

Dynamics of tropical intraseasonal variability: the role of fluxes

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Climate models' simulations of intraseasonal variability are flawed, but improving

Lin et al. 2006

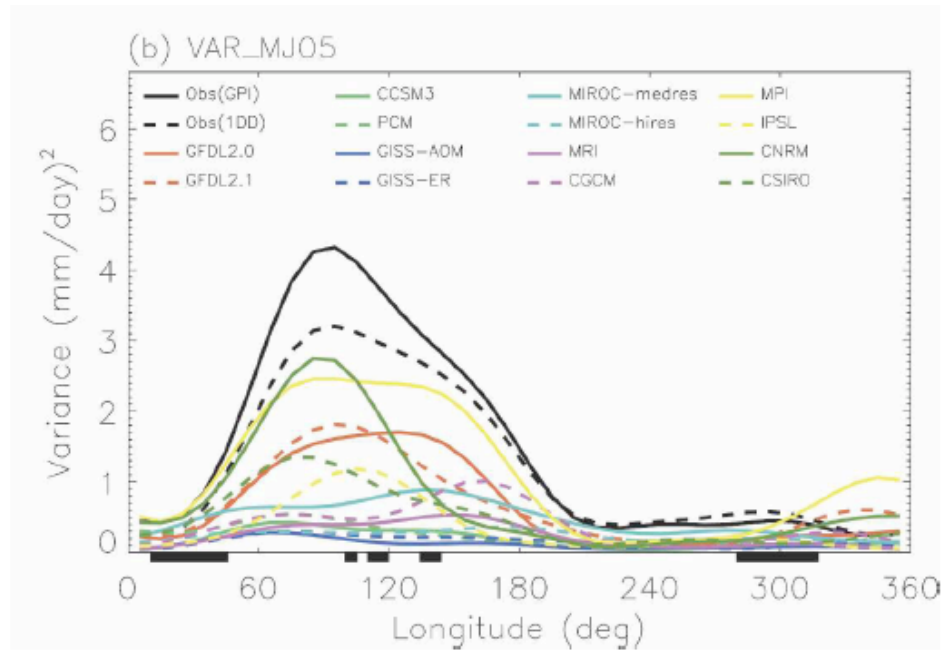
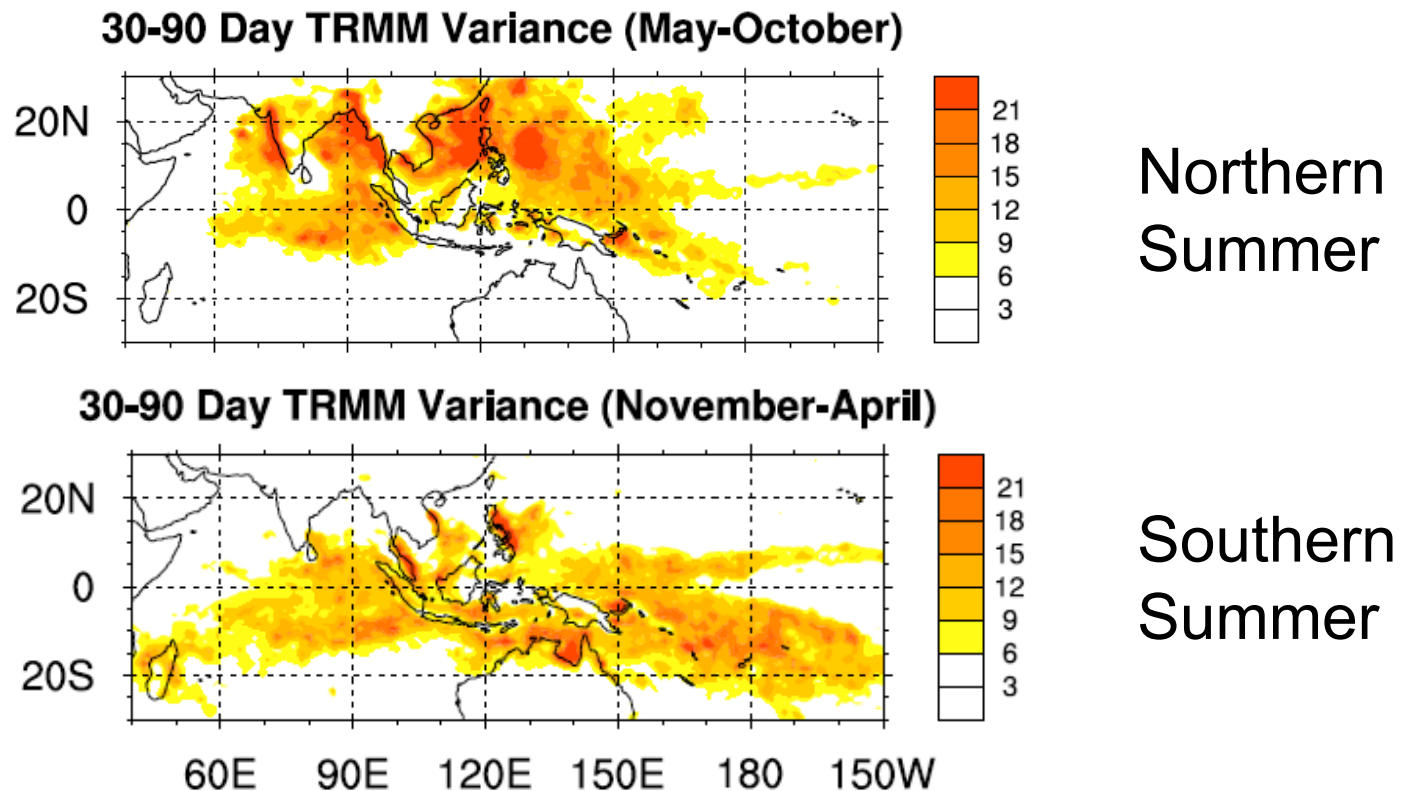


FIG. 9. Variance of the MJO mode along the equator averaged between (a) 15°N–15°S and (b) 5°N–5°S.

But there is no agreement on the basic mechanisms despite ~3 ½ decades of study

Variance of rainfall on intraseasonal timescales shows structure on both global and regional scales

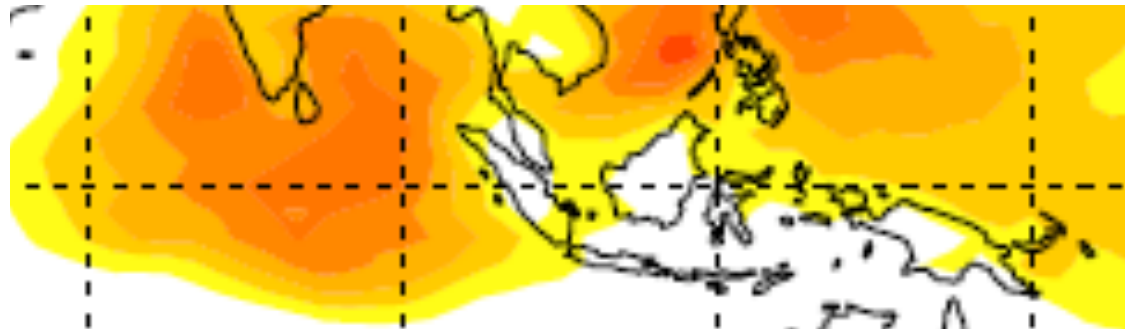
Intraseasonal rain variance



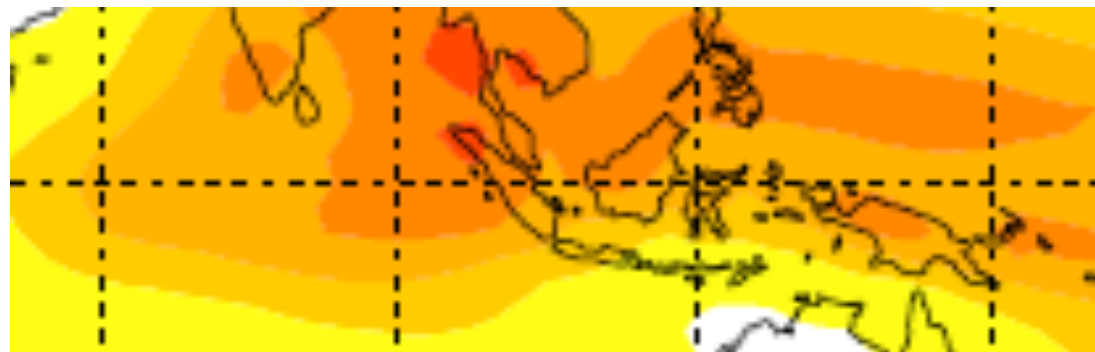
Sobel, Maloney, Bellon, and Frierson 2008: *Nature Geosci.*, **1**, 653-657.

Climatological patterns resemble variance, except that the mean doesn't have localized minima over land

Intraseasonal OLR variance (may-oct)

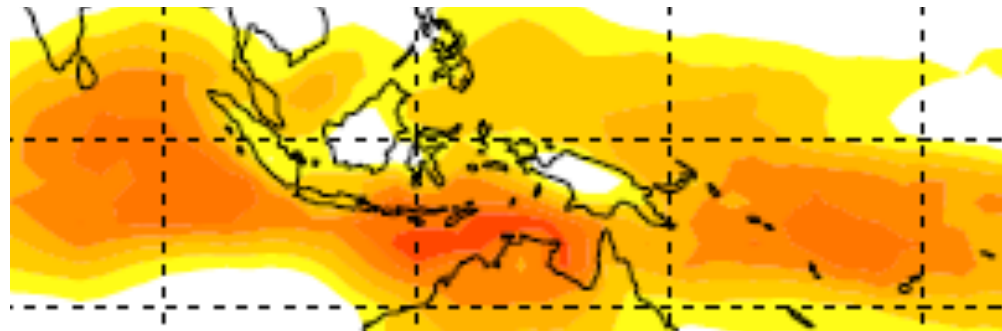


Climatological mean OLR (may-oct)

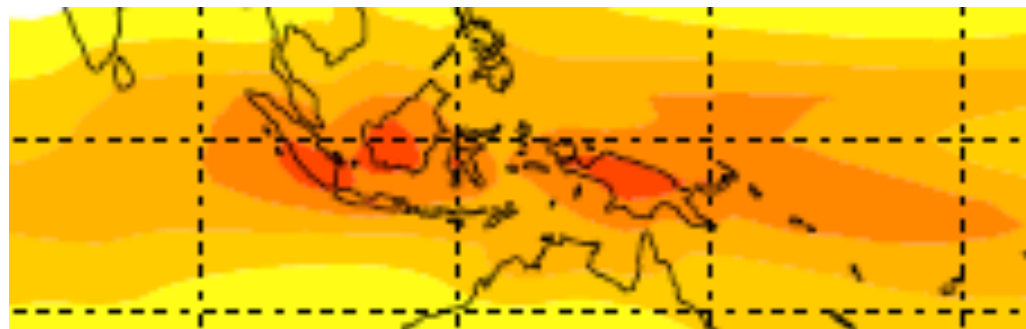


Climatological patterns resemble variance, except that the mean doesn't have localized minima over land

