Added Value of higher resolution for forecasts of severe convection?

SINFONY*

German Weather Service (DWD)

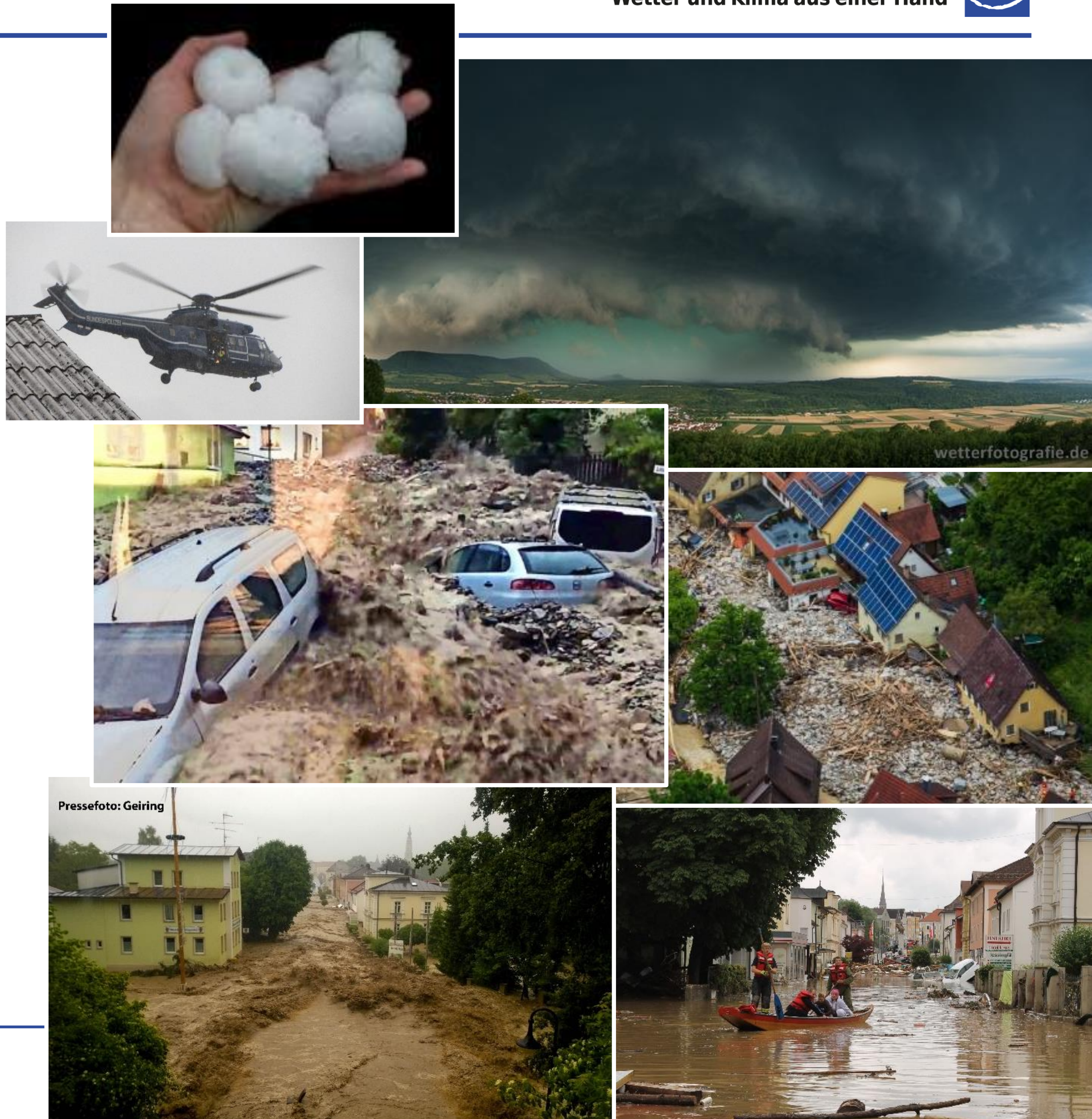
Alberto de Lozar, S. Ulbrich, P. Zschenderlein, Ulrich Blahak

Motivation for SINFONY

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- ➔ In the last years we had a number of catastrophic flooding events at very small scale, often associated with slow moving intense convective events.
- ➔ These bluntly uncovered the challenges and deficiencies in forecasting and warning during such events.
- ➔ We expect increased frequency in changing climate!
- ➔ The problems come from:
  - ➔ Use of different forecasting methods within the very-short-range period.
  - ➔ Individual shortcomings of these methods.
  - ➔ Limits of physical predictability.
  - ➔ Problems with information flow down the warning chain.

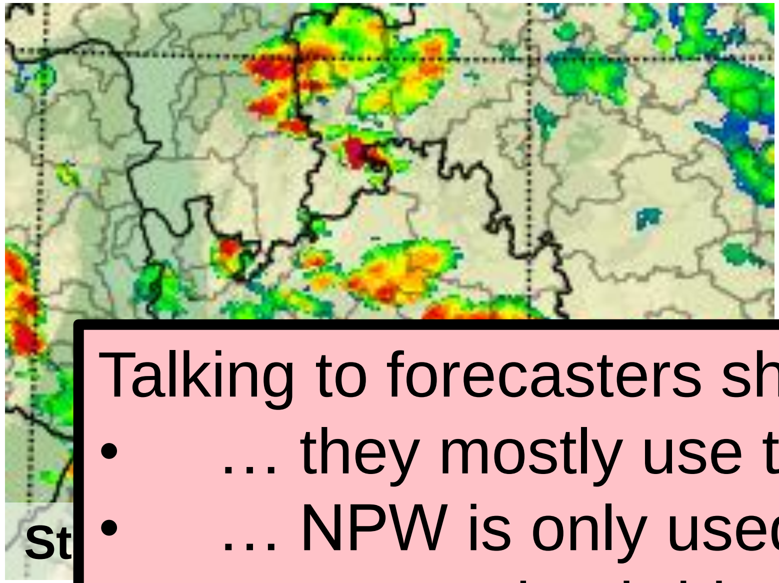
- ➔ **Goal: Want to achieve better convective forecasts from now to the the next 12 h!**



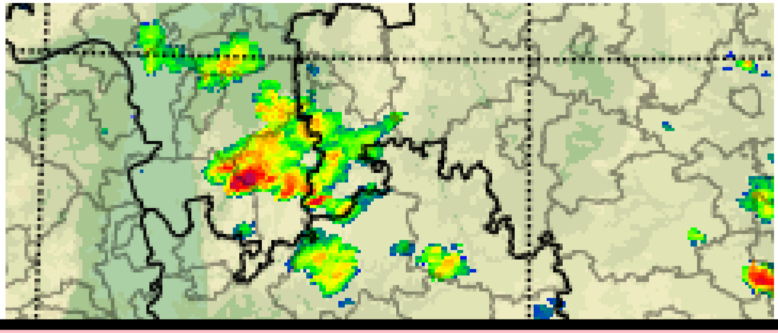
Motivation

Starting point: forecast time range 0-12 h up to now covered by two forecasting methods

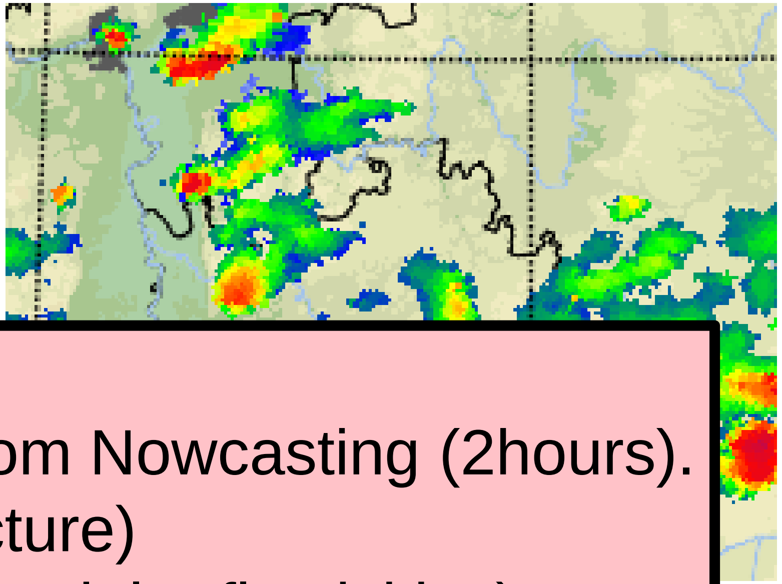
Nowcasting
(0-2 h, every 5 min new)
Based on observations, efficient, deterministic, quickly available



Observations
DWD radar network
9.Juli 2021, Southern Germany
17:00 UTC



Numerical Weather Prediction
(NWP - from +2 h, every 3 h new)
Expensive numerical model, only available after 1-1,5 h



Talking to forecasters showed that …

- … they mostly use the extrapolated reflectivities from Nowcasting (2hours).
- … NPW is only used as a rough guide (general picture)
- ... we need to bridge both worlds together (better model reflectivities).

The efficient forward operator EMVORADO for synthetic radar volume scans from NWP

Deutscher Wetterdienst
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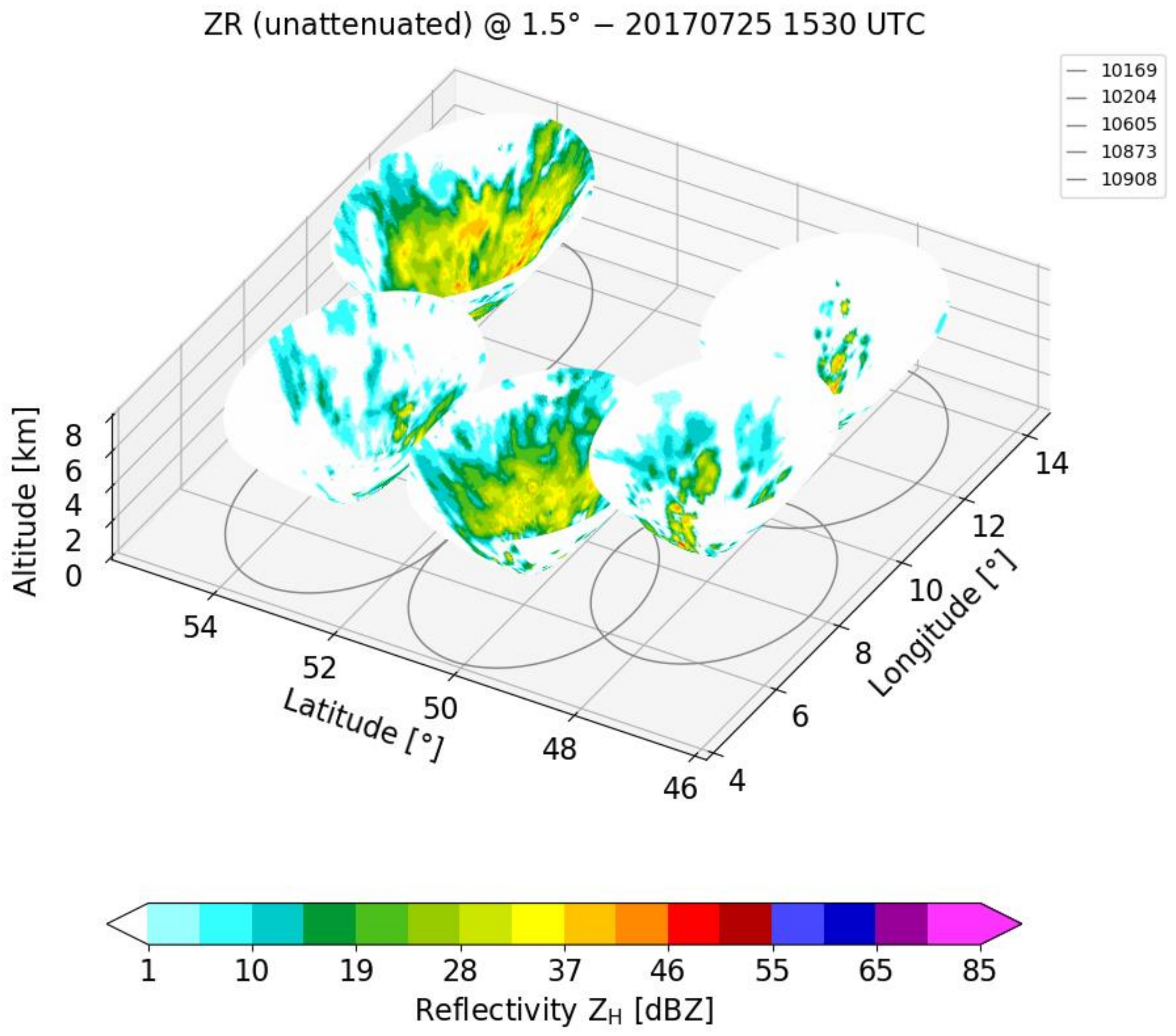


Simulated quantities along all radar rays of all volume scans of large radar networks:

- ➔ **Radar reflectivity Z**
- ➔ **Radial wind V_r**
- ➔ **New: dual polarisation params ZDR, KDP, RHOHV, LDR, …**
- ➔ **For every 5‘ during the entire NWP forecast!**

