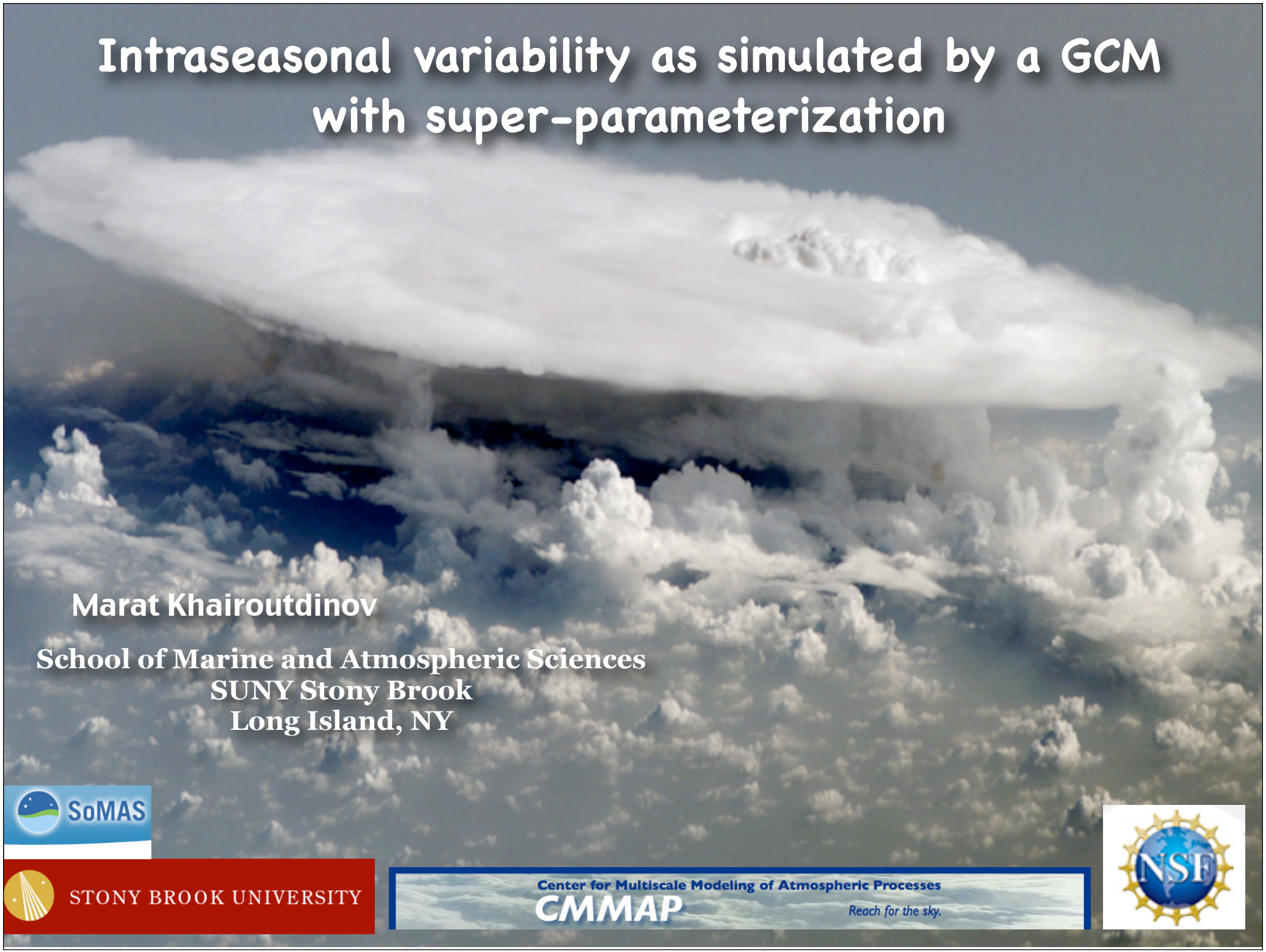
Intraseasonal variability as simulated by a GCM with super-parameterization



Marat Khairoutdinov

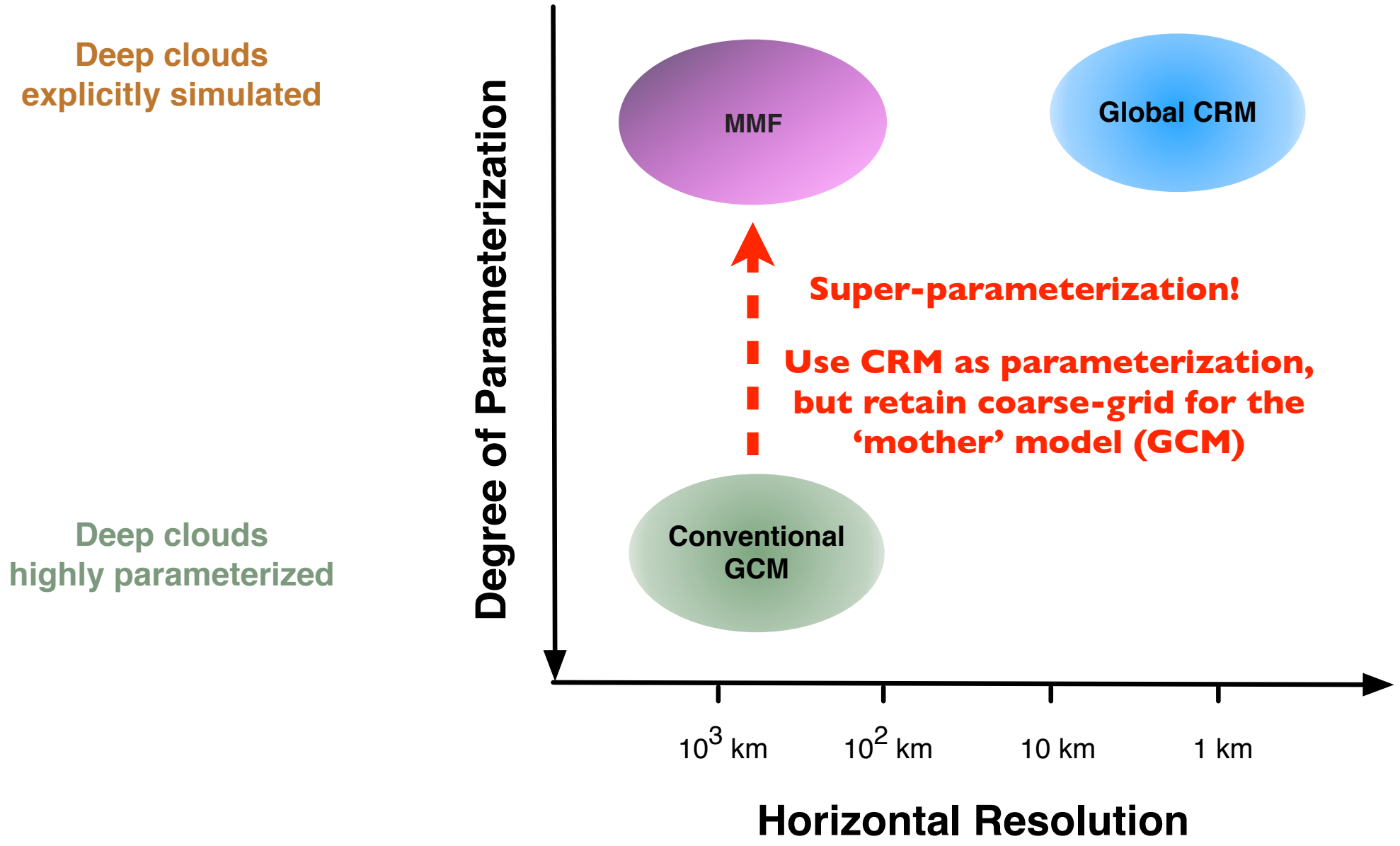
School of Marine and Atmospheric Sciences
SUNY Stony Brook
Long Island, NY

SoMAS

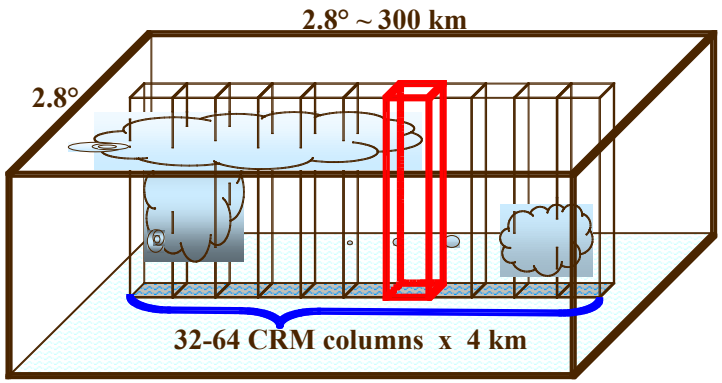
STONY BROOK UNIVERSITY

Center for Multiscale Modeling of Atmospheric Processes
CMMAP
Reach for the sky.

NSF


Deep clouds
explicitly simulated
Deep clouds
highly parameterized
Degree of Parameterization
MMF
Global CRM
Super-parameterization!
Use CRM as parameterization,
but retain coarse-grid for the
'mother' model (GCM)
Conventional
GCM
10^3 km
10^2 km
10 km
1 km
Horizontal Resolution

Prototype MMF Approach:



$$\frac{\partial \overline{s}}{\partial t} = -\overline{\nabla s V} - \frac{\partial \overline{s}\,\overline{\omega}}{\partial p} + Q_1$$

LS Resolved Tendency

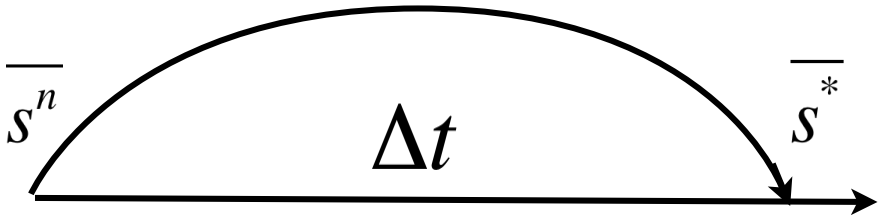
Column-Physics Tendency (super-parameterization)

Host model: CAM/CCSM

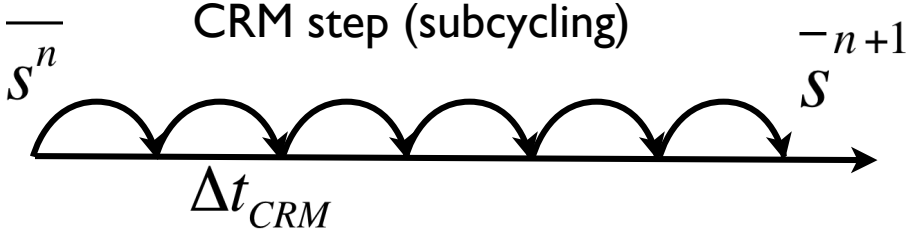
CRM Forcing:

$$-\overline{\nabla s V} - \frac{\partial \overline{s}\,\overline{\omega}}{\partial p} = \frac{\overline{s^*} - \overline{s^n}}{\Delta t}$$

Dynamics (GCM) Step:



CRM step (subcycling)



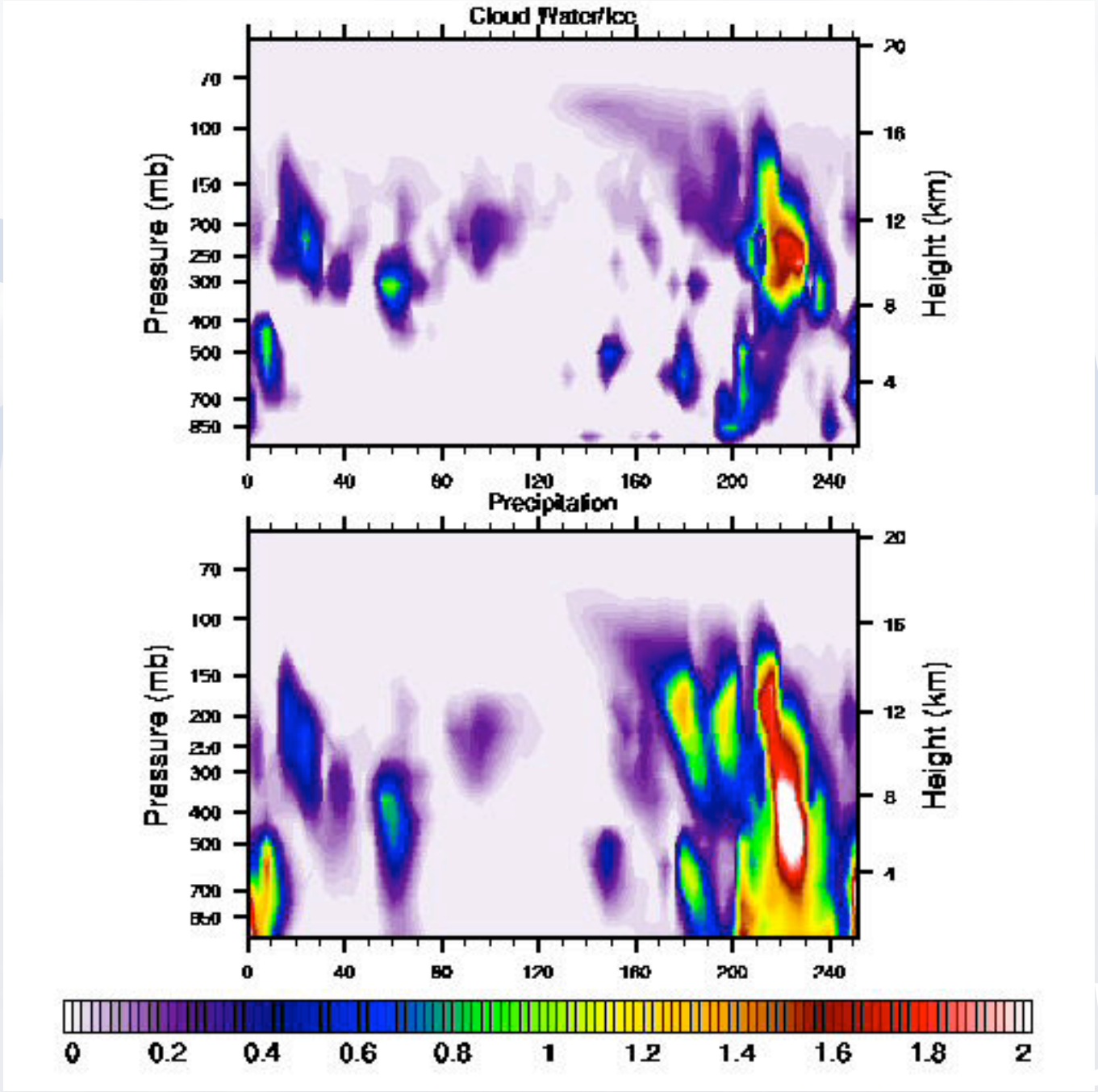
Column-physics Tendency:

$$Q_1 = \frac{\overline{s}^{n+1} - \overline{s^*}}{\Delta t}$$

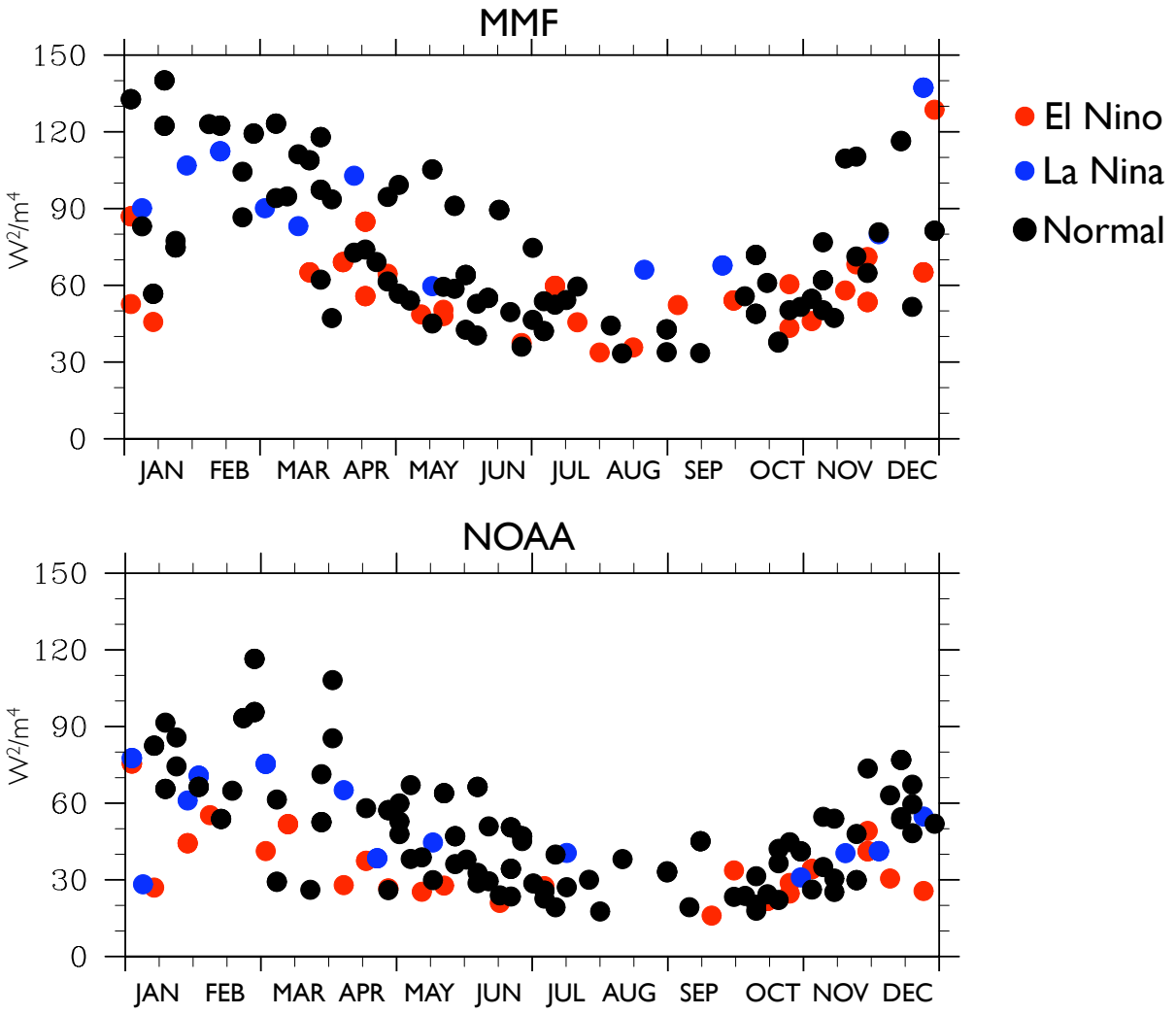
In 2D CRM: No CMT
In 3D CRM: CMT

More details in Khairoutdinov et al (JAS, 2005) and Benedict et al (JAS, 2008)

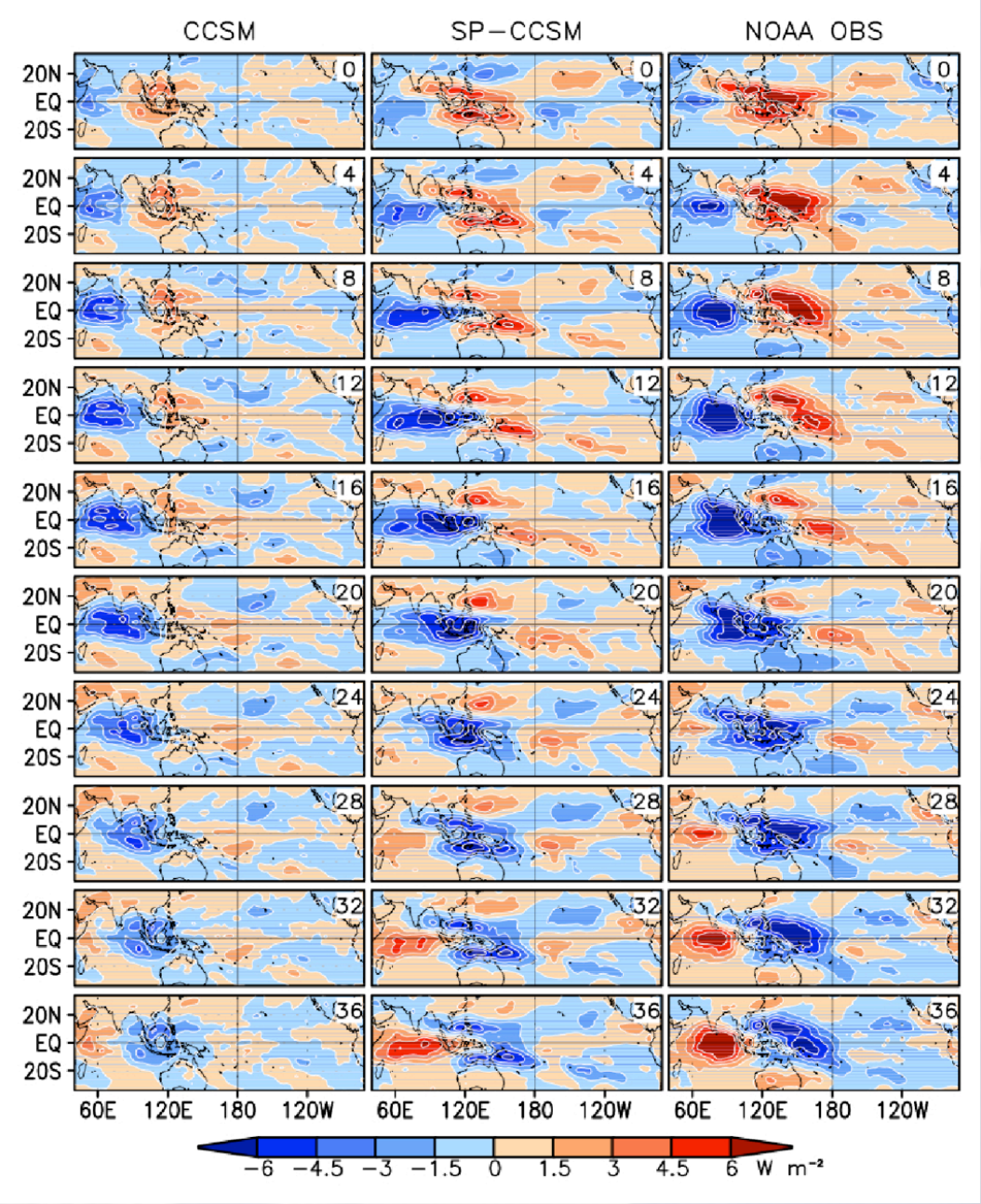
Individual CRM/SP domain (64 cols, 30 levels)
One of 8,192 CRMs running simultaneously in T42 CAM GCM



MJO-event OLR anomalies
1986-2003



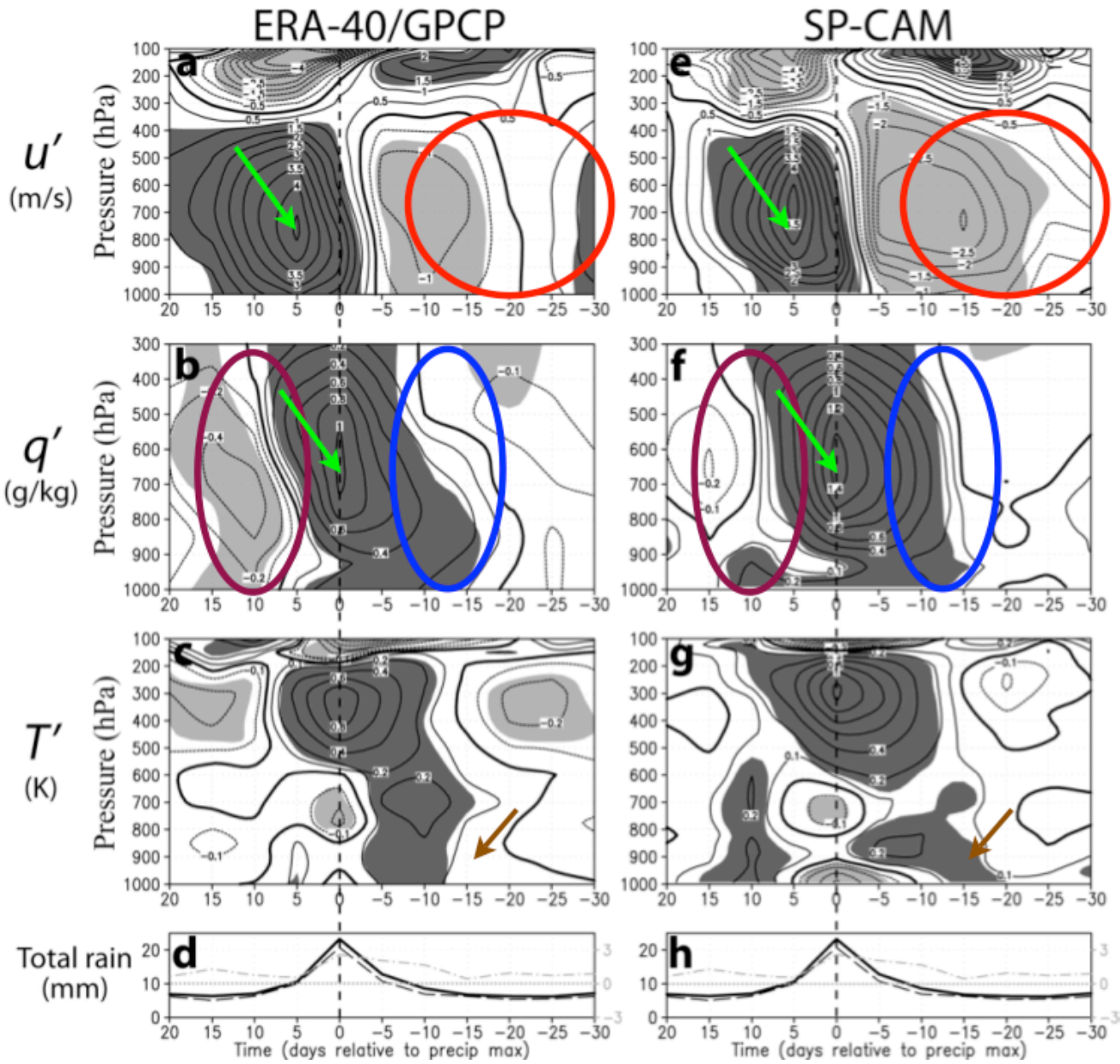
Phase composites of OLR dominant MJO mode



SP-CCSM:
SP-CAM coupled to the ocean

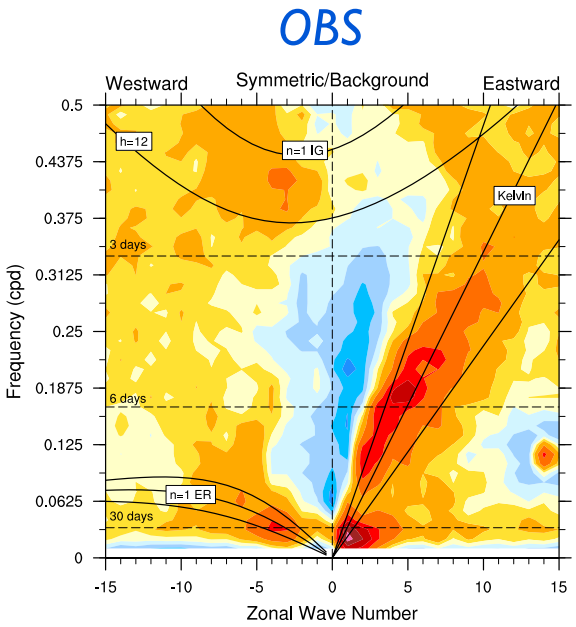
Stan et al (2010)

