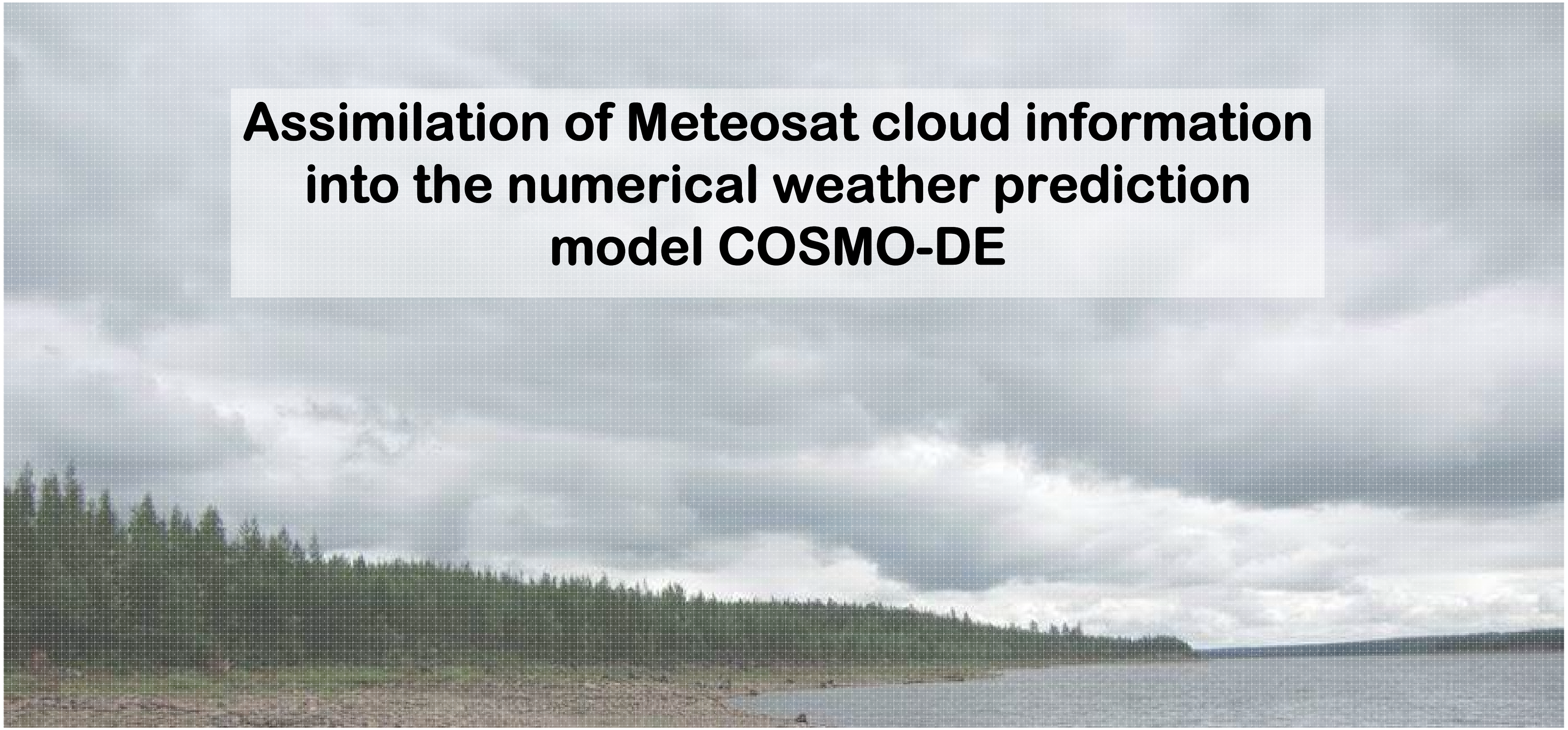
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Assimilation of Meteosat cloud information into the numerical weather prediction model COSMO-DE



Annika Schomburg, Christoph Schraff

annika.schomburg@dwd.de

Local Ensemble Transform Kalman Filter in COSMO (KENDA project)

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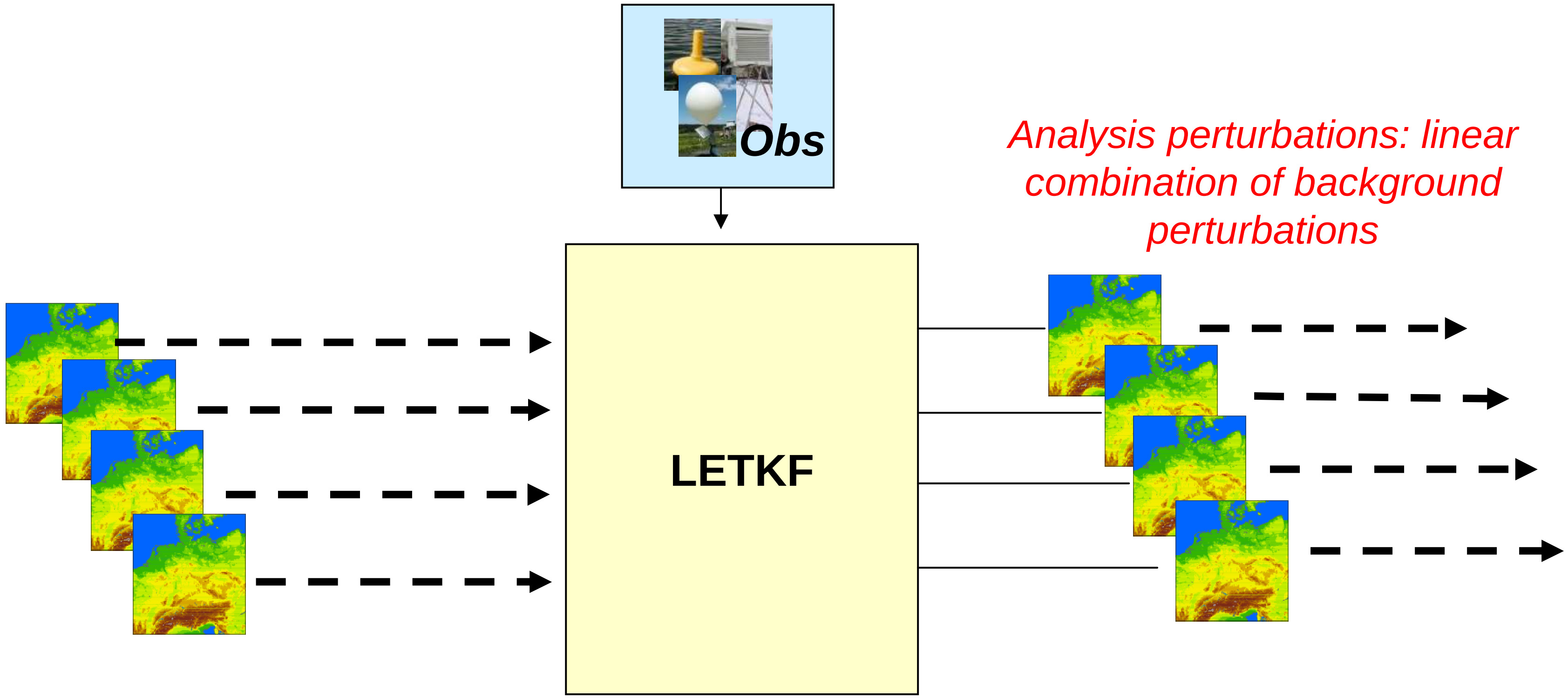
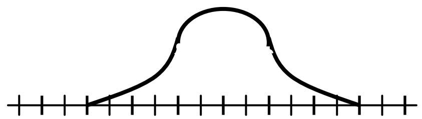


- **L**ocal: the linear combination is fitted in a local region
  - observation have a spatially limited influence region



Assimilation of cloud information into COSMO-DE

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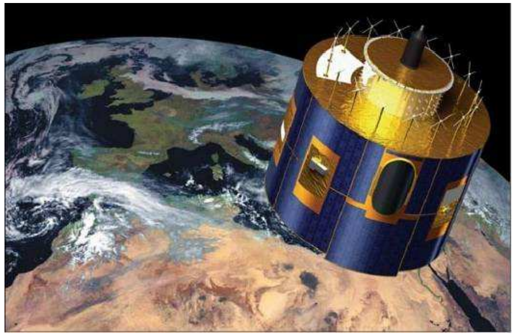

Source: EUMETSAT

- NWCSAF cloud products based on satellite data:
  - **Meteosat-SEVIRI**
    - Δx ~ 5km over central Europe,
    - Δt=15 min

Satellite retrievals:
NWCSAF cloud products (SEVIRI/MSG)

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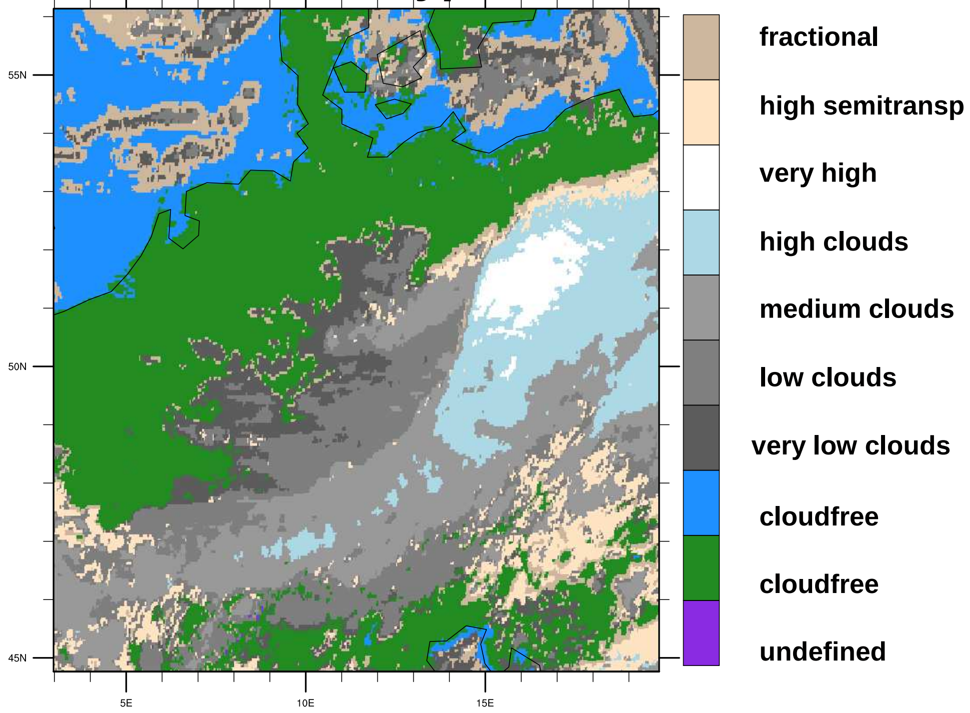
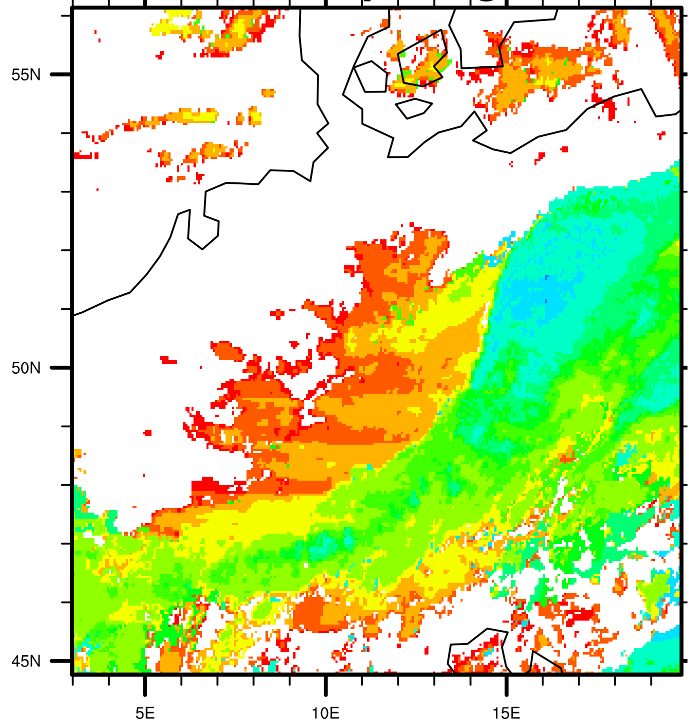
cloud type

