Microphysical uncertainties in cloud system-resolving model simulations of mid-latitude deep convection

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Background

- Several decades of research has indicated the sensitivity of moist deep convection to representation of microphysics (e.g., Lord et al. 1984, Fovell and Ogura 1989, Liu et al. 1997, Dudhia 1989, McCumber et al. 1991, Ferrier et al. 1995, Gilmore et al. 2004, Morrison et al. 2009).

- Recent work to be discussed has focused on sensitivity of moist deep convection in convection-permitting models (Dx ~ 1 km) to parameters in bulk microphysics schemes (Morrison et al. 2009, Bryan and Morrison 2011, Morrison and Milbrandt 2011).

Outline

• **Sensitivity of 3D simulations of VORTEX2 squall line to microphysics and horizontal resolution** (Bryan and Morrison 2011, MWR, submitted).

- What are the relative sensitivities to microphysics and horizontal grid spacing?
- How do microphysical sensitivities vary for different horizontal grid spacings?

• **Sensitivity of 3D idealized supercell simulations to microphysics parameters** (Morrison and Milbrandt 2011, MWR, in press)

- How simulations using two different 2-moment schemes compare, and what are the key parameters?

• **Broader outlook and potential applications for MC3E**

VORTEX2 squall line

- Sensitivities tested:

 - Horizontal grid spacing (4 km to 250 m)

 - 1-moment versus 2-moment bulk microphysics

 - Graupel or hail as the rimed ice species

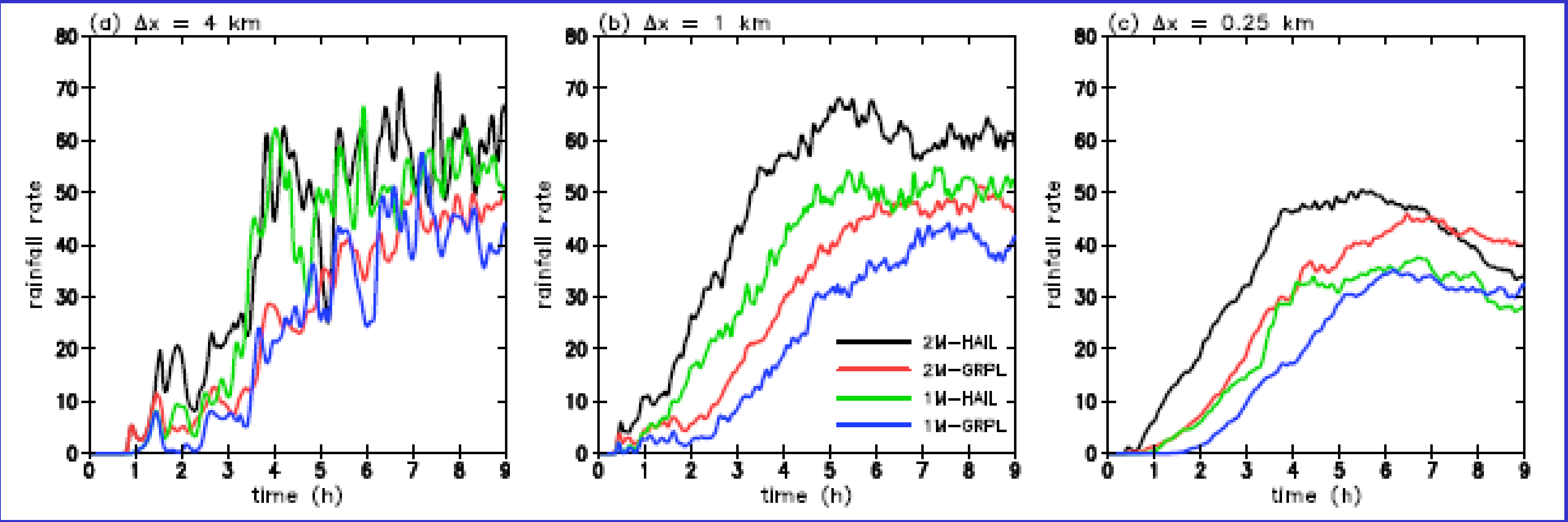
- Short duration simulations focusing on storm development and evolution (9 hrs)

