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Testing sensitivity of hydrological operational models to finer resolution of input data for purpose of applying high resolution Destination Earth forecasts. *Case study, part one*

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Destination Earth On-Demand Extremes Digital Twin is the initiative of European Commission whose aim is to provide forecasts of extreme weather events in high spatial resolution. Such forecasts are essential inputs for various applications, including hydrological models used in flood forecasting. Nine countries have been involved in testing high-resolution meteorological forecasts in national hydrological forecasting systems by analysing a specific historical flood event. The Slovak case study dealt with the analysis of the May 2021 flood in the upper Hron River basin in central Slovakia. The HBV and HEC-HMS rainfall-runoff models used in the national hydrological forecast service were modified to allow comparison of their outputs between both the current and new configurations. The results demonstrated the sensitivity of the models to the input data, in particular the precipitation volume, the redistribution of precipitation in the catchment, and the initial conditions prior to the simulation of the flood wave. Even though the new model configurations did not show significant improvement in terms of standard statistical metrics on the 3-year period, regression analysis revealed better simulations of higher flows.

KEY WORDS: Destination Earth, extreme events, hydrological forecasts

Introduction

An efficient and reliable hydrological forecasting system is a valuable tool for issuing notifications and disseminating information on floods and potential hazardous situations. Forecasts of water levels or discharges at water-gauging stations, as well as predicted water storage in catchments for the coming days or a season are important information for various users. These may include hydroelectric power companies, navigation services, water managers, agricultural sectors, water suppliers, and the general public.

Hydrological forecasting faces many challenges today. As extreme weather situations are occurring more frequently, society is increasingly demanding more accurate forecasts, including predictions of impacts and potential risks (Cloke et al., 2017; Martyniuk and Ovcharuk, 2023; Výleta et al., 2023). This requires a solid network of observations, strong technical equipment, sophisticated hydrological modelling framework, and highly specialised experts who can maintain such a complex system (Cattoën et al., 2022). Meeting these requirements can now be strengthened by enormous improvement in computing and data handling, and by technologies that brought up new capabilities. Different comprehensive datasets are available like e.g. Copernicus (Harrigan et al., 2023) and many others. Forecasting systems today can therefore work with huge amounts of data. To enhance the accuracy of model outputs and strive for more precise modelling of very local atmospheric and hydrological phenomena, efforts are underway to increase both the spatial and temporal resolution of input data and the models used (both atmospheric and hydrological), thereby improving the quality of hydrological predictions (Hoang et al., 2018; Huang et al., 2019; Sleziak et al., 2018). An important component and a significant uncertainty in hydrological forecasting systems are the hydrological models as well as the meteorological data that feed into these models, primarily precipitation (Duan et al., 2019; Valent et al., 2014).

With the aim to improve forecasting of extreme atmospheric events in Europe, the European Commission has launched an ambitious initiative called the Destination Earth (DestinE), which aim is to create Digital Twins (DT) of the Earth system (called „living replica of the Earth system“) supporting climate change adaptation policies and decision-making for reducing the impacts of extremes. One of the main goals of the DestinE is to provide DT forecasts of extreme weather with high spatial resolution about 500–750 m, exploring a finer resolution of up to 200 m for special applications, primarily for national forecasting centres and different users (Randriamampianina et. al., 2023).

The DestinE programme is implemented by three organisations as the European Centre for Medium-Range Weather Forecasts (ECMWF), the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The first phase of the programme focus on configuring, deploying and demonstrating the initial infrastructure building blocks that will support Destination Earth in its future phases (see also: https://digital-strategy.ec.europa.eu/en/policies/ destination-earth, https://www. ecmwf.int/en/about/ what-we-do/environmental-services-and-future-vision/ destination-earth, available on 19 March 2024).

The first phase of the DestinE project includes the "On-demand weather-induced extremes digital twin project (DE_330-MF)", contracted by ECMWF as a component of the DestinE's Extremes DT (Randriamampianina et al., 2023). This project, led by Meteo-France, involves partners from 22 European countries (see: Météo-France-led international partnership wins bid to develop Destination Earth's on-demand extremes digital twin (see: https://stories.ecmwf.int/m-t-o-france-wins-bid-to-develop-destination-earth-s-on-demand-extremes-digital -twin/index.html - available on 19 March 2024)). In this project, one section is focused on hydrological extremes with the aim to reconstruct nine historical extreme flood events across different countries in Europe, gathering experiences and needs from both flood forecasting centres and other local actors.

One of the reconstructed events occurred in central Slovakia, on the Hron River in Banská Bystrica city, in May 2021. The river flood belongs to the most significant in recent period. Despite being classified as a 5-year return period flood based on probability of occurrence, the gauging stations in the upper Hron River basin up to the Banská Bystrica outlet experienced exceedance of the 1st to the 3rd degree of alert levels, leading to various damages being recorded. At that time, the city of Banská Bystrica was in the process of constructing flood protection measures. Therefore, accurate hydrological forecasts of water levels were crucial information. The flood was caused first by convective (12–16 May, 2021), then frontal rainfall (17 May, 2021), which affected the entire catchment. Most of the total rainfall was recorded on May 17th, occurring within a 12-hour period. There was 55 to 70 mm of rainfall recorded in the vicinity of Banská Bystrica, with particularly higher amounts observed on the windward hillslopes. The flood wave was characterised by rapid increase as well as rapid decrease of discharges. In the city of Banská Bystrica several basements, roads, subways were flooded, basement of the hospital was displaced, landslide and electricity cut off were reported.

