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

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Introduction
LETKF & Data
Local Ensemble Transform Kalman Filter in COSMO (KENDA project)

Analysis perturbations: linear combination of background perturbations

- Local: the linear combination is fitted in a local region
  - observation have a spatially limited influence region
Assimilation of cloud information into COSMO-DE ($\Delta x=2.8\text{km}$)

- NWCSAF cloud products based on satellite data: Meteosat-SEVIRI
  - $\sim 5\text{km}$ over central Europe,
  - $\Delta t=15\text{ min}$

Retrieval algorithm uses temperature and humidity profile information from a NWP model as input

$\Rightarrow$ cloud top height might be at wrong height if temperature-profile in NWP model is not simulated correctly!

$\Rightarrow$ use also radiosonde information where available
“Cloud analysis“: Combine satellite & radiosonde information

- 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
Combine satellite & radiosonde information: data availability flag

- 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
Variables assimilated

From one observation of cloud top height several variables are extracted and used to weight the ensemble members in the LETKF (observation $y_i$ and model equivalent $H(x_i)$).

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:

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

\[ \rho: \text{Relative humidity} \quad h: \text{height} \]

- 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

color: observed cloud top
green: model equiv. cloud top

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Deutscher Wetterdienst
Wetter und Klima aus einer Hand
Model equivalents for cloudy column

Assimilated variables: Cloud top height and relative humidity
Model equivalents for cloud-free column

Assimilated variables: Cloud cover

- COSMO cloud cover where observations “cloudfree”
Results
Single observation experiments
„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
Profiles

3 lines on one colour indicate mean and mean +/- spread
Increment cross section for the ensemble mean

Water content [g/kg]

Relative humidity [%]

Observation location

Observed cloud top
Corresponding temperature profiles

Temperature (mean +/- spread)

FG

ANA
Example 2: „false alarm“ cloud in cloudfree case

Cloud free column

Z [km]

12

9

model profile

6

3

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
Profiles: mean and spread

3 lines indicate mean and mean +/- spread
Obs minus model departure histogram

Low cloud cover [octas]  Medium cloud cover [octas]  High cloud cover [octas]

Remember: observed cloud cover = 0

- FG
- ANA
Example 3: cycled experiment in convective case 4 June 2011

40 members

10:00 UTC

11:00 UTC

12:00 UTC

13:00 UTC

14:00 UTC

15:00 UTC
Example: cycled experiment in convective case

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

Relative humidity [%]

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Summary, outlook, conclusions

- **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)
The COSMO model

Limited-area non-hydrostatic numerical weather prediction model

COSMO-DE:
- $\Delta x \approx 2.8 \text{ km} / L50$
- Current Data-Assimilation System:
  - Nudging + Latent Heat Nudging
- Under Development: LETKF (Local Ensemble Transform Kalman Filter, Hunt et al. 2007)
Combine satellite & radiosonde information

Cloud top height

Satellite cloud product

Cloud analysis

Obs-error [m]
COSMO: cloud parameterization

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

Prognostic model variables

- \( qc > 0 \)
- \( qi > 10^{-7} \)
- Convective activity (shallow convection)
- Subgrid-scale clouds \( f(RH) \)

\( clc = 100 \)  
(correction for thin upper-level ice clouds)

\( 0 < clc < 100 \)