A DARE approach for 3D cloud-resolving simulations of large-scale atmospheric circulation

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Global CRMs are expensive!

and not everybody has an Earth Simulator…

The Multiscale-Modeling Framework for reducing the computational cost

- Cloud-resolving convective parameterization, or super parameterization *Grabowski, 2001*
- A sparse net of 2D CRM (Quasi-3D) *Arakawa, 2004*

Diabatic Acceleration and REscaling (DARE)

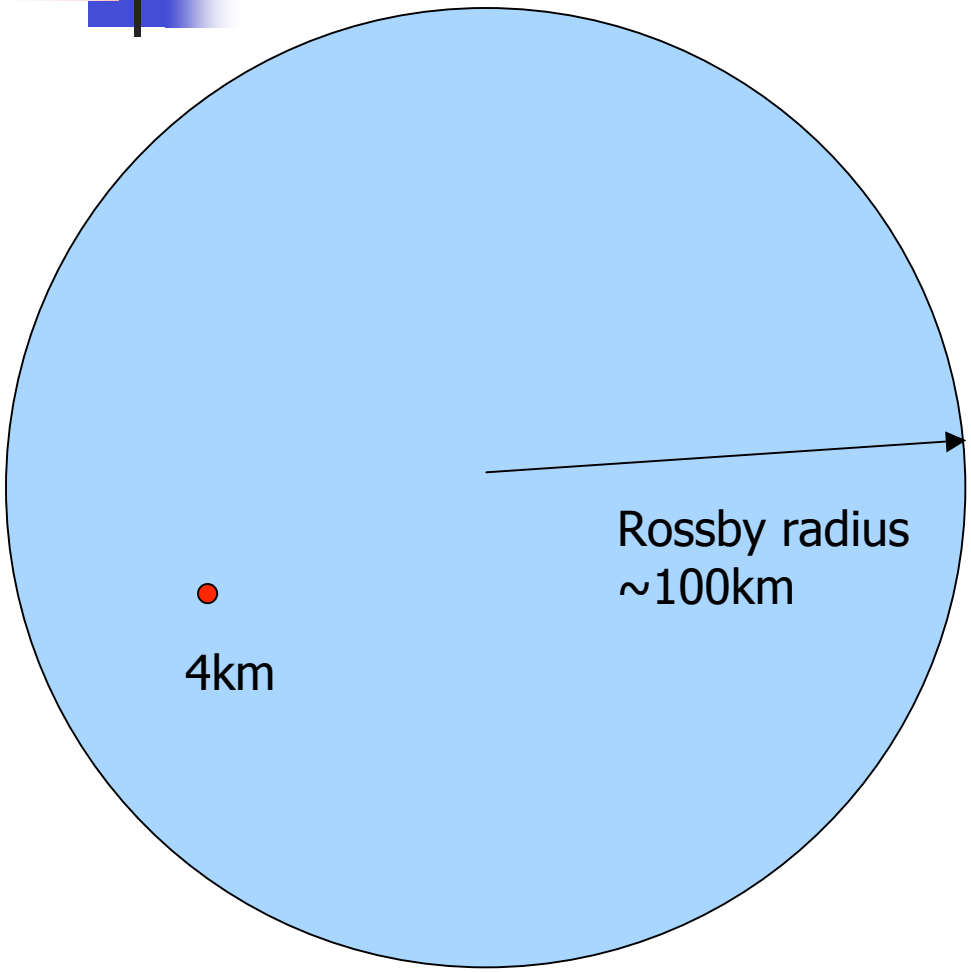
Kuang, Blossey, Bretherton, GRL, 2005

Define the DARE factor $\gamma > 1$

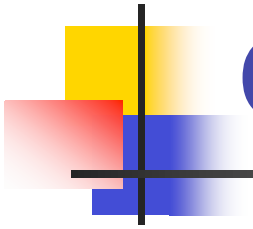
- **1. Accelerate all diabatic processes by a factor of γ**
- **2. Reduce Earth's size and increase its rotation rate by the same factor**

Motivation: reduce the scale separation between the Rossby scale (~1000km) and the cumulus scale (a few km)

A miniature planet γ=10
(saves a factor of ~500 in computation)



- Assume interactions between the cumulus scale and the Rossby scale remain similar, if the two remain well separated.
- No artificial scale break
- Equations for large scale hydrostatically balanced motions unmodified

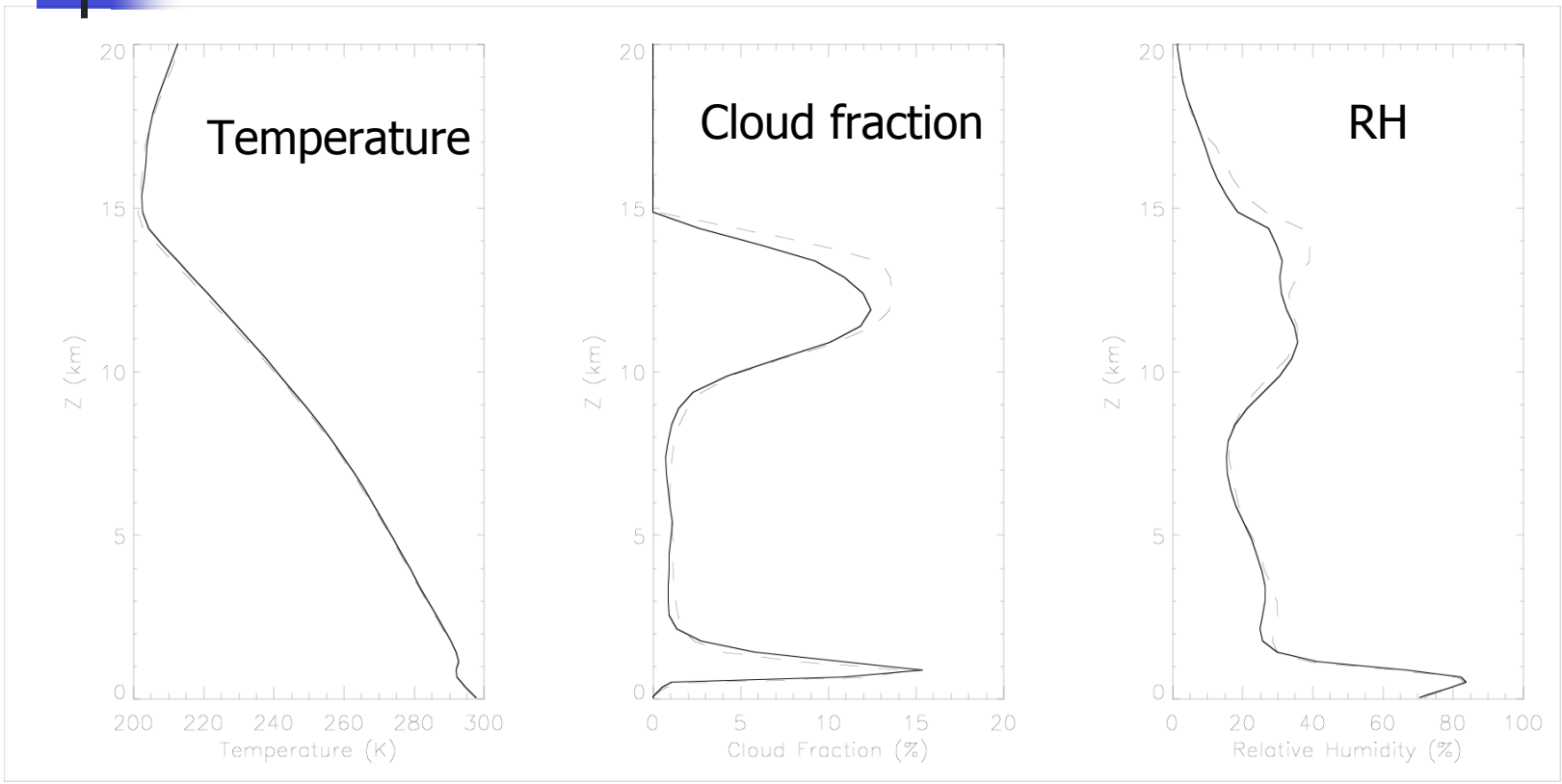


On the small (convective) scale:

- Turbulence is modeled as usual
- Convection is driven more strongly.
- Can diabatically accelerated convection:

1. produce reasonable atmospheric profiles?
2. reproduce the response to large-scale external forcing γ times faster?

