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Testing data assimilation methods on convective-scale dynamics

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Goals

- Create a model hierarchy where the models are computationally cheap but represent some of the key features of convective-scale phenomena.
- Identify and assess promising data assimilation algorithms intended for this scale
- Use the results of toy model experiments to predict the behavior in full models

Models and experiments developed for testing the suitability:

- Stochastic cloud model
- Modified shallow water equations **(presented here)**
- Idealized NWP system experiments

Data assimilation algorithms tested:

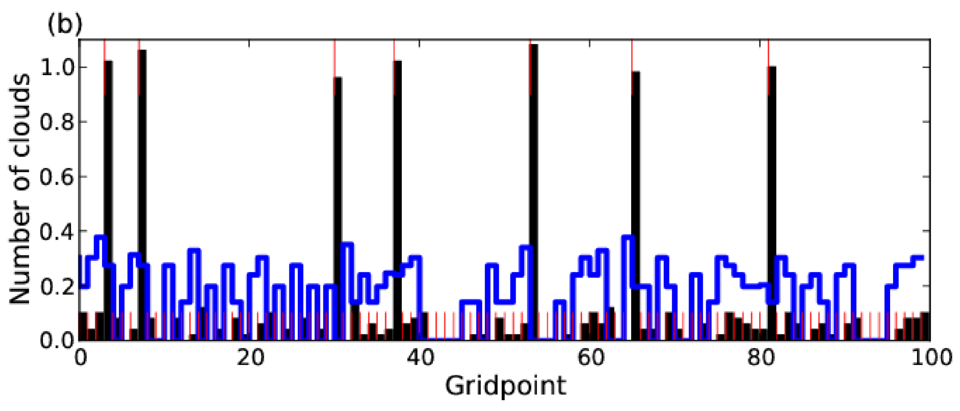
- Ensemble Transform Kalman Filter (ETKF)
- Particle Filter (Sequential Importance Resampling)
- Efficient particle filter (with nudging)

All methods with localization and observation averaging

Stochastic cloud model

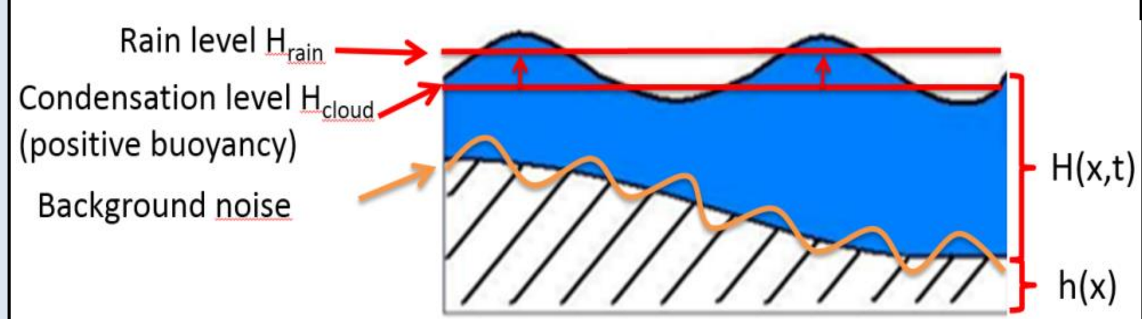
Non-Gaussianity
- Discrete number of clouds in each box
- Low density of clouds (e.g. 0.1)
- No spatial correlation between grid points

Nonlinearity
- Clouds appear and disappear randomly
- Poisson birth-death process with instantaneous birth/death
- Probability of death gives average lifetime



Assimilation with ETKF and ensemble size 50.
Red vertical lines are position of clouds.
- All clouds are assimilated correctly.
- Lots of spurious clouds in the ensemble mean.

Modified shallow water model



1D Shallow water model plus an additional equation for rain.
Velocity equation is modified to initiate formation of clouds.