SINFONY

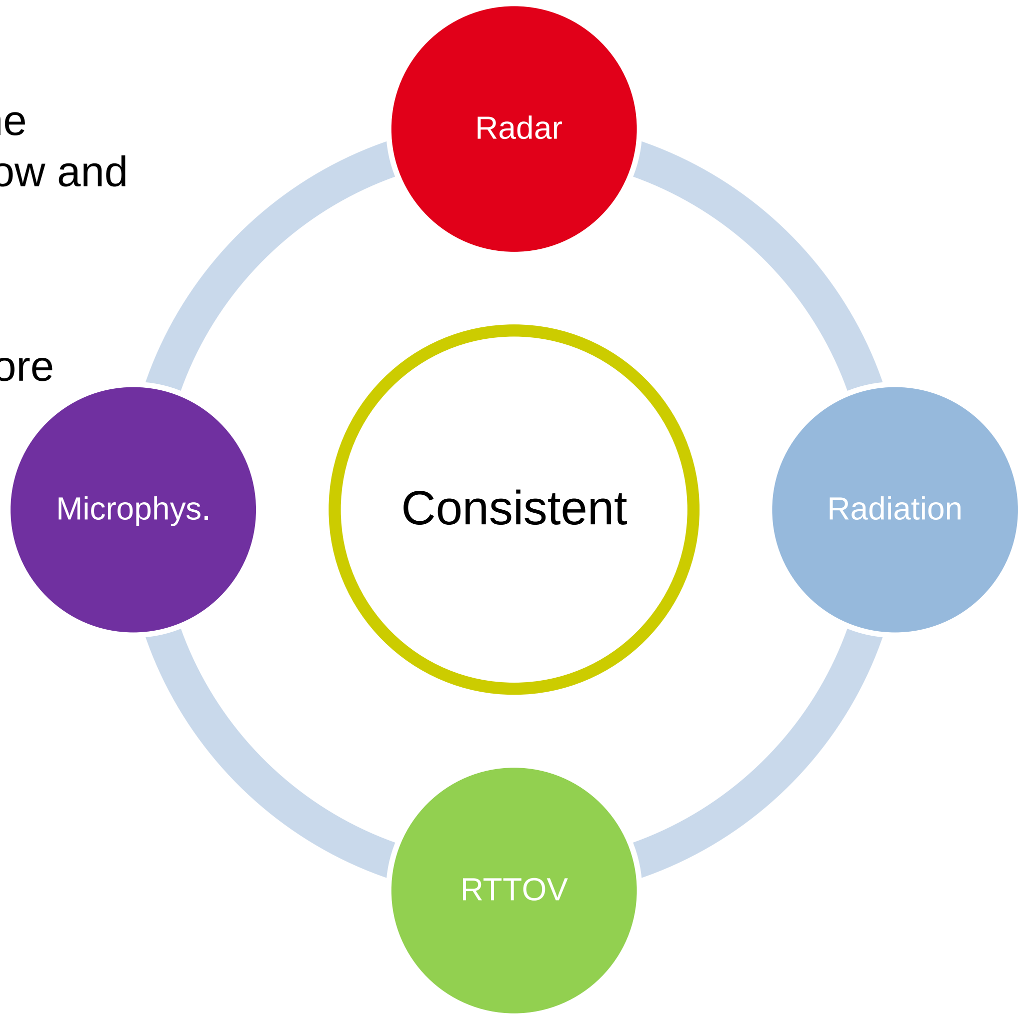
Two-moment microphysics

- Our operational microphysical scheme has a prognostic equation for the mass concentration (q) of each hydrometeor (cloud water, rain, ice, snow and graupel): it does not produce very high reflectivity.

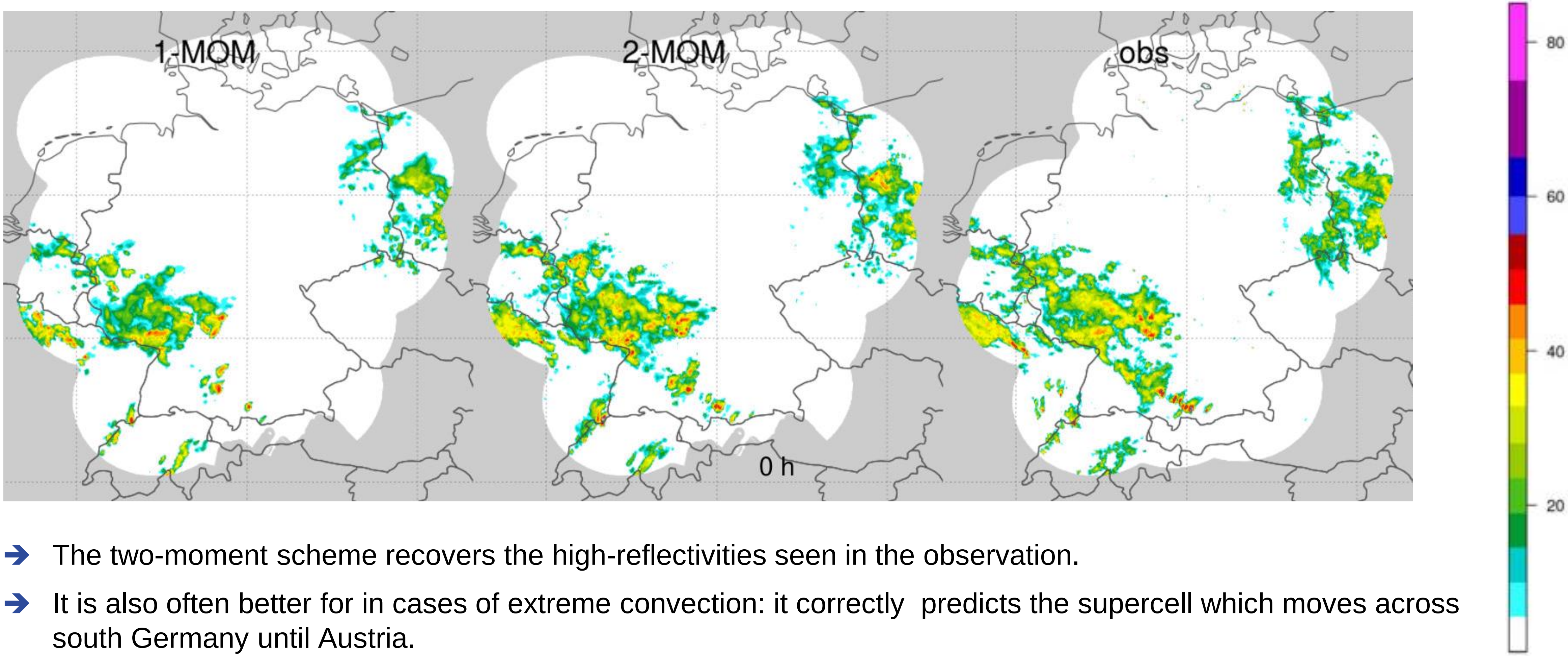
- The two-moment-scheme of Seifert and Beheng (2006) can provide more realistic reflectivities because:
  - Additional prognostic equation for number concentrations (N).
  - Reflectivity is highly non linear: $R \sim r^6 \sim (q/N)^2$
  - Additional hail class allowing for large hail particles.

- We have coupled the two-moment scheme to radiation through the calculation of an effective radius: $r \sim a(q/N)^b$

- Radar and satellite forward-operators (RTTOV) are also consistent with the assumptions and calculations from the microphysics.

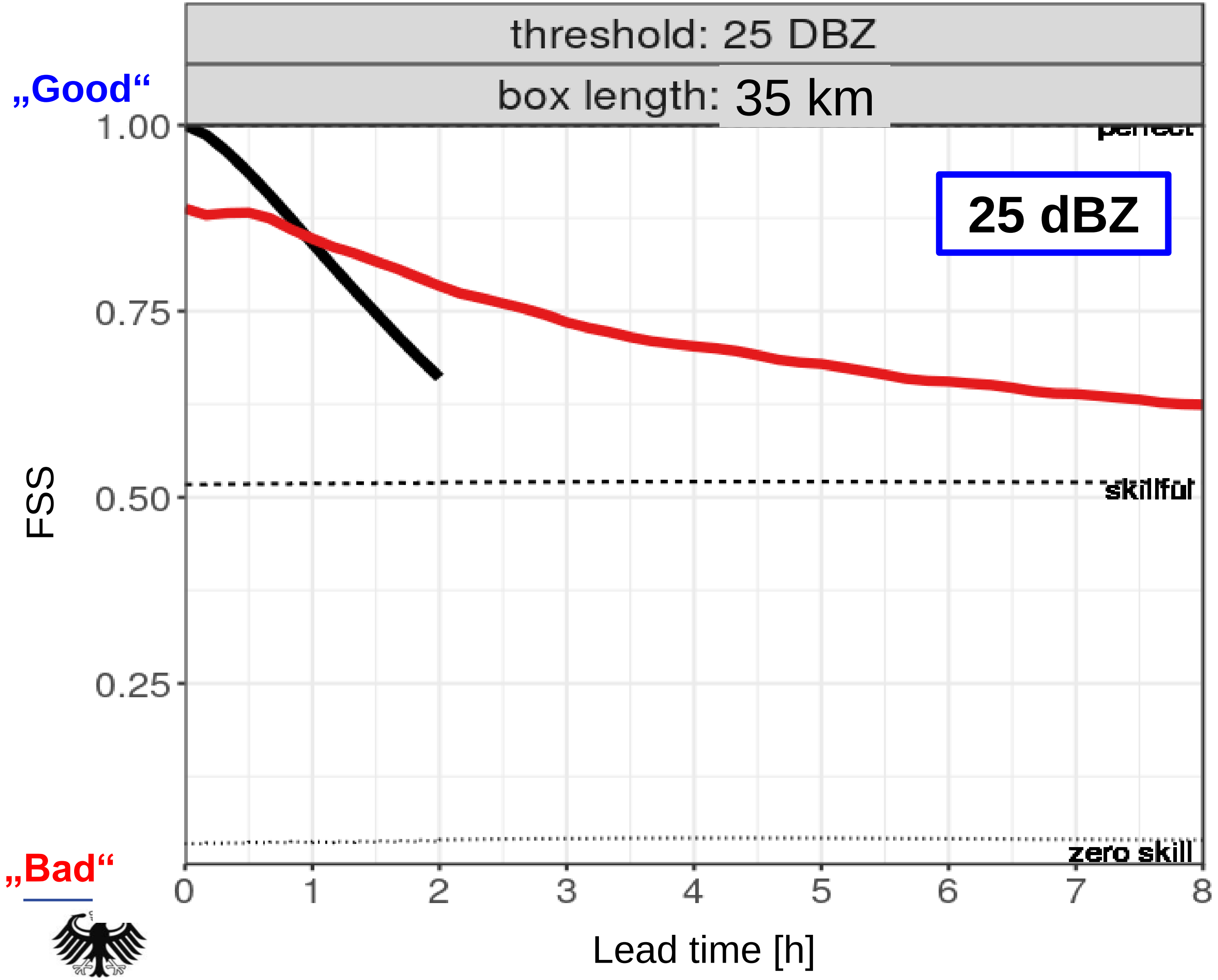


One versus Two-moment microphysics



- ➔ The two-moment scheme recovers the high-reflectivities seen in the observation.
- ➔ It is also often better for in cases of extreme convection: it correctly predicts the supercell which moves across south Germany until Austria.

