Dynamics of tropical intraseasonal variability

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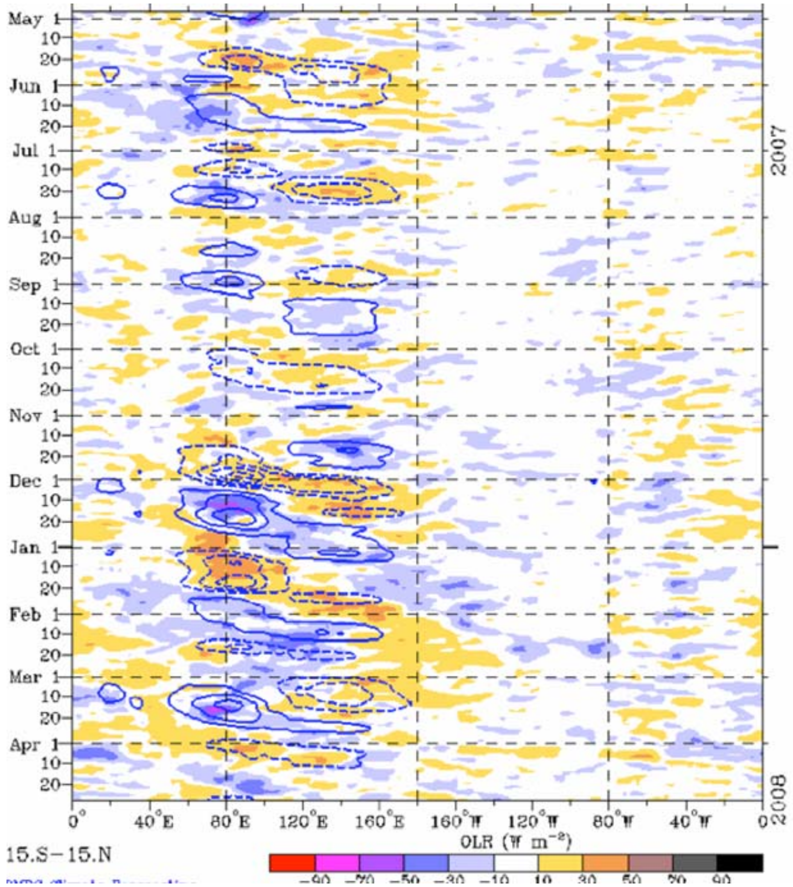
The tropical atmosphere has strong, coherent variability on the intraseasonal (30-60 day) time scale

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

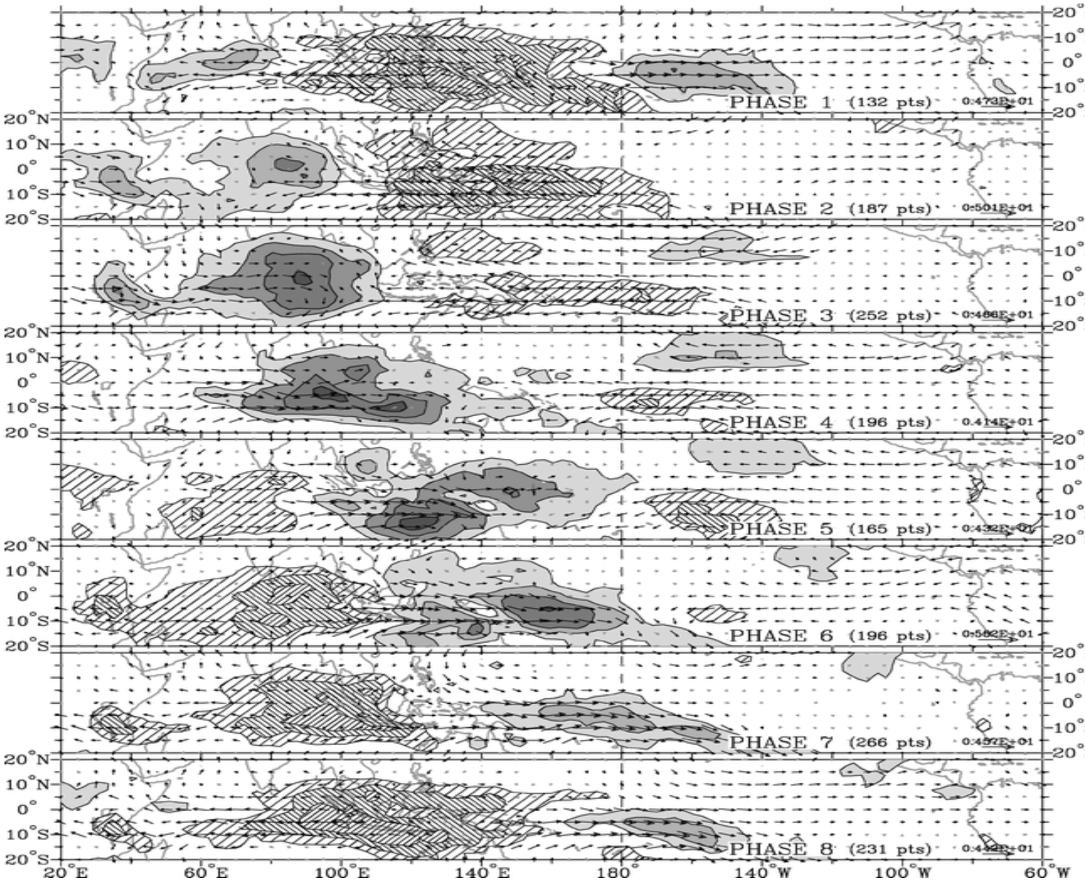


time

longitude

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

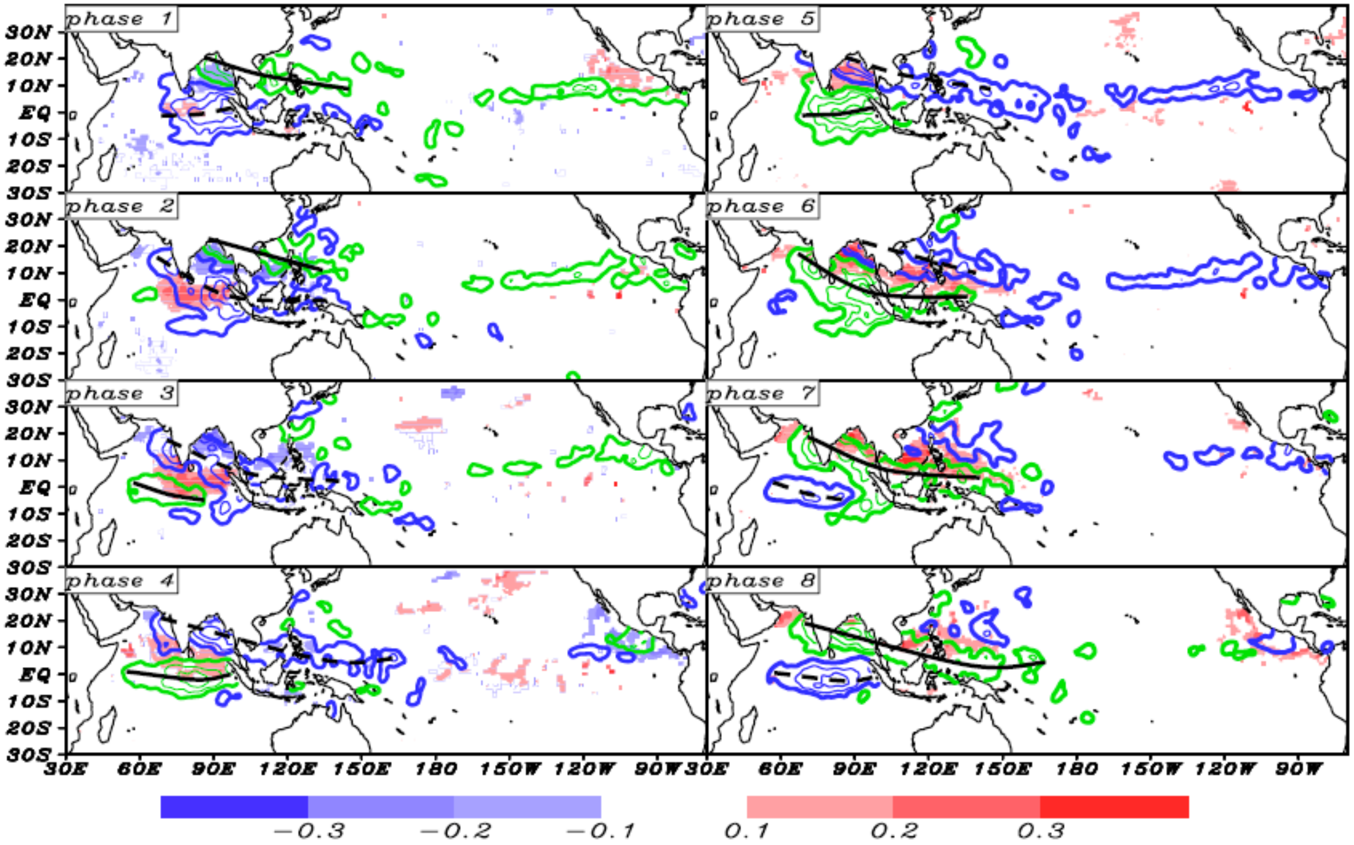
Statistical composite MJO in outgoing longwave radiation and lower tropospheric wind (Wheeler and Hendon 2004)



time

longitude

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



Composite life cycle of QMO rainrate (contour) & SST (shading)

