Temporal behavior of trade-wind cloudiness and its large scale thermodynamic state in observations and models

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“Cloudiness is the manifestation of the effects of a number of subgrid-scale processes and is therefore very sensitive to the model’s ability to represent the atmospheric structure which results from these processes”

J. M. Slingo (1978)

- In addressing the uncertainties in global models, we should (more) closely evaluate how the modeled atmospheric structure couples to cloudiness

- For low-level clouds, physical relationships between the atmospheric structure and cloudiness are known from early field campaigns, Large Eddy Simulation and observational sites

- For the subtropical trade-wind cumulus regimes less observations exist

- These regimes, with moderately subsiding motion and moderately rising motion, are still a major source of uncertainty in the prediction of low-level cloud feedback and climate sensitivity

- There is room for more understanding

Does subtropical cloud amount increase when relative humidity at cloud base is higher? What about LTS?

Is there more cloud during winter when the large-scale vertical motion is subsiding, or during summer when large scale motion is moderately rising?

Approach & outline

We analyze two years of ground-based remote sensing observations on Barbados

1) *What are robust features in the distribution and variability of trade-wind cloud amount that we would like models to reproduce?*

2) *How does the cloud behavior relate to the vertical profiles of humidity and temperature?*

Goal: evaluate such relationships at trade-wind like locations (Barbados) in models

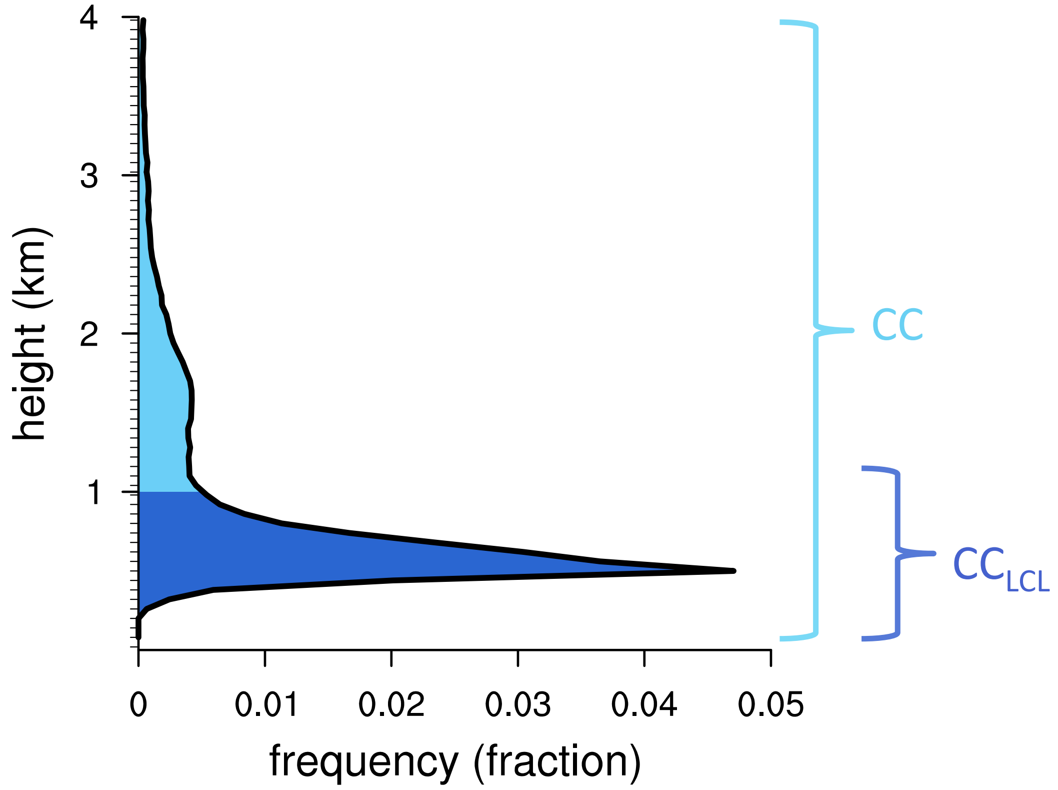
3) *Does the model have a reasonable cloud behavior and atmospheric structure?*

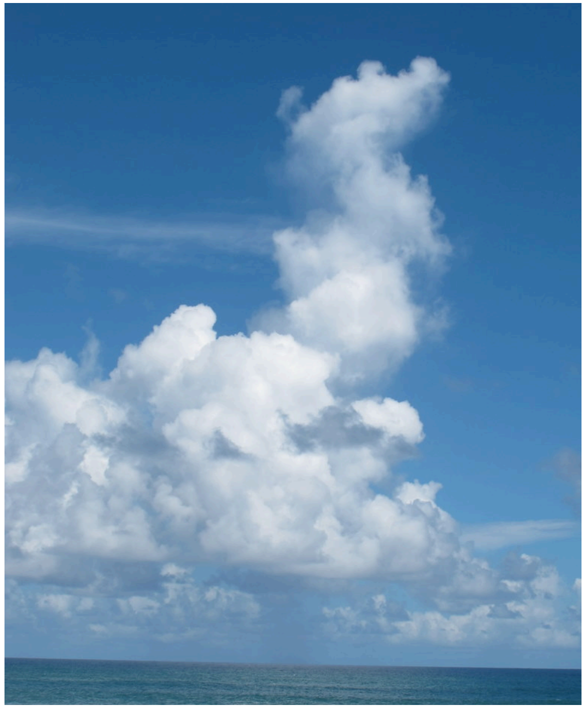
Does the cloud scheme feel changes in the atmospheric structure over longer time scales for instance: does it reproduce a seasonal cycle?

- ECMWF operational analysis
- cfSites output

1. Behavior of trade-wind cloudiness

cloud cover is defined as the number of profiles with cloud anywhere below 4 km

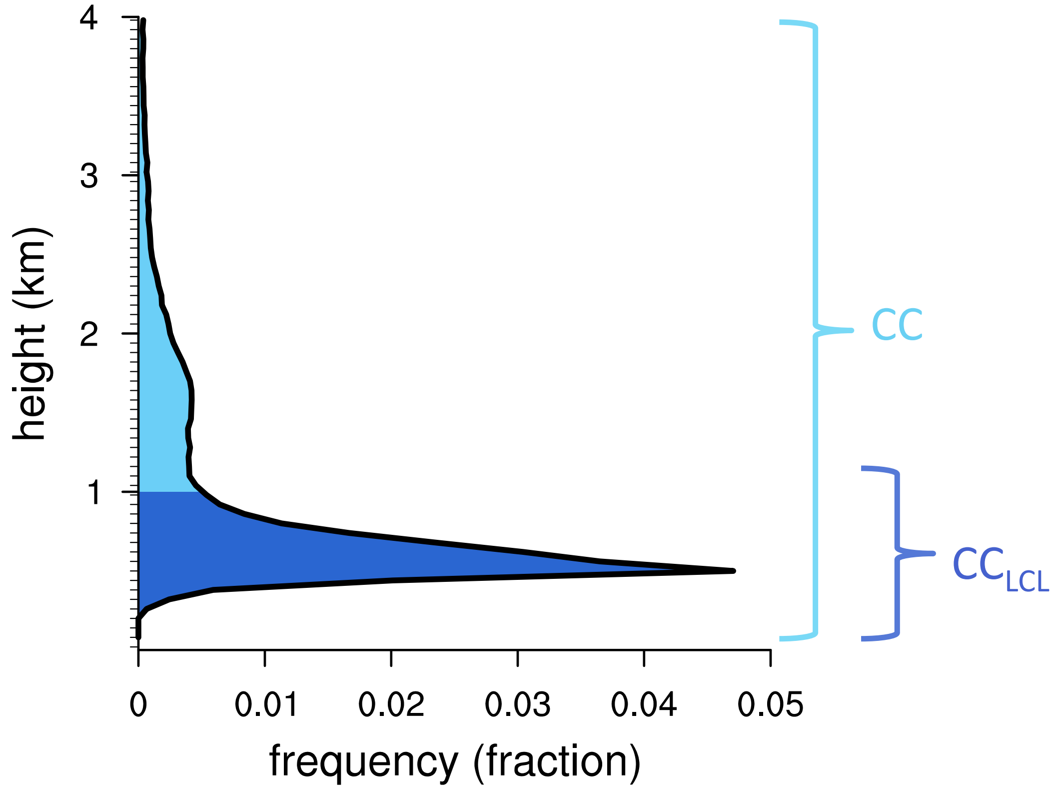


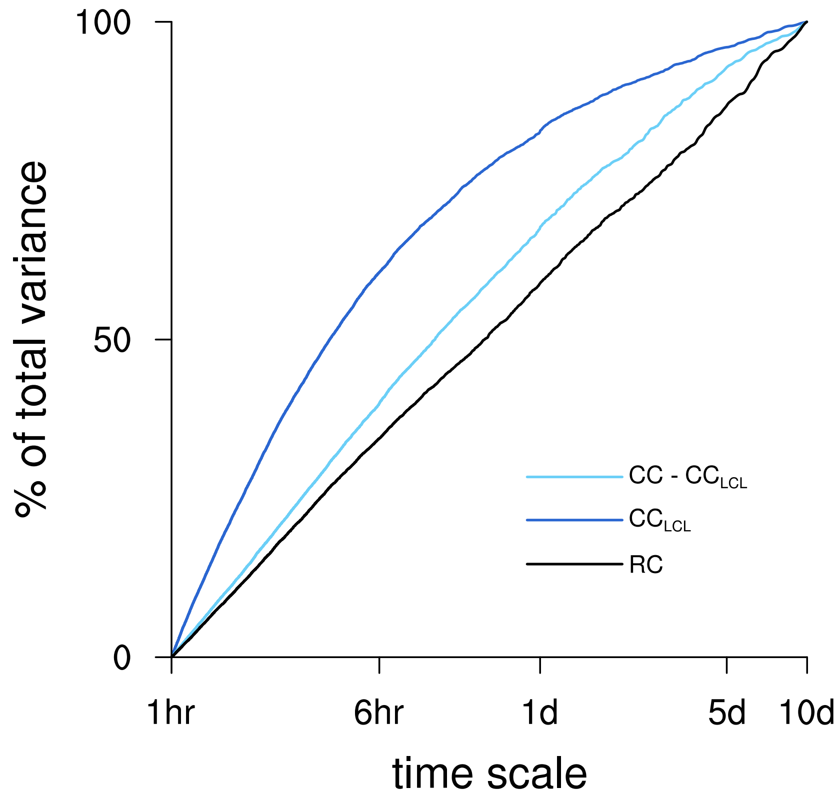


Nuijens et al. (2013) – in review

1. Behavior of trade-wind cloudiness

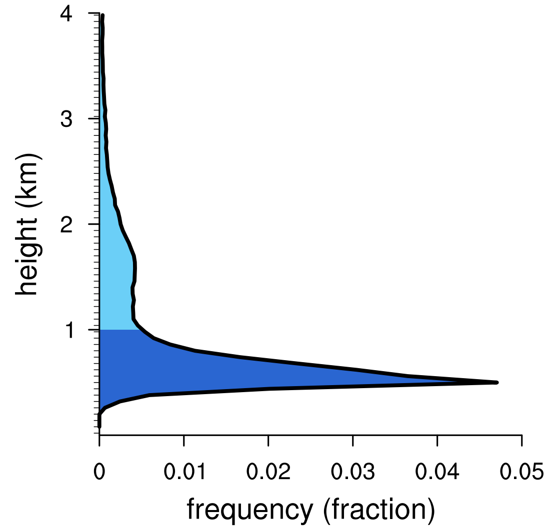
cloud cover is defined as the number of profiles with cloud anywhere below 4 km

