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Analysis of daily and hourly precipitation interpolation supplemented with radar background: Insights from case studies

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Abstract— This study concerns the interpolation of daily and hourly precipitation data in regions where small but intense thunderstorms, such as supercells, have occurred, and which, due to their size, often evade conventional meteorological stations. Consequently, relying solely on these measurements for interpolation can introduce errors and yield incomplete representations. To mitigate these issues, this research incorporates radar background information. The study selects days marked by significant precipitation during summer season and employs the Meteorological Interpolation based on Surface Homogenized Data (MISH) method for interpolation, both with and without radar-derived background data. Furthermore, our research also investigates the adaptability of the MISH method in handling radar anomalies, which encompass errors, missing data, and spurious measurements resulting from unintended radar reflections. Additionally, it examines whether the precipitation measured by radar can be used for climatic purposes on its own (without traditional measurements). Statistical techniques are employed to assess the improvement in interpolation quality with the inclusion of radar data and to quantify the relationship between interpolations with and without supplementary radar information. The study underscores the critical role of combining measurement data and radar products in the interpolation framework. This approach has implications for societal and agricultural sectors and offers potential benefits for hazard forecasting accuracy.

Key-words: precipitation measurements, radar background data, interpolation, MISH method, thunderstorm, Hungary

1. Introduction

It is a common phenomenon that small but intense thunderstorms, particularly supercells, with significant precipitation passes among meteorological stations.

As a result of this, there is often no or hardly any recorded evidence within the measurements and observations of the substantial daily precipitation accumulations, that may occur within relatively small geographic areas. Consequently, the interpolation based solely on these measurements will also be subject to errors and will not provide a complete, accurate picture. The mitigation of potential interpolation errors necessitates the incorporation of background information sources. Such sources may encompass data derived from satellite imagery, weather forecasts, or radar measurements. These auxiliary data play a critical role in refining the accuracy of precipitation interpolation processes, thereby enhancing our understanding of spatial and temporal precipitation patterns.

Different countries have developed different interpolation methods. The German approach to spatially interpolating hourly rainfall employs a multivariate geostatistical method known as kriging with external drift (KED). This method incorporates additional information from sources such as topography, daily rainfall data, and weather radar data to enhance the spatial representation of short-time-step rainfall. Through extensive investigations during various flood events, it was found that the type of semivariogram had a minimal impact on interpolation performance. Weather radar data proved particularly valuable for convective summer events, while daily rainfall data sufficed for stratiform winter events. This method also employs a multi-step interpolation procedure to improve the representation of fractional precipitation coverage, ultimately enabling more accurate hydrological modeling of floods (*Verworn* and *Haberlandt,* 2011). The Austrian approach to spatial precipitation interpolation involves two steps: deriving monthly climatological mean precipitation fields using kriging with external drift and topographic predictors, followed by calculating daily relative anomalies and multiplying them with the respective background fields, ensuring consistency with the climatology and minimizing systematic errors (*Hiebl* and *Frei,* 2023). The Ensemble-based Statistical Interpolation with Gaussian Anamorphosis (EnSI-GAP) is a spatial analysis method for hourly precipitation data which is used in Norway. It combines ensemble forecasts, radar-derived estimates, in situ observations, and citizen observations to synthesize precipitation information. EnSI-GAP assumes locally stationary and transformed Gaussian random fields, with gamma distribution as the marginal distribution at each point. It is designed to run in parallel, considering each hour independently, and can adapt to situations where the background ensemble does not represent the truth accurately, making it valuable for filling gaps in precipitation data and providing accurate estimates, particularly in observation-sparse regions (*Lussana et al*., 2021).

In our research to process the daily precipitation datasets, we employed the MISH (Meteorological Interpolation based on Surface Homogenized Data) method, as detailed in the work of *Szentimrey* and *Bihari* (2007, 2014). The interpolation procedure was executed for the entire geographic expanse of the country, and it was conducted both with and without the incorporation of radar-derived background information.

We also made an effort to investigate how the MISH interpolation method handles radar-related anomalies, including errors, absent data, and spurious measurements arising from unintended radar signal reflections or echoes from non-target sources. To explore this matter, we conducted a comprehensive selection of days characterized by distinct scenarios: firstly, instances where radar measurements failed to detect precipitation over a substantial portion of the country, despite traditional precipitation measuring stations registering precipitation events. Secondly, we identified days featuring the occurrence of *second-trip echo radar errors*. Subsequently, we examined these datasets, which encompassed both measurements and radar-derived products, with the outcomes of the interpolation process. This comparative analysis underscores the critical importance of combining measurement data and radar products in the interpolation framework.

Finally, we sought the answer to whether radar-measured precipitation, beyond its role in the interpolation of daily and hourly data, could serve climatological purposes, specifically for conducting long-term analyses, such as those spanning the period from 2015 to 2022.

Our analytical approach centered on the utilization of statistical techniques to elucidate the extent to which the inclusion of radar-derived data as background information enhanced the quality of the interpolation. Furthermore, our investigation aimed to quantify the robustness of the relationship existing between the interpolations conducted with the integration of radar-derived background information and those performed without such supplementary data.

The occurrence of intense thunderstorm cells, which are frequently associated with substantial precipitation, can result in flash flooding, thereby engendering myriad adverse repercussions in societal and agricultural domains. Consequently, the judicious integration of radar-derived background information into the interpolation process assumes paramount importance. This approach offers substantial advantages within the realms of both society and agriculture, and it holds potential utility in enhancing the accuracy of hazard forecasting.

2. Data and methods

2.1. Precipitation measurements in Hungary

In our research, we harnessed two pivotal sources of meteorological data in Hungary: precipitation measurements and radar-derived data. The former Hungarian Meteorological Service (OMSZ), now HungaroMet operates a comprehensive network of 276 meteorological stations that continuously gather real-time data (shown in *Fig. 1* with dark blue dots). Additionally, HungaroMet collects daily precipitation data from 500 stations on a monthly basis (shown in

Fig. 1 with red dots). This extensive network, including 500 stations, was used to create a rich database interpolated to the entire country using a homogenization process (*Szentes et al.,* 2023) with the software MASH (*Szentimrey*, 1999; 2008; 2017; 2023). This means that for studies conducted before 2023, we created interpolated data using the homogenized daily records from the 500 stations. However, for our daily and hourly rainfall analyses in 2023, we only used data from 276 stations.

Furthermore, HungaroMet maintains a network of five radar stations across Hungary, located in Budapest, Pogányvár, Szentes, Napkor, and Hármashegy, as indicated by the yellow dots in *Fig. 1*. These radar stations cover the entire geographical expanse of the country within a 240-kilometer radius, employing ten different elevation angles in five-minute measurement cycles. For our investigation, we relied on daily and hourly radar-derived precipitation data.

