Multiscale modeling of clouds and process studies using CRM, CSRM, and MMF frameworks

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Knowledge to Go Places

Center for Multi-scale Modeling of Atmospheric Processes

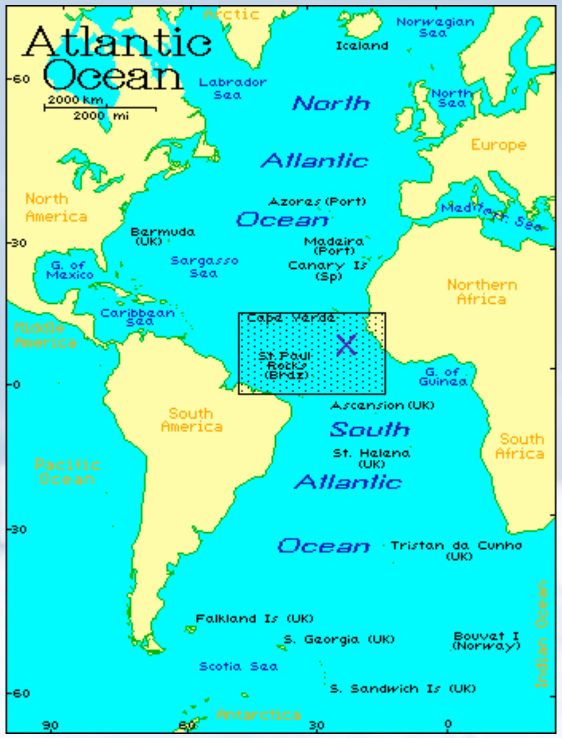
cmmap.colostate.edu

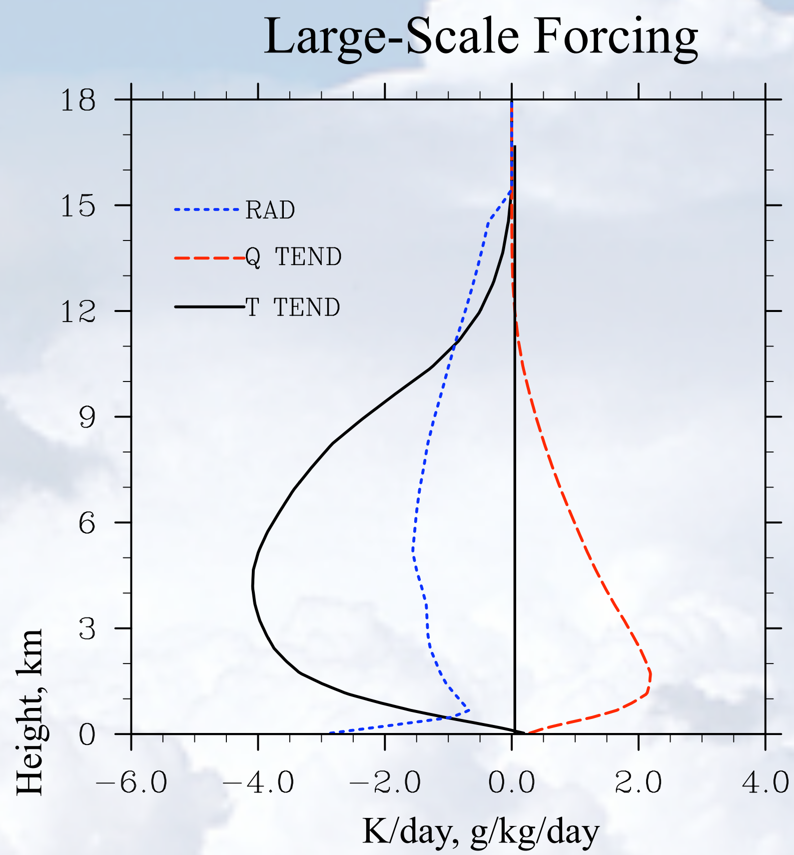
Director: **David Randall**

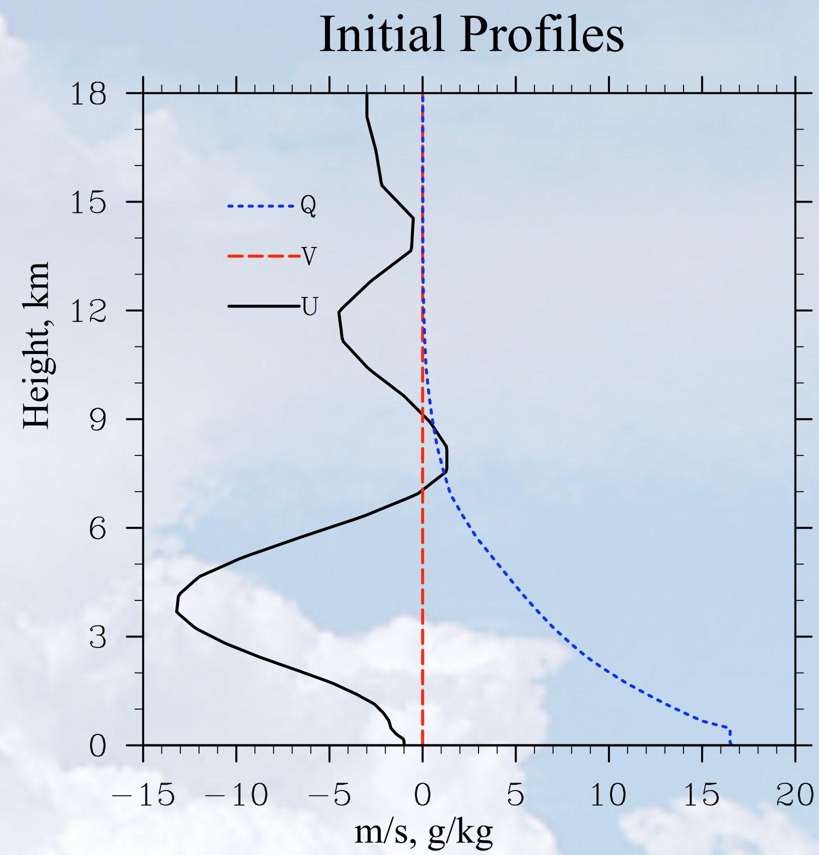
‘Benchmark’ LES of organization of convection on mesoscale

GATE Phase III Mean Conditions

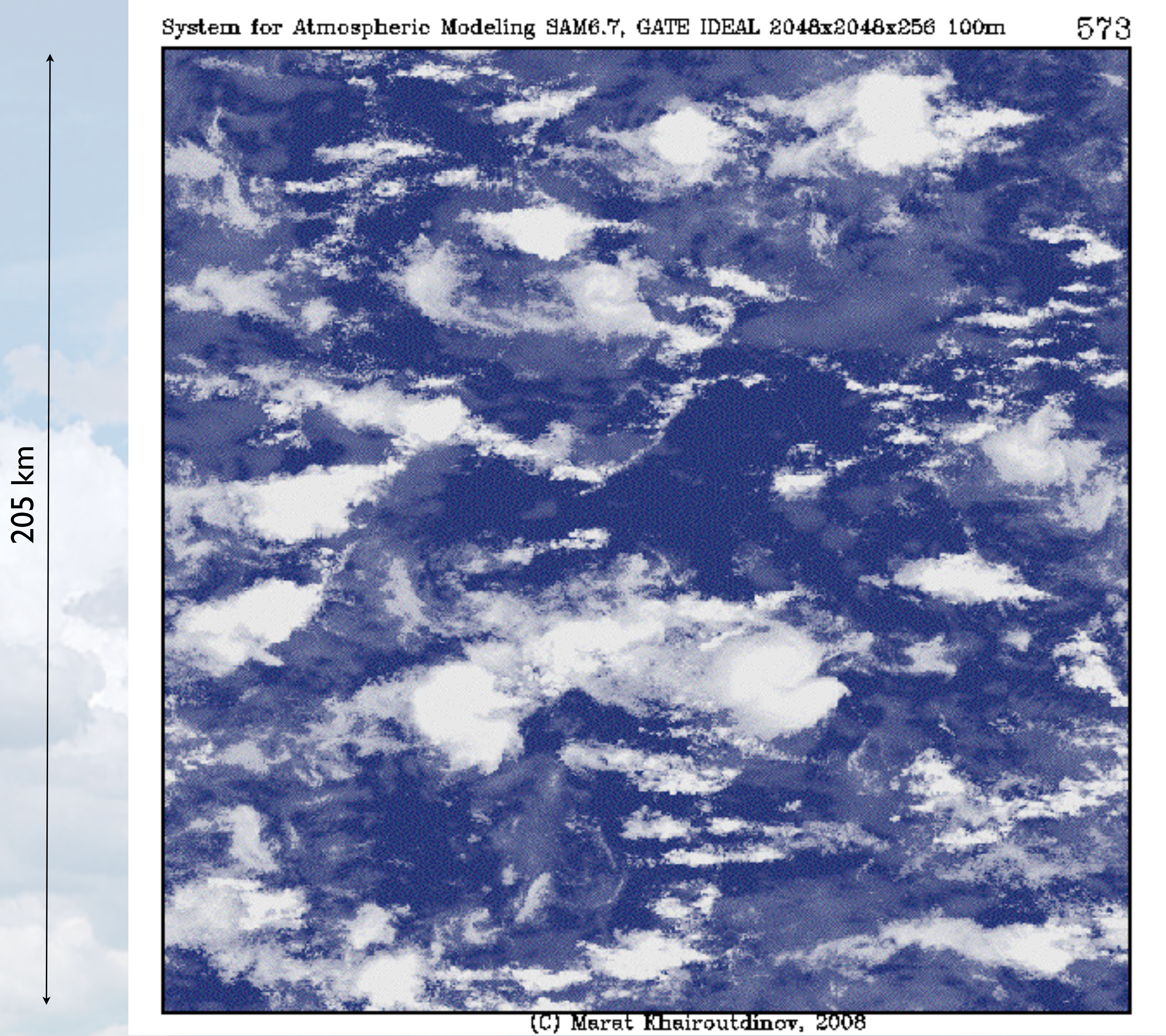
30 August - 19 September, 1974





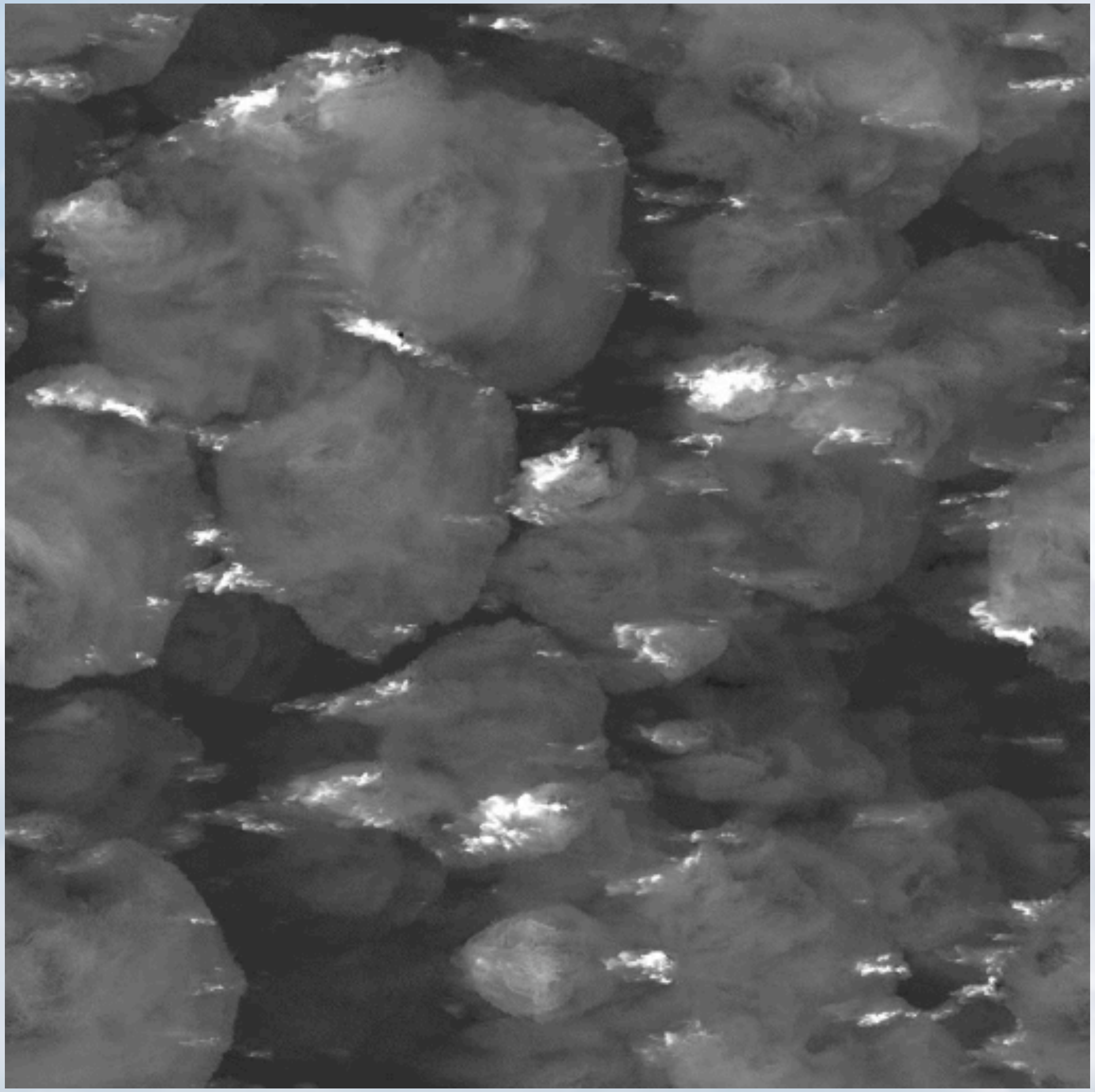


- System for Atmospheric Modeling, SAM 6.7;
    - Grid: 2048 x 2048 x 256, or 205 x 205 x 27 km3;
    - Horizontal res. 100m; periodical lateral boundaries;
    - Vert. res. 50m below 1km,50-100m @1-5km; 100m @5-18km; 100-300m above;
    - Time step 2 sec;
    - Initialization: Random small temperature noise at the lowest grid levels;
    - Durarion of run: 24 hours
    - 2048 processors; IBM BlueGene BG/L @BNL;

