Comparison of different radar-raingauge precipitation-merging-methods for the Tuscany region

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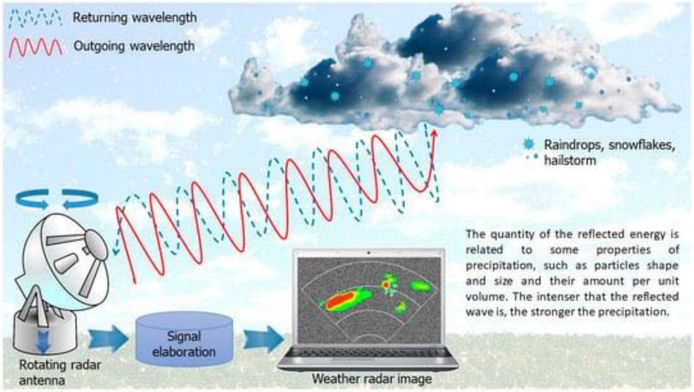
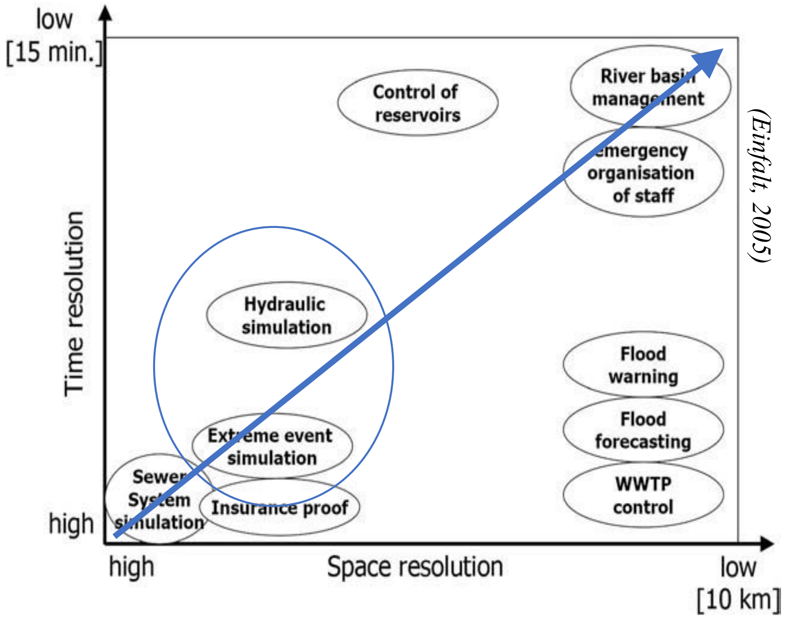
- Precipitation from weather radar:
  a support for hydrological processes modelling



Weather-Radar-Blind-Zone.png—Wikimedia Commons. Available online: https://commons.wikimedia.org/wiki/File:Weather-radar-blind-zone.png

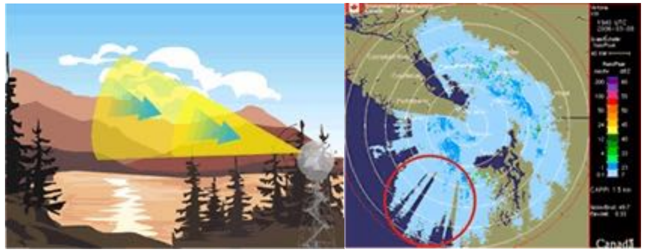


INTRODUCTION

- Due to the sources of error to which this measurement is subject, the quality of the data needs to be improved with corrections based on rainfall observations

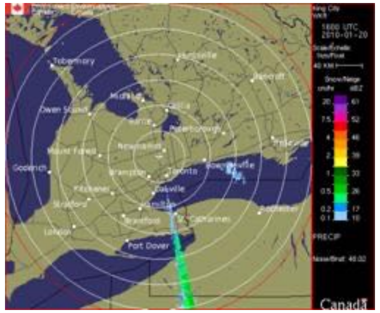
Blocking Beam

Hills and mountains can block a radar beam and leave noticeable gaps in the pattern



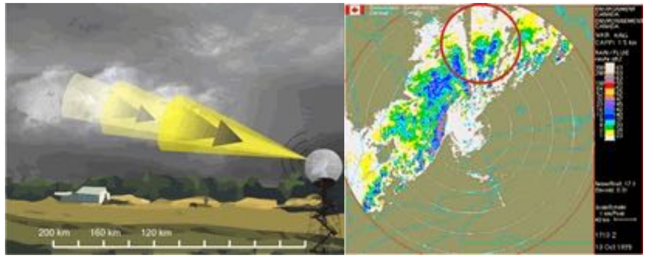
Credit: https://www.canada.ca/en/environment-climate-change/services

Electromagnetic Interference



Beam Attenuation

Storms closest to a radar site reflect or absorb radar energy



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Review of Studies on Intercomparison of Radar-Rain Gauge Merging Methods, Including Categorization by Technique Type, Associated Geographic Scale and Spatial-Temporal Resolution of Application, and Summary of Best Performing Method Identified in Each Study

References	Merging method category: Bias adjustment	Interpolation	Integration	Geographic extent of application and rain gauge (RG) network employed in study	Spatial/temporal resolution	Best performing method(s)
Mazzetti and Todini (2004)	- Brandes - Modified Brandes (Koistinen & Puhakka, 1981)	-	- CoK - BAY	- Numerical experiment - 7-km × 7-km area - 9 pseudo RGs evenly distributed	1 km	BAY
Schuurmans et al. (2007)		- KED	- CCoK	- Three nested areas (225, 10,000, and 82,875 km^2) in the Netherlands - Combined RG data set from two networks: National RG networks (100 km^2/RG) and experimental RG network (7.5 km^2/RG)	2.5 km/1 day	KED
Goudenhoofdt and Delobbe (2009)	- MFB - Brandes - Range-dependent adjustment (RA) - Static kriged (local) bias adjustment + RA	- KED - KRE	-	- Meuse catchment (12,000 km^2) in Walloon region, Belgium - Merging (SPW) network: 160 km^2/RG - Verification (RMI) network: 110 km^2/RG	1.8 km/1 hr	KED
Velasco-Forero et al. (2009)	-	- KED	- CCoK	-A 19 600 km^2 area in Catalonia, Spain - SAIH RG network: 250 km^2/RG	1 km/1 hr	KED
Erdin (2013)	-	- KED - KRE	-	- Whole Switzerland (41,000 km^2) - MeteoSwiss RG network: (546 km^2/RG)	1 km/1 hr	KED
Wang et al. (2013)	- MFB	-	- BAY	- Cranbrook Catchment (9 km^2) in NE London, UK - ICL RG network: 3 km^2/RG	1 km/5 min	BAY
Berndt et al. (2014)	-	- KED - Indicator KED - KRE	-	- Hannover radar site (51,400 km^2), Germany - DWD RG network: 520 km^2/RG	1 km/10 min - 6 hr	KRE
Sideris et al. (2014)	-	- KED - Cokriging with External Drift (CKED)	-	- Whole Switzerland (41,000 km^2) - MeteoSwiss RG network: (546 km^2/RG)	1 km/10 min - 1 hr	CKED
Jewell and Gaussiat (2015)	- Multiquadratic Surface Fitting (MQ)	- KED - KRE	-	- England and Wales (151,000 km^2)\ - UKMO RG network: merging network (212 km^2/RG) and evaluation network (427 km^2/RG)	1 km/15 min - 1 hr	KED
Nanding et al. (2015)	- MFB	- KED - KRE	-	- North England (50,000 km^2) - EA RG network: merging network (300 km2/RG) and evaluation network (940 km^2/RG)	1 km/1 hr	KED
Ochoa-Rodriguez, Wang, Bailey, et al. (2015)	- MFB	-KED	- BAY - Singularity - sensitive Bayesian (sBAY)	- Minworth urban catchment (67 km^2), UK - RG network: 3.5 km^2/RG	1 km/5 min	KED and sBAY
Kumar et al. (2016)	- MFB - Range-dependent adjustment - Brandes - Kriged (local) bias adjustment	- KRE	- BAY - sBAY	- Upper Thames River Basin (3 482 km^2), Canada - RG network: 250 km^2/RG	Not specified	sBAY

Abbreviations: BAY, Bayesian; CCoK, collocated co-kriging; CoK, co-kriging; KED, kriging with external drift; KRE, kriging with radar-based error correction; MFB, mean field bias.

