Combining NWP and Precipitation Nowcasting Ensembles to Improve Short-Term Predictions of Convective Precipitation

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Motivation

Essential Question

What is the rainfall amount in a certain area and time period within the next 6 hours?

Quantities

→ Acc. Precipitation
→ Precipitation Rate
→ Reflectivity

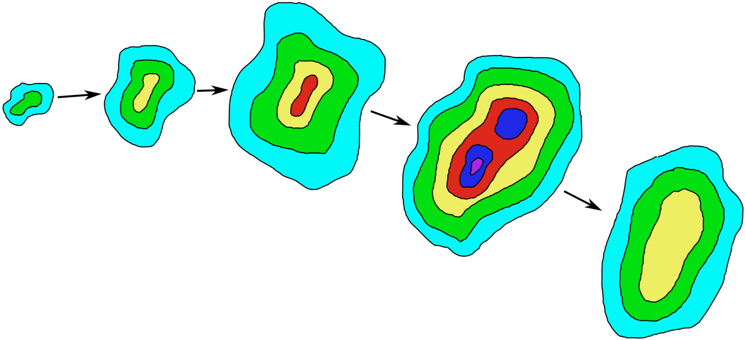
Time Period

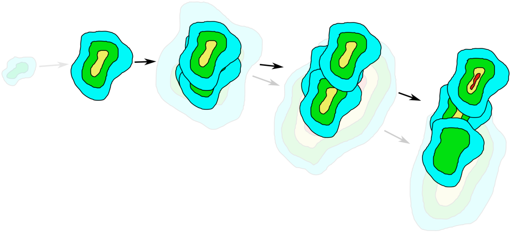
→ 5 min, 1 h, 3 h, 6 h,...
→ instantaneous

Area

→ Precise as possible
→ Up to which temporal and spatial scale are forecasts accurate?

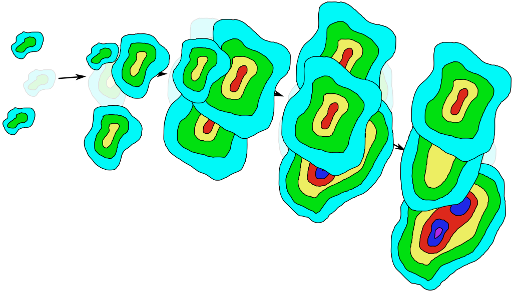
MOTIVATION





PRECIPITATION NOWCASTING

- → Fast available
- → Based on Lagrangian Persistence (Germann and Zawadzki, 2002)
- → Predictability depends on spatial scale (e.g. Venugopal et al., 1999)
- → Sources of uncertainty (e.g. Foresti et al., 2019):
  - growth/decay processes
  - future evolution of the motion vector field
  - Statistical properties of precipitation fields



NWP FORECASTS

→ Approx. 30 min (RUC) - 120 min (regular) after initialization available

→ Covers future evolution of the atmospheric state

→ Sources of uncertainty:

- Outdated initial and boundary conditions
- Data Assimilation
- Discretization of spatiotemporal scales
- Parametrization of subscale processes

Motivation

How can precipitation nowcasting and NWP forecasts be combined to preserve the best quality of both forecasts?

Seamless Combination...

...aims to create a unique and consistent forecast independent of space and forecast time. (Brunet et al., 2015)

...can take place in physical and probability space. (Vannitsem et al., 2021)

Methods

INTENSE (Integration of Ensembles of NWP and Extrapolation) based on Nerini et al., 2019

C^3 (Calibrated and Consistent Combination Using Neural Networks; Schaumann et al., 2021)

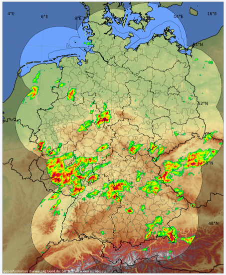
Input Data

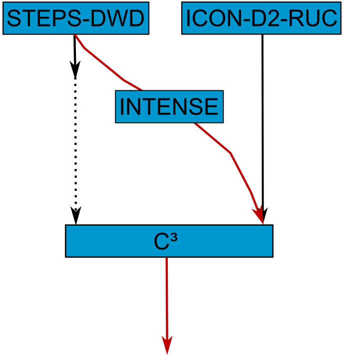
→ Adapted and improved version (Rondinel et al., 2022) of the STEPS approach (e.g. Seed, 2003)

