SINFONY* - the Combination of Nowcasting and NWP on the Convective Scale at DWD

German Weather Service (DWD)

Ulrich Blahak

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* Seamless INtegrated FOrecastiNg sYstem

- At the moment large **pilot project** at DWD to develop a coupled probabilistic system of radar-based precipitation advection nowcasting and very-short-range NWP (hourly forecasts up to +12 h) on the convective scale
- In pilot project, we start with „seamless“ = „from minutes to hours“

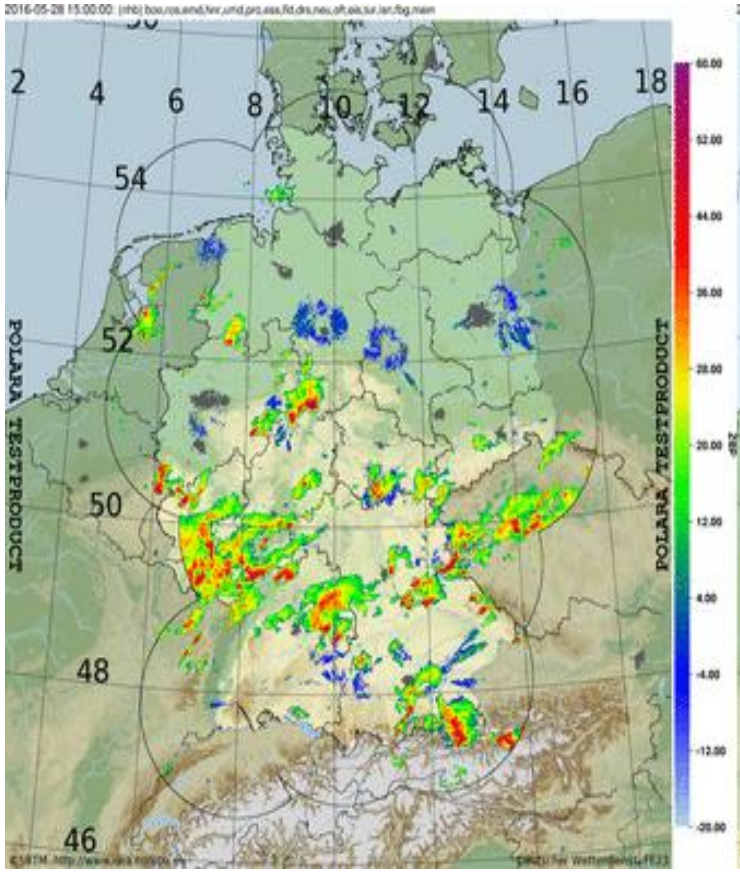
Current forecasting methods @ DWD

Two very different and separate forecasting methods for lead time range 0-12 hours:

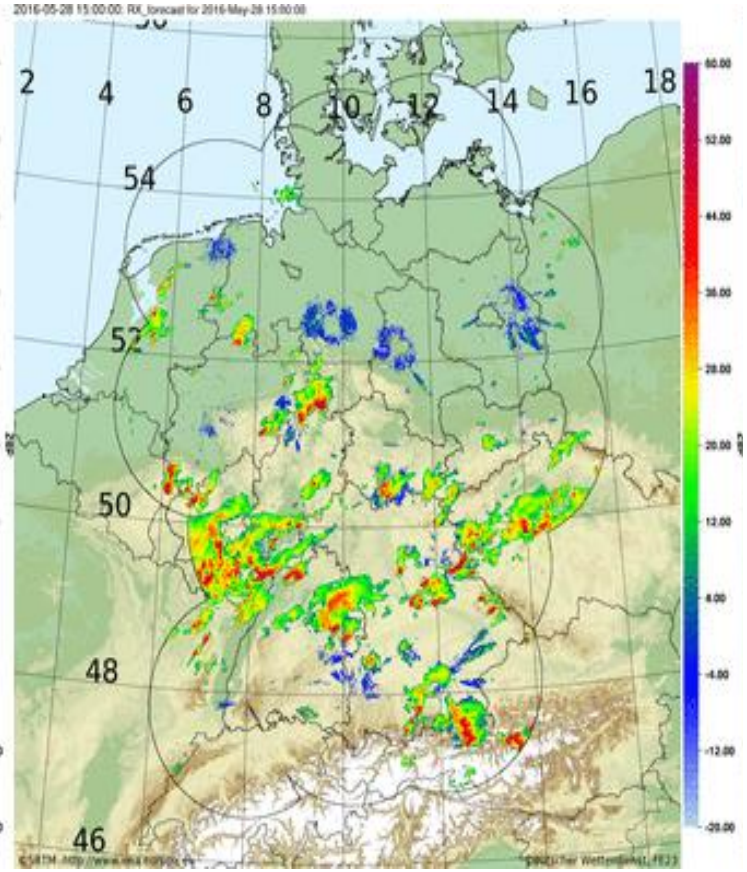
Nowcasting (0-2 hours):

- ➔ Purely deterministic (optical flow + cell objects)
- ➔ „Cheap“, available very soon after the actual date, updates every 5 min

Observations



Optical-Flow Nowcasting



28.5.2016 15-19 UTC (+0 h to + 4 h)

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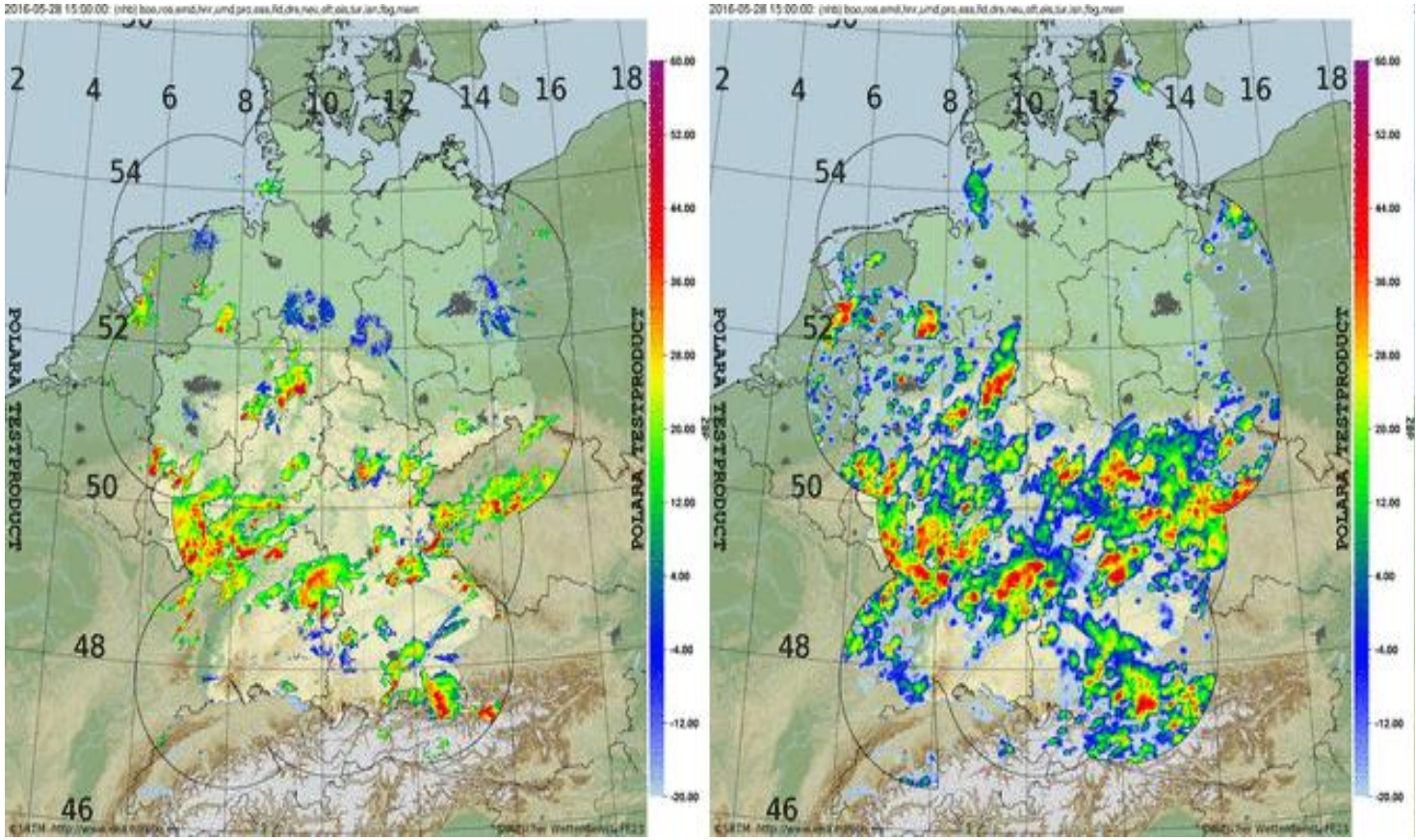
Very-short-range NWP (2-12 hours):

- ➔ Deterministic and ensemble @ 2.2 km grid spacing (currently COSMO-D2 / -EPS, soon ICON-LAM-D2 / -EPS)
- ➔ „Expensive“, new forecasts available ~1 – 1,75 h after the actual date, new forecasts every 3 h up to +27 / +48 h

Up to now no common products

➔ No seamless transition!

Observations | **Deterministic COSMO-DE**

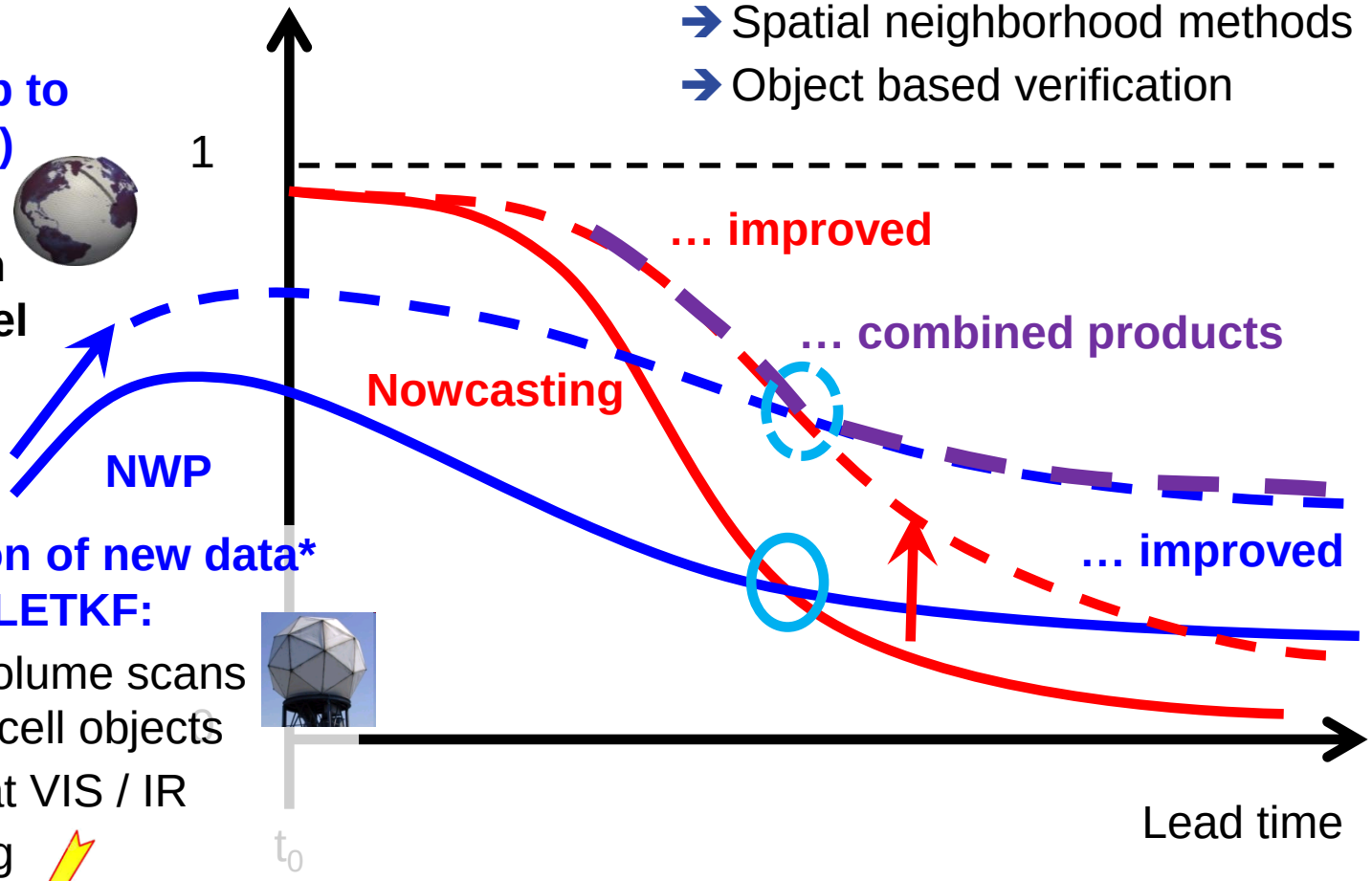


28.5.2016 15-19 UTC (+0 h to + 4 h)

Basic idea and concept of the SINFONY

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Some verification score for convective events



➔ **Hourly new forecasts up to + 12 h (RUC)**

ICON-LAM
Δx = 2 / 1 km
adapted model physics

➔ **Assimilation of new data* in KENDA-LETKF:**

- ➔ Radar volume scans v_r, dBZ, cell objects
- ➔ Meteosat VIS / IR
- ➔ Lightning

➔ **Comparative verification:**

- ➔ Spatial neighborhood methods
- ➔ Object based verification

➔ **For now radar based precipitation Nowcasting**

1) **Gridded fields (mm/h, dBZ)** POLARA Polarimetric Radar Algorithms
2) **Cell objects** KONRAD3D

➔ **Improving methods**

➔ **Ensembles to represent the following uncertainties:**

1) **Configuration parameters**
2) **Scale dependent predictability**
3) **Tendencies / „life cycle“ beyond pure advection**

