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, Jana Mendrok, Mareike Burba, Leonhard Scheck, Annika Schomburg, Christian Berndt, Gregor Pante, Sarah Heibutzki, Thorsten Steinert, Hendrik Reich, Ulrich Friedrich, Arne Spitzer, Lukas Josipovic, Thomas Deppisch, Matthias Gottschalk, Maicon Hieronymus, Fabian Schubert, Cristina Primo-Ramos, Tobias Bergmann, Cornelius Hald, Isabel Schnoor, Nora Strotjohann, 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, Olga Kiseleva, 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, **transiting from obs via Nowcasting ensemble to NWP ensemble**
- ➔ Establish **vivid exchange** and a **co-design approach** with users (DWD forecasters, flood forecasting centres)

The SINFONY as in current transition to operations

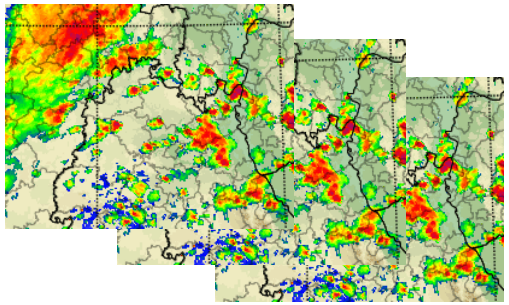
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Some verification score for convective events

- ➔ **Hourly new ENS forecasts up to + 14 h (RUC)**
- **ICON-LAM**
- **Δx = 2 km**
- **adapted model physics**

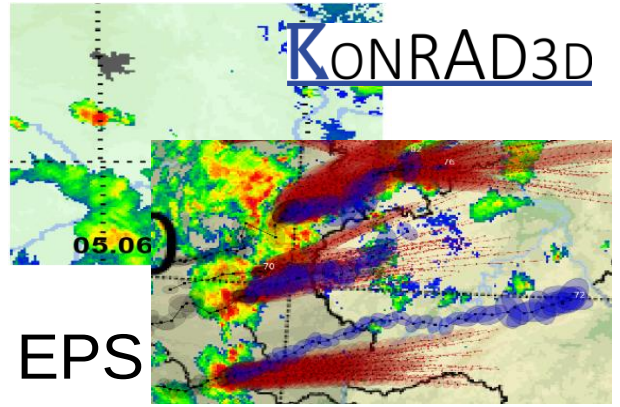
- ➔ **Combined / blended products:**
- ➔ Threshold-based probabilities (mm/h, dBZ)
- ➔ Combined areal ensemble (mm/h, dBZ)
- ➔ Combined cell objects

STEPS-DWD



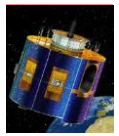
- ➔ **Radar based precipitation Nowcasting**
  1) **Gridded fields (mm/h, dBZ)**
  2) **Cell objects**

KONRAD3D



EPS

- ➔ **Assimilation of new data* in KENDA-LETKF:**
  - ➔ Radar volume scans v_r, dBZ, cell objects
  - ➔ METEOSAT VIS / IR
  - ➔ Lightning



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

SINFONY

The SINFONY as in current transition to operations

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Some verification score for convective events

➔ Hourly new ENS forecasts up to + 14 h (RUC)

ICON-LAM

Fully operational, opendata.dwd.de

➔ Assimilation of new data* in KENDA-LETKF:

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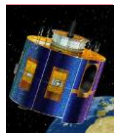


Current crossover at 1 – 1,5 h!

➔ C… products:

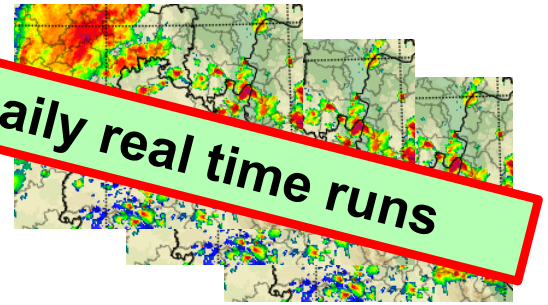
➔ T… (mm/h, …BZ)

➔ …

➔ …

Daily real time runs
Under evaluation by
Forecasters,
Flood forecasting centers
ESSL Testbed

STEPS-DWD



Daily real time runs

➔ Radar based precipitation Nowcasting

1) Gridded fields (mm/h, dBZ)
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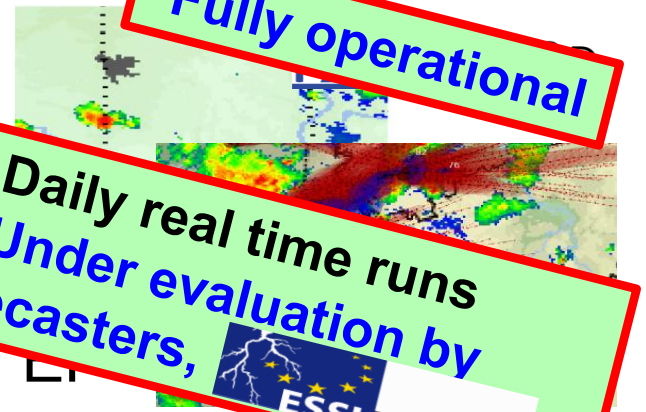

Fully operational

Daily real time runs
Under evaluation by
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SINFONY

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

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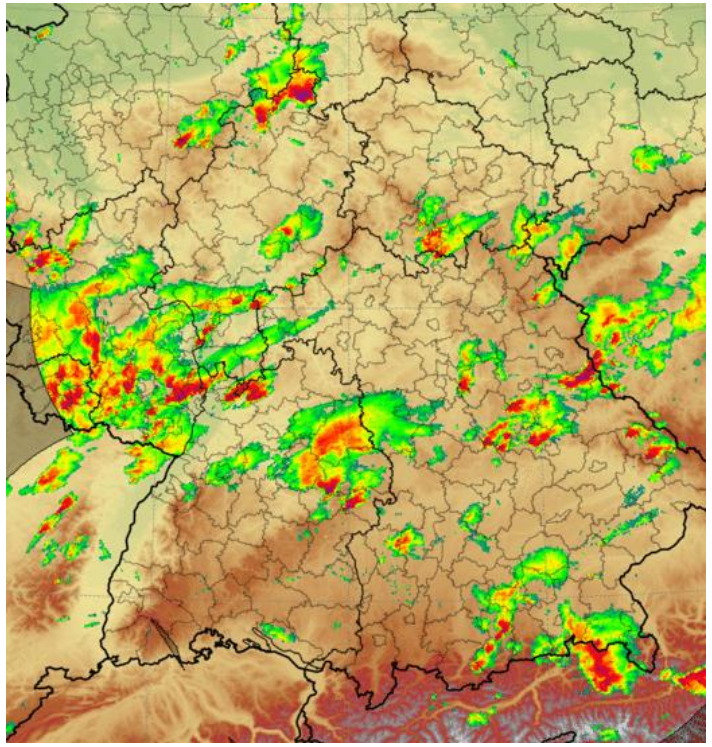
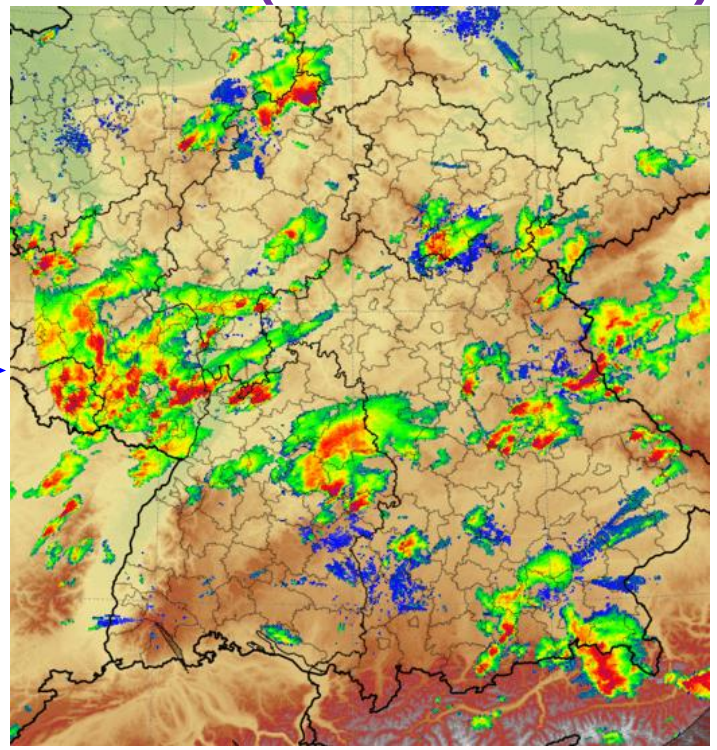
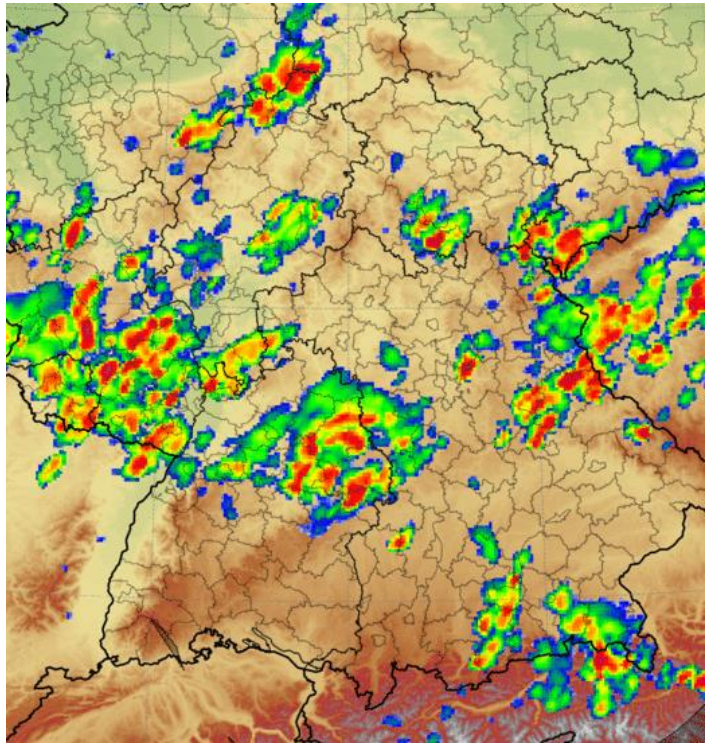
Nowcasting STEPS-DWD



INTENSE (1 of 20 members)