Verification reflectivity STEPS-Nowcasting and SINFONY-RUC vs. radar in 06/2022



Time period: 01.06. – 30.06.2022

Forecast runs: 10, 11, 12, … ,15 UTC (deterministic)

Parameter: Radar reflectivity (dBZ)

Score: fraction skill score (FSS)

STEPS-DWD Nowcasting (det)

ICON-D2-RUC det, 2 km, LHN + 3D-rad

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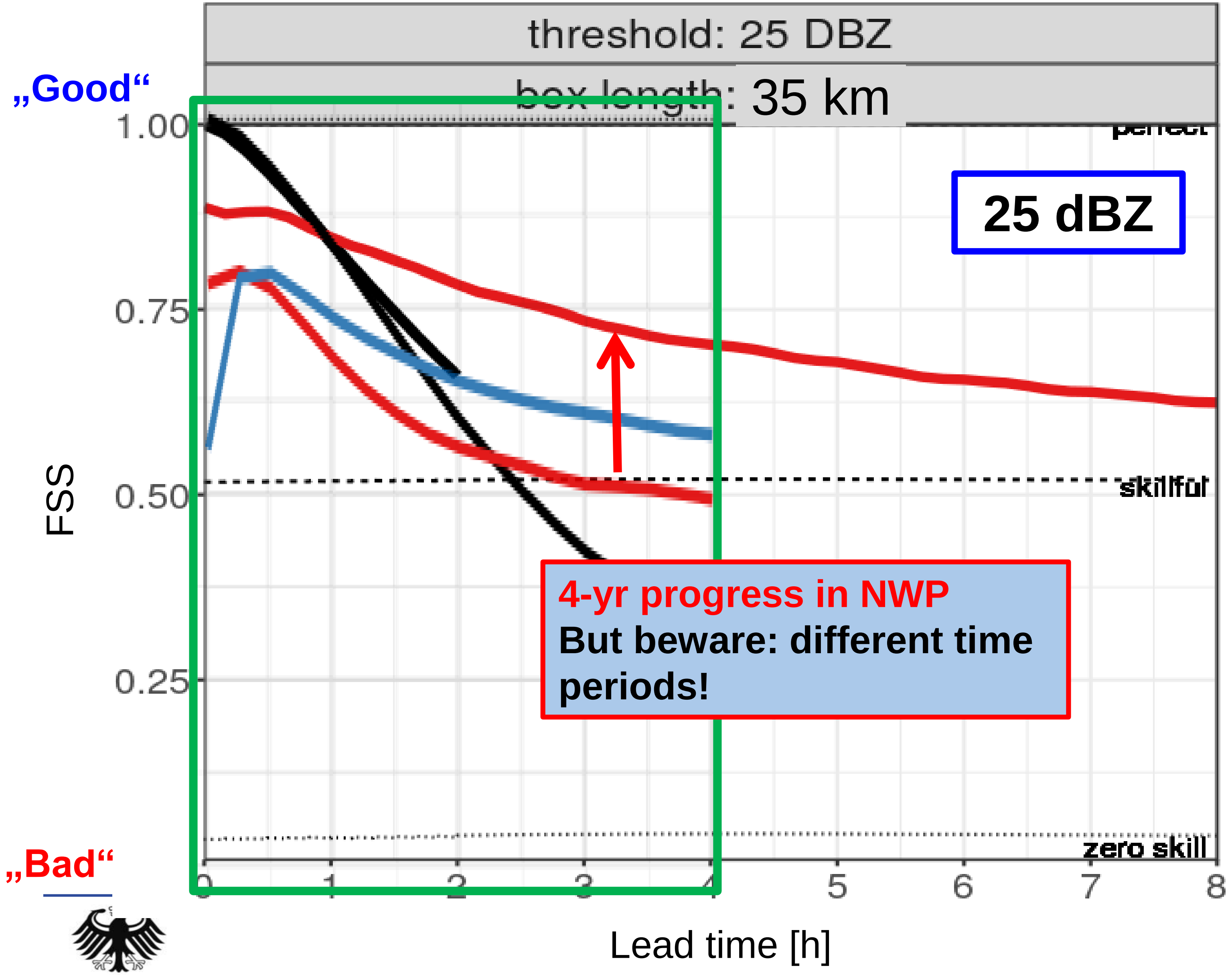

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- STEPS-DWD Nowcasting (det)
- ICON-D2-RUC det, 2 km, LHN + 3D-rad

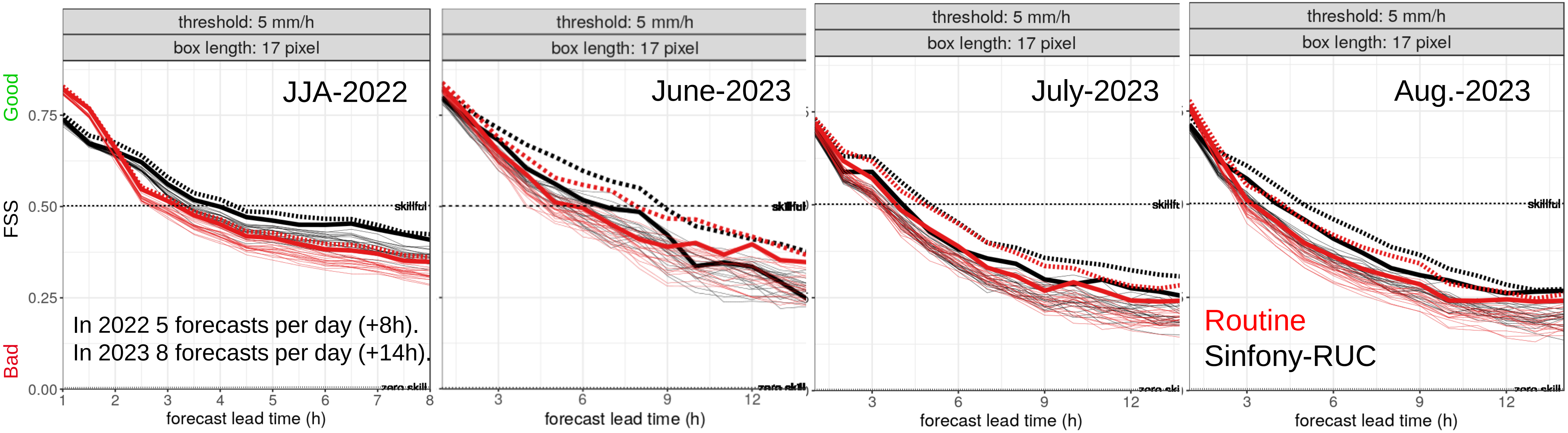
Overlayed: same comparison 4 years ago

Time period: 26.05. – 25.06.2016 !!!

- Earlier version of our STEPS (det)
- COSMO det, 2.8 km, 1-mom, LHN
- COSMO det, 2.8 km, 2-mom, 3D-rad

SINFONY

Heavy precipitation scores



- ➔ FSS (26 km) for 20 ensemble members (thin lines), deterministic (continuous line) and ensemble score (discontinuous) for precipitation (>5mm/h) show a clear advantage for the RUC up to nine hours.
- ➔ Similar scores are observed in summer, but in winter the routine performs better for stratiform precipitation.

Heavy precipitation scores

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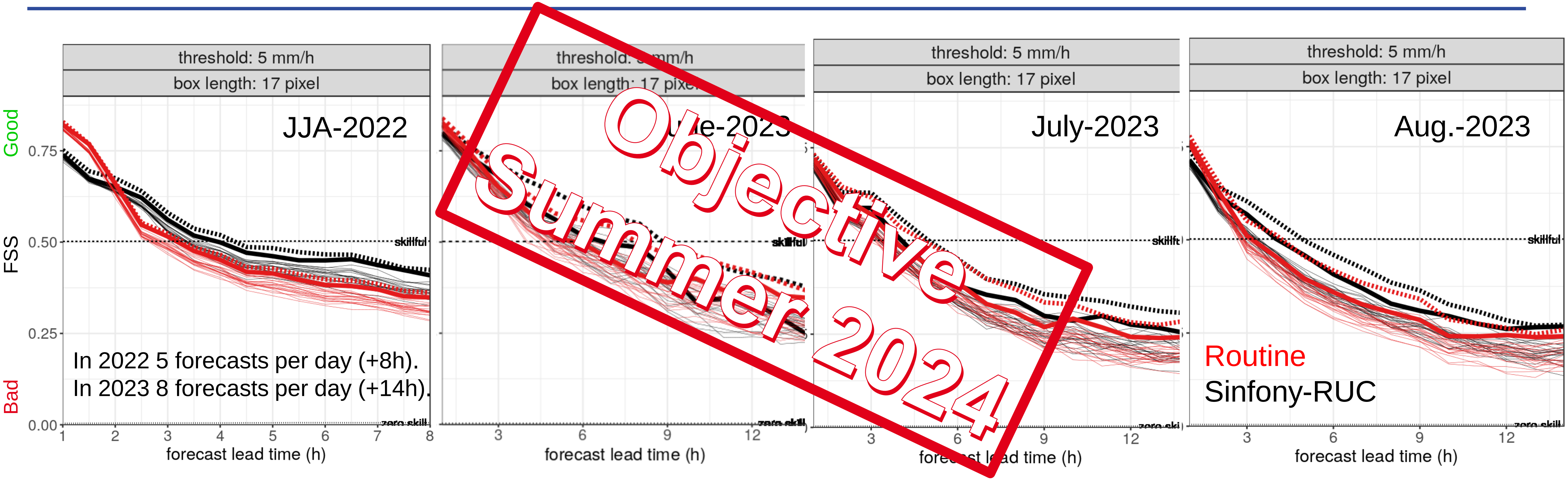
Wetter und Klima aus einer Hand



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Beyond 2km resolution for SINFONY

- The model current resolution 2km resolution. The question is if we can get better predictions by increasing the resolution to 1km or 500m. This is of course much more expensive. Using the two-moment scheme increases the running time by 20-30%. Using a 1km resolution can increases the running time up to 1000%.

- We have performed several experiments with a nested 1km configuration (see Daniela's and Gunther's talks). We have not seen yet any large improvements in scores averaged over a month. Actually, the 2km and 1km simulations look very similar.

- However, it **might be that high-resolution simulations provide an advantage for critical situations**, when it really matters. We investigate only two case studies, focusing mostly on reflectivity. We investigate cases with severe convection (bow echo, super cells), which are more relevant for critical situations.

Case 1: Bow echo in South Germany (P. Zchenderlein)

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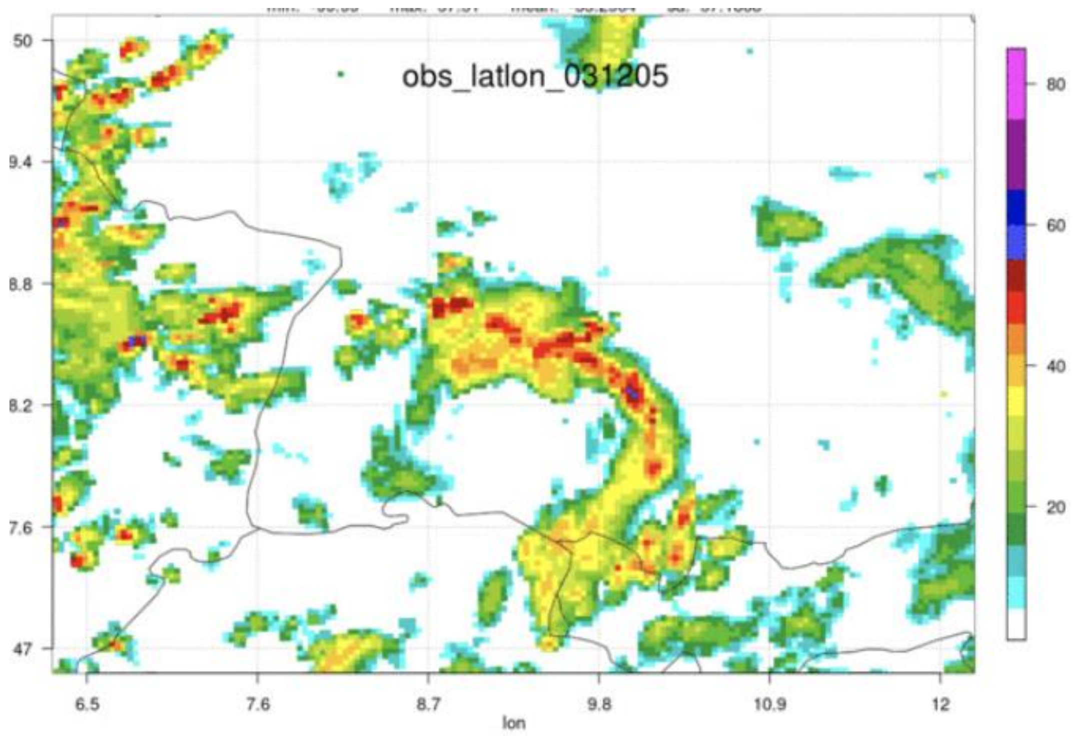
- ➔ Bow echos is a characteristic radar return, which is associated with organized convective systems like squall lines. They might produce major damage and occasionally tornados.

- ➔ A bow echo was observed on the 03.09.2022 in South Germany. The SINFONY-RUC also produced a squall line but not as intense as observed in reality.

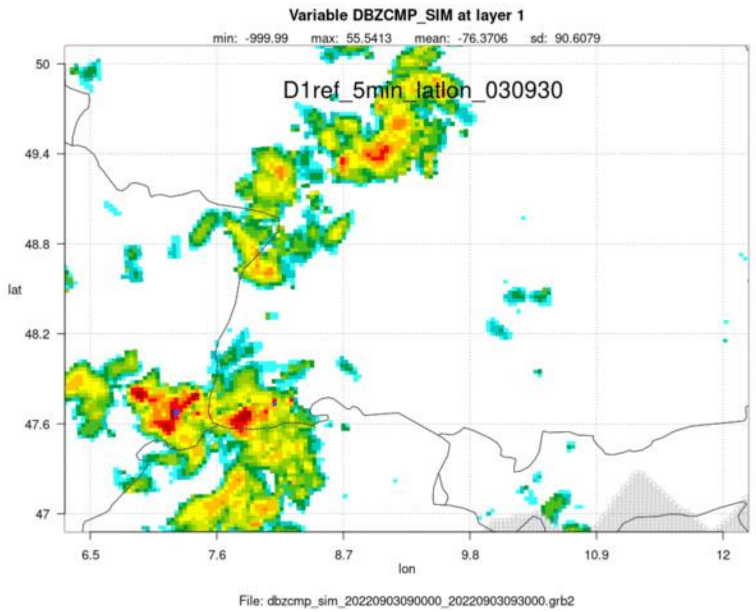
- ➔ We have the subjective impression that convective systems organize less in the model than in reality. This could be a good example.

