Impact of microphysics and horizontal resolution on simulations of deep convection

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CMMAP Physical Processes Breakout

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- “Cloud-resolving” models (Dx ~ 1 km) are often used as benchmarks for studies of moist deep convection and for developing traditional convection parameterizations

- **Significant uncertainties remain in cloud-resolving models, especially for microphysics.**

- There is limited understanding of how microphysics uncertainties couple with other aspects, notably model grid resolution.

Sensitivity of a simulated squall line to parameterization of microphysics and horizontal resolution (Bryan and Morrison, 2012, MWR)

- What are the relative sensitivities to horizontal resolution and microphysics?

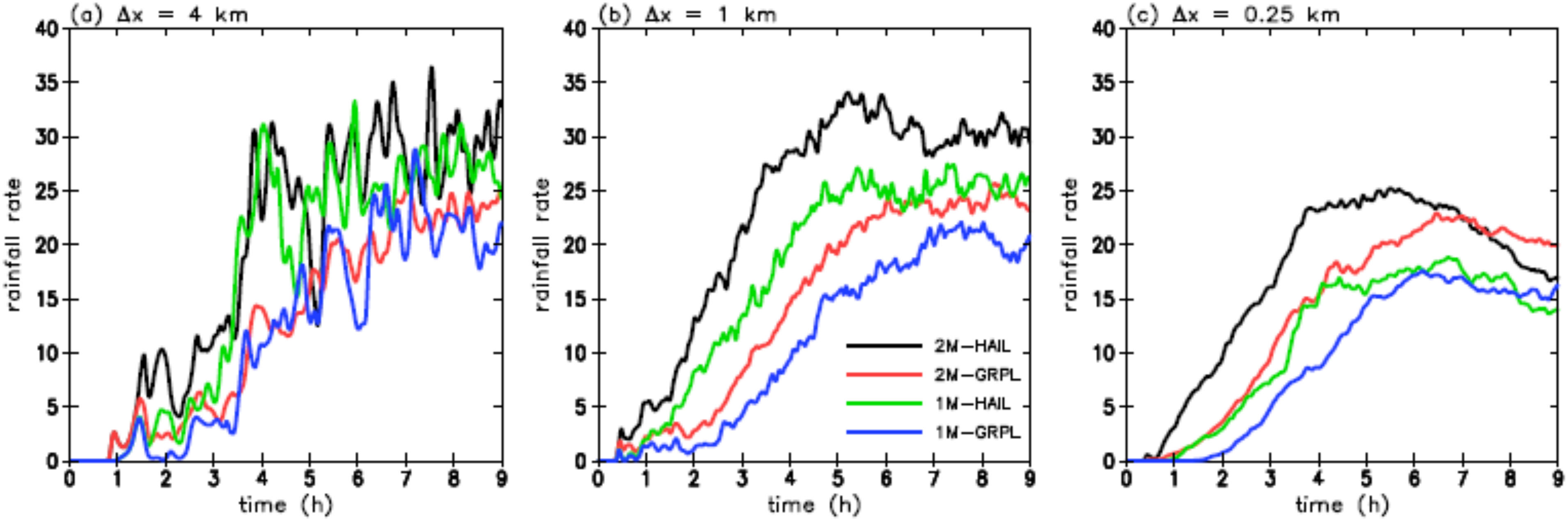
- How do microphysical sensitivities vary with horizontal resolution?

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 sensitivity tests
- Lateral boundaries (open X, periodic Y)
- Neglected: radiation, Coriolis acceleration, surface heat fluxes

Domain-total surface precipitation rate

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

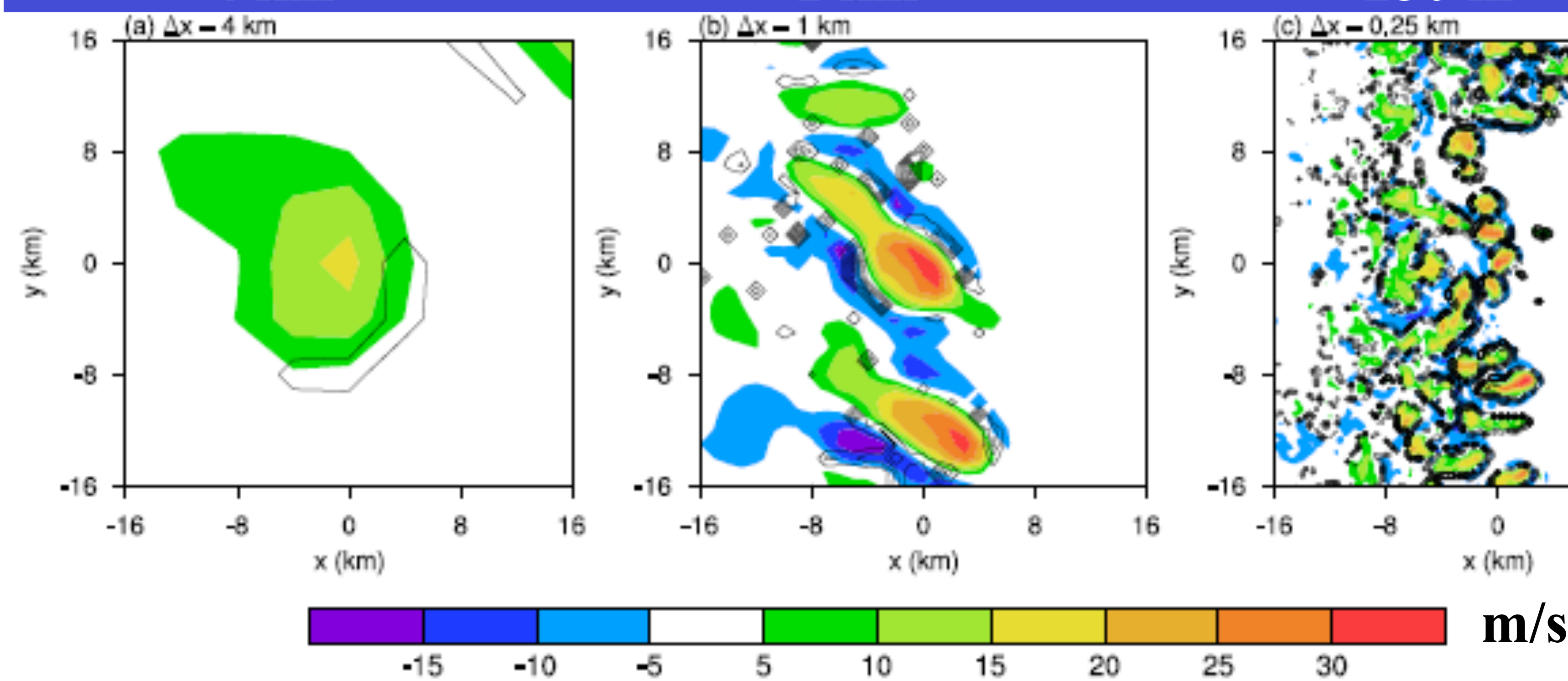


Units: 10^6 kg/s

Sensitivity of surface precipitation to Dx is explained by:

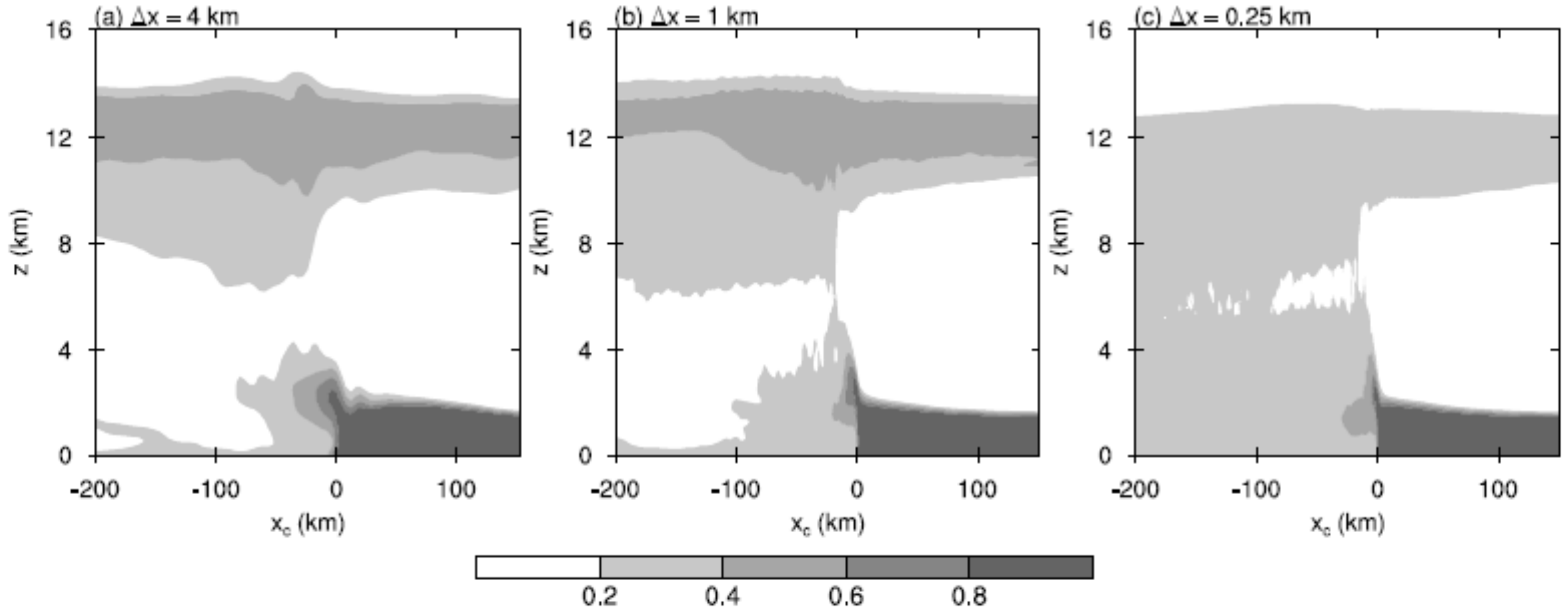
1) Somewhat larger net condensation (~ 15%) for 1 km versus 4 km or 250 m, due to larger convective mass flux
2) Cloud evaporation increases from to 4 km to 1 km to 250 m.

