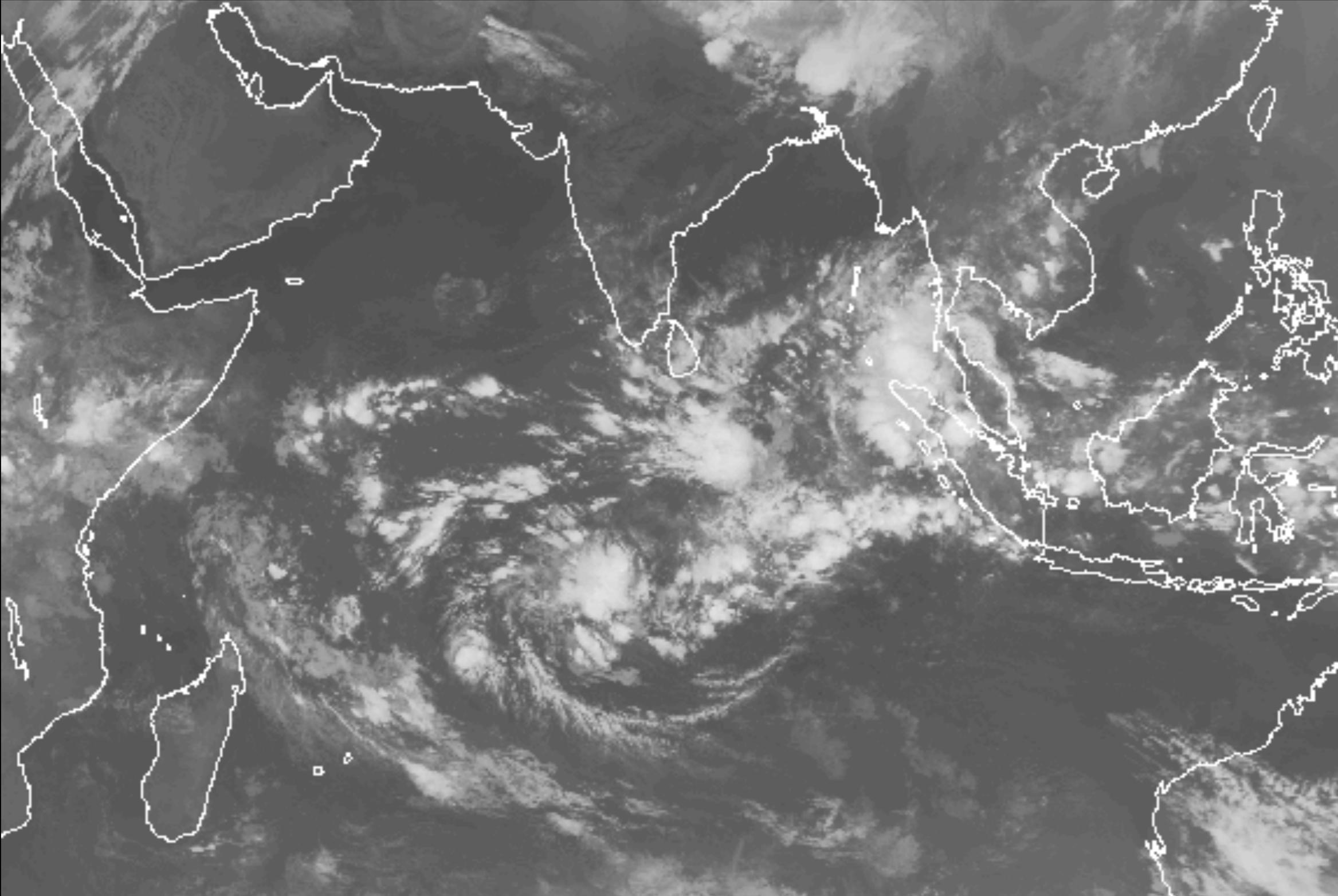


Probing the sensitivities of the
superparameterized Madden-Julian
Oscillation to test dynamical
paradigms.

Mike Pritchard

UC Irvine

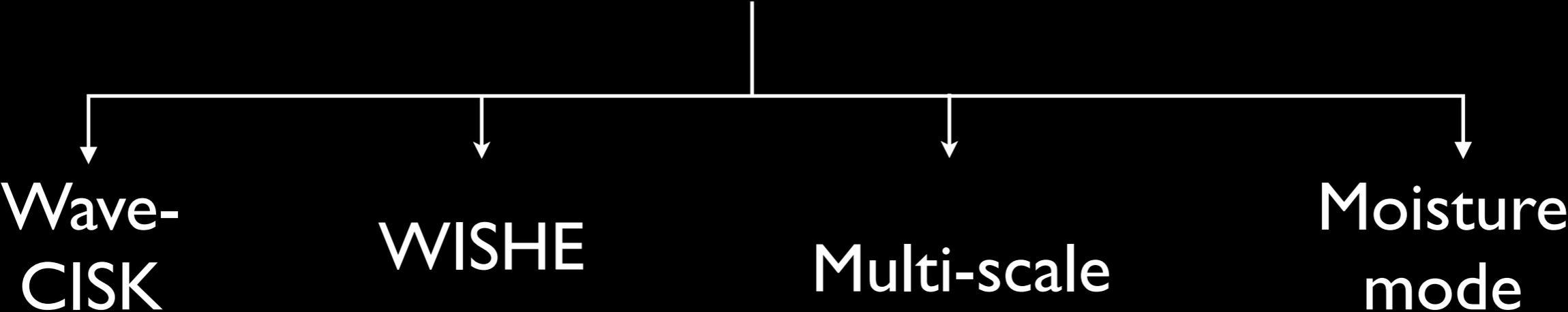
The Madden-Julian Oscillation.



MET-5 IR 29 APR 02 00:00 UTC UW-CIMSS

A simple theory of the MJO is a “holy grail” of tropical dynamics.

A few dynamical paradigms of the MJO.



A few dynamical paradigms of the MJO.



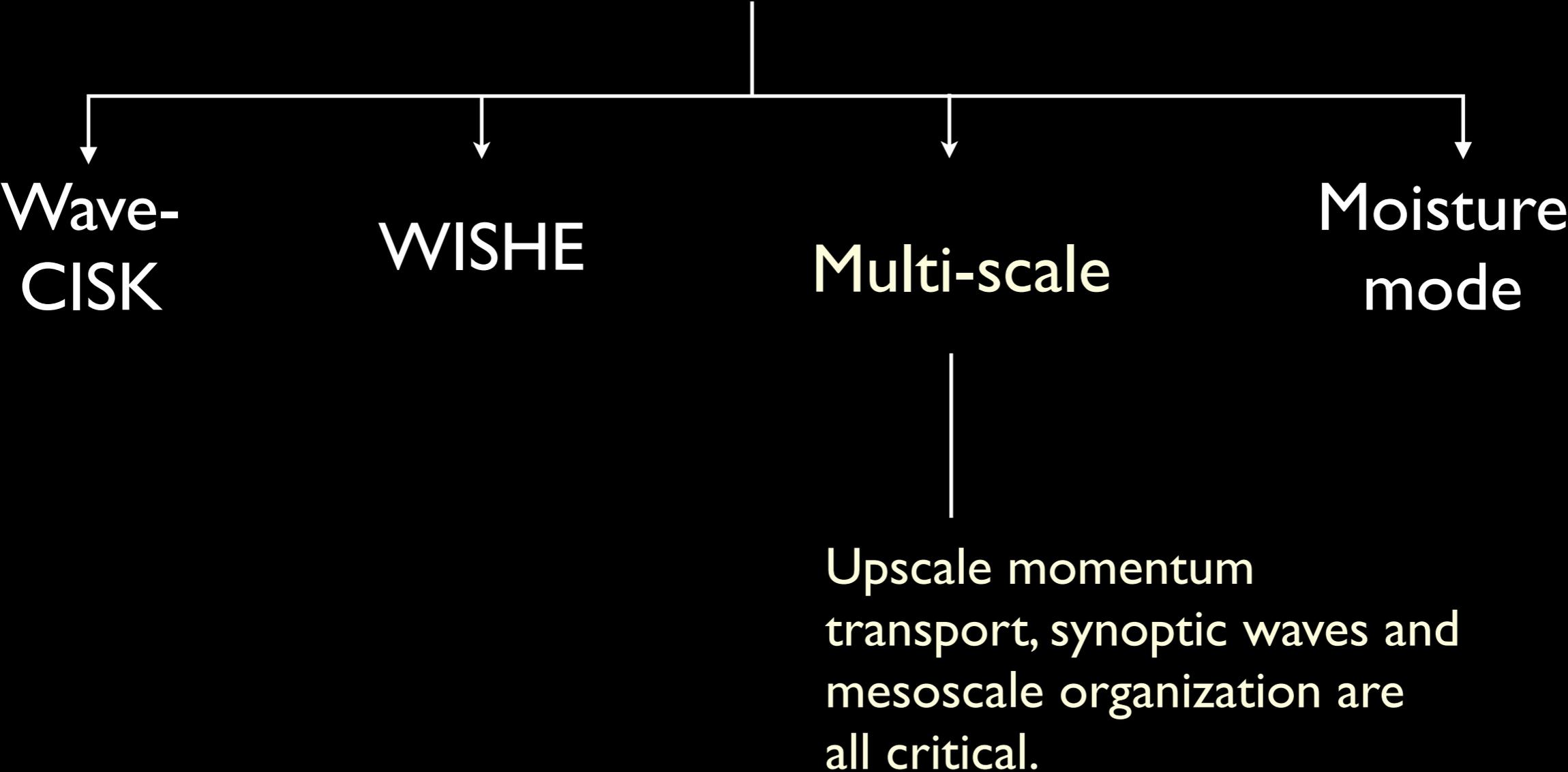
Convective heating exciting circulations that conspire to produce co-incident low level convergence (assuming fixed moisture).

A few dynamical paradigms of the MJO.

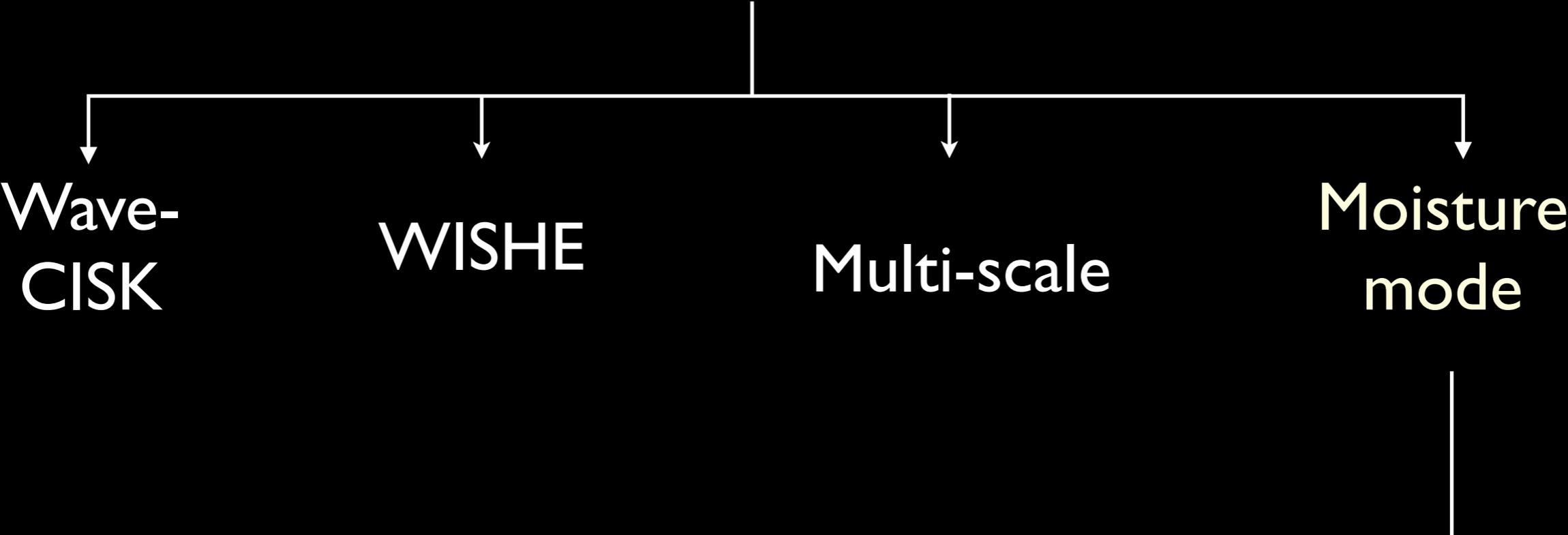


Wind speed anomalies induce latent heat fluxes ahead leading to eastward propagation.

A few dynamical paradigms of the MJO.



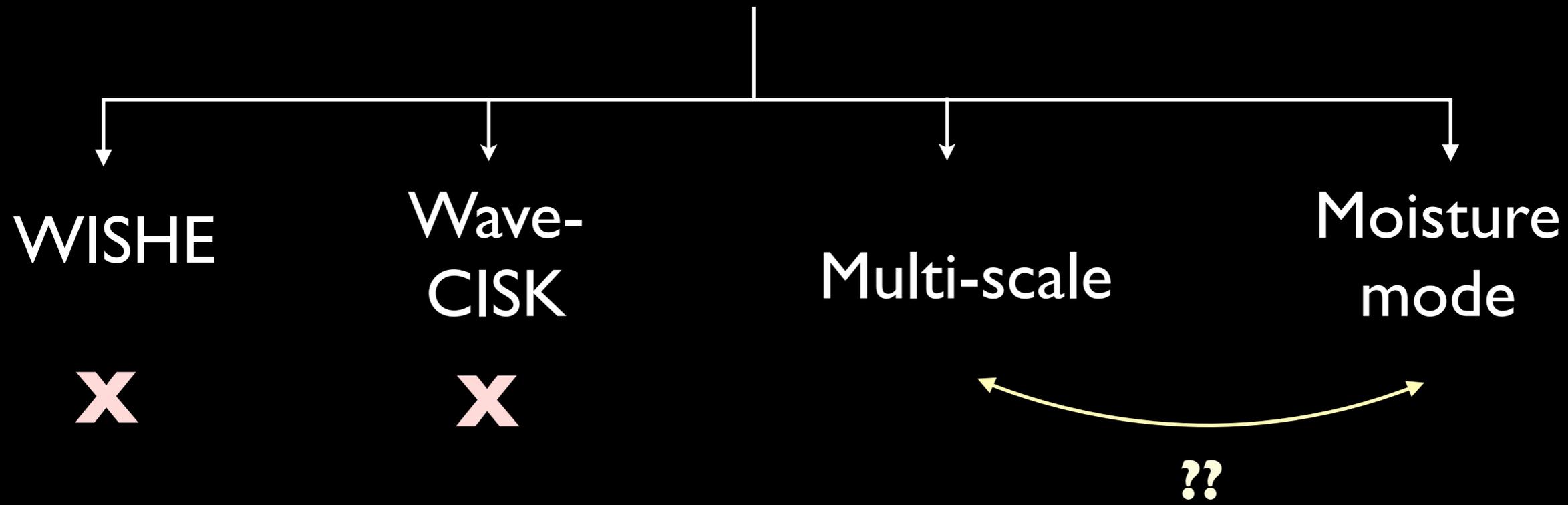
A few dynamical paradigms of the MJO.



Internal thermodynamic feedbacks coupled to horizontal moisture advection are critical.

Pitfalls of dynamical paradigms for understanding the MJO.

Some can be falsified against MJO data diagnostically...



... but others cannot.

In this context, it would be especially useful to:

Apply a *high-degree of freedom* global model,

making minimal assumptions about convection,

but producing a realistic MJO signal,

to examine processes & test their criticality.

Road map

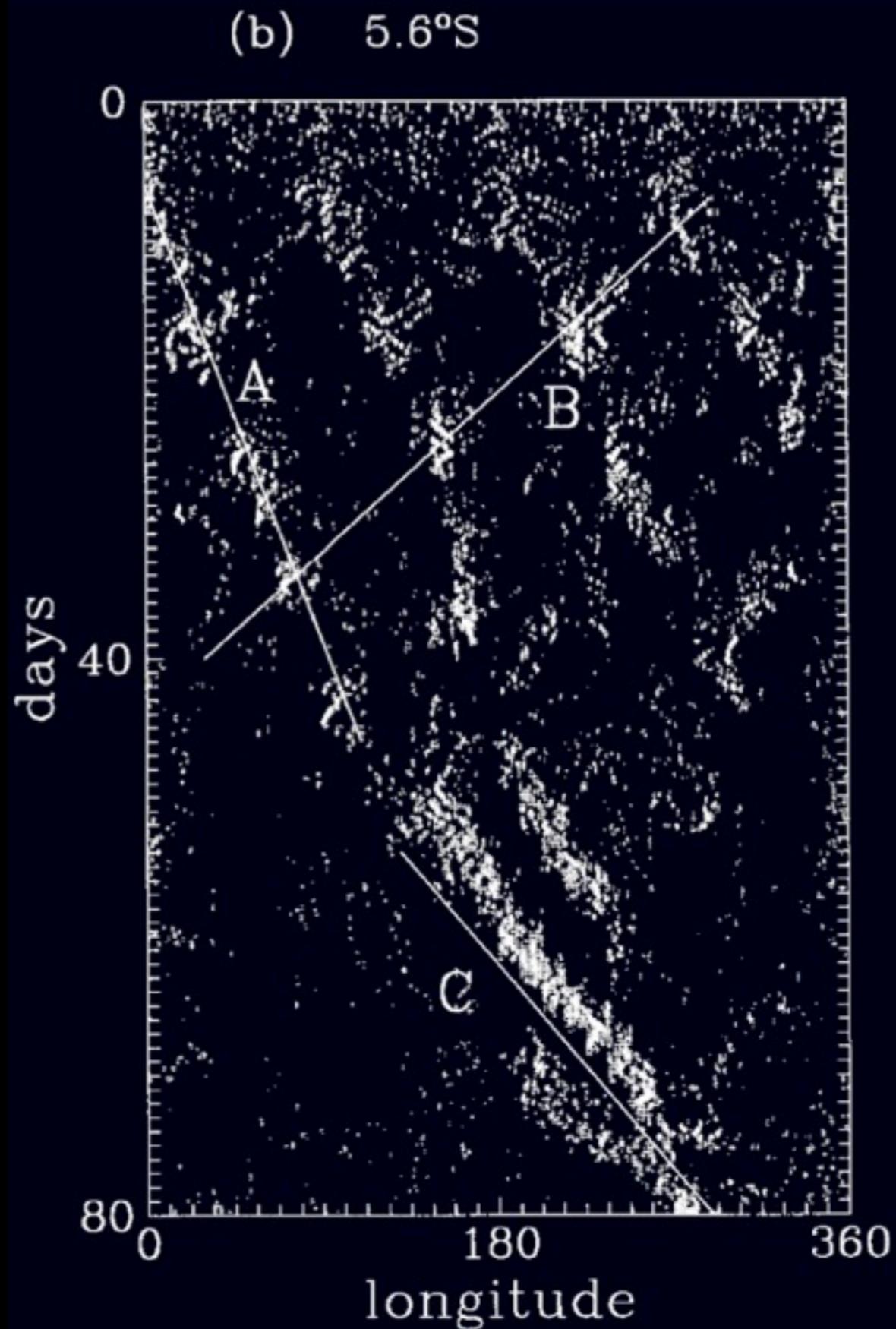
- History of SPCAM's high quality MJO.
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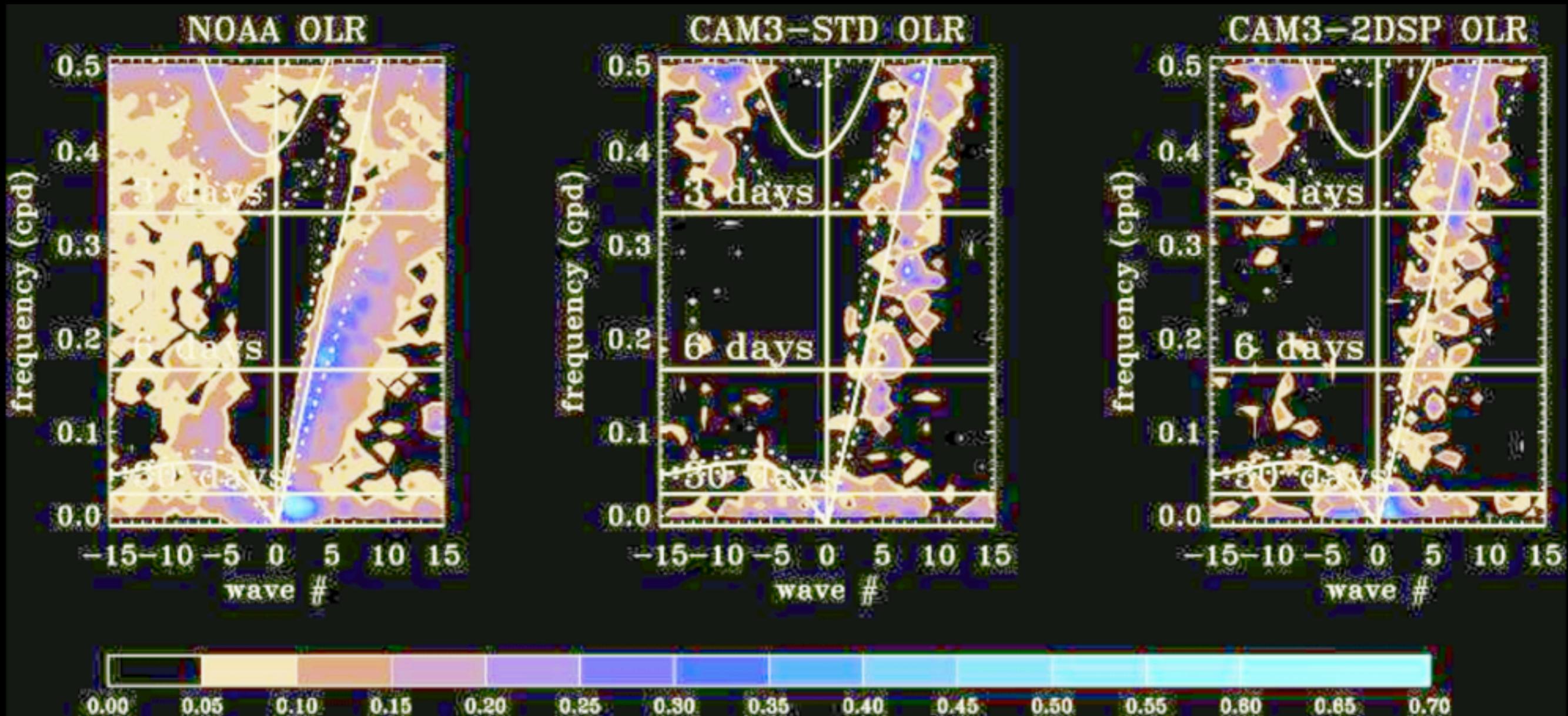
First glimpse of realistic MJO-like variability in proto-MMF (idealized setup).

Precipitation
Hovmuller
from
uniform
aqua-
planet



Grabowski, 2001.

Glimmer of MJO in pioneering runs of real-geography SPCAM (500 days).



Khairoutdinov et al. (2005)

Statistical confirmation of MJO and nice moist Kelvin wave activity in 18-year AMIP simulations in SPCAM3.0.

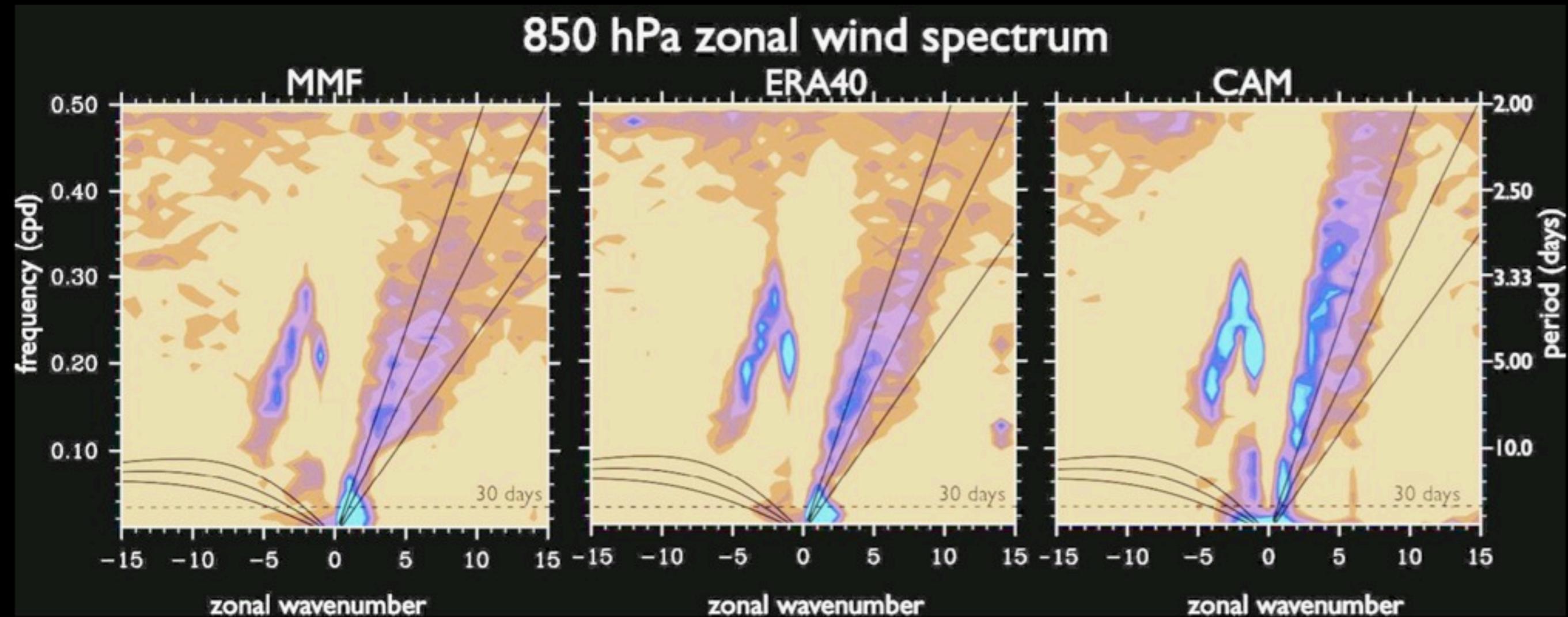
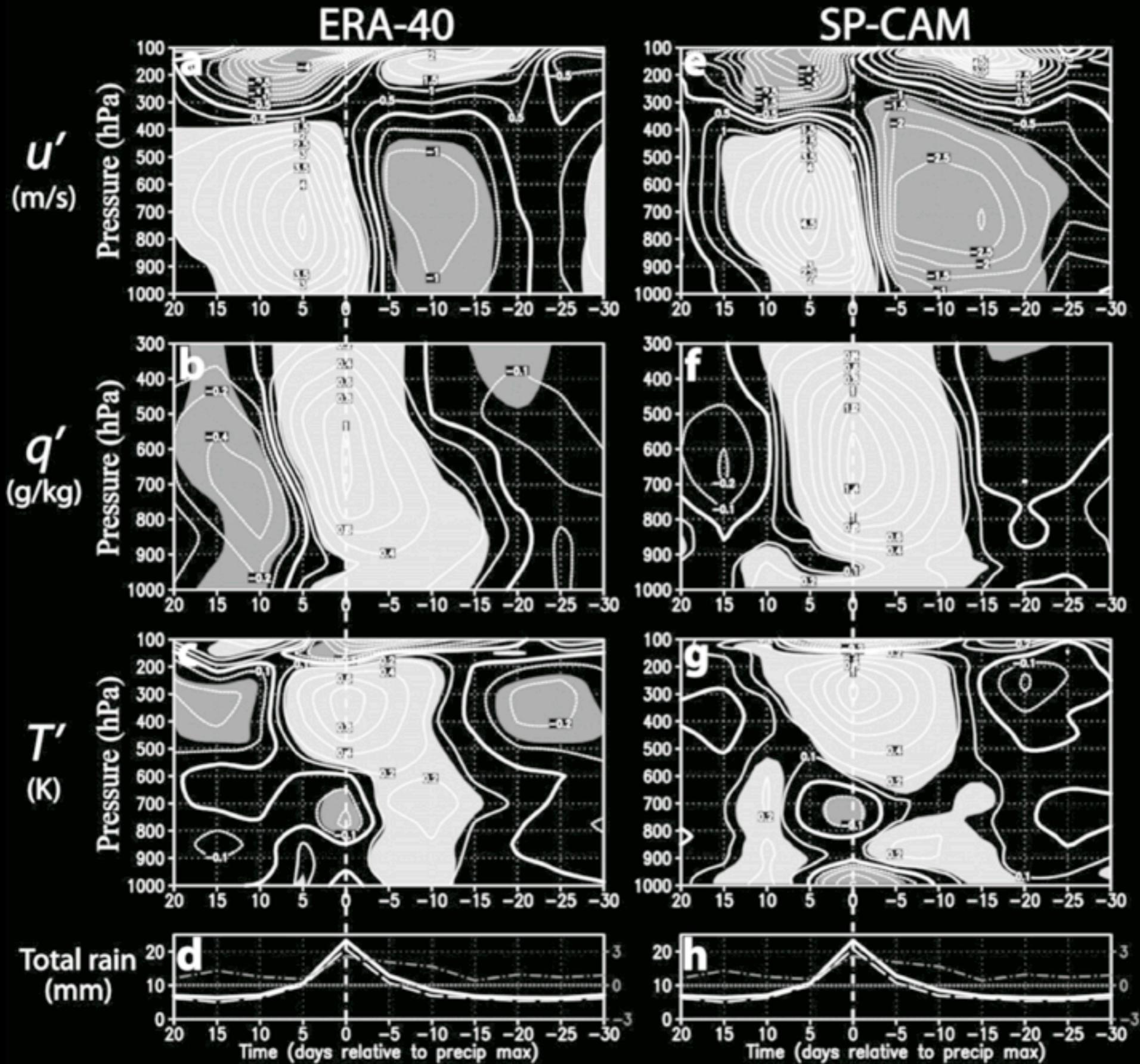


FIG. 10. Similar to Fig. 9, but for the zonal component of wind at (top) 200 and (bottom) 850 mb. The observed daily wind is from the ERA-40 product.

