Large systematic effects of changing model timestep - cause, significance and solution

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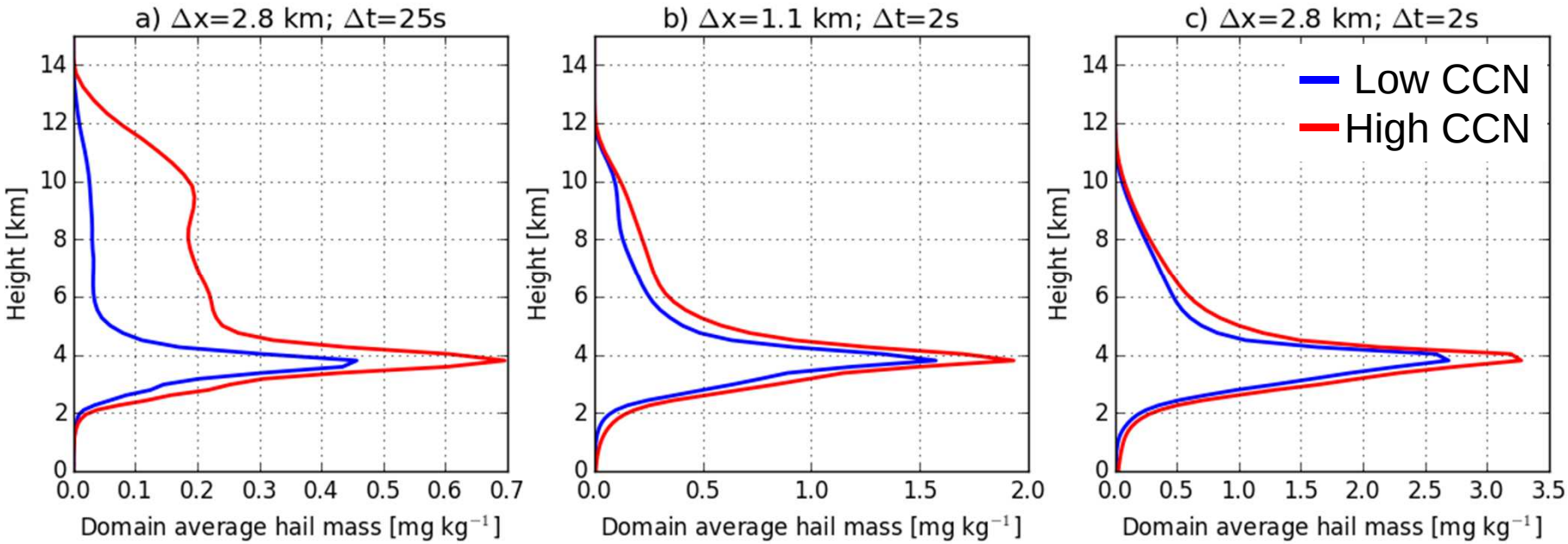
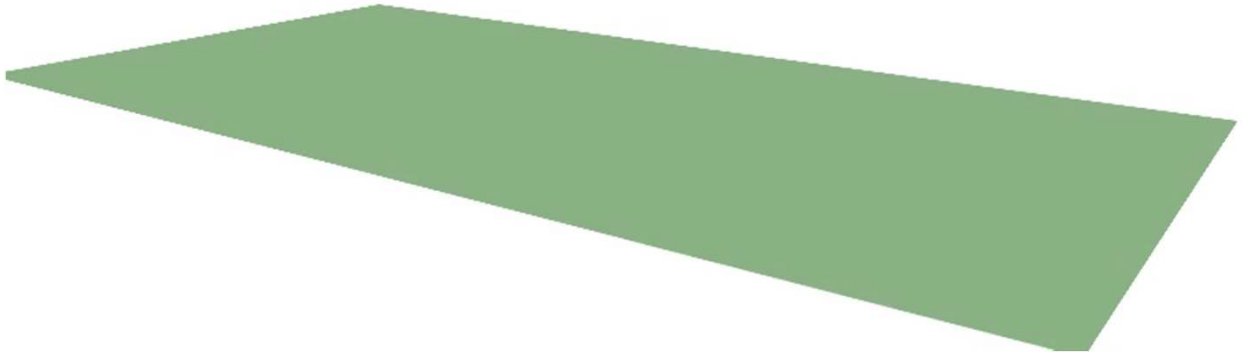
Institute of Meteorology and Climate research – Aerosols, Trace Gases and Climate Processes

