Coupled impacts of the diurnal cycle of sea surface temperature on the Madden-Julian Oscillation

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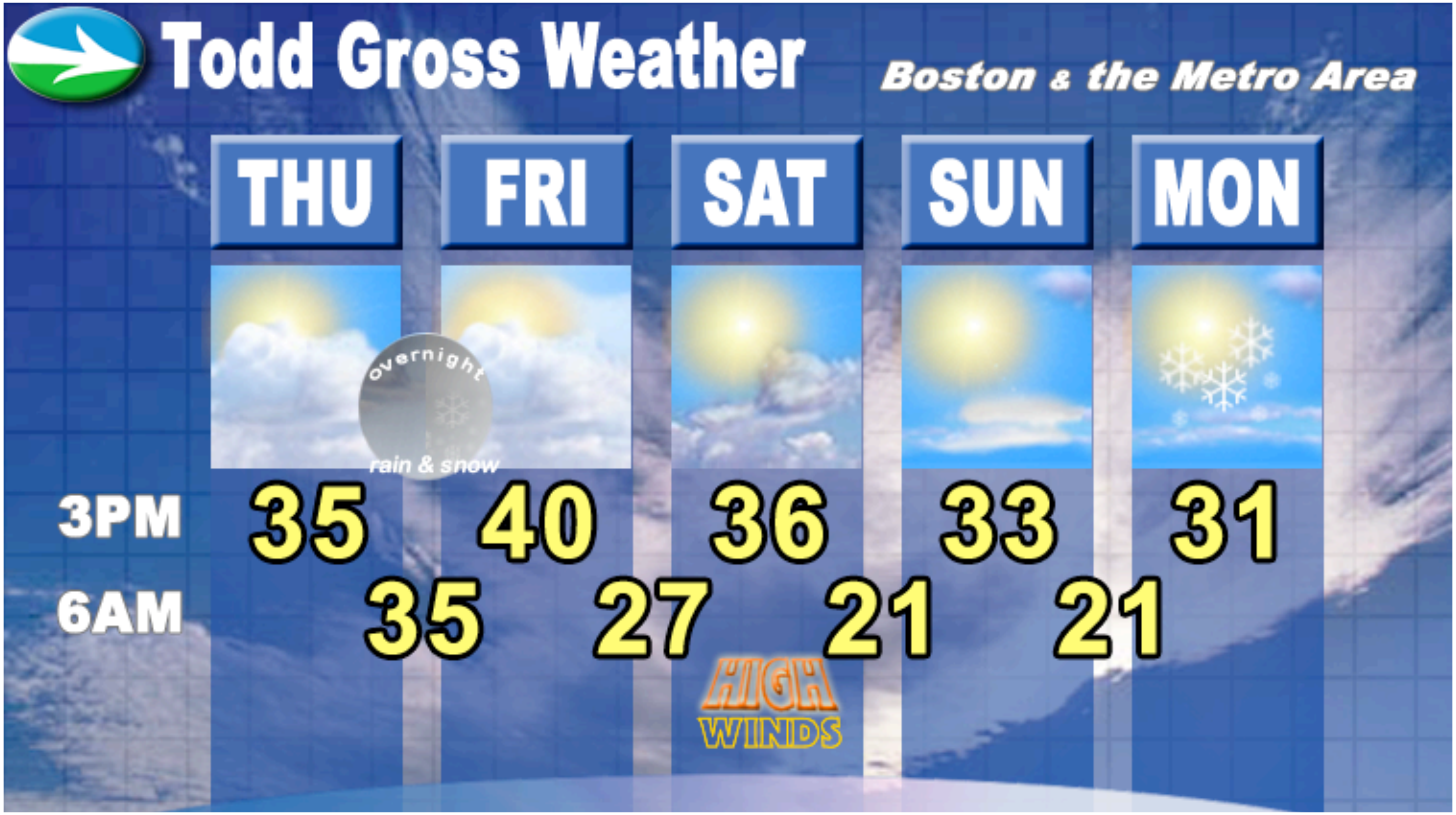
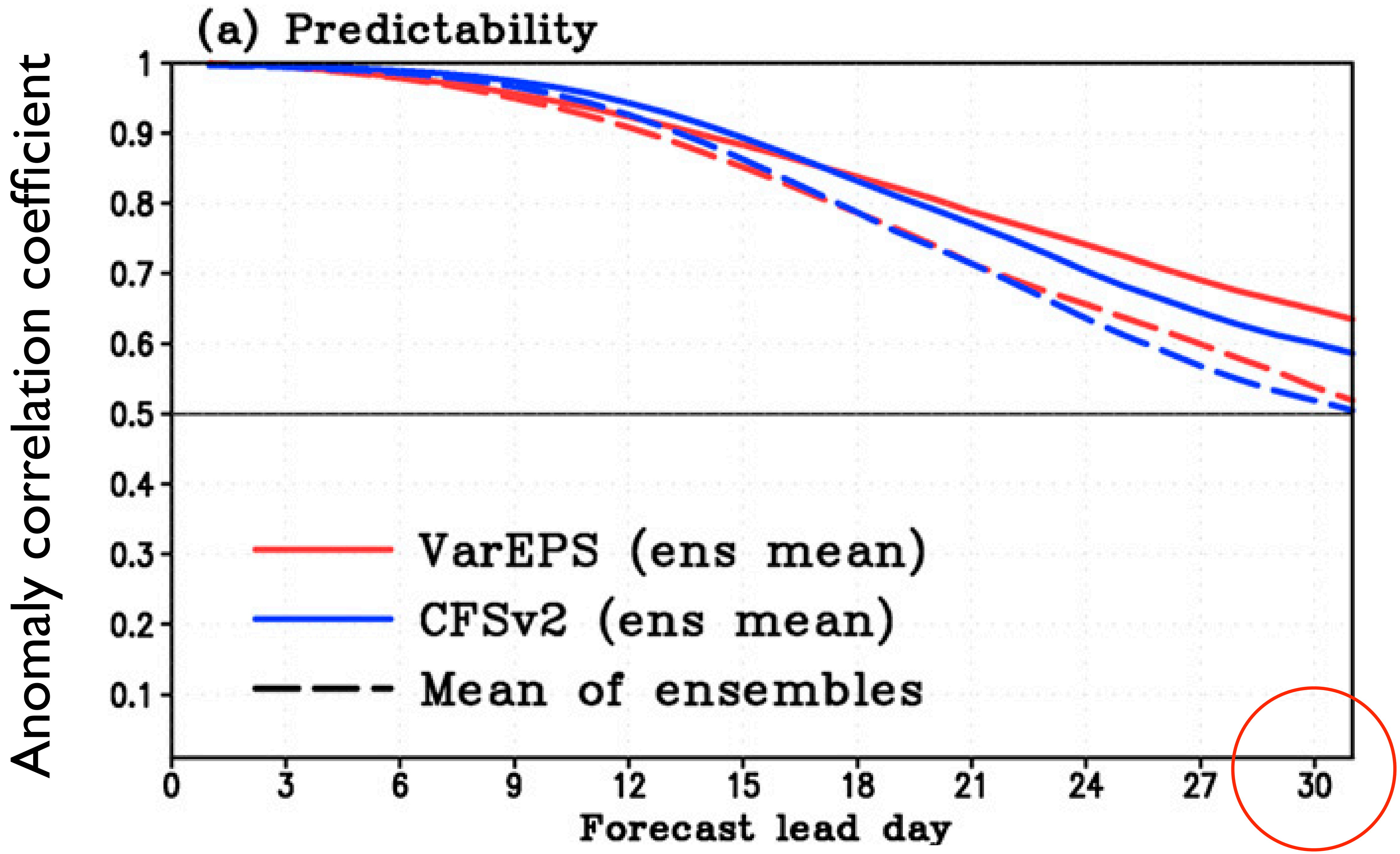
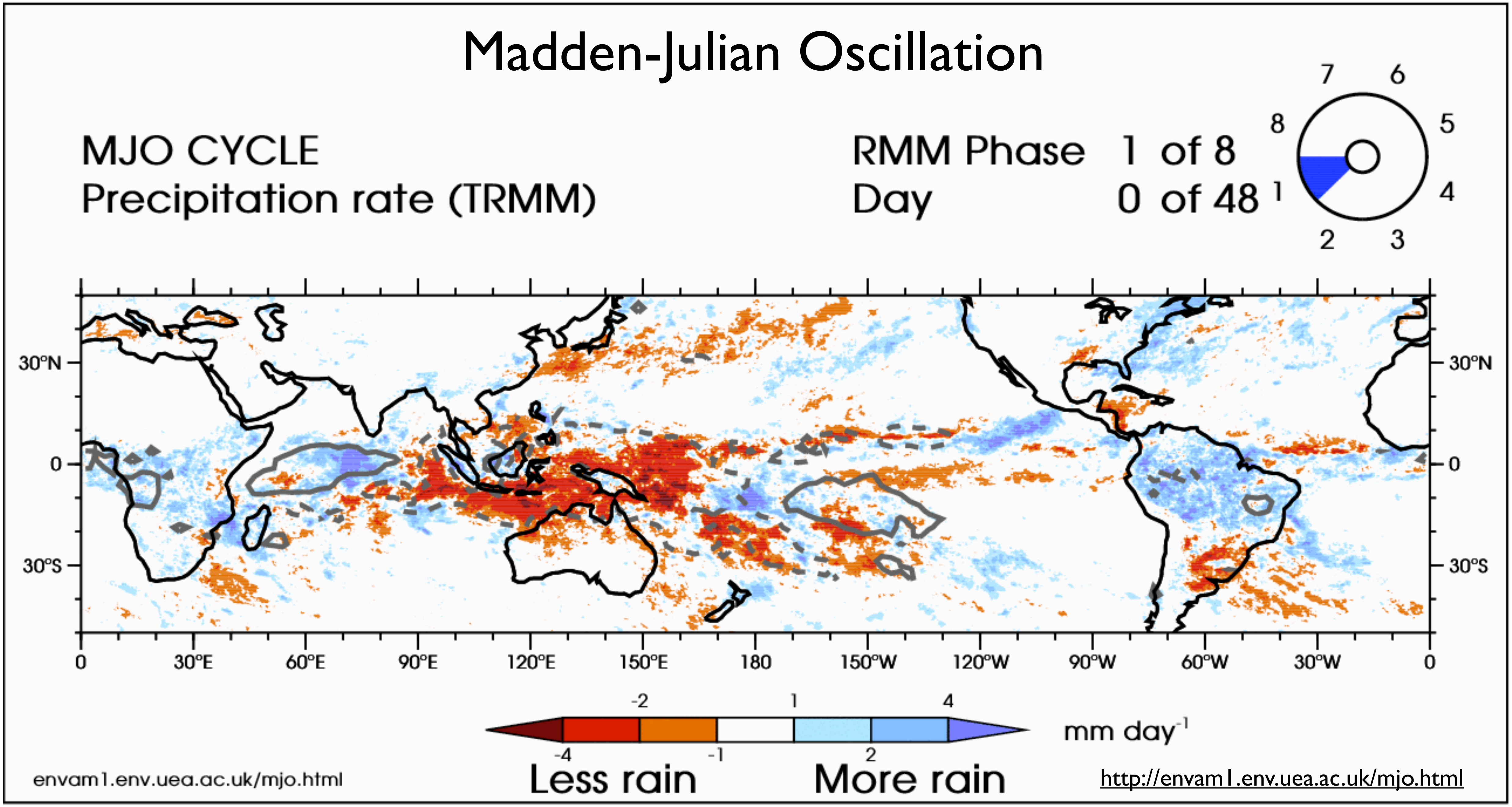
Typical 5-day winter weather forecast in Boston