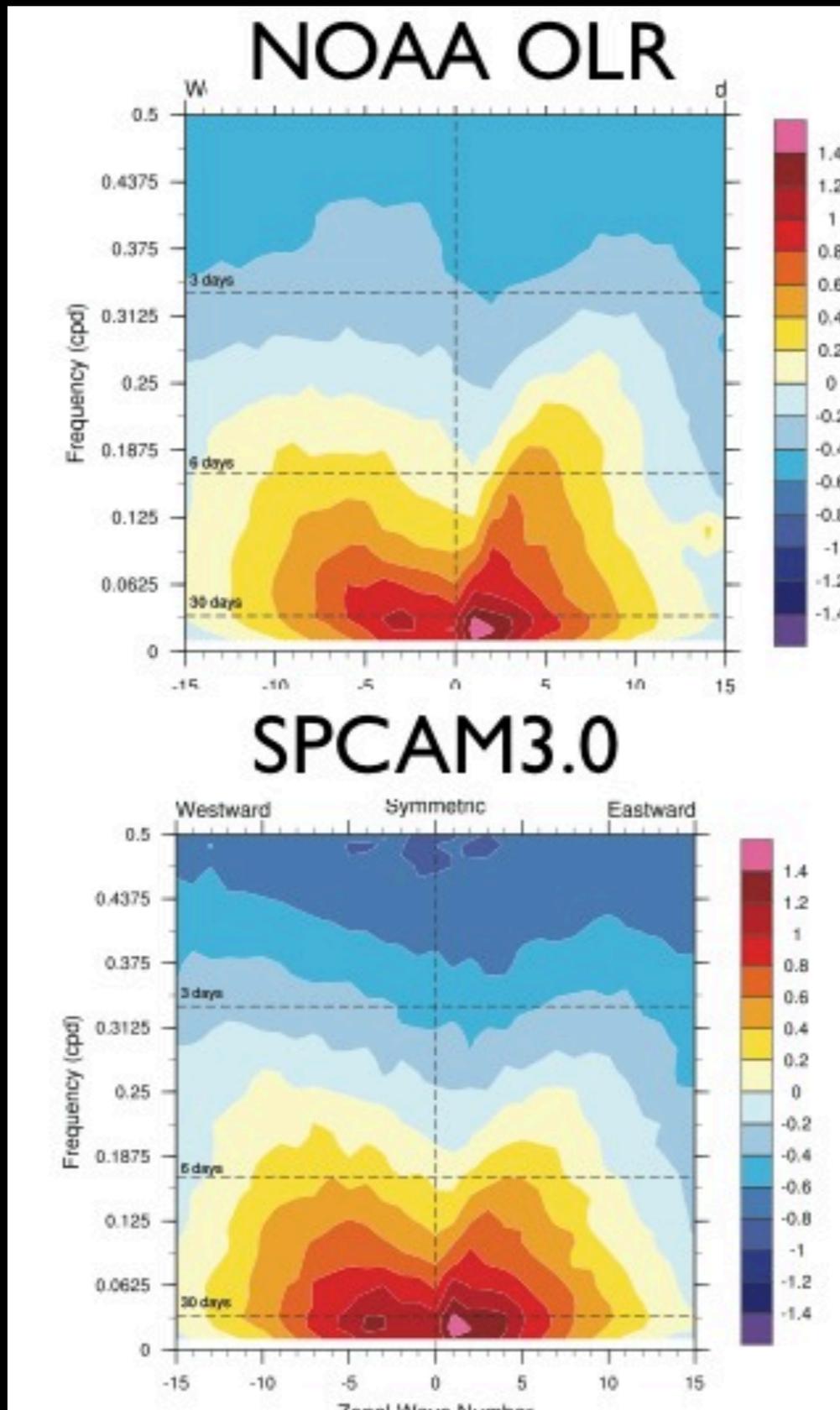
Khairoutdinov et al. (2008)

Confirmation of realistic dynamic and thermodynamic structure.



Height-time MJO composites; Benedict & Randall (2009).

New development: Versions of SPCAM since v.3.0 have lost the high-quality MJO signal.



But SPCAM3.0 provides a useful opportunity to:

Apply a *high-degree of freedom* global model,

making minimal assumptions about convection,

but producing a realistic MJO signal,

✓ ... composite structure.

... forecast skill?

to examine processes & test their criticality.

Road map

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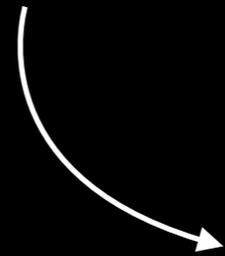
Prior:

Proven quality of SPCAM's
composite MJO.



Hypothesis:

**The SPMJO is a
valid analog to nature.**



Expect:

Nontrivial forecast skill.

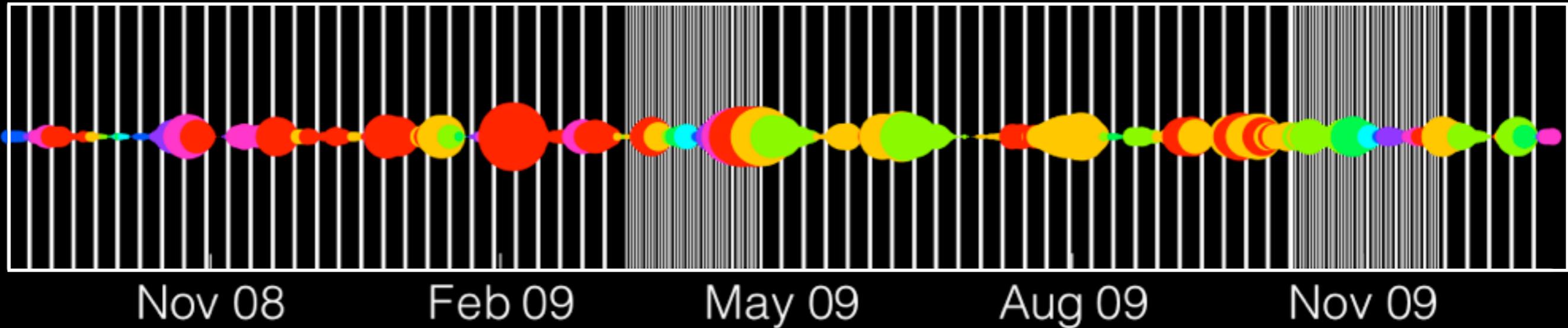
Forecast analysis period

MJO activity during YOTC

Case D

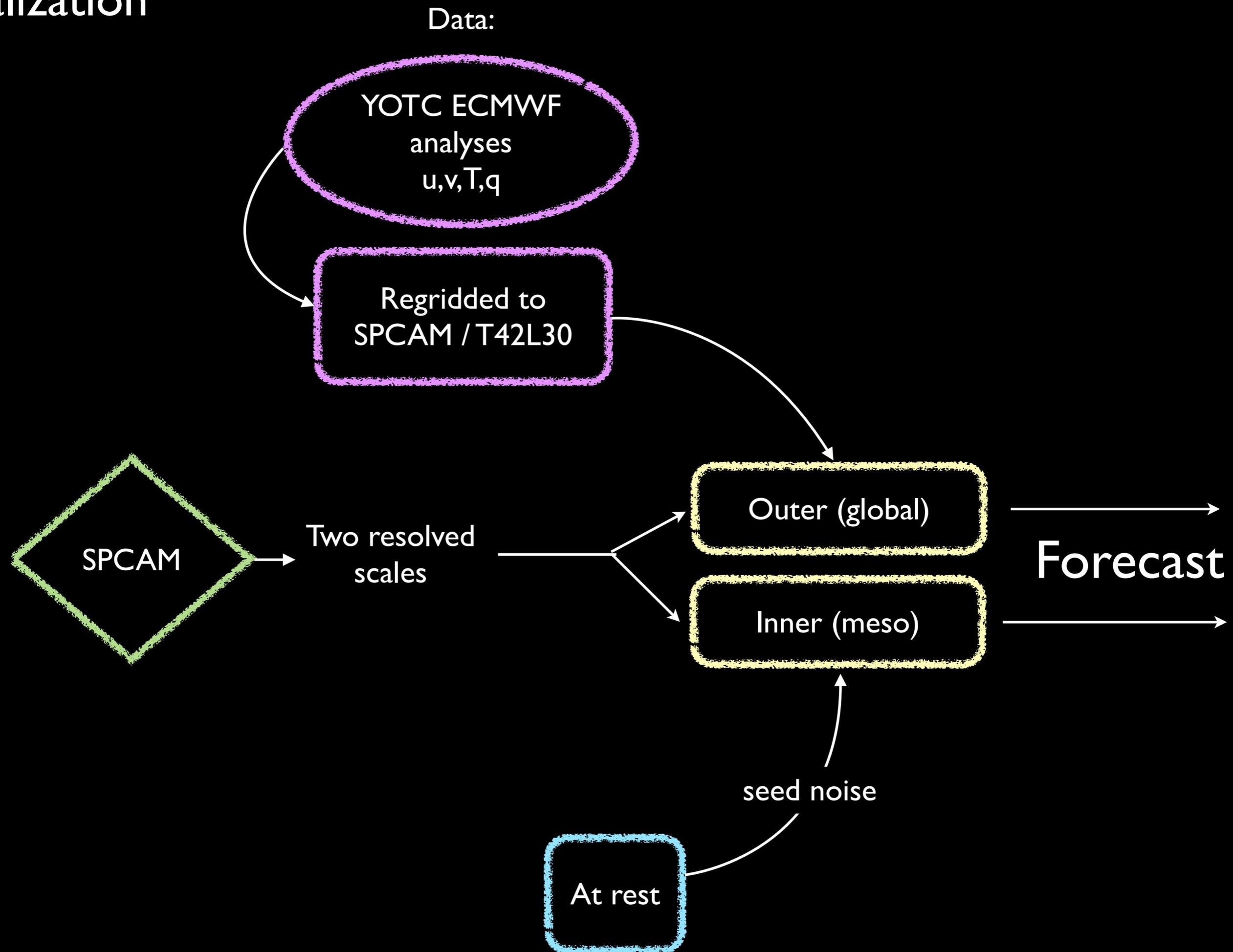


Case E

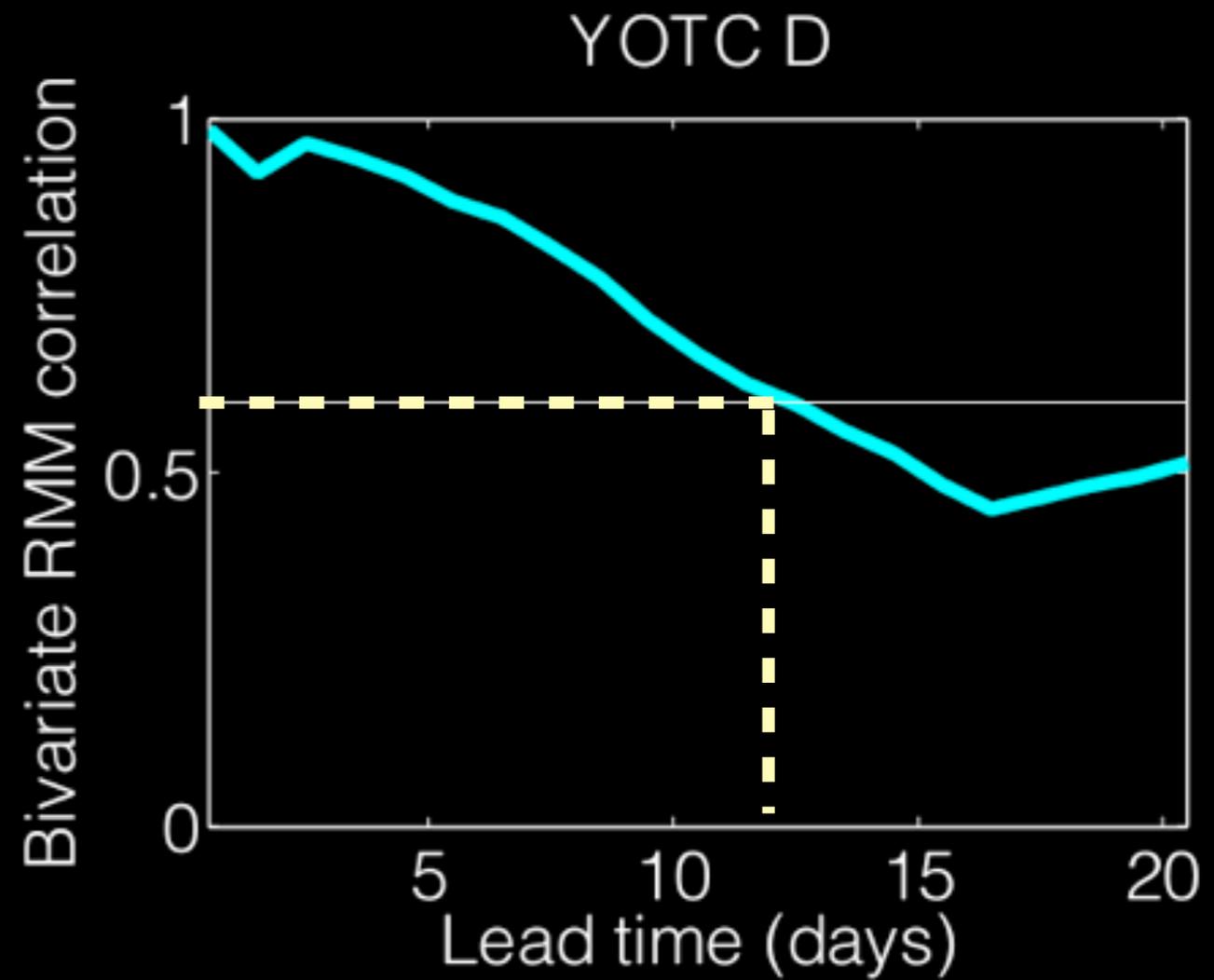
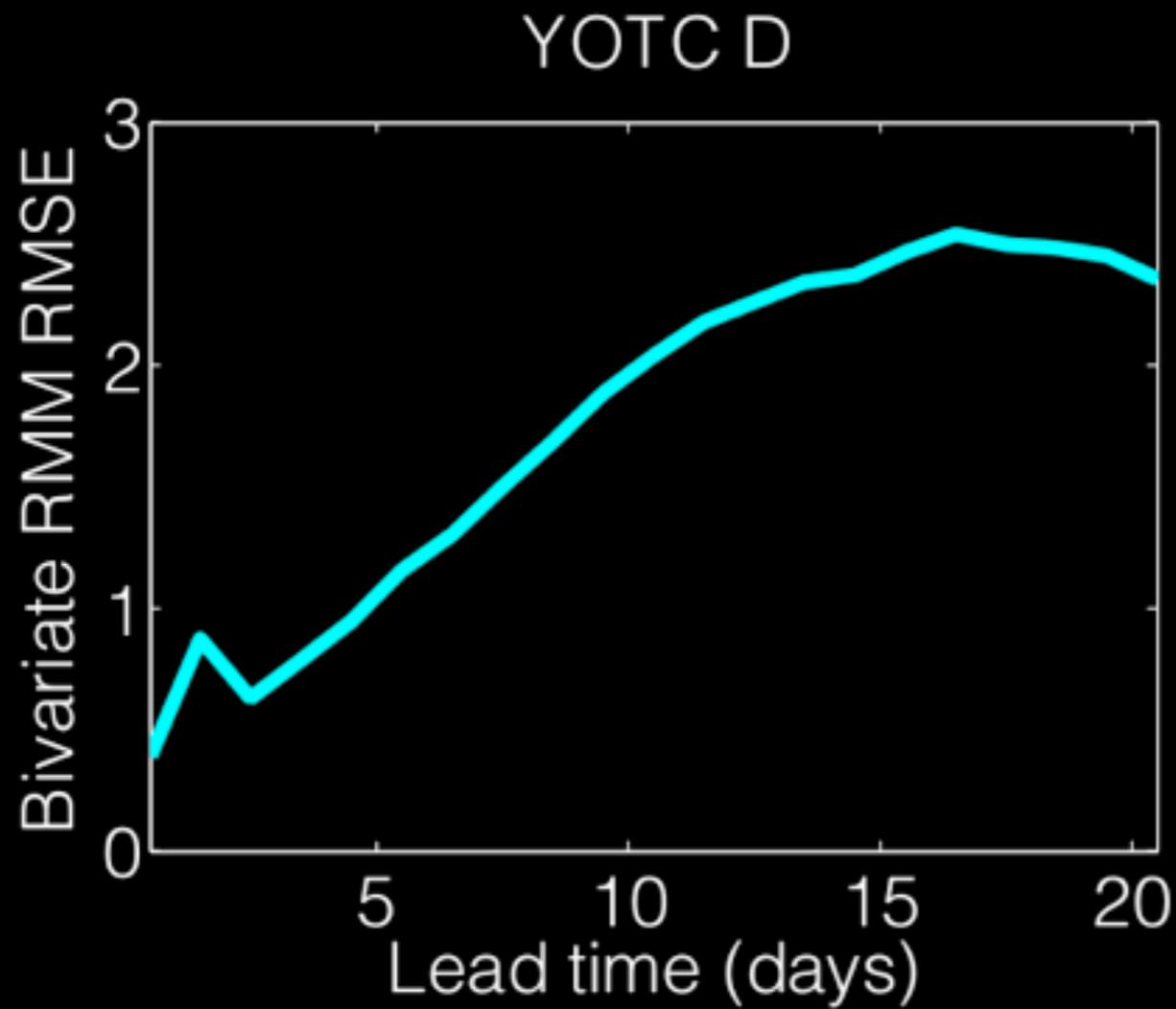


MJO phase

Initialization



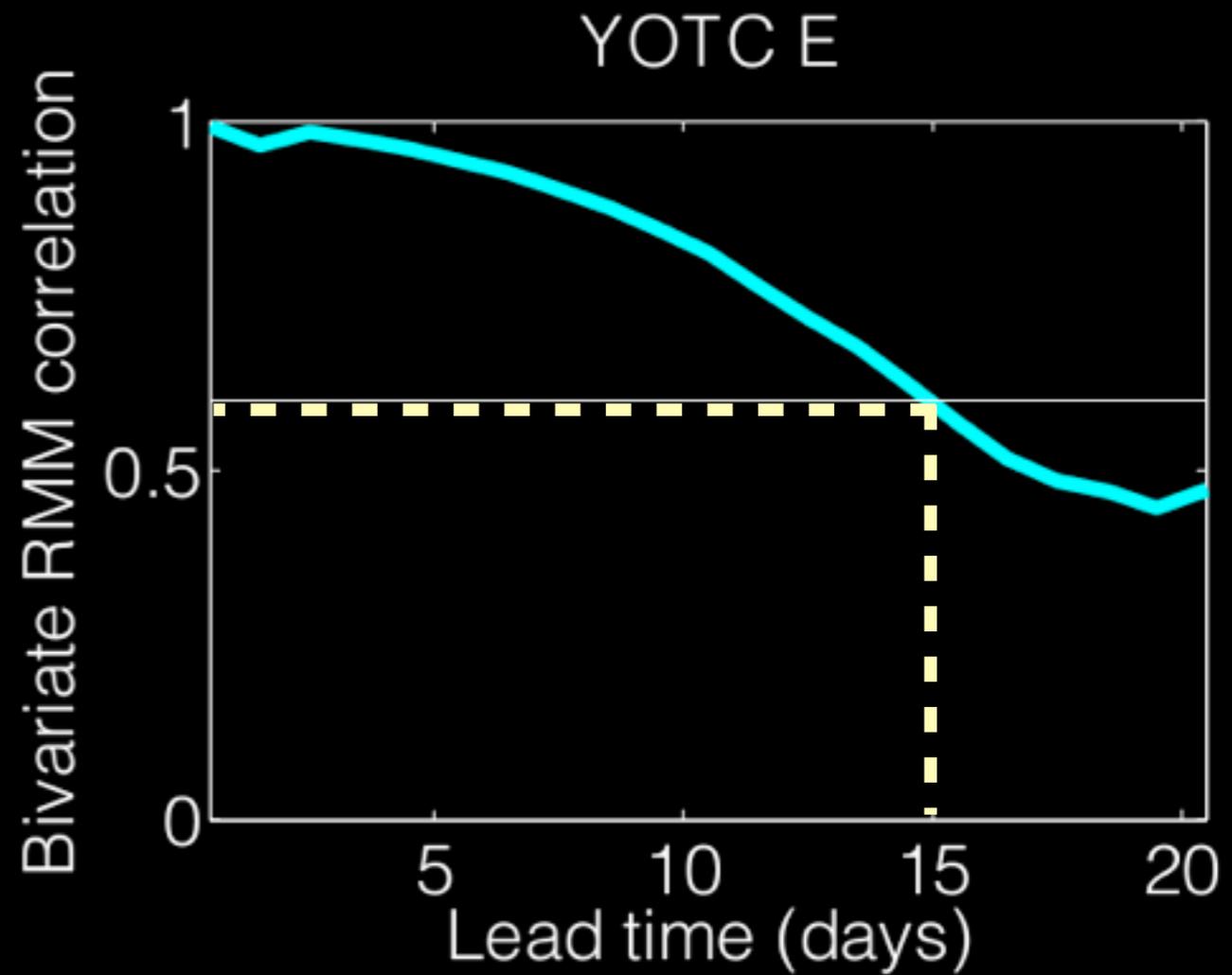
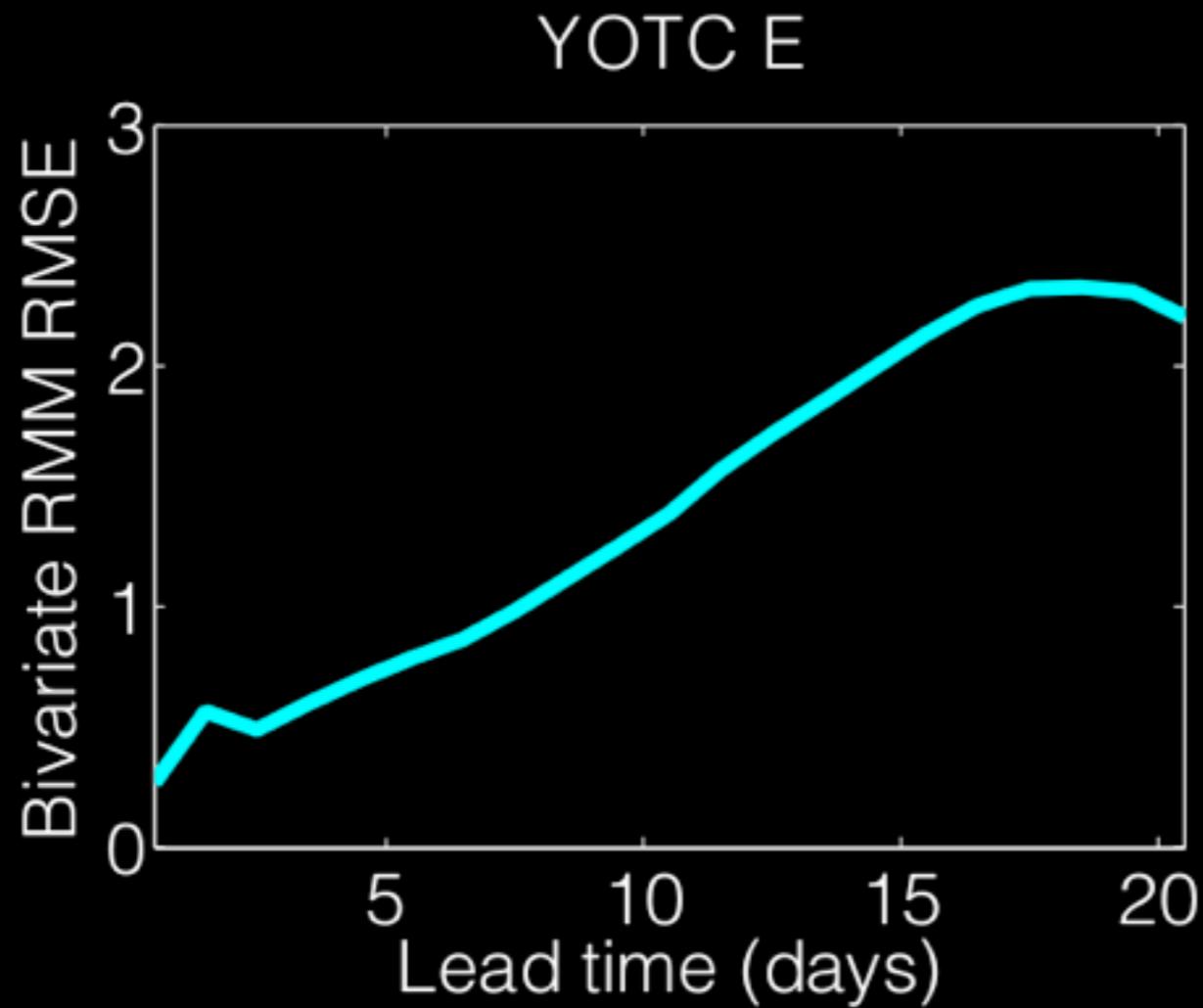
A first look suggests unimpressive skill limit of 12 days...



(29 forecasts)

12 day limit

...15 days for the boreal winter ensemble...



(29 forecasts)

15 day limit

Hypothesis:

**The SPMJO is a
valid analog to nature.**

Is this evidence to the contrary?...

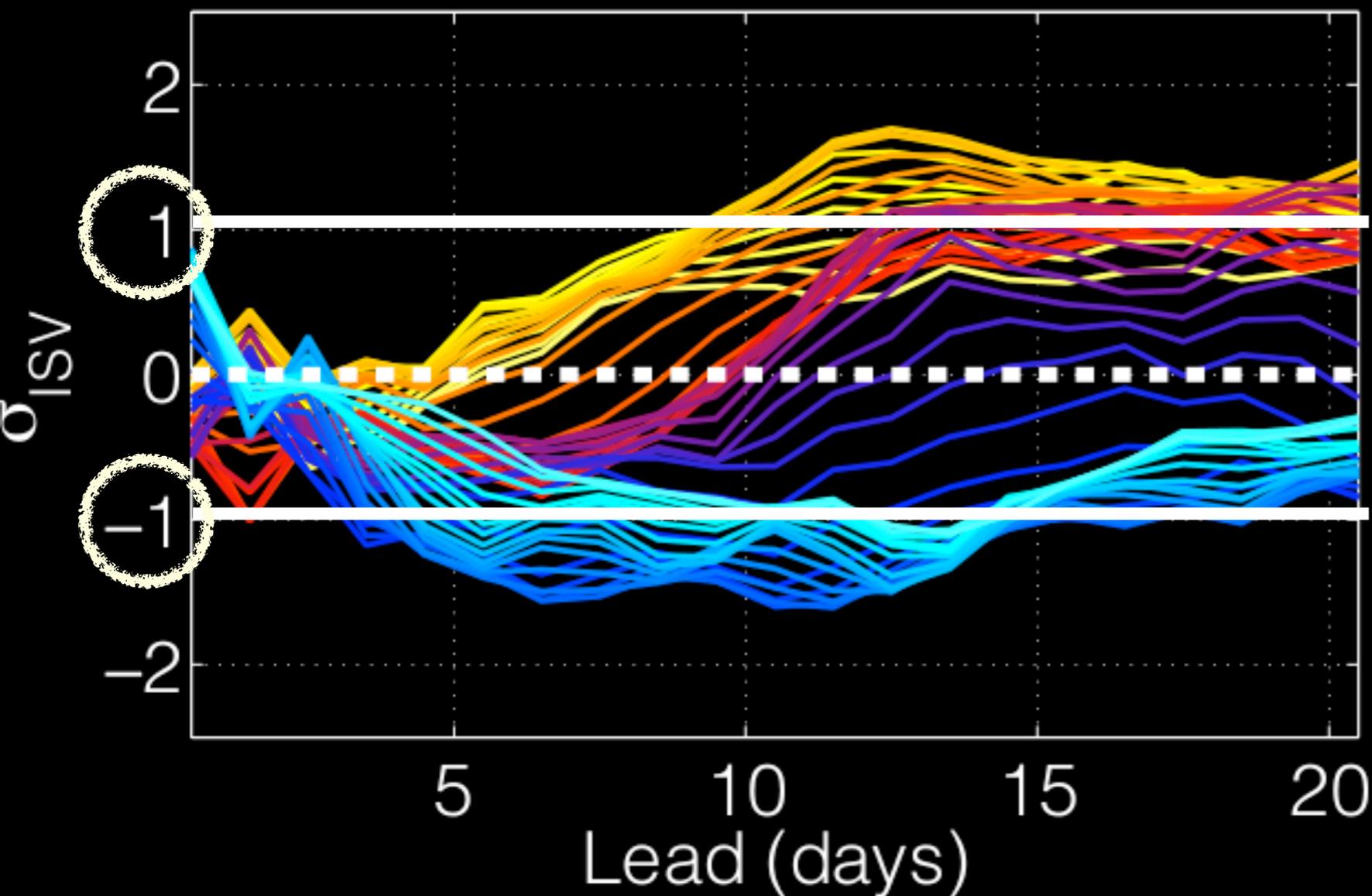
... or an artifact of failing to account for climate drift!

