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Case study: Assessment of radar-based and ground precipitation data during the flood situation in May 2021 in the Upper Hron River basin in Slovakia

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Precipitation is a major factor influencing the results of rainfall-runoff modelling. Errors in precipitation propagate to other phases of water quantity and quality analysis. In the field of operational hydrology, the primary focus is on simulated and predicted discharges. This paper provides a comprehensive analysis of radar-estimated precipitation in comparison with precipitation obtained from rain gauge stations during the monthly period when flooding occurred in the Upper Hron River basin in central Slovakia. The precipitation is analysed from the point of view of its further use in the HBV hydrological model applied for hydrological forecasts in the operational hydrological service of the SHMU. Even though, there are high correlation coefficients between measured and radar precipitation, the underestimation of radar precipitation was investigated, with a clear west-east trend. The radar product generally recorded more hours of rain. Low intensities up to 3 mm hr^{-1} prevailed, while precipitation with higher intensities (above 5 mm hr^{-1}) was detected less frequently compared to ground data. Hydrological evaluation of radar precipitation has shown that bias correction methods applied to precipitation data prior to input to the model can enhance subsequent discharge simulation. The improvement was observed mainly in upstream subbasines, especially in the Čierny Hron subbasin. The NSE was calculated at 0.915. The error in peak flow was also reduced, but the underestimation of the maximum discharge was still observed. The assessment included one month's data, therefore more site-specific situations would need to be analysed for more general conclusions.

KEY WORDS: precipitation uncertainty, hydrological forecasts, HBV model

Introduction

In mid-May 2021, we observed a flood situation that affected most of the river basins on the Slovak territory. At the gauging stations in the Upper Hron River basin up to the Banská Bystrica outlet, we recorded the exceedance of the 1st to 3rd degree of alert levels. The causal precipitation was associated with the passage of several cold fronts, which crossed the territory of Slovakia from the west between 12 and 17 May. Intense convective precipitation predominated during the first days, followed by continuous precipitation. Rainfall activity was highest during the day on 17 May. Most of the total rainfall amount fell in 12 hours between 6:00 and 18:00 CEST. Basin precipitation ranged from 25 mm in the Hron River head area to 45 mm in the western direction. There was 55 to 70 mm of rainfall in the surroundings of Banská Bystrica and exceptionally more on the windward slopes of the Kremnické and Starohorské hills (Hrušková et al., 2021).
The water level on the Hron River at the outlet of Banská Bystrica exceeded the 3rd degree of alert level at midnight on 18 May. The peak discharge occurred in the morning of 18 May and has reached the value of 5-year flood discharge. The most significant peak discharges, 10-year flood discharges, were evaluated at the water gauging stations on the right-hand tributaries the Jasenianský Creek and the Bystrica River. The risk of flooding in Banská Bystrica was not based on the value of the peak runoff, but rather on the construction of flood defences. The May flood is also described in Pekárová et al. (2022). They focused on the reconstruction of the flood wave caused by the breach of the stone dam in Rudno nad Hronom.
During the flood, the Department of Hydrological Forecasts and Warnings (DHFW) of the Slovak Hydrometeorological Institute (SHMU) issued model forecasts updated four times a day. Deterministic forecasts were made using the well-known conceptual semi-distributed rainfall-runoff model HBV (Bergström, 1992). The course of the flood suggested that the model predictions underestimated reality. The predicted onset of the flood was slower and the peak flow lower. This was confirmed by a post-flood feedback evaluation of model performance during the flood. As Vlasák and Krejčí (2021) state, the understanding why hydrological forecasts differ from observations is key to making successful deterministic and probabilistic forecasts.

The DHFW regularly evaluates model performance in both simulation and forecast mode at selected gauging stations (Hlaváčiková et al., 2023). The paper summarises the results of the evaluation of observed precipitation used as climatological forcing data in the HBV model. Climatological forcing data determine the initial conditions of the model prior to the forecast run.

In forecast mode, the hydrological model, calibrated using historical data and simulating runoff with actual meteorological forcing, is run forward in time with the input data provided by the meteorological forecast. The way the hydrological model simulates extreme runoff phases has a strong influence on its ability to set the initial conditions before the hydrological forecast (Hrušková and Hlaváčiková, 2022). It is therefore important that the model describes them as accurately as possible. WMO (2011) states that errors in the initial conditions determine extremely large errors and forecasting uncertainty in the case of rainfall-runoff models. As it further explaines, the soil moisture content at the beginning of an event can change the predicted runoff by an order of magnitude.

The most commonly used sources of precipitation data for hydrological modelling are rain gauges and meteorological radars. Meteorological radars provide real-time, spatially distributed precipitation estimates. Conventional rain gauge data are spatially limited to the exact location and often considered to be true observations at ground level compared to precipitation estimated from other data sources (McMillan et al., 2011). The HBV model is designed to easily incorporate rain gauge precipitation data. The weights are used to convert the point measurement to an area (basin) value (SMHI, 2014).

Precipitation measured at a single point is considered to be the most accurate source of information, but it is characterised by a high degree of spatial variability. The areal average is often poorly represented by point measurements, especially in cases where rain gauges are sparsely distributed or outside the area of interest (Starks and Moriasi, 2009; Tobin and Bennett, 2009; Price et al., 2014). Since mid-May 2019, the DHFW uses radar precipitation estimates merged with rain gauge data (hereafter referred to as "qPrec") as actual meteorological forcing data input to the rainfall-runoff forecasting process (Méri et al., 2021). Radar precipitation estimates are implemented by calculating the mean areal precipitation over the basin (basin precipitation).

It is a generally known fact that precipitations input in hydrological models contain a large source of uncertainty and has a critical effect on the accuracy of hydrological model predictions (McMillan et al., 2011).

Reason is that there is a limited number of available ground based observations and the high spatio-temporal variability of this characteristic (Kavetski et al., 2006). Bardossy et al. (2022) documented that up to 50% of the hydrological model error in their study can be attributed to precipitation uncertainty. In adition, in mountaineous regions the error can be even higher because of the orographic effect (McMillan et al., 2011; Sleziak et al., 2023).