- ➔ We test if this is a resolution problem. We rerun the SINFONY-RUC forecast with two nested domains with 1000m and 500m resolutions. No main change in physics.

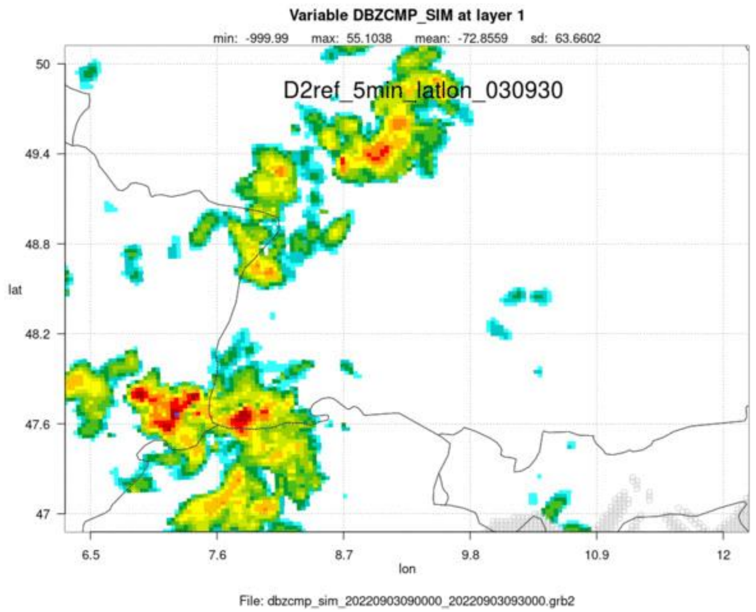


Bow echo in South Germany (P. Zchenderlein)

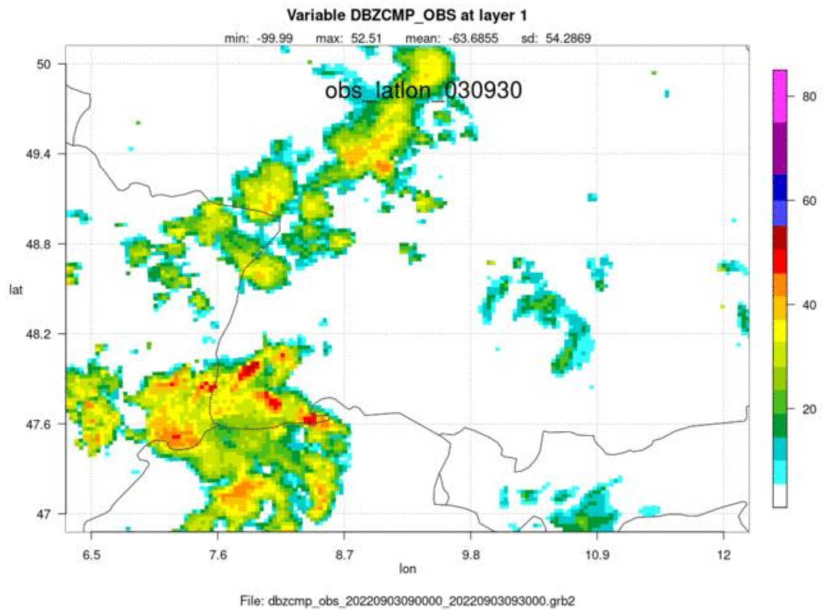
1km forecast domain



Pre-Operarional 2km forecast



Observation



- ➔ Although the dynamics seem quite realistic the bow echo is initially much less intensive in the simulations.
- ➔ Not much differences between 1km and 2km resolutions.

Bow echo for increasing resolution

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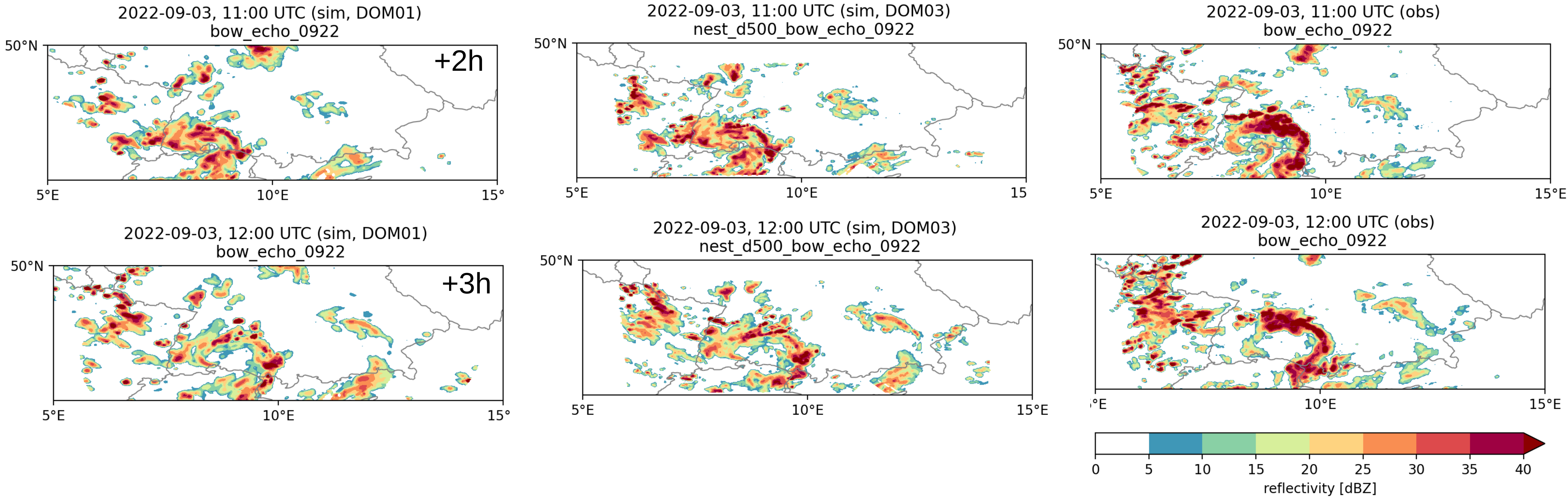
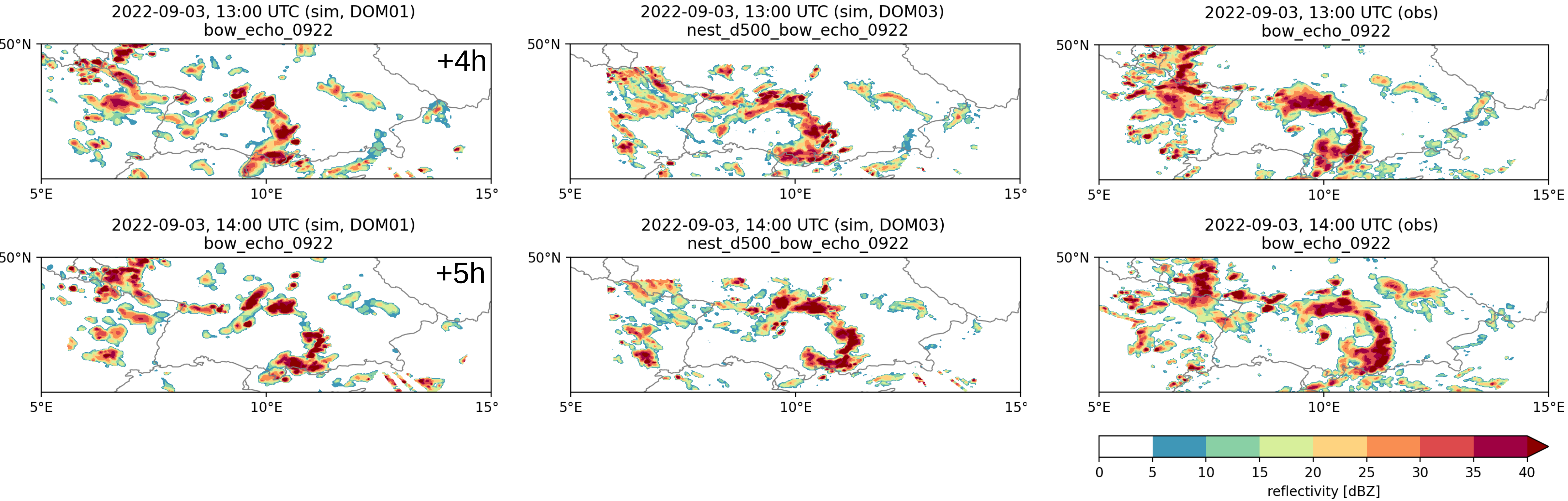
Pre-Operarional 2km forecast | 500 m forecast | Observation



- ➔ The 500 m has very similar dynamics. The problem with the intensity remains, which suggest similar organization. Notice that although the forecasts seem good, the potential damages are greatly underestimated.
- ➔ The 500m have more structure. They look prettier and more realistic?

Bow echo for increasing resolution

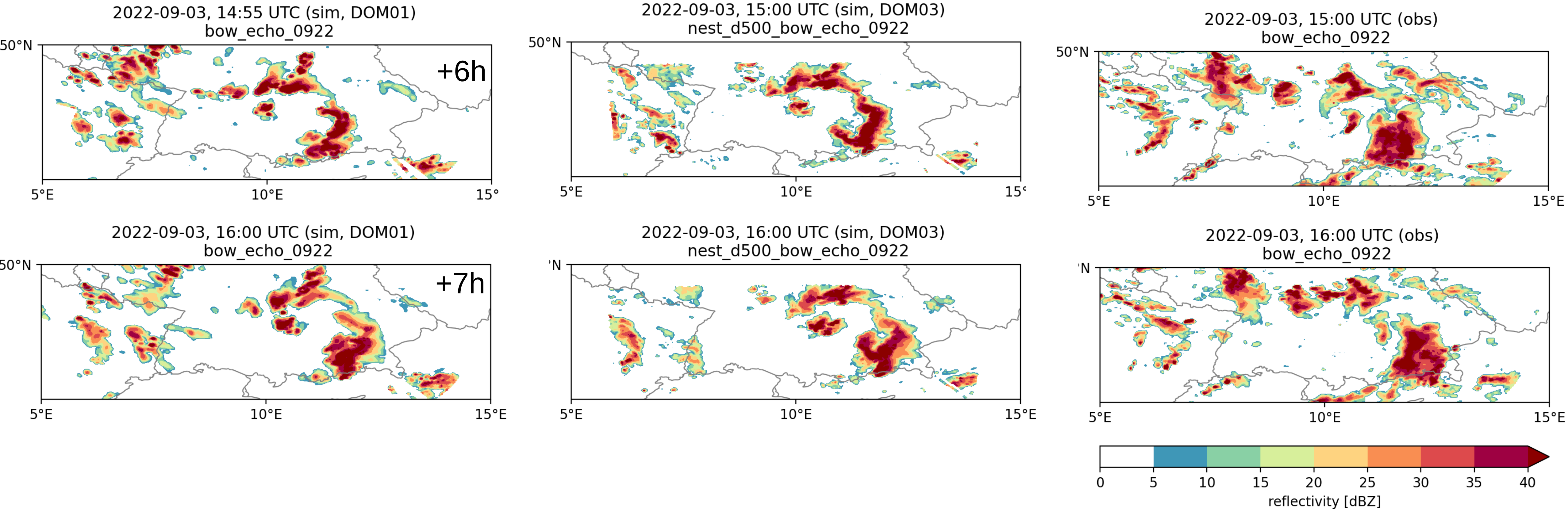
Pre-Operarional 2km forecast | 500 m forecast | Observation



➔ The intensities are right but the problems with organization remain. The 500m seems better organized but still less as as in the observation