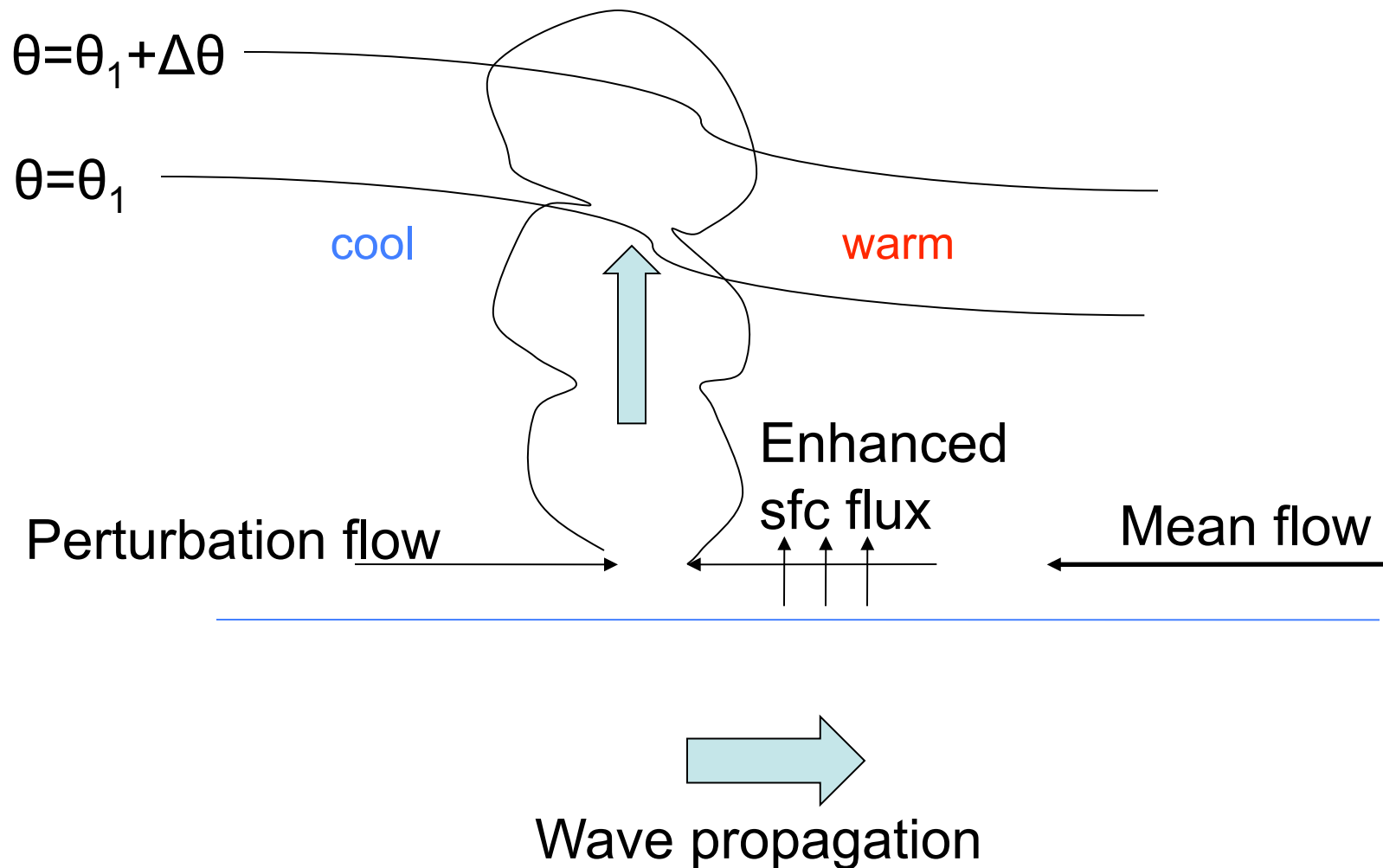
Intraseasonal OLR variance, nov-apr



Climatological mean OLR, nov-apr

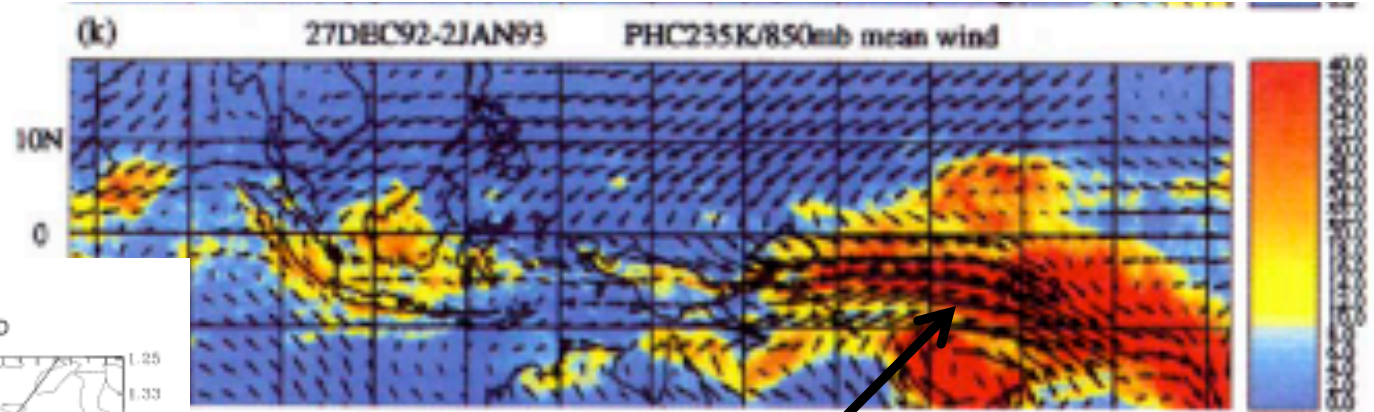


Emanuel (87) and Neelin et al. (87) proposed that the MJO is a Kelvin wave driven by wind-induced surface fluxes (“WISHE”)

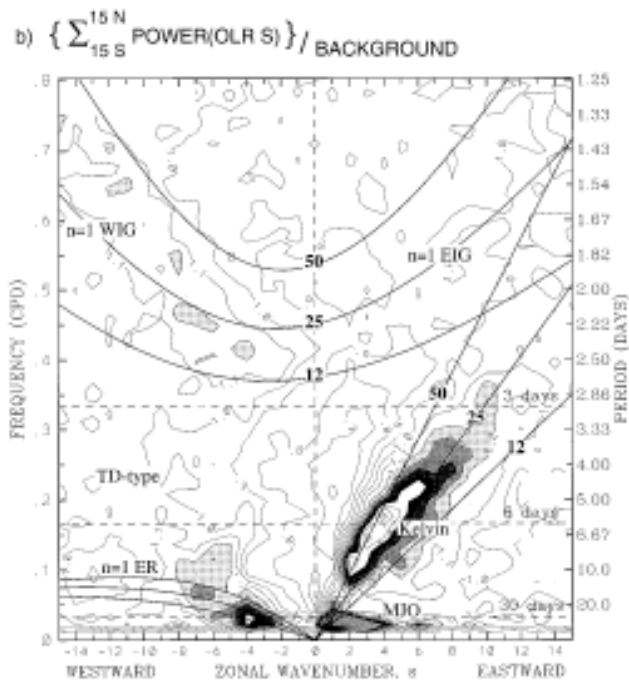


This idea has been somewhat abandoned because the real MJO does not look quite like the original WISHE theory

Observed cloudiness and wind from TOGA COARE (Chen, Houze and Mapes 1996)

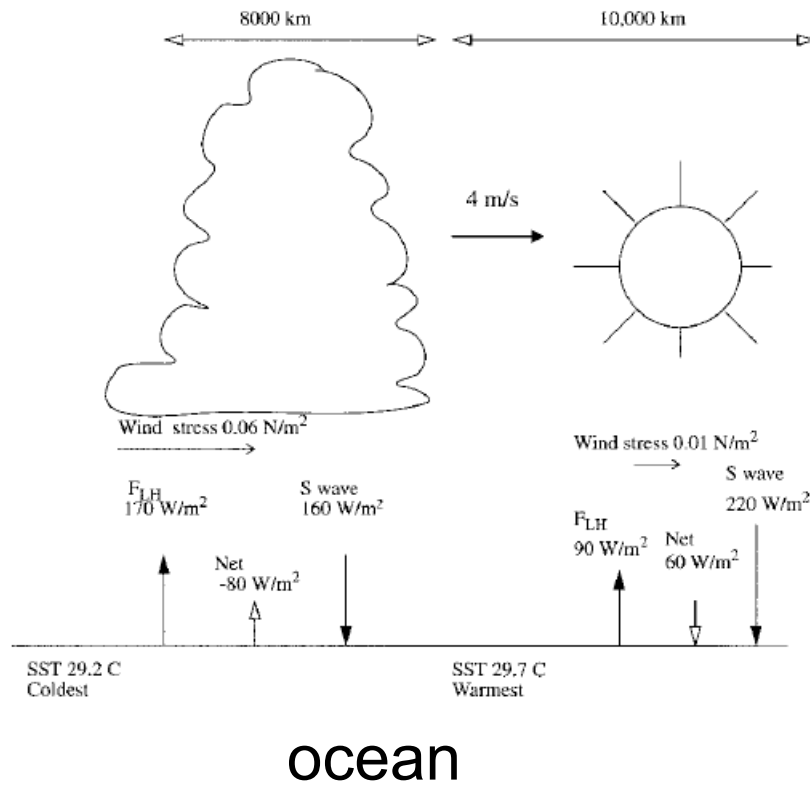


Strongest winds and fluxes are in phase with or lag precipitation, and lie in westerlies



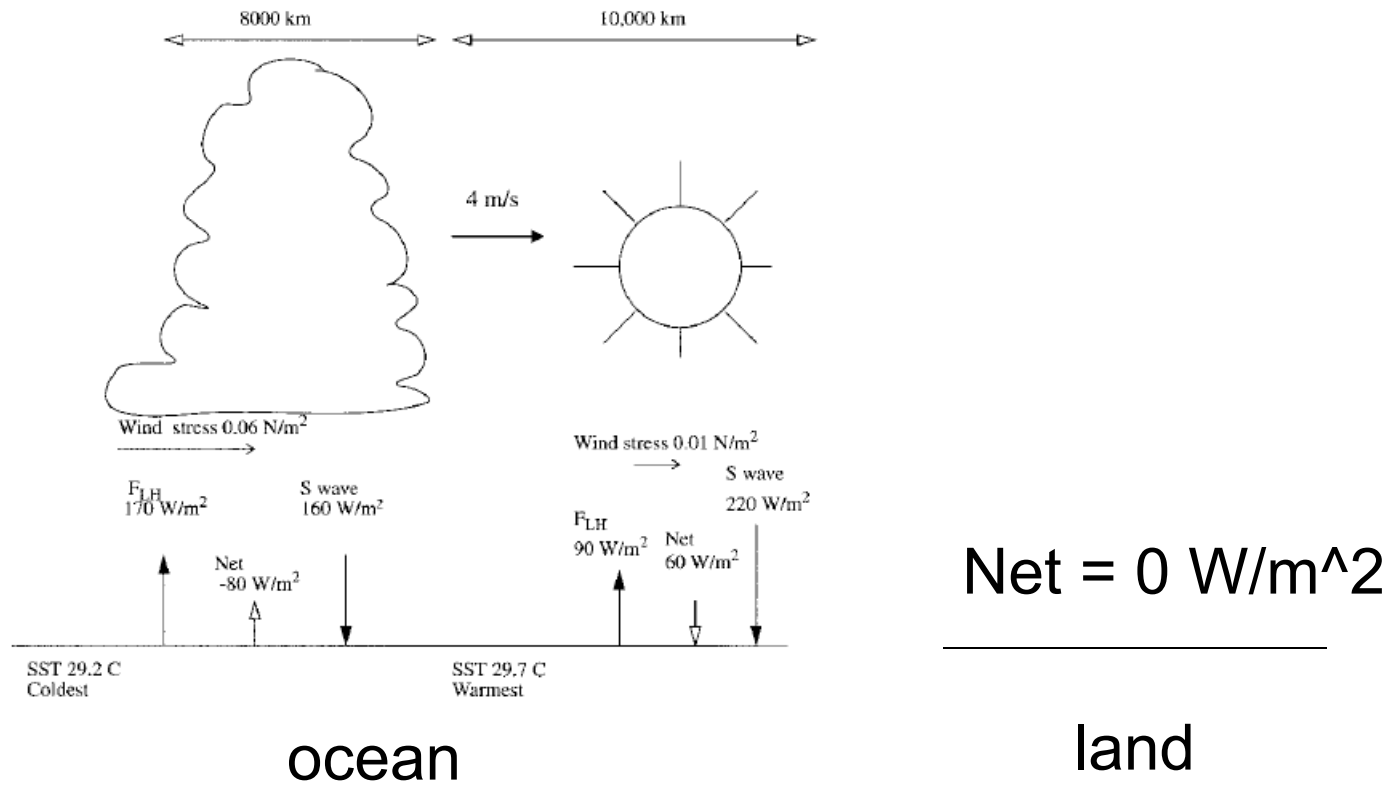
Frequency-wavenumber OLR plot (Wheeler and Kiladis 1999)