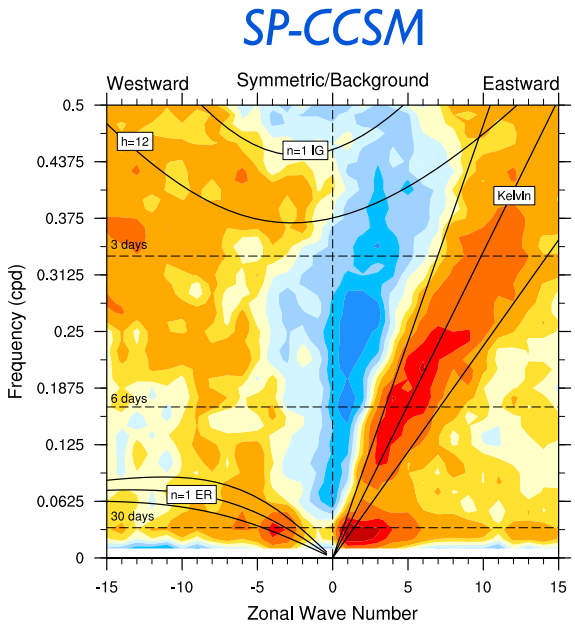
Simulated MJO composite resembles the reality

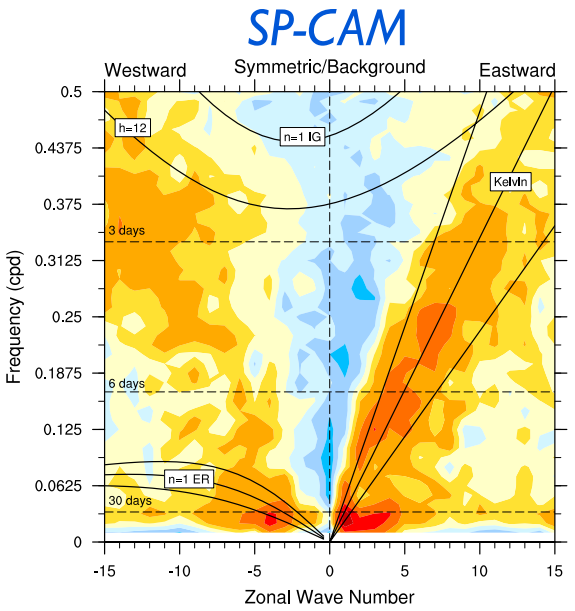


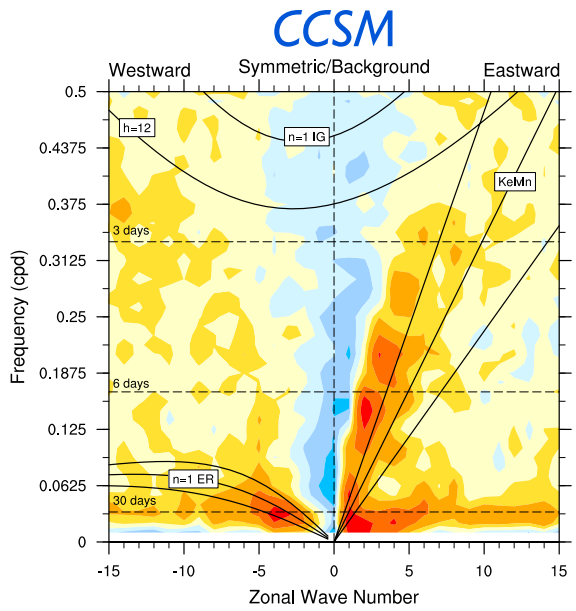
Benedict et al (2008)

Symmetric Equatorial Waves

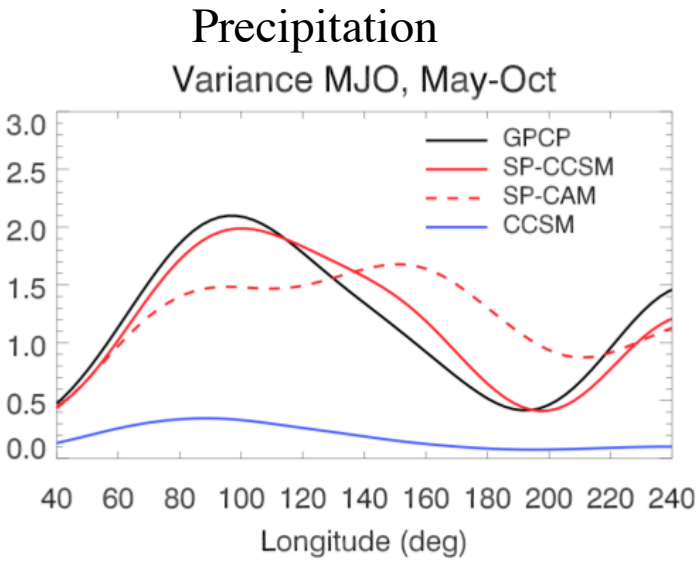








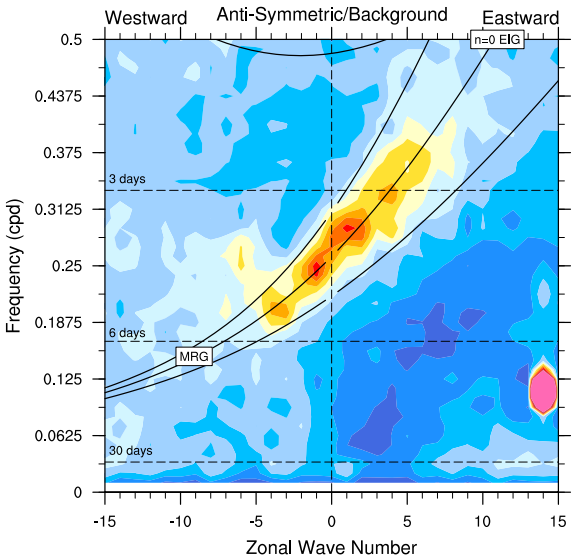
Coupling to the ocean improves subseasonal variability



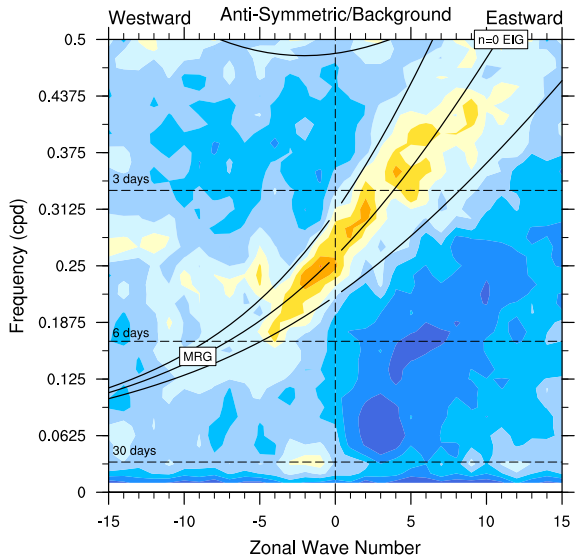
DeMott et al (2011)

