Severe weather studies using high resolution forecast applications at SHMU

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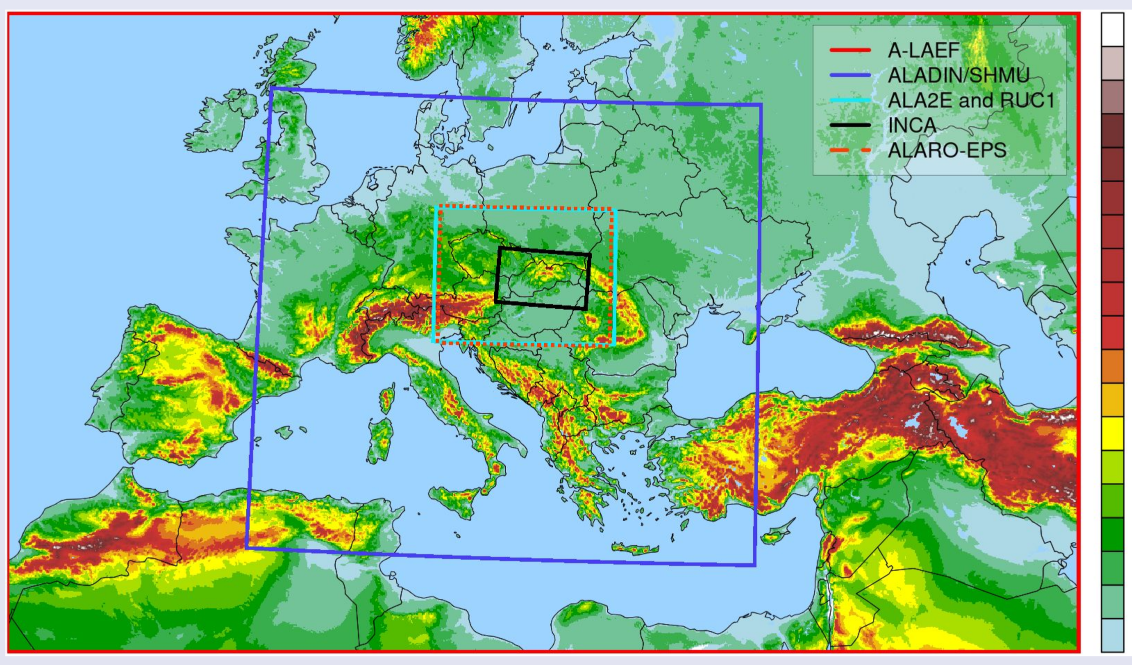
ACCORD – A Consortium for COnvection-scale modelling Research and Development

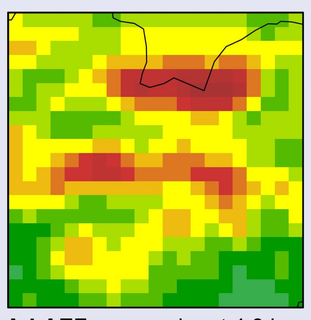
LACE – nwp central europe

During the past decade, several small-scale severe weather events such as floods, hailstorms, downbursts, tornadoes or freezing rain appeared in Slovakia, which posed new challenges in protection of civilians and infrastructure. Early warnings and assessment of impacts require forecasting applications, which are capable of monitoring the evolution of extremes across different scales and forecasting lead times. At SHMU, these are mostly based on the ALARO canonical configuration of the ALADIN NWP system. INCA-SK is a local adaptation of the INCA nowcasting system and provides nowcasts of basic surface meteorological parameters (temperature, wind, humidity). In addition, the qPrec algorithm was developed to refine the precipitation analysis using rain-gauge and radar data – qPrec (quality Precipitation). Since 2021, a rapid update cycle (RUC1) has been developed in order to provide nowcasts and very short range forecasts at high resolution, which should at least partially replace or supplement the INCA outputs in the future. Although not fully operational, RUC1 has been running regularly since 2022, with its forecasts available to forecasters. The main focus of this system is to forecast deep convection, precisely determining its location and intensity at the end of the nowcasting period and at the very short range. The ALA2E, ALADIN/SHMU, and A-LAEF systems are primarily used as operational NWP applications for short range weather forecasting. These systems were successfully used in forecasting precipitation during the September 2024 floods in Central Europe. Mini-EPS configuration based on the A-LAEF uncertainty simulations (containing 6+1 members) has been successfully tested at a 1 km resolution and even at the hectometric scale (750 m resolution). The described systems are constantly being developed and improved, and we experiment with assimilation of additional data types (e.g. radars in RUC1) and with higher spatial resolutions on hectometric domains (up to 250 m resolution).

