Framework for Improvement by Vertical Enhancement: A simple approach to improve low and high level clouds in large scale models

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Low clouds in global models are ~~still poor~~ getting better.

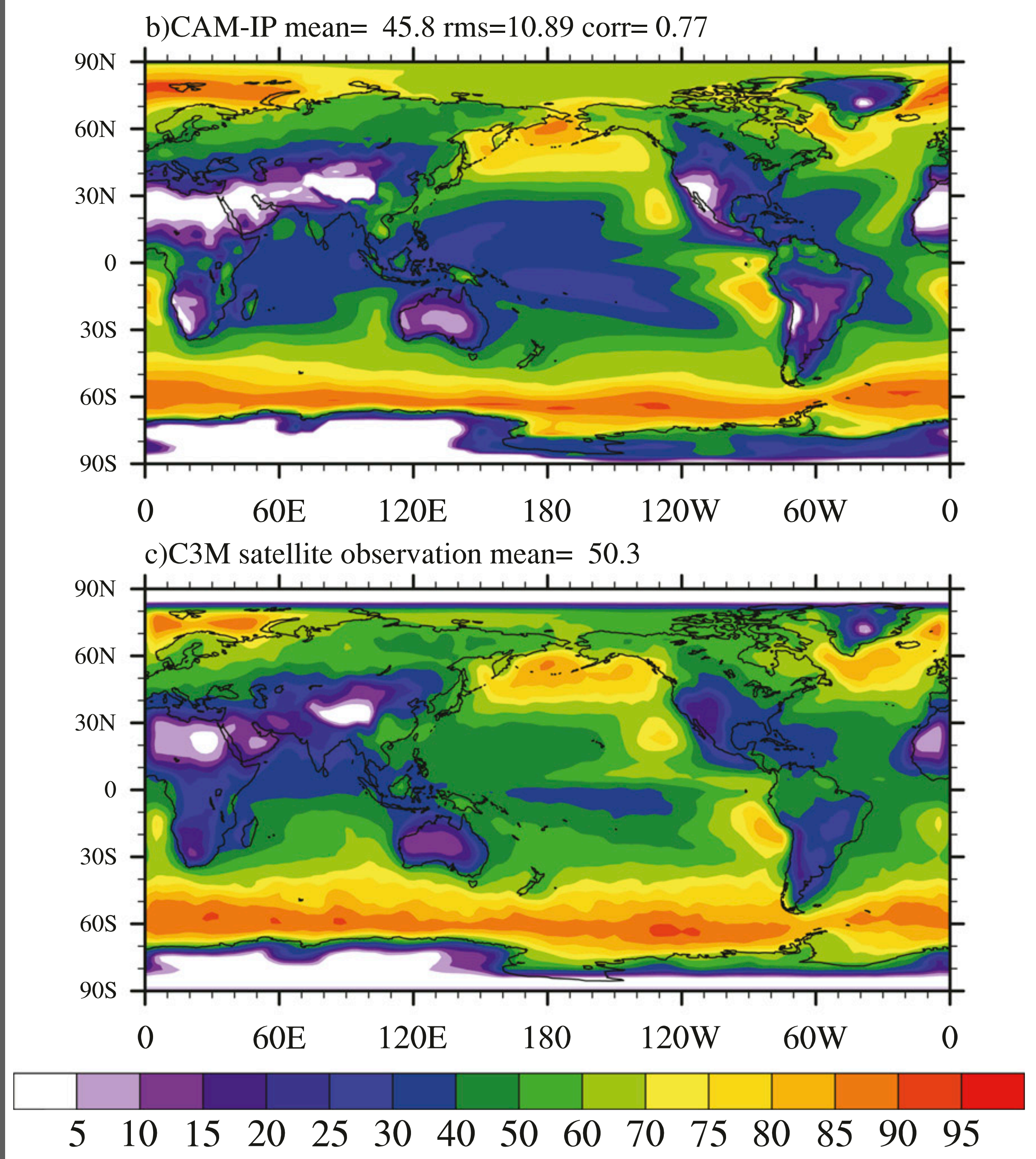
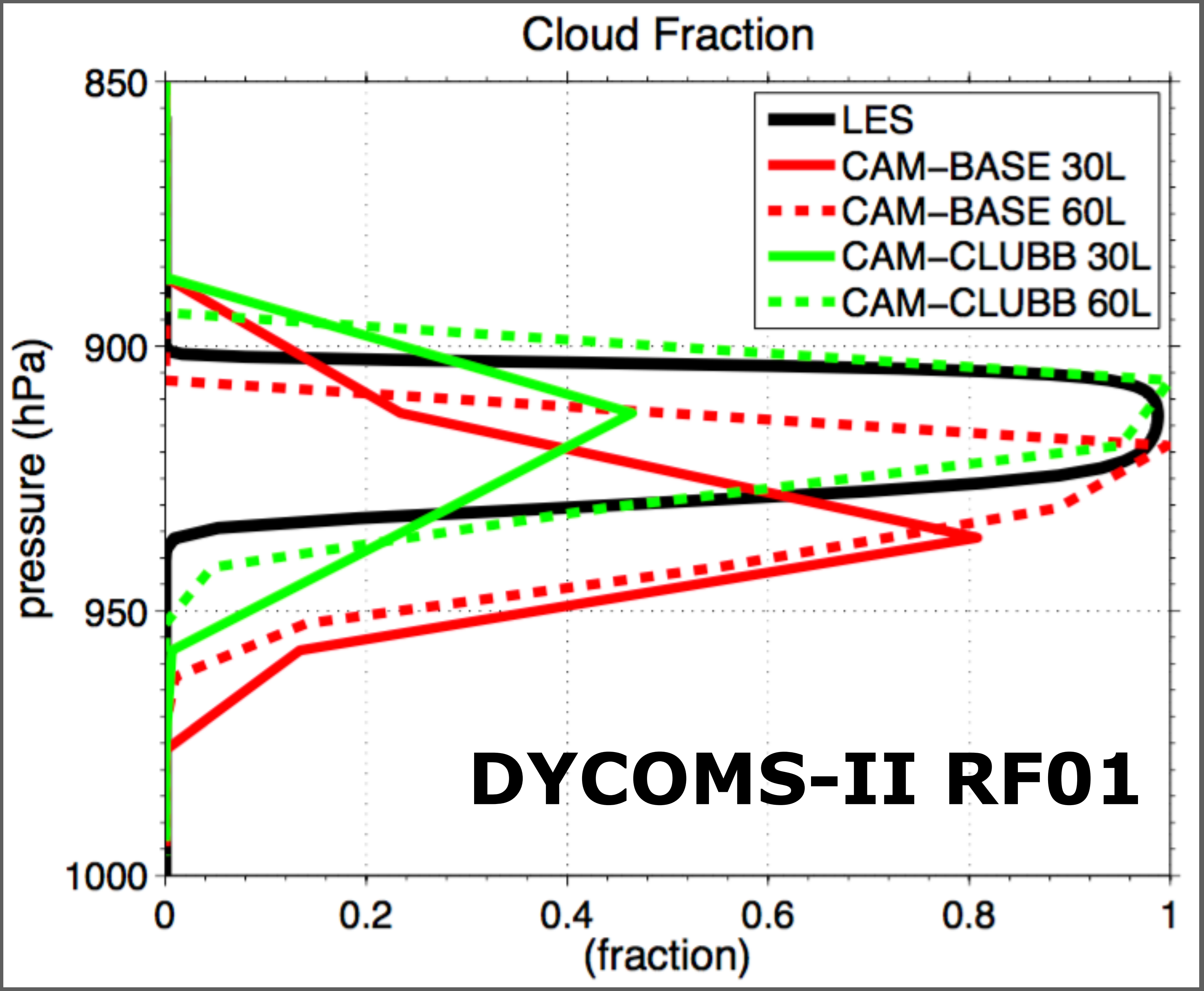