Model setup

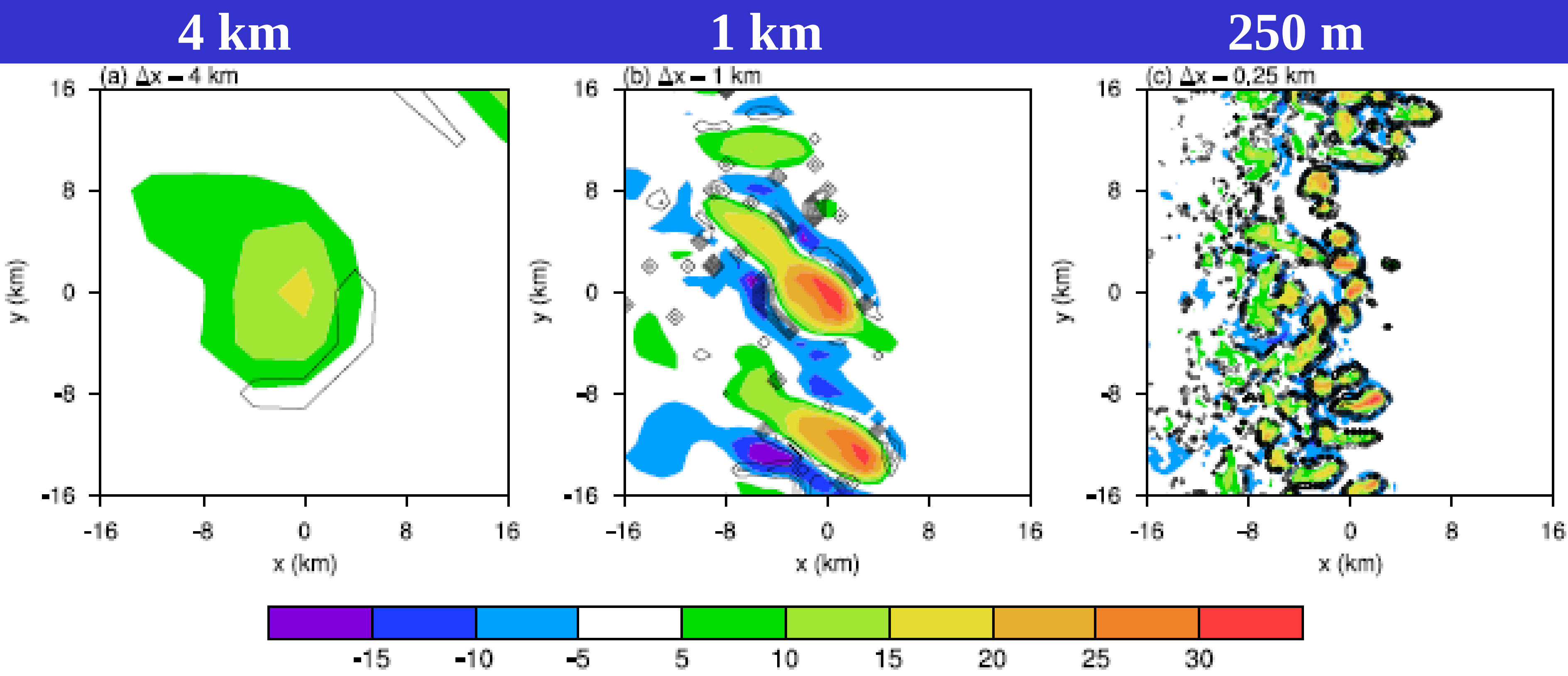
- Model: CM1 (Bryan and Fritsch 2002)
- Domain: 3D, 512 x 144 x 25 km
- Vertical grid spacing: 250 m
- Sounding and shear profile: VORTEX2, 15 May 2009
- Initiation method: Cold pool plus random pert. (+/- 0.2 K)
- Sub-grid turbulence: 1.5 order TKE (Deardorff 1980)
- Microphysics: Morrison et al. (2009), 2-moment w/ with modification to allow 1-moment
- Lateral boundaries (open X, periodic Y)
- Neglected: radiation, Coriolis acceleration, surface heat fluxes

