"Breathing" Clouds and Storms: Inflow and Entrainment, Precipitation and Outflow

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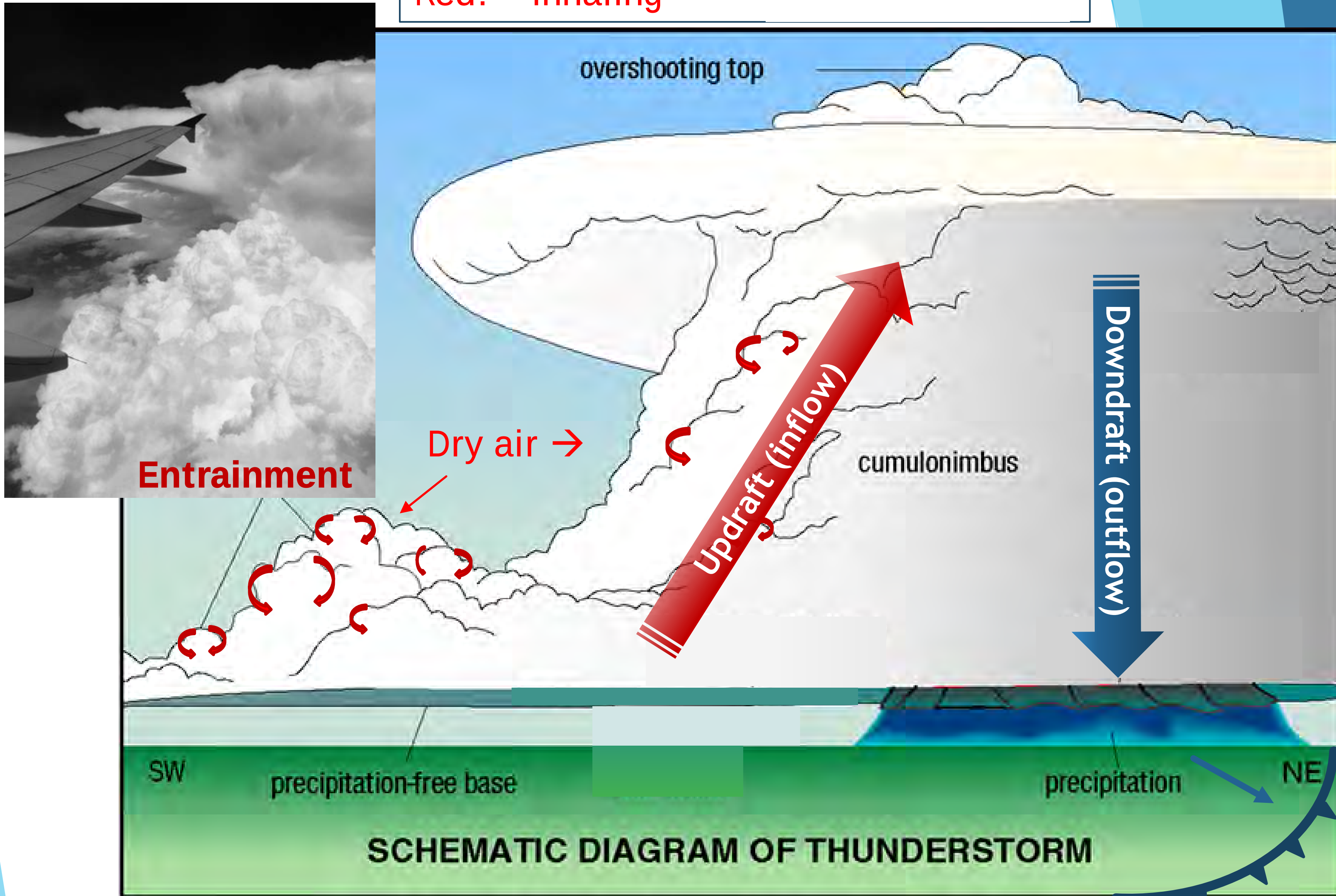
ILLINOIS

Blue Waters Symposium

June 5, 2018

BLUE WATERS
SUSTAINED PETASCALE COMPUTING

Red: “inhaling”



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**

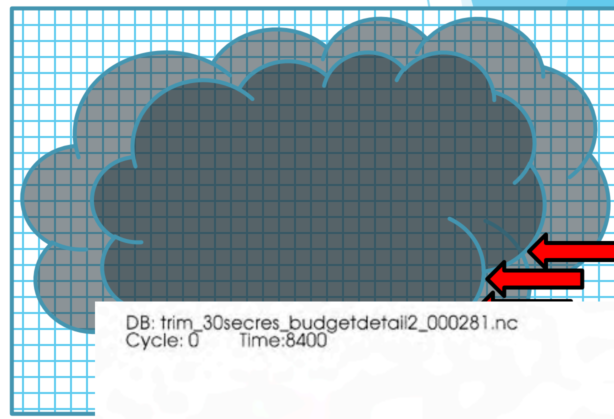
- What kind(s) of precipitation are most important for the strength of the outflow?
  - A stronger storm outflow can generate new storm development
  - **Requires multiple realizations of high-resolution simulations, with high-frequency output of large data files to quantify latent cooling**