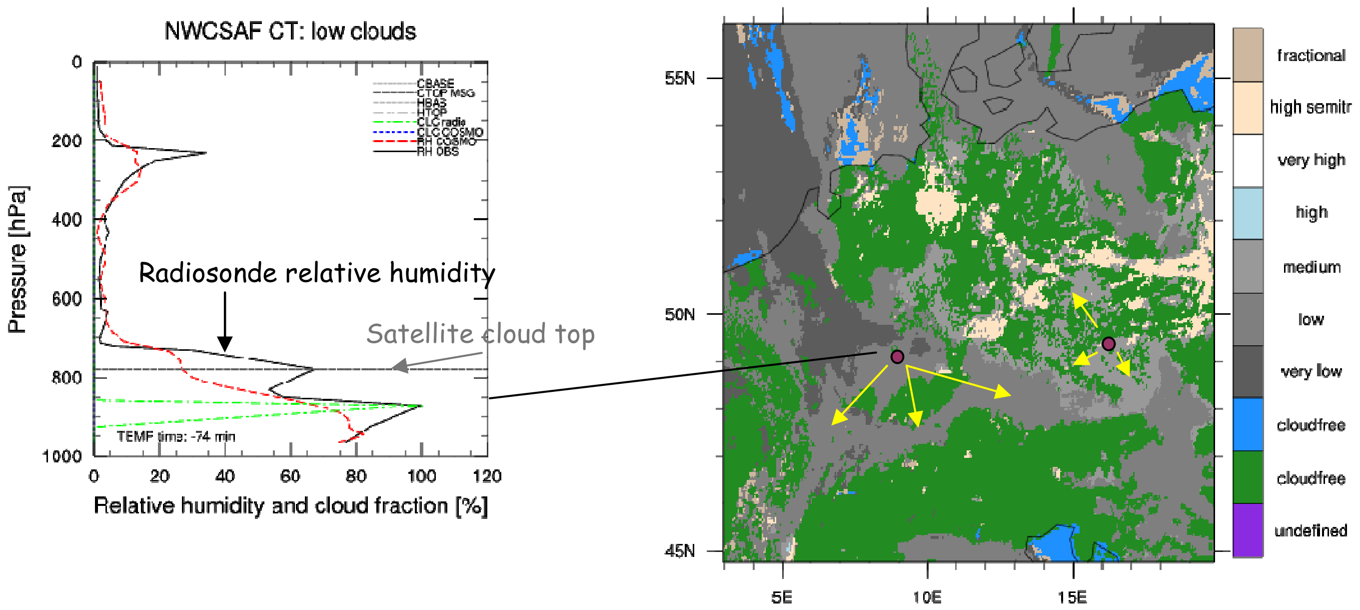


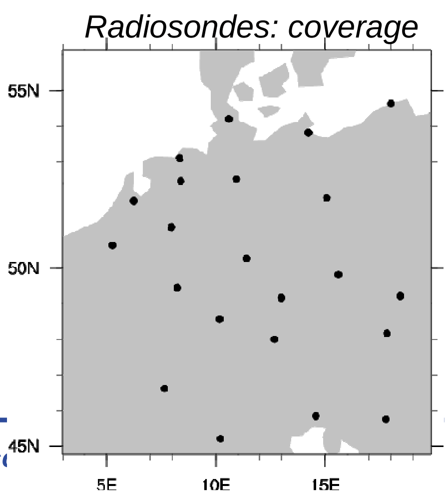
cloud top height



Retrieval algorithm needs temperature and humidity profile information from a NWP model → *cloud top height might be at wrong height if temperature-profile in NWP model is not simulated correctly!* → *use also radiosonde information where available*

- Use **nearby radiosondes within the same cloud type to correct (or approve)** cloud top height from satellite cloud height retrieval





Combine satellite & radiosonde information: data availability flag

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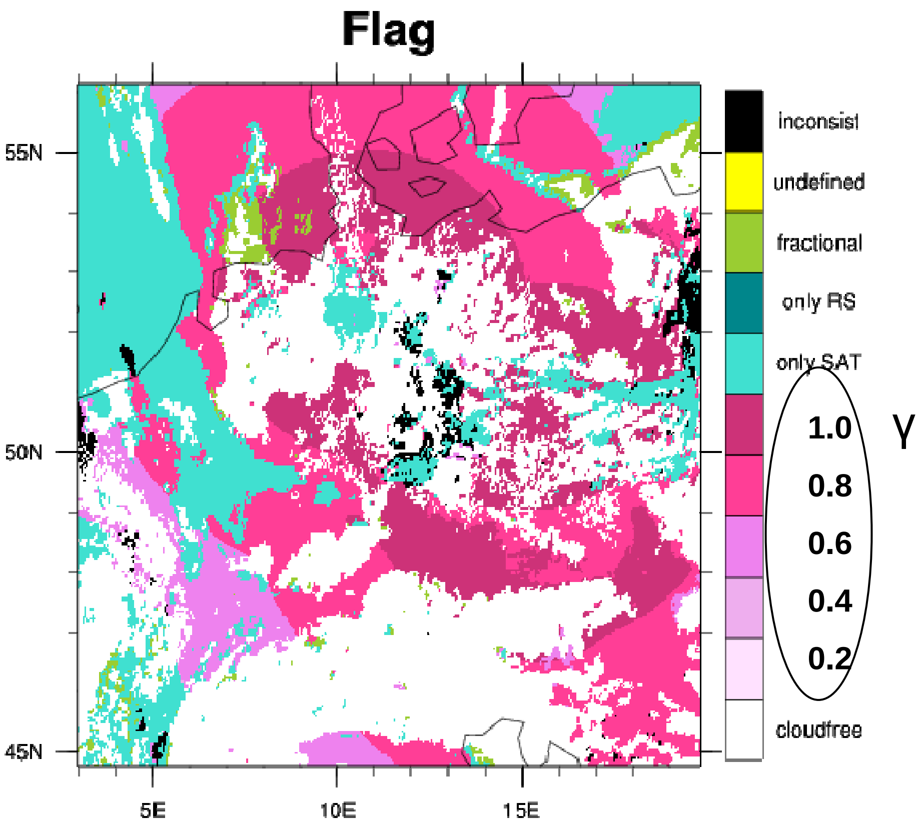


- Use temporal and spatial distance of radiosonde for weighting:

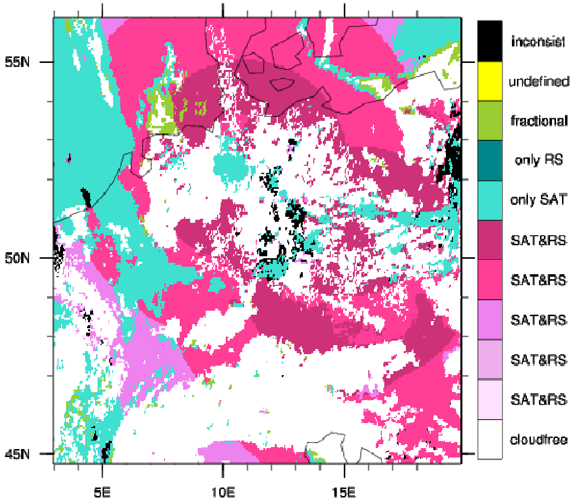
$$cth_{corr} = (1-\gamma)cth_{sat} + \gamma \cdot cth_{rs}$$

- Also use data availability flag for observation error specification:

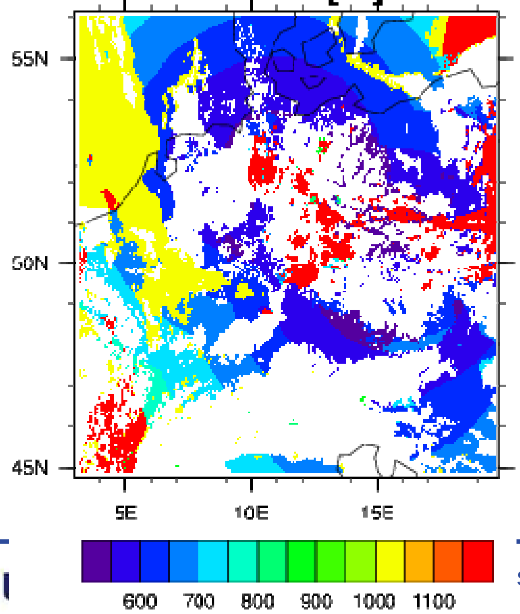
$$e_o = (1-\gamma)e_{sat} + \gamma \cdot e_{rs}$$

Combine satellite & radiosonde information

Flag

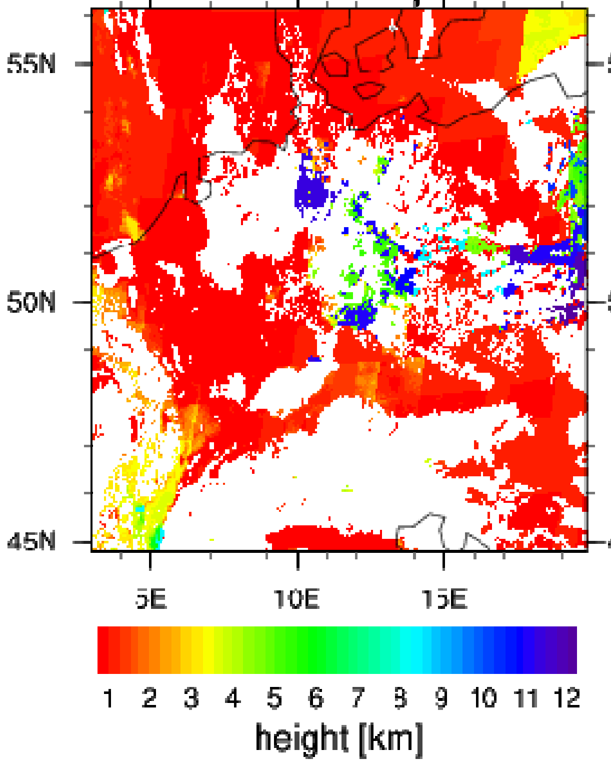


Obs-error [m]

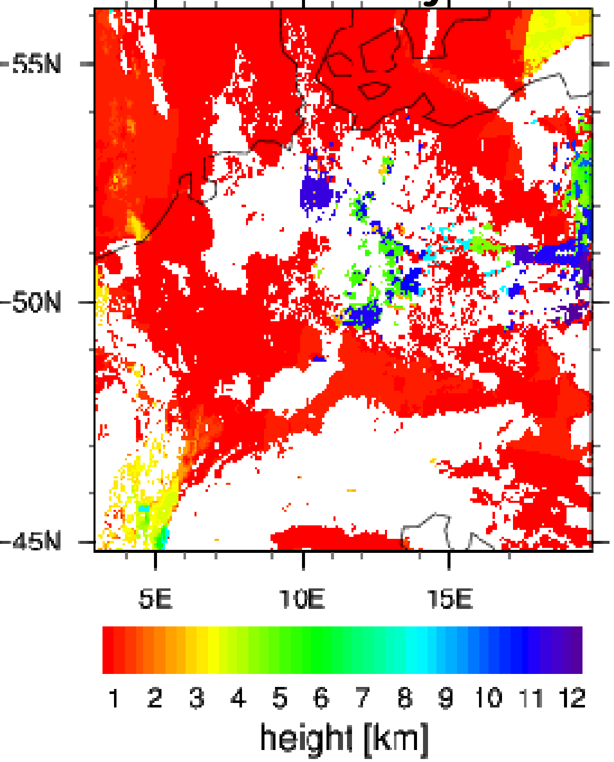


Cloud top height

Satellite cloud product



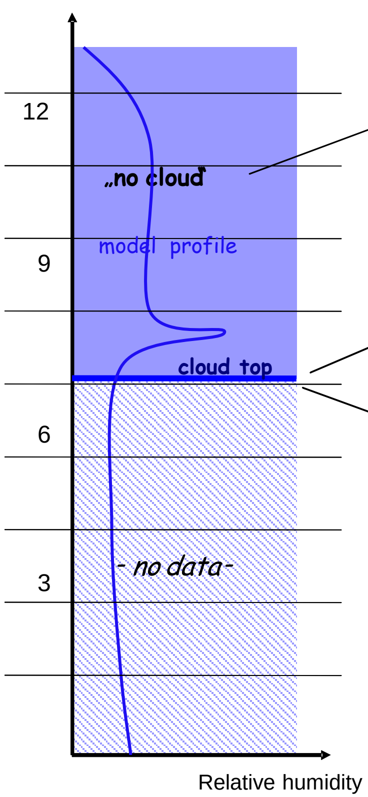
Cloud analysis



Variables assimilated

From one observation of cloud top height several variables are extracted and used to weight the ensemble members in the LETKF:

Cloudy column:

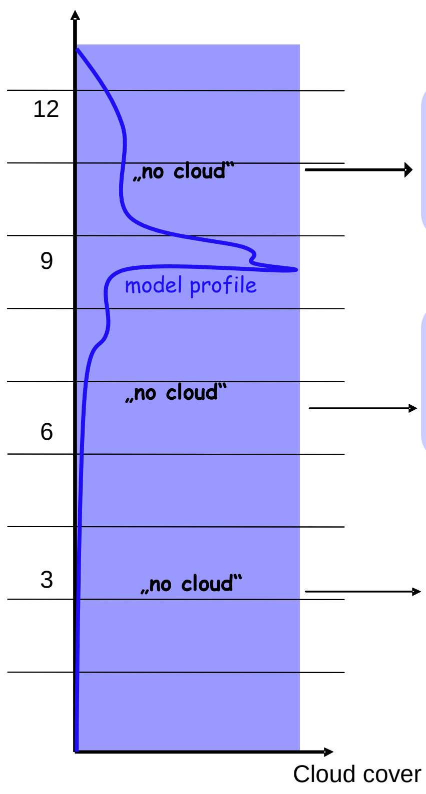


Cloud cover of high/medium clouds
Obs: cloud cover = 0
Model: maximum cloud cover in vertical range

Cloud top height
~~Obs: cloud top height~~
Model: determine cloud top layer k in a fuzzy way depending on relative humidity and vertical height

Relative humidity
Obs = 100%
Model: relative humidity of layer k

Cloudfree column

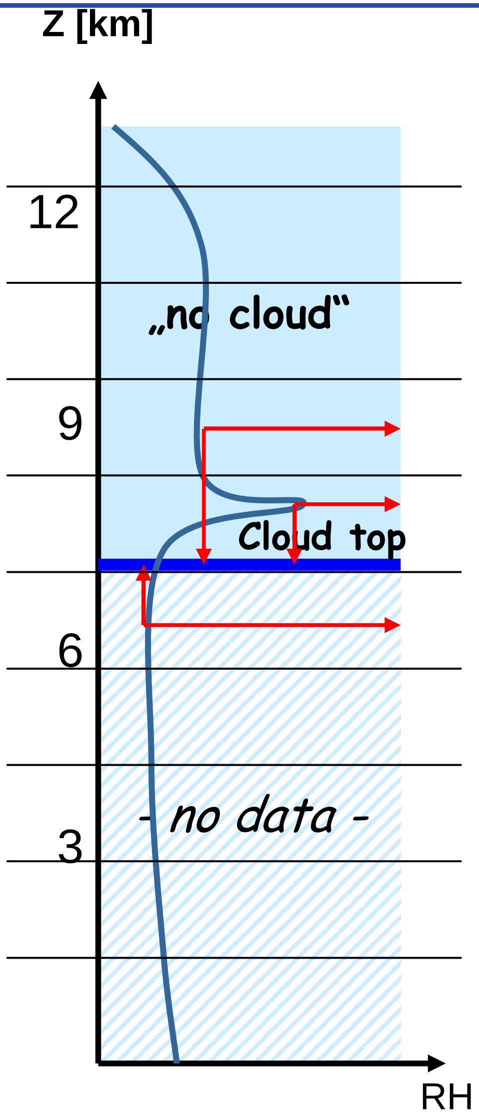


Cloud cover of high clouds
Obs: cloud cover = 0
Model: maximum cloud cover in high cloud range

Cloud cover of medium clouds
Obs: cloud cover = 0
Model: maximum cloud cover in medium cloud range

Cloud cover of low clouds
Obs: cloud cover = 0
Model: maximum cloud cover in low cloud range

Find cloud top height model equivalent



- If using a fixed threshold to define cloud top, one might penalize close members
- Therefore: find model layer optimally fitting the observed cloud top height:

$$d = \min_k \sqrt{(f(\rho_k) - f(\rho_o))^2 + \frac{1}{\Delta h_{max}}(h_k - h_o)^2}$$

ρ: Relative humidity h: height

  – Search in a vertical range (e.g. +/-2500m) the minimum
  – If above a layer exceeds the cloud coverage of the chosen layer or exceeds 70%, then chose the top of that layer

Model equivalents for cloudy column

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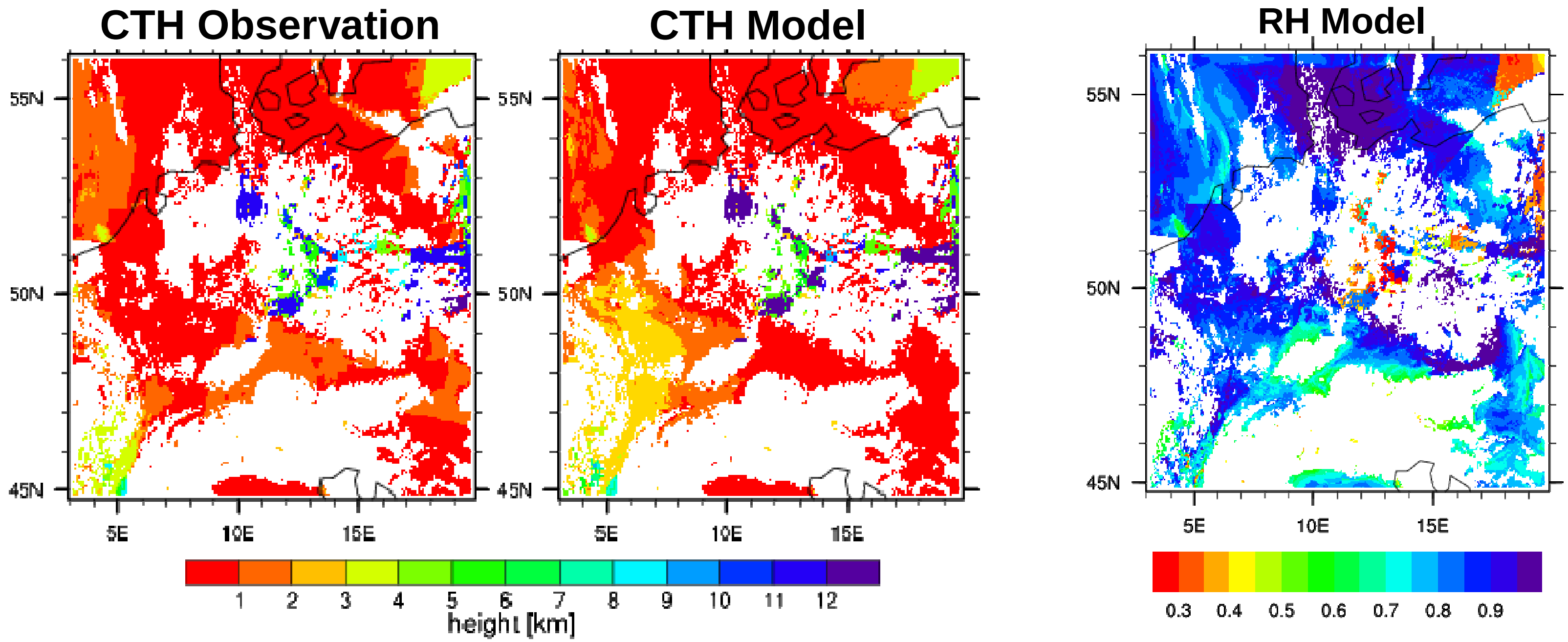
Assimilated variables: Cloud top height and relative humidity

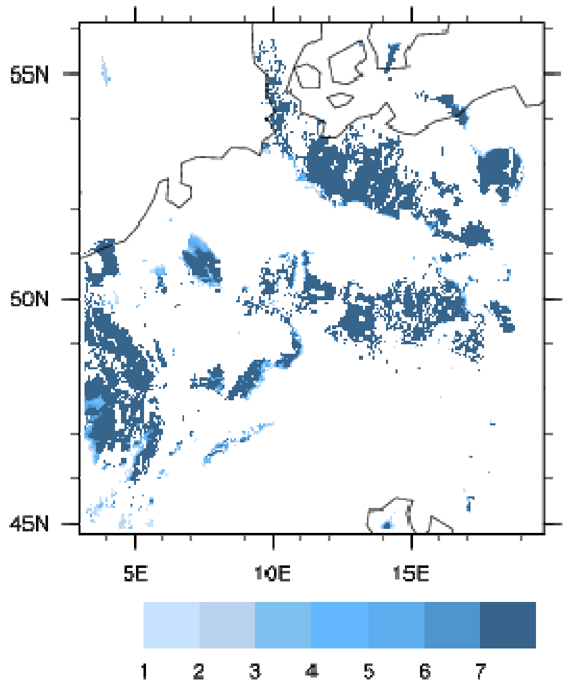


Model equivalents for cloud-free column

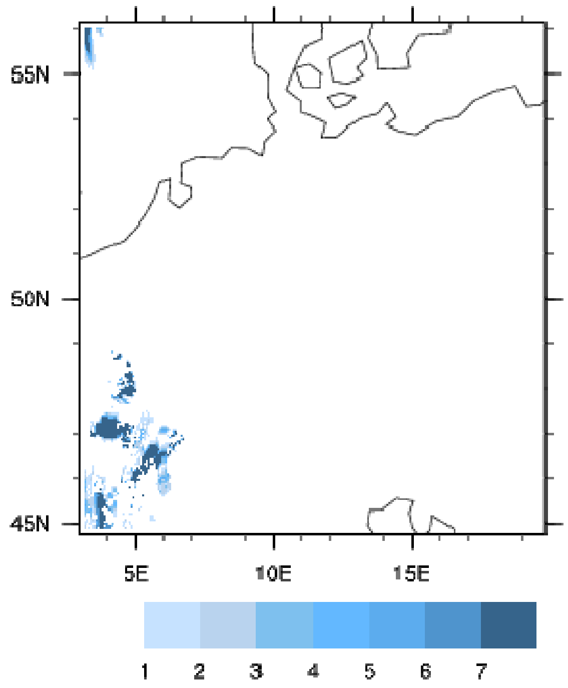
Assimilated variables: Cloud cover

- COSMO cloud cover where observations "cloudfree"

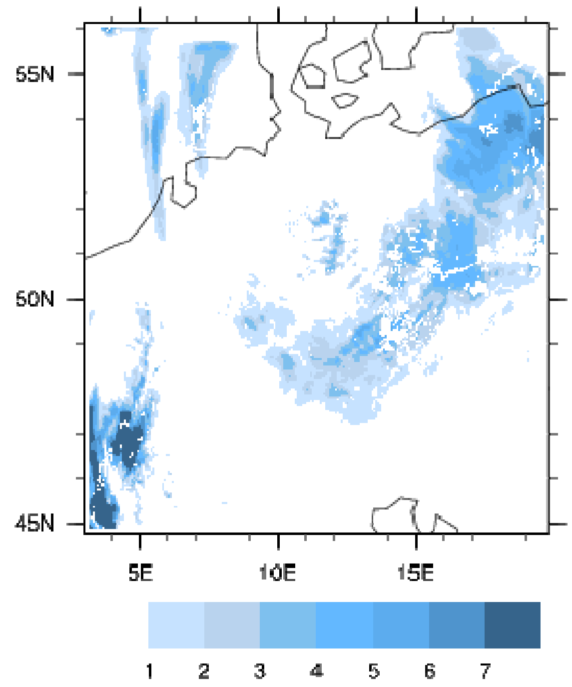
Low clouds (oktas)



Medium clouds (oktas)



High clouds (oktas)



„Single observation“ experiment

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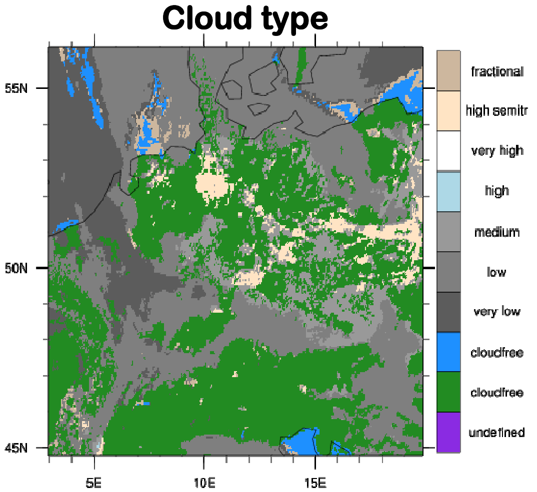
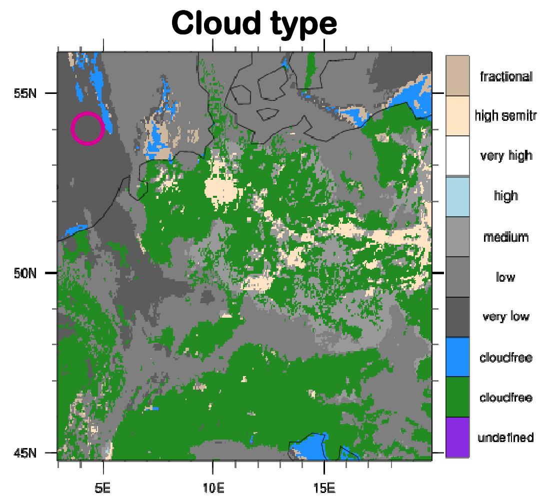
Wetter und Klima aus einer Hand

