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

Ulrich Blahak, on behalf of Team SINFONY & Friends

Deutscher Wetterdienst (DWD)

Team SINFONY & Friends: **Roland Potthast, Kathleen Helmert, Julia Keller, Manuel Werner, Alberto De Lozar, Axel Seifert, Klaus Stephan, Elisabeth Bauernschubert, Christian Welzbacher, Thomas Hanisch, Helmut Frank, Matthias Zacharuk, Robert Feger, Lilo Bach, Michael Hoff, Martin Rempel, Lisa Neef, Kathrin Feige, Markus Schultze, Sven Ulbrich, Kobra Khosravian, Vera Maurer, Jana Mendrok, Mareike Burba, Leonhard Scheck, Annika Schomburg, Klaus Vobig, Christian Berndt, Gregor Pante, Sabrina Wahl, Maike Ahlgrimm, Thorsten Steinert, Hendrik Reich, Ulrich Friedrich, Arne Spitzer, Lukas Josipovic, Thomas Deppisch, Matthias Gottschalk, Tobias Bergmann, Cornelius Hald, Isabel Schnoor, Nora Strotjohann, Malte Schmid, Jan Bondy, Andreas Brechtel, Michael Debertshäuser, Sophie Löbel, Nikolaos Antonoglu, Michael Denhard, Marcus Paulat, Vanessa Fundel, Felix Fundel, Peter Sohn, Andreas Höfer, Friedemann Ebach, Markus Zeindl, Alexander Hartmann, Eleonora Lipovezki, Marcus Werner, Christoph Schraff, Tim Böhme, Björn Breitenbach, Marcus Beyer, Christian Herold, Christina Speicher, Helge Tuschy, Tanja Winterrath, Ewelina Walawender, Armin Rauthe-Schöch, Katharina Lengfeld, Kathrin Wapler, Stefanie Hollborn, Linda Schlemmer, Jan Keller, Julia Frank**

How to transfer the very detailed high-resolution / high-frequent observations (radar, sat, lighting, etc.) into seamless useful forecasts for small-scale high-impact events?

- **Timely** and as **accurate** as possible!
- With **uncertainty estimates!**
- **Useful** and **usable** down the warning chain!

Our goal to that end: Achieve better convective forecasts from now to the the next 12 h!

- Develop a **seamless probabilistic forecasting system** on the convective scale from 0 – 12 h lead time
- Establish **vivid exchange** and a **co-design approach** with users (DWD forecasters, flood forecasting centres)

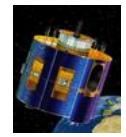
The SINFONY as in current transition to operations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Some verification score for convective events

- Hourly new ENS forecasts up to + 14 h (RUC)
- ICON-LAM Δx = 2 km
- Operational since 11 July 24
- physical simulation
- NWP
- Assimilation of new data* in KENDA-LETKF:
  - Radar volume scans v_r, dBZ, cell objects
  - METEOSAT VIS / IR
  - Lightning

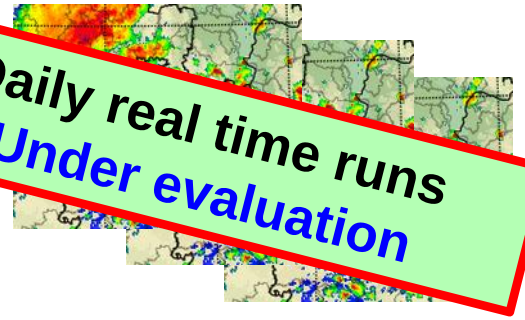
Available ~35 min after the actual date



- Combined / blended products:
- [illegible] probabilities (mm/h,
- [illegible] (mm/h, dBZ)
- Combined cell

Daily real time runs Under evaluation

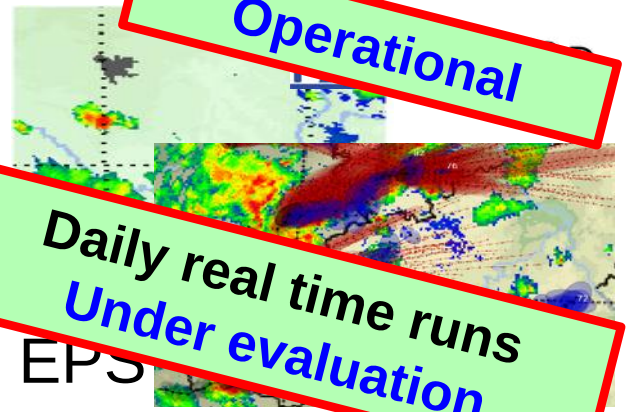
STEPS-DWD



Daily real time runs Under evaluation

- Radar based precipitation Nowcasting
  1) Gridded fields (mm/h, dBZ)
  2) Cell objects

Operational



Daily real time runs Under evaluation

EPS

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

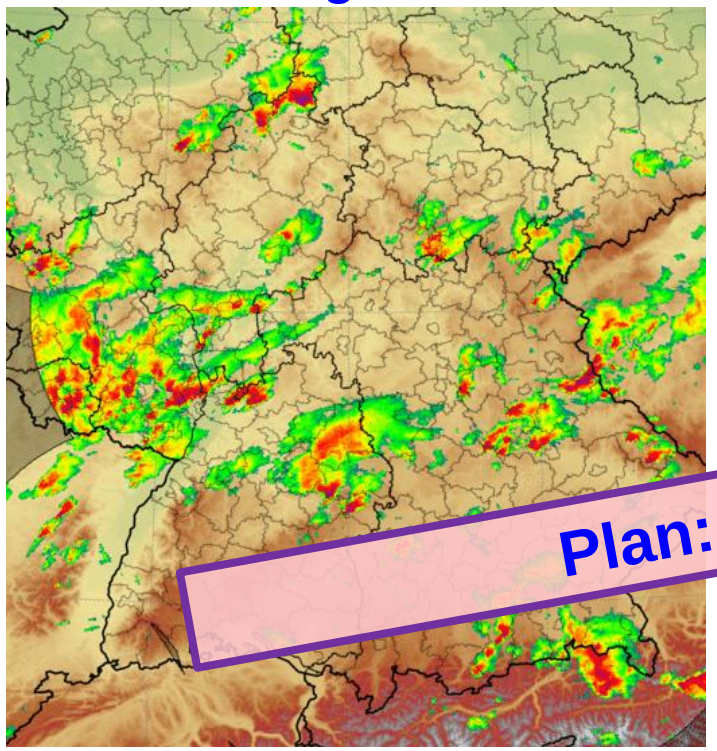
SINFONY

One of our combinded products:
INTENSE – Blending by DA cycle

Poster 85
Martin Rempel

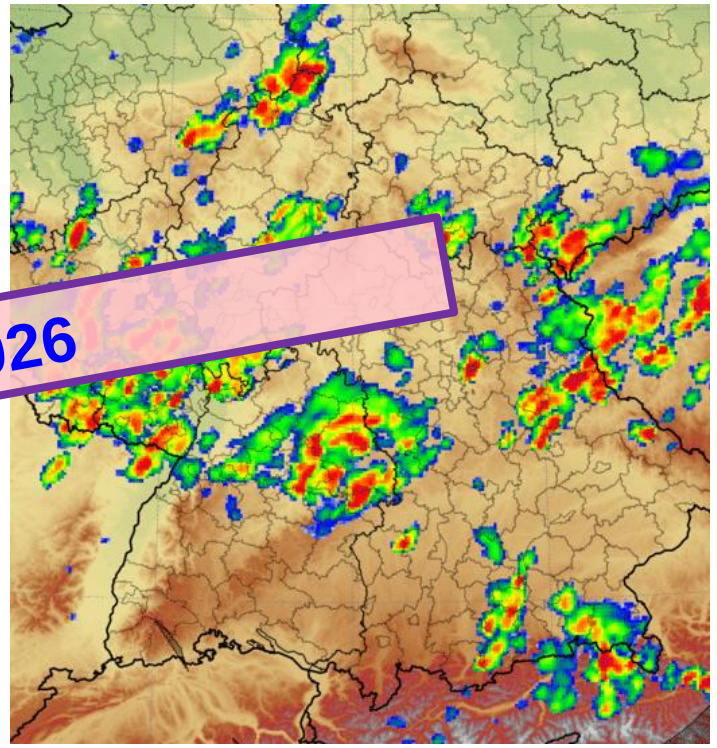
Talk Wed
Christian Berndt

Nowcasting STEPS-DWD



INTENSE (1 of 20 members)

NWP ICON-RUC-EPS



Plan: technically operational in Q1/2026

Nowcasting-ENS (5‘ updates)

SINFONY - Combined products „Best of both worlds“

NWP-ENS (hourly updates)

t_0 → **Fcst lead time**

Combined ENS
Nerini et al. 2019
Gives us 20 scenarios precip and reflectivity

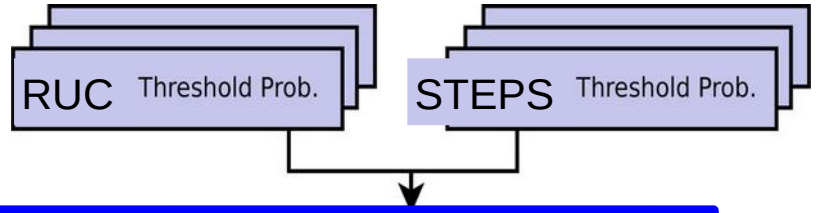
SINFONY

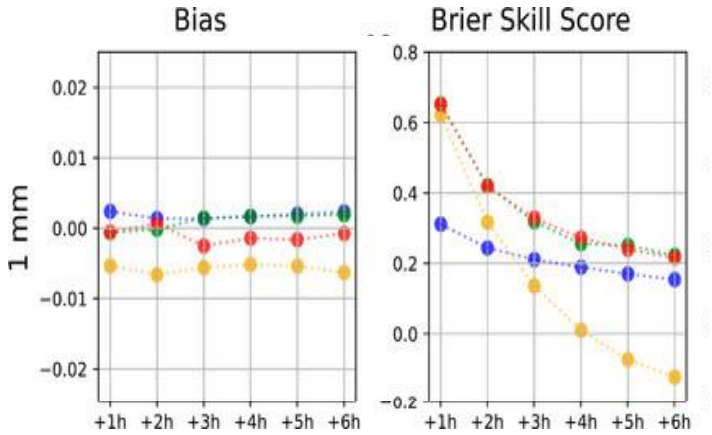
Other ens. combination methods than INTENSE in SINFONY

Martin Rempel et al. (2022), Artif. Intell. Earth Syst., doi:10.1175/AIES-D-22-0020.1

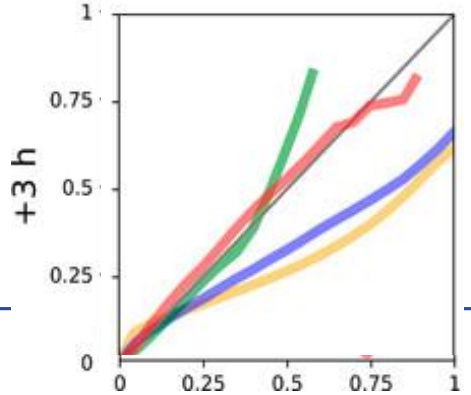
Prototype for NN-approach Consistent Calibrated Combination („C3“)

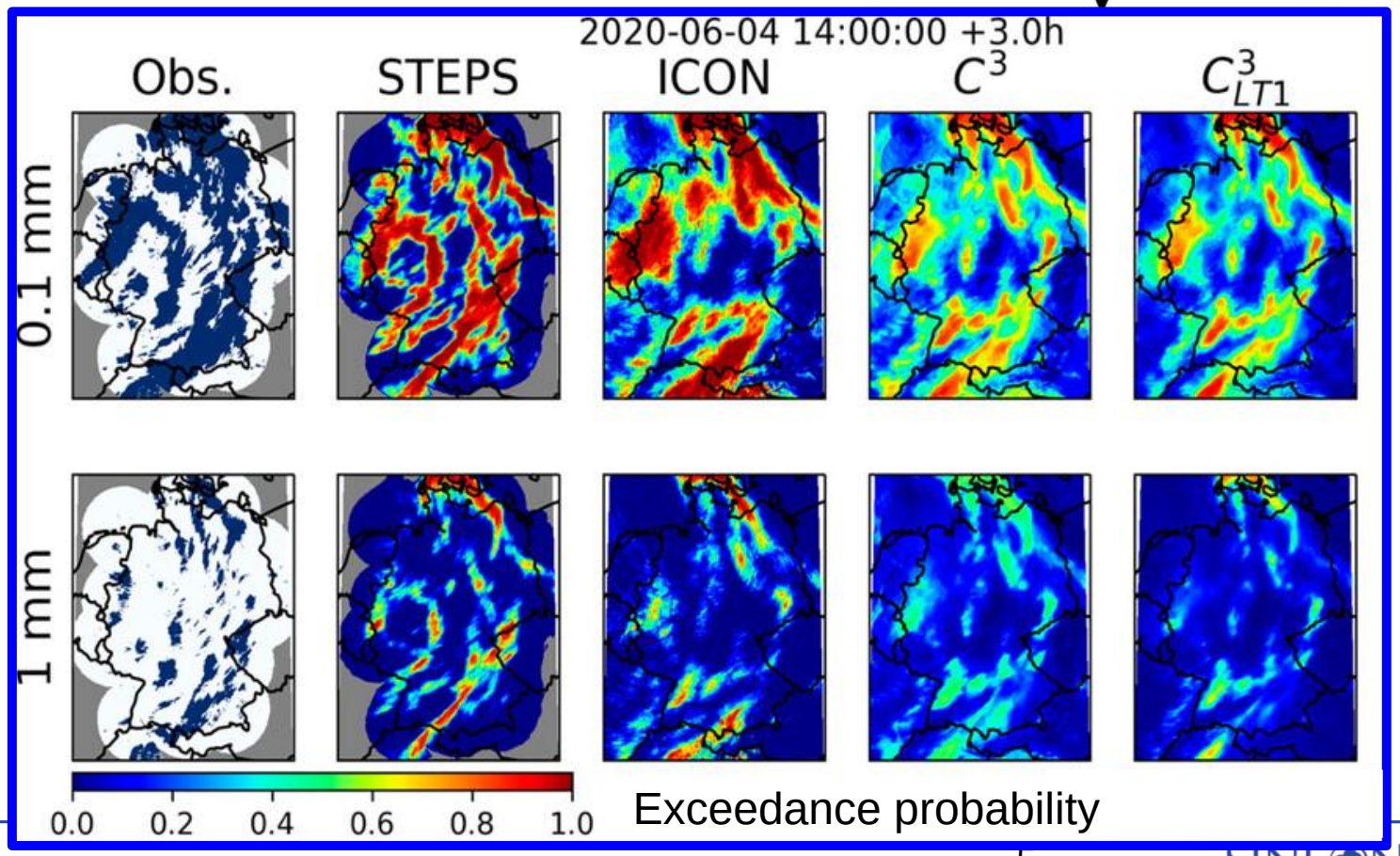
Blended CDF (multiple thresholds simultaneously and consistently) at each location (co-op. with Institute of Stochastics, University Ulm)





Reliability for threshold 1 mm in 1 h at +3h

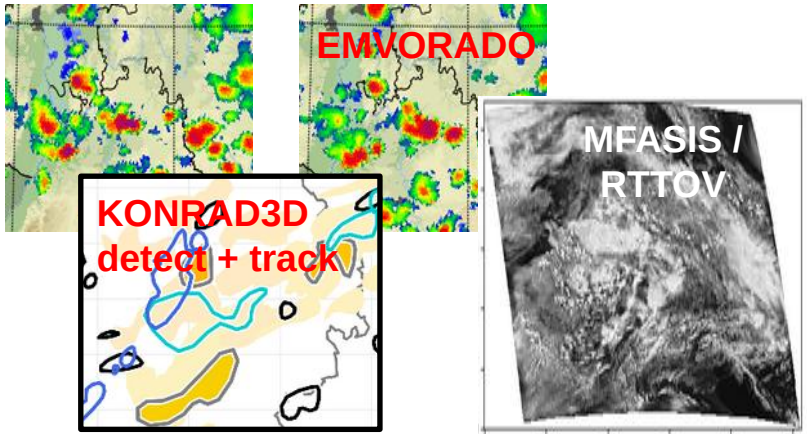




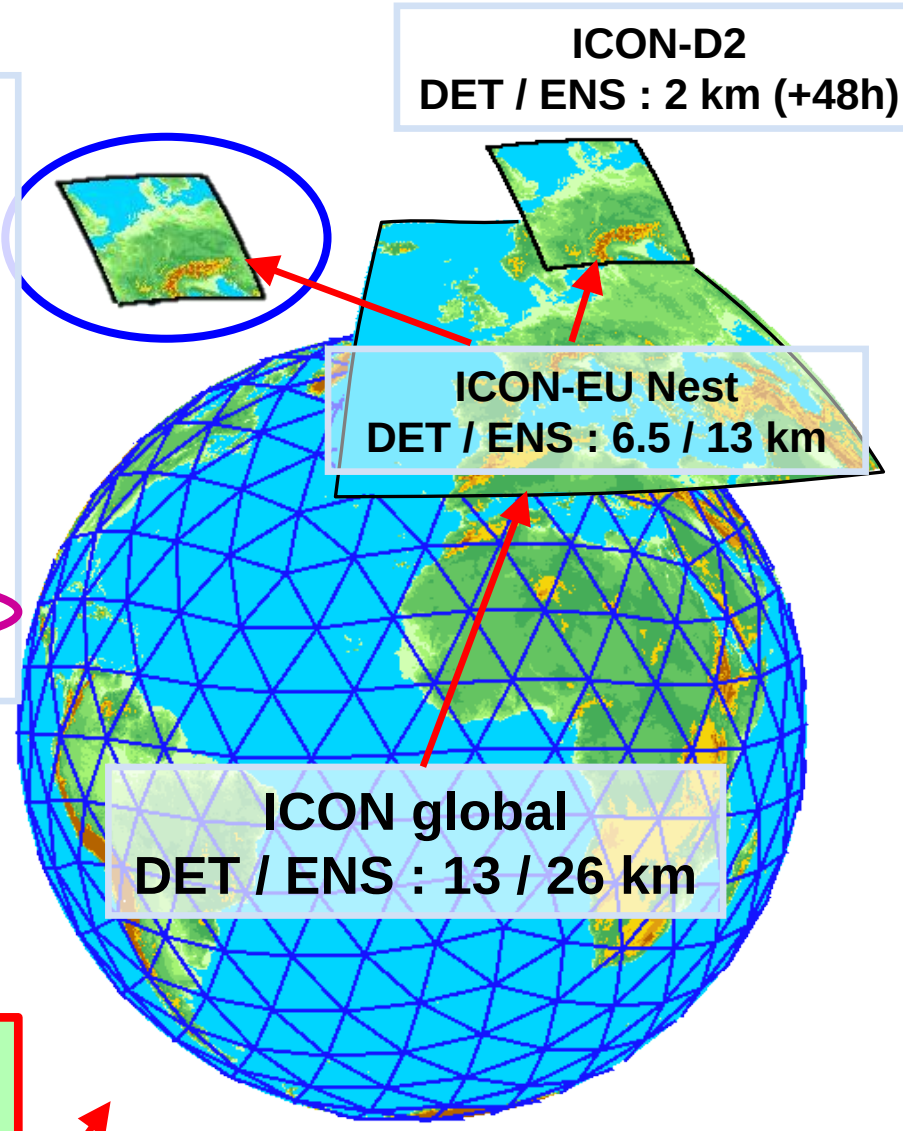
More details on the ICON-RUC

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ **Advanced forward operators:**
- Radar volumes and composites
- Cell objects (KONRAD3D)
- VIS / IR sat data