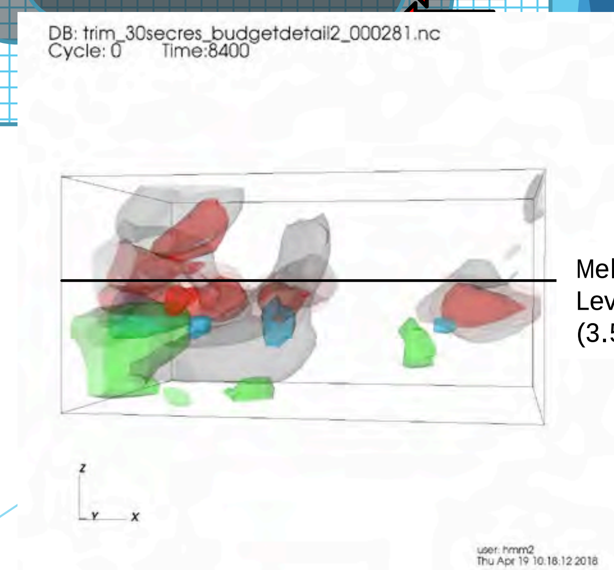
BLUE WATERS SUSTAINED PETASCALE COMPUTING **has allowed us to pursue these questions!**

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



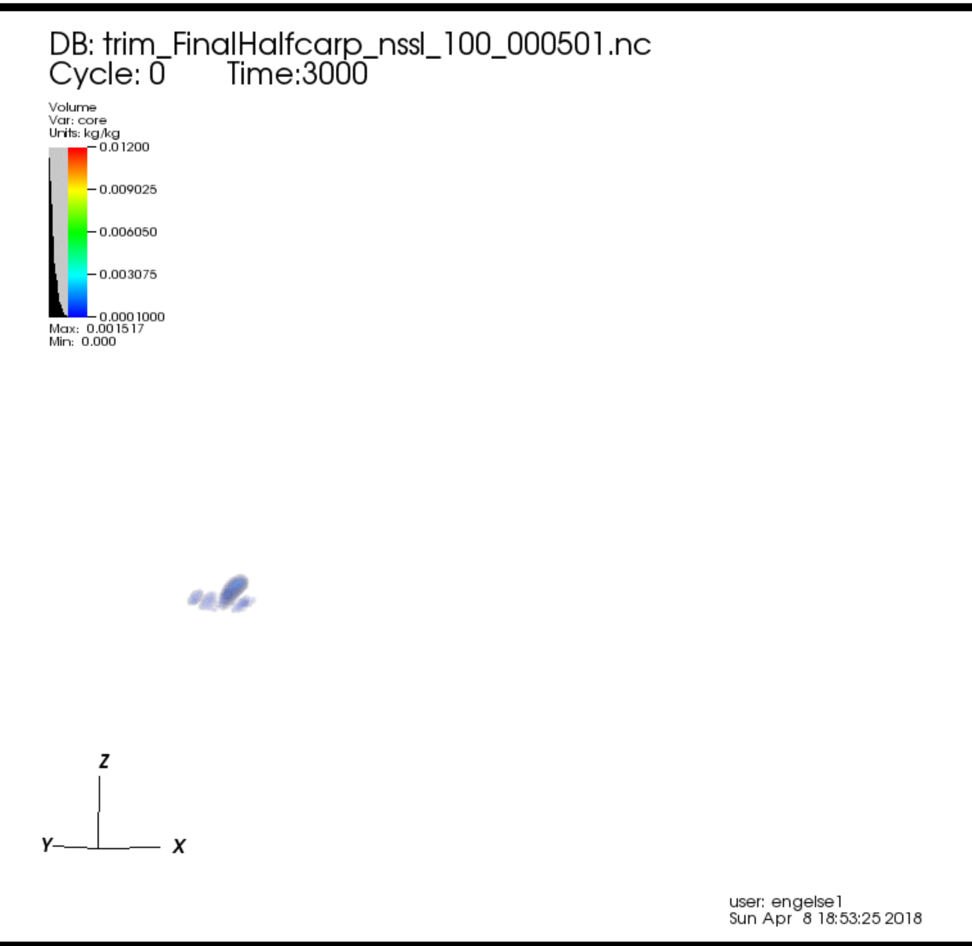


- Calculations of latent cooling in downdrafts (offline):
  - NCL/FORTRAN code searches for “cold pool” & associated downdrafts connected to it, at each output time
  - VisIt useful to understand the different situations we had to address in our new analysis code!