The quality of the precipitation input has an impact on the runoff processes simulation. Without accurate measurements or estimates of precipitation, hydrological modelling cannot be effective. When modelling hydrological processes, precipitation affects several internal state variables of the model, e.g. soil moisture, evapotranspiration, snow or groundwater flow (Bingeman et al., 2006). As such it influences the initial conditions prior to hydrological forecast run. Thus, through the initial conditions, the radar precipitation influences the final hydrological forecast.

The objective of the study was to evaluate the differences between measured and radar-estimated precipitation at selected rain gauge stations in the Upper Hron River basin during flood situation in May 2021 and to assess the influence of qPrec basin averages on model performance. We used the same setup of the HBV model, including parameters, as is used as standard in the hydrological forecasting process at SHMU. Precipitation analysis from an operational hydrology point of view is valuable to better understand the behavior of the calibrated model, especially during flood situations. On the other hand, it provides feedback to the SHMU Department of Remote Sensing to improve its qPrec product.

Materials and methods

Study area

The Upper Hron River basin was selected as the area of interest for our case study (Fig. 1). The catchment area up to the Banská Bystrica outlet is 1766 km^2. The catchment is characterised by a west-east orientation with a high altitude range from 334 m to 2024 m a.s.l.

Processing of ground and radar data

The study uses hourly rainfall data from 16 automatic weather (AWS) and precipitation (APS) stations located in the Upper Hron River basin (Table 1). The exception is the data from Chopok AWS because of only 6-hourly time step of manually measured precipitation data for SYNOP (surface synoptic observations) message. Chopok AWS is a high mountain weather station located on the ridge of the Low Tatras in extreme climatological conditions with strong wind effects and also icing phenomena in winter.

For our analysis, we also used radar rainfall estimates at rain gauge stations from the qPrec software, which is continuously developed and improved by the SHMU Department of Remote Sensing. As Meri at al. (2021) explains, the qPrec software for quantitative precipitation estimation was developed in an iterative approach. Each upgrade or modification of the software (e.g. the incorporation of an additional quality index, new input field, and modified algorithm) was validated against the 24-hour precipitation amount from the network of about 600 climatological and pluviometric stations of the SHMU.

Fig. 2 shows an example of 24-hour precipitation as

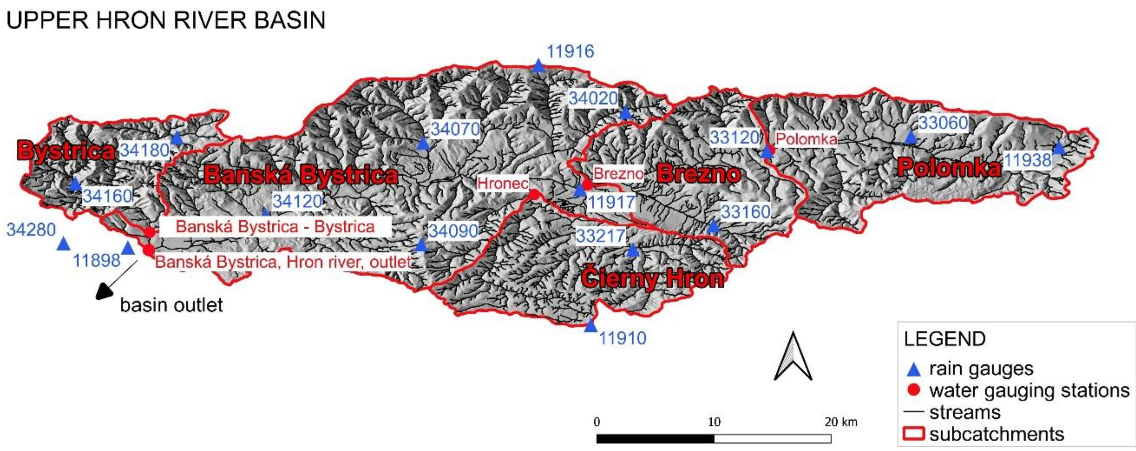

Fig. 1. Map of the Upper Hron River basin study site with main subcatchments, location of rain gauges and water gauging stations.

Table 1. Automatic weather and precipitation stations located in the Upper Hron River basin

	ID	Name	Type	Longitude	Latitude	Altitude [m a.s.l.]
1.	11898	Banská Bystrica	AWS	19.11528	48.73333	427
2.	11910	Lom nad Rimavicou	AWS	19.64917	48.64389	1018
3.	11916	Chopok	AWS	19.58889	48.94333	2002
4.	11917	Brezno	AWS	19.63652	48.80035	487
5.	11938	Telgárt	AWS	20.18920	48.84860	906
6.	33060	Pohorelá	APS	20.01858	48.86111	747
7.	33120	Polomka	APS	19.85234	48.84426	605
8.	33160	Pohronská Polhora	APS	19.79083	48.75861	619
9.	33217	Čierny Balog-Dobroč	APS	19.69787	48.73096	570
10.	34020	Jarabá	APS	19.68929	48.88937	892
11.	34070	Jasenie	APS	19.45593	48.85387	538
12.	34090	Chata pod Hrbom	APS	19.45358	48.73662	1079
13.	34120	Slovenská Ľupča	APS	19.27372	48.77084	389
14.	34160	Dolný Harmanec	APS	19.05461	48.80738	481
15.	34180	Motyčky	APS	19.17182	48.86018	678
16.	34280	Králiky	APS	19.04101	48.73818	627

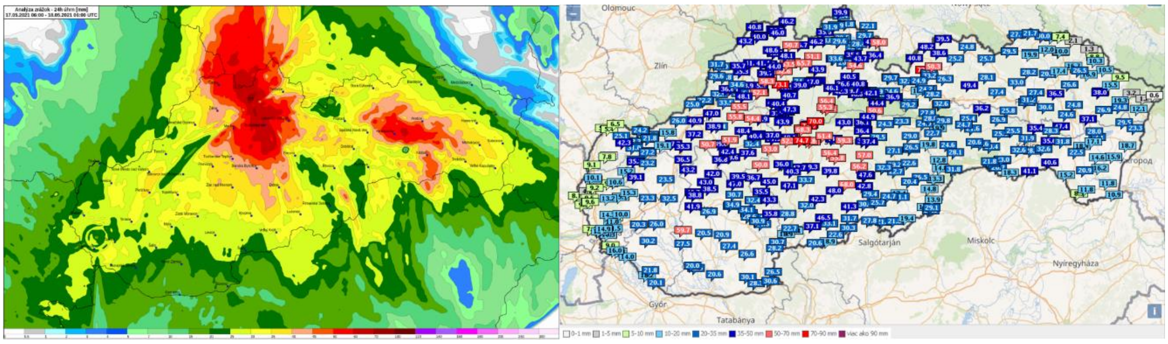

Fig. 2. 24-hour precipitation totals from automatic rain gauge stations until 18. 5. 2021 04:00 UTC (LEFT) and spatial analysis of 24-hour precipitation based on radar estimates until 18. 5. 2021 06:00 UTC (RIGHT).

measured by automatic rain gauge stations (until 18. 5. 2021 04:00 UTC) and based on radar estimates (until 18. 5. 2021 06:00 UTC).

