Assimilation of Cloud Information at the Convective Scale with the Ensemble Kalman Filter

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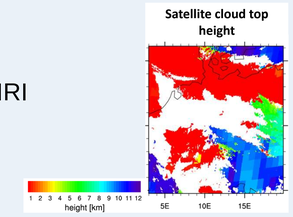
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Introduction

- **Motivation**: Improve initial state of convective scale numerical weather prediction model with respect to cloud cover, with a focus on low stratus clouds in typical stable winter anticyclonic situations where models tend to resolve the clouds too quickly

- **Observation**
  Satellite cloud top height from geostationary satellite Meteosat SEVIRI (Δx~5km, Δt=15min)

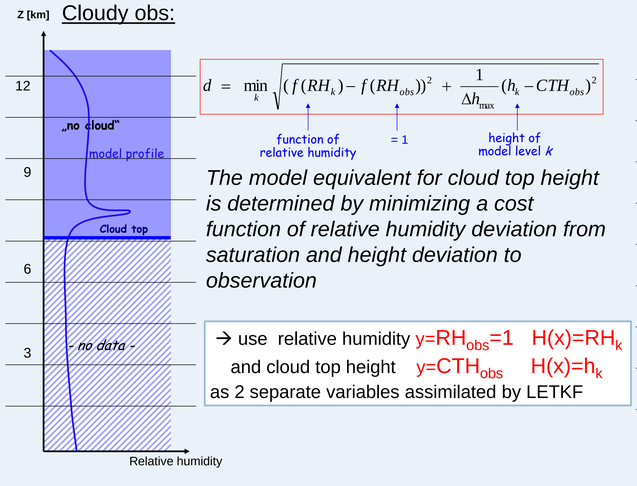


- **Model**: COSMO-DE, a non-hydrostatic limited area model run at 2.8 km horizontal resolution, 50 vertical layers with explicit deep convection
- **Data assimilation system**: Local Ensemble Kalman Filter (LETKF; Hunt et. al., 2007)

Variables assimilated

- How to assimilate the observation ***cloud top height*** into the LETKF?
- We want to avoid too strong penalizing of ensemble members
  - with high humidity but no cloud
  - which are dry at CTH_{obs} but have a cloud or even only high humidity close to CTH_{obs}

→ search in a vertical range Δhmax around CTH_{obs} for a 'best fitting' model level k, i.e. with minimum 'distance' d:

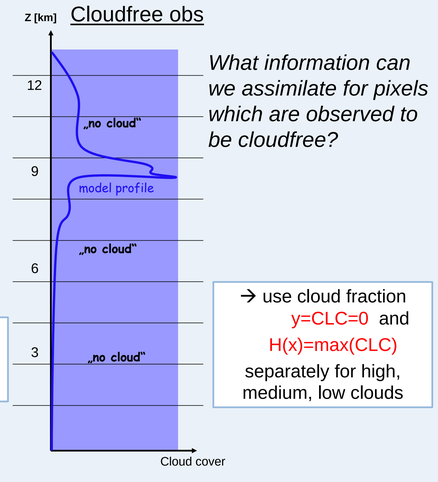


$$d = \min_k \sqrt{(f(RH_k) - f(RH_{obs}))^2 + \frac{1}{\Delta h_{max}}(h_k - CTH_{obs})^2}$$

function of relative humidity; = 1; height of model level k

The model equivalent for cloud top height is determined by minimizing a cost function of relative humidity deviation from saturation and height deviation to observation

→ use relative humidity $y=RH_{obs}=1$ $H(x)=RH_k$
and cloud top height $y=CTH_{obs}$ $H(x)=h_k$
as 2 separate variables assimilated by LETKF

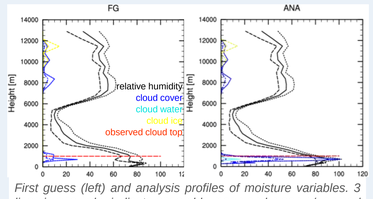


What information can we assimilate for pixels which are observed to be cloudfree?

