Direct assimilation of 3D radar reflectivities with an ensemble-based data assimilation system

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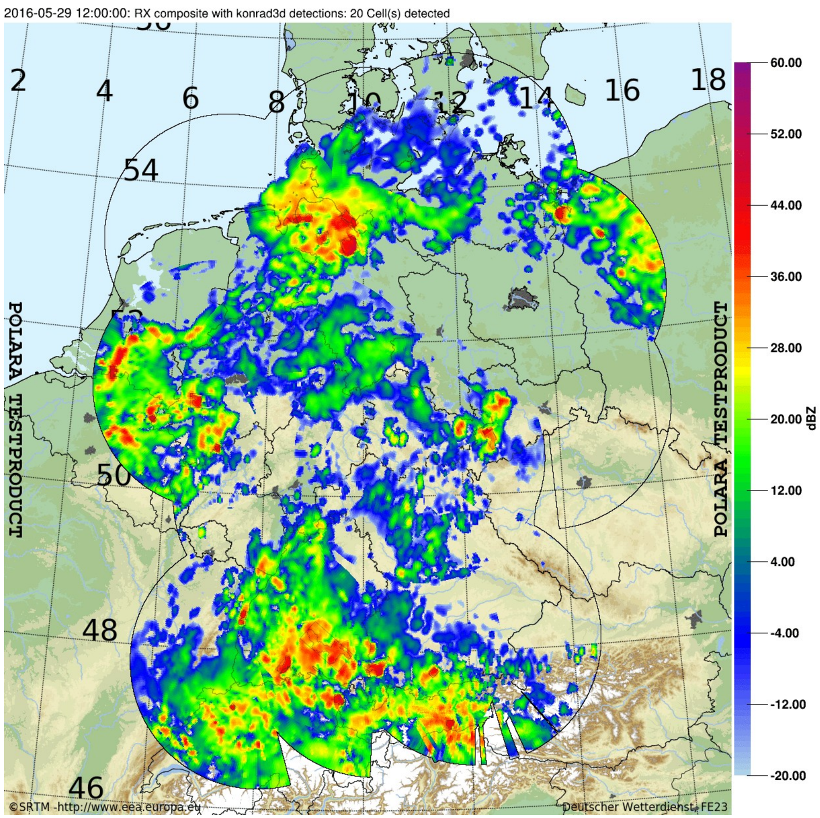
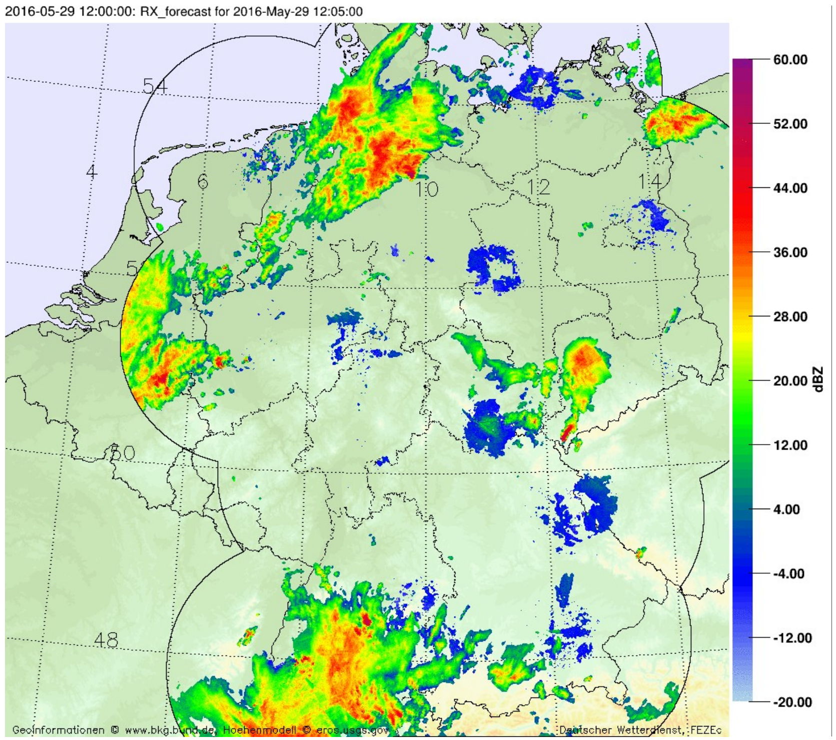
with help from Elisabeth Bauernschubert, Hendrik Reich, Christian Welzbacher, Andreas Rhodin, Markus Junk and many others.

COSMO NWP Model



- It is constructed from physical principles.
- It is started from initial conditions that are constructed with data assimilation techniques. Some spin-up is expected at the beginning (adaptation to a physical consistent state).
- It takes 1.5 hours to produce the first prediction. Reliable for the short to mid range prediction (1.5-24h).

Nowcasting



- It is constructed from interpolation of the Radar fields.
- It is usually better than NWP for the very short term leading times (up to 3 hours).
- It takes only 5 minutes to produce the first prediction.

The SINFONY Project

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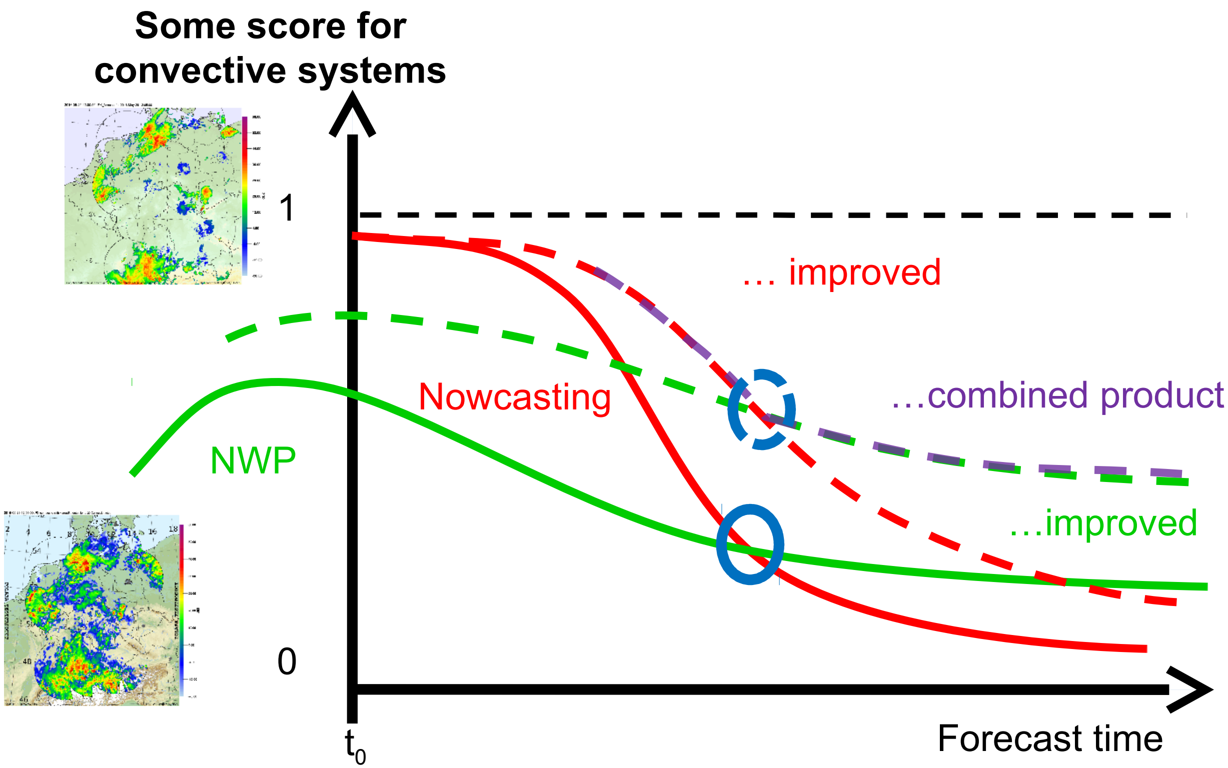

Picture from U. Blahak

- In order to create a product that combines Nowcasting and NWP product, we need to bring NWP closer to the radar observations, specially at the analysis time t_0
- At the same time we cannot degrade the quality of the NWP

Direct Assimilation of Reflectivities

- The assimilation of radar reflectivities in COSMO is performed via Latent Heat Nudging (LHN).

- LHN heats/cools the atmosphere based on the comparison of model precipitation and the radar-precipitation scan.

- The LETKF assimilation system COSMO-KENDA can **directly** assimilate 3D radar scans. COSMO-KENDA is currently used in DWD to assimilate all other observation systems.

- The LETKF corrects the hydrometeors specific densities based on reflectivity measurements. It has thus the potential to produce a more realistic reflectivity picture at analysis time, which could help for the seamless transition between Nowcasting and NWP.

