Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

A Simple Dynamical Model of Cumulus Convection for Data Assimilation Research

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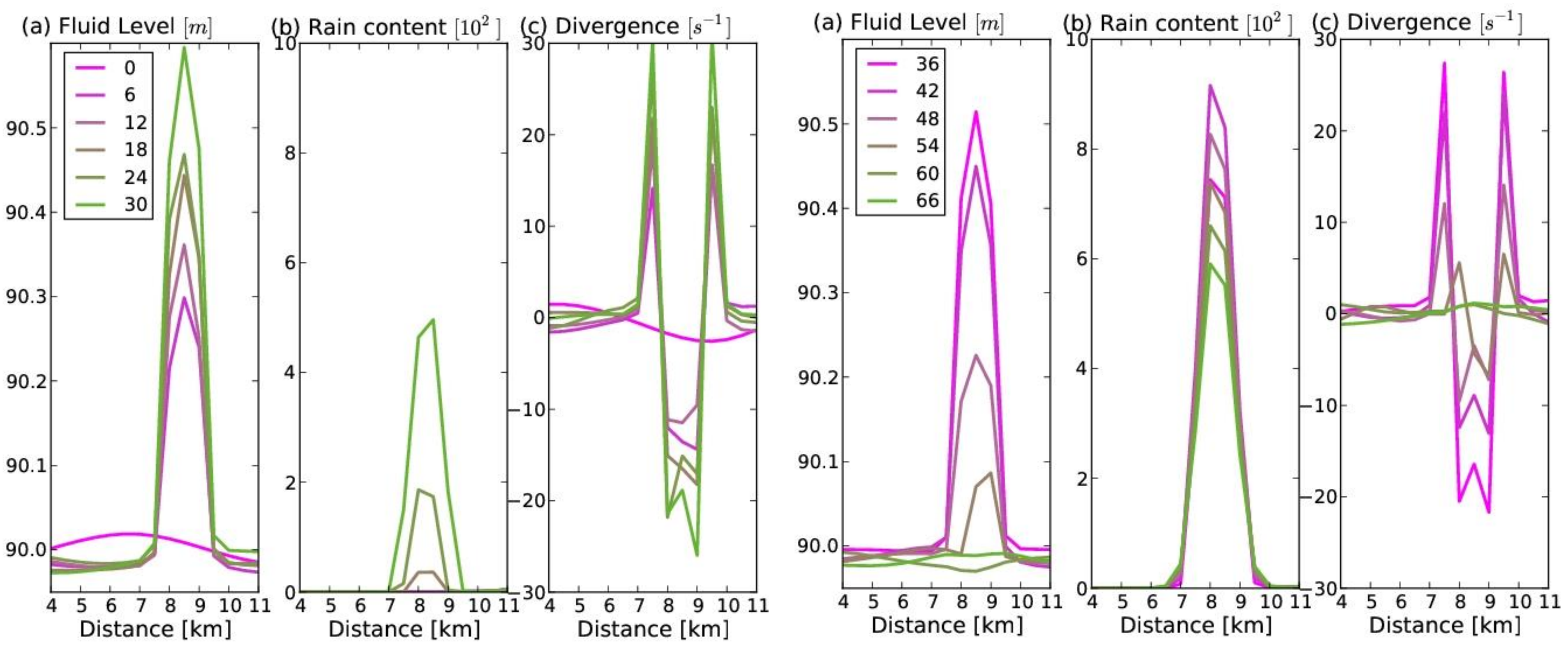
Goals

- Create an idealized model which captures the most important characteristics of convective –scale data assimilation
- Test different data assimilation methods and analysis resolutions to check whether a high-resolution analysis is really needed.
- Verify the ability of the model to be used as such a test model and whether the results can be compared to equivalent experiments in the COSMO-KENDA system.

