Effect of rotational moisture advection on the superparameterized MJO

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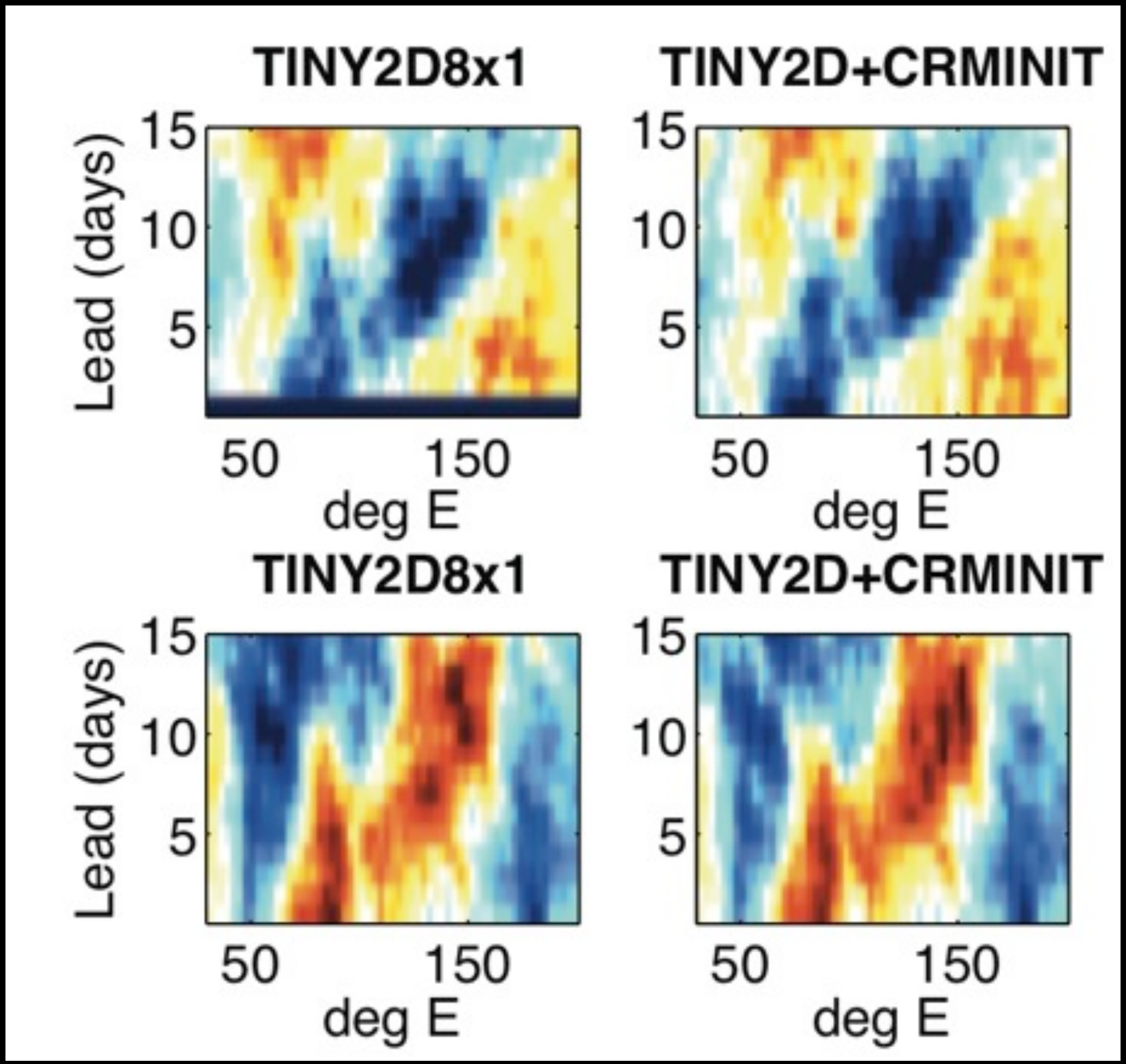
in collaboration with Chris Bretherton

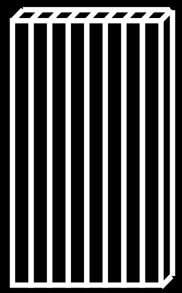
A NOAA Climate & Global Change Postdoctoral Project
University of Washington

Acknowledging: Tom Ackerman, Peter Blossey, Dale Durran and Roj Marchand (UW) Marat Khairoutdinov (Stony Brook) & the NSF Center for Multiscale Modeling of Atmospheric Processes (CSU).

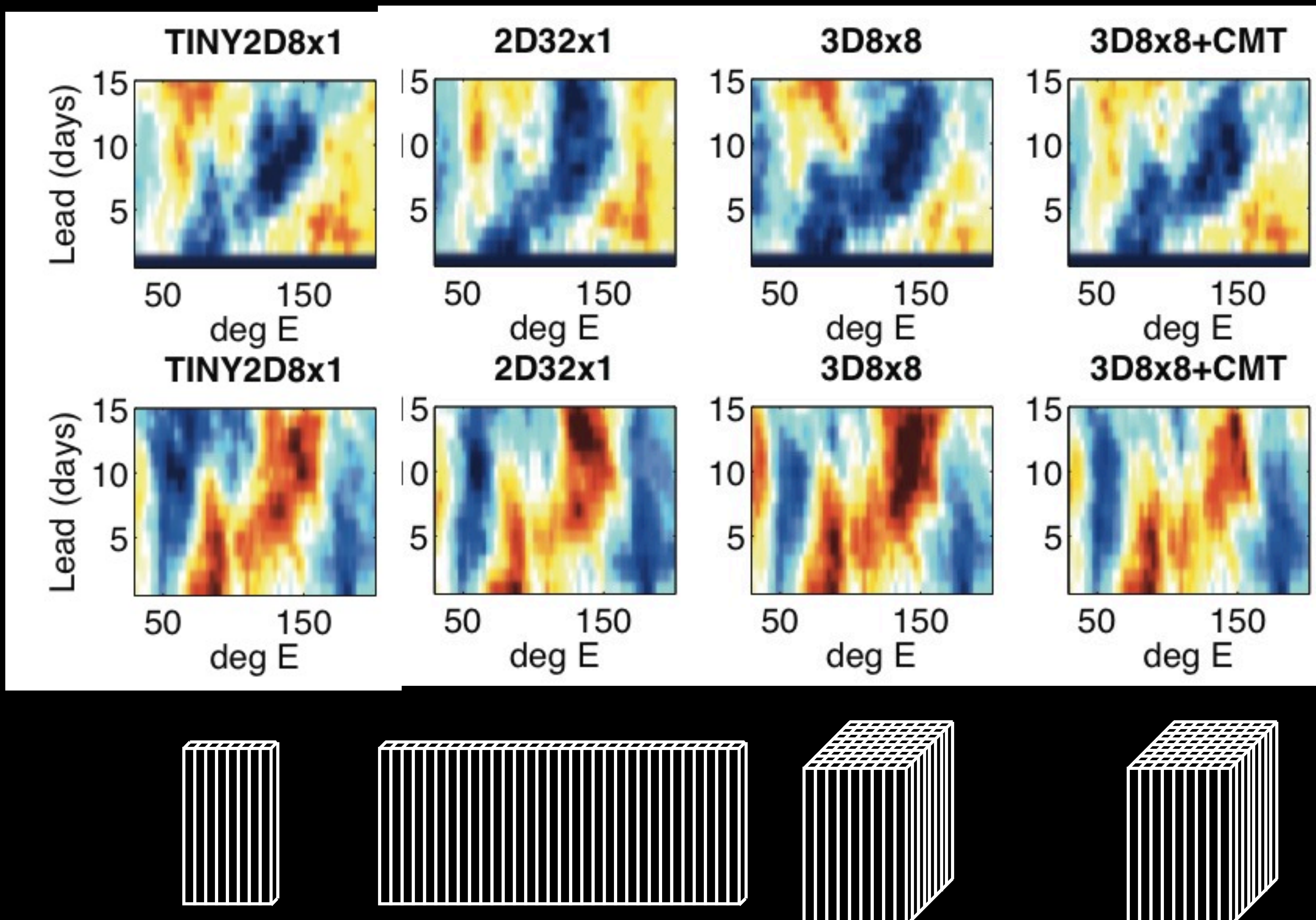
Last time, found insensitivities to a process relevant to the multi-scale paradigm of the MJO (mesoscale organization).

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





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



Last time...

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

Practically, enables use of SPCAM with tiny CRMs for 4x speedup in additional sensitivity testing.

Hypothesis:

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

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

Some relevant sub-components of the SPCAM code circuit.

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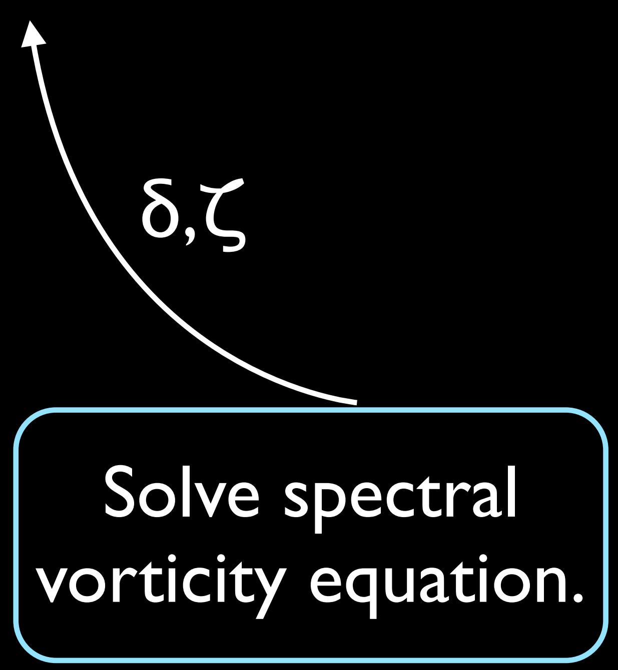
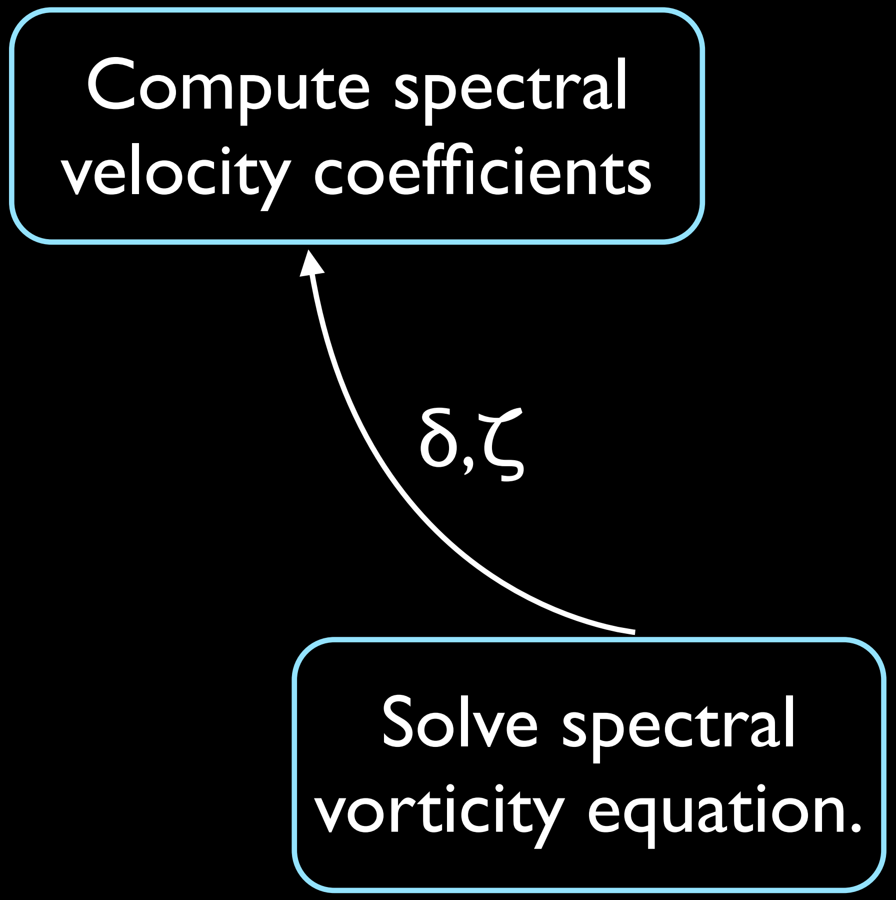
Solve spectral vorticity equation.

Some relevant sub-components of the SPCAM code circuit.



Some relevant sub-components of the SPCAM code circuit.



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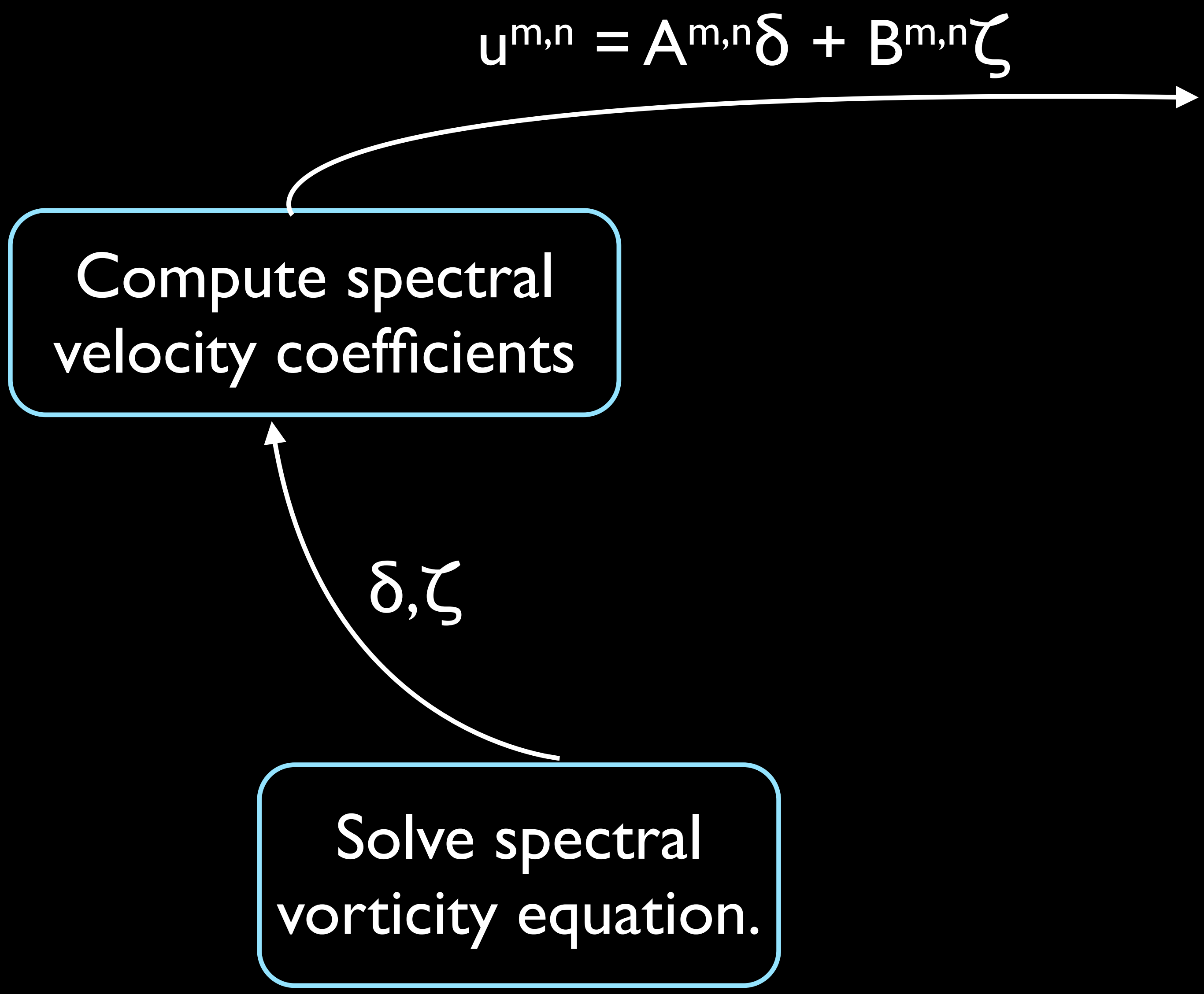

