The Impact of Stable Layers on Downdrafts in Tropical Convection

Charles N. Helms
NPP Postdoctoral Fellow
NASA Goddard Space Flight Center
31 July 2019

Questions to be answered

- Can a stable layer be strong enough to stop downdrafts from reaching the surface?
- Do such stable layers exist in nature?

- Implications for interactions between dry air and tropical cyclones
  - Downdrafts inject low entropy air into the TC inflow layer (Tang and Emanuel 2012)

Prior Studies

REVIEWS OF GEOPHYSICS, VOL. 23, NO. 2, PAGES 183–215, MAY 1985

Convective Cloud Downdraft Structure: An Interpretive Survey

KEVIN R. KNUPP AND WILLIAM R. COTTON

Department of Atmospheric Science, Colorado State University, Fort Collins

...amics de-
questions

...ing down-
...e effects of

...namics of
...s?
...ure forces

...the role of
entrainment in initiating and sustaining downdrafts?

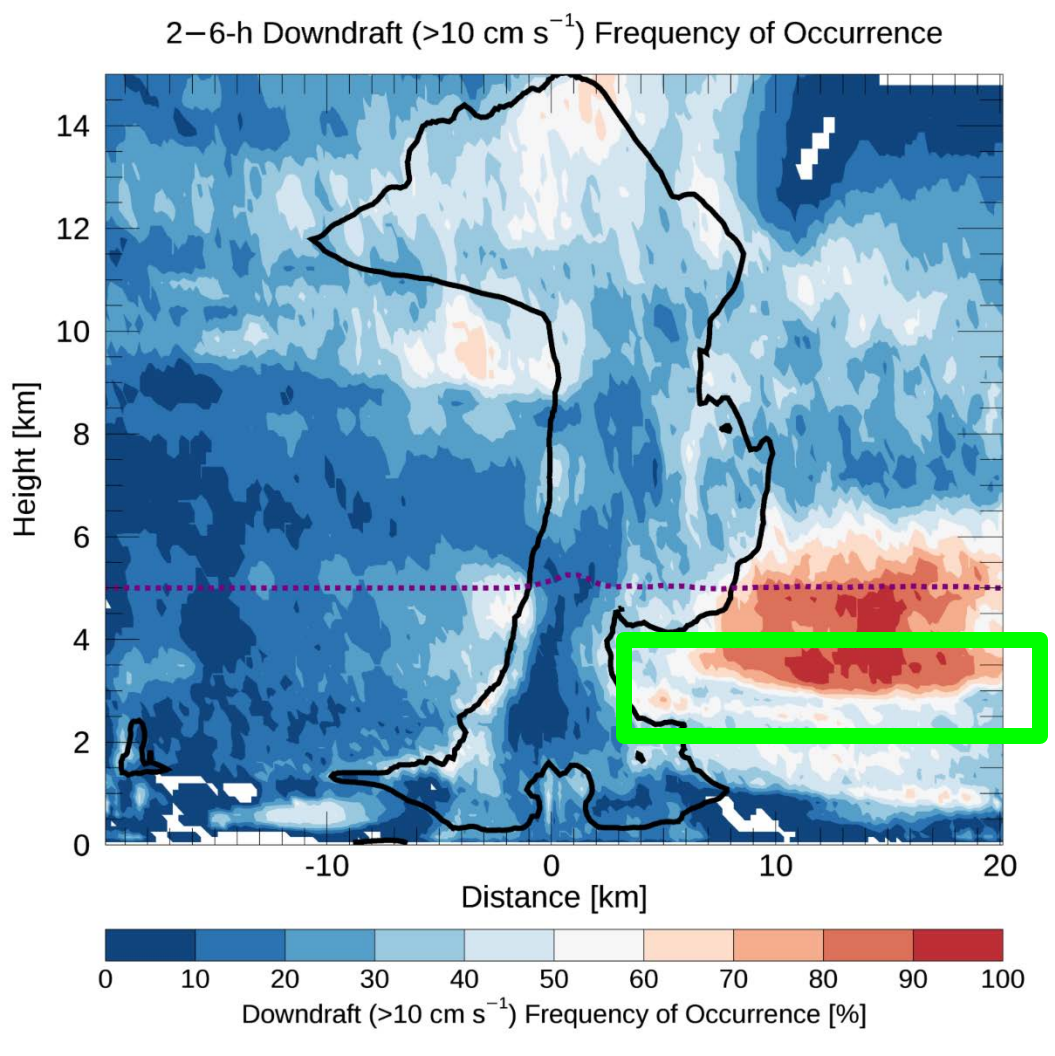
5. How do environmental wind shear and stability profiles affect entrainment and downdraft structure. In particular, how do downdrafts react to stable layers which often exist?

6. How do downdraft outflows affect storm structure, and how do downdraft transports influence larger-scale processes?

Poster at AGU

Storer, R. L., D. J. Posselt, and G. L. Stephens, 2018: Investigating the sensitivity of deep convection to small environmental changes. *2018 AGU Fall Meeting*, A11J-2371.

Origin Story



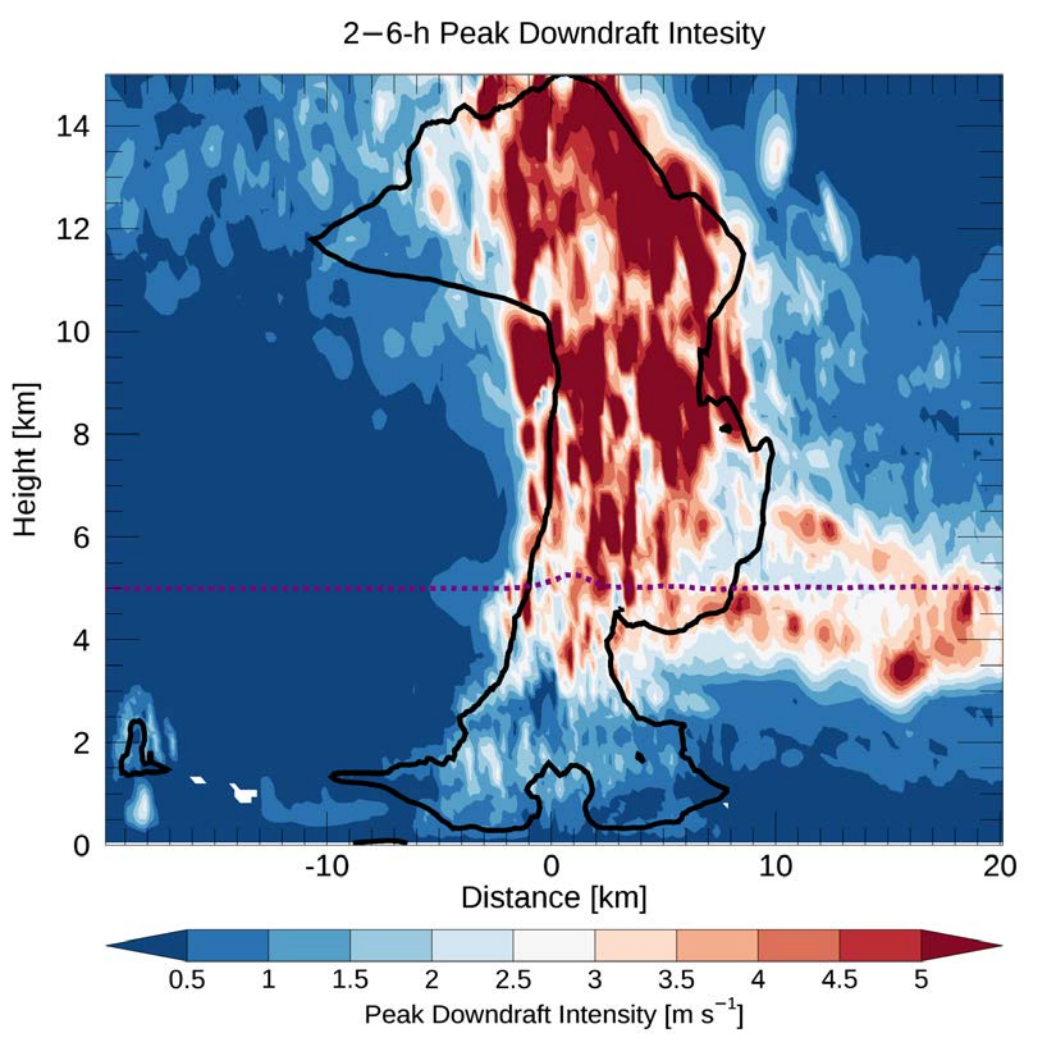
Cloud extent (0.1 g/kg)

Freezing level

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by ongoing surface convergence	

Modified Gabrielle (2013) Dropsonde
CAPE: 1708 J/kg
CIN: 30 J/kg

Stopped Downdrafts



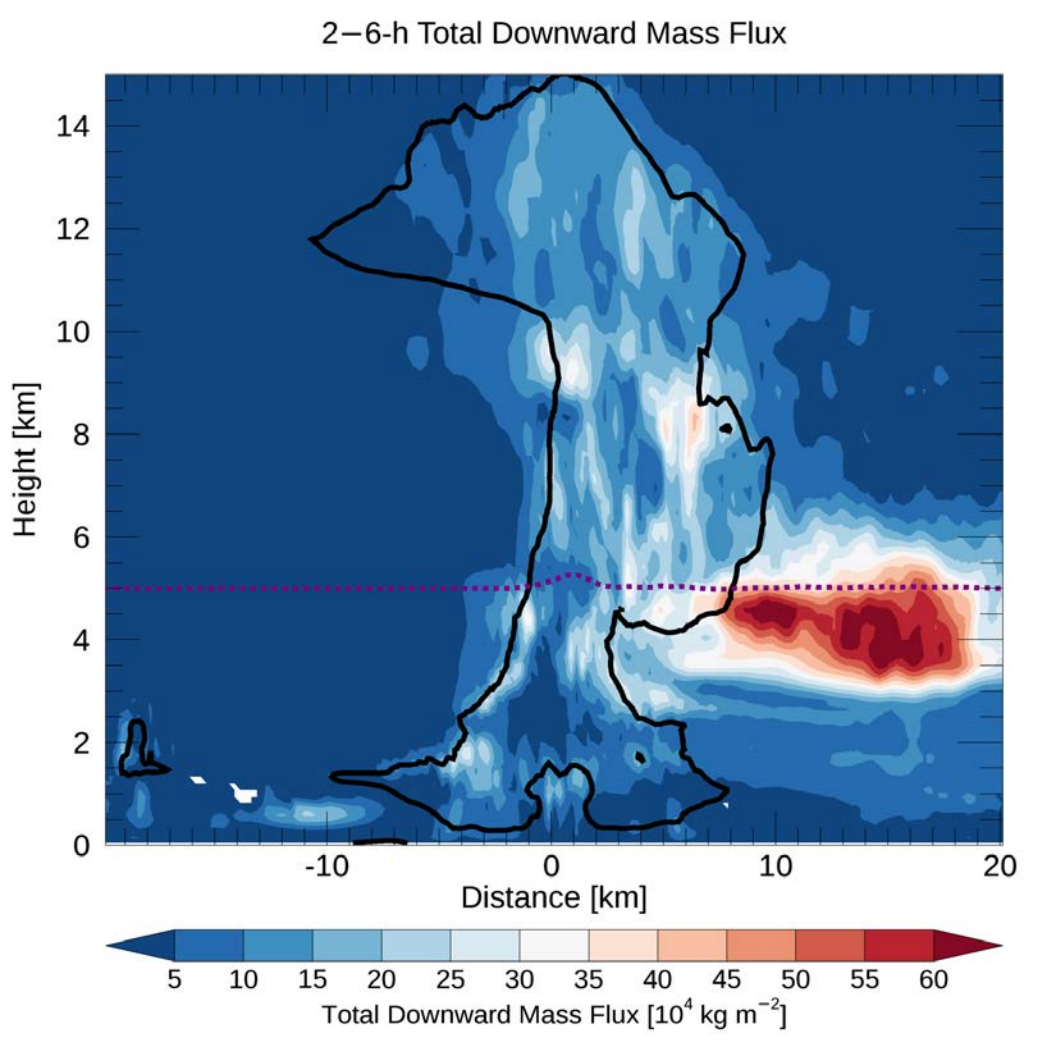
Cloud extent (0.1 g/kg)

