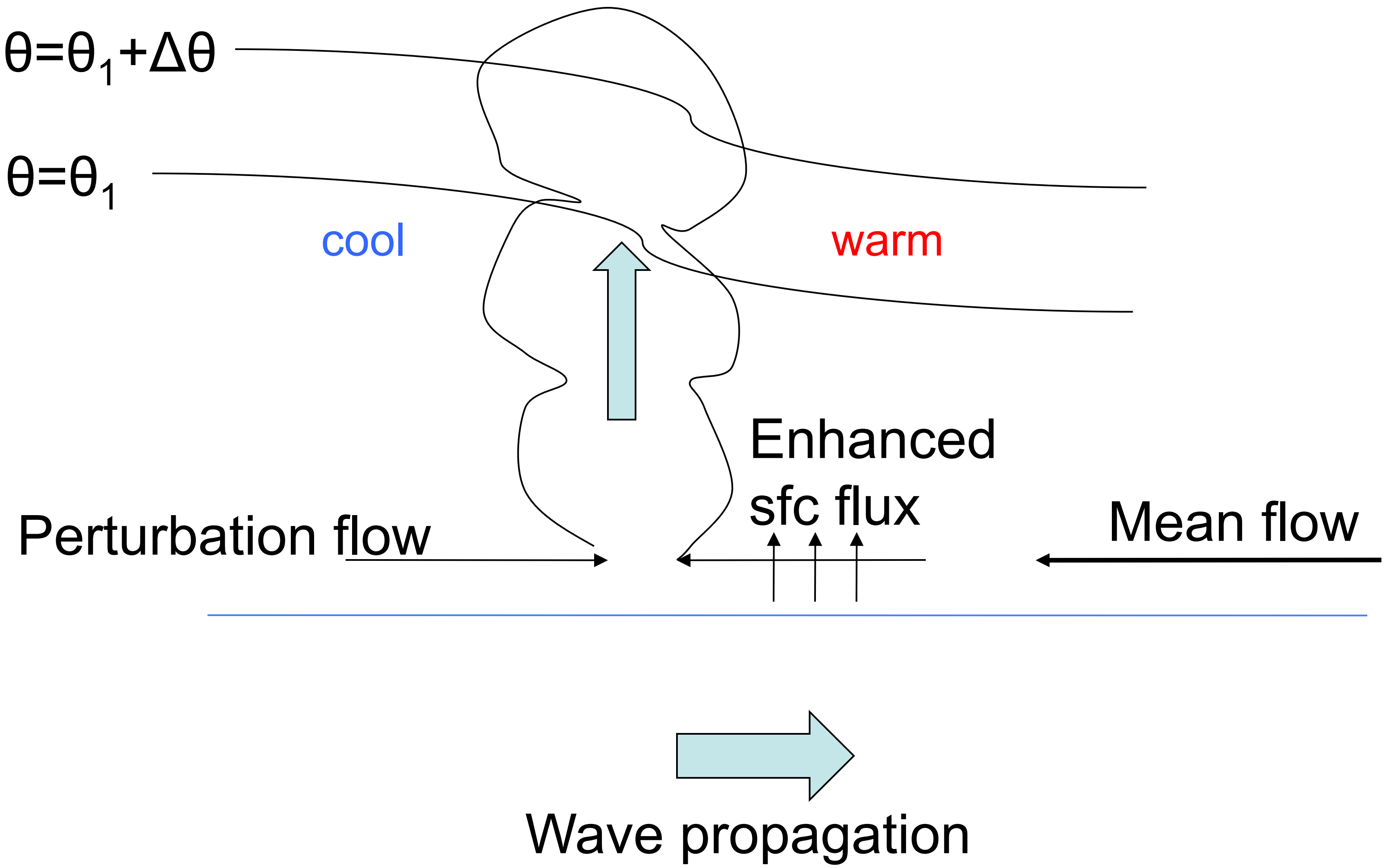
WISHE modes in westerlies

Adam Sobel (Columbia)
Eric Maloney (Colorado State)
(thanks D. Frierson, G. Bellon)

