How can we separate microphysical and dynamical impacts in weather forecast?

A novel modeling methodology

Piggybacking

Noémi Sarkadi

Pécs, 23. March 2018

Friday **A**fternoon **C**loud Physics **T**alk

Outline

- Numerical Weather Forecast - basics
- Microphysical and dynamical interactions
- Piggybacking method
- First results in idealized simulations

Numerical Weather Forecast - basics

- Hidro-termodynamical equation system (HTES):

$$\frac{\mathrm{d}u}{\mathrm{d}t} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv - lw + F_{sx}$$

$$\frac{\mathrm{d}v}{\mathrm{d}t} = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + F_{sy}$$

$$\frac{\mathrm{d}w}{\mathrm{d}t} = \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + lu + F_{sz}$$

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho\nabla V \qquad \frac{\partial\rho}{\partial t} = -\nabla\rho V$$

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{\partial\rho}{\partial t} + u\frac{\partial\rho}{\partial x} + v\frac{\partial\rho}{\partial y} + w\frac{\partial\rho}{\partial z} = -\rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

$$f = 2\Omega\sin\varphi \qquad l = 2\Omega\cos\varphi$$

$$p\alpha = RT$$

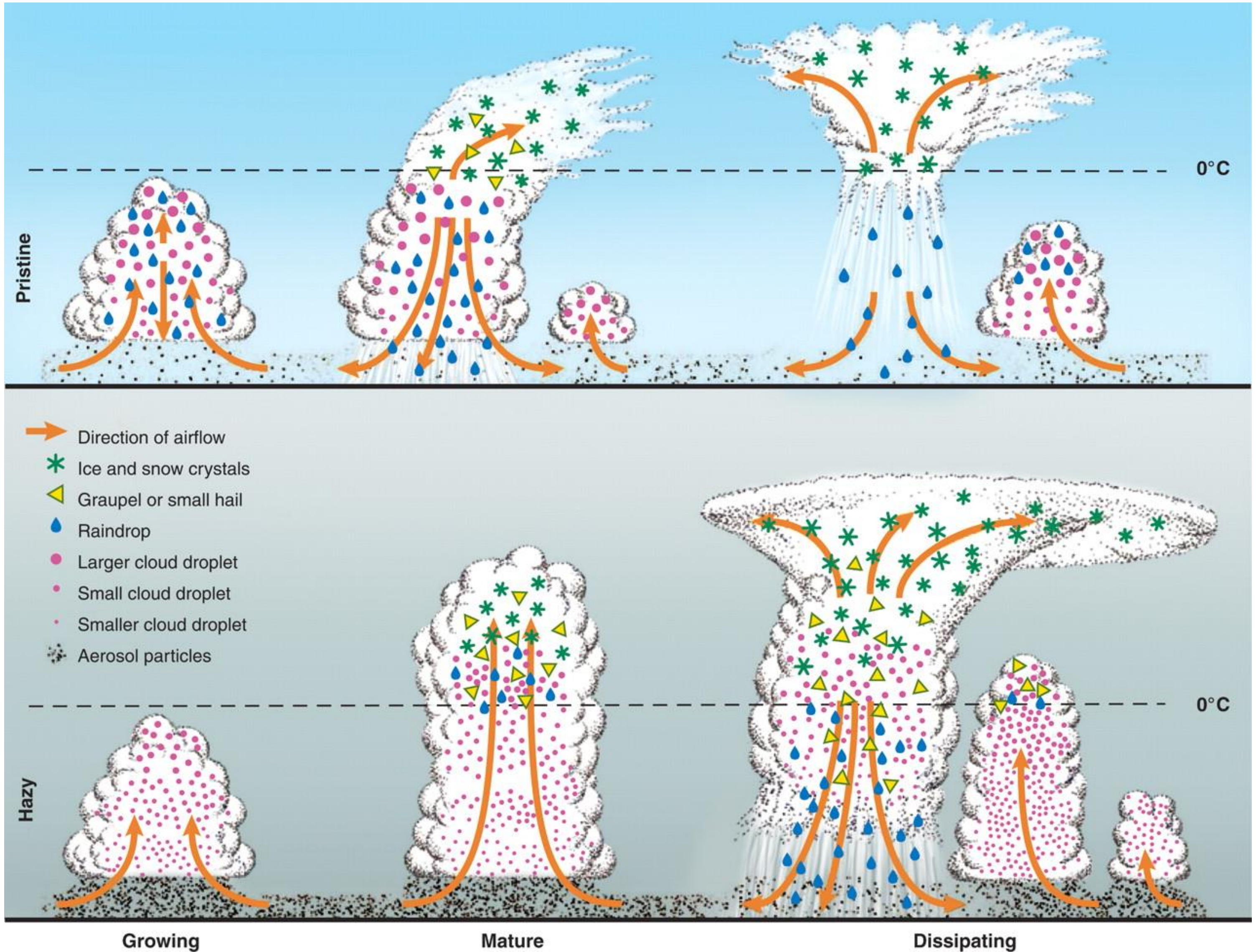
$$\frac{\mathrm{d}\Theta}{\mathrm{d}t} = \frac{\partial\Theta}{\partial t} + u\frac{\partial\Theta}{\partial x} + v\frac{\partial\Theta}{\partial y} + w\frac{\partial\Theta}{\partial z} = -\frac{\Theta}{T}\left(\frac{L_{lv}M_{lv}}{c_{pm}\rho_m} + \frac{L_{iv}M_{iv}}{c_{pm}\rho_m} + \frac{L_{il}M_{il}}{c_{pm}\rho_m}\right) + \frac{\Theta}{T}D_T + \frac{\Theta}{T}\frac{1}{c_{pm}}Q_R$$