Freezing level

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by ongoing surface convergence	

Modified Gabrielle (2013) Dropsonde
CAPE: 1708 J/kg
CIN: 30 J/kg

Less of a Flood, More of a Trickle



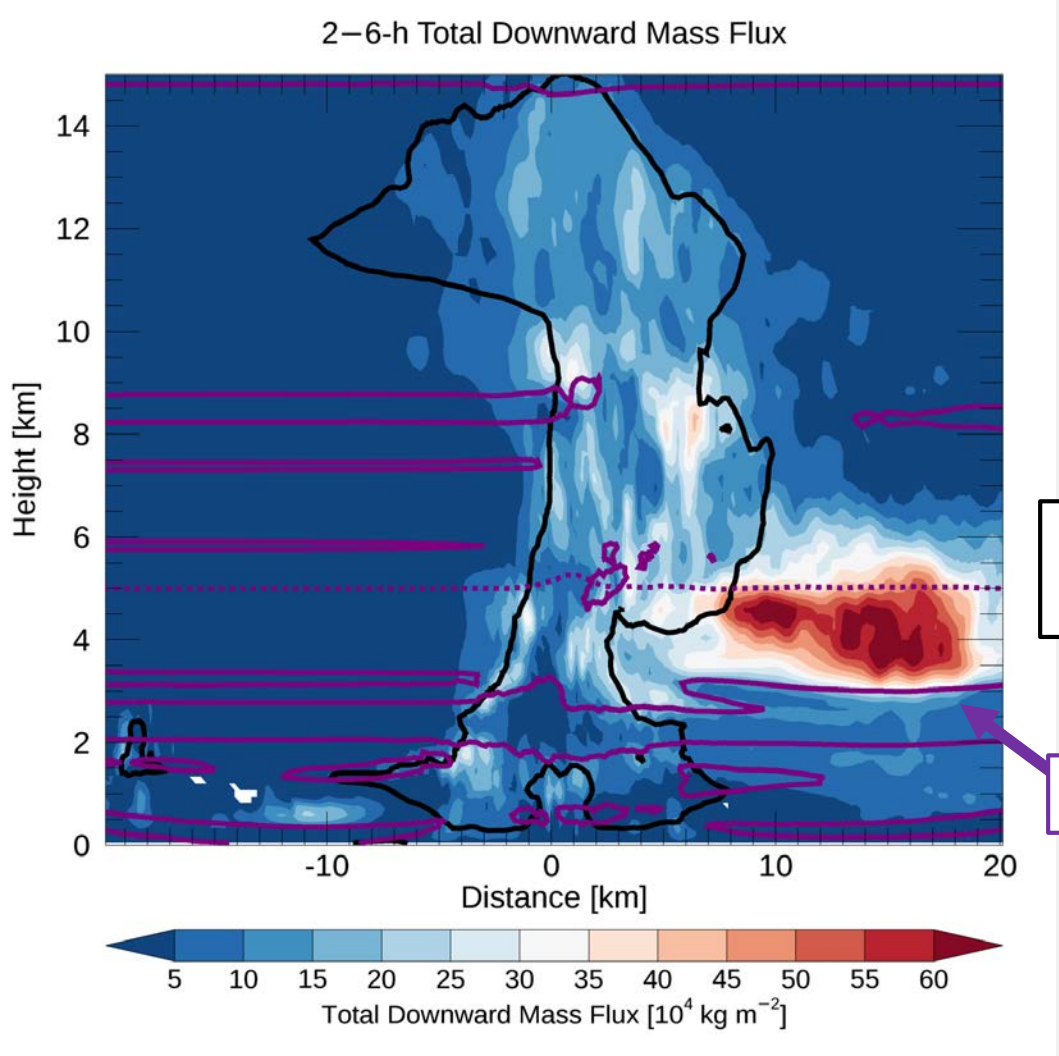
Cloud extent (0.1 g/kg)

Freezing level

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by ongoing surface convergence	

Modified Gabrielle (2013) Dropsonde
CAPE: 1708 J/kg
CIN: 30 J/kg

A Cause?



Cloud extent (0.1 g/kg)

Freezing level

Stability ($\frac{\partial \theta_v}{\partial z}$ = 5 K/km)

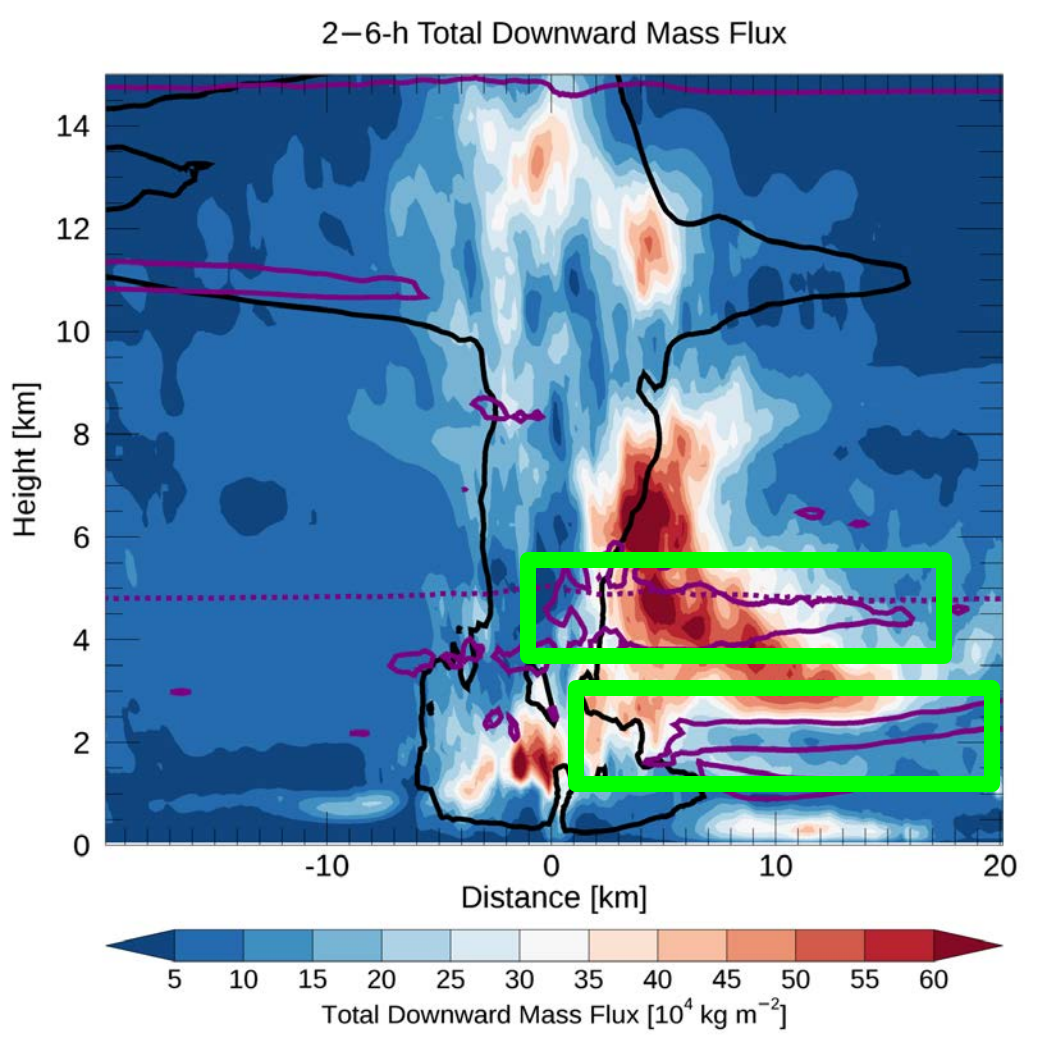
CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
	M w/ Graupel
	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
	by ongoing surface convergence

What if we use a different initial sounding?

Stable Layer

Modified Gabrielle (2013) Dropsonde
CAPE: 1708 J/kg
CIN: 30 J/kg

Same Model, Different Sounding



Cloud extent (0.1 g/kg)

Freezing level

Stability ($\frac{\partial \theta_v}{\partial z}$ = 5 K/km)

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by ongoing surface convergence	

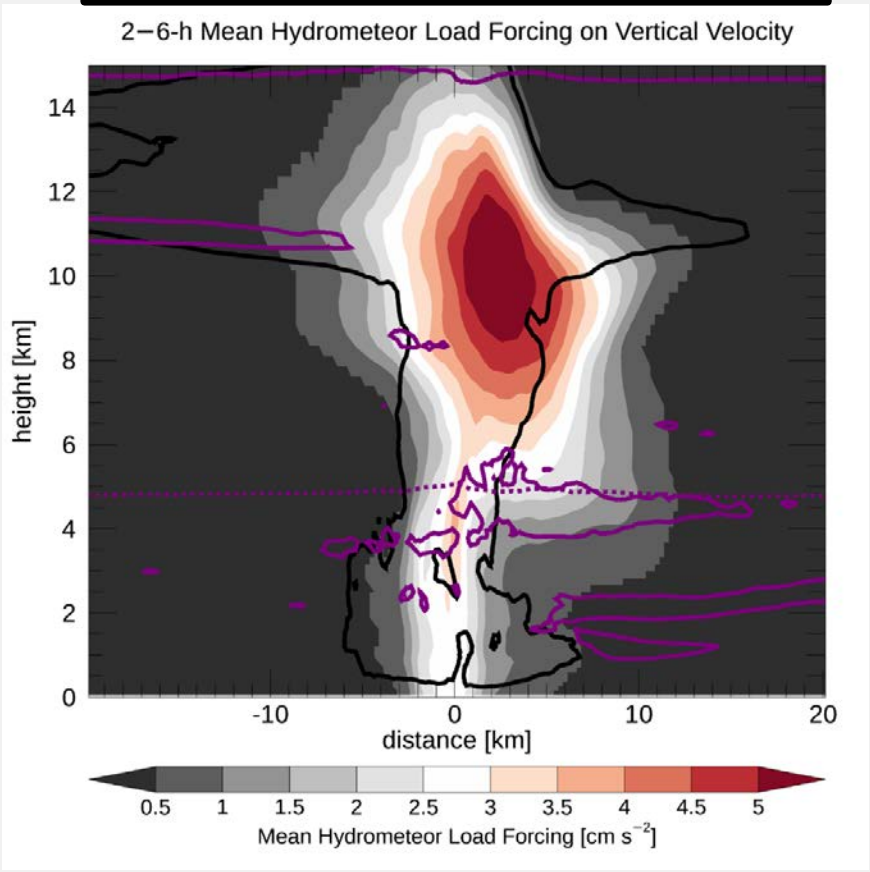
Modified Dunion (2011) Moist Tropical Sounding