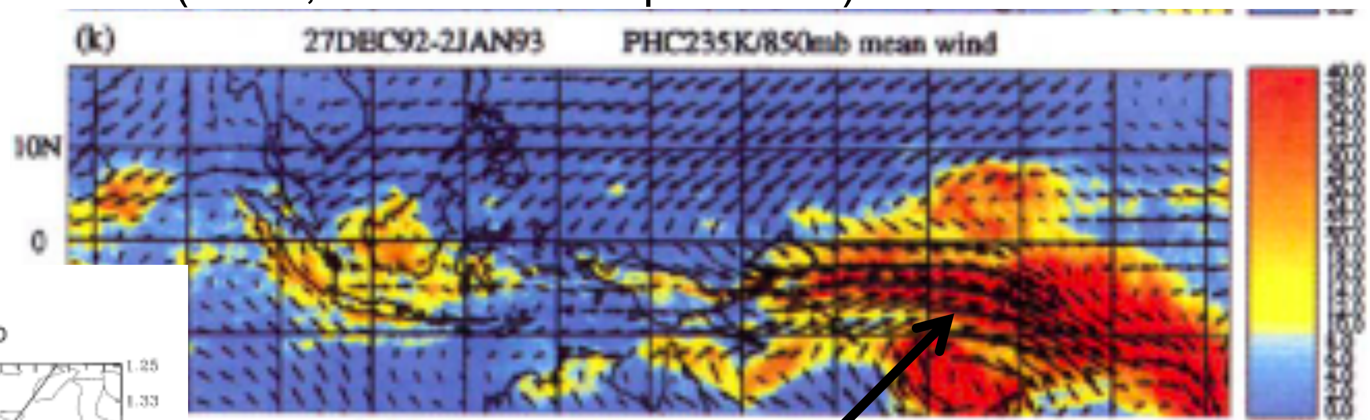
Busan, Korea
June 16 2010

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

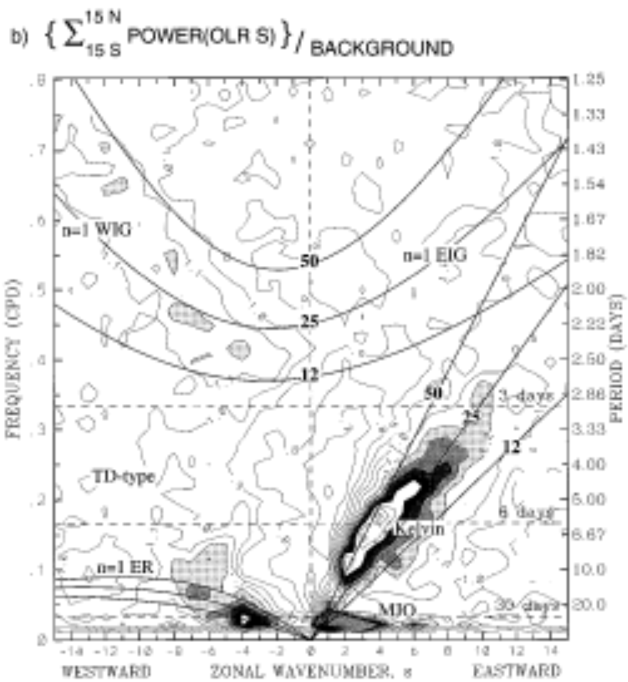


This idea was somewhat abandoned because the real MJO does not look quite like the original WISHE theory

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



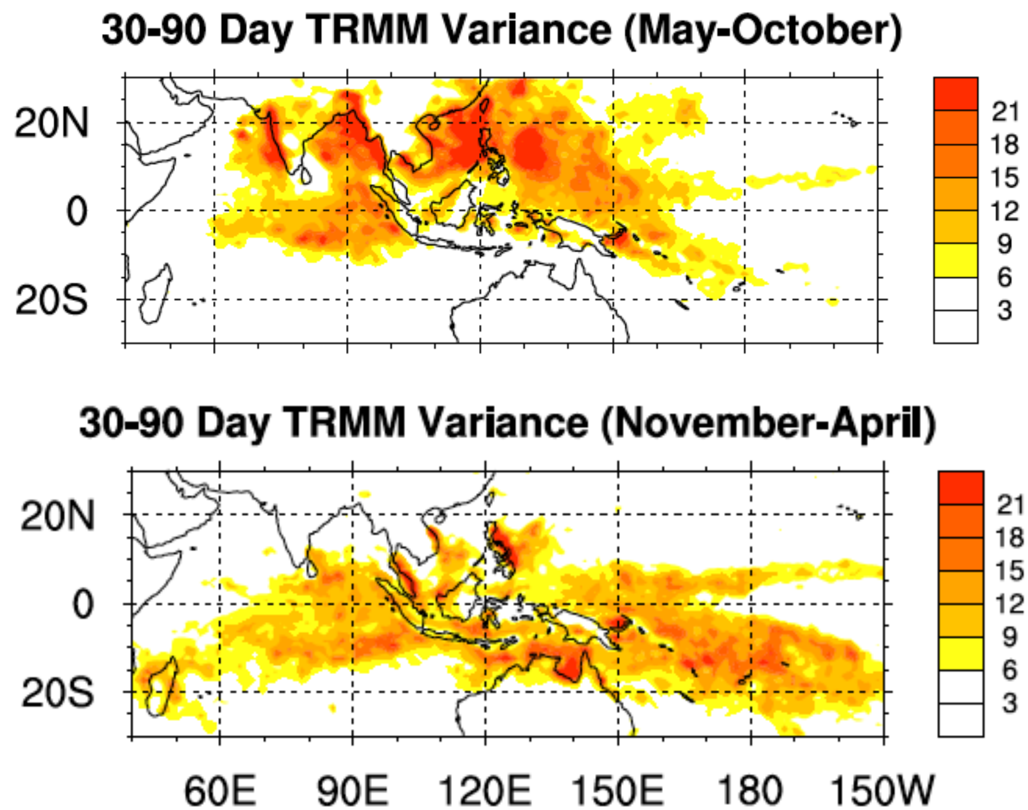
Strongest winds and fluxes are in phase with or lag precipitation, and lie in westerlies



Frequency-wavenumber OLR plot (Wheeler and Kiladis 1999)

Intraseasonal variance of rainfall shows land-sea contrast; this implies that (total) surface flux is important

Intraseasonal rain variance

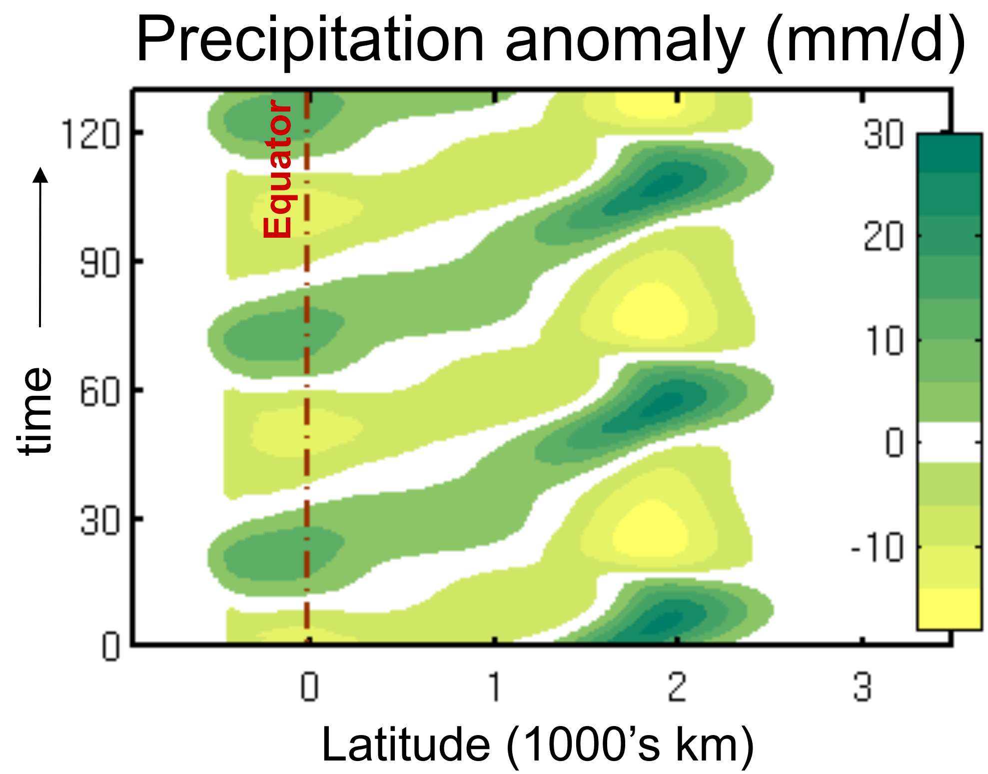


Northern Summer

Southern Summer

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

Briefly about northward propagation: we have a "simple" axisymmetric model which produces it robustly