Neu: ICON-RUC
DET / ENS: 2 km (+14h)
Part of the SINFONY
Hourly new forecasts
Advanced 2-moment cloud microphysics with hail
Optimized for < 12 h and at same time godd reflectivity, clouds and precipitation
Quickly available after 35‘
More frequent output



- ➔ **Seamless Nowcasting-NWP-products**
- ➔ **Verification**
- ➔ **Data assimilation** via **LETKF together with classical Latent Heat Nudging**

Talk Tue L. Neef
Assimilation of lightning and refl. texture fraction

Talk Tue
Kobra Khosravian (SPP-PROM)
Towards ZDR column DA

SINFONY

Advanced 2-moment cloud microphysics scheme in ICON-RUC/-EPS

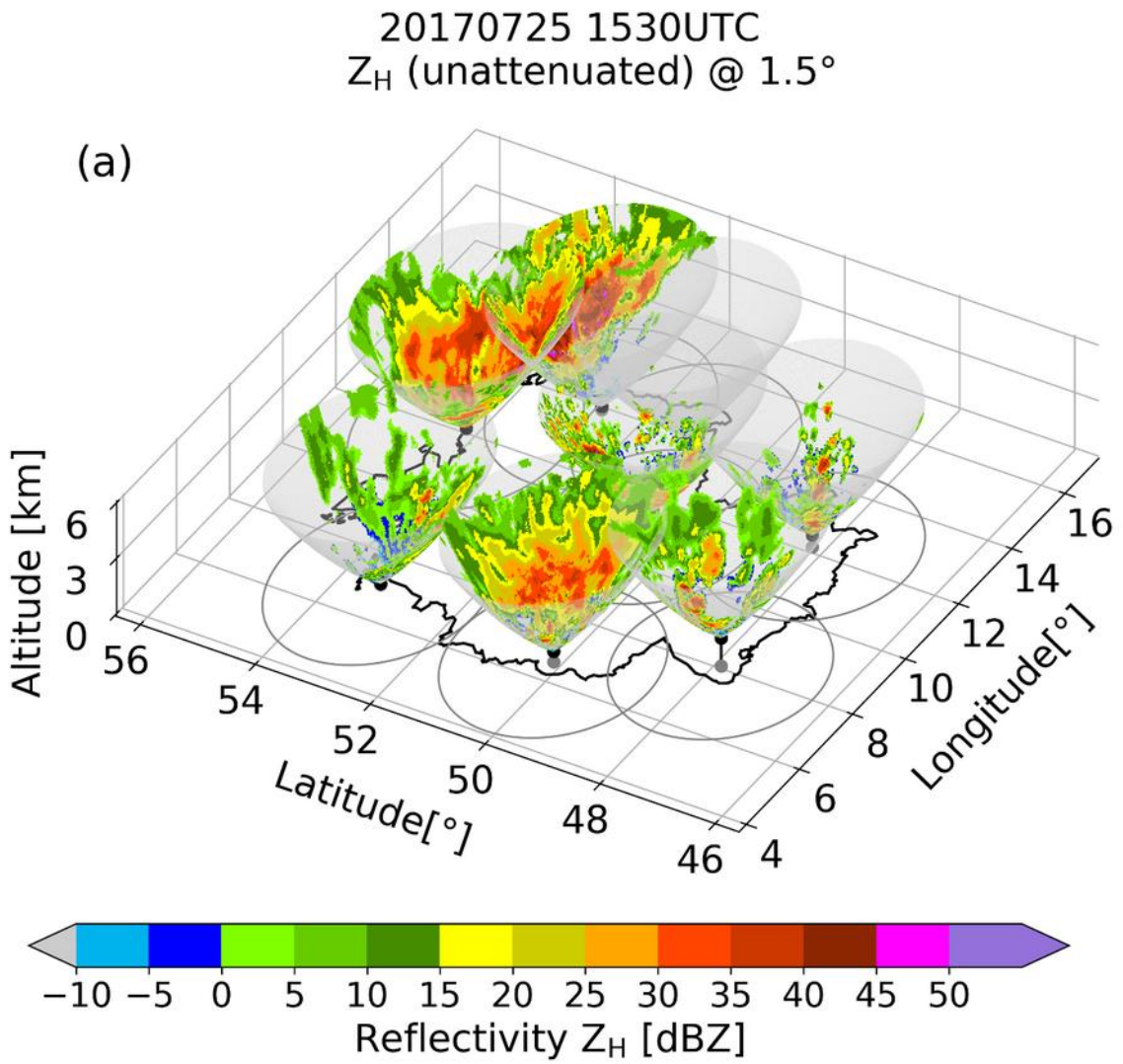
- **Significant investment in 2-moment cloud microphysics** (+50 % runtime compared to ICON-D2)
  - Additional prognostic number concentrations as 2nd moment, additional prognostic hail.
  - Quasi-prognostic hydrometeor size
- **Justified** because it is beneficial for the SINFONY:
  - Bias reduction in DA of radar and sat
  - Combined products in radar observation space

Talk Thu
Sophie Löbel
DSD comparison with distrometers

Talk Fri
Alberto de Lozar
Comparison and tuning based on radar and sat obs

Radar forward operator EMVORADO for volume scans

Talk Fri
Suomi Dutta (SPP-PROM)
Realistic snow flake shapes for polar. moments



Simulated radar moments along all the rays of synthetic volume scans every 5‘:

- **Radar reflectivity Z_h Mie / T-matrix spheroids**
- **Radial wind V_r**
- **Under devel: polarisation parameters Z_v, ZDR, KDP, PHIDP, RHOHV, LDR, A_h, A_v**
- **Radars: DWD + other Europ. radars from OPERA**

Talk Fri
Julian Steinheuer (SPP-PROM)
Evaluation of ICON-2mom by polarimetric radar data

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

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From user perspective: 1h rain sum ICON-RUC and ICON-D2 verified against gauge-adjusted QPE (Radolan RW), 08/2024

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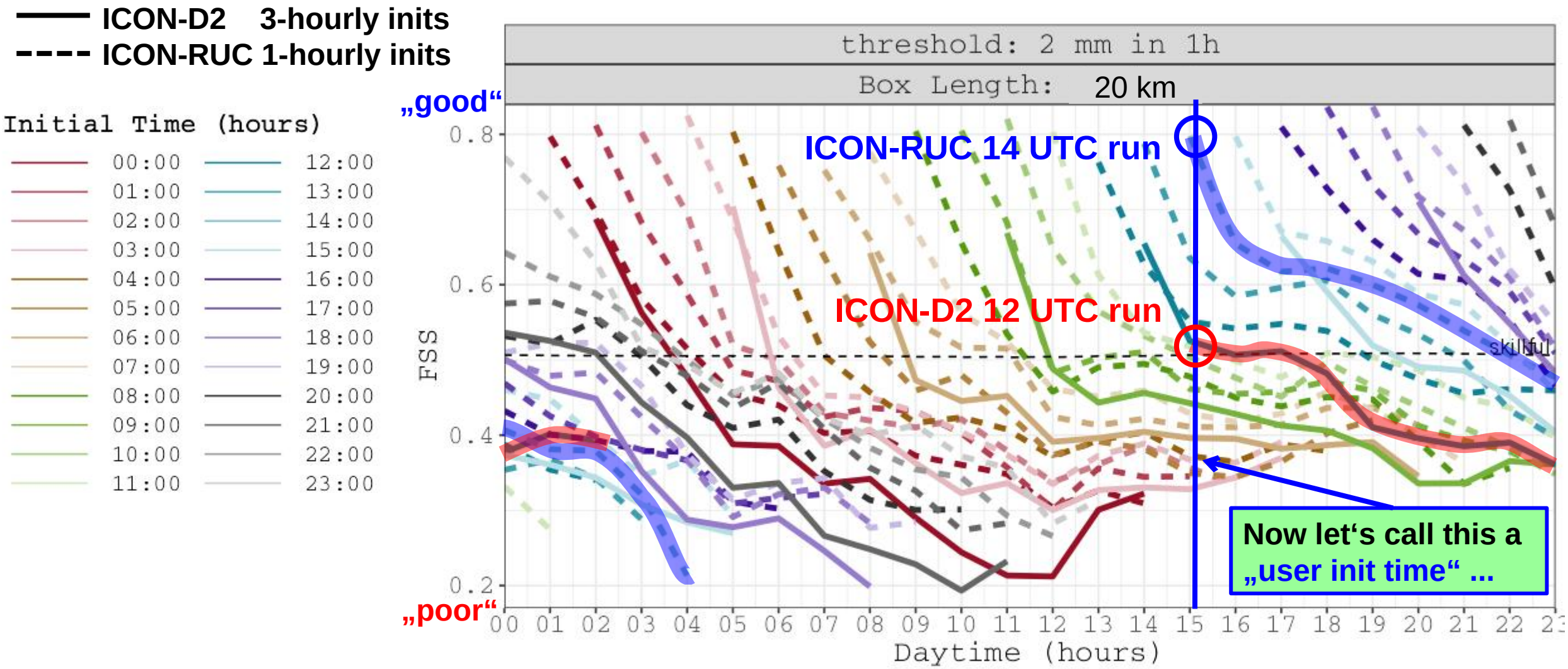
Wetter und Klima aus einer Hand

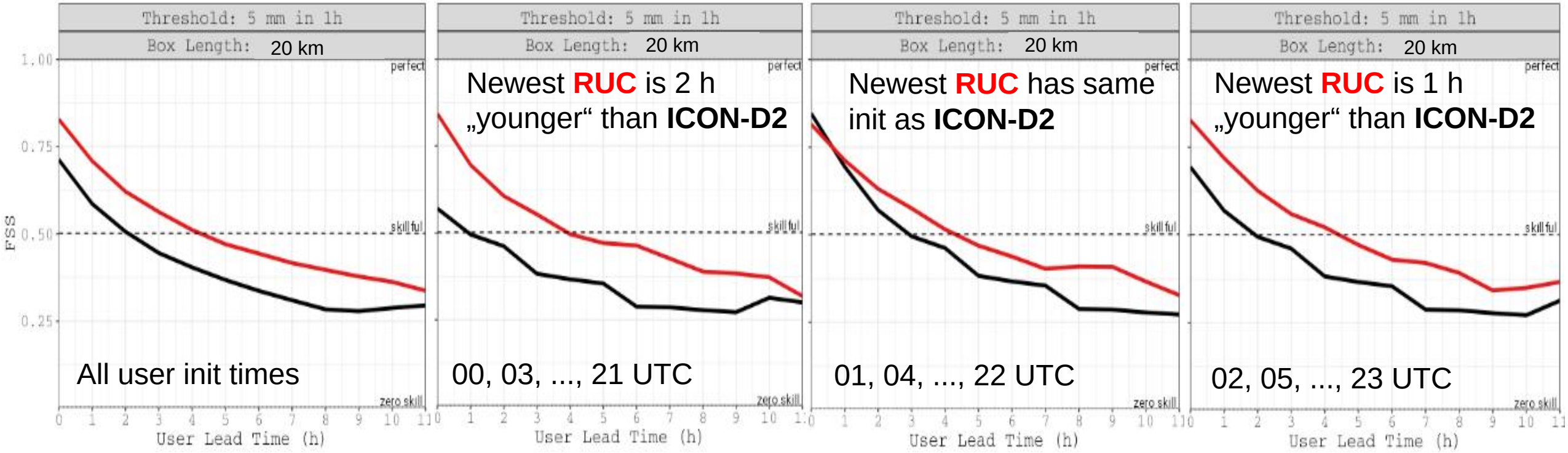


SINFONY

From user perspective: 1h rain sum ICON-RUC and ICON-D2 verified against gauge-adjusted QPE (Radolan RW), 08/2024

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- ... and then we aggregate scores over different user init times (full hours) of the day.
- „User lead time“ is along the remaining forecast time that lies in the future for the user.
- Shows the average forecast quality for a user which always looks at the most recent model run.
- **ICON-D2 = 3-h-updates**, **RUC = 1-h-updates** → **corresponding advantage of RUC has 3-h rhythm:**



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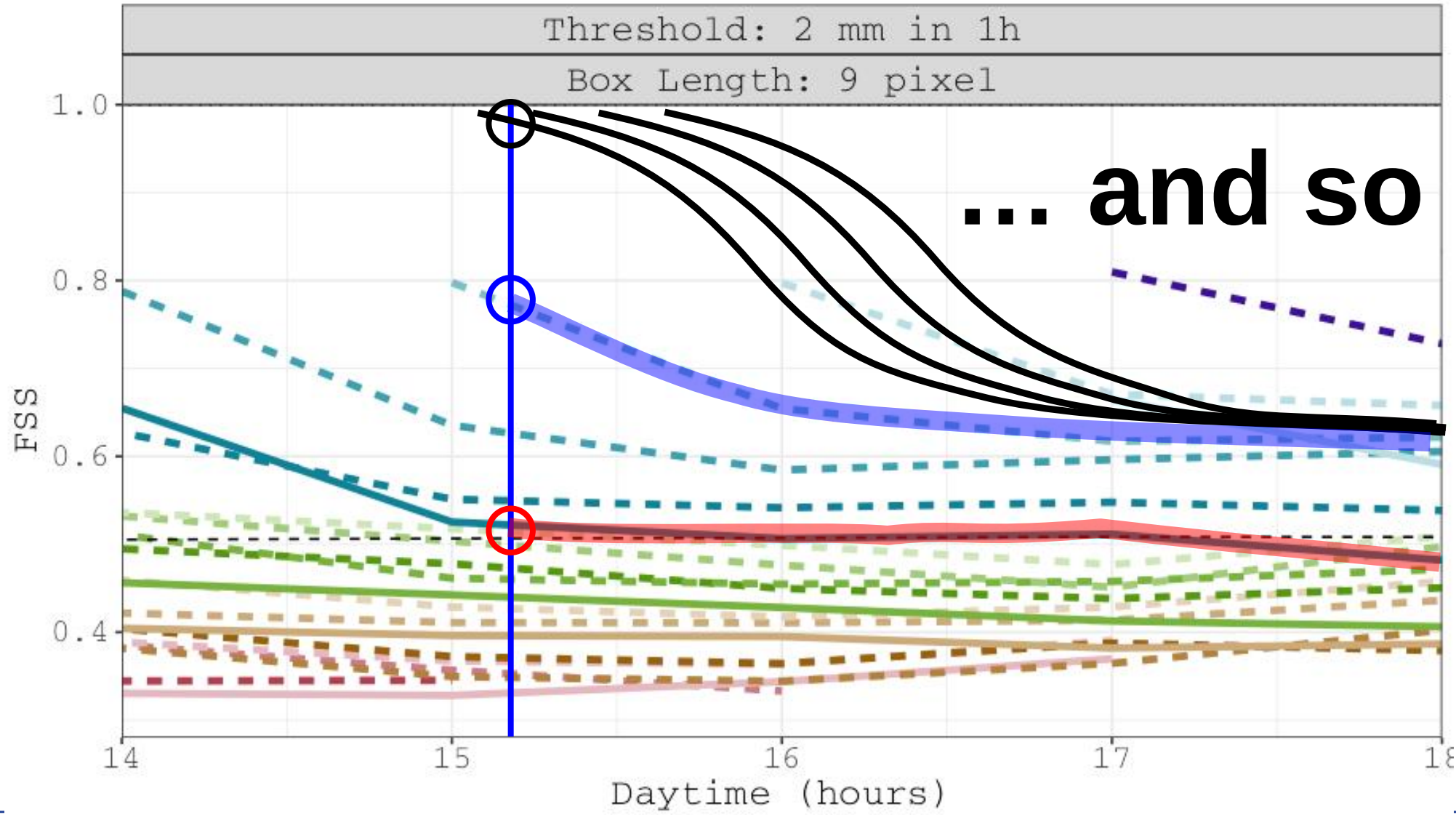
… and now we blend in the Nowcasting in the framework of a combined product:



Achievements by SINFONY developments since 2017?

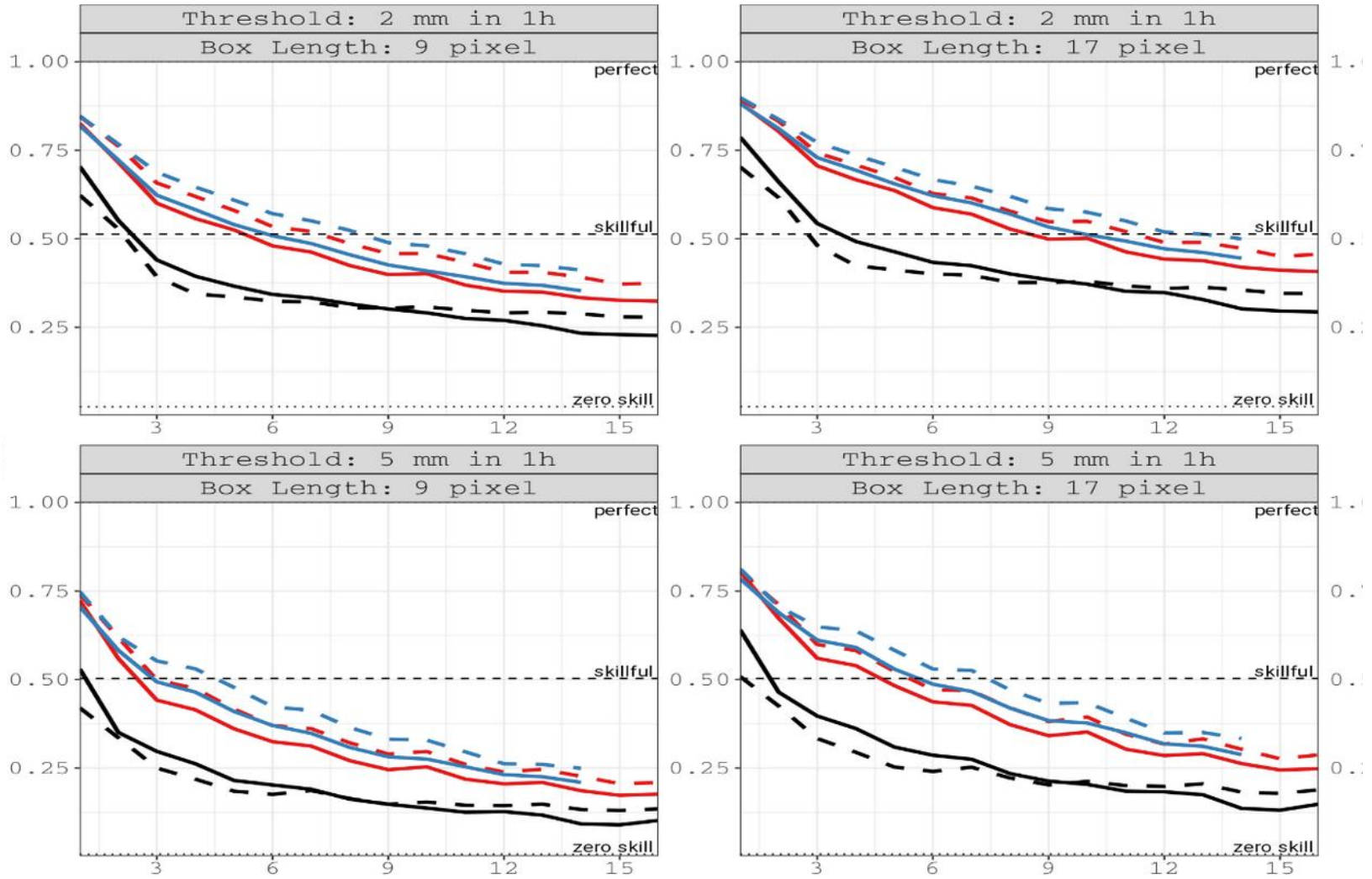
- Heavy convective period May / June 2016 was important motivation for creating the SINFONY
- Flash flood events in Braunsbach (29.5.2016) and Simbach am Inn (1.6.2016)