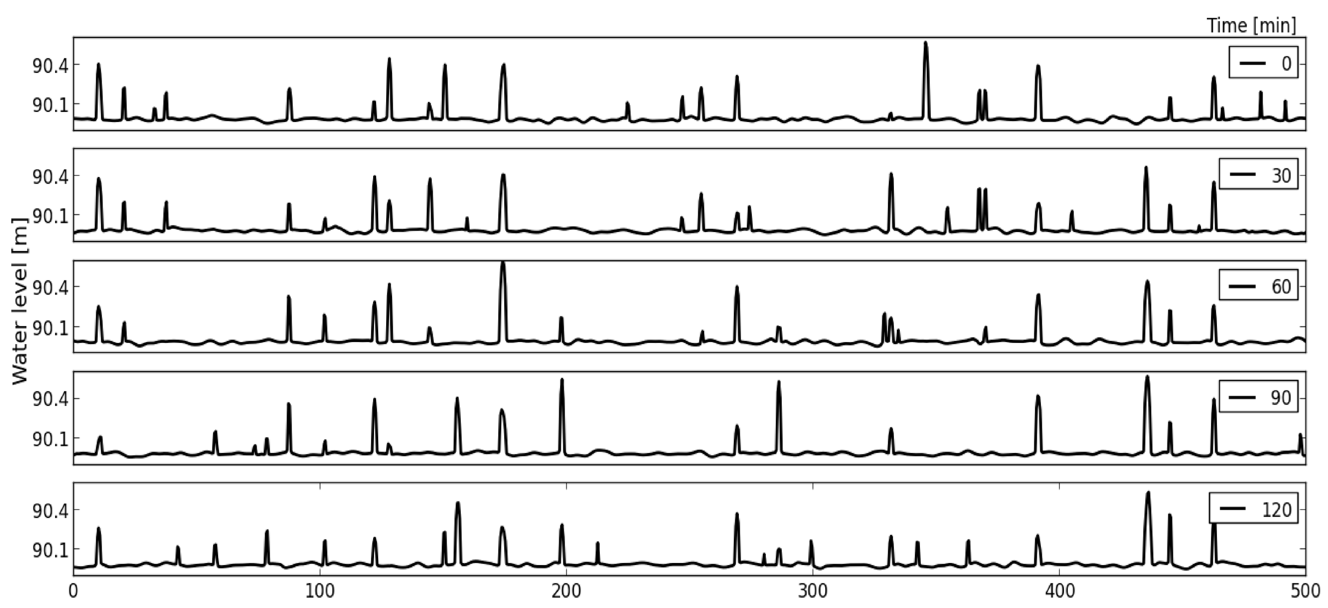
2. Life cycle of a convective cloud



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

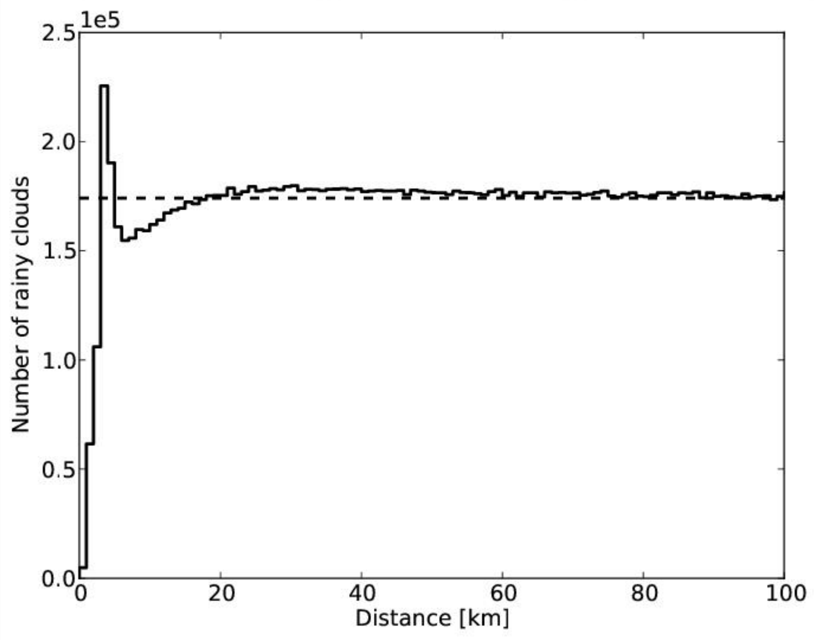
- When the water level reaches 90.04 m, a cloud is being built (upward forcing).
- At the water level of 90.4 m, rain is built and starts to push down the cloud.
- If there is enough rain accumulated, the cloud will be pushed down completely and disappears.