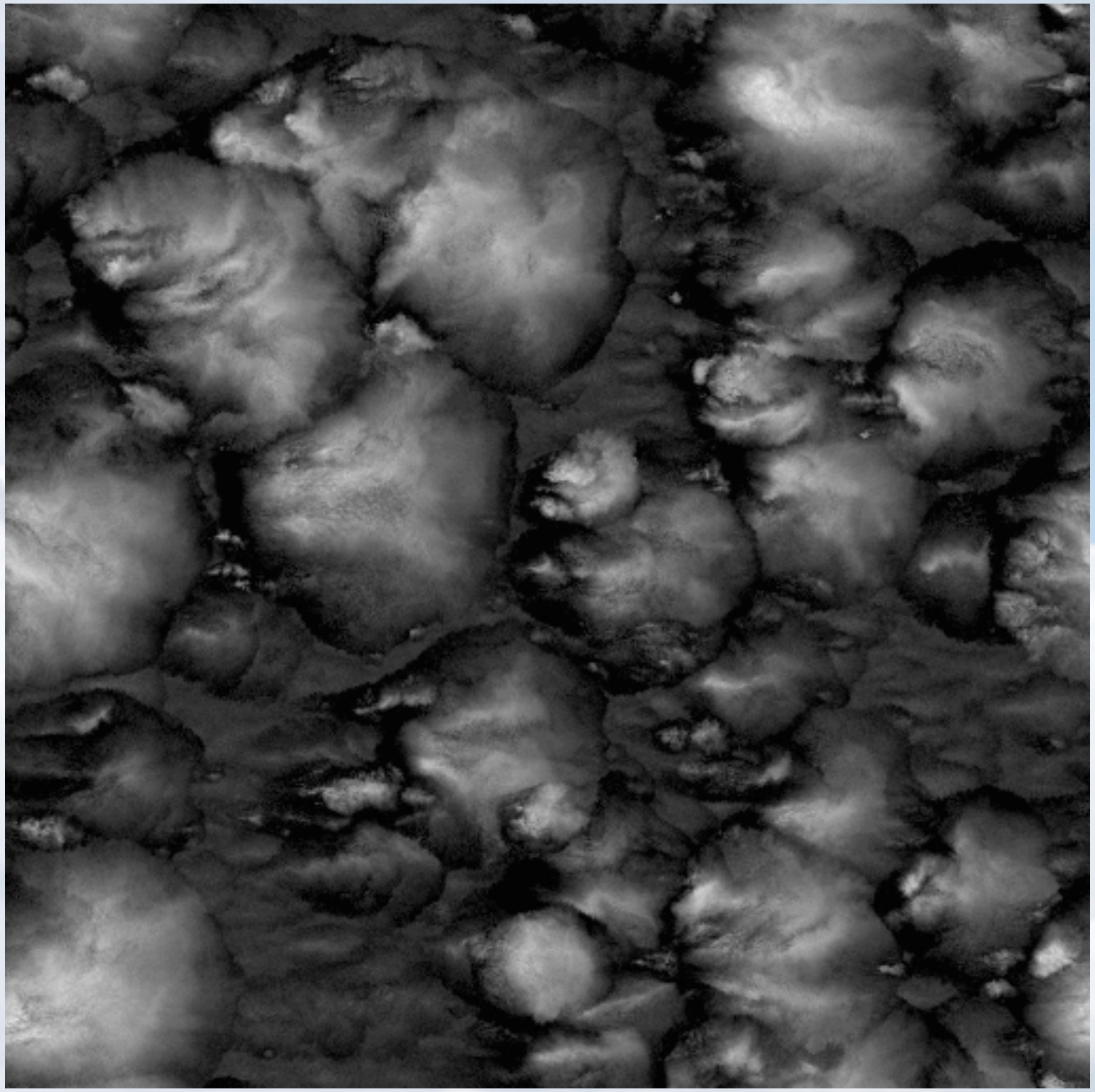


System for Atmospheric Modeling SAM6.7, GATE IDEAL 2048x2048x256 100m
573
(C) Marat Khairoutdinov, 2008
205 km

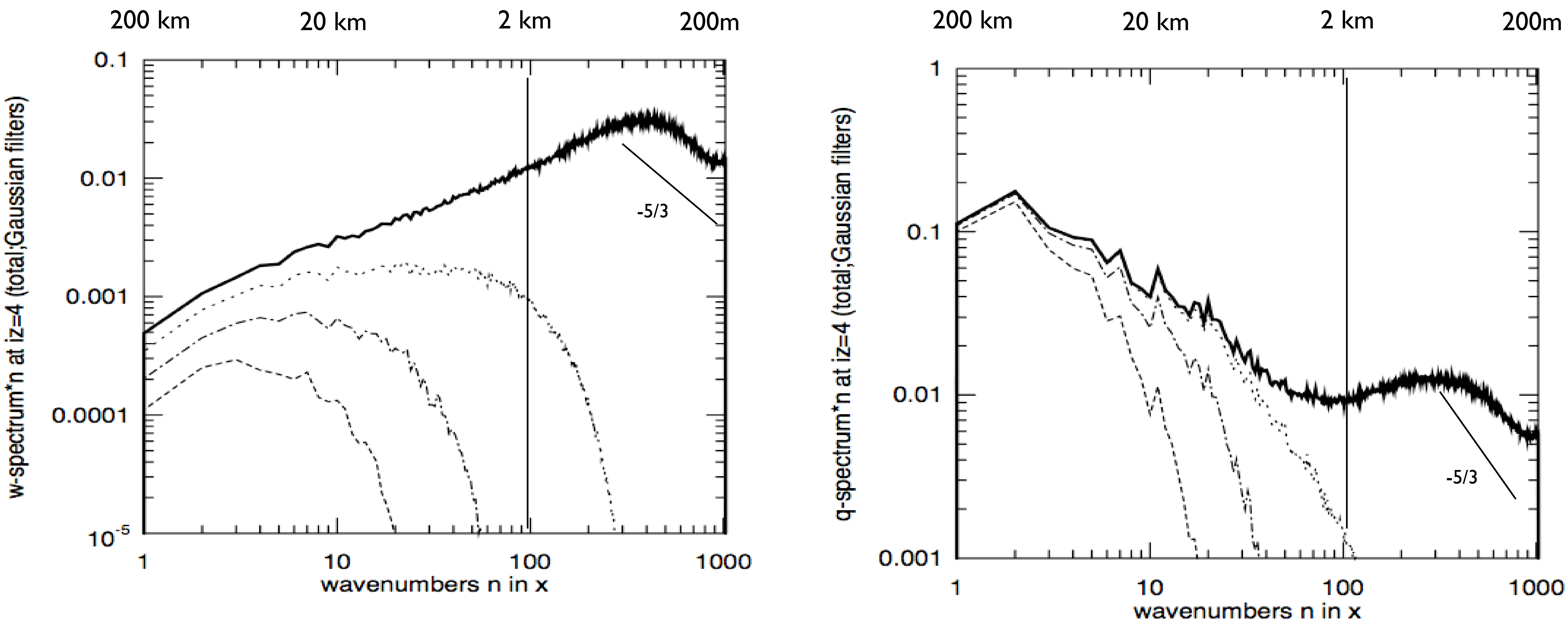
liquid/ice water static energy near the surface



water vapor near the surface

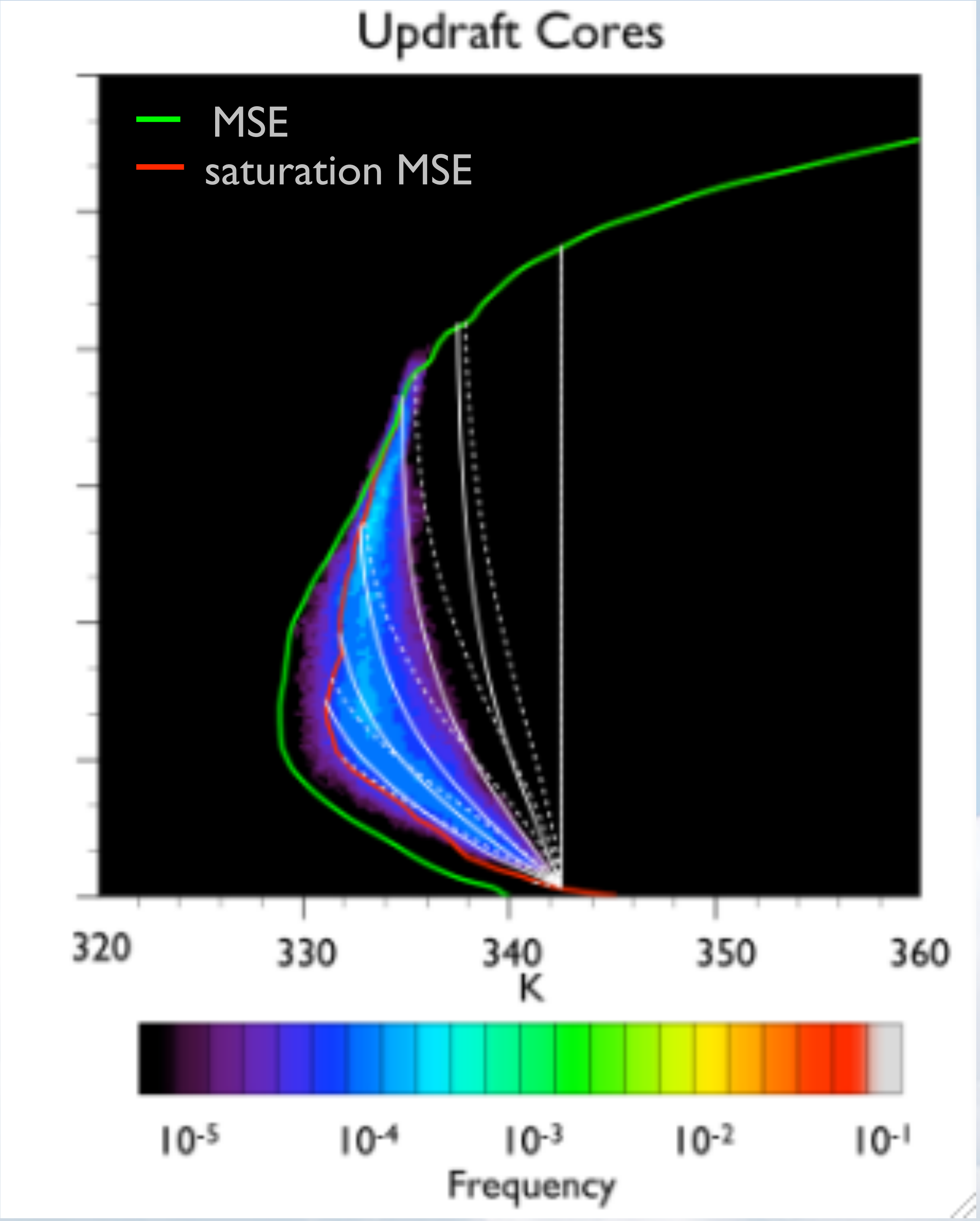


w-spectra   z=200m   q-spectra

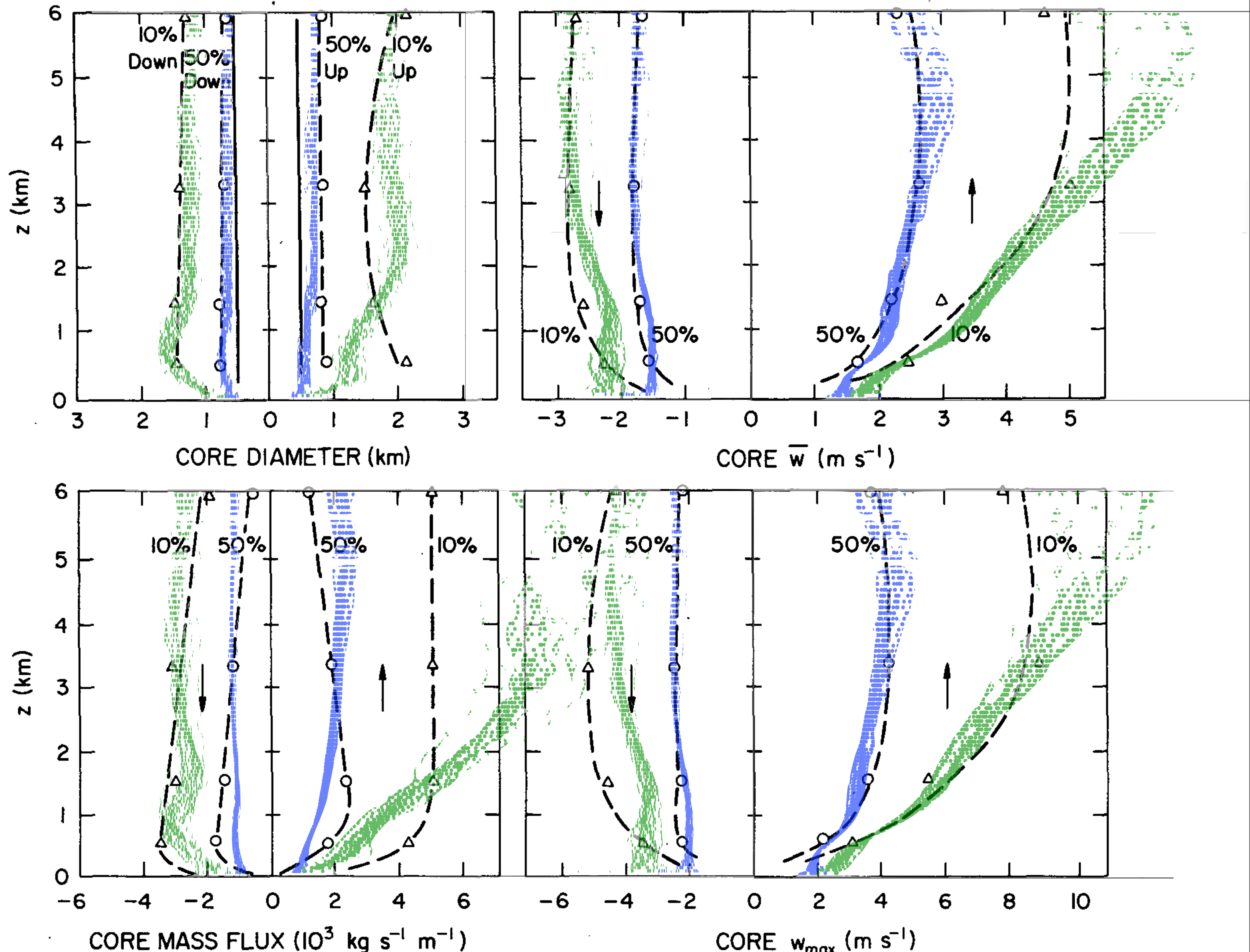


No filter
Gaussian filter with Δ=1km
Gaussian filter with Δ=4km
Gaussian filter with Δ=10km