$$\frac{\mathrm{d}\rho_v}{\mathrm{d}t} = \frac{\partial\rho_v}{\partial t} + u\frac{\partial\rho_v}{\partial x} + v\frac{\partial\rho_v}{\partial y} + w\frac{\partial\rho_v}{\partial z} = -\rho_v\,\mathrm{div}\,\mathbf{V} + M_{lv} + M_{iv} + F_v + D_v$$

$$\frac{\mathrm{d}\rho_w}{\mathrm{d}t} = \frac{\partial\rho_w}{\partial t} + u\frac{\partial\rho_w}{\partial x} + v\frac{\partial\rho_w}{\partial y} + w\frac{\partial\rho_w}{\partial z} = -\rho_w\,\mathrm{div}\,\mathbf{V} - M_{lv} + M_{il} + S_w + F_w$$

$$\frac{\mathrm{d}\rho_i}{\mathrm{d}t} = \frac{\partial\rho_i}{\partial t} + u\frac{\partial\rho_i}{\partial x} + v\frac{\partial\rho_i}{\partial y} + w\frac{\partial\rho_i}{\partial z} = -\rho_i\,\mathrm{div}\,\mathbf{V} - M_{iv} - M_{il} + S_i + F_i$$

Microphysical and dynamical interactions



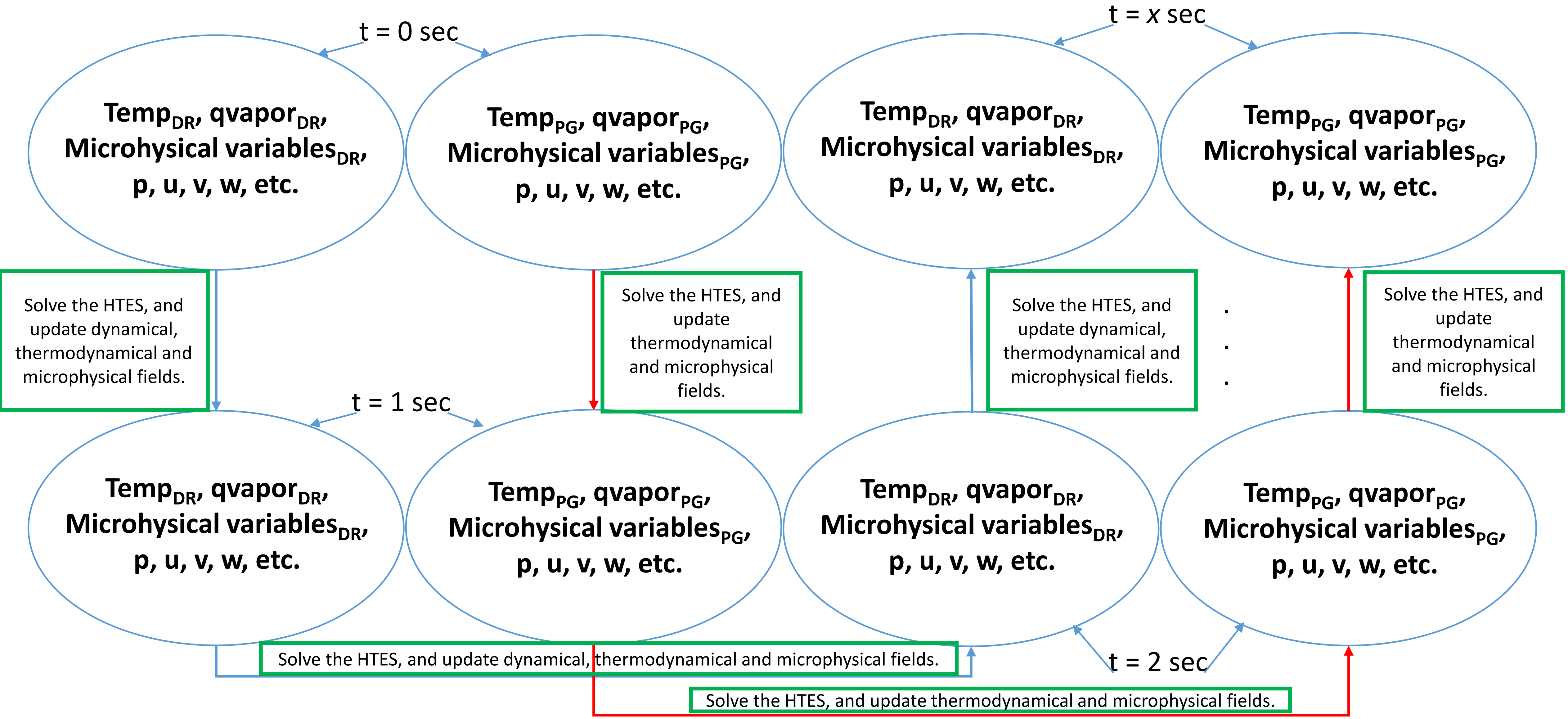
Evolution of deep convective clouds developing in the pristine (top) and polluted (bottom) atmosphere. Cloud droplets coalesce into raindrops that rain out from the pristine clouds. The smaller drops in the polluted air do not precipitate before reaching the supercooled levels, where they freeze onto ice precipitation that falls and melts at lower levels.

The additional release of latent heat of freezing aloft and reabsorbed heat at lower levels by the melting ice implies greater upward heat transport for the same amount of surface precipitation in the more polluted atmosphere.

This means consumption of more instability for the same amount of rainfall. The inevitable result is invigoration of the convective clouds and additional rainfall, despite the slower conversion of cloud droplets to raindrops.