CAPE: 3903 J/kg

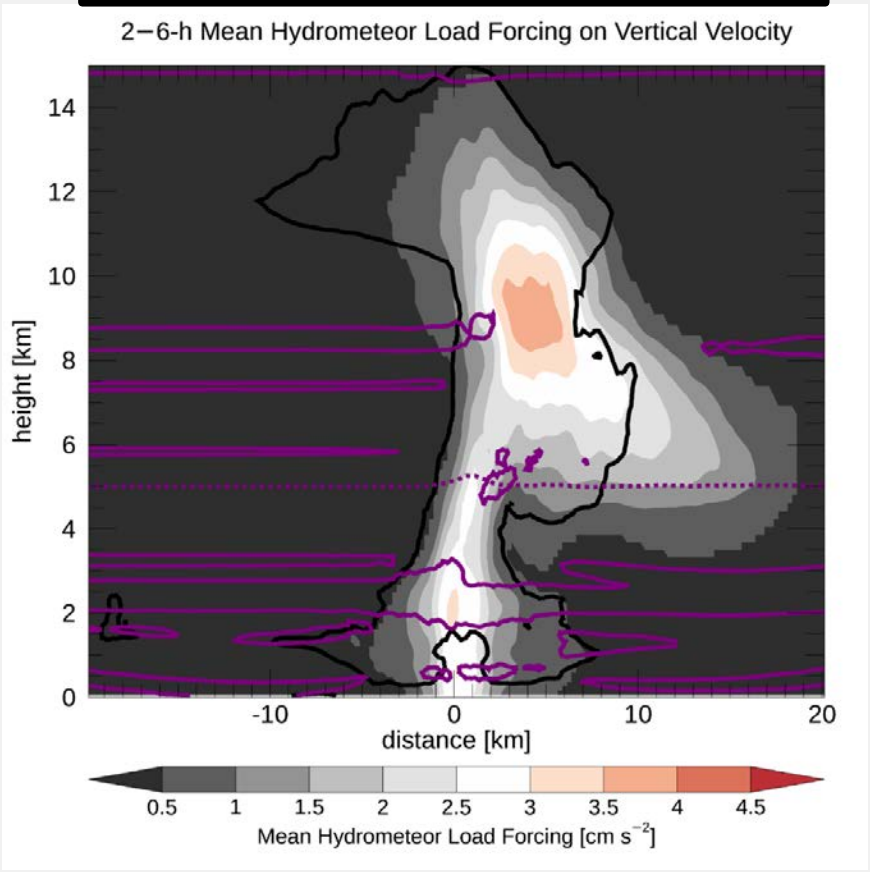
CIN: 1 J/kg

Hydrometeor Loading Differences

New Simulation



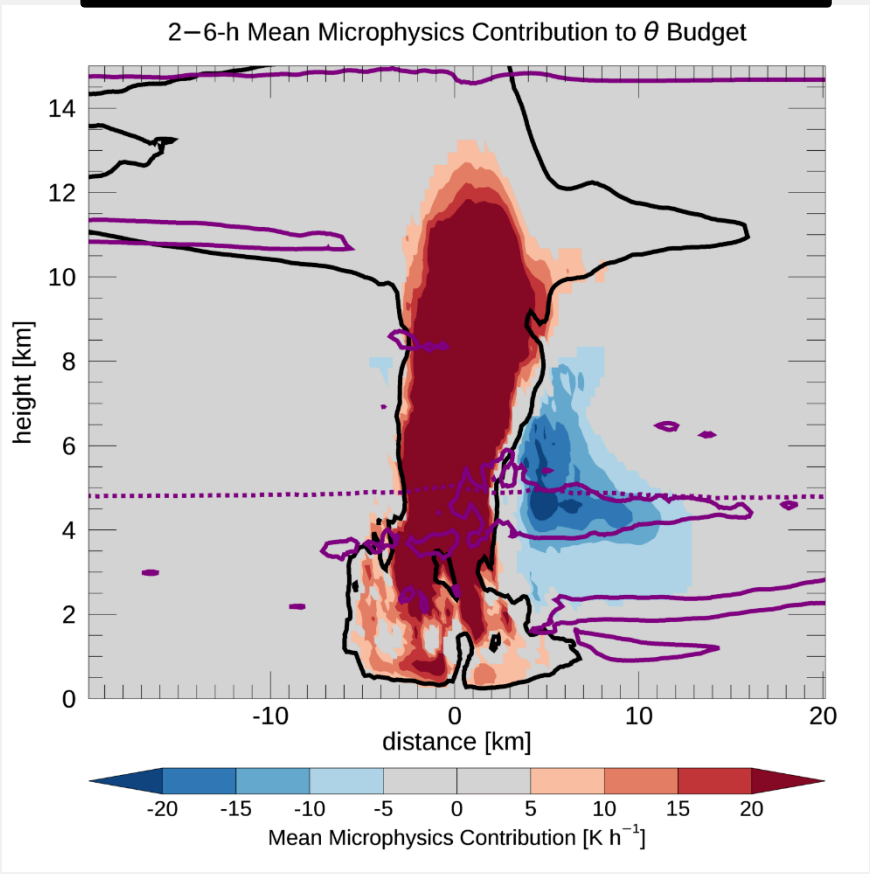
Original Simulation



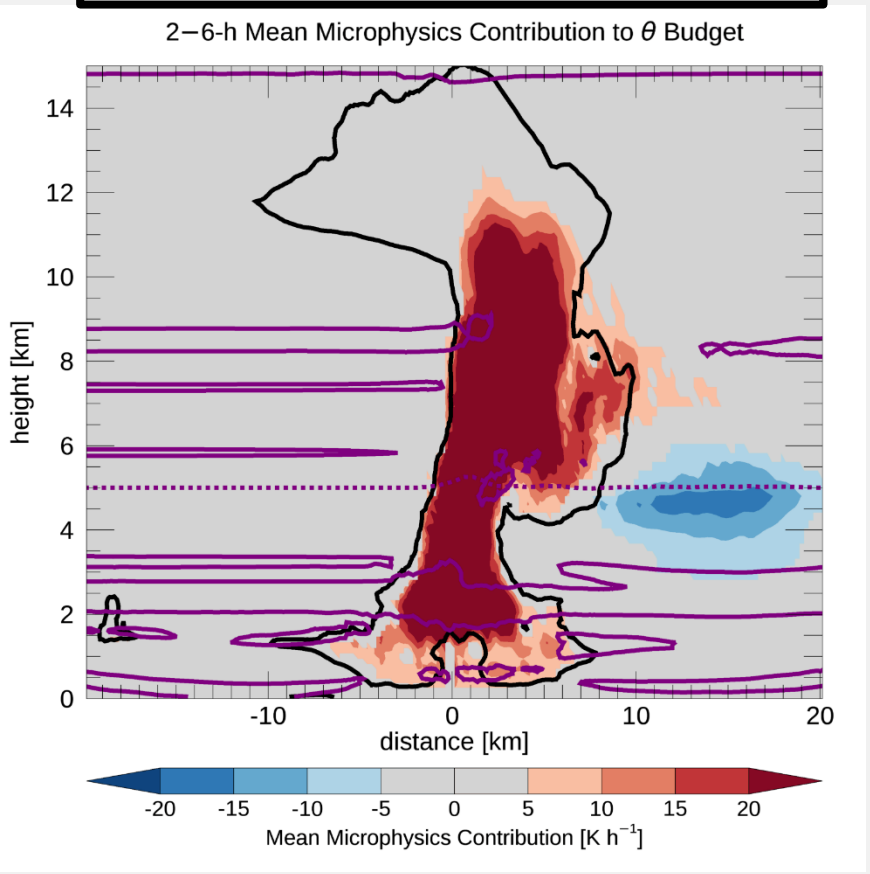
Cloud extent (0.1 g/kg) Freezing level Stability ($\frac{\partial \theta_v}{\partial z}$ = 5 K/km)

Microphysics Cooling Differences

New Simulation



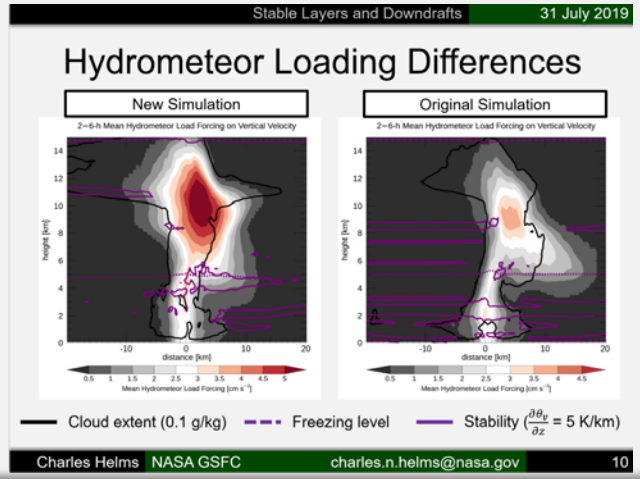
Original Simulation

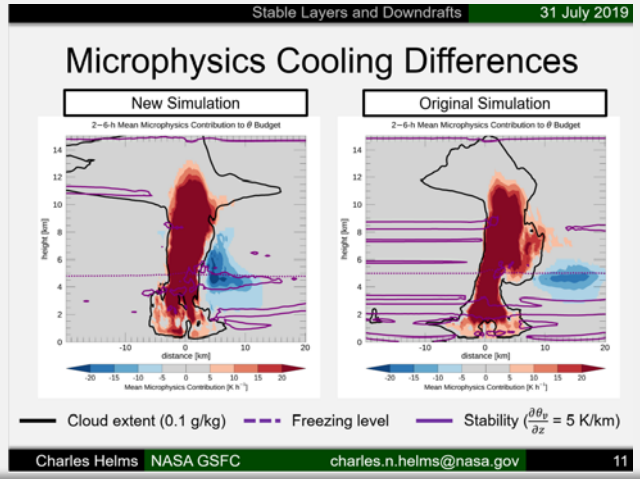


Cloud extent (0.1 g/kg) Freezing level Stability ($\frac{\partial \theta_v}{\partial z}$ = 5 K/km)

Simulation Conclusions

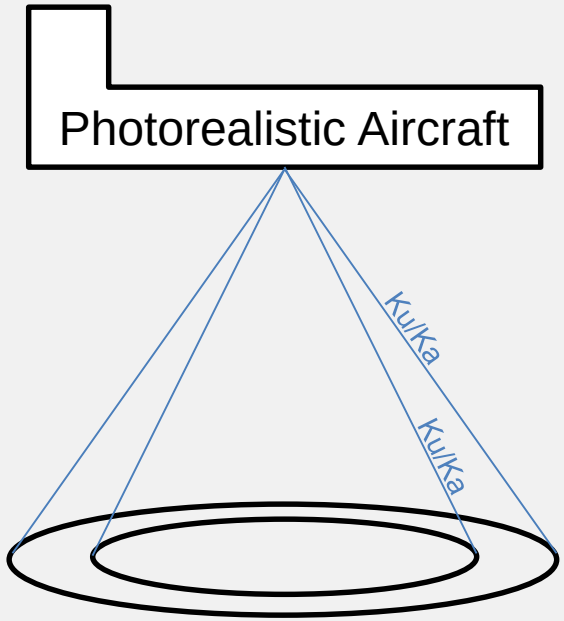
- Stable layer can inhibit precipitation-free downdrafts
- Precipitation-laden downdrafts can penetrate the stable layer
  - hydrometeor loading and evaporation/melting



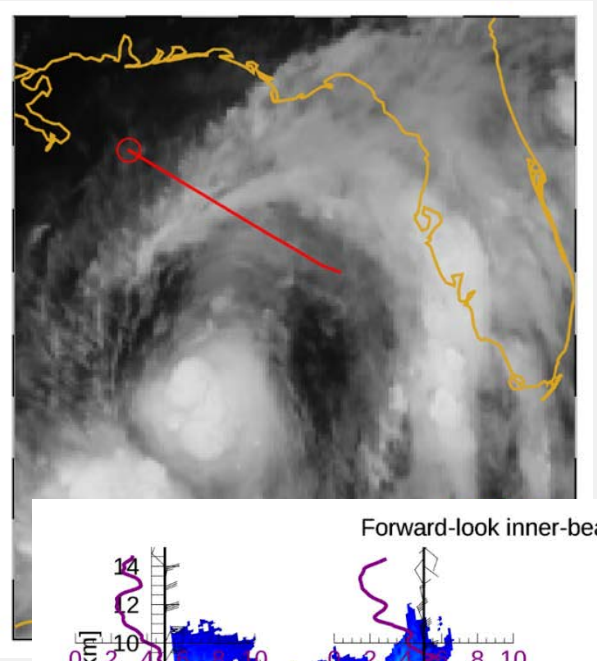


Does this occur in nature?

