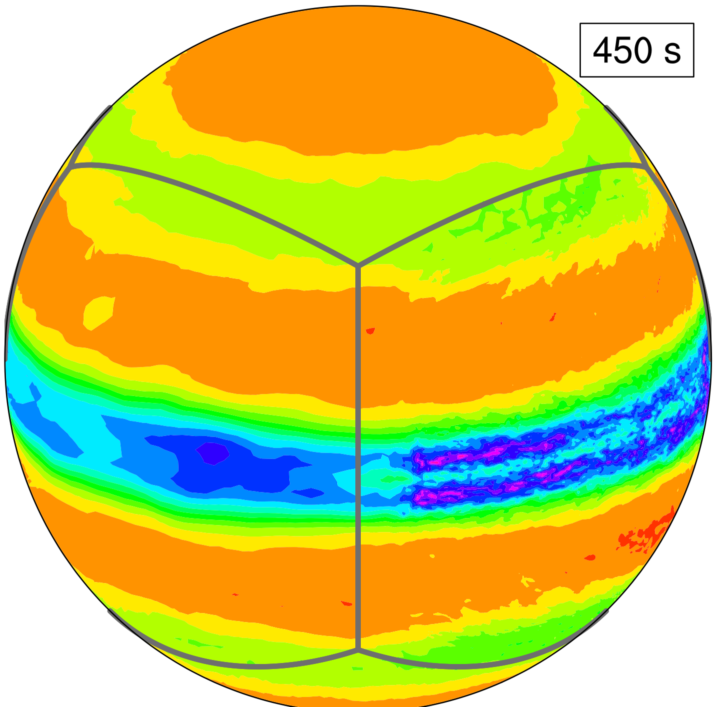
Parameterized Convection, Grid-Scale Clouds and Resolution Sensitivity in CAM-SE-CSLAM



Adam R Herrington

2019 Winter AMWG Meeting

NCAR
Advanced Study Program
Host: Peter H. Lauritzen
AMP

Stony Brook University
Ph.D Advisor: Kevin A. Reed

The Curious Case of Convection

Parameterized Deep Convection Less Active with Increasing Resolution

(Kiehl and Williamson 1991; Williamson et al. 1995; Williamson 1999; Williamson 2008; Li et al. 2011; Reed and Jablonowski 2011a; Reed et al. 2012; O'Brien et al. 2013; Rauscher et al. 2013; Zarzycki and Jablonowski 2014; Lu et al. 2015; Rauscher et al 2016; O'Brien et al 2016)

WHY?

Williamson (2013)

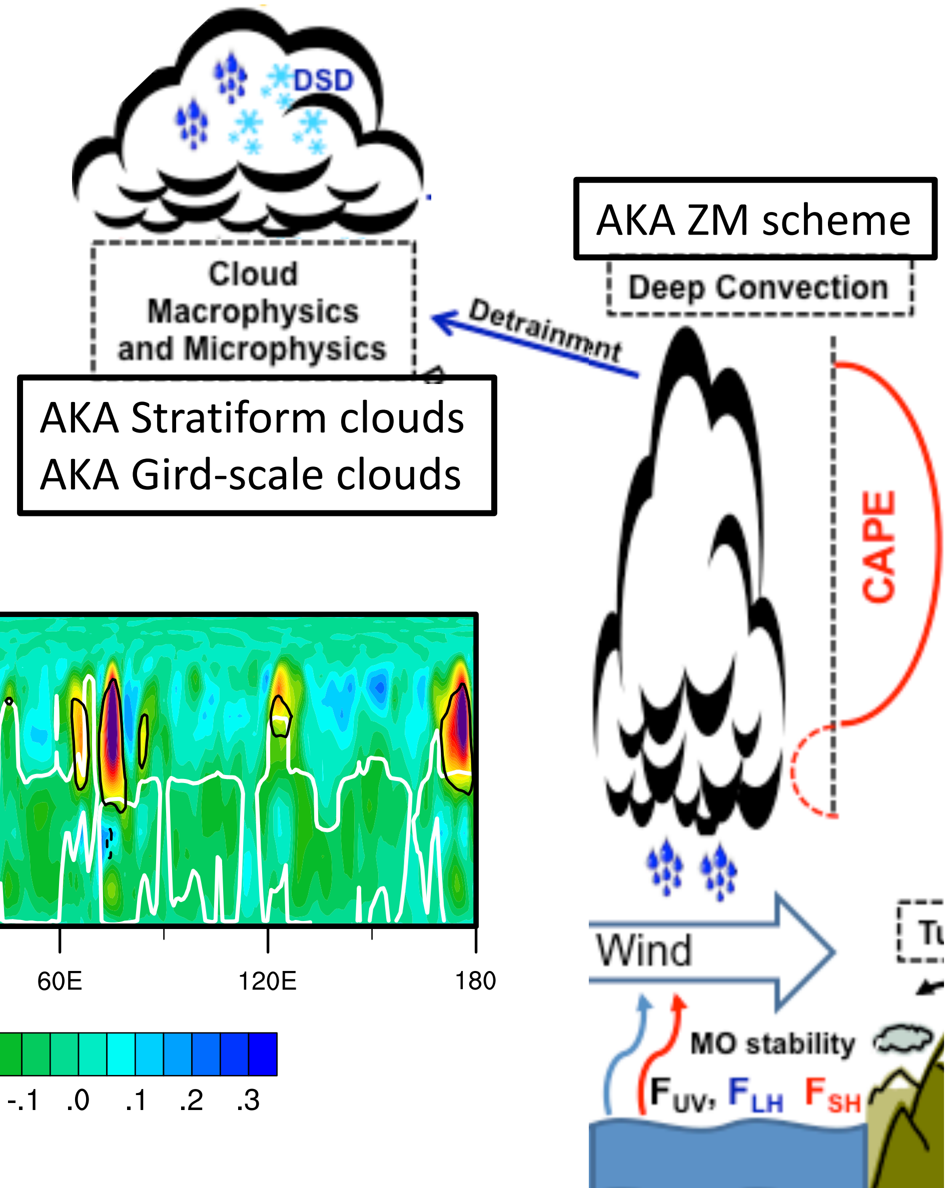
Higher resolution simulations typically use smaller physics time-steps.

