Inter-relationships between convectively generated cold pools, updraft/downdraft characteristics, and microphysical processes

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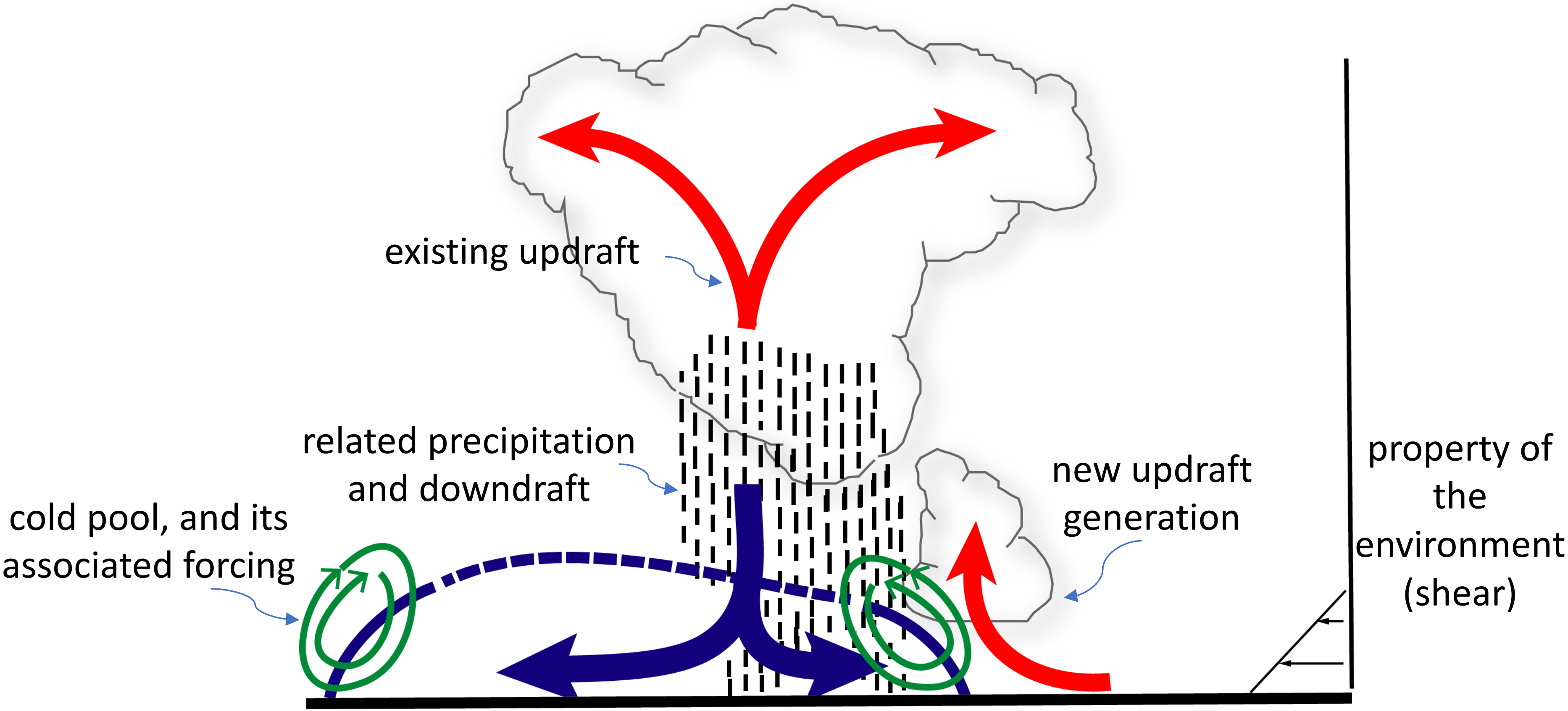
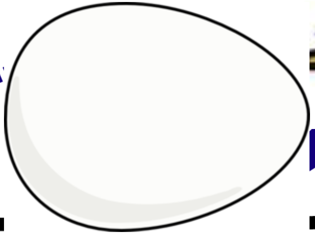
Here's our motivation …

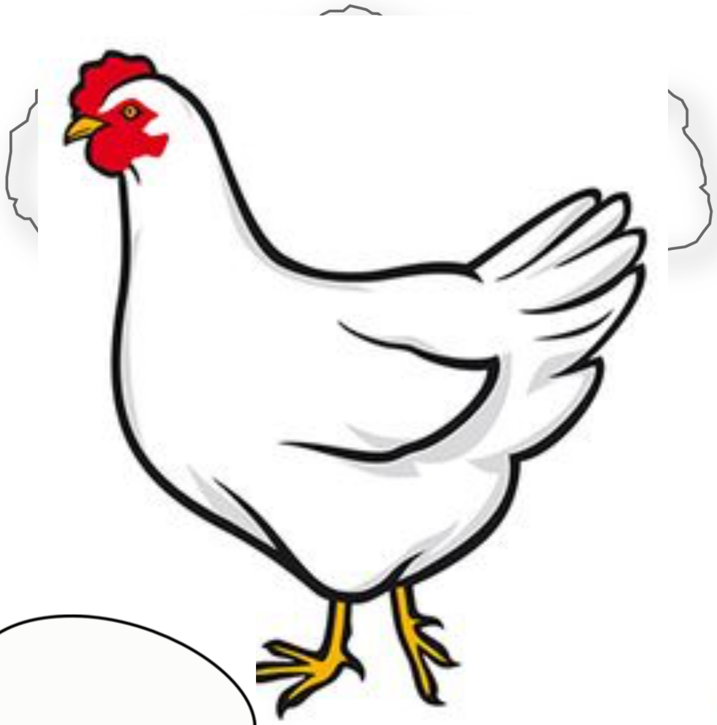


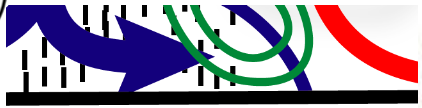
adapted from Rotunno et al. (1988)

Our Focus:

- In this schematic, we seek to understand how the characteristics of the cold pool are coupled to characteristics of (and processes comprising) the downdraft and updraft
- Our specific focus on is cold-pool **depth**, and here we our attempting to understand depth from a 'top-down' perspective:
  - *our hypothesis* is that the cold pool depth is controlled by downdraft area (or mass flux), which is controlled by updraft area (or mass flux) but modulated by the microphysics
    - our additional hypothesis is that the updraft mass flux (or area) is most strongly controlled by the environment





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Why focus on depth?

