Improving Simulated Low Clouds in CSRM/GCM with Dual Vertical Resolution Framework

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

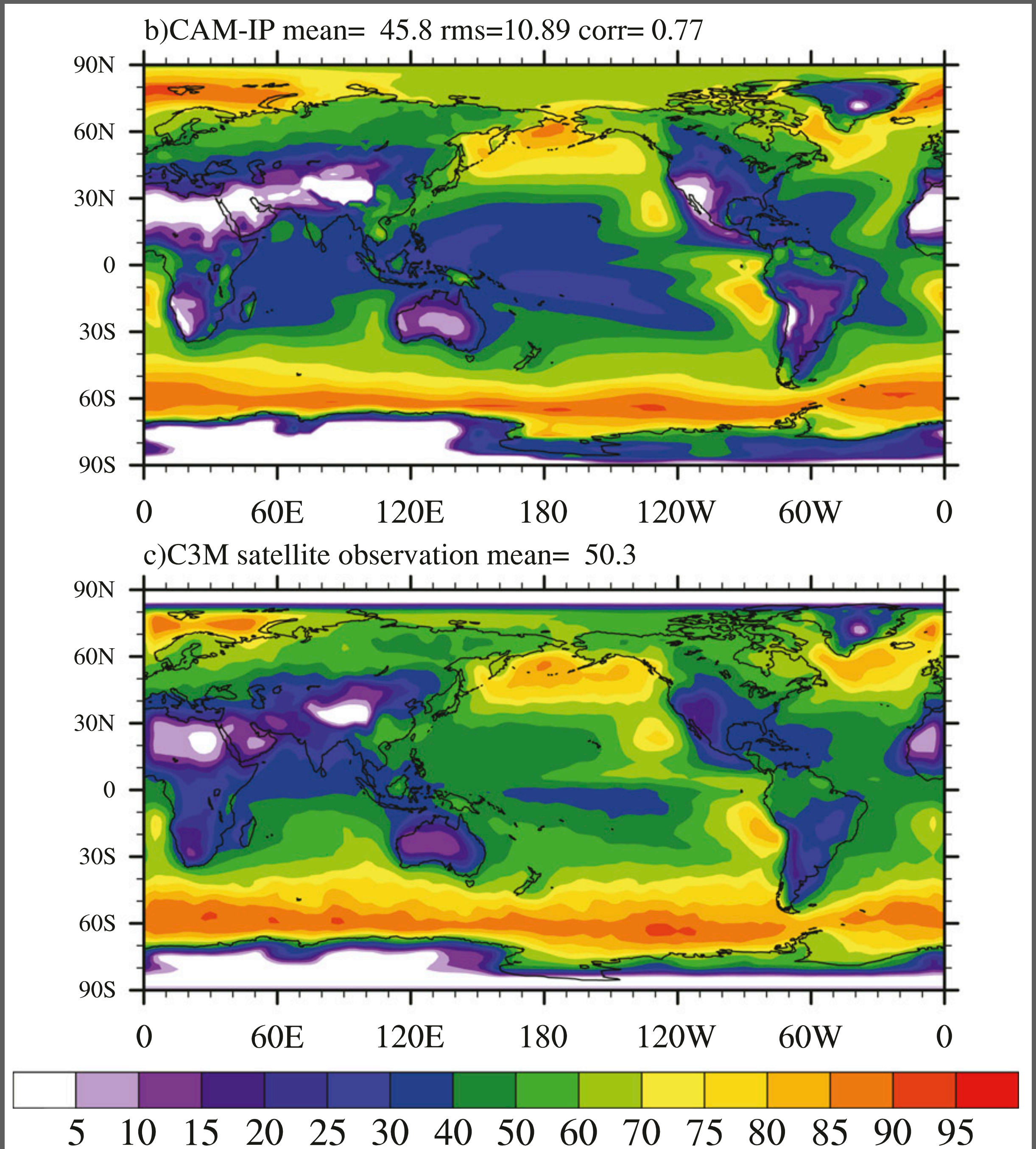
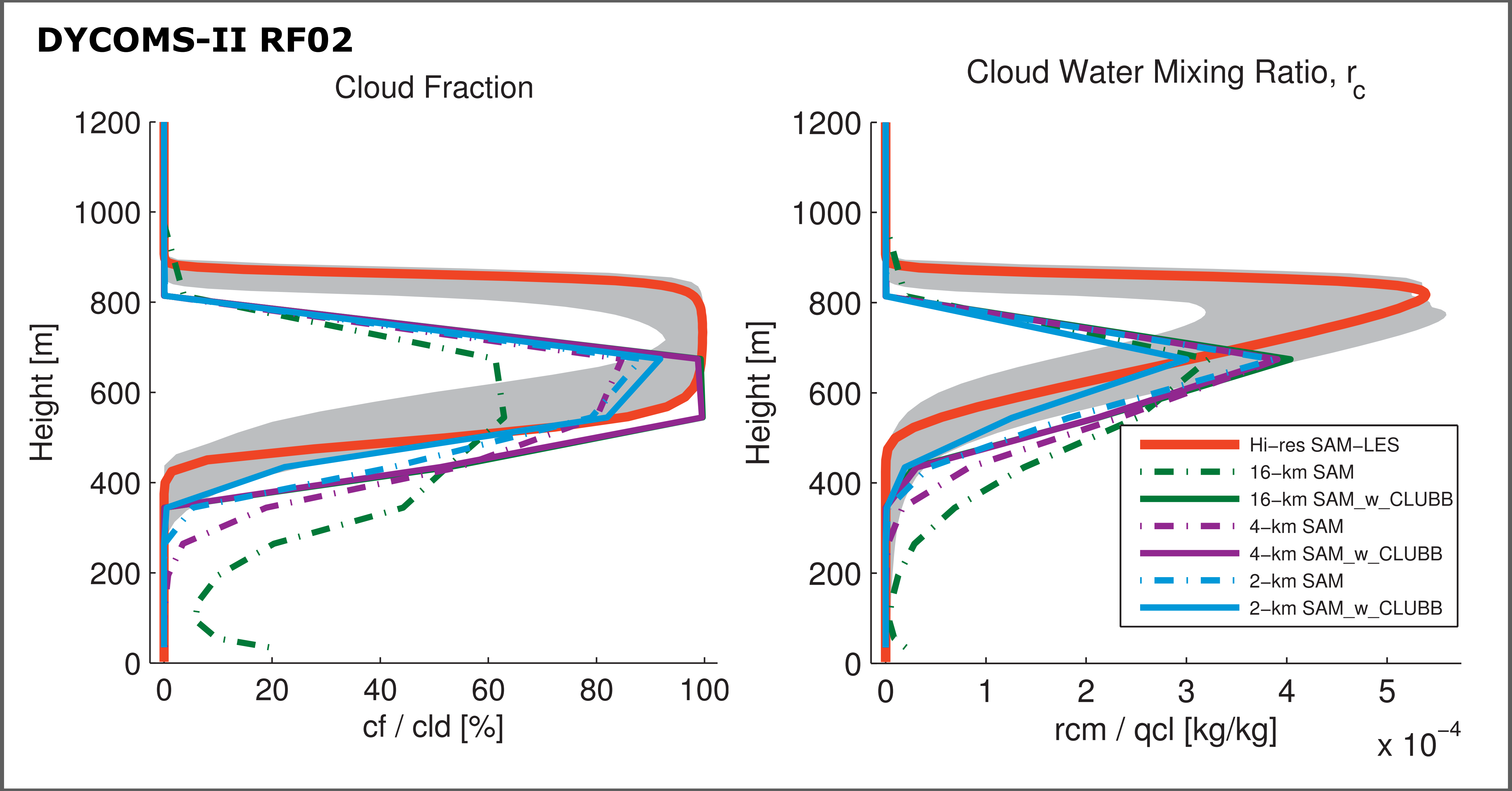


FIG. 3. Global distribution of annual-mean low-level (below 700 hPa) cloud amounts simulated

Cheng & Xu (2015): CAM5-IPHOC

- GCM
  - CAM5-CLUBB (Bogenschutz et al. 2013)
  - AM3-CLUBB (Guo et al. 2014)
  - CAM5-IPHOC (Cheng and Xu 2015)
- MMF
  - SPCAM-IPHOC (Cheng & Xu 2011)
  - SPCAM-CLUBB (Wang et al. 2015)

PBL parameterization improves low clouds in CSRM.



Larson et al. (2012): SAM-CLUBB (90-level stretch grid, Δz ~ 140 m at 1 km)