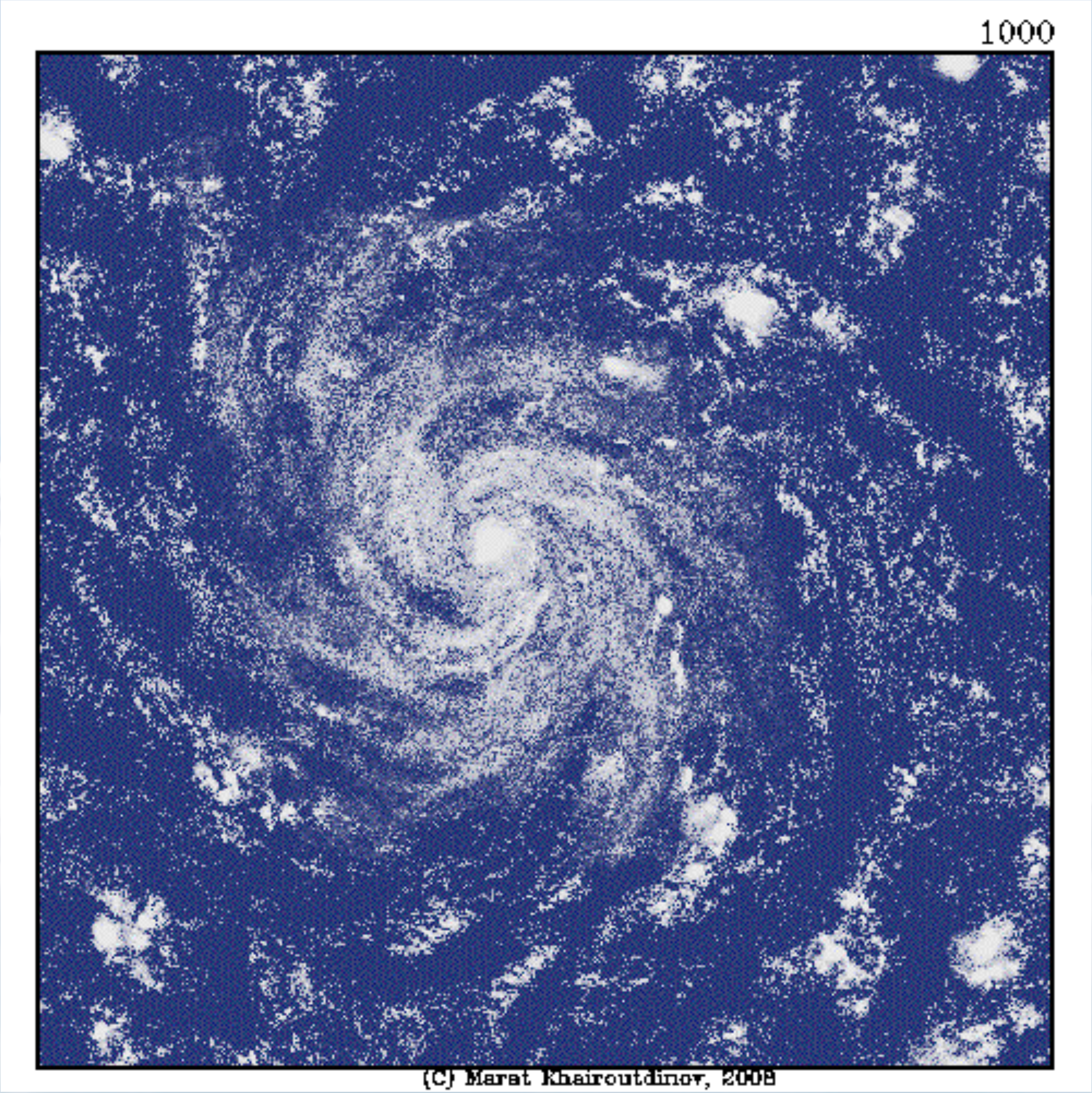
From C.-H. Moeng

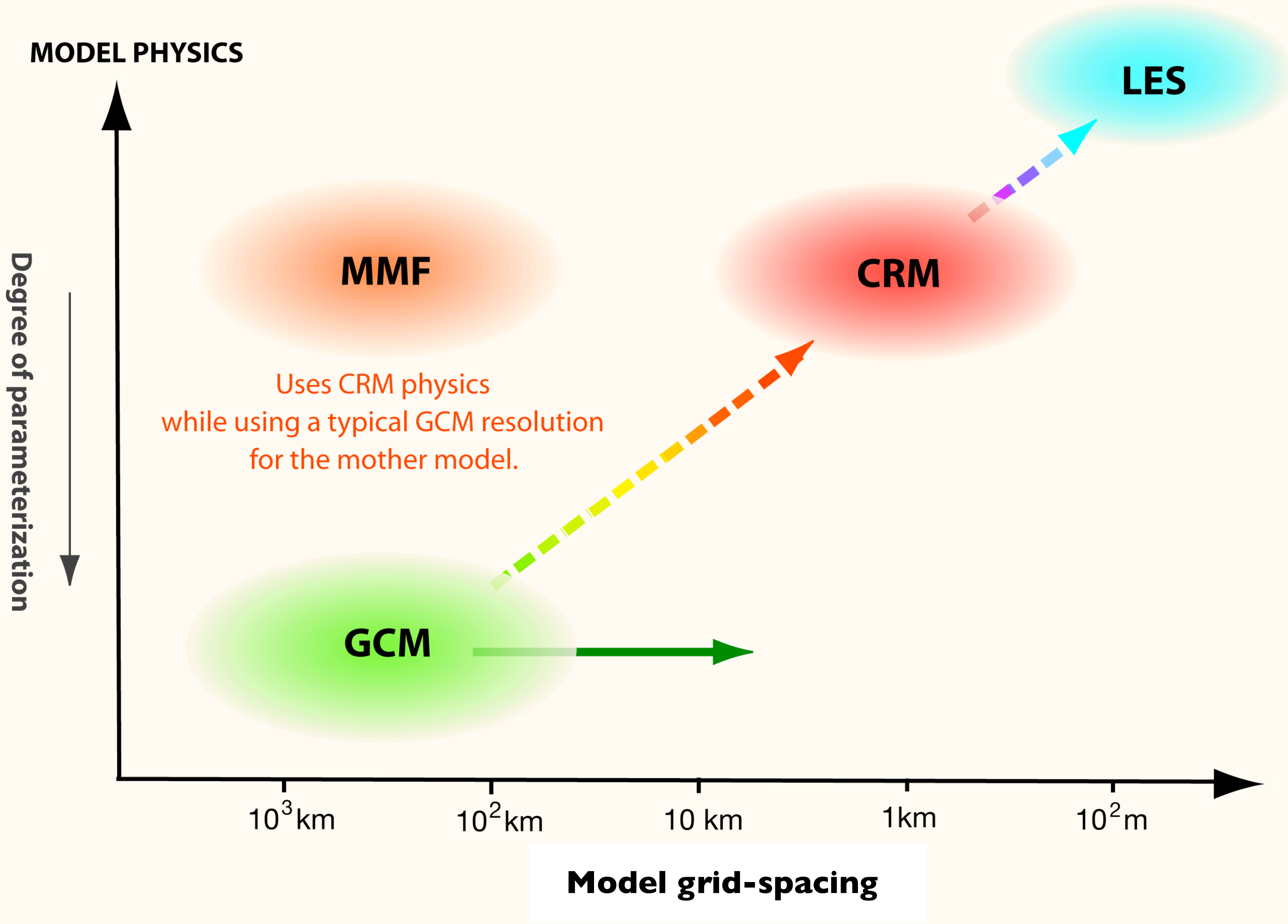

Updraft Cores
MSE
saturation MSE
320
330
340
350
360
K
10-5
10-4
10-3
10-2
10-1
Frequency

Comparison against LeMone & Zipser GATE aircraft core statistics From Steve Krueger, U. Utah



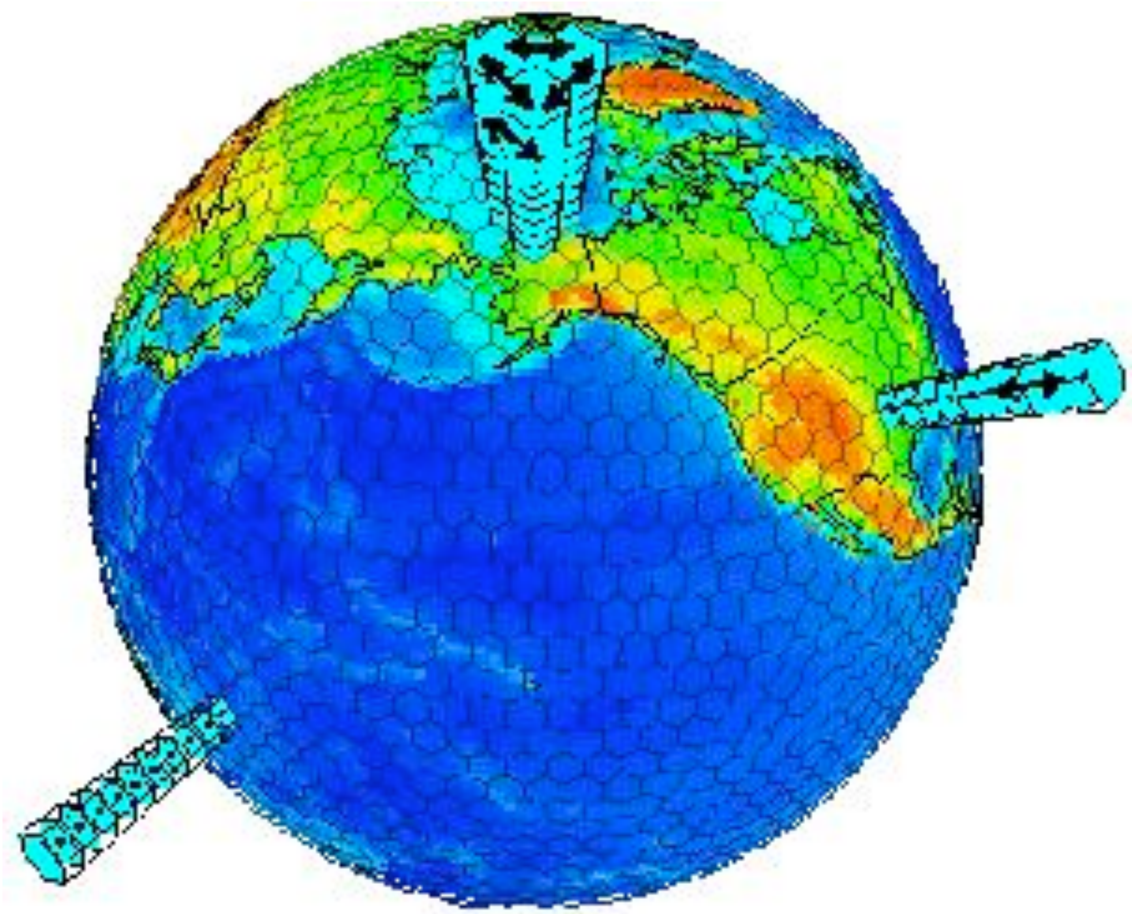
Idealized TC intensification





MODEL PHYSICS
Degree of parameterization
LES
MMF
CRM
Uses CRM physics
while using a typical GCM resolution
for the mother model.
GCM
10^3km
10^2km
10 km
1km
10^2m
Model grid-spacing

The root of MMF is in Single-Column Modeling



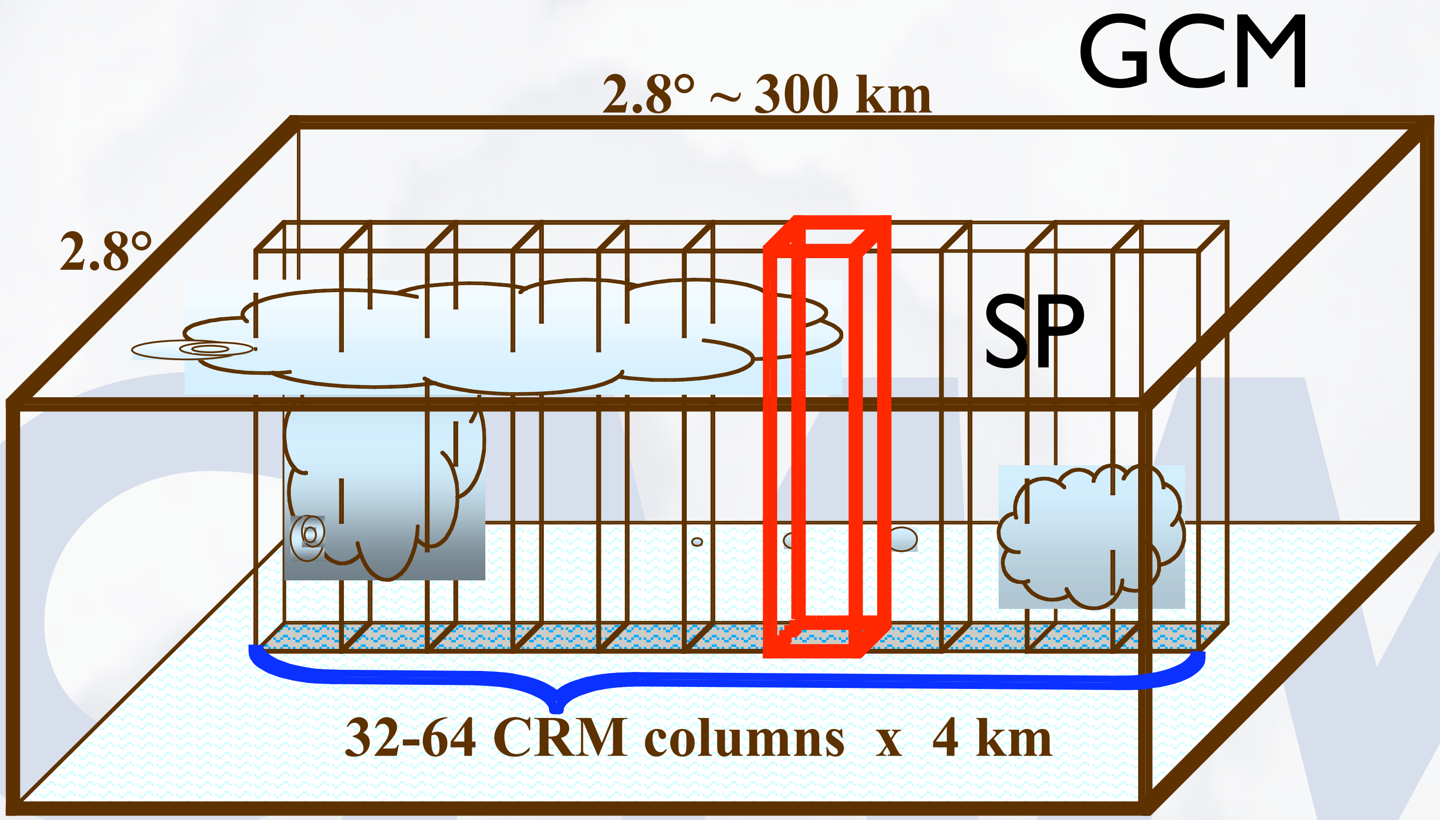
$$\frac{\partial \bar{s}}{\partial t} = \underbrace{-\overline{\nabla s V} - \frac{\partial \bar{s}\bar{\omega}}{\partial p}}_{LSForcing} + \underbrace{Q_1}_{Param's}$$

$$\frac{\partial \bar{q}}{\partial t} = \underbrace{-\overline{\nabla q V} - \frac{\partial \bar{q}\bar{\omega}}{\partial p}}_{LSForcing} - \underbrace{Q_2/L}_{Param's}$$

Traditionally, the large-scale forcing data would come from observations (GATE, TOGA, ARM, KWAJEX, etc.)