Noise due to initialization drift rivals SPCAM's MJO signal.

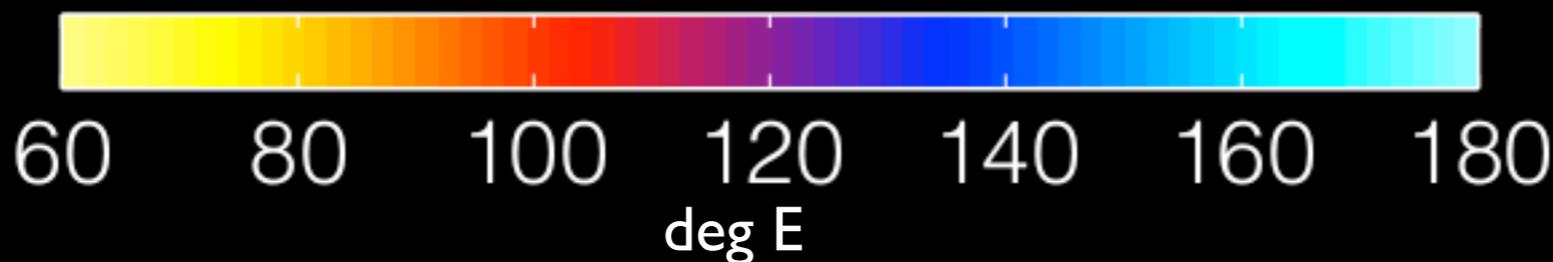
Lead time dependence of time mean anomaly

(Each line represents a forecast ensemble mean)

U850 (YOTC D)

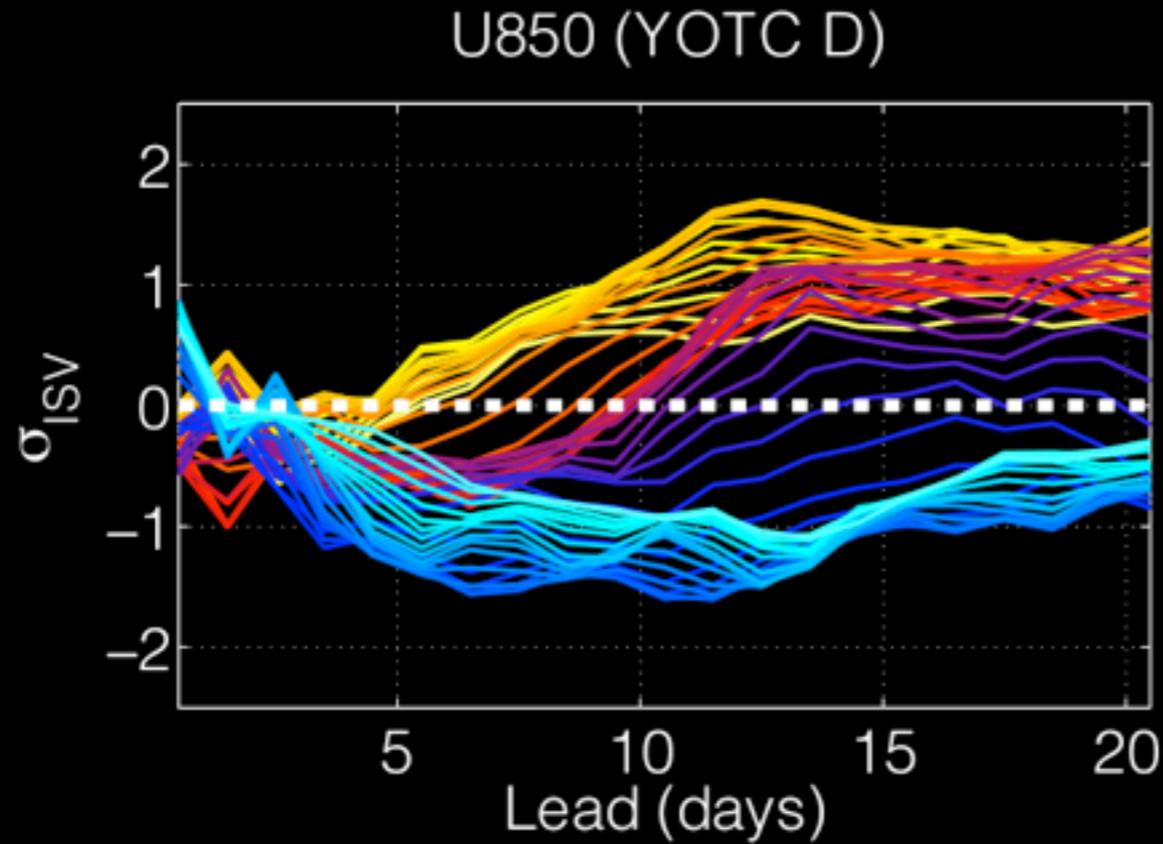


Systematic drift is on the order of MJO amplitude



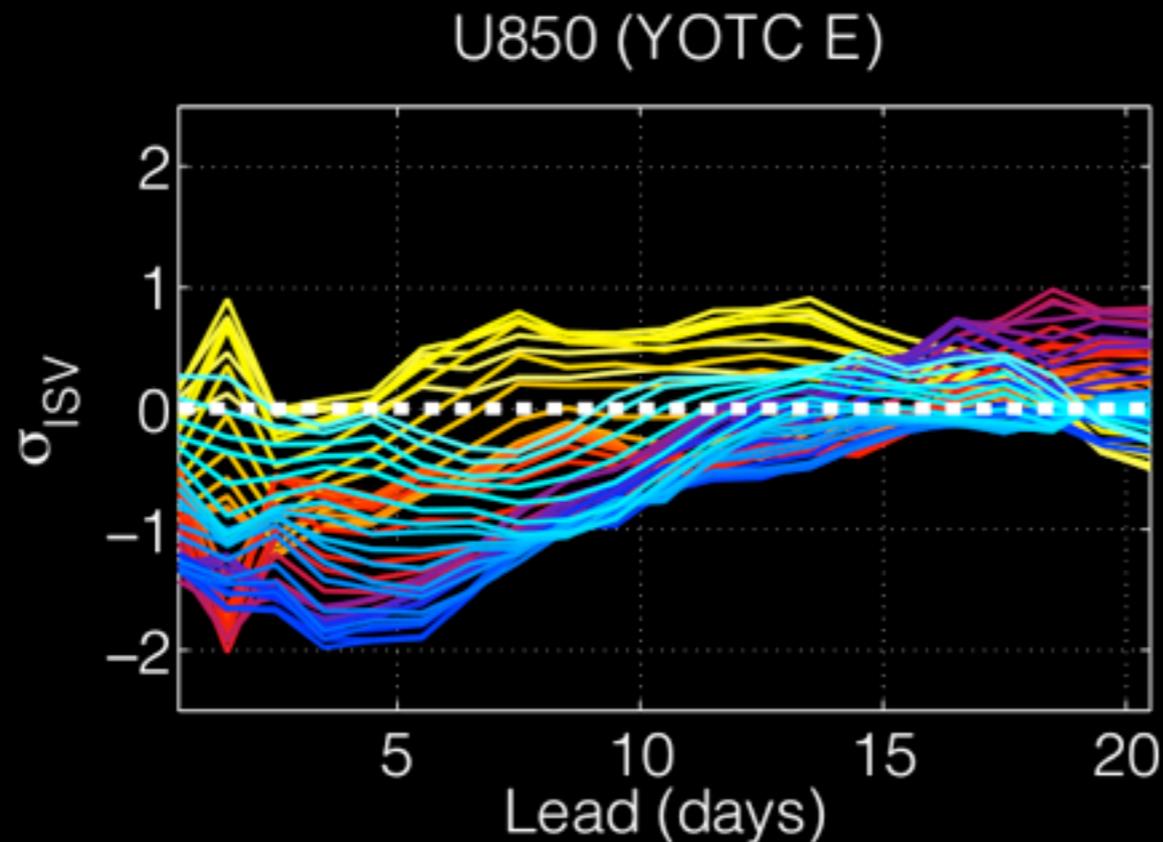
The drift is richly structured zonally and seasonally

Case D
(boreal summer)



Drift out of phase in **Indian ocean** vs. **Central Pacific**. Peaks at leads > 5 days.

Case E
(boreal winter)

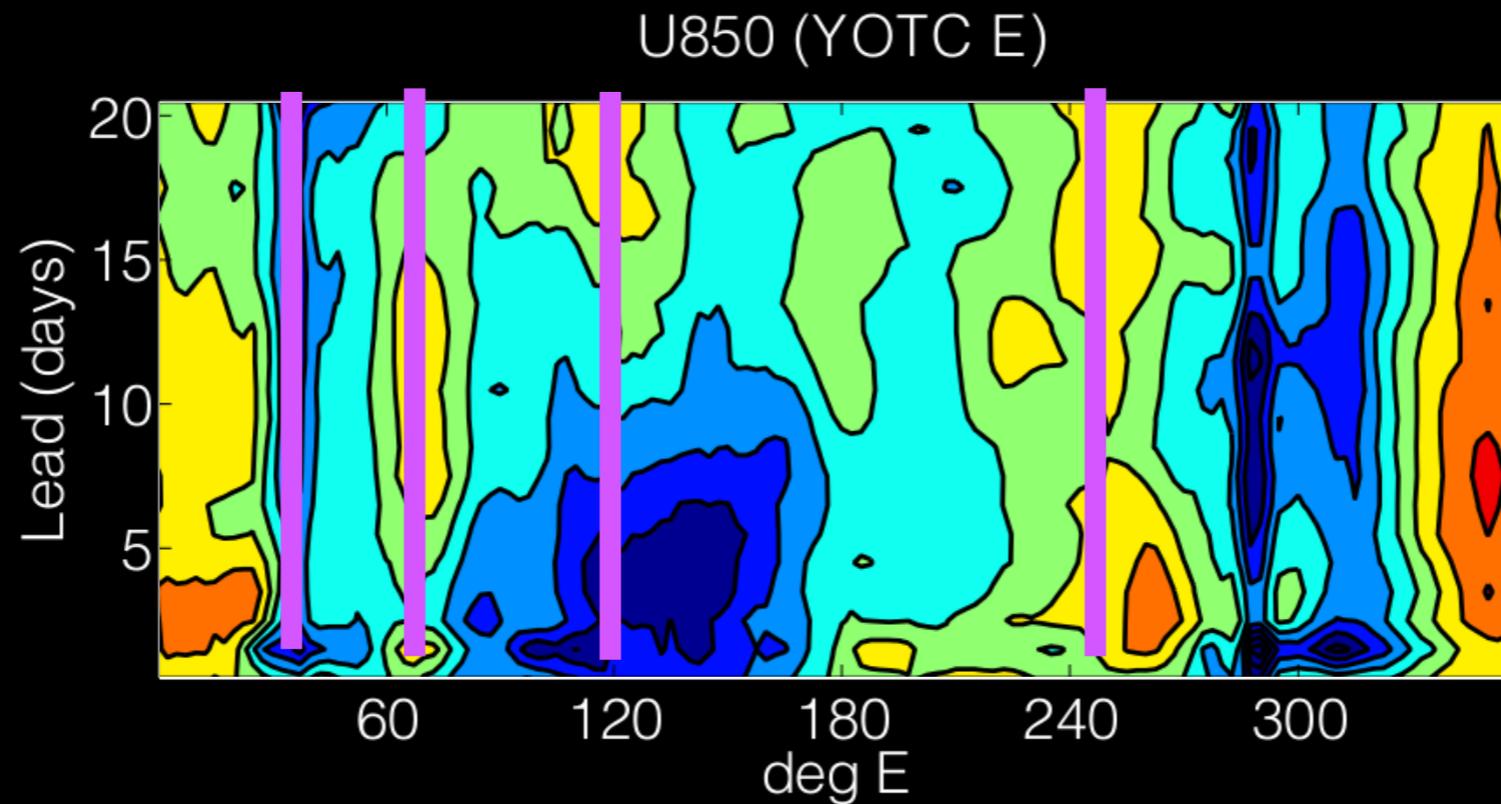
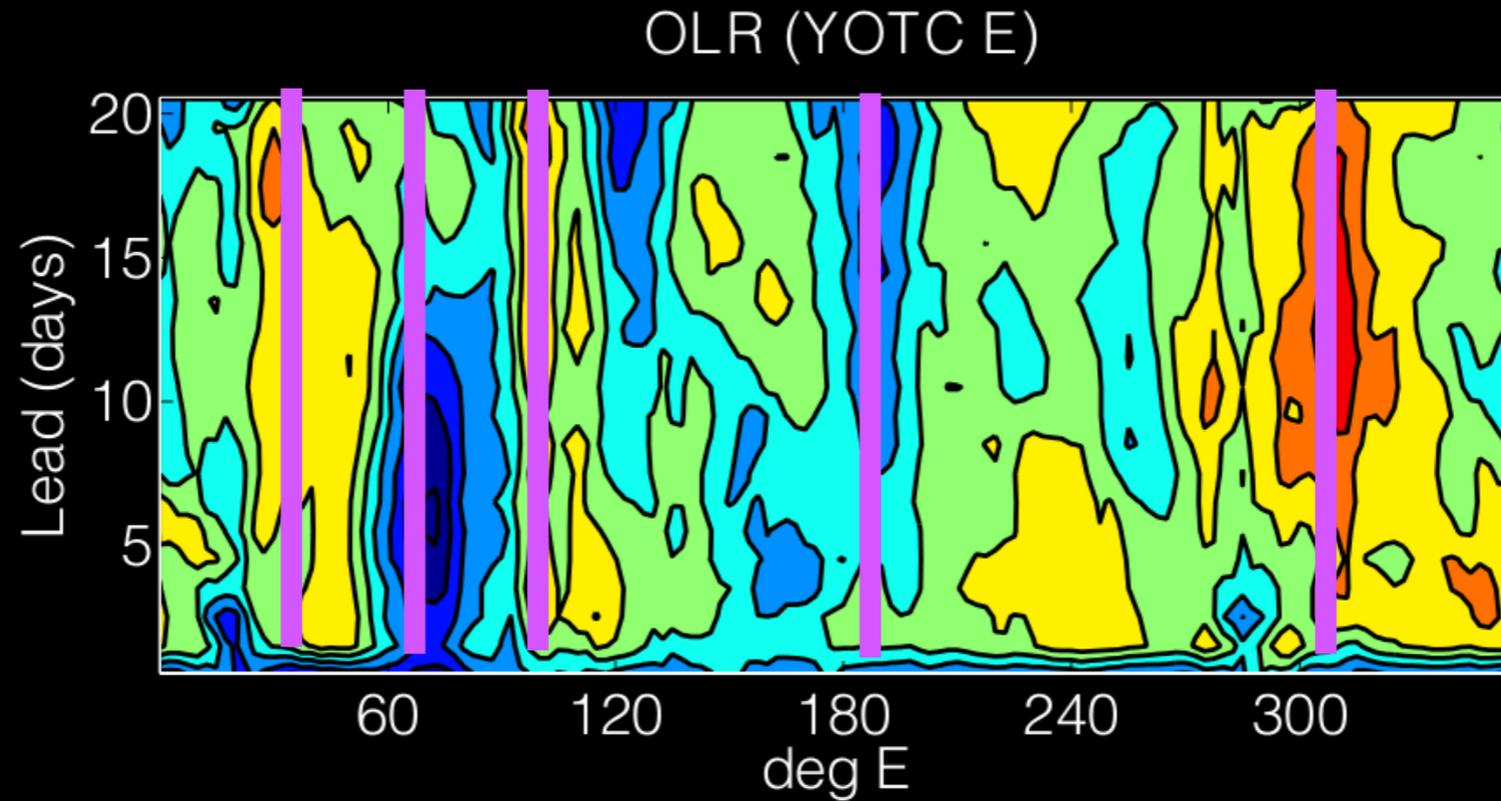


Drift depends on season/case: Regions in phase, peaks at leads < 5 days.

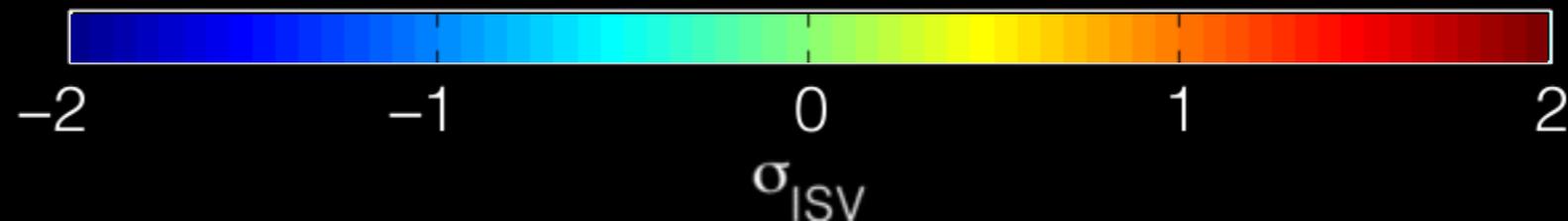


Drift is stationary implying it can be removed.

Lead-time vs.
longitude
structure.

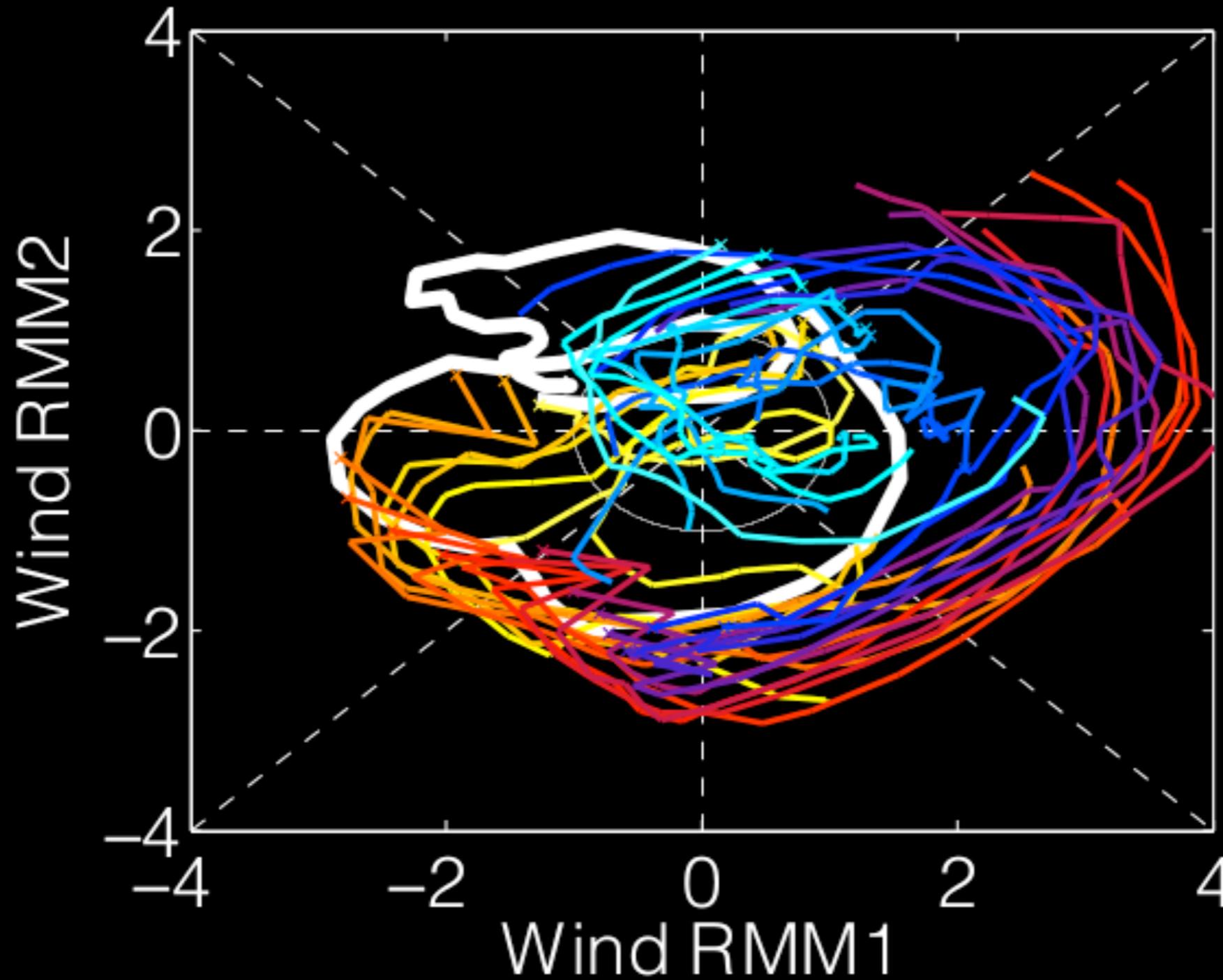


(real-time
mean
across
winter
ensemble;
Case E)



RMM trajectories of forecast case with drift included.

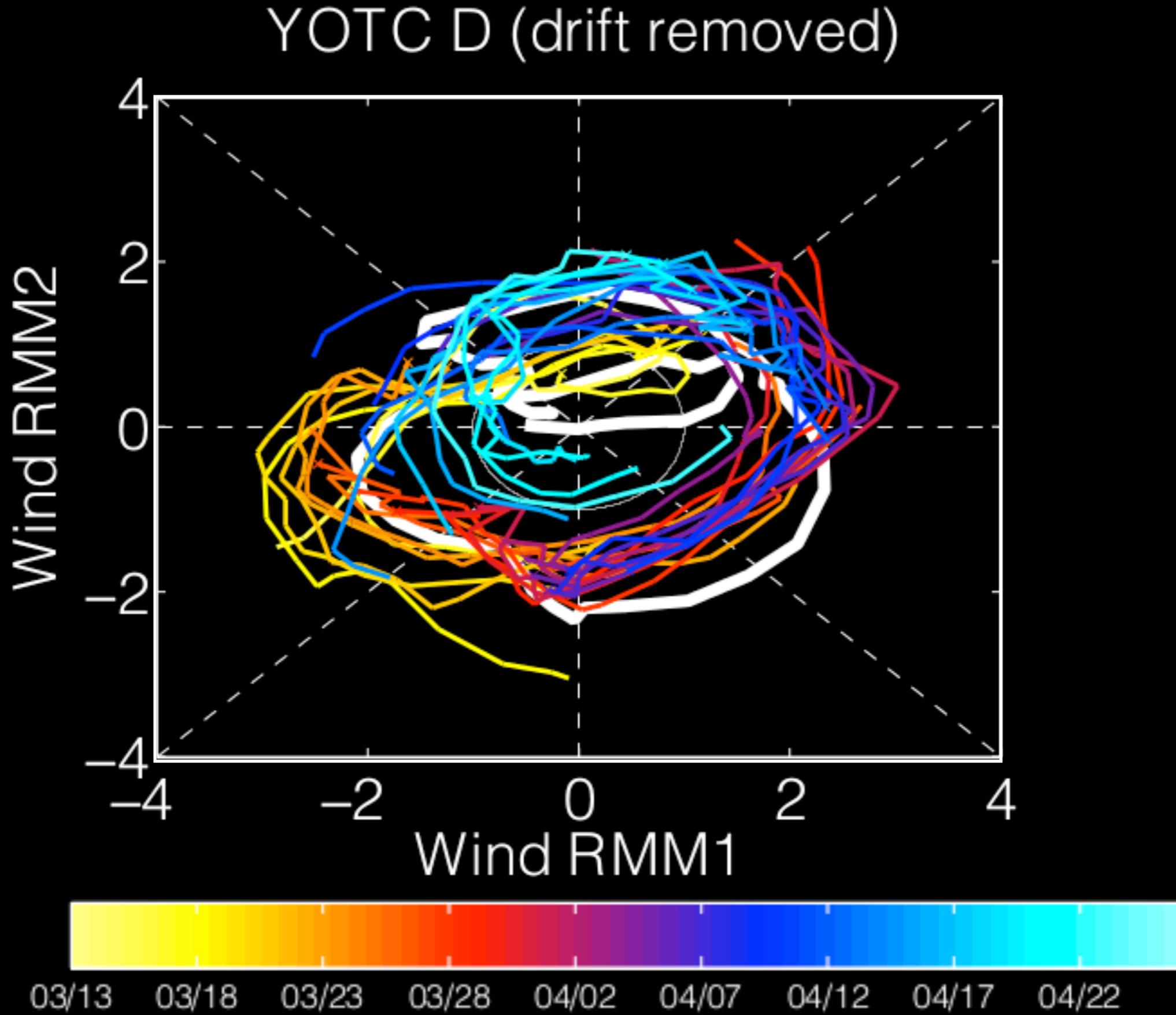
YOTC D (drift included)



initial date

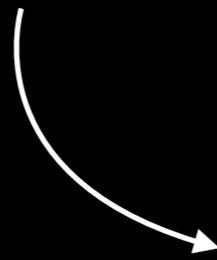
03/13 03/18 03/23 03/28 04/02 04/07 04/12 04/17 04/22

Drift removed. A very different view of SPCAM's MJO.



Hypothesis:

**The SPMJO is a
valid analog to nature.**



Expect:

Nontrivial forecast skill.



An unsolved initialization
problem obscures the
answer.

SPCAM3.0 provides a useful opportunity to:

Apply a *high-degree of freedom* global model,

making minimal assumptions about convection,

but producing a realistic MJO signal,

✓ ... composite structure.

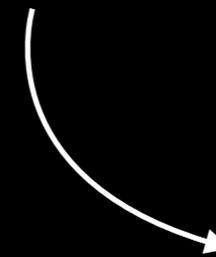
to examine processes & test their criticality.

Road map

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Hypothesis:

**Mesoscale organization is critical
to the dynamics of the SPMJO.**



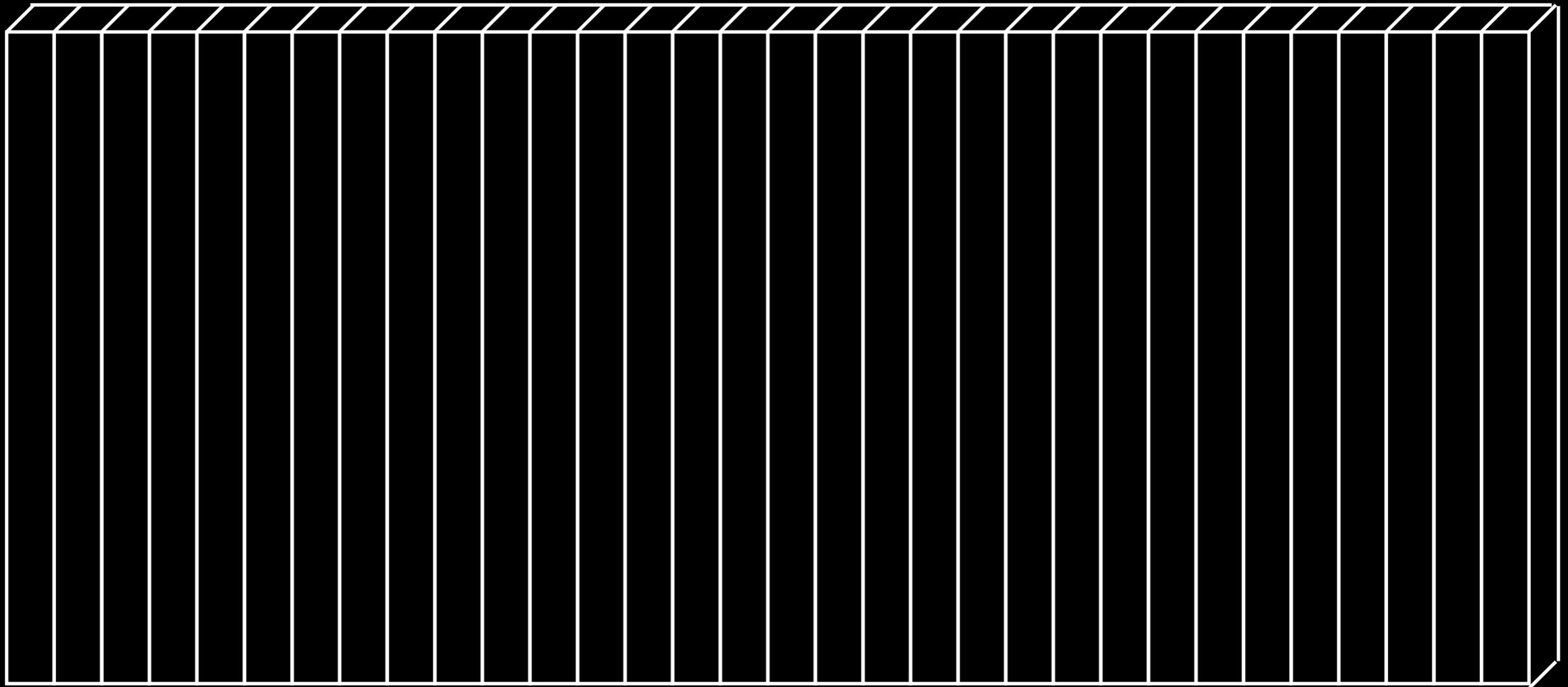
Expect:

The MJO signal depends on
resolving the mesoscale.