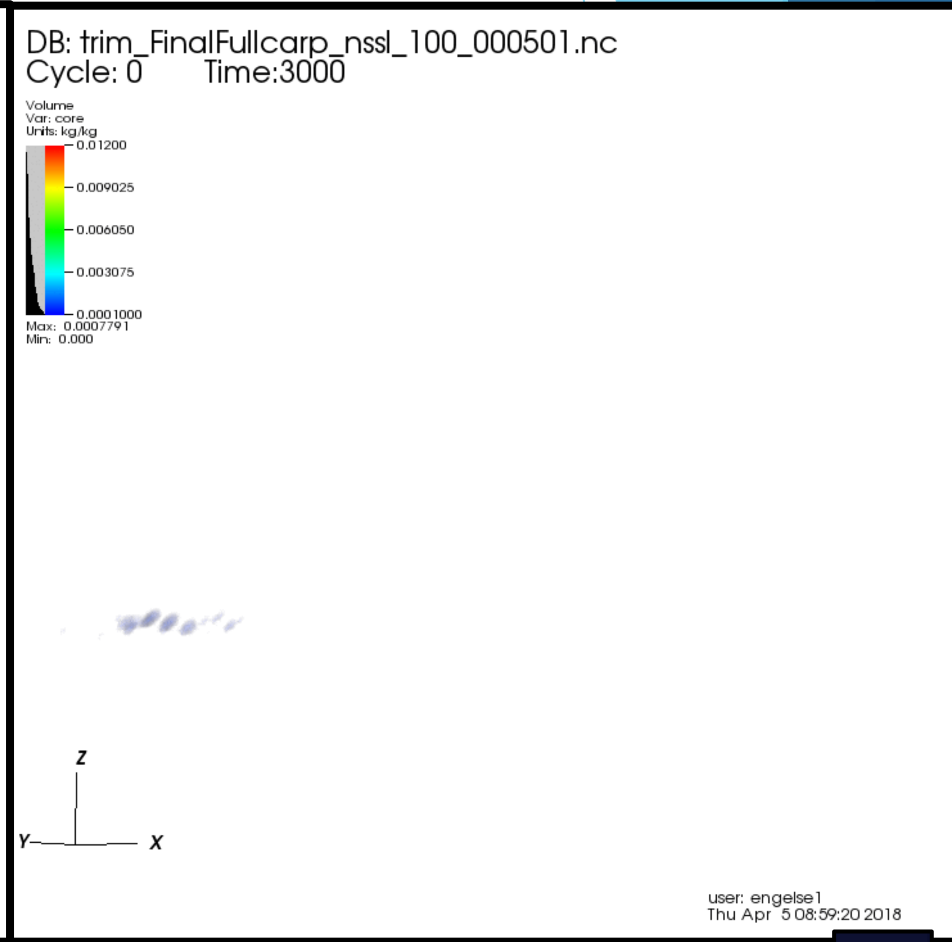
How Much Air Do Thunderstorms “Breathe In”?
= *Entrainment*

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

Half Gaussian – 5 km



Full Gaussian – 10 km

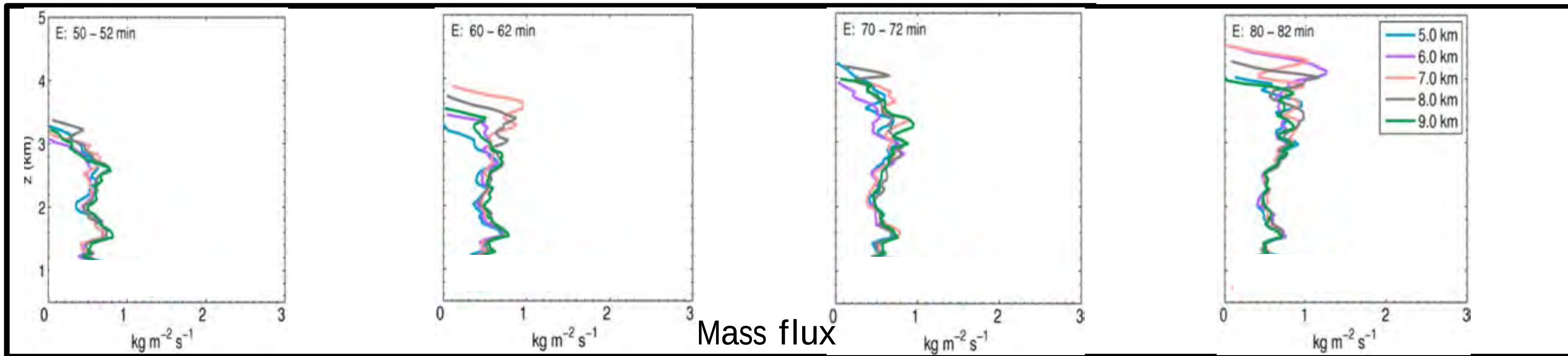


Do cumuli growing in an environment with vertical wind shear entrain more than those growing without it?

Yes, in this particular example, more than 3 times as much!

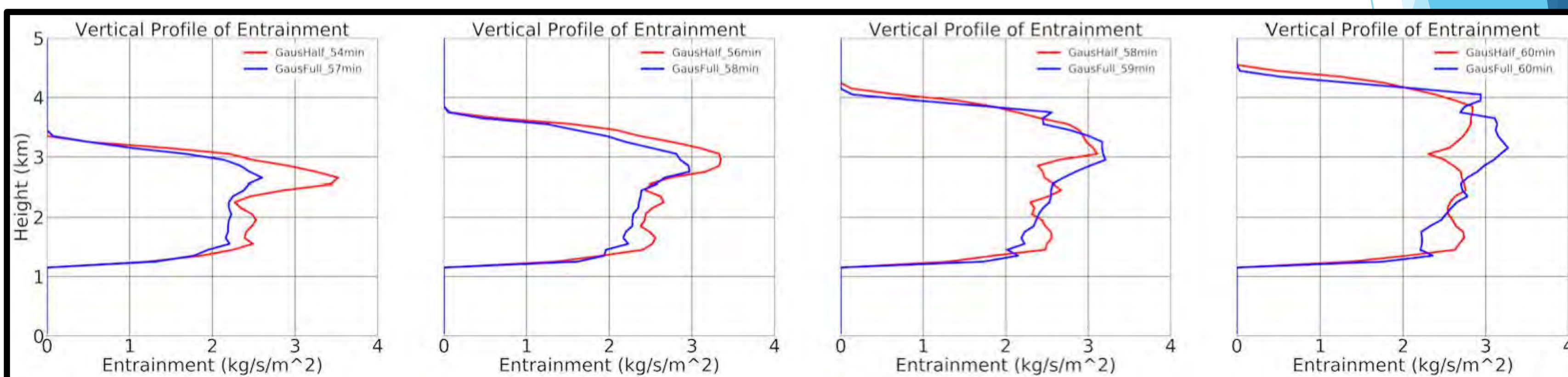
Moser and Lasher-Trapp (2018)