In MMF approach, large-scale forcing for each grid-*column* is explicitly computed by a GCM

Prototype MMF Approach:



SP forcing:

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

SP Source/Sink:

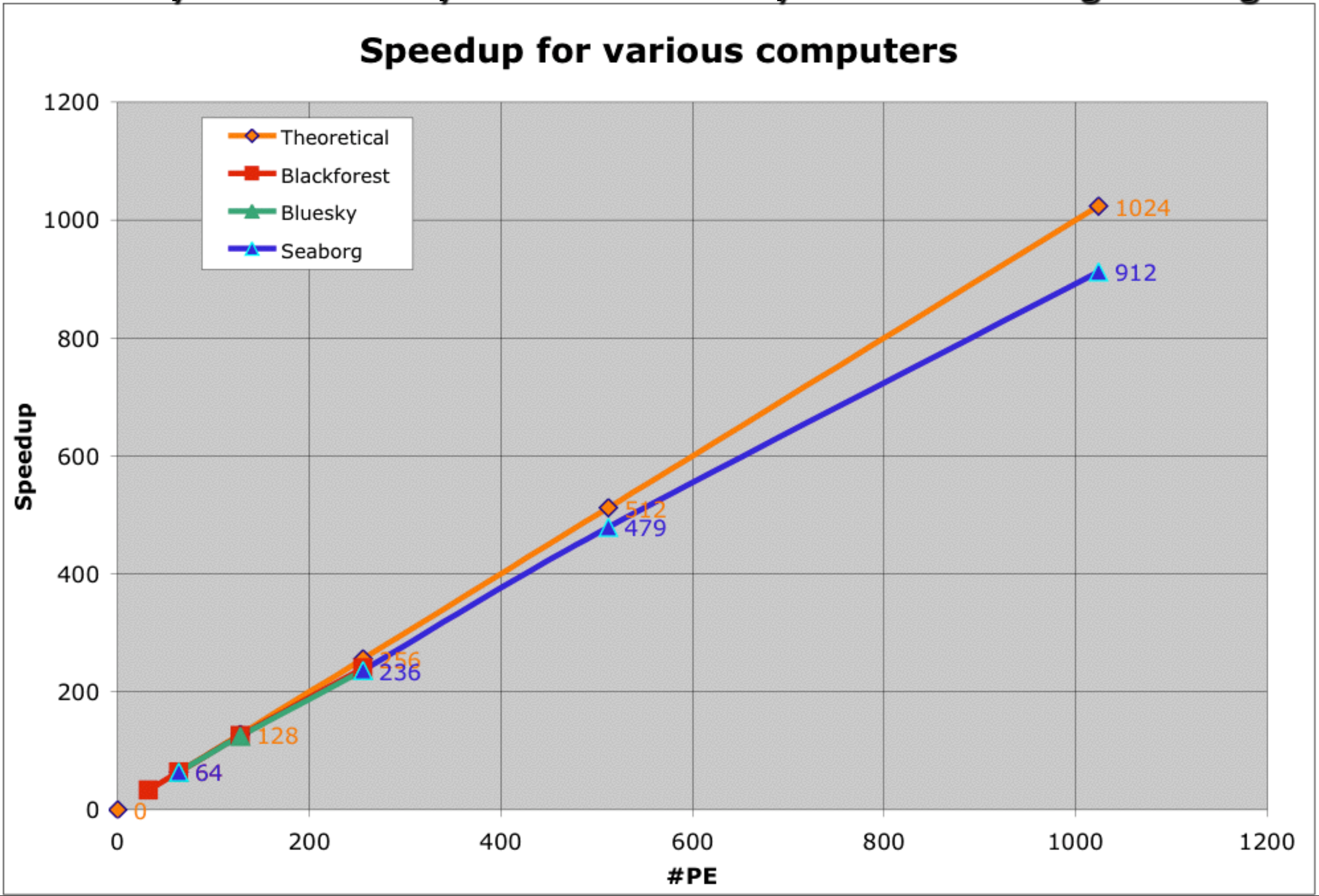
$$Q_n = \frac{\overline{\phi}^{n+1} - \overline{\phi}^{*}}{\Delta t}$$

- Works only for two-level GCM time schemes.

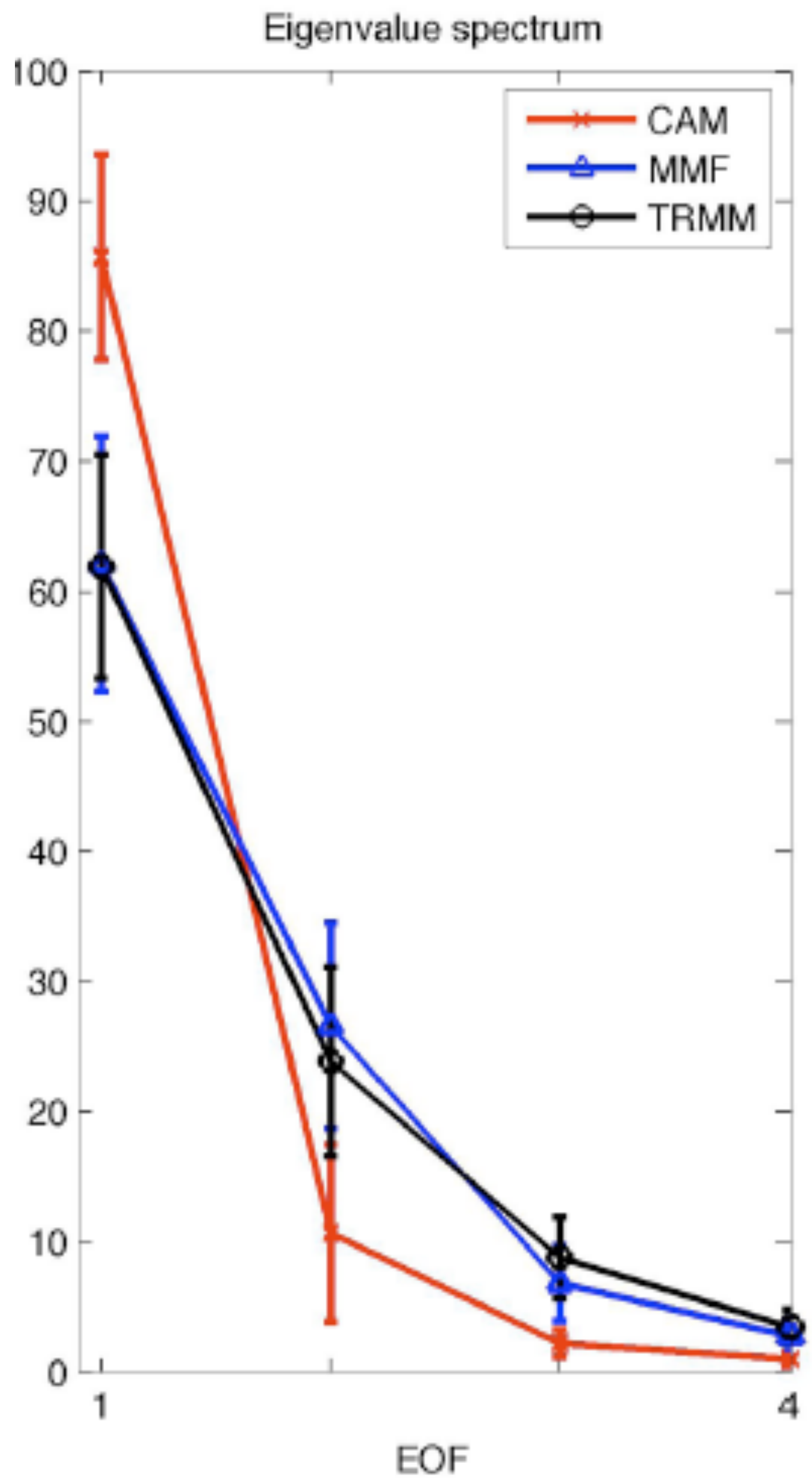
- GCM horizontal grid is not known to SP; consequently
  - ⋆SPs run independently from each other (great parallelism!)
  - ⋆SP should have periodical domain
  - ⋆LS Forcing is applied horizontally uniform
  - ⋆SP domain size is not generally determined by GCM grid size

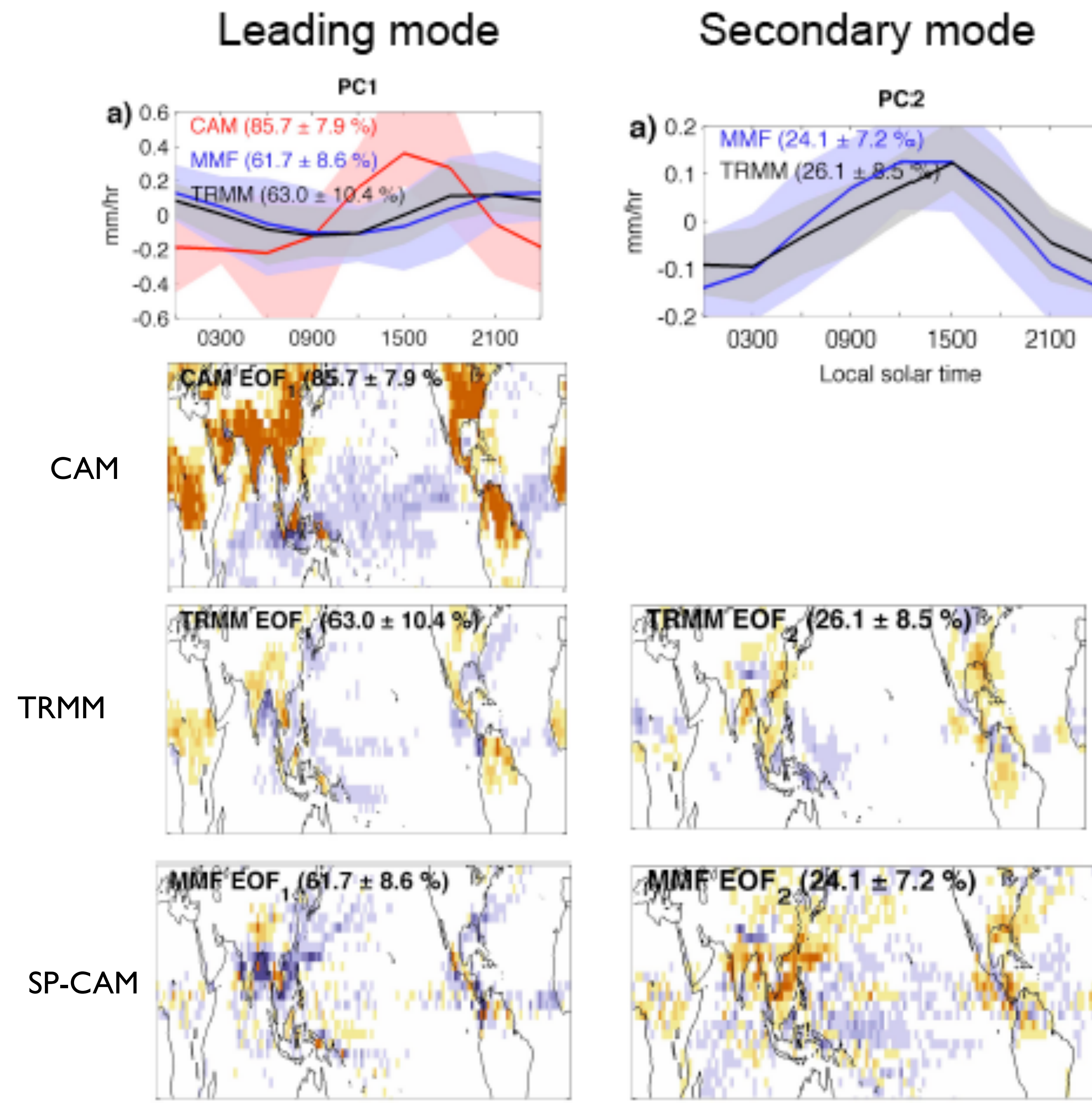
MMF is 100-200 times slower than the CAM when run on the same number of processors. However, due to very small portion of time spent on inter-processor communications, MMF can run on about 10 times more processors just as efficiently.

It currently takes one day to simulate one year on 2.8x2.8 grid using 1024 PEs.



