Synergistic Effect of Mid-level Dry Air and Vertical Wind Shear on the Development of the Tropical Cyclone Secondary Circulation

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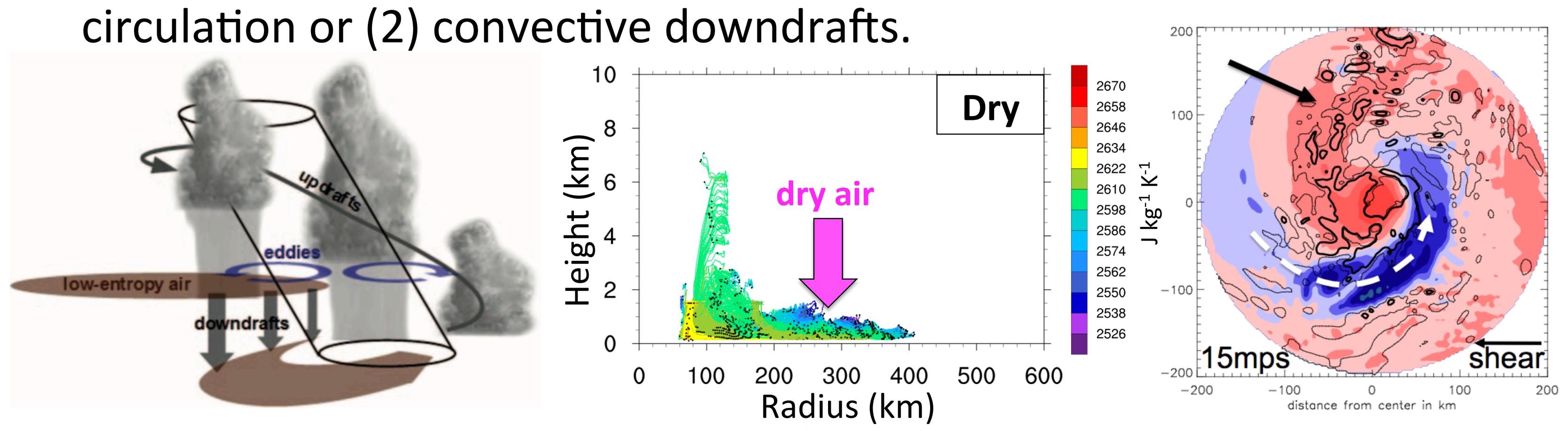
Introduction

It is imperative to better understand the synergistic, or combined, effect of tropospheric dry air and vertical wind shear (VWS) on tropical cyclone (TC) development.

Ventilation: Flux of low-entropy environmental air into the TC inner core.

- **Mid-level pathway:** Dry air ventilates midlevels.
- **Low-level pathway:** Dry air ventilates the subcloud layer via either: (1) subsidence associated with the downward branch of the secondary circulation or (2) convective downdrafts.



mid-level ventilation — Tang and Emanuel (2012b)
low-level ventilation — Alland et al. (2017)
low-level ventilation — Riemer et al. (2010)

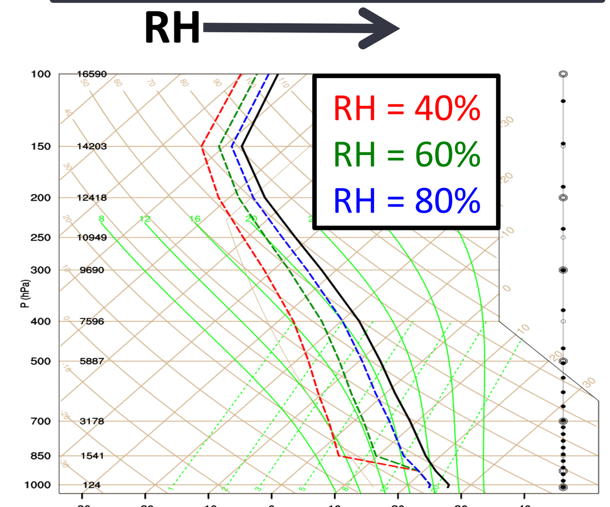
Scientific question: How does the magnitude of dry air and VWS in the free troposphere affect the structure of the TC secondary circulation during development in a 3D model?

