Everything You Always Wanted to Know About Downdrafts*

*(but knew better than to ask)

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January 22, 2013

CMMAP Winter Team Meeting
Boulder, CO

What is a Downdraft?

Cloudy air that flows downward after loading by precipitation or cooling by evaporation.

photo: me

Convective Downdrafts

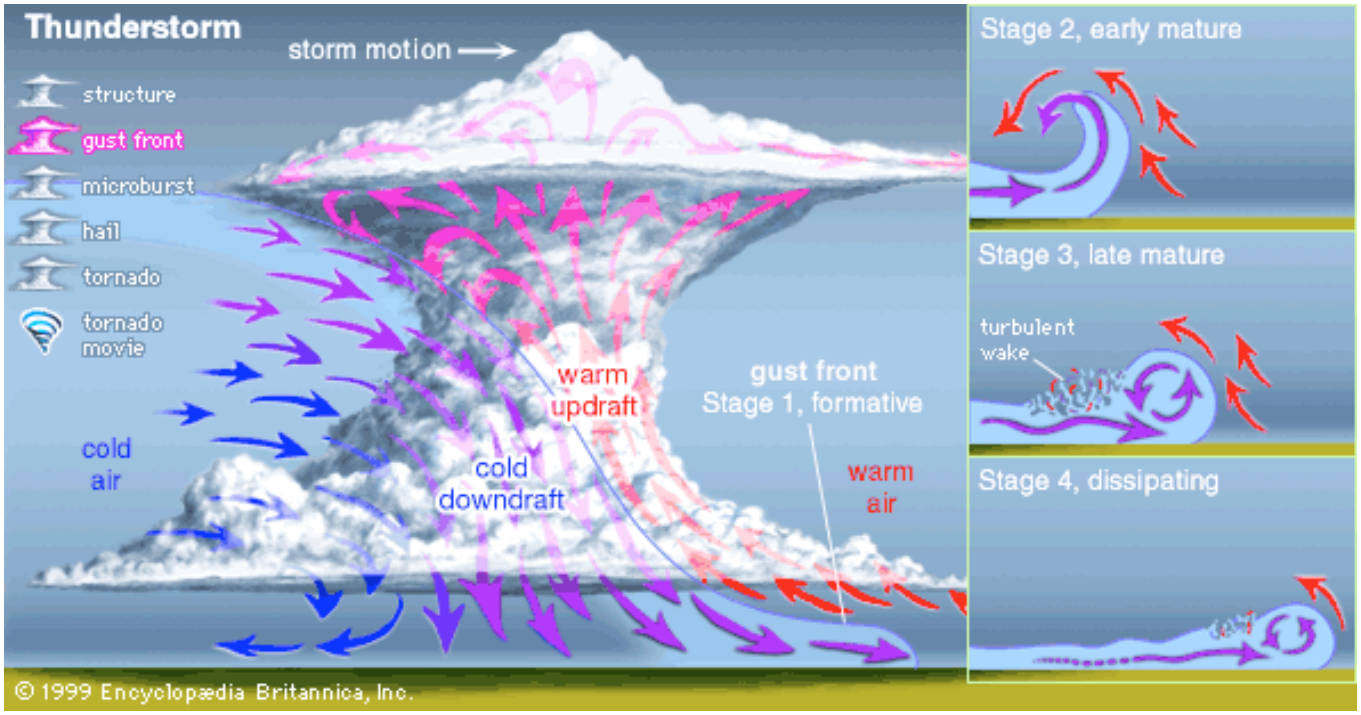


Diagram: http://www.britannica.com/thunderstorms_tornadoes/

- Cloudy air that flows downward after loading by precipitation or cooling by evaporation.

- Cooled air in the boundary layer creates cold pools and gust fronts.

Downbursts and Microbursts

Severe weather

Photo: http://wxbrad.com/downbursts-or-straight-line-winds-vs-tornadoes/

Photo: http://dailymail.com/News/201208200208

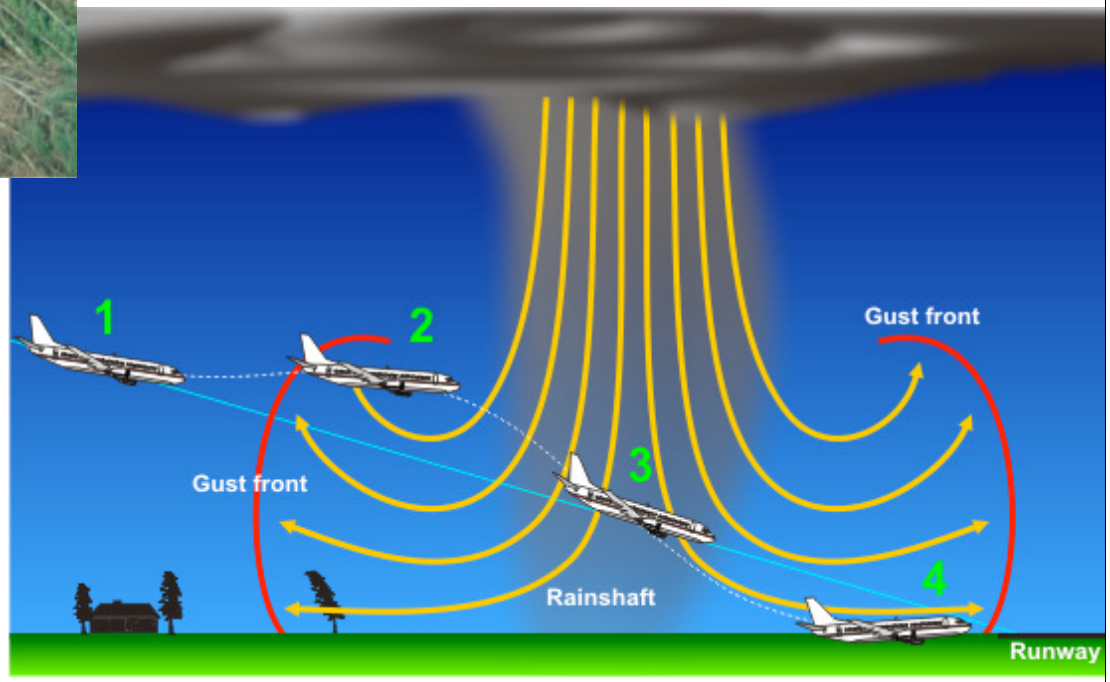


Diagram: http://www.srh.noaa.gov/jetstream/tstorms/wind.htm

Gust Fronts

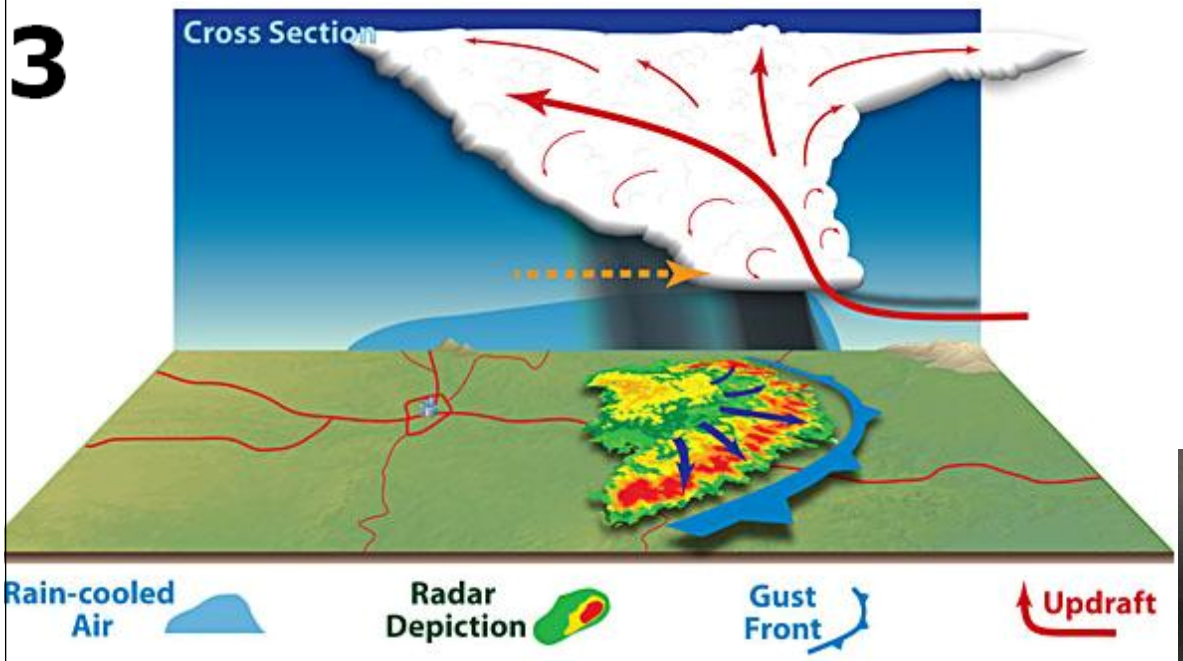
Dust Storms and Haboobs

Pheonix 2011: http://www.huffingtonpost.com/2011/07/06/phoenix-dust-storm-photos-video_n_891157.html

Pheonix 2011: http://blog.flickr.net/2011/07/08/phoenix-haboob/

Gust Fronts

Mesoscale Organization - Derecho



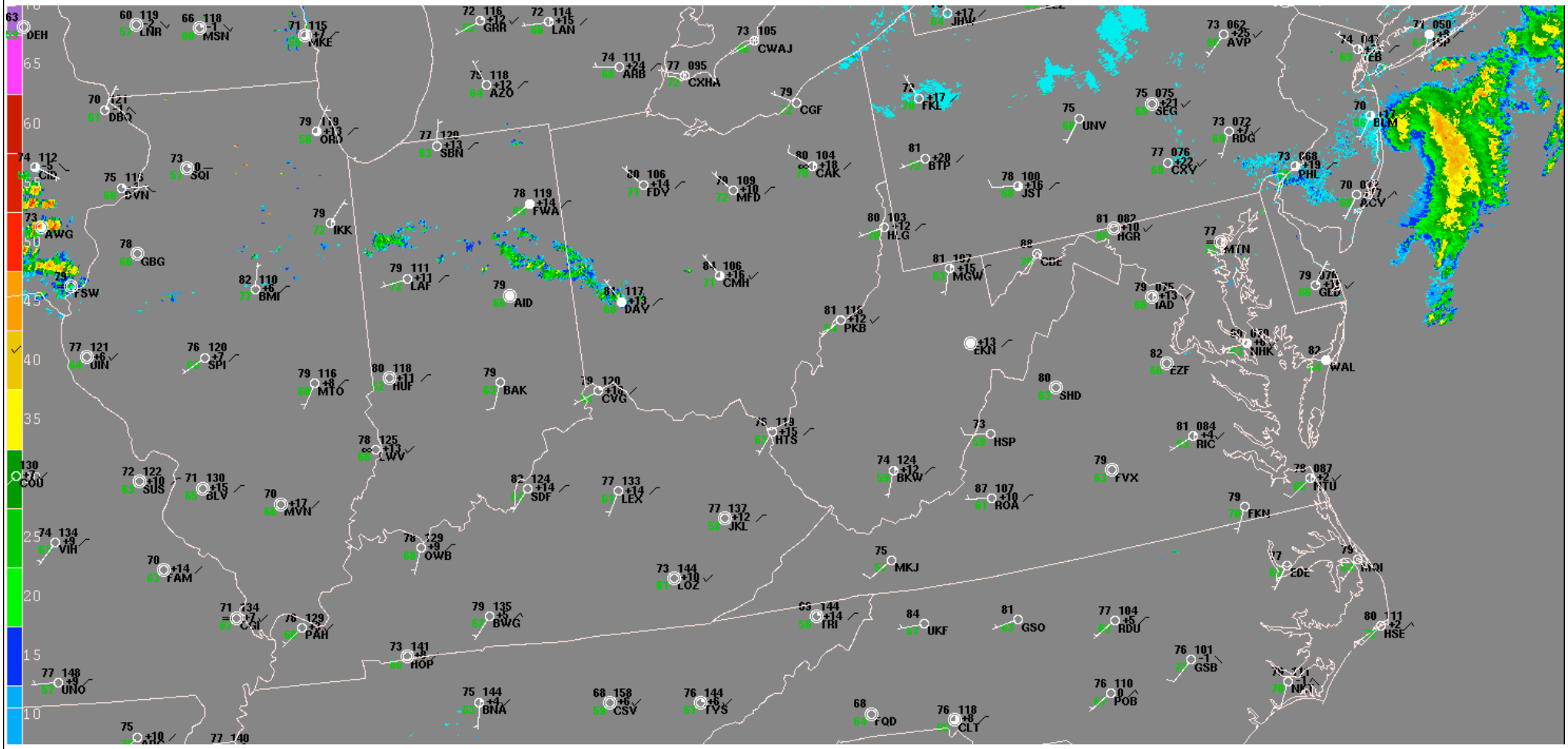
http://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm

Photo: me

Gust Fronts

June 29, 2012 Derecho

http://www.spc.noaa.gov/misc/AbtDerechos/casepages/jun292012page.htm



5 million people lost power, 22 were killed

Gust Fronts

Severe weather

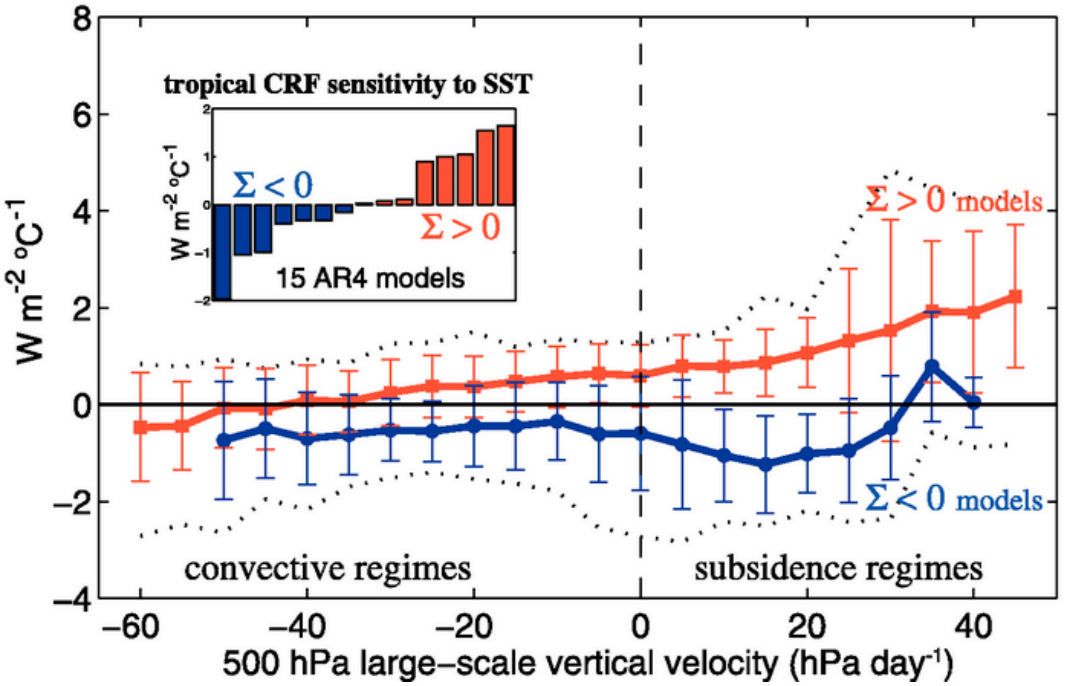
Impacts on People

- Damage from strong winds
- Blowing dust and erosion
- Fire propagation
- Organization of supercells, hurricanes and powerful storms
- Disruption of air traffic and energy generation