Our tool: Basic Cycle (BACY)

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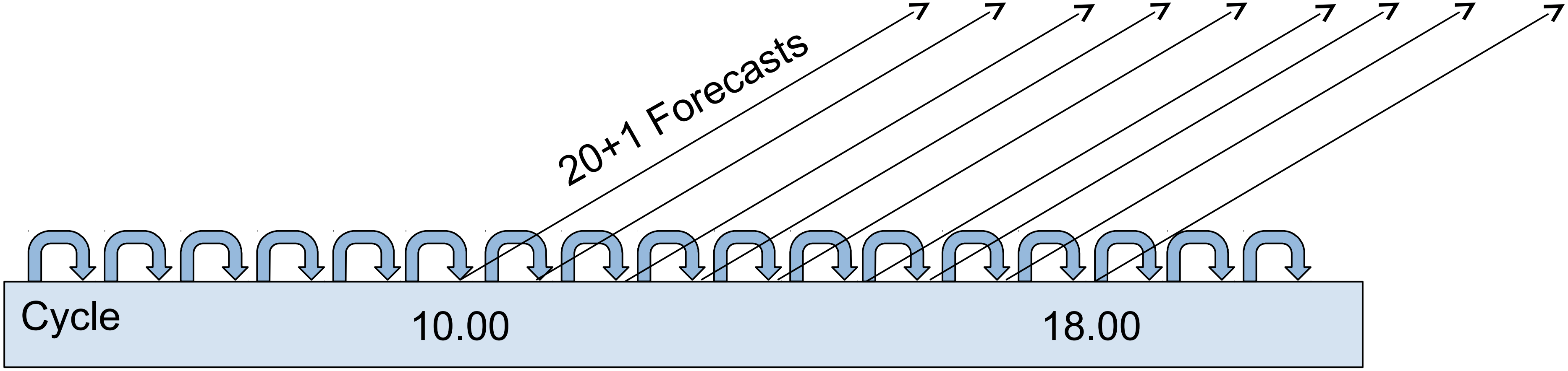
- 1h Cycle with hourly forecast during the convective period (10 -18). The forecasts run for 6 hours.
- COSMO-DE setup (2.8km) with version 5.4h.
- Assimilation with 40 ensemble members. Forecasts with 20 ensemble members.
- Simulations from 27.05.2016 until 02.06.2016 (7 days): In total 1323 forecasts (not independent)
- We evaluate the data during the experiment. No need to save huge amount of data.



What we have learned

- ➔ Spatial Averaging: we use “superobbed” data with a spatial resolution of 10 km.
- ➔ Temporal Thinning: we assimilate only the radar scan measured at the analysis time (every hour). All other radar scans (every 5 minuets) are not used.
- ➔ Ensemble inflation: in our setup relaxation to prior spread (RTPS) is better than relaxation to prior perturbation (RTPP).
- ➔ Observation error estimated with DeRozier statistics.

Scores based on reflectivities

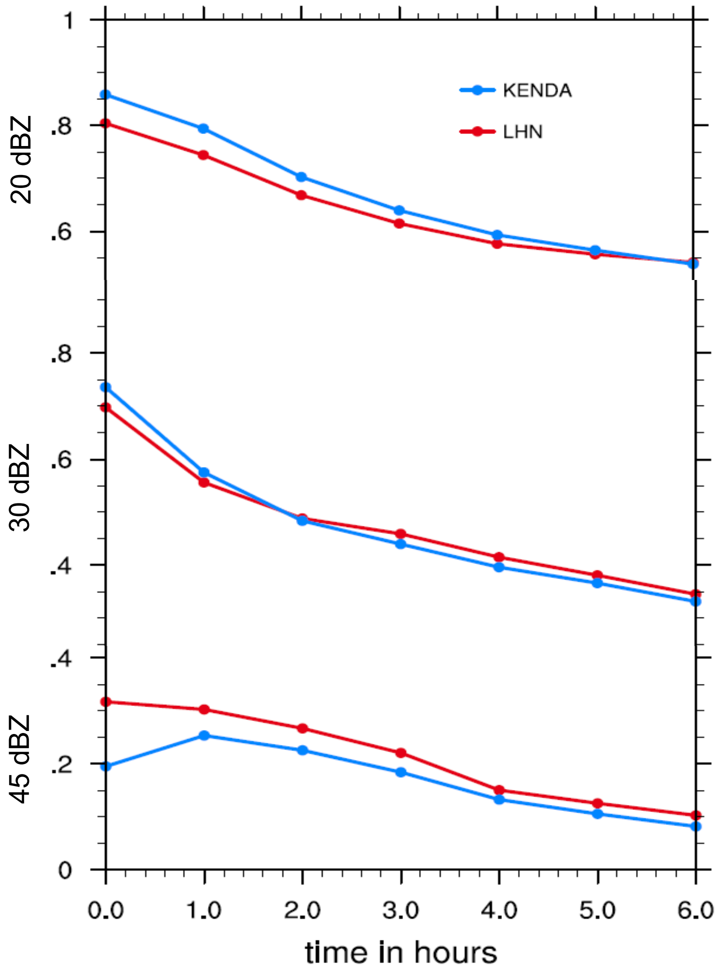
- ➔ We use scores based on Radar composites. Improving score based on reflectivities can help to bridge the gap between Nowcasting and NWP.

- ➔ The Fraction Skill Score (**FSS**) assess, the skill of predicting convection at **a spatial scale (**here 30 km) for a given threshold (Roberts & Lean, 2008)

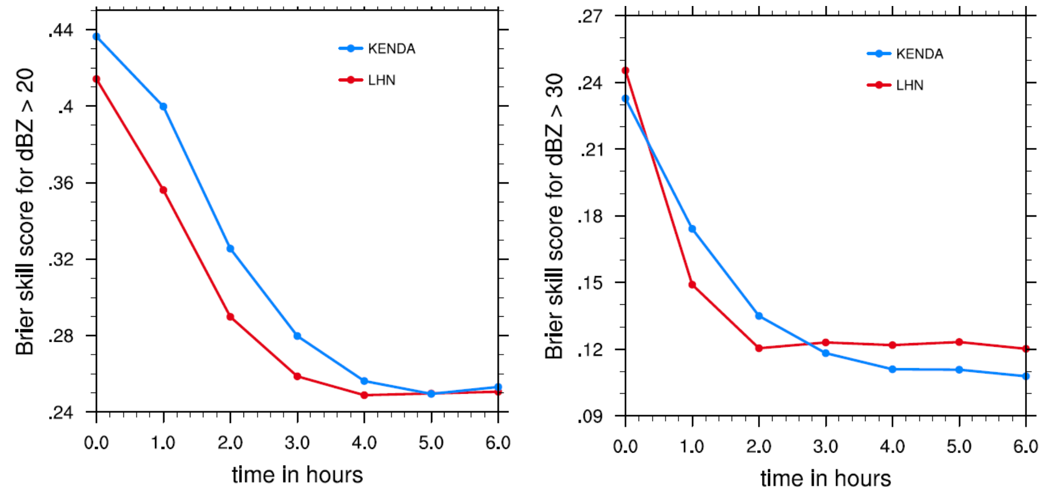
- ➔ The **Brier Score** measures the accuracy of the probability prediction of an **ensemble** for a given threshold. Not very reliable for rare events (very high reflectivities).

COSMO-KENDA vs LHN (Reflect verif.)

FSS (deterministic)



Brier skill score (ensemble)



➔ KENDA shows a small advantage in the first two-three forecast hours.

➔ Higher reflectivities seem to be better captured by LHN. Specially strong thresholds over 45 dBZ are much better.

COSMO-KENDA vs LHN (Reflect verif.)

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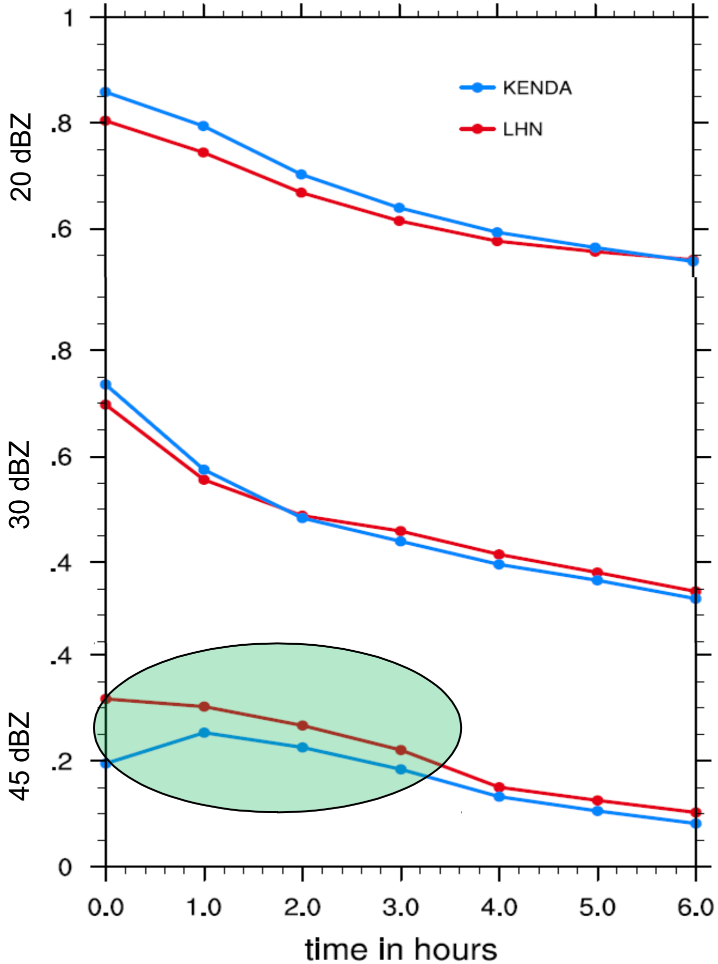
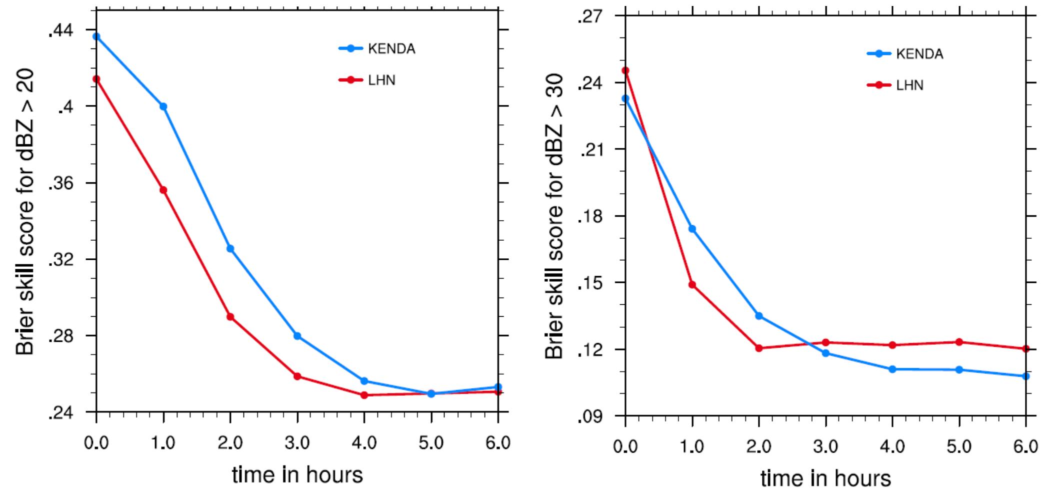


