Arctic surface air temperature response to the Madden-Julian Oscillation during boreal winter

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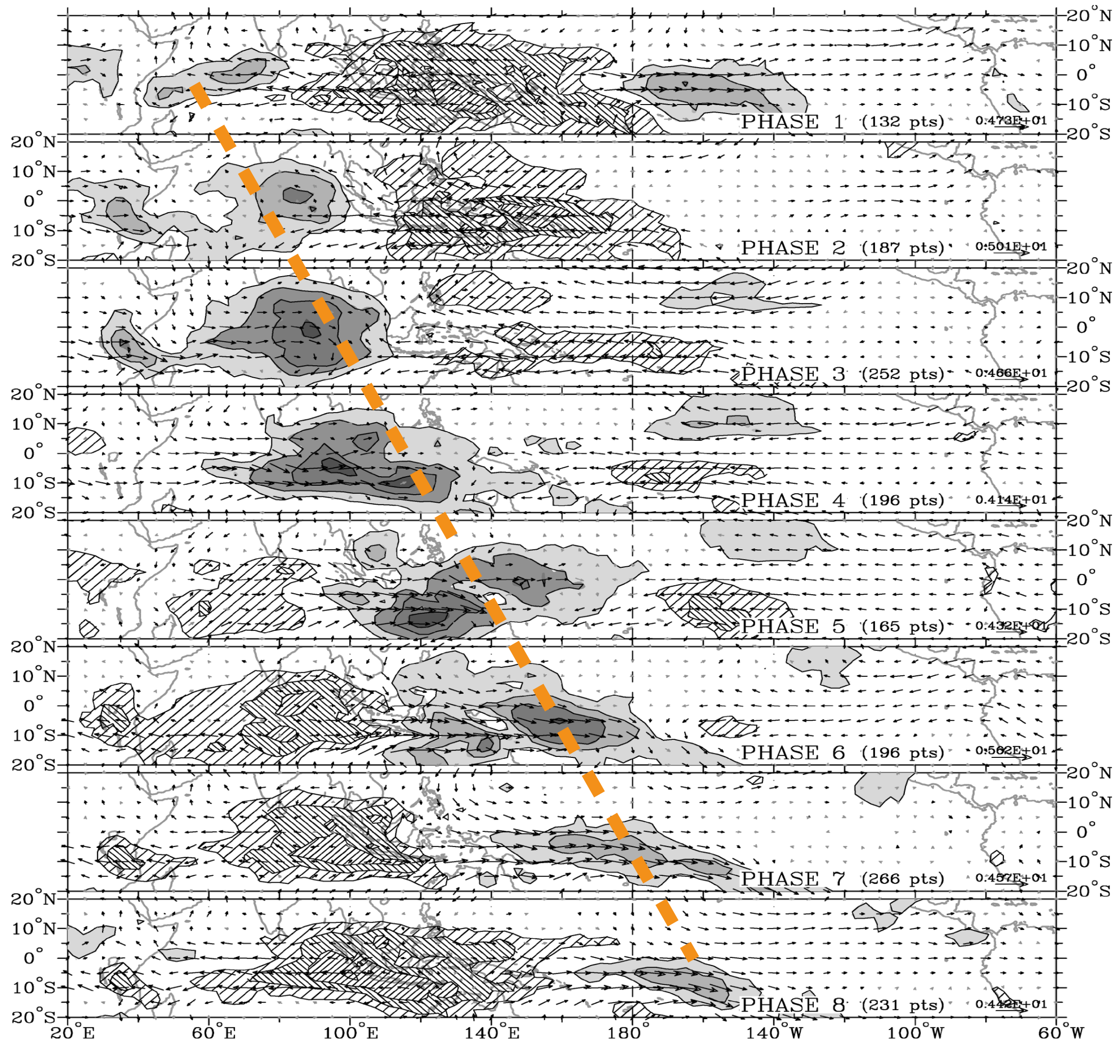
What is the MJO?

- First found by Madden and Julian (1971,1972)
- Dominant mode of subseasonal tropical variability
- Spatially at planetary scale; temporally at 30-60 days