No Shear



Mass flux

Shear

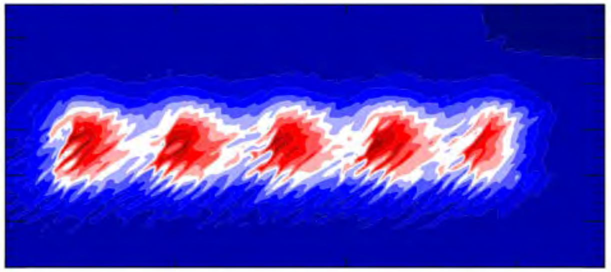


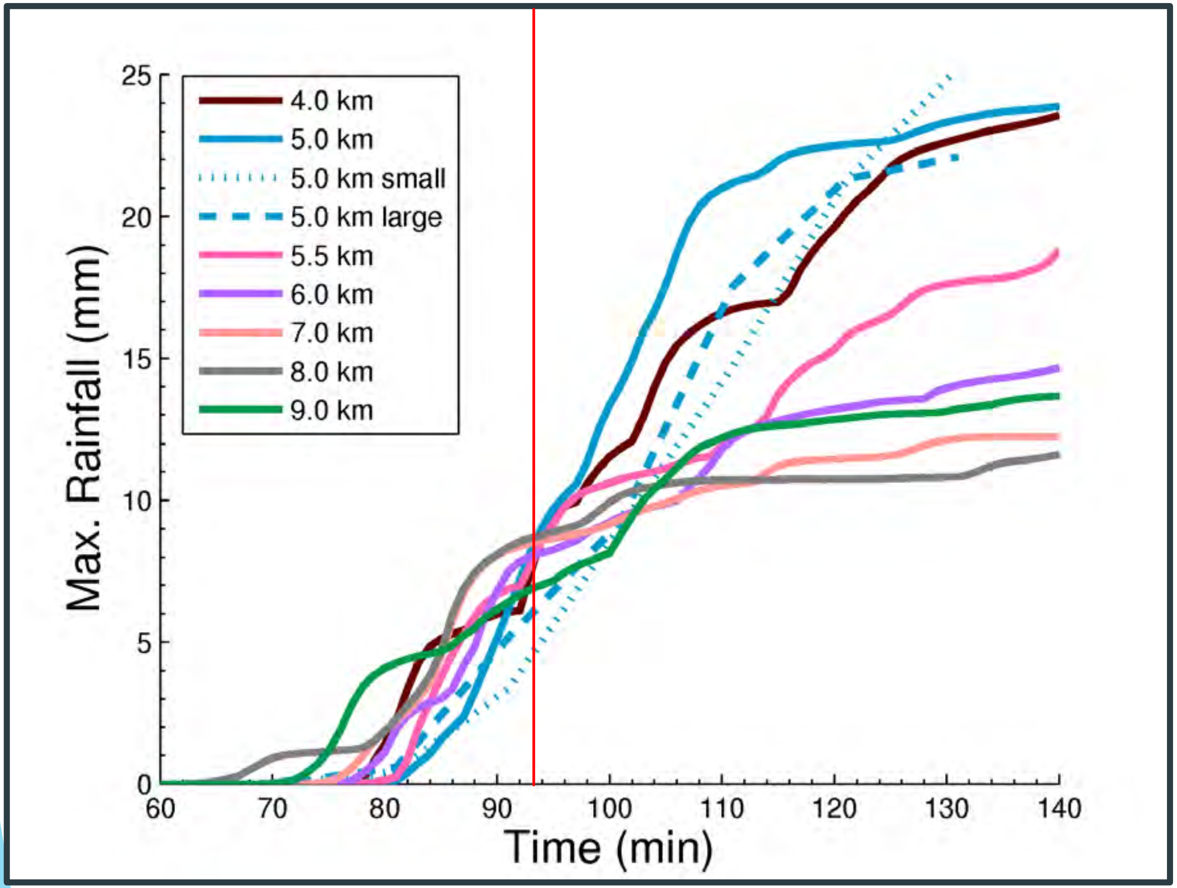
Mass flux

Lasher-Trapp & Engelsen, in prep

Current work: entrainment in rotating vs non-rotating stages of supercell thunderstorms