Anti-Symmetric Equatorial Waves

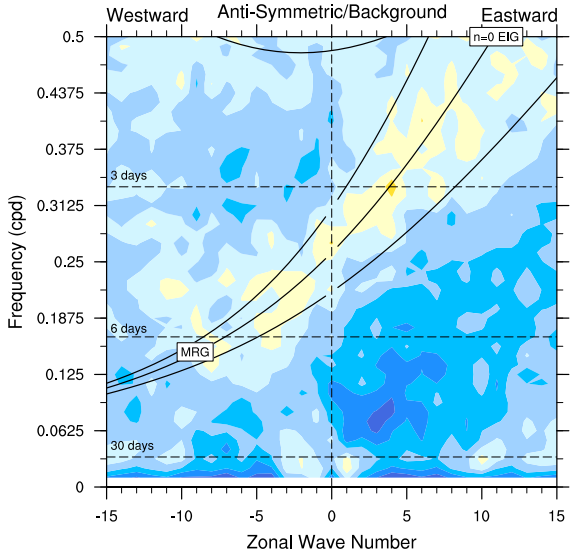
OBS



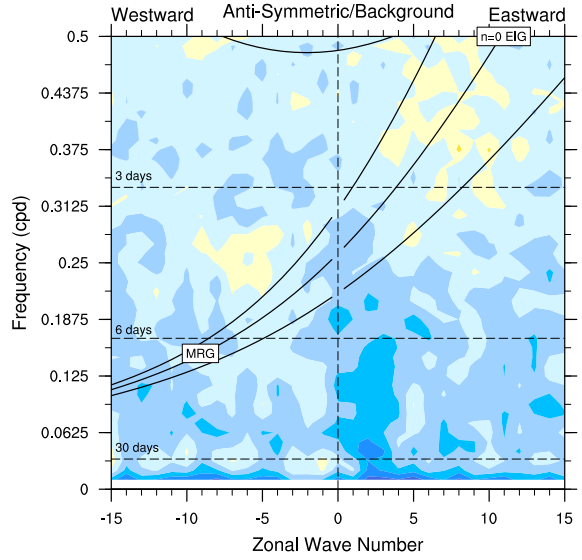
SpCCSM



SpCAM



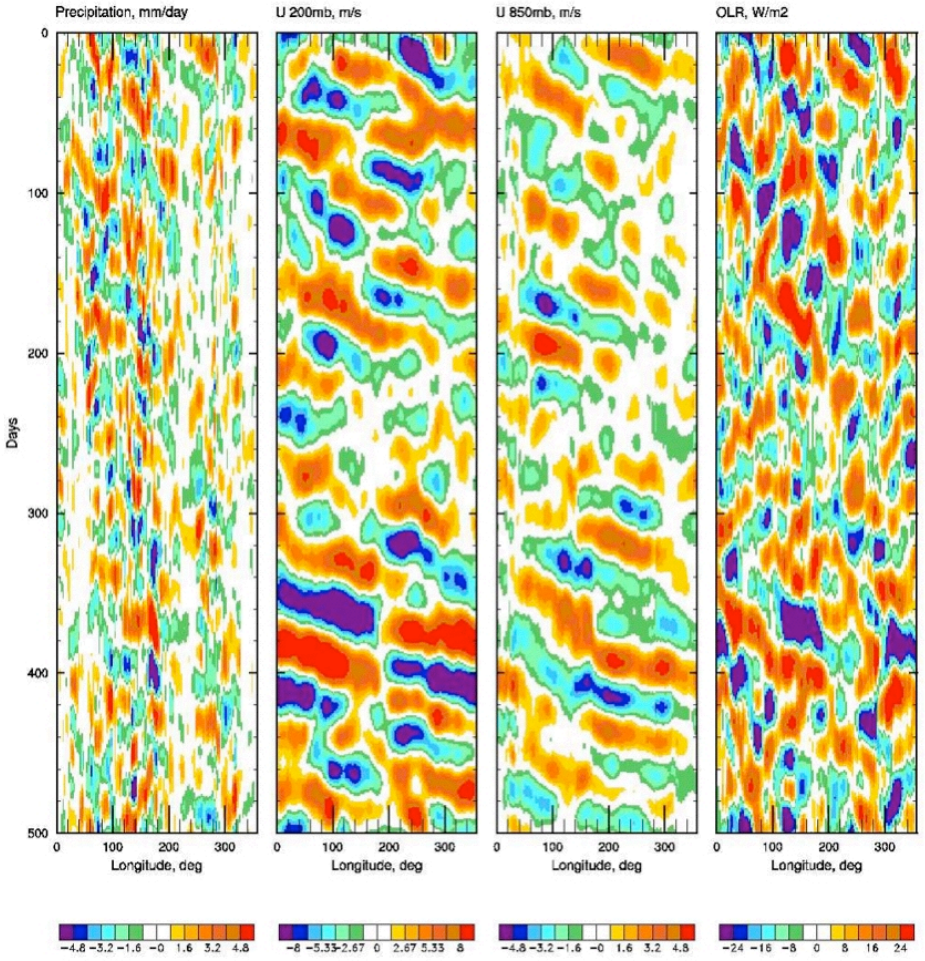
CCSM



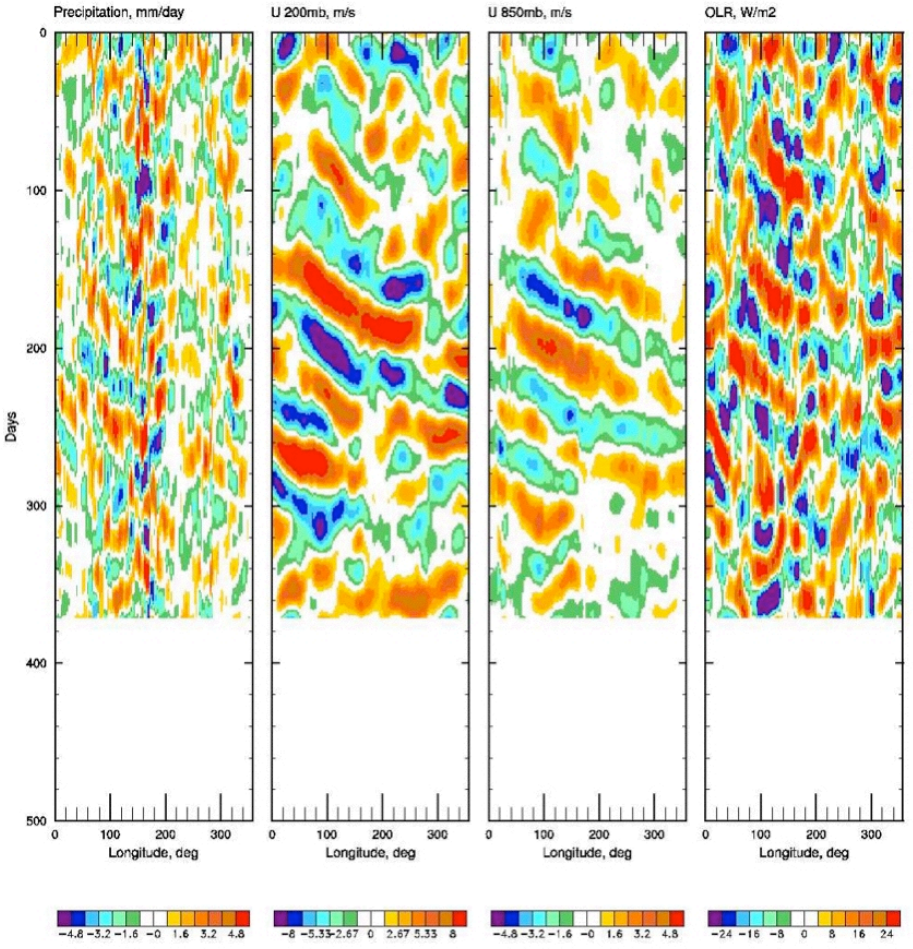
Slide from Charlotte DeMott

CMT seems to slow down propagation speed of MJO

3D-SP



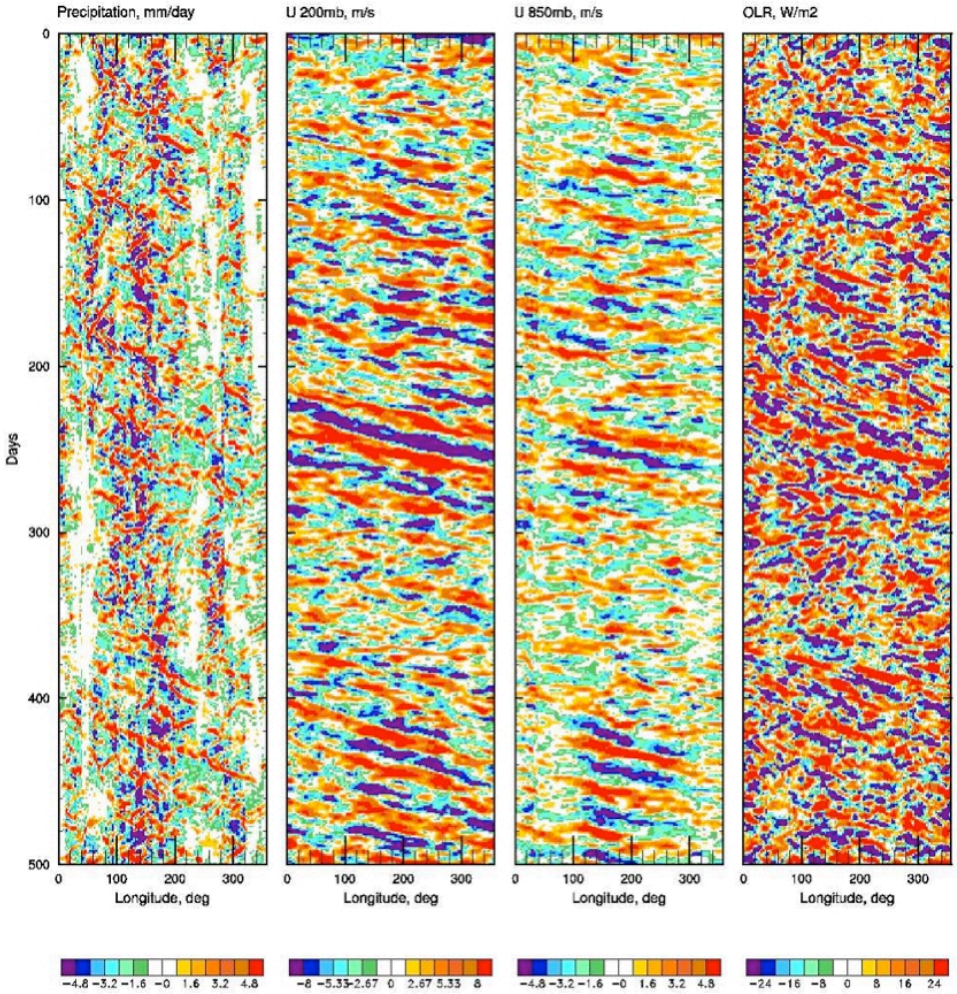
3D-SP -Momentum



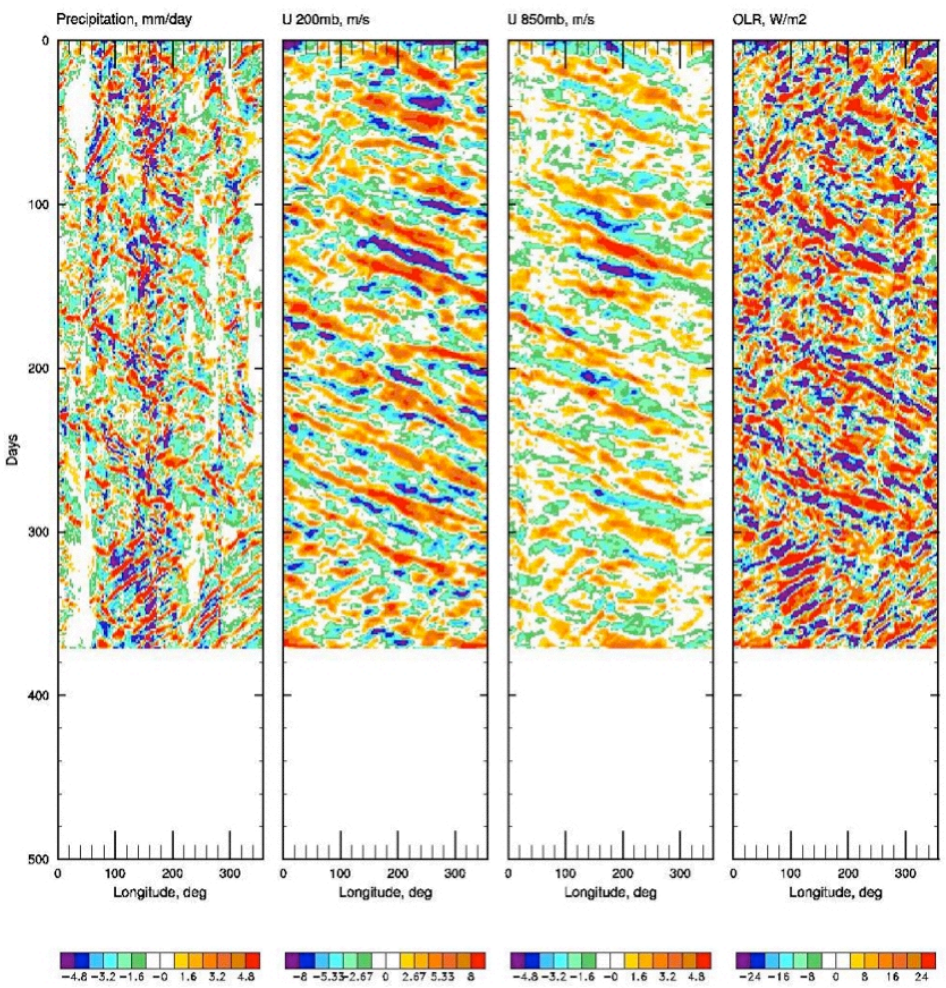
However, you don't need an explicit CMT to simulate MJO.

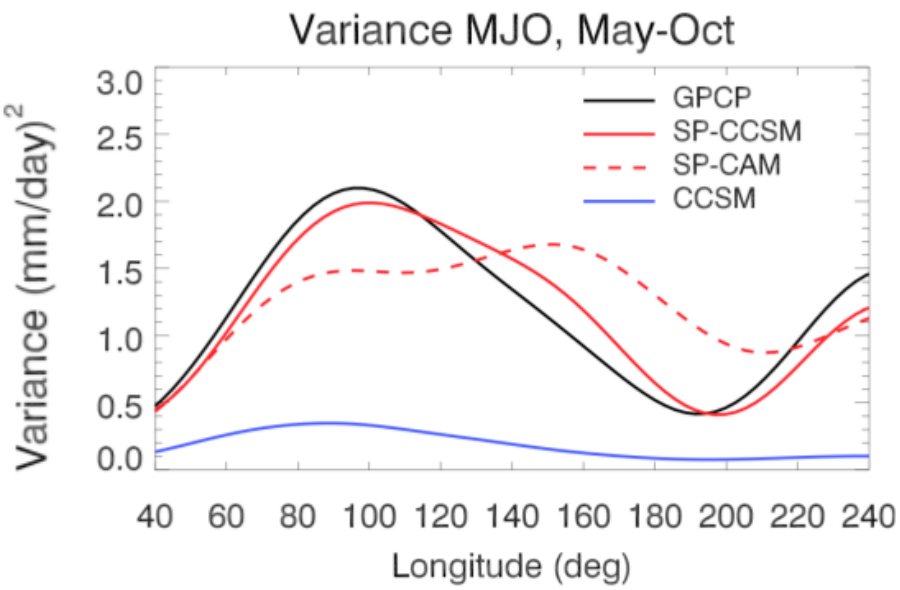
CMT seems also to slow down propagation speed of Kelvin waves

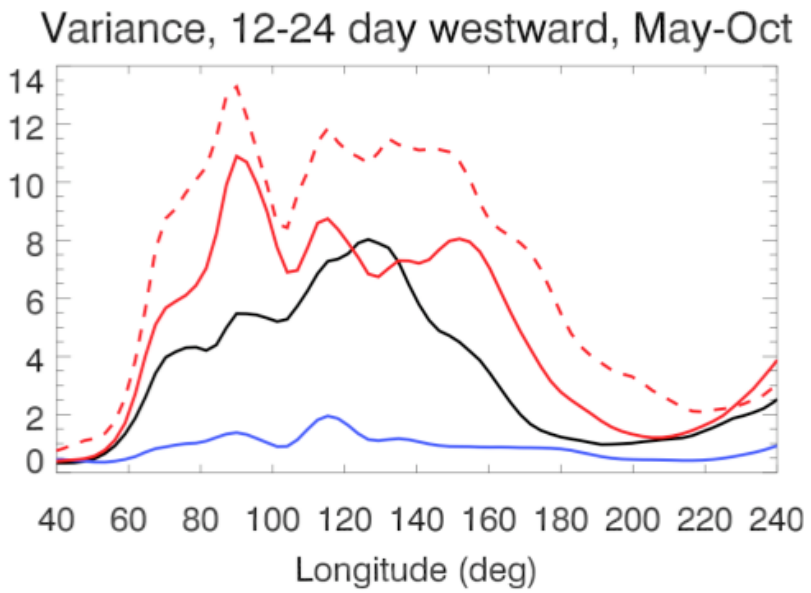
3D-SP



3D-SP-Momentum



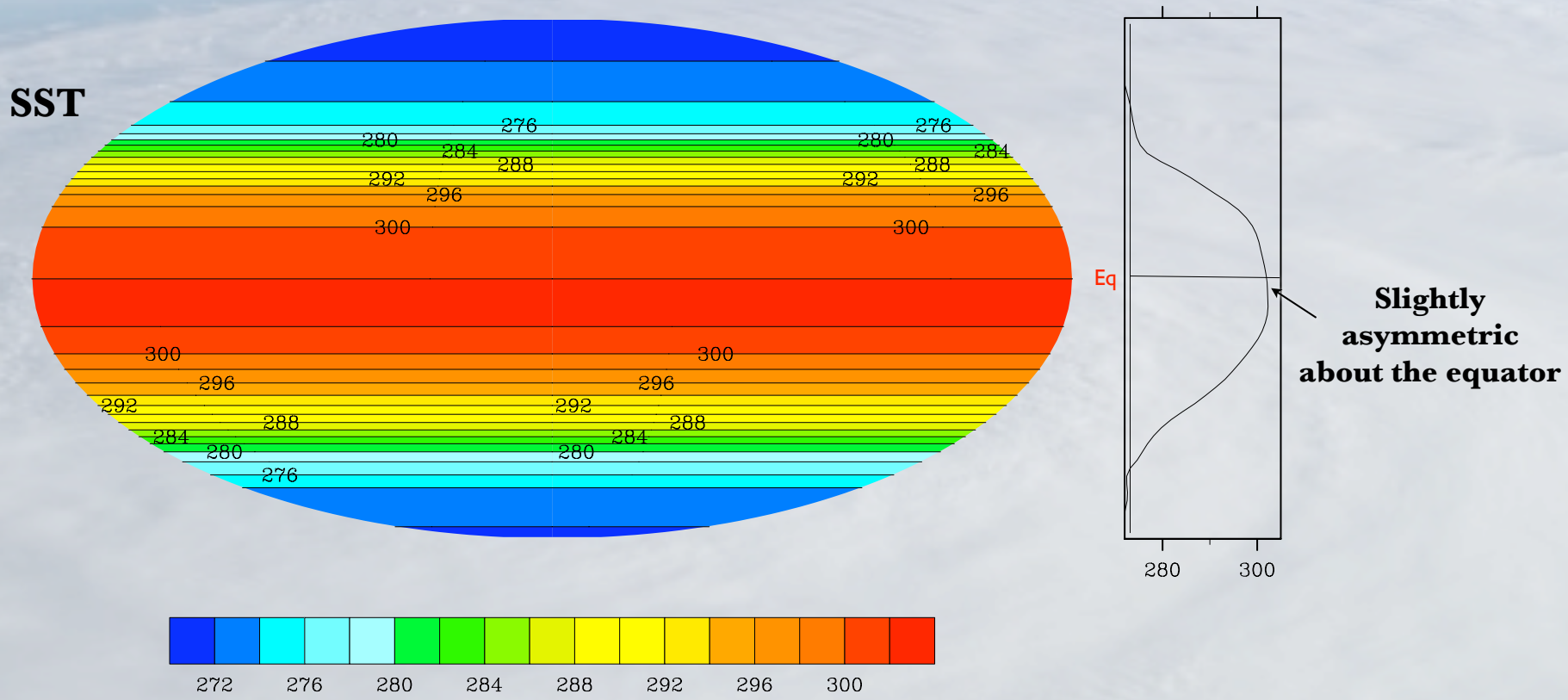




DeMott et al. (2011)

