yes (1 day)	Partial coupling
CFSv2L_RAS_SST10dy	CFSv2L	RAS	Yes (10 days)	

Lagged regression against Indian Ocean precipitation (70°E-100°E)

10°S–10°N average, November - April

Shading: Precipitation
Contour: 850-hPa zonal wind

- **Horizontal resolution** is not a critical parameter (CFSv2_RAS vs CFSv2L_RAS)
- **Coupling** is important (CFSv2L_RAS vs CFSv2L_RAS_SST1dy & CFSv2L_RAS_SST10dy)
- **Convection scheme** is important (CFSv2_RAS vs CFSv2_SAS)

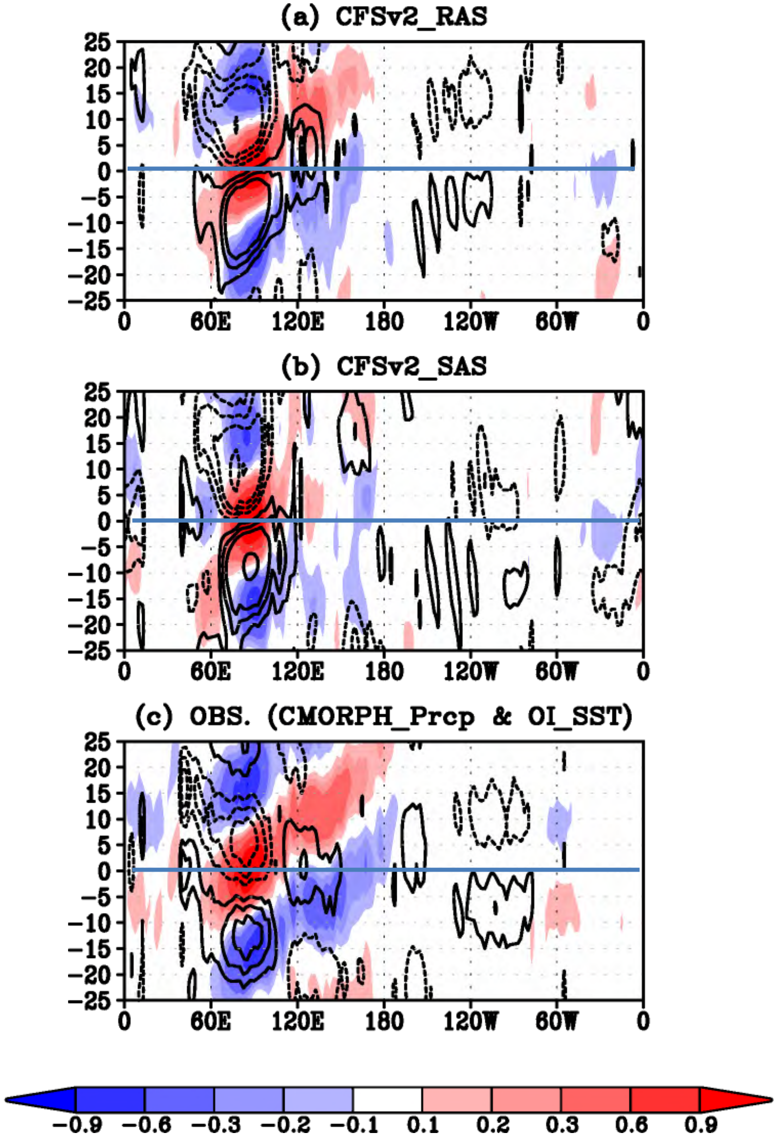


Lagged regression against Indian Ocean precipitation (70°E-100°E)

10°S–10°N average, November - April

Shading: Precipitation
Contour: SST

- Observed SST leads precipitation by 7 days
- Warm SST conditions developed in East MC and WP when enhanced convection is in Indian Ocean
- This features is captured in the RAS run
- The SAS run failed to produce the development of warm SST anomalies in the MC and WP