- NOAA SHOUT field campaign
  - HIWRAP Ku/Ka-band radar
  - Dropsondes
- Vertical velocity from Dual-Doppler analyses
  - Multiple band/angles
- Remove fall speed via statistical bin method

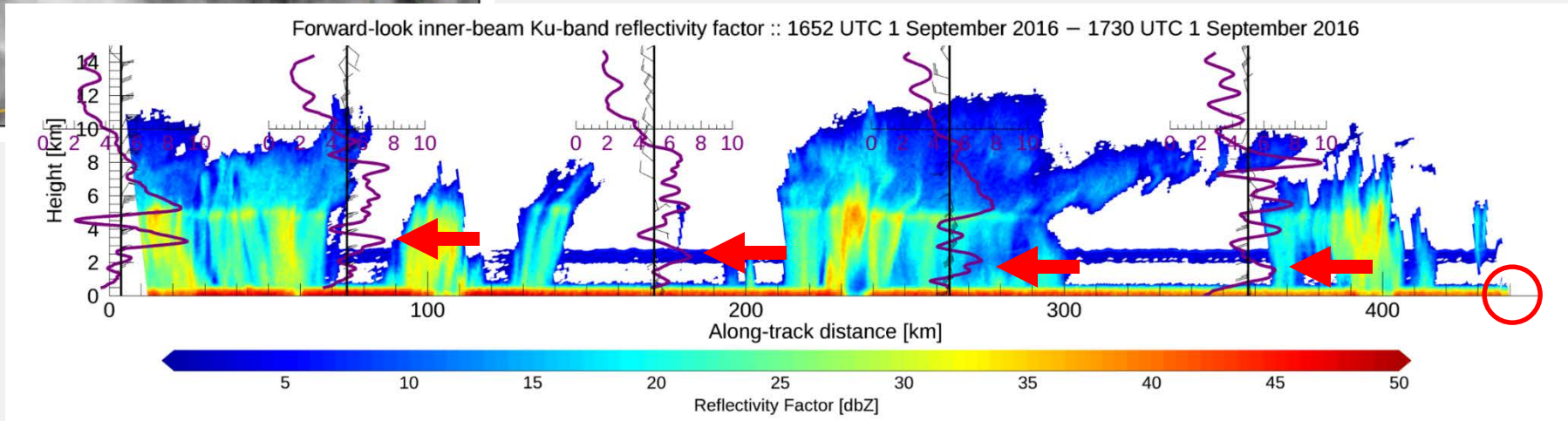


Bin data by reflectivity and altitude → Average hydrometeor vertical velocity within each bin → Subtract bin-mean from hydrometeor vertical velocity for each bin

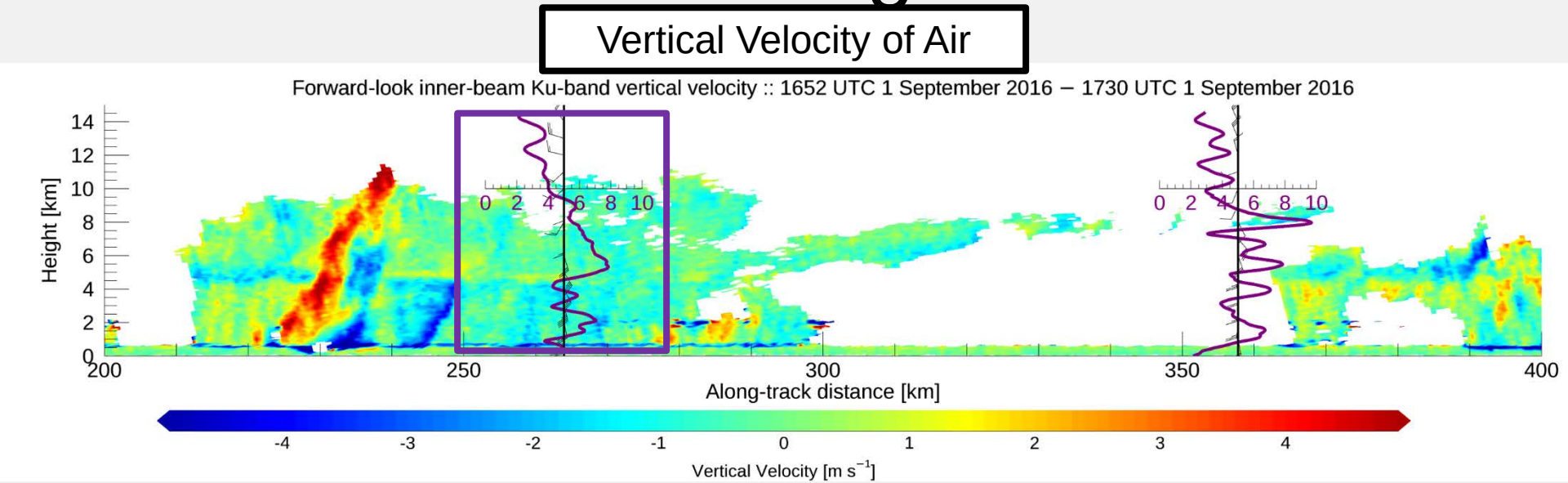


Can we get these stable layers in TCs?

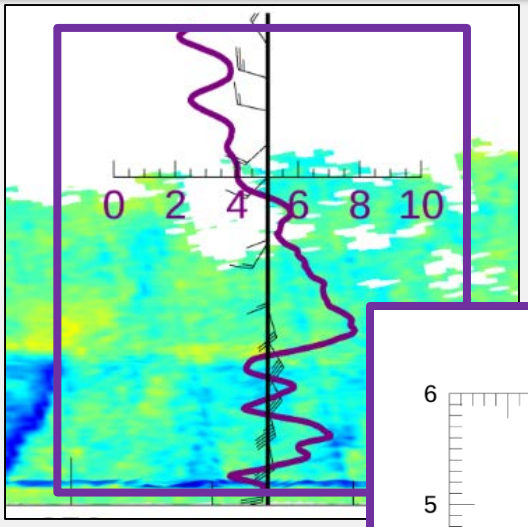
Reflectivity Factor with $\frac{\partial \theta_v}{\partial z}$



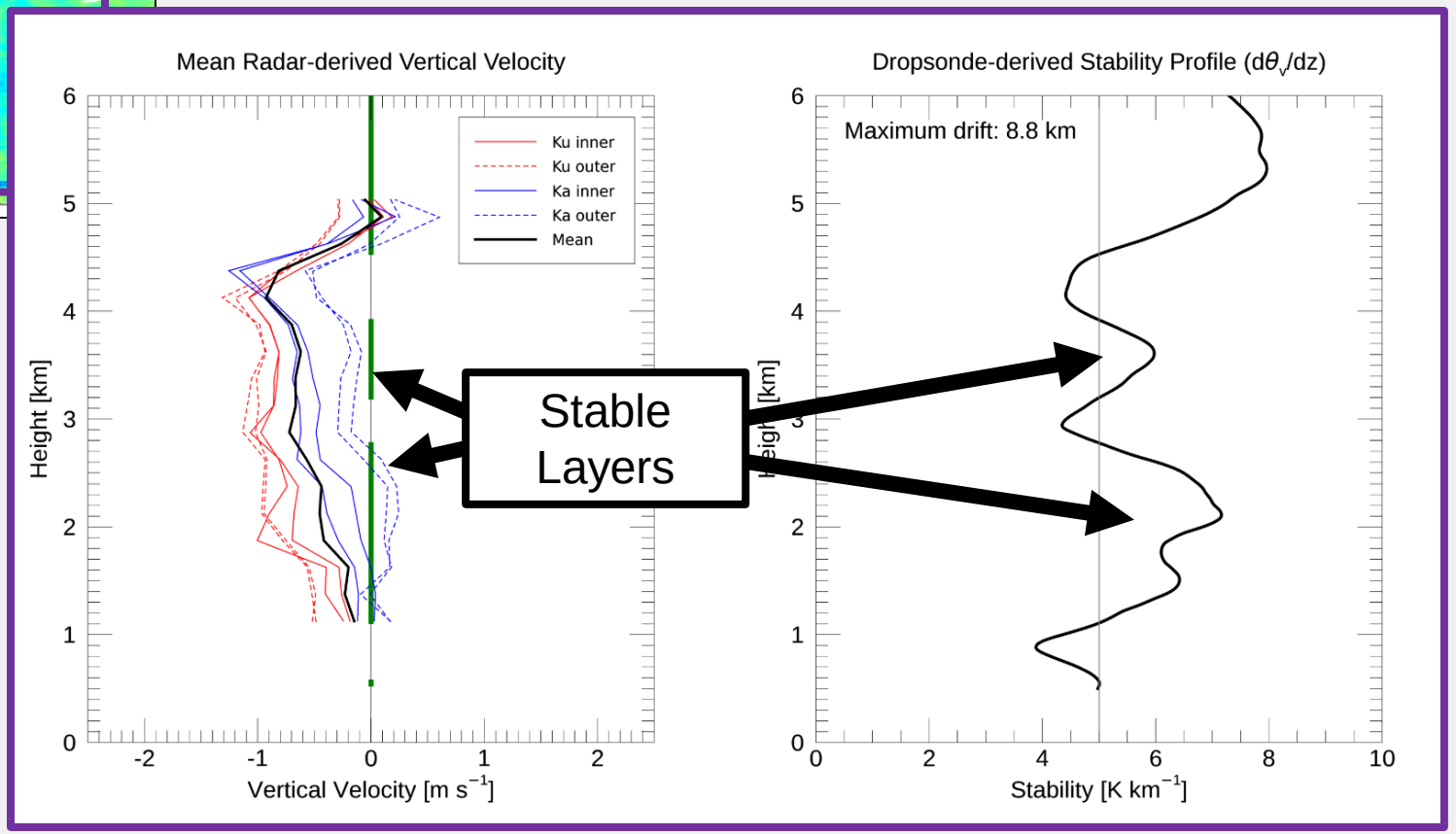
What about blocking a downdraft?



- Recall: Precipitation-laden downdrafts can penetrate the stable layer
- Can we find evidence of a reduction in downdrafts within stable layers?

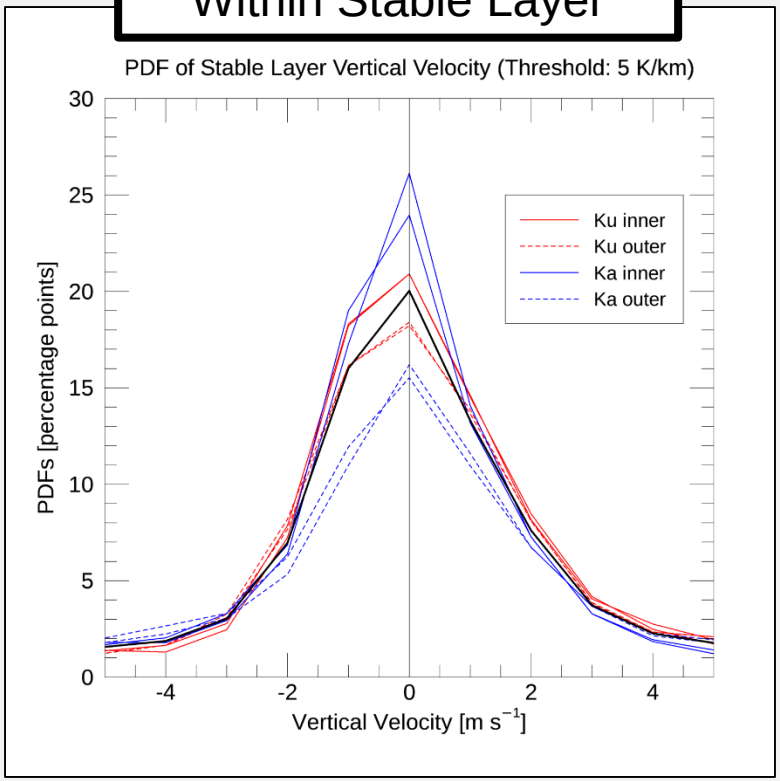


What about inhibiting a downdraft?