Daniel Rosenfeld, Ulrike Lohmann, Graciela B. Raga, Colin D. O'Dowd, Markku Kulmala, Sandro Fuzzi, Anni Reissell, Meinrat O. Andreae, 2008: Flood or Drought: How Do Aerosols Affect Precipitation?, *Science*

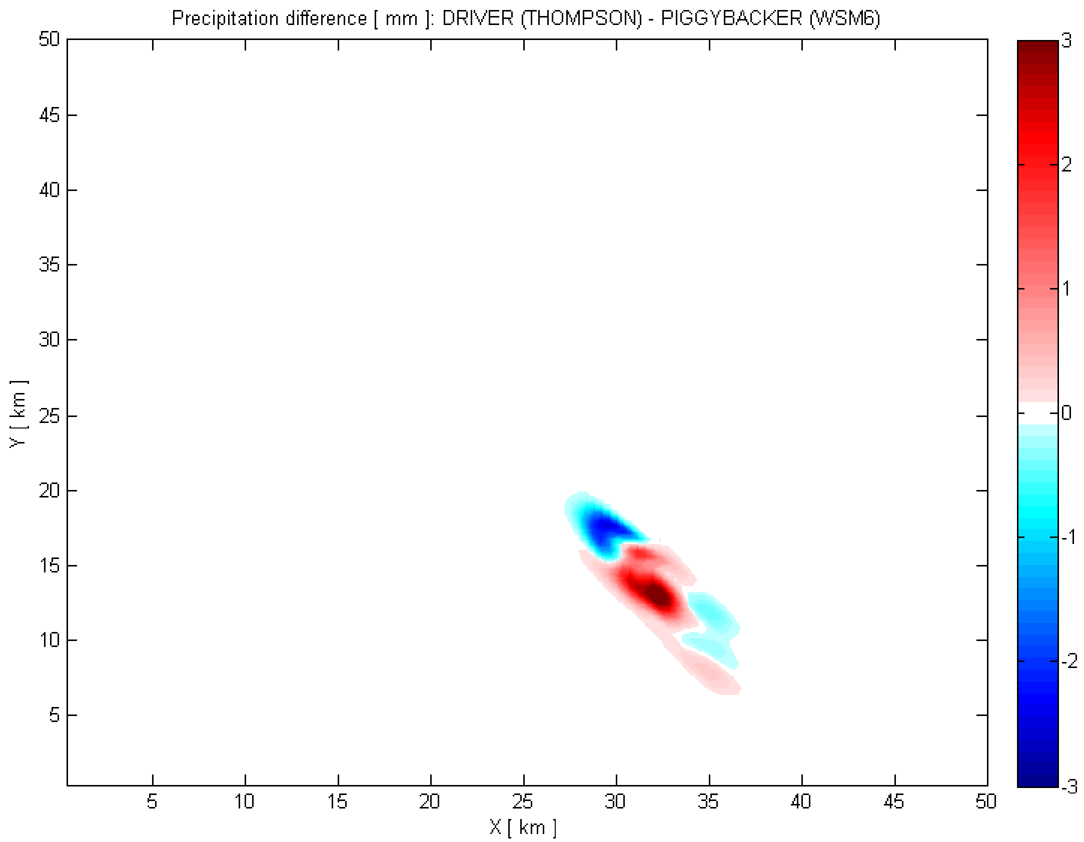
