Topic 1: A-LAEF operational runs - Case studies and verification

In 2021 a lot of work has been spent on the verification of the operational A-LAEF suite. Especially during the very wet summer 2021 several catastrophic flood events occurred in Central Europe which have been investigated and reported. These situations but also the record breaking event in Northern Italy in October have shown the good quality of the A-LAEF system and in general the benefit of using a probabilistic forecasting system.

- **Case study 1: Critical temperature advection in Slovakia (07/02/2021)**

On February 7 2021 there was a strong southerly advection of warm air, however, a temperature inversion developed over the border area of SK, CZ, HU, AT countries indicated by soundings and several forecasts. High differences in T2m forecasts were related to different spread of the mixed PBL region in various models (Figure 1). Most of the models forecast a “tongue” of warmer air spreading toward North, with different extension (Figure 2). T2m was overestimated by about 10 °C in the area of Bratislava. A-LAEF MP clusters 2, 3 (both using QNSE turbulence parameterization with “stable” Geleyn-Cedilnik mixing length) showed significant, systematic improvement compared to the clusters 1 and 4 (with the similar setup as of the operational deterministic model at SHMU).

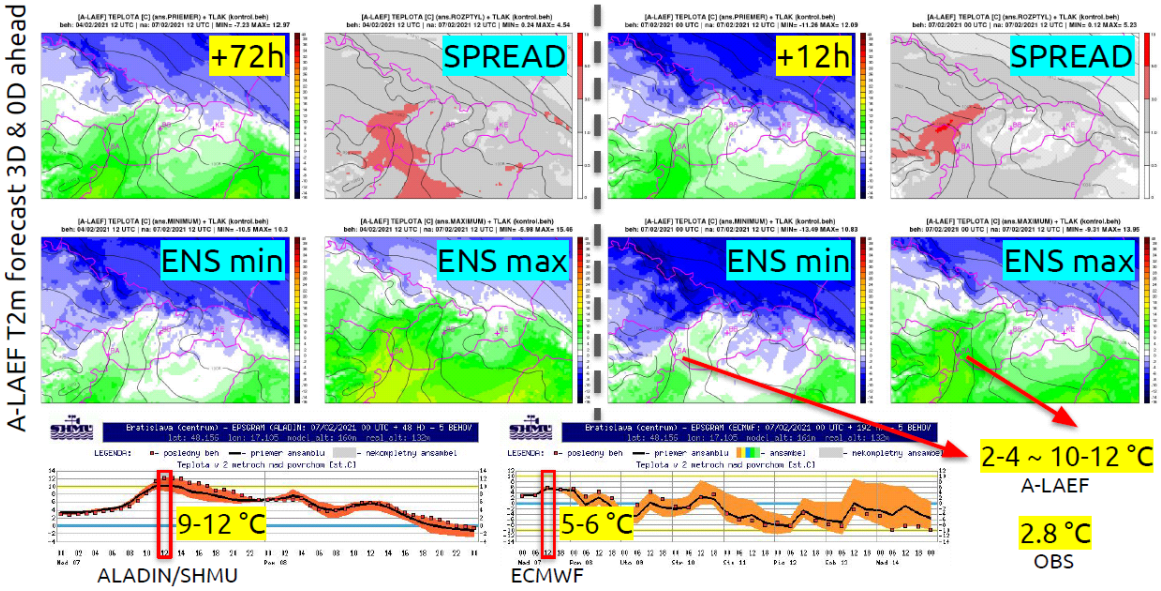


Figure 1: A-LAEF T2m forecast +72h (left) and +12h (right) for ENS average (first panel), ENS spread (second), ENS min (third) and ENS max (fourth), respectively. Lower row shows the model point forecast for A-LAEF (left) and EMCWF-ENS (right) for Bratislava.

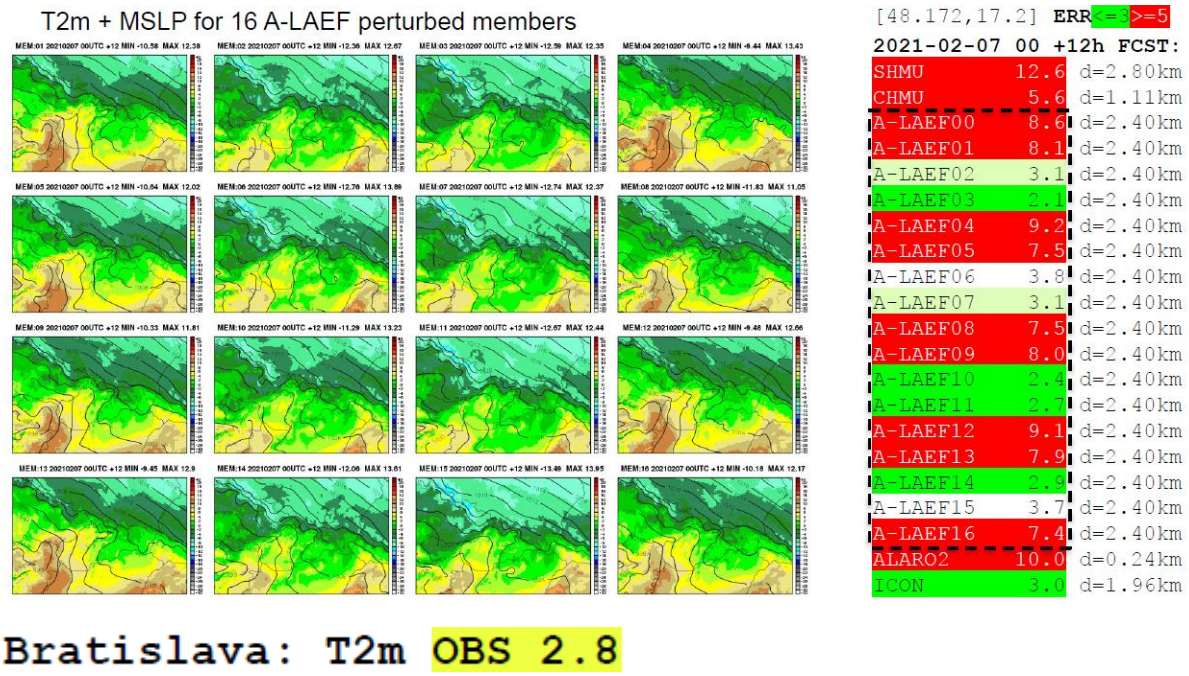


Figure 2: T2m and MSLP forecast for all 16 members of A-LAEF (left) and temperature forecast of different models for grid point of Bratislava (right).

- **Case Study 2: Large scale precipitation in Slovakia (14/03/2021)**

This event was characterized by a significant overestimation of precipitation amounts by the deterministic ALADIN/SHMU model. A-LAEF showed a much better performance for this event for most members (Figure 3).

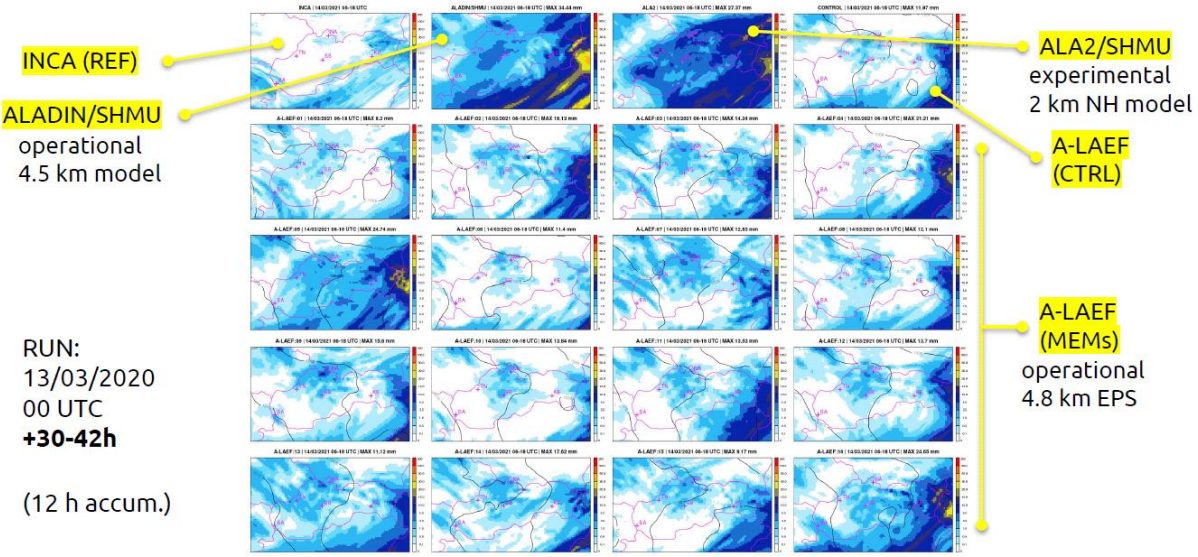


Figure 3: Total precipitation analysis (INCA, panel 1) and forecast for the period from March 14 06-18 UTC for ALADIN SHMU (panel 2), ALADIN SHMU experimental (panel 3) and the 16+1 A-LAEF members.