Brier skill score (ensemble)



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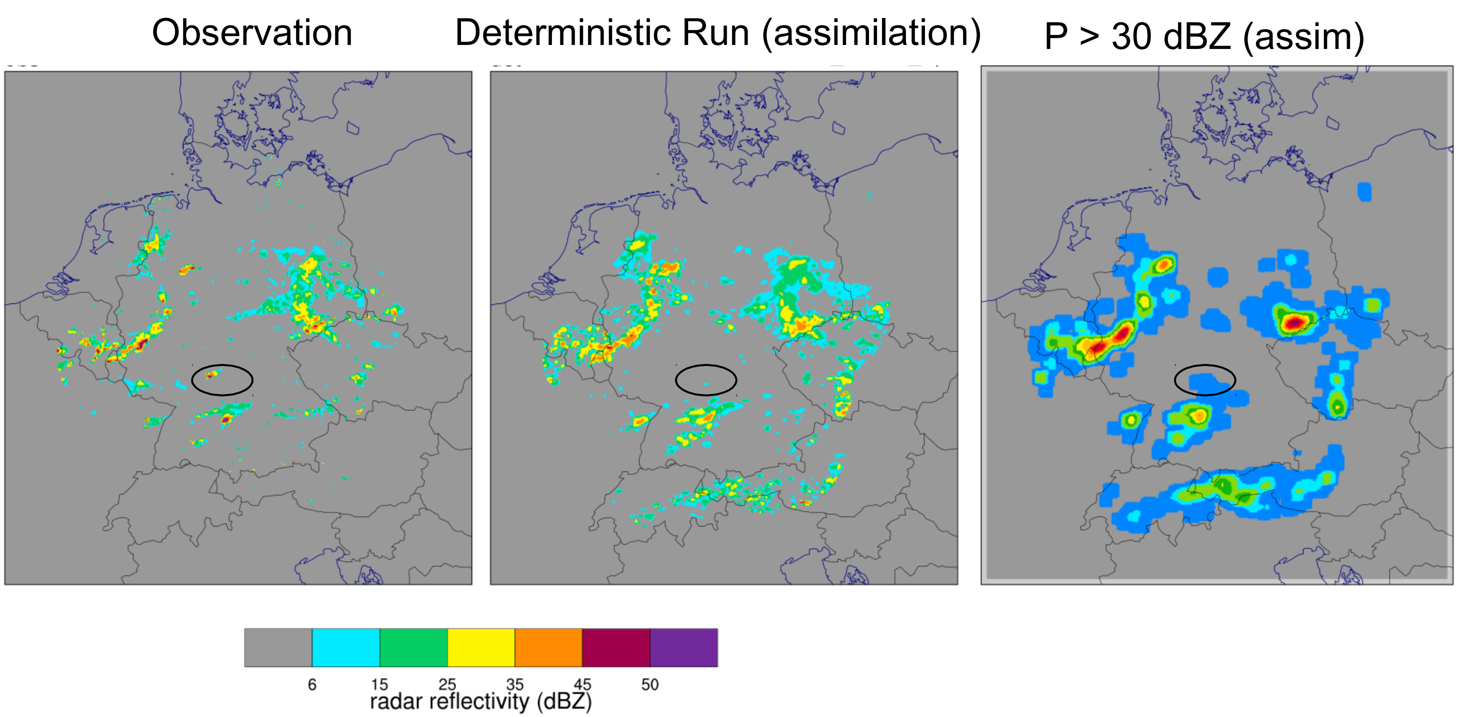
➔ Higher reflectivities seem to be better captured by LHN. Specially strong thresholds over 45 dBZ are much better.

However, some convective cells are not met by any ensemble member,

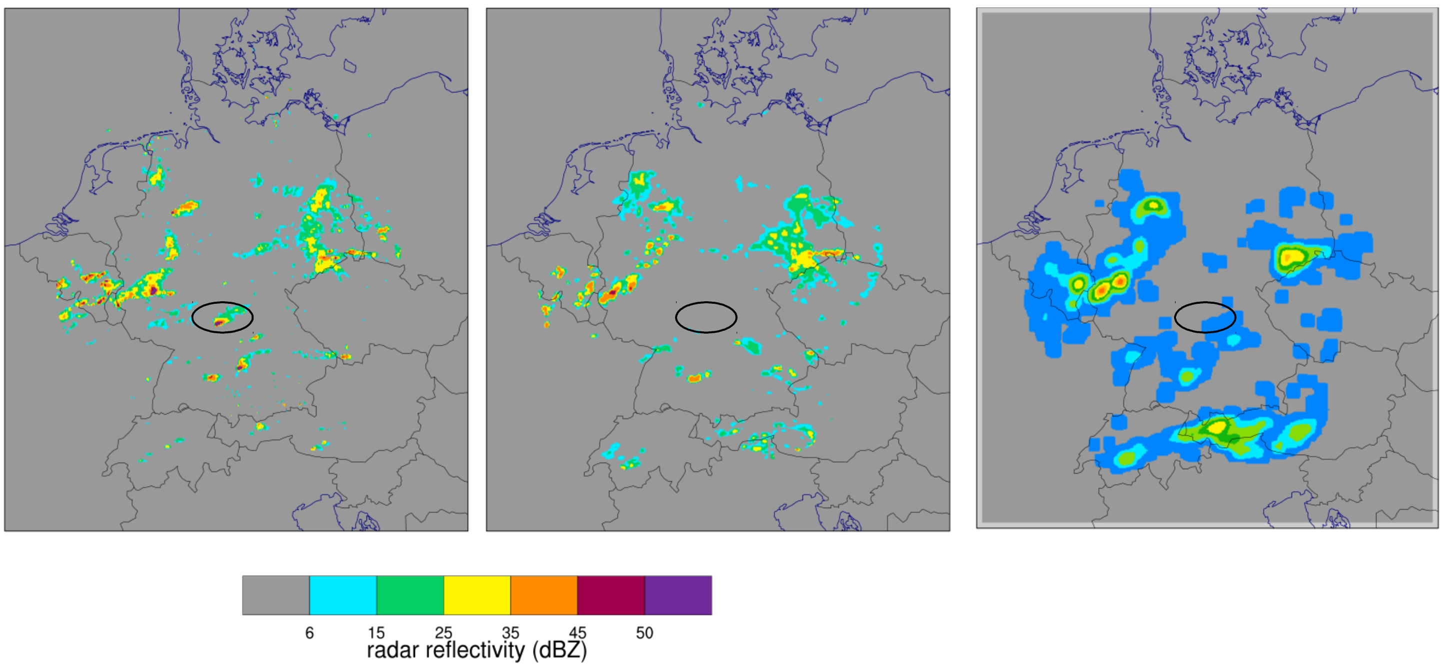
➔ The LETKF cannot build a convective cell, if this is missing in all members. This is a disadvantage of LETKF over Latent Heat Nudging.



