Analytic Representation of the Large-scale Organization of Tropical convection

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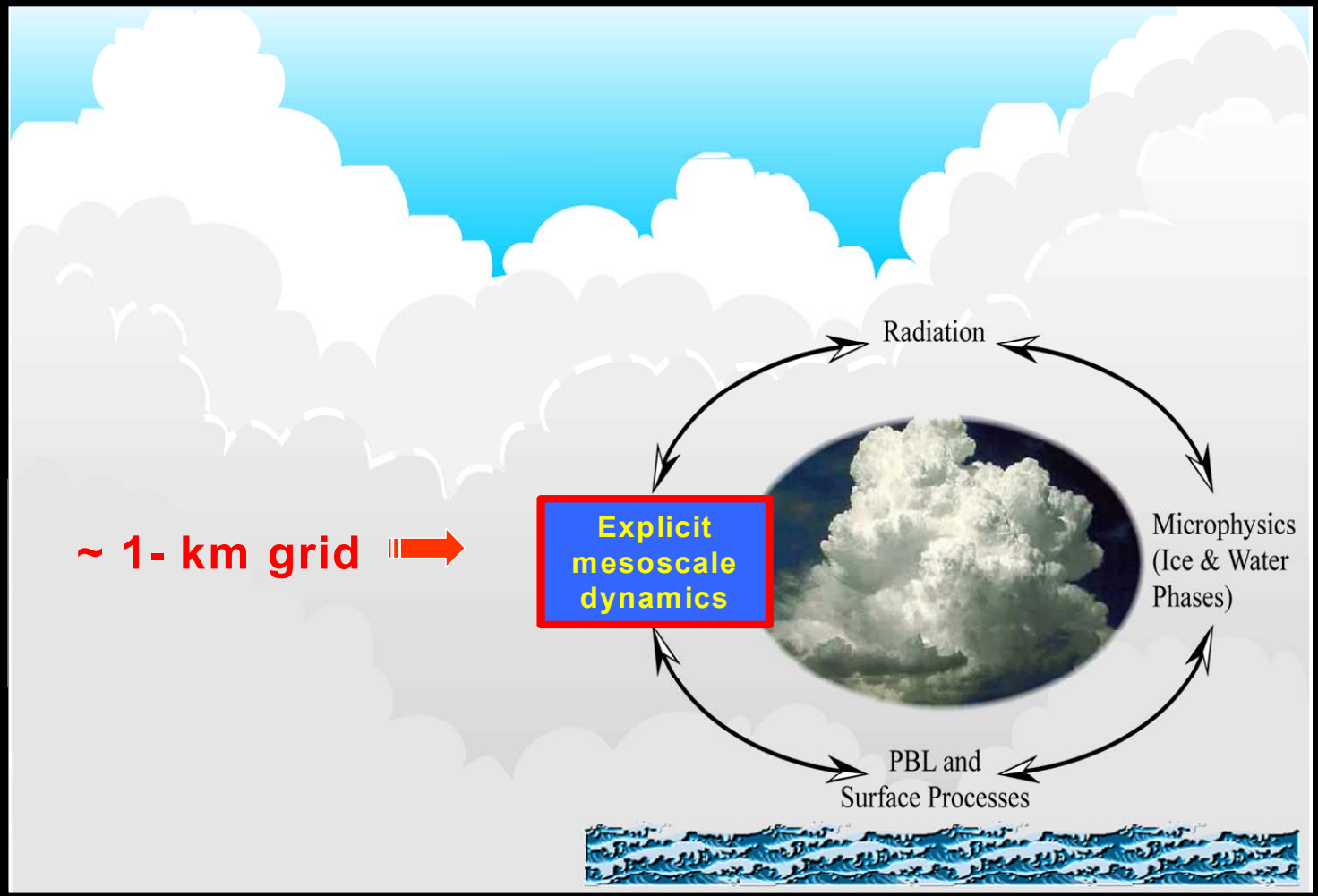
ECMWF/CLIVAR Workshop on Simulation and Prediction of Intra-seasonal Variability with Emphasis on the MJO, ECMWF, Reading UK, 3-6 November 2003.

What's resolved using ~1-km grid ?



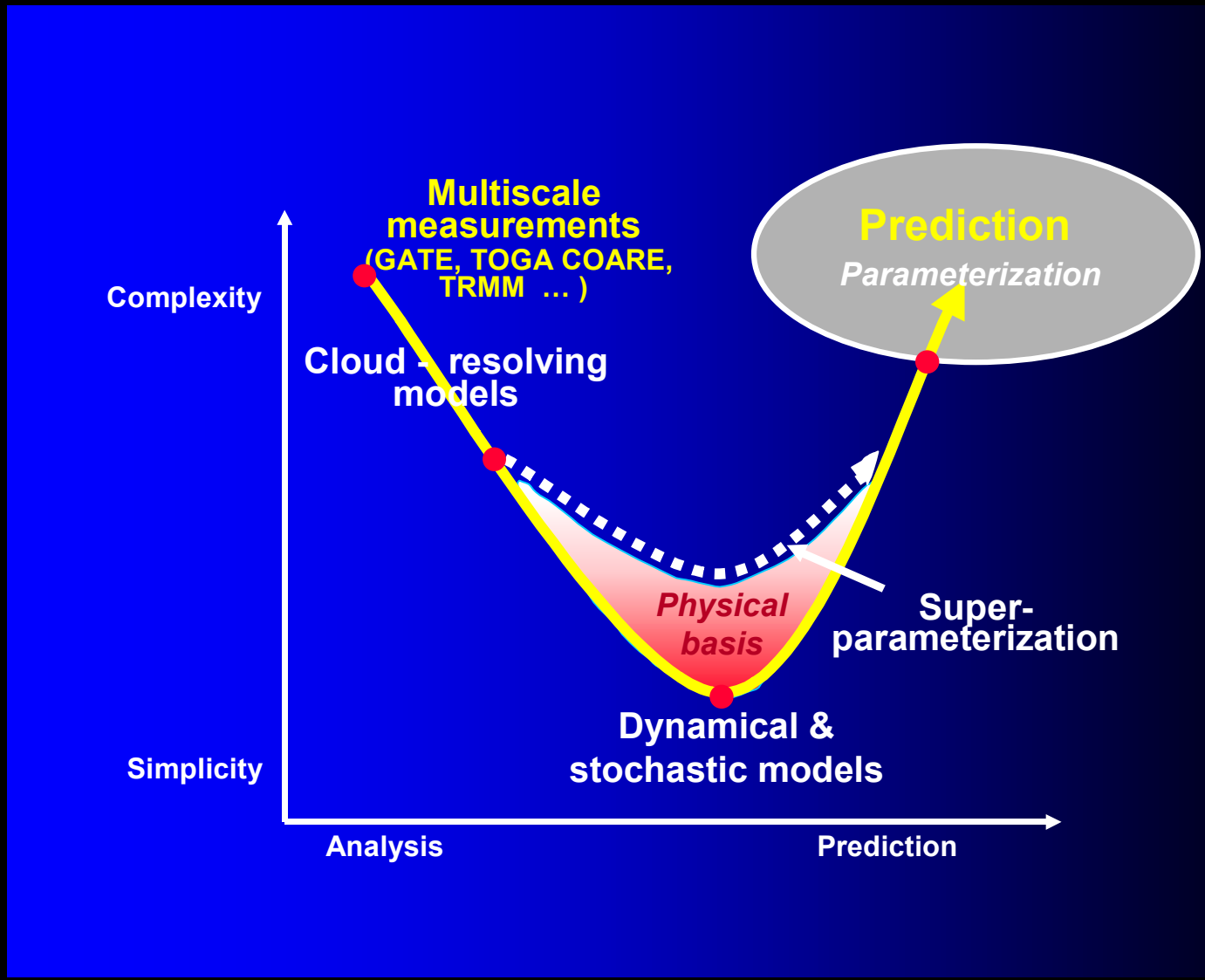
… organization of convection ~10's km +

Question …

Super-parameterization represents the *mesoscale organization of convection and its large-scale interaction*

… what's its physical basis?

Towards a physical basis ..



