Separating physical impacts from natural variability using piggybacking (master-slave) technique

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Rain Enhancement Science

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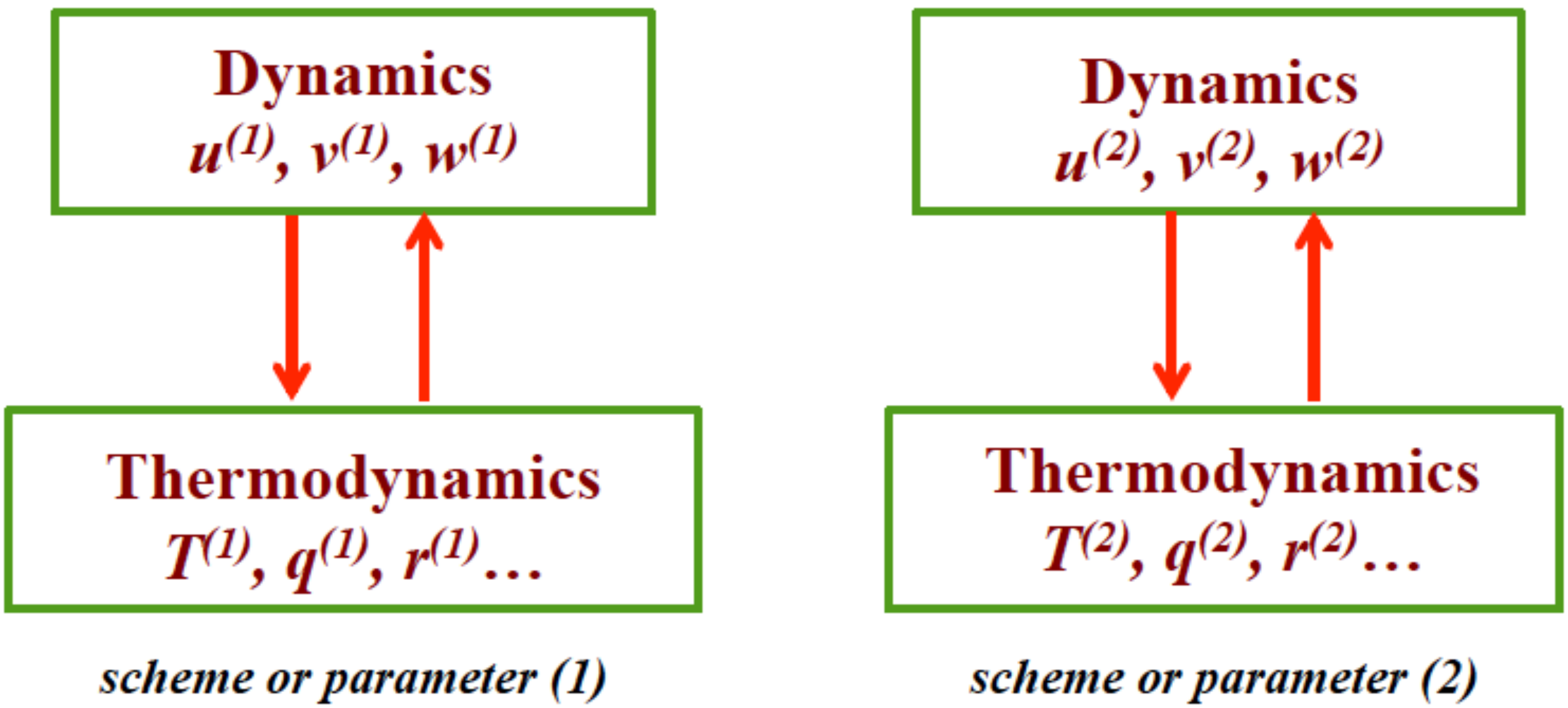
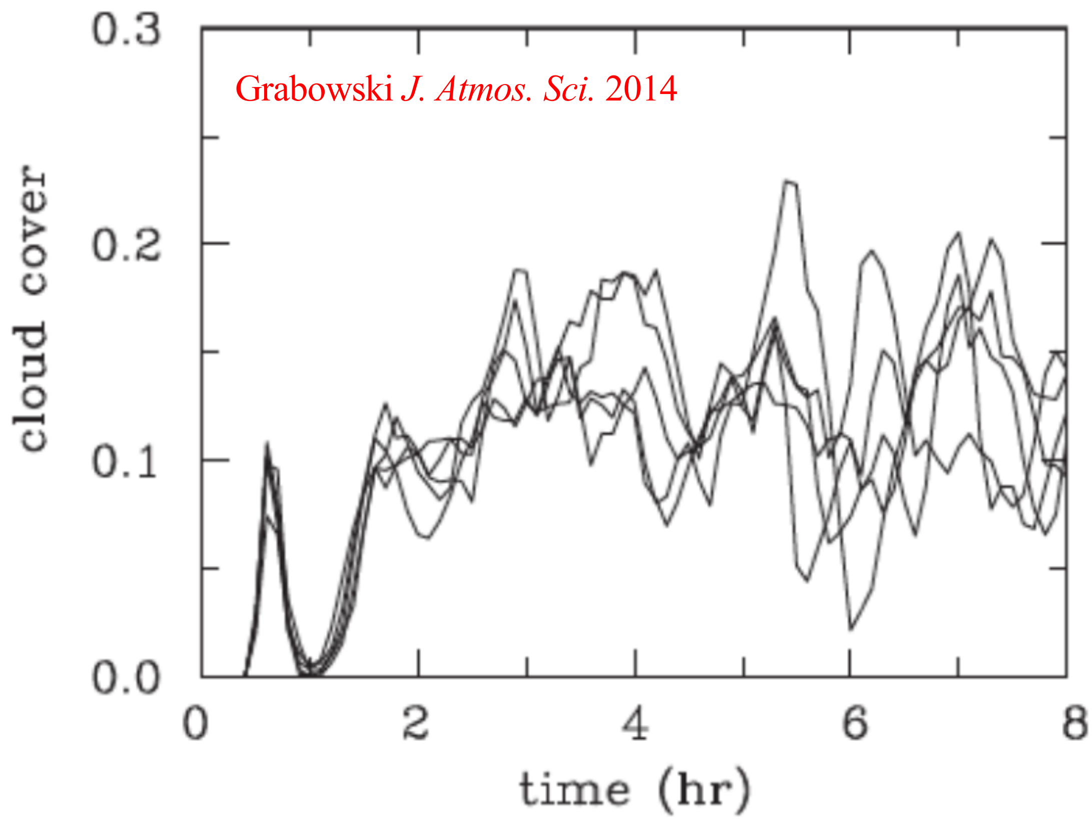
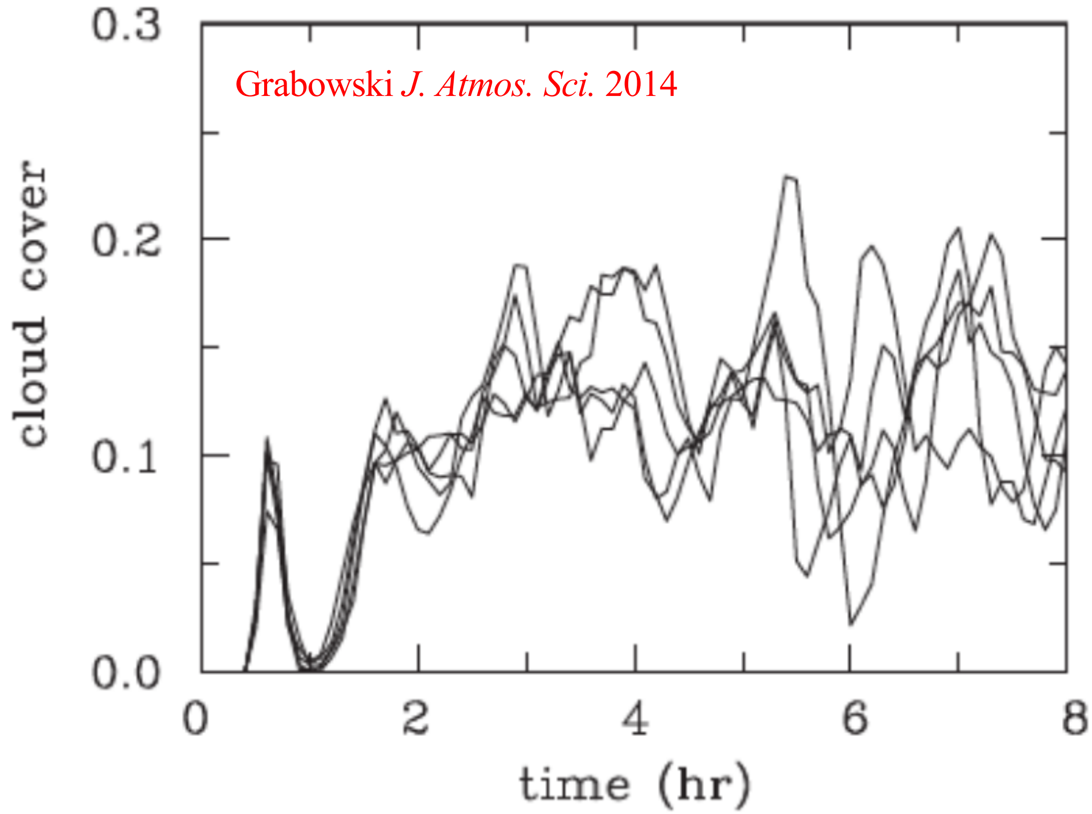
Because of the nonlinear fluid dynamics, separating physical impacts from the effects of different flow realizations in simulations of moist convection is nontrivial ("the butterfly effect"; Ed Lorenz).

