# Highly idealized semi-empirical MJO model

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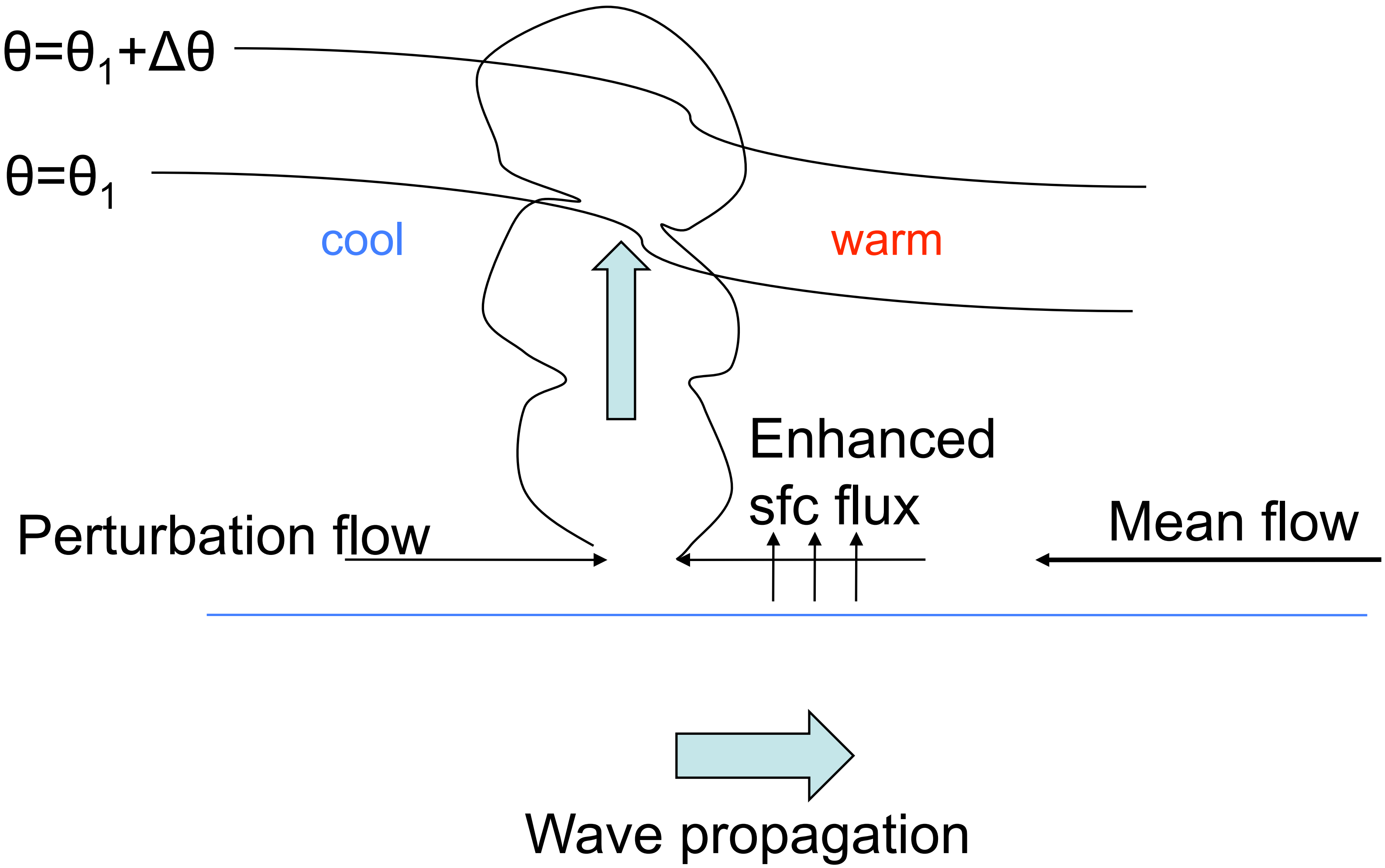
Emanuel (87) and Neelin et al. (87) proposed that the MJO is a Kelvin wave driven by wind-induced surface fluxes (“WISHE”)