- Analysis for 17 November 2011, 6:00 UTC (no cycling)
  - 32 member
- Assimilate every 60th column
- Horizontal localization: 20km
  (weights equal to zero at ~73km=26 grid points)
- Objective:
  - Understand in detail what the filter does with such special observation types
    - Does it work at all?
    - Sensitivity to settings

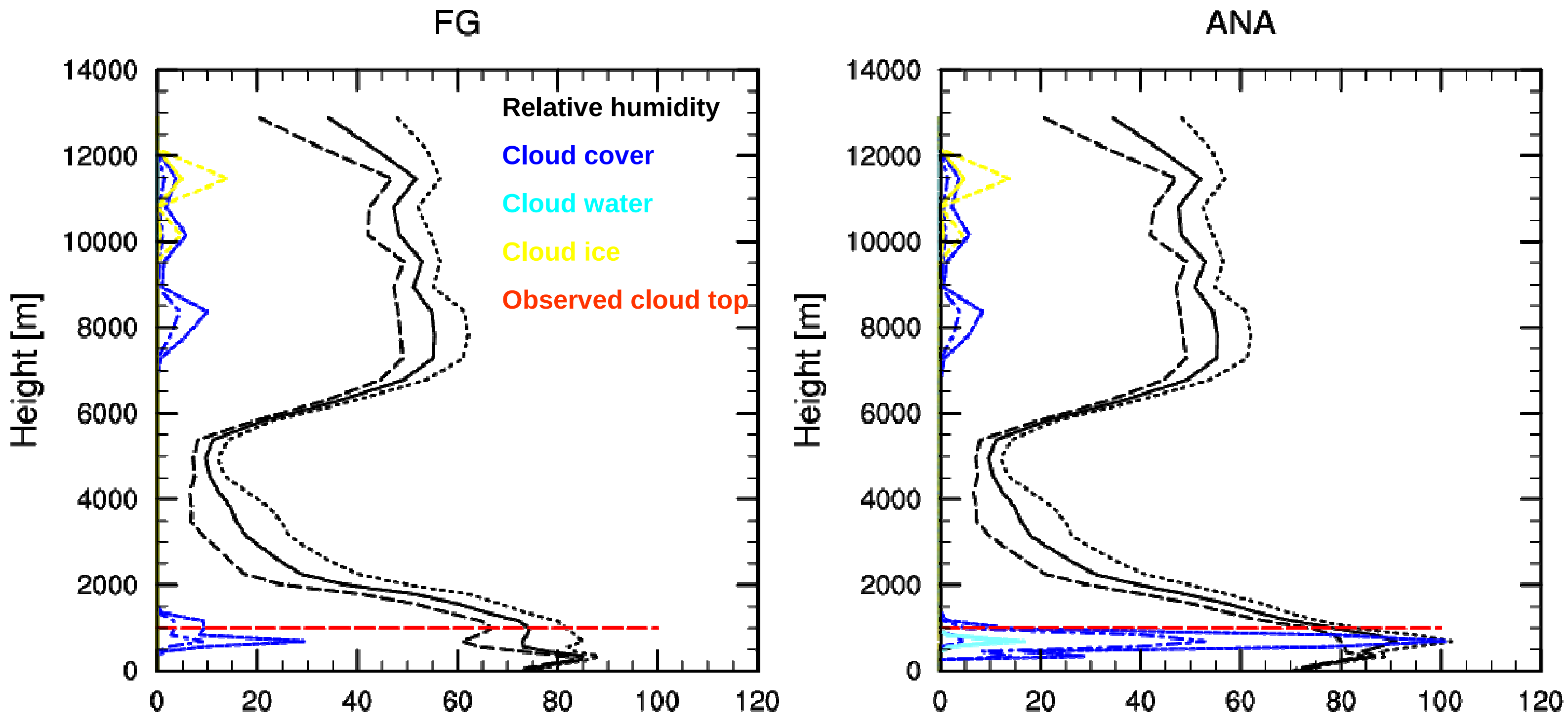


Example 1: no cloud in model

lat 53.9, lon 4.1



Profiles



3 lines on one colour indicate mean and mean +/- spread

Increment cross section for the ensemble mean

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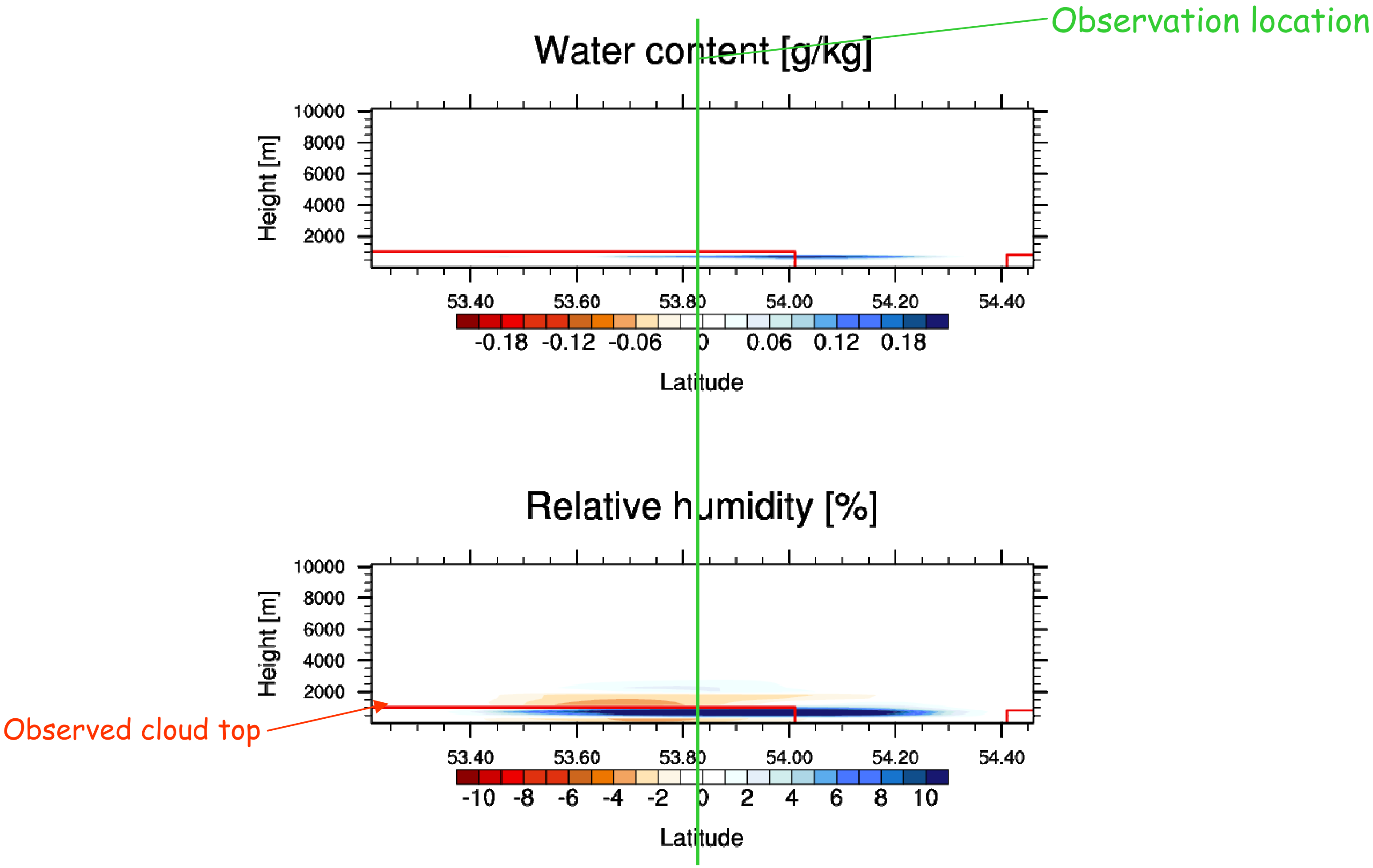
Wetter und Klima aus einer Hand



Corresponding temperature Profiles

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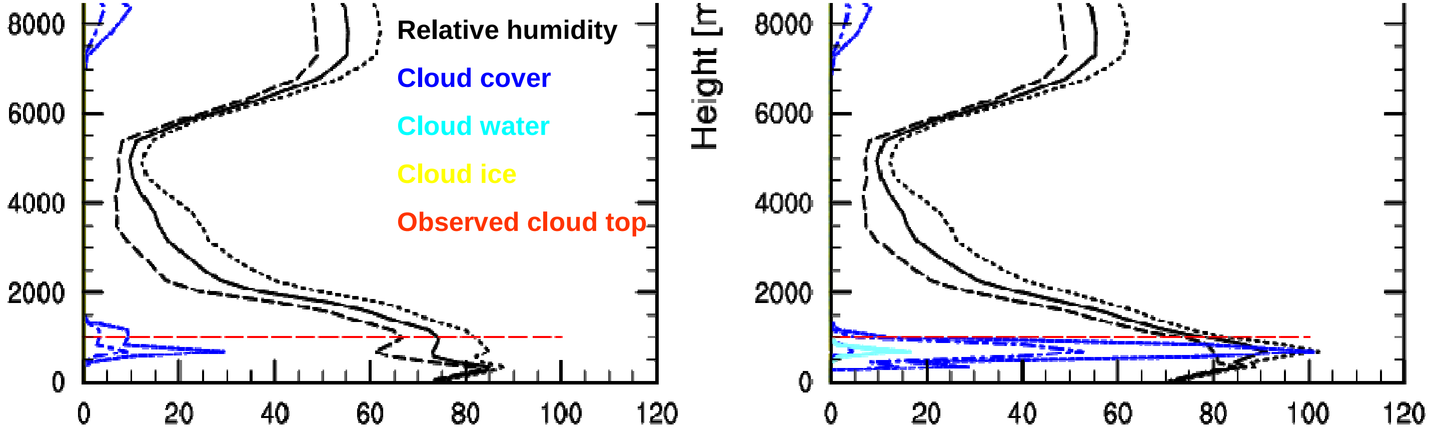
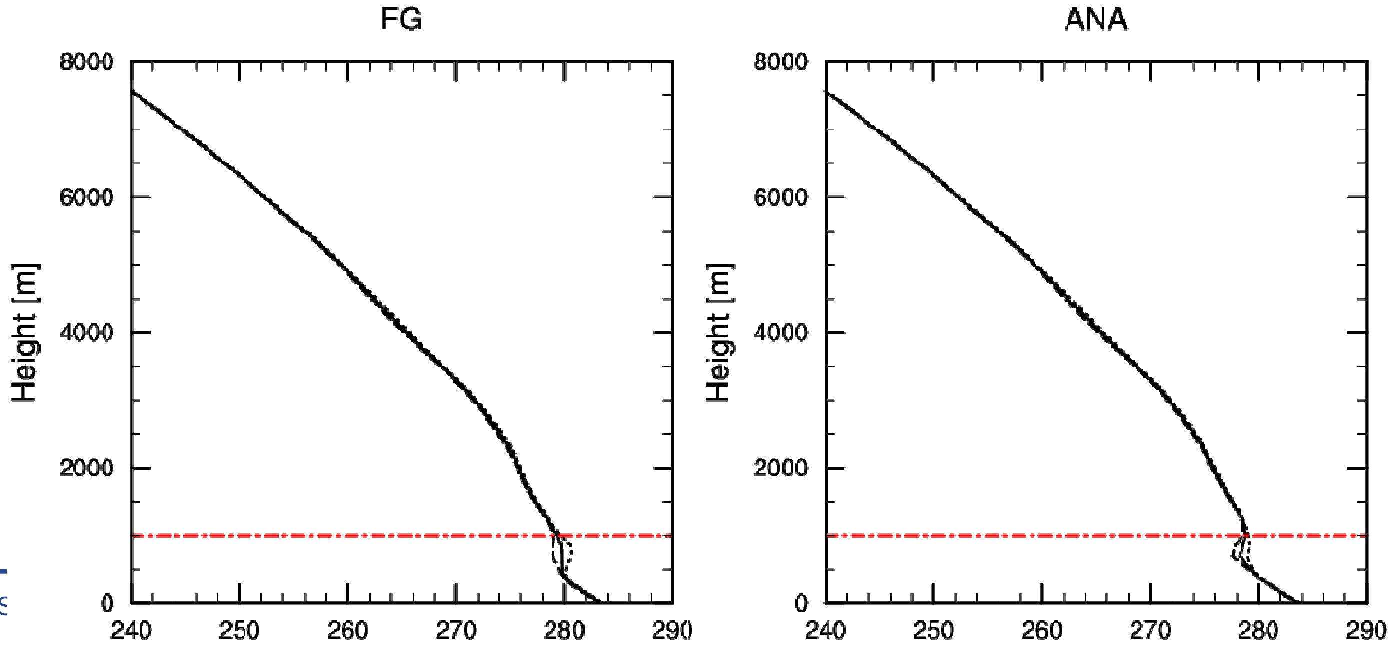
Wetter und Klima aus einer Hand