Wang et al. 2006

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

Lin et al. 2006

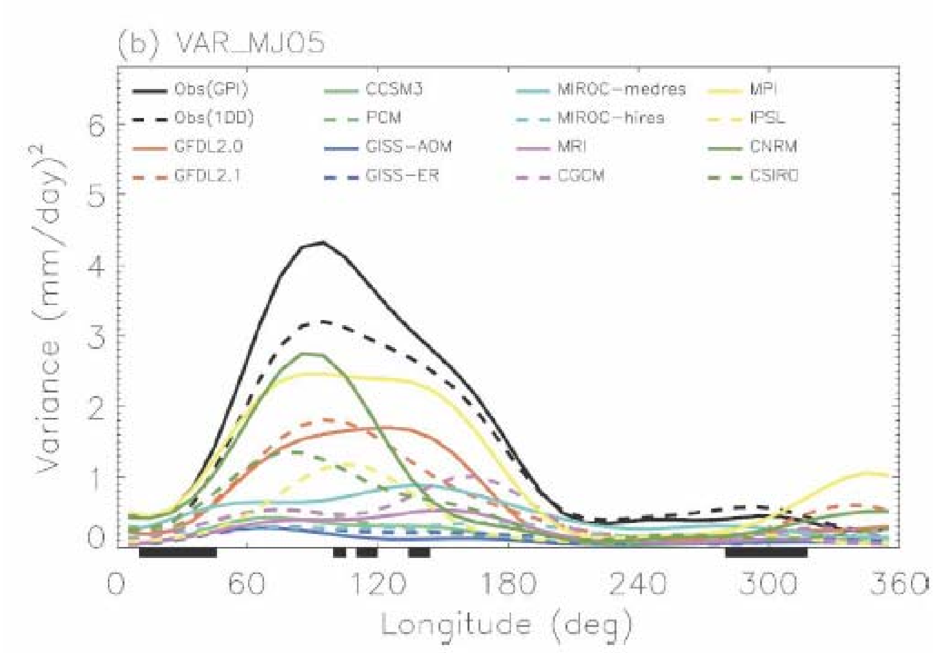


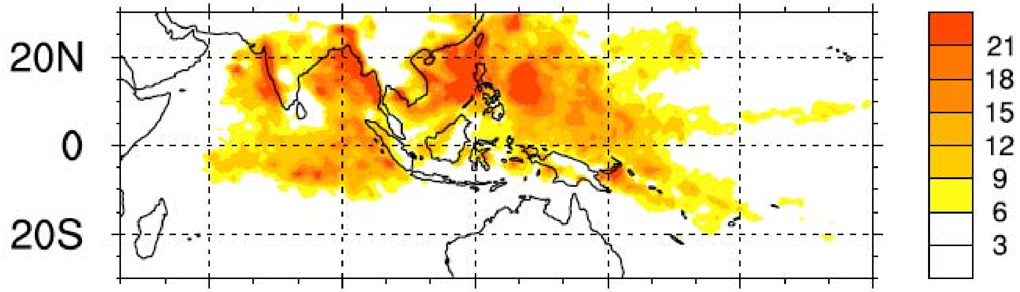
FIG. 9. Variance of the MJO mode along the equator averaged between (a) 15°N–15°S and (b) 5°N–5°S.

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

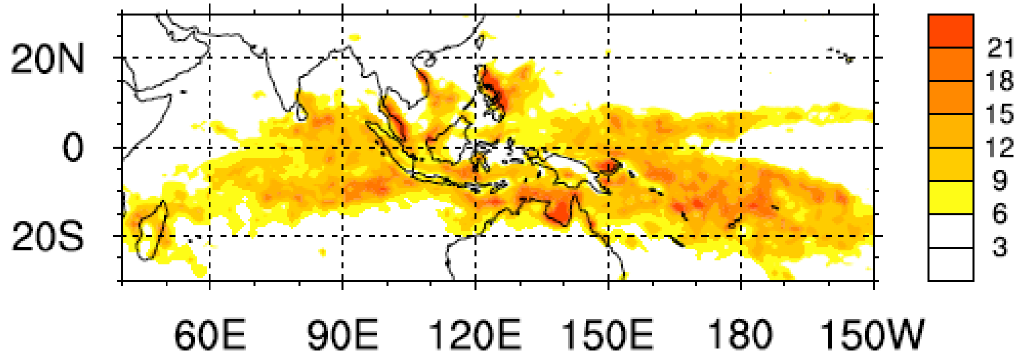
Intraseasonal rain variance

30-90 Day TRMM Variance (May-October)



Northern Summer

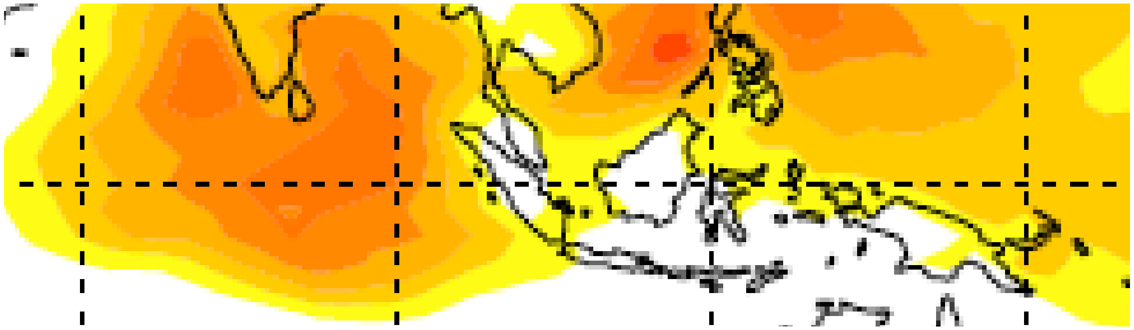
30-90 Day TRMM Variance (November-April)



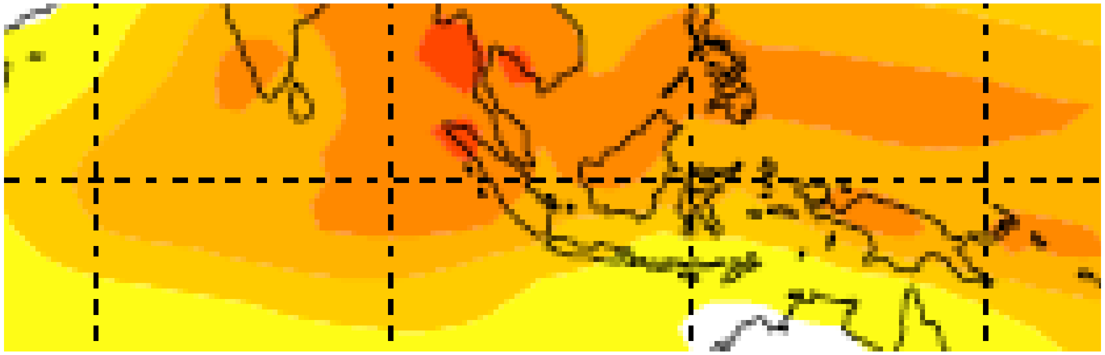
Southern Summer

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

Intraseasonal OLR variance (may-oct)

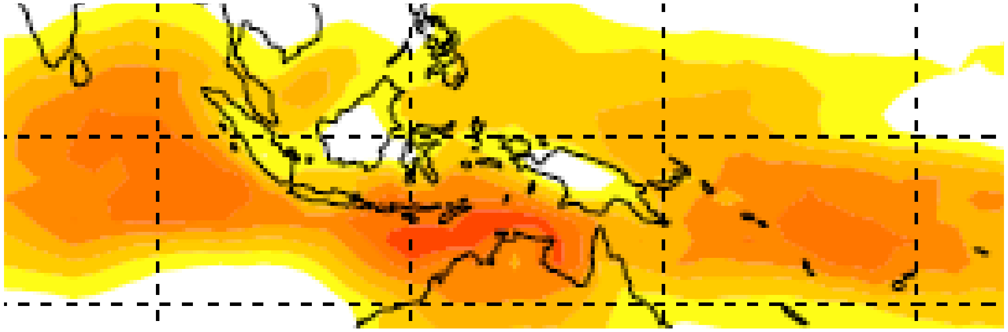


Climatological mean OLR (may-oct)

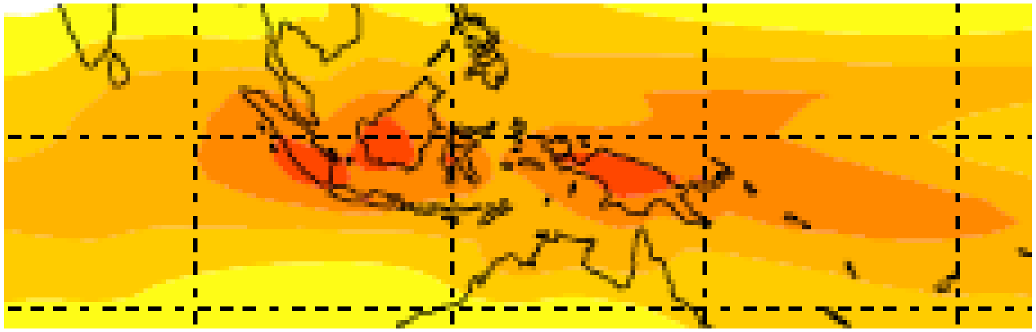


Climatological patterns resemble variance, except that the mean doesn't have localized minima over land

