A moist static energy budget analysis of the MJO in the Superparameterized Community Atmosphere Model

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Several new GCMs seem to produce improved MJOs in tandem with tighter moisture-rainfall coupling.

CAM+RAS+Tk

Maloney's modified version of CAM using Relaxed Arakawa Schubert + limiter.

SPCAM

Super-Parameterized Community Atmosphere Model

CCSM4

Zhang-McFarlane plus R. Neale's implementation of the Raymond & Blythe stochastic mixing scheme.

ECHAM

Tiedke + Nordeng

In two of these models, aspects of the MJO may be consistent with a "**moisture mode**" paradigm.

→ **CAM+RAS+Tk**

Maloney's modified version of CAM using
Relaxed Arakawa Schubert + Tiedke

→ **SPCAM**

Super-Parameterized Community Atmosphere Model

CCSM4

Zhang-McFarlane plus R. Neale's implementation of the Raymond & Blythe stochastic mixing scheme.

ECHAM

Tiedke + Nordeng

What is a **moisture mode**?

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

Tropical convection self aggregates on large scales via. internal feedbacks

Coupled to horizontal advection, can manifest as slow propagation.

Column MSE budget is key:

$$\frac{d}{dt} < MSE > (x,y,t) = \textbf{why?}$$

(column MSE budget tendency variables)

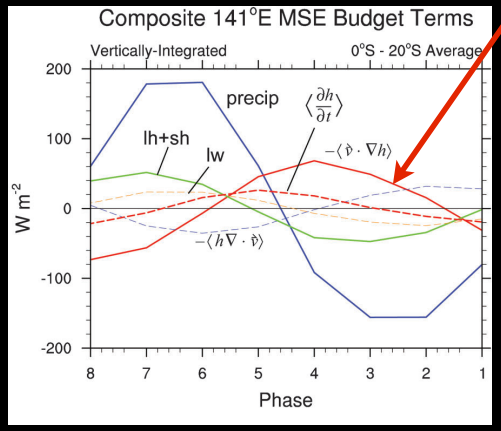
Point out that CRM and SP simulations may be pointing in this direction, which is kind of exciting.

Example:

Maloney's CAM3 w. tighter q-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 →)

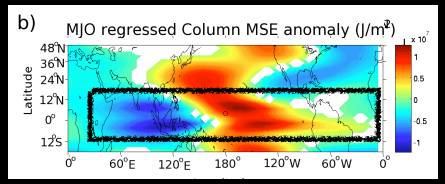
Just point out the fact that horizontal advection is pulling things to the east for now (save the destabilization bit for late).

Example:

Aquaplanet SPCAM w. zonally symmetric SSTs.

(Andersen & Kuang, *J. Clim.*, in press.)

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



This has raised basic questions.

1. How are the intraseasonal moisture modes destabilized?

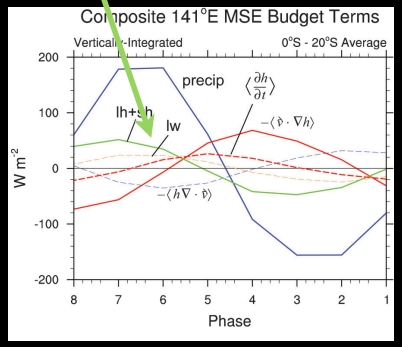
2. How do the intraseasonal column moist static energy anomalies travel through space?

Some aspects of these questions have been addressed...

1. What physics cause the simulated moisture modes to destabilize?

Maloney's CAM3:

Surface fluxes destabilize

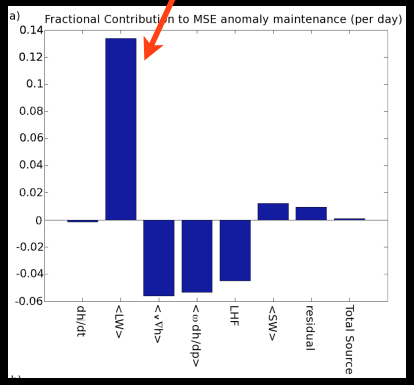


Time (or x ⟶)

Maloney et al., JAMES, 2010

Andersen & Kuang's aquaplanet SPCAM3.5:

Longwave radiation destabilizes



But other aspects of possible GCM moisture mode dynamics have yet to be clarified.

1. How are the intraseasonal moisture modes destabilized?

   Surface fluxes vs. longwave radiation?

   (dependance on basic state idealizations?)

2. How do the intraseasonal column moist static energy anomalies travel through space?

   How does the column MSE move through (x,y,t)?

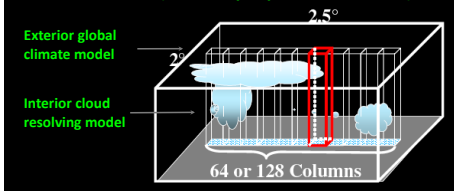
Emphasize Zhiming's work that points to interactions with the extratropics.

Adding another model to the debate: Real-world SPCAM

CMMAP's prescribed SST SPCAM3.0 run.

(Thanks to Marat Khairoutdinov!)