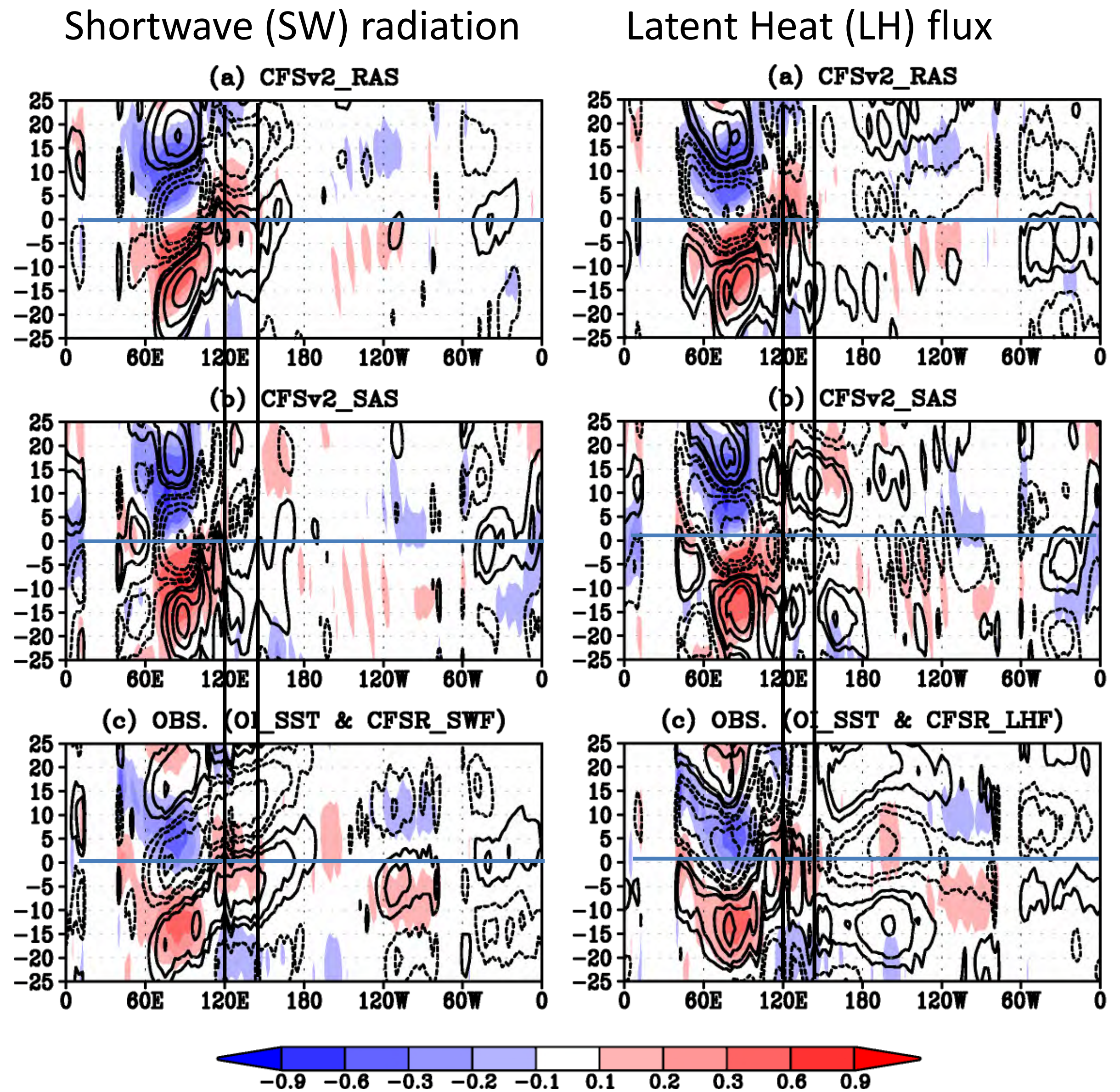


Lagged regression against Indian Ocean precipitation (70°E-100°E)

