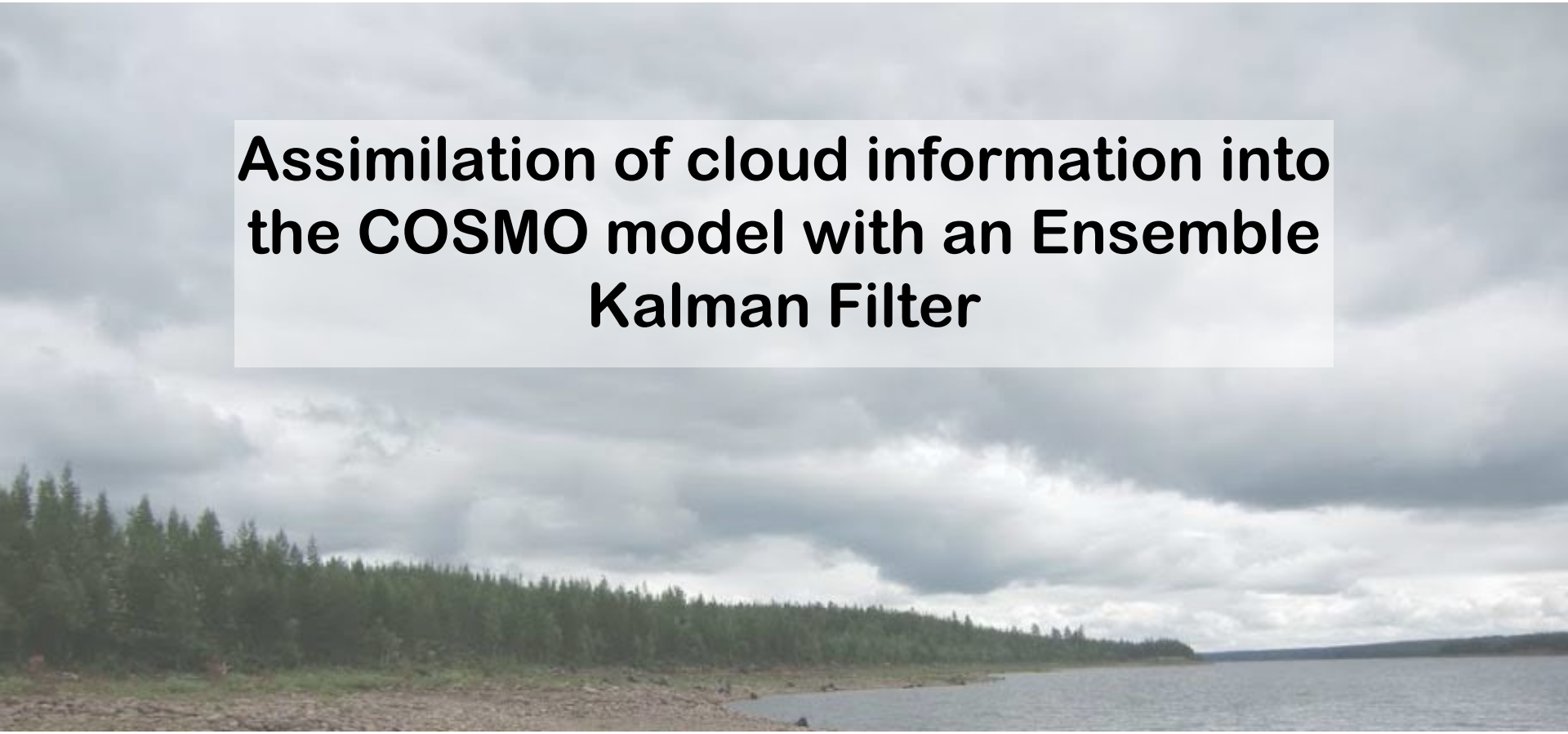
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Assimilation of cloud information into the COSMO model with an Ensemble Kalman Filter

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Introduction

LETKF & Data

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Local Ensemble Transform Kalman Filter in COSMO (KENDA project)

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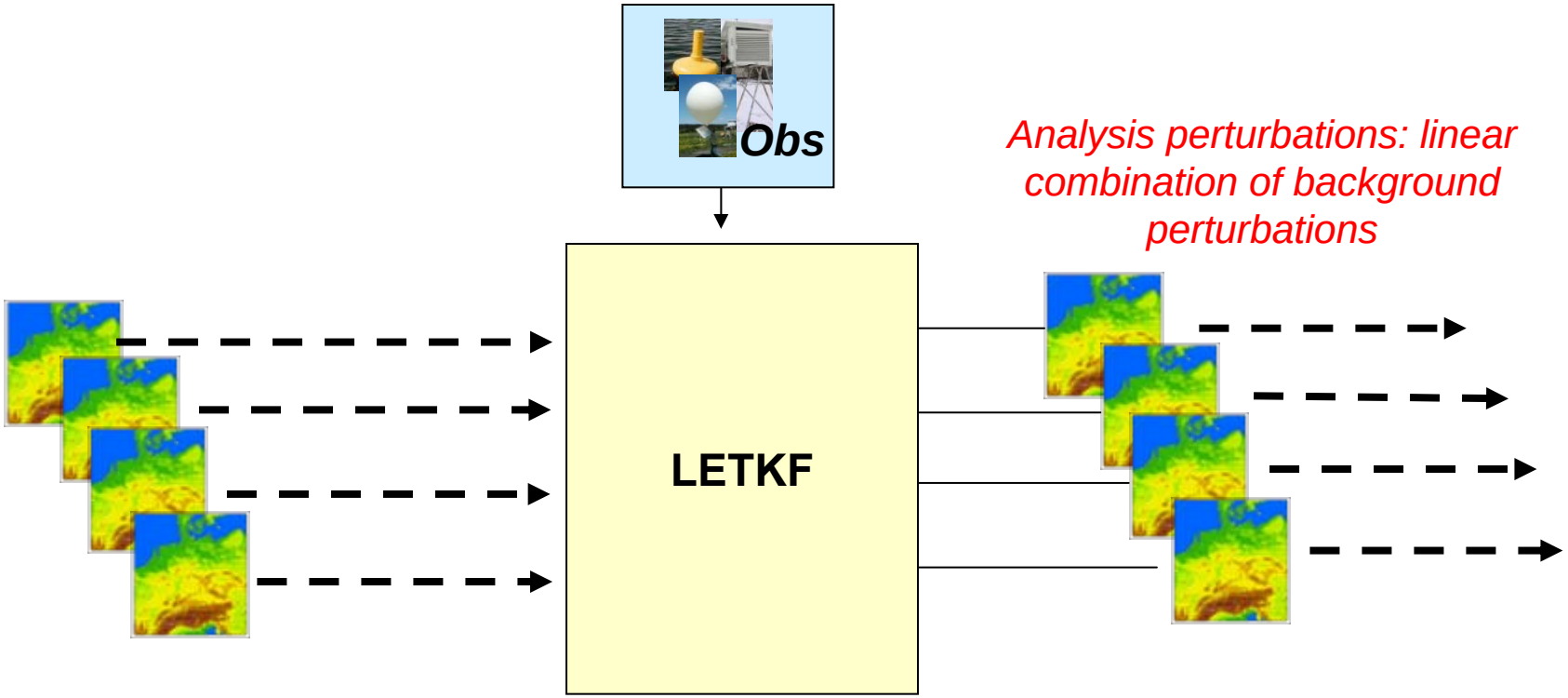
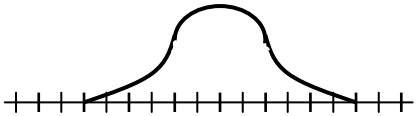


Analysis perturbations: linear combination of background perturbations

- **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 (Δx=2.8km)

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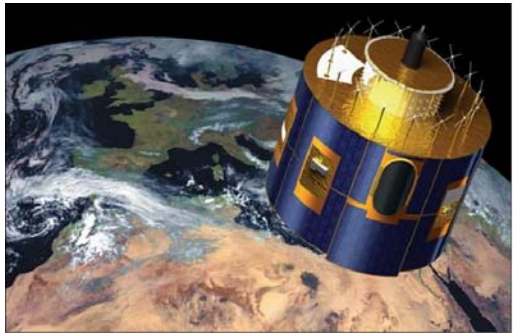
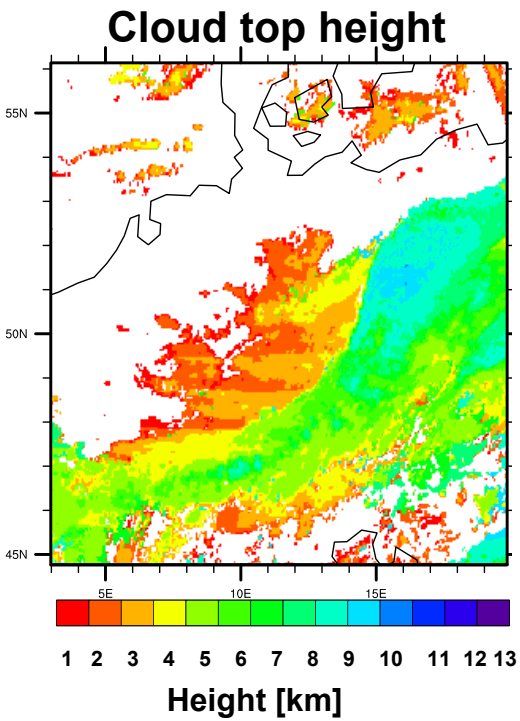
- NWCSAF cloud products based on satellite data: **Meteosat-SEVIRI**
  - ~ 5km over central Europe,
  - Δt=15 min