Piggybacking method



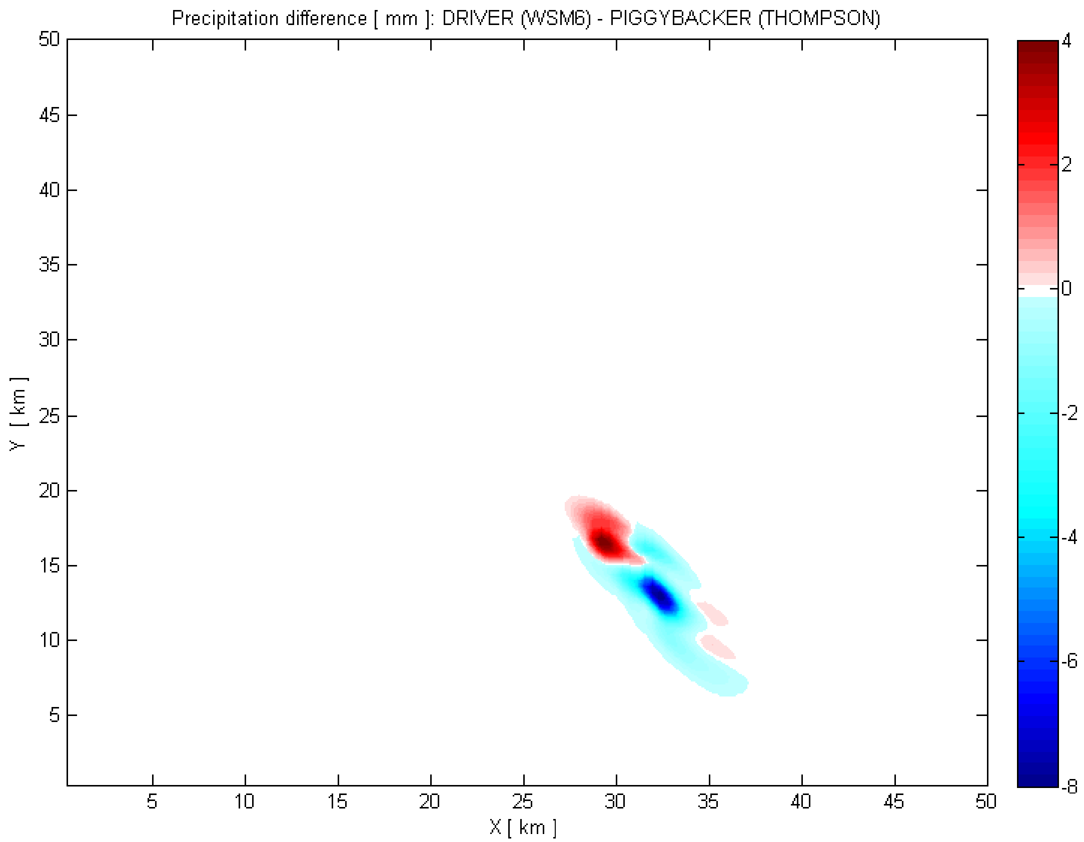
Results

Idealized simulations with Weather Research and Forecasting (WRF) model

Piggybacking with different microphysics schemes – Thompson DRIVER, WSM6 PIGGYBACKER