A **sensitivity test** nearly eliminating the mesoscale in twin 8-year free-running simulations.

SPCAM typically uses “big” cloud resolving arrays, with room for mesoscale storm organization.

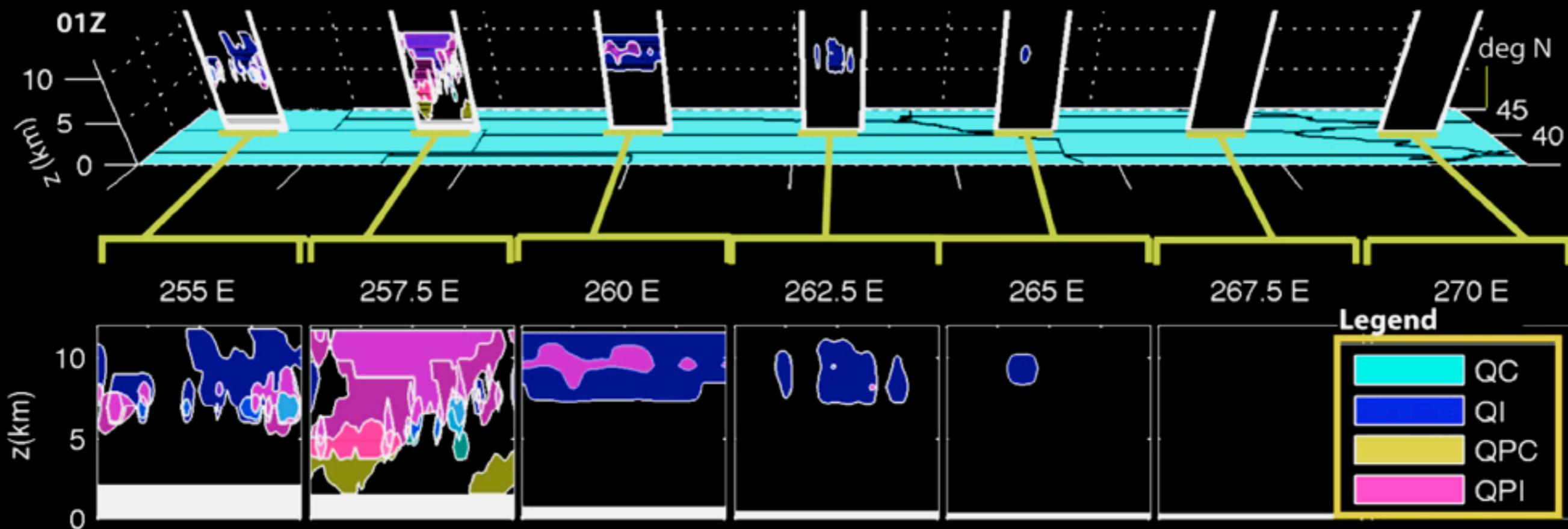
32x4km



← 128 km →

Mesoscale Convective Systems are visible in SPCAM's CRMs.

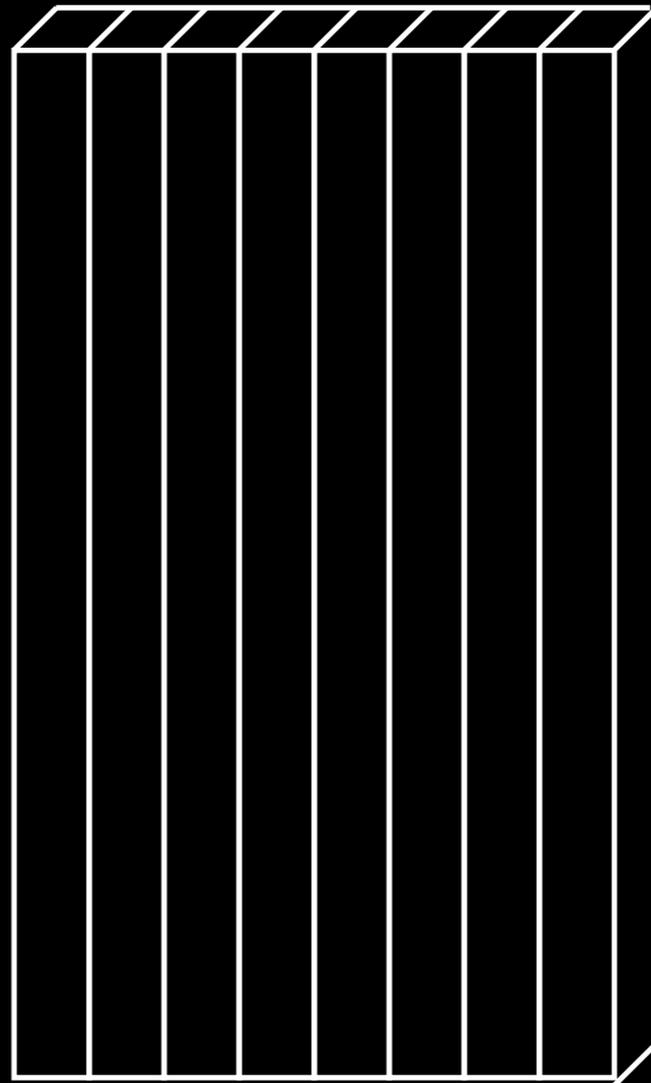
Condensate structure of the embedded cloud models in SP-CAM at 40N



Pritchard et al., JAS, 2011

What if we use an unusually tiny 2D cloud model?

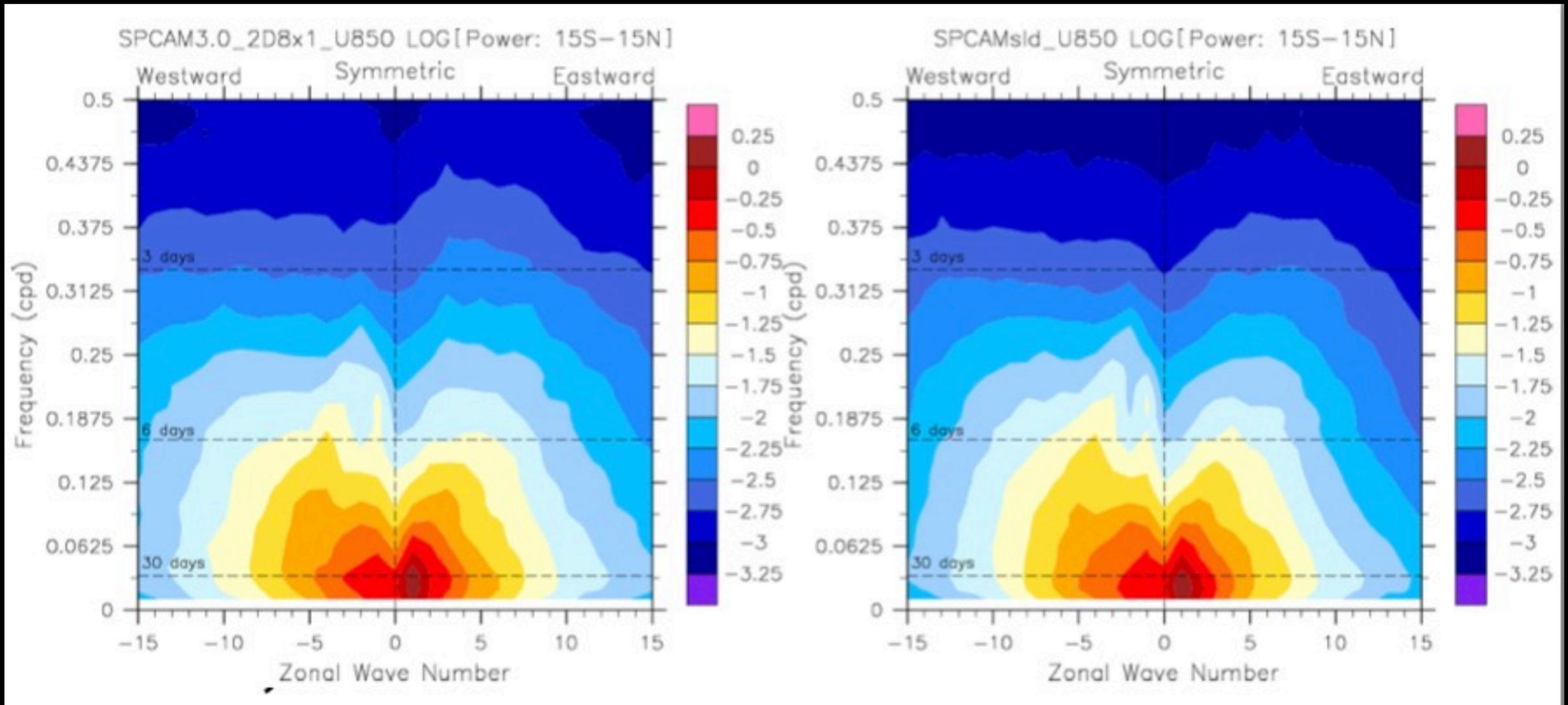
8x4km



← 32 km →

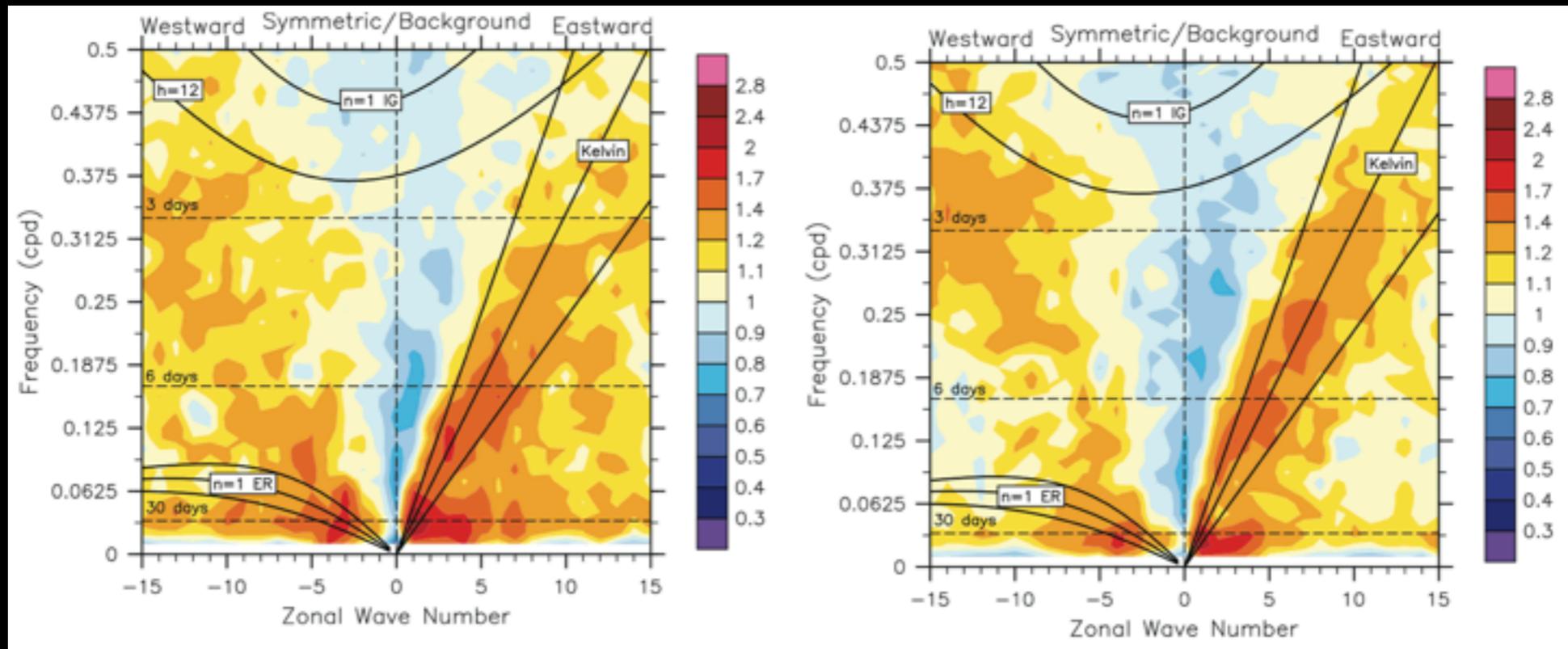
The MJO is robust to configurations with no mesoscale.

Tiny CRMs vs. Control



Wavenumber-frequency U850 spectra.

Tiny CRMs vs. Control



Wavenumber-frequency OLR signal-to-noise spectra.

Hypothesis:

Mesoscale organization is critical to the dynamics of the SPMJO.

Expect:

More MJO predictability if mesoscale initially spun-up.

Expect:

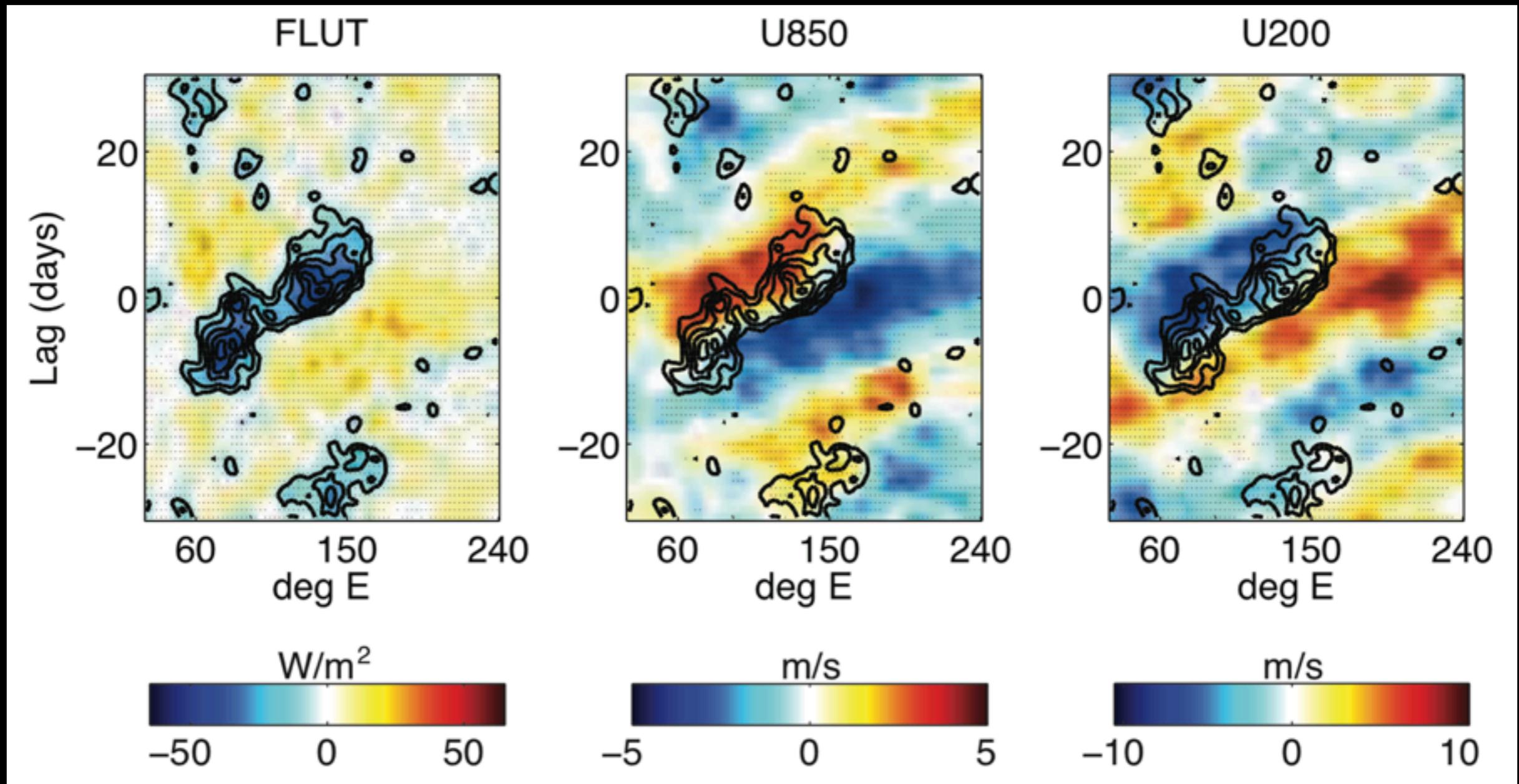
Predictability responds to changing inner model geometry.

Expect:

The MJO signal depends on resolving the mesoscale.



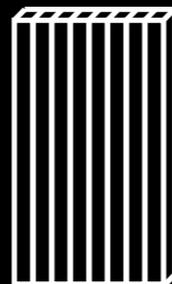
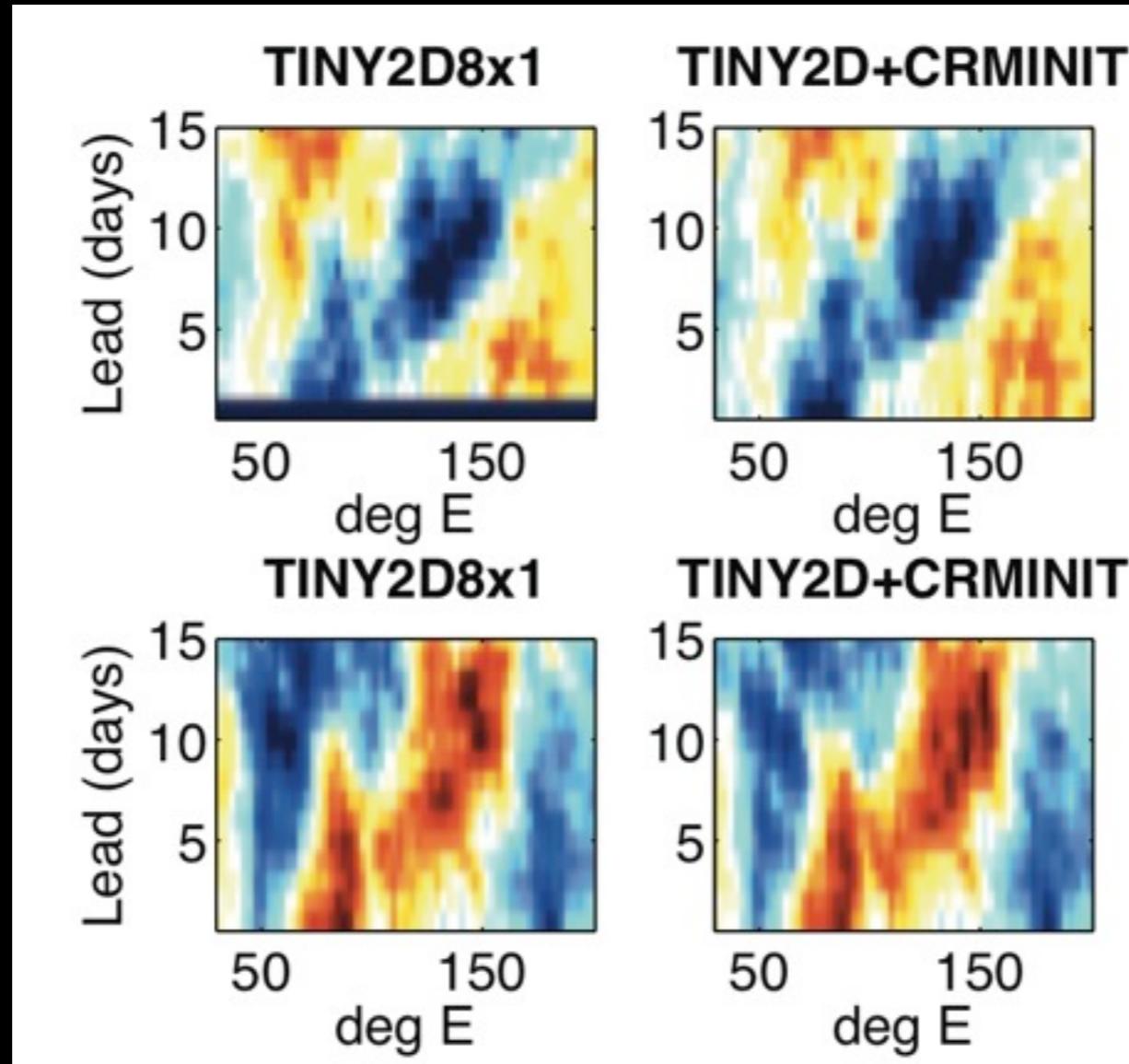
Baseline composite structure of an I I-event intrinsic* MJO forecast ensemble, phase-aligned with OLR EOFs.



Strategy: Re-forecast from model states,
validate against free-running trajectory.

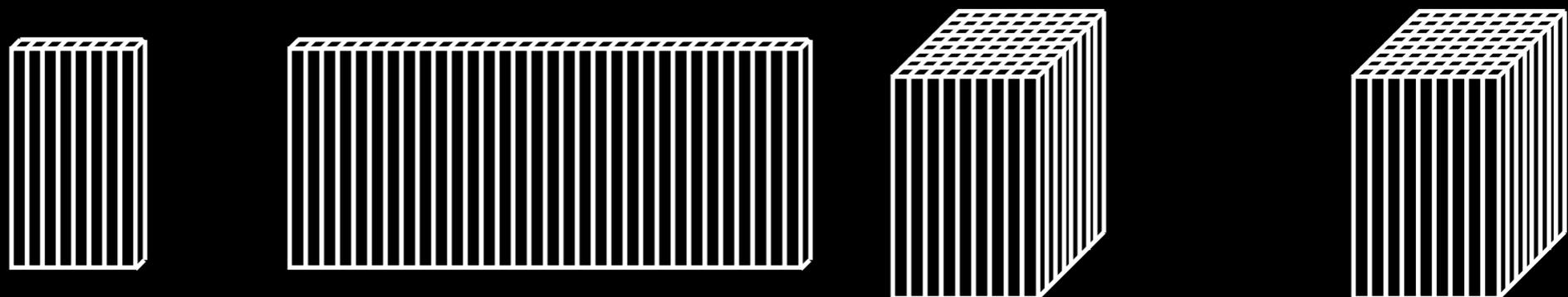
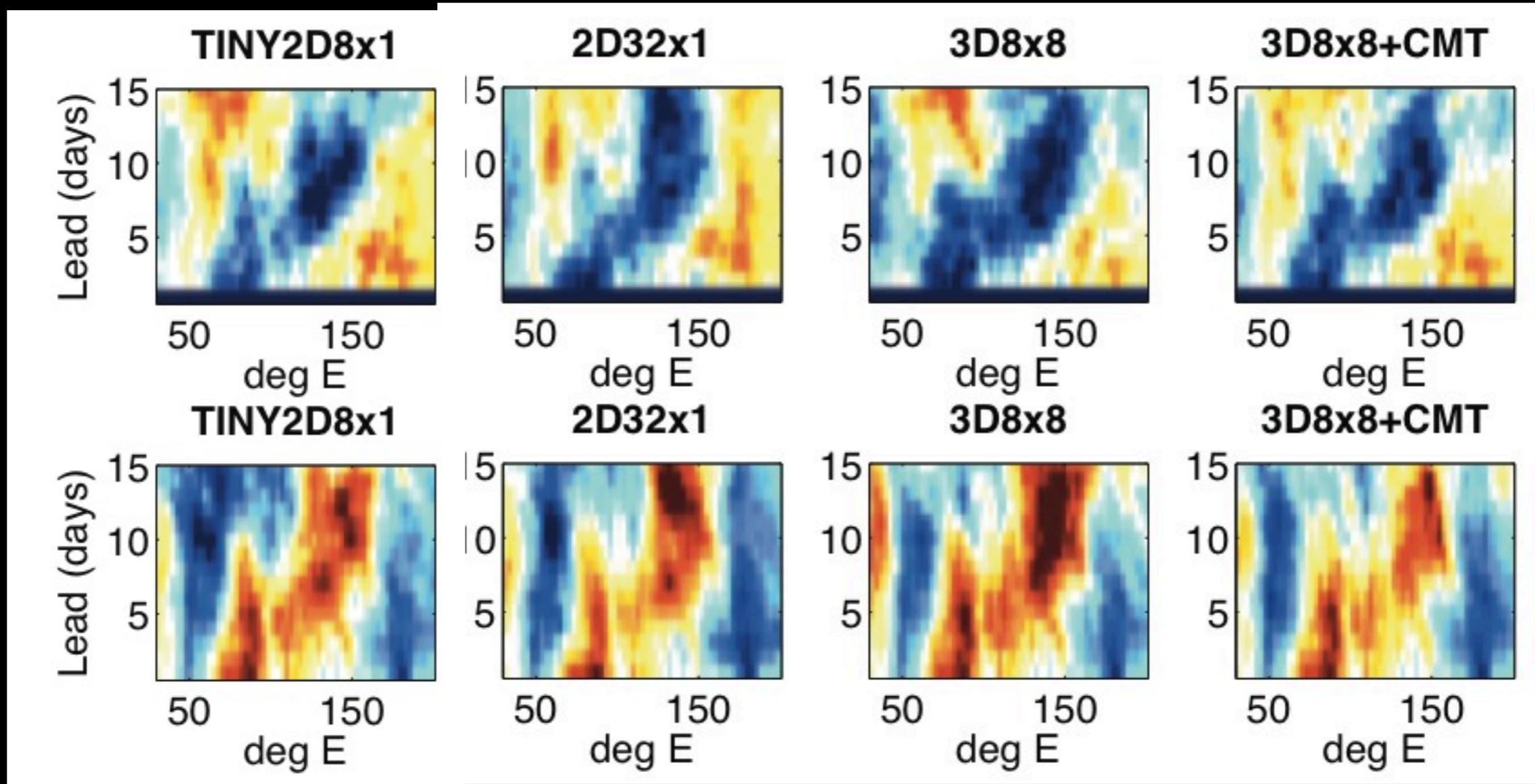
A *sensitivity test* of the importance of CRM-scale initiation on SPCAM's intrinsic MJO predictability.

Intrinsic MJO predictability is insensitive to initial conditions with no knowledge of mesoscale state.



A *sensitivity test* of the importance of upscale momentum transport and mesoscale organization on predictability.

Intrinsic MJO predictability is robust to decisions affecting the mesoscale organization of the cloud resolving arrays.



Hypothesis:

Mesoscale organization is critical to the dynamics of the SPMJO.

Expect:

More MJO predictability if mesoscale initially spun-up.

X

Expect:

Predictability responds to changing inner model geometry.

X

Expect:

The MJO signal depends on resolving the mesoscale.

X

So far, we have found insensitivities to a process relevant to the multi-scale paradigm of the MJO (mesoscale organization).

“relevant” not “critical”

(i.e. this does not say a multi-scale paradigm is invalid.)