→ Predictability depends on spatial scale

→ Non-predictable scales are replaced by correlated stochastic noise

→ 30 members; every 5 min up to +2 h



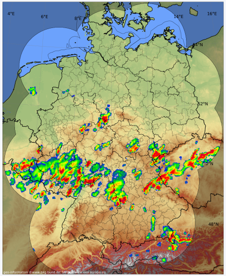


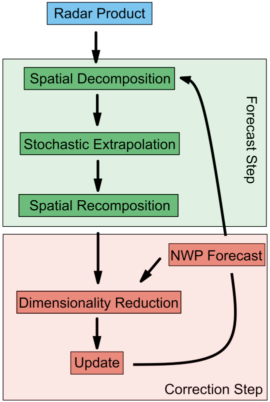
→ Near real-time test mode with daily forecasts between 6 and 18 UTC up to +8 h

→ Assimilation of 3D radar reflectivities and radial winds

→ EMVORADO for simulated radar reflectivities

→ 20 members + det.; output every 15(5) min





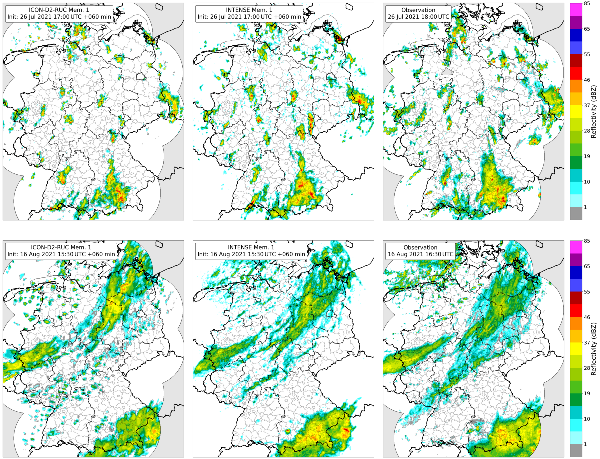
→ Combination based on an ensemble Kalman filter

→ Algorithm of STEPS-DWD is used as forward model

→ NWP information is used to correct the nowcasting

→ Utilization of a PCA for dimensionality reduction

INTENSE



→ Approach strongly depends on the precipitation coverage within the considered domain

→ In cases with low precipitation the spread generated by STEPS is too small

→ Combined forecast is then purely extrapolation-based without any NWP information

INTENSE

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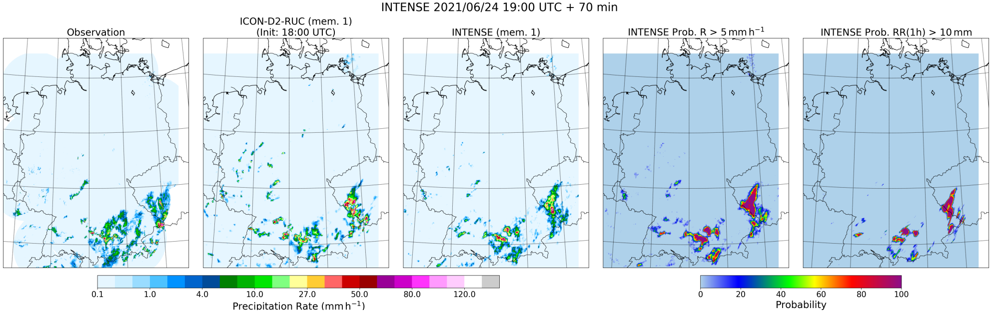
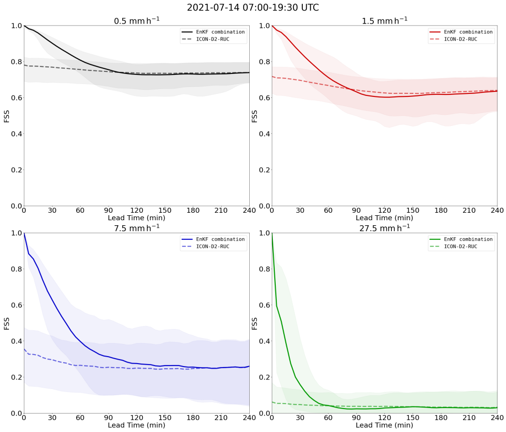
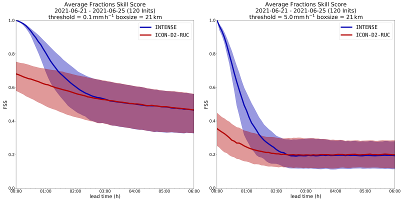
Wetter und Klima aus einer Hand