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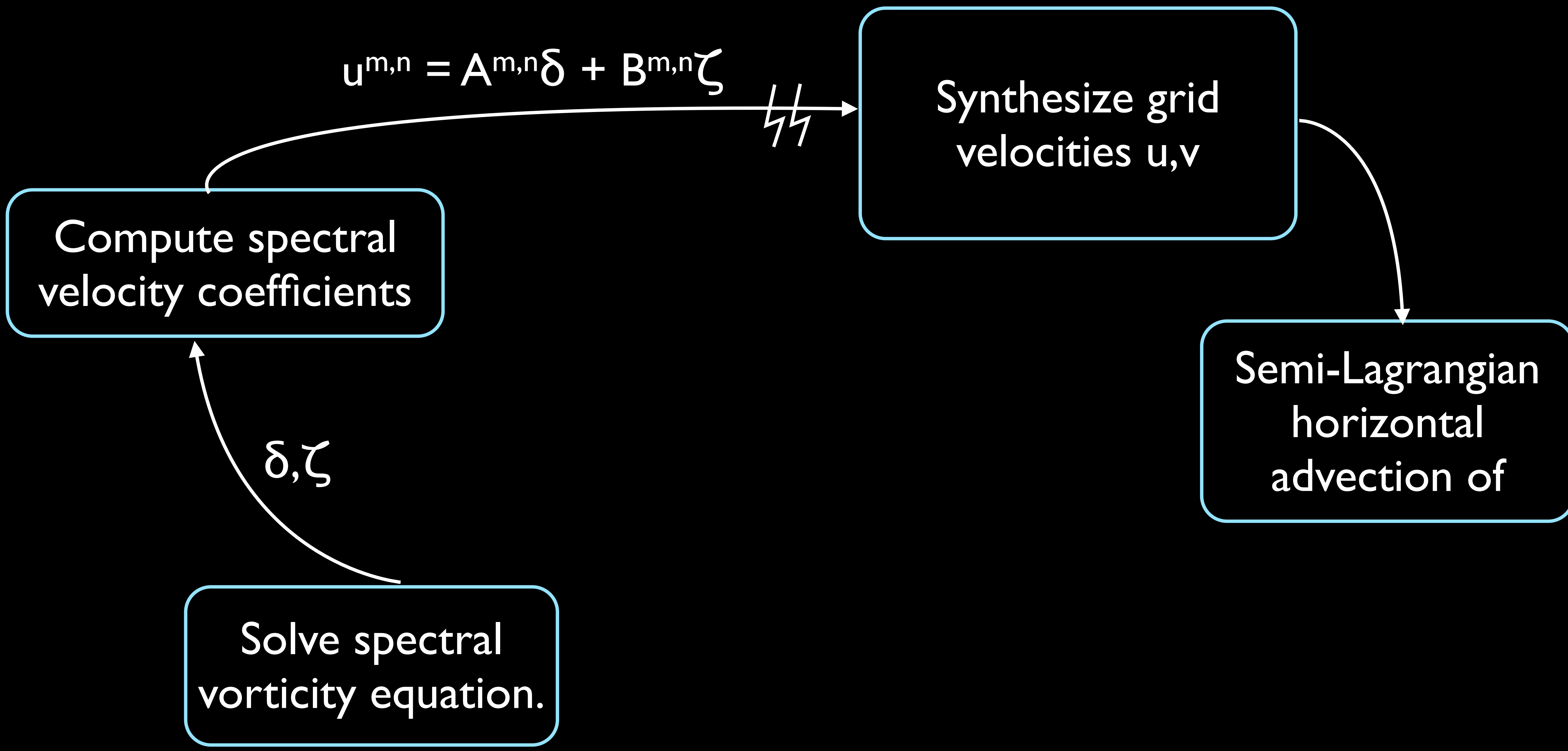

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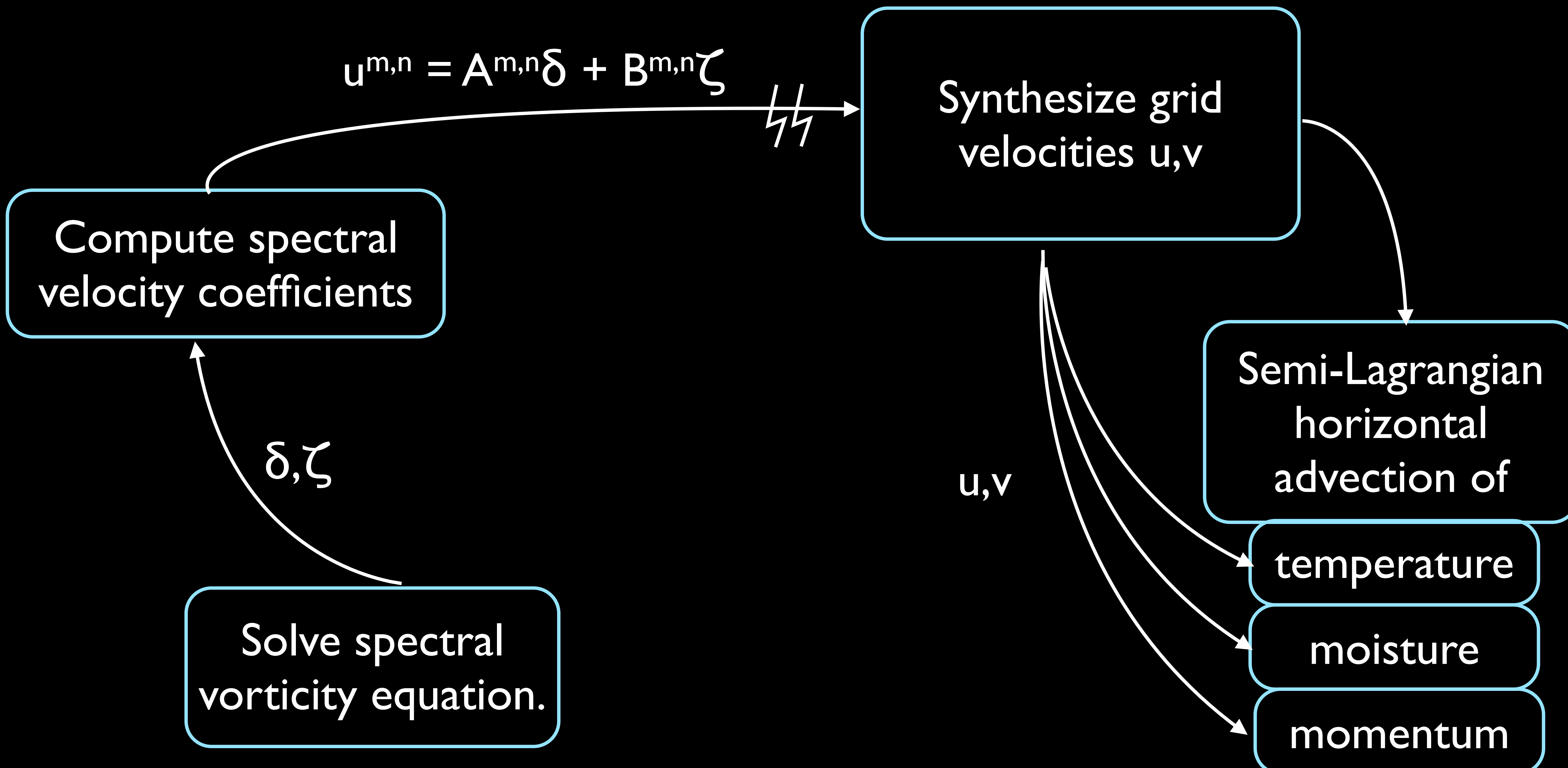

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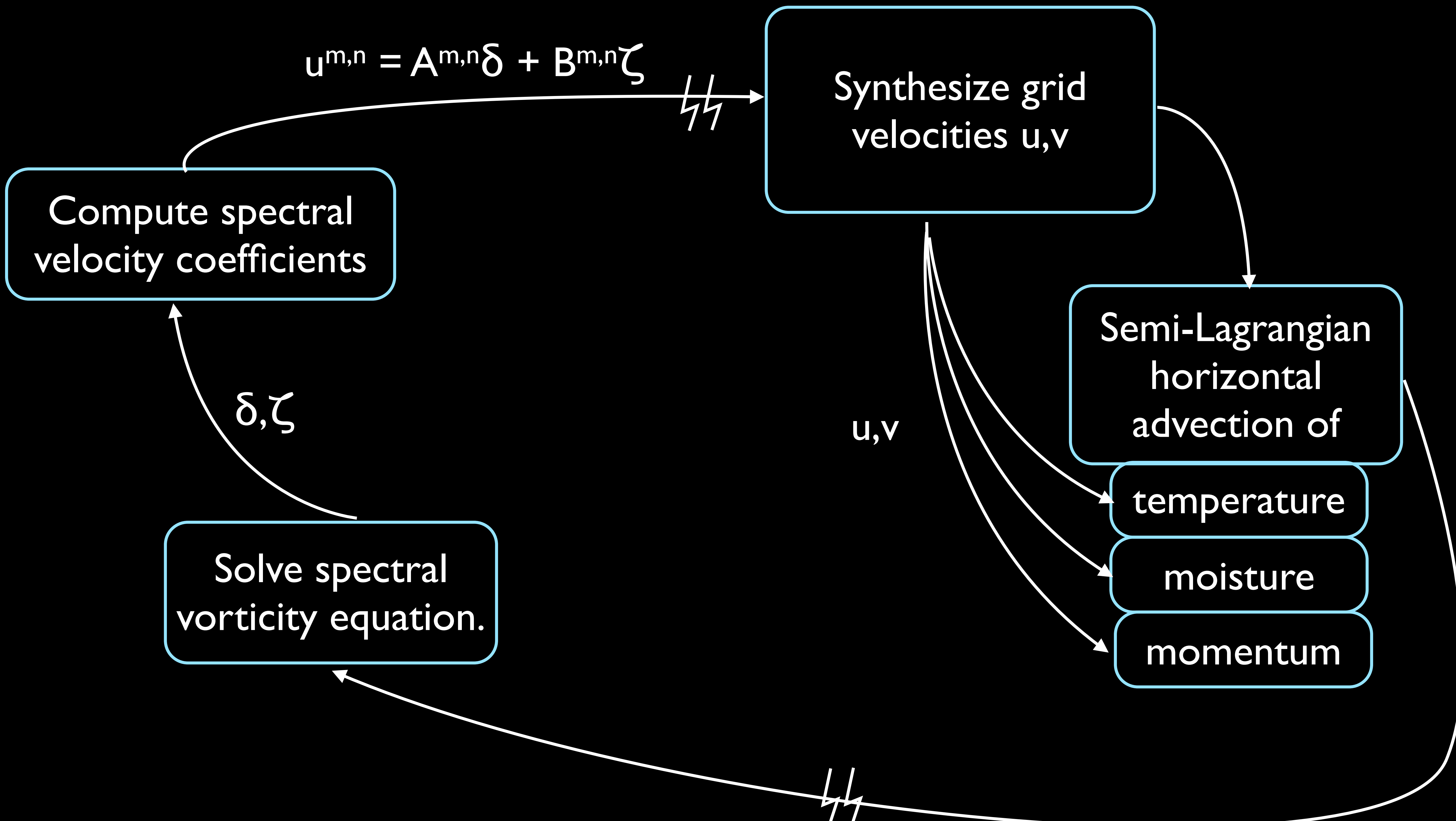
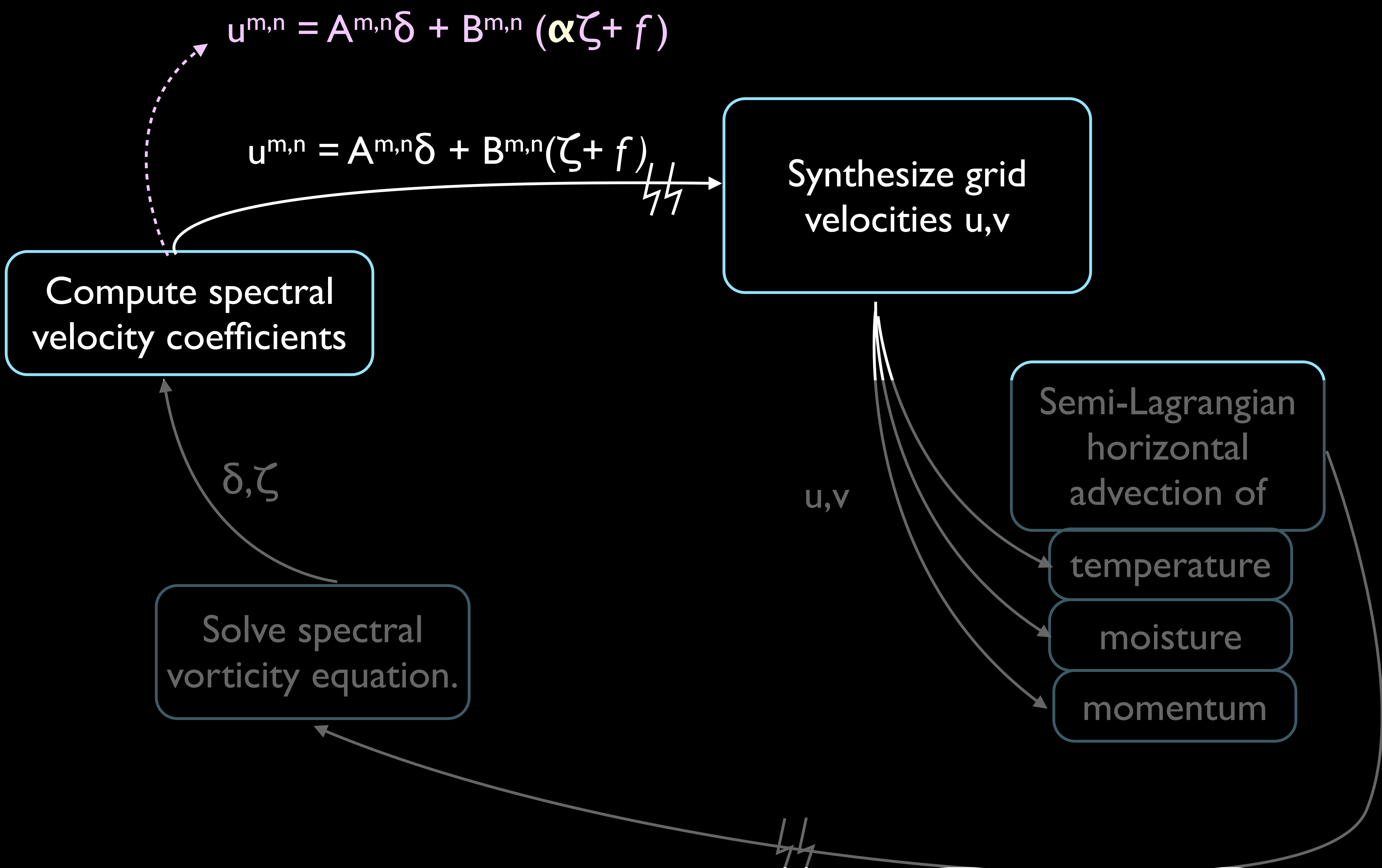


Adding an auxilliary velocity circuit with modulated vorticity.