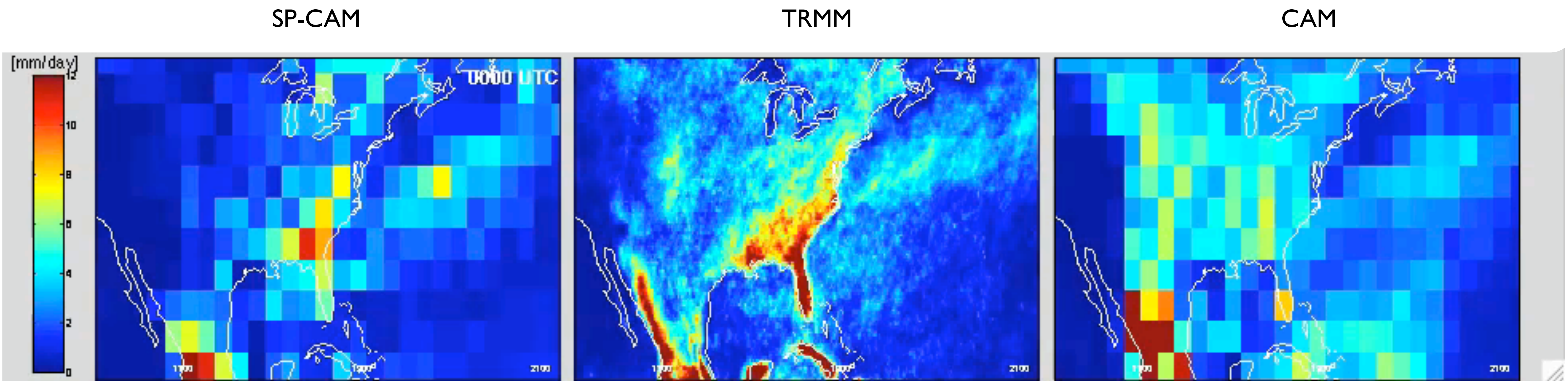
Diurnal Cycle of Precipitation: EOFs





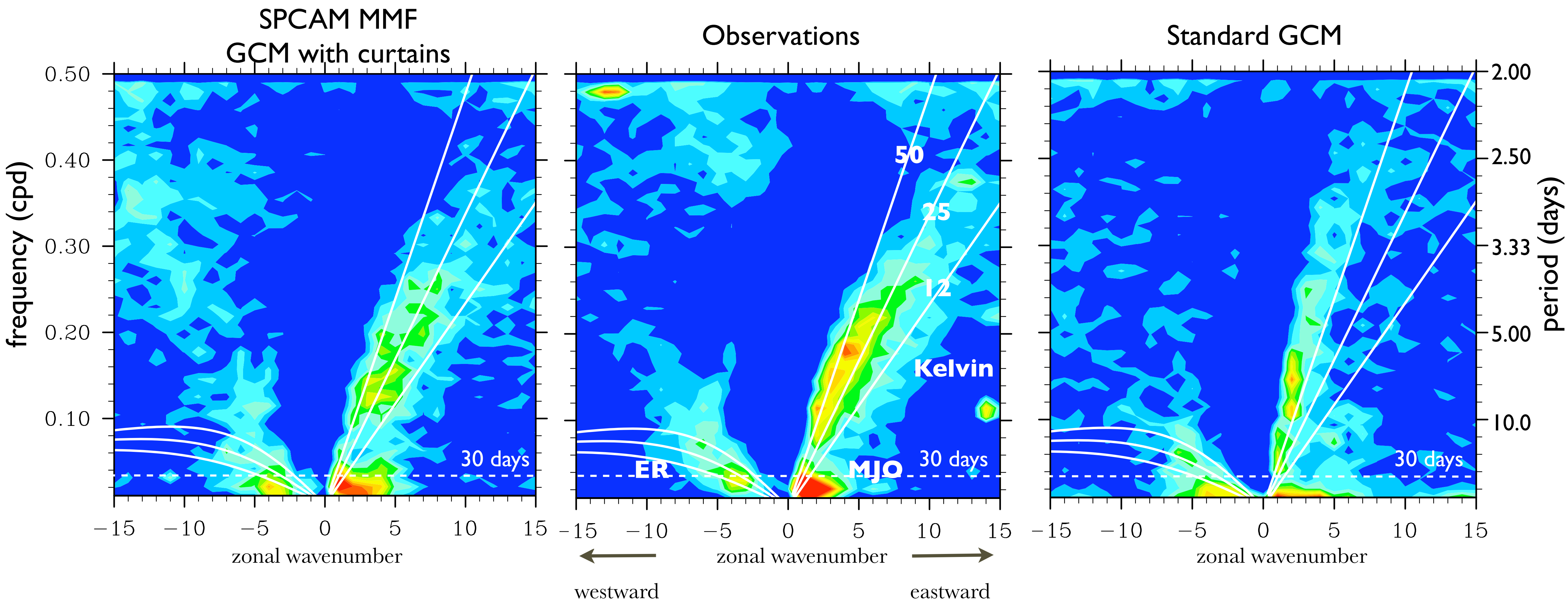
from Michael Pritchard (Scripps, UCSD)

Composite Diurnal Cycle of Precipitation: North America



from Michael Pritchard (Scripps, UCSD)

Simulated sub seasonal tropical variability
OLR

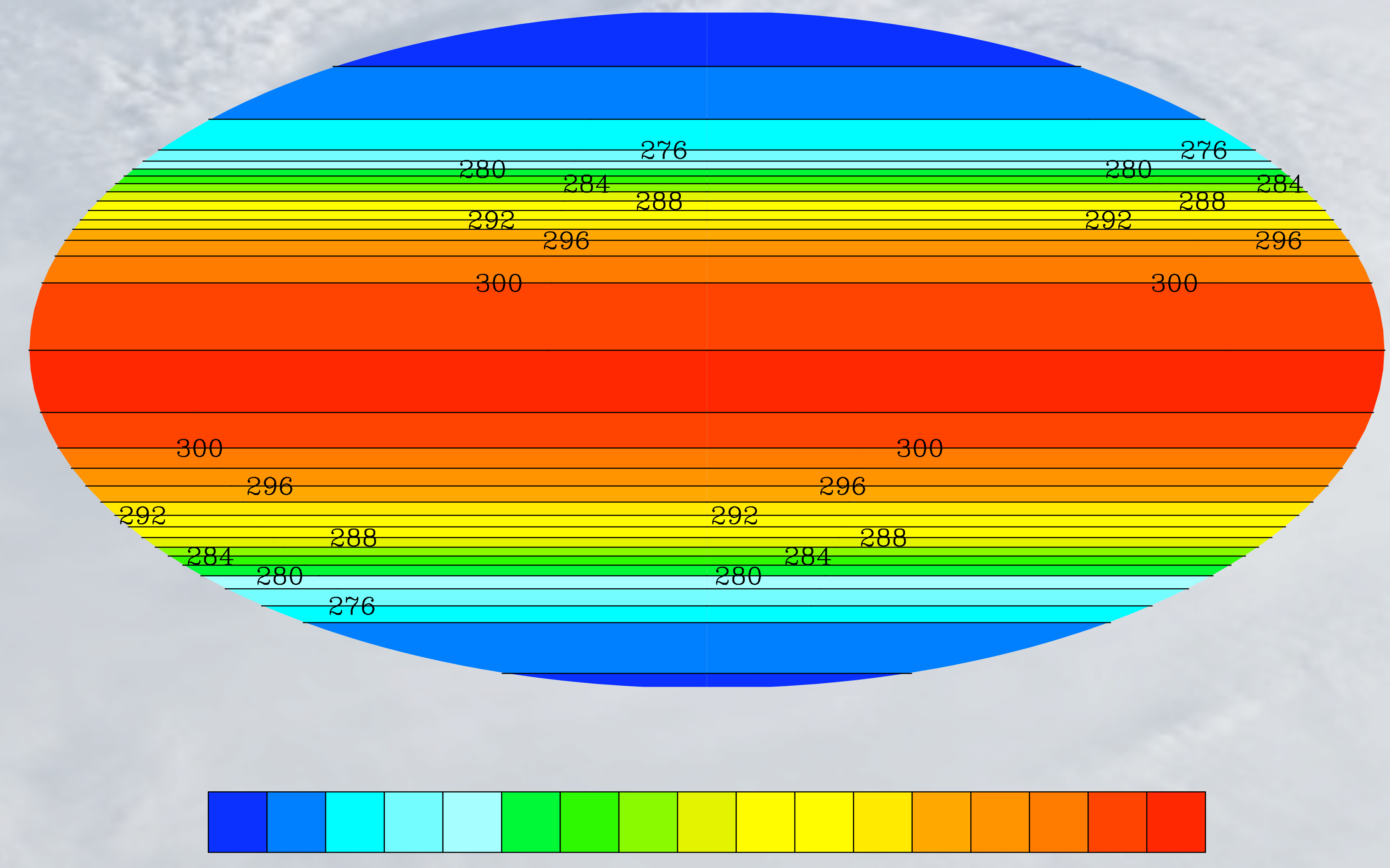


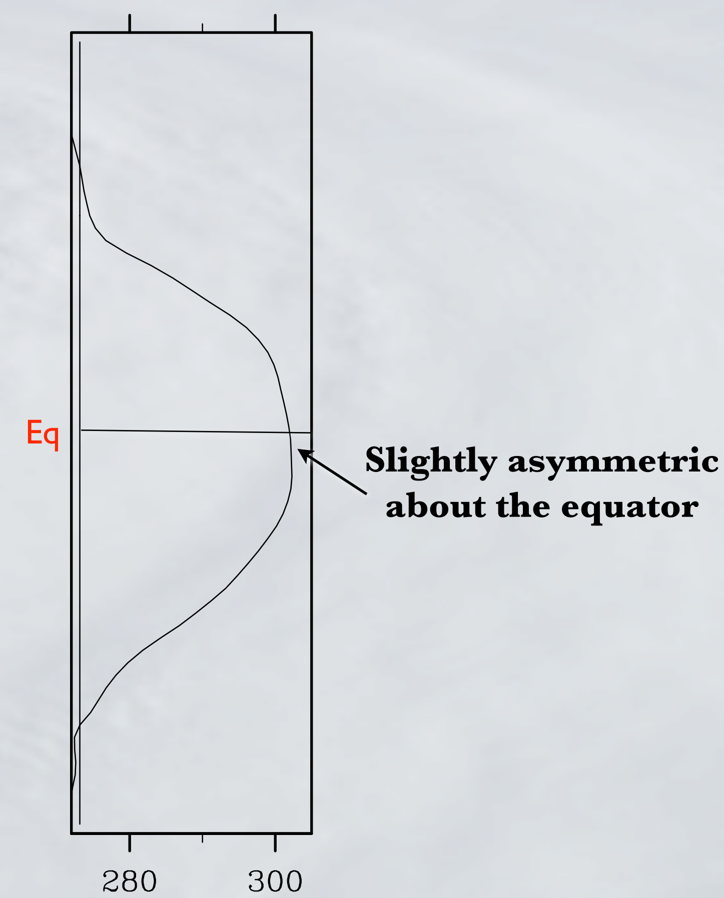
MJO on Aquaplanet/Water World

Why Aquaplanet? Simplicity!

- no polar ice, no land/soil/terrain complications
- heat and vapor fluxes over water - we know how
- zonally symmetric (zonal means direction of latitude circle)
- perpetual equinox - no seasons
- Mean climate resembles the Earth's
- Still has MJO and main equatorial waves

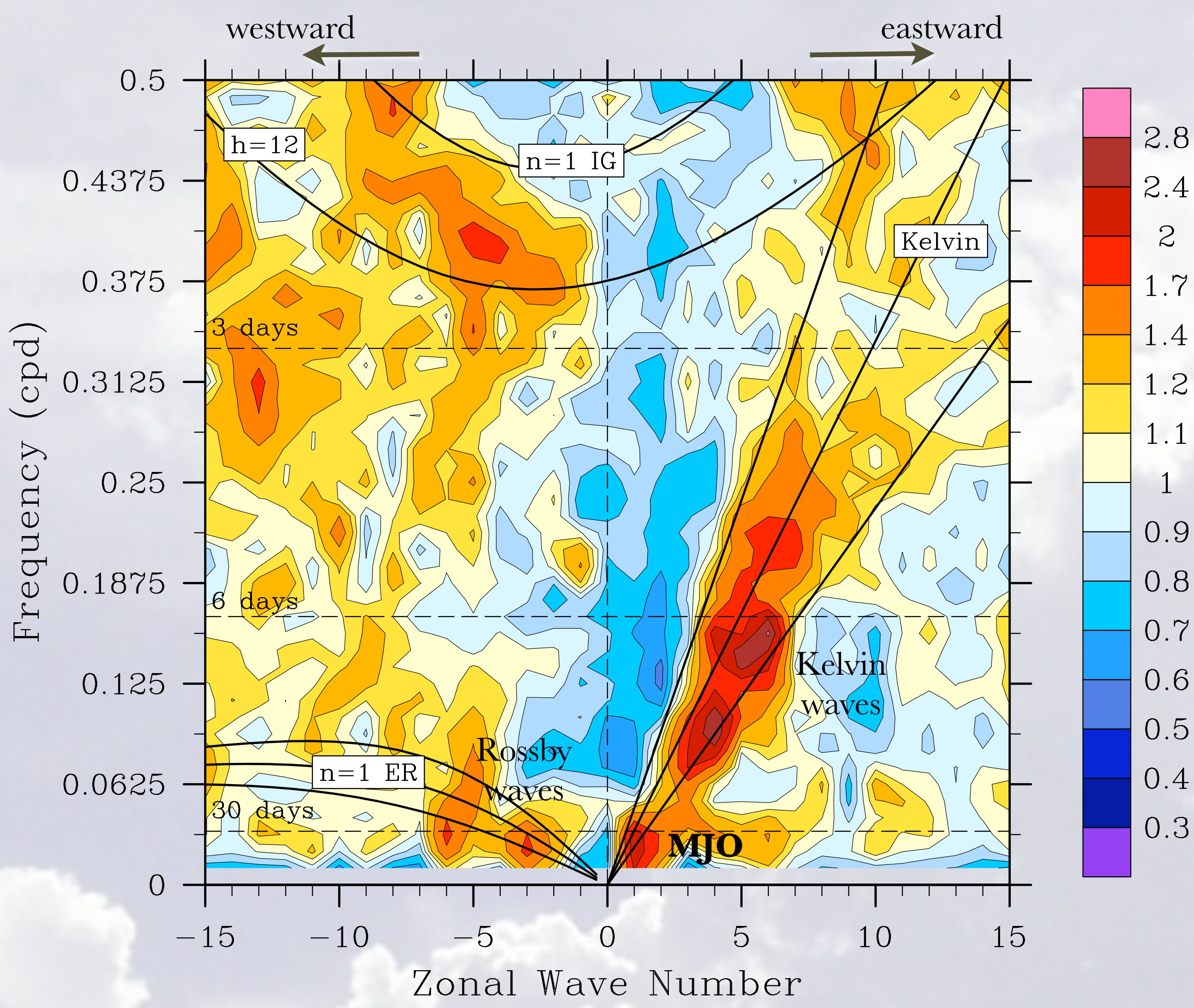
Sea Surface Temperature (prescribed)



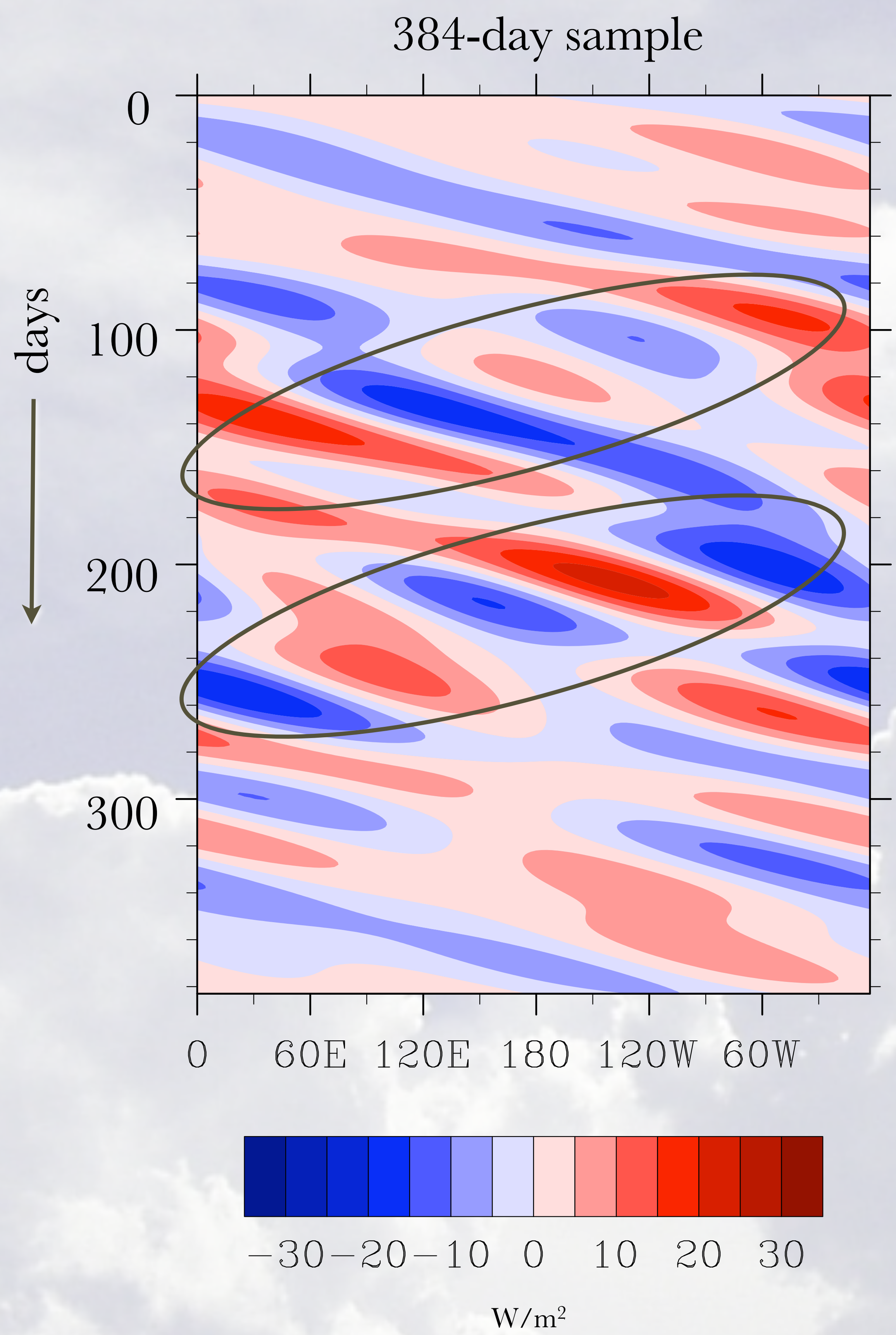


Simulated tropical variability on Aquaplanet looks similar to subseasonal tropical variability on Earth