Statistical evaluation

The ground data were compared to hourly radar-based precipitation estimates. Using paired hourly data, Pearson's correlation coefficient was applied to measure the degree of linear relationship between radar based and observed precipitation. Percent bias (PBias) was used to investigate the tendency of the radar based precipitation to over- or underestimate the measured data.

$$PBias = \frac{P_{radar} - P_{meas}}{P_{meas}} * 100 \quad (1)$$

where

P_{radar} – monthly precipitation based on radar estimates [mm],

P_{meas} – monthly measured precipitation at rain gauge station [mm].

The hourly intensities were divided into several intervals (0.1–1, 1–3, 3–5, 5–7, 7–9, 9–11, 11–15, >15mm) and frequency analysis was performed. For this purpose, all hourly values for which both data types reported zero precipitation (less than 0.1 mm) were neglected.

To show the distribution of the numerical data and their skewness, the data were presented in a box plots using the five-number summary of a data set – including the minimum score, first (lower) quartile, median, third (upper) quartile, and maximum score.

Hydrological modelling

The next step was to try to answer the question of how to use the results of precipitation analysis in operational hydrological modelling. The hydrological model used to achieve our goal was the HBV rainfall-runoff model, with the same settings as those regularly used by the DHFW for the discharge forecasting process.

Five forecasting gauging stations naturally define five subbasines in the Upper Hron River basin, which are summarised in the Table 2 and shown in Fig. 1. Upstream subbasines are connected to downstream ones and the simulated discharge flows downstream to the basin outlet on the Hron River in Banská Bystrica. This means that the rainfall runoff process is simulated in three upstream subbasins (Polomka, Hronec, Bystrica), while in the remaining two subbasines it is combined with a single flood routing (Brezno, Banská Bystrica).

The HBV model contains subroutines for snow accumulation and melt, soil moisture accounting procedure, routines for runoff generation and routing. Detailed information on the model structure and parameters can be found in the literature (Bergström, 1992; SMHI, 2014).

The HBV model is a continuous semi-distributed rainfall runoff model that solves water balance at each computational time step. Catchments are divided into sub-catchments, elevation zones of 100 m each, and vegetation zones (as forest or field). Basin averages of radar-based precipitation estimates and air temperature, both at a hourly time step, are used as input data to the model. Radar-based precipitation estimates based on measurements from four Slovak meteorological radars are operational from May 2016.

Continuous basin mean series of the radar-based precipitation product for the model calibration (qPrec) have been available since June 2016. The calibration itself covered the period from August 2016 to December 2020. The results of the model calibration are summarised in the Table 3 below. The table includes the performance evaluation by Nash-Sutcliffe Efficiency (Nash and Sutcliffe, 1970; Moriasi et al, 2007) and the parameter values for each subbasin. Calibrated model outputs are used as a benchmark for the next analysis.

For each sub-basin, some rain gauge stations were selected to calculate the correction factor to adjust the rainfall estimates. A quantitative relationship between monthly measured and estimated radar precipitation was calculated for each rain gauge station. The basin-averaged ratio was used to correct original hourly radar data (qPrec), which was then used as the adjusted basin precipitation input to the hydrological model. Monthly values were used to smooth out extremes in precipitation data contained in a short time step (high value of hourly intensities) and to find a long term basin value of the correction factor. Fig. 3 shows an overview of the rain gauges used in the analyses for particular subcatchment.

Model parameters were not changed when simulating, they were the same as in the benchmark setup. The results of the simulation, hourly discharges to five outlets, were assessed by Nash-Sutcliffe Efficiency (NSE) and compared to the benchmark. Several output variables were also evaluated. Soil moisture storage, upper and lower zone filling describe initial conditions at the beginning of the discharge forecasting process. To assess the accuracy of the peak flow, the percentage error in peak flow in percentages (PE) was used (Cheng et al., 2017):

Table 2. The overview of the subbasins allocated in the Upper Hron River basin

	Subbasin					Upper Hron River basin
	Polomka	Brezno	Čierny Hron	Bystrica	Banská Bystrica	
River	Hron	Hron	Čierny Hron	Bystrica	Hron	Hron
Outlet	Polomka	Brezno	Hronec	Banská Bystrica	Banská Bystrica	Banská Bystrica
Area [km^2]	329.54	252.54	239.41	160.46	784.53	1766.48

Table 3. Parameter values followed by Nash-Sutcliffe efficiency for sub-basins in the Upper Hron River basin, valid for the calibration period August 2016 to December 2020. Detailed description of the parameters can be found in Bergström, 1992 or SMHI, 2014

Parameter	Unit	Polomka	Brezno	Čierny Hron	Bystrica	Banská Bystrica
rfcf	-	0.930	0.950	0.938	0.943	0.874
sfcf	-	1.480	1.480	1.400	1.400	1.700
cfmax	mm °C^{-1} day^{-1}	4.200	4.250	3.597	5.000	5.000
tt	°C	-0.229	0.000	-0.105	-1.029	2.000
dttm	°C	0.360	0.025	0.285	-0.230	-2.000
fc	mm	95.000	82.000	142.115	204.000	174.747
lp	-	1.000	0.550	0.841	0.913	1.000
beta	-	2.300	3.500	4.000	2.943	4.000
cflux	mm day^{-1}	1.870	1.500	0.000	0.905	0.010
ecorr	-	1.050	0.726	0.959	0.700	0.713
k4	day^{-1}	0.025	0.012	0.072	0.025	0.002
perc	mm day^{-1}	2.000	1.250	4.203	4.950	0.013
khq	day^{-1}	0.099	0.120	0.177	0.110	0.066
alfa	-	0.950	0.950	0.634	0.929	1.500
maxbaz	day	0.090	0.000	0.000	0.000	0.000
NSE	-	0.847	0.945	0.806	0.906	0.815

