Assimilating Cloud-affected Radiances in Idealized Simulations of Deep Convection

Josef Schröttle[1,2], Martin Weissmann[1,2], Leonhard Scheck[1,2], Axel Hutt[3,4]

1) Hans-Ertel-Centre for Weather Research, Data Assimilation Branch
2) Ludwig-Maximilians-Universität, Department of Physics, Munich
3) Deutscher Wetterdienst, Data Assimilation, Offenbach, Germany
4) Department of Mathematics, University of Reading, United Kingdom

I) Motivation

II) Numerical Configuration

- Idealized Simulations
- Variability in Ensemble
- Data Assimilation Experiments

III) Nature Run

- Synthetic Satellite Fields of Ice Clouds
- Lower Boundary Layer Induced Water Clouds

IV) Assimilating Cloud-affected Radiances

- Brightness Temperature Fields
- Impact on Ice, Water, Wind & Temperature

V) Conclusions & Outlook

I) Motivation: Why do we assimilate Cloud-affected radiances?

- **Early coherent** and strong signal
- > **6000 measurements** every hour in case study
- Satellite measures radiation at **suitable spatial (≈ km)** and **temporal** (15 min) scales

Goal: improve the forecast of

- **Precipitation**, **Temperature**, **Wind**

over the whole domain and especially inside convective cells at the **convective time scale**, for short term **weather forecasts**

II) Numerical Configuration

Lange & Craig (2014): The Impact of Data Assimilation Length Scales on Analysis and Prediction of Convective Storms, MWR

Nature Run for Observation System Simulation Experiments (OSSE), *5* min output
Initial *U(z), V(z), θ(z), ...* profile from Radiosonde
(**Payerne**, Switzerland at 12 UTC, July 20th 2007)
Cyclic boundary conditions with *(n, m, l) = (200, 200, 50)*
The increments *dx* and *dy* are ≈ ***2*** **km**.
The model levels *dz* vary from ***100*** **m** at the surface to **800 m** at domain top.
Overall, *(Lx, Ly, Lz) corresponds to (394* km, *394* km, *22* km*)*
Timestep *dt* = *6* s, can be increased to *12* s, *24* s
120 members are computationally affordable

new:

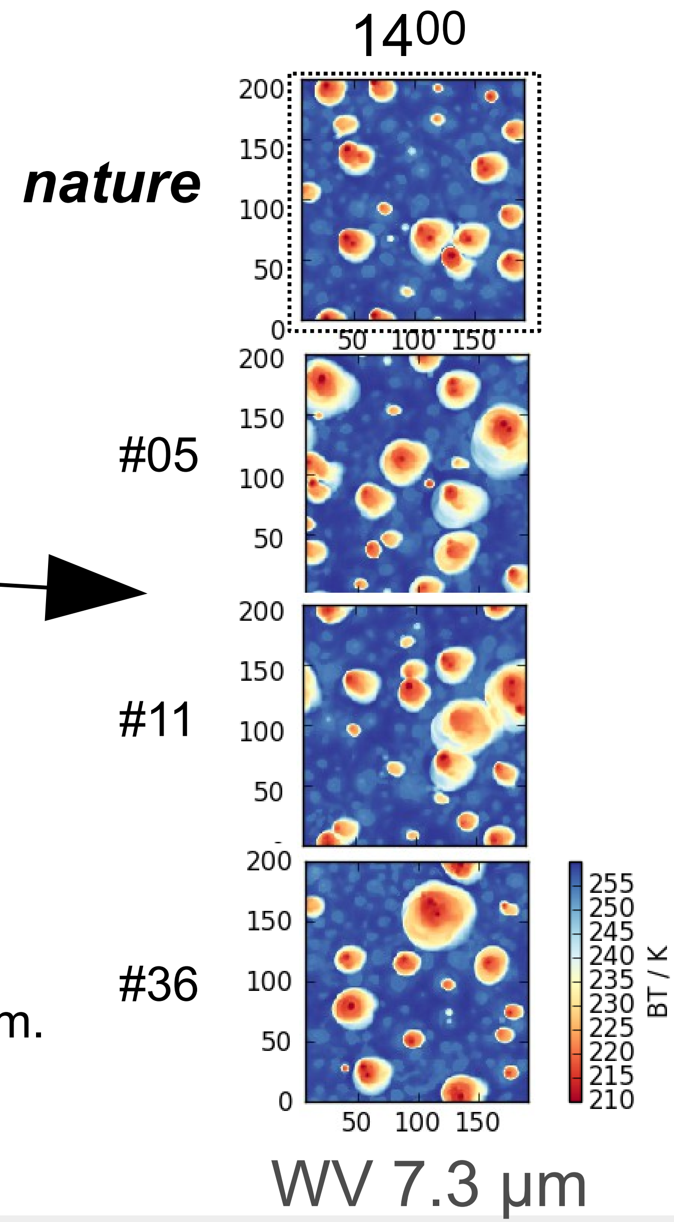
RTTOV 12, for infrared satellite images
MFASIS for solar reflectance