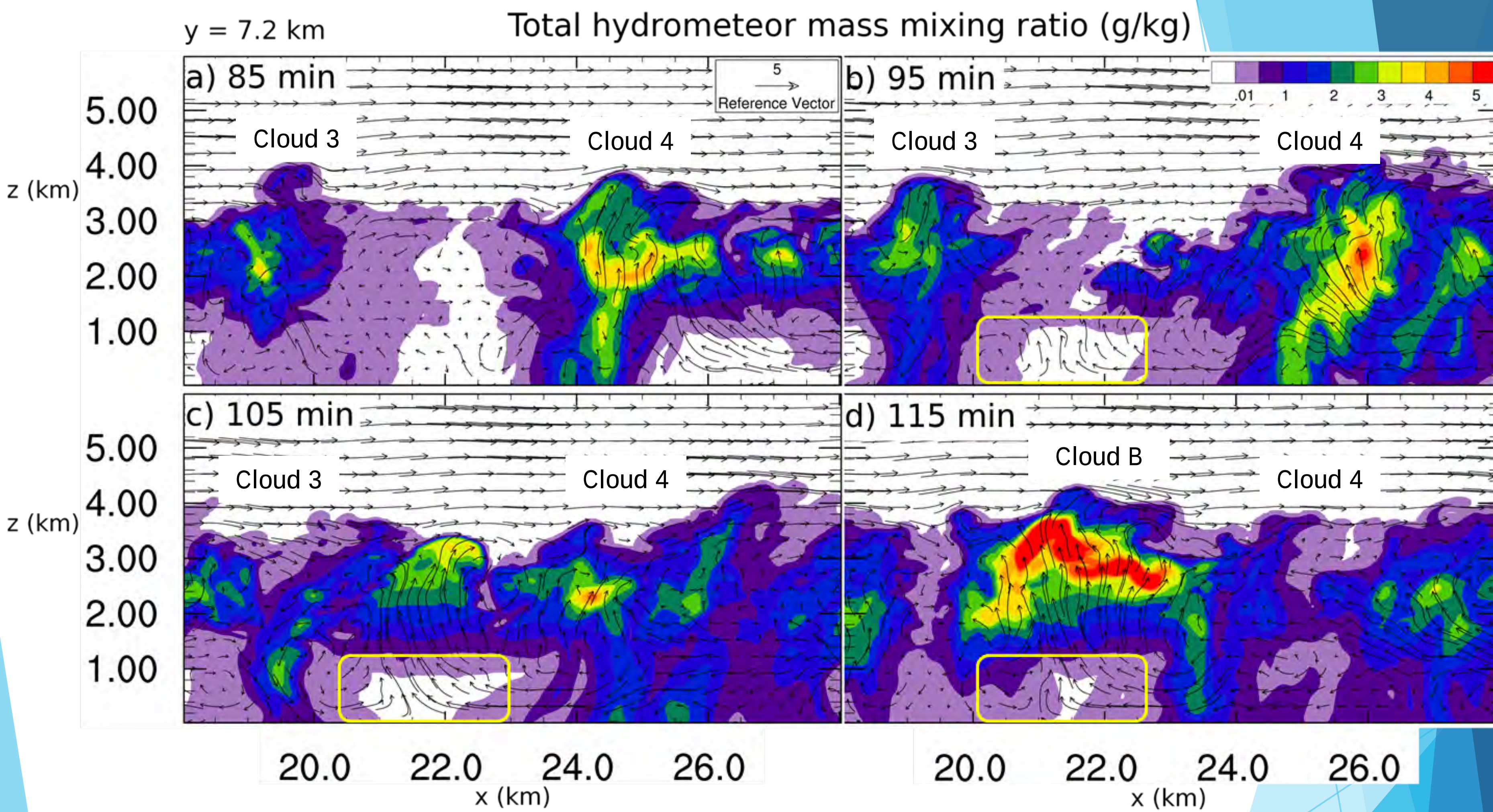
Can Cloud Spacing Affect Entrainment?





Moser & Lasher-Trapp, in review

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

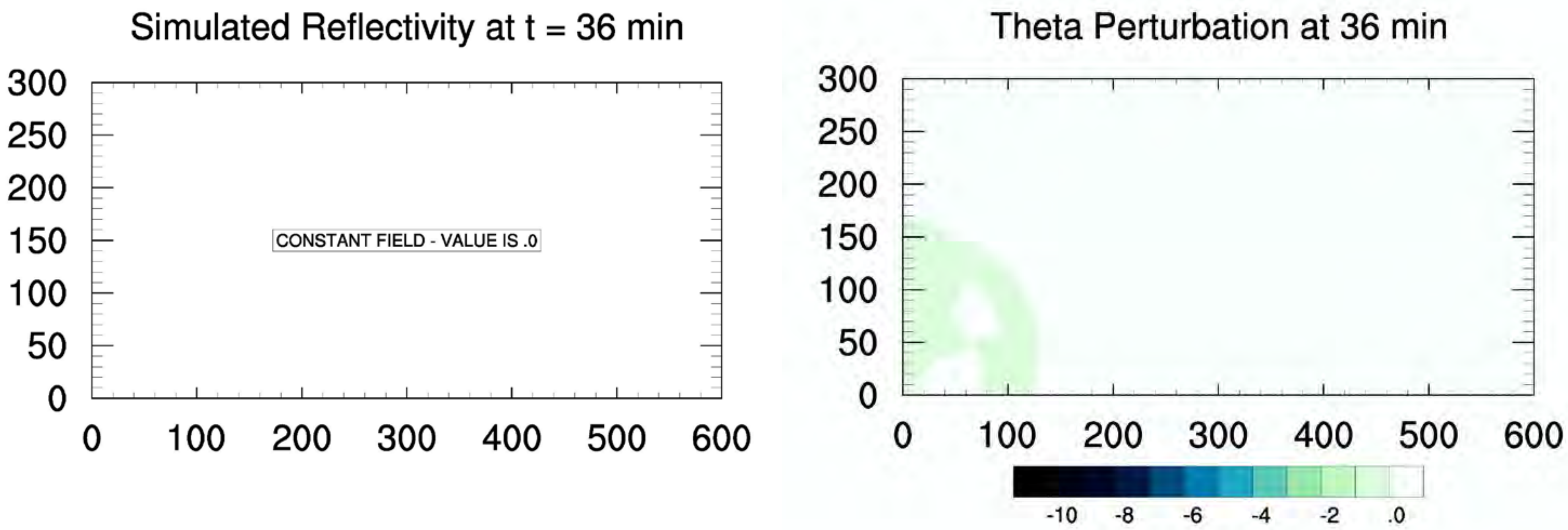


Moser & Lasher-Trapp, in review

- 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)

Precipitation Outflows (Cold Pools)