FIG. 3. Global distribution of annual-mean low-level (below 700 hPa) cloud amounts simulated

Cheng & Xu (2015): CAM5-IPHOC

Sensitivity on vertical resolution



Bogenschutz et al. (2012)

Sensitivity on vertical resolution

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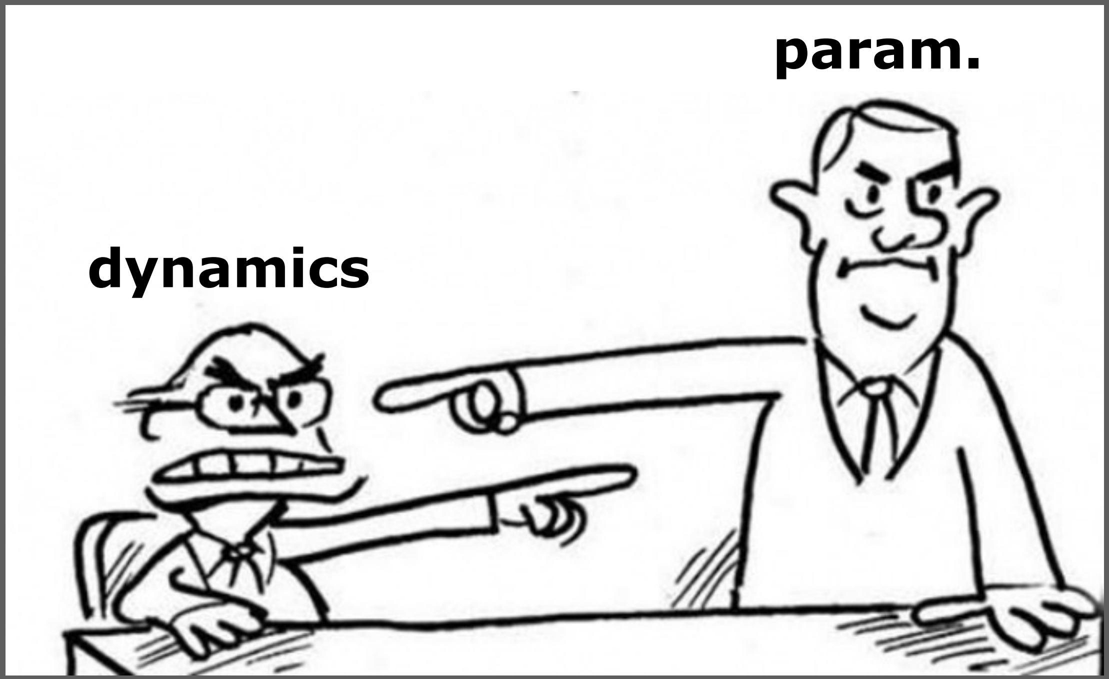
Key Points:
- Vertical grid spacing has a large impact on tropical cirrus clouds and OLR
- Vertical grid spacing of 400 m or less is needed to resolve cirrus structures

Vertical grid spacing necessary for simulating tropical cirrus clouds with a high-resolution atmospheric general circulation model

Tatsuya Seiki[1], Chihiro Kodama[1], Masaki Satoh[1,2], Tempei Hashino[3], Yuichiro Hagihara[4], and Hajime Okamoto[4]

What needs to be further improved?



or vertical resolution?