NWP ICON-RUC-EPS



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

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

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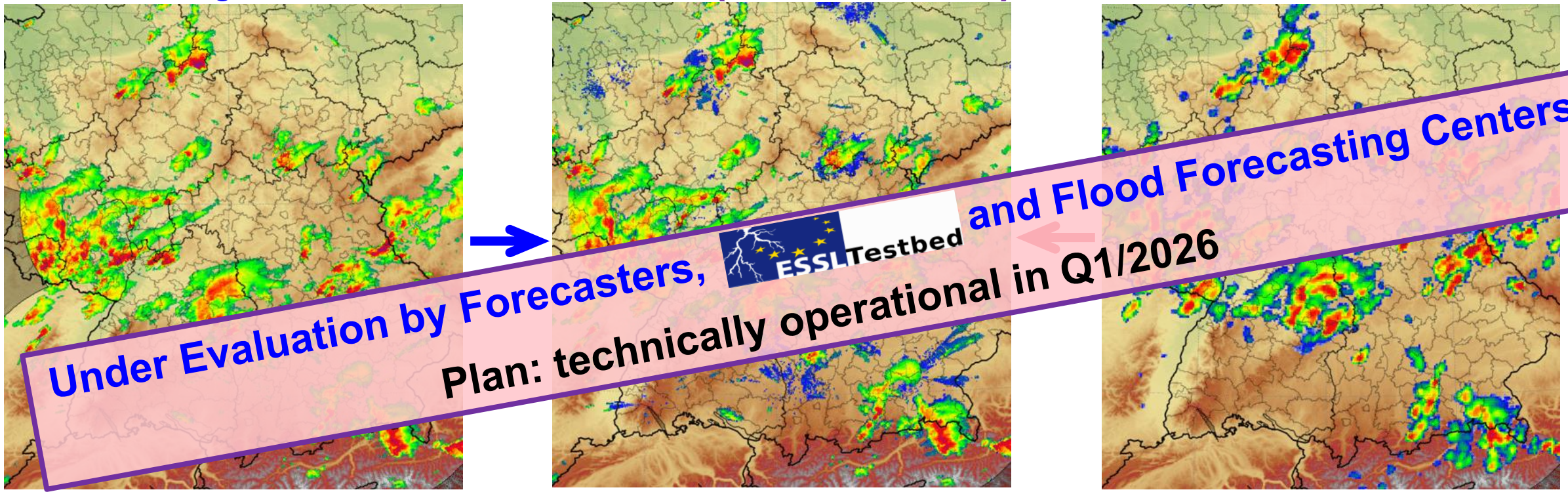
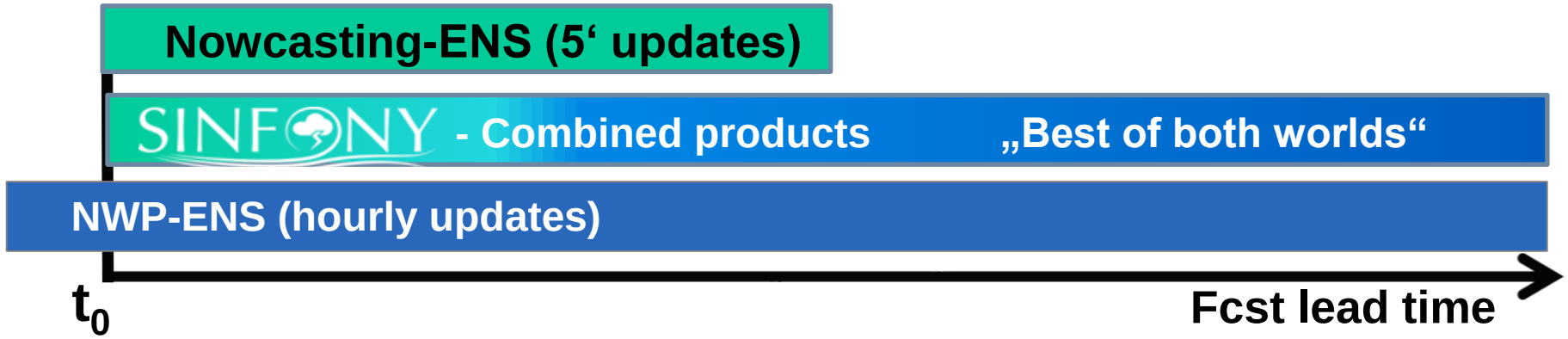
Wetter und Klima aus einer Hand

Nowcasting STEPS-DWD | **INTENSE (1 of 20 members)** | **NWP ICON-RUC-EPS**



Under Evaluation by Forecasters, ESSL Testbed and Flood Forecasting Centers

Plan: technically operational in Q1/2026



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

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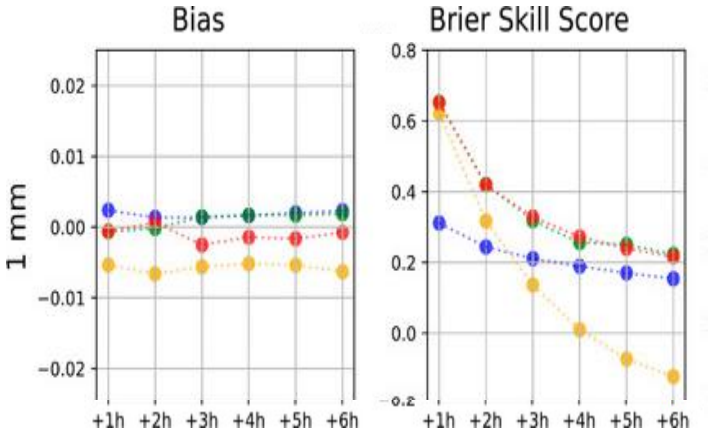
Another approach: blending in probability space

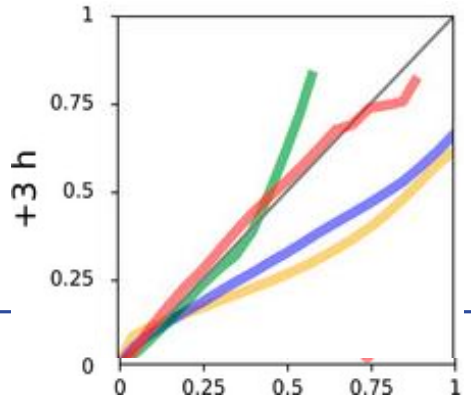
Rempel et al. (2022), Artif. Intell. Earth Syst., doi:10.1175/AIES-D-22-0020.1

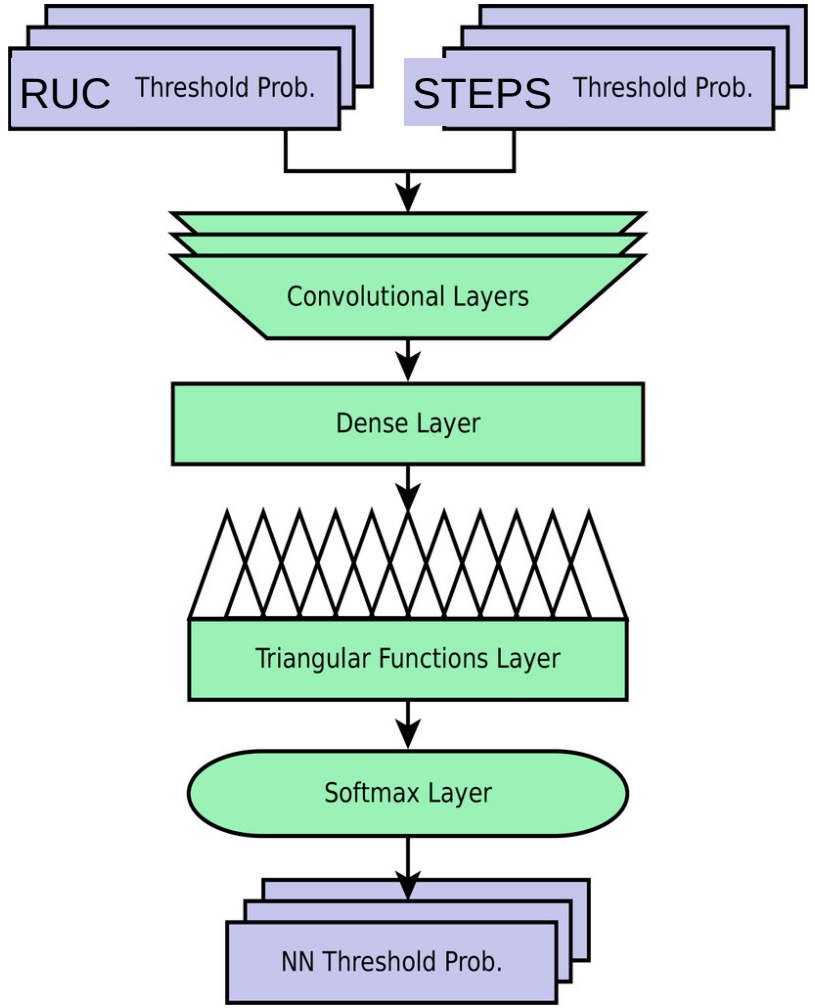
Prototype for NN-approach Consistent Calibrated Combination („C3“)

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





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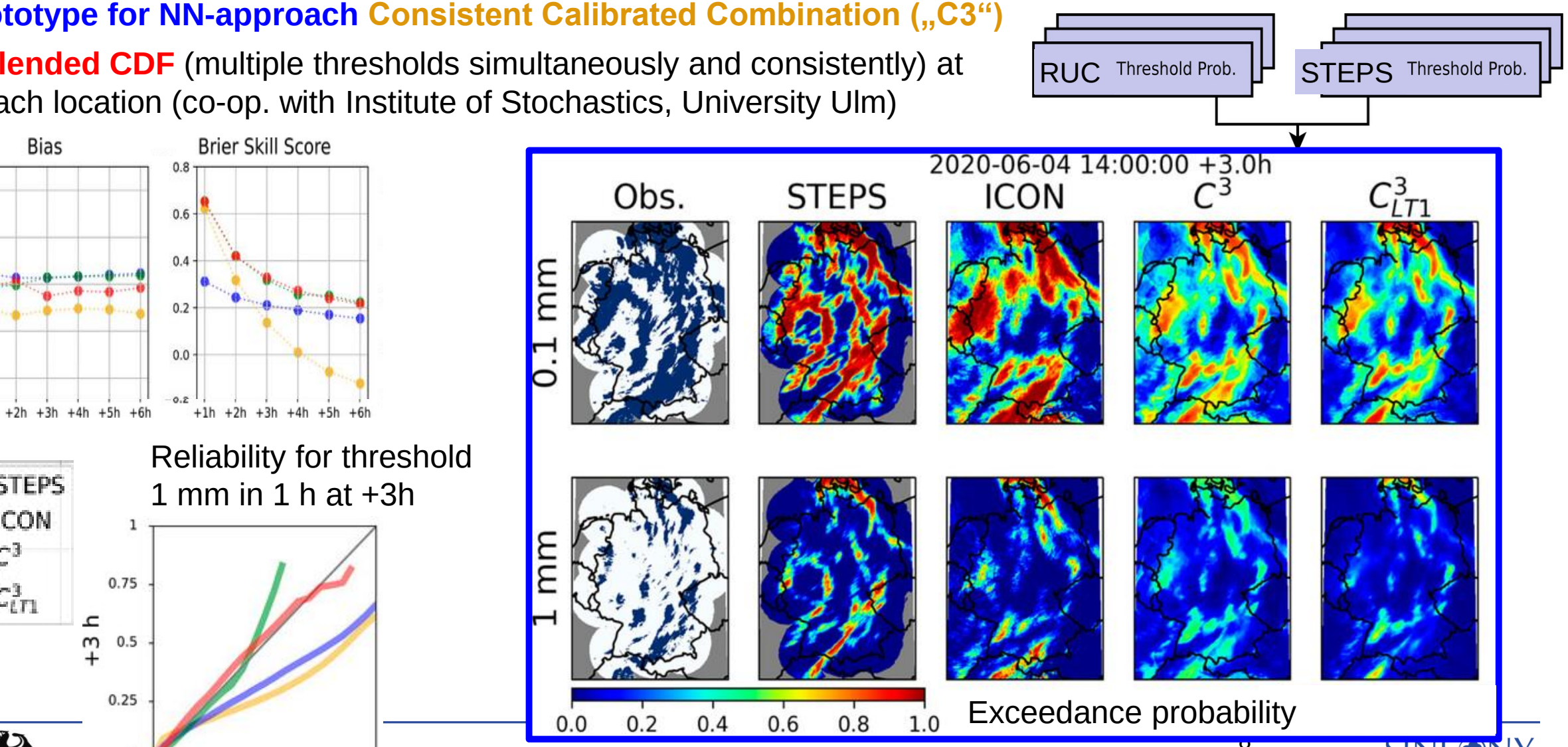

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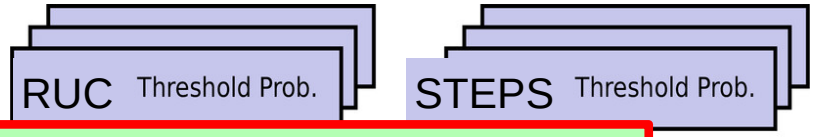
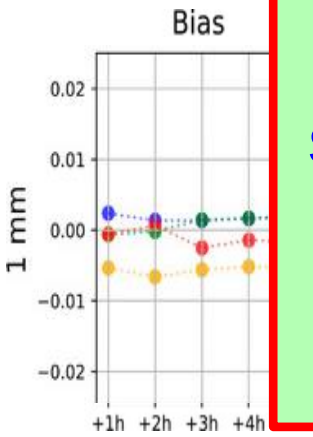


Also: first try to generate scenarios with “classical” methods which are consistent with the combined calibrated point probabilities:

Schaumann et al. (2024), Generating synthetic rainfall fields by R-vine copulas applied to seamless probabilistic predictions, Quart. J. Roy. Met. Soc., doi:10.1002/qj.4751