But the real MJO does have significant net surface heat flux variations, roughly in phase with convection



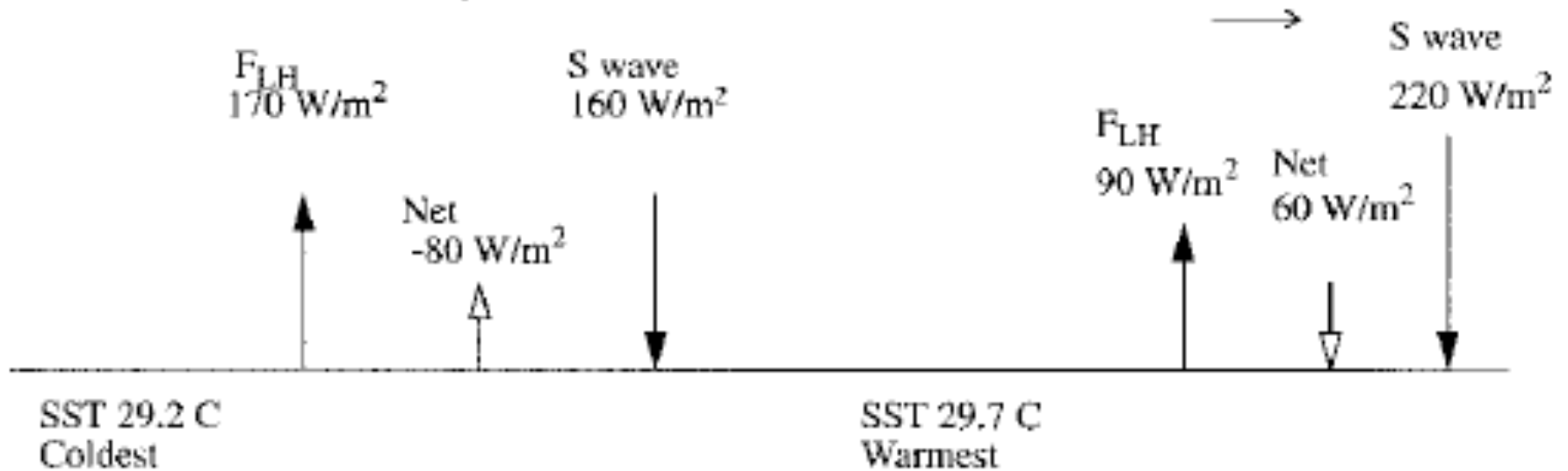
Shinoda et al. 1998

Over land, there can be no significant net flux variations on intraseasonal time scales - so if net flux were important to ISO, the observed variance maps should look as they do!



Shinoda et al. 1998

The flux variations over ocean are roughly half radiative, half turbulent. Both are *nonconservative* with respect to moist static energy or moist entropy.



How do we think about small-scale variance patterns embedded in the planetary-scale MJO?

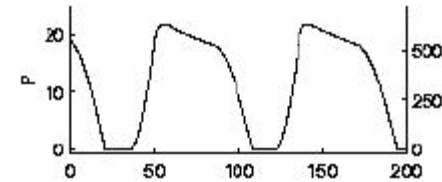
A simple way is to use single-column models.

We then make a connection to GCM experiments.

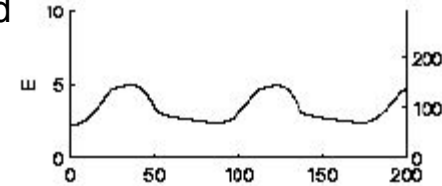
We can make a very simple single-column model that has a recharge-discharge oscillation somewhat like found in observational studies*

(*e.g., Waliser 1996, Stephens et al. 2004)

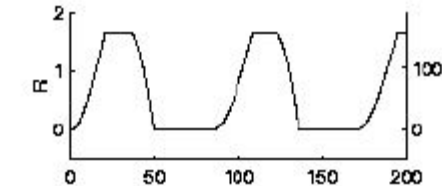
precipitation



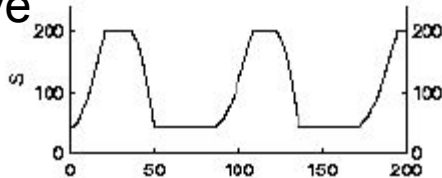
evaporation (perturbed only due to sfc. humidity difference)



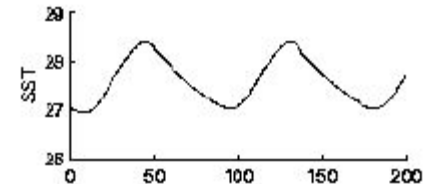
atmospheric rad. cooling



surface shortwave (+ "wind induced" evaporation)

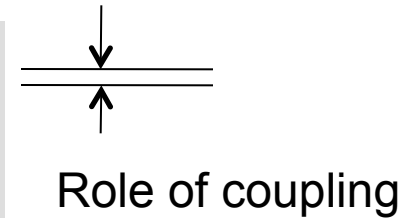
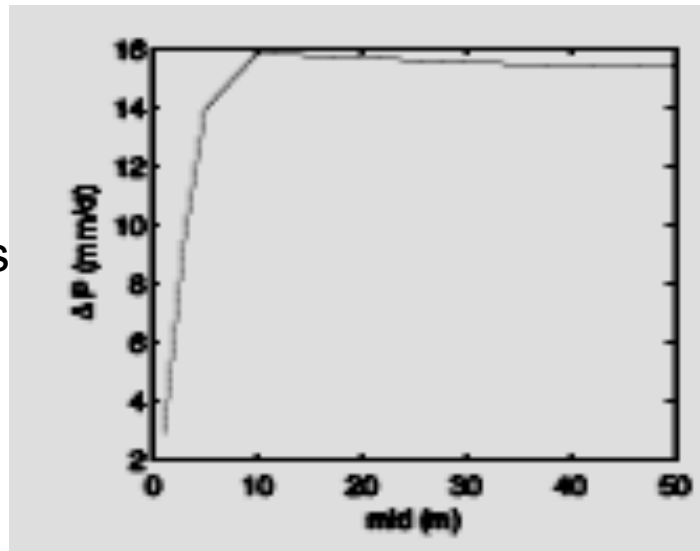
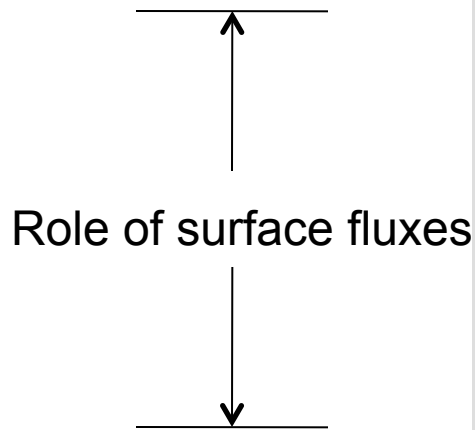


SST



We can model regional-scale intraseasonal variability by considering single columns forced by a planetary-scale traveling ISO disturbance, taken to be external.

Precipitation amplitude as function of mld



mld=0 is like land

Mixed layer depth (m)

Mld= ∞ is like prescribed SST

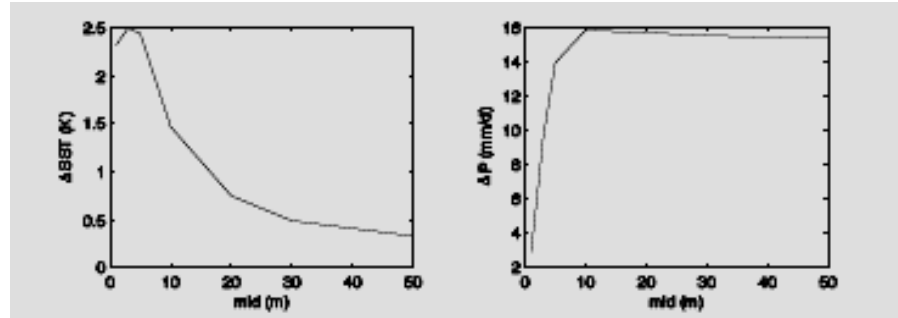
Maloney and Sobel 2004

Some GCMs behave similarly to simple model as surface thermal inertia is varied (no inertia = no surface flux)

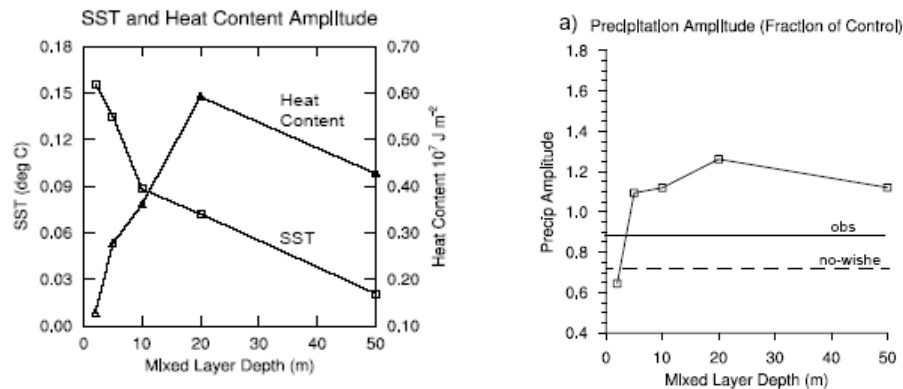
SST

Precip

Simple model
(amplitude is max-min)



GCM (amplitude is std. dev. of filtered data)