$\theta=\theta_1+\Delta\theta$

$\theta=\theta_1$

cool

warm

Enhanced sfc flux

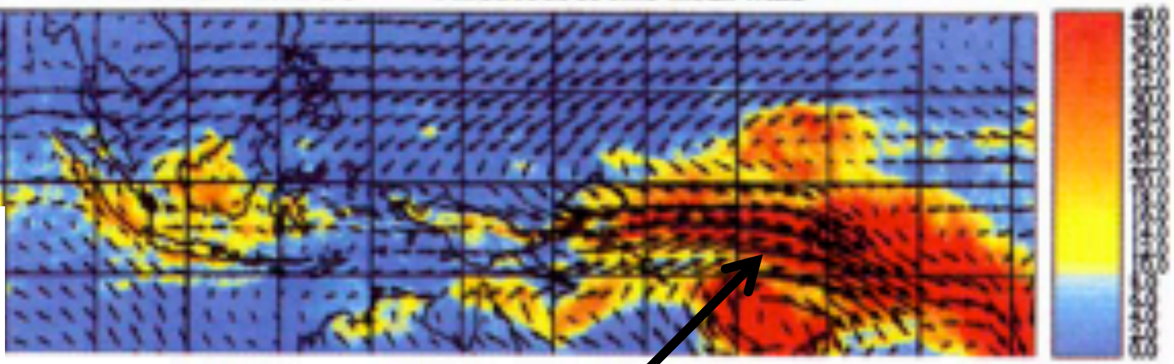
Perturbation flow

Mean flow

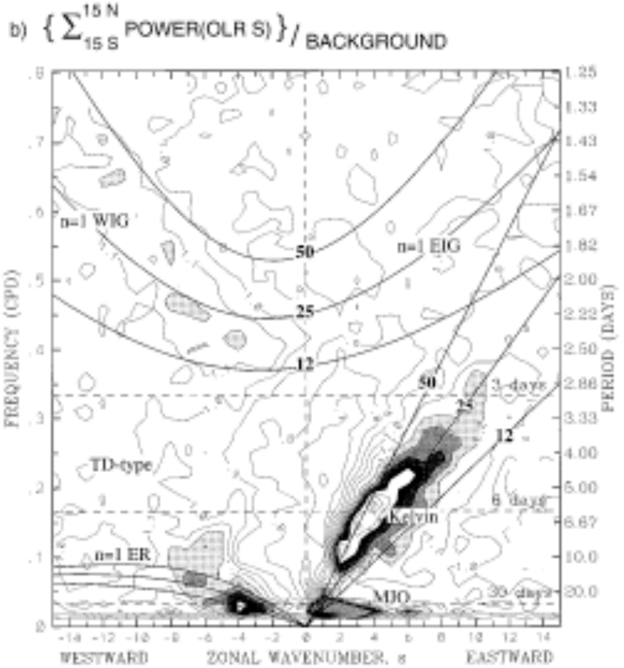
Wave propagation

# This idea was 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)



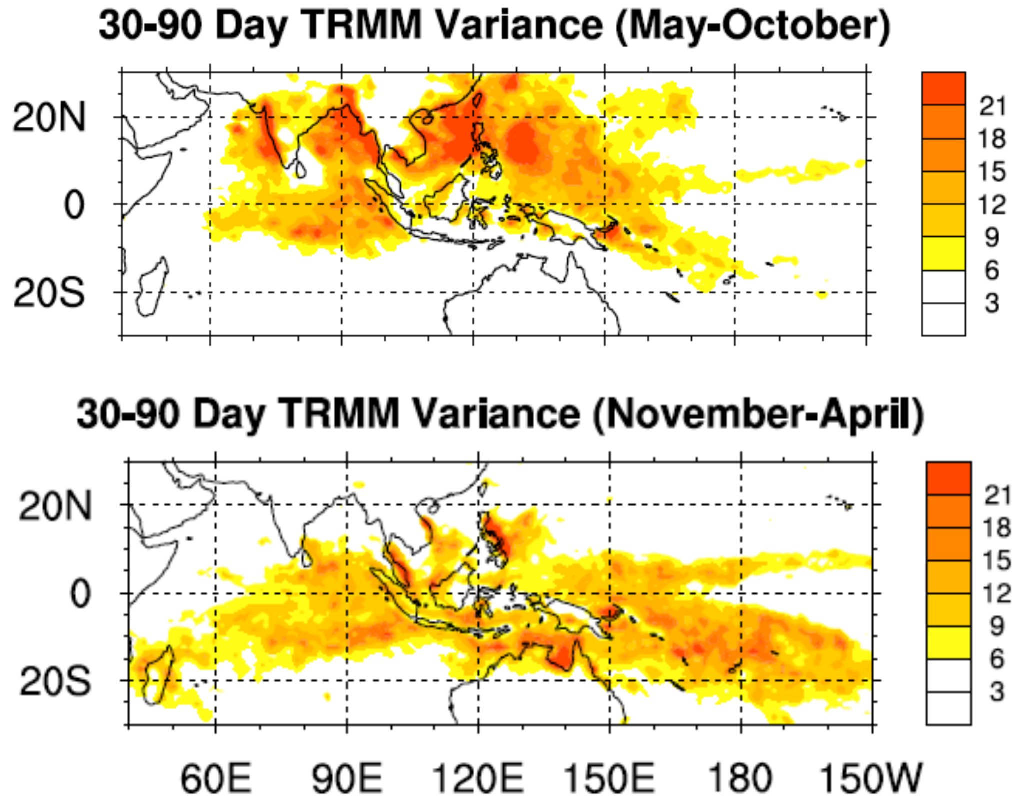
Strongest winds and fluxes are in phase with or lag precipitation, and lie in westerlies



Frequency-wavenumber OLR plot
(Wheeler and Kiladis 1999)