Ochoa-Rodriguez (WRR, 2019)

EU HORIZON 2020 PROJECT:

Soil Erosion under extreme rainfall events: Detecting and modelling using a Radar- Runoff-Nowcasting-System

✓ **Fellowship MSCA – EUROPEAN COMMISSION - Horizon 2020**
Department of Earth Science, University of Florence

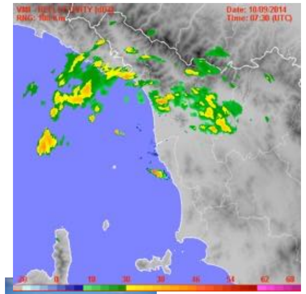
2022-2024
University of Florence

Objective:

Quantifying the effect of heavy rainfall on soil erosion:
- use of radar data and rainfall observations
- Modeling soil erosion and runoff at regional scale

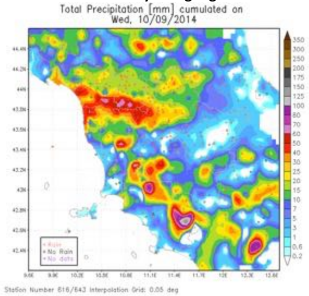
Extreme rainfall

Rainfall by radar



X-band radar

Rainfall by rain gauges



Regional meteo-data network

High Value:

High-definition spatial and temporal scale, dynamic follow-up of the events

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Department of Earth Sciences - University of Florence (IT)
UNESCO Chair on the Prevention and Sustainable Management of Geo-Hydrological Hazards

LaMMA Consorzio (Weather Agency for the Tuscany Region – CNR (National Research Council))

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie, Grant Agreement n. 101033236."

OBJECTIVES

→ **Comparison between three different procedures for combining radar and rainfall data on the regional territory**

→ Sub-hourly and daily data of a selected number of rainfall events

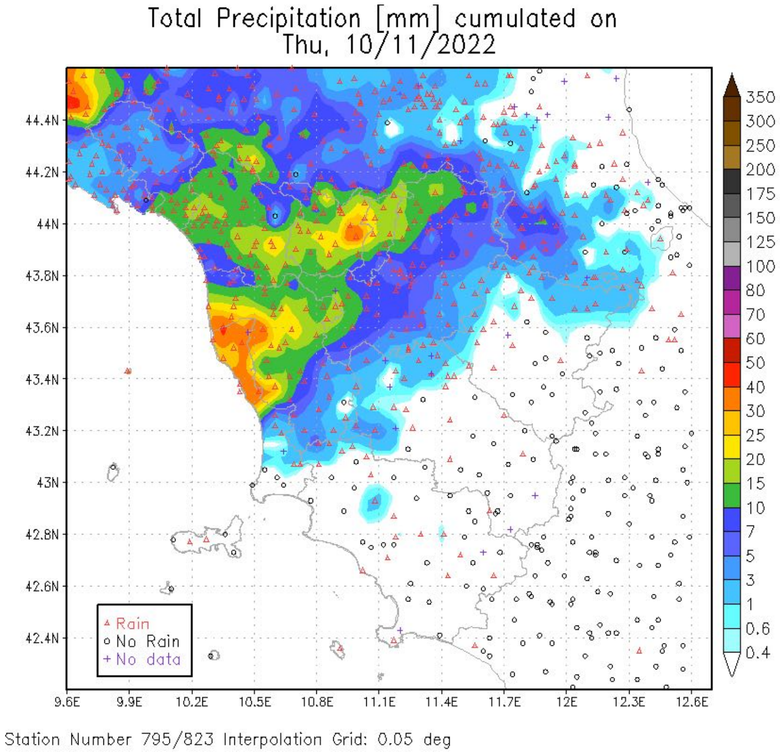
The methods we have adopted include:

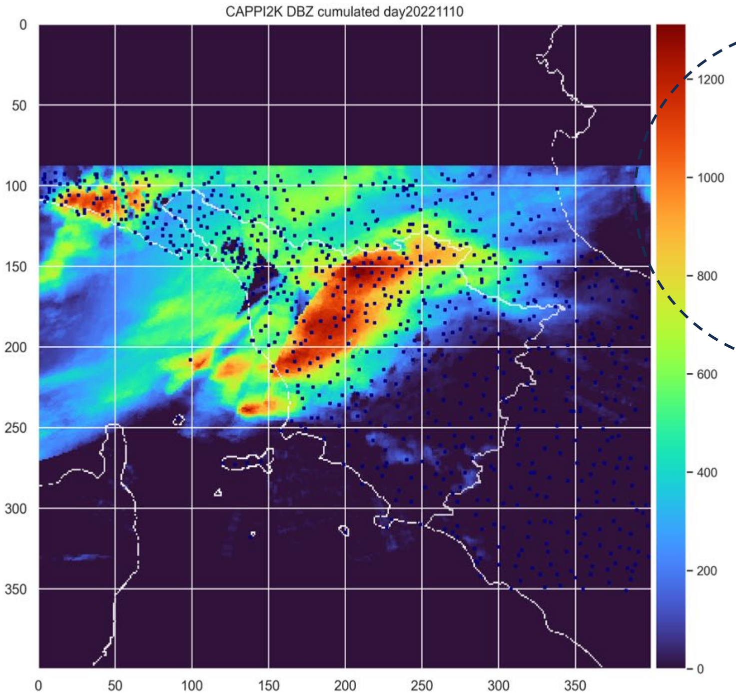
1) Kriging with External Drift (KED) (Wackernagel 1998)
2) Probability-Matching-Method (PMM, Rosenfeld et al., 1994)
3) Adjusted Conditional Merging (Sinclair-Pegram, 2005), mixed Kriging method (ADj-DPCN) made available by the DPCN (National Department of Civil Protection)

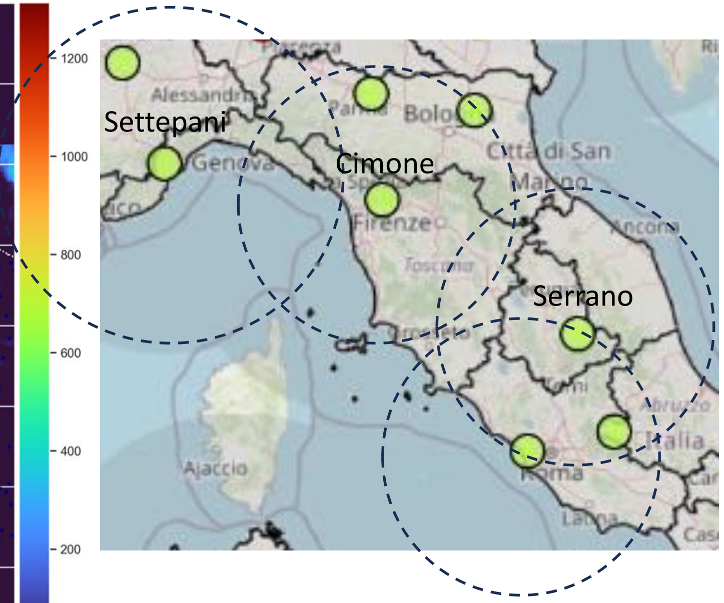
We didn't adopt Marshall-Palmer equation

These methods have been applied on the territory of the Tuscany Region using:

- Precipitation recorded by rain gauges with a time frame of 15' (about 800 gauges)
- CAPPI (DPCN) (Constant Altitude Plan Position Indicator) (dBZ, Reflectivity) reflectivity images at altitudes 2000/3000/5000 m, with 10' sampling time







METHODS

1. Kriging with External Drift (KED)

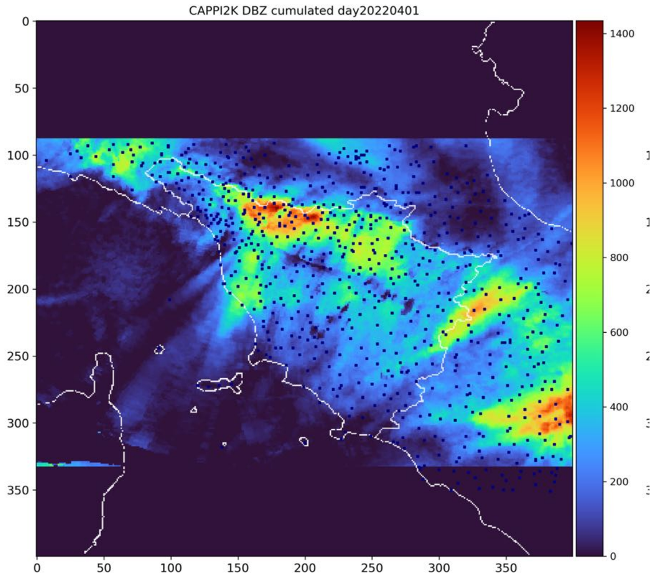
The interpolation is carried out using the data observed by the rain gauges with **kriging in the presence of a spatial trend**, here represented by the radar **reflectivity** (kriging with external drift). In KED, the forecast in the new positions is given by:

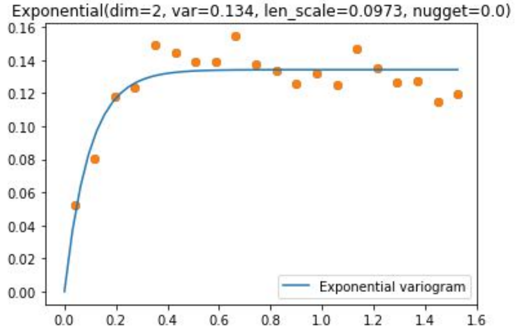
$$\boldsymbol{E}[Z(\boldsymbol{x})] = a_0 + b_1 s(\boldsymbol{x})$$

$$Z_{KED}(S0) = \sum_{i=1}^{n} \boldsymbol{\omega}_i^{KED}(S0).z(Si)$$

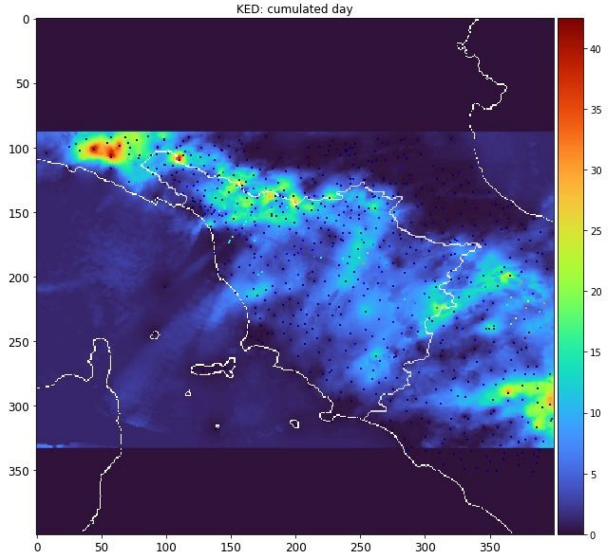
$$Z_{KED}(S0) = \boldsymbol{\delta}_0^{T}.z$$

Where Z is the objective variable, z is the vector of n observations at the original positions, S0 is the new positions, and δ0 is the vector of the weights KED ($\boldsymbol{\omega}_i^{KED}$).





e.g. caculated variogram over a single frame 01.04.22 03h00



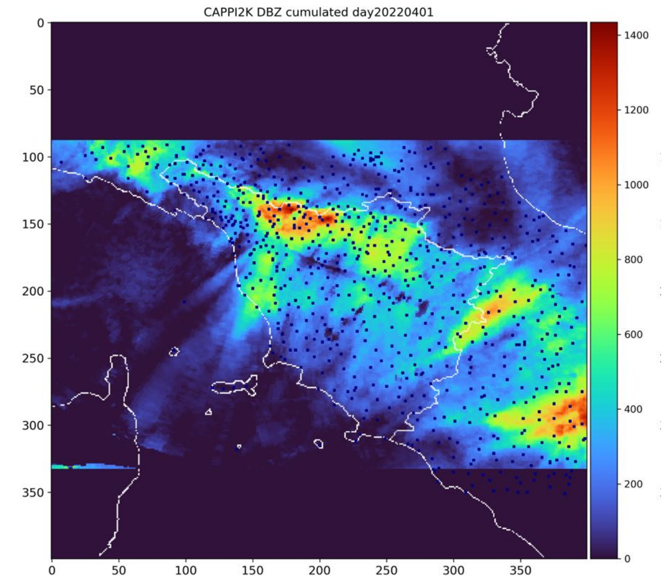
METHODS

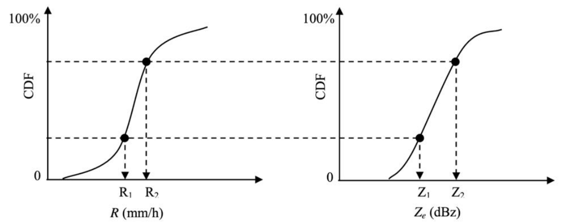
2. Probability Matching Method (PMM)

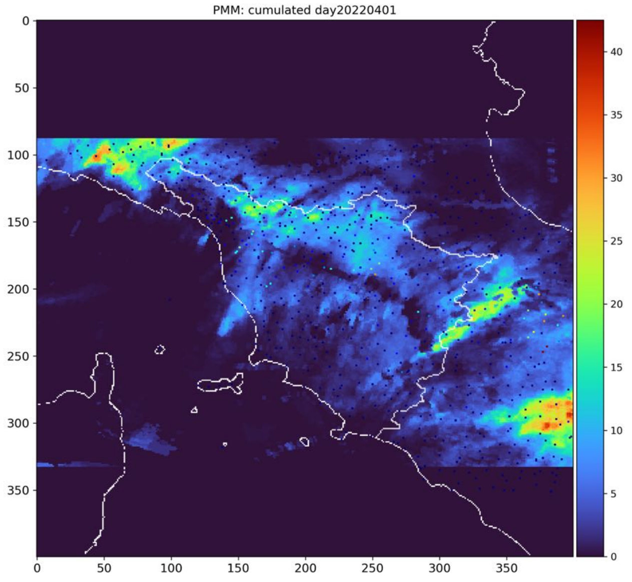
The PMM method (Rosenfeld et al., 1993, Piman et al., 2007) relates non-synchronous radar-CAPPI reflectivity pairs and rainfall intensities measured in rain gauges through a Z-R relationship based on the respective CDFs **(cumulative distribution functions):**

$$\int_{R_i}^{\infty} P(R)dR = \int_{Z_{ei}}^{\infty} P(Z_e)dZ_e$$

where P(R) and P(Z) are the probability density function of the rainfall intensities measured by the rain gauge and the reflectivity values measured by the radar, respectively.







3. Adjusted Conditional Merging (ADj)

The Adjusted Conditional Merging technique (Ehret 2002; Sinclair-Pegram, 2005), based on elaborations available at the DPCN (National Department of Civil Protection), uses an Ordinary Kriging (e.g. Cressie, 1991) for the observed data. The relative differences, detected locally (Marshall-Palmer relation) by the radar reflectivity field (Kriged interpolated on the same spatial grid), are then added to the model.

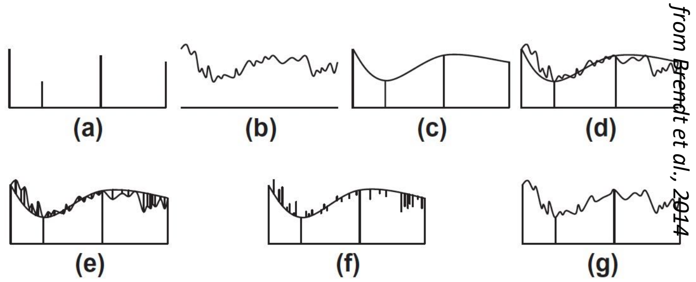
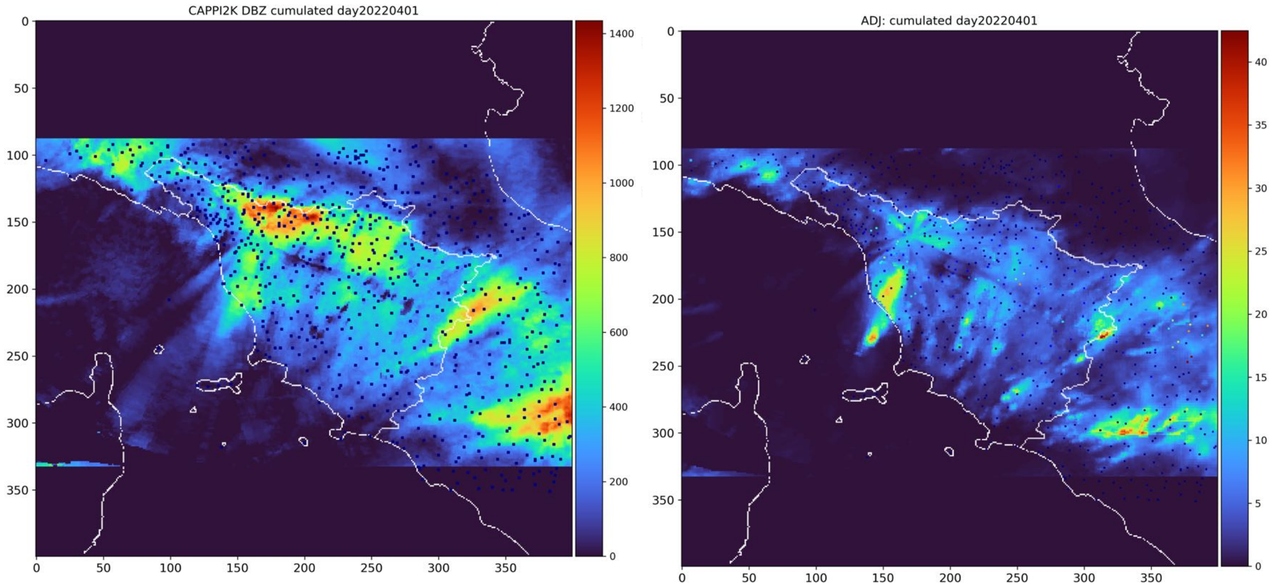


Fig. 1. The conditional merging process. (a) Rain gauge observation at discrete points. (b) Radar observation on a regular grid. (c) Interpolation of rain gauge observations by using ordinary kriging. (d) Interpolation of corresponding radar pixel information. (e) Computation of deviation between observed radar grid interpolated radar grid. (f) Addition of deviation grid to the grid of rain gauge interpolation. (g) Resulting rainfall field (Sinclair and Pegram, 2005).