10°S–10°N average, November - April

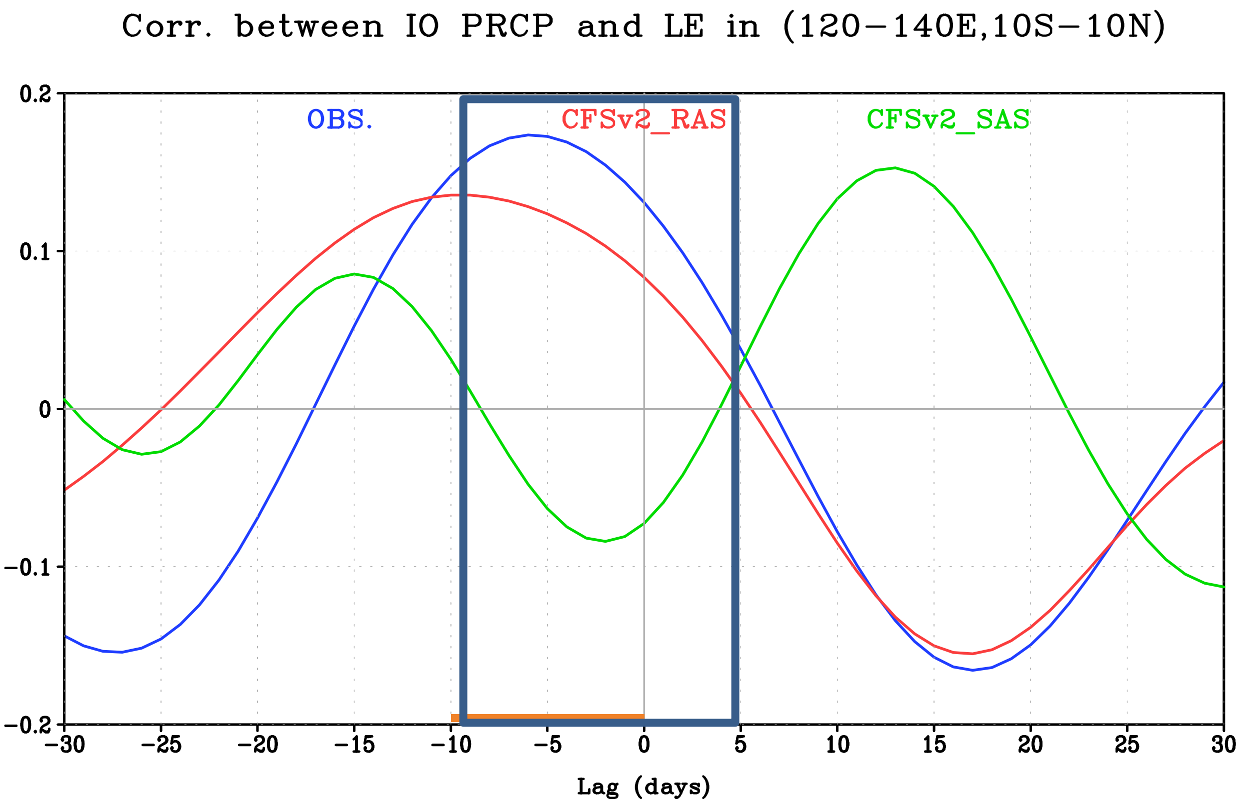
Shading: SST
Contour: SW or LH

- Similar patterns in SW to the East of MC (120E-140E)
- Large differences in LH in this region



Lagged correlation of LH in East Maritime Continent/West Pacific (120E-140E) with Indian Ocean precipitation (70°E-100°E)

- The lag correlation in CFSR_RAS is in phase with that in observation for day -15 to day 30
- CFSv2_SAS is out of phase for day -10 to day 20
- Of particular importance is the difference from day -10 to day 5 during which LH in OBS and CFSv2_RAS accumulatively contribute to warming up SST in East Maritime Continent/Western Pacific

