Idealized Studies of the Intertropical Convergence Zone and its Multi-Level Circulations

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And some new contributions from:

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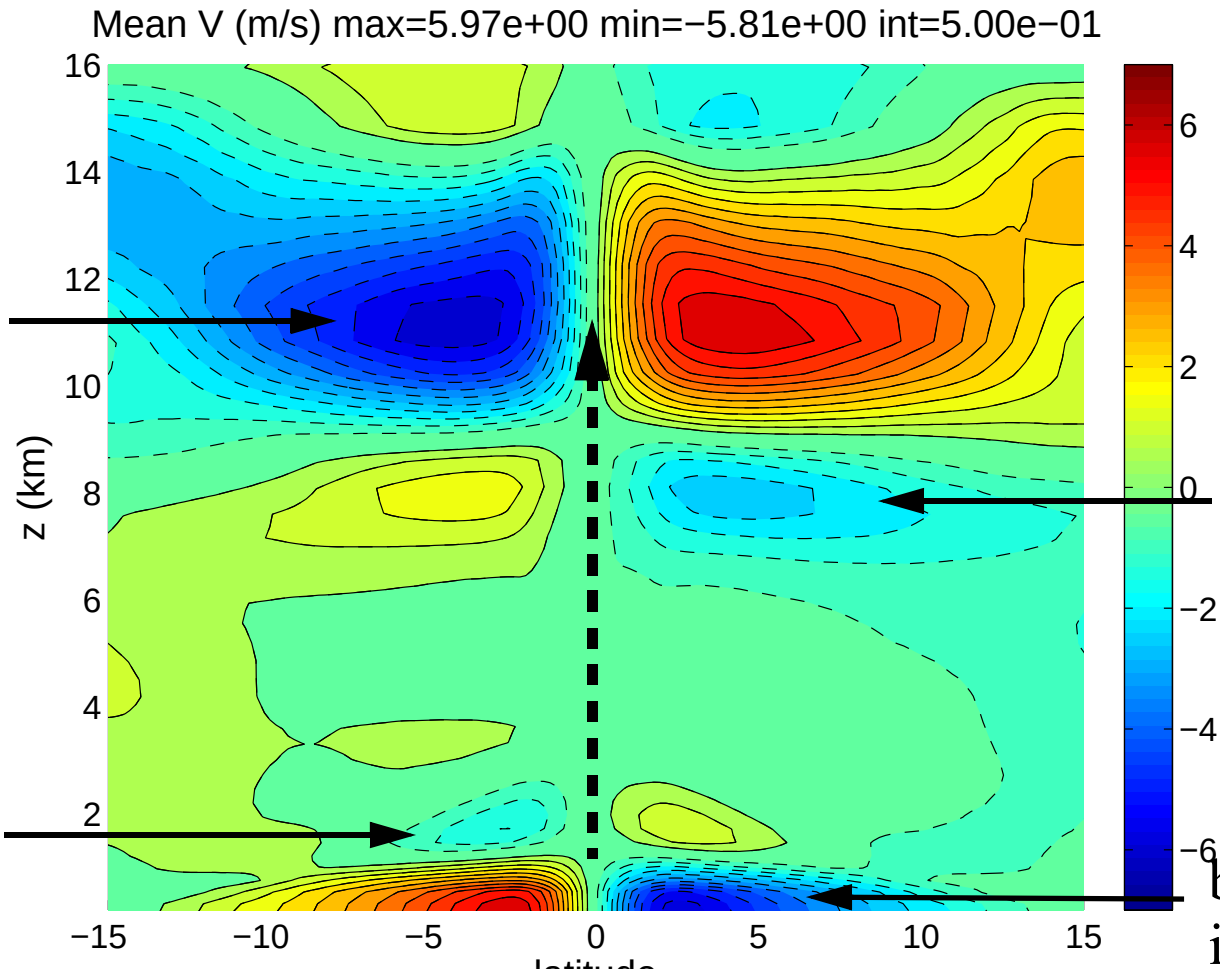
I. What are the "Multi-Level Circulations?"

- A moderately high resolution, idealized simulation of the Intertropical Convergence Zone produces inflow and outflow at many levels:



upper level outflow (ULO)

shallow return flow (SRF)

mid-level inflow (MLI)

boundary layer inflow (BLI)

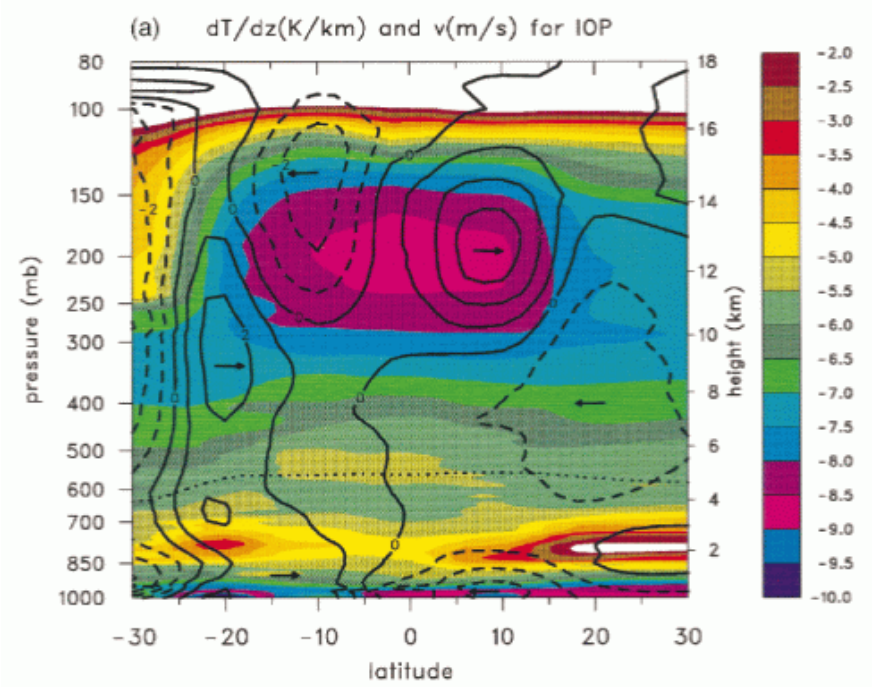
SST maximum

- Other than the familiar BLI and ULO, are these flows real?

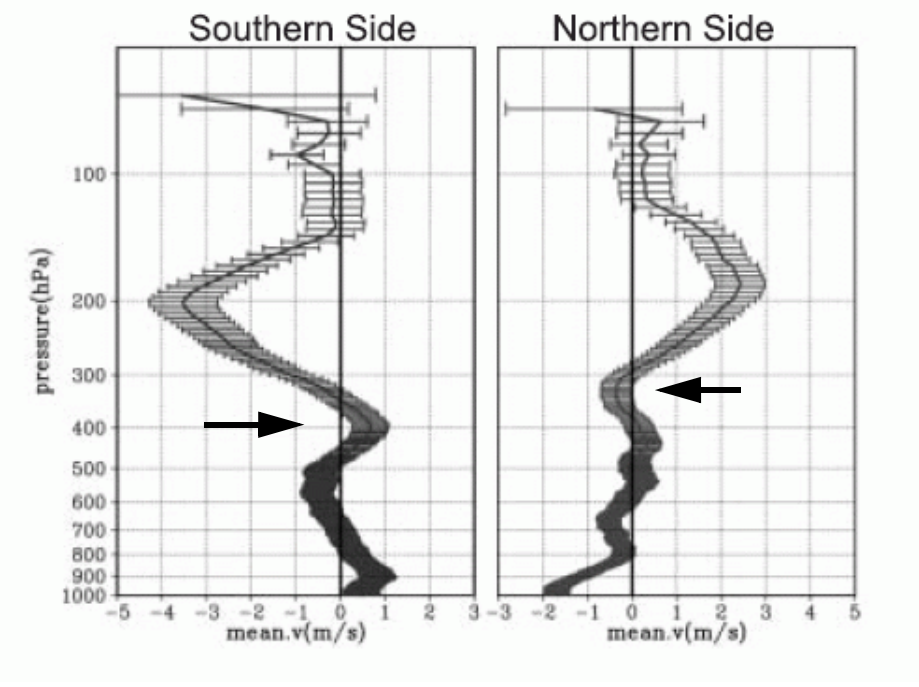
- The SRF was identified in large part by the EPIC 2001 field program, and is documented in Zhang, McGauley and Bond (2004, J. Climate)

  In our previous paper, Nolan, Zhang, and Chen (2007, JAS), we showed that the SRF is a local sea-breeze-like response to strong SST gradients

- What about the mid-level inflow?
  Features like it have been seen around the West Pacific ITCZ:

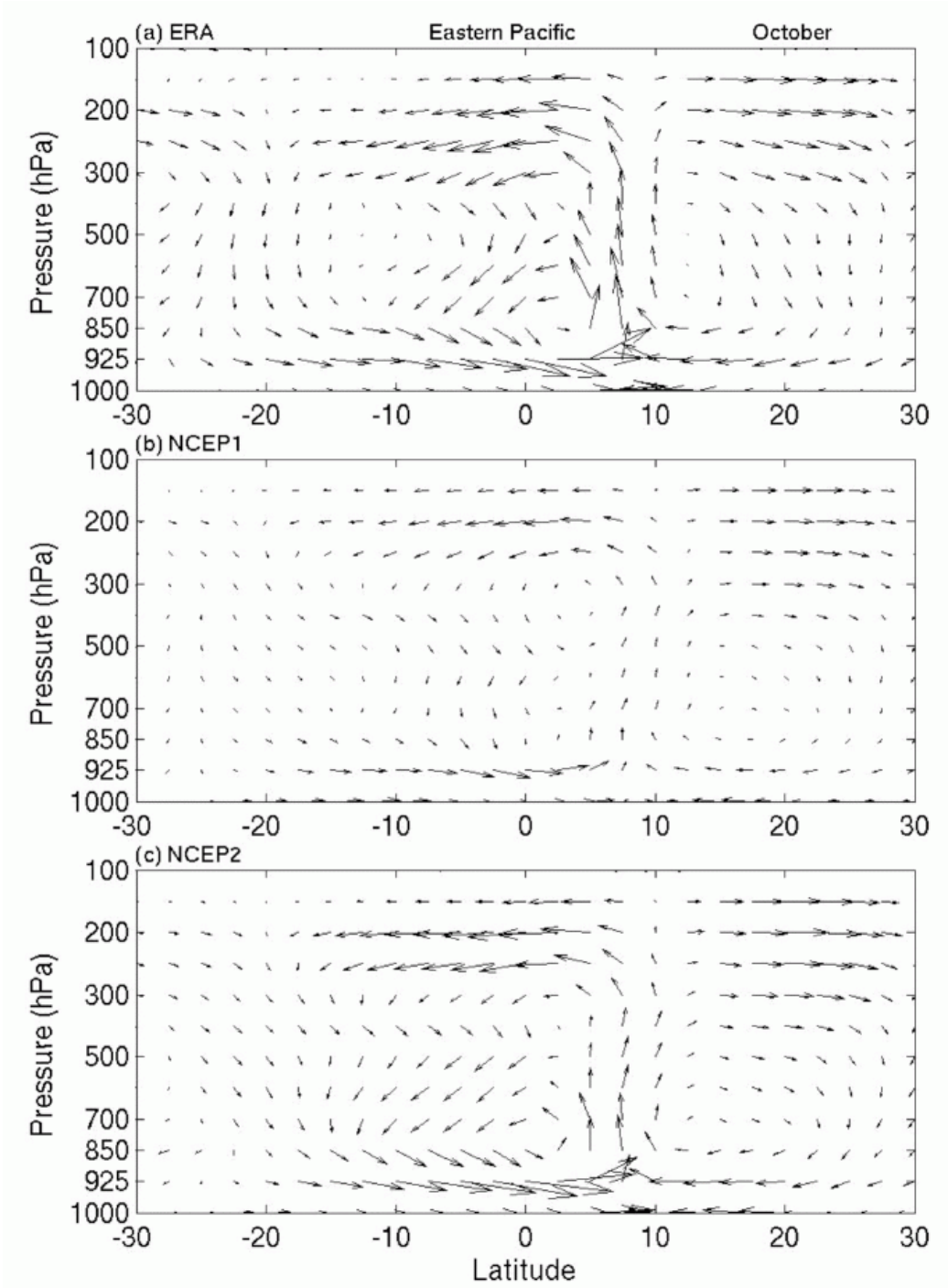


Johnson et al. (1999, J. Climate)