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

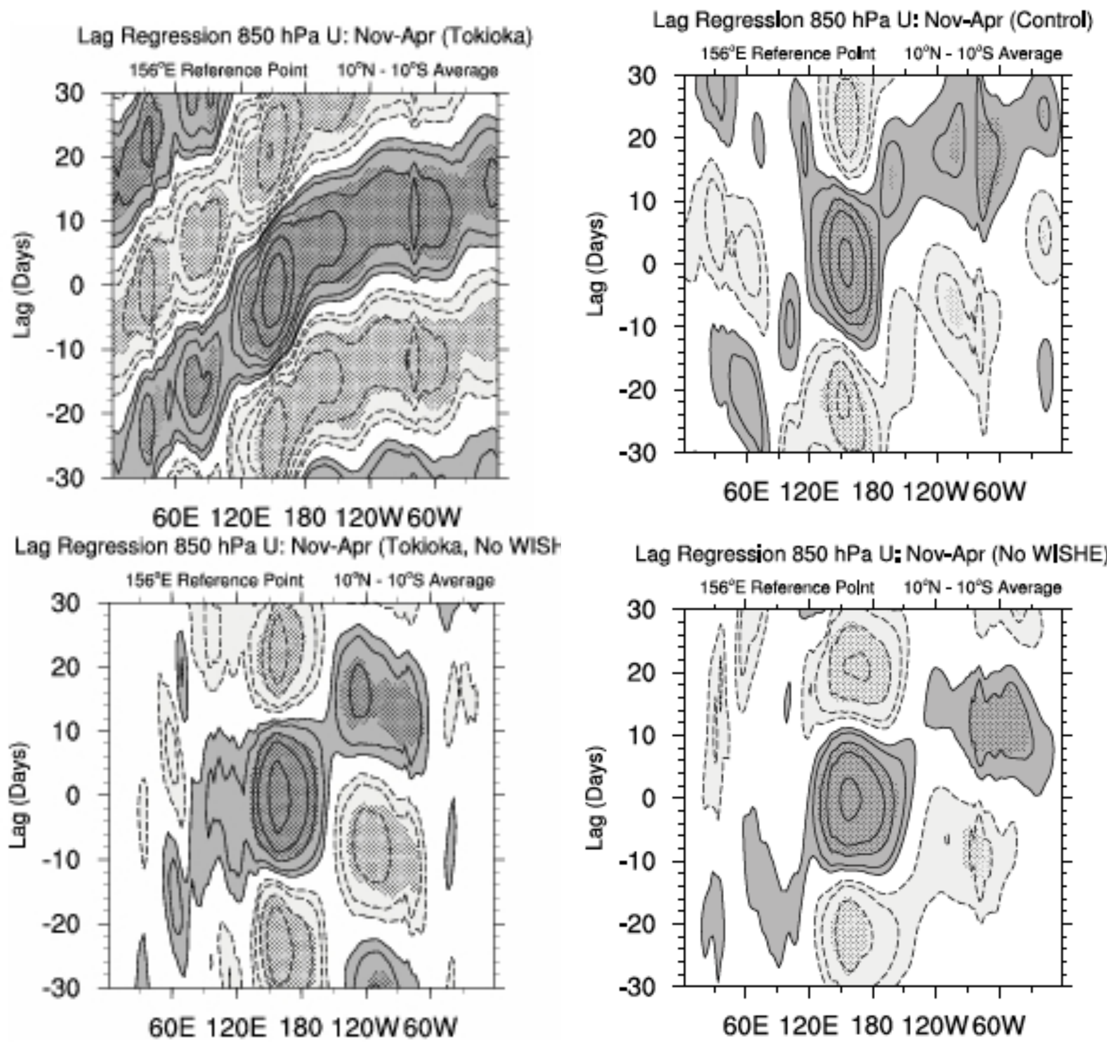
Bellon and Sobel 2008, *J. Atmos. Sci.*, **65**, 470-489.