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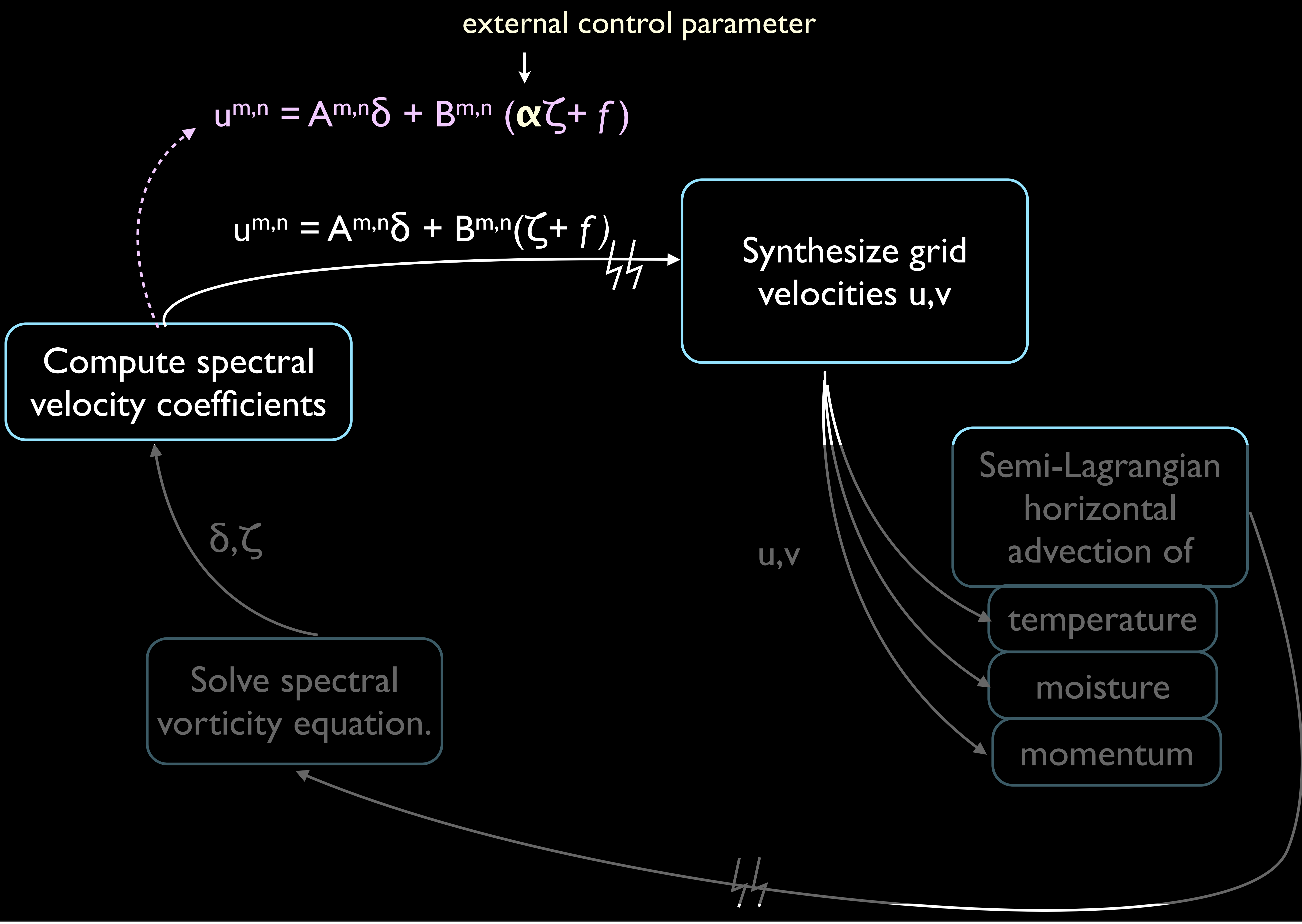
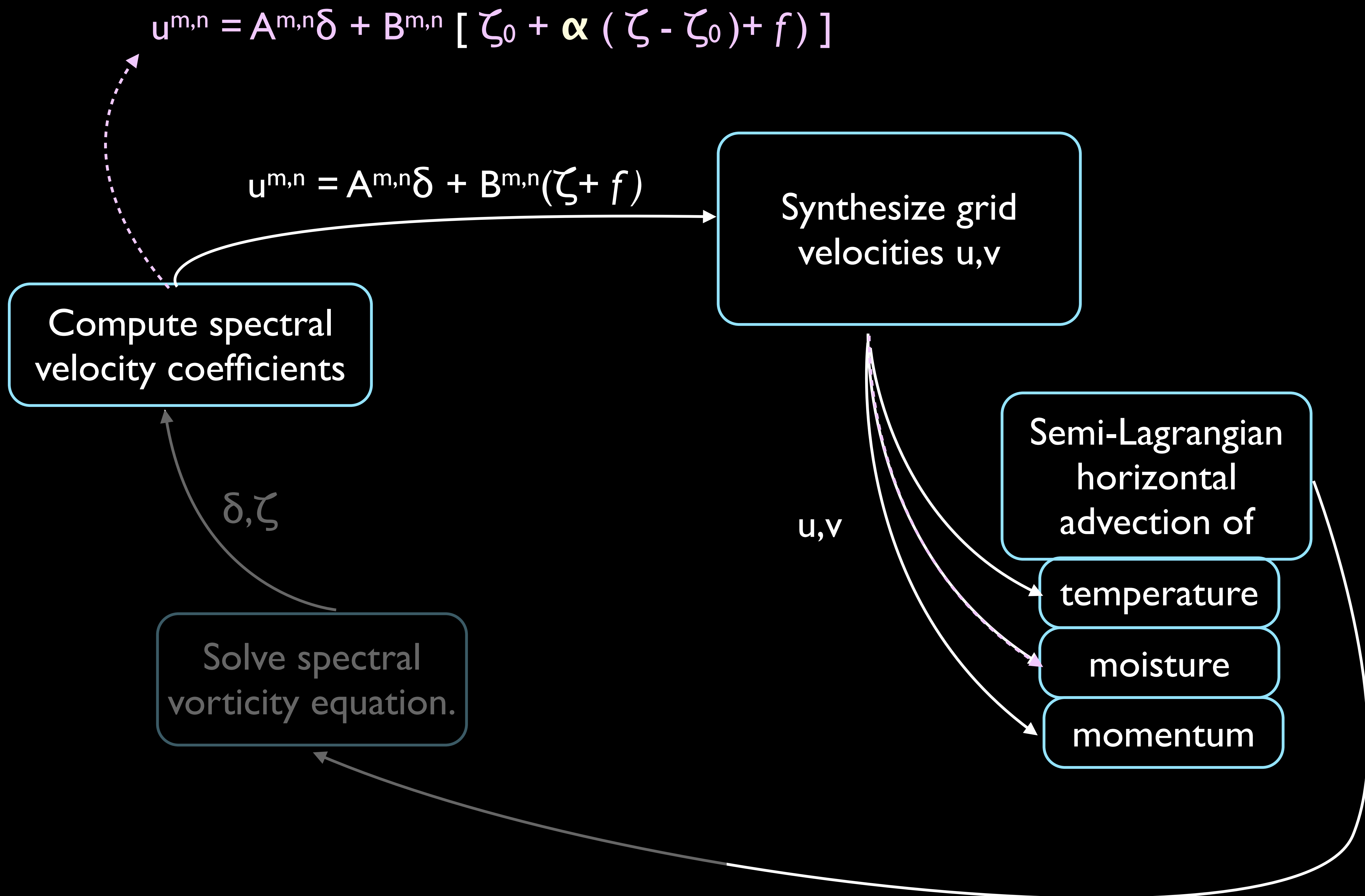


In practice, the vorticity modulation is implemented in an anomaly sense to preserve the seasonal cycle.

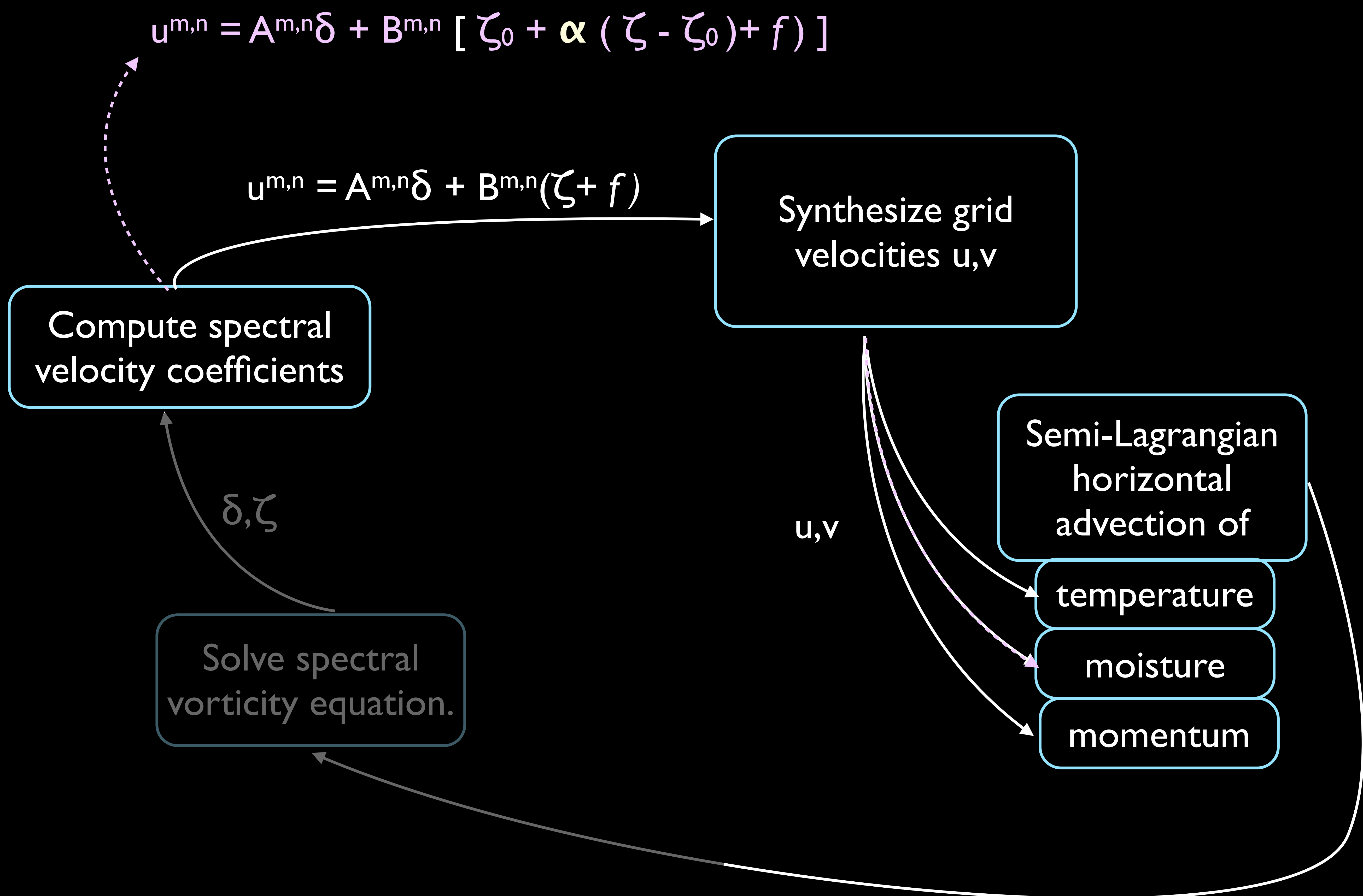
$$u^{m,n} = A^{m,n}\delta + B^{m,n} (\alpha \zeta + f)$$

$$u^{m,n} = A^{m,n}\delta + B^{m,n} [\zeta_0 + \alpha (\zeta - \zeta_0) + f)]$$

Mean seasonal cycle of spectral vorticity, accumulated from offline 12-year reference run.


$u^{m,n} = A^{m,n}\delta + B^{m,n} [\zeta_0 + \alpha (\zeta - \zeta_0) + f)]$
$u^{m,n} = A^{m,n}\delta + B^{m,n}(\zeta + f)$
Synthesize grid velocities u,v
Compute spectral velocity coefficients
Semi-Lagrangian horizontal advection of
temperature
moisture
momentum
u,v
δ,ζ
Solve spectral vorticity equation.

Limit the vorticity interference to the tropics.



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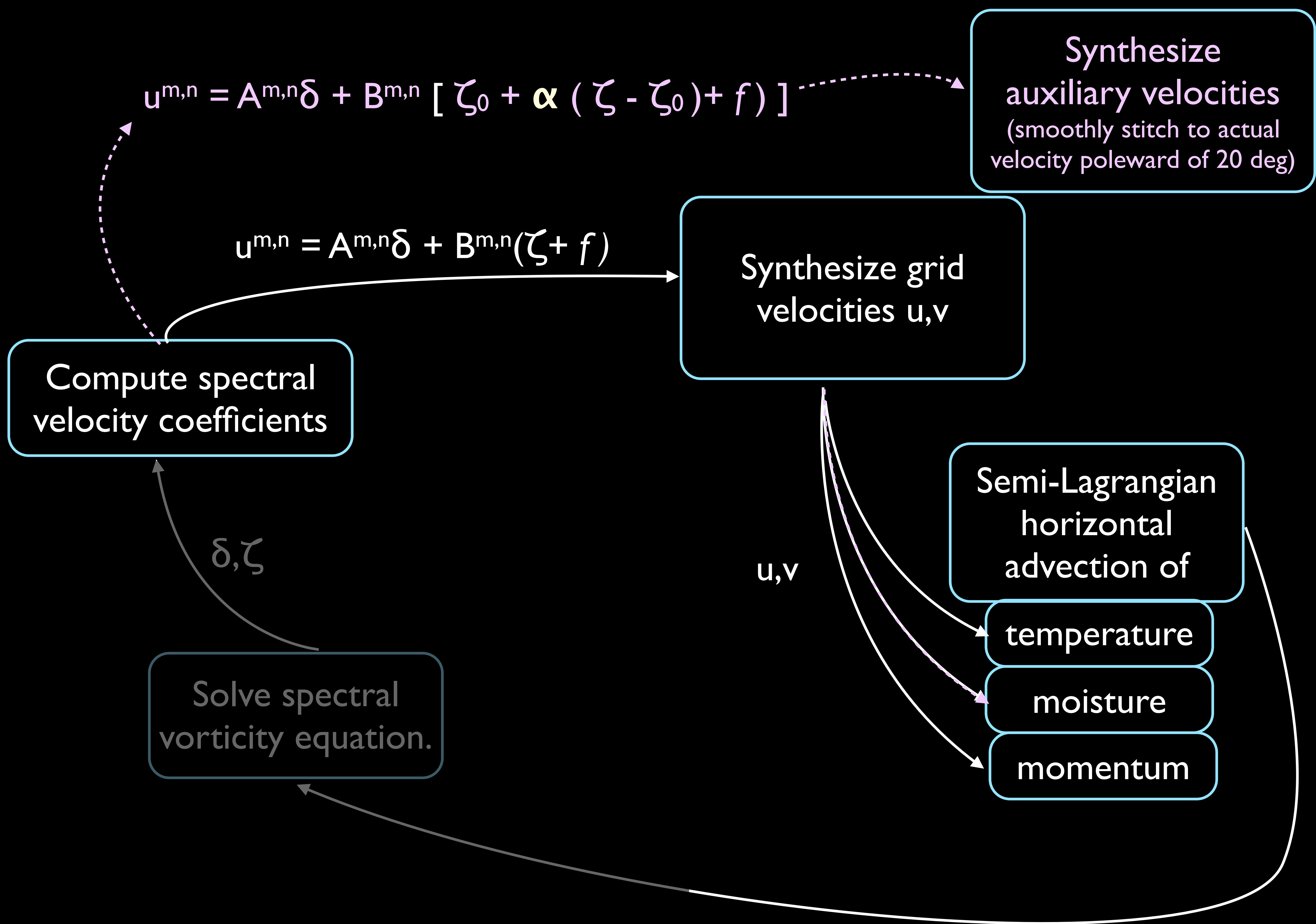
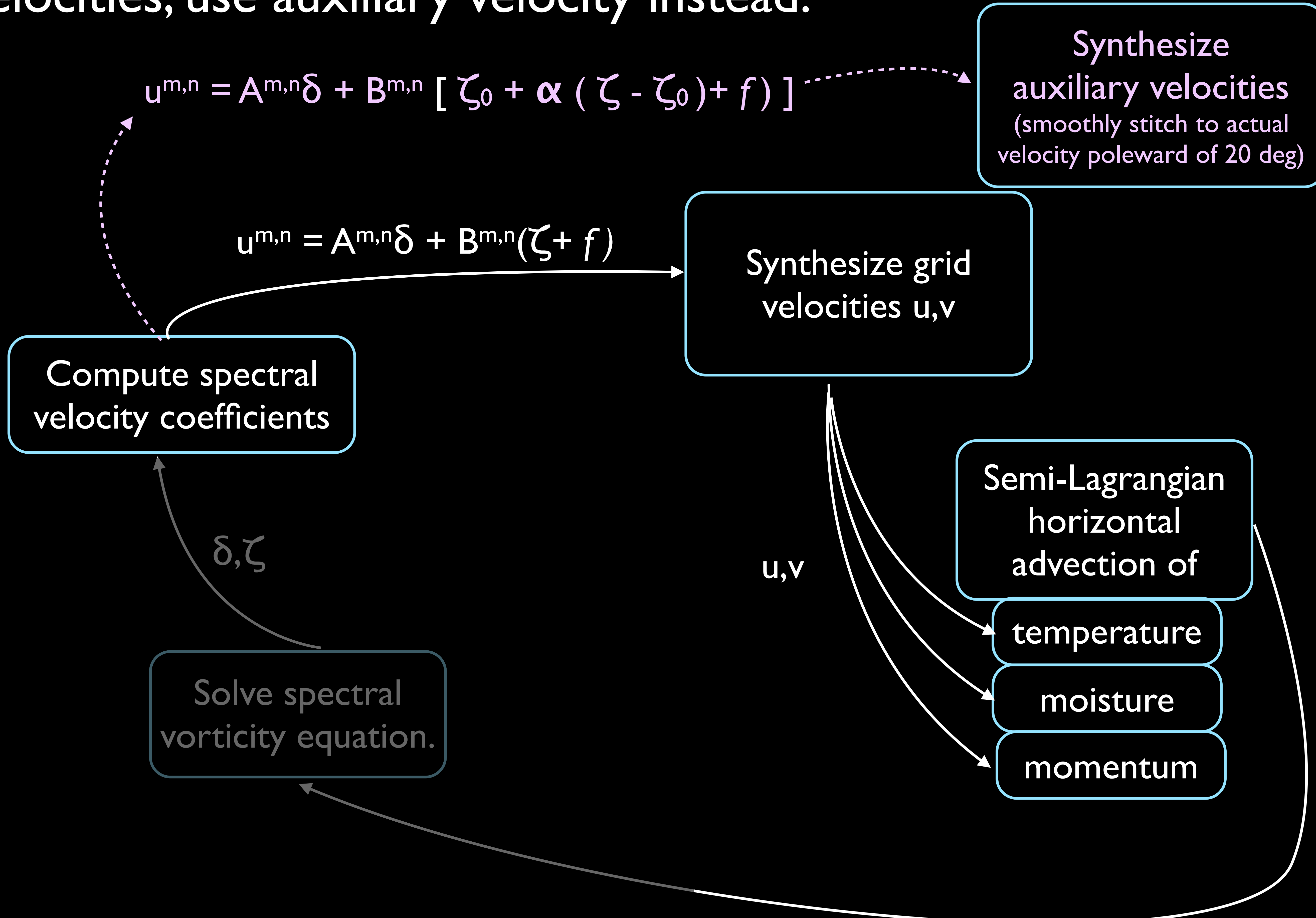


