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)

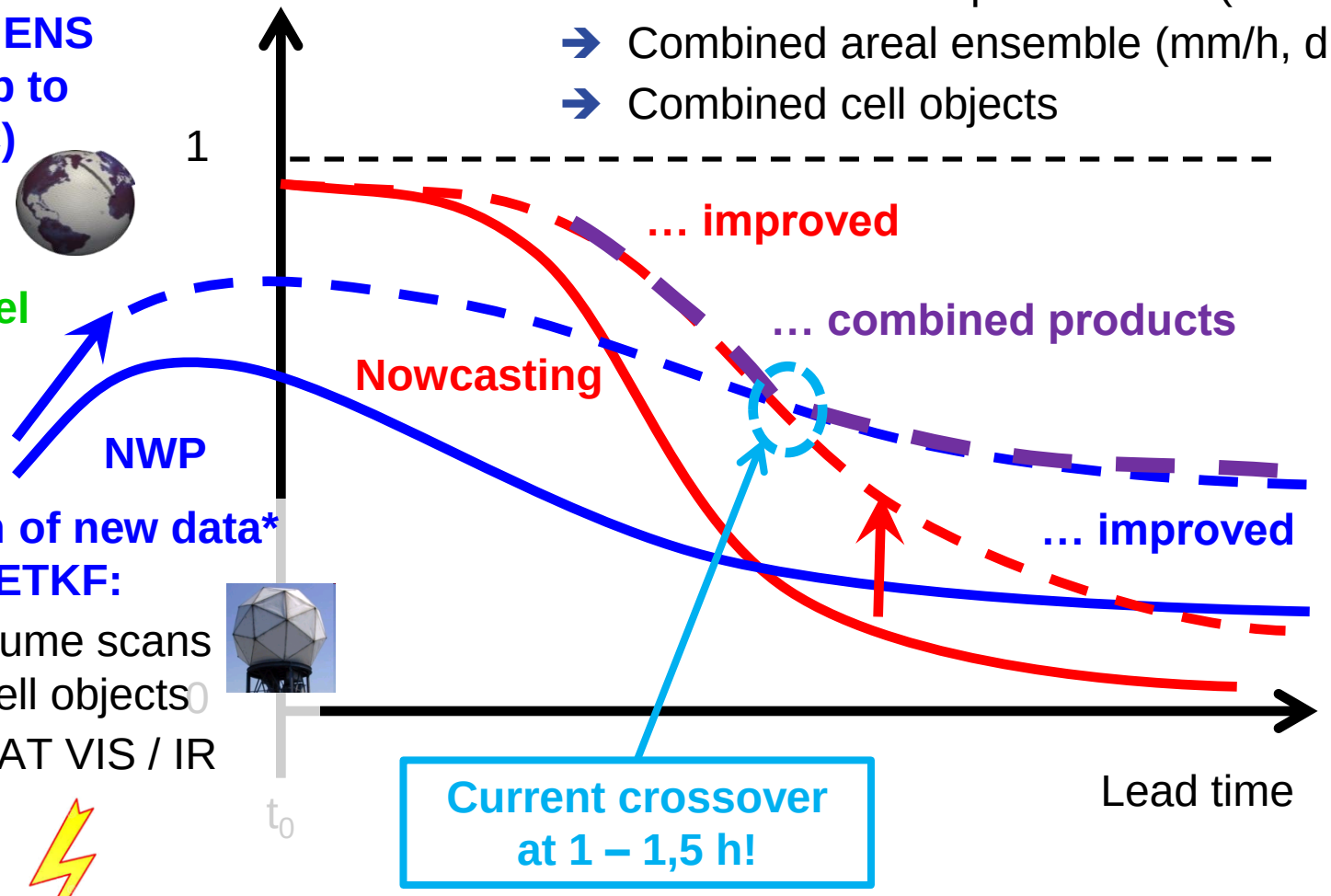
The SINFONY as in current transition to operations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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

ICON-LAM
Δx = 2 km
adapted model physics

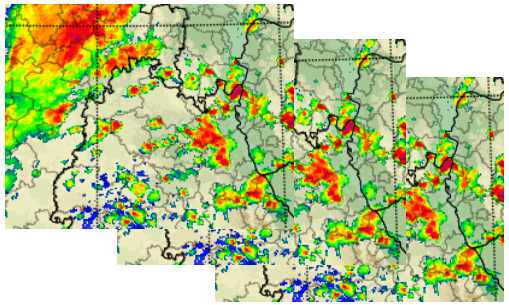
Some verification score for convective events



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

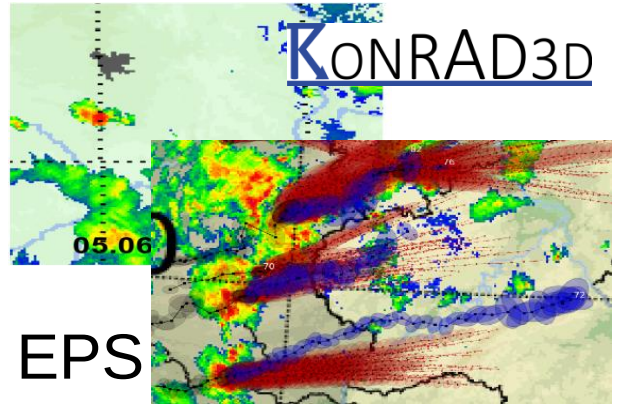
➔ **Combined / blended products:**
- ➔ Threshold-based probabilities (mm/h, dBZ)
- ➔ Combined areal ensemble (mm/h, dBZ)
- ➔ Combined cell objects

STEPS-DWD



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

KONRAD3D



EPS

*) 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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Wetter und Klima aus einer Hand

Some verification score for convective events

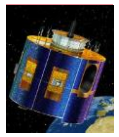
➔ Hourly new ENS forecasts up to + 14 h (RUC)

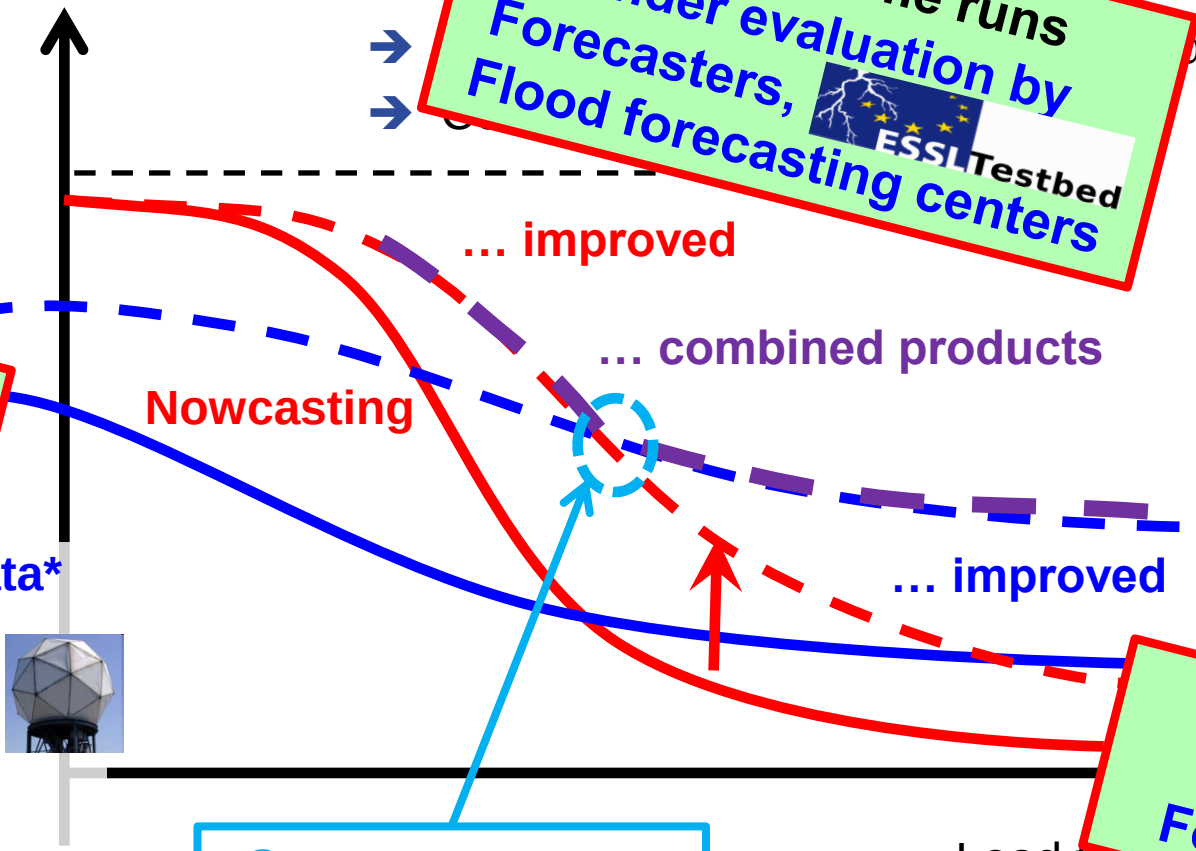
ICON-LAM

Fully operational, opendata.dwd.de

➔ Assimilation of new data* in KENDA-LETKF:

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





Current crossover at 1 – 1,5 h!