- **Re-forecast** of the period 26.5. – 29.6.2016 **with all components of today‘s SINFONY system** and **comparison** with the **original operational COSMO-DE/-EPS forecasts from that time**

Achievements in NWP: FSS precipitation 26.5. – 30.6.2016

COSMO-DE
ICON-D2
ICON-D2-RUC

Deterministic
Neighborhood ENS probability (NEP)



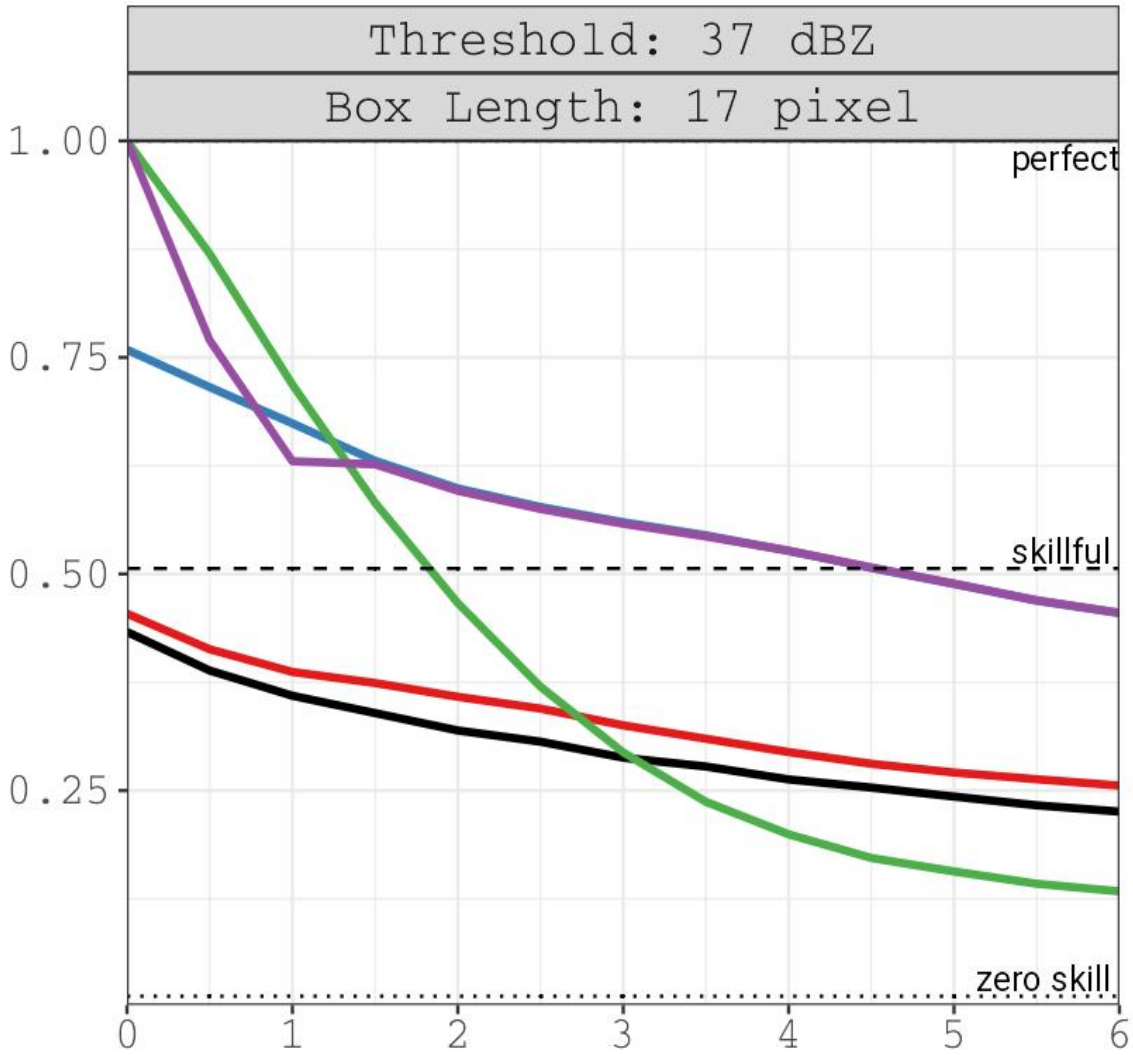
6 years progress in NWP
Common result of many general ICON developments and of the SINFONY developments

SINFONY

Achievements in NWP and combined products:
FSS Radar Reflectivity 26.5. – 30.6.2016

➔ **User perspective,** aggregated over all user init times

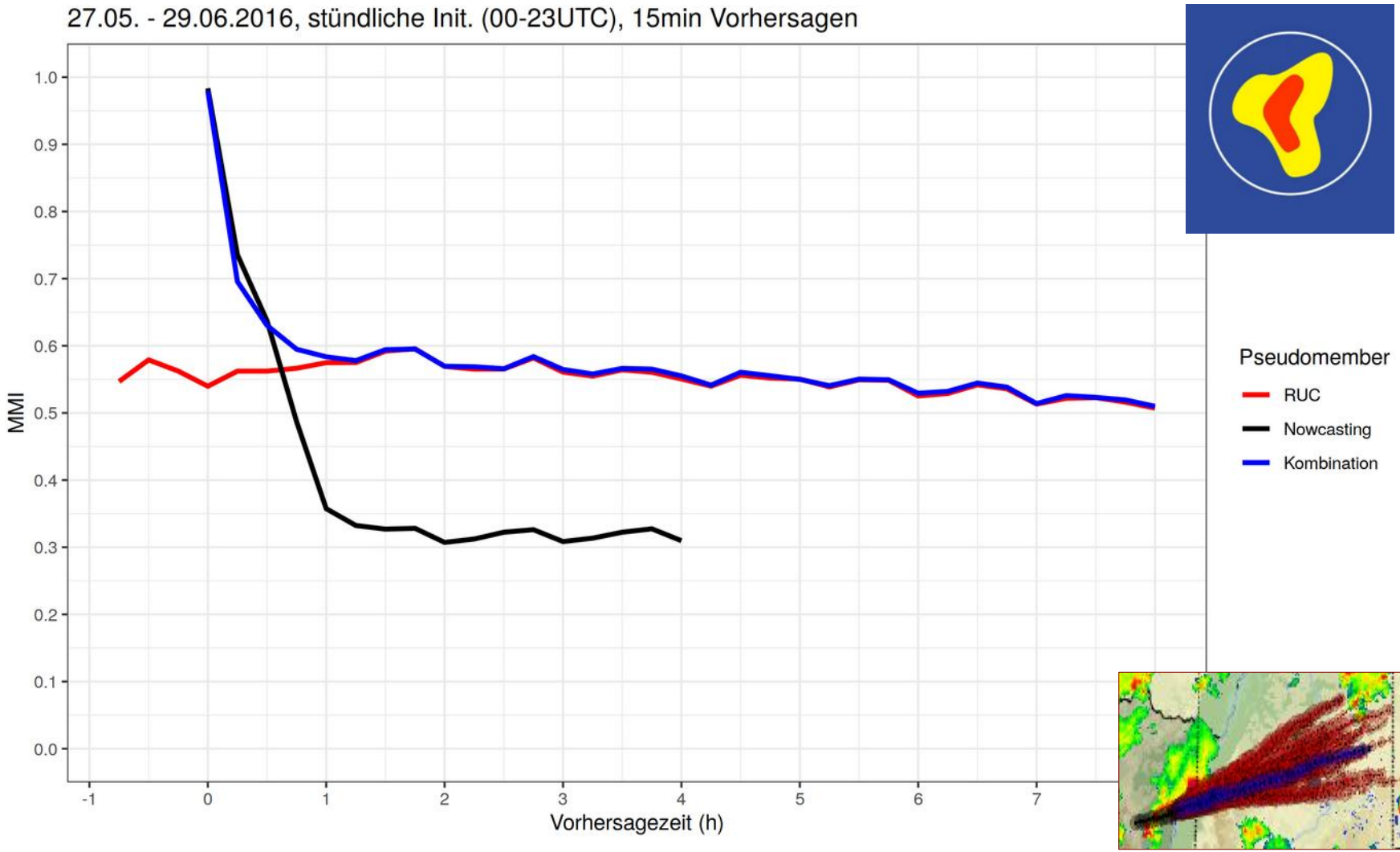
- COSMO-DE
- ICON-D2
- ICON-D2-RUC
- STEPS-DWD Nowcasting
- INTENSE Combination



Achievements in NWP and combined products: Cell objects verification by MMI-Score 27.5. – 29.6.2016

Core areas from all elevations = 3D cell object

- MODE (Davies, 2009)
- MMI = Median of Maximum Interest
- Composite score
- Cell properties considered in the MMI:
  - Cell centroid distance to observed cell
  - Cell area ratio
  - Cell severity



Talk Wed
L. Josipovic
KONRAD3D-SINFONY

Poster 87
N. L. Strotjohann
KONRAD3D-SINFONY

SINFONY

Achievements in NWP for Braunsbach case

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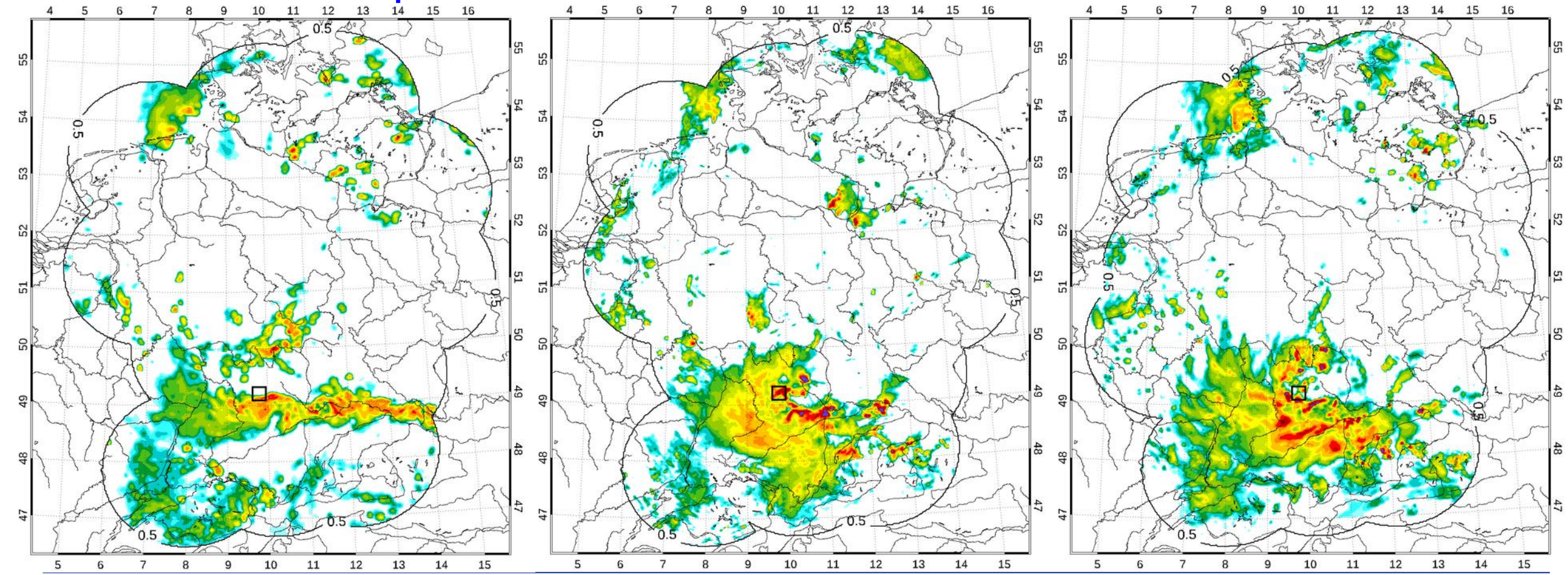
Wetter und Klima aus einer Hand

➔ Radar reflectivity, Braunsbach flash flood case, 29.5.2016

Reflectivity composites of EMVORADO at 17:30, init 12 UTC

Old COSMO-DE-like det. exp. from 2019 | **OBS** | **ICON-RUC det. re-forecast**



1 5 10 14 19 23 28 32 37 41 46 50 55 60 65 75 ≥75 dBZ

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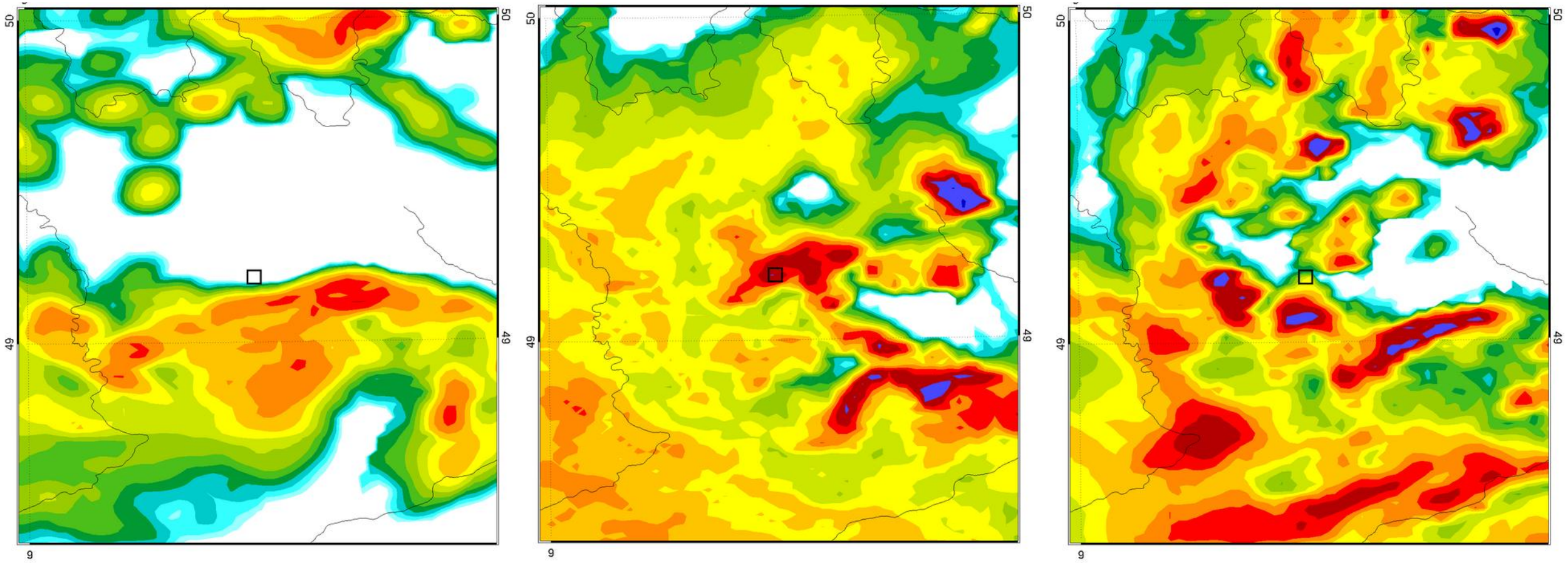


SINFONY

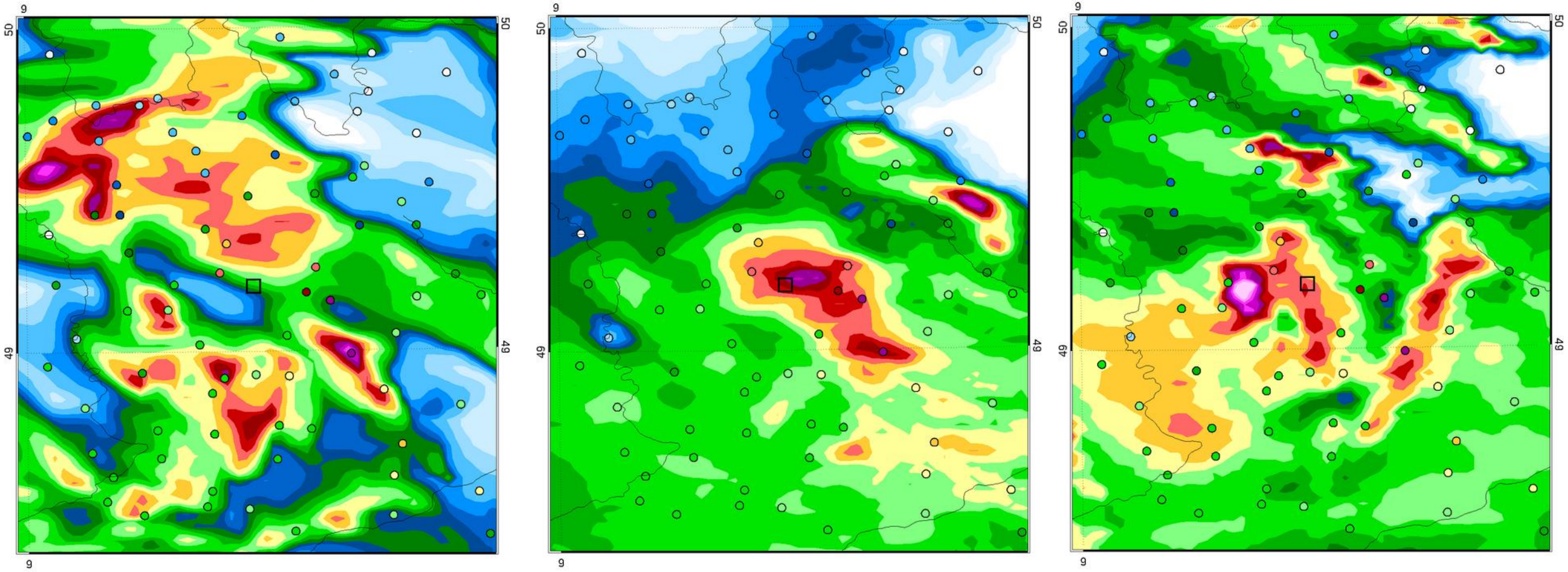
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE det. init 12 UTC | **OBS** | **ICON-RUC det. re-forecast init 12 UTC**