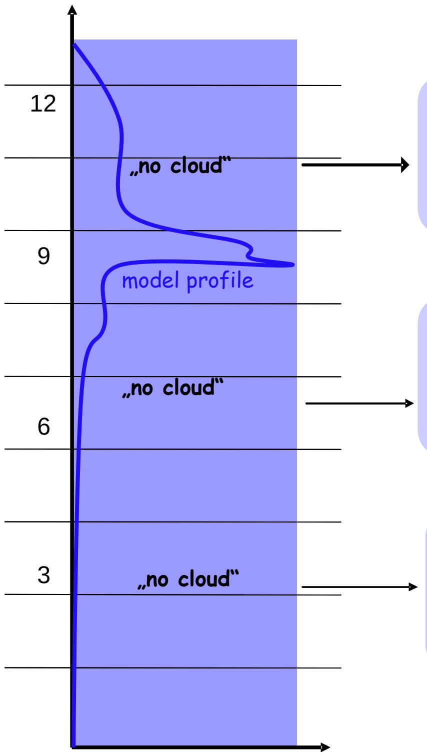


Temperature (mean +/- spread)



Example 2: „false alarm“ cloud in cloudfree case

Cloudfree column

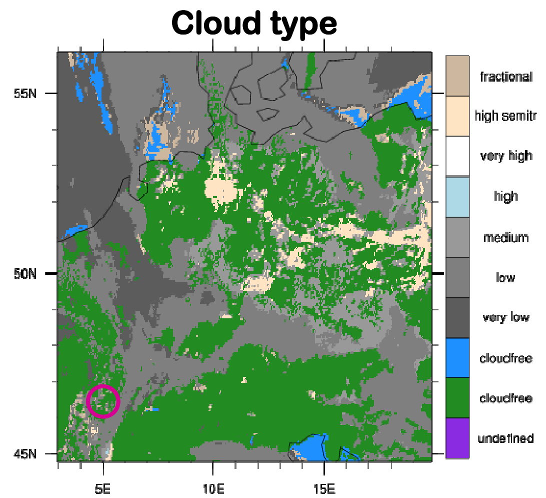


Cloud cover of high clouds
Obs: cloud cover = 0
Model: maximum cloud cover in high cloud range

Cloud cover of medium clouds
Obs: cloud cover = 0
Model: maximum cloud cover in medium cloud range

Cloud cover of low clouds
Obs: cloud cover = 0
Model: maximum cloud cover in low cloud range

4, lon 4.9



annika.schomburg@dwd.de

Profiles: mean and spread

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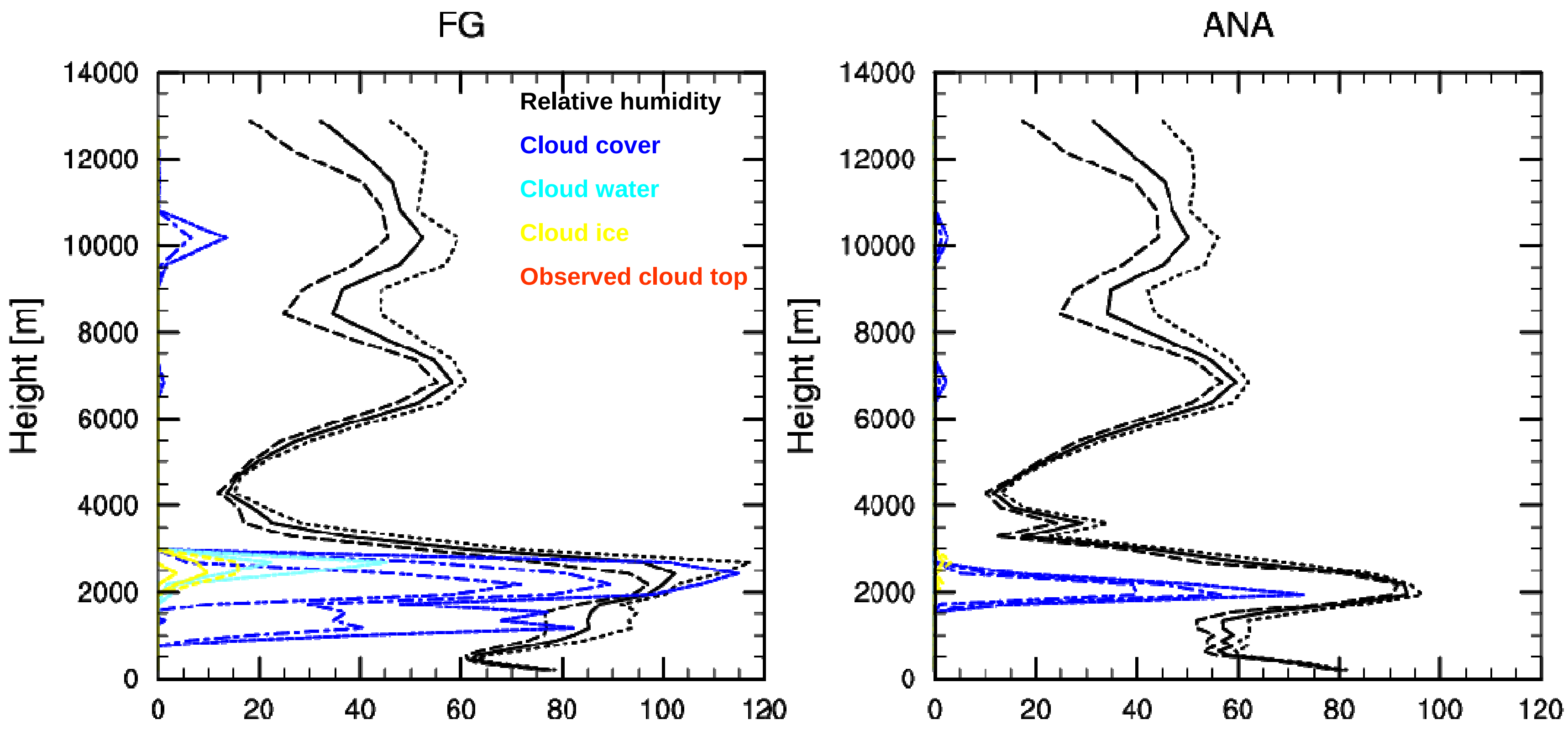
Wetter und Klima aus einer Hand



3 lines indicate mean and mean +/- spread

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Obs minus model departure histogram

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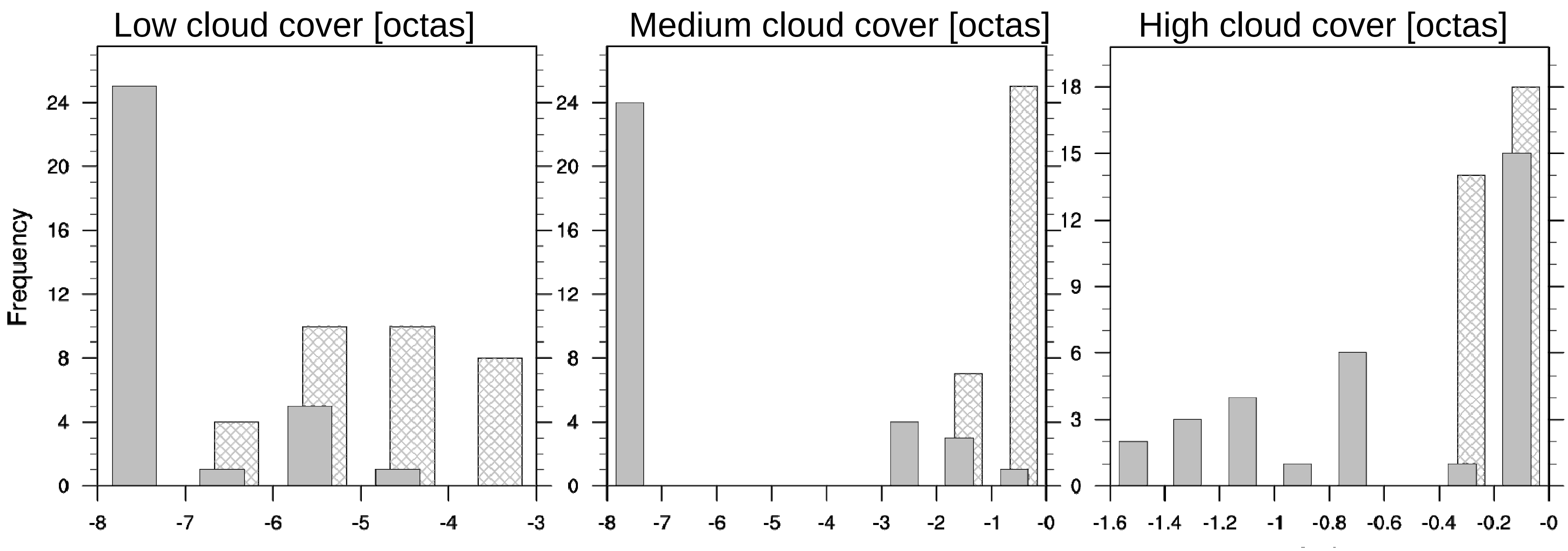

Remember: observed cloud cover = 0

FG

ANA

Increment cross section ensemble mean

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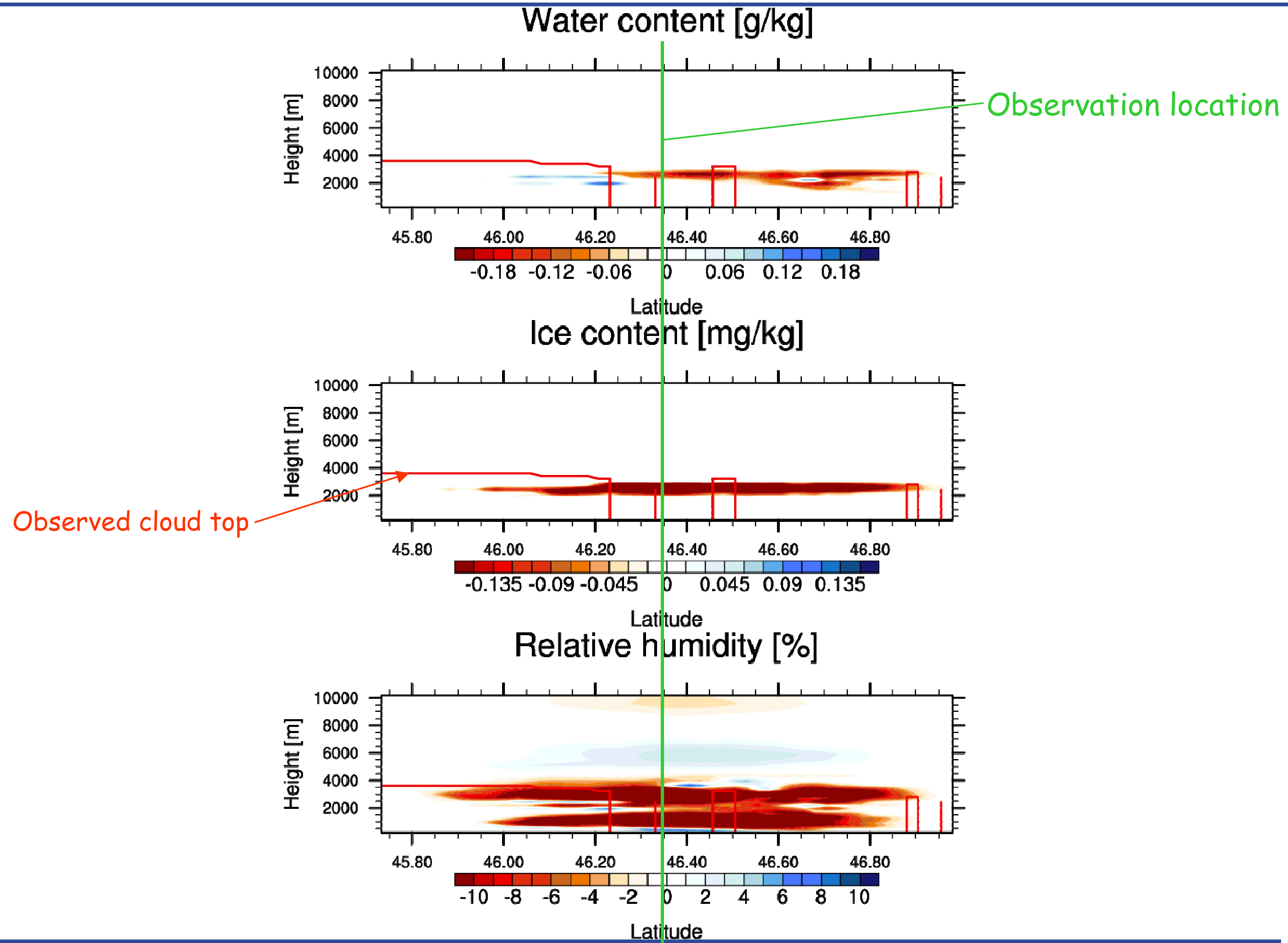

Conclusions

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Wetter und Klima aus einer Hand

- **LETKF** offers new perspectives for assimilating unconventional data
  - Nudging can only assimilate prognostic model variables, less suitable for indirect observations
  - In the LETKF the **observations are used to weight the different ensemble membes** → Assimilate also non-state variables
  - No linearized/adjoint model/physics necessary
  - → Here: assimilation of clouds
    - Can be useful for e.g. stable high-pressure systems in winter, to give higher weights to members which simulate the observed low stratus better

- **Single observation** experiments show:
  - Assimilation of cloud products
    - gives reasonable, comprehensible results,
    - draws ensemble closer to observation
  - Only small improvement if no ensemble member has cloud (→ physics perturbations needed in ensemble generation…)

Outlook

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Wetter und Klima aus einer Hand

- **Next steps:**
  - Currently: set up of cycled experiments with 40 members
  - With better lateral forcing from GME 40-member LETKF
  - Experiments with dense observations
    - Thinning?
    - Observation errors?
    - Localization?
  - Effects on ensemble spread

Thank you for your attention.