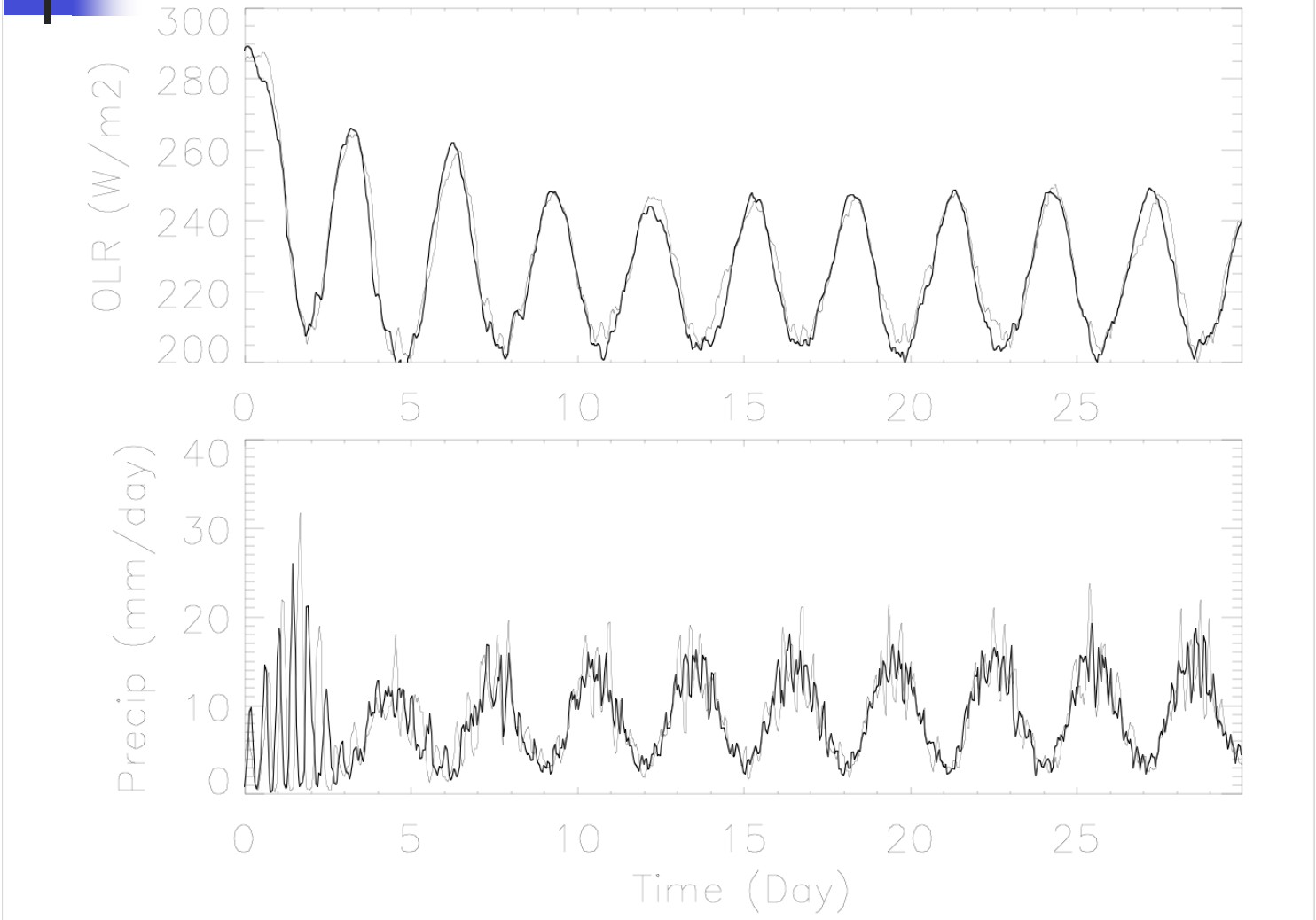
Test I: radiative-convective equilibrium profiles



Control DARE4

dx=3km, nx=ny=192(control),48(dare)
using SAM by Marat Khairoudinov

Test II:
Response to external forcing



An alternative interpretation: RAVE (Rescaling of Acceleration in the VErtical)

$$\gamma^2 \frac{Dw}{Dt} = -\frac{\partial p'}{\rho \partial z} + B$$

Plus modified SGS model

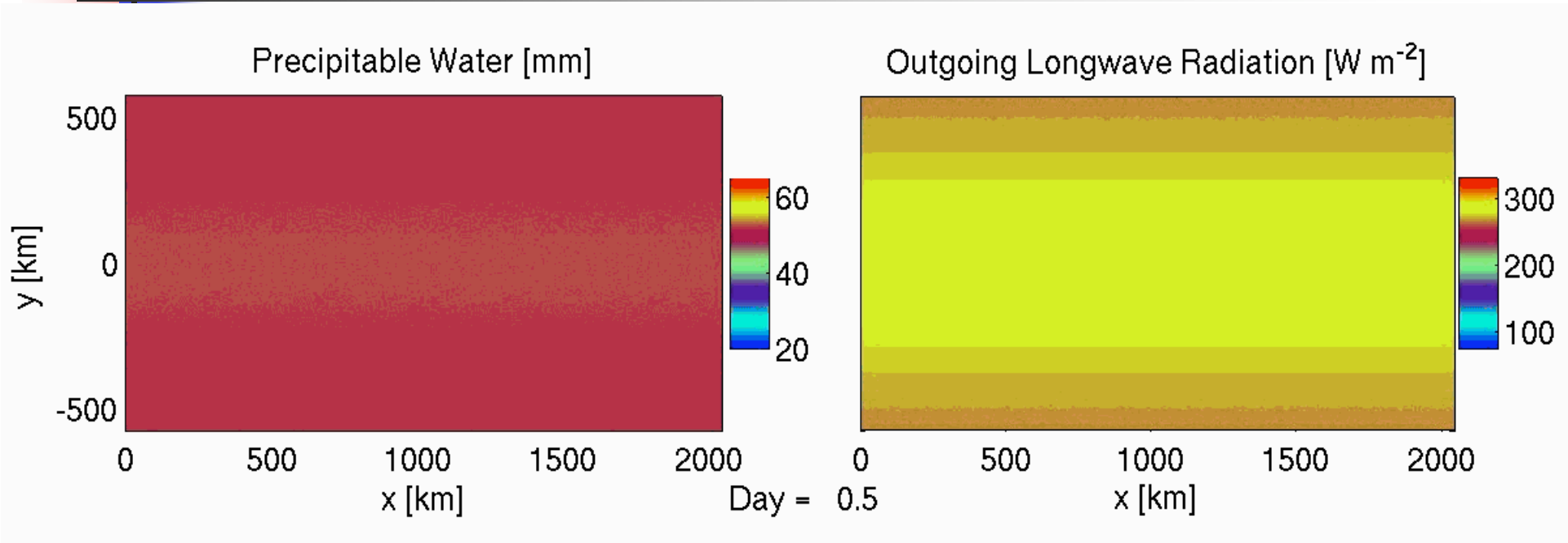
- γ=0 hydrostatic approximation

  γ=1 normal, γ>1: DARE/RAVE
- Hydrostatic motions unmodified
- Can be also viewed as reducing gravity and increasing Z. $\frac{D\gamma w}{Dt} = -\frac{\partial p'}{\rho \partial \gamma z} + B/\gamma$

What is DARE?

- It is one type of coarse horizontal resolution (strongly anisotropic grid) non-hydrostatic model, so formulated that it behaves like a fine horizontal resolution (more isotropic grid) model that is driven more strongly.