To interfere, decouple only moisture advection from actual velocities, use auxiliary velocity instead.



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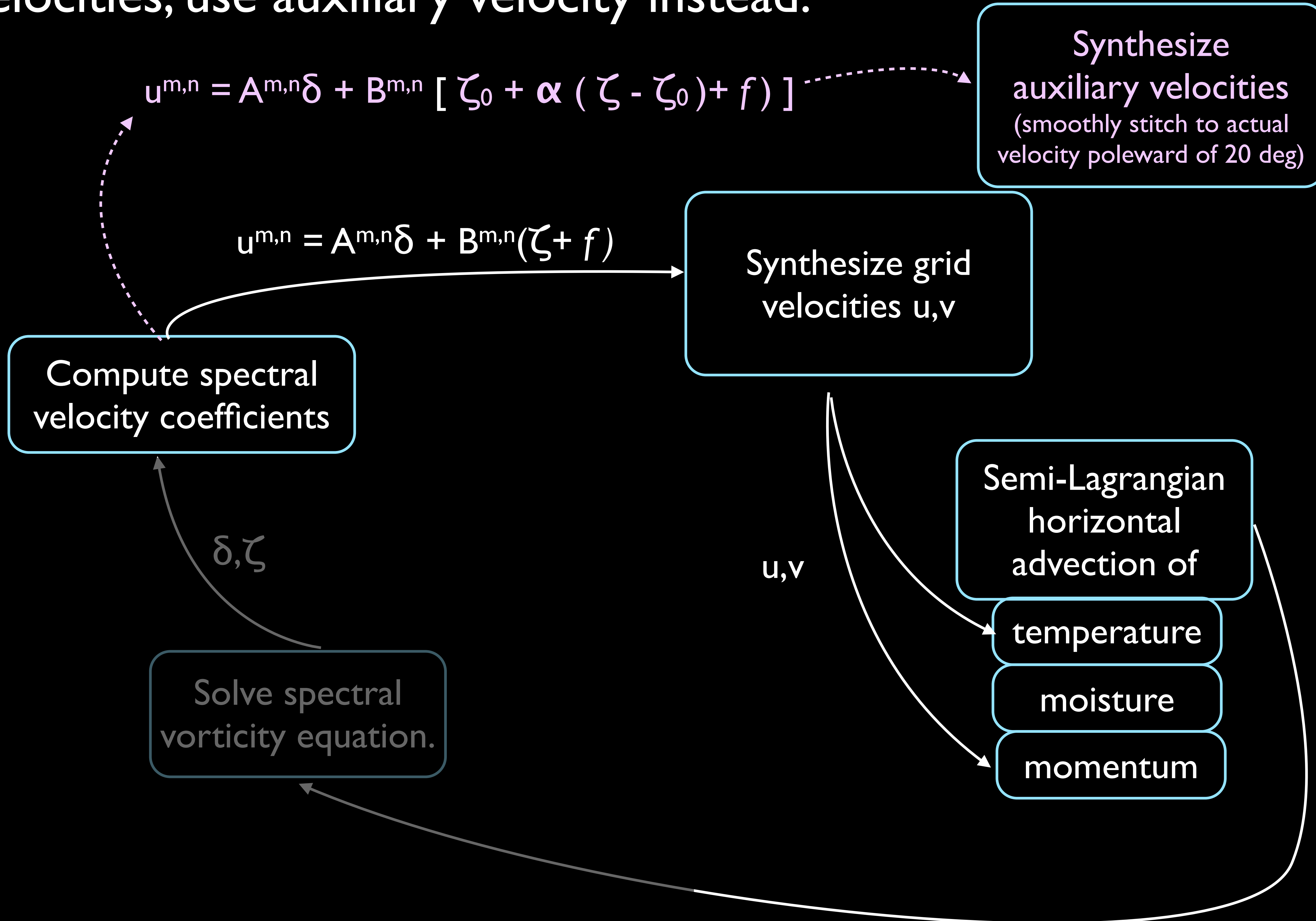

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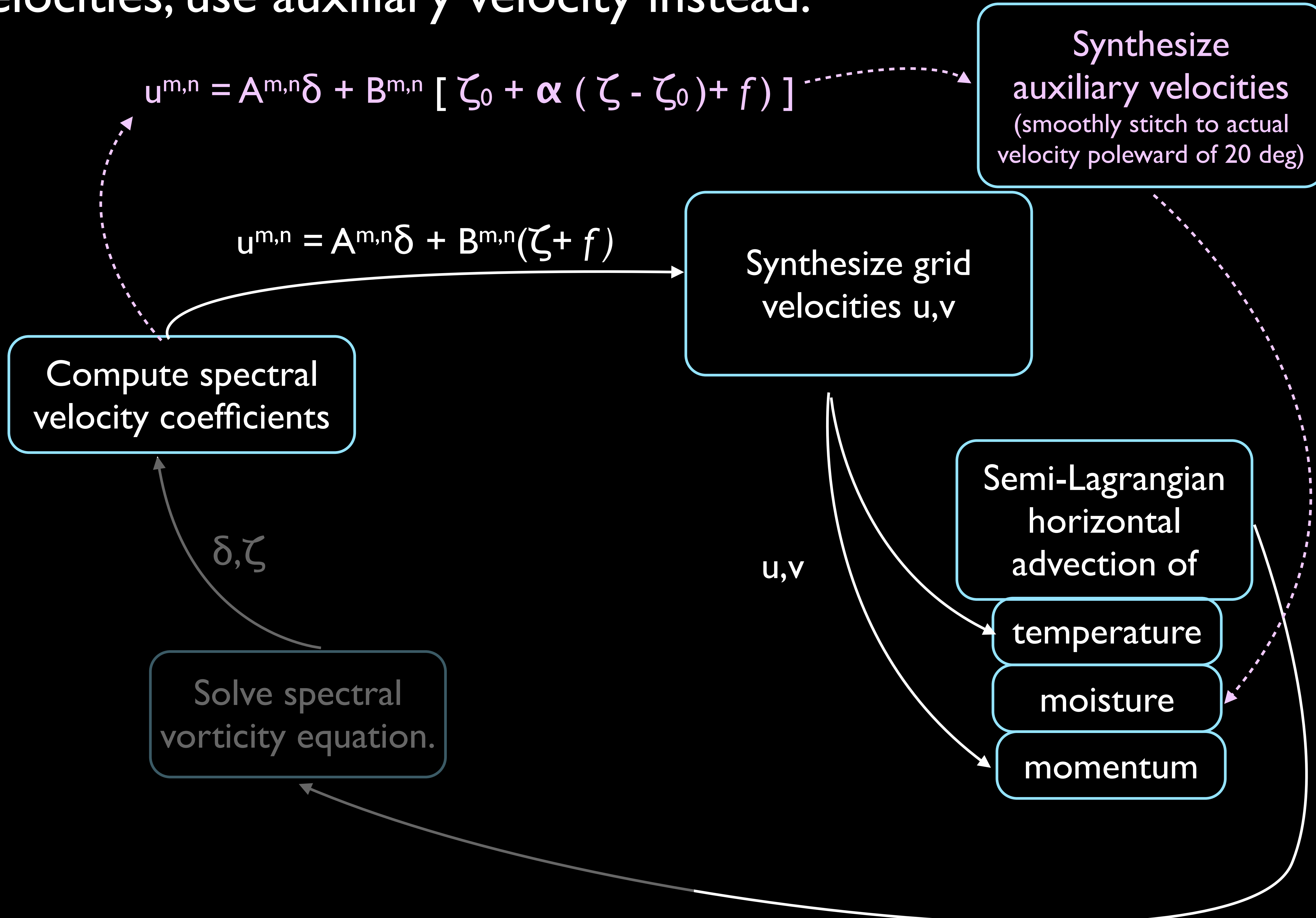

In summary, an external control parameter α has been added to SPCAM such that

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moisture advection due to tropical vorticity anomalies.

Hypothesis:

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

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Expect:

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

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(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, consistent with hypothesis.

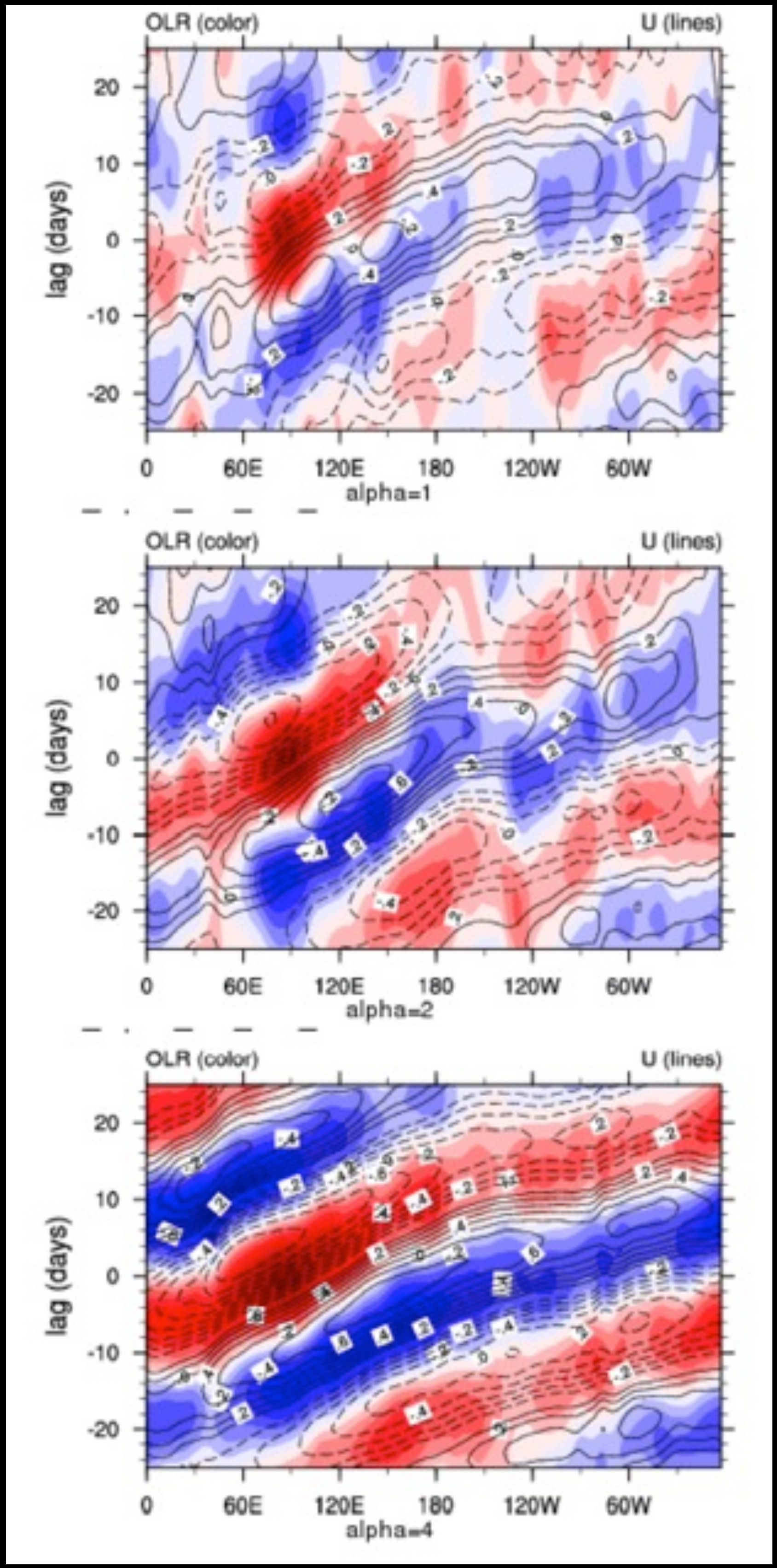
Control

α = 1

Amplifying moisture advection due to tropical vorticity anomalies.