➔ C… products:

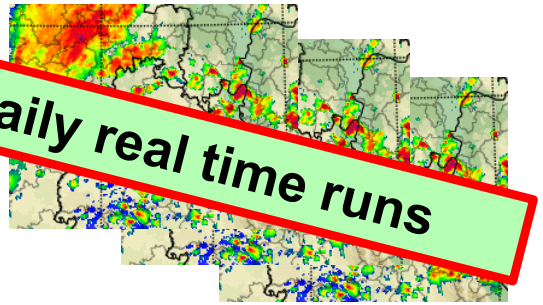
➔ T… (mm/h, …BZ)

➔ …

➔ …

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

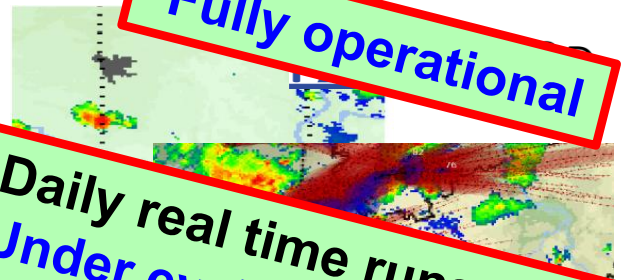
STEPS-DWD



Daily real time runs

➔ Radar based precipitation Nowcasting

1) Gridded fields (mm/h, dBZ)
2) Cell objects



Fully operational

Daily real time runs
Under evaluation by
Forecasters,
ESSL Testbed

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

SINFONY

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

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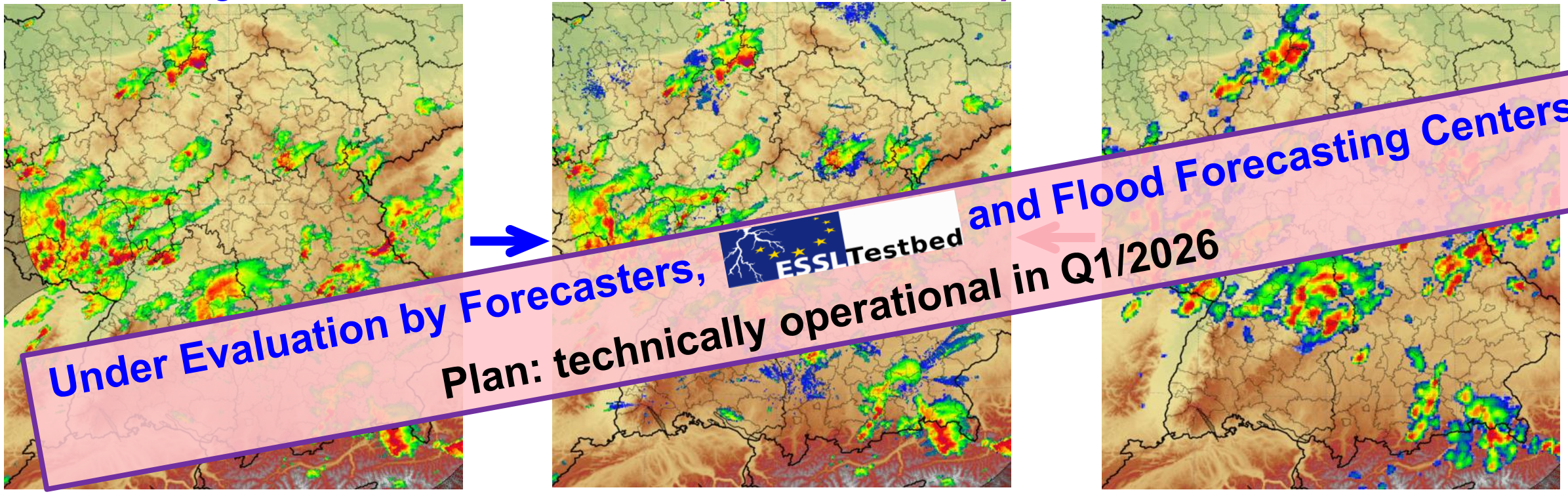
Nowcasting STEPS-DWD | **INTENSE (1 of 20 members)** | **NWP ICON-RUC-EPS**



Under Evaluation by Forecasters, ESSL Testbed and Flood Forecasting Centers

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

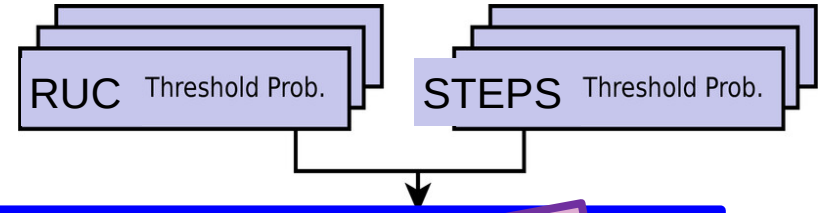
SINFONY

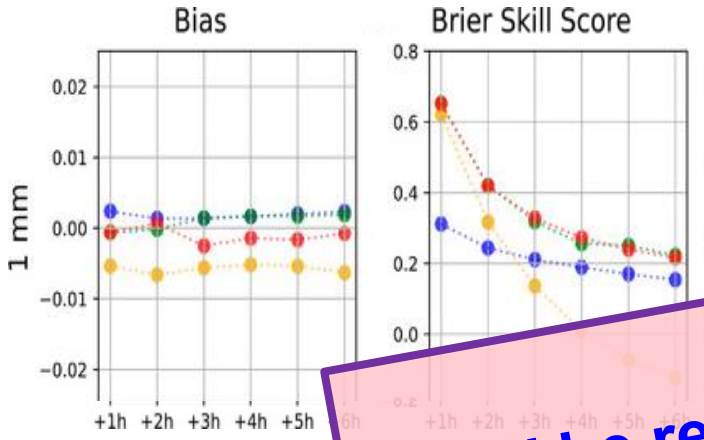
Another approach: blending in probability space

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

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

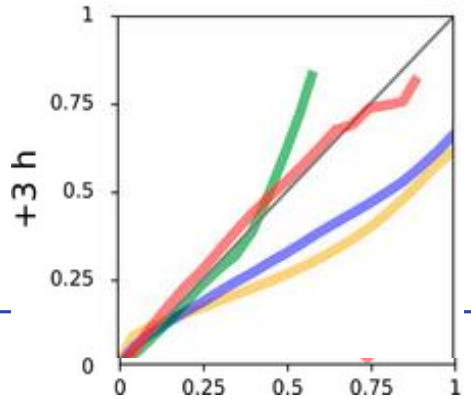
Blended CDF (multiple thresholds simultaneously and consistently) at each location (co-op. with Institute of Stochastics, University Ulm)