- **Case Study 3: Cold front passage in Slovakia (12-13/04/2021)**

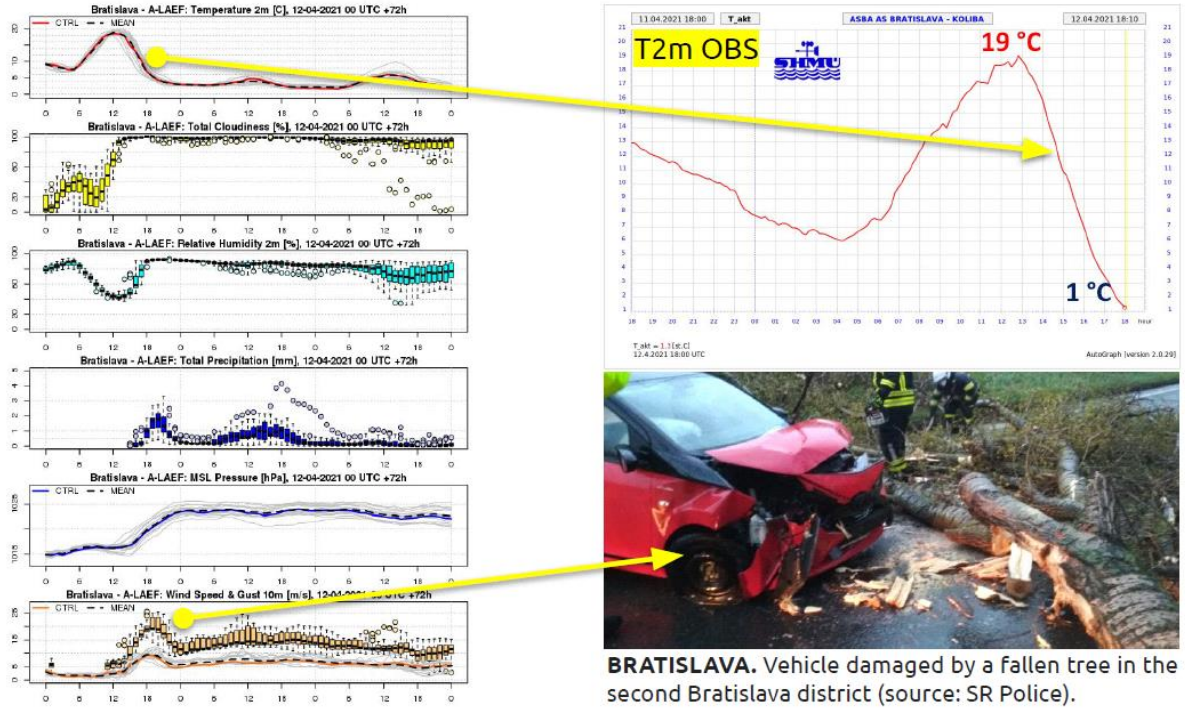


Figure 4: A-LAEF forecast (left) for temperature, cloudiness, relative humidity, precipitation, MSLP and wind gusts for Bratislava. Upper right panel shows T2m observation for SHMU station in Bratislava.

After the passage of a strong cold front on 12/04/2021, the cold air quickly invaded the southwest of Slovakia. From noon values around 20 °C, it cooled down to 1-3 °C in a few hours (Figure 4). Mixed precipitation and gradually snowfall appeared also in lowlands. Simultaneously, wind gusts exceeded 70 km/h, with a maximum of about 90 km/h. The Slovak Hydrometeorological Institute issued second level warning for strong winds in Bratislava and Pezinok districts. Several property damage was recorded mainly in connection with wind gusts. Both massive temperature drop and strong wind gusts were well captured by A-LAEF ensemble, while the uncertainty was related rather to the precise timing of the event.

- **Case Study 4: Catastrophic flood event in Germany (13-15/07/2021)**

After several episodes of heavy rain, the cyclonic weather system “Bernd” caused persistent or recurring heavy rainfall. The central parts of Germany were affected locally, but the west of Rhineland-Palatinate and the southern half of North Rhine-Westphalia were largely affected. As a result, small rivers and flash floods began to expand locally. In addition to immense property damage, over 160 people lost their lives.

A-LAEF ensemble successfully captured the precipitation event, with well localized patterns (even with unusually high probabilities of extreme precipitation amounts) – Figures 5-8.

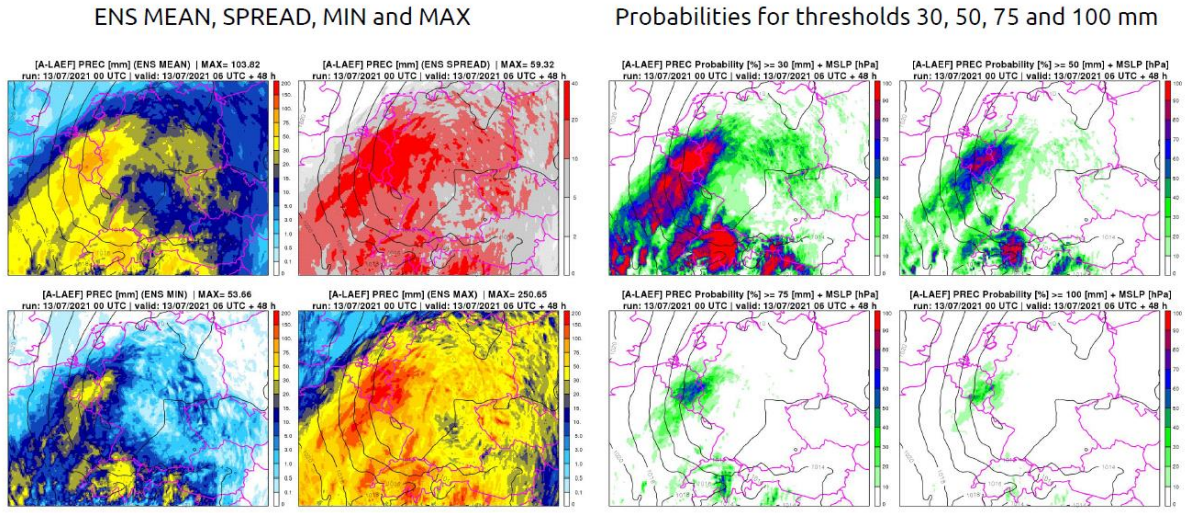


Figure 5: A-LAEF (13/07/2021 00 UTC run) precipitation forecast for the 48h period between 13/07 and 15/07/2021 06 UTC. On the left hand side ensemble mean, spread, min and max are shown, while on the right hand side probabilities for exceeding for 30, 50, 75 and 100mm are displayed.

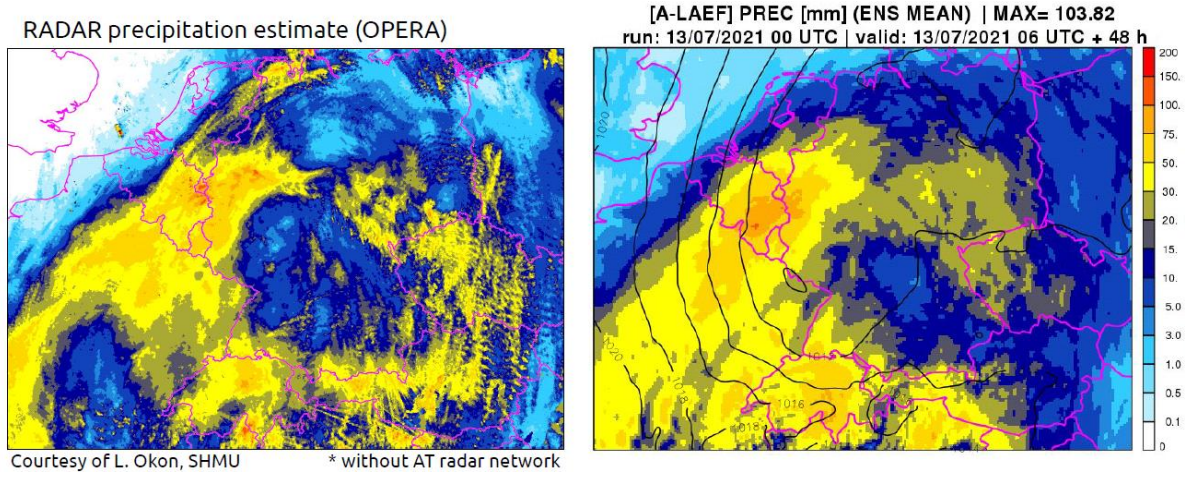


Figure 6: 48h accumulated precipitation (13/07 – 15/07/2021 06 UTC) from RADAR composite (left) and A-LAEF forecast (ensemble mean, right).

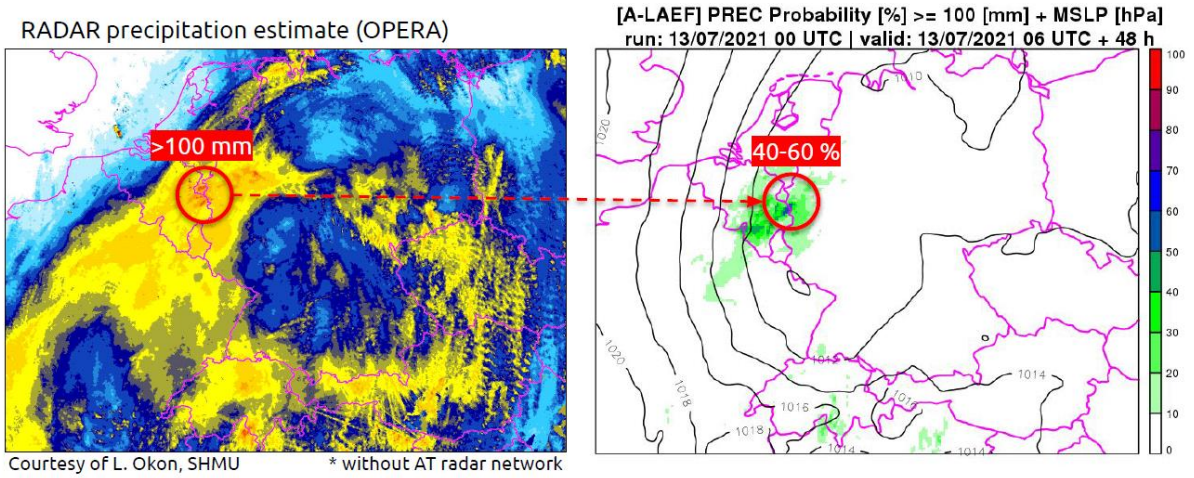


Figure 7: 48h accumulated precipitation (13/07 – 15/07/2021 06 UTC) from RADAR composite (left) and A-LAEF probability of exceeding 100mm/48h (right).

source: TASR/Rhein-Erft-Kreis via AP

Figure 8: Some images of devastating flood in Germany in July 2021.