Bow echo for increasing resolution

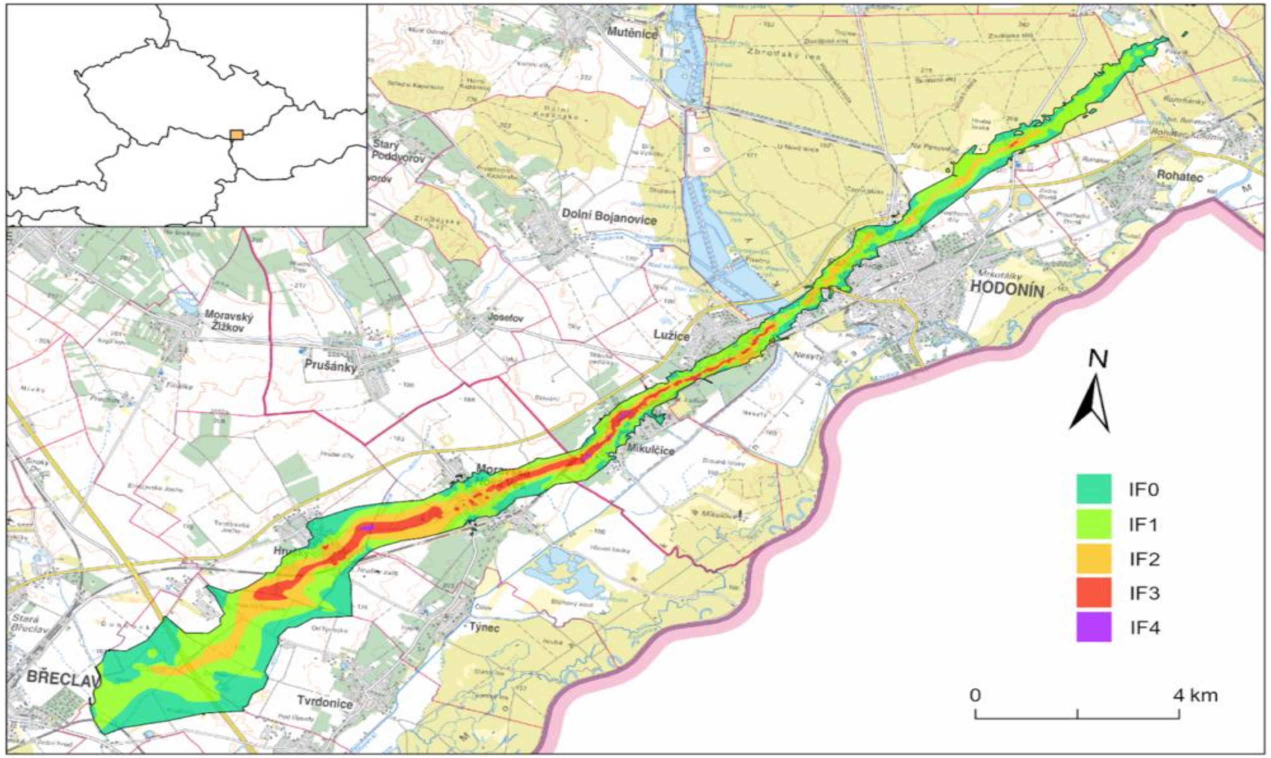
Pre-Operarional 2km forecast | 500 m forecast | Observation



➔ The breaking of the bow echo is well represented, although a bit late. Again, very similar for different resolutions.

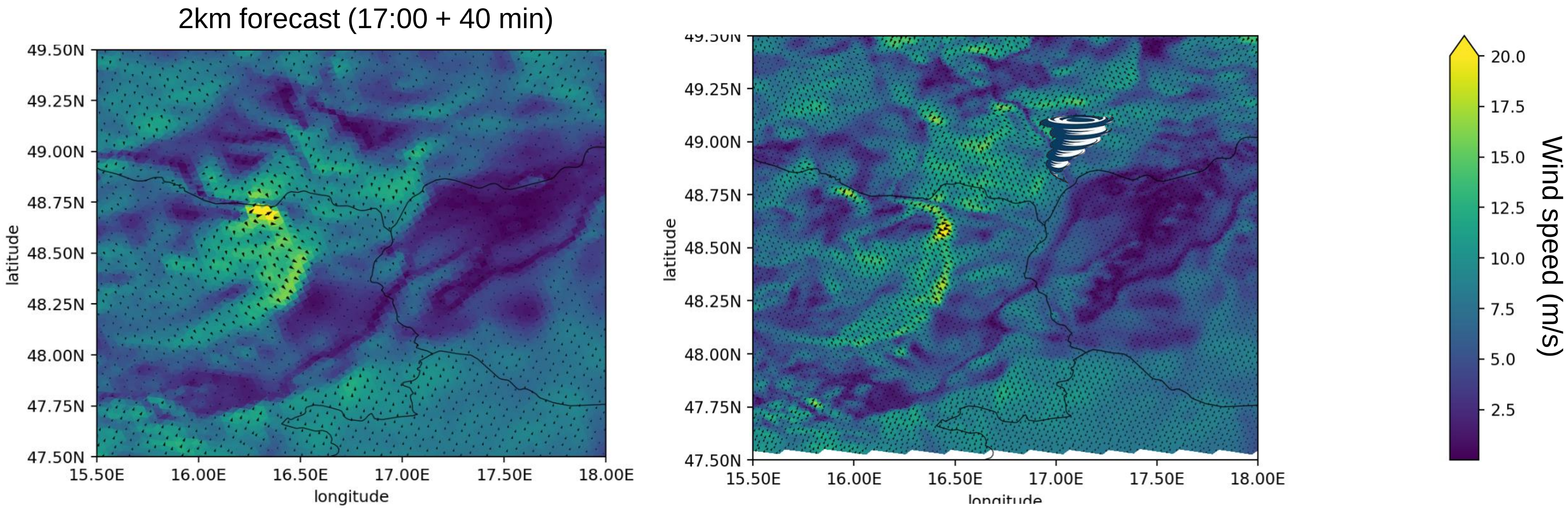
Case 2: Tornado over Czech Republic (Sven Ulbrich)

- On 24 June 2021 between 17:14 and 17:53 UTC a tornado formed within a cluster of convective cells and hit Hodonin, Czech Republic, where it caused huge damages (IF4, ~105 m/s) .
- Together with T. Pucik (European Severe Storm Laboratory) we investigate the DWD‘s RUC (Rapid Update Cycle) system to predict such extreme events.
- Our model cannot simulate tornados with the current resolution (D~200m). We look for tornado signatures.



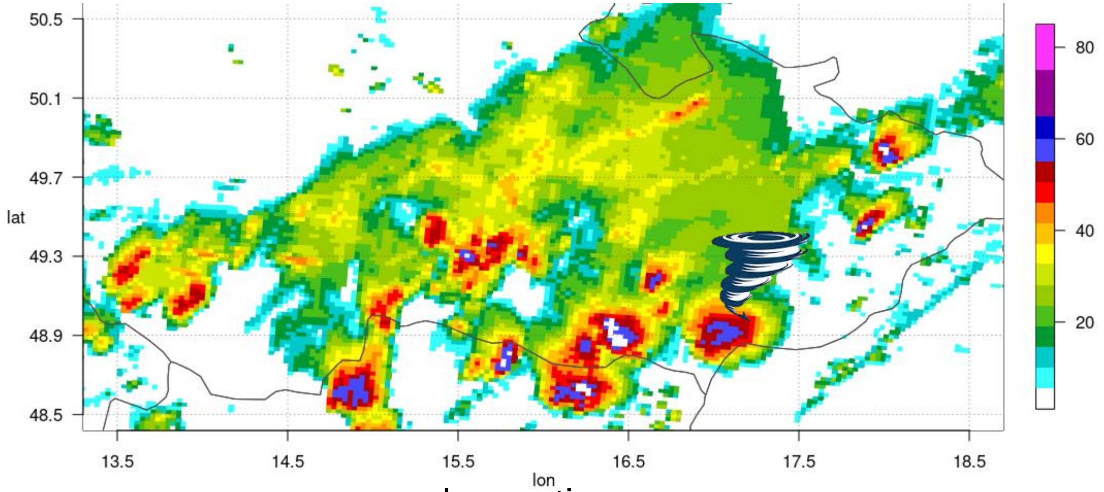
Case 2: Tornado over Czech Republic (Sven Ulbrich)

- ➔ For this purpose, we adapted the simulation domain and assimilated also Czech and Slovakian radar data. In addition, we included a 1-km nest to evaluate the impact on the atmospheric parameters and dynamics.
- ➔ The assimilation cycle starts from the ICON-EU analysis and runs for 36h in RUC setup before the relevant forecasts.
- ➔ The velocity fields close to the surface at 1km resolution show a clear finer structure.

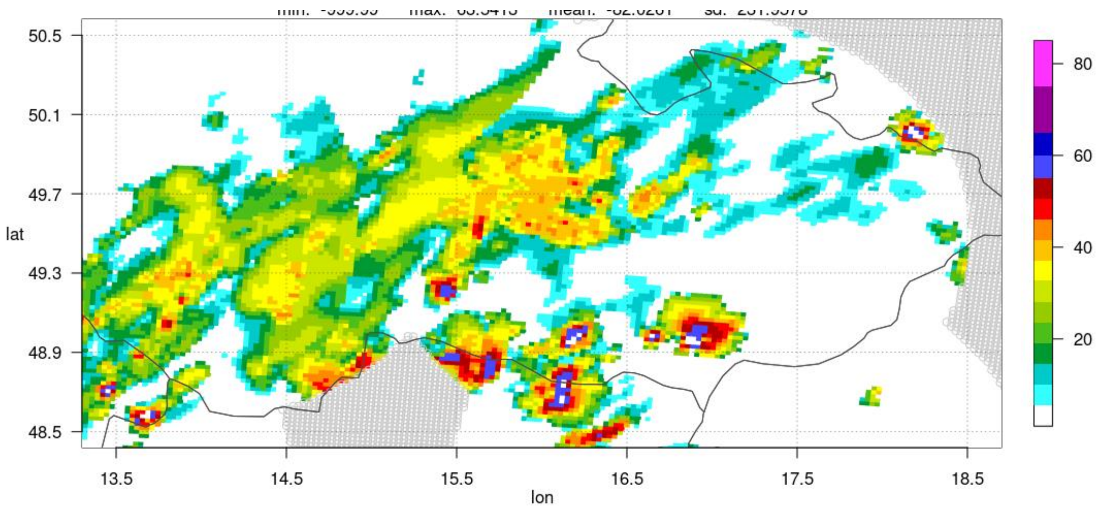


Case Tornado: radar composites (30 min forecast)

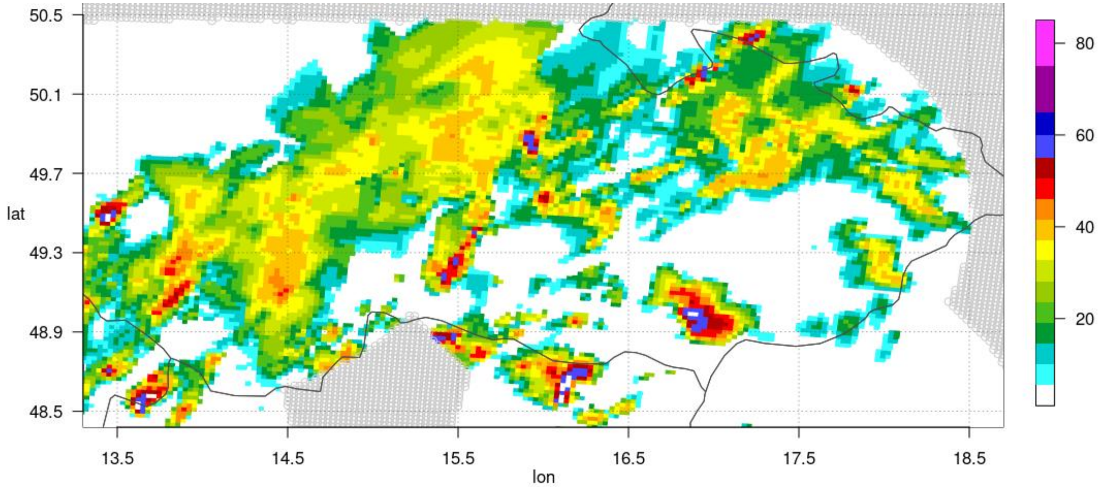
- This is just after the assimilation. Both models predict a strong convective cell where the tornado was observed.
- The situation is rather chaotic. Both predictions differ, but it is difficult to see which prediction is better.
- The forecast with 1km might be more active.