30~60 days



phase 1

phase 2

phase 3

phase 4

phase 5

phase 6

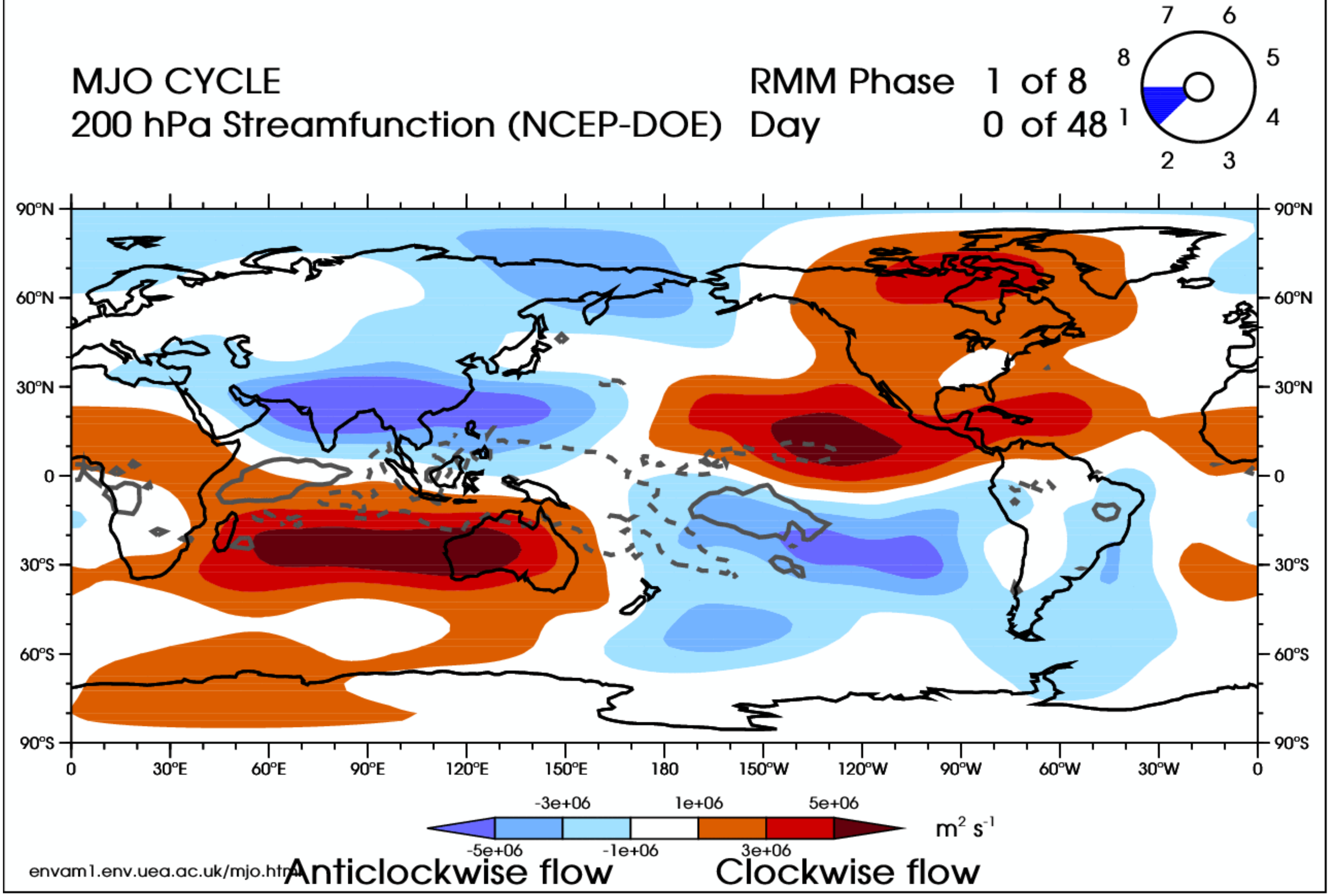
phase 7

phase 8

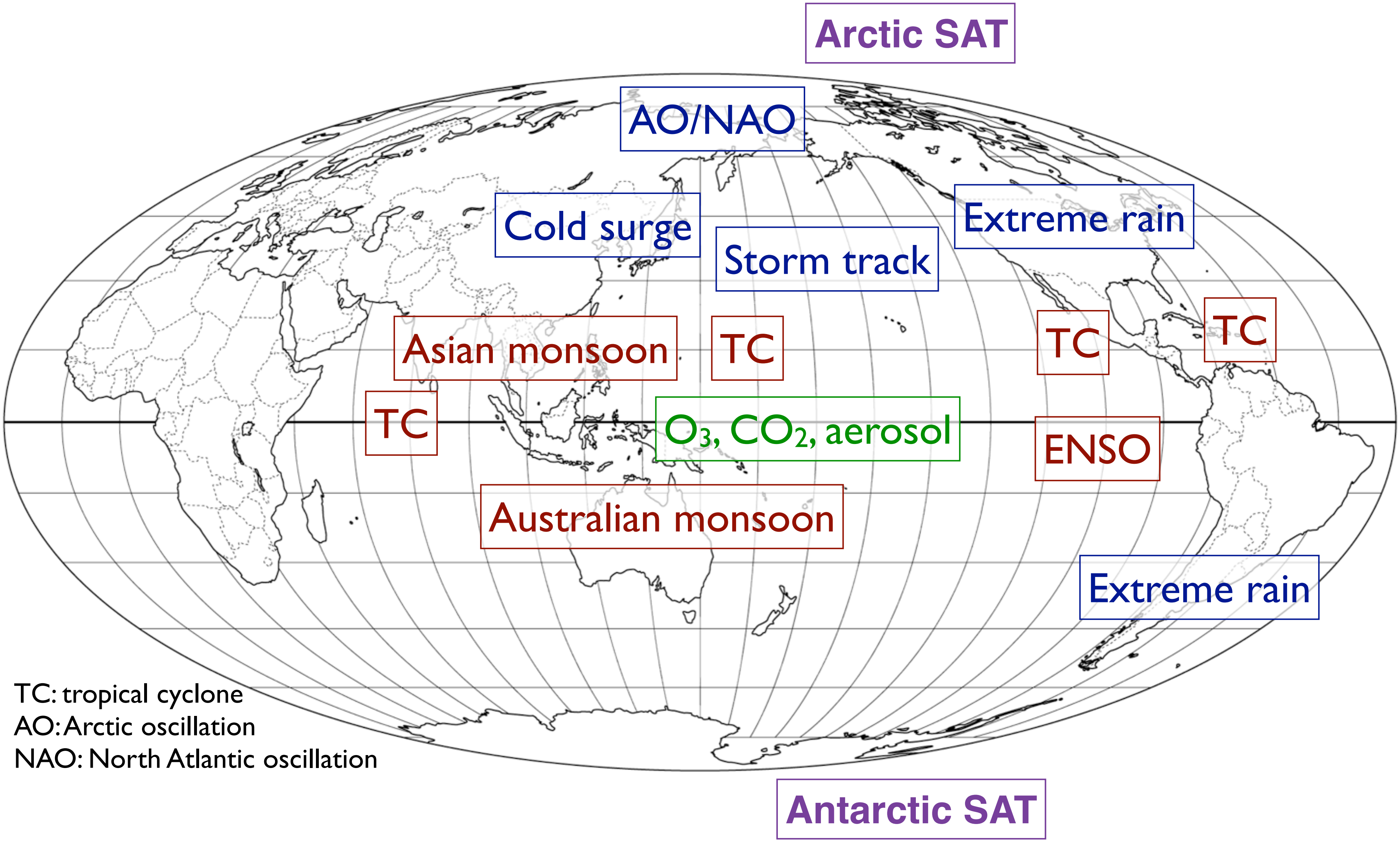
Wheeler and Hendon 1994

200 hPa Streamfunction

from Adrian Matthew's webpage



Global impact of the MJO



TC: tropical cyclone
AO: Arctic oscillation
NAO: North Atlantic oscillation

This slide from D. Kim.

Goal of this study

- We address whether and how the MJO influences

  subseasonal variability of Arctic surface air temperature.

- Observational evidence (ERA-interim 1979-2012)
- Initial value calculations (Dynamical core of GFDL)
- Climate model simulations (CAM5 + UNICON)

Does the MJO influence Arctic SAT?

MJO phase 5 (phase 1) leads to
Arctic warming (cooling) in 10 days.

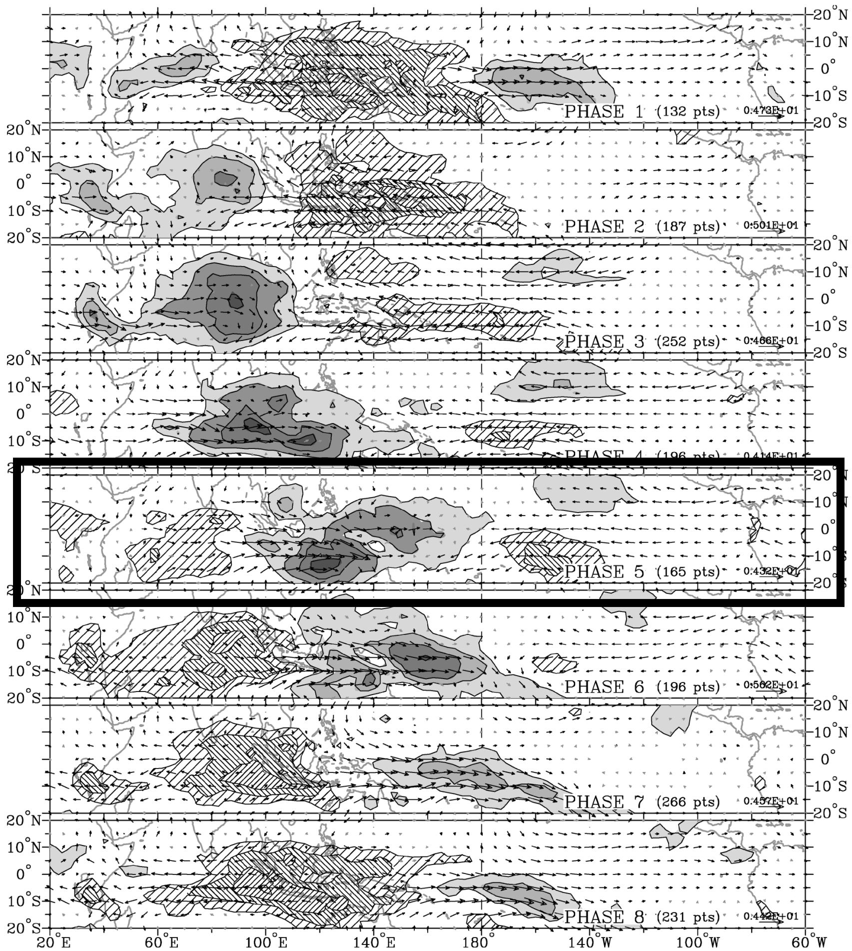
How we do MJO composites

- **Wheeler and Hendon MJO index**
  - PCs of two leading EOFs of OLR, 200- and 850-hPa zonal wind between 5S-5N.
  - The 120-day running mean is removed.