Equatorial β-plane experiments

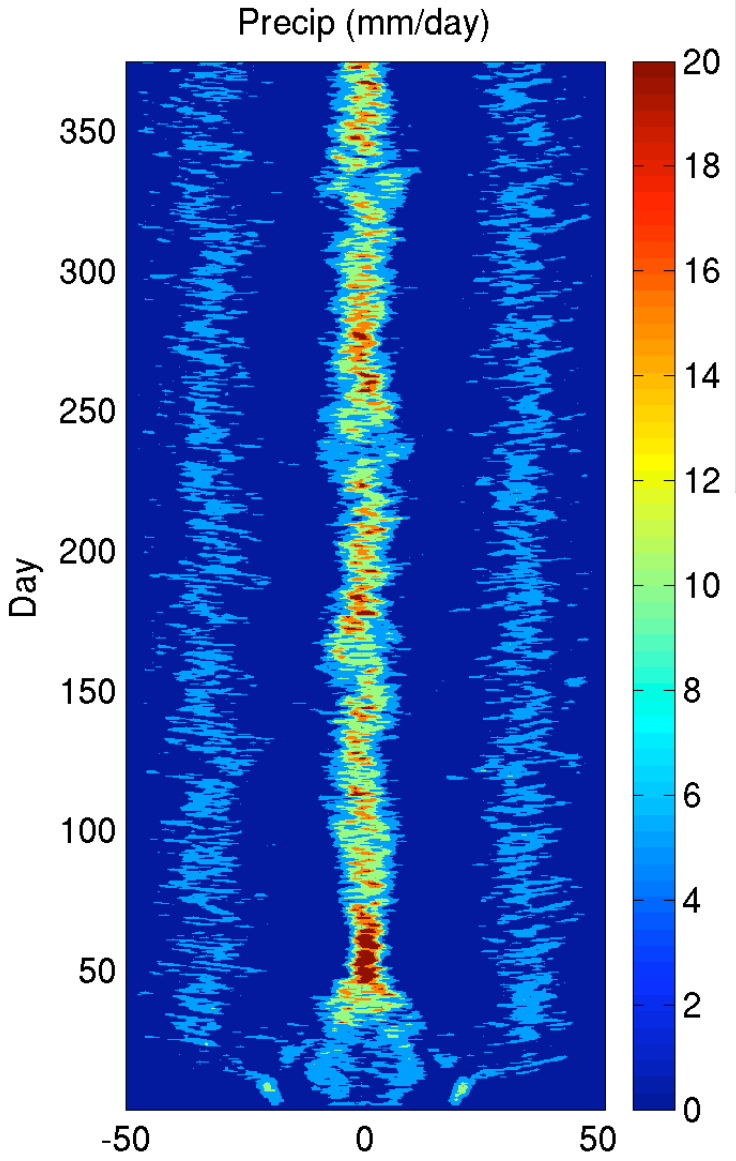


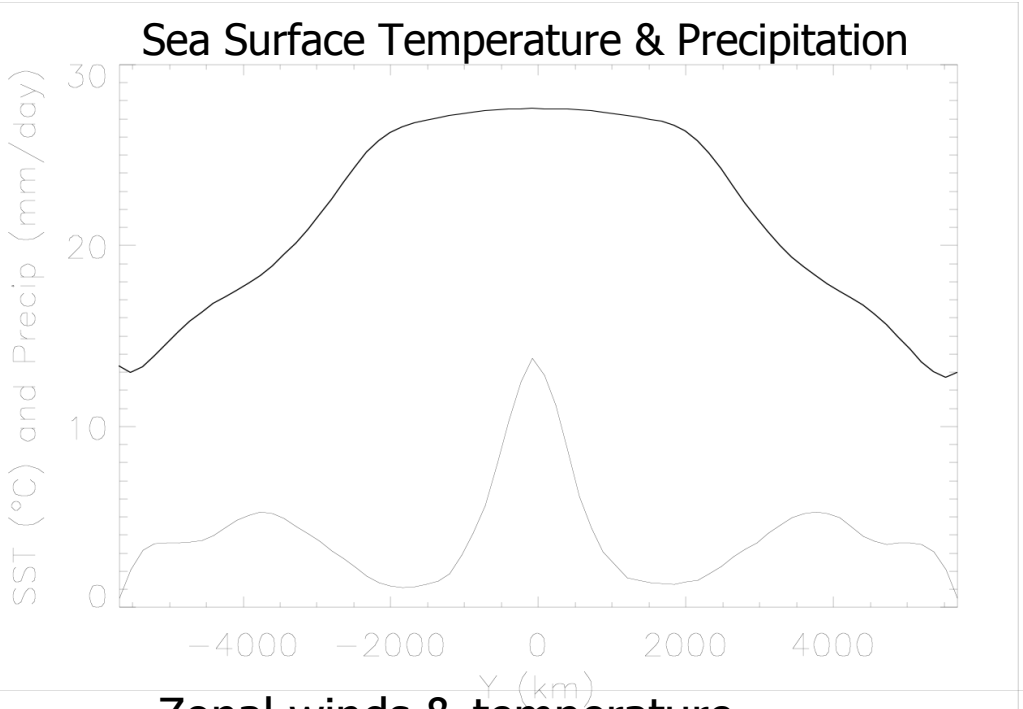
γ=10, dx=4km, Equinox insolation

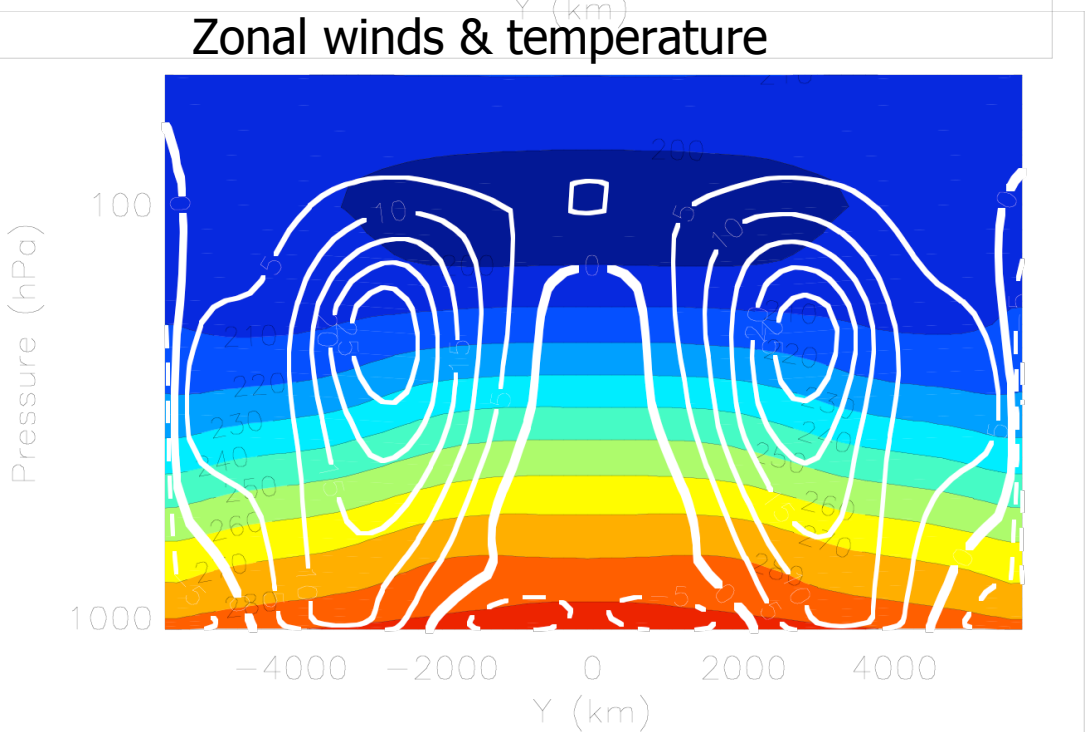
15m mixed-layer ocean, zero oceanic heat flux