Momentum equation:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+\frac{\partial(\phi+r)}{\partial x}=K\frac{\partial^2 u}{\partial x^2}+F,\quad \phi=\begin{cases}\phi_c+gH, & Z>H_c\\ g(H+h), & \text{otherwise}\end{cases}$$

Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}=K\frac{\partial^2 h}{\partial x^2},$$

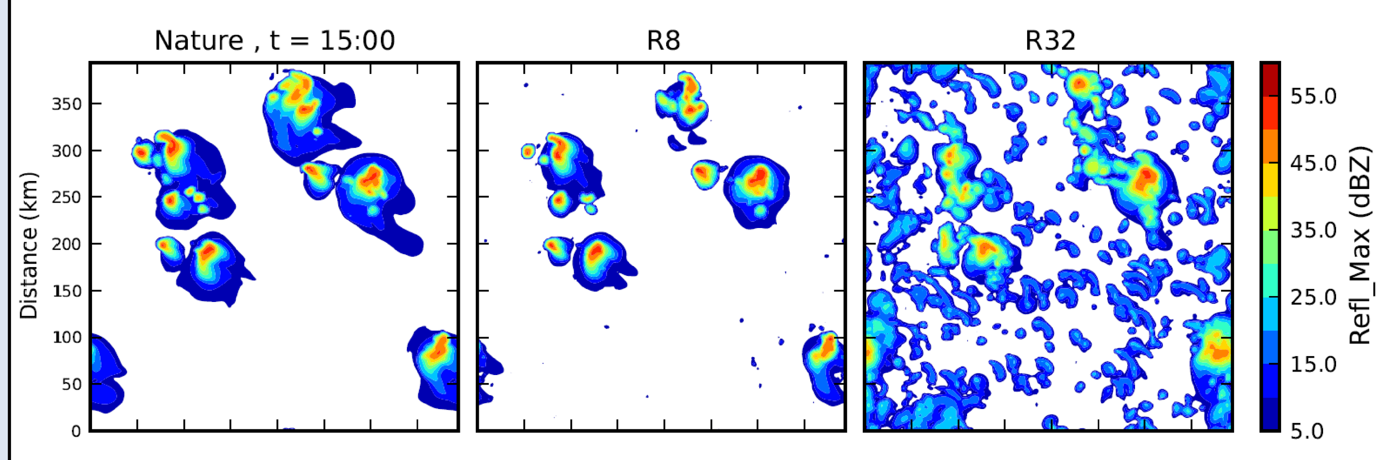
Rain equation with advection, production and removal of rain

$$\frac{\partial r}{\partial t}+u\frac{\partial r}{\partial x}=K_r\frac{\partial^2 r}{\partial x^2}-\alpha r-\begin{cases}\beta\frac{\partial u}{\partial x}, & Z>H_r \text{ and } \frac{\partial u}{\partial x}<0\\ 0, & \text{otherwise,}\end{cases}$$

Model settings:
Gravity wave speed = 30m/s, H_0=90m
dx=500m, dt=5s, domain=500km, H_c=90.04,H_r=90.4