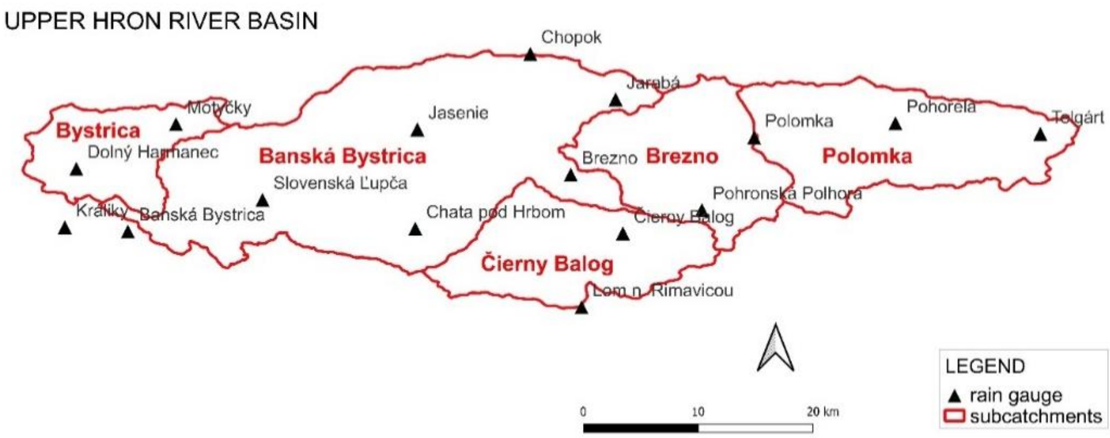

Fig. 3. The overview of rain gauge stations within the subcatchments.

$$PE = \frac{Q_{max} - Q'_{max}}{Q_{max}} * 100 \qquad (2)$$

where
Q_{max} –the observed peak value [m^3 s^{-1}],
Q'_{max} –the simulated peak value [m^3 s^{-1}].

Results and discussion

Comparison of radar-based and ground precipitation data

Radar-based and ground precipitation data show strong relationship described by Pearson's correlation coefficient (Fig. 4). The values range from 0.745 (Chopok AWS) to 0.937 (Jasenie APS). The lowest value is influenced by six-hourly timestep of analysed data. The second lowest value is 0.847 for Pohronská Polhora APS. Higher correlation coefficients were calculated in the western part of the basin, where higher monthly precipitation totals and also higher underestimation are observed. Detailed analysis showed that the pairwise differences in hourly data were systematically biased in the western part of the basin, while in the eastern part the same differences were randomly spreaded. This resulted in comparable monthly totals from both precipitation sources in the eastern part, but with a slightly lower correlation. Similar findings are presented in the publication of Sleziak et al. (2023). As they indicate, high values of the correlation coefficients may suggest that although the radar-based precipitation are underestimated compared to measured precipitation, but the underestimation at individual sites is in analysed situation relatively stable.

The west-easterly orientation of the basin influenced the amount of measured precipitation. The prevailing synoptic situation brought more precipitation to the western part of the basin. Monthly precipitation sums decrease towards the east. Monthly radar estimates show the same but a more moderate trend. According to the trend lines in Fig. 5, the differences between the corresponding measured and estimated monthly data decrease in the west-east direction. The compared monthly values at Polomka (33120) and Pohorelá (33060) were almost identical. The lowest monthly precipitation sums based on radar estimates were observed at stations in the southern part of the basin – Lom nad Rimavicou (11910), Čierny Balog (33217) and Pohronská Polhora (33160).

Rain gauge stations in the northern part of the basin recorded more precipitation than stations in the southern part. In addition, the southern stations show larger deviations from radar estimates than the northern stations. This includes the southern station of Chata pod Hrbom (34090; 1079 m a.s.l.) too, which is not shown in the Fig. 6. The southern rain gauge stations, which are at a higher altitude, mostly showed lower precipitation totals for May 2021 than the station (Brezno AWS, 11917) in the Hron valley.

Our work did not find that the underestimation of radar precipitation was related to elevation, as was the case of Sleziak et al. (2023) shown in the mountain basin analyses. However, it must be said that we only analysed one month of data for a specific hydrologic situation, and more site-specific situations would need to be analysed for more general conclusions.

The greatest differences between measured and radar-estimated precipitation was found for the stations located in the west and decreased towards the east (Fig. 7). The radar-based precipitation underestimates measured monthly precipitation totals by 6 to 40%, with the exception of two rain gauge stations. Polomka (33120) and Pohorelá (33060) show a positive deviation of 0.25% and 3.62%, 0.33 mm and 4.39 mm respectively. The underestimation of 29 to 40% was found at Králiky APS (34280) and at the southern rain gauge stations Chata pod Hrbom (34090), Lom nad Rimavicou AWS (11910), Čierny Balog APS (33217) and Pohronská Polhora APS (33160). Králiky APS (34280) is the westernmost rain gauge station in the basin.

The analysis of the hourly data using scatter plots (Fig. 8) show a systematic underestimation of radar-based precipitation in comparison with ground measurements. For higher rainfall intensities, which are critical for correct peak flow simulations, the underestimation is most pronounced. Although the amount of precipitation estimated by the radar is clearly underestimated, the timing of the radar-based precipitation events is in good agreement with the measured data, as is shown in the example in Fig. 9.