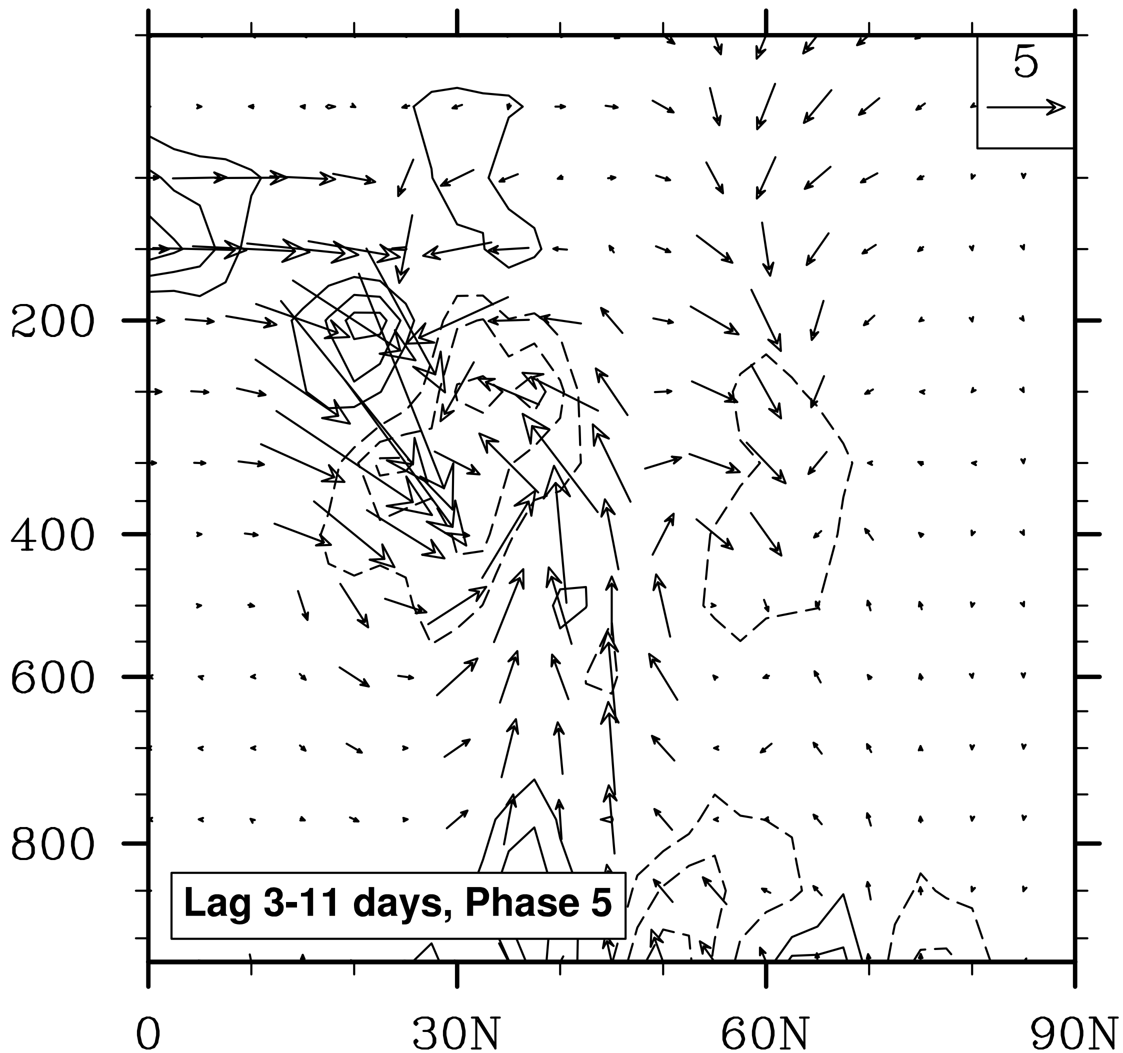
- **An active MJO event** is defined following (L'Heureux and Higgins 2008)
  - the MJO amplitude > 1 for consecutive pentads
  - MJO phase indicates eastward propagation
  - MJO persists for at least six consecutive pentads, but does not remain in one particular phase for more than four pentads.

- Composited variables are **20-100-day filtered**.

Poleward wave activity increases for MJO phase 5



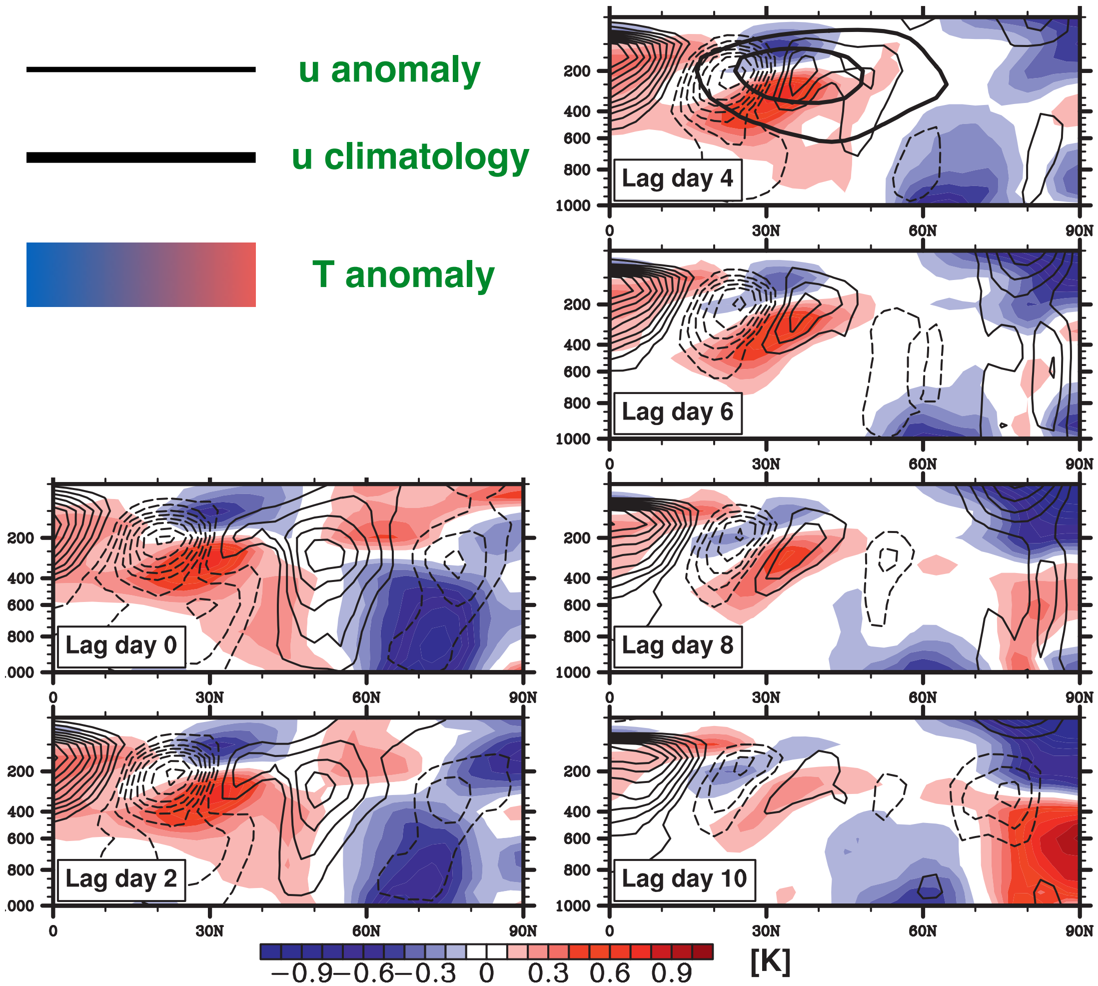
Anomalous EP flux for MJO phase 5



Yoo et al. 2012b

Zonal mean picture

- Tropical forcing leads to acceleration in the tropics.
- In the extratropics, wind and temperature are in thermal wind balance.

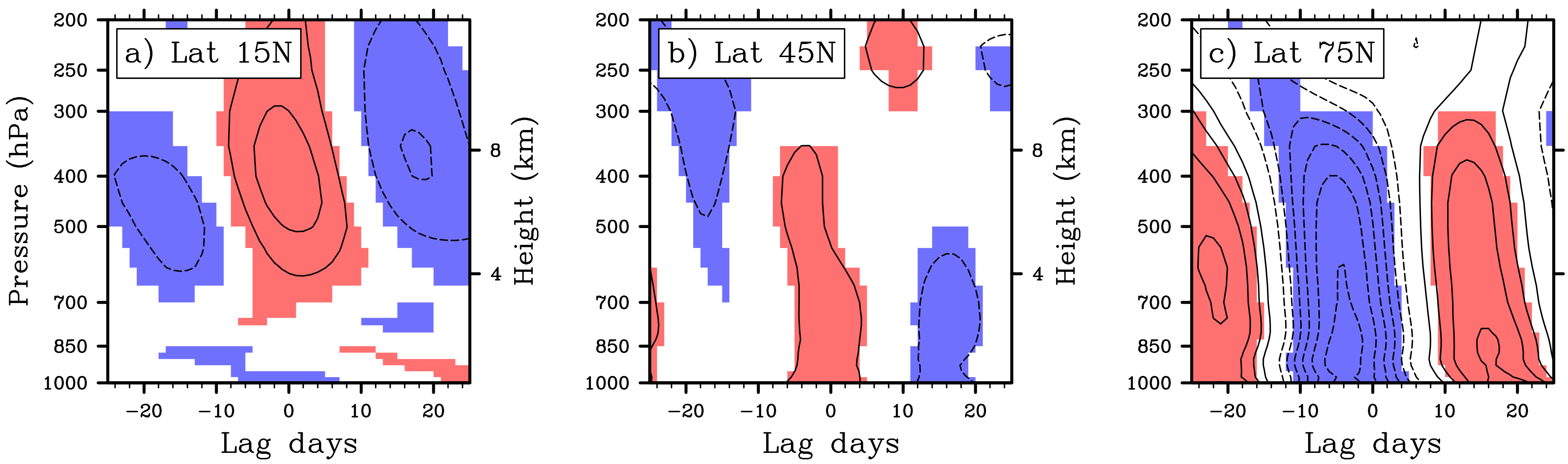


Yoo et al. 2012b

Zonal mean T in lag - height

- About 40-day oscillation is clear both in the tropics and the Arctic.
- The anomalies show top heaviness in the tropics vs bottom heaviness in the Arctic.