- **Case study 5: Record rainfall in Italy (04/10/2021)**

A European record was broken in Northern Italy (Liguria region), where more than 740 mm of rain fell within the 12 hours period on October 4, 2021, causing floods, landslides, and several rivers broke their banks. There was also 178 mm of rainfall measured in just 1 hour (Urbe Vara Superiore), and over 900 mm in 24 hours (Rossiglione, Figure 9).

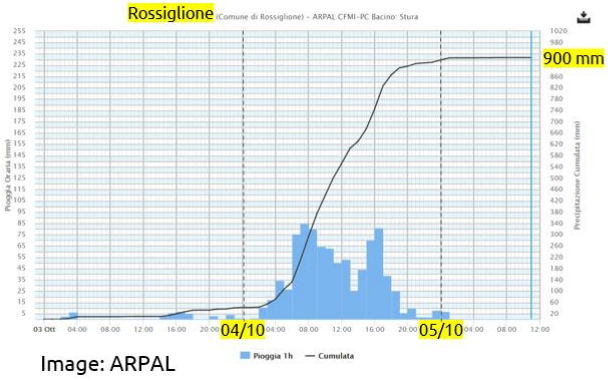


Image: ARPAL

Photo: President of Liguria Giovanni Toti

Figure 9: Record rainfall in Rossiglione on 04/10/2021.

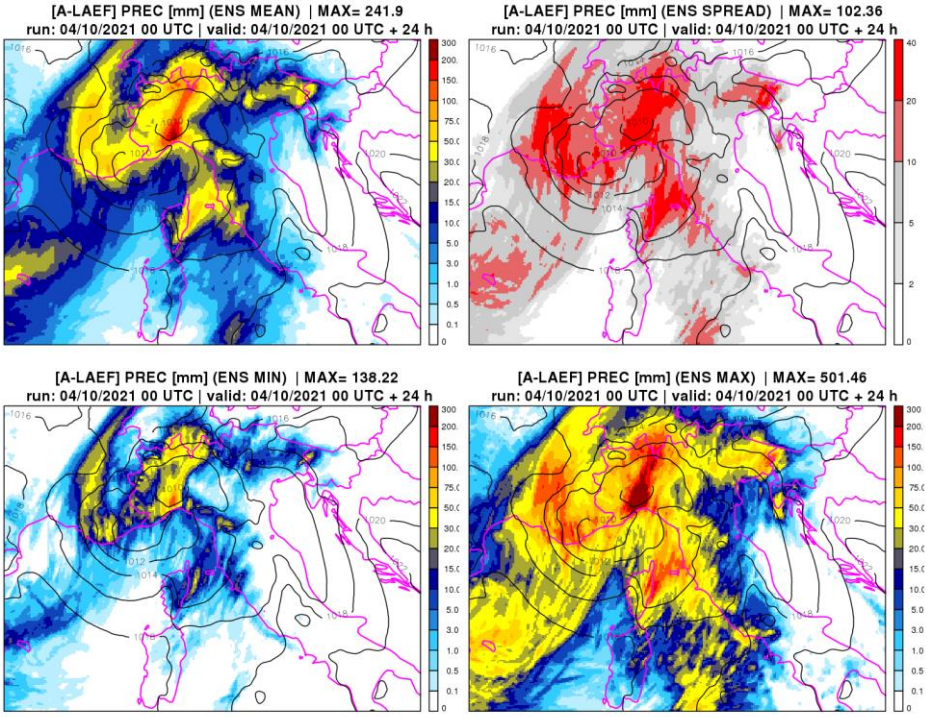


Figure 10: A-LAEF (04/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours. Ensemble mean, spread, min and max [mm] are shown.

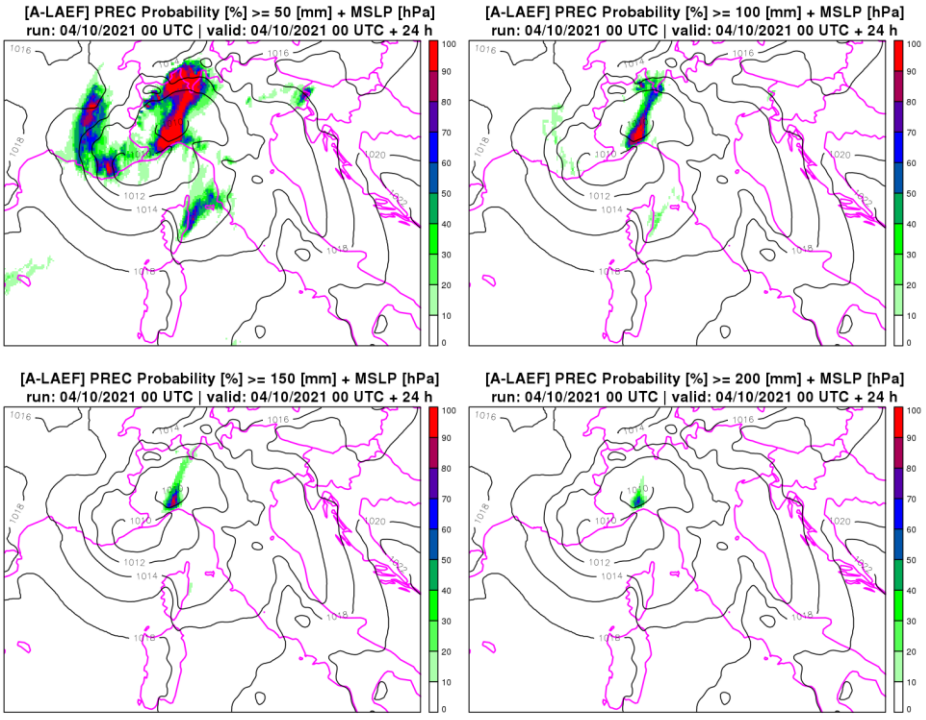


Figure 11: A-LAEF (04/10/2021 00 UTC run) probabilities for exceeding thresholds of 50, 100, 150 and 200 mm in 24 hours.

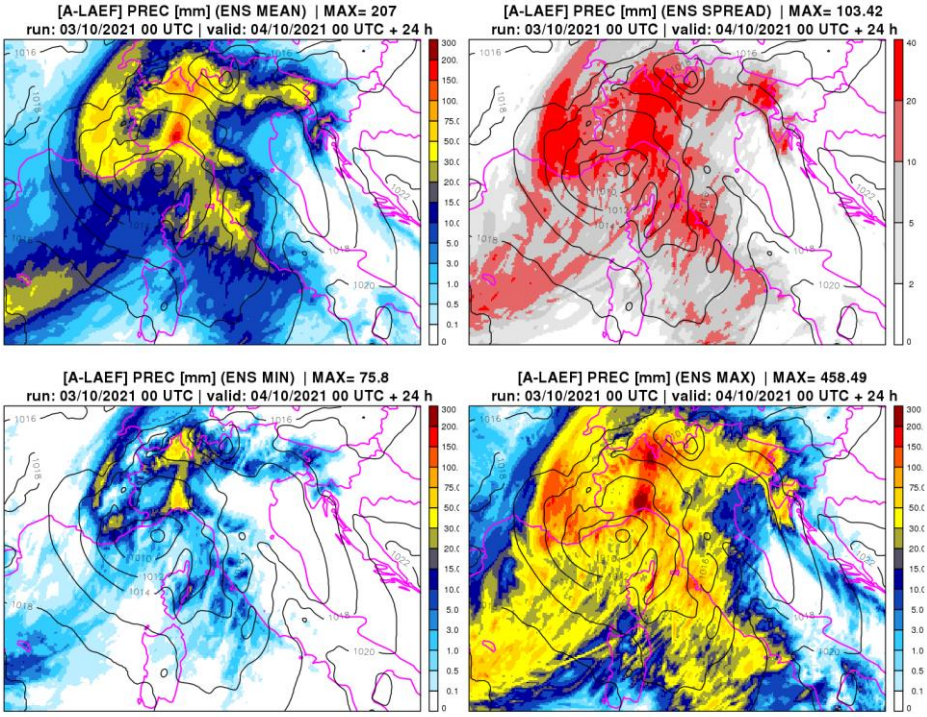


Figure 12: A-LAEF (03/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours. Ensemble mean, spread, min and max [mm] are shown.