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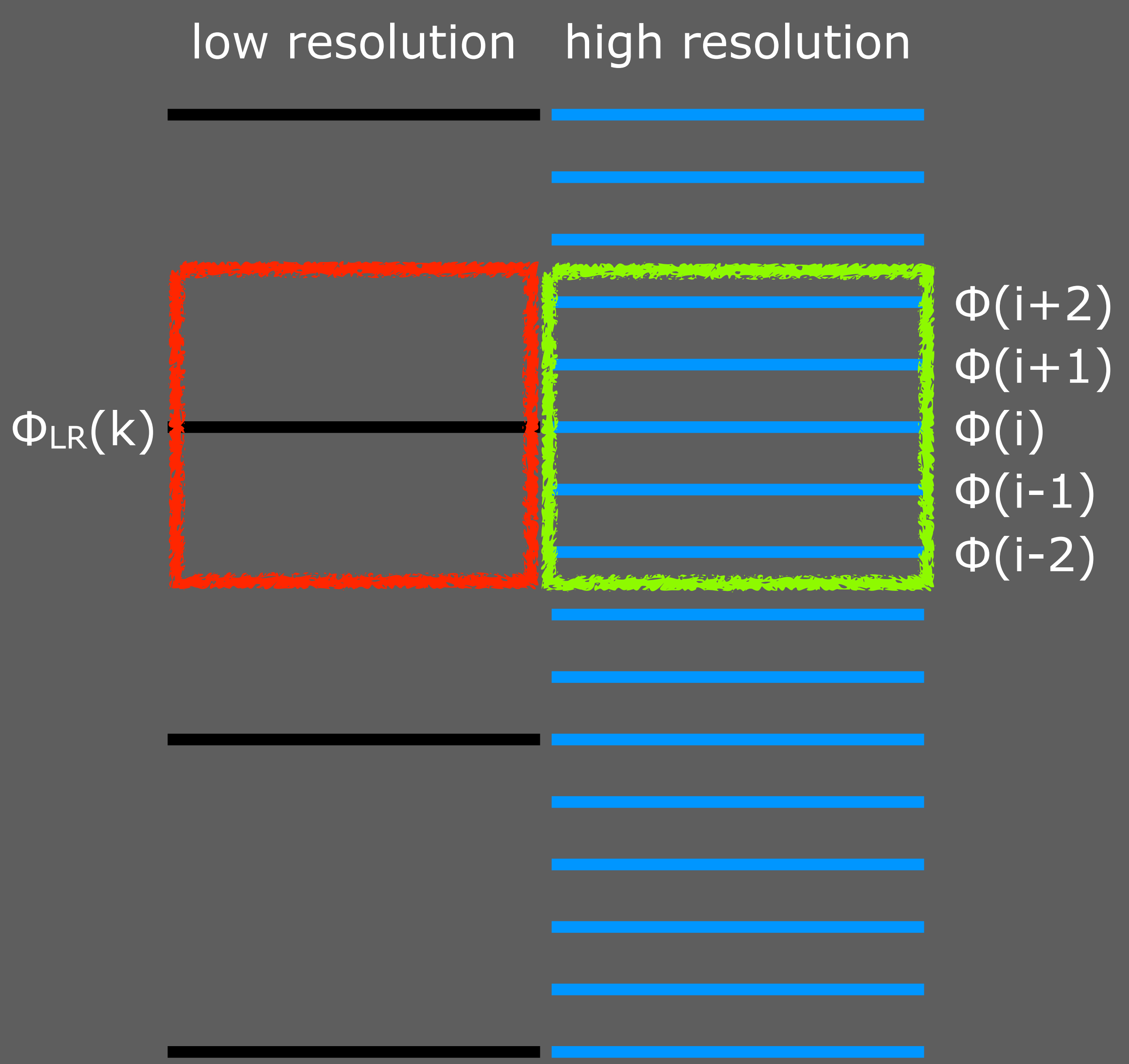
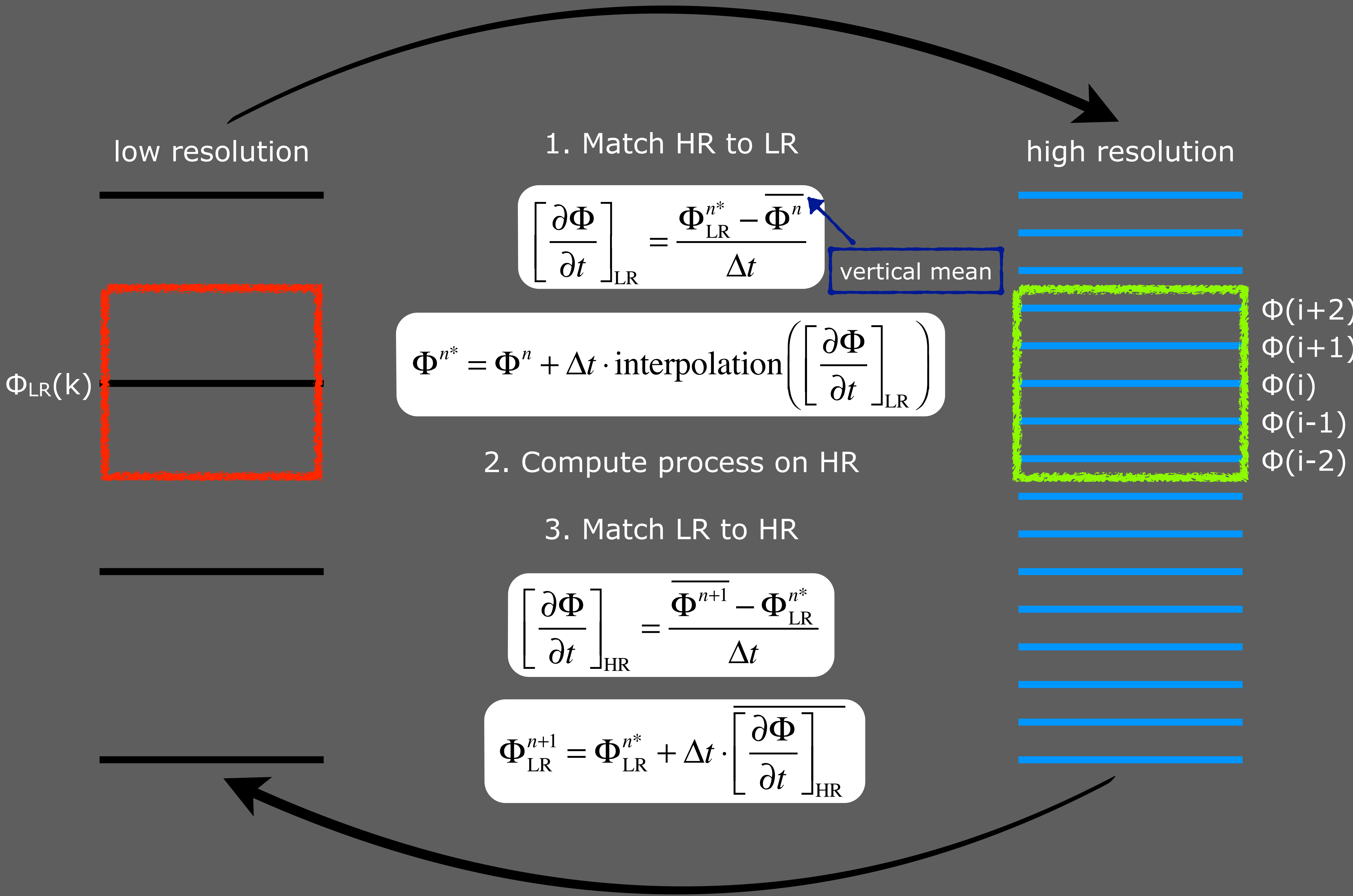
Which processes are more sensitive to Δz?

Dual Vertical Resolution Framework (DVRF)

- A model updates quantities on two vertical levels: low resolution (LR) and high resolution (HR).
- Each process is computed on either LR or HR level.
- One constraint: Mass-weighted layer mean of HR value **always** has to be equal to the corresponding LR value. i.e., $\Phi_{LR}(k) = \Sigma[\rho(i)\Phi(i)\Delta z(i)] / \rho_{LR}(k)$
- DVRF = MMF type approach in z





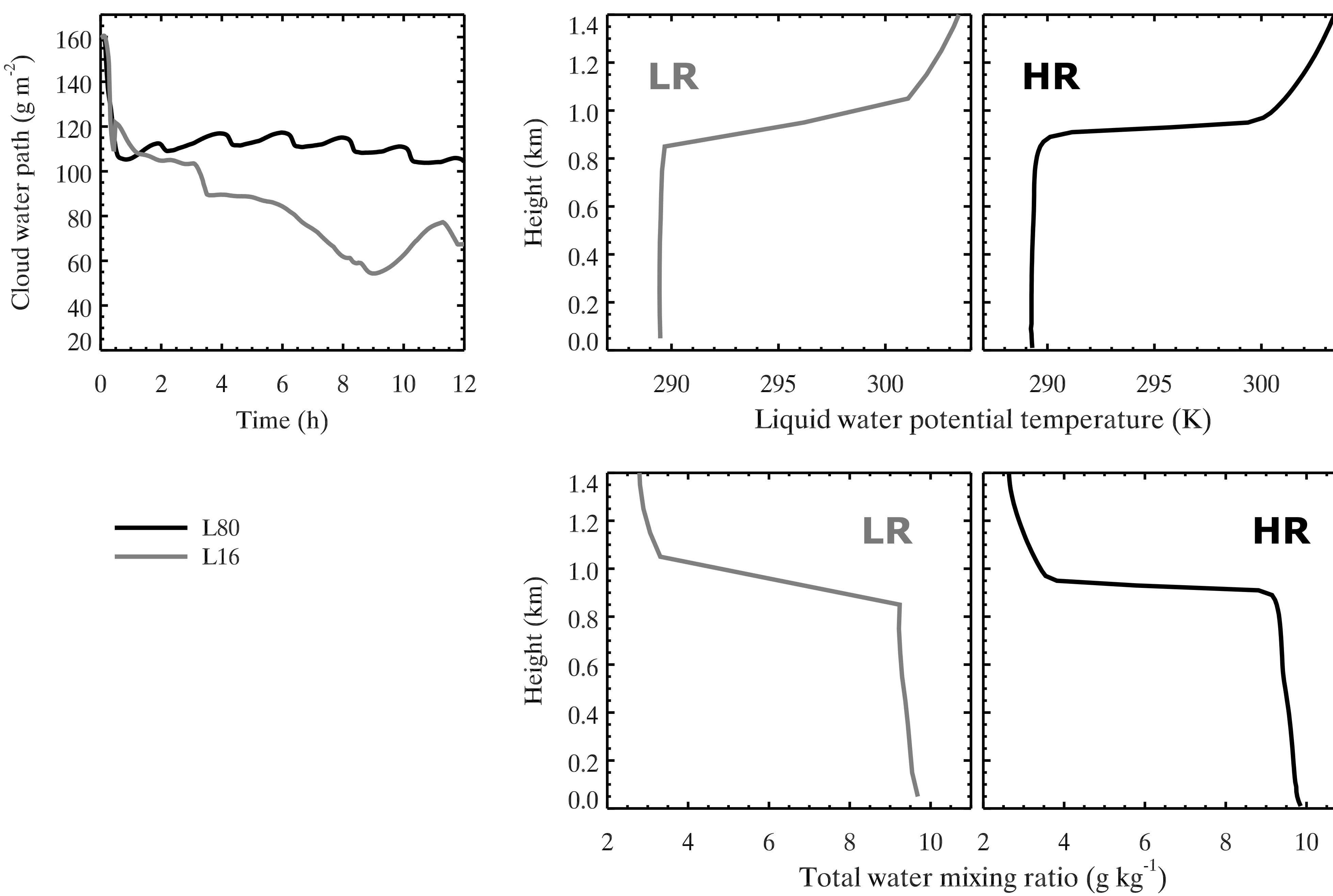
A new LR tendency interpolation scheme satisfies the constraint between LR and HR.