Problem: computationally not feasible for larger domains



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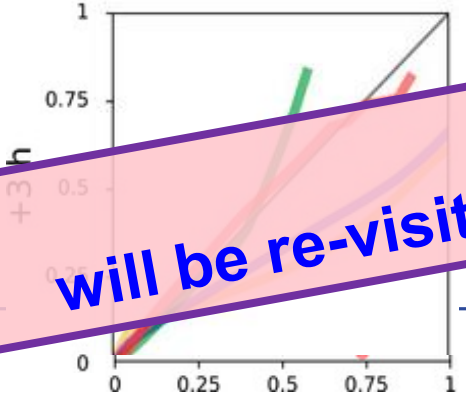

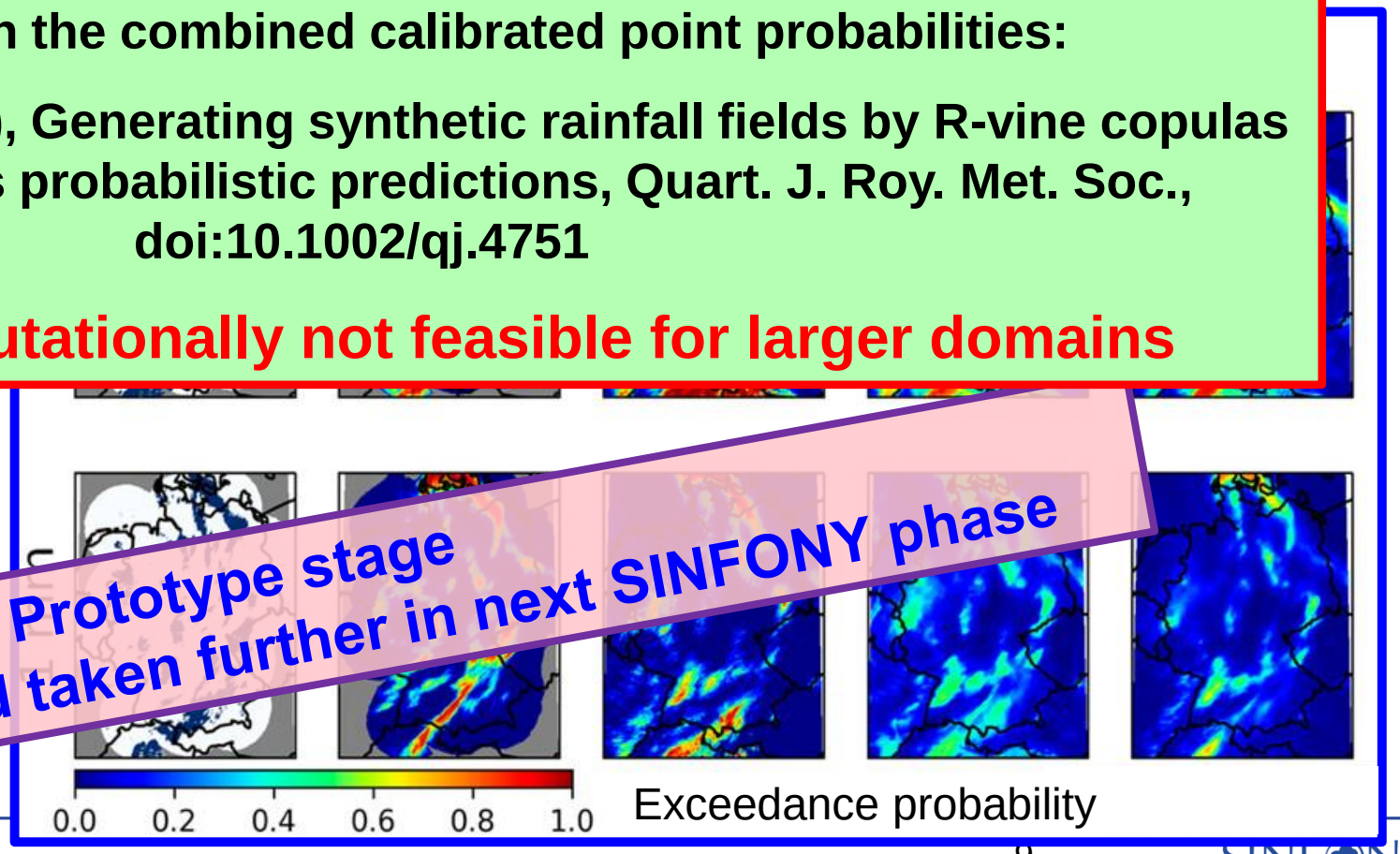

Prototype stage will be re-visited and taken further in next SINFONY phase

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More details on the ICON-RUC

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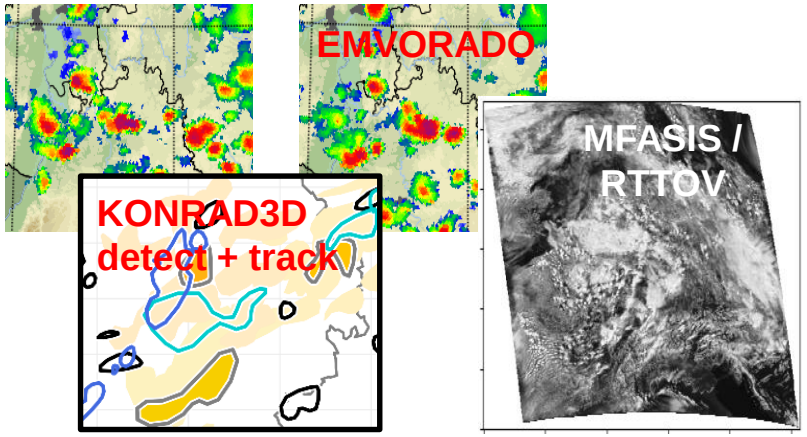
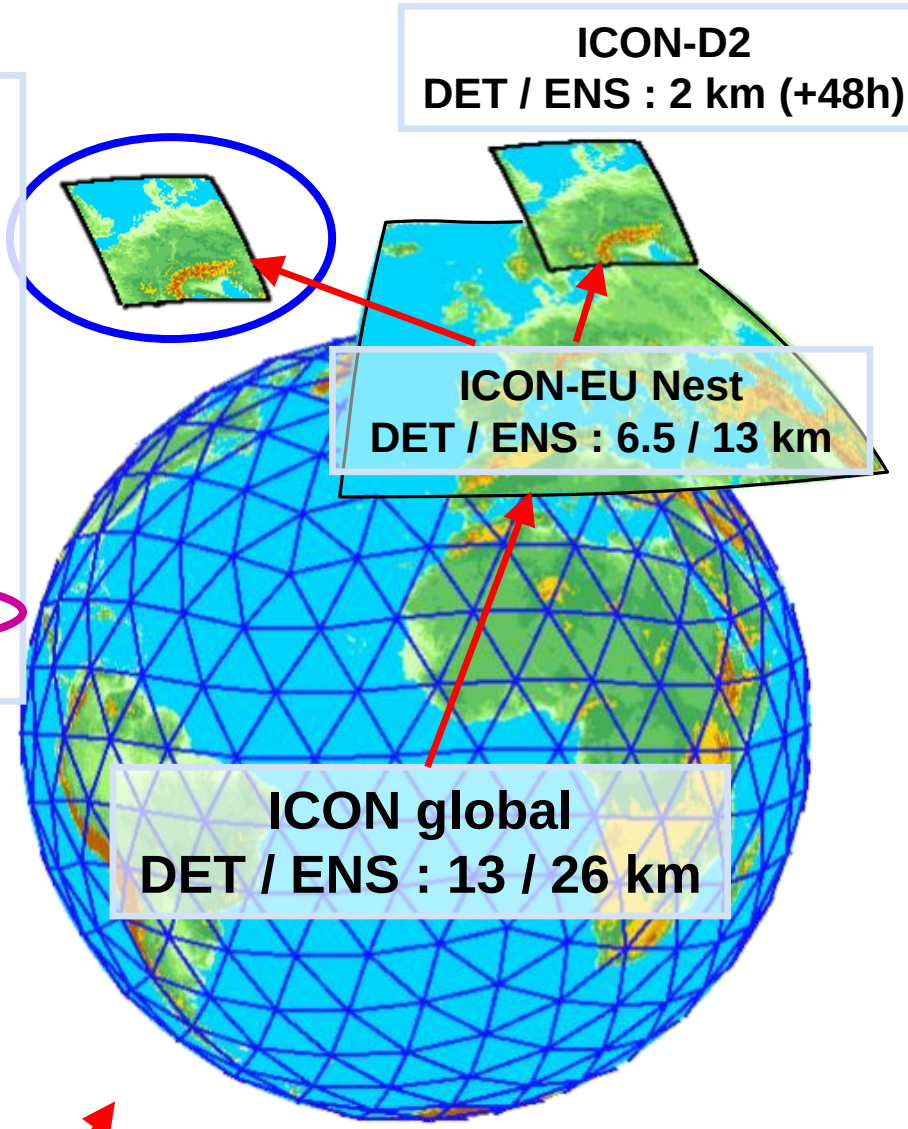
➔ **Advanced forward operators:**
Radar volumes and composites
Cell objects (KONRAD3D)
VIS / IR sat data



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 (LHN)

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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
- ➔**Prognostic hail accumulation and hail rate at ground from NWP!**

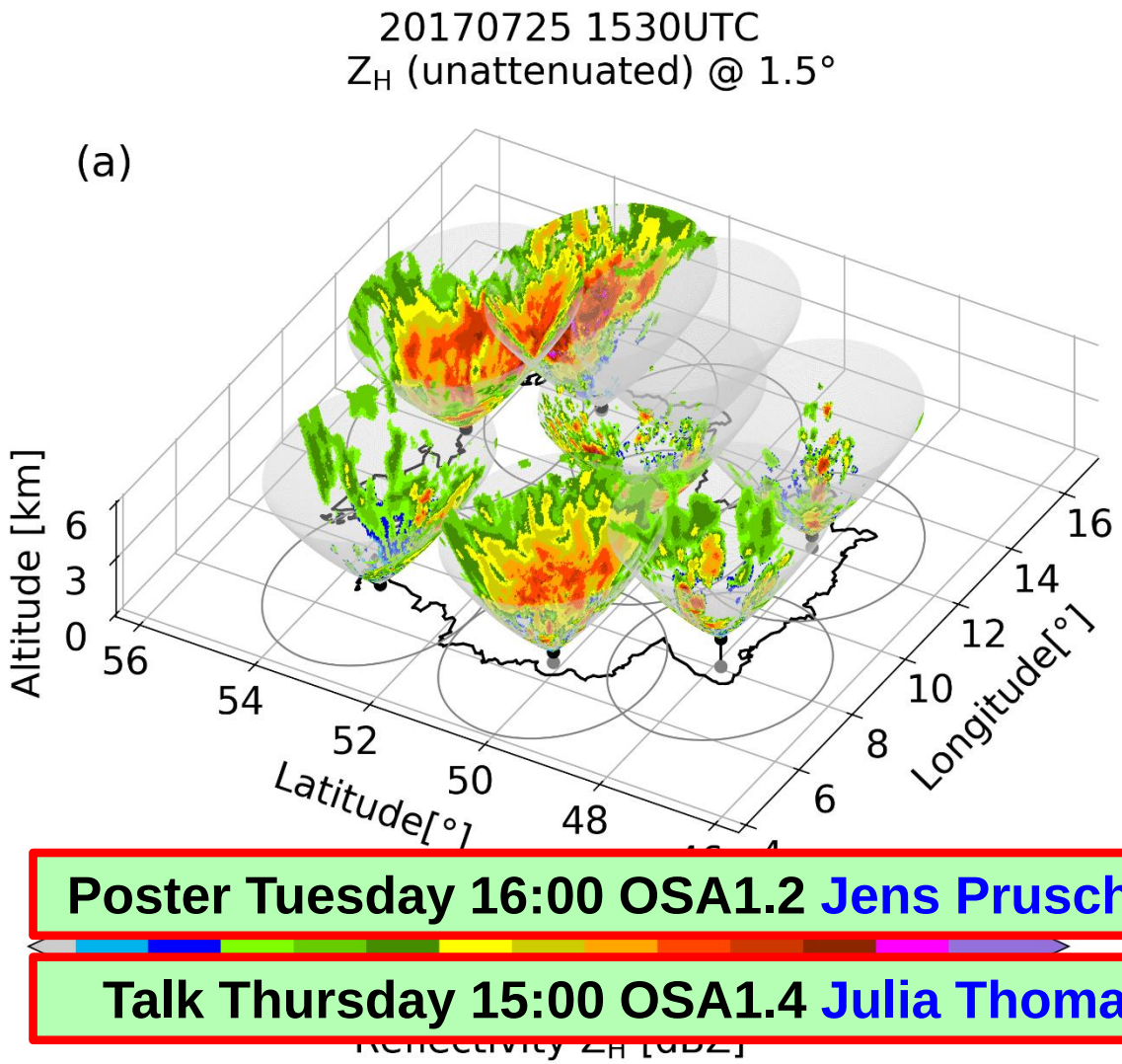
Justified because **beneficial** for **ICON-RUC** and **SINFONY combined products:**