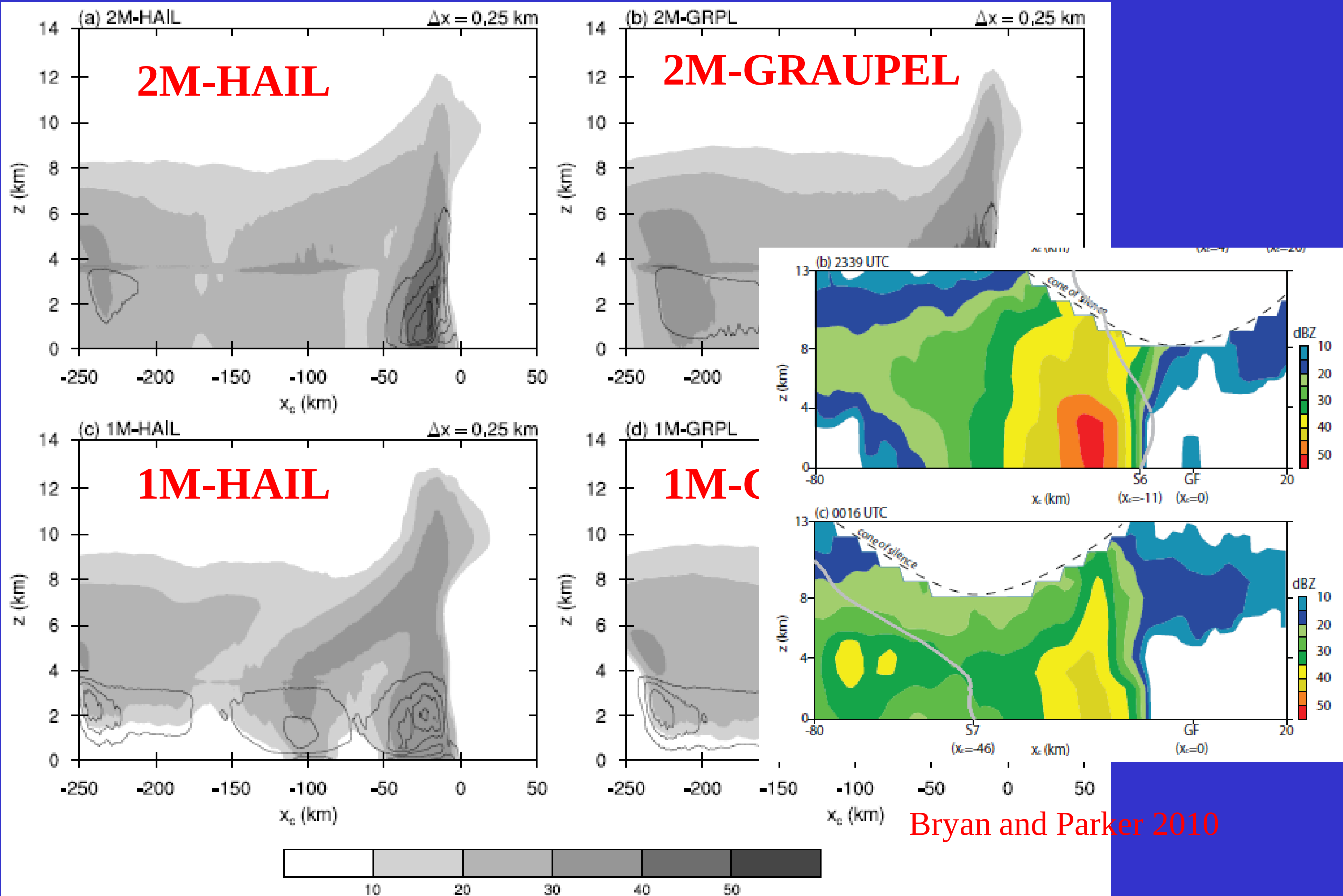
Domain-wide surface precipitation rate

4 km **1 km** **250 m**



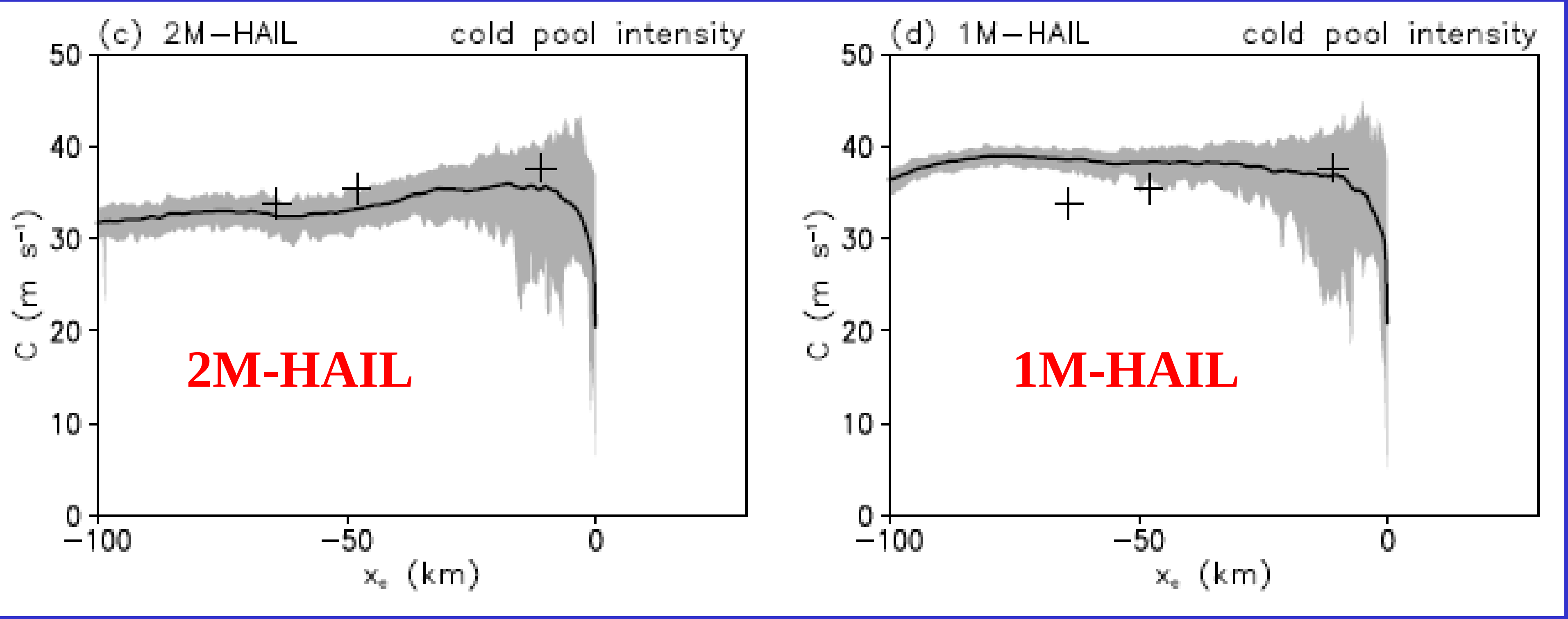
Sensitivity of surface precipitation to Dx is explained mostly