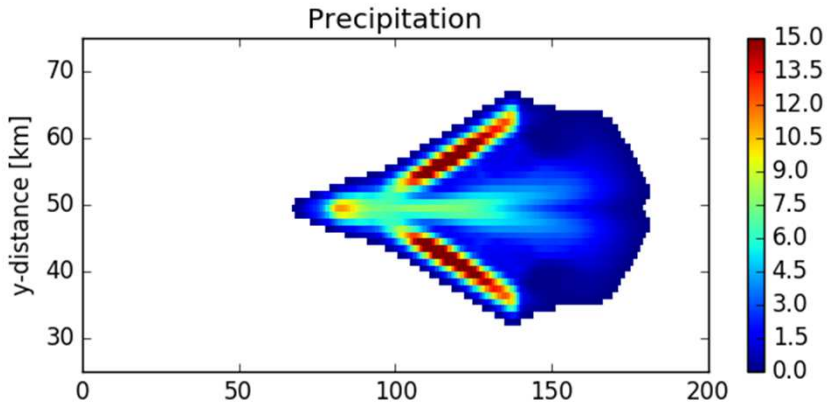
Aerosol effects on hail in COSMO

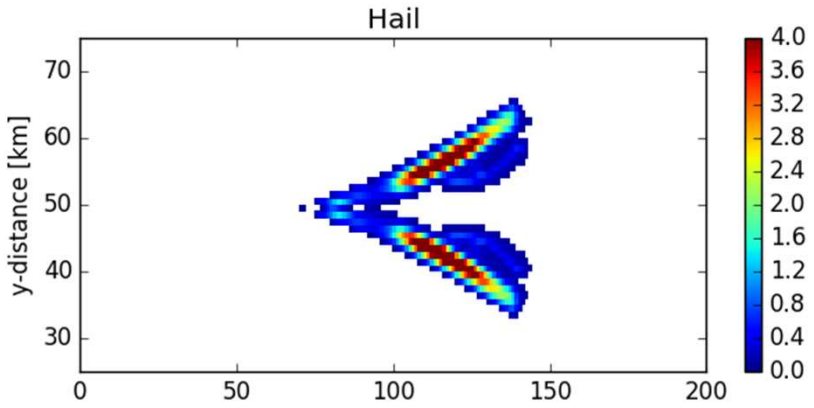


Simulation overview

CLOUD
RAIN
ICE
SNOW
GRAUPEL
HAIL

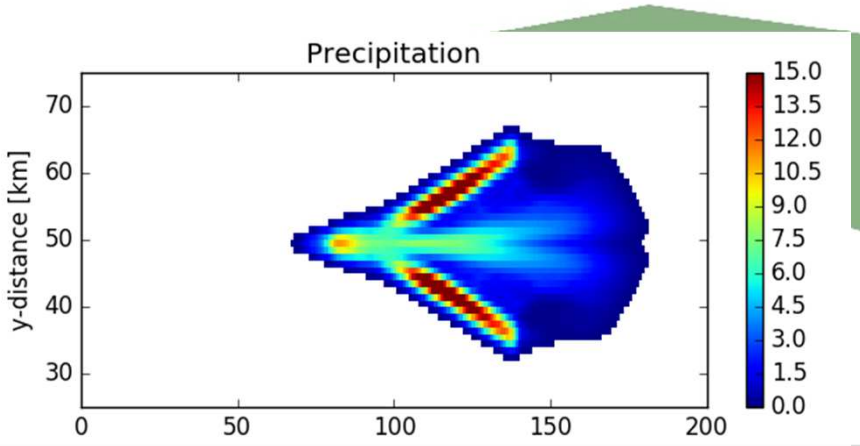


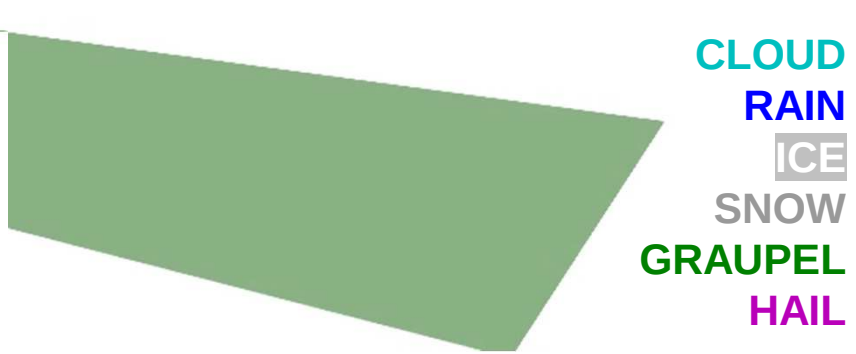




Model setup

- Idealised 2-hour simulation using COSMO 5.3
- 1-km resolution; 64 vertical levels; timestep 1-20 s
  - Weisman-Klemp thermodynamic profile; 2K warm bubble
- Seifert & Beheng 2-moment microphysics
  - Two different aerosol settings:
    - clean = 100 CCN cm^{-3} ; continental = 1700 CCN cm^{-3}





CLOUD
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COSMO model setup

- COSMO 5.3
- 1-km resolution; 64 vertical levels; timestep 1-20 s
- Idealised simulation
  - Weisman-Klemp thermodynamic profile
  - 2K warm bubble
- 2-hour simulation
- Seifert & Beheng 2-moment microphysics
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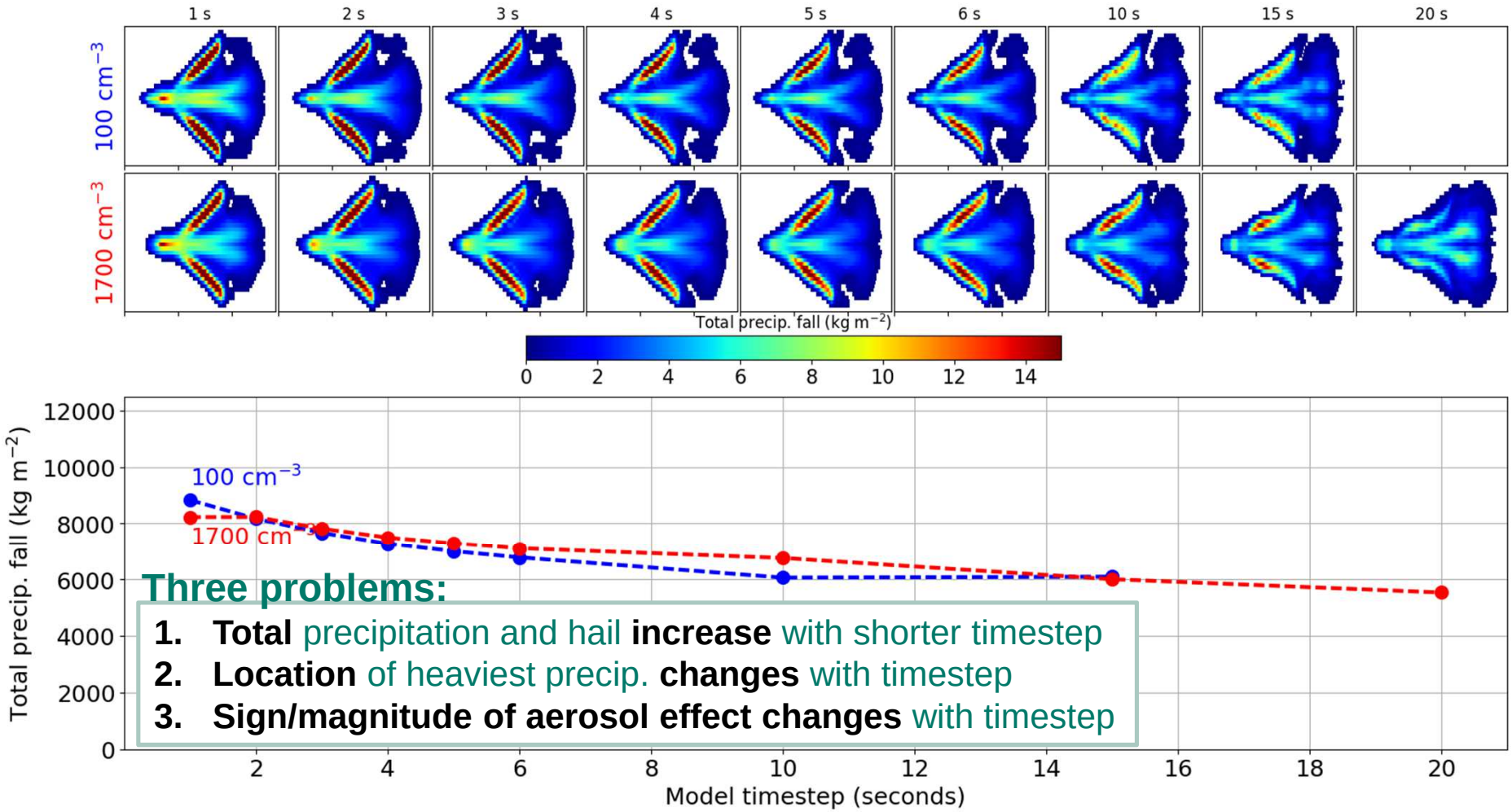
Total precipitation: aerosol and timestep effects

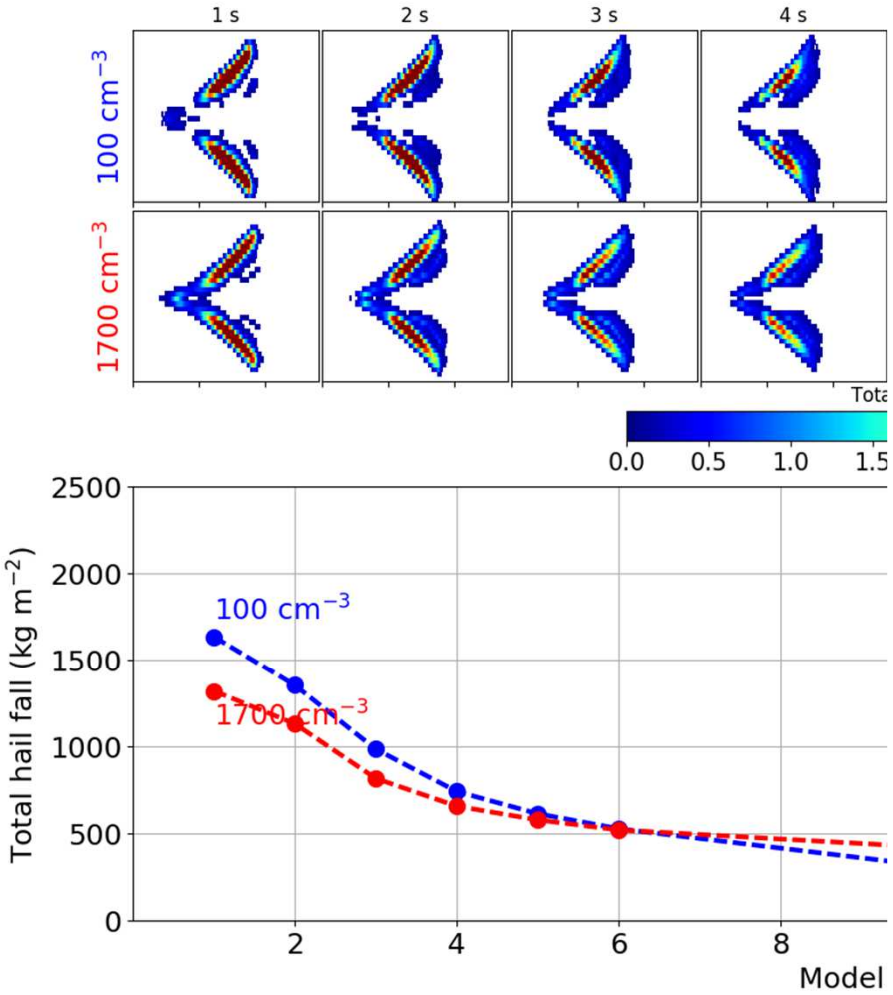


Three problems:

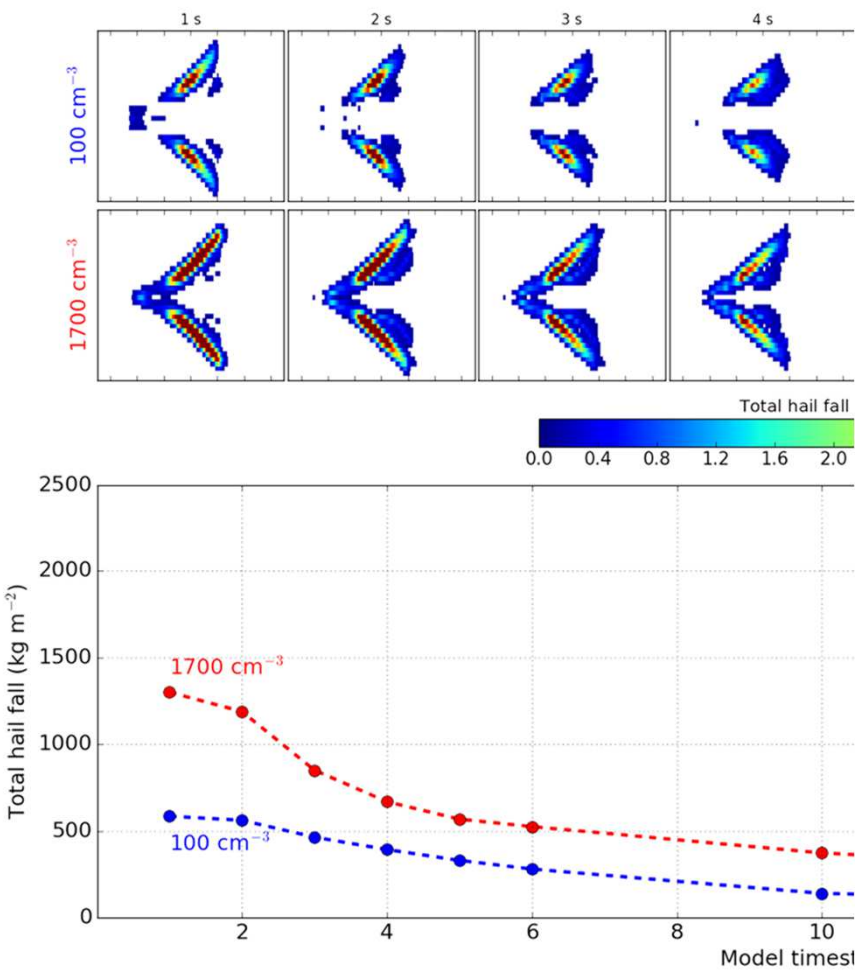
1. **Total** precipitation and hail **increase** with shorter timestep
2. **Location** of heaviest precip. **changes** with timestep
3. **Sign/magnitude of aerosol effect changes** with timestep

Total hail: aerosol and timestep effects

Default setup



Saturation adjustment before microphysics

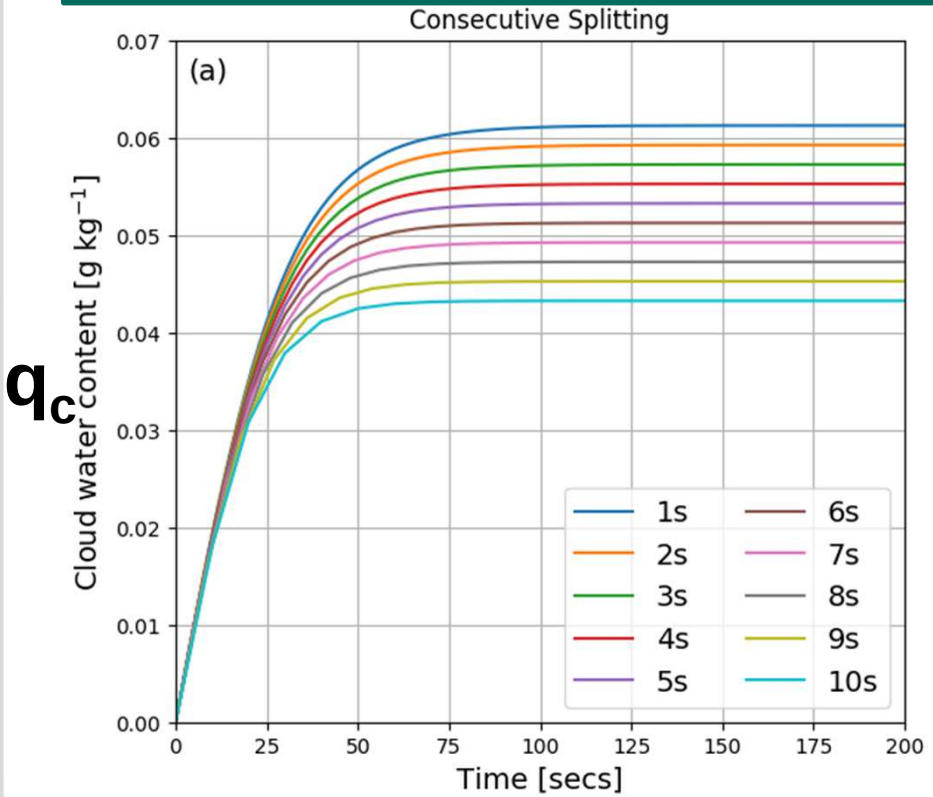


Timestep dependence in a simple model

$$\frac{dq_c}{dt} = C - Aq_c^2$$

Condensation

Autoconversion (microphysics)



q_c

C = "Dynamics"

- Updraft
- → cooling
- → condensation

Aq_c^2 = "simplified microphysics"