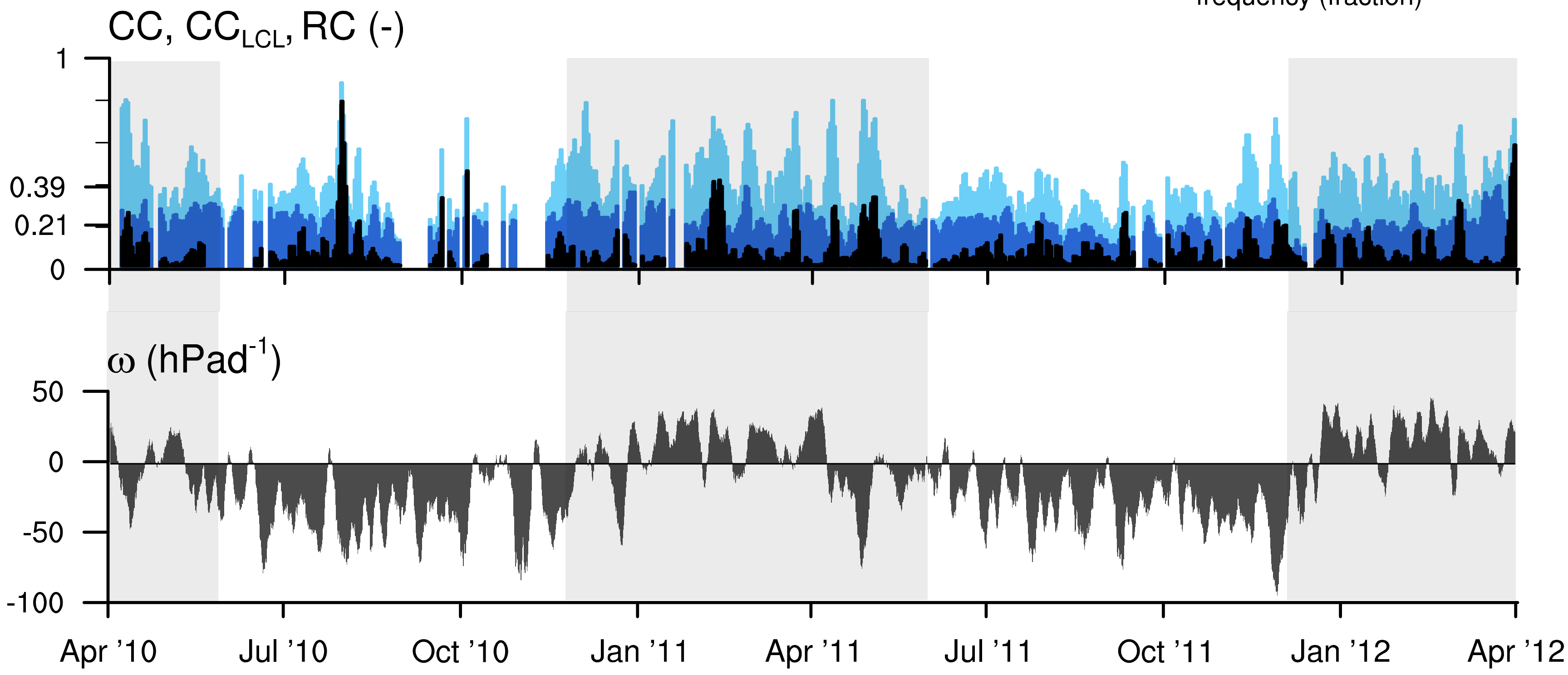




Nuijens et al. (2013) – in review

1. Behavior of trade-wind cloudiness





Nuijens et al. (2013) – in review

1. Behavior of trade-wind cloudiness

The amount of non-raining cloud near the lifting condensation level (LCL) is about 20% and dominates total projected cloud cover

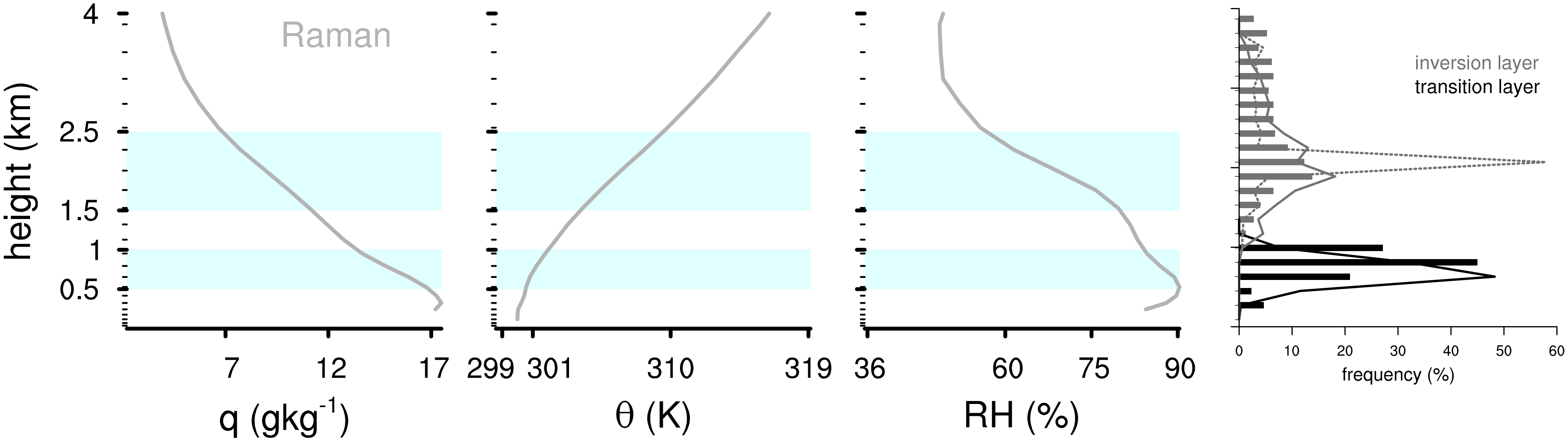
Cloud further aloft (> 1 km) has a smaller contribution to cloud cover of on average about 10%

Cloudiness near the LCL varies remarkably little across the wide range of large-scale conditions experienced on Barbados, which is consistent with existing theories, e.g. the cumulus valve mechanism and fast adjustment of the sub-cloud layer

Neggers et al. (2006), Bellon and Stevens (2012)

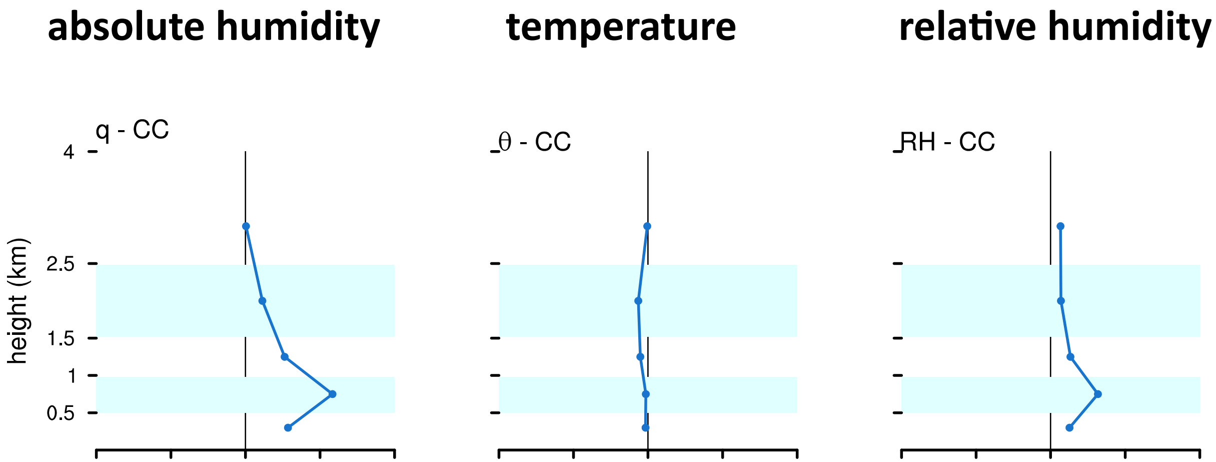
Variability in cloudiness aloft is more pronounced and associated with variations in cloud depth and a stratocumulus-like cloud mode near 1.5-2 km, even this far into the trades