- **Other than the fact that $V_{cold\ pool} = k\sqrt{gd\ \Delta\theta_v/\overline{\theta_v}}$, depends explicitly on depth (*d*), why do we care about depth?**

positive effect: the potential for the initiation of new convective clouds by the cold pool is more strongly related to depth than to other cold-cool characteristics (intensity, area) (e.g., Droegemeier and Wilhelmson 1985)

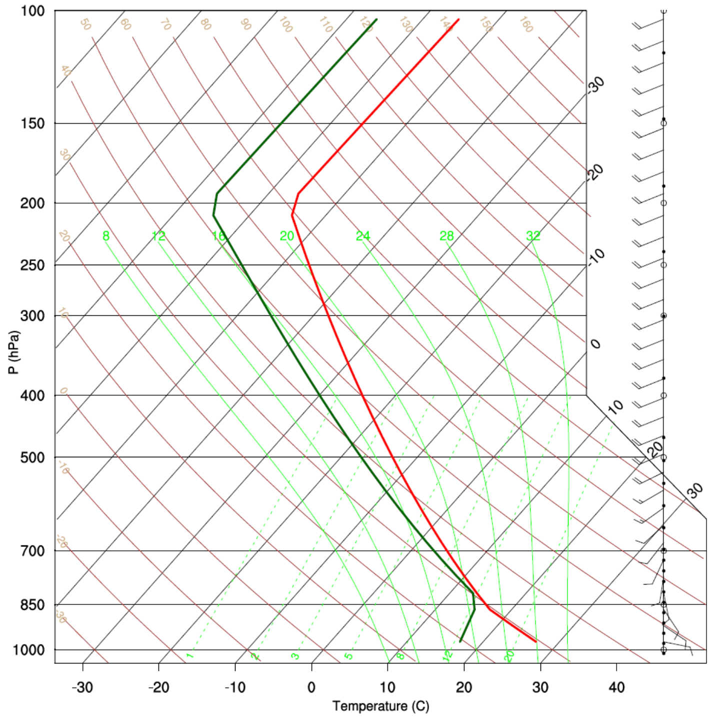
negative effect: the time scale for in-situ elimination of the cold pool, and thus of in-situ elimination of (surface-based) convective inhibition, also directly depends on depth (e.g., respective papers by Del Genio, van den Heever, Trapp)

Addressing this hypothesis:

- We use idealized numerical simulations of highly organized convective storms, in continental midlatitude environments like those observed during MC3E (and to be observed in CACTI)
- ***supercellular convection*** is the particular morphology of interest, because
  - updrafts, downdrafts, and cold pools are discrete and readily quantifiable
  - also, supercells provide a key developmental pathway to MCSs, which generate much of the warm-season rainfall…

Idealized Modeling

- **CM1 (version 18)**
- **Initial/boundary conditions from analytic thermodynamic and wind profiles**
- **Convection initiation via a *warm bubble***
- **500-m grid lengths, free-slip lower boundary, Morrison microphysics**
  - 125-m grid lengths, NSSL microphysics

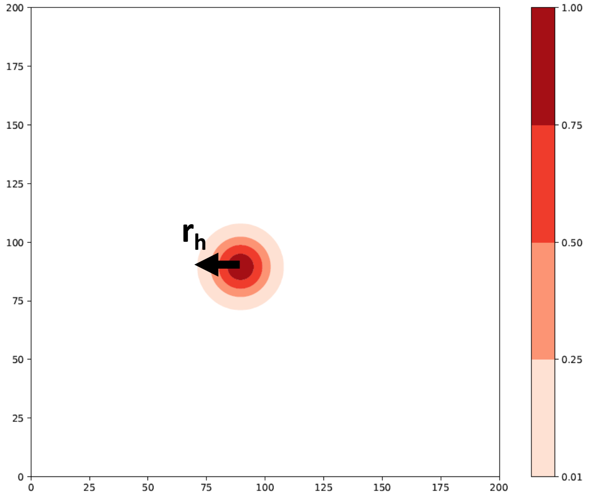


How to control for updraft area?

- **To address our top-down hypothesis, we wish to generate supercellular thunderstorms with different updraft areas.**
- **How?**

Experimentation with warm bubble size

Perturbation Potential Temperature (Horizontal Cross Section)

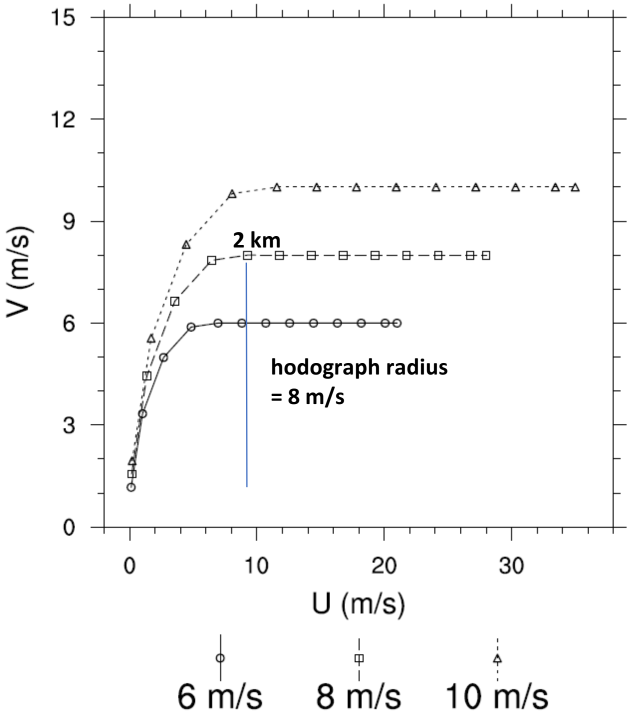


Although a wider bubble leads to initially larger updraft, the <u>peak</u> updraft area is *insensitive* to bubble width

