Probabilistic products for convective hazards

In collaboration with ESSL

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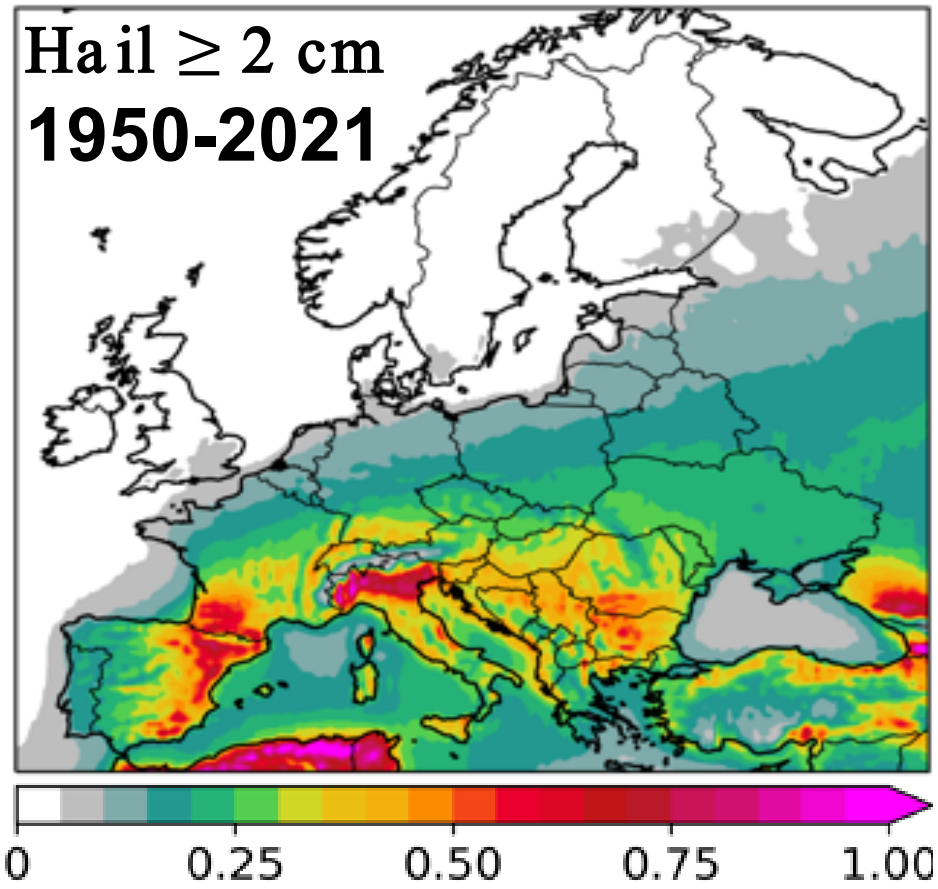
ECMWF