The Multi-scale Modeling Framework (MMF) approach
(a.k.a. "super-parameterization")



Superparameterization configuration:

CAM3 T42 SLD exterior

N-S 32 x 4km CRM interior

Advantages

MJO has been validated

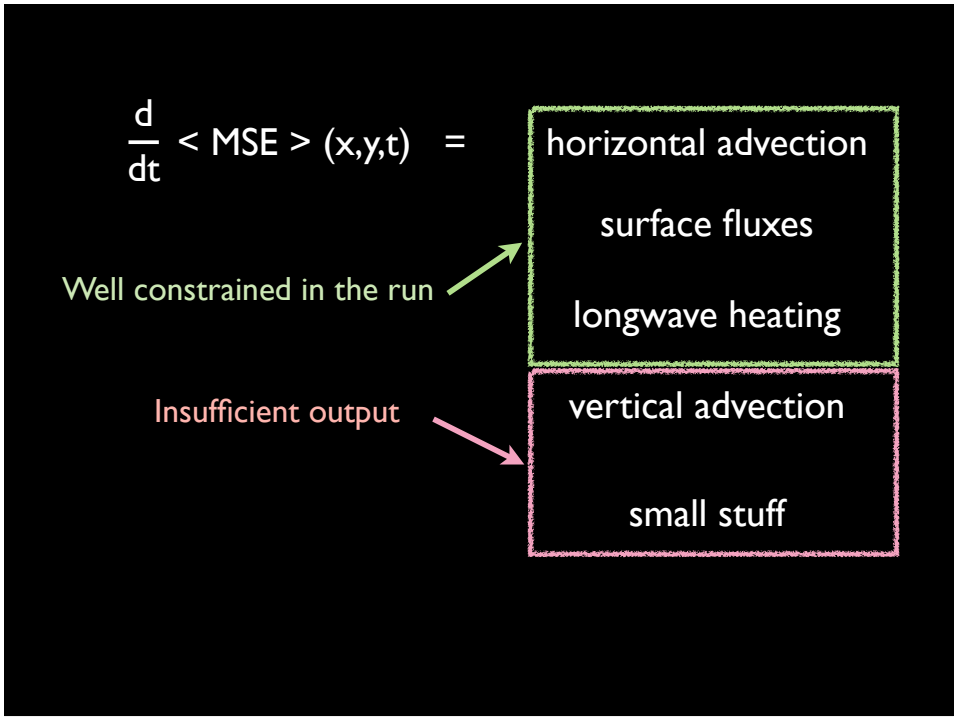
Realistic basic state

Long record (20 years) for good statistics

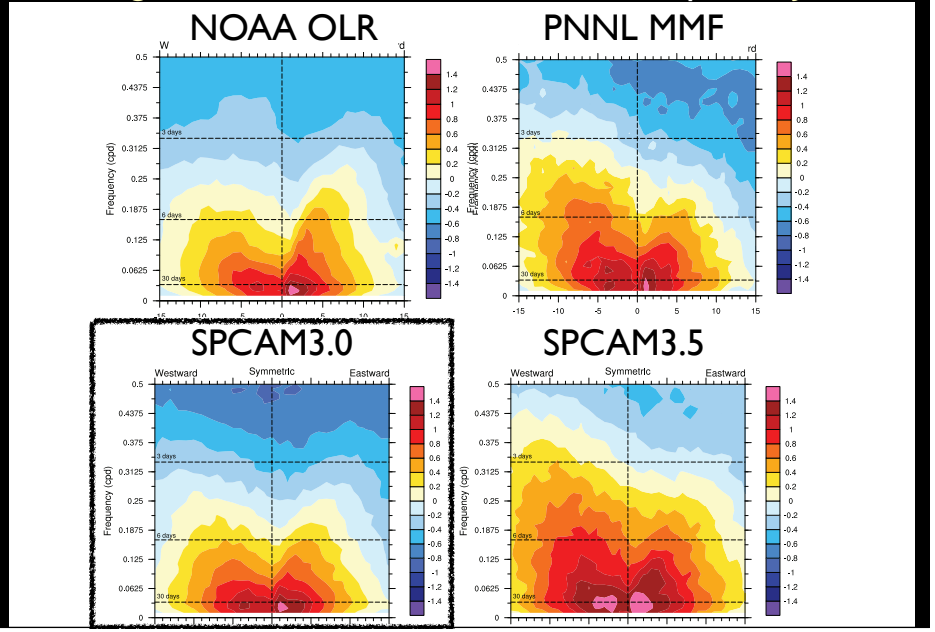
Disadvantages

Insufficient output to completely close the column MSE budget

Khairoutdinov et al., 2008
Benedict & Randall, 2009


$\frac{d}{dt} < MSE > (x,y,t) =$
horizontal advection
surface fluxes
longwave heating
Well constrained in the run
Insufficient output
vertical advection
small stuff

Why not analyze one of the newer prototype MMFs?
The original SPCAM3.0 has a better uncoupled MJO.



This is an unambiguous observation OLR. This was what was known about SPCAM's MJO circa 2005, 2008 (Marat).
Much more rigorous look follows. Statistical composites from reanalyses show us that...

Questions

What destabilizes the mature
Pacific moisture mode in real-world SPCAM?

I don’t think the answer to the second question will surprise anybody.

Use established methods to probe the (x,y) structure of MJO related variations in column MSE budget terms.

- Isolate MJO phases using multivariate EOFs for boreal winter.

(as in Maloney et al. 2010)

- Pick a baseline regression time series: 20-100 day filtered OLR averaged in a zonally phase-aligned 10-deg wide box, 10S-5N.

