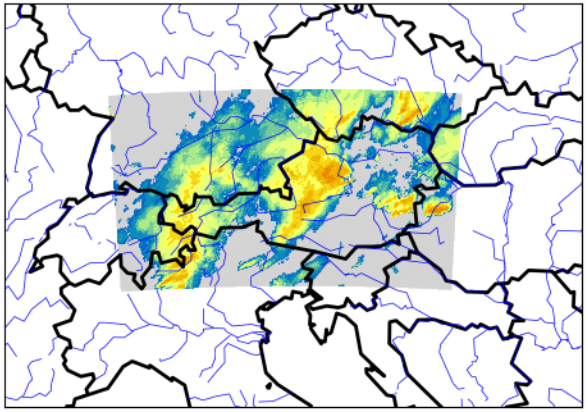
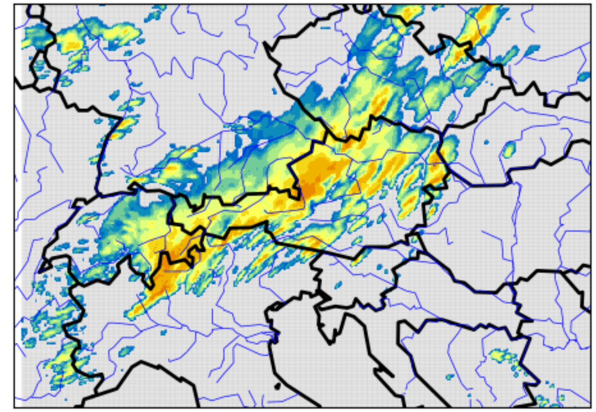
Impact of Bayesian weighting in a probabilistic nowcasting from INCA and C-LAEF

A. Atencia*, *A. Kann, Y. Wang and C. Wastl*

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

INCA and C-LAEF





Nowcasting system – INCA:

- Extrapolation of latest analysis
- Motion vectors by correlation and model correction
- Intensity-dependent elevation effect

AROME-EPS – C-LAEF:

- Convection permitting – Limited Area Ens. Forecasting
- A Hybrid-stochastic physics perturbation scheme
- IC perturbation EDA + ensemble Jk

INCA:

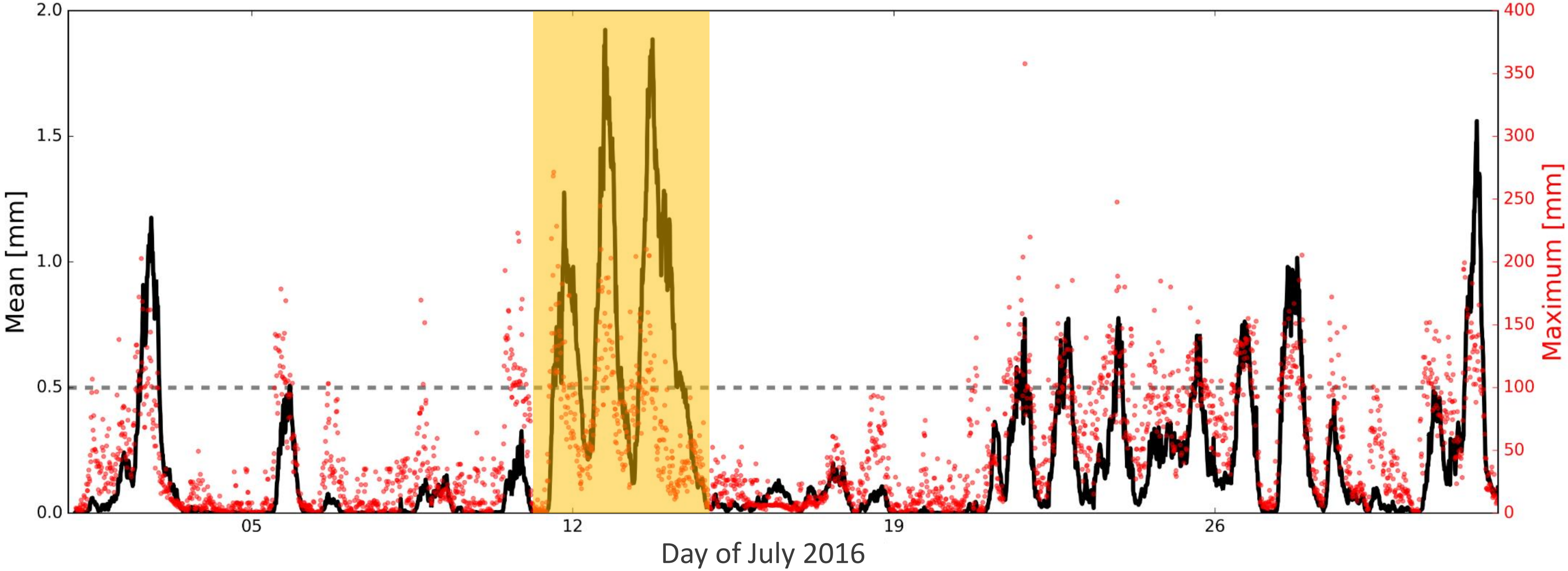
- Spatial resolution:
  - ✓ 1 x 1 km (701x401)
- Temporal resolution:
  - ✓ 15 m – 6 h lead-time / 15 m

AROME-EPS:

- Spatial resolution:
  - ✓ 2.5 x 2.5 km (594x492)
- Temporal resolution:
  - ✓ 1 h – 30 h lead-time / 24h RUN

Test month

This study is carried out for the whole month of July of 2016:



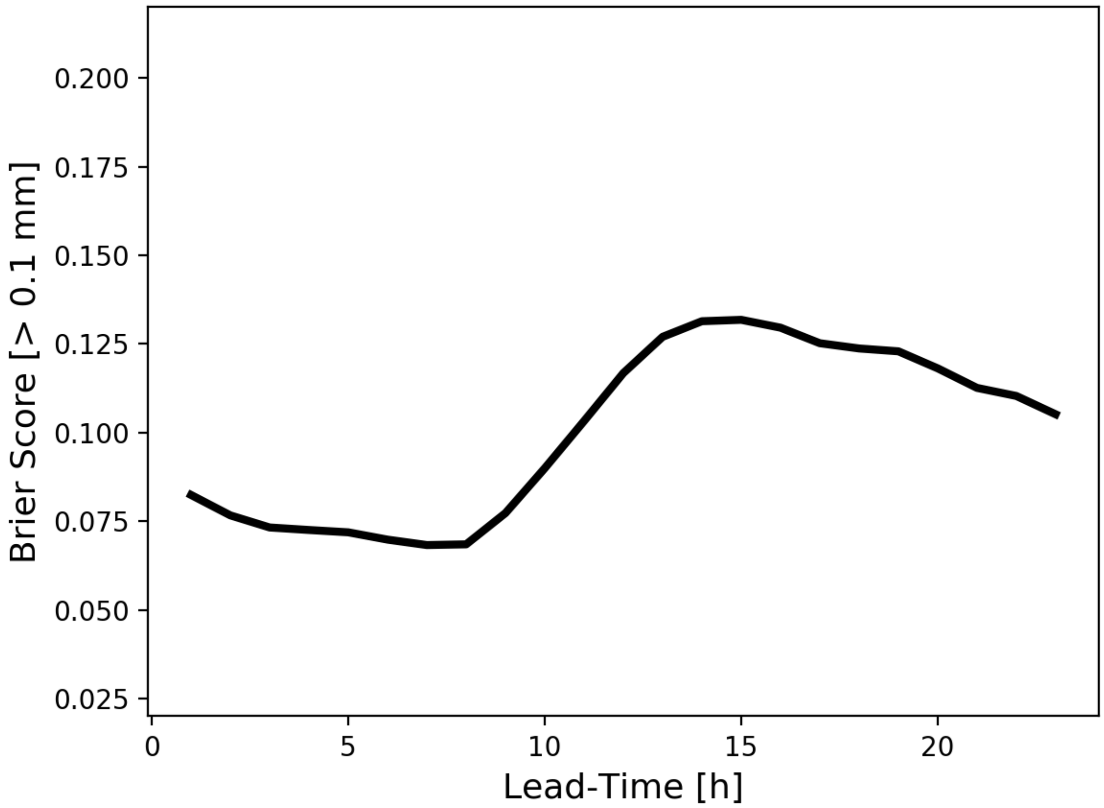
11 to 14 July:

Temporary heat wave with increasing thunderstorm activity. 12 July the storms organized into several large front-like systems that persisted over many hours; it was the worst severe weather day of the year, there were numerous extreme wind and hail damages, and forecast quality was poor. On 13 July, thunderstorm activity continued on the south side of the Alps while it was replaced by prolonged rain elsewhere as a cold front entered Austria.