Source: EUMETSAT



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

"Cloud analysis": Combine satellite & radiosonde information

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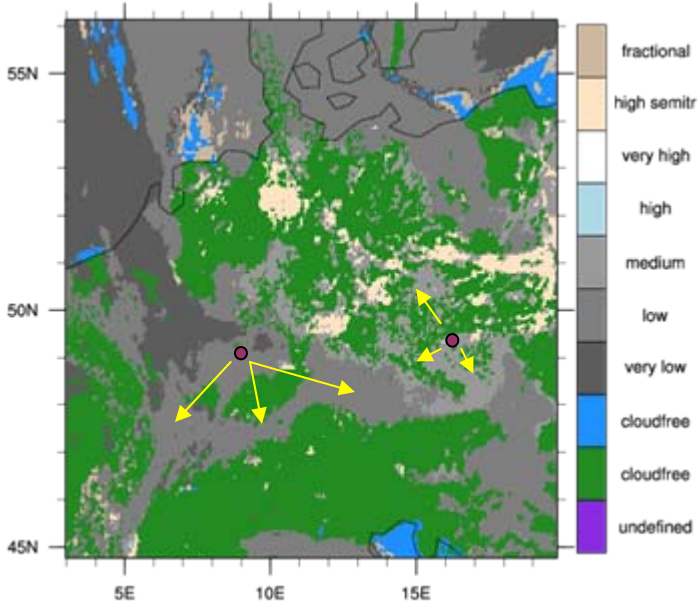
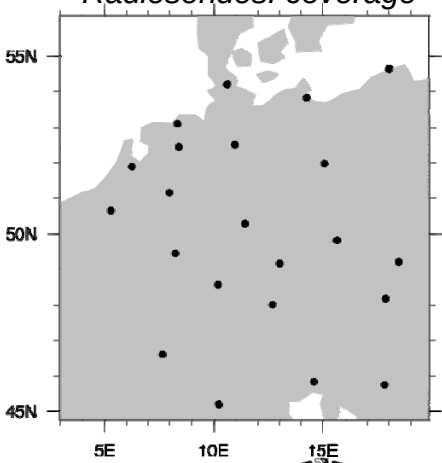
- Use **nearby radiosondes within the same cloud type (according to satellite cloud product)** **to correct** **(or approve)** cloud top height from satellite cloud height retrieval



Radiosondes: coverage



Combine satellite & radiosonde information: data availability flag

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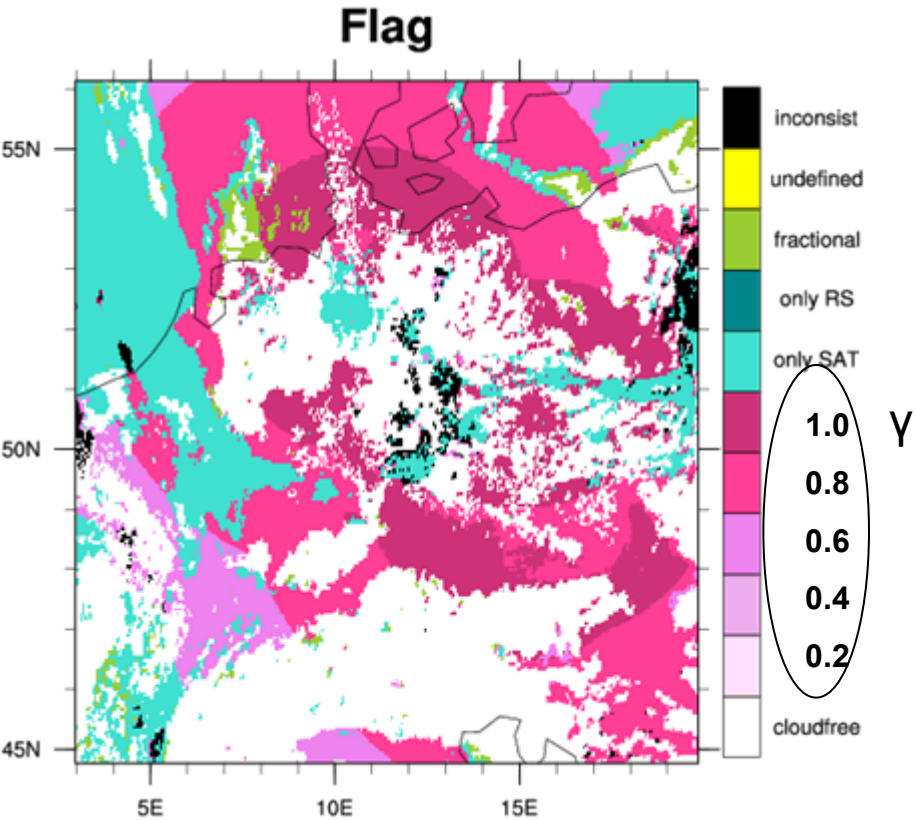

- Use temporal and spatial distance of radiosonde for weighting:

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

- Also use data availability flag for observation error specification:

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

Assimilation concept

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Variables assimilated

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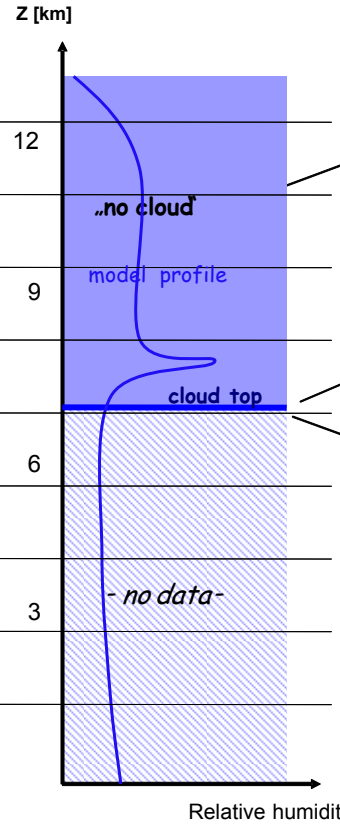
From one observation of cloud top height several variables are extracted and used to weight the ensemble members in the LETKF (observation $\mathbf{y}_i$ and model equivalent $\mathbf{H}(\mathbf{x}_i)$)

Cloudy pixel:

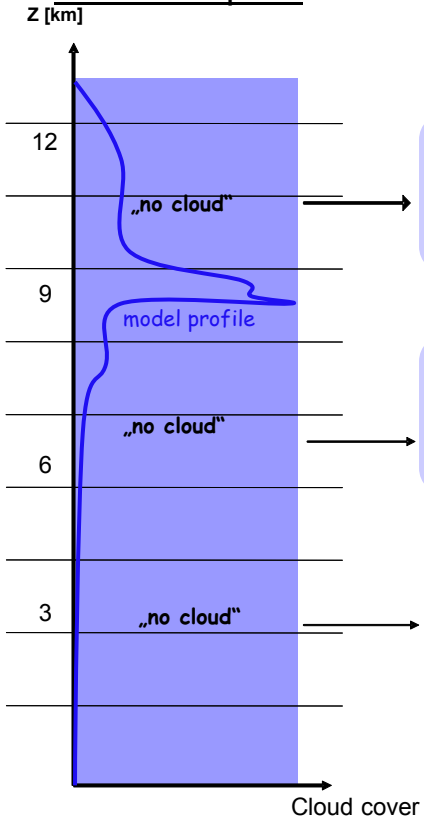


Cloud cover of high/medium clouds
Obs: cloud cover = 0
Model: maximum cloud cover in vertical range

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 pixel:

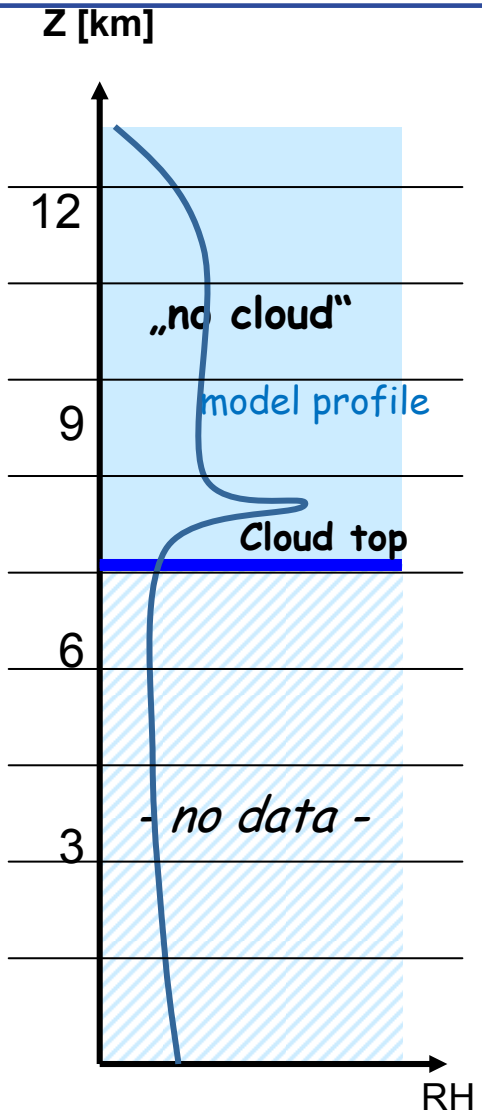


Cloud cover of high clouds
Obs: cloud cover = 0
Model: maximum cloud cover in high cloud range

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

Example for 40 single profiles

red: observed cloud top

green: model equiv. cloud top

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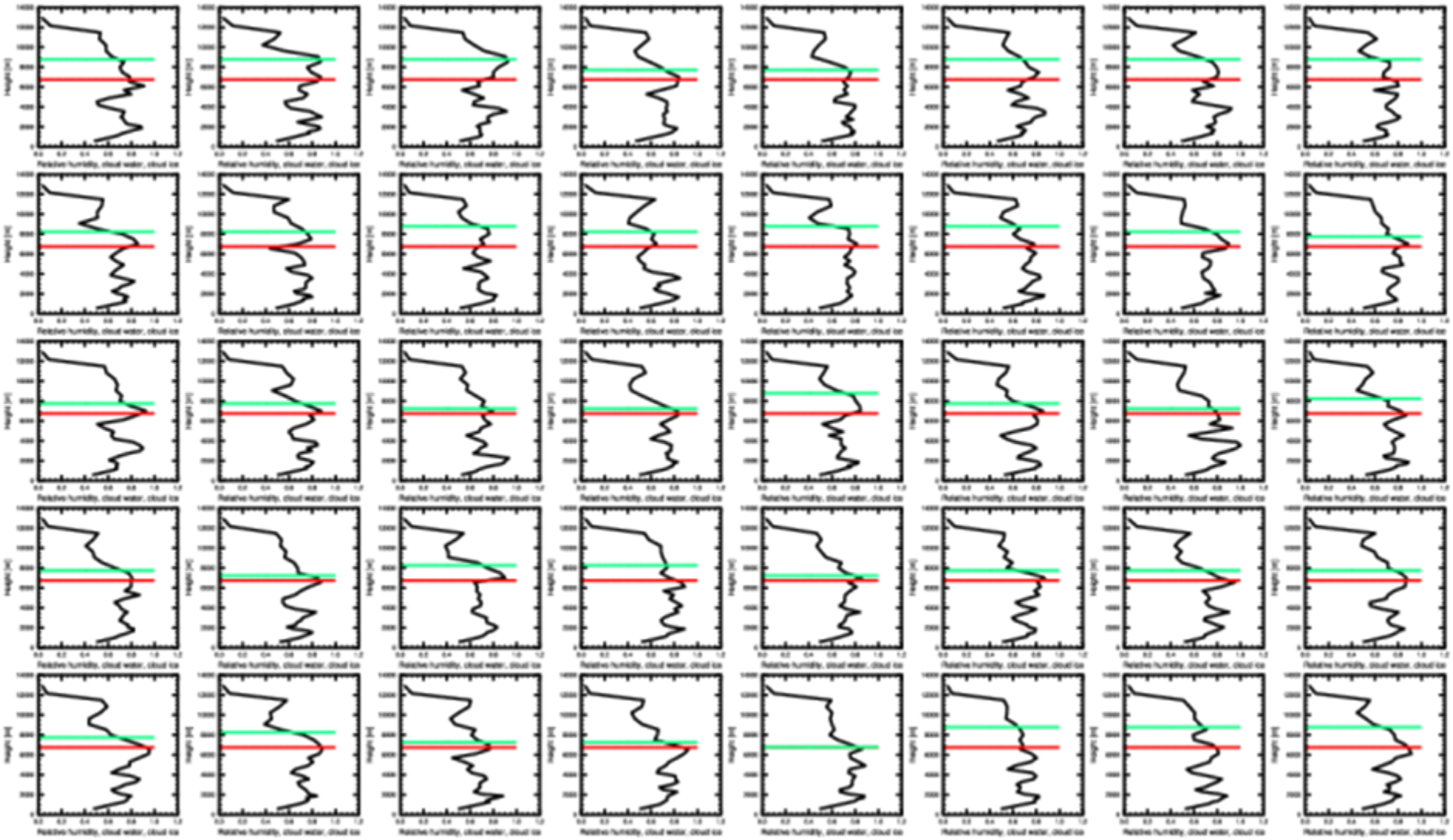

Model equivalents for cloudy column

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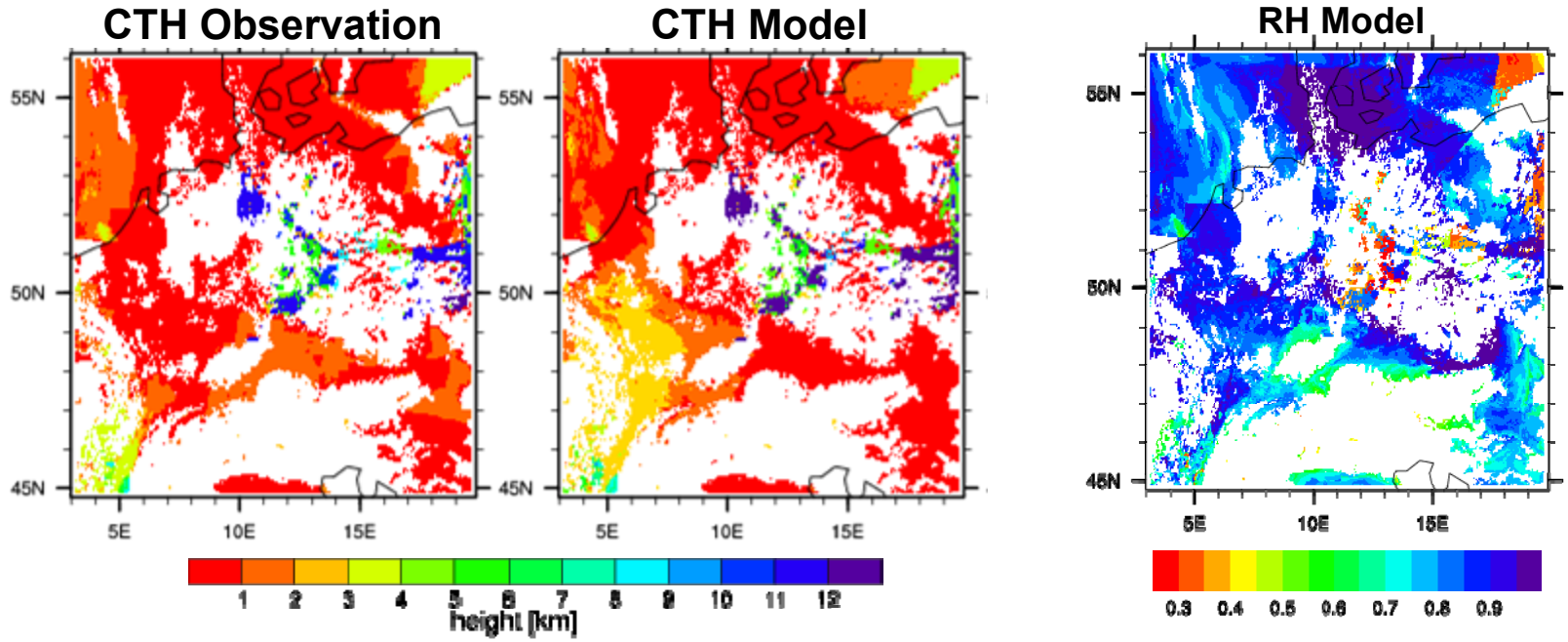
Wetter und Klima aus einer Hand