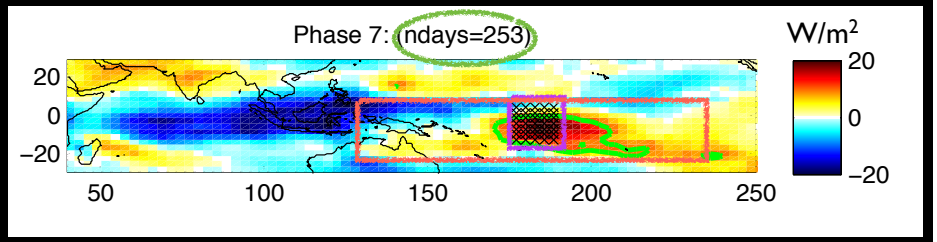
- Lag-regress in (x,y) unfiltered column MSE budget terms, visualize statistically significant regression slopes.

(as in Andersen & Kuang 2011)

For consistency with other models, focus on (x,y) budget during a mature Pacific MJO phase.

Phase 7: The MJO convection index (negative filtered OLR) composite

~ 250 boreal winter sim-days
available for statistical analysis



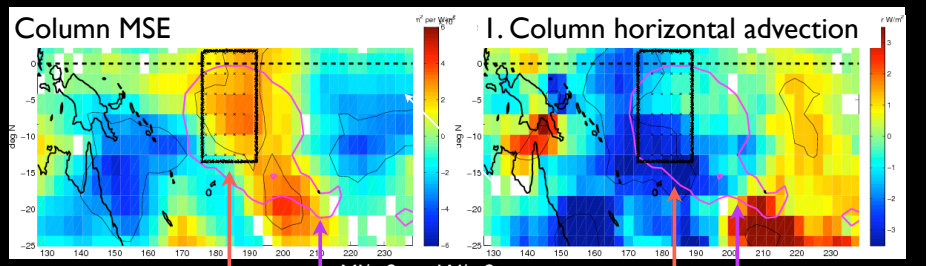
Lag (x,y) regression will be against index time series averaged in this box

Focus on column MSE budget at latitudes of maximum MJO convection

Regarding the final box in the build, it's just to emphasize in advance that most of the convective anomalies are occurring in the southern hemisphere for our composite, so we'll be mostly trying to understand budget relationship in that sector.

Real-world SPCAM's phasing of horizontal column MSE advection is consistent with a moisture mode.

Lag (x,y) regression slope magnitude of (left) unfiltered column MSE & (right) the horizontal advection tendency term in its budget.



(Regressed against MJO convection index in these boxes)

This OLR contour outlines the convective center

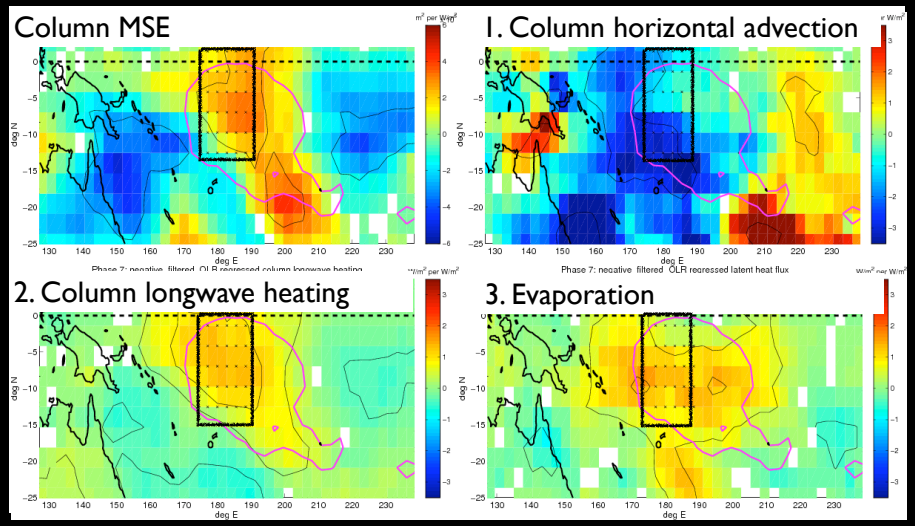
LINGERING PROBLEM: It would be ideal to have a *tendency* subpanel here. This is needed to support the claim that advection is helping move the anomaly to the east, which is a key signature of moisture mode behavior.

Things to point out. We will focus on the SH (where the MJO variance is highest during SPCAM's boreal winter). The horizontal advection is helping erode the MSE anomaly to the west and move it to the east. (focus on the -25 to to 0 latitude band).

The sign of the LH flux term is opposite to what is found in aquaplanet SPCAM3.5.

Surface fluxes play a major role in maintaining real-world SPCAM's intraseasonal column MSE.

The 3 budget tendencies are shown on the same color scale (W/m2 per W/m2)