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

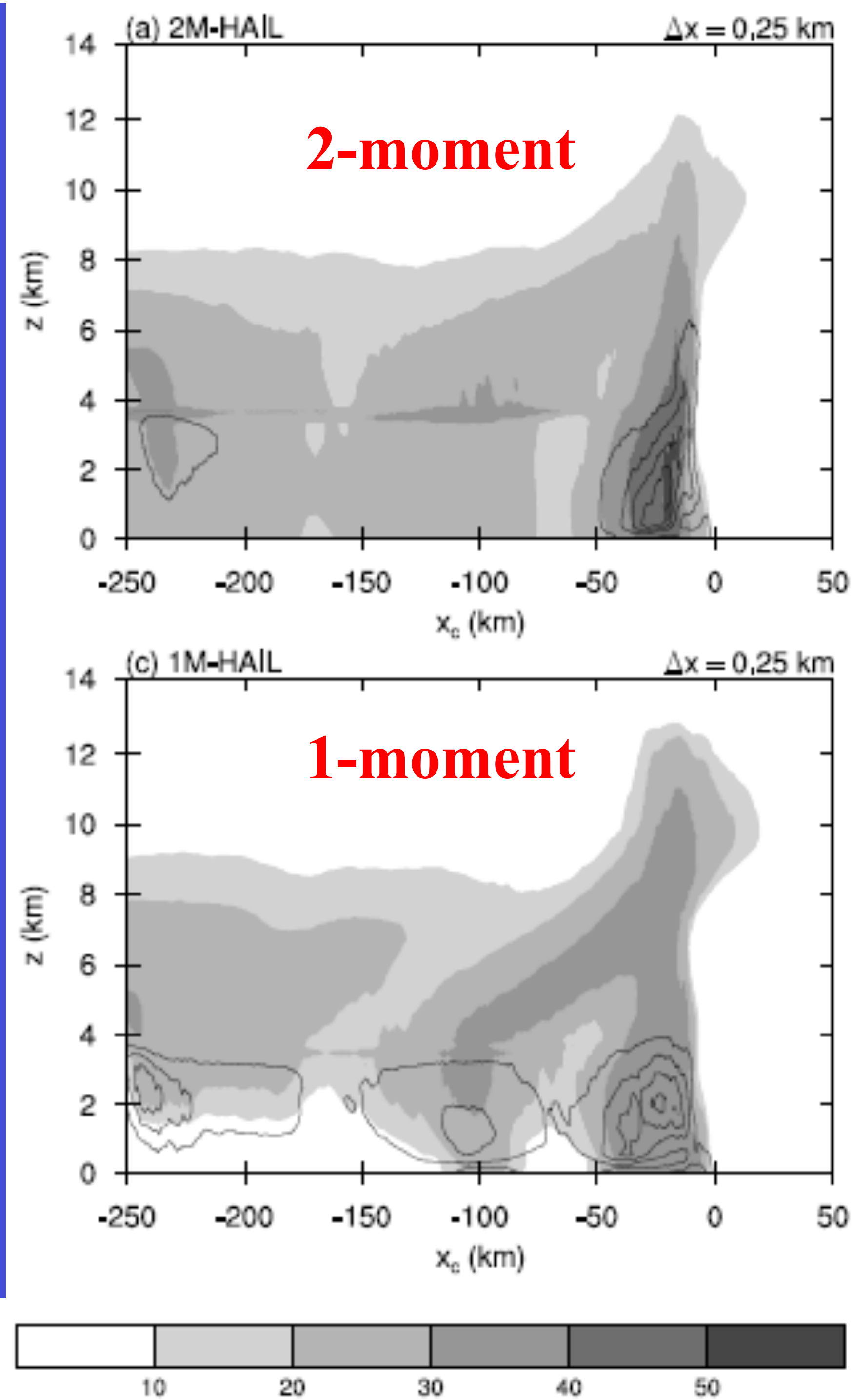


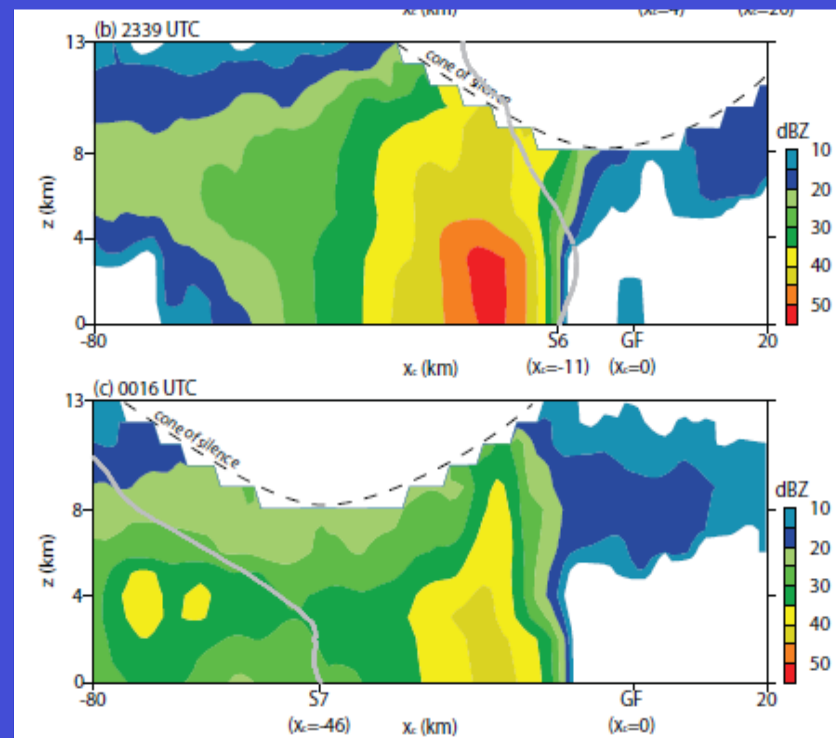
Evidence for increased turbulent mixing at higher resolution – evolution of a passive tracer:

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



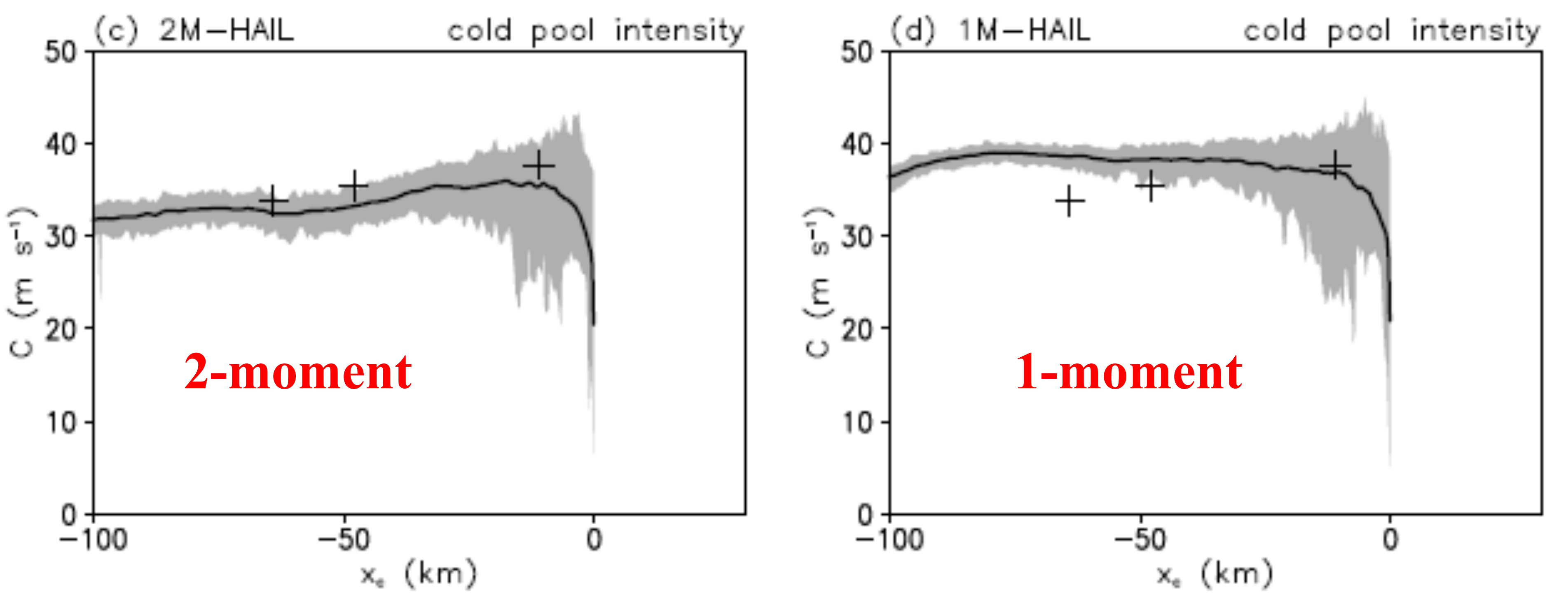
t = 9 h



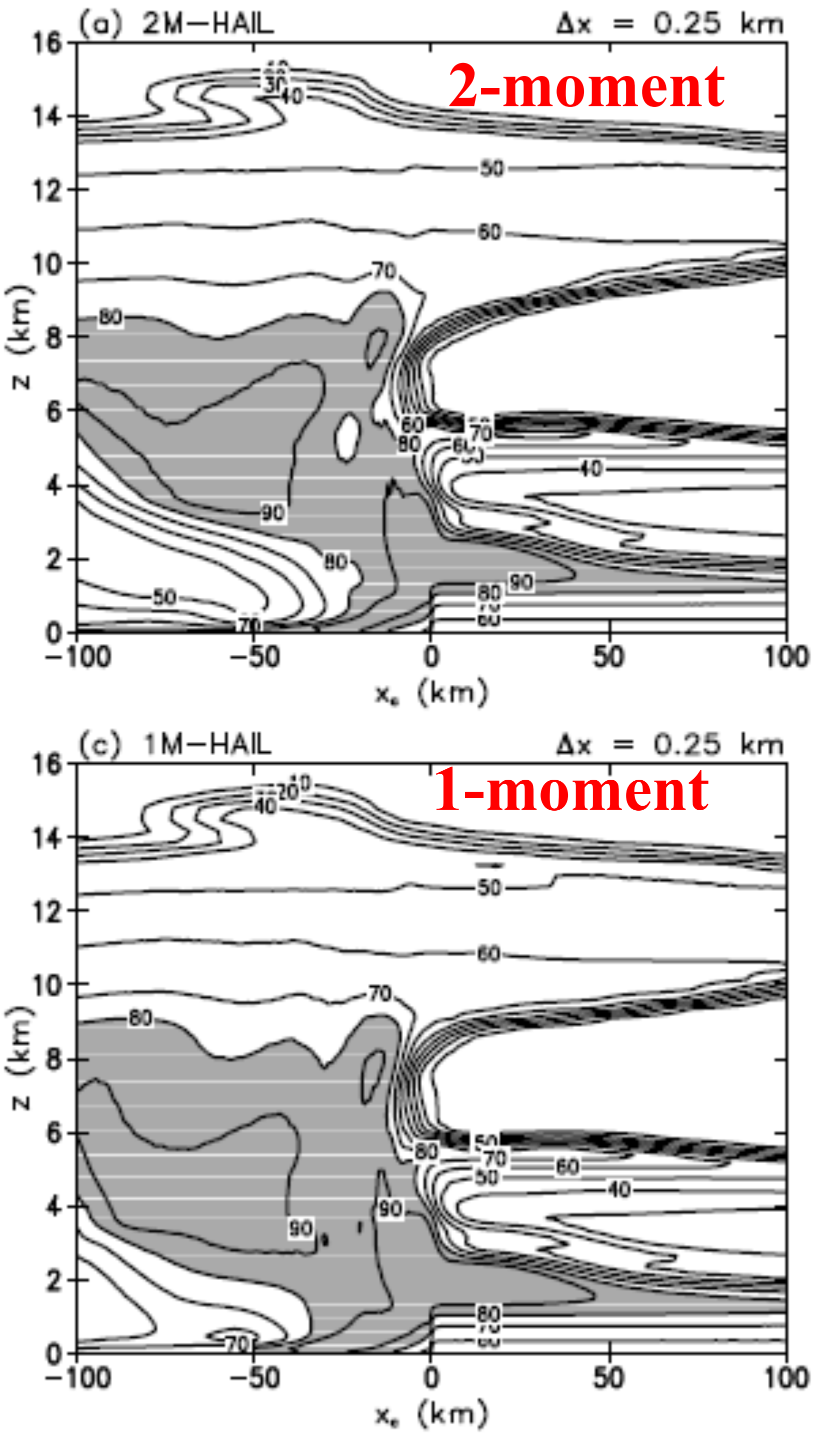


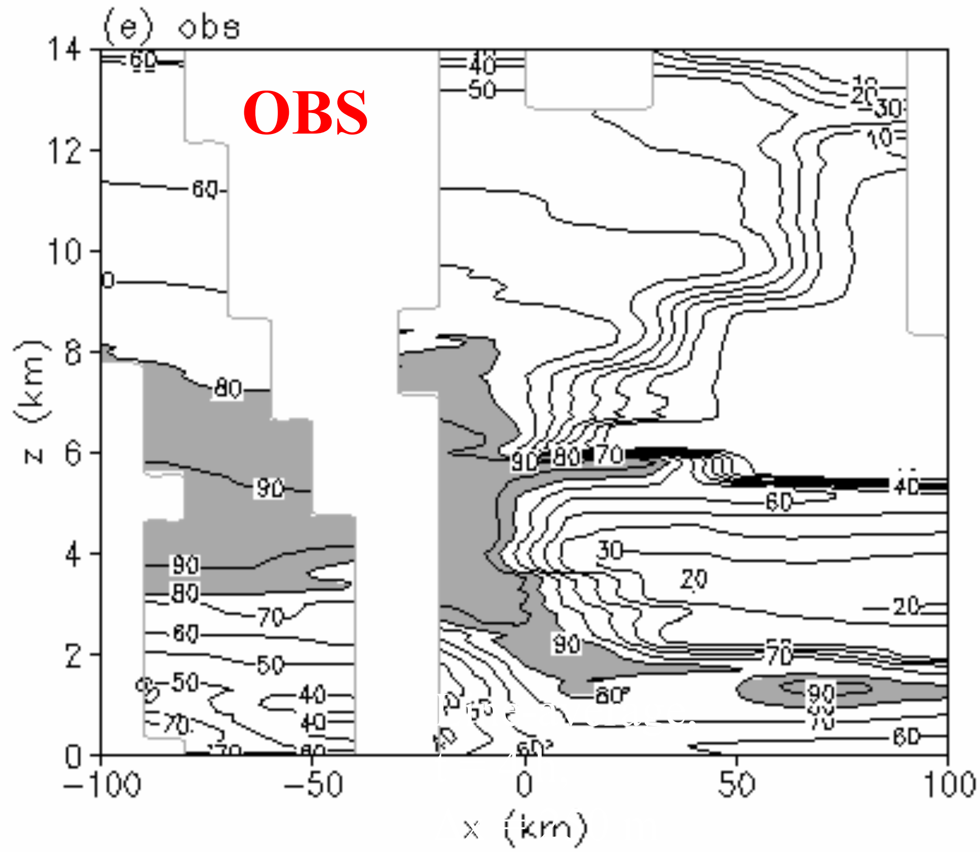
Bryan and Parker 2010

Impact on cold pool intensity



Impact on RH


(a) 2M—HAIL
Δx = 0.25 km
2-moment
(c) 1M—HAIL
Δx = 0.25 km
1-moment
z (km)
x (km)


(e) obs
OBS
z (km)
x (km)

This sensitivity is mostly explained by differences in treatment of the rain drop size distributions →

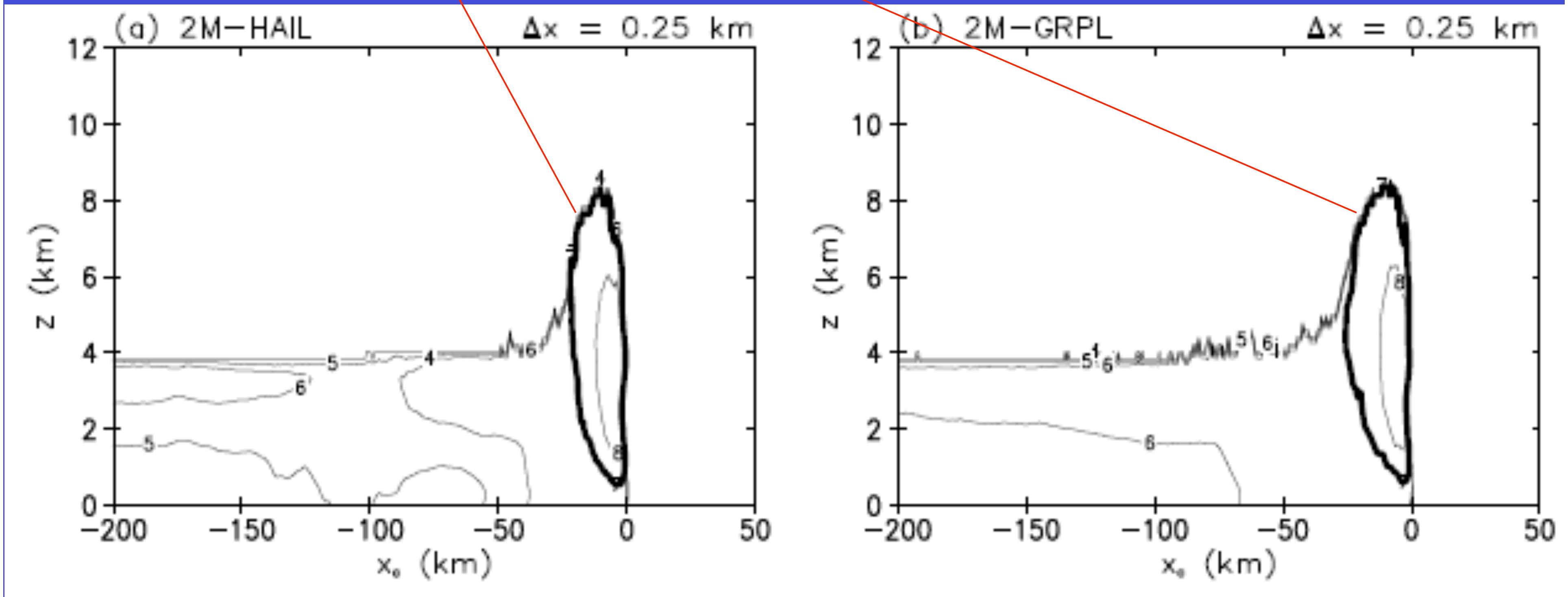
- 2-moment produces larger mean drop size in trailing stratiform rain and lower toward the surface

