bjorn stevens
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- ***what factors (formulaic and physical) are important to the development of rain in shallow cumulus?***

- ***what key processes determine the dynamic evolution of precipitating cumulus?***

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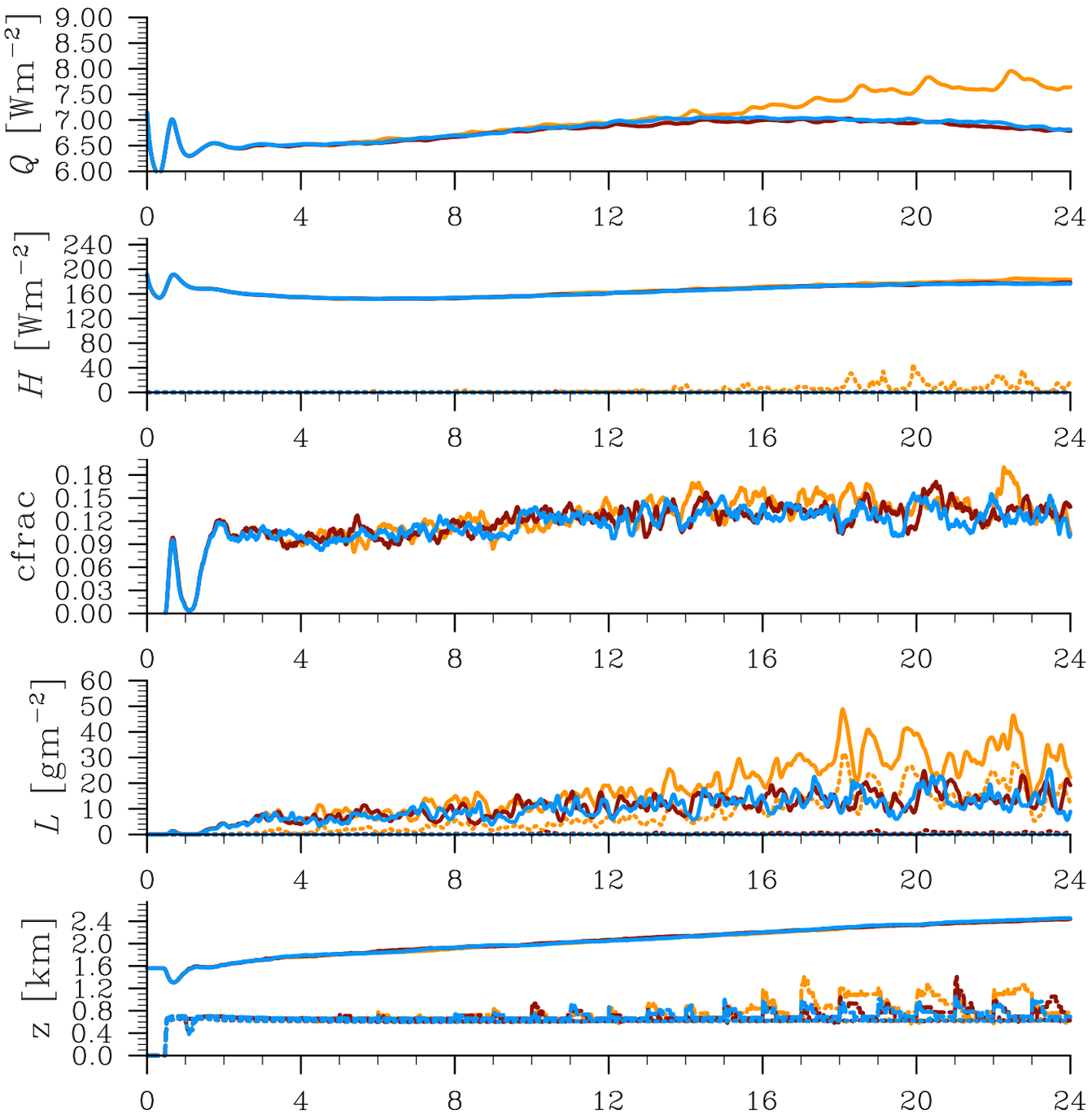
- ***what key processes determine the dynamic evolution of precipitating cumulus?***

outline:

- explore rico-like cloud simulations (rainscheme|specification|domainsize|ndroplets|meshsize).
- introduce an idealization.
- understand the dynamics of the idealization.

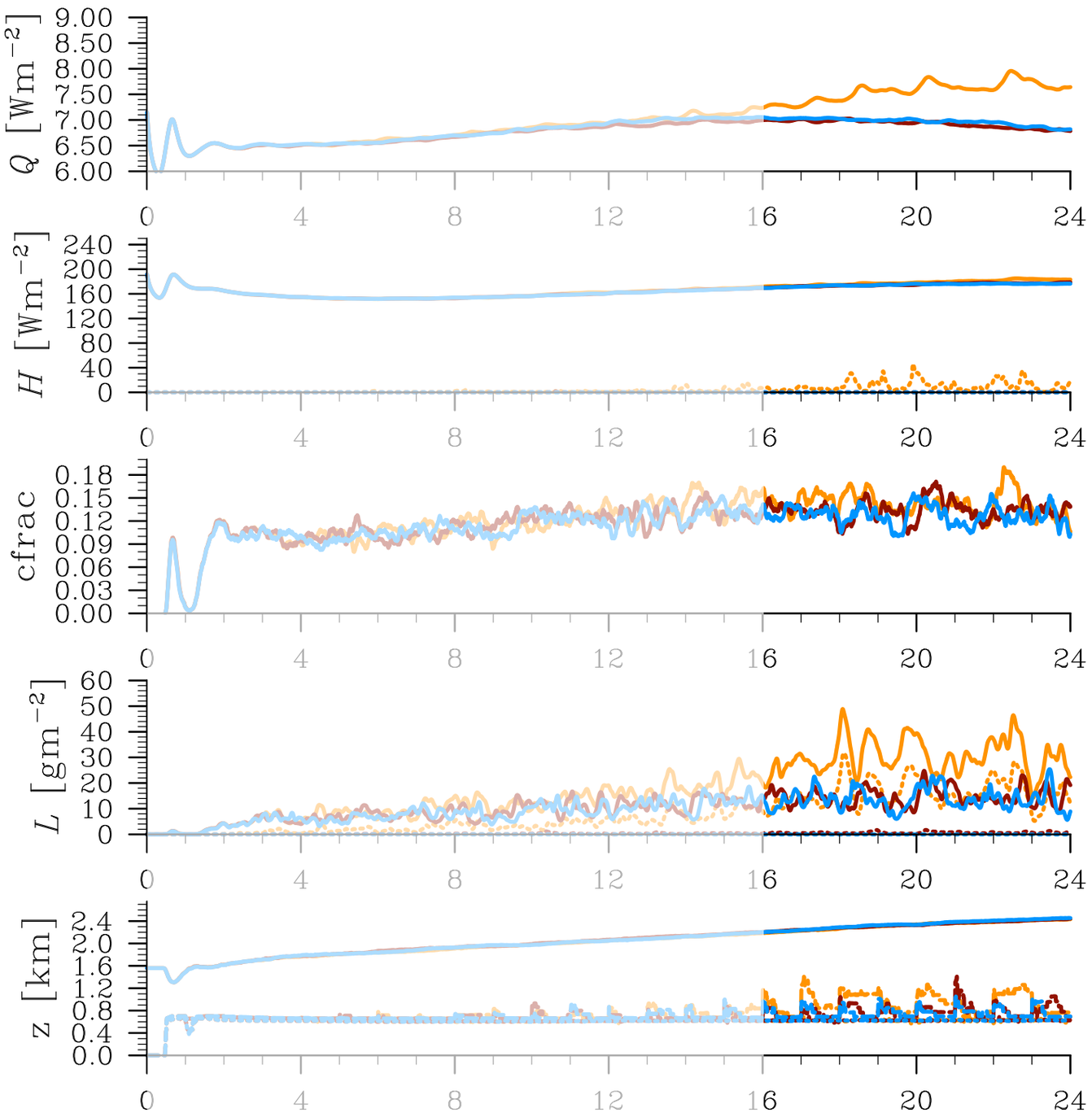
rainscheme.g10



rainscheme: none|KK|SB

- SB produces significantly more rain than KK
- more rain is associated with more cloud (xie & feingold)
- **rwp** significant fraction of **lwp**

rainscheme.g10



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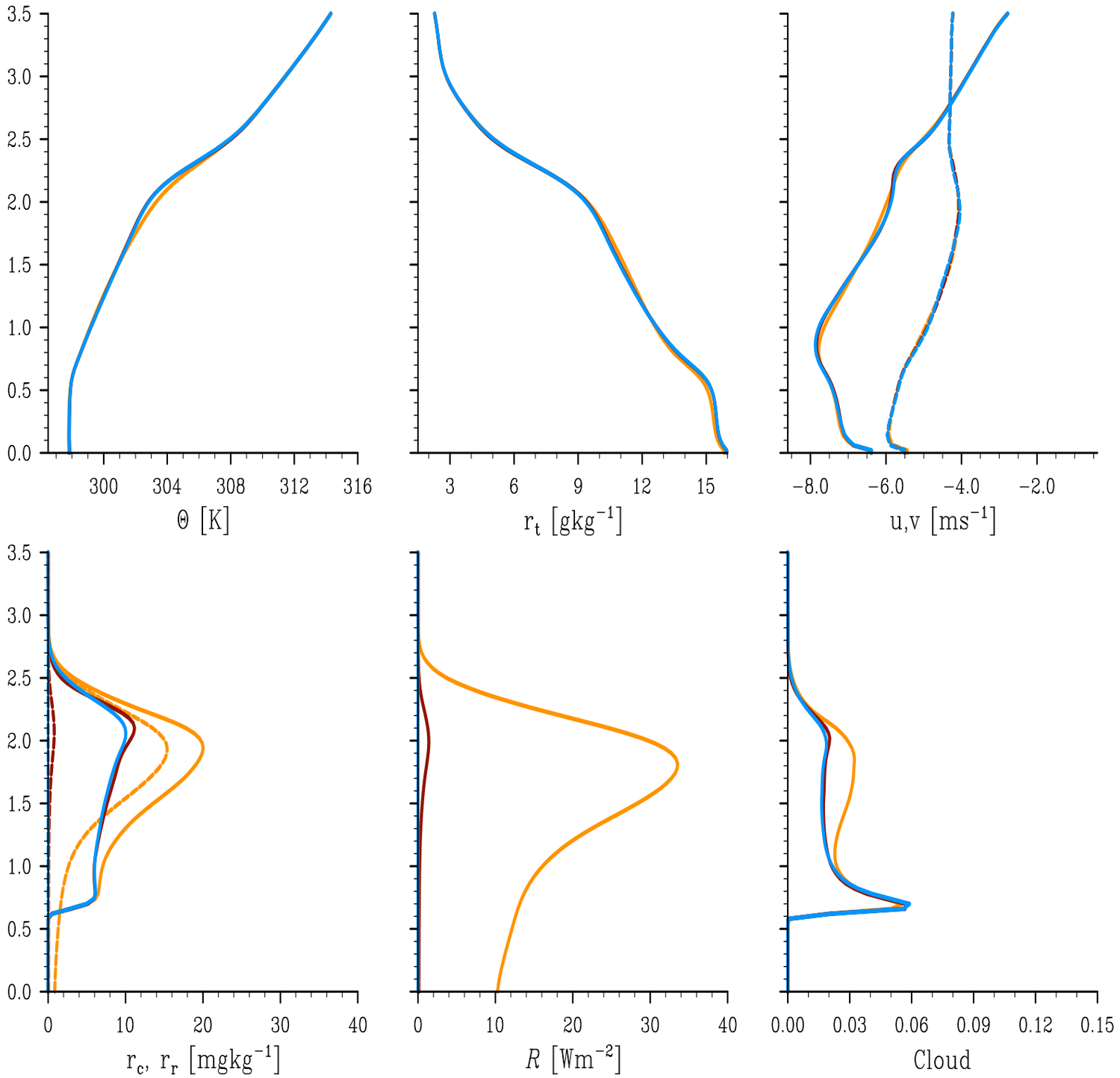
rainscheme.g10p