MJO on Aquaplanet

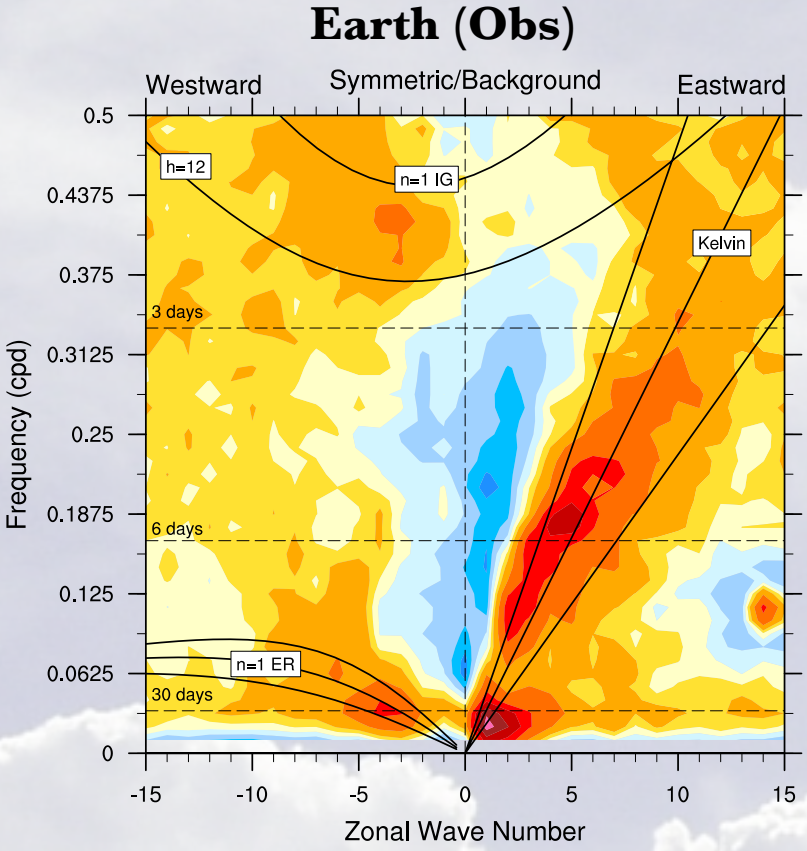
Sea Surface Temperature

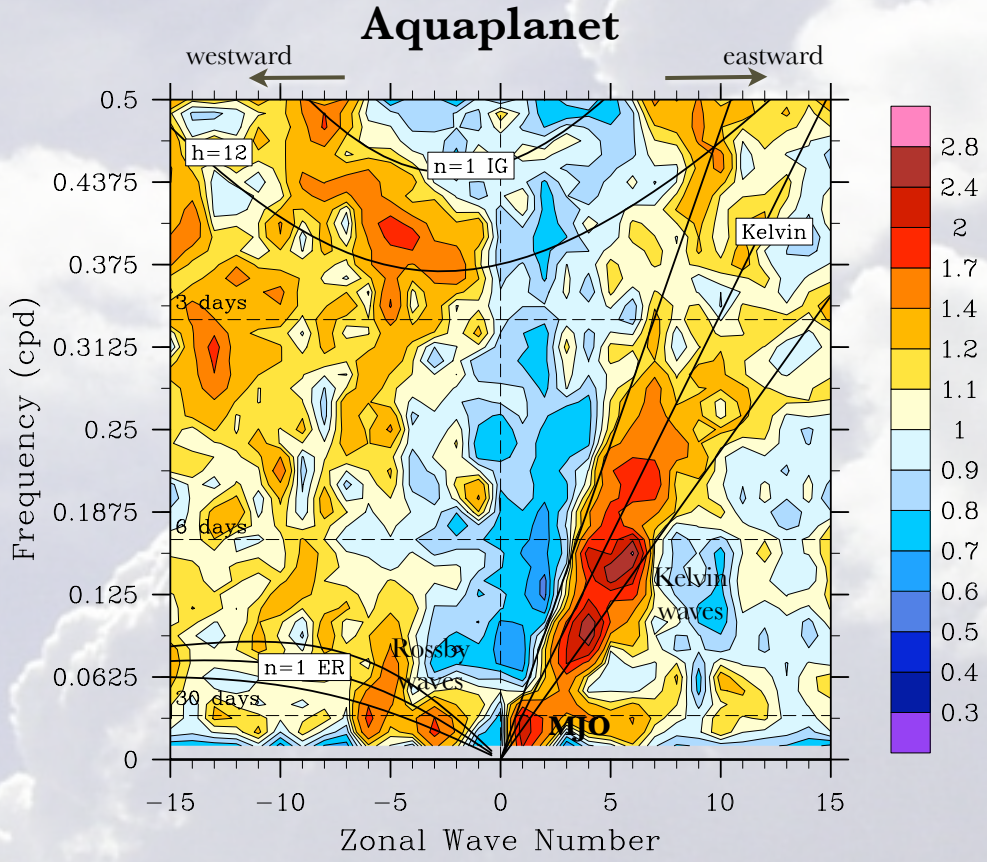


SSTs come from observed January SSTs zonally averaged between 60E and 120E

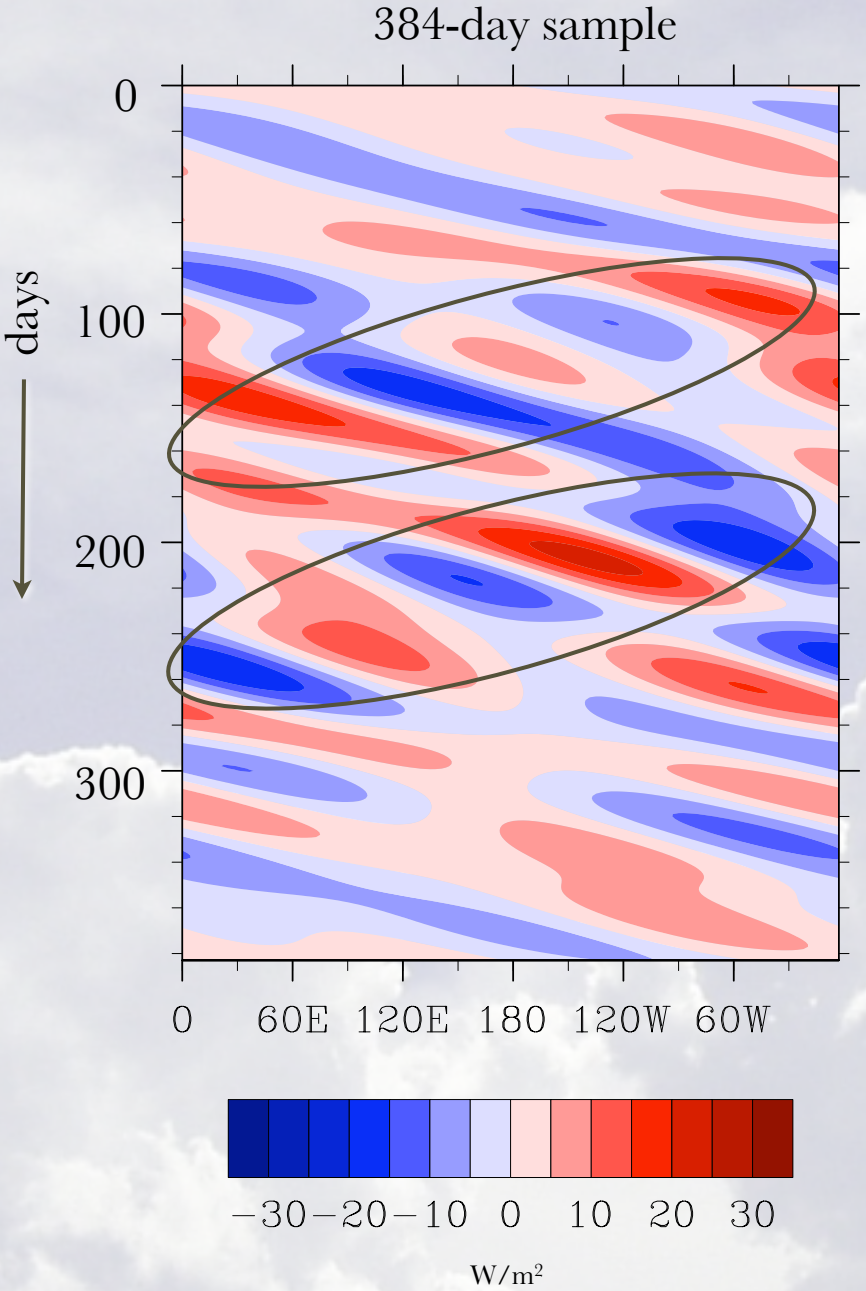
Simulated tropical variability on Aquaplanet looks similar to subseasonal tropical variability on Earth