# Intraseasonal variance of rainfall shows land-sea contrast -> sfc fluxes important

Intraseasonal rain variance



Northern
Summer

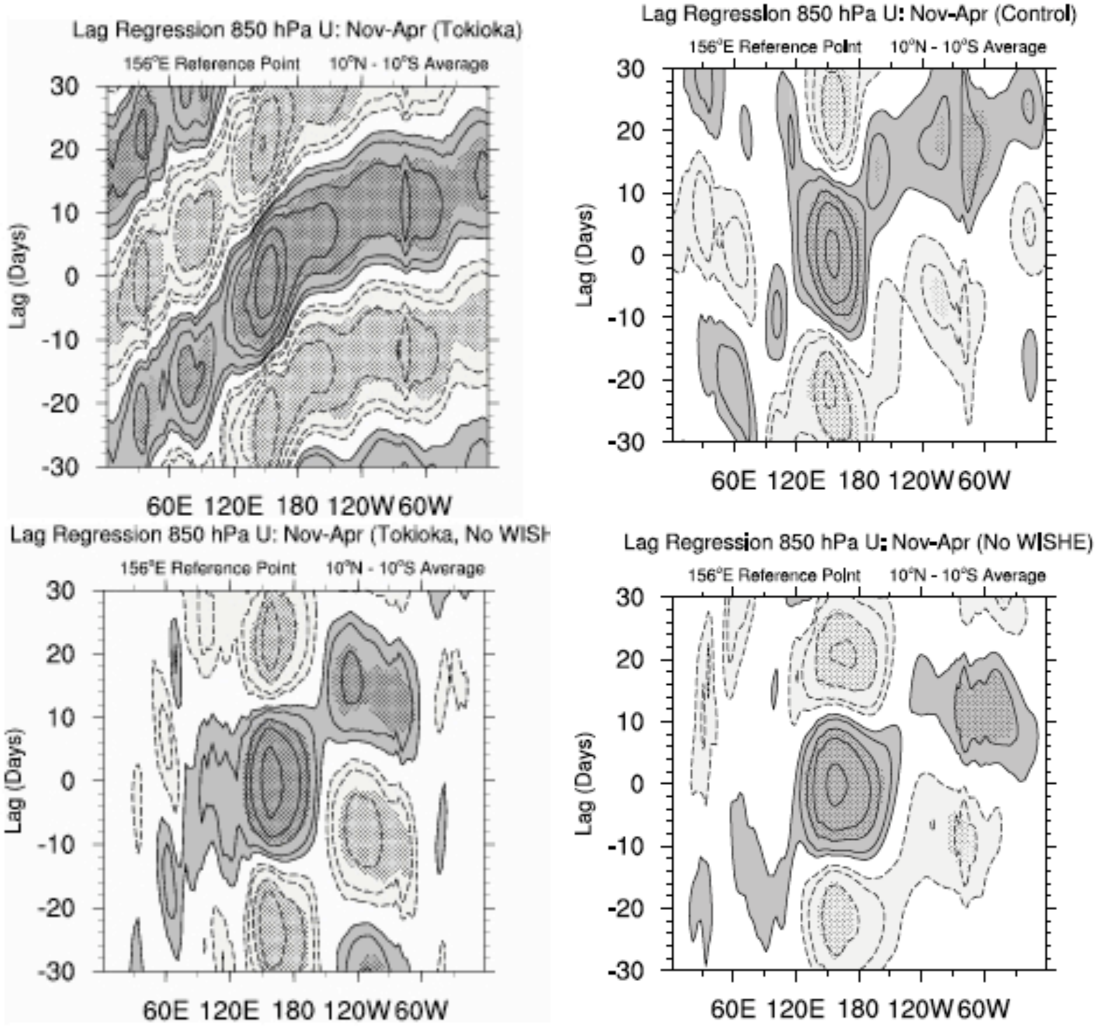
Southern
Summer

Sobel, Maloney, Bellon, and Frierson 2008: *Nature Geosci.*.
Sobel, Maloney, Bellon, and Frierson 2010: *J. Adv. Model Earth Sys.*

# GCMs with better MJO simulation tend to have larger role for surface fluxes (in small sample studied)

control

No-WISHE
(const sfc
wind speed)