DVRF in SAM-CLUBB

- DVRF is implemented in SAM-CLUBB.
- CLUBB, microphysics, radiation, and vertical advection for scalar can be processed on HR.
- Prognostic variables on HR: u, v, LWSE, micro.
- w & subsidence are linearly interpolated from LR.
- This version of SAM-CLUBB can be run as a 1D model.
- Tests are performed for DYCOMS-II RF02 (nocturnal drizzling stratocumulus case): Δx = 16 km, Δt = 10 s, 12-h duration, GCSS simple LW code.

	Δz_{LR} (m)	Δz_{HR} (m)	processes on HR
L80	20	20	n/a
L16	100	100	n/a
L16-H80-C			CLUBB
L16-H80-M			microphysics
L16-H80-R			radiation
L16-H80-W	100	20	vertical advection
L16-H80-CM			CLUBB, microphysics
L16-H80-CR			CLUBB, radiation
...			...

1D results: (1) CLUBB needs to be on HR.



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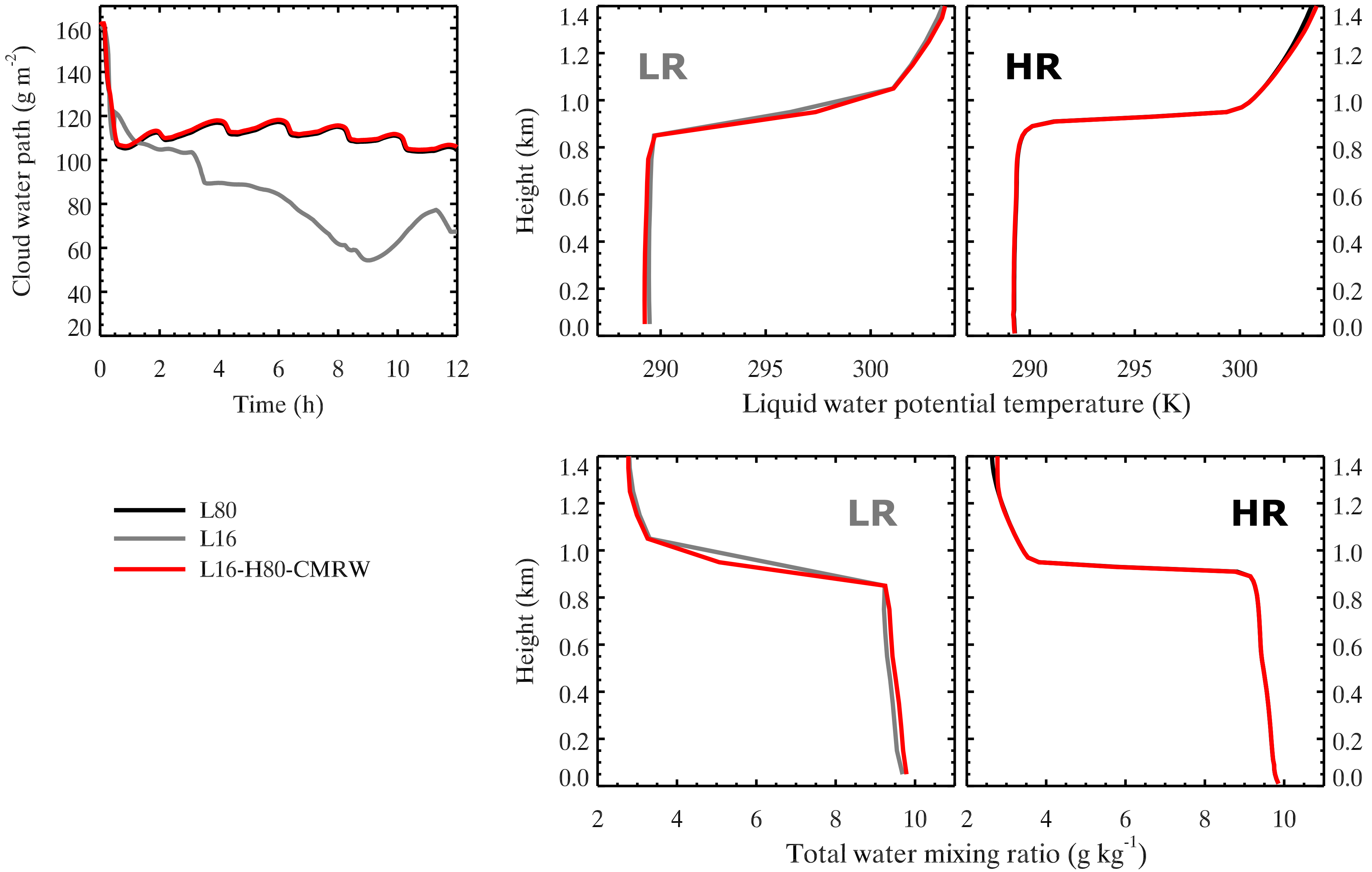

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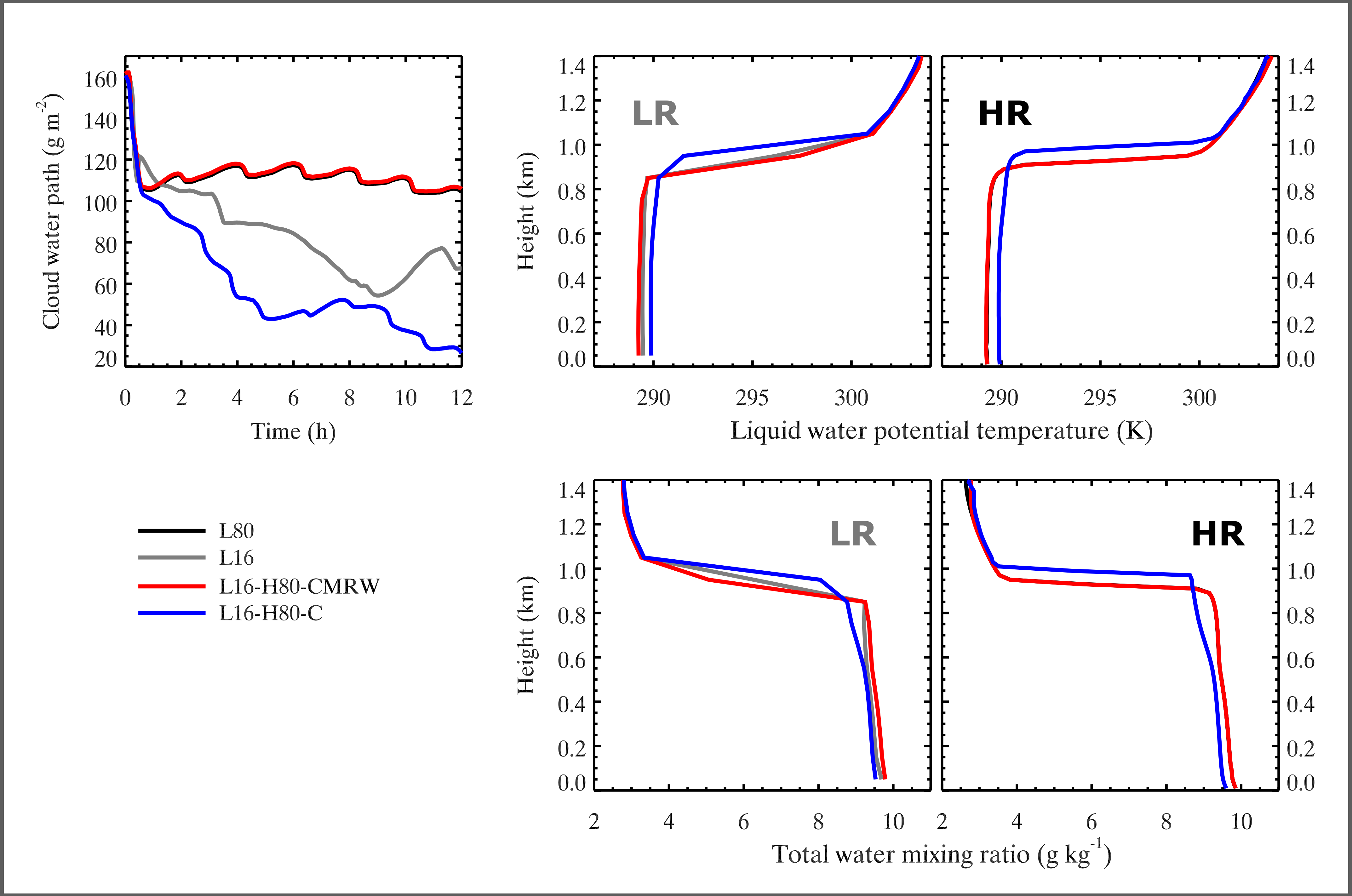