by increased net evaporation with smaller Dx.





Bryan and Parker 2010

Impact on cold pool intensity



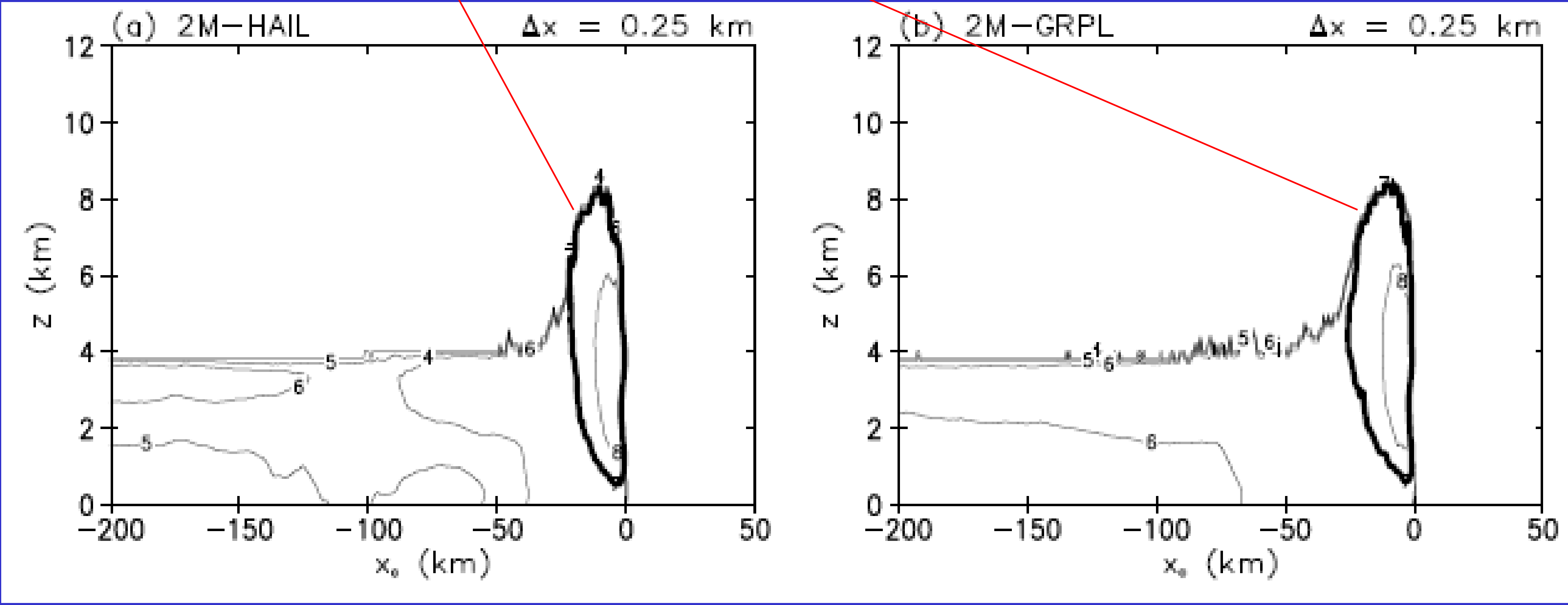
Why is rain evaporation reduced using the 2-moment scheme?