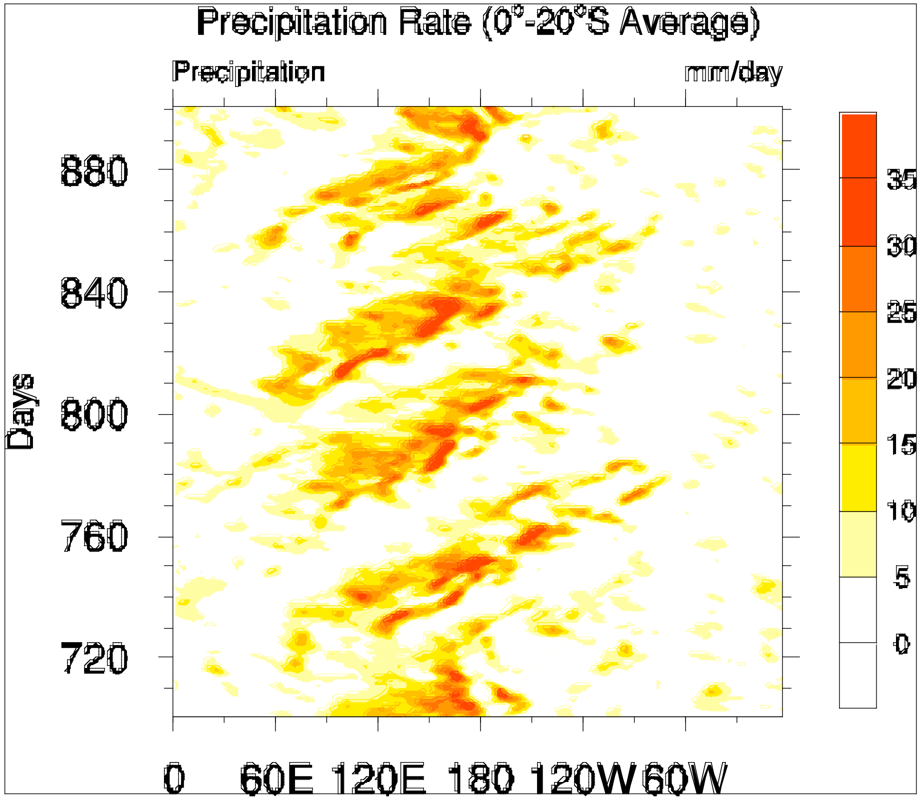
GFDL AM2

better model

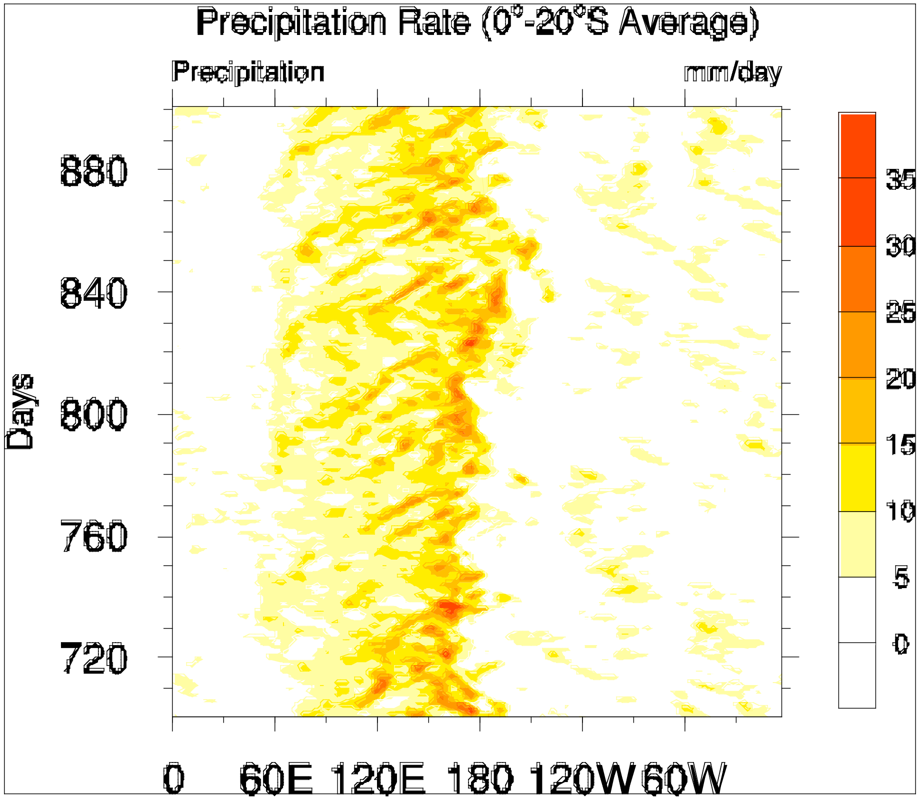
worse model

# Aqua planet simulation with modified CAM3 and small eq-pole SST gradient shows strong MJO destabilized by WISHE

Control



No-WISHE



Analysis of the MSE budget suggests that horizontal advection plays an important role in the propagation dynamics

Maloney, Sobel, Hannah 2010 *J. Adv. Model Earth Sys.*

# To summarize some key recent and old results

- Evidence from obs & models that sfc fluxes (& radiation) are important to destabilization
- Evidence from models for both fluxes and gross moist instability (e.g., Raymond & Fuchs)
- Nonlinearity may be important (e.g., perturbation winds > mean winds and also > phase speed)
- Some of this difficult to capture in consistent models with fixed vertical structure (e.g., Sugiyama)
- Wind structure is reasonably represented by quasi-steady response to heating a la Gill

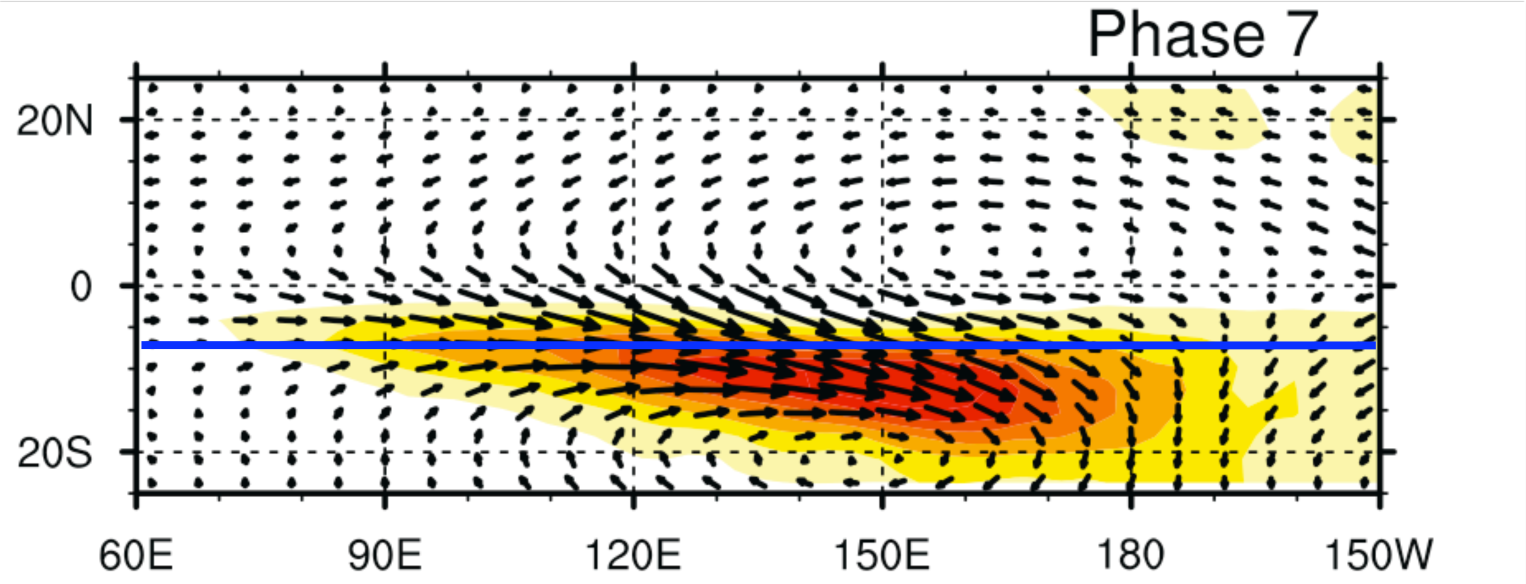
We construct an idealized, semi-empirical model to allow us to study these mechanisms and their interaction. We do not try to derive all key aspects from first principles or theory, but tune them to match obs or numerical model simulations (esp. Maloney et al. 2010)

We try to model the MJO as a quasi-stationary moisture mode propagated by advection and destabilized by WISHE and/or cloud-radiative feedback

# Moisture Modes

- A moisture mode (e.g., Sobel, Nilsson & Polvani 2001) is a balanced disturbance in which the large-scale dynamics are regulated by the weak temperature gradient approximation:
  $\omega \, \partial\theta/\partial p = Q$ (where Q is diabatic heating)
- Properties are strongly regulated by local interactions between convection and tropospheric moisture; $P \approx P(q)$, thus $Q \approx Q(q)$
- Essential dynamics of the mode involve processes that control the tropical moisture field, including latent heat flux and horizontal advection by a wind field that depends on Q, thus q
- Recent studies with reduced complexity models have hypothesized that that the MJO is a moisture mode (e.g. Raymond and Fuchs 2007, 2009; Sugiyama 2009).