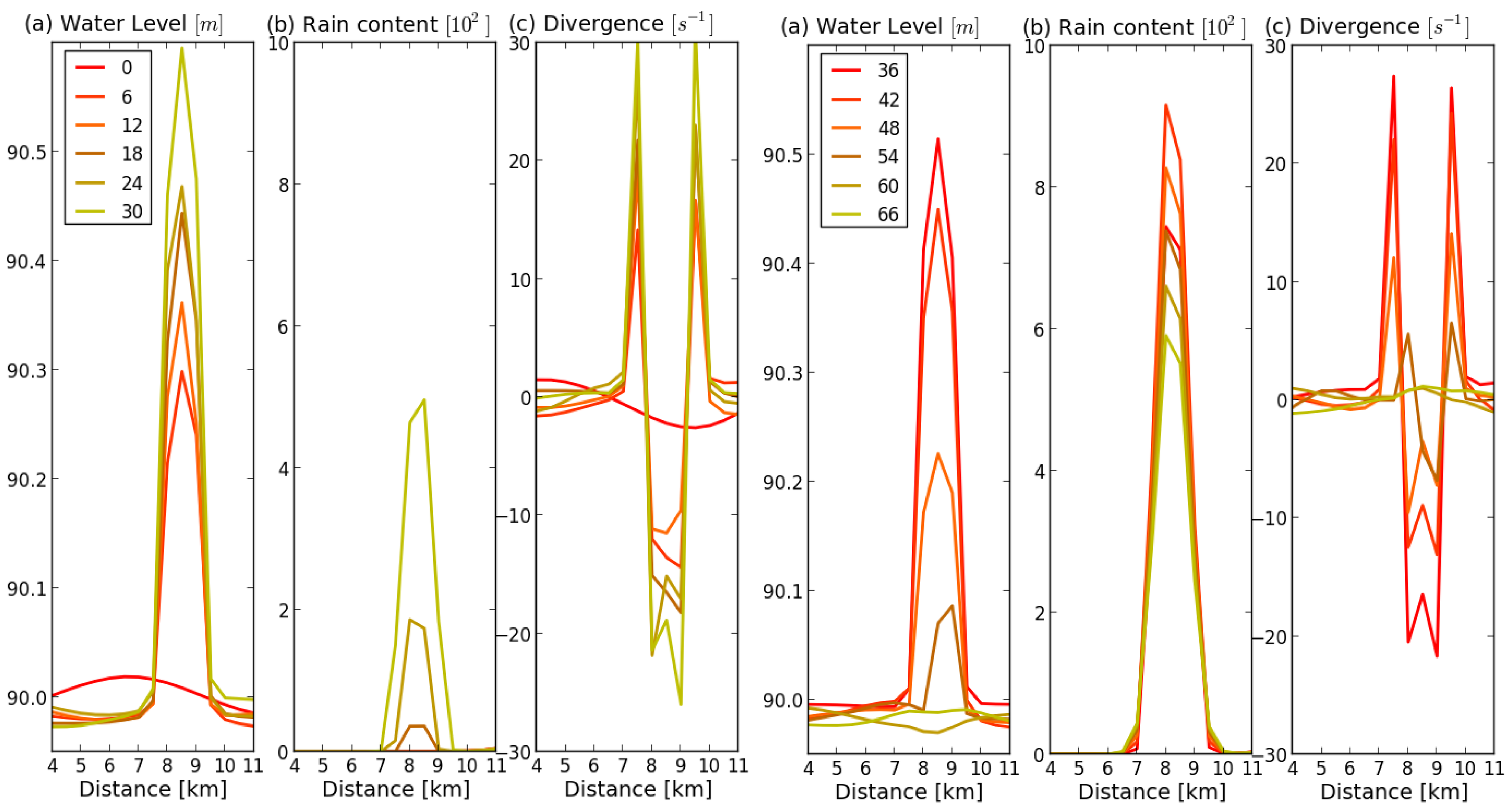
Idealized NWP System Experiments

COSMO
Non-hydrostatic, convection-permitting, NWP model
Domain: 396 x 396 x 20 km, cyclic boundary conditions
Resolution: 2 km horizontal, 50 vertical levels, 12 s time step
Initial sounding: 2200 J/kg CAPE, unidirectional shear
KENDA
50 members LETKF, initialized with random T and w perturbations. Assimilation every 5 min using Doppler winds, averaged to 4 (or 8) km.
Gaspari-Cohn localization radius of 16 (or 32) km.



Analysis after 1 hour of assimilation
- Short-lived clouds are not captured well.
- More spurious clouds in R32 experiment.
- After 3 hours of free forecast R8 and R32 give similar results.