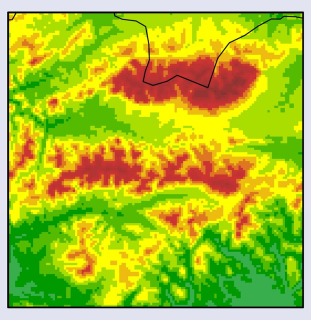
NOWCASTING AND VERY SHORT RANGE FORECASTING SYSTEMS			SHORT-RANGE FORECASTING SYSTEMS		
Characteristics	*INCA-SK*	*Regular RUC1*	ALA2E	ALADIN/SHMU	A-LAEF
Type	Extrapolation-based nowcasting system blended with NWP model	NWP model as a rapid update cycle, deterministic	Limited area NWP model, deterministic	Limited area NWP model, deterministic	Limited area NWP model, EPS, 16+1 members (with perturbed INIT, LBC, model physics)
Assimilated data	Surface data (T2m, U, V, q), raingauge + radar data (qPrec method for precipitation analysis)	CANARI and 3DVAR: OPLACE (surface), TEMP, AMDAR, MODE-S, METEOSAT HRW	No data assimilation, only dynamical downscaling, initial conditions from the A-LAEF control member INIT	CANARI+3DVAR+blending: OPLACE (surface), TEMP, AMDAR, MODE-S, METEOSAT HRW	ESDA assimilation of surface data (with perturbed OBS), upper-air spectral blending
Driving model	ALADIN/SHMU for blending	ARPEGE (LBC, 1h coupling frequency)	ECMWF (LBC, 3h coupling frequency)	ARPEGE (LBC, 3h coupling frequency)	ECMWF ENS (LBC, 6h coupling frequency)
Horizontal resolution	1 km	1 km	2.0 km	4.5 km	4.8 km (750m and 1 km tested in experimental mode)
Forecasting range	+12 h	hourly, up to +12 h, +24 h at 00/06/12/18 UTC	+84 h	+78 h	+72 h
Update frequency	hourly	hourly	00/12 UTC	00/06/12/18 UTC	00/12 UTC
Time-slot for collecting data	15 min.	0.5 h (short cut-off)	None	Long cut-off	1 h

Domains of computation





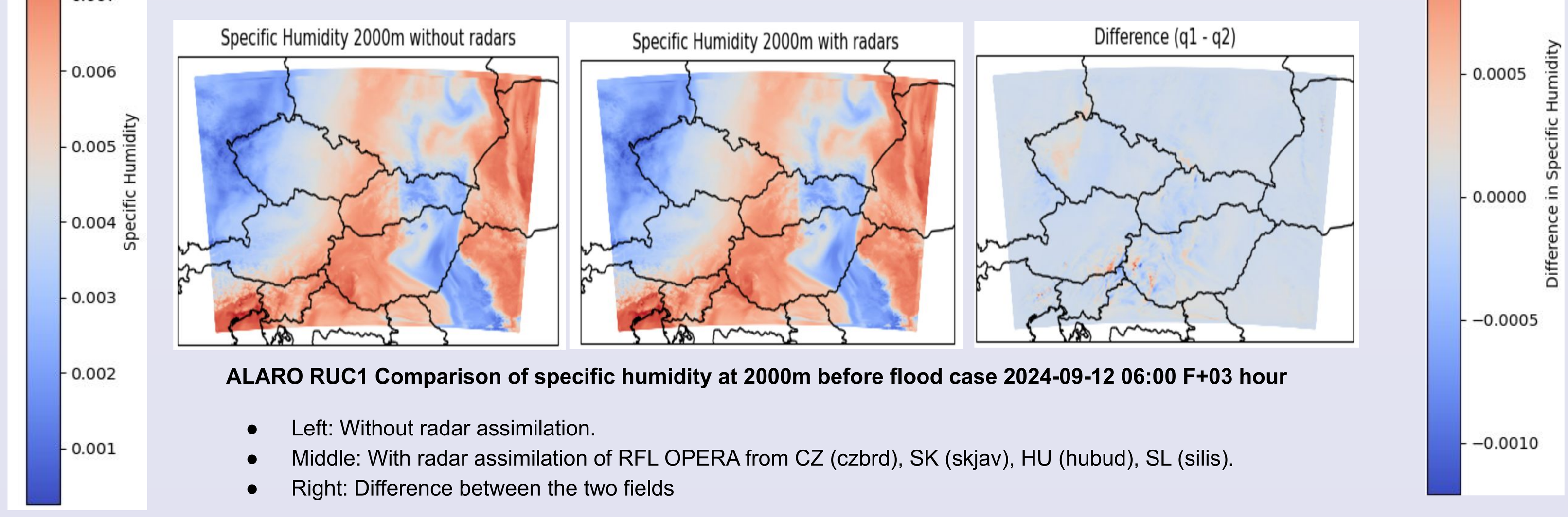
A-LAEF: orography at 4.8 km zoomed over Tatra Mountains