2. How does this variability relate to the thermodynamic structure?



observations

< 8 hours

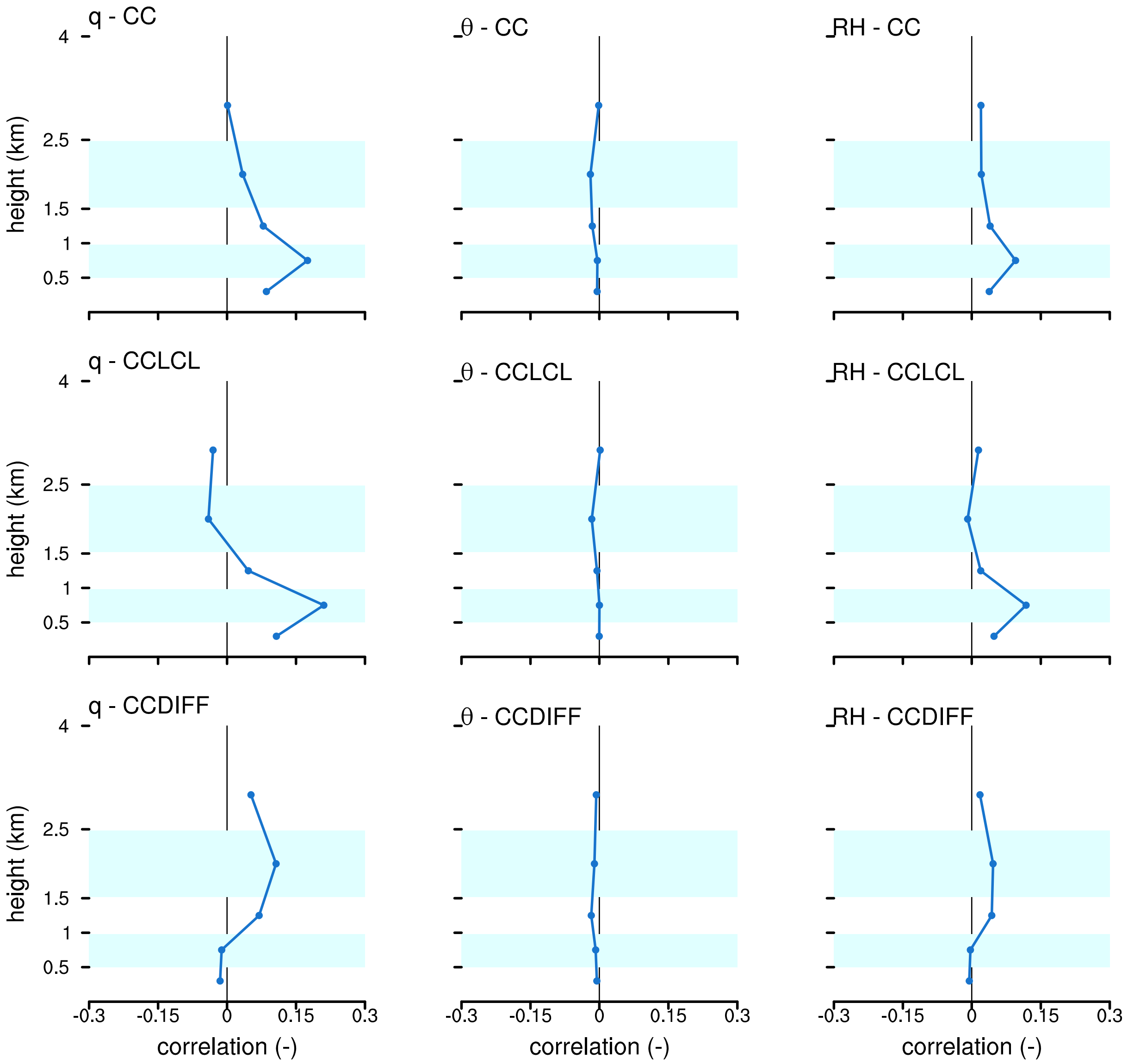


total cloud cover

absolute humidity **temperature** **relative humidity**

observations

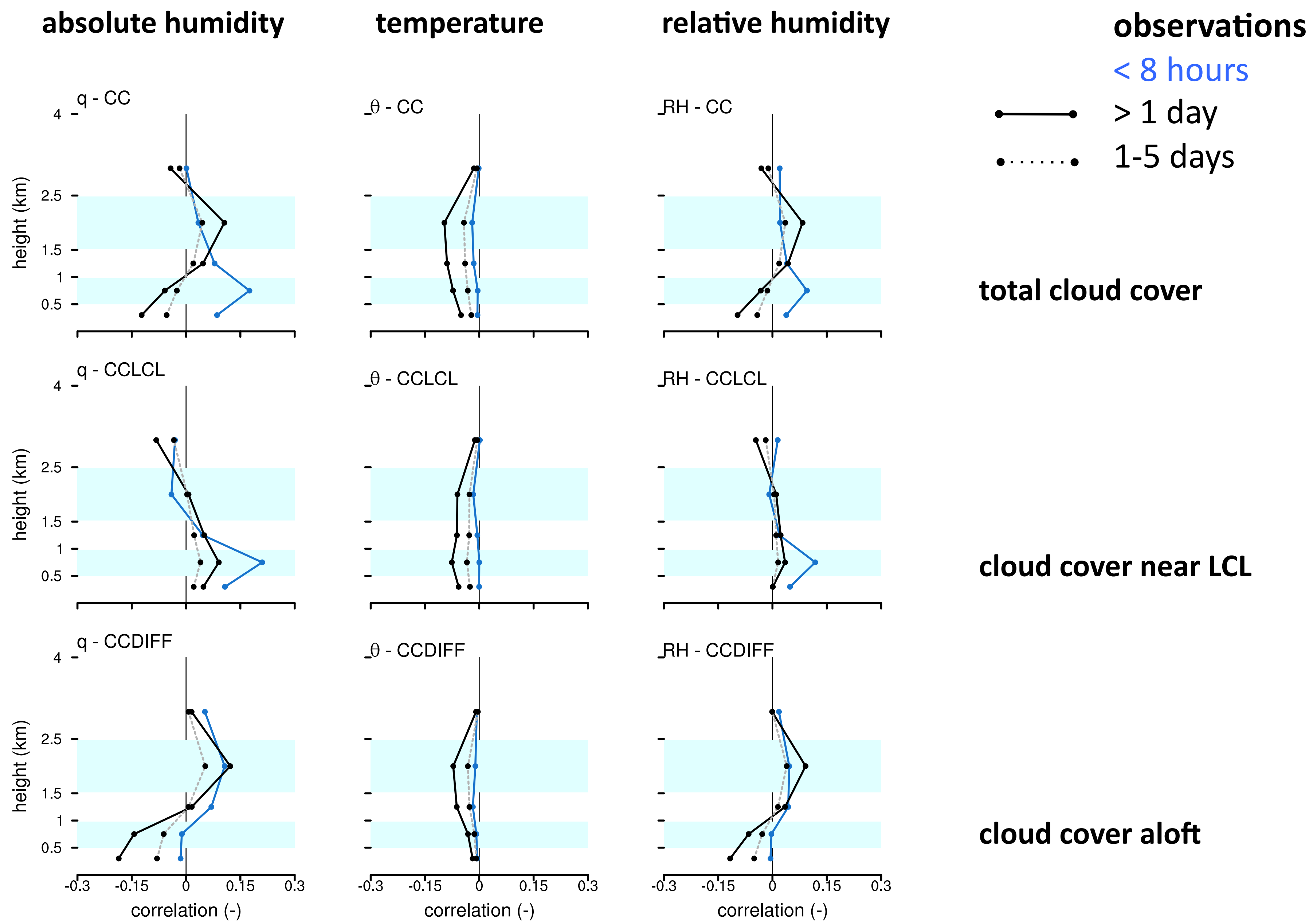
< 8 hours



total cloud cover

cloud cover near LCL

cloud cover aloft

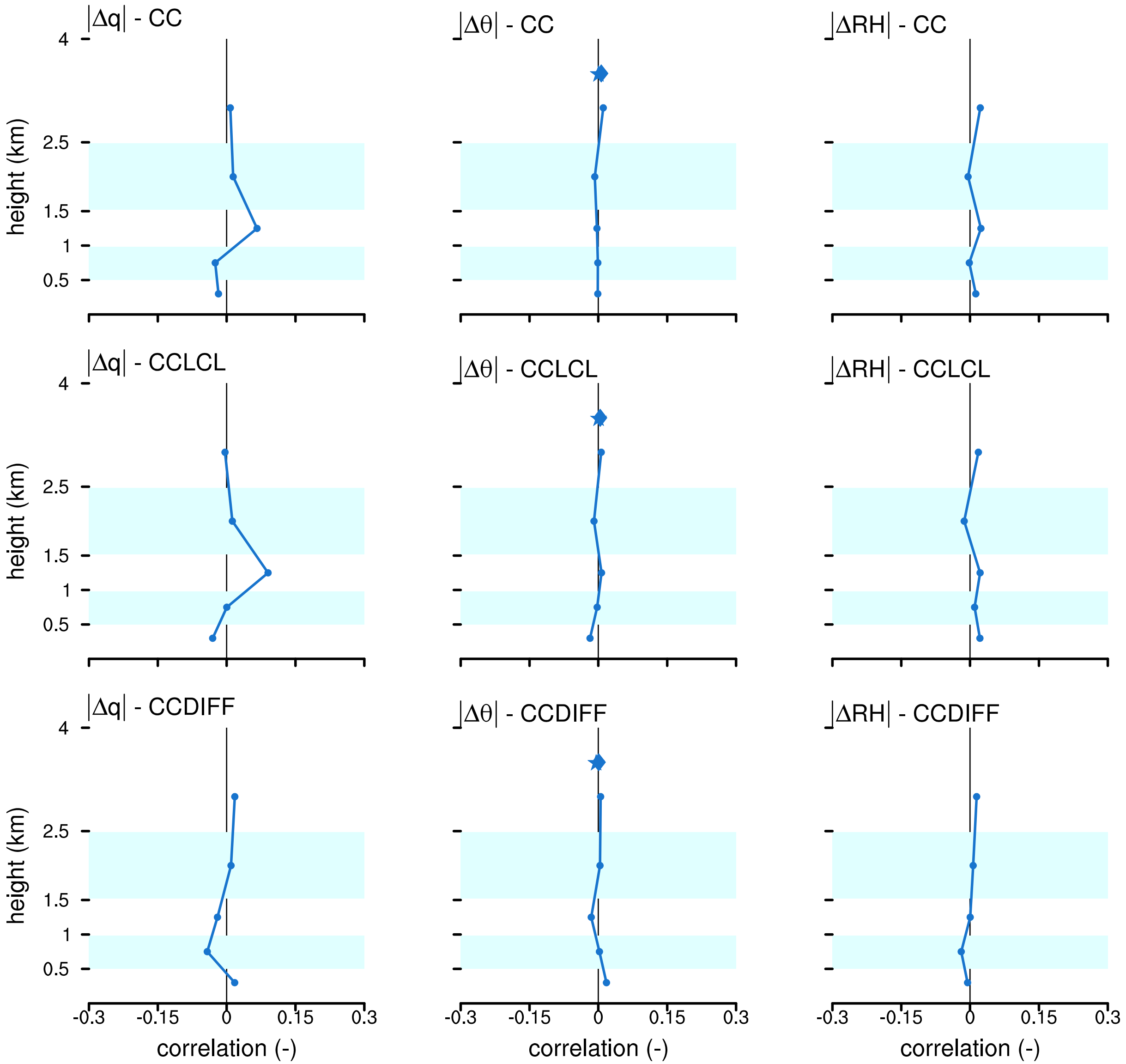


absolute humidity
temperature
relative humidity
observations
< 8 hours
> 1 day
1-5 days
q - CC
θ - CC
RH - CC
total cloud cover
q - CCLCL
θ - CCLCL
RH - CCLCL
cloud cover near LCL
q - CCDIFF
θ - CCDIFF
RH - CCDIFF
cloud cover aloft
height (km)
4
2.5
1.5
1
0.5
-0.3
-0.15
0
0.15
0.3
correlation (-)