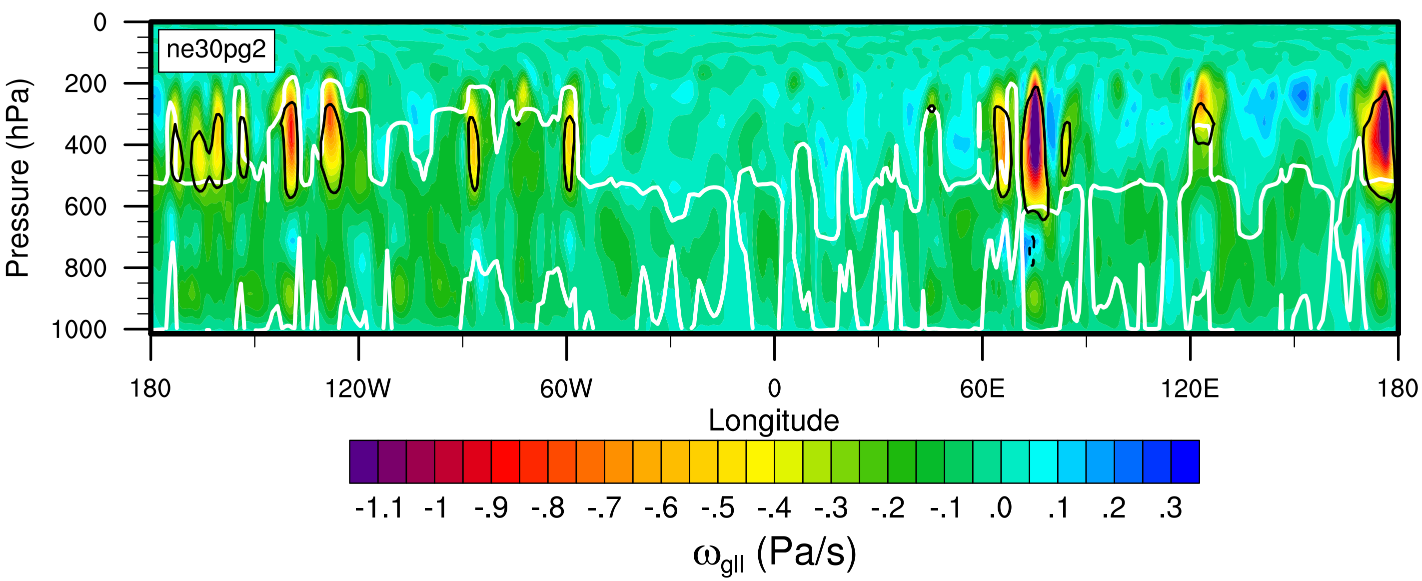
- Deep convection scheme removes instability at ~ (fixed rate * Δt_{phys})
- Grid-scale clouds remove remaining instability instantaneously

O'Brien et al (2013), Herrington and Reed (2017)

Convergence tests with fixed physics time-step,
Deep convection still less active with resolution

Deep Convection in CAM



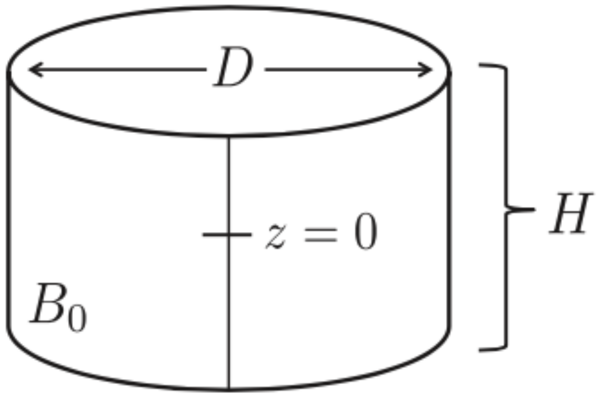


Schematic courtesy of AMWG

Theory…

Equations of Motion have inherent scale dependencies at hydrostatic scales

"Cloud"