ALARO-EPS: orography at 750 m zoomed over Tatra Mountains

RUC1 Radar data assimilation case study with CY46T1

One of the aims of the SHMU NWP team is the development of a high-resolution rapid update ALARO-1 model with radar data assimilation. The national radar data are processed by OPERA in the NIMBUS HUB.



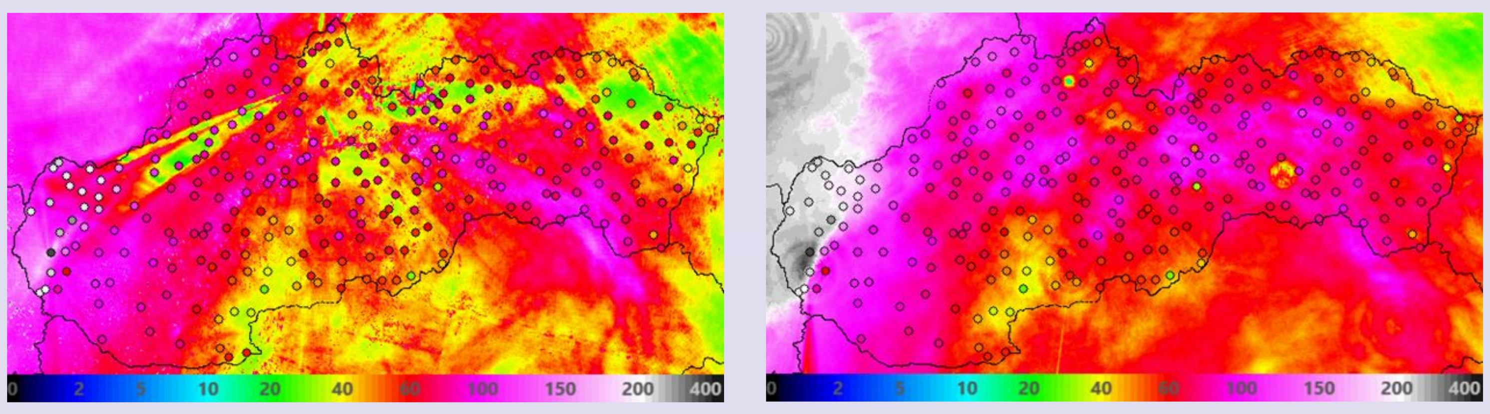
ALARO RUC1 Comparison of specific humidity at 2000m before flood case 2024-09-12 06:00 F+03 hour

- Left: Without radar assimilation.
- Middle: With radar assimilation of RFL OPERA from CZ (czbrd), SK (skjav), HU (hubud), SL (silis).
- Right: Difference between the two fields

Development of the "qPrec" method

SHMU developed its own method to obtain high quality analysis of precipitation using rain-gauge and radar data – qPrec (quality Precipitation). The precipitation analysis is computed every 5 minutes with the latest radar and rain-gauge inputs. 6 radar sites (4 SK, 1 CZ, 1 HU) and data from cca. 300 automatic rain-gauges serve as input. The processing algorithm consists of several steps:

1. Generation of 2D radar product (CMAX in this case) together with a quality field, based on quality-controlled (beam-blockage, distance from radar, attenuation, …) 3D volume data from each radar site separately
2. Conversion of CMAX fields to rain-rates on the basis of conversion functions calibrated and adjusted in real-time by rain-gauge data
3. Compositing (merging) of the calibrated rain-rate maps weighted by the quality fields
4. Generation of uncorrected 60 min. sum from the composite rain-rates from the last hour and computation of correction field according to the uncorrected-sum/rain-gauge-sum coefficient based on the "distance inside the rain-rate and topographic height fields"
5. Correction of the 60 min. sum and the rain-rate by the correction field and 25 computations of longer interval sums based on the corrected data

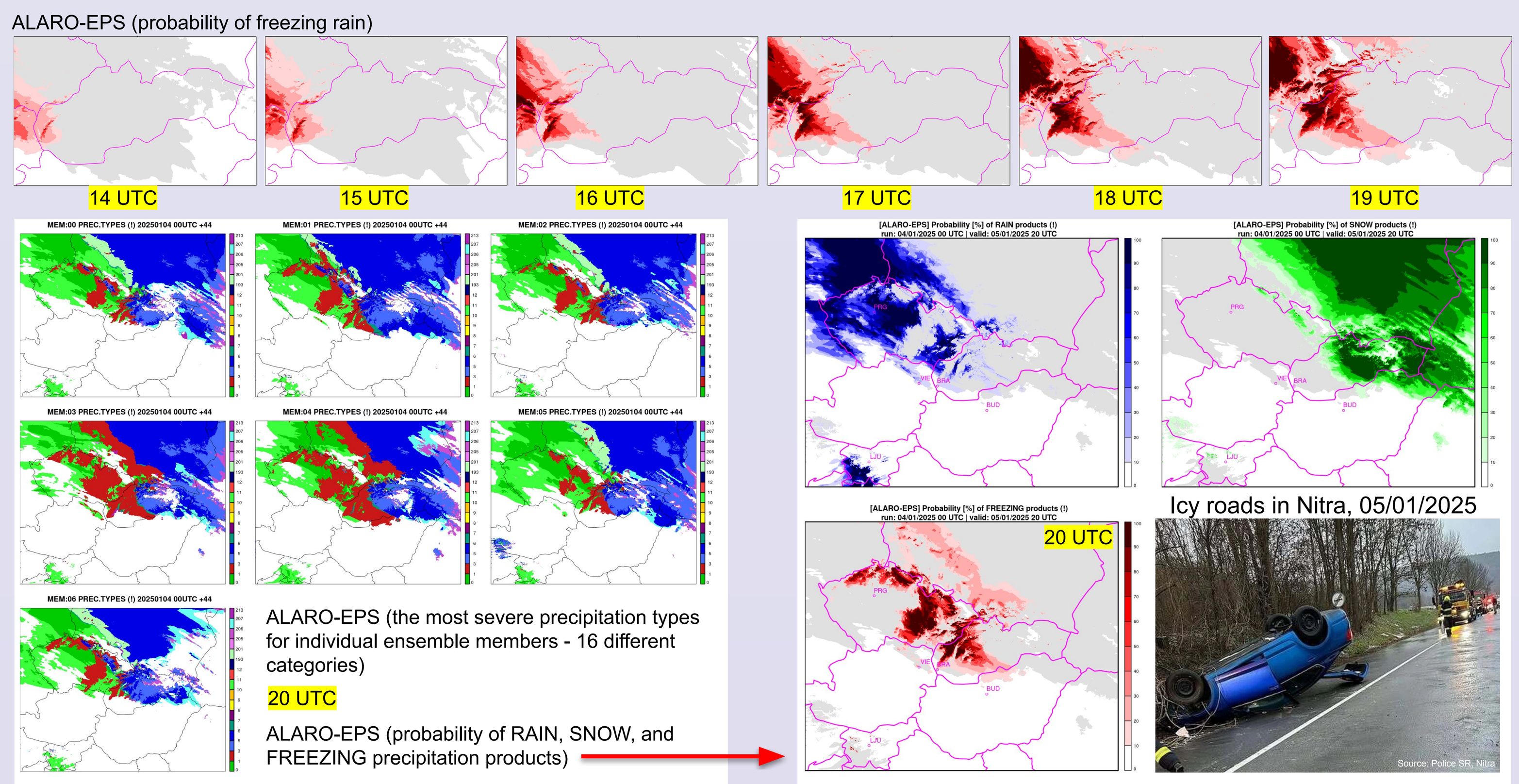


Figures above: One week rainfall accumulation [mm] from 12.09.2024 06:00 to 19.09.2024 06:00 UTC during the Boris low-pressure system computed by the previous Rainbow DPSRI product (left) and by the SHMU qPrec method (right) compared to the automatic rain-gauge network (colored dots)

Modeling of extreme weather events