observations

< 8 hours

absolute humidity | temperature | relative humidity

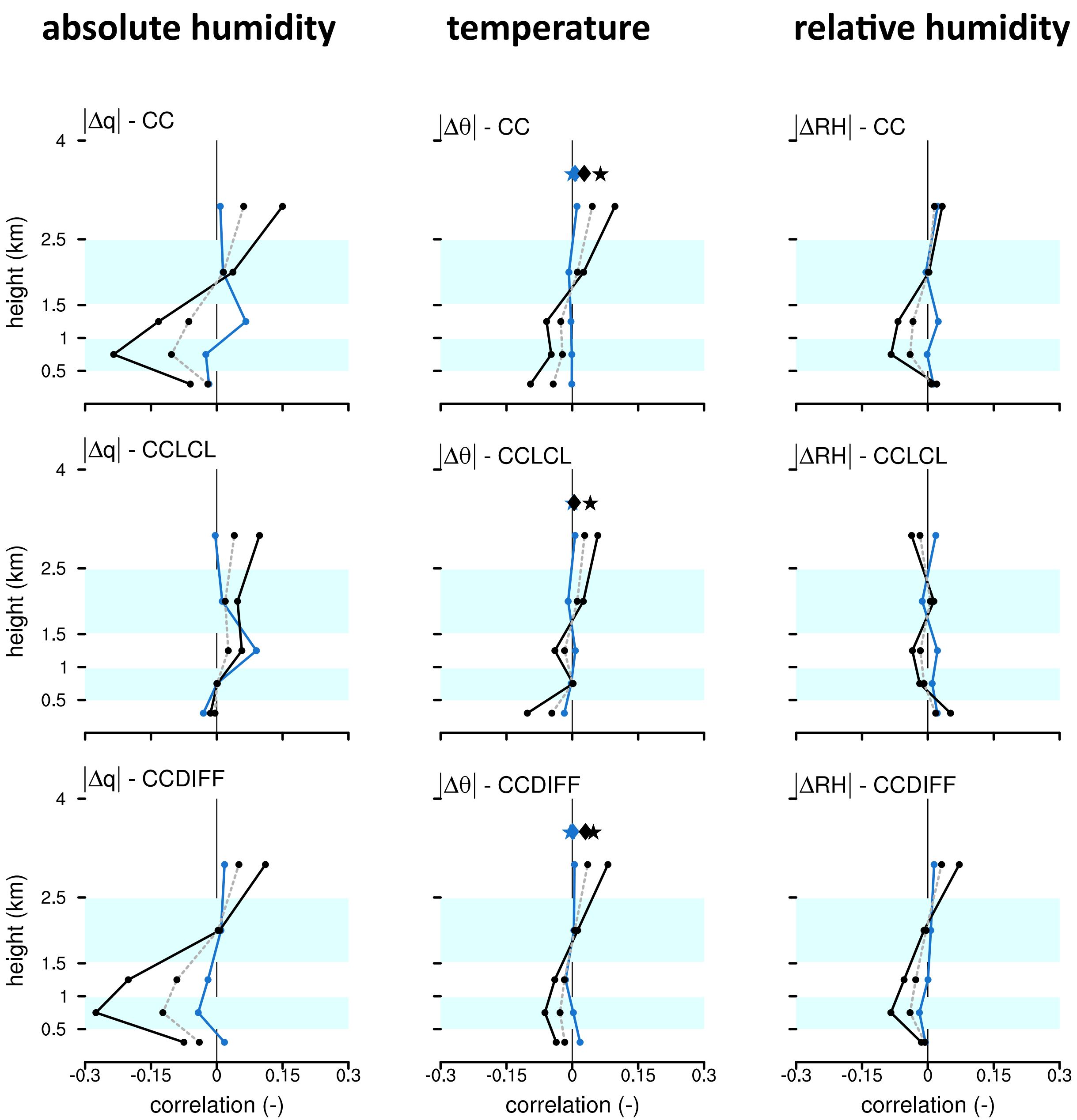


total cloud cover

cloud cover near LCL

cloud cover aloft

★ LTS ◆ kappa



observations

< 8 hours

> 1 day

1-5 days

total cloud cover

cloud cover near LCL

cloud cover aloft

★ LTS ◆ kappa

2. How does this variability relate to the thermodynamic structure?

On shorter time scales, cloud base cloudiness correlates (poorly) with humidity near cloud base

? statistical versus relative humidity based cloud schemes ?

On longer time scales, the contribution of cloud aloft correlates with humidity aloft, but not with humidity at lower altitudes

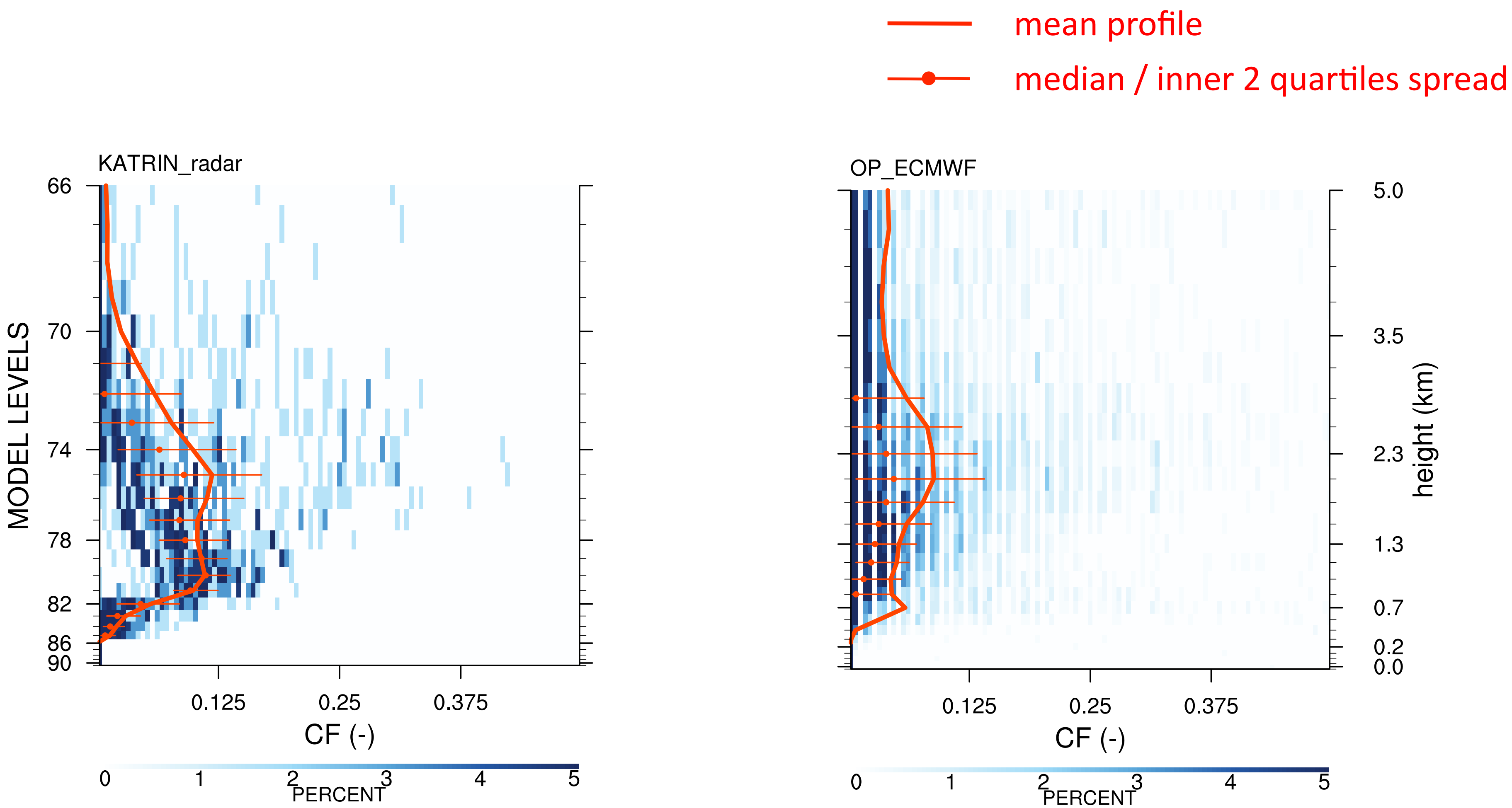
The underlying mechanism is the shift to stronger more northeasterly winds, that advect drier and colder air, trigger larger surface fluxes, which combined with stronger subsidence (upstream) leads to a build up of moisture in the cloud layer

Cloud aloft is poorly correlated with bulk stability measures (LTS, kappa)

Local gradients matter, especially the lapse rate of humidity in the lower cloud layer

3. Is such behavior present in models?

Frequency distribution **cloud fraction** from cloud radar observations and ECMWF analysis:



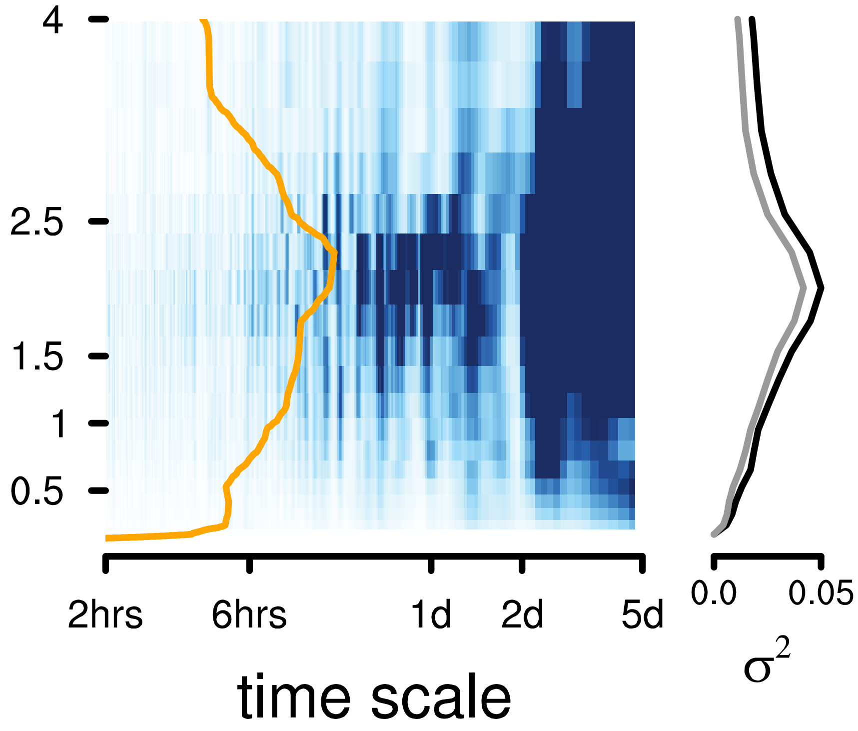
Ahlgrimm and Koehler (2010)