To ensure, that DT meteorological forecasts with high spatial resolution can provide added value to national hydrological forecasts, sensitivity analyses of national hydrological models to high-resolution meteorological forcing data were needed to be performed. The Slovak Hydrometeorological Institute (SHMU), that is responsible for issuing hydrological forecasts and warnings in Slovakia, utilizes the HBV (IHMS 6.4), and the HEC-HMS operational hydrological models on daily basis. For the purpose of this study, both models were used in current (old) and new setups.

The objective of this paper was to determine whether the new model setup, with finer spatial or time resolution and utilizing gridded meteorological forcing data, could better leverage high-resolution DT forecasts compared to the current operational setup. To fulfil the objective, we have analysed and quantified the sensitivity of two hydrological operational models to: 1) the spatial and temporal resolution of input data; 2) the initial conditions prior to the modelled flood event; and 3) the volume and redistribution of input precipitation.

Material and methods

Study area

The upper Hron River basin, located in central Slovakia, 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 2043 m a.s.l. Runoff regime of the upper Hron River is nivo-pluvial. The highest mean monthly discharges at the outlet section occur in April, the lowest ones in August, September with secondary minimum in January, February. The long-term average discharge (1961–2000) of the Hron River in Zlatno is 1.4 m^3 s^{-1}, in Brezno 7.4 m^3 s^{-1}, and in Banská Bystrica 26.0 m^3 s^{-1}. According to Climate Atlas of Slovakia (2015), the upper Hron River basin is mostly located in a moderately cool to cool and humid to very humid climatic region.

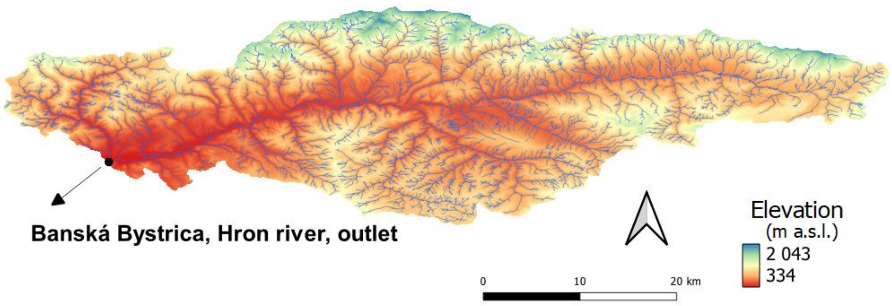


Fig. 1. Digital elevation model, river network and the outlet of the upper Hron River basin at Banská Bystrica water gauging station.

The lowest parts of the basin are in a moderately warm and humid to very humid climatic region. Long-term average annual precipitation (1981–2010) varies from 800 mm to more than 1500 mm in the highest mountain areas. The mean annual air temperature ranges between 4°C and 5°C. July is the warmest month, with mean monthly air temperature in the range of 14°C to 16°C. The coldest month is January, mean monthly air temperature ranges from –4°C to –6°C. The area shows a relatively well-preserved natural runoff regime. Forest covers 75% of basin area (PHPR, 2018).

Hydrological models

Two semi-distributed conceptual hydrological models were used, both in old and new setups: the HBV (IHMS 6.4, licensed) and the HEC-HMS (version 4.10). Models contain subroutines for snow accumulation and melt, soil moisture accounting procedure, routines for runoff generation and routing. Catchments are divided into sub-catchments, elevation zones of 100 m each. In the case of the HBV model we can also define the vegetation zones (as forest or field). Detailed information on the models´ structure and parameters can be found in the literature (Bergström, 1992; SMHI, 2014) for the HBV model or at the website (https://www.hec.usace.army.mil/software/hec-hms/ – available on 18 March 2024) for the HEC-HMS. The HBV and the HEC-HMS models, in both old and new setups, were calibrated over a 3-year period of June 1, 2019–June 1, 2022 (flood event included).

Input data

For configuration of the new model setups, model calibration and simulation of the flood event, different data were needed using the national data sources of SHMU. Real time or historic data were applied as follows: 1) precipitation data derived from merged radar – rain-gauge product, referred to as *qPrec* (Méri et al., 2021), in GRIB format (with 1 x 1 km^2 spatial resolution, and 15 min time step) and as sub-catchment areal data with 1 hour time step; 2) air temperature from INCA product, in GRIB format (1 x 1 km^2 spatial resolution, hourly time step), and as sub-catchment areal data with hourly time step; 3) potential evapotranspiration as long term mean monthly values; 4) discharges as time-series (15-min and 1 hour time step); based on the SHMU State Hydrological Network. Measured precipitation and temperature data served as forcing data for hydrological model simulations. For finer catchment discretization, setting the elevation zones, calculating the proportion of the land use, or catchment delineation the elevation data from DEM10 and Land cover from Slovak Geodetic Portal, version 2021.00, were used.