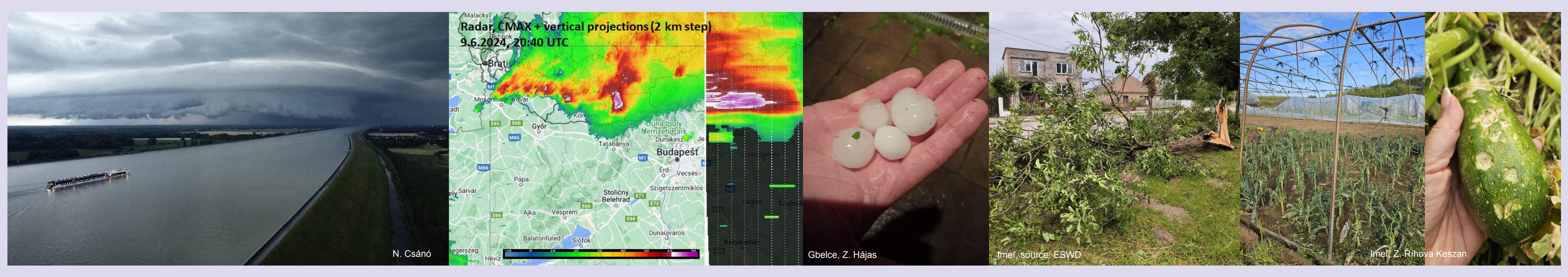
Morning snowfall transitioned to rain by the afternoon, while surface temperature remained below freezing point, resulting in freezing rain across western Slovakia. Ice-covered sidewalks and roads became a major hazard in several cities, aligning closely with the forecasted area (see below).

ALARO-EPS (750 m) forecast of precipitation types valid on 5 January 2025 (+38 ~ +44 h):

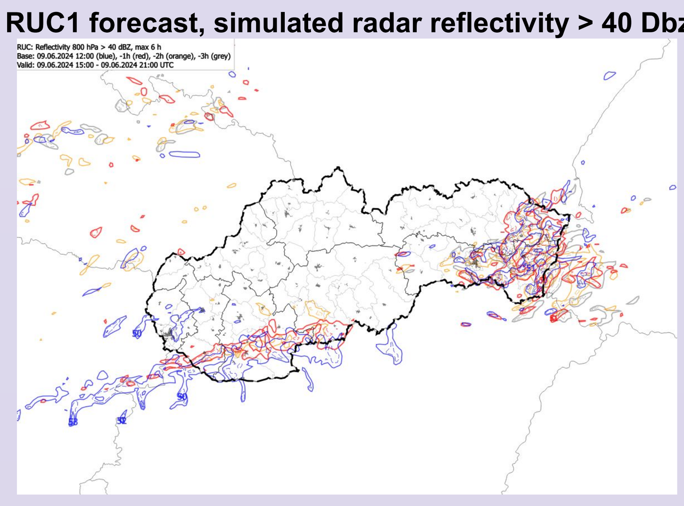


High-resolution simulation of supercell storms

In the summer time of 2024 (June, July, August) the RUC1/SHMU successfully forecast several severe events related to deep convection (windstorms, flash floods). On 09 June 2024, supercell thunderstorms appeared in the area of eastern Alps (border territory of Austria and Hungary) propagating toward southwestern Slovakia. Tornadoes were spotted at Hannersdorf (A) and Narda (H) at about 17 UTC. Later, storms causing hail, severe gusts and heavy precipitation reached the area of southwestern Slovakia as well. The most devastating damage was recorded in the village of Imeľ, where a downburst occurred with large hailstones with a diameter of approximately 3 cm.