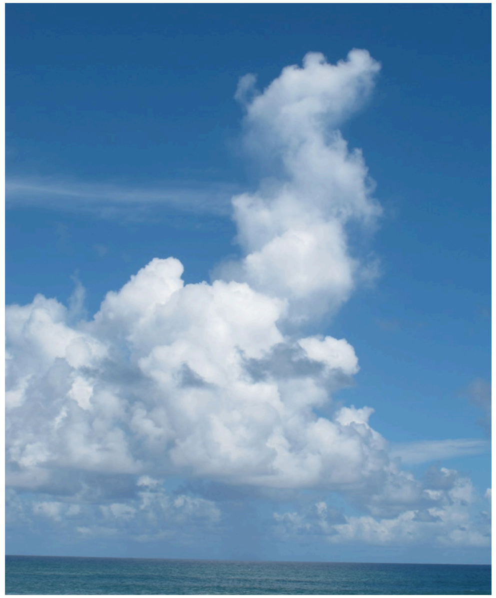
3. Is such behavior present in models?

Variance spectrum as a function of height and time:

time scale ~ 50% of total variance

total variance

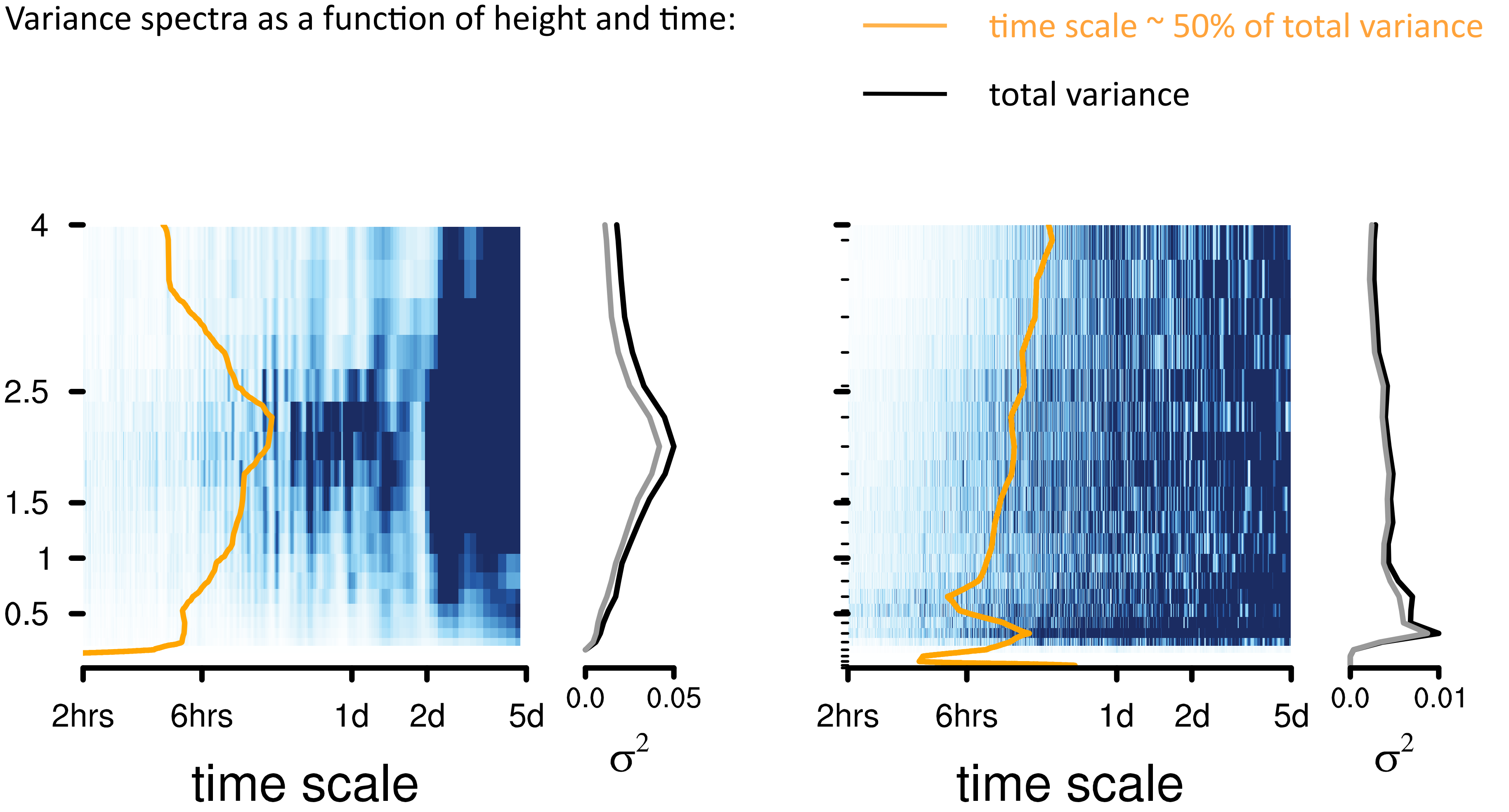




The observations show the maximum variance in cloud fraction near 2 km

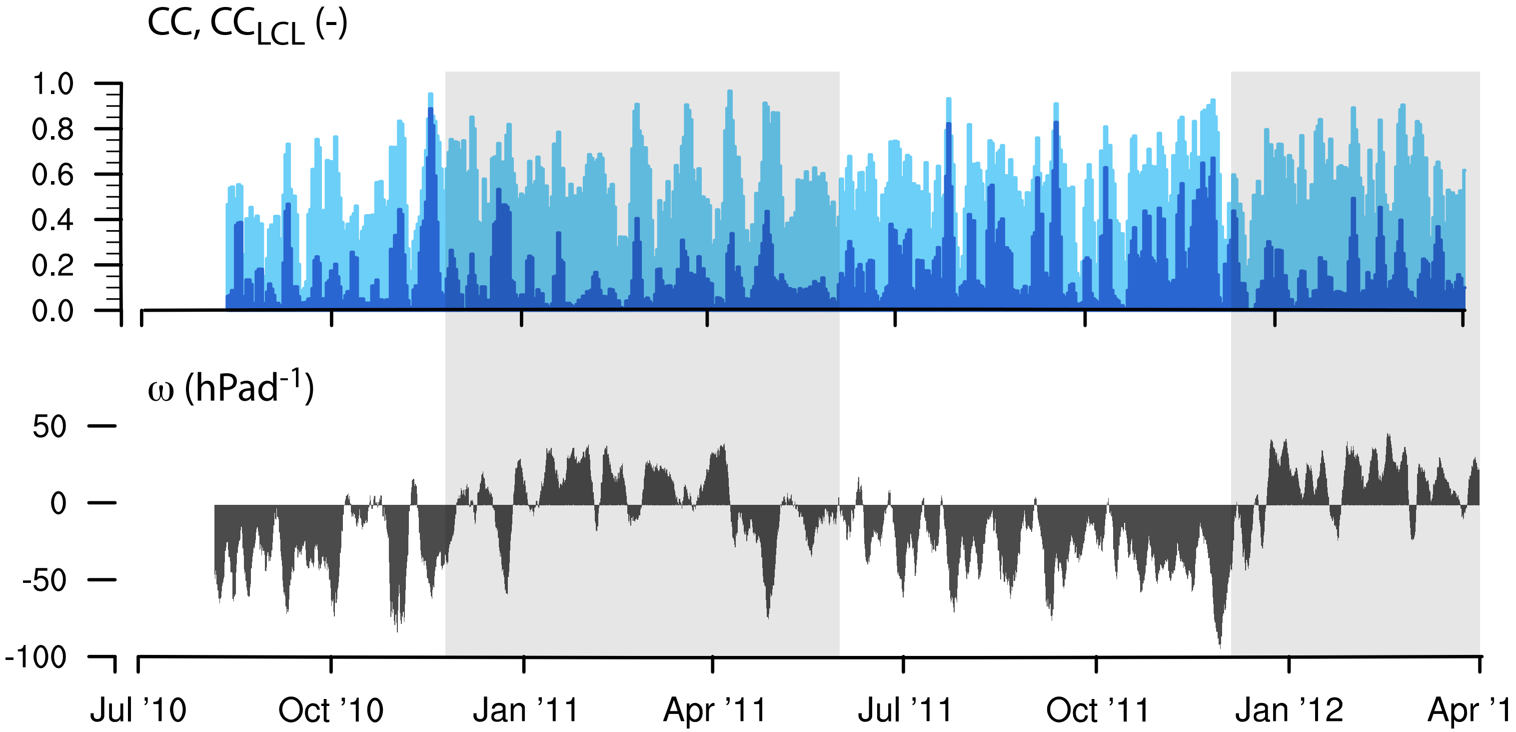
3. Is such behavior present in models?