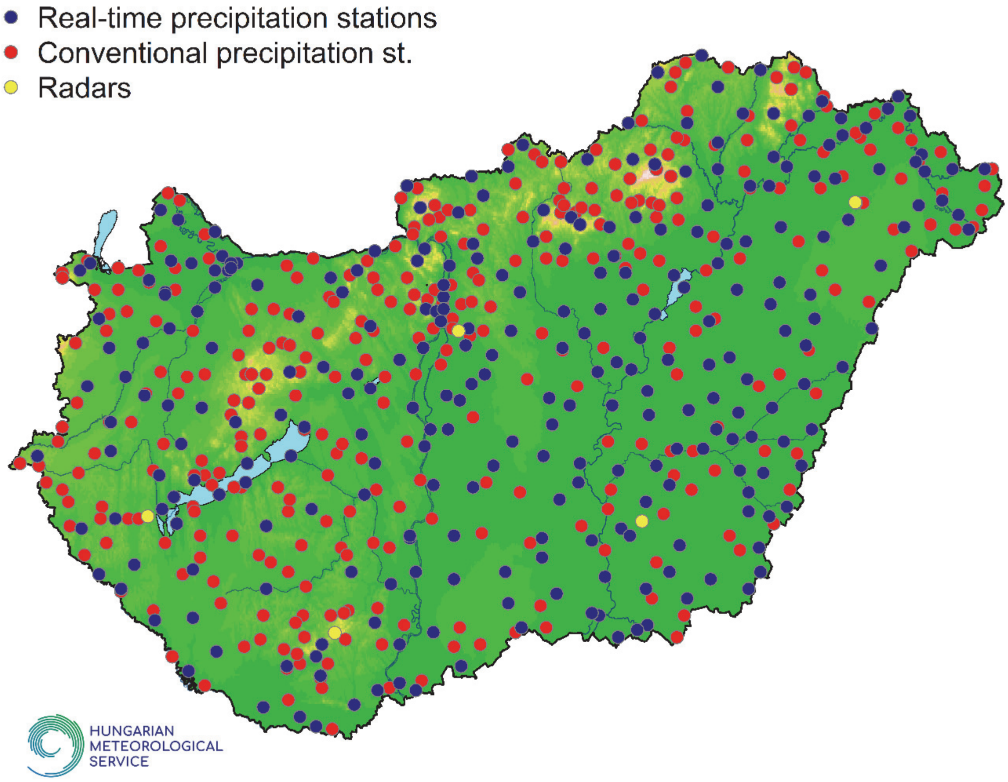

Fig. 1. Radar network (yellow), real-time (dark blue), and traditional precipitation measurement stations (red) of the HungaroMet.

During the process of day selection, our foremost consideration was to opt for days falling within the summer semester, given that this period is characterized by the occurrence of localized, intense rainfall-producing showers and thunderstorms. The three days chosen for this purpose are

- June 5, 2021,

- July 16, 2021,
- July 13, 2023.

In the case of the latter date, we conducted not only daily but hourly precipitation interpolation.

2.2. *Methods and software*

2.2.1. *SOFTWARE MISHv1.03*

The software version MISHv1.03 consists of two units that are the modeling and the interpolation systems. The interpolation system can be operated on the results of the modeling system. We summarize briefly the most important facts about these two units of the developed software (*Szentimrey* and *Bihari*, 2014).

Modeling subsystem for climate statistical (local and stochastic) parameters:

- Based on long homogenized data series and supplementary deterministic model variables. The model variables may be such as height, topography, distance from the sea, etc..
- Benchmark study, cross-validation test for interpolation error or representativity.
- High resolution grid (e.g., 0.5’×0.5’),

Interpolation subsystem:

- Additive (e.g. temperature) or multiplicative (e.g. precipitation) model and interpolation formula can be used depending on the climate elements.
- Daily, monthly, seasonal values and many years’ means can be interpolated.
- Capability for application of supplementary background information (stochastic variables) e.g., satellite, radar, forecast data.
- Data series completion (missing value interpolation for daily or monthly station data).
- Interpolation, gridding of monthly or daily station data series for given predictand locations.

The MISH-MASH software can be downloaded from:
http://www.met.hu/en/omsz/rendezvenyek/homogenizationand_interpolation/software/

2.2.2. *Multiplicative interpolation (precipitation)*
Mathematical model

Let us assume that
$Z(\boldsymbol{s}_0, t)$ is the predictand,
$Z(\boldsymbol{s}_i, t) \quad (i = 1, \ldots, M)$ are predictors (where $\boldsymbol{s}$ represents space and t represents time)

The linear or additive model is appropriate in case of normal probability distribution. However, in case of a quasi lognormal distribution (e.g., precipitation sum), we deduced a mixed additive multiplicative formula which is used also in our MISH system, and it can be written in the following form,

$$\hat{Z}(\boldsymbol{s}_0) = \vartheta \cdot \left(\prod_{q_i \cdot Z(\boldsymbol{s}_i) \geq \vartheta} \left(\frac{q_i \cdot Z(\boldsymbol{s}_i)}{\vartheta}\right)^{\lambda_i}\right) \cdot \left(\sum_{q_i \cdot Z(\boldsymbol{s}_i) \geq \vartheta} \lambda_i + \sum_{q_i \cdot Z(\boldsymbol{s}_i) < \vartheta} \lambda_i \cdot \left(\frac{q_i \cdot Z(\boldsymbol{s}_i)}{\vartheta}\right)\right) \quad (1)$$

where the interpolation parameters are $\vartheta > 0$, $q_i > 0, \lambda_i \geq 0$ $(i = 1, \ldots, M)$, and $\sum_{i=1}^{M} \lambda_i = 1$.

The interpolation parameters are related to the median: $\vartheta = m(\boldsymbol{s}_0), q_i = \frac{m(\boldsymbol{s}_0)}{m(\boldsymbol{s}_i)}$, where $m(\mathbf{s}_i)$ $(i = 0, \ldots, M)$ are the spatial median values.

The optimum interpolation parameters are uniquely determined by the climate statistical parameters (local parameters, stochastic connections). Modeling of climate statistical parameters can be based on long data series and model variables.

Since the parameters q and ϑ are defined with the median, it is clear that the multiplication part of the interpolation formula itself dominates for precipitation amounts reaching the median, so the first part of the formula holds. If little or no precipitation is measured, the interpolation formula is limited to the additive part. Thus, the good properties of the quasi-multiplicative formula itself give us the ability to interpolate with the same modeled climate statistical parameters for each time of day or hour as for the daily values.