- Observations (e.g., radar, disdrometer) are *critical* for constraining and testing microphysics like rain DSDs

(Morrison, Tessendorf, Ikeda, Thompson, MWR 2012)

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

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

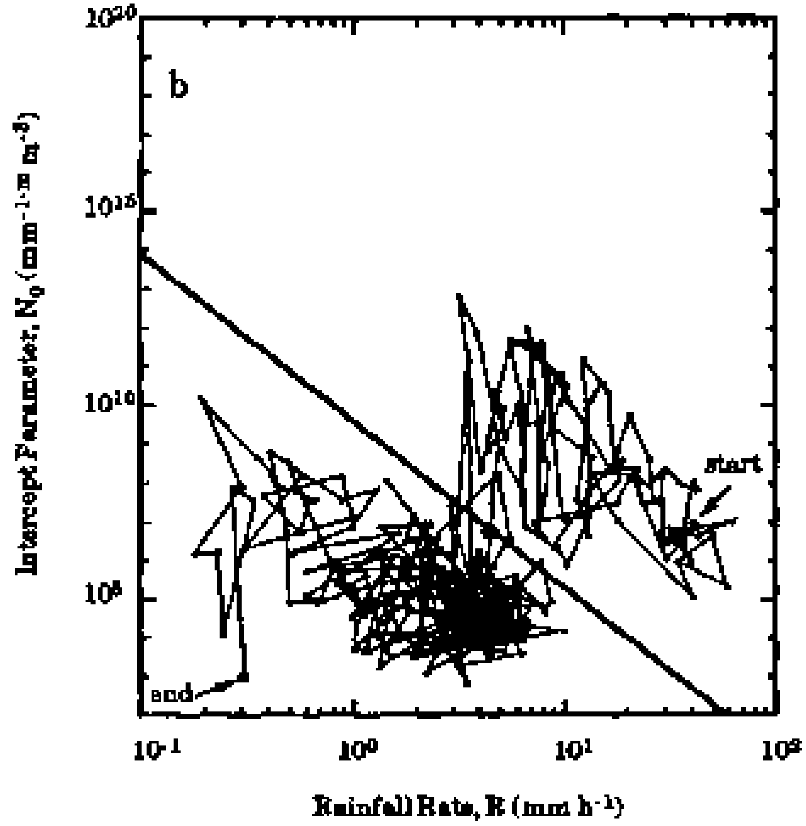


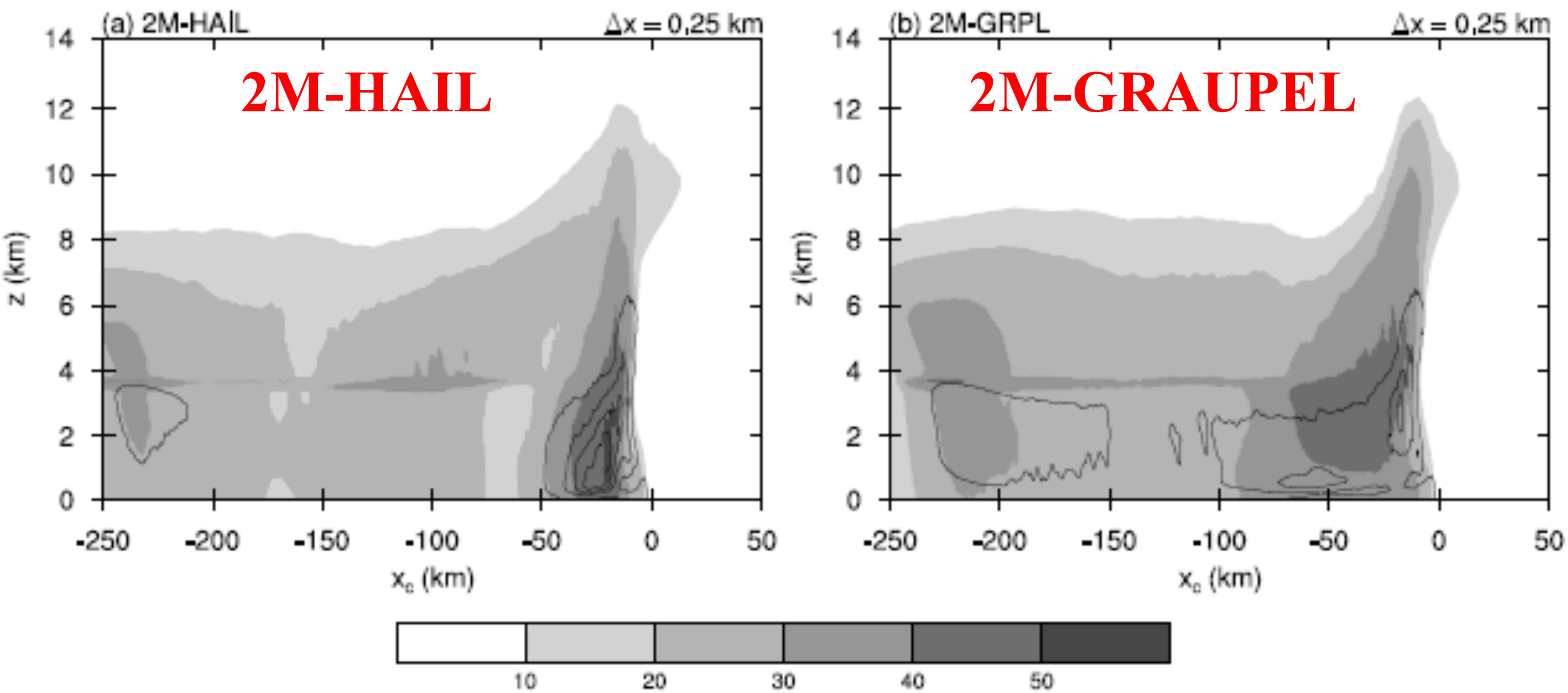
Spatial structure of N_0 in 2-moment scheme is consistent with observations (e.g., Waldvogel 1974; Tokay and Short 1996).