Model Setup

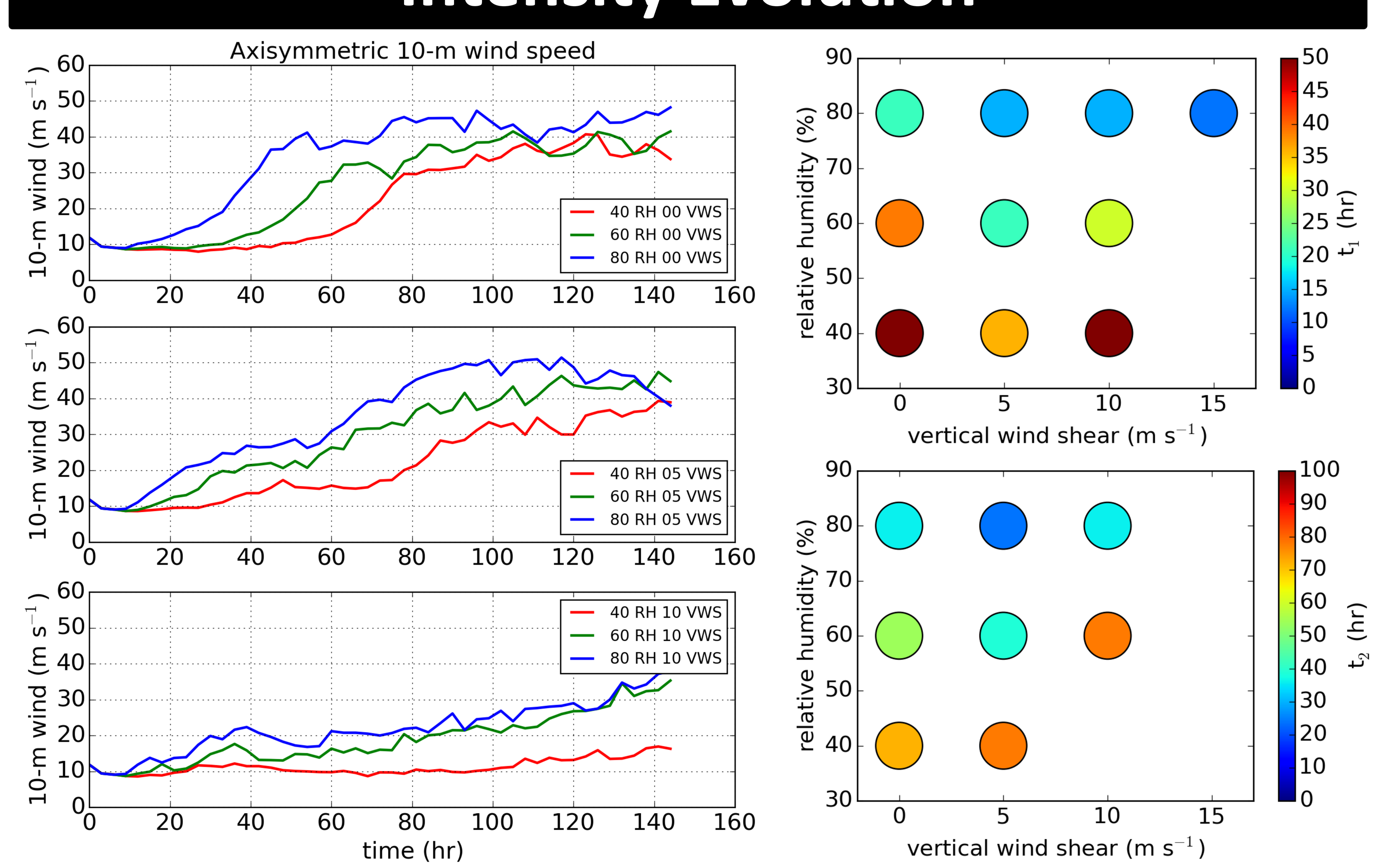
Cloud Model 1 (CM1)