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Motivation

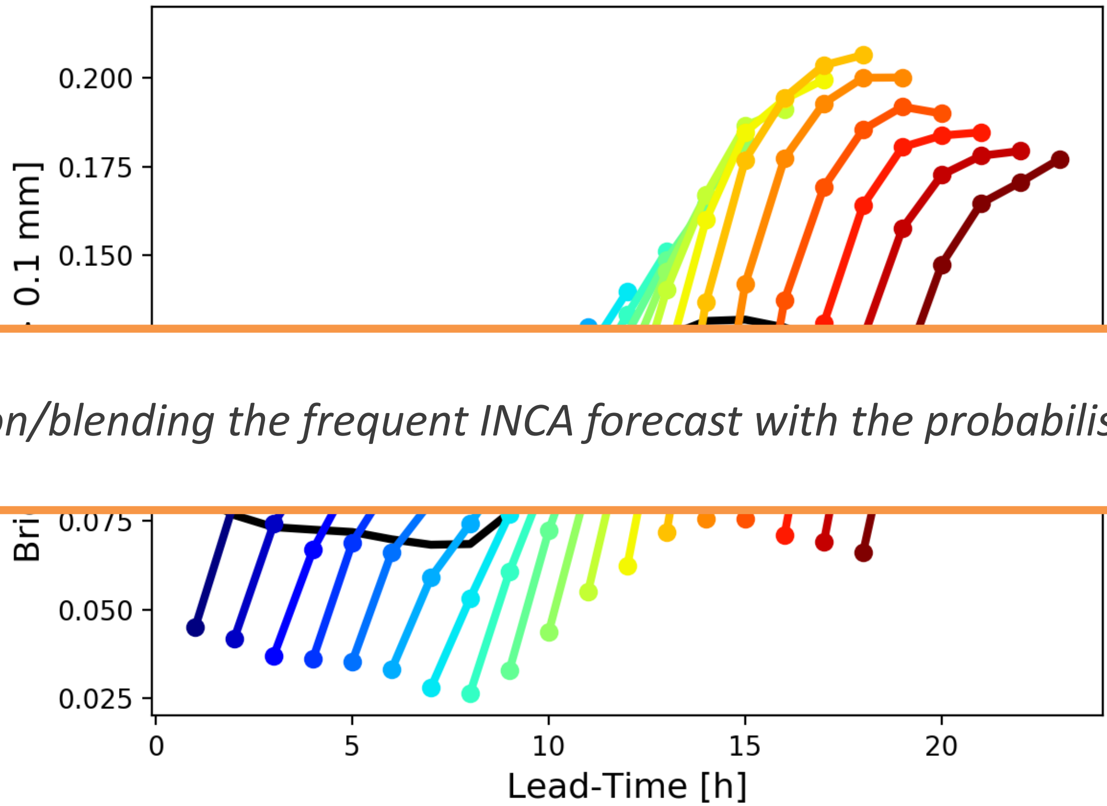
The probabilistic information of an EPS system as AROME-EPS is crucial for very-short range forecasting.



Motivation

The probabilistic information of an EPS system as AROME-EPS is crutial for very-short range forecasting.

Yet, AROME-EPS runs are less frequent than INCA because they are computationally more expensive.



Integration/blending the frequent INCA forecast with the probabilistic AROME-EPS

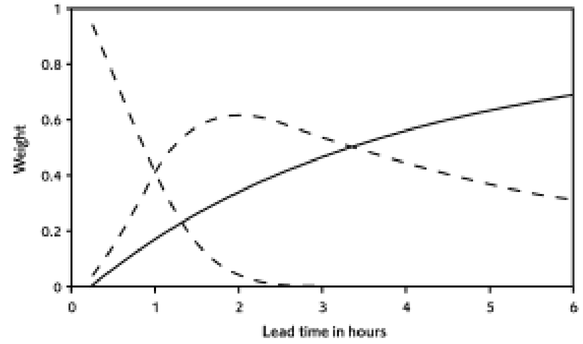
State of the art

The current state of the art for blending NWP with NWC is still adding:

1. Linearly both fields (Golding, 1998),

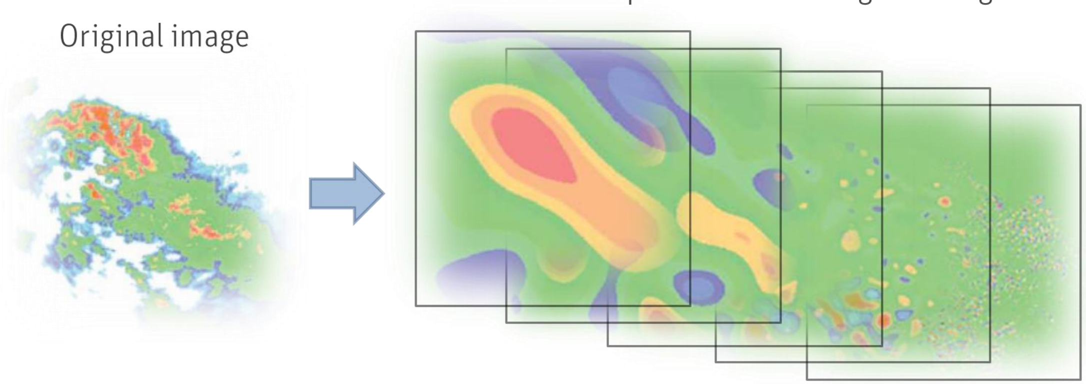
$$W_A = \exp\left(\mathrm{Ln}\left\{\frac{C_0[(dt-1)/5]}{C_A}\right\}\right)$$

$$W_M = C_0 + \frac{C_M(C_A - C_0)}{C_A}$$



2. Probabilities of occurrence (Kober et al., 2012) depending on the synoptic forcing (Kober et al., 2014)
3. Cascades from a scale decomposition of the reflectivity fields (Bowler et al., 2006) from both sources the Lagrangian extrapolation and the NWP output