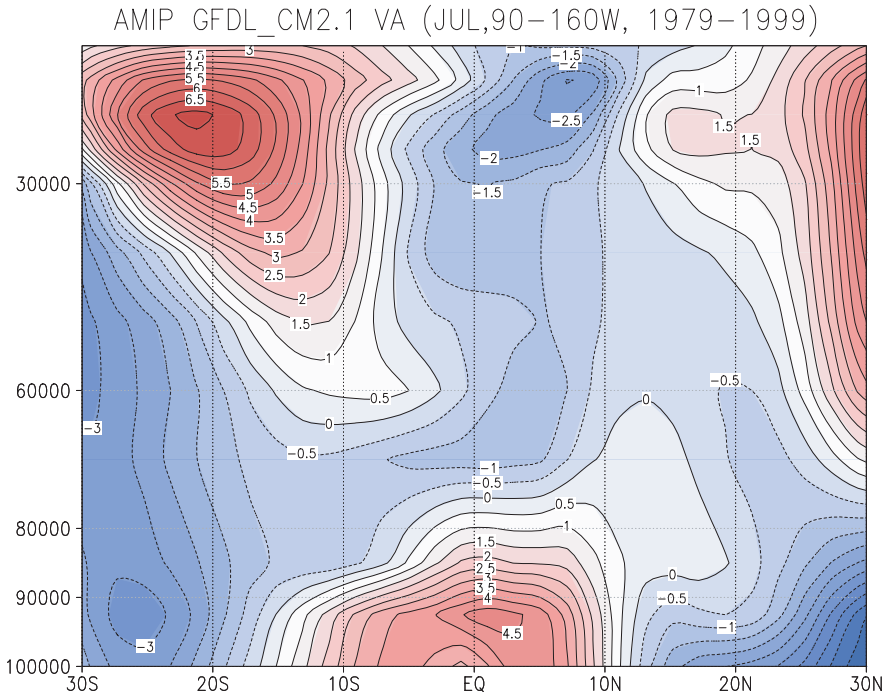
Takayabu et al. (2006, JMS Japan)

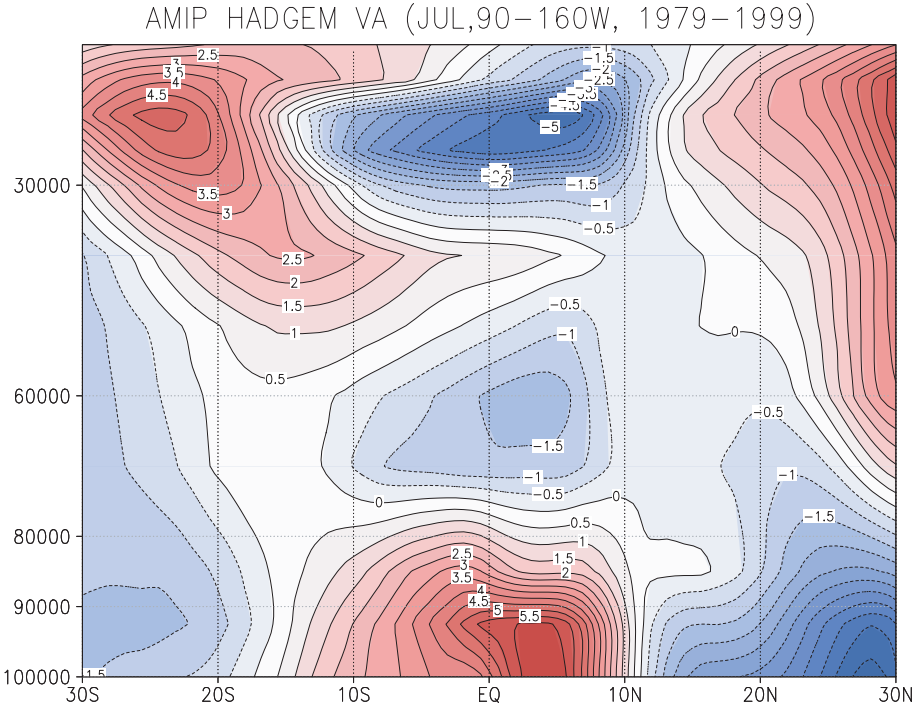
- The SRF and MLI are also apparent in (some) reanalysis data sets:

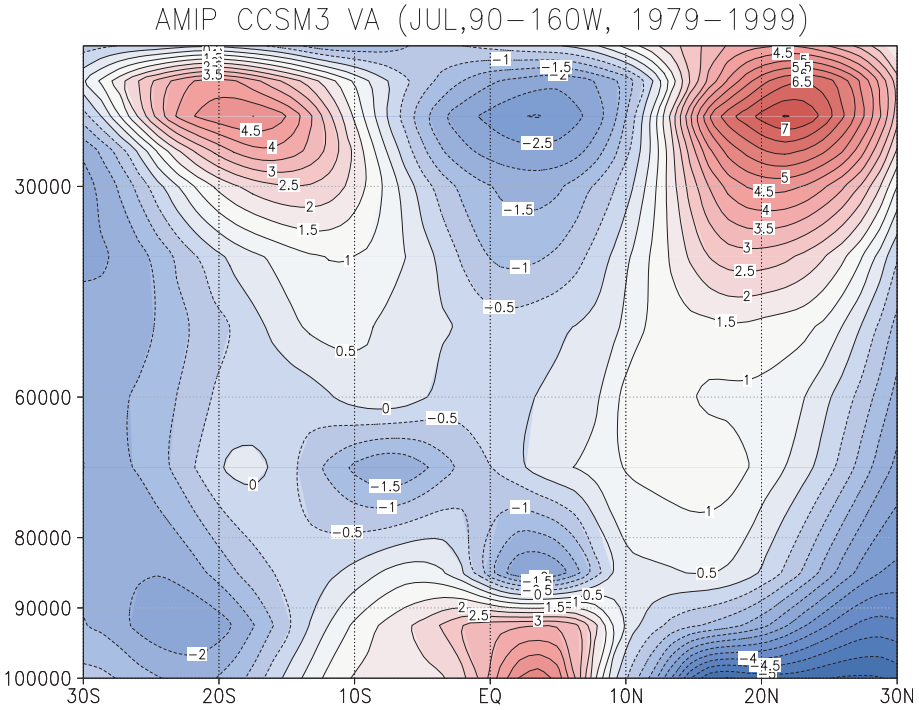


Zhang, Nolan, Thorncroft, and Nguyen (2008, J. Climate)

...and some of the AMIP simulations:







(Analysis and figures provided by Robert Burgman, RSMAS)

II. Idealized Simulations of the ITCZ

- Weather Research and Forecast Model (WRF) Version 2.1.2, with:

- Geometry: tropical channel, 28S to 28N, zonally periodic, 4200 km long

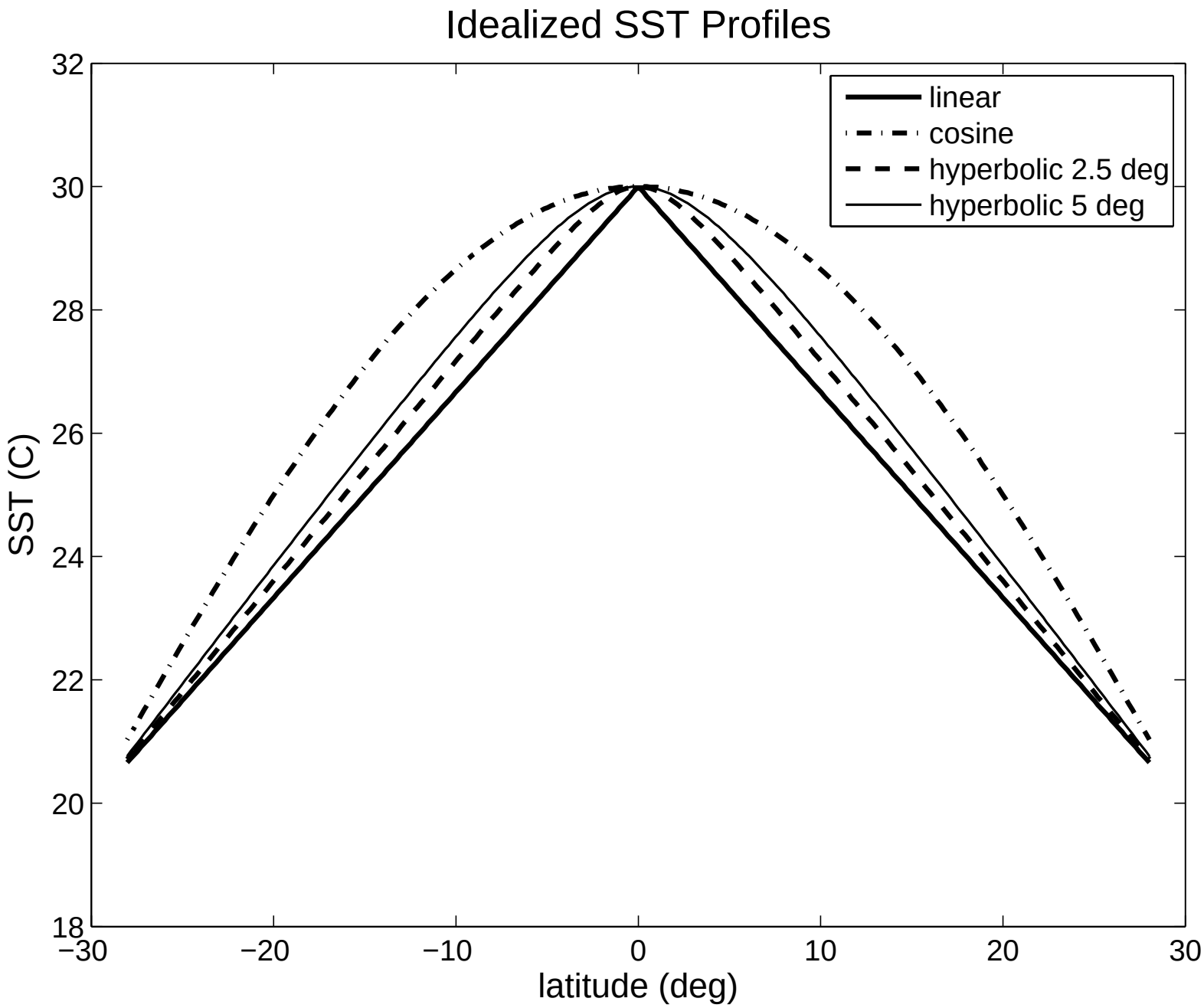
- Resolution: $\Delta x = \Delta y = 21$ km; 40 vertical levels.