- → FSS for forecasts of the 14 July 2021 (four thresholds; left) and a period from 21 June to 25 June (two thresholds; bottom)
- → Smooth transition toward the NWP forecasts over the range of thresholds



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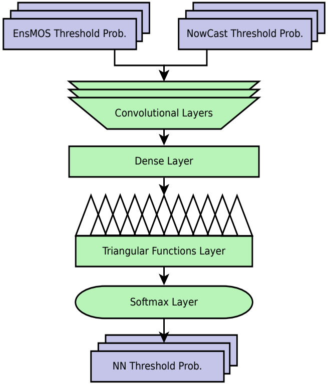


Aim

Development of a ML-based combination model that is able to produce simultaneously calibrated forecasts for several threshold exceedances in an operational setting

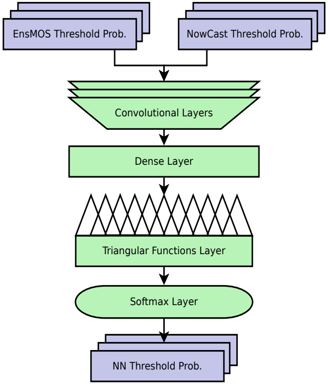
Demands

→ Architecture should be simple and robust as possible against changes in the dataset

→ Training data should consist of only a few predictors

→ Forecasts that are consistent between individual thresholds as well as individual initializations

→ Forecasts that represent the best combination of the individual input forecasts for each forecast time

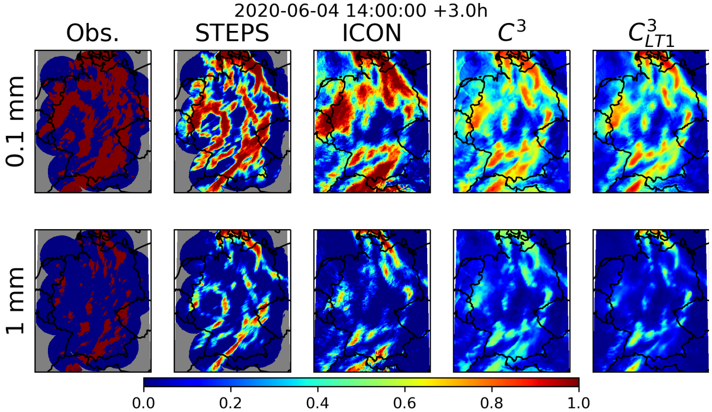


Architecture

- → Generalization of the LTI model (Schaumann et al., 2020)
- → Convolutional Layers to include information of surrounding grid boxes
- → Dense Layer to represent the interaction terms
- → Triangular functions to provide forecast calibration
- → Softmax layer to provide consistency between thresholds