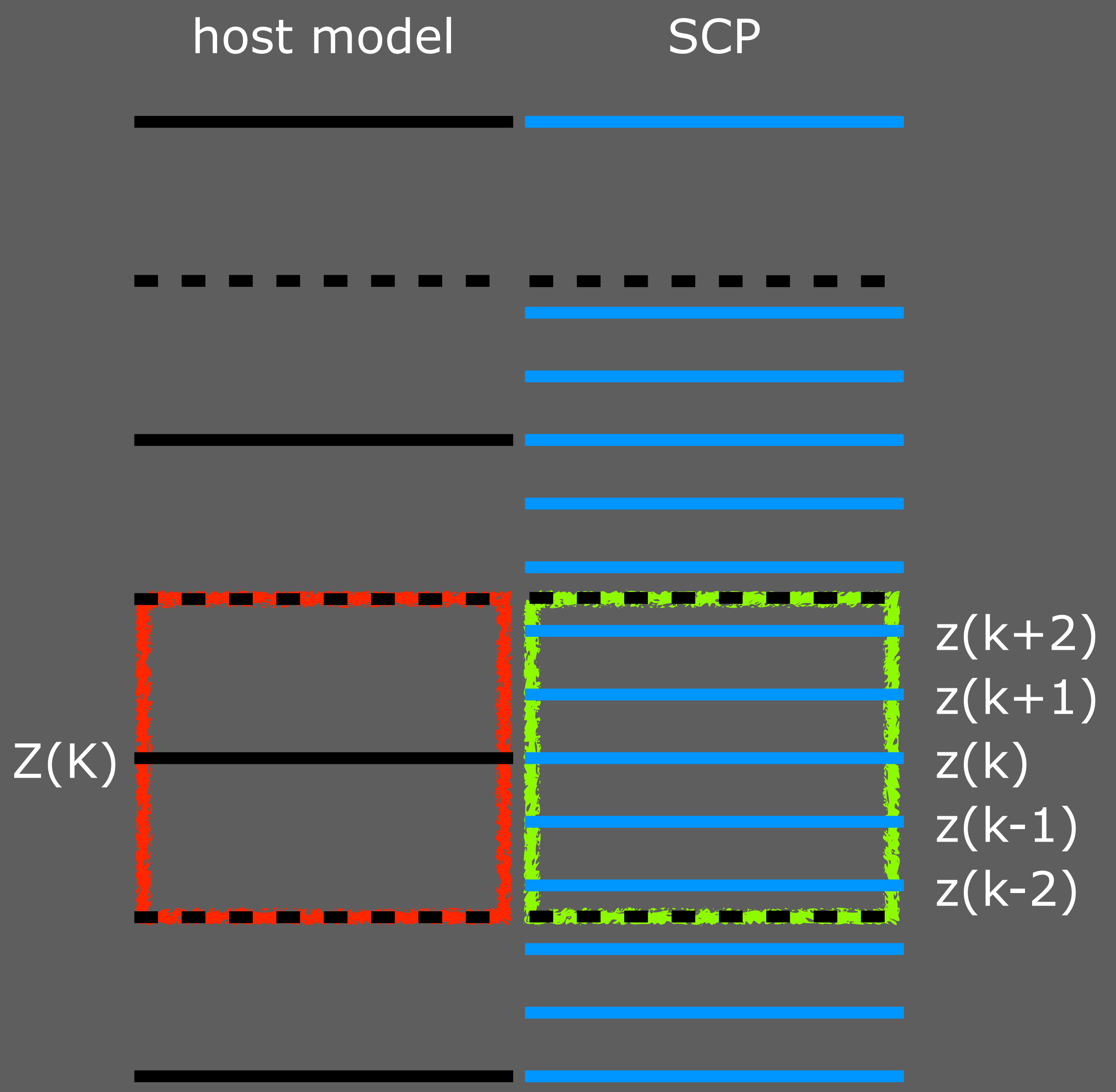
Model development takes time …

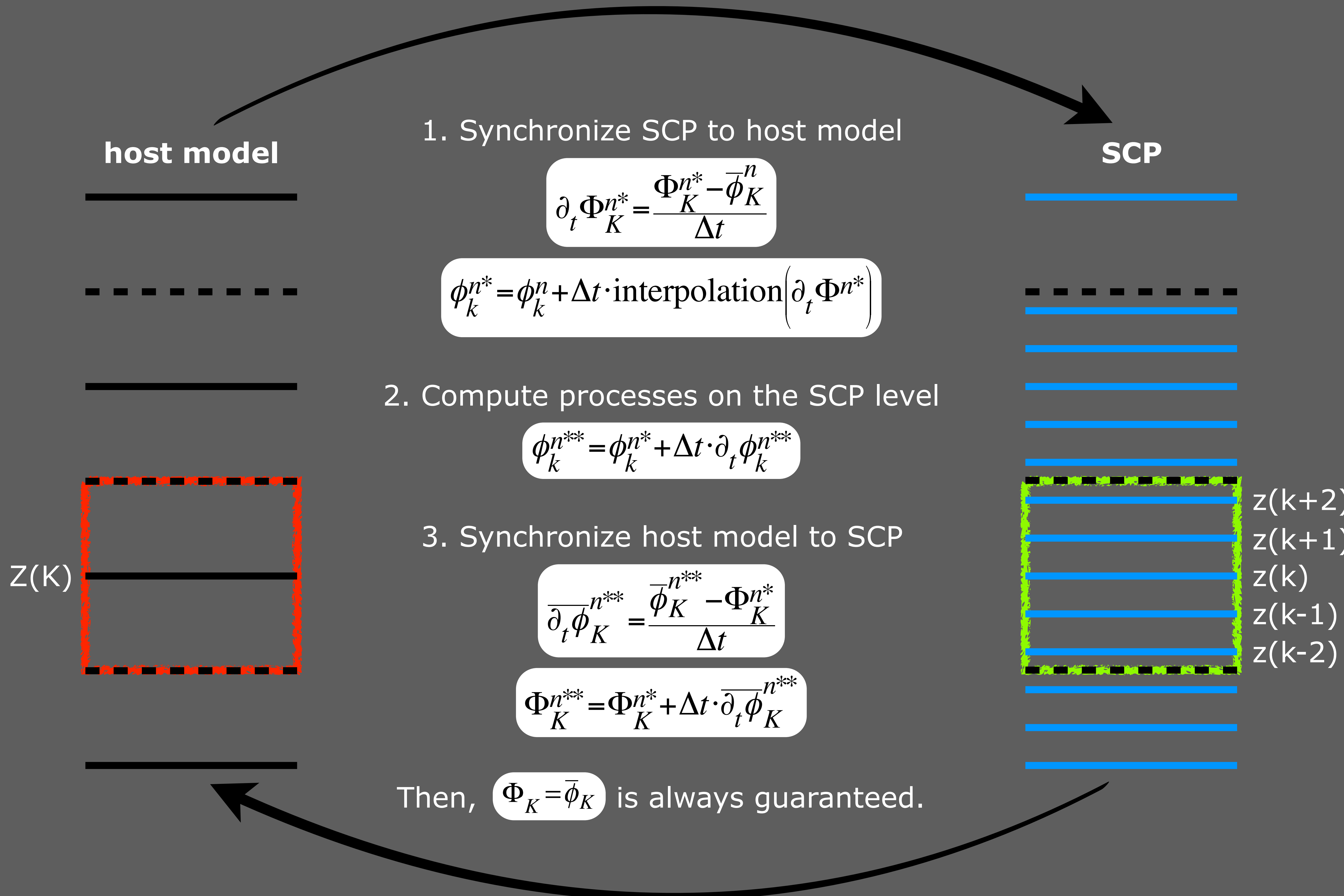
Using high vertical resolution is expensive …

Does using different Δz for different process improve simulation?

Framework for Improvement by Vertical Enhancement (FIVE)

- Selected processes are computed on a locally high resolution vertical grid.
  - "Locally" - PBL, cirrus region
  - Selected Column Physics (SCP)
- Variables are allocated and prediction is performed for both host model and SCP.
  - High resolution information is kept.
- Synchronization between host model and SCP is done by passing tendency back and forth.
- One constraint: Mass-weighted layer mean of SCP **always** has to be equal to the corresponding host model layer value.
- FIVE shares properties of MMF/nesting/ multigrid method.




host model
SCP
1. Synchronize SCP to host model
$\partial_t \Phi_K^{n*} = \frac{\Phi_K^{n*} - \overline{\phi}_K^{n}}{\Delta t}$
$\phi_k^{n*} = \phi_k^{n} + \Delta t \cdot \mathrm{interpolation}\left(\partial_t \Phi^{n*}\right)$
2. Compute processes on the SCP level
$\phi_k^{n**} = \phi_k^{n*} + \Delta t \cdot \partial_t \phi_k^{n**}$
3. Synchronize host model to SCP
$\overline{\partial_t \phi}_K^{n**} = \frac{\overline{\phi}_K^{n**} - \Phi_K^{n*}}{\Delta t}$
$\Phi_K^{n**} = \Phi_K^{n*} + \Delta t \cdot \overline{\partial_t \phi}_K^{n**}$
Then, $\Phi_K = \overline{\phi}_K$ is always guaranteed.
Z(K)
z(k+2)
z(k+1)
z(k)
z(k-1)
z(k-2)

Prototype FIVE

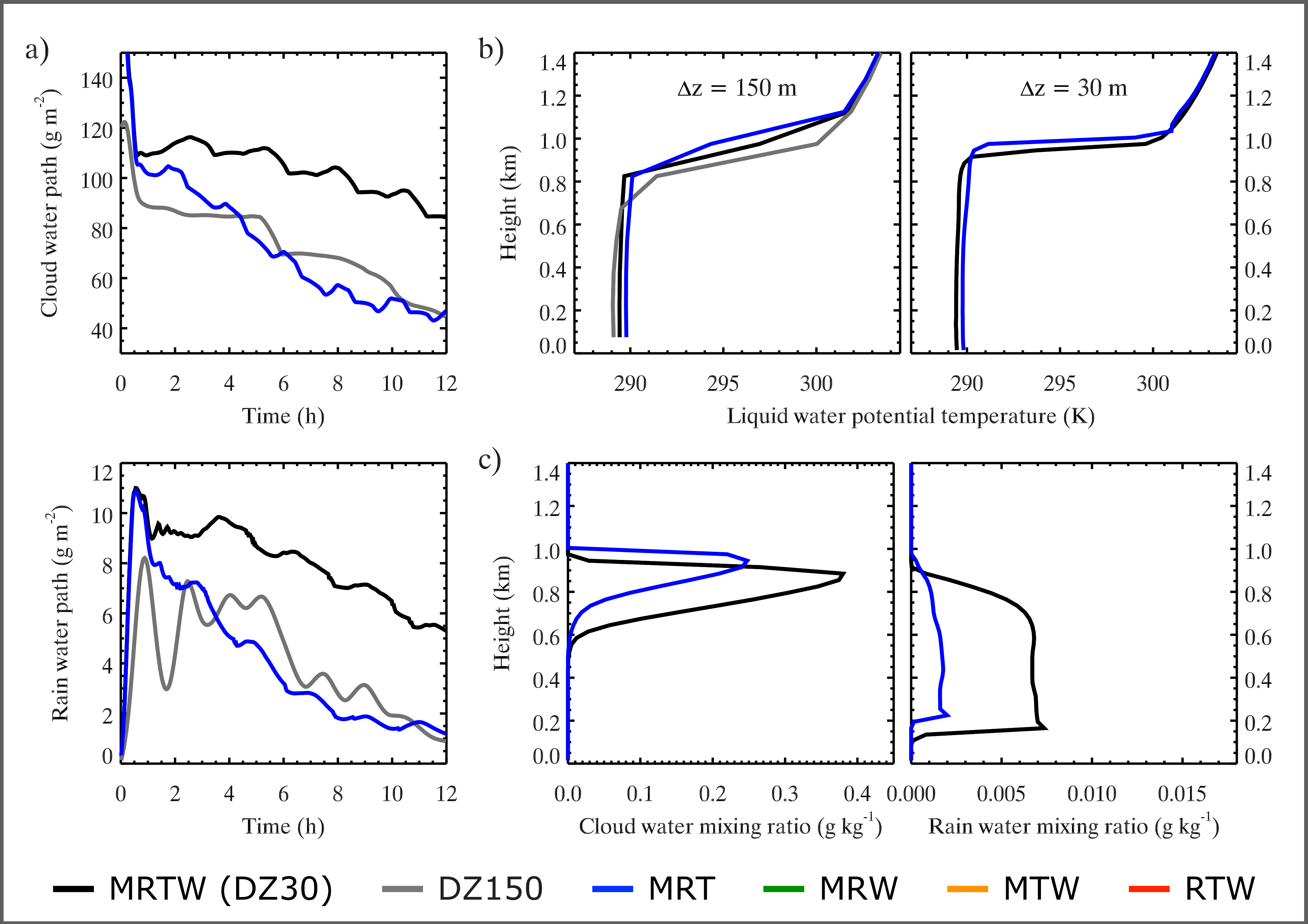
- FIVE is implemented in SAM-CLUBB.
  - SAM (Khairoutdinov and Randall 2003)
  - CLUBB (Larson and Golaz 2005)
- Processes can be computed in SCP
  - Microphysics,
  - Radiation,
  - Turbulence (CLUBB), and
  - Vertical advection due to large scale w.
- This version of SAM-CLUBB can be run as a SCM.