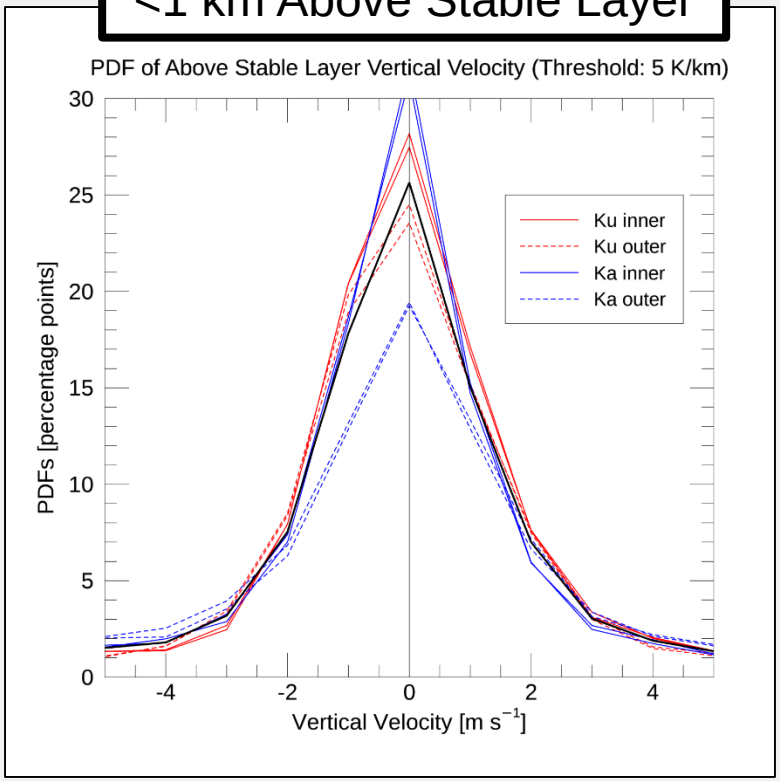


Do stable layers inhibit downdrafts?

Within Stable Layer

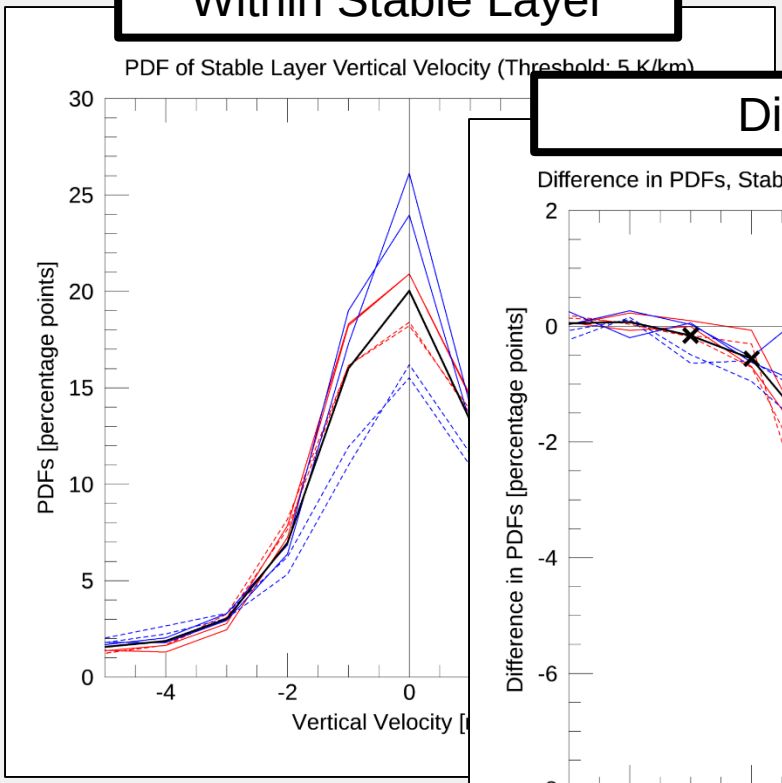


<1 km Above Stable Layer

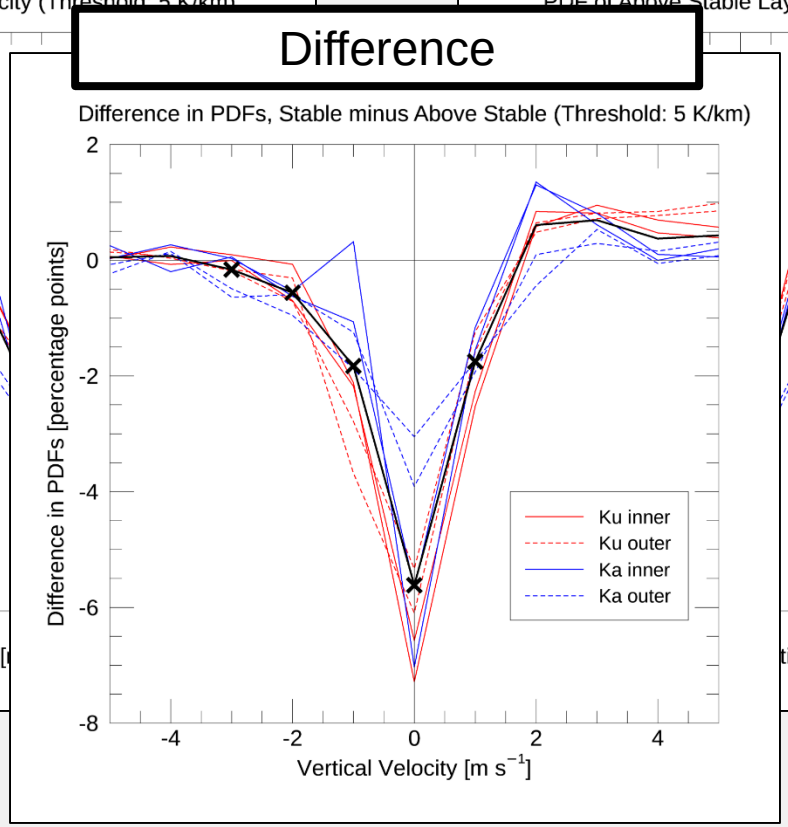


Do stable layers reduce downdrafts?