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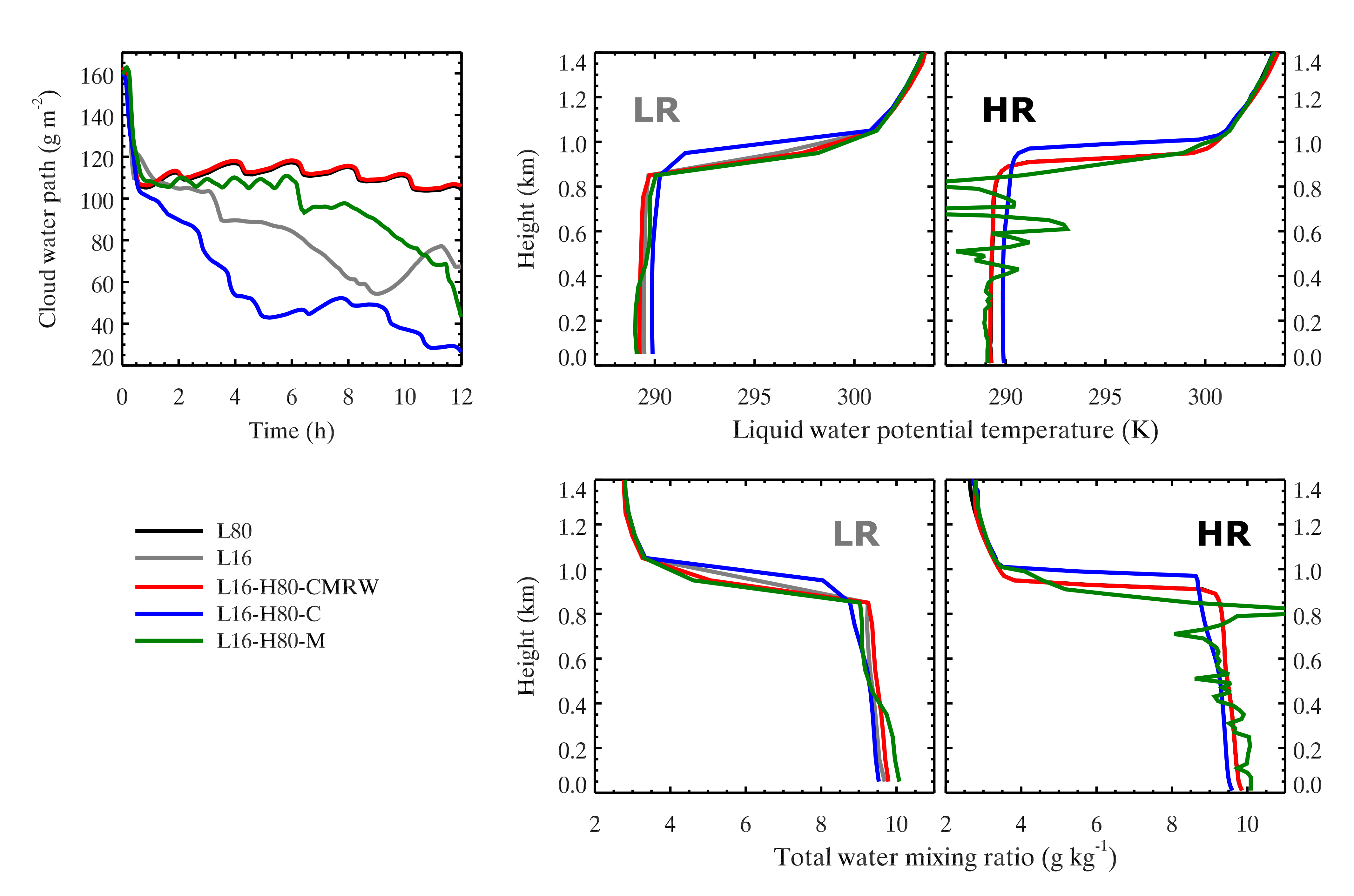

LR CLUBB can not see the variability created on HR.

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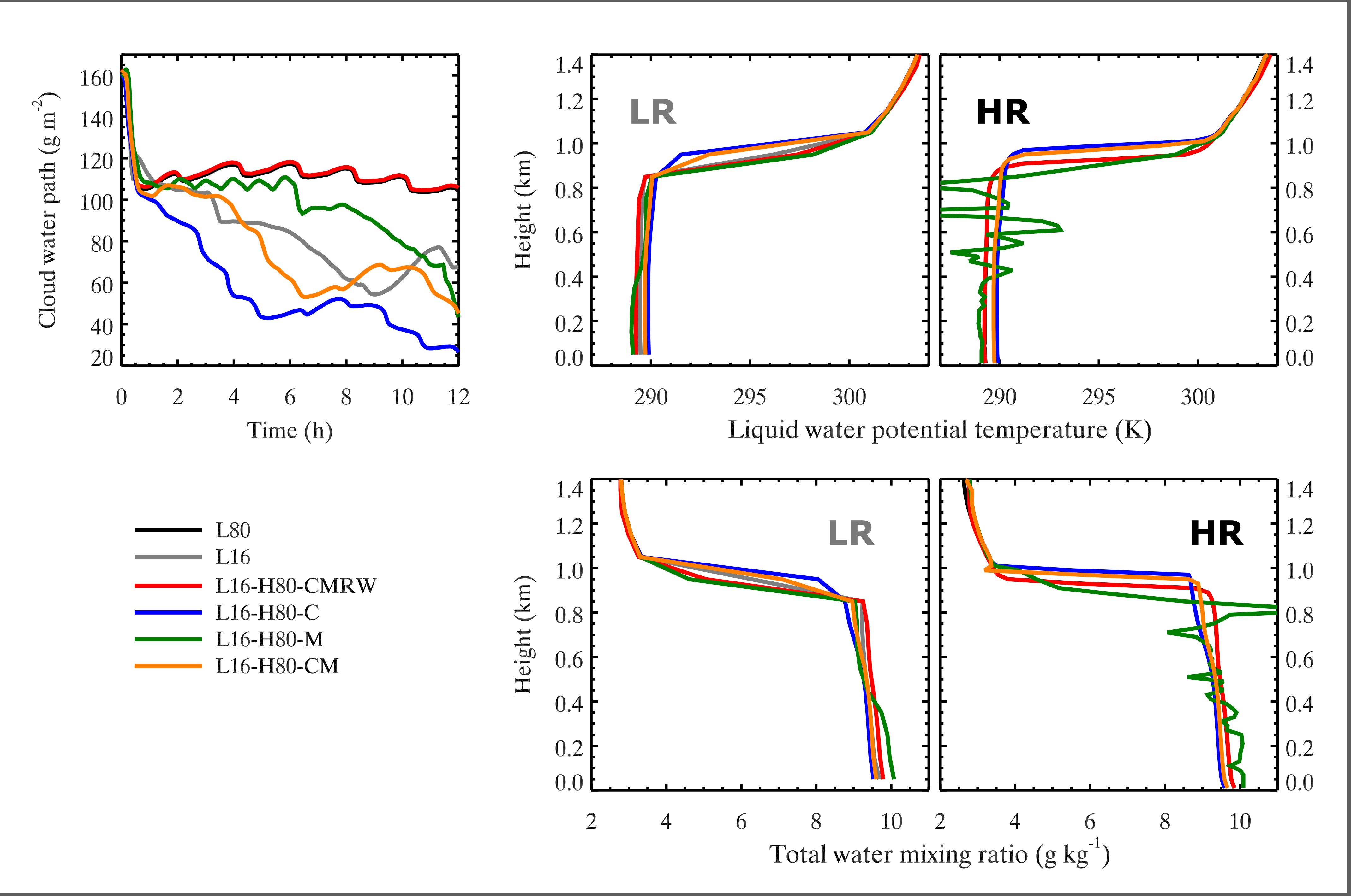

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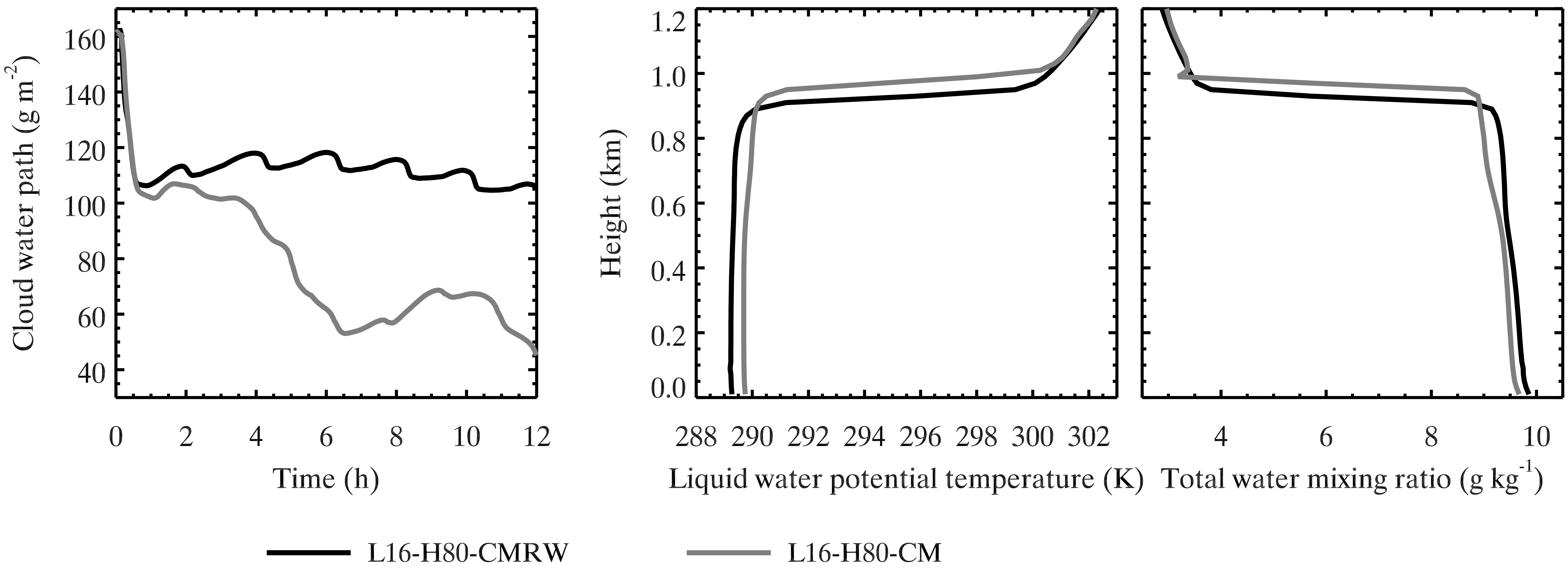
1D results: (2) Vertical transport is key.