Spatial and temporal resolution of the models

The old HBV model, currently operational in the upper Hron River basin, is configured with a spatial resolution that discretizes the basin into 5 sub-catchments with the average size of 350 km². The model also employs a time resolution of 1 hour.
In the new HBV model setup with finer spatial resolution, the basin was discretized into 17 sub-catchments closed by outlets, with the average size of 104 km^2. Additionally, a total 26 sub-catchments were defined for precipitation and temperature input, with the average size of 68 km^2. The temporal resolution remains at a 1-hour time step, consistent with the old setup.
The HBV model configurations are shown in Fig. 2. Basin averages of radar-based precipitation estimates and air temperature are used as input data in both setups of the HBV models.
Similarly, the old HEC-HMS model, which is currently in operation, retains the same spatio-temporal resolution as the old HBV model setup. The basin is discretized into 5 sub-catchments with the average size of 350 km^2 and with 1 hour time step. The new HEC-HMS model setup features a structured discretization of 1000 m cell sizes, with one computation point (one catchment) covering an area of 1766 km^2. Basin averages of radar-based precipitation estimates and air temperature are used only in the old setup of the model. In the new setup, gridded precipitation and temperature input data with 15-min time step are used. The original hourly temperature data were aggregated by linear interpolation to a 15-minute time step. The HEC-HMS model configurations are shown in Fig. 3.

Sensitivity analyses

For quantification of model sensitivity to the finer resolution of input data, finer discretization of sub- catchments, various initial states, volume and

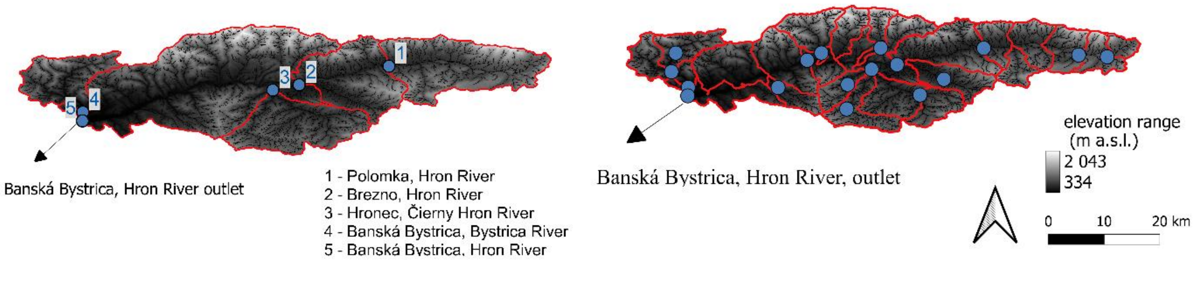
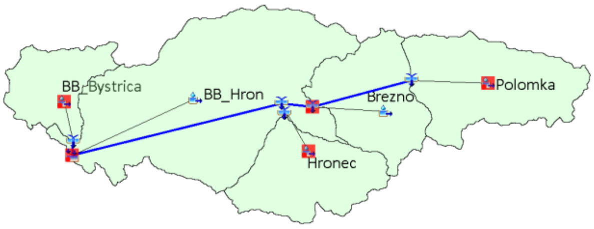


Fig. 2. Spatial configuration of the HBV model: a) the old model setup (left), b) the new model setup (right).



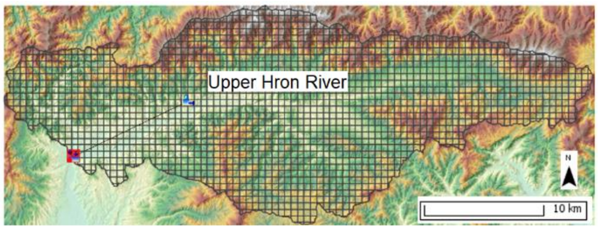


Fig. 3. Spatial configuration of the HEC-HMS model: a) the old model setup (left), b) the new model setup (right).

redistribution of precipitation within the catchment, different statistical metrics were applied. During the calibration period, which included flood event under consideration, various statistical metrics suitable for hydrological applications were used to assess the performance of the hydrological model simulations. These include Nash-Sutcliffe (NSE), Kling-Gupta (KGE) efficiencies, Root Mean Square Error (RMSE), Mean Relative Error (MRE), Pearson correlation coefficient (R^2), relative bias, error in the peak discharge, and error in the timing of the peak discharge.

Results and discussion

We analysed the capability of two hydrological models in their new setups to benefit from finer spatial discretization or a finer time-step of input data. Additionally, we investigated the sensitivity of the models to volume or redistribution of precipitation data. Comparison of the model results over a 3-year period reveals that both the old and new setups of both models yielded very similar results in terms of statistical metrics (Table 1). For example, the HBV model showed a little improvement in NSE with value 0.838 compared to 0.803 simulated with the old model setup. The HEC-HMS model provided a little worse value of NSE 0.775 in the new model setup compared to the old one (NSE 0.787). However, by visual inspection of hydrographs and regression analyses, a clear improvement in the area of large observed flows was identified (Fig. 4). This was further confirmed through simulation of the May 2021 flood event at the Banská Bystrica water gauging station (Hron River) using the HBV model (Fig. 5, Table 2). It was possible to compare modelling results for 5 water gauging stations, where other two stations Banská Bystrica (Bystrica River), and Brezno (Hron River) showed flood simulation improvement as well. Furthermore, 3-year simulations from other 11 water gauging stations provided by the new model setup showed also a satisfactory or a good performance (NSE was in the range 0.51 – 0.86), with only one station (Harmanec Papieren) exhibiting unsatisfactory results (NSE 0.29), likely due to manipulations of the hydraulic structure on the river.