Experimentation with wind profile

- **Vary radius of *quarter-circle* hodograph, from 6 to 10 m s^{-1}**

- **Scale upper level winds to maintain quarter-circle hodograph shape:**

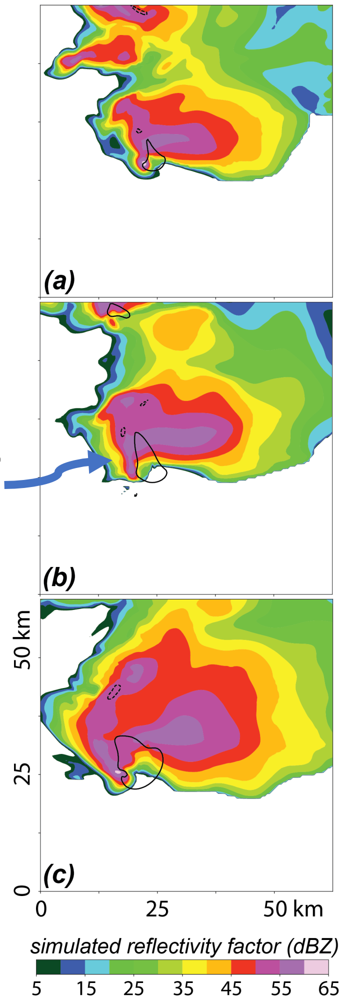


“Low Shear” “High Shear”

SRH: 115-450 m^2 s^{-2}

0-6 km Bulk Shear: 21-36 m/s

Trapp et al. (2017, *JAS*)



20 m/s w-contour
@6.25 km

“low” shear

“moderate ” shear

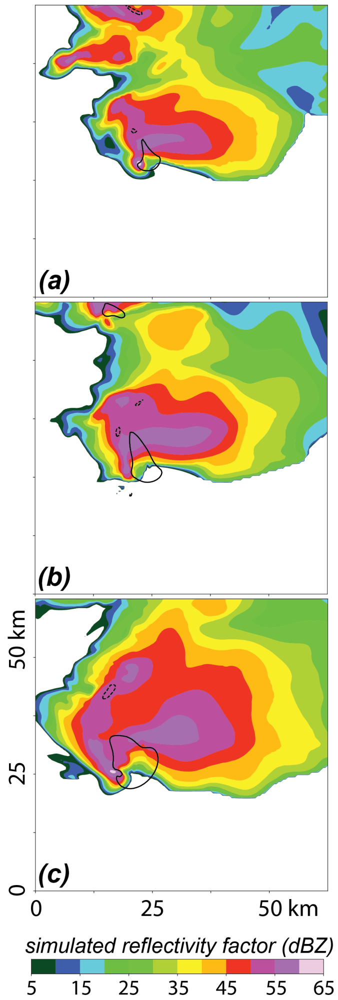
“high” shear

Trapp et al. (2017, *JAS*)

"low" shear

"moderate " shear

"high" shear

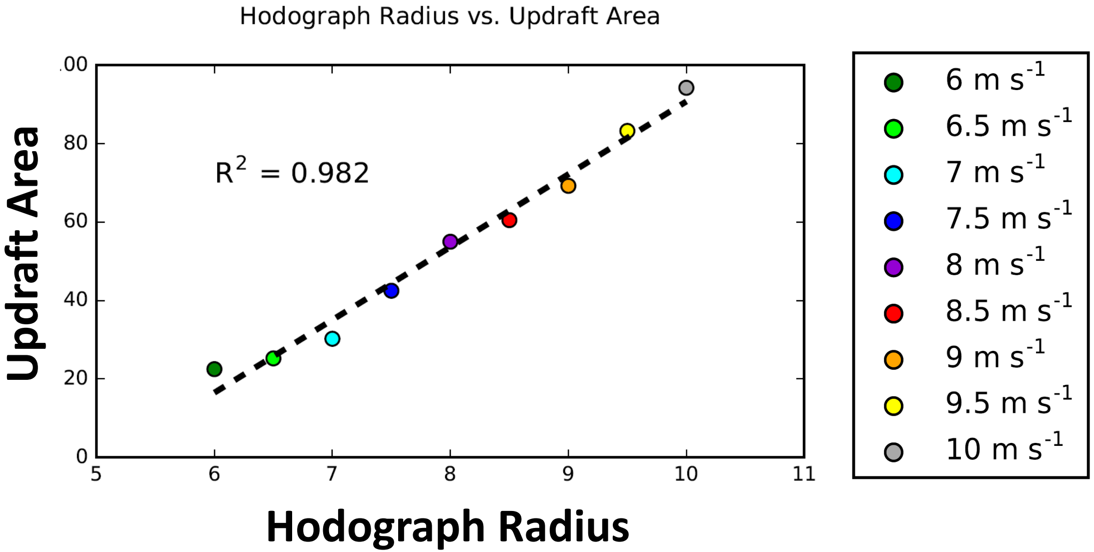


quantify updraft (<u>core</u>) <u>area</u> by number of contiguous gridpoints with w ≥ 20 m/s at z=6.25 km; determine <u>peak</u> core area up to the time of peak cold-pool depth

Trapp et al. (2017, *JAS*)

Experimentation with wind profile

<u>Peak</u> updraft area exhibits a large sensitivity to vertical wind shear (hodograph radius), with monotonic increase of area with shear/radius.