Traditional approach: parallel simulations with different microphysical schemes or scheme parameters





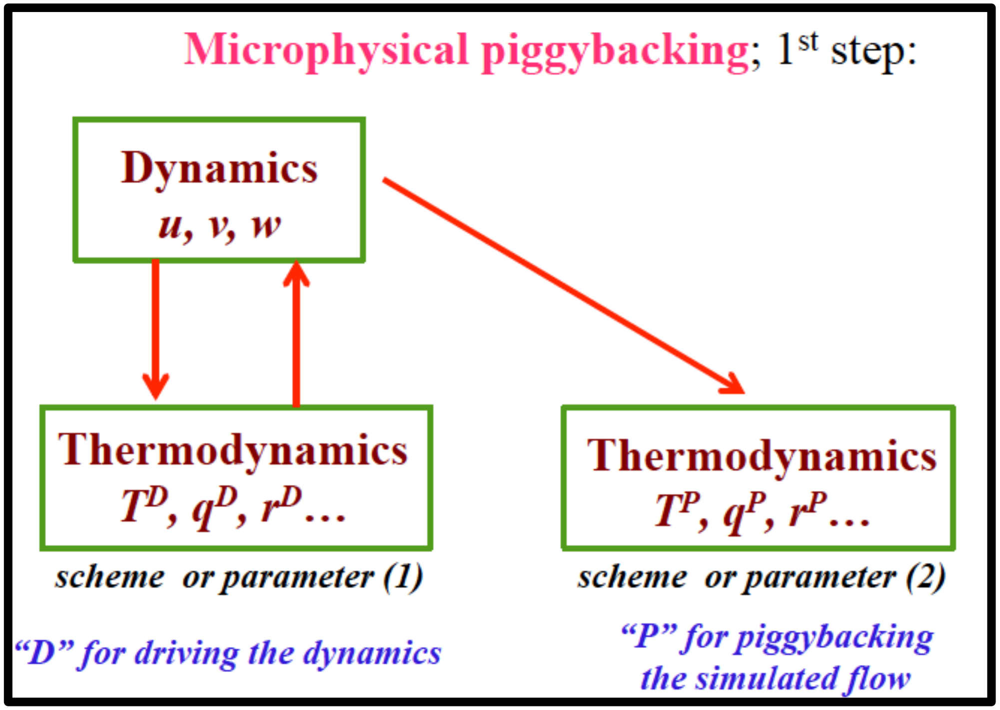
Evolution of cloud cover in 5 LES simulations of shallow cumulus cloud field, the BOMEX case. The only difference is in random small temperature and moisture perturbations at t=0.

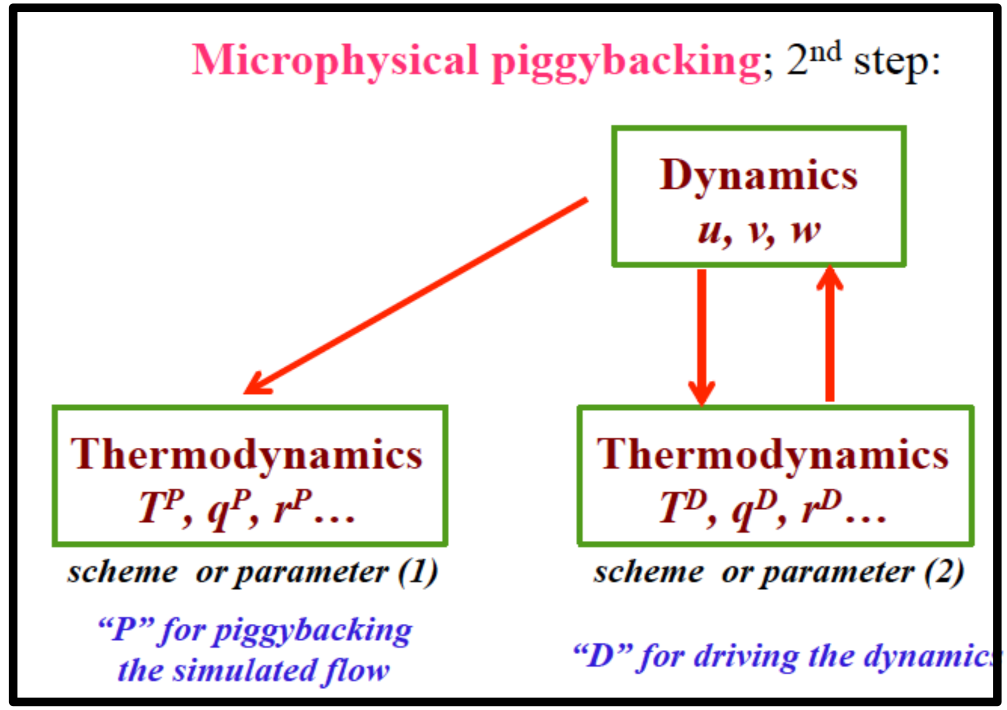


Evolution of cloud cover in 5 LES simulations of shallow cumulus cloud field, the BOMEX case. The only difference is in random small temperature and moisture perturbations at t=0.

One possibility: run ensemble of simulations to separate effects of modified physics from effects of different flow realizations…

More appealing methodology: *the piggybacking (or master-slave)*





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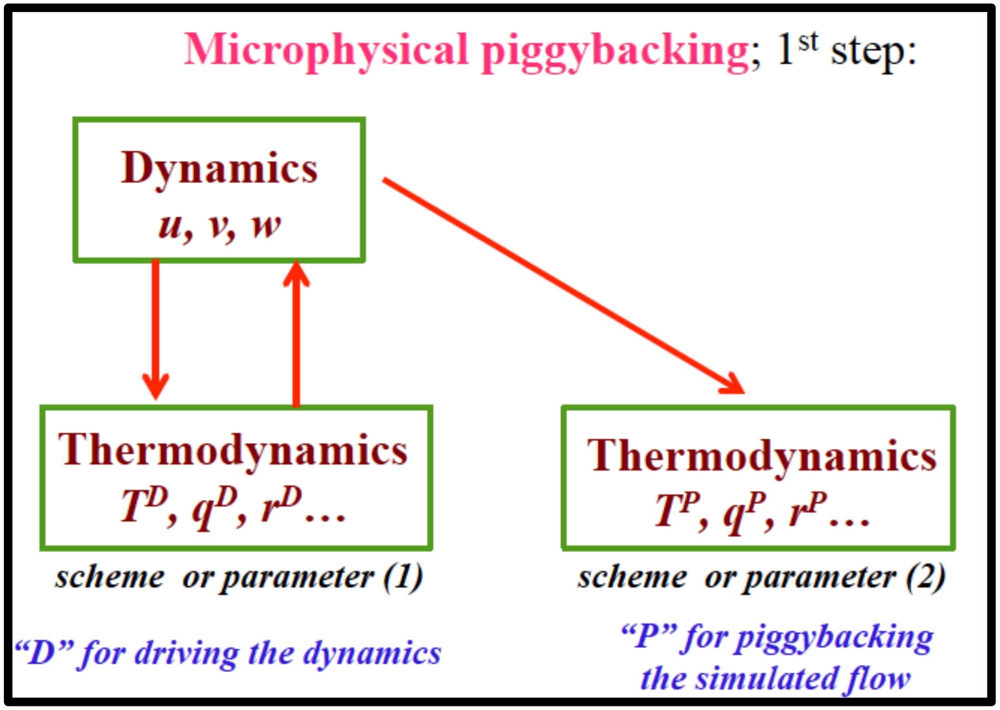

