Extreme precipitation event in Slovakia in September 2024

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Introduction

Extreme precipitation events pose significant risks to society, impacting infrastructure, agriculture, and ecosystems. In mid-September 2024, Storm Boris brought heavy rainfall, flooding, and significant damage to Central and Eastern Europe. This event severely impacted Austria, the Czech Republic, Poland, Romania, and Slovakia, with significant precipitation also recorded in Germany. The exceptional scale and intensity of the event highlight the escalating meteorological and climatological challenges in an era of increasing climatic variability. This study analyzes the intensity, spatial distribution, and meteorological drivers of this extreme preciptation event.

Situation in Europe

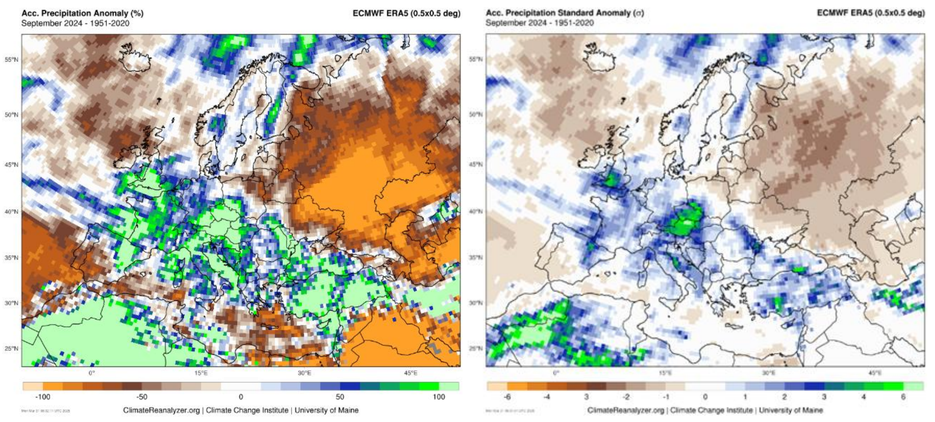

Fig. 1 *Accumulated precipitation anomaly [%] (left) and standard anomaly of accumulated monthly precipitation [σ] (right) in Europe in September 2024 based on the ERA5 reanalysis (ClimateReanalyzer.org).*

Selected stations

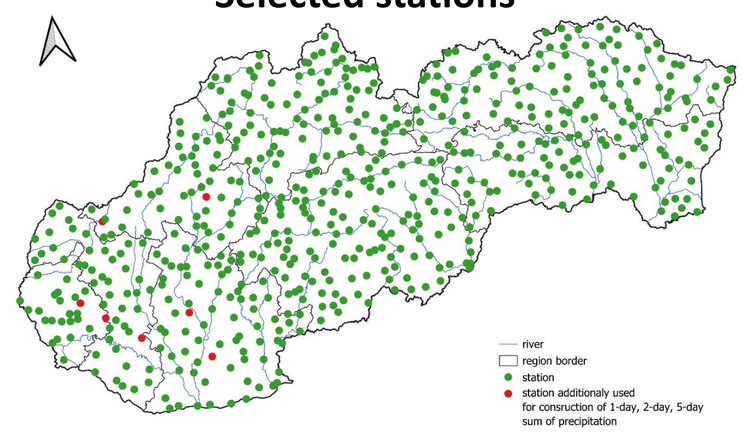

Fig. 2 *Selected precipitation stations.*

Synoptic situation

Storm Boris developed toward the end of the second week of the month as a strong low-pressure system and moved from the western Mediterranean, where the above-average temperatures favored the evaporation of large amounts of moisture, which was subsequently transported into central Europe. The low-pressure area remained sandwiched between high-pressure zones, and this led to the rainfall persisting for several days (Kimutai et al., 2024). The primary driver of this extreme rainfall was a Vb cyclone, a meteorological phenomenon first identified by Wilhelm Jacob van Bebber (1891). This mechanism was responsible for some of the most severe flooding events in Europe's history, including the Elbe flood of 2002 and the Oder flood of 1997 (Niesen et al., 2013; Ulbrich et al., 2023). In September 2024, the Vb system remained stationary for an extended period, allowing unprecedented amounts of rainfall to accumulate over several days.

Data and methods

For the spatial analysis of maximum daily precipitation totals (Rx1D), maximum 2-day totals (Rx2D) and maximum 5-day totals (Rx5D) 601 stations, owned and operated by the SHMÚ were used. For the statistical analysis of maximum daily and multiday precipitation totals, only currently active stations with at least 50 years of digitized precipitation records were considered. To evaluate the extremity, we analyzed and ranked the Rx1D, Rx2D, and Rx5D values and computed relative anomalies, defined as the ratio between the 2024 value and the previous maximum value for each station with at least 50 years of data.