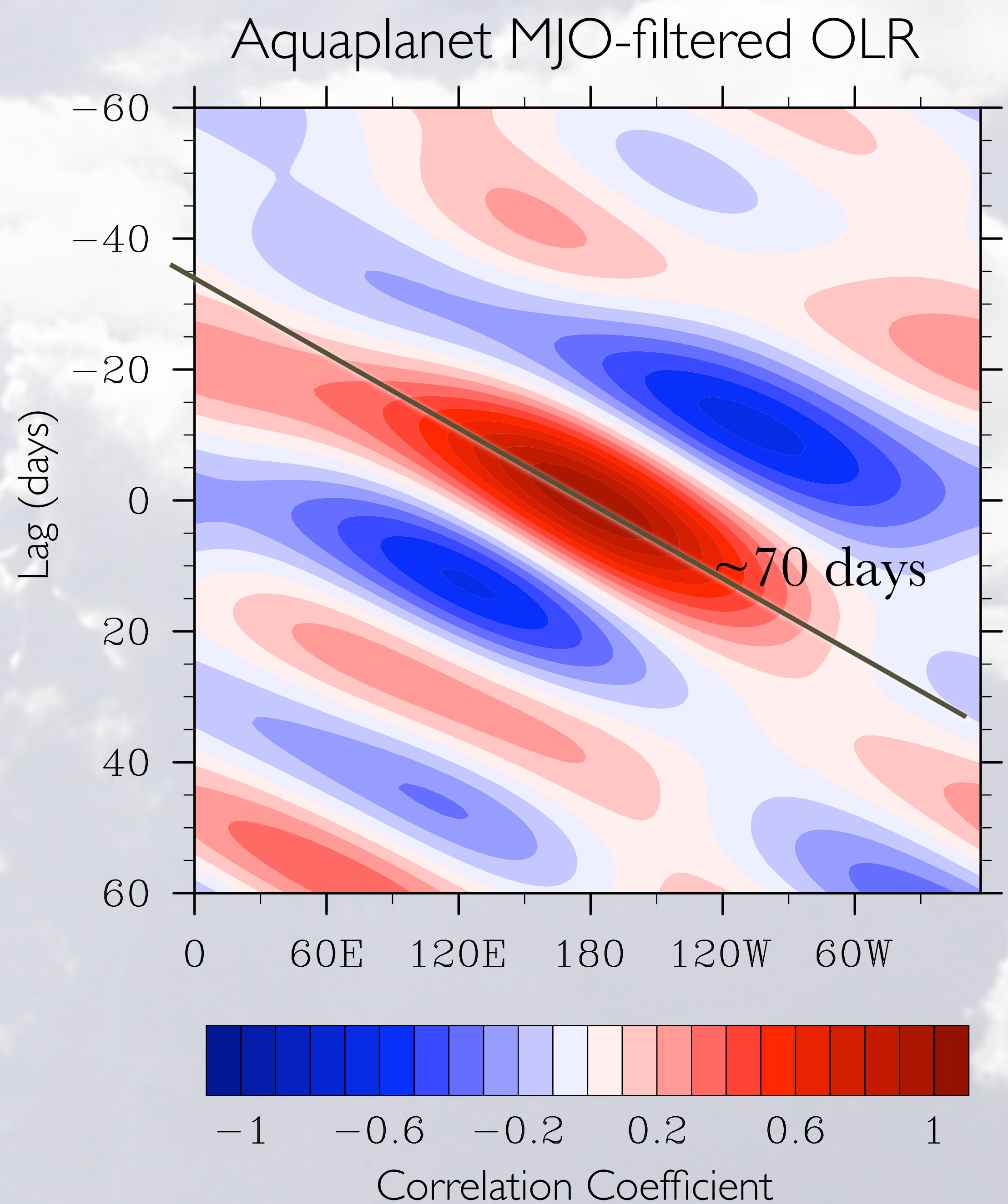
OLR



MJO forms 'wave packets' on Aquaplanet



Text

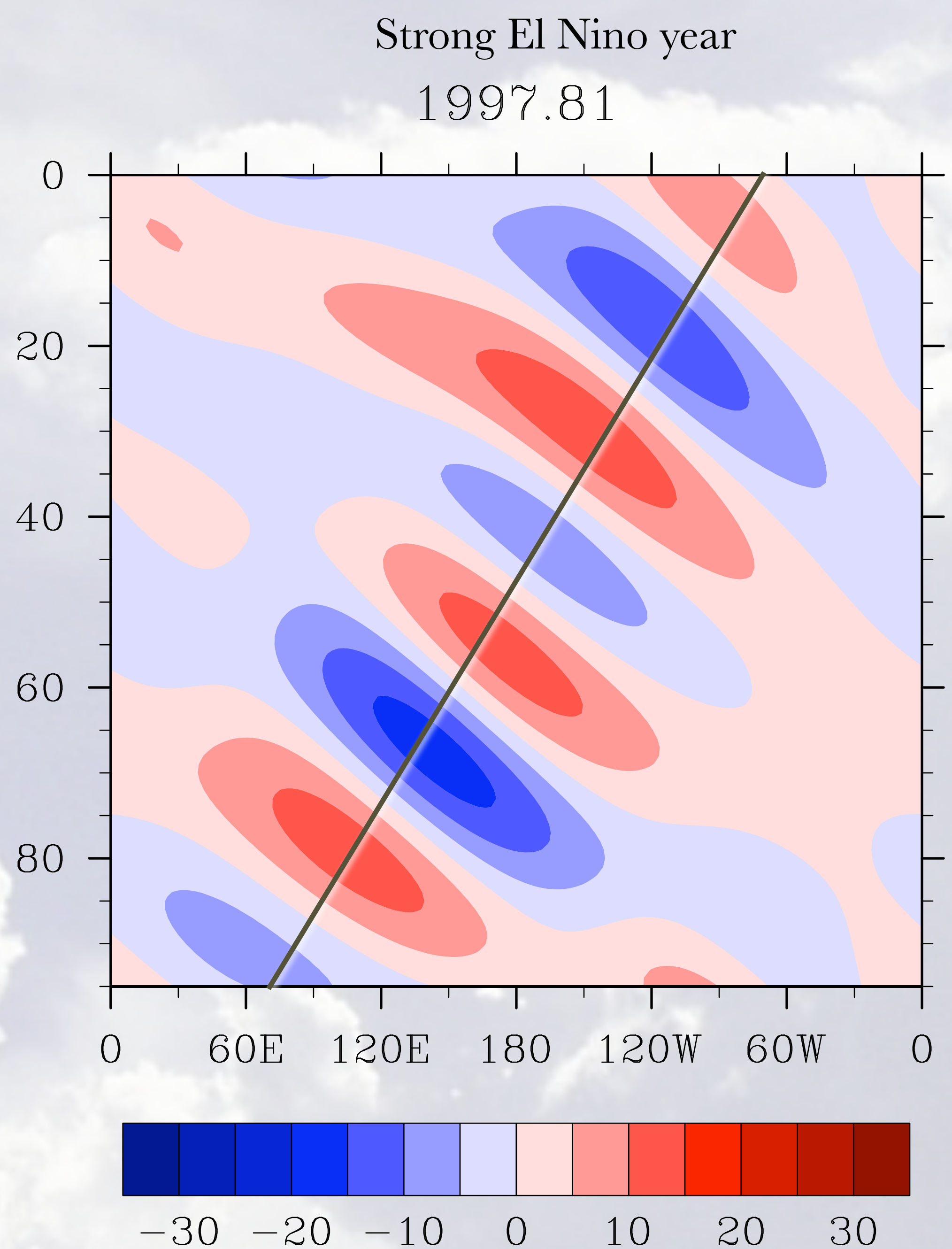


W/m²

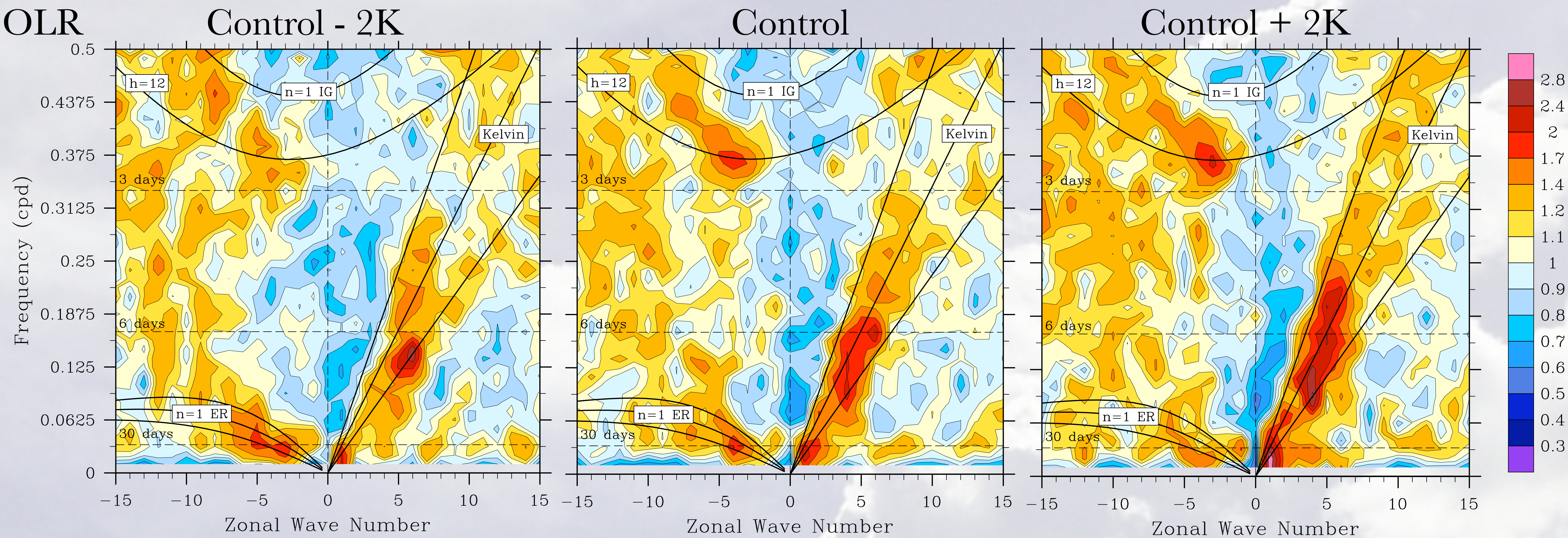
on Earth too

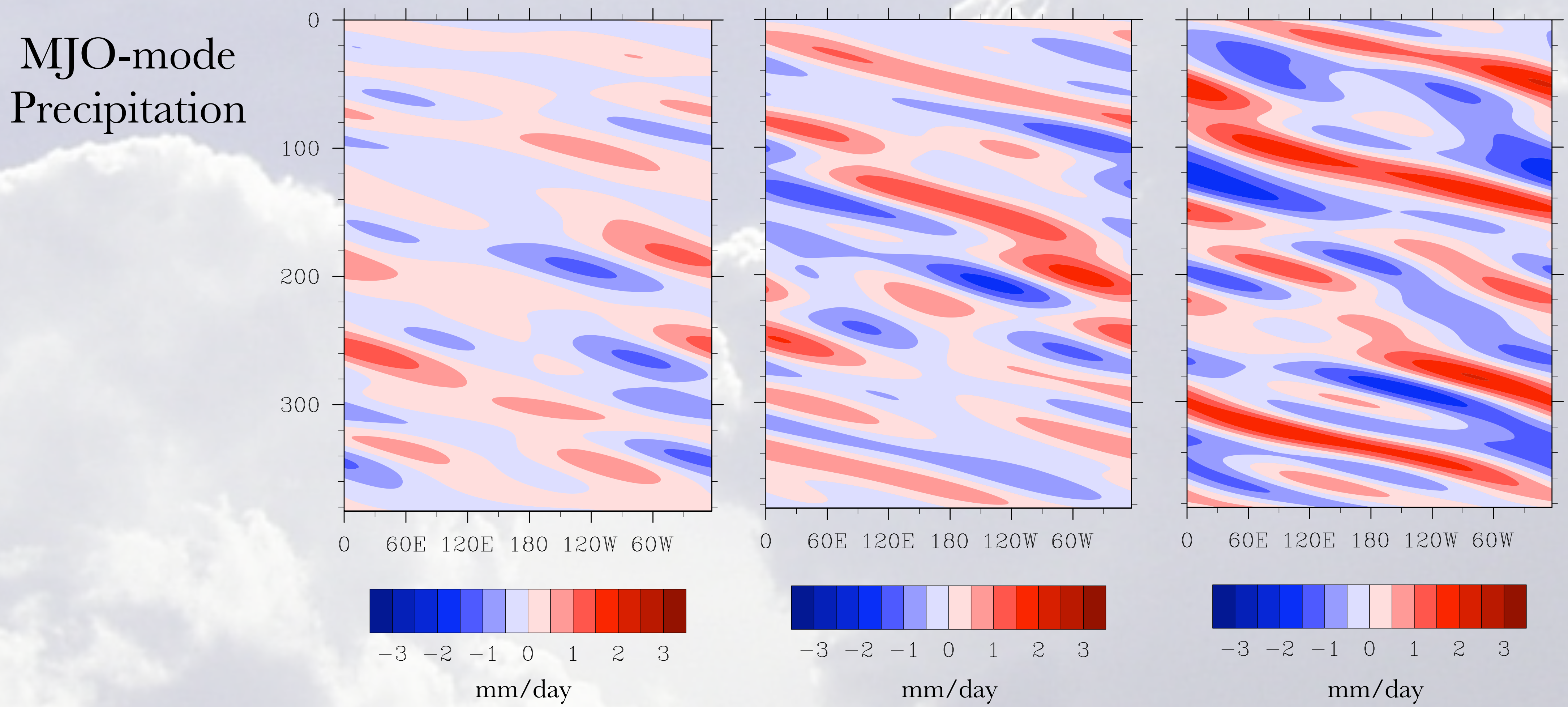
NOAA OLR

(Satellite observations, not a model)



Sensitivity to Aquaplanet Sea Surface Temperature





Positive SST perturbation causes stronger MJO and Kelvin modes, but weaker Rossby mode.