- Radiation: Long wave - RRTM scheme (Mlawer et al. 1997)
  Short wave - Goddard scheme (Chou et al. 1998)

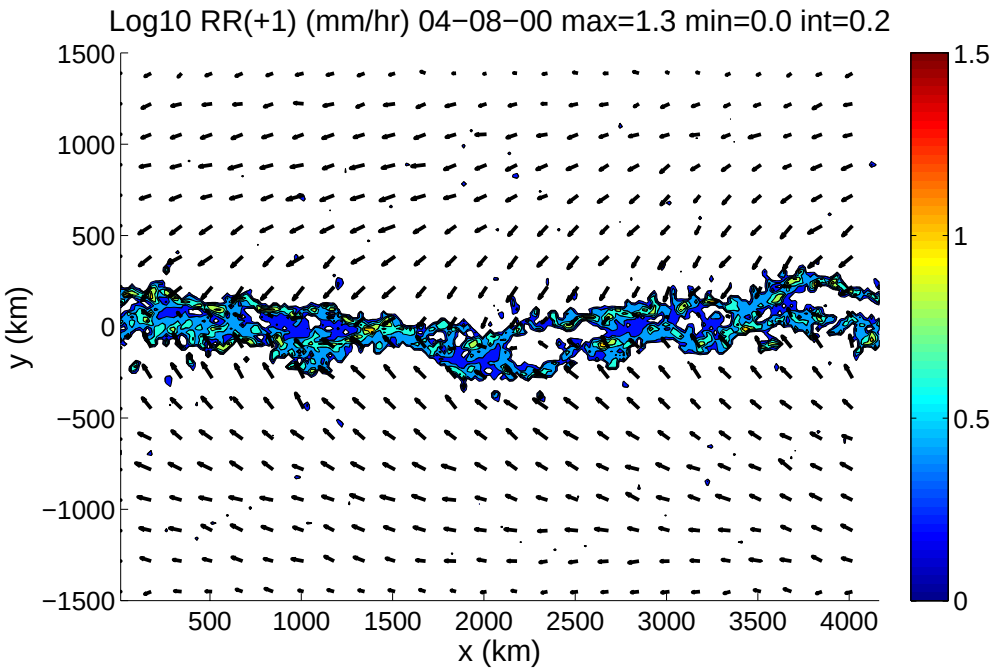
- Boundary layer: YSU scheme (improved MRF scheme, Noh et al. 2003).

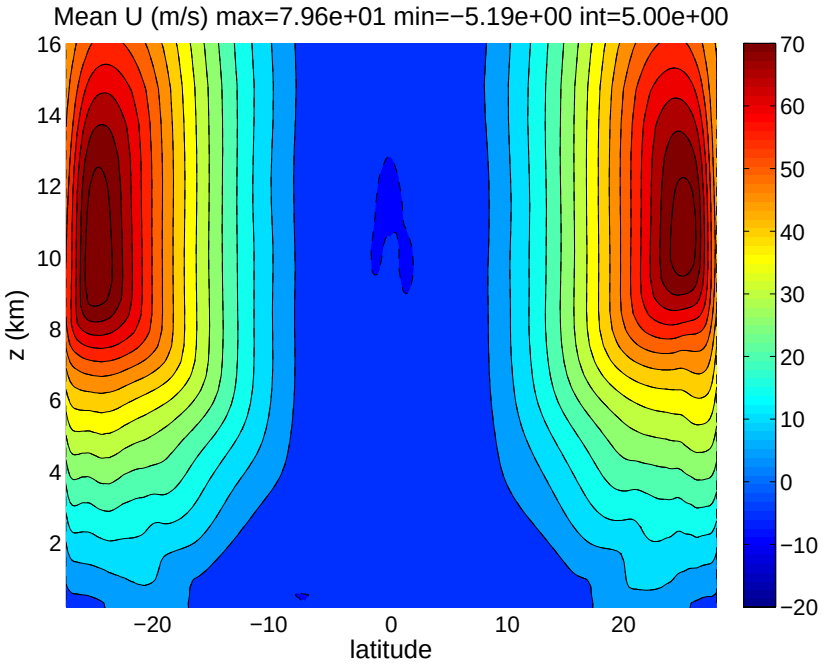
- Microphysics: WRF 5-class microphysics scheme (Hong, Dudhia, and Chen 2004)

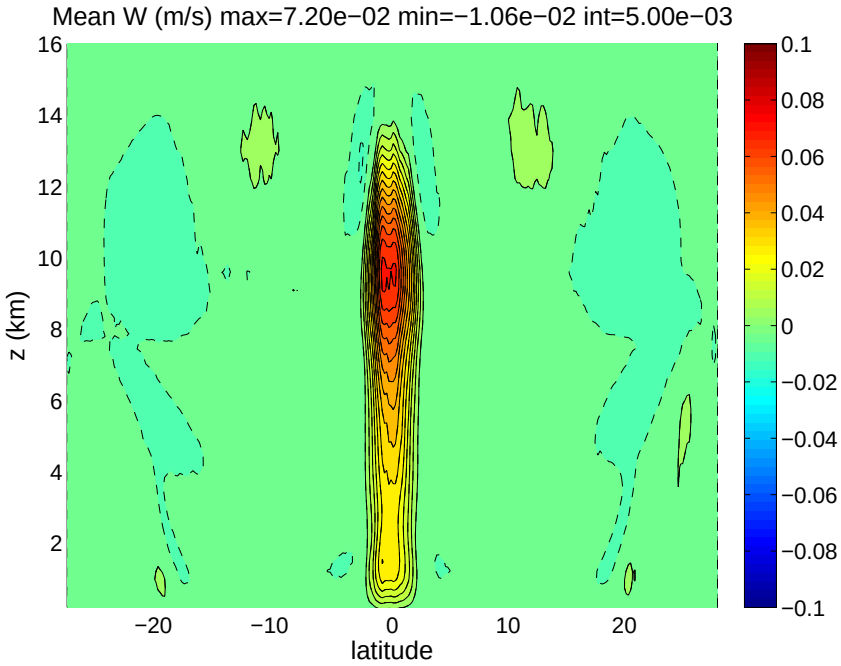
- Cumulus: Grell-Devenyi ensemble (Grell and Devenyi 2002)
  (averages over 144 combinations of parameters for three different convective triggering mechanisms)

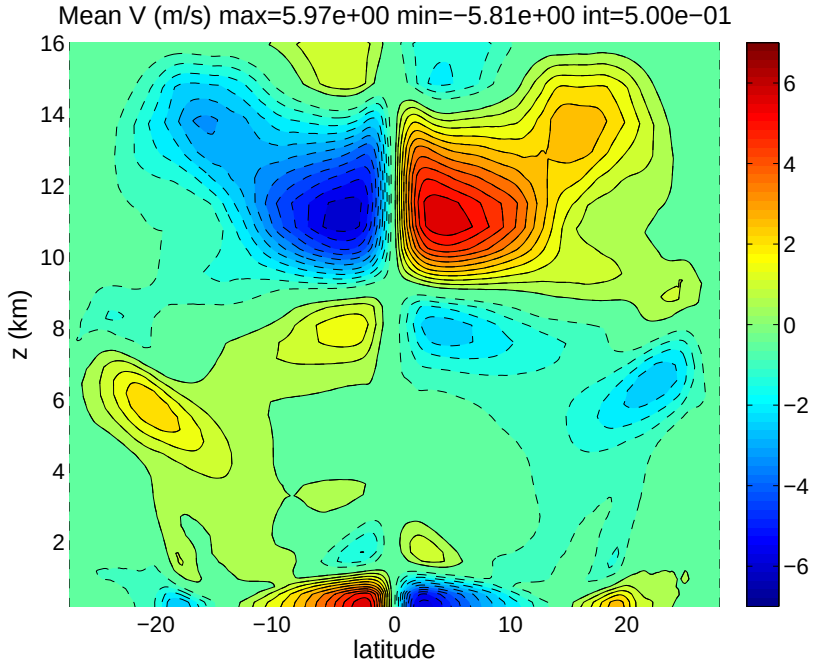

Idealized SST Profiles
linear
cosine
hyperbolic 2.5 deg
hyperbolic 5 deg
SST (C)
latitude (deg)
32
30
28
26
24
22
20
18
−30
−20
−10
0
10
20
30

Hyperbolic SST profile, $d = 2.5$ deg (narrower profile)