Impacts on Climate

- Important flux of cool air from upper to low levels
- Source of surface flux energy
- Reduces energy available to convection by injecting cold air below clouds, increases it for new clouds
- Organization of tropical waves that dictate much of the weather variability and ocean-atmosphere coupling in those regions

Clouds and Climate Models

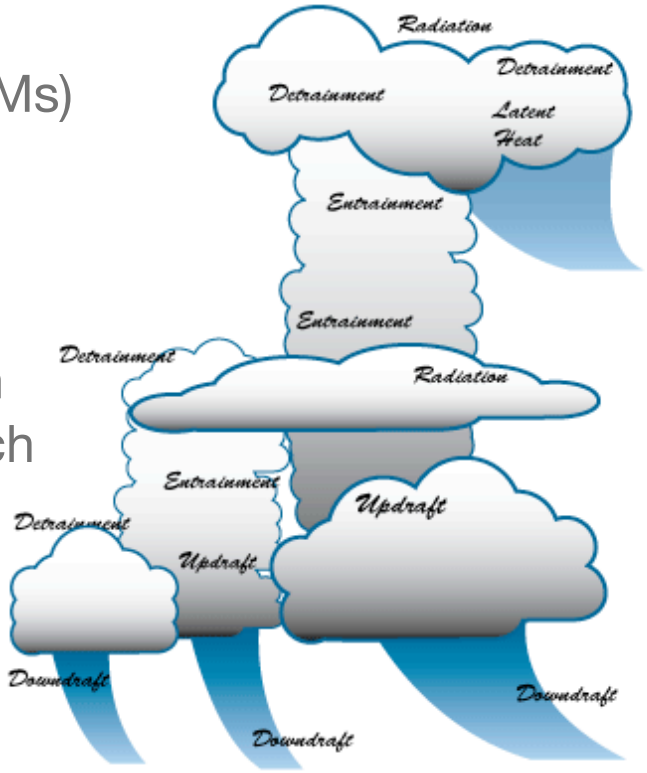


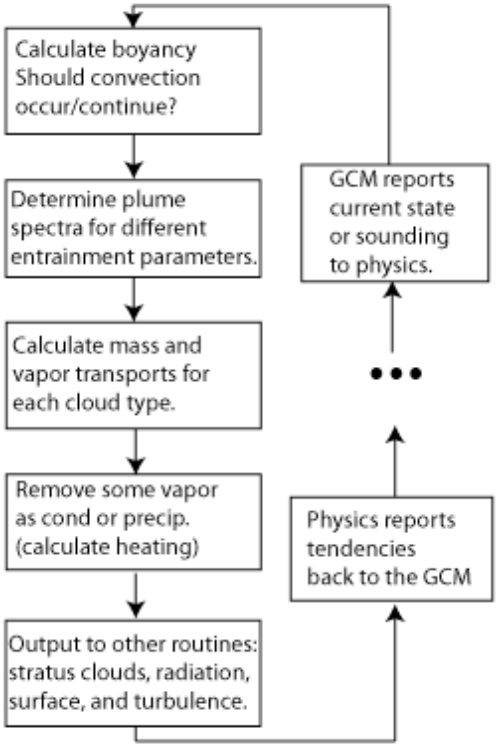
IPCC AR4 WG1 Fig 8.15

"In many climate models, **details in the representation of clouds can substantially affect the model estimates of cloud feedback and climate sensitivity** ([refs]). Moreover, the spread of climate sensitivity estimates among current models arises primarily from inter-model differences in cloud feedbacks ([refs]). Therefore, cloud feedbacks remain the largest source of uncertainty in climate sensitivity estimates."
-IPCC AR4 (2007)

Parameterization

- Global Climate Models (GCMs) have gridcells that are often nearly 100km wide
- Clouds are usually less than 10km wide (sometimes much less)
- A parameterization is a subroutine in the GCM that calculates the average effects of clouds, if there had been some inside of a gridcell.





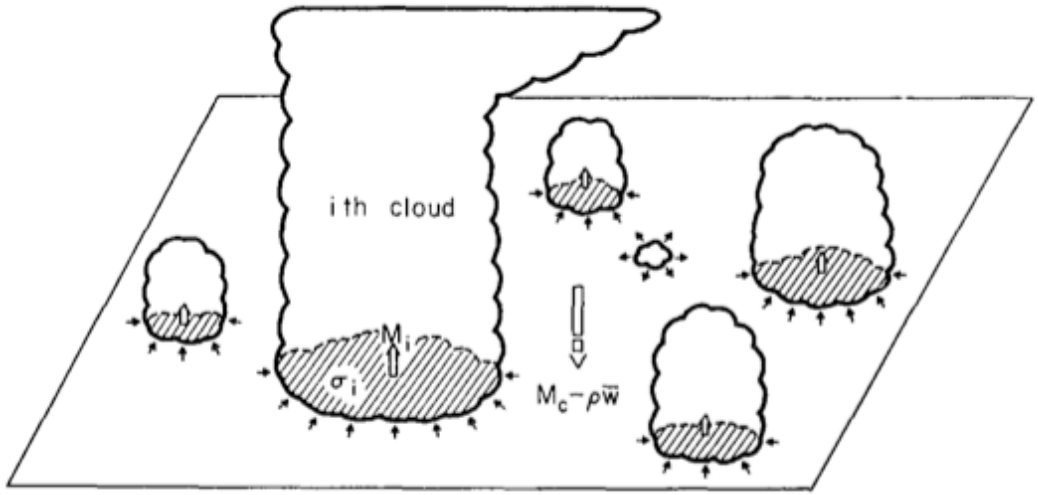


Diagram: Arakawa and Schubert (1974)

- **Arakawa and Schubert (1974)** : plume-based with no mention of downdrafts.
- **Moorthi and Suarez (1992)** : Relaxed AS, commonly used today, no downdrafts.
- **Pan and Randall (1998)** : No explicit downdrafts
- **Park and Bretherton (2009)** : The CAM5 “shallow” scheme, no downdrafts.

How are Downdrafts represented in Global Climate Models?

In convective parameterizations.

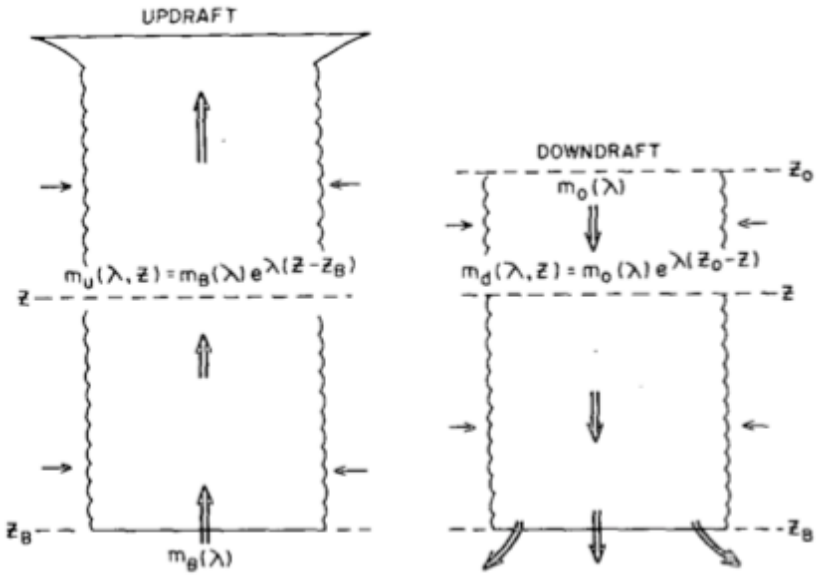


Diagram: Johnson (1976)

- **Johnson (1976)** : no mixing up/downdrafts, Md is a fixed fraction of Mu, Zd is a set fraction of updraft height
- **Zhang and McFarlane (1995)** : no mixing, Md is a fixed fraction of Mu, Zd is at min h*, evaporation limited to 20% of rain, all downdraft detrainment below cloud base
- **Emanuel (1991)** : Only environmental air entrained, fixed amount of precip available to evaporate

How are Downdrafts represented in Global Climate Models?

In convective parameterizations.

How realistic are all of those assumptions?

Photo: me

Testing Method

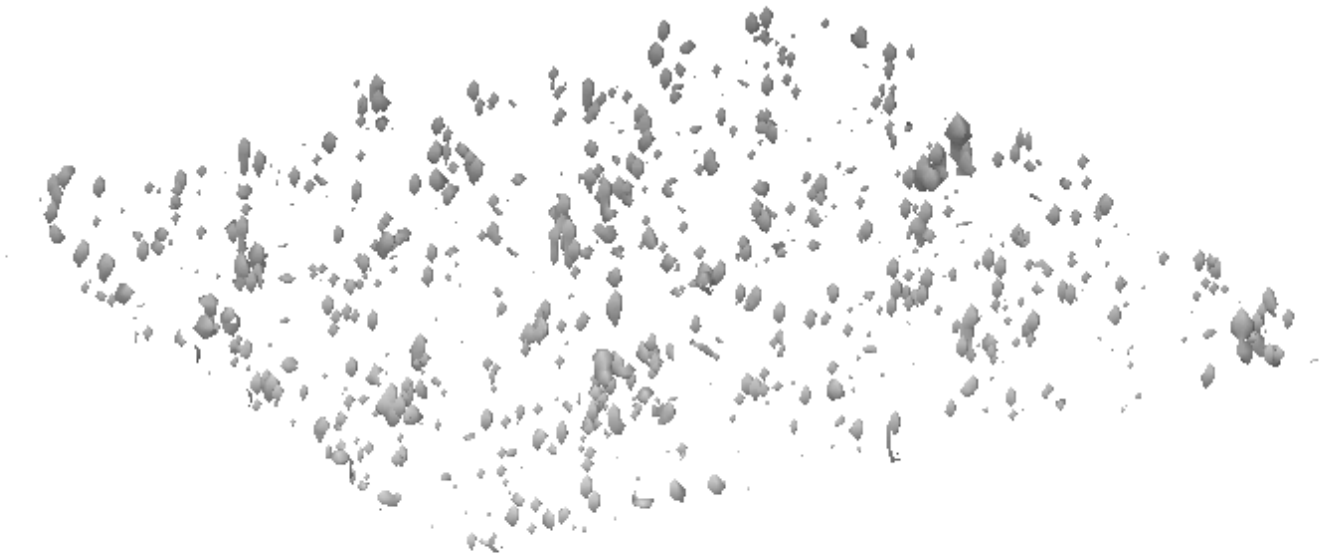
- Method: Use high resolution Cloud Resolving Model (CRM) runs to examine the effects of downdrafts.
- Model: System for Atmospheric Modeling (SAM) v6.8.2
  - Anelastic equations
  - Prognostic liquid water/ice static energy, total non-precipitating water, and total precipitating water
  - Single moment microphysics, RRTM radiation, and parameterized sub-grid-scale turbulence

About the Simulations

- All results shown here are from two runs, both have
  - 128x128 km^2 domain with 1km horizontal resolution
  - 64 vertical levels up to 5hPa (About 100m resolution near the surface)
  - 10 second timestep, ocean surface
- *Radiative-Convective Equilibrium* (RADCONV)
  - No large-scale forcing, includes a diurnal cycle, run for 50 days and use the last 20 days for results.
- *TOGA-COARE Run* (TOGA)
  - Large-Scale forcing from 21 days during the IOP at the end of December (includes passage of one MJO event)

What do clouds look like in your model?

First 12.5 days of TOGA



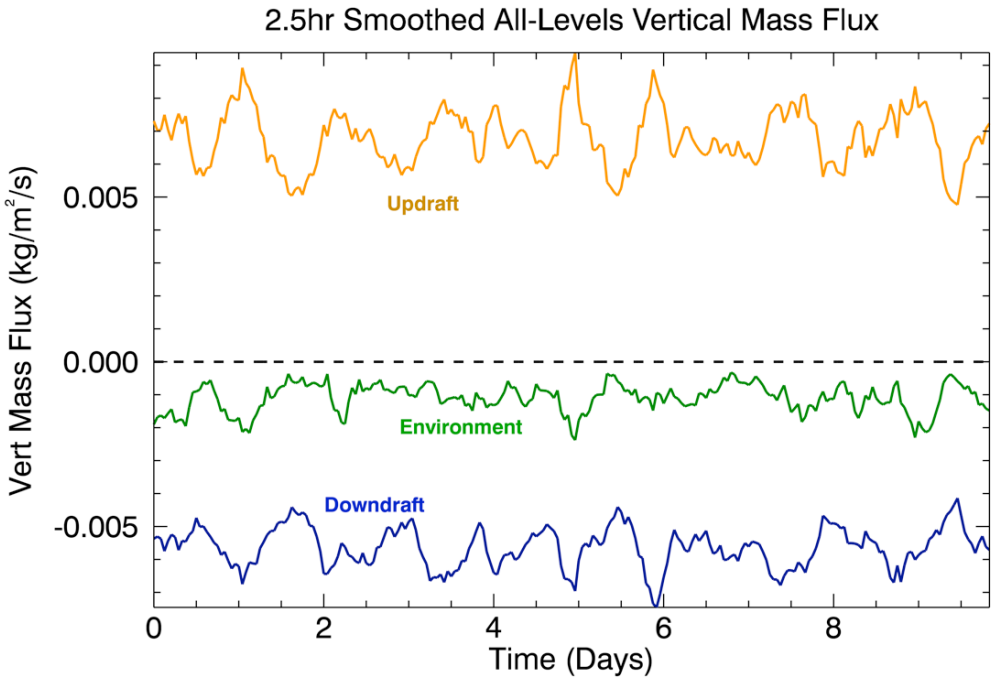
How do you define a downdraft?

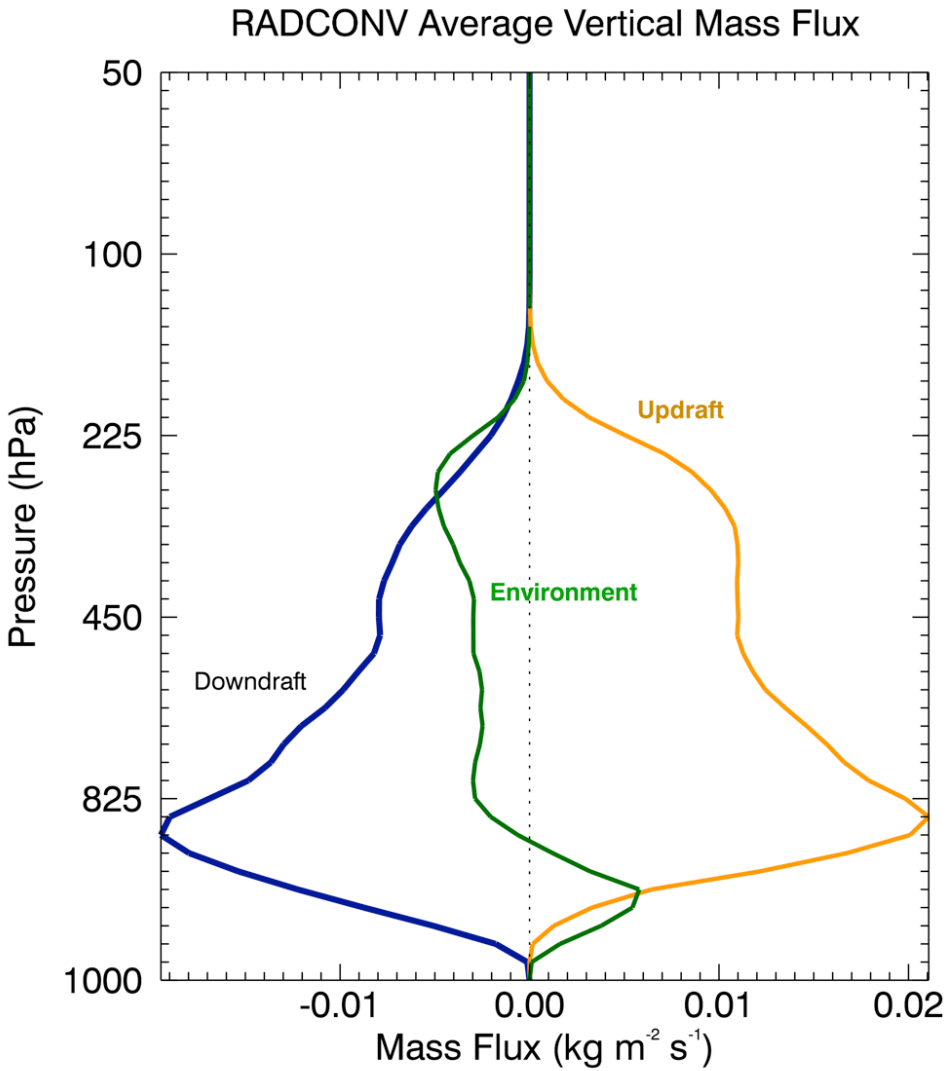
- **Core Downdrafts**
  - In 3D data, within a cloud or rain shaft, has a vertical velocity less than -1 m/s, continuous for two levels.
  - Updrafts must be within a cloud, and have a vertical velocity greater than 1 m/s, continuous for two levels.
- **Cloud Downdrafts**
  - In 3D data, within a cloud or rain shaft, and has any negative vertical velocity.
  - Updrafts must be within a cloud and have a positive vertical velocity.