3. Statistics of convection



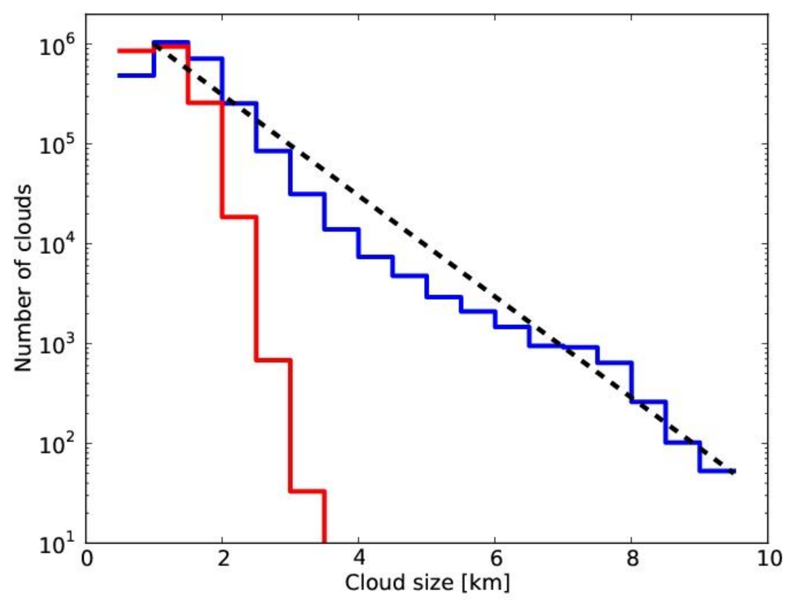
Water level at 30 minutes intervals:

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



Distribution of the distance between different precipitating clouds.

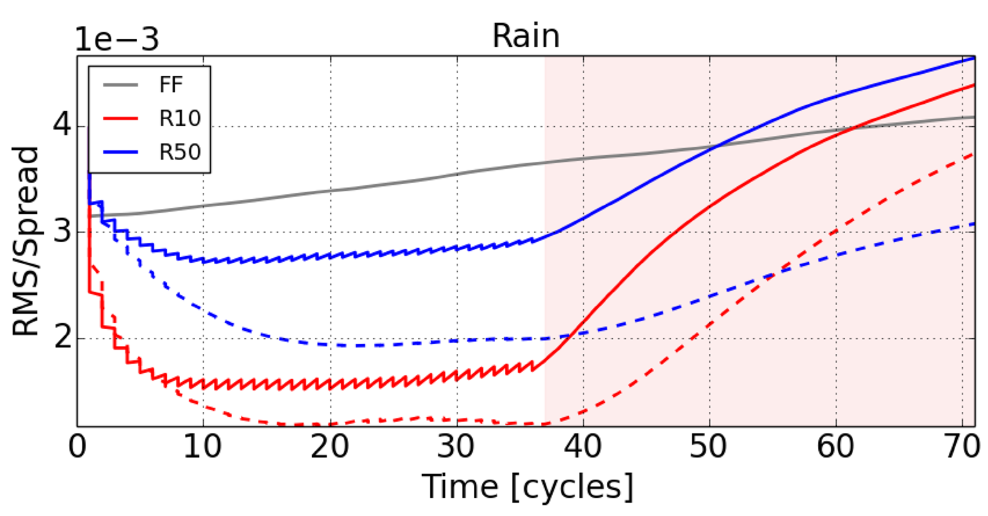
- Maximum at 3.5 km, minimum ~7 km.
- Then distribution approaches random.