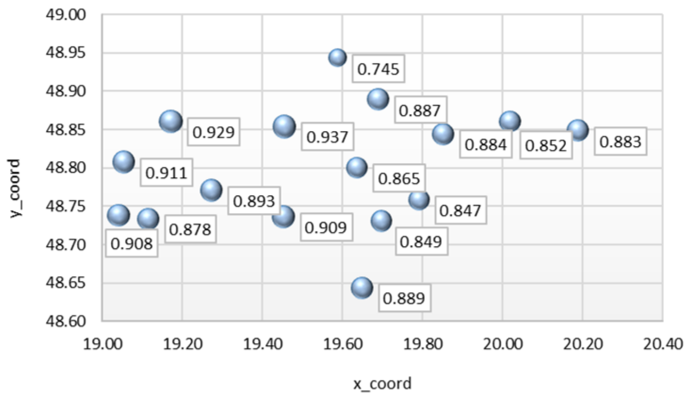

Fig. 4. Spatial variability of Pearson's correlation coefficients [-] between radar-based and ground precipitation data at selected precipitation stations in May 2021.

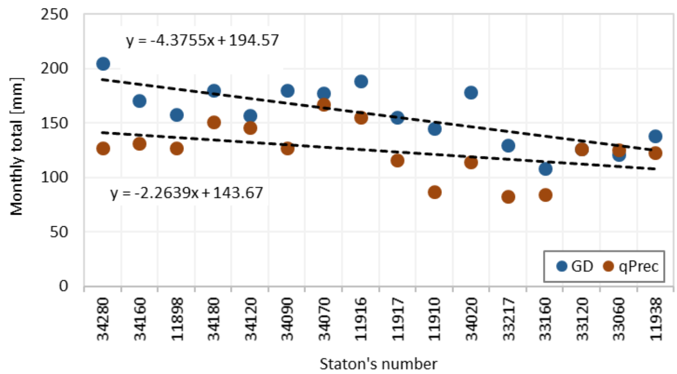

Fig. 5. Measured and radar-estimated monthly precipitation totals in the west-east direction (precipitation stations are ordered by longitude). GD is measured ground data and qPrec radar based estimates of precipitation at a rain gauge station.

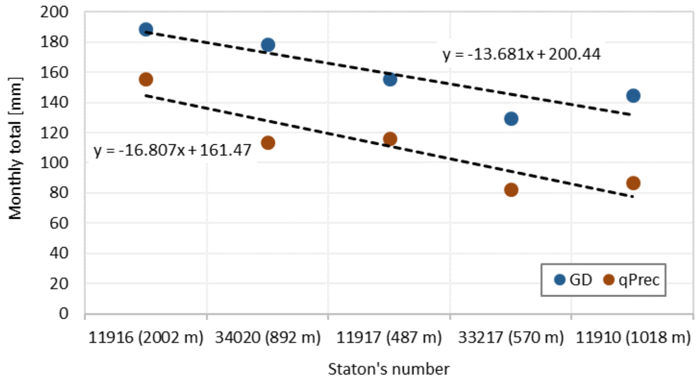

Fig. 6. Monthly precipitation values derived from radar estimates compared to data from precipitation stations (ID) in north-south crossection. The numbers in brackets indicate the altitude of the rain gauge stations. GD is measured ground data and qPrec radar based estimates of precipitation at a rain gauge station.

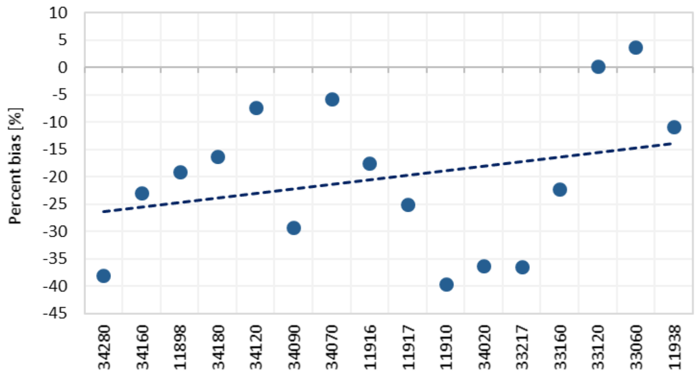

Fig. 7. Percent bias values at raingauge stations in the Upper Hron River basin in May 2021. Minus signs indicate that the radar-based precipitation underestimates the observed precipitation. The rain gauge stations are arranged according to their longitude from west to east.

A comparison of hourly rainfall intensities showed that the radar detected more hours with rain. In only one case (34020, Jarabá APS), the total number of hours with rain was higher compared to the radar data. The radar-based precipitation with lower intensities (up to 3 mm hr^{-1}) was assessed much more frequently. On the other hand, radar-based precipitation with higher intensities (above 5 mm hr^{-1}) was detected less frequently than in the case of the observed precipitation (Fig. 10). These results suggest a negative bias towards higher radar estimated precipitation intensities.

Result indicates that the mountainous relief of Slovakia has a significant influence on radar estimates of precipitation. For a basin surrounded by mountains, such as the Upper Hron River basin, the mountains form a natural barrier that affects any measurement of meteorological radar because of beam-blockage and beam height above the terrain (Méri et al, 2021; Sleziak et al, 2023).

The results in Fig. 11 show that the radar-based hourly precipitation was systematically underestimated (lower median, upper quartile and maximum values compared to measured data). Similar results were reported by Sleziak et al. (2023) for the mountain catchment in the Western Tatra Mountains. Visual interpretation of the interquartile range of each box plot indicates a higher concentration of radar data around the median, which means that the radar data are more clustered and show less time variability than measured data.

Hydrological modelling results

The subbasin means of the ratios between monthly measured and radar estimated precipitation at selected rain gauge stations are given in the Fig. 12. The specific values range from 1.028 to 1.617. The lowest value was calculated for the Polomka subbasin. This confirms the results of the previous analysis that the monthly totals of the hourly radar based data in the eastern part of the Upper Hron River basin correspond reasonably well to the measured precipitation. The highest mean value shows that the greatest underestimation of measured precipitation was observed at rain gauge stations in the Čierny Hron subbasin. Using the calculated basin-averaged ratio, the original hourly radar data (qPrec) were modified and used as the adjusted basin precipitation input to the HBV hydrological model.