Variance spectra as a function of height and time:



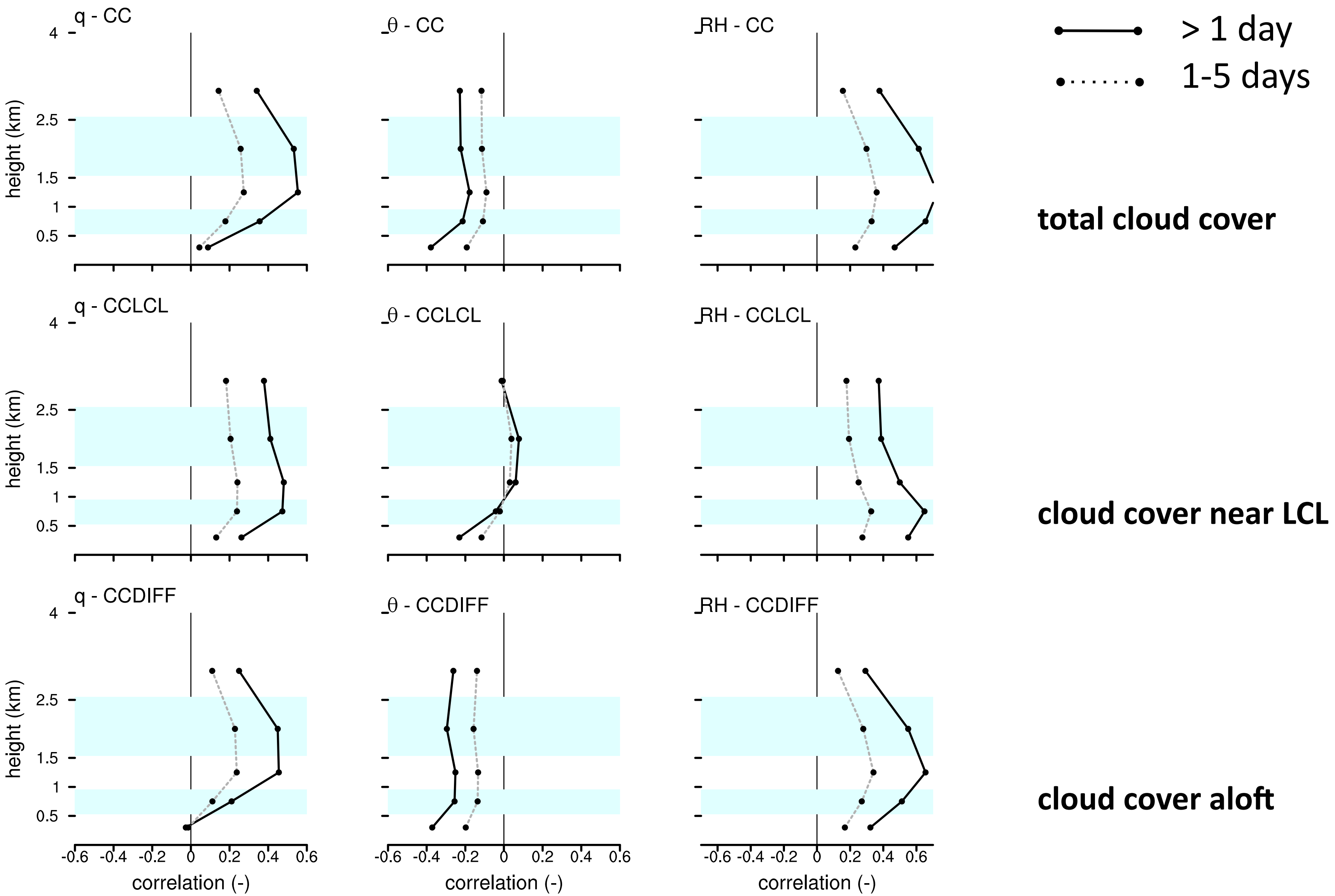
The cloud fraction profile in the analysis is more noisy, with the maximum variance near cloud base

3. Is such behavior present in models?



ECMWF OP

absolute humidity | **temperature** | **relative humidity**



Conclusions

Cloud near cloud base is overall the largest contributor to the total cloud cover, especially when the cloud field consists of shallower and smaller clouds. Even when the shallow optically thinner clouds are excluded, the contribution of cloud near cloud base is rarely less than a half.

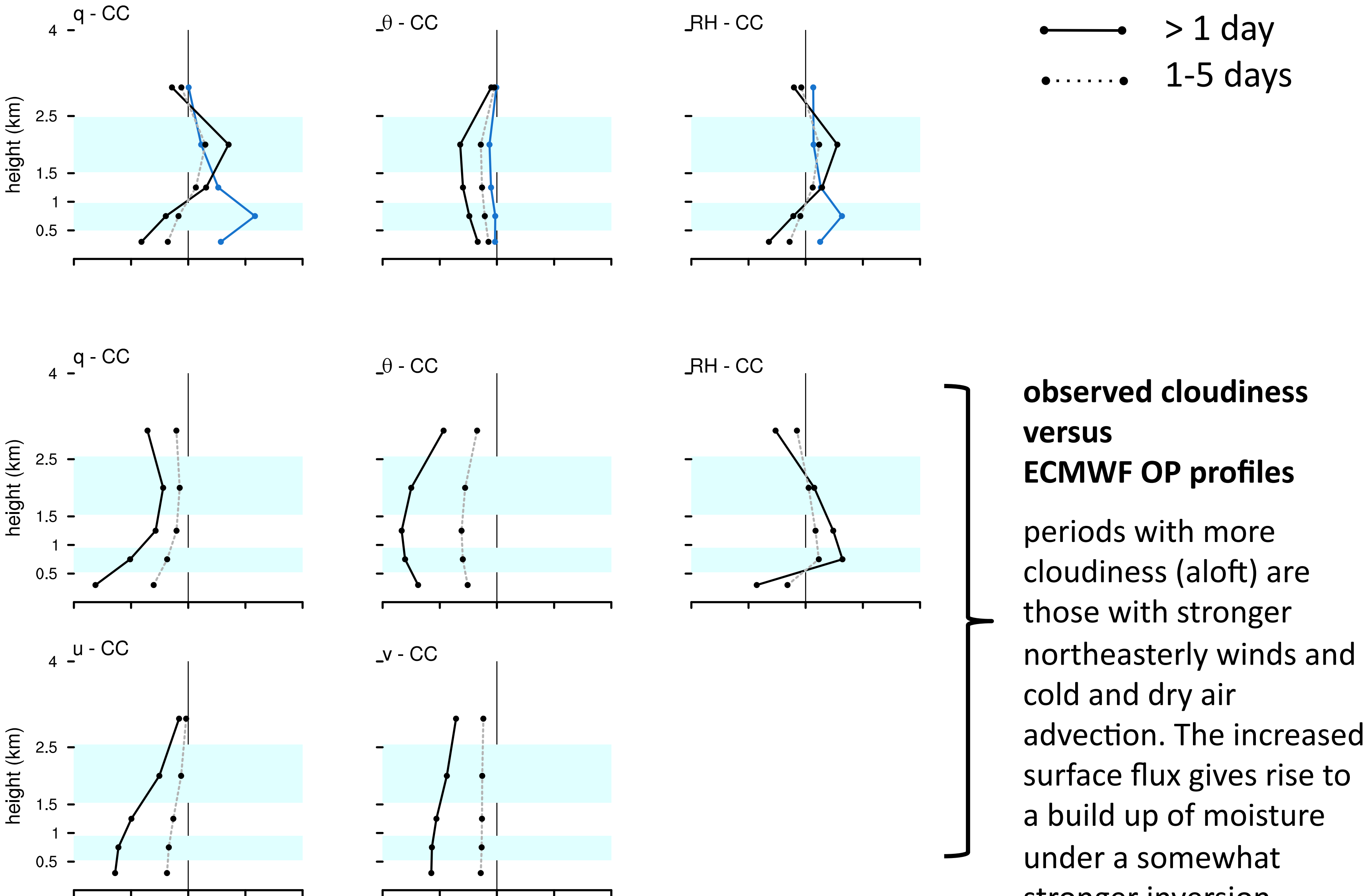
Because that part of the cloud field does not systematically vary, we may hypothesize that the sensitivity of cloud cover in the trades to changes in meteorology and climate is limited

Correlations between trade-wind cloudiness and (relative) humidity are poor. That reflects the very subtle nature of these clouds and their relationship to the environment

That is probably good and bad news

We intend to further evaluate how the modeled atmospheric structure couples to cloudiness, and in particular how the short time scale response matters for reproducing long time scale behavior, such as the seasonal cycle and other shifts in meteorology