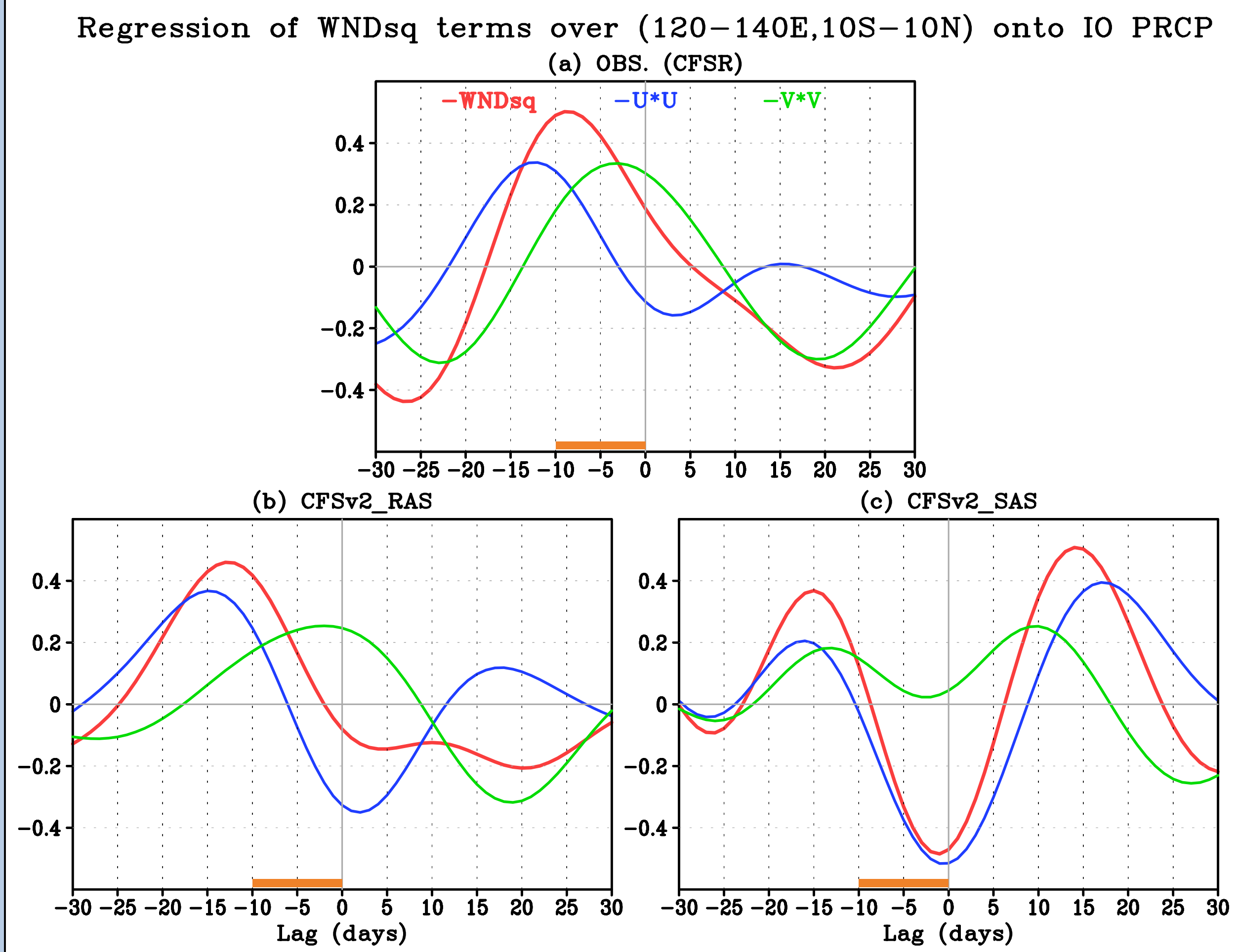


$$LHF \sim w(q_a - q_s)$$

$$dLHF \sim dw*(\overline{q}_a - \overline{q}_s) + \overline{w}*(dq_a - dq_s) + e$$

Lagged regression of -W^2(-WNDsq), -U^2, and -V^2 in East Maritime Continent/West Pacific (120E-140E) with Indian Ocean precipitation (70°E-100°E)

- In OBS, positive regression of the total wind speed from day -17 to day 0. U component dominates before day -8 and V component dominates after day -8
- These evolutions and partitioning are well captured in CFSv2_RAS
- CFSv2_SAS simulates too strong negative values of U component and too weak positive values of V component after day -10



Part 4 Summary

- Air-sea coupling establishes consistent ocean surface conditions in the East Maritime Continent (MC) and far West Pacific, and is necessary for simulating MJO propagation across the MC

- Both zonal and meridional wind anomalies must be correctly simulated to produce realistic surface latent heat flux anomalies. Coupling alone is not sufficient to maintain a realistic MJO propagation across the MC.