Rain-fields comparison (i.e., 30 mins step)

1. Validation with **L-O-O** for **PMM** and **KED** methods
2. Analysis of variance and explanatory coefficients based on differences (residuals) between different methods:
   BIAS, **RMSE** (Root Mean Square Error), **MAD** (Median Absolute Deviation), non-parametric **K-S indexing (D, Kolmogorov-Smirnov)**, Cumulative Distribution Function (**CDF**) comparison
3. Visual pattern comparison.

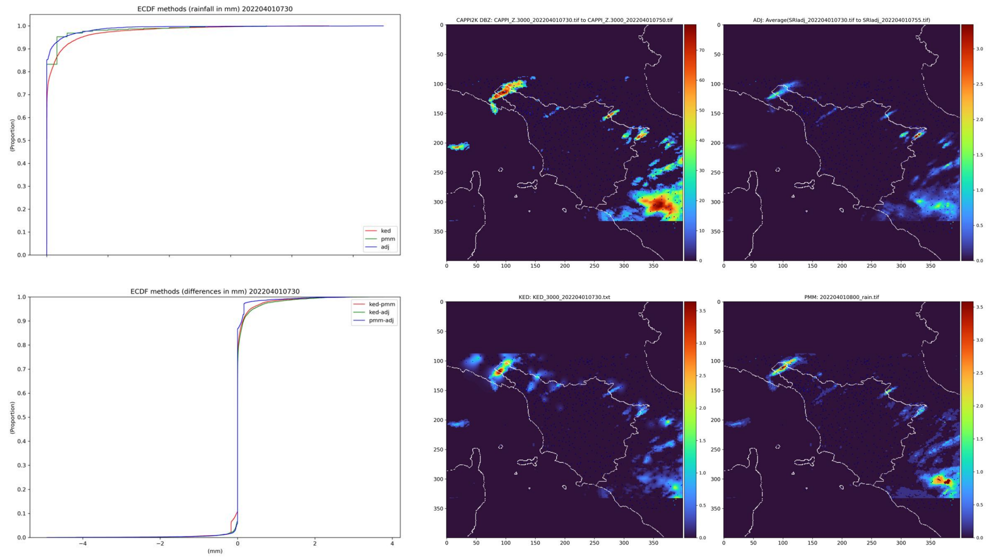
$$\Delta i = \left\{ \begin{array}{c} \text{KED - PMM} \\ \text{KED – Adj} \\ \text{PMM - ADj} \end{array} \right\}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_i^{obs} - y_i^{RE}\right)^2}$$

$$\mathrm{Bias} = \frac{1}{N}\sum_{i=1}^{N}\left(y_i^{obs} - y_i^{RE}\right)$$

$$MAD = median(|x_i - m|)$$

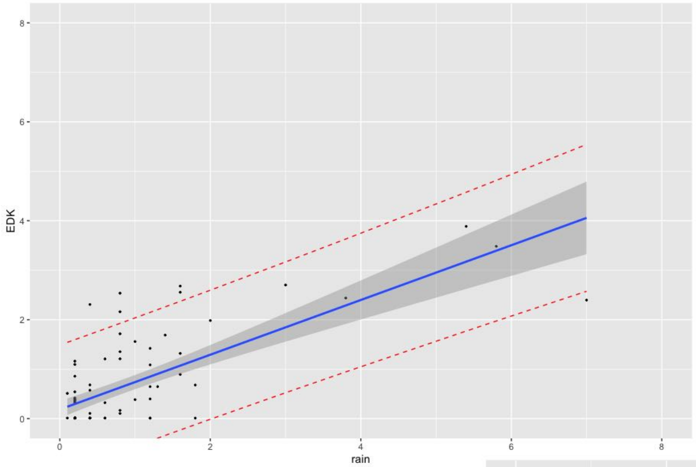
$$D = \max_{1 \le i \le N} \left| F(Y_i) - \frac{i}{N} \right|$$



RESULTS

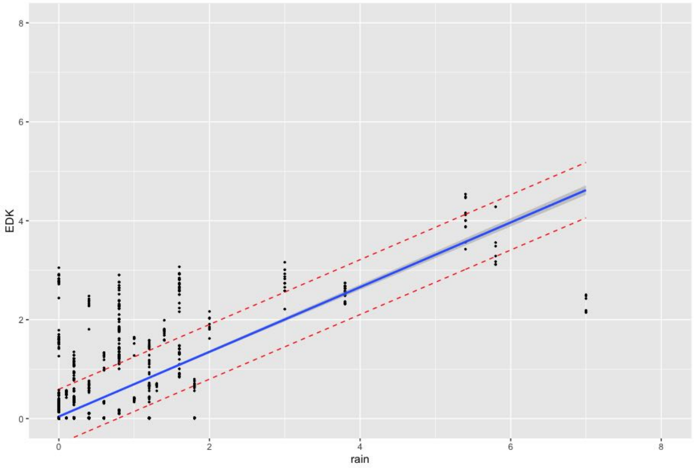
1. Validation with **L-O-O** for **KED** method

1. Kriging with External Drift (KED)

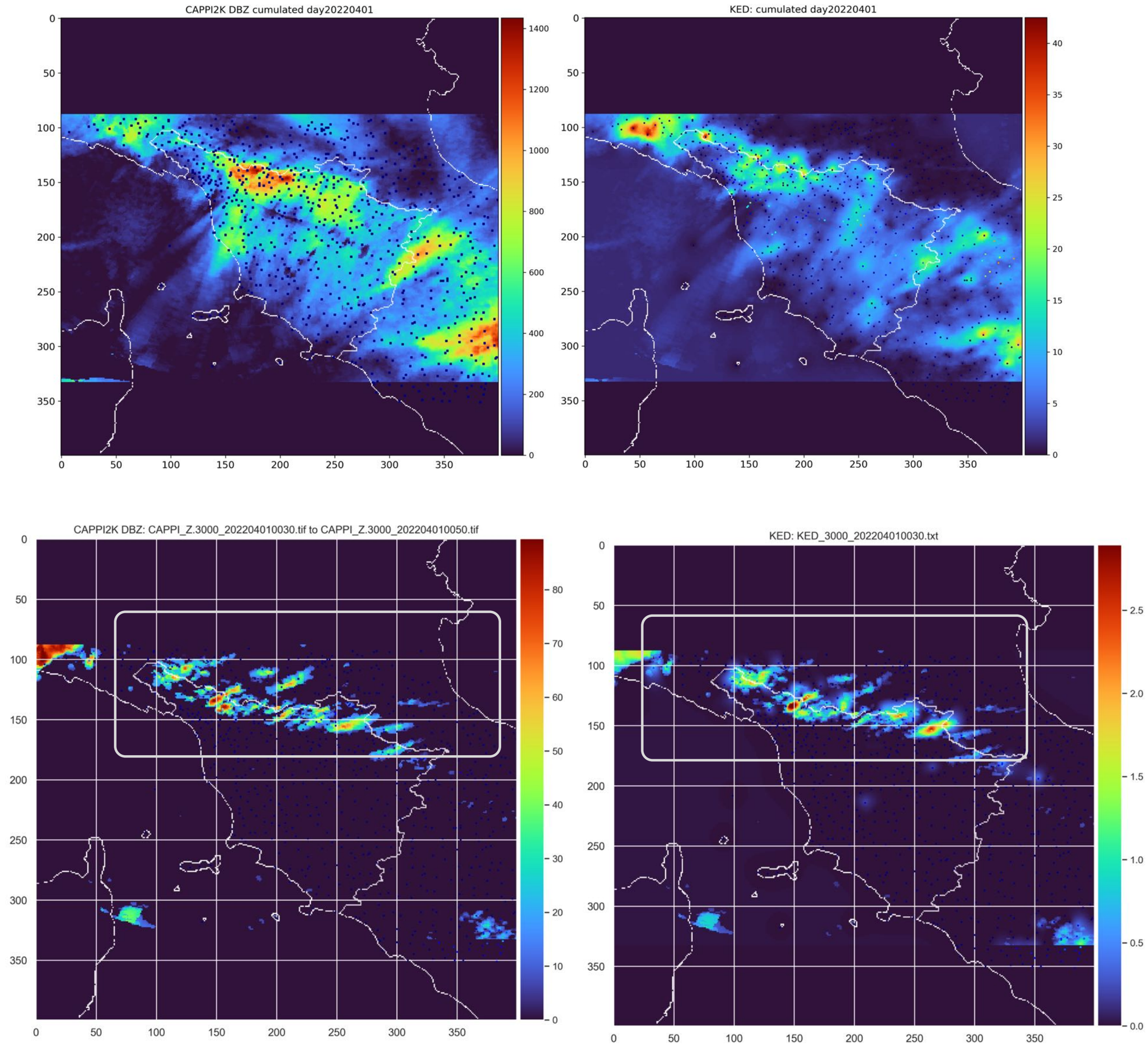


- single leave

- 10% leave



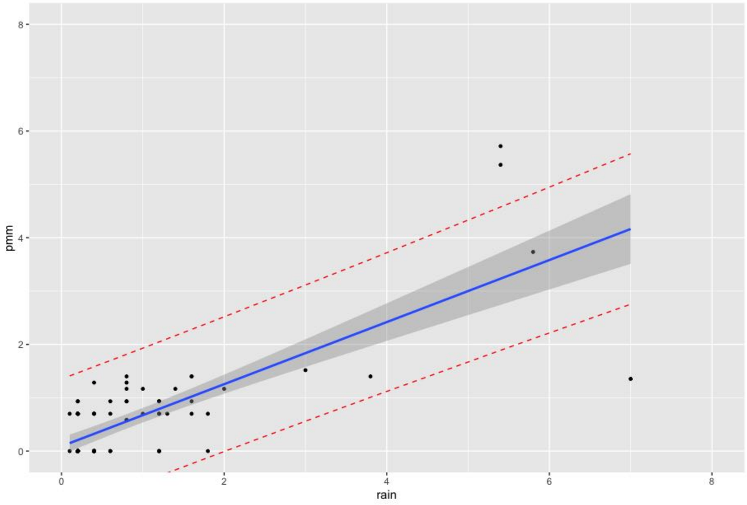
01.04.2022 (medium rainfall) (1)