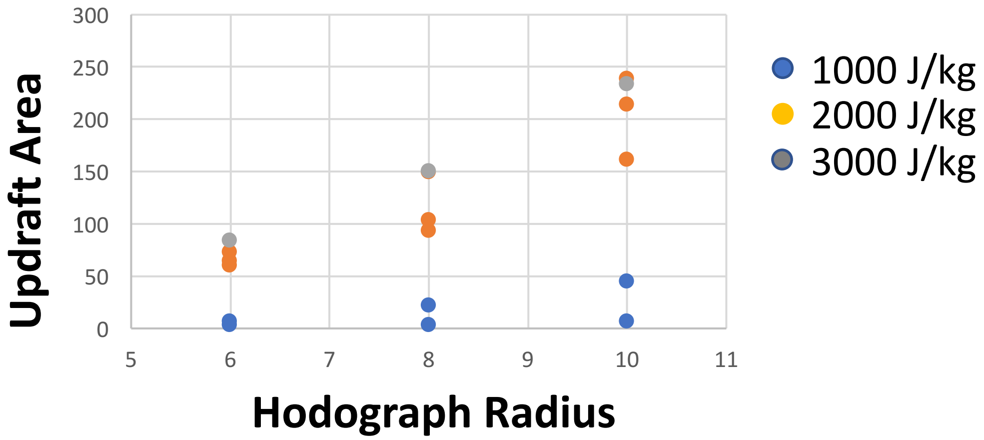


Trapp et al. (2017, *JAS*)

Experimentation with environmental wind and thermodynamic profiles

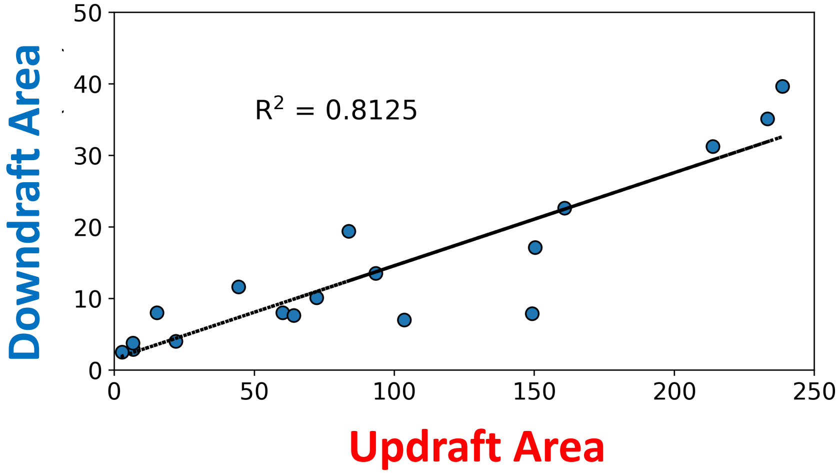
Updraft-area control by shear is modulated by CAPE

(…and the parameters used to control for CAPE, e.g., level of maximum buoyancy)



Marion et al. (2018, *JGR*, to be submitted)

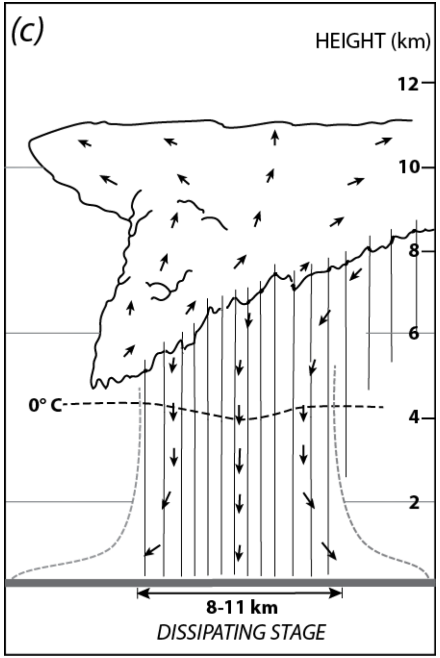
Is this environmental control on updrafts imparted to downdrafts? Yes: Across all experiments, large updrafts beget large downdrafts



Quantify downdraft area by same methodology as updraft (number of contiguous gridpoints with *w* < -8 m s^{-1} at z ~ 3.25 km)

Physical relationship between downdraft area and updraft area?

- **The area of precipitation that is generated in rising air is imparted to the downdraft, as the precipitation begins to fall relative to the updraft**
- **The characteristics of the downdraft are in turn imparted to the cold pool:**
  - **stronger, deeper, cold pool with increasing downdraft area**



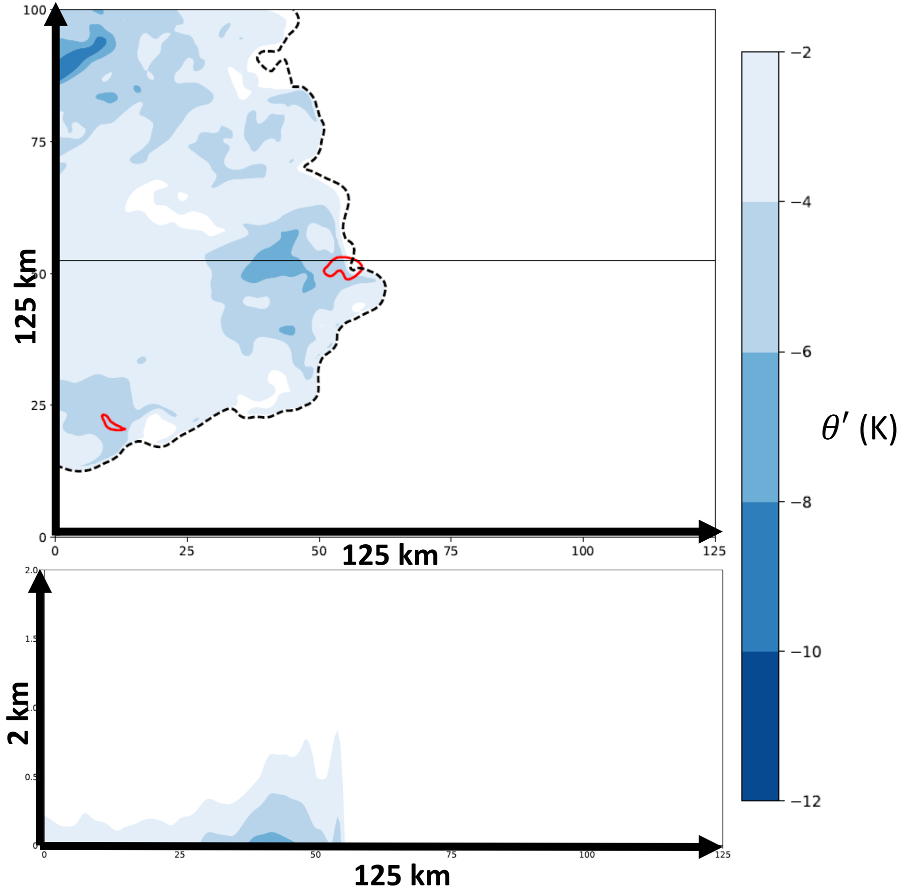
adapted from Doswell (1985)