Outline

I. Importance of the SST accuracy
   – Simulating the MJO/MISO with an atmosphere-only model

II. Importance of ocean vertical resolution
   – SST variability with an ocean-only model

III. Impact of SST diurnal and intraseasonal variations, and mean state
   – MISO simulations with atmosphere-only and coupled models

IV. Importance of the air-sea interaction
   – Simulating the MJO with a coupled model

V. Dependence of MJO predictability/prediction on convection
   – Perfect model predictability
   – Prediction skill dependence on convection scheme

Dependence of MJO predictability/prediction skill on convection scheme

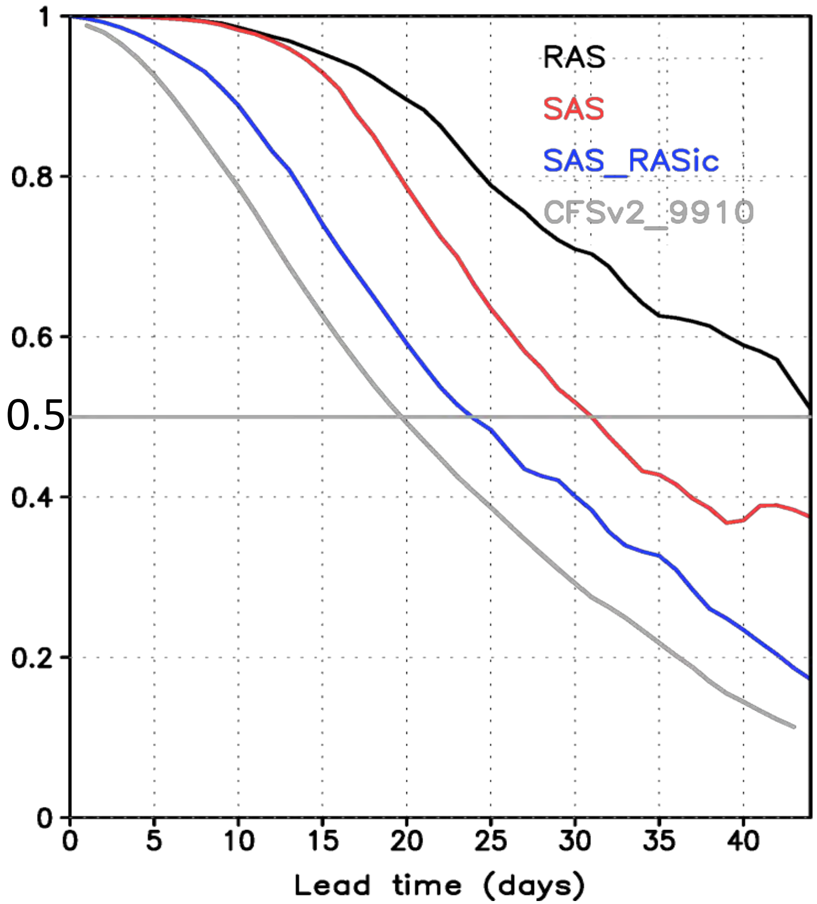
- Does the MJO have larger predictability with RAS scheme?

- To what extent the MJO prediction skill in CFSv2 is degraded due to the use of SAS scheme?

MJO predictability/prediction coupled model experiments

- **Experiments**
  - RASmod: 30-year CFSv2 free simulations with RAS
  - SASmod: 30-year CFSv2 free simulations with SAS
  - Perfect model predictions (10 members, 45-day)
    - RAS: RASmod, RASic
    - SAS: SASmod, SASic
  - Prediction experiment
    - SAS_RASic: SASmod, RASic