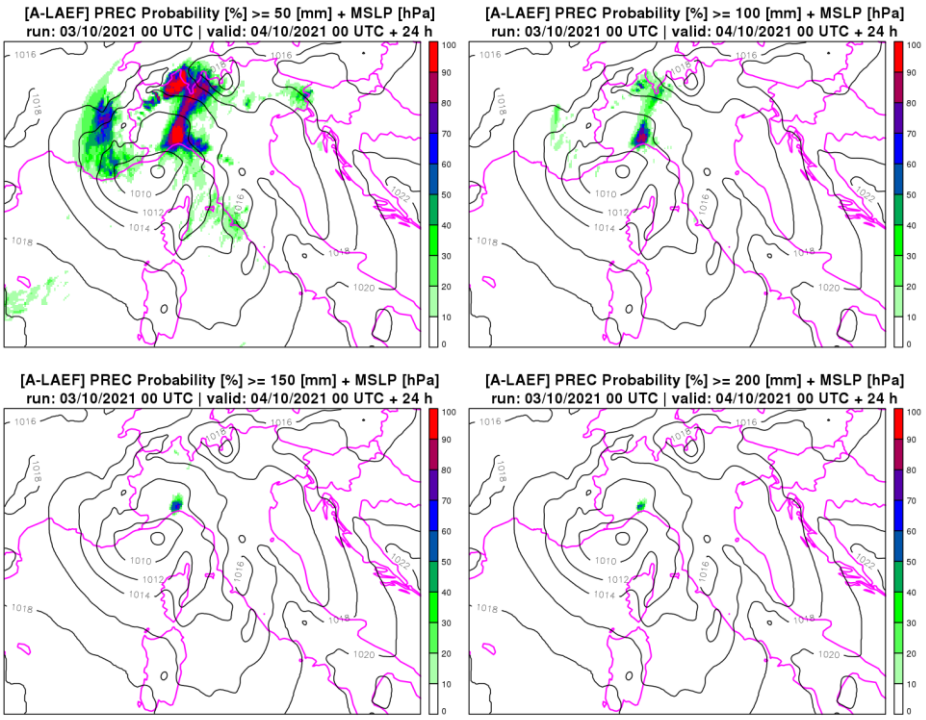


Figure 13: A-LAEF (03/10/2021 00 UTC run) probabilities for exceeding thresholds of 50, 100, 150 and 200 mm in 24 hours.

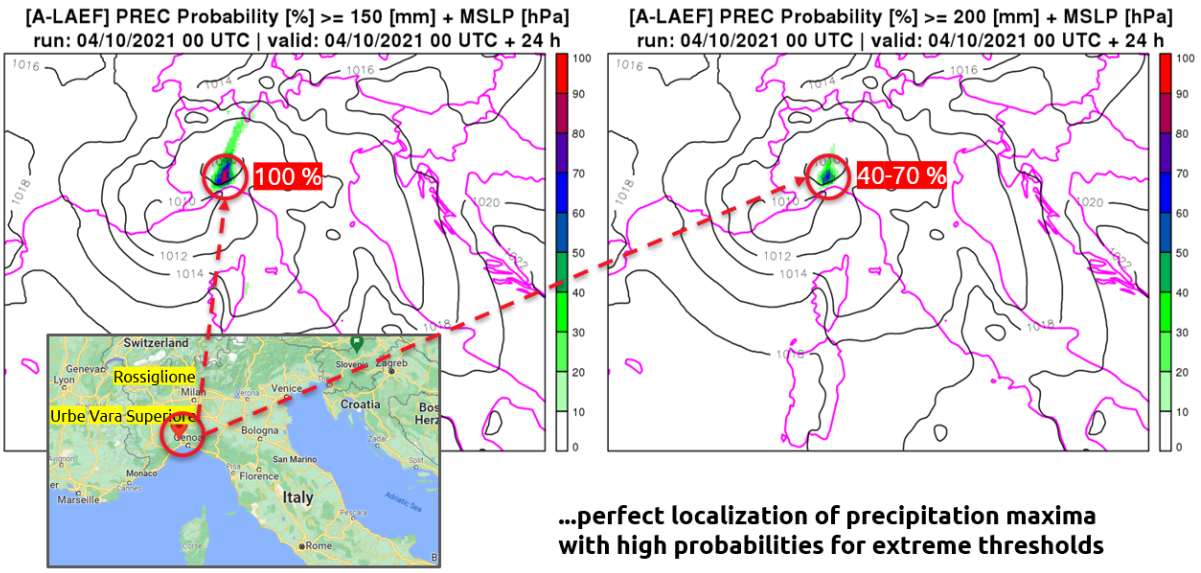


Figure 14: A-LAEF (04/10/2021 00 UTC run) probabilities for exceeding thresholds of 150 and 200 mm in 24 hours.

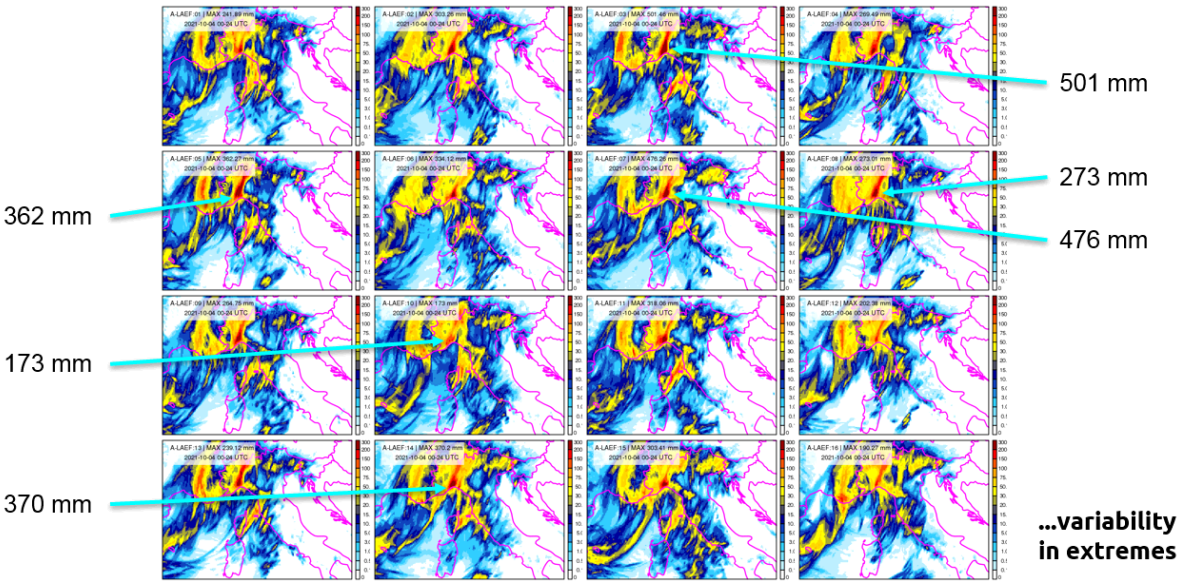


Figure 15: A-LAEF (04/10/2021 00 UTC run) variability in predicted extremes.

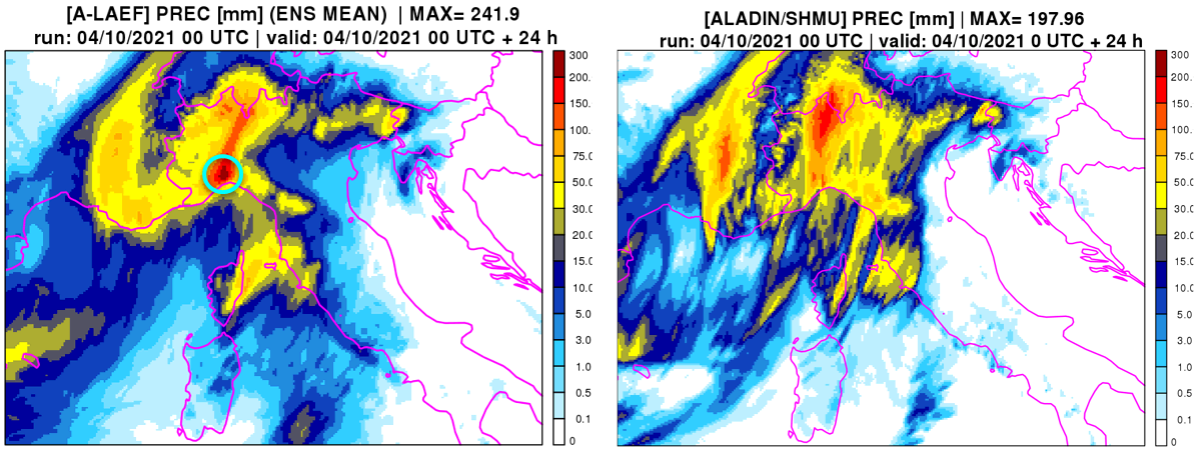
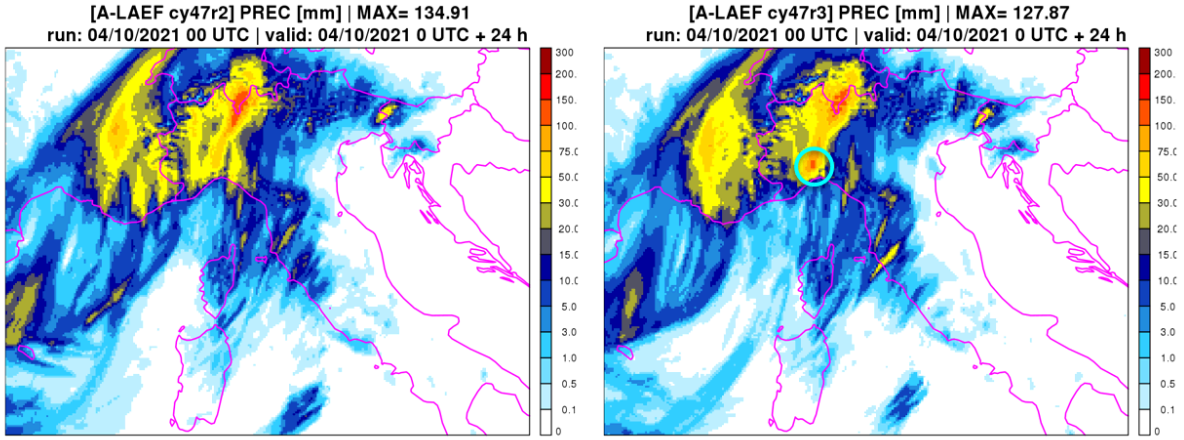


Figure 16: A-LAEF ENS Mean (left, 04/10/2021 00 UTC run) and ALADIN/SHMU (right, 04/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours.