Additionally, we assessed the extremity of the recorded precipitation using the standard deviation (σ) of long-term daily and multiday precipitation totals and conducted a frequency analysis using quantiles corresponding to return periods return periods of 50-, 100-, and 200 years.

Daily and cumulative precipitation 11.09. – 16.09.2024

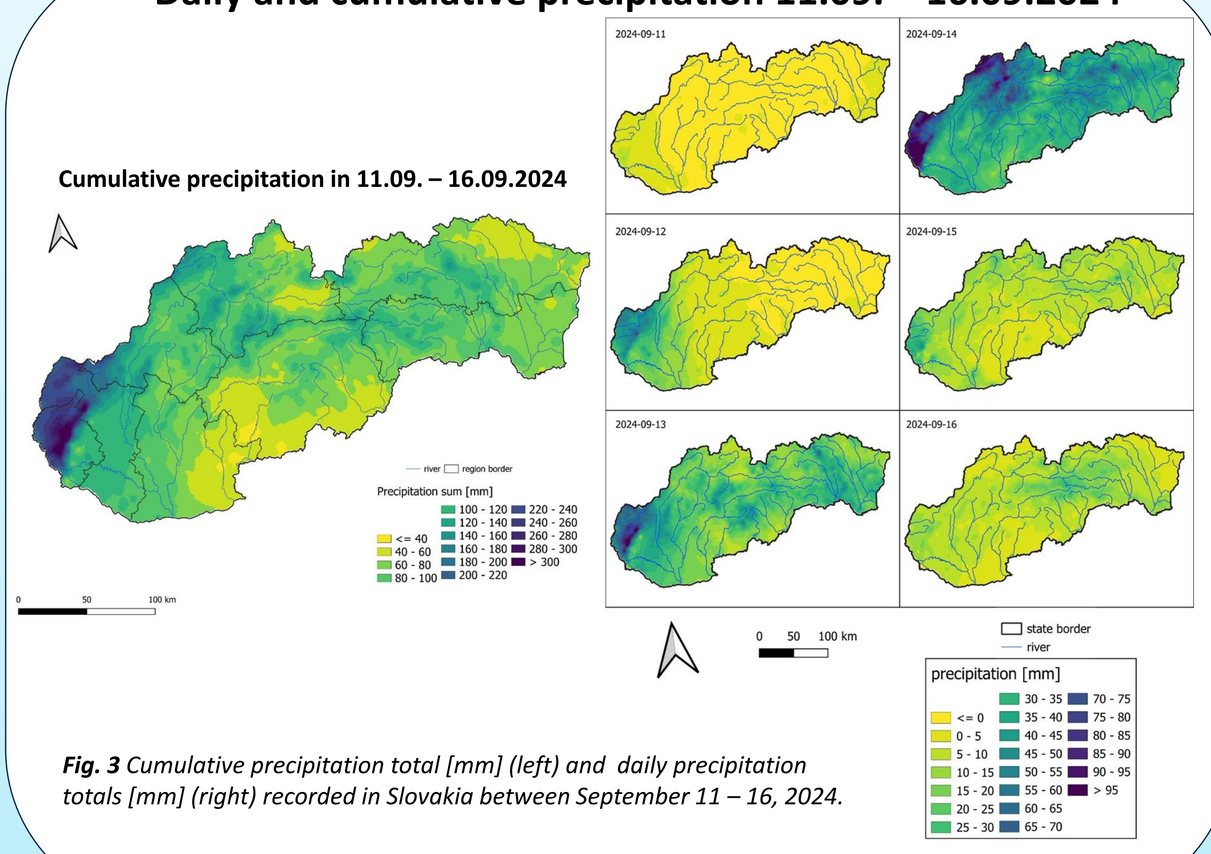

Fig. 3 *Cumulative precipitation total [mm] (left) and daily precipitation totals [mm] (right) recorded in Slovakia between September 11 – 16, 2024.*

Results and conclusions

The 2024 event broke multiple Slovak national precipitation records. The highest-ever 2-day and 5-day precipitation totals were recorded at Borinka (Rx2D 267.3 mm) and Pernek (Rx5D 379.8 mm) both situated in the Záhorie region at the foothills of the Little Carpathians. More than 20% of stations with at least 50 years of measurements set new records for 2-day or 5-day rainfall, and in many cases these records exceeded previous maxima by more than 100%. In extreme cases, relative anomalies for multi-day totals surpassed 200%, indicating a dramatic departure from historical norms.