SINFONY

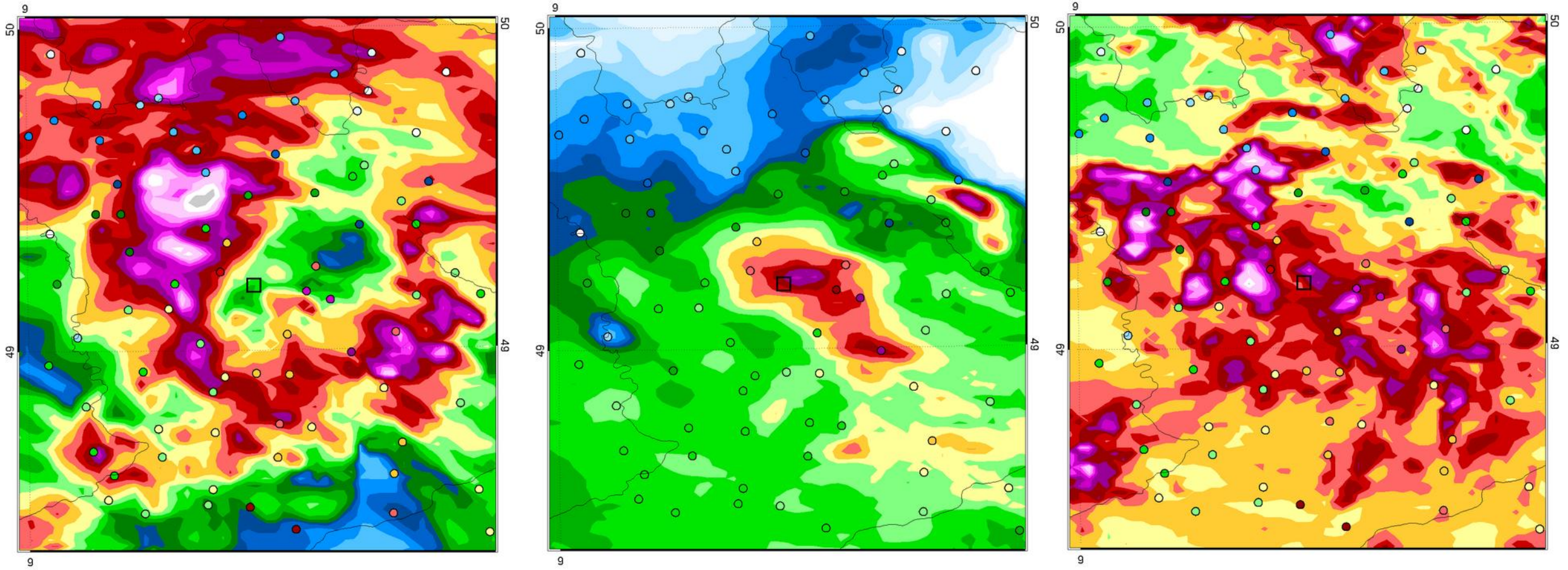
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE ensmax init 12 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 12 UTC**



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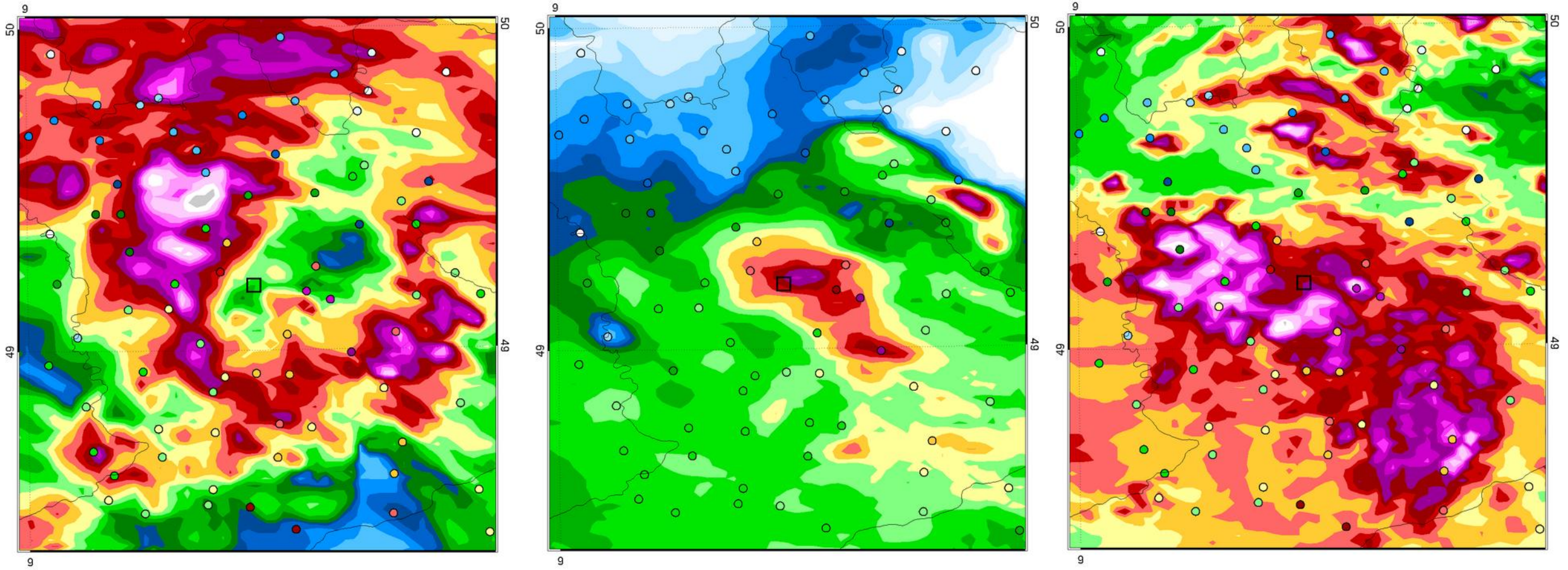
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE ensmax init 12 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 14 UTC**



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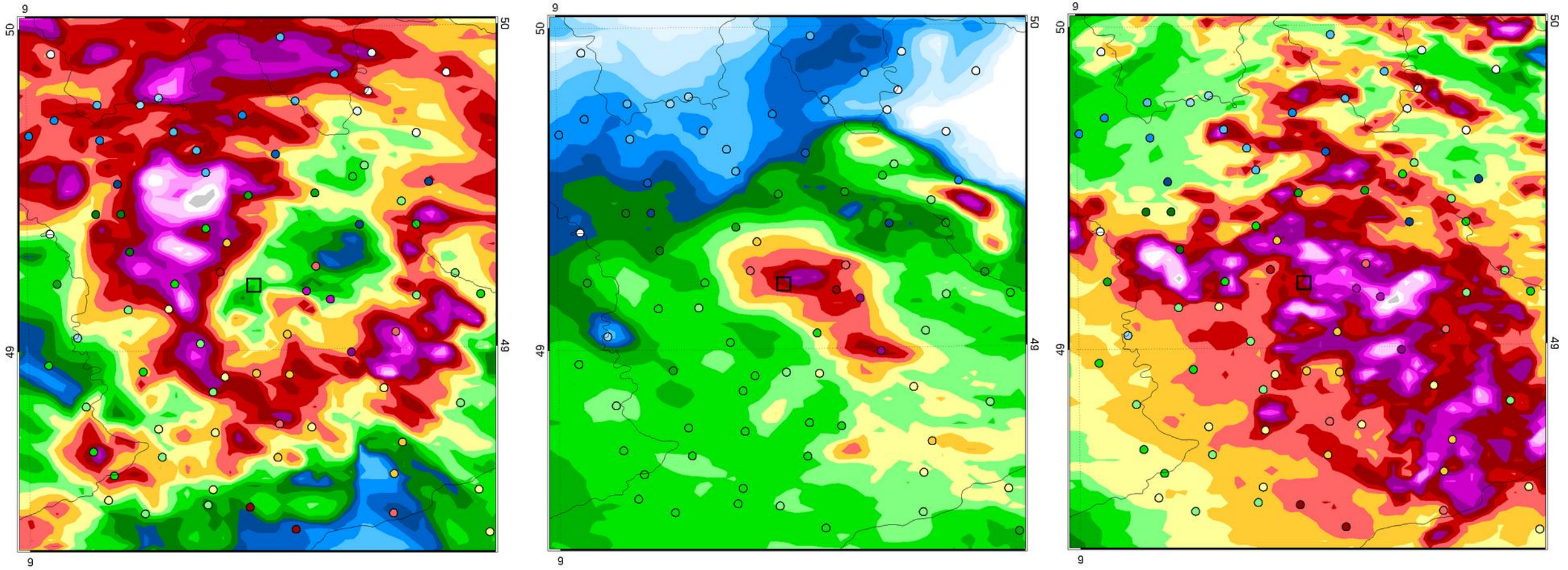
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE ensmax init 12 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 14 UTC**



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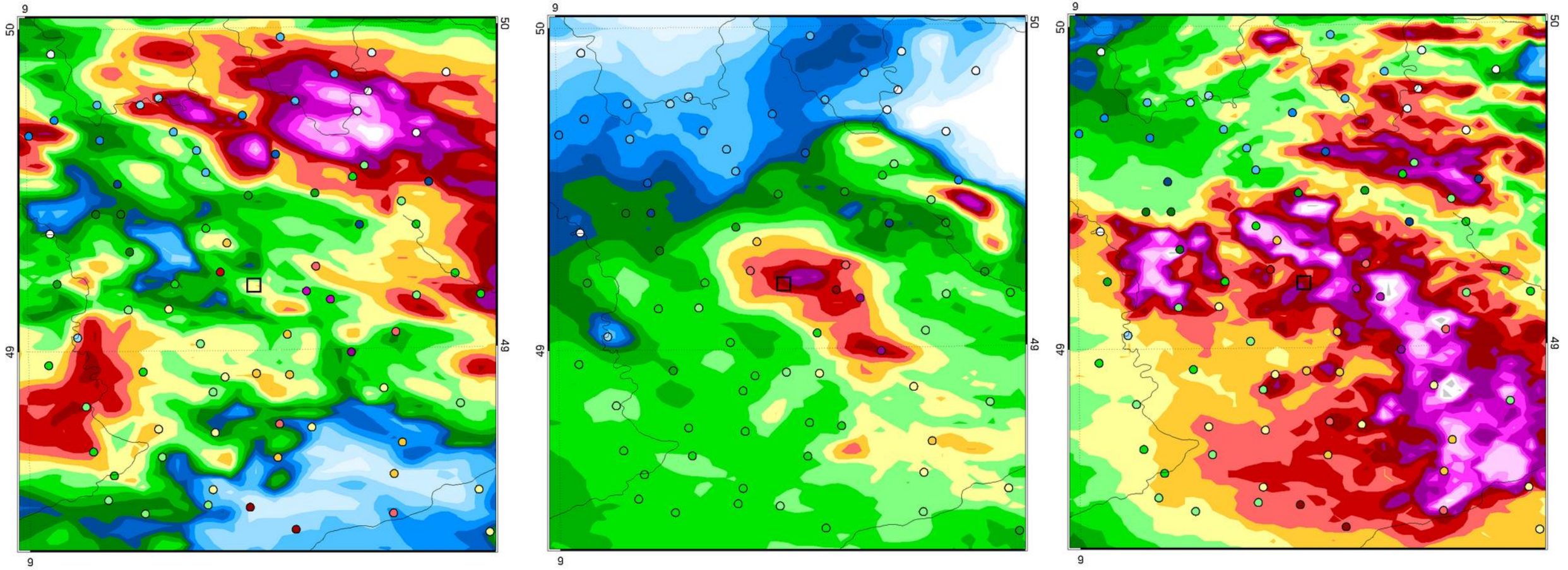
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

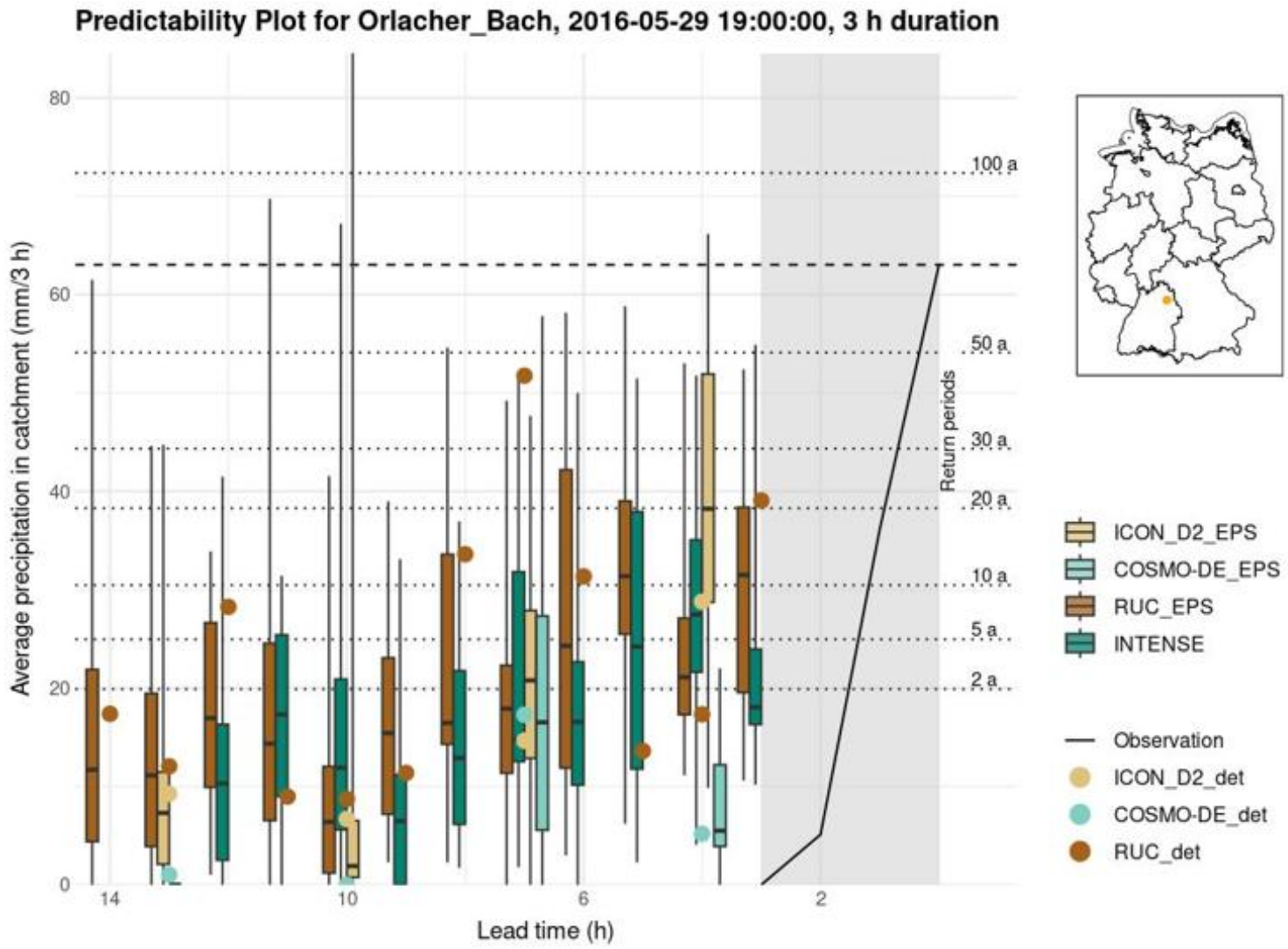
Old COSMO-DE ensmax init 15 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 15 UTC**



SINFONY

Predictability of catchment precipitation for Braunsbach case

Poster 139
Ina Blumenstein-Weingartz
Predictability Plots

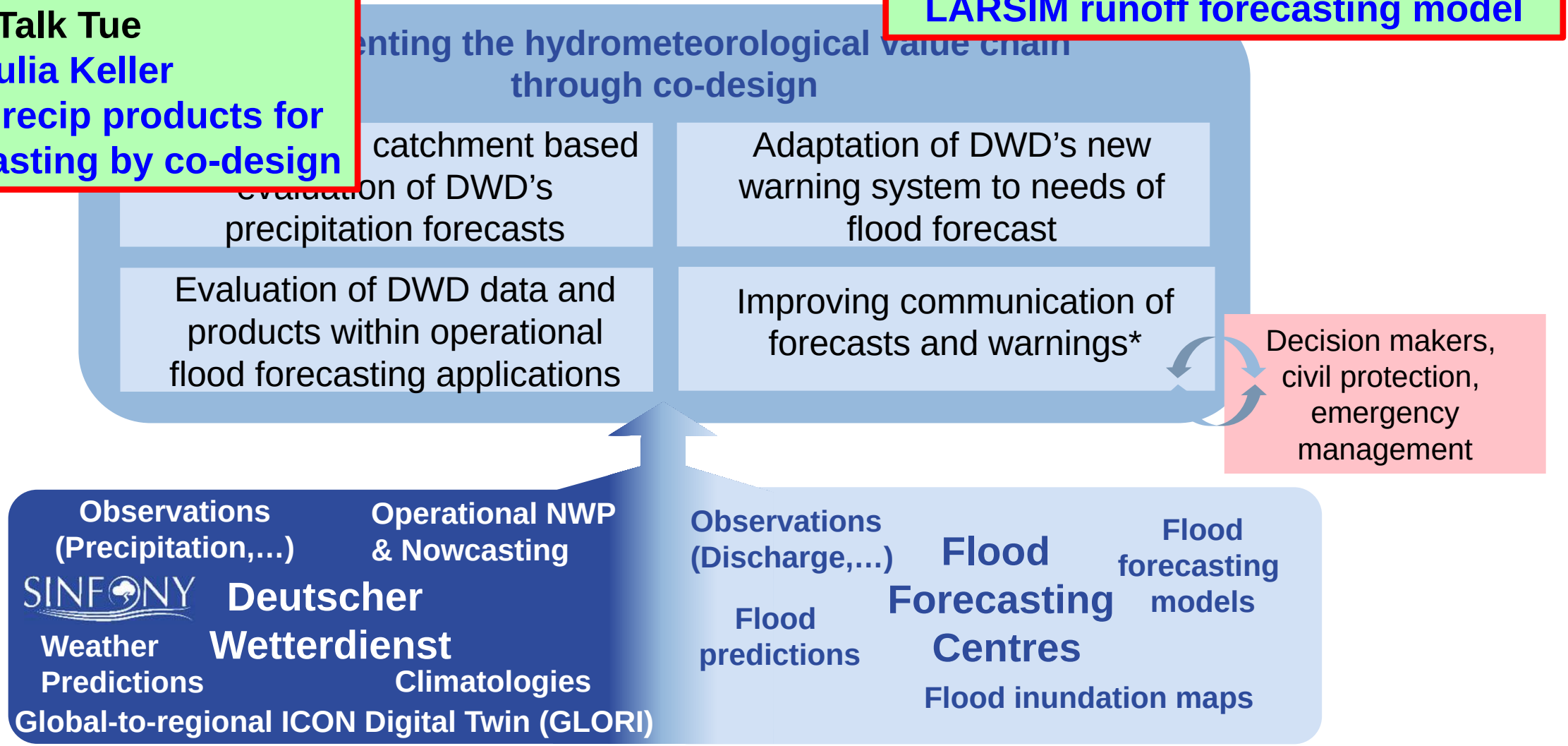


- Catchment very small (< 10 km²)
- Quasistationary cell was very small
- Very hard to predict, small spatial shifts have large negative impact
- Nearly none of the ensembles got it within its bounds
- However, ICON-D2 and RUC considerably closer than the old COSMO-DE
- Note: INTENSE appears shifted by 1 h, because involves 1-h old RUC

Co-Design in hydro-meteorological partnership

Poster 39
Olga Kiseleva
Eval of SINFONY precip products in LARSIM runoff forecasting model

Talk Tue
Julia Keller
Tailoring precip products for flood forecasting by co-design