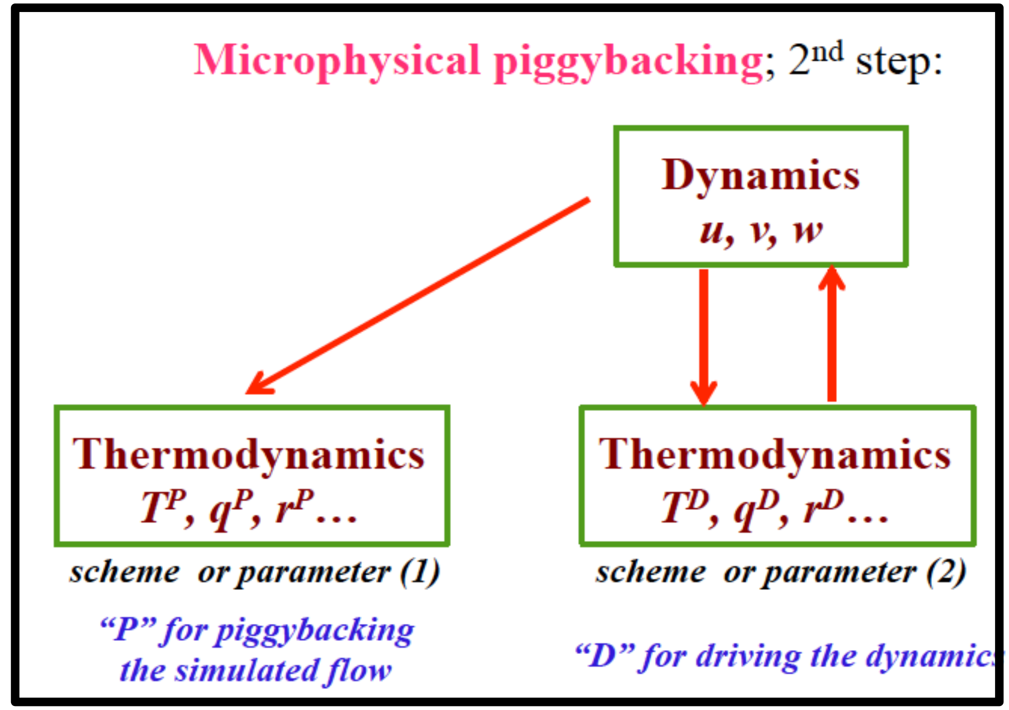

th, qv, qc, qr,…

th7, qv7, qc7, qr7,…

buo = f(th, qv, qc, qr…)

buo7 = f(th7, qv7, qc7, qr7…)

Apply "buo" in the first step, and "buo7" in the second

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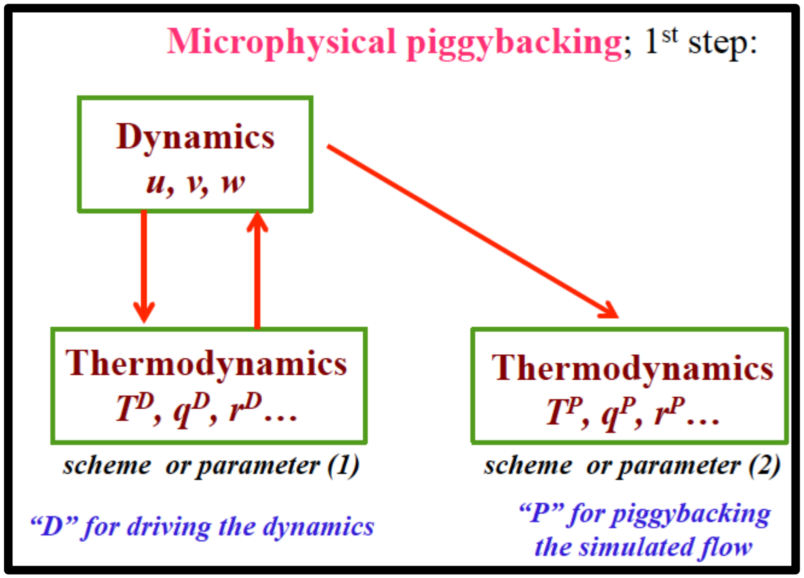

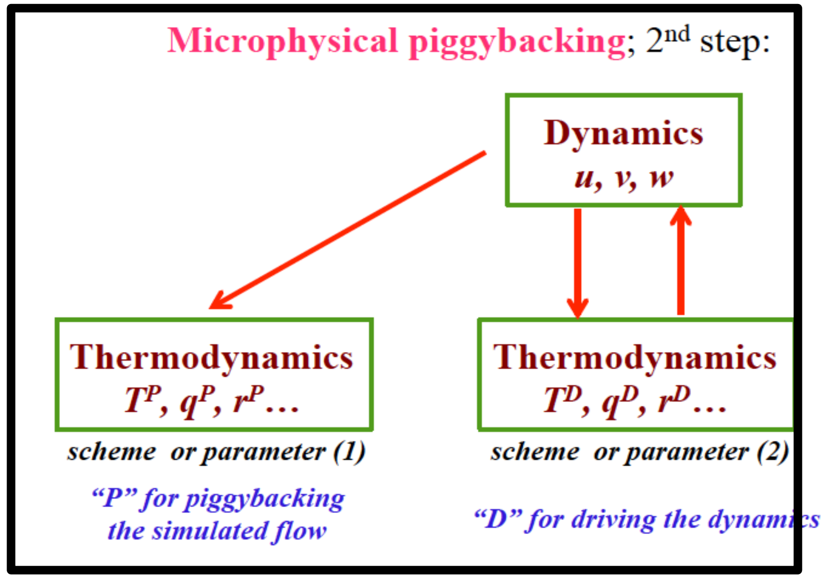

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Shallow convection
(Grabowski *JAS* 2014)

Extracting Microphysical Impacts in Large-Eddy Simulations of Shallow Convection

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Effect of cloud droplet concentration on drizzle/rain from shallow cumulus field

bulk microphysics (Grabowski 1998) with autoconversion depending on the cloud droplet concentration: 70 versus 100 per cc

A Large Eddy Simulation Intercomparison Study of Shallow Cumulus Convection

A. Pier Siebesma,[a] Christopher S. Bretherton,[b] Andrew Brown,[c] Andreas Chlond,[d] Joan Cuxart,[e] Peter G. Duynkerke,[f*] Hongli Jiang,[g] Marat Khairoutdinov,[h] David Lewellen,[i] Chin-Hoh Moeng,[j] Enrique Sanchez,[k] Bjorn Stevens,[l] and David E. Stevens[m]

JAS 2003

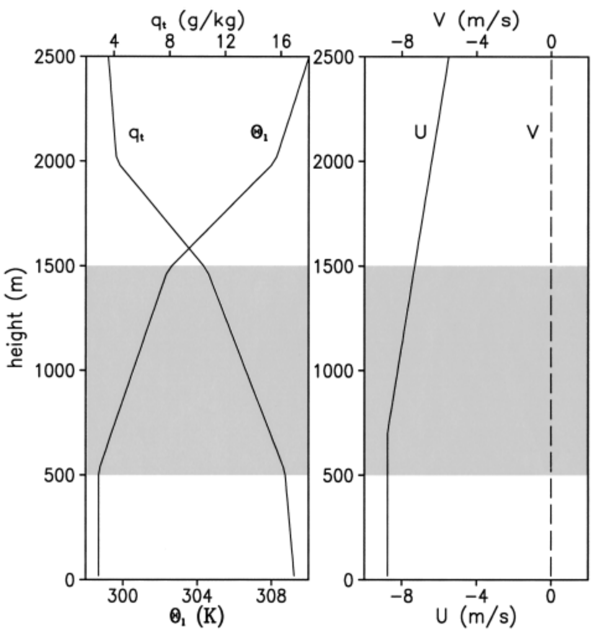
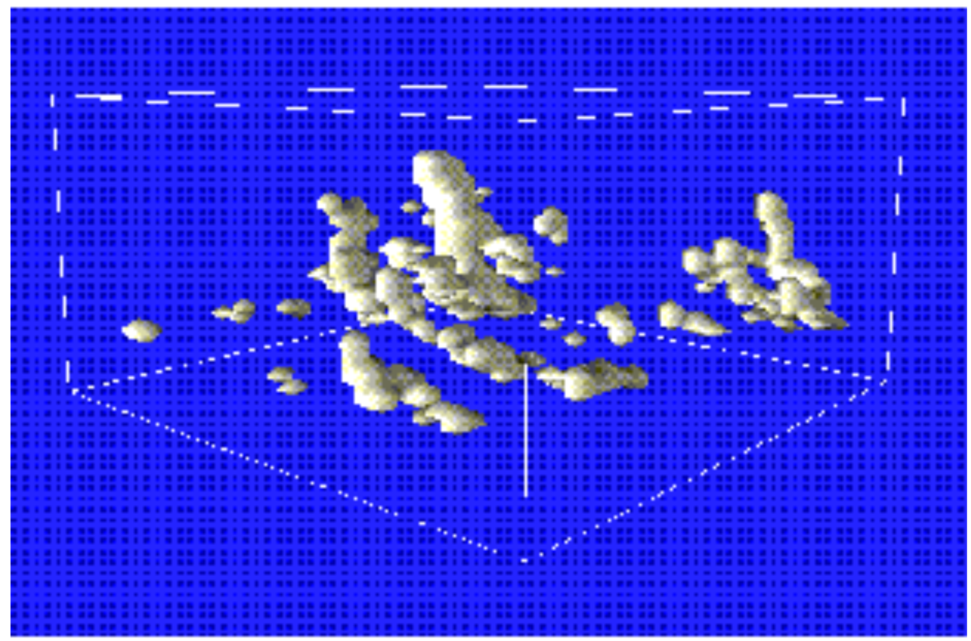