- **Resolution:** 4 km horizontal; 59 vertical levels
- **Microphysics:** Kessler (1969)
- **Radiation:** Newtonian Relaxation (Rotunno and Emanuel 1987)
- **Turbulence:** Down-gradient parameterization
- **Other specifications:**
  - Initial vortex: Rotunno and Emanuel (1987)
  - Moist tropical temperature profile (Dunion 2011)
  - Sea surface temperature of 28°C
  - *f*-plane
  - VWS added using the point-downscaling methodology (Nolan 2008)

VWS \ RH	40%	60%	80%
15 m s^{-1}			
10 m s^{-1}			
5 m s^{-1}			
0 m s^{-1}			

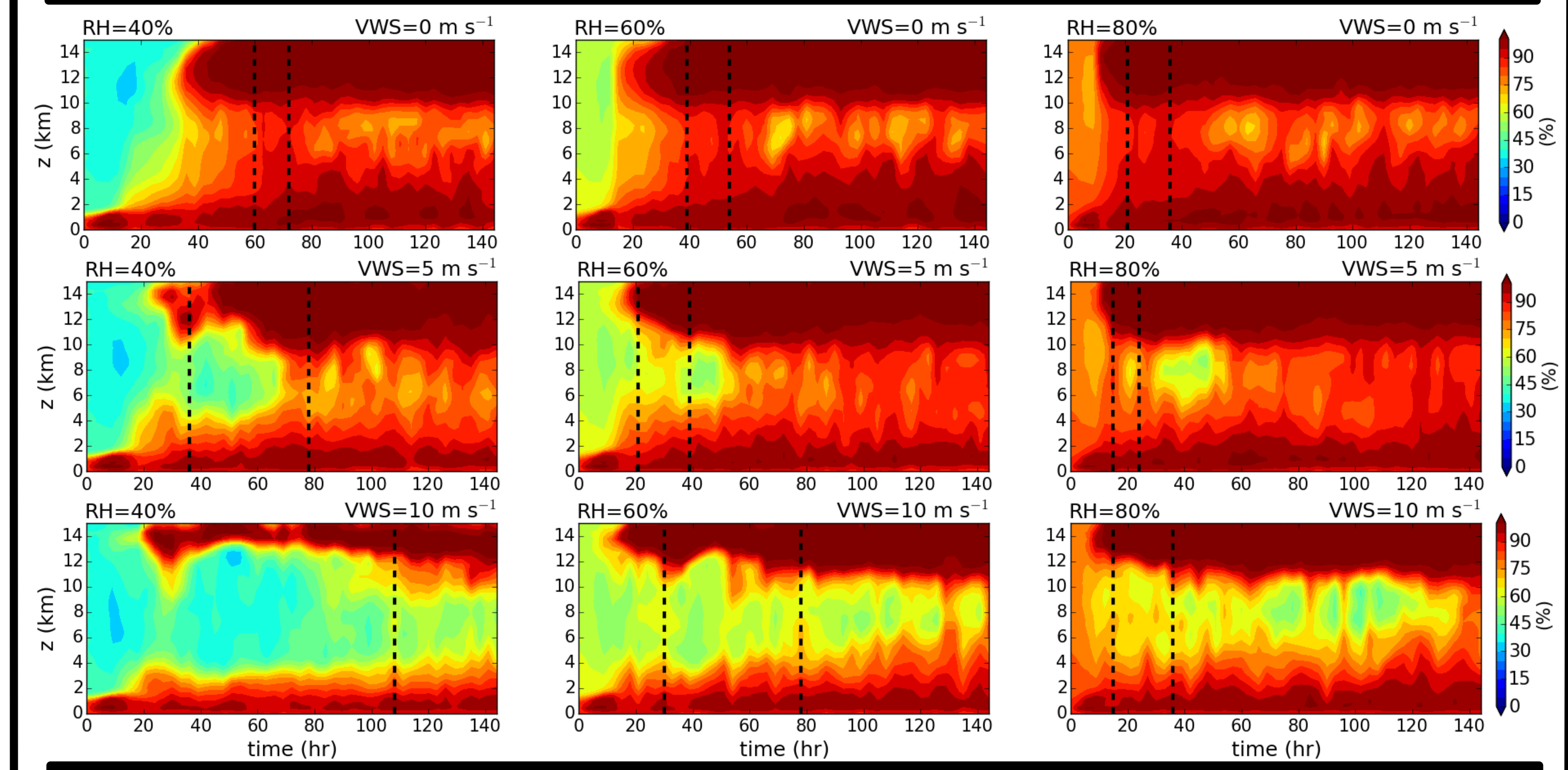


Intensity Evolution



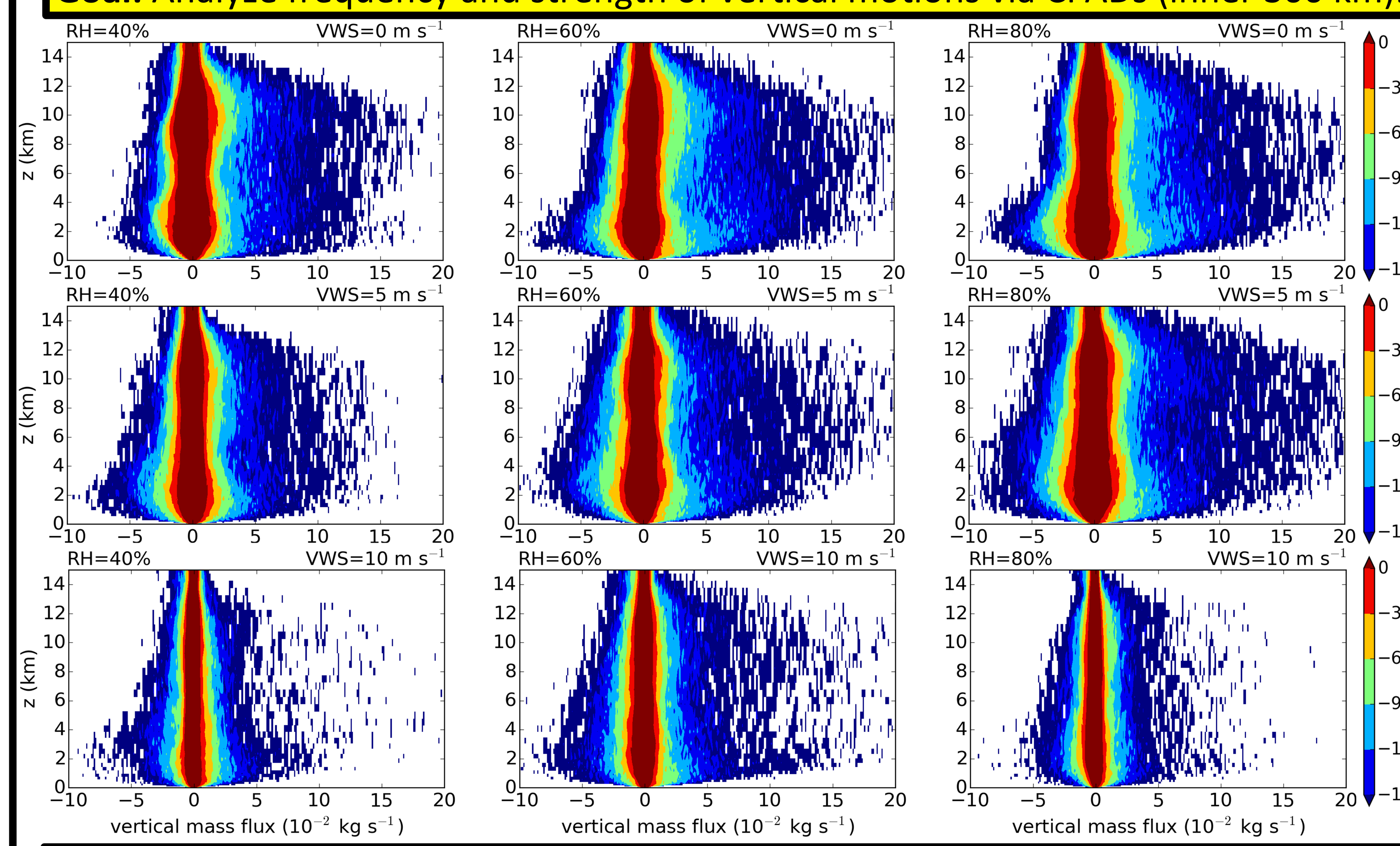
Relative Humidity Evolution

Goal: Investigate the relative humidity evolution near the circulation center to diagnose potential ventilation pathways.