Weather prediction time-scale for tropical circulation



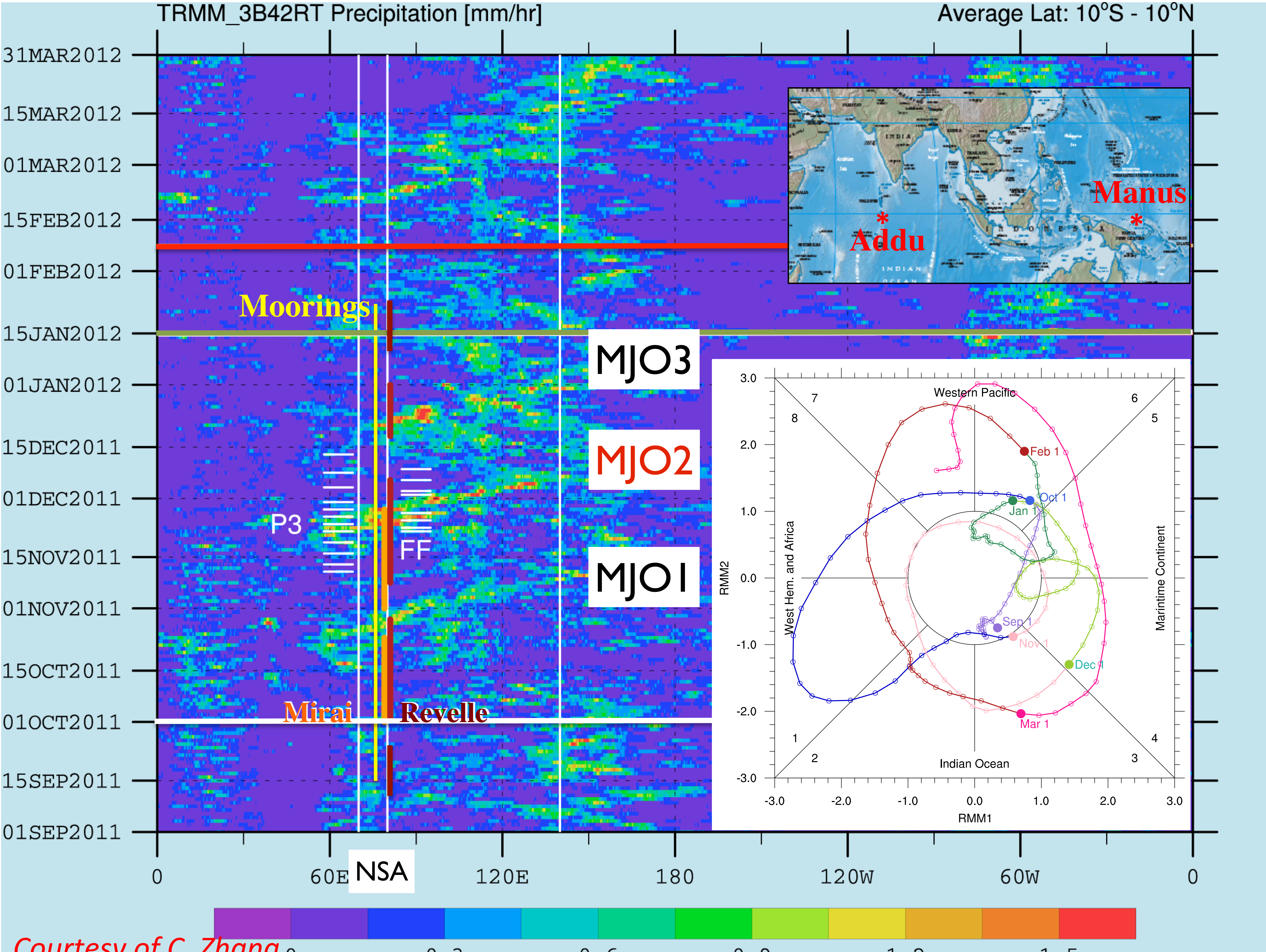
Kim et al. 2014



- Planetary-scale (k=1~3), eastward-propagating (~5ms^{-1}), equatorially-trapped, baroclinic oscillations
  - *Active*: deep convection, heavy precipitation, westerly wind, cool SST, weak diurnal SST
  - *Suppressed*: weak convection, strong insolation, easterly wind, warm SST, strong diurnal SST
- Many aspects of the MJOs remain poorly simulated and predicted:
  - Initiation and intensity of MJO convection in the equatorial Indian Ocean
  - Role of the upper-ocean variability and air-sea interactions

DYNAMO (Dynamics of MJO): Multi-national field experiment

Three MJOs during DYNAMO



Courtesy of C. Zhang

My contribution to the DYNAMO project

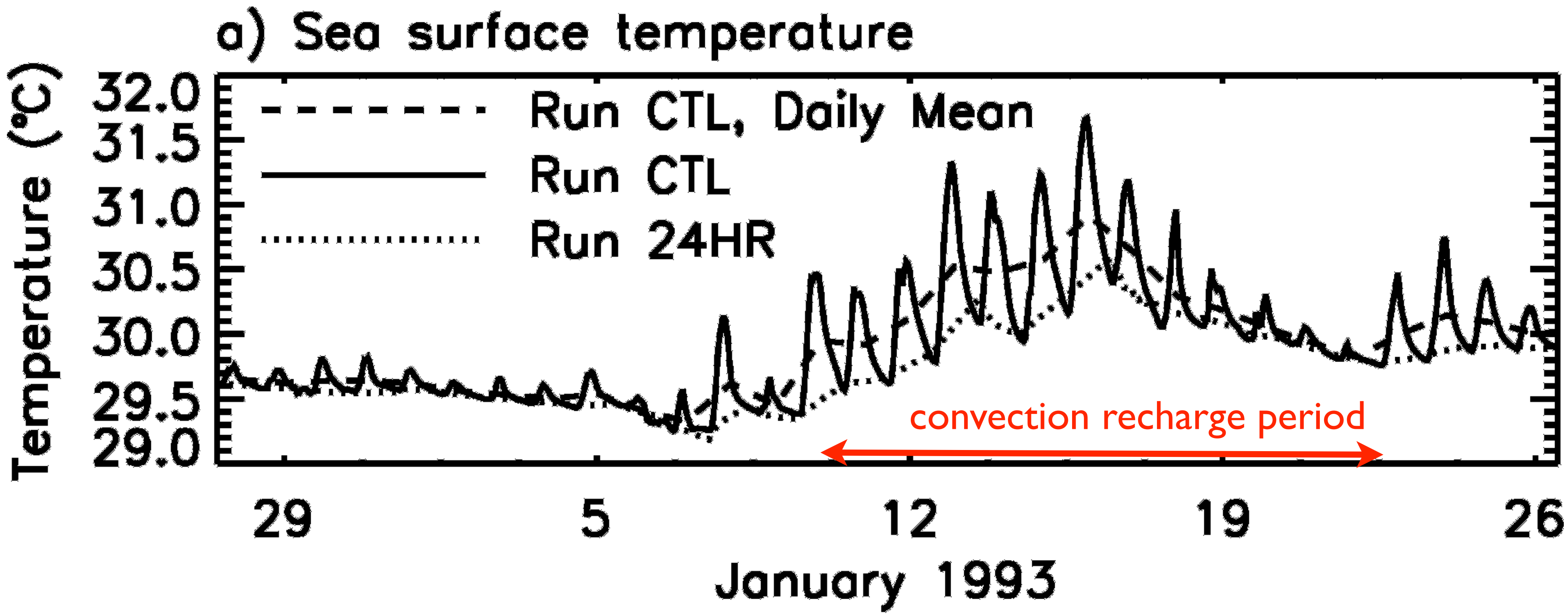
Process modeling: the role of "*oceanic process*" in the initiation and maintenance of MJO convection

Oceanic process, barrier layer, shear driven mixing, diurnal variation in the upper ocean stratification, and mixing-layer entrainment, controls the upper ocean heat content, SST and thus air-sea flux and the MJO convection.

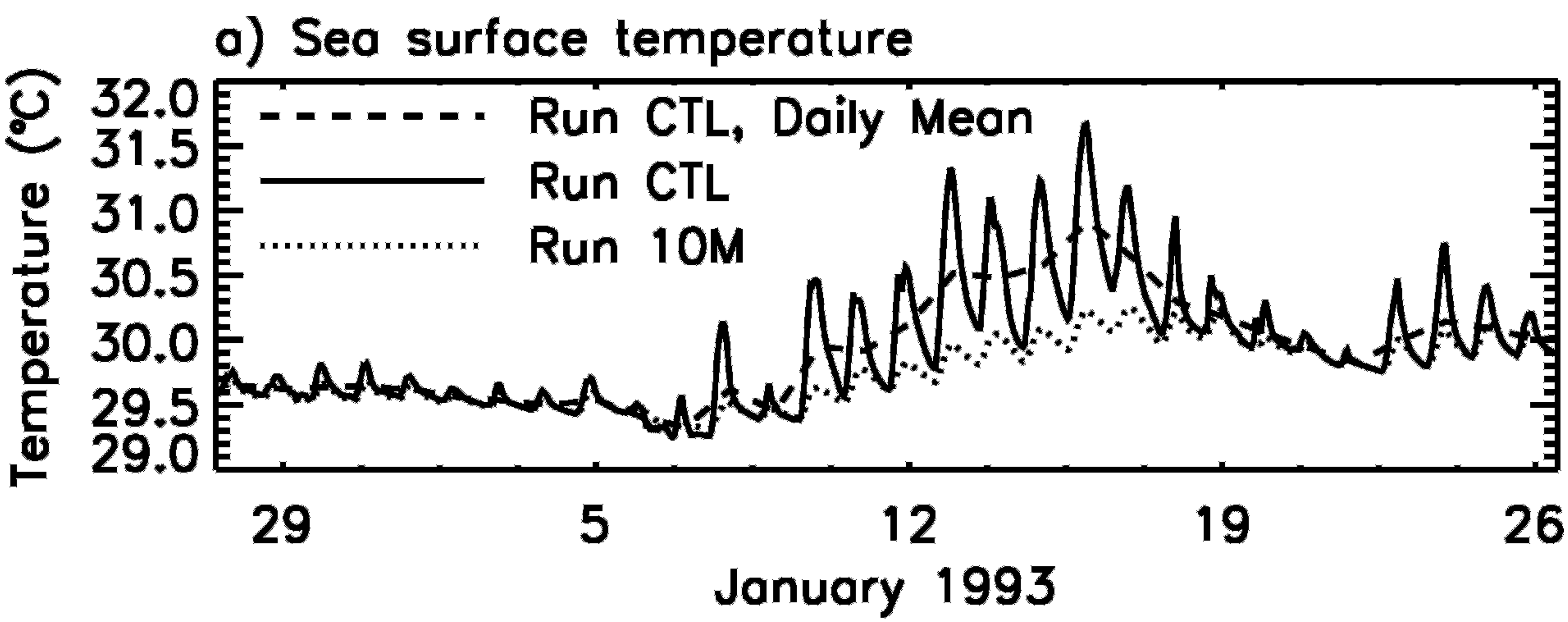
*Focus of this study:
Diurnal cycle of the upper ocean temperature
Why diurnal cycle?