Zonal mean temperature anomalies

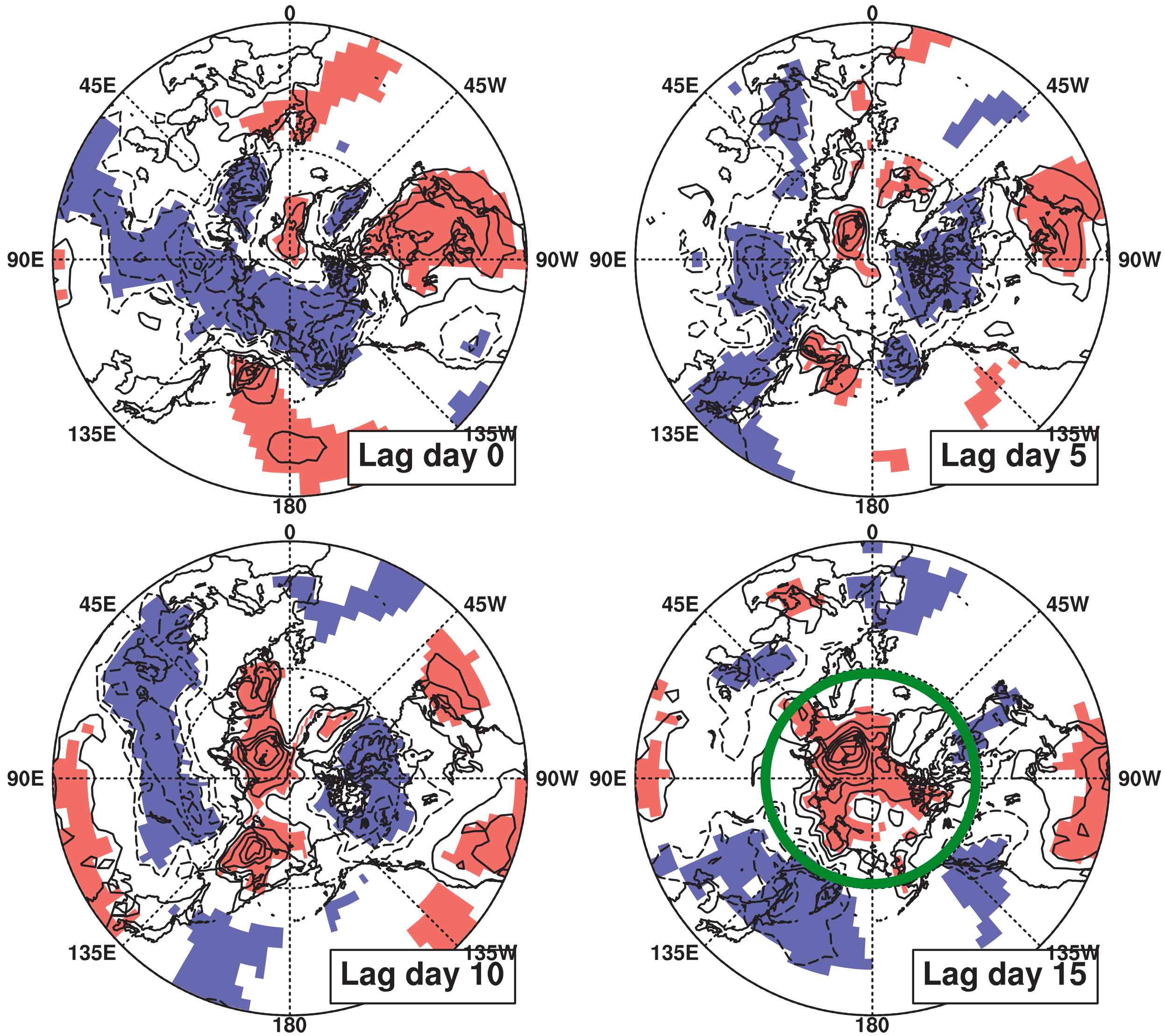


Shading indicates $p < 0.05$.

Yoo et al. 2014

SAT for MJO phase 5

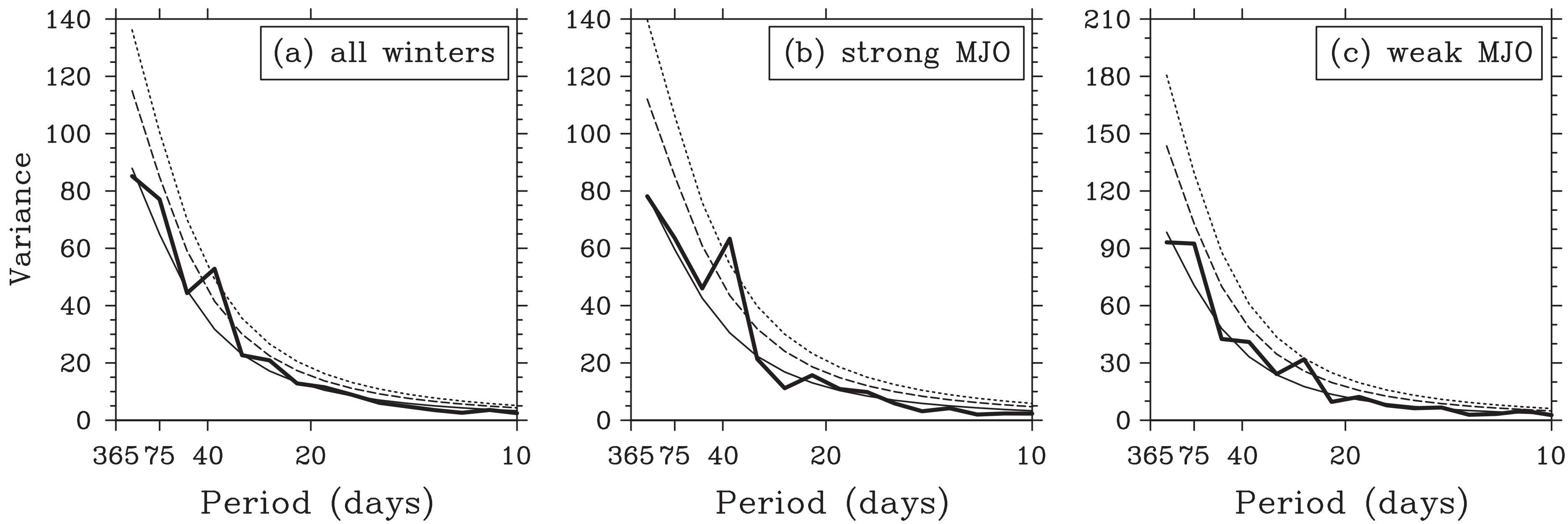
Shading indicates $p < 0.05$.



Yoo et al. 2012b

Area averaged SAT power spectra

- How we calculated the power spectrum for SAT over 60N-90N:
  - Annual cycle is removed.
  - Power spectrum is calculated for each winter.
  - Then the spectra for each winter are averaged.



power spectrum (thick), red-noise (thin), 95% and 99% levels (dashed and dotted)

Yoo et al. 2014

How does the MJO influence Arctic SAT?