2.2.3. Interpolation with background information in MISH

The background information, such as forecast, satellite, and radar data can efficiently decrease interpolation errors. Let us assume that
$Z(\boldsymbol{s}_0, t)$: predictand,
$\hat{\boldsymbol{Z}}(\boldsymbol{s}_0, \boldsymbol{t})$: interpolated predictand without background information.
Moreover, background information on a dense grid is also given:
$\boldsymbol{B} = \{B(\boldsymbol{s}, t) \mid \boldsymbol{s} \in D\}$, where D is the space domain.
$\hat{Z}_B(\boldsymbol{s}_0, t)$: interpolated predictand with background information.

The linear regression model is given by:

$$\frac{Z(\boldsymbol{s},t)}{E(\boldsymbol{s})} = \beta_0(t) + \beta_1(t) \cdot \frac{B(\boldsymbol{s},t)}{E(\boldsymbol{s})} + \varepsilon(\boldsymbol{s}, t) \quad (2)$$

where $E(\boldsymbol{s})$ represents spatial trend and $\varepsilon(\boldsymbol{s}, t)$ is the noise term.

Estimation of parameters $\beta_0(t)$ and $\beta_1(t)$, as well as the correlation $R(t) = \operatorname{corr}\left(\frac{Z(s,t)}{E(\boldsymbol{s})}, \frac{B(s,t)}{E(\boldsymbol{s})}\right)$, we rely on $Z(\boldsymbol{s}_i, t)$ and $B(\boldsymbol{s}_i, t)$ for $(i = 1, \ldots, M)$, along with a modeled spatial trend.

$$\hat{Z}_B(\boldsymbol{s}_0, t) = \hat{Z}(\boldsymbol{s}_0, t) + \beta_1(t) \cdot \left(B(\boldsymbol{s}_0, t) - \hat{B}(\boldsymbol{s}_0, t)\right) \tag{3}$$

where

$\hat{Z}(\boldsymbol{s}_0, t) = F_M(Z(\boldsymbol{s}_1, t), \ldots, Z(\boldsymbol{s}_M, t); q_1, .., q_M, \lambda_1, .., \lambda_M)$,

i.e., the interpolation without background information,

$\hat{B}(\boldsymbol{s}_0, t) = F_M(B(\boldsymbol{s}_1, t), \ldots, B(\boldsymbol{s}_M, t); q_1, .., q_M, \lambda_1, .., \lambda_M)$

i.e., the same interpolation formula for the background information, and $\beta_1(t)$ is the estimated regression coefficient.

Remark:

– If $R(t) = 0$ then $\hat{Z}_B(\boldsymbol{s}_0, t) = \hat{Z}(\boldsymbol{s}_0, t)$.

That is, the background information is so bad that we do not use it at all.

– If $B(\boldsymbol{s}_i, t) = Z(\boldsymbol{s}_i, t)$ $(i = 1, \ldots, M)$ then $R(t) = 1$ and $\hat{Z}_B(\boldsymbol{s}_0, t) = B(\boldsymbol{s}_0, t)$.

That is, the measurements are the same as the radar information, in which case the radar information will also be the value of $\hat{Z}_B(\boldsymbol{s}_0, t)$ at the points where no measurements are taken.

3. Results

3.1. June 5, 2021

On June 5, 2021, a precipitation zone traversed the country, accompanied by showers, thunderstorms, and sporadic hail in some areas. The highest daily precipitation amounts were observed in the southwestern region of the country, with measurements of 19.3 and 19.8 mm recorded at Nagykanizsa and Letenye stations. At Becsehely station, 39 mm of precipitation was reported. The result of interpolation without background information is shown in *Fig. 2*, which displays a maximum precipitation amount of 35.3 mm in the southwestern region, while lesser amounts of precipitation occurred in the north and northeastern parts of the country.

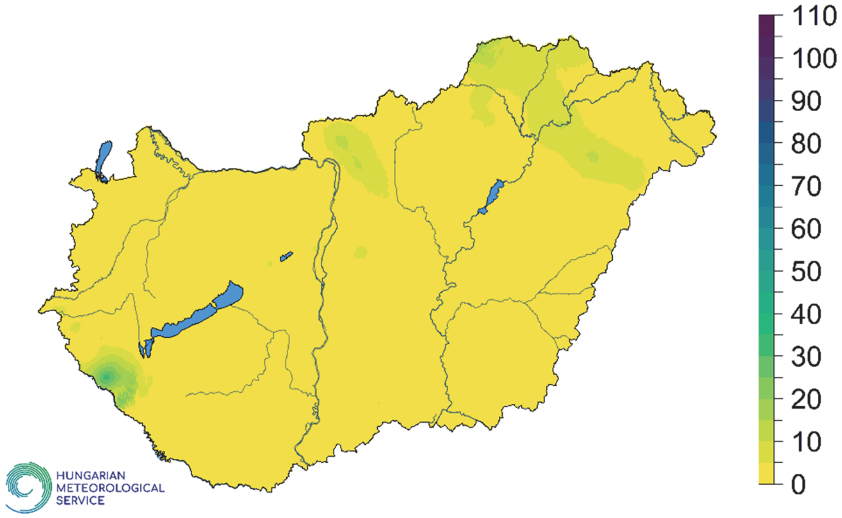

Fig. 2. Interpolation of 24-hour total precipitation [mm] on June 5, 2021, without background information (using 500 measurements).

Fig. 3 illustrates the 24-hour radar rainfall amount, which was used as background information during the interpolation process. Evidently, it is observable that a significantly higher 24-hour precipitation total appears in the southwest, in contrast to *Fig. 2*, where the absence of this pronounced precipitation maximum suggests that the most intense and substantial precipitation from the thunderstorm cell bypassed the surface precipitation monitoring stations, but was nevertheless detected by the radar.

In addition to the prominent values in the southwest, *Fig. 3* also reveals a band of 15–20 mm equivalent precipitation in the western regions of the country and the Transdanubian region, which does not appear among the measurements.