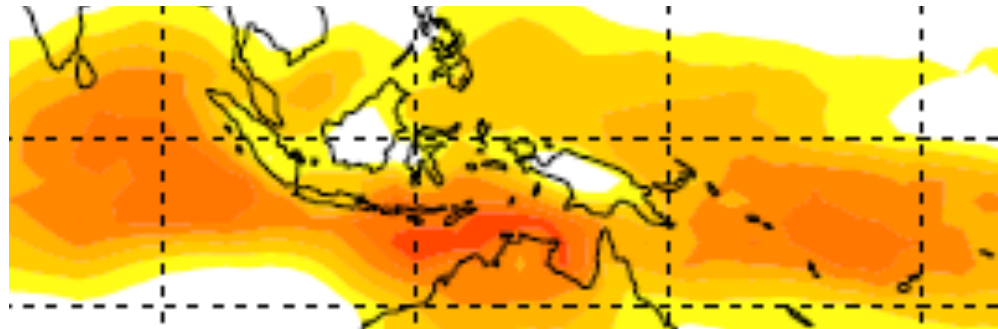


Mixed layer depth ->

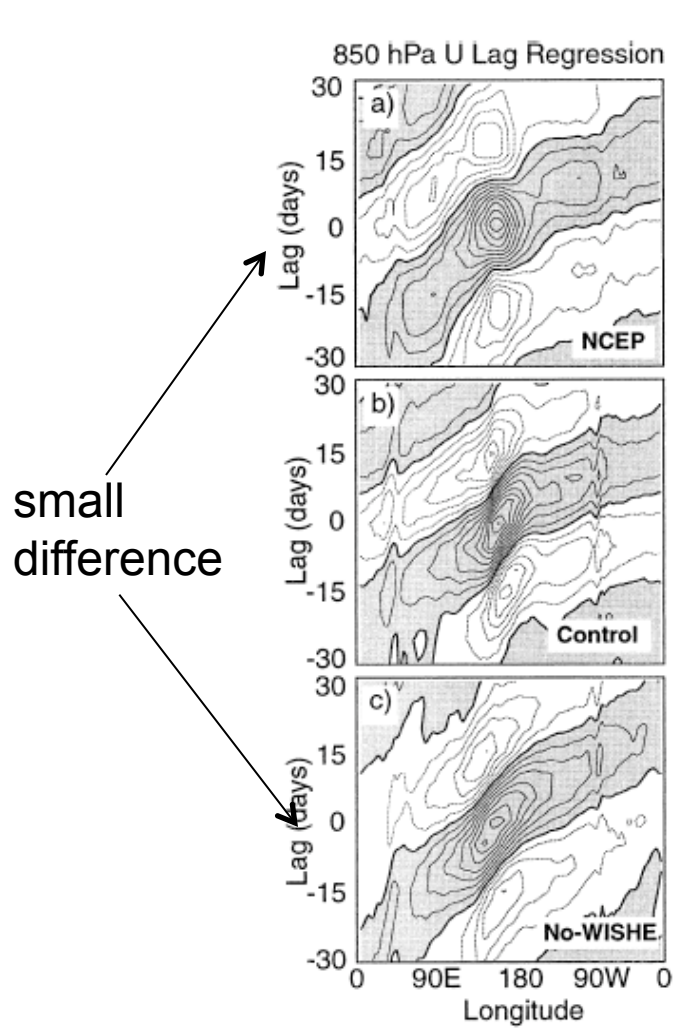
(Maloney and Sobel 2004)

Wet land is like a mixed layer of zero depth (swamp). Thus if MJO is dependent on surface energy fluxes (turbulent, radiative, or both) it should weaken over land... as observed.

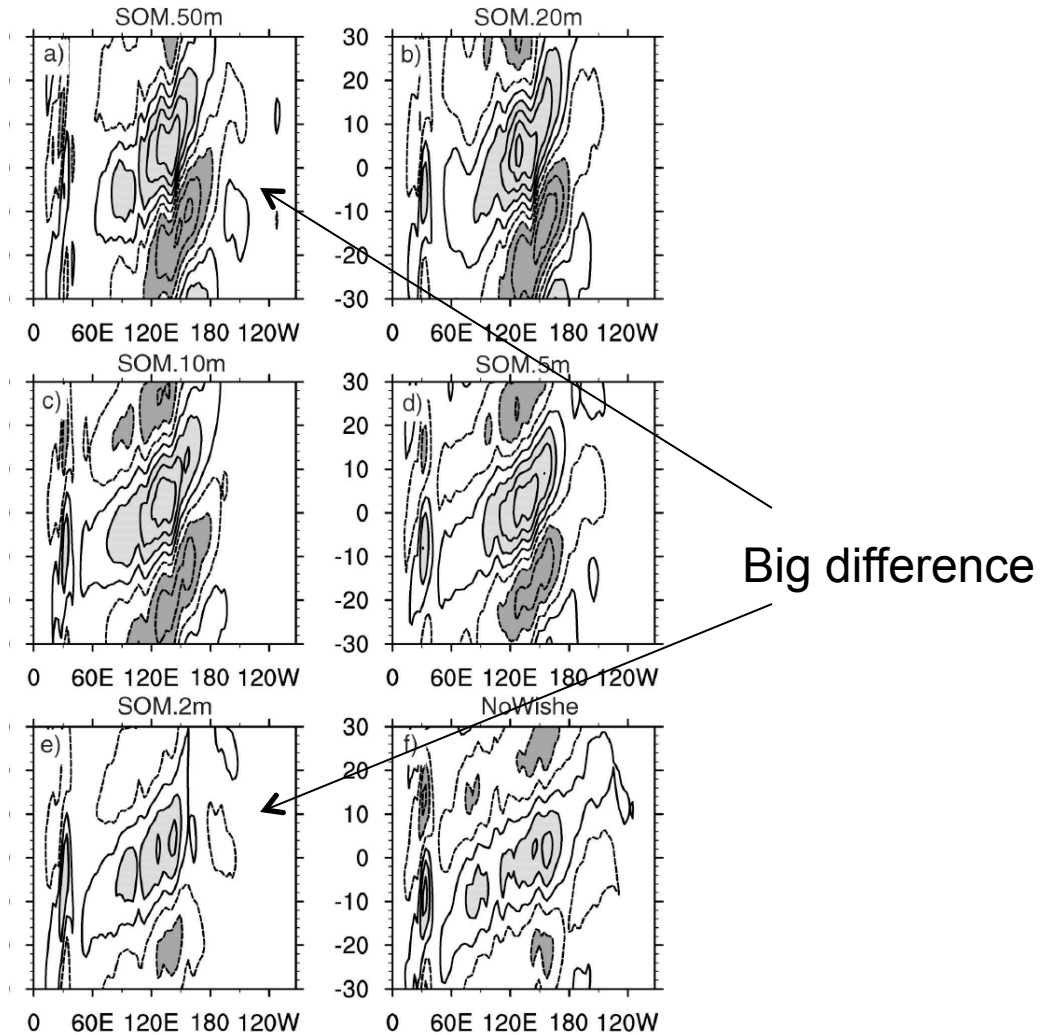
Intraseasonal OLR variance, nov-apr



The GCM-simulated dependence on surface turbulent flux feedback is very dependent on convective scheme.



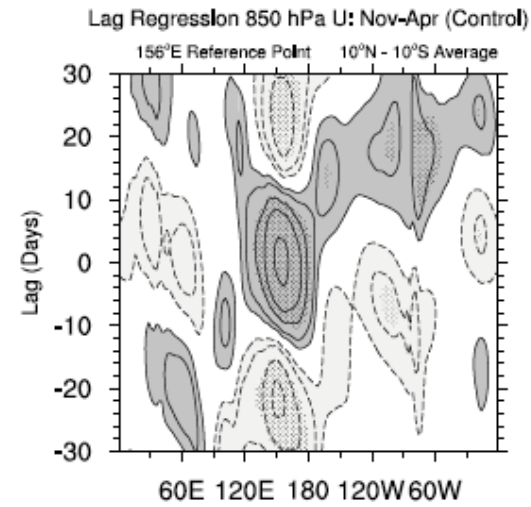
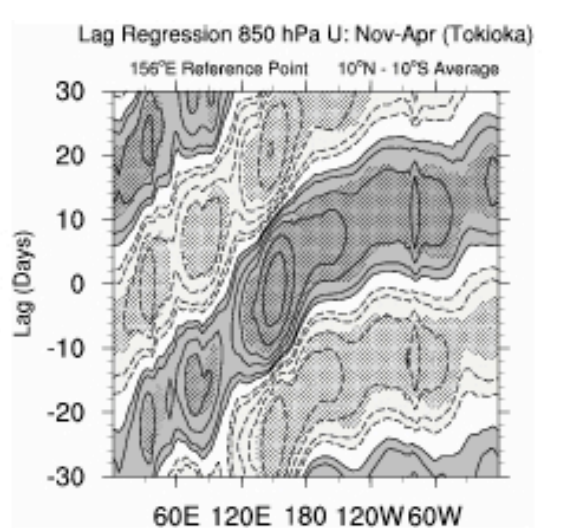
Precip (Maloney 2002)



Precip (Maloney & Sobel 2004)

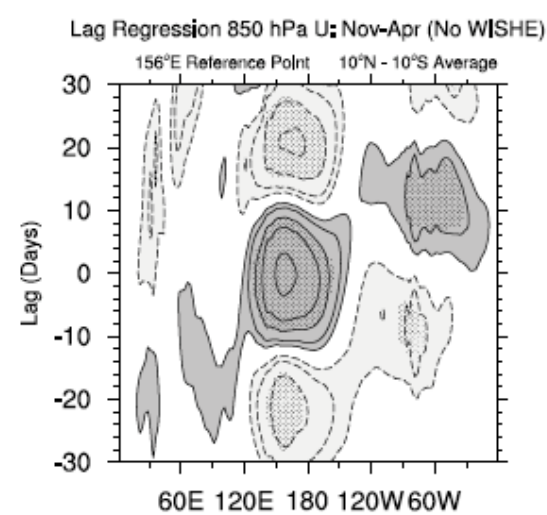
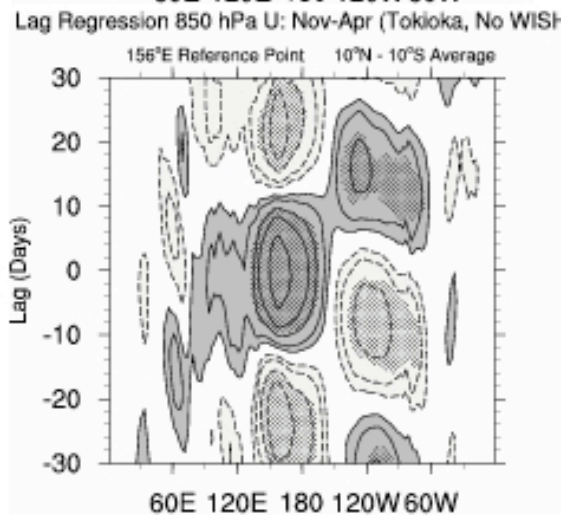
There is a definite suggestion that better MJO simulation corresponds to larger role for surface fluxes

control



GFDL AM2

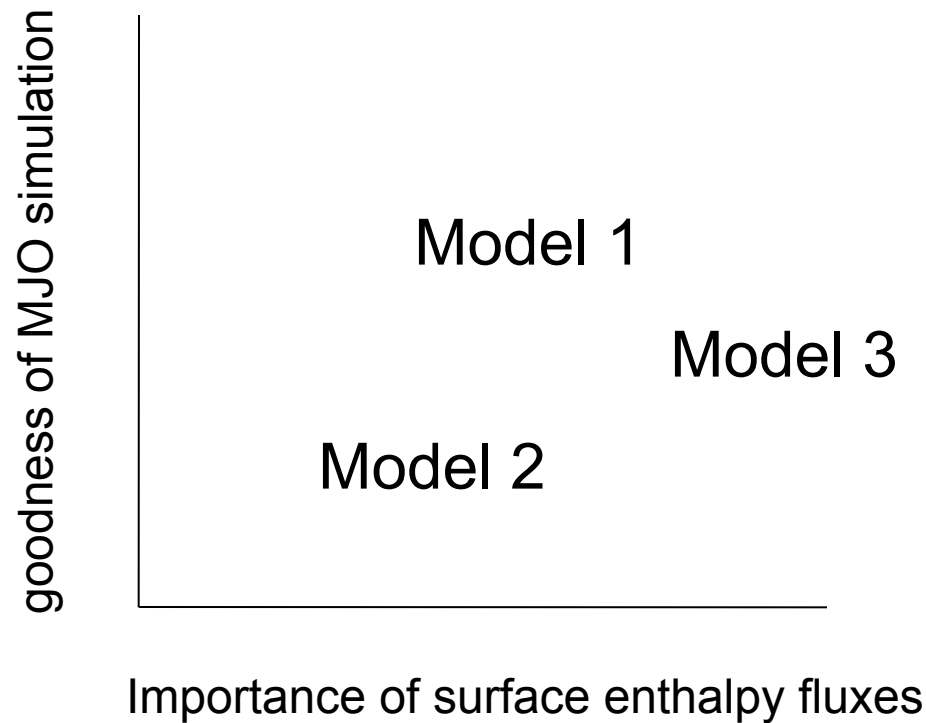
No-WISHE
(const sfc
wind speed)