Context …

- **The prevalence of organized convection is an outstanding result of field campaigns *and* 1-km grid-resolution numerical models during the past three decades**

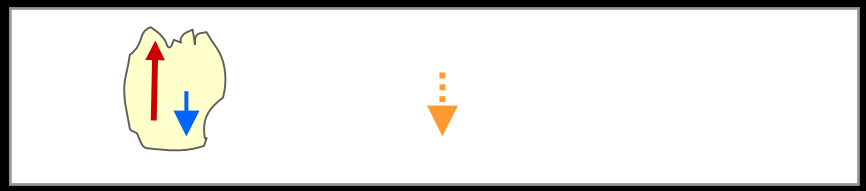
- **Underpinned by nonlinear analytic models (author and colleagues)**

- **But this result is not captured by conventional convection parameterizations**

- **That organized convection is prominent in super-parameterization (and multiscale modeling) suggests the analytic models should be revisited**

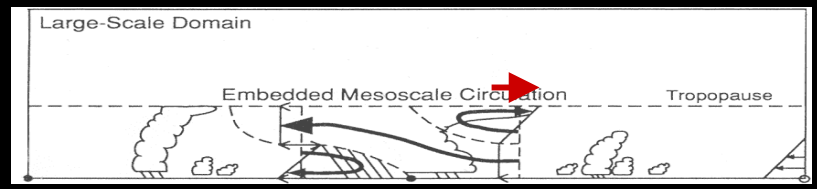
Basic distinction …

Ordinary convection



- Small-scale entrainment
- Shear effects ignored
- Propagation ignored
- Weakly interactive with large scale
- Local effects

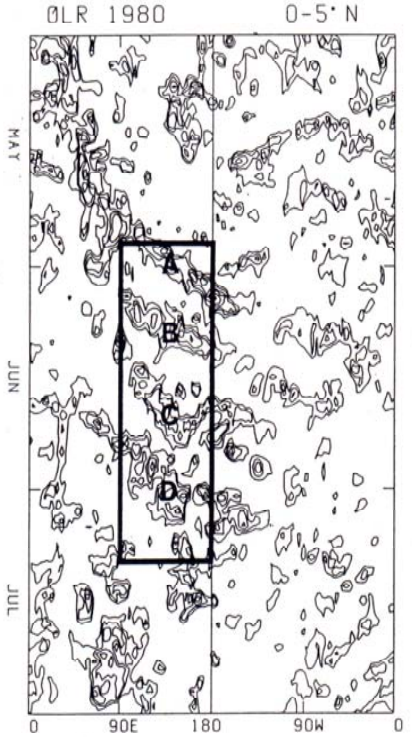
Organized convection

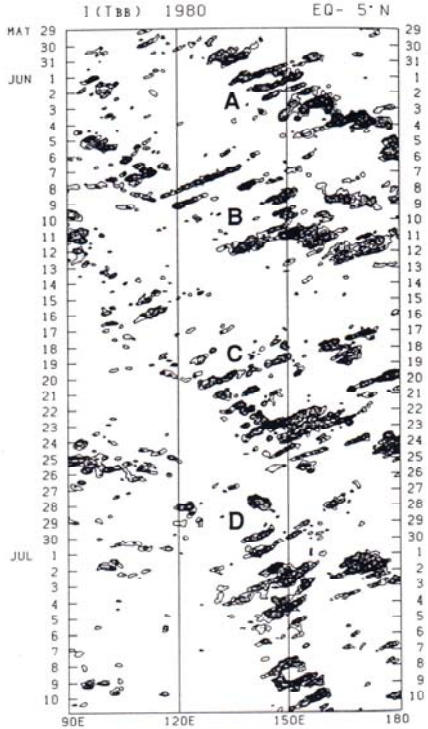


- Coherent dynamics
- Shear control
- Propagation intrinsic
- Weakly interactive with large scale
- Remote effects

Ordinary and organized convection occur together

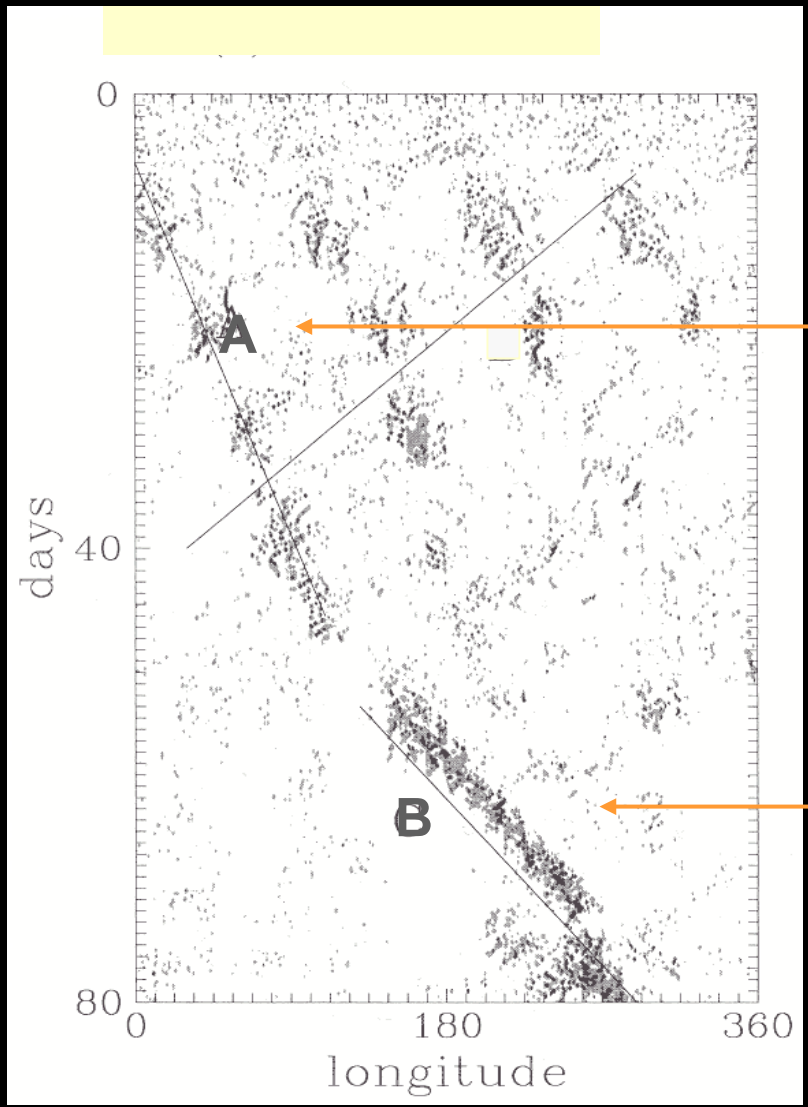
Superclusters and organized convection observed from space





Nakazawa (1988)

Super-parameterization: Two regimes

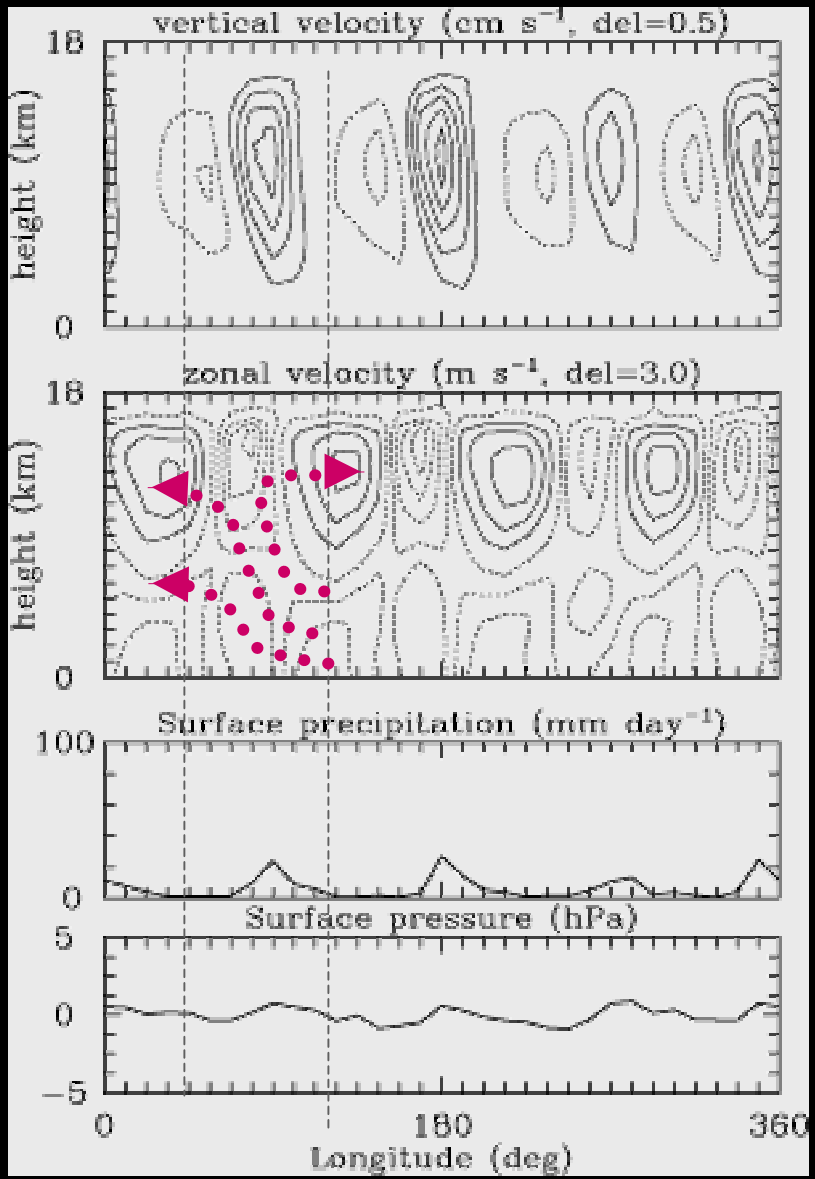


Convectively-coupled system (c = 3.5 m/s)