*) In addition to the „conventional“ data, such as SYNOP, TEMP, profiler, MODE-S

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Planned SINFONY radar Nowcasting ensembles: gridded fields and „objects“

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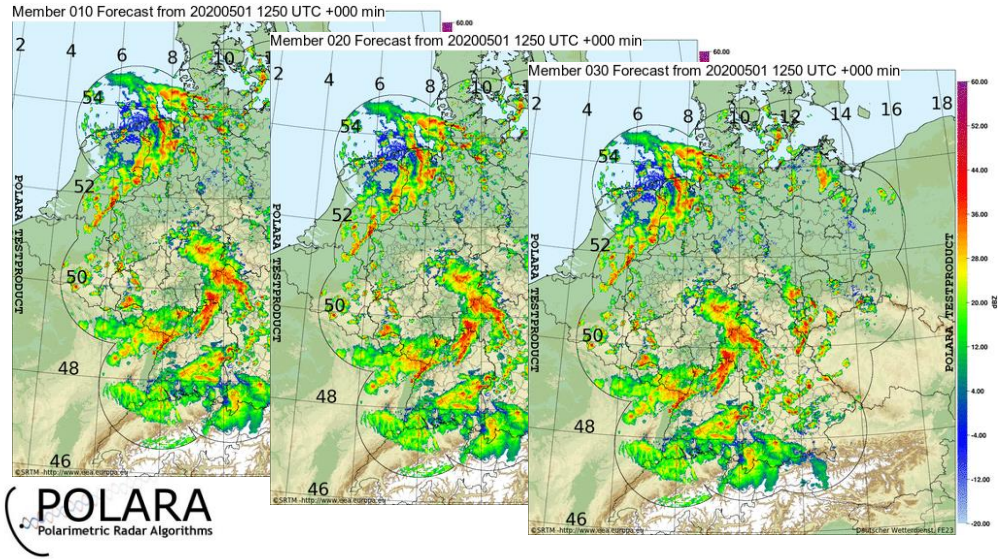
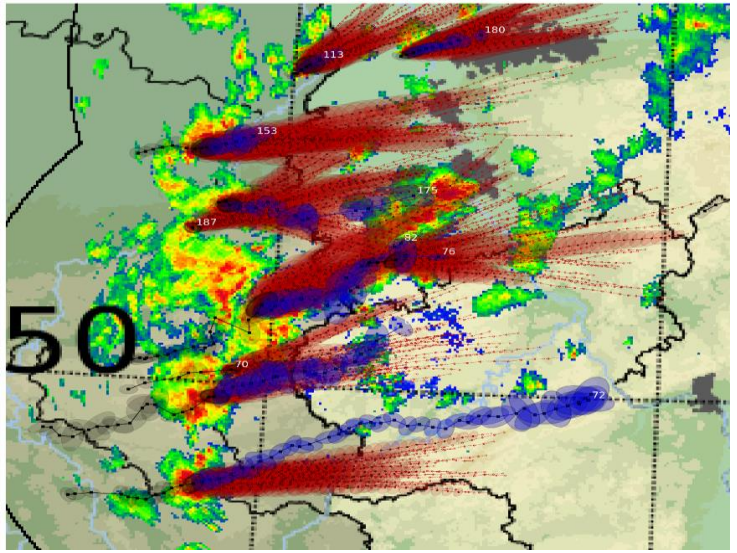
➔ **Ensemble** Nowcasting methods, update every 5‘ and forecast time range up to t_0 + 6 h





KONRAD3D
EPS

- ➔ Grid-based (composits): reflectivity, mm/h
- ➔ „Optical flow“ motion analysis
- ➔ To date: determ. linear advection forecast

- ➔ Objects = simplified (yet 3D) representation of cells
- ➔ Cell detection and -tracking in 3D volume scans
- ➔ To date: determ. linear advection forecast

➔ How to impose a meaningful „life cycle“ (growth, decay) and/or its uncertainty on top of linear advection, based on statistical analysis of the past?

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Prototype „Optical Flow“ radar Nowcasting ensemble: Scale dependend predictability

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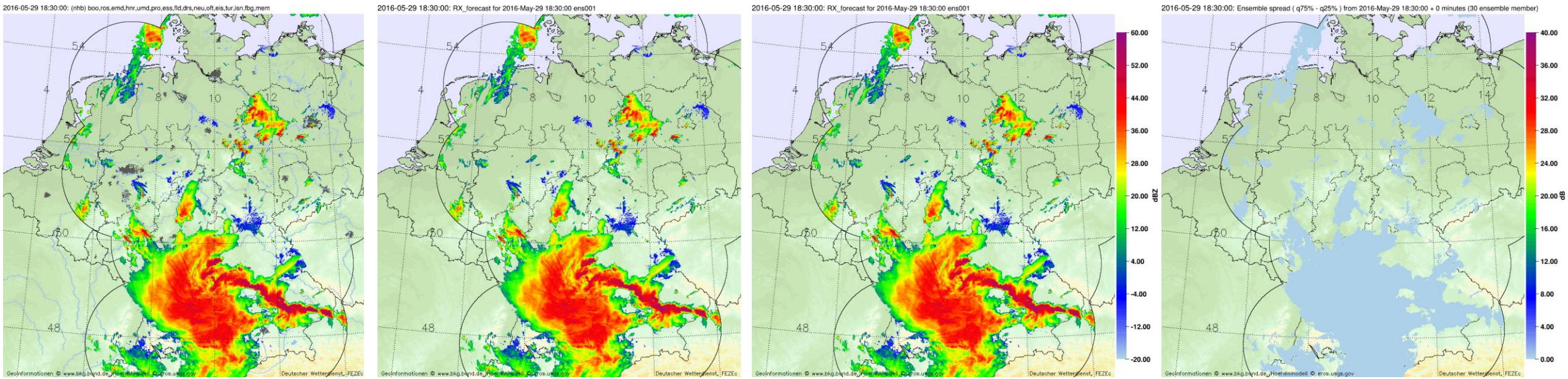
Use elements of the STEPS system (BoM, MetOffice, MeteoSwiss, …) ➔ STEPS-DWD

1) Eliminate the ever-growing unpredictable scales
   ➔ **Forecast of the „predictable“ (deterministic)**
2) Replace „unpredictable“ scales by several realisations of suitable correllated noise
   ➔ **Grid-based SINFONY Nowcasting ensemble**

Observation | **Nowcast of the “predictable”** | **Nowcast – ensemble member 1** | **Interquartile range 75 – 25 %**



Nowcasting ensemble with 20 members, initialised at 29.05.16, 18:30 – 19:55 UTC, radar reflectivity

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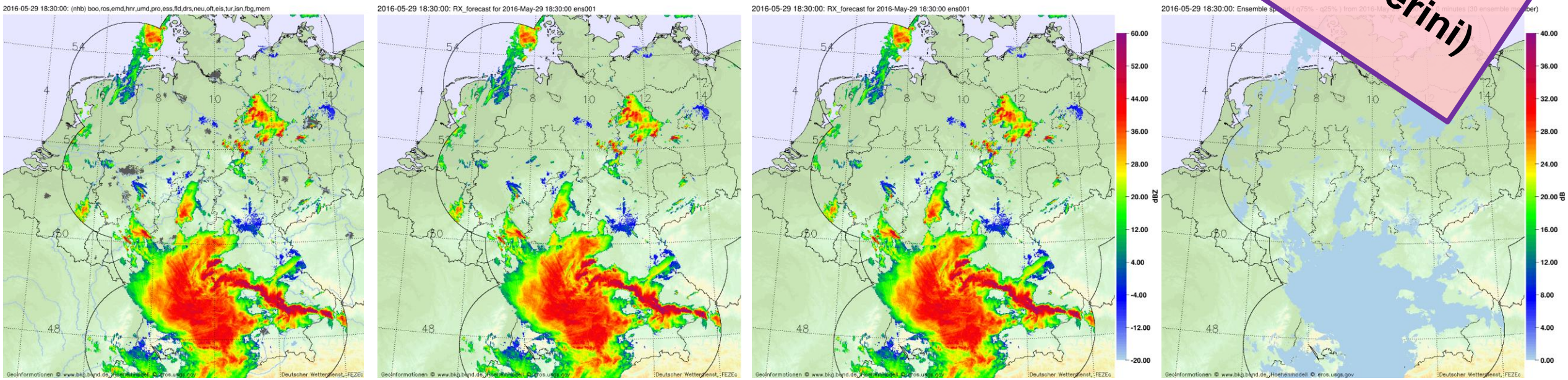
Thanks for much help and advice from MeteoSwiss (Loris Foresti, Daniele Nerini) ➔ pySTEPS

Observation | **Nowcast of the “predictable”** | **Nowcast – ensemble member 1** | **Interquartile range q75 - q25 %**



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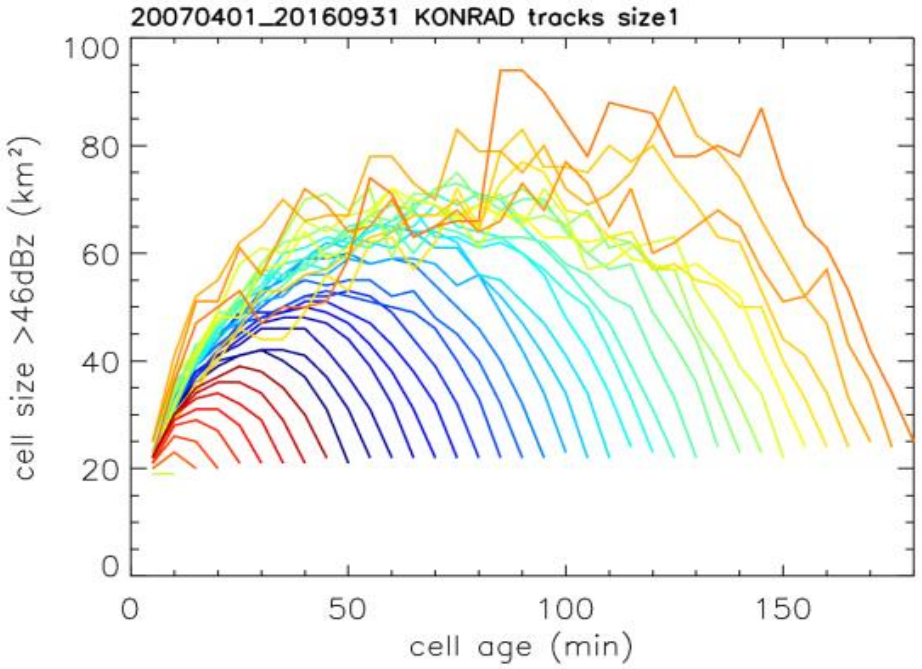
Prototype object-based SINFONY Nowcasting ensemble:

Ansatz to generate object ensemble:

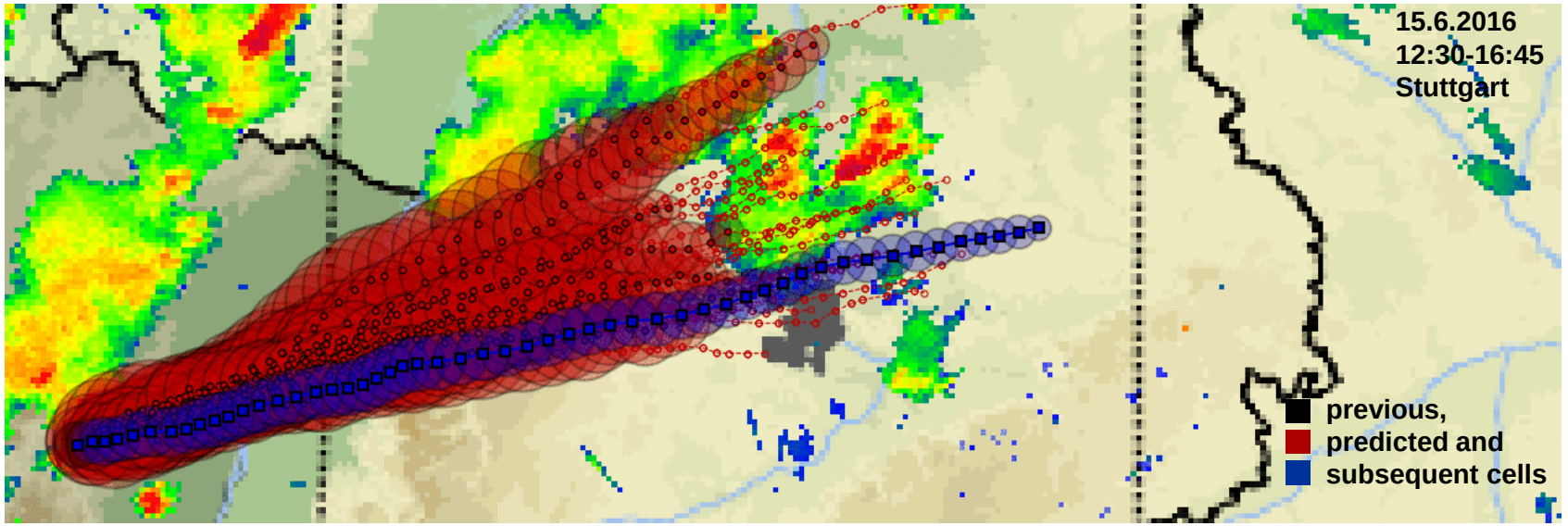
- **For now:** For newly detected cells, „first-guess“ parabola ensemble with wide-spread shape- and width parameters as initial forecast. Successive correction by **Ensemble Kalman Filter**