better model

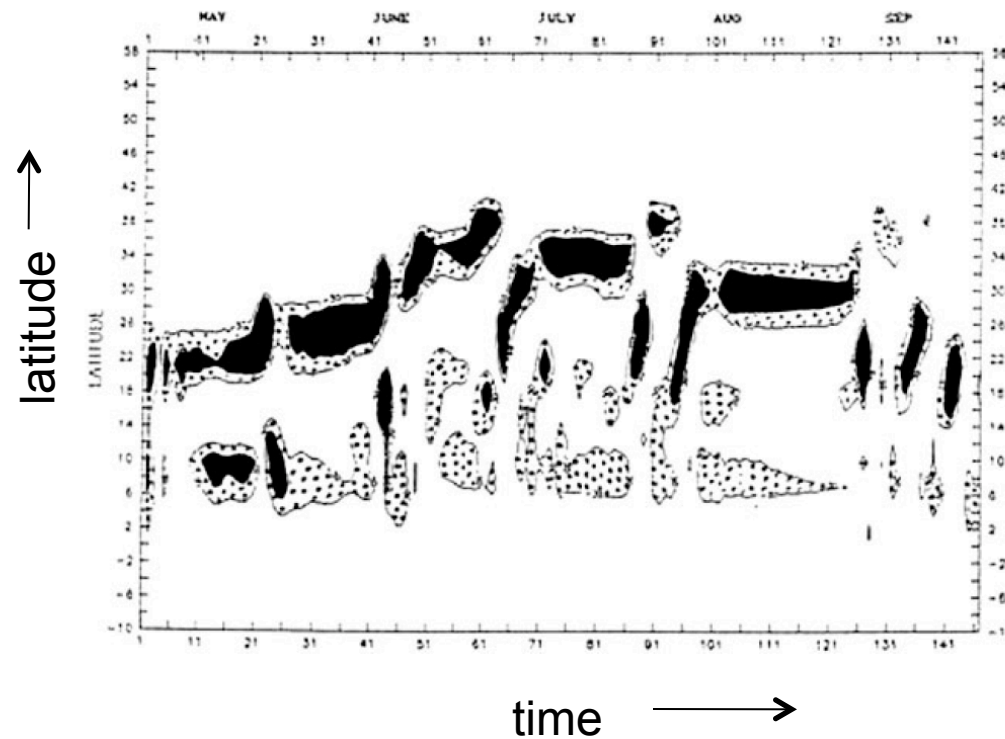
worse model

We can imagine a model intercomparison project that might help us to get useful information about mechanisms out of flawed models



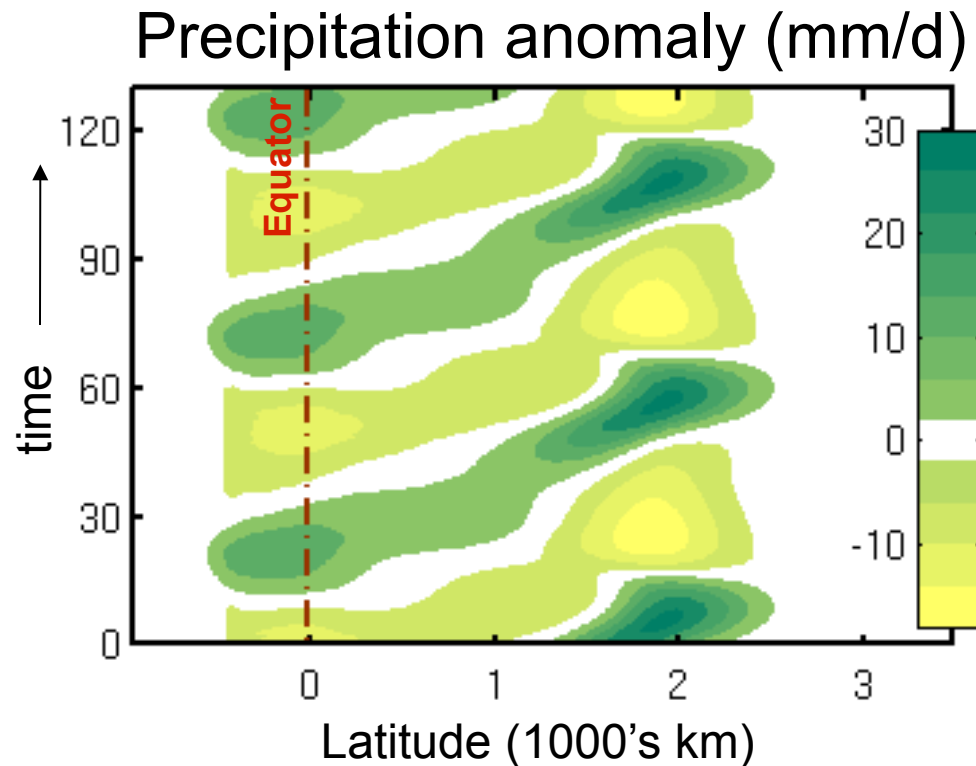
It would be especially nice to be able to include global CRMs and MMF.

The surface flux argument is attractive because it appears likely to work in both hemispheres and seasons



Nanjundiah et al. 1992

We also have a “simple” axisymmetric model which produces an intraseasonal northward-propagating oscillation, robustly to parameters (like in Asian monsoon)



Wind-induced sfc fluxes are crucial to the model instability.

Summary

- Simple models of several types have intraseasonal oscillations that depend on surface flux feedbacks.
- At least two GCMs work similarly (though at least one other doesn't).
- Observed ISO (at least in SH summer) has substantial net surface energy flux anomalies in more or less correct phase to drive the oscillation.
- Observed variance of ISO is maximum over ocean, minimum over land, in both seasons and hemispheres – this is evidence that surface fluxes are important.

Concluding remarks

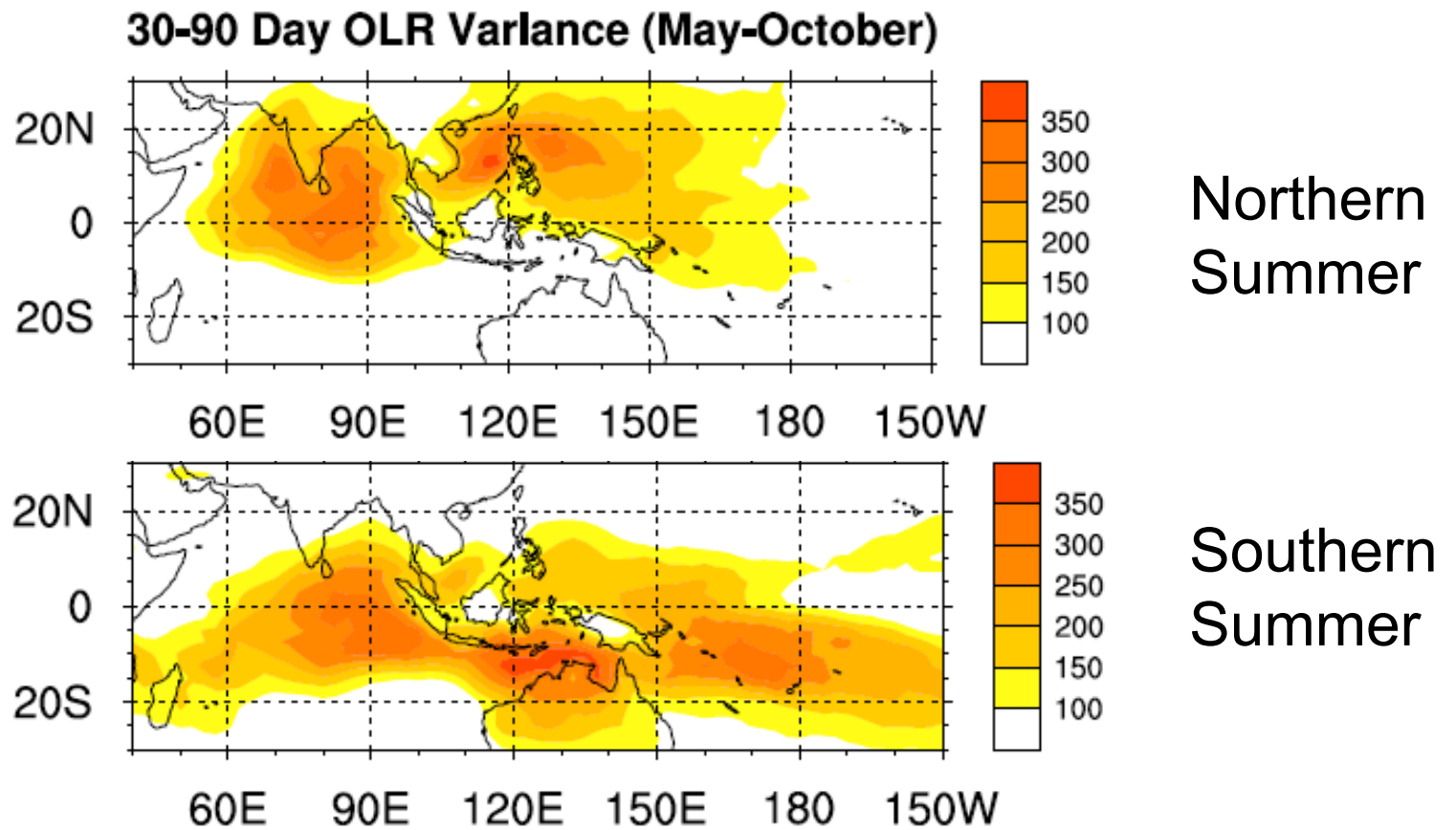
- We argue that **surface fluxes** (turbulent and radiative) **are important to the energetics of intraseasonal variability.**
- This is testable in models.
- Even if true, it would neither mean we deeply understand the ISO, nor that we could necessarily simulate or predict it better.
- Still, if we could decide conclusively on this it would be a step forward.

Sobel, Maloney, Bellon, and Frierson 2008a: *Nature Geosci.*, **1**, 653-657.

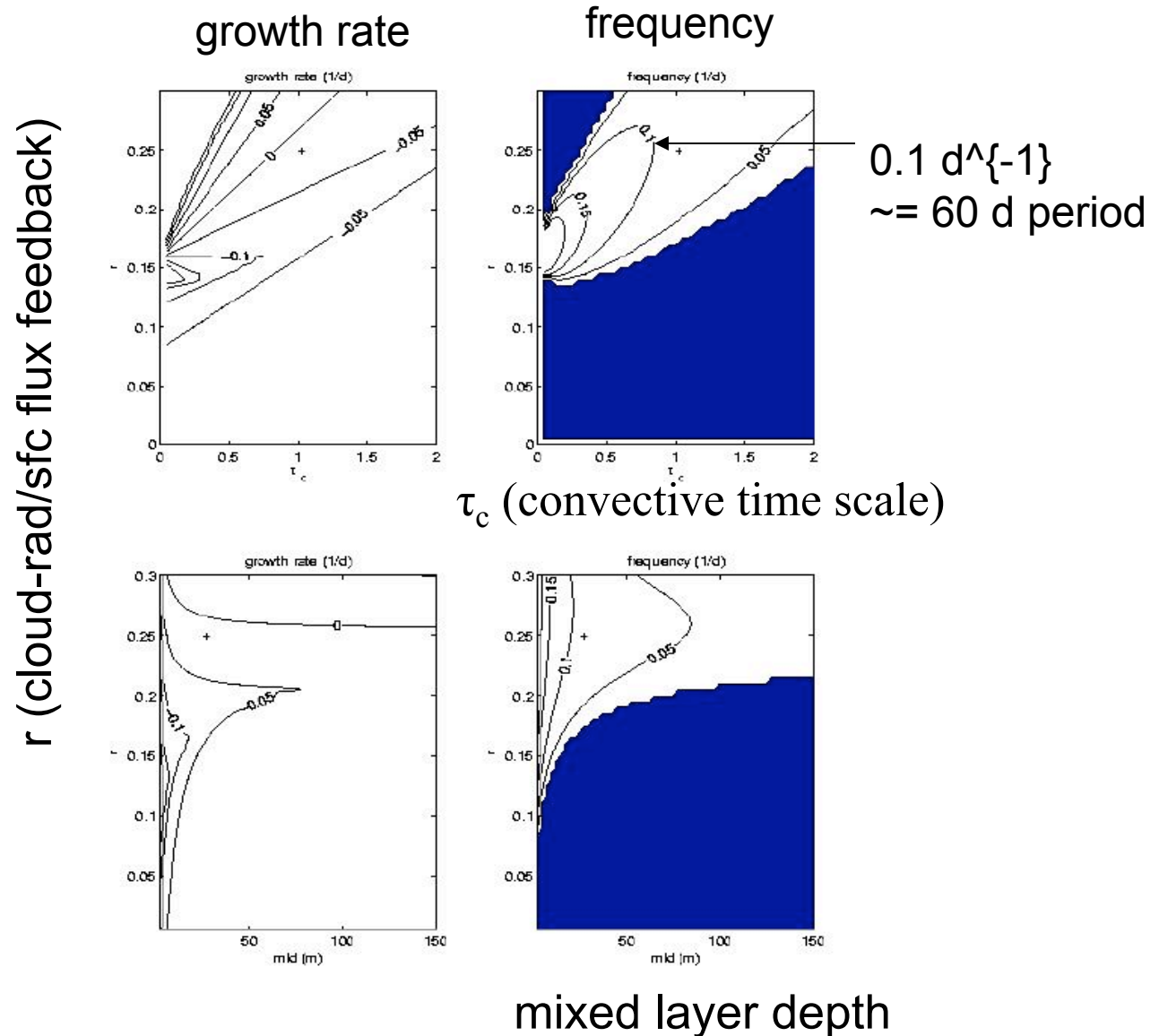
Sobel, Maloney, Bellon, and Frierson 2008b: *JAMES-D*, submitted