Diurnal cycle enhances the daily mean and intraseasonal SST

1-D KPP modeling study (Bernie et al. 2005)



Forcing frequency
3h vs 24h



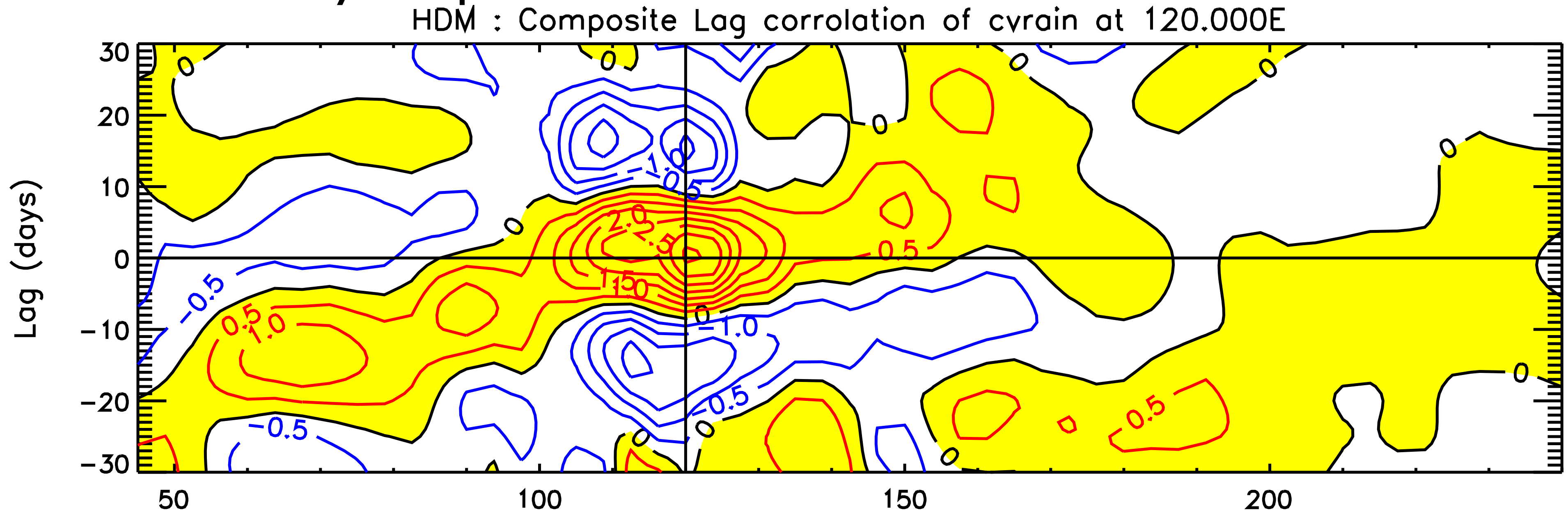
Vertical resolution:
1m vs 10m

How does it impact the MJO convection?

Stronger and more coherent MJO

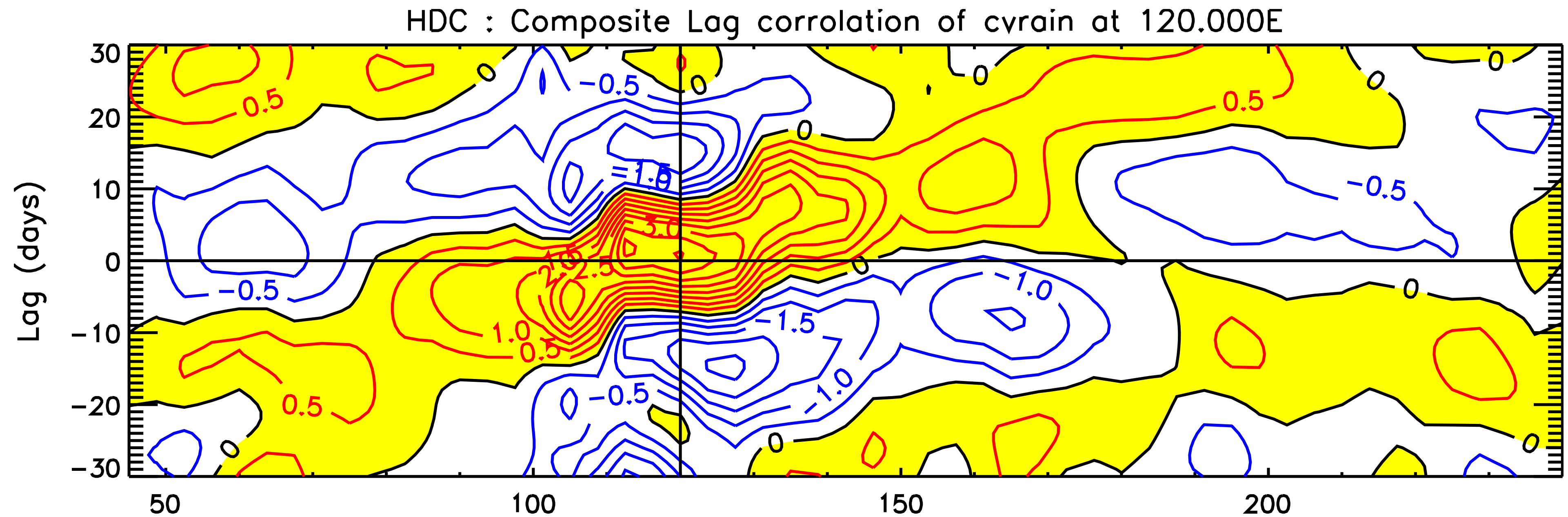
A coupled GCM study (Bernie et al. 2008)

Daily coupled



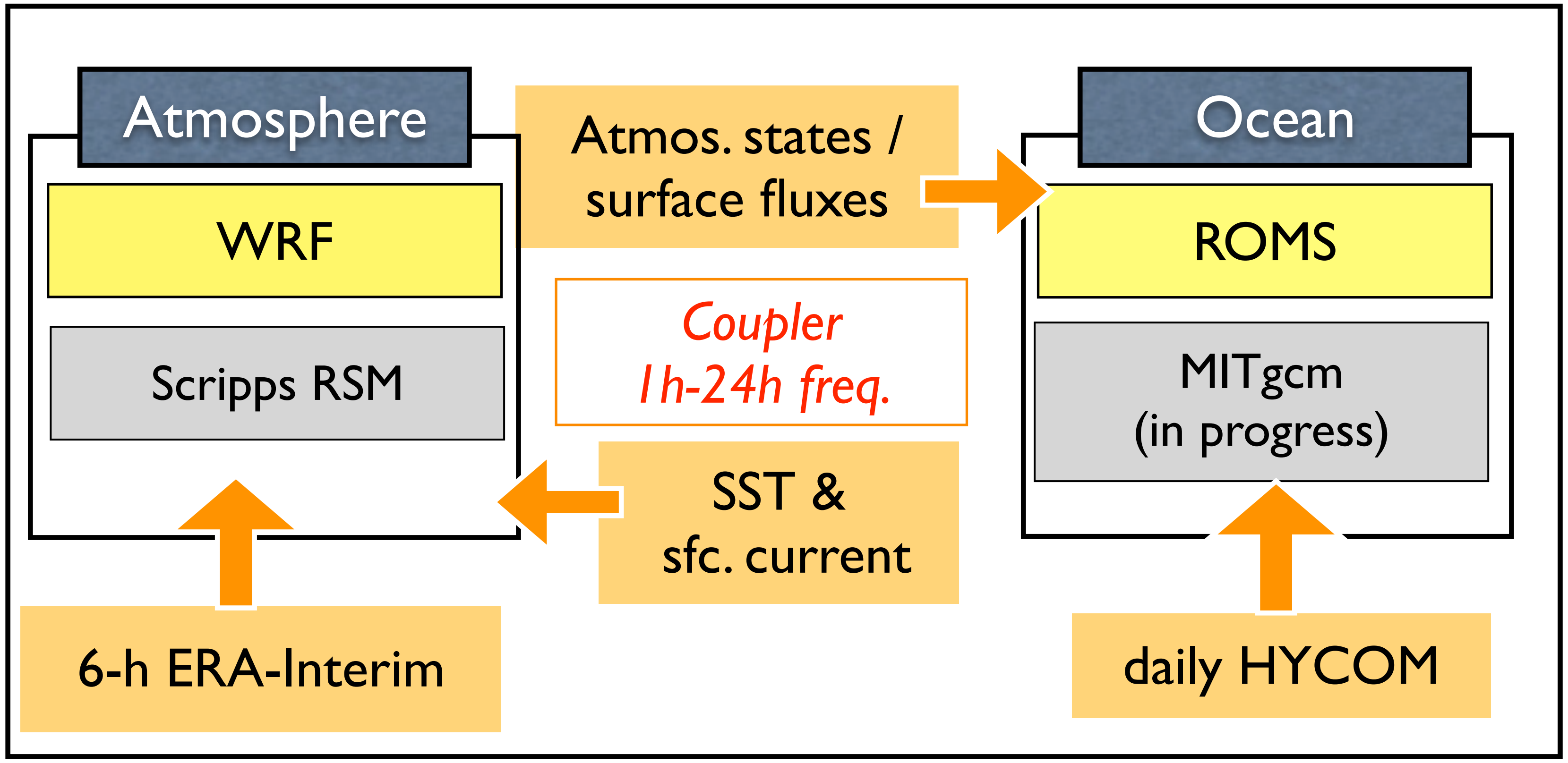
Lagged composites of convective precipitation

3-h coupled

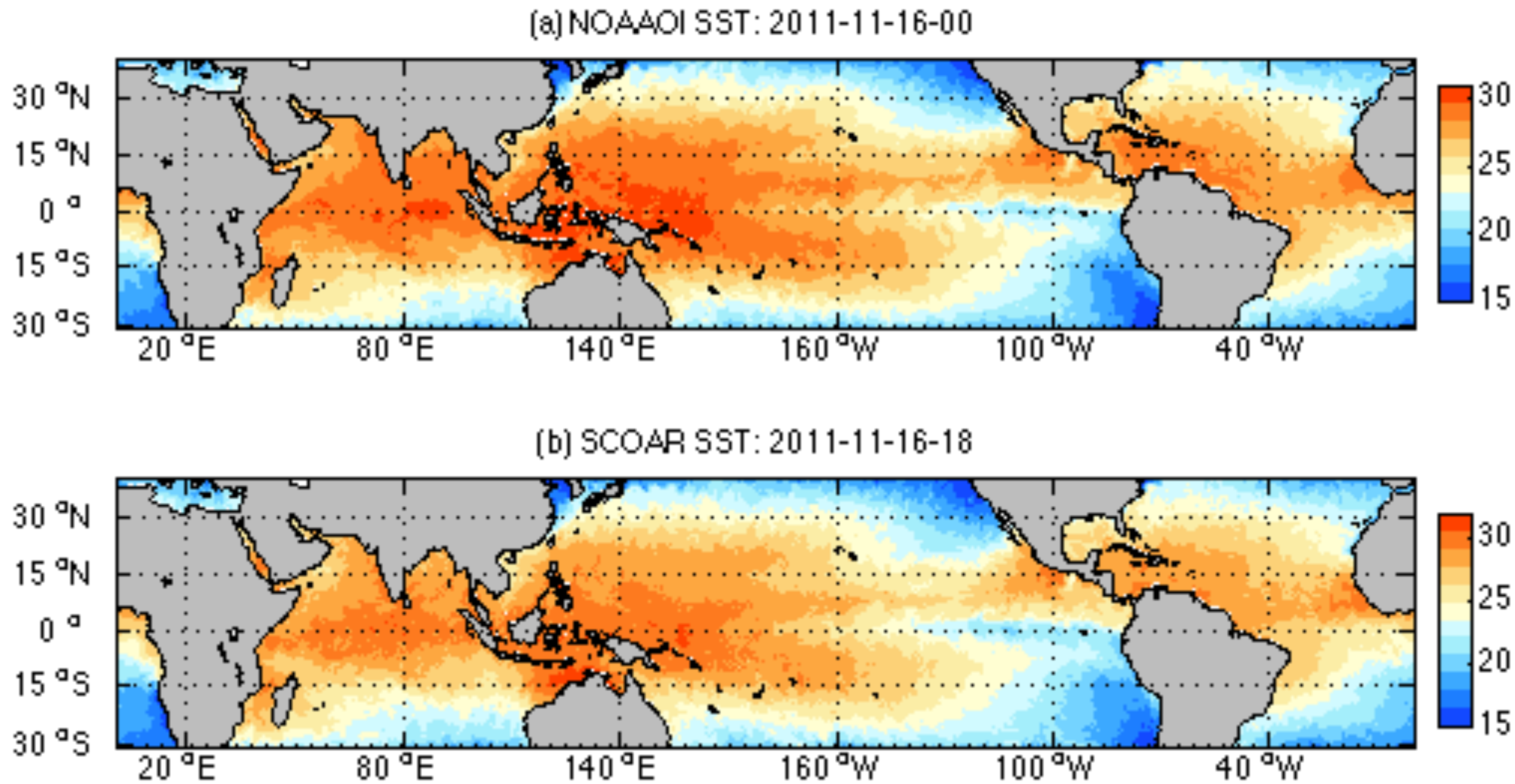


No studies exist that examined "physical process" for the diurnal SST cycle —MJO connection.