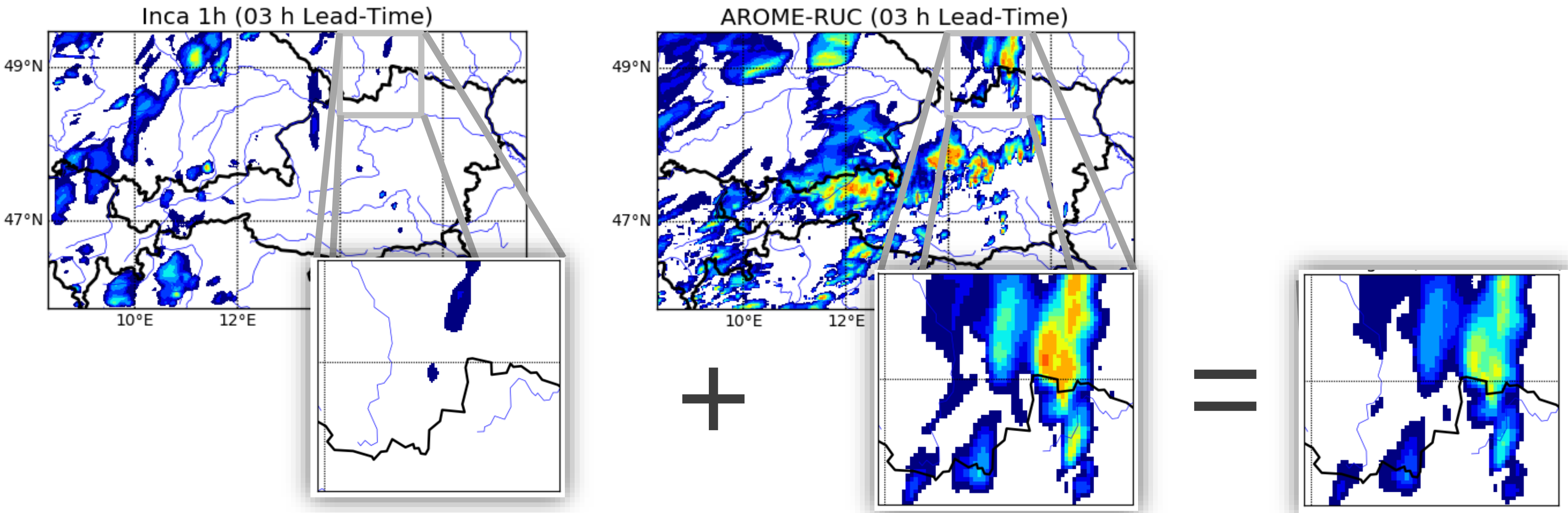
   (e.g. STEPS, Alan Seeds).



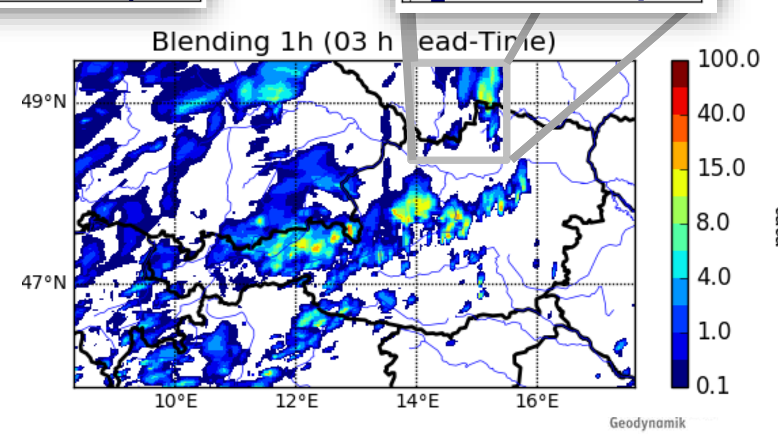
ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Challenges of the current methodologies

Methodologies **1** and **3** are **Blending in the intensity space**. They involve the following challenges which need to be tackled:

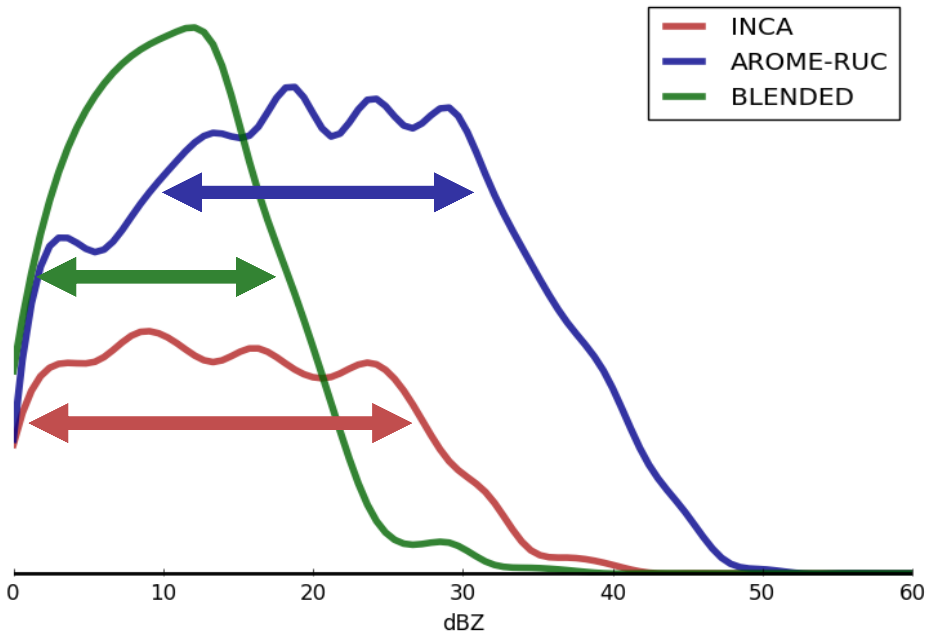


The thunderstom (>35 mm/h) modelled by the NWP is smoothed (~ 18 mm/h) in the blended forecast due to the lack of precipitation in the radar-based extrapolation.



Challenges of the current methodologies

Also, the **intensity-based blending** (**1** and **3**) reduces the heavy rainfall and the variance :

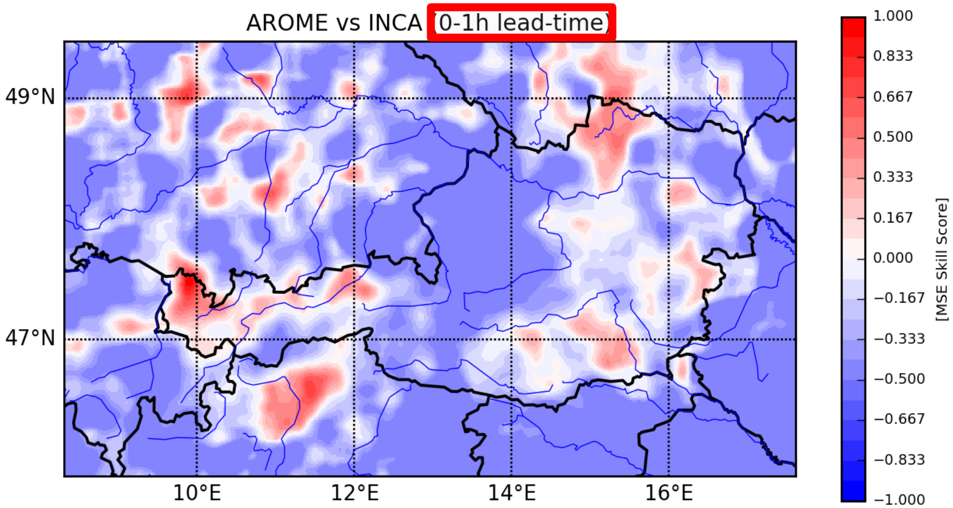


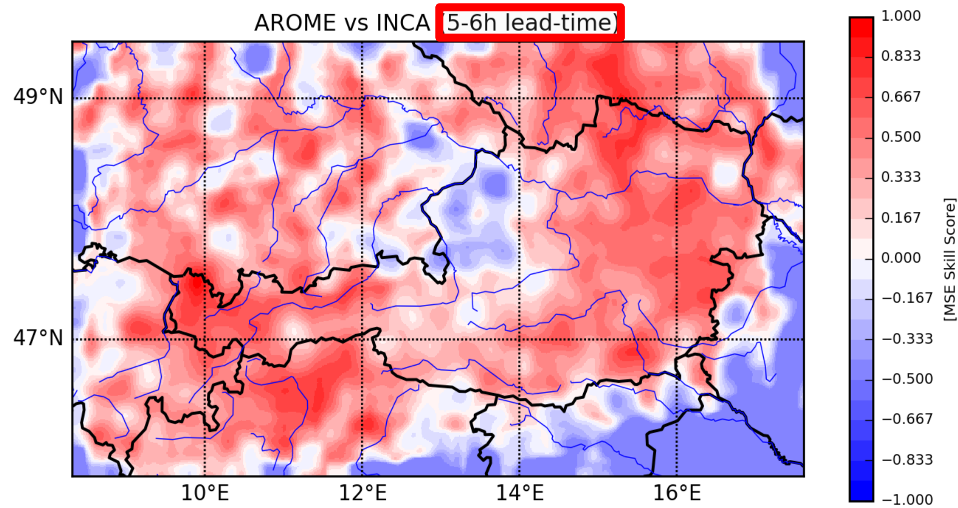
The empirical probability distribution of rainfall values of both INCA (radar extrapolation) and AROME-RUC (NWP) is compared to the epdf of the blended forecast showing the lessening of the intense rainfall and also the reduction of variance.