Testing FIVE: SCM simulations

- DYCOMS-II RF02 (Ackerman et al. 2009)
- 12-h duration
- For SCM setup, MRTW is equivalent to DZ30.

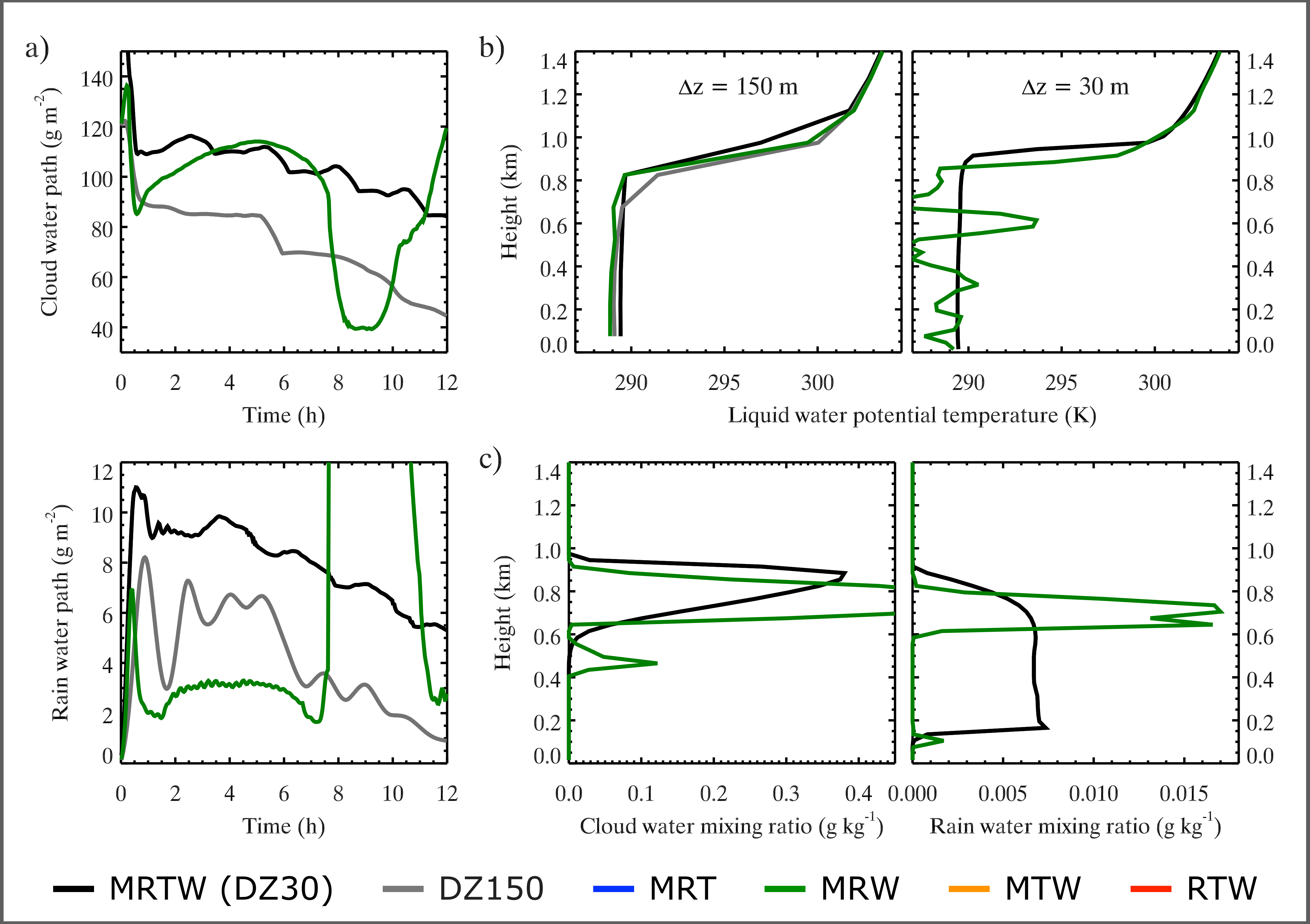
cases	ΔZ (m)	Δz (m)	processes on SCP
DZ30	30	30	n/a
DZ150	150	150	n/a
M	150	30	microphysics
R			radiation
T			turbulence
W			vertical advection
MR			microphysics, radiation
...			...
MRT			micro., radiation, turb.
...			...

1D results



a)
Cloud water path (g m-2)
Time (h)
Rain water path (g m-2)
Time (h)
b)
Δz = 150 m
Δz = 30 m
Height (km)
Liquid water potential temperature (K)
c)
Height (km)
Cloud water mixing ratio (g kg-1)
Rain water mixing ratio (g kg-1)
MRTW (DZ30)
DZ150
MRT
MRW
MTW
RTW