II) Variability in Idealized Ensemble

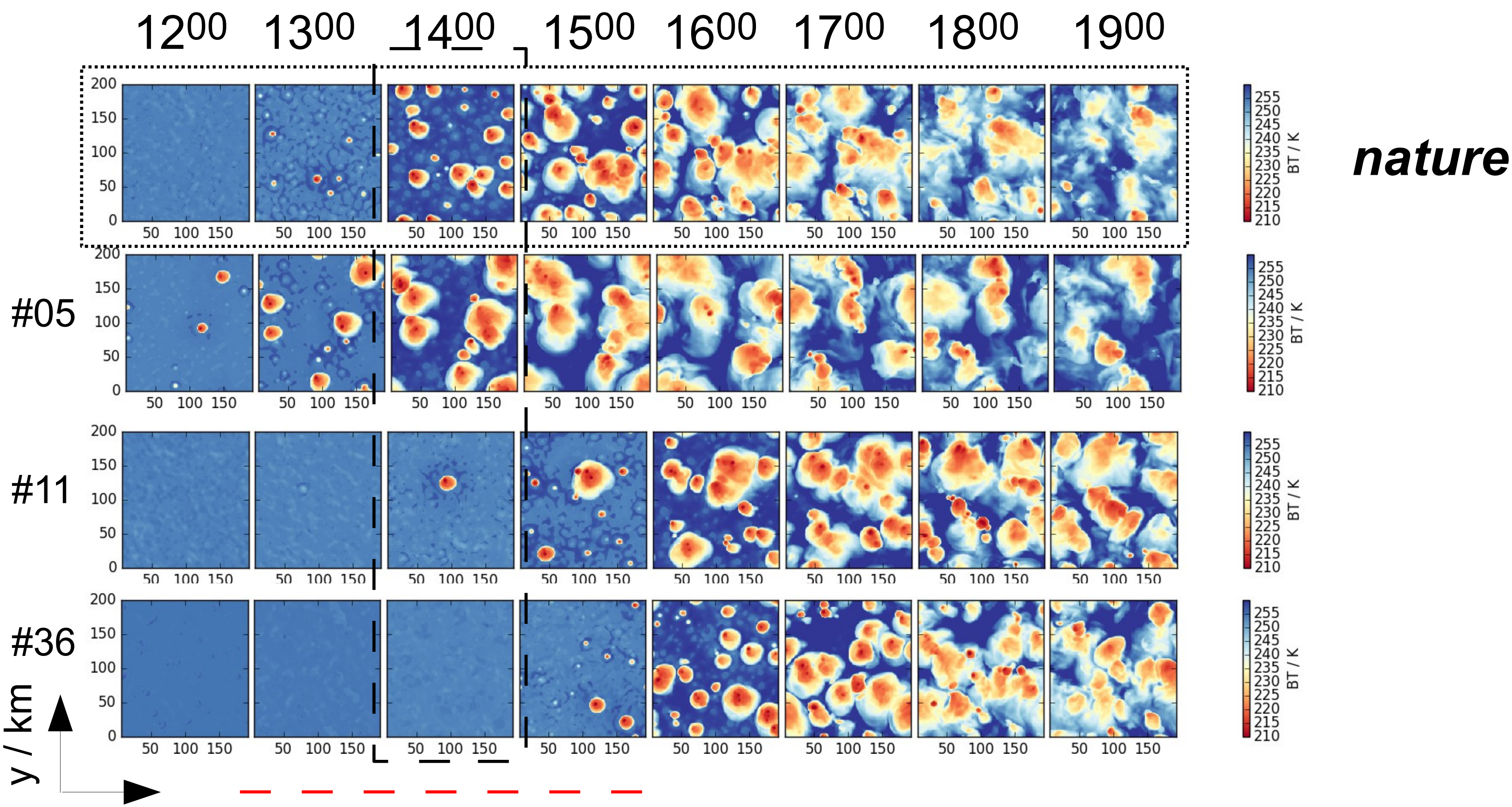
•**Operational local area models** comprise large scale **variability in initial conditions due to boundary conditions.**

In idealized setup so far **only spatial variability**, i.e., position of cells due to white noise in initial conditions, e.g., after 8 h at 14 UTC **(right)**

•We add **temporal variability** by superimposing random large scale perturbations on initial conditions as *T'(z), u'(z), v'(z), rh'(z)* with standard deviation *0.25* K, *0.25* m/s and *2* % relative humidity variation at a vertical wavelength of approximately *8* km, up to $z = 30$ km.