absolute humidity	temperature	relative humidity

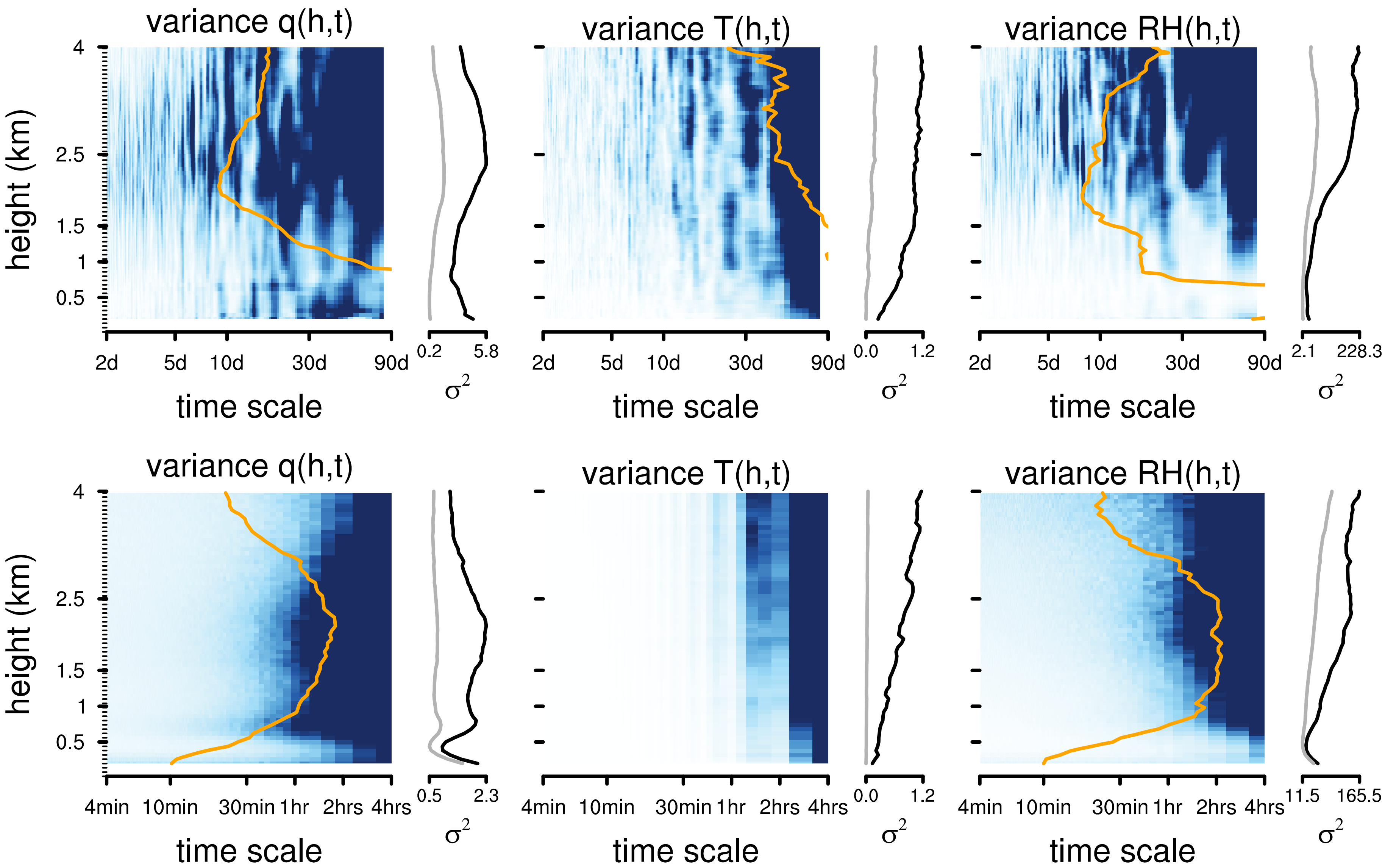


observed cloudiness versus ECMWF OP profiles

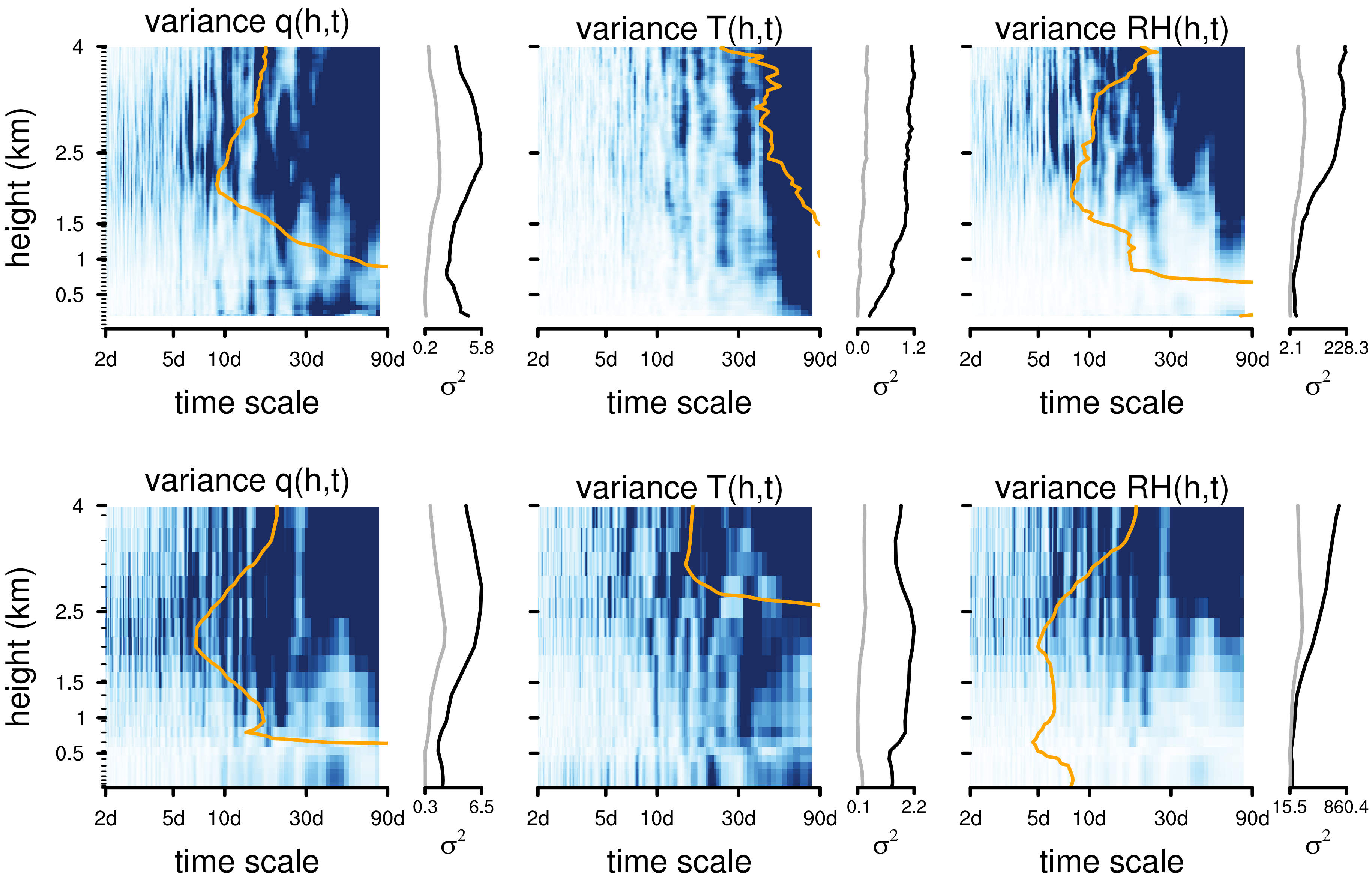
periods with more cloudiness (aloft) are those with stronger northeasterly winds and cold and dry air advection. The increased surface flux gives rise to a build up of moisture under a somewhat stronger inversion