1D results



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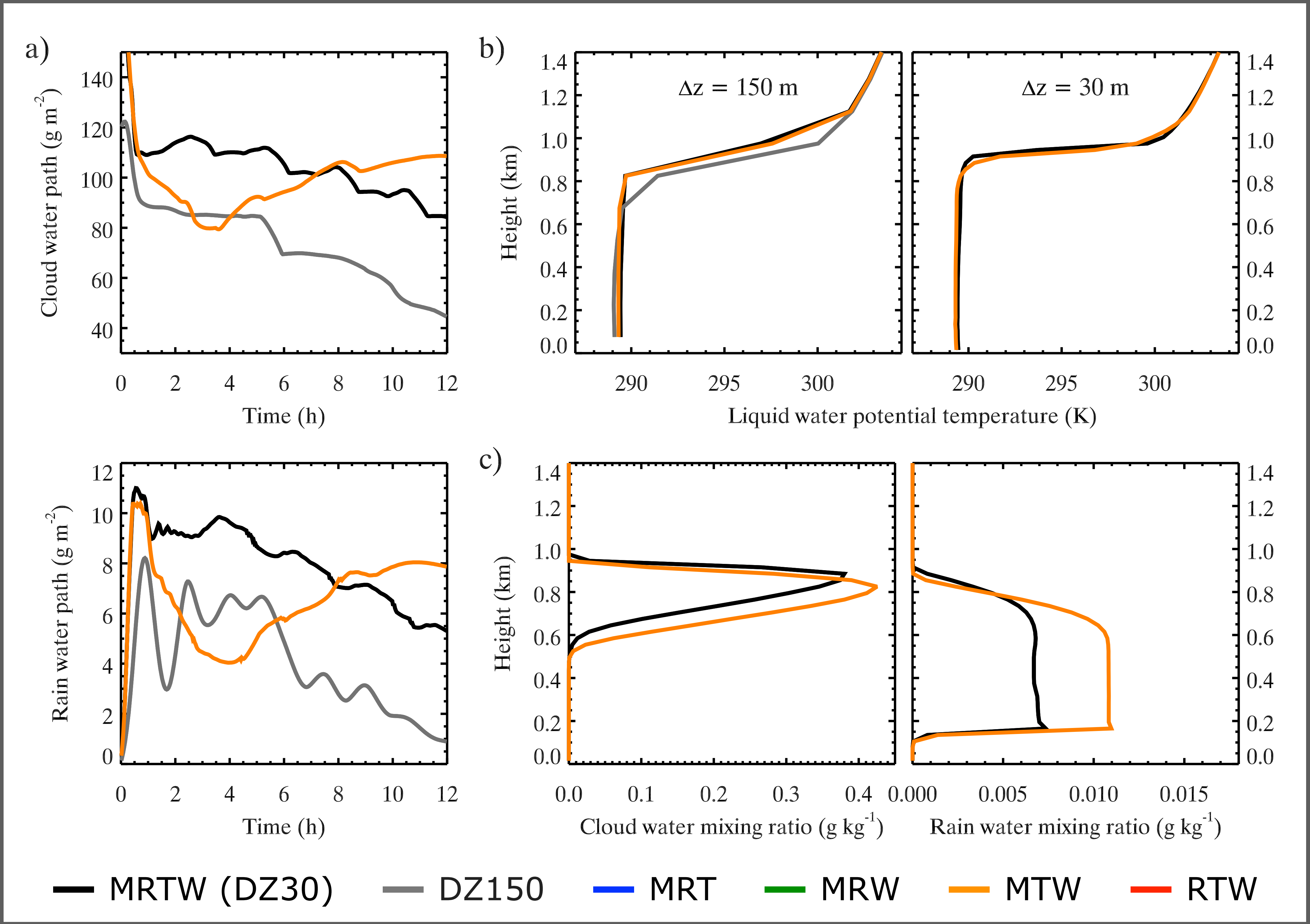
MRTW (DZ30)
DZ150
MRT
MRW
MTW
RTW

1D results



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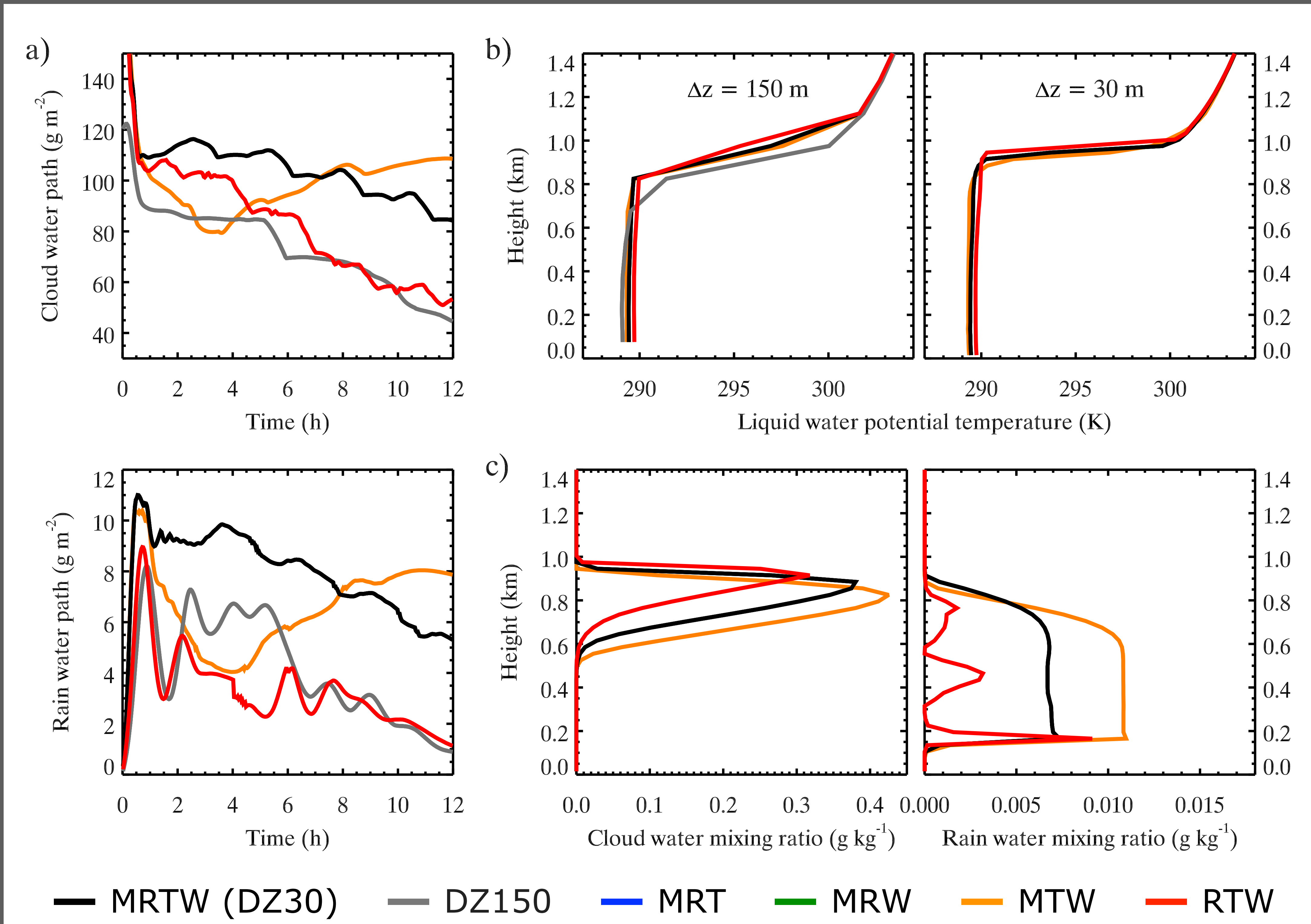
MRTW (DZ30)
DZ150
MRT
MRW
MTW
RTW