<http://adv-model-earth-syst-discuss.org/index.php/JAMES-D/article/view/15>

The patterns are robust across different data products



The growth rate in this model is sensitive to parameters, period isn't - it is robustly intraseasonal



We can make a very simple model that has such a recharge-discharge oscillation (Sobel and Gildor 2003)

$$M_s \nabla \cdot \mathbf{u} = P - R$$

$$\frac{\partial q}{\partial t} - M_q \nabla \cdot \mathbf{u} = E - P$$

$$C \frac{\partial T_s}{\partial t} = S - E$$

with

$$P = H(q - T) \frac{q - T}{\tau_c}$$

$$R = R_{clr} - \max(rP, R_{clr})$$

$$S = S_{clr} - \max(rP, S_{clr})$$

Simple Betts-Miller convection

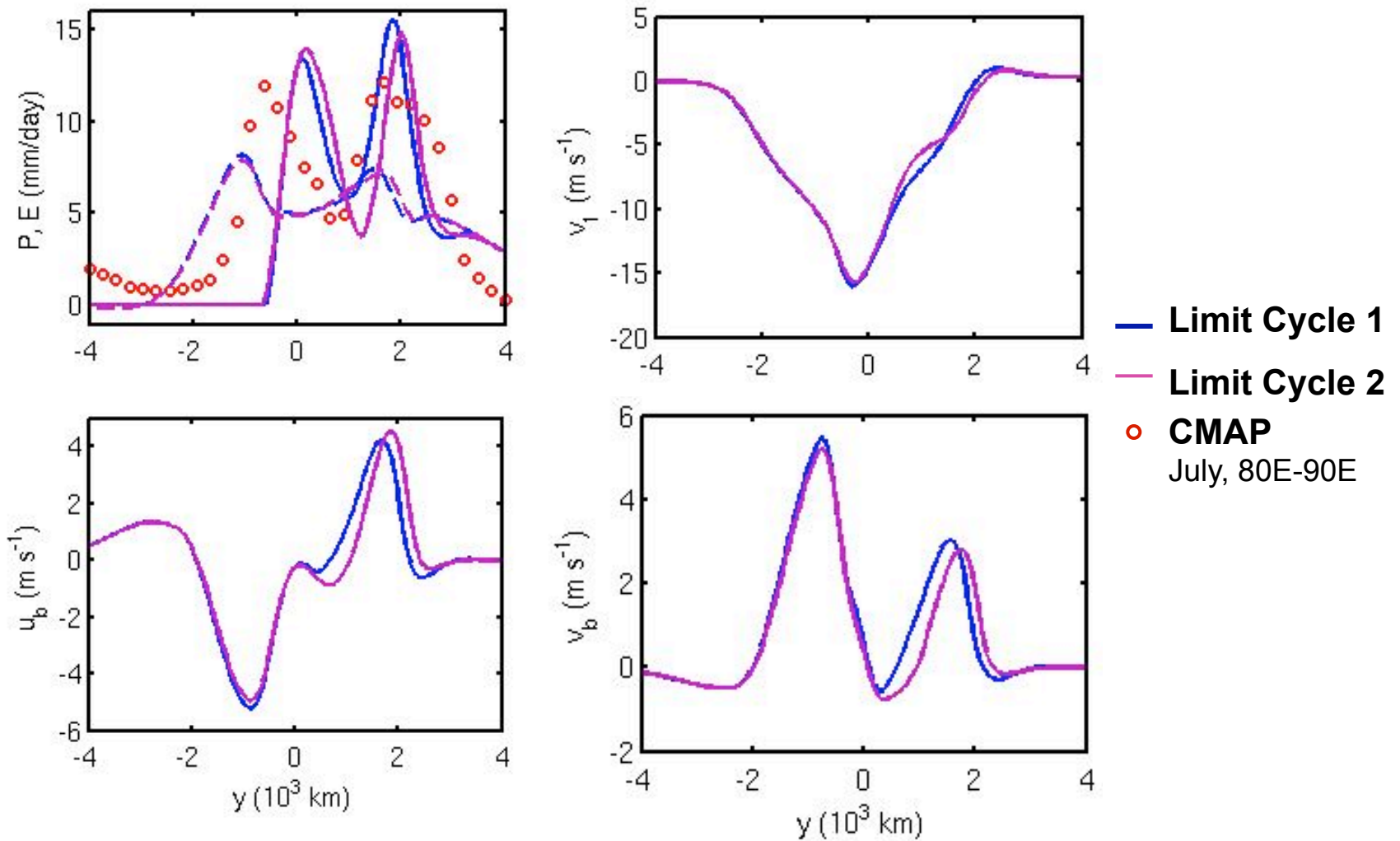
Linear cloud-radiative feedback, SW and LW cancel at TOA

Sfc wind constant for starters (will relax this)

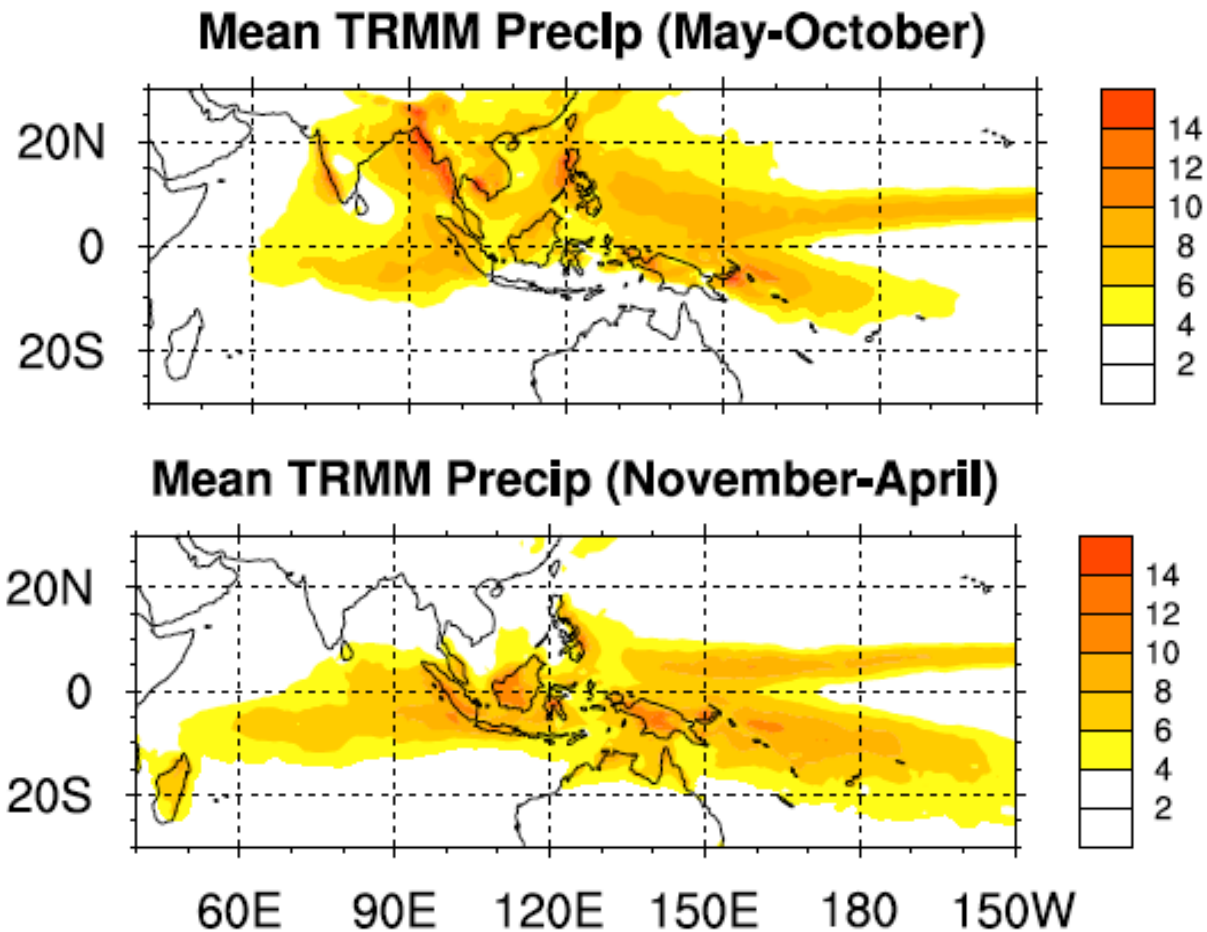
$$E = \frac{q^*(T_s) - q}{\tau_E}$$

Results: two limit cycles

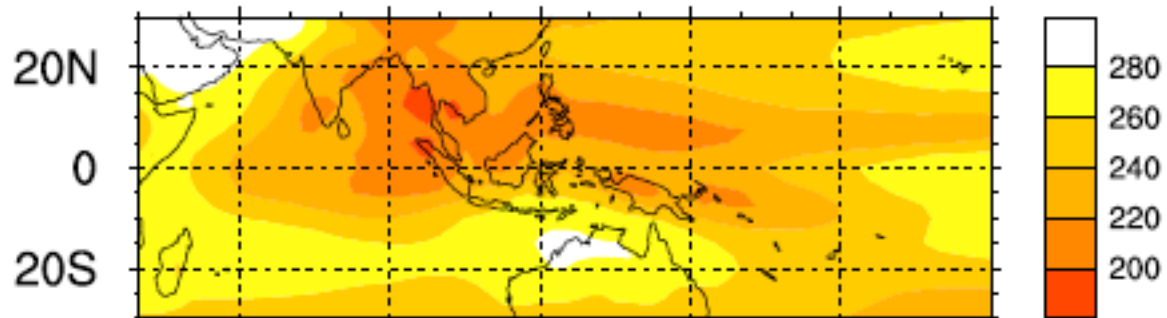
Mean states



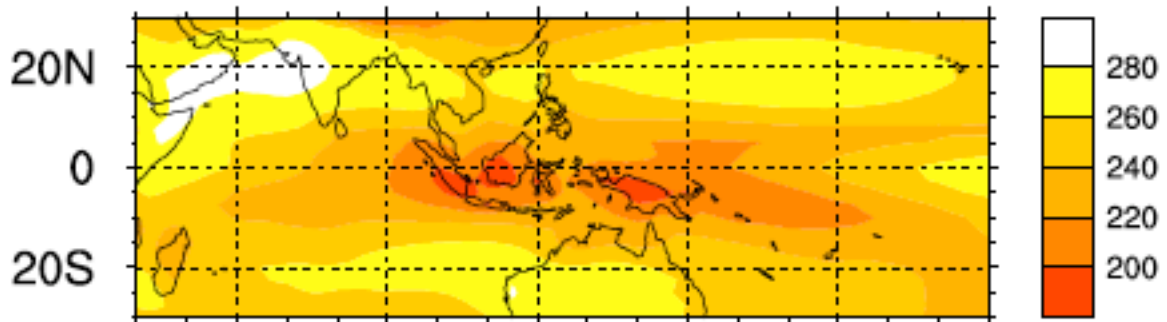
Climatological rainfall patterns resemble variance, except that the mean rainfall doesn't have localized minima over land