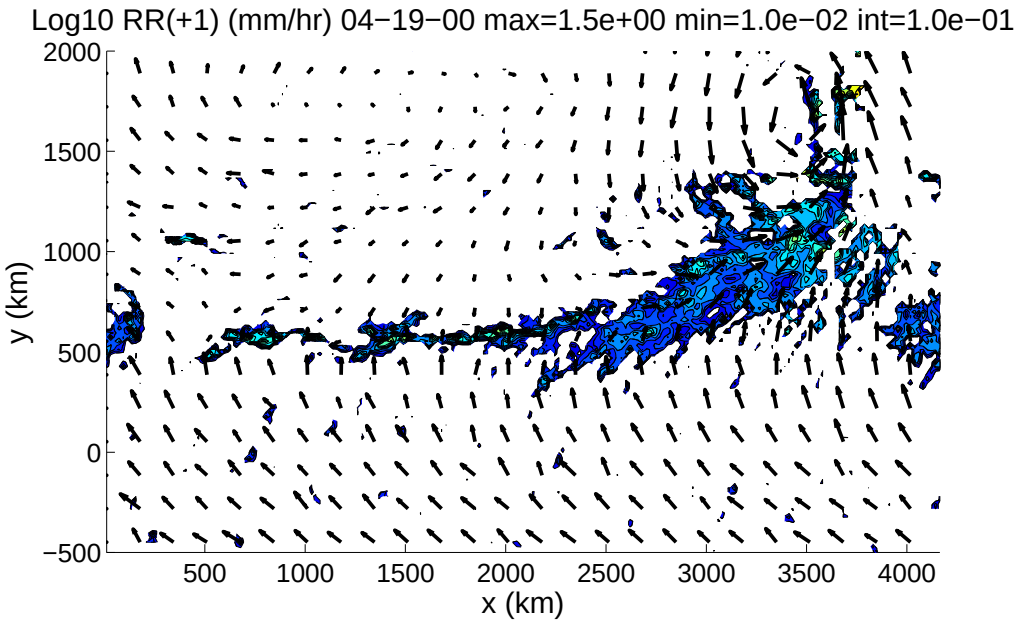


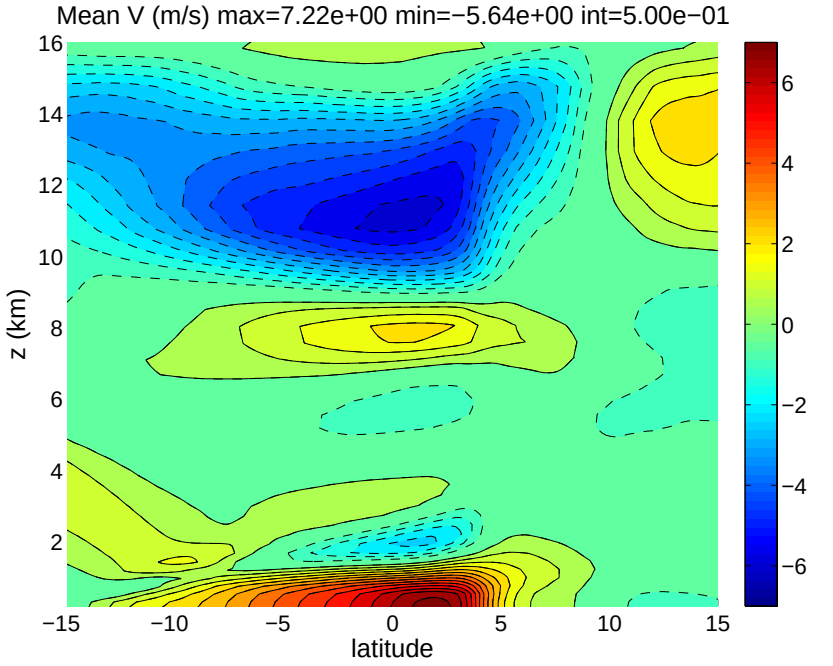


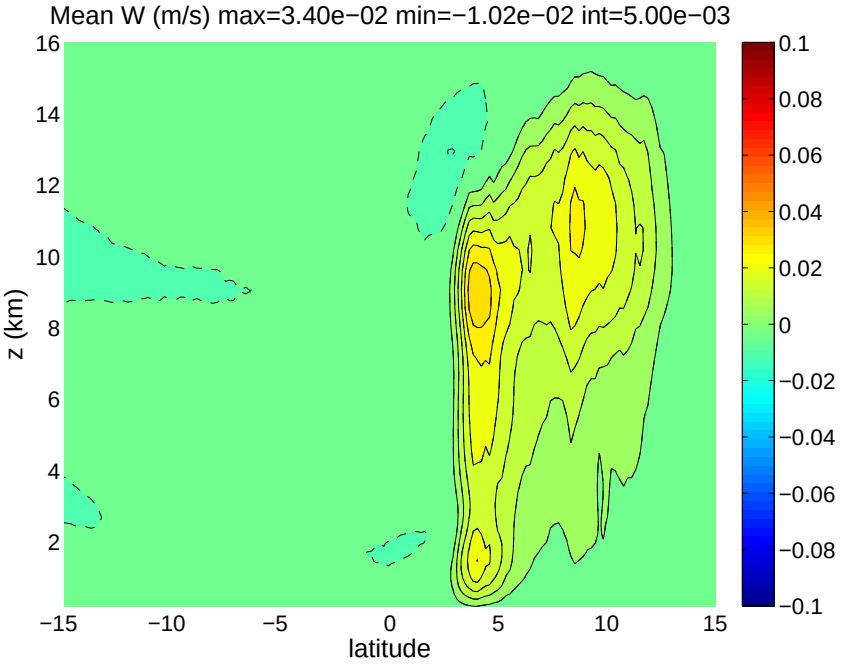


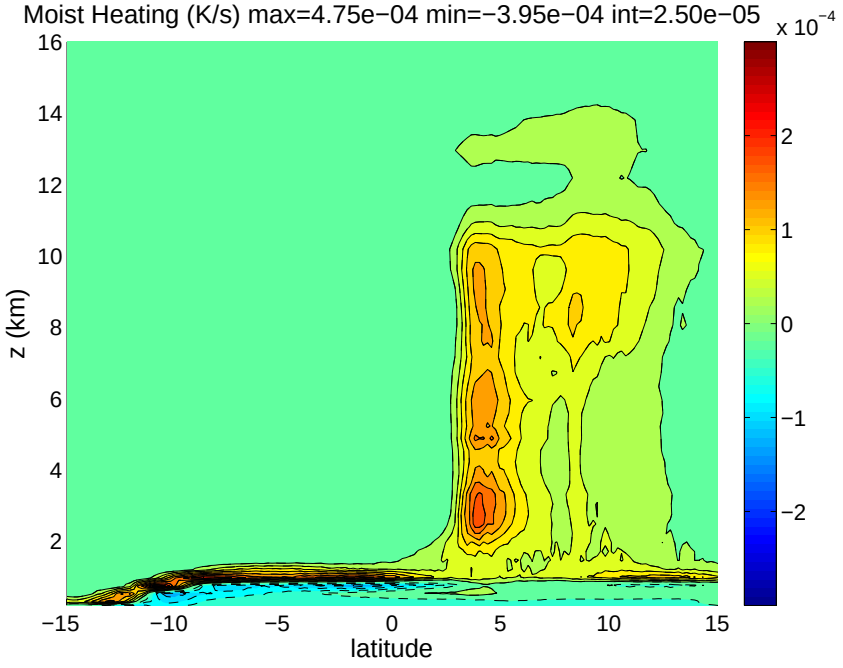


Hyperbolic, SST Maximum at 8N



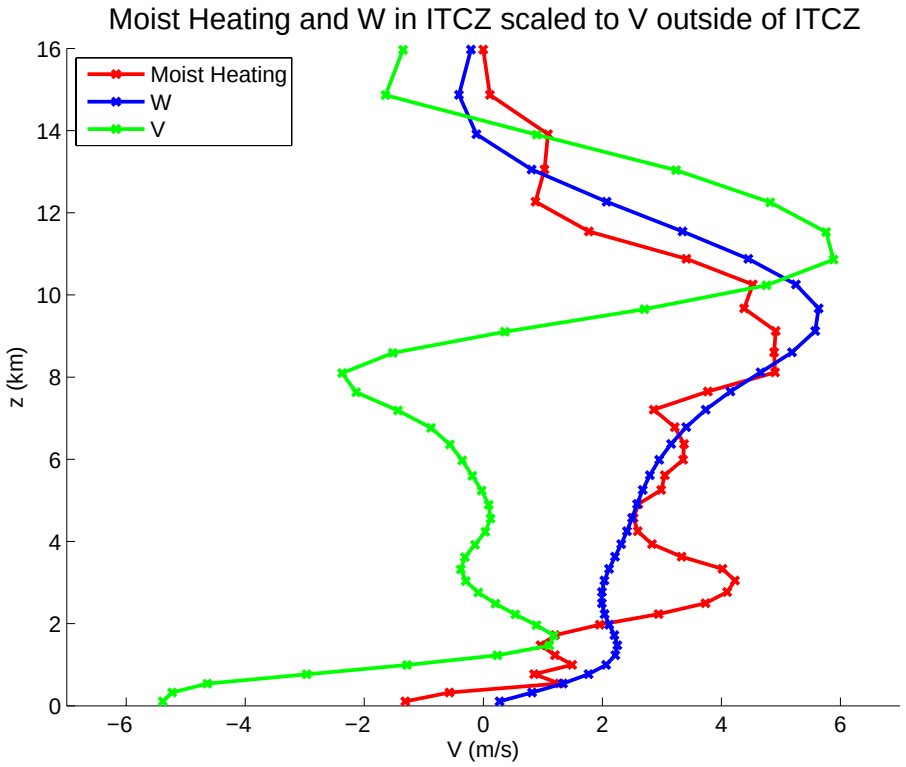


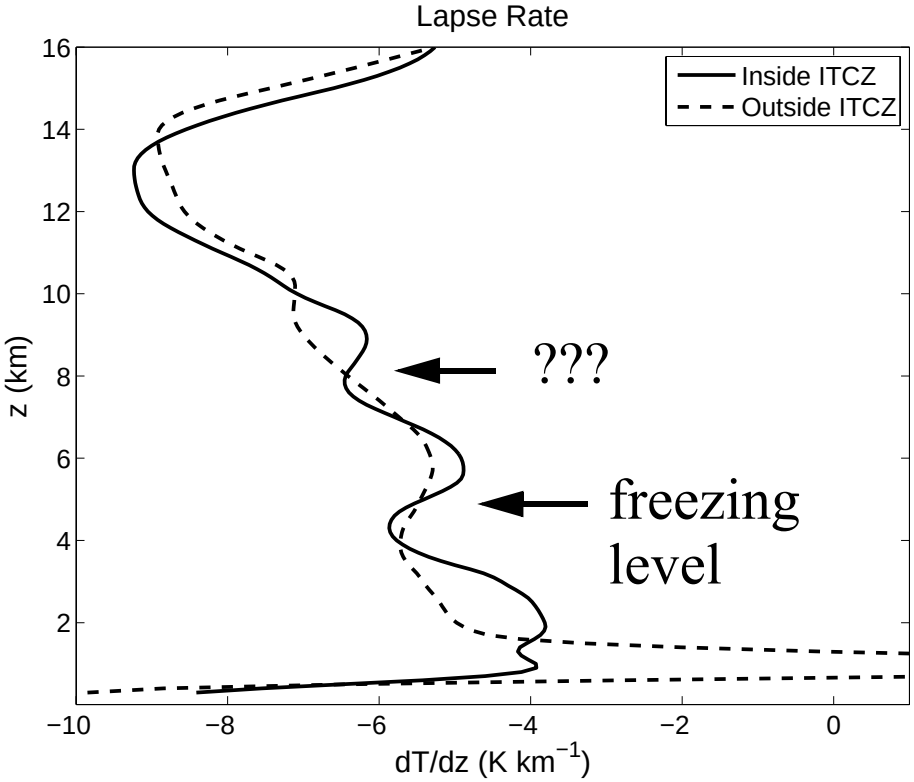




- Mapes (2001, QJRMS, "Water's two height scales...") first identified the MLI.

He proposed it is associated with the upper level heating maximum:





- The MLI is *very* robust with/without cumulus parameterization, with/without L_f, with/without interactive radiation, etc...