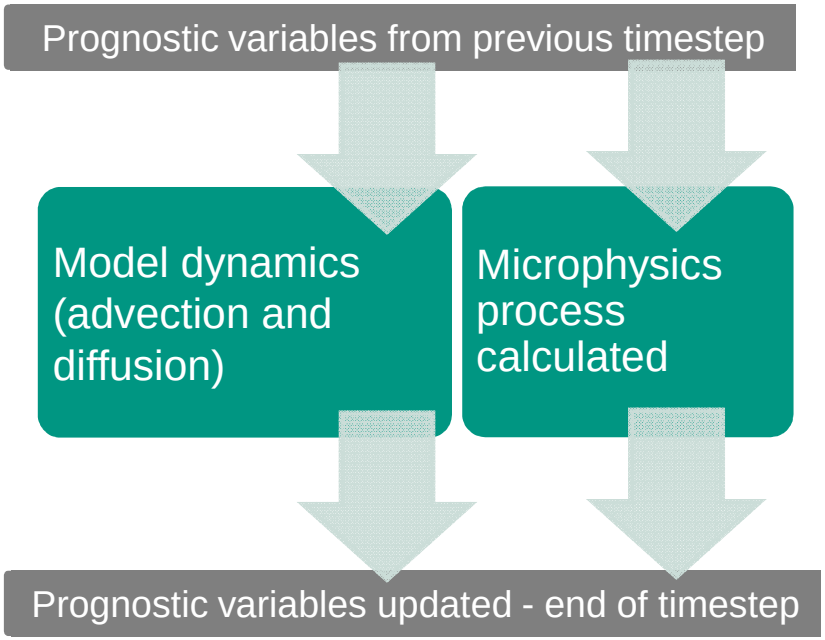
Consecutive vs Simultaneous Splitting

$$\frac{dq_c}{dt} = C - Aq_c^2$$

Condensation

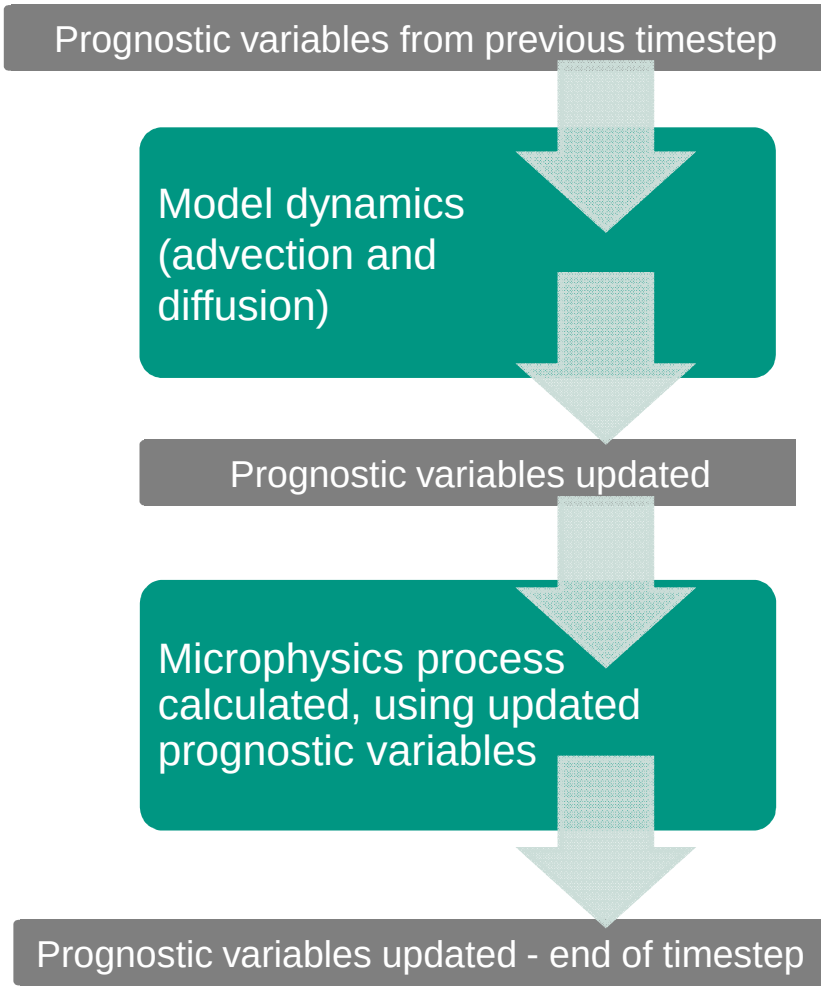
Autoconversion (microphysics)

A different option:



"Additive Splitting"

Process splitting in COSMO:



"Operator Splitting" or "Additive Splitting"

Consecutive vs Simultaneous Splitting

$$\frac{dq_c}{dt} = C - Aq_c^2$$

Condensation

Autoconversion (microphysics)

Consecutive splitting

- First, calculate process #1

$$q_c(*) = q_c(t = 0) + C\Delta t$$

- Then, calculate process #2

$$q_c(t = \Delta t) = q_c(*) - Aq_c^2(*)\Delta t$$

Simultaneous splitting

- Calculate processes together, with same initial conditions

$$q_c(t = \Delta t) = q_c(t = 0) + C\Delta t - Aq_c^2(t = 0)\Delta t$$

Timestep dependence in a simple model

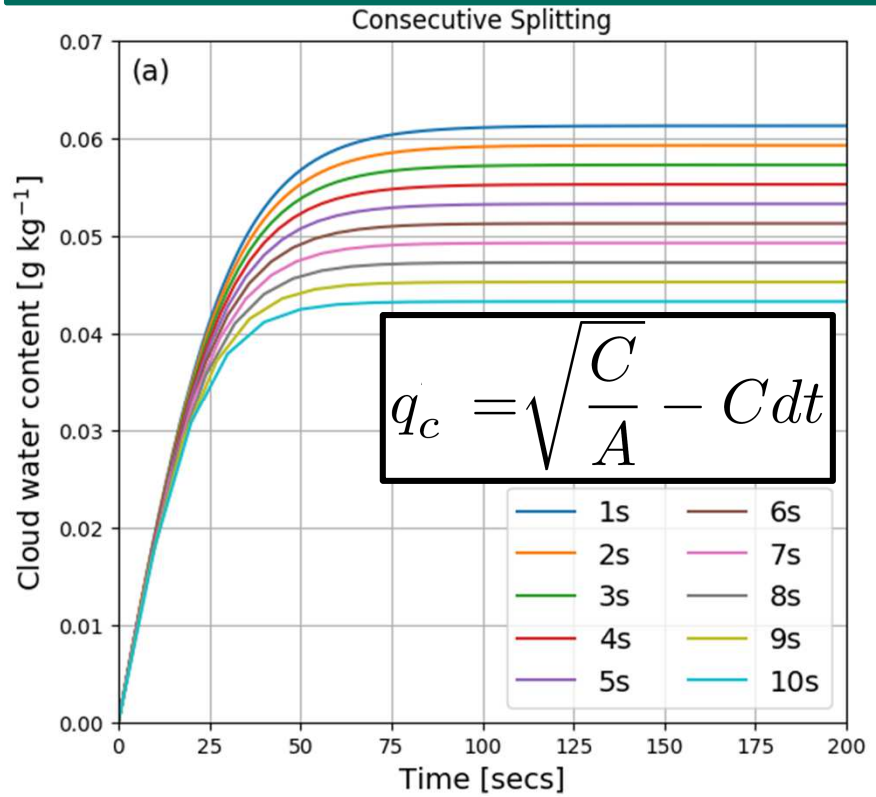
$$\frac{dq_c}{dt} = C - Aq_c^2$$

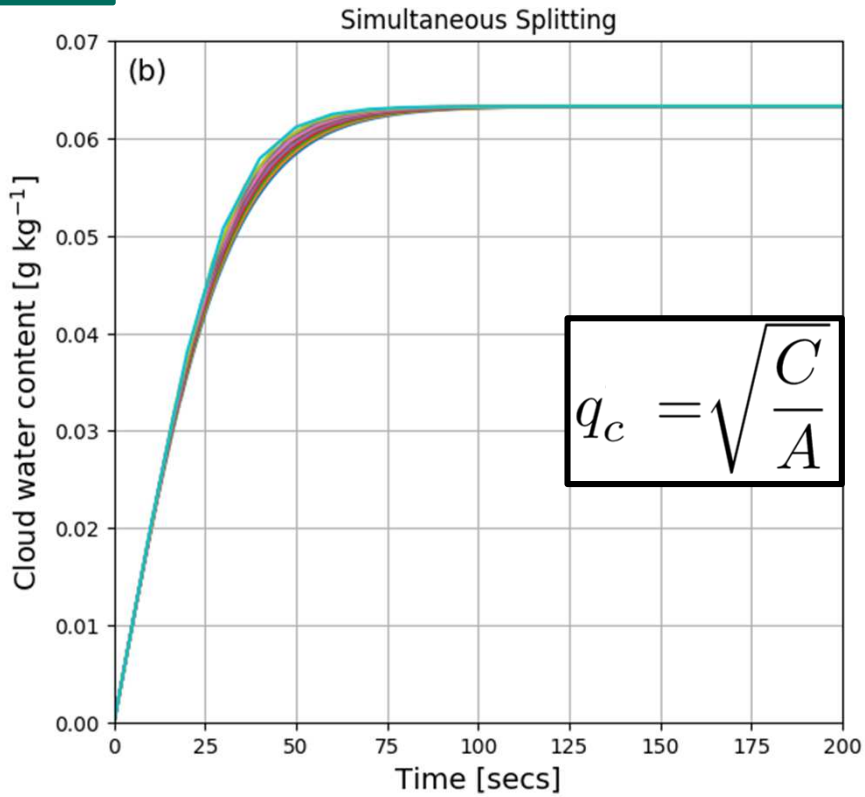
Condensation

Autoconversion (microphysics)