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

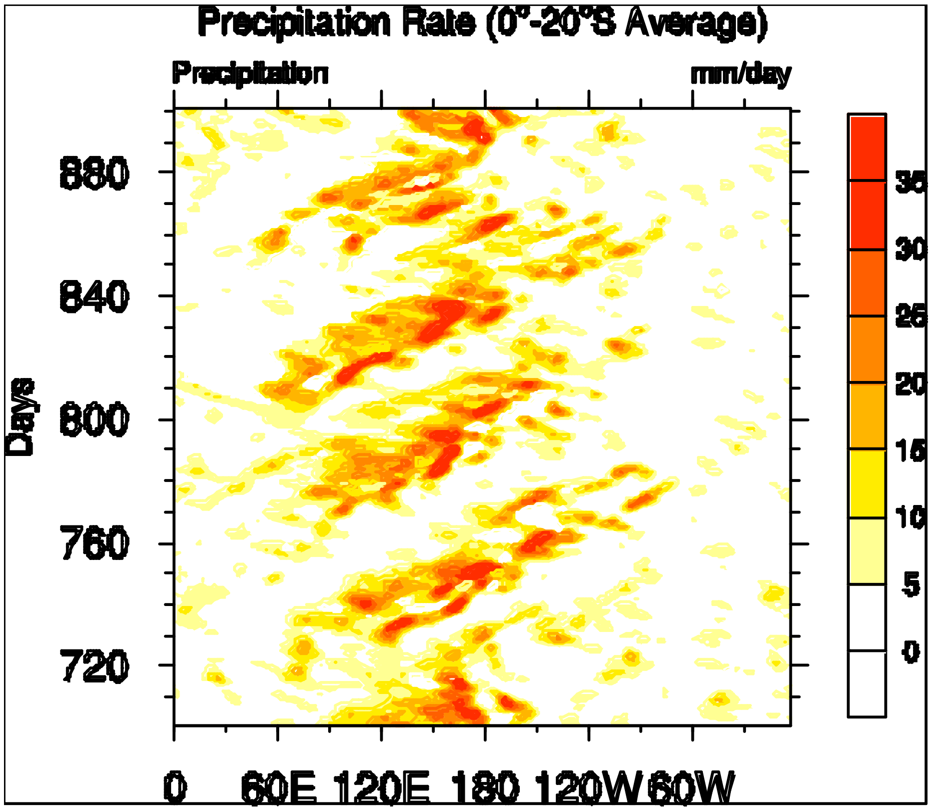


better model

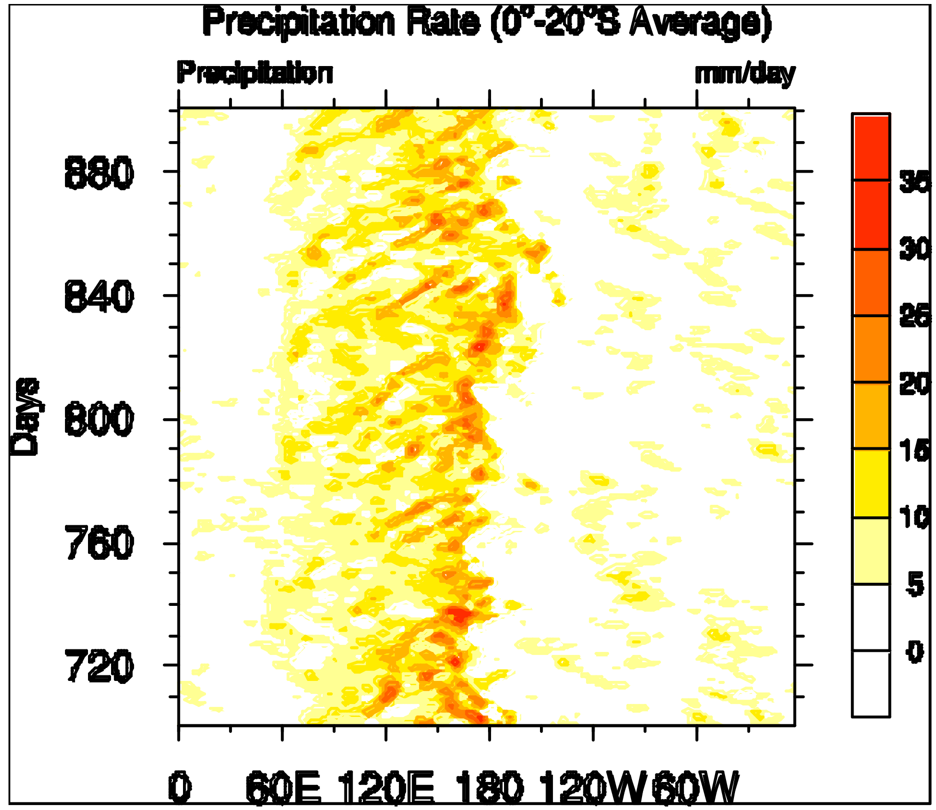
worse model

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

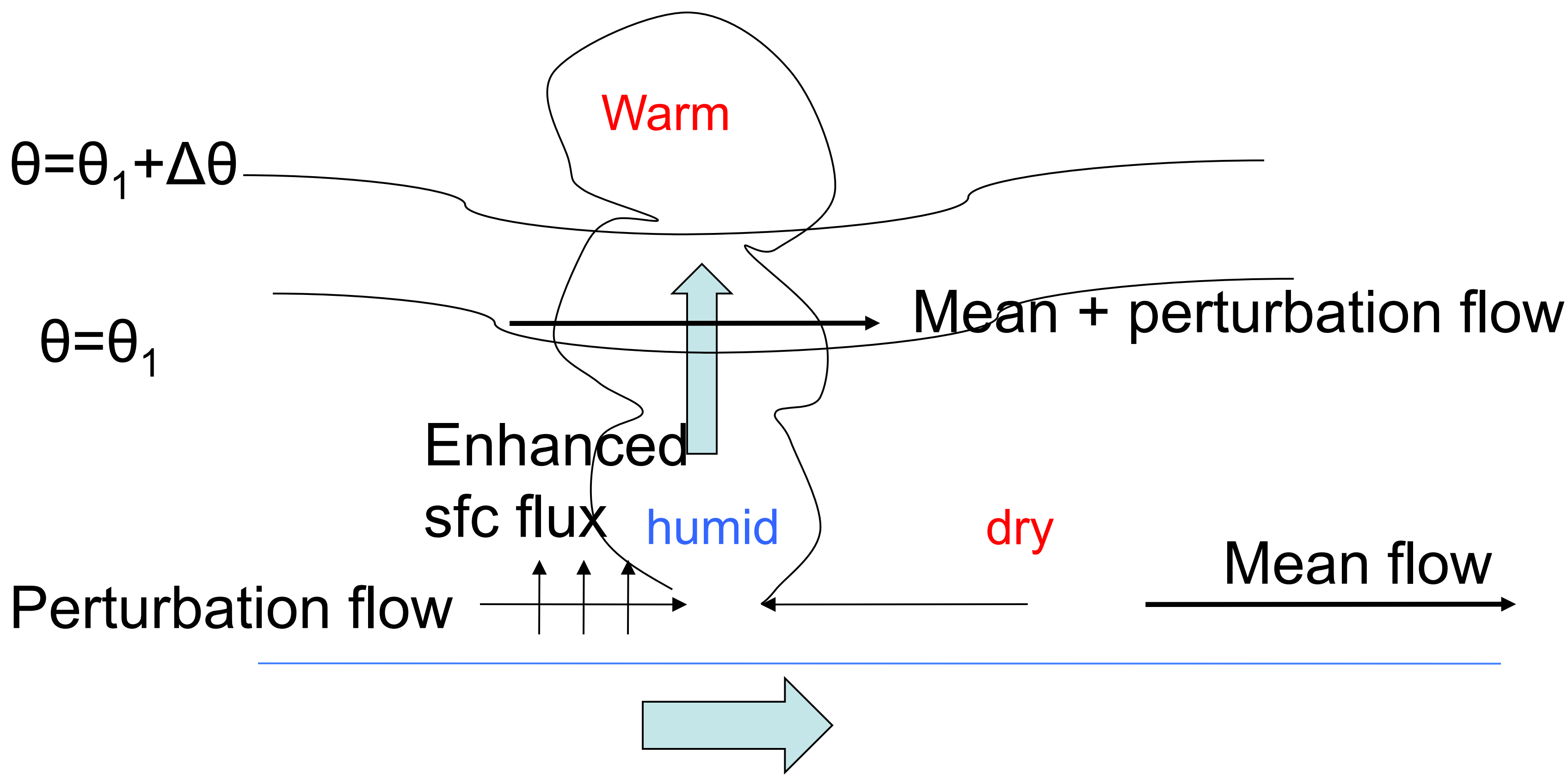
- Evidence from obs & models that sfc fluxes (& radiation) are important to destabilization
- Evidence from models for both fluxes and gross moist instability (e.g., Raymond & Fuchs)
- Nonlinearity may be important (e.g., perturbation winds > mean winds and also > phase speed)
- Some of this difficult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

We construct an idealized, semi-empirical model framework. We do not try to derive all key aspects from first principles, but tune them to obs or numerical model simulations.