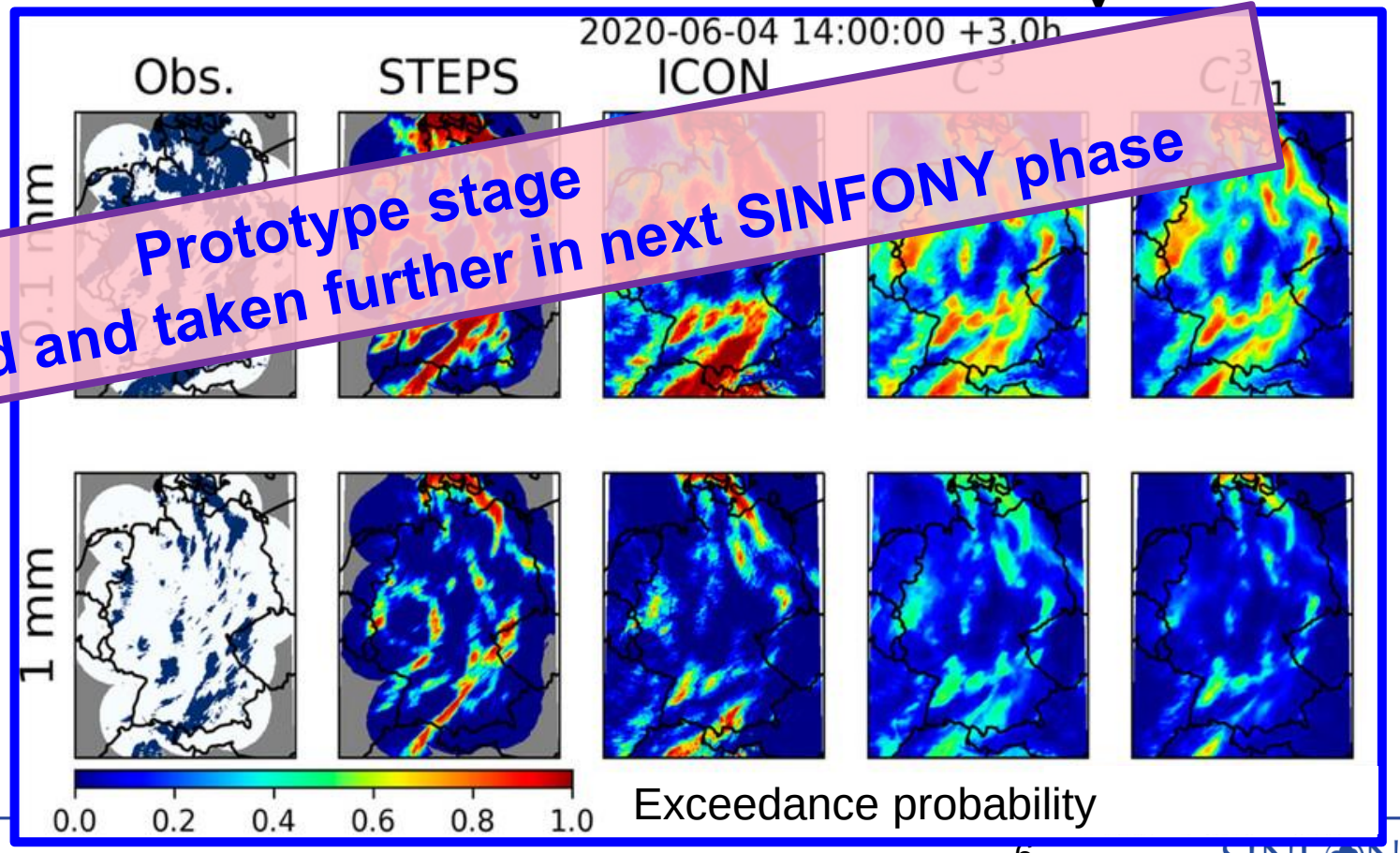




Prototype stage will be re-visited and taken further in next SINFONY phase

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





More details on the ICON-RUC

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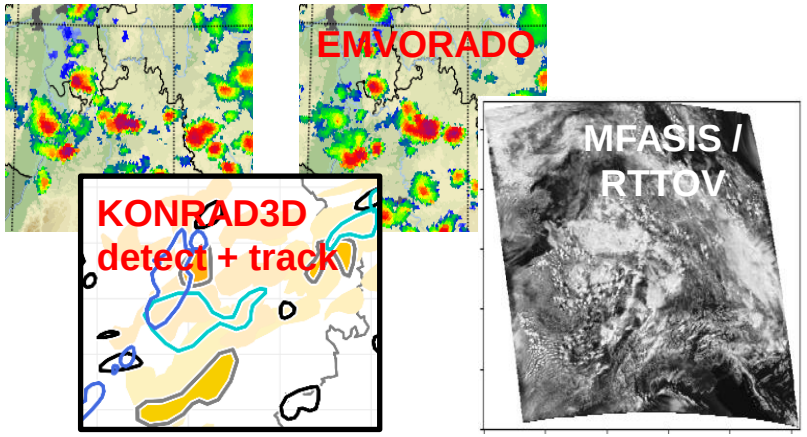
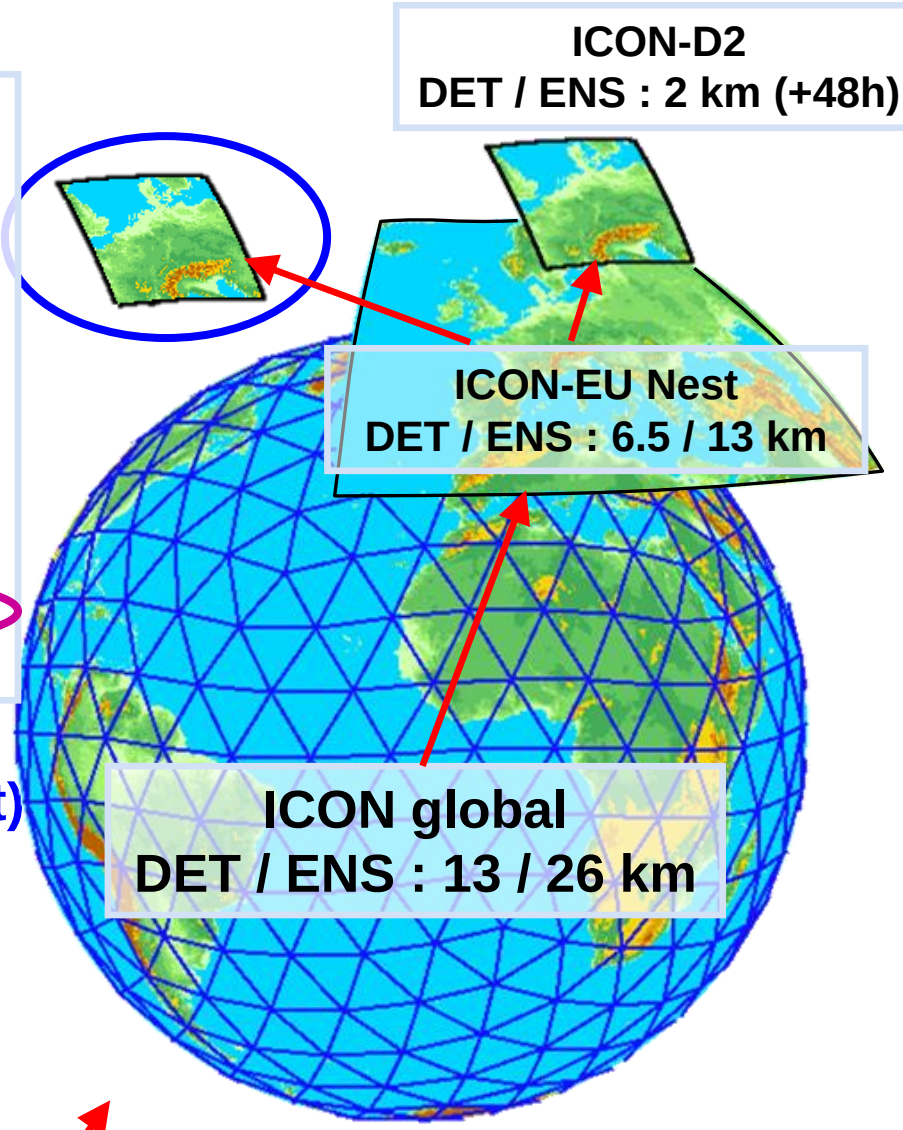
➔ **Advanced forward operators:**
Radar volumes and composites
Cell objects (KONRAD3D)
VIS / IR sat data



New: 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 good reflectivity, clouds and precipitation
Quickly available after 35‘
More frequent output



➔ **Seamless Nowcasting-NWP-products (5‘ updates, 5‘ output)**

➔ **Verification directly in observation space**

➔ **Data assimilation** via **LETKF**
together with classical Latent Heat Nudging (LHN)

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 (ratio mass con. / number conc.)
- ➔**Prognostic hail accumulation and hail rate at ground from NWP!**

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

- ➔Considerable **bias reduction** of simulated radar- and VIS/IR satellite data
- ➔Accepts more of these data in assimilation