Three step processes:

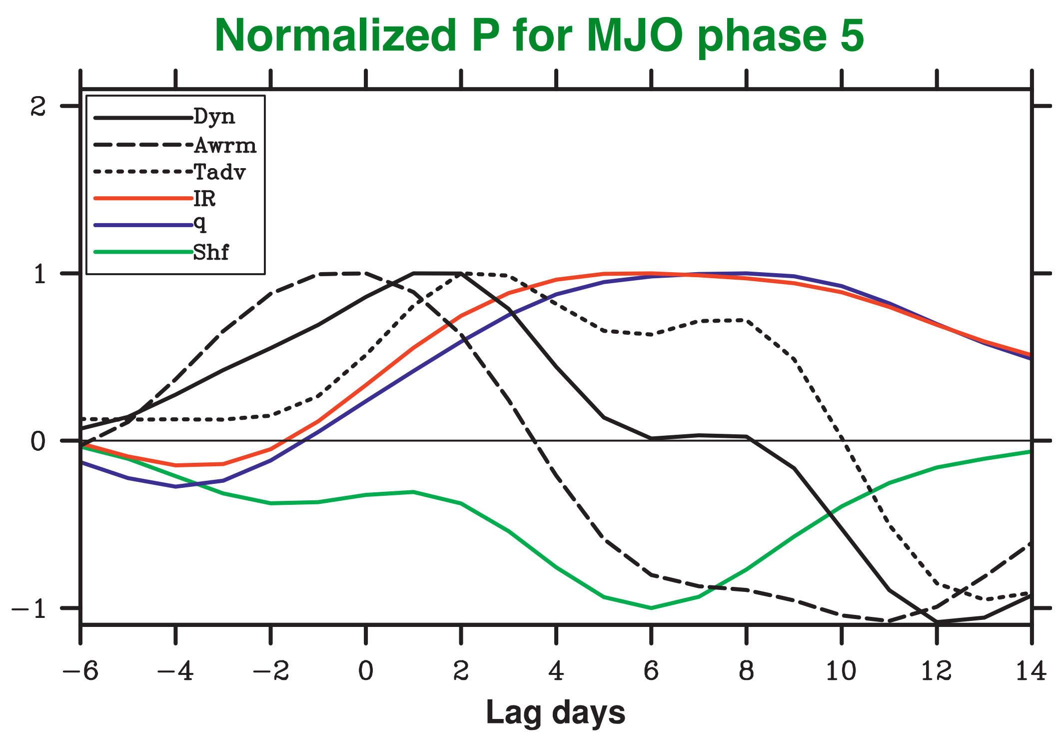
1. Adiabatic warming
2. Temperature advection
3. Radiative heating by IR

- We start from the thermodynamic energy equation:

$$\frac{\partial T}{\partial t} = -\mathbf{u} \cdot \nabla T - N^2 R^{-1} H w + Q, \qquad (1)$$

- We project each term onto $\bar{T}$, lag +3 to +11 days mean:

$$P_i \equiv \sum_j \xi_{ij}(\lambda, \theta) \overline{T_j}(\lambda, \theta) \cos\theta, \qquad (3)$$



Yoo et al. 2012b

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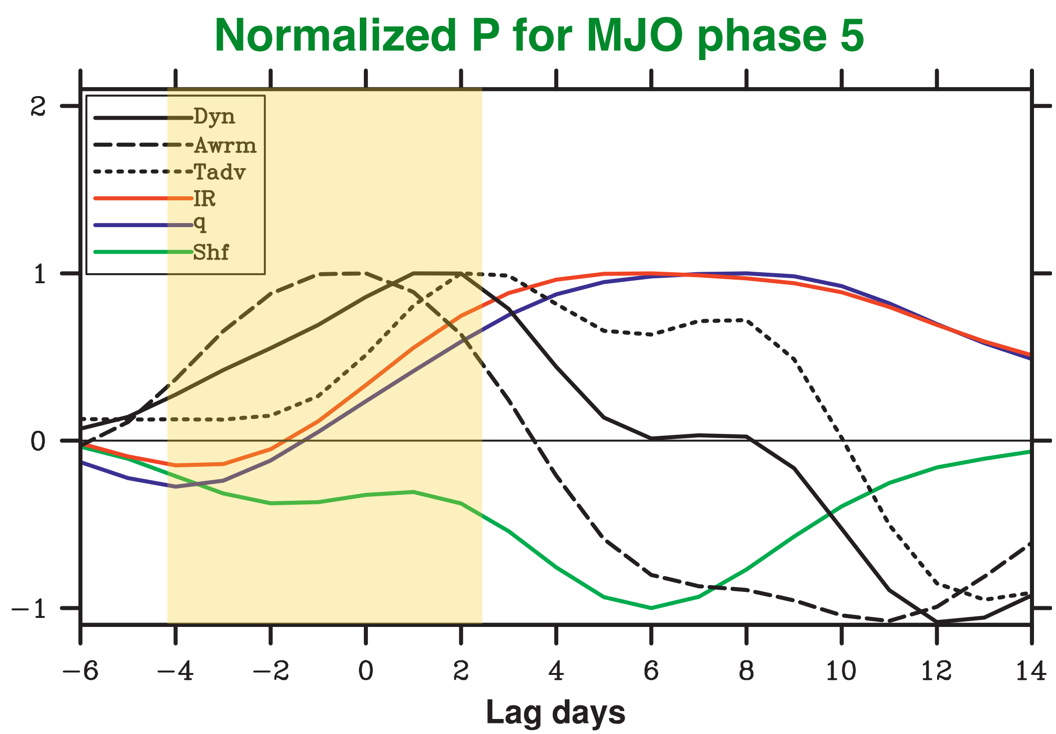

Yoo et al. 2012b

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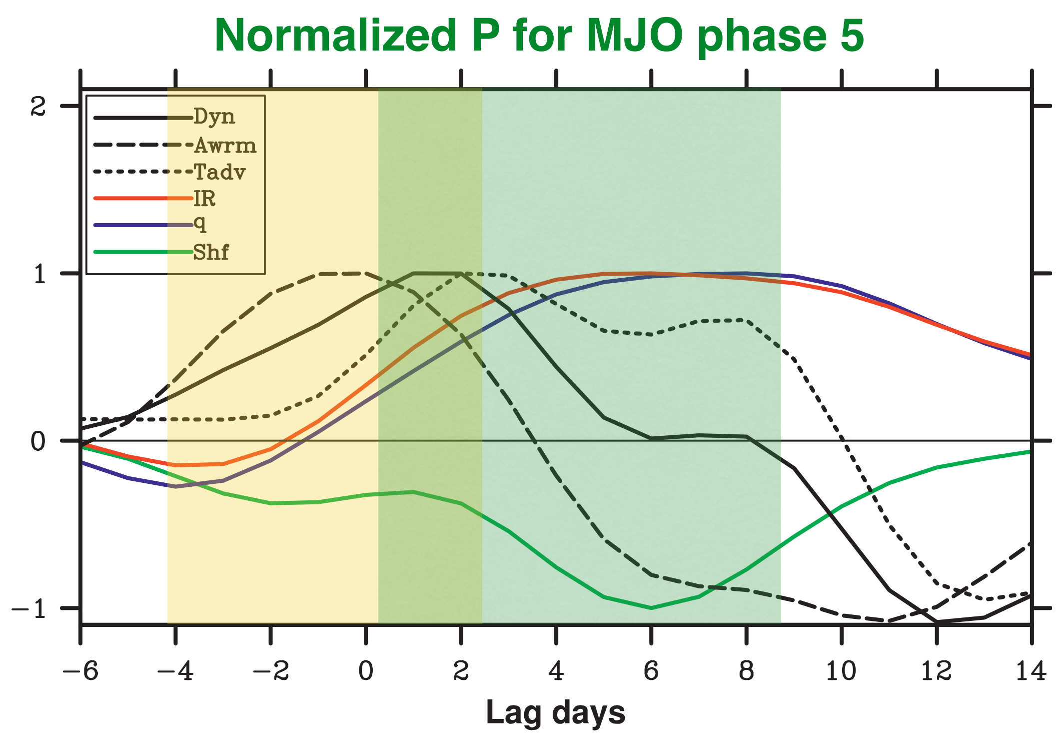