What do downdrafts look like in your model?

CORE Mass Fluxes

RADCONV





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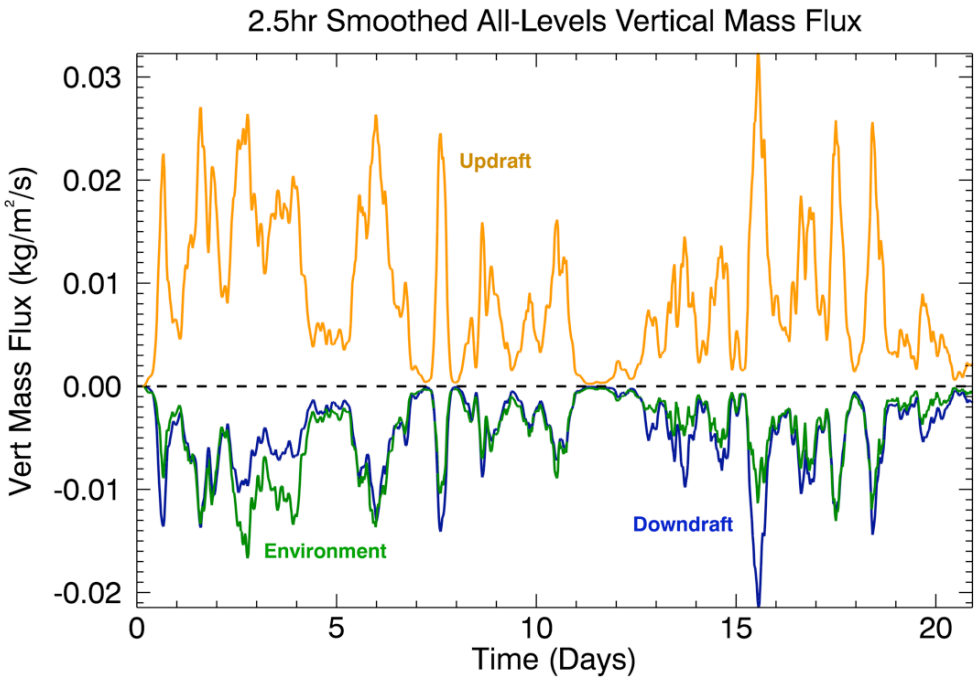
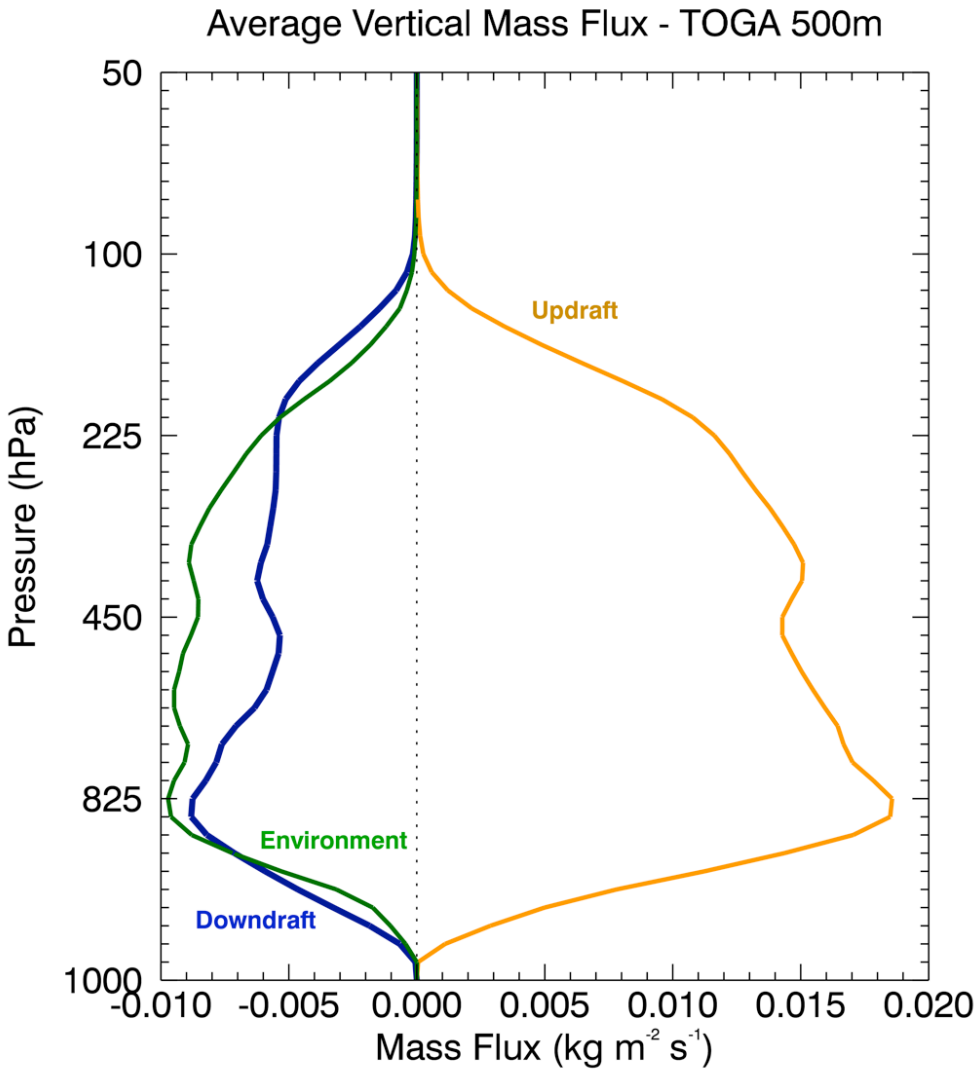
CORE Mass Fluxes

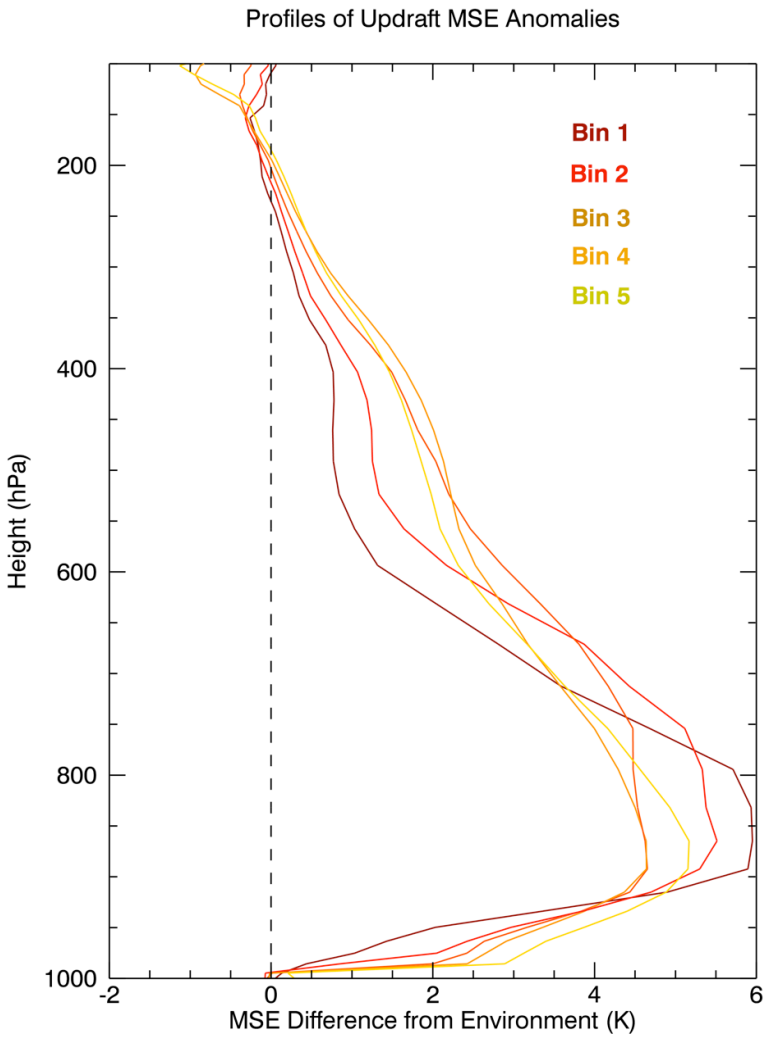
TOGA



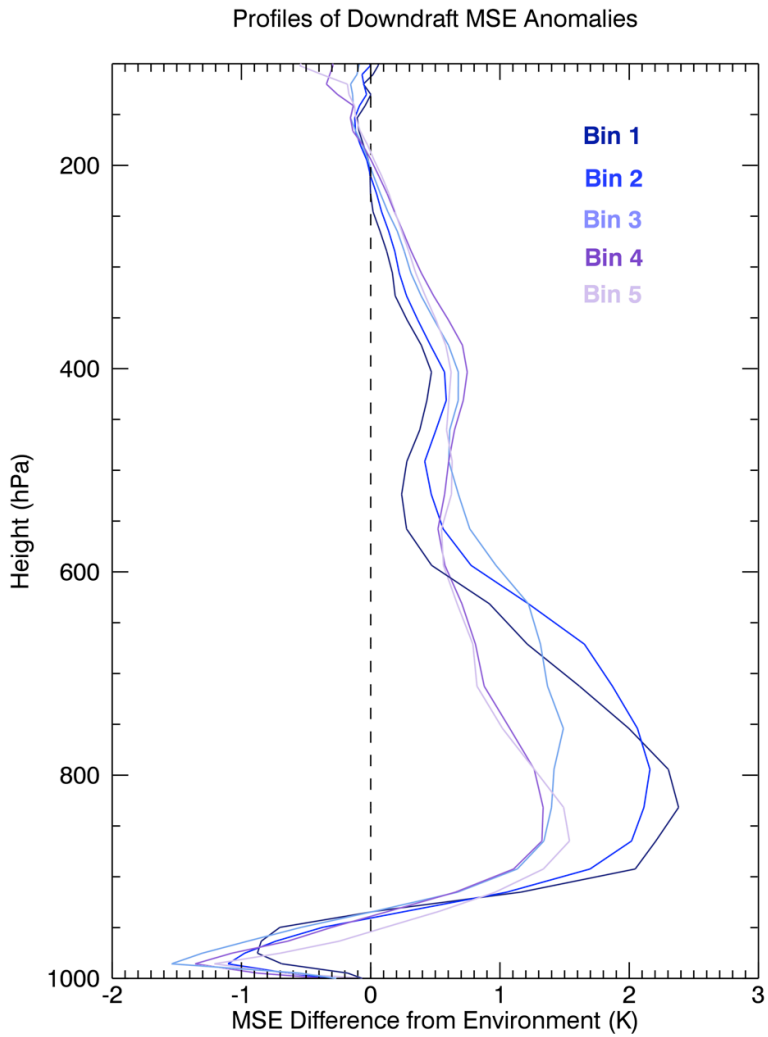


What do downdrafts look like in your model?

Anomalous MSE Profiles



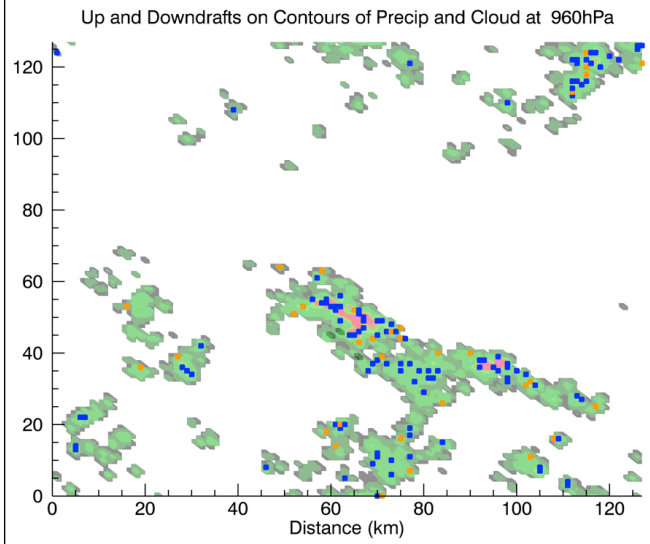
Core Updrafts

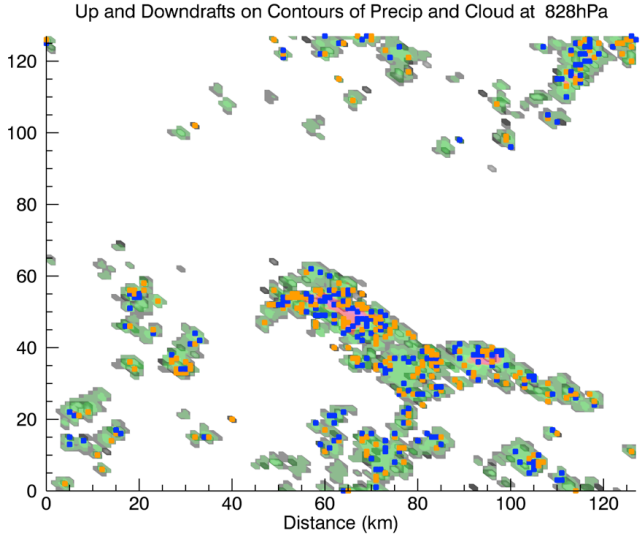


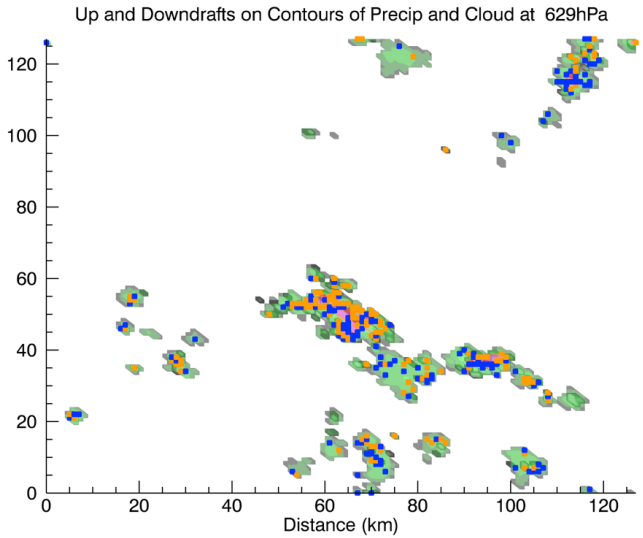
Core Downdrafts

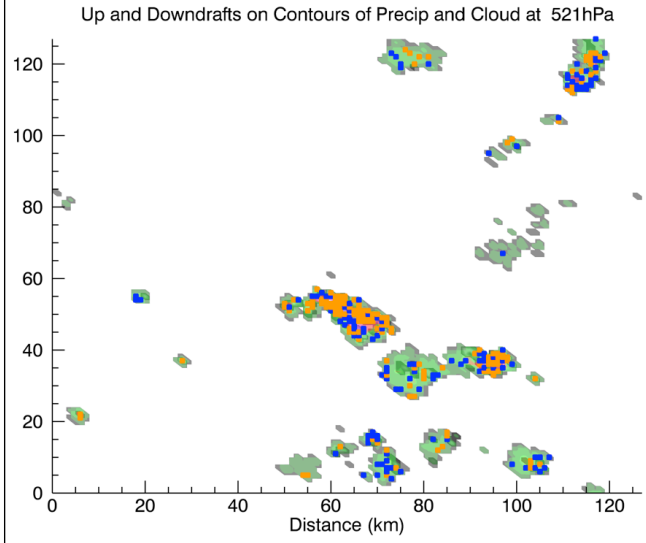
What do downdrafts look like in your model?