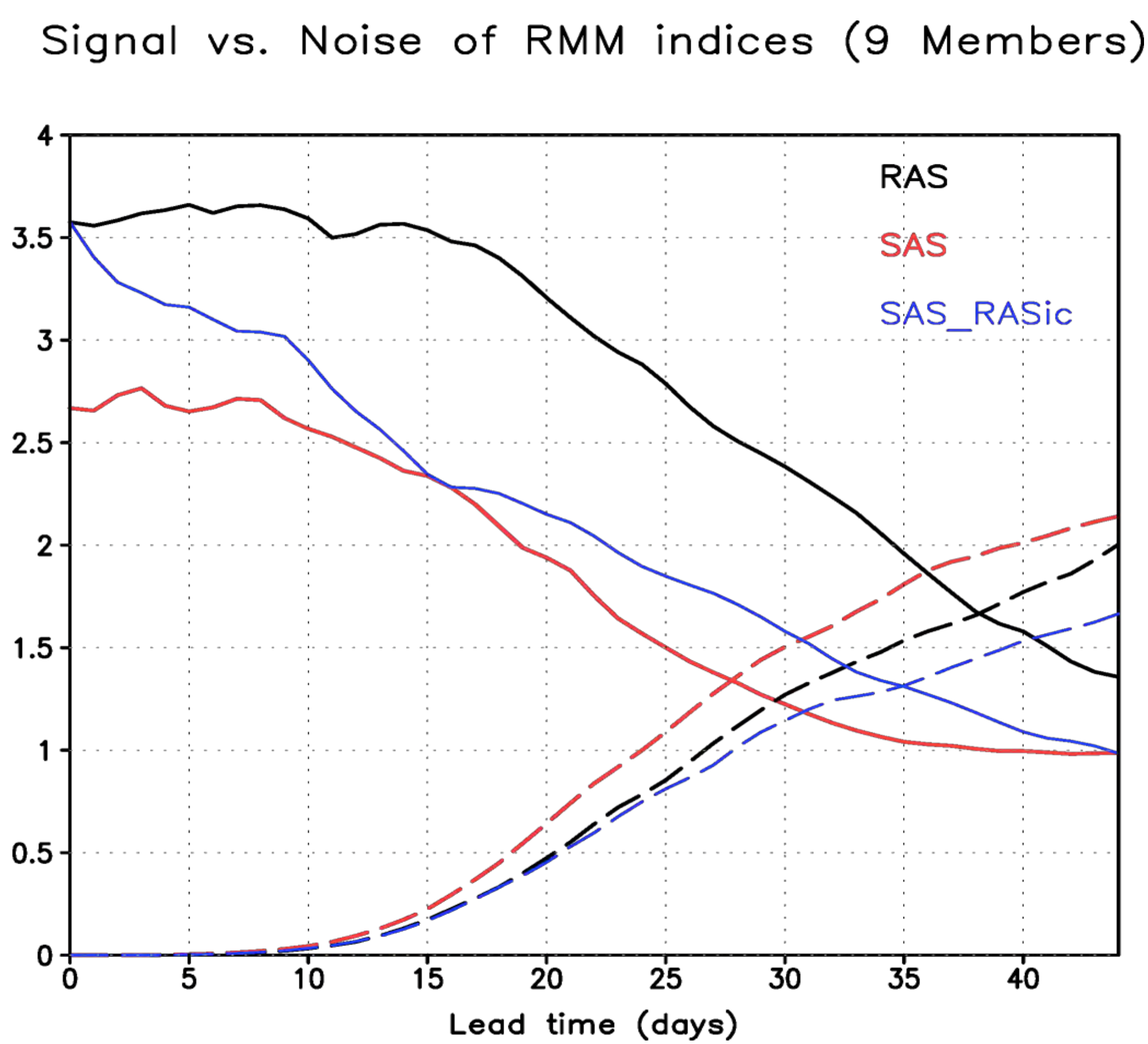
Prediction skill of RMM indices



- Large predictability difference of 15 days due to convection scheme (>45 days in RAS vs 31 days in SAS)
- Prediction skill drop of 20 days due to convection scheme (>45 days in RAS vs 24 days in RAS_RASic)
- Similar skill decrease rate in SAS, SAS_RASic, and CFSv2 (all using SAS)