FIG. 1. Initial profiles of the total water specific humidity q_t, the liquid water potential temperature θ_ℓ, and the horizontal wind components u and v. The shaded area denotes the conditionally unstable cloud layer.

$\Delta x = \Delta y = 100$m; $\Delta z = 40$m



The Barbados Oceanographic and Meteorological Experiment (BOMEX) case (Holland and Rasmusson 1973)

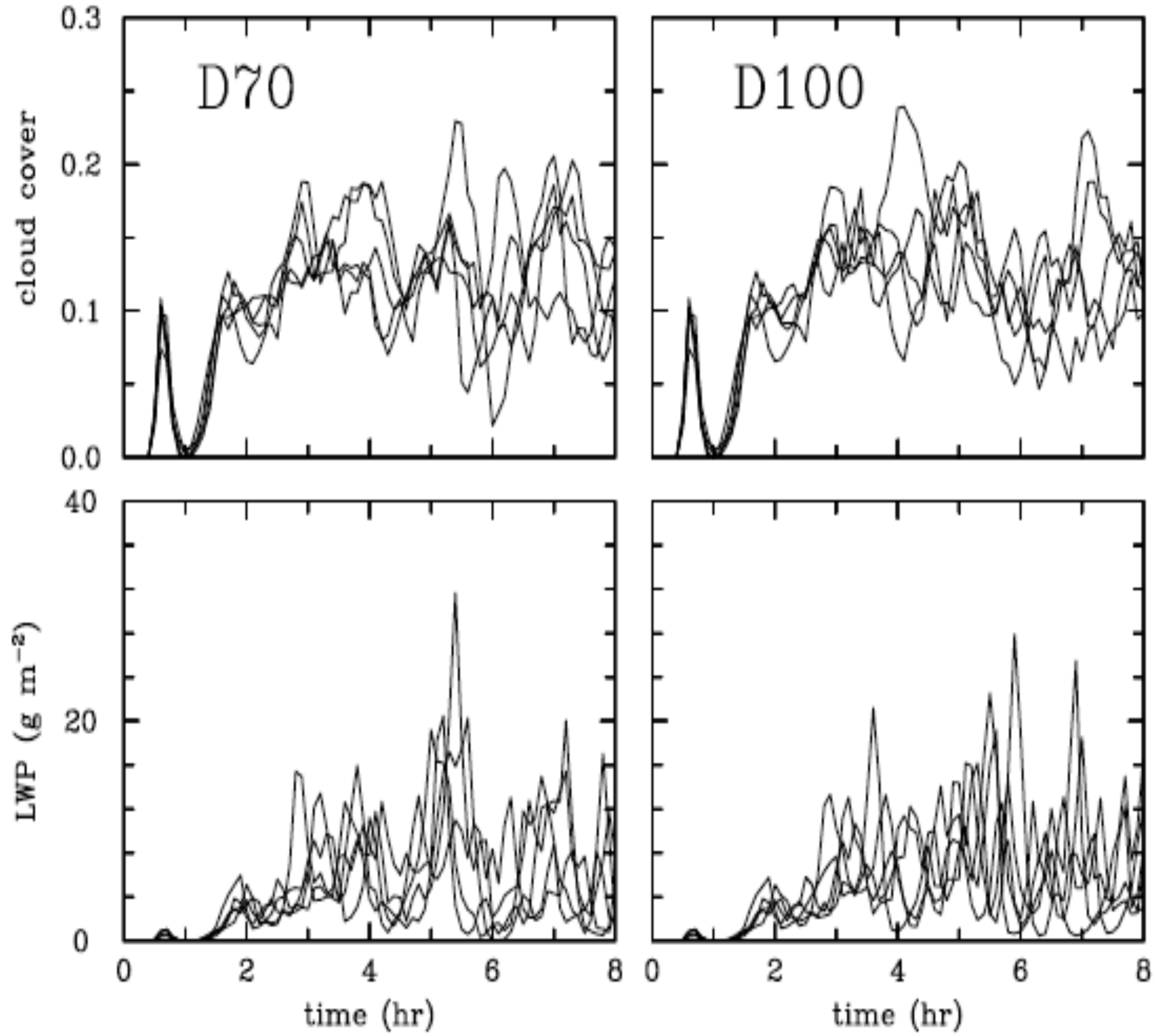
Simulations:

ensemble of 5 simulations driven by 70 per cc – D70, P100
ensemble of 5 simulations driven by 100 per cc – D100, P70

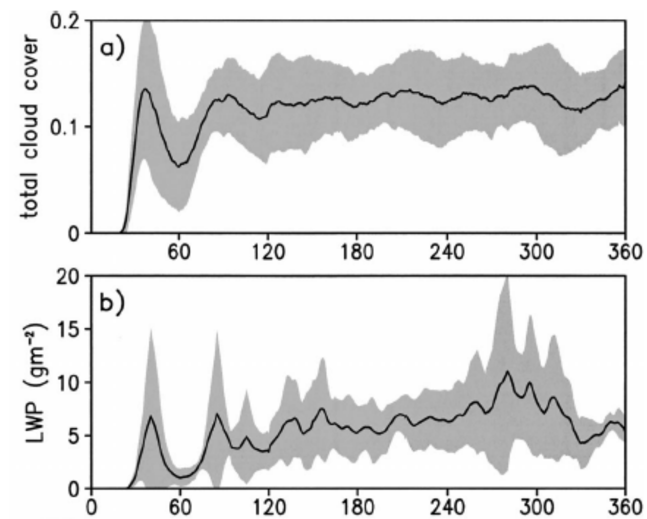
- look at D simulations only (traditional approach)
- look at D/P simulations (the new methodology)

NB: An increase of the assumed droplet concentration from 70 to 100 per cc reduces the autoconversion parameterization by about 30% at cloud water mixing ratios of 0.1 and 1 g/kg, and by about 7% for 10 g/kg.

Comparison of two D simulation ensembles (5 members):