Assimilated variables: Cloud top height and relative humidity



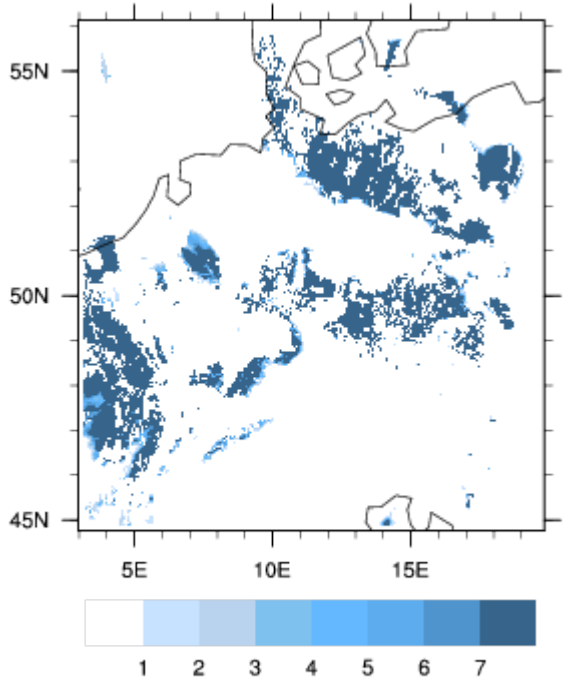
Model equivalents for cloud-free column

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

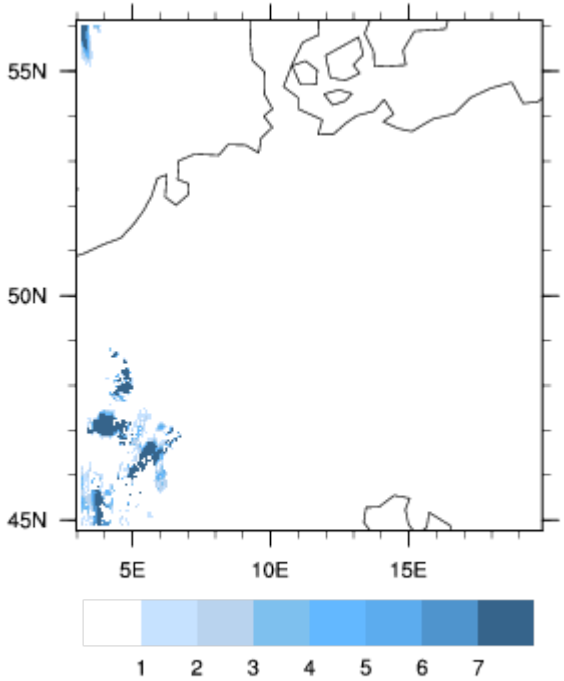
Assimilated variables: Cloud cover

- COSMO cloud cover where observations "cloudfree"

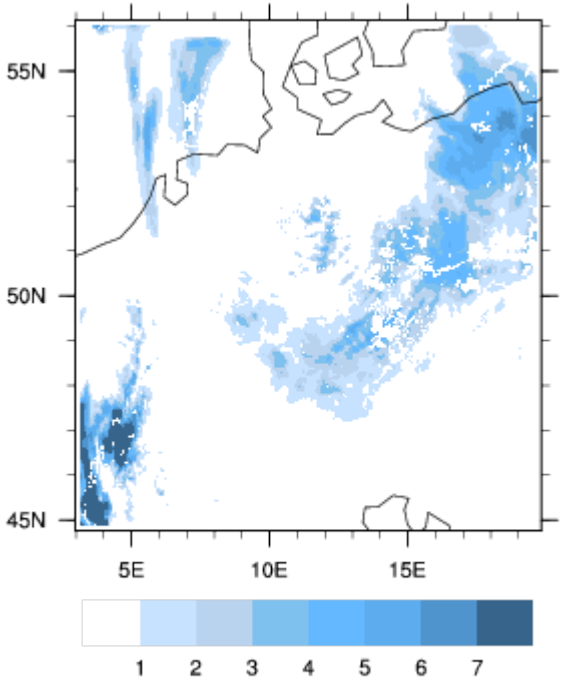
Low clouds (oktas)



Medium clouds (oktas)



High clouds (oktas)



Results

Single observation experiments

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„Single observation“ experiment

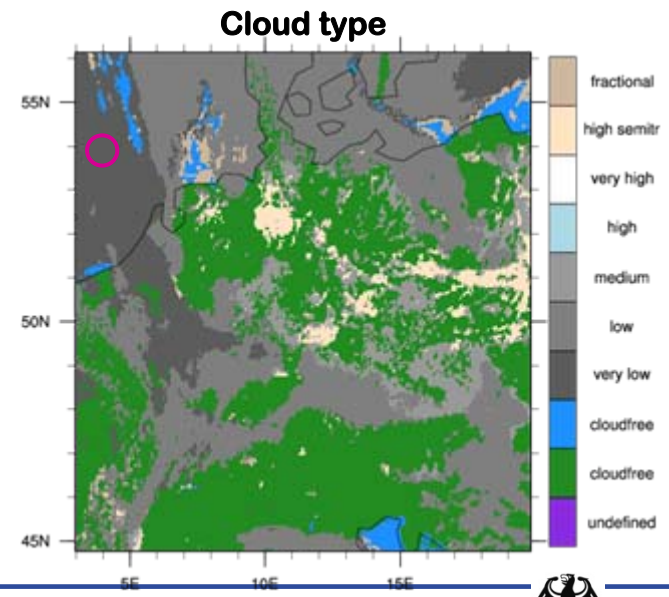
- Objective:
  - Understand in detail what the filter does with such special observation types
    - Does it work at all?
    - Sensitivity to settings

- Assimilate every 60th column

- Horizontal localization: 20km
  (weights equal to zero at ~73km=26 grid points)