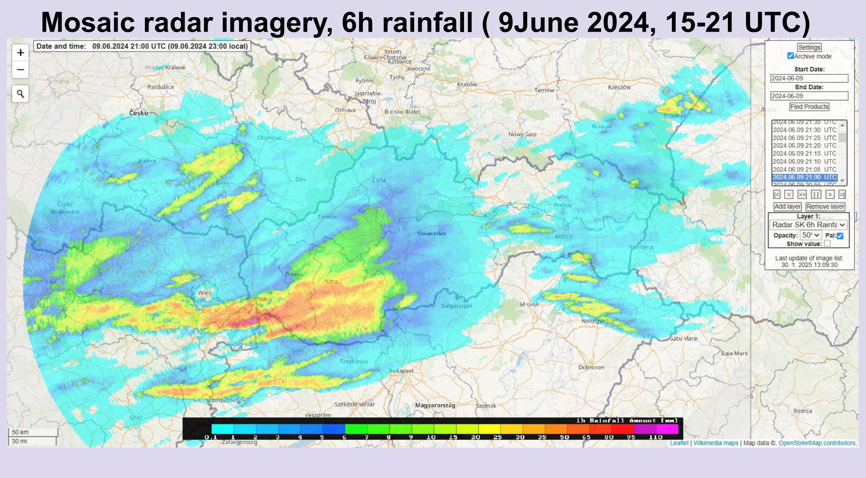


RUC1 forecast, simulated radar reflectivity > 40 Dbz



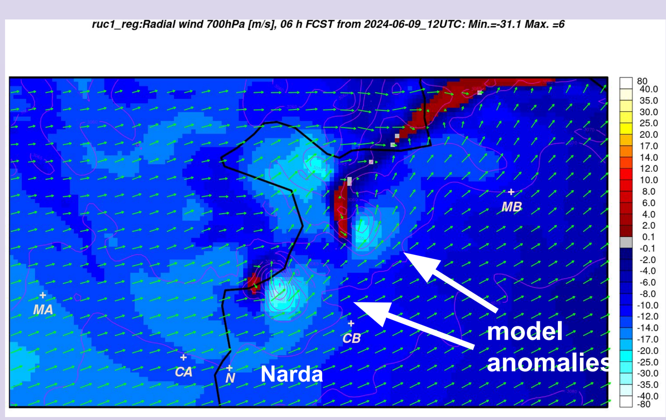
RUC1: 9 June 2024 forecasts of radar reflectivity patterns exceeding 40 Dbz from 4 consecutive runs: 9 UTC (grey), 10 UTC (orange), 11 UTC (red), 12 UTC (blue) valid for the 15-21 UTC period. The earlier runs matched better the position and motion of cells reaching southwestern Slovakia, while the 12 UTC run forecast predicted the supercell development in Austria and Hungary.

Mosaic radar imagery, 6h rainfall (9June 2024, 15-21 UTC)



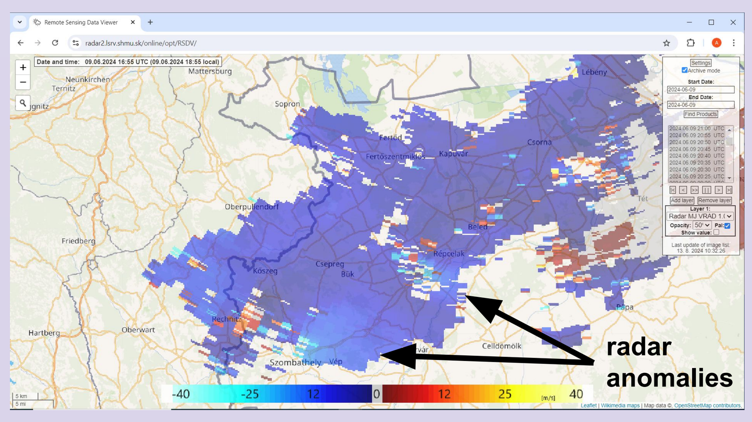
OBS: 6h accumulated rainfall (mm) from the mosaic radar imagery and measurements of 09 June 2024 between 15-21 UTC. High rainfall indicates the track of the cells affecting northwestern Hungary and southwestern Slovakia. The motion of the strongest cells was typically zonal, in contrary to the more southwest-northeast direction in the model (the propagation of real supercells could more alter to the right from the prevailing flow, possibly due to more intense rotation?).