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Challenges of the current methodologies

Besides, recent studies about the performance of NWP flood forecasts (Cloke et al. 2017) and Nowcasts (Berenguer et al, 2016) have shown that both forecast qualities vary locally. The MSE skill score* of AROME-RUC (NWP with data assimilation) versus the INCA (extrapolation radar-based nowcasting) for different lead-times is computed to demonstrate that local dependence of the forecasting systems.





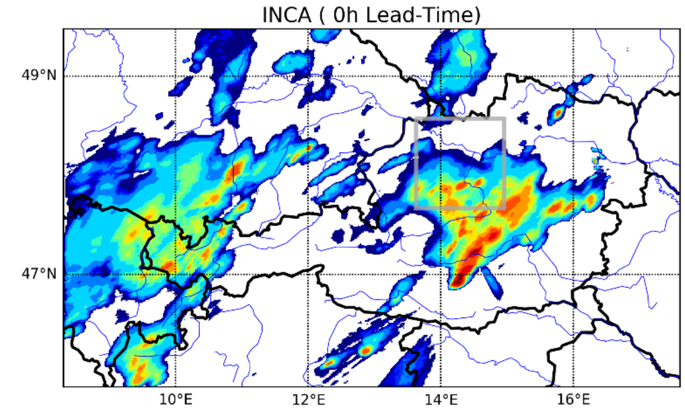
$$(*)\ MSE-SS' = \begin{cases} 1 - \frac{MSE_{INCA}}{MSE_{AROME}} & : MSE_{INCA} < MSE_{AROME} \\ \frac{MSE_{AROME}}{MSE_{INCA}} - 1 & : MSE_{INCA} \geq MSE_{AROME} \end{cases}$$

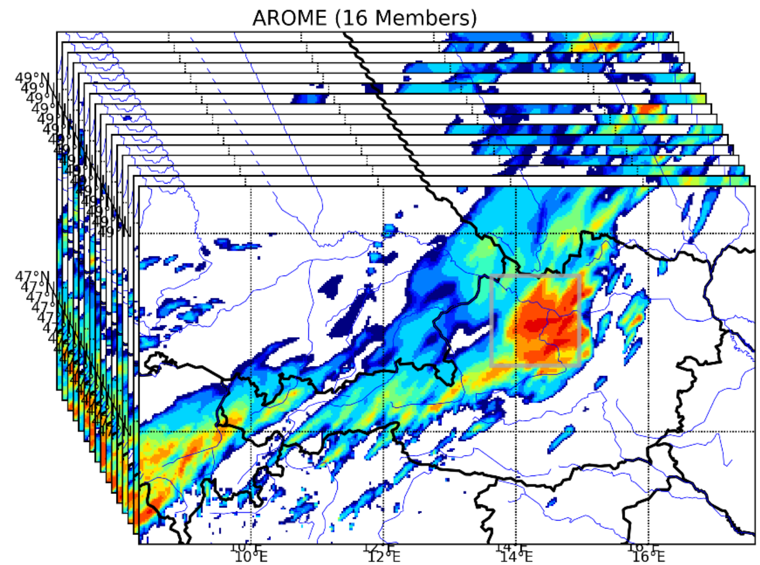
ZAMG Zentralanstalt für Meteorologie und Geodynamik

Main goals of the proposed methodology

The present methodology is a probabilistic blending of a radar-based extrapolation Nowcasting (INCA) with a Ensemble Prediction System (EPS) implemented in a Convective-permitting NWP (AROME):

- Taking advantage of the latest observations by including INCA analyses
- Taking advantage of the probabilistic information from the 16 members of the AROME-EPS
- Keeping the lead-time dependence on the weights W=W(LT)
- Computing a location-dependent weight for the blending of the different ensemble members W=W(LT, x)
- Benefiting from the ensemble members “closer” to the latest observations.
W=W(LT, x, Member)
- Using a technique for obtaining an epdf of rainfall values without losing the extreme/high values and by keeping the variance





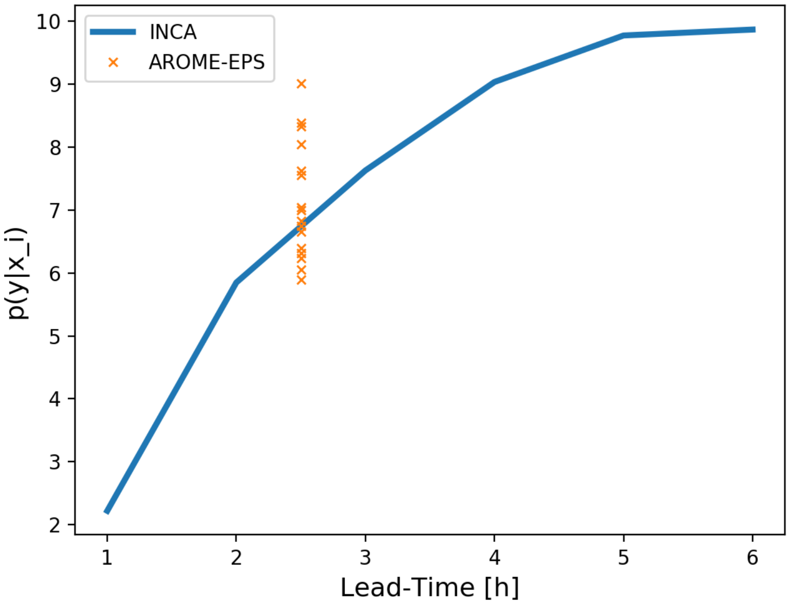
Bayesian weighting

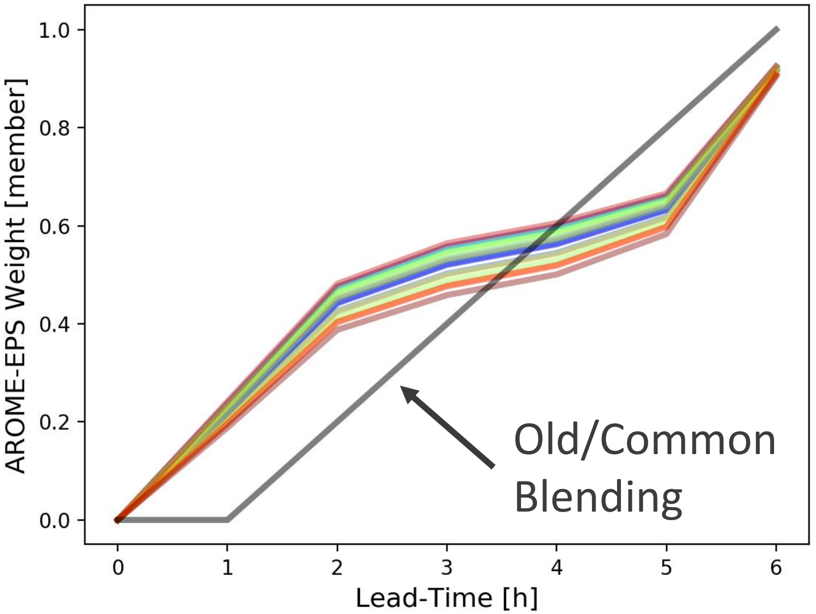
Using Bayes' theorem, the posterior probability can be computed as:

$$p(x|y) = \frac{p(y|x)p(x)}{p(y)}$$

In order to avoid the weight collapse, Van Leeuwn (2003) proposed a Cauchy distribution to compute the likelihood of a observation (y) given a forecast member (x^k)

$$p(y|x_i) = \left(1 + \frac{||y - x_i||}{\sigma^2}\right)^{-1} \longrightarrow w_i = \frac{p(y|x_i)}{\sum_{j=1}^{N} p(y|x_j)}$$