Example 1
Stable high pressure situation
17 November 2011, 6:00 UTC

Observation: Low stratus clouds
no cloud in model



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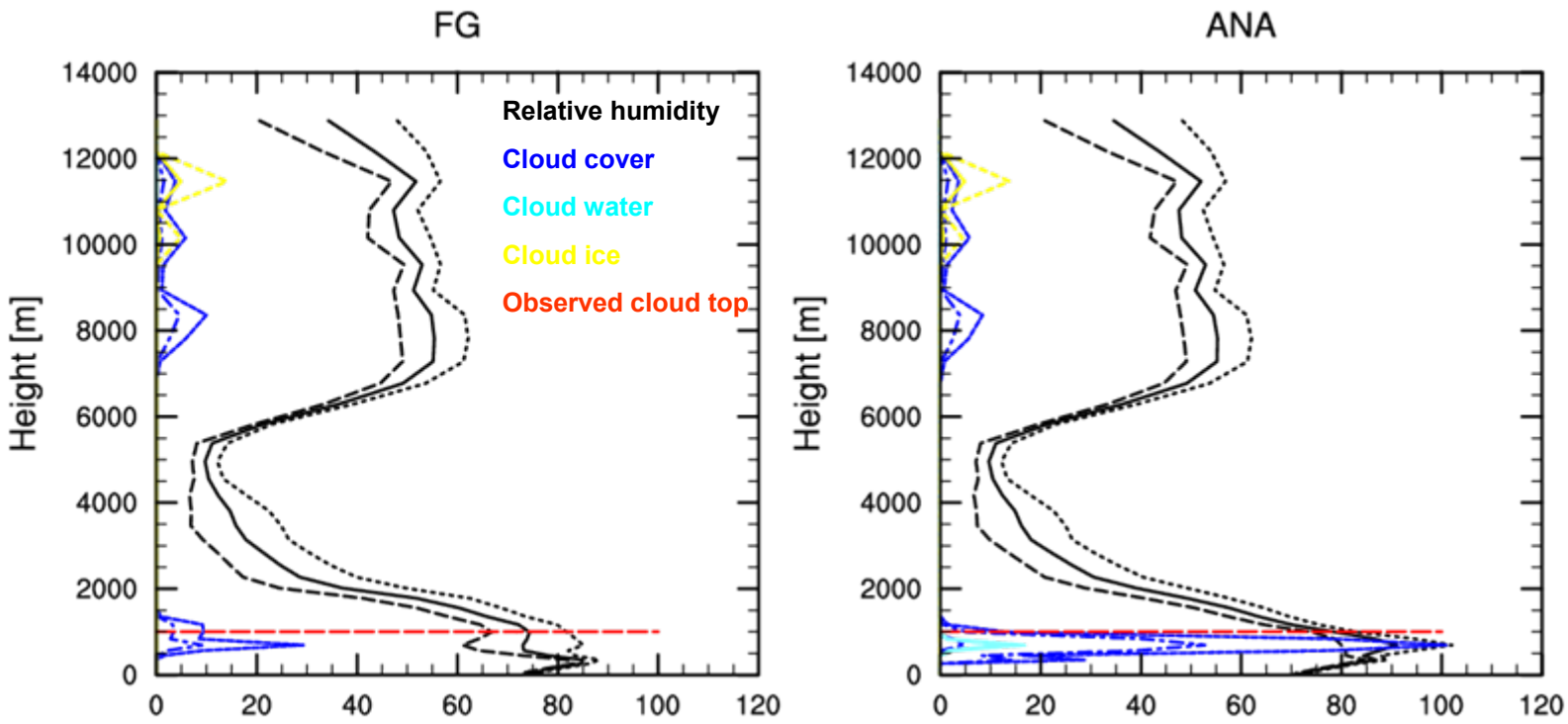
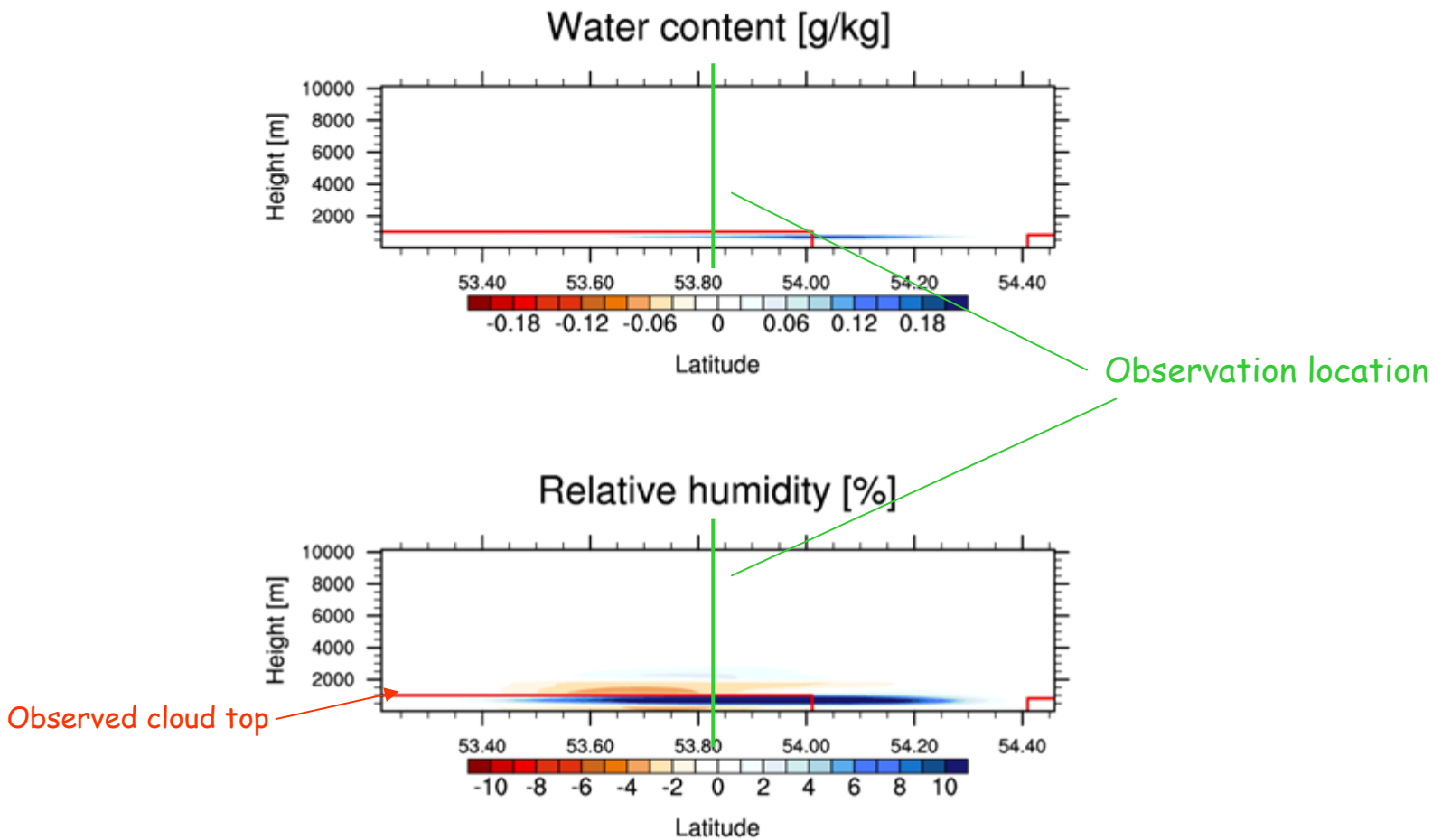
Profiles



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

Increment cross section for the ensemble mean



Corresponding temperature profiles

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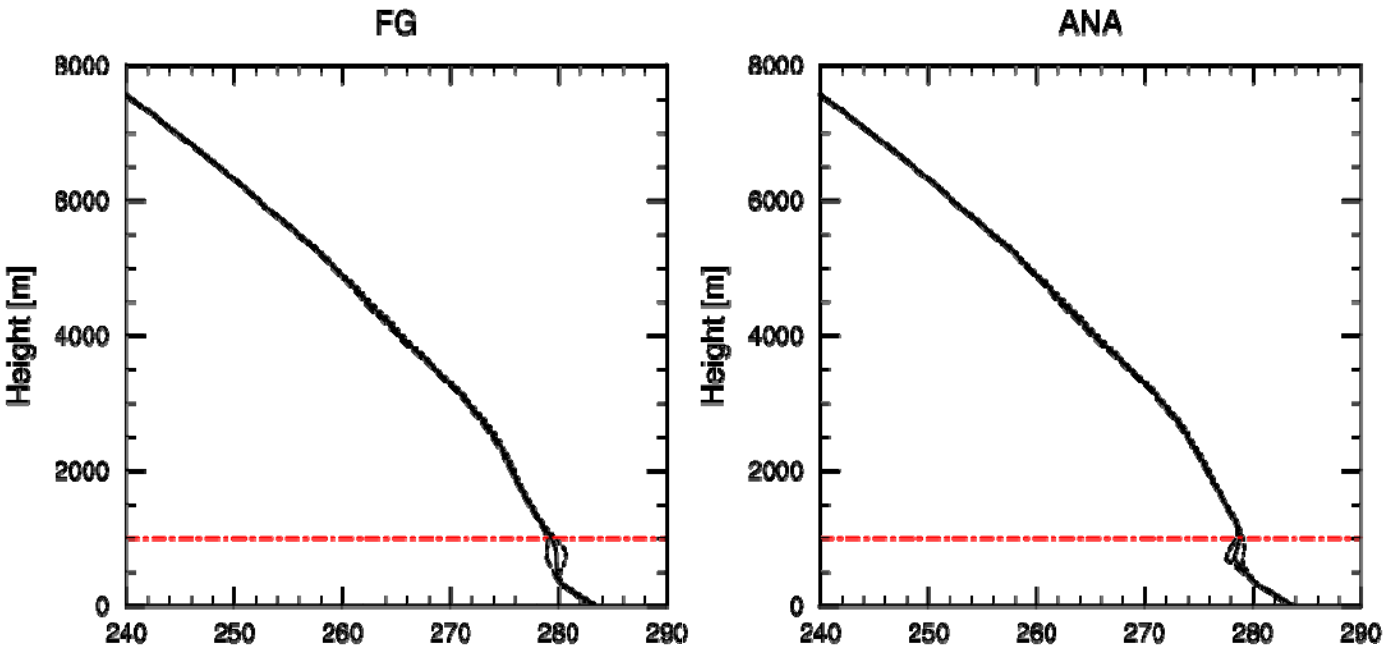
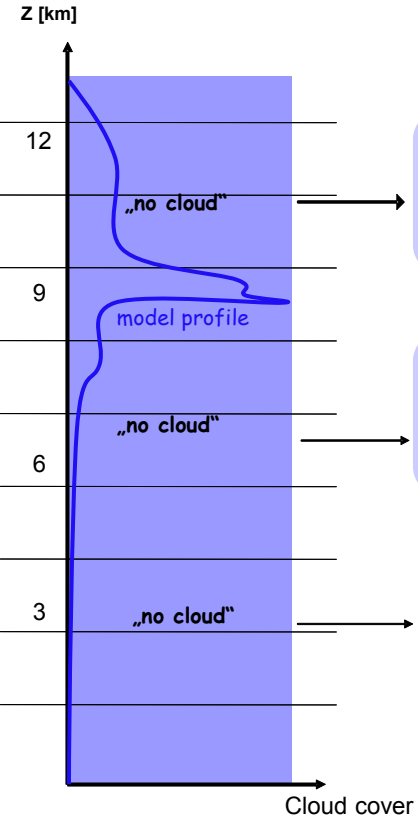
Temperature (mean +/- spread)