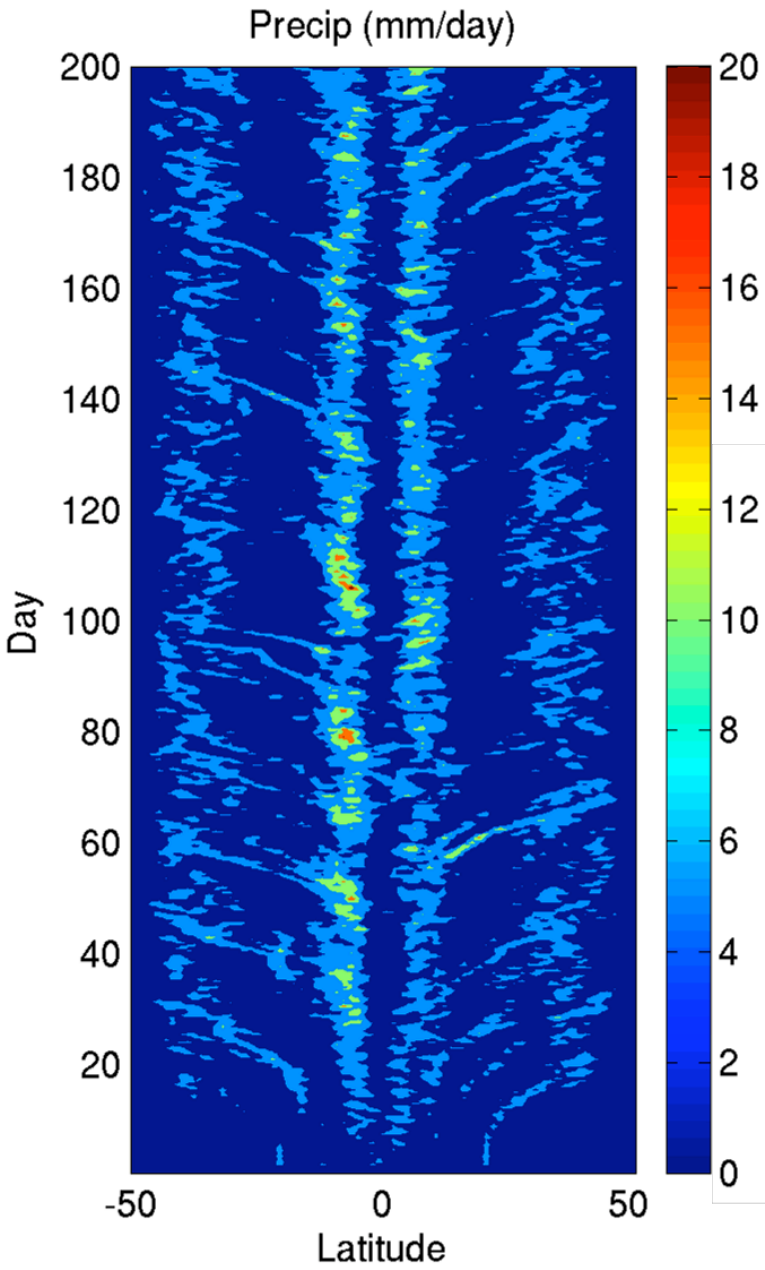
The CRM used is provided by Marat Khairoudinov

A single-ITCZ
(the mixed layer ocean case)

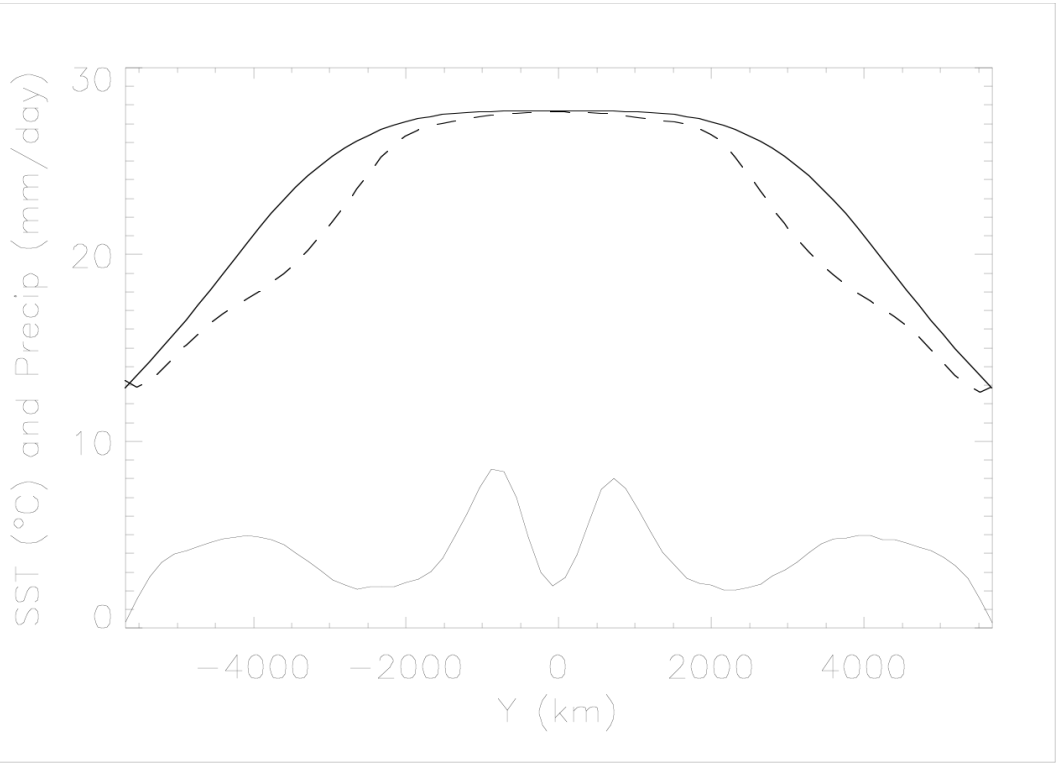




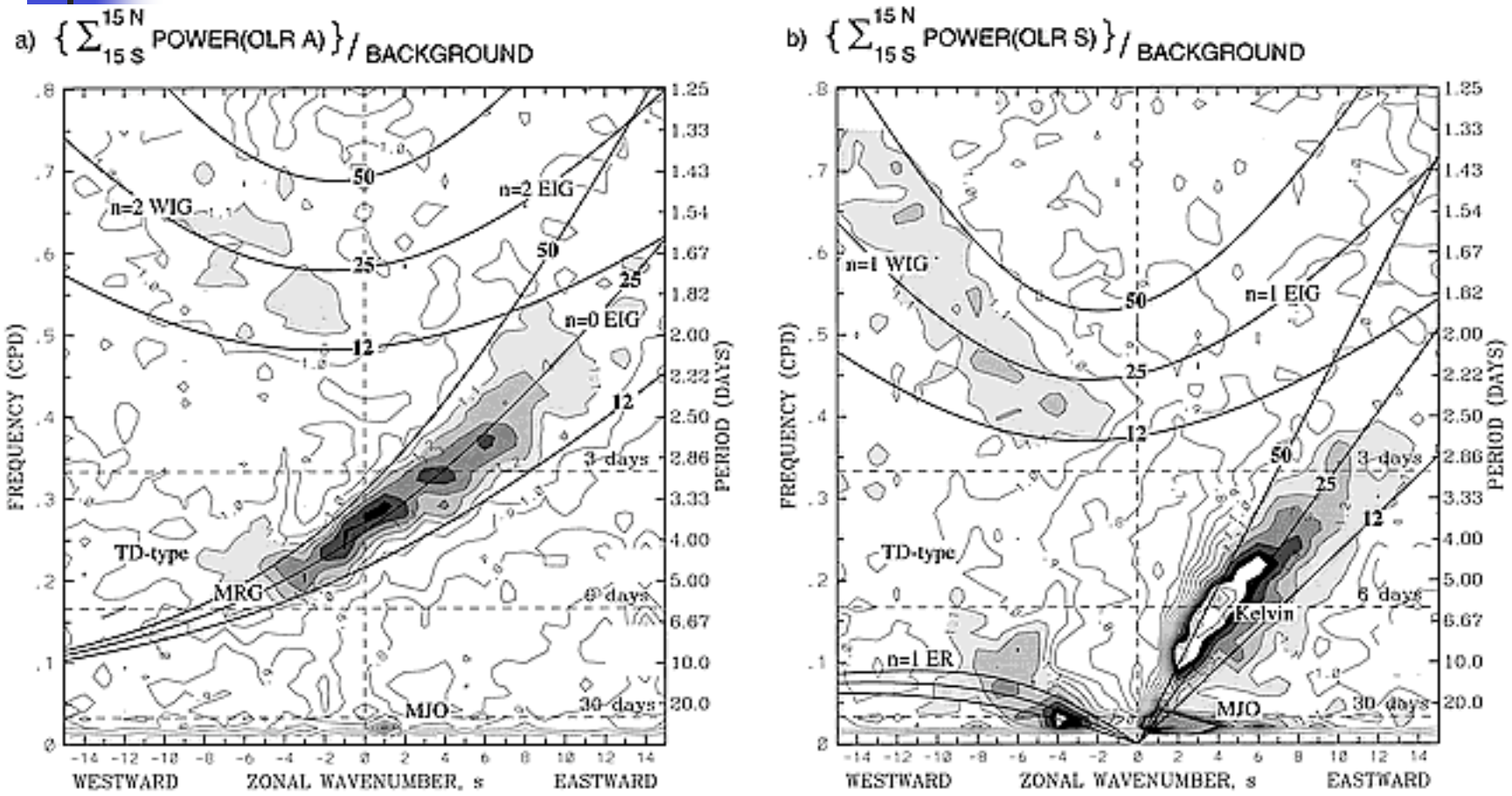




A double-ITCZ (a fixed SST case)