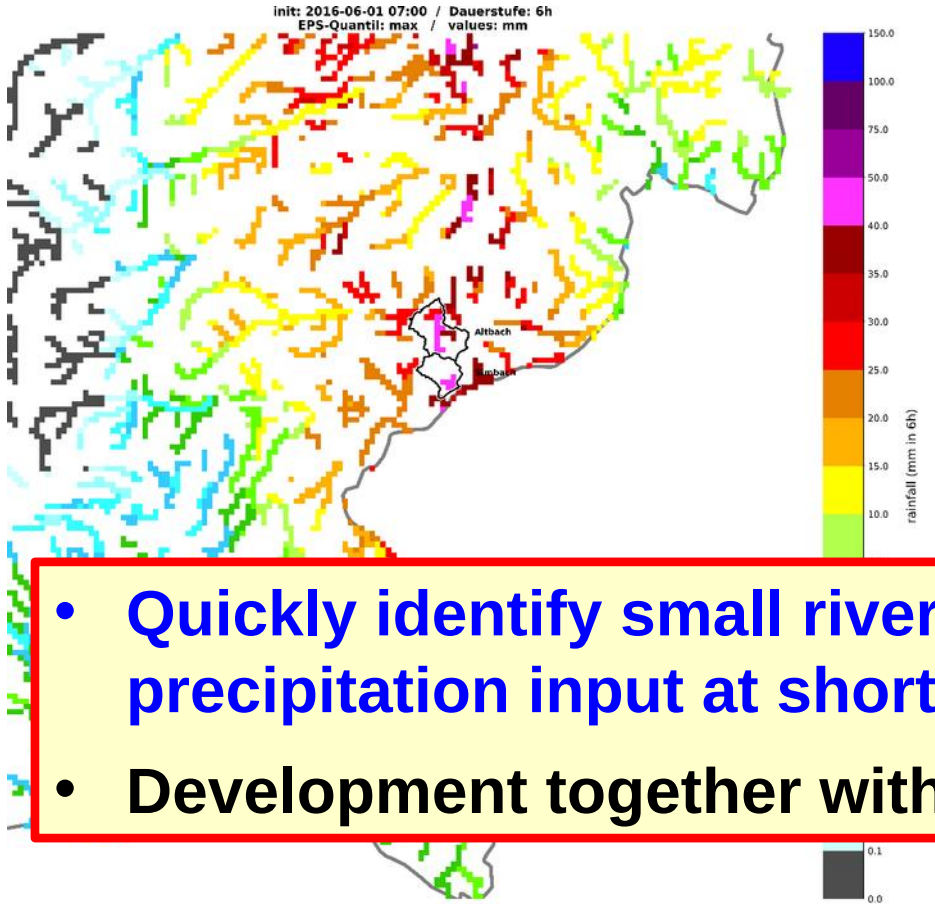
* Sub-project, co-financed by the Landesamt für Umwelt Rhineland-Palatinate

Aggregation of INTENSE over catchment area (AREA)

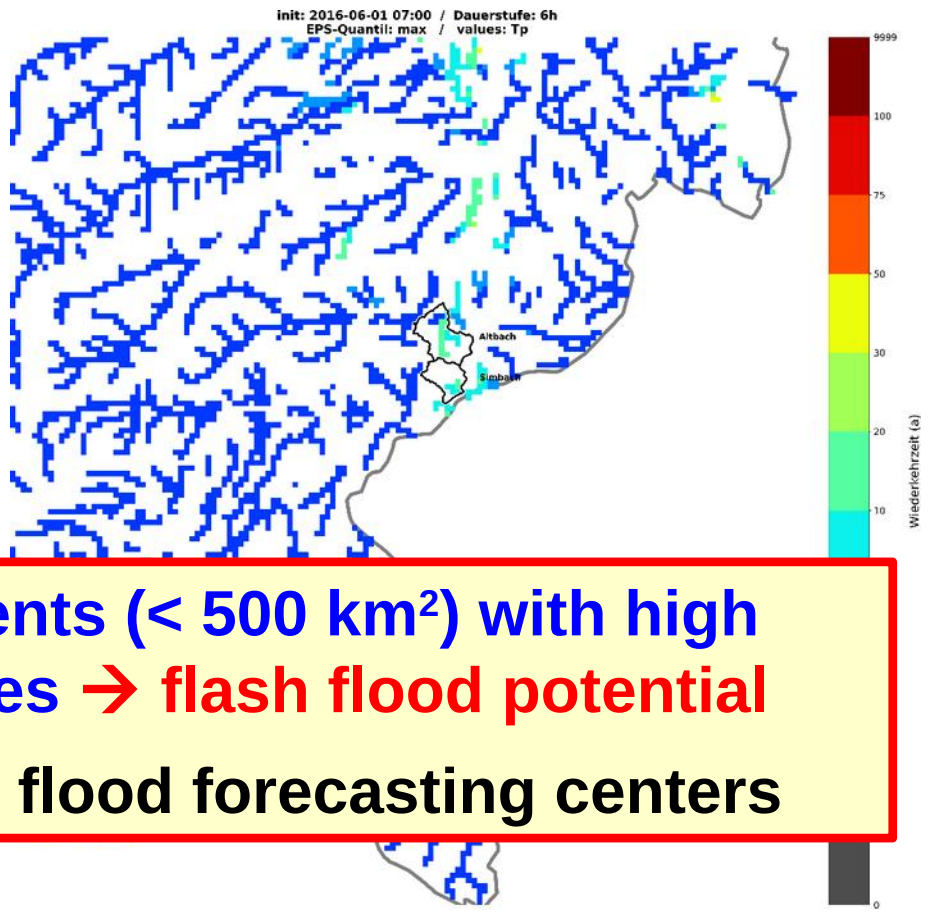
Poster 95
Jan Bondy
AREA

Simbach case, 7 UTC INTENSE, EPS max

6 h rain sum [mm] in catchment upstream of each pixel



Return period [years]



- **Quickly identify small river catchments (< 500 km²) with high precipitation input at short lead times → flash flood potential**
- **Development together with German flood forecasting centers**

Summary and outlook SINFONY

- **Promising prototypes developed**, now phase of consolidation, **step-by-step operational introduction in the next years, longterm operations & maintenance**
- ICON-RUC(-ENS) already operational and available on opendata.dwd.de
- SINFONY components work good for convective season. **But need to work on winter and other phenomena!**
- Therefore, **further research activities 2025 – 2028** in project **SINFONY 3.0:**
  - Extend focus to other types of weather (e.g., stratiform, winter, fog) and other customers like aviation, energy sector
  - Seamless beyond 12 h and for other parameters (wind, temperature, clouds)
  - Integrate satellite Nowcasting
  - Improve QPE
  - AI-methods more and more used in all of these projects

Poster 74
N. Antonoglou
Radar and Rain DSD‘s

- We try **co-design with users / customers: test data, evaluations, common projects** (e.g., in the framework of our Co-Design projects)

Thank you for your attention!

SINFONY Tutorials / E-Learning:
www.dwd.de/sinfony → E-learning
(in German language)

www.dwd.de/sinfony sinfony@dwd.de

Our external partners

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Cooperate with other projects and external partners:

- HErZ, Extramural research
- MeteoSwiss
- Waves2Weather
- IMK@KIT
- University Ulm
- University Tübingen
- DFG research group RealPeP
- DFG priority program PROM
- European Severe Storms Laboratory (ESSL) Testbed

Hans-Ertel-Zentrum für Wetterforschung

WAVES TO WEATHER

PROM

RealPEP

KIT Karlsruher Institut für Technologie

ulm university universität ulm

ESSL Testbed

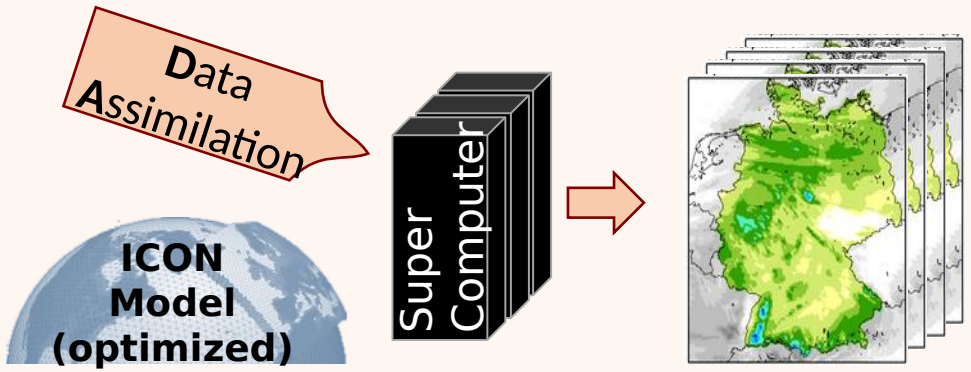
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

SINFONY

The SINFONY as in current transition to operations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

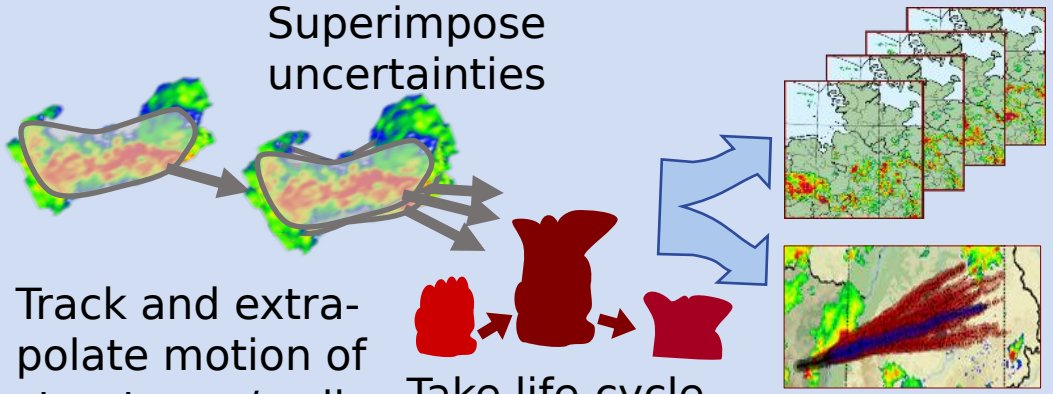
Numerical Weather Prediction (convection allowing)



New in SINFONY:

- **ICON-RUC** ensemble-forecast up to +14 h
- hourly inits (**R**apid **U**pdate **C**ycle)
- Adapted physics
- New data in DA:
  - **Radar Vol dBZ, v_r**
  - **SAT VIS / IR**

Nowcasting



New in SINFONY:

- **STEPS-DWD** precipitation fields **ensemble-**nowcast
- **KONRAD3D(-EPS)** convective cell objects

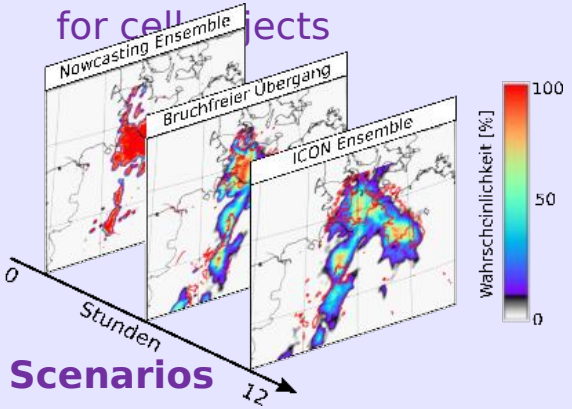
1) Probabilistic

2) Full ensemble

Seamless combined forecast products

Obs → Nowcasting → NWP

- **INTENSE** ensemble for fields
- **C3** exceedance probabilities
- **KONRAD3D-SINFONY** ensemble for cell objects



- **Scenarios**
- **Exceedance probabilities**
  - for thresholds
  - for presence of conv. cells
- **Best estimate of** expected precipitation

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Some more details on the ICON-RUC

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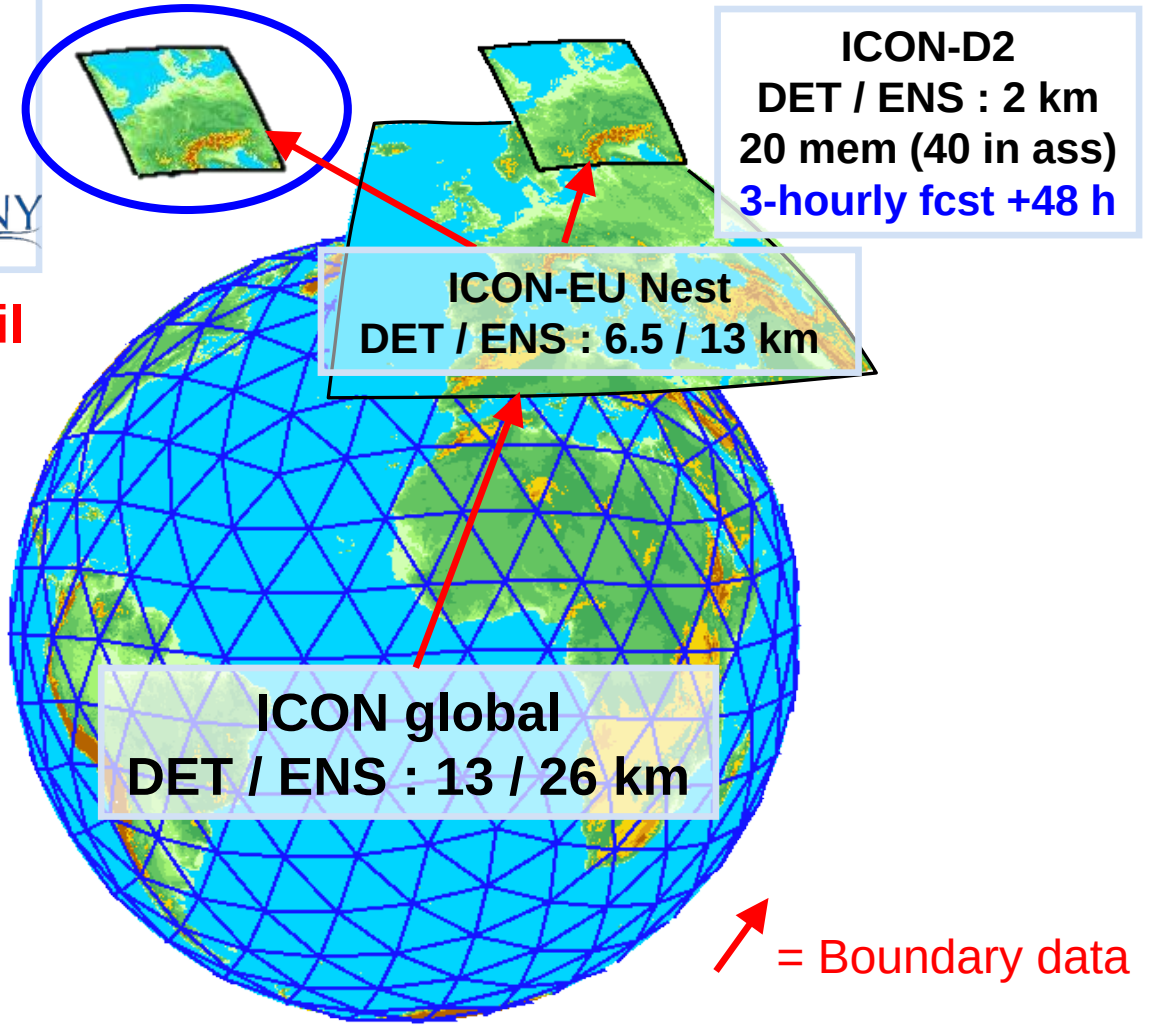
Other differences to ICON-D2:

- Focus on **good precipitation and clouds / synthetic cloudy obs at the same time**
- **2-moment cloud microphysics with explicit hail**
- **For the first time** hourly NWP update **at DWD**

New: ICON-RUC
DET / ENS: 2 km
1-hourly fcst +14 h
20 mem (40 in ass)
SINFONY
Part of the



➔Available after 35'!

➔Operational since July 2024

➔Now on opendata.dwd.de

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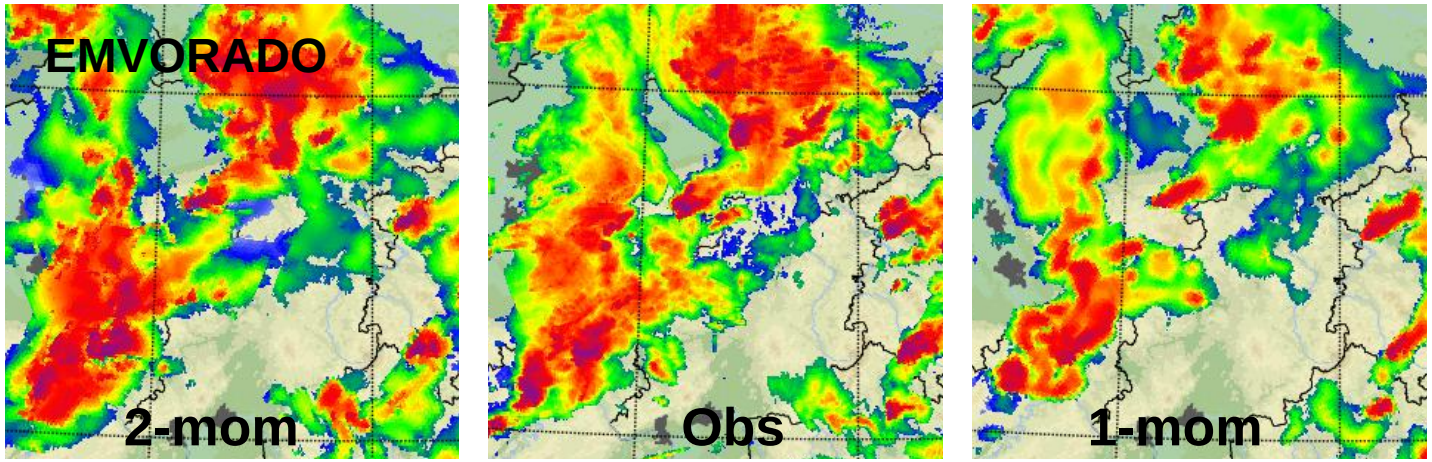
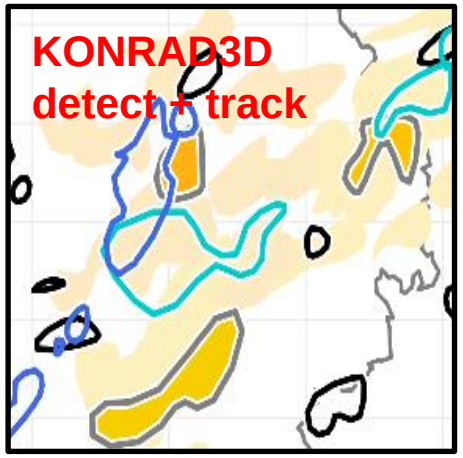
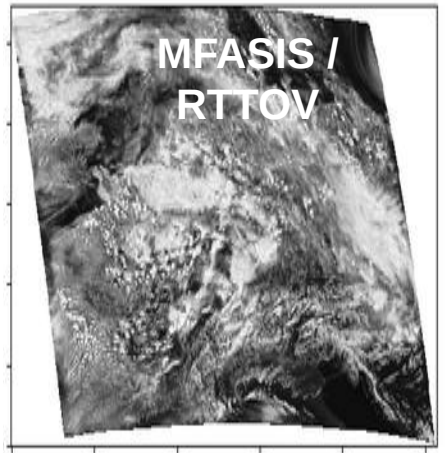
NWP results in observation space
(dBZ, cell objects, Sat IR / VIS channels)