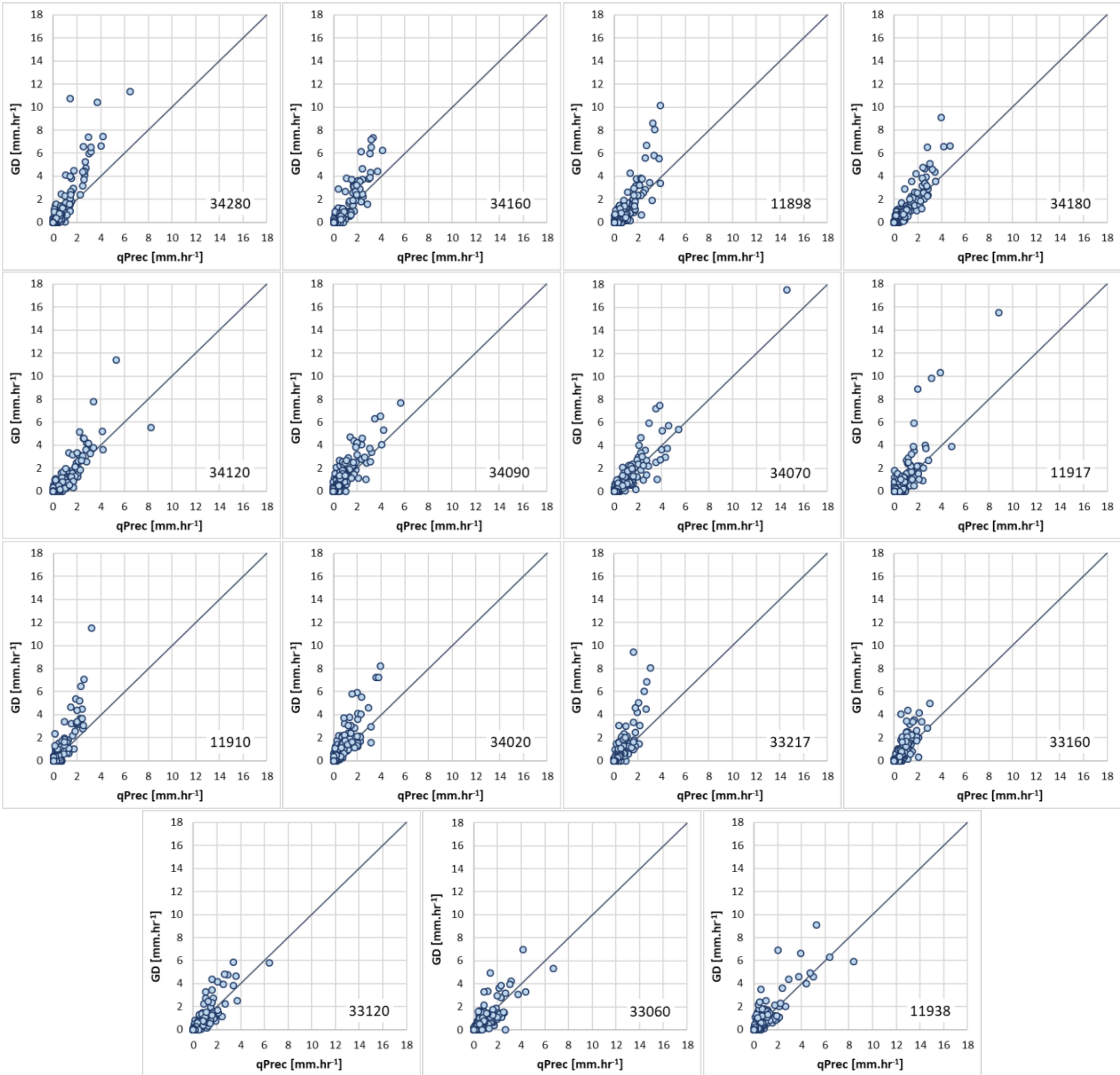

Fig. 8. Scatter plots of measured (GD) and radar estimated (qPrec) hourly precipitation at raingauge stations in the Upper Hron River basin in May 2021 (the station ID is in the bottom right corner). The diagonal line corresponds to the identity line.

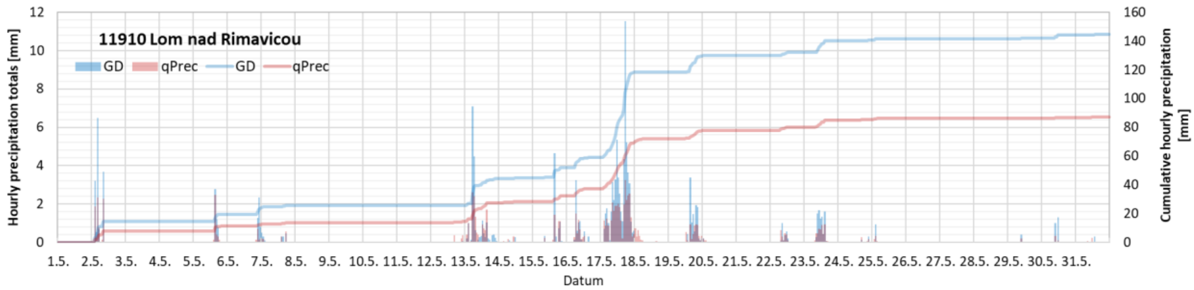

Fig. 9. Measured (GD) and radar estimated (qPrec) hourly precipitation totals and cumulative hourly precipitation at selected raingauge station in the Upper Hron River basin in May 2021.