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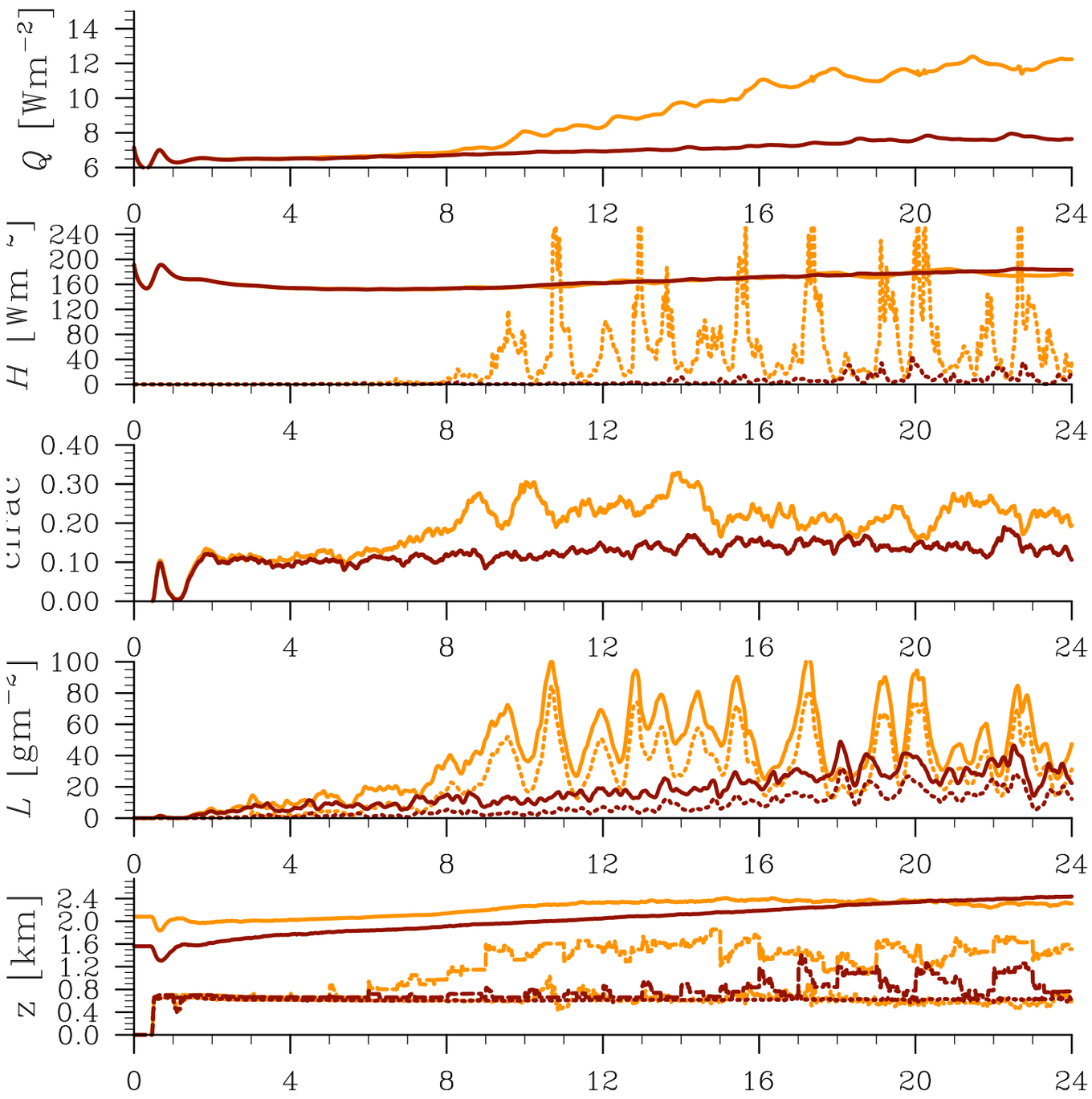
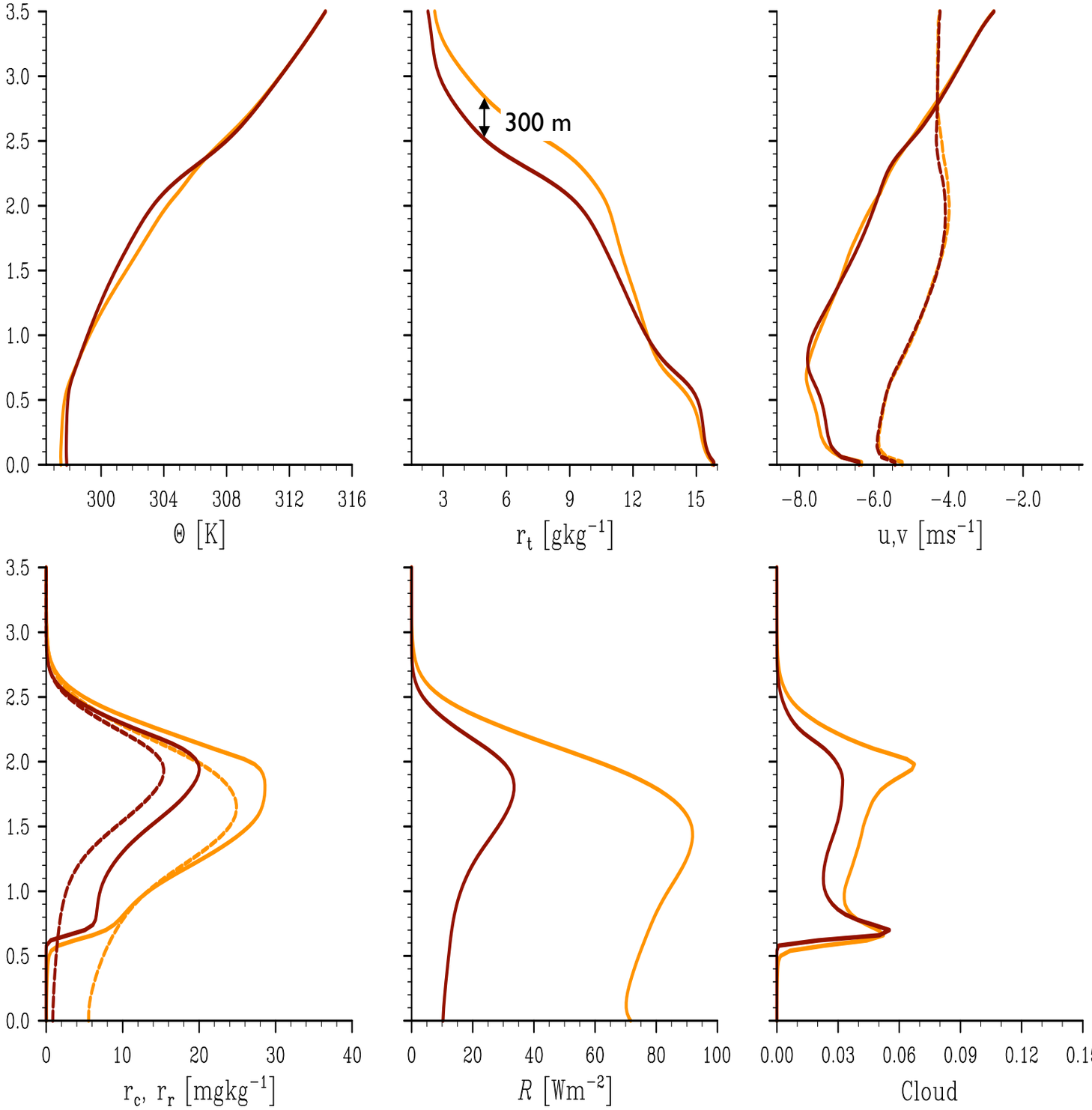
specification.g10



specification: control | p

- the perturbation experiment does not let the moisture profile feel the subsidence.
- perturbation develops more rain, cloud cover and liquid water.
- perturbation deepens cloud layer less rapidly.
- rwp a much more significant fraction

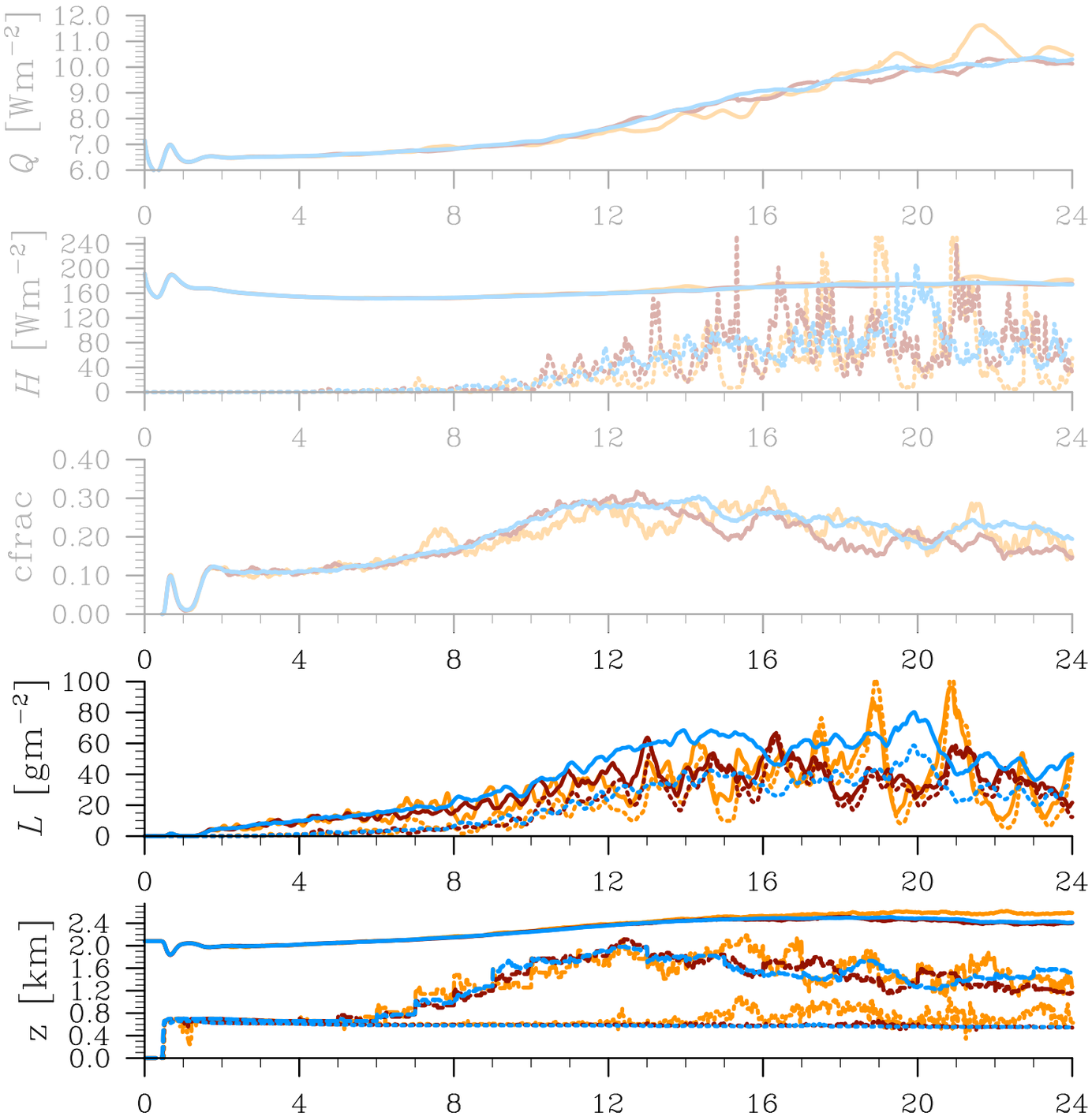
specification.g10



specification: control | p

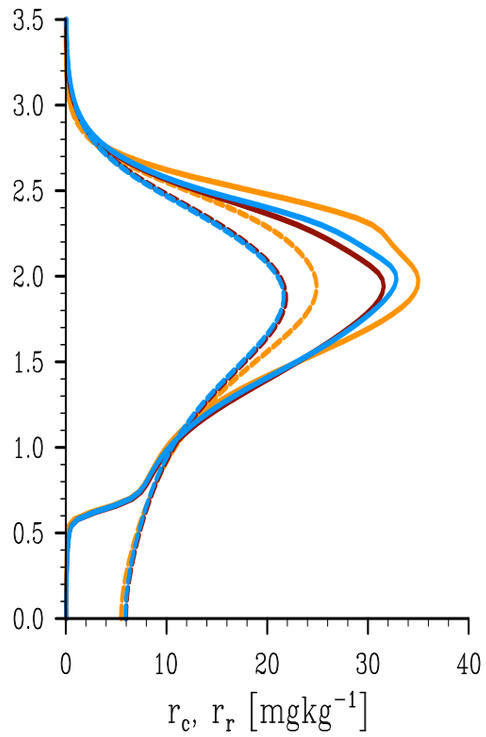
- the perturbation ~~experiment~~ mistake yields a deeper moist layer.
- perturbation cloud cover excess is in upper layers.
- perturbation rain fraction much higher.
- perturbation mean rain rates much larger.