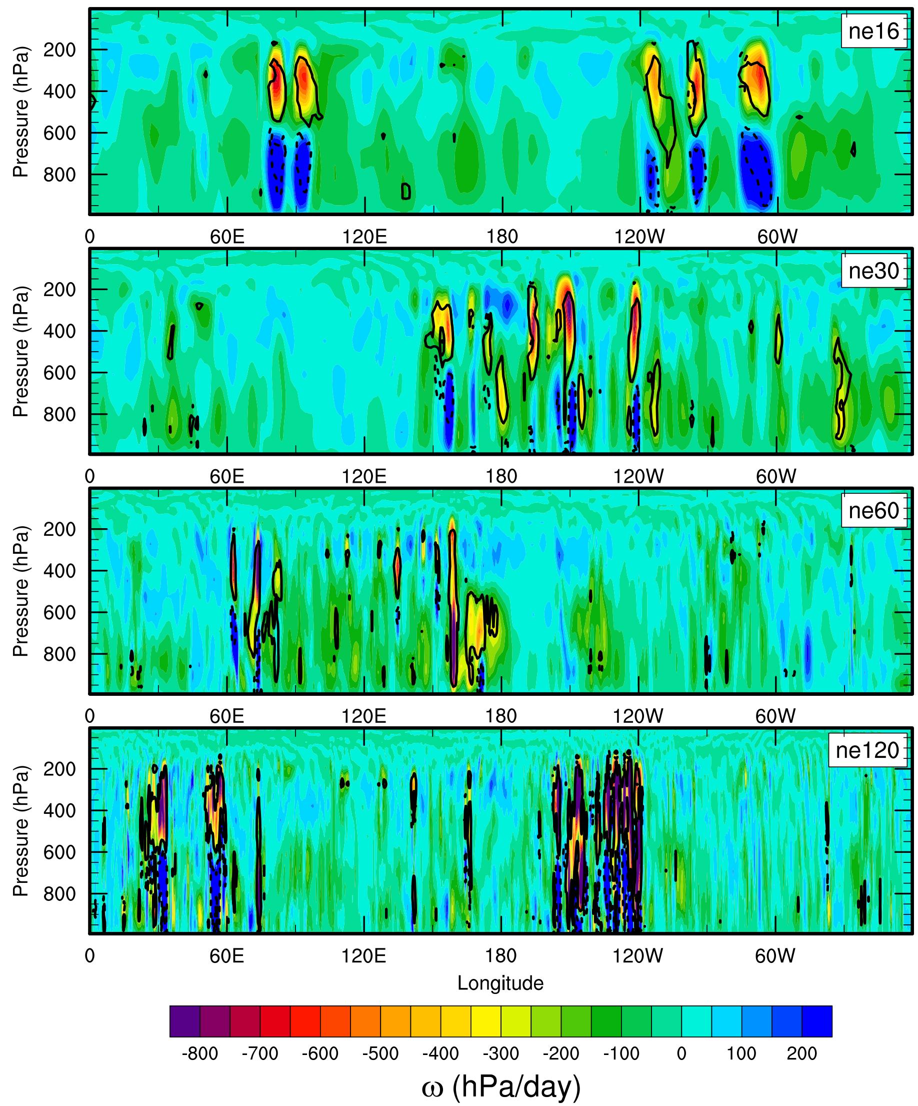


Vertical velocity scale due to the Archimedean Buoyancy, B_0

$$W = \sqrt{B_0 H}\, {}^{H}\!/_{D}$$

***Assume $D \sim \Delta x$, B_0 and H are cnst*

$$\frac{W_1}{W_2} = \frac{\Delta x_2}{\Delta x_1}$$



Orlanski 1981; Jeevanjee and Romps (2015); Herrington and Reed (2018)

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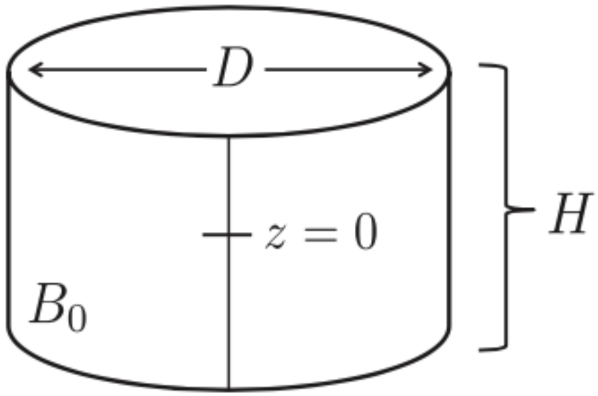

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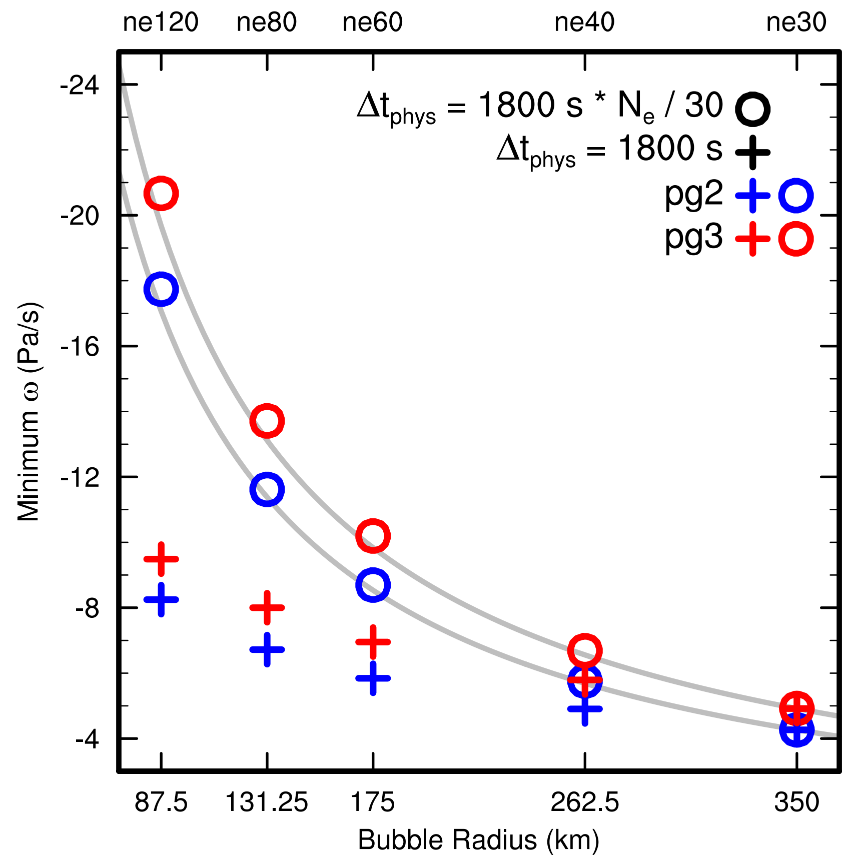
Moist Bubble Test