Siebesma et al. *JAS* 2003



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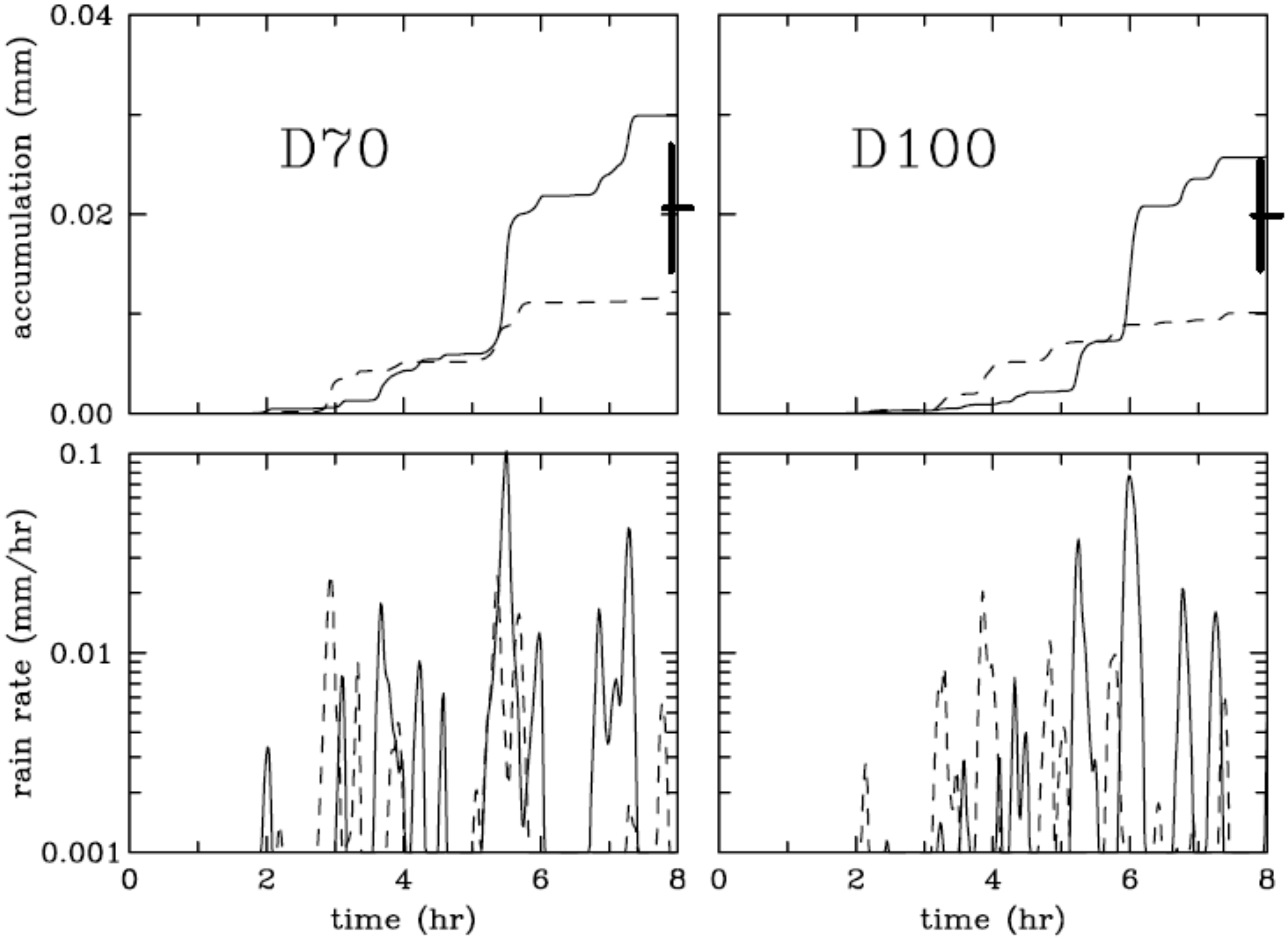

	8-hr rain accumulations (in units of 0.01 mm)	ensemble mean, st. dev.
D70	2.54, 1.72, 2.99, 1.81, 1.22	2.06, 0.63
D100	1.01, 1.97, 1.96, 2.58, 2.43	1.99, 0.55

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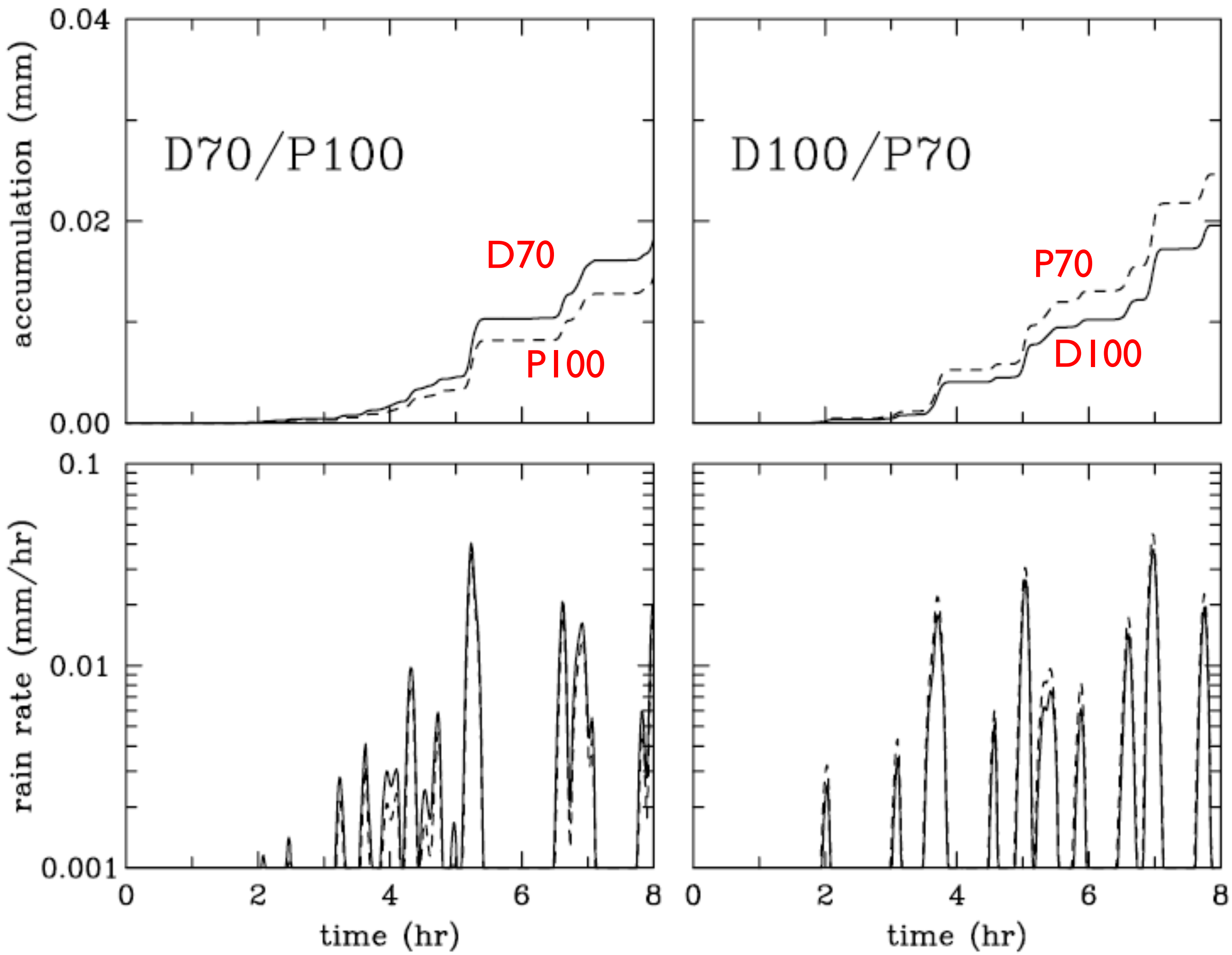
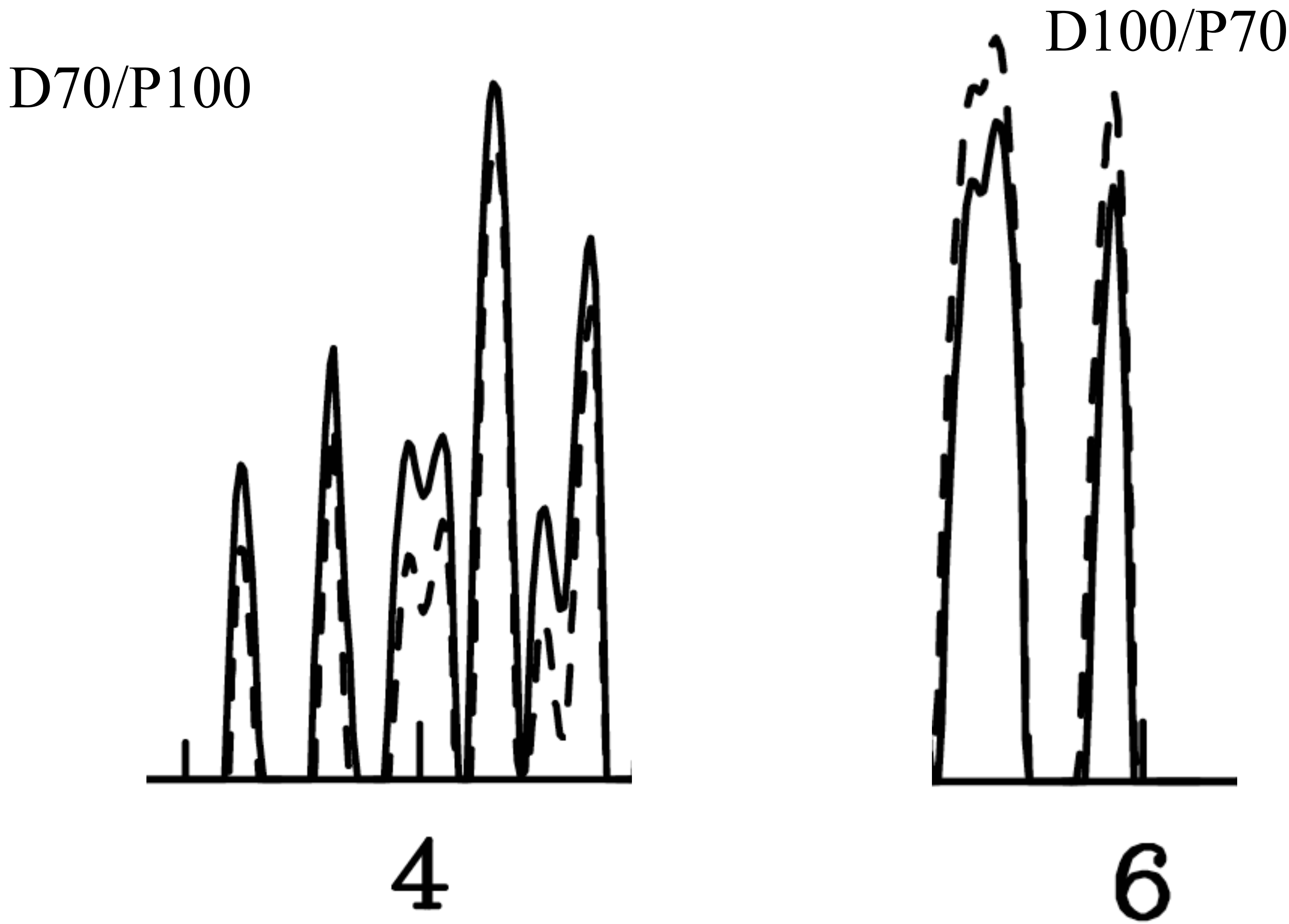
D100	1.01, 1.97, 1.96, 2.58, 2.43	1.99, 0.55