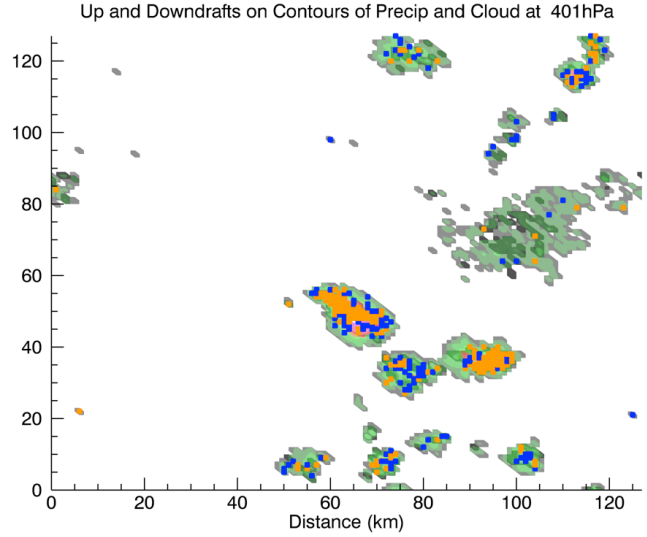
Cloud Geometry

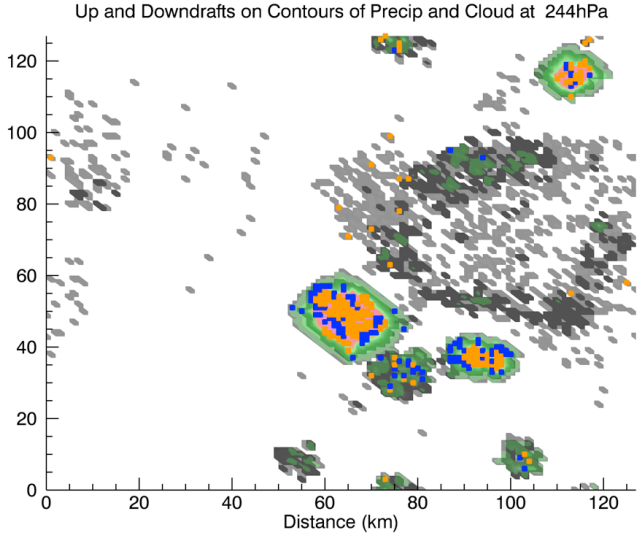






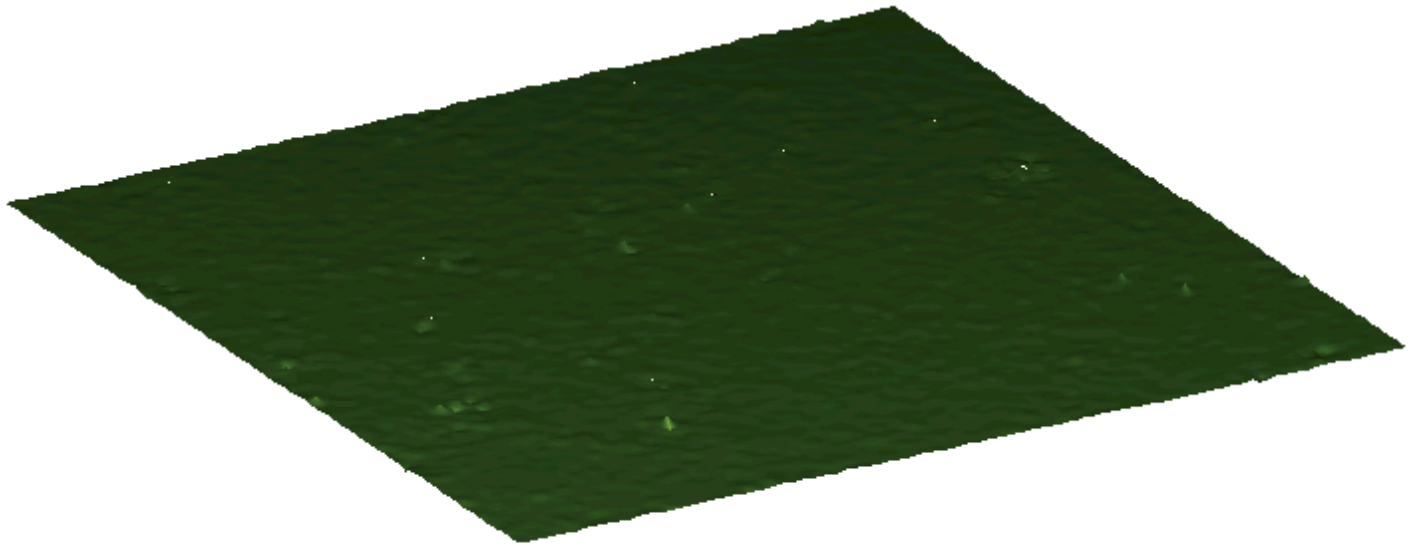






Cold pools help convection organize and propagate.

Cold pools and gust front convergence



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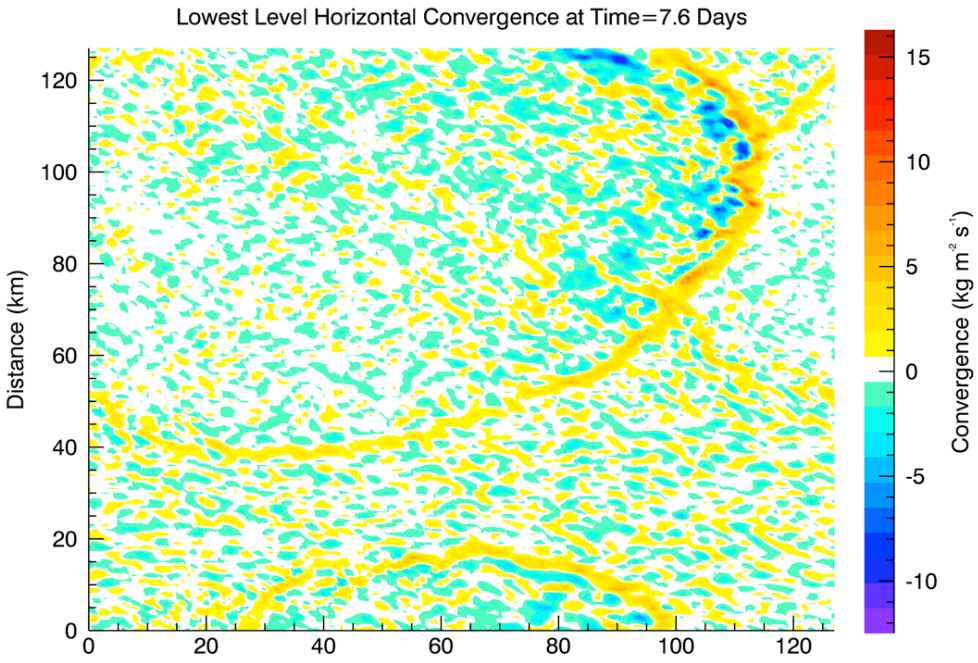
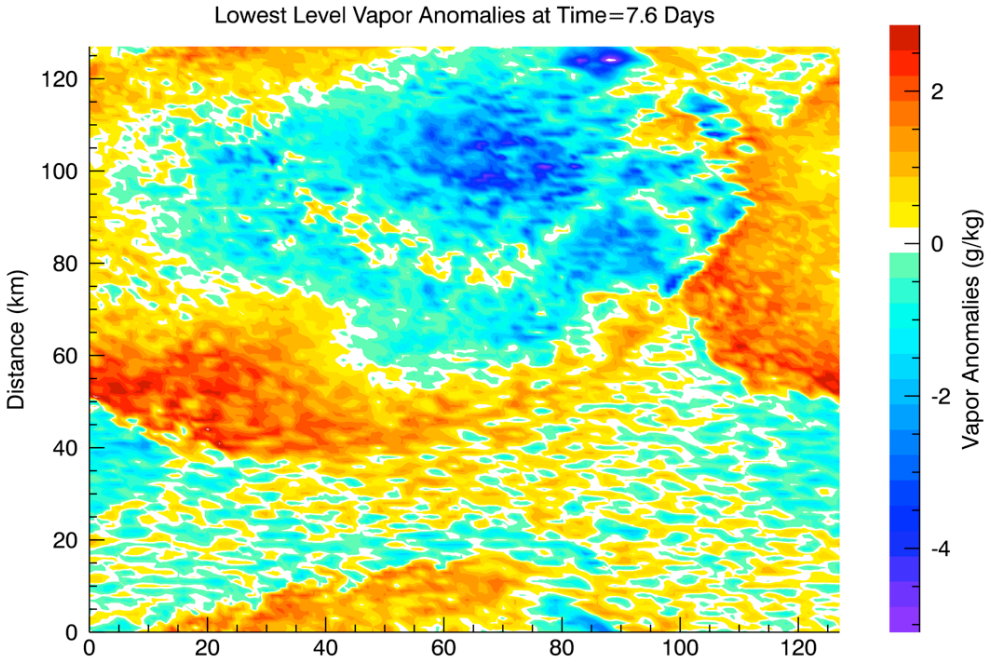


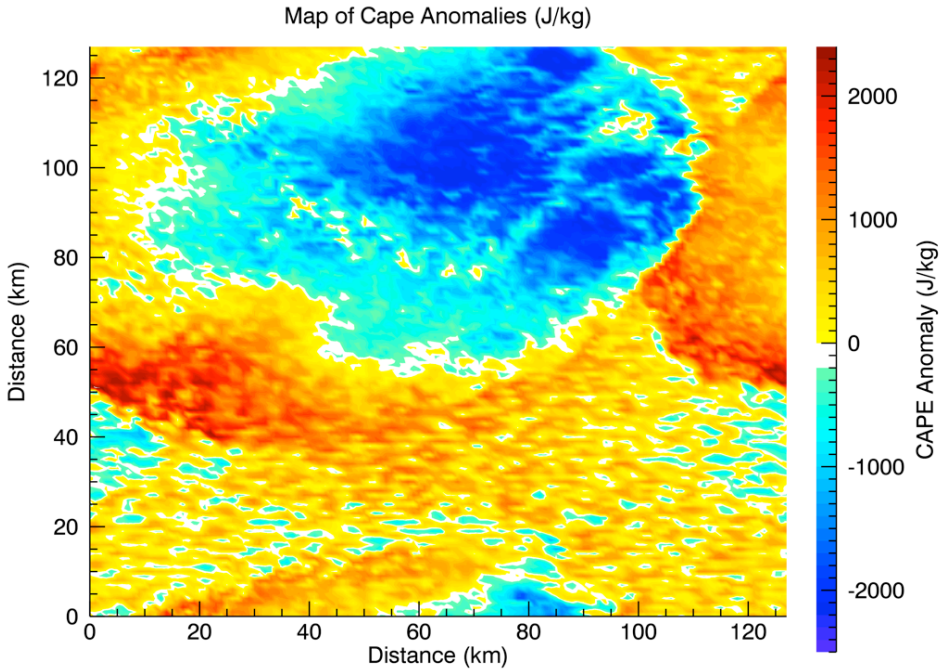
Mass Convergence



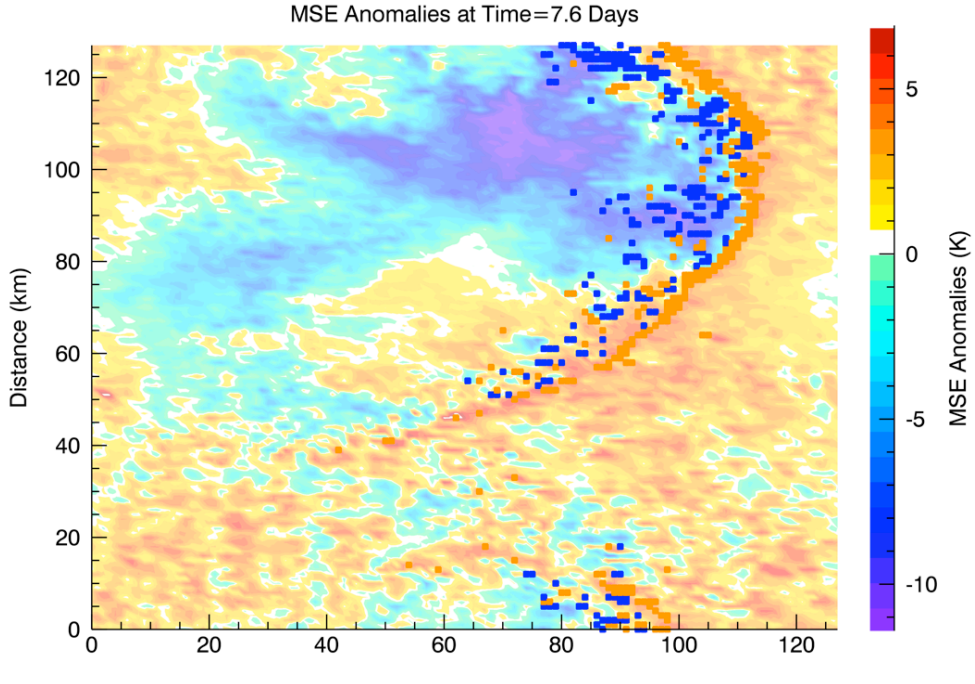
Water Vapor

Cold pools help convection organize and propagate.