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

A number of different theories can be fit in this framework.

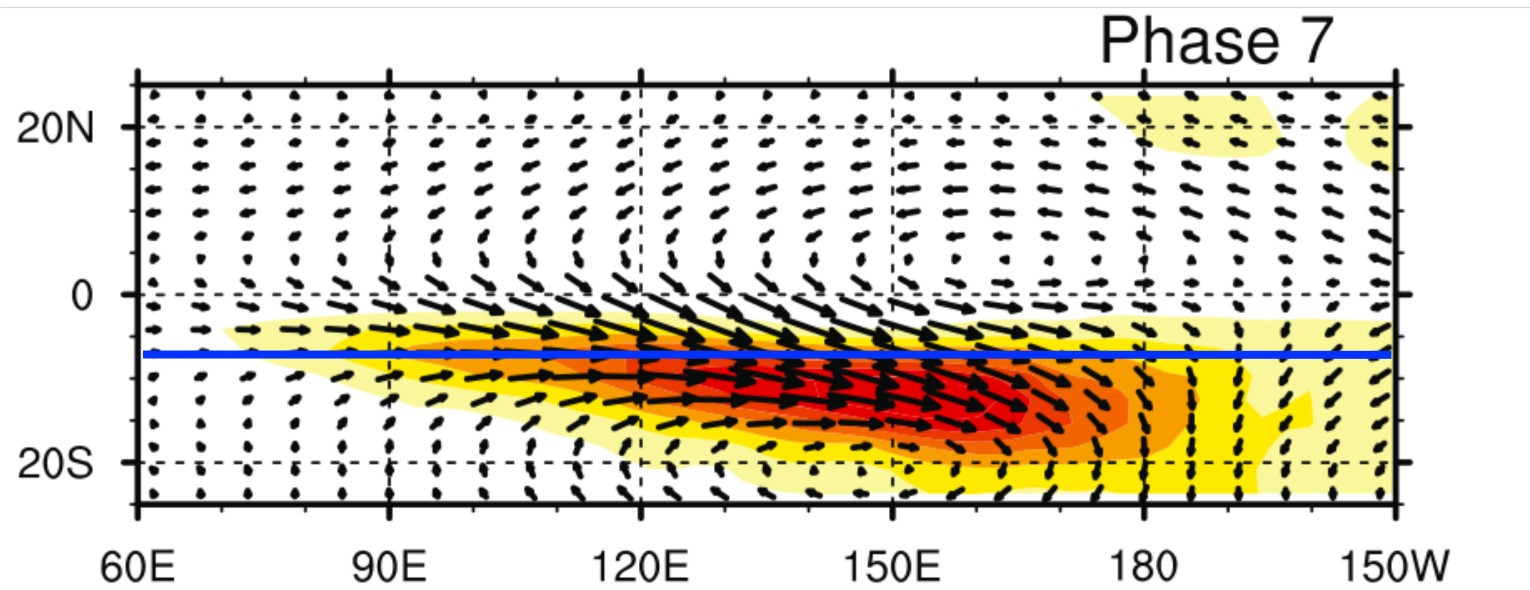
Schematically:



Disturbance propagation (via horizontal advection +?)

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

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

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

± 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 - and hide much implicit vertical structure.
We do explicitly parameterize at this point

$R = \max(R_0 - rP, 0)$ with R_0, r constants.

Substituting into the MSE equation and expanding the total derivative,

$$\frac{\partial W}{\partial t} + u\frac{\partial W}{\partial x} = -[\tilde{M}(W)(1+r) - r]P(W) + E(|u|, W, T_s) - (1 - \tilde{M}(W))R_0.$$

"effective" NGMS (including cloud-radiative feedback)

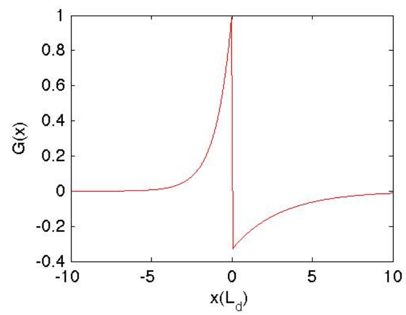
u is the zonal wind at a a nominal steering level for W, presumably lower-tropospheric.

To compute u, rather than solve momentum equations, we assume the wind is a quasi-steady response to heating. Thus we compute it from a projection operator:

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

For example, if we were to compute *G* by taking a longitudinal cut along the equator for a delta function forcing in the Matsuno-Webster-Gill Problem with forcing centered on the equator, we get

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



L depends on equivalent depth and damping rate.

Sometimes, we cheat and shift *G* relative to forcing by a small amount. (in reality details sensitive to nonlinear advection, CMT…)

Model is 1D, we do *not* assume that the divergence = ∂u/∂x. (there is implicit meridional structure, ∂v/∂y ≠ 0)

Relatedly, the mean state is not assumed to be in radiative-convective equilibrium. Rather it is in weak temperature gradient balance. Zonal mean precip is part of the solution.

$$\frac{\partial W}{\partial t} + u\frac{\partial W}{\partial x} = -[\tilde{M}(W)(1+r) - r]P(W) + E(|u|, W, T_s) - (1 - \tilde{M}(W))R_0.$$

We parameterize precipitation on saturation fraction by an exponential (Bretherton et al. 2004):