The difference is consistent with the expected effect of droplet concentration on surface rainfall from shallow convection, but the confidence is low: the difference is much smaller that the standard deviations among ensemble members. More ensemble members needed…

Comparison of two piggybacking D/P simulations:




D70/P100
D100/P70
4
6

	8-hr rain accumulations (in units of 0.01 mm)	ensemble mean, st. dev.	D-P mean, st. dev.
D70	2.54, 1.72, 2.99, 1.81, 1.22	2.06, 0.63	0.41, 0.08
D100	1.01, 1.97, 1.96, 2.58, 2.43	1.99, 0.55	-0.43, 0.07
P100	2.06, 1.33, 2.48, 1.44, 0.94		
P70	1.32, 2.38, 2.46, 3.04, 2.91		

Applying the piggybacking methodology, the effect of droplet concentration is estimated with significantly higher confidence…

Deep convection

(Grabowski *JAS* 2015, Grabowski and Morrison *JAS* 2016)

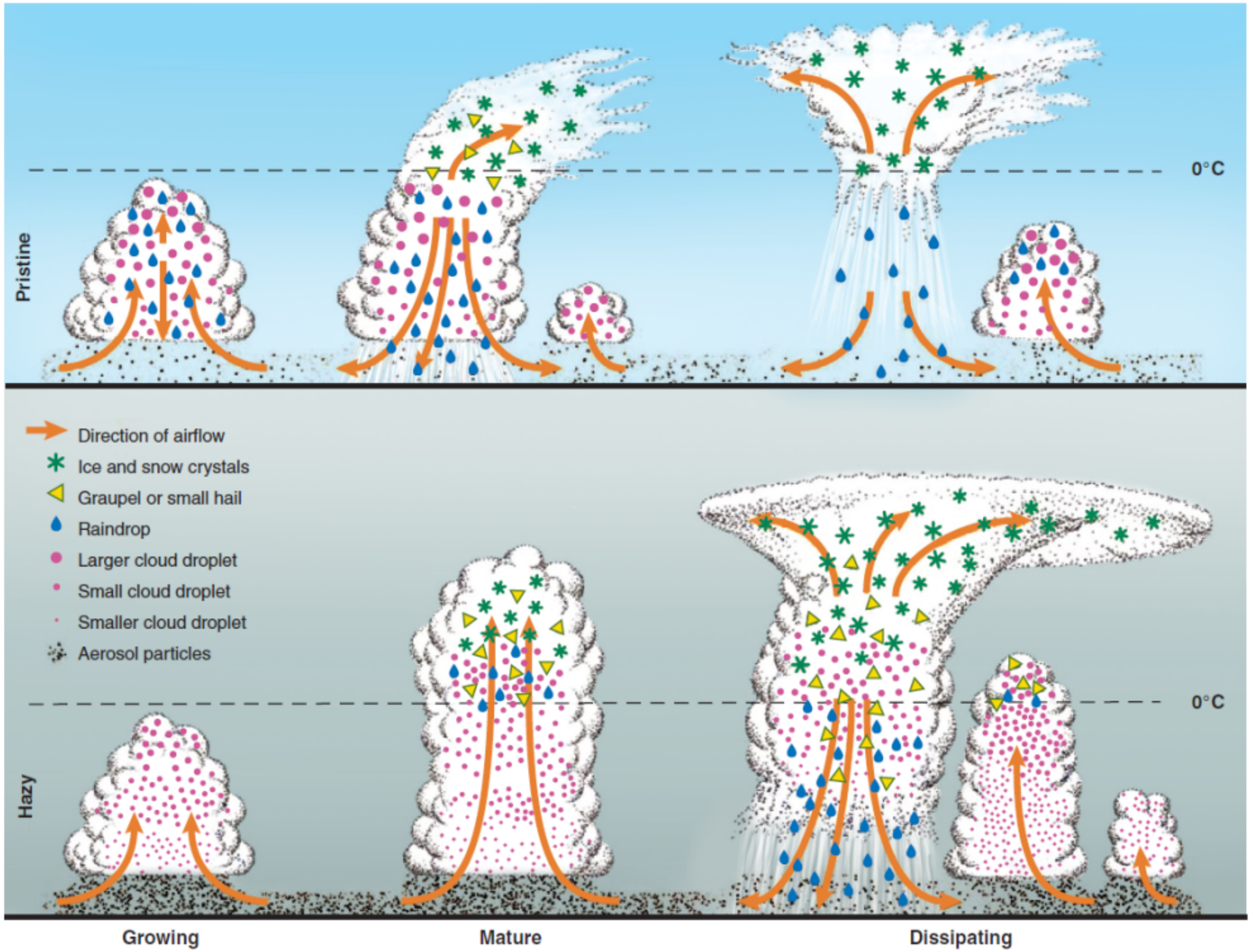
Untangling Microphysical Impacts on Deep Convection Applying a Novel Modeling Methodology. Part II: Double-Moment Microphysics

WOJCIECH W. GRABOWSKI AND HUGH MORRISON

Mesoscale and Microscale Meteorology Laboratory, National Center for Atmospheric Research,[a]
Boulder, Colorado

clean

polluted



Rosenfeld et al. *Science*, 2008
"Flood or Drought: How Do Aerosols Affect Precipitation?"

Liquid condensate freezing: the impact of latent heating approximately balances loading effect:

potential density temperature

$$\Theta_d = \Theta\,(1 + \varepsilon q_v - q_c)$$

δq – change of cloud water mixing ratio

$$\delta\Theta_d \sim \delta\Theta + \Theta\,\delta q$$

$$\delta\Theta \sim L_f/cp\,\delta q \sim 3 \cdot 10^2\,\delta q$$

$L_f \sim 3 \cdot 10^5\ J/kg$

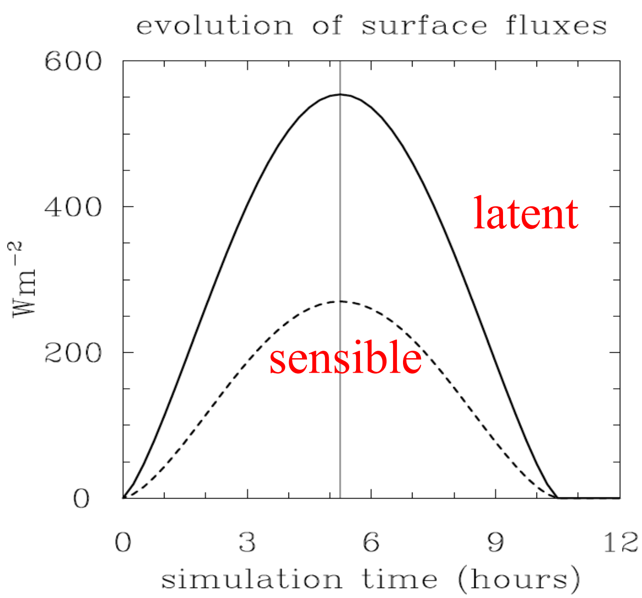
$$\Theta\,\delta q \sim 3 \cdot 10^2\,\delta q$$