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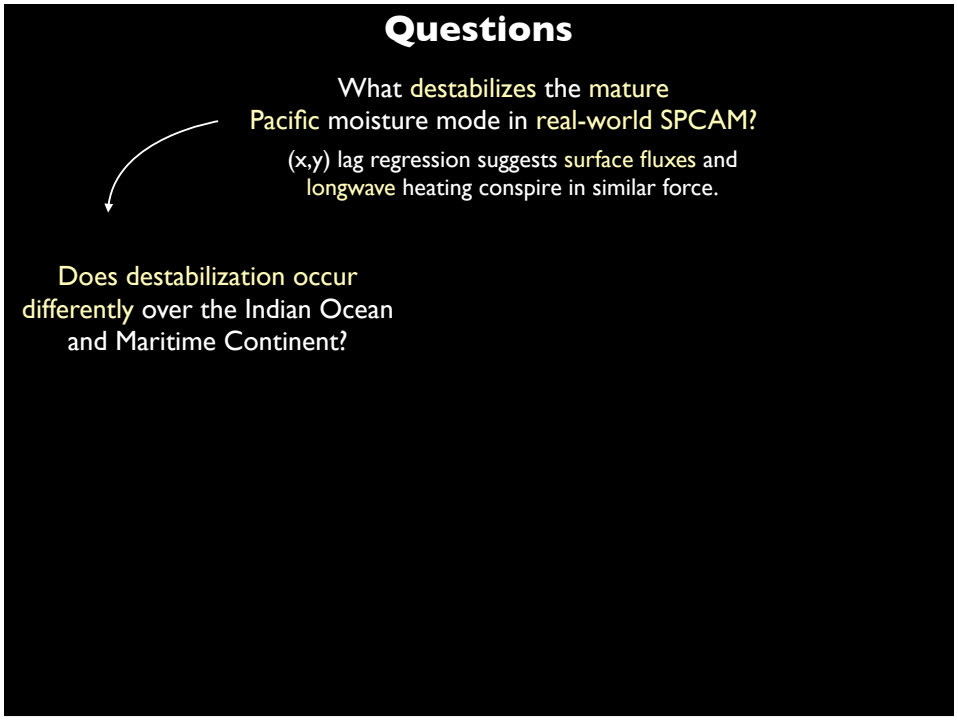
How does real-world SPCAM's mature phase oceanic intraseasonal moisture mode compare to other models?

	Modified CAM3 Maloney et al. 2010	**SPCAM3.5** Andersen & Kuang 2011	**SPCAM3.0**
Basic state configuration	Aquaplanet w. warm pool + 1/4 dSST/dy	Aquaplanet w. zonally symmetric SSTs	Real-world
Horizontal column MSE advection appears to mediate eastward travel?	✔	✔	✔
Role of longwave heating anomalies?	Hard to say	Strongly destabilizing	Moderately destabilizing
Role of surface flux anomalies?	Strongly destabilizing	Stabilizing	Moderately destabilizing

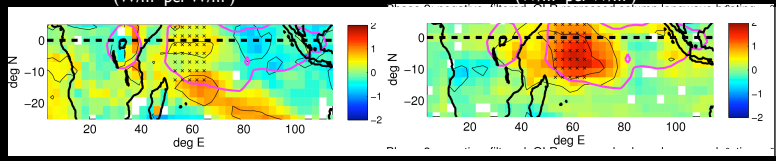


I don't think the answer to the second question will surprise anybody.

Radiative destabilization seems to play a larger role in the column MSE budget over the Indian Ocean and Maritime Continent sectors.

Evaporation (W/m^2 per W/m^2) vs. Column longwave heating (W/m^2 per W/m^2)

Phase 2 (initiation)



(As before, colors show regression slope magnitude of unfiltered budget tendencies relative to MJO convection index in central region)

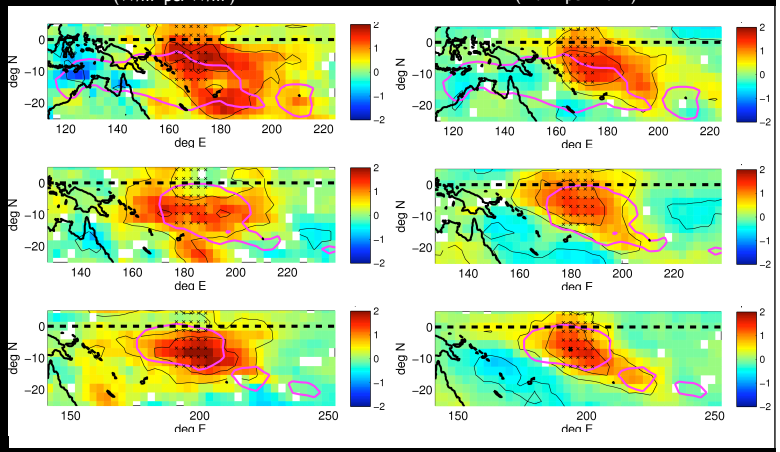
Evaporative destabilization is dominant over all Warm Pool phases.

Evaporation (W/m² per W/m²) vs. Column longwave heating (W/m² per W/m²)