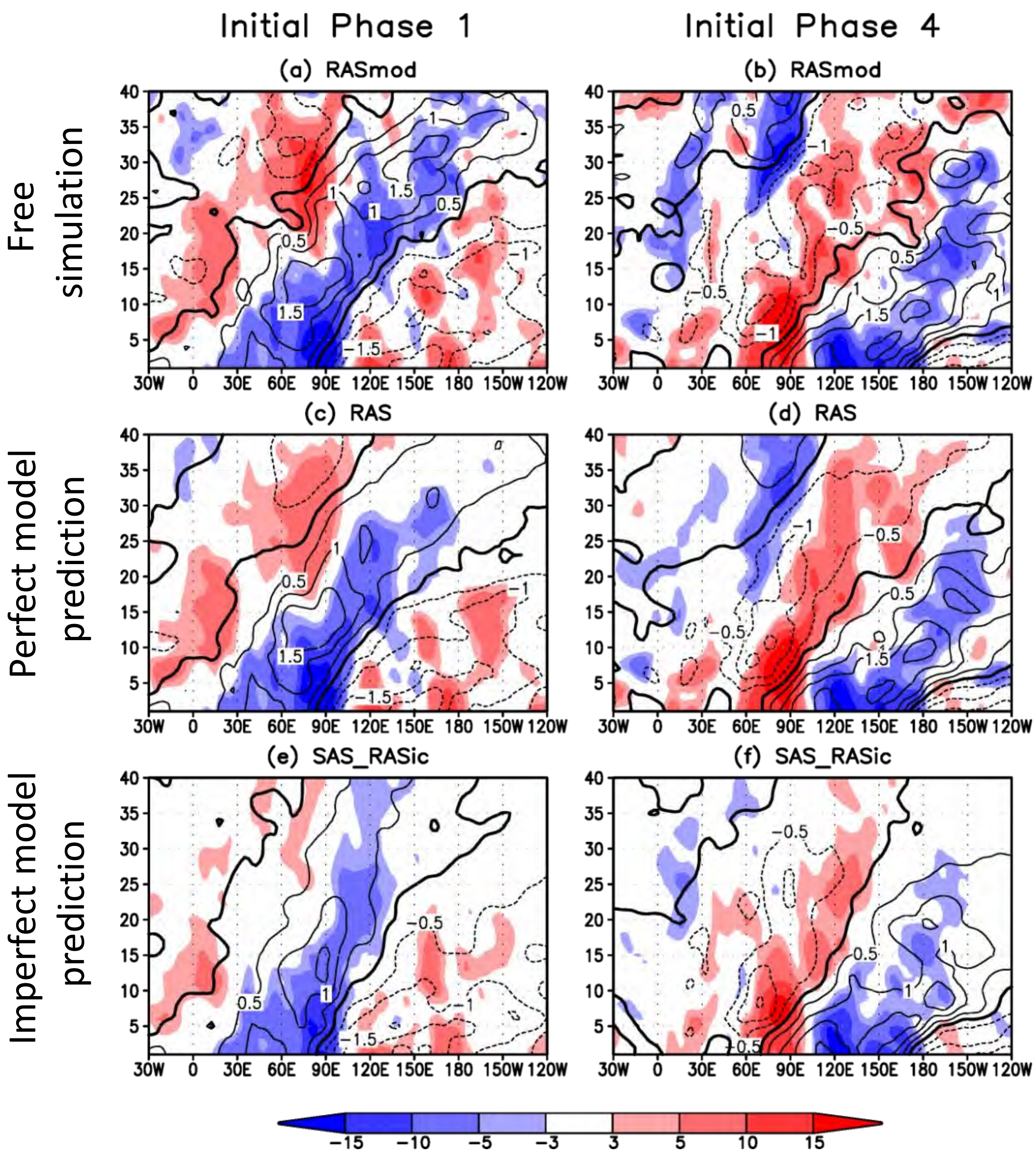
- Optimal skill gain from initialization: 5 days (CFSv2 to SAS_RASic)
- Optimal skill gain from convection scheme: 20 days (SAS_RASic to RAS)

Why the predictability is larger in RAS than in SAS?



- Predictability is determined by signal to noise ratio (SNR).
- Smaller predictability in SAS is largely due to the difference in signal
- Consistency between prediction skill and SNR is less clear

Evolution of anomalies



Shading: OLR
Contour: U850

- Convection propagated more slowly in SAS_RASic
- U850 also propagated more slowly in SAS_RASic
- Weaker OLR amplitude in SAS_RASic than in RASmod and RAS

Part 5 Summary

- Convection scheme alone can have substantial influence on the estimate of MJO predictability (differing by as much as 15 days)

- The shorter predictability with SAS scheme is mainly caused by too weak MJO signal

Reference

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謝謝！