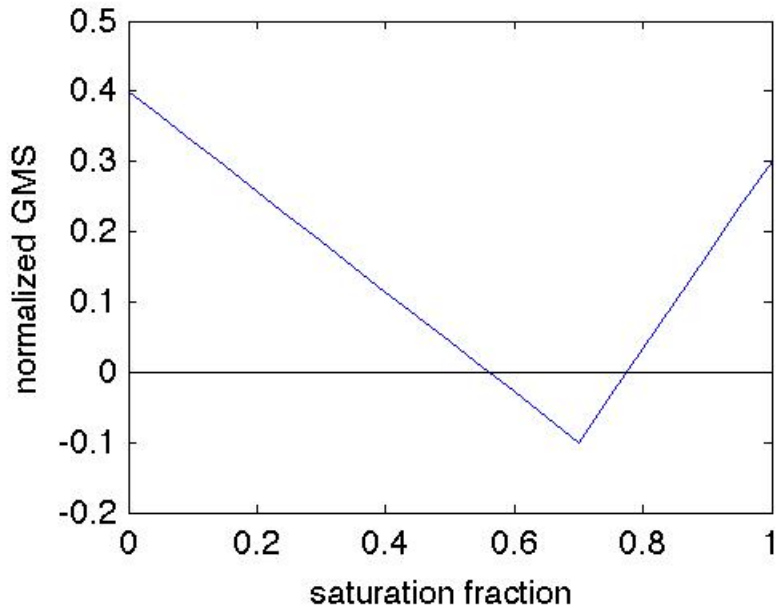
$$P = \exp[a_d(R - r_d)],$$

(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.

We represent the normalized GMS either as a constant or as a specified function of W. NGMS is very sensitive to vertical structure and so the most important (implicit) assumptions about vertical structure are buried here.

We represent the normalized GMS either as a constant or as a specified function of W. NGMS is very sensitive to vertical structure and so the most important (implicit) assumptions about vertical structure are buried here.

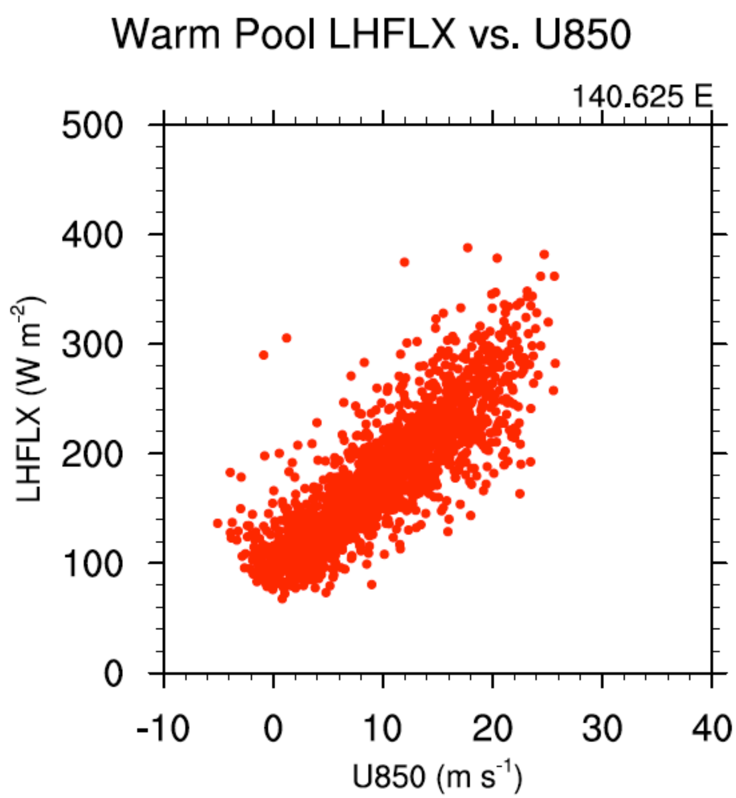
E.g., consider an NGMS which is negative over a narrow range of saturation fraction:



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

$$E = 100 + 7.5u$$

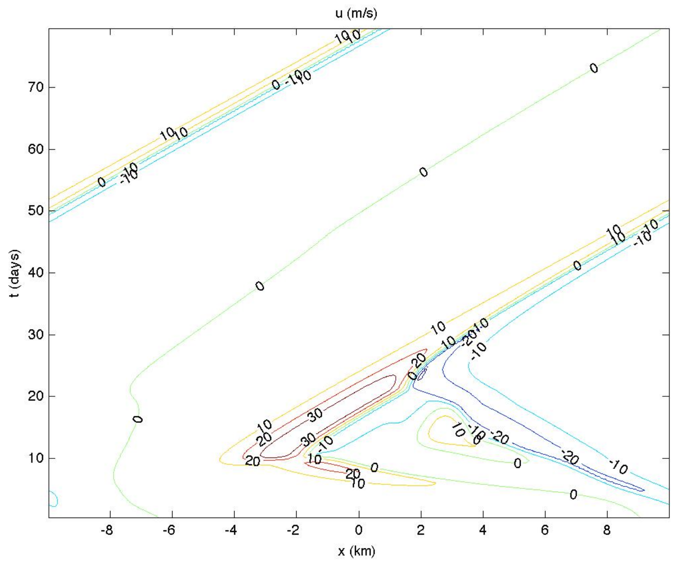
With E in W/m^2 and u in m/s. Note there is no dependence on W or SST. In practice it assures that simple model does not have very different wind-evaporation feedback than the GCM.



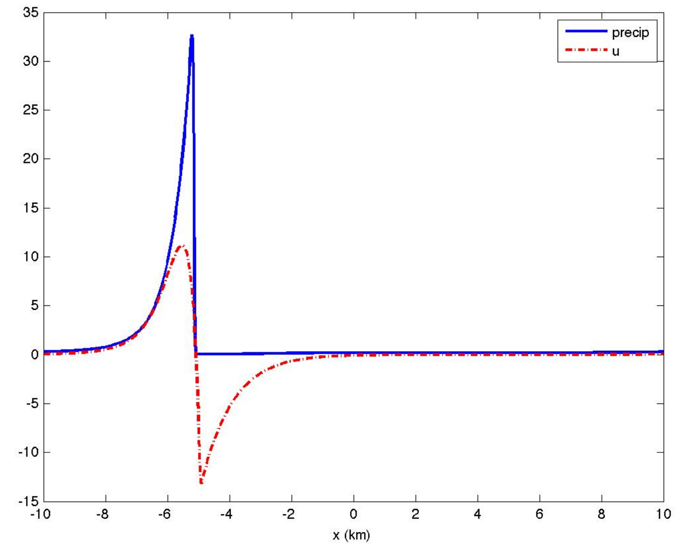
Model configuration details

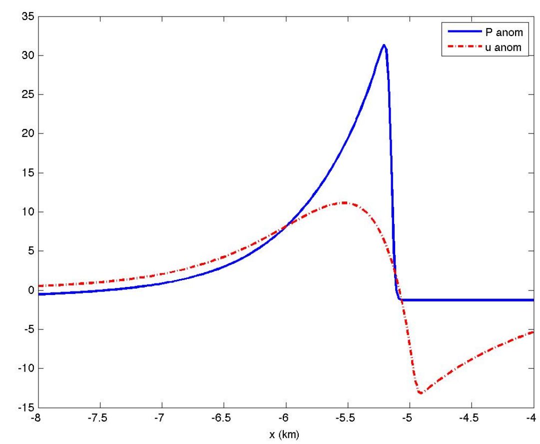
- 1D domain 20 equatorial deformation radii (~30,000 km) long, periodic boundaries
- Background state is uniform zonal flow – **eastward at 5 m/s**; perturbation flow is added to it for advection and surface fluxes.
- In simulations shown below NGMS as shown above; CRF=0.1; W_{sat}=70 mm; these factors largely control stability