observation



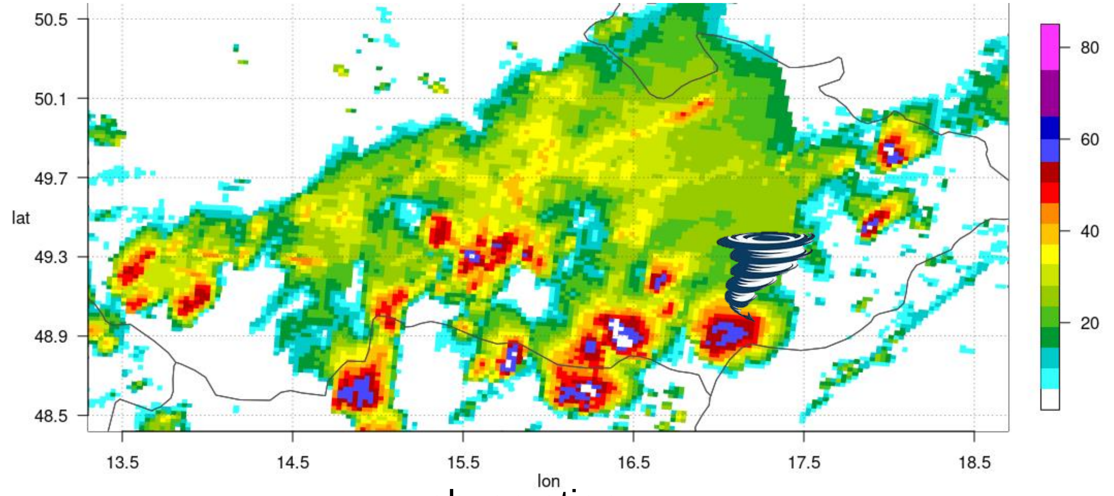
2km forecast



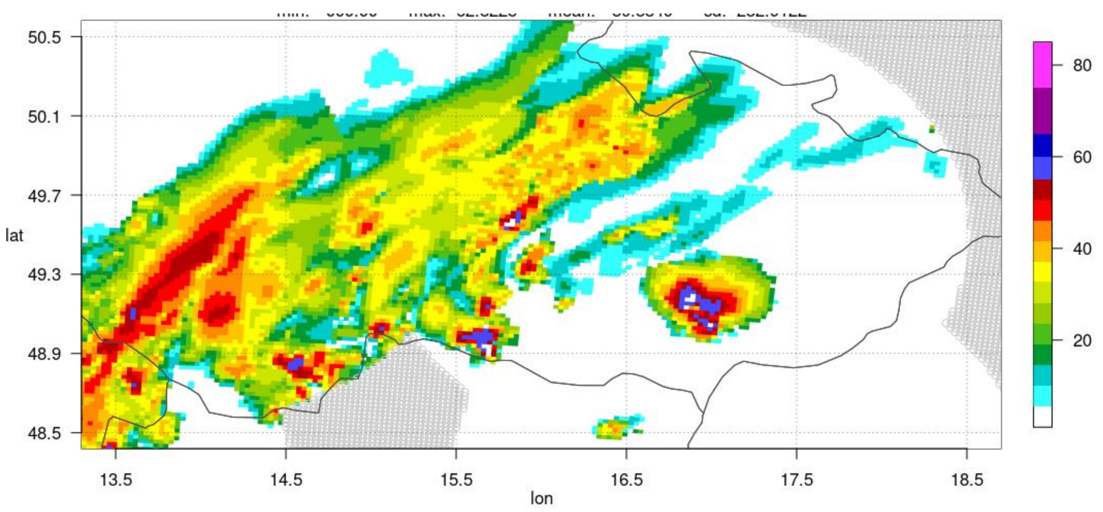
1km forecast

Case Tornado: radar composites (2h 30 min forecast)

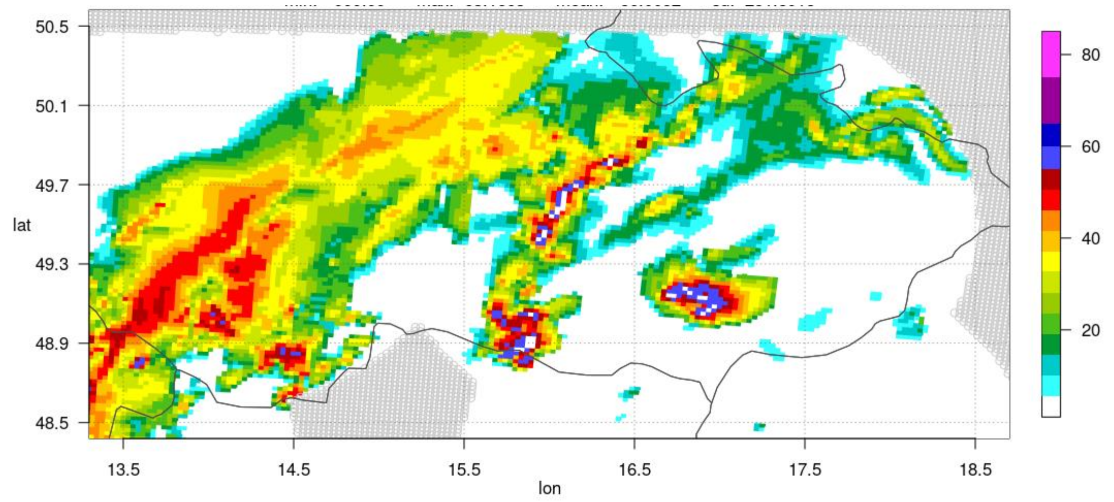
- ➔ Both models predict a strong convective cell ~30km far from where the tornado was observed.
- ➔ The forecasts are more similar now.



observation



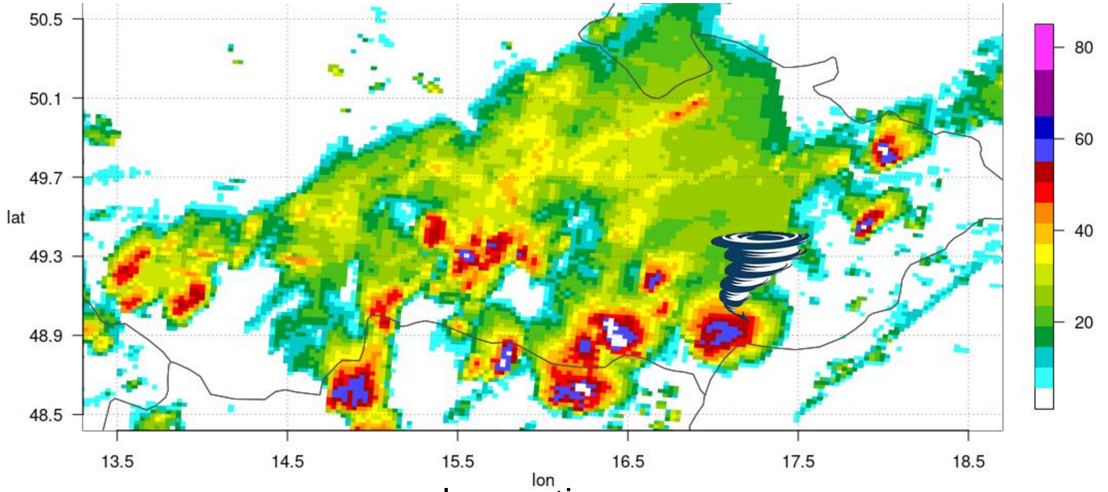
2km forecast



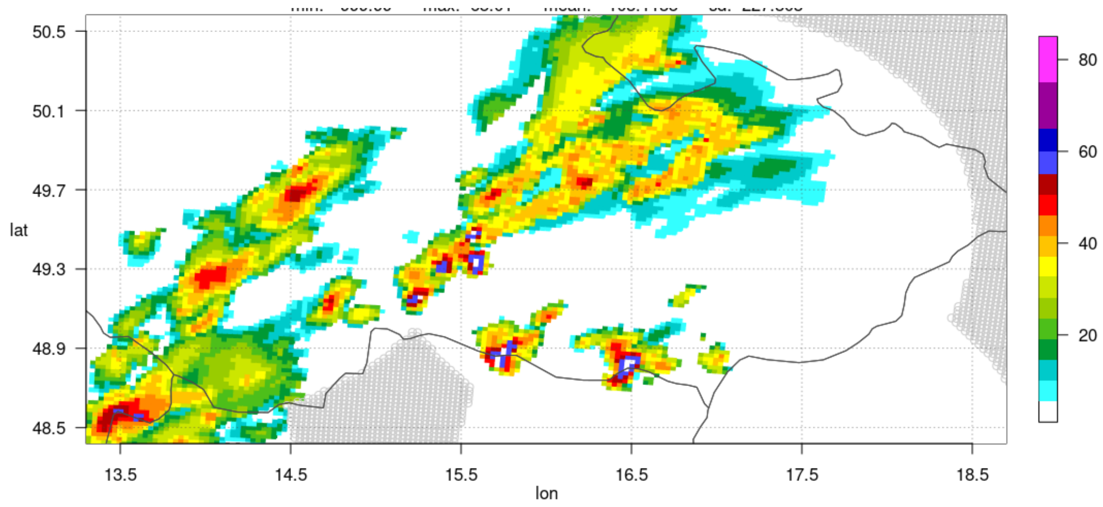
1km forecast

Case Tornado: radar composites (4h 30 min forecast)

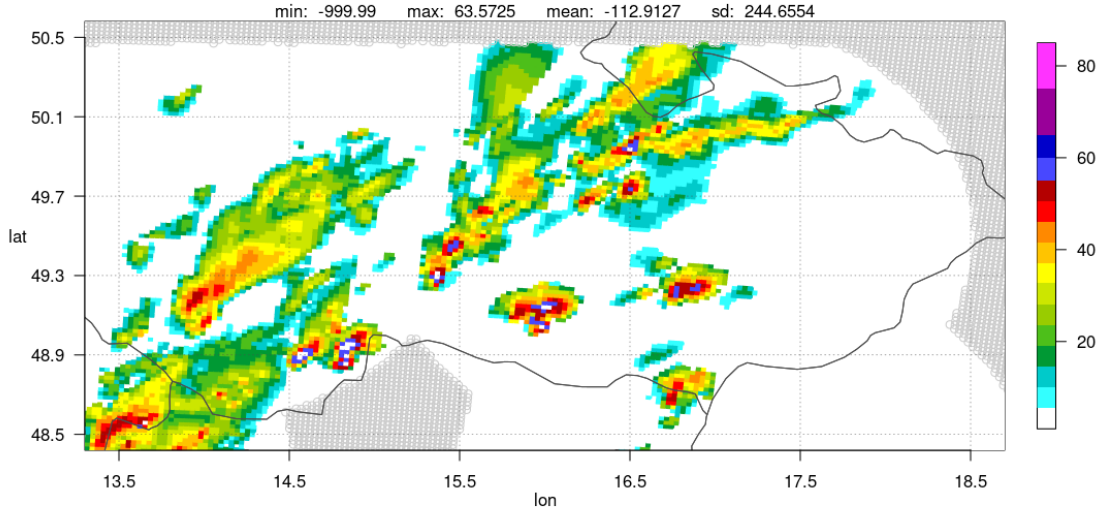
➔ No clear strong cell, but both forecasts predict convection close to the tornado region.



observation

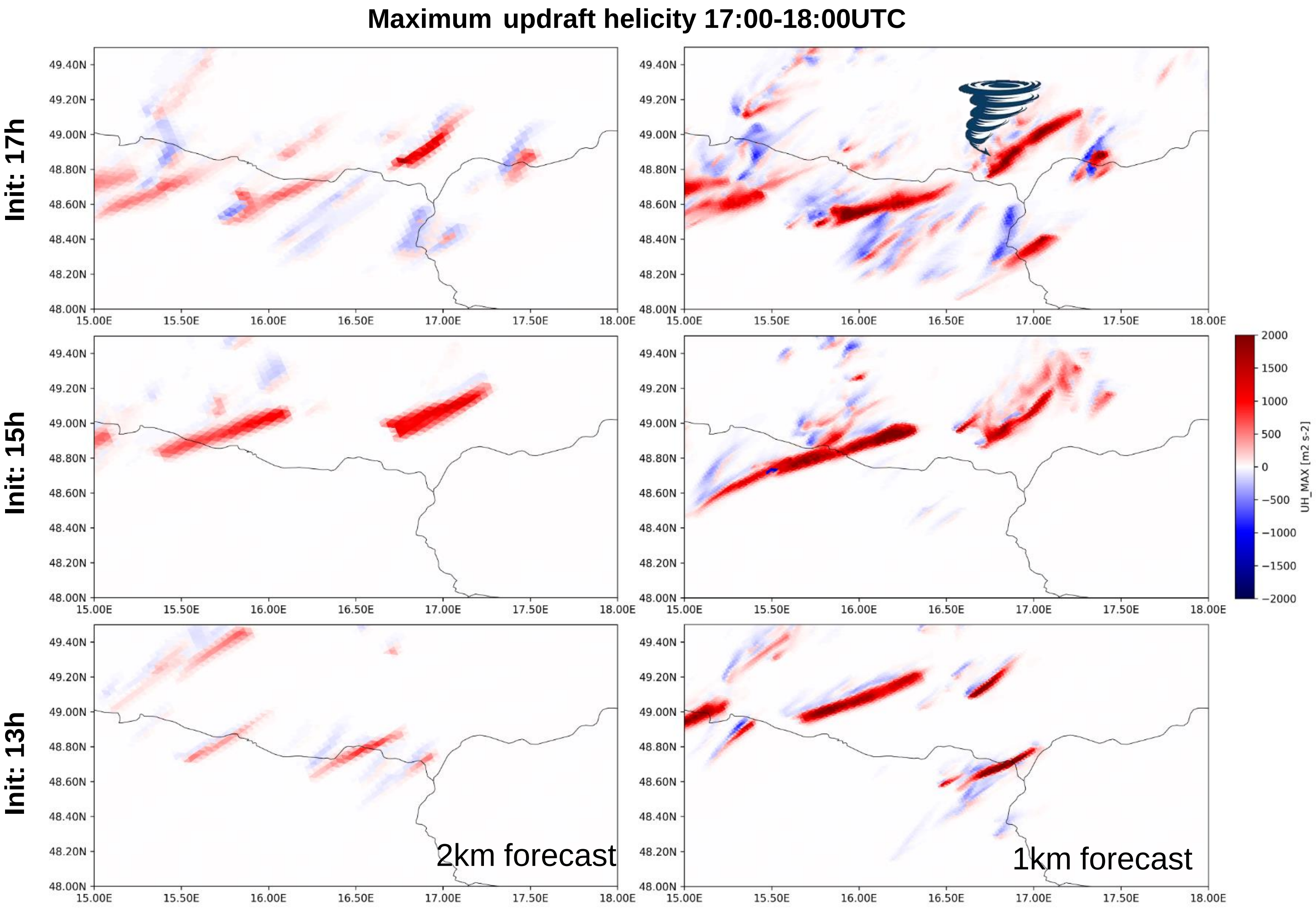


2km forecast



1km forecast

Case Tornado: maximum updraft helicity tracks

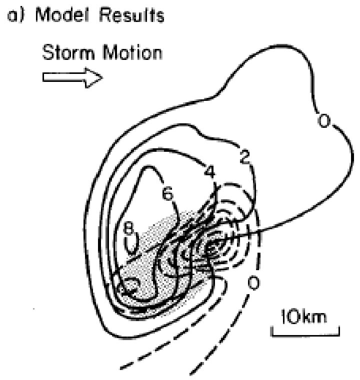


- ➔ Both models produce many cells with high updraft velocity close to the observed tornado.
- ➔ The 1km models produces higher (and more realistic) values. These values clearly indicate the possibility of a tornado.