Representation of rain drop size distributions are much different between 1-moment and 2-moment schemes → rain DSD is important!

2-moment scheme qualitatively captures "N_0 jump" between convective and stratiform regions.

Predicted rain N_0 in 2-moment scheme (log values shown)

Specified N_0 in 1-moment scheme = 10^7 m^{-4}



Predicted rain N_0 is broadly consistent with disdrometer observations showing "N_0 jump" (e.g., Tokay and Short 1996)

Idealized supercell

• 1 km WRF simulations using two different 2-moment schemes: 1) Morrison et al. scheme, 2) Milbrandt-Yau

• 2-hr simulations to look at storm development and early evolution

• Sensitivities tested:

- representation of hail/graupel

- representation of rain drop breakup

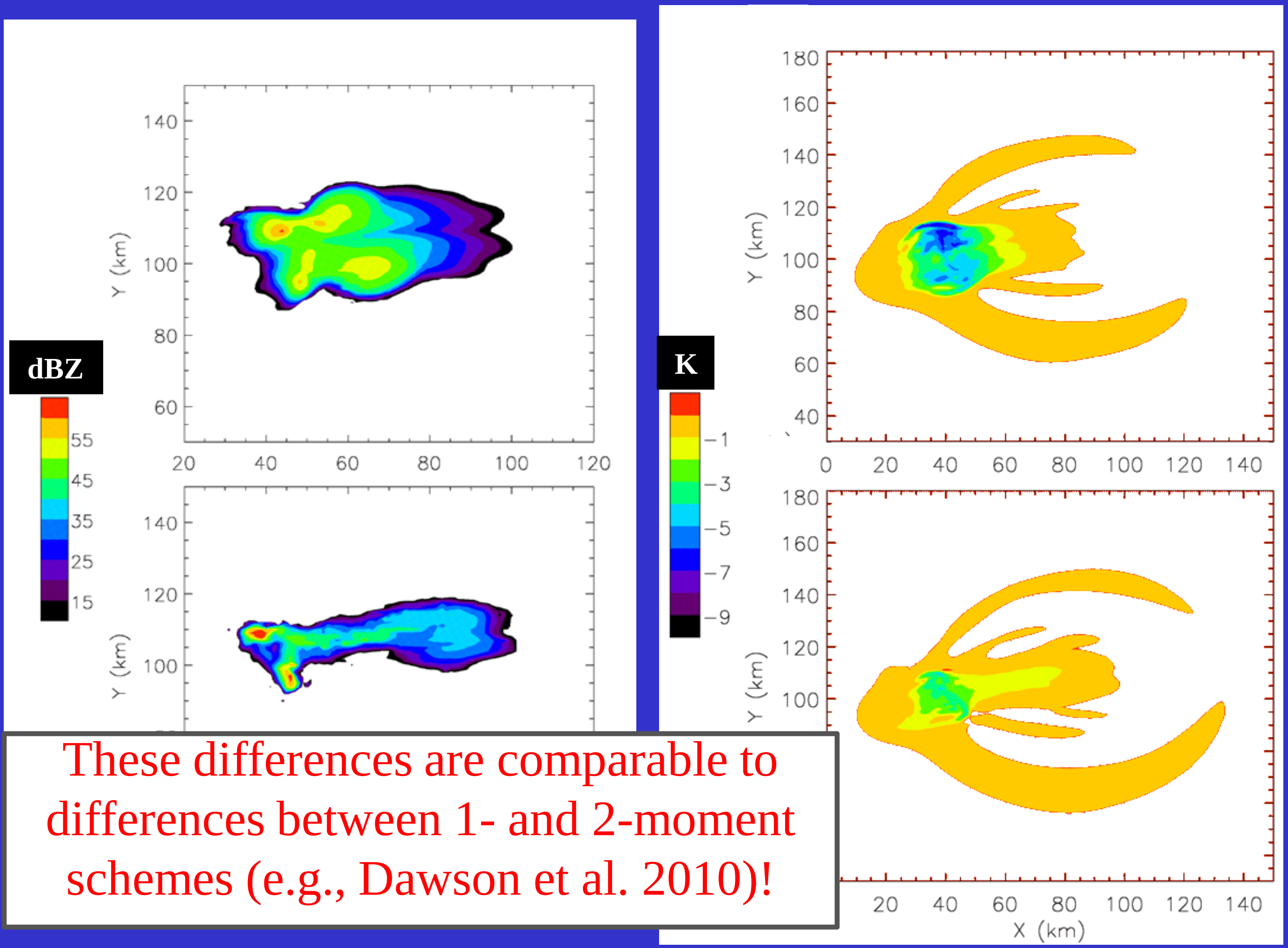
BASELINE (CONTROL) SIMULATIONS

Radar Reflectivity | **θ'**

z = 0.25 km

Morrison:
(hail-only)

Milbrandt-Yau:
(predicts graupel and hail separately, but favors graupel)



These differences are comparable to differences between 1- and 2-moment schemes (e.g., Dawson et al. 2010)!