OLR

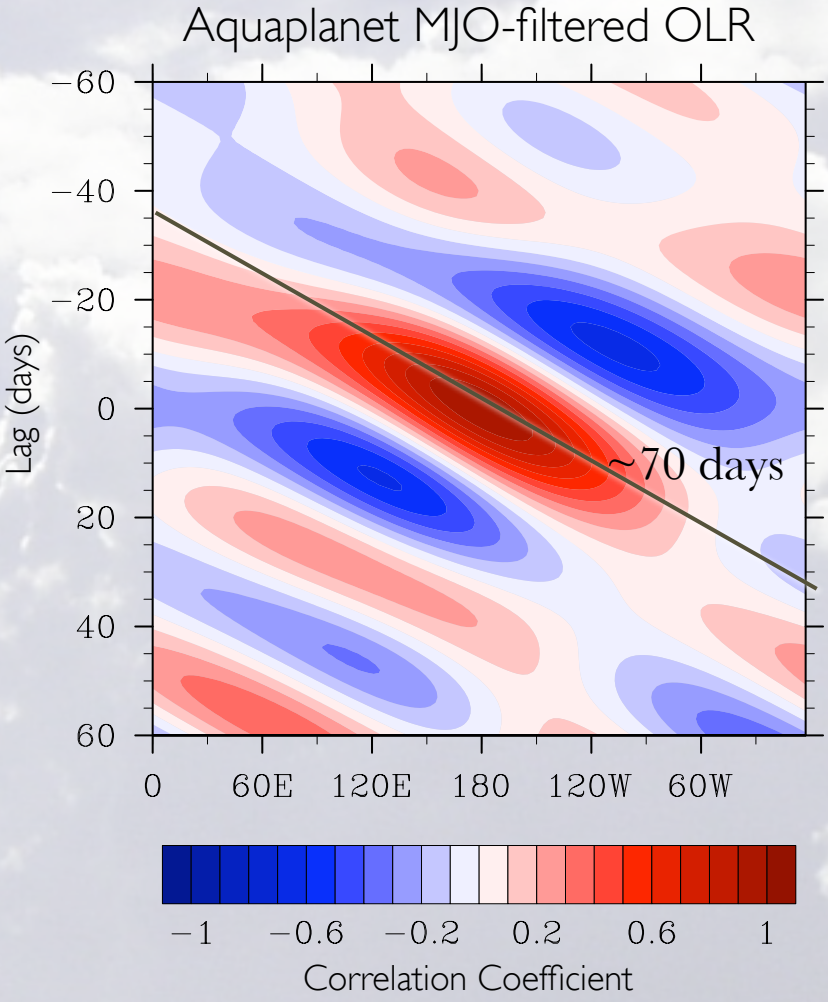




MJO forms ‘wave packets’ on Aquaplanet

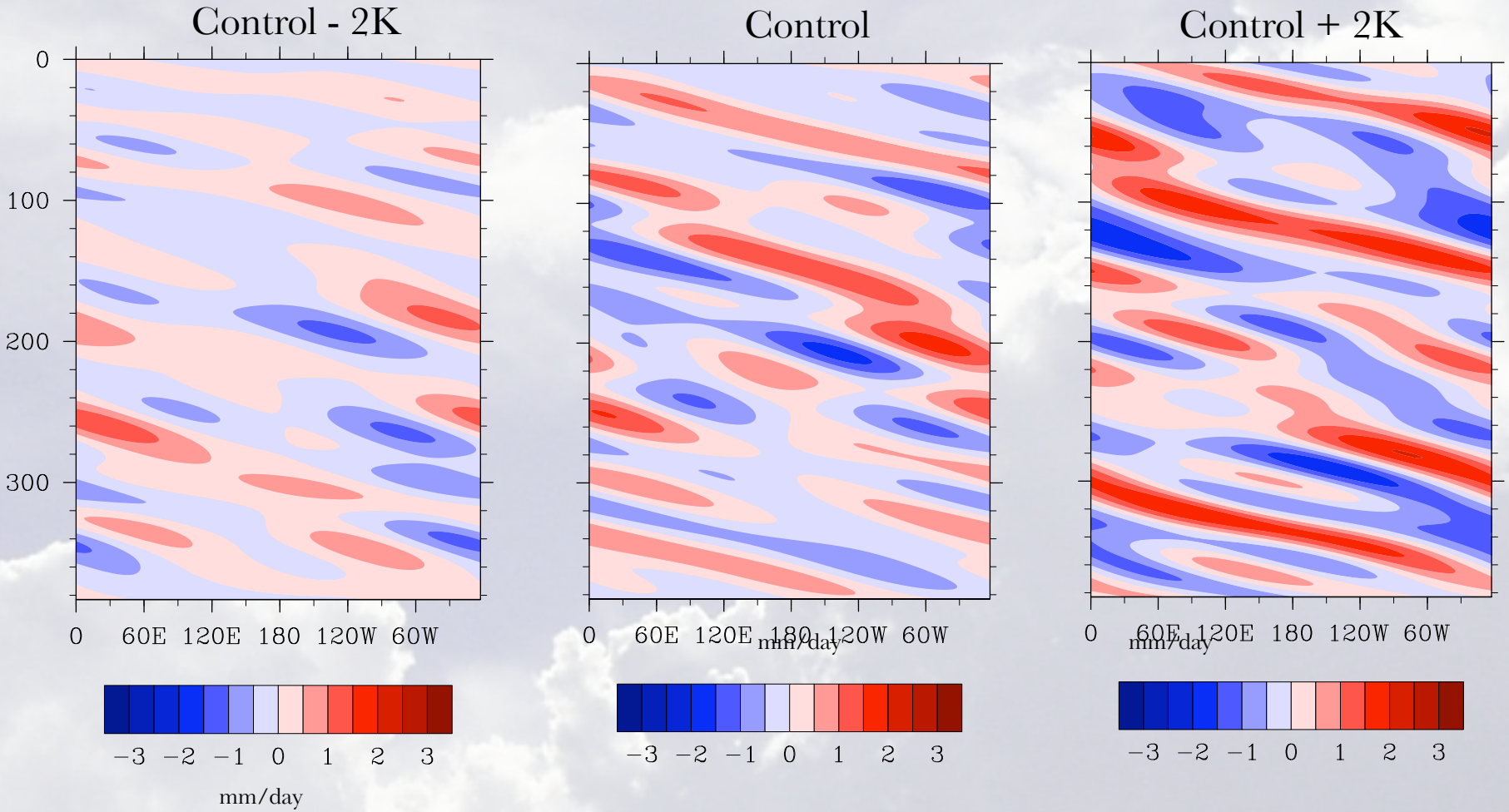


Text



Sensitivity to Sea Surface Temperature

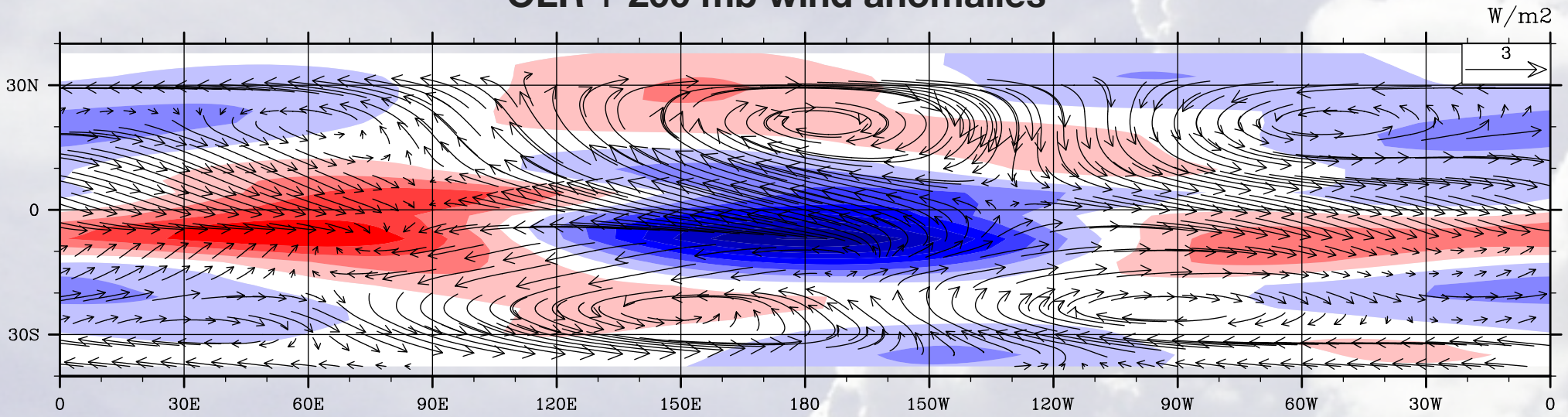
MJO-filtered Precipitation



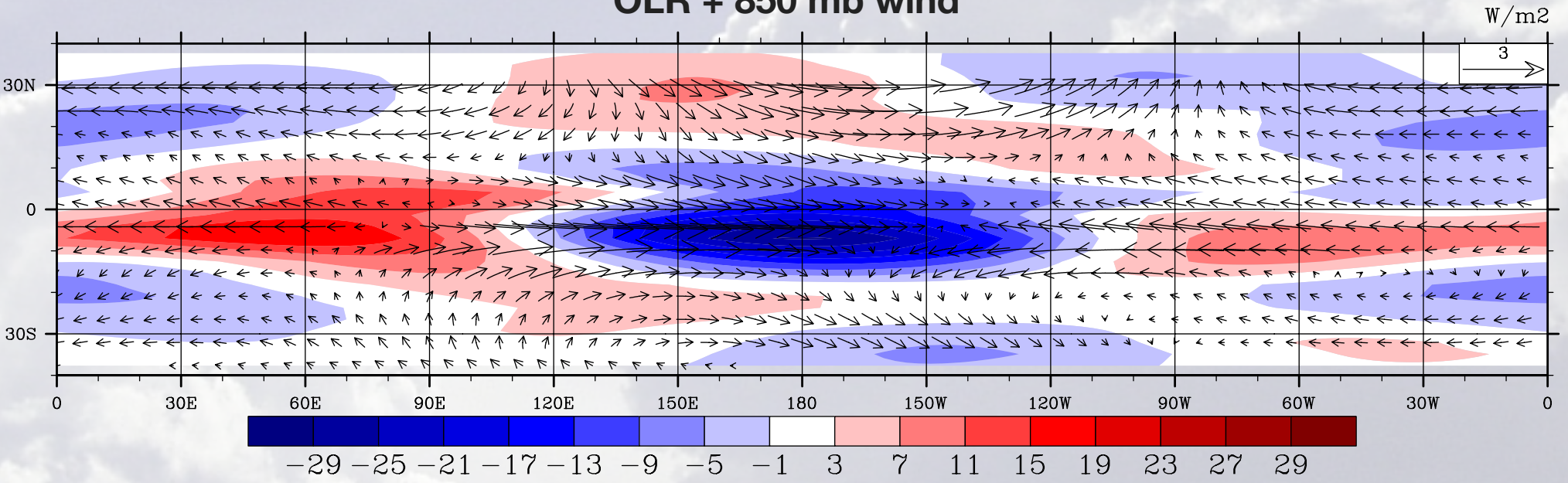
Rising CO_2 → **Warmer Tropical SST** → **Stronger MJO and ISO**

Aquaplanet MJO Composite
Control run

OLR + 200 mb wind anomalies



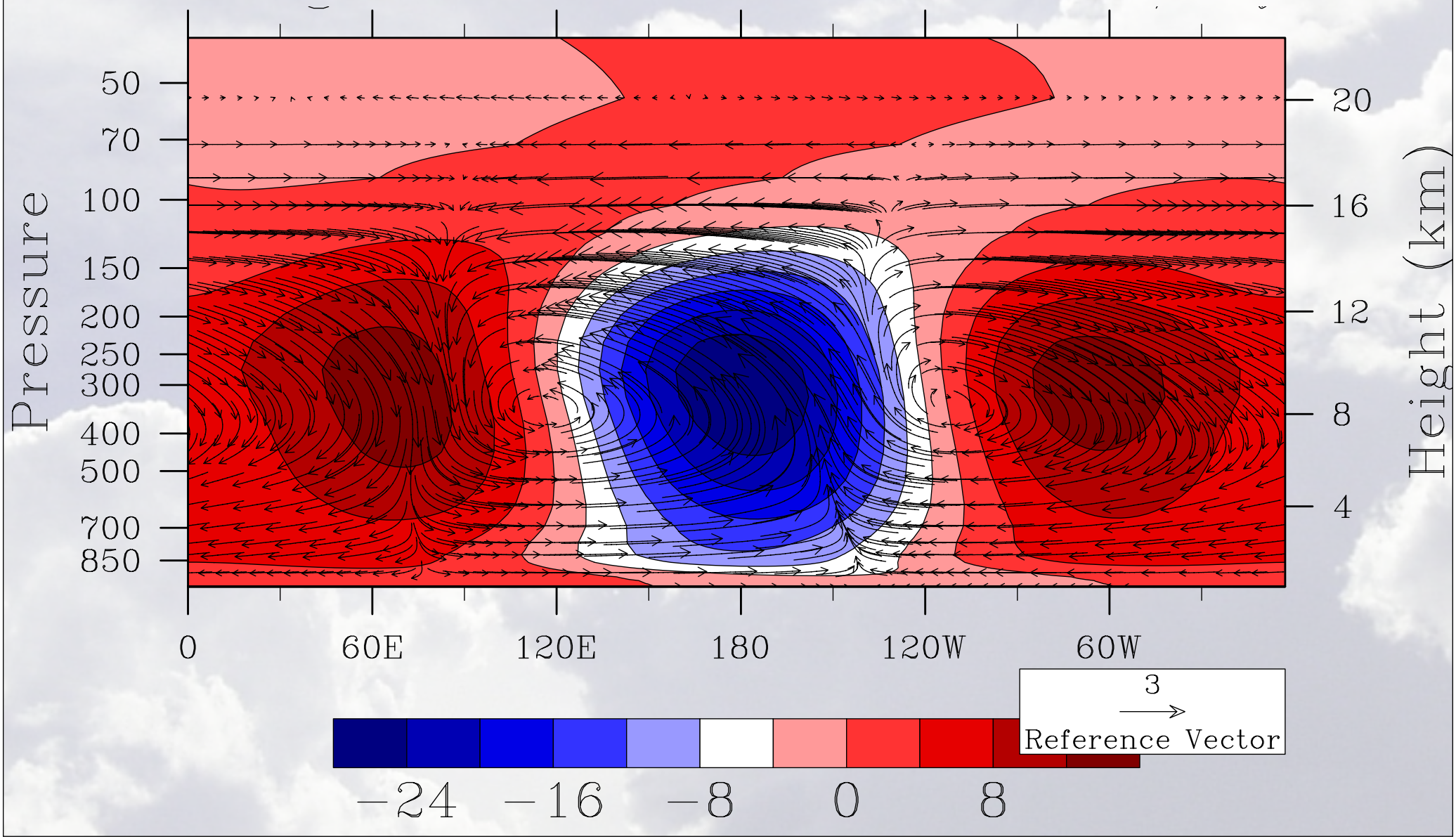
OLR + 850 mb wind



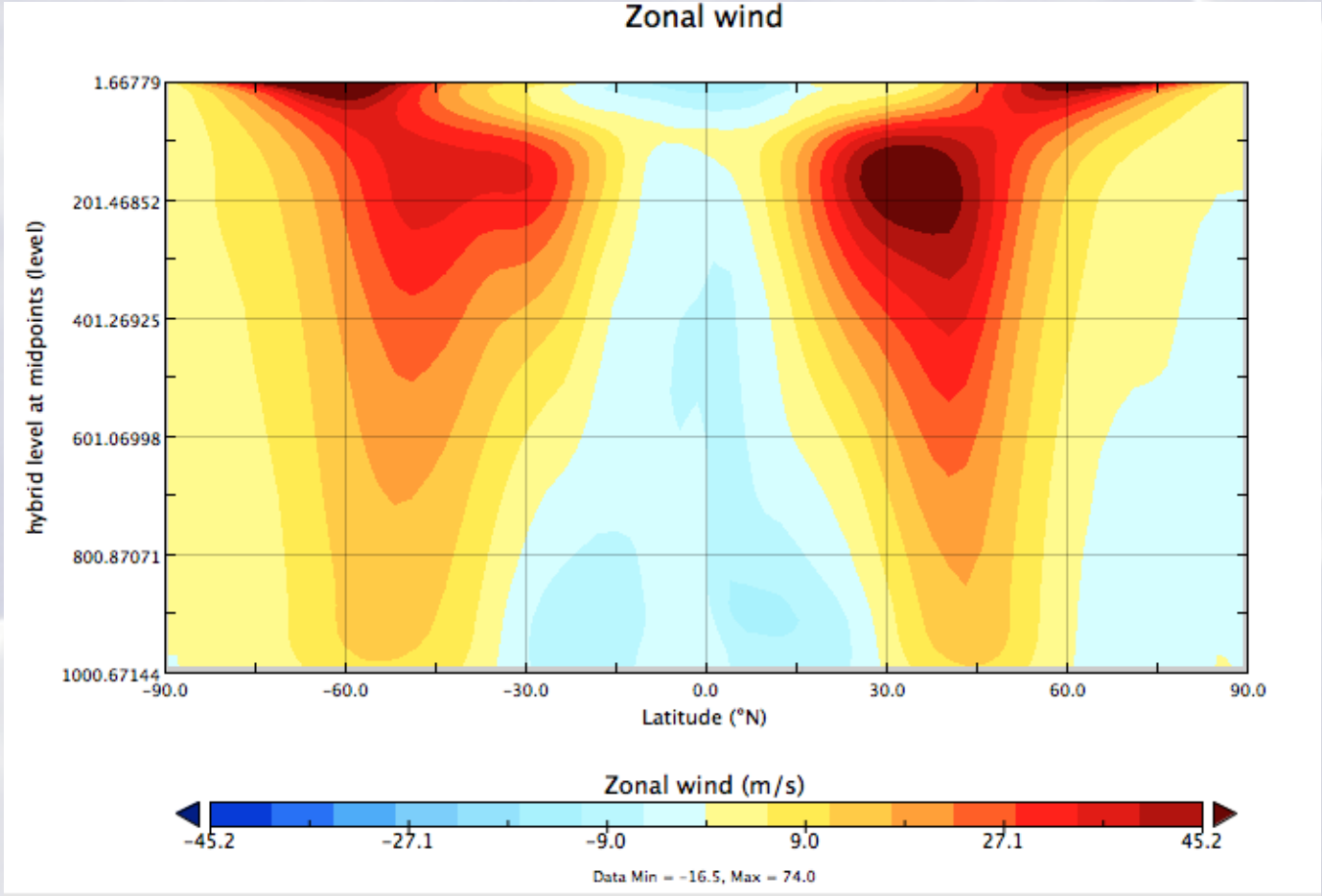
Aquaplanet MJO Composite

+2K Run

Vertical velocity (mb/d) + Wind Anomalies



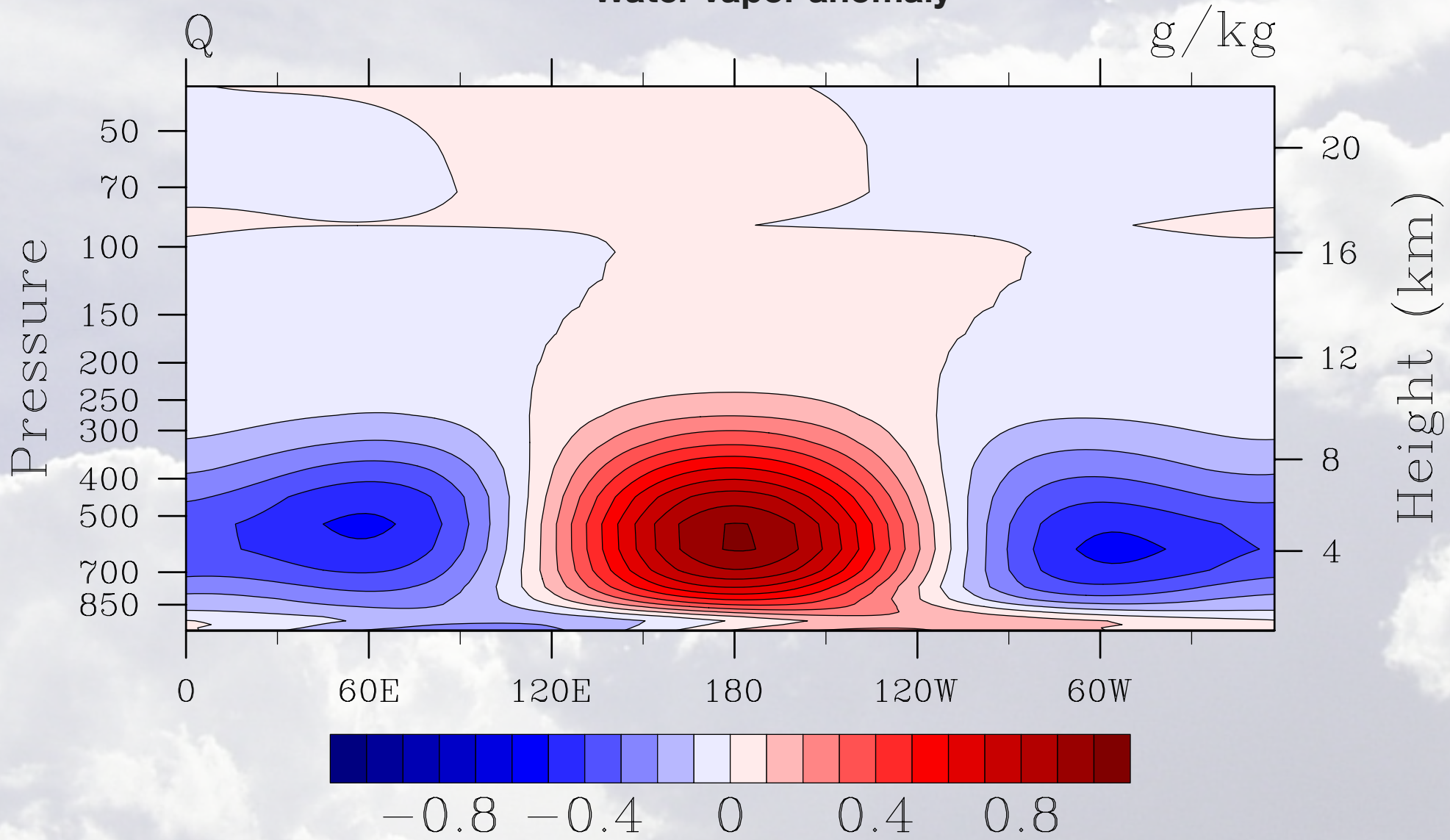
No super-rotation on Aqua-planet was simulated