Local Ensemble Transform Kalman Filter in COSMO (KENDA project)

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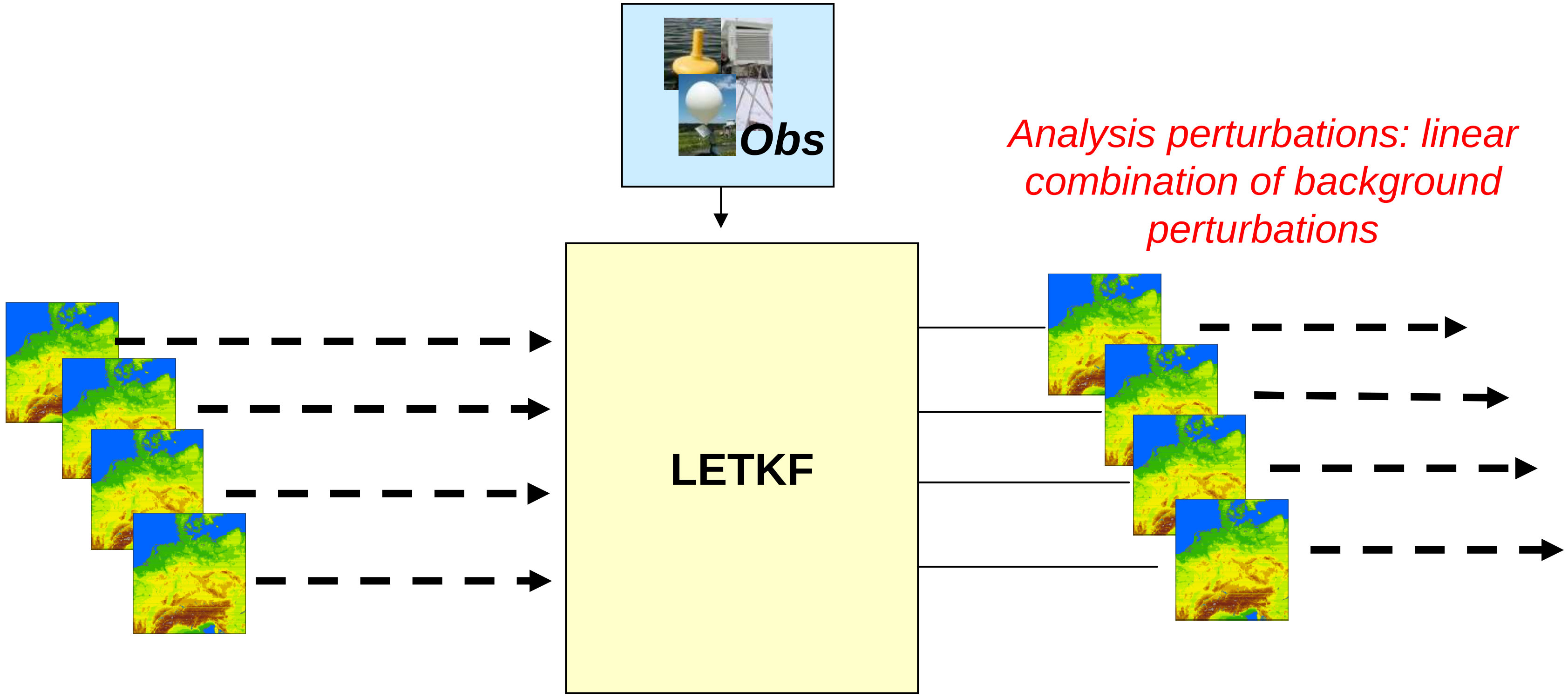
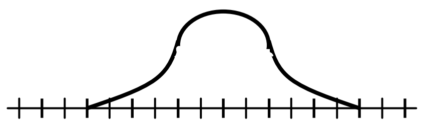


- **L**ocal: the linear combination is fitted in a local region

  - observation have a spatially limited influence region



- **T**ransform: most computations are carried out in ensemble space

  → computational efficient

Local Ensemble Transform Kalman Filter

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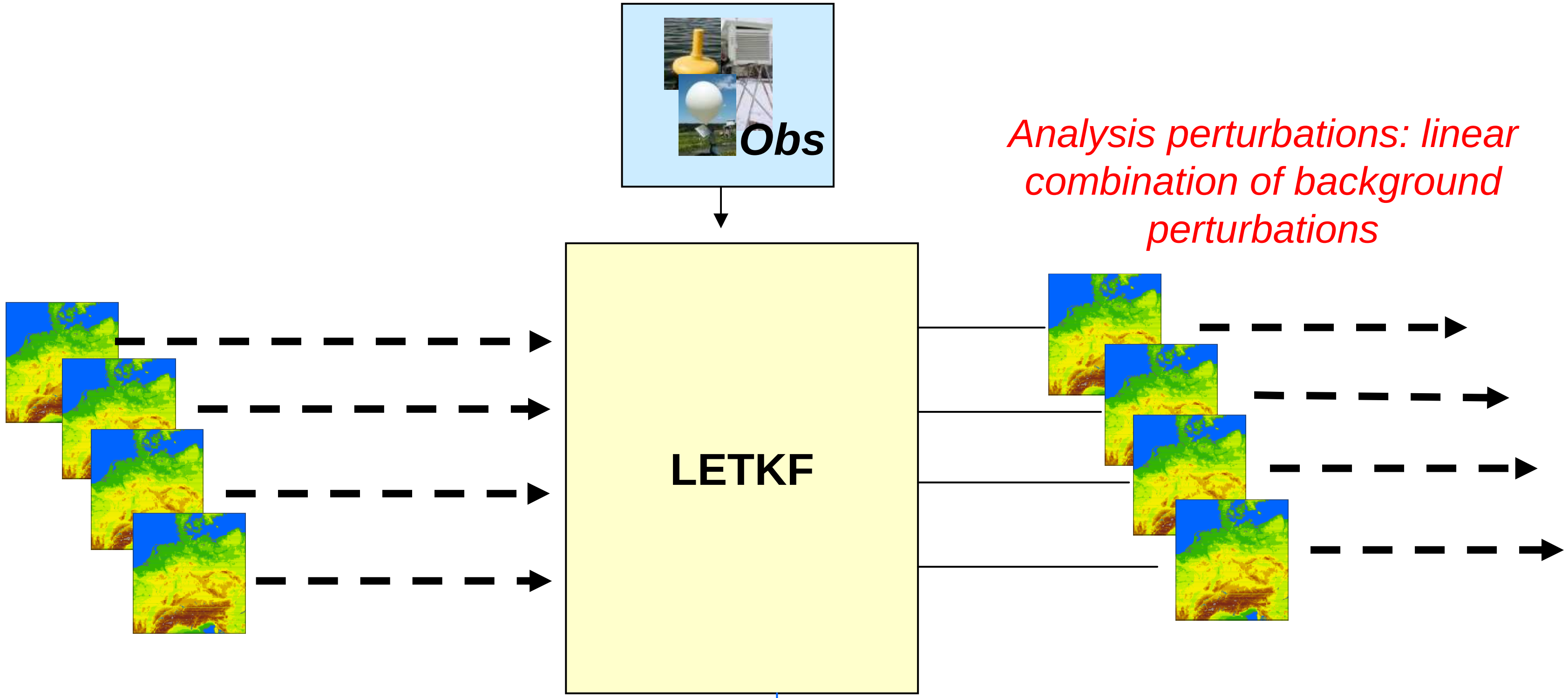
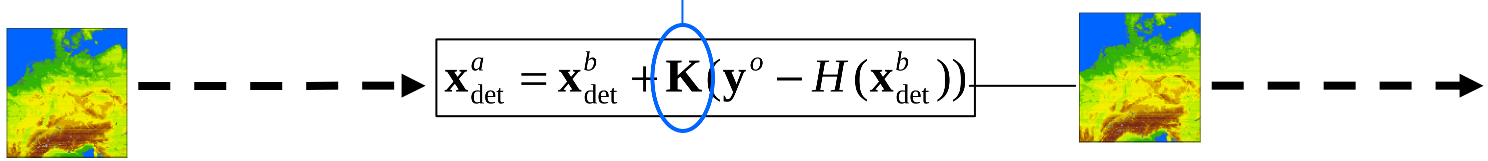


Additional: one deterministic run:



$$\mathbf{x}^a_{\text{det}} = \mathbf{x}^b_{\text{det}} + \mathbf{K}\left(\mathbf{y}^o - H(\mathbf{x}^b_{\text{det}})\right)$$

Kalman gain matrix from LETKF

COSMO:
cloud parameterization

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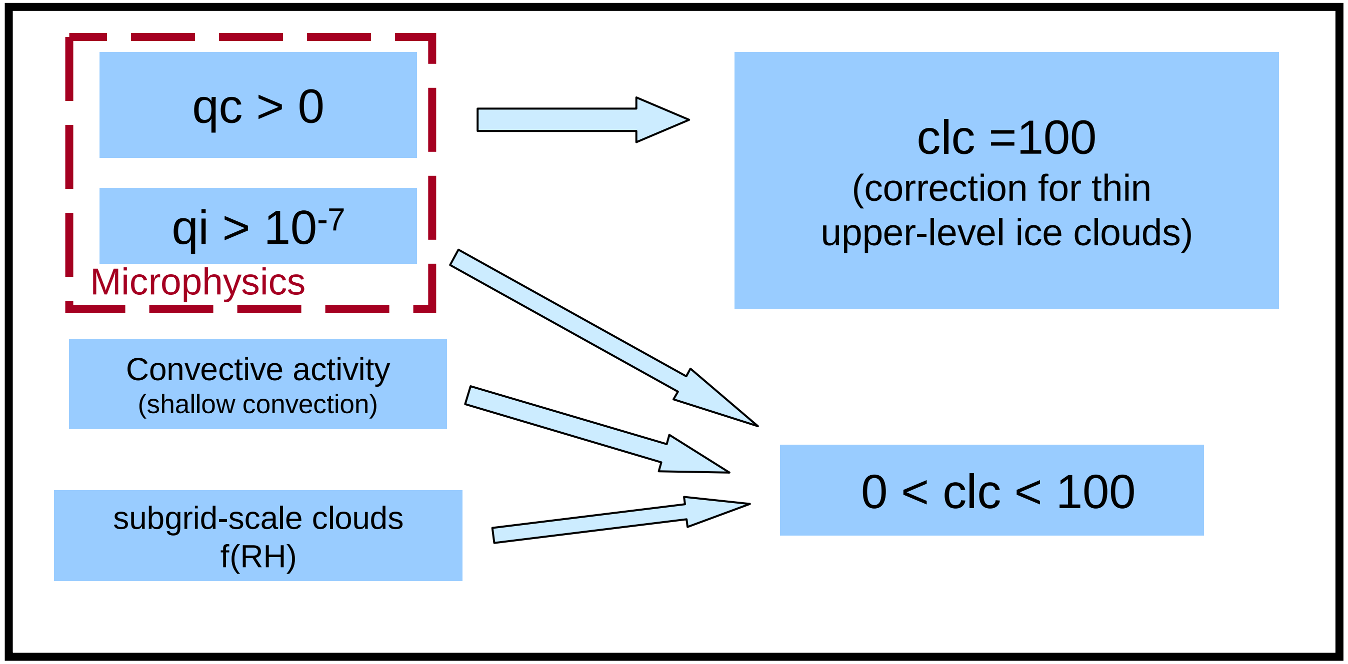
- Relevant variables (3D):
  - Cloud Water qc [kg/kg]
  - Cloud Ice qi [kg/kg]
  - Cloud cover clc [%]