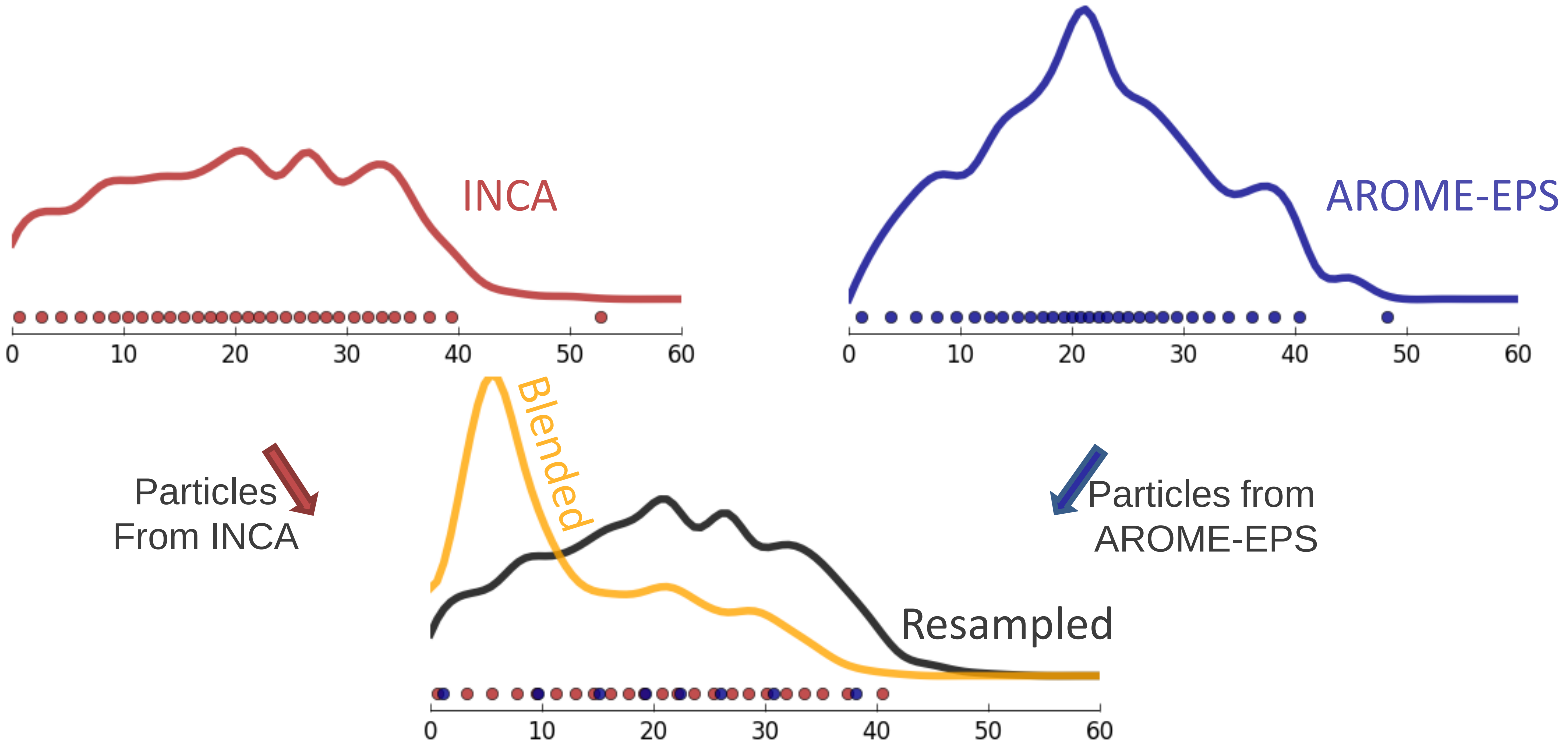




Resampling and Matching Method

To avoid losing the heavy rainfall values and also the reduction of variance caused by the intensity-based blending methods, a matching method is applied to each of the subdomains. This method can keep the chosen empirical distribution of rainfall values.

However, a method to blend both empirical distribution has to be developed as well. Taking into account the non-Gaussian shape of the distribution, a resampling method from the sorted distribution of both sources of rainfall values (INCA and AROME-EPS member) is applied.