RESULTS

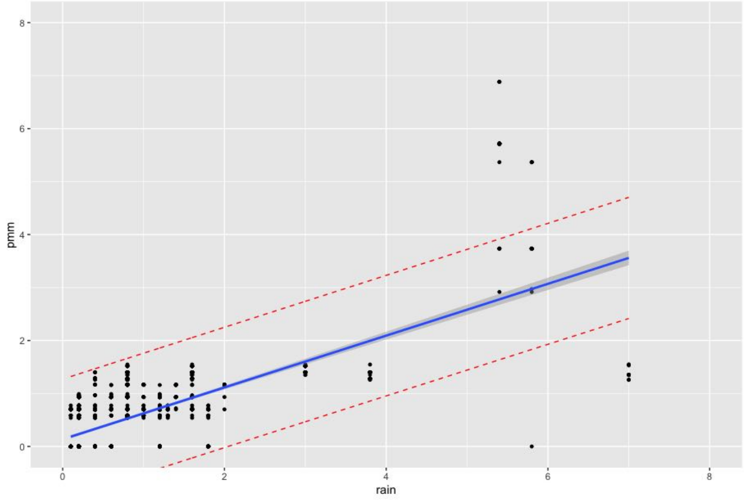
1. Validation with **L-O-O** for **PMM** method

2. Probability Matching Method (PMM)

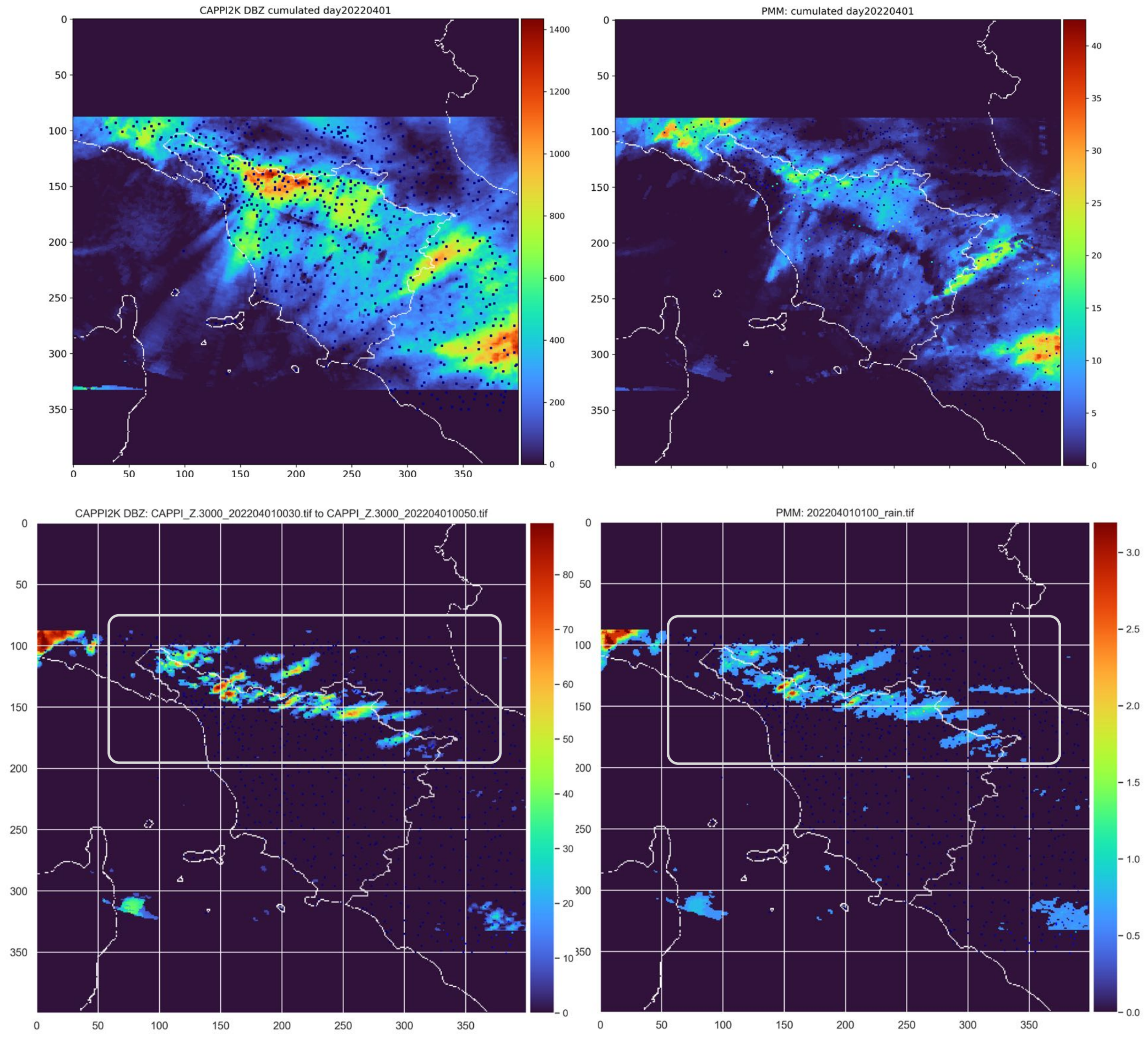


- single leave

- 10% leave



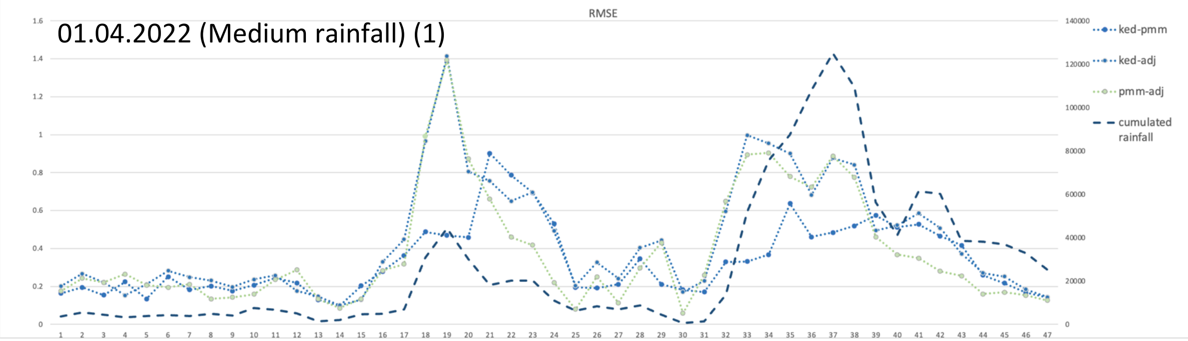
01.04.2022 (medium rainfall event) (1)



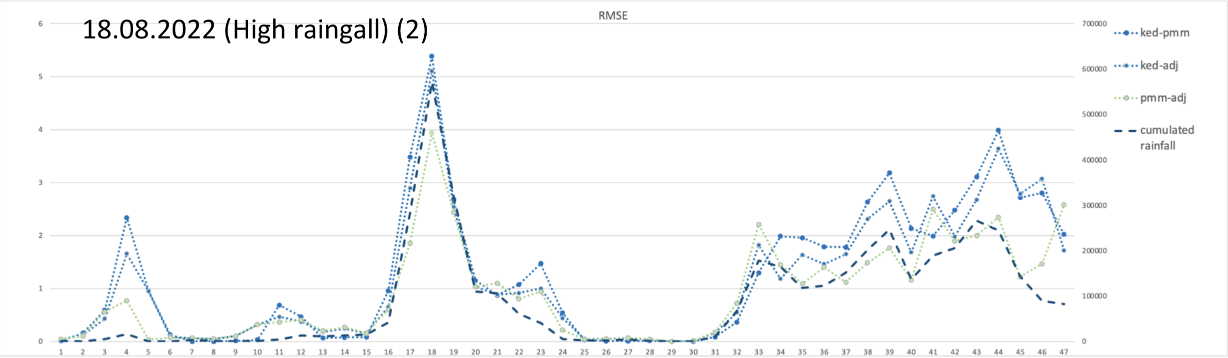
RESULTS

- **3.** RMSE /BIAS time series (30-minute) between KED-PMM, KED-ADj and PMM-ADj

01.04.2022 (Medium rainfall) (1)