So the condensate off-loading is the key…

Q. J. R. Meteorol. Soc. (2006), **132**, pp. 317–344 doi: 10.1256/qj.04.147

Daytime convective development over land: A model intercomparison based on LBA observations

By W. W. GRABOWSKI[1]*, P. BECHTOLD[2], A. CHENG[3], R. FORBES[4], C. HALLIWELL[4], M. KHAIROUTDINOV[5], S. LANG[6], T. NASUNO[7], J. PETCH[8], W.-K. TAO[6], R. WONG[8], X. WU[9] and K.-M. XU[3]



D-PRI
(pristine)

D-POL
(polluted)

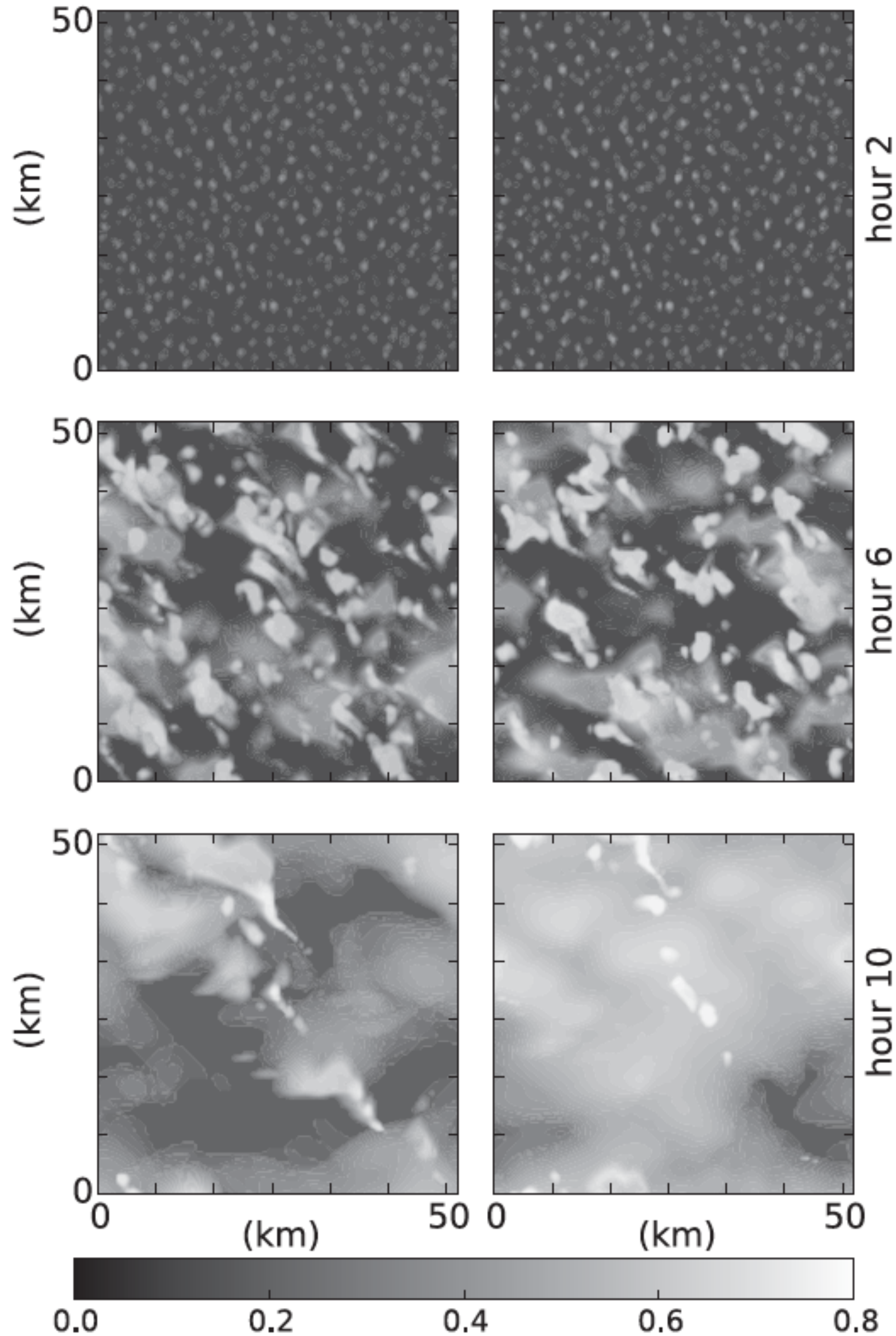


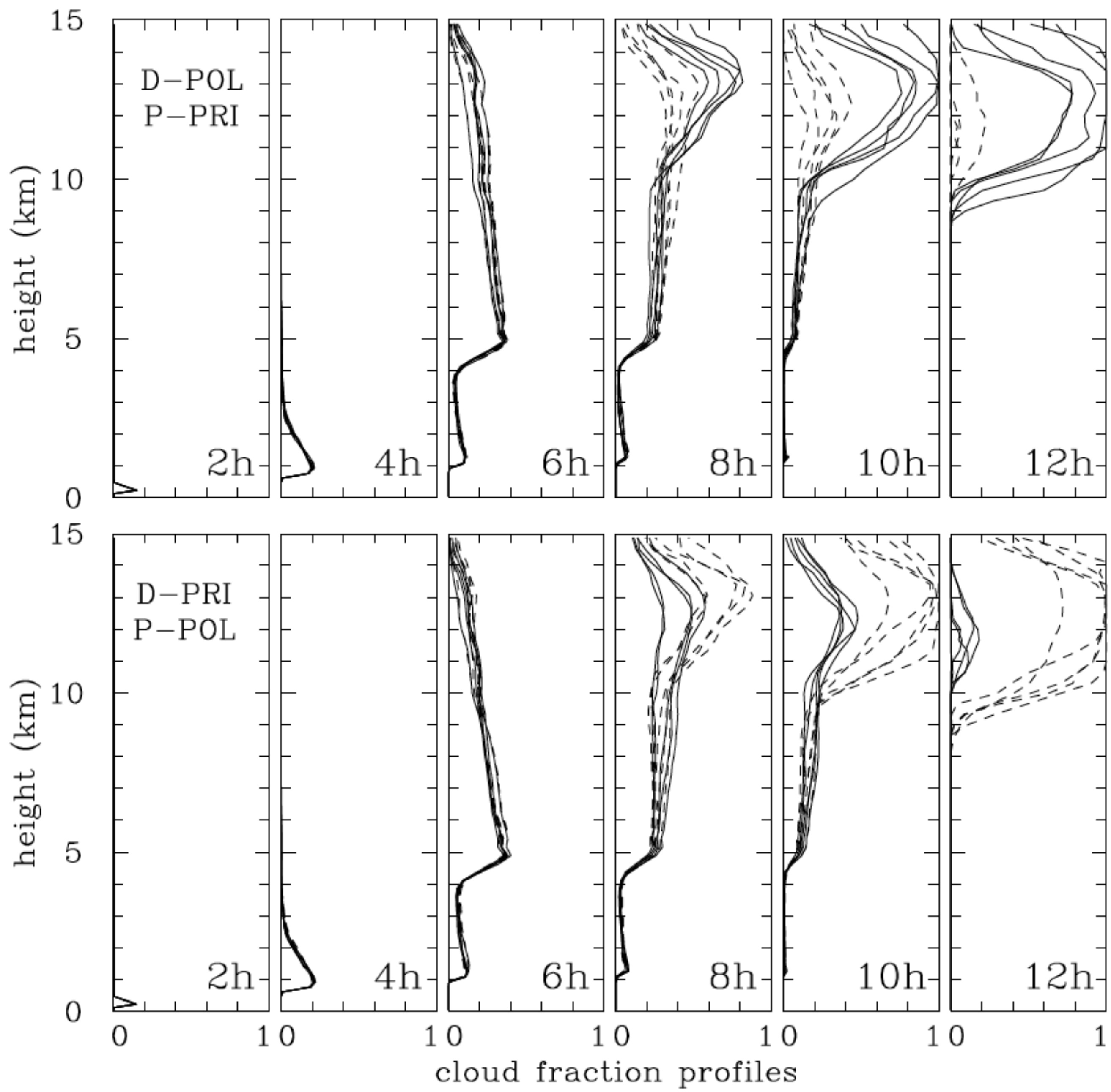
FIG. 2. Albedo at hours (top)–(bottom) 2, 6, and 10 for two simulations from (left) D-PRI and (right) D-POL ensembles.