Mean OLR (May-October)



Mean OLR (November-April)

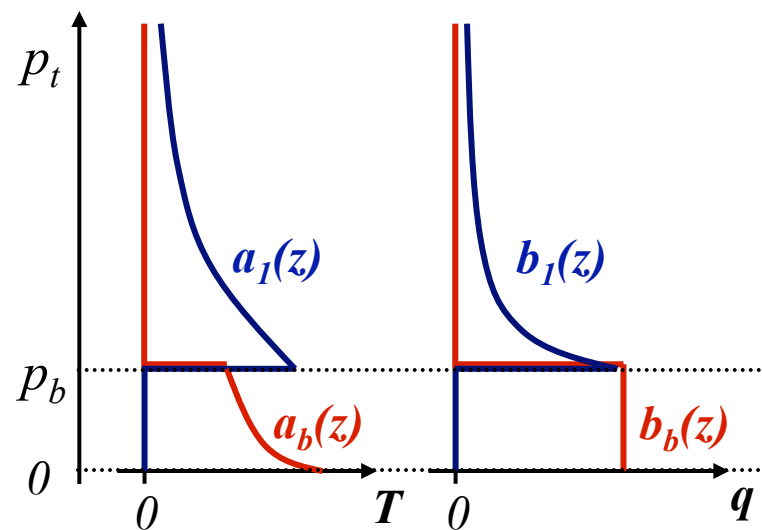
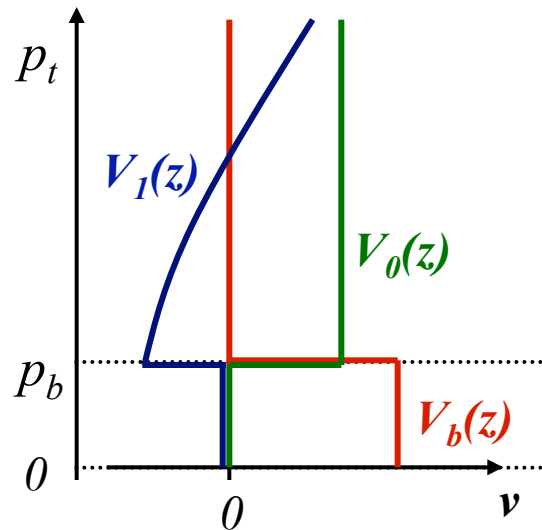


60E 90E 120E 150E 180 150W

To model northern summer northward mode, we use the “QTCM2” (Sobel and Neelin 2006, building on Neelin and Zeng 2000)

Vertical structure:

$$\begin{cases} v(t,y,z) = v_0(t,y)V_0(z) + v_1(t,y)V_1(z) + v_b(t,y)V_b(z) \\ T(t,y,z) = T_{ref}(z) + T_1(t,y)a_1(z) + s_b(t,y)a_b(z) \\ q(t,y,z) = q_{ref}(z) + q_1(t,y)b_1(z) + q_b(t,y)b_b(z) \end{cases}$$



Mass conservation: $(p_t - p_b) \partial_y v_0(t,y) = - p_b \partial_y v_b(t,y)$

Model is axisymmetric and run over an idealized SST field loosely based on the Bay of Bengal in monsoon season

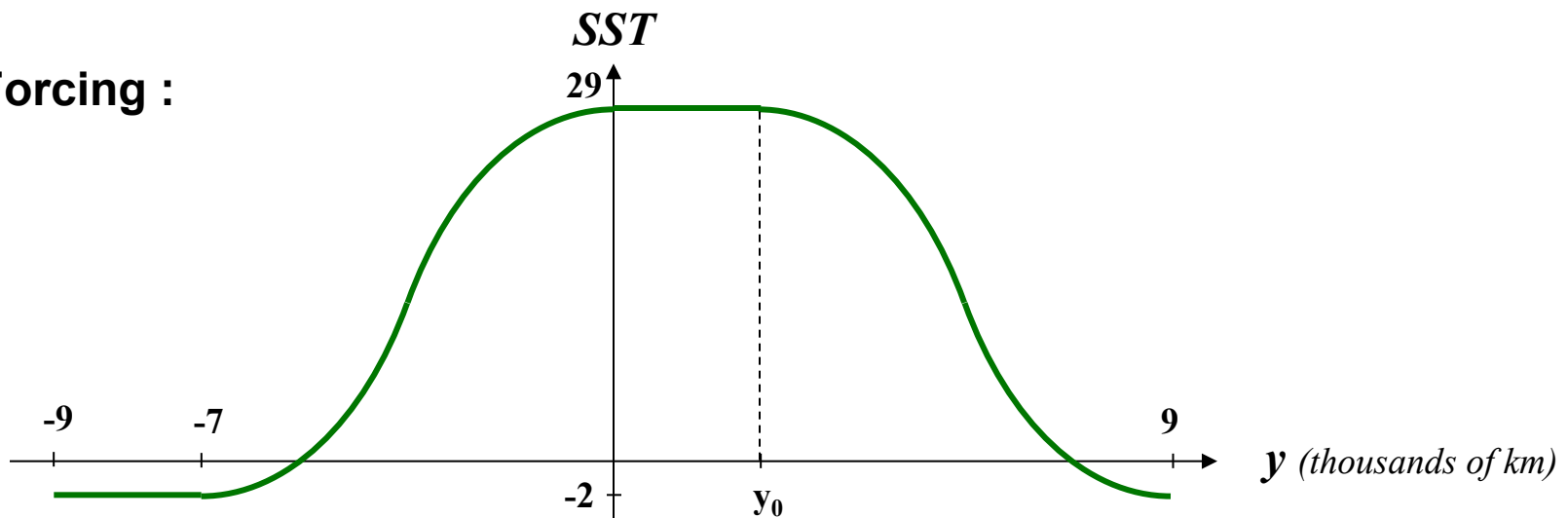
Parameterizations :

Convection: Betts-Miller (a quasi-equilibrium scheme);

Radiation: newtonian cooling towards a uniform temperature.

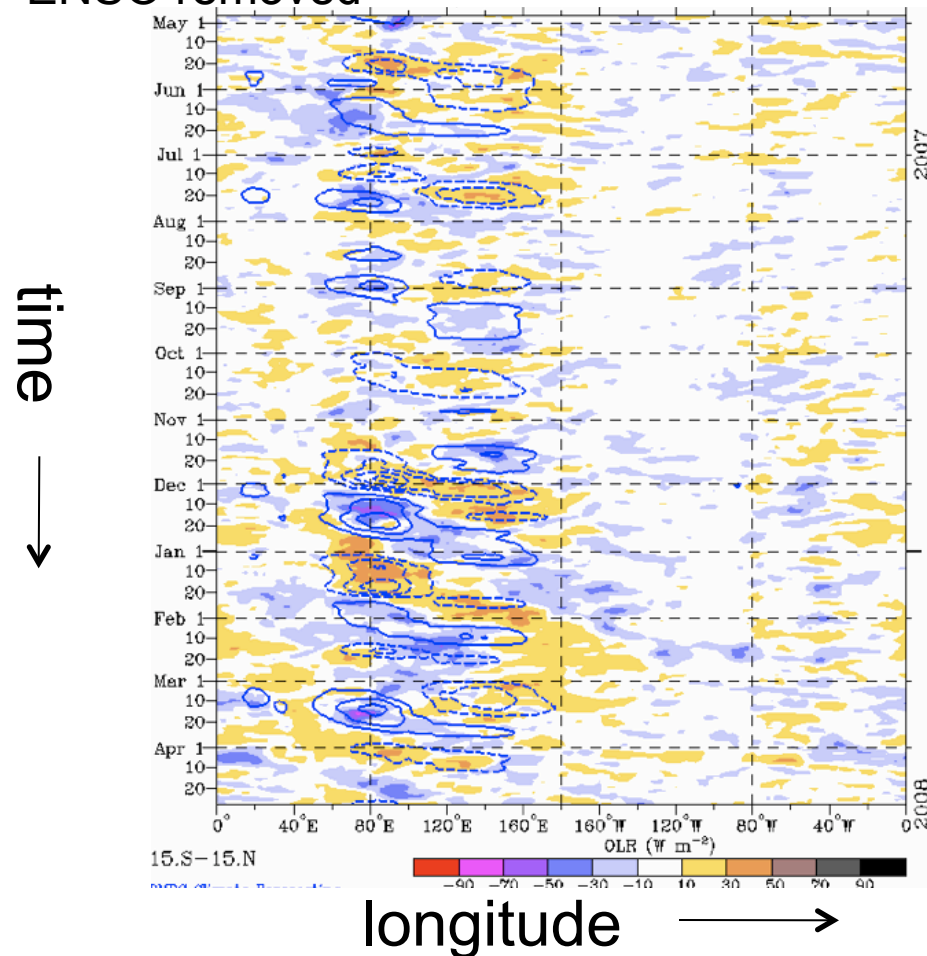
Aquaplanet, axisymmetric, on the β -plane;

Forcing :



