On the Benefits of a High-Resolution Analysis for Convective Data Assimilation of Radar Observations using a Local Ensemble Kalman Filter

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Limited predictability, scale-dependent

Obstacles of forecasts:

- Model error
- Initial value problem: Predictability limited by error growth in the chaotic atmospheric system
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Forecast window: 3 hours
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OSSE: Fine vs. Coarse Assimilation

Local analyses of storm systems using LETKF (Hunt et al., 2007)

- **Nature Run**: single cells of an elongated squall line
- **Fine Analysis R4**: single cells taken from best fitting member(s)
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- **Coarse Analysis R16**: coarse fit from coarsely fitting member(s)
COSMO model setup

- **Domain:** 198 x 198 x 50 gridpoints
  - periodic lateral boundaries conditions
- **Resolution:** 2 km horizontally
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**Initial state:** Horizontally homogenous sounding,
$\text{CAPE} = 2200 \frac{J}{kg}$,
random white noise on T (0.02 K) and W (0.02 m/s)
in the boundary layer
Nature Run and Ensemble

**COSMO model setup**

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- **Resolution**: 2 km horizontally
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  - random white noise on $T$ (0.02 K) and $W$ (0.02 $\frac{\text{m}}{\text{s}}$) in the boundary layer
- **Model**: Full COSMO physics with active radiation scheme
- **Forecast**: 8 hour spinup until convection evolves:
  - long-lived cells, lifetime $\geq 6 \text{ h}$
  - horizontal position *fully random* in ensemble
Fine vs. Coarse Assimilation

Assimilation setup

- 50 member ensemble (perfect model)
- simulated observations of radial wind and (no)-reflectivity
- analysis produced by LETKF (Hunt et al, 2007) in KENDA

\(^a\) Kilometre-scale ENsemble Data Assimilation, developed at DWD Offenbach (Hendrik Reich, Andreas Rhodin)
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- Fine assimilation scheme R4
- Coarse assimilation scheme R16

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Fine vs. Coarse Assimilation Scheme: Setup

**Fine Analysis Scheme (R4)**

- Convergence of analysis onto observed clouds
- Spurious clouds suppressed
- Small error and variance

**Coarse Analysis Scheme (R16)**
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**Coarse Analysis Scheme (R16)**
- Position of clouds roughly coincident with observations
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- Larger error and variance
Fine vs. Coarse Assimilation Scheme: Setup

**Fine Analysis Scheme (R4)**

1. 4 km Localization length
2. 2 km Observations
3. $R$-matrix:
   - $R_{\text{wind-obs}} = \left(5 \frac{\text{m}}{\text{s}}\right)^2$
   - $R_{\text{refl-obs}} = (20 \text{ dBZ})^2$
4. 5 min assimilation interval

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**Coarse Analysis Scheme (R16)**
1. 16 km Localization length
2. 8 km SuperObservations
3. Inflated \( R \)-matrix:
   - \( R_{\text{wind-SuperObs}} = (5\, \text{m/s})^2 \)
   - \( R_{\text{refl-SuperObs}} = (20 \, \text{dBZ})^2 \)
4. 20 min assimilation interval

- Position of clouds roughly coincident with observations
- Spurious clouds allowed
- Larger error and variance
Assimilation Results: Nature vs. Analysis Ensemble Means

- Nature Run 01, 14 UTC
- R4 Analysis EnsMean
- R16 Analysis EnsMean

- Reflectivity (dBZ)
- Temperature (T), z = 150m
- Vertical Wind (W), z = 3500m

Distance (km):
0 50 100 150 200 250 300 350

Reflectivity (dBZ):
0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0

Temperature (T), z = 150m:
288.0 289.0 290.0 291.0 292.0 293.0 294.0 295.0 296.0 297.0 298.0

Vertical Wind (W), z = 3500m:
-5.0 -2.4 0.2 2.8 5.4 8.0 10.6

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Fine vs. Coarse Storm Assimilation 7/14
Assimilation Results: Nature vs. Analysis Ensemble Means

Nature Run 01, 15 UTC
R4 Analysis EnsMean
R16 Analysis EnsMean

Distance (km)

Refl_Max (dBZ)

T (K), z = 150m

W (m/s), z = 3500m

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Assimilation Results: Nature vs. Analysis Ensemble Means

Nature Run 01, 16 UTC
R4 Analysis EnsMean
R16 Analysis EnsMean

- Distance (km)
- Refl Max (dBZ)

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- Refl Max (dBZ)
- T (K), z = 150m
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Analysis Members R4

Fine Analysis R4, Realization 01, t = 17 UTC

Nature Run
Member 001
Member 013
Member 025
Member 037
Member 050

Distance (km)

Nature Run Member 001 Member 013
150 200 250 300

Distance (km)

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Fine vs. Coarse Storm Assimilation
Analysis Members R16

Coarse Analysis R16, Realization 01, t = 17 UTC

Nature Run  
Member 001  
Member 013

Member 025  
Member 037  
Member 050

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Fine vs. Coarse Storm Assimilation
Analysis Ensemble Distributions

Ensemble distribution where $\text{Refl}_{\text{nature}} = 40 \pm 0.5 \text{ dBZ}$

- **R4**
- **R16**
RMSE-Statistics: U, W

U - wind

W - wind

- **Red**: RMSE of Ensemble Mean
- **Blue**: RMSE of Ensemble Mean
- **Dash**: RMSE of Free-Ensemble Mean
- **Red dashed**: Spread of Ensemble
- **Blue dashed**: Spread of Ensemble
- **Dash**: Spread of Free-Ensemble
Forecast Results: Nature vs. Forecast Ensemble Means

Nature Run 01, 20 UTC
R4 Forecast EnsMean
R16 Forecast EnsMean

Distance (km)
Distance (km)
Distance (km)

Refl_Max (dBZ)

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Displacement of forecast field with respect to observations, measured by the amplitude of the morphing vector field:

![DAS-DIS Displacement Score](image_url)

**DAS-DIS of Refl_Max (Mean Score of Ensemble Members)**

- **R4**
- **R16**

Hours: 0.00, 0.05, 0.10, 0.15, 0.20, 0.25

DIS: 0.00, 0.05, 0.10, 0.15, 0.20
Methods:

- Successful assimilation of long-lived convection by LETKF using only radar observations of radial wind and reflectivity.
- 3 hours of cycled assimilation followed by 3-h forecast.
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Fine scheme R4
- precise fit onto observed clouds
- low analysis errors and spread
- skillful 3-h ensemble forecasts
Summary

Methods:
- Successful assimilation of long-lived convection by LETKF using only radar observations of radial wind and reflectivity
- 3 hours of cycled assimilation followed by 3-h forecast

Fine scheme R4
- precise fit onto observed clouds
- low analysis errors and spread
- skillful 3-h ensemble forecasts

Coarse scheme R16
- initializes equally good 3-h forecasts
- needs much less computational power
Conclusions

- less overfitting in coarse scheme
- coarse analysis possibly closer to model climatology
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Outlook

- radar assimilation schemes in KENDA of COSMO-DE and COSMO-MUC
- predictability horizons of convection in real-world model
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References

Hunt et al 2007
Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter

H. Lange and G.C. Craig 2013
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*Monthly Weather Review*, submitted
Rigorous Convergence vs. Relaxation

(a) $\sigma_o = 5$ dBZ

(b) $\sigma_o = 20$ dBZ