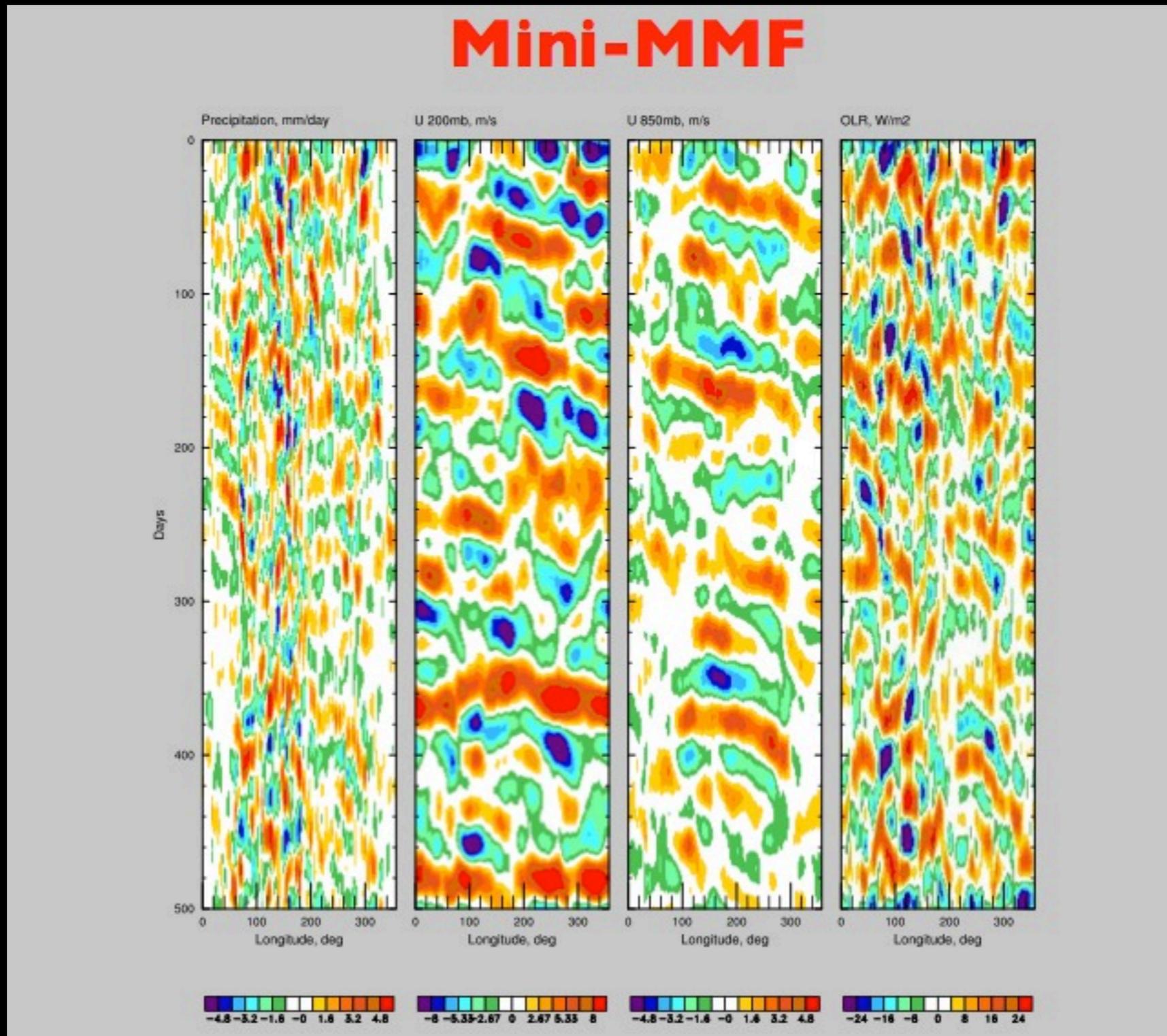
So far, we have found insensitivities to a process relevant to the multi-scale paradigm of the MJO (mesoscale organization).

Practically, mini-CRM enables 400% model speedup paving the way for enhanced SPMJO sensitivity testing.

Road map

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Glimmers of realistic intraseasonal behavior in an 8x1 CRM configuration of SPCAM have been seen before....



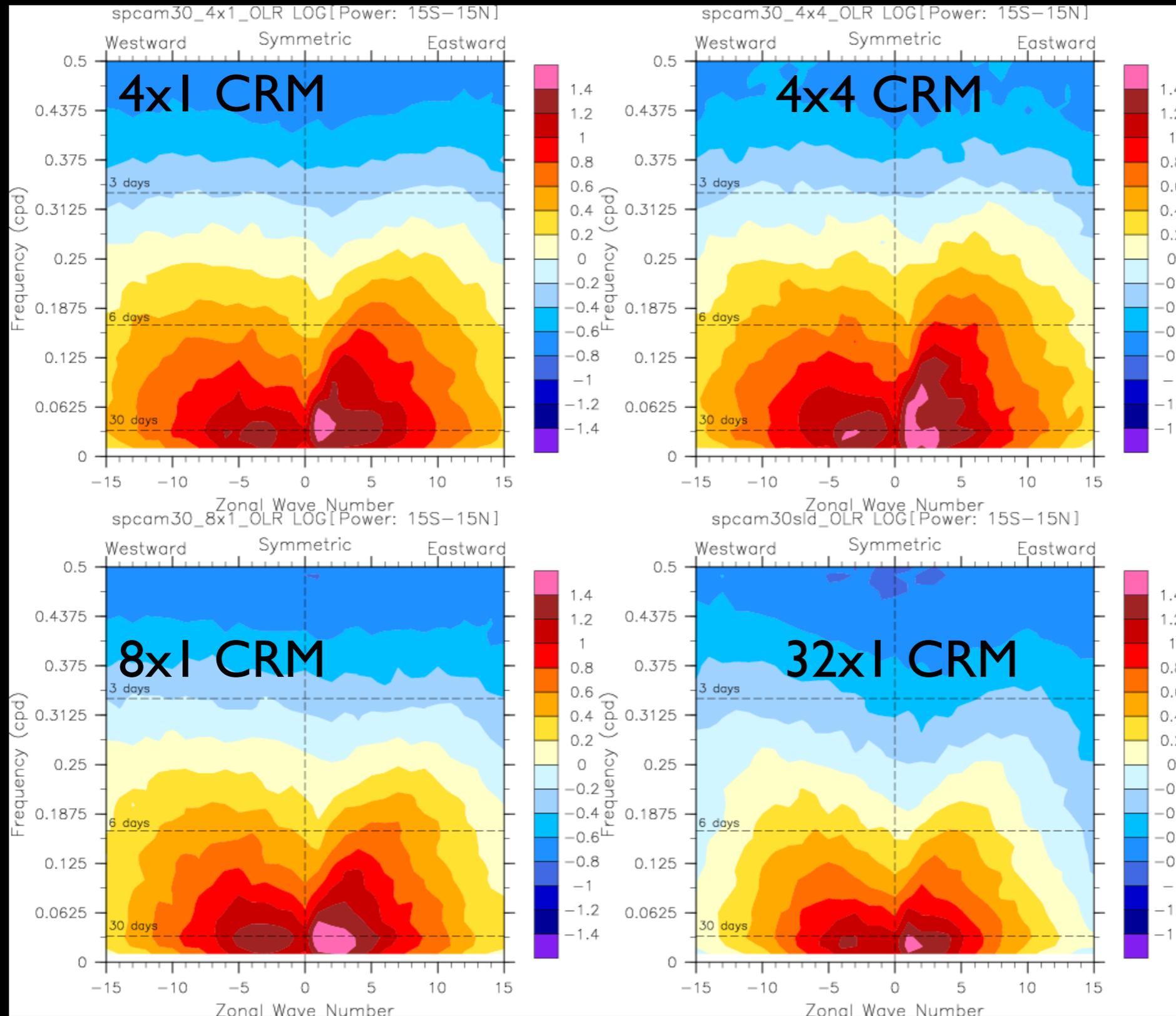
UCLA, 2004 CMMAP meeting
(slide c/o Dave Randall)

How low can you go?



UCLA, 2004 CMMAP meeting
(slide c/o Dave Randall)

The 8x1 “mini-CRM” configuration is actually a mysteriously lucky sweet spot for SPMJO fidelity...

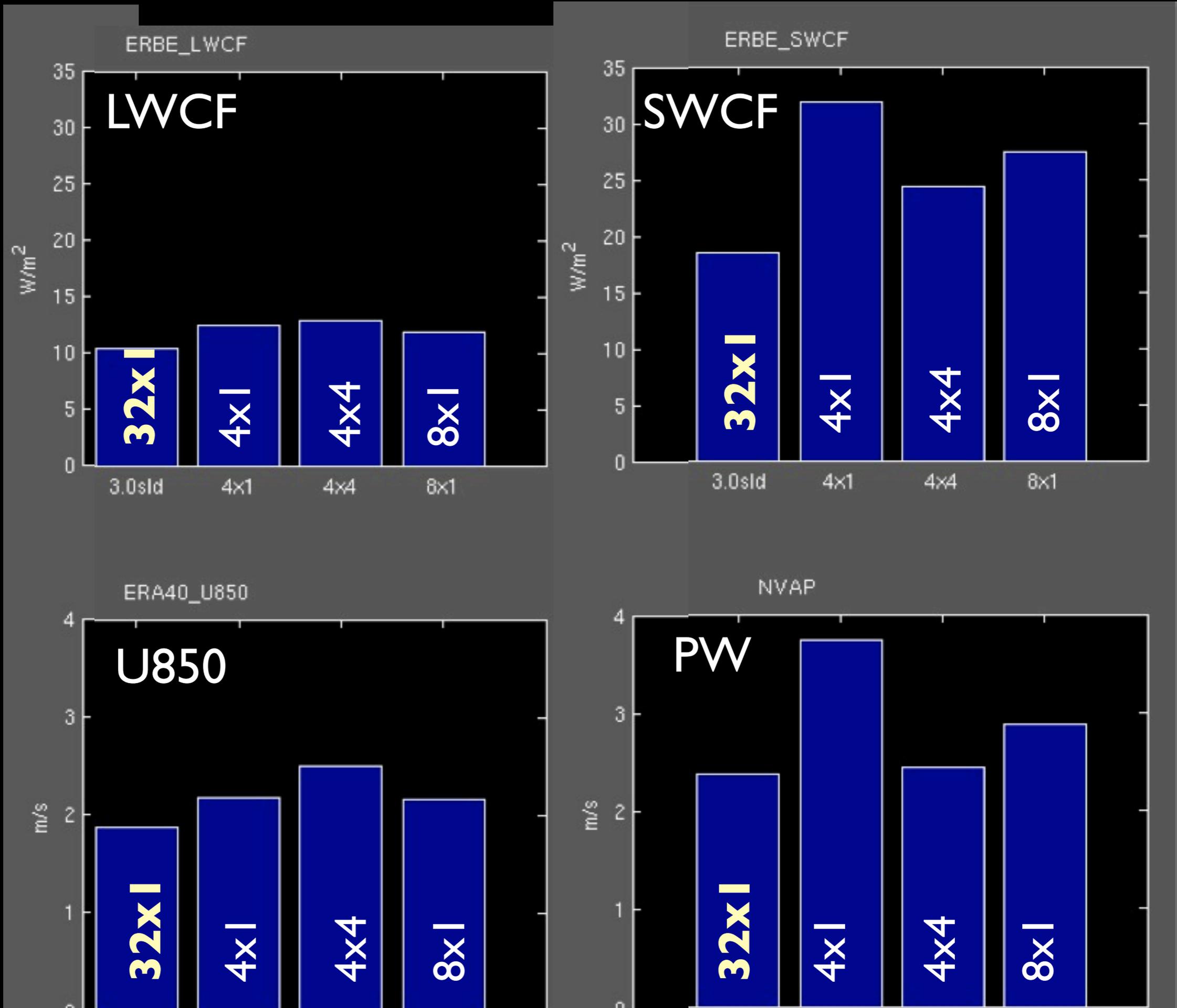


(9-year integrations)

And also for the mean state climatology.

Mean DJF
RMSE in
three
tiny-CRM
versions
of
SPCAM.

(9-year
integrations)



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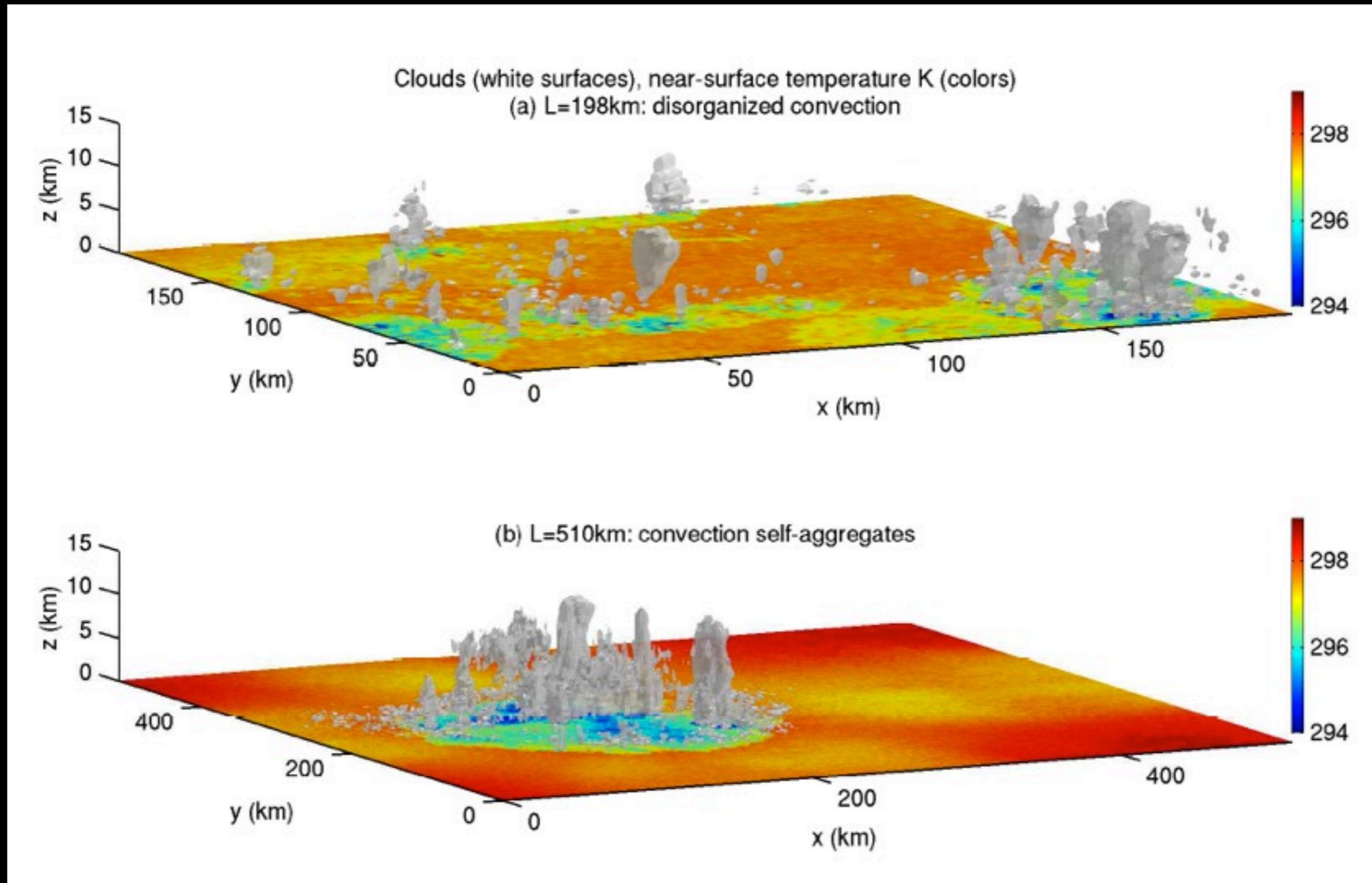
Hypothesis:

**Rotational moisture advection is critical
to the eastward propagation of the SPMJO.**

The moisture mode idea.

One way to think of how intraseasonal convection couples to large-scale circulations.

Undisturbed tropical convection self aggregates on large scales via internal feedbacks...



Large-domain cloud resolving model simulations from Muller & Held (2012).

... Coupled to horizontal advection, manifests as slow propagation - MJO as a **moisture mode**.

Column MSE budget is key diagnostic:

$$\frac{d}{dt} \langle \text{MSE} \rangle (x,y,t) = \text{why?}$$

(column MSE budget tendency variables)

Horizontal moisture advection is a critical mechanism.

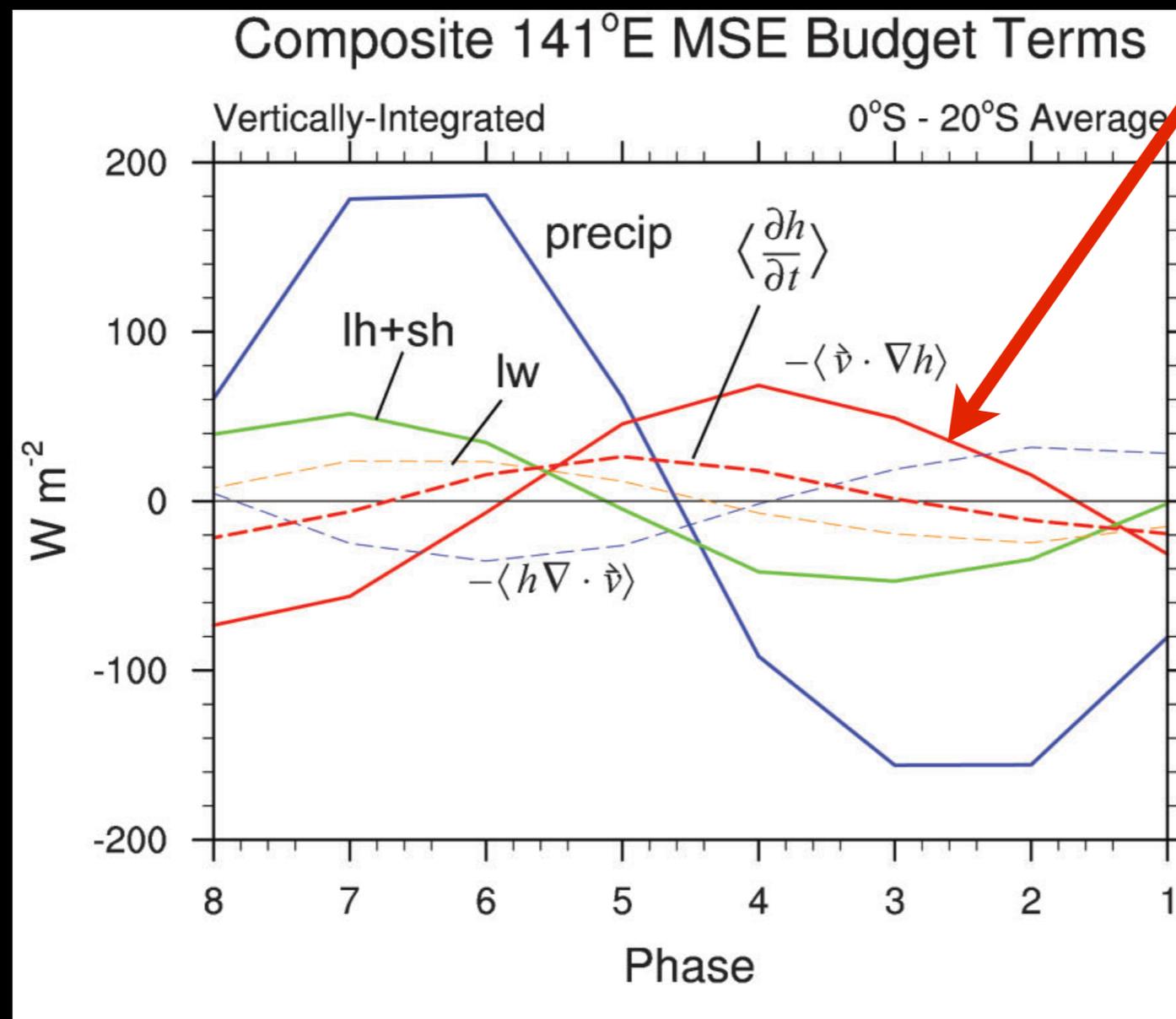
Example of a model with a moisture mode signature.

Maloney's CAM3 w. tightened RH-precip coupling.

- Comparing MJO-related variations in the column moist static energy budget.

A moisture mode signature:

Horizontal MSE advection mediating propagation



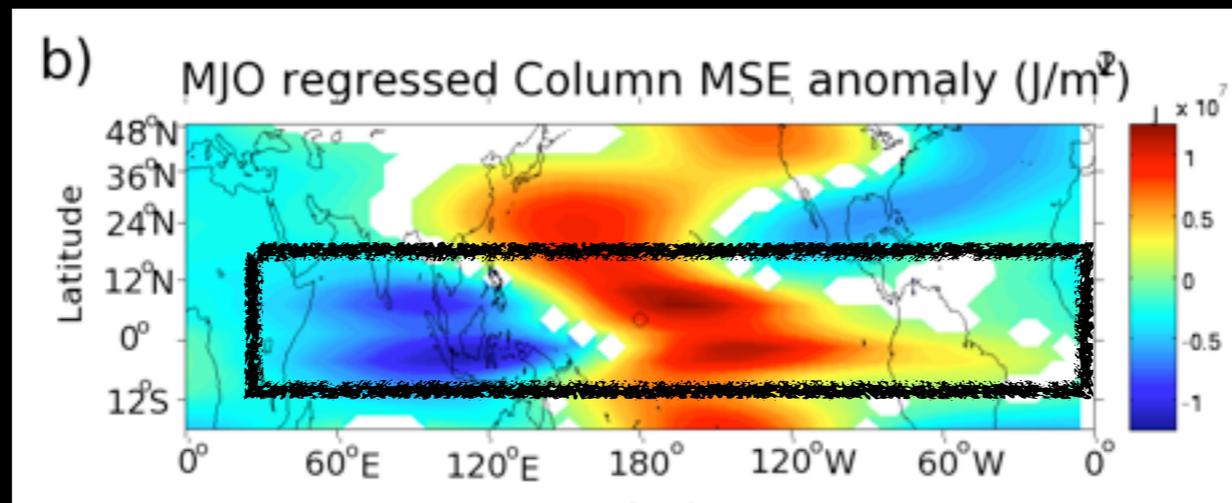
Maloney et al.,
JAMES, 2010

← Time (or x →)

A superparameterized model with a moisture mode MJO. Aquaplanet SPCAM3.5 w. zonally symmetric SSTs.

(Andersen & Kuang, *J. Clim.*, 2012.)

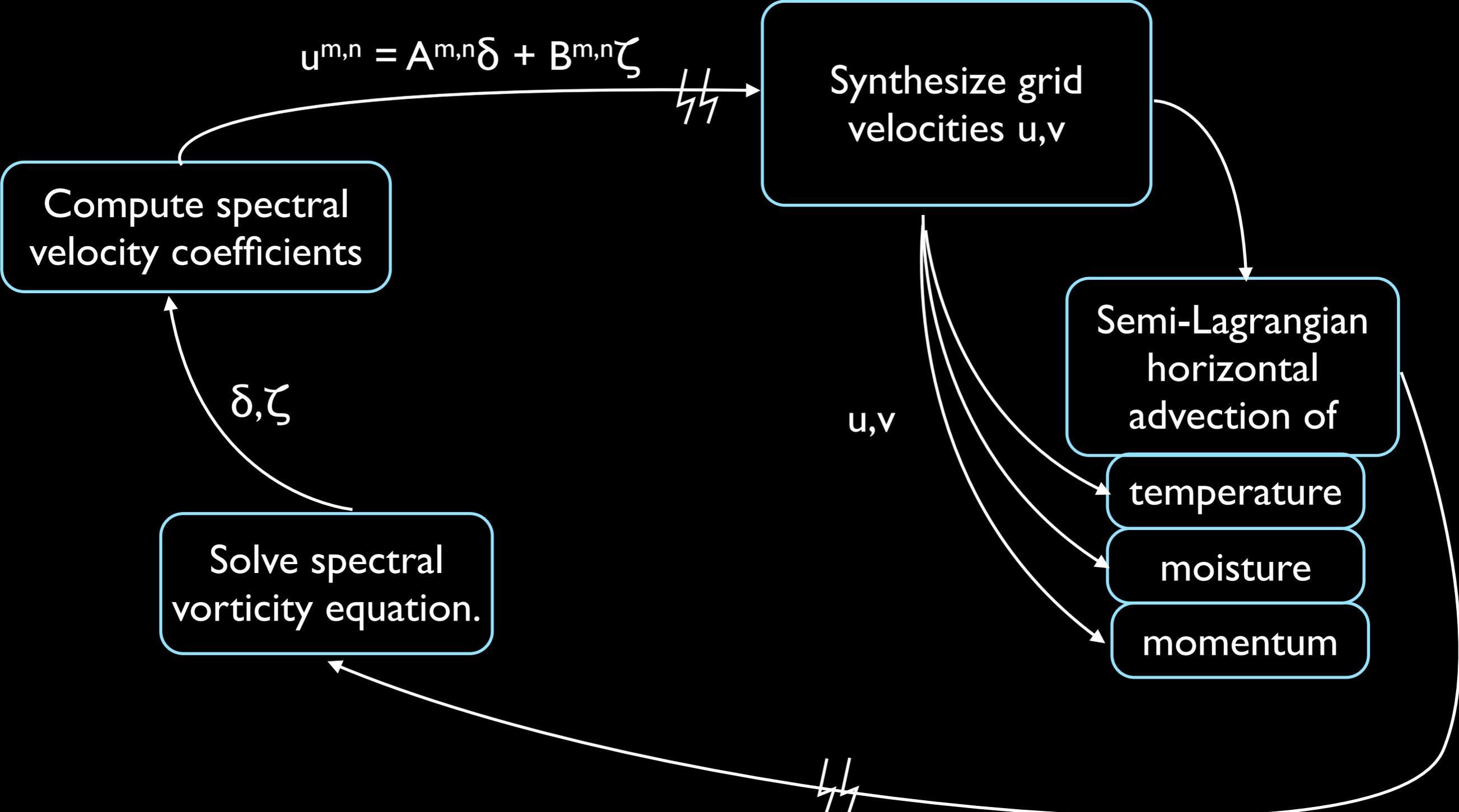
(x,y) structure of MJO-related column MSE anomaly



suggestive
zonal phase
quadrature

A new strategy to interfere with horizontal moisture advection in SPCAM3.0.

Some relevant sub-components of the SPCAM code circuit.



Adding an auxiliary velocity circuit with modulated vorticity.

external control parameter



$$u^{m,n} = A^{m,n}\delta + B^{m,n}(\alpha\zeta + f)$$

$$u^{m,n} = A^{m,n}\delta + B^{m,n}(\zeta + f)$$

Synthesize grid velocities u, v

Compute spectral velocity coefficients

δ, ζ

Solve spectral vorticity equation.

u, v

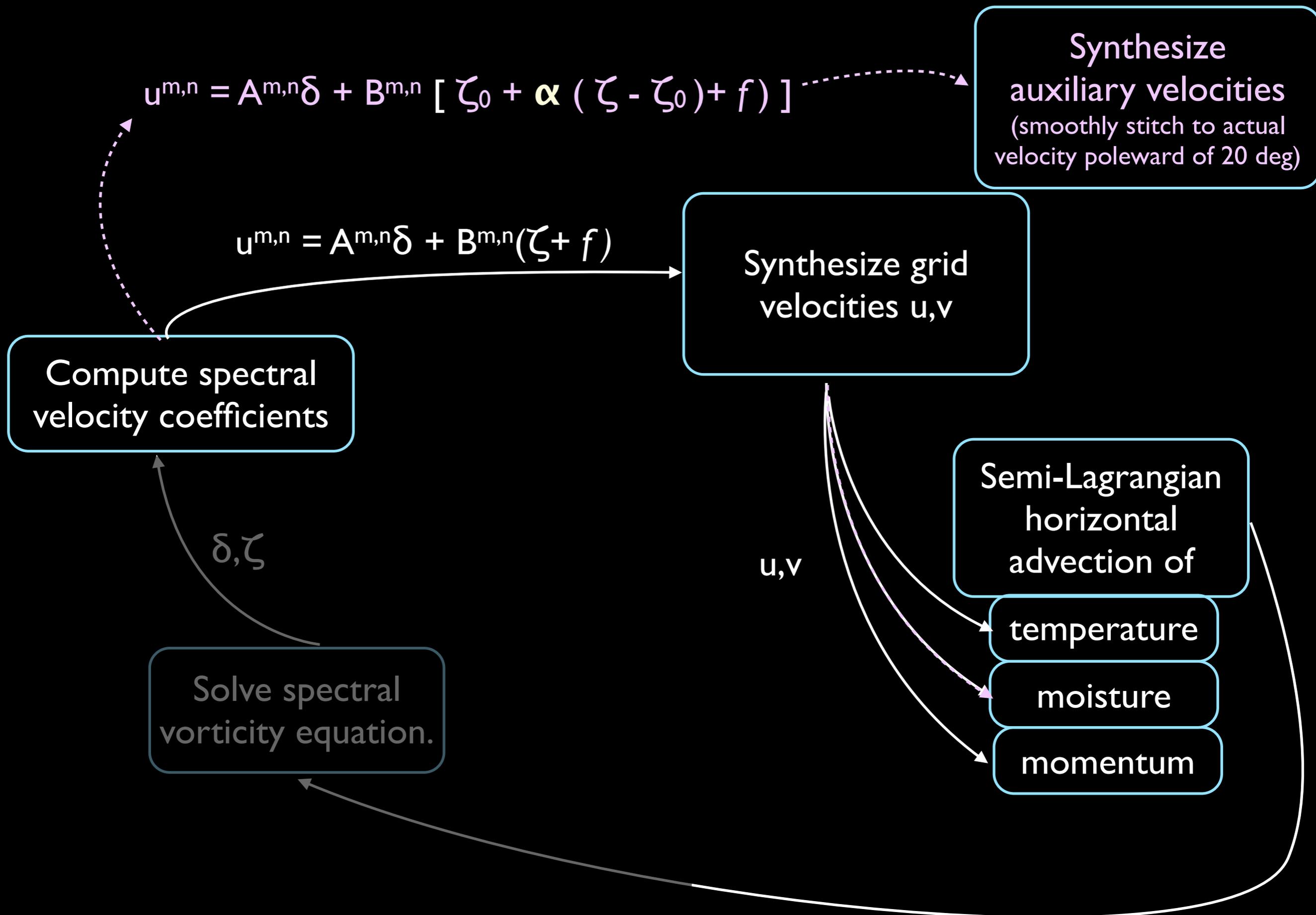
Semi-Lagrangian horizontal advection of

temperature

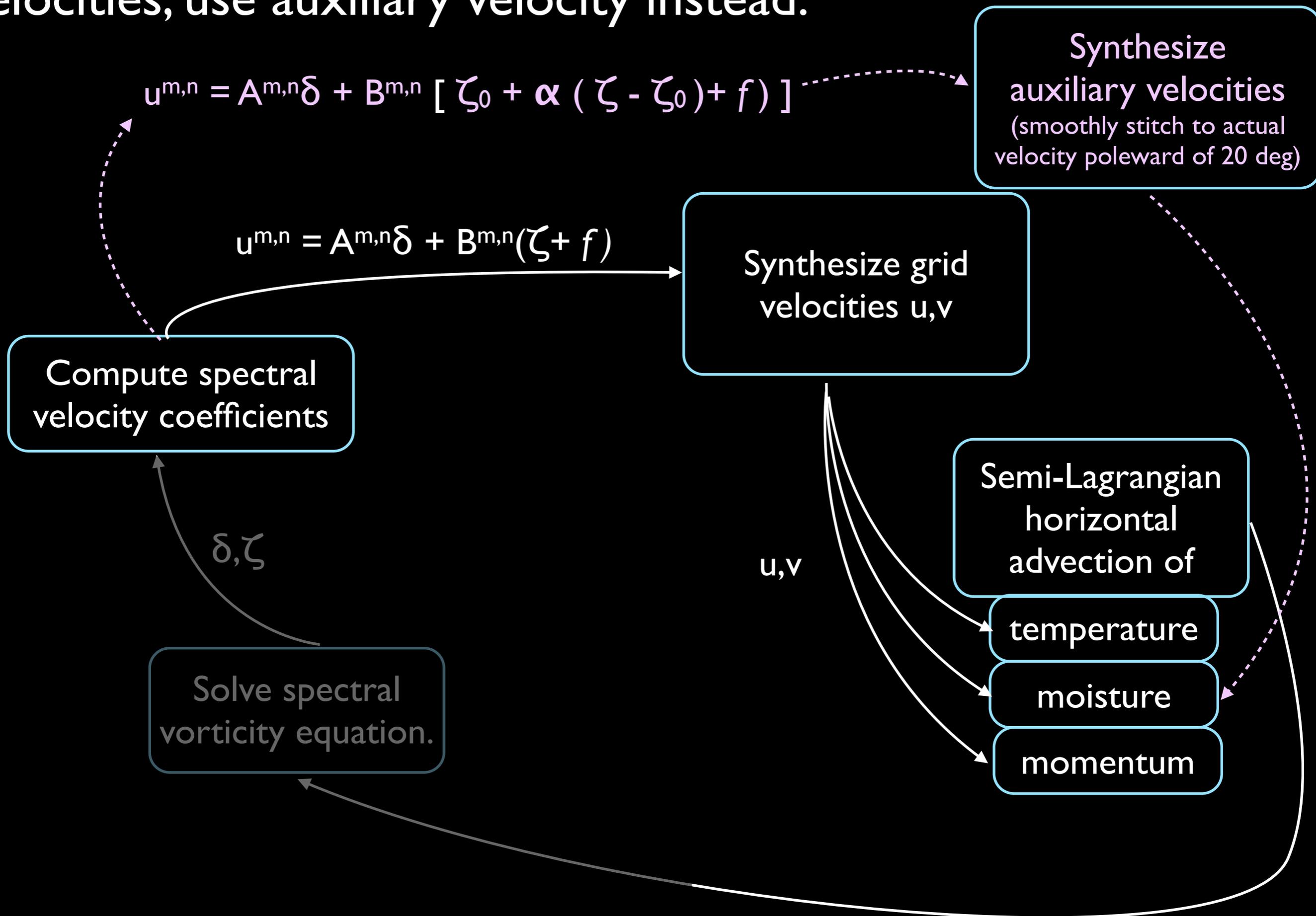
moisture

momentum

Limit the vorticity interference to the tropics.



