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

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Here’s our motivation …

cold pool, and its associated forcing

existing updraft

related precipitation and downdraft

new updraft generation

property of the environment (shear)

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
Why focus on depth?

• Other than the fact that \( V_{\text{cold pool}} = k \sqrt{gd \, \Delta \theta_v / \theta_v} \), 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

Although a wider bubble leads to initially larger updraft, the peak 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:

**SRH**: 115-450 m\(^2\) s\(^{-2}\)

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

“Low Shear”

“High Shear”

Trapp et al. (2017, *JAS*)
"low" shear

"moderate" shear

"high" shear

Trapp et al. (2017, JAS)
“low” shear

“moderate” shear

“high” shear

quantify updraft (core) area by number of contiguous gridpoints with \( w \geq 20 \text{ m/s} \) at \( z=6.25 \text{ km} \); determine peak core area up to the time of peak cold-pool depth

Trapp et al. (2017, JAS)
Peak 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)

![Graph showing the relationship between updraft area and hodograph radius for different CAPE values.]

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 $w < -8 \text{ m s}^{-1}$ at $z \sim 3.25 \text{ km}$)

$R^2 = 0.8125$
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 $\theta'$

Vertical Cross Section $\theta'$

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

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

Black line: Vertical Cross Section

Relating cold pool depth/area to downdraft
Relating cold pool depth/area to downdraft

“high” shear

Surface $\theta'$

Vertical Cross Section $\theta'$

Red contour:

$w = 20 \text{ m s}^{-1}$

at $z = 6.25 \text{ km}$

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 km², and a vertical velocity no less than \( w = -3 \text{ m s}^{-1} \)
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

Reflectivity Factor

Cloud Top Temperature

20 m/s w-contour @6.25 km

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: jtrapp@illinois.edu