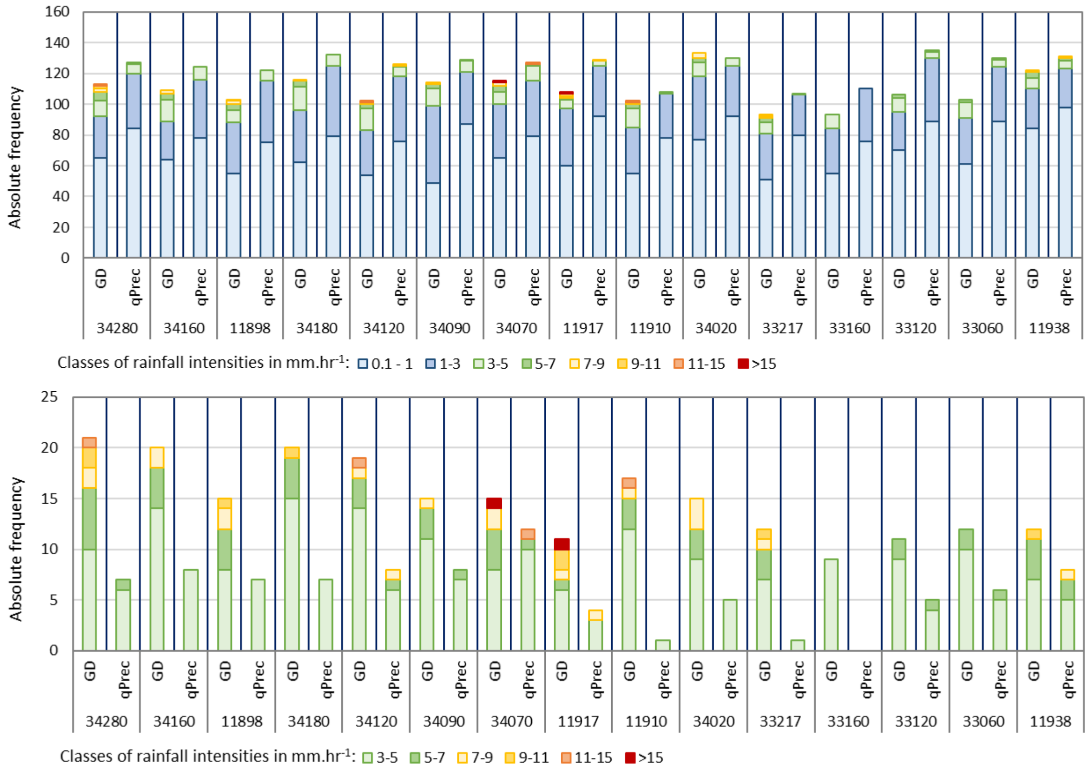

Fig. 10. Absolute frequency of measured (GD) and radar estimated (qPrec) hourly rainfall intensities higher than 0.1 mm hr^{-1} (up) and 3 mm hr^{-1} (down) at selected rain gauge stations in May 2021.

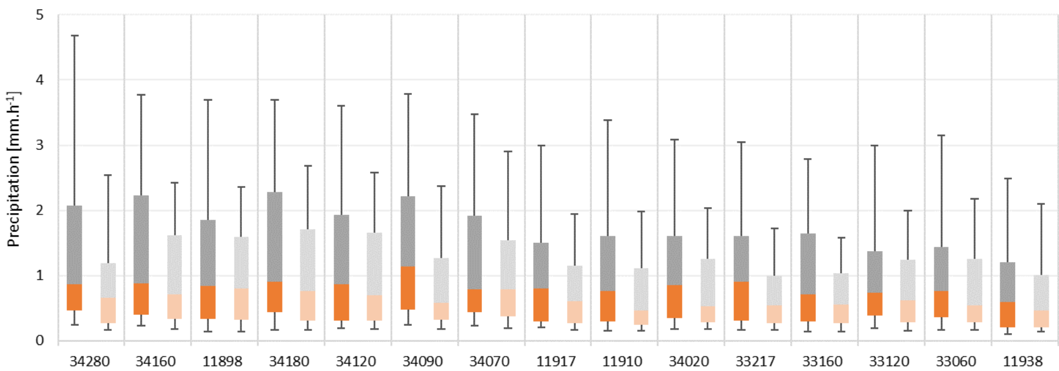

Fig. 11. Boxplots of measured and radar-based precipitation in hourly time step at selected rain gauge stations in the Upper Hron River basin in May 2021; the whiskers represent percentiles 10 and 90, the boxes are the upper and lower quartiles and the center line shows medians.

During the simulation, model parameters were not changed. They remained the same as those used in the benchmark run. Table below shows the values of the NSE for the benchmark run as well as for the run with the modified precipitation inputs in each subbasin. In all subbasines, the benchmark underestimated the observed discharges. According to NSE (Table 4), the statistically best values were obtained in the Bystrica and Banská Bystrica subbasines. The weakest benchmark result was detected in the Čierny Hron subbasin. The simulated discharge significantly underestimated the observed one.

The simulation with modified precipitation input showed the greatest improvement in the Čierny Hron subbasin. The simulated discharge corresponds to the observed runoff more closely compared to the benchmark (Fig. 13). This also confirms the high value of NSE (Table 4), although the observed peak flow is still underestimated.

In four of the five subbasines, the simulations with modified precipitation input improved model performance. According to the NSE value, the decrease in model efficiency occurred in the Banská Bystrica subbasin. In the benchmark simulation, there was an underestimation of the peak flow by almost 27%. A 15% overestimation of the peak flow was calculated in the simulation with modified precipitation input. This means, that in this case the runoff generation in the subbasin Banská Bystrica, which is the most downstream subbasin, is more influenced by upstream inflows than by rainfall runoff processes in the subbasin itself. At the same time, it can be seen that the model calibration to some extent corrects errors or biases in the precipitation data through parameter adjustment.

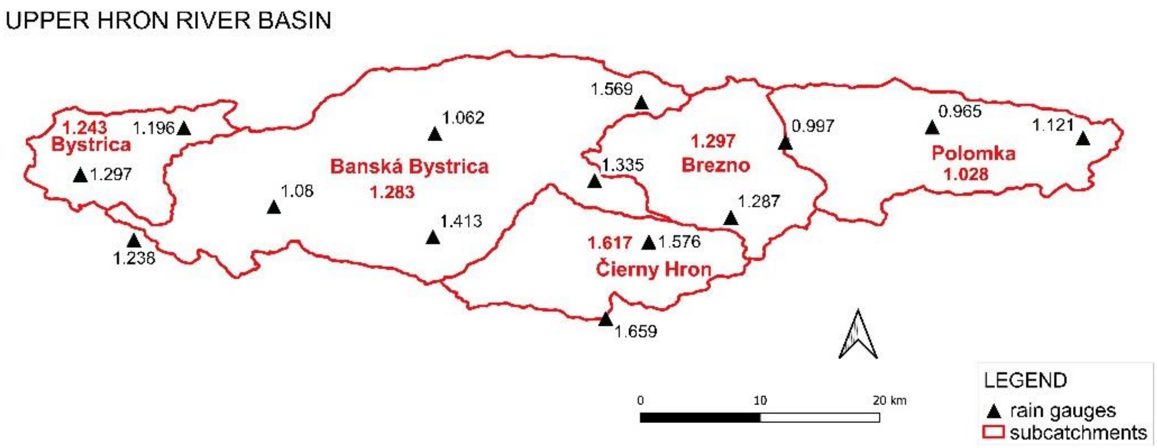

Fig. 12. The ratios between monthly sums of measured and radar estimated precipitation at selected rain gauge stations and mean subbasin values used to adjust hourly precipitation estimates (qPrec) input to the hydrological model.