(operational on October 4, 2021)
...and still, the correct location of extreme values in ensemble mean (!)

(operational since October 12, 2021)
...slight improvement against cy47r2 (for CTRL)

Figure 17: A-LAEF (coupled with ECMWF cy47r2) ENS Mean (left, 04/10/2021 00 UTC run) and A-LAEF (coupled with ECMWF cy47r3, right, 04/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours.

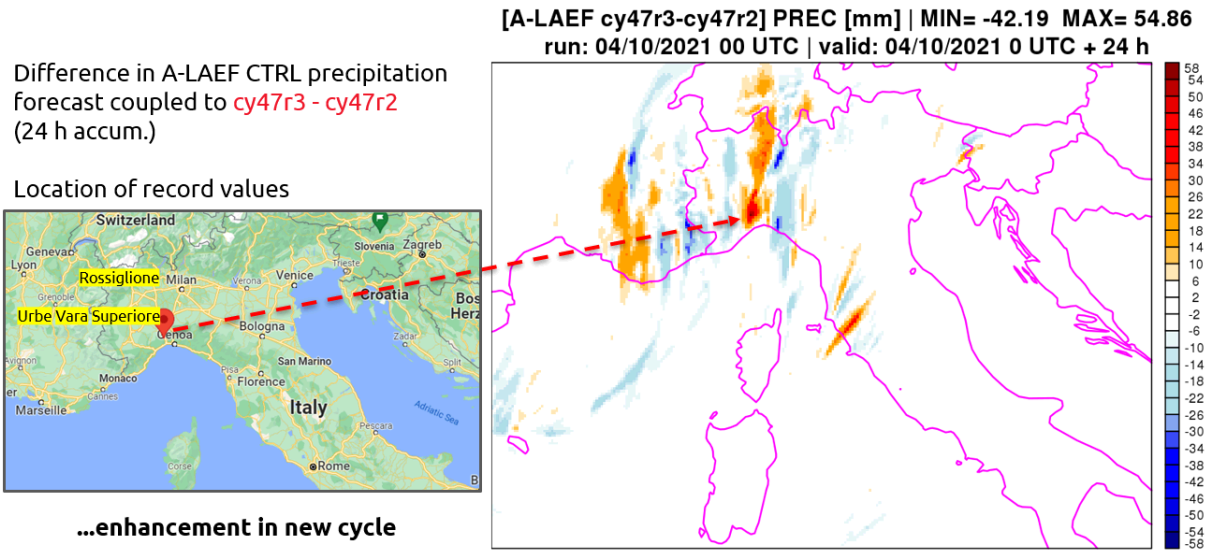


Figure 18: Difference in A-LAEF Ctrl 24h precipitation forecast [mm] between A-LAEF (coupled with ECMWF cy47r2) and A-LAEF (coupled with ECMWF cy47r3).

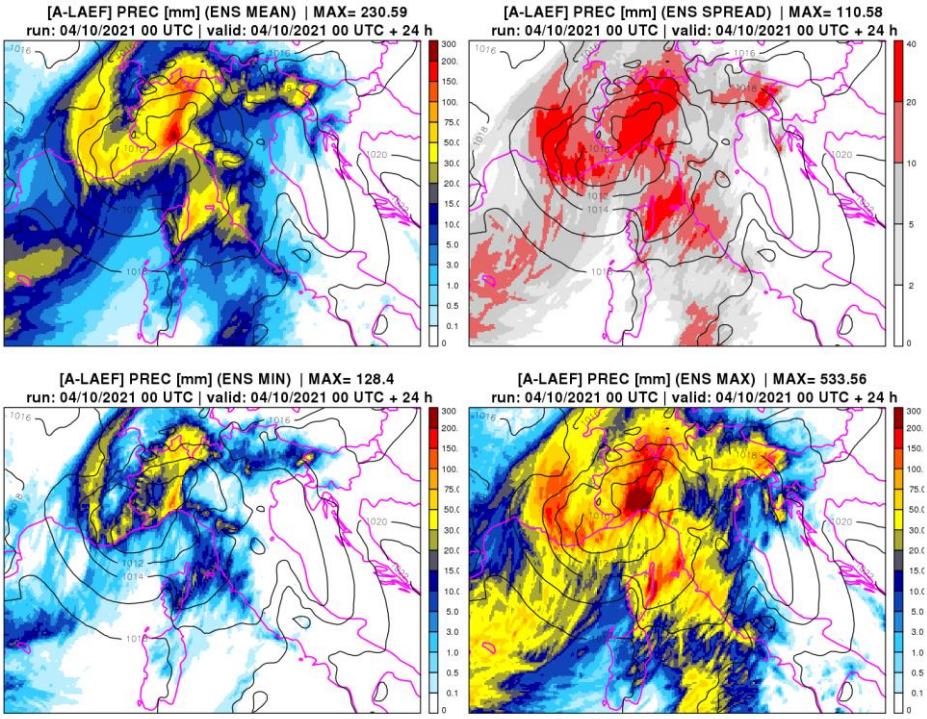


Figure 19: A-LAEF (coupled with ECMWF cy47r2, 04/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours. Ensemble mean, spread, min and max [mm] are shown.

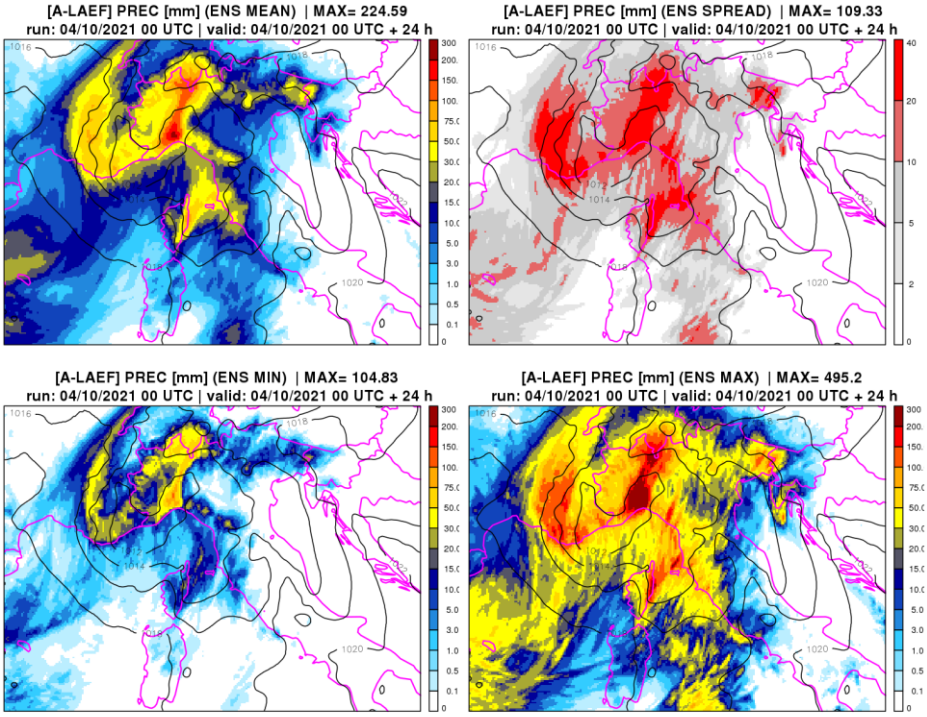


Figure 20: A-LAEF (coupled with ECMWF cy47r3, 04/10/2021 00 UTC run) precipitation forecast for the 24h period between 24/10 00 UTC and 25/10 00 UTC hours. Ensemble mean, spread, min and max [mm] are shown.

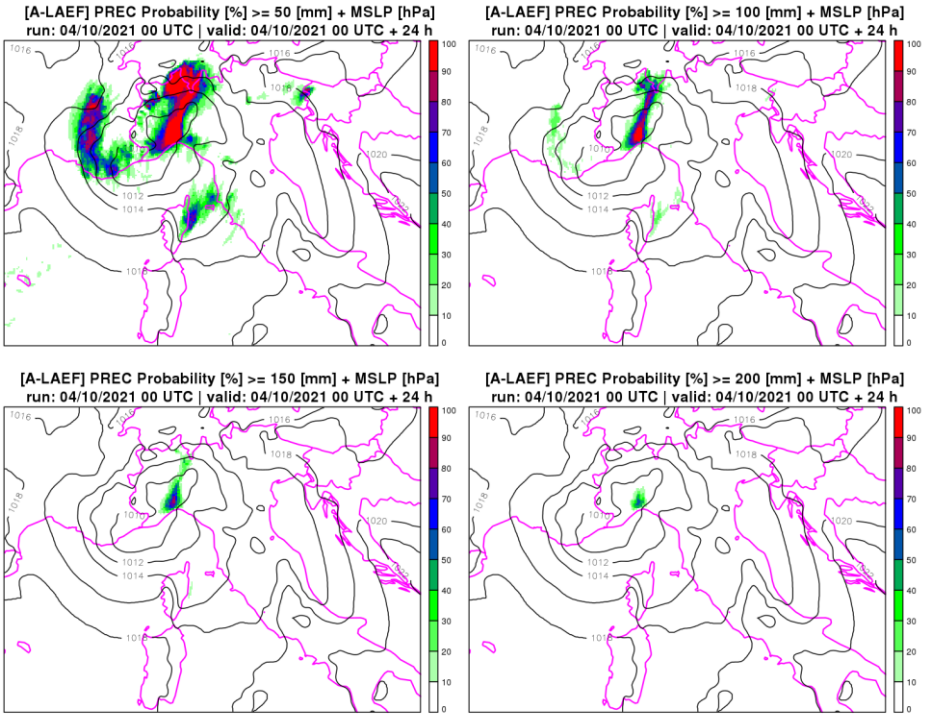


Figure 21: A-LAEF (coupled with ECMWF cy47r2, 04/10/2021 00 UTC run) probabilities for exceeding thresholds of 50, 100, 150 and 200 mm in 24 hours.