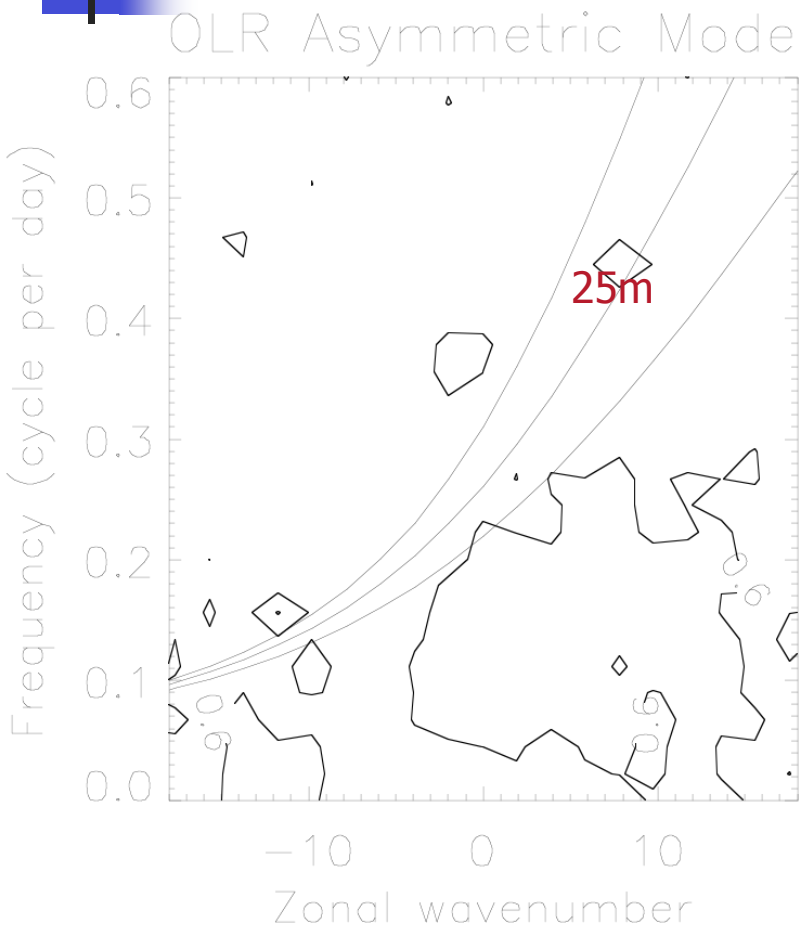


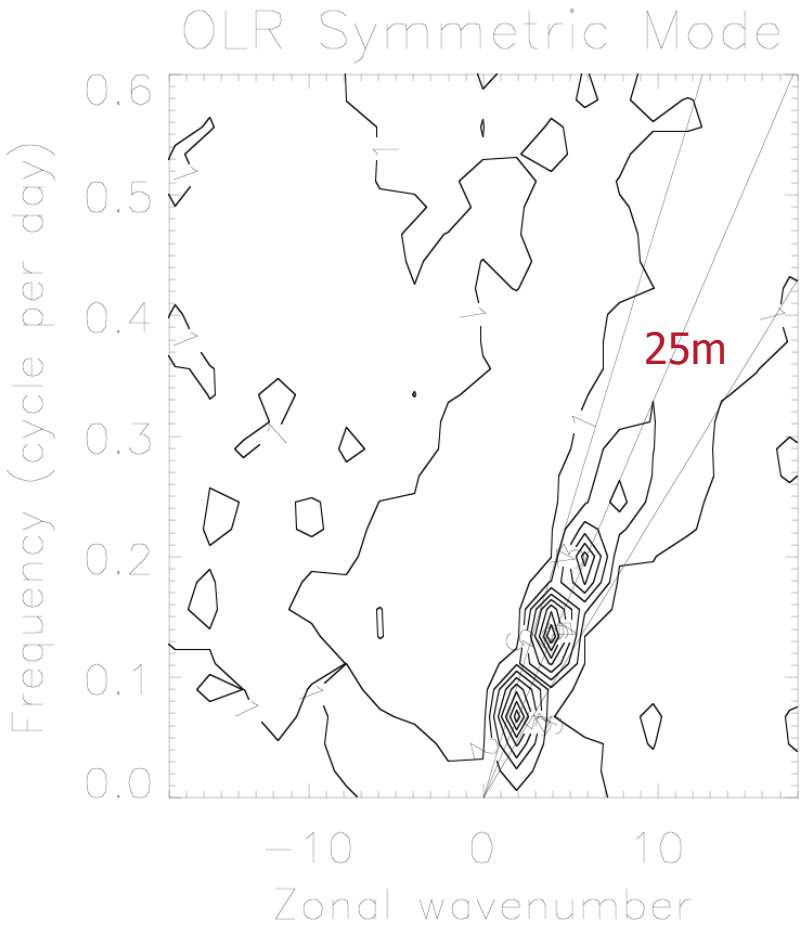
Convectively coupled waves



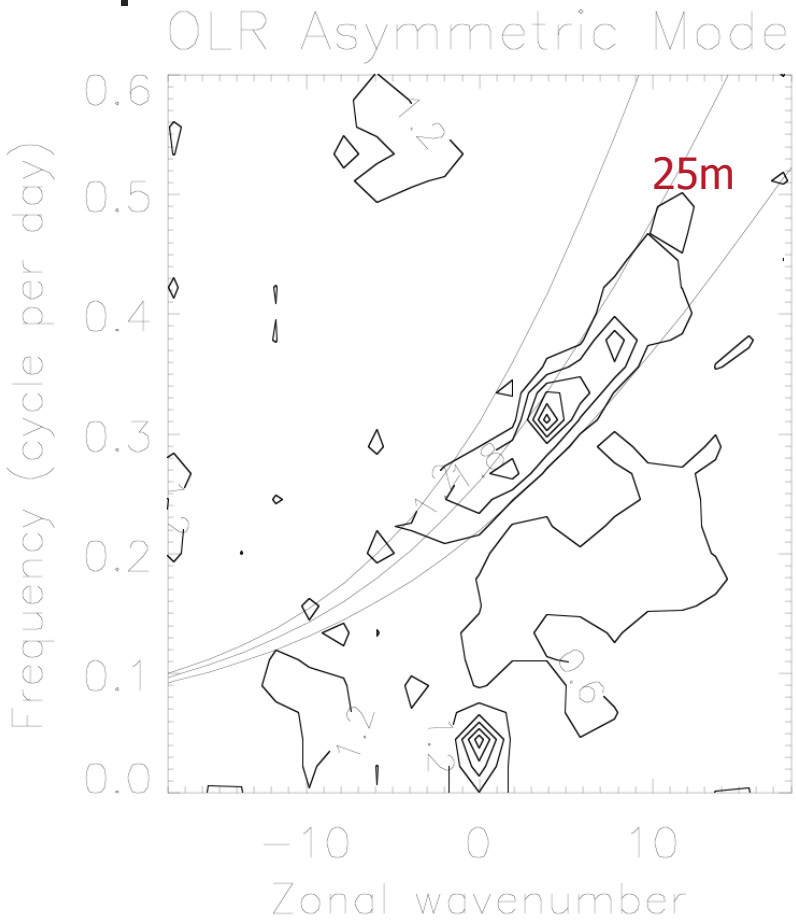
Wheeler and Kiladis, J. Atmos. Sci., 1999