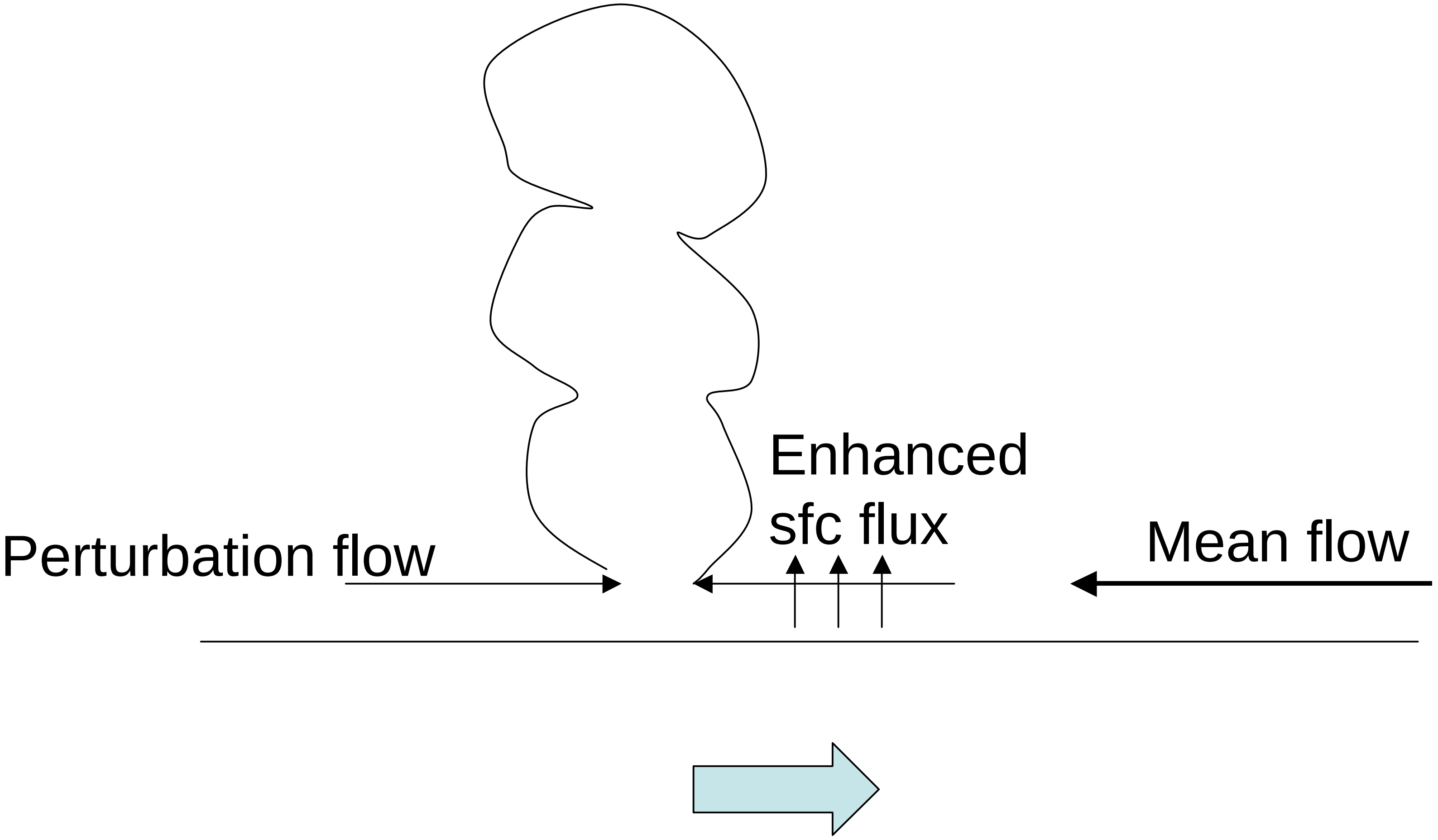
Intraseasonal OLR variance, nov-apr



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”)



Enhanced sfc flux

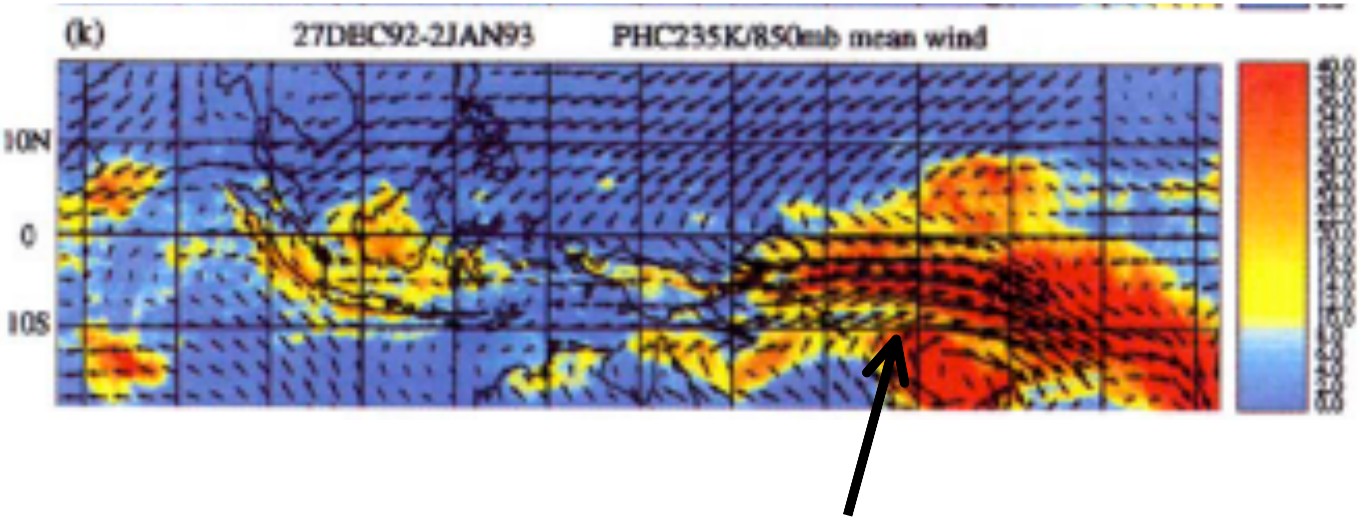
Perturbation flow

Mean flow

Wave propagation

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

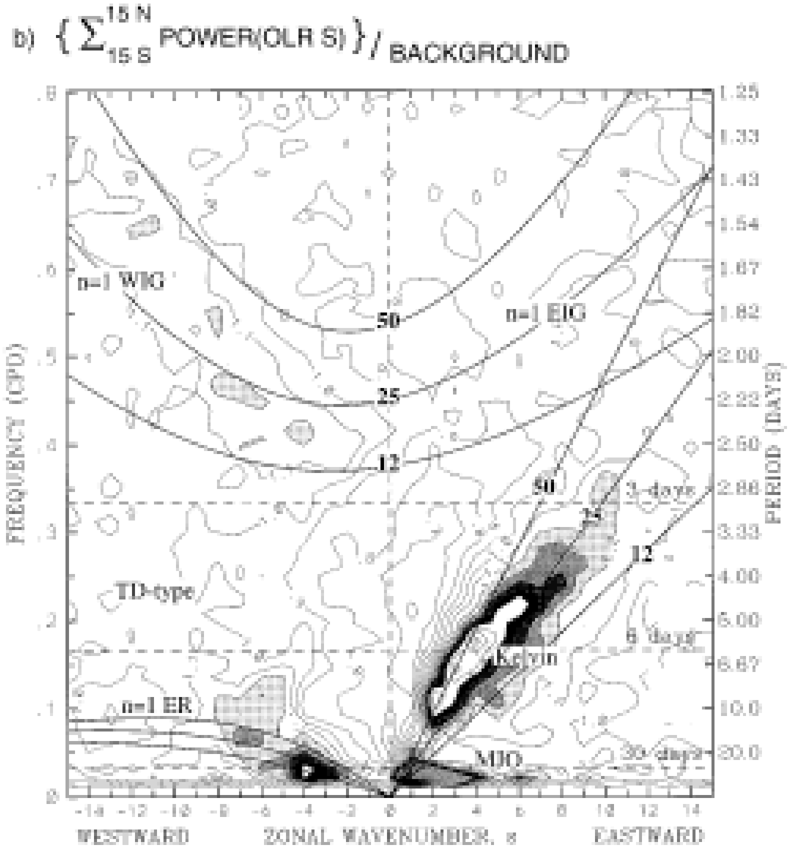
Observed cloudiness and wind from TOGA COARE
(Chen, Houze and Mapes 1996)



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

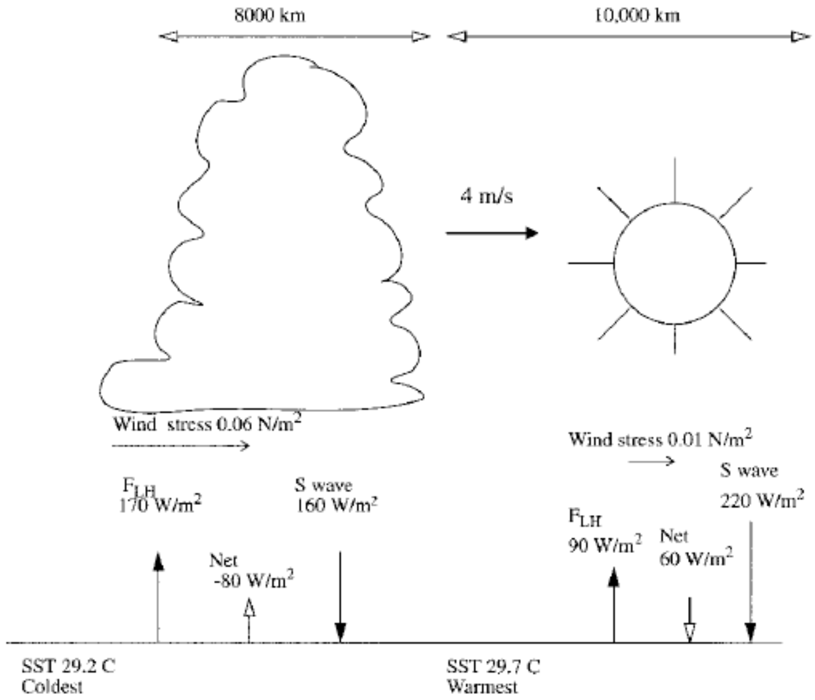
Wheeler and Kiladis (1999) used spectral analysis to show that the MJO is not a Kelvin wave

frequency



wave number

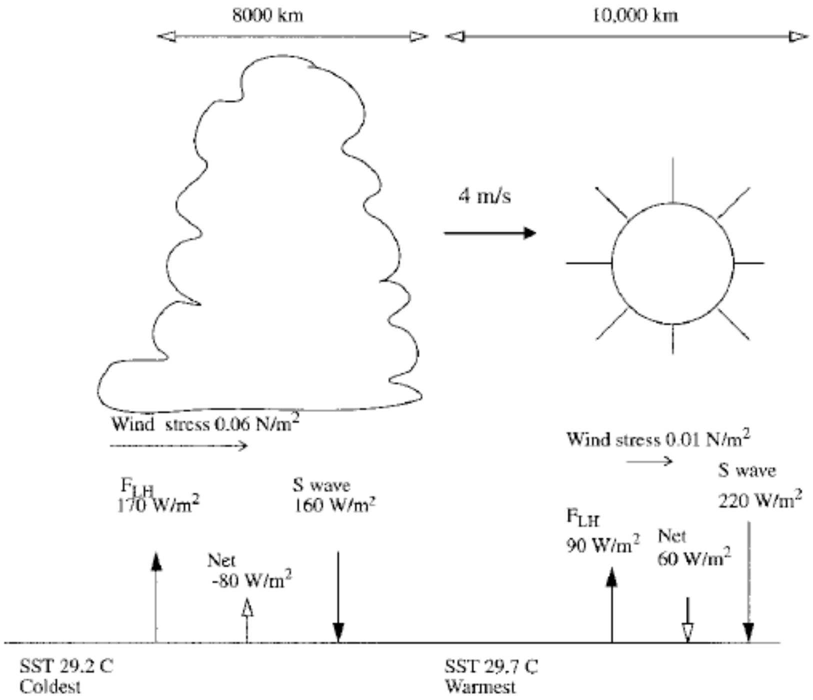
But the real MJO does have significant net surface heat flux variations, roughly in phase with convection



ocean

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!