- ➔Considerable **bias reduction** of radar- and VIS/IR satellite data
- ➔Accepts more of these data in assimilation
- ➔Compared to ICON-D2, **this compensates for adverse effects** of shorter data cutoff time, shorter LHN period at the beginning of each forecast, and BCs from older ICON-EU

In the development pipeline:

- ➔ New hail forecast products: estimated **max. hail diameter** at ground, **hail kinetic energy**
- ➔ Further **improvements based on observed raindrop size distributions at ground:**
  - ➔Thies distrometer (LNM) at ~150 DWD SYNOP stations for several years
  - ➔dataset 2019-2024 freely available to the community via **https://zenodo.org/records/17065117**
- ➔ **Updated configuration** for non-convective precipitation, especially in winter

Radar forward operator EMVORADO in ICON



Poster Tuesday 16:00 OSA1.2 Jens Pruschke

Talk Thursday 15:00 OSA1.4 Julia Thomas

Simulated radar moments along all the rays of synthetic PPI 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**

Experimentally also applied to:

- ➔ **Commercial Microwave Links (CML)**
- ➔ **Vertically pointing cloud radars**
- ➔ **X-Band research radars**

Zeng, Blahak 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

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**

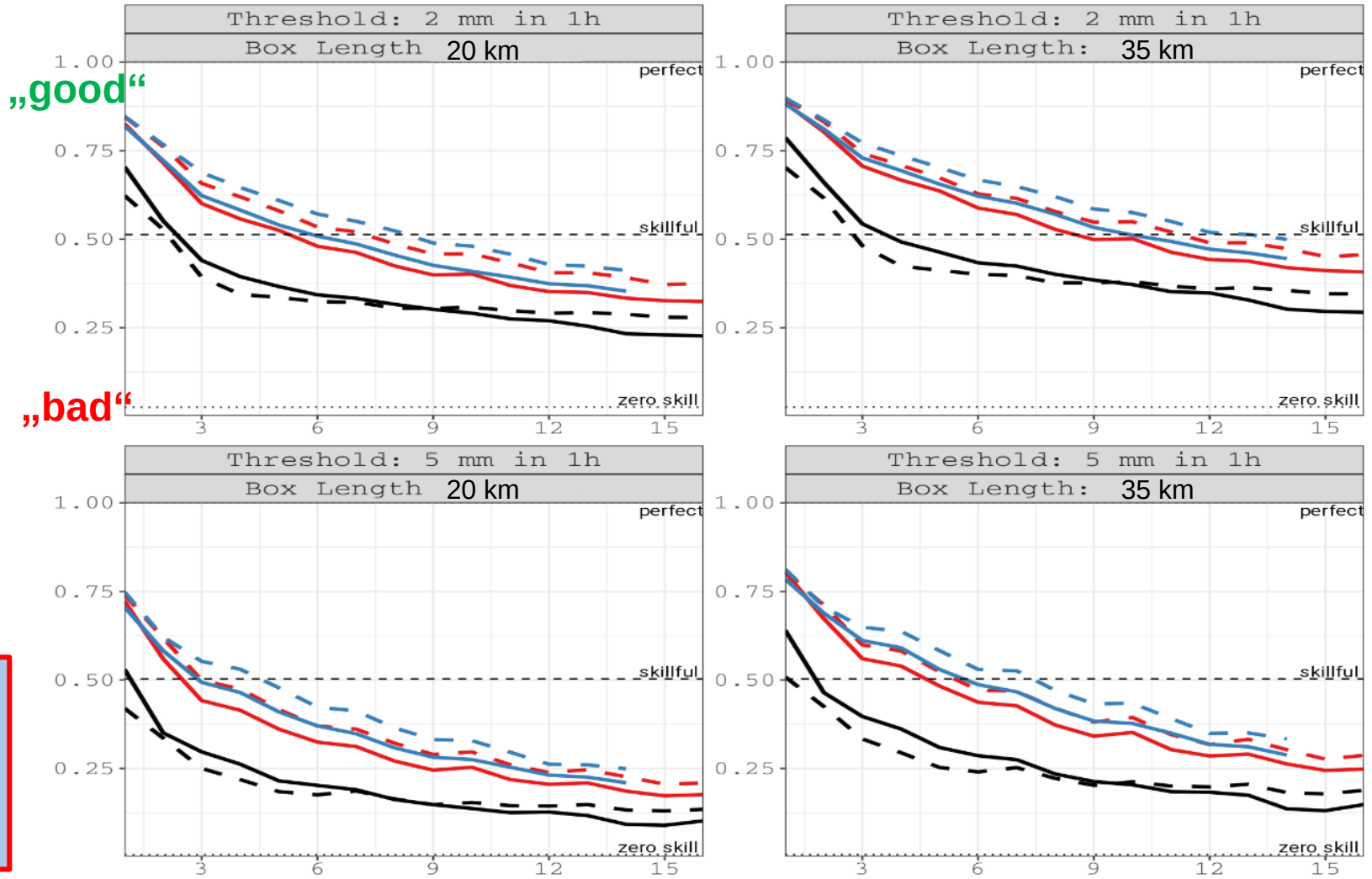
Achievements in NWP: Fraktions Skill Score (FSS)
1h-precipitation 26.5. – 30.6.2016

- COSMO-DE **(3-h inits)**
- ICON-D2 **(3-h inits)**
- ICON-RUC **(3-h inits)**

- Deterministic
- Neighborhood ENS probability (NEP)

***Comparison of 3-houly inits as function of forecast lead time**

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



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COSMO-DE **(3-h inits)**

ICON-D2 **(3-h inits)**

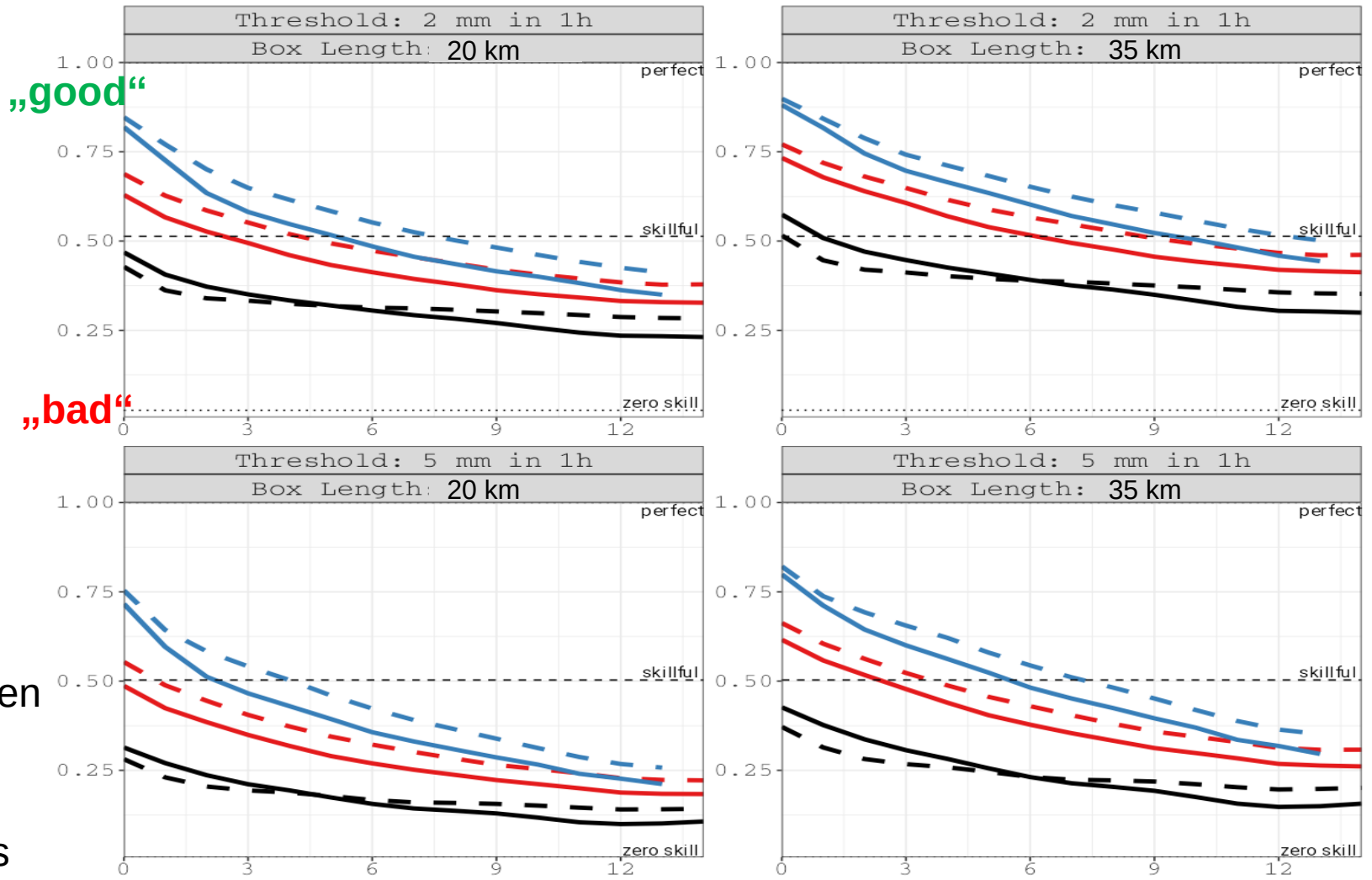
ICON-RUC **(1-h inits)**

Deterministic

Neighborhood ENS probability (NEP)

***Comparison from user's perspective:**

- At each time of day, take the **latest practically available forecast:** RUC init 3 x more often and very short computing time!
- **„User lead time"** is along the remaining forecast time that lies in the future for the user.