*Logarithmic cloud size distribution for clouds with a height above 90.04 m (**blue**) and clouds without rain (**red**).*

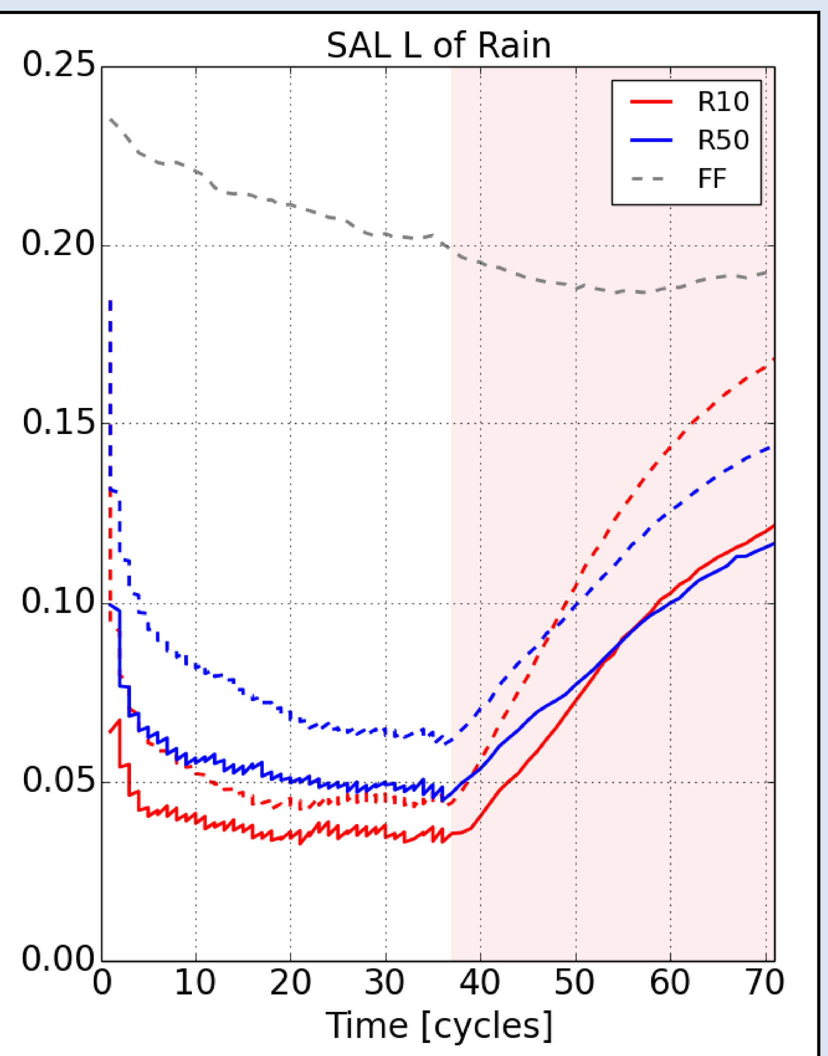
- Average cloud size is 3.4 km
- Mean number of clouds in the domain is 14.9
- Therefore 5% of the grid points are cloudy.