Consider a 1D problem representing an equatorial or near-equatorial longitudinal slice – meridional structure is purely implicit



Composite precip and 850 hPa wind, Maloney et al. 2010

Vertically integrated equations for moisture and dry static energy, under WTG approximation

$$\frac{dW}{dt} - M_q\delta = E - P,$$
$$M_s\delta = P - R.$$

$\delta$ is upper tropospheric divergence. Add to get moist static energy equation

$$\frac{dW}{dt} = -\delta M + E - R,$$

Substitute to get

$$\frac{dW}{dt} = -\tilde{M}P + E - (1 - \tilde{M})R.$$

where $\tilde{M} = M/M_s$

is the “normalized gross moist stability”

Our physics is semi-empirical:

$$\tilde{M} = \tilde{M}(W),$$
$$P = P(W).$$

The functional forms chosen are key components of the model.
We do explicitly parameterize at this point

$R=R_0-rP$, with R_0, r constants.

Substituting into the MSE equation and expanding the total derivative,

$$\frac{\partial W}{\partial t} + u\frac{\partial W}{\partial x} = -\underbrace{[\tilde{M}(W)(1+r) - r]}_{\text{“effective” NGMS (including CRF)}}P(W) + E(|u|, W, T_s) - (1 - \tilde{M}(W))R_0.$$

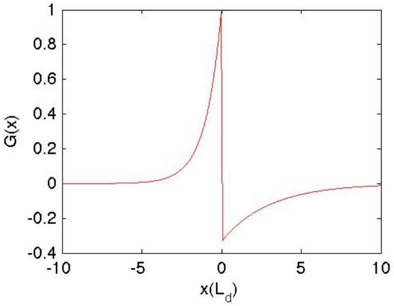
Here u is the zonal wind at a a nominal steering level for W, presumably lower-tropospheric. Surface evaporation is written as a function of wind, W, and SST (but we will make it even simpler).

To compute u, rather than solve momentum equations, we assume that we are looking at slow modes such that the wind is a quasi-steady response to heating, a la Gill model. Thus we compute it from a projection operator, functionally equivalent to a Green's function:

$$u(x,t) = \int G(x|x')P(x',t)dx'.$$

For example, if we were to compute G by taking a longitudinal cut along the equator from the Green's function for the Gill problem with forcing centered on the equator, we get

$$G(x|x') = -Ae^{-(x-x')/L}, \quad x > x',$$
$$G(x|x') = 3Ae^{3(x-x')/L}, \quad x < x',$$



With L a length scale dependent on equivalent depth and damping rate, and A a constant chosen to get similar relationship between u and P as in Maloney et al. (2010) simulations.

We parameterize P on W by an exponential (Bretherton et al. 2004):

$$P = \exp[a_d(R - r_d)],$$

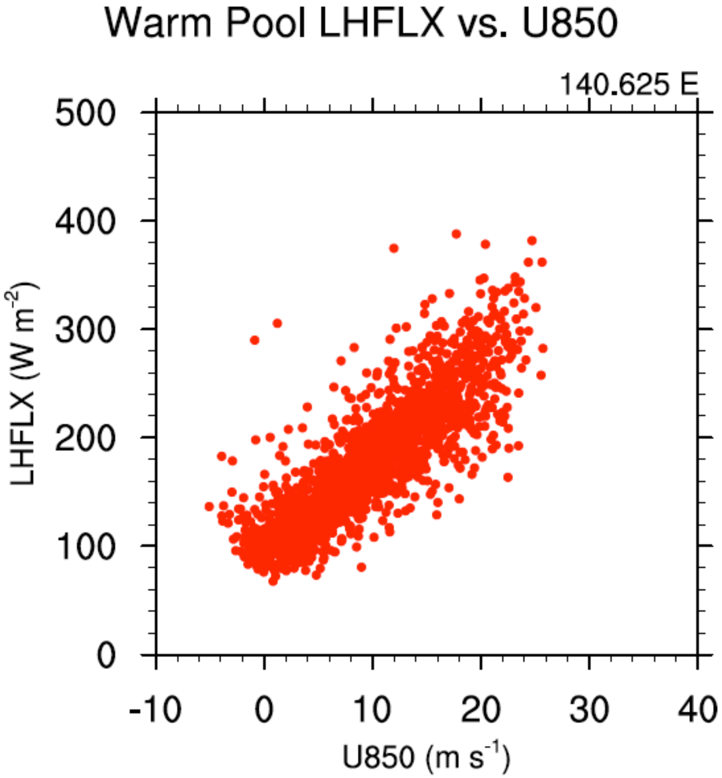
with, e.g., $a_d$=15.6, $r_d$=0.603, and R is the saturation fraction, R=W/W*. Here W*, the saturation column water vapor, is assumed constant as per WTG.

For starters, we will take the normalized GMS constant; later we will introduce a more complex parameterization.

Rather than use a bulk formula for E, we go directly to the simulations of Maloney et al. A scatter plot of E vs. $U_{850}$ in the model warm pool yields the parameterization

$$E = 100 + 7.5u$$

With E in W/m^2 and u in m/s.
Note there is no dependence on W or SST; this amounts to assumptions that SST is constant (one giant warm pool) and E depends much more on wind speed than on air humidity.
In practice it assures that simple model does not have very different wind-evaporation feedback than the GCM.