Relating cold pool depth/area to downdraft

“low” shear

Surface θ'

Vertical Cross Section θ'



Red contour: $w = 20\ m\ s^{-1}$ at $z = 6.25\ km$

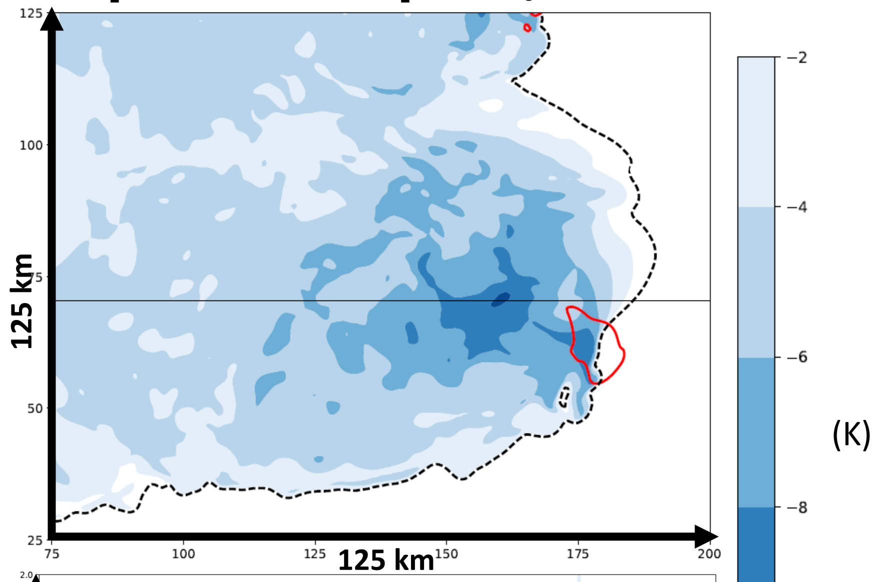
Black dashed contour: $\theta' = -1\ K$

Black line: Vertical Cross Section

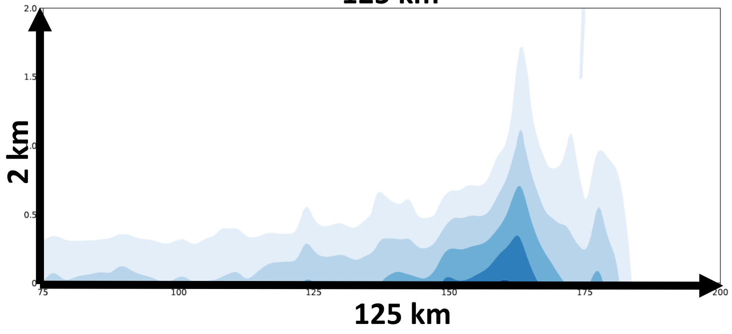
Relating cold pool depth/area to downdraft

“high” shear

Surface θ'



Vertical Cross Section θ'