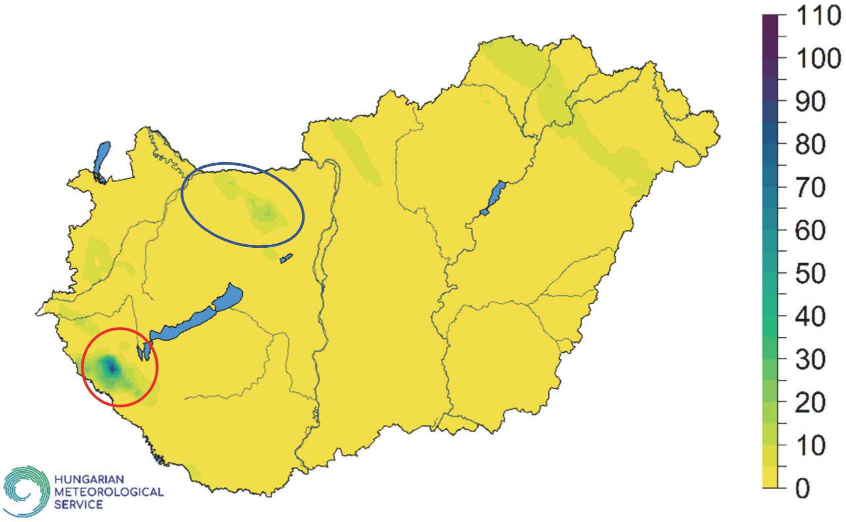

Fig. 3. 24-hour radar precipitation amount [mm] (June 5, 2021).

While interpolation without the radar background information indicate 35–39 mm of maximum precipitation within 24 hours, the incorporation of radar background information into the MISH interpolation revealed a precipitation total of 106.9 mm in the southwestern region (*Fig. 4*).

A strong relationship was observed between the observations and the background information, with a high correlation coefficient of R = 0.889. Furthermore, with the inclusion of background information in the interpolation, higher precipitation amounts were also observed in the northern Transdanubian region. It is apparent that while 0–5 mm of precipitation is depicted in the northern Transdanubian region without background information, the utilization of radar data results in daily precipitation totals of 5–30 mm.

For lesser amounts of precipitation that fell over a larger area, the two interpolation products exhibited greater agreement (in northern and northeastern Hungary), yielding values ranging between 5–15 mm in both cases.

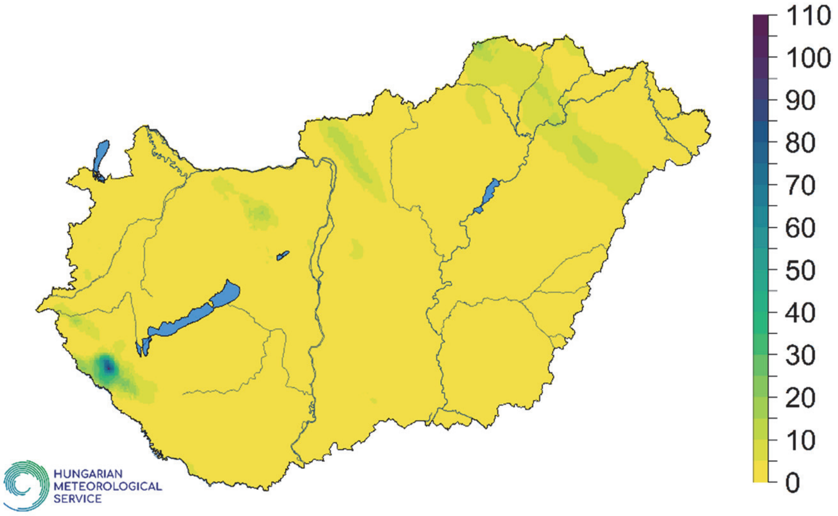

Fig. 4. 24-hour interpolated precipitation amount [mm] on June 5, 2021, with radar background information (using 500 measurements).

3.2. Flash flood in Kunfehértó (July 16, 2021)

On July 16, 2021, meteorological conditions in Hungary were significantly impacted by a cold front at elevated altitudes, leading to the occurrence of inclement weather characterized by rainfall and storms across various regions of the country. The most substantial levels of precipitation were observed in several areas, including southern Transdanubia, the Southern Great Plain, the region situated between the Danube and Tisza rivers, and Pest County. Furthermore, notable thunderstorms with associated copious rainfall were witnessed in the

Szatmár Plain and Bodrogköz regions located in the eastern part of the country. The meteorological measurements indicated that the highest daily precipitation total was recorded at Báta station, amounting to 49.2 mm. An interpolation conducted without the incorporation of background information suggested an even greater maximum daily precipitation total just a few kilometers from Báta, specifically in the village of Dávod, where it reached 65.02 mm (refer to *Fig. 5*).

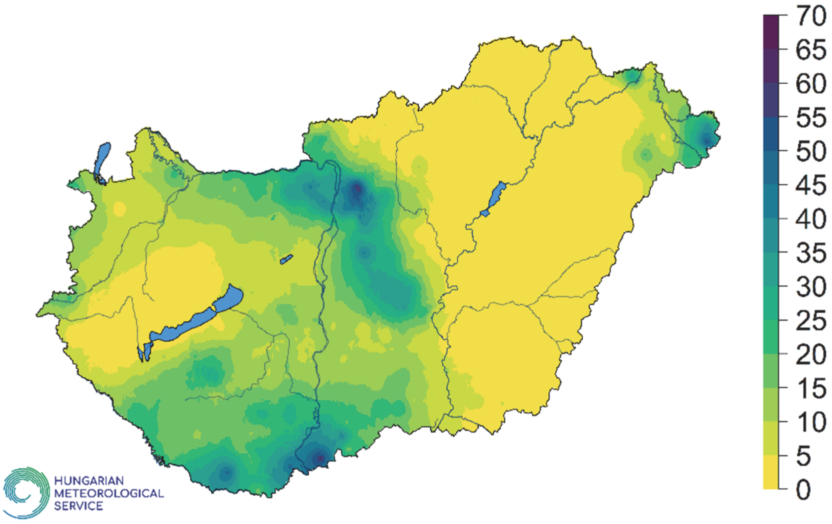

Fig. 5. Interpolation of 24-hour total precipitation [mm] on July 16, 2021, without background information (using 500 measurements).

The three figures displaying 24-hour rainfall totals, as depicted in *Figs. 5–7*, exhibit remarkable similarity. They collectively reveal a pronounced correlation of 0.918 between the observed data and the radar background information. All three figures consistently depict higher levels of precipitation in the southern and northern regions of Hungary. However, it is noteworthy that the radar failed to capture the elevated precipitation values observed in the Szatmár Plain and Bodrogköz regions (refer to *Fig. 6*), where the recorded 24-hour precipitation levels ranged from 5 to 15 mm. In contrast, the interpolation without the use of radar background information (*Fig. 5*) suggested the presence of approximately 60 mm of precipitation within a smaller area, particularly reflecting 57.2 mm of rainfall over a 24-hour period at Gacsály station on July 16, 2021.