Morrison and Milbrandt 2010

t = 60 min

BASELINE (CONTROL) SIMULATIONS

Vertical Velocity

$z = 0.8$ km

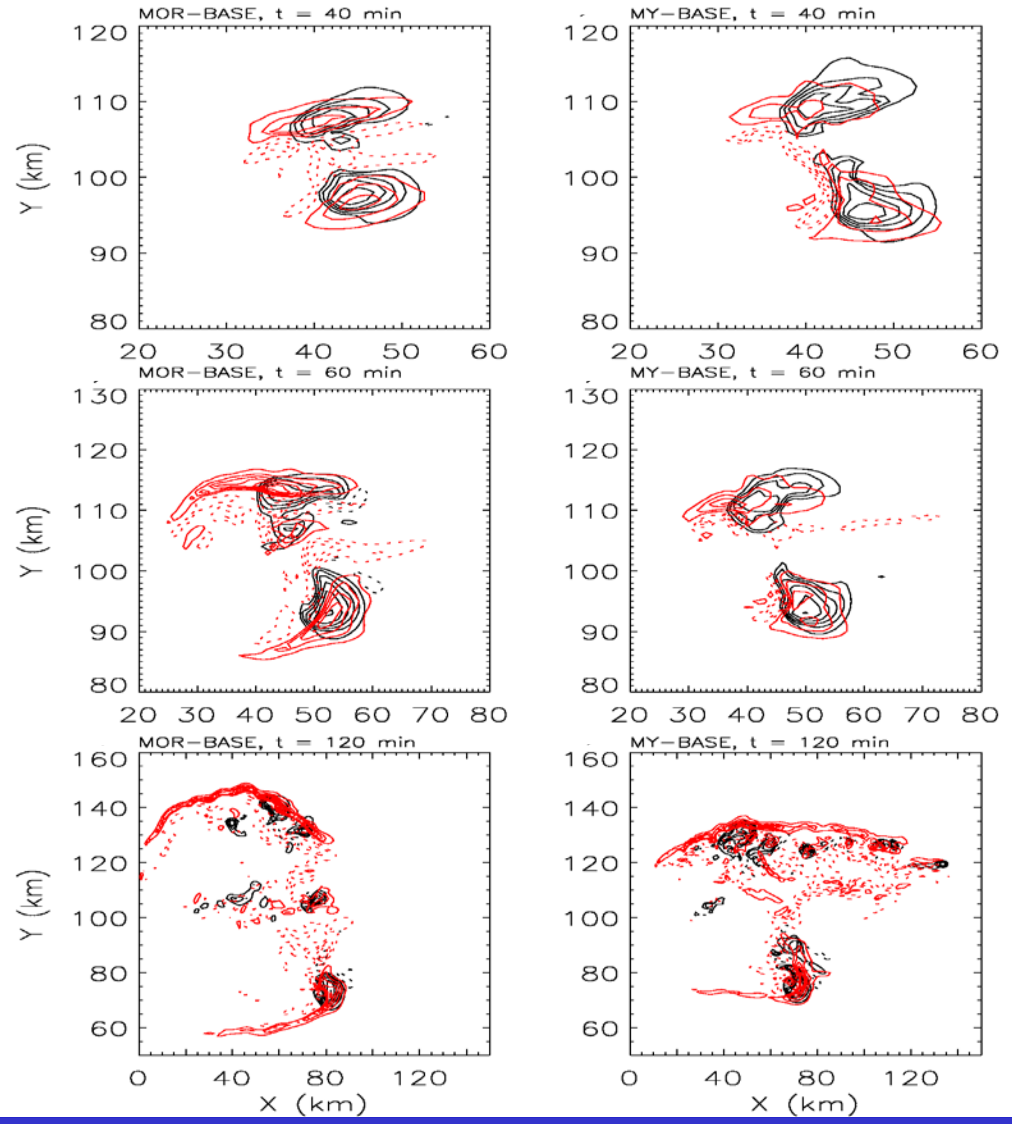
$z = 4.7$ km

Morrison: **Milbrandt-Yau:**

$t = 40$ min

$t = 60$ min

$t = 120$ min



Morrison and Milbrandt 2010

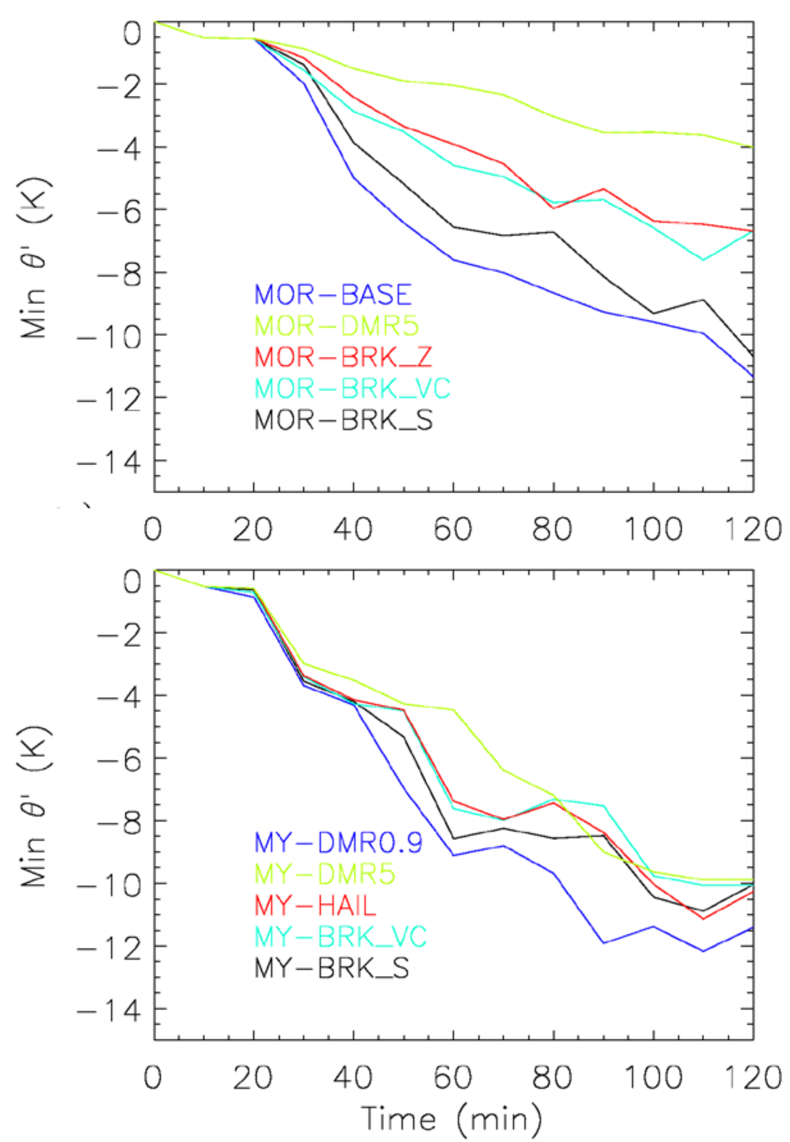
SENSITIVITY EXPERIMENTS: PARAMETERIZATION OF DROP BREAKUP

Cold Pool Strength* (min. θ')

Morrison:

Morrison and Milbrandt (2011, in press MWR)

Milbrandt-Yau:



All runs with **HAIL**-only

Summary

• Horizontal grid spacing (4 km to 250 m), type of scheme (1-moment vs. 2-moment) and treatment of rimed ice (hail vs. graupel) are all important.

• Microphysical sensitivities are similar to different grid spacings → implication for testing schemes at lower resolution…?