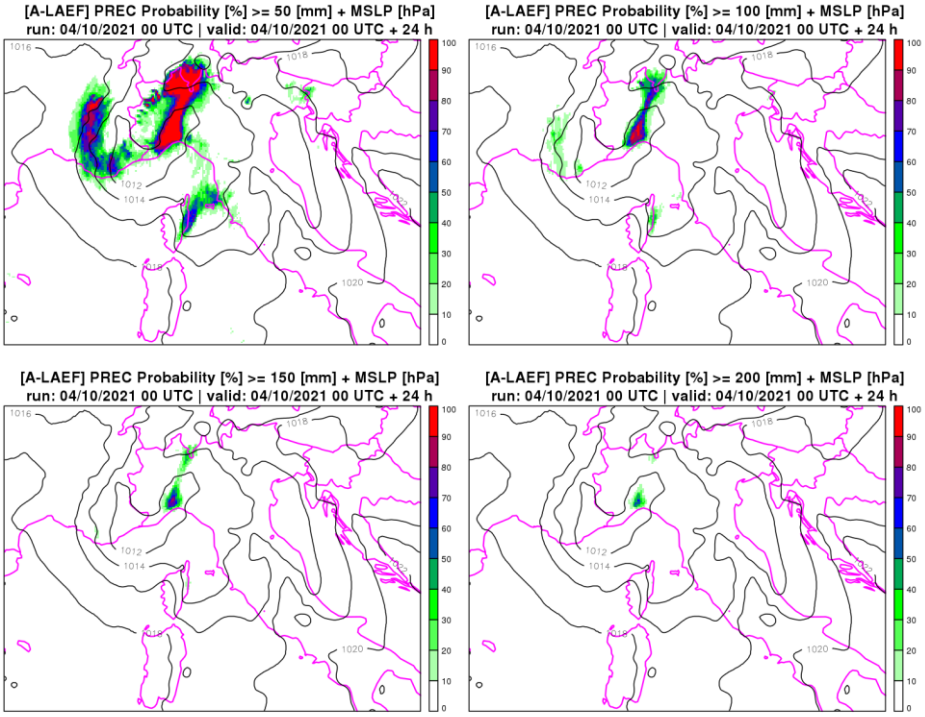


Figure 22: A-LAEF (coupled with ECMWF cy47r3, 04/10/2021 00 UTC run) probabilities for exceeding thresholds of 50, 100, 150 and 200 mm in 24 hours.

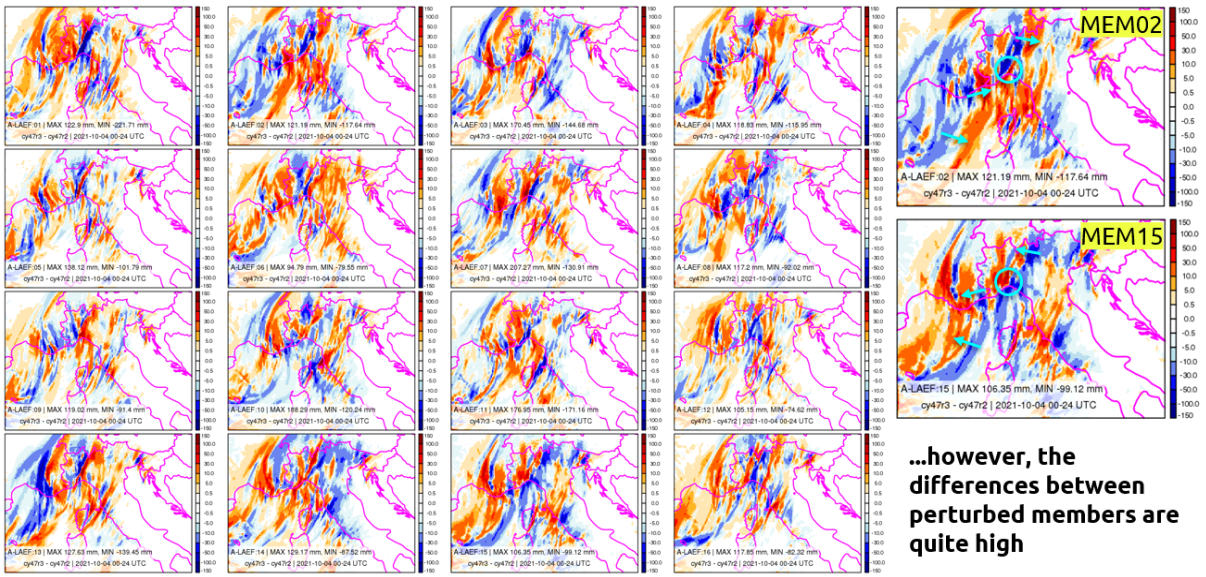


Figure 23: Differences in A-LAEF members precipitation forecast [mm] between A-LAEF (coupled with ECMWF cy47r2) and A-LAEF (coupled with ECMWF cy47r3).

- **Case Study 6: Flash flood event in Austria (17-19/07/2021)**

Just a few days after the devastating flood situation in Germany the heavy rain area of the same system reached Salzburg and Tyrol in Austria. Damaging floods affected areas along the Salzach River and its tributaries in the state of Salzburg (it was reported as a 50-year flood event). The town of Hallein was particularly badly affected. Vienna experienced more than a month's rainfall in a few hours during thunderstorms on Saturday July 17. Heavy rain also created a risk of flooding and mudslides across Styria, the levels of small rivers rose quickly (Figures 9-11).

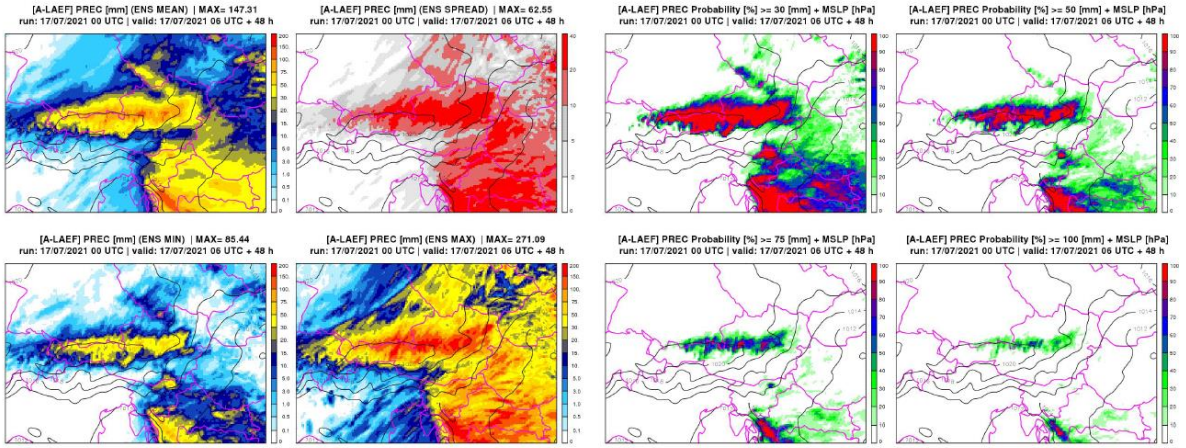


Figure 24: A-LAEF (17/07/2021 00 UTC run) precipitation forecast for the 48h period between 17/07 and 19/07/2021 06 UTC. On the left hand side ensemble mean, spread, min and max are shown, while on the right hand side probabilities for exceeding for 30, 50, 75 and 100mm are displayed.

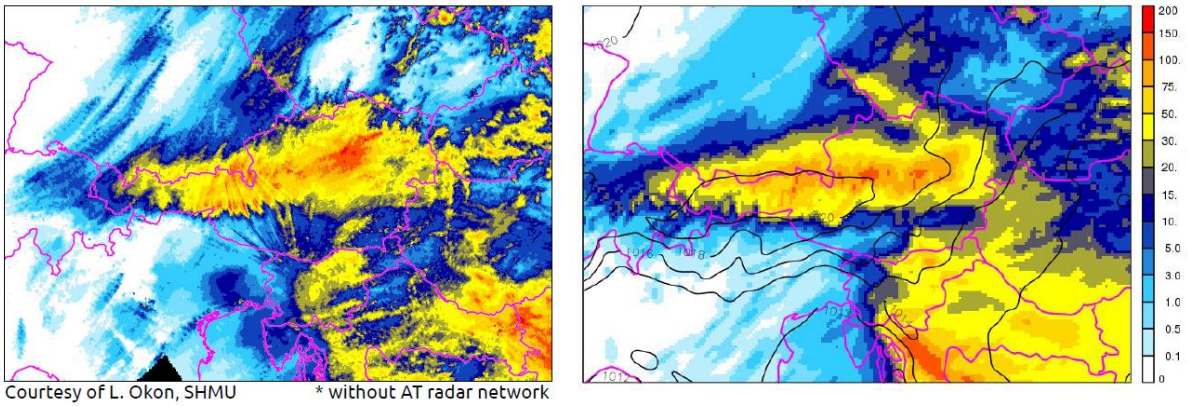


Figure 25: 48h accumulated precipitation (17/07 – 19/07/2021 06 UTC) from RADAR composite (left) and A-LAEF forecast (ensemble mean, right).