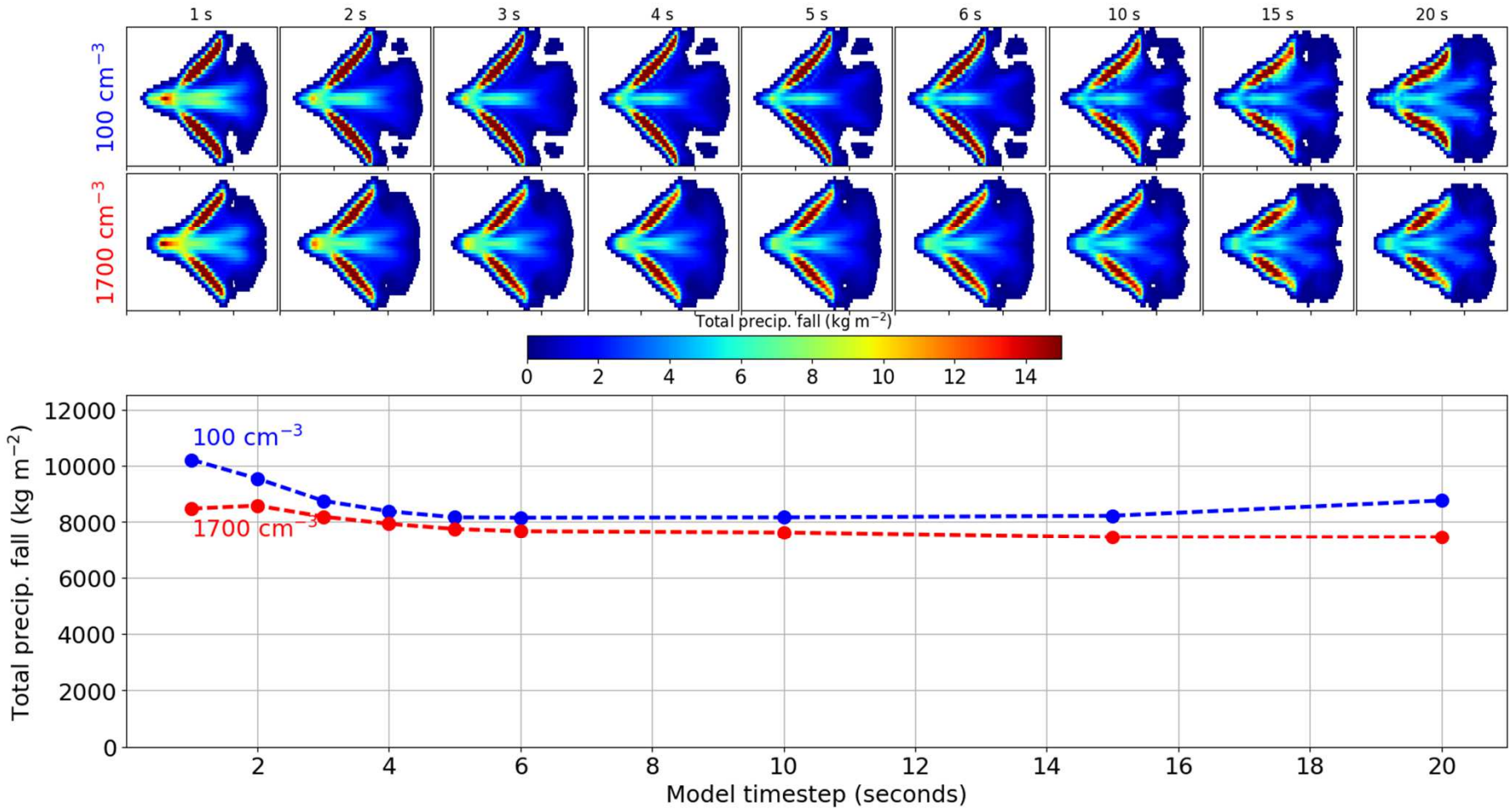
Reaches equilibrium at:

$$q_c = \sqrt{\frac{C}{A}}$$

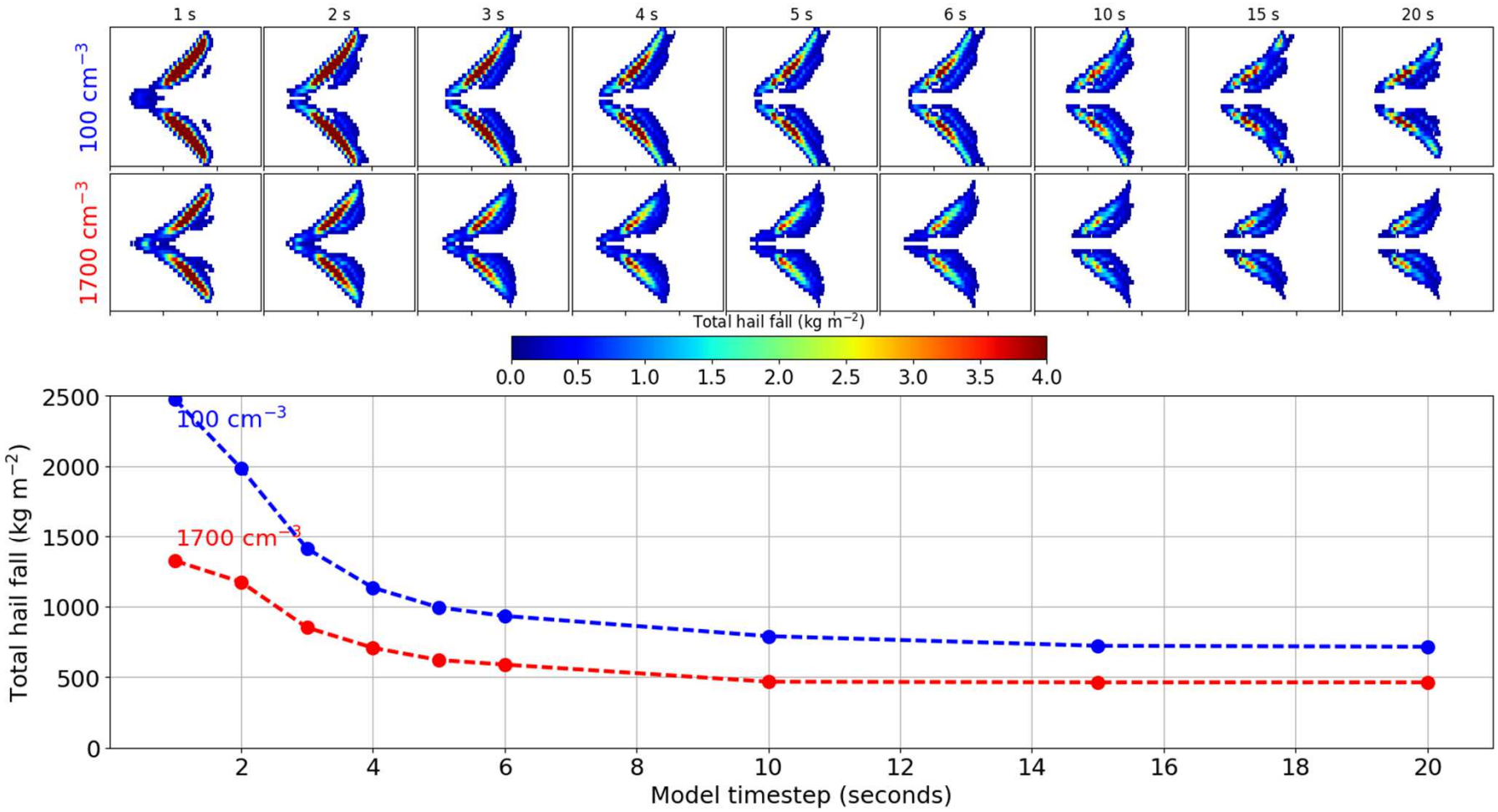




COSMO with Simultaneous Splitting



COSMO with Simultaneous Splitting



Air parcel in an updraft

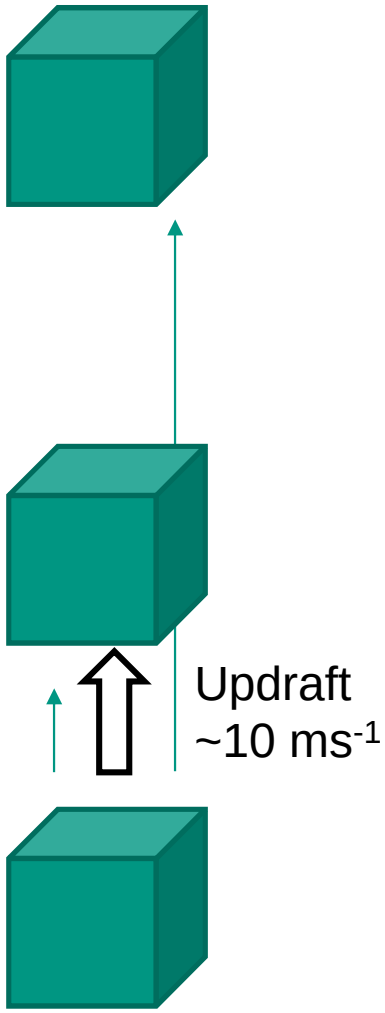
SATURATION ADJUSTMENT

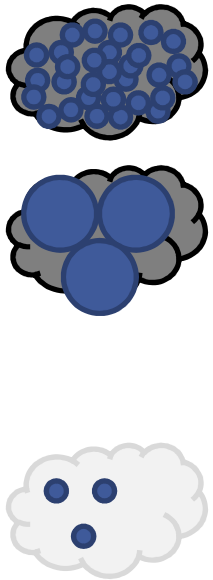
Karlsruhe Institute of Technology

Δt = 20 s
Δz = 200 m T = -2.0°C RH_w = 115.8% RH_i = 118.1% $q_i = q_c = 0$

Δt = 2 s
Δz = 20 m T = -0.2°C RH_w = 101.5% RH_i = 101.7% $q_i = q_c = 0$

T = 0°C RH_w = 100.0% RH_i = 100.0% $q_i = q_c = 0$





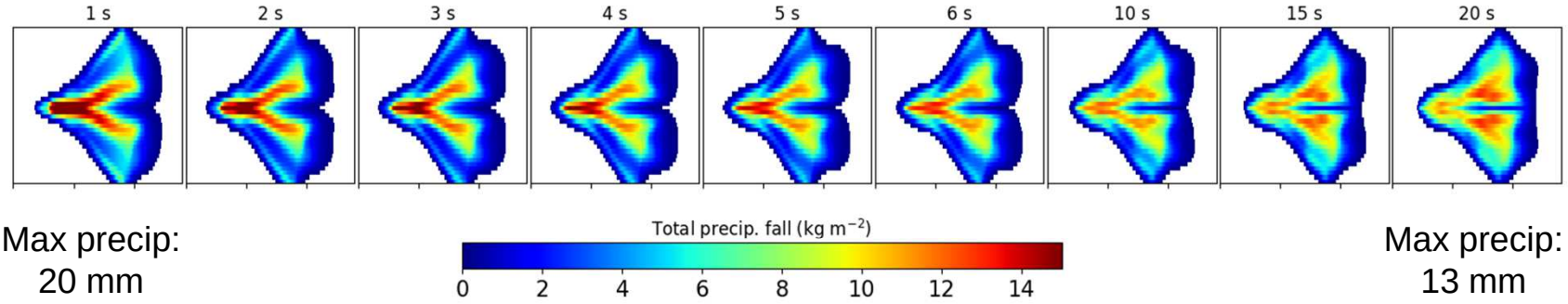
+ Numerical Weather Prediction – long timesteps are required

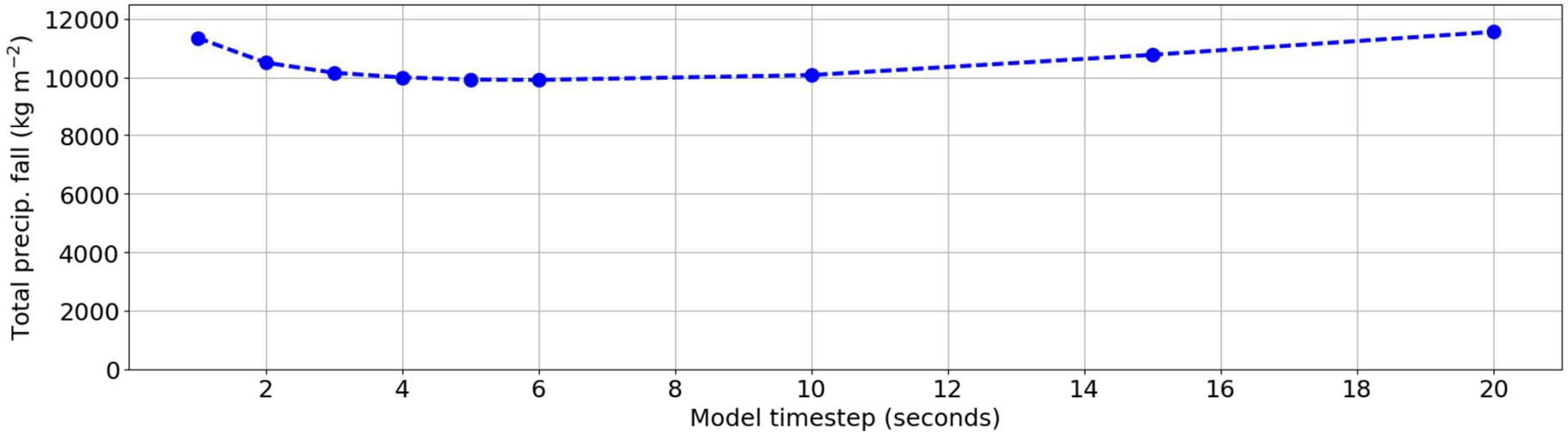
+ Sensitivity studies (e.g. vertical distribution of water, impact of ice nuclei, impact of aerosol)