III. Convectively Coupled Waves

linear ("peaked") SST

anomalies 2.5S to 2.5N

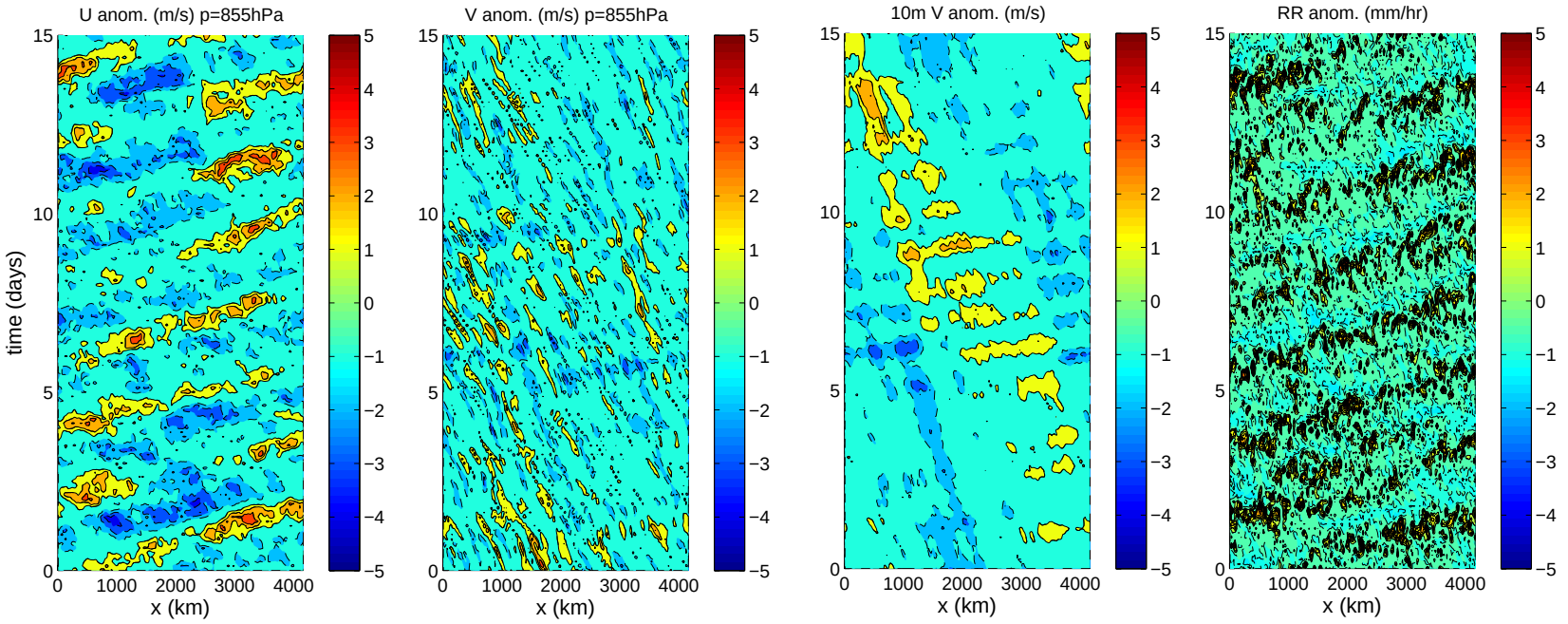
850 U

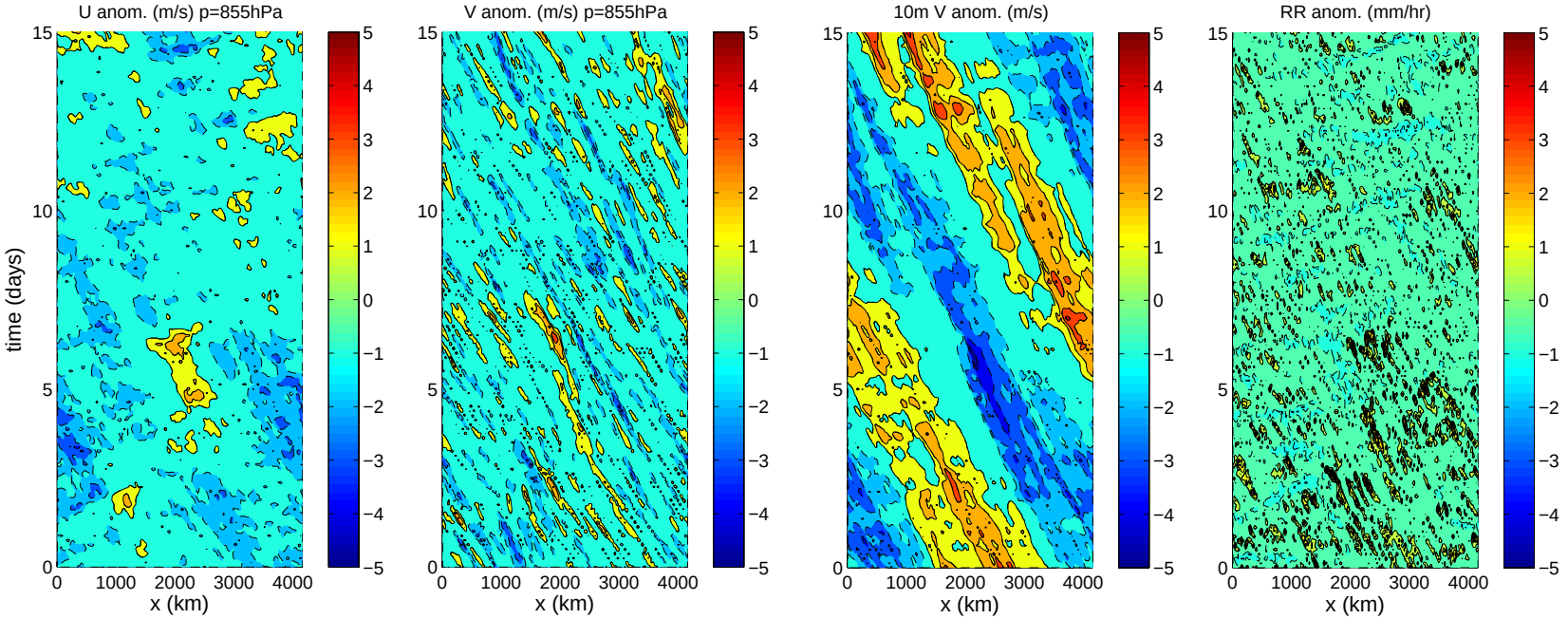
850 V

Surf. V

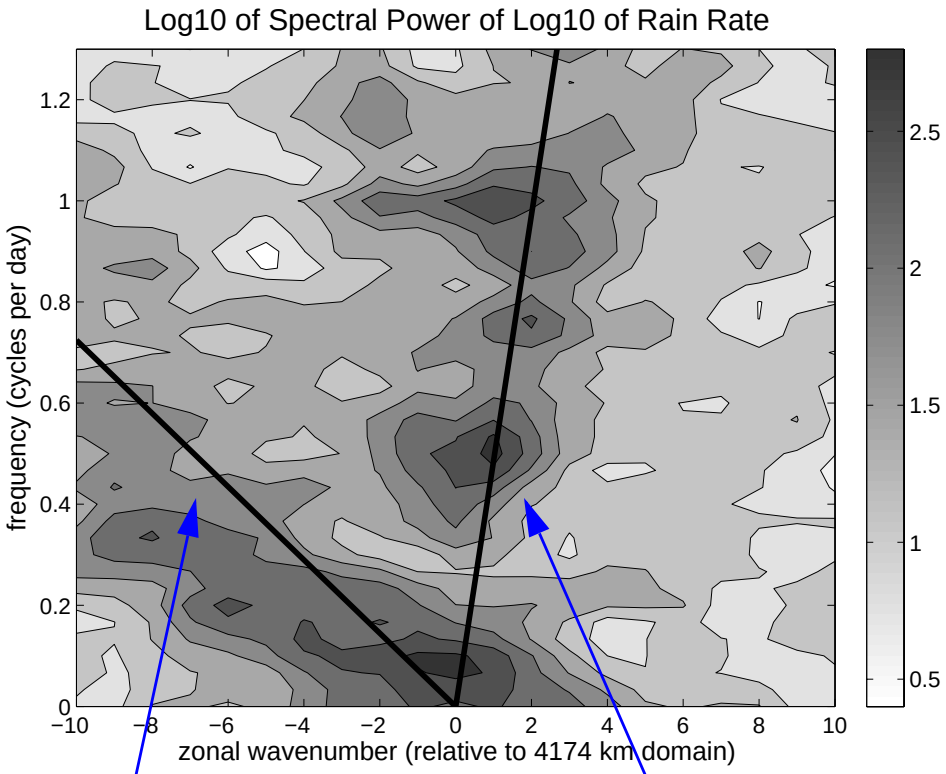
Rain

hyperbolic SST

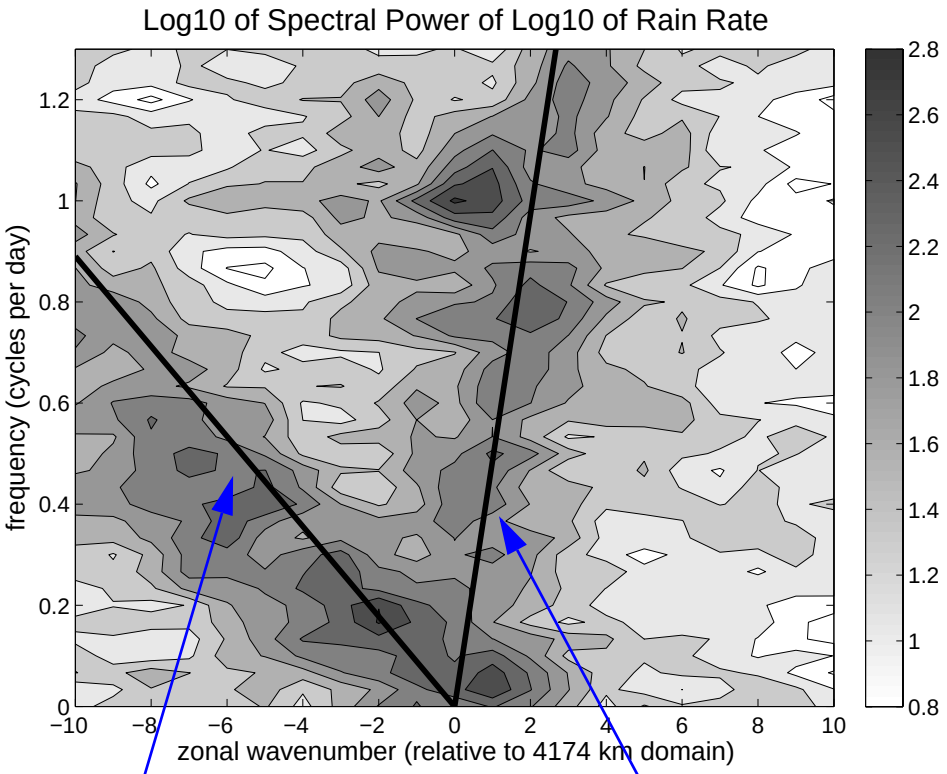




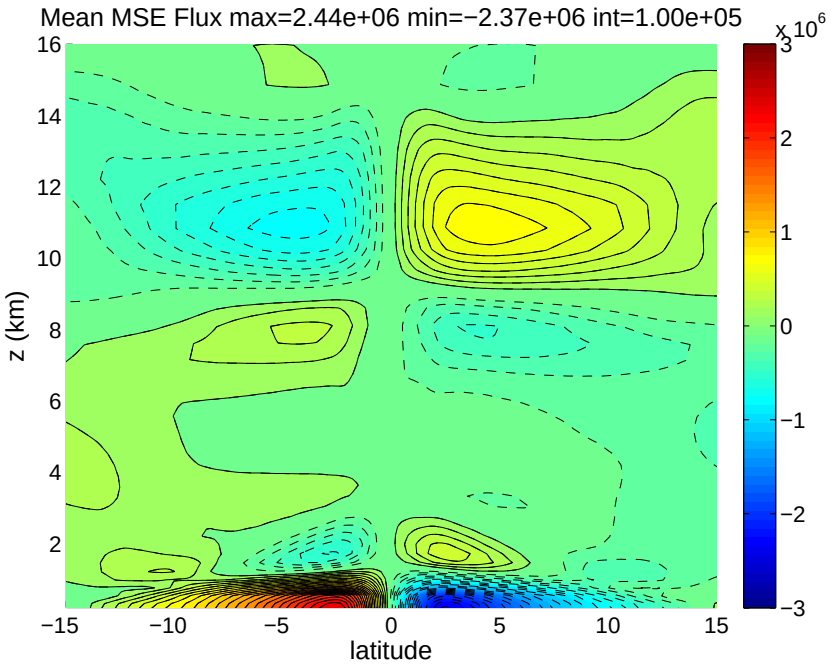
linear ("peaked") SST profile

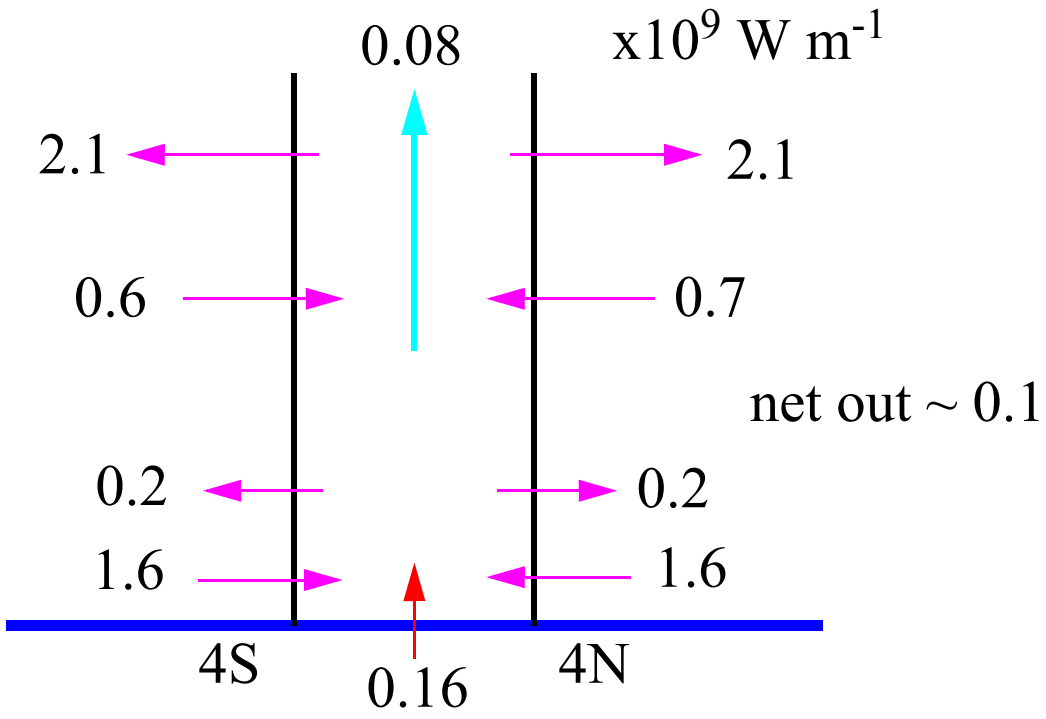