Eastward propagation



Snapshot of precip and zonal wind

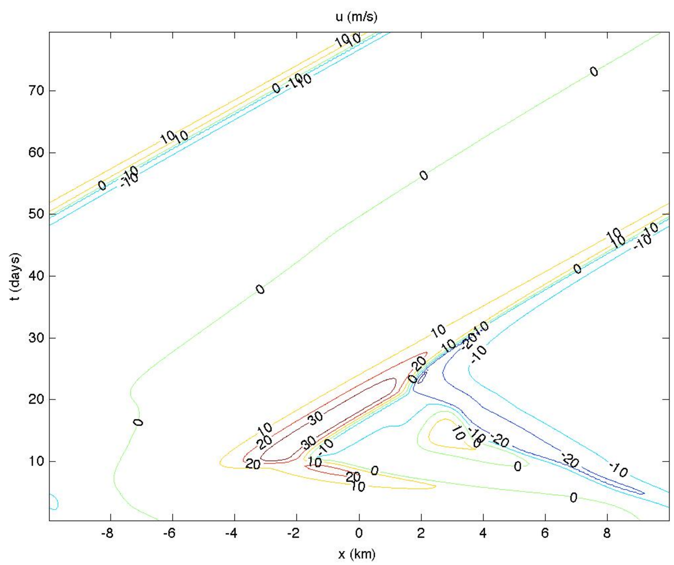




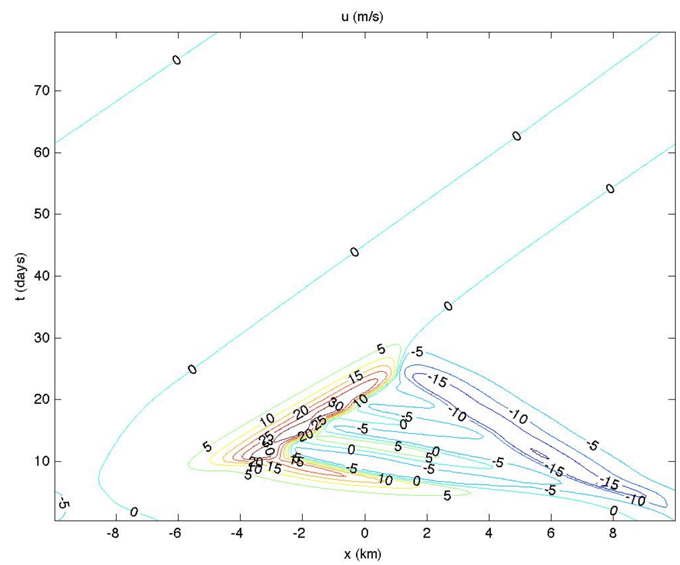
But we cheated! Shifted G forward 300 km relative to forcing .

If we don't do that, eastward propagating disturbance is not sustained.

shift



no shift



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.

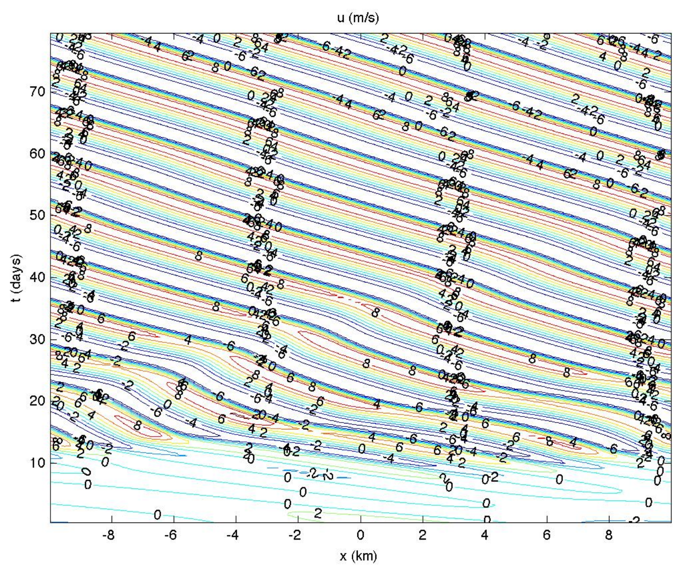
Key parameters:

- The gross moist stability
- Cloud-radiative feedback
- Mean state – zonal wind and mean rainfall/divergence
- The quasi-steady wind response to a delta function heating (*G*) – very sensitive to small longitudinal shifts!
- Precip as function of saturation fraction

These can all in principle be derived from/tuned to diagnostics of global models. This is an explicitly hierarchical modeling approach.

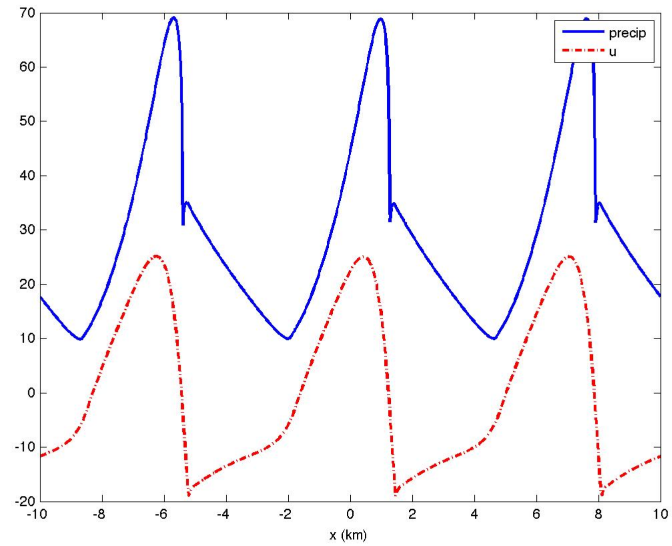
With NGMS=0.1, r=0.02, L=1500 km, mean eastward flow of 5 m/s, get westward WISHE mode.