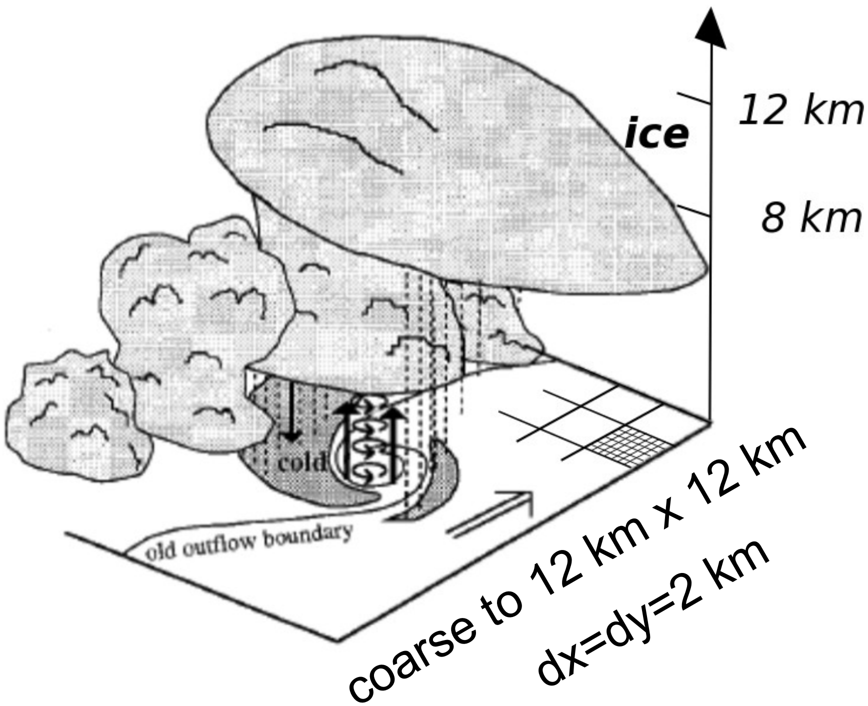
II) Variability in Idealized Ensemble around Nature Run



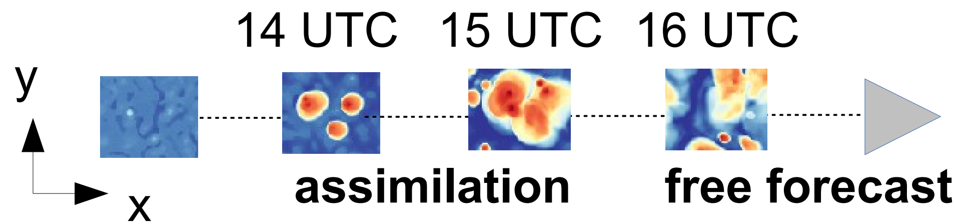
x / km

onset of deep convection varies by more than three hours

II) Data Assimilation Experiments (with LETKF in COSMO-KENDA)



Brightness temperature is simulated with an error of 3 K for WV 6.2 µm, 7.3 µm.



We assimilate every 15 min for 8 cycles, after 8 h lead time with 2 h free forecast. Currently, 40 members run in the cycle. We do not localize in the vertical.

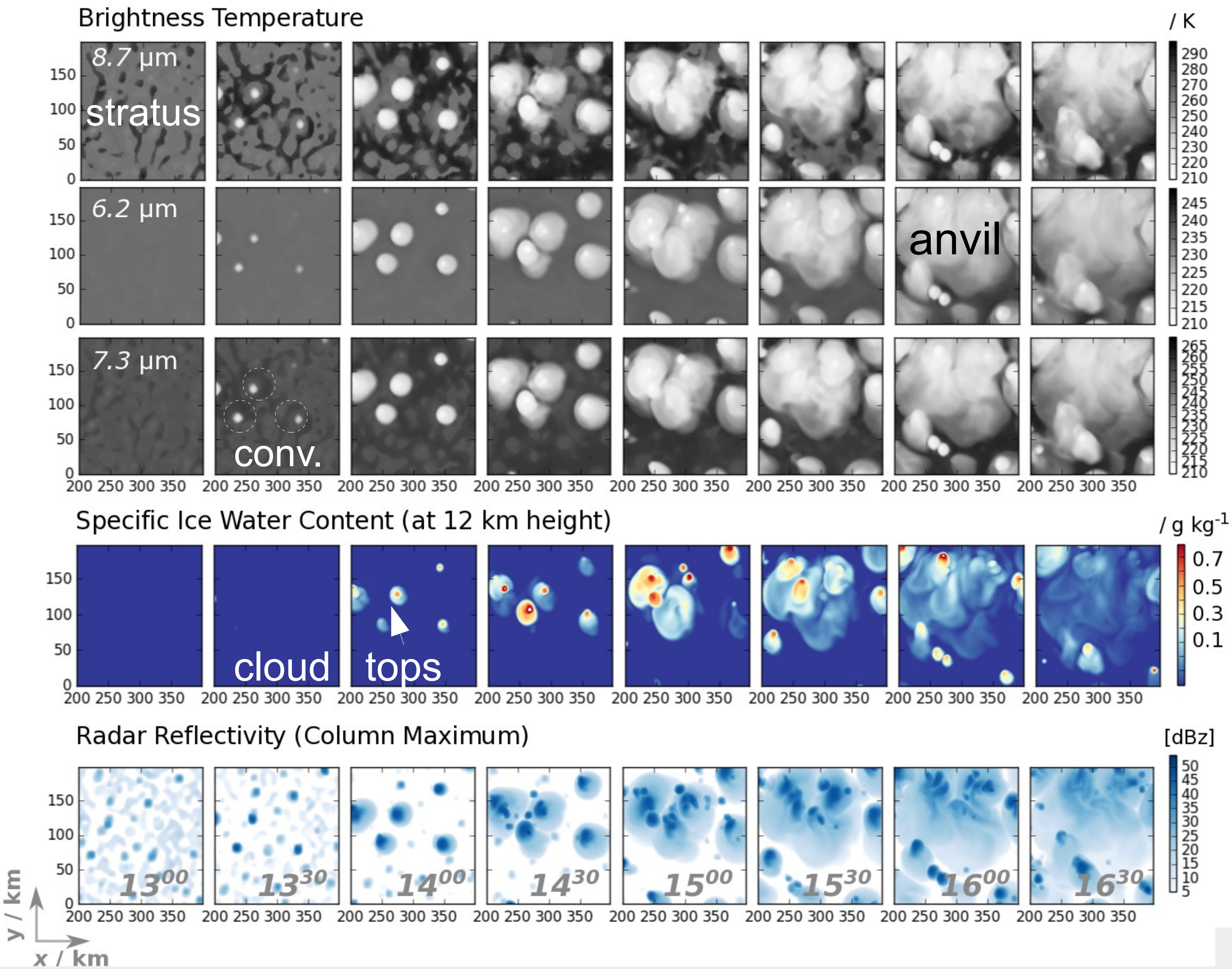
Horizontal localization is L_h= 32 km.