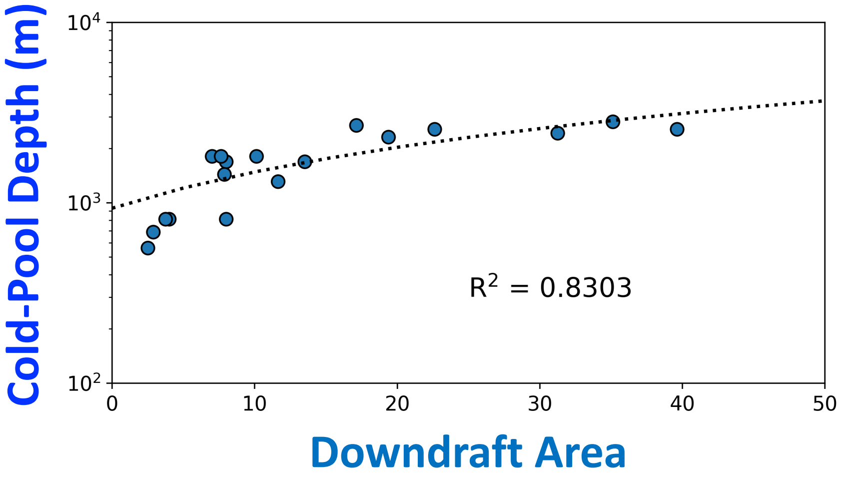


Red contour:
$w = 20\ m\ s^{-1}$
at $z = 6.25\ km$

Black dashed contour:
$\theta' = -1\ K$

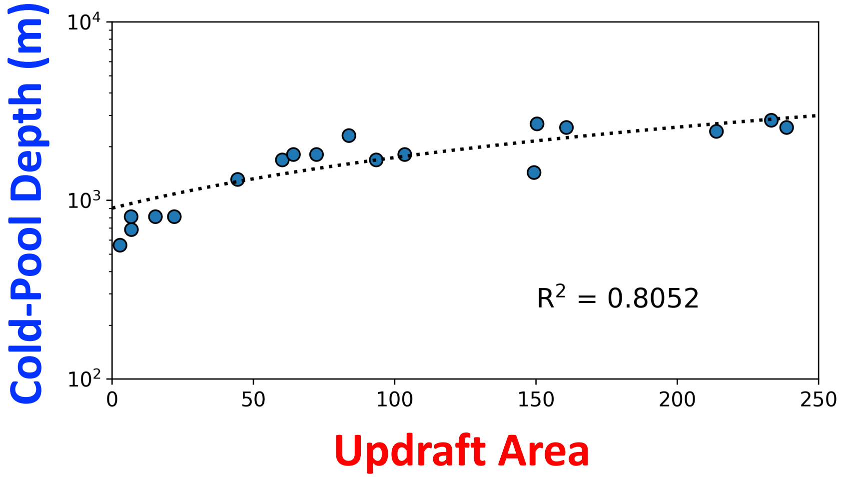
Black line:
Vertical Cross Section

Across all experiments, large downdrafts beget deep cold pools

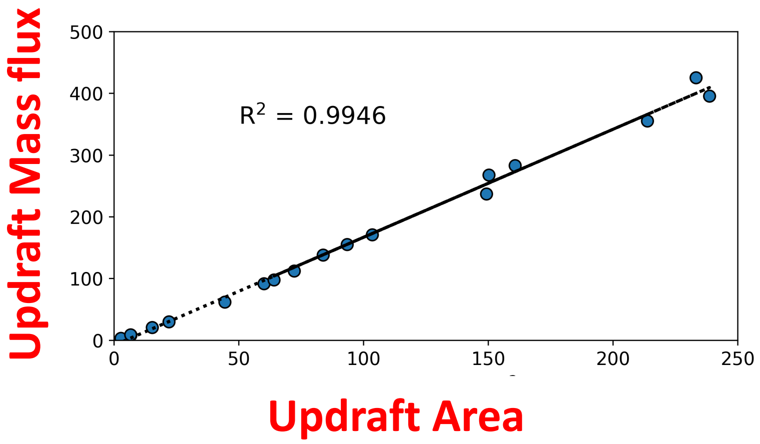


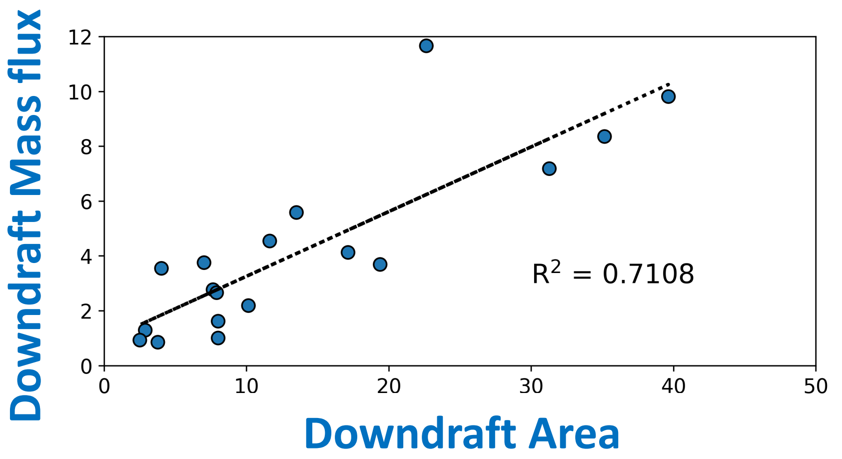
Quantify cold pool depth as largest height of the -3 K isosurface with a contiguous area of at least 1 km^2, and a vertical velocity no less than w = -3 m s^{-1}

Accordingly, across all experiments, large updrafts also beget deep cold pools

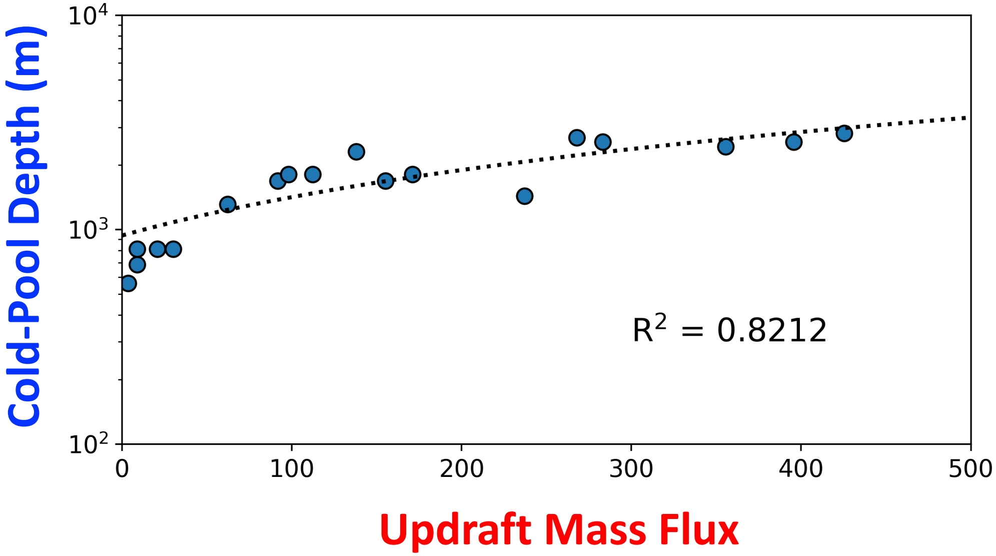


Noting that these results can also be expressed in terms of *mass flux*, i.e., large updraft (downdraft) cores also have large updraft (downdraft) mass flux …





We can conclude that large updraft mass flux begets deep cold pools



Summary

- **Idealized numerical simulations were used to support the hypothesis that updraft (core) area controls downdraft (core) area and thus cold-pool depth**
- **In organized convection in the midlatitudes, the environment is a key driver of cold-pool depth**
  - especially vertical wind shear, and also the profile of buoyancy (CAPE)