Another significant discrepancy arises from the fact that the radar database exclusively registered the occurrence of 60 mm of rainfall within an hour and a half, which led to a flash flood in Kunfehértó, while this event remained unrecorded by the primary meteorological stations. Consequently, when conducting interpolation without radar background information, only an estimated 15–20 mm of precipitation is indicated in the proximity of Kunfehértó. All of this also points to the importance of integrating radar data into rainfall interpolation.

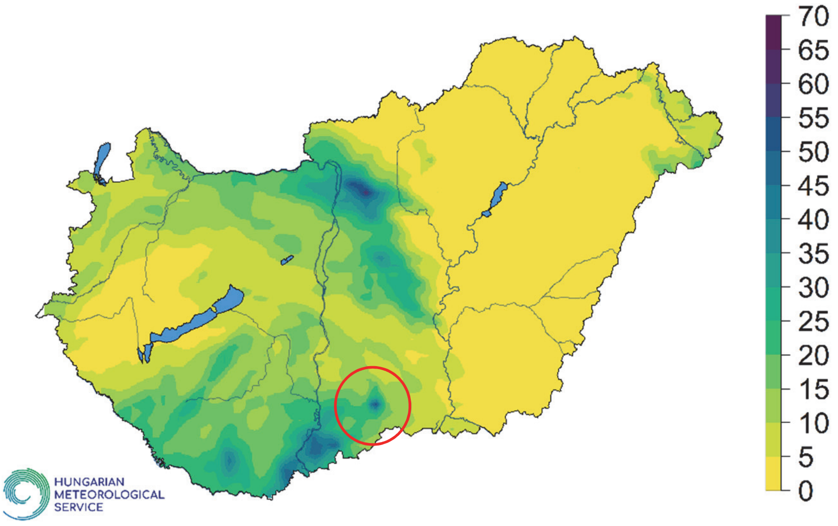

Fig. 6. 24-hour radar precipitation amount (July 16, 2021).

The results obtained through interpolation employing radar background information are presented in *Fig. 7*. This representation elucidates the higher daily precipitation totals observed in eastern Hungary, as well as the significant precipitation event surpassing 60 mm, which was responsible for the flash flood incident in Kunfehértó over the 24-hour period.

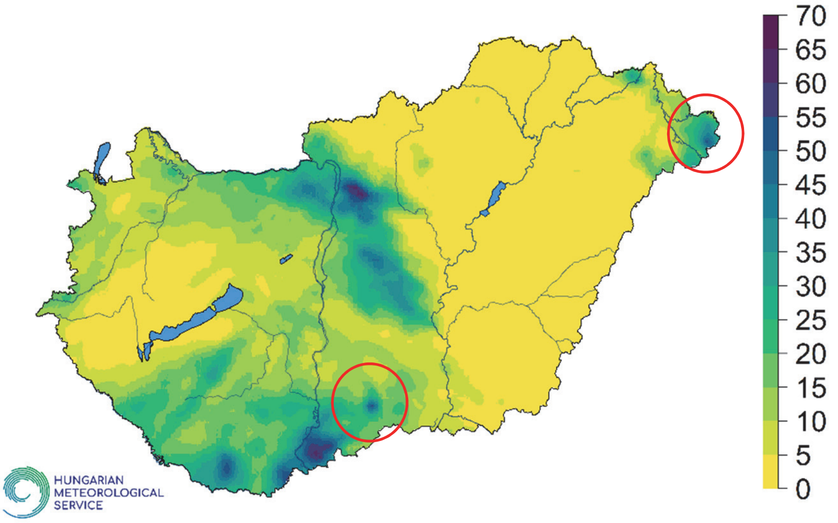

Fig. 7. 24-hour interpolated precipitation amount on July 16, 2021, with radar background information (using 500 measurements).

3.3. July 13, 2023

In the early hours of July 13, 2023, an advancing thunderstorm system, characterized by its northeasterly trajectory, precipitated copious rainfall and intense downpours across the entire country. Subsequently, this precipitation zone dissipated later in the afternoon, thereby ceasing its impact on the country.

On July 13, 2023, some irregularities occurred in precipitation measurement. Therefore, we are examining the day on an hourly basis. Comparing the results of the interpolated daily precipitation amount measured by precipitation gauges (*Fig. 8*) with the results of radar measurements (*Fig. 9*), it is evident that in a significant part of the country, including the Great Plain and the northern regions, there is little to no precipitation due to the temporary absence of radar measurements. Regarding the regional average, there is a difference of 2 mm between the two precipitation datasets, however in some areas (northern Hungary), a difference of 10–14 mm can be observed.

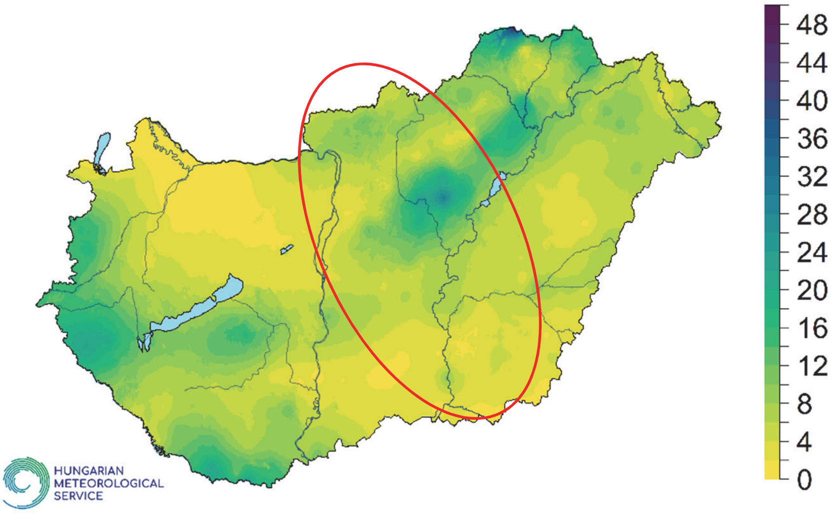

Fig. 8. Interpolation of 24-hour total precipitation [mm] on July 13, 2023, without background information (using 276 measurements).

The significant disparity between the interpolated dataset, which lacks radar background information (*Fig. 8*), and the radar measurements (*Fig. 9*) can be attributed to the smaller number of precipitation stations; additionally, the absence of radar measurements further exacerbates this difference. Consequently, the correlation coefficient that quantifies the association between these two datasets is notably diminished, standing at a modest value of **0.556**.