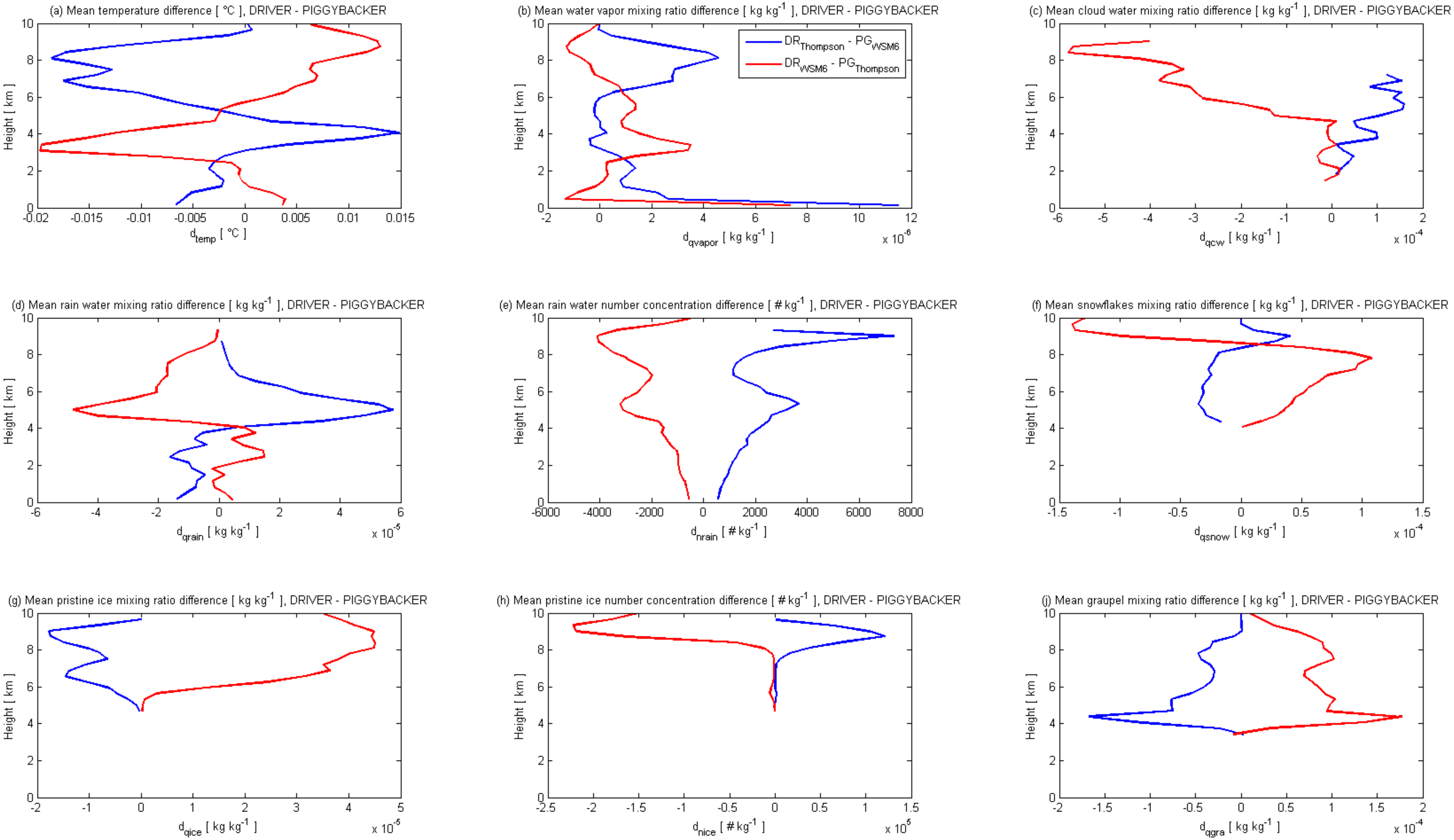


Piggybacking with different microphysics schemes – WSM6 DRIVER, Thompson PIGGYBACKER



Difference fields

Thompson_{DR} – WSM6_{PG}
WSM6_{DR} – Thompson_{PG}


(a) Mean temperature difference [°C], DRIVER - PIGGYBACKER
Height [km]
d_temp [°C]
(b) Mean water vapor mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
DR_Thompson - PG_WSM6
DR_WSM6 - PG_Thompson
d_qvapor [kg kg-1]
x 10-6
(c) Mean cloud water mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
d_qcw [kg kg-1]
x 10-4
(d) Mean rain water mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
d_qrain [kg kg-1]
x 10-5
(e) Mean rain water number concentration difference [# kg-1], DRIVER - PIGGYBACKER
d_nrain [# kg-1]
(f) Mean snowflakes mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
d_qsnow [kg kg-1]
x 10-4
(g) Mean pristine ice mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
d_qice [kg kg-1]
x 10-5
(h) Mean pristine ice number concentration difference [# kg-1], DRIVER - PIGGYBACKER
d_nice [# kg-1]
x 10-5
(j) Mean graupel mixing ratio difference [kg kg-1], DRIVER - PIGGYBACKER
d_qgra [kg kg-1]
x 10-4

Piggybacking in WRF - Possibilities

- **<u>Option 1:</u>** Using same microphysics as a driver and as the piggybacker, but with different initial conditions (temperature and moisture).
  - *Why does it good for us?*
  - We can **separate the effect** of the different micropyhsics on precipitation formation.
  - This is the way how we can test the **CCN concentration** impacts on cloud formation.
- **<u>Option 2:</u>** Using the same initial conditions, but with two different sets of microphysics
  - *Why does it good for us?*
  - We can test how the different initial conditions affect the cloud and precipitation formation → investigation of **climate change**.

Thank You for Your Attention! Questions?