Talk Tue 09:20
Nora Strotjohann
KONRAD3D-SINFONY

- **Advanced forward operators for:**
- **Radar volumes/composites** EMVORADO (Vr, Refl, pol. par.)
- **Cell objects** EMVORADO + KONRAD3D (cell tracking in each RUC member)
- **VIS / IR sat images** MFASIS / RTTOV







- **Seamless combined Nowcasting-NWP-products** (5‘ update, 5‘ time resolution)
- **Verification / model development**
- **Assimilation** by our **LETKF together** with **conventional data** and **Latent Heat Nudging (LHN)**

Poster No. 52 Mon
Jana Mendrok
Polar. eval ICON-RUC

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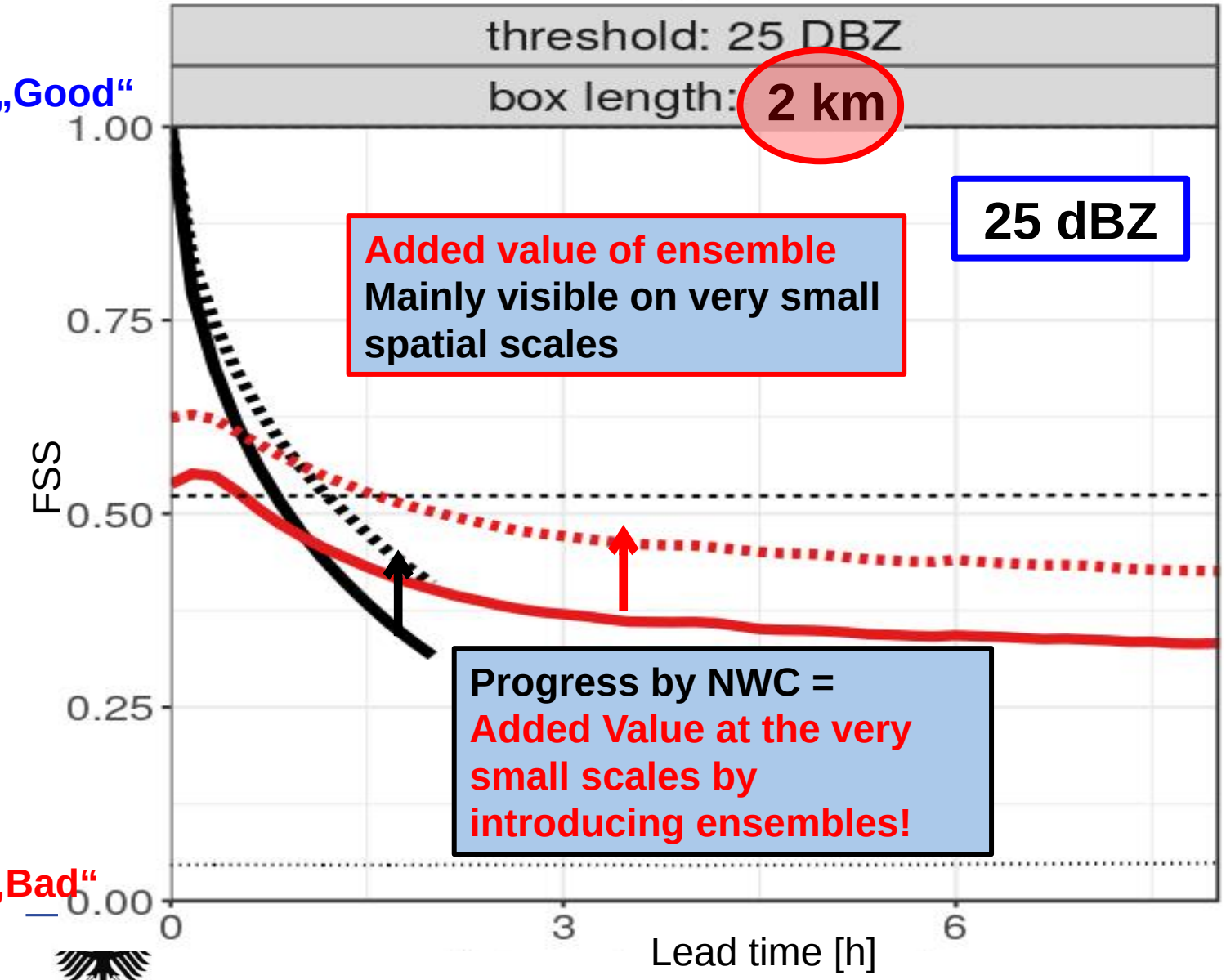
Verification reflectivity STEPS-Nowcasting and RUC vs. Radar in 07/2023 (det + ens)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Time period: 01.07. – 31.07.2023

Forecast runs: 12, 13, 14, … ,18 UTC (deterministic)

Parameter: **Radar reflectivity (dBZ)**

Score: **fraction skill score (FSS)**

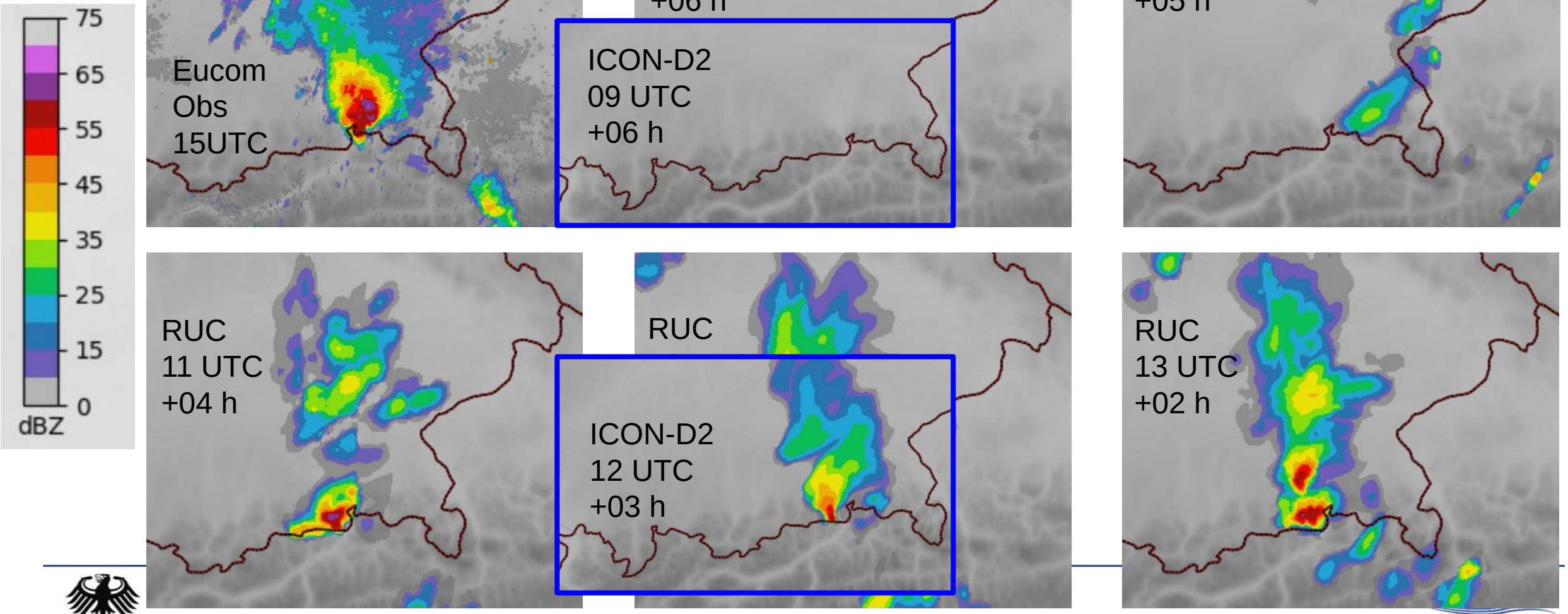
STEPS-DWD Nowcasting (det)

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

Neighbourhood ENS Prob. (NEP)

SINFONY

Performance of ICON-RUC in forecasting a supercell near Berchtesgaden at 20.6.2024



Added value of the ensemble, e.g., for hail forecasting

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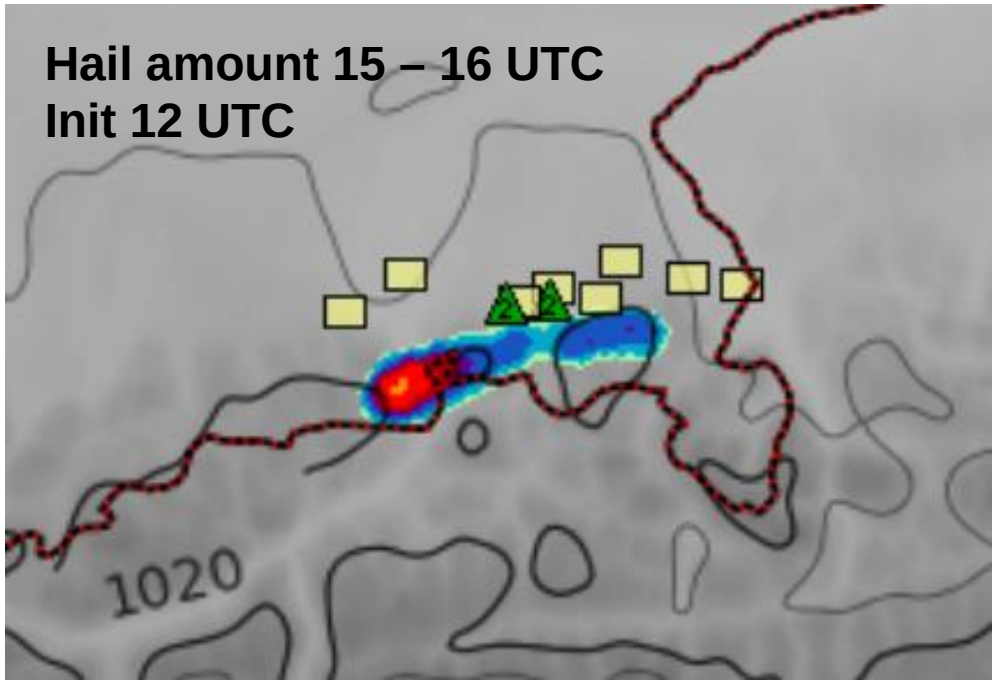
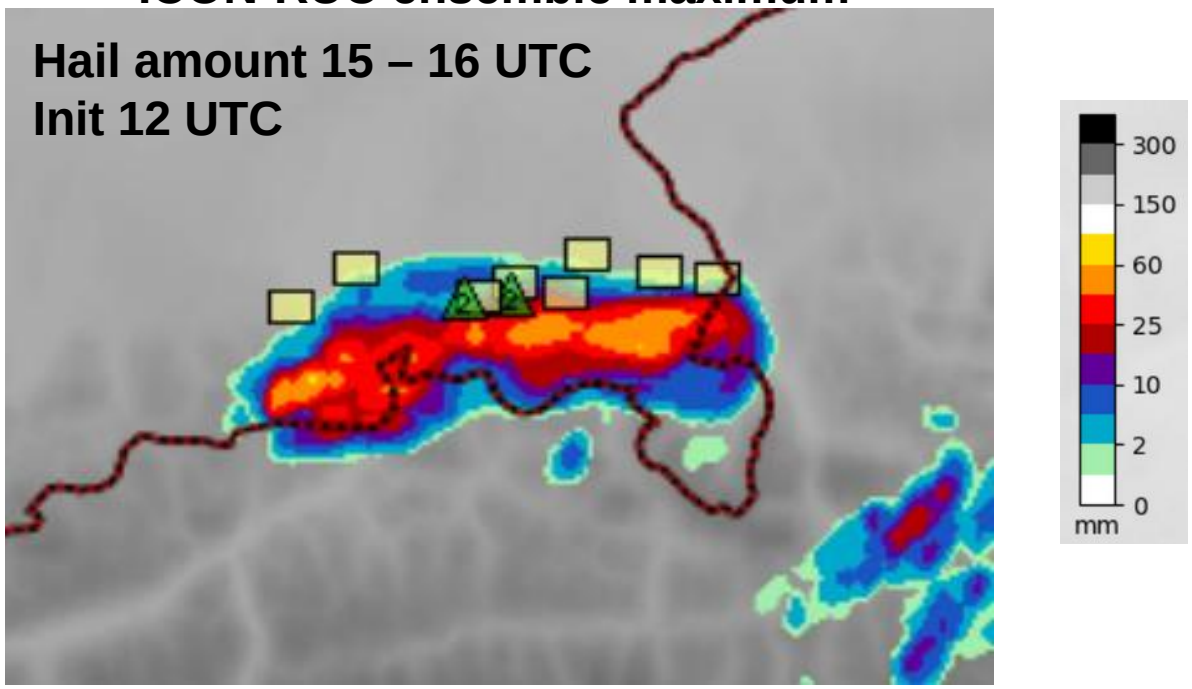
Comparison with ESWD and DWD crowd reports

ICON-RUC deterministic



ICON-RUC ensemble maximum



- Direkt output for hail amount and mean size at the ground
- Currently work on max size estimate and gaining some experience

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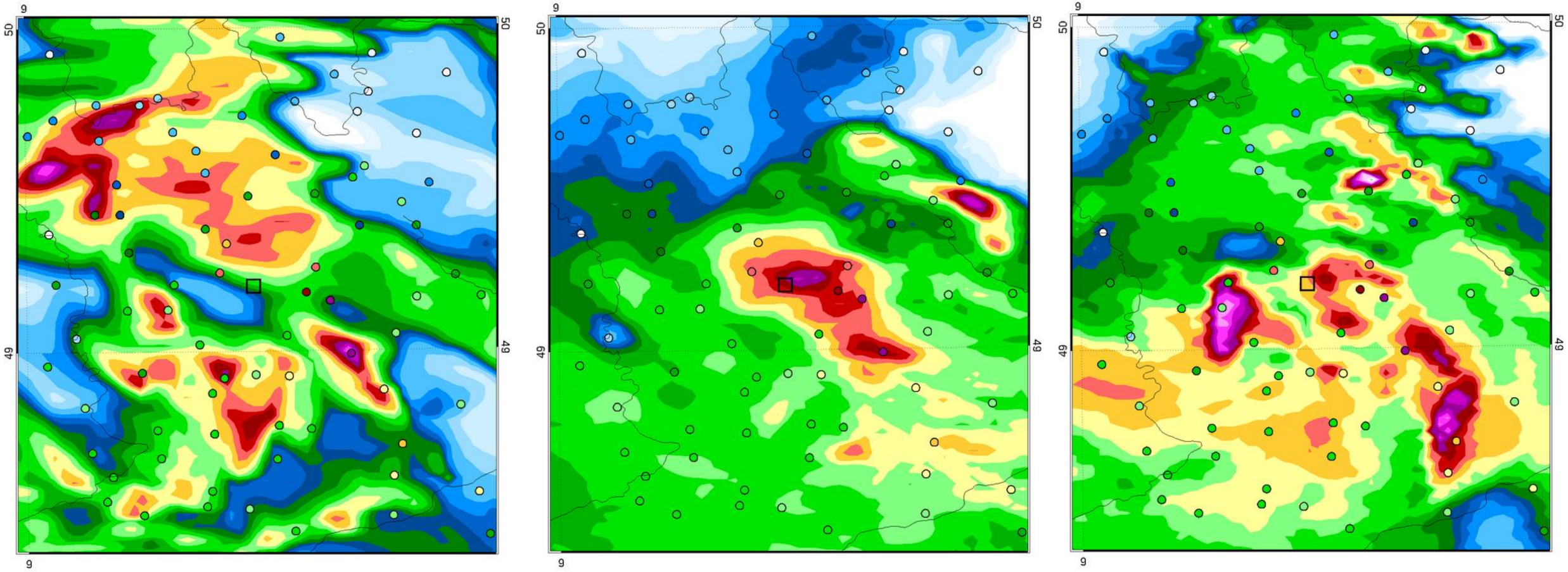
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE det. init 12 UTC | **OBS** | **ICON-RUC det. re-forecast init 13 UTC**



SINFONY

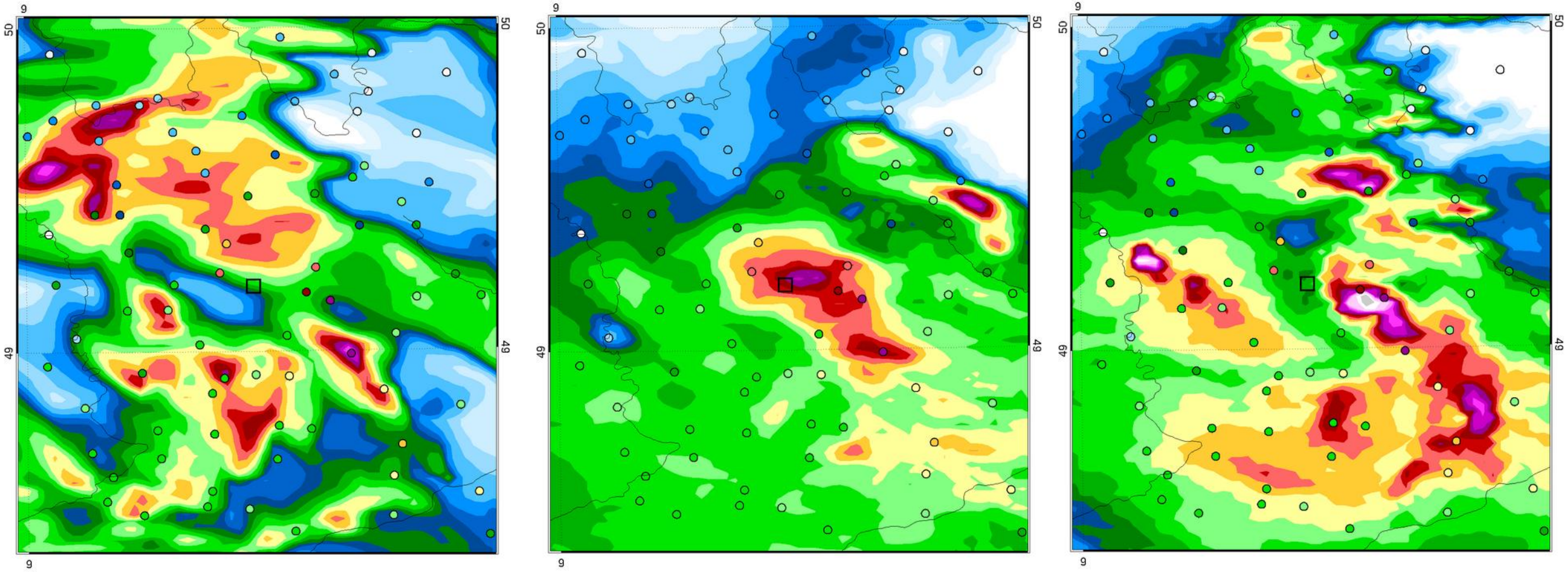
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE det. init 12 UTC | **OBS** | **ICON-RUC det. re-forecast init 14 UTC**