Vertical localization is L_v= ∞.

Error model by Harnisch et al. (2016) ranging from ≈ 2 K in clear sky to ≈ 10 K in cloud regions for WV 6.2 µm

What is the **potential of assimilating cloud-affected radiances** ?

III) Nature Run: Time Series of Satellite Fields & Radar Reflectivity



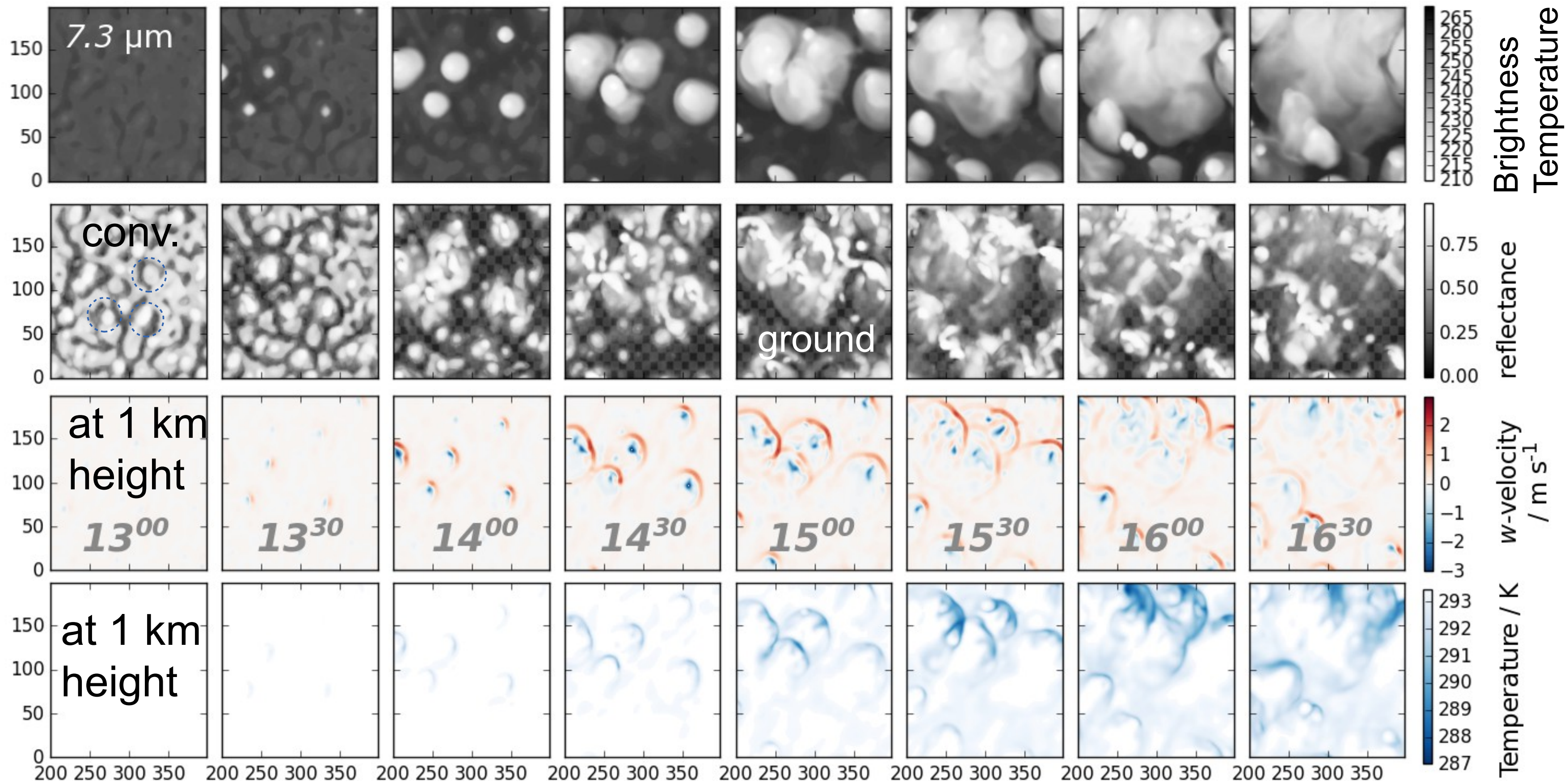
In the infrared, **ice clouds** are present at later times.