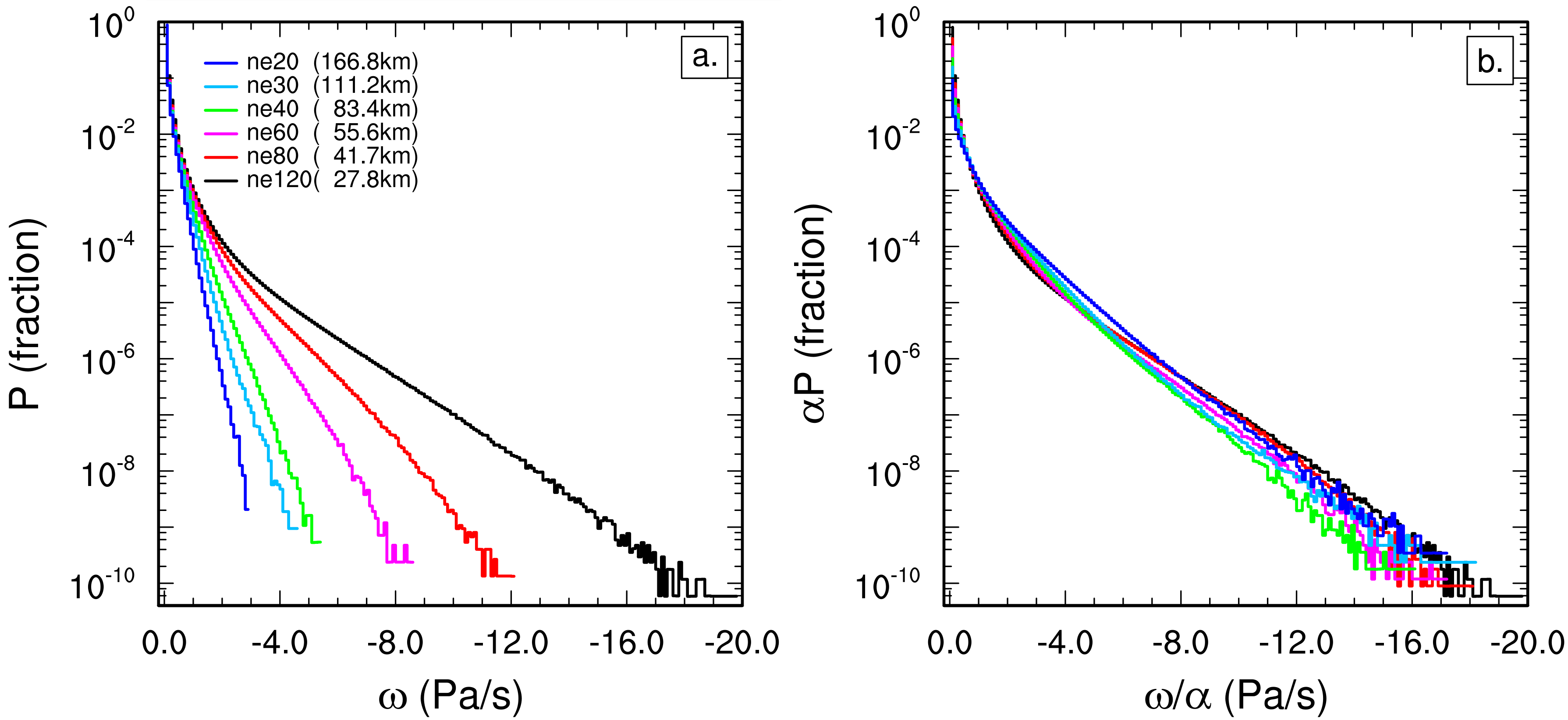
Orlanski 1981; Jeevanjee and Romps (2015); Herrington and Reed (2018)

Aqua-planets follow the scaling

Grid name	Δx_{dyn}	Δt_{dyn}	Δt_{phys}
ne20pg3	166.8km	450s	2700s
ne30pg3	111.2km	300s	1800s
ne40pg3	83.4km	225s	1350s
ne60pg3	55.6km	150s	900s
ne80pg3	41.7km	112.5s	675s
ne120pg3	27.8km	75s	450s