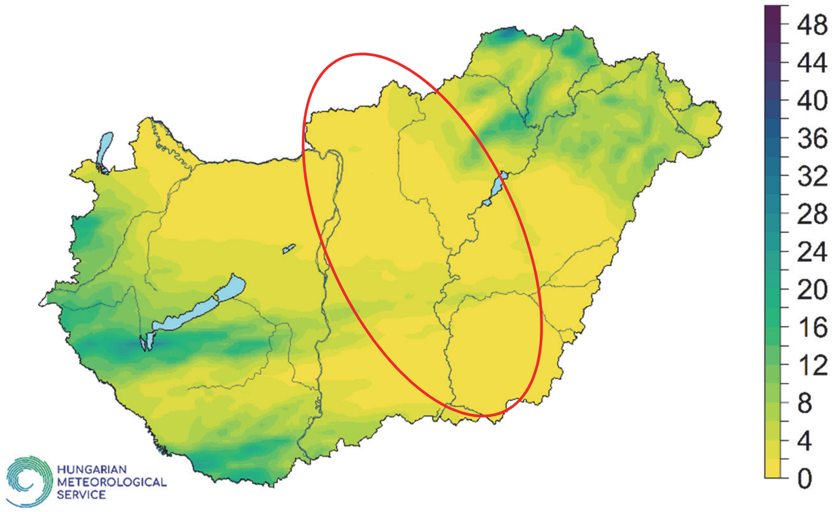

Fig. 9. 24-hour radar precipitation amount (July 13, 2023).

Subsequent to the incorporation of radar-derived background information in the interpolation process of precipitation measurements, the daily precipitation amount of 2–6 mm missing from the radar measurements also appeared in the central and southeastern parts of the country (*Fig. 10*).

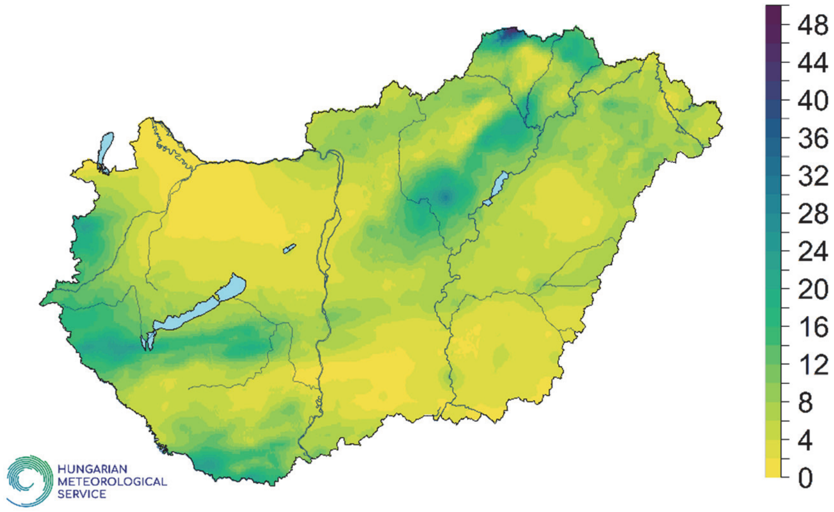

Fig. 10. 24-hour interpolated precipitation amount on July 13, 2023, with radar background information (using 276 measurements).

In addition to the temporary absence of radar measurements, there was also a rare occurrence of a so-called second-trip echo radar error when multiple reflections from an extremely intense thunderstorm cell in the area of Slovenia were observed on the radar images (*Fig. 11*).

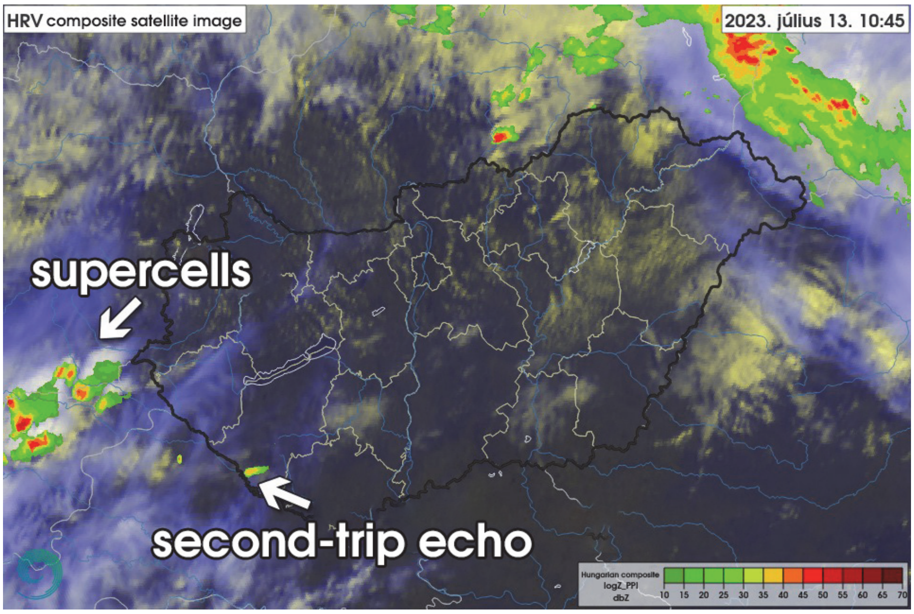

Fig. 11. Second-trip echo radar error caused by extremely high thunderstorms.

3.4. *Hourly analysis*

On July 13, 2023, an examination of the hourly precipitation amounts revealed that the amount of precipitation that fell in the Great Plain and the southeast, according to traditional measurements, which is missing from the 24-hour radar precipitation amount, could have fallen in the morning hours, around 7 UTC (*Fig. 12*).

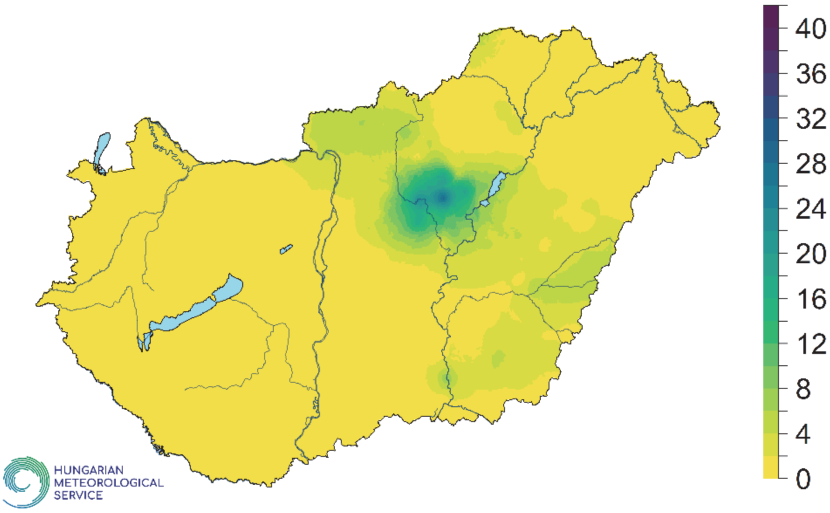

Fig. 12. Interpolation of hourly total precipitation [mm] on July 13, 2023, 7 UTC without background information (using 276 measurements).