domainsize.g10p

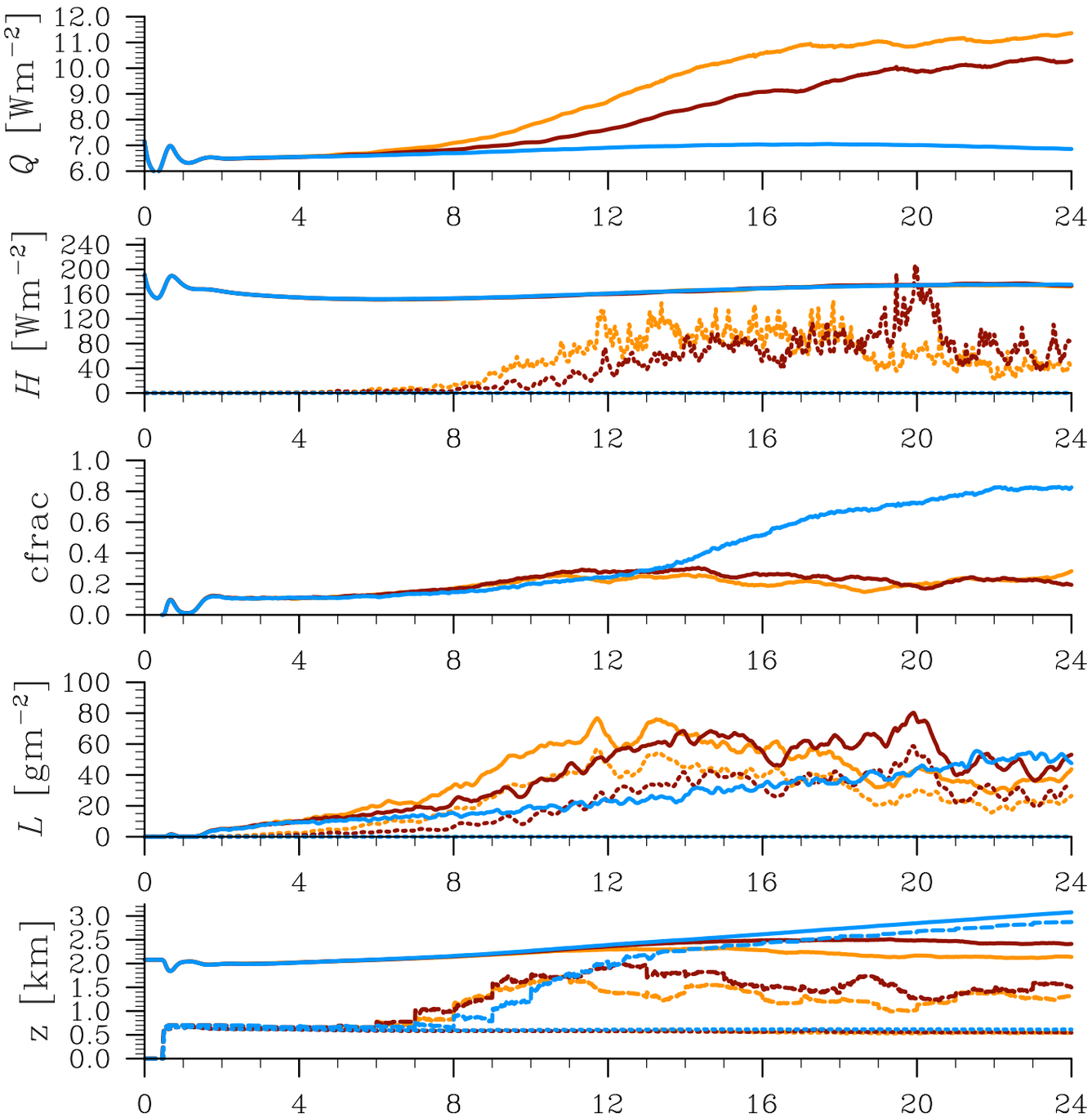


domainsize: 51|26|13 km

- bigger domain better sampling
- time series relatively similar, especially between 26 and 51 km
- biggest effect in rwp versus lwp



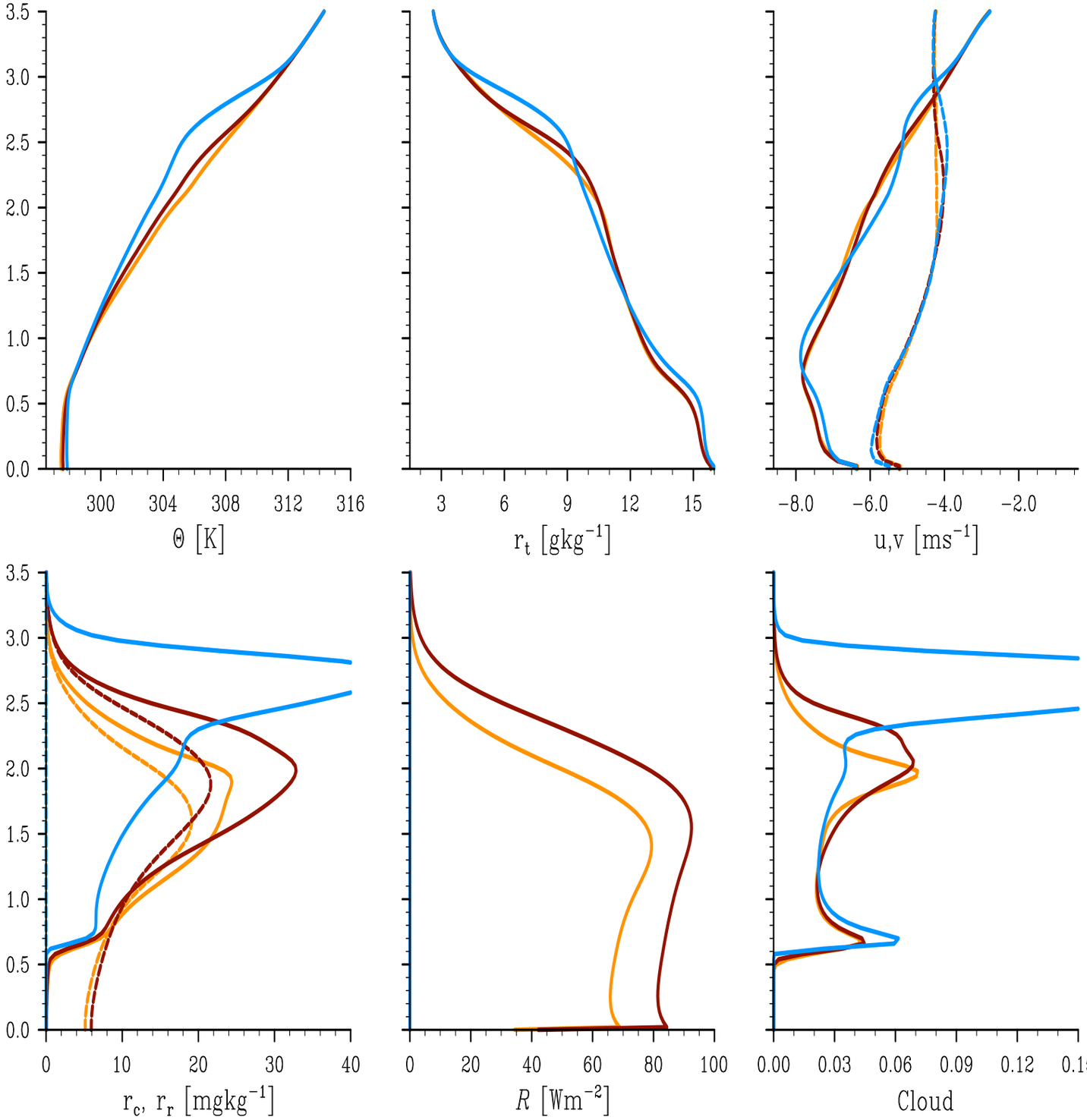
ndroplets.g10p



ndroplets: infinite |100 |45

- no rain deeper layer
- deeper layer more rain
- fewer drops, less rain, then more
- more drops more rain