Implications

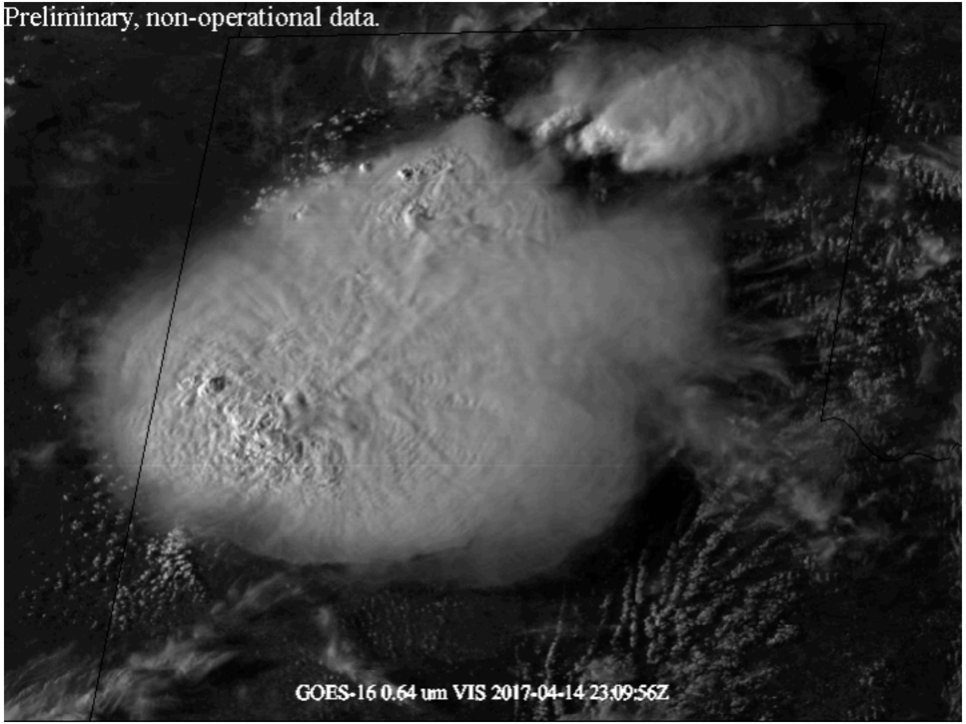
- Implication for **convective parameterization**:
  - our results suggest that the cold pool (depth) determines whether or not new deep convective clouds will be initiated…
  - …but, the cold pool does not impart its characteristics to those of the new clouds: i.e., what the new clouds generate (e.g., rainfall, diabatic heating) … will still be heavily controlled by the environmental wind (and also thermodynamics)

Ongoing/future work

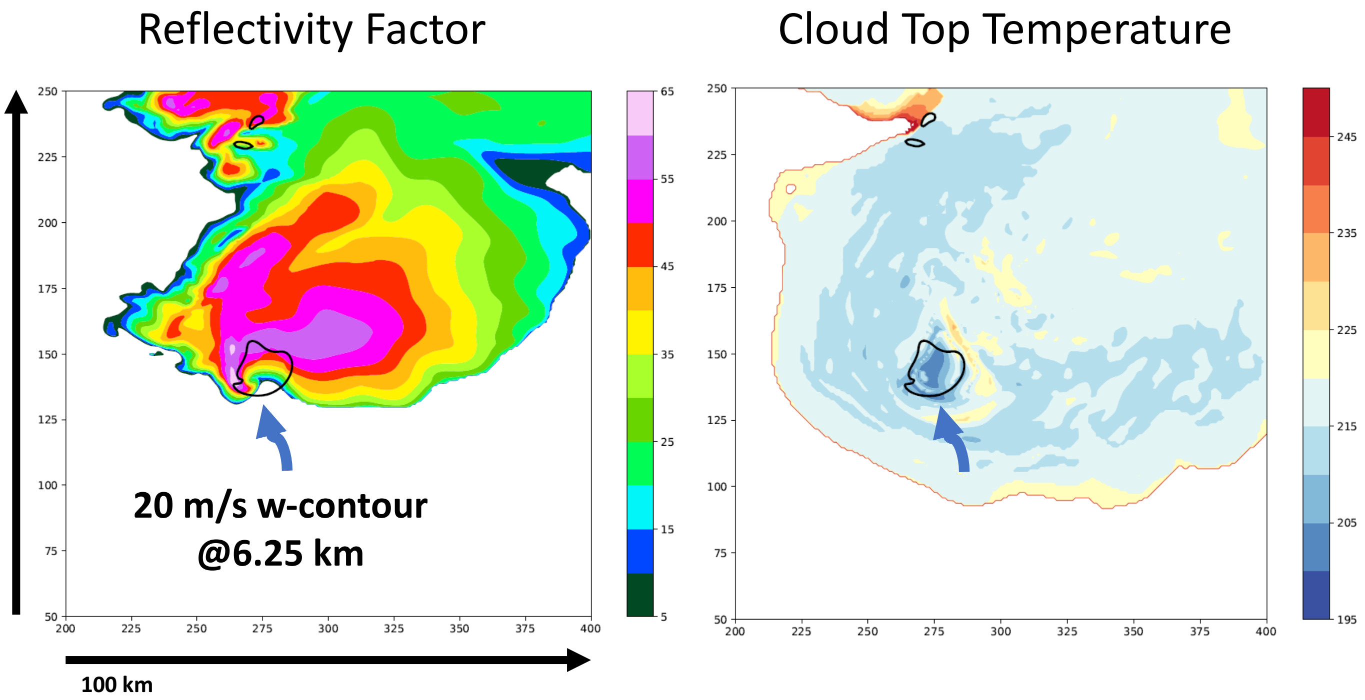
- Understand how the microphysics modulates this linkage
- Find support in observations
  - MC3E
  - CACTI-RELAMPAGO – mobile soundings in targeted cold pool, fixed & mobile radar, etc.

Another way to estimate cold pools: Overshooting Tops?

The area of the over-shooting top (OTA) should scale as the updraft core area … which could possibly tell us something about cold pools!



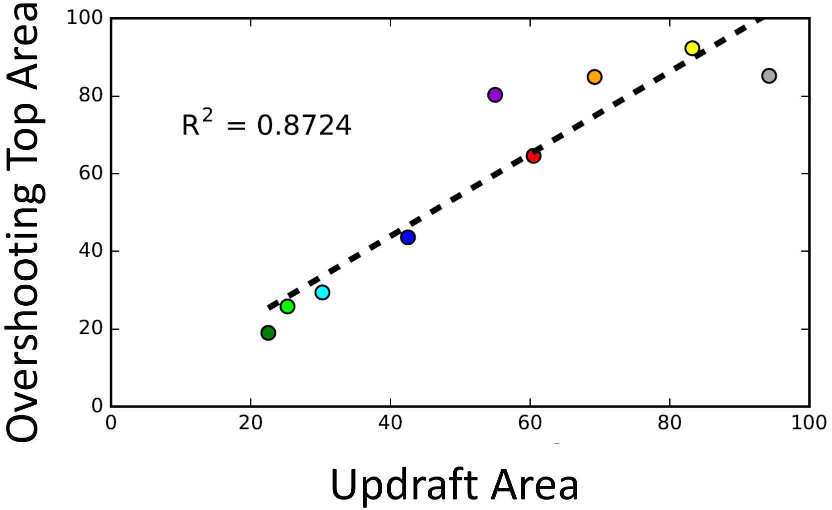
Overshooting Top Area – Using Simulations