Regional coupled modeling study: SCOAR model



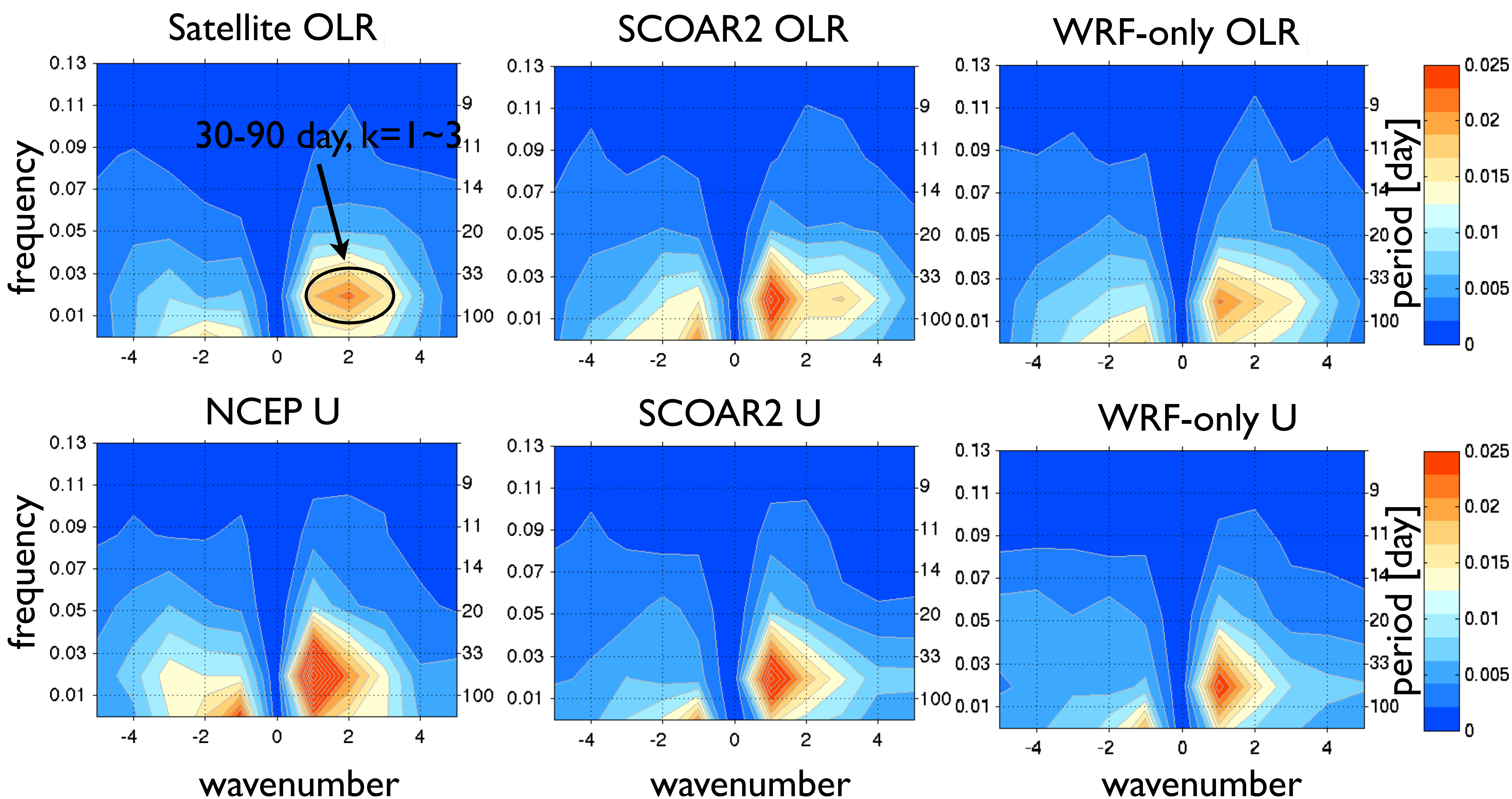
- SCOAR1: RSM-ROMS
  - *Seo et al. 2007*
- SCOAR2: WRF-ROMS
  - *Seo et al. 2014*
- *An input-output based coupler;*
  - *portable, flexible, expandable*



- Circum-equatorial tropical disturbances are allowed to interact with high-resolution oceanic process
- 40 km O-A resolutions & matching mask
- Deep & shallow convection and PBL schemes for MJO simulation

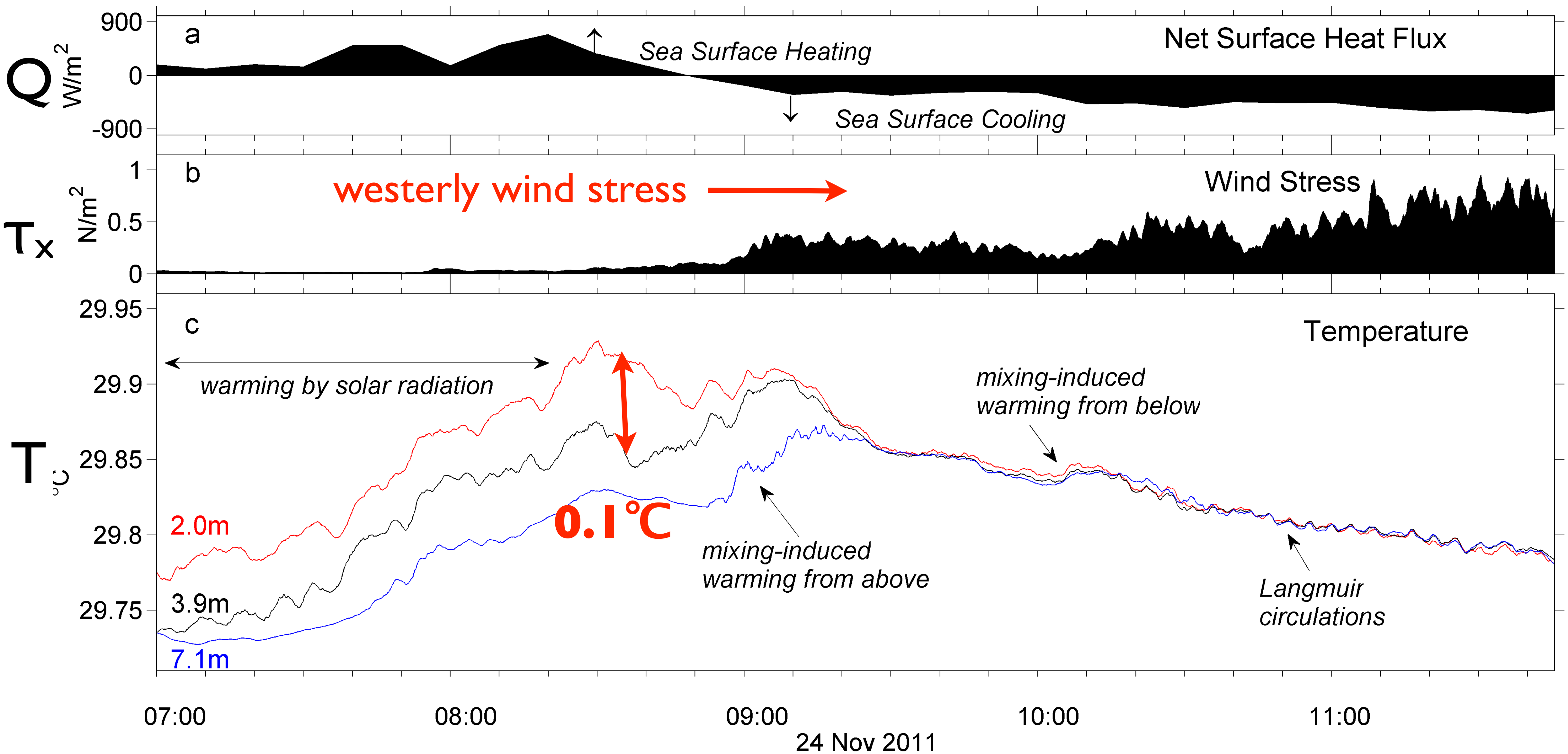
MJO diagnostics from the 5-yr baseline SCOAR simulation

Wavenumber-frequency spectra of symmetric component of OLR and U10m

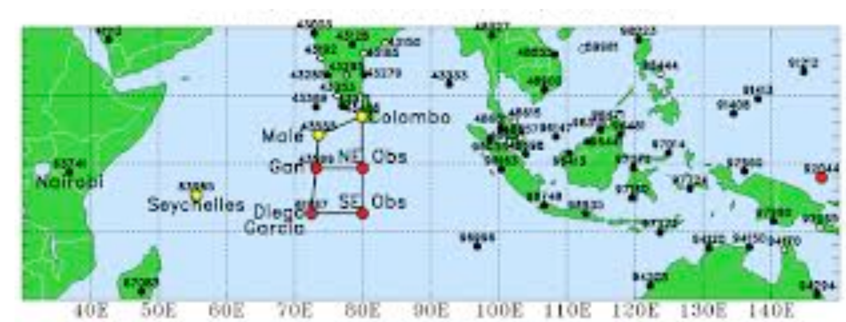


- SCOAR reproduces reasonably the observed level of power at MJO κ-ω band.
- Interactive SST acts to straighten the MJO.
- Have some trust in model and its credibility for MJO simulation!