We also compared model simulations using two different time steps (1-hour and 15-minute intervals) with the old HEC-HMS model setup. Results were almost identical across various metrics such as peak flow, total runoff volume, and hydrograph shape, indicating no significant change. Thus, for this specific case, the time-step variations had minimal impact on outcomes.

Simulation of flood event in May 2021

When simulating the flood wave, it was necessary to set the initial conditions of the models to match the actual conditions as closely as possible. Nevertheless, the model simulations showed that both hydrological models in the old and new-setups underestimated peak flow of the flood event at Banská Bystrica, Hron River. Simulations underestimated the observed peak discharges, with relative errors ranging from -0.296 (HBV old model) to -0.167 (HBV new model). Simulated peak discharges occurred earlier than the observed ones by 3 hours for the HEC-HMS old model, 1.75 hour for HEC-HMS new model, and 1 hour for the HBV old model. Only the HBV new model simulated correctly the timing of the peak discharge. Flood wave simulation with the HBV model showed improvement at the outlet Banská Bystrica, Hron River station (Fig. 5), and in three other stations as Polomka, Brezno, and Banská Bystrica, Bystrica River. At the Hronec station simulations with both models were comparable, but they underestimated the peak discharge. The flood event simulation by the HEC-HMS model showed very comparable results from both model setups, with the new setup even resulting in slightly worse statistical metrics (Table 3). No substantial improvement was observed. In the HEC-HMS, the new model setup was treated as one distributed catchment that utilized gridded temperature and precipitation inputs, compared to the old model with 5 sub-basins. Nevertheless, the model did not improve as expected, which could be due to several reasons: i) calibration was particularly time-consuming due to the computational demands of the gridded model and the fine calibration time step of 15 minutes, thus, it is possible that the calibration process itself was not carried out sufficiently, contributing to the lack of improvement; ii) consolidating catchment parameters as the model transitioned from 5 separate sub-basins, each with its own parameters, to a unified catchment with common parameter values, may have contributed to the model's lack of improvement. Therefore, it should be noted that one event for testing is not sufficient, and we cannot draw general conclusions. We see challenges regarding the HEC-HMS new model setup in improving the calibration and including more computing points into the model.

Influence of initial conditions

In this task the role of initial conditions in model simulations were deeper analysed. The main goal was to determine the sensitivity of the model to initial conditions. Eight different realistic initial states covering dry through medium to extreme runoff conditions were used and results are presented at Fig. 6 and Table 4.

Initial condition resulting from the very dry season (corresponding to InSt. 1 and low initial discharge value), that hypothetically may occur before the precipitation event, would cause that the HBV model will simulate the peak discharge smaller by 61% compared to

Table 1. Different statistical metrics used for comparing the old and the new model results from the period of June 2019–June 2022. Water gauging station Banská Bystrica, Hron River

	model setup	NSE	KGE	RMSE	MRE	R^2
HBV	old_model	0.803	0.863	8.575	0.28	0.828
	new_model	0.838	0.862	7.758	0.3	0.864
HEC_HMS	old_model	0.787	0.856	8.901	0.23	0.814
	new_model	0.775	0.801	9.155	0.29	0.821

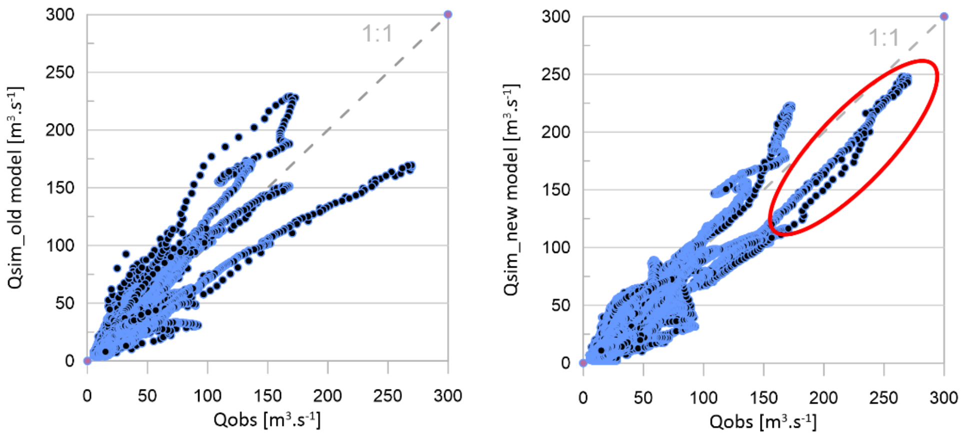


Fig. 4. Comparison of the observed flows (Qobs) with simulated flows from the old model (Qsim_old) (left) and the new model (Qsim_new) (right) for the water-gauging station Banská Bystrica, Hron River and time period of June 2019–June 2022. Results from the HEC-HMS model.