Example 2: „false alarm“ cloud in cloudfree case

Cloudfree column

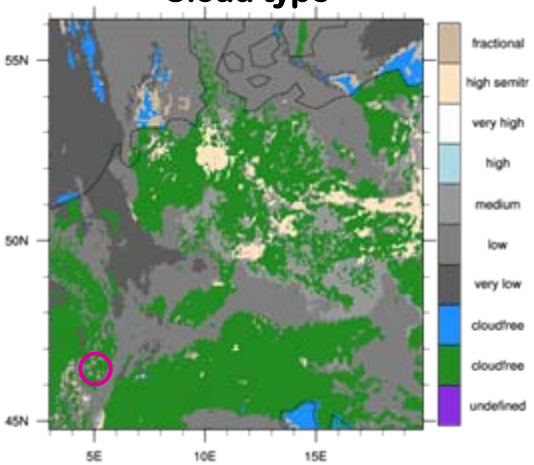


Cloud cover of high clouds
Obs: cloud cover = 0
Model: maximum cloud cover in high cloud range

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

Cloud type



Profiles: mean and spread

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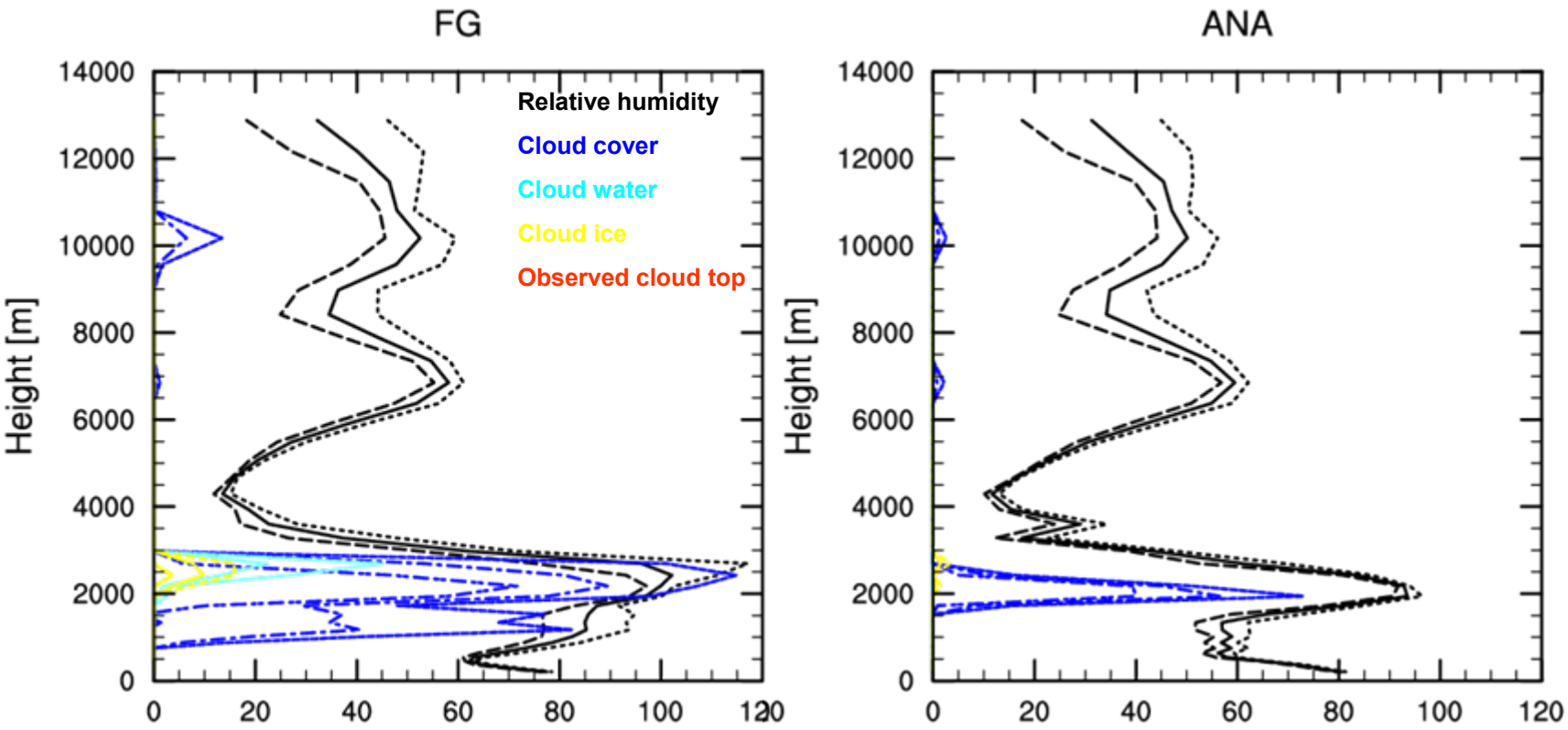

3 lines indicate mean and mean +/- spread

Obs minus model departure histogram

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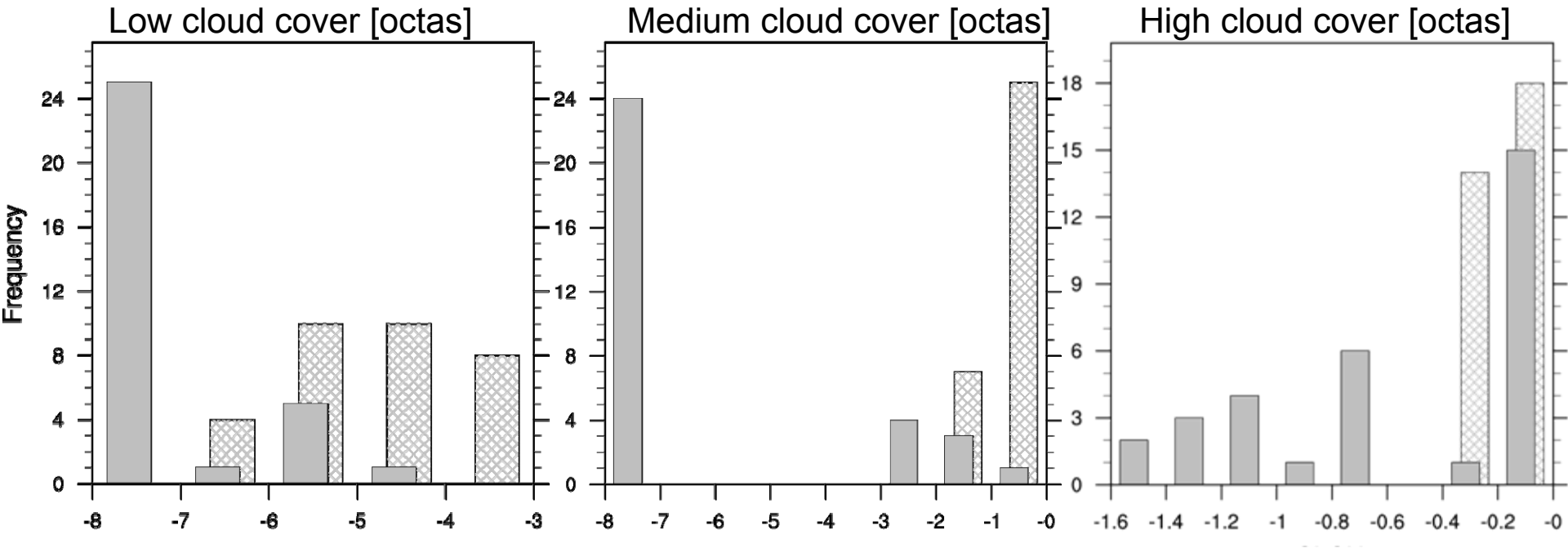