Deep convection sets as cirrus **anvils** develop.

The ice clouds block the view on **lower clouds in the infrared**.

Lower clouds cause rain as visible in more **intermittent radar reflectivity** fields.

III) Nature Run: Clouds in Reflectance of Solar Radiation



Scheck et al. (2016): A fast radiative transfer method for the simulation of visible satellite imager, Journal of Quantitative Spectrospcopy and Radiative Transfer, 175, 54-67.

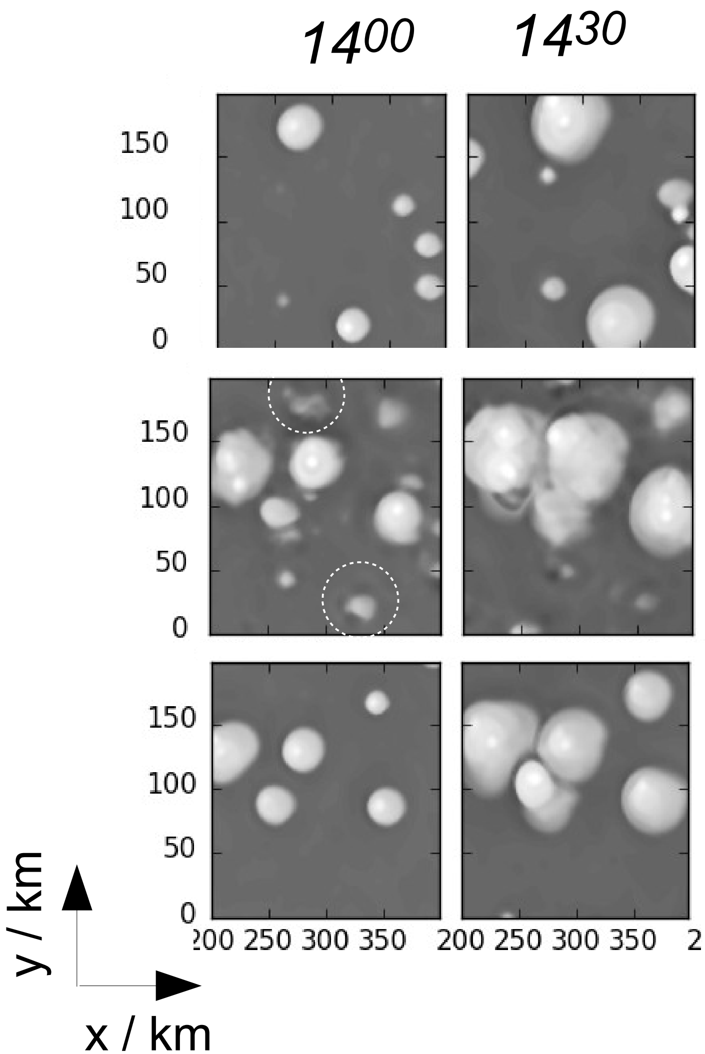
III) Nature Run: Clouds in Reflectance of Solar Radiation

In observation system simulations high, medium and low clouds occur as:

- **Ice clouds** in the **water vapor bands**
- **Water clouds** in the **infrared window channels & visible**
- **Lower boundary layer induced clouds** in the **visible** reflectances

(all in half hour intervals)