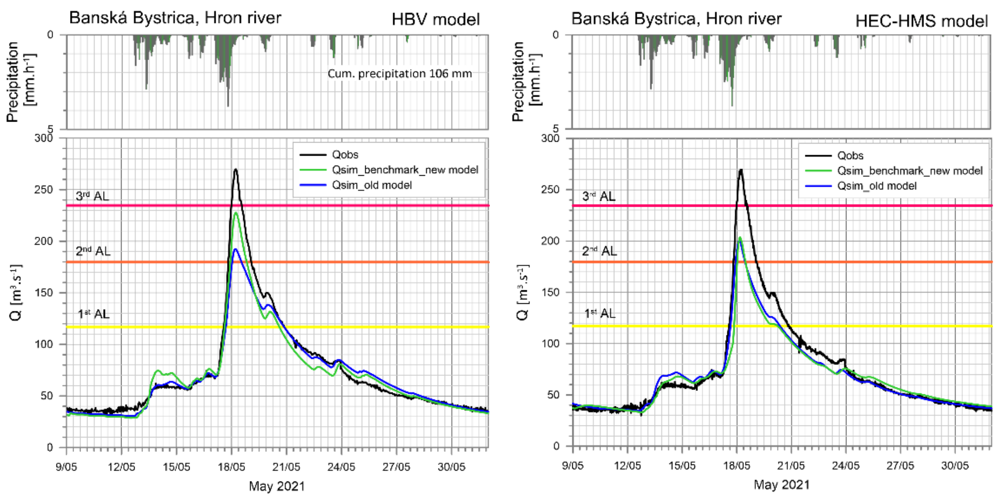


Fig. 5. Observed (Qobs) and simulated (Qsim) discharges at Banska Bystrica outlet from different model setups (old and new model) of the two hydrological models in use (HBV, left and HEC-HMS, right) for the May 2021 flood event. Observed catchment-averaged rainfall is shown in the upper panels. AL: alert level.

Table 2. **Comparison of the old and the new HBV model setups´ simulations during the flood event in May 2021 for different sub-catchment outlets. AL means alert level**

Water-gauging station	model setup	NSE	KGE	relative BIAS	Error in the peak discharge	error in the timing of the peak discharge [-/+ hrs]	exceedance of the threshold (simulated AL/ observed AL)
Banská Bystrica, Hron River	old	0.915	0.782	0.955	-0.296	-1	2/3
	new	0.950	0.842	0.947	-0.167	0	2/3
Polomka, Hron River	old	0.934	0.836	0.998	0.022	-4	1/1
	new	0.942	0.869	0.934	-0.010	-2	1/1
Brezno, Hron River	old	0.954	0.938	0.964	-0.133	1	1/1
	new	0.963	0.896	0.986	-0.013	3	1/1
Hronec, Čierny Hron River	old	0.652	0.512	0.737	-0.595	2	0/2
	new	0.642	0.494	0.739	-0.573	8	0/2
Banská Bystica, Bystrica River	old	0.553	0.518	1.005	-0.535	2	0/1
	new	0.844	0.858	1.067	-0.22	2	0/1

Table 3. **Comparison of the old and the new HEC-HMS model setups´ simulations during the flood event in May 2021 for Banská Bystrica outlet. AL means alert level**

Water-gauging station	model setup	NSE	KGE	relative BIAS	Error in the peak discharge	error in the timing of the peak discharge [-/+ hrs]	exceedance of the threshold (simulated AL/ observed AL)
Banská Bystrica, Hron River	old	0.907	0.733	0.934	-0.265	-3	2/3
	new	0.874	0.686	0.925	-0.254	-1.75	2/3

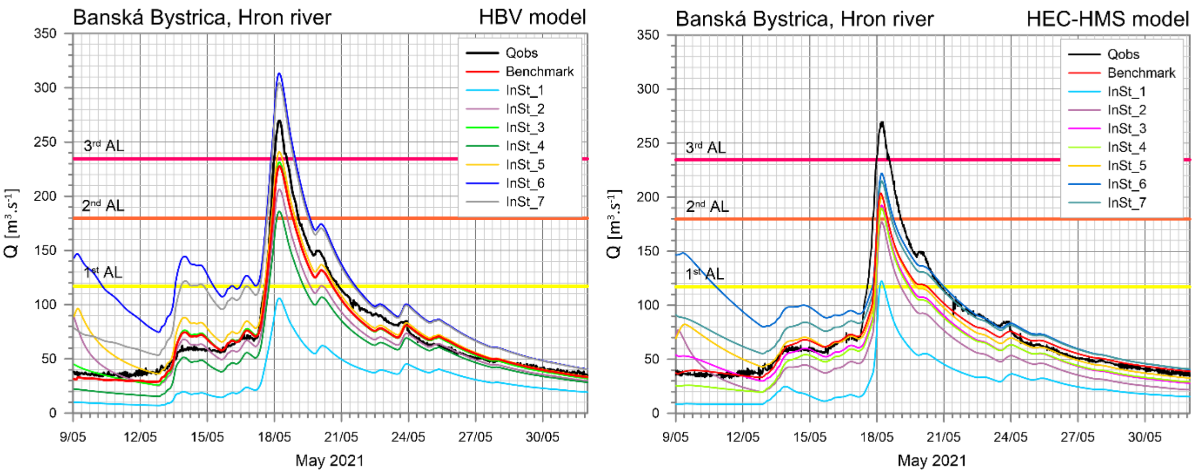


Fig. 6. *Observed (Qobs) and simulated discharges at Banska Bystrica outlet from the benchmark new models (red line) and different model initial states (InSt_1 to InSt_7) (coloured lines) for the two hydrological models in use (HBV, left and HEC-HMS, right) for the May 2021 flood event. AL: alert level.*

the observed one, and smaller by 55% with the HEC-HMS model, respectively. On the other side, very wet condition (corresponding to InSt. 7 and large initial discharge) may cause simulation of the peak discharge by 11% larger than the observed one with the HBV model. However, the HEC-HMS model would still simulate smaller peak discharge by 21% compared to the observed one, not exceeding the highest (3rd) alert level. From these experiments, it can be seen that both models are very sensitive to different initial states. Since initial states belong to the key components for accurate flood forecasting, their setting-up in operation is crucial for providing realistic forecasts (Li et al., 2018). Table 4 provides various statistical metrics quantifying the models´ sensitivity to different initial states.