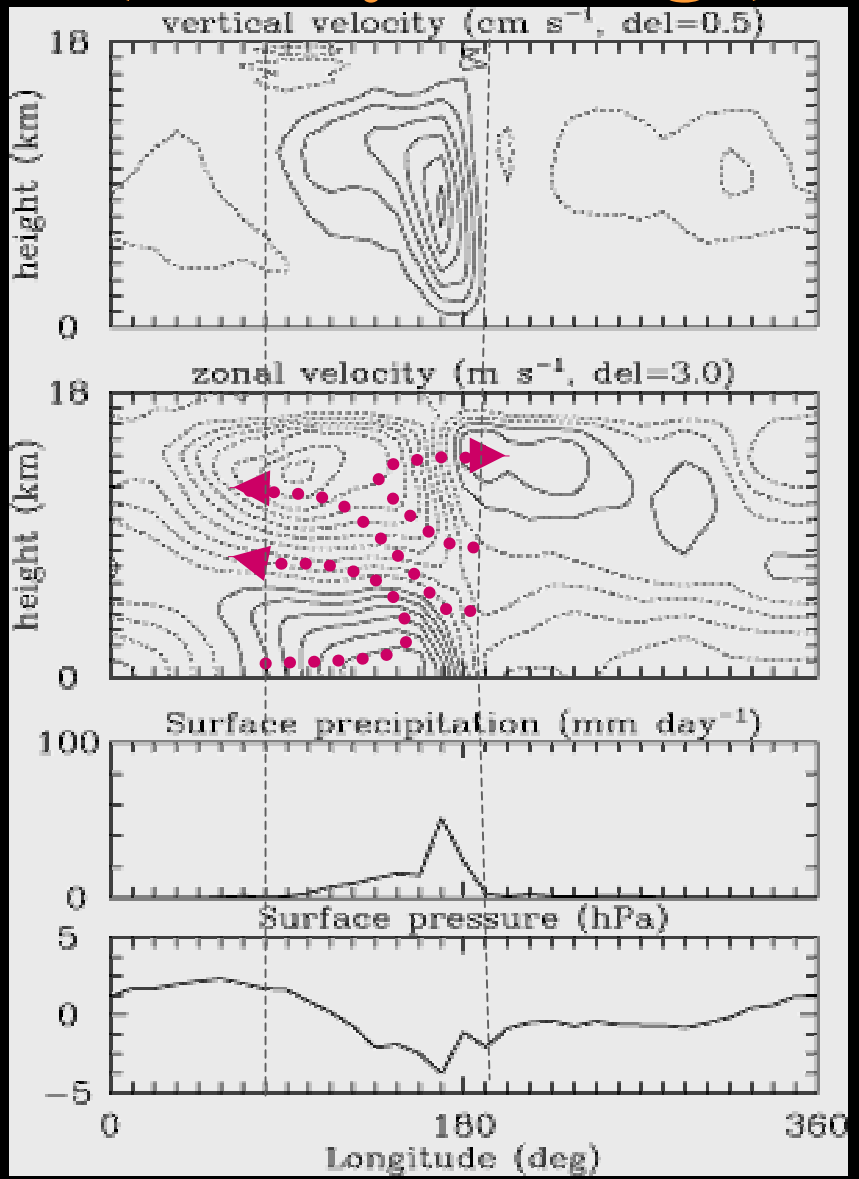
MJO-like system (c = 8 m/s)

Grabowski (2001)

Vertical structure (20-day average)

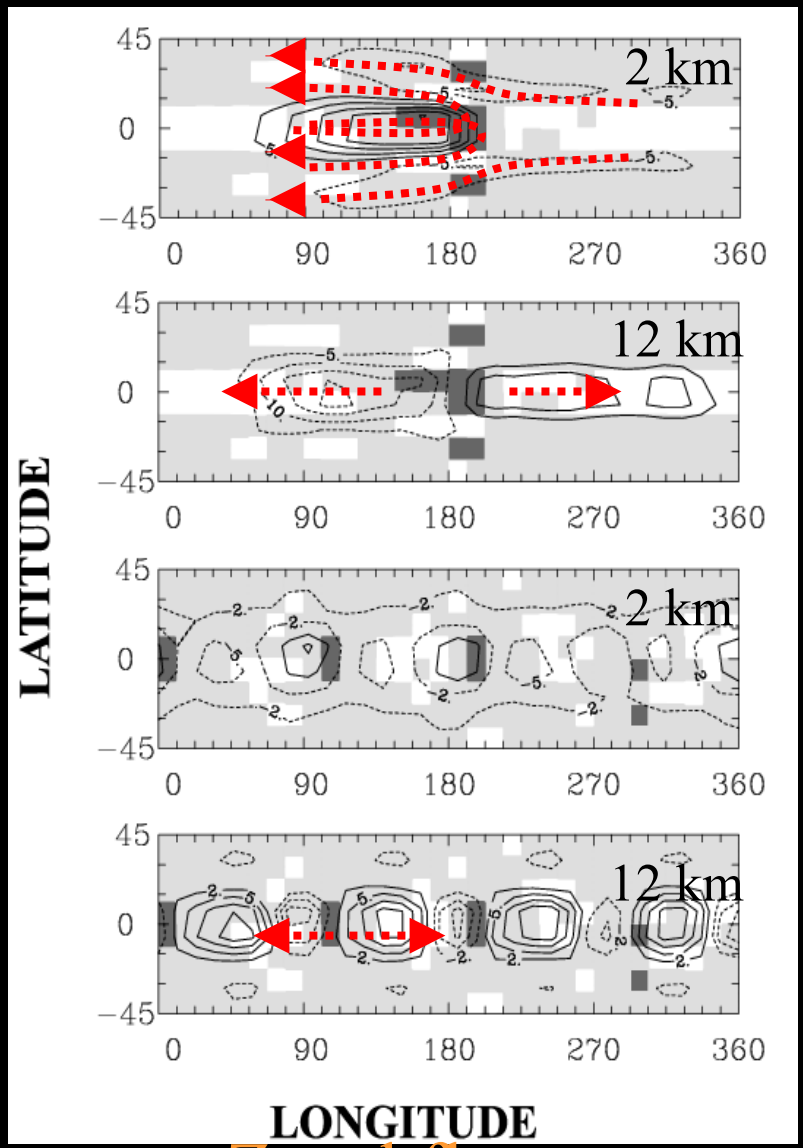


Convectively-coupled system

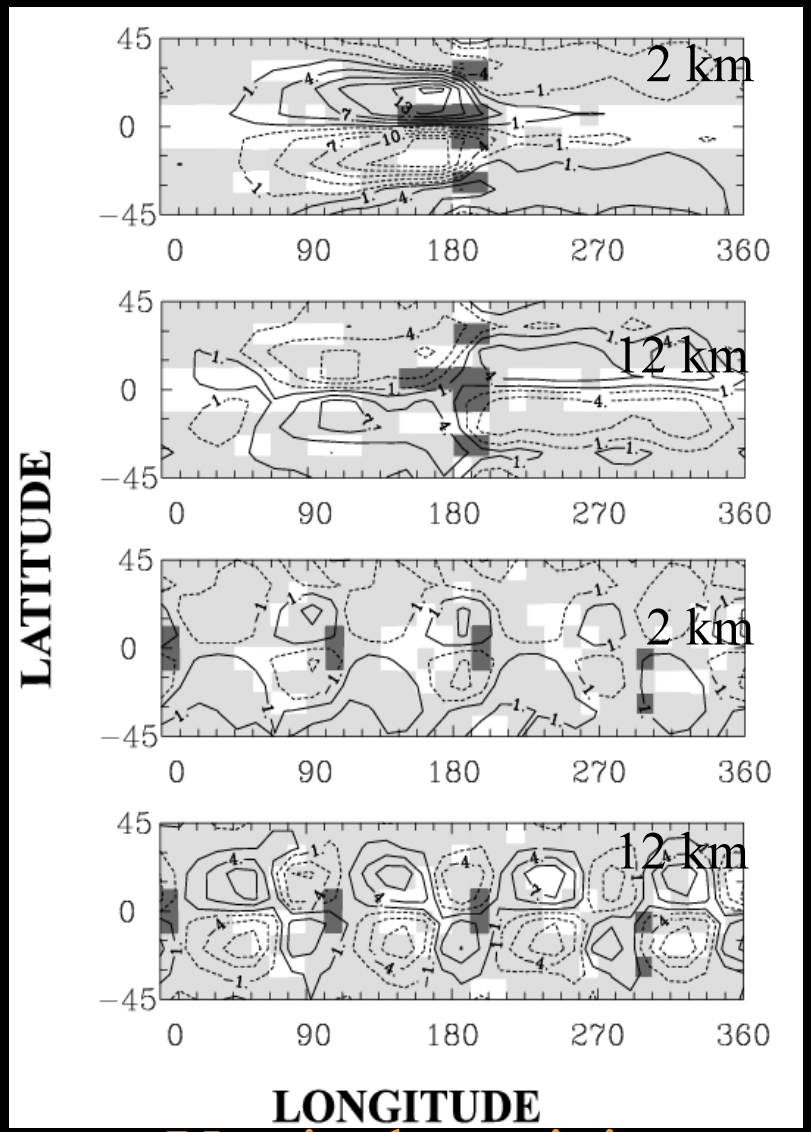


MJO system

Horizontal structure (20-day average)