Trapp et al. (2017, *JAS*)

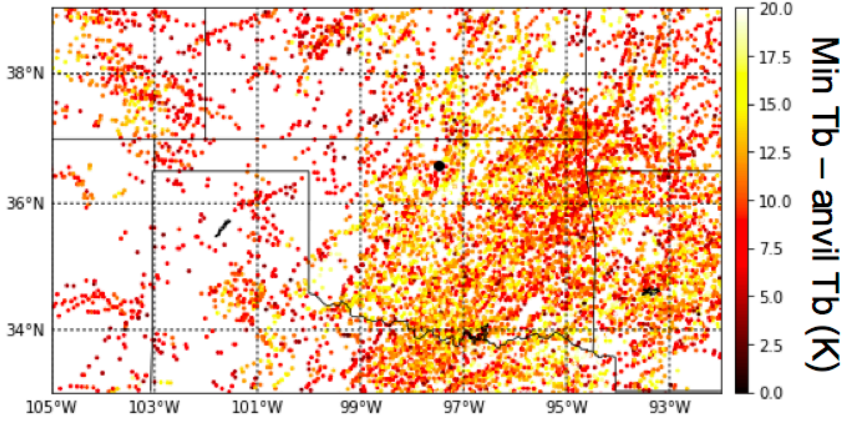
Overshooting Top Area – Using Simulations

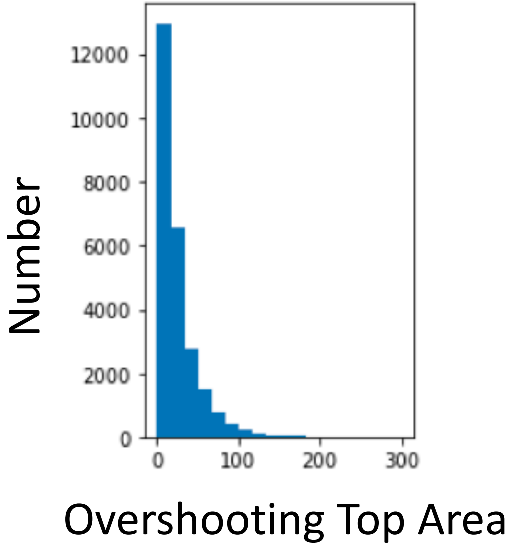
- OTA defined by number of gridpoints at threshold cloud top temperature (210 K)
  - **high correlation between OTA and updraft area**



Trapp et al. (2017, *JAS*)

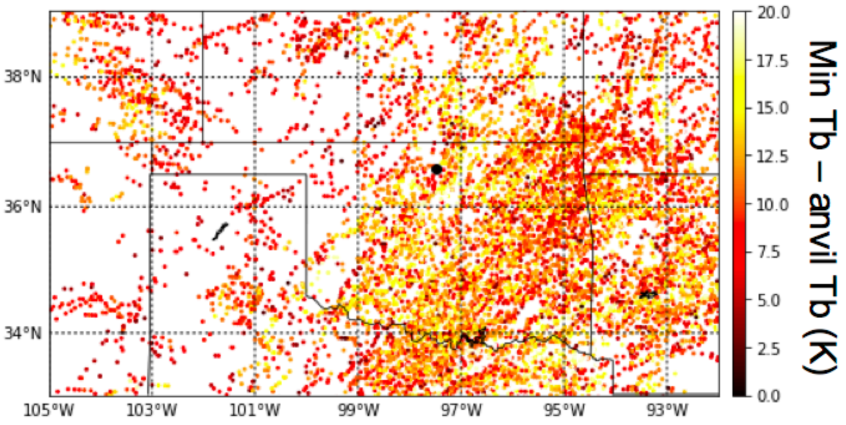
Overshooting Top Characteristics during MC3E (2011) from GOES-13

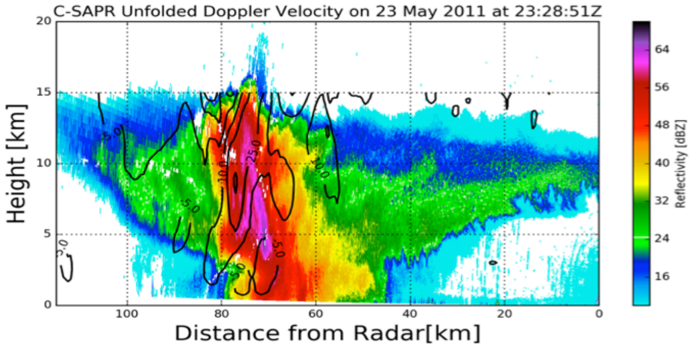


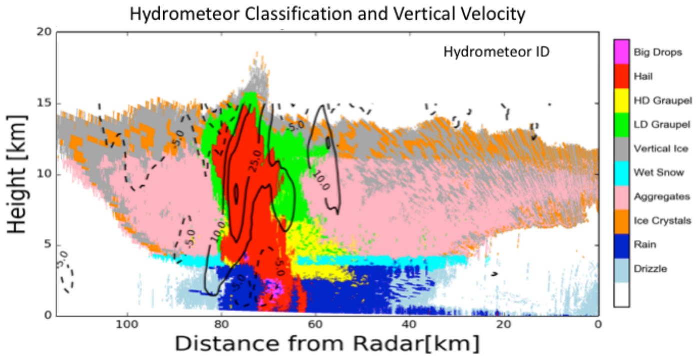


courtesy of Steve Nesbitt

Next step: Use MC3E radar data to help relate OTA to cold pools in select storms







Thank you for your attention!

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More questions or comments:
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