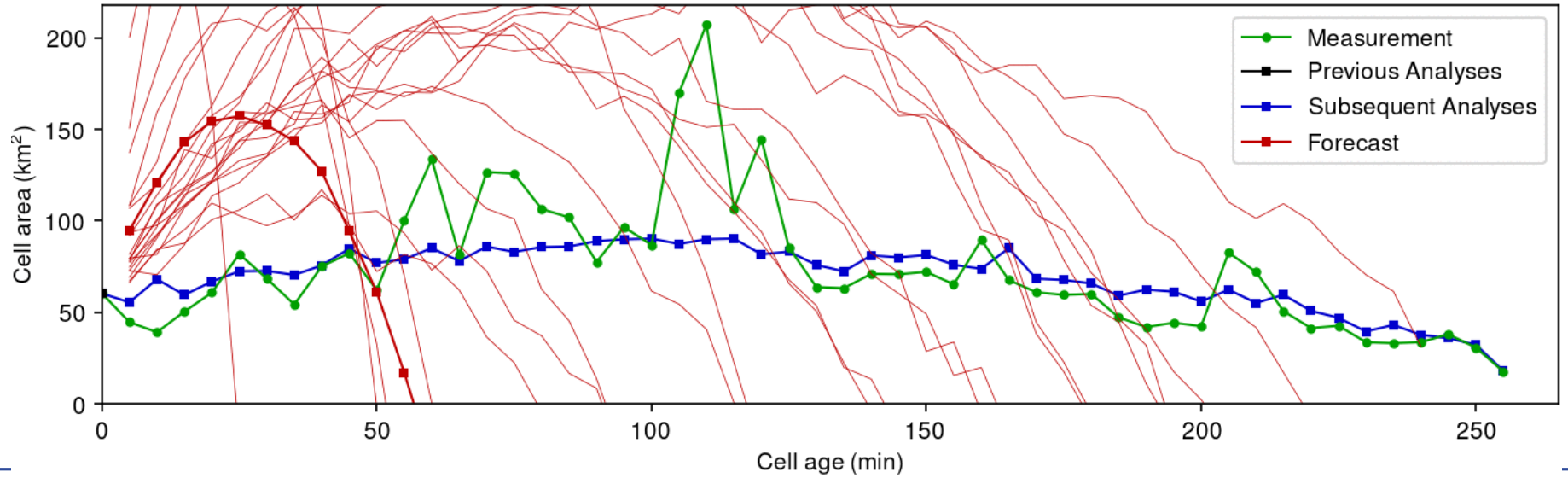
- **Later:** replace first-guess“ parabolas by refined / more advanced mathematical models, potentially depending also on evironmental conditions from NWP (project @ KIT)



Climatology (Wapler et al. 2017): Median cell size as function of cell age for different life-time classes (colors), Germany, 2007 – 2016.
However: huge deviations for individual cases!

Prototype object-based SINFONY Nowcasting ensemble:





Some Further plans for SINFONY Nowcasting

- ➔ Start to investigate AI methods for different aspects of Nowcasting
- ➔ Verification of KONRAD3D-EPS
- ➔ Refine KONRAD3D-EPS: more accurate „first guess“ ensemble, covariance inflation

Planned SINFONY NWP Rapid Update Cycle Ensemble

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ICON-LAM

ICON-LAM-D2 ENS: 2 km
IC: KENDA-LETKF data assimilation
BC: ICON-EU Nest ENS
New forecasts every 3 h to + 48 h

SINFONY-RUC-ENS:
ICON-LAM @ 2 (+ 1) km
IC: KENDA-LETKF data assimilation
with 3D Radar, SEVIRI-VIS / IR, lightning
BC: ICON-EU Nest ENS
New forecasts every 1 h to + 12 h
Combination with Nowcasting
(precipitation, cell objects)

ICON-EU Nest ENS / DET: 6.5 km

ICON global ENS / DET

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SINFONY RUC-ENS:
ICON-LAM-D2 (+ 1) km
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with 3D Radar, SEVIRI VIS, Lightning
BC: ICON-EU Nest ENS
New forecasts every 1 h to + 12 h
Combination with Nowcasting
(precipitation, cell objects)

Available ~ 45 min after the actual date

ICON-EU Nest ENS / DET: 6.5 km

ICON global ENS / DET

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Some challenges for SINFONY RUC development

- Km-scale NWP at DWD moves from COSMO-model to ICON-LAM – we have to follow!

ICON-LAM

- ICON-LAM model development is very dynamic – we have to follow with our experiments!
- Resources on our previous HPC (Cray) were relatively limited, given the demands of SINFONY-RUC! ➔ Slow and sometimes cumbersome experimentation.
- Currently, a new and considerably larger HPC (NEC SX Aurora) is installed. Only now better situation for experimentation coming up.
- Pre-operations to be started in 2021, first internal evaluation in 2022, operations in 2023

Another challenge: model results in observation space (dBZ, objects, Sat IR / VIS channels)

- ➔ Radar reflectivity, satellite observations (IR / VIS) and cell objects as well as their Nowcasts are very helpful for convective warnings and are extensively used
- ➔ Why not presenting model results also in these observation metrics? ➔ **forward operators, KONRAD3D objects**
- ➔ This enables seamless combined Nowcasting-NWP-products
- ➔ For verification: very „direct“ comparison of obs and model, also by way of Nowcast objects
- ➔ **Pilot project:** reflectivity, KONRAD3D-objects, precipitation rate/ -sum, SEVIRI-VIS channel
- ➔ This enables assimilation of 3D radar volumes (radial wind, reflectivity, KONRAD3D objects) and SEVIRI-VIS channels in SINFONY-RUC-ENS by DWD‘s **Localized Ensemble Transform Kalman Filter (LETKF)**

Forward operator MFASIS for Meteosat SEVIRI-VIS

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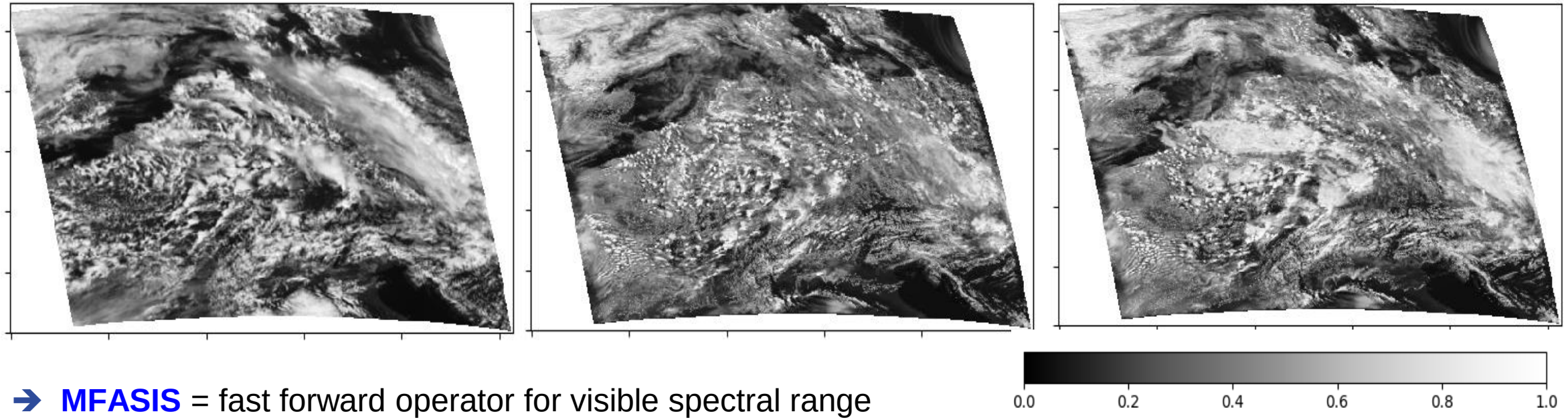
15.6.2016

Observation | **1-moment cloud microphysics** | **2-moment cloud microphysics**



- **MFASIS** = fast forward operator for visible spectral range (University of Munich LMU)
- DWD + LMU provide MFASIS for the community in the RTTOV framework (NWP-SAF)
- Scheck et al. (2016, 2018)

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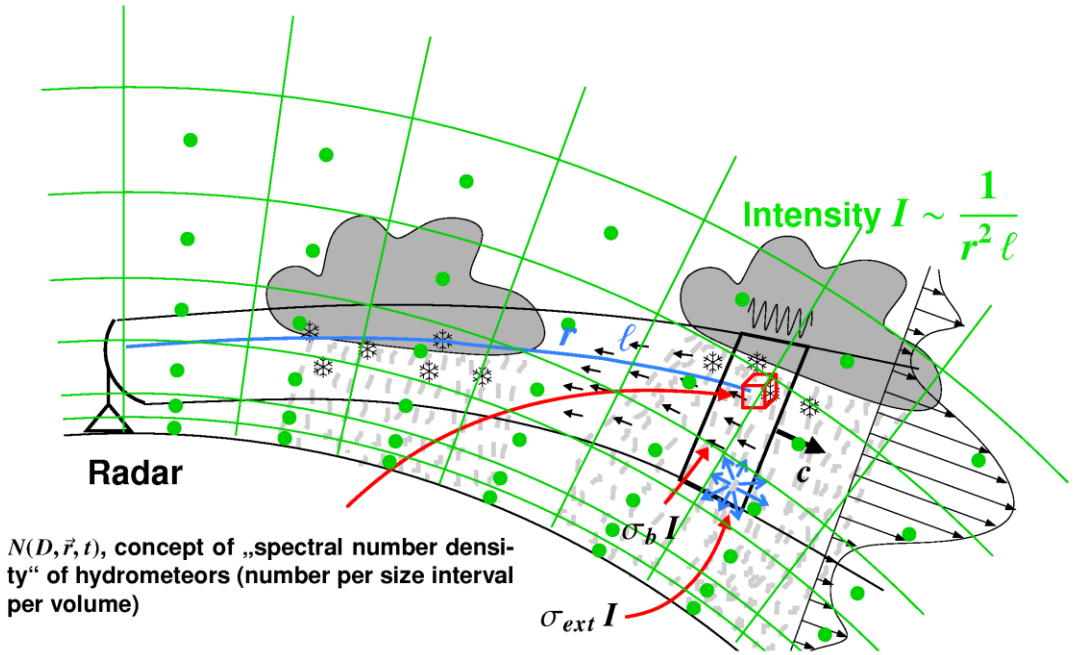
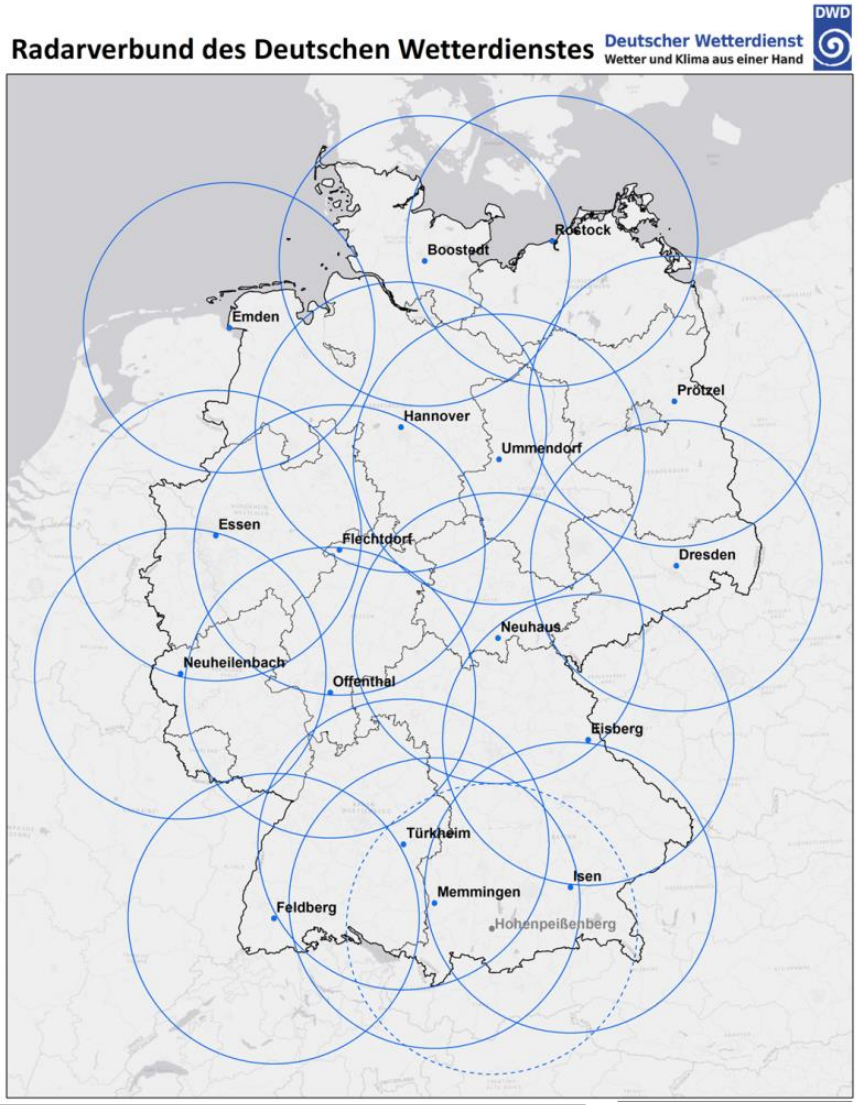
Radar forward operator EMVORADO

Model grid and weather radar



Simulated parameters along radar rays of 3D volume scans:

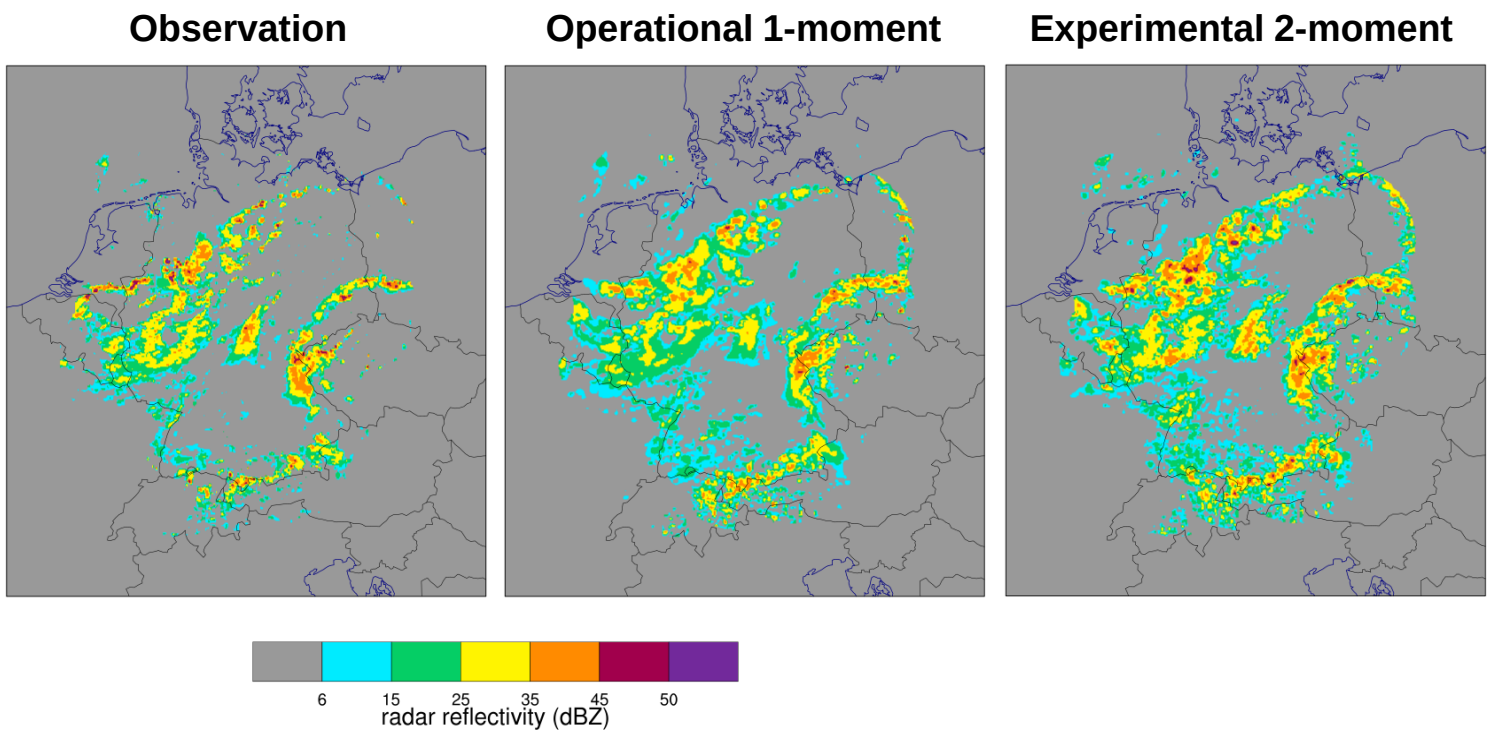
- ➔ **Radar reflectivity Z**
- ➔ **Radial wind V_r**



Zeng et al., 2016: An efficient volume-scanning radar forward operator for NWP models: description and coupling to the COSMO model, QJRMS, **142**, 3234-3256, doi:10.1002/qj.2904

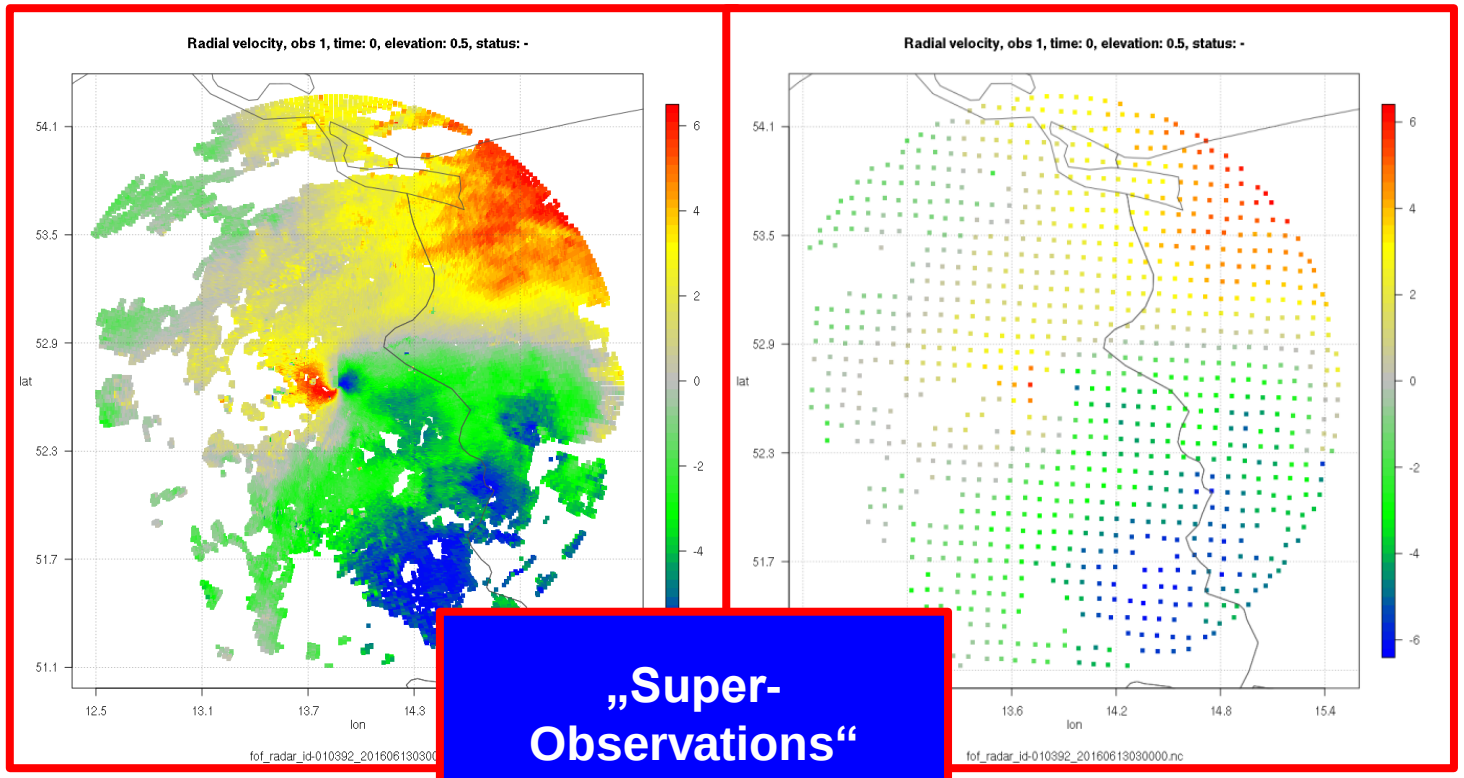
Radar reflectivity and more accurate cloud microphysics

- „Good“ precipitation and simulated reflectivity big challenge for bulk cloud microphysics schemes!
- The ICON standard 1-moment bulk microphyiscs has problems with high reflectivities in convective cores
- We test the **more expensive 2-moment bulk scheme** of Seifert and Beheng (2006), Blahak (2008) and Noppel et al. (2010)

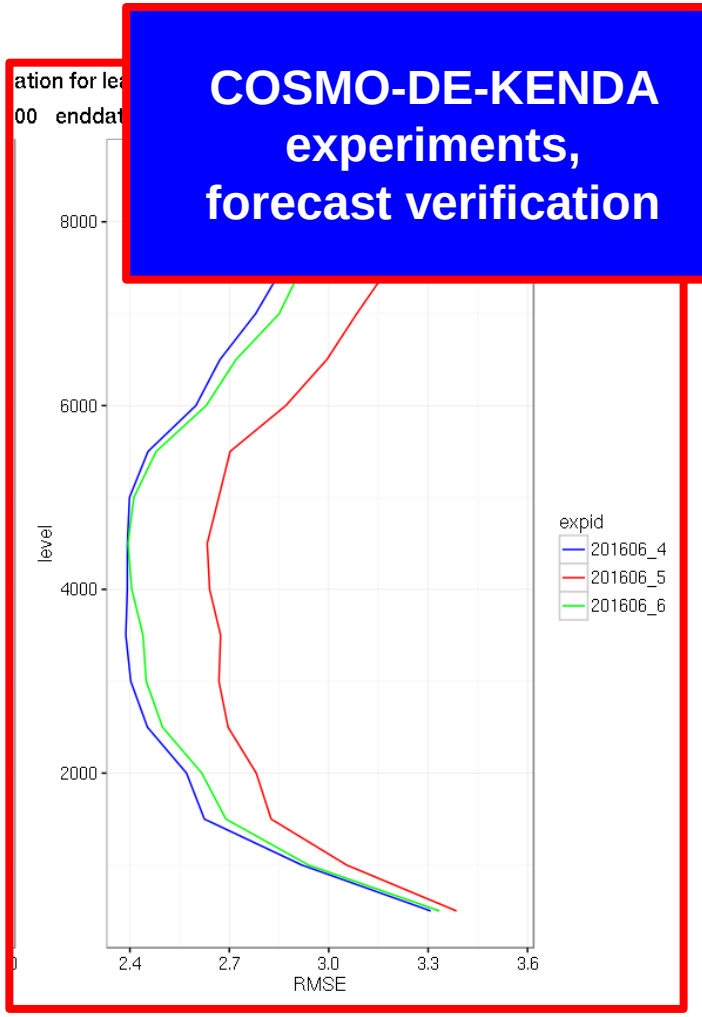


- **Hail** as additional prognostic species on top of cloud water, cloud ice, rain, snow, graupel
- **Prognostic number-** and mass densities of all species
- Allows the simulation of **„relatively“ few but very large hydrometeors** (e.g. rain, graupel, hail) and associated very high reflectivity – **good for data assimilation, cell detection etc**.

How do we assimilate 3D radar data?
Example: radial winds



„Super-Observations“



COSMO-DE-KENDA experiments, forecast verification

How do we assimilate 3D radar data?
Example: radial winds

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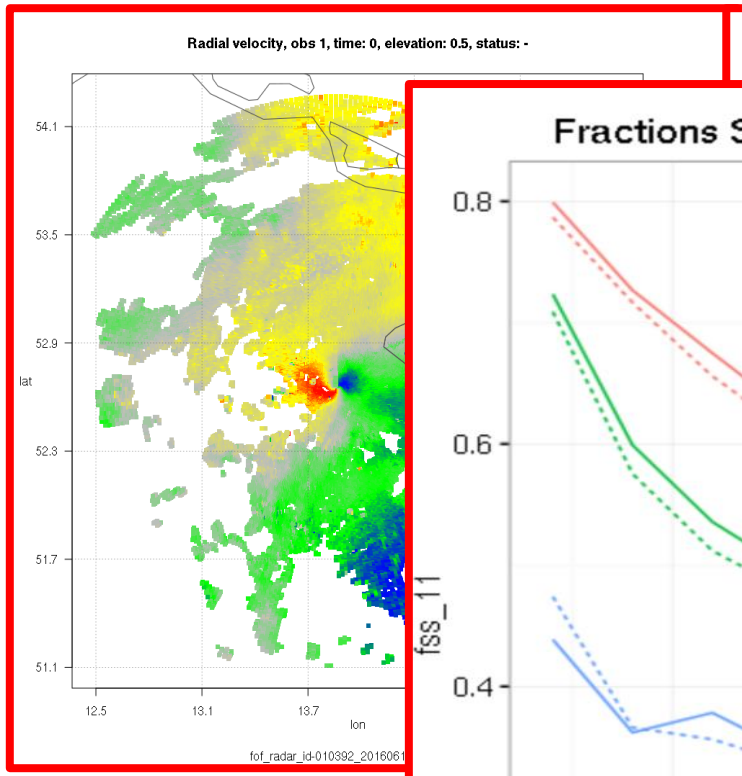

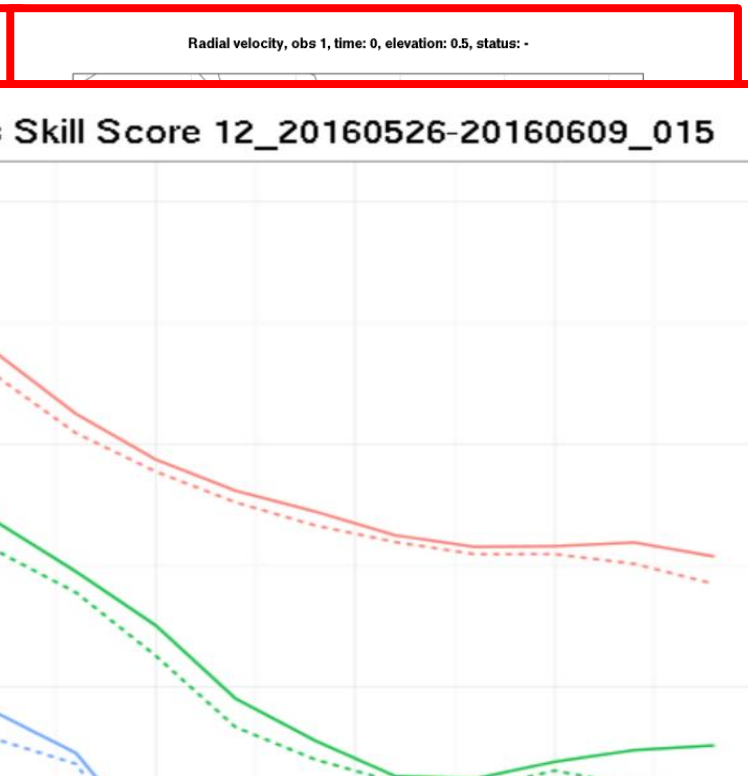

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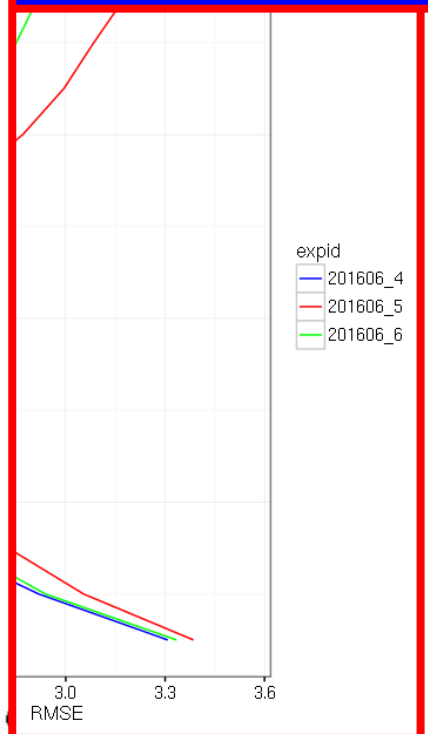