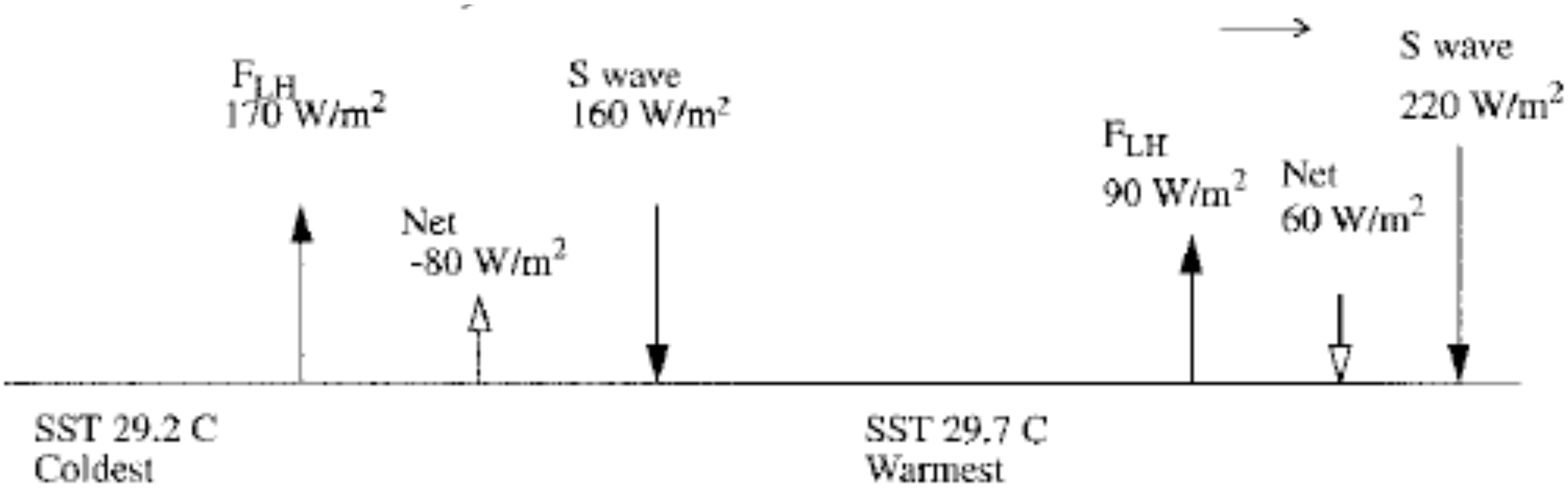
ocean

Net = 0 W/m^2

land

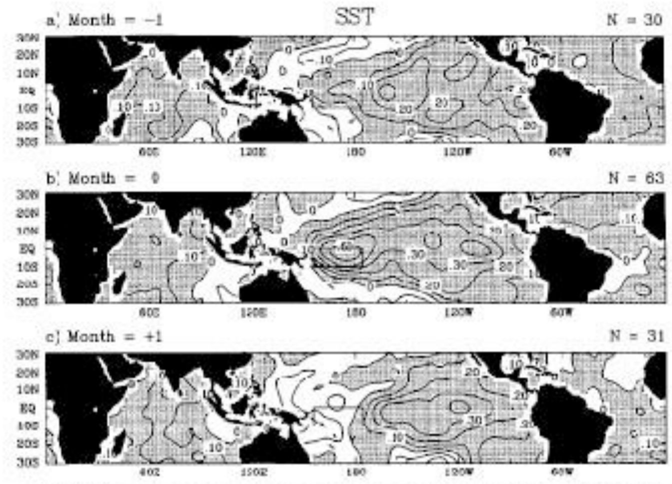
Shinoda et al. 1998

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



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

SS
T



Month -1

Month 0

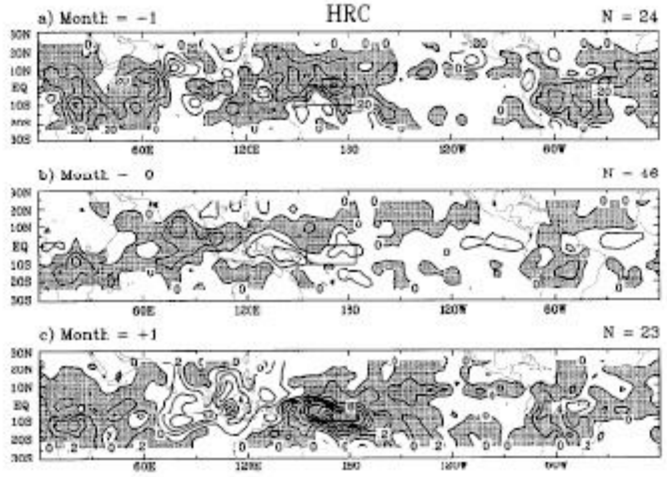
Month
+1

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>29.5C for a period > 1 month

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

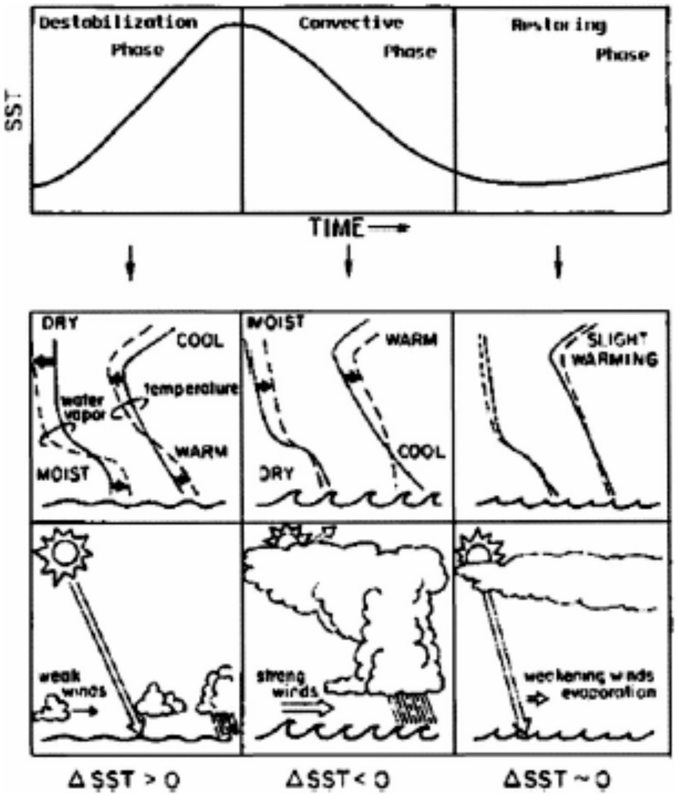
There are three aspects in the above composites that are particularly interesting to consider. First, the HRC anomalies appear to be organized on a very large scale.



Highly
reflective
cloudiness

FIG. 6. Same as Fig. 5 except for HRC; contour intervals are 0.2 days mo^{-1}.

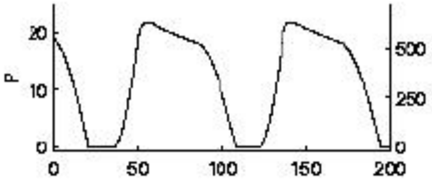
This has the appearance of a local recharge-discharge oscillation; the storage is in the ocean mixed layer



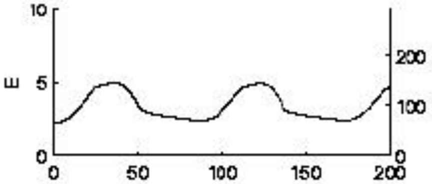
Stephens et al. 2004

We can make a very simple model – no horizontal structure, very simple vertical structure - that has such a recharge-discharge oscillation

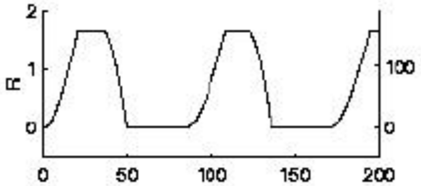
precipitation



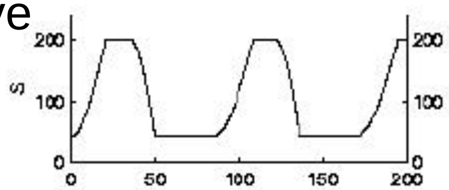
evaporation
(perturbed
only due to sfc. humidity
difference)



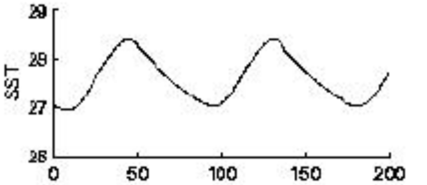
atmospheric
rad. cooling



surface shortwave
(+ “wind induced”
evaporation)

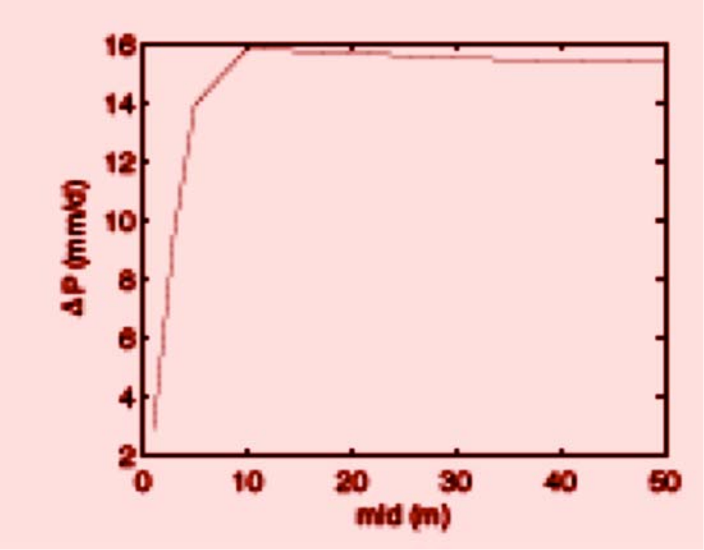


SST



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



Role of surface fluxes

Role of coupling

Mixed layer depth (m)