Vertical transport: turbulence mixing, subsidence, sedimentation

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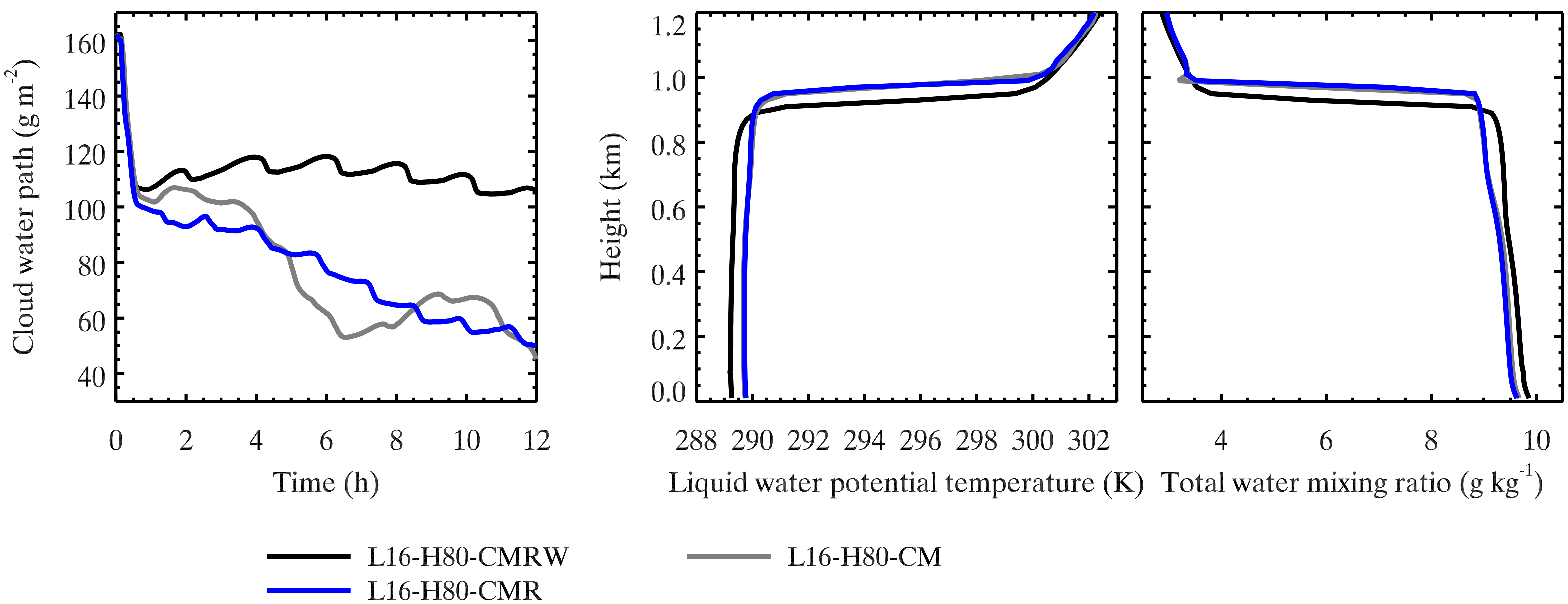

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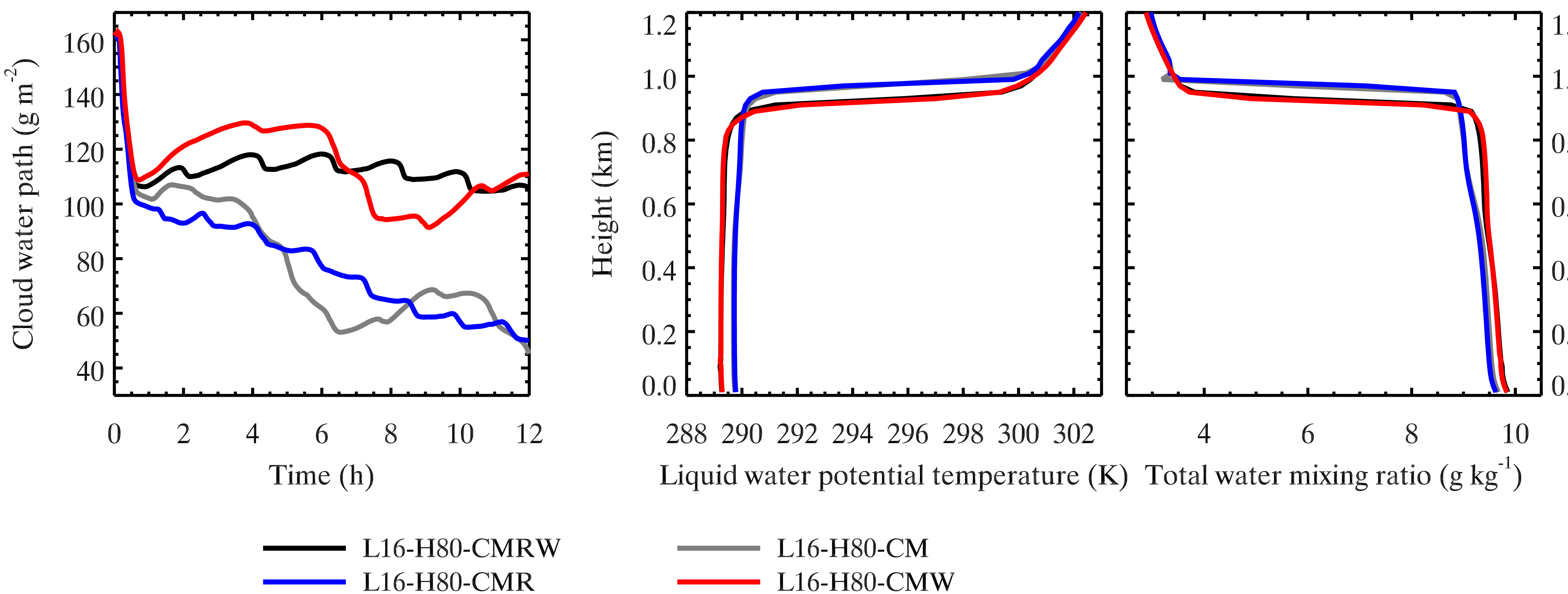

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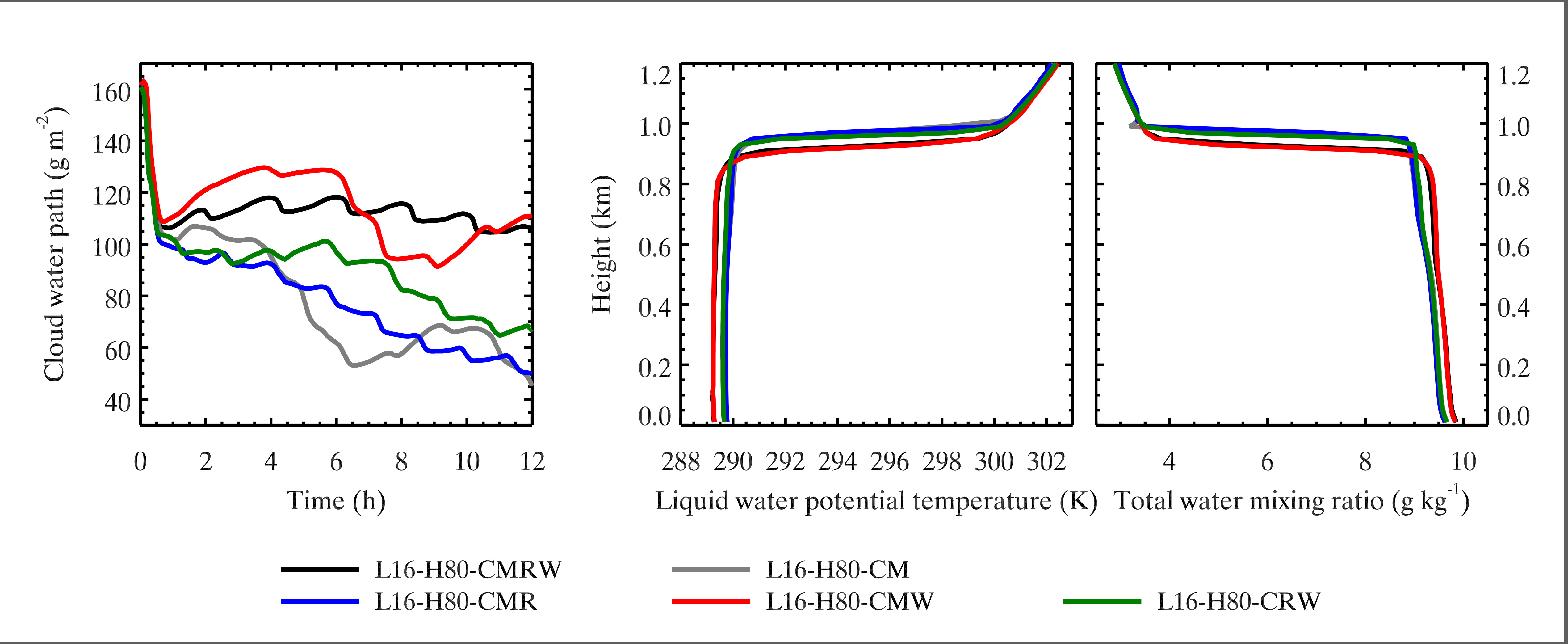