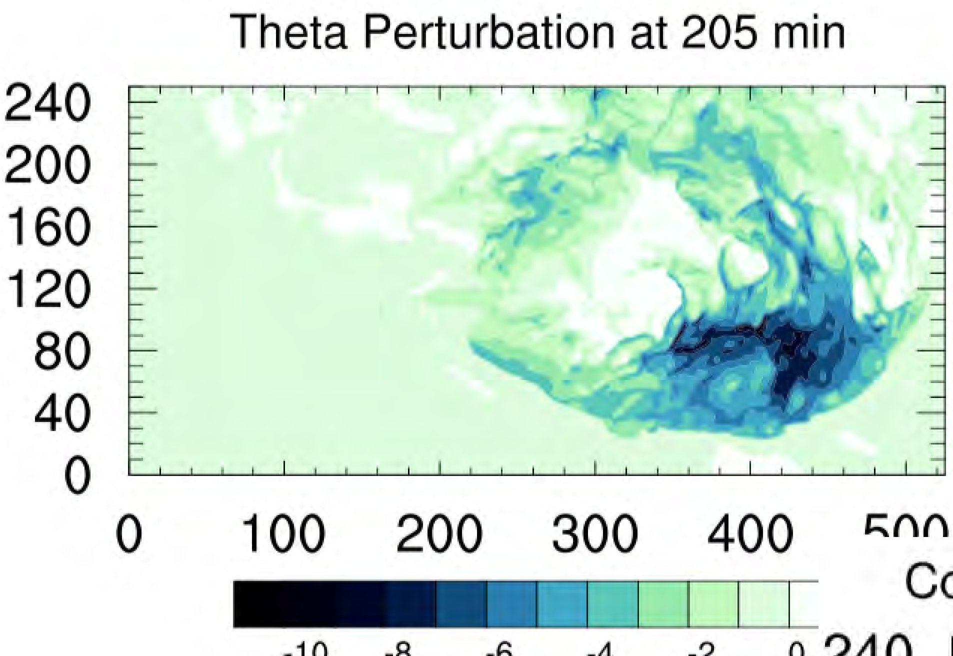
<u>Per 3.5 to 6 hour simulation</u>: 80M grid points;
(10 simulations) 800-1450 node hours;
2 to 3.5 TB data