SINFONY

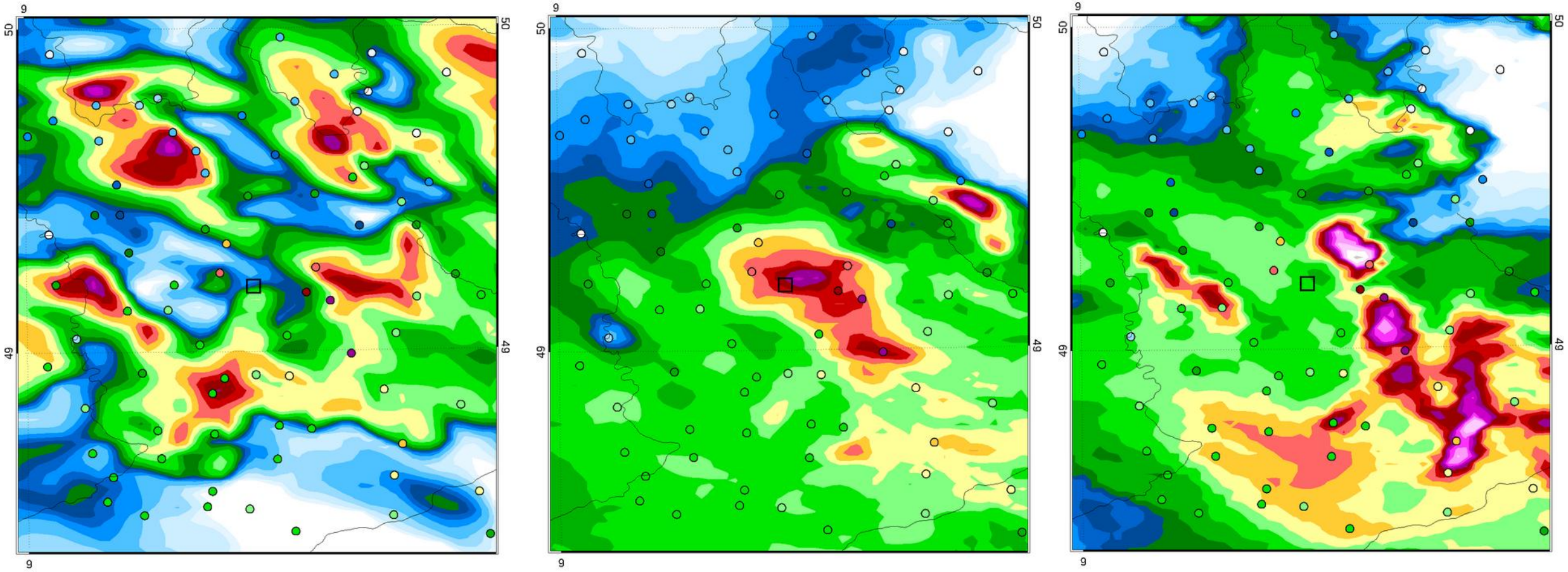
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE det. init 15 UTC | **OBS** | **ICON-RUC det. re-forecast init 15 UTC**



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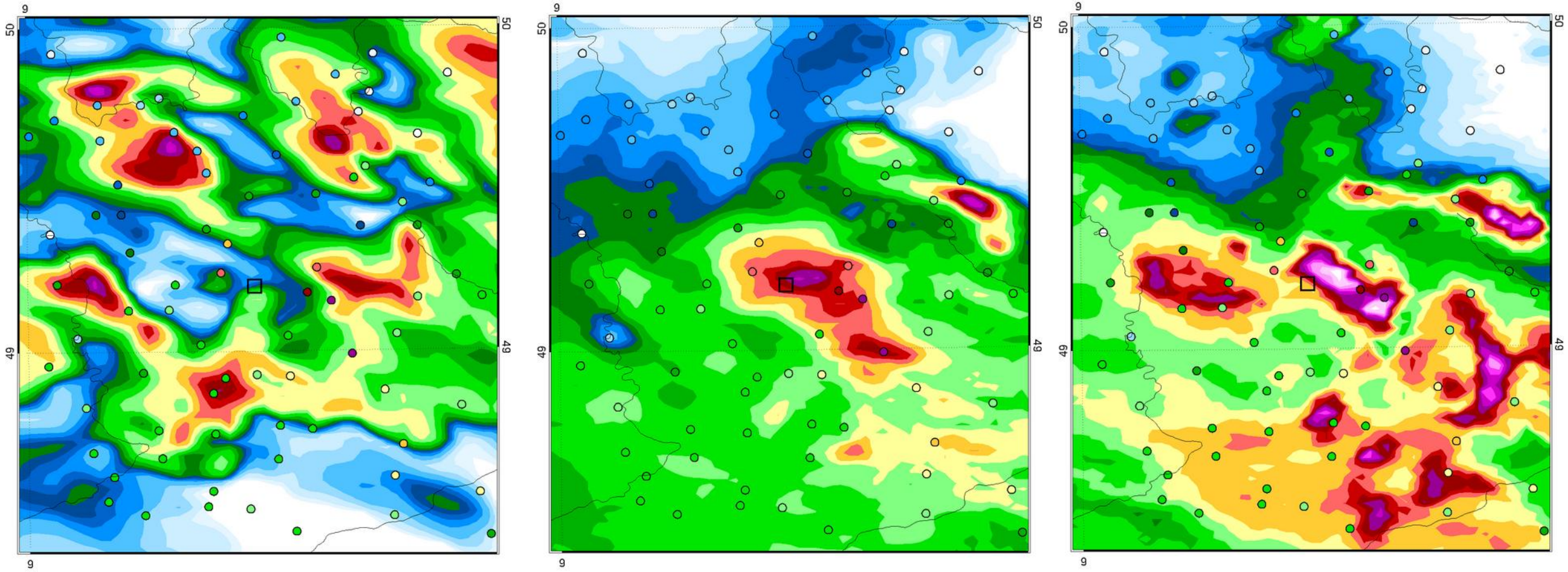
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Braunsbach flash flood case, 29.5.2016

Accumulated precipitation from 17 – 19 UTC

Old COSMO-DE det. init 15 UTC | **OBS** | **ICON-RUC det. re-forecast init 16 UTC**



SINFONY

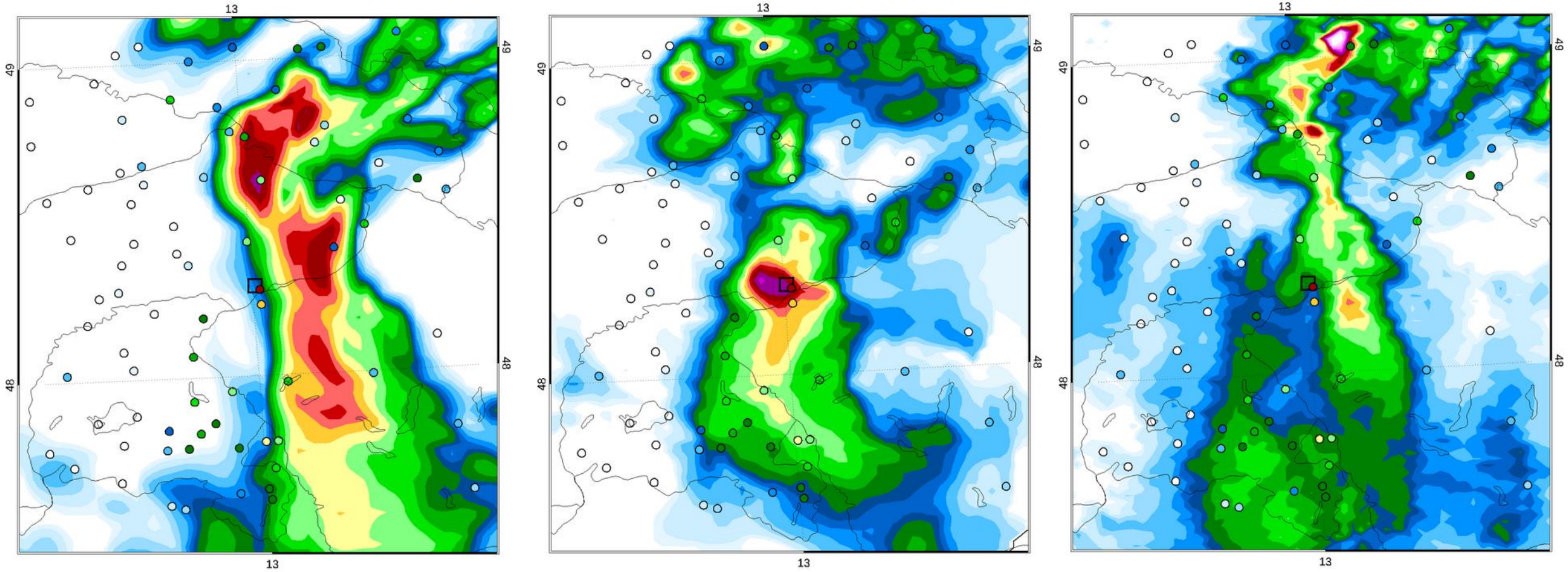
Achievements in NWP for Simbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE det. init 03 UTC | **OBS** | **ICON-RUC det. re-forecast init 03 UTC**



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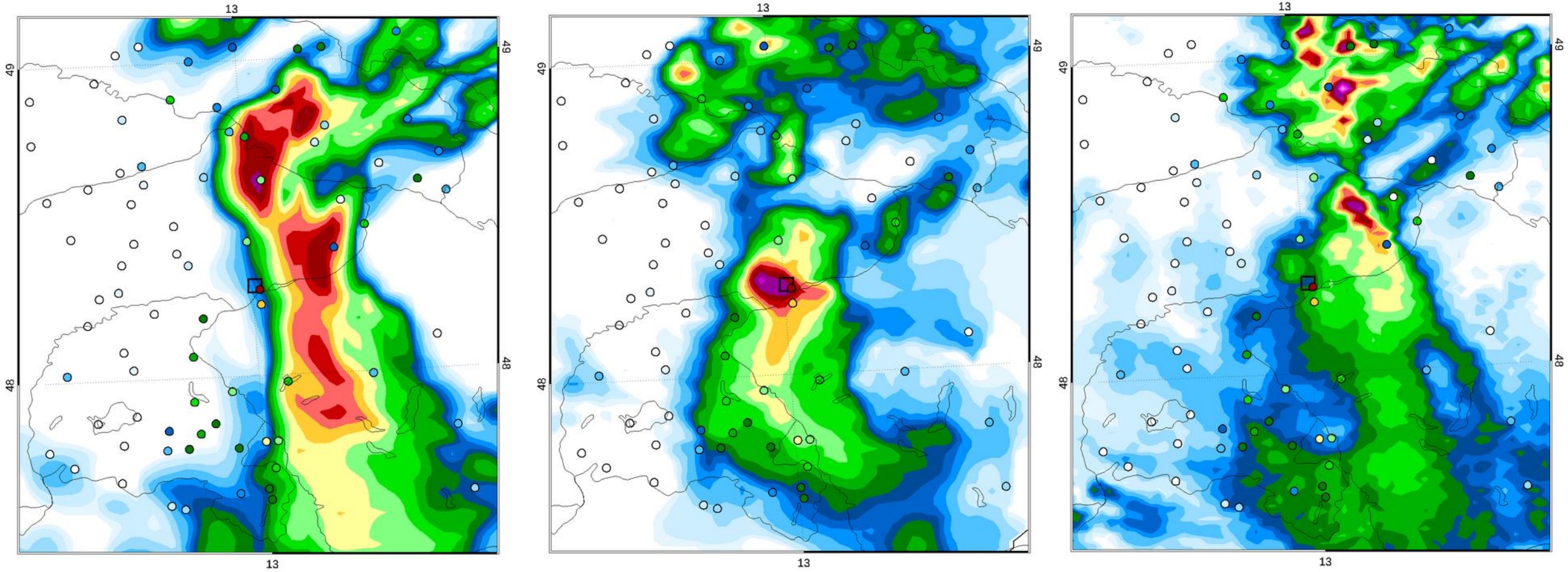
Achievements in NWP for Simbach case

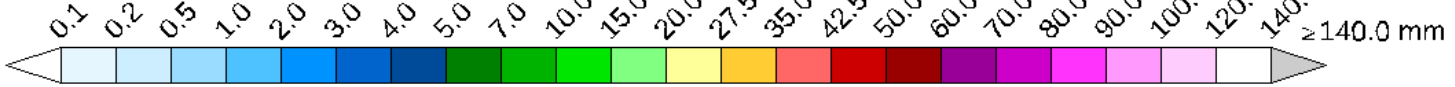
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE det. init 03 UTC | **OBS** | **ICON-RUC det. re-forecast init 04 UTC**





SINFONY

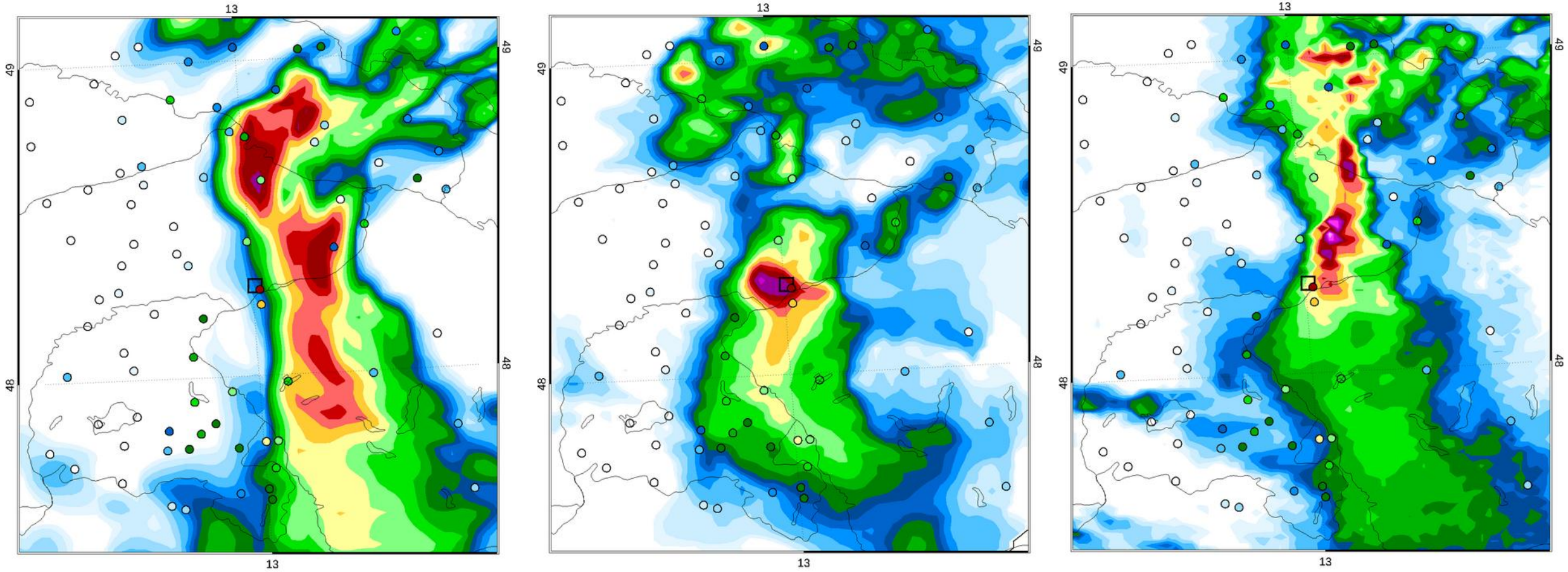
Achievements in NWP for Simbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE det. init 03 UTC | **OBS** | **ICON-RUC det. re-forecast init 05 UTC**



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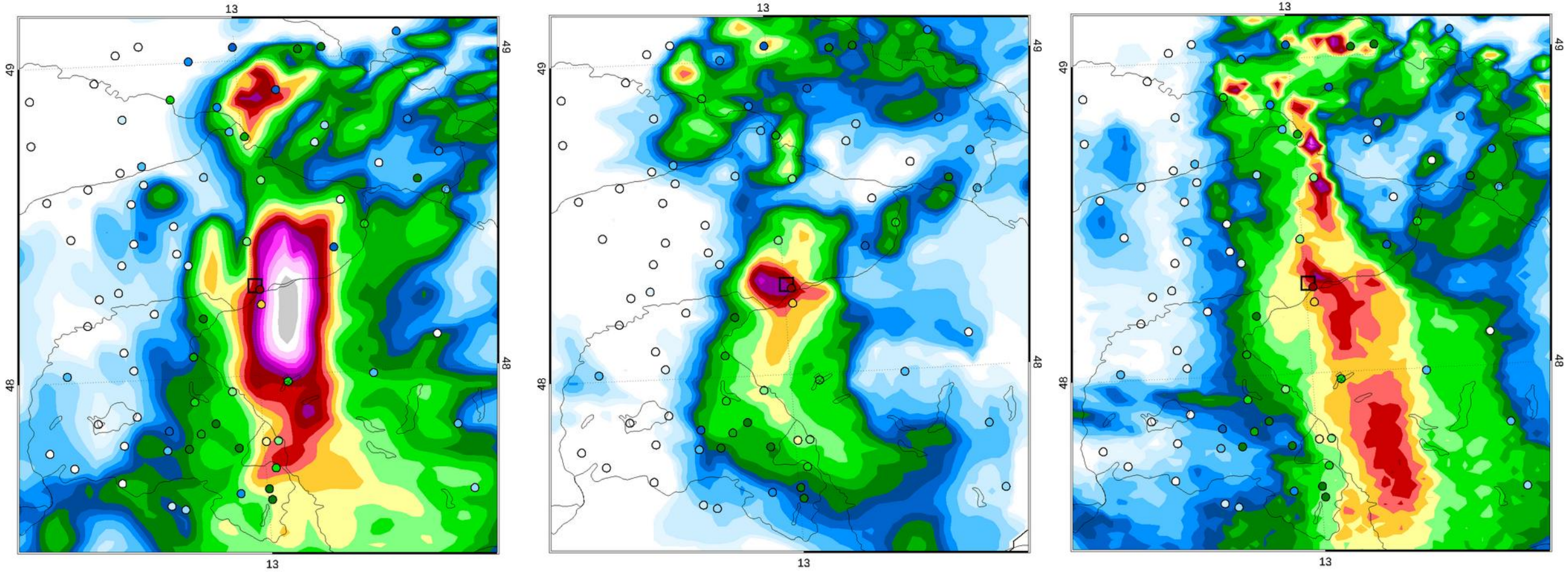
Achievements in NWP for Simbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE det. init 06 UTC | **OBS** | **ICON-RUC det. re-forecast init 06 UTC**