Observed diurnal warm layer during DYNAMO



- Diurnal warm layer thickness of ~1 to 5 m
- >0.1℃ temperature difference across the diurnal warm layer



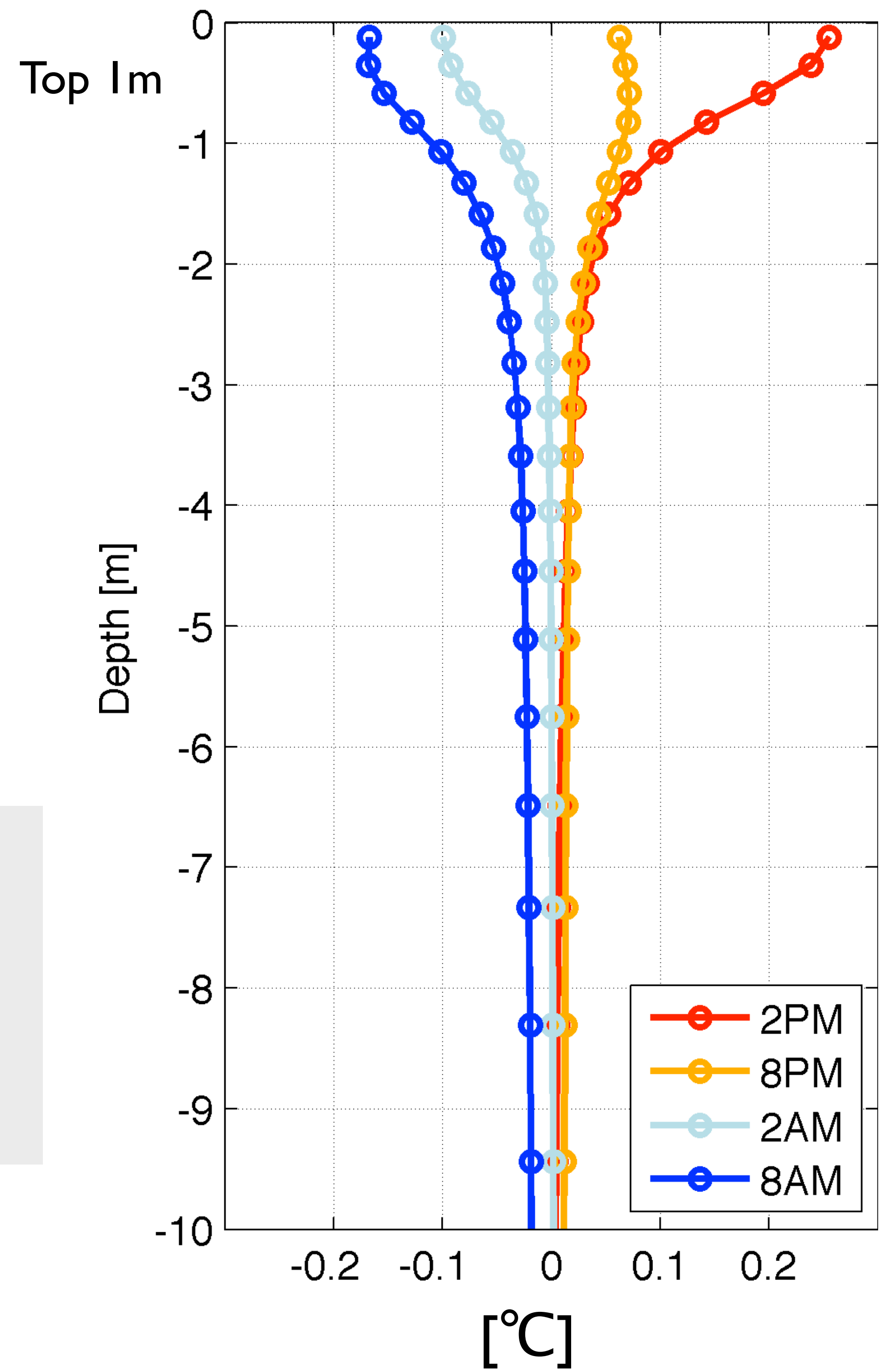
SCOAR model configuration

to better capture this observed ***thin*** diurnal warm layer

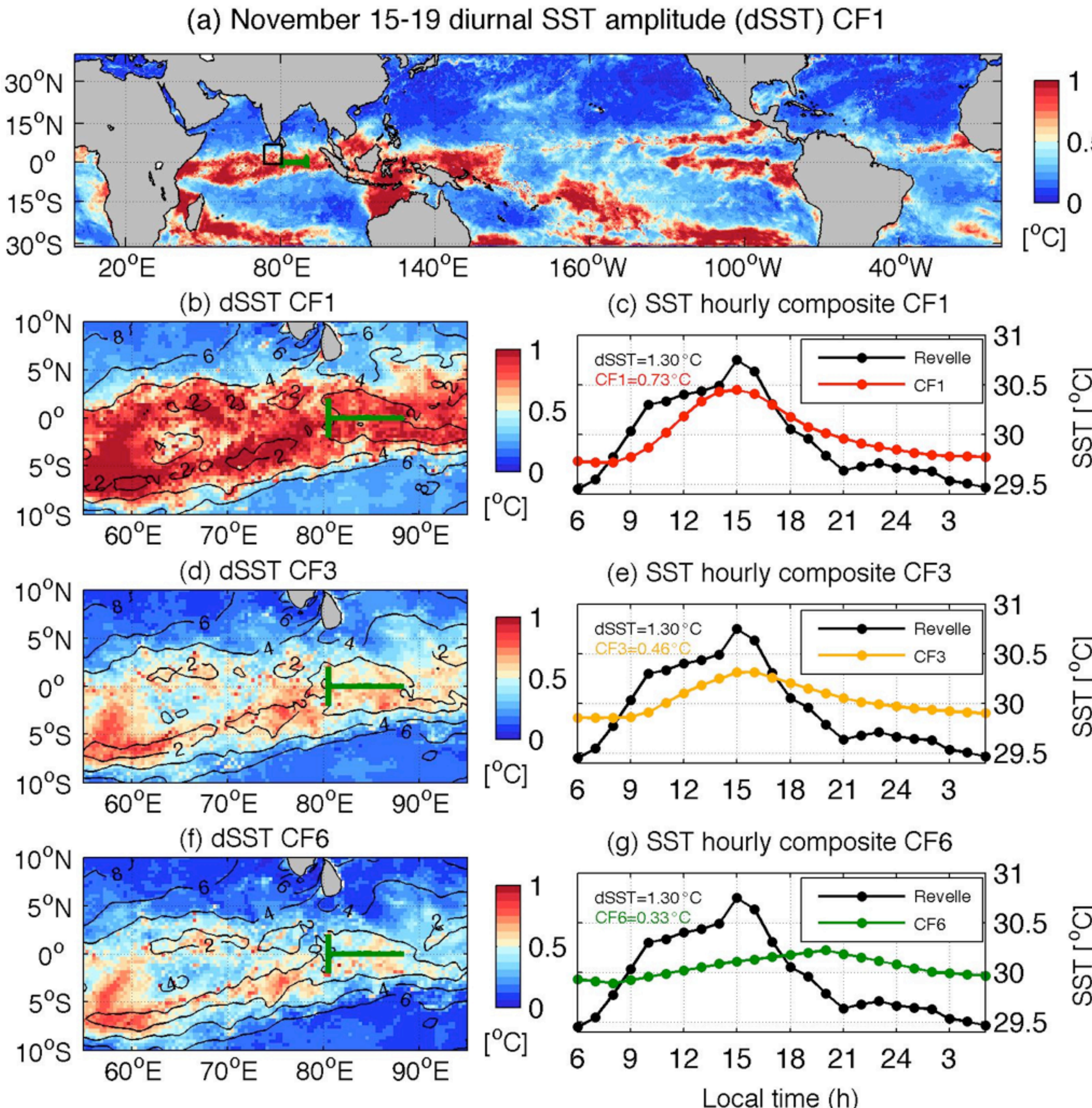
- **Need extremely high vertical resolution**
  - Total 55 levels;
  - 5 levels in the upper 1-m (dz=20cm)
  - 15 levels in the upper 15 m (dz=1m)

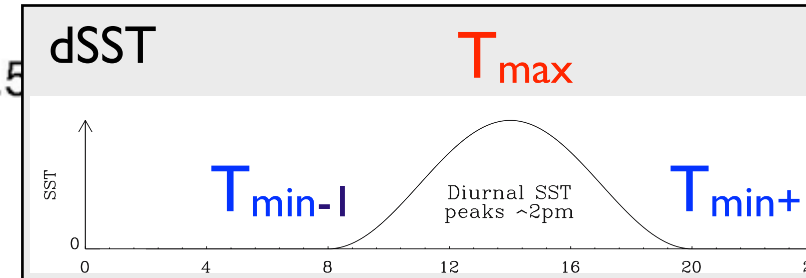
- Experimental configuration:
  - 5 Coupled 1-month-long runs with various coupling frequency (CF):
    - CF1, CF3, CF6, CF24

temperature 6 hourly composite anomalies



diurnal SST amplitude (dSST) prior to the MJO2 convection

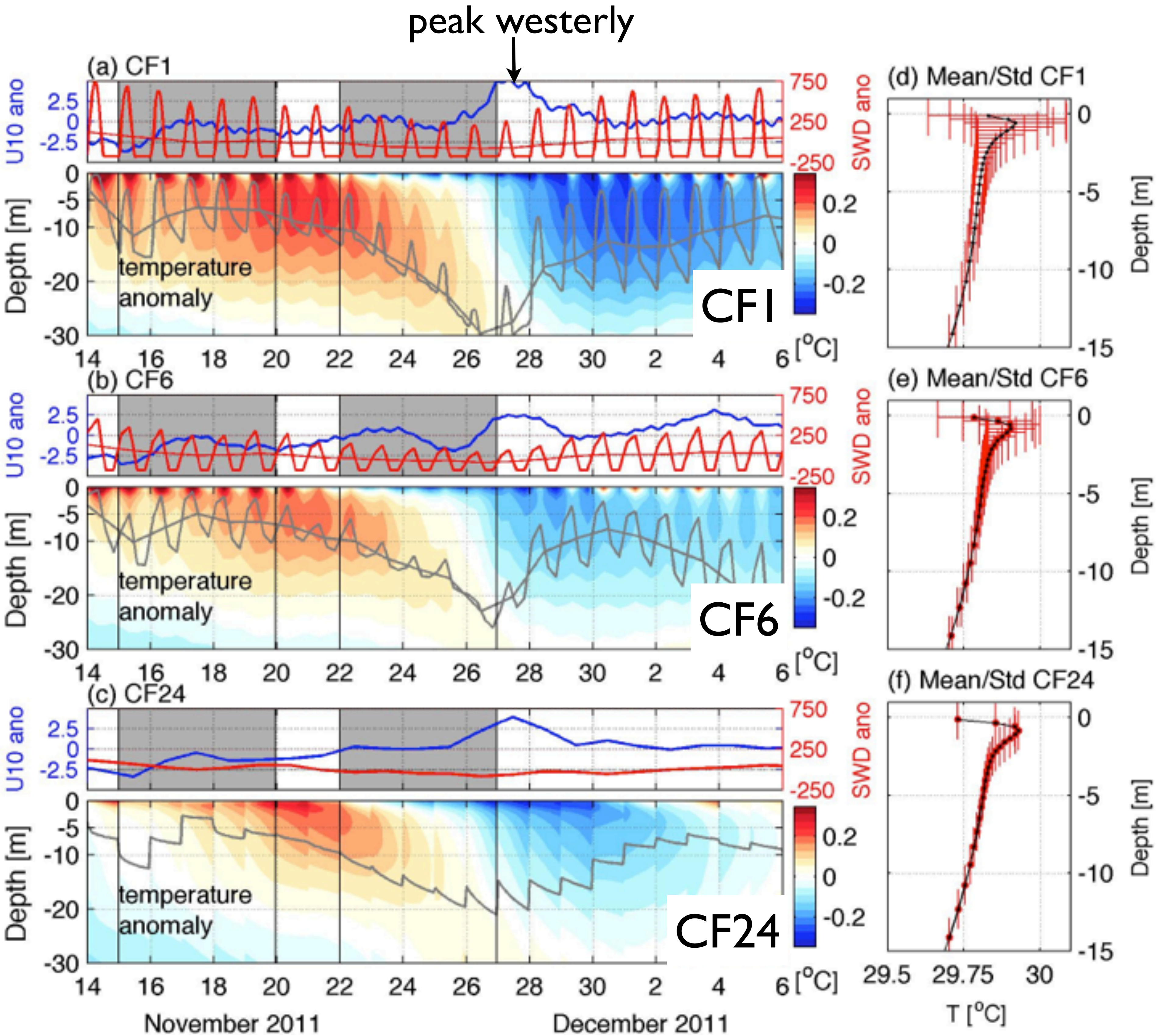




$$dSST = T_{max} - 1/2*(T_{min-1} + T_{min+1})$$

- Enhanced dSST (>1 ℃) in regions of weak wind speed (<4ms^{-1})
- CF1 represents about 56% of the observed dSST.
- Higher CF leads to greater dSST