Additive Logistic Regression Convective Hazard Model – AR-CHaMo

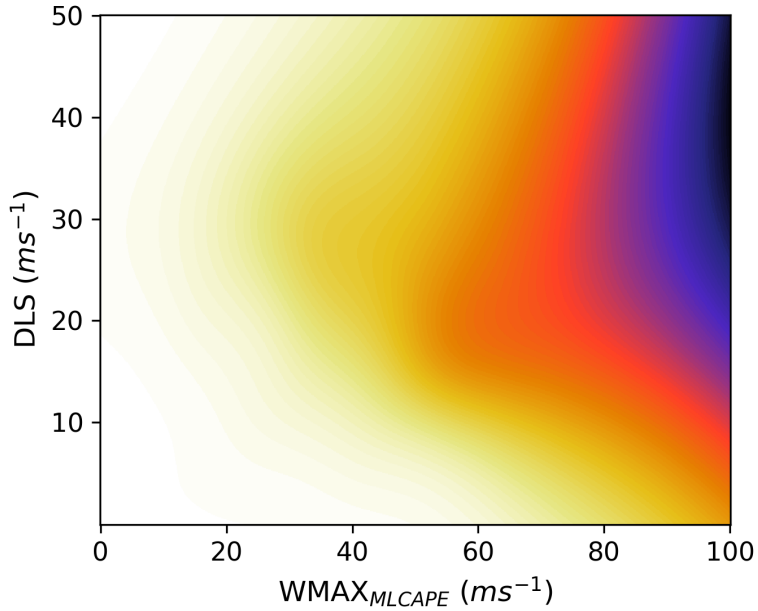


$$\mathbf{P}(hazard) = \mathbf{P}(storm) \cdot \mathbf{P}(hazard|storm)$$

- High-resolution convection-allowing models are run for short-term periods and regional domains. For medium-range forecasting or climate applications, the risk of convective hazards is usually assessed using pre-convective environments at a coarser grid resolution that does not allow to explicitly resolve convection.
- ESSL developed statistical regression model AR-CHaMo (Rädler et al., 2018; Battaglioli et al., 2023a) initially for detection of climate trends.
- Battaglioli et al. (2023b) applied AR-CHaMo for large hail to ECMWF re-forecasts.
- ECMWF is collaborating with ESSL to apply AR-CHaMo to 51-member ECMWF operational ensemble for forecasting:
  - ✓ Large hail (over 2 cm)
  - ✓ Very large hail (over 5 cm)
  - ✓ Severe convective wind gusts (over 25 m/s)
- The probabilities represent the likelihood of an event within the circle with a radius of 40 km.

AR-CHaMo models for large and very large hail

Fraction of lightning environments with hail ≥ 2cm



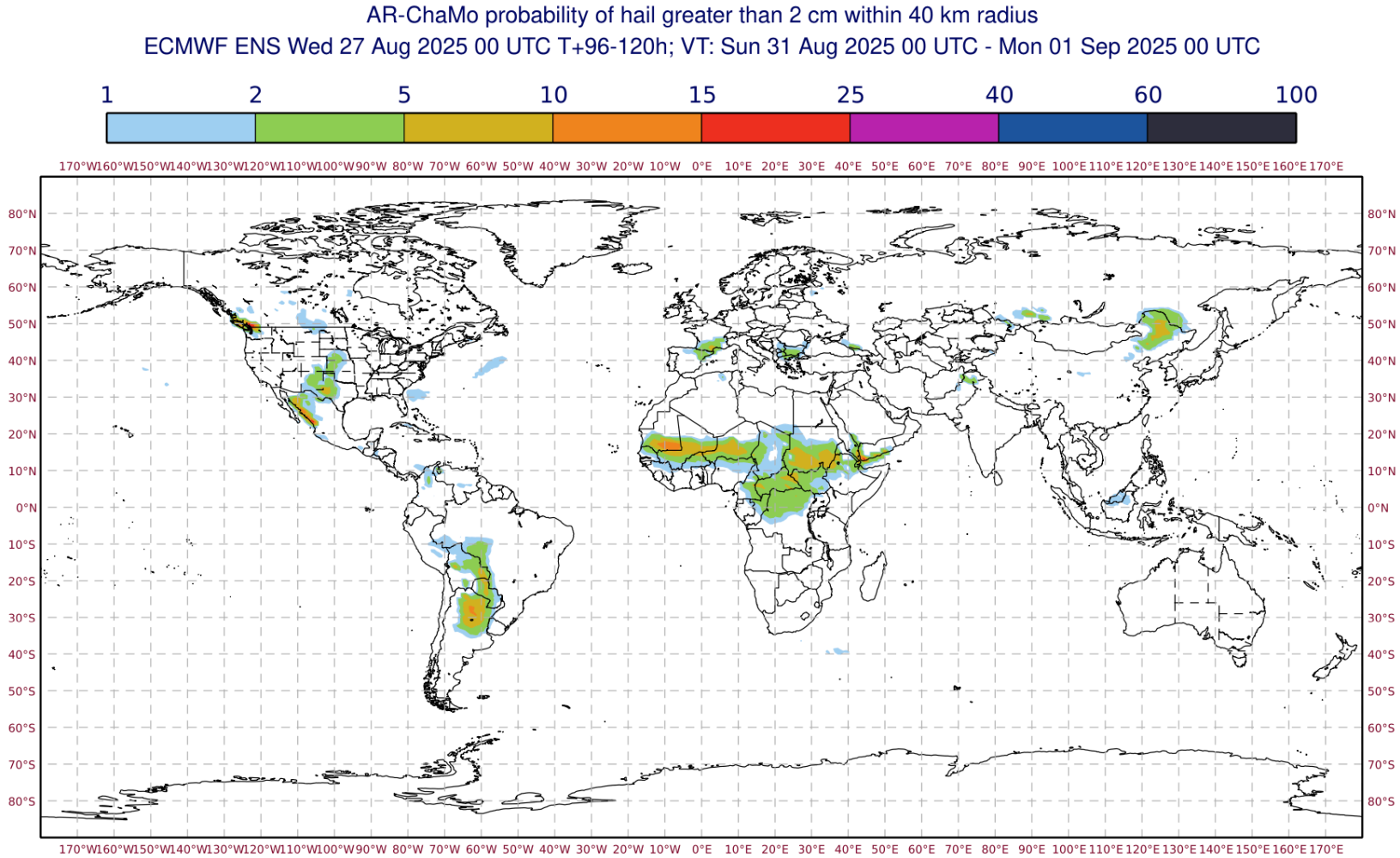
- Lightning:
  - ✓ Most unstable LI;
  - ✓ Most unstable mixing ratio
  - ✓ Mean RH 850-500 hPa
  - ✓ Convective precipitation
  - ✓ Land-sea mask