(qc and qi: Prognostic model variables)



- Weight for cloud top height correction and error correction:

$$\gamma = \frac{(r - r_{max})}{(r + r_{max})} \cdot \frac{(t - t_{max})}{(t + t_{max})}$$

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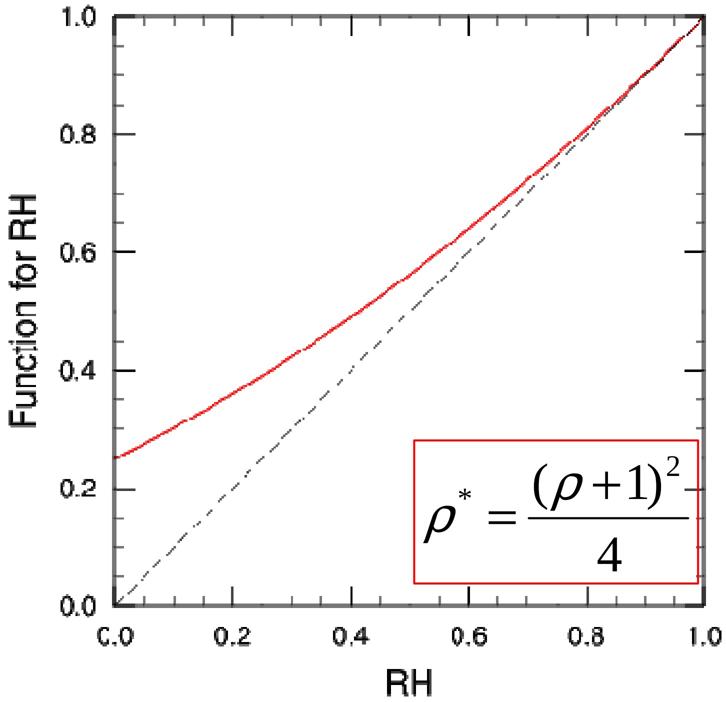
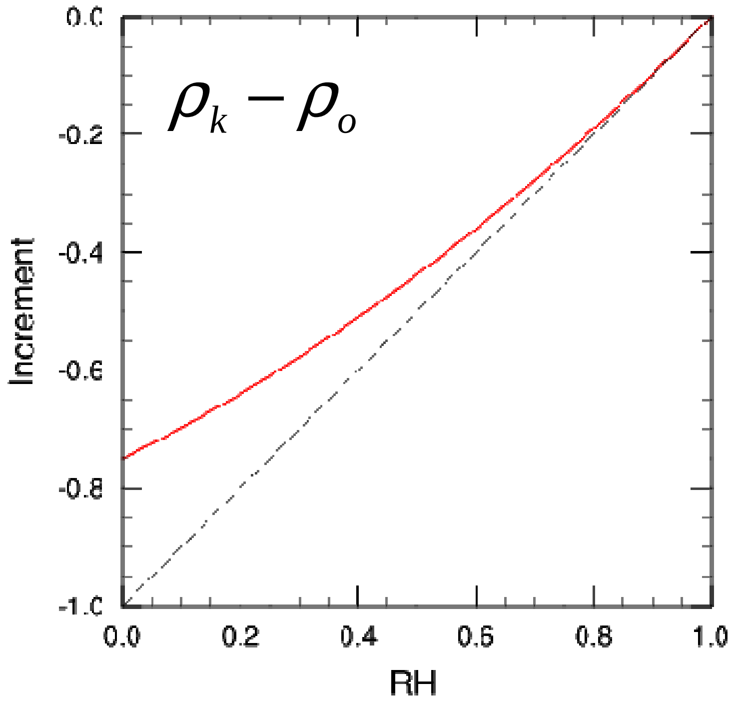
Function for relative humidity





Single profiles: FG

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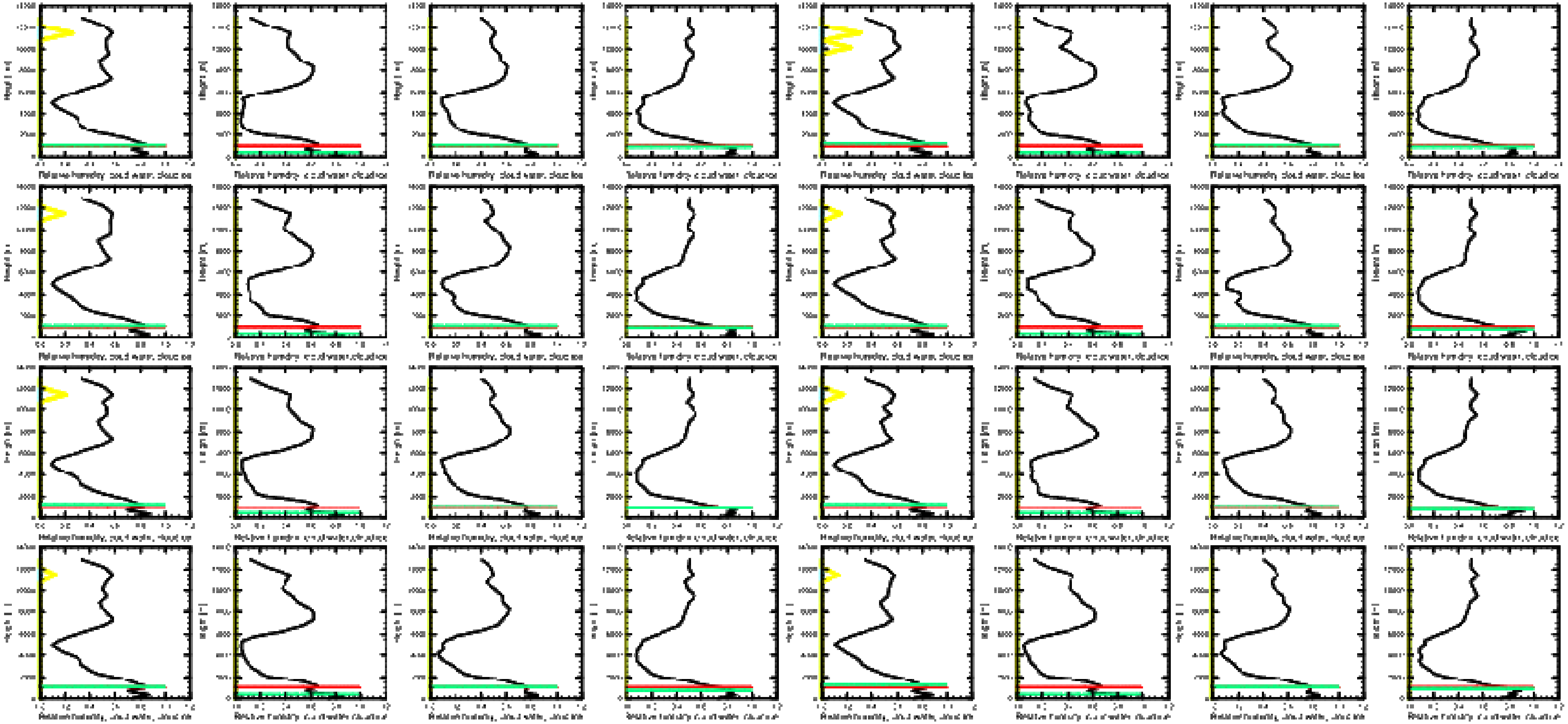

Relative humidity

Cloud water

Cloud ice

Observed cloud top

Model equ. cloud top

Single profiles: ANA

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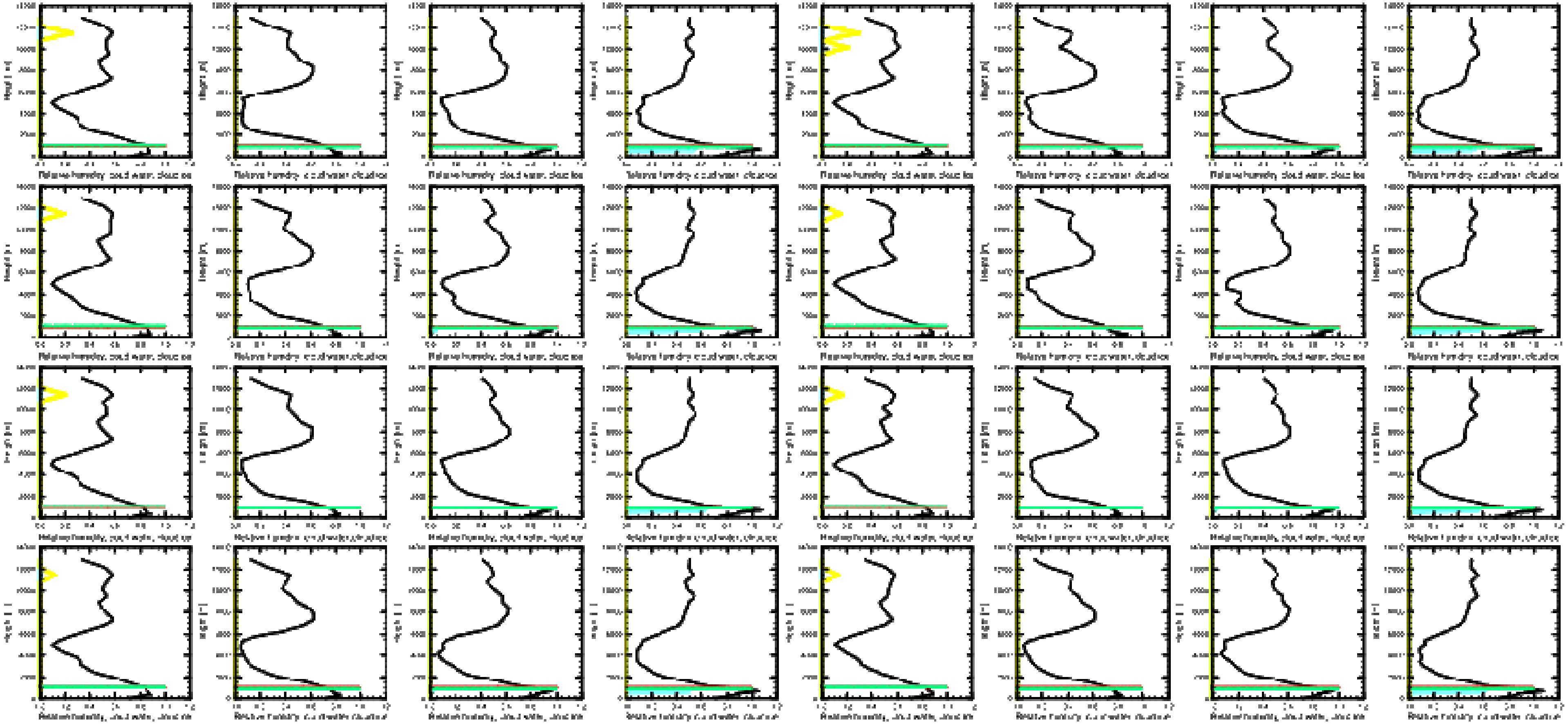
Wetter und Klima aus einer Hand