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How do we assimilate 3D radar data?
Example: radial winds

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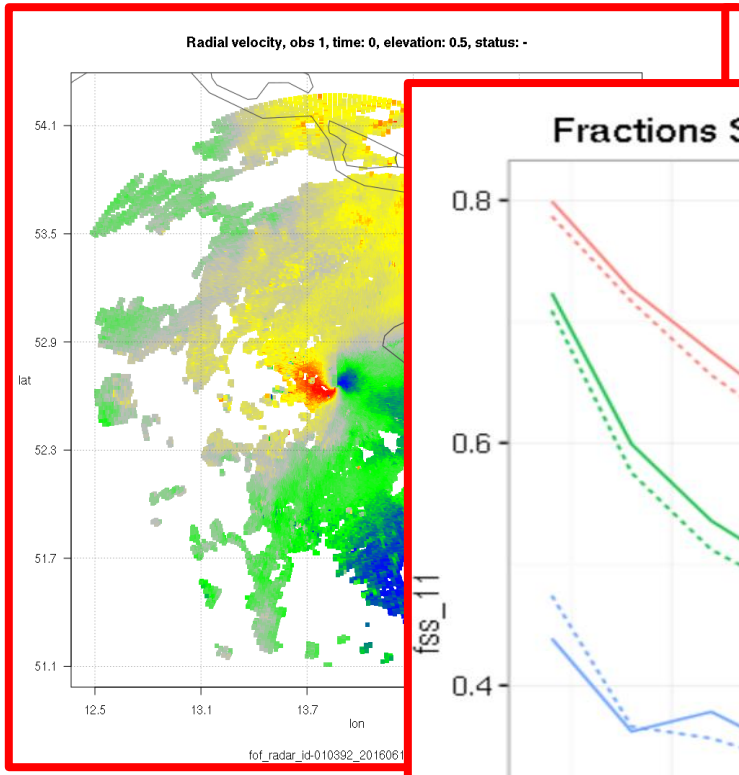

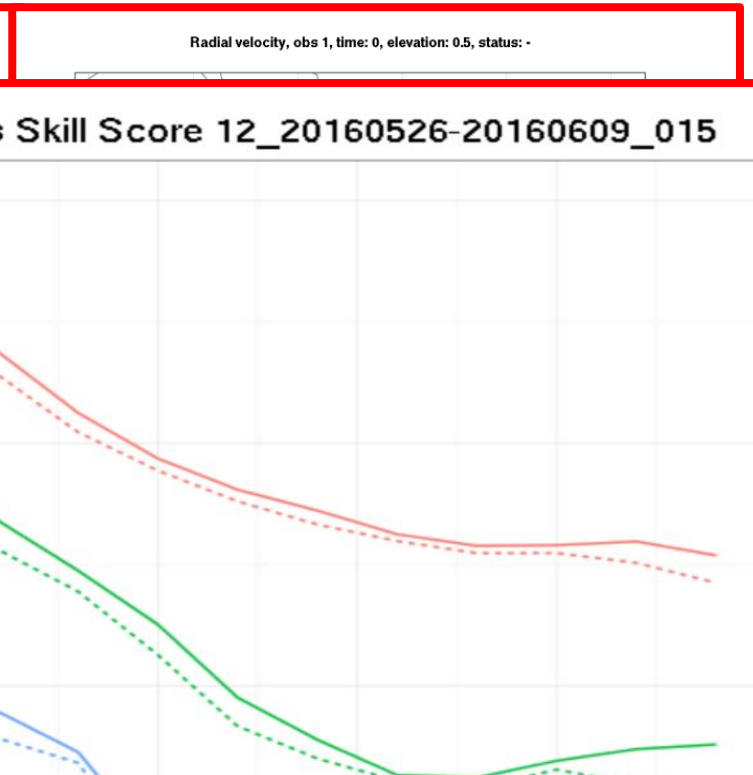

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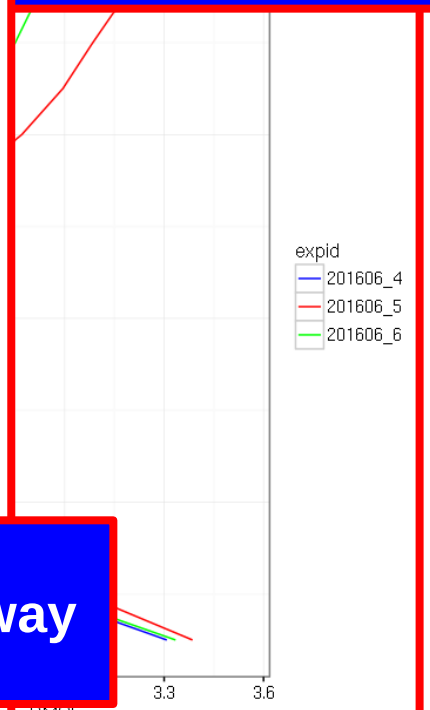
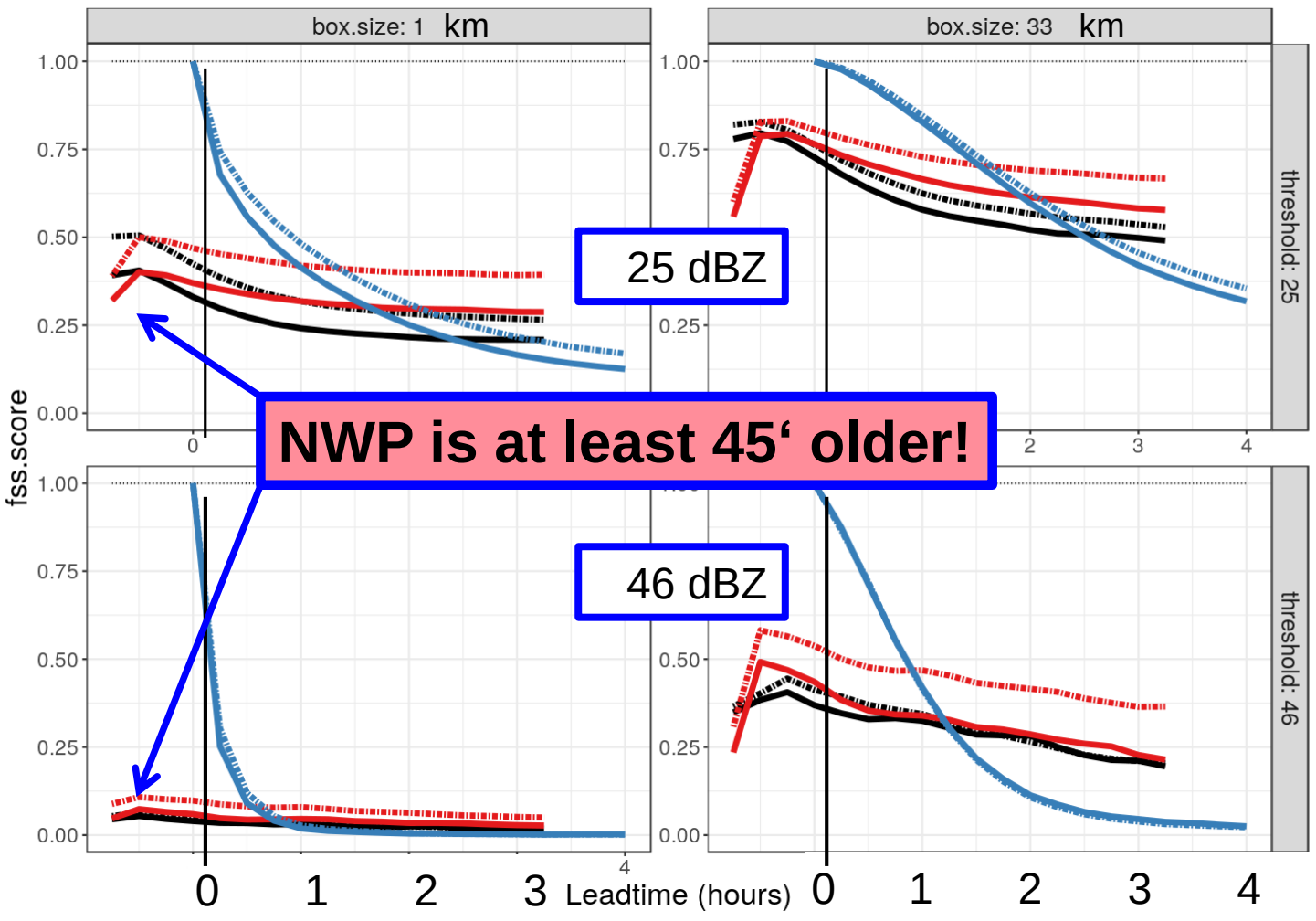


3D reflectivities are assimilated in similar way

Bick, Th., et al., 2016: Assimilation of 3D radar reflectivities with an ensemble Kalman filter on the convective scale, QJRMS, **142**, 1490-1504

Last SINFONY score plot with the COSMO-model



Time period: 26.05. – 25.06.2016

Forecast runs: 10 – 21 UTC (deterministic)

Parameter: radar reflektivity (dBZ)

Score: **Fraction Skill Score (FSS)**

Neighborhood Ens Prob (NEP)

Nowcasting

COSMO-DE
LHN
1-mom

COSMO-DE
3D-Radar
2-mom

Newest ICON-LAM experiment verification (1-mom μφ, June 2019)

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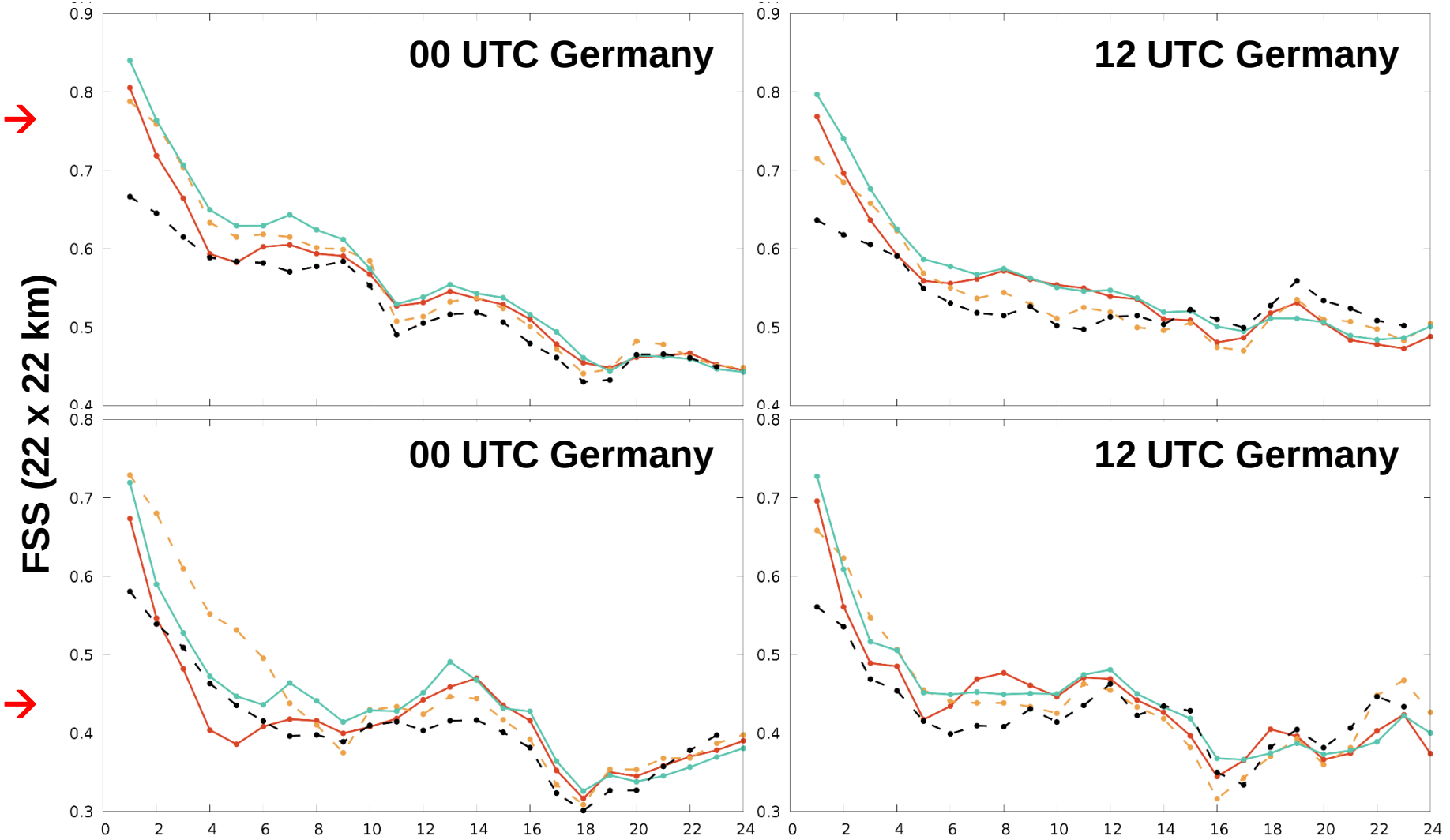
0.1 mm/h →

1.0 mm/h →



Some further plans for ICON-LAM and DA

- Additional 1 km Nest over Germany
- New stochastic PBL scheme in ICON, replacing the current „shallow convection“ parameterization
- EnVAR data assimilation (deterministic run + ensemble re-centering) at the km-scale