+ In possibly all models…

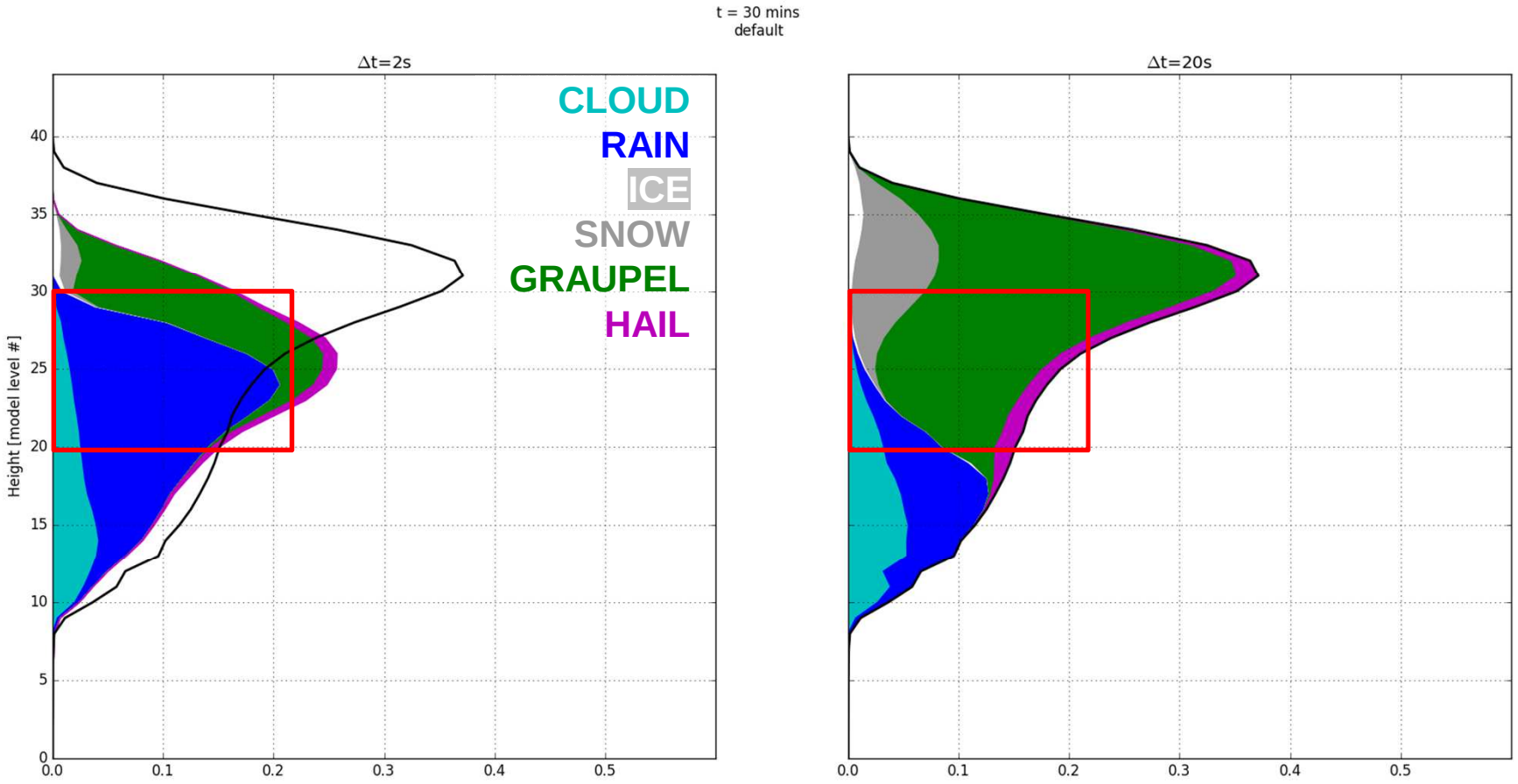
IMPACTS

COSMO one-moment microphysics

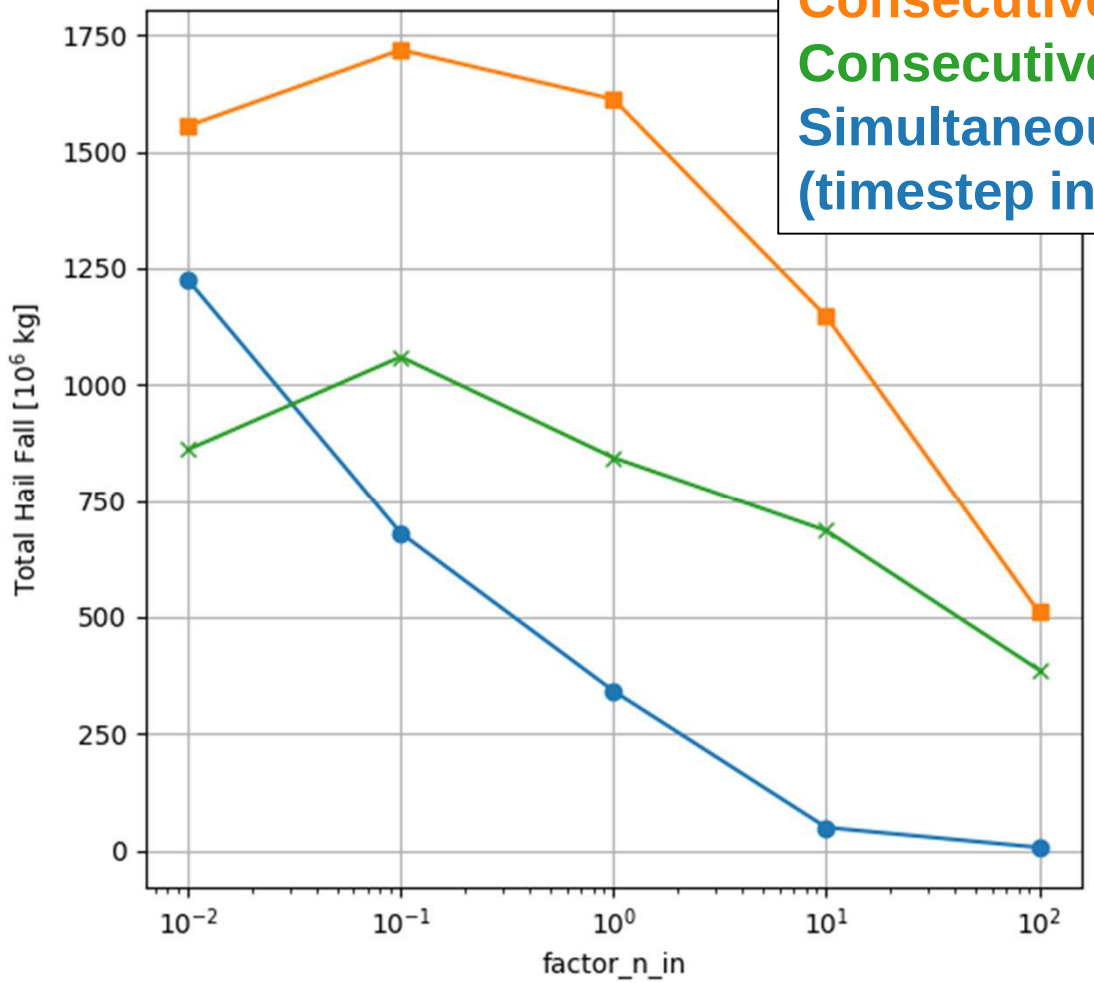




Average water content with height (in 2-moment scheme)