Cold pools and gust front convergence



CAPE



MSE

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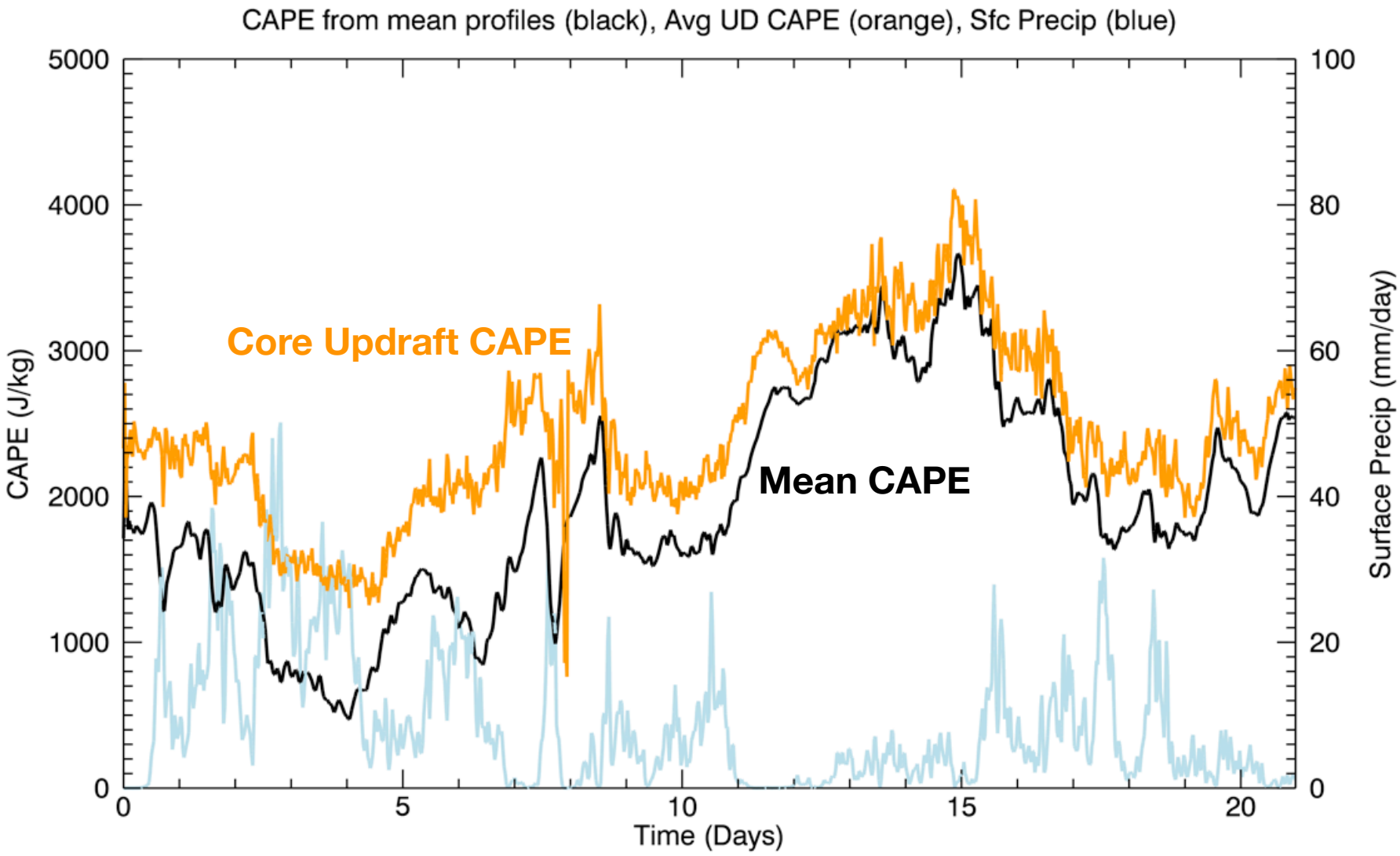
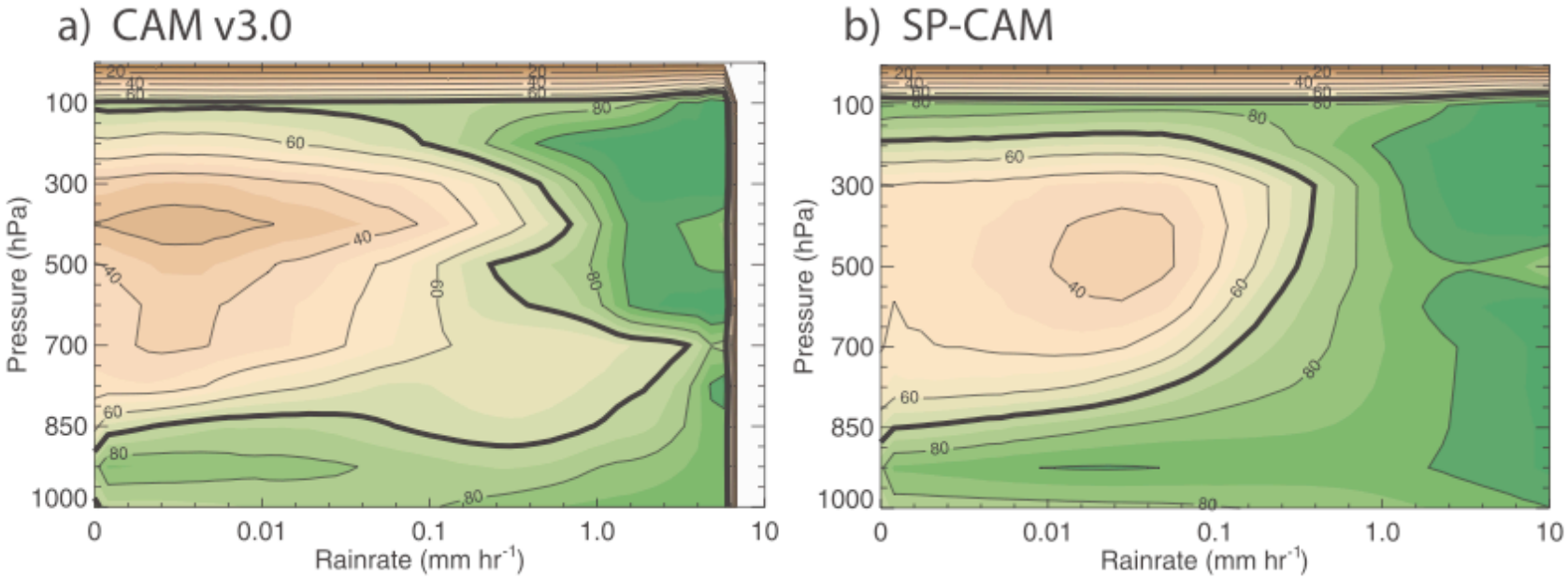


Downdraft sensitivity to mid-level relative humidity

Can downdrafts help couple deep convection and high RH?



Tropical Relative Humidity Profiles per Rainrate

Three Ways to Decrease the Frequency of Deep Convection

1. Relative Humidity Cut-Off Criteria (Tokioka et al, 1988)
- Do not allow deep convection to occur until shallow and stratiform convection (and SGS fluxes) have sufficiently moistened the boundary layer or column.

2. Increased Updraft Entrainment
- Increased entrainment will decrease the buoyancy of updraft parcels when they encounter dry air and deep convection will not occur until the column is sufficiently moistened.

3. Better Downdrafts
- As precipitation falls through dry air in the mid-troposphere, it evaporates more, increasing boundary layer cooling by downdrafts (and increasing the mid-troposphere moisture). Future convective energy is reduced.

Downdraft sensitivity to mid-level relative humidity

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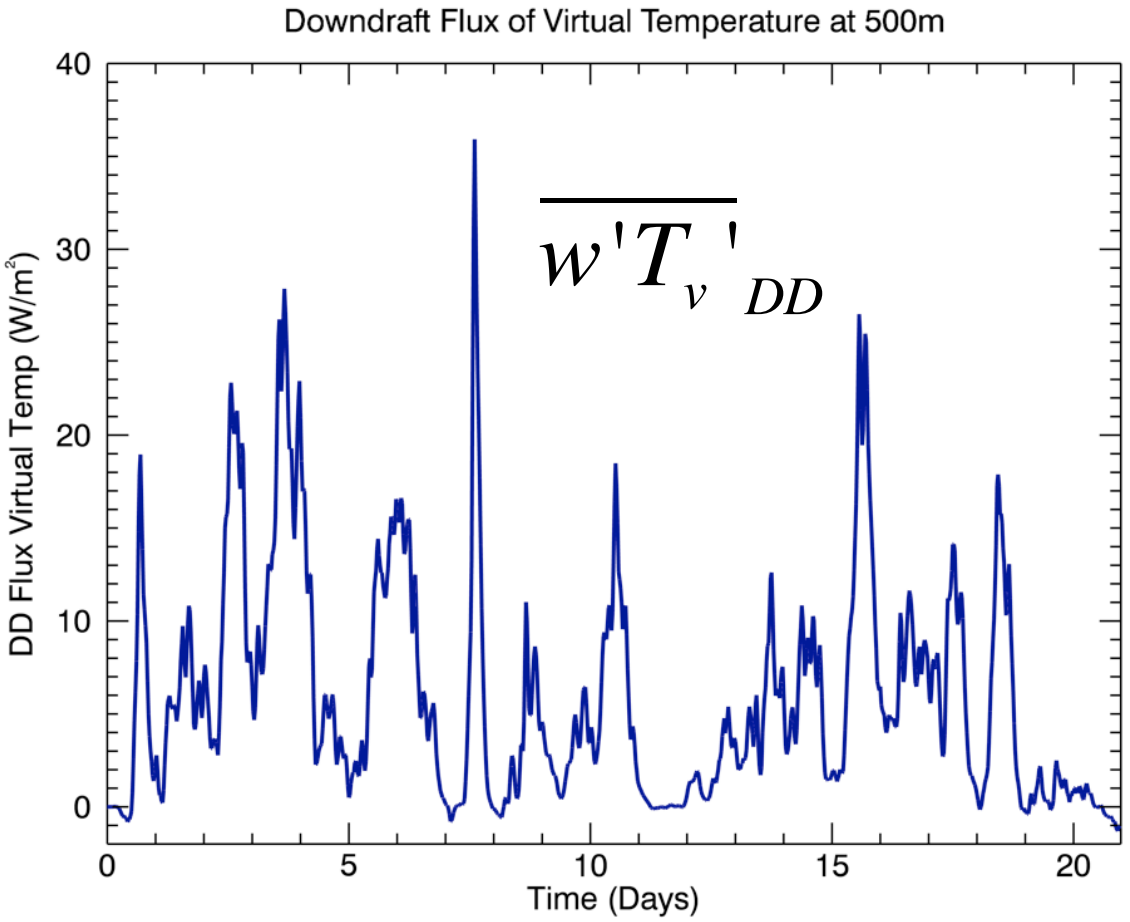
Cloud Downdrafts



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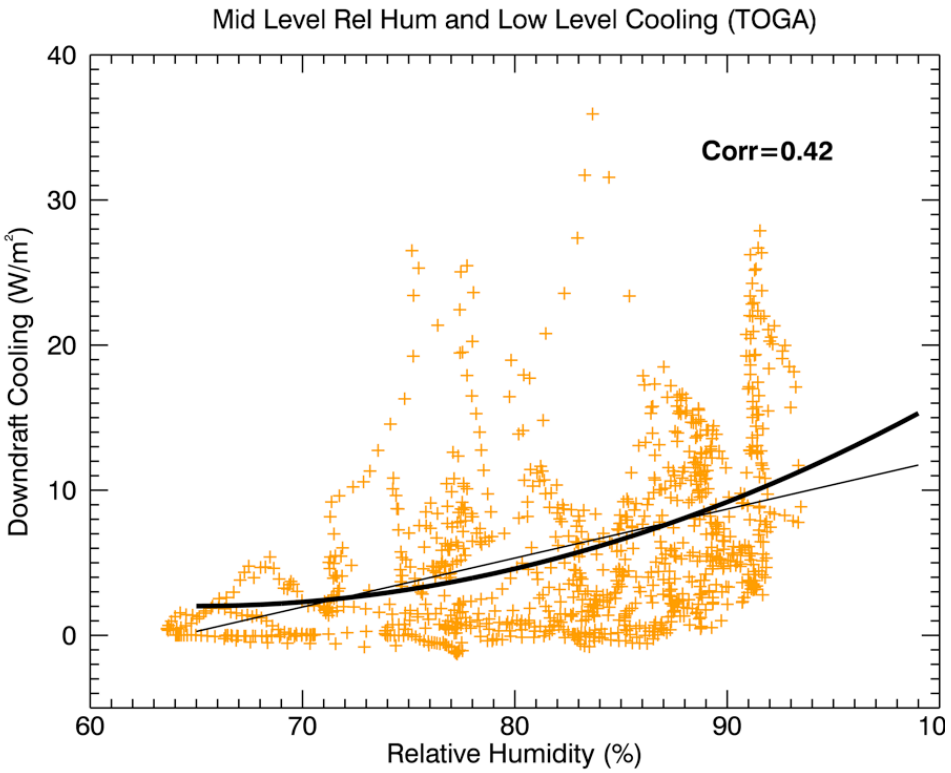
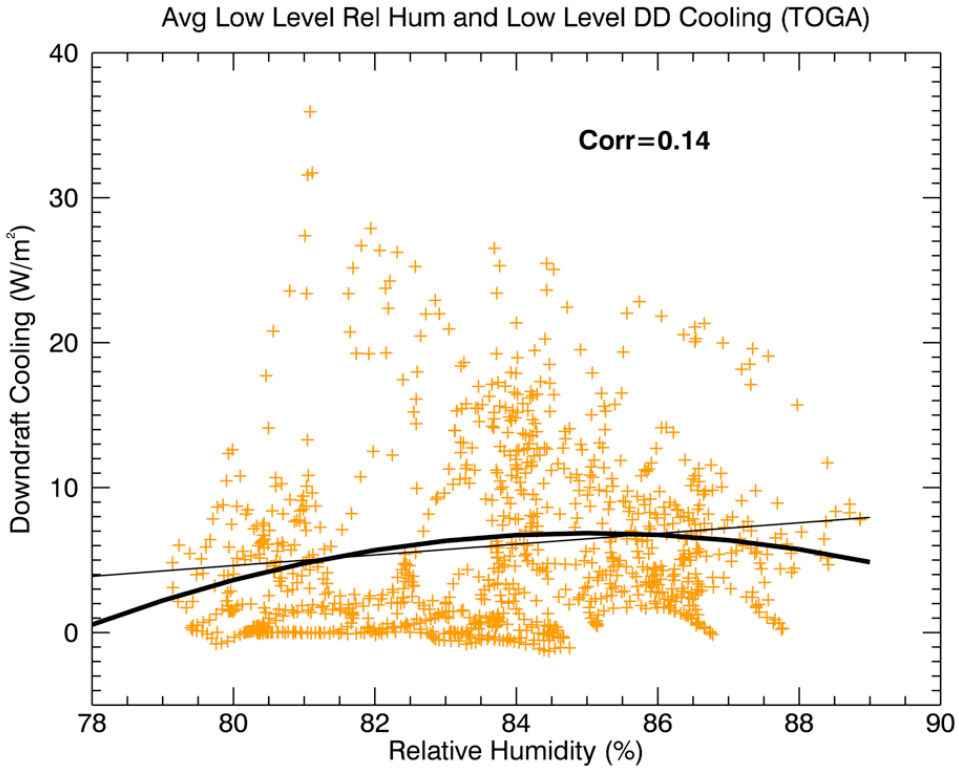
$$\overline{w'T_v'}_{DD}$$