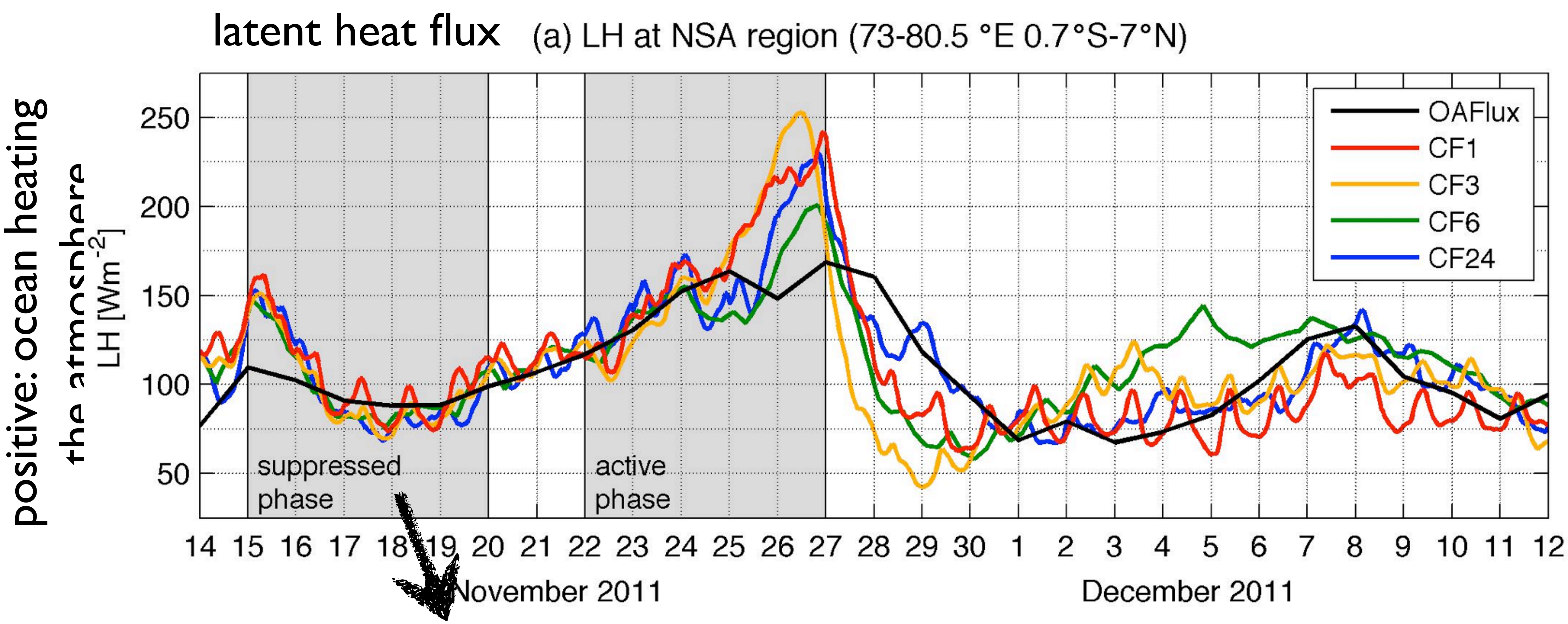
Warmer upper ocean temperature before convection

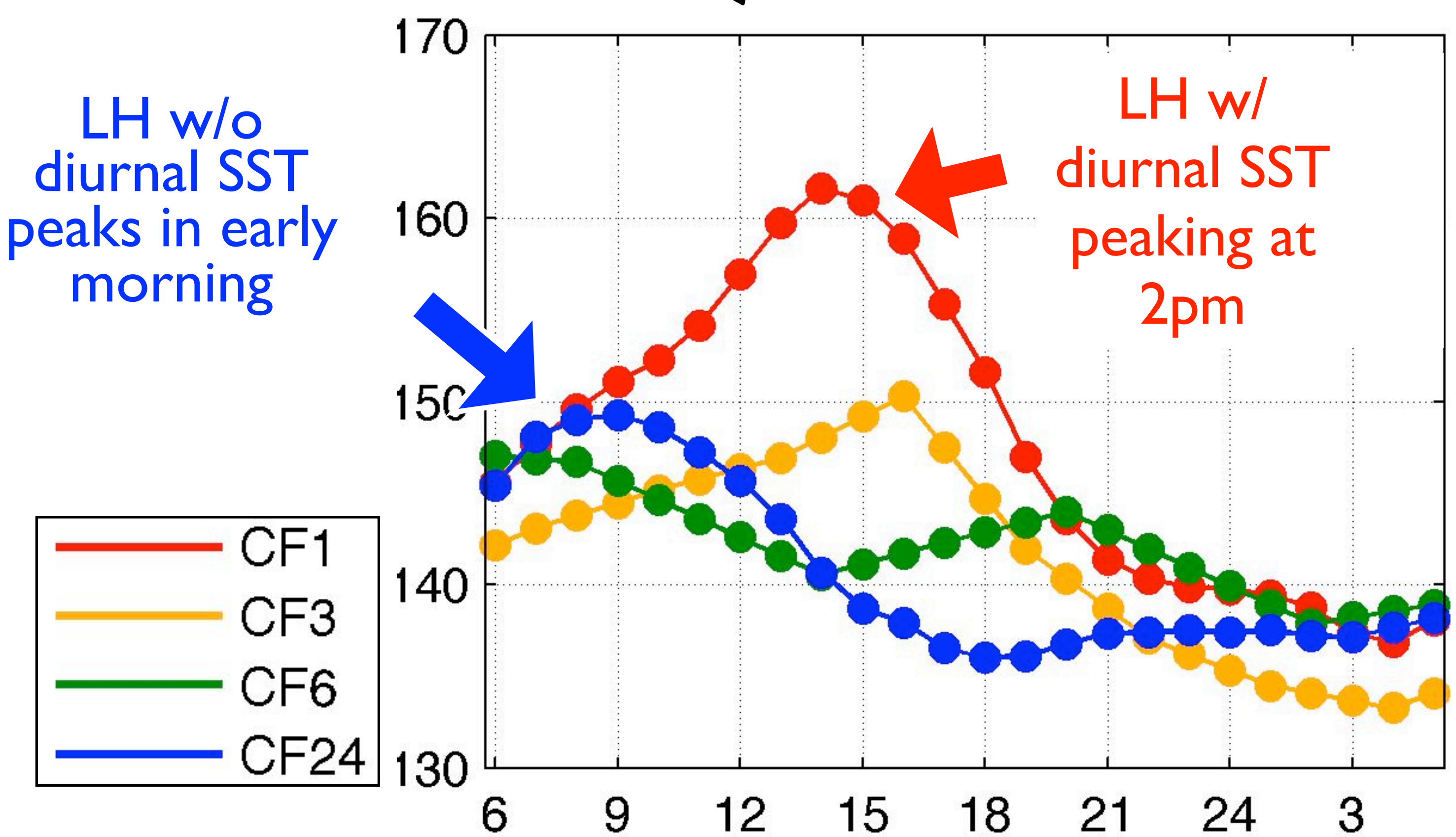


	Suppressed phase	
	Mean T	dSST
CF1	29.8	0.6
CF3	29.7	0.4
CF6	29.7	0.3
CF24	29.7	0.0

- Stronger diurnal variation helps achieve higher (>0.1℃) SST on a diurnal basis.

The higher diurnal SST, the stronger moistening of the atmosphere



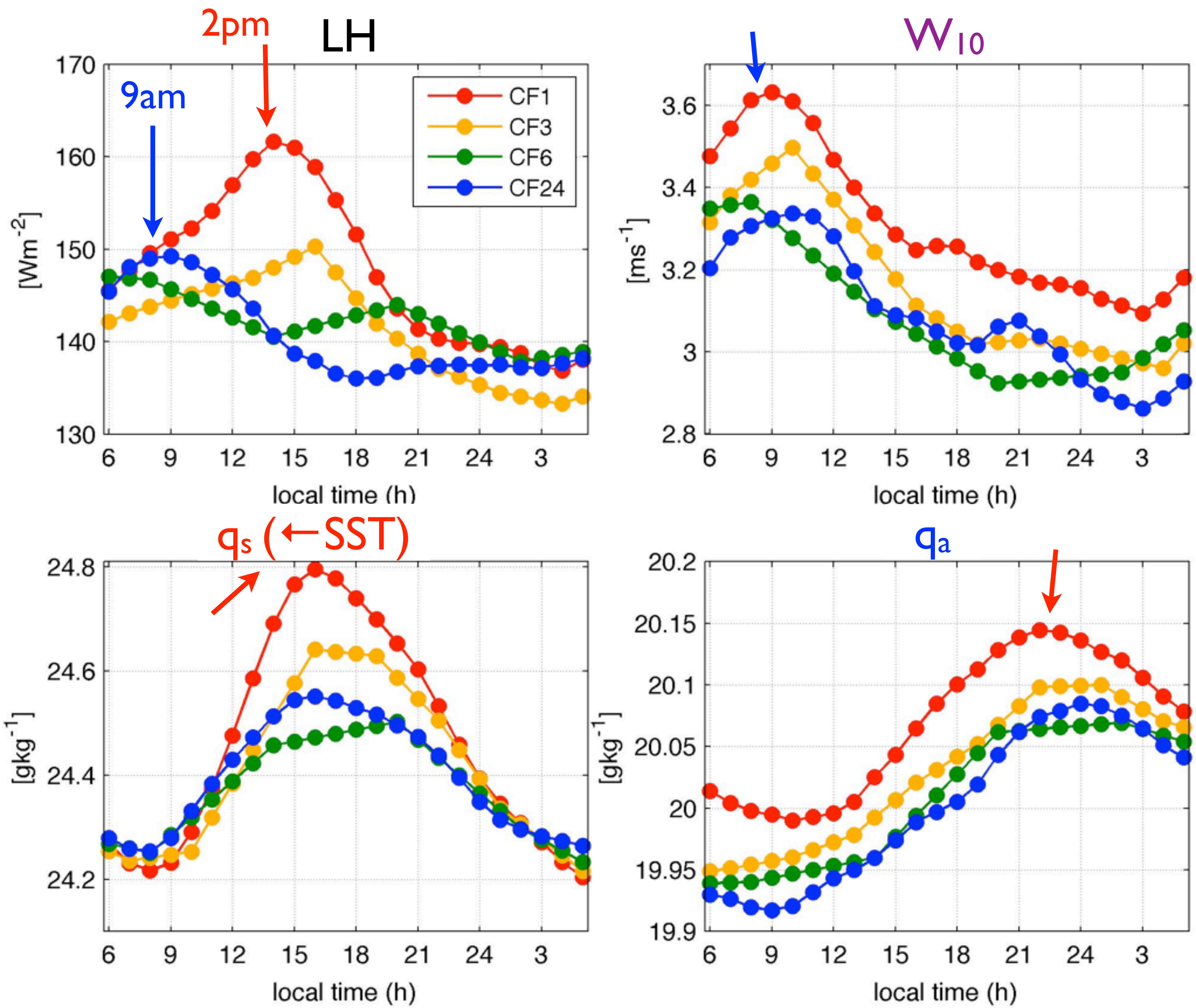


	Suppressed phase	
	Mean LH	dLH
OAFlux	95.9	N/A
CF1	103.8	30.2
CF3	99	24.6
CF6	98	21.1
CF24	97.7	30.2

Stronger moistening of the atmosphere with diurnal SST.