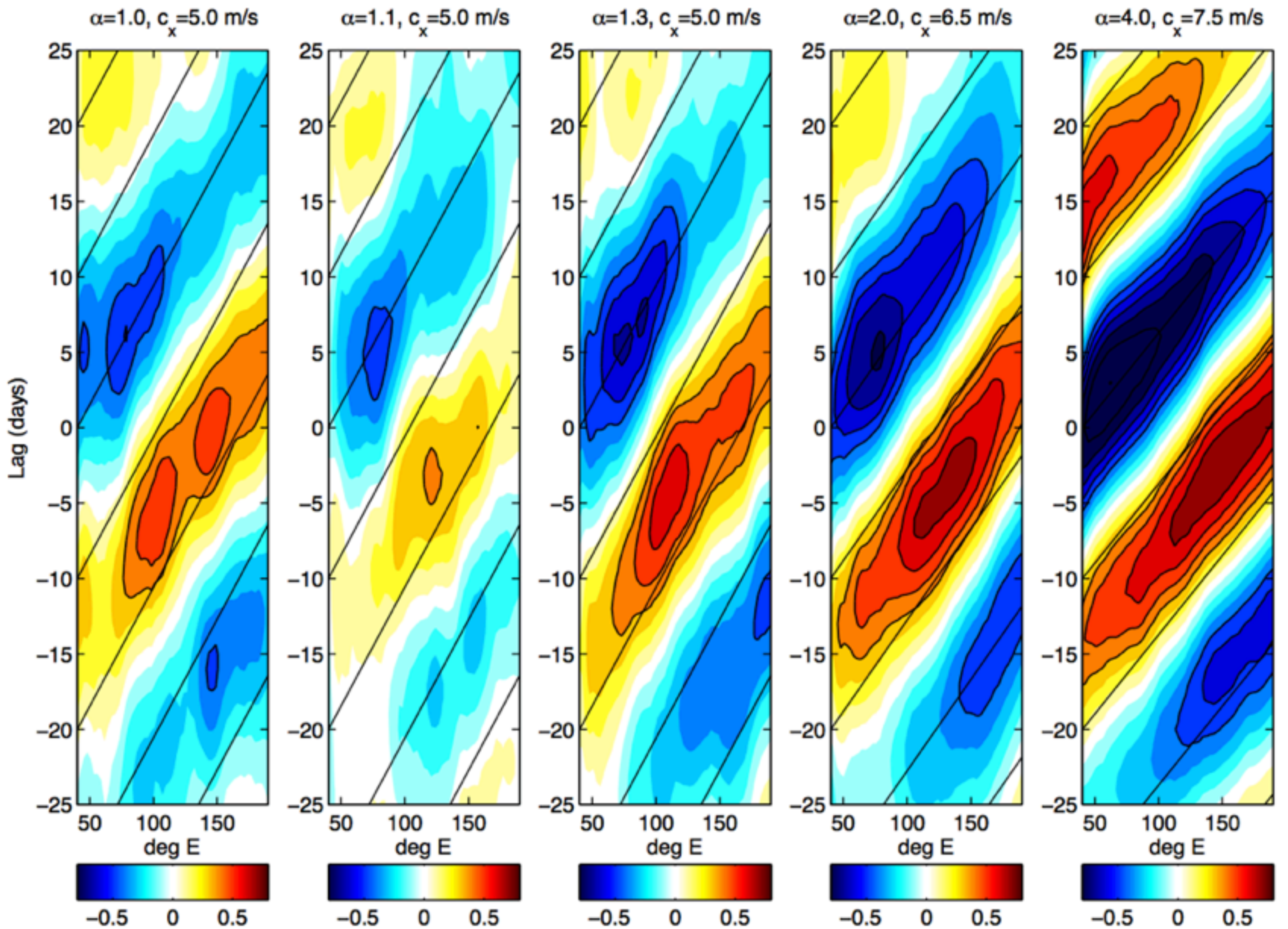
α = 2

α = 4



Time-longitude lag correlation of OLR (color) and low-level wind (contour) anomalies relative to a base point in the Indian Ocean.

Eastward phase speed increases from 5 to 7.5 m/s.



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Causal evidence supporting the hypothesis?

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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.

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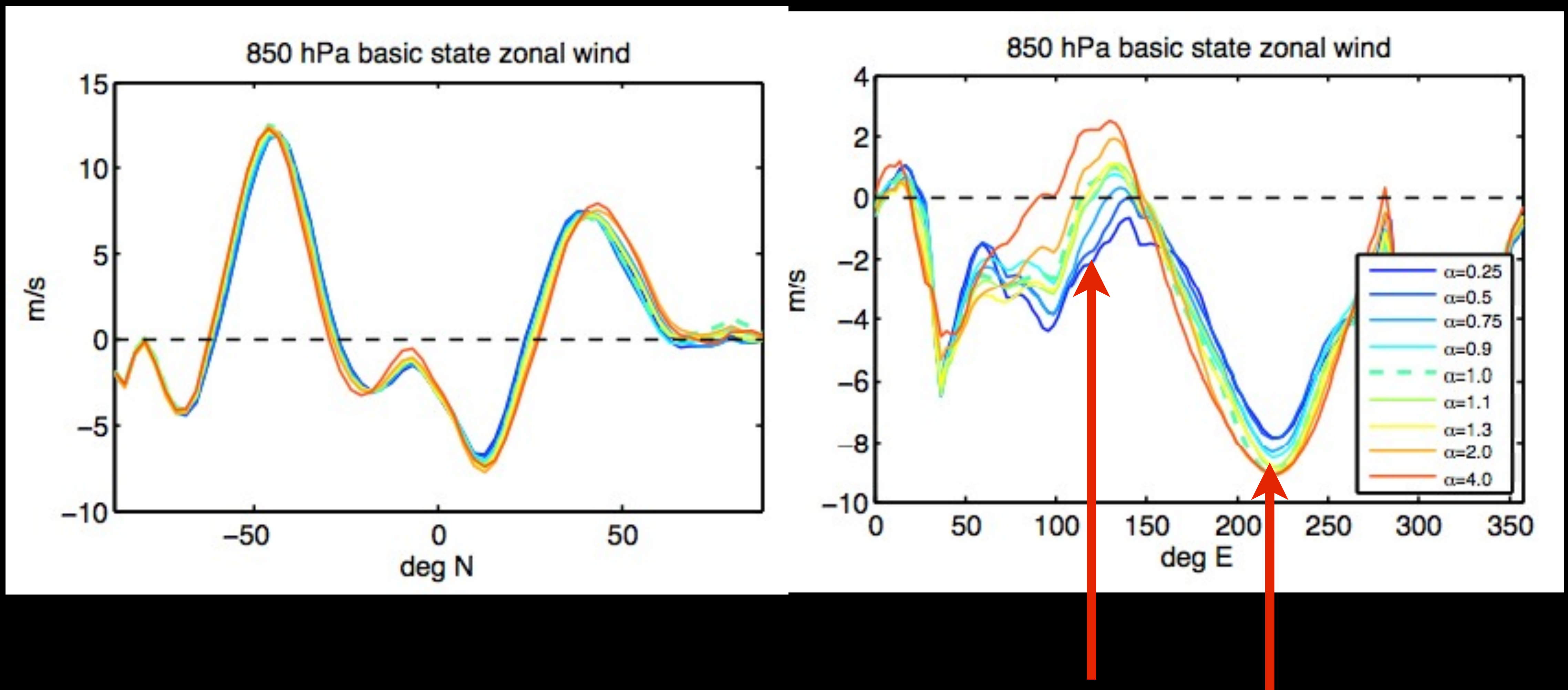
Speedup, expect:

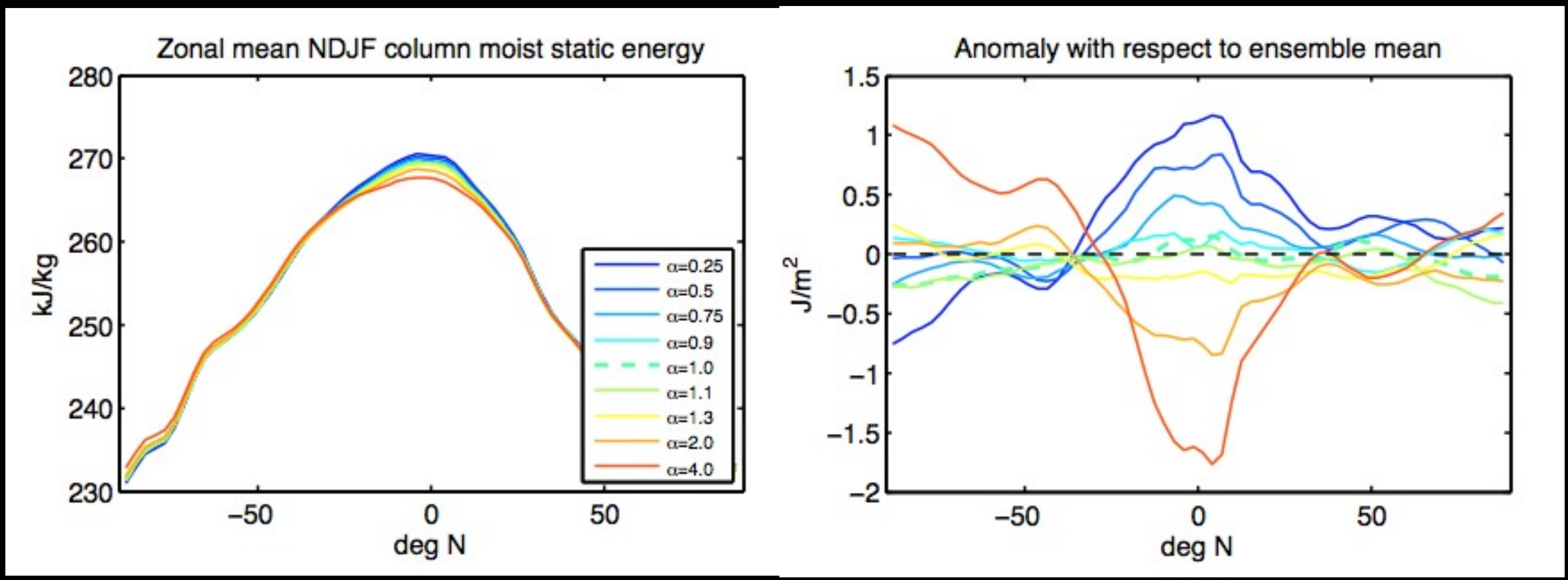
Westerly acceleration of mean zonal winds throughout tropics or narrowing of the ITCZ.

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



Reversal of flow response within MJO speedup region.

Boosting moisture advection enhances extratropical mixing, (drying) the tropics and flattening the meridional MSE gradient, inconsistent with MJO speedup.



This effect is mitigated but not eliminated by restricting α's effect to the tropics.

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Speedup, expect:

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

X

Null hypothesis:

MJO speedup is an artifact of basic state adjustment.

Speedup, expect:

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

X

Causal evidence supports the hypothesis.

What about the MJO amplitude?

MJO shuts down when moisture advection is limited.

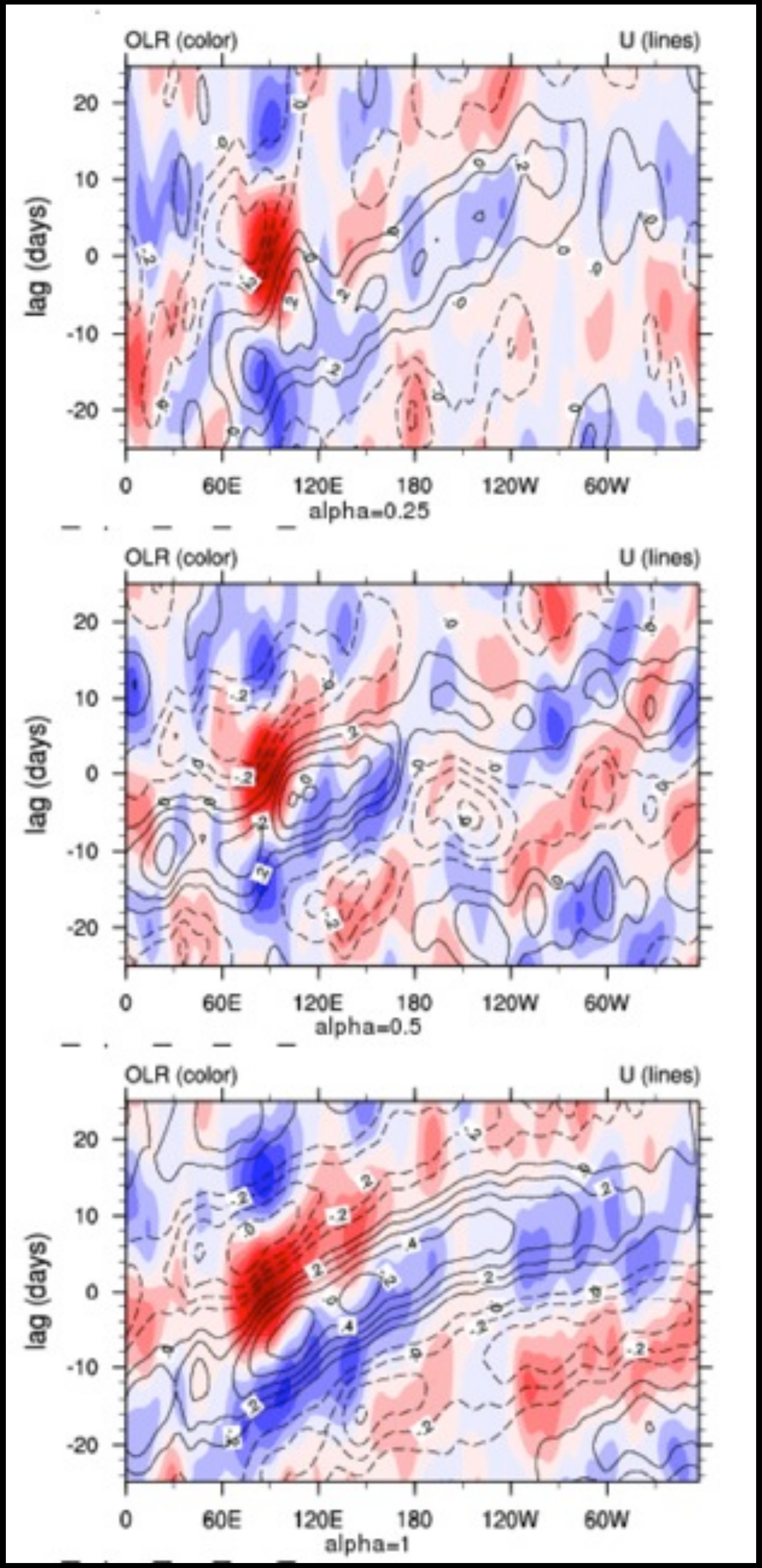
Damping moisture advection due to tropical vorticity anomalies.