5. Data assimilation – error measures



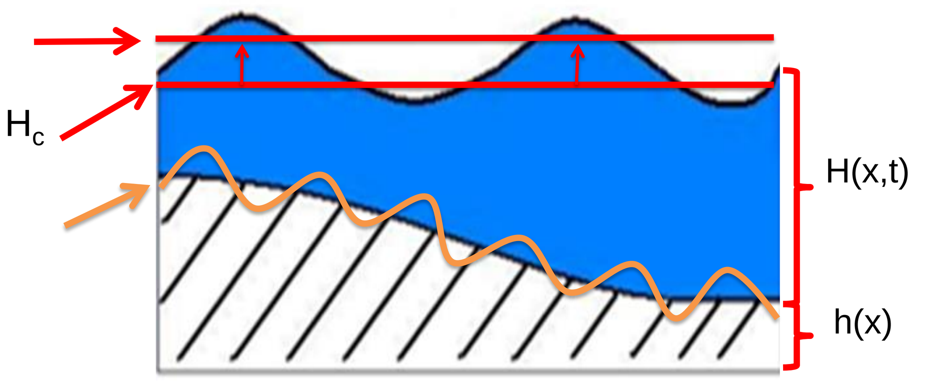
*RMS and spread of the rain field for **R10** and **R50***

- During the first assimilation cycles most of the improvement is achieved.
- Most of the rain regions are assimilated.
- R10 has a better analysis in both measures.
- R10 and R50 have a good positioning of the rain.
- During the free forecast the error increases quite fast, especially in R10.
- The advantage of R10 over R50 is gone within 10 to 20 minutes during the free forecast phase.



*Location-Score of rain for **R10** and **R50***

1. Modified shallow water model



One dimensional shallow water model plus an additional equation for rain. Momentum 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.

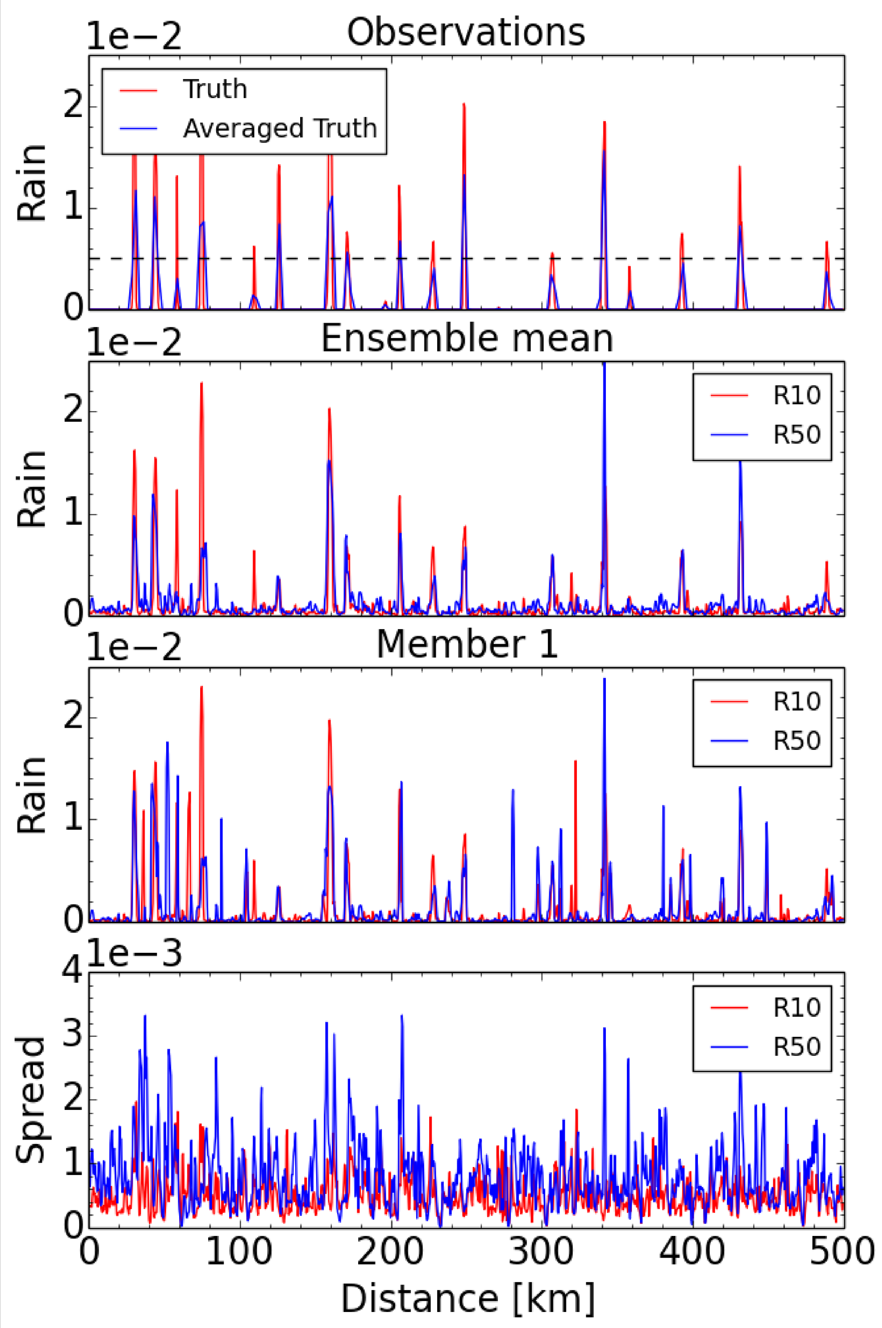
$$\frac{\partial r}{\partial t} + u\frac{\partial r}{\partial x} = K_r\frac{\partial^2 r}{\partial x^2} - \alpha r - \begin{cases} \beta\frac{\partial u}{\partial x}, & Z > H_r \text{ and } \frac{\partial u}{\partial x} < 0 \\ 0, & \text{otherwise,} \end{cases}$$