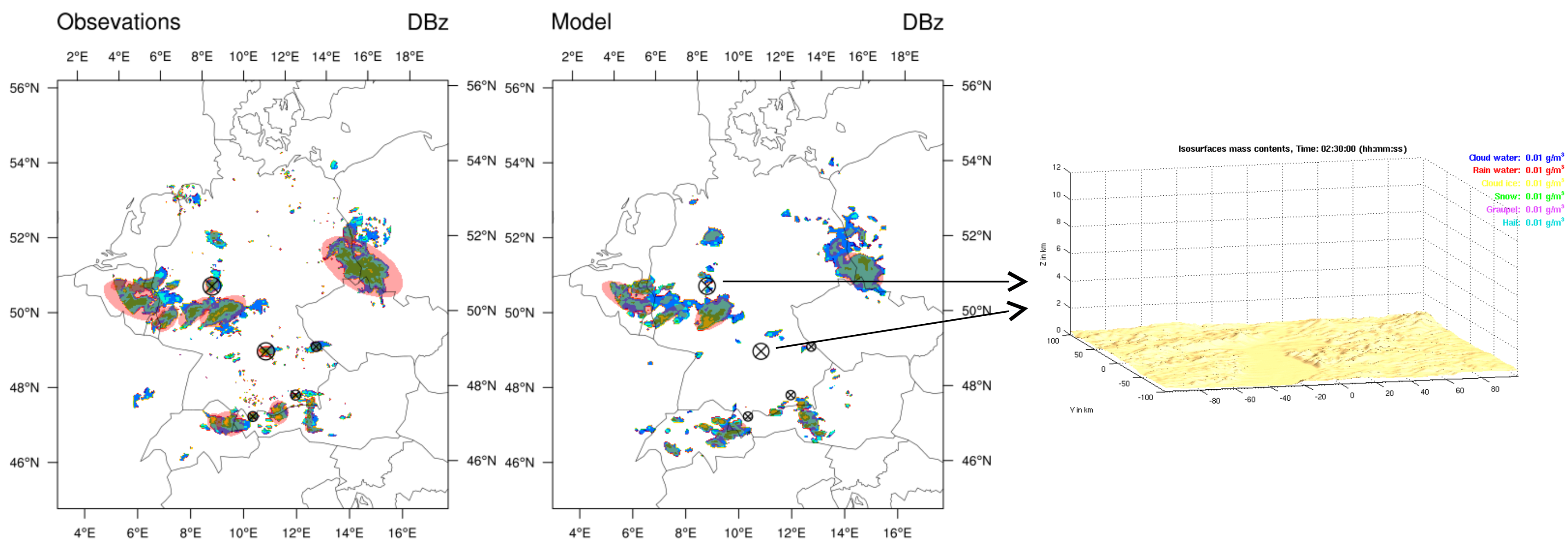
, which might lead to missing severe storms

- Due to a small number of members (N=40 in this case), assimilating some storms becomes random.

Observation | Deterministic Run (1h forecast) | P > 30 dBZ (1h forecast)

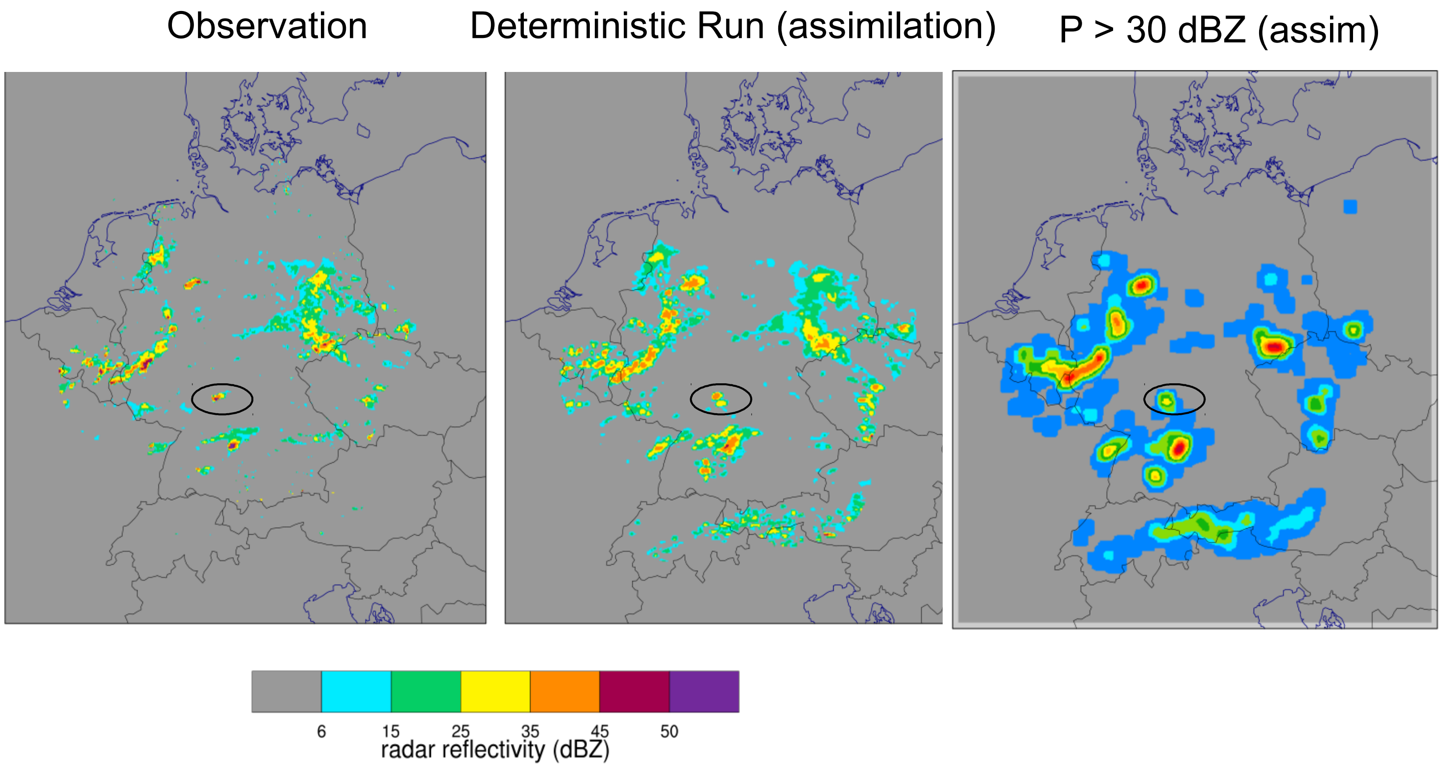


Automatic Bubbles



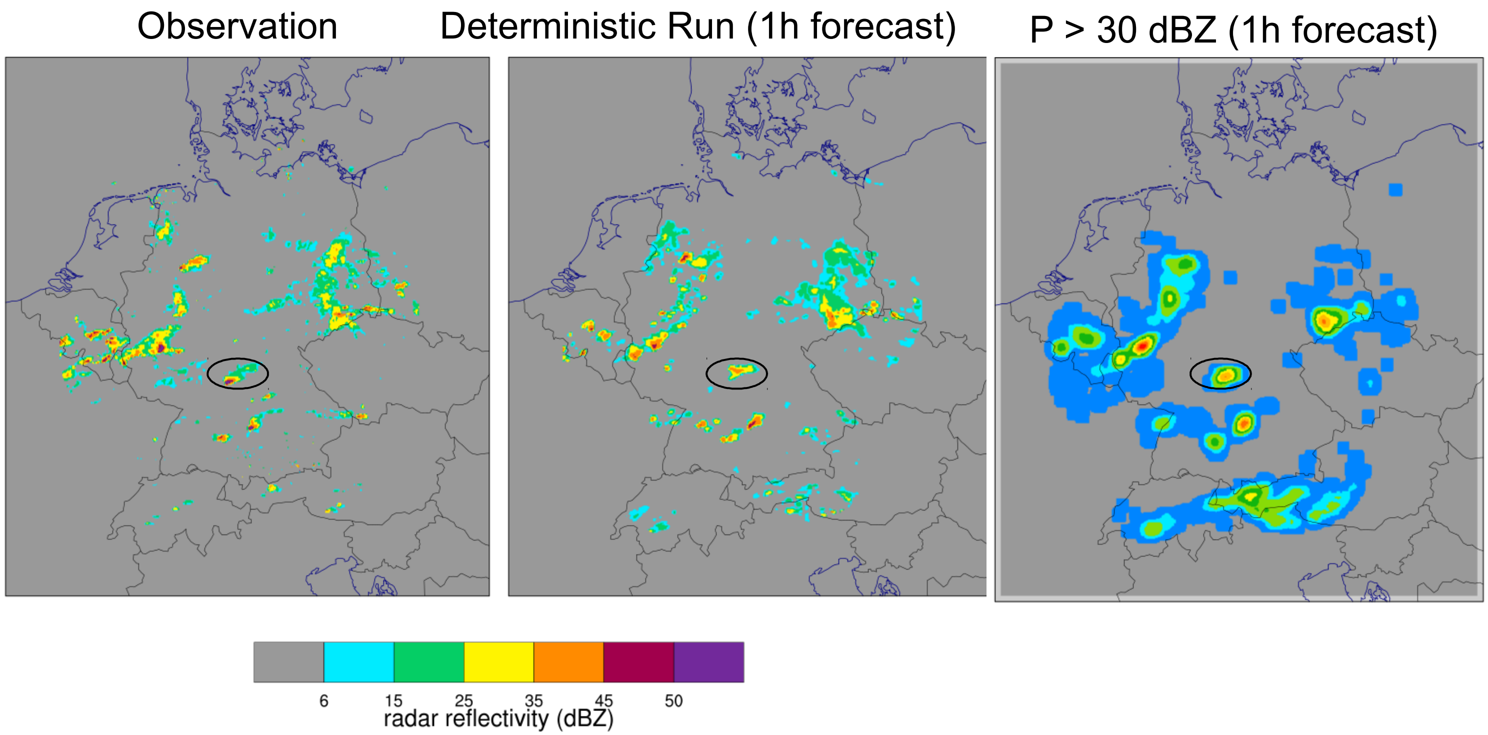
- We trigger warm bubbles in regions where the radar composite shows a convective cell, but there is none in the model. We check every 15 minutes.
- Bubbles warm a region ~10x10kmx2km with averaged heating rate ~0.001 K/s, during 15 minutes.
- This is not latent-heat nudging. Once the bubble is triggered, the convective cell is free to evolve depending on the local meteorological conditions. Some bubbles do not develop into a convective cell.