Hovmoeller of u



longitude->

snapshot of u, p

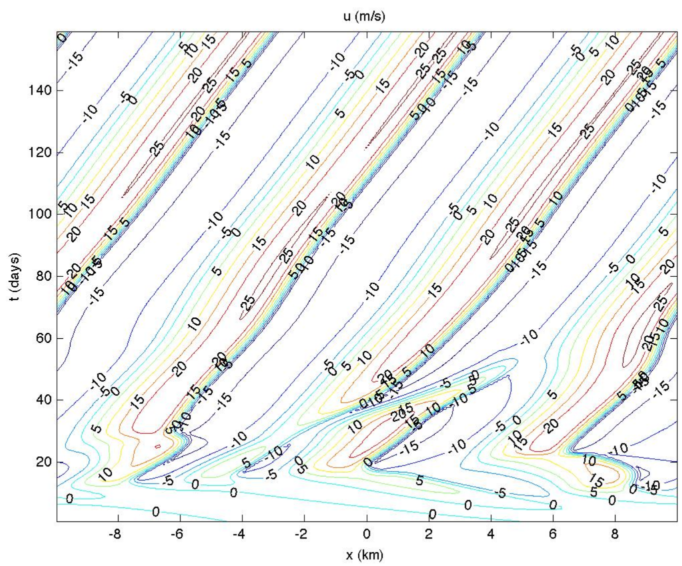


longitude->

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.

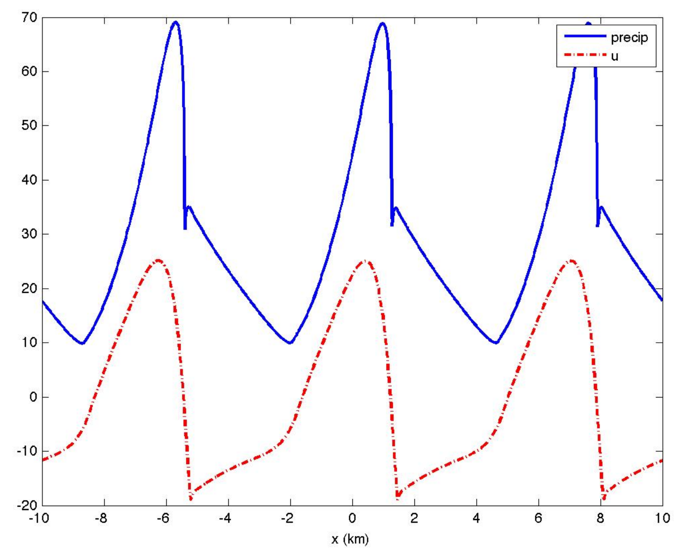
Hovmoeller of u

time->



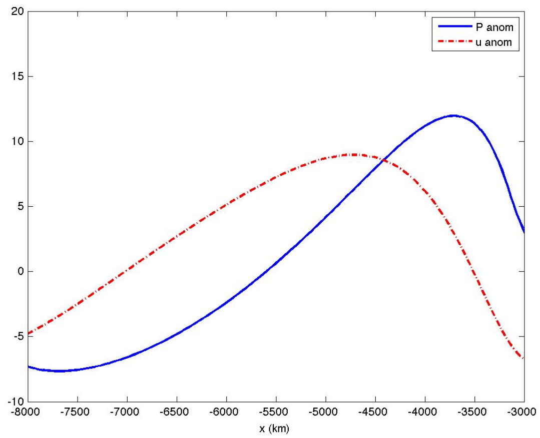
longitude->

snapshot of u, p

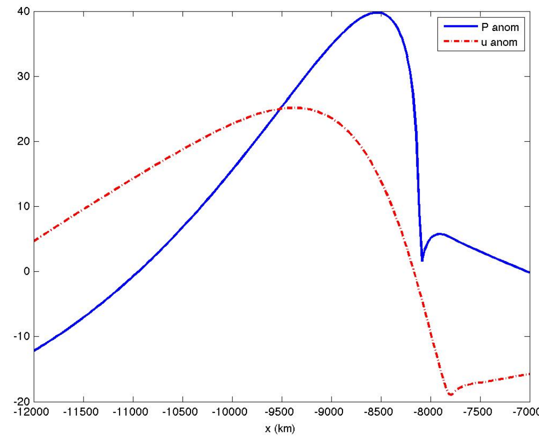


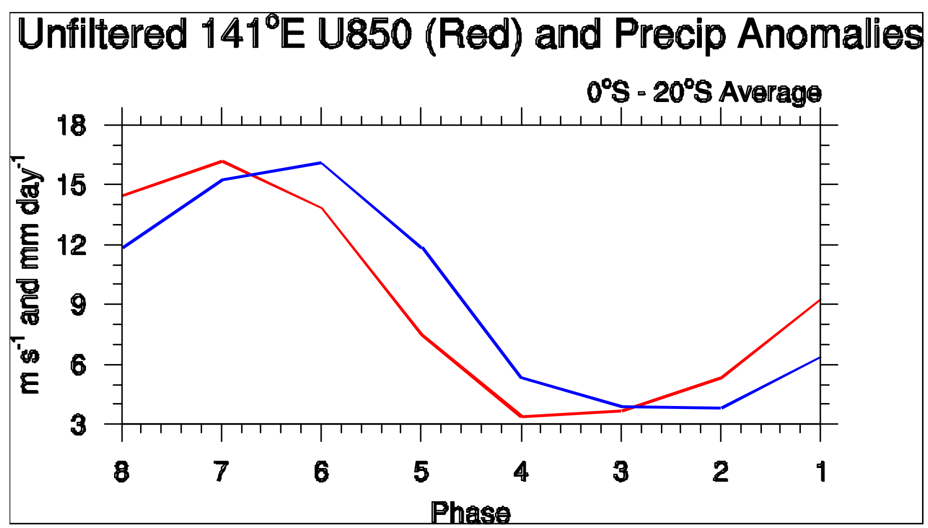
longitude->

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



With 300 km eastward shift





Maloney et al. 2010 GCM