Yoo et al. 2012b

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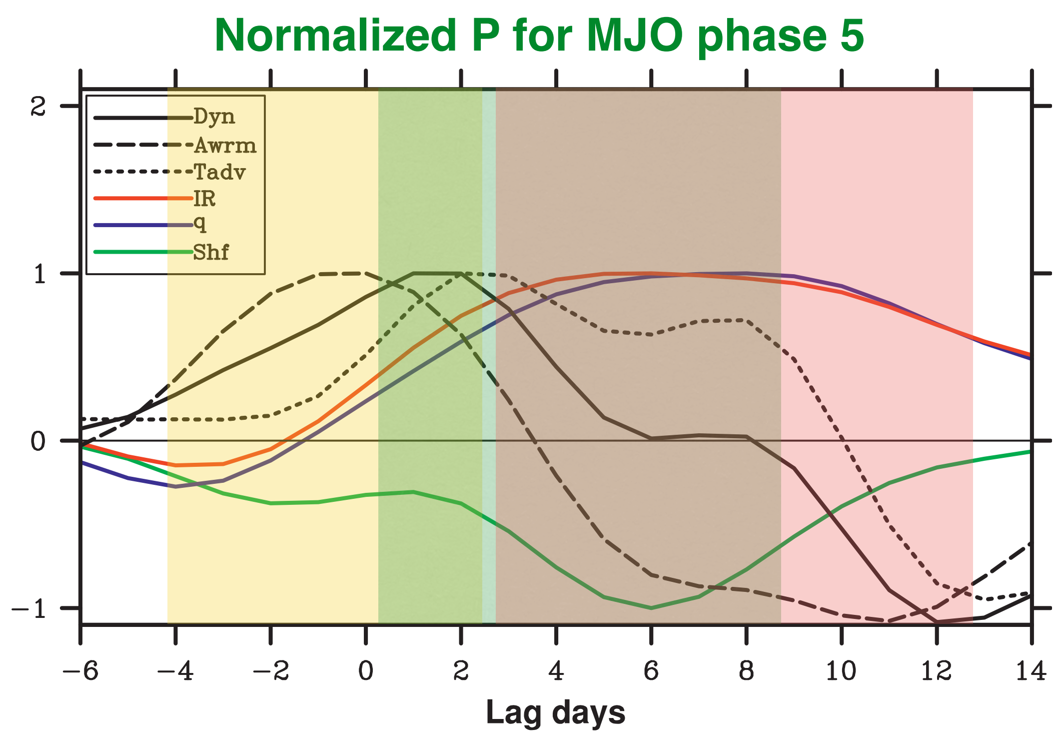


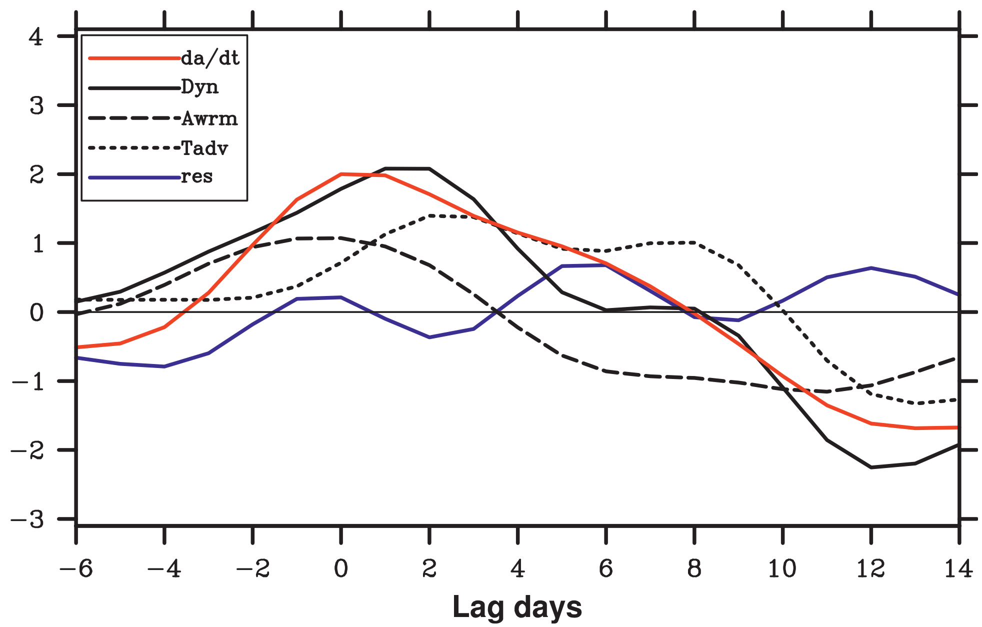
Yoo et al. 2012b

- We further write

$$T(\lambda,\theta,t) = a(t)\overline{T}(\lambda,\theta) + T'(\lambda,\theta,t), \quad a(t) = \left[\frac{\sum_j T(\lambda,\theta,t)\overline{T}_j(\lambda,\theta)\cos\theta}{\sum_j \overline{T}_j^2(\lambda,\theta)\cos\theta}\right],$$

- Then, (1) becomes

$$\frac{da}{dt} = \frac{\sum_{i=1}^{2} P_i}{\sum_j \overline{T}_j^2 \cos\theta},$$



- i) The adiabatic warming initiates the SAT change,
- ii) but subsequent warm advection makes a greater contribution
- iii) and IR (sensible heat flux) change further amplifies (dampens) the warming.

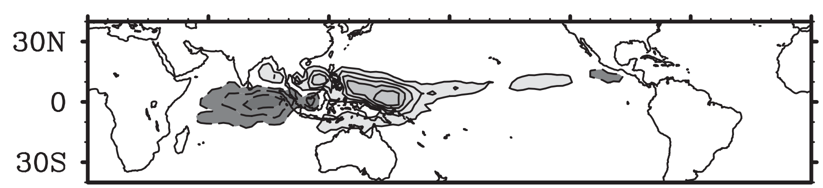
Initial value calculations

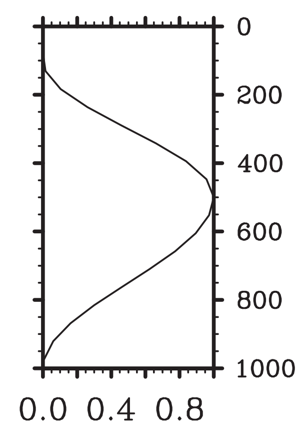
Can this be understood as a linear response to a tropical convective heating?

How we set up

- **Model**
  - GFDL spectral dynamical core at T42 with 19 levels
  - Simplified physics (Newtonian damping, Rayleigh friction, and diffusion)

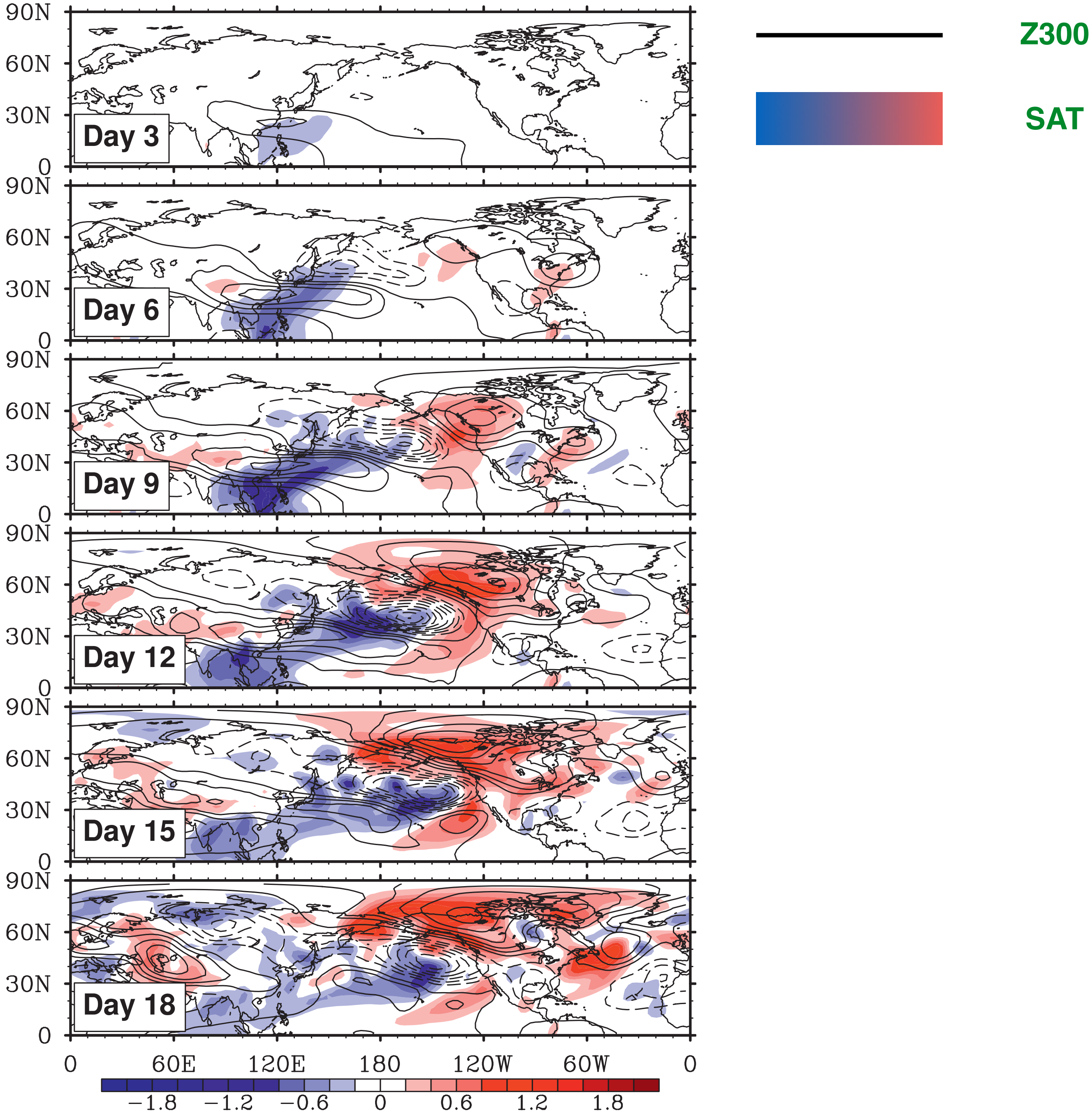
- **Set up**
  - Model is initialized using DJF 1979-2008 climatology.
  - Model is balanced by a stationary additional forcing.
  - Tropical heating is on until day 5 using CMAP precipitation composites.