ZAMG Zentralanstalt für Meteorologie und Geodynamik

Verification and comparison with previous methodologies

OBS

INCA

Ens mean old blend

Ens mean new blend

AROME #1

Old Blending #1

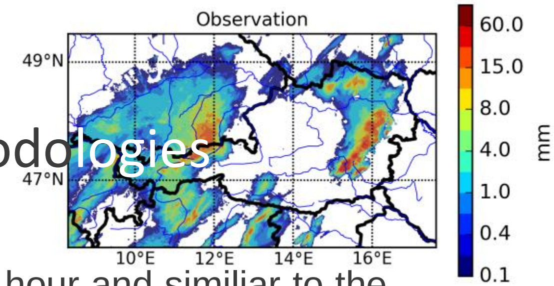
New Blending #1

AROME #2

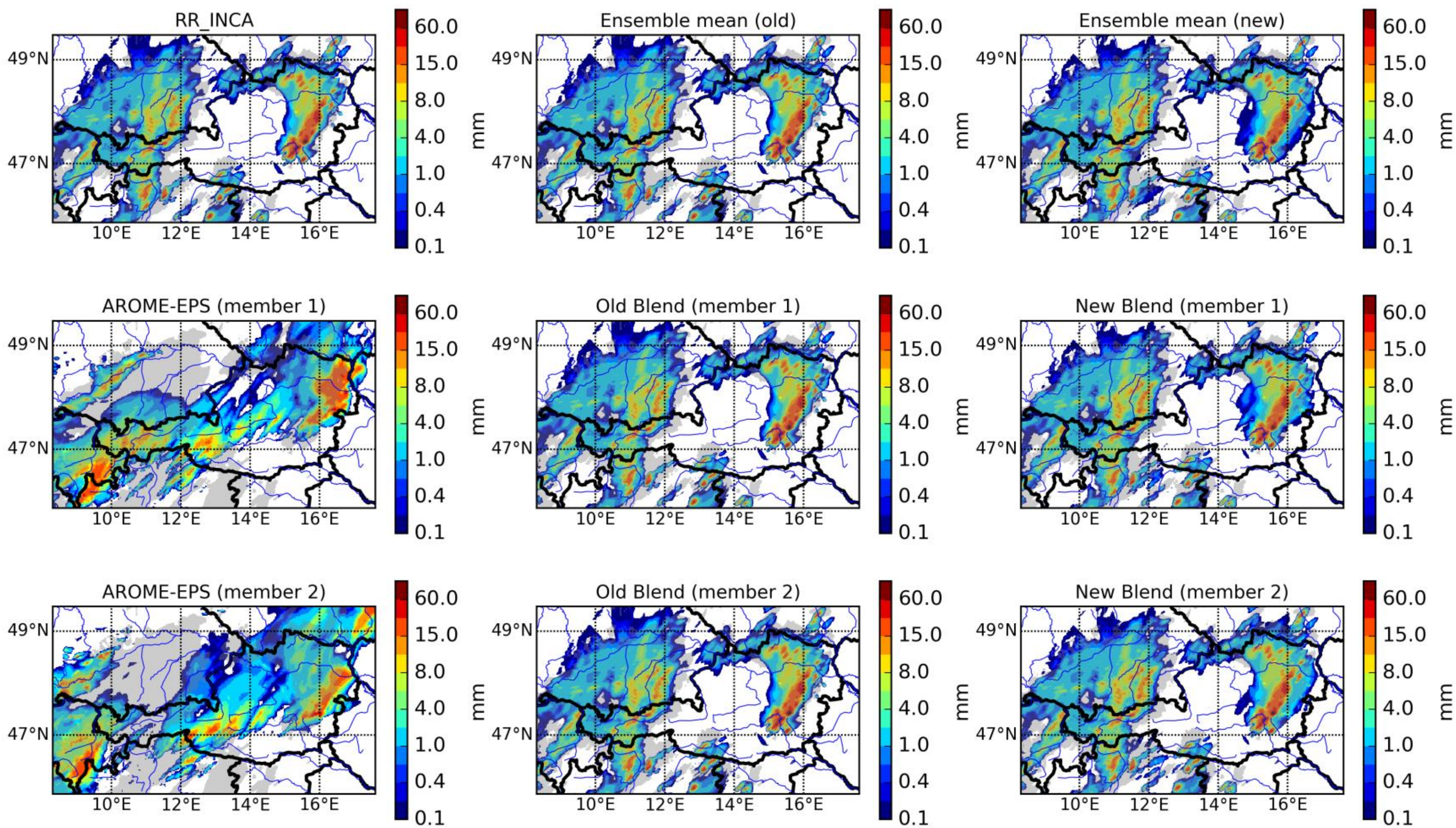
Old Blending #2

New Blending #2

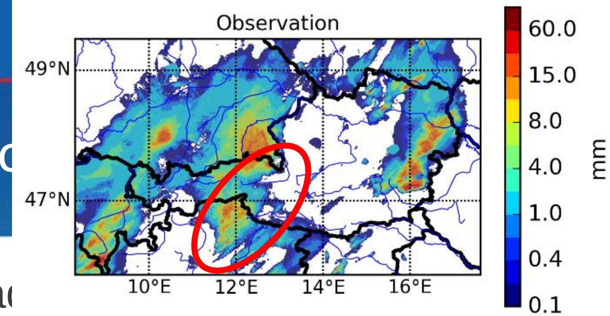
Verification and comparison with previous methodologies



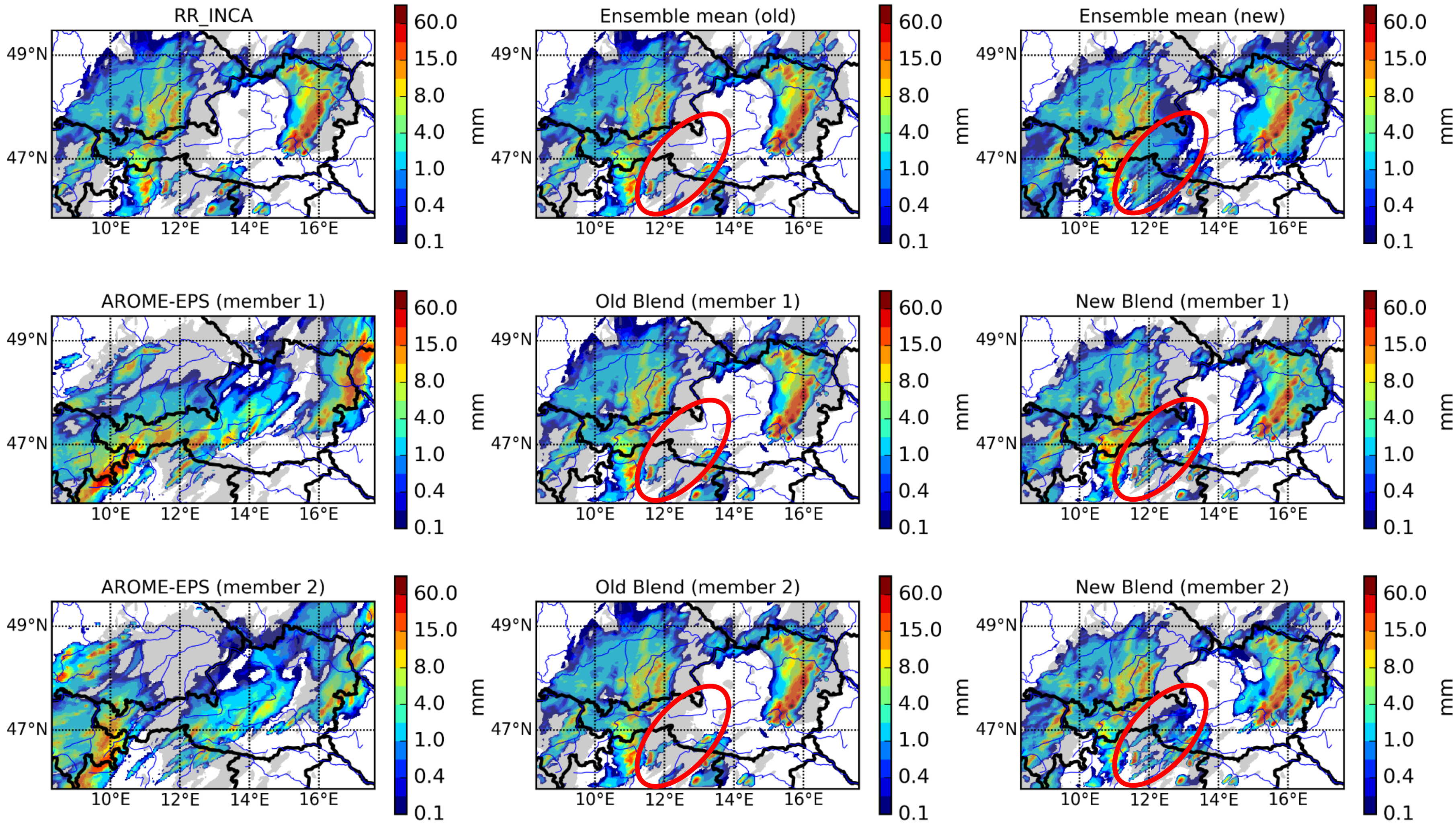
The proposed blended field is similar to the INCA forecast for the first hour and similiar to the AROME-EPS for the latests time step with realistic structures in between. The variance/values are similar to the observed one (no smoothing)



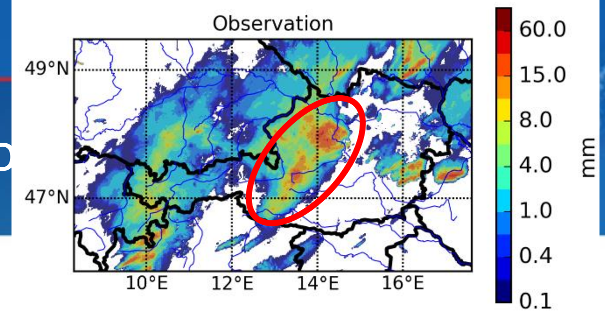
Verification and comparison with previous methodo