Aquaplanet MJO Composite

+2K Run

Water vapor anomaly

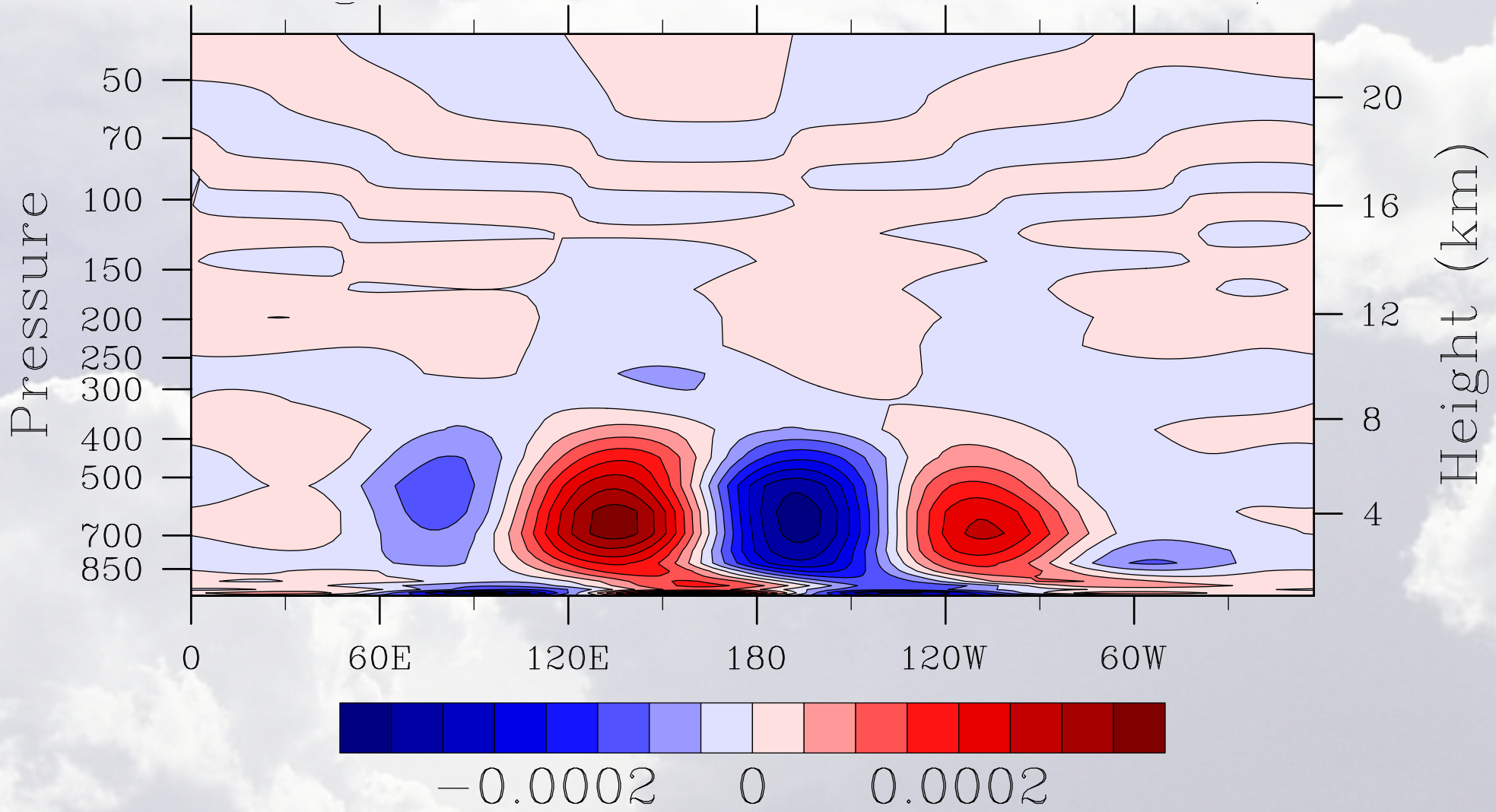


Aquaplanet MJO Composite

+2K Run

Small compared to first term

$$\frac{\partial}{\partial x} uq + \frac{\partial}{\partial y} vq$$

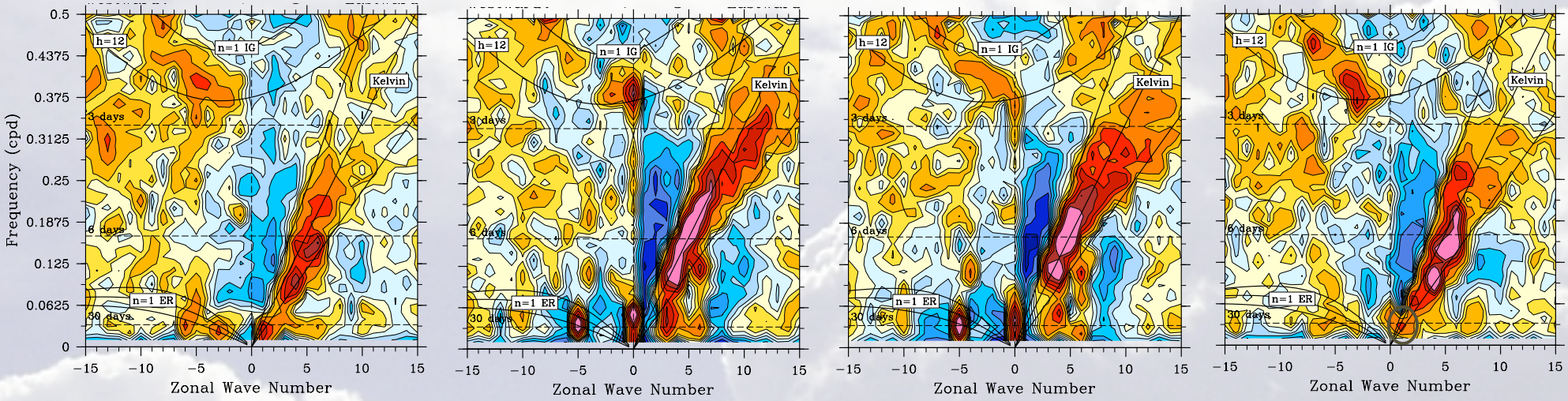


Sensitivity to Zonally Homogenized Water Vapor

- **Zonal Homogenization: Nudge (relax) water vapor to zonally averaged values over <u>diurnal</u> time scale;**

OLR

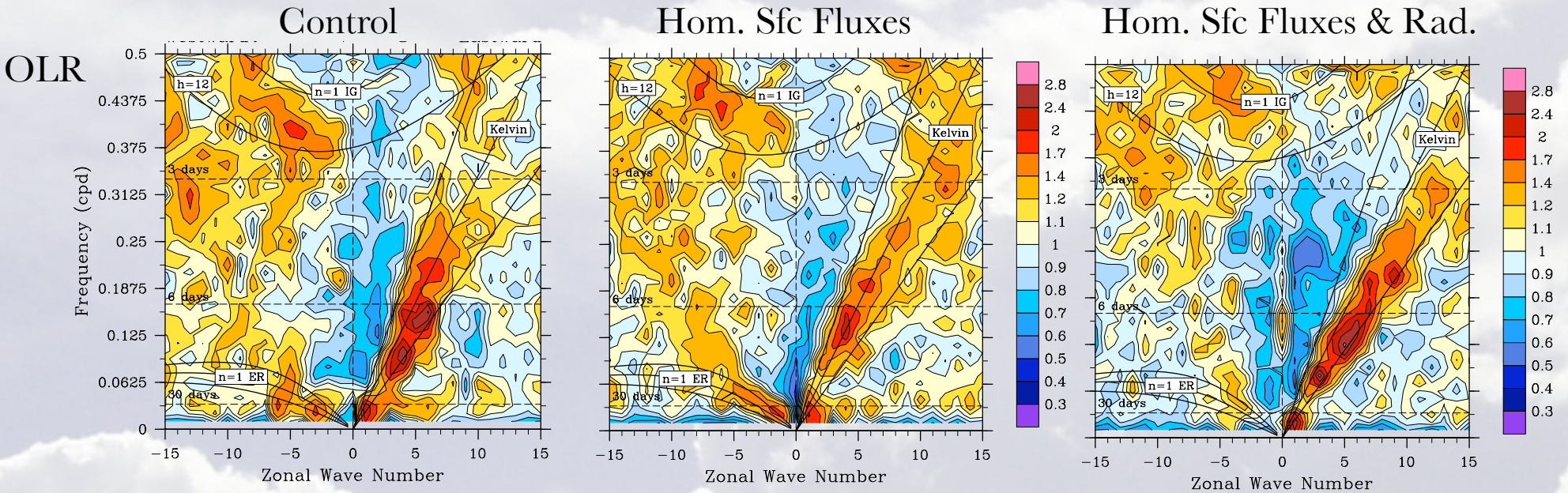
Control | Hom. all levels | Hom. above 850mb | Hom. above 400mb



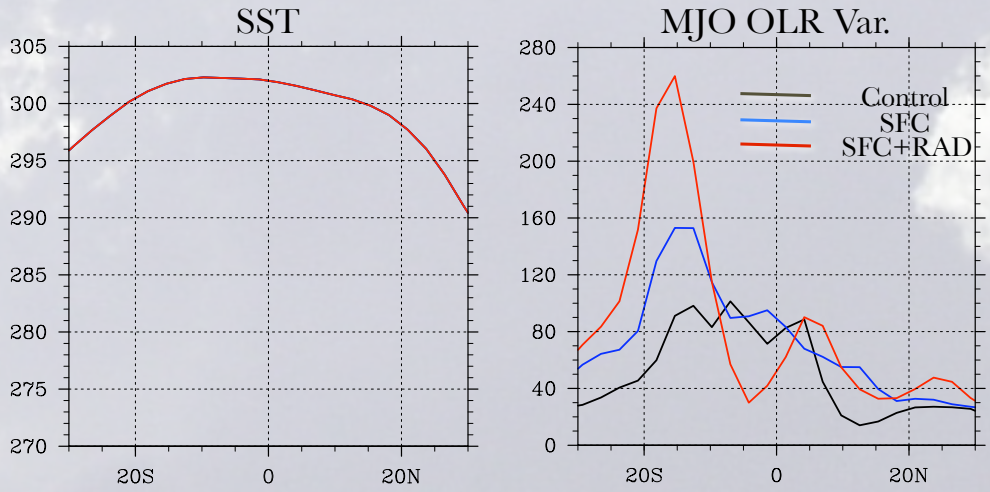
- **The existence of mid-to-low troposphere (but above PBL) water-vapor anomalies is the key for the existence of simulated MJO.**