Yoo et al. 2012a

Response to MJO phase 5



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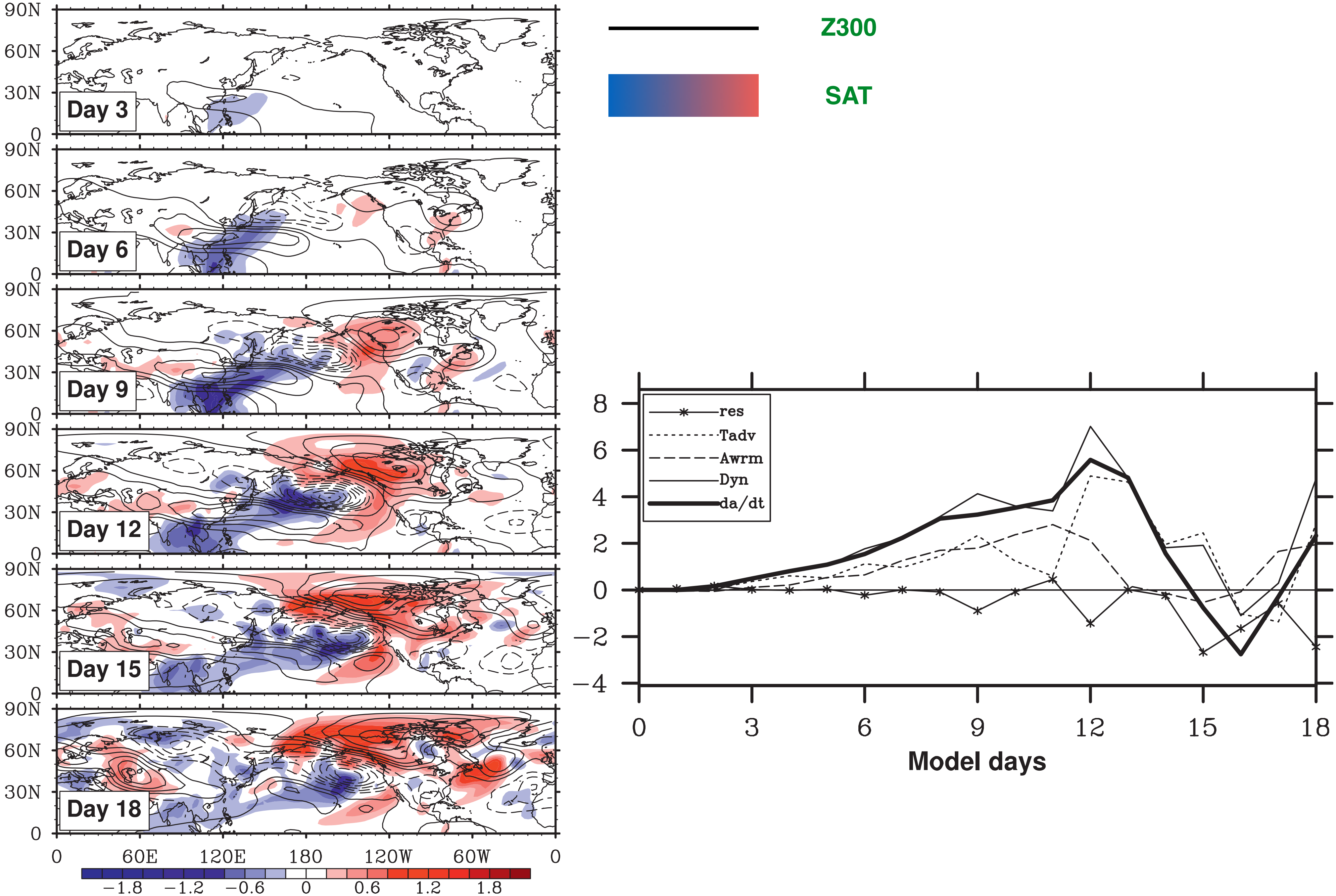


Climate model simulations

Do climate models reproduce the results?

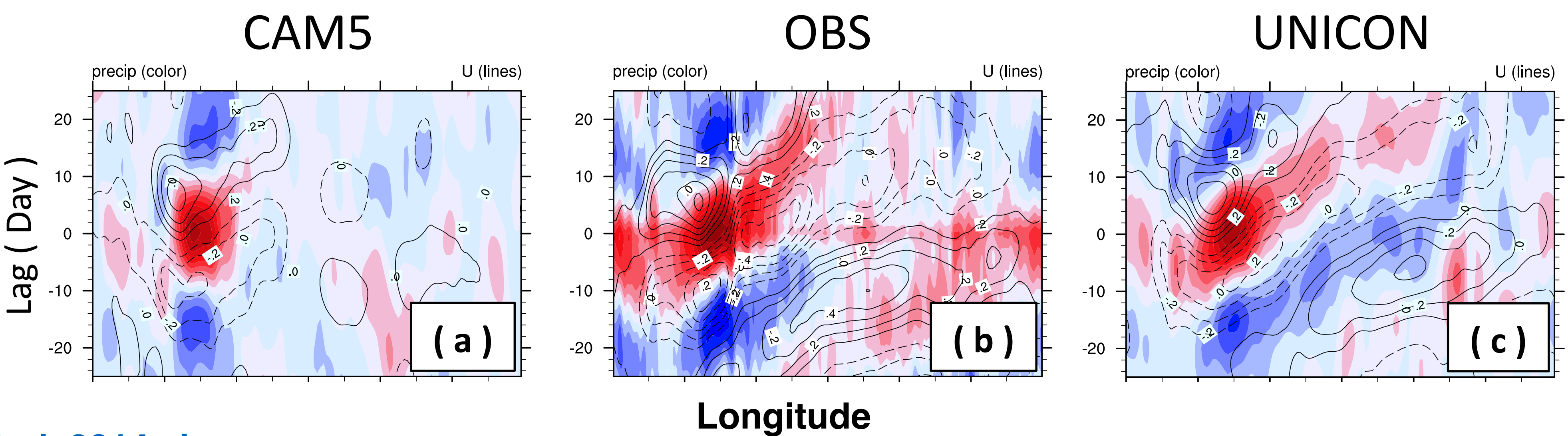
Climate models

- **The MJO is not well represented in climate models.**
  - Only 2 of 14 models in the CMIP3 had the variance of the MJO comparable to the observed value.
  - Many of the CMIP3 models were lack of pronounced peaks in the power spectrum at the MJO time scales, and did not produce realistic eastward propagation of the MJO (Lin et al. 2006).
  - In CMIP5 models, simulated variance of the MJO was generally increased, but still many other aspects of the MJO needed to be further improved (Hung et al. 2013).
- **For MJO teleconnection, we need realistic MJO, as well as the basic state.**
  - Modifying a certain feature in convection scheme often results in degradation in basic state (Kim et al. 2014).