RUC1 forecast, simulated radial velocity



RUC1: 700 hPa wind (arrows), its radial component toward the Maly Javornik radar (color shades) and geopotential (lines) forecast valid for 09 June 2024 18 UTC (6h ahead).

Observation, radial Doppler wind velocity



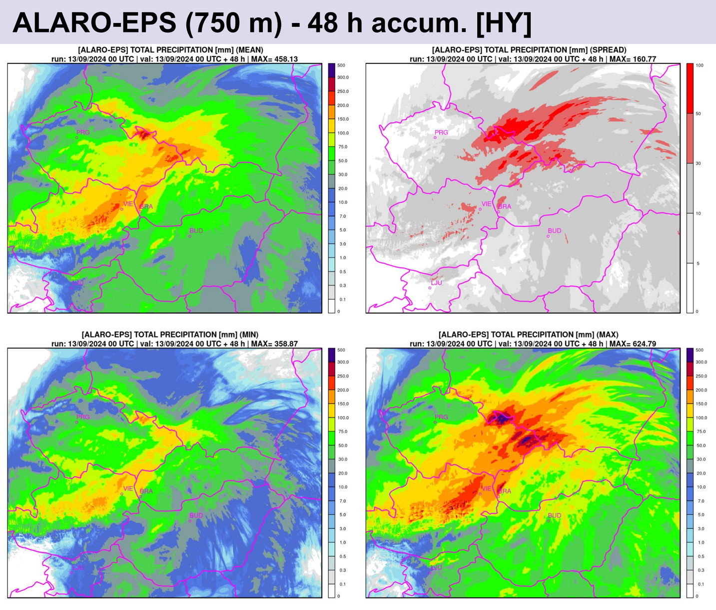
OBS: Radial Doppler wind velocity at PPI 1 deg. of the Maly Javorník radar measured on 09 June 2024 1655 UTC

Floods in Central Europe, 13-16 September 2024

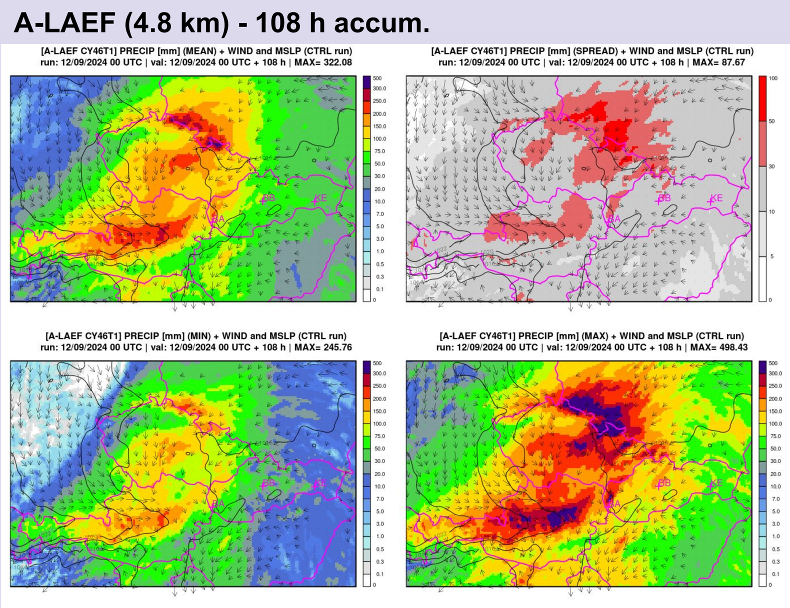
Between September 13 and 16, 2024, a low-pressure system named Boris brought record-breaking rainfall and extreme winds to central Europe, resulting in severe flooding, blocked roads by fallen trees and damaged power lines. The most affected areas included eastern Austria, regions along the Czech-Polish border, and western part of Slovakia. The flooding caused extensive damage, and tragically, loss of lives was also reported.