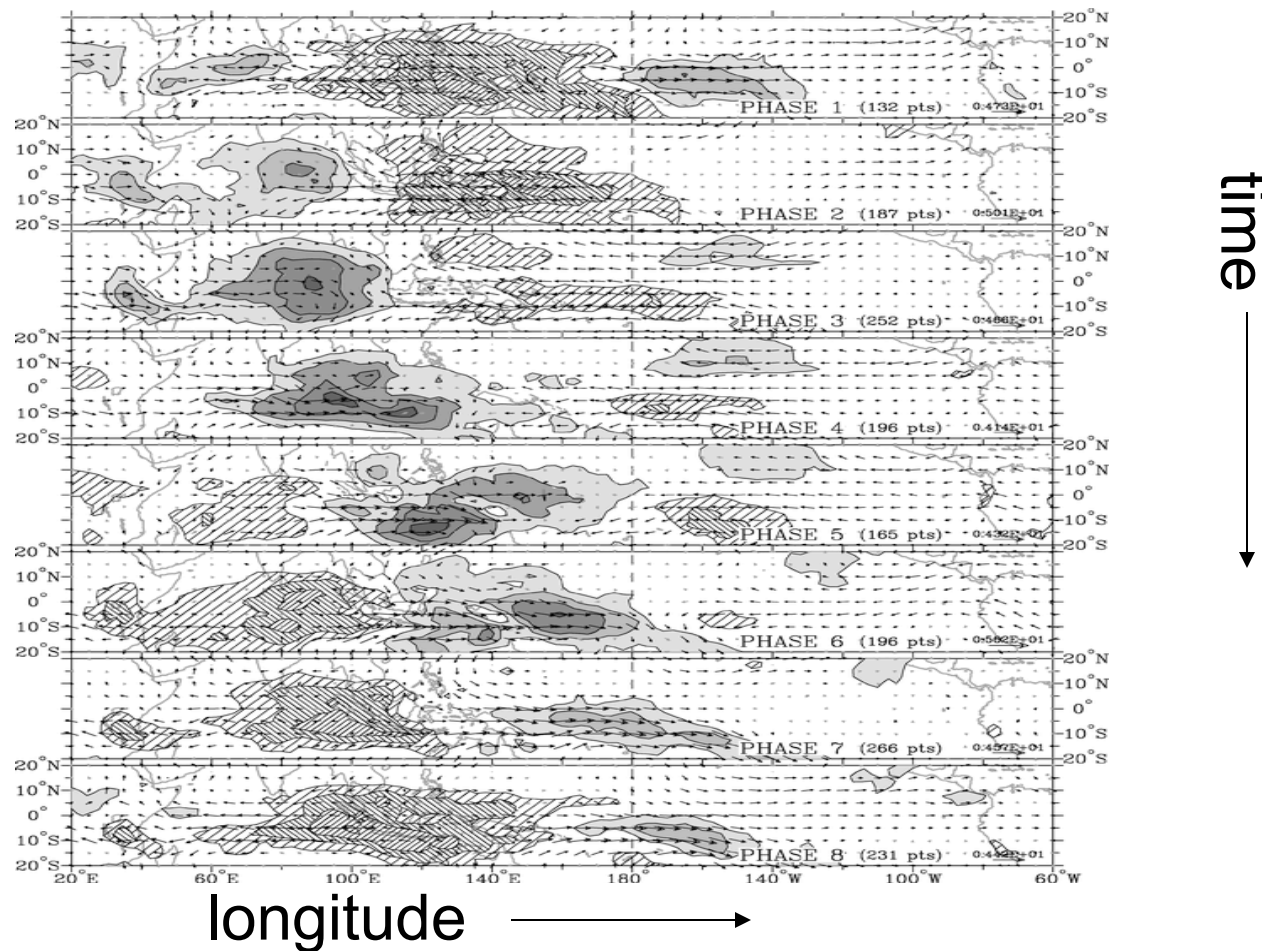
The tropical atmosphere has strong, coherent variability on the intraseasonal (30-60 day) time scale

Equatorial outgoing longwave radiation, a measure of deep, high cloudiness (shading) – annual cycle & ENSO removed

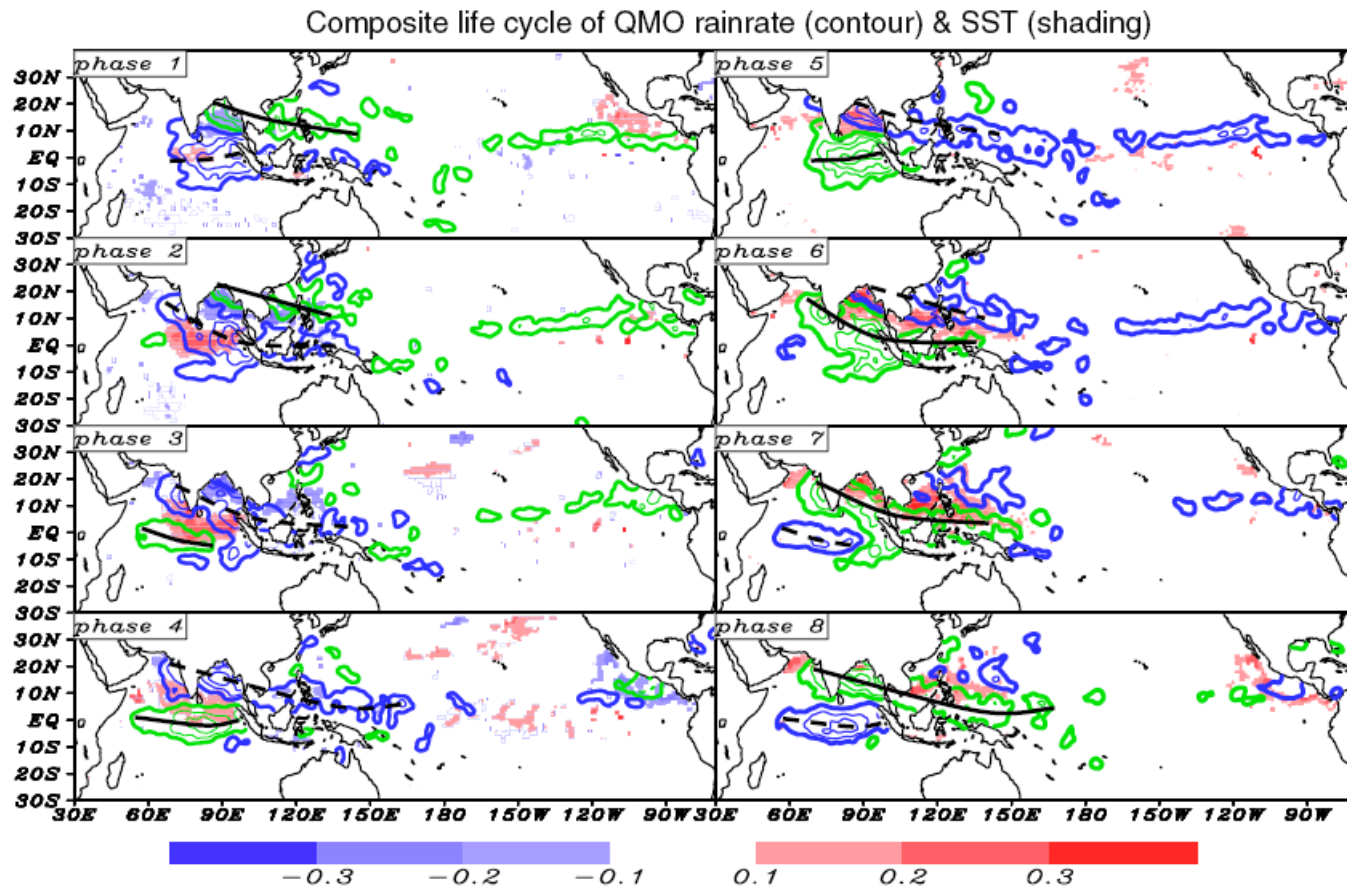


The “Madden-Julian oscillation” (MJO) propagates eastward in a belt around the equator

Statistical composite MJO in outgoing longwave radiation and lower tropospheric wind (Wheeler and Hendon 2004)



In northern summer, the Asian monsoon active and break periods also oscillate intraseasonally



Wang et al. 2006

The simplest intraseasonal variability is seen in a local analysis (Waliser 1996)

SST

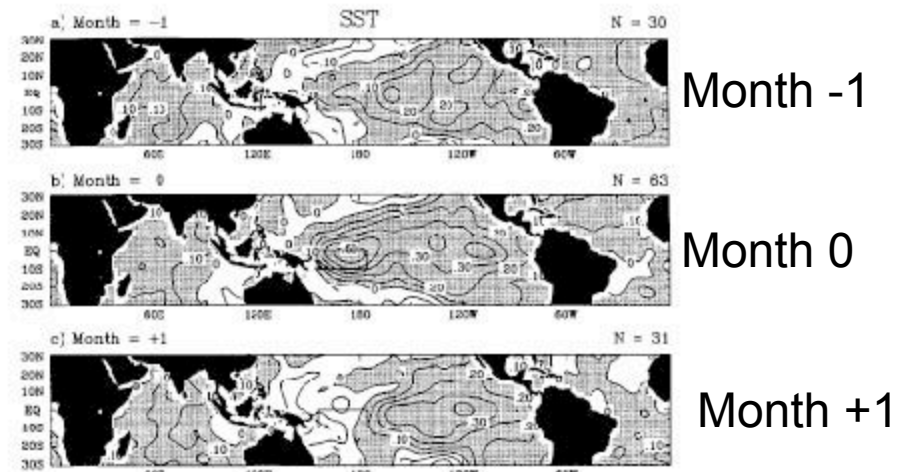


FIG. 5. (a) Composite anomalous SST for all the months (a) just prior to (month = -1), (b) during (month = 0), and (c) just after (month = +1) the occurrence of an ocean hot spot in the selection region. Contour intervals are 0.1°C, and positive anomalies are shaded. Shown in the upper right of each map is the number of monthly observations in each composite's average. The rectangular "selection region" is plotted on each composite to facilitate comparisons between different composites (see Fig. 3 and section 3b).

Time-varying composites of "hot spots" - SST > 29.5°C for a period > 1 month

Indian Ocean during the month = ±1 composites are also associated with rainfall anomalies of about -30 mm mo⁻¹.

There are three aspects in the above composites that are particularly interesting to consider. First, the HRC anomalies appear to be organized on a very large scale.

Highly reflective cloudiness

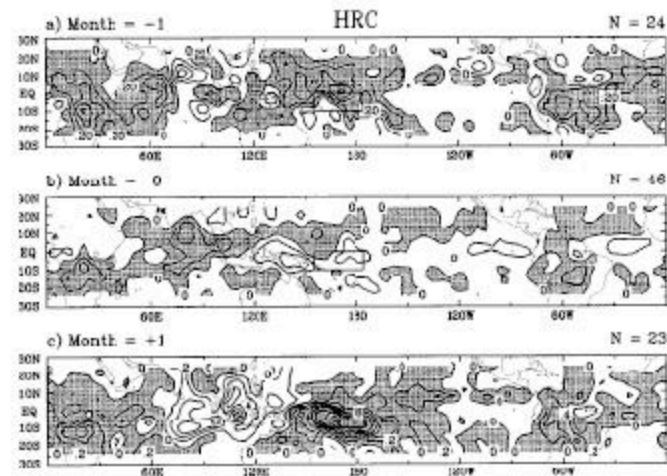
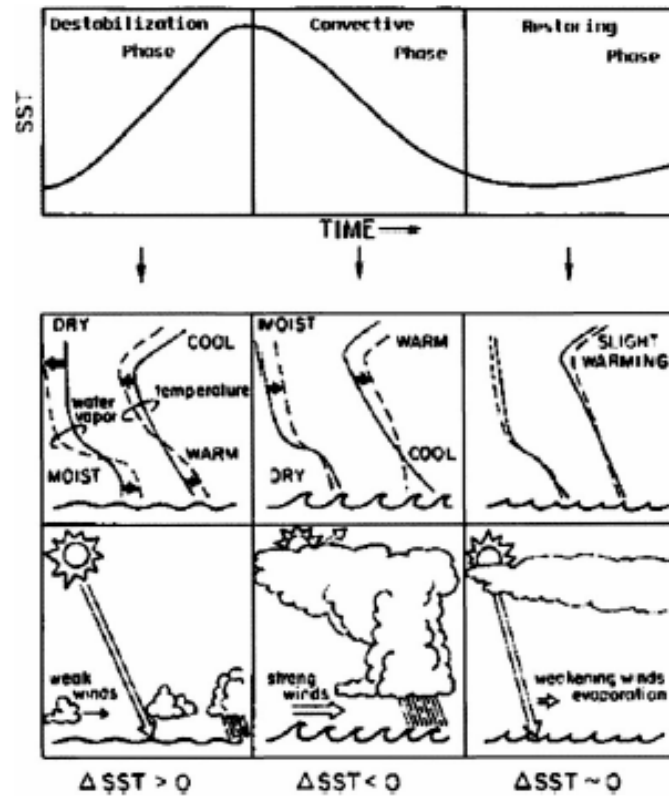


FIG. 6. Same as Fig. 5 except for HRC; contour intervals are 0.2 days mo⁻¹.

This has the appearance of a local recharge-discharge oscillation; the storage is in the ocean mixed layer



Stephens et al. 2004

Wind-induced sfc fluxes are crucial to the model instability. No oscillation for small surface thermal inertia.

Period & growth e-folding time (1/growth rate) from linear model