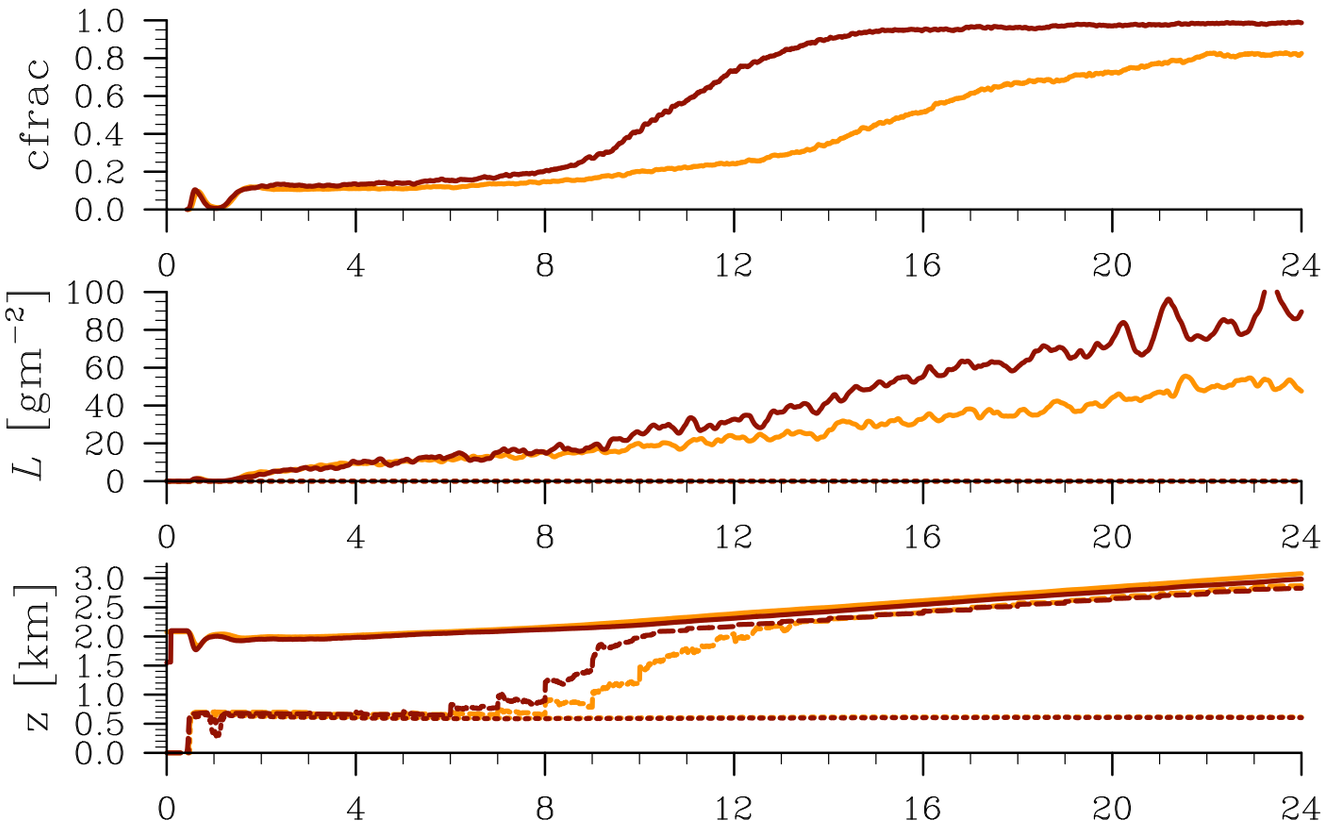
ndroplets.g10p

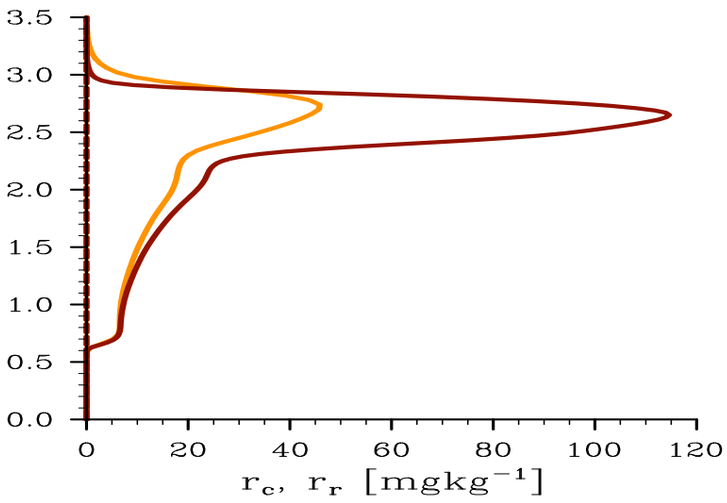


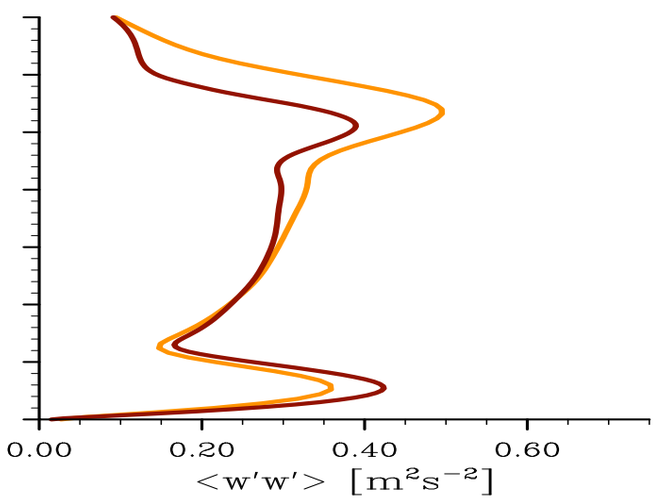
ndroplets: infinite |100 |45

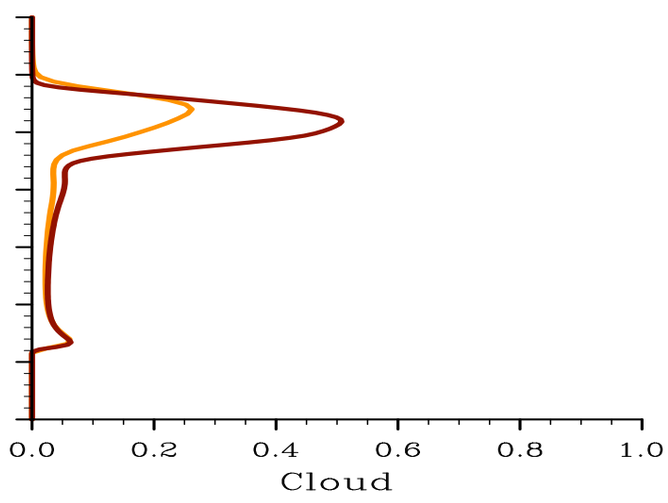
- fewer droplets => shallower layer
- fewer droplets need not imply more rain
- rain mitigates formation of stratiform layer.
- rain can affect mean lapse rate, effective stability, and development (or not) of inversion.

meshsize.g10p









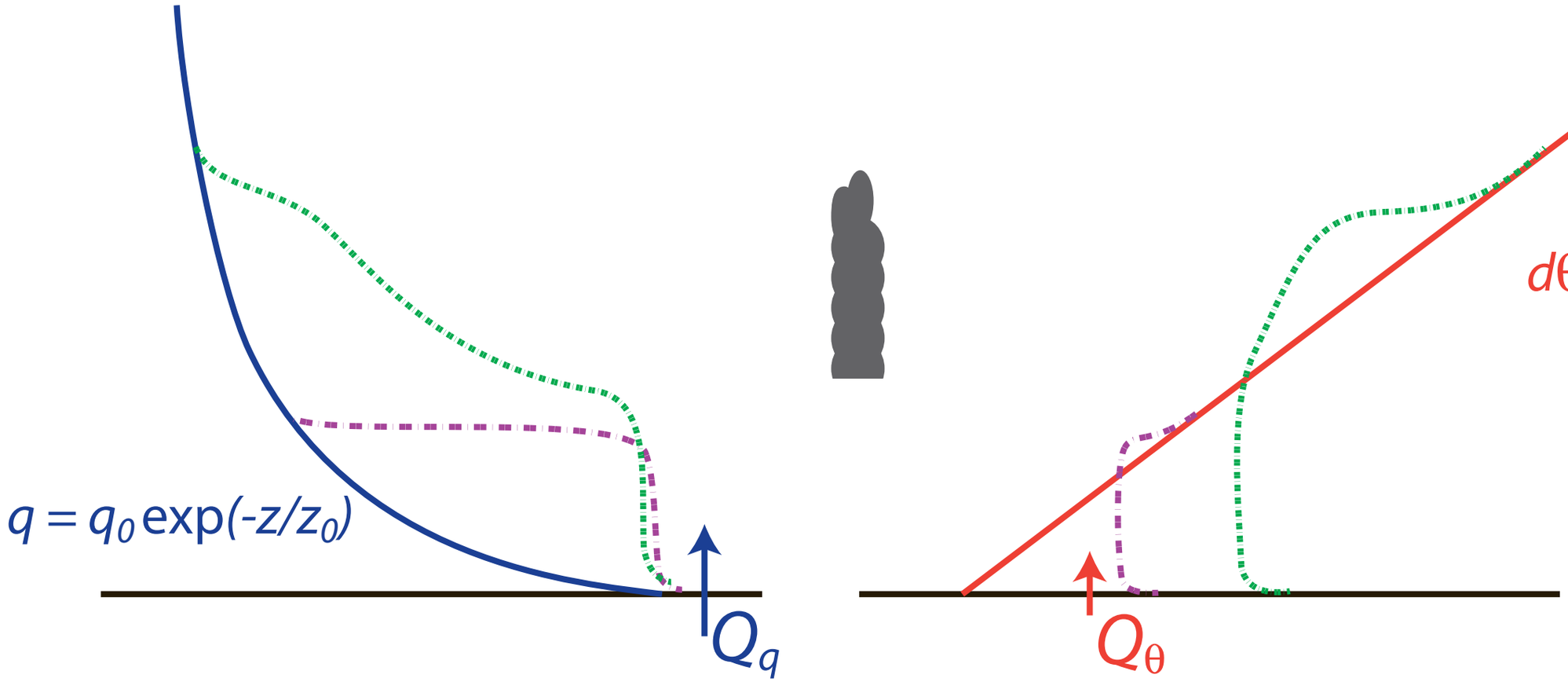
meshsize: 50/20 | 100/40

- there are all non precipitating.
- finer grid develops stratiform layer faster.
- liquid water quite sensitive (probably to vertical grid).
- vertical velocity variances sensitive to grid (this is resolved component).

remarks.g10

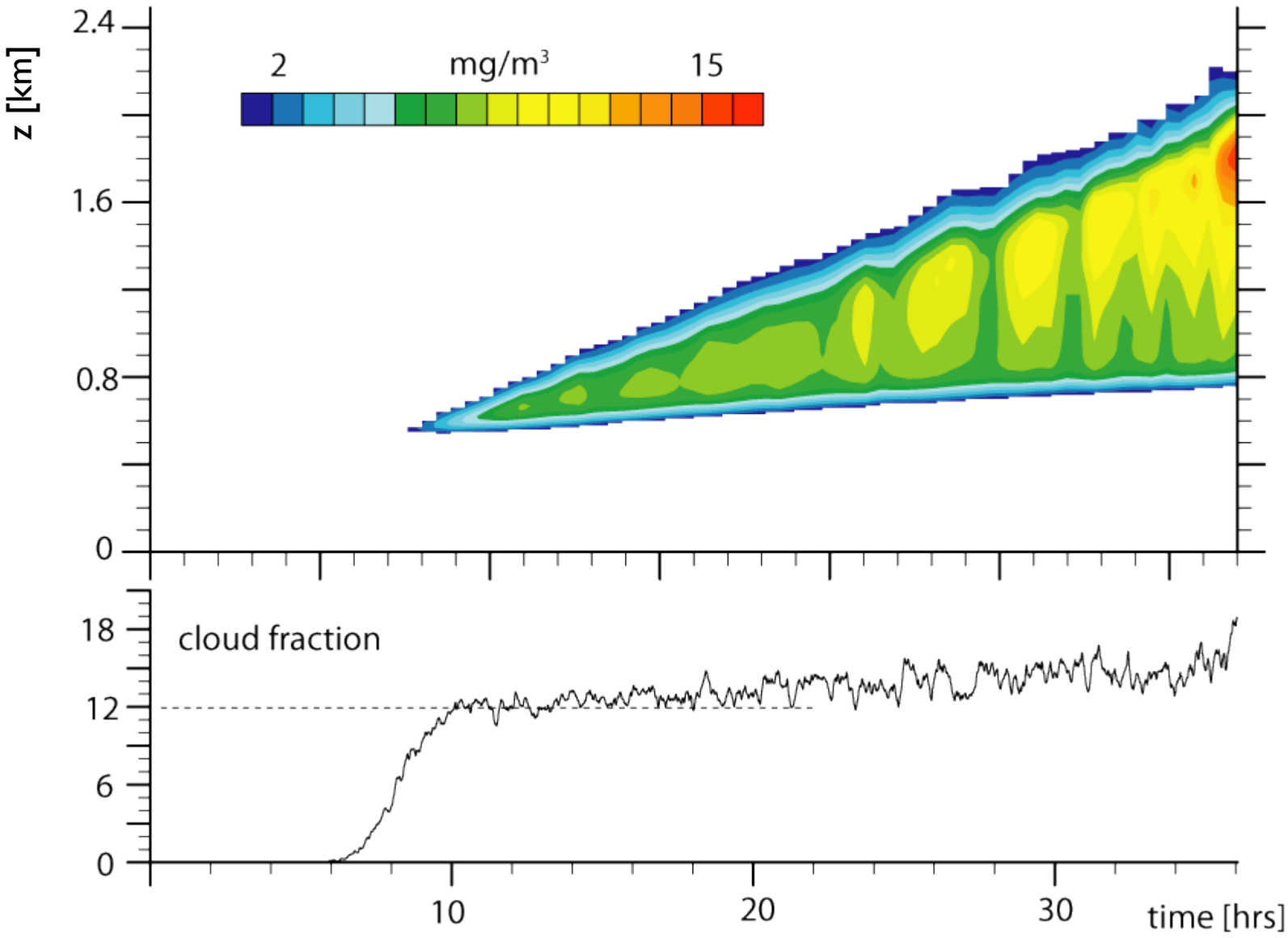
- order of magnitude rain-rate sensitivities to formulation of microphysics & mean state.
- in many cases more rain meant more cloud.
- less rain typically meant deeper layers (which could make more rain).
- domain probably too small and grid spacing probably too large.
- at large rain rates, qr approximately equals ql.
- profile typically insensitive to rain-rates, but for large rain-rate differences, differences in mean cloud layer stratification become apparent, and are significant.

simple.prototype

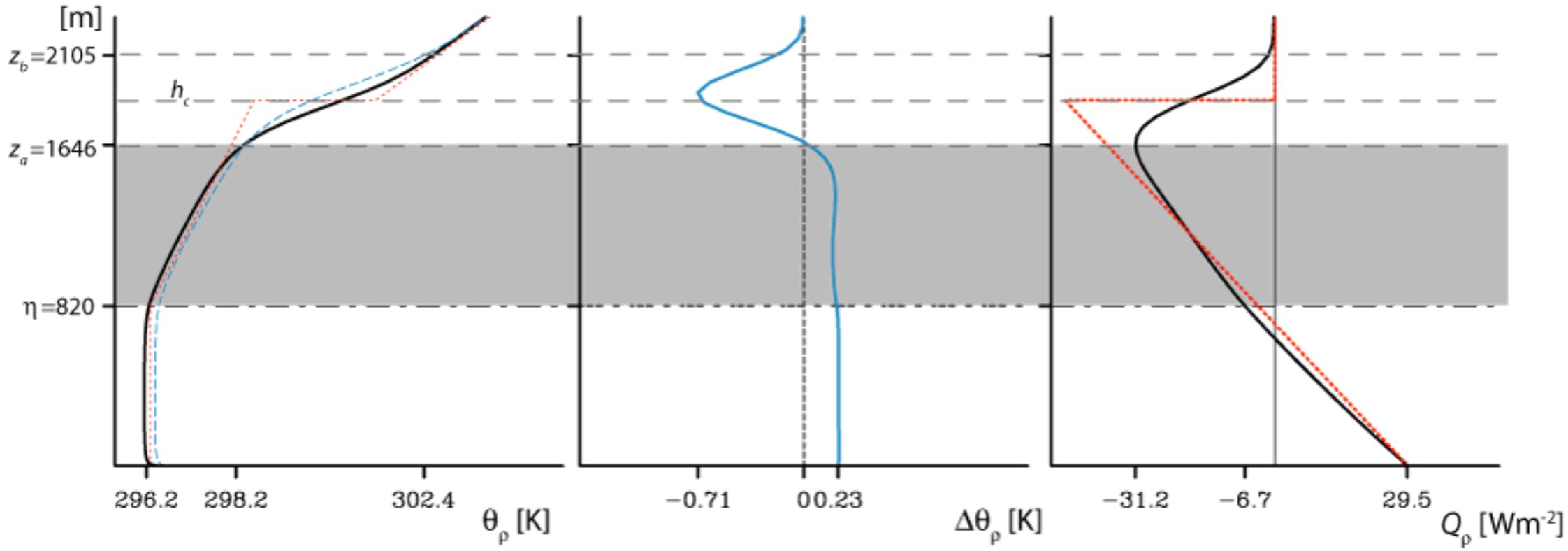


- what determines growth rate of layer?
- cloud fraction?
- how does precipitation scale with the depth of the layer?
- how does rain affect the statistics of the layer?