Influence of precipitation volume and spatial redistribution on the HBV modelling

This part of the work was focused on testing the sensitivity of the hydrological models to precipitation redistribution and precipitation volumes. The experiment was involved by redistributing the volume of precipitation by adjusting different proportion of original radar precipitation estimate in the west and the east halves of the catchment (Fig. 7). Different scenarios as alternatives from 1 to 6 are shown in Table 5.

Our previous analyses of radar precipitation estimate (qPrec product) showed that radar precipitation was significantly underestimated in the western part of the basin, whereas in the eastern part they were overestimated, compared to point measurements obtained from rain-gauging stations (results not shown here). In fact, the highest precipitation was recorded in the western and southern part of the catchment, with 24-hour precipitation totals in the range of 55–70 mm (up to 18 May 2021 8:00 UTC).

When we look at the model´s simulations, the simulated flood event showed varying degrees of underestimation at several stations, including Hronec, Banská Bysrica (Bystrica River and also Hron River) (see Fig. 8, also Fig. 5). In many cases, the reason is the underestimation of precipitation data entering the model (qPrec product). Therefore, this task can provide deeper insight into the role of the placement and the volume of precipitation throughout the catchment, which is needed to improve the modelling results.

From Fig. 8, it is evident that at stations located in the eastern and central parts of the catchment (such as Polomka, Hronec, and Brezno), the HBV model simulated larger discharges under alternative 1, which then decreased towards alternative 6. Precipitation volume was increased by 30% in alternative 1 in the eastern half of the catchment (Table 5), resulting in an improved simulation of the flood event at Hronec station compared to the benchmark simulation at the same station. The results also show that the flood event at Polomka and Brezno stations is the best simulated between alternatives 3 and 4, which corresponds to the benchmark simulation with no change in rainfall volume. In these stations, alternative 1 to 3 overestimated the peak discharge, while alternative 4 to 6 underestimated it.

The situation is different for stations located in the western part of the catchment, such as Banská Bystrica, Bystrica River and Banská Bystrica, Hron River. The simulated discharges increase from alt. 1 to alt. 6, corresponding to increased precipitation in the western half of the catchment and decreased precipitation in the eastern part. The best result for Banská Bystrica, Hron River was achieved under alternative 5 or 6 (an increase in precipitation in the western part of the basin by 20–30% and a simultaneous decrease by 20–30% in the eastern part of the basin). For Banská Bystrica station, Bystrica River, the best result was achieved under alt.5 (increase in precipitation in the western part of the catchment by 20%). Since this catchment is entirely located in the western part of the catchment, the change in precipitation in the eastern part of the upper Hron River catchment had no effect on the simulations in this particular basin. Our analysis underscores

Table 4. Evaluation of different initial model states on the May 2021 flood wave simulations. The minus sign in the timing of the peak discharge means, that the peak is simulated earlier than was observed. AL means alert level

Different initial states	NSE	KGE	relative BIAS	Error in the peak discharge	error in the timing of the peak discharge [-/+ hrs]	exceedance of the threshold (simulated AL/ observed AL)
			HBV model			
Init.1	-0.155	0.174	0.419	-0.612	-1	0/3
Init2	0.858	0.710	0.879	-0.245	-1	2/3
Init.3	0.951	0.850	0.950	-0.153	-1	2/3
Init.4	0.741	0.615	0.743	-0.319	-1	2/3
Init.5	0.903	0.834	1.059	-0.118	-1	3/3
Init.6	0.177	0.489	1.484	0.148	-1	3/3
Init.7	0.669	0.658	1.327	0.115	-1	3/3
benchmark	0.950	0.842	0.947	-0.167	-1	2/3
			HEC-HMS model			
Init.1	-0.269	0.146	0.372	-0.552	-1	1/3
Init2	0.548	0.492	0.680	-0.351	-0.75	1/3
Init.3	0.765	0.603	0.815	-0.295	-0.75	2/3
Init.4	0.733	0.598	0.752	-0.305	-0.75	2/3
Init.5	0.783	0.637	0.941	-0.266	-0.75	2/3
Init.6	0.373	0.549	1.261	-0.187	-0.75	2/3
Init.7	0.788	0.658	1.103	-0.213	-0.75	2/3
benchmark	0.874	0.686	0.925	-0.254	-1.75	2/3

Table 5. Volume of precipitation (proportion of radar product) redistributed in Western and Eastern part of the catchment in alternatives 1–6. Benchmark is without any redistribution

	benchmark	alt.1	alt.2	alt.3	alt.4	alt.5	alt.6
West	1	0.7	0.8	0.9	1.1	1.2	1.3
East	1	1.3	1.2	1.1	0.9	0.8	0.7

Fig. 7. The division of the upper Hron River basin into western and eastern parts for the purpose of the precipitation redistribution analysis.