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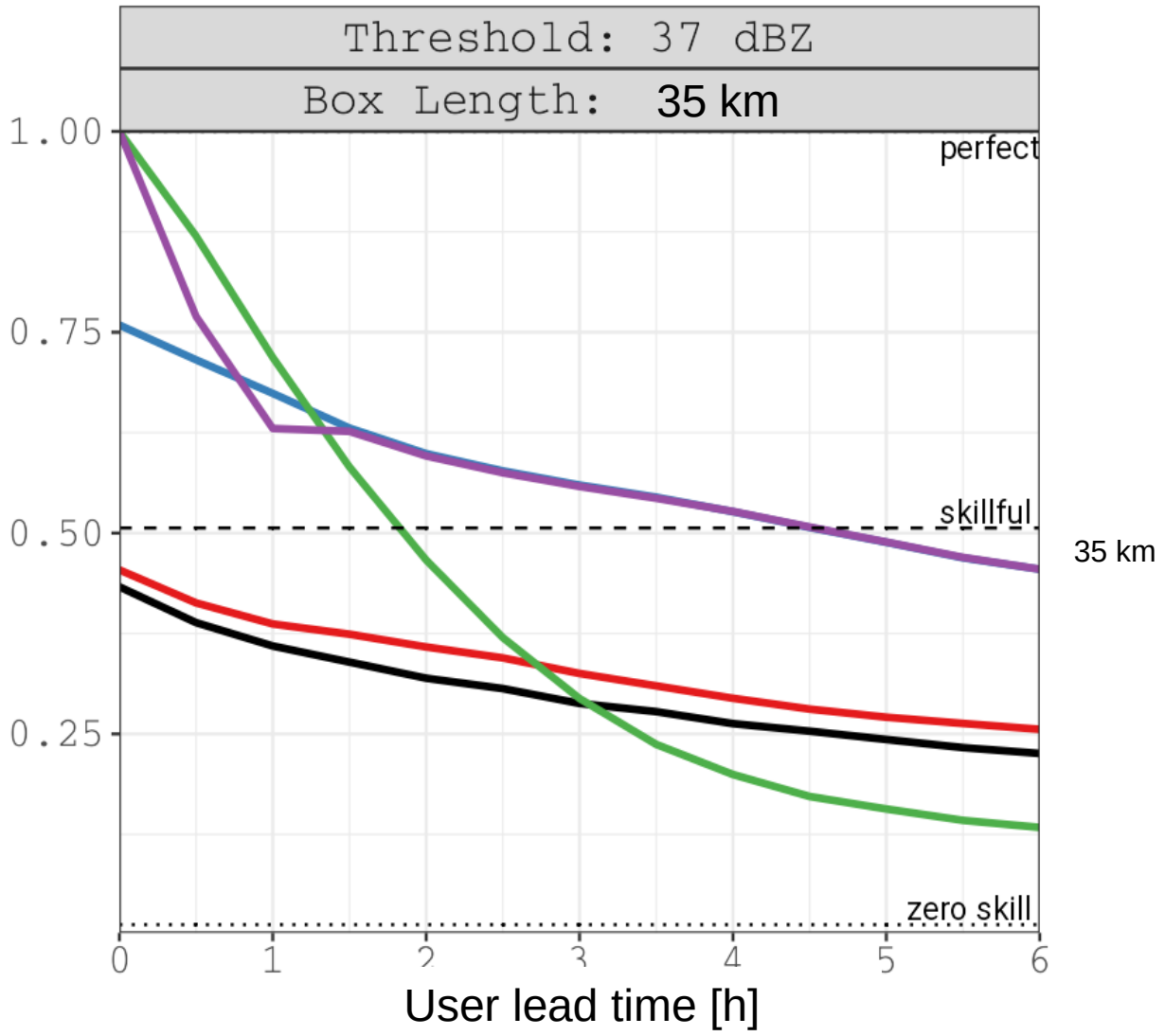
Achievements in NWP and combined products:
FSS Radar Reflectivity 26.5. – 30.6.2016

➔ **User perspective**

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



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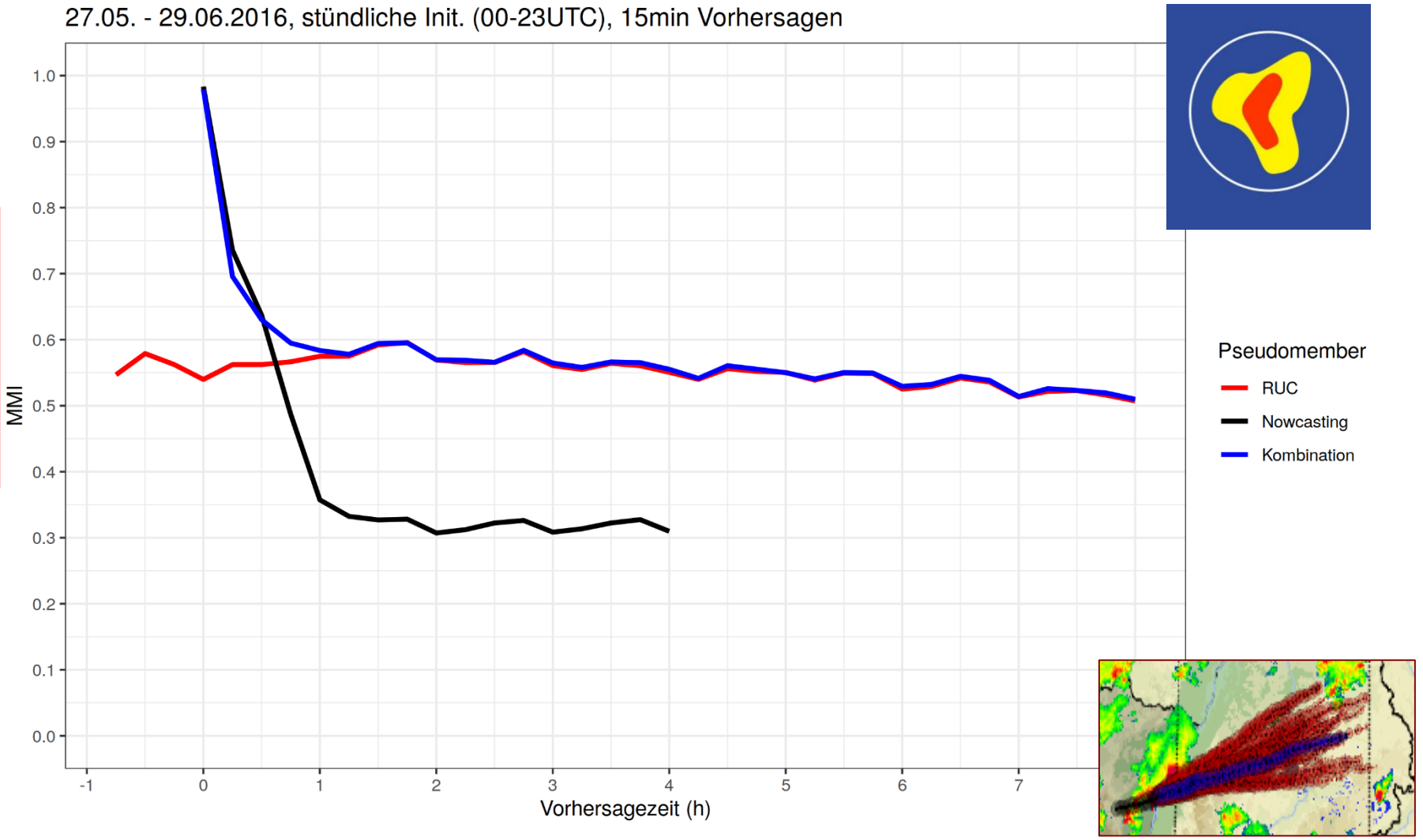
Achievements in NWP and combined products: Cell objects verification by MMI-Score 27.5. – 29.6.2016

Core areas from all elevations = 3D cell object

Next 2 talks in this session:

L. Josipovic: Nowcasting

N. L. Strotjohann: Combination



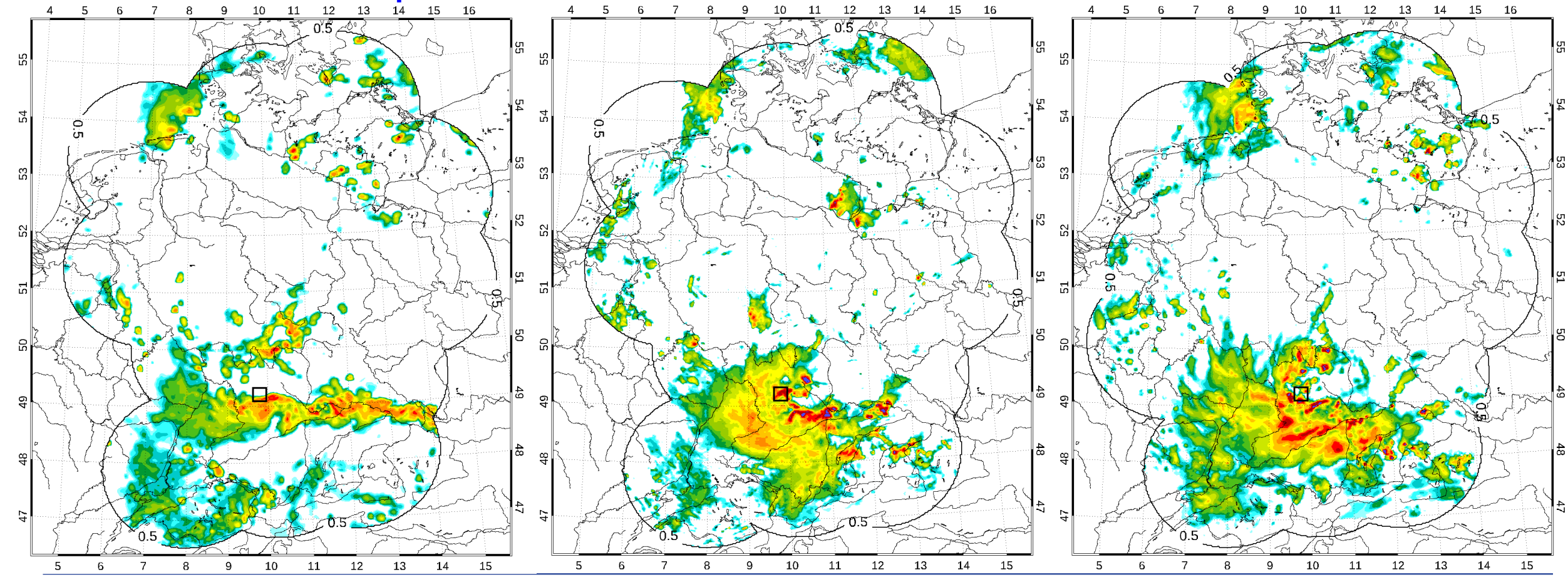
Achievements in NWP for Braunsbach case

Deutscher Wetterdienst
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**



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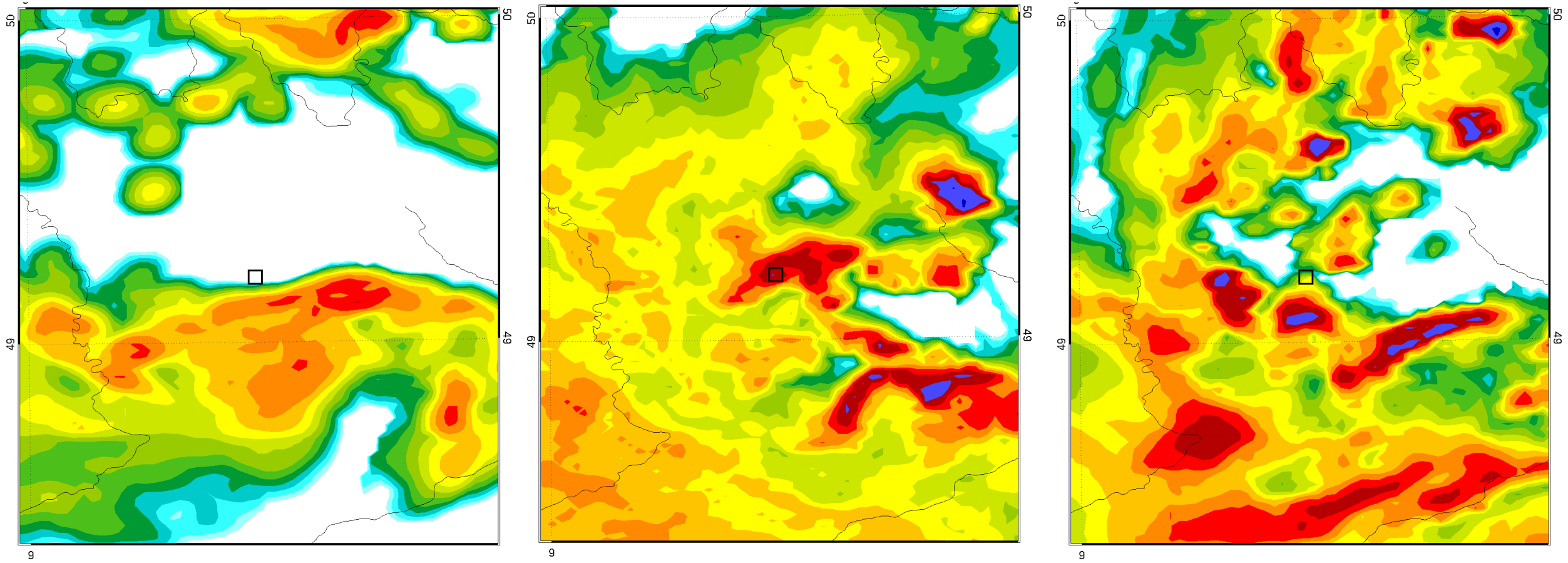

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Accumulated precipitation from 17 – 19 UTC