1D results



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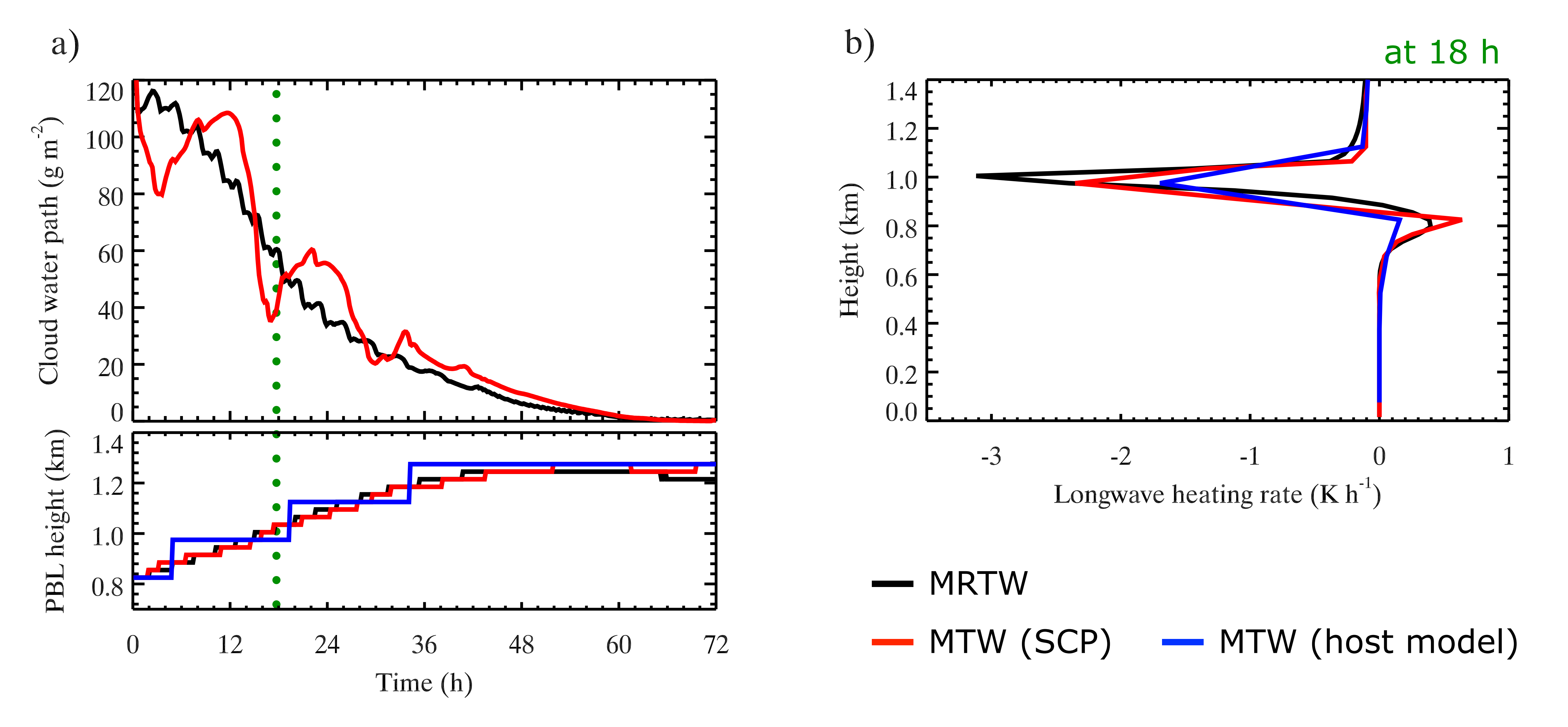
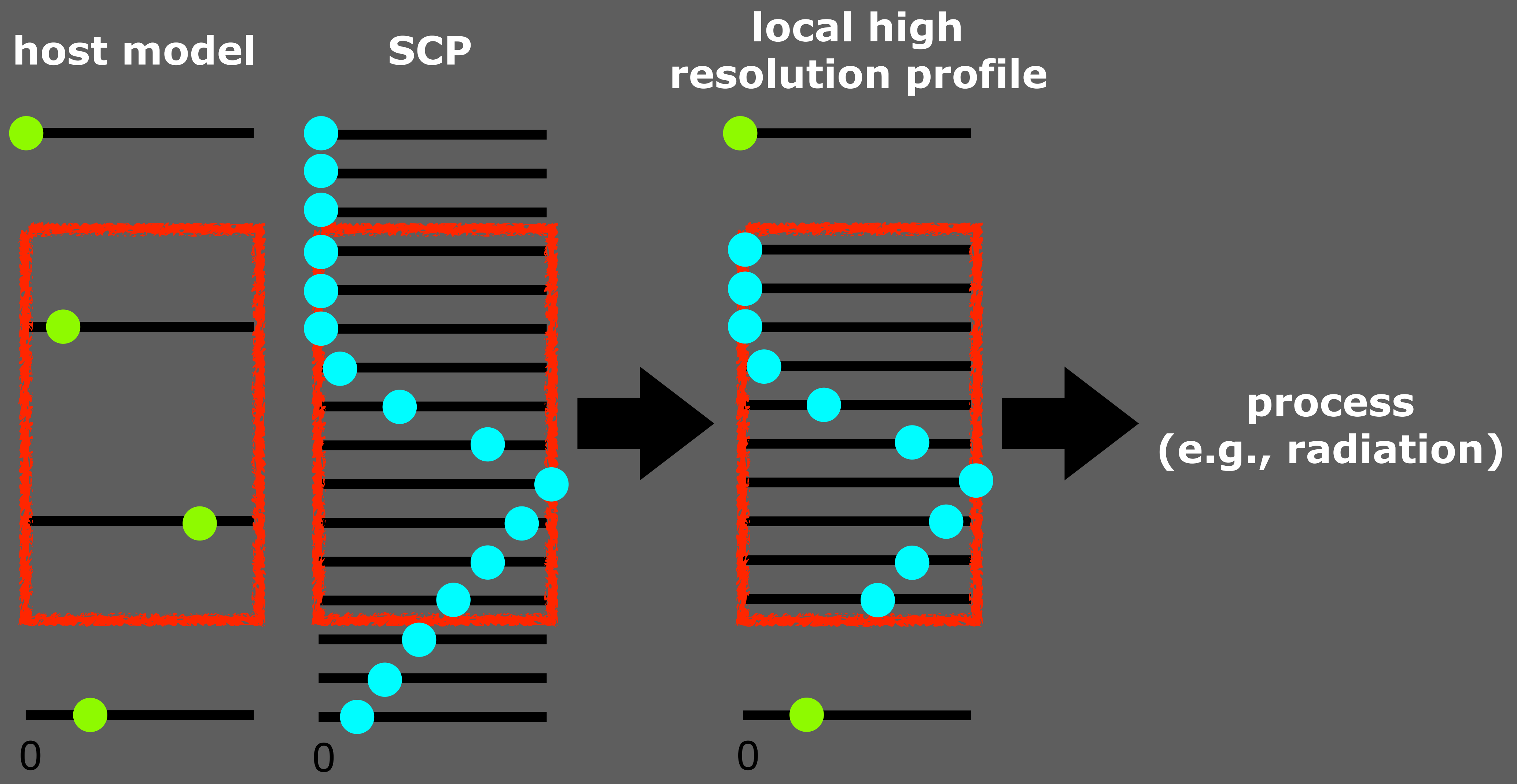
MRTW (DZ30)
DZ150
MRT
MRW
MTW
RTW

Interpolation causes the oscillation for MTW.