The algorithm triggers a small convective cell,

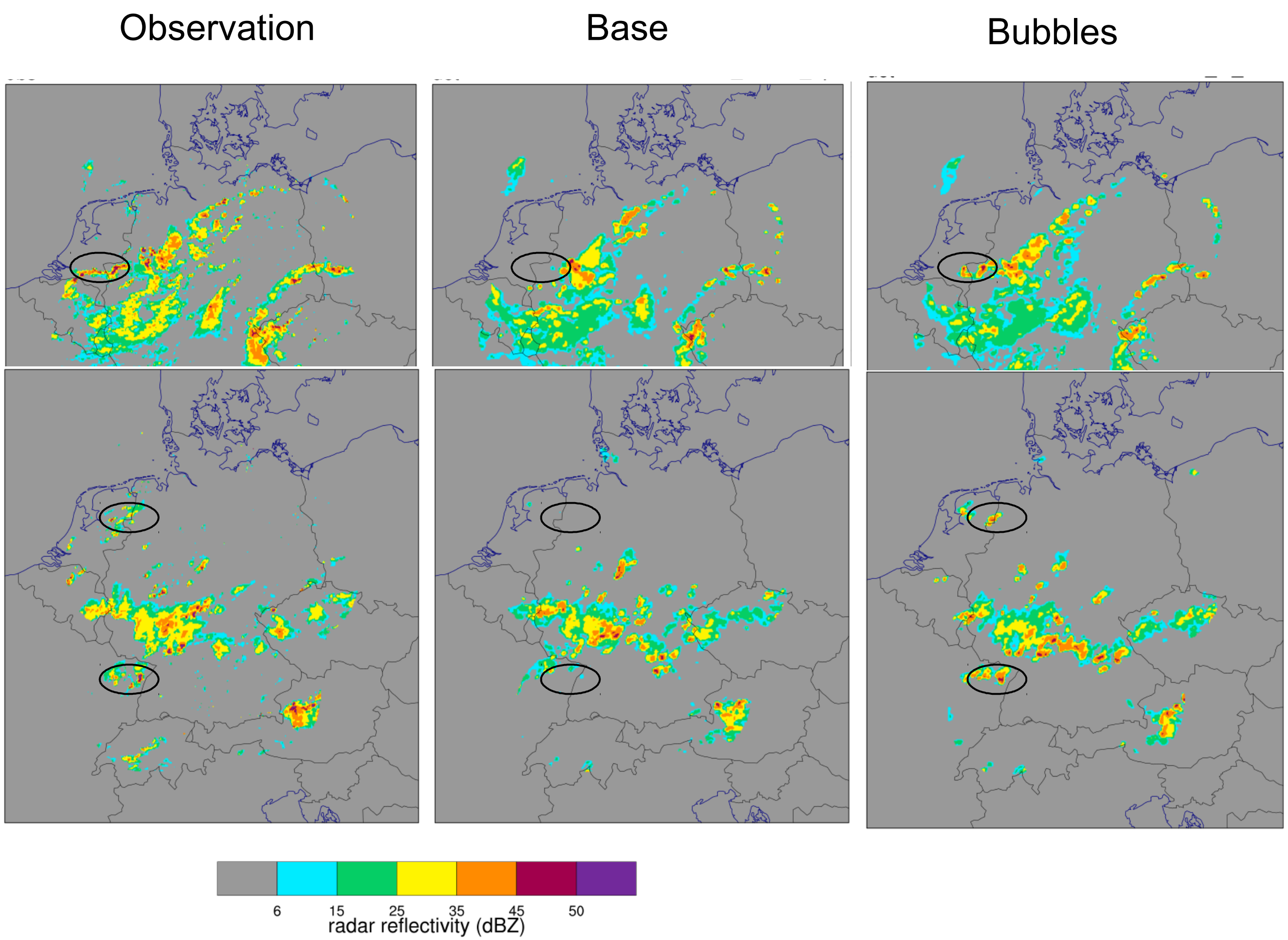


which develops into a larger cell

➔ The cell develop stronger in some members, as shown that not all members achieve more than 30 dBZ



Other examples (1h forecast)



KENDA vs LHN (Reflect verification)

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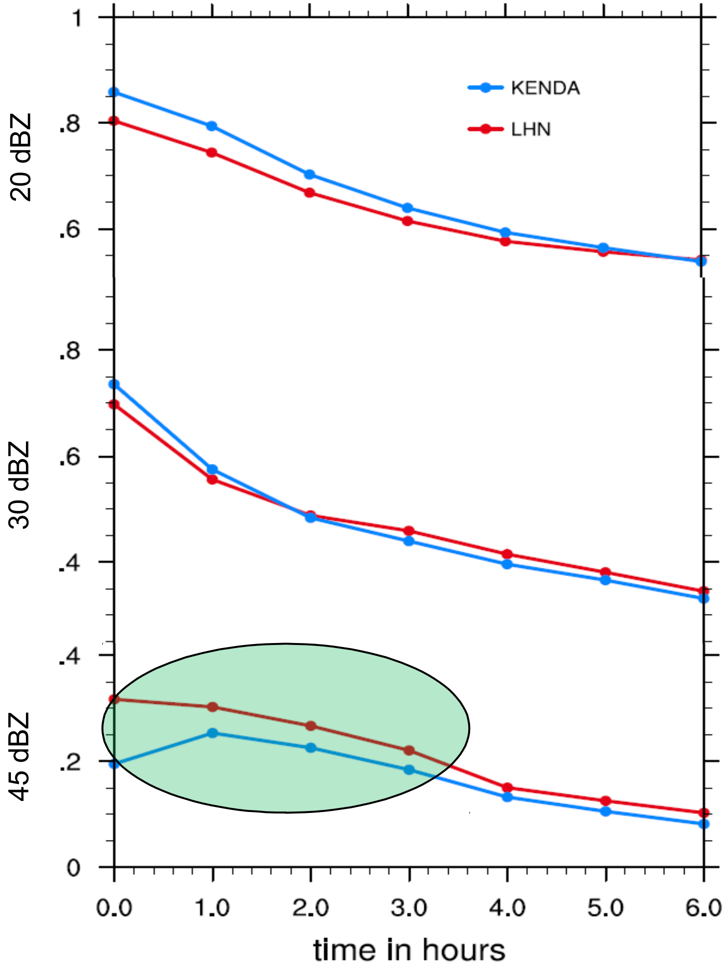
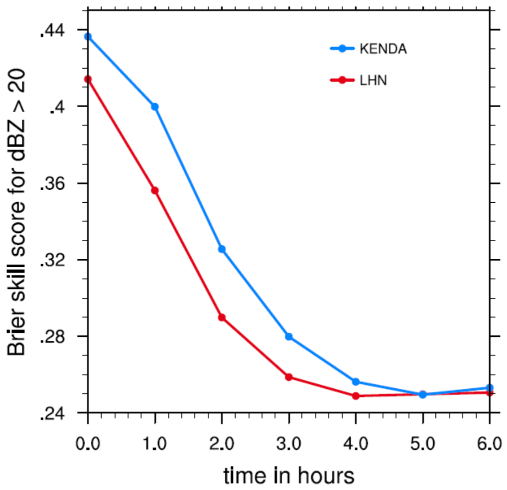
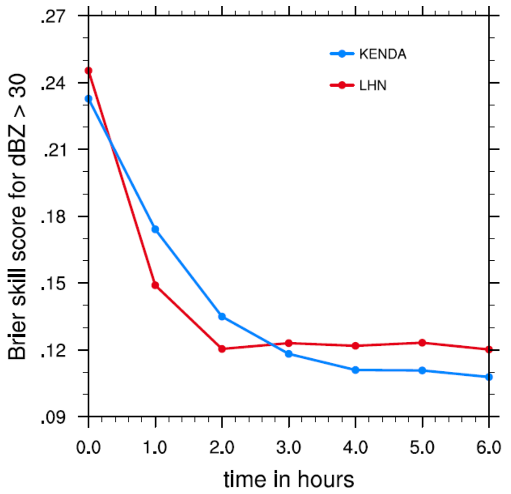
DWD

FSS (deterministic)



Brier skill score (ensemble)