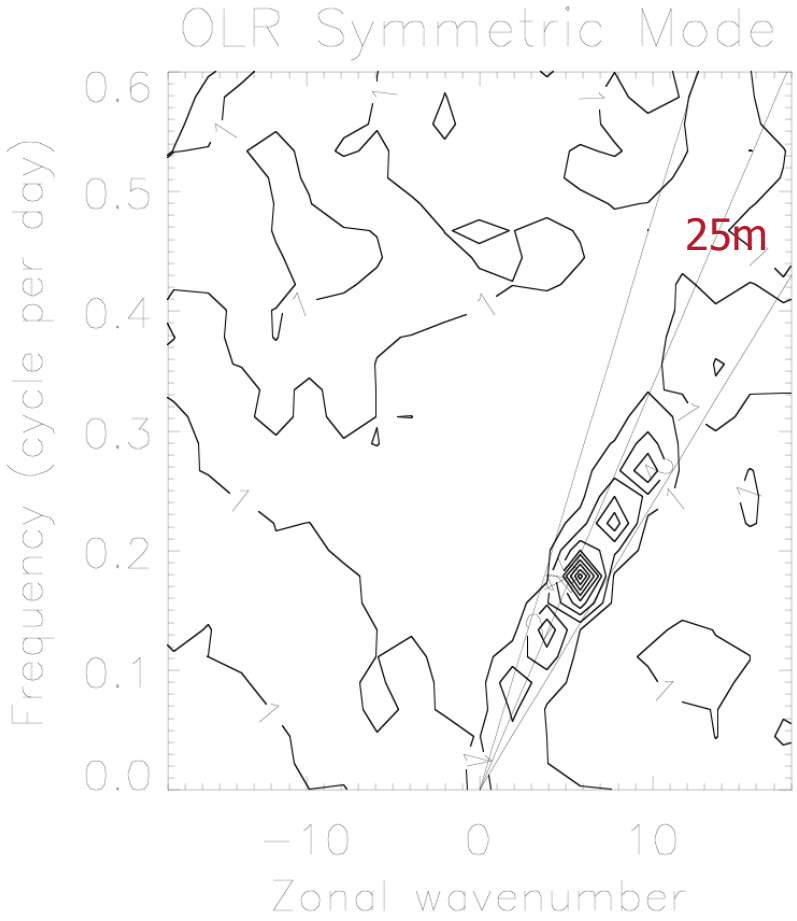
DARE simulation (the single-ITCZ case)