Rising CO_2

↓

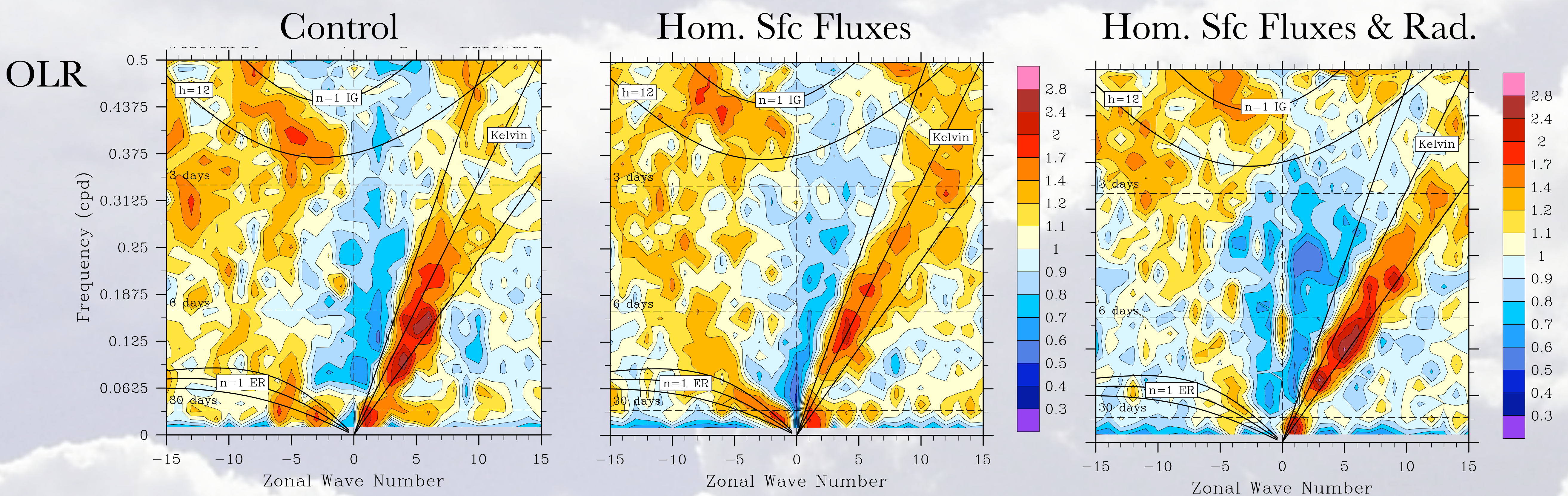
Warmer Tropical SST

↓

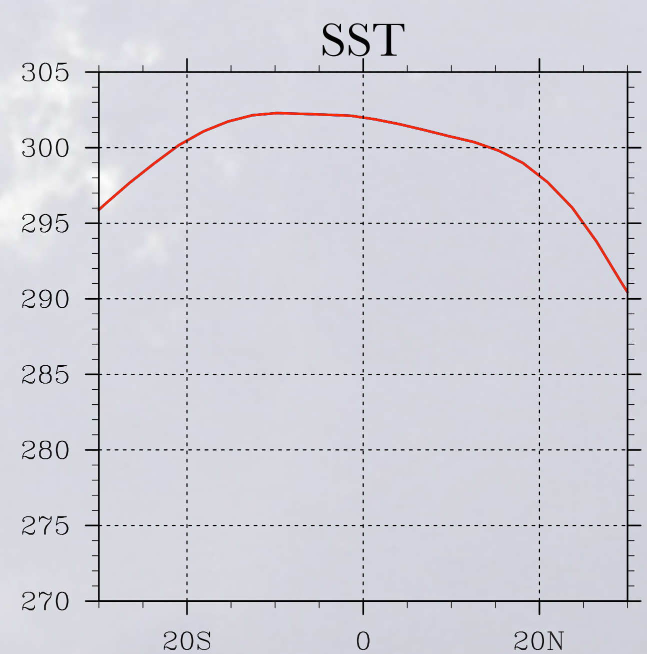
More extreme rain associated with MJO in the future?

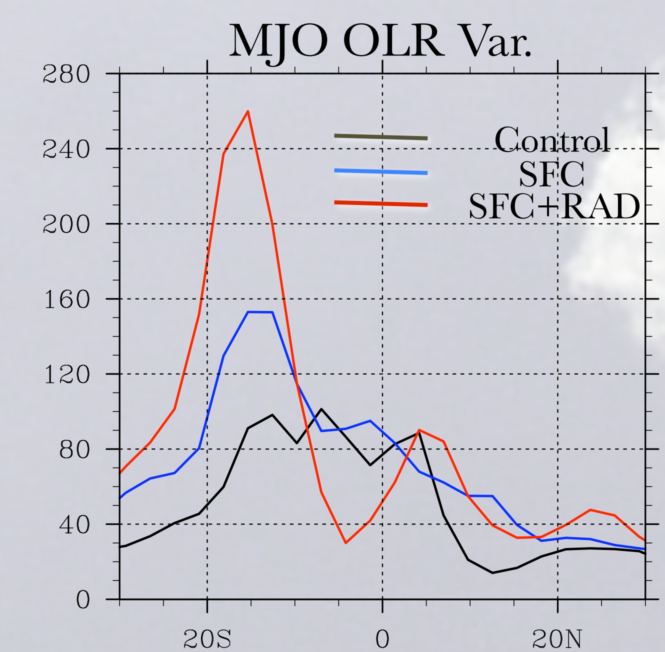
Sensitivity to Zonally Homogenized Surface fluxes and Radiative Heating

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



- Homogenization shifts MJO towards warmer SSTs and concentrates MJO into narrower band;
- Zonal variation of surface fluxes and radiative heating doesn't seem to be essential for maintaining simulated MJO;

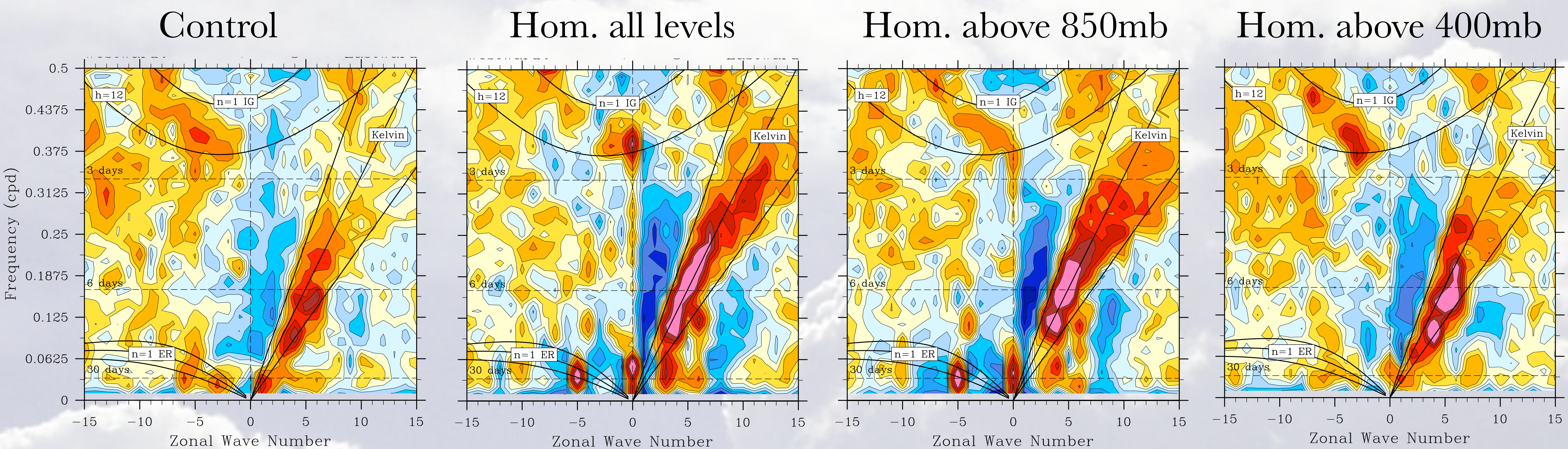




Sensitivity to Zonally Homogenized Water Vapor

- Zonal Homogenization: Nudge (relax) water vapor to zonally averaged values over diurnal time scale;

OLR



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

• The anomalies are associated with the shallow and congestus cloud activity - hence, representation of those cloud types in GCMs is the key for MJO simulation

First ever coupled-MMF simulation

Cristiana Stan[1*], Marat Khairoutdinov[2], Charlotte A. DeMott[3], V. Krishnamurthy[1,4], David M. Straus[1,4],

David A. Randall[3], James L. Kinter III[1,4], and J. Shukla[4,5]

Lead: Center for Ocean-Land-Atmosphere studies (COLA)

		SP-CCSM	CCSM3.0
Atmospheric Model	Horiz. Res.	T42 (sld)	T42 (sld)
	Vert. levels	30	26
	Deep conv.	CRM	ZM
	Shallow conv.	CRM	Hack
Ocean Model	Horiz. Res.	gx3v5	gx3v5
	Vert. levels	25	25
Sea-Ice Model		CSIM4	CSIM4
Land Model		CLM3.0	CLM3.0