Brueck et al. (2013) – in preparation

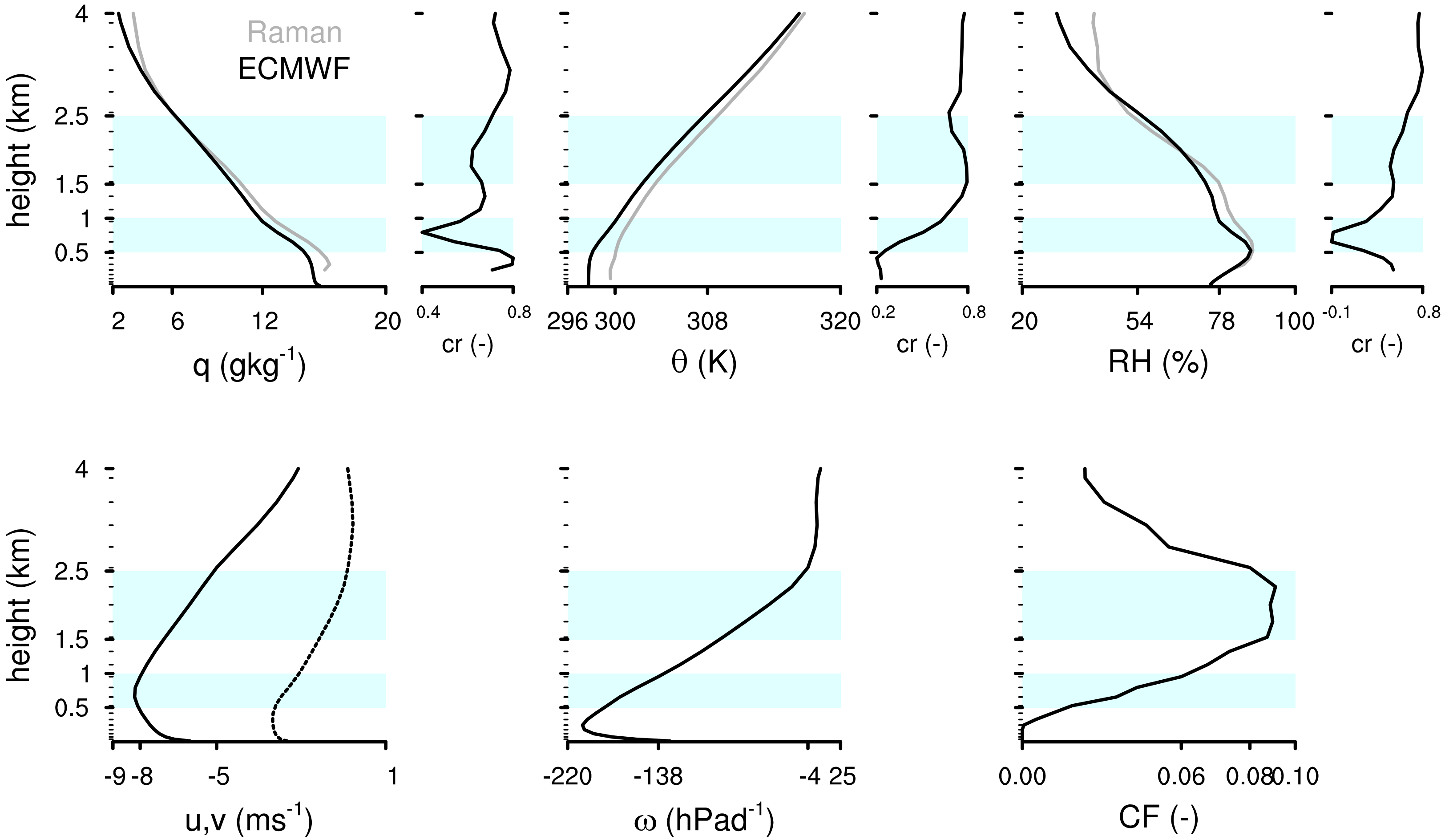
Variance spectra



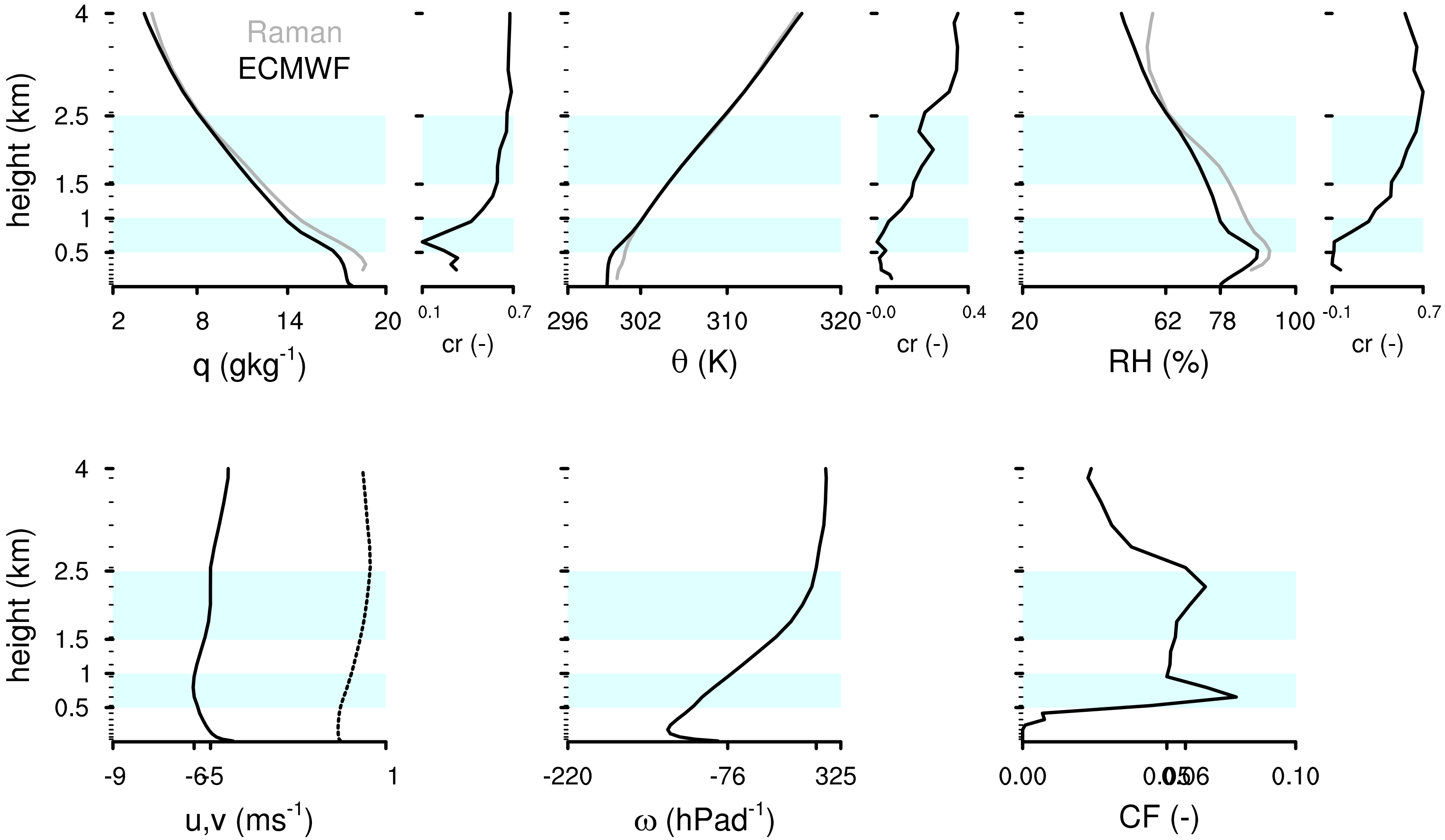
Variance spectra



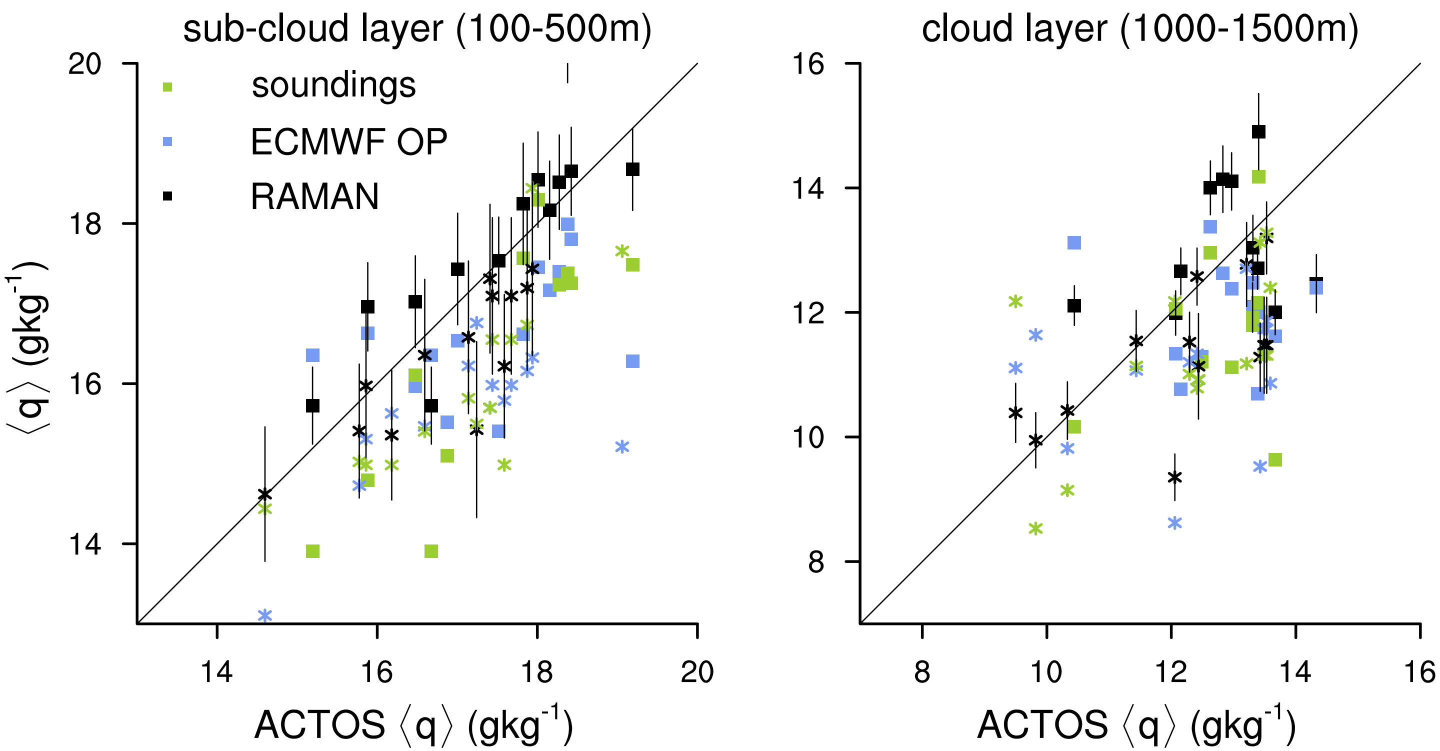
Winter

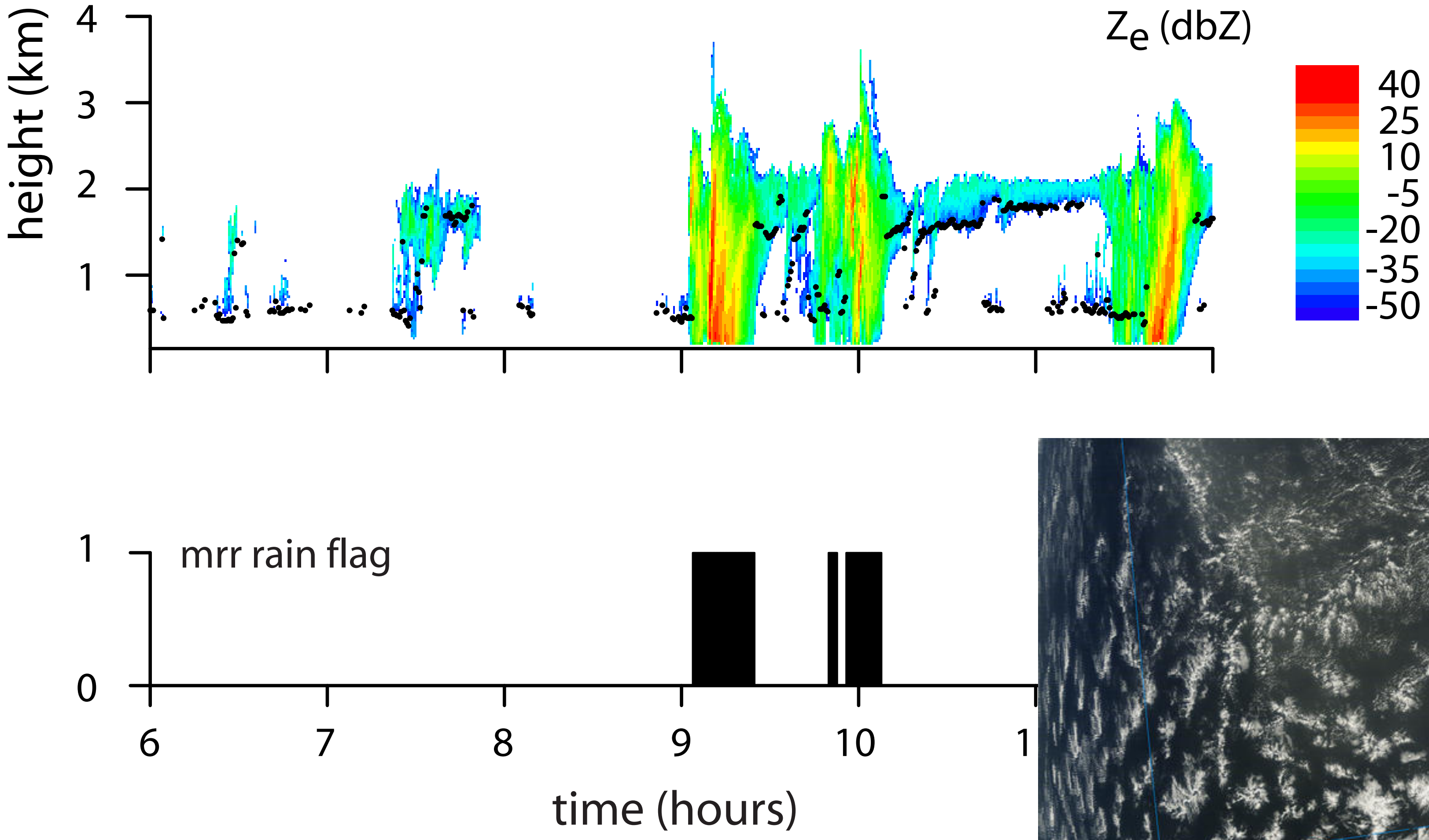

Raman
ECMWF
height (km)
4
2.5
1.5
1
0.5
2
6
12
20
q (gkg-1)
0.4
0.8
cr (-)
296 300
308
320
θ (K)
0.2
0.8
cr (-)
20
54
78
100
RH (%)
-0.1
0.8
cr (-)
height (km)
4
2.5
1.5
1
0.5
-9 -8
-5
1
u,v (ms-1)
-220
-138
-4 25
ω (hPad-1)
0.00
0.06
0.08 0.10
CF (-)

Summer


Raman
ECMWF
height (km)
4
2.5
1.5
1
0.5
2
8
14
20
q (gkg-1)
0.1
0.7
cr (-)
296
302
310
320
θ (K)
-0.0
0.4
cr (-)
20
62
78
100
RH (%)
-0.1
0.7
cr (-)
height (km)
-9
-65
1
u,v (ms-1)
-220
-76
325
ω (hPad-1)
0.00
0.0506
0.10
CF (-)

Validation thermodynamic profiles




height (km)
4
3
2
1
Ze (dbZ)
40
25
10
-5
-20
-35
-50
mrr rain flag
1
0
6
7
8
9
10
1
time (hours)