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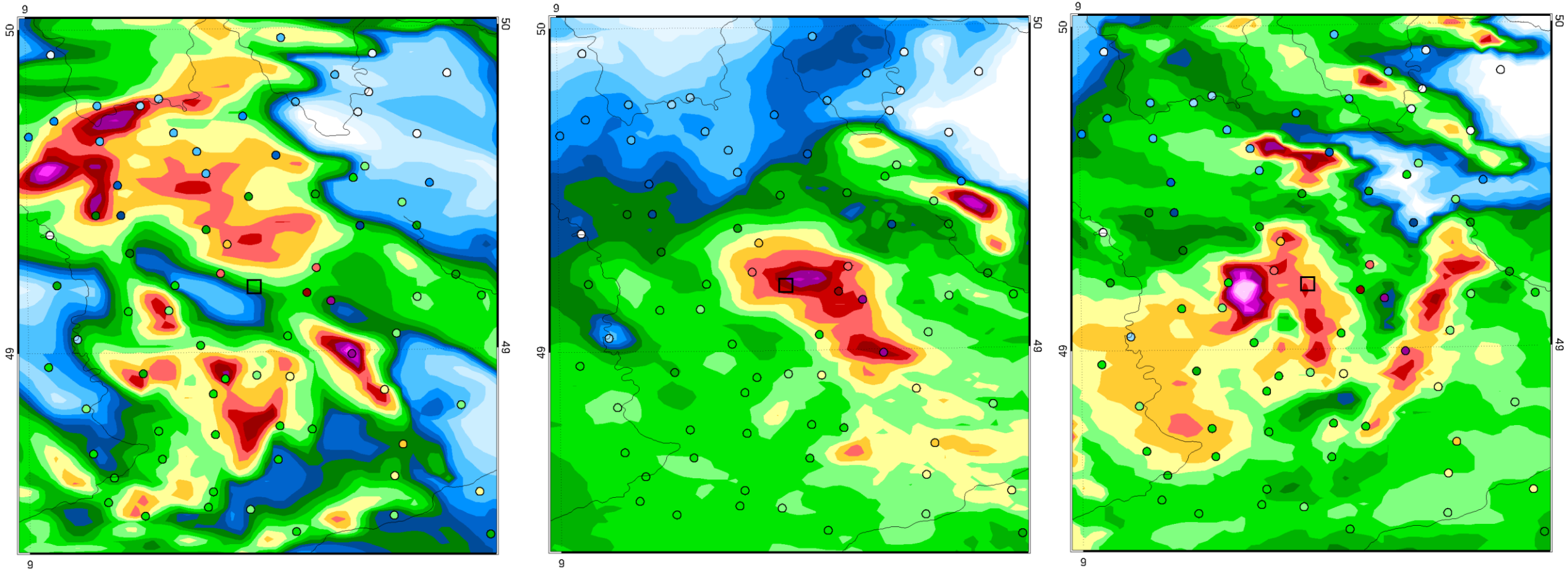

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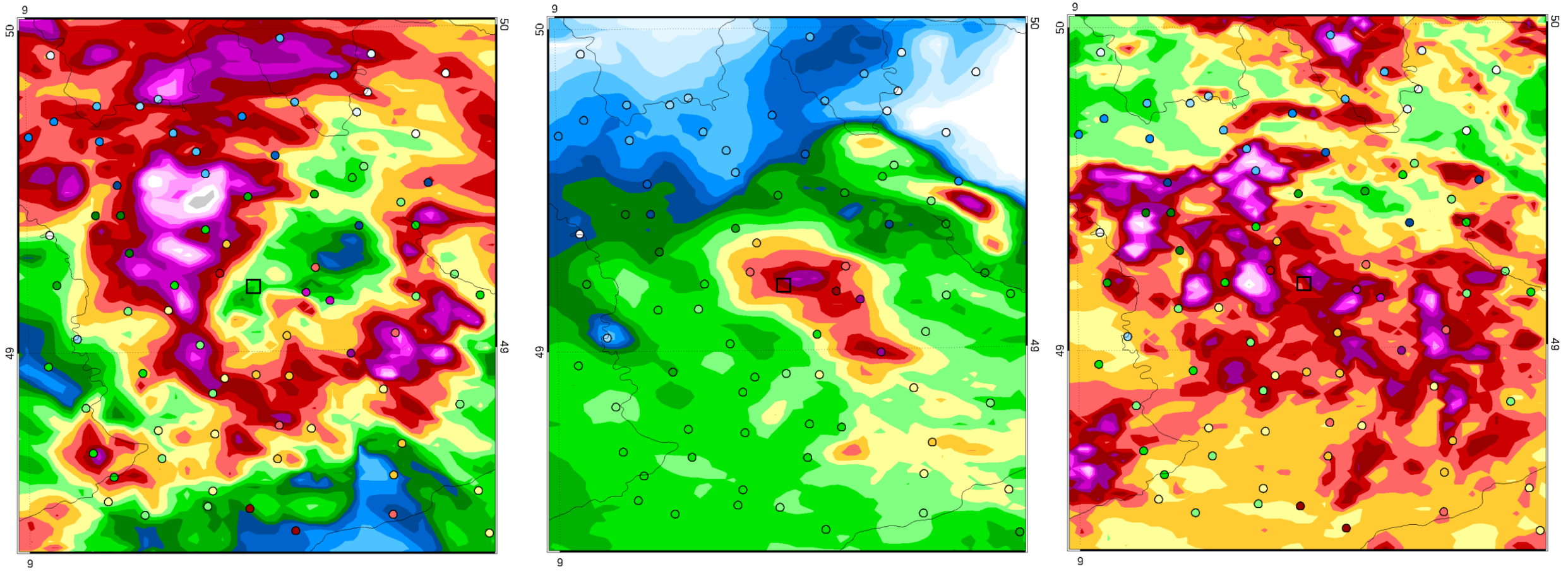

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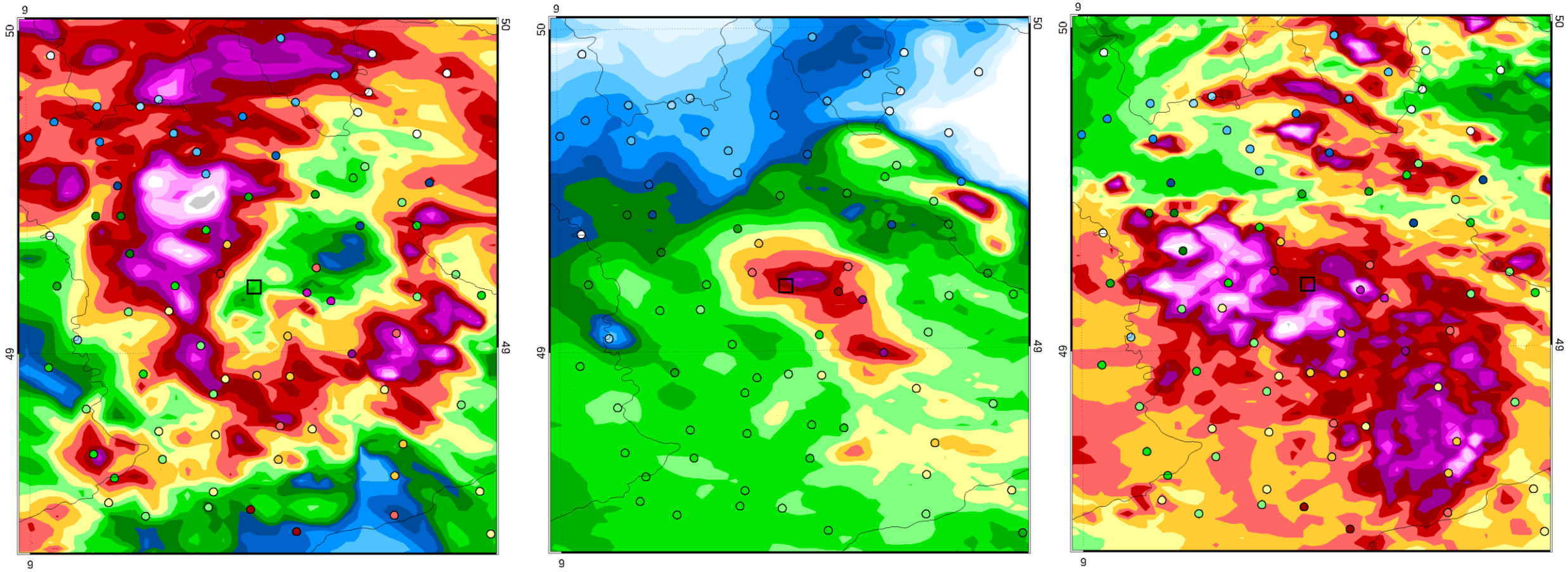

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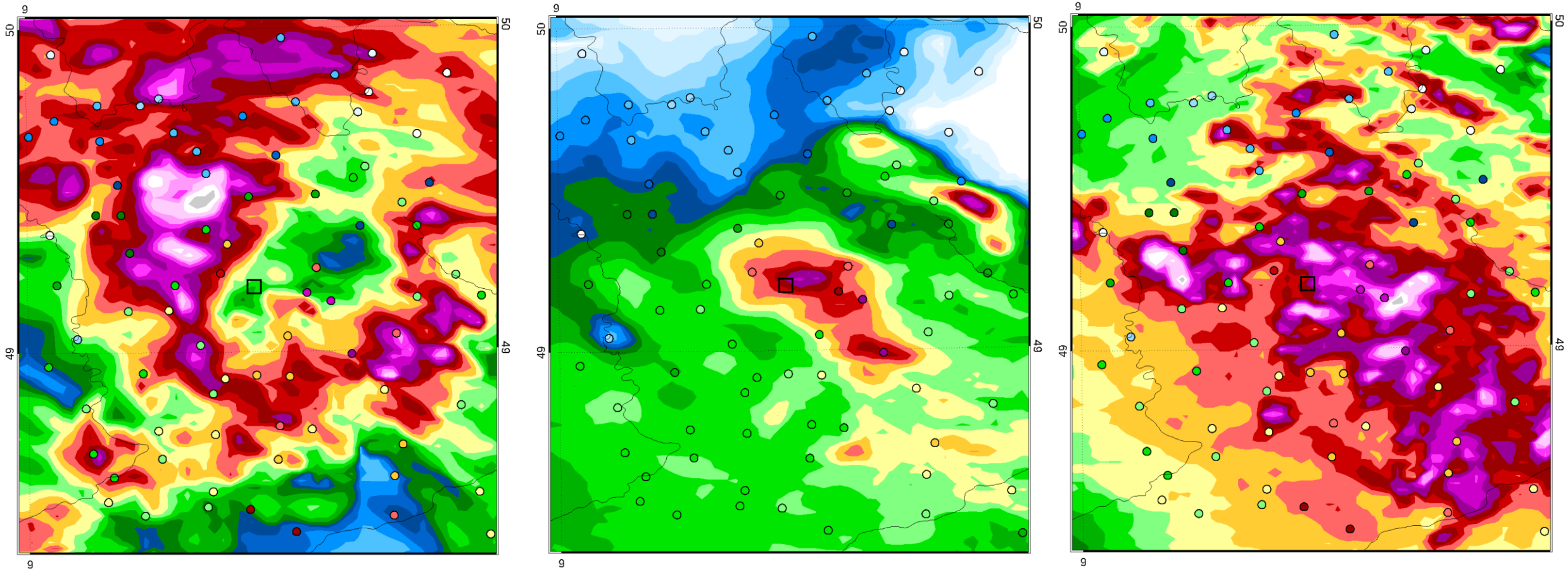
Accumulated precipitation from 17 – 19 UTC