Remember: observed cloud cover = 0

FG

ANA

Example 3: cycled experiment in convective case 4 June 2011

40 members

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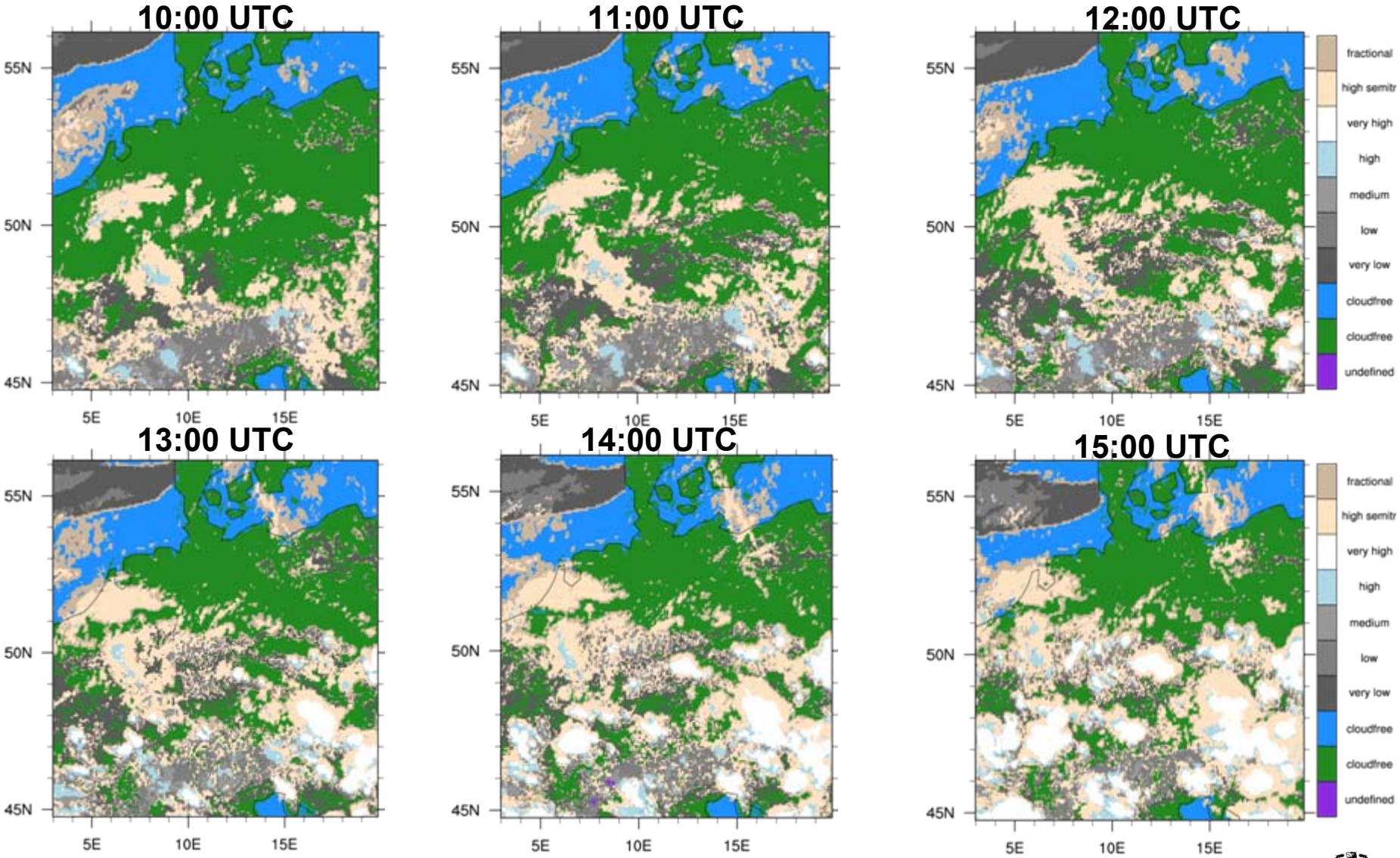

Example: cycled experiment in convective case

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11:00 UTC
(13:00 local time)

13:00 UTC

15:00 UTC

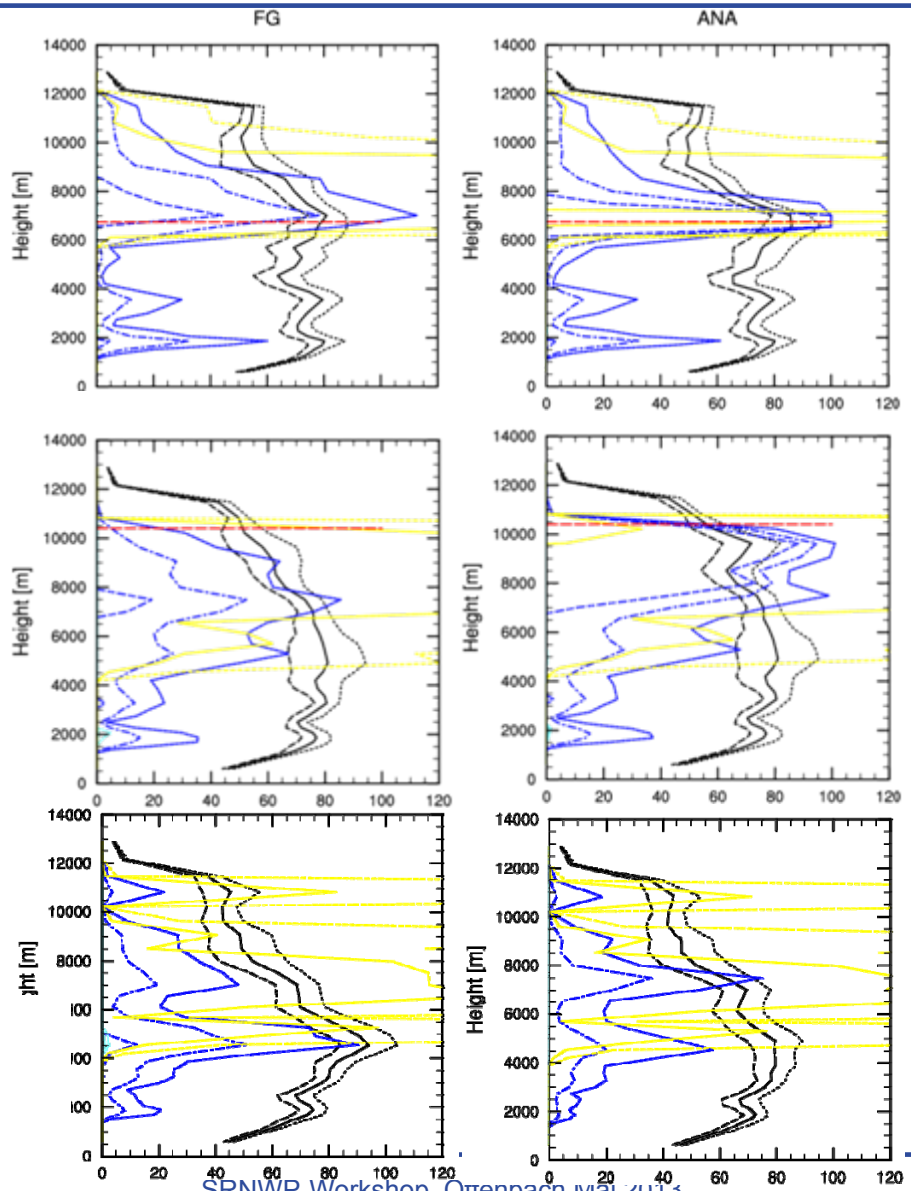
Relative humidity

Cloud cover

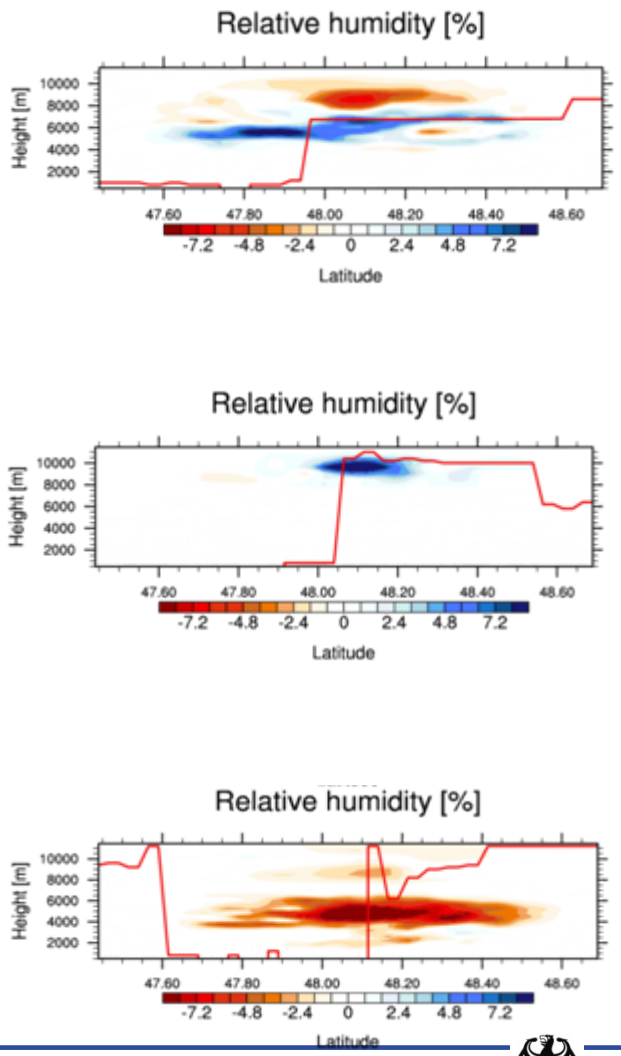
Cloud water

Cloud ice

Observed cloud top



Increments



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Summary, outlook, conclusions

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- **Single observation** experiments show:
  - Assimilation of cloud products gives reasonable, comprehensible results, draws ensemble closer to observation
- **Next step:**
  - Currently: Cycled experiments with dense observations
    - Thinning? Localization?