Table 4. Values of NSE [-] and errors in peak flow PE [%] for benchmark simulations (qPrec) and simulations with modified precipitation input (qPrec_M) for individual subbasins in May 2021. A positive sign of PE indicates an underestimated and a negative sign an overestimated simulated peak flow compared to observed data

	Statistical criteria	Subbasins				
		Polomka	Brezno	Čierny Hron	Bystrica	Banská Bystrica
Benchmark (qPrec)	NSE	0.655	0.777	0.098	0.827	0.917
	PE	24.439	31.639	74.277	25.527	26.629
Modified (qPrec_M)	NSE	0.693	0.904	0.915	0.869	0.763
	PE	21.600	5.973	30.796	-9.384	-15.374

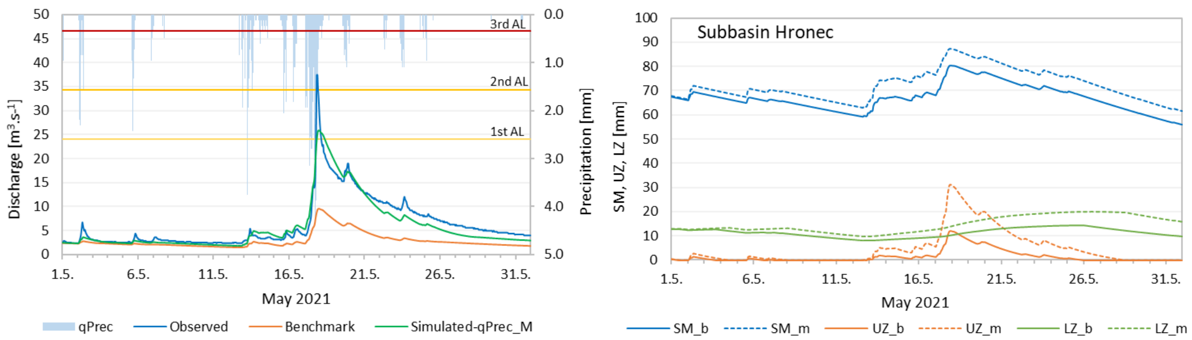

Fig. 13. The hydrograph of observed and simulated discharges at selected outlet in May 2021 (LEFT). "Benchmark" is simulated with radar estimates qPrec, "Simulated-qPrec_M" using modified precipitation input. The 1st to 3rd alert levels (AL) are also marked. Simulated soil moisture (SM), upper (UZ) and lower (LZ) zone storage at selected outlet in May 2021 (RIGHT). Outputs from the benchmark run (_b) are shown as a single lines, dashed lines correspond to outputs from the model run with modified precipitation input (_m).

Conclusion

For SHMU Department of Hydrological Forecasts and Warnings, radar-based precipitation estimates from qPrec software are the primary source of precipitation data used as climatological forcing data in hydrological modelling and forecasting. The grid outputs with 1 km resolution and hourly time step are converted to subbasin averages, which are then used as input to the semi-distributed HBV model.

In our case study, we focused on the flood event that affected the Upper Hron River basin in May 2021. We compared measured precipitation at selected automatic rain gauge stations with radar-based estimates at a location of the ground measurement. There are high correlation coefficients between measured and radar-estimated precipitation data. However, the underestimation of radar precipitation was found at both monthly and hourly time steps, with a clear west-east trend. Negative percent bias decreased towards the eastern part of the Upper Hron River basin. An analysis of the hourly rainfall intensities showed that the radar product recorded more hours with rain in general, but low intensities up to 3 mm hr^{-1} prevailed. On the other side, radar-based precipitation with higher intensities (above 5 mm hr^{-1}) was detected with less frequency than in the case of ground data.

Radar-based precipitation estimates are usually verified by ground measurements. An effective way to evaluate the performance of such data is to verify them using a hydrological model, particularly with a focus on extreme runoff situations. Basin averages from qPrec were fed into the HBV model. The model setup (including parameters) was the same as that operationally used by the SHMU hydrological forecasting service. Simulated and measured discharges were evaluated for five subbasines defined in the Upper Hron River basin. According to statistical criteria, a really poor discharge simulation with qPrec as input was detected for the Čierny Hron subbasin. The NSE for the flood event was close to zero. All discharge simulations underestimated peak flows, mostly in the range of 24–32%. In the case of the Čierny Hron subbasin the underestimation reached 74%. Using the basin-averaged ratio between monthly measured and radar precipitation at selected rain gauge stations, the original hourly radar data (qPrec) were modified and used as the modified basin precipitation input to the HBV model. The simulation with corrected precipitation showed improvement in four upstream subbasines, the greatest being in the Čierny Hron subbasin. The NSE was calculated at 0.915. Errors in peak flow were also reduced, but the underestimation was still observed at most outlets. For the Banská Bystrica subbasin, which is the most downstream and the largest subbasin, the runoff simulation with modified qPrec input resulted in worse model performance than in the case where the original qPrec data were used. The NSE decreased and the error in peak flow indicated an overestimation of maximum discharge. In terms of hydrological forecasting, this means that the runoff simulation and forecast at the Banská Bystrica outlet in May 2021 ware more influenced by the rainfall runoff processes in the upstream subbasins, than by the rainfall-runoff process in the subbasin itself.

In the future work, we would like to focus on how to implement the findings gained into the hydrological forecasting process. How to compensate the bias of the qPrec product prior to its input to the hydrological model? First of all, we need to carry out similar analyses so that we have knowledge about other river basins. The precipitation analysis carried out on a regular basis can help to understand the model performance in both simulation and forecast modes, especially during the floods. It must be said, we have only assessed one specific hydrological event using one month's data. More site-specific situations need to be analysed to make more general conclusions.

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