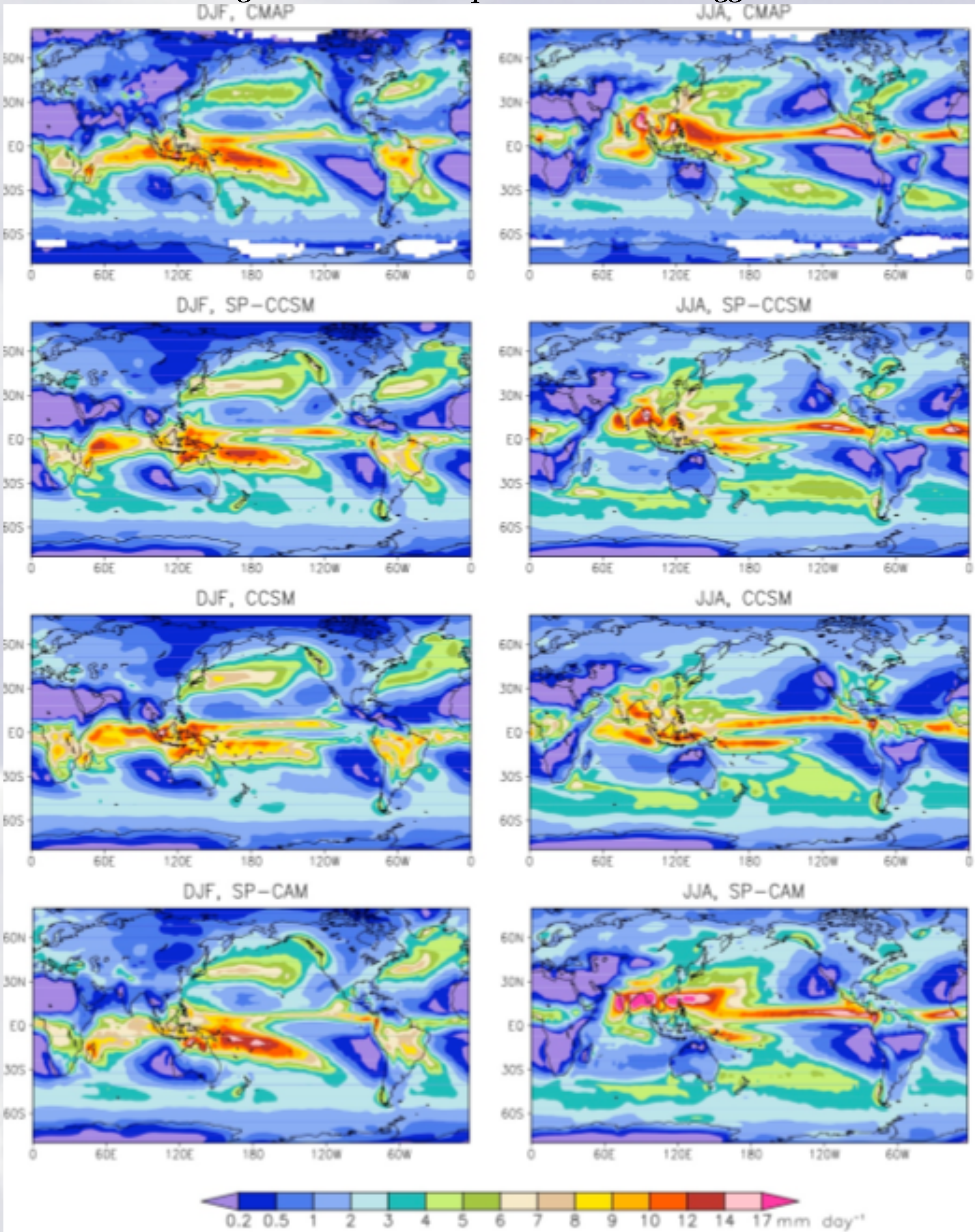
DJF Precipitation JJA

CMAP

SP-CCSM

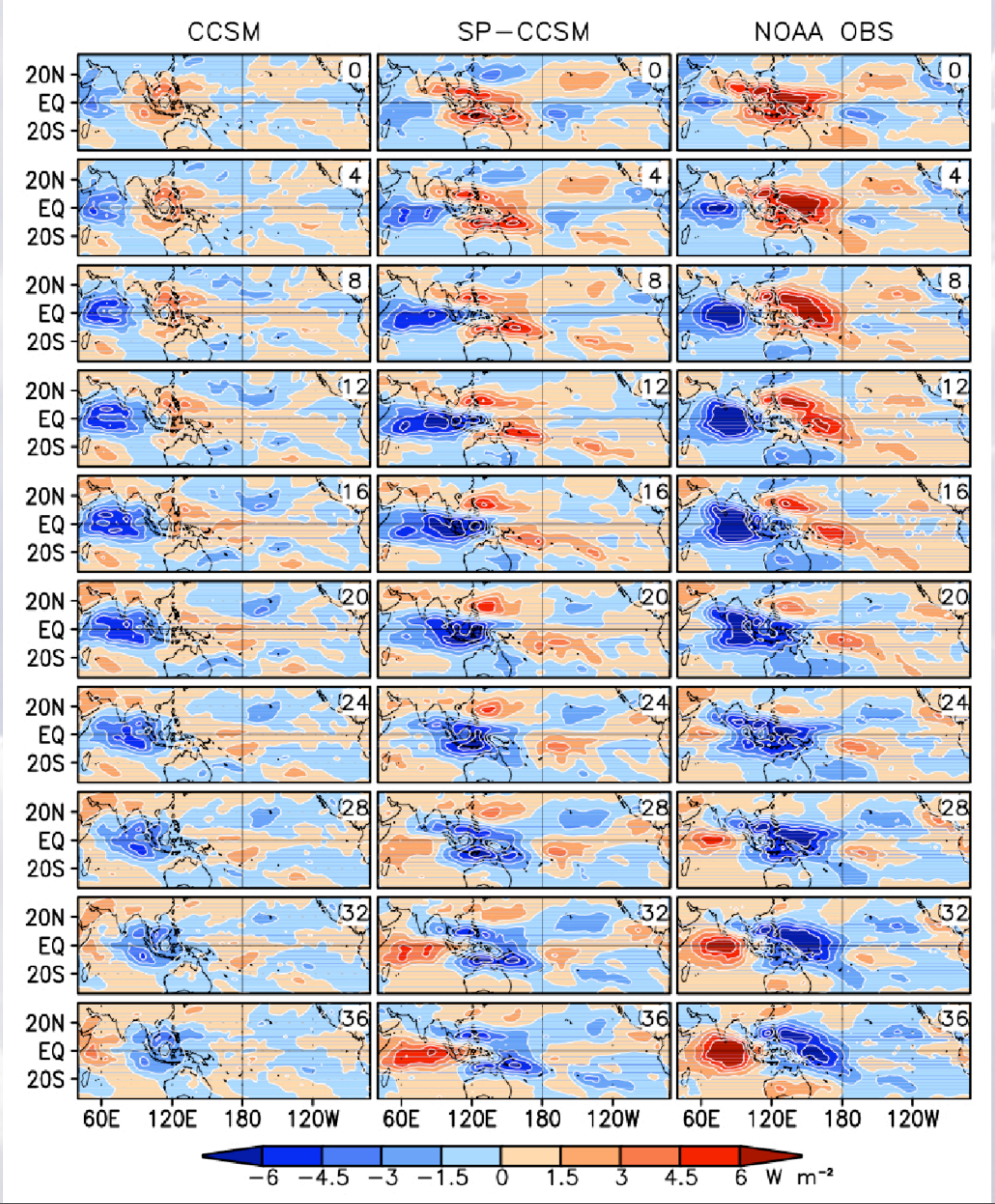
CCSM

SP-CAM



Stan et al 2009

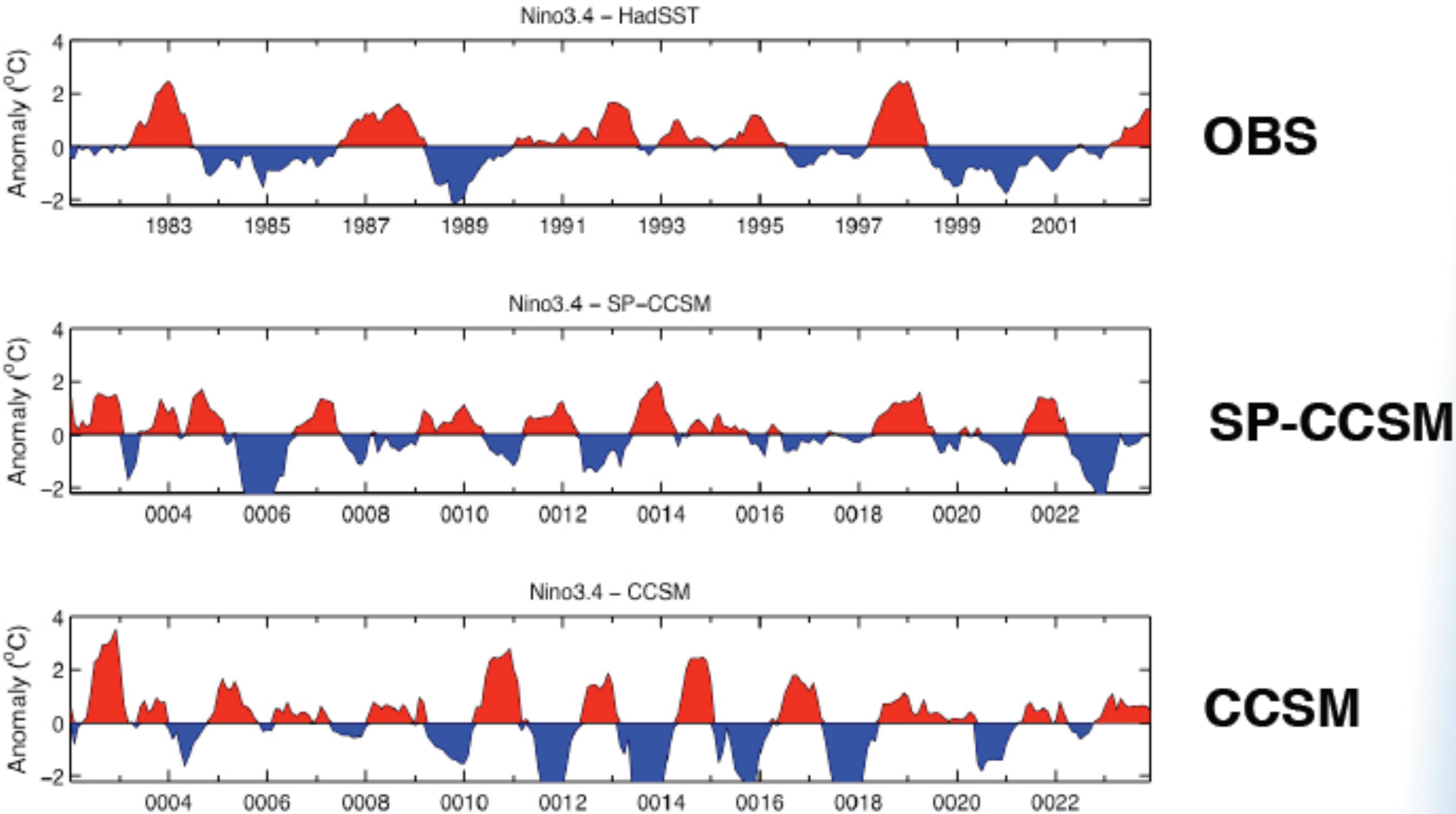
Phase composites of OLR dominant MJO mode



Stan et al 2009

ENSO Simulation

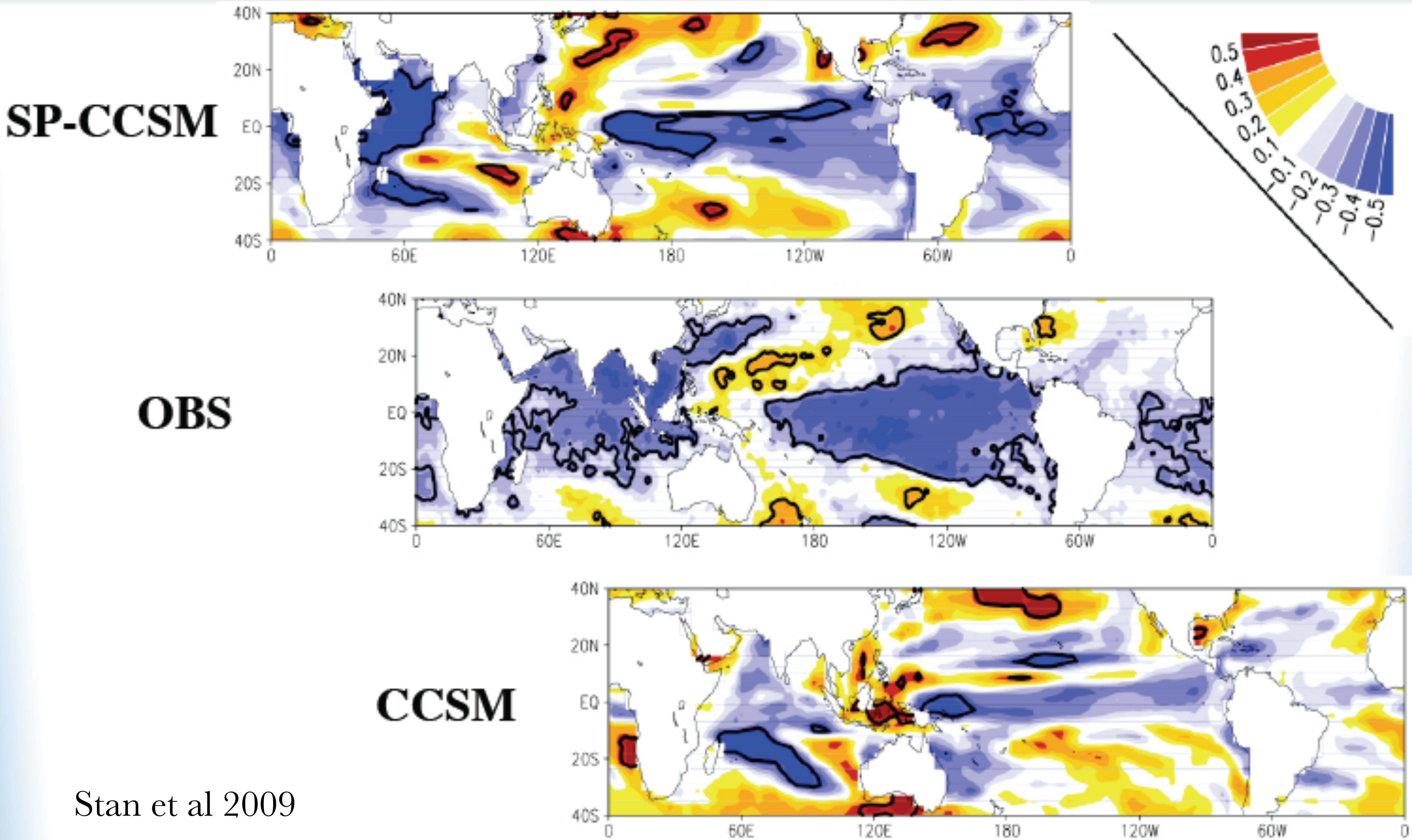
Niño 3.4 (5S-5N,170W-120W)



Stan et al 2009

ENSO-Monsoon Relationship

IMR (JJA), SSTA(DJF-1)



Stan et al 2009

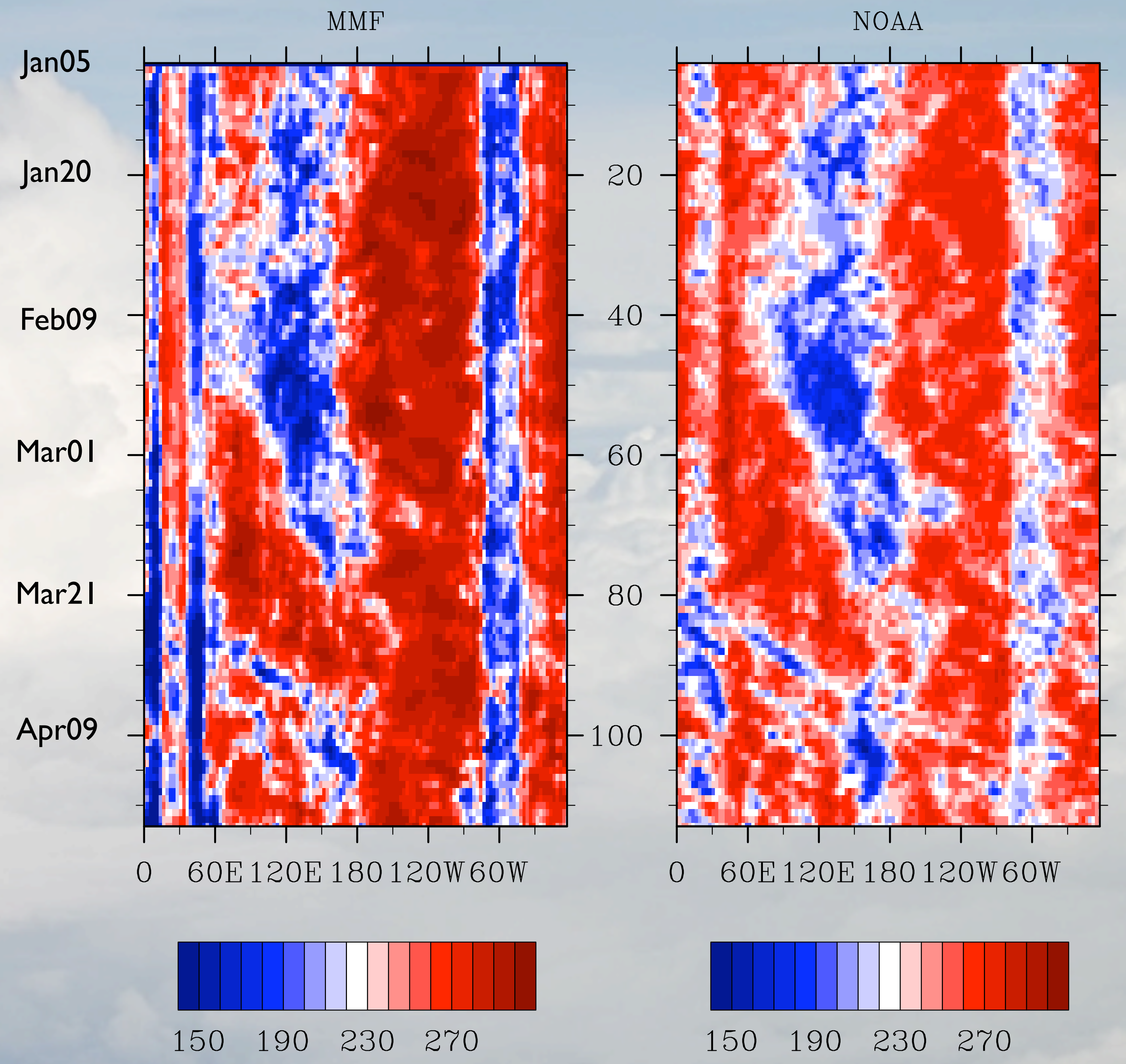
Conclusions on SP-CCSM run

- Improved ENSO;
- Improved relationship between Indian Monsoon and SST anomalies in the Eastern Pacific the following season;
- Robust and realistic MJO simulation

Towards hindcasts using SP-CAM: Generating initial conditions

OLR, tau=6h

u,v,omega,T,q, and ps are nudged to ERA40



Proposed Contributions to YOTC

- Hindcasts over YOTC period starting from ECMWF analysis;
- Free-runs (ensemble?) with prescribed SSTs;
- Couple runs with SP-CCSM over YOTC period