A comparison of the very high-resolution 750 m simulations using ALARO-EPS ensemble (6+1 members, +48 h forecast) in both hydrostatic (HY) and non-hydrostatic (NH) regimes with the (quasi) operational A-LAEF ensemble forecast at 4.8 km resolution (16+1 members, +108 h forecast), can be seen below.

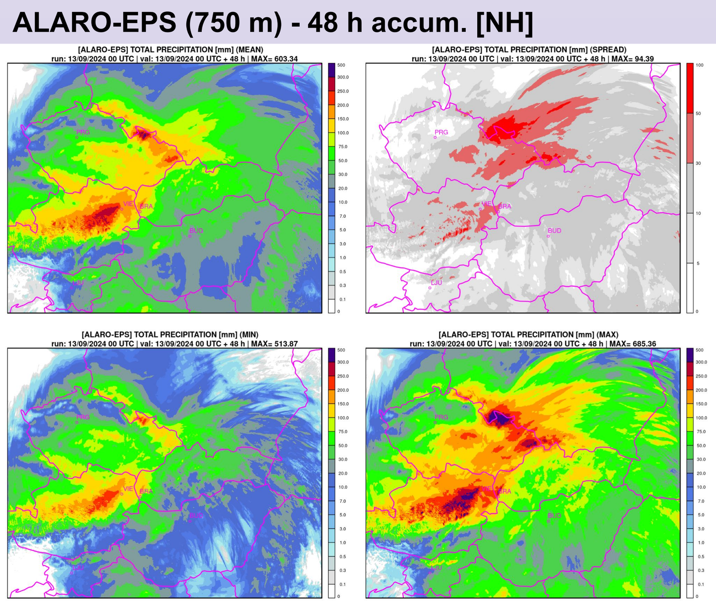
ALARO-EPS (750 m) - 48 h accum. [HY]



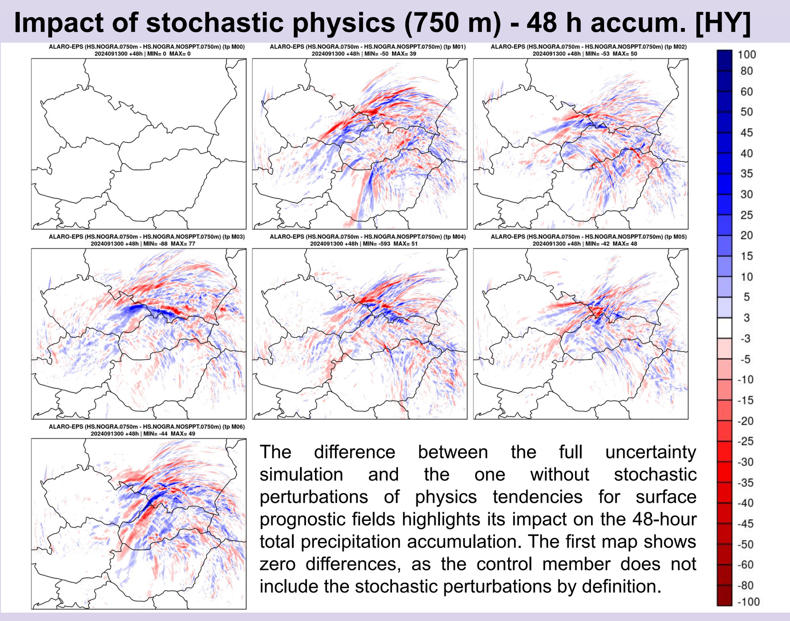
A-LAEF (4.8 km) - 108 h accum.



ALARO-EPS (750 m) - 48 h accum. [NH]



Impact of stochastic physics (750 m) - 48 h accum. [HY]



The difference between the full uncertainty simulation and the one without stochastic perturbations of physics tendencies for surface prognostic fields highlights its impact on the 48-hour total precipitation accumulation. The first map shows zero differences, as the control member does not include the stochastic perturbations by definition.

References

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