Grabowski and Morrison (*JAS* 2016)

solid lines: driving set
dashed lines: piggybacking set

POL drives,
PRI piggybacks

PRI drives,
POL piggybacks



Grabowski and
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solid lines: driving set
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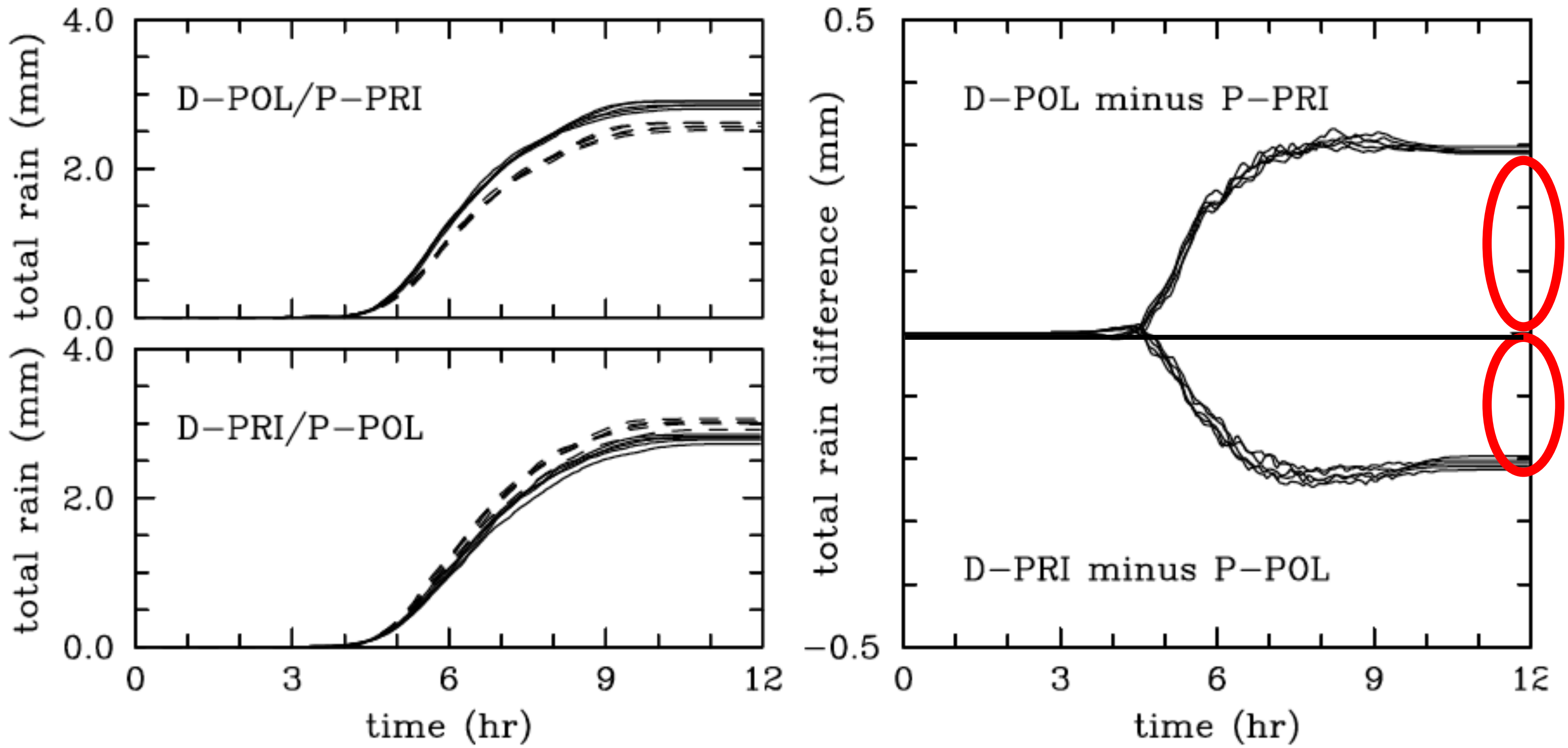


POL has more rain regardless if it drives or piggybacks…

Impact on the cloud dynamics!
This can be shown by looking at the updraft statistics (no time to show that, see Grabowski and Morrison *JAS* 2016).

The piggybacking methodology allows confident assessment of the impact of cloud microphysics on deep convection simulation.

POL versus PRI simulations with 2-moment bulk scheme in Grabowski and Morrison 2016:

- **small modification of the cloud dynamics in the warm-rain zone due to differences in the supersaturation field, ~10% more rain in polluted cases;**
- **significant *microphysical* impact on convective anvils.**

Discussion:

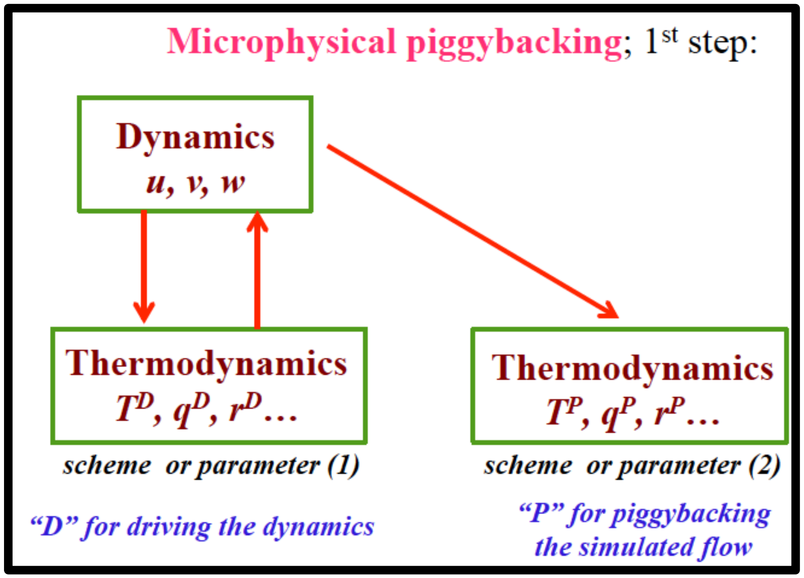
- "Piggybacking is a wrong name; kinematic model is the correct one".
  - . piggybacking is a sophisticated kinematic model!

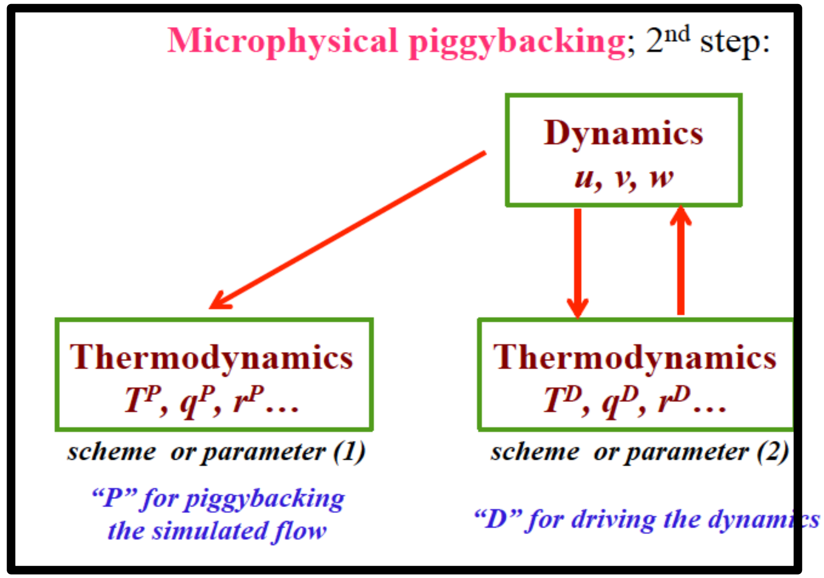
- "The piggybacker set is inconsistent with the driver flow".
  - . what about the kinematic model?
  - . this is why each set drives and then piggybacks

- The two drivers typically have different flow realizations, but the focus is on the driver-piggybacker differences.

- Why mini-ensembles?
  - . to compare "natural variability" with one driver with the simulations driven by the two drivers.

More appealing methodology: *the piggybacking (or master-slave)*





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