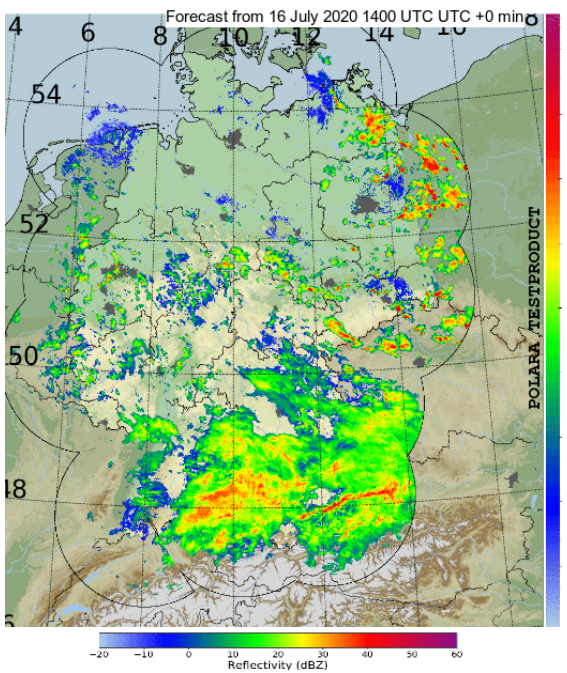
Development of combined products for precipitation quantities

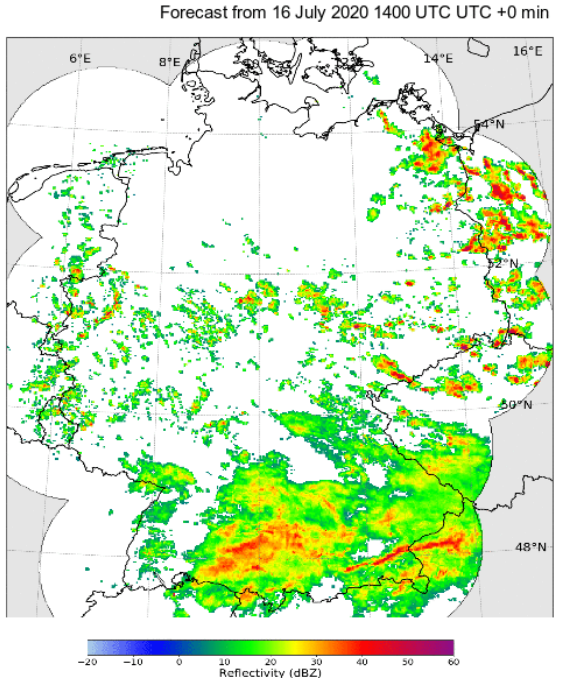
- „Combination“ = optimal linear combination of NWC- and NWP-forecasts
- Weight is function of lead time and weather situation
- Combination of grid-based NWC ensemble with NWP ensemble:
  - Precipitation and radar reflectivity
  - Linear combination of threshold exceedance probabilities
  - Combined ensemble members (challenging!)
- Combination of cell objects from Nowcasting and NWP:
  - For each observed cell object, the Nowcasting object ensemble is combined with the „most fitting“ objects from all members of the NWP ensembles (best cluster).
  - Probabilities from overlap of object ensemble members

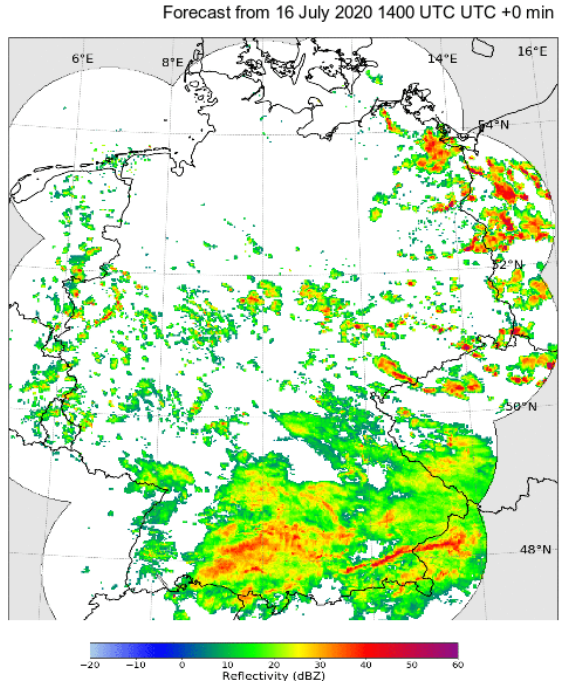
Grid-based combination of Nowcasting and NWP in ensemble space

- Method of Nerini et al. (2019): The model ensemble as „observation“ for an EnKF data assimilation on the Nowcasting ENS (after a PCA to reduce dimensionality)
- Result: combined ensemble members, which individually look like „weather“, but to be interpreted only in the ensemble context. Quantities: radar reflectivity and mm/h

Three ensemble members, forecast from 16 July 2020, 14:00, for 0 to +360 min







Corresponding observation

Grid-based combination of Nowcasting and NWP in ensemble space

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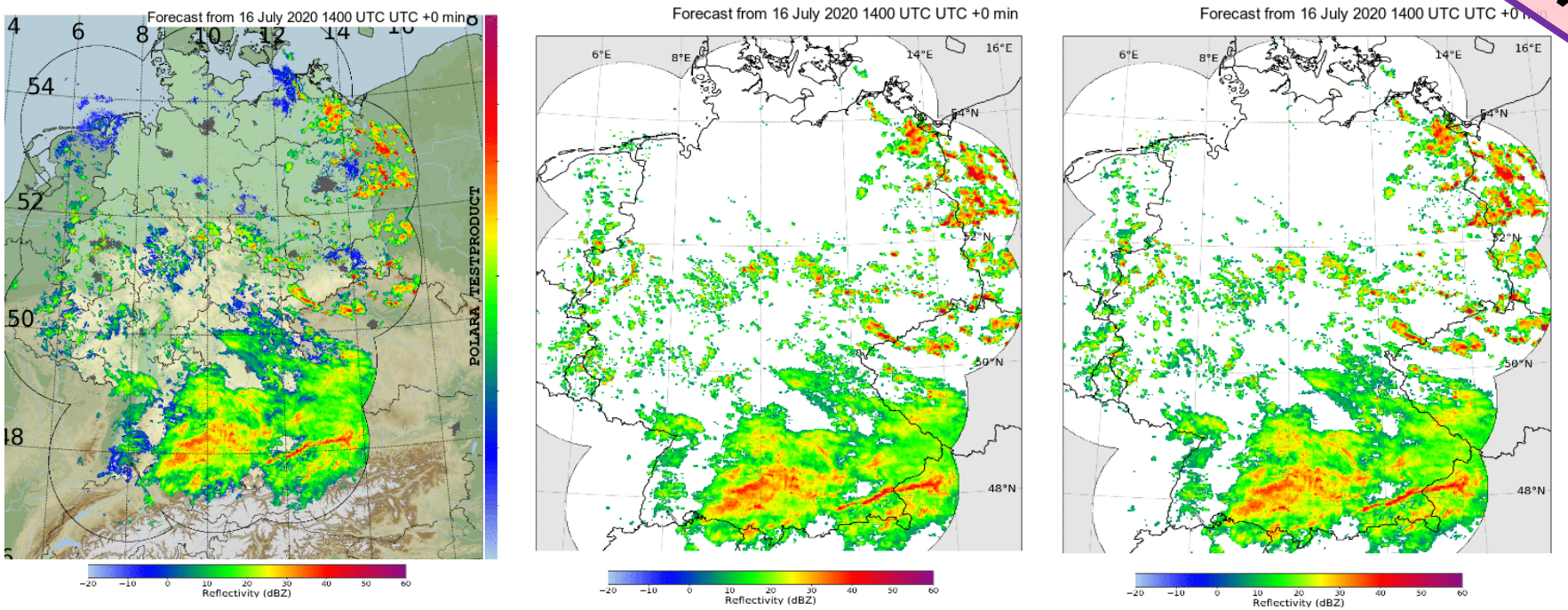

Corresponding observation

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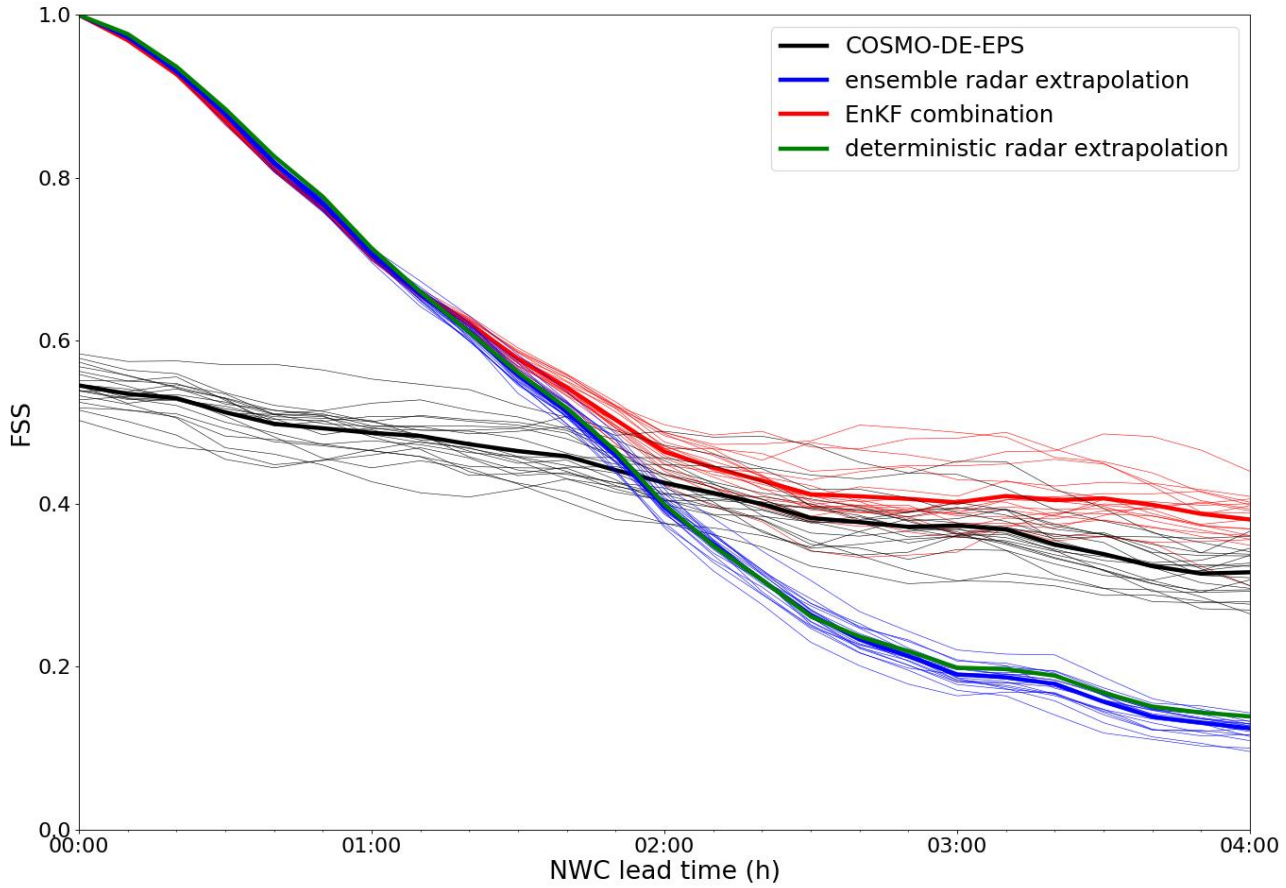
Grid-based EKF Combination, verification for May/June 2016

FSS for NWP, NWC and combined ensemble - period May/June 2016 (threshold: 25 dBZ; boxsize = 22 km)



However:

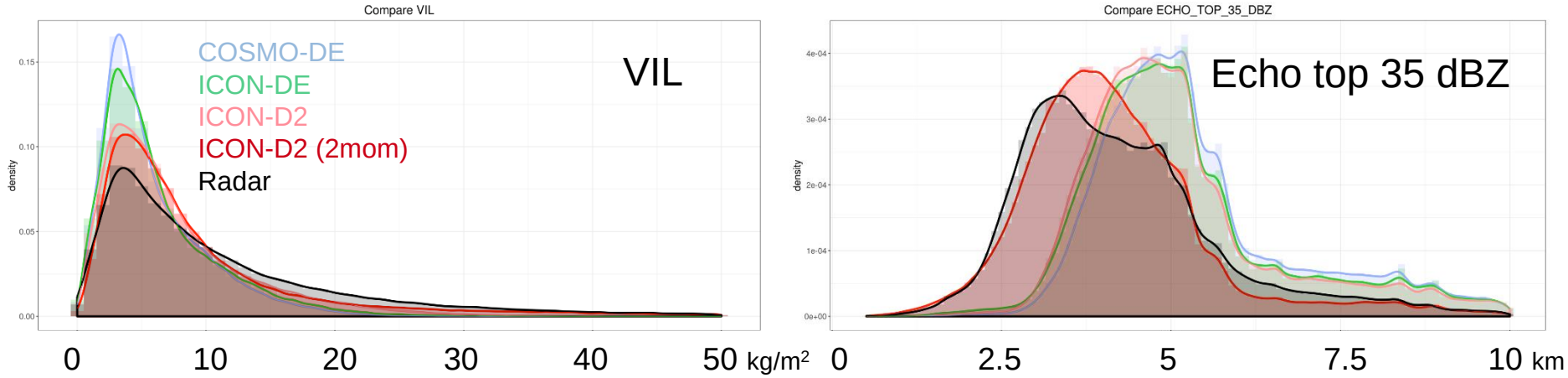
- ➔ Spread-based combination
- ➔ „Best of both worlds“ - skill **NOT** guaranteed
- ➔ Works better for periods of decaying convective activity, less good for growing convective activity

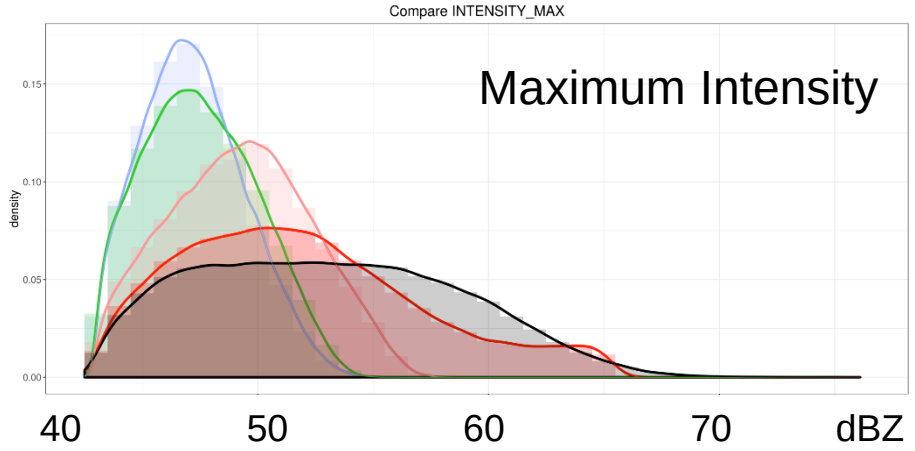
SINFONY simulated cell objects

- ➔ Cell detection and tracking on simulated volume scans from model forecasts with exact same algorithm as for the observations (KONRAD3D):
  - ➔ Allows model verification in comparison with observed cells and their life cycle.
    How good is the model in representing convective cells?