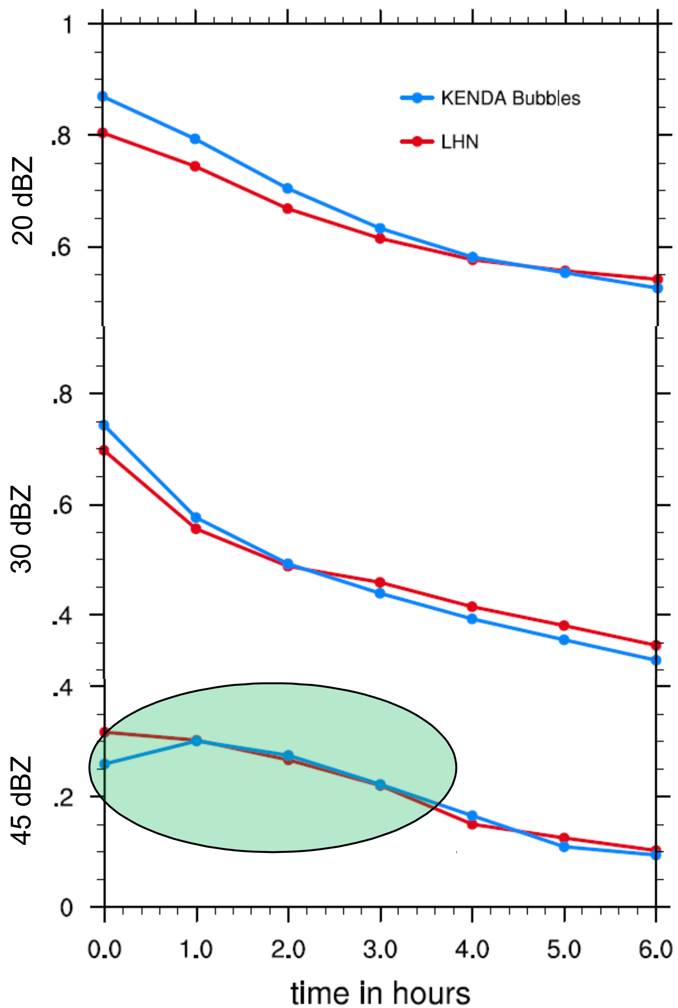


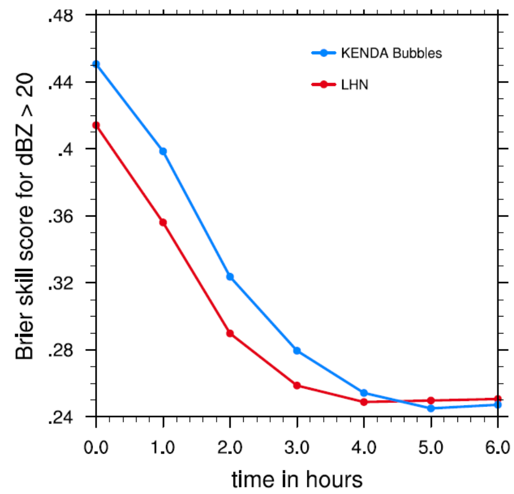


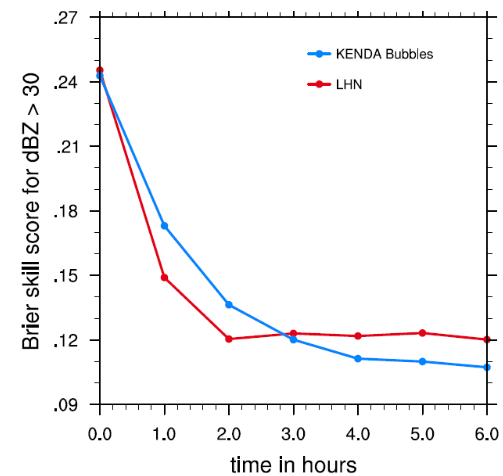
- ➔ KENDA shows a small advantage in the first two-three forecast hours.
- ➔ Higher reflectivities (over 45 dBZ) seem to be better captured by LHN. This might be a problem for the identification of convective cells.

KENDA vs LHN (Now with bubbles.)

FSS (deterministic)







➔ Bubbles correct the high reflectivities.

➔ All other scores change very little.

Standard verification

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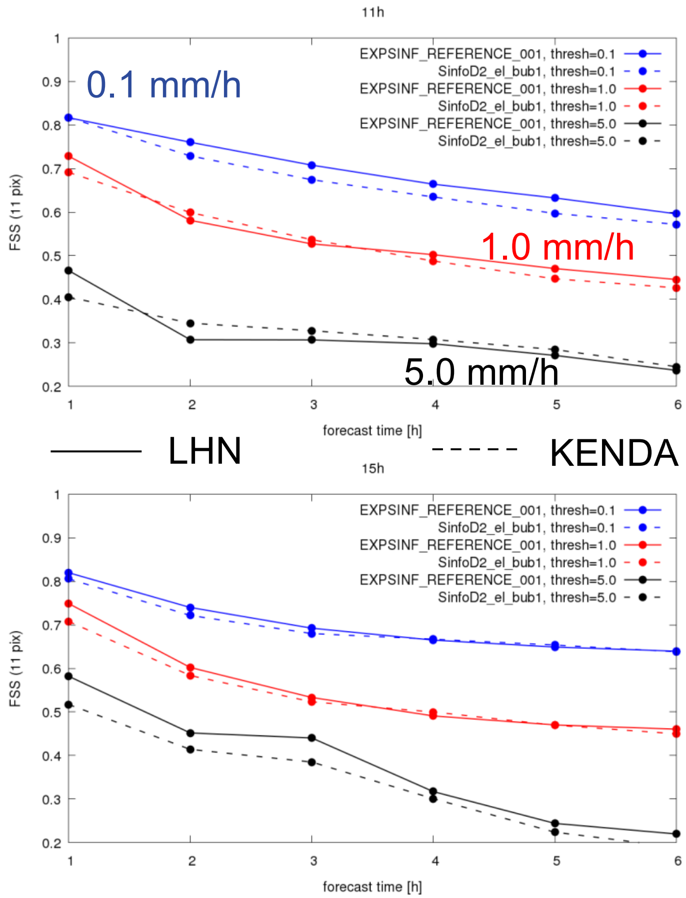
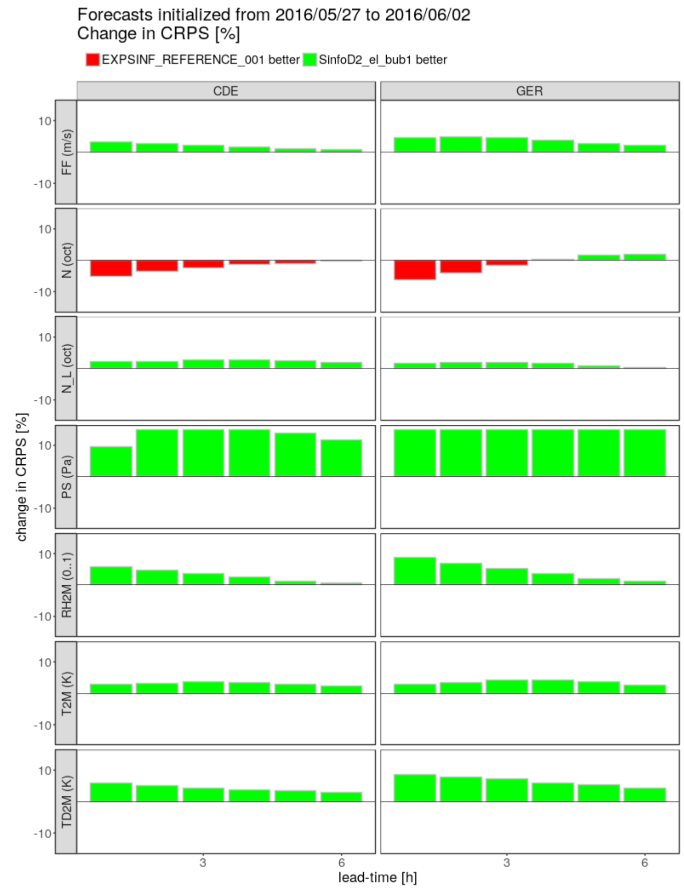
Precipitation verification (FSS)



Surface Stations verification (CRPS)



➔ KENDA performs better for the surface verification. LHN performs slightly better for precipitation.

Beyond direct assimilation (C. Welzbacher)

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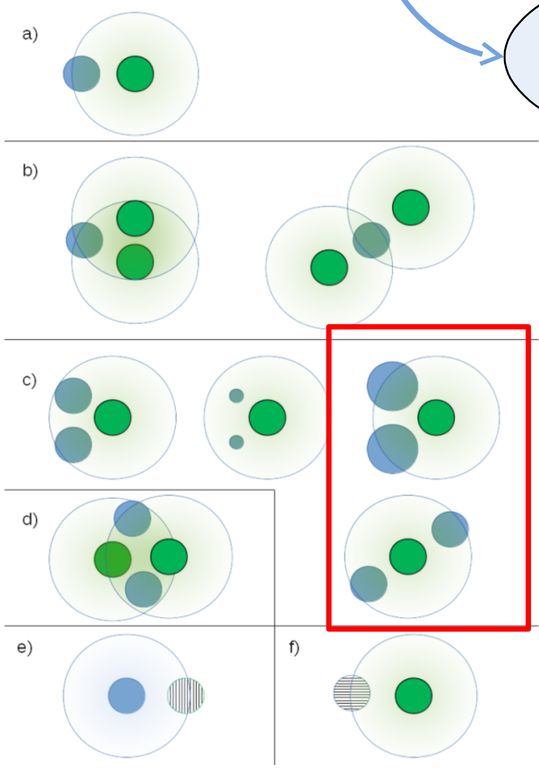
Direct assimilation of 3D radar data

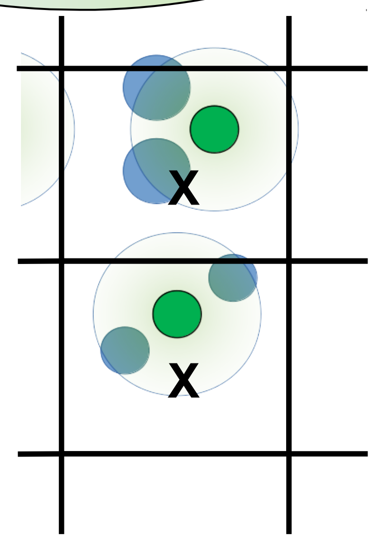
direct

Assimilation of (radar) objects

indirect

Assimilation of texture/features





- ➔ Determine object-related properties as „averages“ in a local neighbourhood around a fixed location **X** in space
- ➔ e.g. #objects > thresh, area > thresh, mean distance betw. obs & sim objects, lightning activity, Echo tops/base
- ➔ Do this both for **obs** and **simulations**
- ➔ Assimilate this „gridded“ information locally at **X**

Conclusions

➔ The assimilation of 3D Radar Reflectivities with our LETKF system COSMO-KENDA shows promising results. In some scores the LETKF is better than the currently operational Latent-Heat Nudging (only one week).