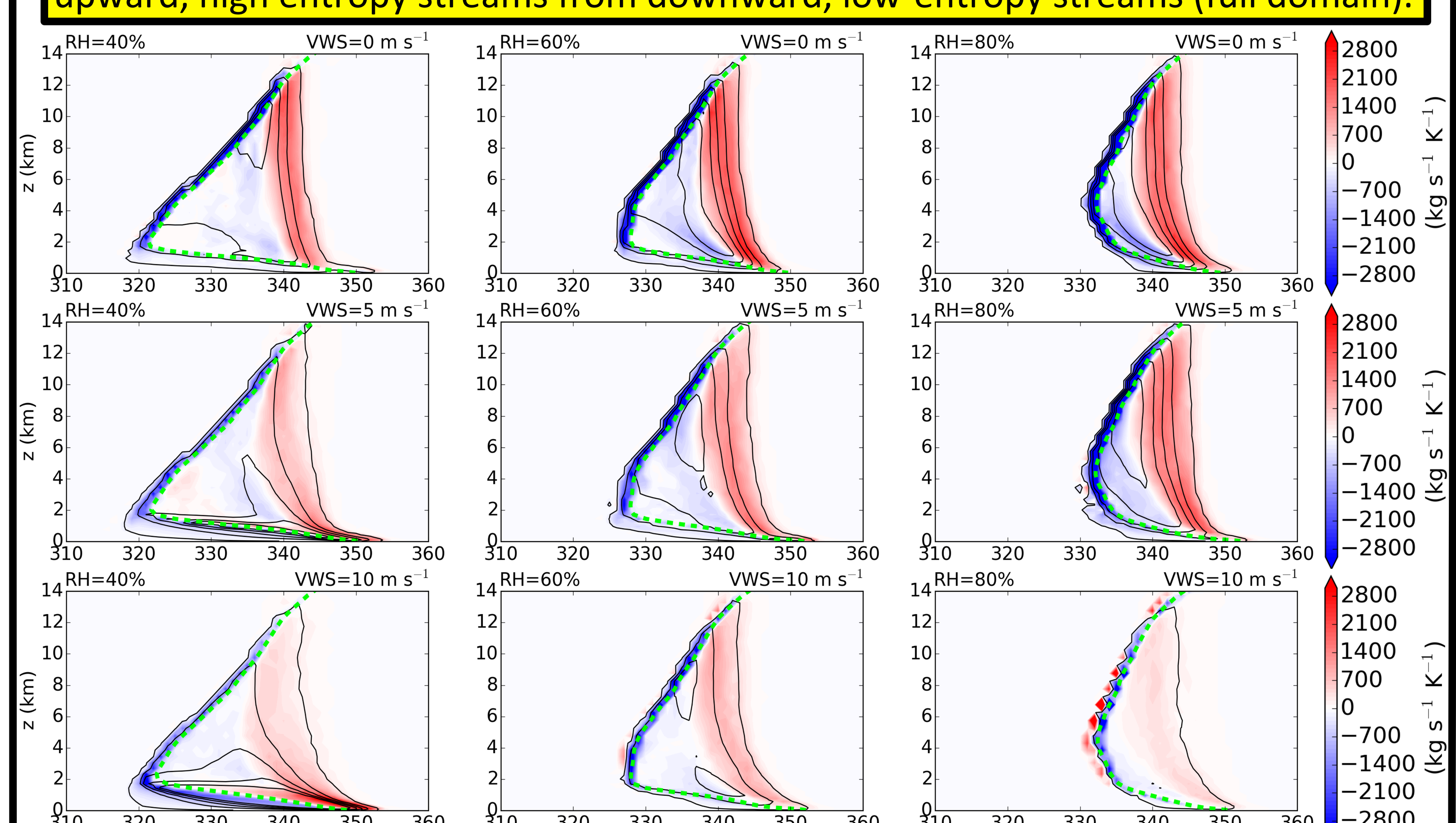
Eulerian Analysis: CFADs

Goal: Analyze frequency and strength of vertical motions via CFADs (inner 300 km).