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

Poster Thursday P17:
S. Löbel et al.
ICON-RUC hail size forecast

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

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)**

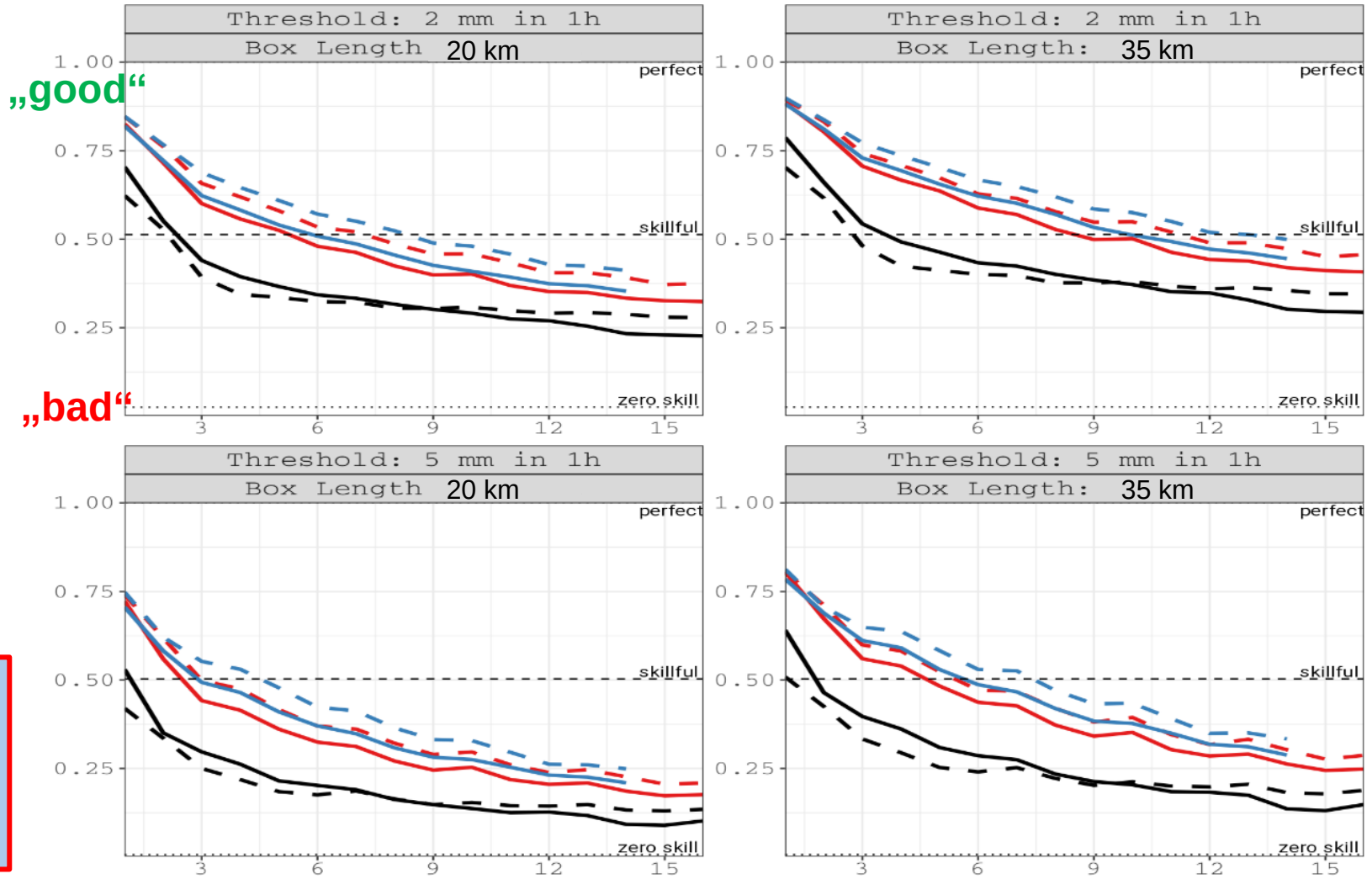
ICON-D2 **(3-h inits)**

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

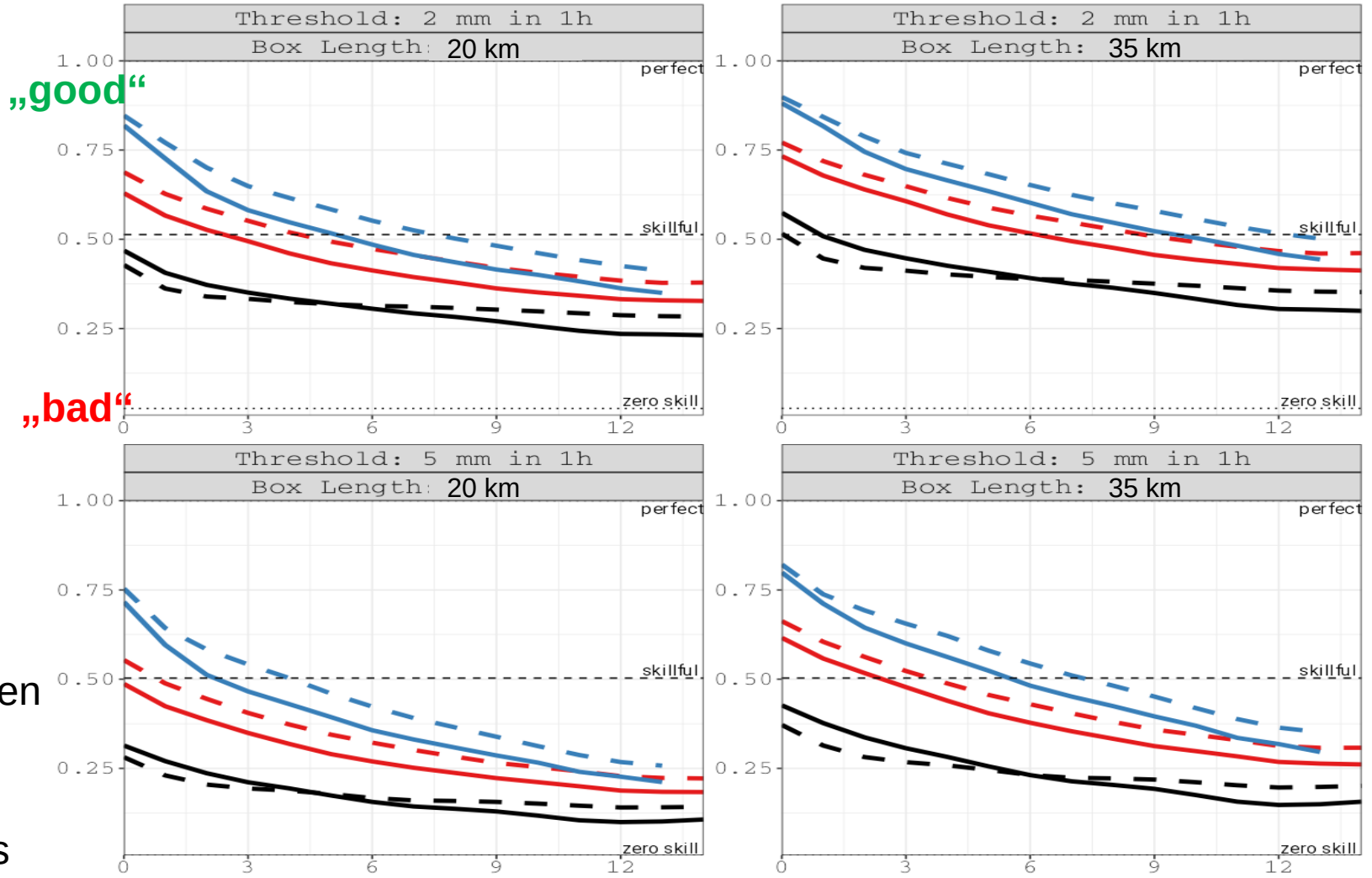
Achievements in NWP: Fraktions Skill Score (FSS)
1h-precipitation 26.5. – 30.6.2016

- COSMO-DE **(3-h inits)**
- ICON-D2 **(3-h inits)**
- ICON-RUC **(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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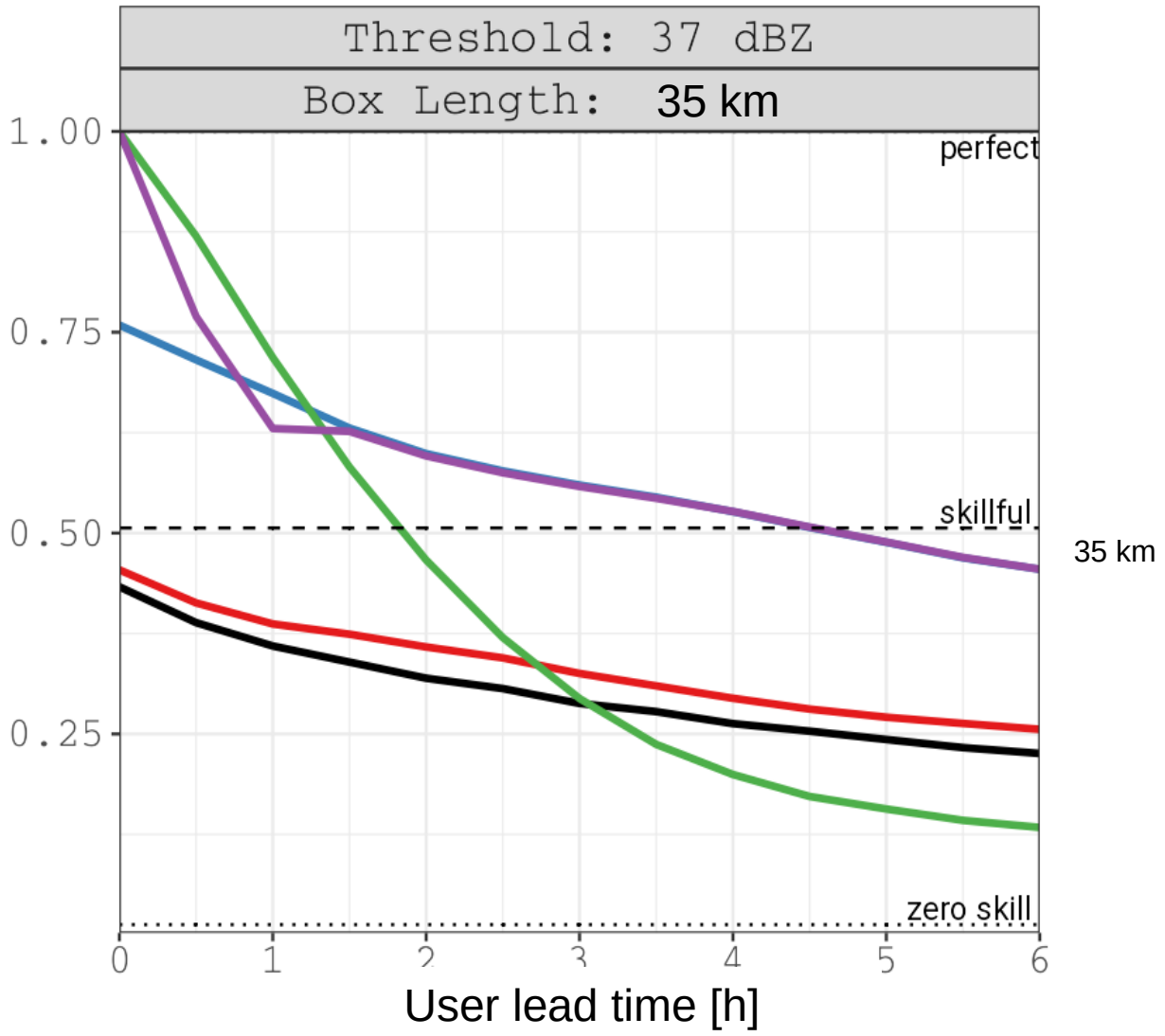
Achievements in NWP and combined products:
FSS Radar Reflectivity 26.5. – 30.6.2016