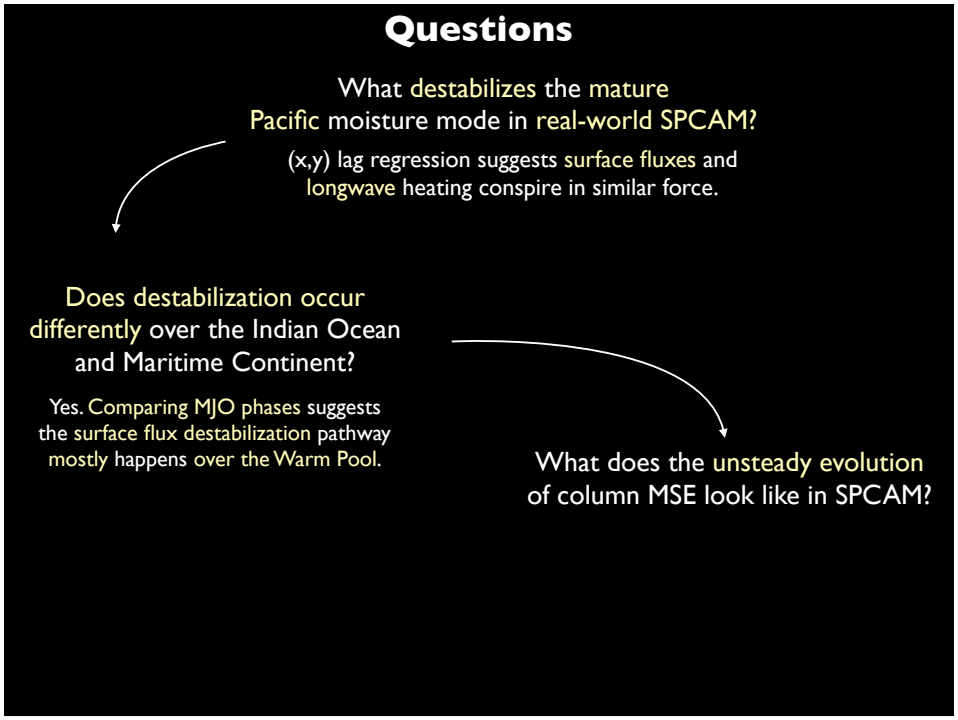
Phase 6

Phase 7

Phase 8



Regression slope of unfiltered latent heat flux and column radiative heating against 20-100 day MJO convection index across the reference region.



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Exploring the idea of moisture mode dynamics means examining column moist static energy evolution.

$$\frac{d}{dt} < MSE > (x,y,t) \quad = \quad \textbf{why?}$$

(budget tendency variables)

So far we have used a traditional **time mean (x,y)** composite view of intraseasonal anomalies to this balance.

What does an **unsteady (x,y,t)** view say about how SPCAM's column MSE is evolving via self-aggregation physics?

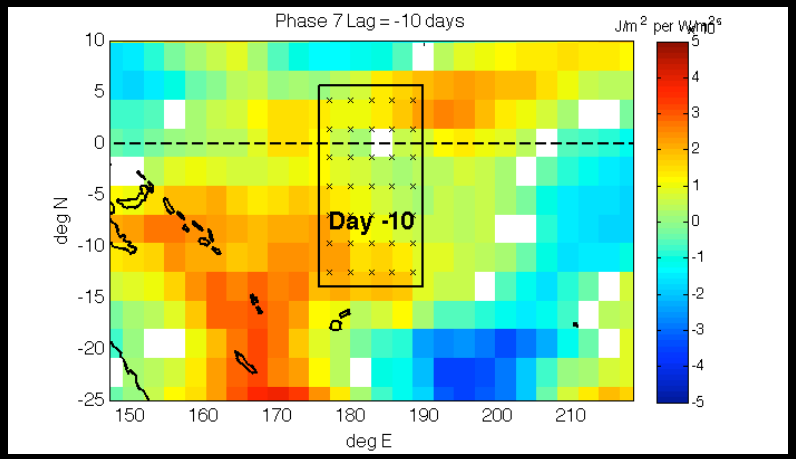
Unsteady variations in the intraseasonal balance anomalies are key to understanding how moisture modes amplify, decay, and travel to ultimately produce eastward MSE travel.

To also clarify unsteady, we will retain full (x,y,t) variability using enhanced visualization techniques.

Extending the lag regression of column MSE to (x,y,t)

The unsteady evolution of column MSE in SPCAM's composite MJO is richly structured in (x,y,t).

Phase 7: (Mature, Pacific)



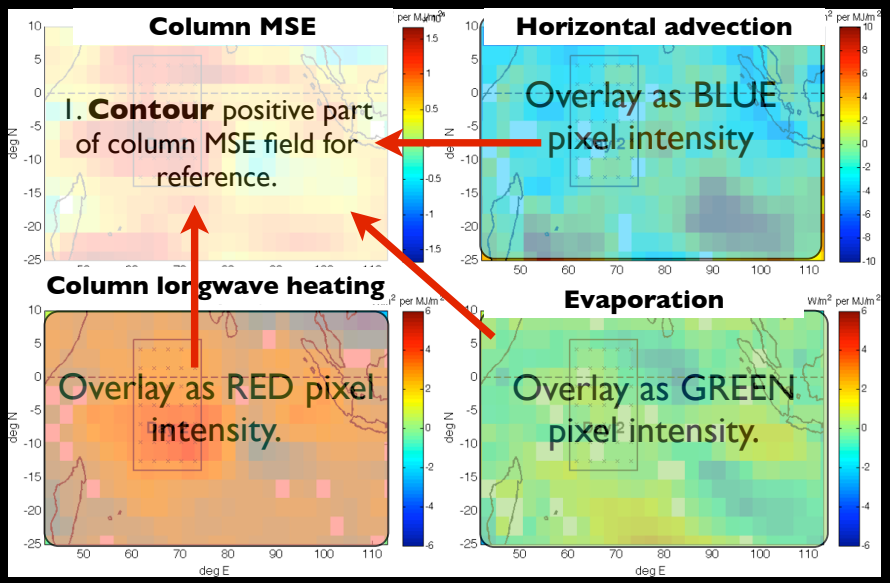
Colors show the regression slope of unfiltered column MSE lag-regressed against 20-100 day filtered column MSE across the reference region.

Emphasize that the pattern is not simple eastward motion of a blob of MSE!

Over the Indian Ocean, the behavior is not a "simple" moisture mode picture.