Control

$\alpha = 0.25$

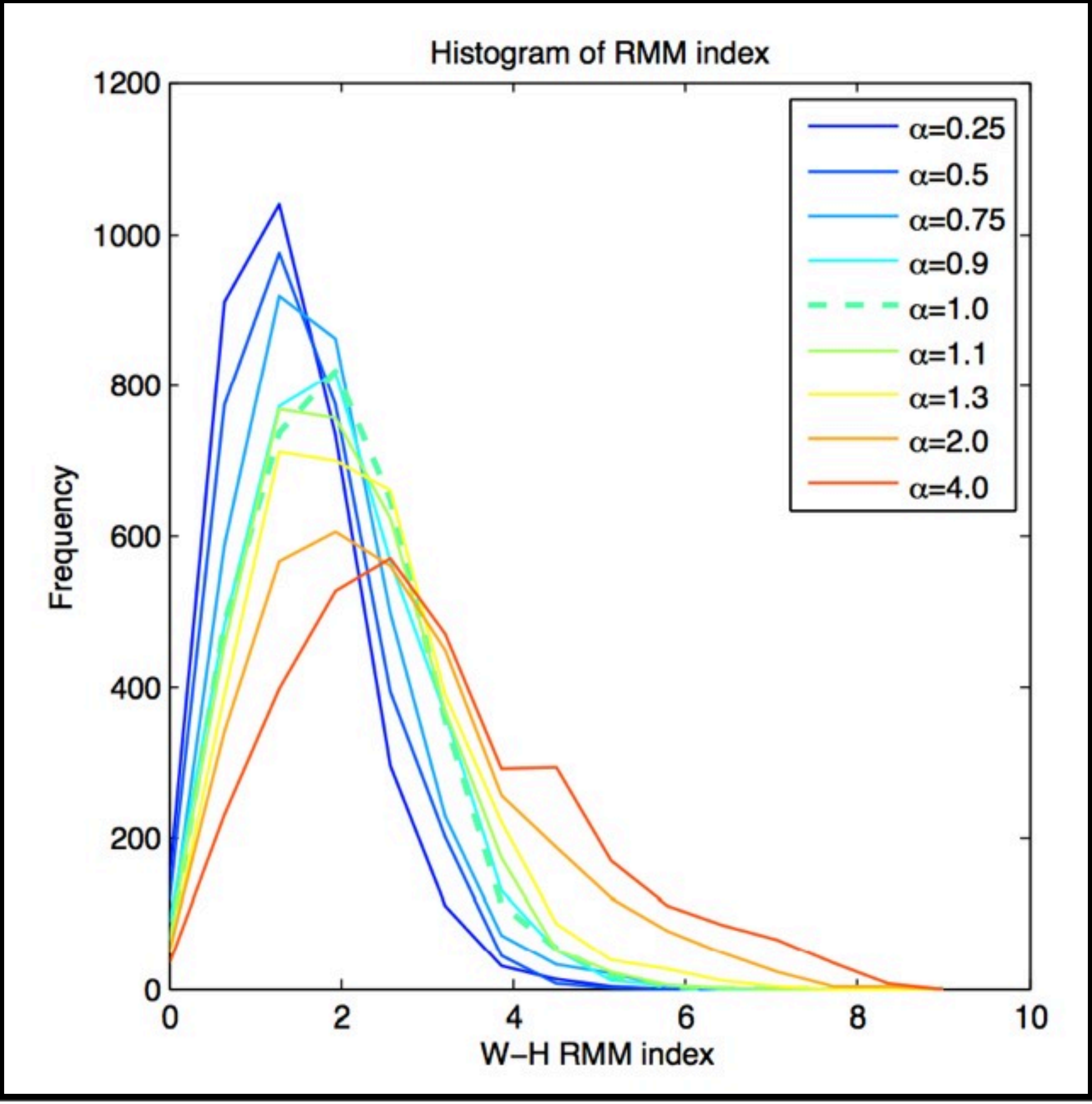
$\alpha = 0.5$

$\alpha = 1$



Time-longitude lag correlation of OLR (color) and low-level wind (contour) anomalies relative to a base point in the Indian Ocean.

MJO amplification in Wheeler-Hendon MJO index histogram response to α.



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Expect:

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Expect

MJO amplitude unchanged under modulated horizontal moisture advection.

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

✔

Expect

MJO amplitude unchanged under modulated horizontal moisture advection.

✘

Hypothesis:

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Expect:

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

✔

Expect

MJO amplitude unchanged under modulated horizontal moisture advection.

✘

Revise hypothesis.

Revised Hypothesis:

Rotational moisture advection is critical to the eastward propagation of the SPMJO. (and maintenance?)

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Rotational moisture advection is critical to the eastward propagation of the SPMJO. (and maintenance?)

MJO amplifies if horizontal moisture advection is boosted and shuts down if it is limited.

✔

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

✔

Revised Hypothesis:

Rotational moisture advection is critical to the eastward propagation of the SPMJO. (and maintenance?)

MJO amplifies if horizontal moisture advection is boosted and shuts down if it is limited.

✔

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

✔

Only if the null hypothesis can be ruled out.

Null hypothesis:

MJO amplitude is due to basic state adjustment.

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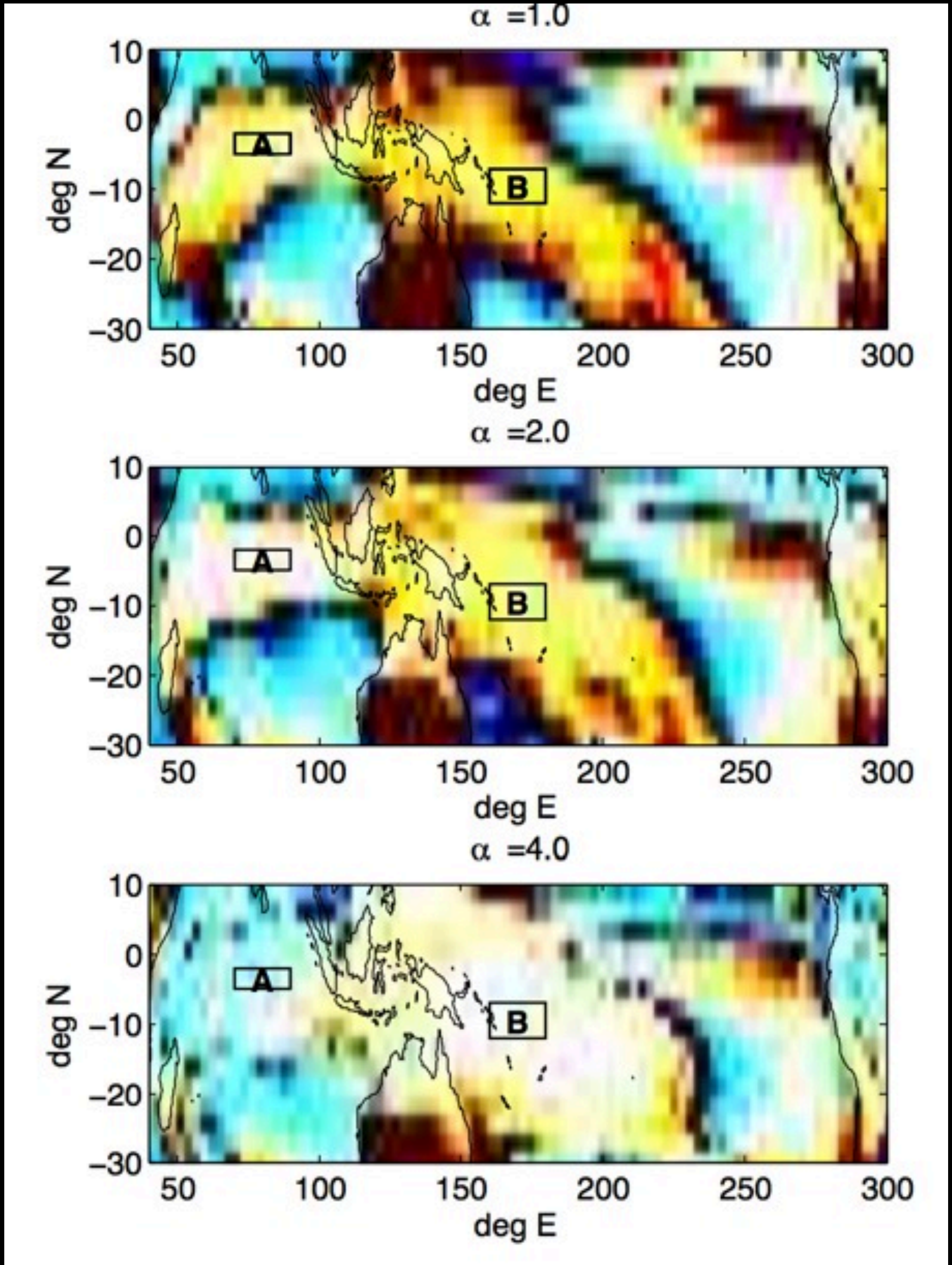
MJO amplitude is due to basic state adjustment.

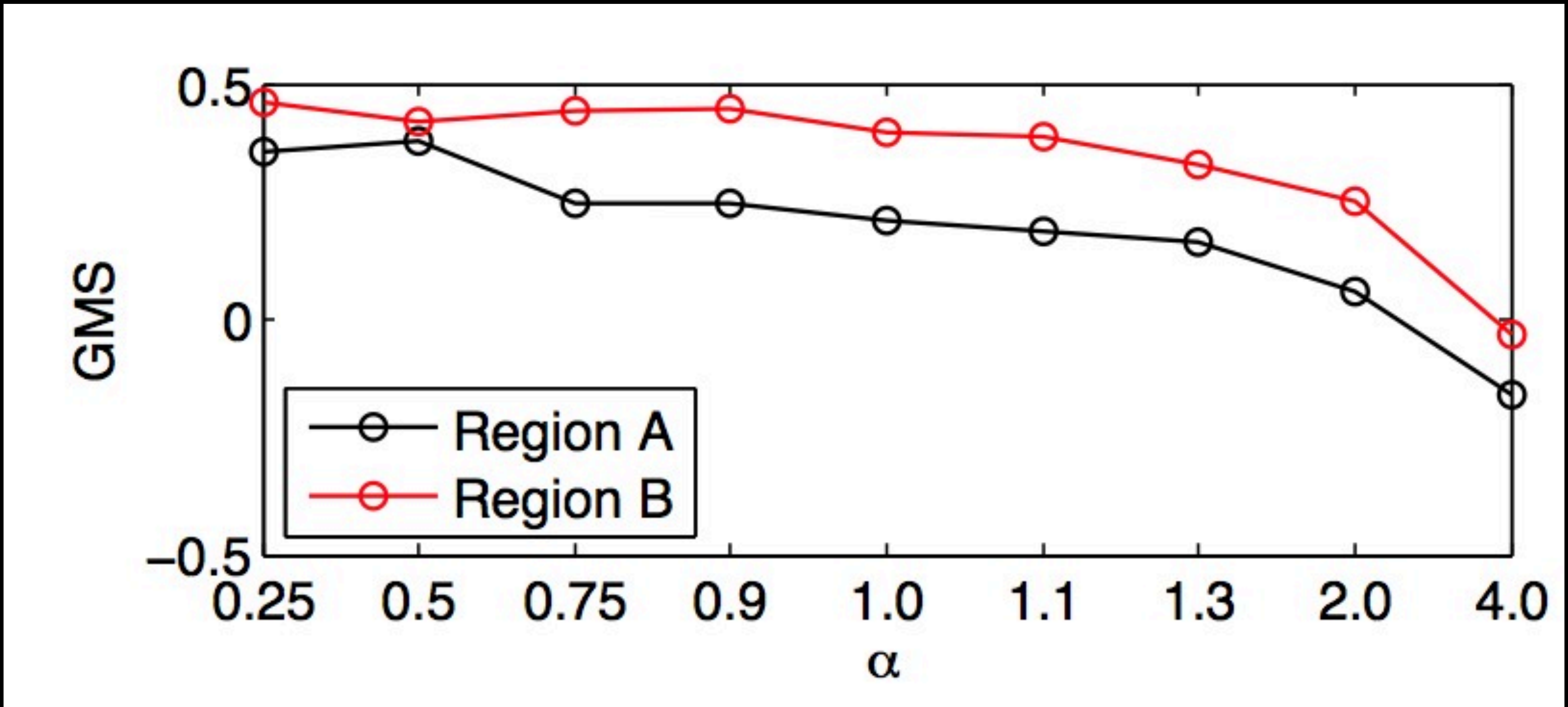
Expect:

Reduced normalized gross moist stability or increased moist static energy.

Gross moist stability decreases with α, consistent with the MJO amplification.



Gross moist stability decreases as a function of α.



Null hypothesis:

MJO amplification is due to basic state adjustment.

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✔

Null hypothesis:

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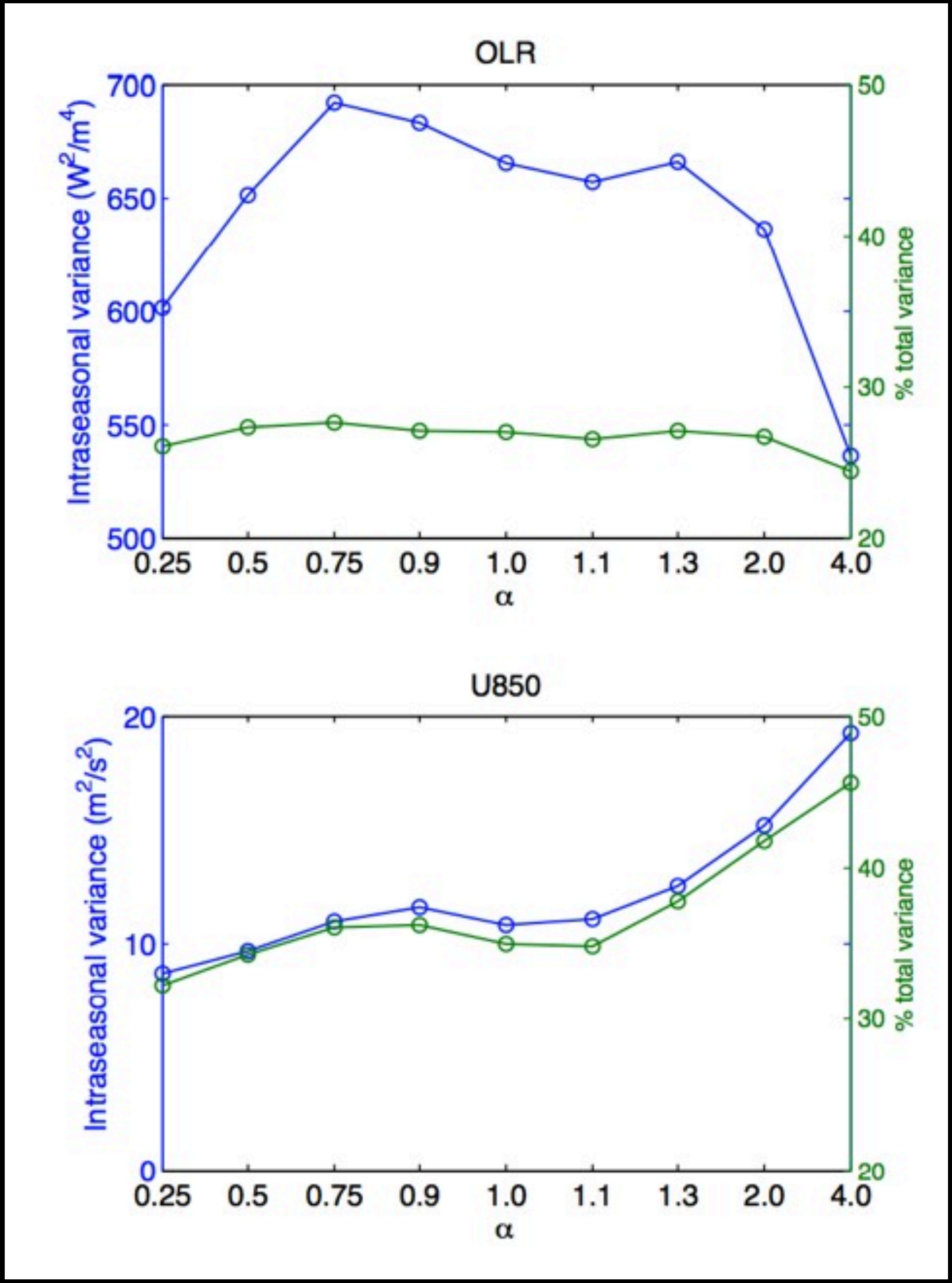
✔