simple.prototype



simple.prototype



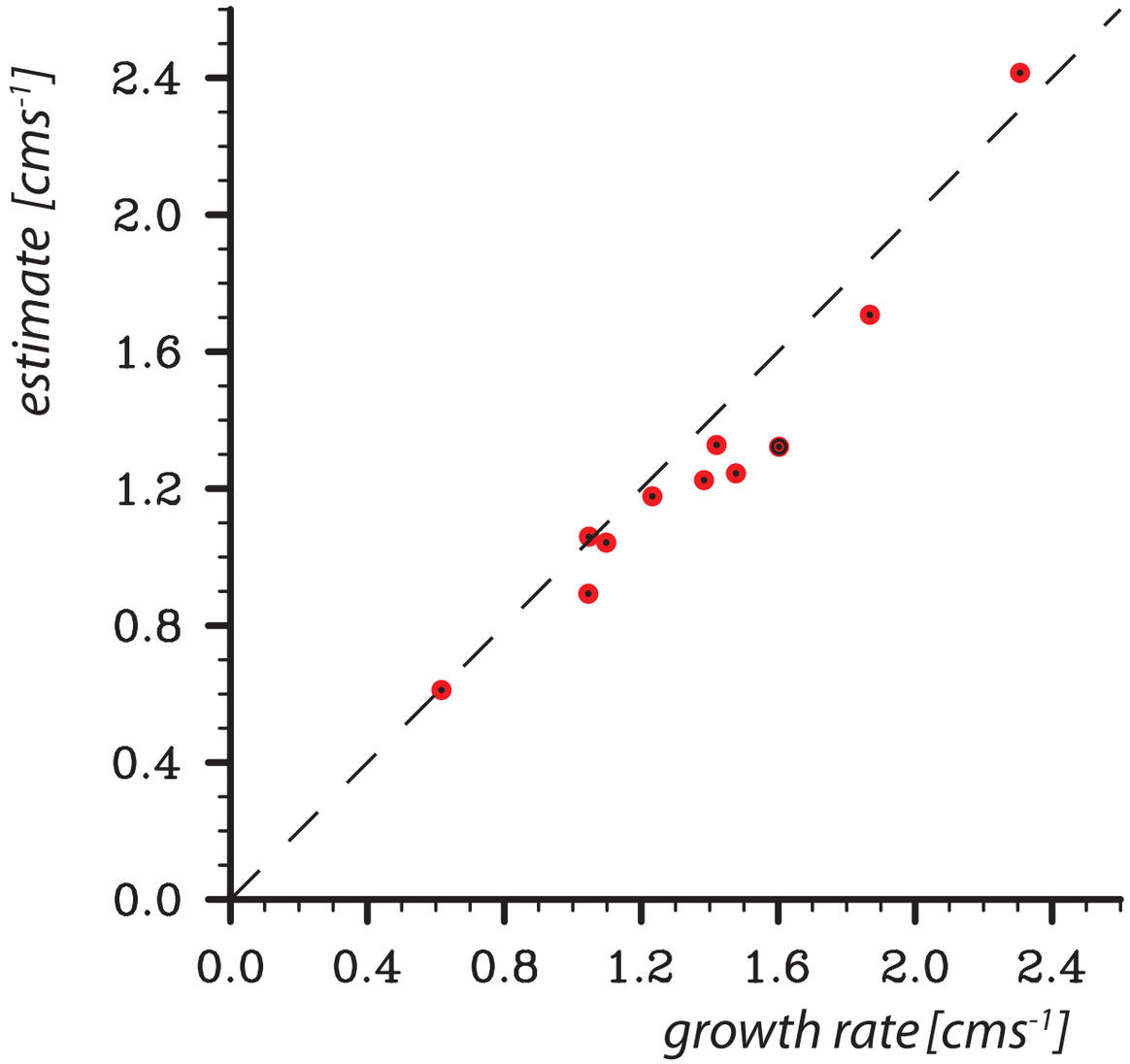
$$\frac{dh}{dt} = -\frac{\tilde{Q}_\rho(z=h)}{\Delta\theta_\rho}$$

$$\frac{dh}{dt} = \frac{\tilde{Q}_{\rho,0}(1-1.25\frac{h}{\eta})}{\Theta + \Gamma h - \left(\widehat{\theta}_\rho + \Gamma_c(h-\eta)\right)}$$

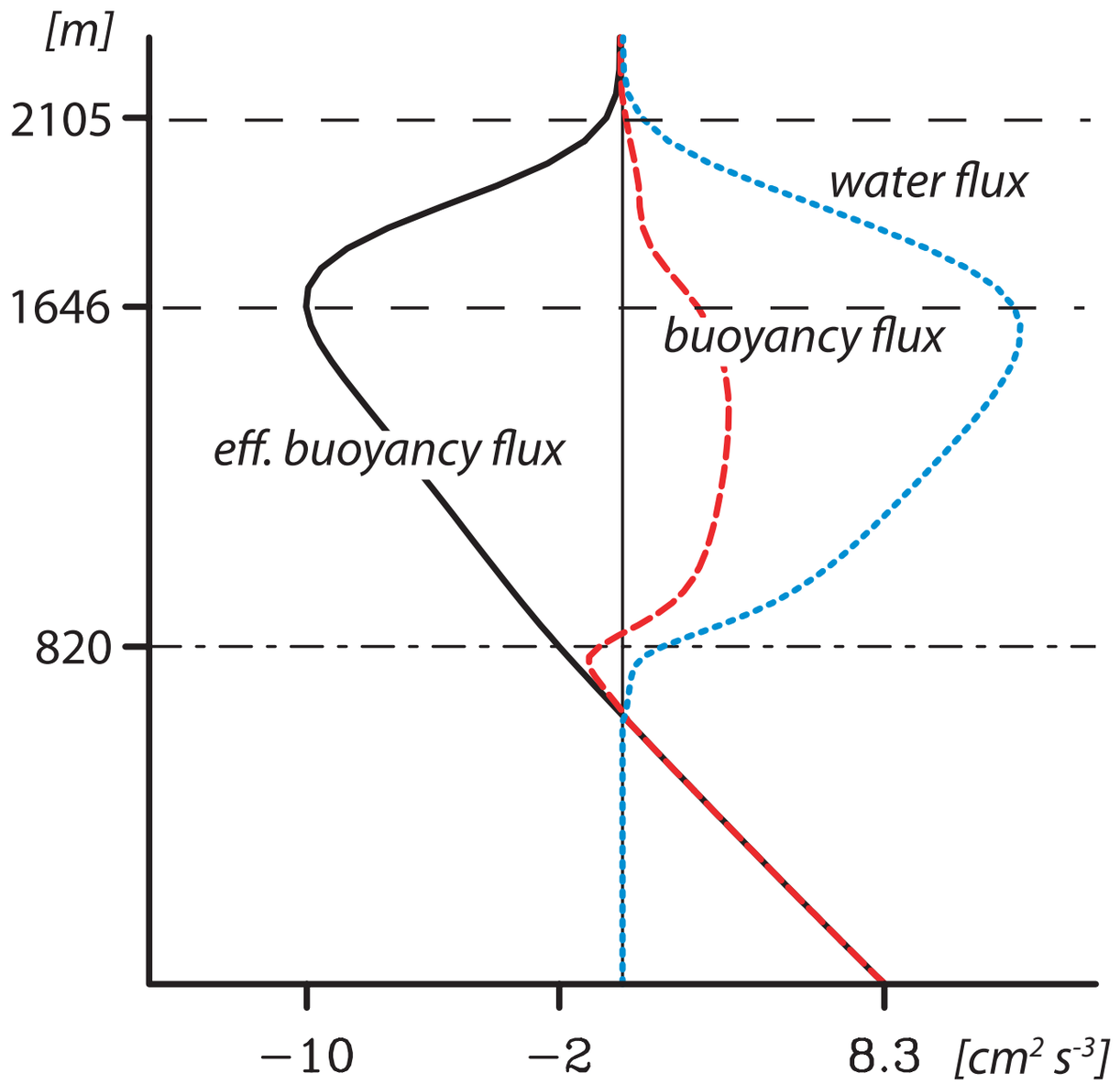
simple.prototype

3 assumptions

- subcloud layer <=> dry cbl
- cloud water *in cloud layer* is stationary
- cloud layer density slaved to sublcoud layer