Understanding the (x,y,t) structure of balances in the column MSE budget visually can be challenging.

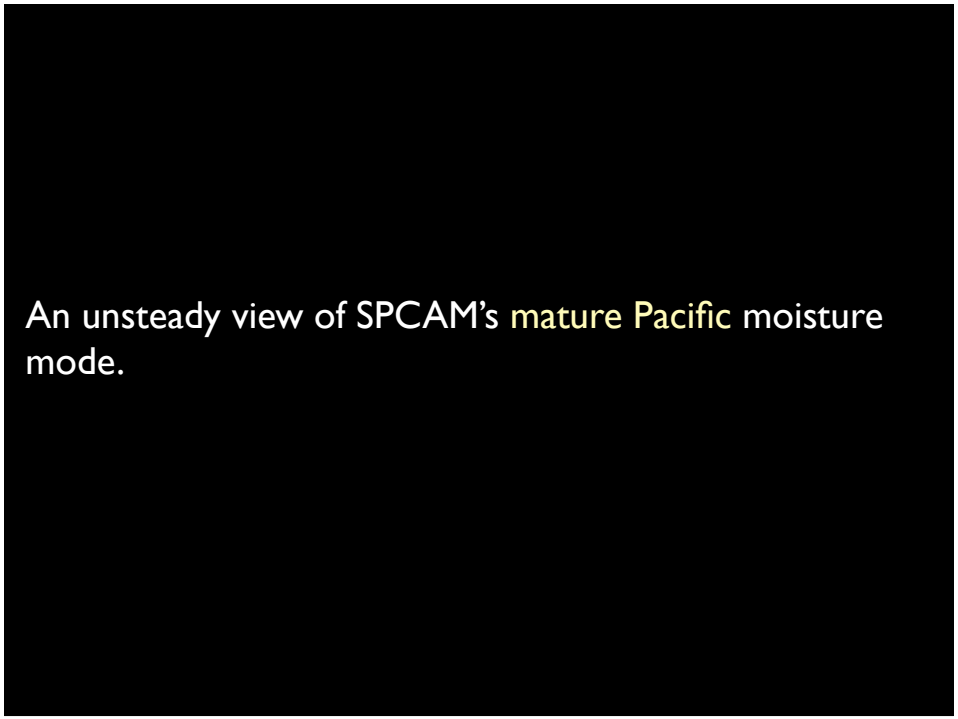
A visualization strategy to clarify SPCAM's moisture mode dynamics.



Use the color dimension more intelligently to clarify the interplay of horizontal advection, latent heat fluxes, and

(nb. it could really be nicer to be encoding dMSEdt as a contour map but we'll have to let our eye see that instead).

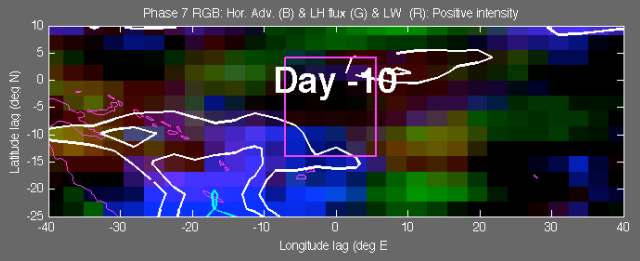
Re-orient: We can tell the space-time pattern correlator in our brain to think about the link between where the MSE is building up and decaying (the contour map evolution) and try to untangle how this is related to the information in the colors...



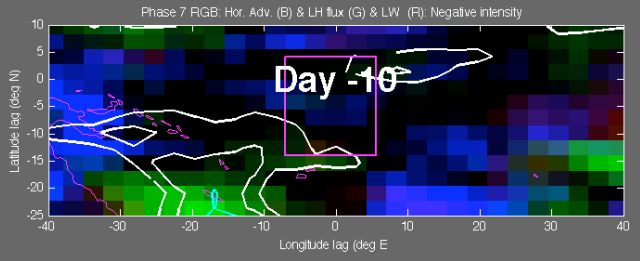
An unsteady view of SPCAM's mature Pacific moisture mode.

The contours show where the column MSE is.
Colors show horizontal advection + latent heat flux + longwave heating

Sources



Sinks



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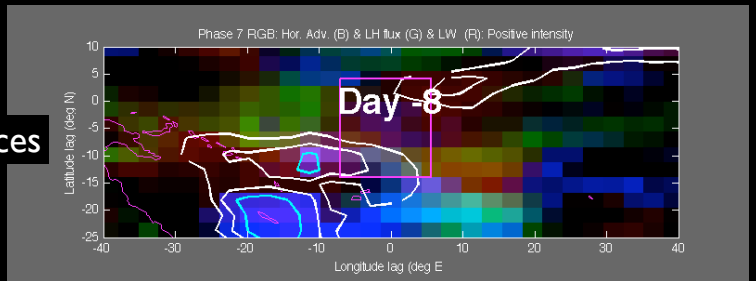

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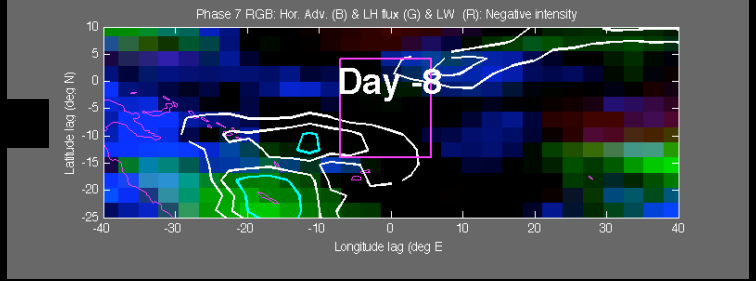