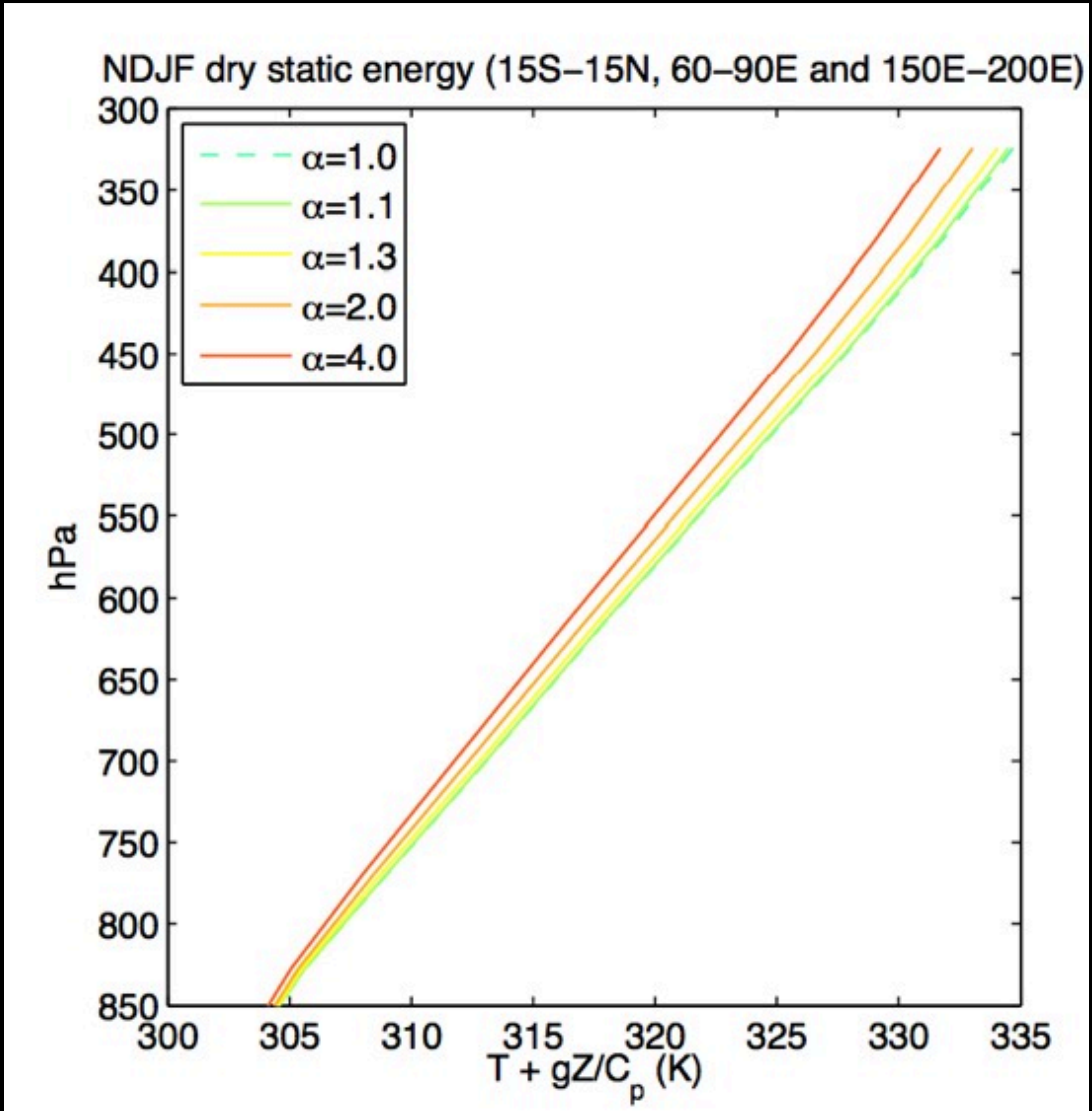
Cannot rule out null hypothesis for amplitude response.

Additional remarks

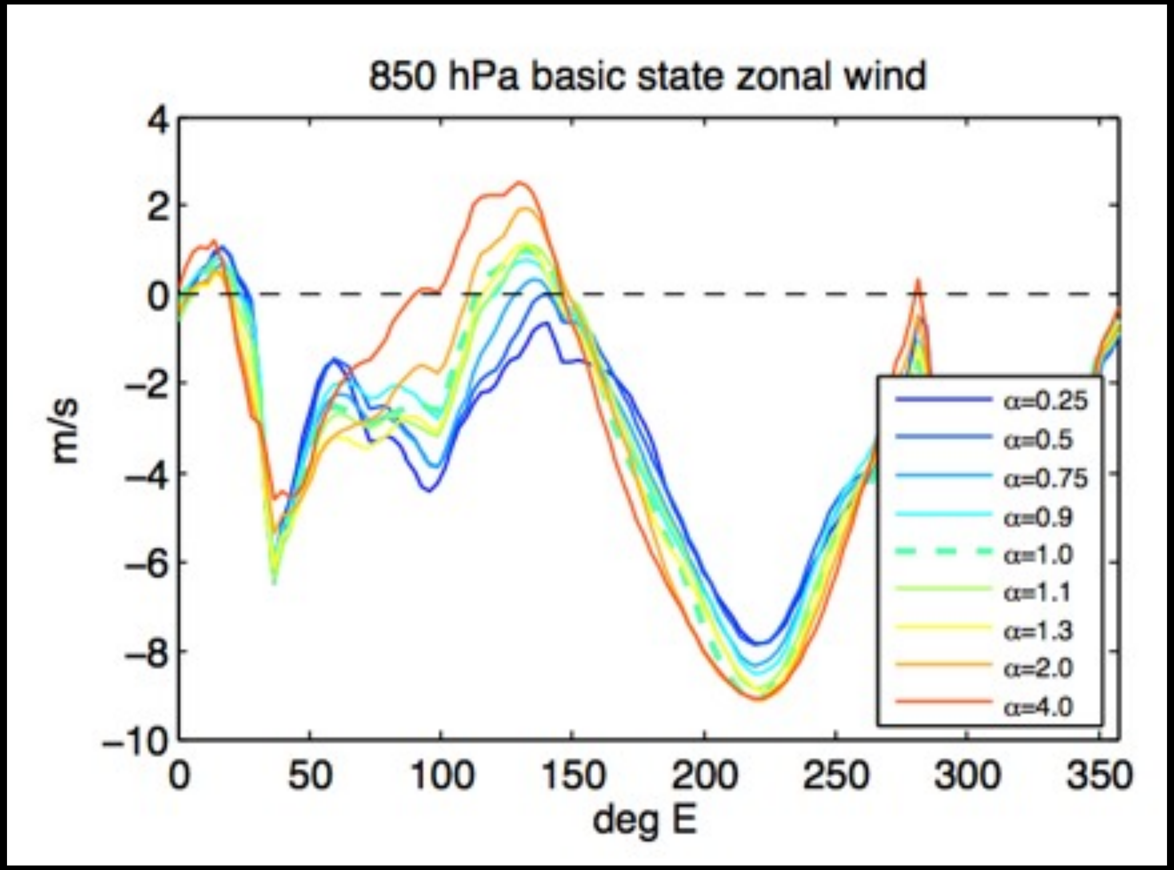
The amplification signal only exists in *wind-centric* metrics. OLR variance actually *decreases* at high α.

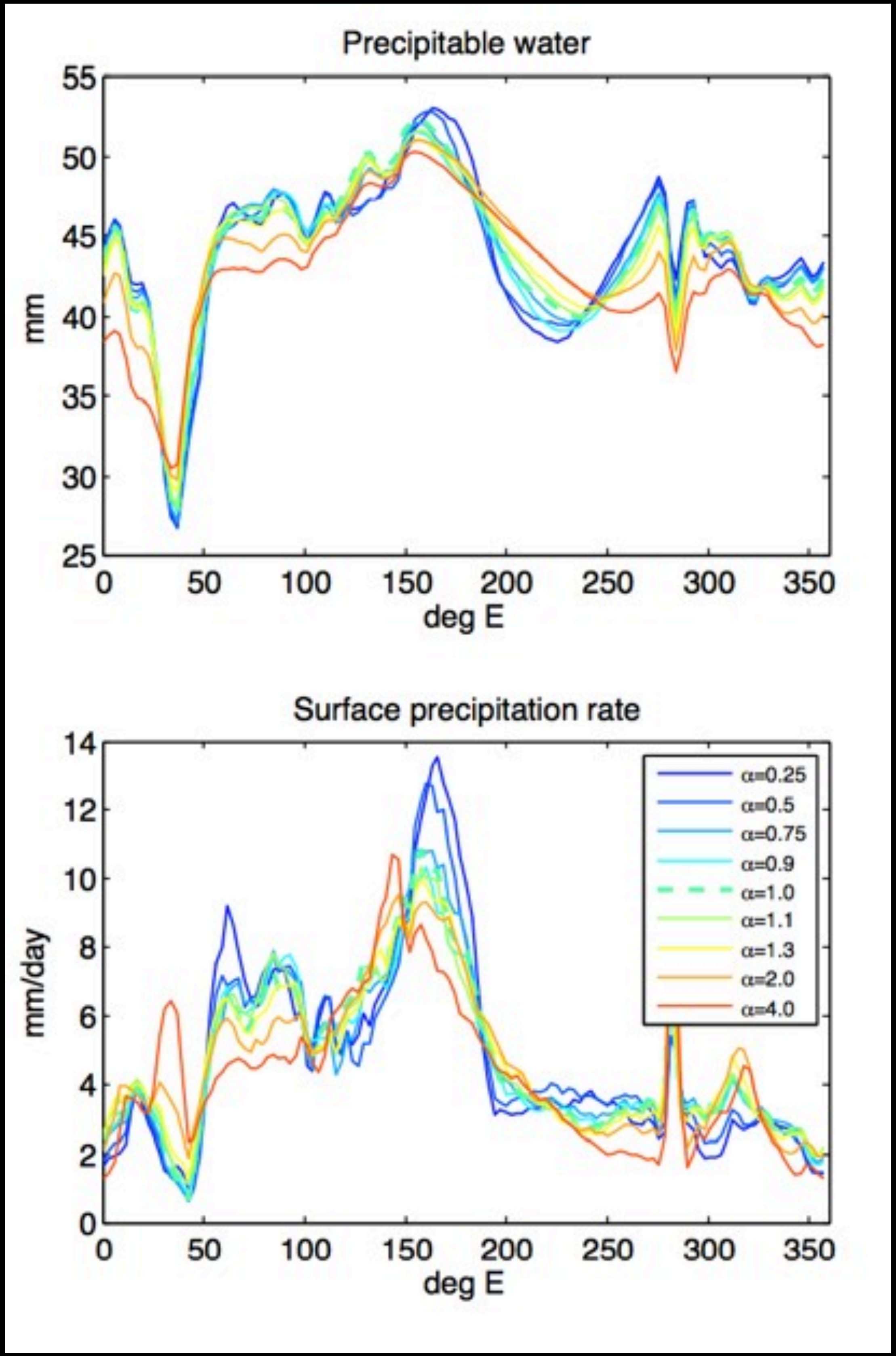


Reduced environmental dry static stability is not strong enough to explain the discrepant OLR vs. wind amplitude response.



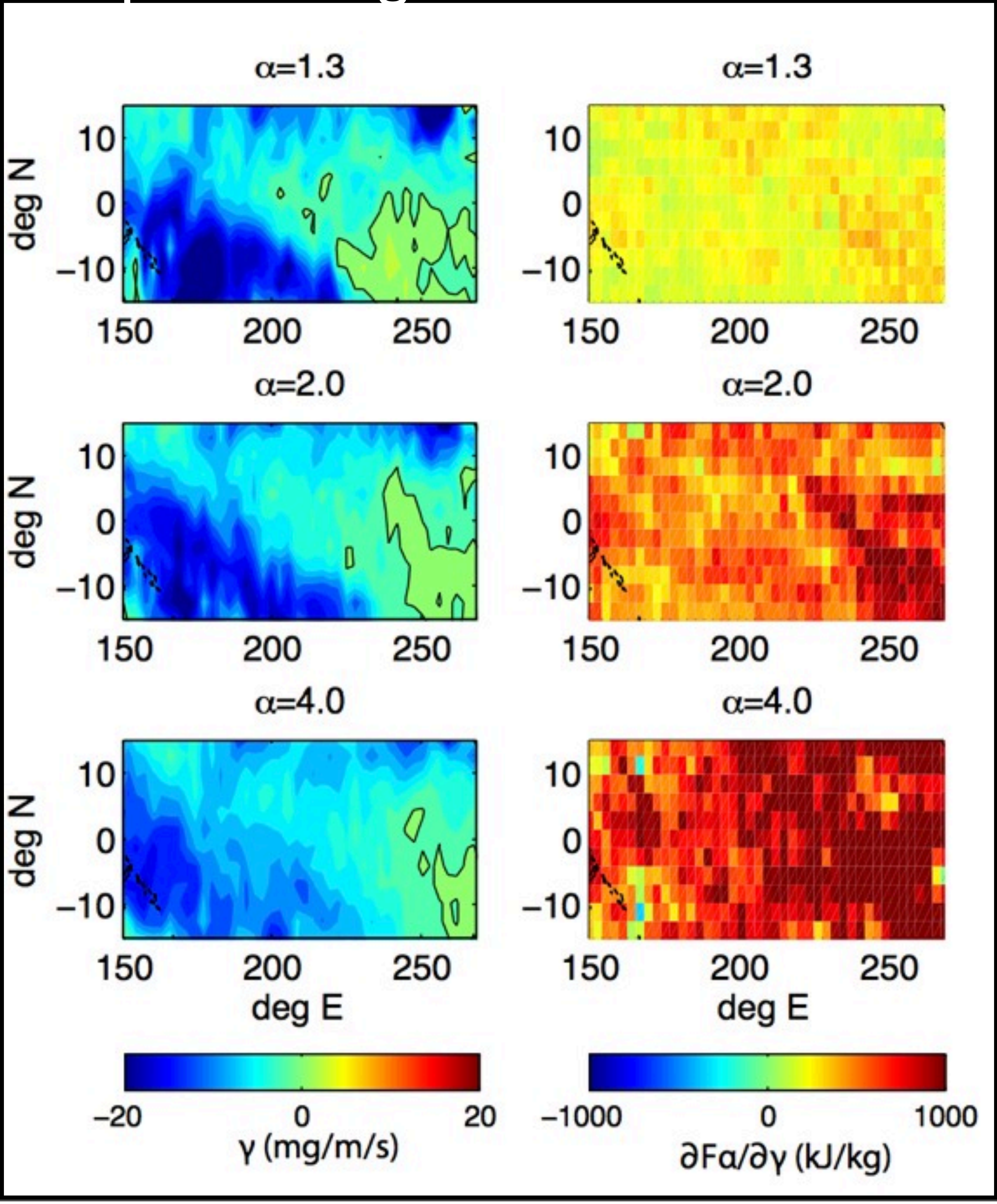
The Walker cell responds dramatically in these runs in tandem with flattening zonal PW gradients at high α.





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

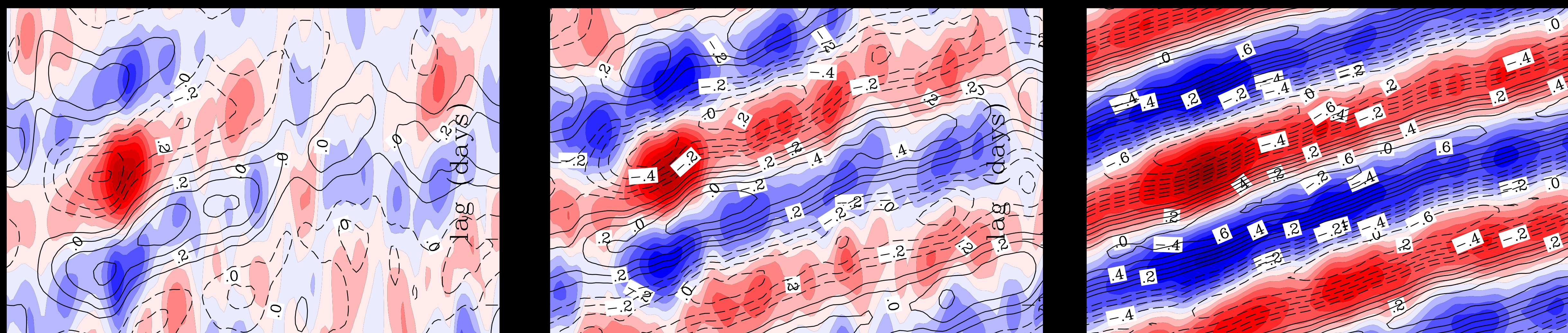
Proxy for zonal moisture advection by eddy winds.



Regression of MSE tendency due to alpha on eddy advection.