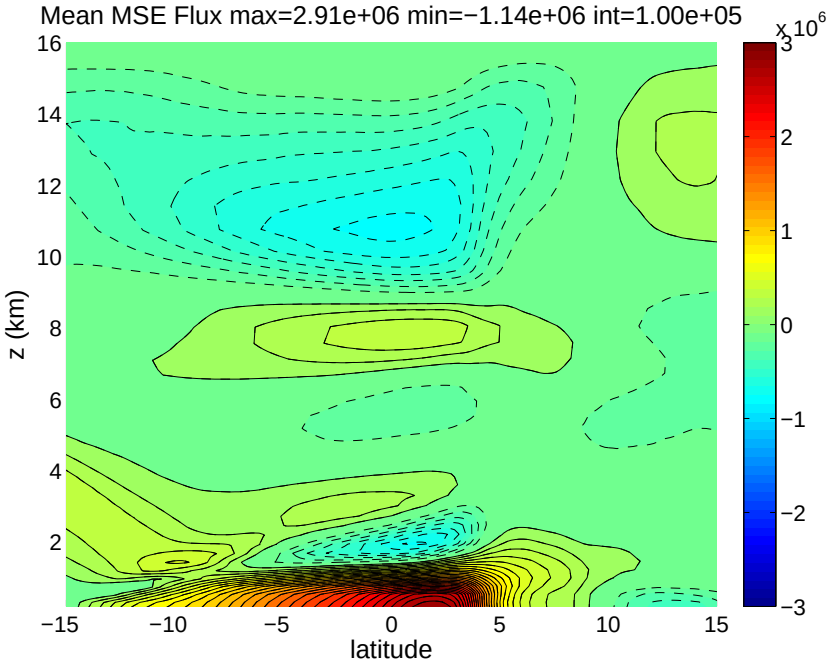
hyperbolic SST profile

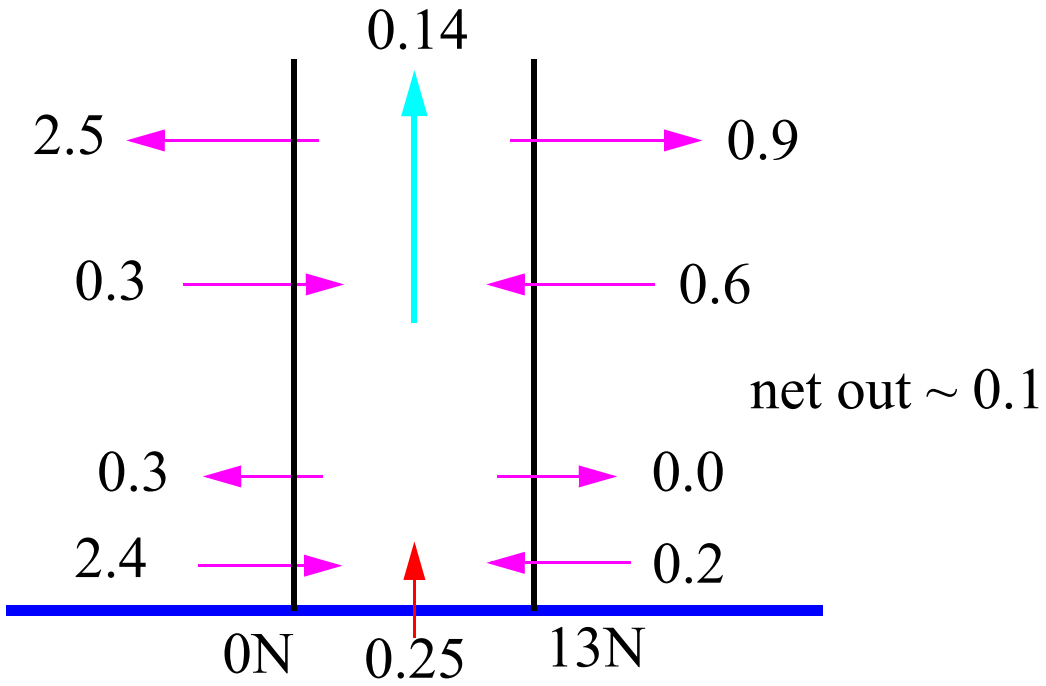


IV. Moist Static Energy



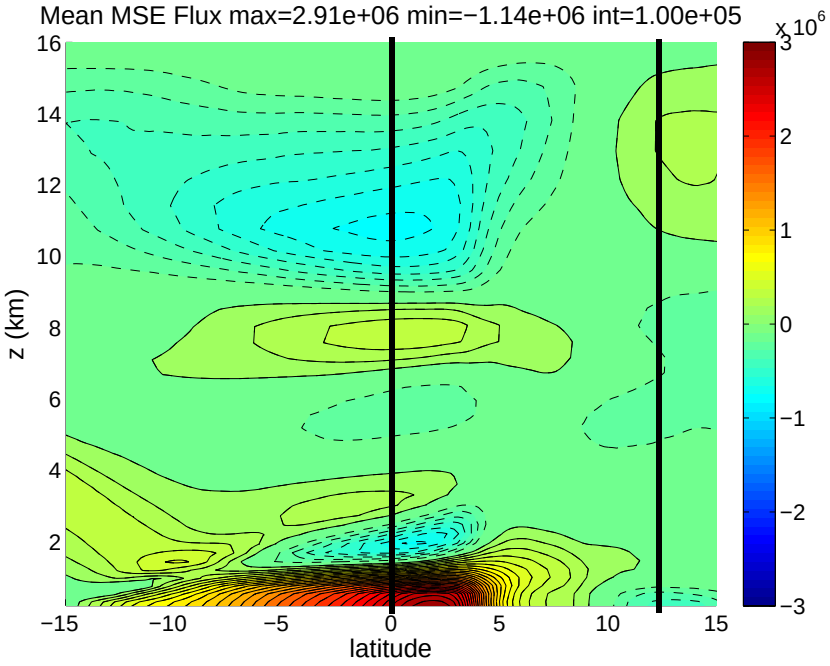


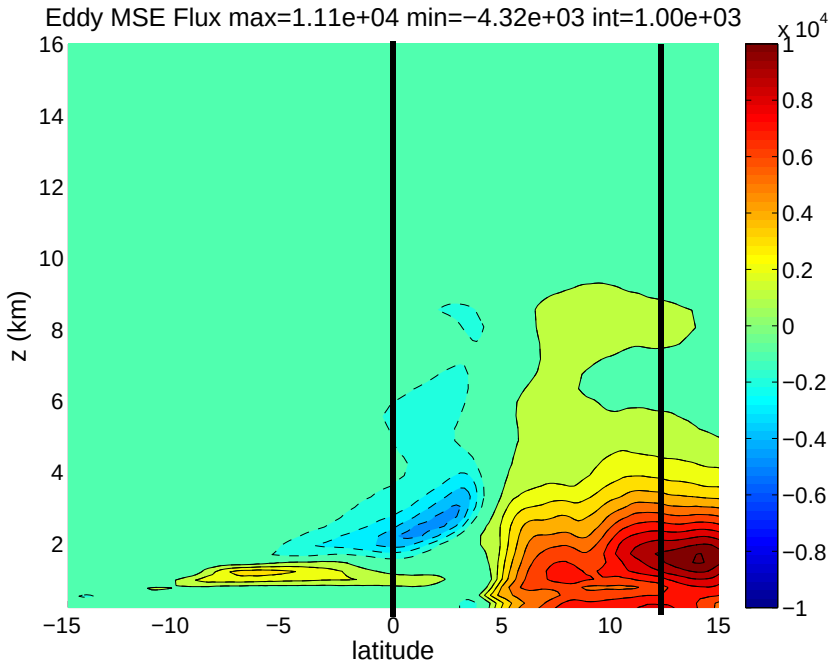




Eddy Fluxes of MSE:

$$[\overline{vh}] \qquad [\overline{vh}] - [\bar{v}][\bar{h}] = [\bar{v}^*\bar{h}^*] + \overline{[v'][h']} + [\overline{v'^*h'^*}]$$