mld=0 is like land

Mld=∞ is like prescribed SST

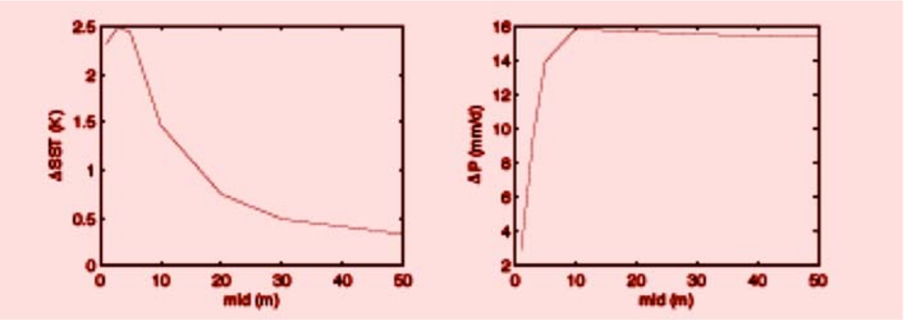
Maloney and Sobel 2004

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

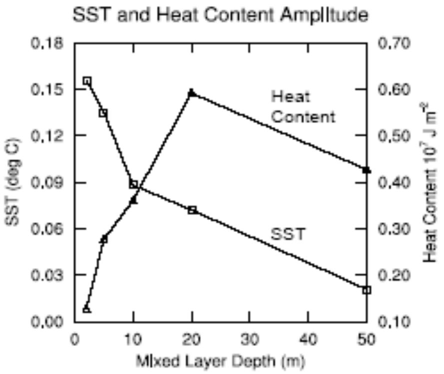
SST

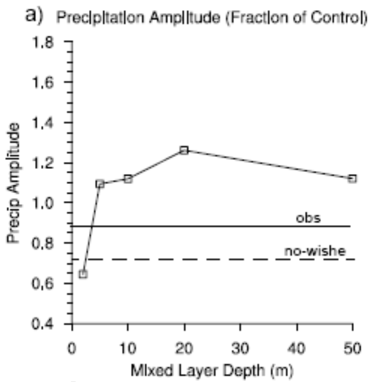
Precip

Simple model (amplitude is max-min)



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



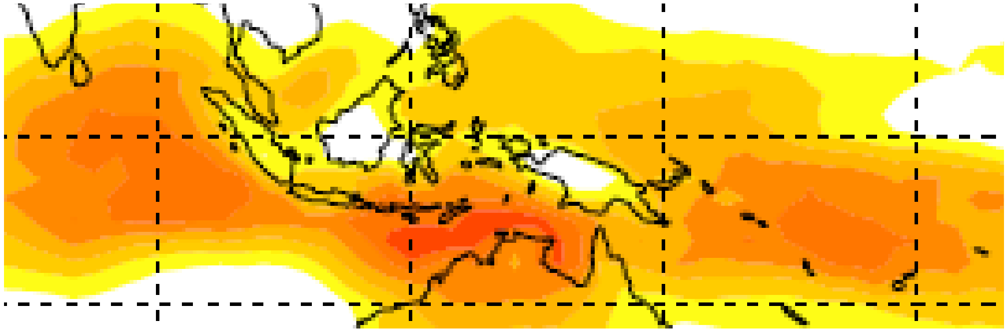


Mixed layer depth ->

(Maloney and Sobel 2004)

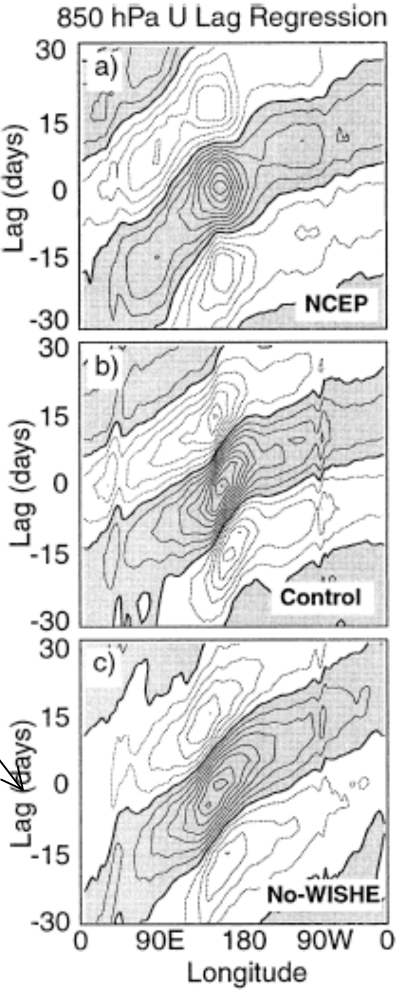
Wet land is like a mixed layer of zero depth (swamp). Thus if MJO is dependent on surface energy fluxes (turbulent, radiative, or both) it should weaken over land… as observed.

Intraseasonal OLR variance, nov-apr

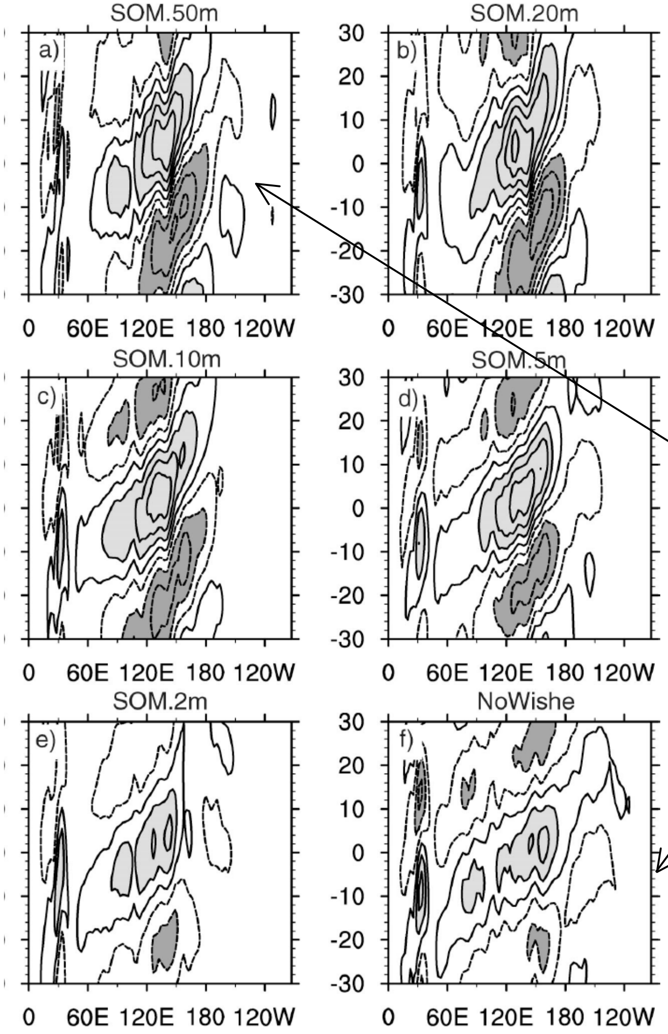


The GCM-simulated dependence on surface turbulent flux feedback is very dependent on convective scheme.

small difference



Precip (Maloney 2002)



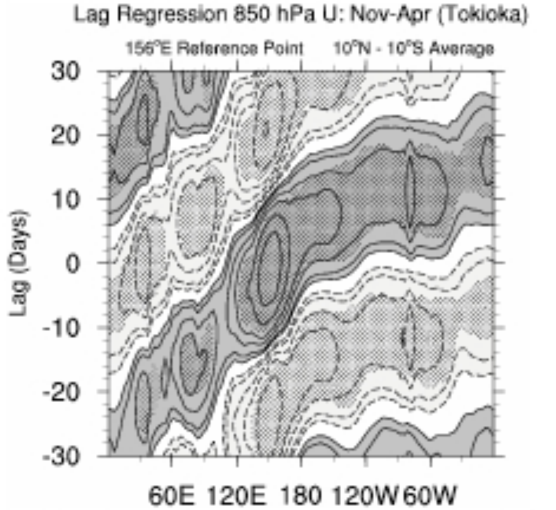
Precip (Maloney & Sobel 2004)

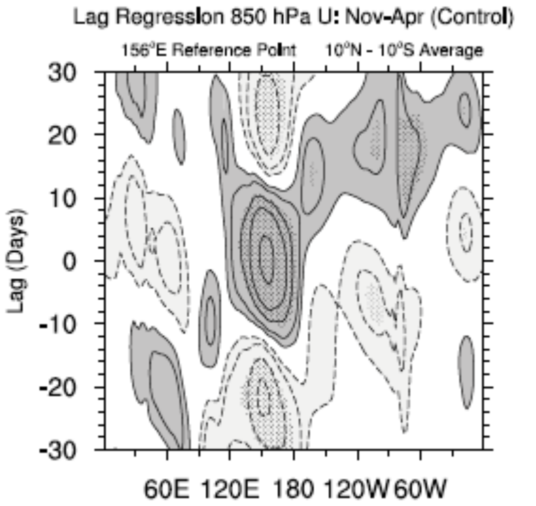
Big difference

this is just
~1/2 of the
possible flux
feedback;
radiation is
comparable

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

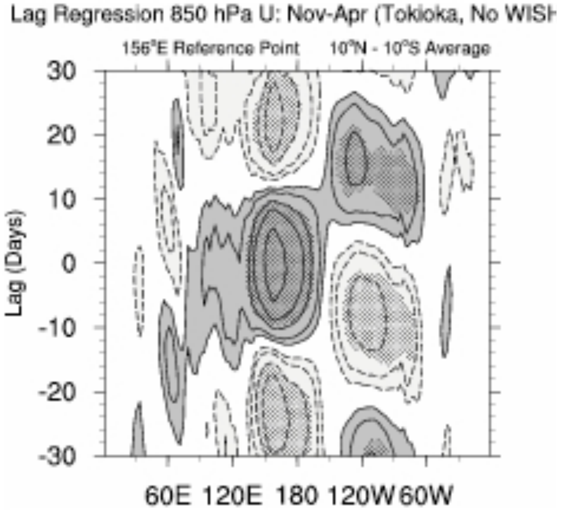
control

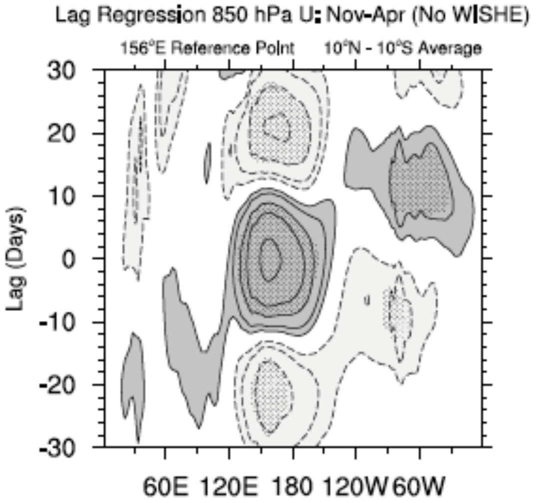




GFDL AM2

No-WISHE
(const sfc
wind speed)