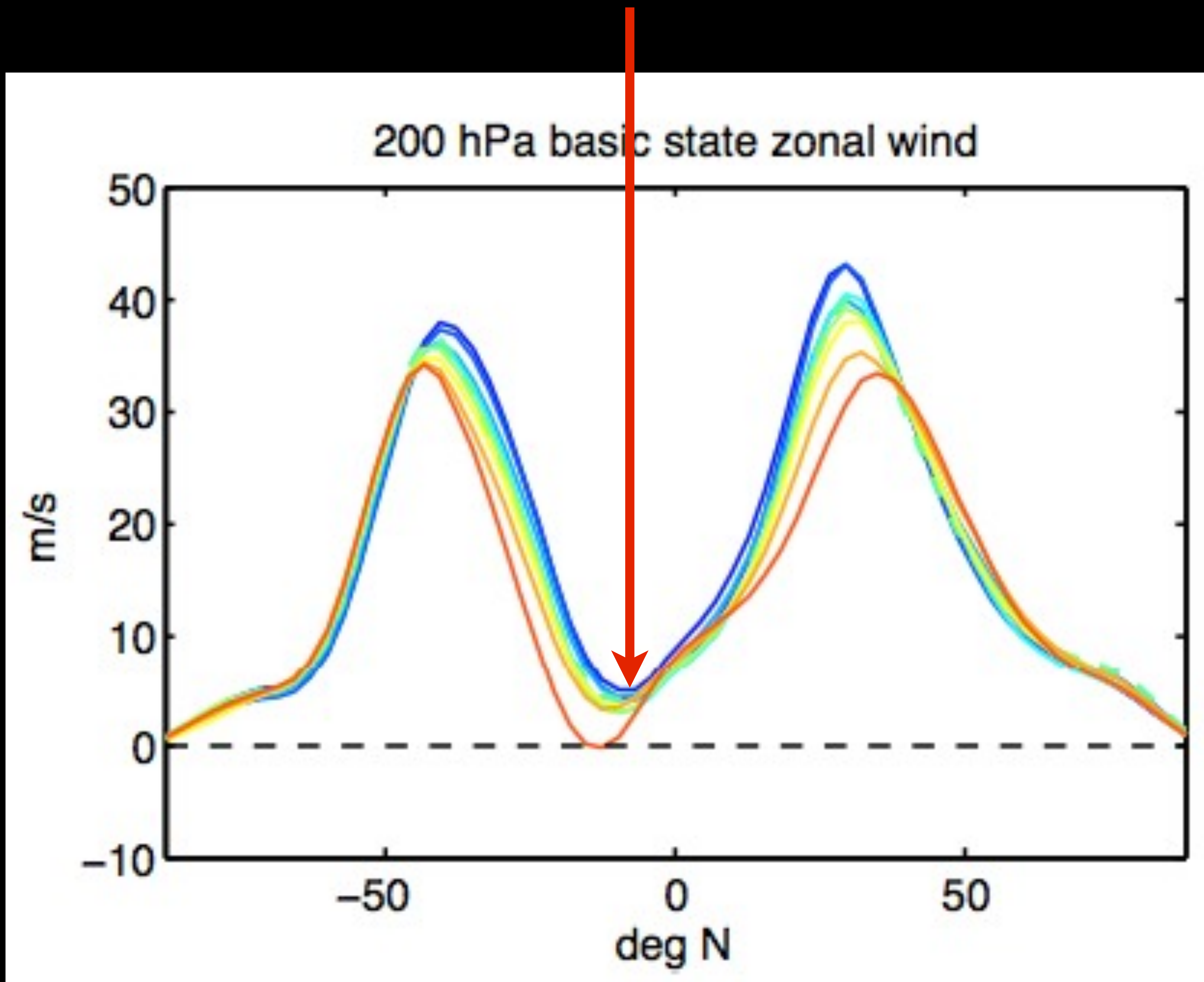
The amplification and speedup with alpha are reproducable on a zonally symmetric aquaplanet.

α = 0.25 α = 1 α = 4

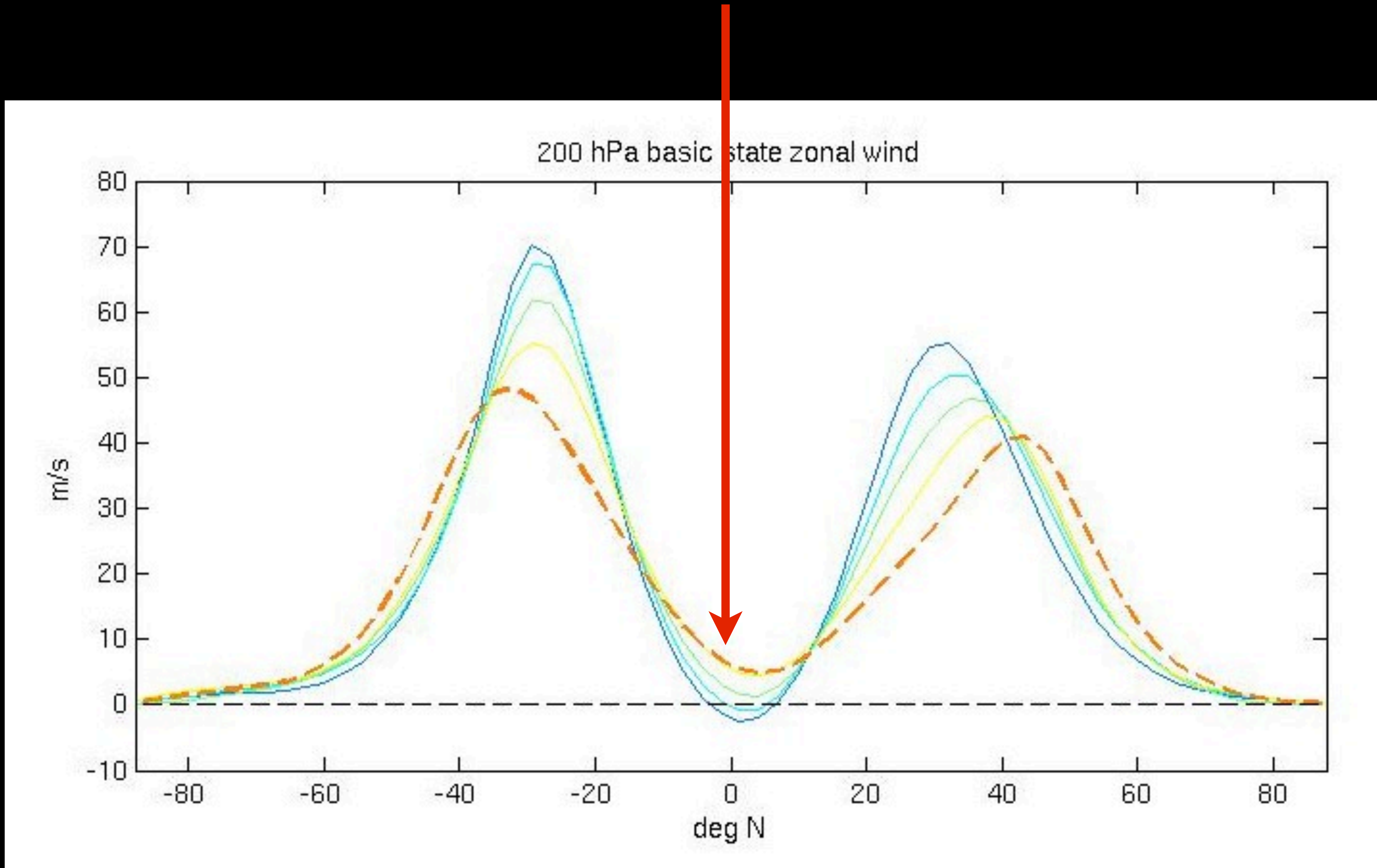


Basic state sensitivities to α are mostly similar in symmetric aquaplanet and real-geography mode *except...*

Equatorial superrotation *reduces* at elevated α in real-geography SPCAM...



… but superrotation *enhances* at elevated α in *real-geography* SPCAM.



Conclusions

Sensitivities 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 articifically enhanced.

✔

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

✔

Causal evidence supporting the hypothesis.

Many questions.

- How does α reduce mean GMS to amplify MJO?
- Why a discrepant wind vs. OLR amplitude response?
- How does α impact extratropics, the Hadley cell?
- Why an opposite superrotation response in aquaplanet vs. real-geography SPCAM?
- How is α impacting the MJO structurally?...

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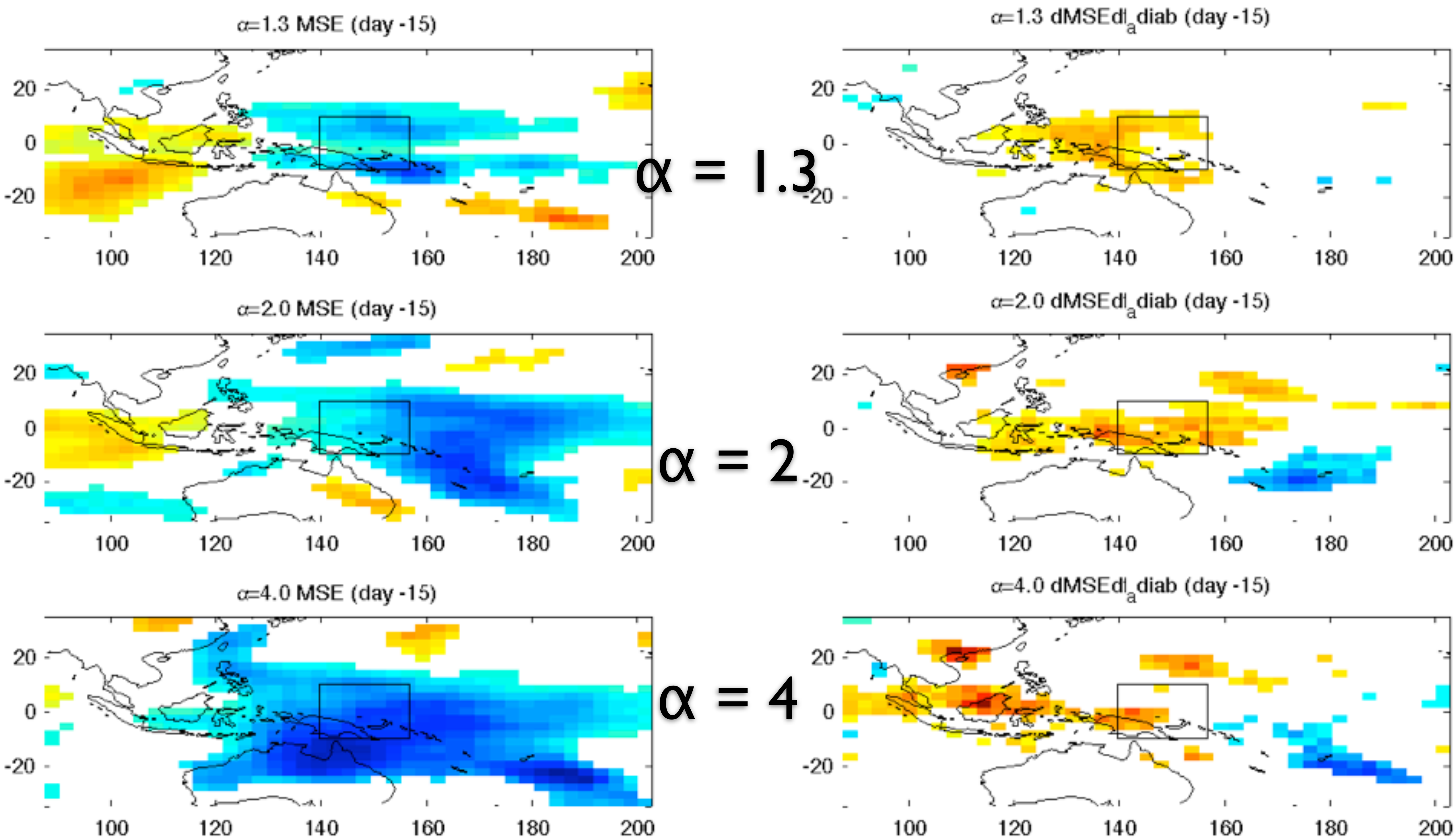
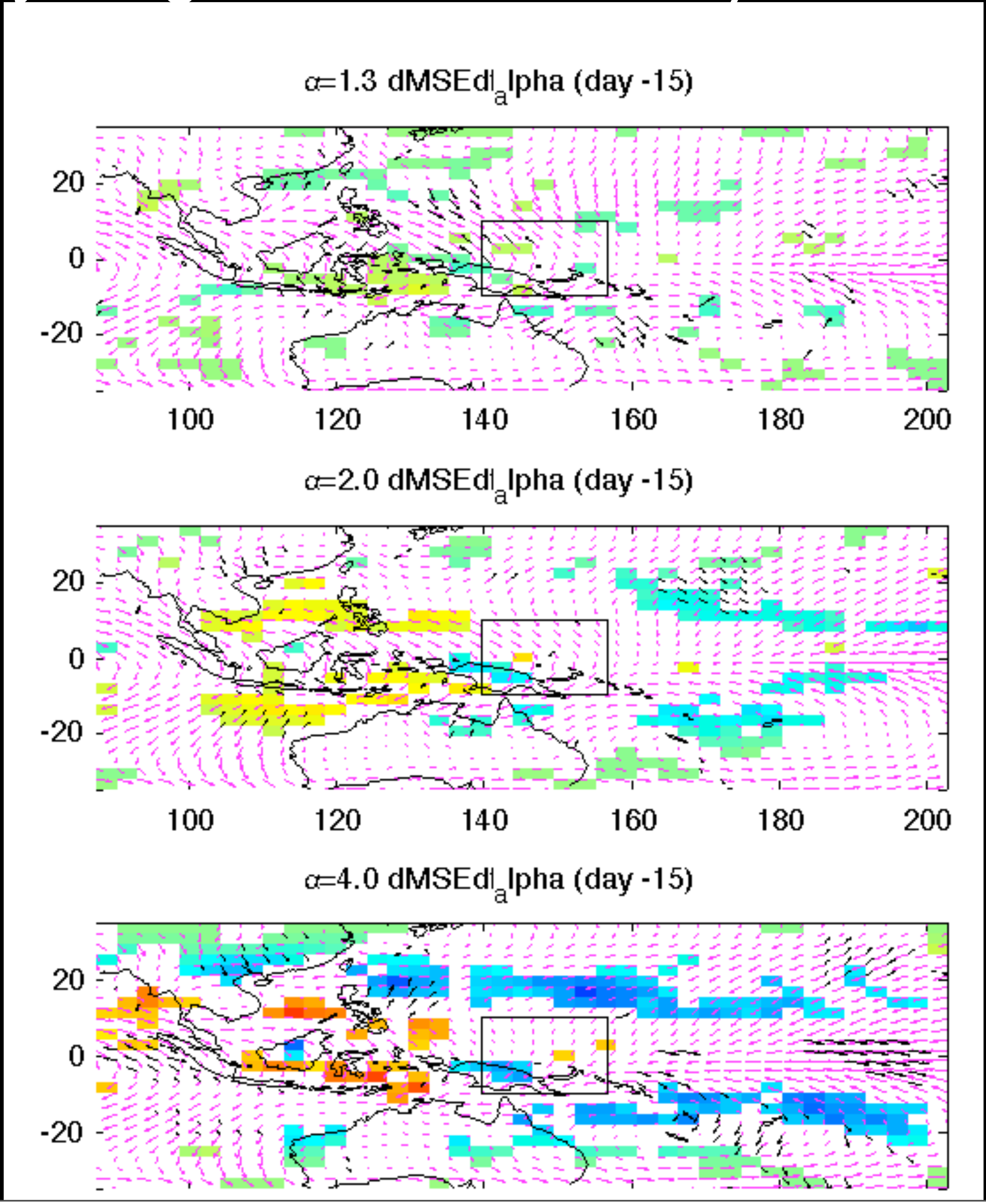
MJO-regressed MSE

MJO-regressed MSE advection



MJO-regressed MSE tendency due to α



α = 1.3

α = 2

α = 4

Thanks

To Chris, for the insight.

To NOAA CGC, for funding.

To Marat for making & sharing SPCAM3.0.

To Tom, Dargan, Peter, Roj & Dale for great conversations.