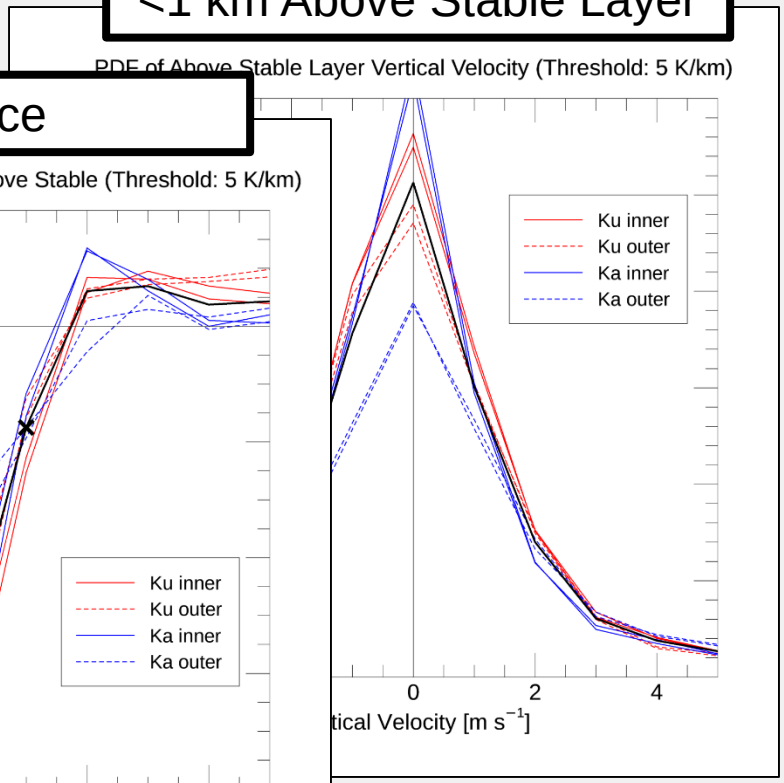
Within Stable Layer



Difference

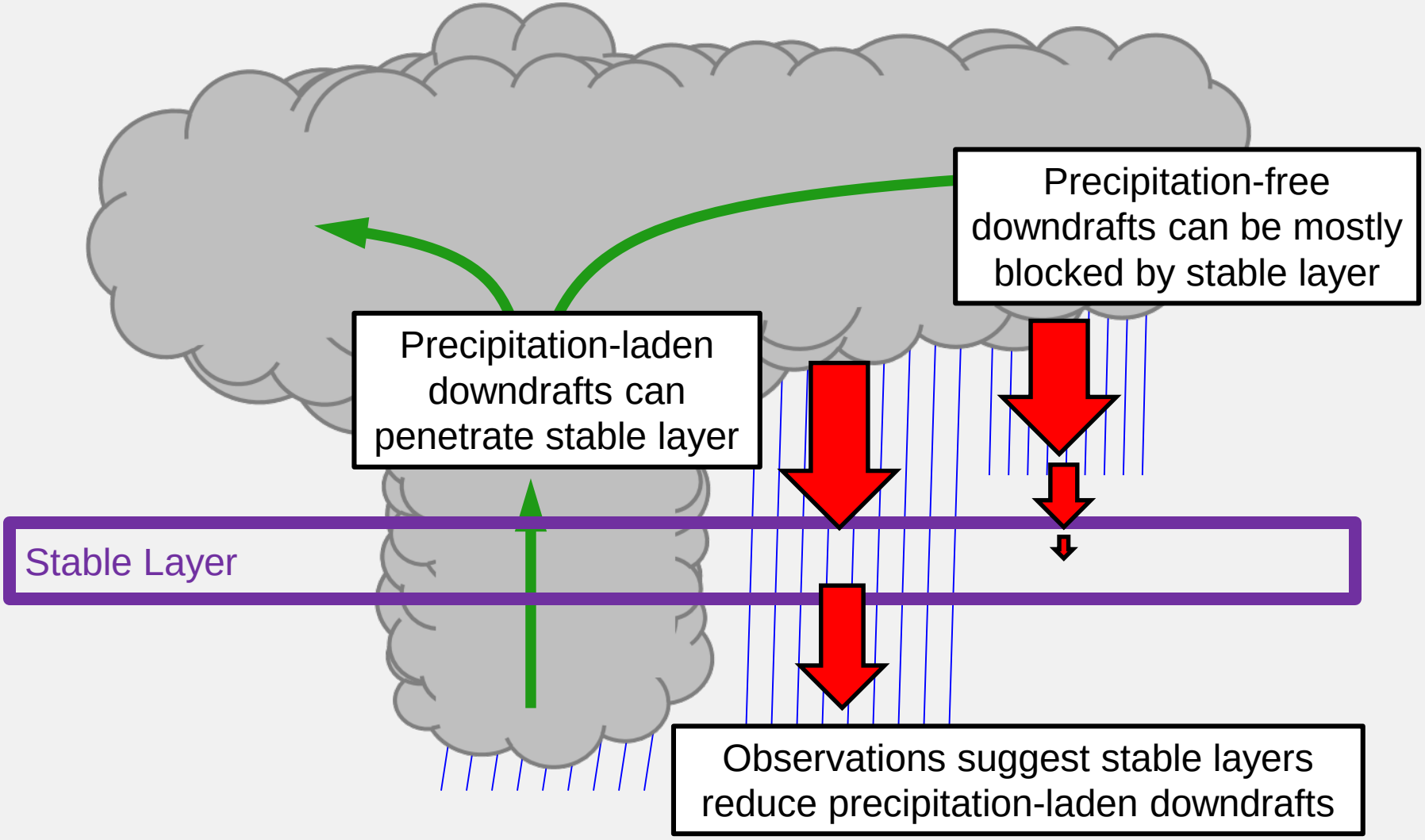


<1 km Above Stable Layer



✕ = Statistically significant decrease

A Schematic Summary



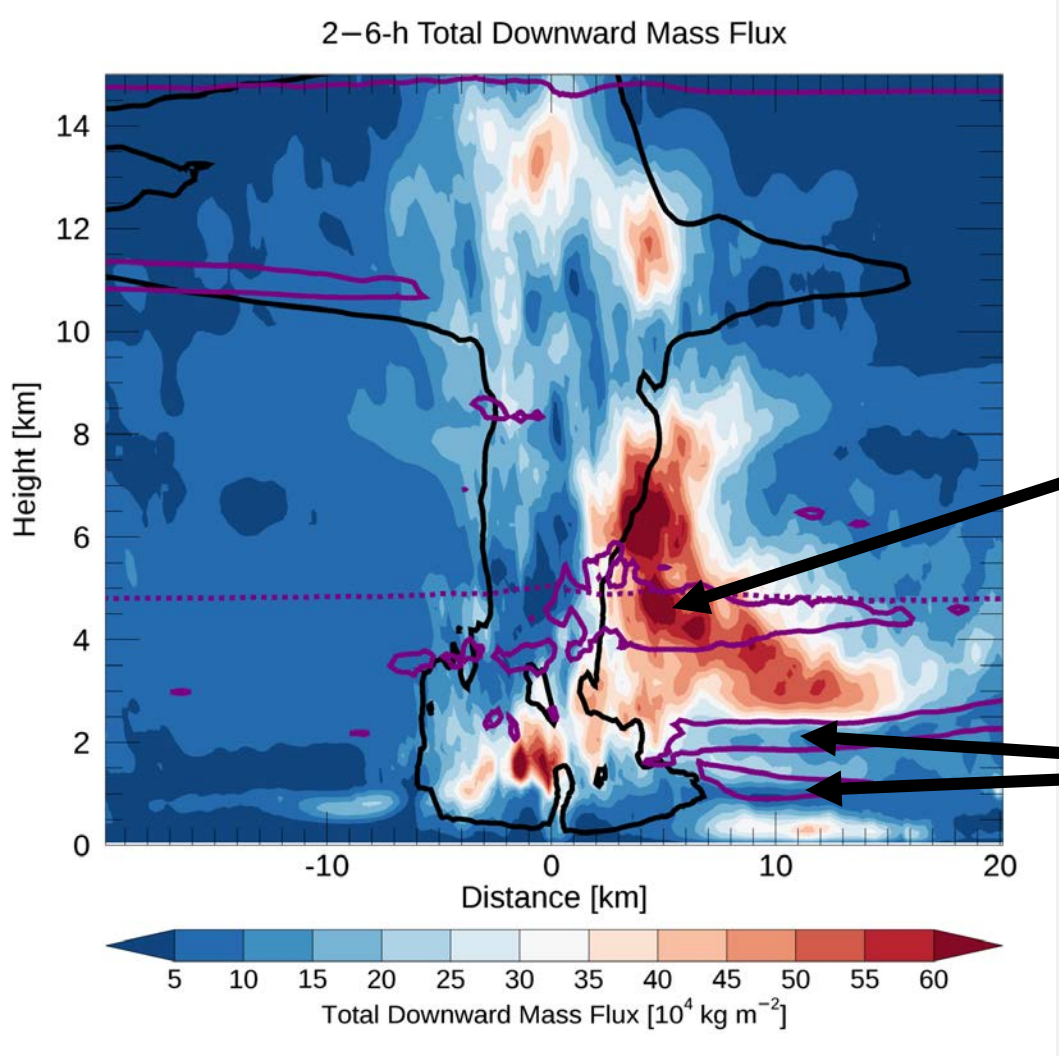
END

Simulation Details

- Base soundings
  - Gabrielle (2013) dropsonde from NASA HS3 field campaign
    - Located just west of disturbance
  - Dunion (2011) moist tropical sounding
    - Gabrielle sounding winds/location
- Modifications
  - Subtract mean 0–3-km wind
  - Set 0–3-km wind to 0 m/s
  - Above 10 km: blend with ERA5
  - Below 1 km: moisten until at least 95% RH
  - 1 – 12 km: moisten until at least 80% RH
    - Keep virtual temperature unchanged

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by constant surface convergence	

Same Model, Different Sounding



Cloud extent (0.1 g/kg)

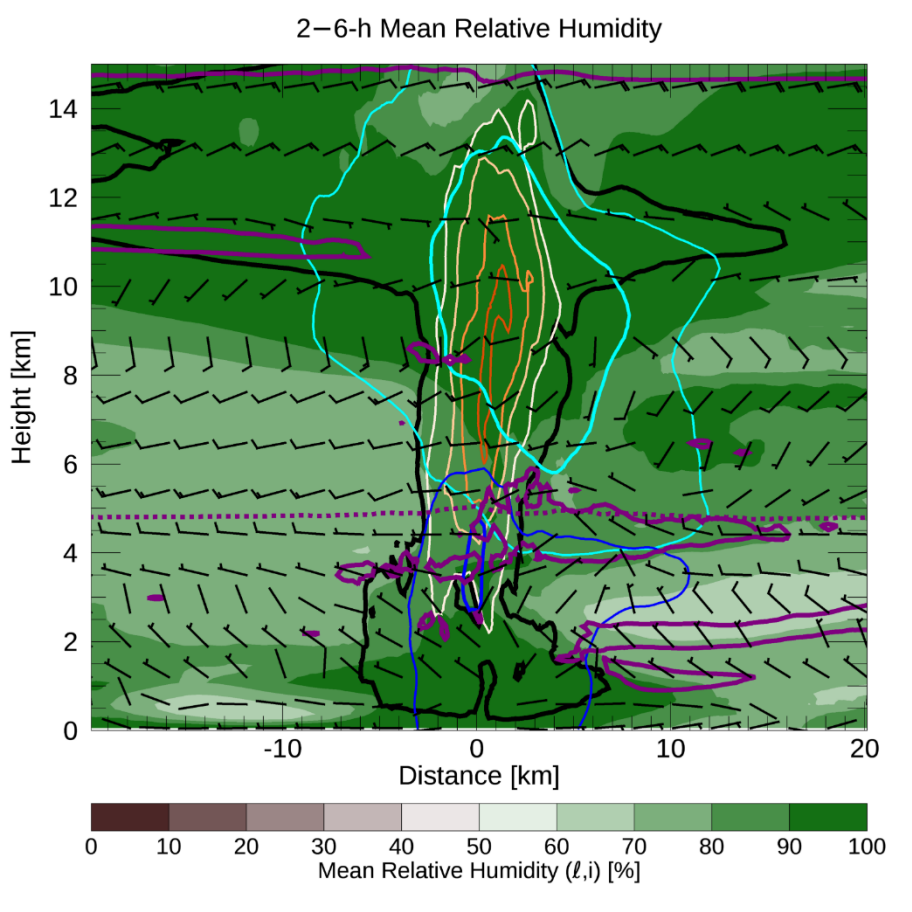
Freezing level

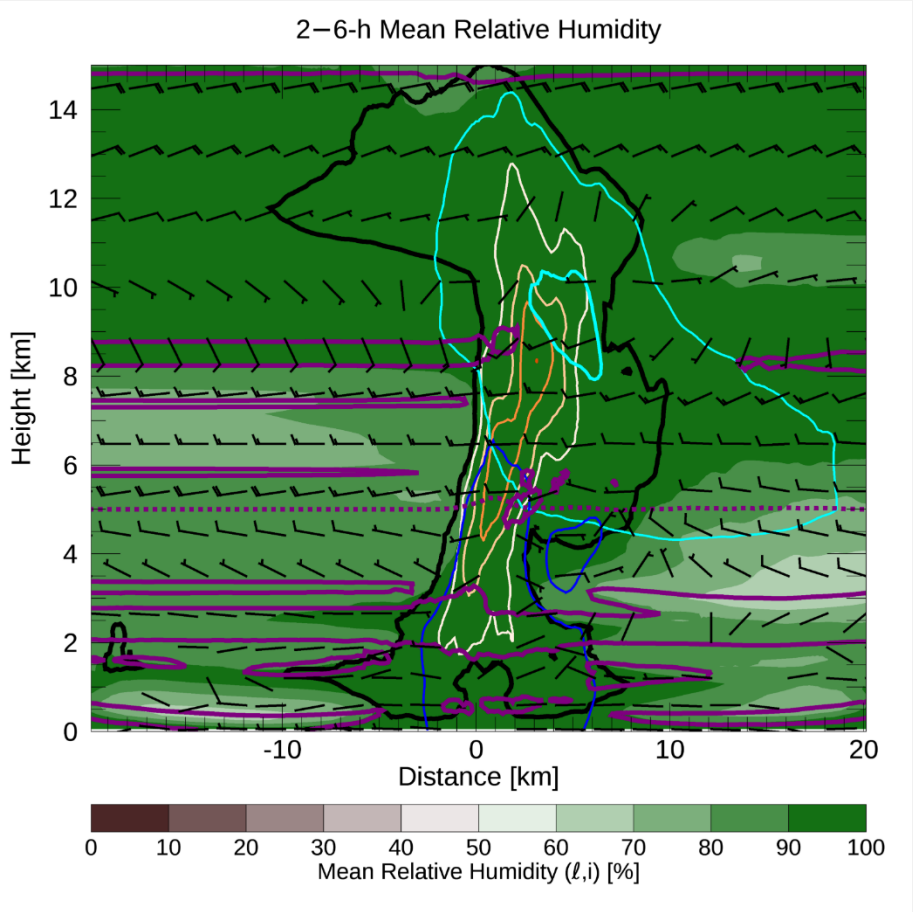
Stability ($\frac{\partial \theta_v}{\partial z}$ = 5 K/km)

Peak downward mass flux passes through mean stable layer

Downdraft mass flux drops off for these stable layers

Side-by-side Comparison





Cloud extent (0.1 g/kg)

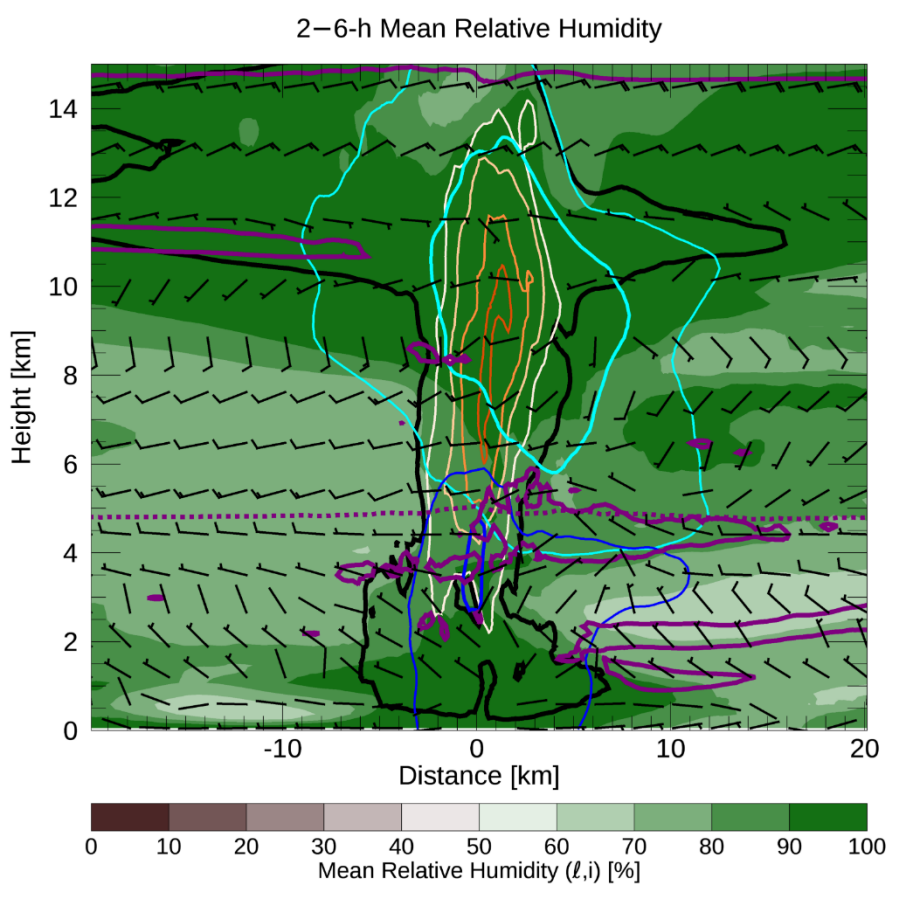
Liquid precip (0.5 g/kg)