Relative humidity

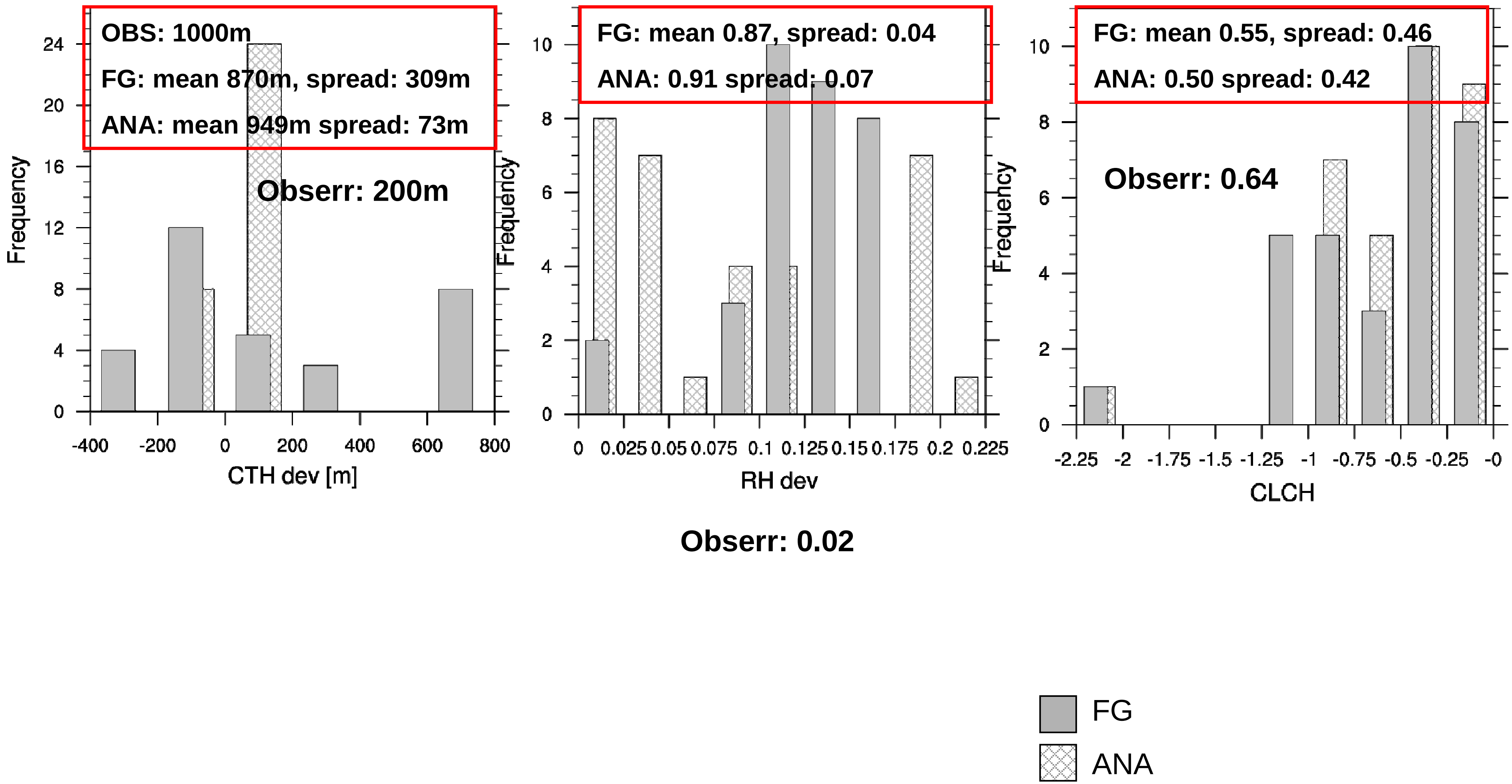
Cloud water

Cloud ice

Observed cloud top

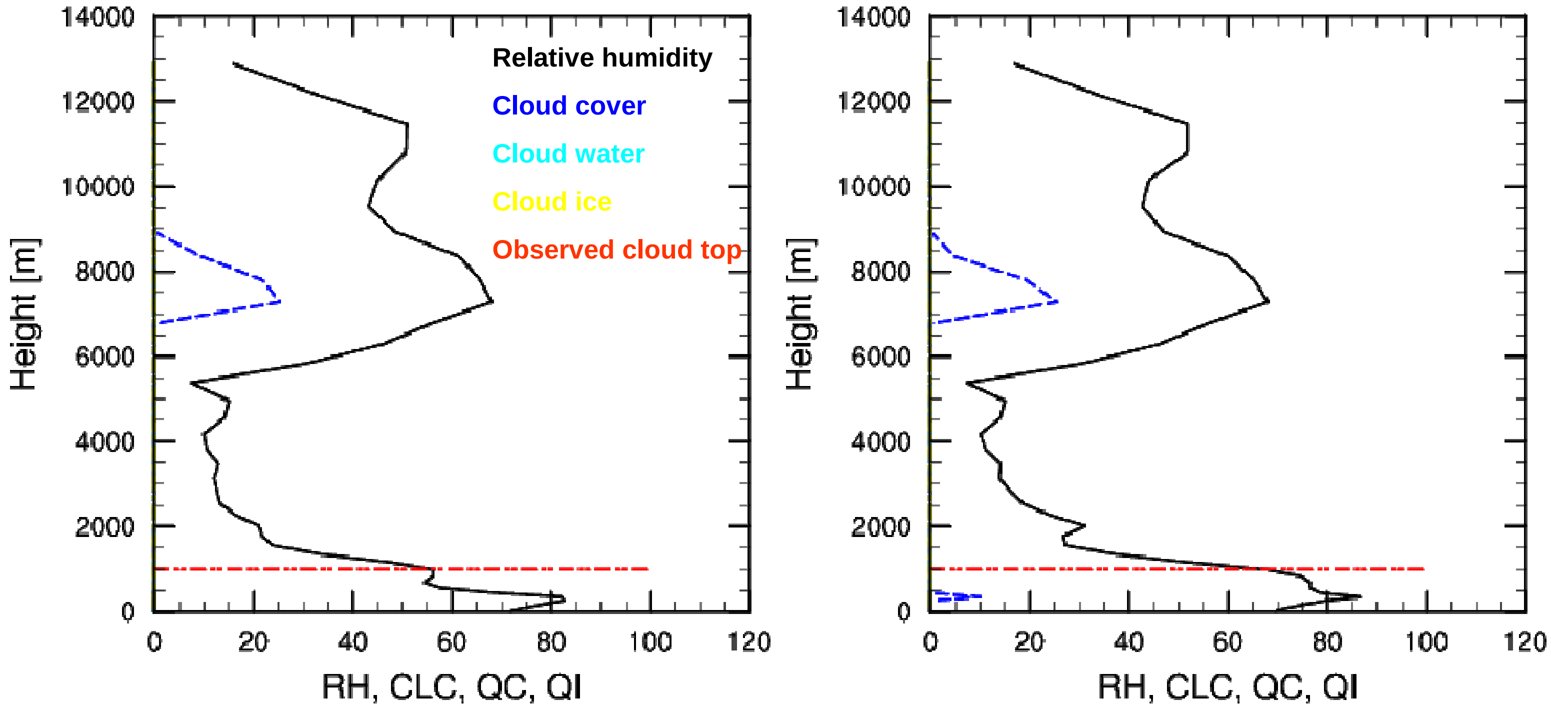
Model equ. cloud top

Deviation-histograms: Obs minus model, lat 53.9, lon 4.1 (example 1)



Deterministic run

First guess **Analysis**



Humidity at cloud layer is increased in deterministic run

Deterministic run, example 2

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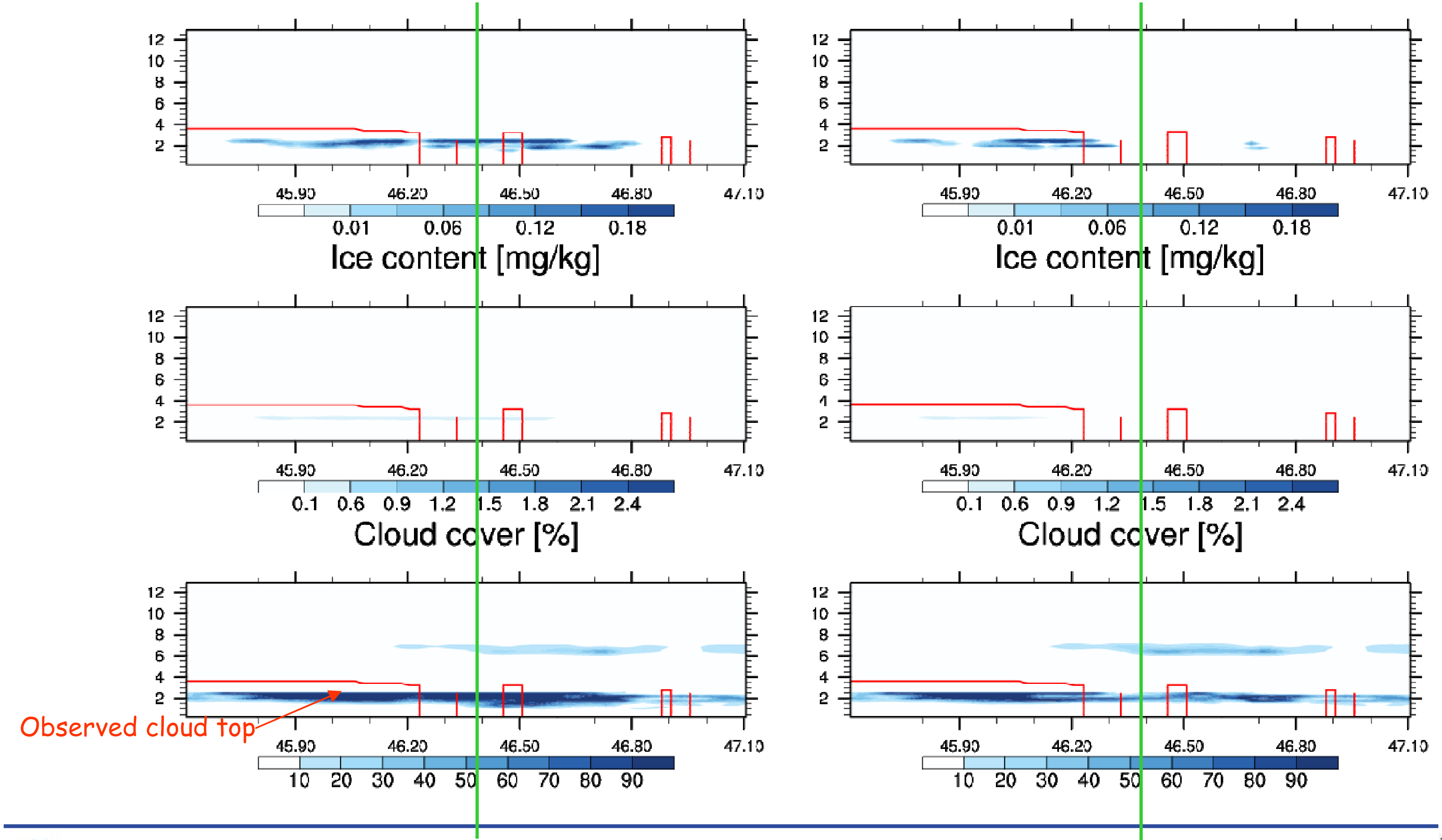
First guess / Analysis



Deterministic run

Deutscher Wetterdienst
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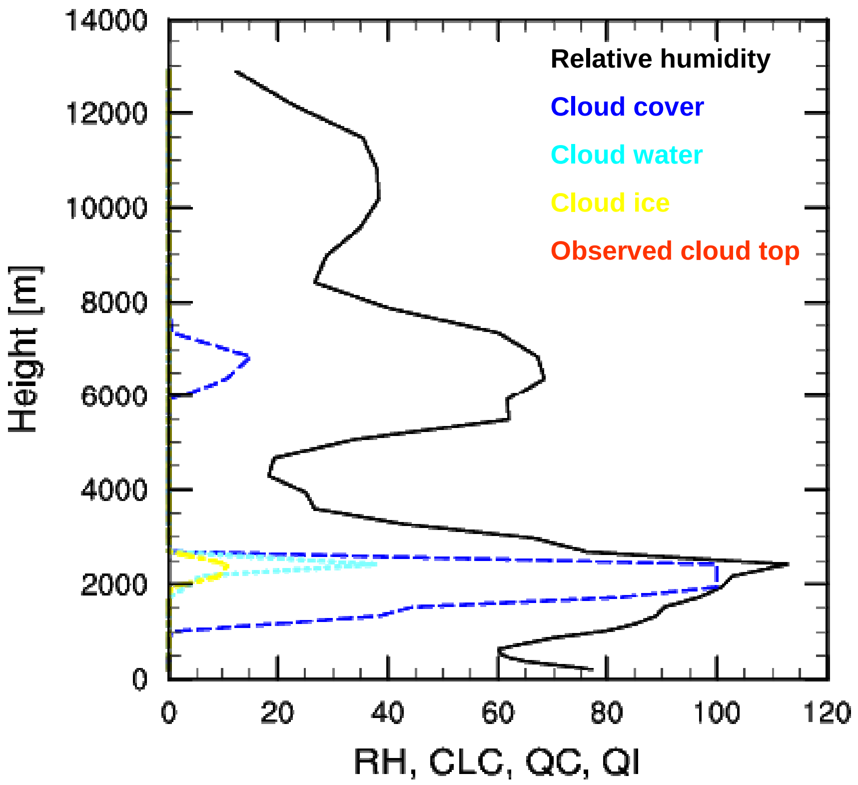
First guess



Analysis