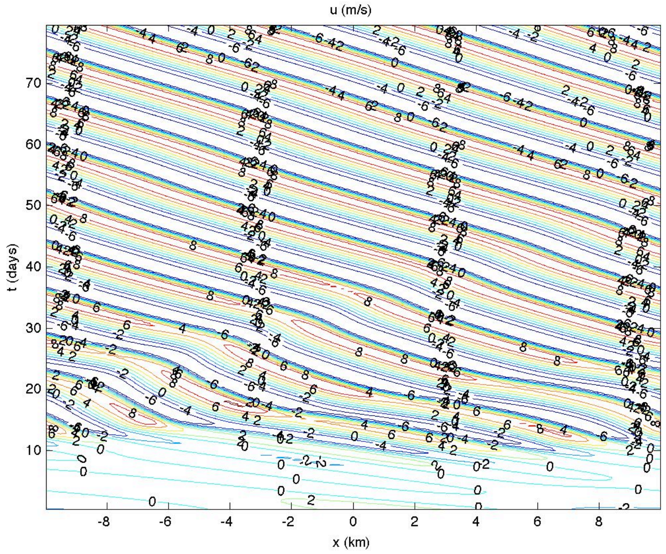


# Model specifications

- 1D domain 20 equatorial deformation radii (~30,000 km) long, periodic boundaries
- Background state is uniform zonal flow – **eastward at 5 m/s**; perturbation flow is added to it for advection and surface fluxes.
- Don’t have explicit SST - flux is function of wind only
- In simulations shown below normalized GMS=0.1, CRF feedback factor=0.02 – these factors largely control stability
- Saturation W=65 mm
- Currently under investigation but not shown: variable GMS

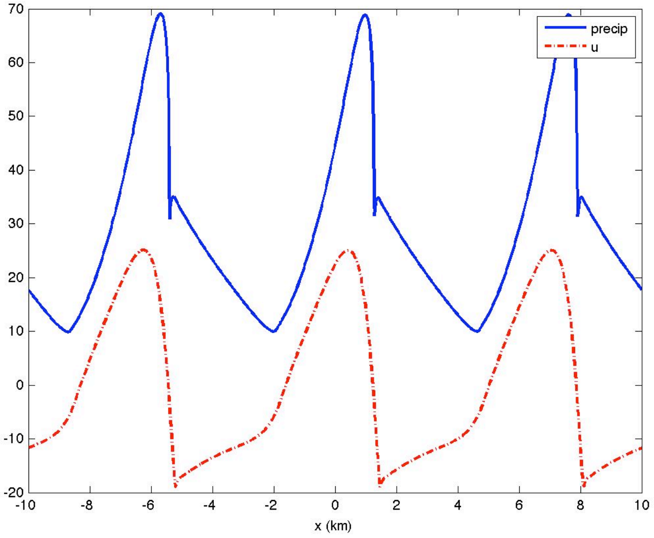
# With NGMS=0.1, r=0.02, L=1500 km, mean eastward flow of 5 m/s, get westward WISHE mode.

Hovmoeller of u



longitude->

snapshot of u, p

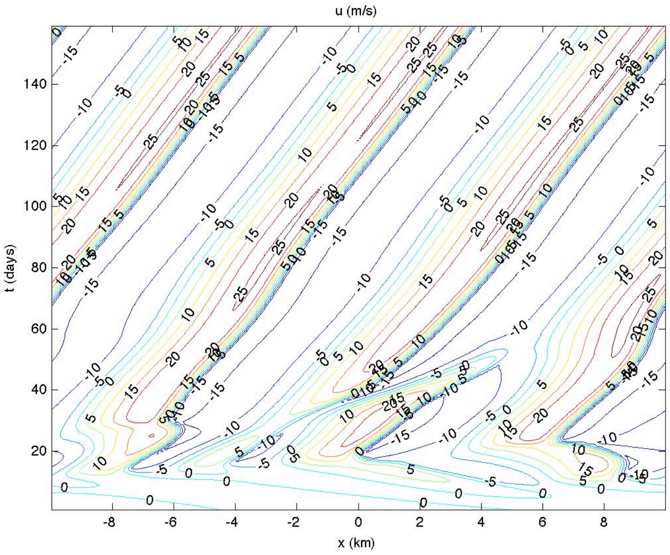


longitude->

# Shift projection function for u 10 grid points (300 km) eastward, get slow eastward (~1.5 m/s) WISHE mode. Still westward relative to mean flow.