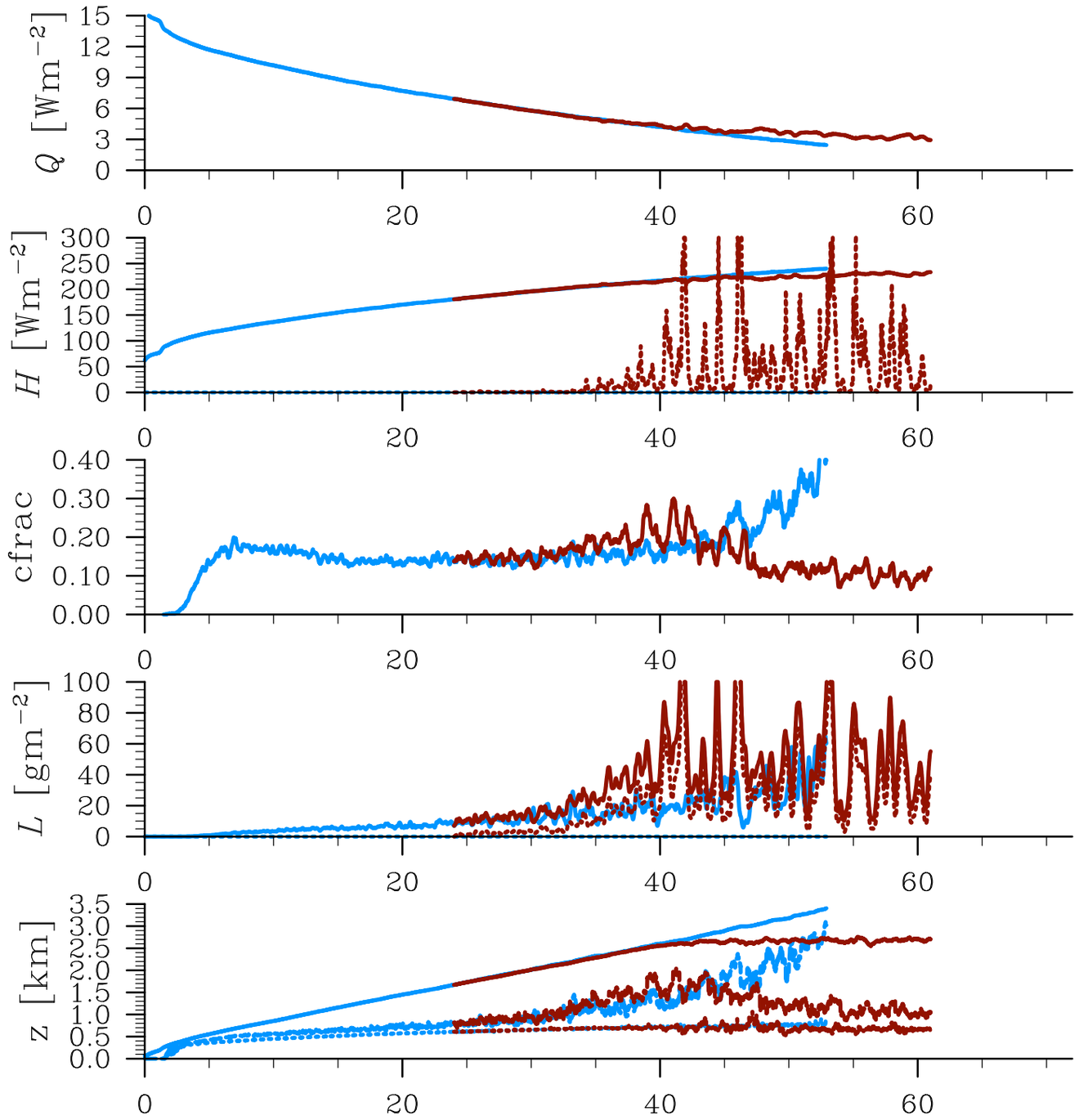


simple.prototype

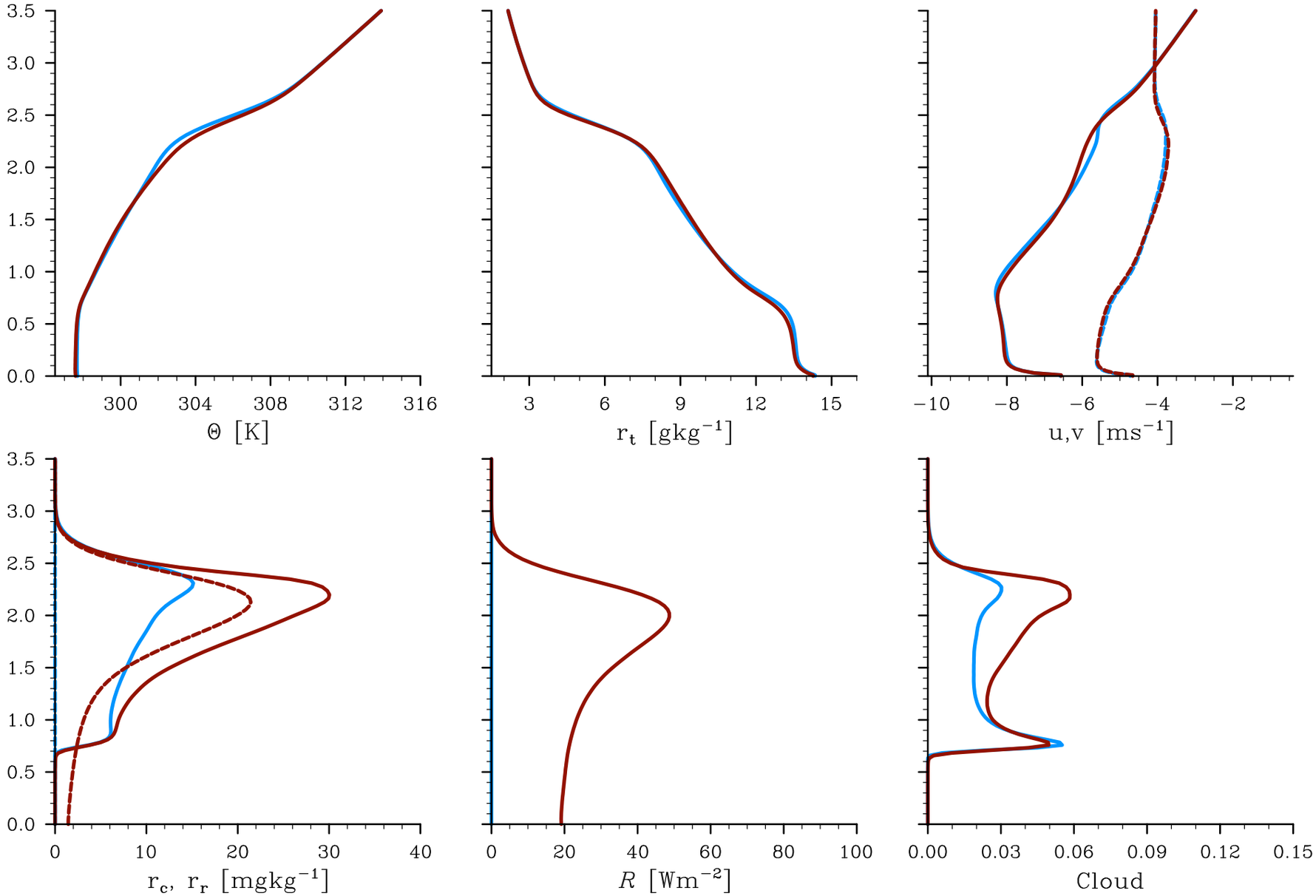


$$\partial_t \theta_\rho = -\underbrace{[\overbrace{(a\partial_z Q_l + \epsilon\theta\partial_z R)}^{\partial_z \tilde{Q}_\rho} + b\theta\partial_z R_l]}_{\partial_z Q_\rho} + b\theta\mathcal{C}$$

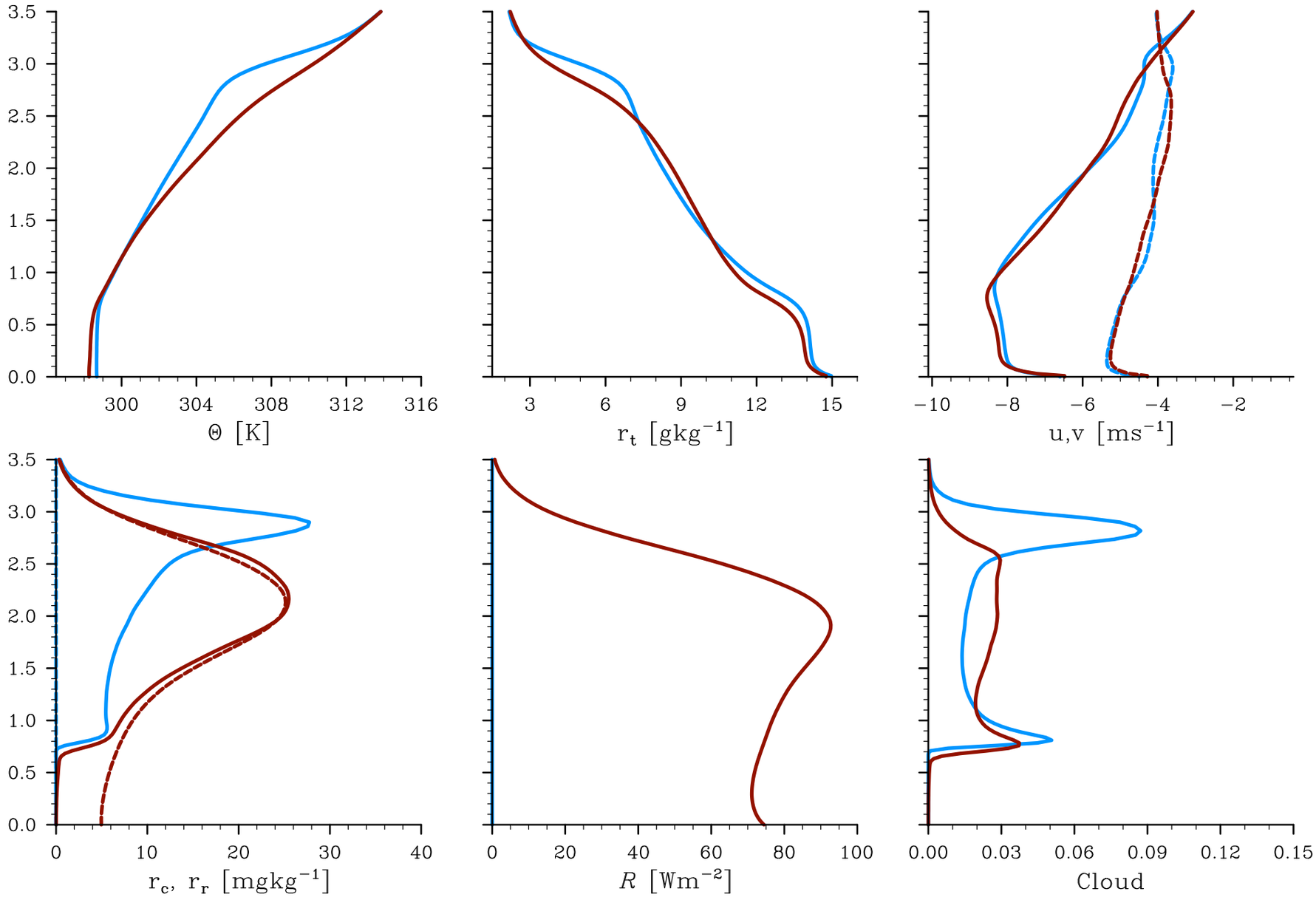
simple.rico


Q [Wm^{-2}]
15
12
9
6
3
0
0
20
40
60
H [Wm^{-2}]
300
250
200
150
100
50
0
0
20
40
60
cfrac
0.40
0.30
0.20
0.10
0.00
0
20
40
60
L [gm^{-2}]
100
80
60
40
20
0
0
20
40
60
z [km]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60

simple.rico


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
300
304
308
312
316
Θ [K]
3
6
9
12
15
r_t [gkg^-1]
−10
−8
−6
−4
−2
u,v [ms^-1]
0
10
20
30
40
r_c, r_r [mgkg^-1]
0
20
40
60
80
100
R [Wm^-2]
0.00
0.03
0.06
0.09
0.12
0.15
Cloud

simple.rico


3.5
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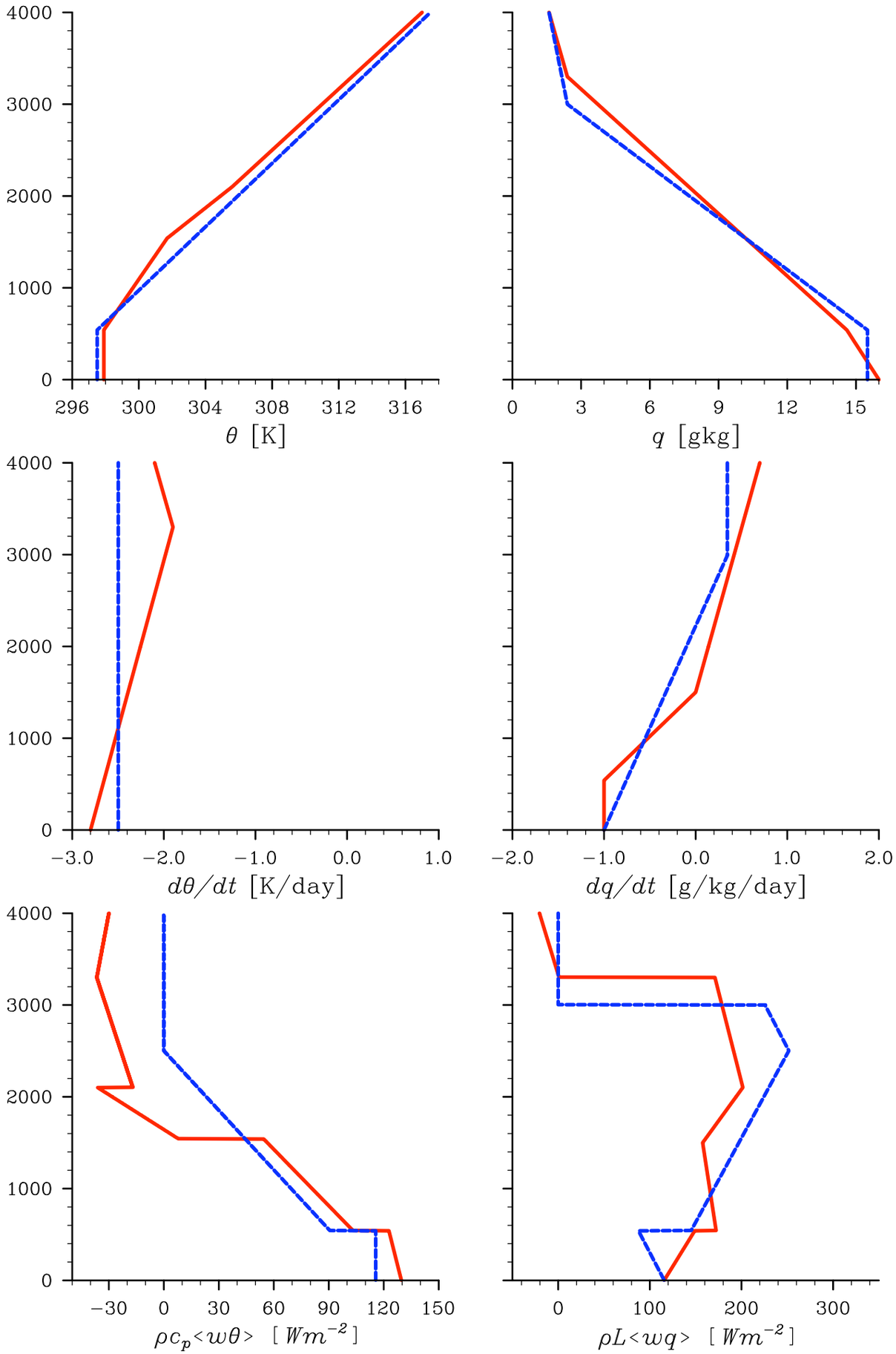
r_t [gkg^{-1}]
−10
−8
−6
−4
−2
u,v [ms^{-1}]
0
10
20
30
40
r_c, r_r [mgkg^{-1}]
0
20
40
60
80
100
R [Wm^{-2}]
0.00
0.03
0.06
0.09
0.12
0.15
Cloud