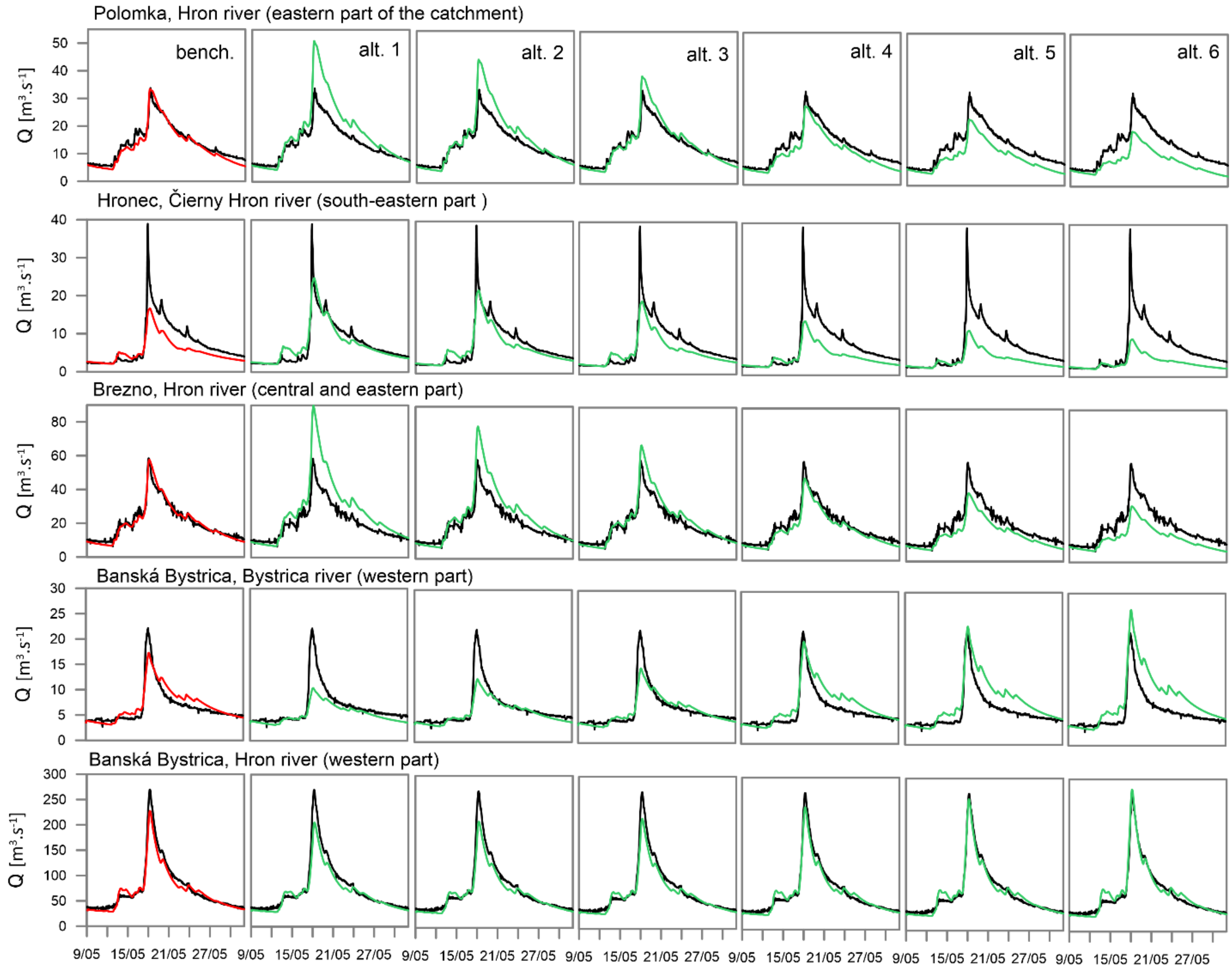


Fig. 8. Sensitivity of the HBV model to precipitation redistribution and volume for the May 2021 flood event at different water-gauging stations within various alternatives (alt. 1–alt. 6, benchmark simulation is without precipitation correction. Black lines denote to observed discharges, coloured lines correspond to simulated discharges).

the significance of the identified differences in precipitation volume and distribution across the catchment, as demonstrated by the examination of alternative scenarios and their effects on flood event simulations. These findings aligns with previous research, such as (Emmanuel et al. 2015), which has documented the influence of rainfall spatial variability on the modelling of catchment response. Emmanuel et al. (2015) also reported that the impact of rainfall spatial variability on runoff modelling at the catchment scale depends on the combined influence of several factors as rainfall patterns, catchment characteristics, and runoff generation processes.

Influence of precipitation volume on the HEC-HMS modelling

Using the HEC-HMS model, an experiment was performed by increasing the volume of precipitation by 5, 10 and 15% percent of the original radar data. An increase in precipitation volume by 15% resulted in the simulated discharge being overestimated compared to the observed peak discharge (ΔQ=0.082) (Fig. 9). In other cases, although the model simulations were displaying an overall better performance than the benchmark (simulation without radar precipitation correction), they still underestimated the peak flow (relative error in peak discharge for +5% and +10% were -0.144 and -0.032, respectively). The increase in precipitation volume improved the model simulations, e.g. values of NSE were in the range of 0.930 to 0.968 compared to the benchmark performance (0.874) (Table 6). The results obtained confirm model sensitivity to rainfall volume.