500-850 hPa RH



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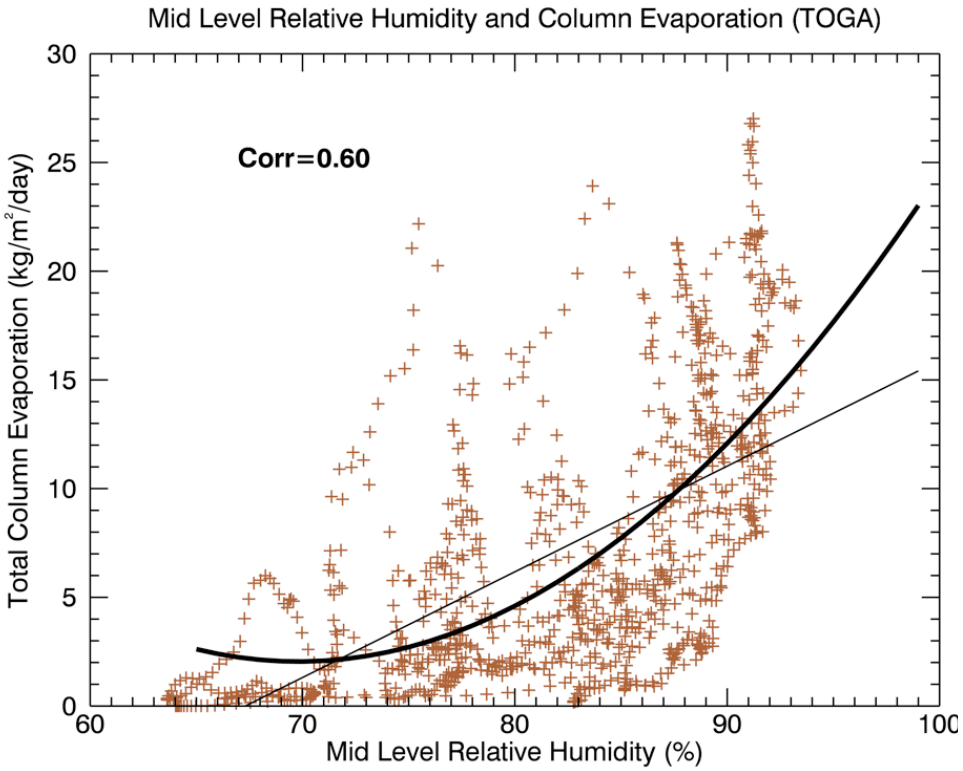
Column Evaporation



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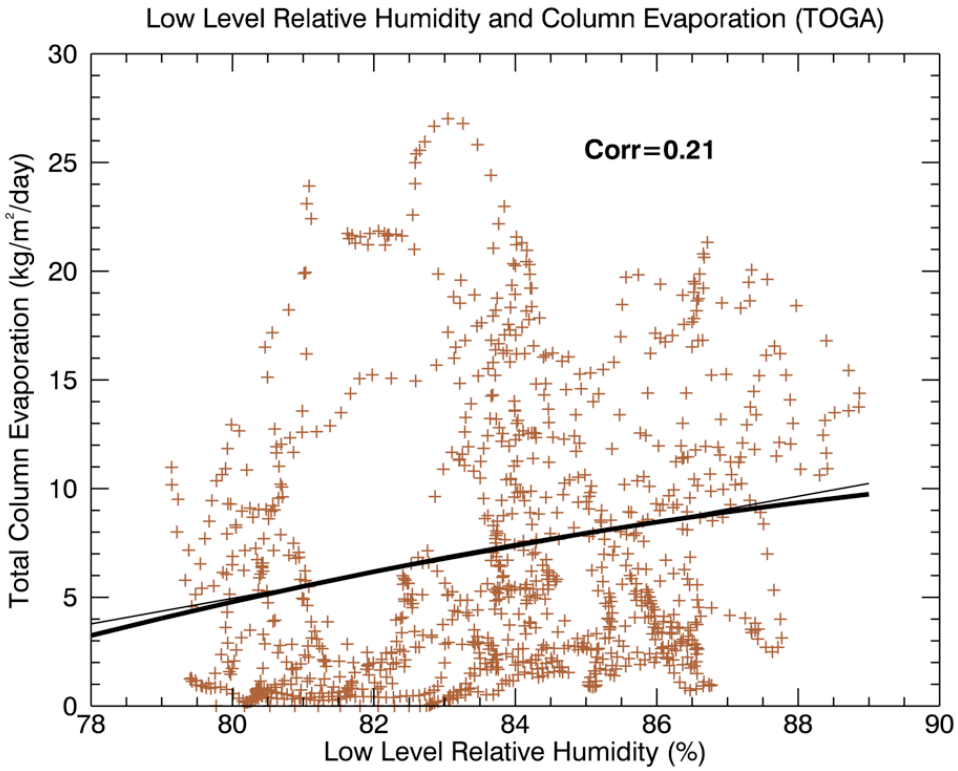

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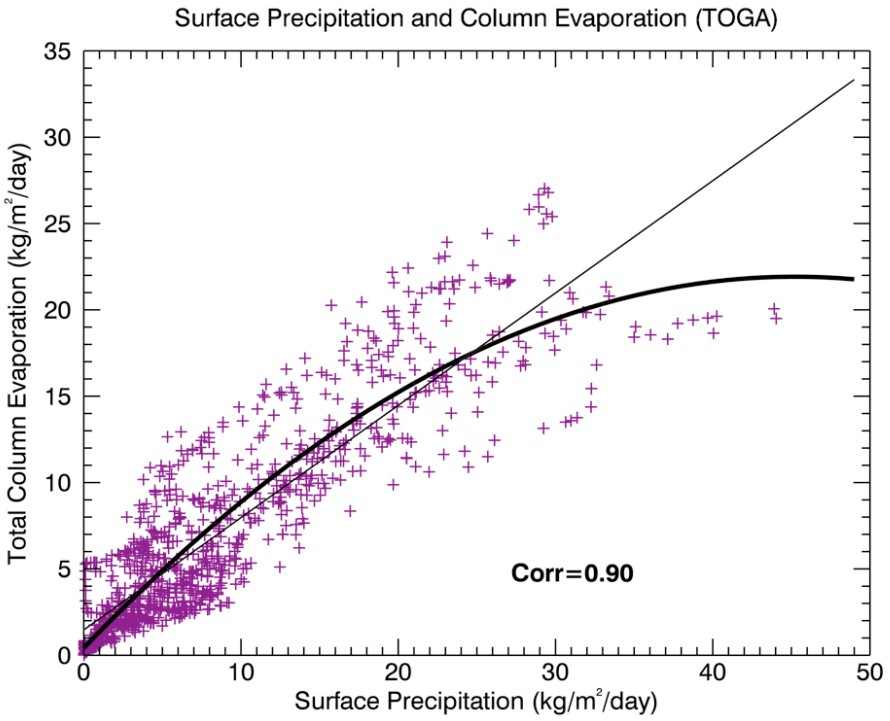
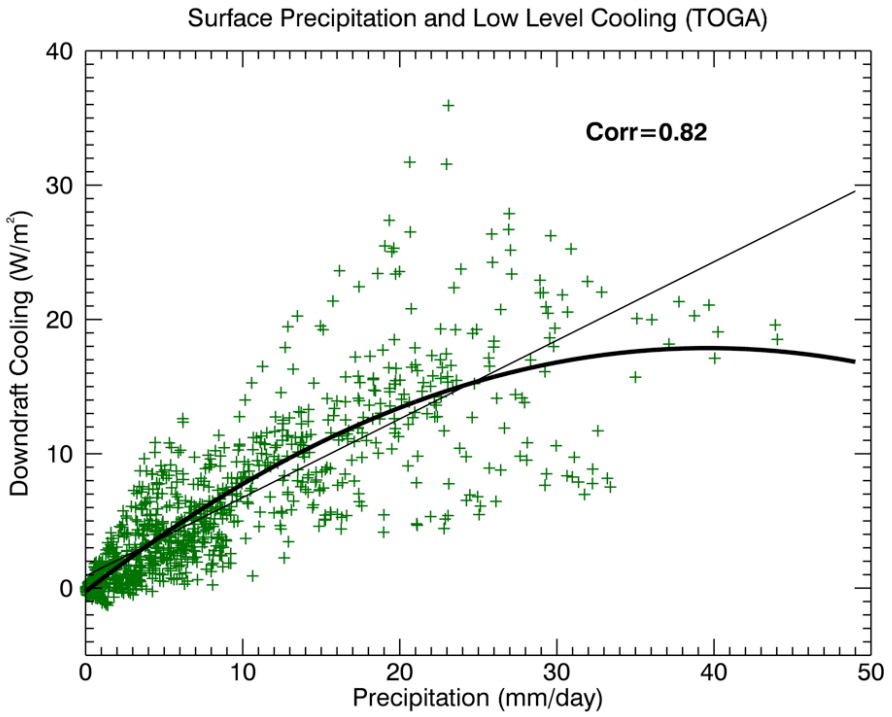
Precipitation and Evaporation





Precipitation and DD Cooling

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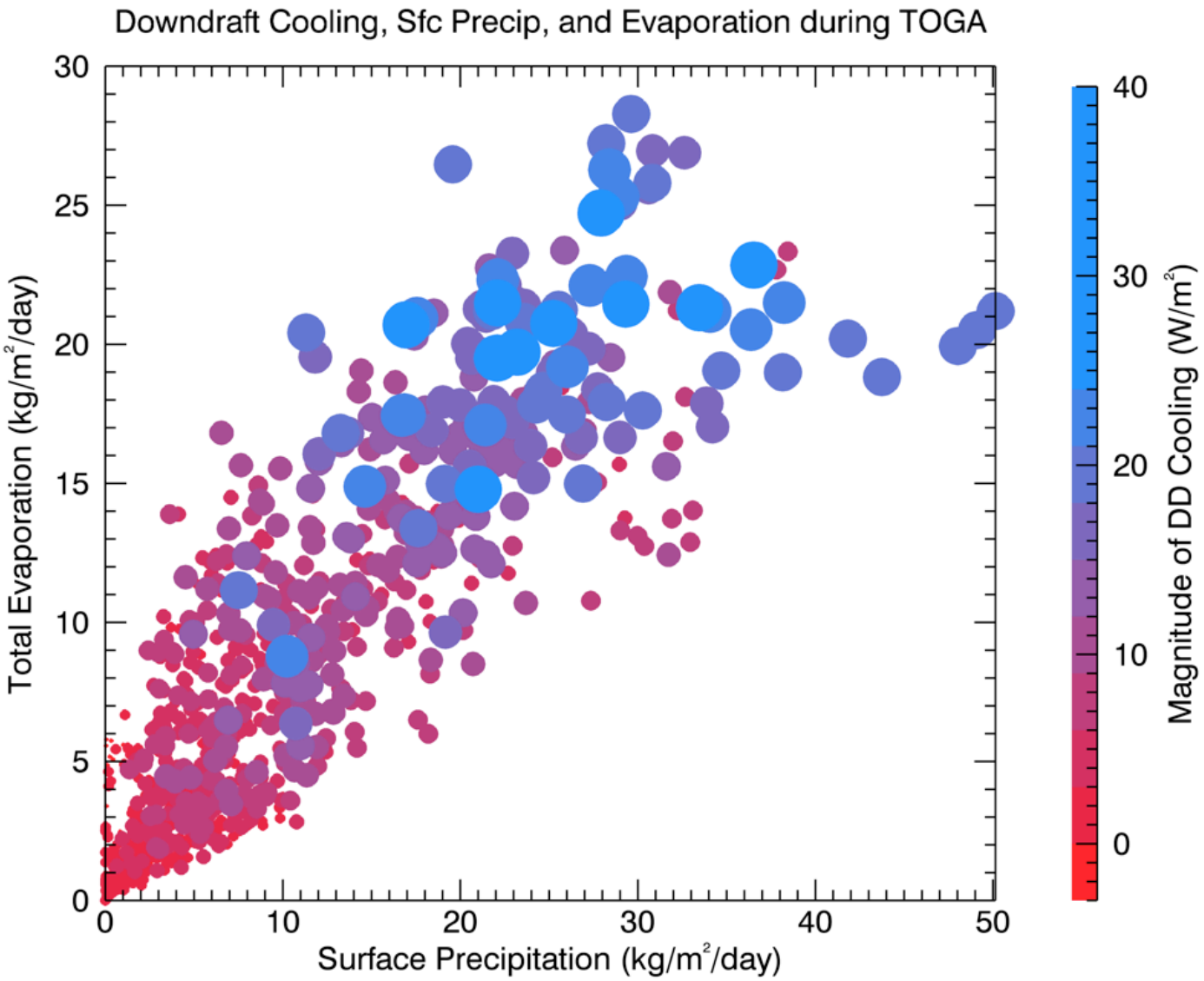
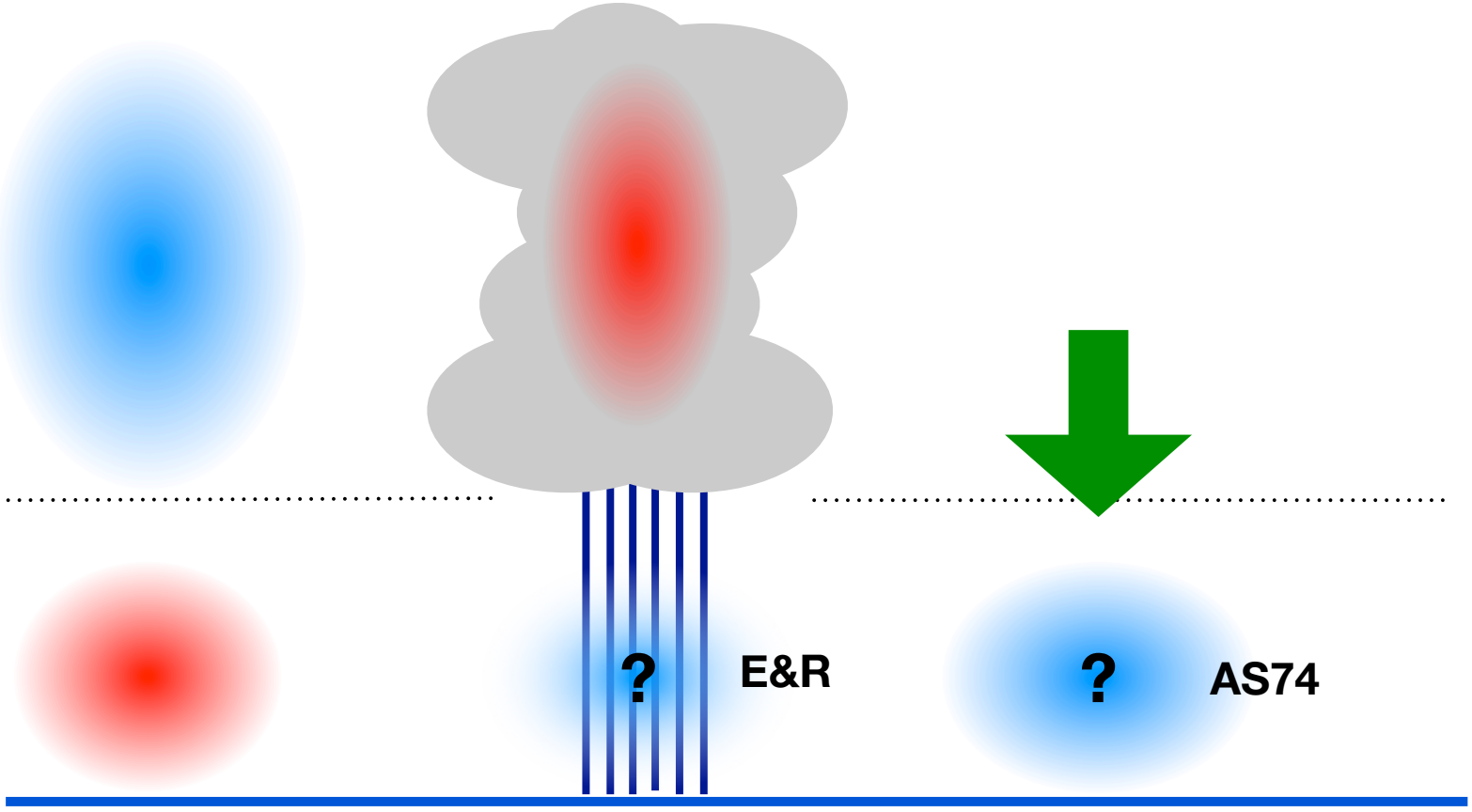


Boundary layer quasi-equilibrium

Do downdrafts or environmental entrainment balance surface fluxes?