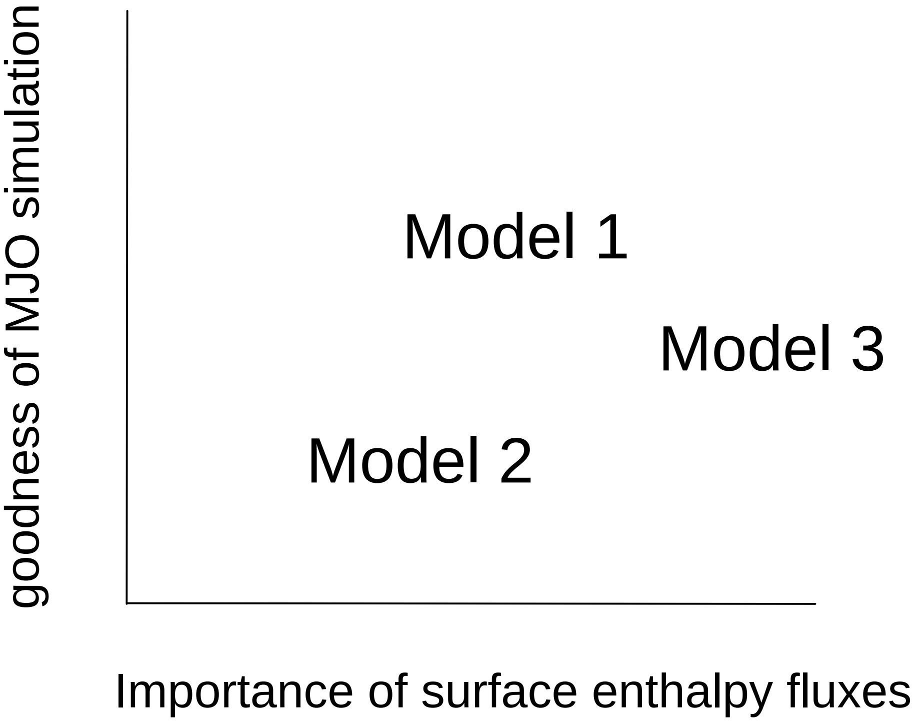




better model

worse model

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


goodness of MJO simulation

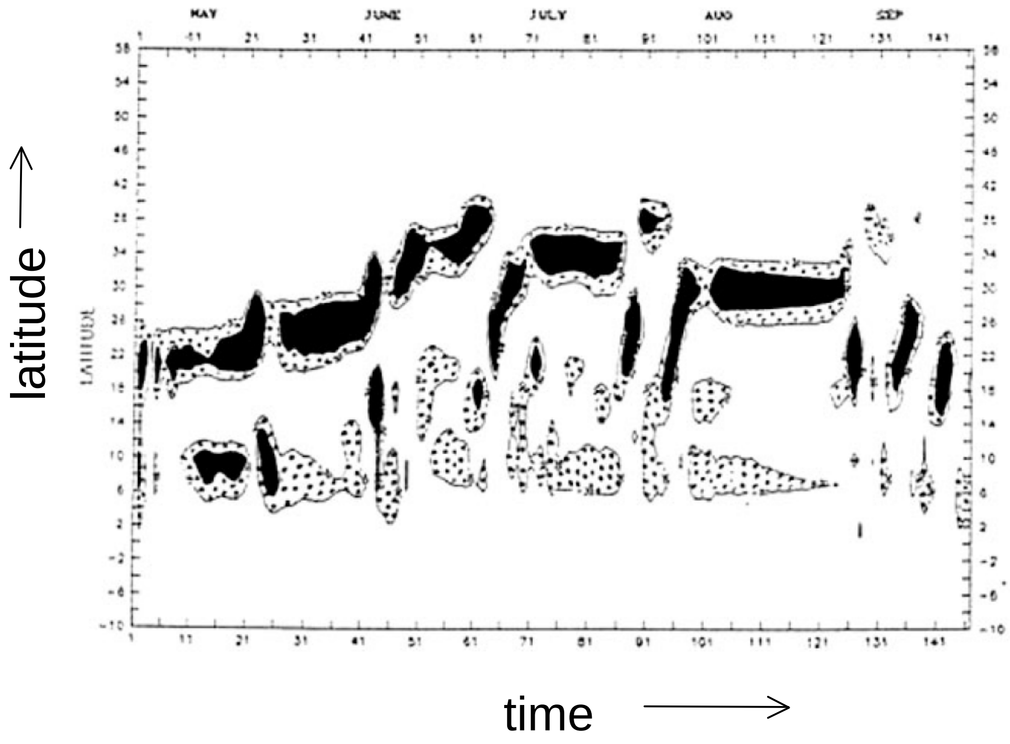
Model 1

Model 3

Model 2

Importance of surface enthalpy fluxes

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

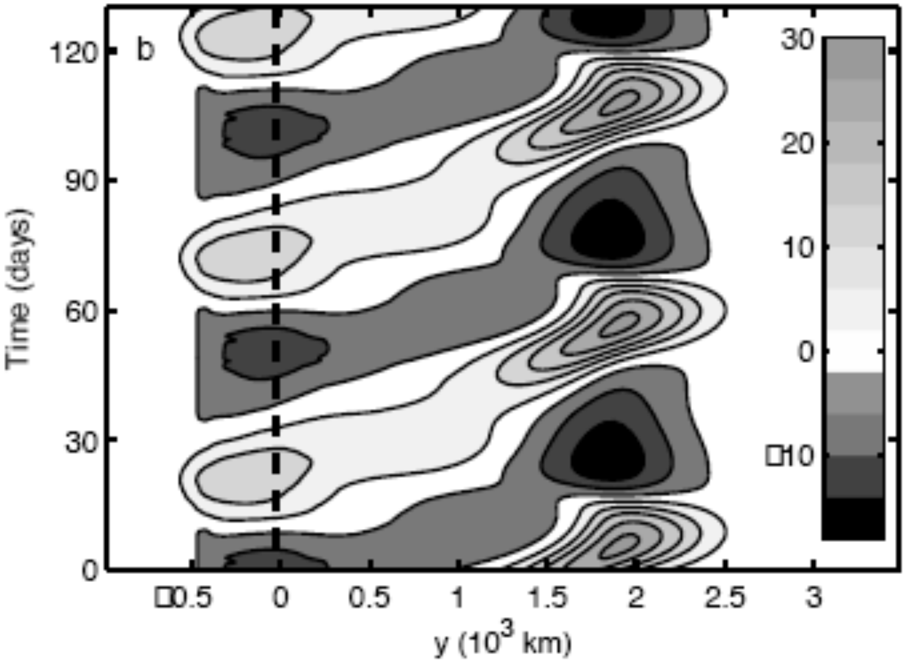


Nanjundiah et al. 1992

We have a “simple” axisymmetric model which produces an intraseasonal northward-propagating oscillation, robustly to parameters

Precipitation (mm/d)