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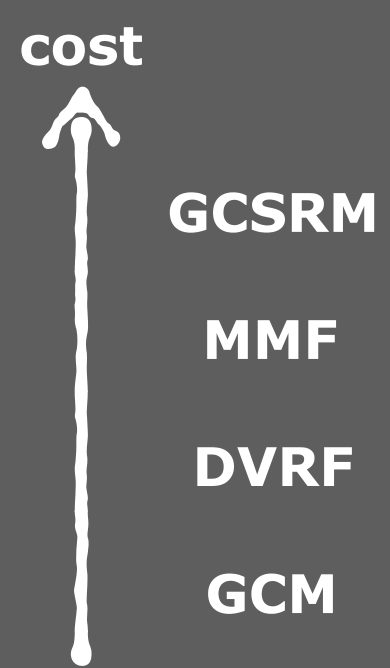
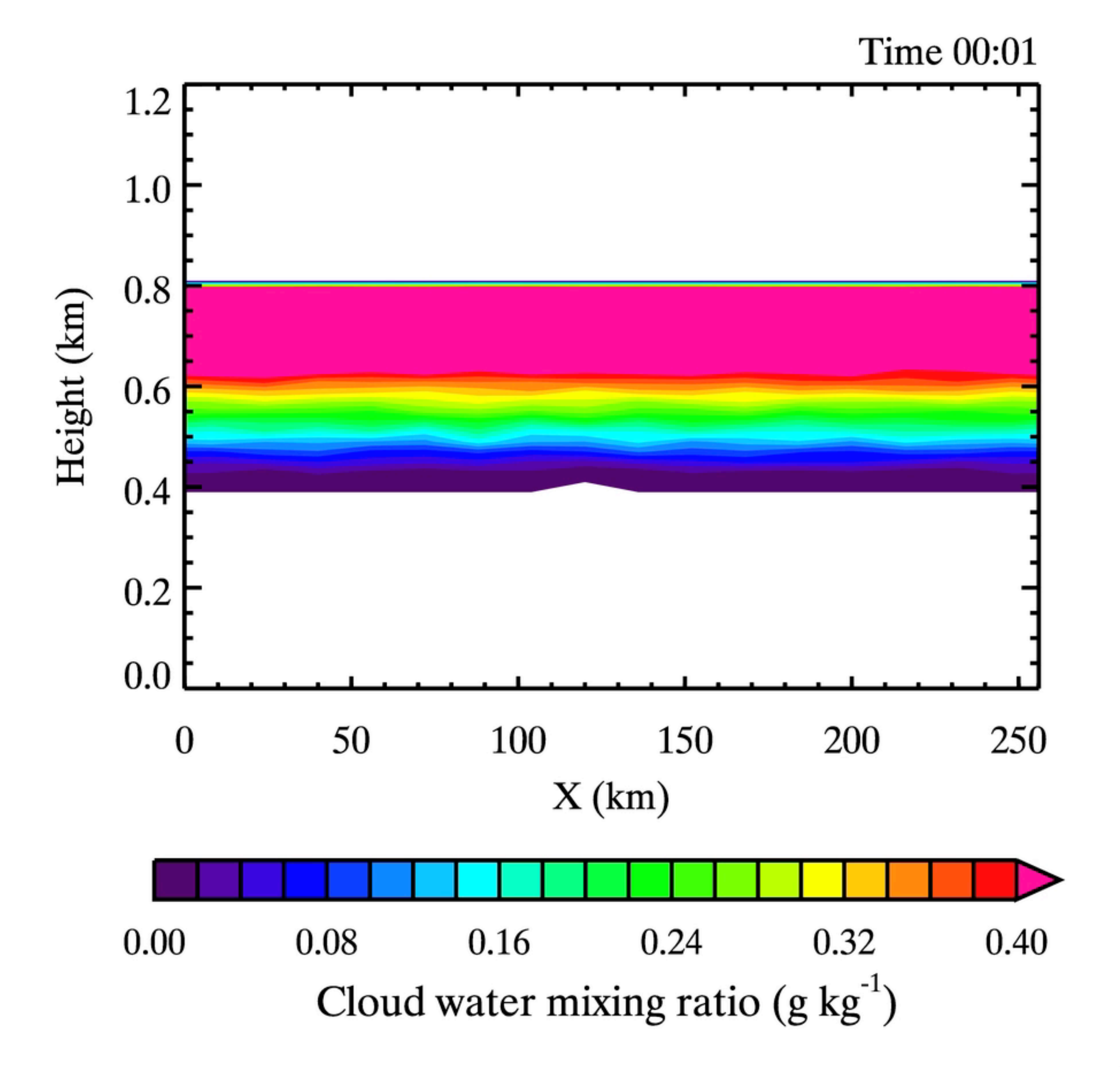
Is DVRF useful for simulation?



- DVRF can be used with ANY PBL parameterization.
- Fewer processes on HR, DVRF gets faster.
- Adaptive vertical grid approach may be utilized for speed up.

2D test



- DYCOMS-II RF02
- N_x = 16 and Δx = 16 km
- A warm pool (i.e., stronger surface fluxes) to generate stronger horizontal gradient.
- W on HR
  - Only subsidence is processed on HR.
  - Modification for scalar advection is ongoing.

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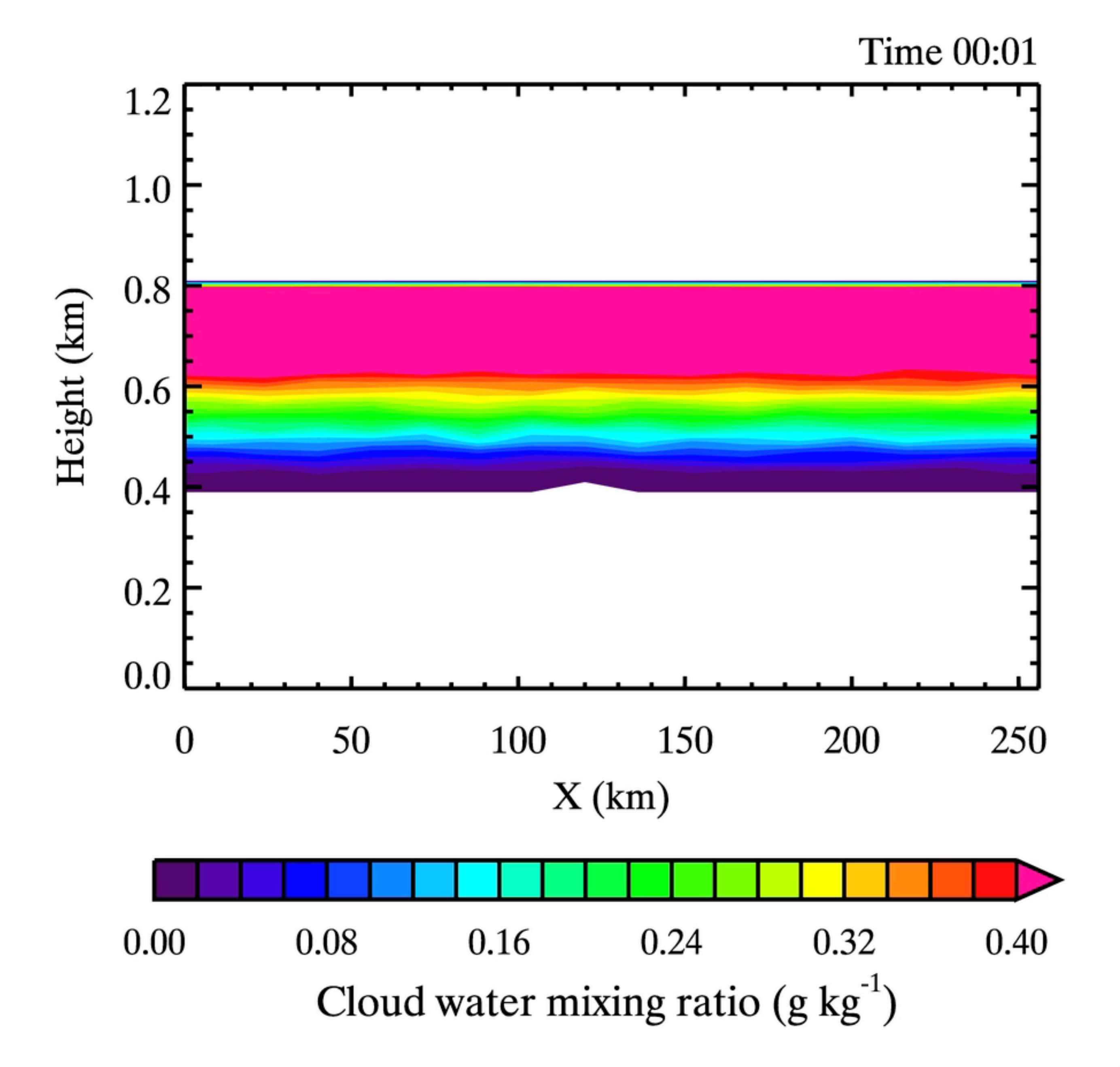