➔ **User perspective**

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



SINFONY

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

Poster Thursday P72:

M. Werner et al.

On Nowcasting KONRAD3D(-EPS)

Next talk in this session:

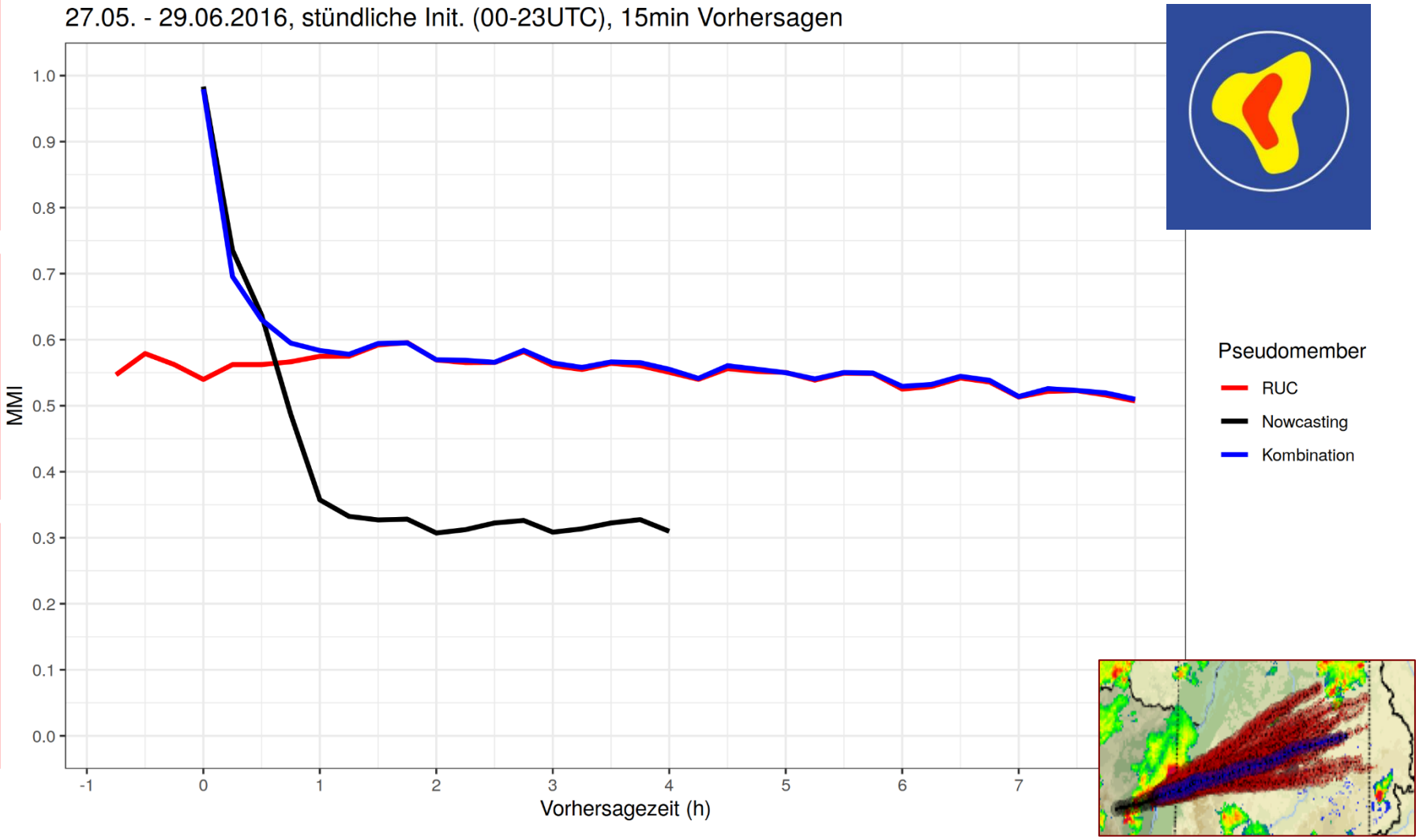
N. L. Strotjohann et al.

on the combination KONRAD3D-SINFONY

Poster Thursday P46:

M. Debertshäuser et al.

Integrating KONRAD3D cells in NowCastMix



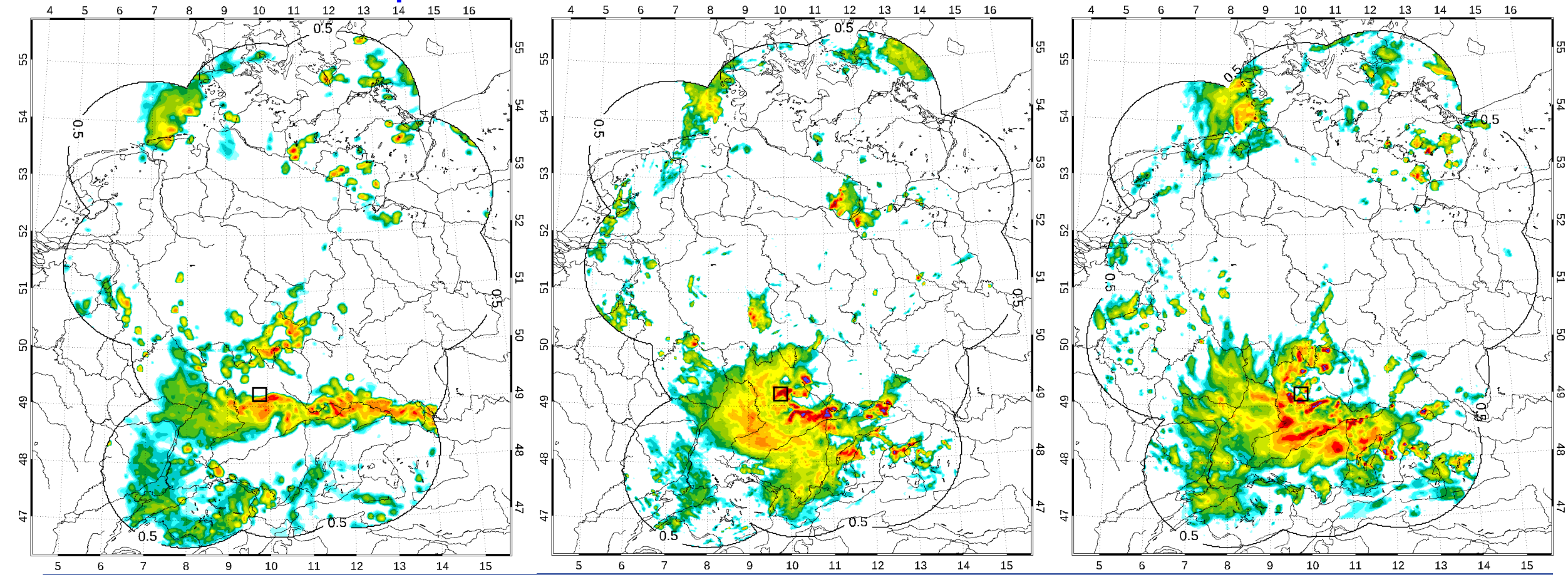
Achievements in NWP for Braunsbach case

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**



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

SINFONY

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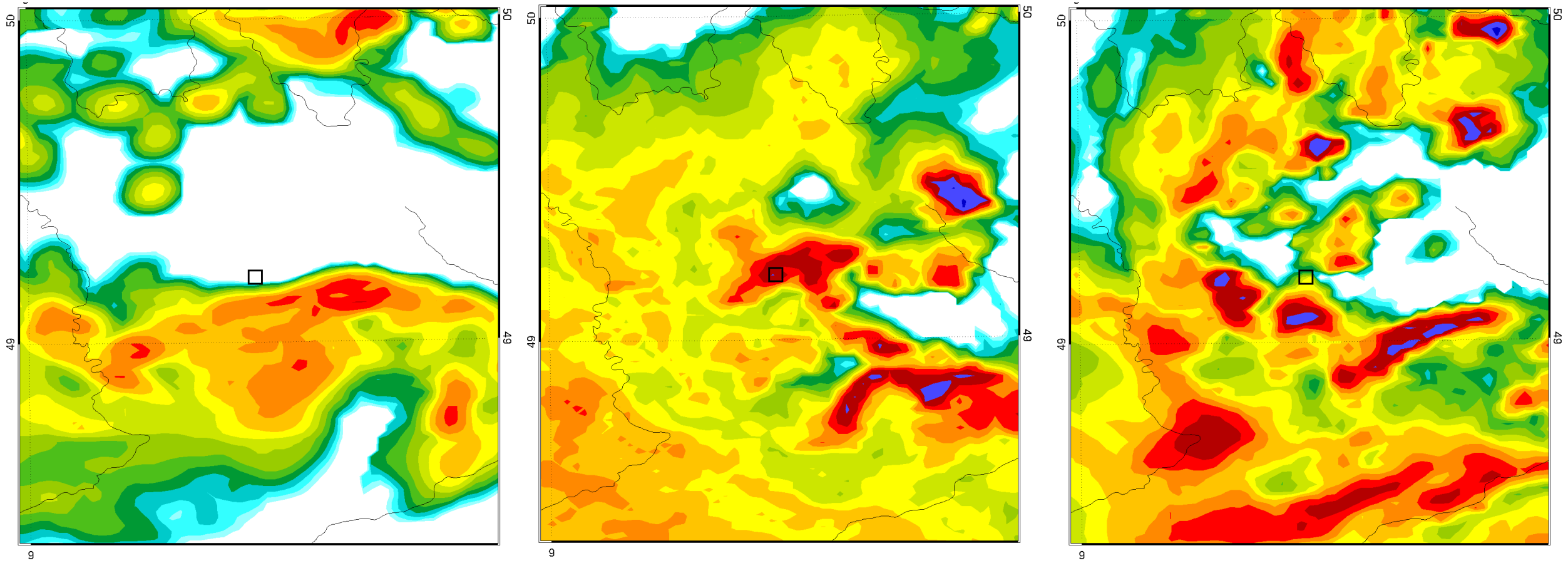