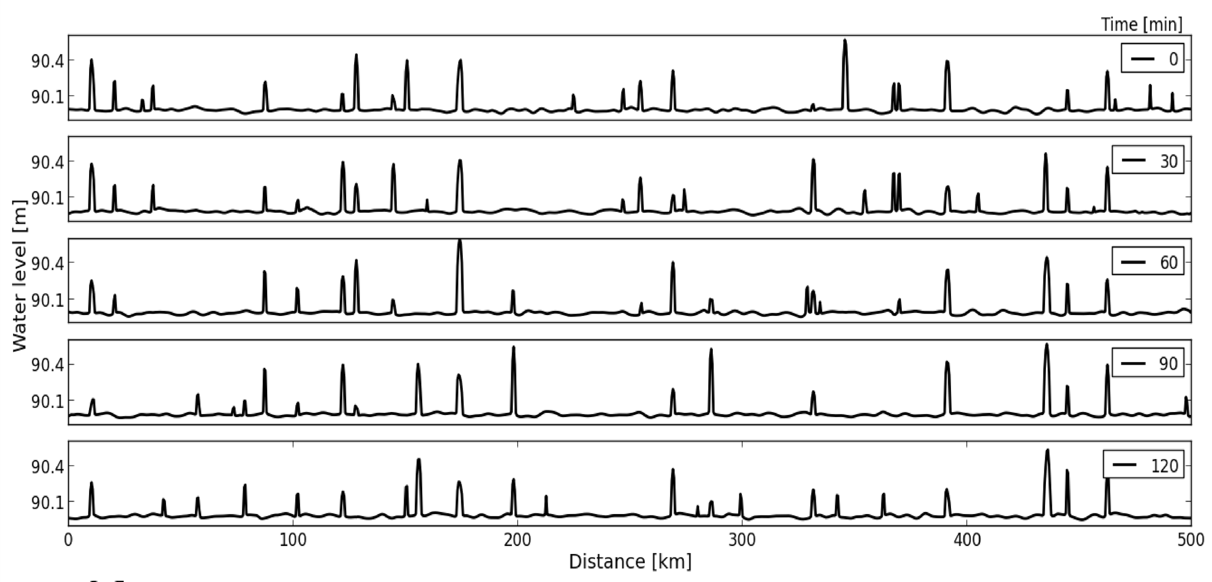
1. Life cycle of a convective cloud



Updraft (left) and downdraft (right) phase of a cloud. Different colors correspond to different times in minutes.

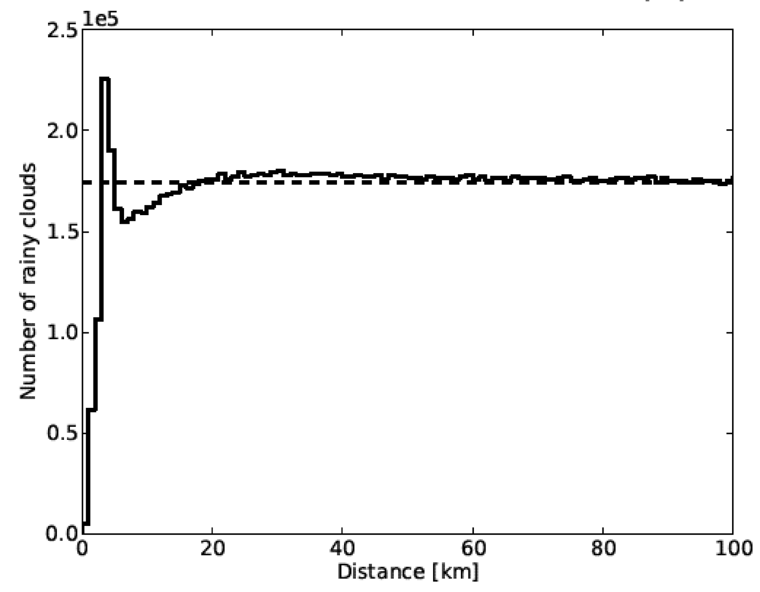
- When the water level reaches the cloud threshold, the updraft starts.
- At the water level of 90.4 rain starts to be produced.
- When rain reaches the maximum, the cloud is forced downward again.