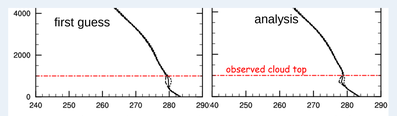
→ use cloud fraction
$y=CLC=0$ and
$H(x)=max(CLC)$
separately for high, medium, low clouds

Results Test case:: November 2011 with low stratus clouds in a stable high pressure system

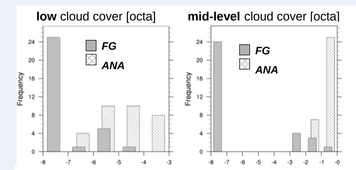
I. Single observation experiments (one assimilation step, only cloud data assimilated)



First guess (left) and analysis profiles of moisture variables. 3 lines in one color indicate ensemble mean and mean +/- spread for a cloud event missed by first guess ensemble



Temperature profile (mean +/- spread) corresponding to the humidity profiles in the previous figure.



Observation minus model departure histogram over ensemble members for a cloud-free observation.

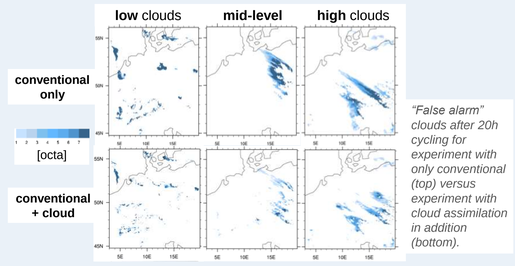
→ *Moisture and cloud cover is increased at observed cloud level.*

→ *LETKF introduces inversion due to RH – T cross correlations in ensemble background perturbations*

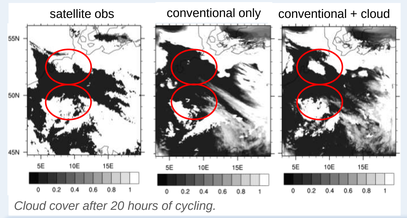
→ *LETKF decreases erroneous cloud cover despite very non-Gaussian distributions*

II. Cycled assimilation over 21 hours:

1-hourly updates, thinning: 14 km, experiment with only conventional data vs experiment with conventional and cloud obs



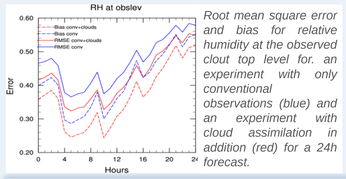
"False alarm" clouds after 20h cycling for experiment with only conventional (top) versus experiment with cloud assimilation in addition (bottom).



Cloud cover after 20 hours of cycling.

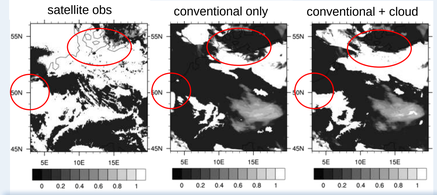
→ *After 20 hours of cycling the experiment with cloud assimilation has more of the observed stratus clouds and less "false alarm" clouds.*

III. Impact on forecast: 24 h forecast



Root mean square error and bias for relative humidity at the observed clout top level for. an experiment with only conventional observations (blue) and an experiment with cloud assimilation in addition (red) for a 24h forecast.

→ *Relative humidity errors at observed cloud level are lower throughout a 24 hour forecast if cloud information has been assimilated..*



→ *Still after 12 hours of forecast the experiment with cloud assimilation has more of the observed stratus clouds.*

Summary/Conclusion

- A new approach to assimilate cloud information (relative humidity at cloud top and cloud top itself for cloudy observations and cloud cover itself for cloudfree observations) derived from a satellite cloud top product with an ensemble Kalman filter for a numerical weather prediction model at the convective scale is presented.
- Results show an improvement in cloud characteristics in first experiments for low stratus clouds for the analysis. Relative humidity (and cloud cover) is increased at the observed cloud level, and cloud cover is reduced for cloud-free observations. The improvement is obtained despite non-Gaussian first guess distributions. Moreover due to background error correlations in the first guess ensemble a temperature inversion in the analysis, which is typical for the wintertime low stratus clouds. The impact lasts through a 24 hour forecast started after 21 hours of cycling.

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