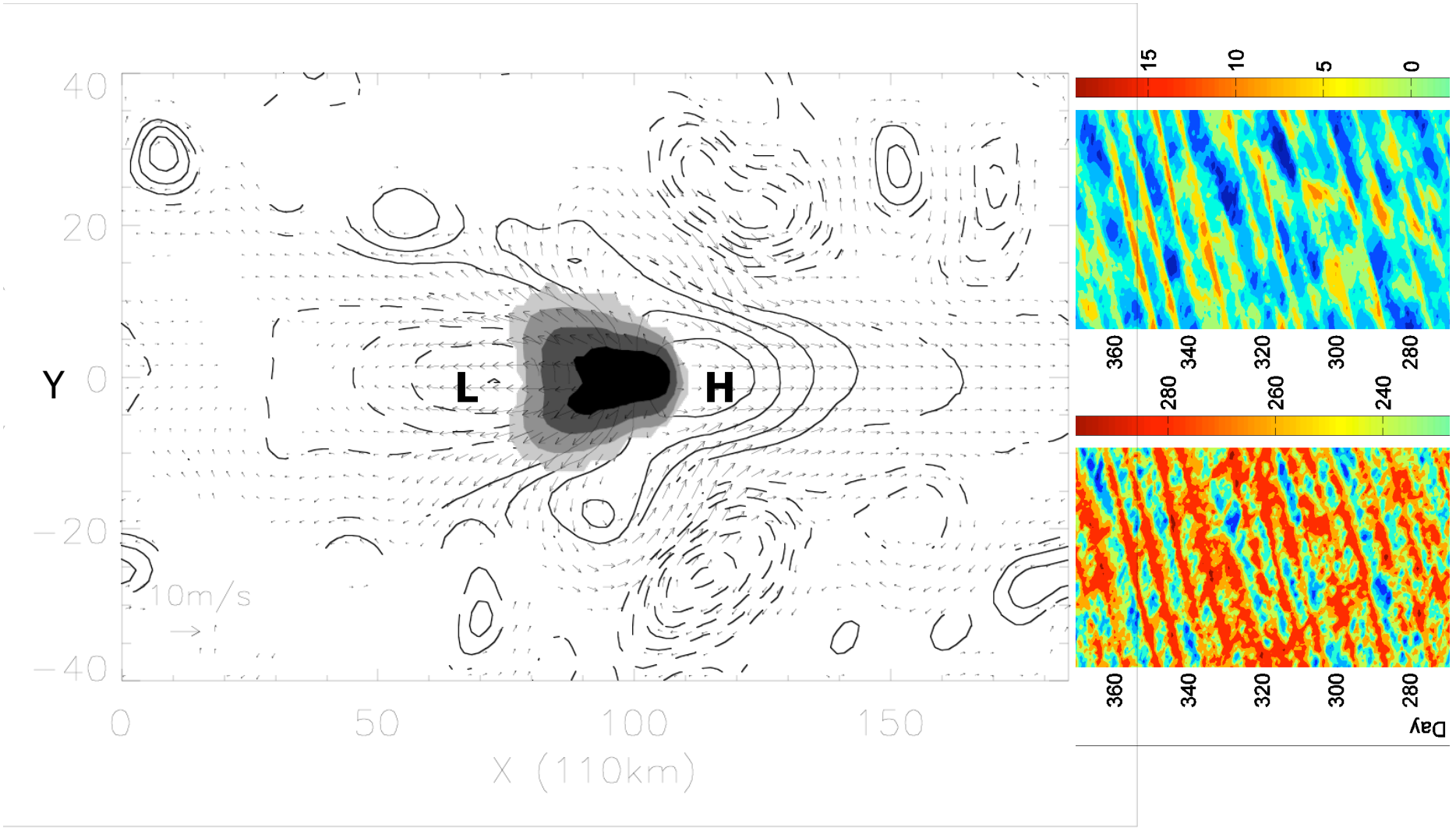


The double-ITCZ case



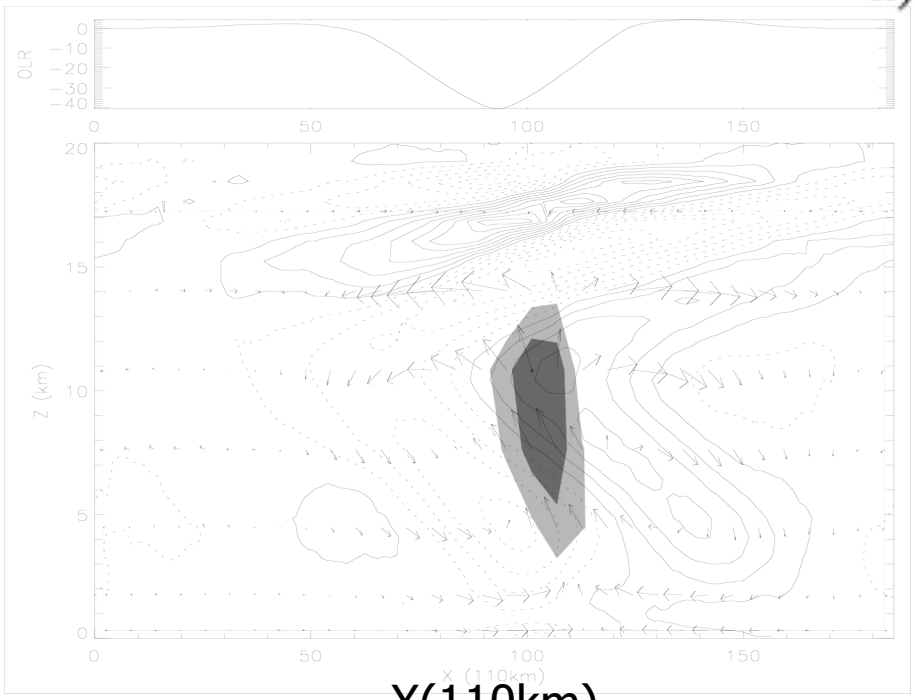


Kelvin waves



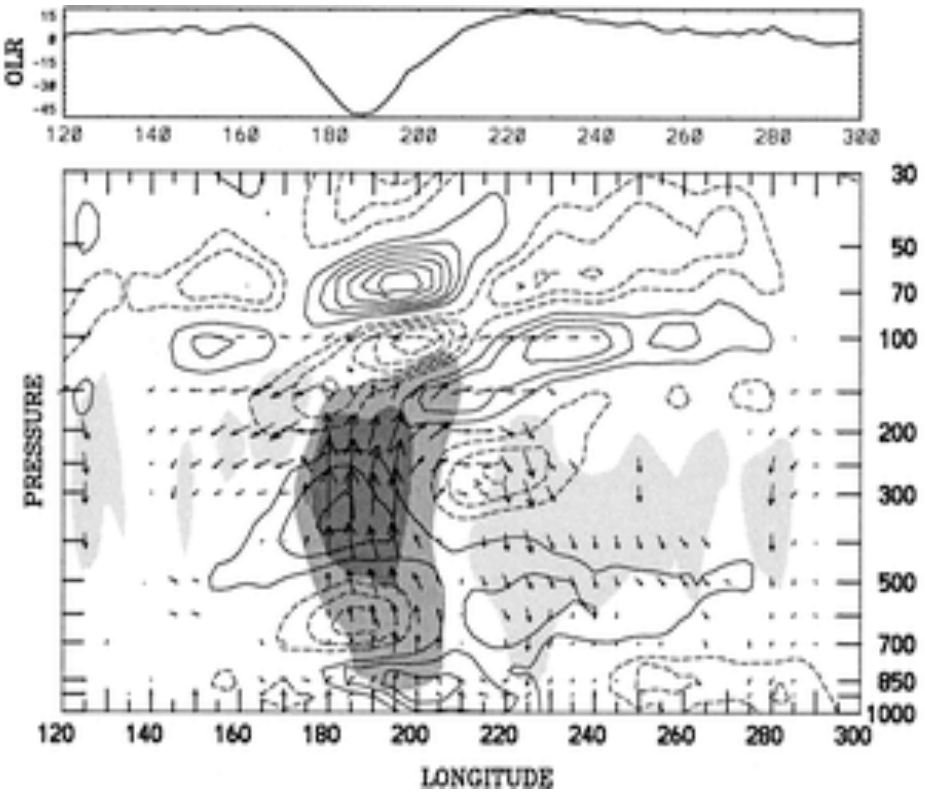
Kelvin waves: vertical structure

DARE temperature & winds



X(110km)

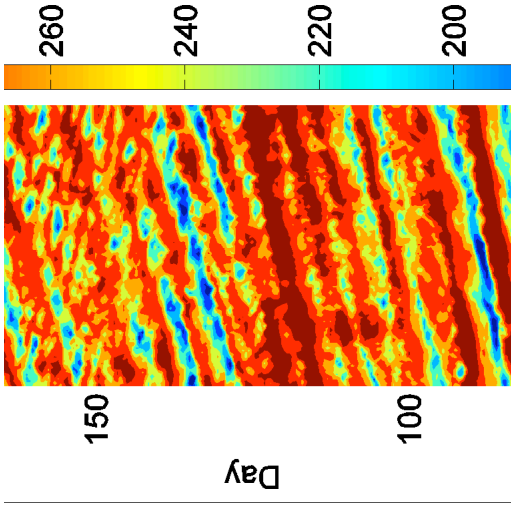
NCEP Reanalysis



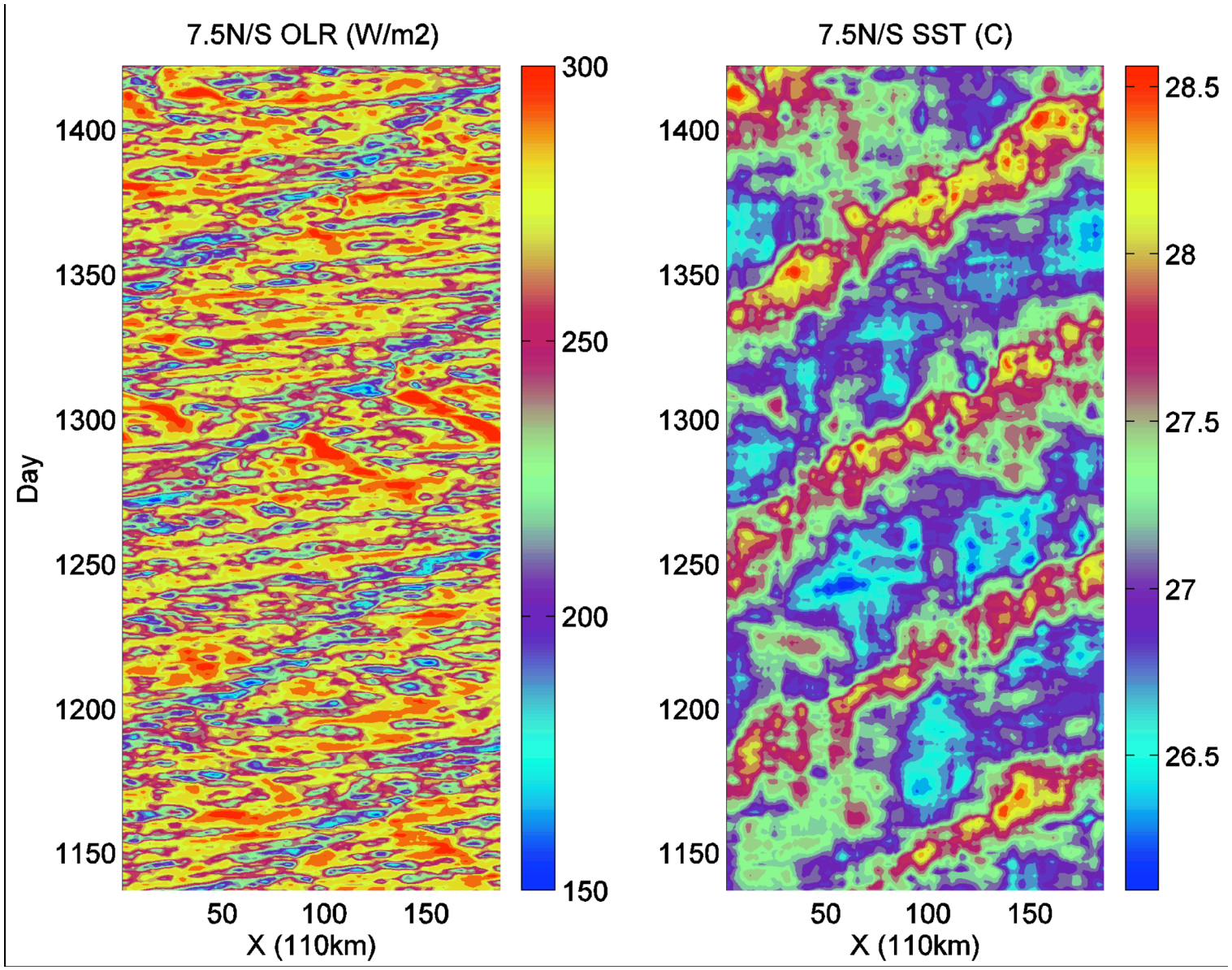
Straub and Kiladis, J. Atmos. Sci., 2003

Testing ideas on the waves

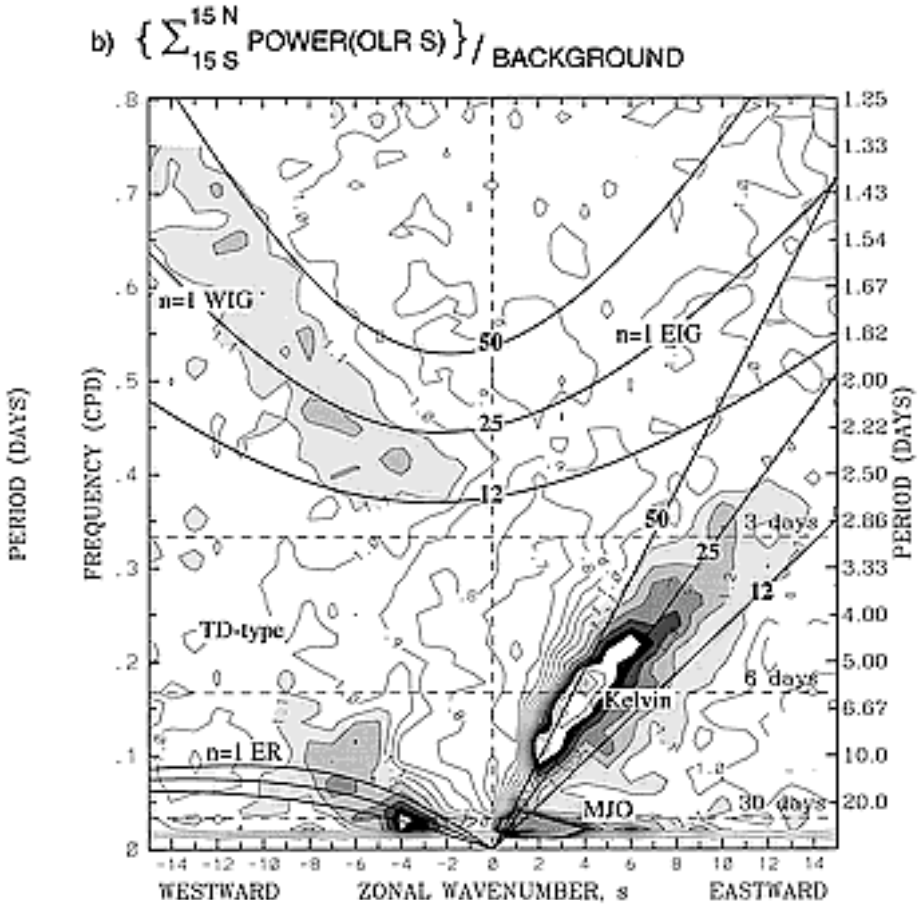
- Kelvin waves remain prominent without WISHE and radiation feedback
- Second baroclinic mode appears essential