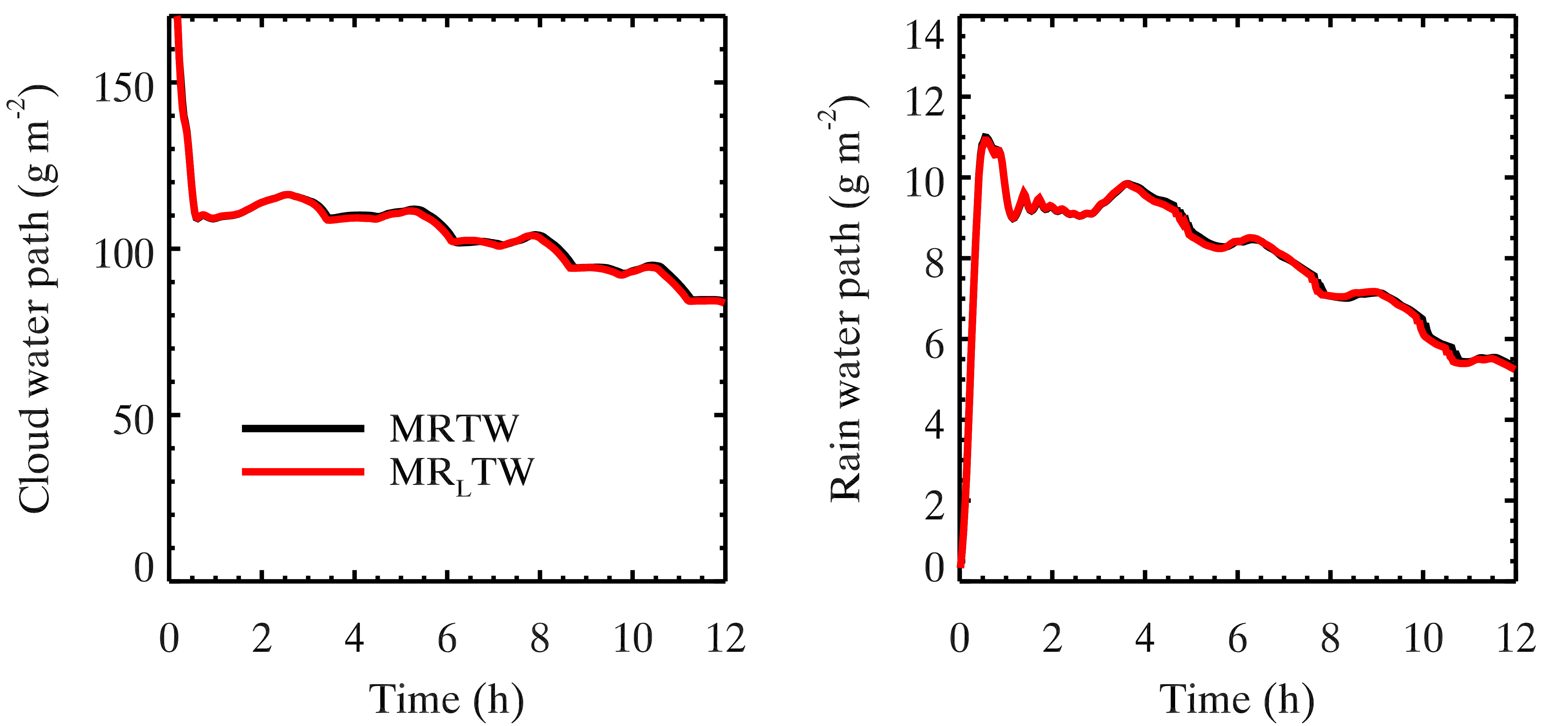


Local vertical mesh refinement

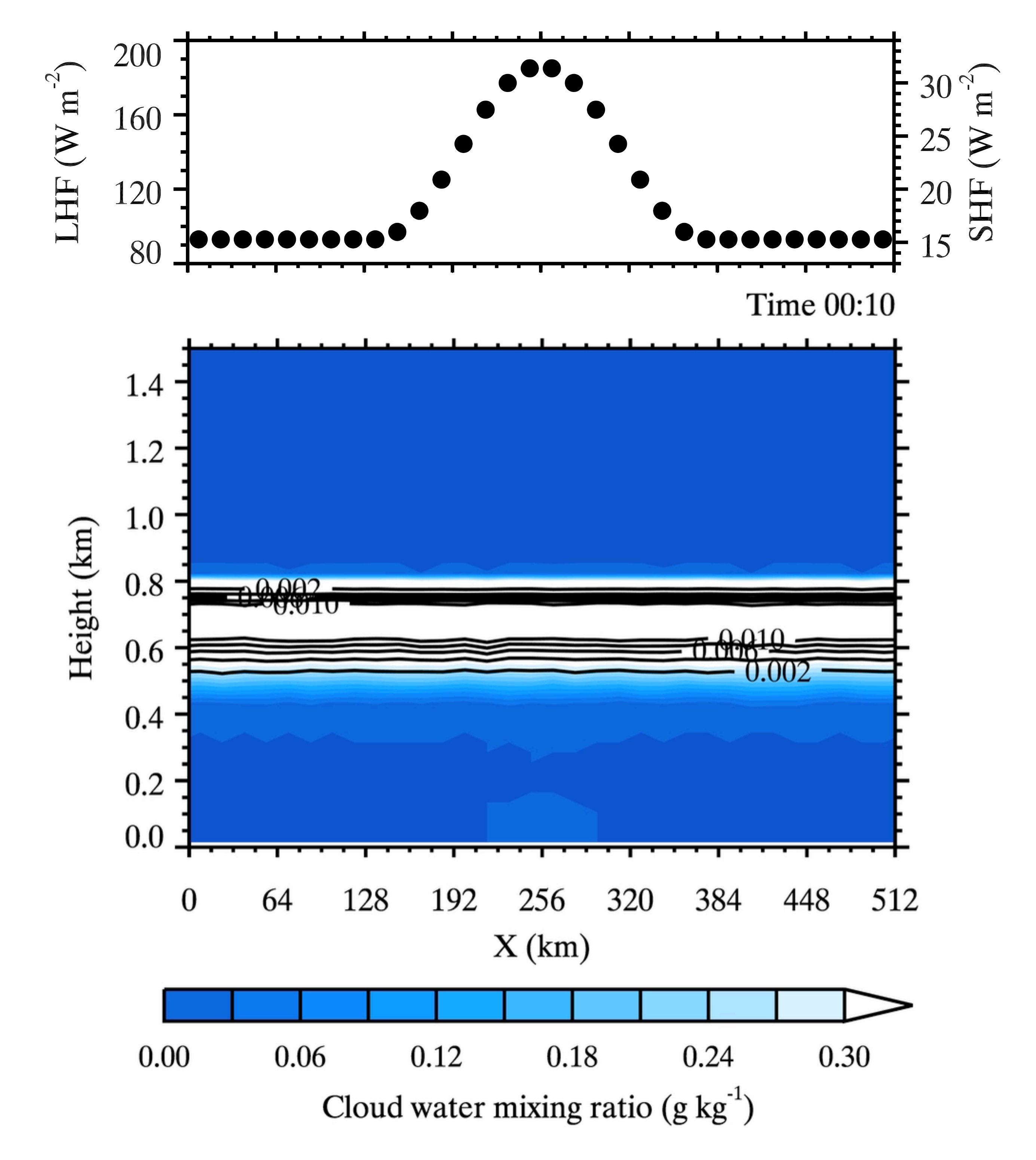


Since FIVE always has the high resolution profiles,
no interpolation is necessary for mesh refinement.