"Whenever the situation changed from uniform (widespread rain) to convective (shower or thunderstorm), there was a sudden increase in the parameter N_0….the contrary was true when the situation changed from widespread to convective." – Waldvogel (1974)

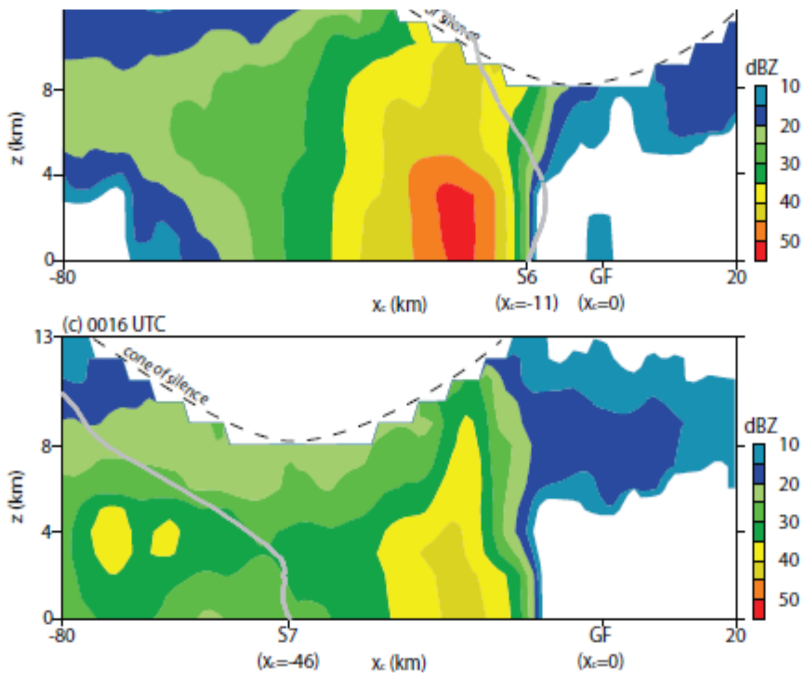
"N_0 jump"

Disdrometer-measured N_0 in a tropical squall line (Tokay and Short 1996)





Bryan and Morrison 2012



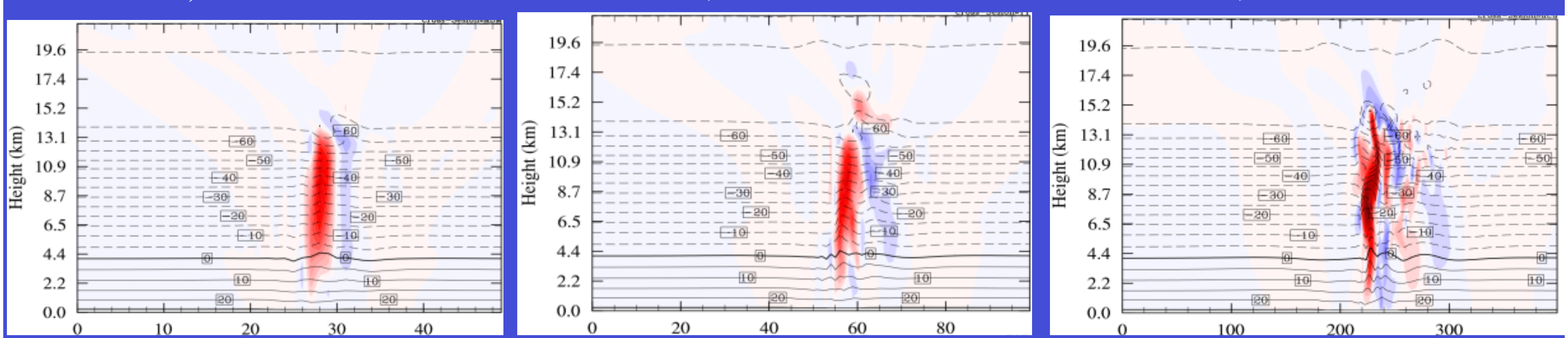
Bryan and Parker 2010

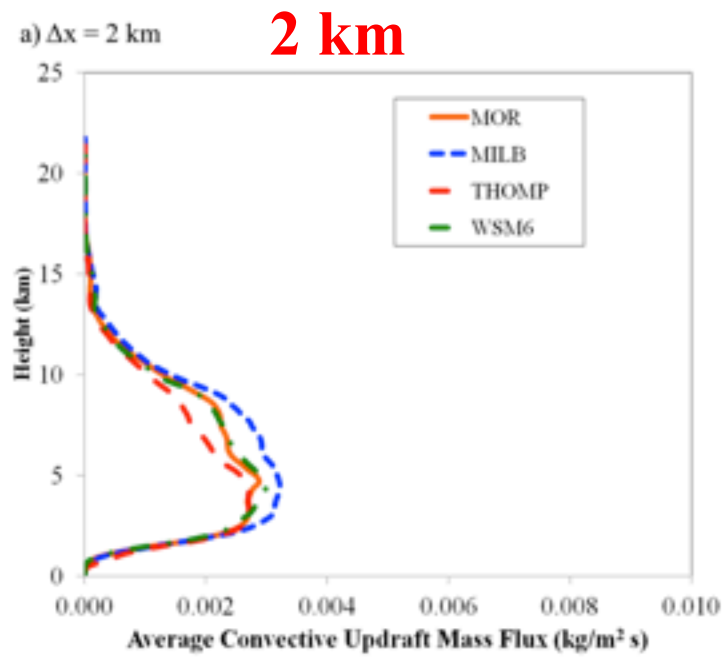
What about the case of unorganized convection in weak shear?

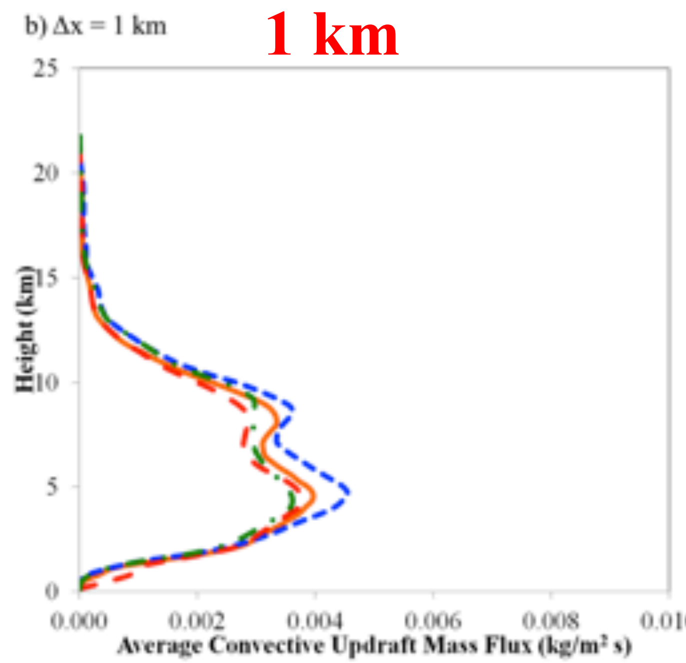
Test 4 different microphysics schemes at 2, 1, 0.25 km grid spacing using WRF