Unexpectedly, the 7-hour cumulative radar precipitation data reveals the existence of a precipitation zone in central and southeastern Hungary (*Fig. 13*) that is absent in the corresponding 24-hour radar measurements (*Fig. 9)*.

We sought to identify the cause of the unexpected outcome, focusing on the likely disparities between corrected and uncorrected hourly precipitation sums. We assumed that while the corrected precipitation amount reflects the missing precipitation, this deficiency remains uncompleted in the uncorrected dataset. Consequently, we examined the uncorrected hourly radar sum. However, our initial hypothesis was not confirmed, as the investigation of uncorrected radar precipitation sums yielded similar results, wherein the precipitation deficit from the 24-hour total also manifested.

Notwithstanding this, using the MISH method, both hourly and daily interpolation effectively captures the precipitation amounts in question for the northern part of Hungary, as well as the central and southeastern parts of the country (*Fig. 10* and *Fig. 14)*. The relationship which was observed between the hourly observations and the background information is really high despite the absent precipitation, the correlation coefficient is 0.91.

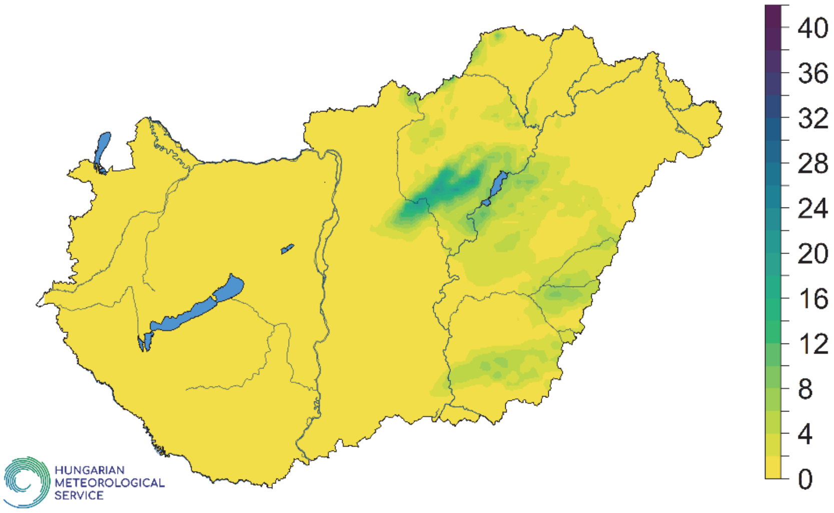

Fig. 13. Hourly radar precipitation on July 13, 2023, 7 UTC.

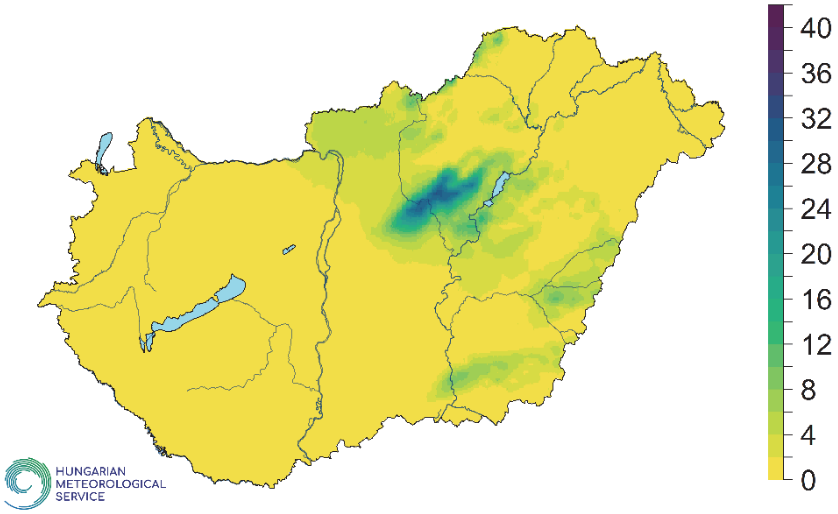

Fig. 14. Interpolation of hourly total precipitation [mm] on July 13, 2023, 7 UTC with background information (using 276 measurements).

The "second-trip echo" radar error signal that occurs around 10 UTC (*Fig. 11*) cannot be identified in the display of the 24-hour radar precipitation amount (*Fig. 9*), so it is worth examining the hourly precipitation at 10 UTC to make sure of the presence of a false precipitation signal.

Fig. 15 illustrates that inaccuracies stemming from deceptive reflections undergo filtration within the radar database, consequently precluding their incorporation in the display.

Fig. 15. Hourly radar precipitation [mm] on July 13, 2023, 10 UTC.

3.5. Correlation between measurements and radar information, monthly values

Through the presentation of case studies, it becomes evident that the integration of radar precipitation data holds considerable utility in the interpolation. Simultaneously, the inquiry arises regarding the suitability of radar-measured precipitation for climatological applications. To address this query, we aggregated monthly precipitation data obtained through radar measurements from the year 2015 (the commencement of available radar data) to 2022, subsequently conducting a comparative analysis with conventionally measured precipitation. Employing data encompassing homogenized precipitation records from 500 stations (*Szentes et al*., 2023) over the period 2015–2022, we applied the MISH interpolation technique to the monthly precipitation values.

For each month, we calculated the spatial average and calculated the correlation between the two datasets. The strongest linear relationship occurs in August, while February has the weakest correlation (*Fig. 16*).