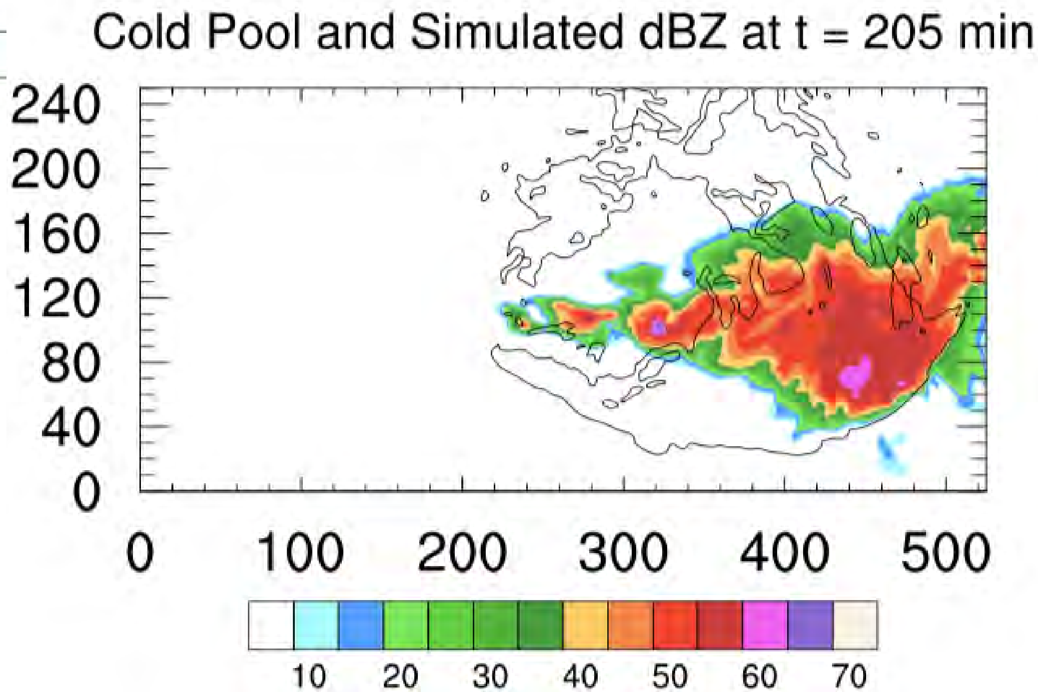
Control

Lasher-Trapp & Mallinson, in prep

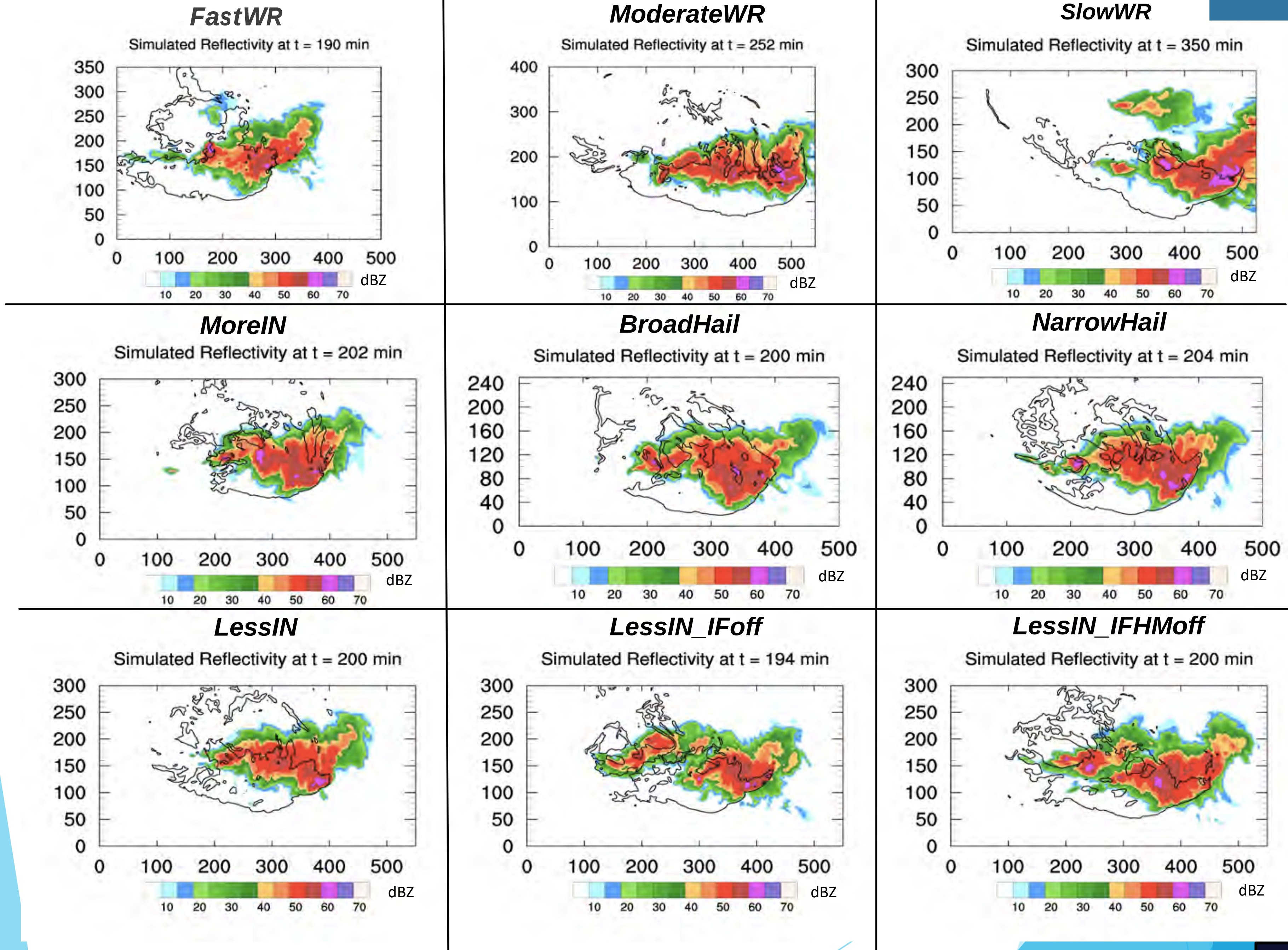
Precipitation Outflows (Cold Pools)