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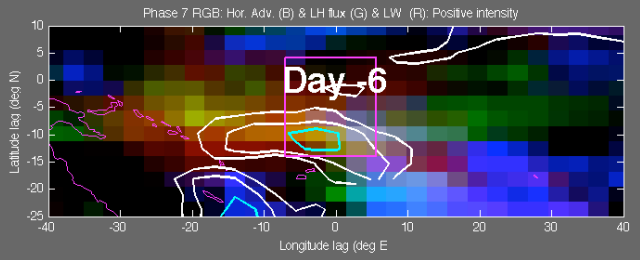

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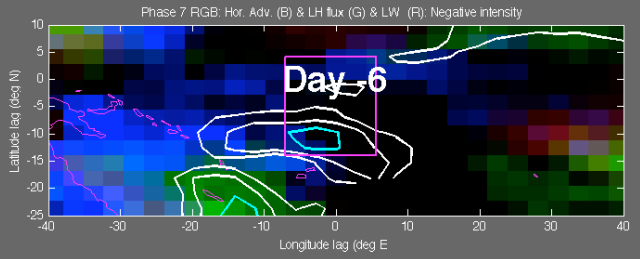

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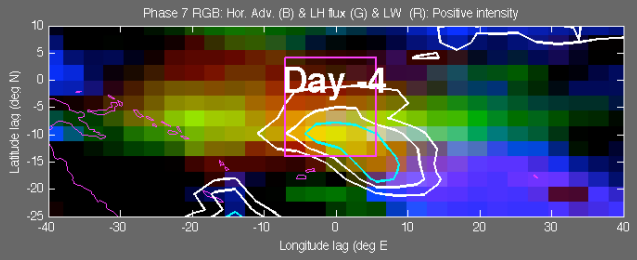

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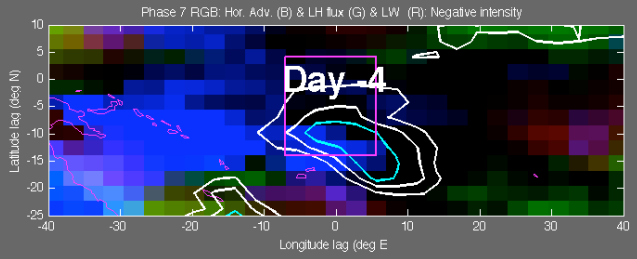

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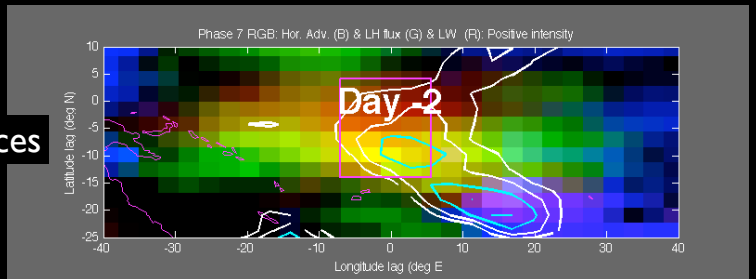

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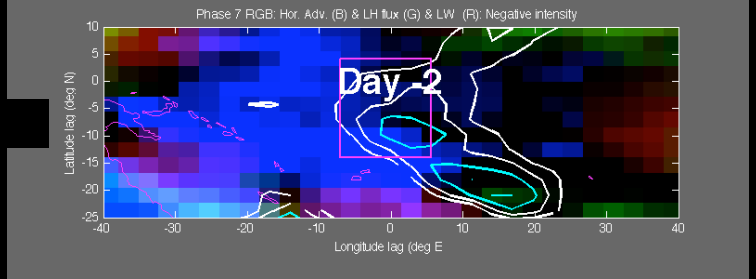

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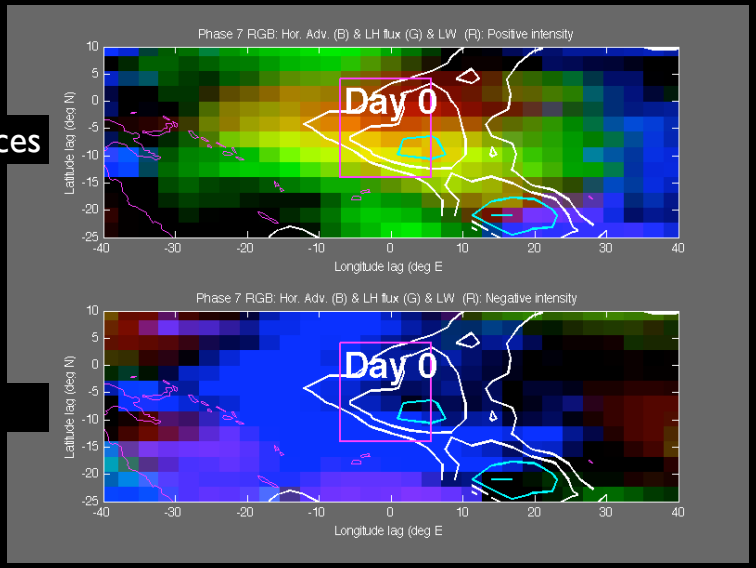

Sinks

The mature Pacific moisture mode in real-world SPCAM.