To interfere, decouple only moisture advection from actual velocities, use auxiliary velocity instead.



In summary, an external control parameter α has been added to SPCAM such that

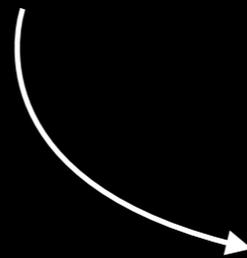
$\alpha > 1$ amplifies

$0 < \alpha < 1$ damps

moisture advection due to tropical vorticity anomalies.

Hypothesis:

Rotational moisture advection is critical to the eastward propagation of the SPMJO.



Expect:

The MJO signal speeds up if horizontal moisture advection is artificially enhanced.

(Focus: *Rotational flow*, real-geography basic state, fully nonlinear world.)

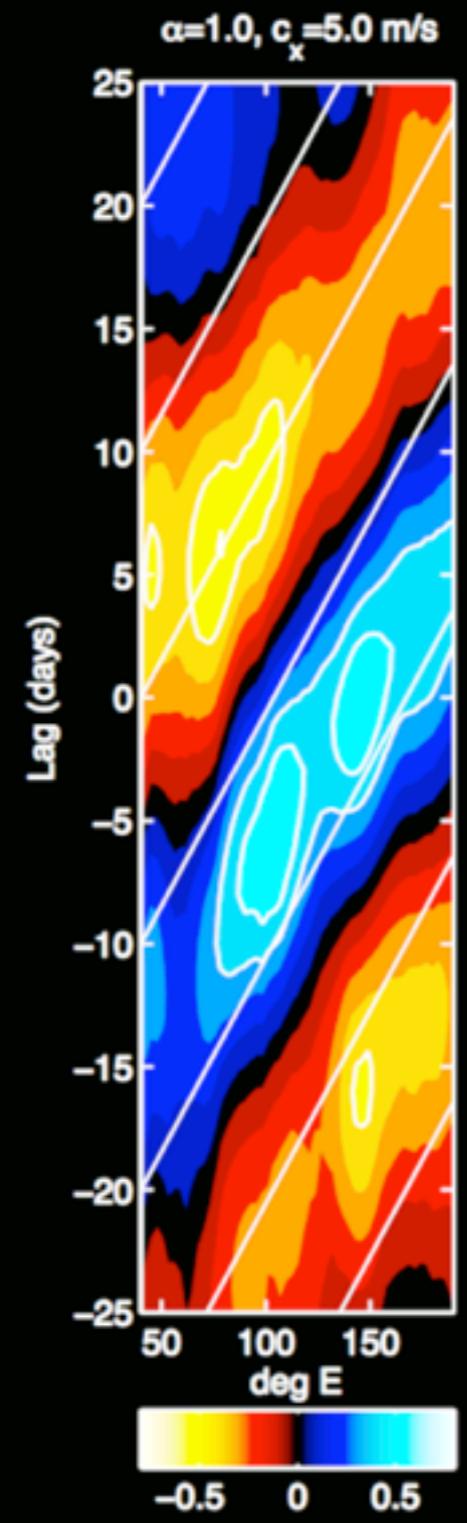
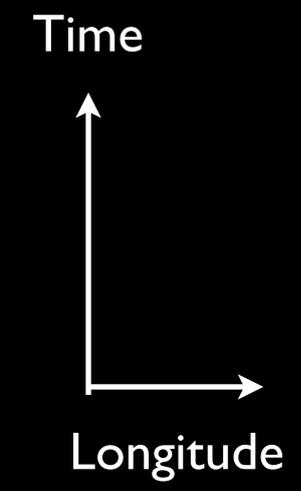
Effect of varying α on SPCAM's MJO.

8-year SPCAM runs, accelerated using tiny CRM approach.

Expected MJO speedup when boosting moisture advection, MJO phase speed response.

From 5 m/s to 7.5 m/s. Increasing α from unity \longrightarrow

MJO-regressed
850 hPa winds,
lagged in

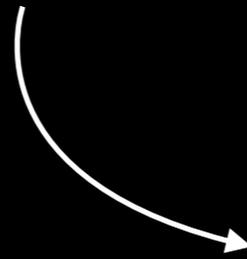


Hypothesis:

**Rotational moisture advection is critical
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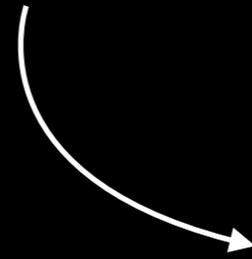


Causal evidence supporting the hypothesis?

Only if the null hypothesis can be ruled out.

Null hypothesis:

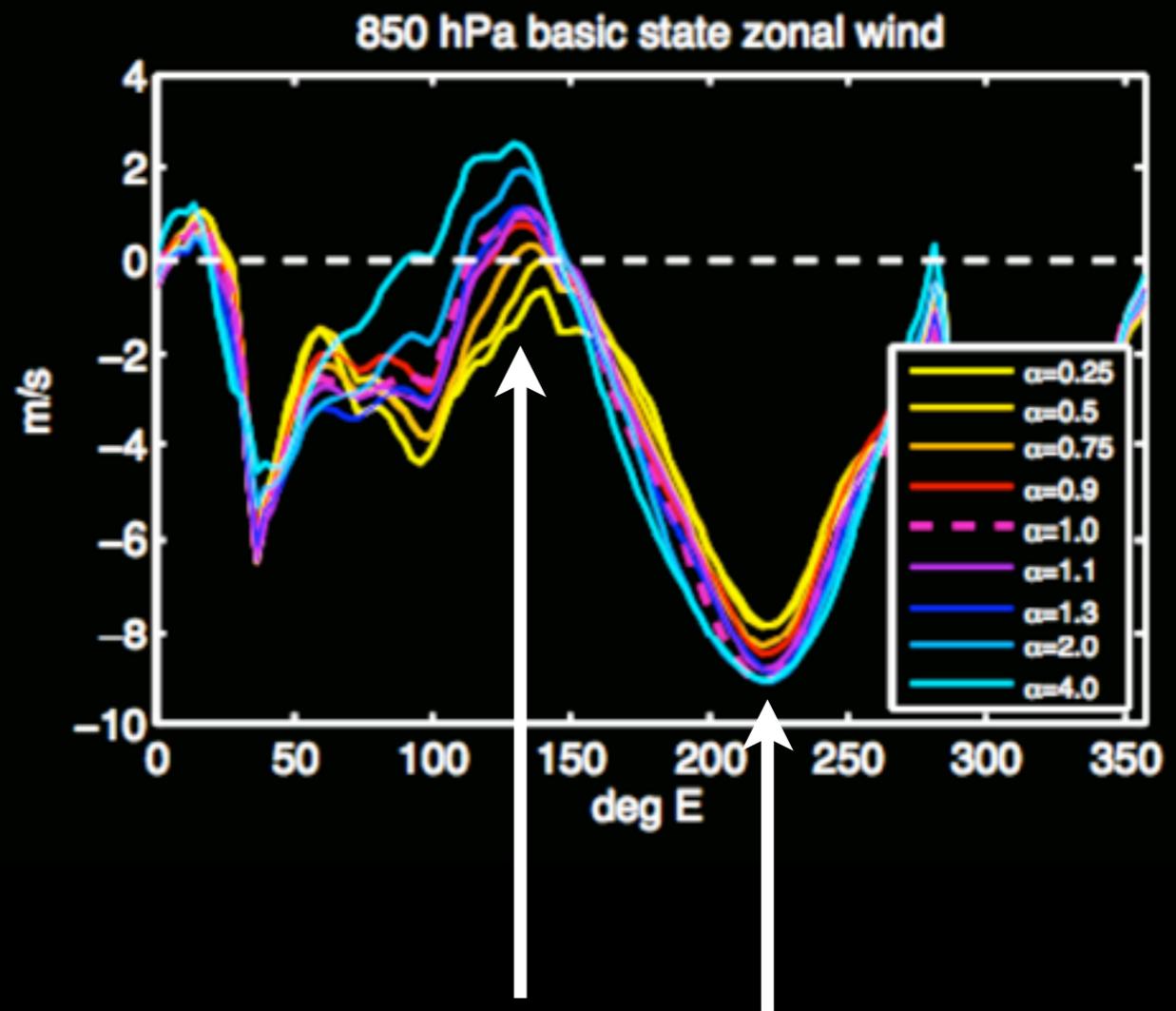
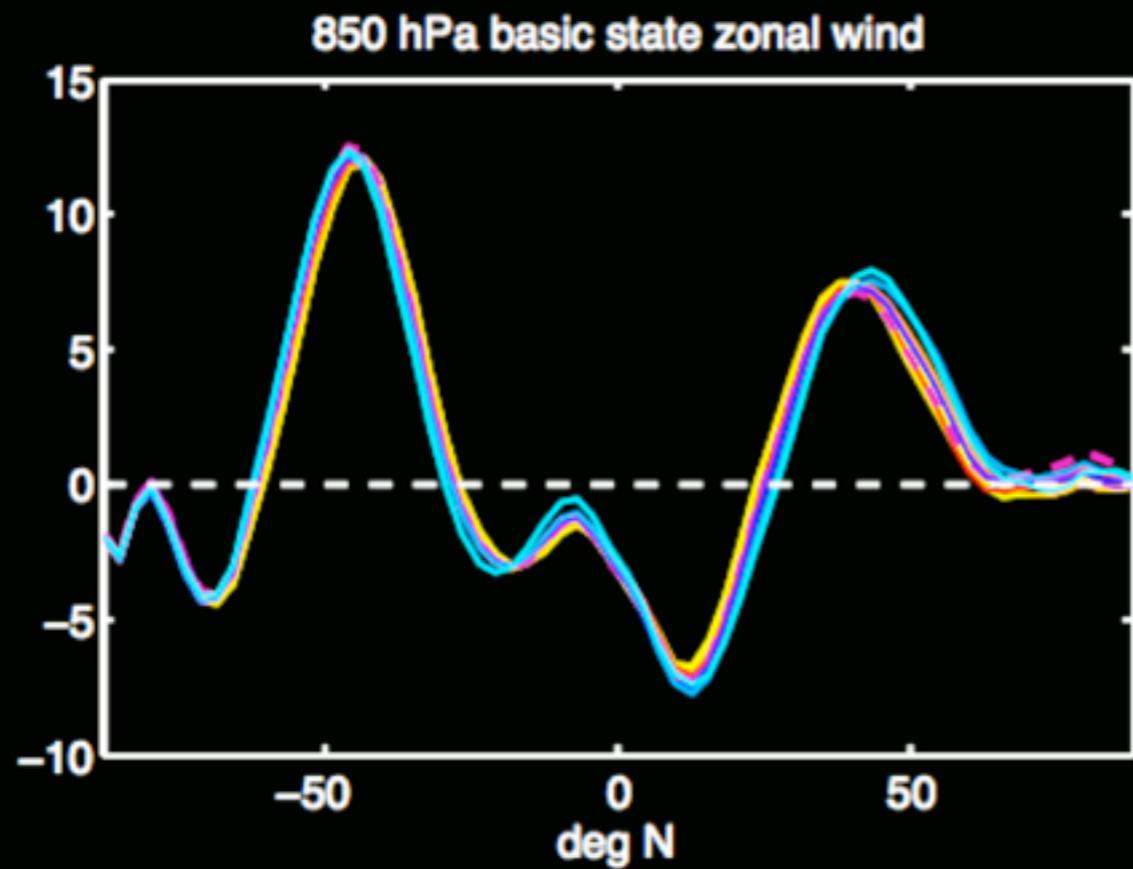
MJO speedup is an artifact of basic state adjustment.



Speedup, expect:

Westerly acceleration of mean zonal winds throughout tropics.

Low-level flow response to enhanced advection is inconsistent with MJO speedup.



Reversal of flow response within MJO speedup region.

Null hypothesis:

MJO speedup is an artifact of basic state adjustment.

Speedup, expect:

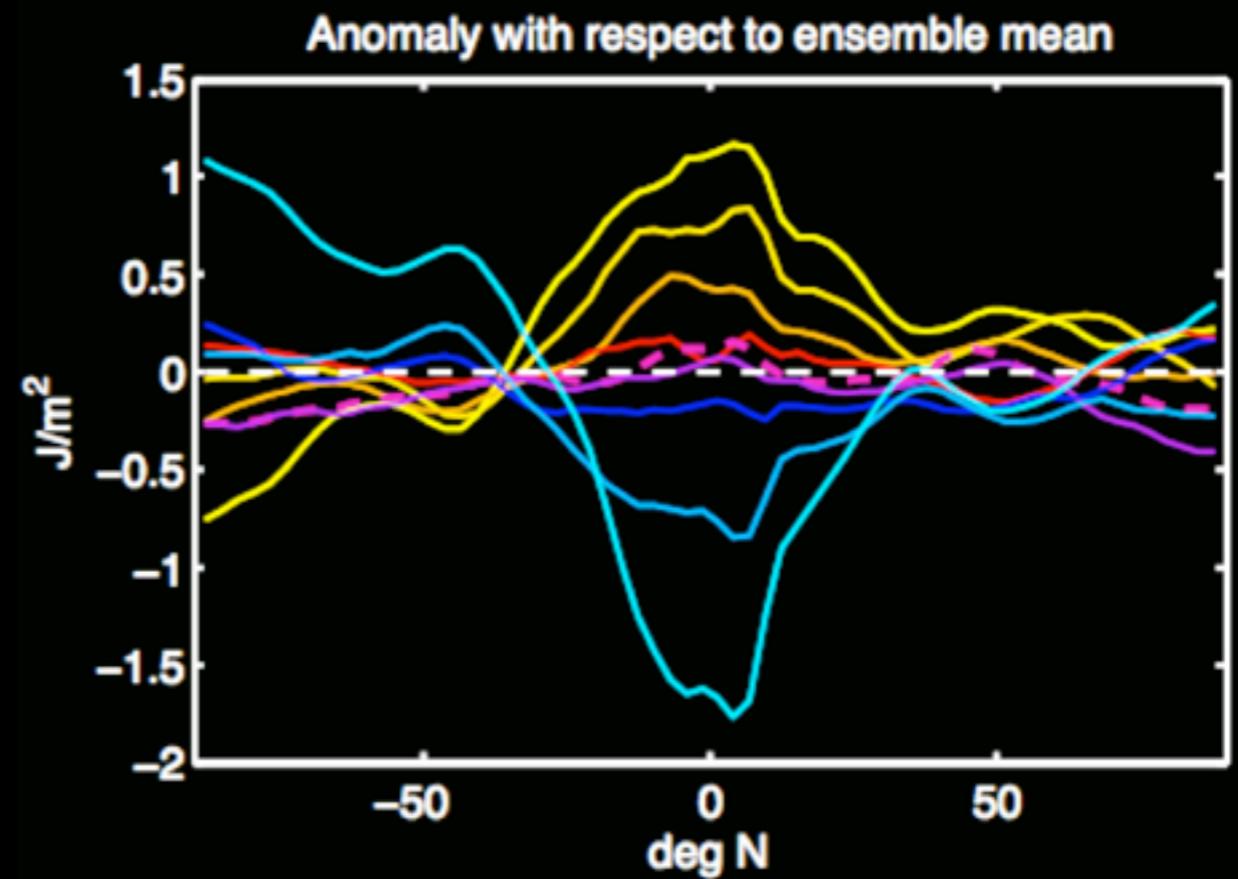
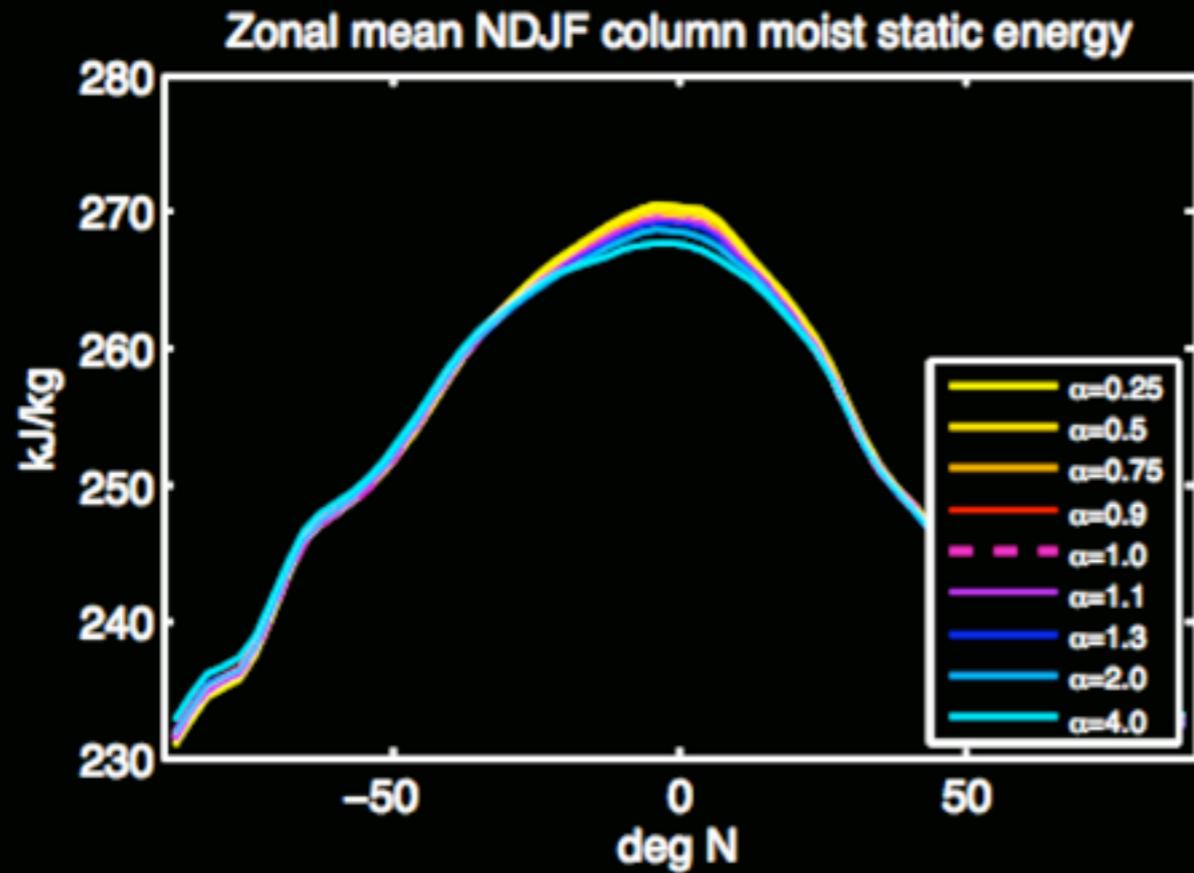
Sharpening of meridional MSE gradient, enhanced drying by MJO gyres.

Speedup, expect:

Westerly acceleration of mean zonal winds throughout tropics or narrowing of the ITCZ.

X

Flattened background meridional MSE gradient, also inconsistent with MJO speedup.



Null hypothesis:

MJO speedup is an artifact of basic state adjustment.

Speedup, expect:

Steepening of meridional MSE gradient, enhanced drying by MJO gyres.

X

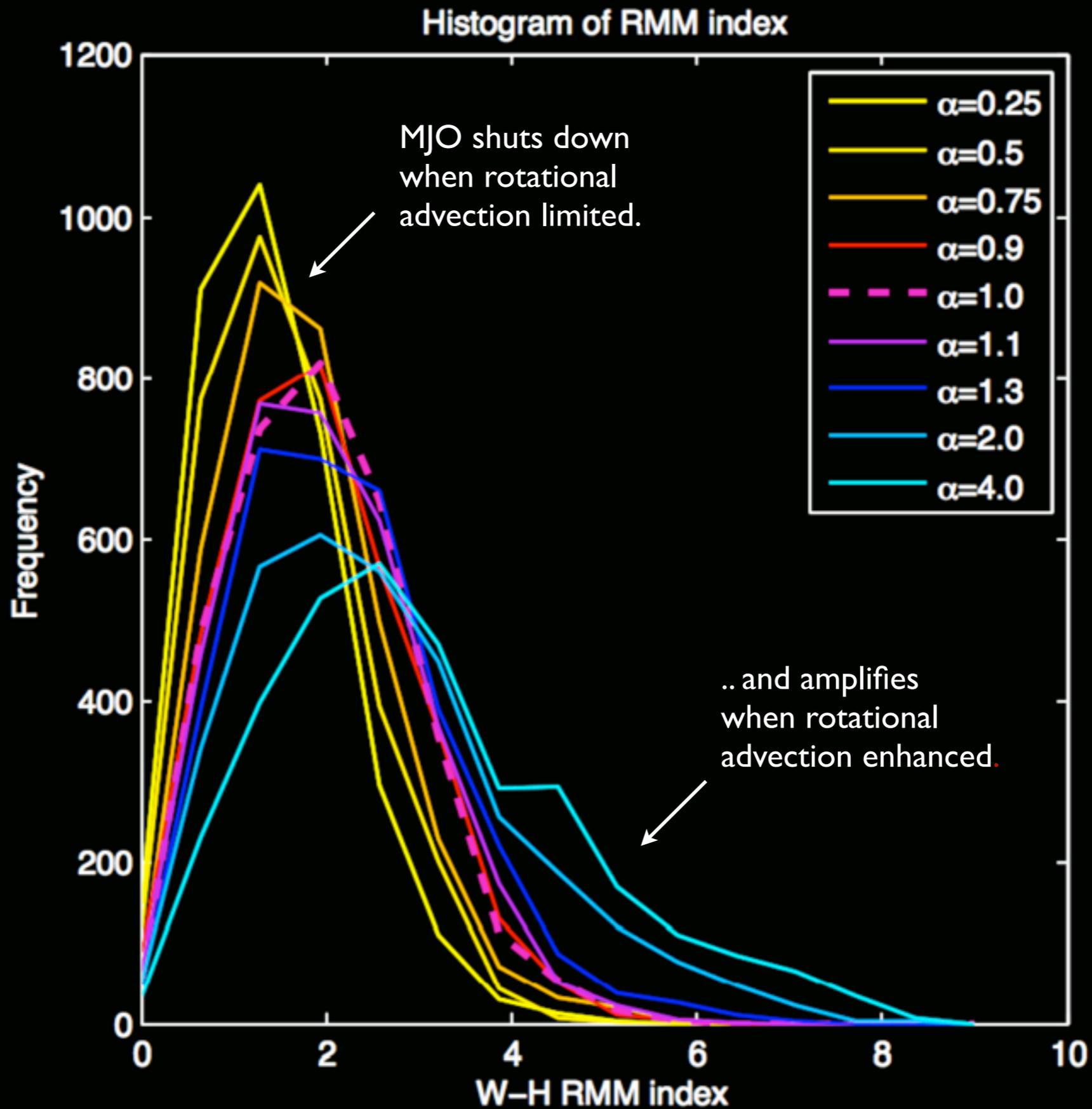
Speedup, expect:

Westerly acceleration of mean zonal winds throughout tropics or narrowing of the ITCZ.

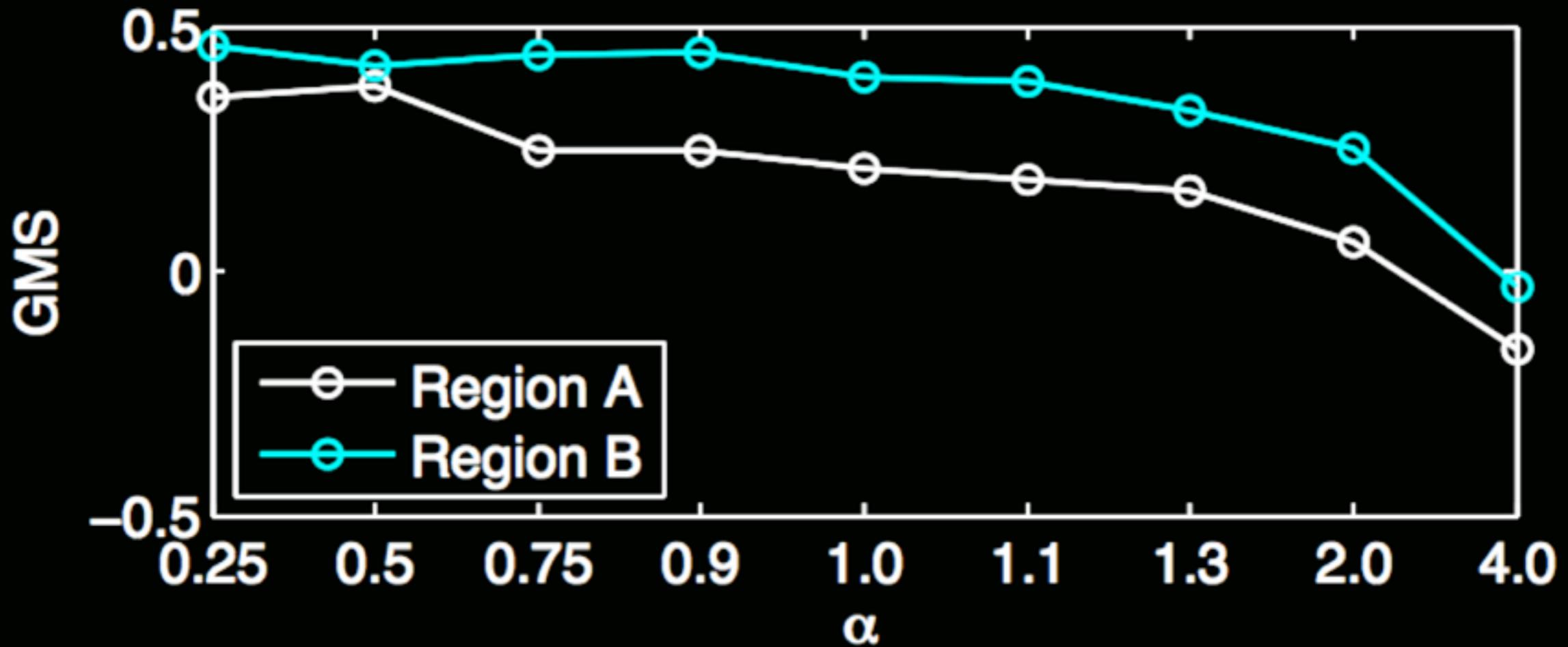
X

Causal evidence supports the hypothesis.