“Control” Case

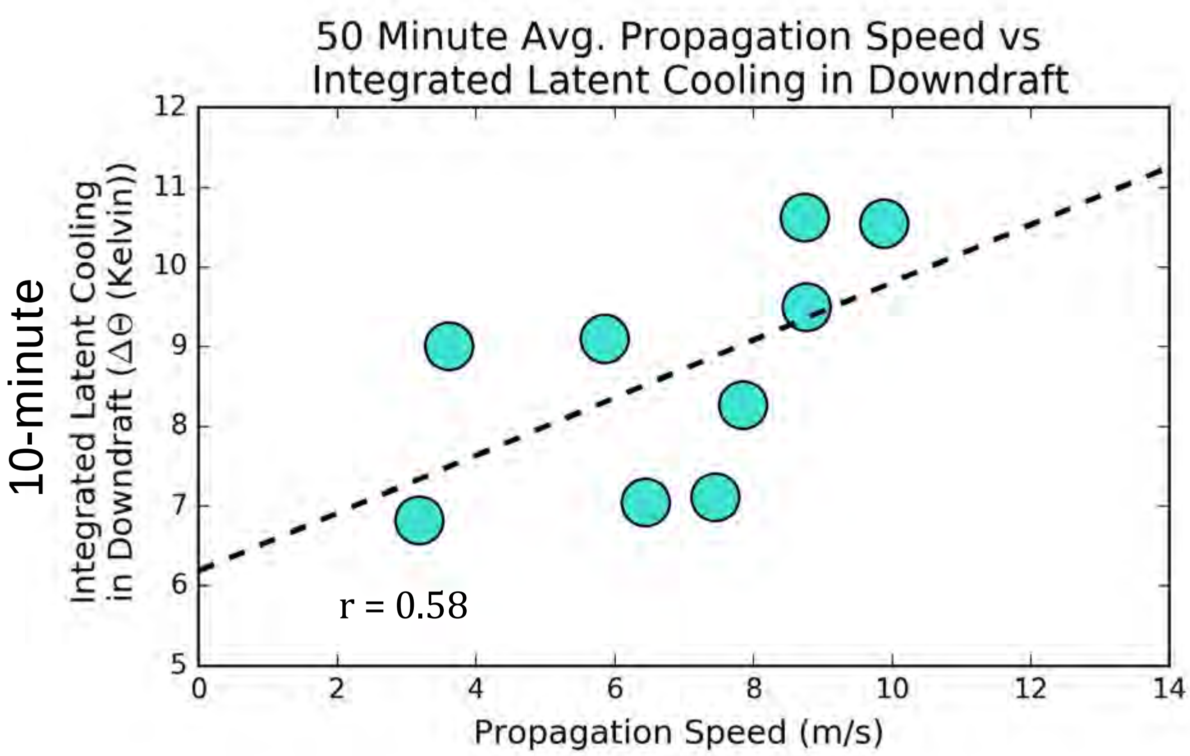


Lasher-Trapp & Mallinson, in prep



Lasher-Trapp & Mallinson, in prep

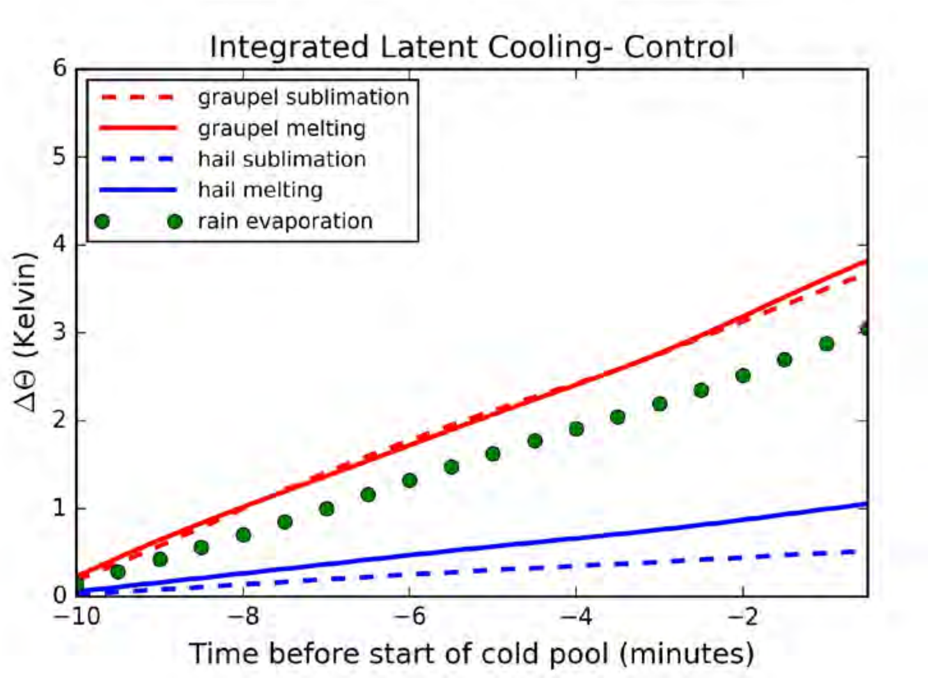
Latent Cooling in (initial) Downdraft vs. Propagation Speed of Outflow



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

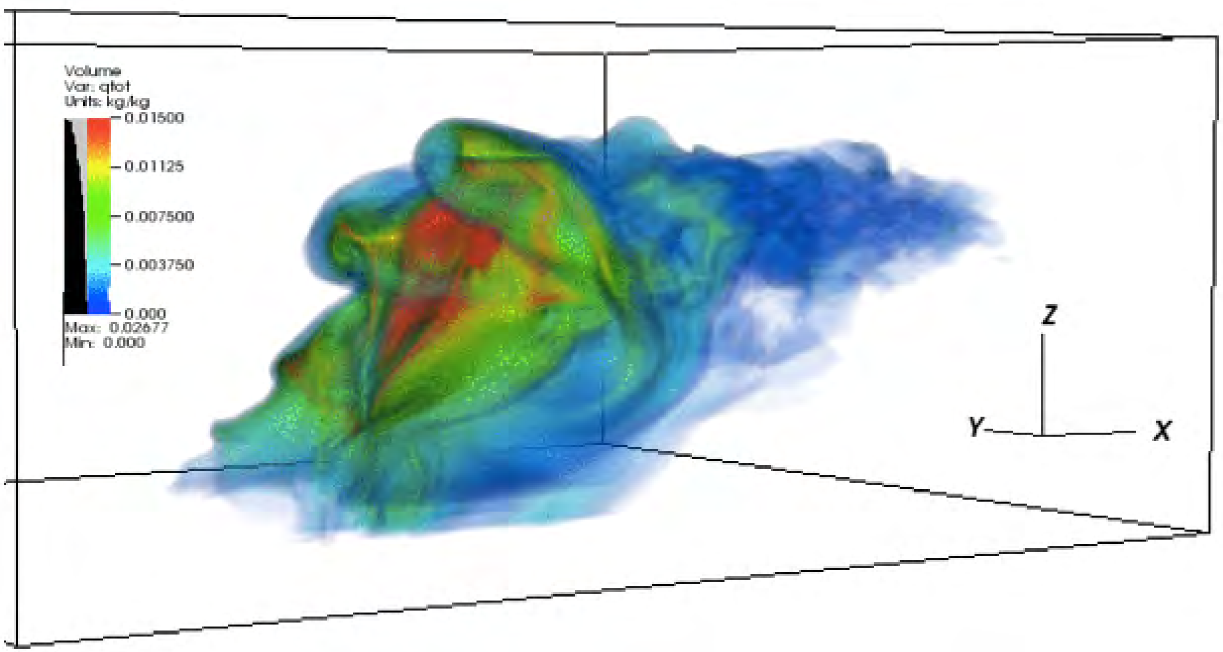
Lasher-Trapp & Mallinson, in prep

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!

Acknowledgements

- Blue Waters Project and Team, NCSA
- George Bryan for use of the CM1 community model
- NSF (AGS-1230292, AGS–1725190) and DOE (DE-SC0014101)



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