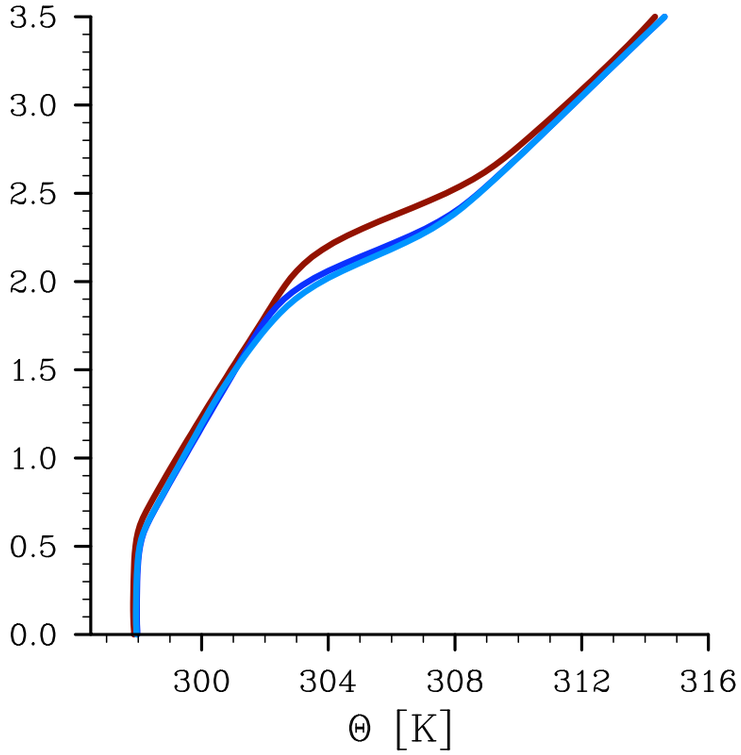
remarks.simple

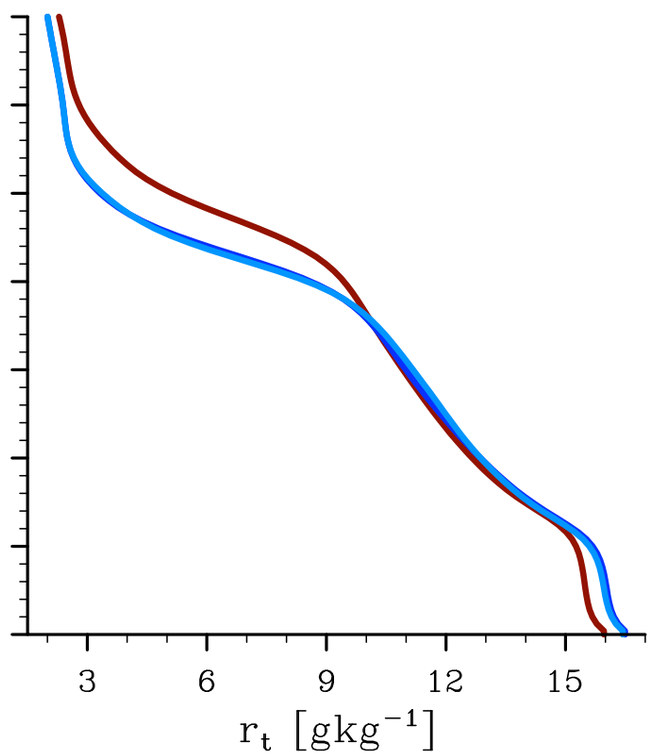
- growth of cloud layer largely explained by flux of liquid water into the inversion.
- this implies that rain can limit the growth of the cloud layer ... it does.
- but deeper clouds should produce more rain ... they do.
- this can lead to uncanny sensitivity in the cloud behavior ... and does
- probably enough "aerosol effects" for each of us to attach our name to one.

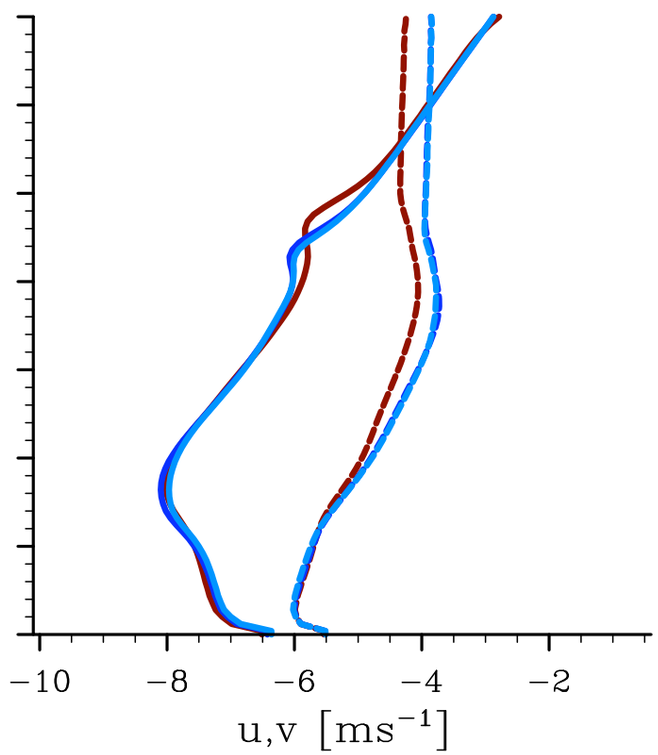
newcase.simple

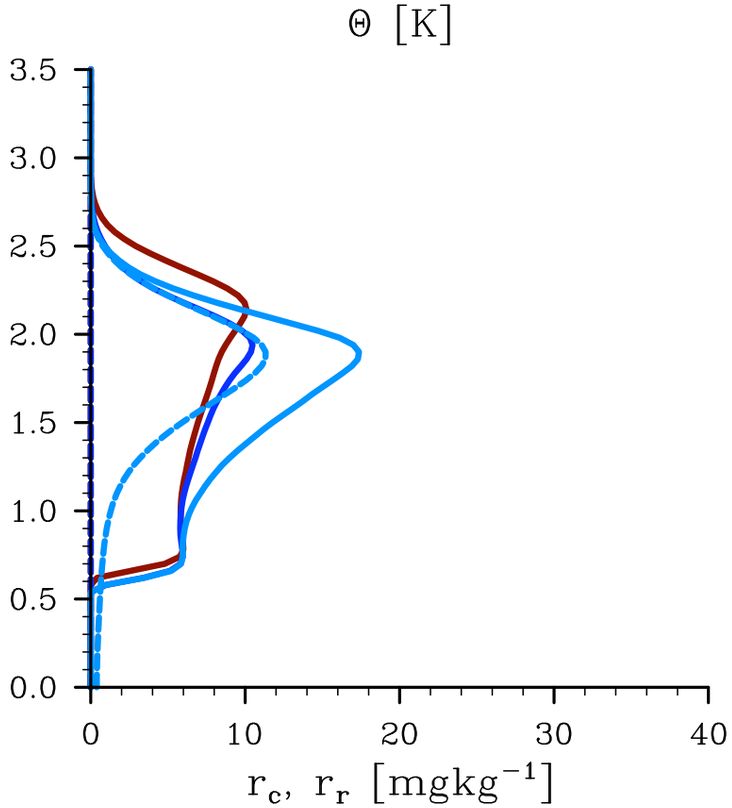
- come up with the simplest plausible composite.
- have balanced forcings in the troposphere
- avoid the stratocumulus catastrophe.

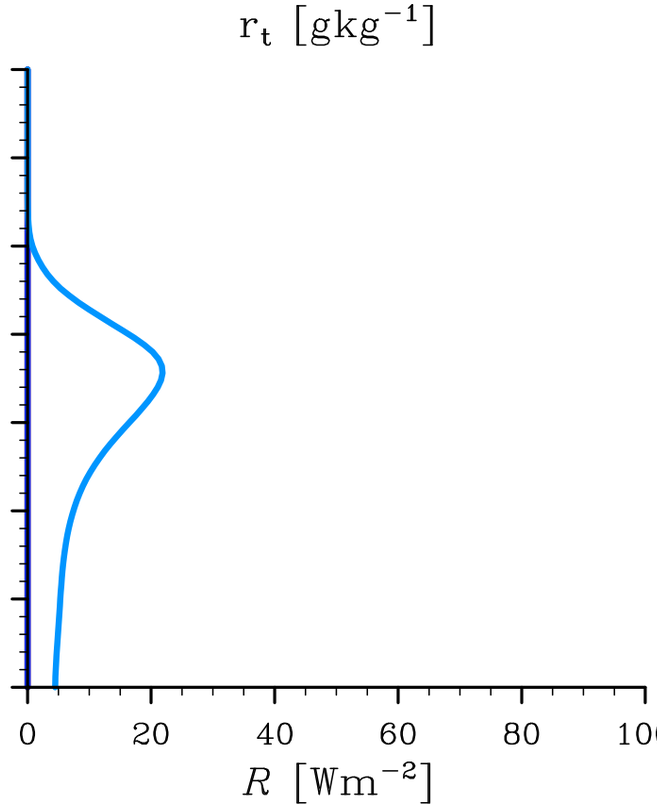

4000
3000
2000
1000
0
296
300
304
308
312
316
θ [K]
0
3
6
9
12
15
q [gkg]
−3.0
−2.0
−1.0
0.0
1.0
dθ/dt [K/day]
−2.0
−1.0
0.0
1.0
2.0
dq/dt [g/kg/day]
−30
0
30
60
90
120
150
ρc_p<wθ> [Wm^-2]
0
100
200
300
ρL<wq> [Wm^-2]

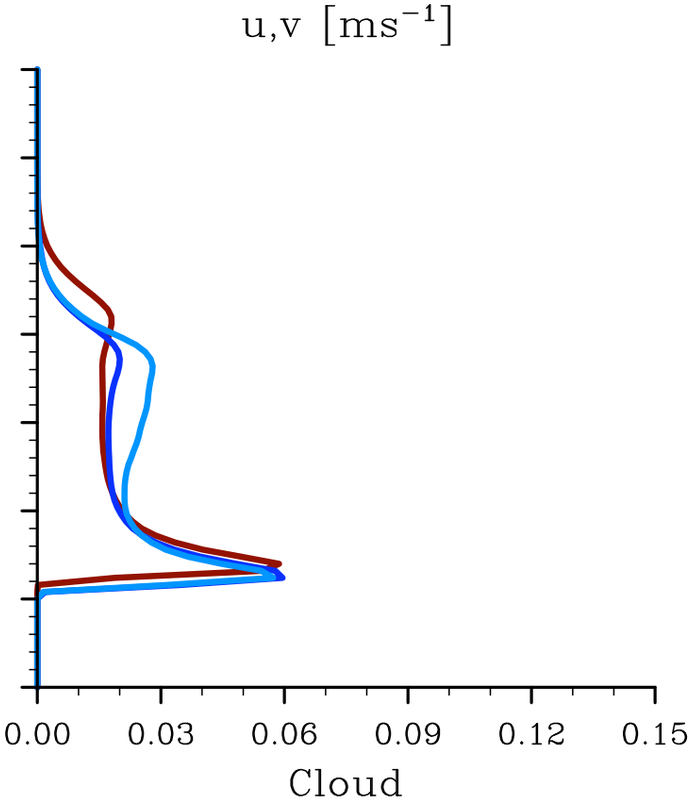

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
300
304
308
312
316
Θ [K]