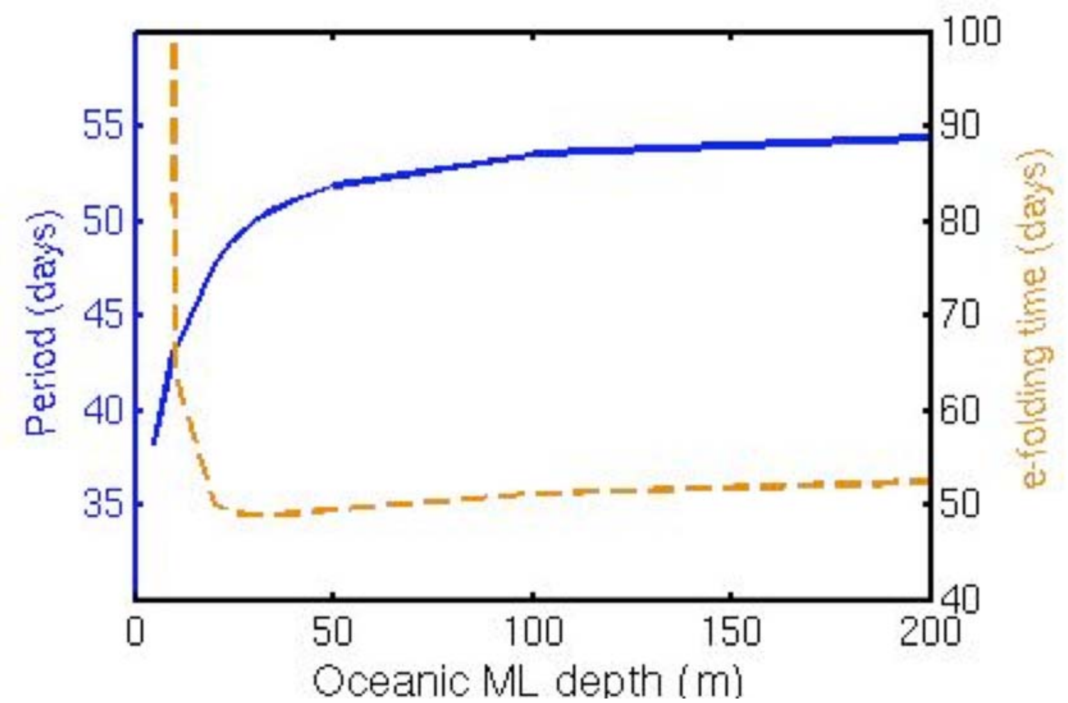
time



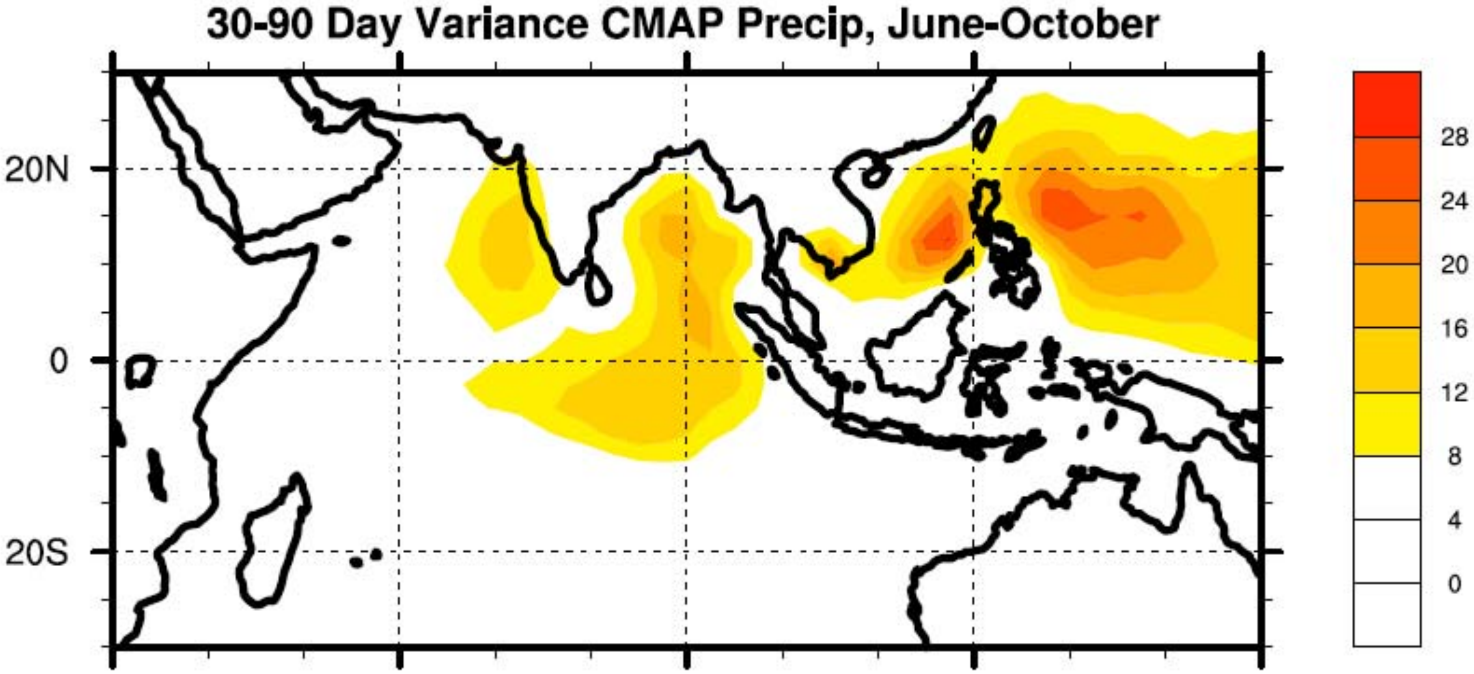
Latitude (1000’s km)

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



If this model were relevant to reality, it would imply damping of intraseasonal variability over land in NH summer, as observed



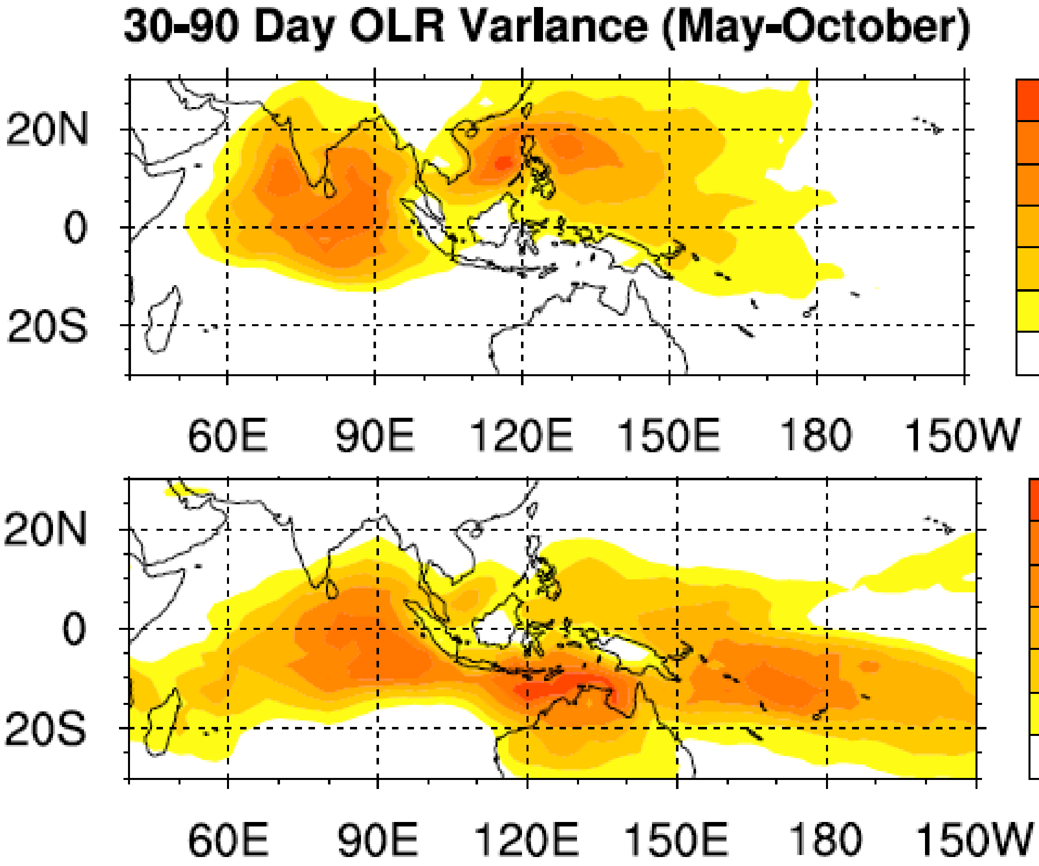
Summary

- 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.

The patterns are robust across different data products



Northern Summer

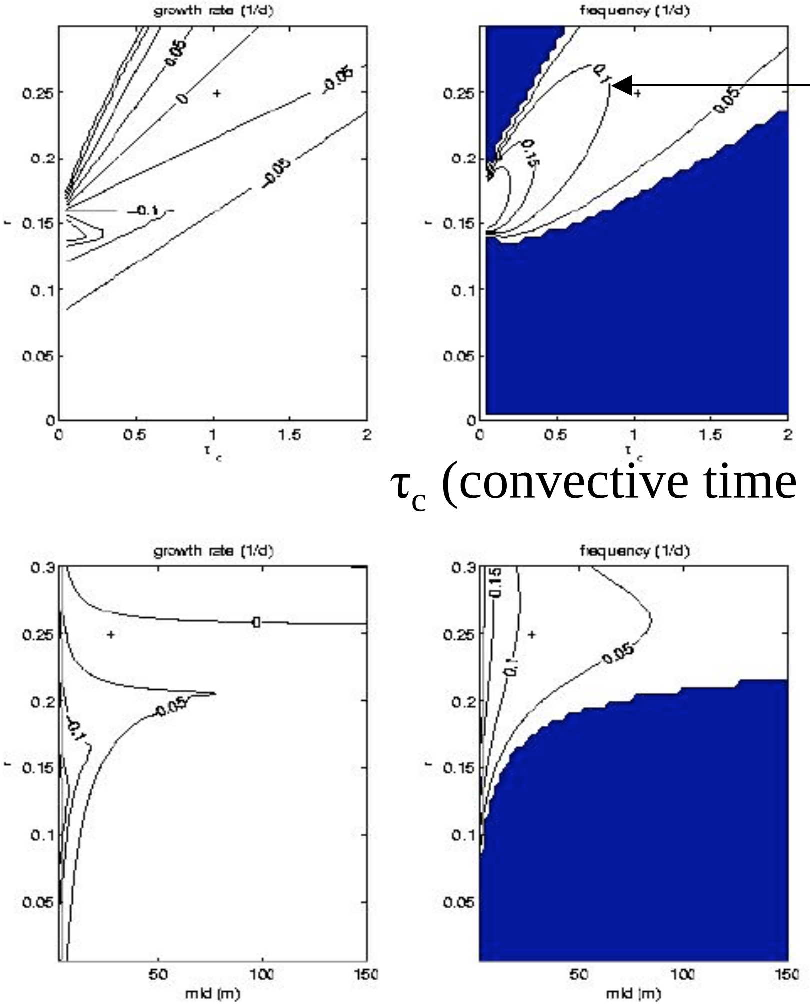
Southern Summer

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

growth rate

frequency

r (cloud-rad/sfc flux feedback)



τ_c (convective time scale)

0.1 d^{-1}
~= 60 d period

mixed layer depth

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

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

Simple Betts-Miller convection

$$\left. \begin{aligned} R &= R_{clr} - \mathrm{max}(rP, R_{clr}) \\ S &= S_{clr} - \mathrm{max}(rP, S_{clr}) \end{aligned} \right\}$$

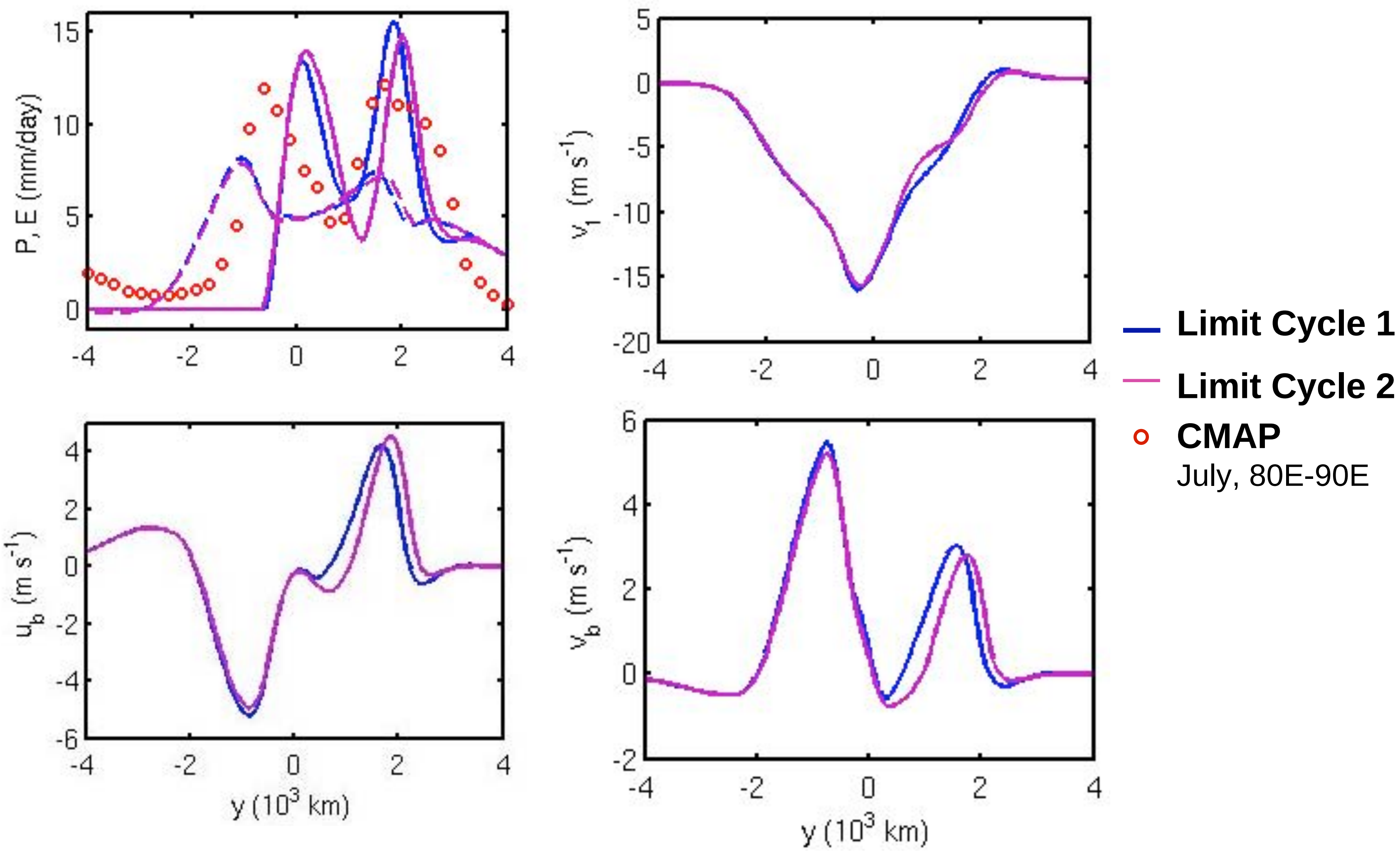
Linear cloud-radiative feedback, SW and LW cancel at TOA