MTW + local mesh refinement for radiation = MR_LTW

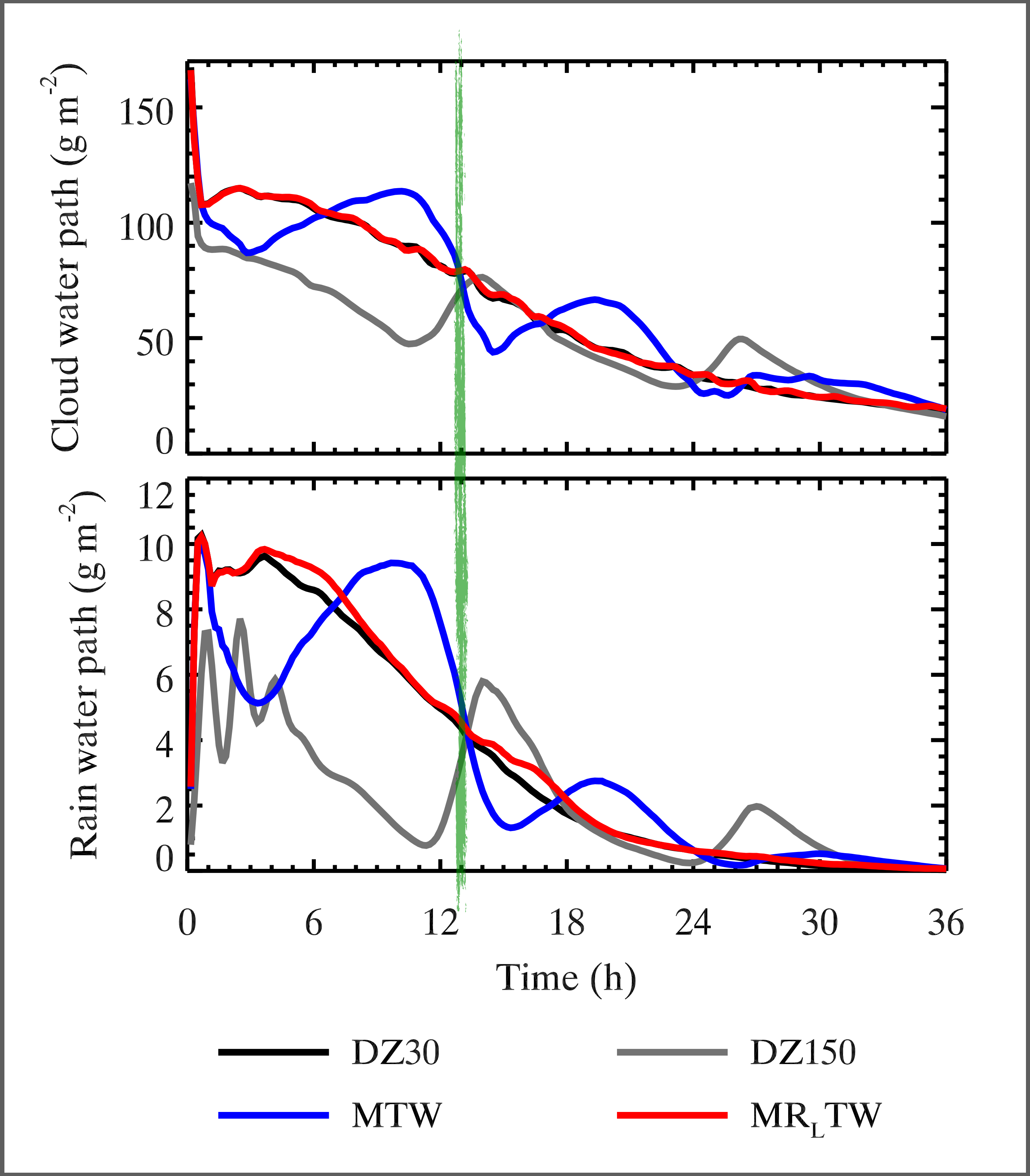


2D test



- DYCOMS-II RF02
- N_x = 32 and Δx = 16 km
- Duration: 36 h
- Modification to have stronger horizontal gradient:
  - A warm pool (i.e., stronger surface fluxes) and
  - Stronger u wind.

2D test



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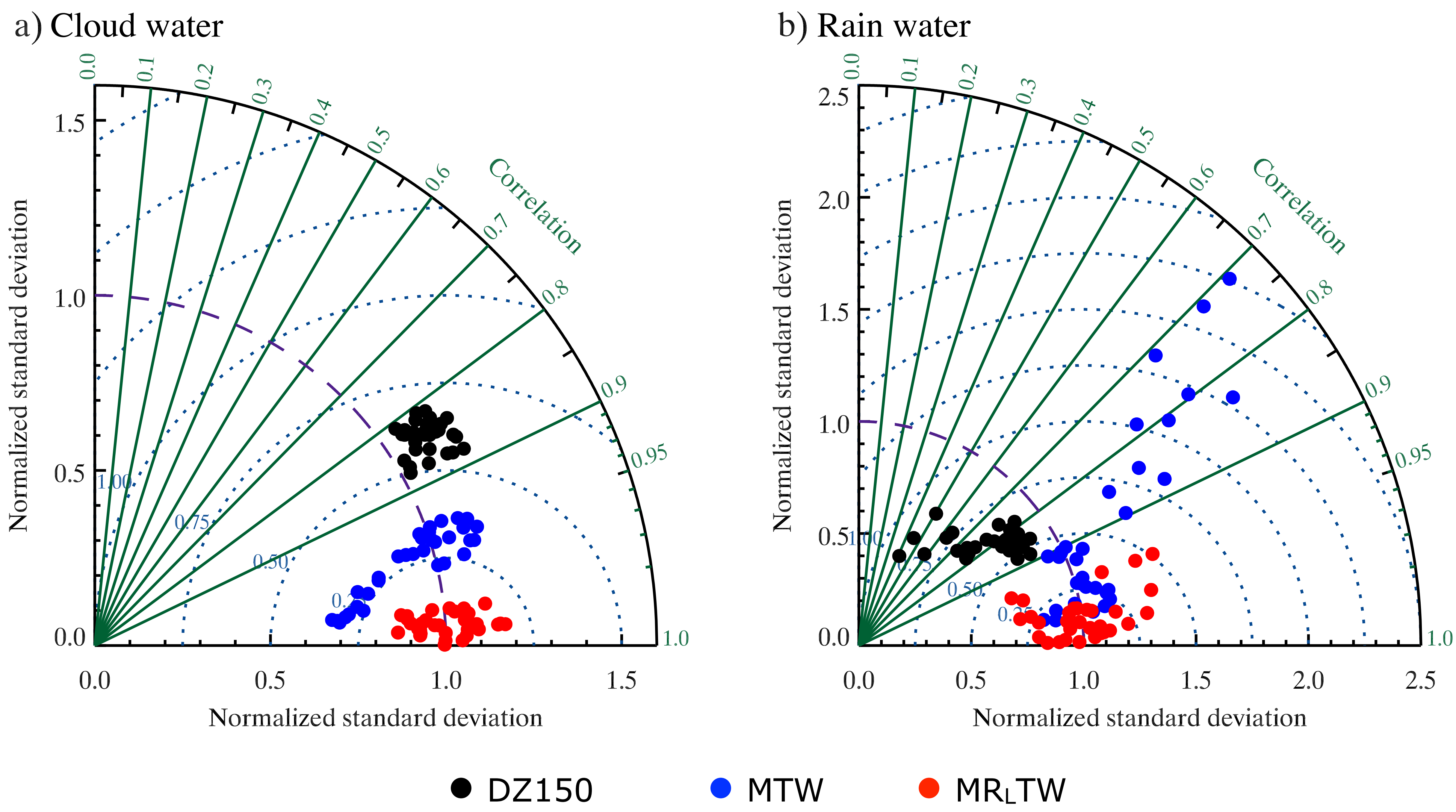
a) Cloud water
b) Rain water
Correlation
Normalized standard deviation
DZ150
MTW
MR$_L$TW

Summary and outlook

- FIVE is introduced to better represent low and high clouds.
- Prototype FIVE
  - All vertical transports are required to be computed in SCP.
  - Radiation may be computed on the host model but incurs an unphysical oscillation.
  - Local vertical mesh refinement circumvents the oscillation.
- Further development/test of FIVE
  - Improve the interpolation scheme using high resolution profiles.
  - Test with GCM, CSRM.
  - Cirrus clouds