➔ Warm bubbles help to assimilate severe convective systems that are missing otherwise. The bubbles improve scores related to higher reflectivities.

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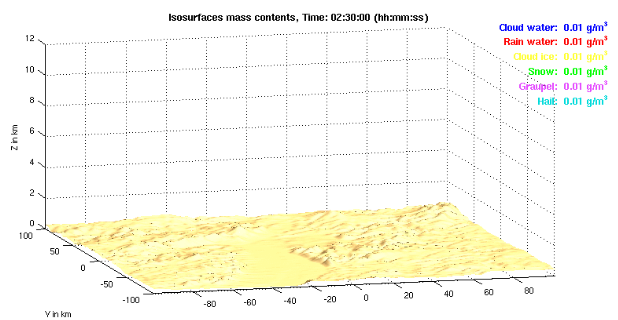
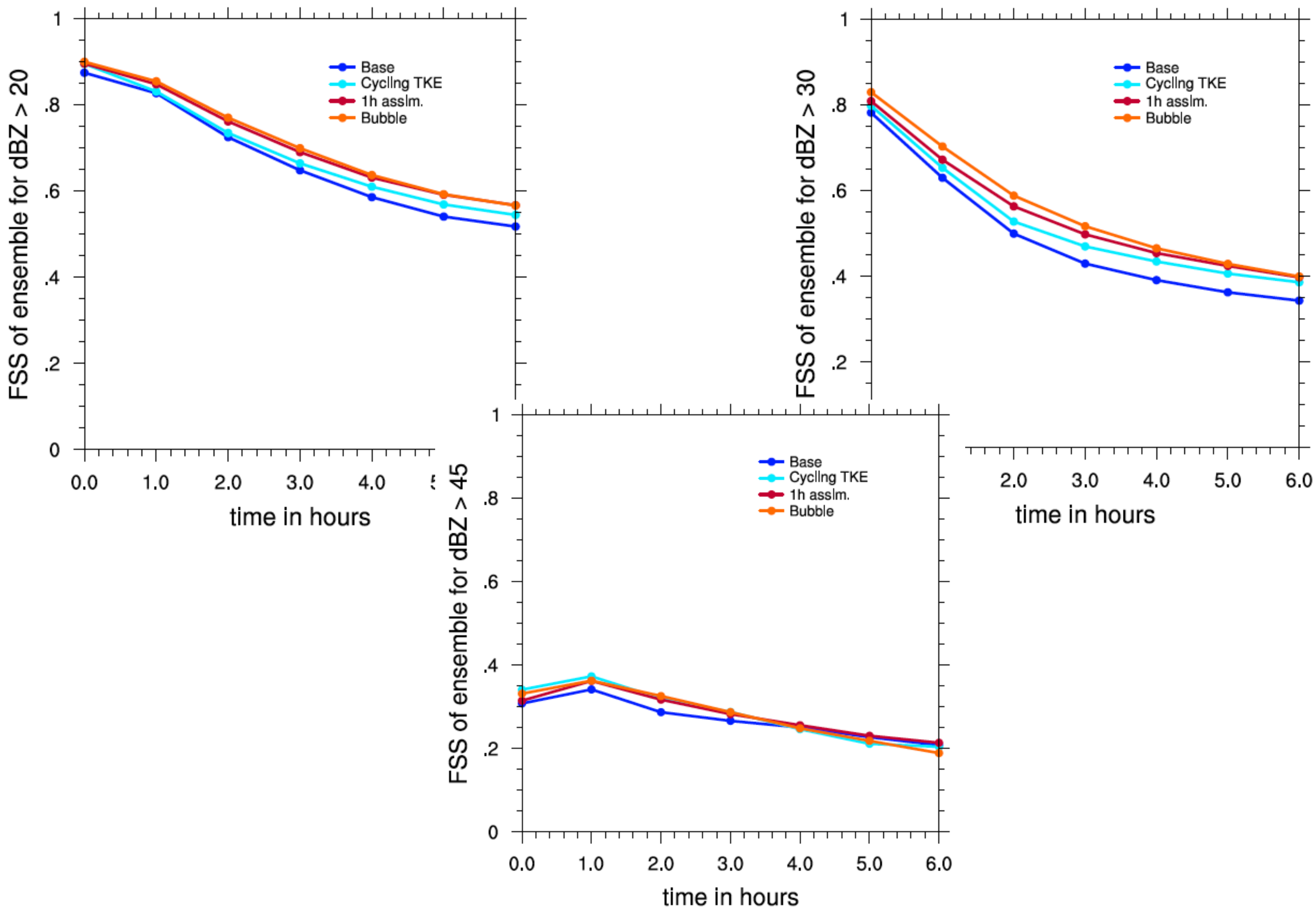
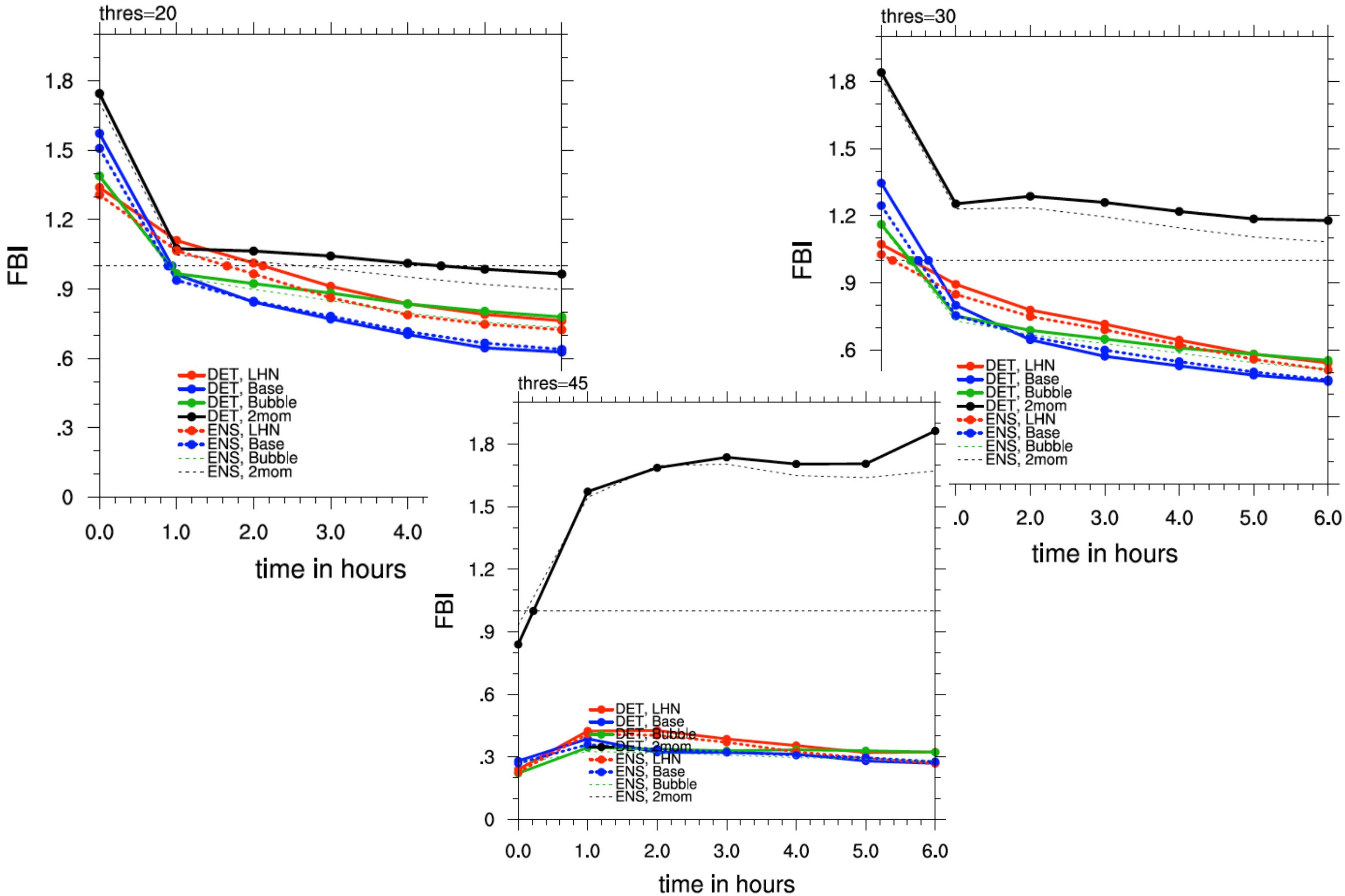
Thank you!