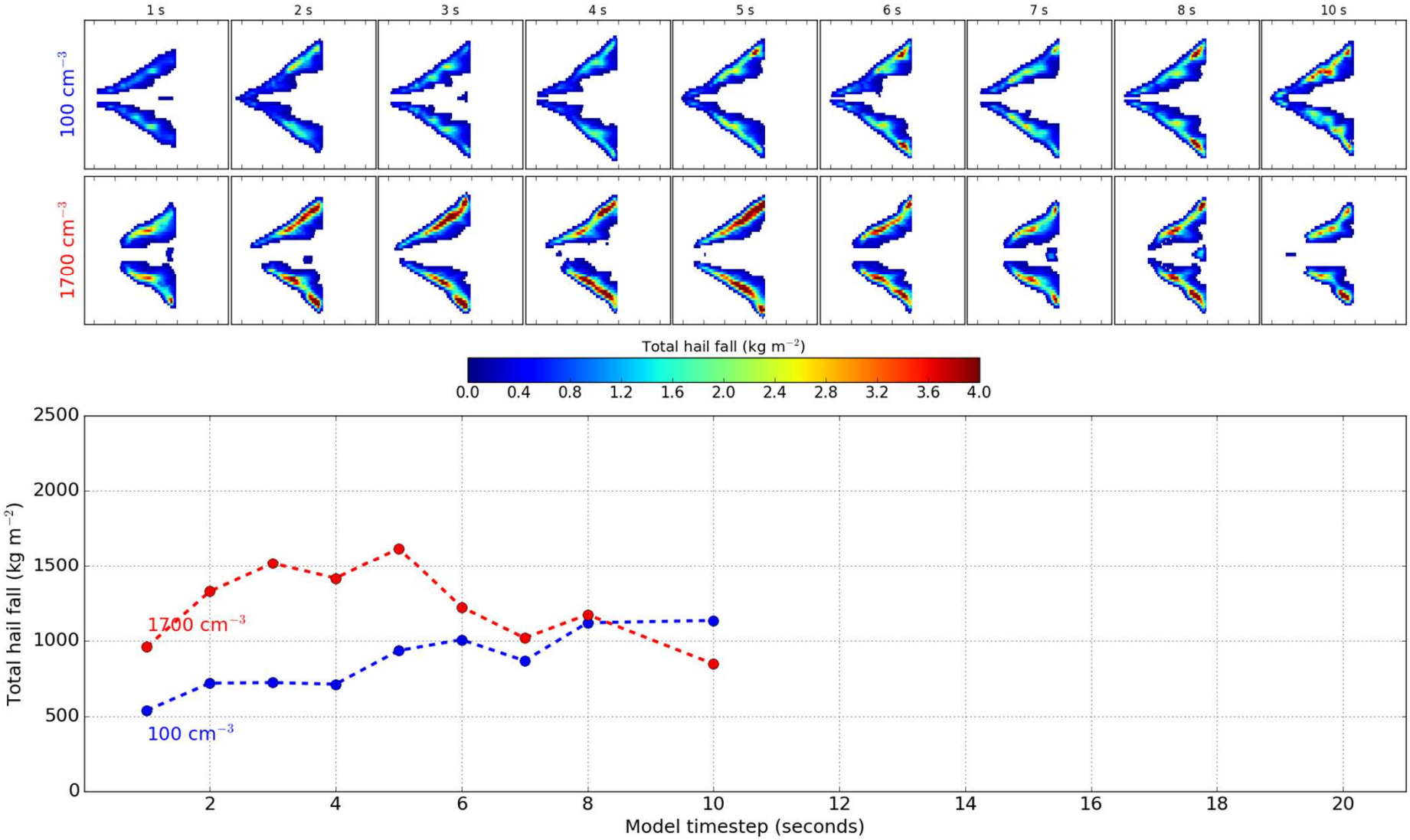
Splitting: changes sensitivity to ice nuclei



Consecutive Splitting #1
Consecutive Splitting #2
Simultaneous Splitting (timestep independent)

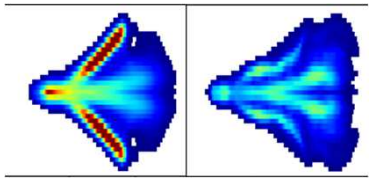
Sensitivity to changed model physics depends on choice of numerics

WRF simulations (2K): hail



Summary

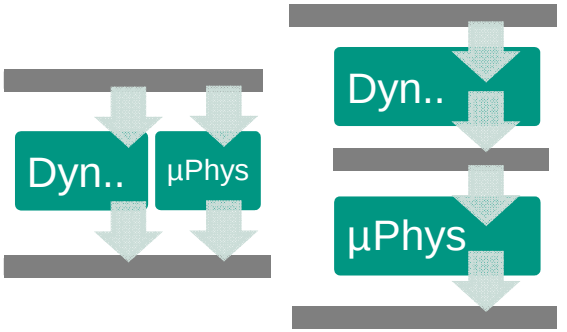
- Large and systematic effect of model timestep on convection-permitting simulations



50% increase in precipitation

50km change of maximum precipitation

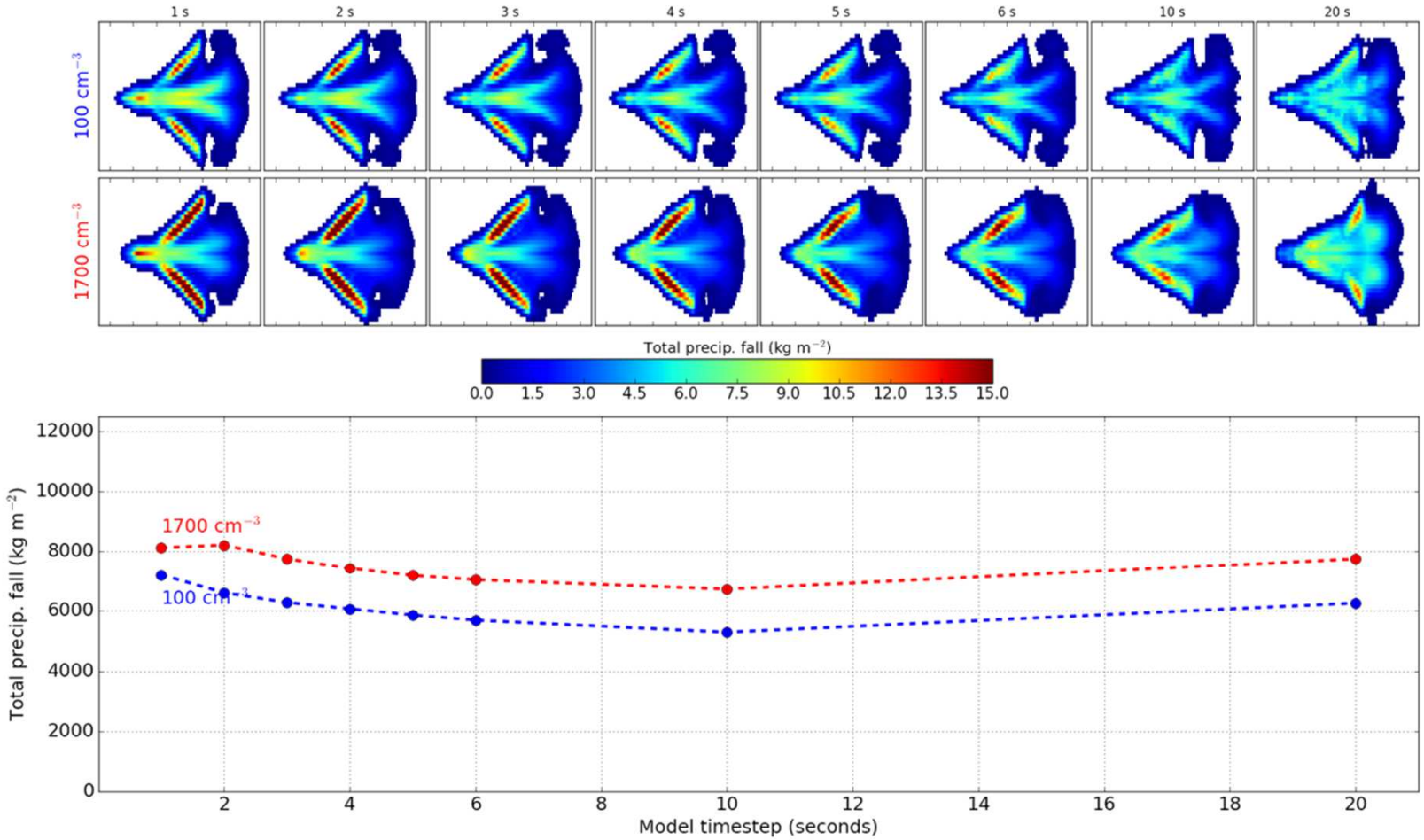
- Caused by “Consecutive Splitting”
  - Dynamics calculated first, then microphysics
  - Results much better with “Simultaneous Splitting”



- Affecting NWP simulations and sensitivity studies … in most (all?) models

- Solution: Changing input for microphysics – easy to change in model

Total precipitation: aerosol and timestep effects (with l2mom_satads=.TRUE.)



Total hail fall: aerosol and timestep effects (with l2mom_satads=.TRUE.)