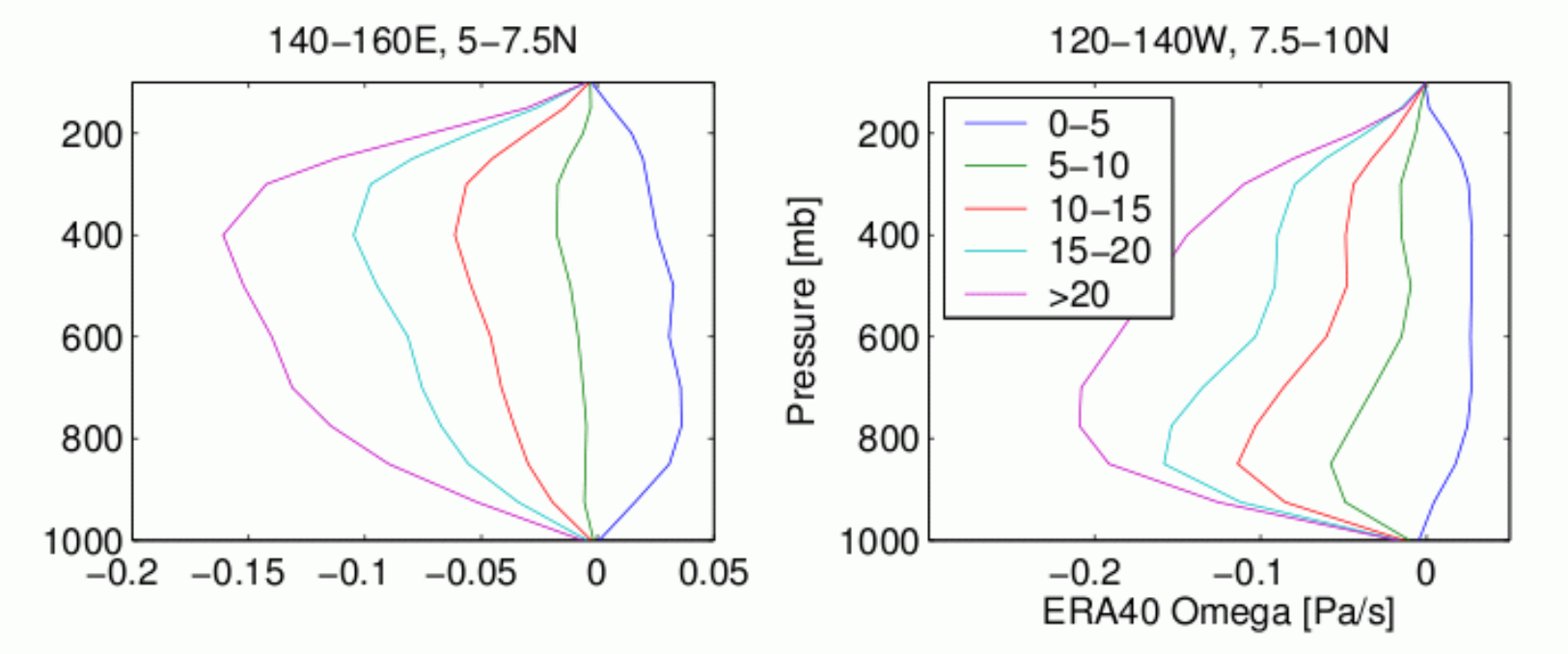


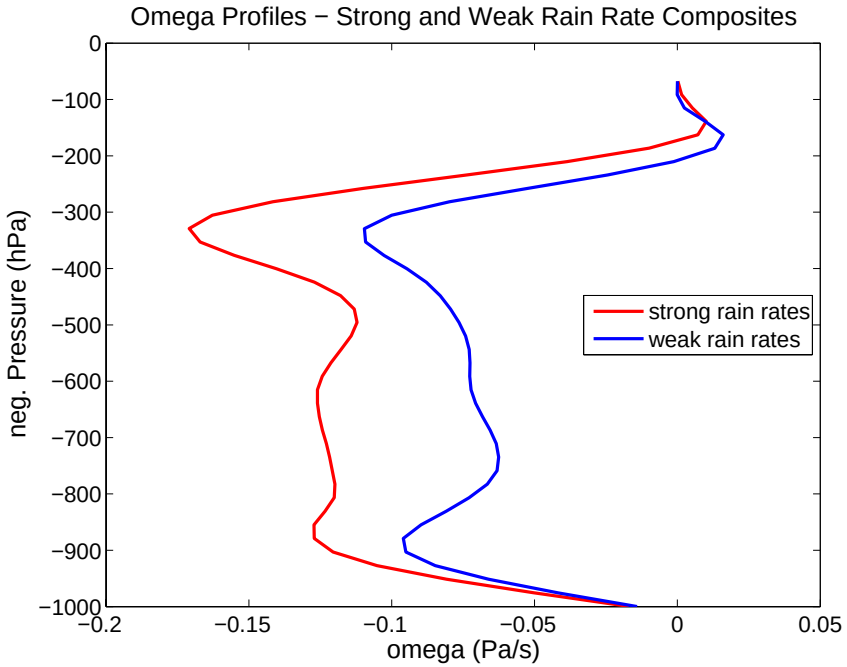


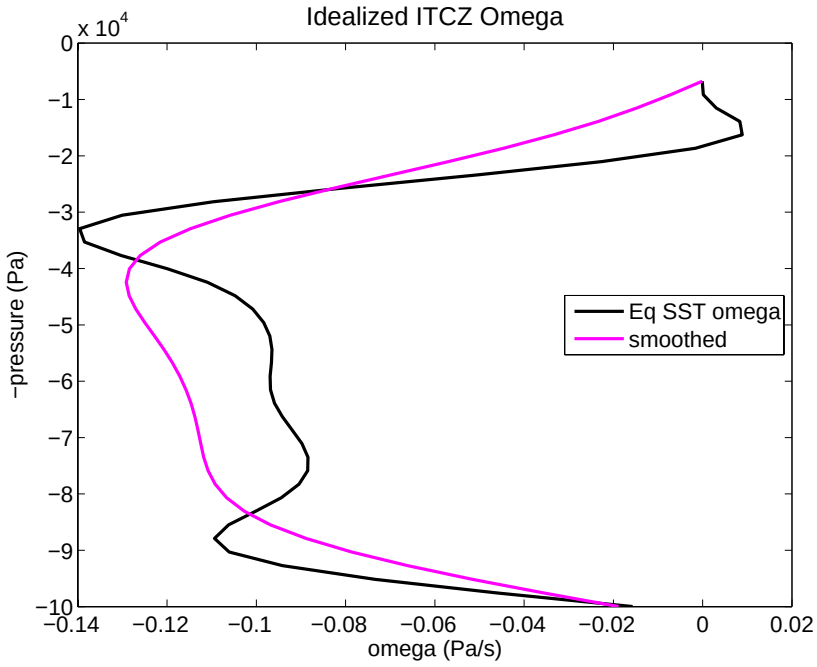
net out: 4.3×10^7 net out: 6.3×10^7

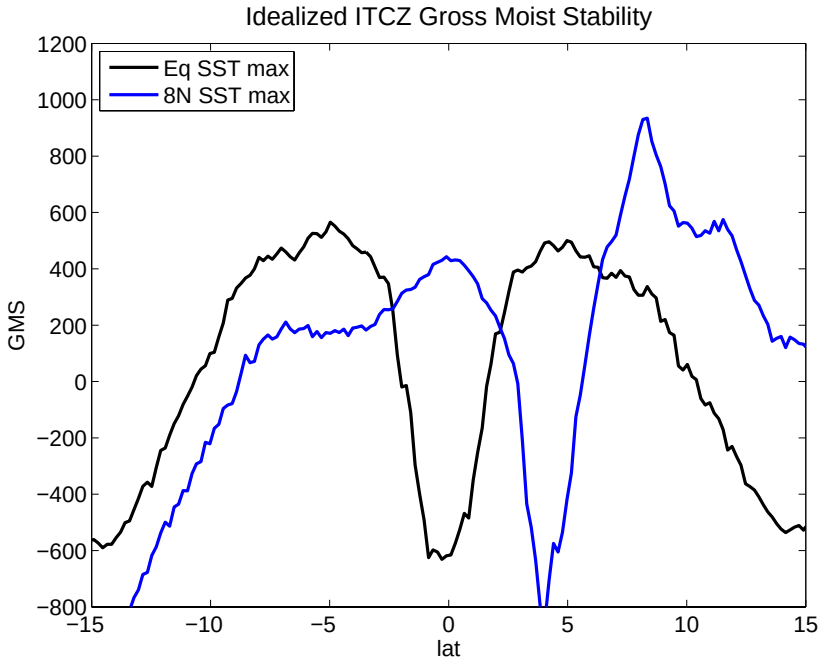
eddy out: 0.76×10^7 eddy out: 4.2×10^7

Back and Bretherton (2006, GRL)
WestPac and EastPac Omega Profiles



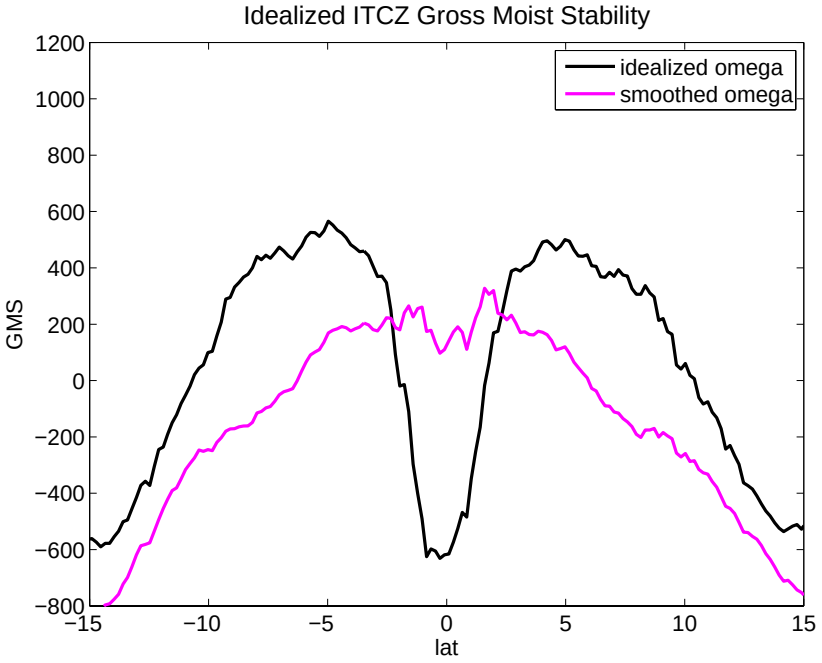


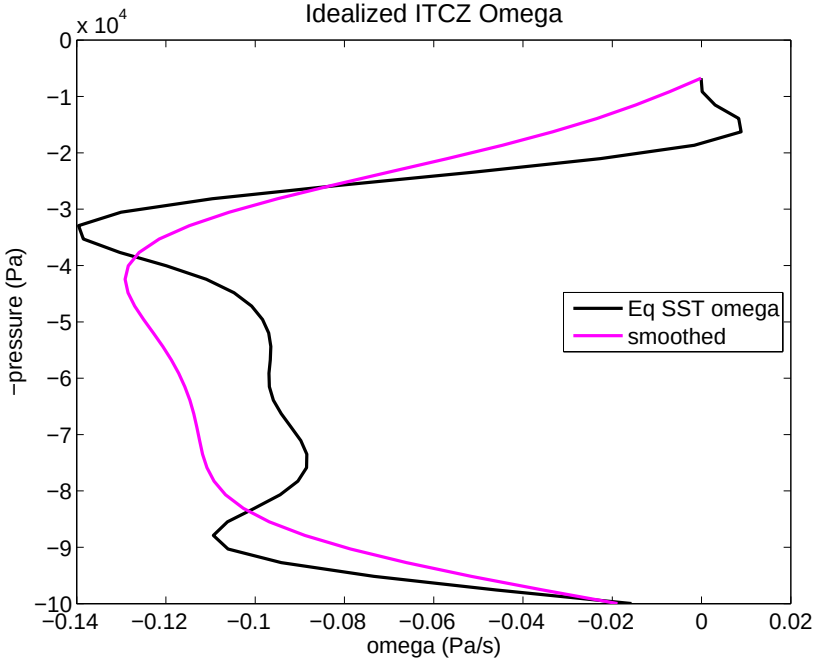




* "Standard" gross moist stability calculation shows narrow region of negative *M* inside ITCZ and broad positive *M* outside

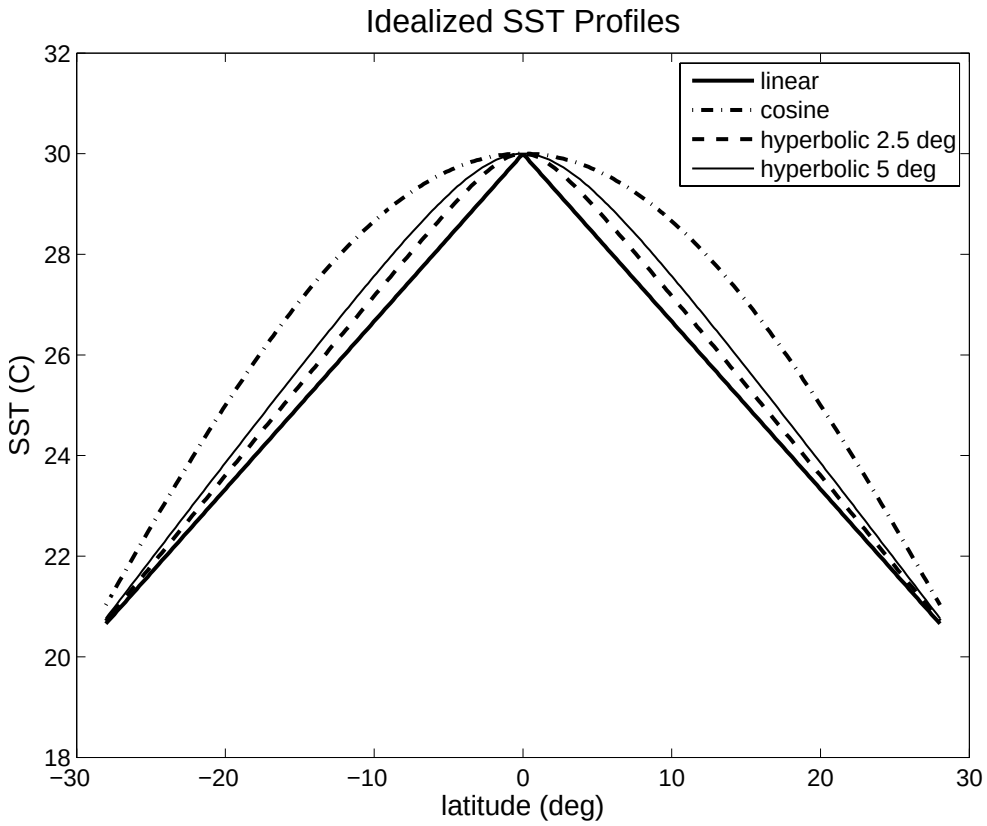
* Using an omega profile smoothed to look like the WestPac profile gives very different *M* values