III) Assimilating Cloud-affected Radiances

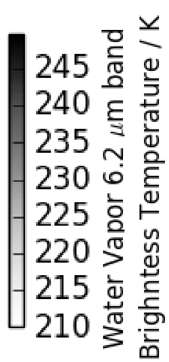


Member #1

No data assimilation

Member #1

Assimilating *Brightness Temperature* of Water Vapor 6.2 µm band



Nature Run

$BT(x, y)$ for 6.2 µm

III) Assimilating Cloud-affected Radiances

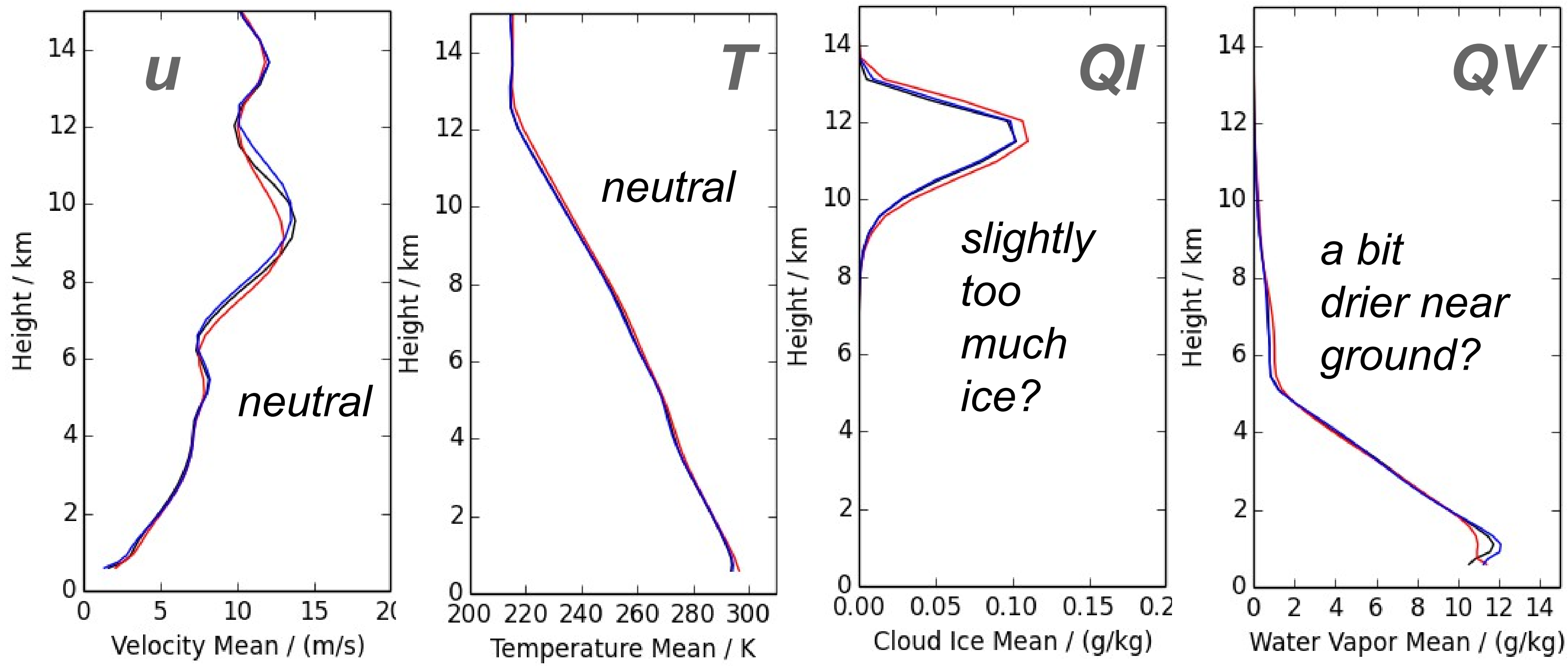
LETKF creates conditions for clouds to:

- **Dissolve**, where no clouds exist in nature
- **Form**, where clouds exist in nature run

What is the impact on other variables?

IV) Impact on Wind, Temperature, Ice, Water Vapor

17-18 UTC (Second hour of free forecast, 4 x 15 min first guesses):
Horizontal and ensemble **mean** of ...

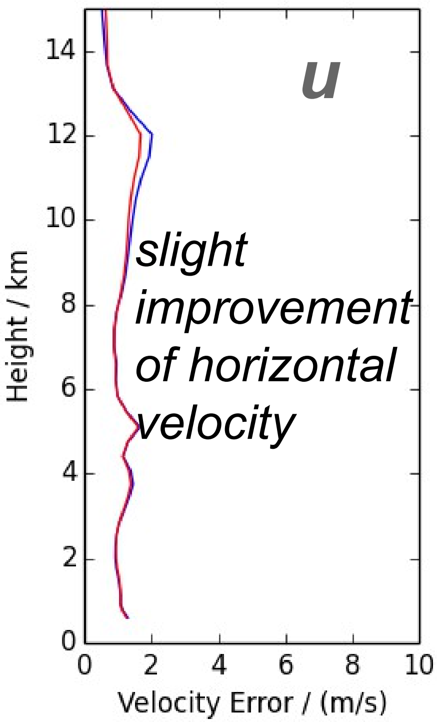


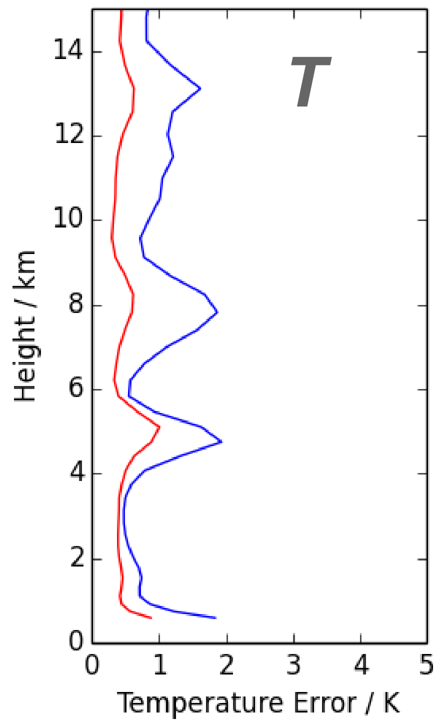
nature — free ensemble — assimilated ensemble

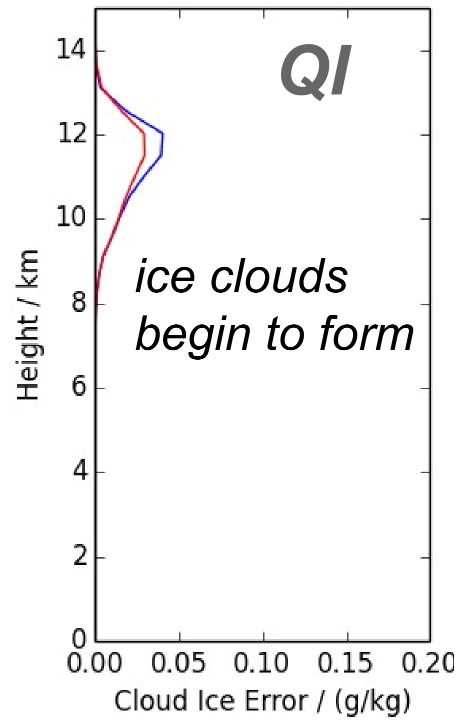
Overall no significant bias!