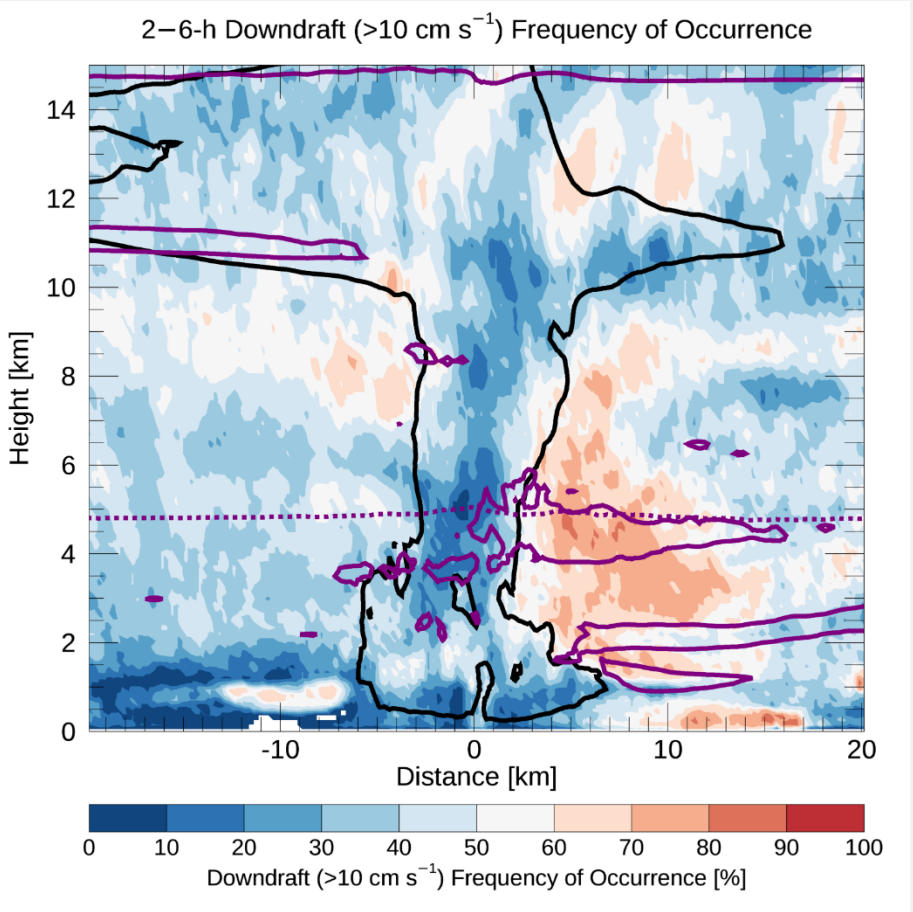
Updraft speed (2 m/s intervals)

Freezing level

Horizontal winds (knots)

Side-by-side Comparison





Cloud extent (0.1 g/kg)

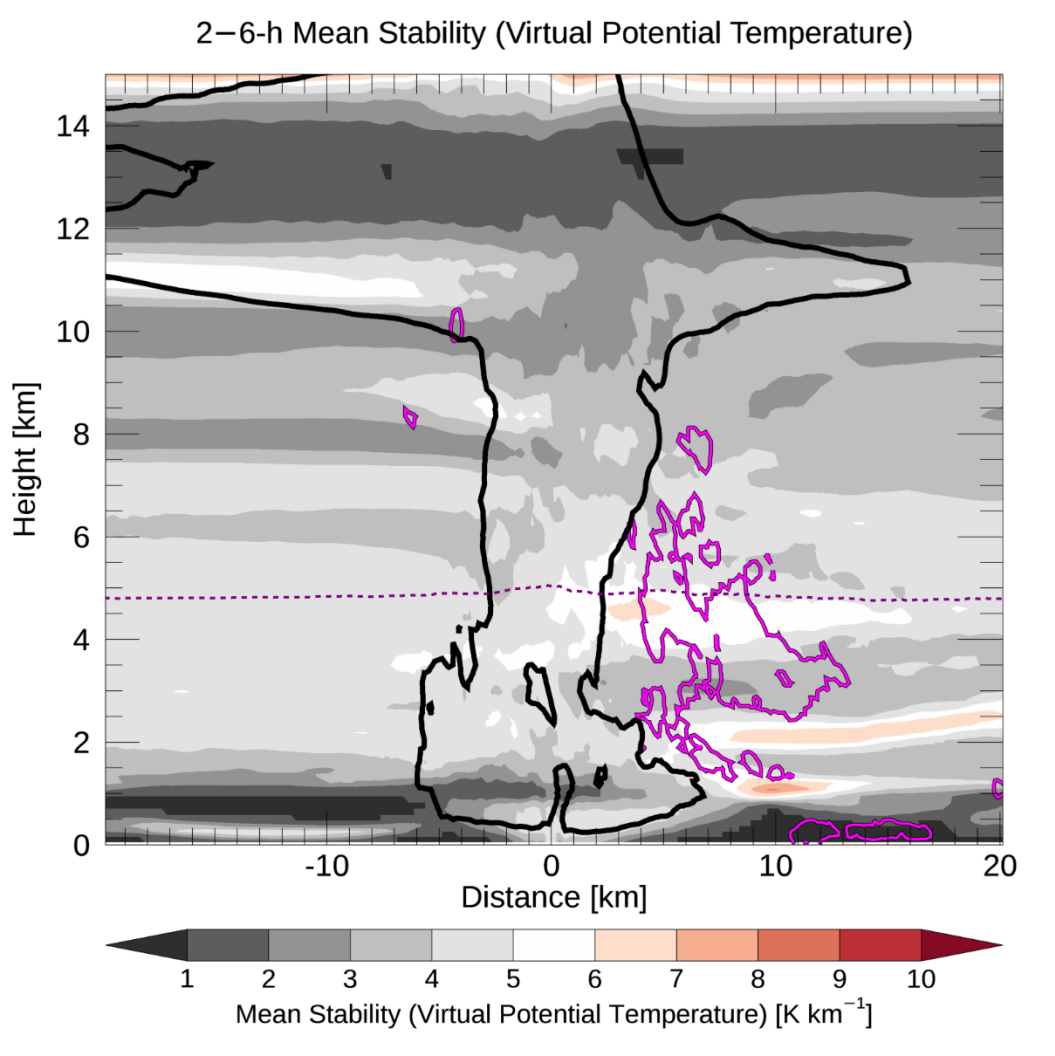
Liquid precip (0.5 g/kg)

Updraft speed (2 m/s intervals)

Freezing level

Horizontal winds (knots)

The Search for Differences

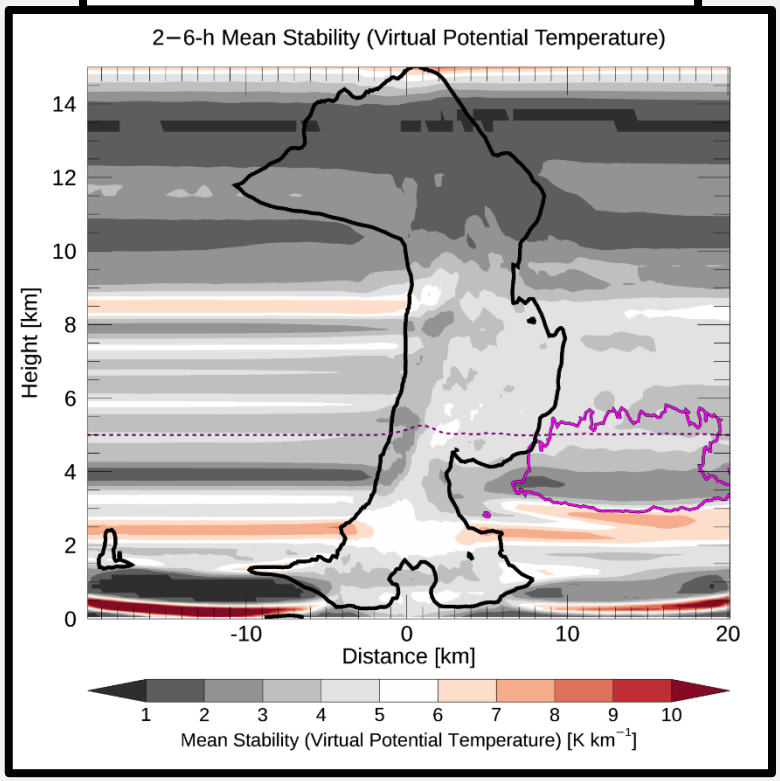


Cloud extent (0.1 g/kg)

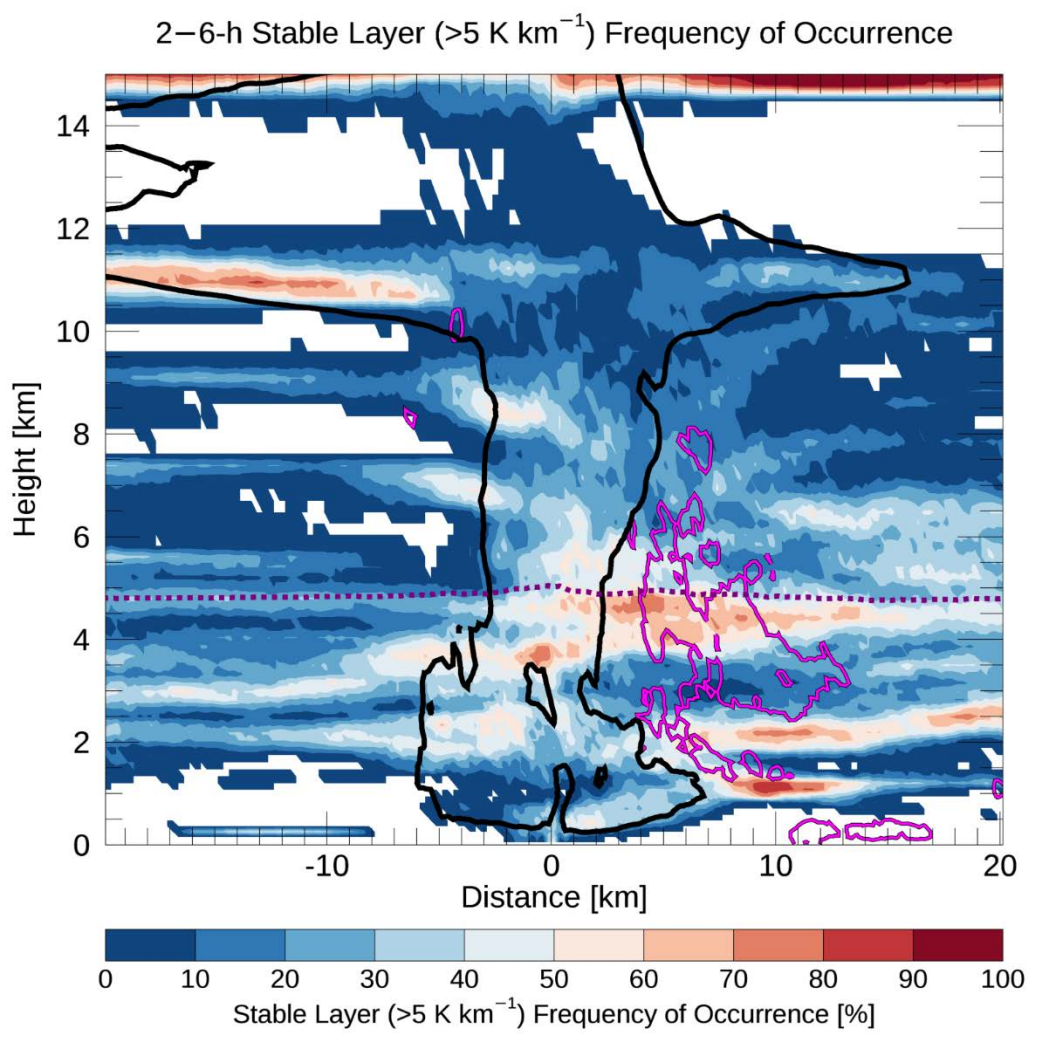
Freezing level

70% Downdraft Freq.