AMIP type CAM5 simulations

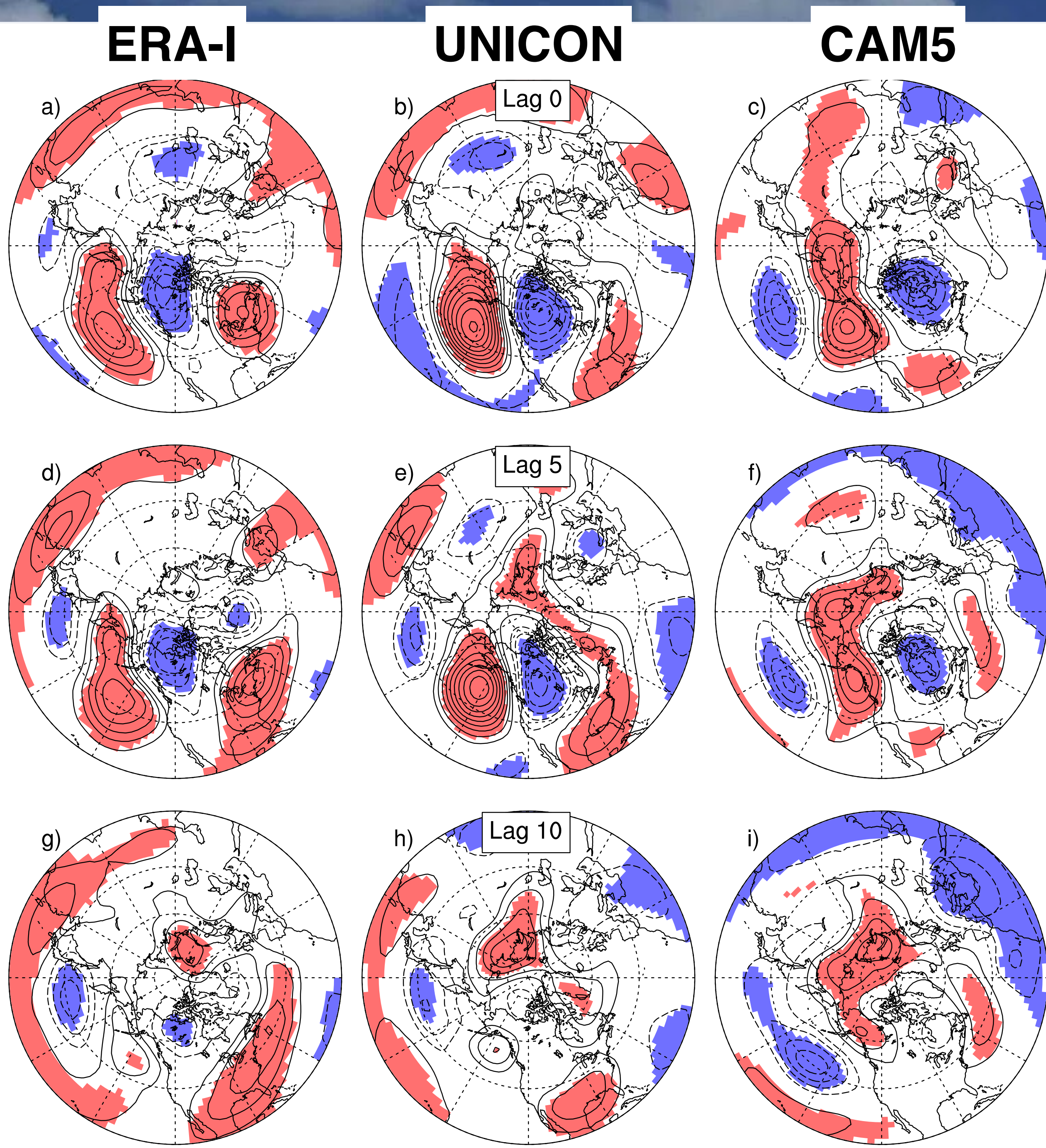
- CAM5 with default setting vs CAM5 + UNICON
- UNICON replaces deep and shallow convection schemes.
- In UNICON, treatment for entrainment rate and plume organization are better represented. This leads to improved diurnal cycle of precipitation and the MJO.
- Mean winds in CAM5 vs UNICON are not much different.

Lag correlations of subseasonal precipitation

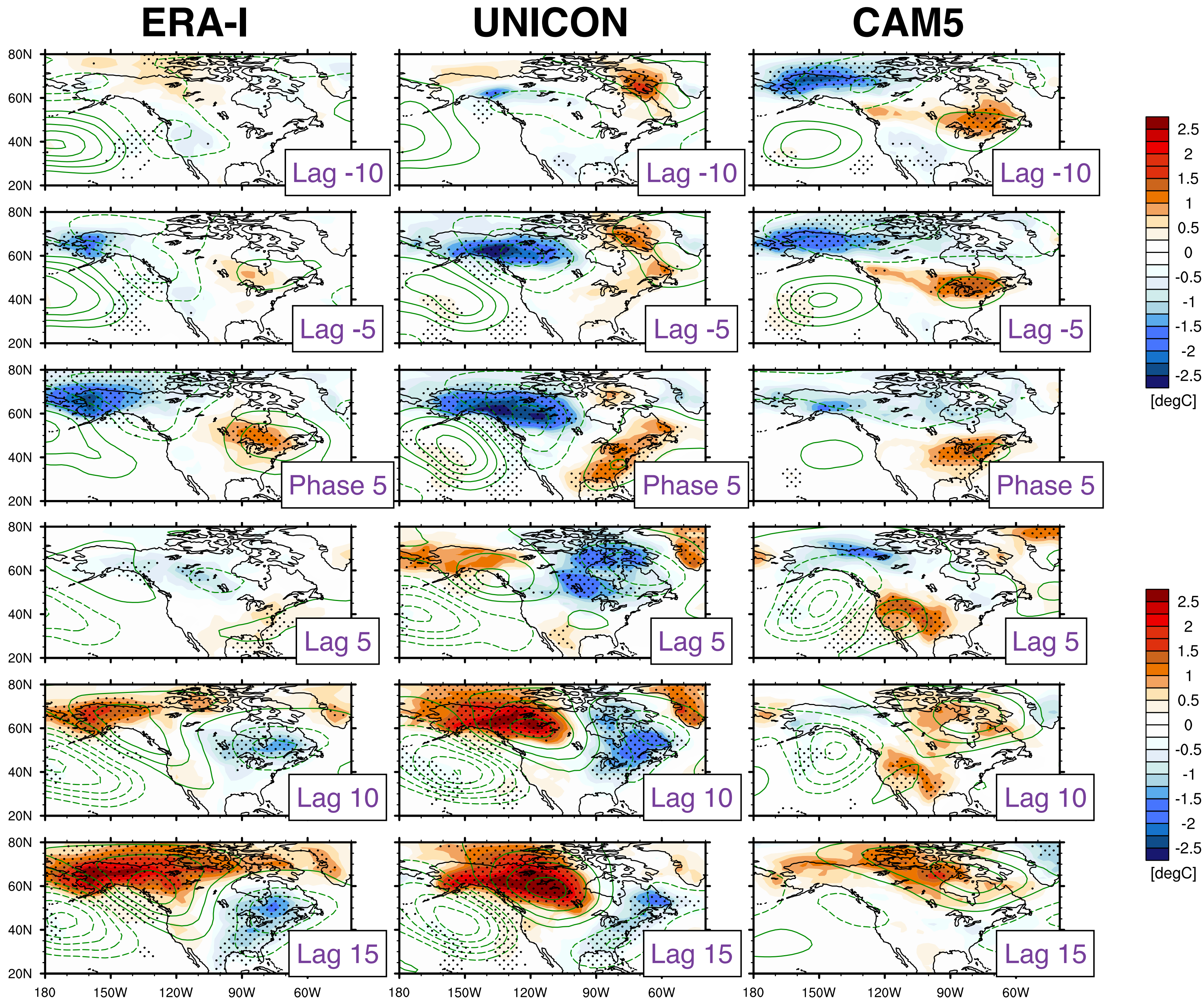


Park 2014a,b

Z300



Yoo et al. in prep.


ERA-I
UNICON
CAM5
Lag -10
Lag -5
Phase 5
Lag 5
Lag 10
Lag 15
80N
60N
40N
20N
180
150W
120W
90W
60W
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
[degC]

Discussion

- Does the MJO have an **impact on sea ice?**
  - "MJO modulates Arctic sea ice in both summer and winter seasons, with the region of greatest variability shifting with the migration of the ice margin poleward (equatorward) during the summer (winter) period." (Henderson et al. 2014)

- How would the MJO change with climate change?
  - For past decades, MJO **phases 4-6 have been more frequently occurred** while phases 1-2 have shown a moderate decrease in their frequency of occurrence (Yoo et al. 2011).
  - The RCP8.5 simulation of CCSM4 suggests **stronger MJO amplitude** in the future (Subramanian et al. 2014).

Thank you