“Breathing” Clouds and Storms: Inflow and Entrainment, Precipitation and Outflow

Sonia Lasher-Trapp
Blue Waters Professor

Contributions by grad students:
Daniel Moser*
Holly Mallinson
Bryan Engelsen

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Questions:

- How much **entrainment** occurs in different stages of a **supercell thunderstorm**?
  - Entrainment has a negative effect upon storm longevity and precipitation
  - Requires high-resolution simulations with high-frequency output of large files to quantify mass flux

- How does **cloud spacing** affect **entrainment**?
  - Smaller gaps between clouds might “protect” them
  - Requires high-resolution simulations with high-frequency output of large files to quantify mass flux

- What kind(s) of **precipitation** are most important for the **strength of the outflow**?
  - A stronger storm outflow can generate new storm development
  - Requires **multiple realizations** of high-resolution simulations, with high-frequency output of large data files to quantify latent cooling

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has allowed us to pursue these questions!
Model and Analysis Tools

**CM1 model - George Bryan, NCAR**
- Coarse-grained, pure MPI, 3D cloud model, designed to scale to tens of thousands of processors, written in FORTRAN
- 3rd-order RK integration; 5th/6th order advection
- NSSL double-moment microphysics (important for precip development, but increases number of calculations and memory required)
- Domain sizes are tens to hundreds of kilometer wide; grid spacing ranges from 50 m to 100 m to 250 m with time step < 0.1 sec

**Entrainment & dilution calculations (offline):**
- Triangulation algorithm (Dawe and Austin 2011) in FORTRAN/NCL to derive cloud core surface at sub-grid scale
- Creates vertical profiles of entrainment in time, and amount of core dilution
- Requires model output at high temporal resolution (3 to 6 seconds)
- Runs on single processor, but can divide the job up into time segments to spread work among many processors

**Calculations of latent cooling in downdrafts (offline):**
- NCL/FORTRAN code searches for “cold pool” & associated downdrafts connected to it, at each output time
- VisIt useful to understand the different situations we had to address in our new analysis code!
How Much Air Do Thunderstorms “Breathe In”? = *Entrainment*

Per 2.5 hour simulation: 307.5M grid points; 14,400 node hours; 60 TB data

Half Gaussian - 5 km

Full Gaussian - 10 km

DB: trim_FinalHalfcarp_nssl_100_000501.nc
Cycle: 0  Time:3000

DB: trim_FinalFullcarp_nssl_100_000501.nc
Cycle: 0  Time:3000
Do cumuli growing in an environment with vertical wind shear entrain more than those growing without it?

Yes, in this particular example, more than 3 times as much! Moser and Lasher-Trapp (2018)

Lasher-Trapp & Engelsen, in prep

Current work: entrainment in rotating vs non-rotating stages of supercell thunderstorms
Can Cloud Spacing Affect Entrainment?

- Closer-spaced clouds rain less initially, but later produce the most rainfall.
- Why? Entrainment differences?
- Not really…

*Moser & Lasher-Trapp, in review*
- Precipitation-driven downdrafts from initial clouds converge in sub-cloud layer
- Strong forcing of new updrafts between initial clouds leads to a second generation of clouds (named Cloud B)

*Moser & Lasher-Trapp, in review*
Precipitation Outflows (Cold Pools)

Per 3.5 to 6 hour simulation: 80M grid points; (10 simulations) 800-1450 node hours; 2 to 3.5 TB data

Simulated Reflectivity at t = 36 min

Theta Perturbation at 36 min

Control

Lasher-Trapp & Mallinson, in prep
Precipitation Outflows (Cold Pools)

Theta Perturbation at 205 min

“Control” Case

Cold Pool and Simulated dBZ at t = 205 min

Lasher-Trapp & Mallinson, in prep
Latent Cooling in (initial) Downdraft vs. Propagation Speed of Outflow

Lasher-Trapp & Mallinson, in prep
Integrated Latent Cooling Prior to Outflow/Cold Pool Formation: *melting/sublimating graupel wins!*

Graupel Melting = -3.9 K
Graupel Sublimation = -3.8 K
**Latent Cooling of Graupel** = -7.7 K
Rain Evaporation = -3 K
**Latent Cooling of Rain** = -3 K
Hail Melting = -1 K
Hail Sublimation = -0.5 K
**Latent Cooling of Hail** = -1.5 K

**TOTAL LATENT COOLING** = -12.2 K

*Lasher-Trapp & Mallinson, in prep*
Challenges (and simple fixes)

- Slow I/O, or NCL routines running out of memory
  → output fewer variables

- Faster analysis with VisIt and NCL codes
  → we “trim” the data files, removing most of the empty space around the clouds/storms, for analysis and longer-term storage

- Searching large domains for continuous surfaces meeting certain criteria (e.g. latent cooling in downdrafts that touch the ground)?
  → Inelegant FORTRAN/NCL routines right now
  → Would like to know how other people do this!

- Storage of all these data files while we analyze them- still a problem!
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*Lasher-Trapp & Engelsen, in prep*