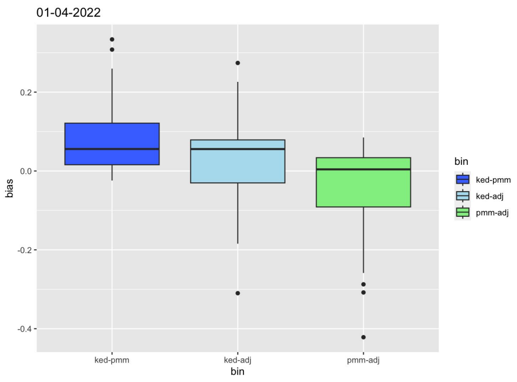


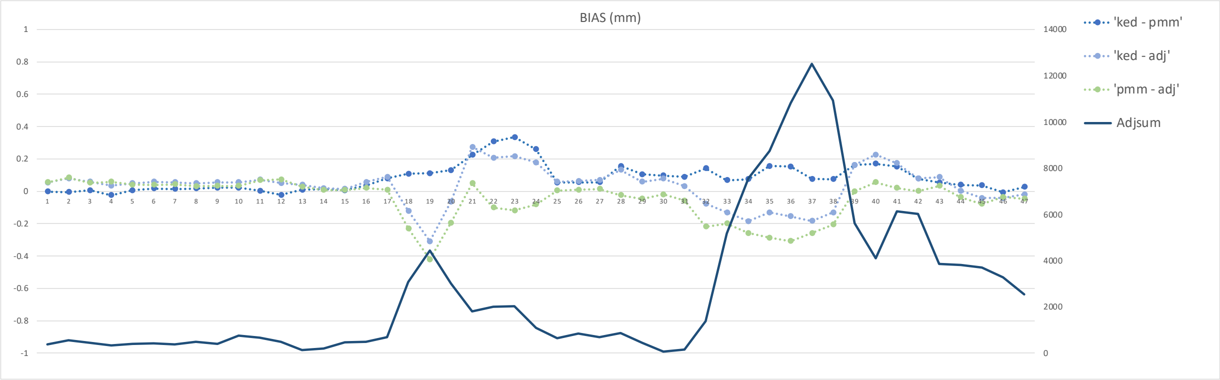
18.08.2022 (High raingall) (2)

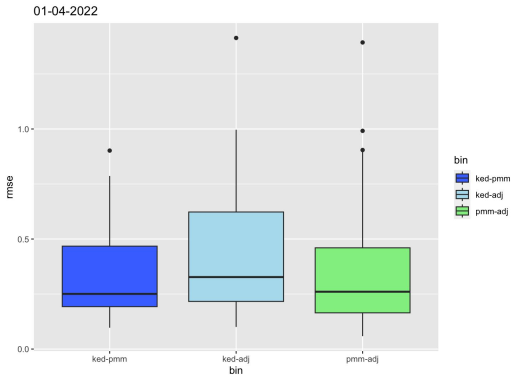


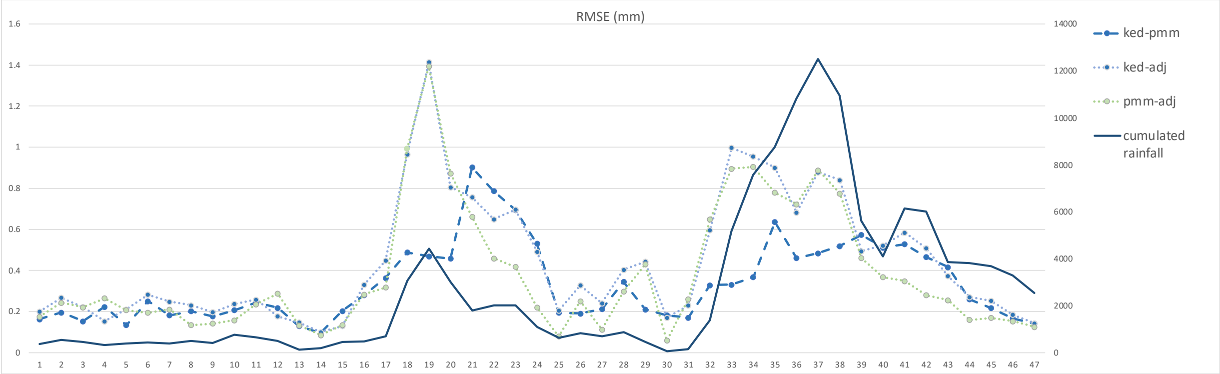
First results on some case studies

01.04.2022 (Medium rainfall) (1)







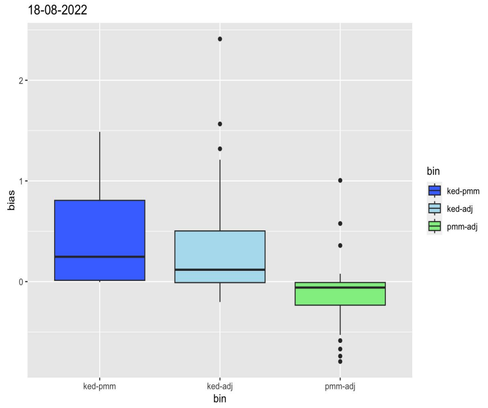


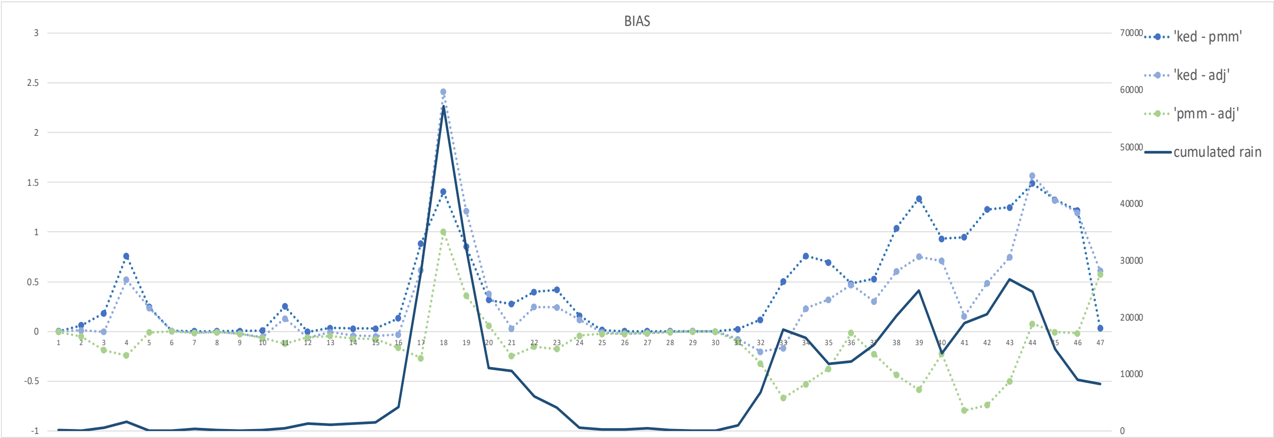
Sub-hourly (30min) series of **BIAS** and **RMSE** (differences in rain between methods) shows:

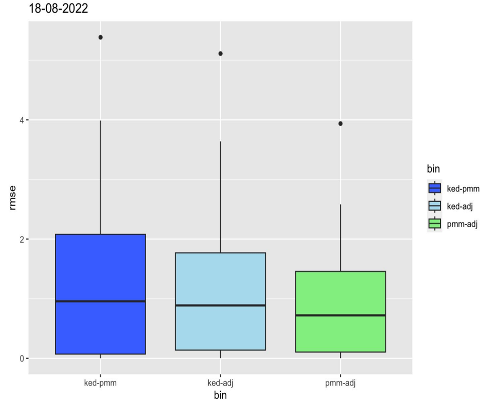
1. Slightly negative BIAS for PMM-Adj (underestimation of rainfall due to cumulative R-Z relationship in PMM i.e. no spatial structure
2. Positive BIAS KED-PMM influence of major KED forcing at the observed points (rain gauges)
3. RMSE rises in intervals with high-rain-intensity (dark blue dash) (i.e. high signa extension)
4. Low RMSE between KED/PMM, High RMSE values between KED – PMM and ADj (systematic?)