Sensitivity to Zonally Homogenized Surface fluxes and Radiative Heating

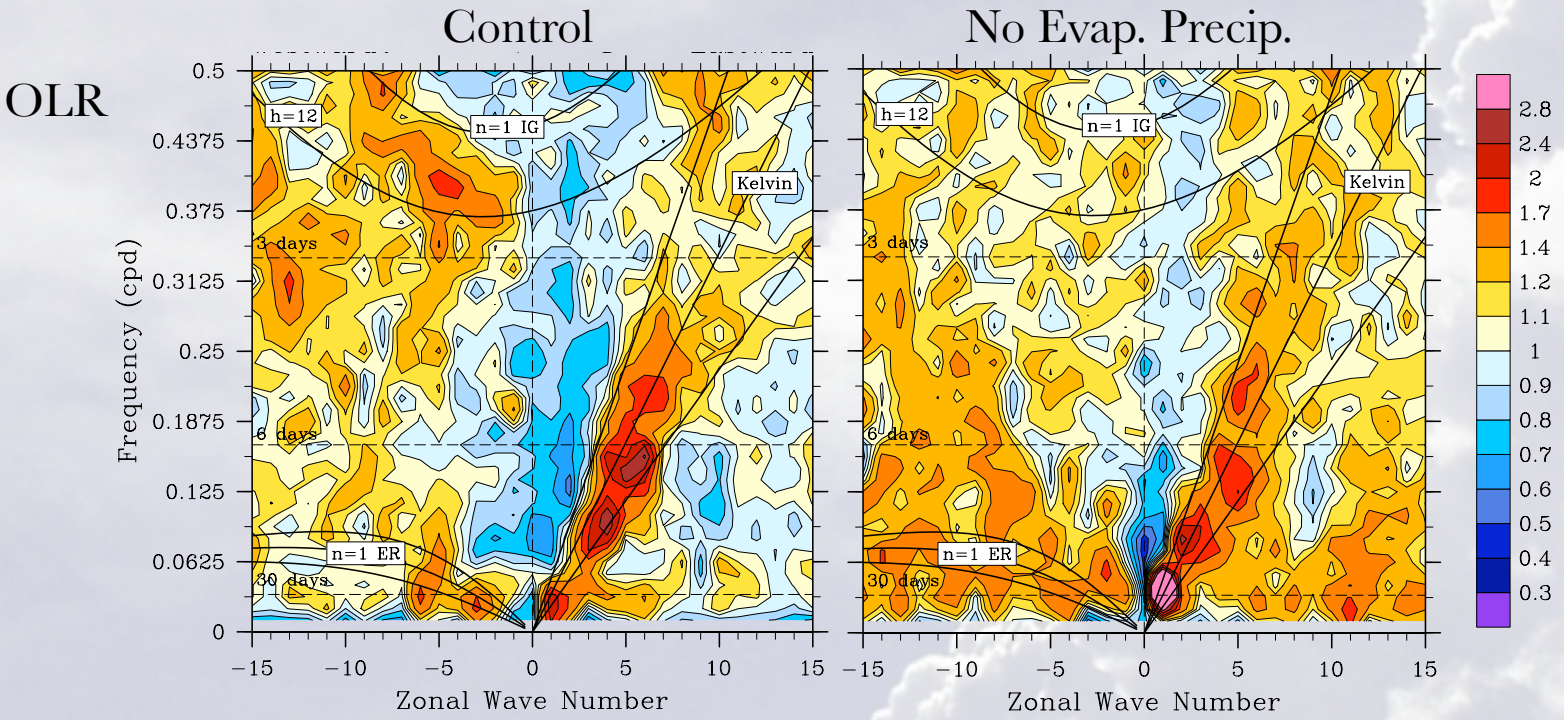
- **Zonal Homogenization: Compute surface fluxes and radiation heating rates as usual but apply them zonally averaged.**



- **Zonal variation of surface fluxes (incl. WISHE) and radiative heating doesn't seem to be essential for maintaining the simulated MJO;**



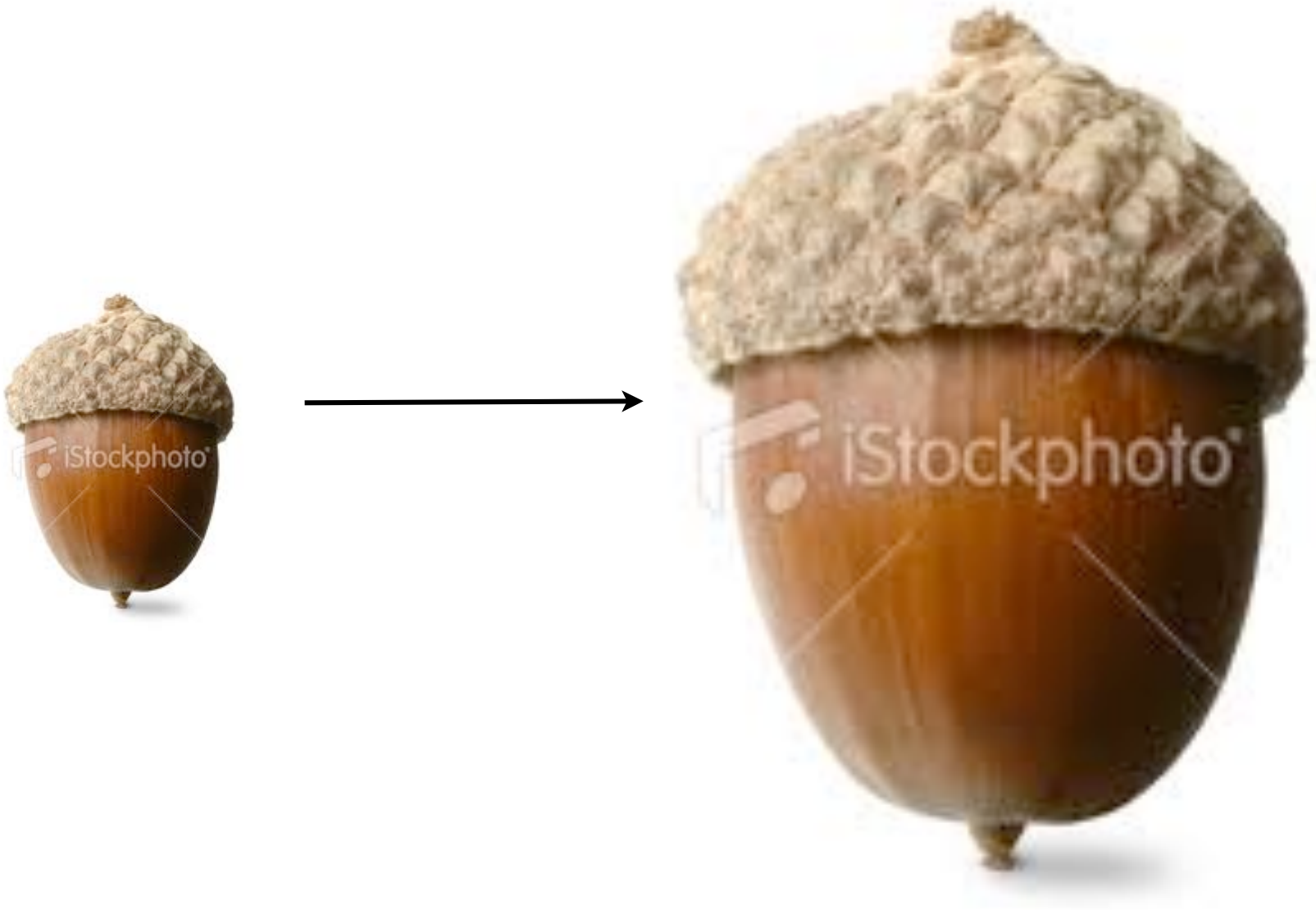
Shutting off Evaporation of Precipitation
(Basically, no stratiform-rain cooling mode)



- **MJO-like mode propagates as fast as the Kelvin-wave mode with pick of variability in the periods of about 30 days**

Nonlinear Reality

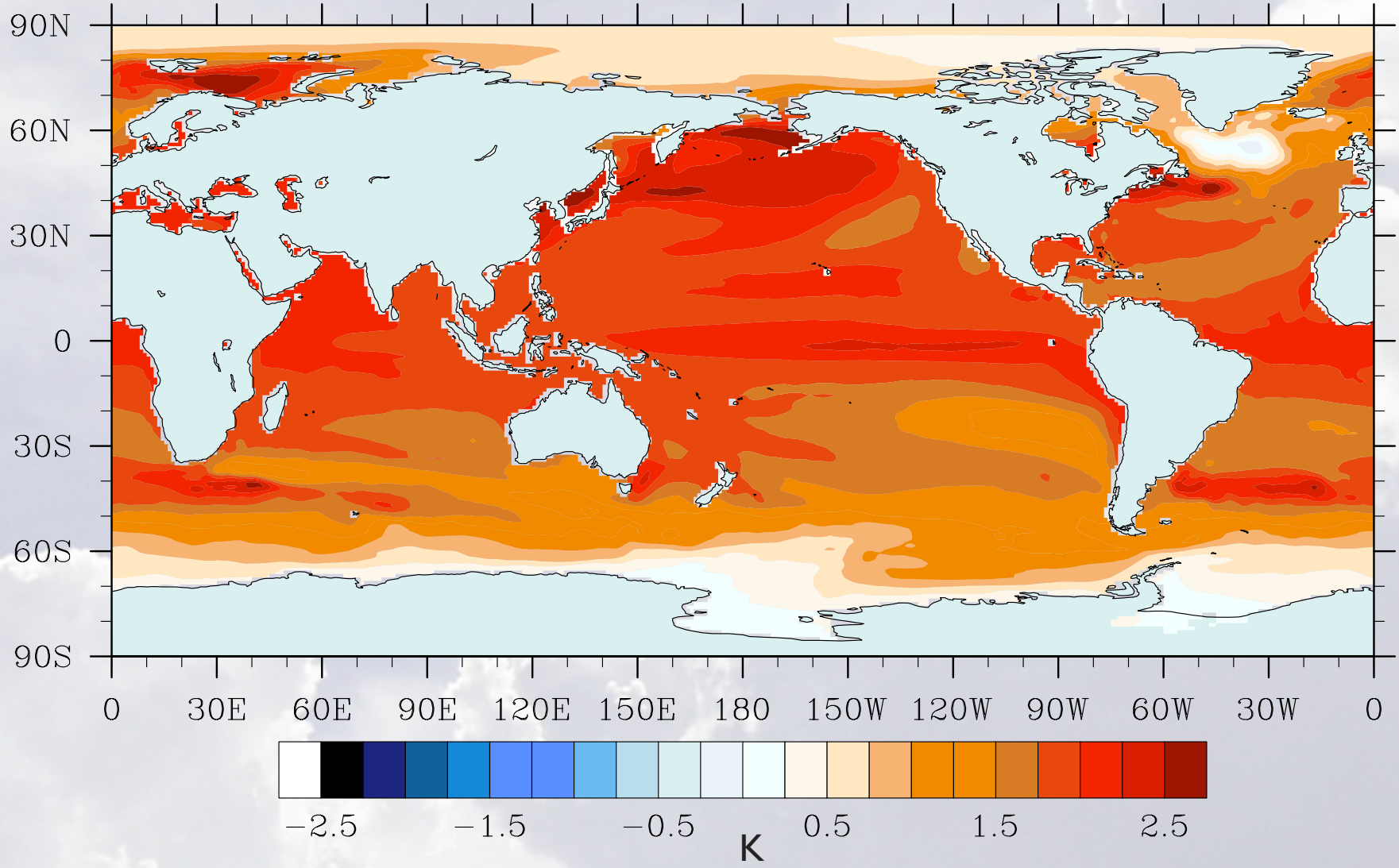
Linear Theory



ANN Composite AR4 Models SST A1B Anomaly

2090s - 2000s

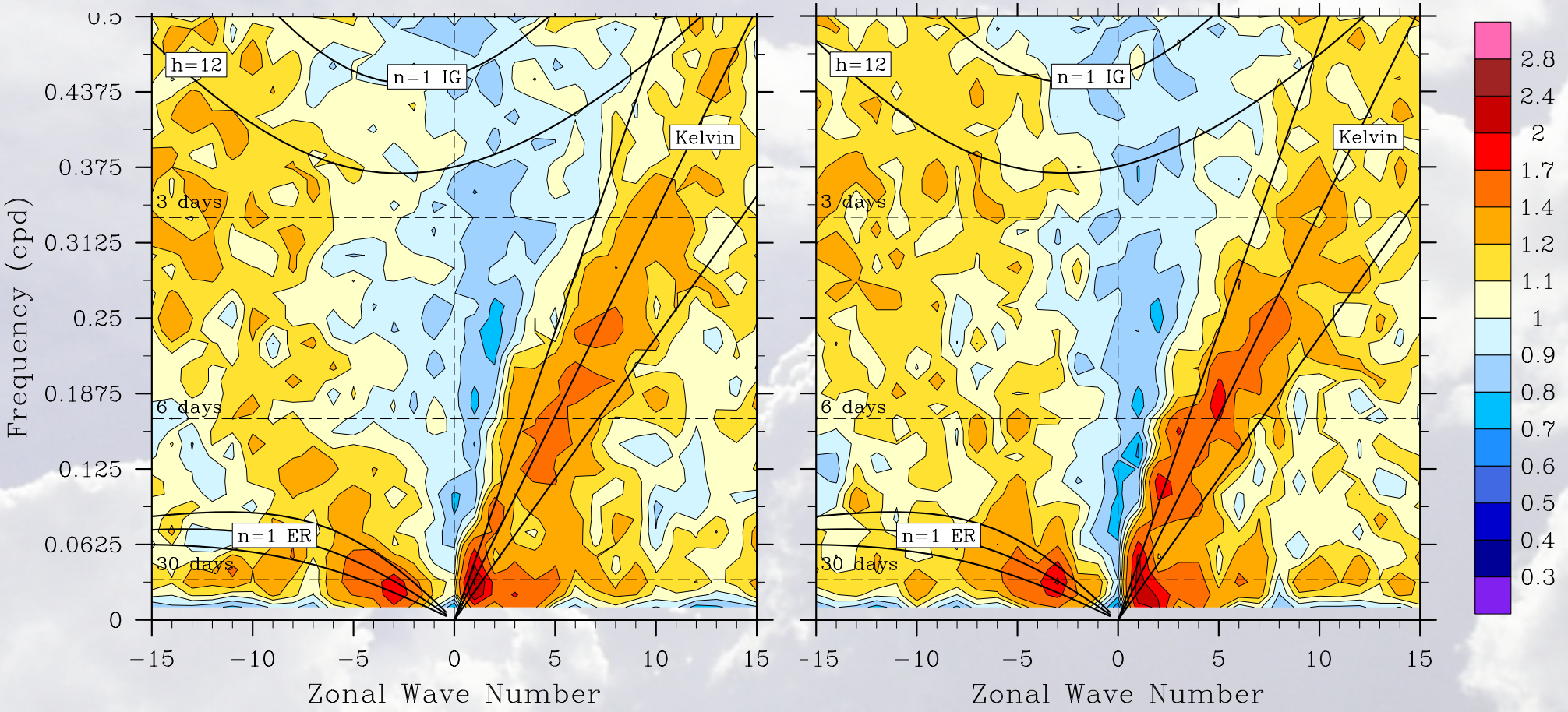
Model Bias substructed



SP-CAM Time-slice Simulation using Composite AR4 Models SST A1B Anomaly 2090s - 2000s

Present SSTs

A1B Future SSTs



MJO is projected to get stronger in the warming world

Take-home messages

Coupling to the ocean seems to be essential for realistic simulation of MJO in SP-CAM.

Mid-tropospheric moisture anomaly is necessary for simulated MJO.

Variations of the surface fluxes and radiation across the MJO scales don't seem to be essential for MJO maintainance.

Aqua-planer simulations suggest that MJO variability may increase in warmer climate.

The importance of CMT is not clear (SP-CAM does NOT have the CMT)