2. Statistics of convection

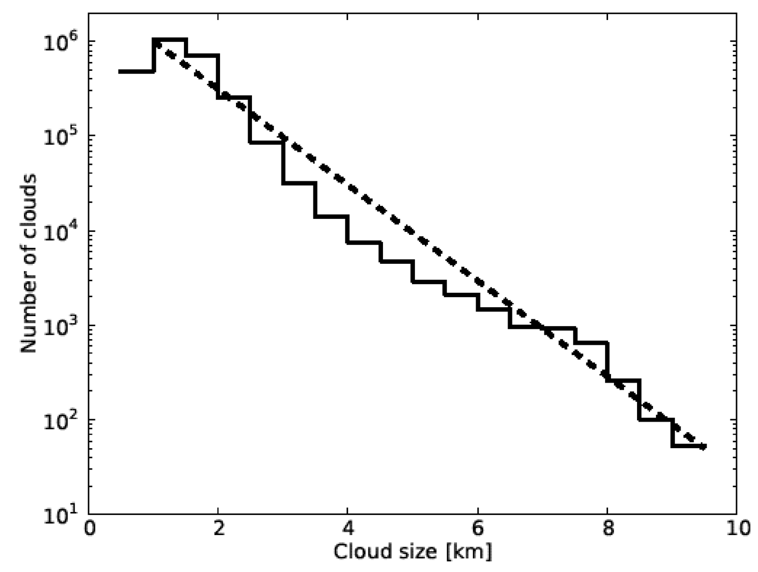


Water level at 30 minutes intervals:

- Typical evolution of the cloud field in the whole model domain.
- Wide range of different sized clouds.
- Diverse convective activity is present.

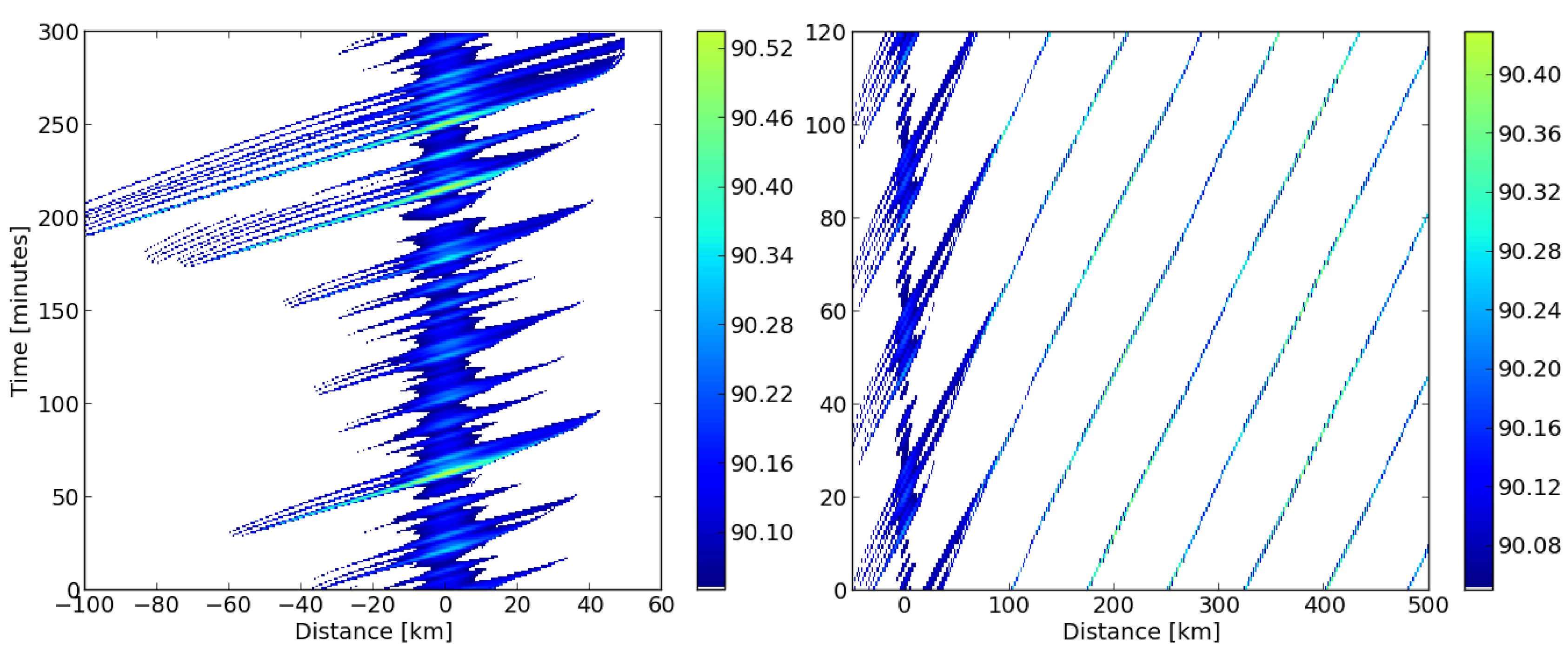


Distribution of the distance between different precipitating clouds.
- Maximum at 3.5 km, minimum around 7 km.
- Farther away, the distribution is random.