Reflectivities: cell properties

➔ Histograms (pdf) of properties of cells detected by KONRAD-3D that live at least one hour:



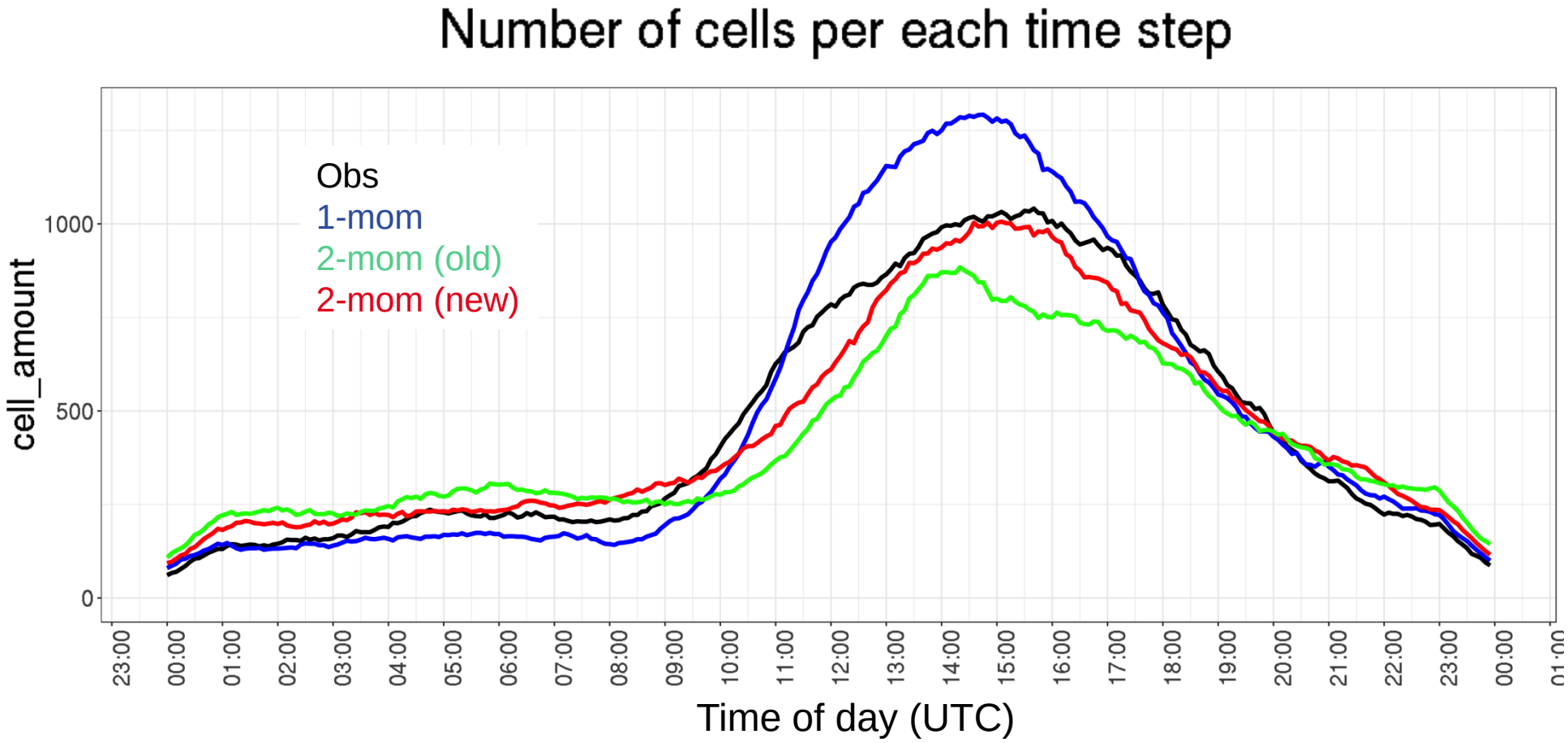


➔ The two-moment scheme produces more realistic cells. This can be very useful for SINFONY products.

➔ VIL and cell size (not shown) are more sensitive to resolution, while echo-top and intensity depend more on model physics.

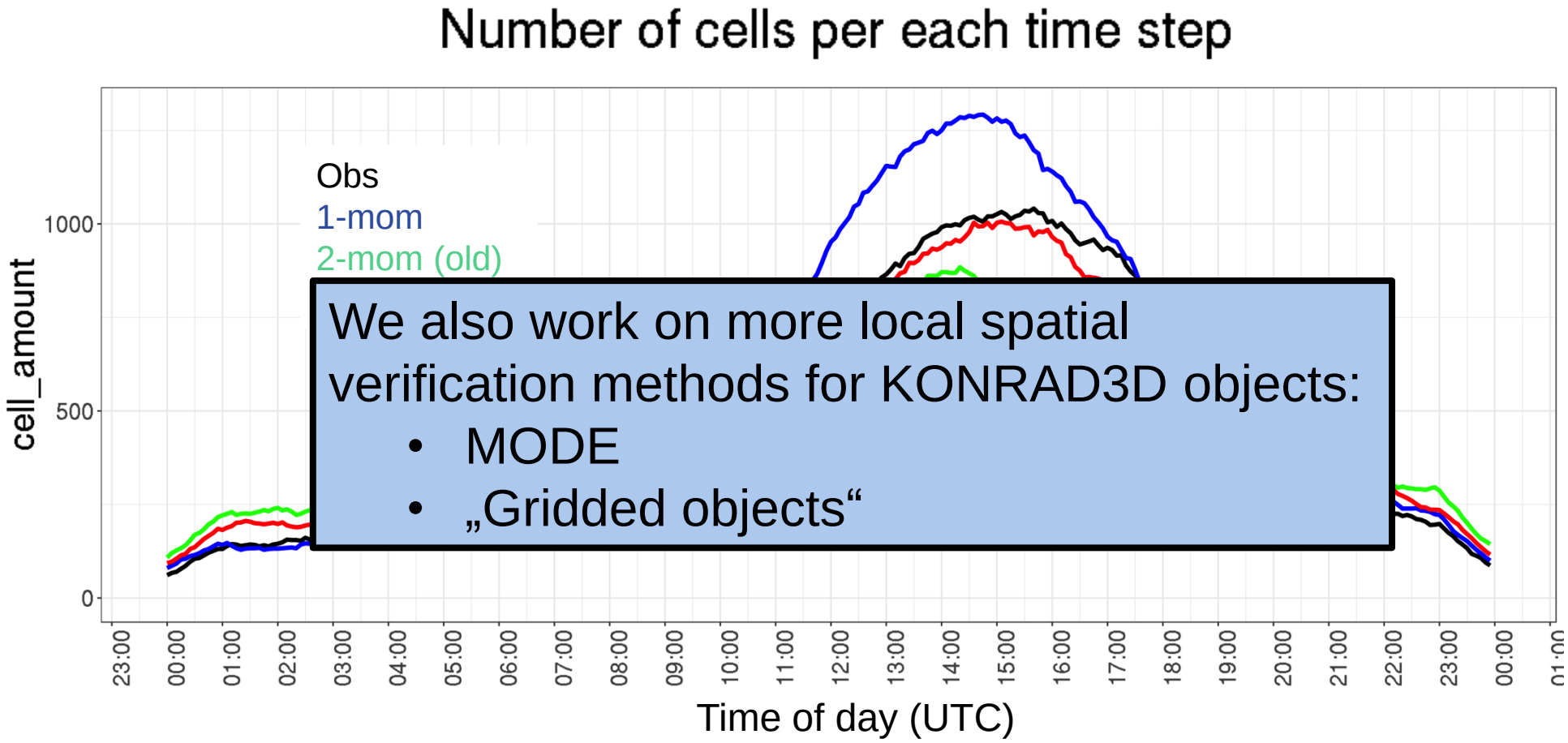
Diurnal cycle of number of long-lived cells (t > 60 min)

➔ More realistic diurnal cycle, but still slightly delayed.



Diurnal cycle of number of long-lived cells (t > 60 min)

➔ More realistic diurnal cycle, but still slightly delayed.



We also work on more local spatial verification methods for KONRAD3D objects:

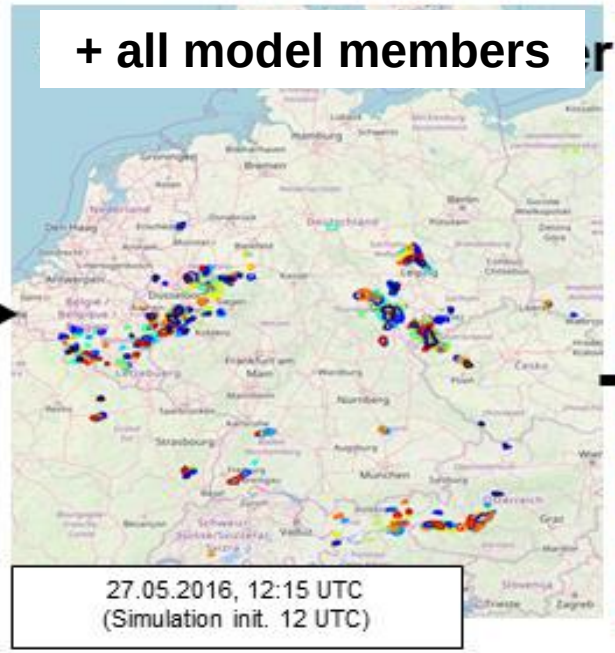
- MODE
- „Gridded objects“

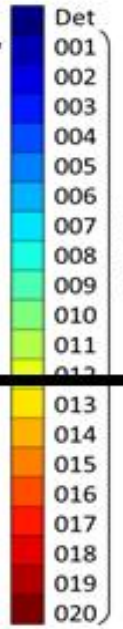
SINFONY simulated cell objects

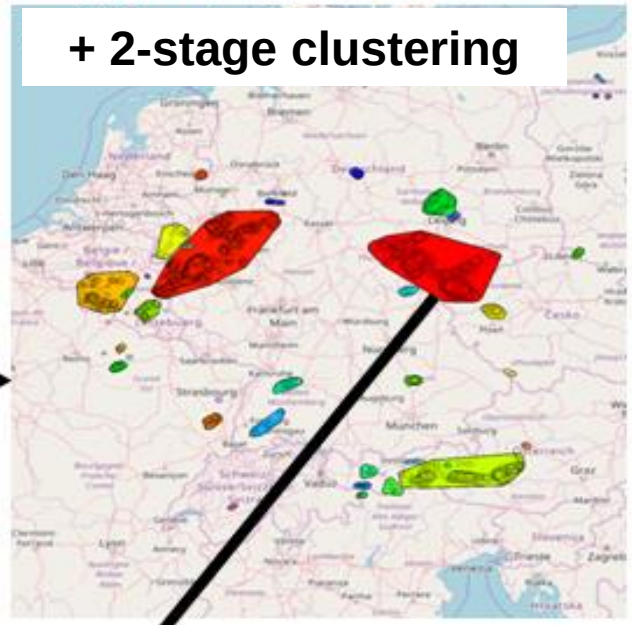
- ➔ Cell detection and tracking on simulated volume scans from model forecasts with exact same algorithm as for the observations (KONRAD3D):
  - ➔ Allows model verification in comparison with observed cells and their life cycle. **How good is the model in representing convective cells?**
  - ➔ **One way to condense the relevant information from convective model forecasts for warning services**

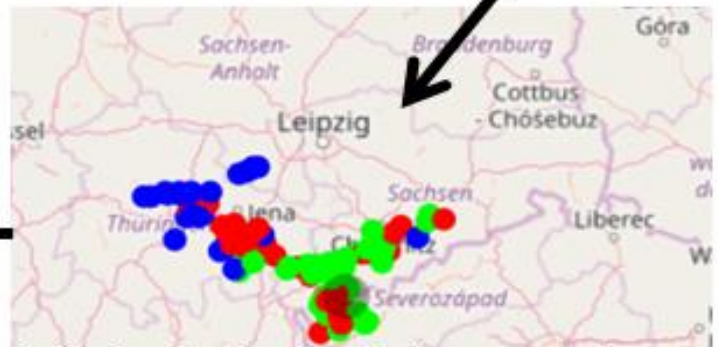
Prototype “reasonable cell selection” of KONRAD3D objects from SINFONY-NWP-ENS