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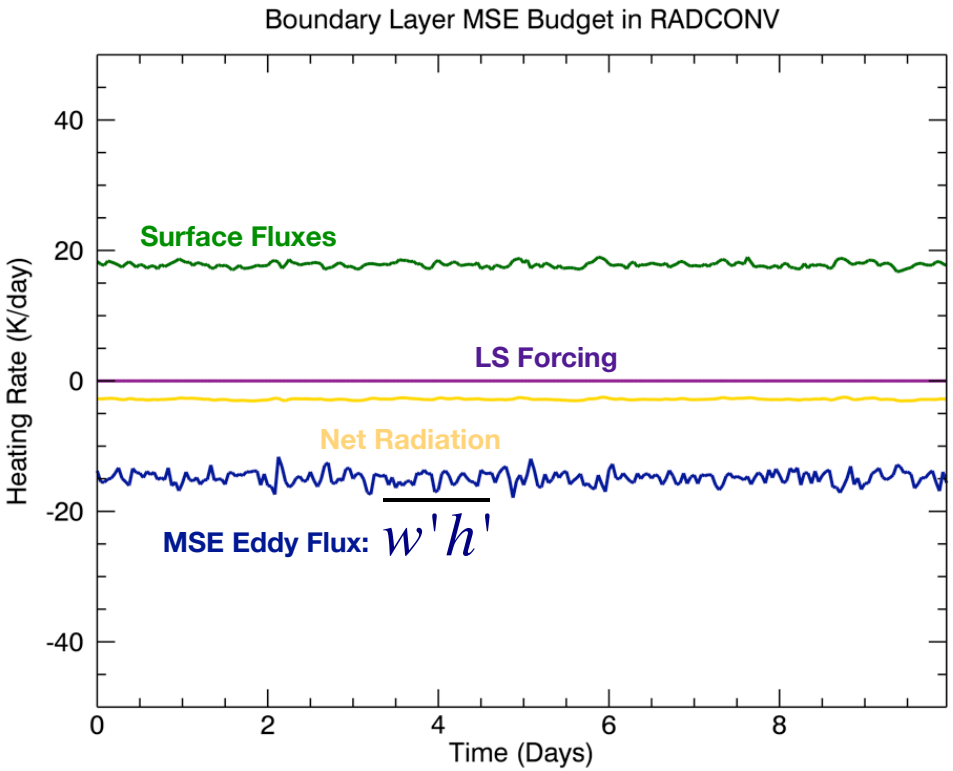
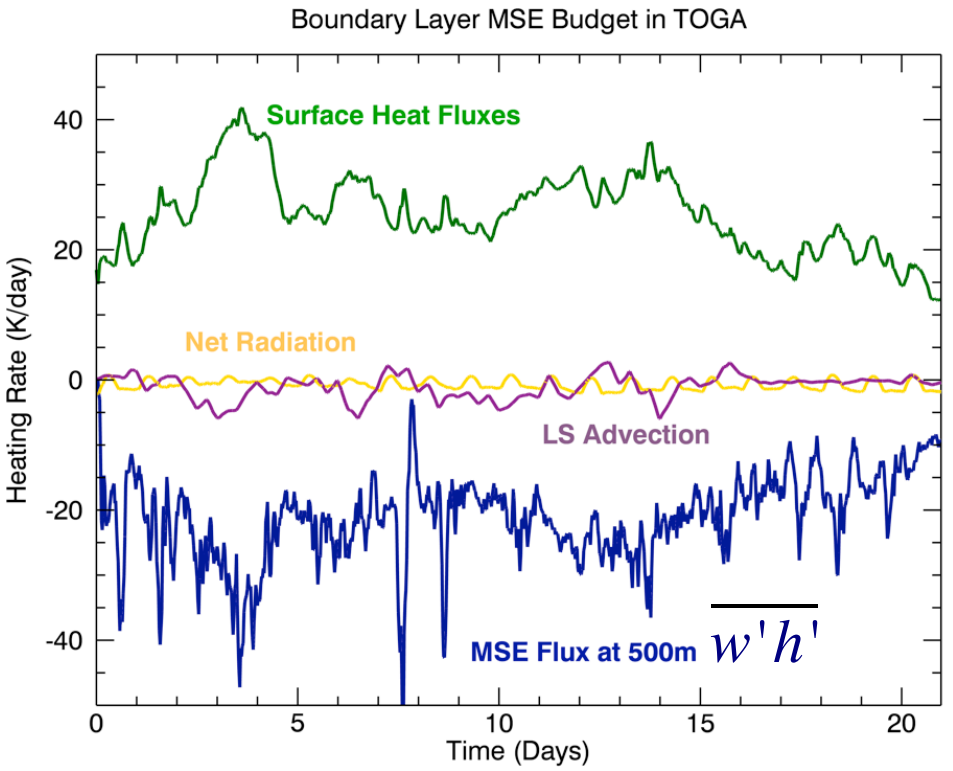


RADCONV



TOGA

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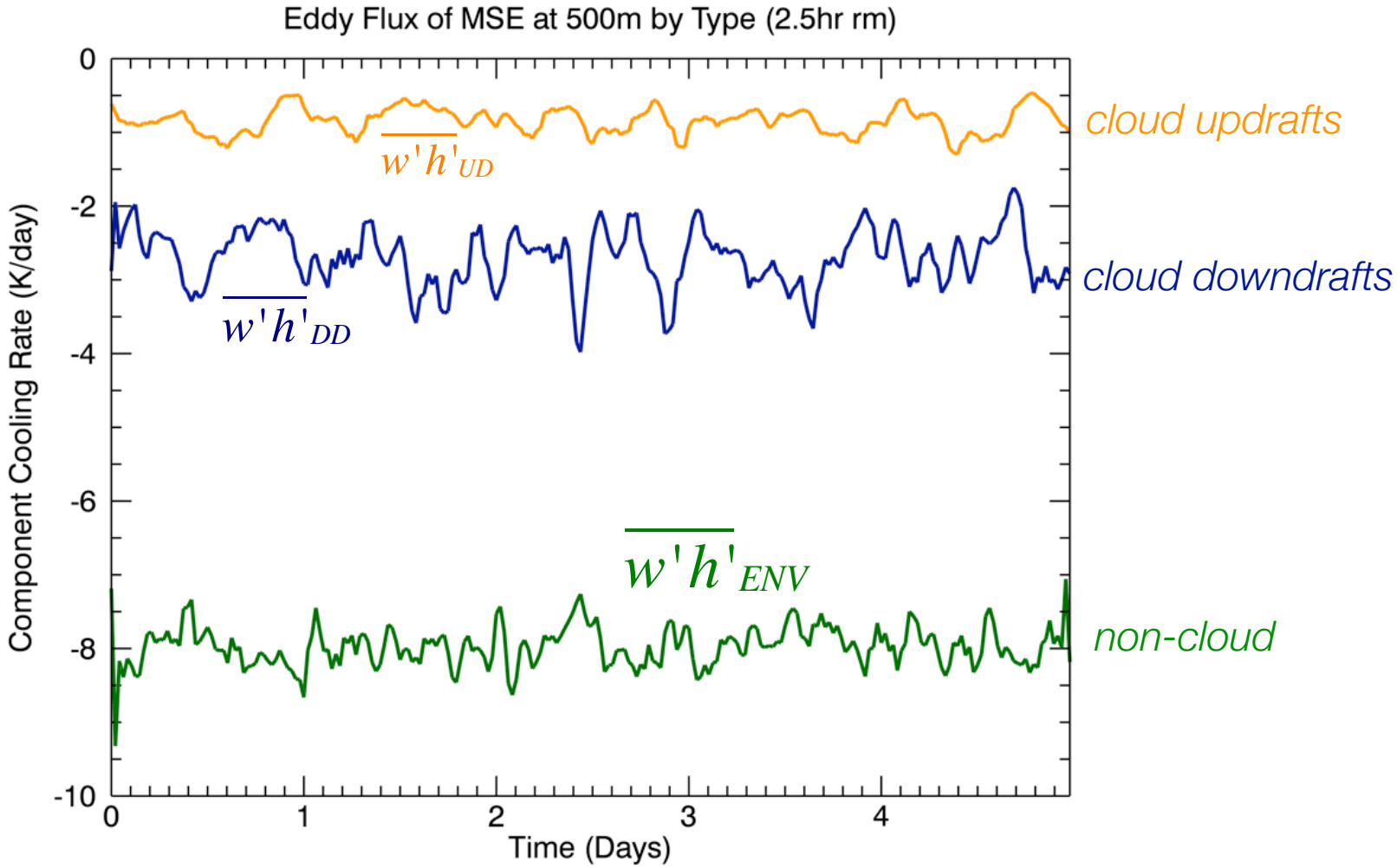

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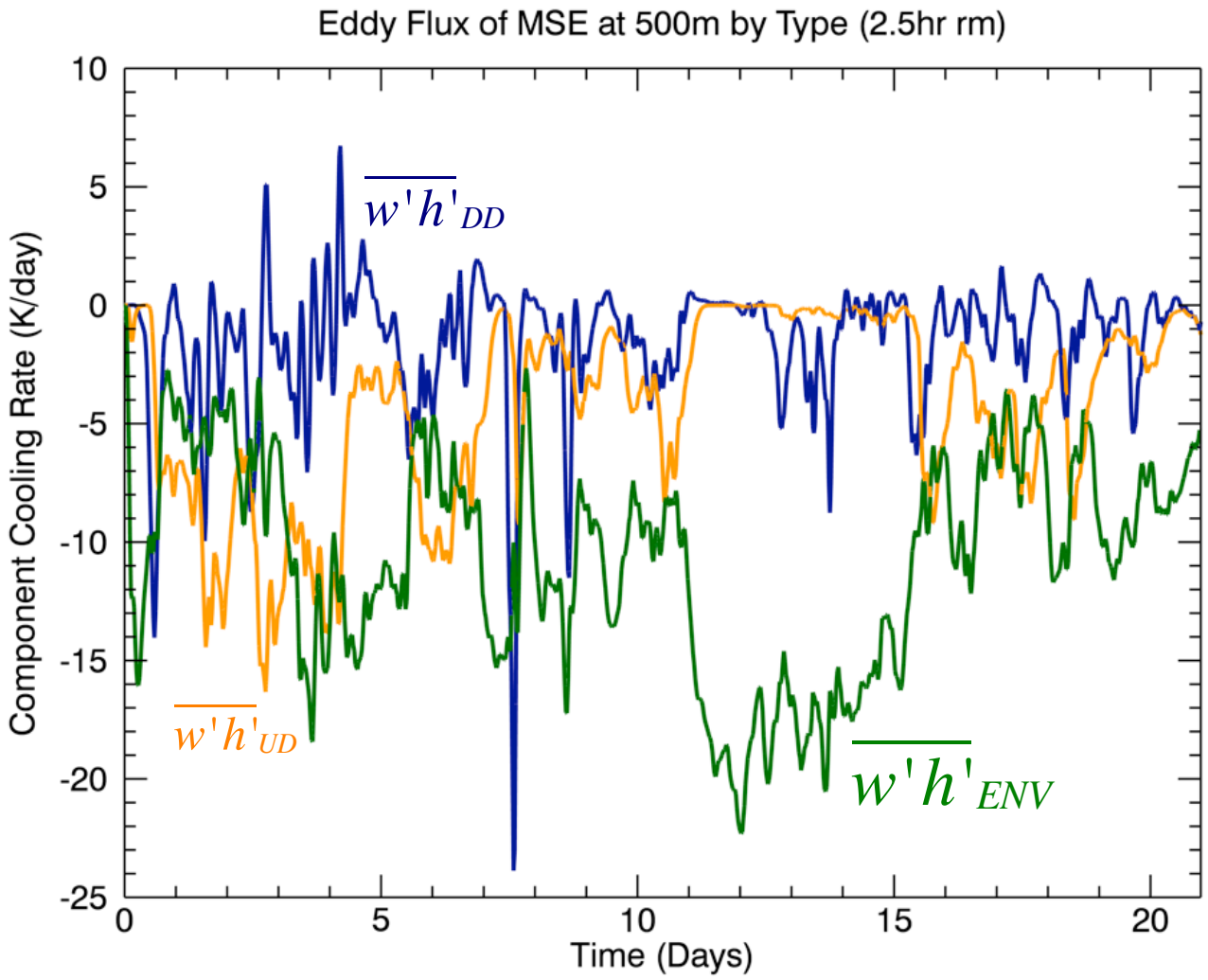