- Additive regression uses:
  - ✓ Model predictors derived from ERA5 calculated with ThundeR package
  - ✓ European Severe Weather Database reports
  - ✓ US severe storm reports
  - ✓ Severe storm reports from Australia
  - ✓ ATDnet (UKMO) and NLDN (USA) lightning data

- Hail ≧ 2 cm:
  - ✓ Most unstable CAPE above -10°C;
  - ✓ Effective bulk shear for most unstable parcel
  - ✓ Most unstable mixing ratio
  - ✓ Height of 0°C isotherm

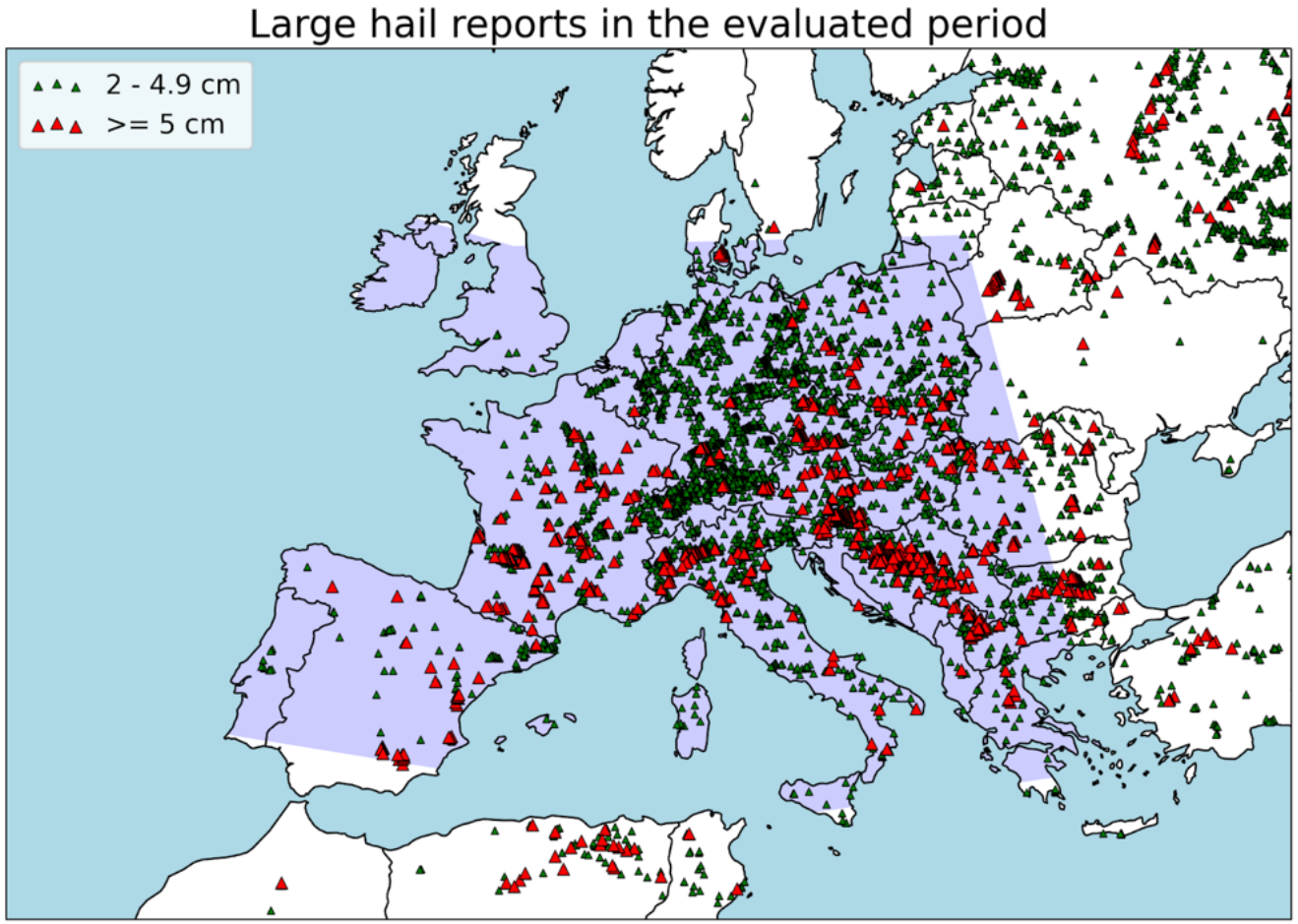
- Hail ≧ 5 cm:
  - ✓ Most unstable CAPE above -10°C;
  - ✓ Effective bulk shear for most unstable parcel
  - ✓ Most unstable mixing ratio
  - ✓ Mixed-layer lifted condensation level