Conclusion

Destination Earth aims to provide on-demand forecasts for extreme weather events at high spatial resolution. Their use in impact applications has the potential to improve national forecasting and decision-making processes related to extreme weather events, such as issuing warnings and conducting risk assessments. In order for such forecasts to be effectively utilized in hydrological forecasting systems, it was necessary to test the sensitivity of hydrological models used in national forecasting services for the spatial resolution of input data, particularly precipitation. In the framework of the DE_330_MF project, 9 historical floods from 9 European countries were analysed.

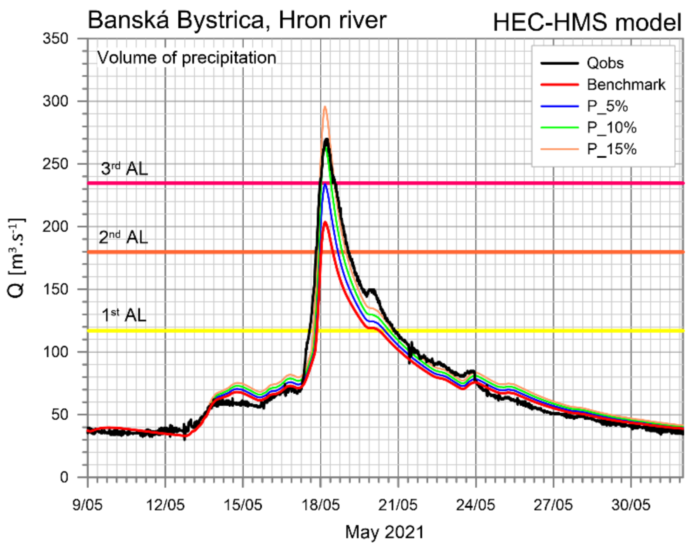


Fig. 9. Observed discharge (Qobs), benchmark discharge (red line), and simulated discharges considering different precipitation volumes (colored lines) during the flood event in May 2021 at Banska Bystrica outlet from the HEC-HMS model. AL: alert level.

Table 6. Evaluation of the HEC-HMS model sensitivity to the precipitation volume

Precipitation multiplication factor	NSE	KGE	relative BIAS	Error in the peak discharge	error in the timing of the peak discharge [-/+ hrs]	exceedance of the threshold (simulated AL/ observed AL)
1.05	0.930	0.778	0.966	-0.144	-2	2/3
1.1	0.962	0.870	1.007	-0.032	-2	3/3
1.15	0.968	0.938	1.049	0.082	-2	3/3
benchmark	0.874	0.686	0.925	-0.254	-1.75	2/3

In this work, results from Slovakia using two rainfall-runoff hydrological models, HBV and HEC-HMS, were presented. Both models have the same operational setup, consisting of 5 sub-basins, with hourly average areal rainfall and air temperature inputs for each sub-basin. In the new configuration, however, the HBV model was discretized into 17 sub-basins enclosed by a water gauging station, with input data obtained from 25 sub-basins. In contrast, the HEC-HMS model in the new setup consisted of a single distributed basin, with input data provided in the form of a 1000x1000 m grid and a time step of 15 minutes.

Simulations conducted over the three-year period from June 2019 to June 2022 revealed that both the old and new model setups yielded comparable results for the Banská Bystrica station. Specifically, the NSE for the HBV old model was 0.803, whereas for the new model, it improved slightly to 0.838. Similarly, for the HEC model, the NSE was 0.787 in the old setup, whereas it decreased slightly to 0.775 in the new setup. Through regression analysis and comparison of simulated hydrographs, it was observed that both models exhibit improved simulations of high flows at the mentioned station. However, both models underestimated the peak discharge on May 2021 at Banska Bystrica in both model setups. This was partly due to underestimated radar precipitation estimate in the western and southern parts of the basin. The best simulation was obtained by the new HBV model setting. The NSE was 0.95, the error in the peak discharge was -0.167, the timing of the peak was correctly captured.

The sensitivity of the models to initial conditions prior to the flood event, rainfall volume and rainfall redistribution was tested with new model settings. The analysis of eight different initial conditions corresponding to dry, medium, and extremely wet conditions revealed that the initial condition belongs to key parameters significantly impacting the subsequent simulation of the flood wave for both models. While the HBV model resulted in an overestimation of the flood wave under two most extreme wet initial conditions, the HEC-HMS model failed to capture the peak, even under these extreme conditions. For the HEC-HMS model, addressing this issue required increasing the rainfall volume across the entire catchment by 10% or more. This adjustment resulted in an NSE of 0.962 and a peak discharge error of 0.08, with the peak simulated to occur two hours earlier than observed.

The HBV model was assessed for precipitation redistribution and precipitation volume sensitivity using various combinations of original radar precipitation proportions in the western and eastern halves of the basin. This task shows the importance of proper precipitation location and volume. In addition to initial conditions, these are key factors for a correct hydrological forecast.

In the upcoming second part of the case study, we would like to focus more on the hydrological forecasts of the flood event obtained using DT high-resolution meteorological forecasts, which were at 700 m and 2 km spatial resolutions. These forecasts will be compared with national meteorological forecasts from the ALADIN/SHMU model at a resolution of 4.5 km.

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