Diurnal moistening is maximized by the diurnal SST

Hourly composites of $\mathbf{LH}=\rho L C_H W_{10}(q_s - q_a)$

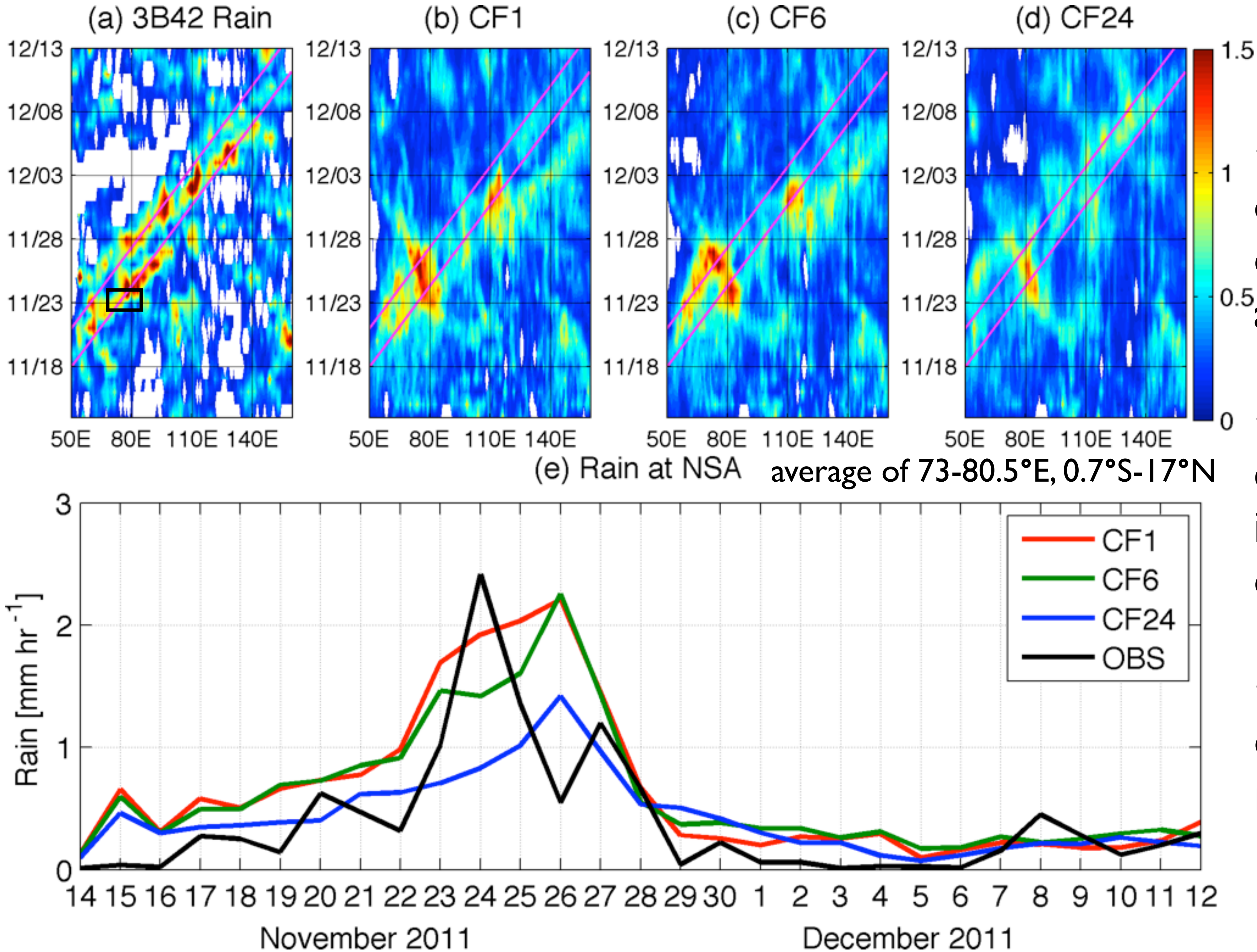


- Without diurnal SST peak in the afternoon, LH peaks in the morning following W10.
- q_s (SST) plays a leading role in maximizing the moistening effect of the troposphere.

What is the consequence on the MJO convection?

Precipitation intensity response to diurnal SST

10S-10N mean precipitation rates



- MJO2 rainfall event on Nov. 24 with the eastward propagation at 5 ms^{-1}.
- Models: qualitatively consistent intraseasonal evolution of rainfall.
- Higher dSST and dLH leads to higher rainfall!

Why does it rain more with the stronger diurnal SST?

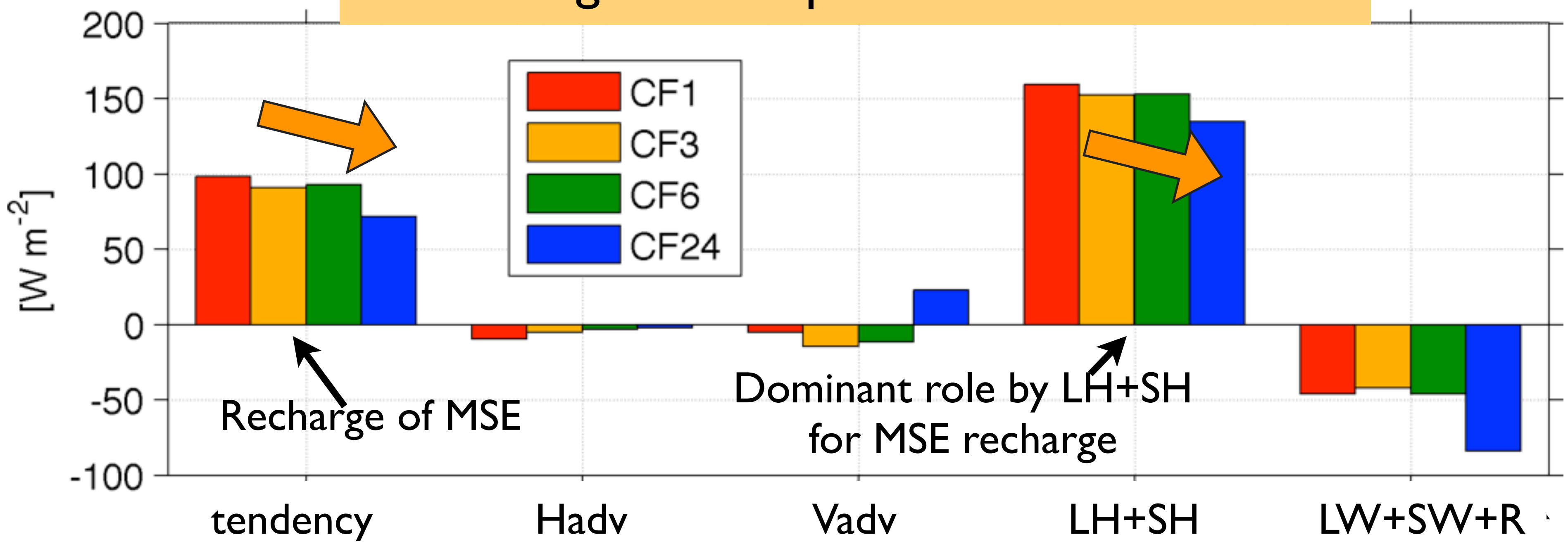
Column-integrated moist static energy (MSE) budget

$$\underbrace{\langle m_t \rangle}_{tendency} = \underbrace{-\langle v_h \cdot \nabla m \rangle}_{horizontal\ advection} \underbrace{-\langle \omega m_p \rangle}_{vertical\ advection} + \underbrace{(LH + SH)}_{latent+sensible\ flux} + \underbrace{\langle LW + SW \rangle}_{long+shortwave\ flux}$$