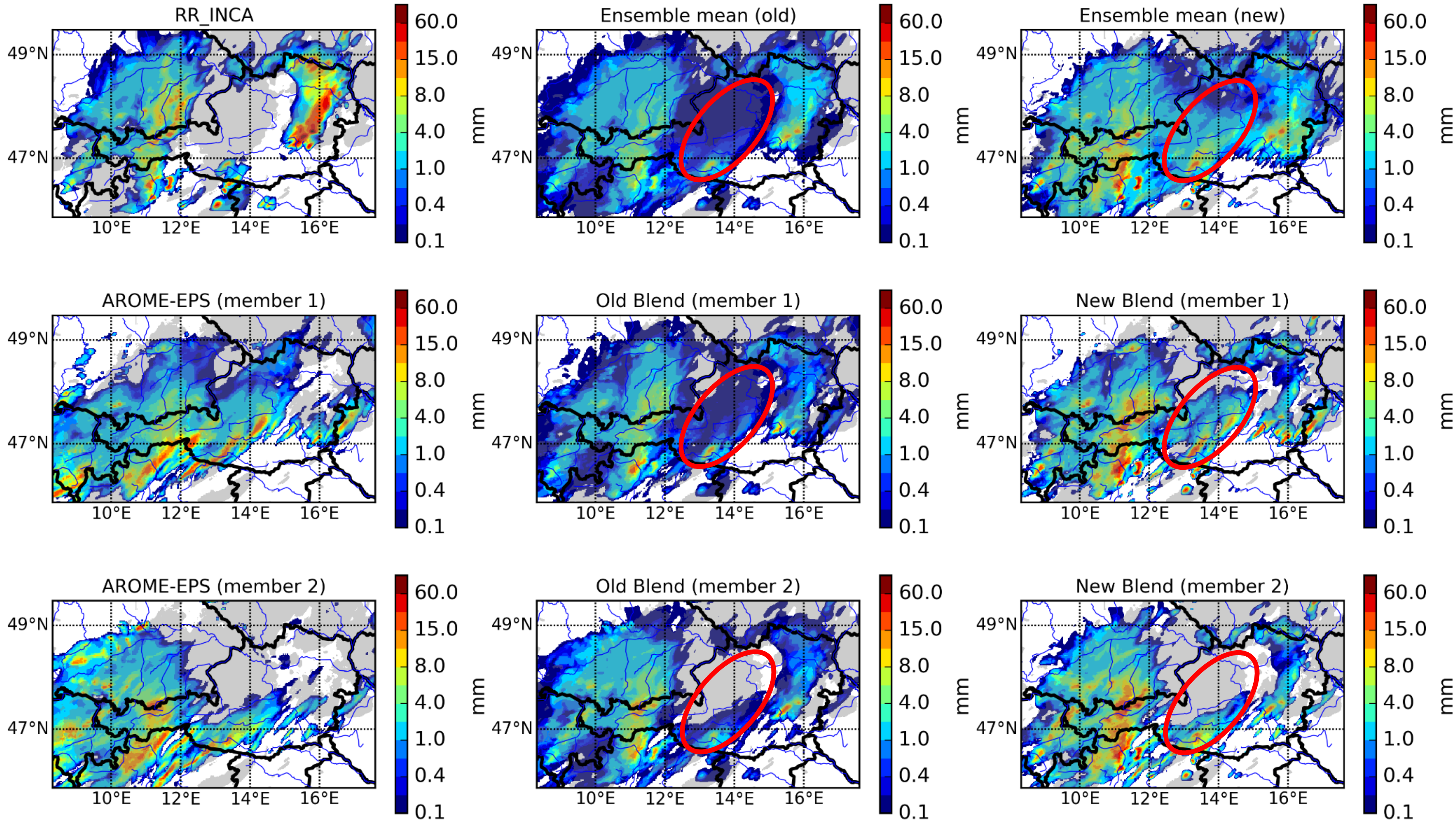
Effect of the localized/Bayesian weights observed in the 2[nd]h lea



Verification and comparison with previous methodo

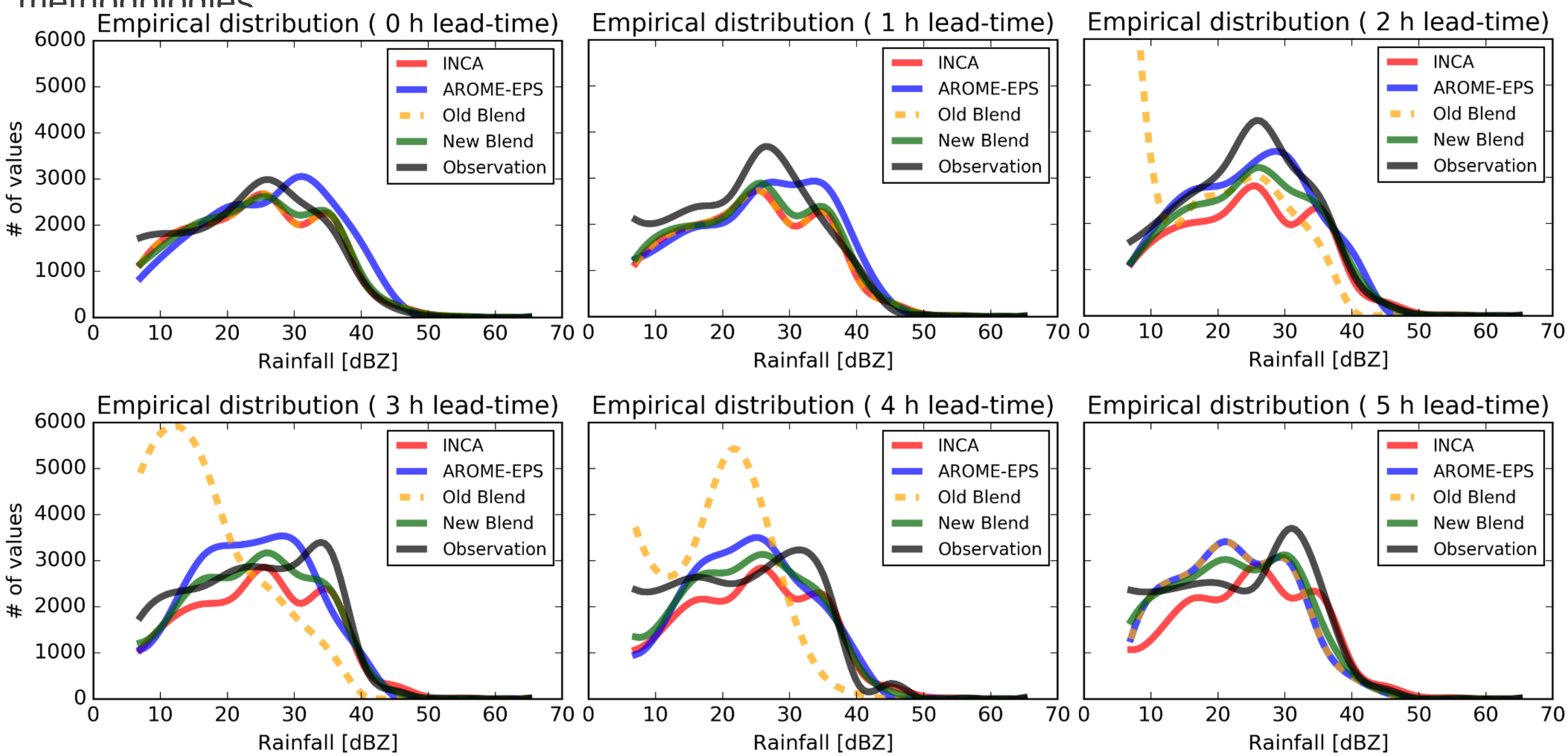


Effect of the resampling of the distributions in the 4th h lead-time.