Figure 26: Some images of flash flood events in Austria in July 2021.

Topic 2: C-LAEF operational runs - Case studies and verification

- **Case Study 1: Thunderstorm event in Austria (22-23/06/2021)**

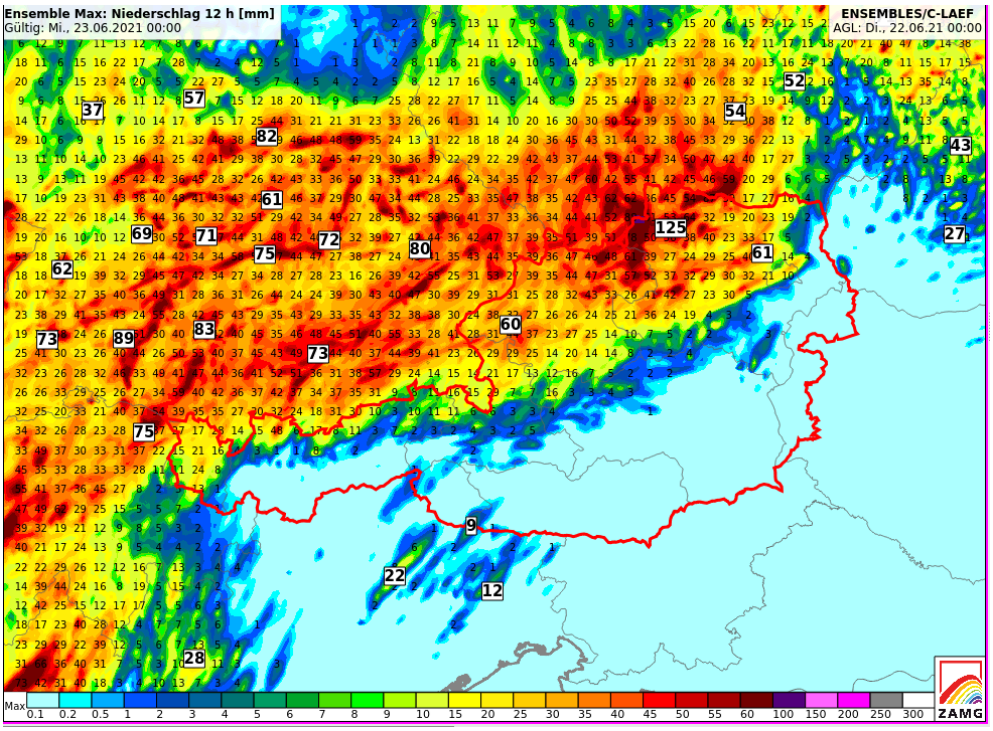


Figure 27: C-LAEF ensemble max precipitation for the 12-h period between 22/06 12 UTC and 23/06 00 UTC based on the C-LAEF run of 22/06 00 UTC.

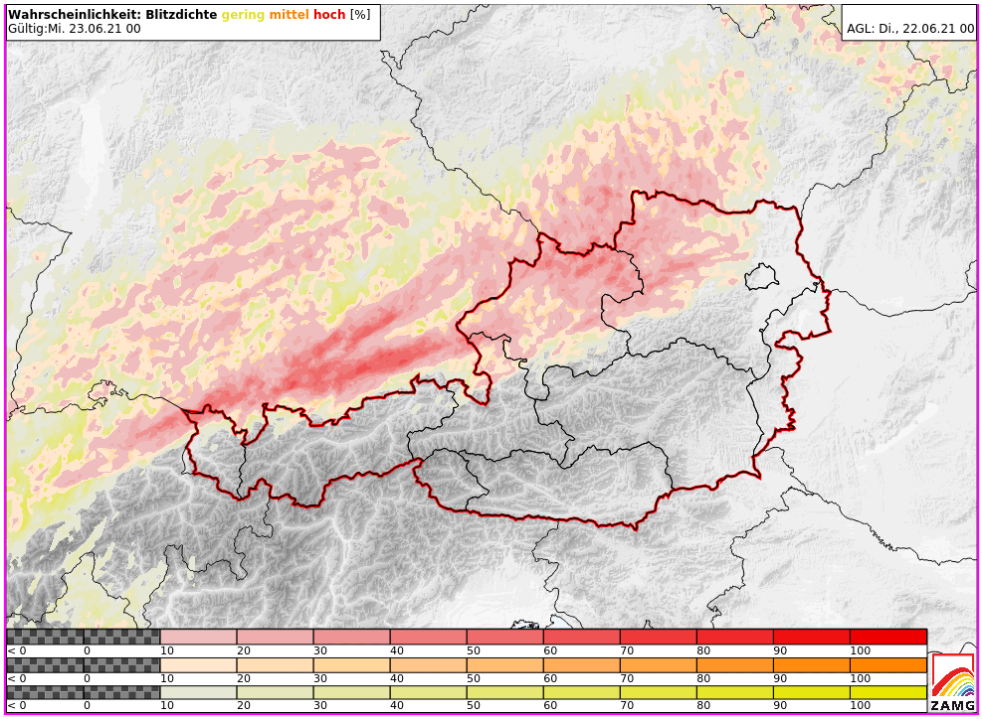


Figure 28: C-LAEF lightning probability for 23/06 00 UTC based on the C-LAEF run of 22/06 00 UTC.

The first event occurred in the afternoon and evening hours of 22 June 2021. Significant convective activity could be observed from the northern Alpine foreland in Bavaria to Lower Austria causing a lot of damage. C-LAEF predicted very high precipitation amounts (ensemble mean about 30mm, ensemble max with more than 100mm in 12h) accompanied by a high probability of lightning and hail with excessive gusts above 100 km/h (Figures 27-30) for this event. Localization and also intensity of the severe thunderstorms was very well predicted in C-LAEF. In a very similar situation, just one day later, a massive hailstorm and a severe tornado occurred near the Austrian/Czech border with about 250 persons injured. Also this situation was well captured by C-LAEF (Figure 31).

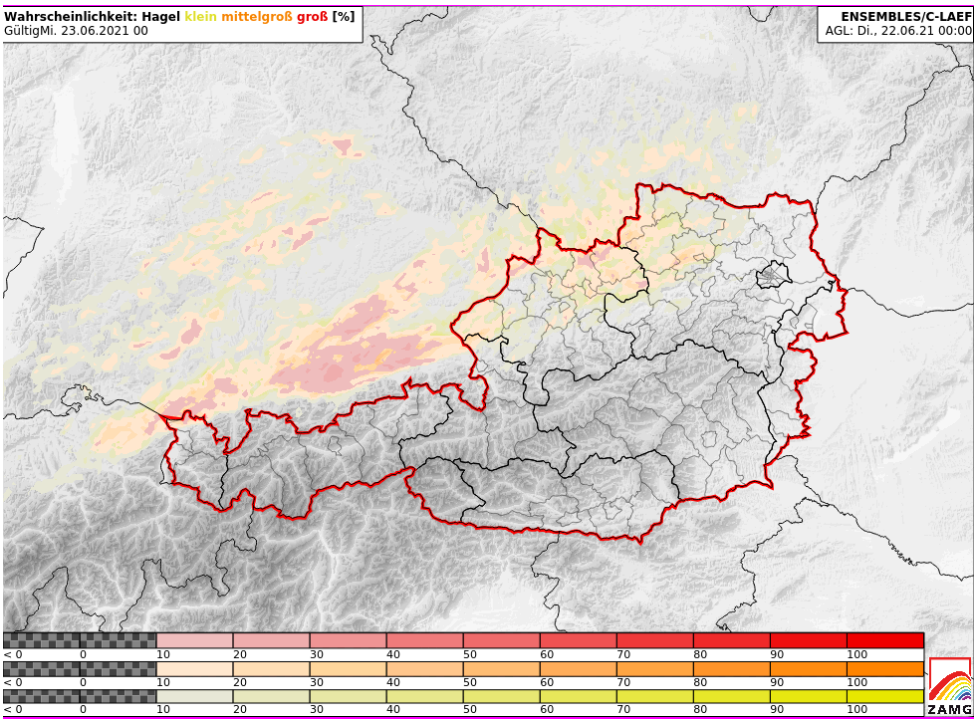


Figure 29: C-LAEF hail probability for 23/06 00 UTC based on the C-LAEF run of 22/06 00 UTC.