• Similar 2-moment schemes or small changes in parameters in a given 2-moment scheme can produce very different results → broadly speaking, these differences can be as large as differences between 1-moment and 2-moment schemes

• Simulations also sensitive to many other microphysical parameters settings that were not discussed here…

Outlook

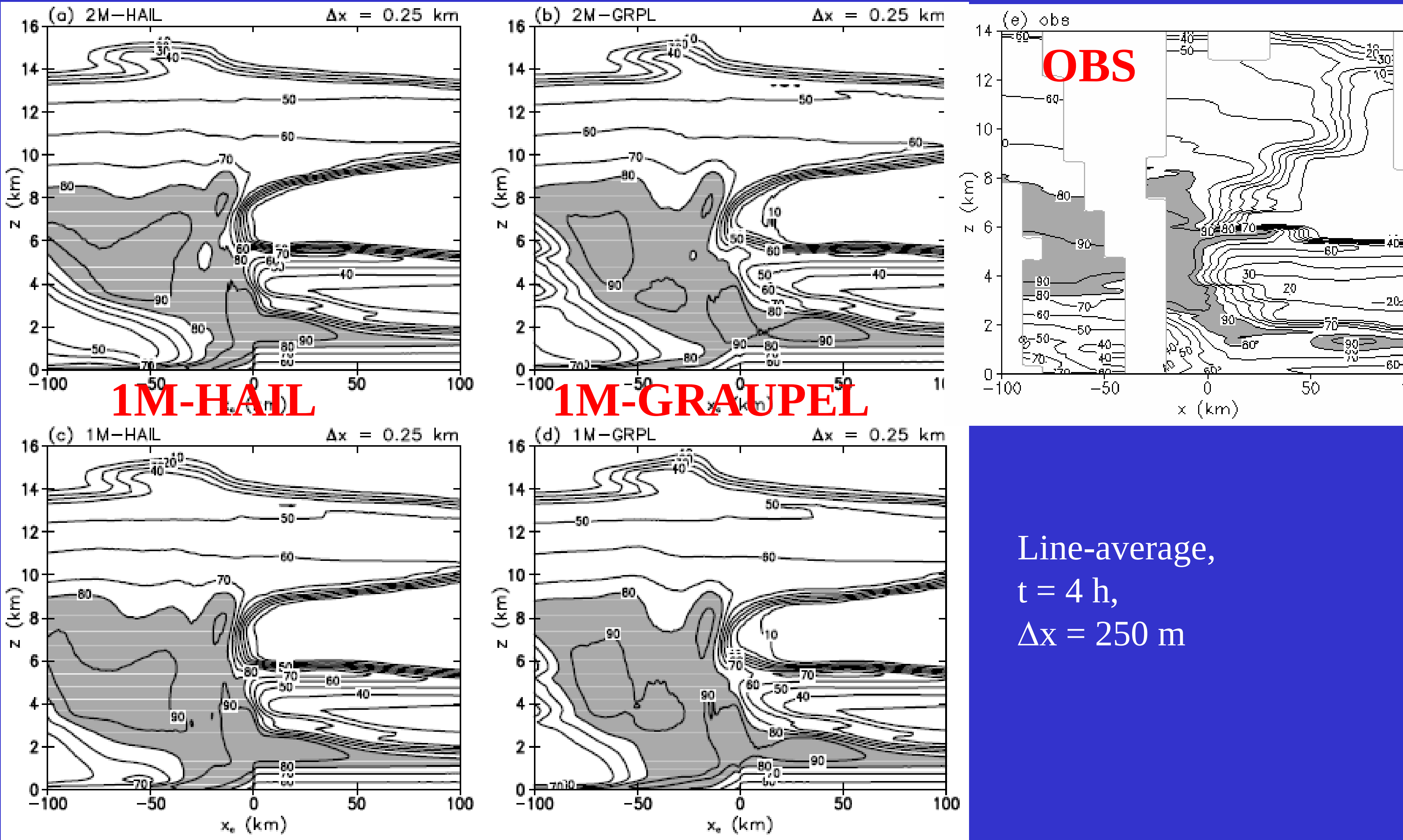
- **Importance of rain drop size distribution (incl. breakup) on storm evolution and cold pool → Can we use measurements from MC3E to help test and constrain relevant parameters (surface disdrometer, but also DSD's above surface from profilers/aircraft…)?**

- **Timescales of interest → The simulations described here were short duration focusing on storm evolution in a quasi-constant environment. How do model these sensitivities vary over longer timescales (> ~ 1 day) when feedback with the environment begins to play a critical role and cloud-radiative interaction is a key focus?**

- **~ 1.5 month duration MC3E provides a great opportunity to look at this using longer simulations.**

Impact on RH

2M-HAIL 2M-GRAUPEL



Line-average,
t = 4 h,
Δx = 250 m