Step by step


FSS of ensemble for dBZ > 20
time in hours
Base
Cycling TKE
1h assim.
Bubble
FSS of ensemble for dBZ > 30
time in hours
Base
Cycling TKE
1h assim.
Bubble
FSS of ensemble for dBZ > 45
time in hours
Base
Cycling TKE
1h assim.
Bubble
0
.2
.4
.6
.8
1
0.0
1.0
2.0
3.0
4.0
5.0
6.0

Frequency bias



Scores based on reflectivities

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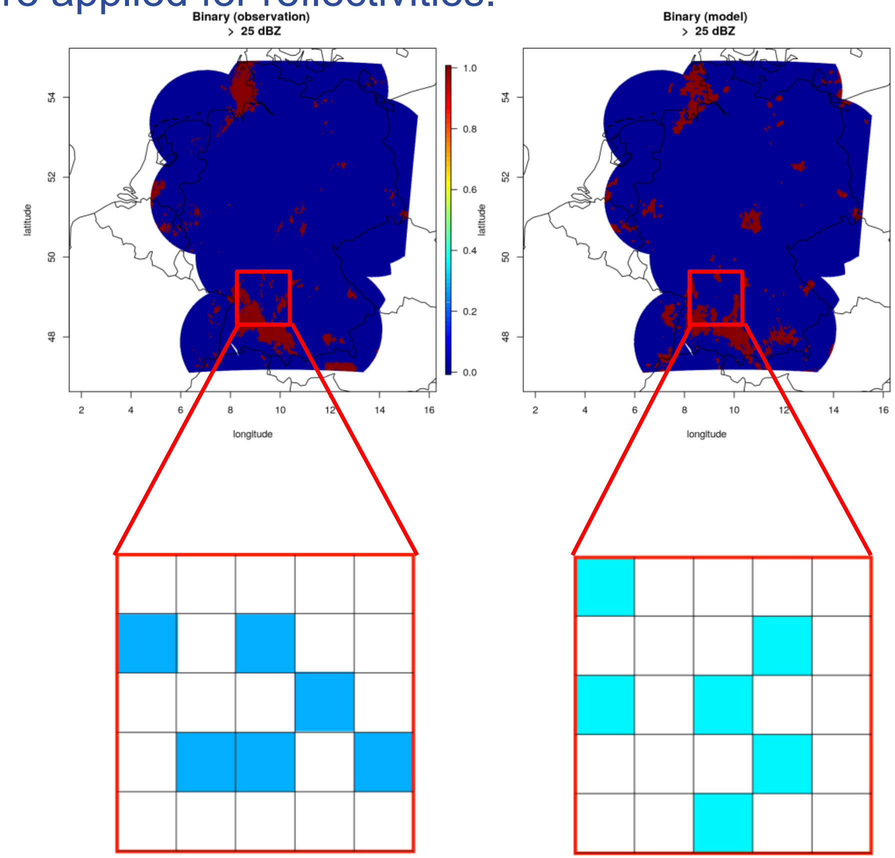
Fraction Skill Score (Roberts & Lean, 2008), here applied for reflectivities.

- The FSS assess the skill of predicting convection at **a spatial scale** for a given threshold (here 30 km).

$$FSS = 1 - \frac{\frac{1}{N}\sum_{i=1}^{N}(P_{fcst} - P_{obs})^2}{\frac{1}{N}\sum_{i=1}^{N}P_{fcst}^2 + \frac{1}{N}\sum_{i=1}^{N}P_{obs}^2}$$

- The Brier Score measures the accuracy of the probability prediction of an **ensemble**.

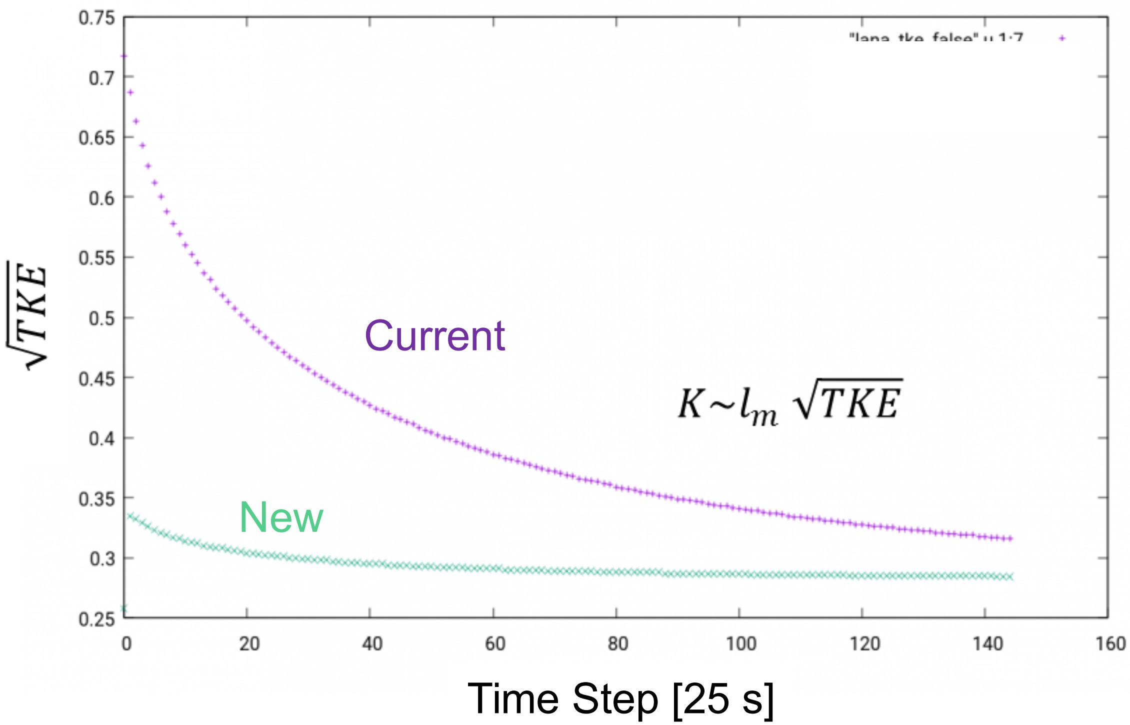
$$BS = \frac{1}{N}\sum_{t=1}^{N}(f_t - o_t)^2$$



P_{obs}= 6/25 P_{fcst} = 6/25

Abbildung von M.Hoff

Improving the TKE Cycling



- ➔ TKE is currently initialized at each COSMO start, which happens every cycle (each1h)
- ➔ The LETKF is a local procedure that produces too much shear, and therefore too much TKE.
- ➔ TKE is now **cycled** (no initialization)
- ➔ At the same time the turbulent mixing length scale was set to a more physical value (von l_m = 150 m zu l_m = 500 m)

Assimilation nur stündlicher Daten

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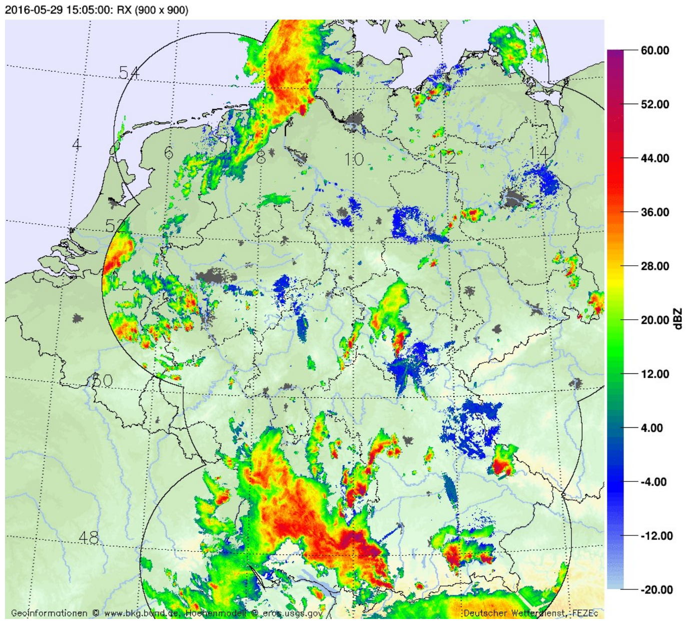
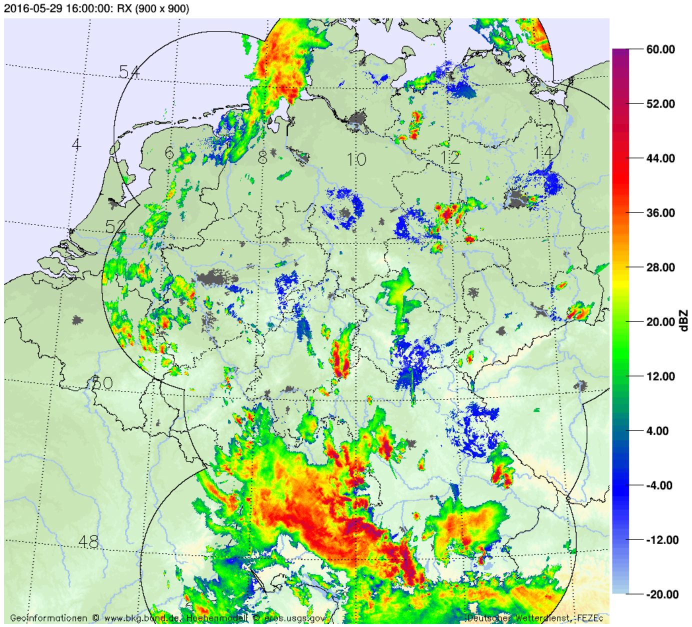
- Wir assimilieren jetzt die Radardaten nur für die Analysezeit (statt alle 5 Minuten)
- Das ist eine Datenreduktion **um Faktor 12**, die für Radar-Winde schon einen positiven Effekt gezeigt hat
- Wir benutzen auch die neuen, korrigierten Radardaten



5 min Daten



1 h Daten