$$m = c_p T + gz + Lq$$

Maloney 2009

MSE budget terms prior to the convection



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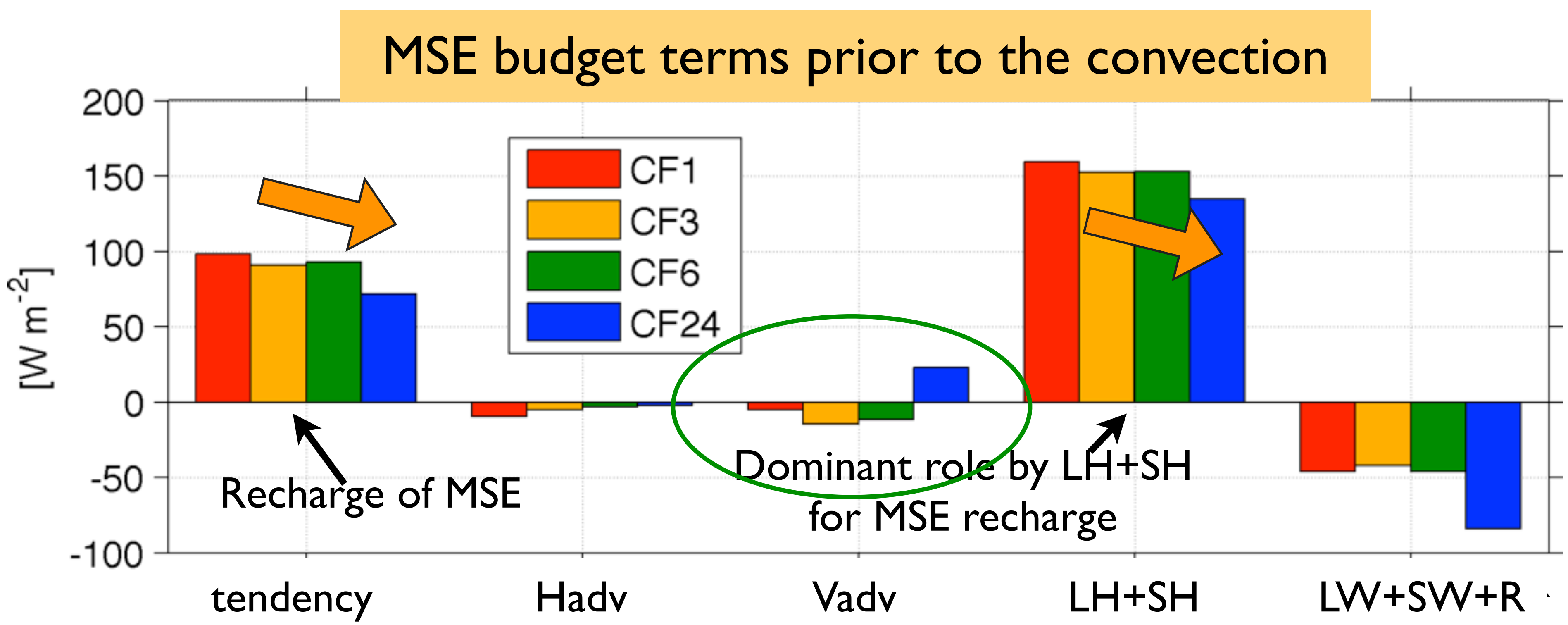
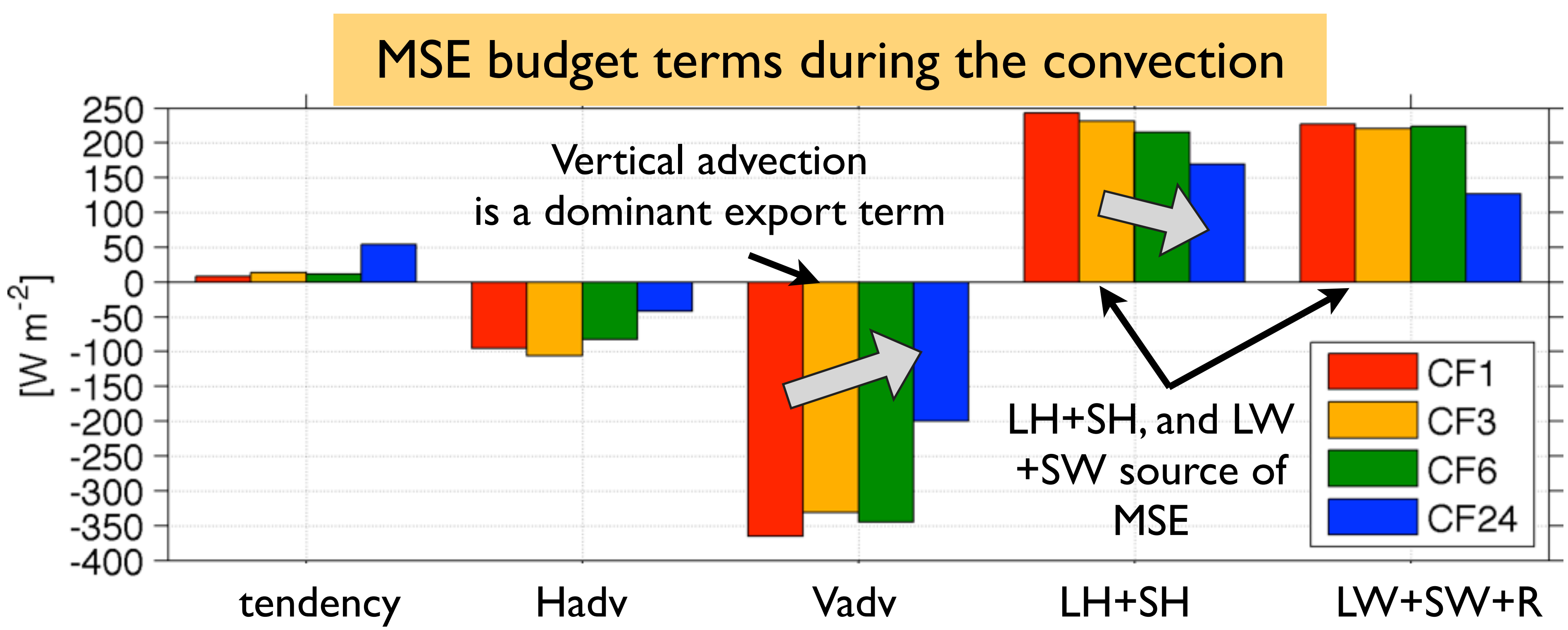
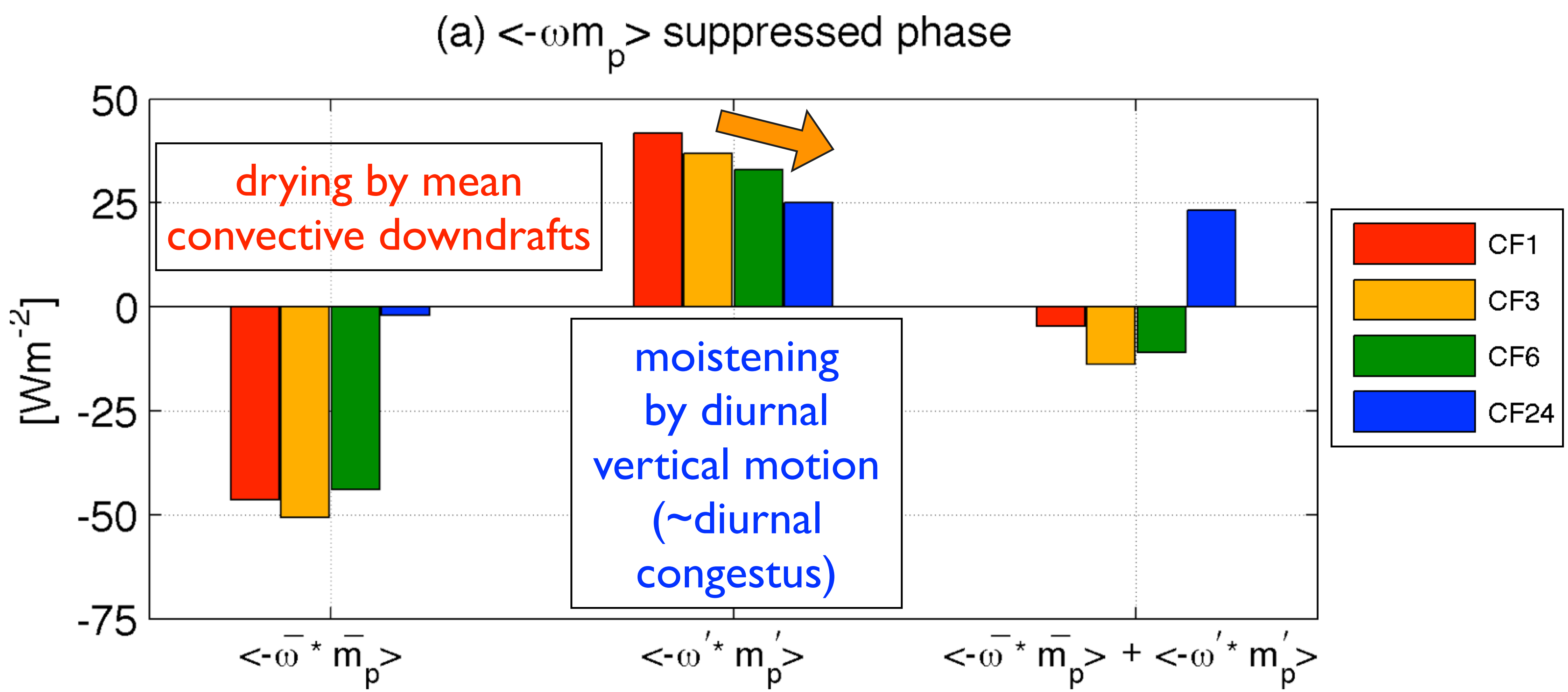




Diurnal moistening of the lower troposphere

$$\langle -\omega m_p \rangle = -(\langle \overline{\omega m_p} \rangle + \langle \omega' m'_p \rangle)$$



- The daily mean advection
  - Exports MSE by the mean convective downdrafts
  - No obvious proportionality to dSST
- Diurnal moistening
  - A source of MSE
  - A clear proportionality to dSST

Summary (1)

1. SCOAR regional coupled modeling for the MJO
   - EW channel configuration
   - Specific combination of WRF deep & shallow convection and PBL schemes for MJO simulation
     - Modified ZM deep and UW shallow convection & PBL schemes
   - Higher (especially in the ocean) horizontal resolution: 40 km
   - High vertical resolution (~1m in the top 15 m)
   - Hourly model coupling

2. SCOAR2 supports significant eastward propagating convectively coupled disturbances in the MJO κ-ω band
   - True regardless of coupling
   - Coupling enhances the intraseasonal power and coherence

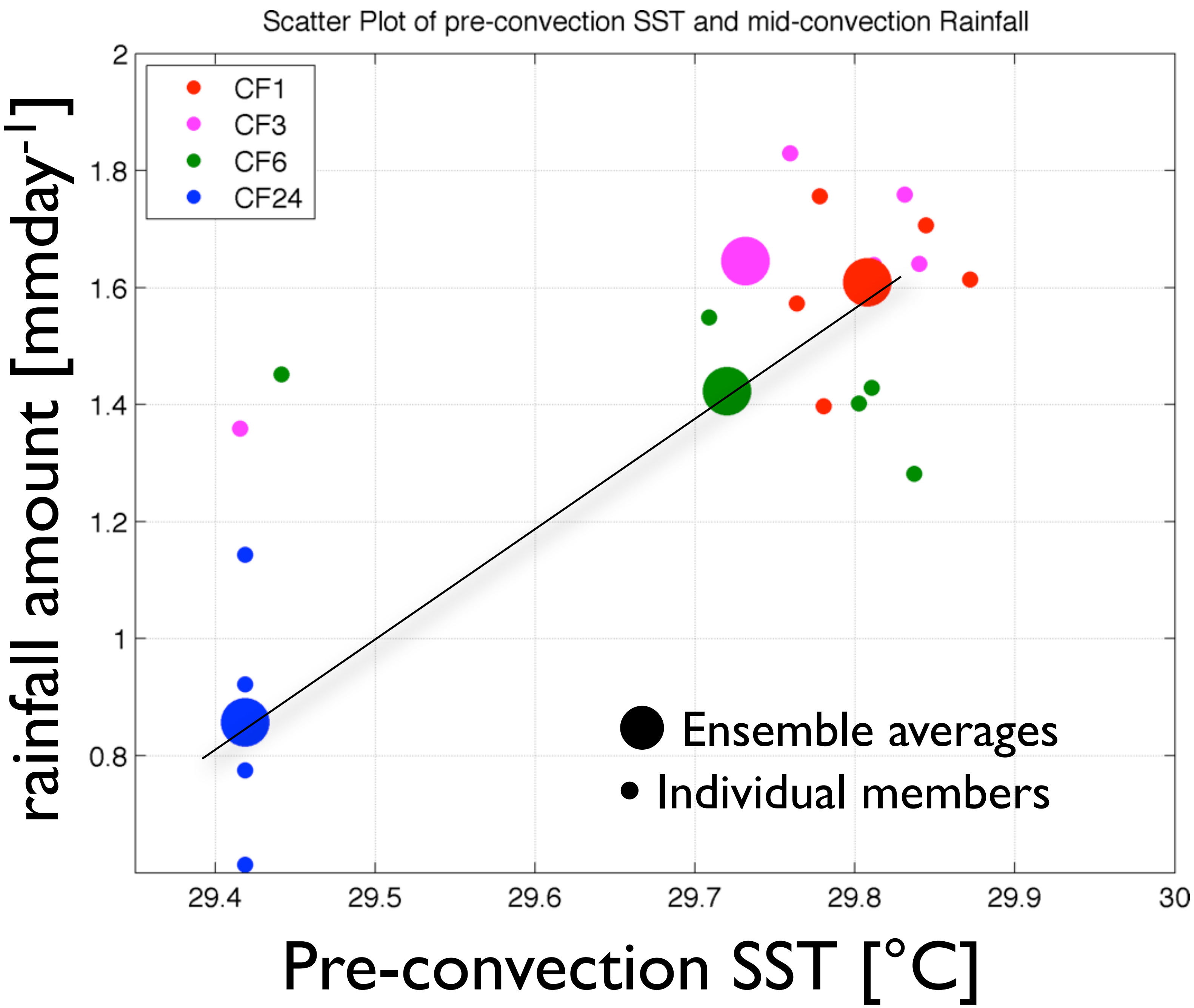
Summary (2)

3. Diurnal SST variability prior to the deep convection
    - raises the time-mean SST and LH: via diurnal rectified effect
    - enhances the diurnal moistening: via coincident diurnal peaks of LH & SST

4. Further sensitivity experiments (not really discussed today) suggest
    - the first mechanism dominates and more efficiently expedites the recharge of the MSE.
    - But the diurnal moistening is a non-negligible process
        - cancel out the drying effect by the convective downdrafts.

Summary (3)

5. Precipitation amount scales quasi-linearly with pre-convection diurnal SST



- LH+SH feedback over higher SST instrumental in stronger convection intensity (Arnold et al. 2013)

- Consistent with previous studies: an improved representation of diurnally evolving SST as a potential predictability source of MJO.

Thanks for listening,
and
九州大学に私を招待していただきありがとうございます!

Seo, Subramanian, Miller and Cavanaugh, 2014:
Coupled impacts of the diurnal cycle of sea surface temperature on the Madden-Julian Oscillation. J. Climate, doi: http://dx.doi.org/10.1175/JCLI-D-14-00141.1