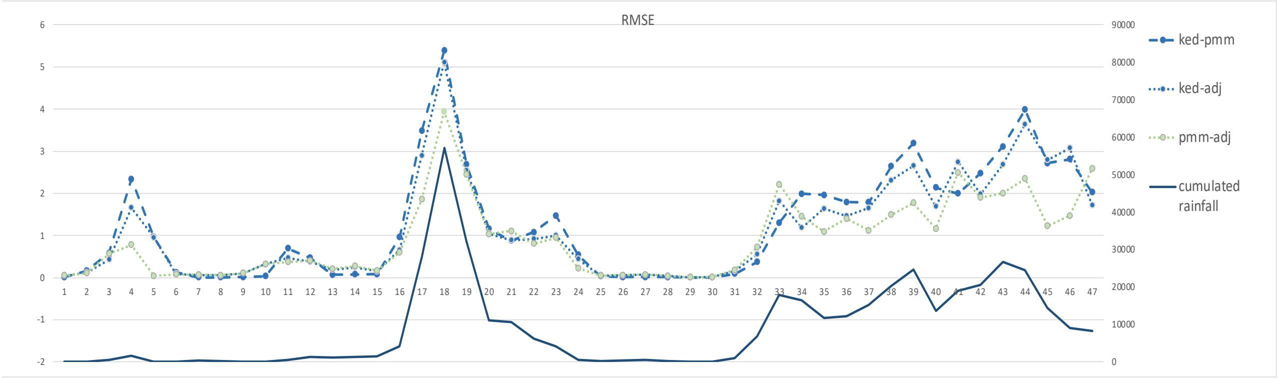
First results on some case studies

18.08.2022 (High rainfall) (2)









Sub-hourly (30min) series of **BIAS** and **RMSE** (differences in rain between methods) shows:

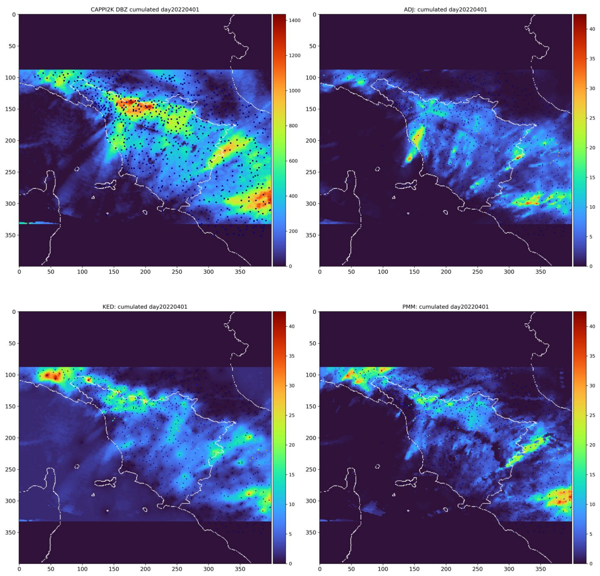
1. Slightly negative BIAS for PMM-Adj (underestimation of rainfall due to cumulative R-Z relationship in PMM)
2. Positive BIAS KED-PMM influence of a forcing at the measuring points (rain gauges)
3. RMSE rises in intervals with high-rain-intensity (dark blue dash) (i.e. high signal extension)
4. Low values of RMSE differences between the two PMM methods – Adj (Strong influence of radar in methods?)

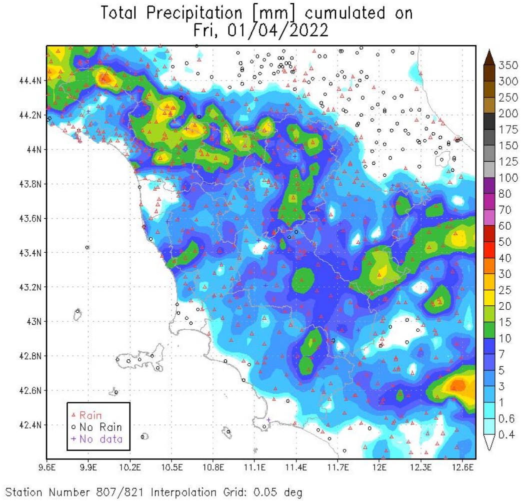
RESULTS

3. Visual comparison radar rainfall VS rain gauge interpolation

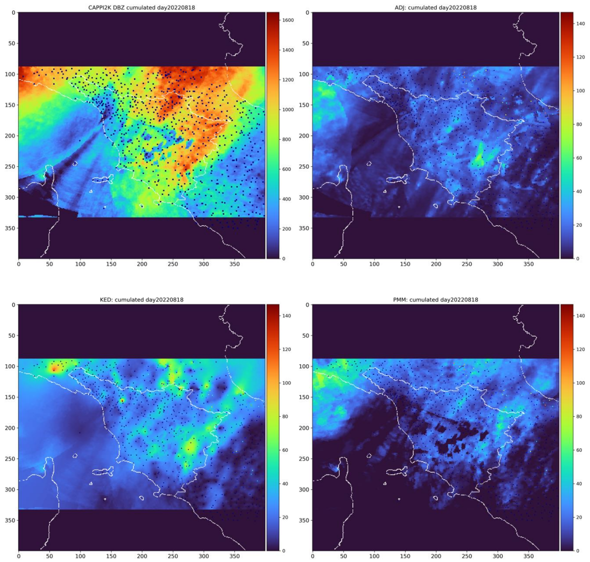
- Case study

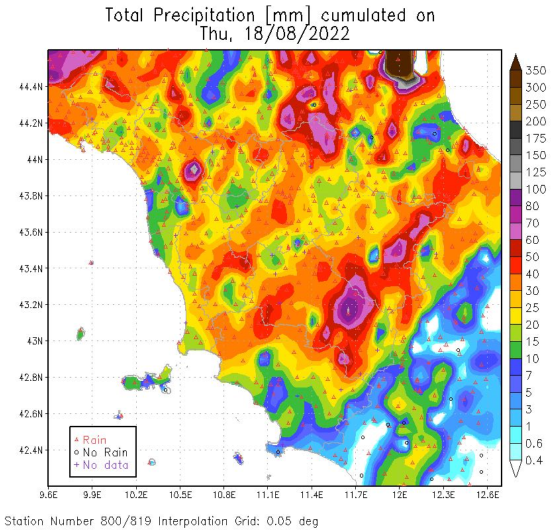
01.04.2022 (medium rainfall) (1)



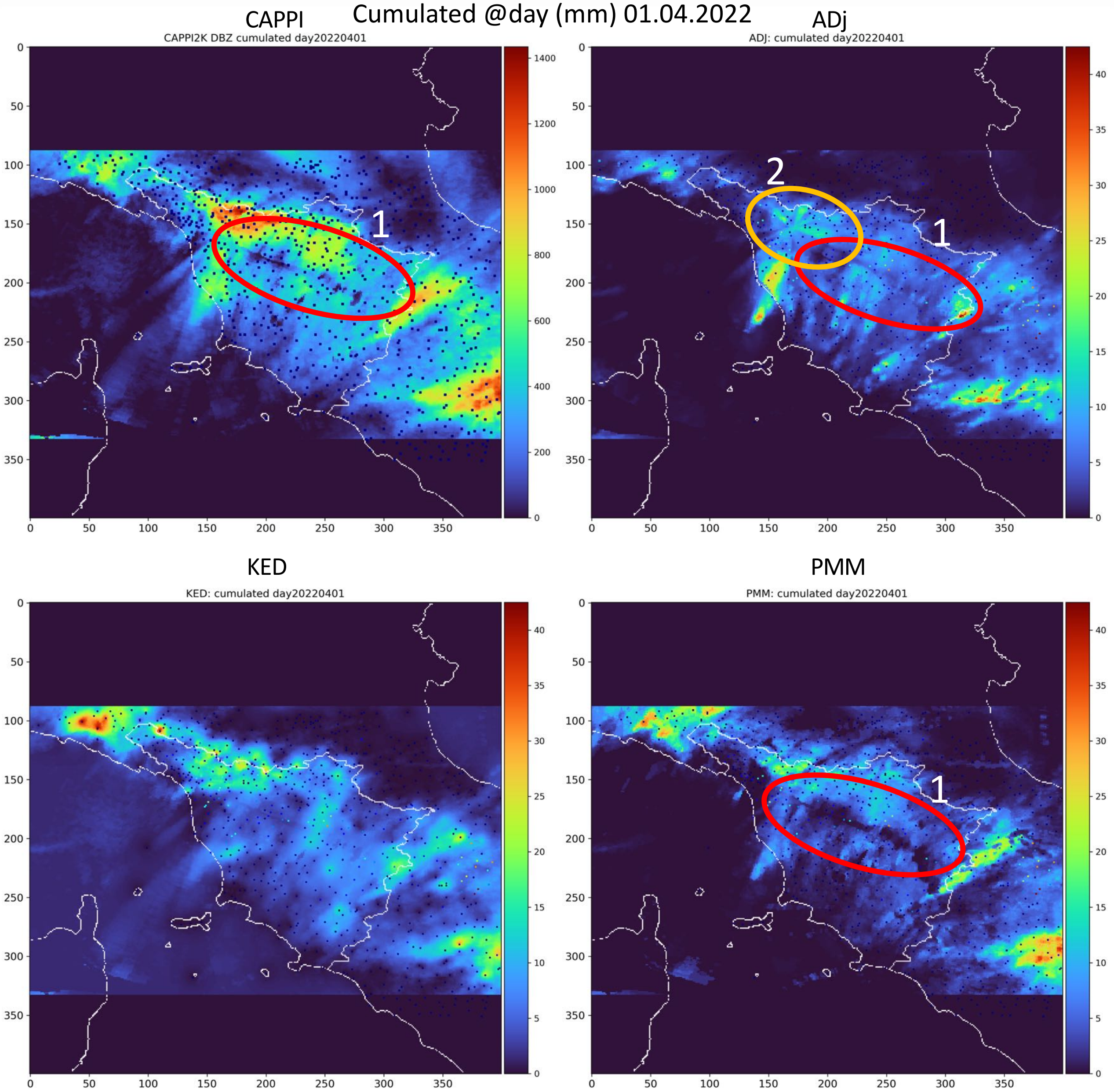


18.08.2022 (high rainfall) (2)