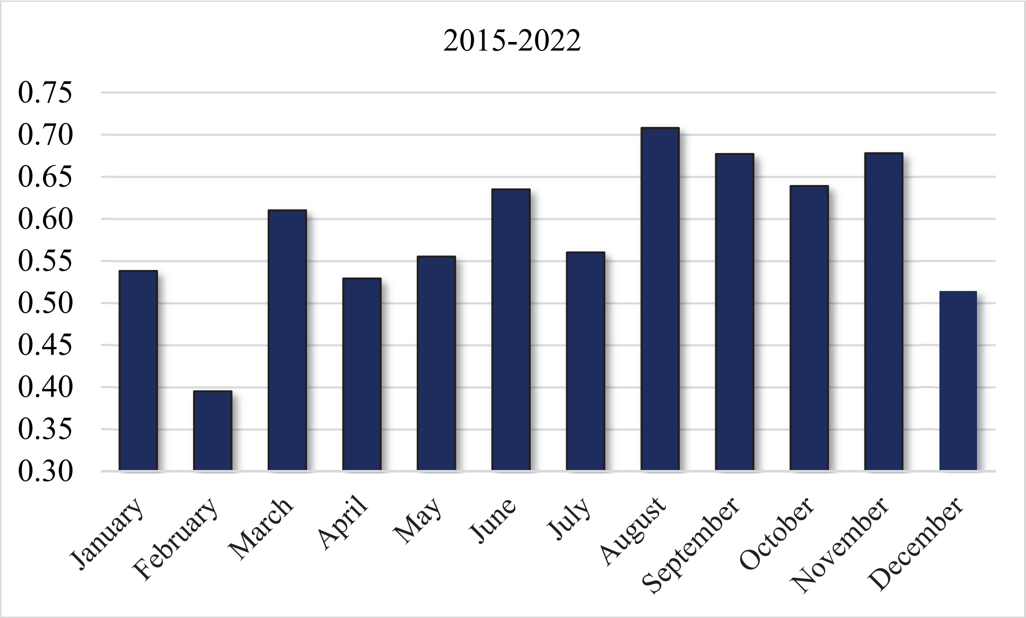

Fig. 16. Correlation between measurements and radar information, spatial average.

While radar-measured precipitation proves valuable in scenarios involving the passage of smaller, convective cells across the country, thus circumventing conventional meteorological stations, its suitability for climatological purposes is a subject of ongoing debate. *Fig. 17* shows the average precipitation amount in July averaged over the period 2015–2022. This observation implies that the radar data greatly underestimates the measured precipitation totals on July. There can be several reasons why radar measurements might underestimate monthly precipitation amounts, especially when considered for climatological purposes. Some common factors include:

- Beam blockage: Radar beams are not perfectly straight, they follow the curvature of the Earth. Terrain features such as mountains or tall buildings can block the radar beam, leading to underestimation of precipitation in the shadowed areas.
- Attenuation: Raindrops can absorb and scatter radar signals, especially at higher frequencies.
- Z-R relationship: The radar reflects the intensity of precipitation, and this is converted to rainfall rates using a Z-R relationship (reflectivity to rainfall rate). However, the relationship can vary with temperature, type of precipitation, and other factors. If the chosen Z-R relationship is not appropriate for the conditions, it can lead to inaccuracies (*Krajewski et al*., 2010).

Our observation suggests that, currently, radar data is not a viable substitute for conventional measurements, thus rendering its utility limited in the context of climate-related applications. However, in cases where there is a strong correlation between radar information and measurements, they are definitely additional information compared to point measurements. In this article we also presented cases where radar information is an effective complement to measurements. Accurate precipitation estimates are needed for hazard warning, for insurance companies to settle claims, and of course for the public to justify the damage.

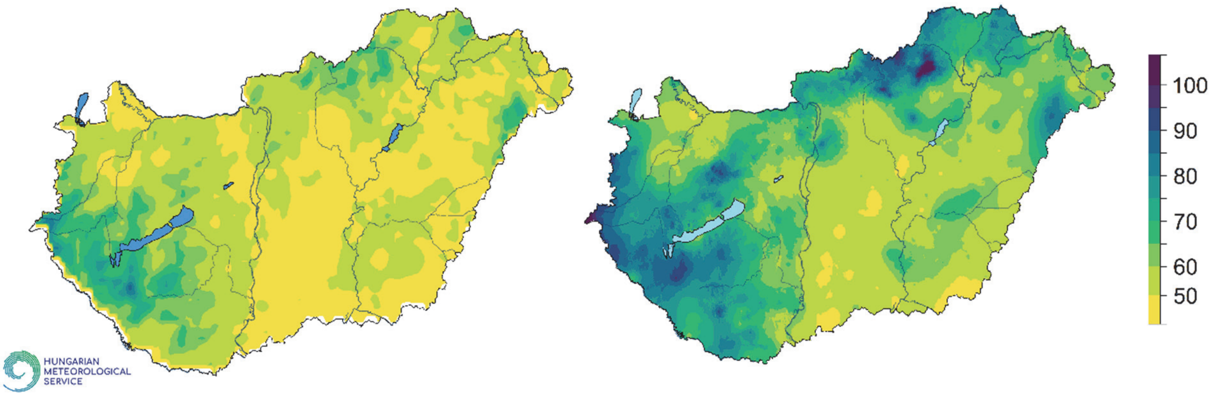

Fig. 17. Representation of July radar precipitation totals (left) and measurements (right) for the averaged period 2015–2022.

4. Conclusion

In conclusion, this study has demonstrated the significant impact of incorporating radar-derived background information in the interpolation of daily and hourly precipitation data, especially in regions prone to small but intense thunderstorms, such as supercells. The research focused on the MISH (Meteorological Interpolation based on Surface Homogenized Data) method and its adaptability in handling radar anomalies, including errors, missing data, and spurious measurements.

The results from the analysis of three specific days in Hungary highlight the critical role of radar data in improving the accuracy of precipitation interpolation. In cases where traditional meteorological stations failed to capture the most intense and substantial precipitation events, radar data filled the gaps, providing a more complete and accurate picture. The incorporation of radar background information resulted in higher daily precipitation totals, and the correlation between observed data and radar background information was consistently strong.

Furthermore, the study emphasizes the importance of integrating radar data into the interpolation process for hazard forecasting. Small but intense thunderstorms can lead to flash flooding and have adverse repercussions in societal and agricultural domains. Therefore, the combination of measurement data and radar products offers substantial advantages, enhancing accuracy in hazard forecasting and improving our understanding of spatial and temporal precipitation patterns.

Although in the long term (e.g., 2015-2022 average) radar precipitation amounts cannot be used for climate purposes, as they significantly underestimate the amount of measured precipitation, in instances where a robust correlation exists between radar-derived information and measured values, the former can provide supplementary insights compared to conventional measurements.

In future studies, it may be beneficial to improve the time resolution of the assessments. Instead of focusing solely on daily or hourly precipitation data, the inclusion of even shorter intervals, like 10- or 5-minute data, in precipitation interpolation along with radar information could be a valuable avenue for investigation.

Overall, this research underscores the critical role of radar-derived background information in precipitation interpolation, offering valuable insights for meteorological and hydrological applications, ultimately contributing to better decision-making in managing and mitigating the impacts of extreme weather events.

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