The contours show where the column MSE is.
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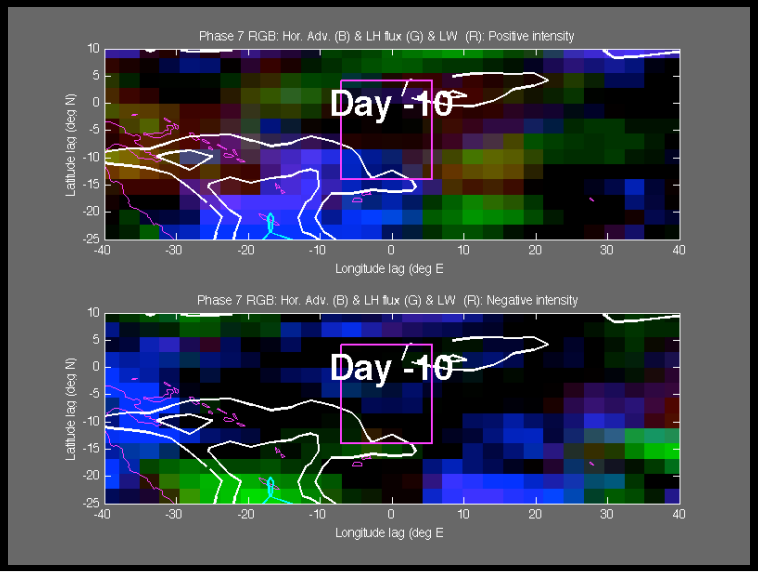
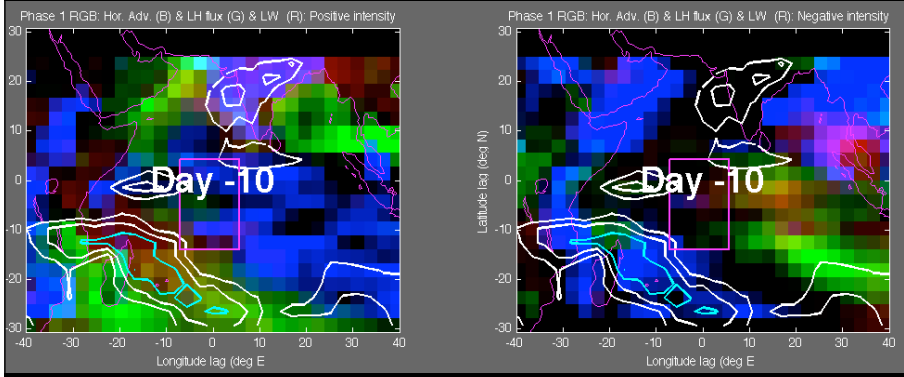


One gets the sense of a passing MSE anomaly that comes from the west, departs advectively to the southeast, and spawns a lagged, stationary, surface flux driven, amplifying chunk in the regression region.

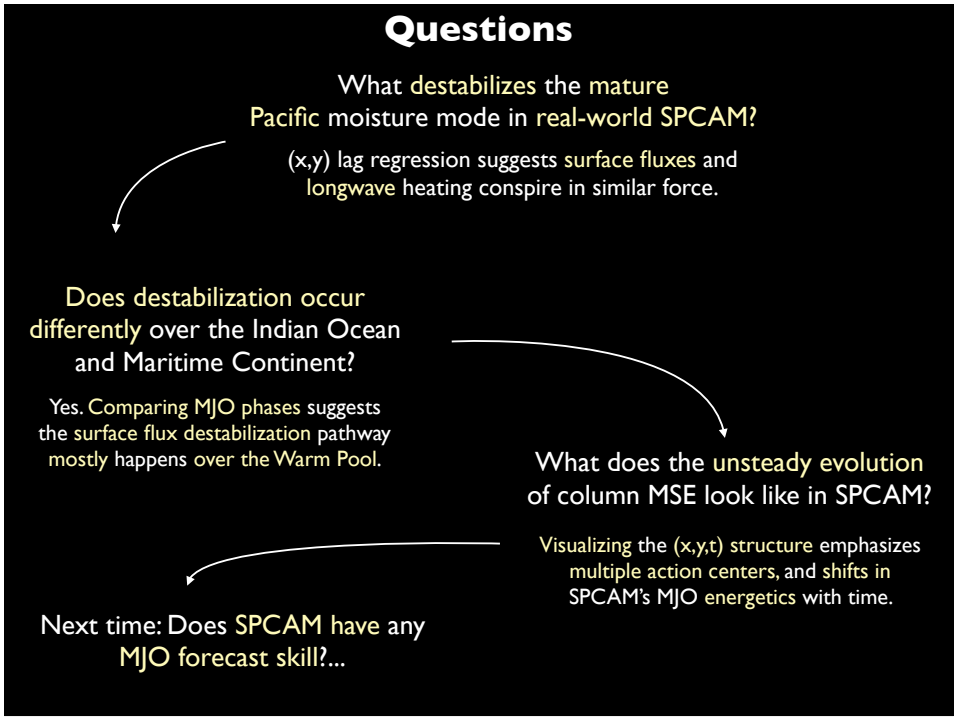
Initiation of SPCAM's MJO in the Indian Ocean.

The contours show where the column MSE is.
Colors show horizontal advection + latent heat flux + longwave heating

MSE sources **MSE sinks**



Regression time series: 20-100 day column MSE in reference region.



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