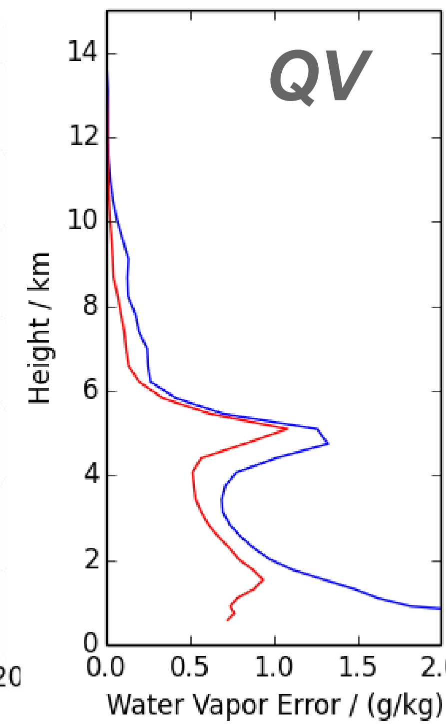
IV) Impact on Wind, Temperature, Ice, Water Vapor

14-15 UTC (First hour of data assimilation, 4 x 15 min first guess):
Horizontal and ensemble mean absolute **error** of ...









free ensemble

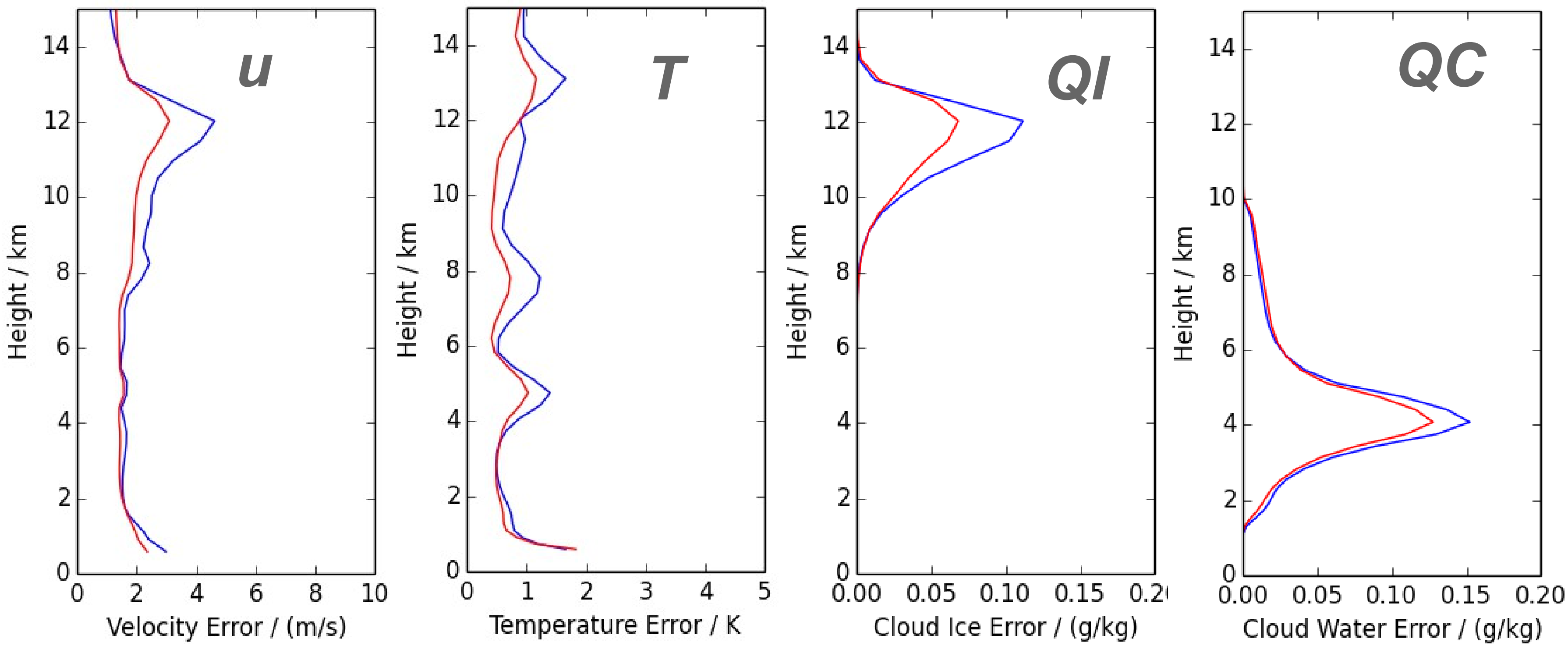
assimilated ensemble

clear improvement of temperature at all heights

w/out ice clouds, clear improvement of water vapor at all heights

IV) Impact on Wind, Temperature, Ice & Cloud Water

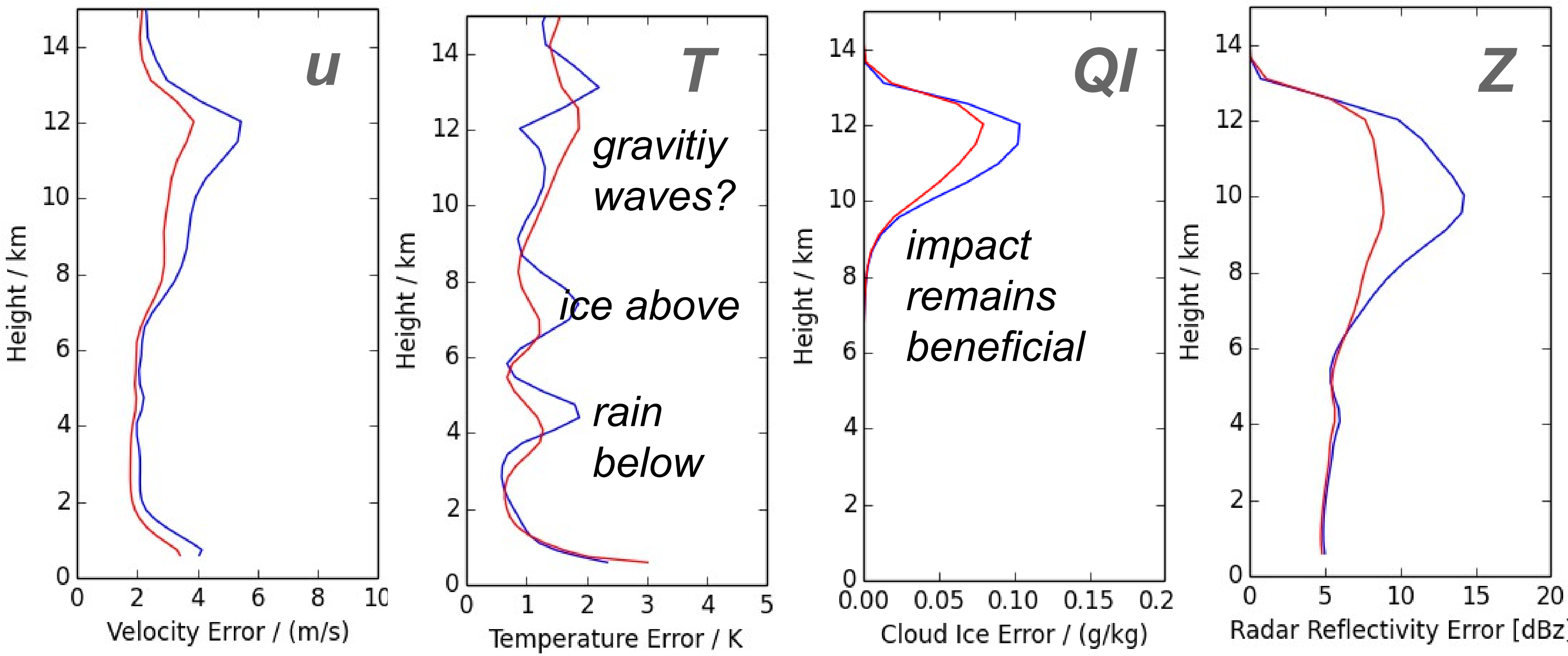
15-16 UTC (Second hour of data assimilation, 4 x 15 min first guess):
Horizontal and ensemble **mean** absolute error of ...



free ensemble — assimilated ensemble

IV) Impact on Wind, Temperature, Ice & Radar Ref ectivity

17-18 UTC (Second hour of free forecast, 4 y 15 min first guess):
Horizontal and ensemble mean absolute **error** of ...



clear improvement of horizontal velocity remains in forecast

beneficial where cloud processes are involved

free ensemble

assimilated ensemble

clear improvement of radar reflectivity over height of sat weighting function

V) Conclusions: What is the potential of assimilating brightness temperature?

- The assimilated **brightness temperature** fields improve.
- **Radar reflectivity** improves significantly over the height of the ice clouds.
- **Cloud related quantities** as **cloud ice and water vapor error decrease**.
- **Temperature and wind fields improve significantly.**
- Improvement depends on **cloud impact, i.e., the improvement is largest** at times **when** and at locations **where clouds are present (in OSSE).**

V) Outlook: What is the most efficient way to assimilate Clouds?

- **Longer Forecasts** of up to 5 hours
- **Update Variables:** select cloud variables or only wind & temperature
- **Direct assimilation** of another instrument, e.g. **visible** 0.6 µm
- **Cloud structure**, e.g., average cloud cover $\langle C(x,y)\rangle_{Area}$, cloud displacement & amplitude score $DAS(x_0,y_0)$, smoothness $\triangle BT\ (x_0, y_0)$, fractal dimension D_H
- **Temporal difference** of brightness temperature $BT_{diff}(x_0, y_0)$

Thank you for your attention!