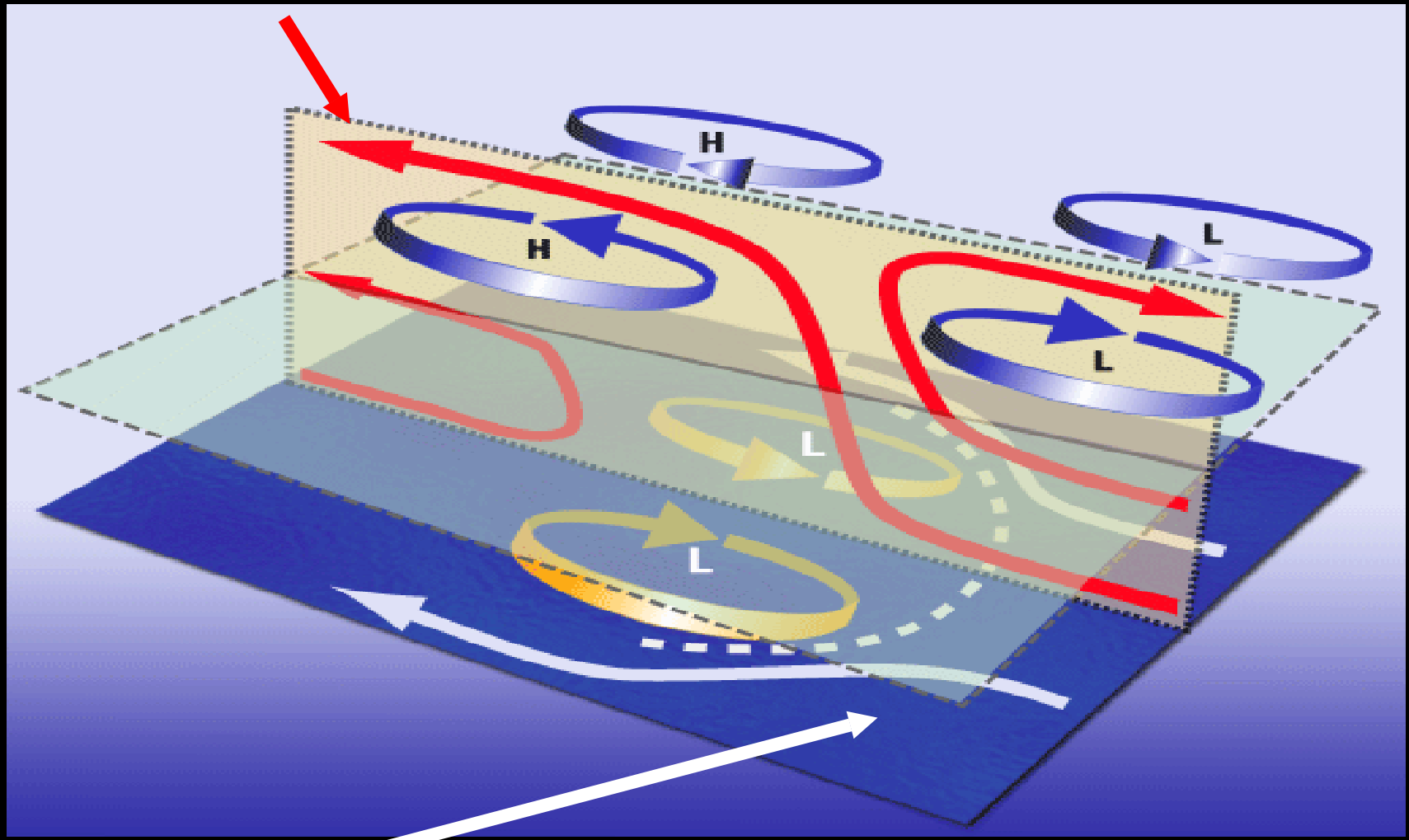
Zonal flow



Vertical vorticity

2D-analytic
mesoscale
parameterization

Idealization



Two-layer large-scale circulation

Two interacting scales

- Analytic parameterization of the mesoscale organization of deep convection

- Explicit large-scale coherent circulations

"The structure of MJOs must be understood in terms of scale interactions between large-scale circulation and mesoscale systems"

-Chidong Zhang, this workshop

Interlocking the scales

- Transformation between vertical and horizontal vorticity equations (Rossby number → convective Richardson number)
- Dynamical closure
- Integral constraint

Vorticity transformation

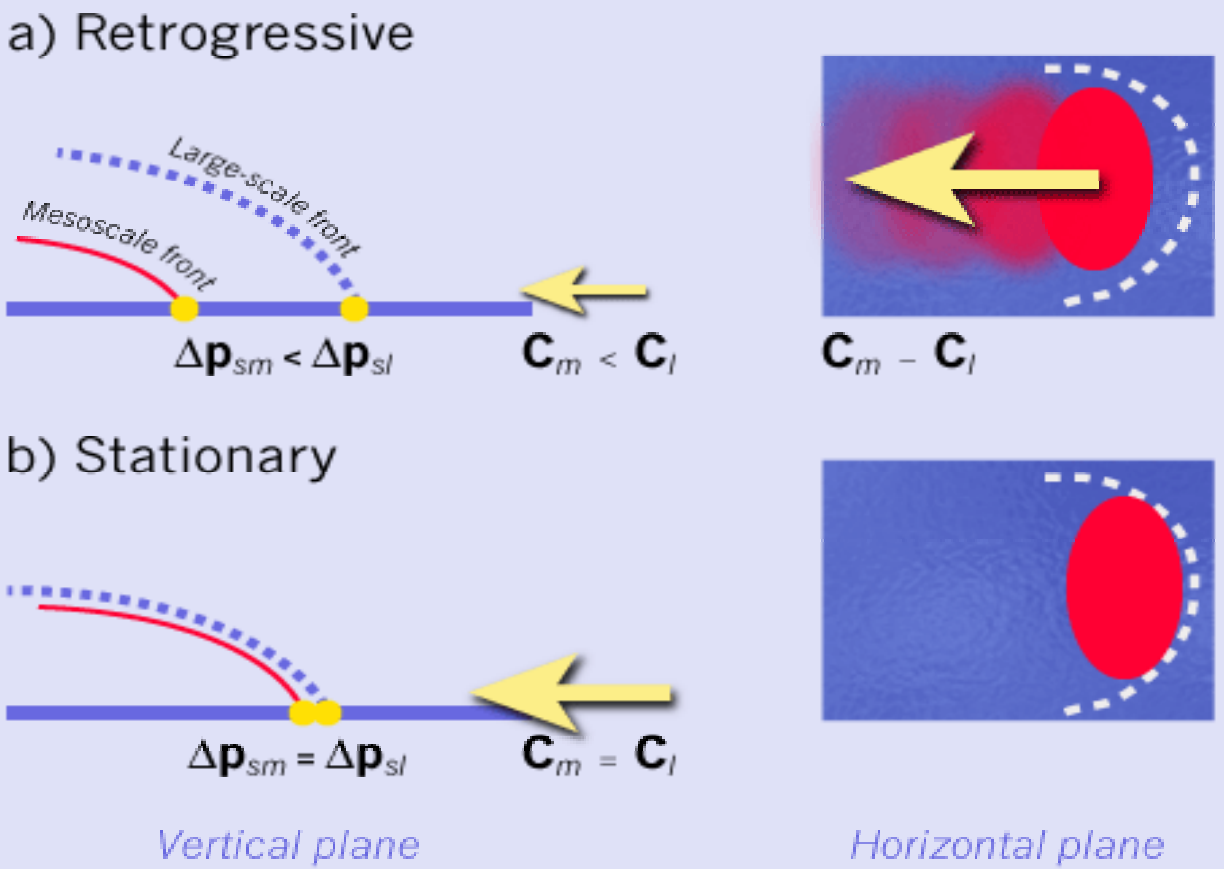
- **Horizontal (y-vorticity)**

$$\eta - \int_{z_0}^{z} \left(\frac{\partial B}{\partial \psi} \right)_z dz = S_z(\psi)$$

- **Vertical (z-vorticity)**

$$\zeta + \int_{y_0}^{y} \left(\frac{\partial C}{\partial \varphi} \right)_y dy = S_y(\varphi)$$

Dynamical closure



Integral constraint

- In a bounded domain with free-slip boundary conditions momentum

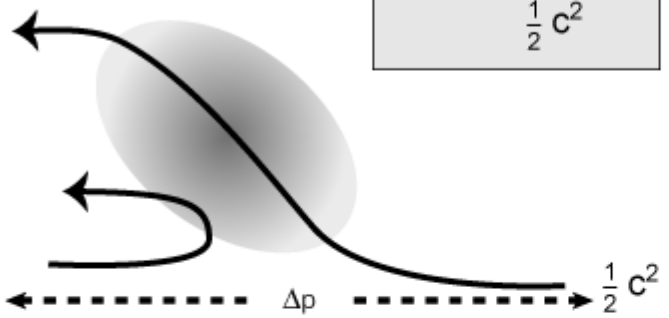
$\rho u w$

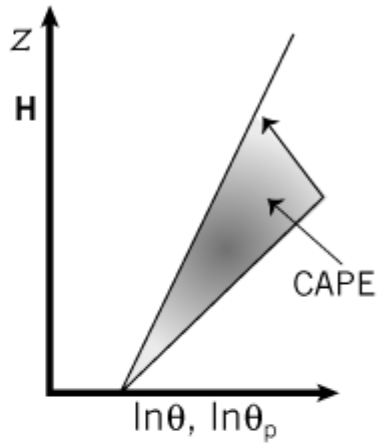
$\rho u v$

… may be redistributed but not generated:

a) Mesoscale circulation: convective Richardson number

$$R = \frac{CAPE}{\frac{1}{2}c^2}$$





b) Large-scale circulation: generalized inverse Rossby number

$$\lambda = \sqrt{\frac{\beta - \alpha}{c}}\, L$$

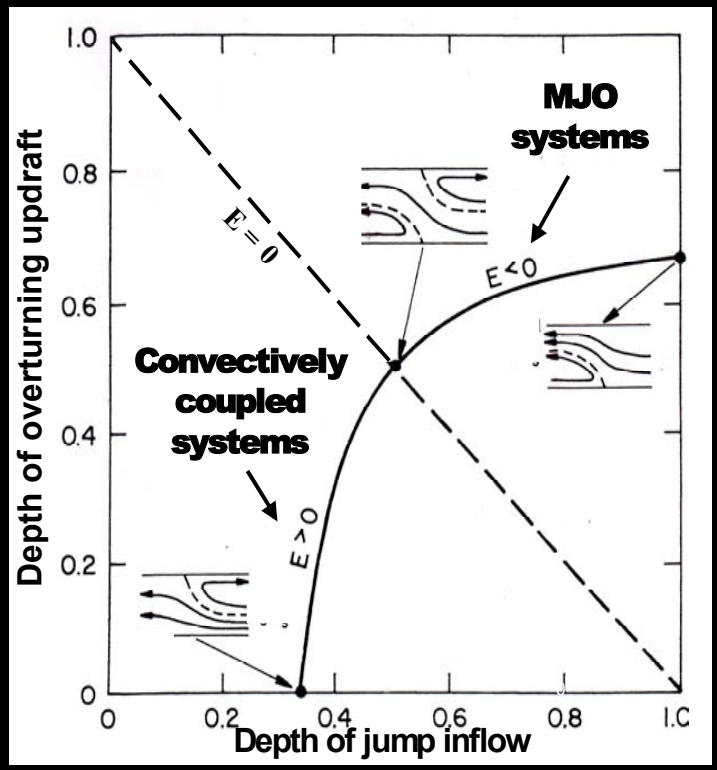
c) Propagation speed: Bernoulli number

$$E = \frac{\Delta p}{\frac{1}{2}\rho c^2}$$

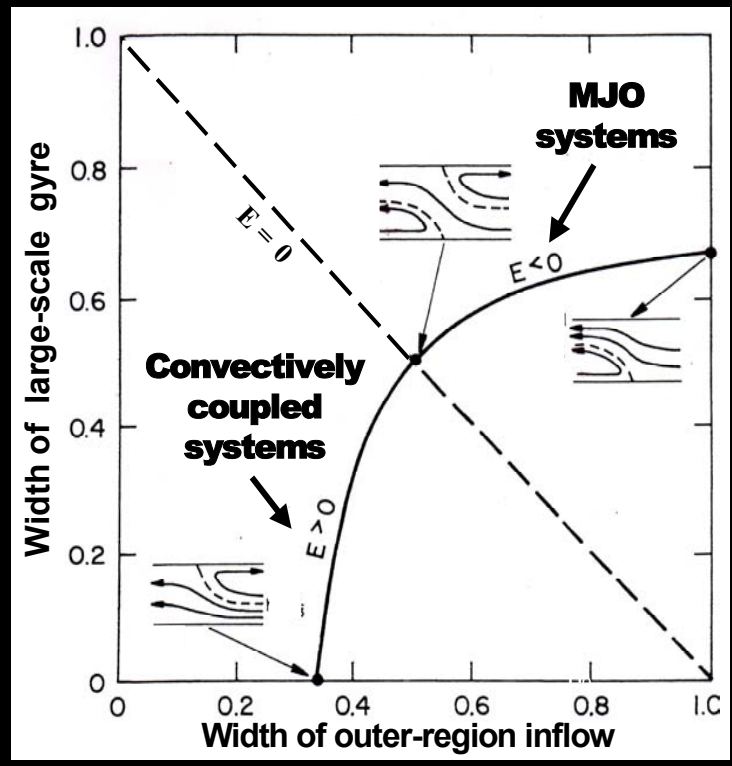
Another propagation formula

Brutal simplification … the archetype

Mesoscale parameterization



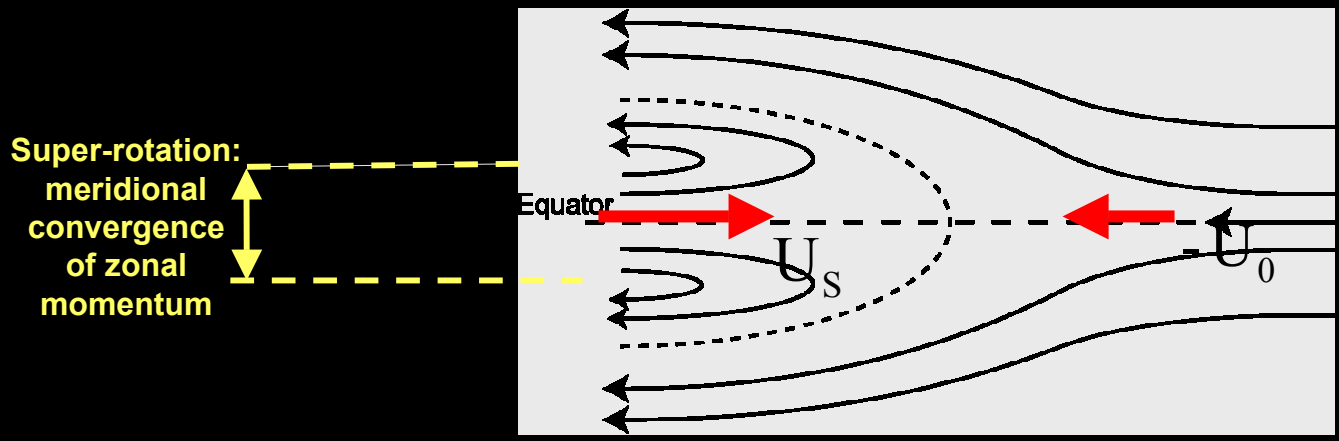
Large-scale circulation



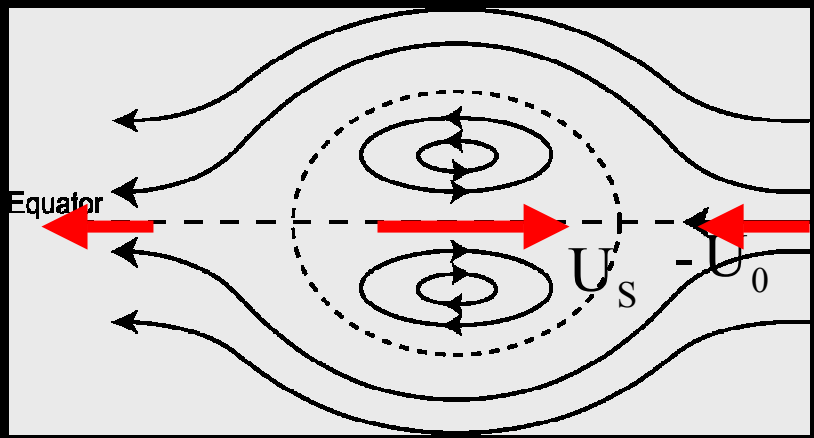
Summary of key results

- Convection interlocked with large-scale circulation
- Convectively-coupled waves and MJO-like systems captured by same dynamical theory
- Lower-tropospheric Rossby gyre the distinguishing feature – upper-tropospheric gyre driven by mesoscale outflow from (families of) mesoscale systems
- Westward tilt of mesoscale convection with height
- Another propagation formula for the MJO
- Distinctive vertical and meridional transports of zonal momentum (multi-scale coherence)