Verification and comparison with previous methodologies

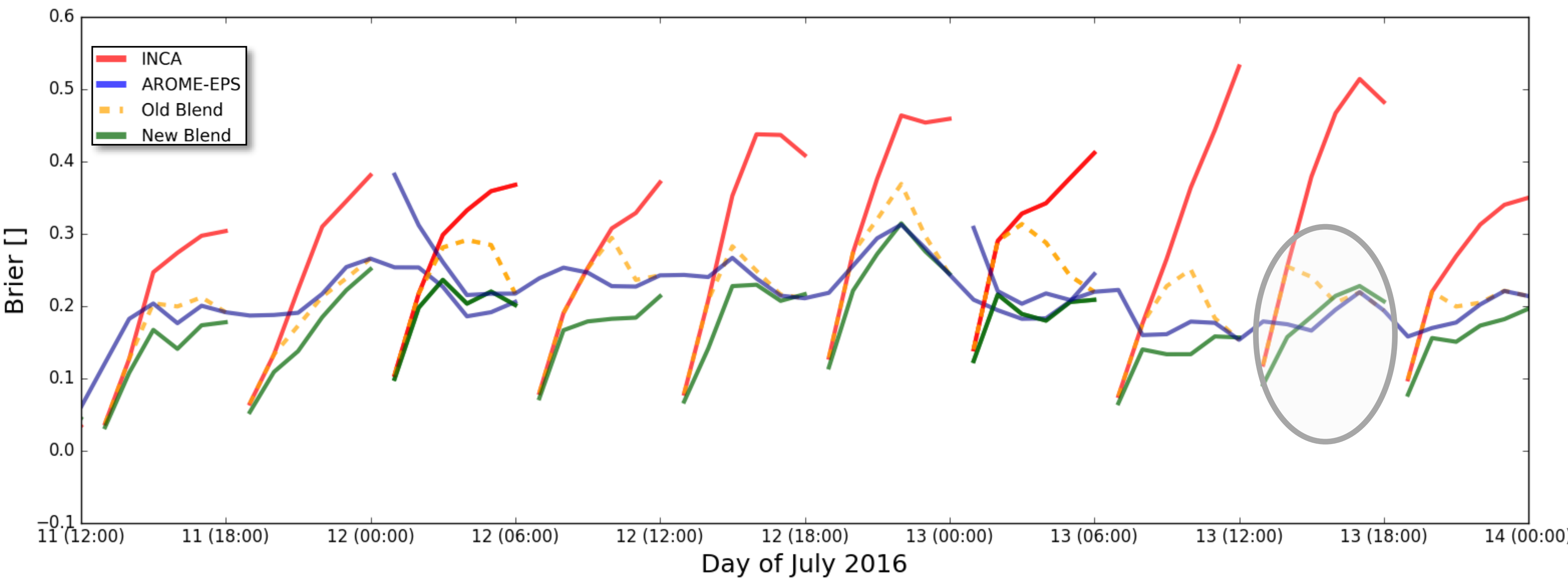
The resampling can be observed during the whole forecasting period showing the reduction of the variance for the intermediate lead times in the previous methodologies



ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Verification and comparison with previous methodologies

The probabilistic verification is carried out for each hour …

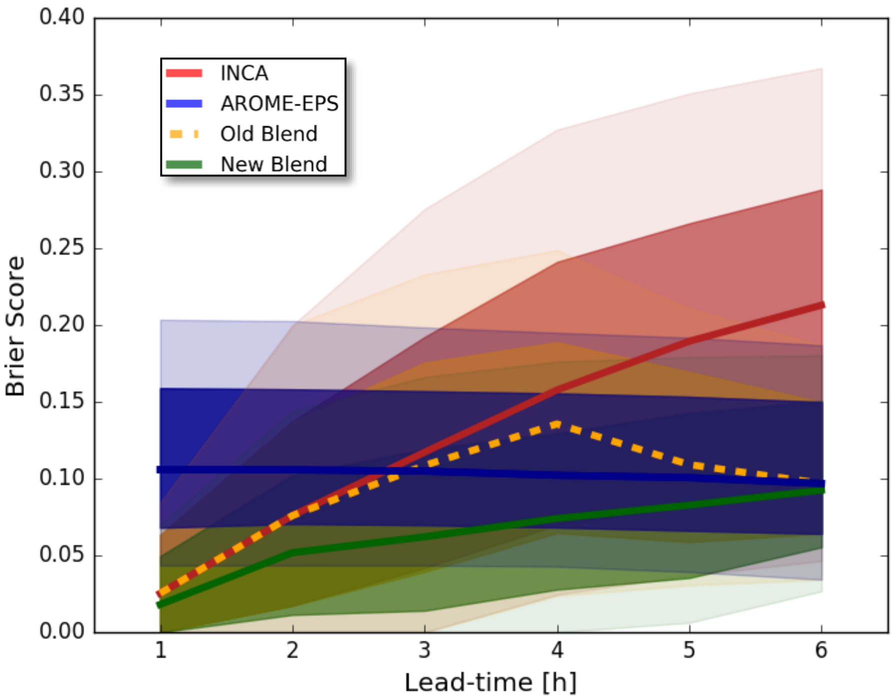


The threshold of 0.1 mm has been selected because the previous methodology for blending shows even worse results for larger rainfall amounts. The introduction of observation improves the performance of AROME-EPS during the different lead-times of the 24 hours forecast horizon. The blending methodology not always improve the forecast (grey circle highlight an example).

ZAMG Zentralanstalt für Meteorologie und Geodynamik

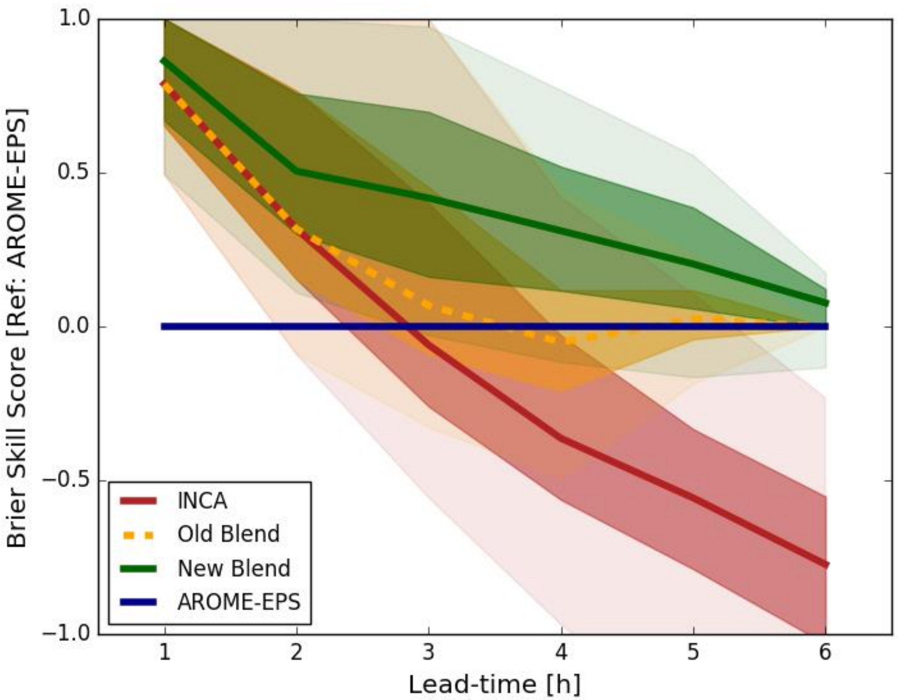
Verification and comparison with previous methodologies

… and then the results are pooled for the whole month of July



The aggregated results of the Brier Score for the whole month shows the benefits of the proposed methodology over the existing methodology. The median is shown as a solid line, whereas the episode to episode variability can be observed with the shaded areas 25-75% and 5%-95%.

To remove the episode to episode variability, the Brier Skill Score using AROME-EPS as a reference has been computed and pooled for the whole month. The results shows the improvement of both blending methodologies and the benefits of the new one even for the first lead-times against INCA.



Summary

- The problems or challenges of the previous methodologies have been presented in order to face them in the proposed methodology.
  - Global weight: The quality of the forecast has a location depedency.
  - Intensity blending: Variance reduction and missing the high values.

- The new methodology tries to solve these problems by combining:
  - The domain is divided into subdomains and weights are computed at each one.
  - A different weight can be given to each ensemble member (Bayesian approach)
  - Resampling of the distributions from both forecasts sources.

- **The results show that**
  - **the Bayesian weight introduce information from NWP from the first hour**
  - **the proposed methodology has a realistic distribution after resampling**
  - **the comparison with the previous methodology shows an improvement in the probability information (Brier Score) present in the new approach**

Thank you!

For details: Aitor.Atencia@zamg.ac.at

ZAMG
Zentralanstalt für Meteorologie und Geodynamik