Original Simulation



The Search for Differences

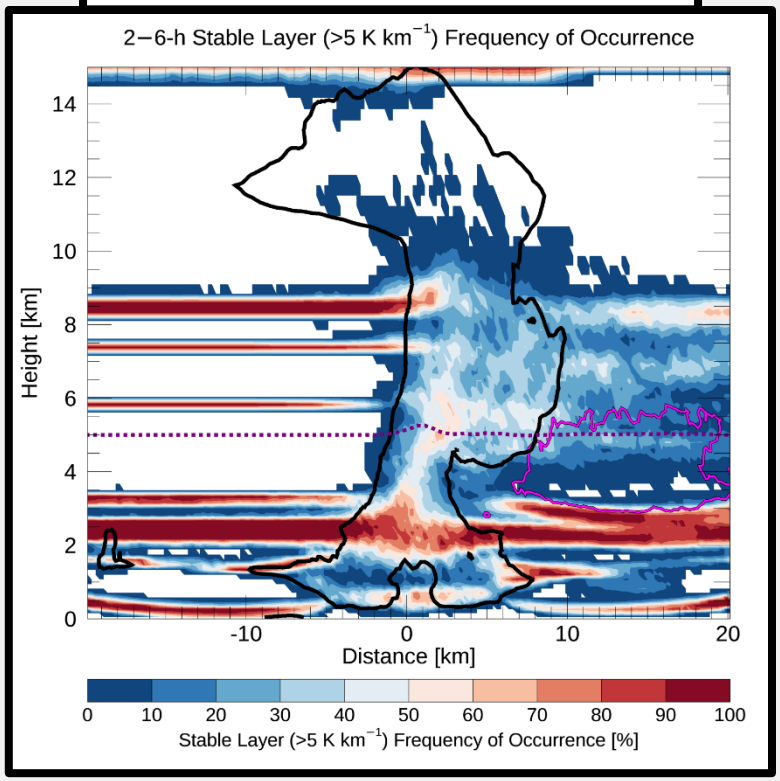


Cloud extent (0.1 g/kg)

Freezing level

70% Downdraft Freq.

Original Simulation

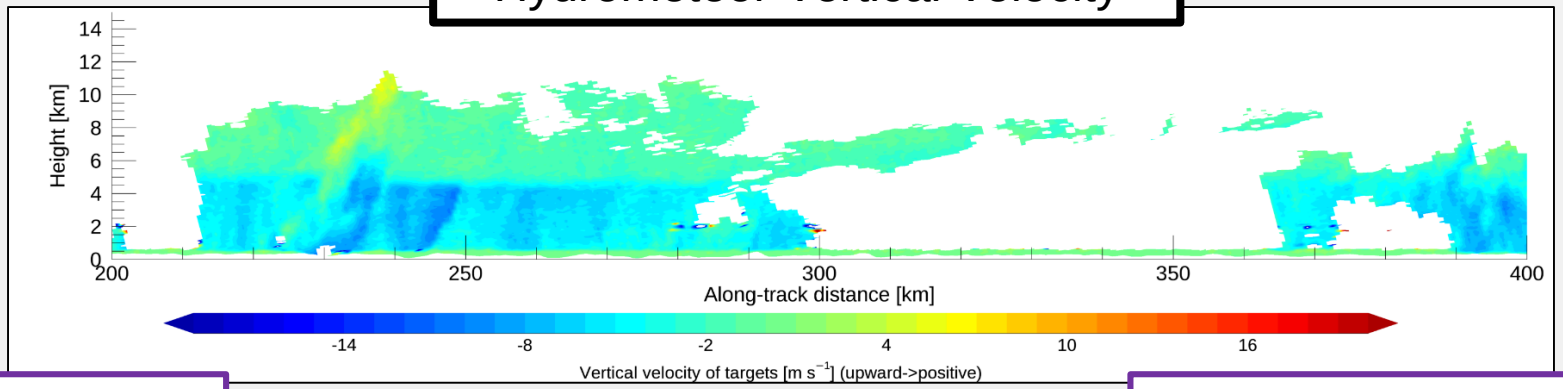


Vertical Velocity Retrieval

- Radar measures hydrometeor velocity
- Must remove terminal fall speed to get vertical air velocity
- Statistical bin method
  - Categorize data points by reflectivity factor and altitude
  - Assuming updrafts and downdrafts are equally represented, bin average is terminal fall speed

Vertical Velocity Retrieval

Hydrometeor Vertical Velocity



Bin data by reflectivity and altitude

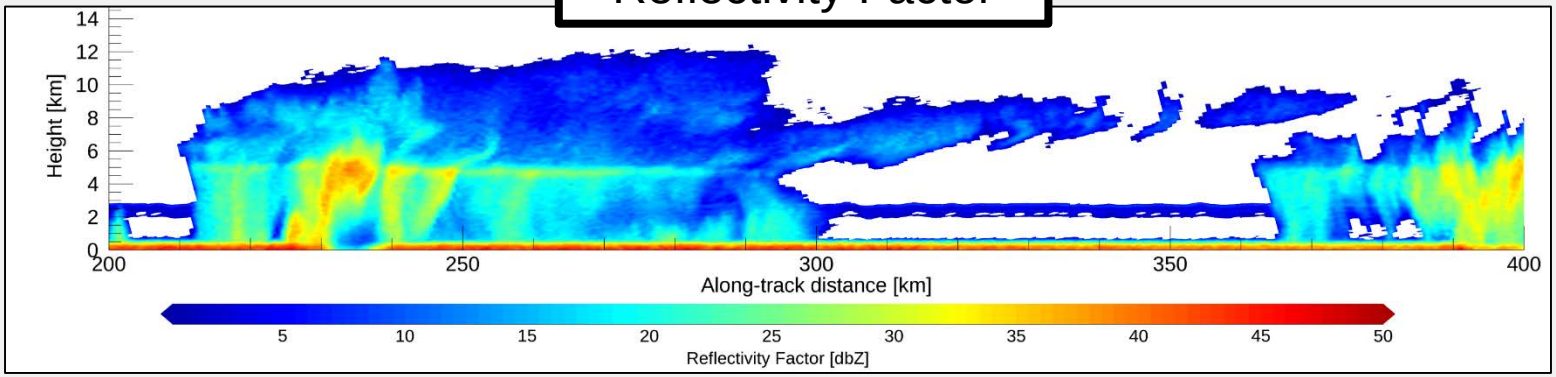
→

Average hydrometeor vertical velocity within each bin

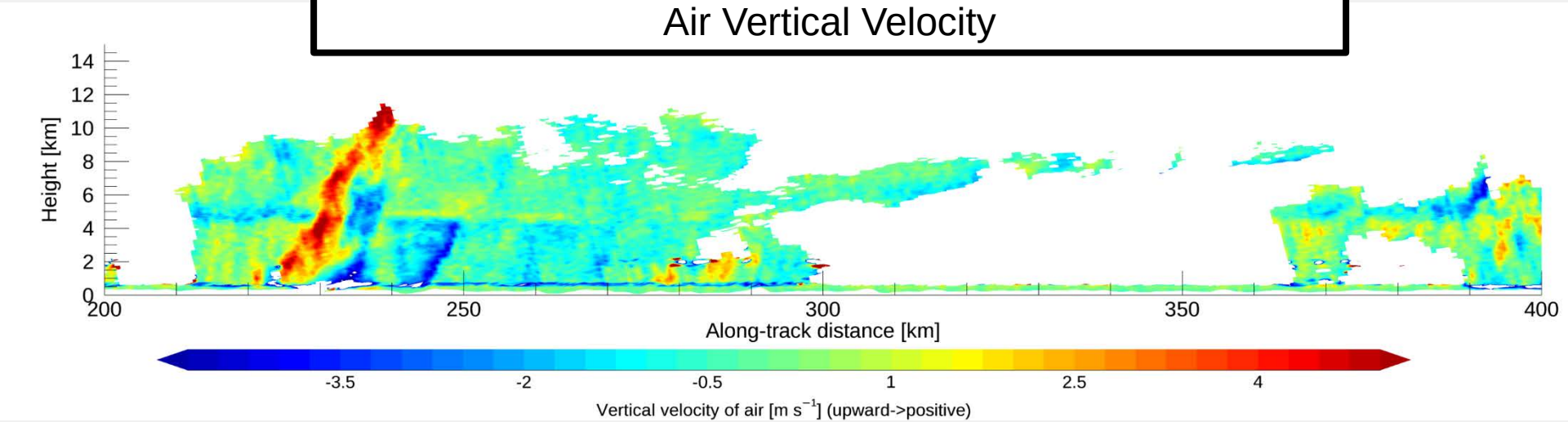
→

Subtract bin-mean from hydrometeor vertical velocity for each bin

Reflectivity Factor



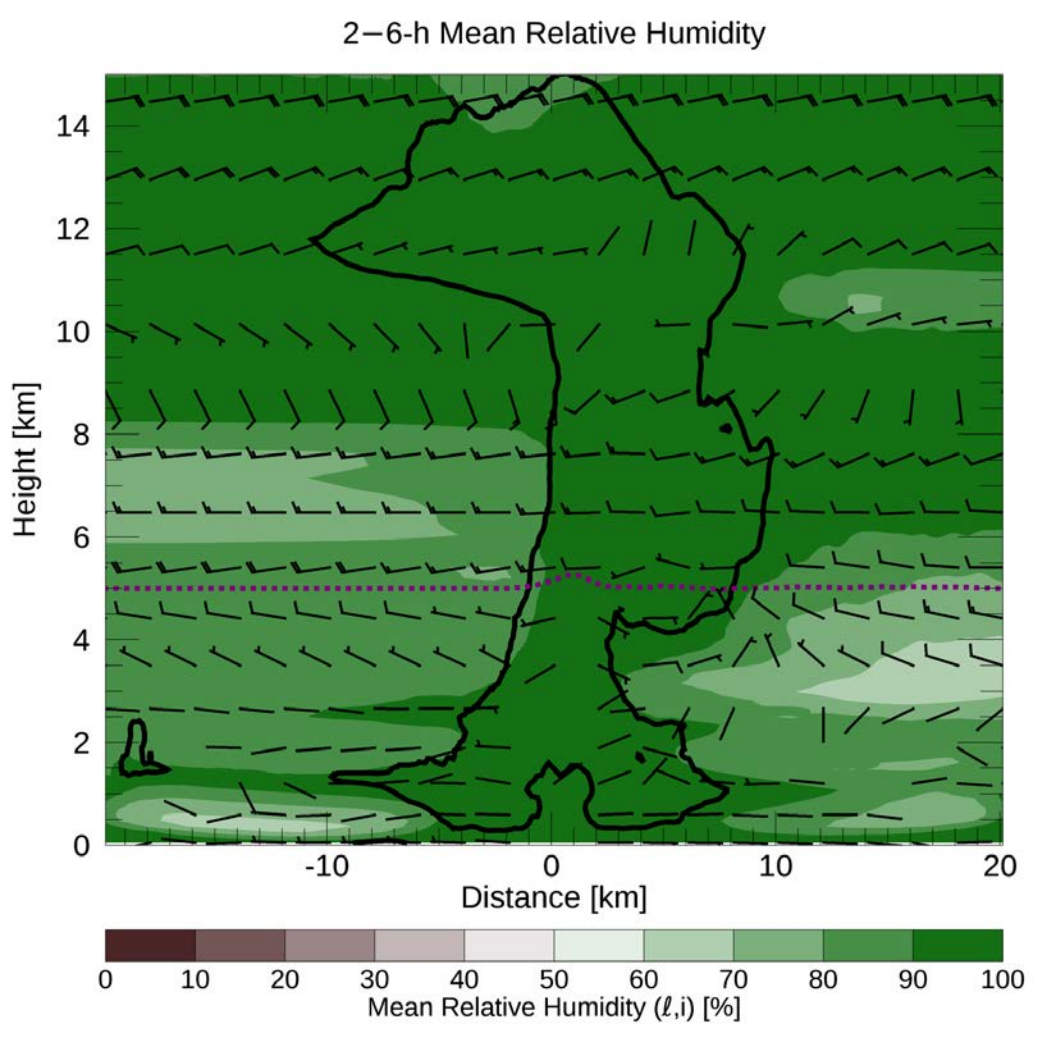
Vertical Velocity Retrieval



Summary

- Simulations: Stable layers can block precipitation-free downdrafts
- Observations: Stable layers reduce precipitation-laden downdrafts
- Limitation: Radar unable to observe precipitation-free downdrafts

Origins



Cloud extent (0.1 g/kg)

Freezing level

Horizontal winds (knots)

CM1 Model Setup	
Δx, Δy, Δz	250 m, 250 m, ~250 m
Domain	100 km x 100 km x 25 km
Microphysics	Morrison 2M w/ Graupel
Coriolis Force	No
Radiation	No
Surface Fluxes	Constant Moisture Surface Flux
Convection forced by ongoing surface convergence	

CAPE: 1708 J/kg
CIN: 30 J/kg