SINFONY

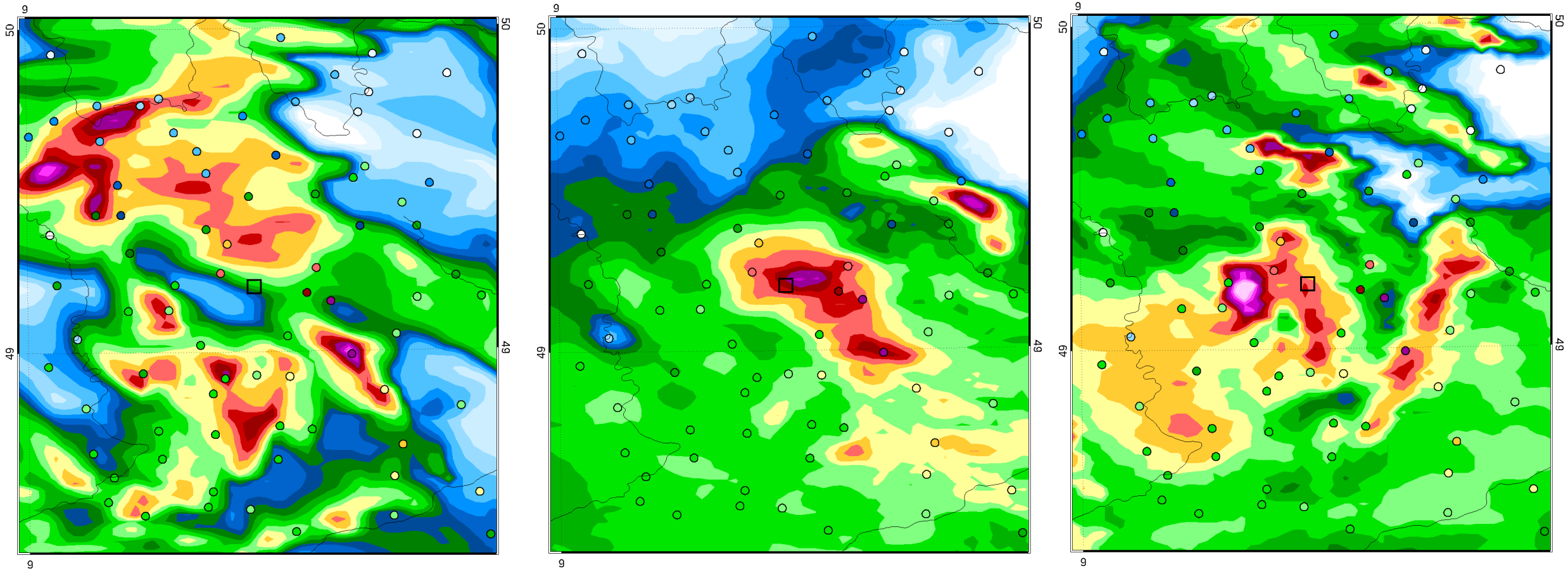
Achievements in NWP for Braunsbach case

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

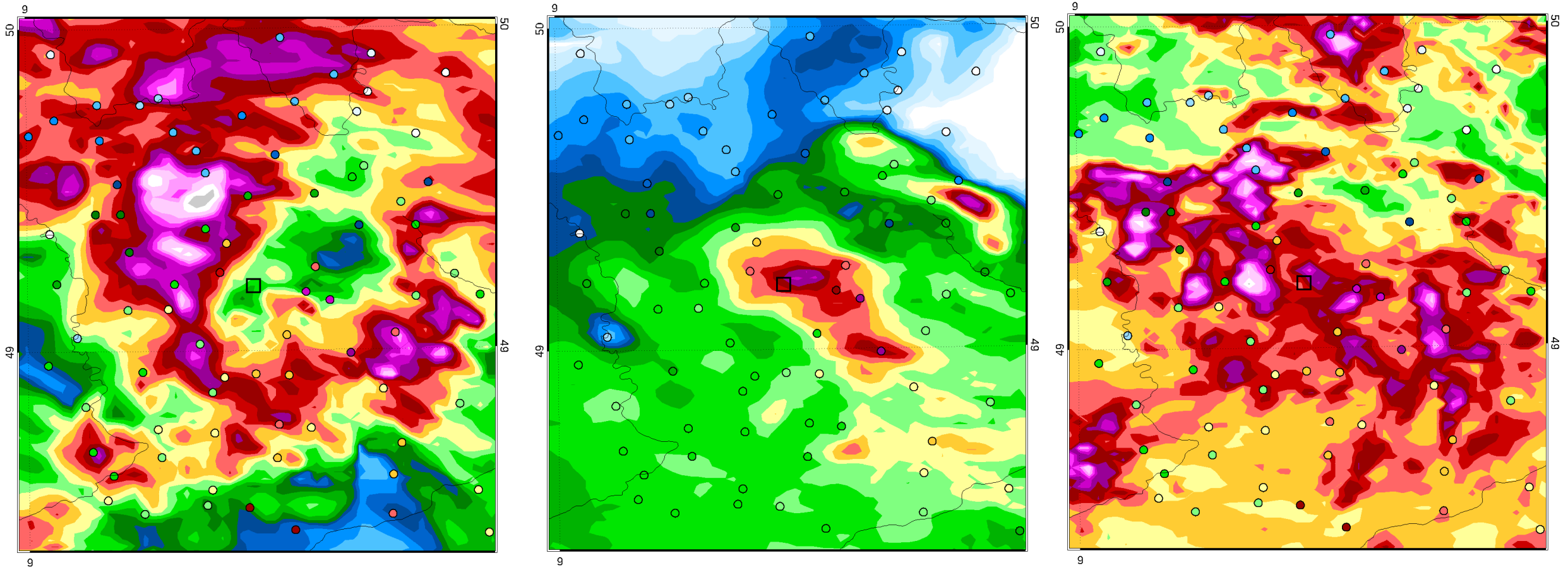
Achievements in NWP for Braunsbach case

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

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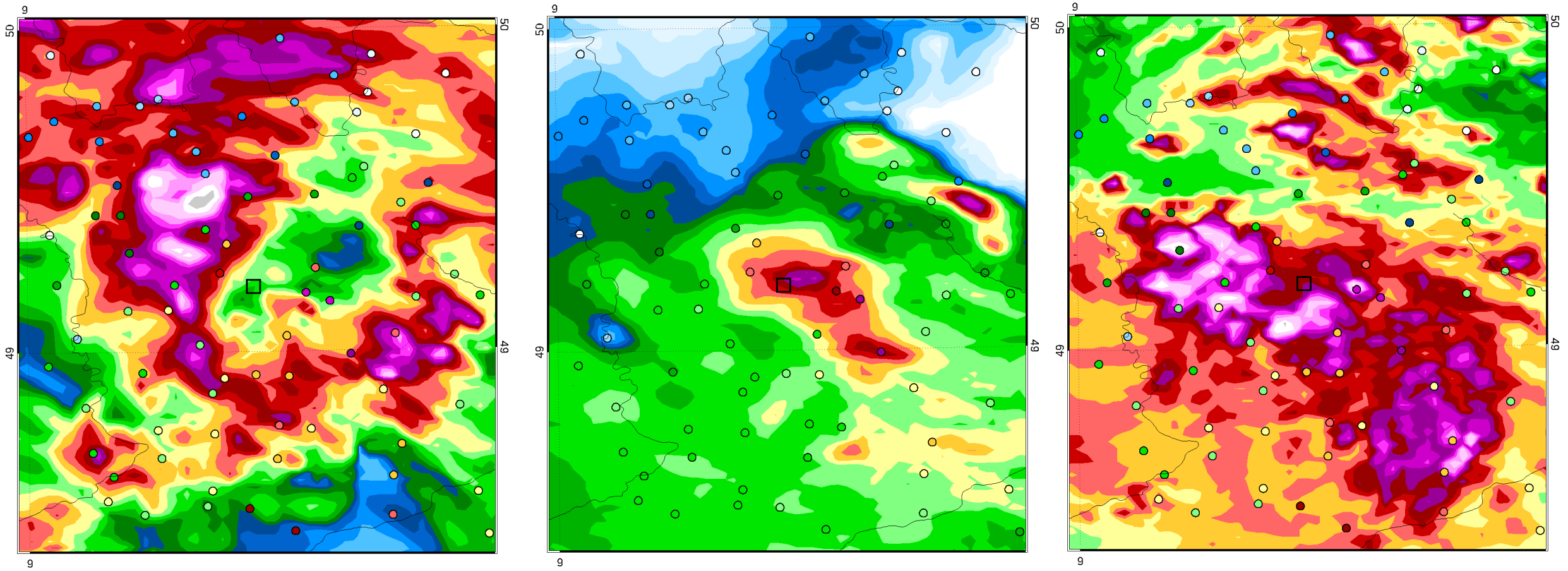
Wetter und Klima aus einer Hand

➔ 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 13 UTC**



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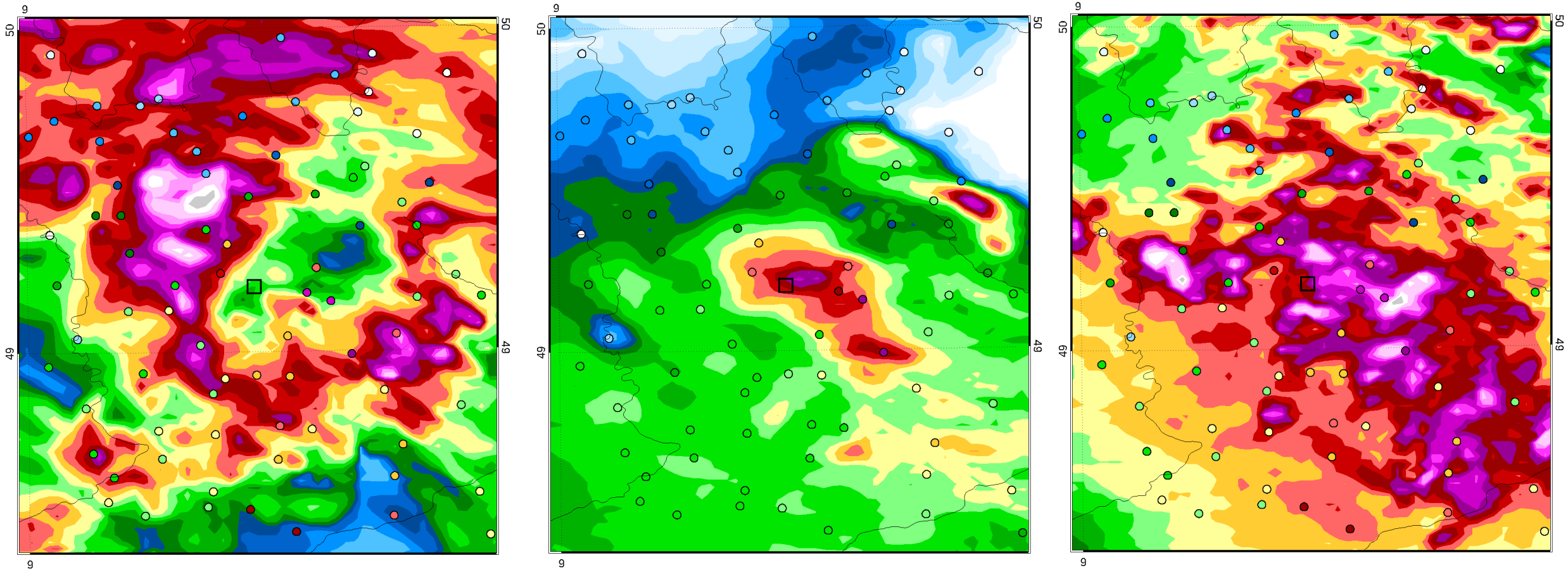
Achievements in NWP for Braunsbach case