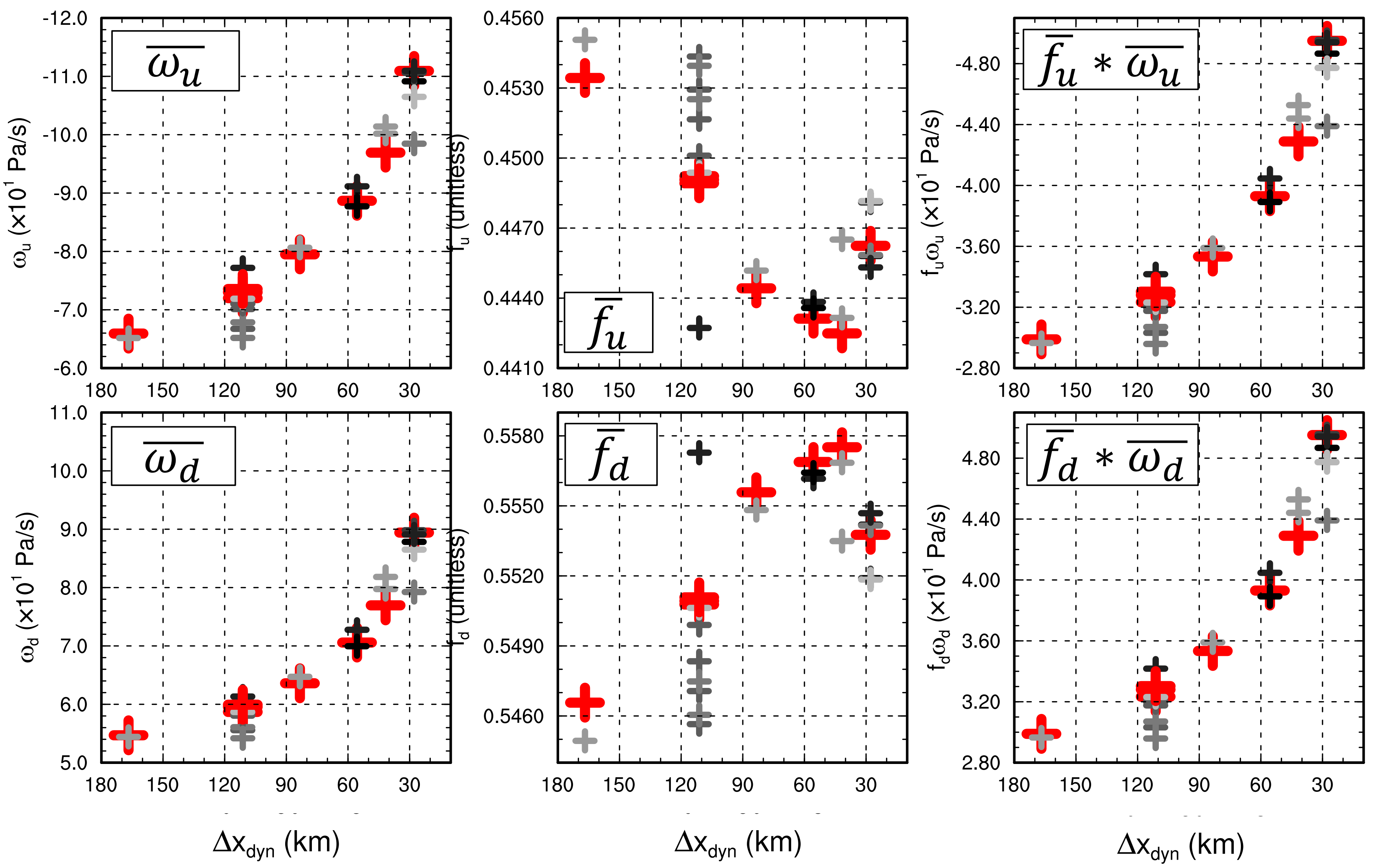
$$P(\omega)_{ne120} = \alpha P(\omega/\alpha),$$

$$\alpha = \Delta x_{ne120}/\Delta x$$



Global Mean Climatology

$$\overline{\omega} = \overline{f_u} * \overline{\omega_u} + \overline{f_d} * \overline{\omega_d}$$