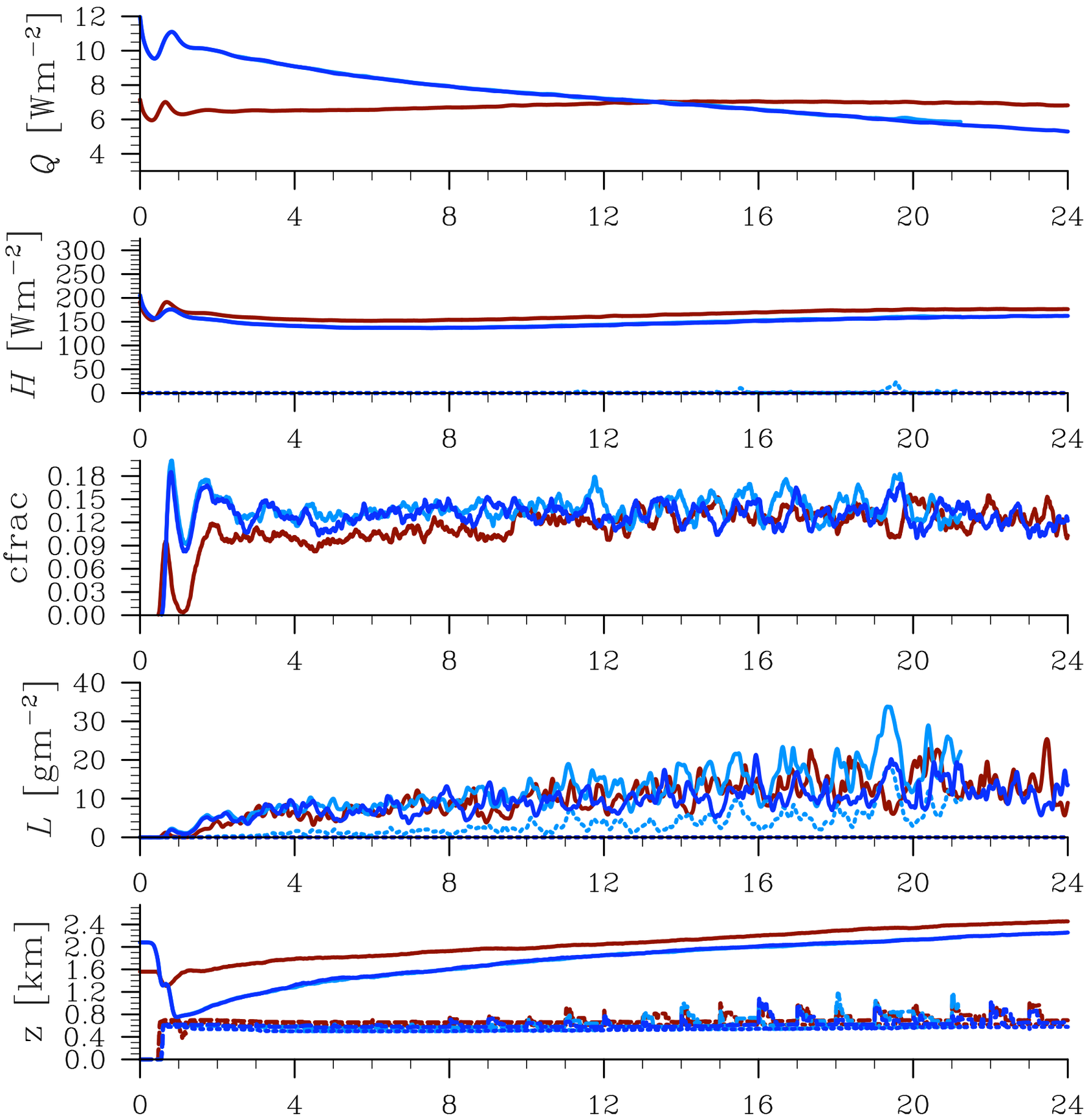

3
6
9
12
15
r_t [gkg^-1]

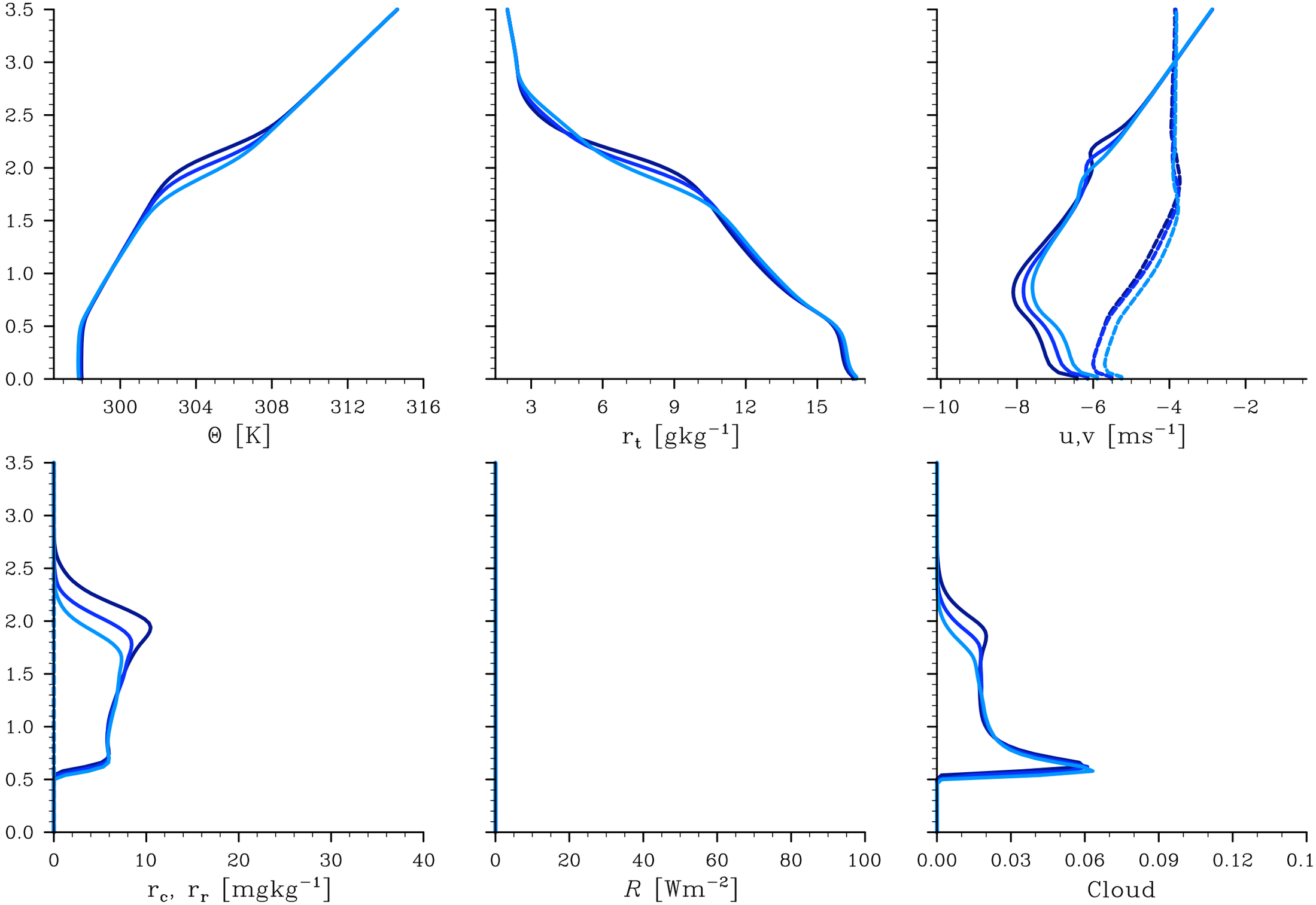

−10
−8
−6
−4
−2
u,v [ms^-1]


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
r_c, r_r [mgkg^-1]


0
20
40
60
80
100
R [Wm^-2]


0.00
0.03
0.06
0.09
0.12
0.15
Cloud


Q [Wm^{-2}]
12
10
8
6
4
0
4
8
12
16
20
24
H [Wm^{-2}]
300
250
200
150
100
50
0
cfrac
0.18
0.15
0.12
0.09
0.06
0.03
0.00
L [gm^{-2}]
40
30
20
10
z [km]
2.4
2.0
1.6
1.2
0.8
0.4
0.0


3.5
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Θ [K]
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−8
−6
−4
−2
u,v [ms^{-1}]
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20
30
40
r_c, r_r [mgkg^{-1}]
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100
R [Wm^{-2}]
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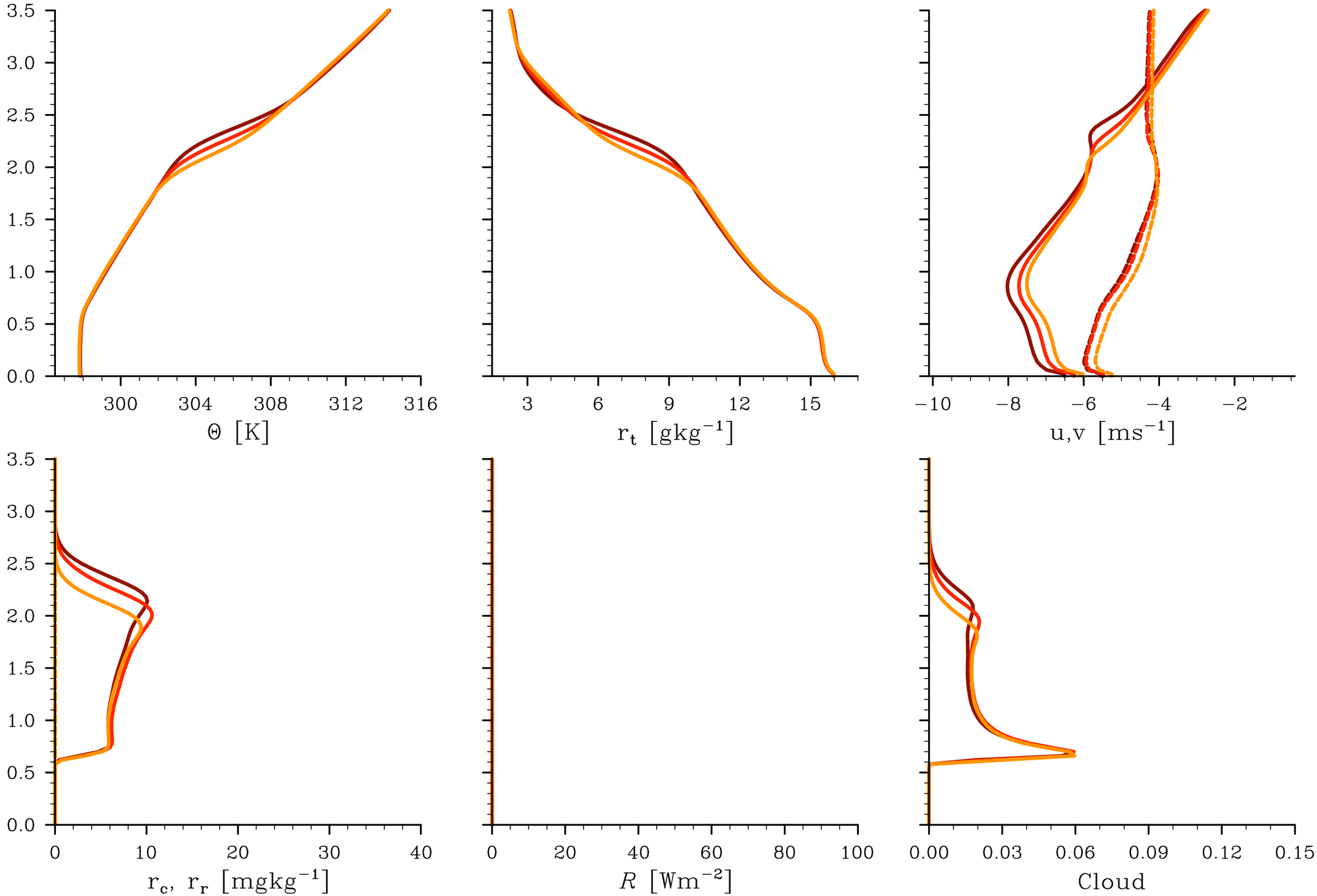
Cloud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Θ [K]
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15
r_t [gkg^{-1}]
−10
−8
−6
−4
−2
u,v [ms^{-1}]
0
10
20
30
40
r_c, r_r [mgkg^{-1}]
0
20
40
60
80
100
R [Wm^{-2}]
0.00
0.03
0.06
0.09
0.12
0.15
Cloud

newcase.simple

- new case seems to meet design objectives.
- surface sensible heat flux evolves more, but perhaps better in other respects.
- suggest running microphyiscs for only last eight hours.
- damp net tendeancies, exp(-(z-3500)/500) for z > 3500m