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



SINFONY

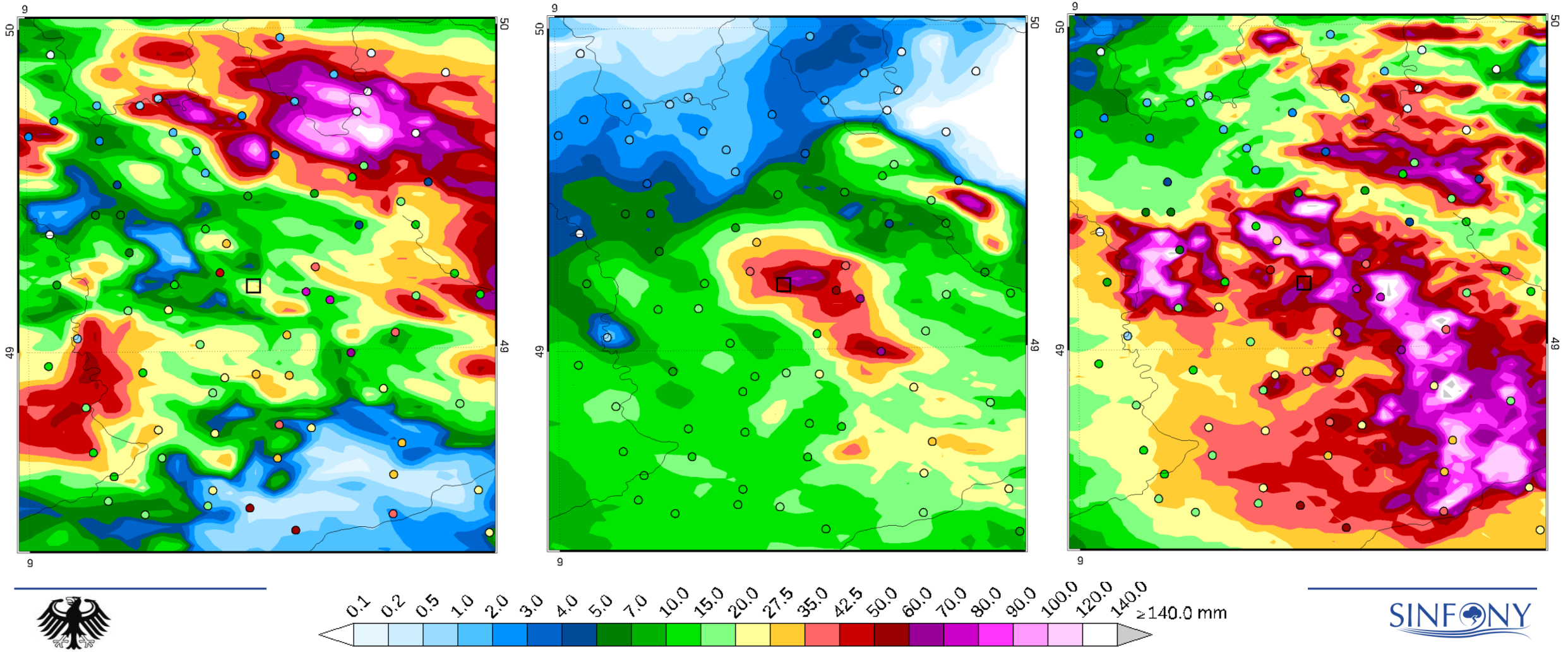
Achievements in NWP for Braunsbach case

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



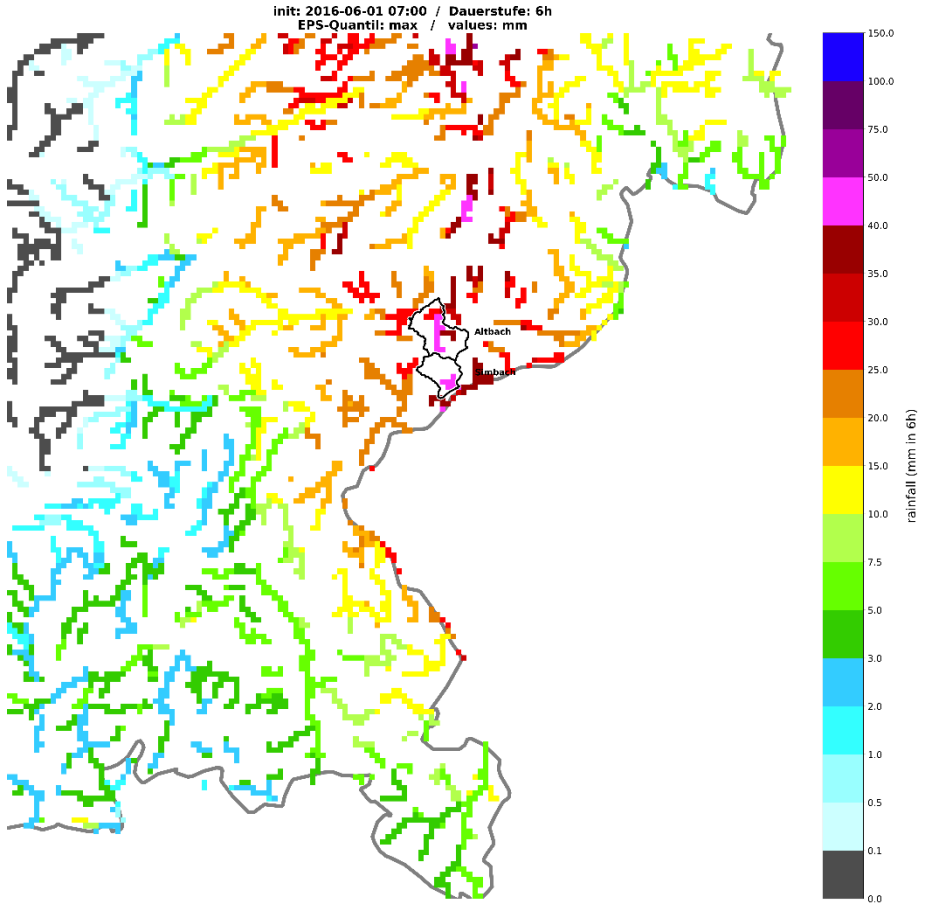
SINFONY

Aggregation of INTENSE over catchment area (AREA)

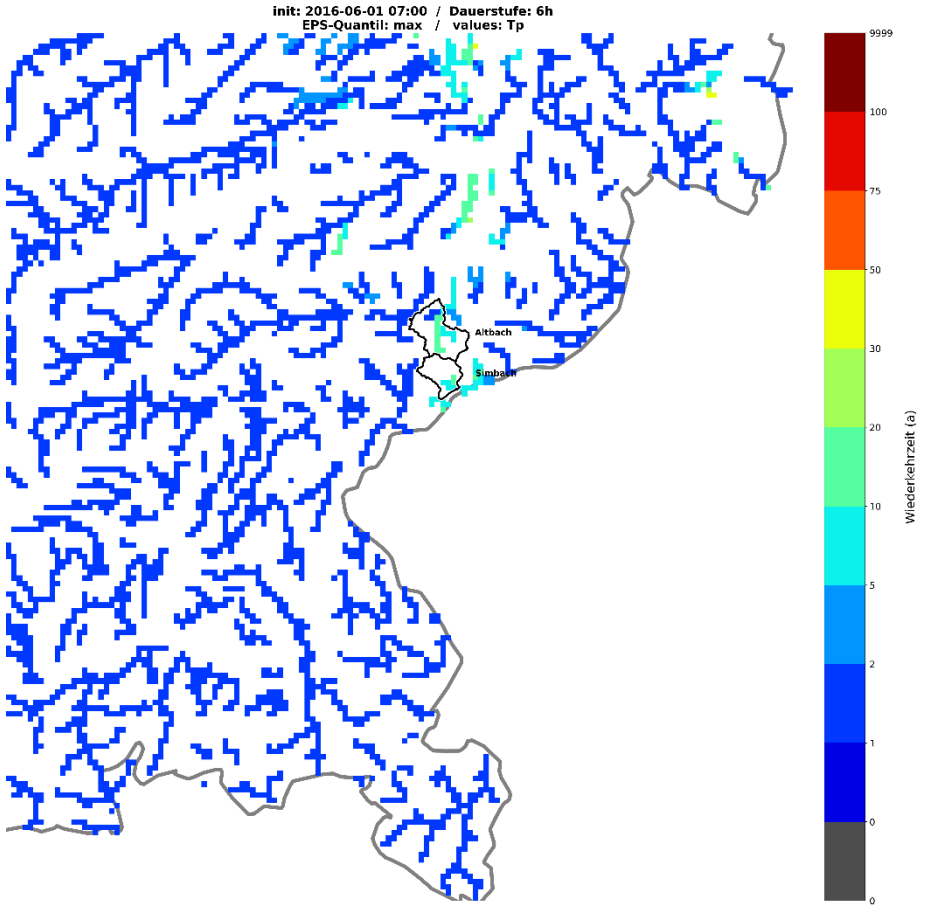
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Simbach case, 7 UTC INTENSE, EPS max

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



Return period [years]

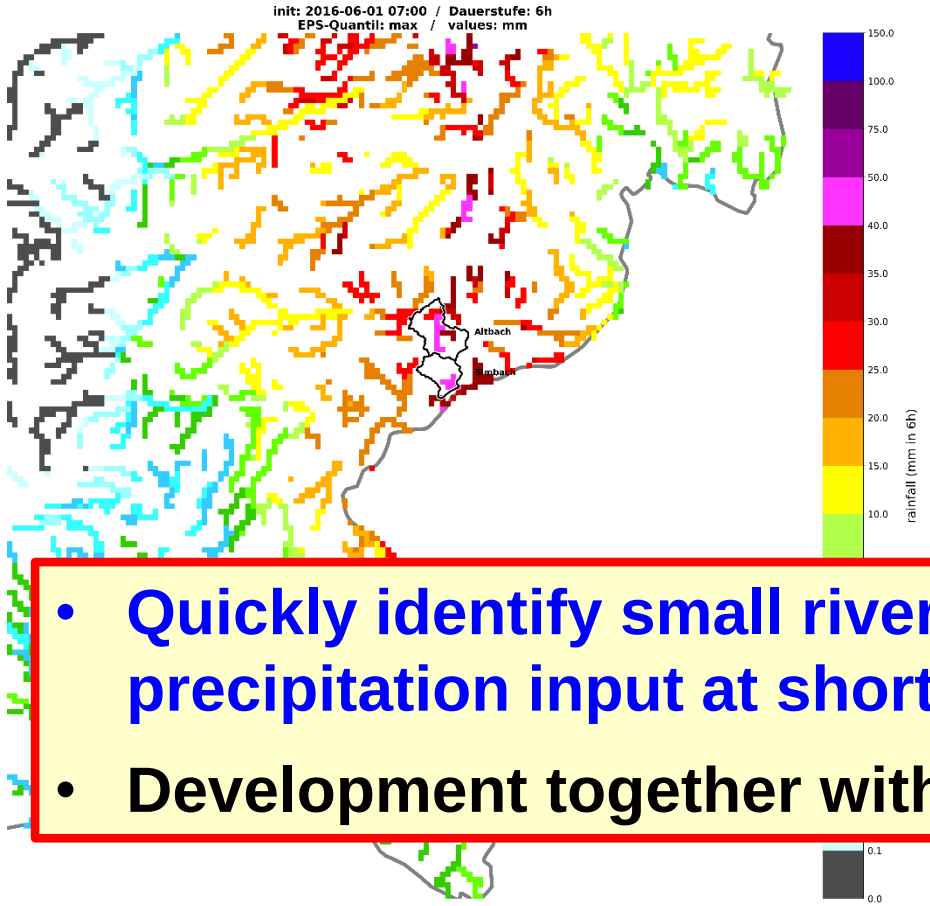


SINFONY

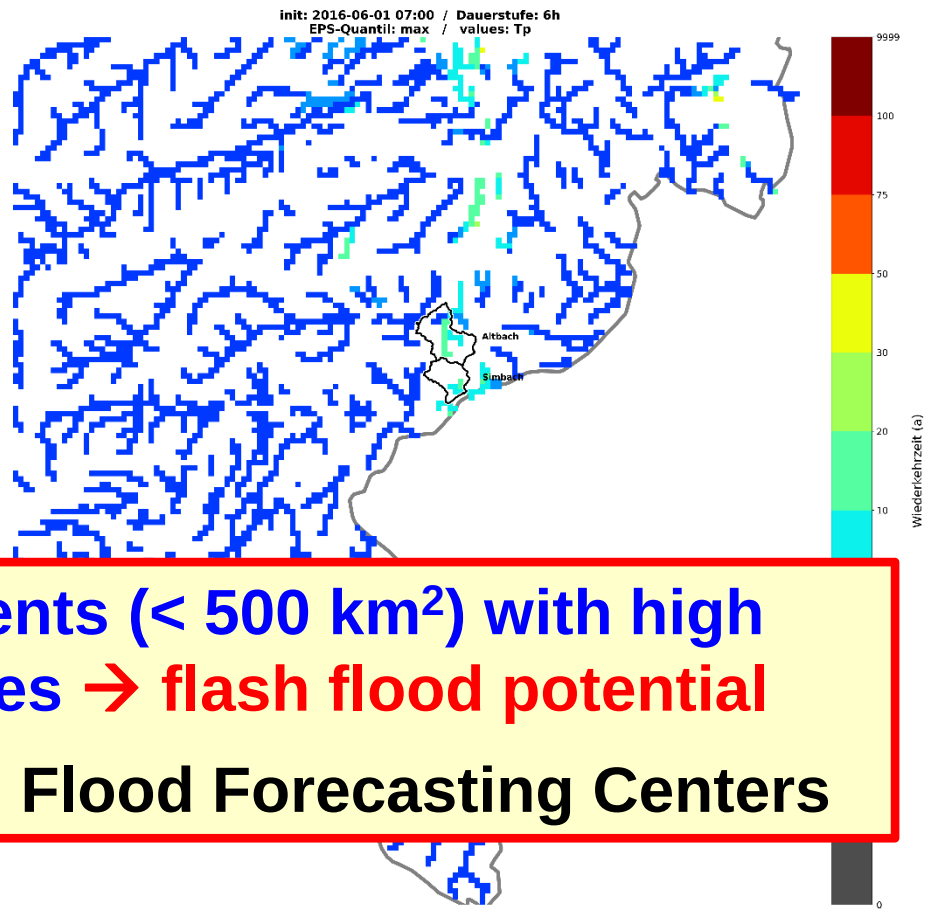
Aggregation of INTENSE over catchment area (AREA)