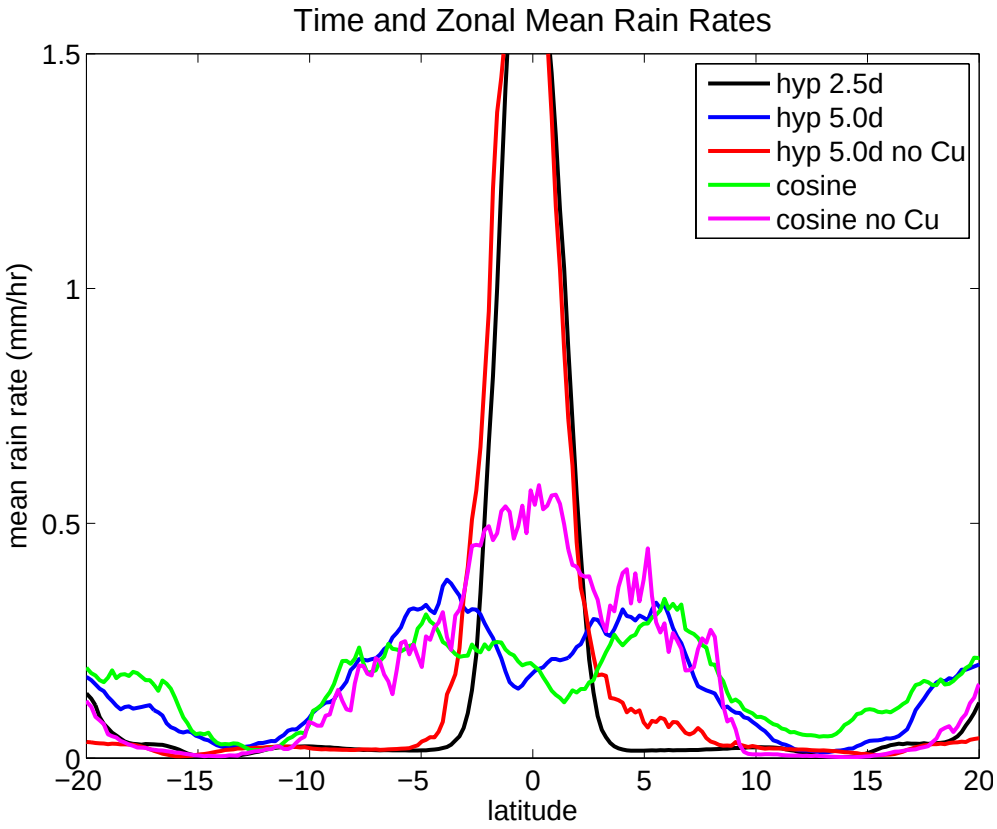




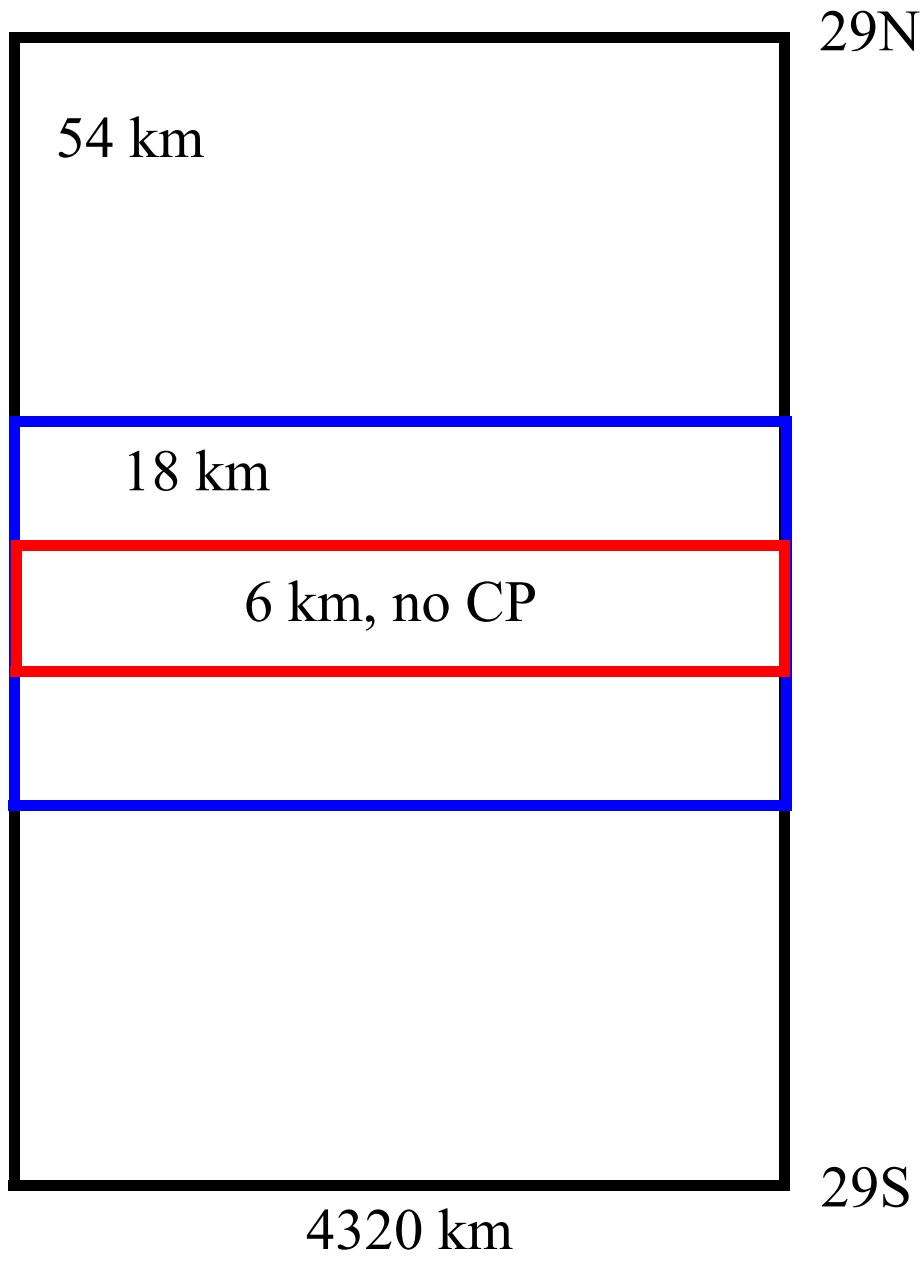
V. Cloud-Resolving ITCZ Simulations

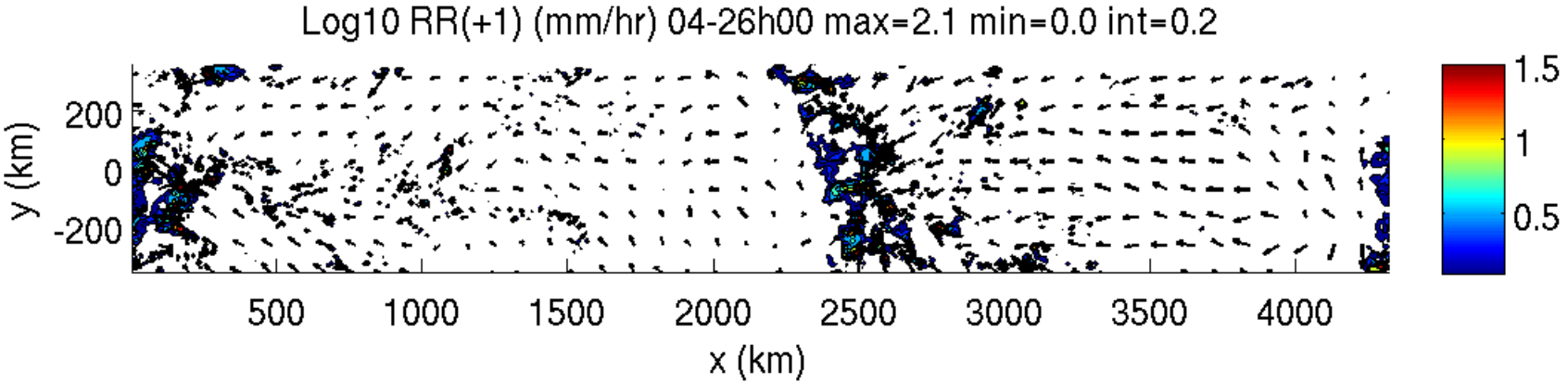
•Some frightening sensitivities...

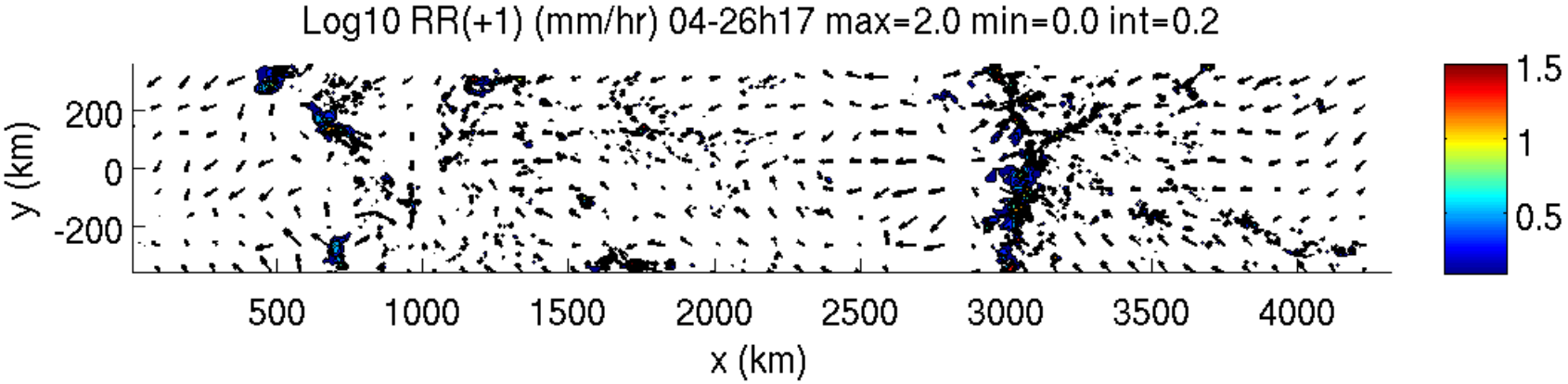


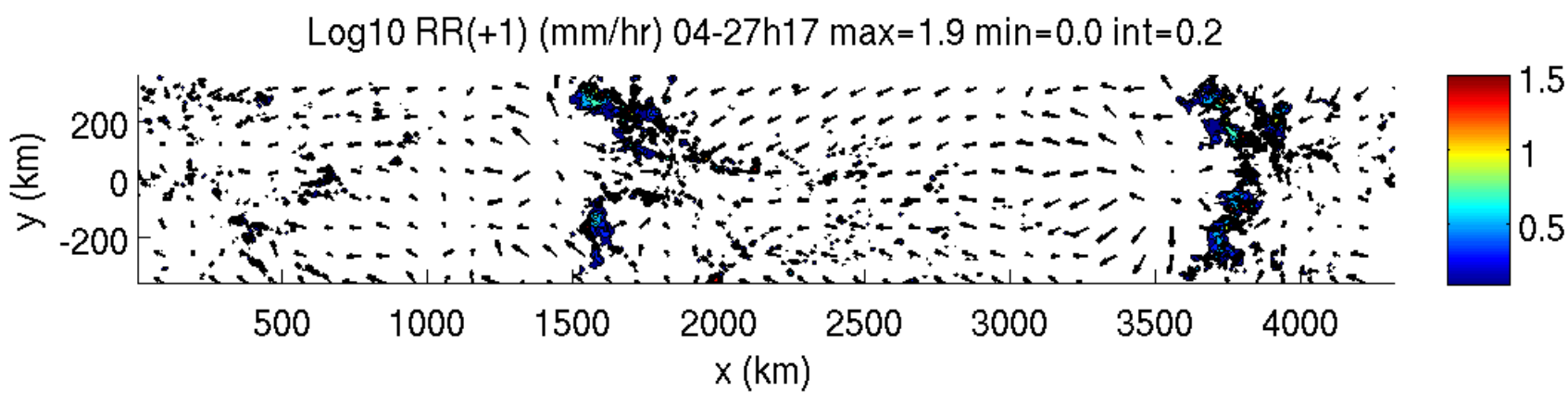


- Stefan Tulich has developed a version of WRF that allows nesting across periodic boundaries.




Log10 RR(+1) (mm/hr) 04-26h00 max=2.1 min=0.0 int=0.2
y (km)
200
0
-200
500
1000
1500
2000
2500
3000
3500
4000
x (km)
1.5
1
0.5


Log10 RR(+1) (mm/hr) 04-26h17 max=2.0 min=0.0 int=0.2
y (km)
200
0
-200
500
1000
1500
2000
2500
3000
3500
4000
x (km)
1.5
1
0.5


Log10 RR(+1) (mm/hr) 04-27h17 max=1.9 min=0.0 int=0.2
y (km)
200
0
-200
500
1000
1500
2000
2500
3000
3500
4000
x (km)
1.5
1
0.5

Summary

- Idealized ITCZ simulations produce "multi-level circulations."

- These circulations are present in data and reanalyses where there is a persistent and coherent ITCZ north of the equator.

- The shallow return flow is a response to meridional SST gradients;

  The mid-level inflow is caused by the upper-level heating maximum associated with rapid growth of condensate by ice processes.

- The idealized multi-level circulations make non-trvial contributions to MSE budgets; eddy fluxes of MSE are a significant fraction of vertically integrated transport.

- Cloud-resolving ITCZ simulations can hopefully resolve single/double ITCZ issues and show detailed evolution of convectively coupled waves.