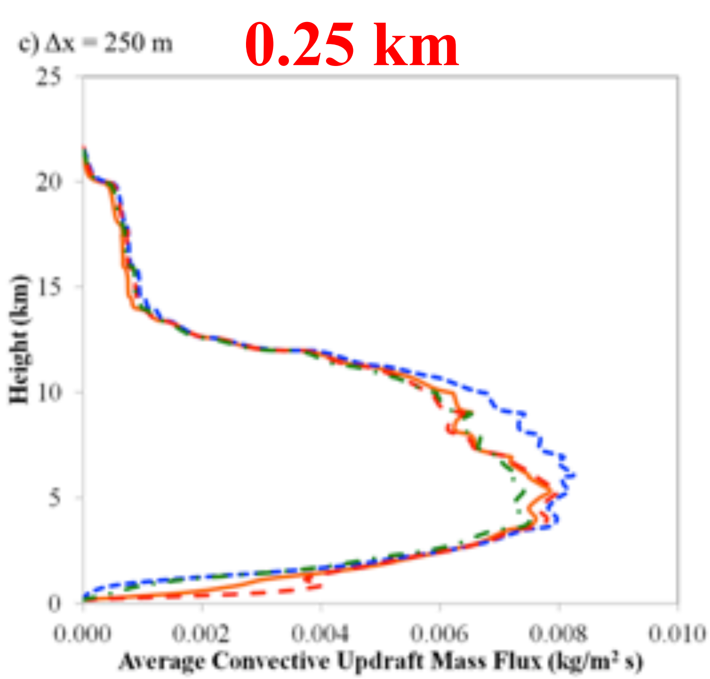
(Morales et al. 2012, in prep.)

a) Δx = 2 km b) Δx = 1 km c) Δx = 250 m









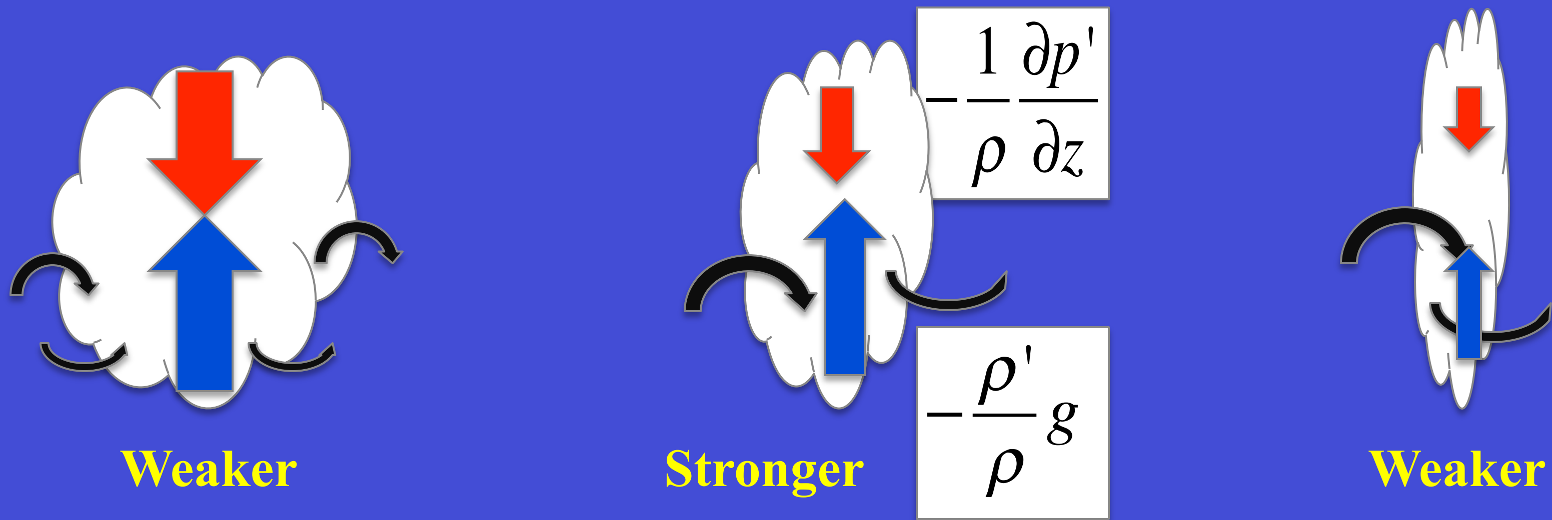
•Decreasing grid spacing →

- Greater convective updraft mass flux
- Larger net condensation
- Greater surface precip (~ factor of 2)

Differences from squall line case…
(different environments, numerical models???)

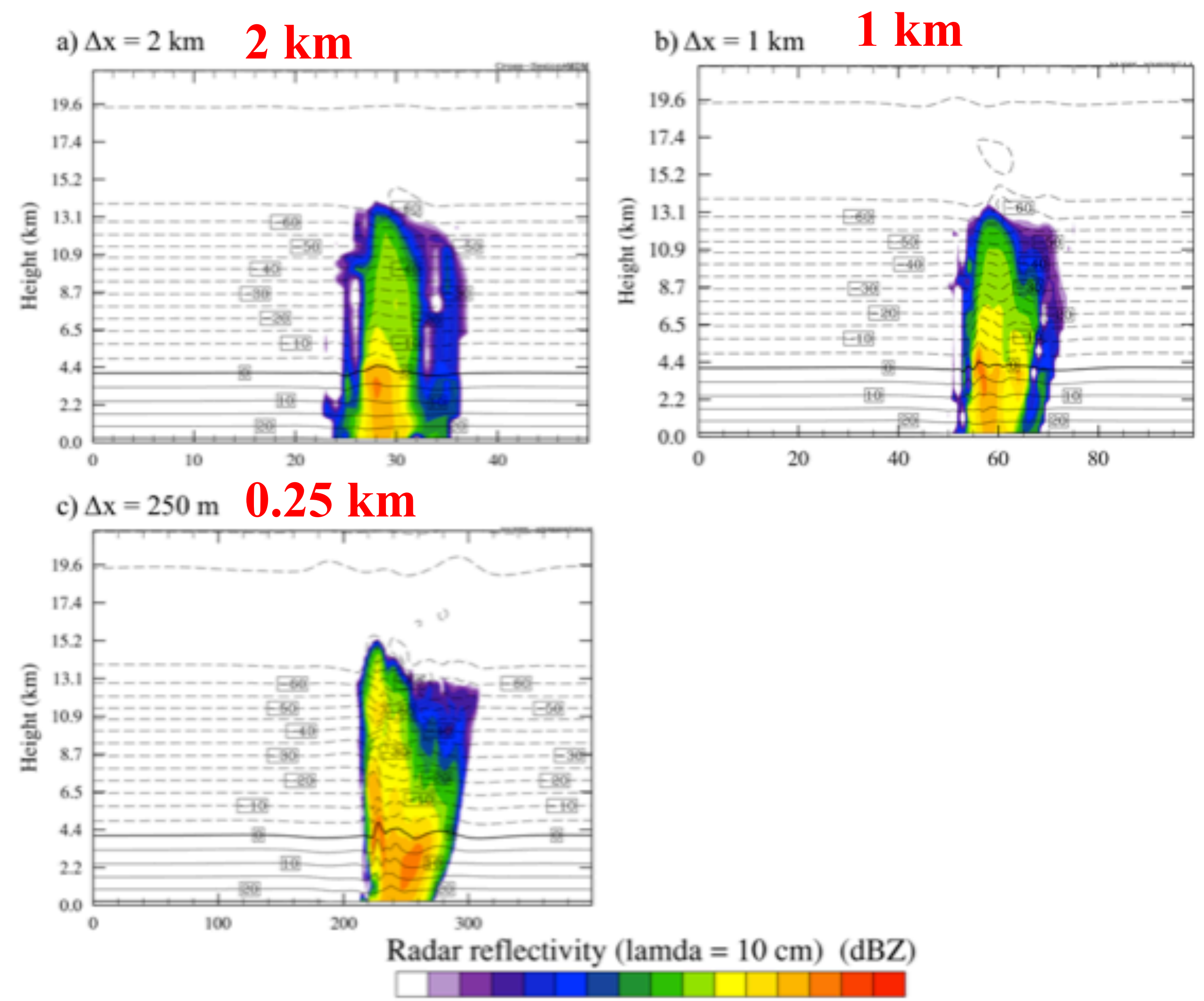
We propose there are two competing effects explaining sensitivity of convective mass flux to horizontal grid spacing:

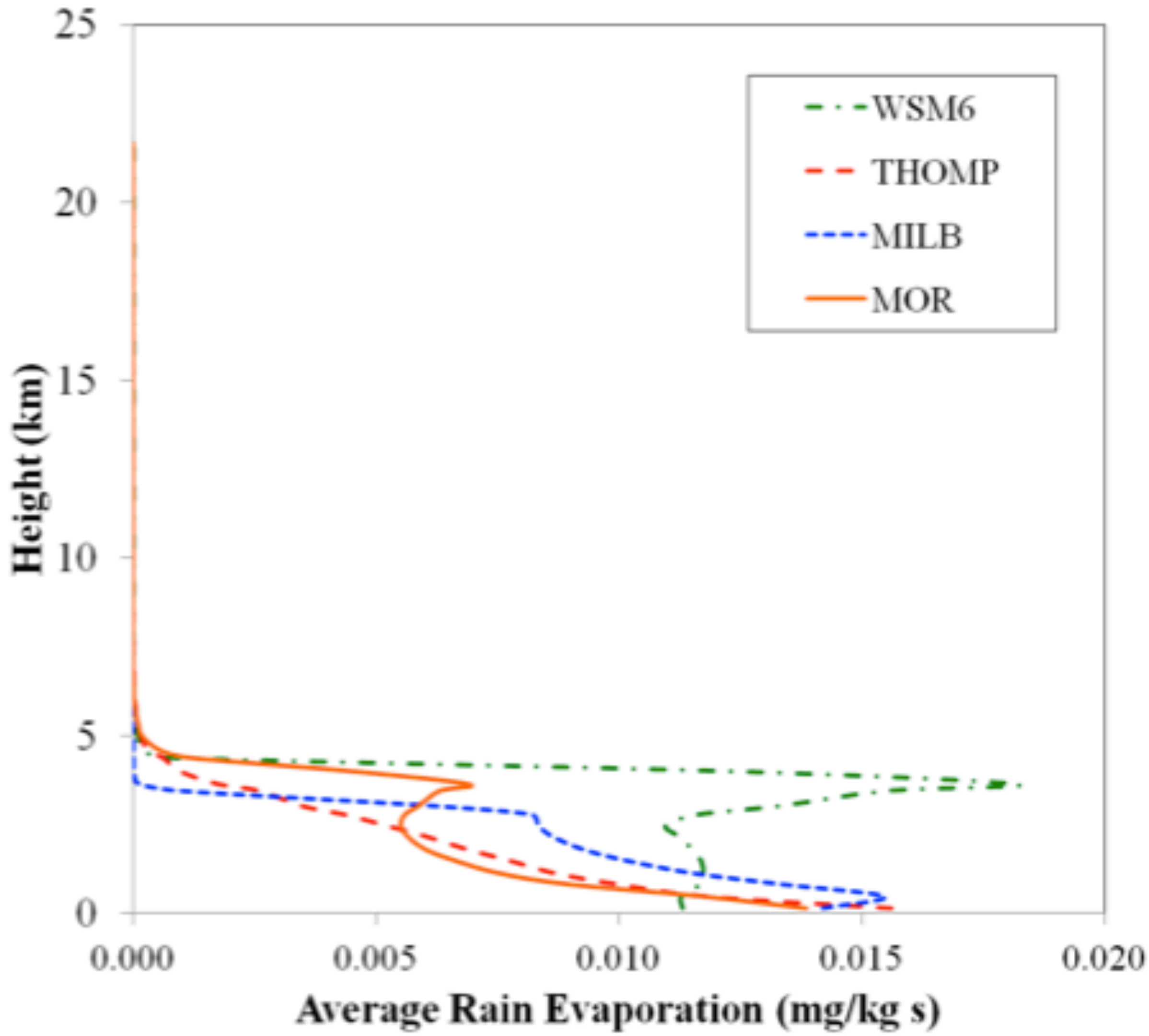
1) Impact on vertical perturbation pressure gradient force
2) Impact on entrainment/mixing



Decreasing horizontal grid spacing →

Vertical shear in the environment and updraft tilting and/or meso-organization could affect this picture…


a) Δx = 2 km
2 km
b) Δx = 1 km
1 km
c) Δx = 250 m
0.25 km
Height (km)
19.6
17.4
15.2
13.1
10.9
8.7
6.5
4.4
2.2
0.0
0
10
20
30
40
60
80
100
200
300
Radar reflectivity (lamda = 10 cm) (dBZ)



•**Microphysics sensitivities are similar at different grid spacings**

- Much smaller precipitation in one-moment scheme (WSM6) compared to two-moment due to treatment of rain DSDs, greater rain evap, reduced precip eff.

Conclusions

• Large sensitivity of "convection permitting" simulations to horizontal grid spacings between ~ 0.25 to 4 km - can we develop appropriate sub-grid schemes w/o going to *O*(100 m) spacing?

• Sensitivity of convective drafts to grid spacing affects microphysics (e.g., via cloud evaporation and precipitation efficiency). Currently looking at impact on cloud radiative forcing…

• Sensitivity to grid spacing differs qualitatively in strongly sheared versus weakly-sheared environments, but more systematic testing is needed (i.e., model vs. environment).

• Microphysics sensitivities are also critical but generally similar at different horizontal grid spacings.

Thank you!
Questions?