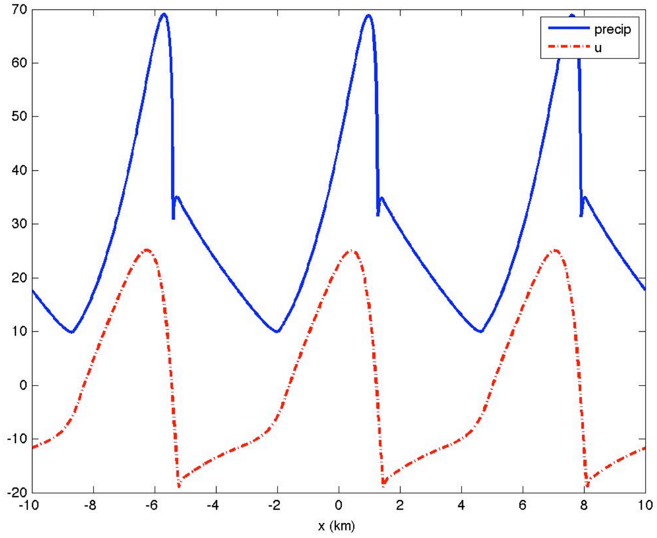
Hovmoeller of u

time->



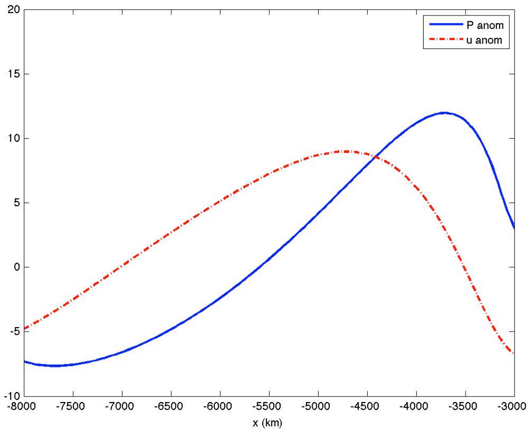
longitude->

snapshot of u, p

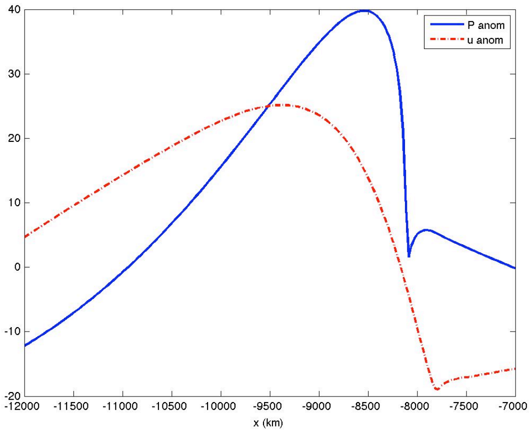


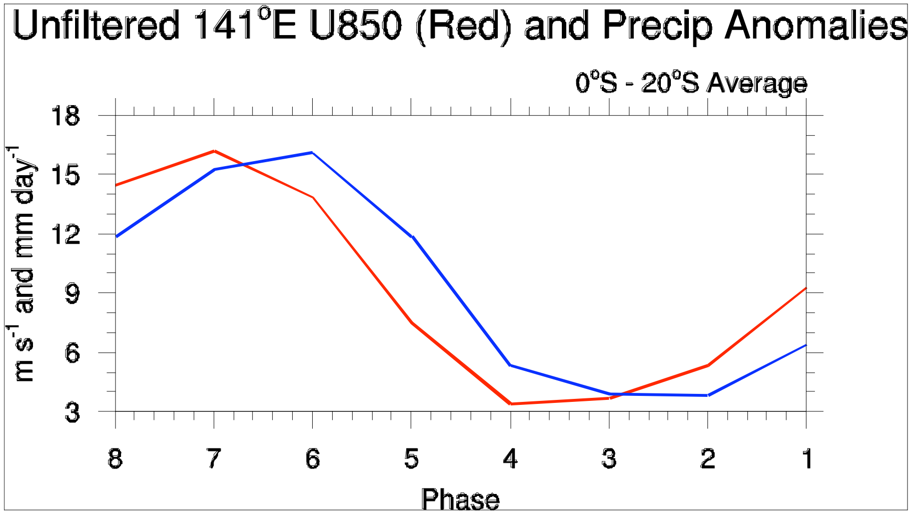
longitude->

Precip and wind anomalies, no shift in G (Gill model)