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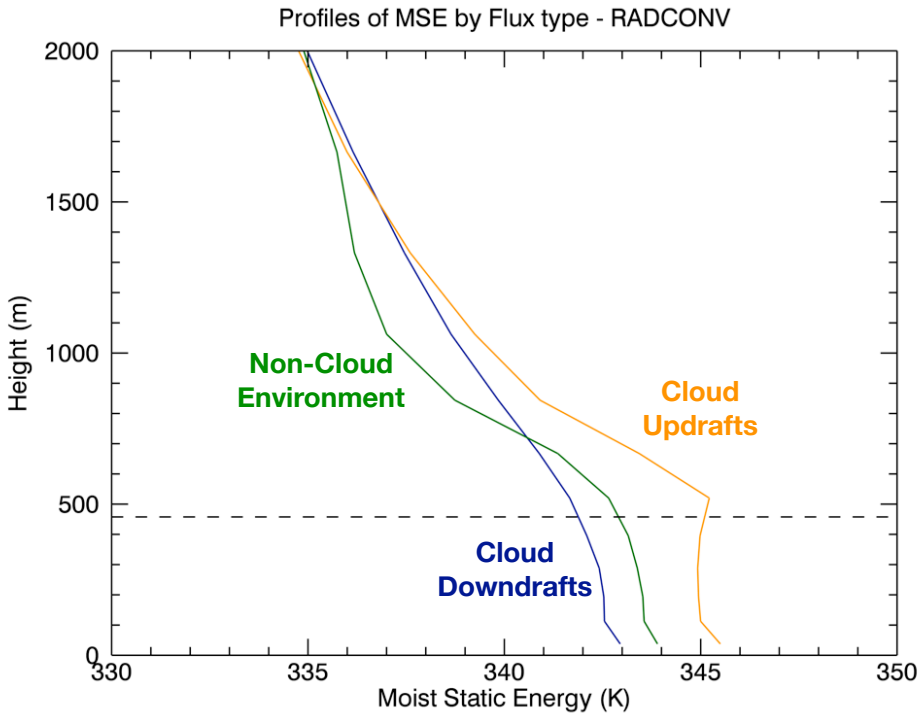
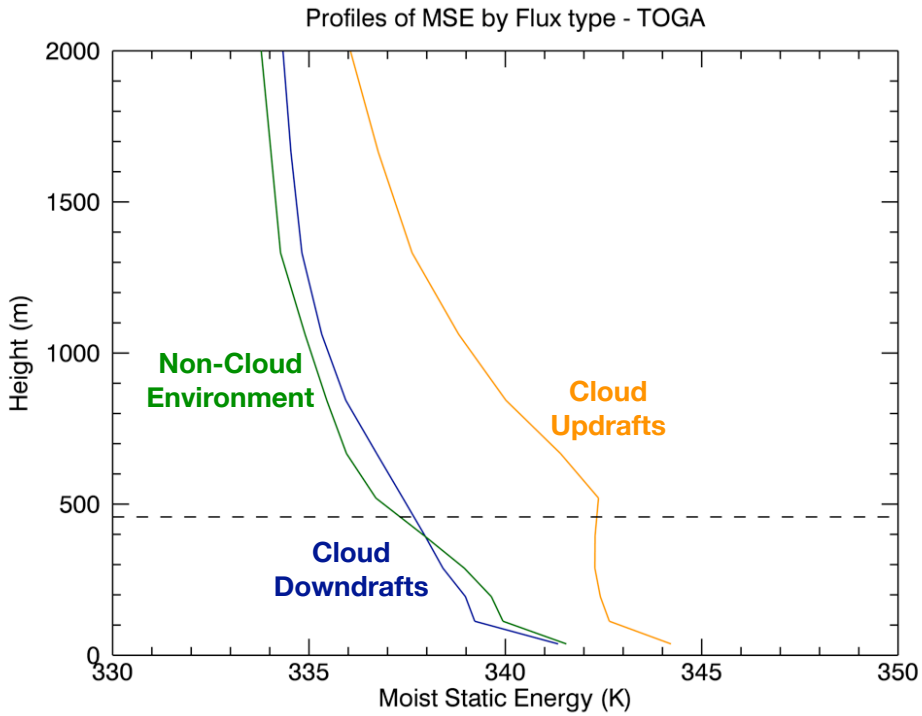
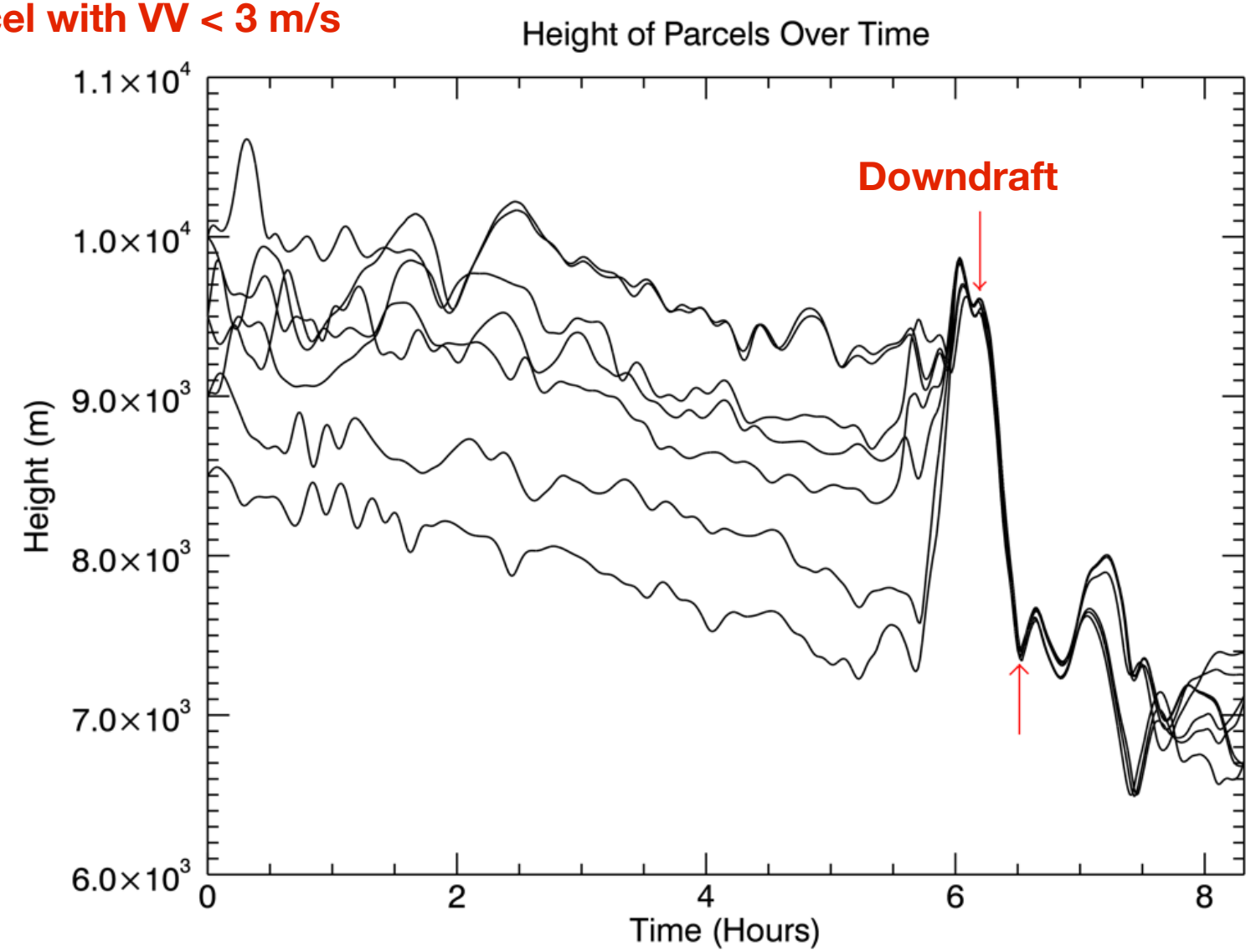




Lagrangian Parcel Tracking

Are downdrafts always saturated and negatively buoyant?

LPT Downdraft:
Any Parcel with VV < 3 m/s



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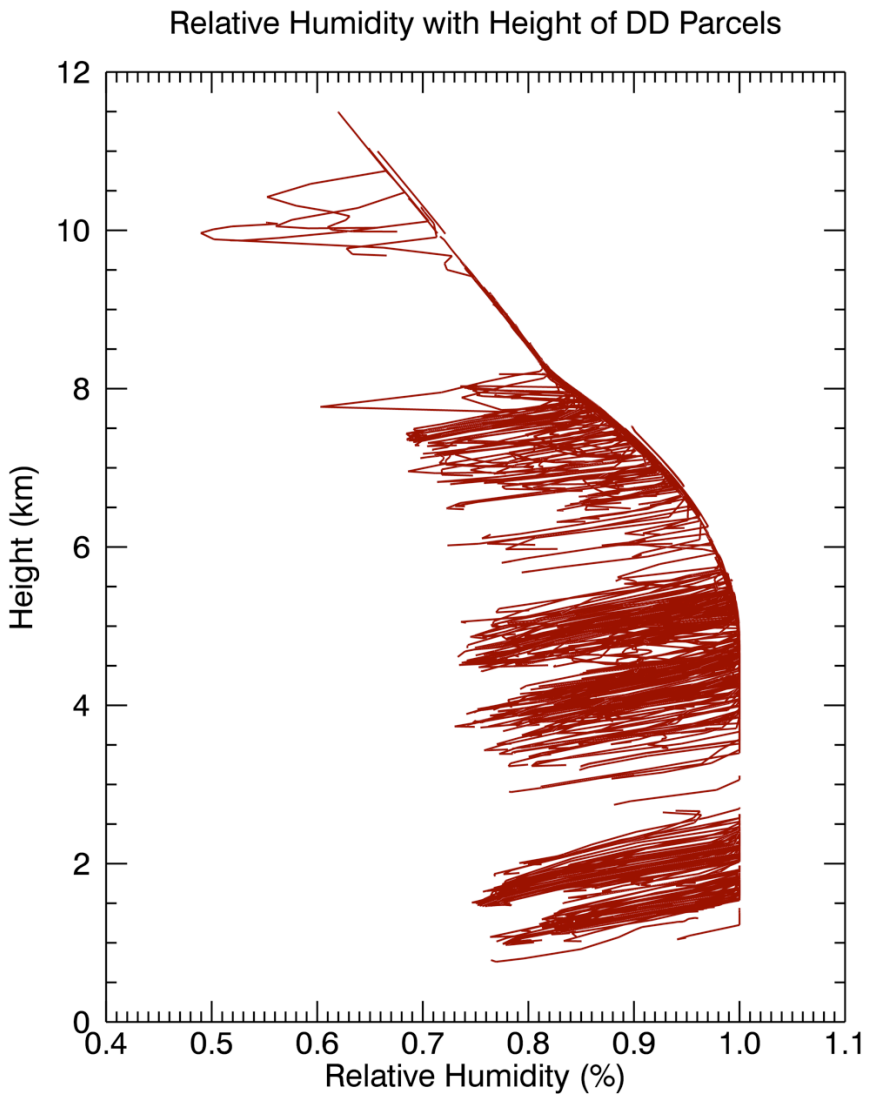
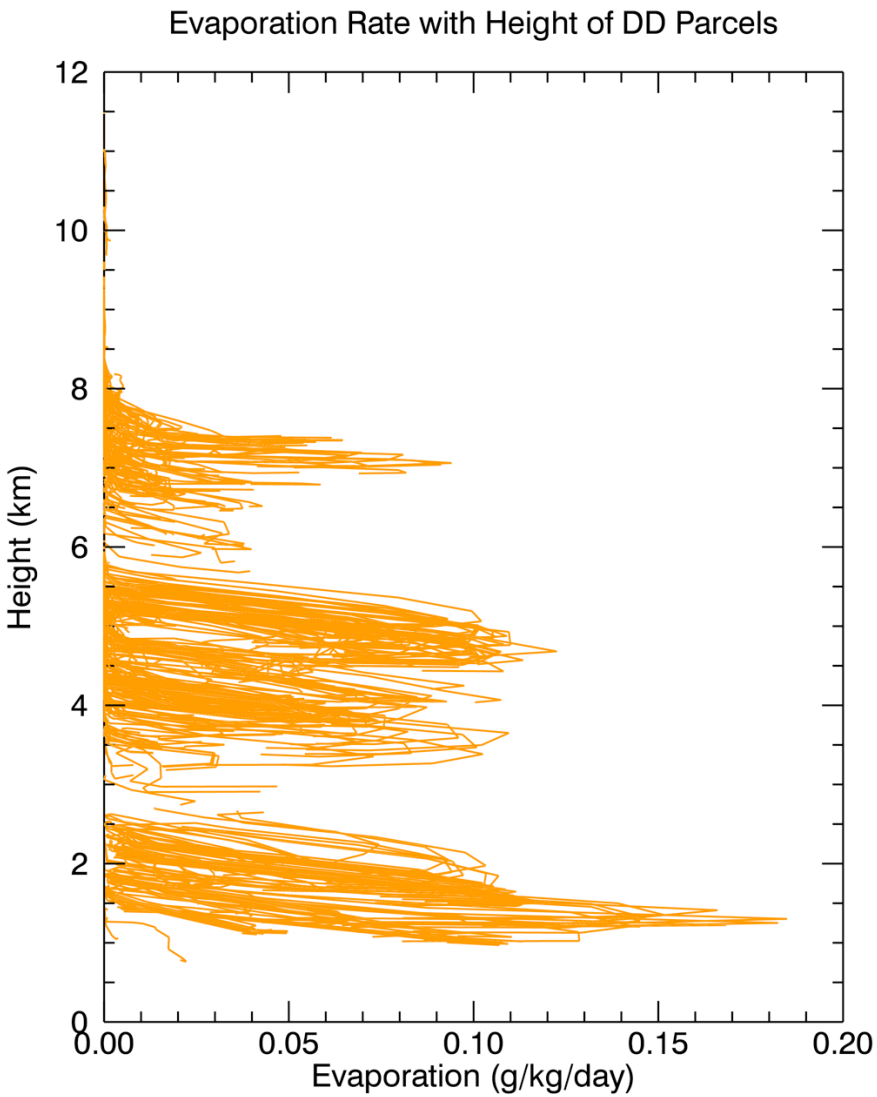
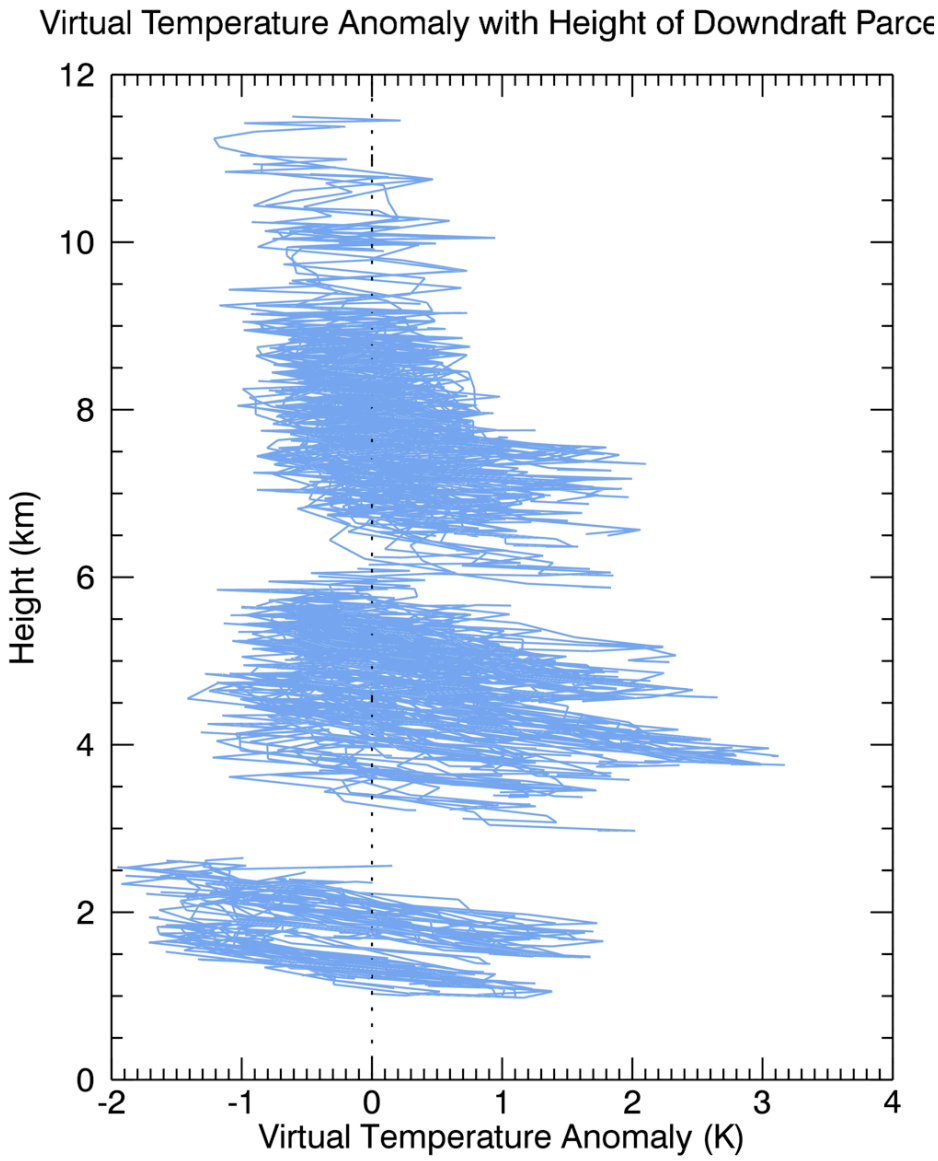
Are downdrafts always saturated and negatively buoyant?





Lagrangian Parcel Tracking

Are downdrafts always saturated and negatively buoyant?



Summary

- Cloud Resolving Models can help us learn about important convective processes that are difficult to observe in the real world.
- Downdrafts are a significant part of the convective cloud mass flux.
- Cold pools increase the CAPE and MSE of updraft parcels.
- Downdrafts are not very sensitive to environmental relative humidity, and are tightly coupled to the amount of precipitation in the domain.
- Environmental entrainment is a more important source of low MSE in the boundary layer than downdraft transport.
- Downdrafts begin in a saturated state, but rapidly dry out.
- Undershooting bottoms and downdrafts with positive virtual temperature anomalies do exist in our model.

Future Work

- More simulations or case studies. How are mid-latitude downdrafts different from tropical downdrafts?
- Sensitivity to microphysics. How do droplet size distributions or aerosol loading affect downdrafts?
- Implement suggested changes in a GCM parameterization.
- Further investigation into the interaction between downdrafts and environmental entrainment in the boundary layer.

Photo: me

Thank You!

Questions?