RESULTS

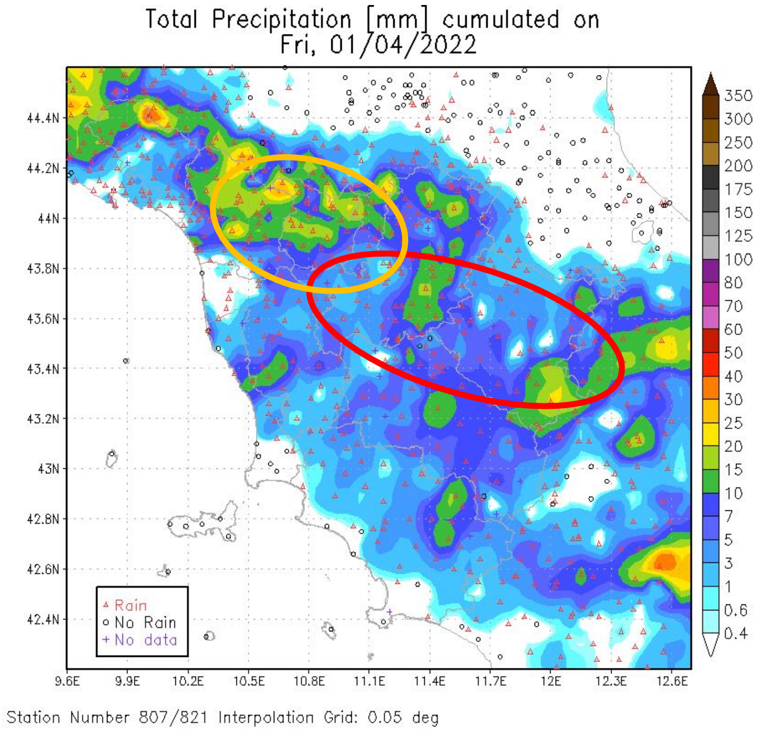


01.04.2022 (Medium rainfall) (1)

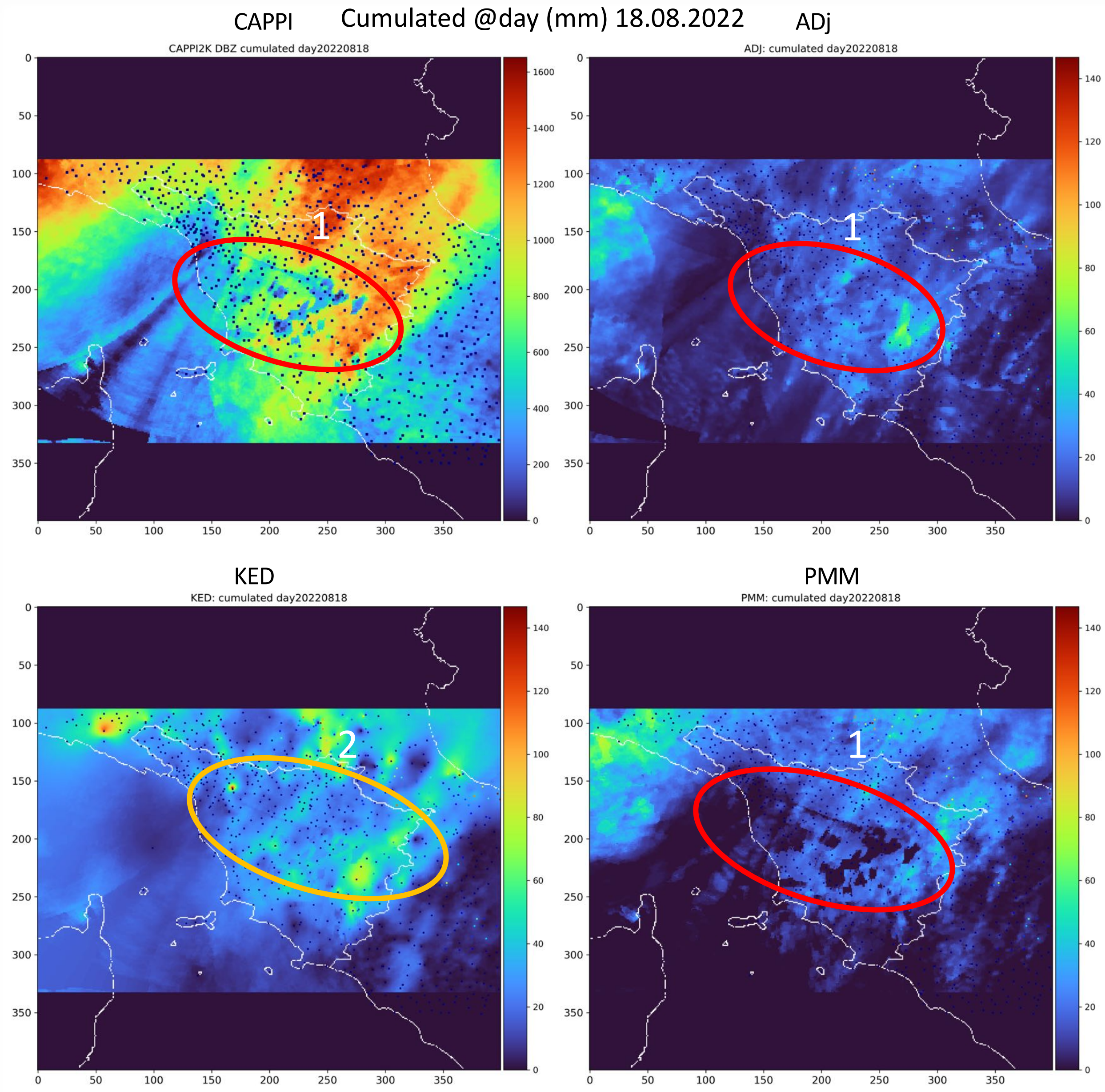
1. Radar Shadows Not Addressed by ADJ and PMM
2. Local anomalous radar data (unwanted radar echo)

→ Matching with SRIAdj performance maps (DPCN)

Interpolated gauges (IDW)



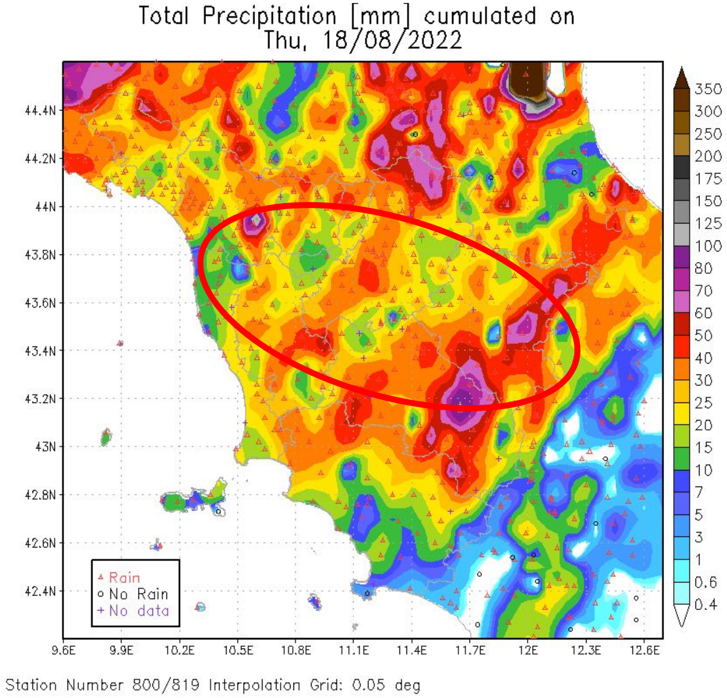
RESULTS



18.08.2022 (high rainfall) (2)

1. Radar shadow areas with Adj and PMM methods
2. More balanced response than KED

Interpolated gauges (IDW)



CONCLUSIONS

- The elaborations produce different spatial reconstructions depending on the procedure applied, closer to radar variability when using PMM and ADj-DPCN, more responding to the raingauge data adopting KED

- The ADj-DPCN methodology seems not show an upper limit effect due to the spare raingauge observations thanks to the contribution of the radar component (i.e., Marshall-Palmer), which is additive in the procedure, a limit instead present in PMM

- In general, there is a different response of the performance depending on the type of rain due to the gauges/radar interaction, it should be considered in the choice of the model for relative advantages and disadvantages

- In validation recursive 10% L-O-O procedure allows to extract 5 and 95% confidence bands for prediction, that, interpolated with the same method can give images of respective bounds.

Comparison of different radar-raingauge precipitation-merging-methods for the Tuscany region

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Thank you

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