SINFONY

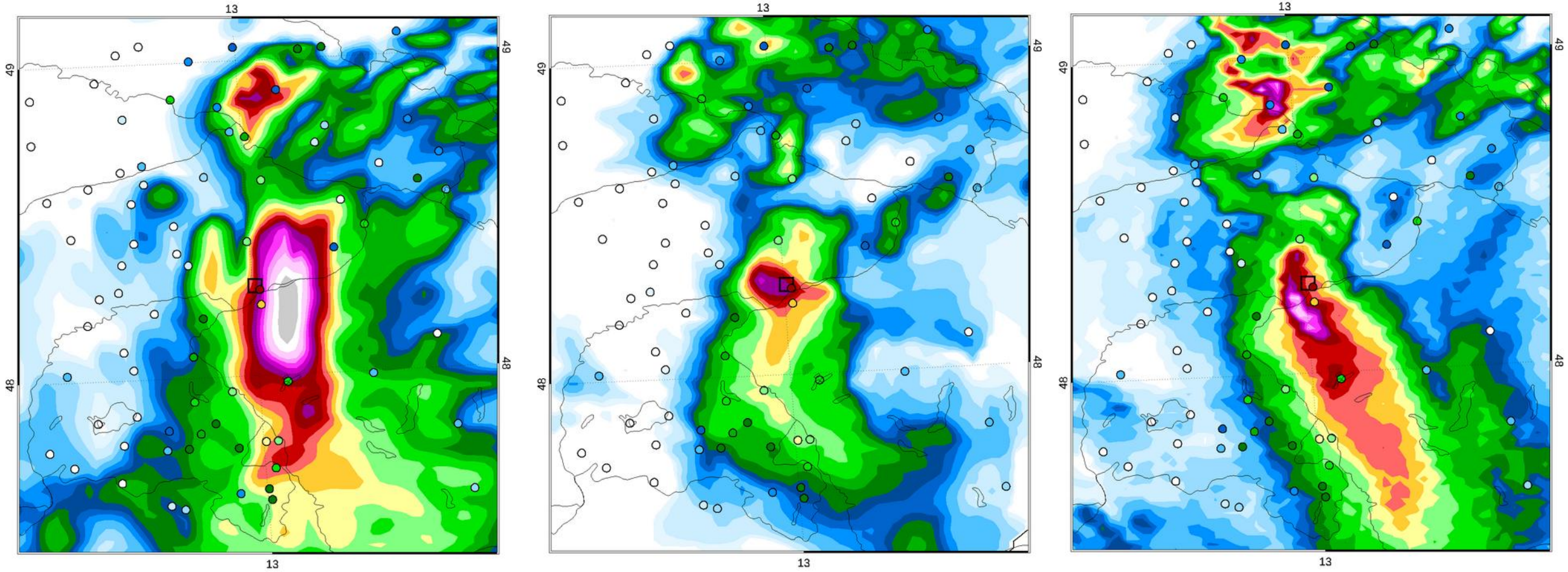
Achievements in NWP for Simbach case

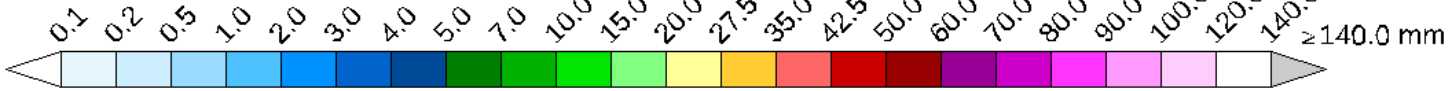
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE det. init 06 UTC | **OBS** | **ICON-RUC det. re-forecast init 07 UTC**





SINFONY

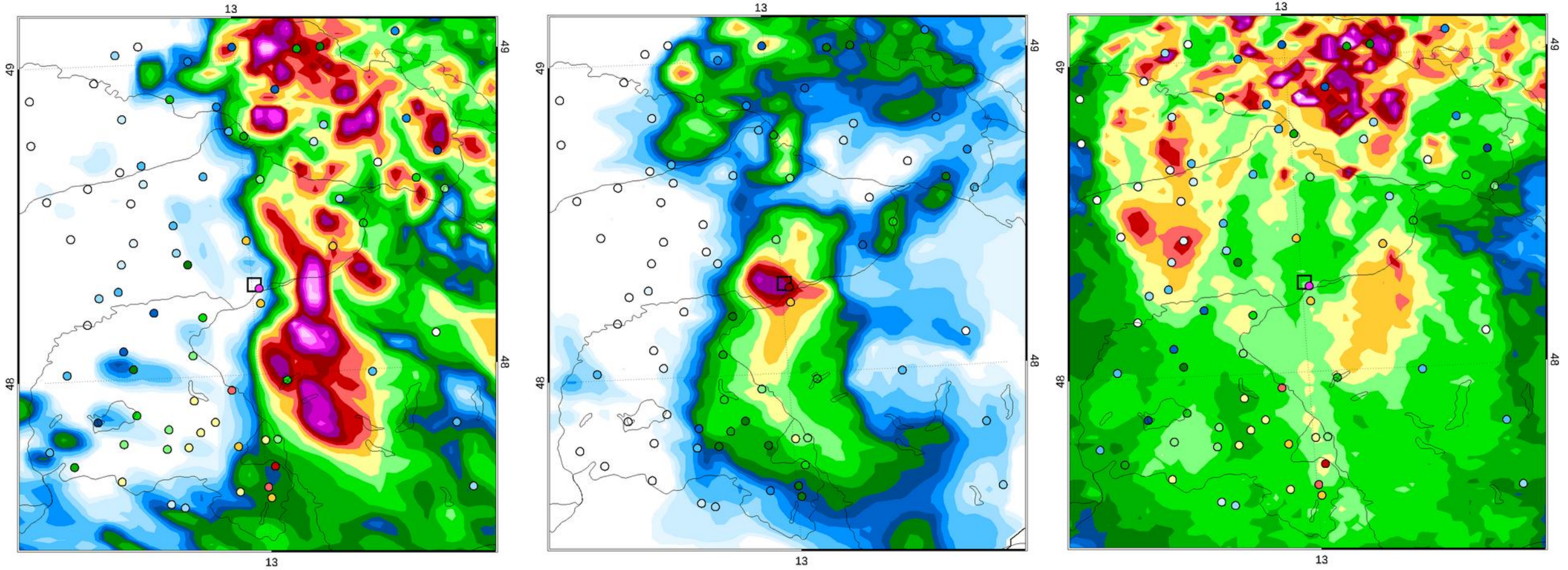
Achievements in NWP for Simbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

Accumulated precipitation from 9 – 13 UTC

Old COSMO-DE ensmax init 03 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 03 UTC**



SINFONY

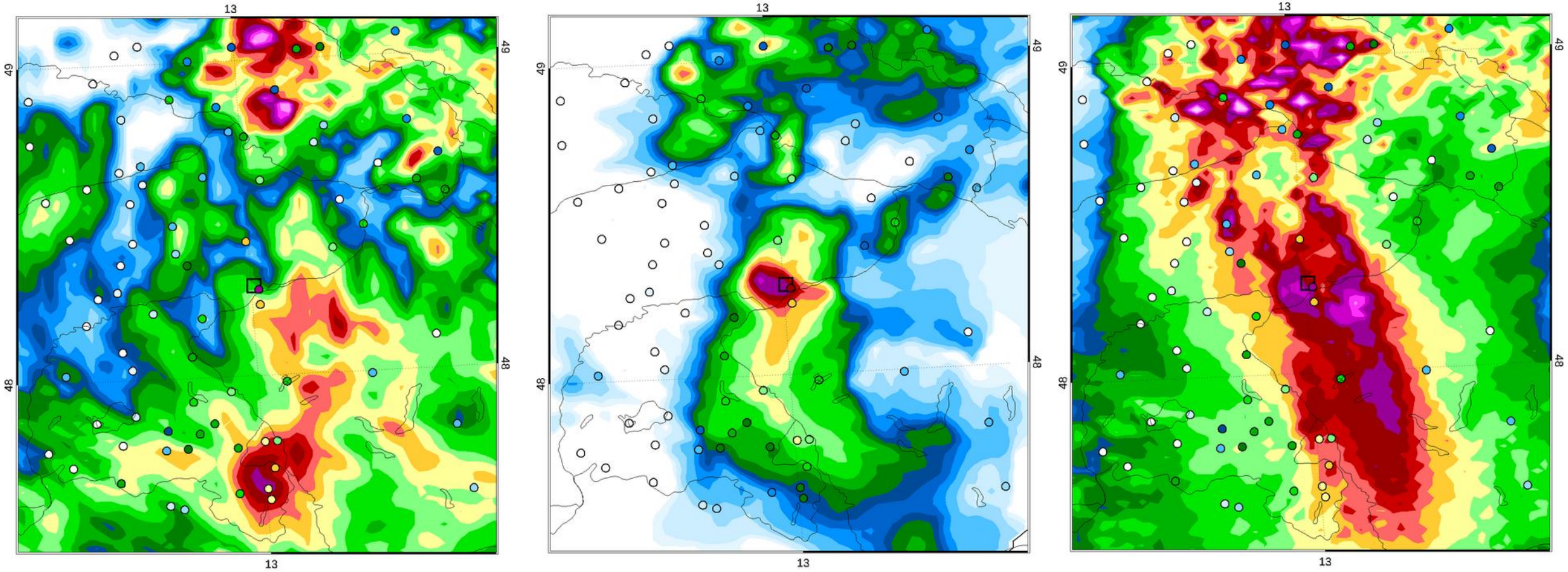
Achievements in NWP for Simbach case

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

➔ Precipitation, Simbach flash flood case, 1.6.2016

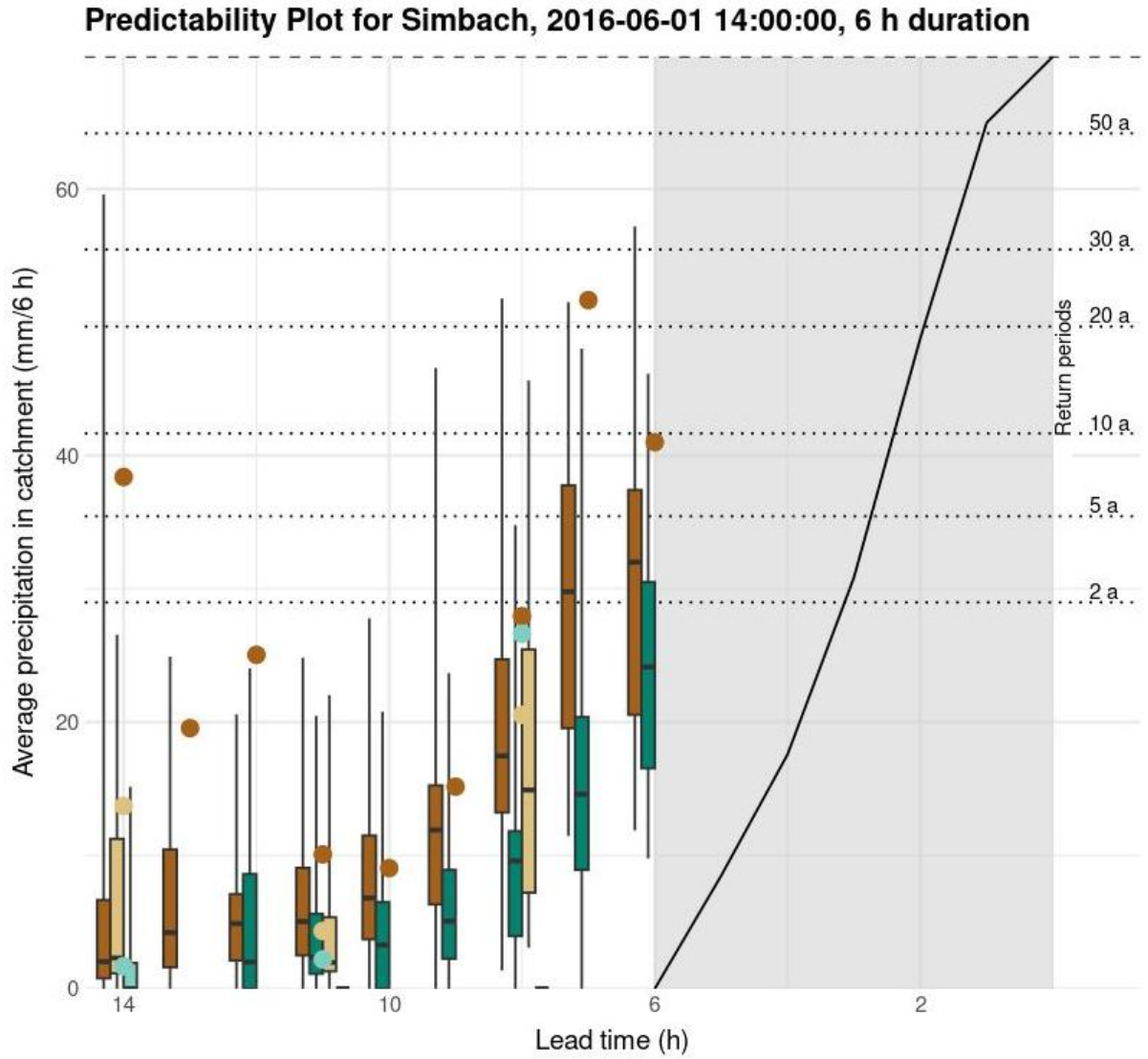
Accumulated precipitation from 9 – 13 UTC

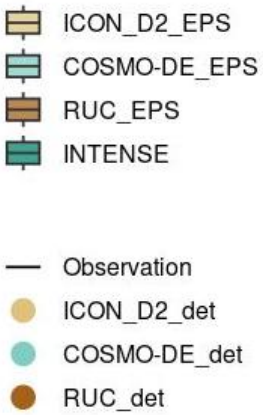
Old COSMO-DE ensmax init 06 UTC | **OBS** | **ICON-RUC ensmax re-forecast init 06 UTC**



SINFONY

Predictability of catchment precipitation for Simbach case





- Catchment very small (~ 15 km²)
- Quasistationary cell was very small
- Very hard to predict, small spatial shifts have large negative impact
- None of the ensembles got it within its bounds
- However, RUC and ICON-D2 showed at least some signal, while for COSMO-DE only the det. run had some signal
- Note: INTENSE appears shifted by 1 h

(Ina Blumenstein-Weingartz Co-Design project)

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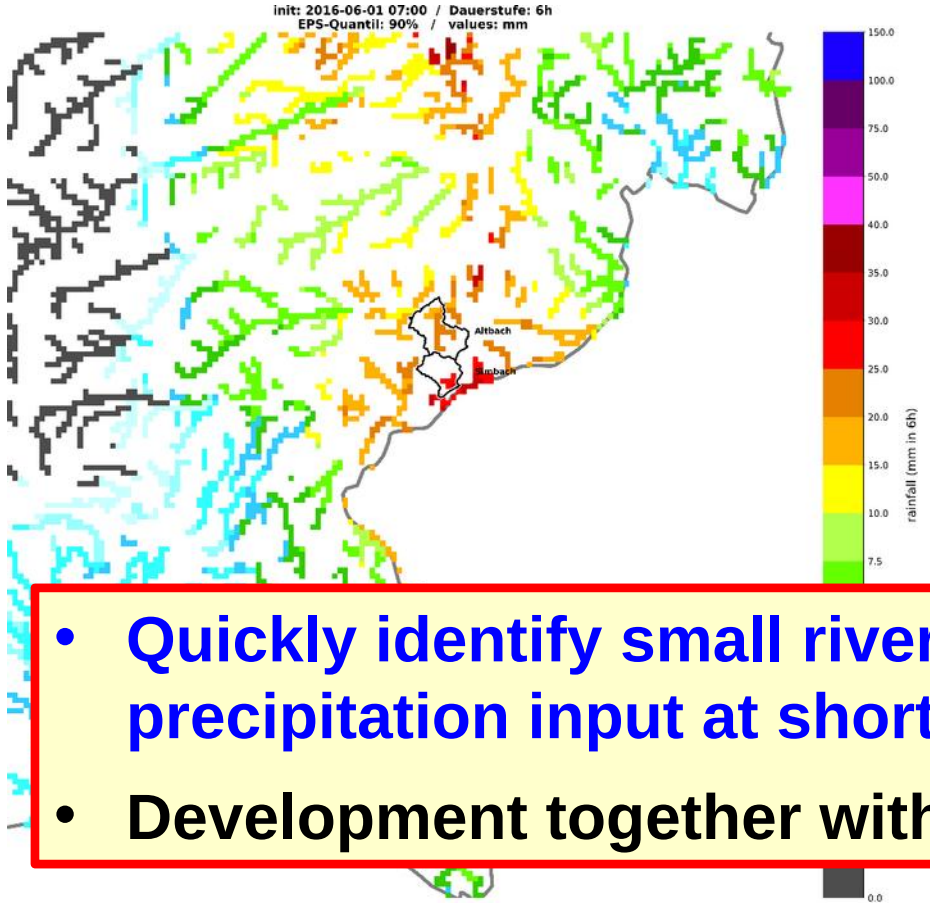
Aggregation of INTENSE over catchment area (AREA)

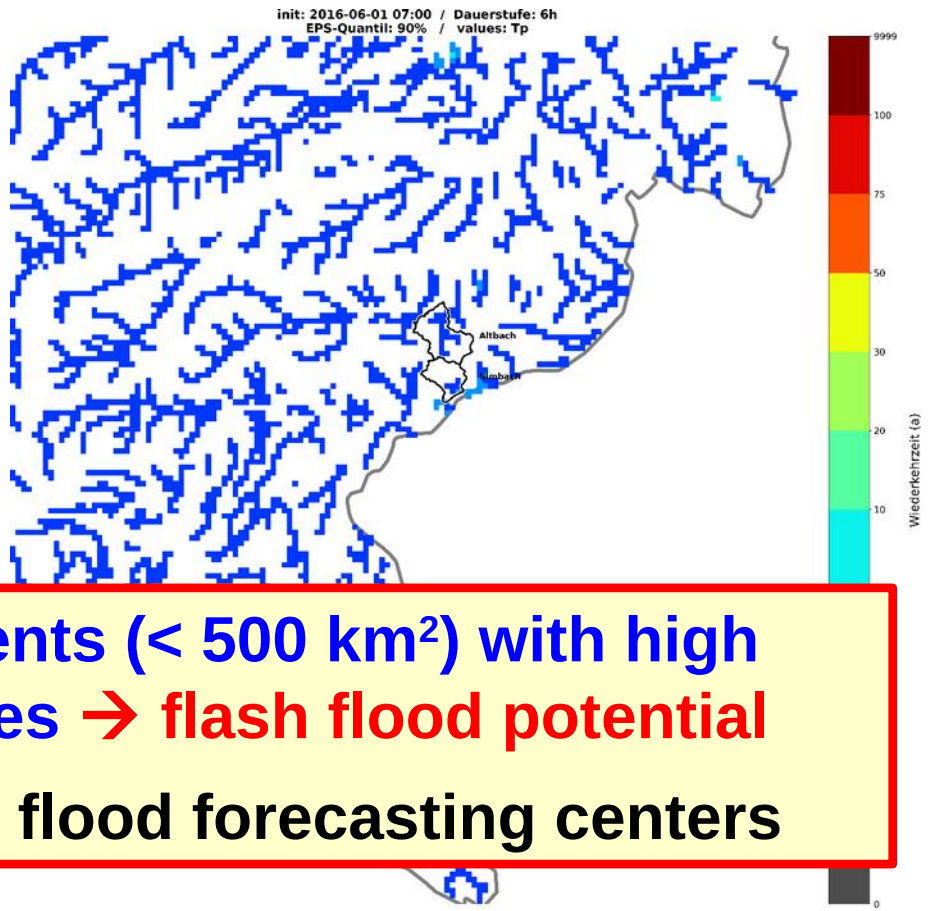
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Simbach case, 7 UTC INTENSE, EPS 90 % percentile

6 h rain sum [mm] in catchment upstream of each pixel



Return period [years]



- **Quickly identify small river catchments (< 500 km²) with high precipitation input at short lead times → flash flood potential**
- **Development together with German flood forecasting centers**