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

4. Data assimilation – Observation types and example run

- Rain, no-rain and radial wind are observed at every grid point.
- Strong forcing towards rain, 50 ensemble members in an LETKF.
- One run with a localization radius of 10 grid points (R10).
- Second run with superobservations averaged over 5 grid points (R50).
- Analysis every minute, 36' assimilation followed by 36' of free forecast.

Assimilated state after 36 cycles.



*Rain field in the **truth** and with **averaged observations***

- Superobservations have a smaller amplitude

*Analysis for **R10** and **R50***

- Most of the rain regions are captured
- Rain regions in R50 are a little bit broader

*Ensemble member 1 for **R10** and **R50***

- The ensemble member is quite similar to the ensemble mean, especially for R10.

*Spread for **R10** and **R50***

- The spread is quite small.
- R50 has a little more spread.

6. Summary

- The modified shallo water model produces clouds aind rain with a realistic life cycle and represents the key features of convection.
- Data assimilation with an LETKF is possible and leads to reasonable results.
- The fine resolved analysis leads to a smaller error. This advantage over the coarse resolution is only preserved for a limited amount of free forecast time.
- The coarse experiment still captures the rain regions well, only with more spread around the true location.
- The fine analysis produces unphysical fields and problems with mass conservation.
- The general behaviour shows many similarities to experiments obtained with an idealized COSMO-KENDA setup (Lange & Craig, 2013).
  Talk on Tuesday by H. Lange
- The model is a useful test model for convective-scale data assimilation.

References

- Craig, G. C. and Würsch, M. (2013), The impact of localization and observation averaging for convective-scale data assimilation in a simple stochastic model. Q.J.R. Meteorol. Soc., 139: 515–523.
- Lange, H. and Craig, G.C. On the Benefits of a High-Resolution Analysis for Convective Data Assimilation of Radar Observations using a Local Ensemble Kalman Filter. MWR (submitted)
- Würsch, M. and Craig, G.C. A simple dynamical model of cumulus convection for data assimilation research. Meteorol. Z., (submitted).