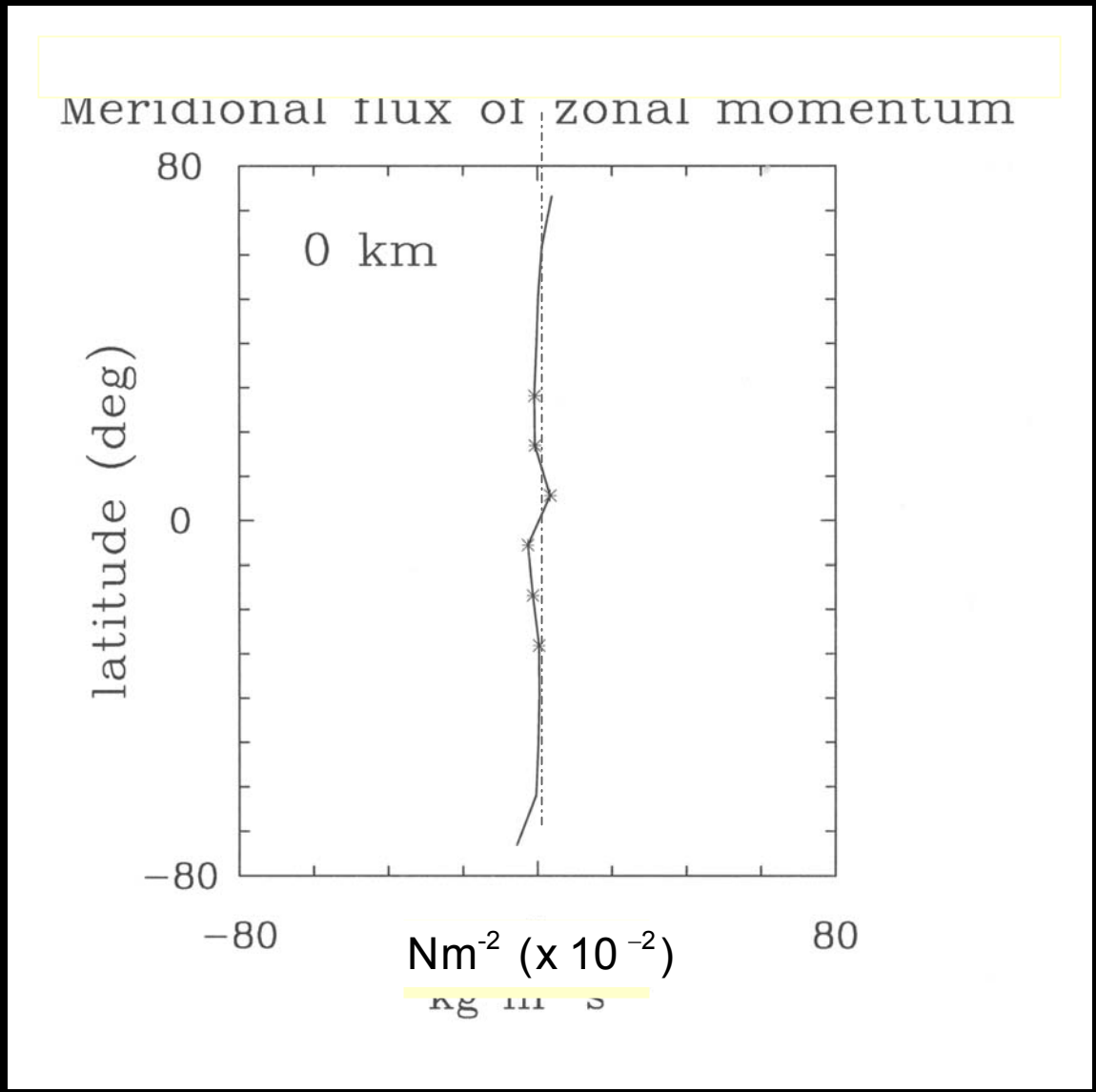
Open gyre: westerly wind burst, super-rotation



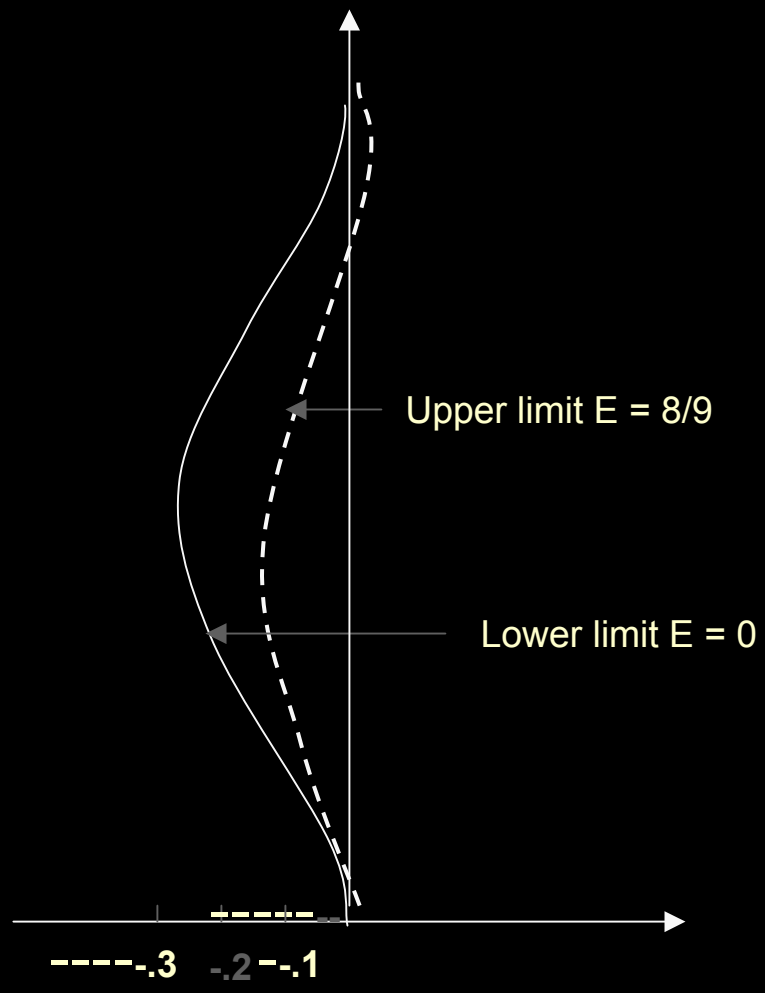
Closed gyre: westerly wind burst, no super-rotation