Isentropic Analysis

Goal: Analyze convective motions and the secondary circulation by separating upward, high entropy streams from downward, low-entropy streams (full domain).



Shading: isentropic vertical mass flux (kg s^{-1} K^{-1}); **Contours:** isentropic streamfunction (kg s^{-1})

Entropy Budget

Goal: Quantify mid- and low-level ventilation, as well as the effect of surface fluxes on the entropy evolution in the subcloud layer.

$$\frac{\partial\langle\rho s\rangle}{\partial t} = -\frac{1}{V}\iint_Q(\rho\bar{\mathbf{u}}\bar{s})\cdot\hat{\mathbf{n}}dQ - \frac{1}{V}\iint_Q(\rho\mathbf{u}'s')\cdot\hat{\mathbf{n}}dQ$$

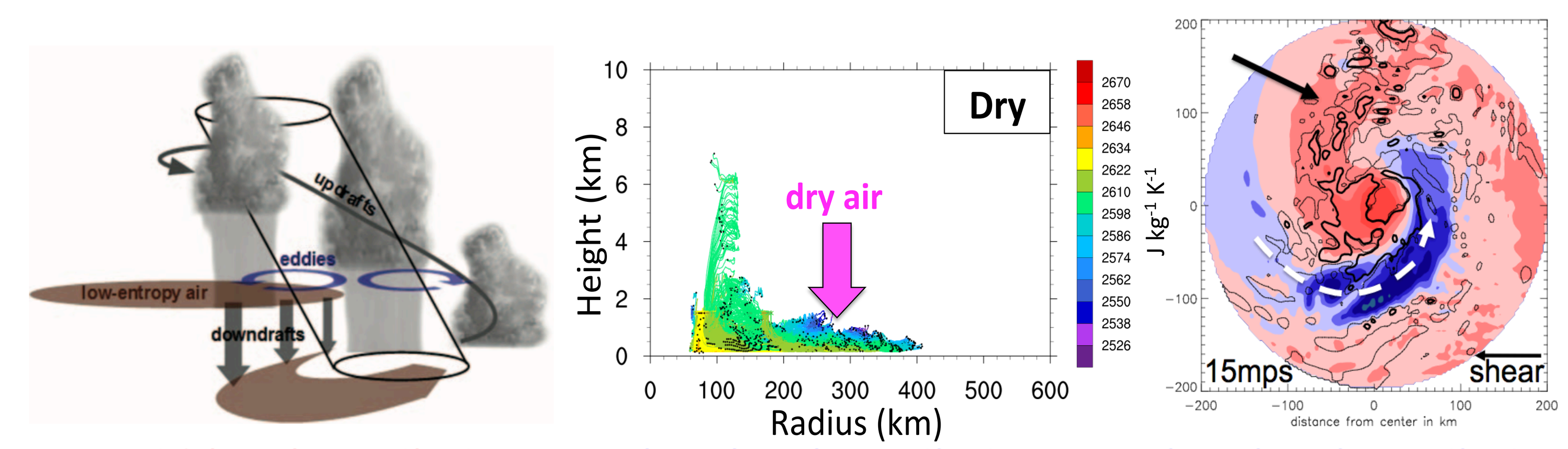
lateral entropy transport

$$-\frac{1}{V}\iint_A\left(\rho\bar{w}\bar{s}\big|_{z2} - \rho\bar{w}\bar{s}\big|_{z1}\right)dxdy - \frac{1}{V}\iint_A\left(\rho w's'\big|_{z2} - \rho w's'\big|_{z1}\right)dxdy$$