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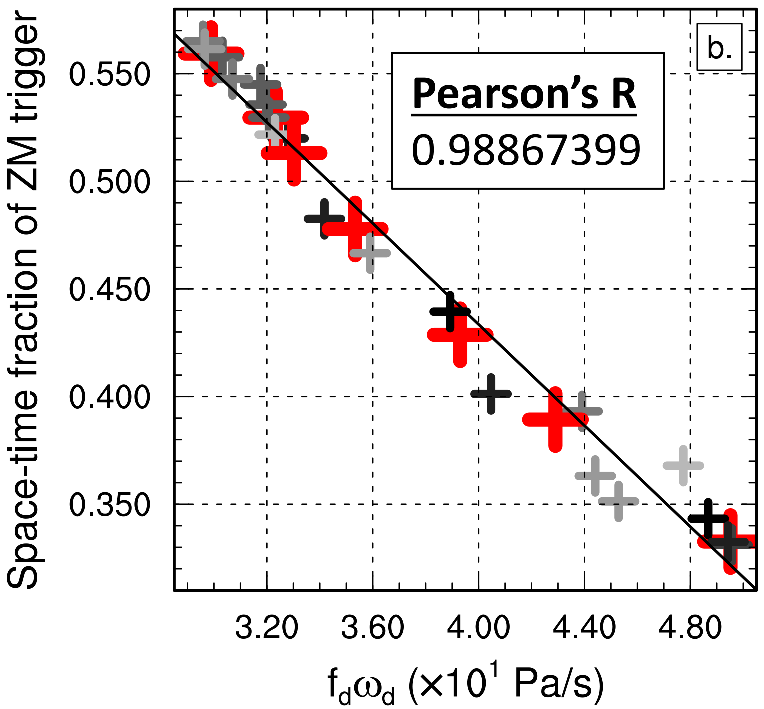
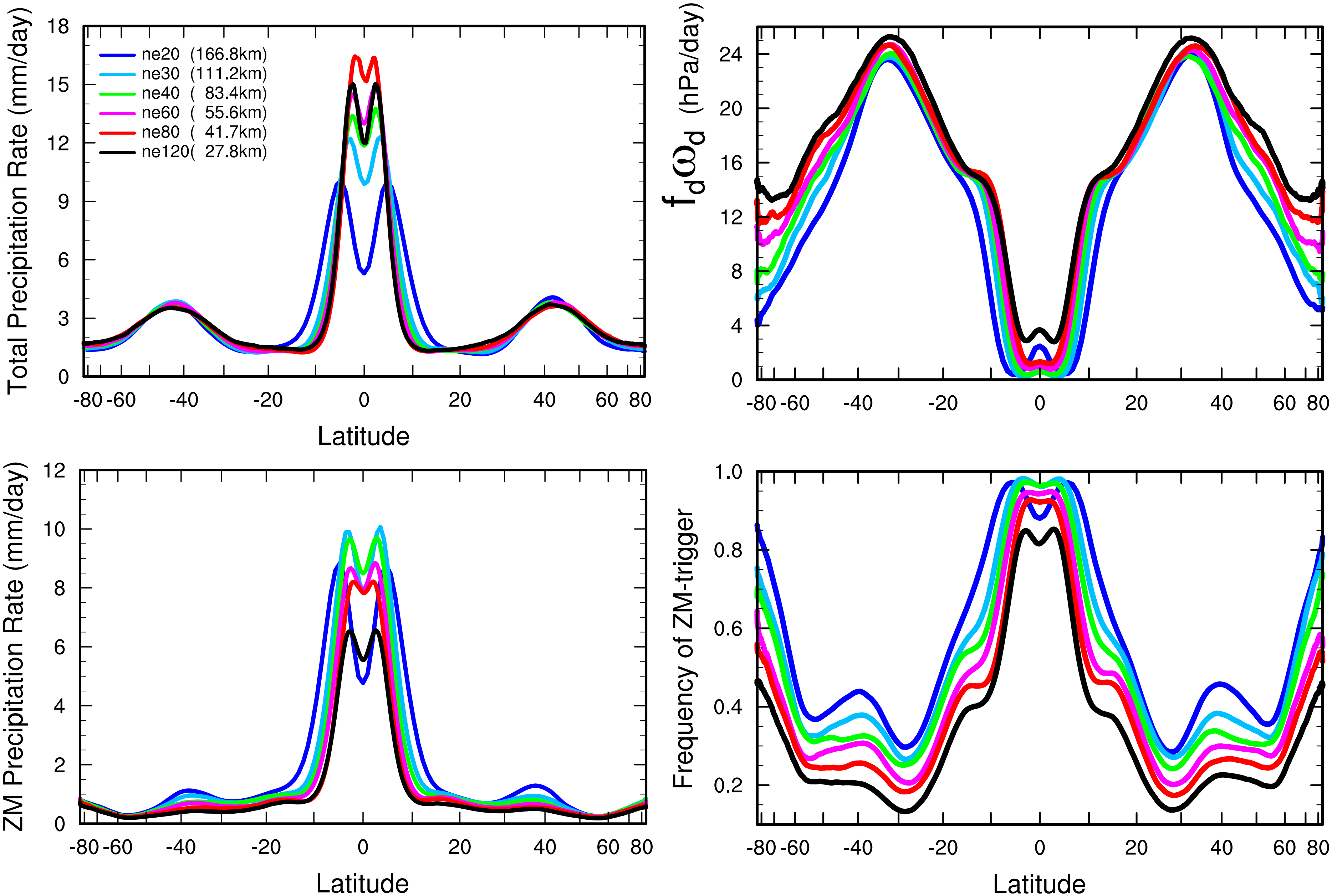
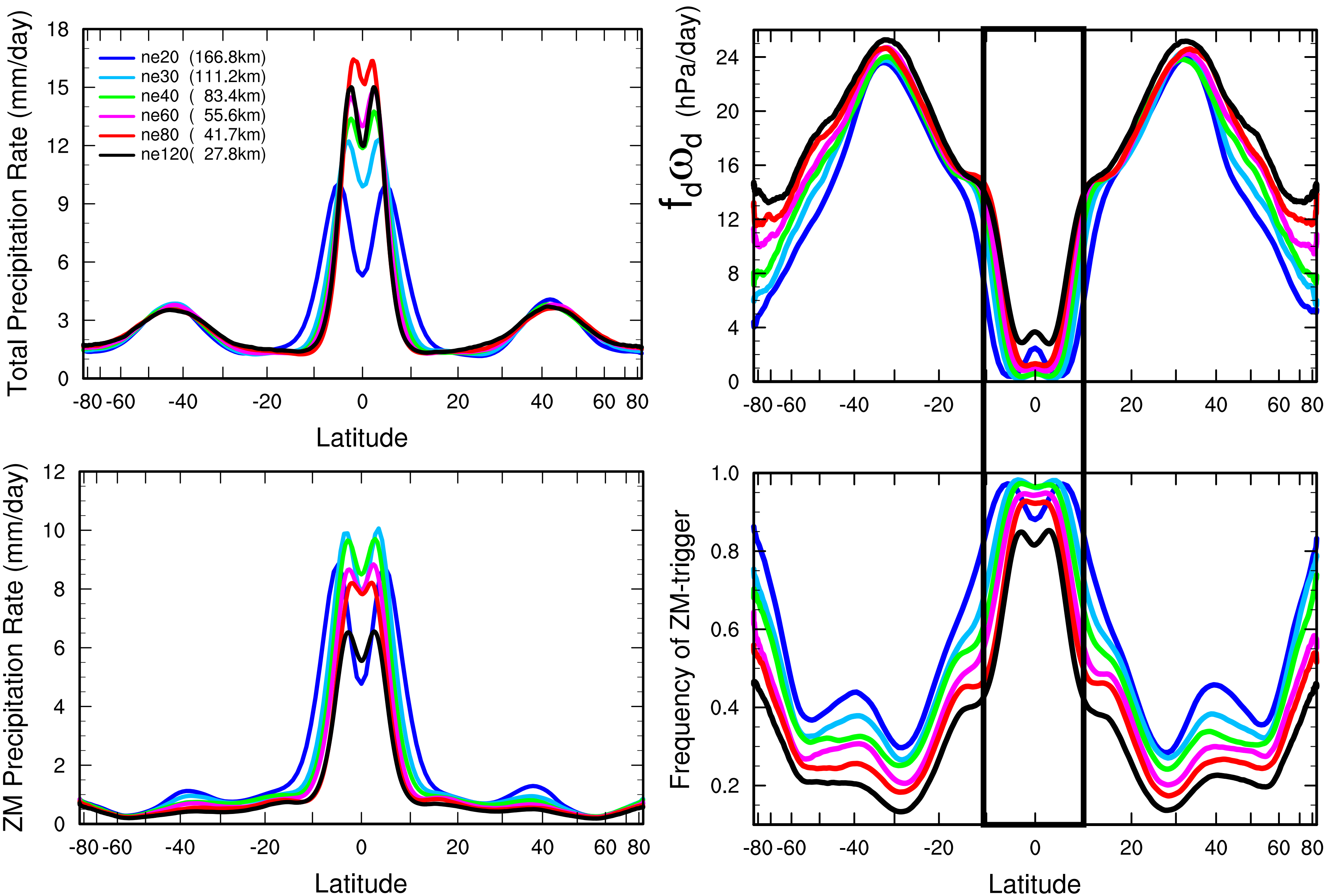