Simbach case, 7 UTC INTENSE, EPS max

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



Return period [years]

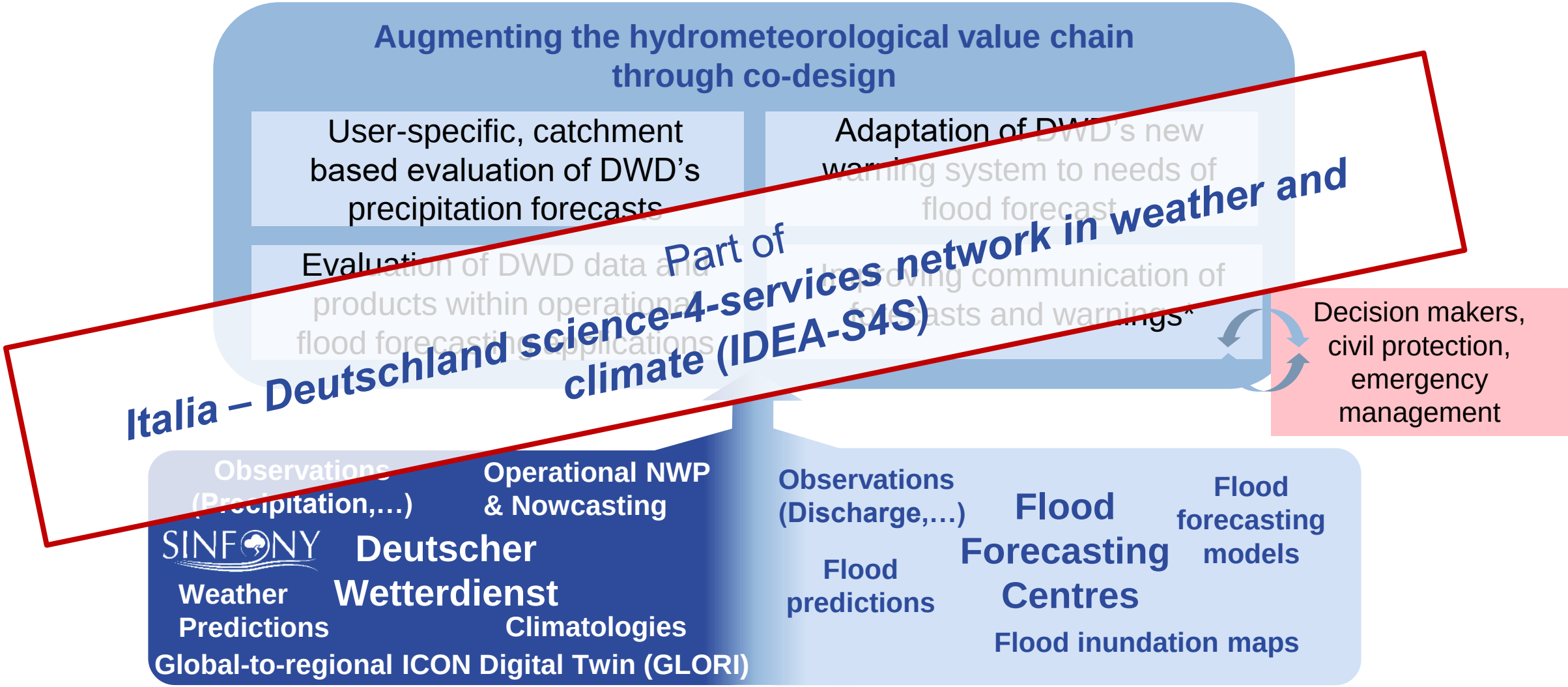


- **Quickly identify small river catchments (< 500 km²) with high precipitation input at short lead times → flash flood potential**
- **Development together with German Flood Forecasting Centers**

SINFONY

A complementary project framework: Co-Design in hydro-meteorological partnership

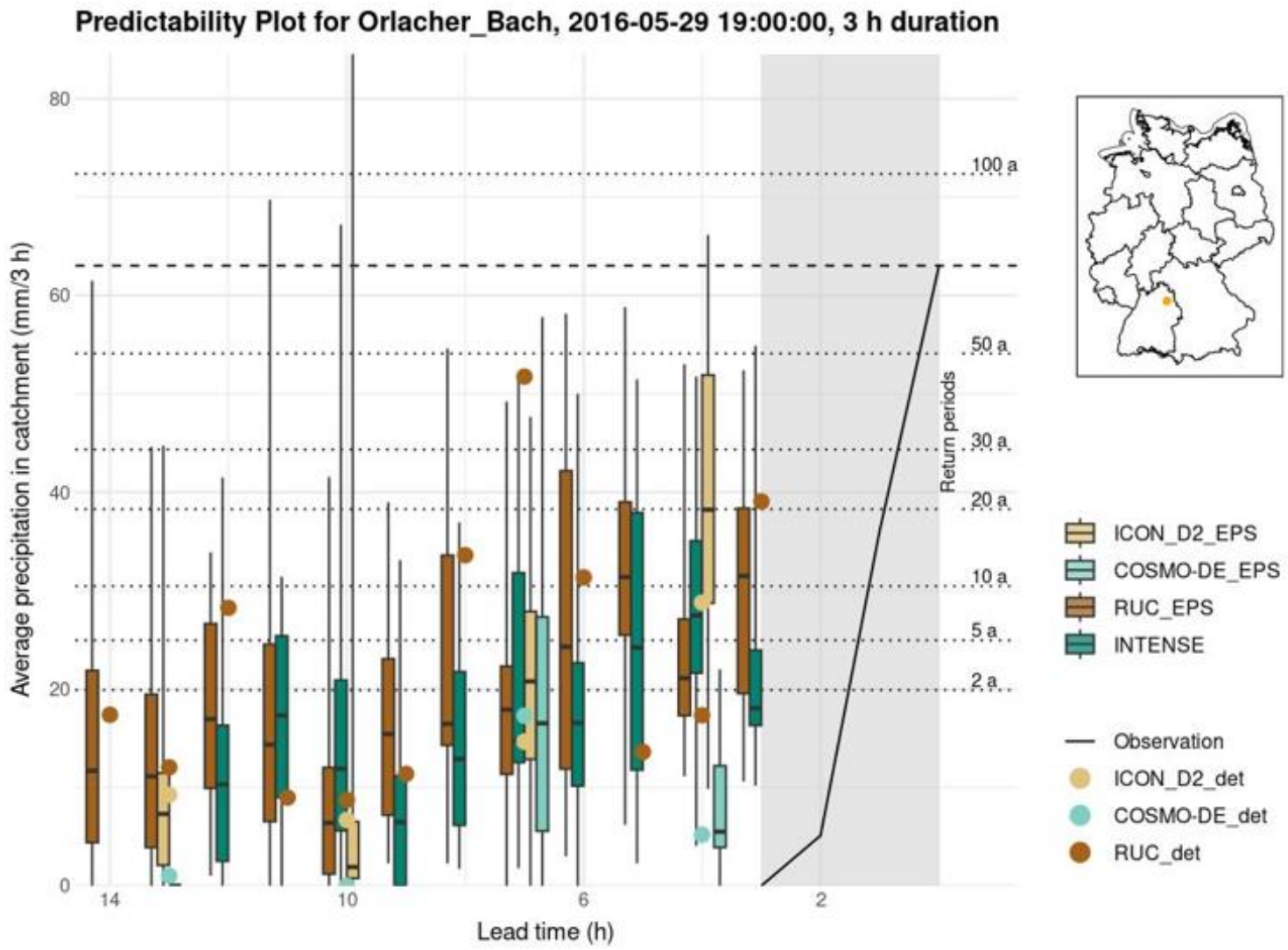
Talk Thursday 14:00 UP2.2
Jan Bondy et al.



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

Predictability of catchment precipitation for Braunsbach case

Talk Thursday 14:30 UP2.2
Ina Blumenstein-Weingartz et al.



- Catchment very small (< 10 km^2)
- 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

Current status of SINFONY

- End of 2nd project phase reached.
- SINFONY components work good for convective season.
- Tailored to precipitation, reflectivity and convective cells hazards.
- ICON-RUC operational, other components not yet.
- Future needs:
  - **Further operationalisations + longterm operations & maintenance**
  - **Further research:**
    - **need to work on winter and other phenomena,**
    - **want to address also other user groups like aviation and energy sector,**
    - **want to become seamless also for other parameters and longer lead times > 12 h.**

Long-term strategy – SINFONY 3.0 and beyond

Twofold:

➔ **Operationalisation of the full SINFONY + long-term operation & maintenance:**

- ➔ **Next components for operationalisation will be INTENSE and KONRAD3D-SINFONY**
- ➔ **By permanent staff from different disciplines and departments**

➔ **Further research projects 2025 – 2028** in project **SINFONY 3.0:**

- ➔ Seamless beyond 12 h and extend to other parameters (wind, temperature, clouds)
  (Cf. to earlier slide about the “C3”-method and scenarios)
- ➔ Seamless from obs to RUC for other parameters by AI-based ultra-rapid data assimilation
- ➔ Integrate satellite (MTG FCI, IRS, LI) and radar in Nowcasting
- ➔ Improve RUC NWP for fog and visibility (e.g. for aviation)
- ➔ How to integrate probabilistic forecast information into user portals (e.g., our Warning App)?
- ➔ AI-methods more and more used in all of these projects

SINFONY is becoming a long-term, cross-cutting, multi-disciplinary, managed network activity at DWD

With close ties to other activities:

- ➔ DWD's future automated warning system **RainBoW**
- ➔ DWD's new internal **Center for AI**
  - ➔As general framework for our AI activities
  - ➔Collaborative work package with our precipitation climate group to enhance realtime QPE by integrating new opportunistic sensors into surface-station-adjusted radar products
    - ➔Commercial microwave links (CML)
    - ➔Other crowd sensors (e.g. NetAtmo)

Several talks tomorrow morning in OSA1.1

Building on existing experiences
Talk Friday 11:00 UP1.4
Tanja Winterrath et al.

Our external partners

➔ 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
- ➔Co-Design (IDEA-S4S)
- ➔RainBow

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

Thank you for your attention!

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

Kapitel 1 - Problemstellung und Einführung

Lernziel: *Was ist die Idee hinter dem SINFONY und warum brauchen wir es?*

Dauer: ca. 23 Minuten

Kapitel 2 - Der SINFONY-Ansatz und Co-Design

Lernziel: *Was wird konkret für das SINFONY entwickelt und wie wird es umgesetzt?*

Dauer: ca. 20 Minuten

Kapitel 3 - Nowcasting

Lernziel: *Wie funktionieren die Nowcasting-Verfahren des SINFONY und welche Prinzipien stecken dahinter?*

Dauer: ca. 35 Minuten

Kapitel 4 - NWV-Modell

Ist in Vorbereitung.

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