Sfc wind constant for starters (will relax this)

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

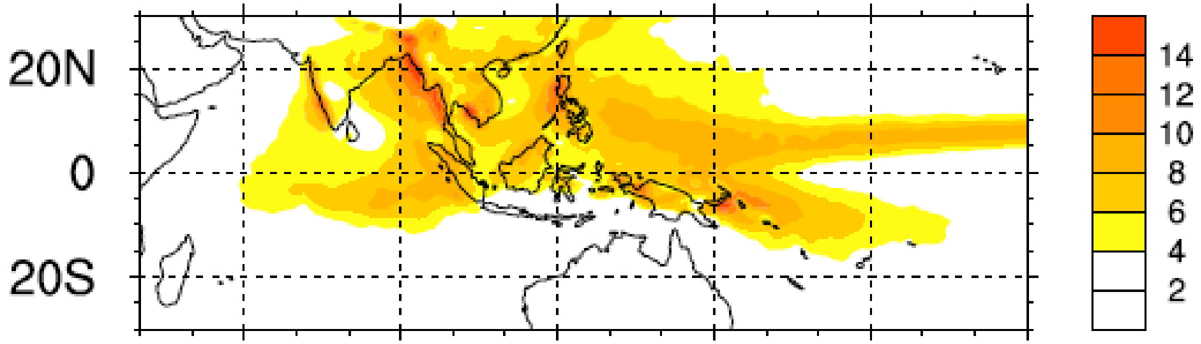
Results: two limit cycles

Mean states

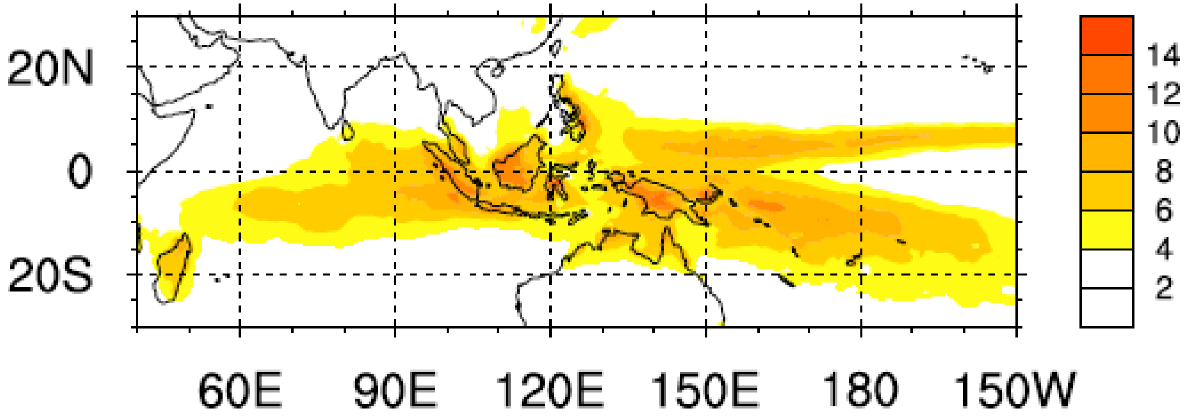


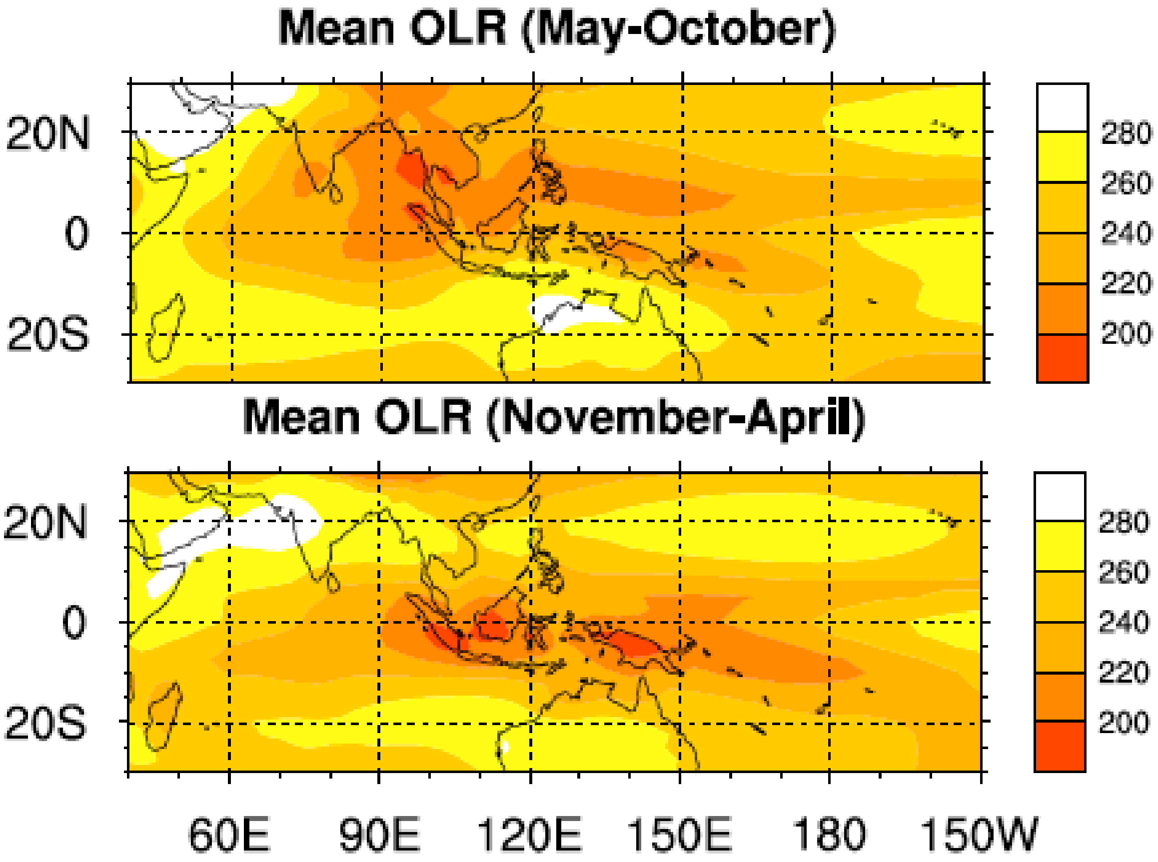
Climatological rainfall patterns resemble variance, except that the mean rainfall doesn't have localized minima over land

Mean TRMM Precip (May-October)



Mean TRMM Precip (November-April)





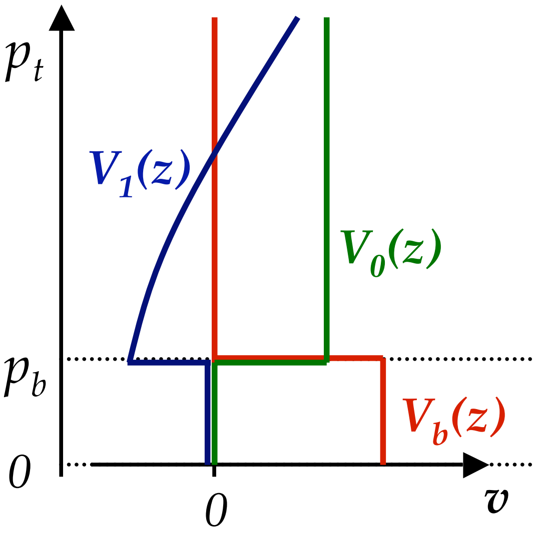
Mean OLR (May-October)

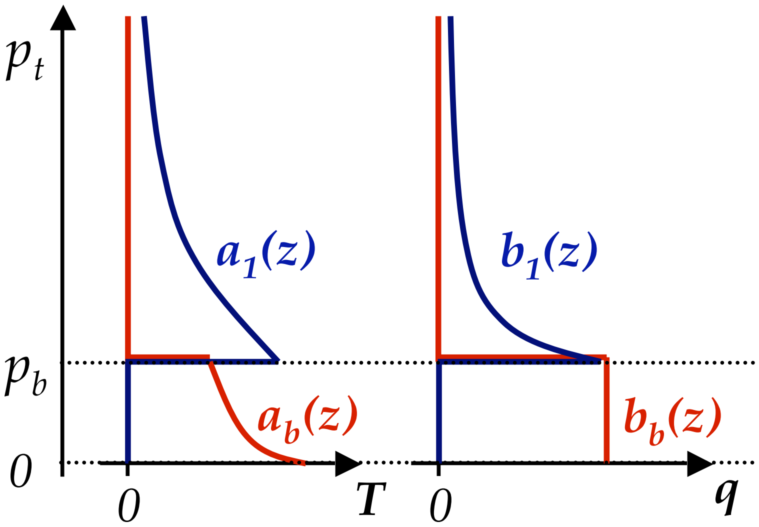
Mean OLR (November-April)

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 :