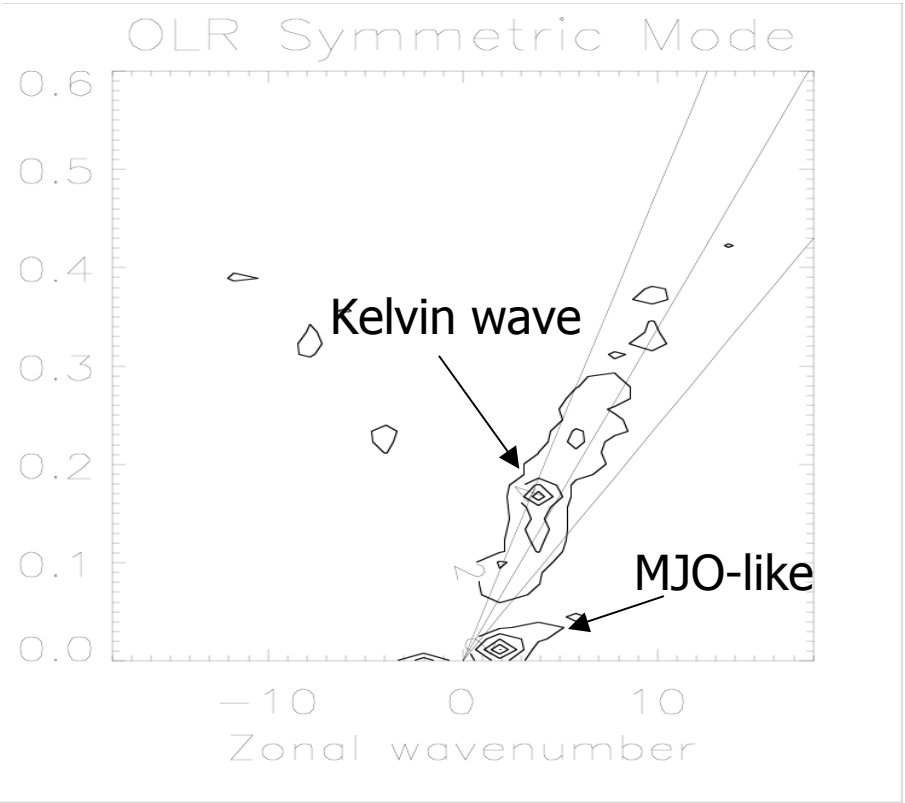


MJO-like disturbances dx=2km and γ=20

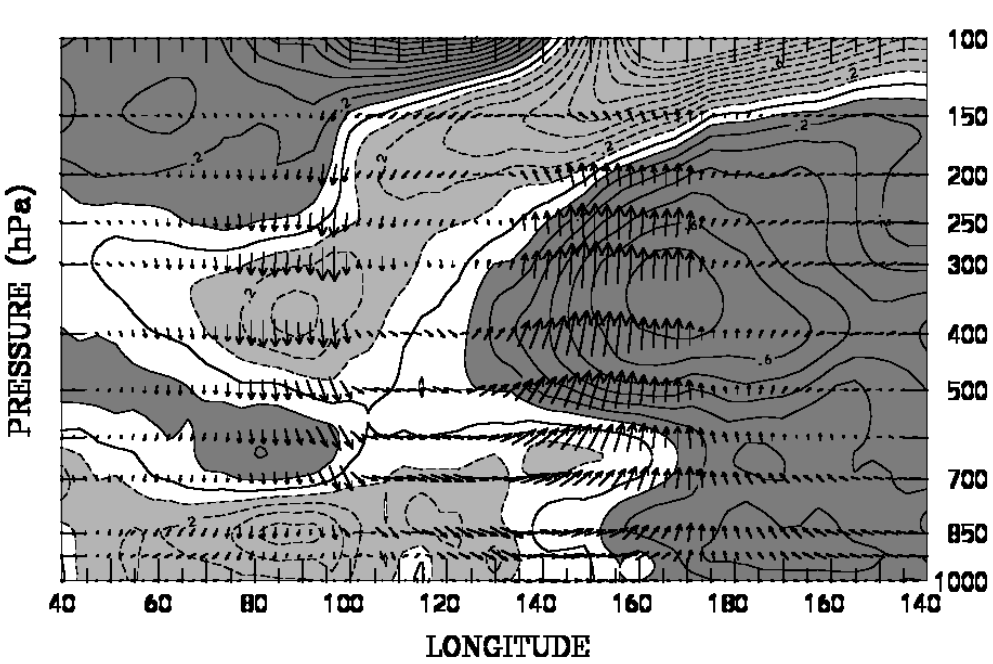


Space-time spectrum

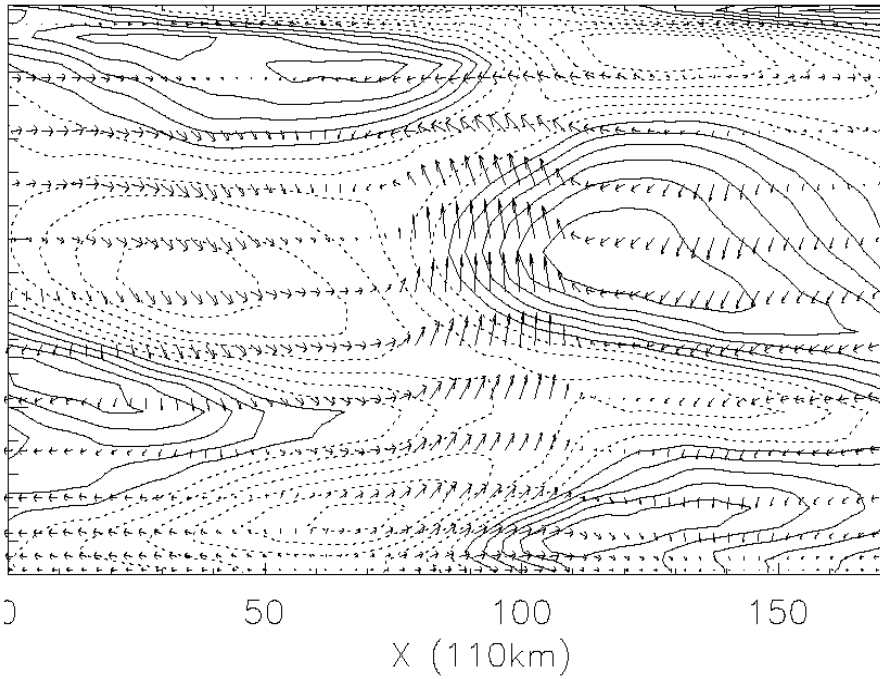




“MJO” Structure



Observed, Kiladis et al, 2005



DARE simulation

Conclusions

- We propose DARE as a way to simulate the interaction between large-scale circulation and convection
- Easy to implement; fully 3D; fine with land/topography; saving in computation $\sim O(\gamma^3)$;
- As γ reduces to 1, the DARE model smoothly converges to a global CRM
- Can be used within MMF as well

Conclusions (cont.)

- The simulated convectively coupled waves and "MJO" resemble those observed in terms of their spectra and structures.
- Convective coupled waves exist without WISHE or radiative feedback
- The simulated "MJO" only exists with ocean coupling and surface/radiative flux feedbacks

Ongoing work

- Better understand the effect of DARE and explore potential improvements
- Include shallow convective parameterization
- Examine mechanisms of convectively coupled waves, and realism of the simulated MJO, its sensitivity to resolution, microphysics/ radiation schemes etc…
- Realistic climate/weather simulations with DARE