- **LETKF** offers new perspectives for assimilating unconventional data
  - in the LETKF the **observations are used to weight the different ensemble members**
  - Easy to assimilate also non-state variables (in contrast to nudging)
  - Easy to set up: no linearized/adjoint model/physics necessary

  → Here: assimilation of clouds

  - Useful for example in synoptically stable high pressure situations with low stratus clouds

  - Might be useful for Photovoltaic power production predictions (renewable energy projects)

Thank you for your attention.

The COSMO model

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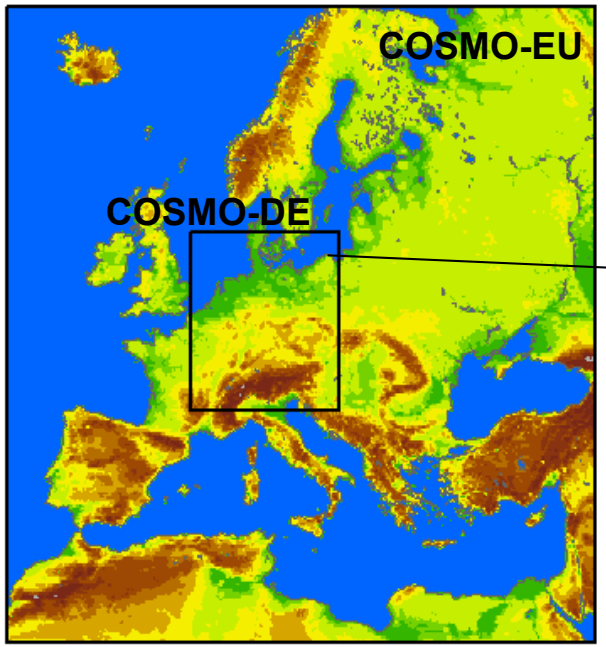
CONSORTIUM FOR SMALL SCALE MODELING
COSMO



Model domain

Limited-area non-hydrostatic numerical weather prediction model

COSMO-DE :

- $\Delta x \cong 2.8$ km / L50
- Current Data-Assimilation System:
  - Nudging + Latent Heat Nudging
- Under Development: **LETKF** (Local Ensemble Transform Kalman Filter, Hunt et al. 2007)

Combine satellite & radiosonde information

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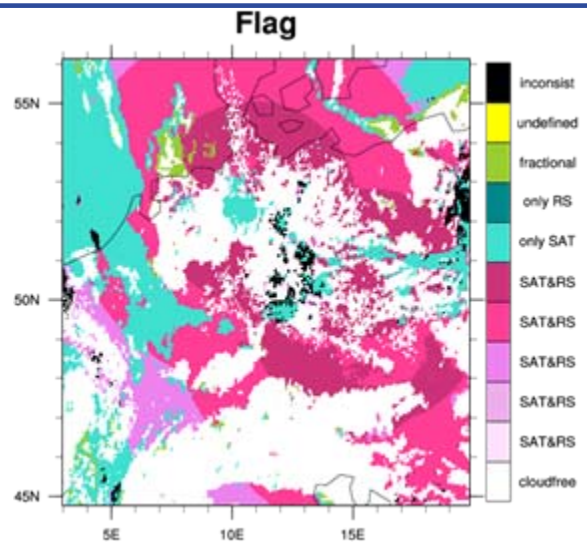
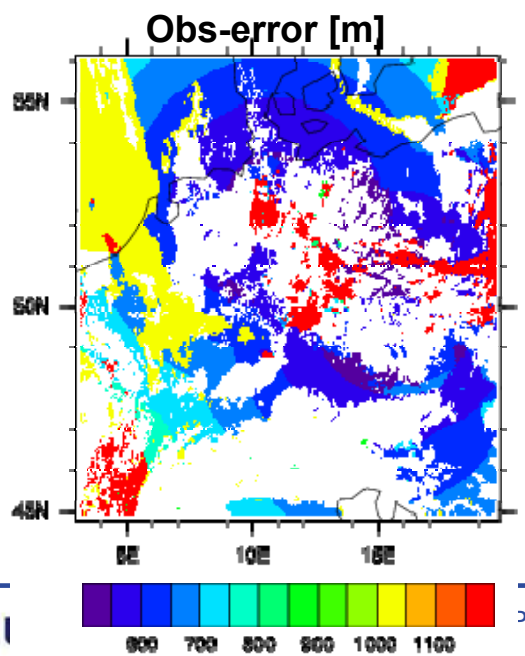
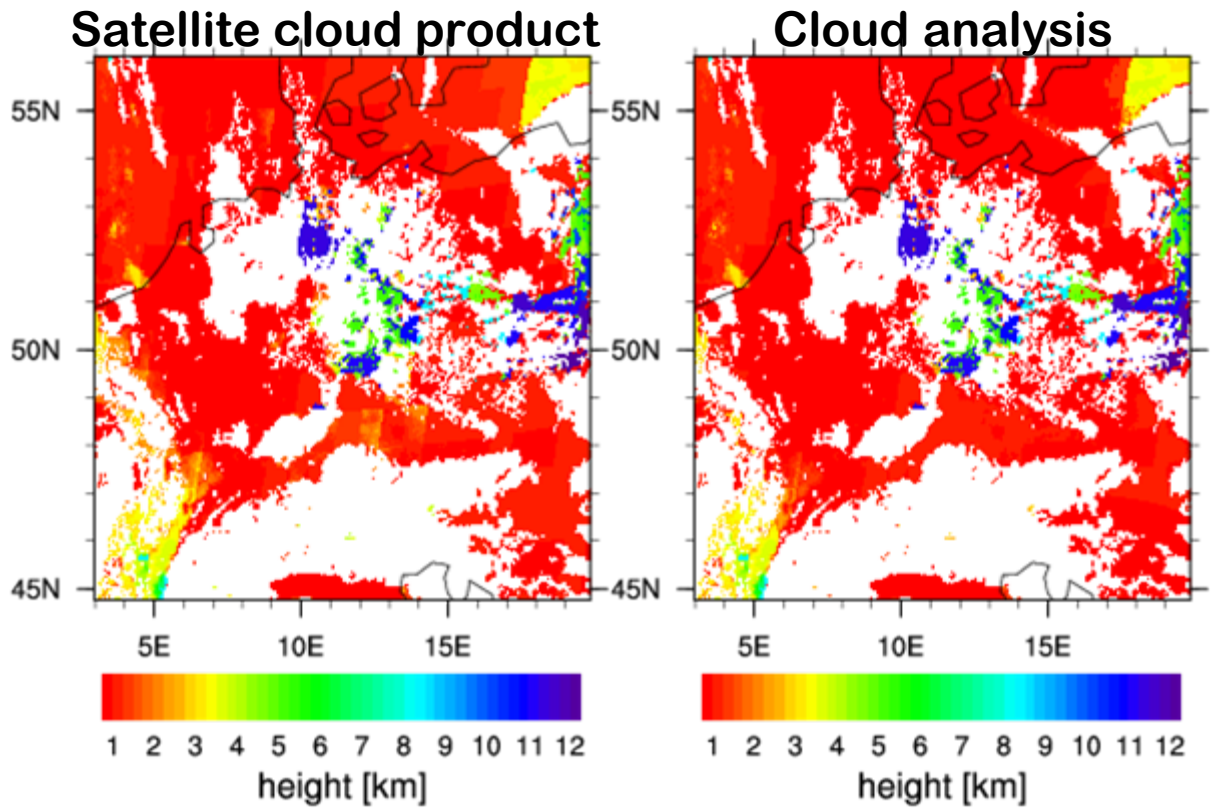




Cloud top height



COSMO: cloud parameterization

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

  } Prognostic model variables