There is also a strong unexpected amplitude response.

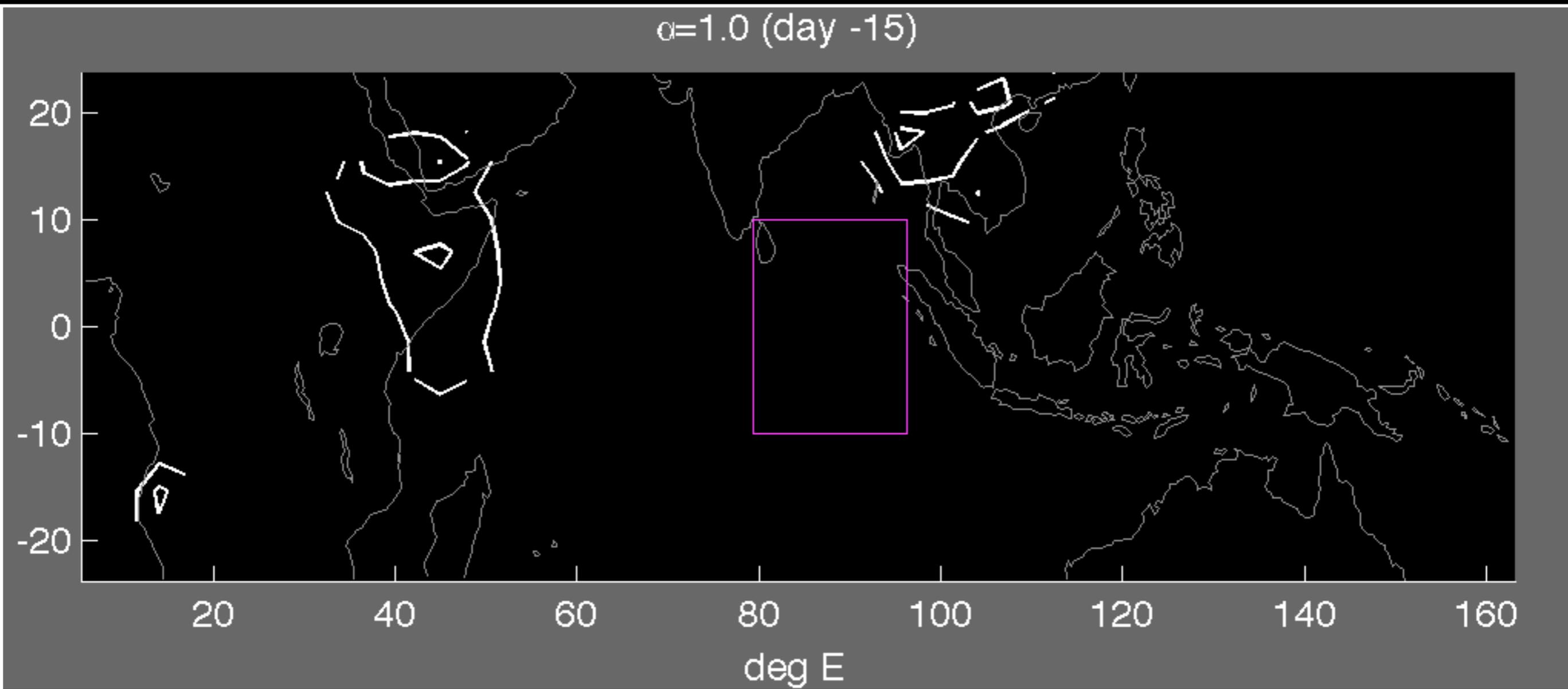


Amplification consistent with decrease in time mean environmental gross moist stability.



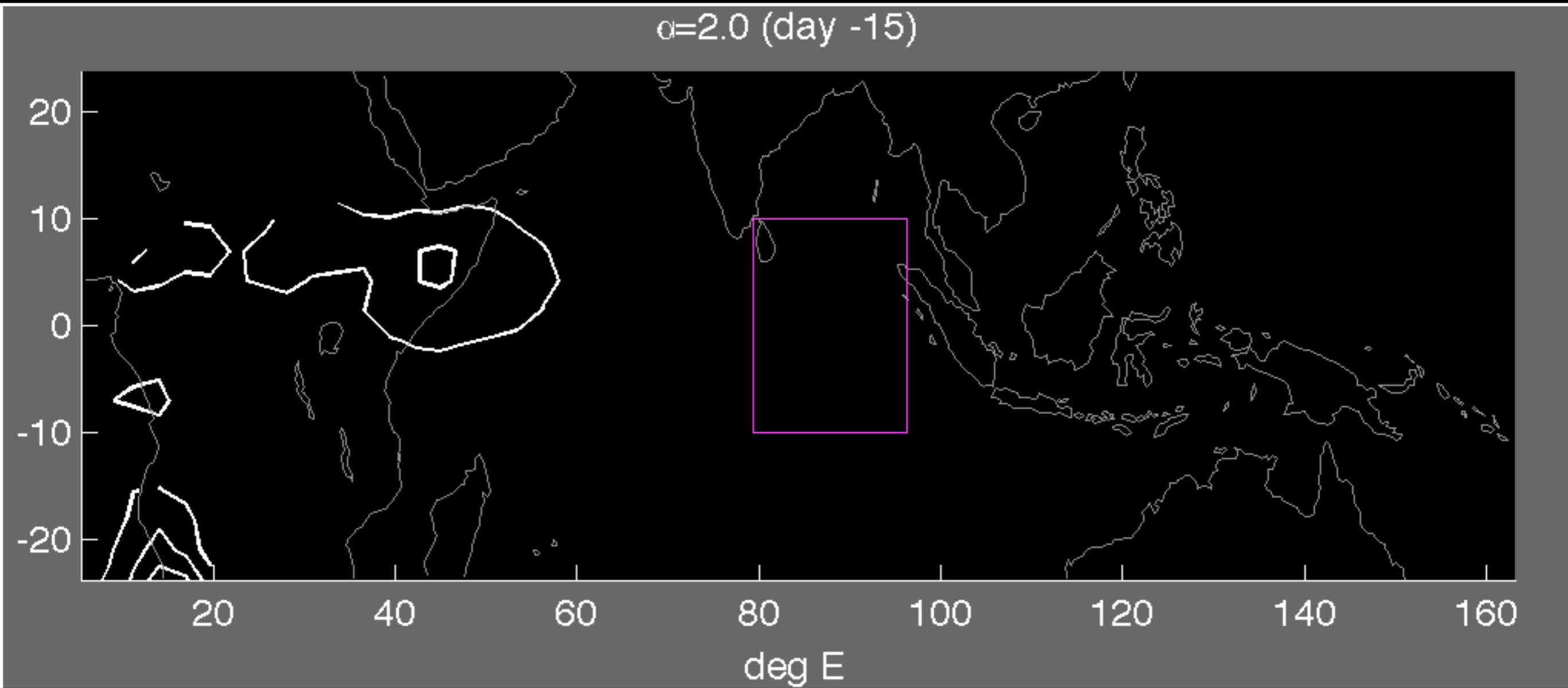
Visualizing the effect of α on MJO energetics.

Eastward propagating MJO energy core in baseline run.



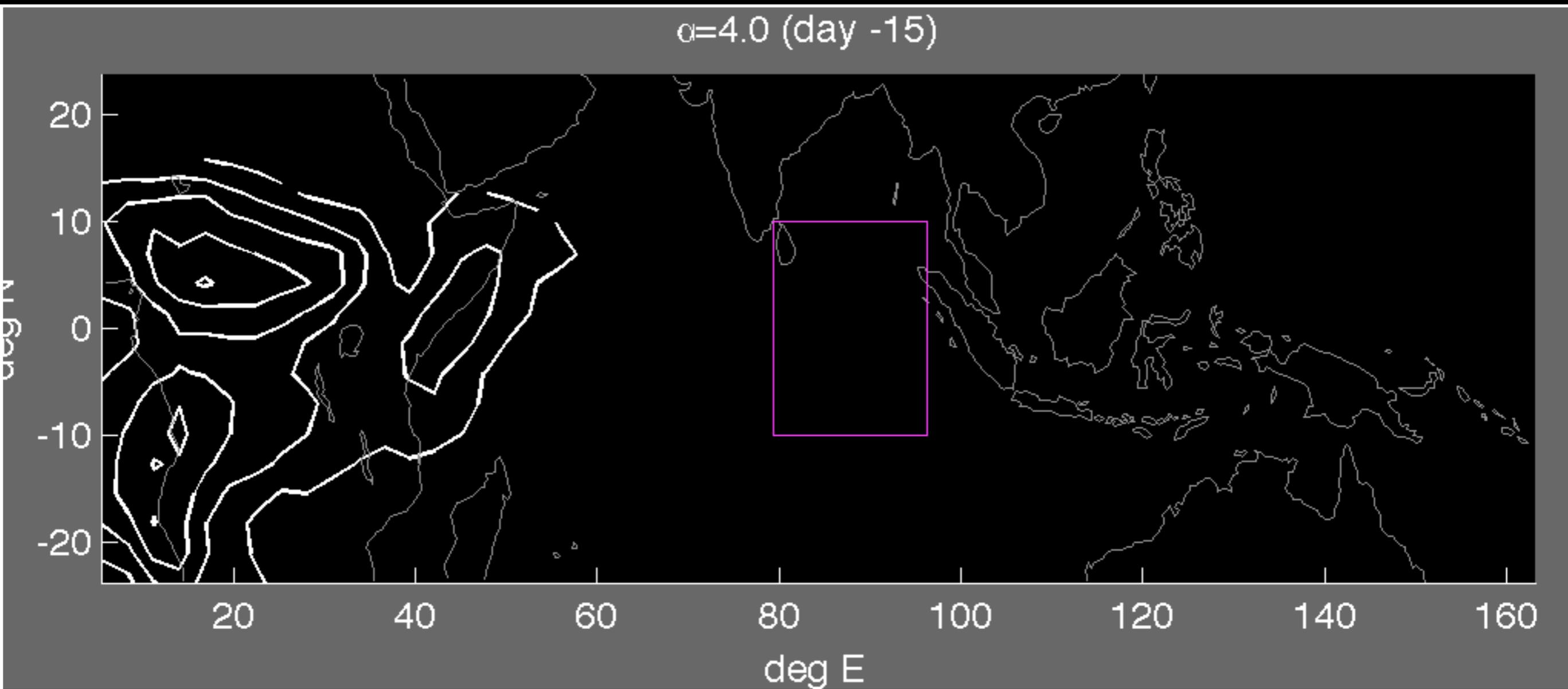
MJO-regressed MSE anomalies lagged in (x,y,t) relative to magenta box.

In ($\alpha = 2$): A stronger energy anomaly moving faster



MJO-regressed MSE anomalies lagged in (x,y,t) relative to magenta box.

$(\alpha = 4)$ Even stronger, bigger & faster



MJO-regressed MSE anomalies lagged in (x,y,t) relative to magenta box.

Column vapor budget:

Clearly, a large MSE sensitivity

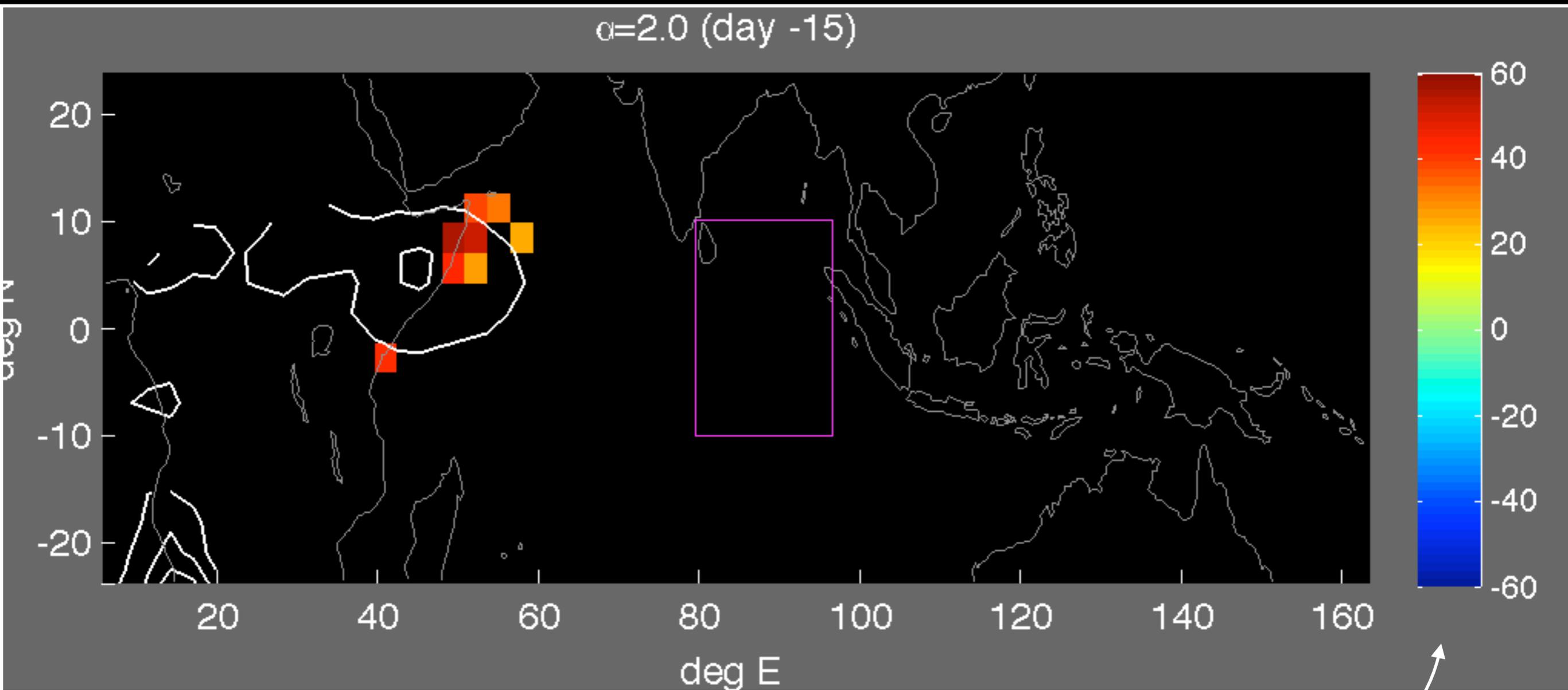
That is a result
of this interference due to α

$$\left\langle L_v \frac{\partial q}{\partial t} \right\rangle' + L_v \left\langle \mathbf{V} \cdot \nabla q + \omega \frac{\partial q}{\partial p} \right\rangle' \approx \underbrace{F'_\alpha}_{\text{circled}} + LH - L_v P'$$

Which bits of the MJO felt α ?

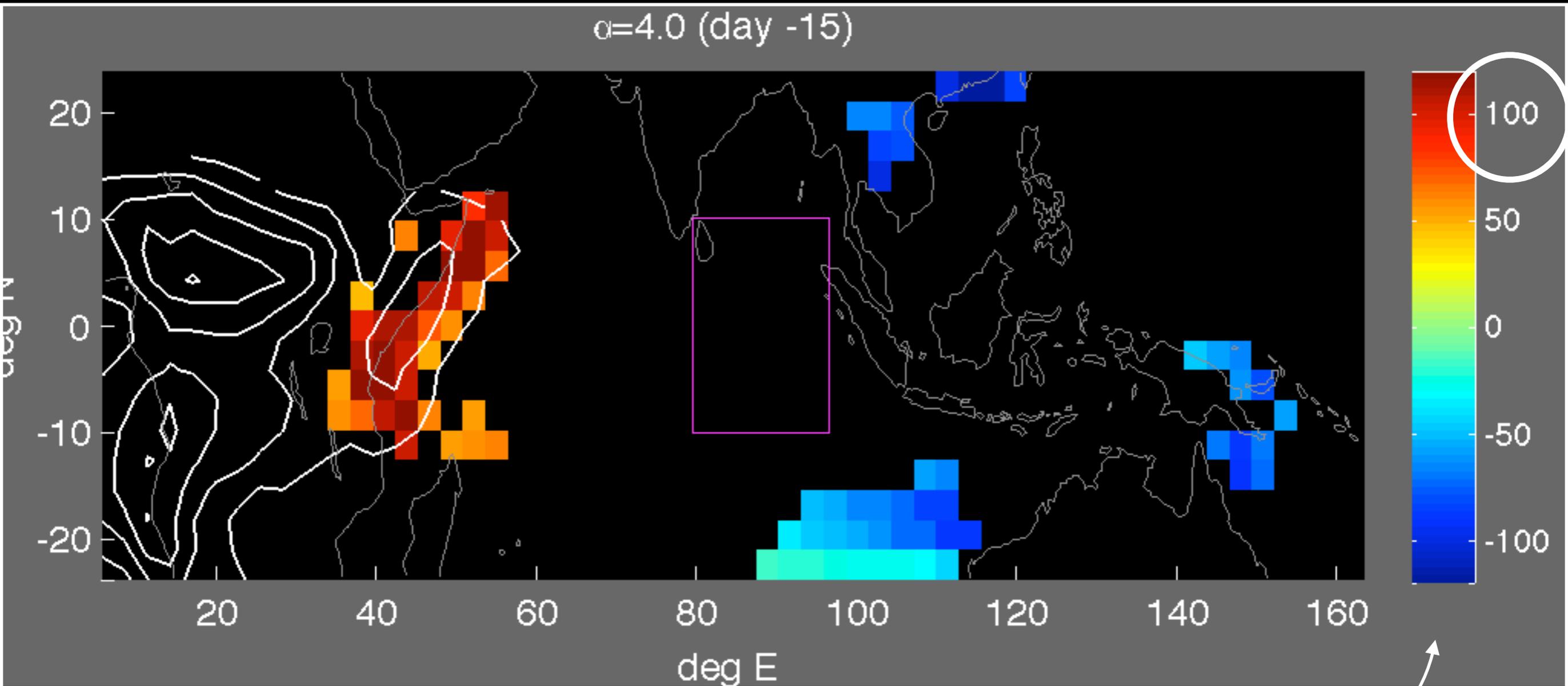
Visualize \mathbf{F}_α

How F_α ($\alpha = 2$) helped create a bigger, faster MJO



Colors show MJO-
regression of F_α

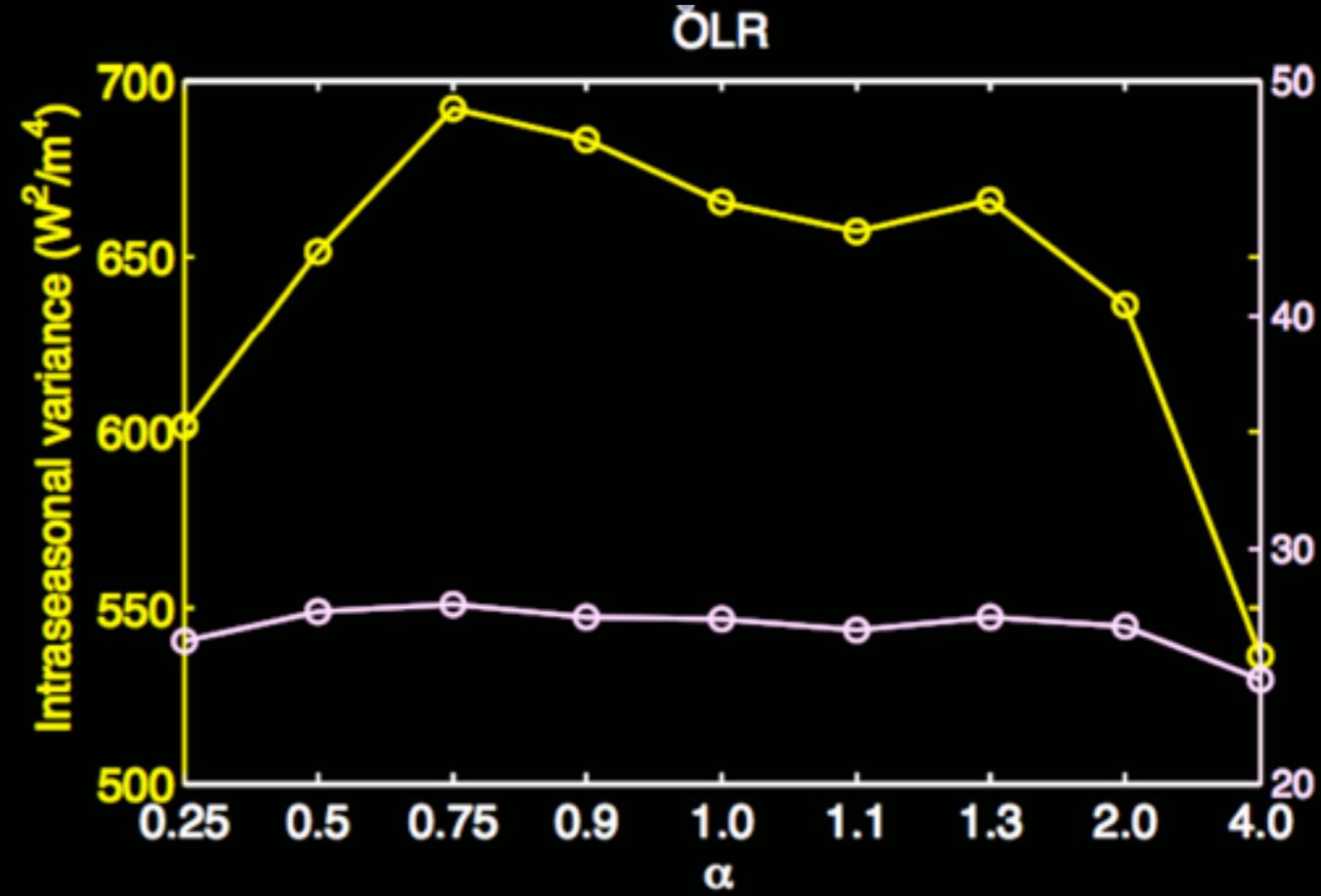
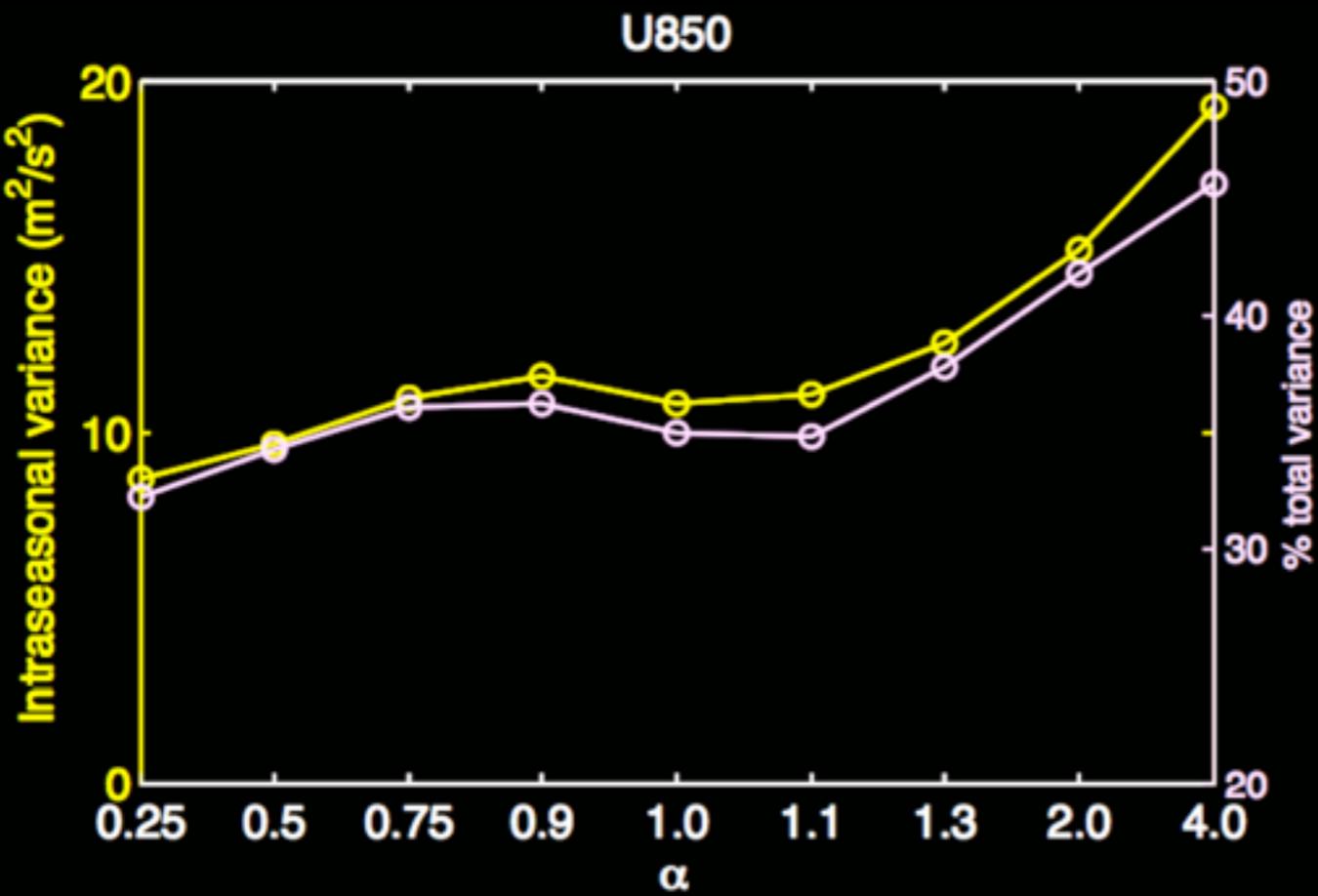
How F_α ($\alpha = 4$) helped make it even bigger and faster.