Discussion

- When looking at the reflectivity we do no see much differences between 500m, 1km and 2km forecasts when forecasting severe convection. Higher resolutions produce a little more convective activity. This suggests that *convective-permitting* simulations are also quite *convective-resolving* for large deep-convective systems.

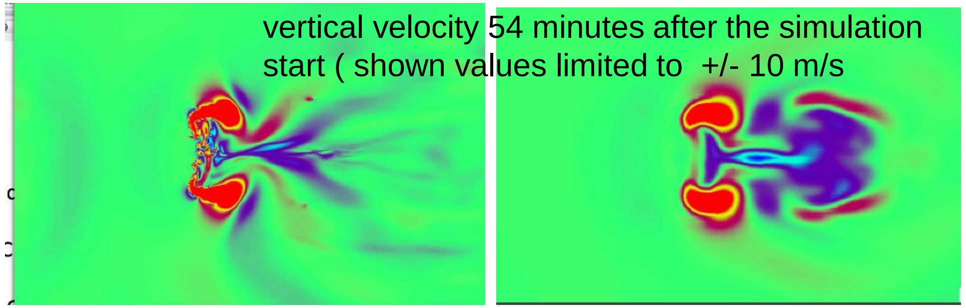
- Other parameters like the updraft helicity become more realistic for higher resolutions. Also the cell structure looks more realistic (updrafts are thinner and fasters, not shown). This does however not have a strong effect on convective dynamics/organization for the cases studied here.



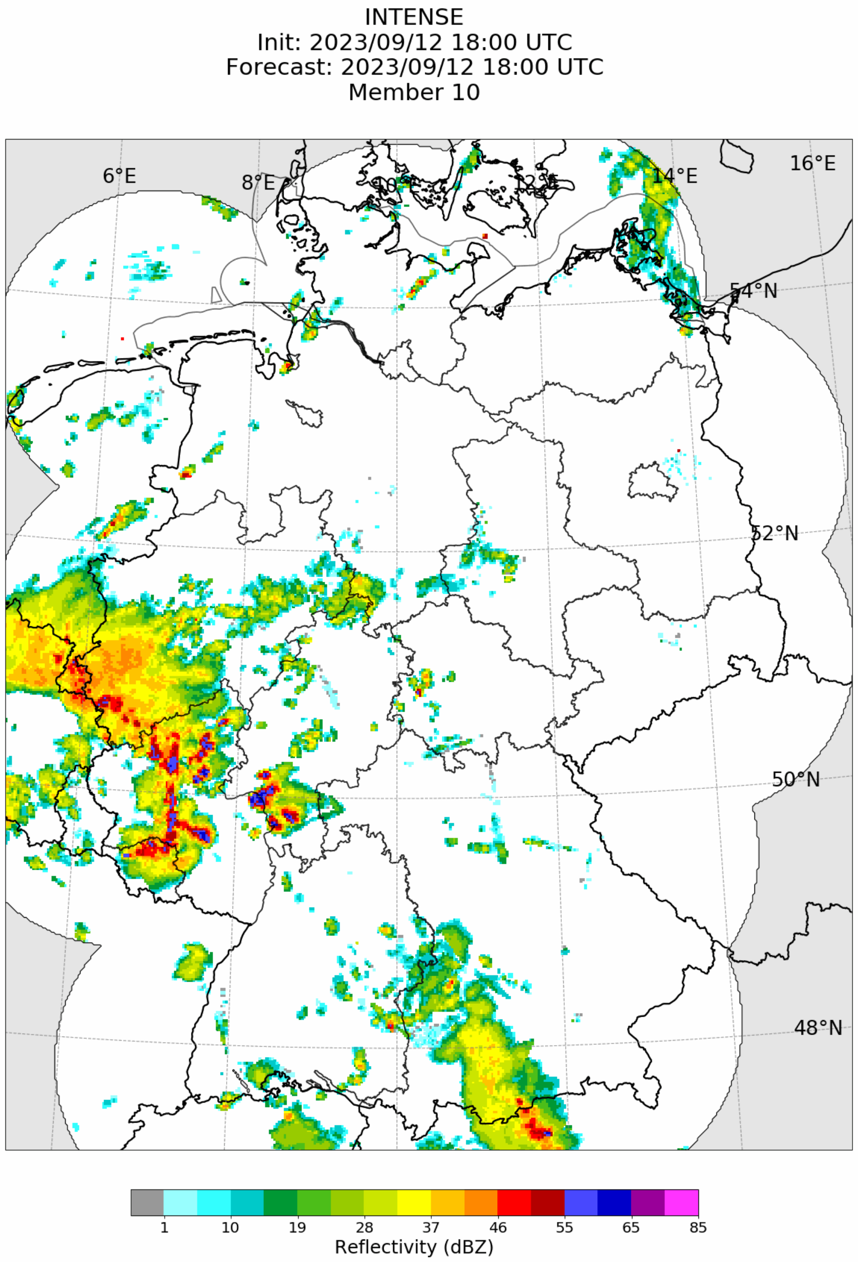
- Can we do better? Should we use different physics (like 3D turbulence) for higher resolutions?

- Test with idealized Weisman-Klemp supercells show very similar dynamics in 100 m-LES and 1km-ICON when using identical microphysics (thanks to Chiel van Heerwaarden). Larger differences are found when changing the microphysics.

vertical velocity 54 minutes after the simulation start (shown values limited to +/- 10 m/s



microHH (100m LES) ICON (1km NWP)


INTENSE
Init: 2023/09/12 18:00 UTC
Forecast: 2023/09/12 18:00 UTC
Member 10
6°E
8°E
14°E
16°E
54°N
52°N
50°N
48°N
1
10
19
28
37
46
55
65
85
Reflectivity (dBZ)

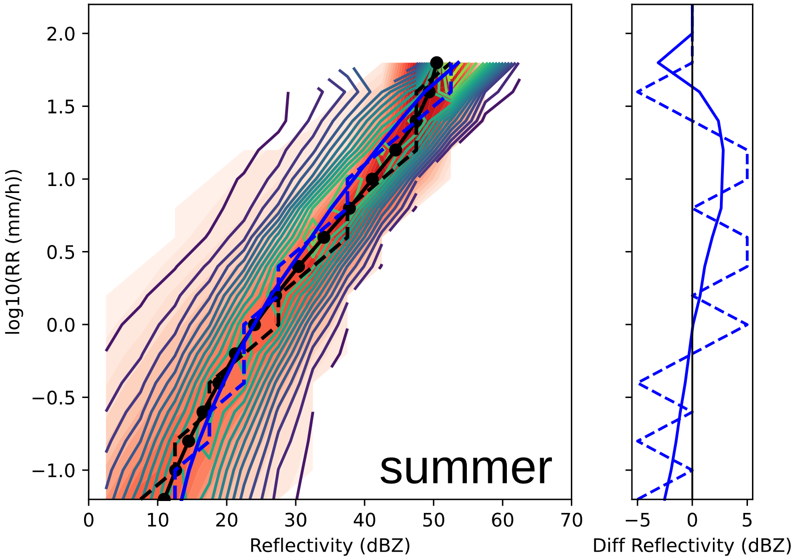
THANK YOU!

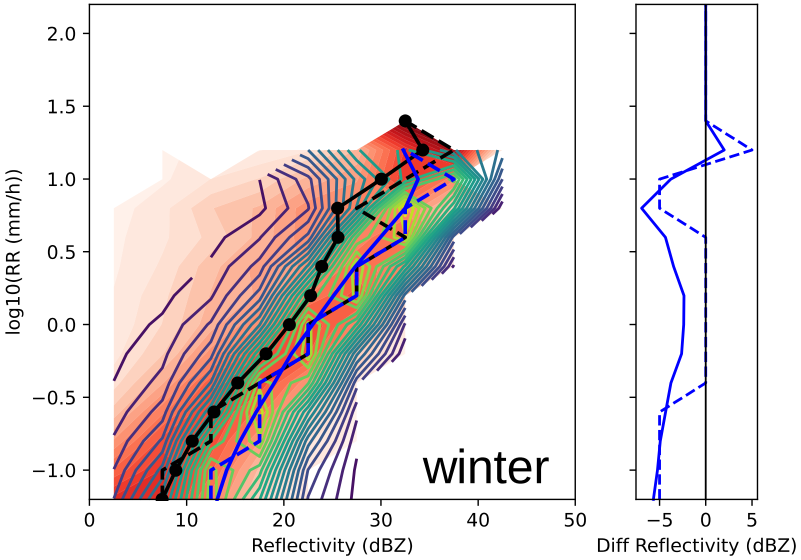
Evaluation by DWD forecasters and ESSL

- ➔ Apart from our verification suite we let the model to be evaluated by our warning-forecasters and European Severe Storm Laboratory (ESSL). Both groups provide a subjective evaluation of the model in severe weather conditions, which complements our verification suite.

- ➔ Last year the reviews were mostly positive, with both groups seeing an added value of the SINFONY forecasts. One common critic was that we have to correct the **Z-R relationship**.

- ➔ As a consequence we have added a Z-R plots for our verification.





Some lessons from Tuning

- ➔ The number of Cloud Condensation Nuclei (CCN) was adjusted for the radiation balance and visible reflectances from SEVIRI.
- ➔ Increased ice-ice collisions reduces the radiation bias and improve IR reflectances.
- ➔ Changing the density of Ice Nuclei (IN) does have a minor impact (especially in summer).
- ➔ Reducing graupel-graupel (from 0.1 to 0.05) and snow-snow collisions (Connolly 2012) lower the high reflectivities and improve Z-R relationship.
- ➔ Use realistic capacitances for condensation/evaporation (Westbrook 2007) for ice and snow and realistic graupel velocity (Heyms 2014) improves stratiform regions behind large-scale convective systems.
- ➔ We did come back to an exponential droplet-size distribution for rain and added turbulence effects on autoconversion (Onishi), which increases drizzle.