With 300 km eastward shift

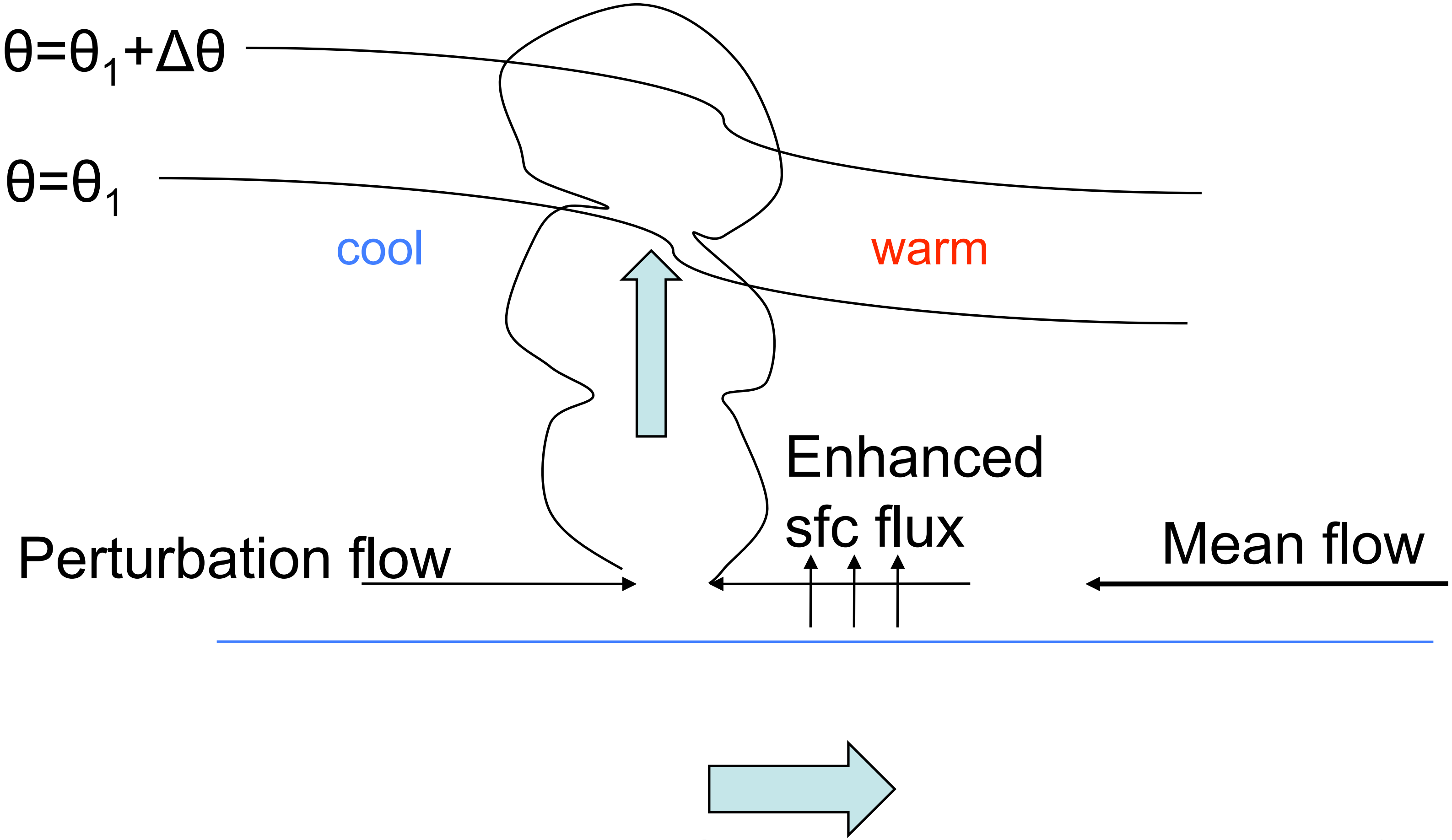




Maloney et al. 2010 GCM

# Again: Kelvin wave driven by surface flux feedbacks

(Emanuel 1987, Neelin et al. 1987)



$\theta=\theta_1+\Delta\theta$

$\theta=\theta_1$

cool

warm

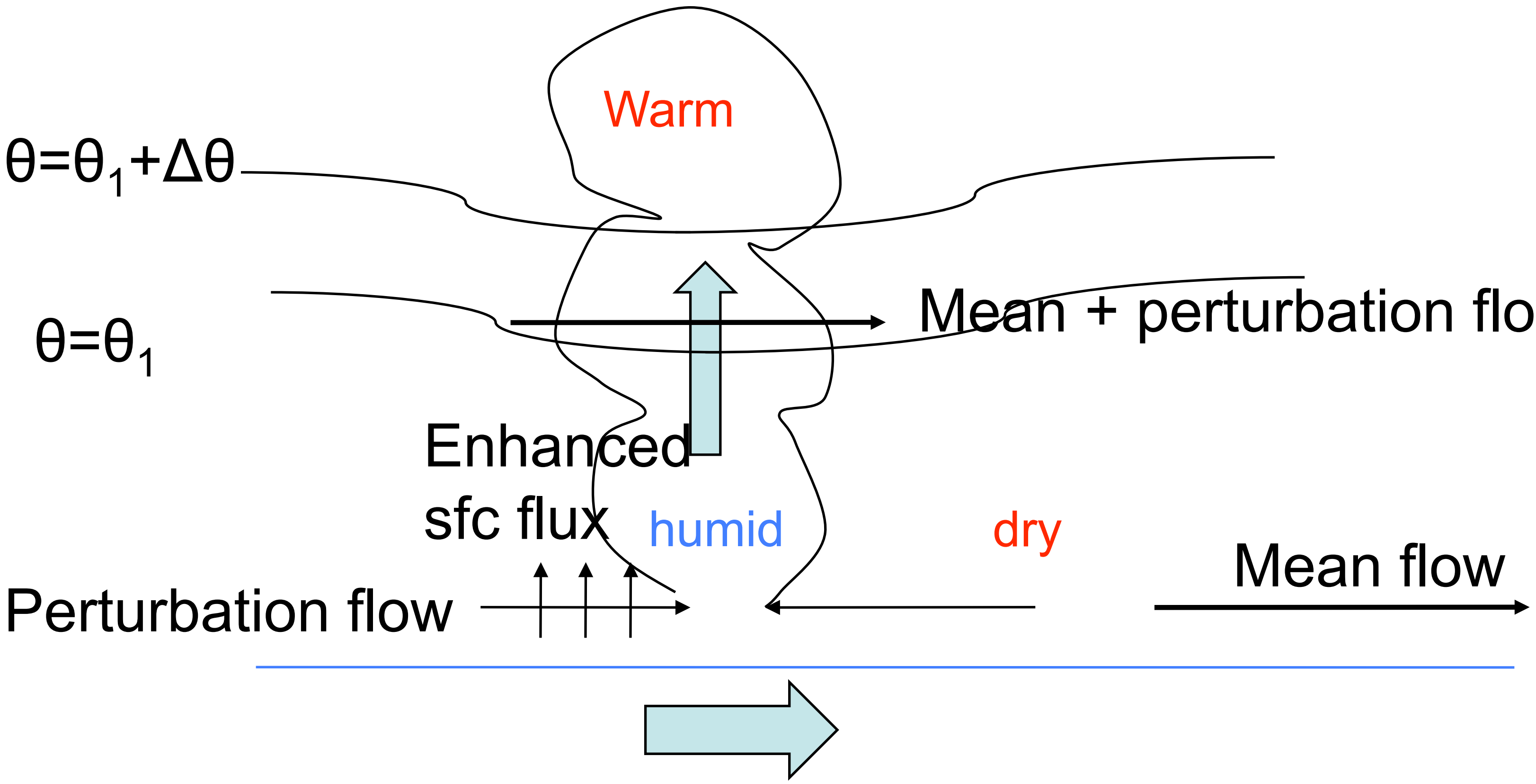
Enhanced sfc flux

Perturbation flow

Mean flow

Wave propagation (via gravitational restoring force)

## Instead we propose a moisture mode driven by surface flux feedbacks



Warm

$\theta=\theta_1+\Delta\theta$

Mean + perturbation flow

$\theta=\theta_1$

Enhanced sfc flux

humid

dry

Mean flow

Perturbation flow

Disturbance propagation (via horizontal advection +?)

Maloney, Sobel & Hannah, *J. Adv. Model. Earth Sys. –D*, 2010

This semi-empirical model is not a complete theory for the MJO (certainly not yet). It is a framework within which the consequences of a number of other ideas can be explored.

Key parameters:

The gross moist stability

The quasi-steady wind response to a delta function heating (G) –
fine-scale details matter!

The relevant steering level for moisture advection and the relationship
of wind at this level to surface fluxes

Cloud-radiative feedback