Logarithmic cloud size distribution for clouds with a height above 90.04.
- Average cloud size is 3.4 km.
- Mean number of clouds in domain is 14.9.
- Therefore 5% of the grid points are cloudy.

3. Orographically triggered convection



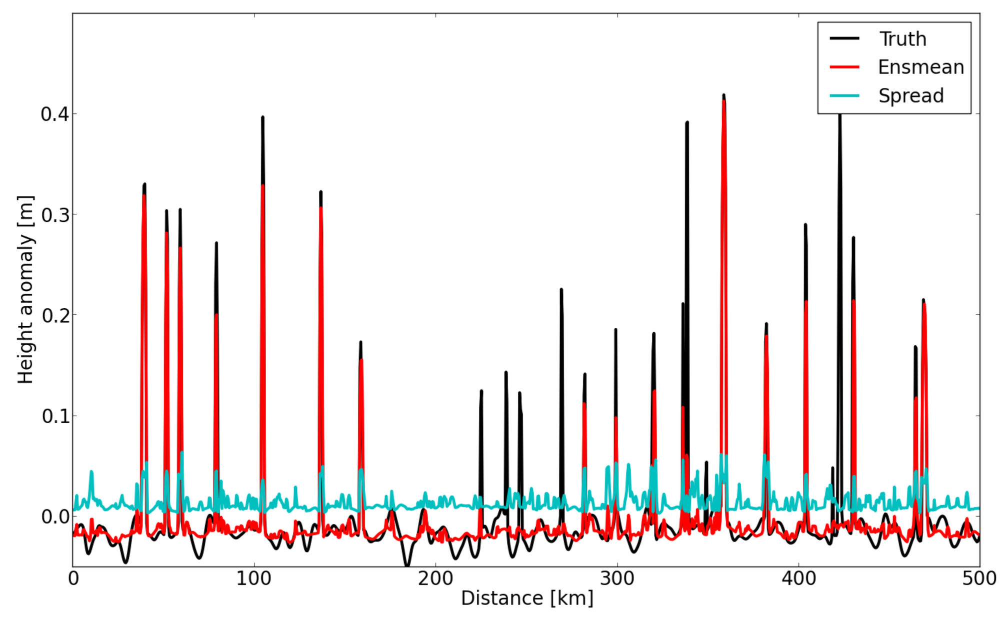
Hovmöller diagrams for a mean wind of 30 m/s (left) and 40 m/s (right)
A mountain with half-width 10 km and a height of 0.2 m is located at distance 0 km.

- In case of a weak mean wind, the clouds are not able to move past the orography
- In case of a stronger mean wind, a sequence of clouds is built and propagates downstream.
- Comparable to simulations of flow over a ridge (Chu and Lin, 2000)

4. Data assimilation

- Radar observations and radial wind as synthetic observations.
- More thorough analysis of different observation configurations ongoing.

Preliminary Results:
- A good fraction of clouds is assimilated when observing all grid points and using quite a small observation error.
- Fastest evolving clouds not captured.
- Ensemble is underdispersive.



Height analysis after 10 LETKF cycles with observations every 5 minutes and 20 ensembles.
All fields are observed at every grid point.

References

- Chu, C.-M. and Y.-L. Lin, 2000: Effects of Orography on the Generation and Propagation of Mesoscale Convective Systems in a Two-Dimensional Conditionally Unstable Flow. – J. Atmos. Sci. **57**, 3817-3837
- Craig, G. C. and Würsch, M, 2012: The impact of localization and observation averaging for convective-scale data assimilation in a simple stochastic model. Q.J.R. Meteorol. Soc.. doi: 10.1002/qj.1980
- Würsch, M. and Craig, G.C. A simple dynamical model of cumulus convection for data assimilation research. Meteorol. Z., in preparation.