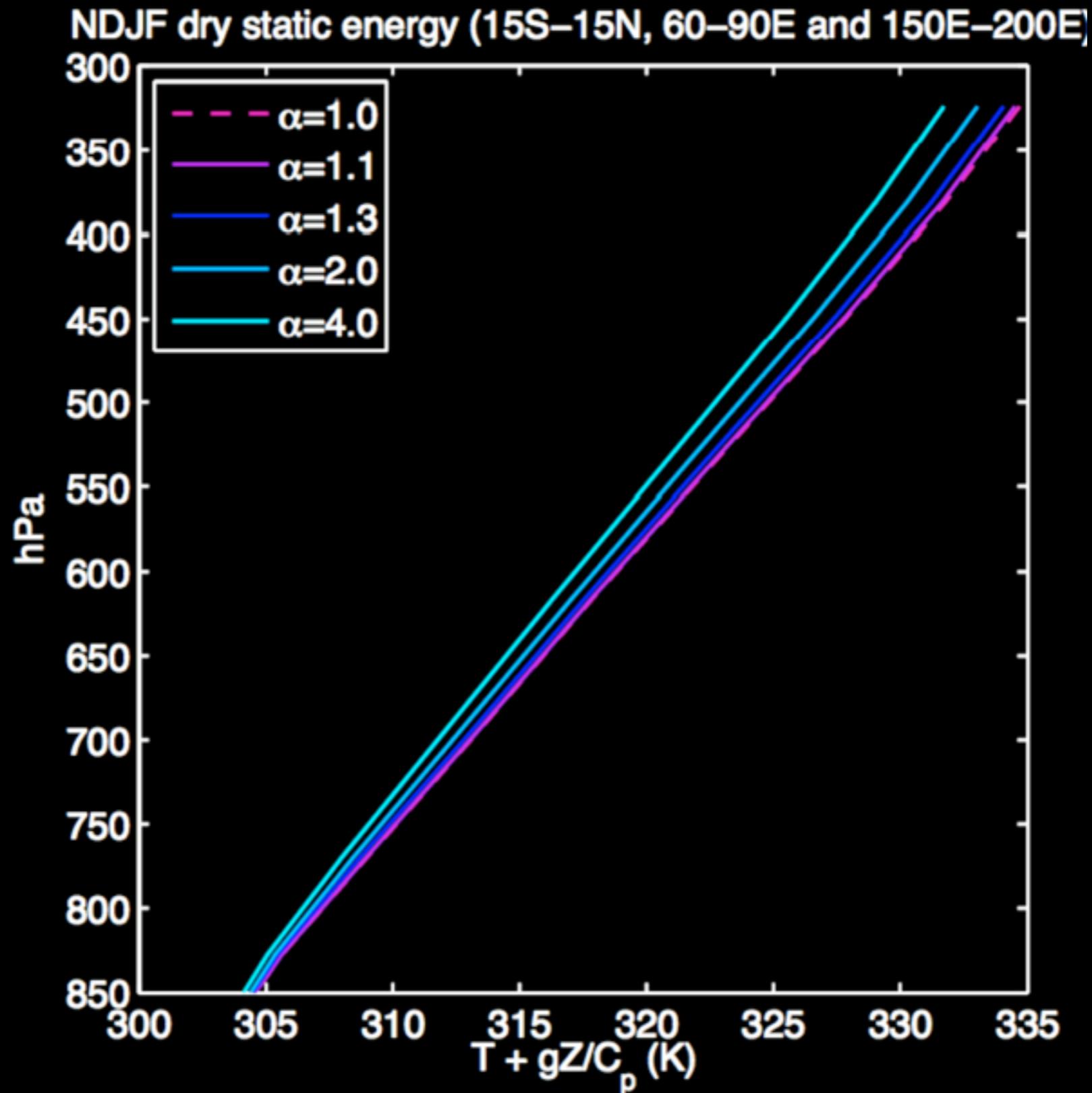
Colors show MJO-regression of F_α

Additional remarks

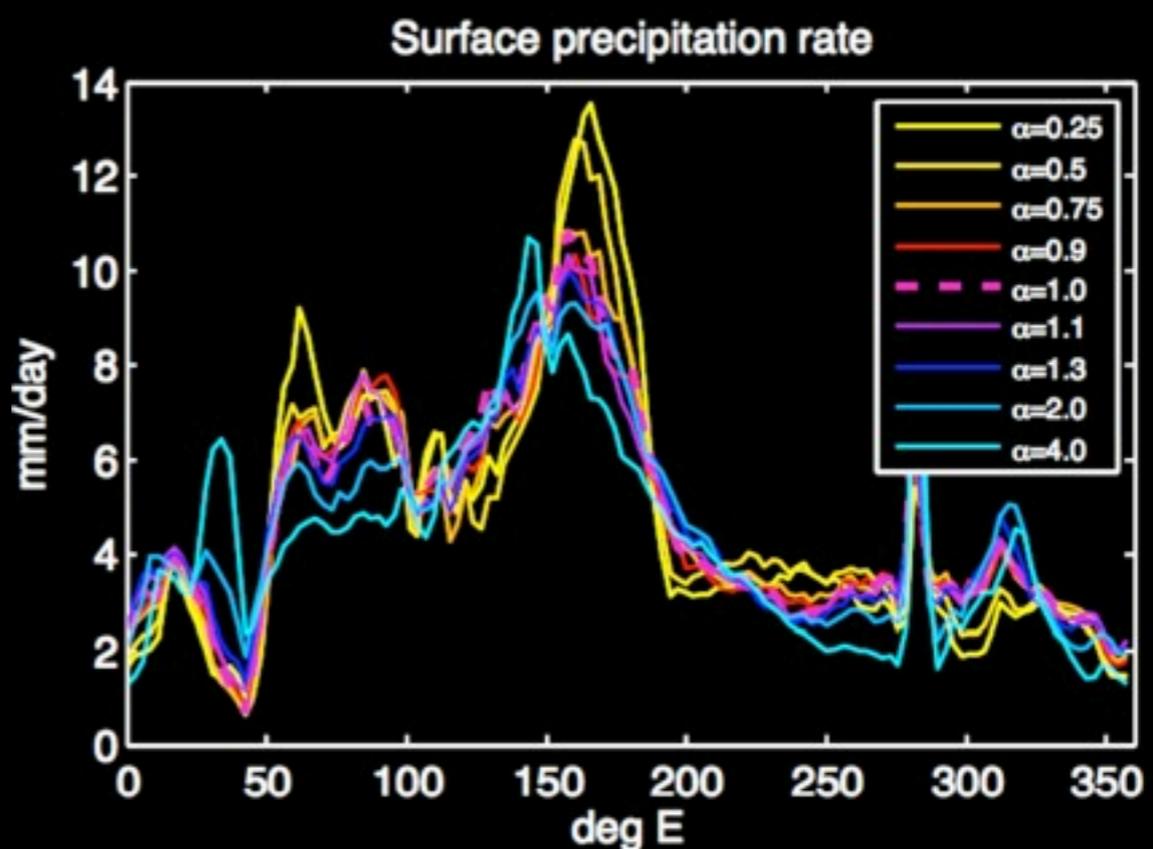
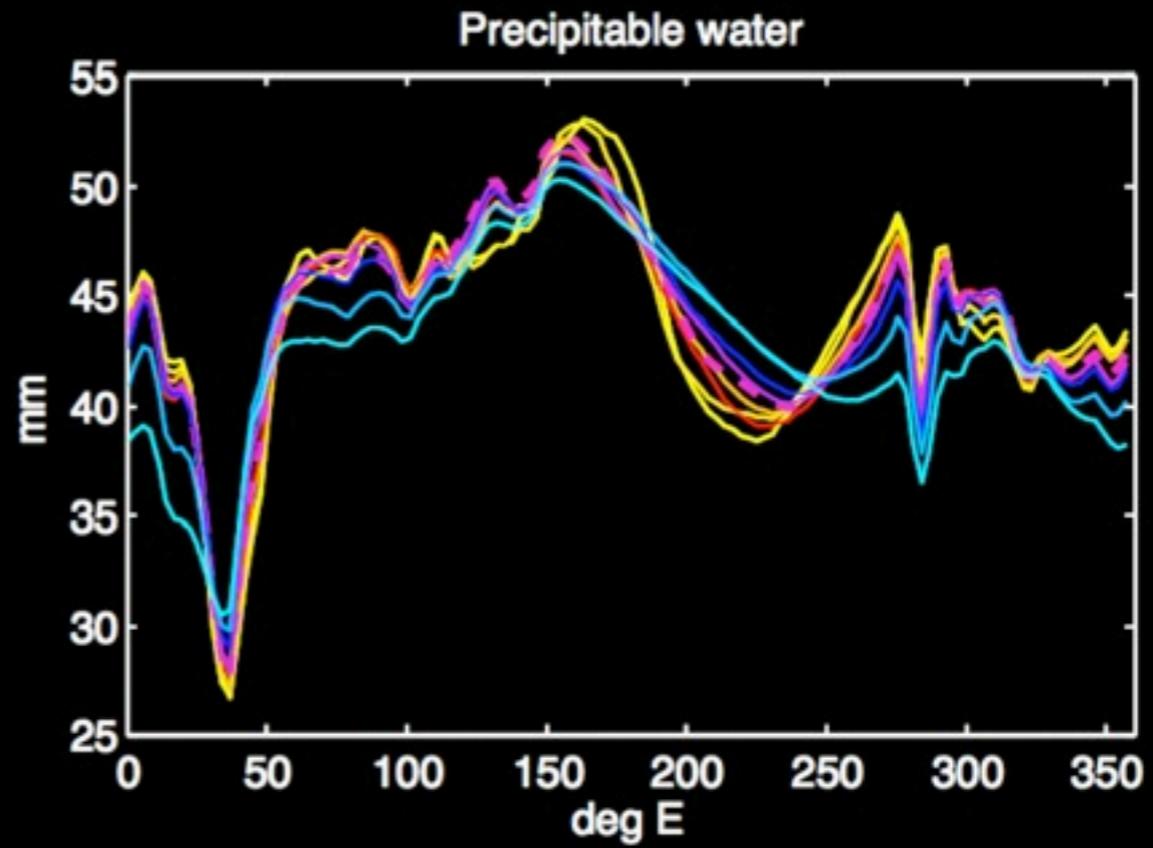
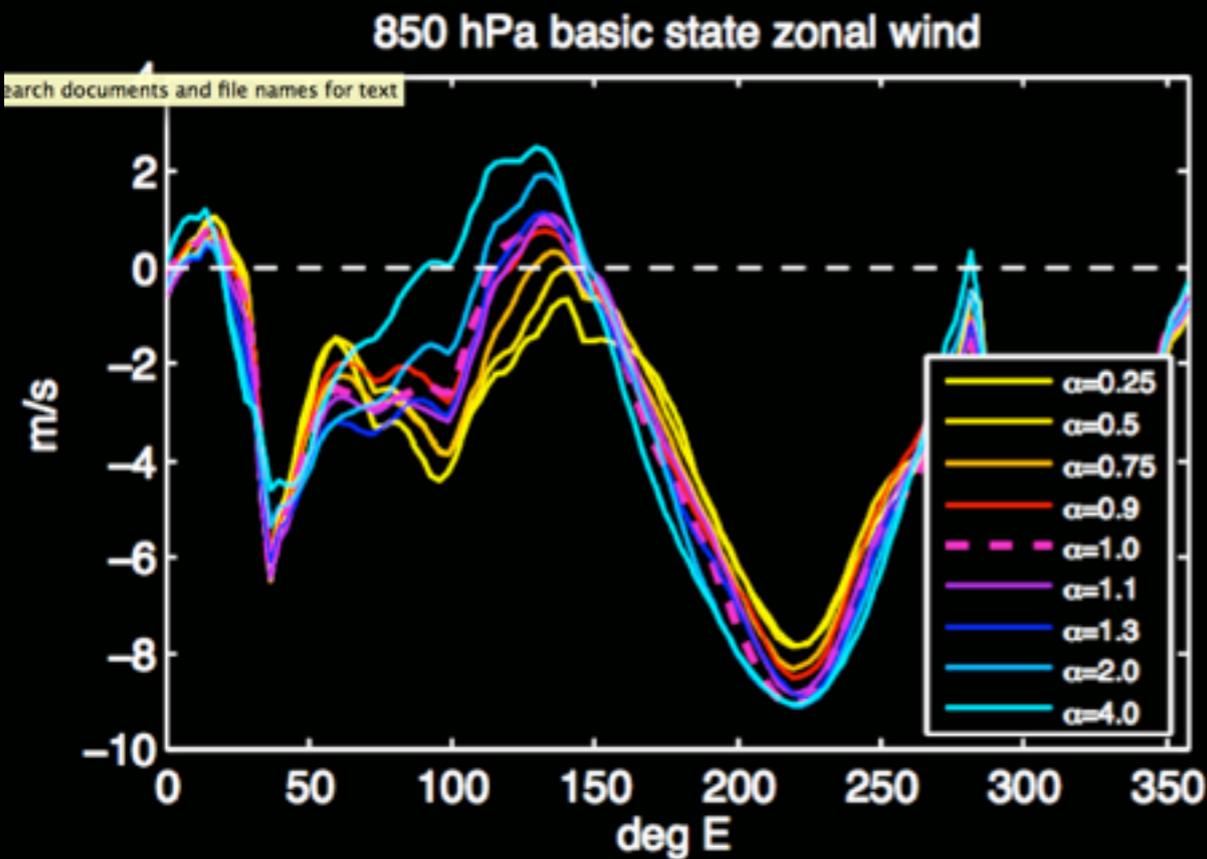
The amplification signal only exists in *wind-centric* metrics.
OLR variance actually *decreases* at high α .



Reduced environmental dry static stability is not strong enough to explain the discrepant OLR vs. wind amplitude response.

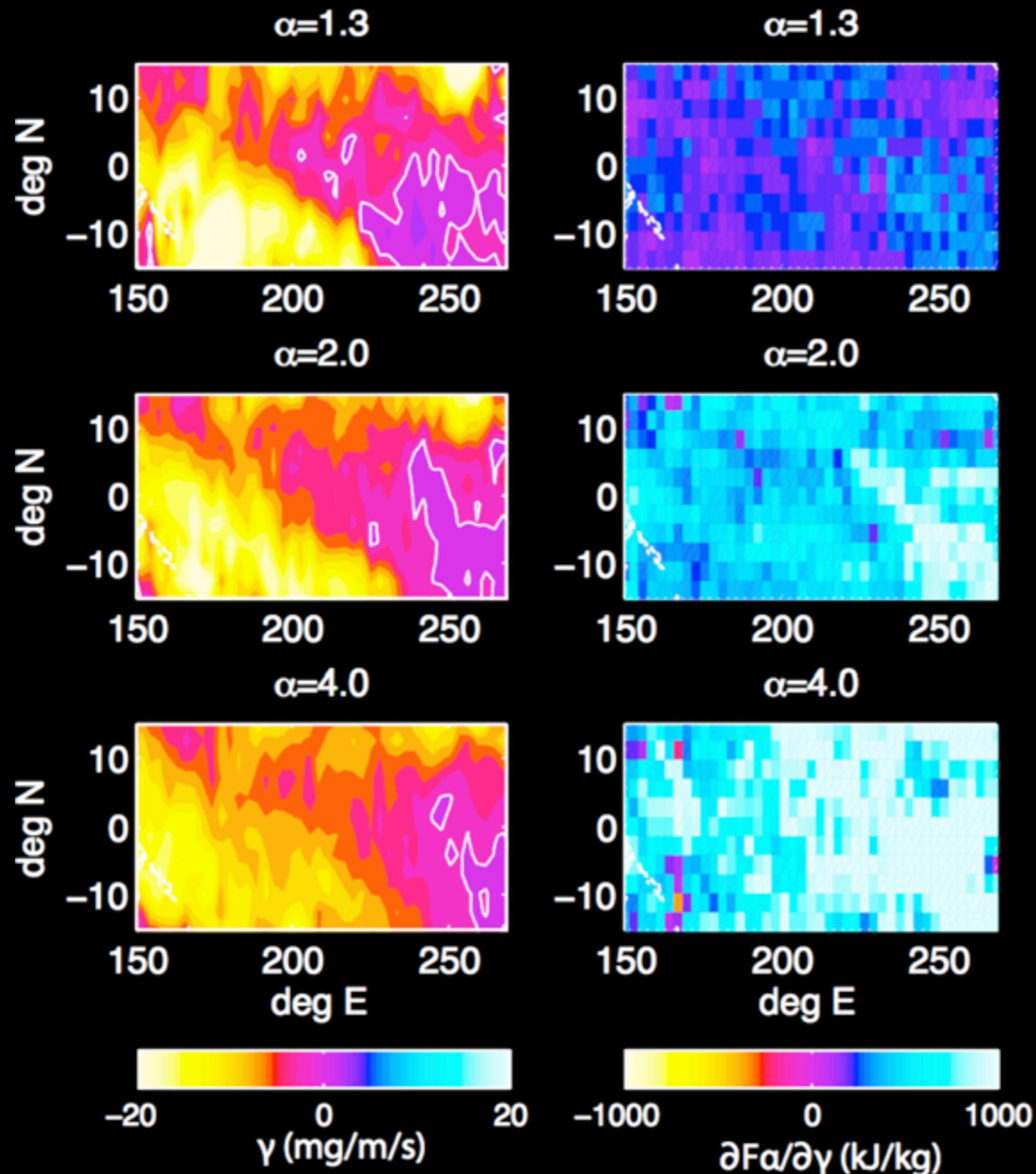


The Walker cell responds dramatically in these runs in tandem with flattening zonal PW gradients at high α .



Enhanced zonal eddy moisture advection plays a key role in flattening the tropical PW gradient.

Proxy for zonal moisture advection by eddy winds.



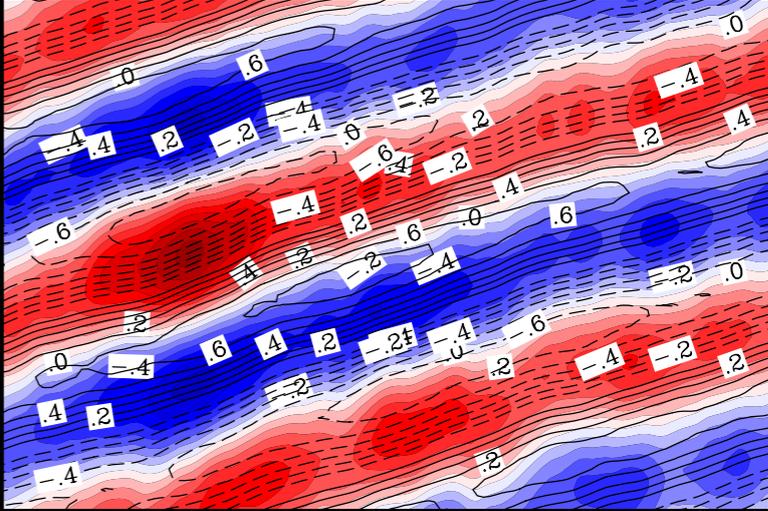
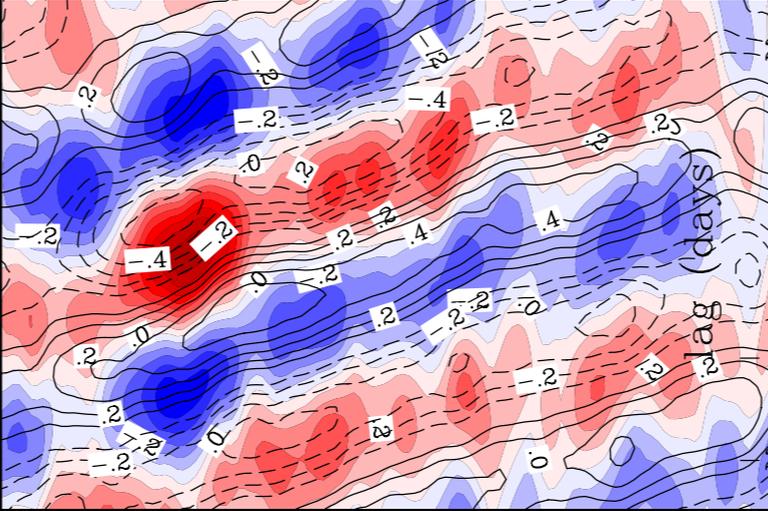
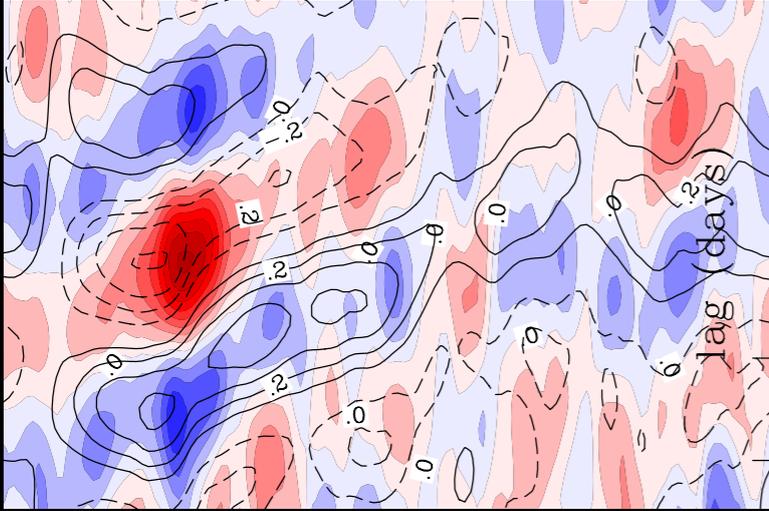
Regression of MSE tendency due to alpha on eddy advection.

The amplification and speedup with alpha are reproducible on a zonally symmetric aquaplanet.

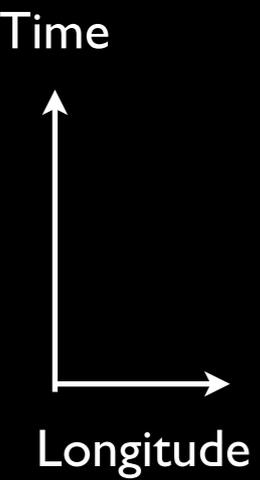
$\alpha = 0.25$

$\alpha = 1$

$\alpha = 4$

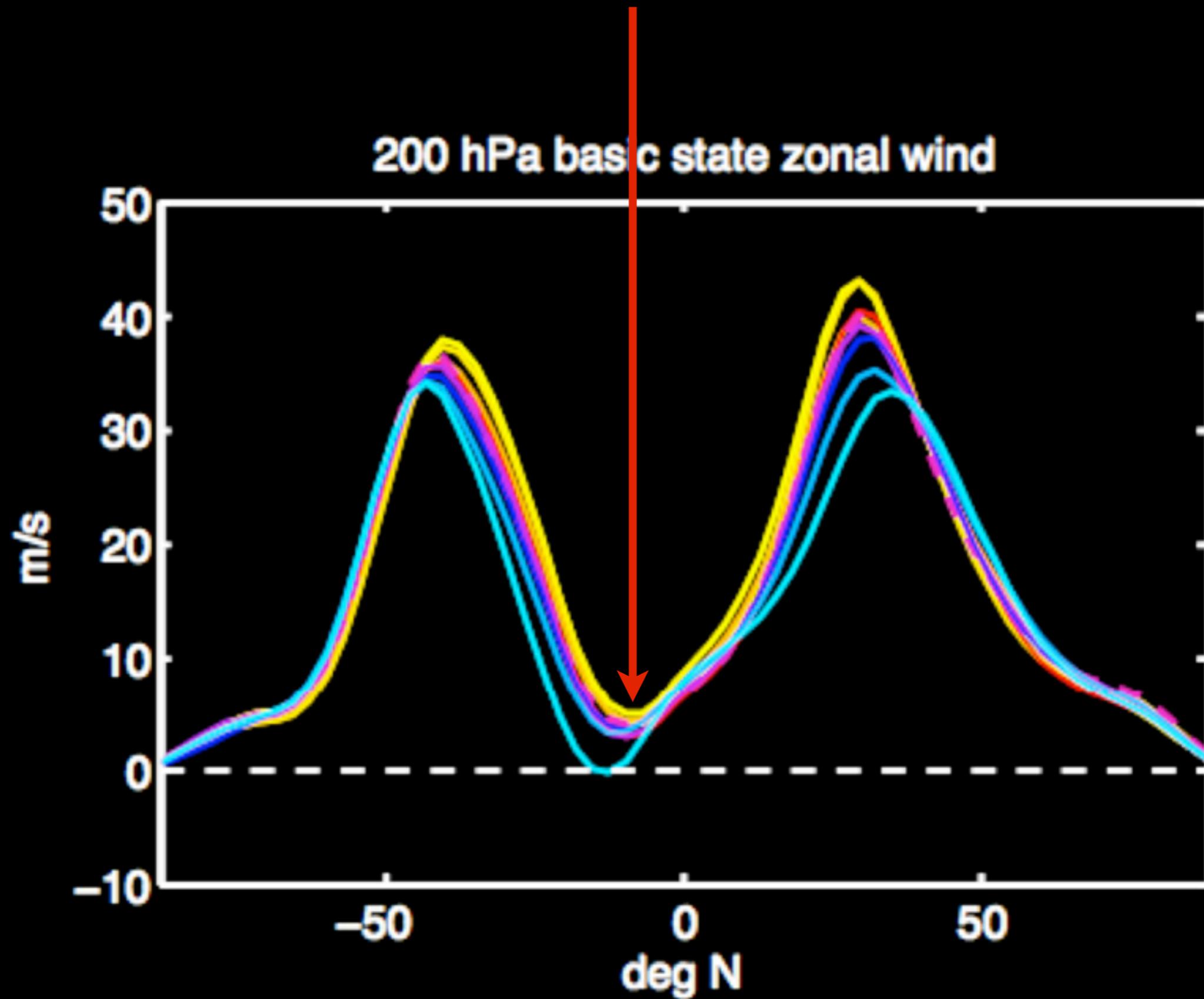


MJO-regressed
850 hPa winds,
lagged in

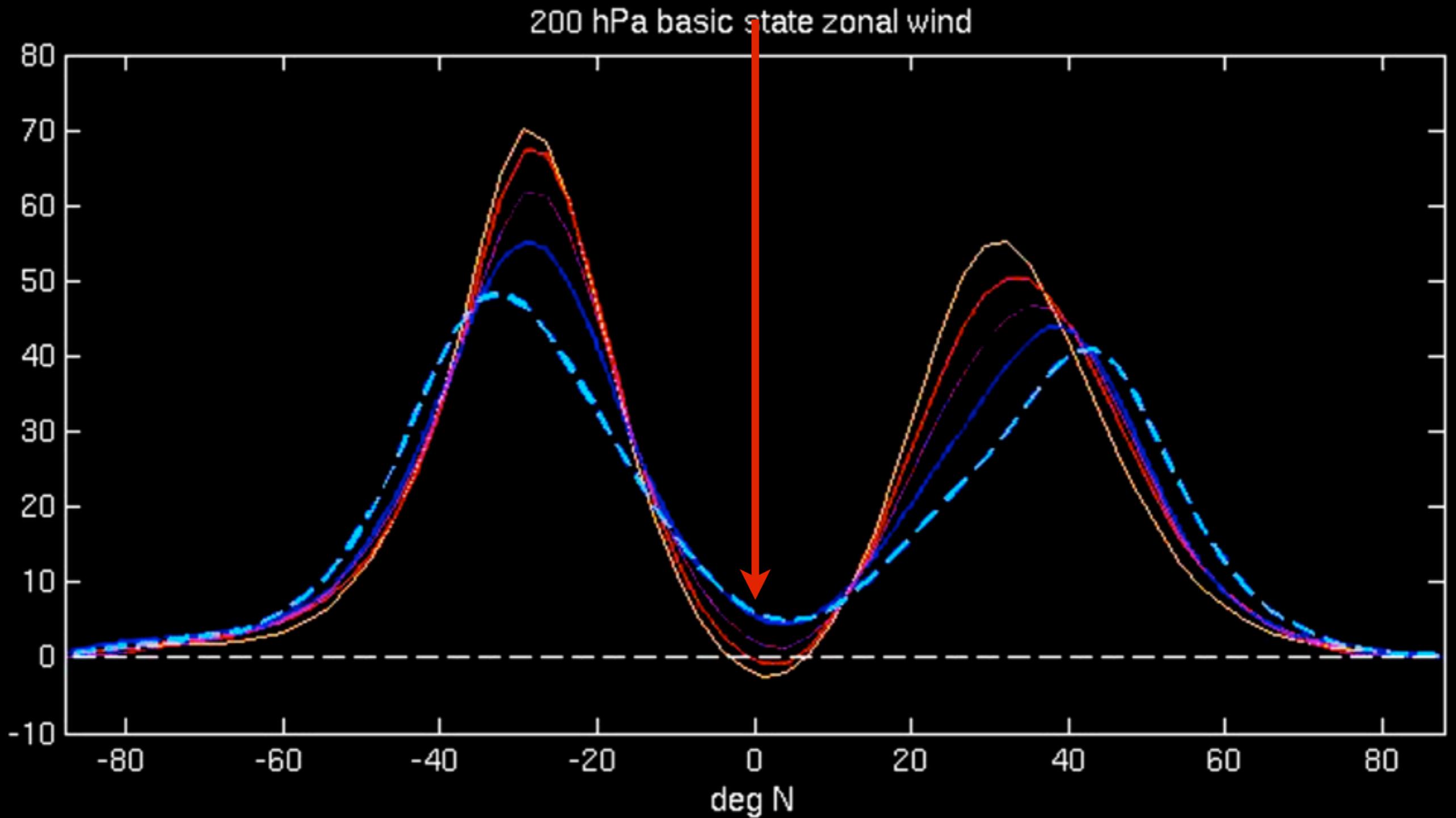


Basic state sensitivities to α are mostly similar in symmetric aquaplanet and real-geography mode except...

Equatorial superrotation reduces in tandem with MJO amplification at elevated α in real-geography SPCAM...



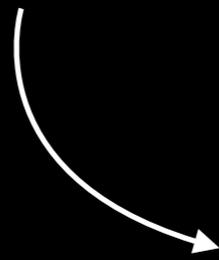
... but superrotation enhances at elevated α in aquaplanet SPCAM.



Conclusions

Hypothesis:

**The SPMJO is a
valid analog to nature.**



Expect:

Nontrivial forecast skill.



An unsolved initialization
problem obscures the
answer.

Apply a *high-degree of freedom* global model,

making minimal assumptions about convection,

but producing a realistic MJO signal,

to examine processes & test their criticality.

Road map

- History of SPCAM's high quality MJO.
- Issues at the frontier of MMF MJO forecasting.
- Insensitivities of the SPMJO to factors affecting mesoscale organization.
- How to speed up SPCAM by 400% for MJO process studies.
- Causative evidence that rotational moisture advection is critical to MJO propagation.

Insensitivities of the SPMJO to treatment of the mesoscale.

Hypothesis:

Mesoscale organization is critical to the dynamics of the SPMJO.

Expect:

More MJO predictability if mesoscale initially spun-up.

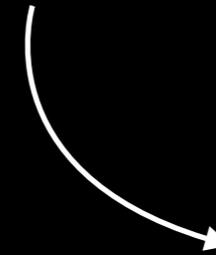
X



Expect:

Predictability responds to changing inner model geometry.

X



Expect:

The MJO signal depends on including the mesoscale.

X

Sensitivities may affirm a moisture mode view.

Hypothesis:

Rotational moisture advection is critical to the eastward propagation of the SPMJO.

The MJO signal speeds up if horizontal moisture advection by vorticity anomalies is artificially enhanced.

The null hypothesis that speedup is an artifact of mean state adjustment is false.

Causal evidence supporting the hypothesis.

Thanks

To Chris, for all the insight.

To NOAA for funding.

To Tom, Zhiming, Dargan, Peter, Roj & Dale for the support.

To Marat for making & sharing SPCAM3.0.

To Mark, for preserving v.3.0 in a svn!

To Eric, for great feedback.