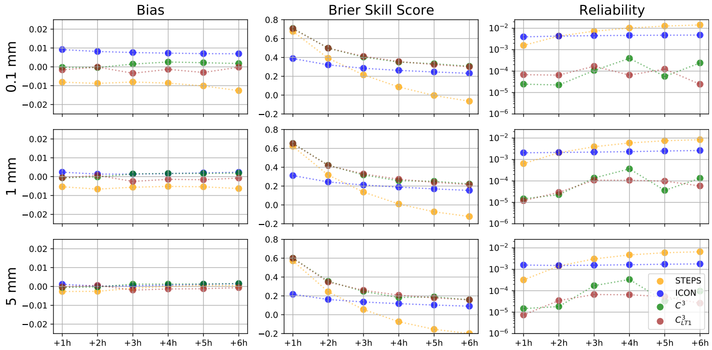
Training Data

- → Lead-time-dependent hyper parameter optimization of the architecture (04-06/2016; EnsMOS and RadVOR)
- → Training and validation based on three one-month datasets (06/2016, 06/2019, 06/2020; ICON-D2 and STEPS-DWD)
- → Robustness against changes in the dataset (Schaumann et al., 2021)



Products

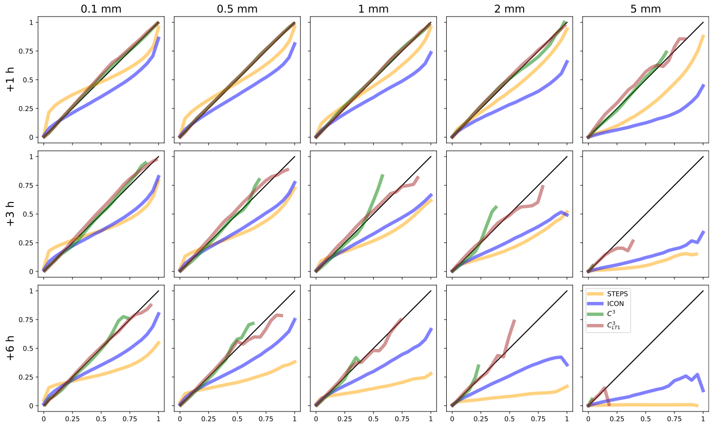
6 h forecasts of exceedance probabilities for nine thresholds regarding hourly rainfall amounts



Verification

→ Bias, Brier Skill Score, and Reliability area evaluated over the entire training period

→ Combined forecasts are bias-corrected, well-calibrated, and exhibit an improved forecast skill for all forecast times



VERIFICATION

→ Improvements in Brier Skill Score may arise due to smoothing effects.

→ However, for many thresholds and lead times the combined forecasts are well-calibrated in the sense of reliability diagrams

How can precipitation nowcasting and NWP forecasts be combined to preserve the best quality of both forecasts?

→ **INTENSE**

- Utilization of data assimilation techniques to combine nowcast and NWP
- Provides a full ensemble forecast up to 6 h ahead with output every 5 min
- Needs no training period and adapts to individual situations
- Provides forecasts of a range of precipitation quantities
- However, situations with low precipitation or in a preconvective environment are challenging

→ **C^3**

- ML-based adaptive blending algorithm intended to provide forecasts in an operational setting
- Provides exceedance probabilities for a set of nine thresholds of hourly rainfall amount up to +6 h in steps of 1 h
- Only a short training period (3 months) is necessary
- Forecast results are robust against changes in the dataset and, further, a smoothing effect due to the optimization is hardly visible

Next steps & ideas

→ **STEPS-DWD**

- Temporal evolution of the motion vector field by Burger's equations
- Local adjustment of the motion vector field based on slow-moving precipitation structures (Christian Berndt)
- Advanced localization of noise addition
- Span an ensemble by an ARI-process

→ **INTENSE**

- Advanced handling of intermittency of precipitation
- Optimization in situations with low precipitation
- Utilize other filter methods: PF, LETKF

→ **C^3**

- Use of additional orographic predictors, with a training data set extended to include the winter months 21/22
- Utilization of R-vine copulas to derive areal probabilities in predefined areas

→ **Predictive Skill**

- Determine the skillful lead time of combined forecasts dependent on region (catchment, municipal area) size and event duration (e.g. Imhoff et al., 2020)