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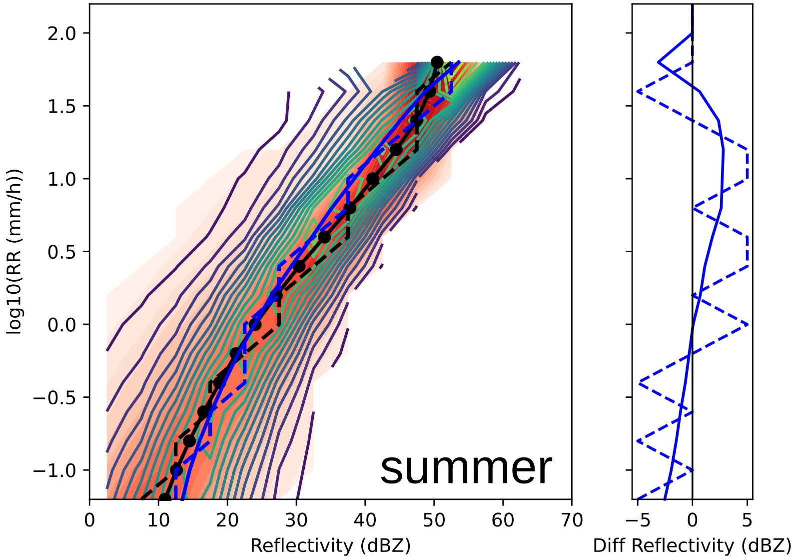
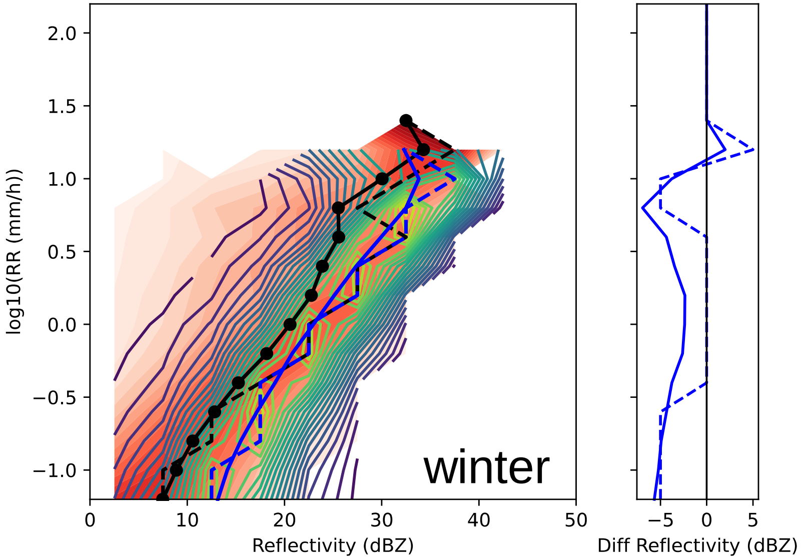
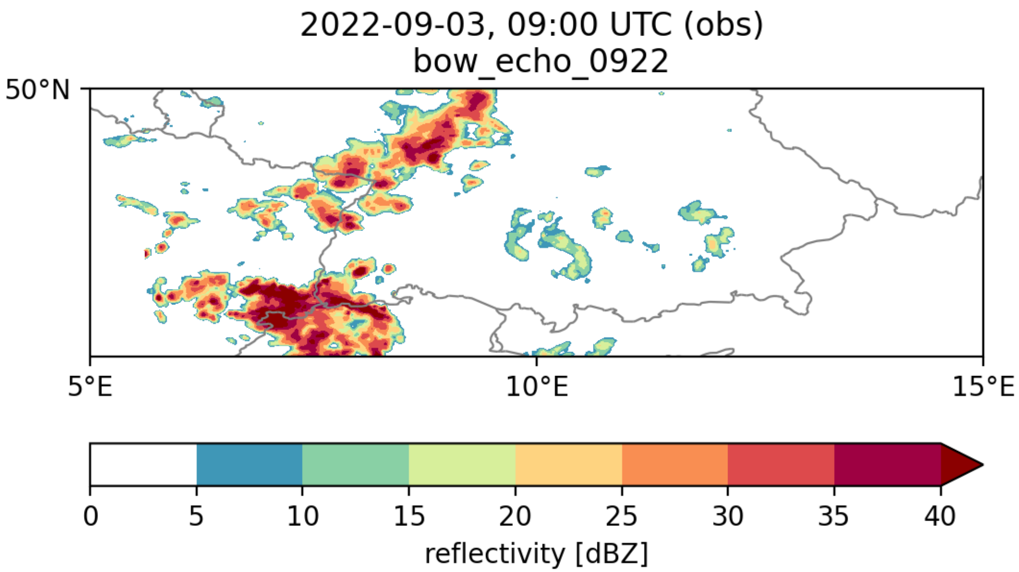
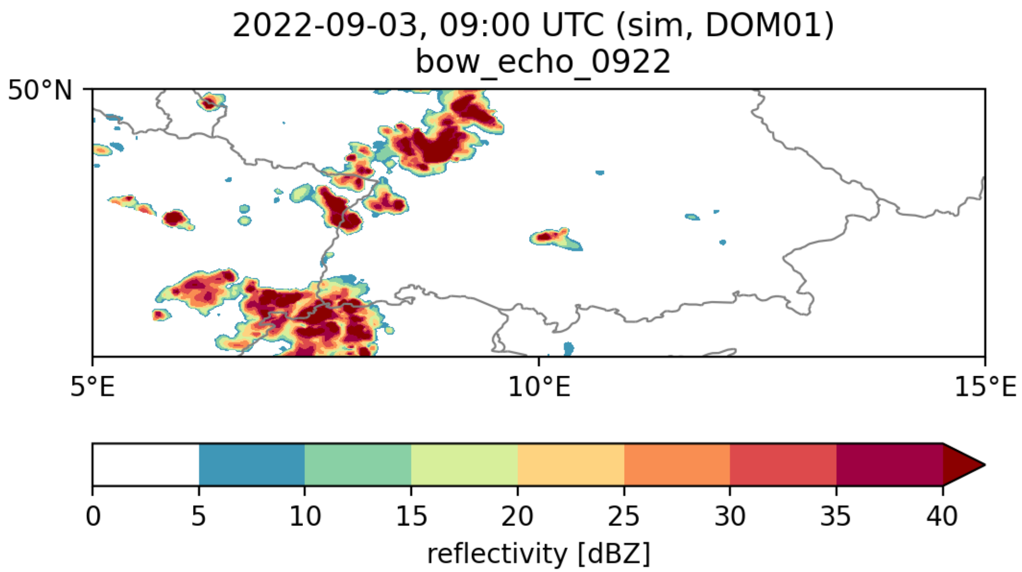


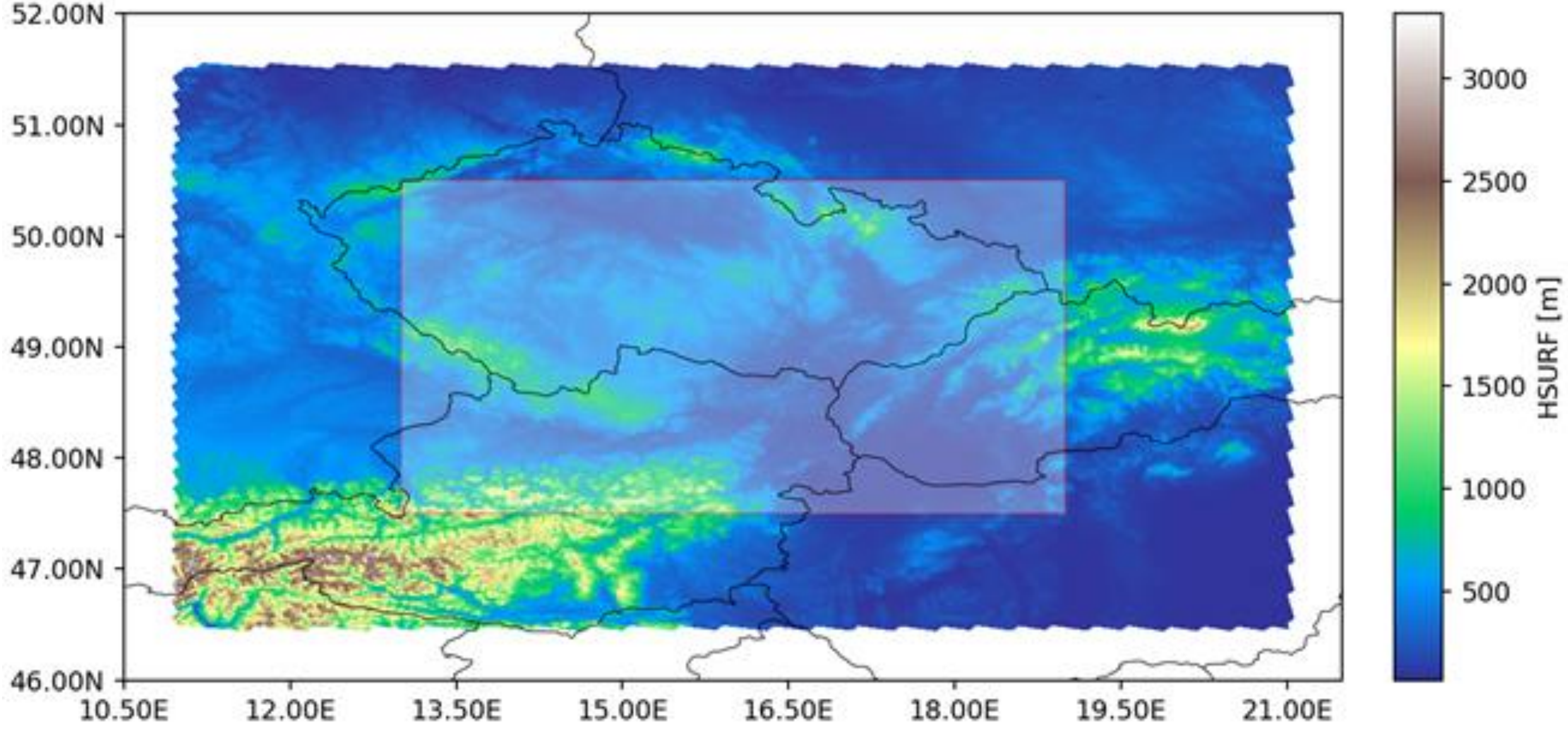


Bow echo for different resolutions (assimilation step)





Case 2: Tornado over Czech Republic domain



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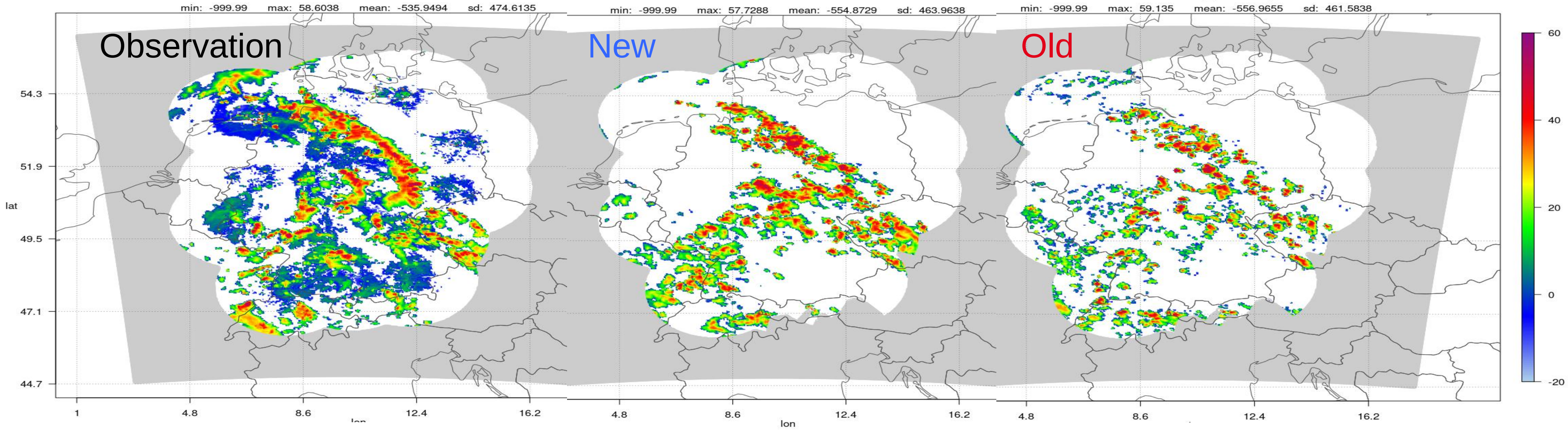

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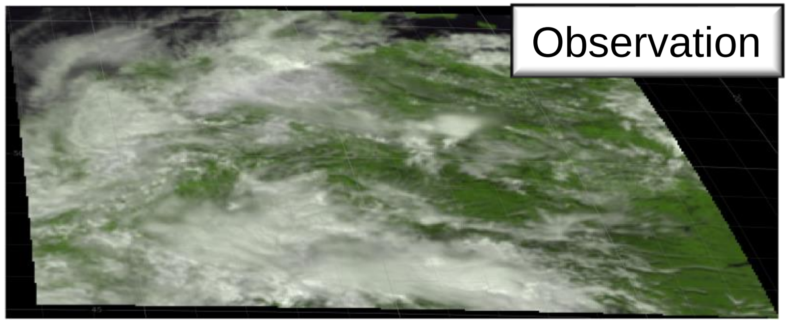
- ➔ We did come back to an exponential droplet-size distribution for rain and added turbulence effects on autoconversion (Onishi), which increases drizzle.

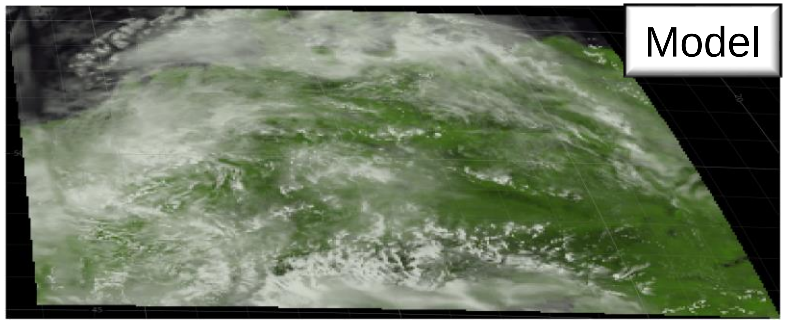
From research to operational

- ➔ The two-moment scheme has been previously used for research, mostly for case studies. Now it must perform every hour of every day for all weather conditions.

- ➔ The model had been prepared to work with our assimilation system LETKF, the convective parameterization and latent-heat nudging.

- ➔ Extensive tuning is necessary:
  - We aim to produce realistic reflectivities to facilitate the prediction of severe storms.
  - But at the same time the model cannot become worst for the variables it is usually verified (radio sondes, surface station, sensors on aircrafts and rain).
  - We further use satellite information (mostly from visible and infrared channels) with the aim to get more realistic clouds. The forward operator RTTOV uses the particle size provided by the two-moment scheme.





- Seamless combination of Nowcasting and Numerical Weather Prediction for short-term forecasts (+12h).
- Ingrediens: high frequency forecasts, aggressive assimilation, two-moment scheme, sophisticated radar operator, combined products.
- The initial focus is on severe convective events, typically in summer.
- We explore the advantage of using nested high resolution for the forecasts.