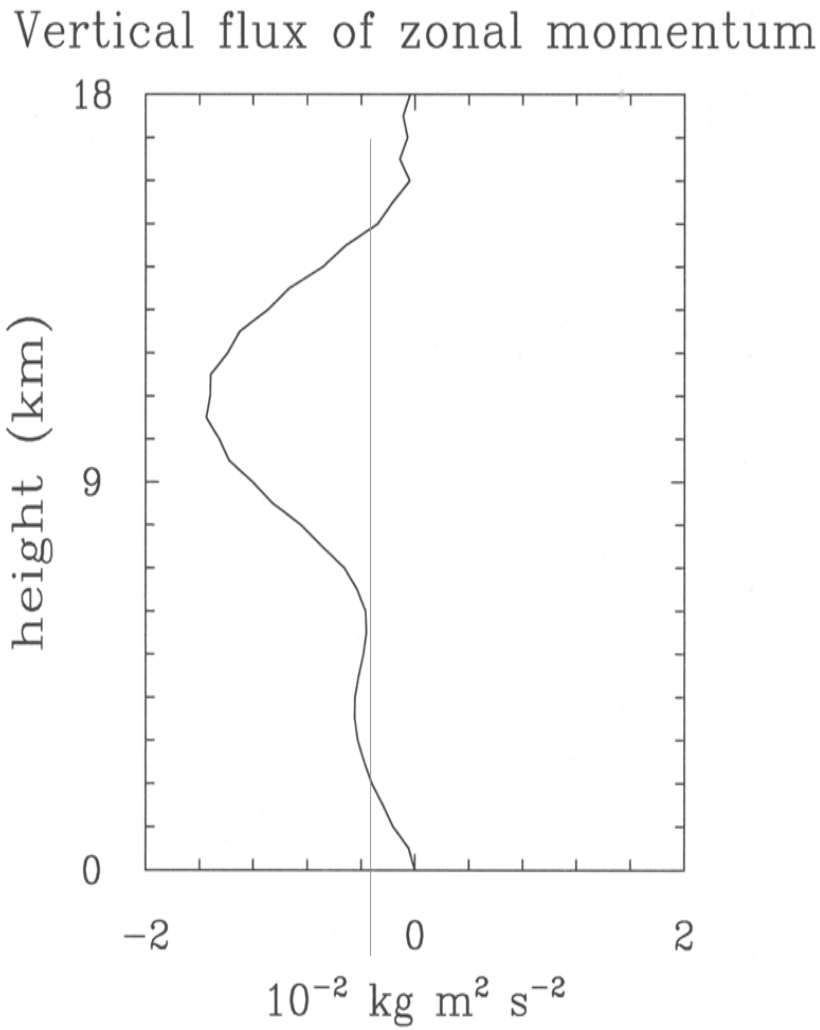


Convectively coupled systems



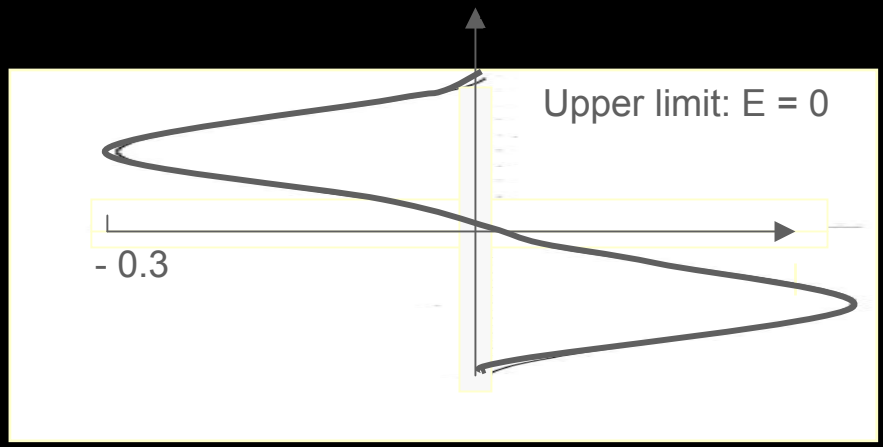
Convectively coupled systems

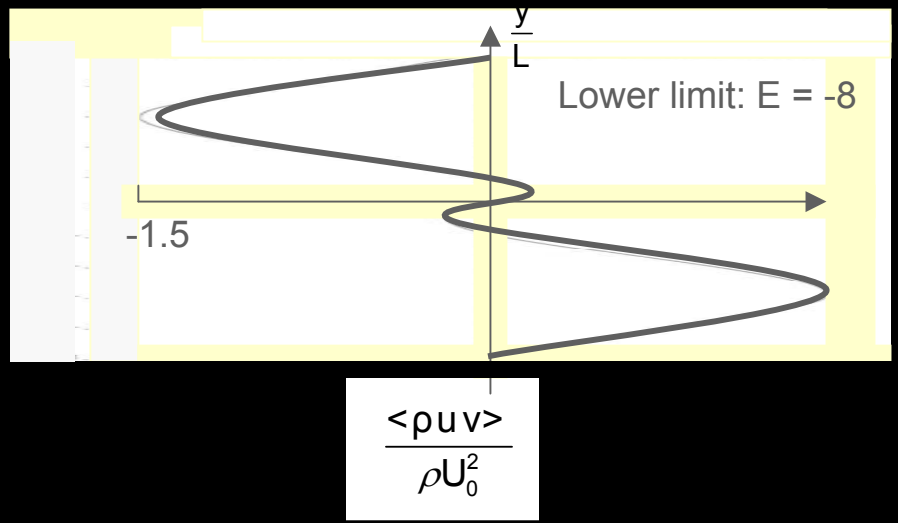


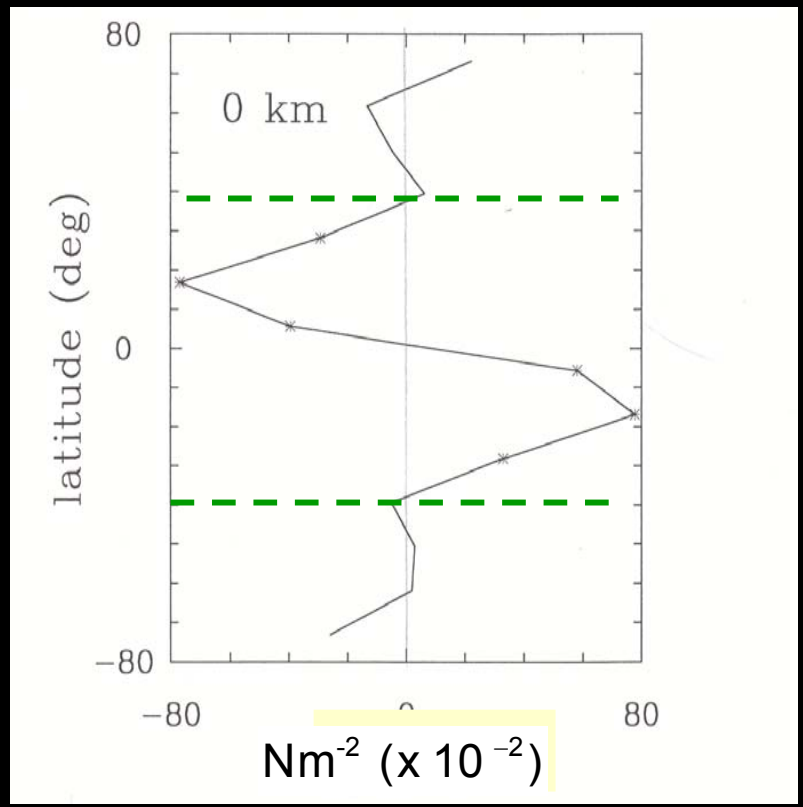


Nm^{-2} (x 10^{-2})

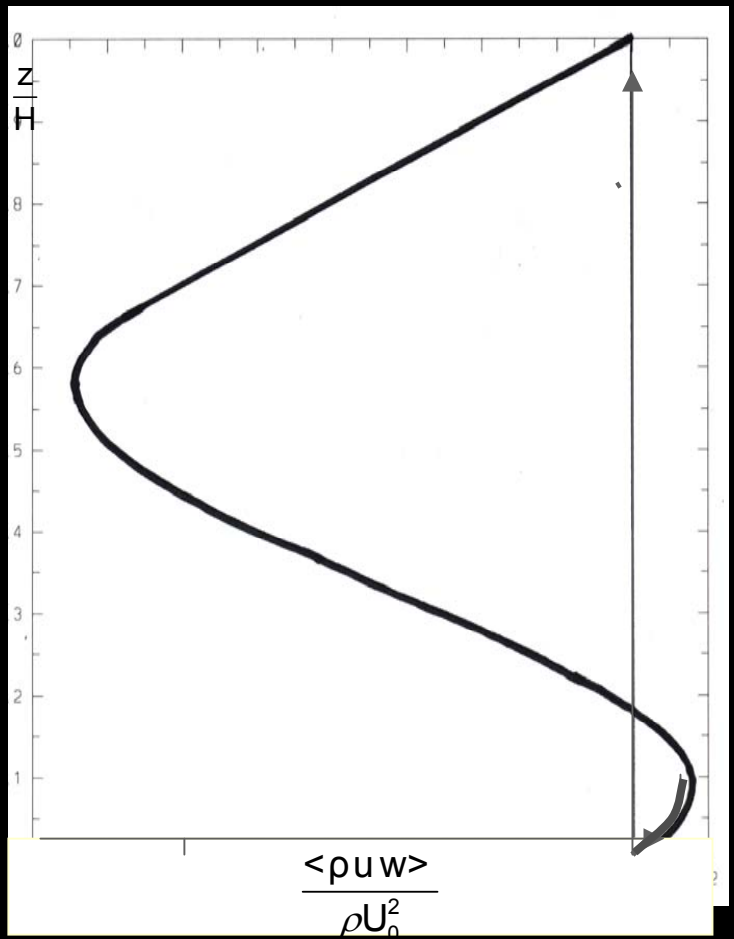
Meridional flux of zonal momentum (MJO-like)

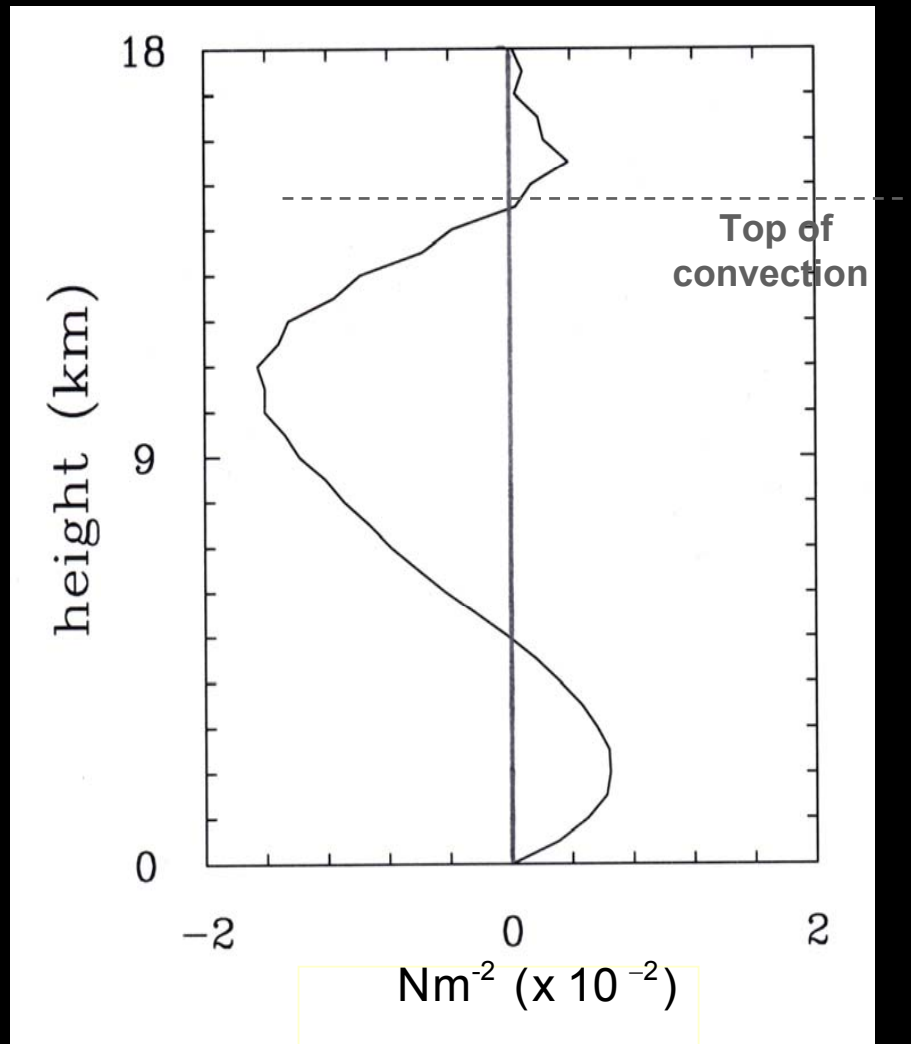






Vertical flux of zonal momentum (MJO-like)