vertical entropy transport

$$+\langle S_0\rangle + \langle R_0\rangle$$

entropy source and radiation terms



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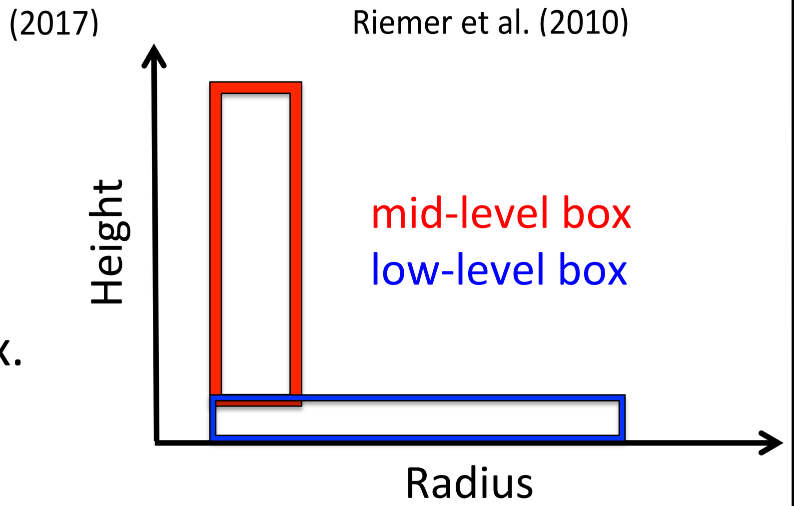
Procedure to quantify ventilation:

(1) Calculate the budget in mid- and low-level boxes.
(2) Magnitude of mid-level (low-level) ventilation from mid-level (low-level) box.
(3) Calculate spatial distribution of ventilation.



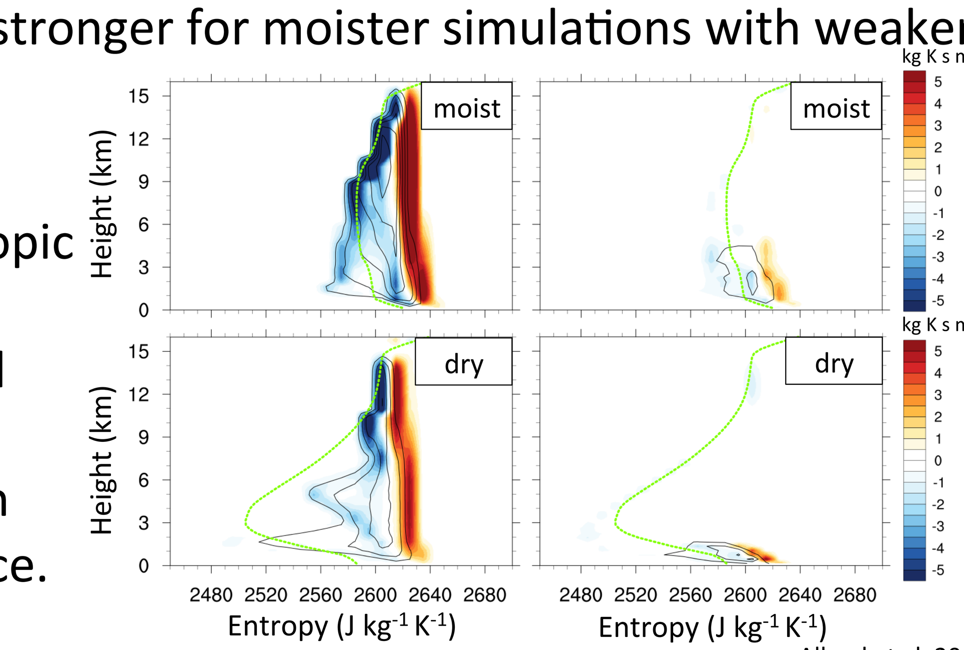
Conclusions

The following preliminary conclusions describe the synergistic effect of dry air and VWS on the development of the TC secondary circulation:

- Moister simulations develop quicker for a specific magnitude of VWS.
- Mid-level ventilation near the circulation center is presumed to inhibit development.
- Convective upward and downward motions are stronger for moister simulations with weaker VWS.
- The secondary circulation is stronger for moister simulations with weaker VWS.

Future work:

- Conduct Eulerian and isentropic analyses in subdomains.
- Conduct entropy budget and trajectory analyses.
- Run additional simulations in the bivariate parameter space.



Alland et al. 2017

Acknowledgements

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