Zonal Means



Total Precipitation Rate (mm/day)
ne20 (166.8km)
ne30 (111.2km)
ne40 (83.4km)
ne60 (55.6km)
ne80 (41.7km)
ne120(27.8km)
Latitude
$f_d\omega_d$ (hPa/day)
ZM Precipitation Rate (mm/day)
Latitude
Frequency of ZM-trigger
Latitude

Zonal Means



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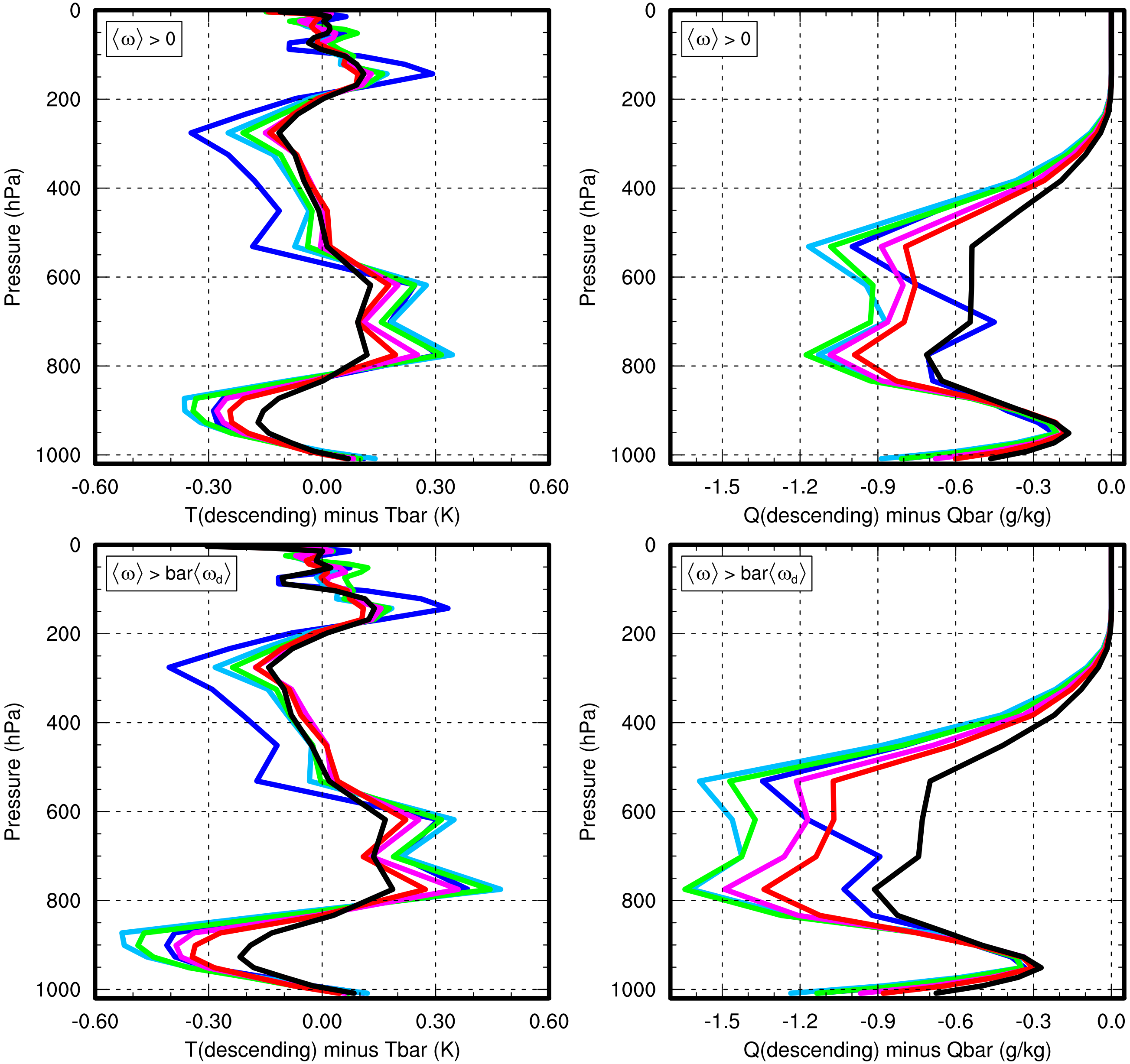
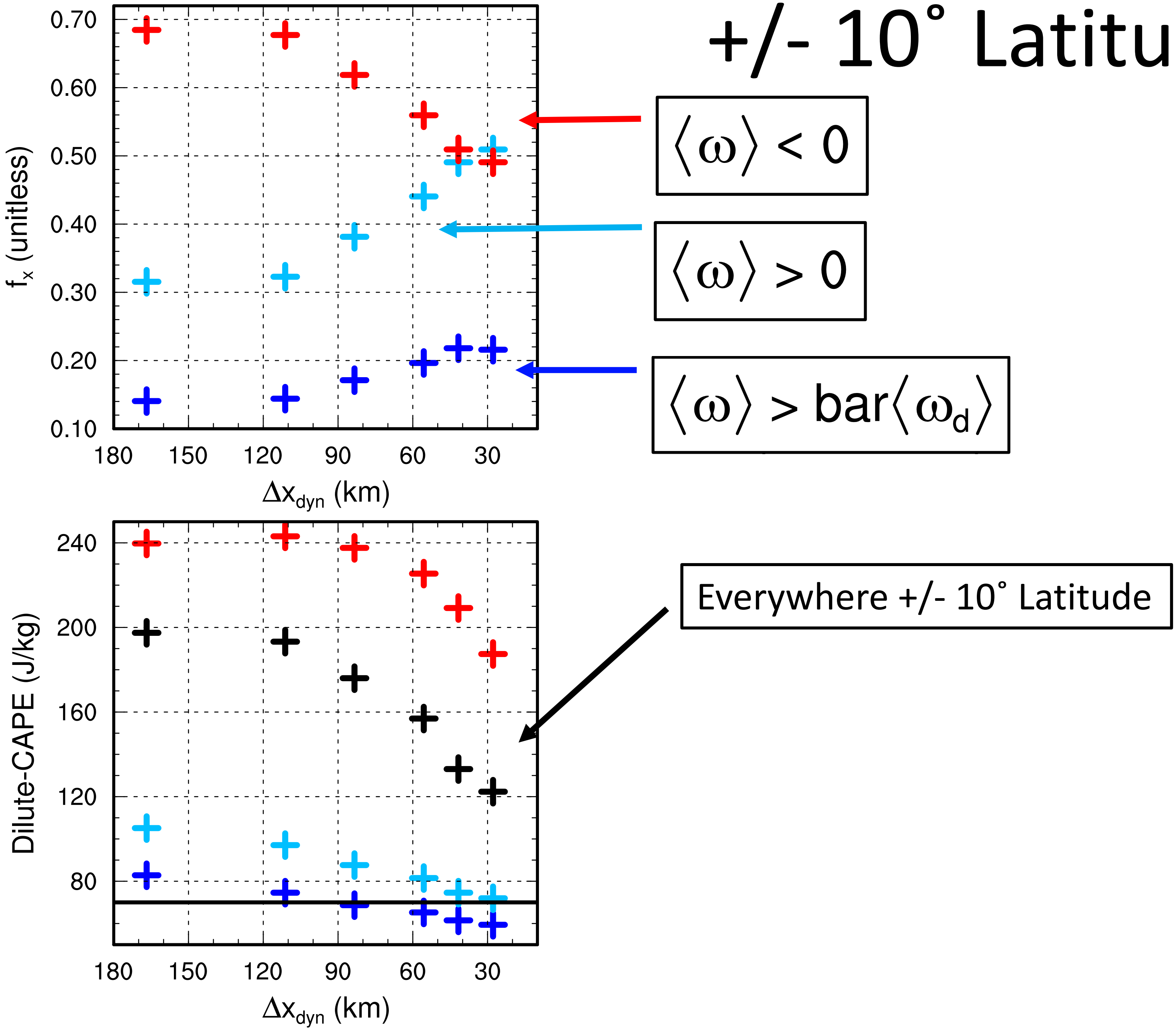
+/- 10˚ Latitude



⟨ω⟩ > 0

⟨ω⟩ > bar⟨ω_d⟩

+/- 10˚ Latitude



f_x (unitless)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
180
150
120
90
60
30
Δx_dyn (km)
⟨ω⟩ < 0
⟨ω⟩ > 0
⟨ω⟩ > bar⟨ω_d⟩
Dilute-CAPE (J/kg)
240
200
160
120
80
180
150
120
90
60
30
Δx_dyn (km)
Everywhere +/- 10˚ Latitude

Conclusions

- Deep Convection Scheme is designed to produce stratiform clouds in upper-troposphere
- The following is observed to occur in the Tropics with an increase in resolution:
    - **Magnitude** of stratiform induced resolved vertical motion **increases like** Δx^{-1}
    - Areal **extent** of these 'updrafts' **decrease**
    - Areal **extent** and **magnitude** of resolved compensating subsidence **both increase**
    - Deep convection triggers less frequently, and is highly correlated with subsidence
- Evidence suggests the increase in resolved subsidence dries and stabilizes the Tropics, reducing convective triggering
- Consistent with tropical drying over the W. Pacific Warm Pool at high resolution

  (Bacmeister et al. 2014, see Xiaoning's talk later)

Resolution sensitivity has a simple origin: higher resolution grids support tighter gradients