At least 25 stations recorded 5-day precipitation totals exceeding the estimated 200-year quantile, while dozens more surpassed the 100-year threshold. Similarly, 2-day totals exceeded 200-year quantiles at 15 stations. These findings suggest that the event's intensity is consistent with precipitation magnitudes expected only once in multiple centuries. Numerous stations recorded multi-day precipitation totals more than 6σ above the long-term mean, with Pernek and Kuchyňa – Nový Dvor exceeding the 8σ threshold. Such values indicate exceptionally rare events with very low statistical probabilities, reinforcing the interpretation that this was a highly anomalous event, even within the broader context of a changing climate.

Maximum 1-day, 2-day and 5-day precipitation totals 11.09. – 16.09. 2024

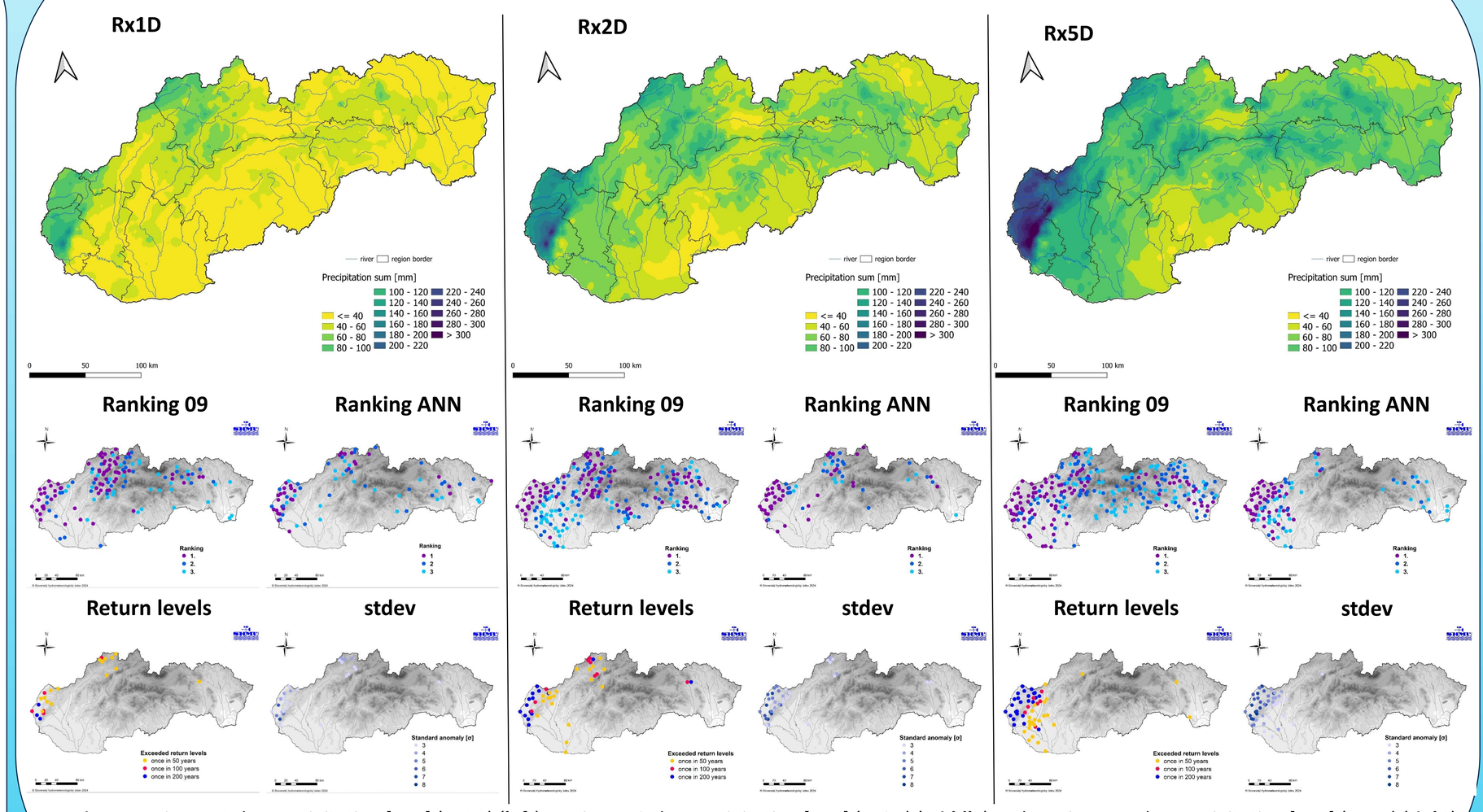

Fig. 4 *Maximum 1-day precipitation [mm] (Rx1D) (**left**) maximum 2-day precipitation [mm] (Rx2D) (**middle**) and maximum 5-day precipitation [mm] (Rx5D) (**right**) in Slovakia during the period 11 – 16, 2024, with rankong among the September totals (Ranking 09), ranking among the annual totals (Ranking ANN), exceeeded return levels (Return levels) amd standart anomaly of respective totals (stdev).*

References

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