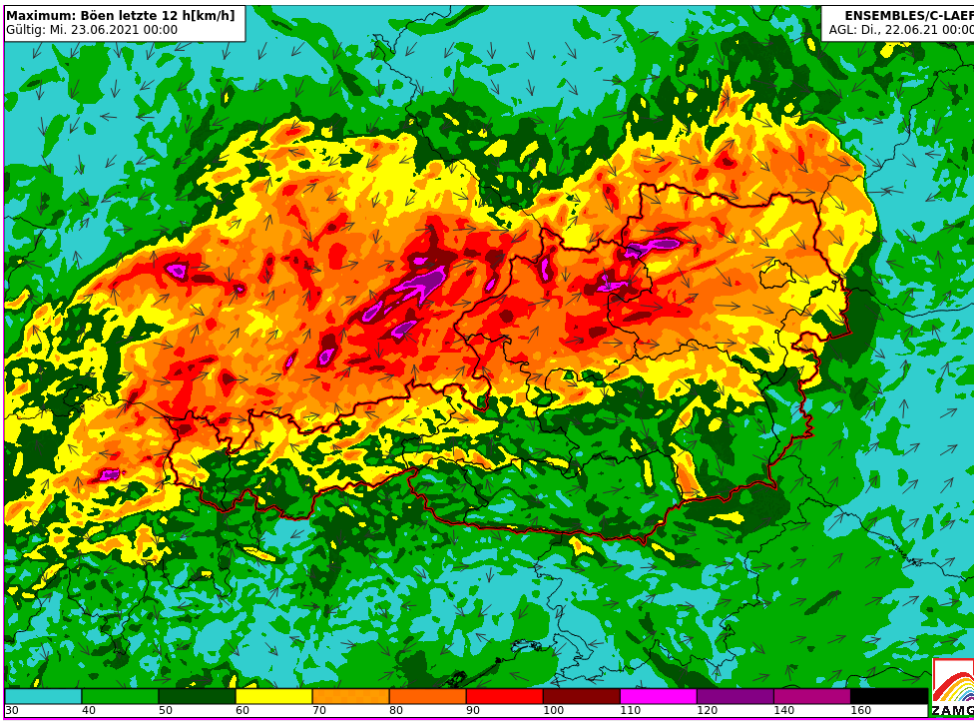


Figure 30: C-LAEF ensemble max wind gusts for the 12-h period between 22/06 12 UTC and 23/06 00 UTC based on the C-LAEF run of 22/06 00 UTC.

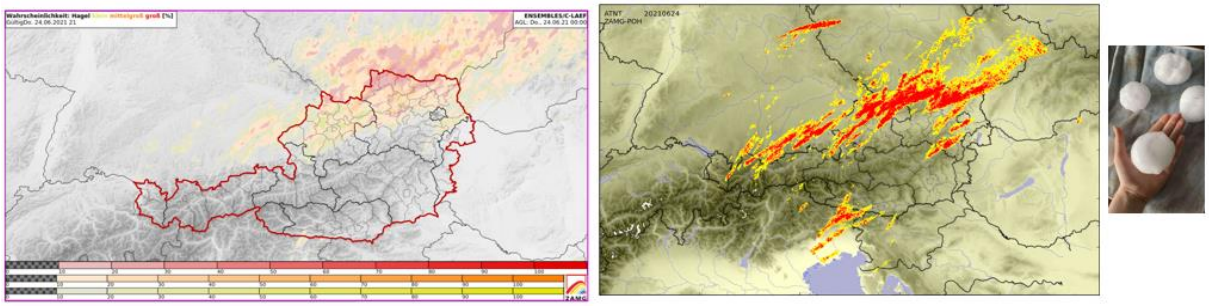


Figure 31: C-LAEF probability of hail (left) and hail analysis (right) for 24/06 21 UTC. Massive hailstones near the Austrian/Czech border (www.hagel.at).

- **Case Study 2: Flash flood event in Austria (17-19/07/2021)**

The second event occurred on the weekend from 17 July to 19 July 2021 and was already well predicted some days before by the global IFS model. With the first upcoming C-LAEF runs covering the event it was clear that a very strong precipitation event with very likely strong flooding will occur. Figure 32 shows the INCA analysis and the forecasts from several NWP models (probabilistic and deterministic) for the main precipitation phase (17/7 00 UTC to 19/7 00 UTC). Highest precipitation sums (up to 200mm/48h) were predicted for the Northern Alps between Tyrol and Lower Austria. C-LAEF predicted high probabilities (> 80%) of exceeding the 100mm threshold for the event in large parts of this region, especially in the areas with strong orographic precipitation enhancement (Figure 33).

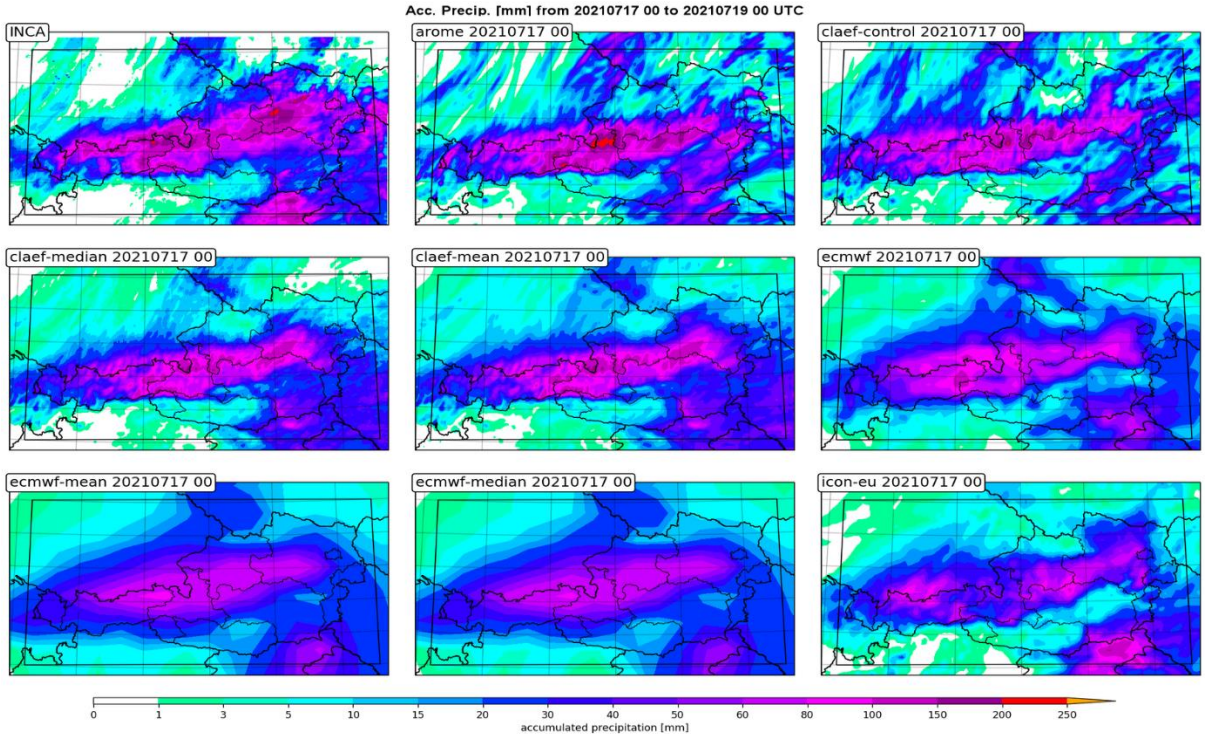


Figure 32: 48h accumulated precipitation (17/7 00 UTC - 19/7 00 UTC) based on the 17/7 00 UTC runs of several NWP models. The first panel shows the respective precipitation analysis from the INCA system.

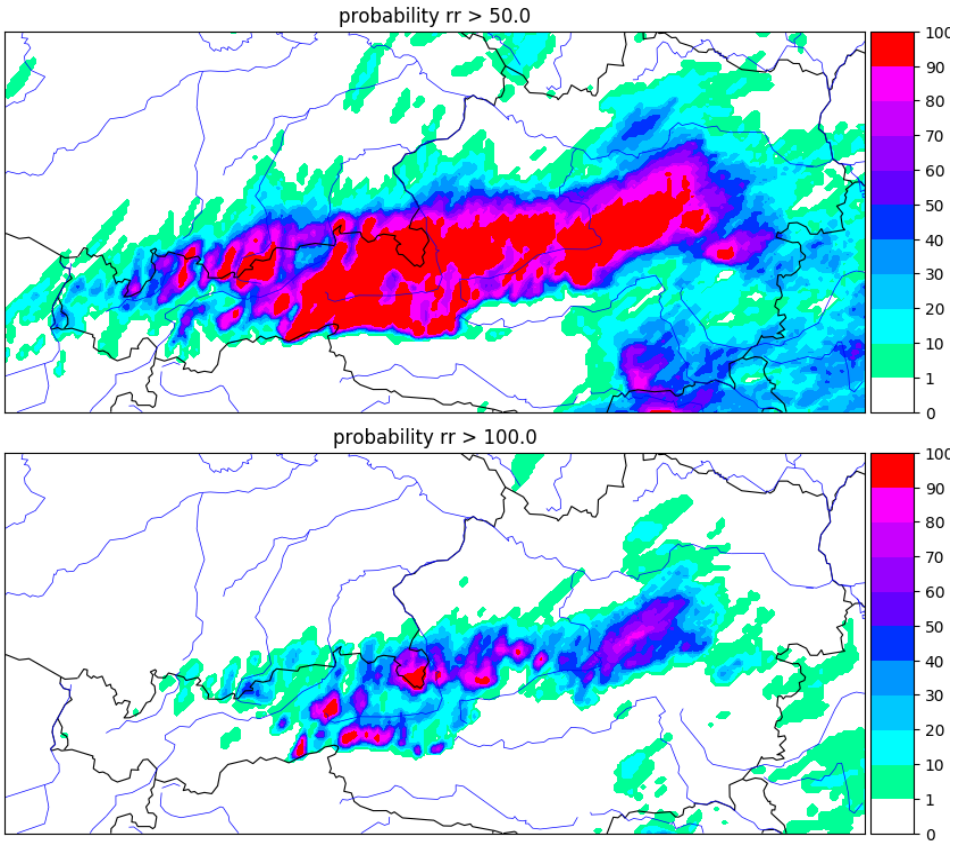


Figure 33: C-LAEF probabilities for exceeding 50mm (upper) and 100mm in 48h between 17/7 00 UTC and 19/7 00 UTC based on the 17/7 00 UTC run.

When comparing the different models (ECMWF, AROME, ICON, C-LAEF) for this event, C-LAEF showed a very strong performance with the best scores for the C-LAEF median.