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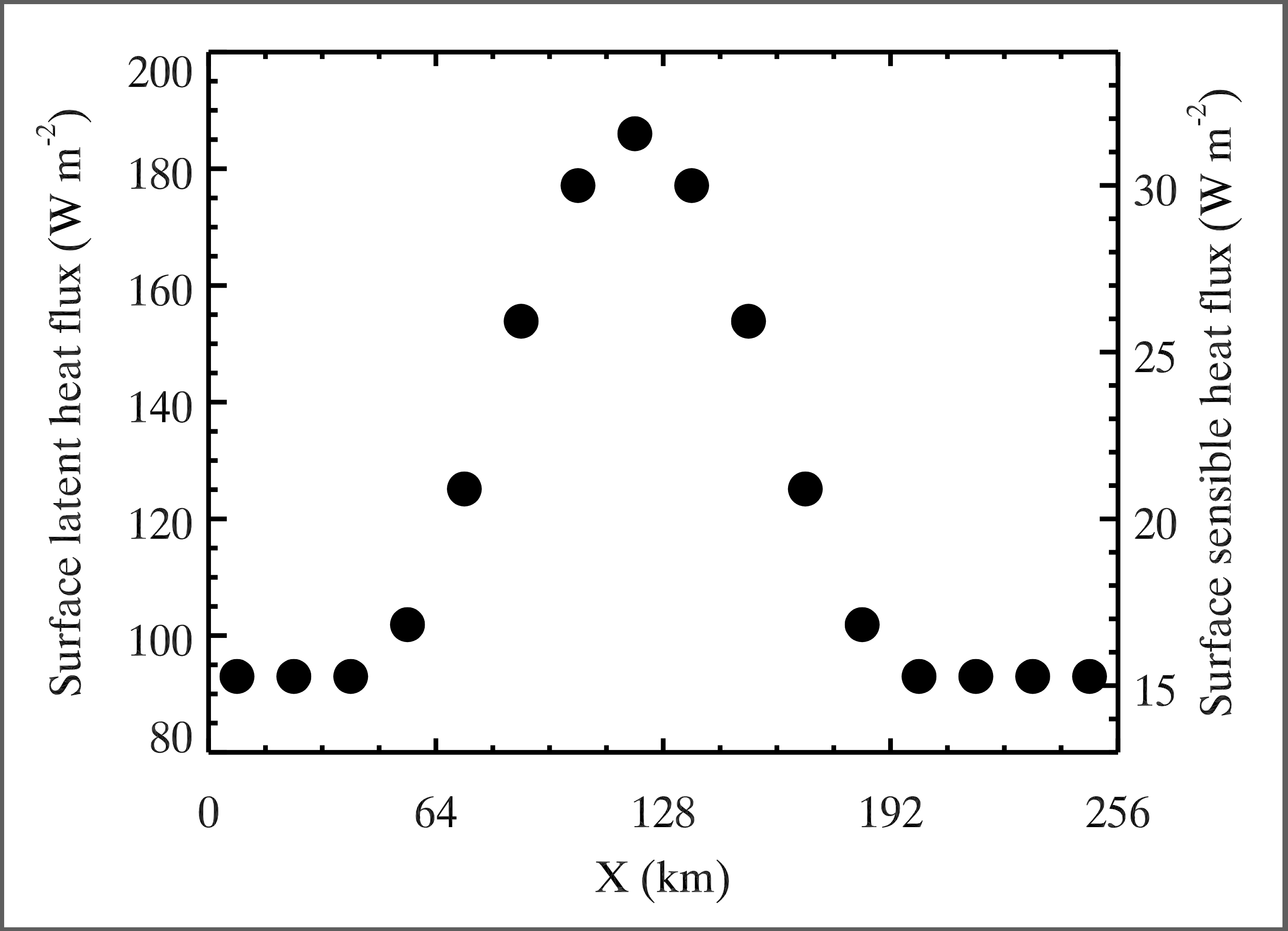

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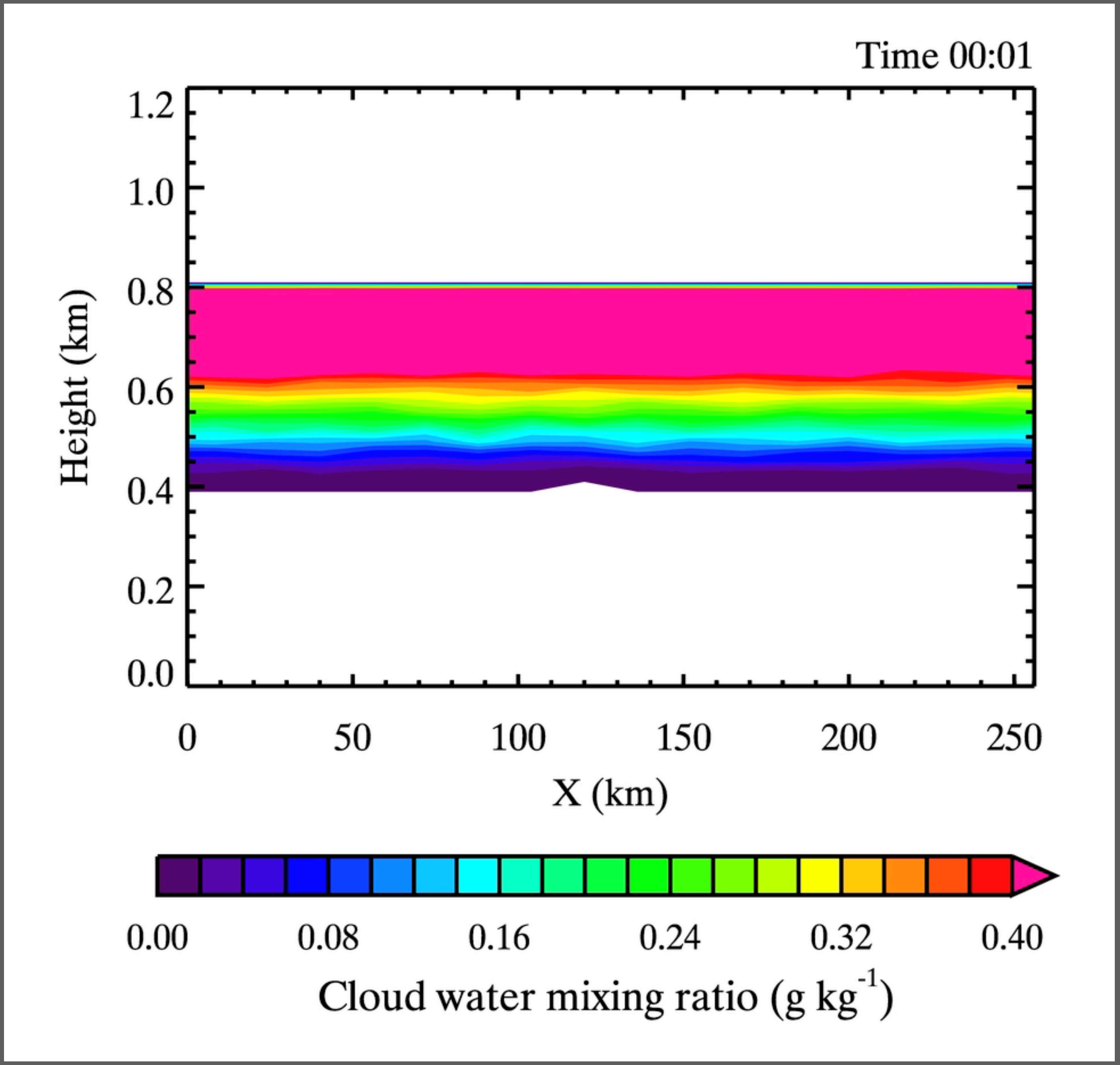