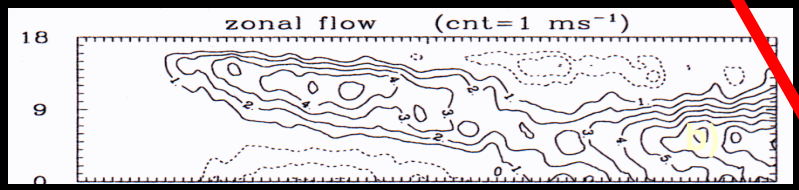


Equatorial super-rotation

Mesoscale momentum transport

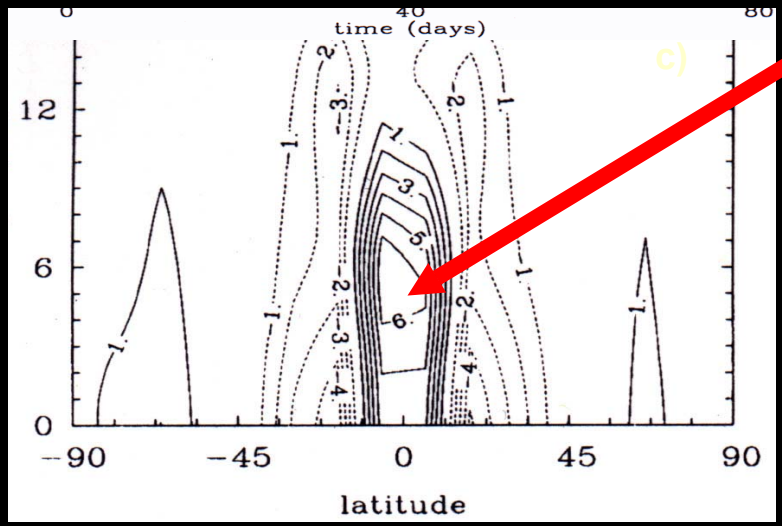
Convectively-coupled system

MJO-like system



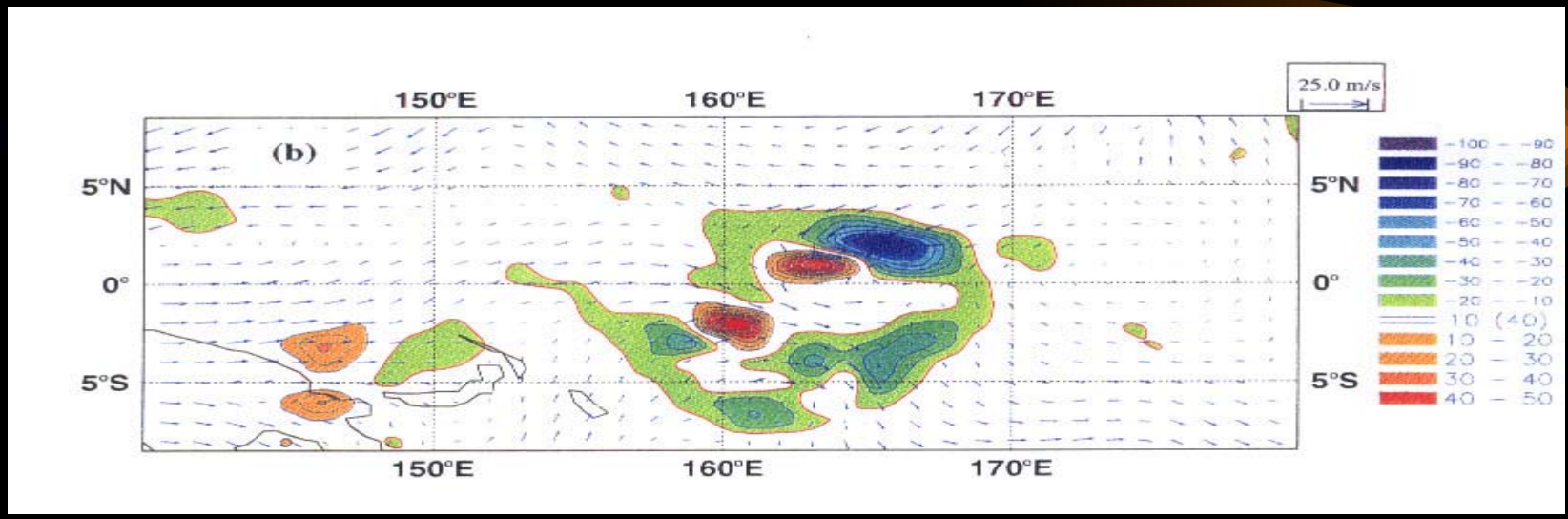
0- 80 days

Meridional momentum transport

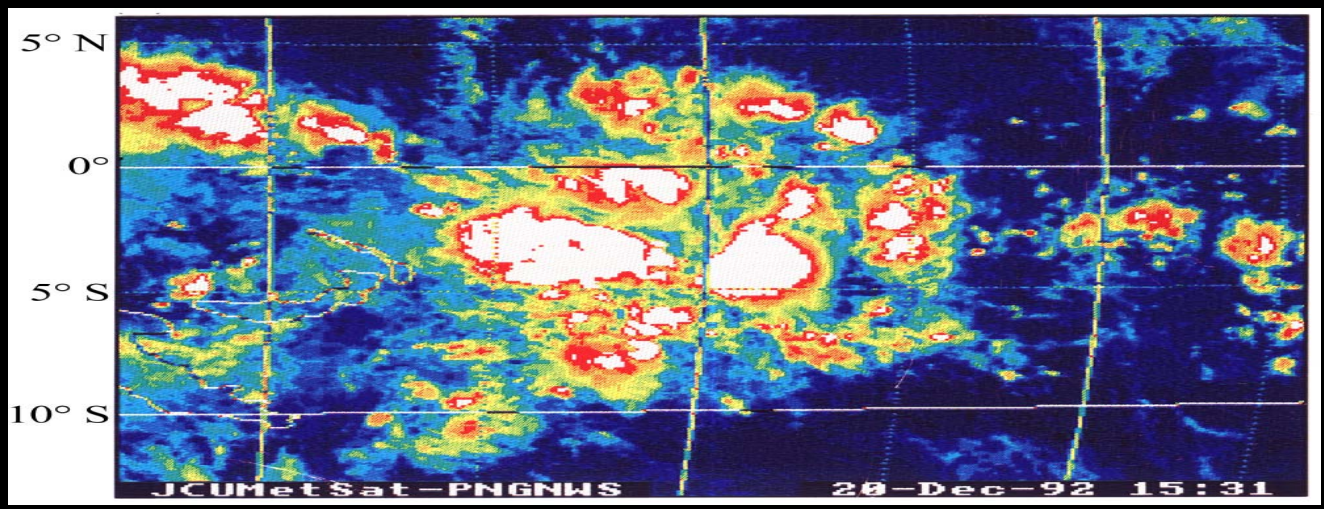


Day 80

Super-cluster in ECMWF T213

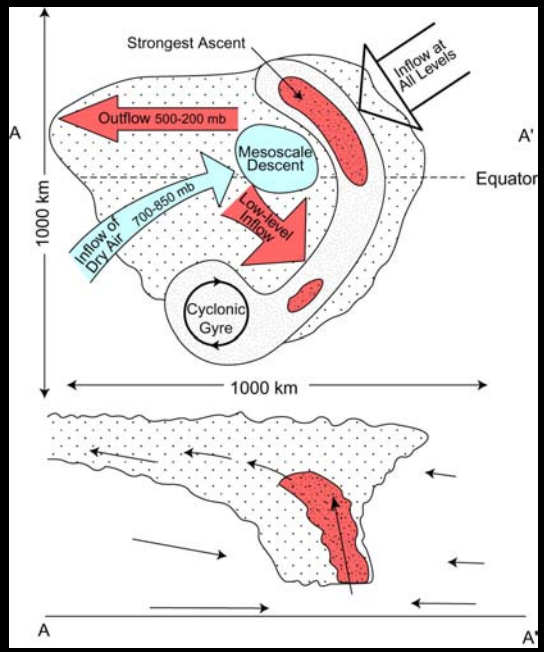


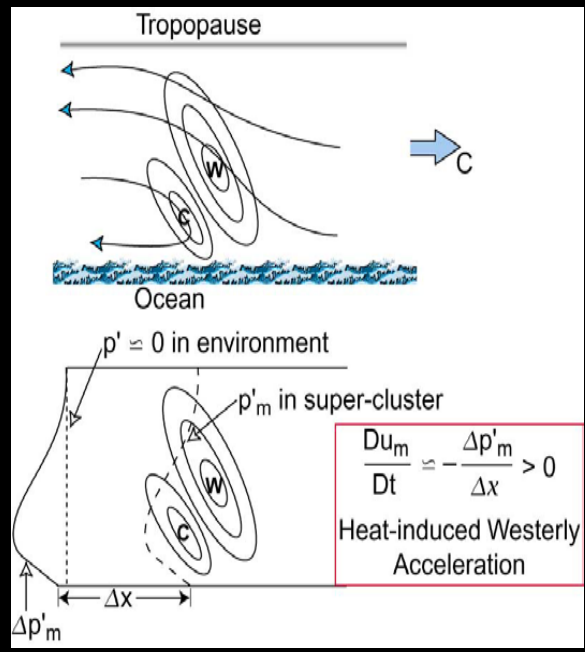
TOGA COARE)



Moncrieff & Klinker (1997)

Structure





Grid-scale convection, not parameterized convection

Heat-generated low → low-troposphere/upper-troposphere eastward/westward acceleration as in squall-lines

Conclusions

- **Theoretical basis for super-parameterization, mesoscale organization of convection a key aspect**
- **Organized convection and MJO dynamics interlocked through remarkable dynamical relationships**
- **Organized convection represented by (surrogate) grid-scale circulations in NWP models**
- **No fundamental impediment to representing organized convection by conventional methods, need to represent systems of scale much larger than the grid**