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**



SINFONY

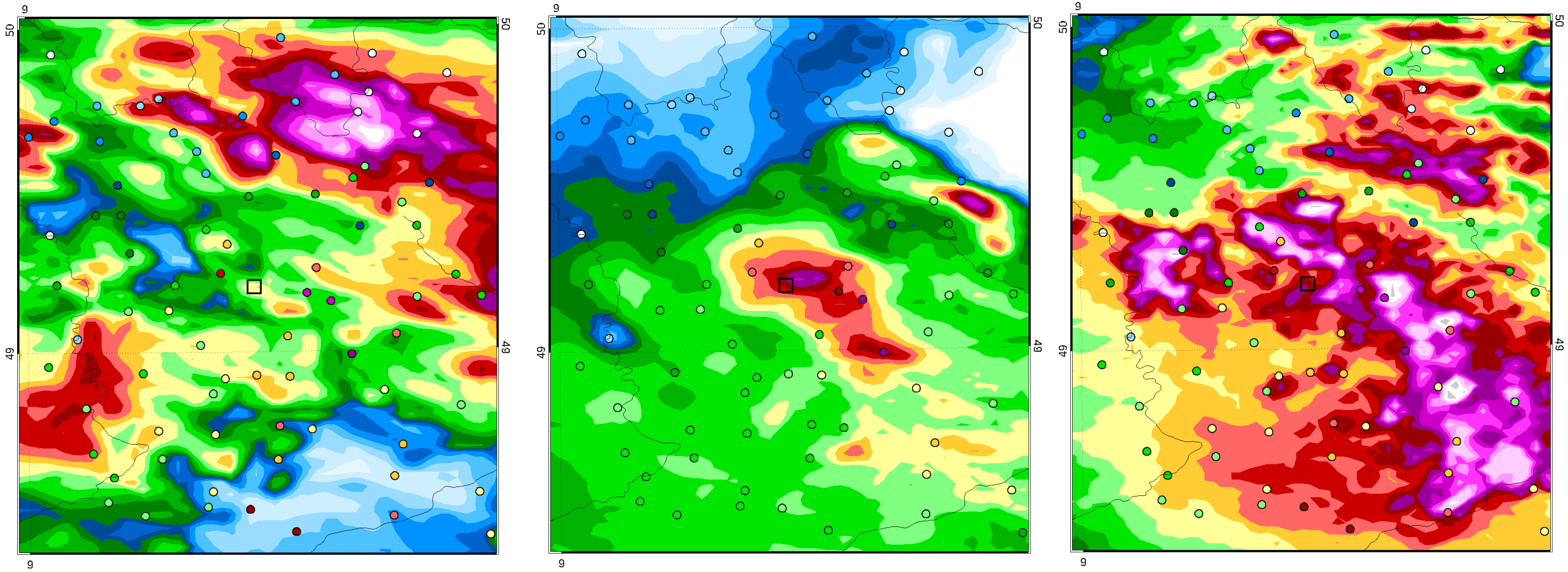
Achievements in NWP for Braunsbach case

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**

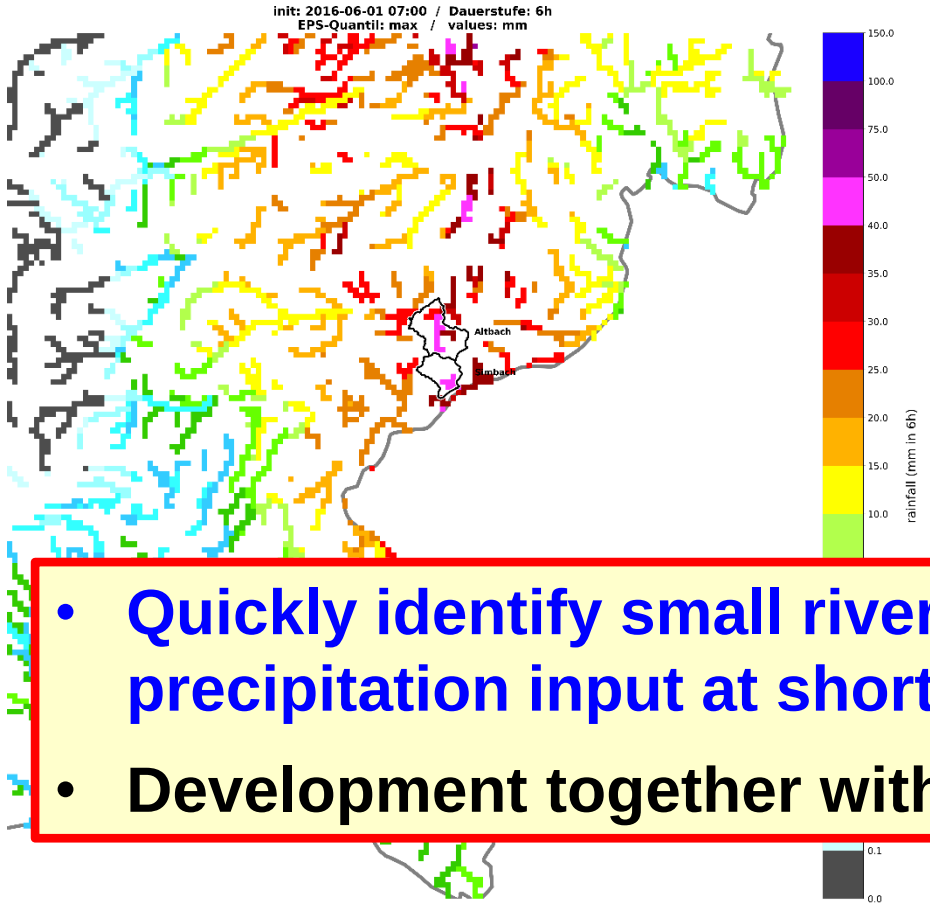


SINFONY

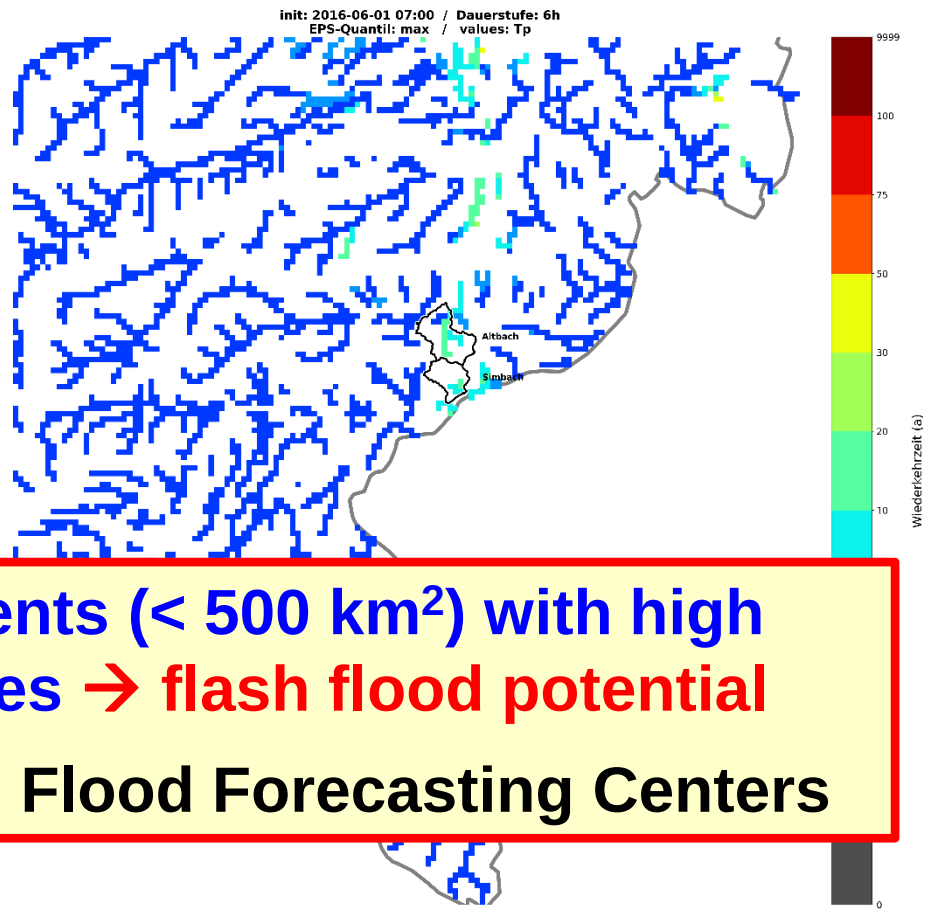
Aggregation of INTENSE over catchment area (AREA)

Simbach case, 7 UTC INTENSE, EPS max

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



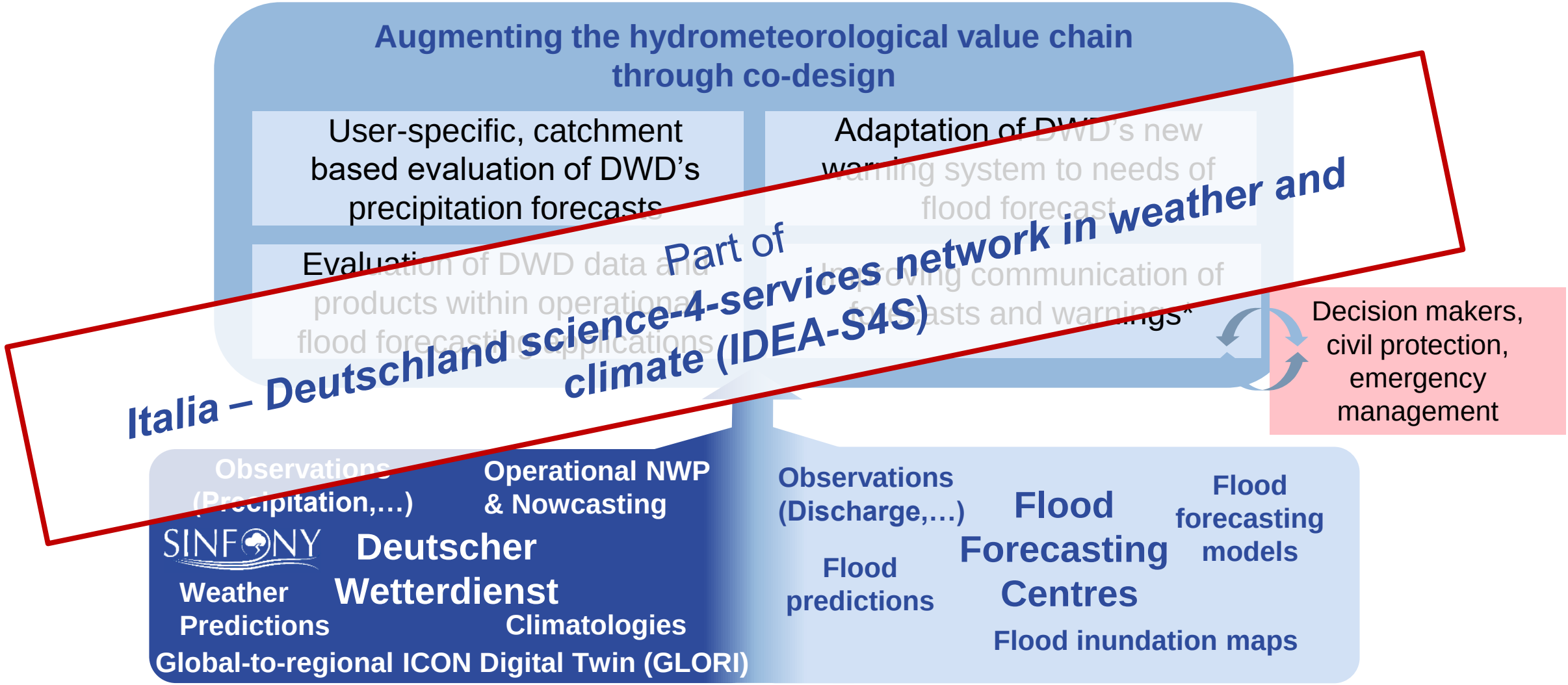
Return period [years]



- **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**

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

Poster Thursday P81
J. Keller et al.



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

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 – 2029** in project **SINFONY 3.0:**

- ➔ Seamless beyond 12 h and extend to other parameters (wind, temp., clouds) by combining ICON-RUC and ICON-D2
- ➔ Seamless from obs to RUC for other parameters by AI-based Ultra-Rapid Data Assimilation as a postprocessing
- ➔ 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

Poster Tuesday P66
F. Schubert et al.

Poster Thursday P68
S. Heibutzki et al.

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

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

Thank you for your attention!

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