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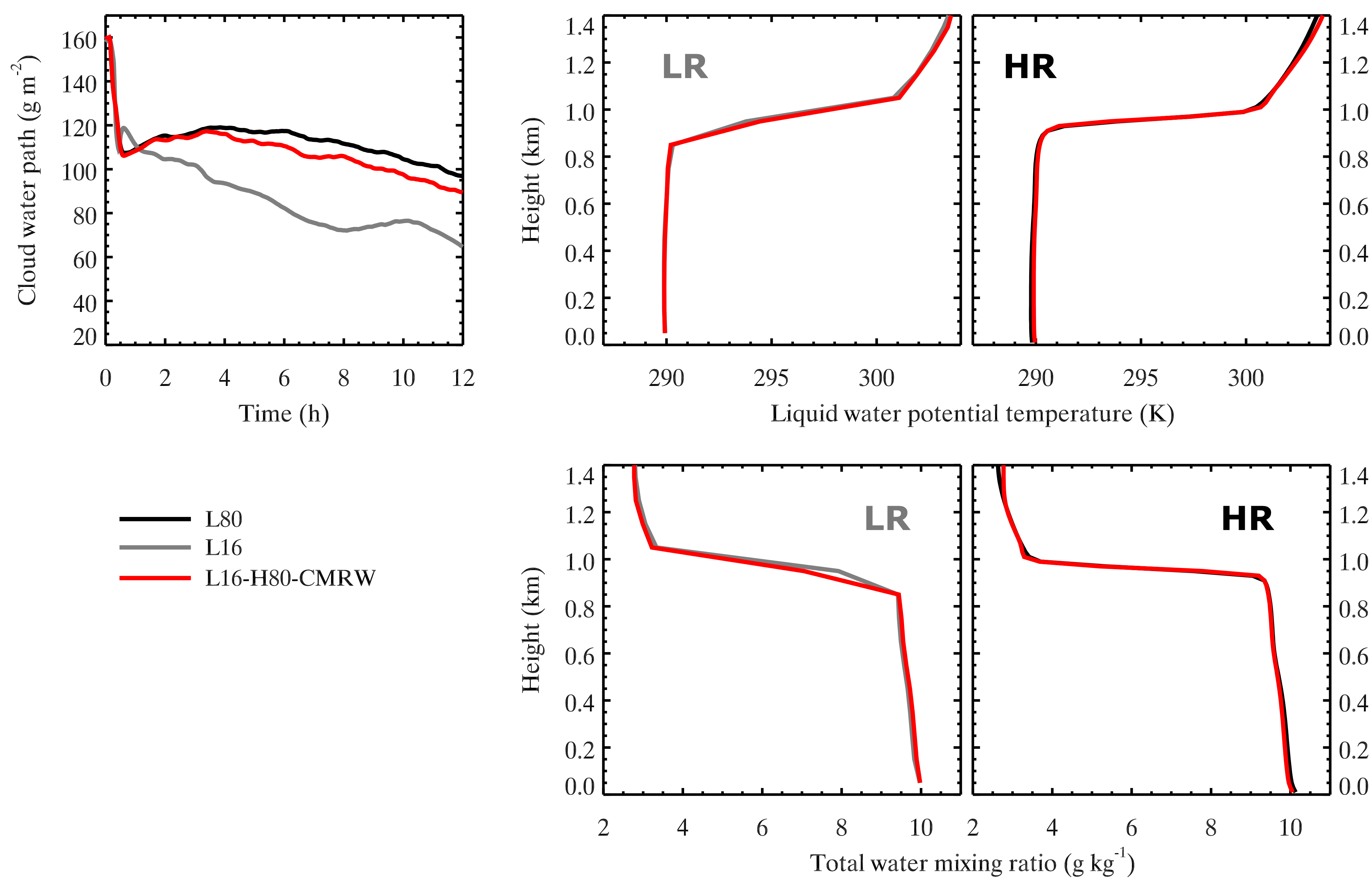
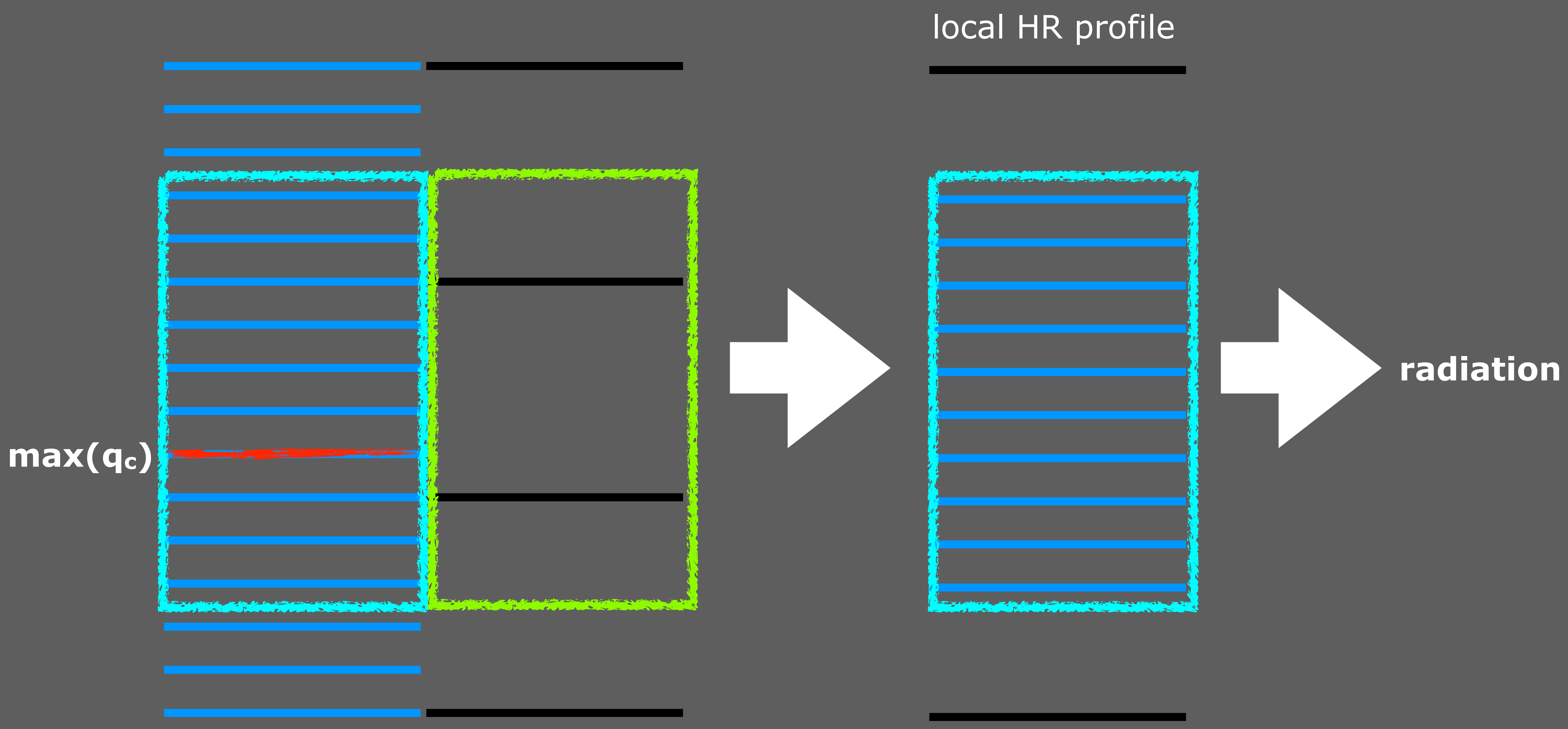
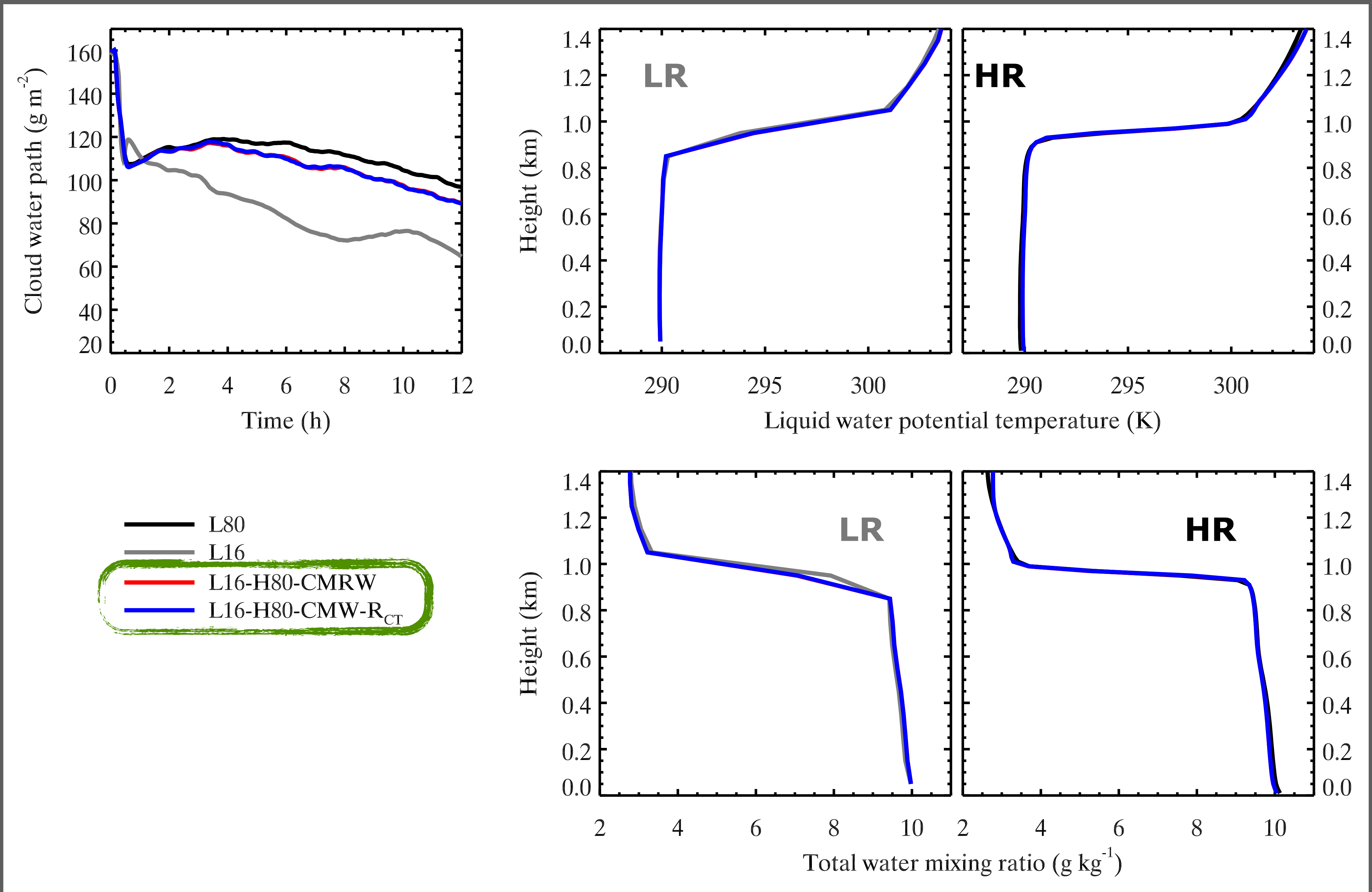

Cloud water path (g m^-2)
Time (h)
Height (km)
Liquid water potential temperature (K)
Total water mixing ratio (g kg^-1)
LR
HR
L80
L16
L16-H80-CMRW

Accurate and faster radiation calculation



- The HR profile around cloud top is embedded into the LR profile (local HR profile).
- DVRF always has the HR profiles, so no interpolation is necessary unlike an adaptive level method.

Results



Cloud water path (g m^{-2})
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
Time (h)
L80
L16
L16-H80-CMRW
L16-H80-CMW-R_{CT}
LR
HR
Height (km)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
290
295
300
Liquid water potential temperature (K)
Total water mixing ratio (g kg^{-1})

Summary and outlook

- Diagnosis with DVRF shows that
  - CLUBB only on HR evaporates stratocumulus.
  - Vertical transport on HR improves results greatly.
  - Radiation may be computed on LR.
- Is DVRF useful for simulation?
  - Adaptive level method is easily utilized and gives accurate results because HR profiles are known.
  - DVRF can distinguish between stratocumulus and shallow cumulus - e.g., radiation calculation on LR for shallow cumulus.
  - Grey zone? Cirrus cloud?

Interpolation scheme for LR tendency to HR

- First guess value at the LR interface level (●).
- Estimate value at the LR center level (●).
- Interpolate with ● and ● to get ○.
- Limiter
  - Bound ● with the maximum magnitude of inflection value (= inflection factor × LR value).
  - Shift the interface value so that layer mean = LR value (●).
  - Construct ● with bounded ● and ●.