Deutscher Wetterdienst
Wetter und Klima aus einer Hand







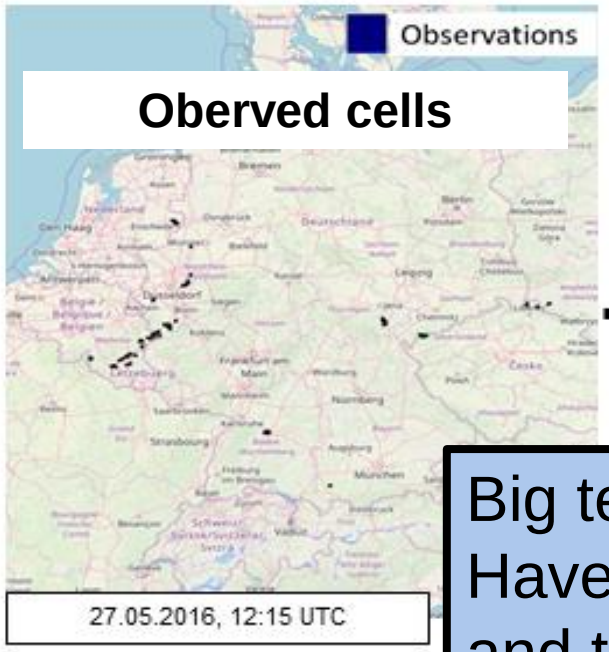


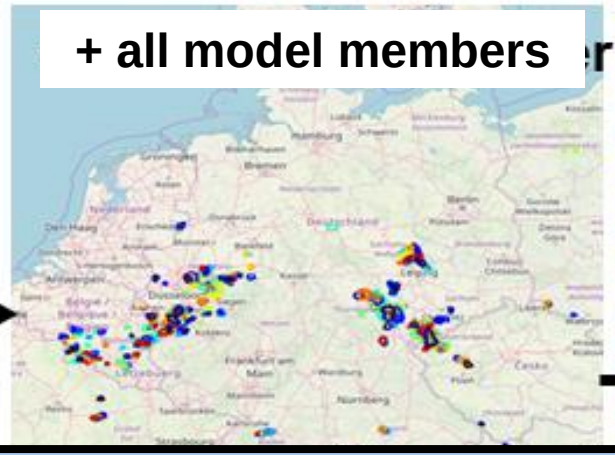
+ „best cluster selection“ for each observed object

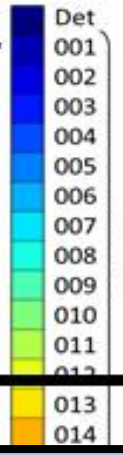
+ „pragmatic“ correction of object positions and fcst trajectories

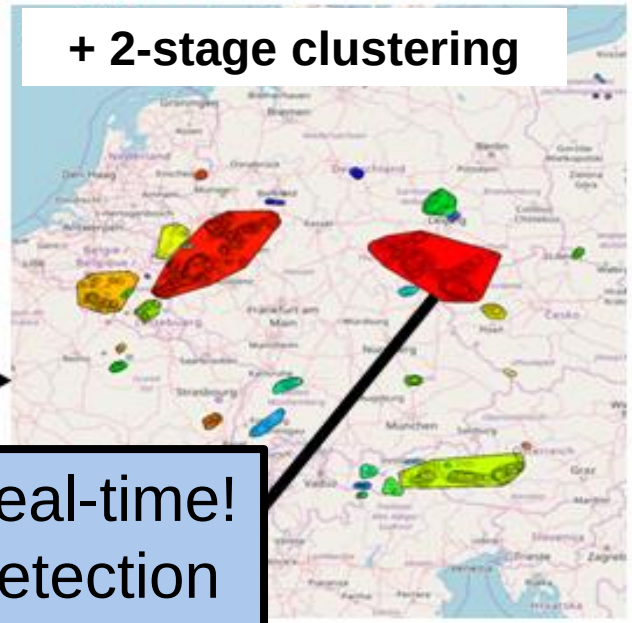
Prototype “reasonable cell selection” of KONRAD3D objects from SINFONY-NWP-ENS

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

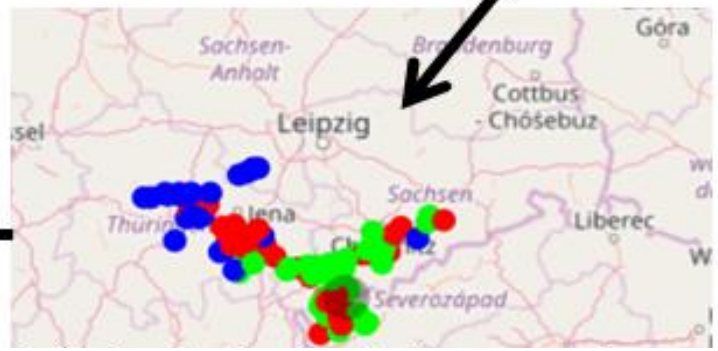








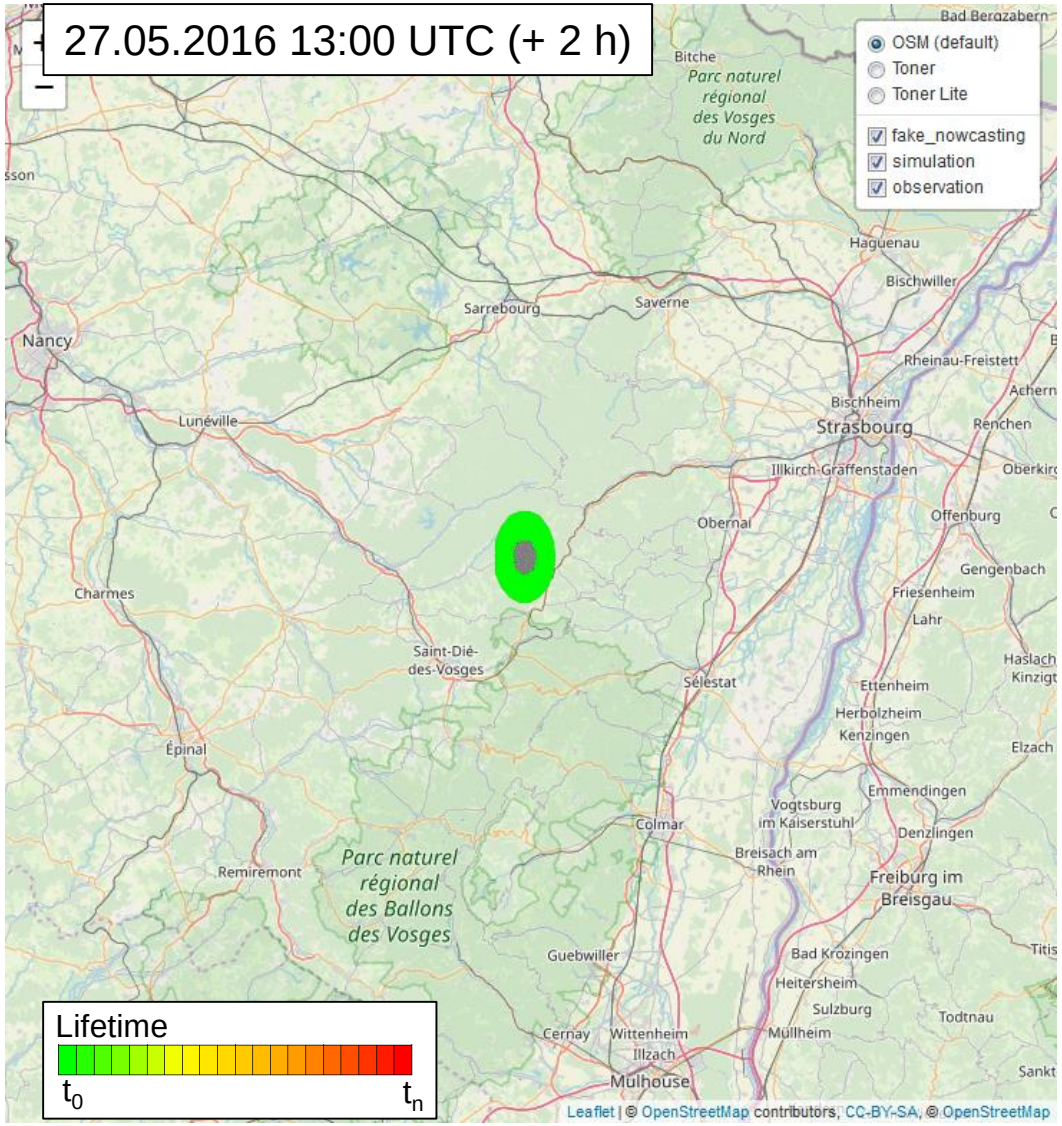
Big technical challenge to do this in real-time! Have to speed up KONRAD3D cell detection and tracking!



+ „best cluster selection“ for each observed object

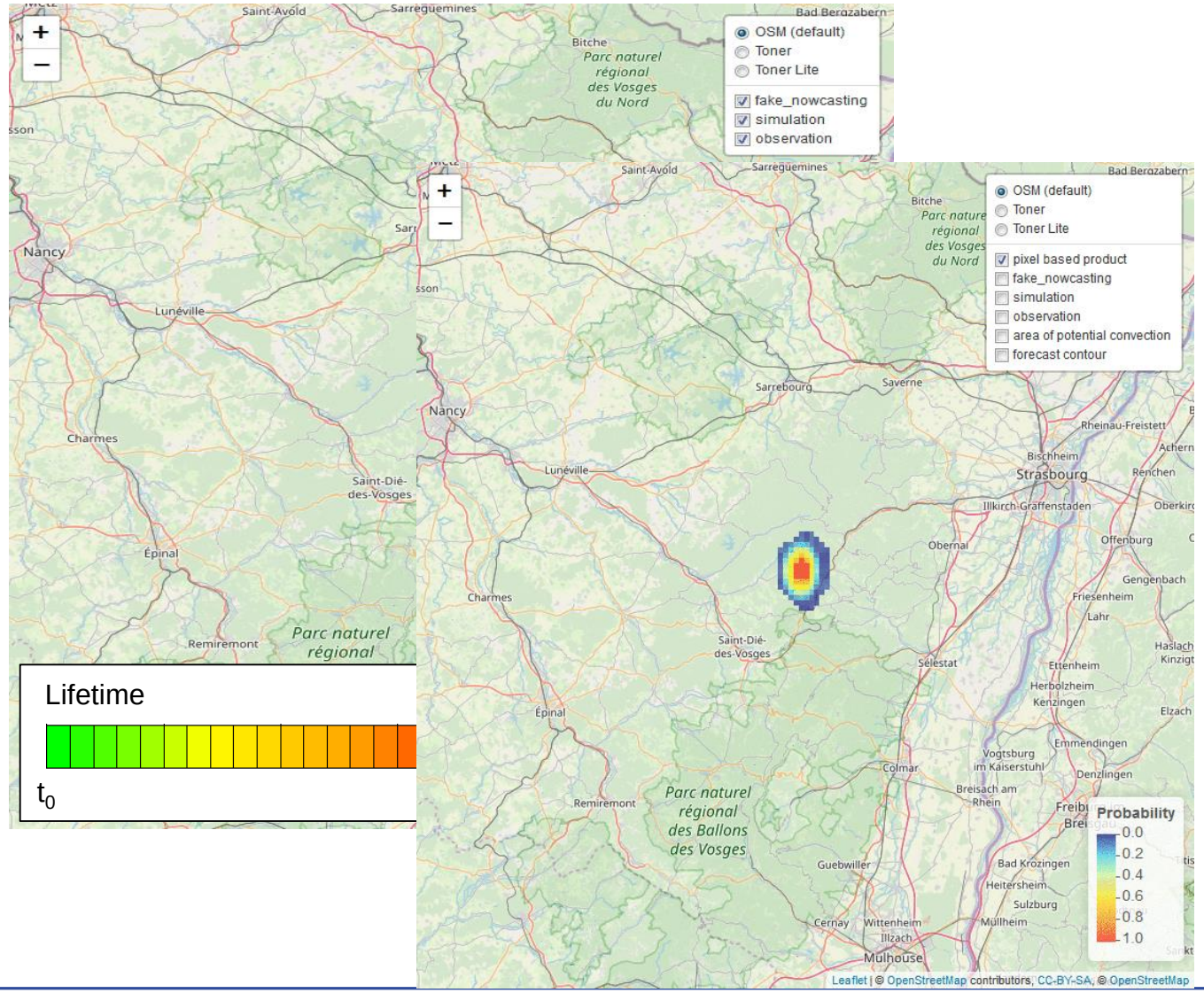
+ „pragmatic“ correction of object positions and fcst trajectories

Prototype of combining KONRAD3D objects from Nowcasting- and NWP-ENS



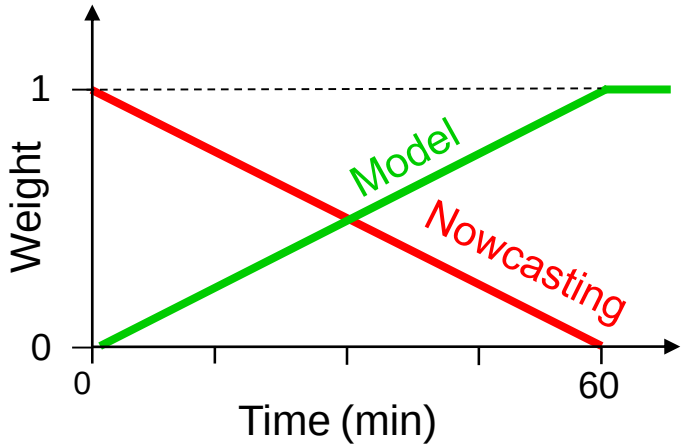
- „Most similar“ NWP-simulated cells at observation time are displaced to the position of observation
- Their forecast trajectories are displaced simultaneously by the same vector
- Nowcasting cells also plotted. Here only an idealized „fake“ version; in future it will be KONRAD3D-EPS

Examples of combined products of KONRAD3D objects from Nowcasting- and NWP-ENS



Object-based product:

- Weighting of Nowcasting and simulated objects with forecast lead time, represented by transparency:



Pixel-based product:

- Weighted probability that an observed cell will „hit“ a location at a given forecast time

* Seamless INtegrated FOrecastiNg sYstem

- At the moment large **pilot project** at DWD to develop a coupled probabilistic system of radar-based precipitation advection nowcasting and very-short-range NWP (hourly forecasts up to +12 h) on the convective scale
- In pilot project, we start with „seamless“ = „from minutes to hours“
- **Focus in SINFONY pilot project:**
  - Basic developments for ensemble Nowcasting and NWP at DWD
  - Focus on strong summertime convective events
  - Our „customers“: internal DWD warning proces, hydrology (flood forecasting authorities)
  - First „combined“ products of Nowcasting- and NWP ensembles for precipitation, dBZ, convective cell objects
- First promising prototypes developed, now we enter the phase of consolidation and step-by-step operational introduction until 2023
- In parallel, further R&D activities
- **Further information:** www.dwd.de/sinfony