AR-CHaMo models for large and very large hail



- Predictors from ECMWF ensemble
- Probabilities derived for each ensemble member then combined probability presented
- Global product at O640
- 3h output up to T+144h, 6h output afterwards
- Up to T+240h

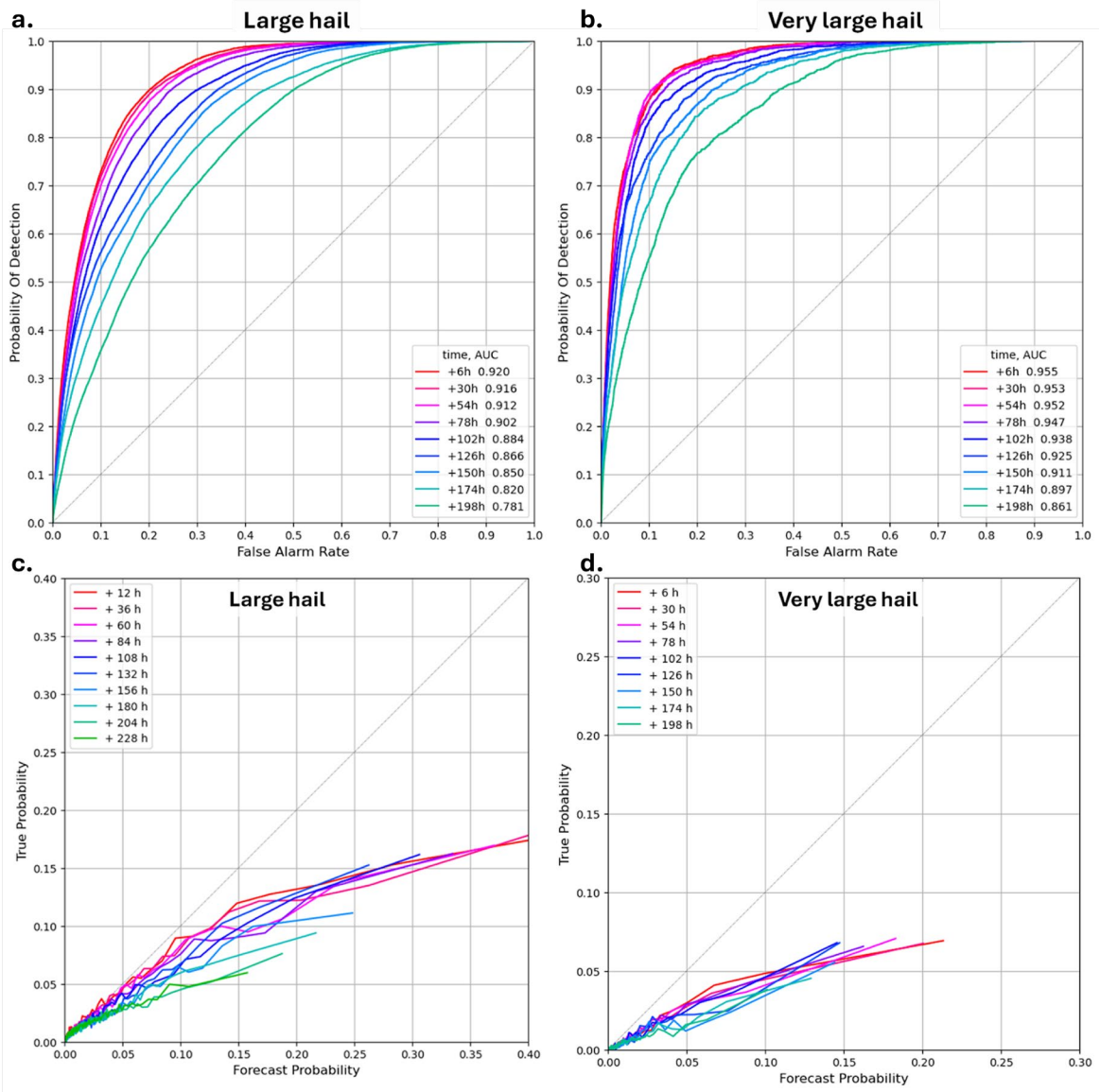
AR-CHaMo models for large and very large hail – skill assessment



Large and very large hail reports between 1 May and 30 September 2024. The purple area represents the domain used for the quantitative evaluation of the AR-CHaMo forecasts.

- Skill measures:
  - ✓ area under the ROC curve (AUC) – how well the forecast is able to distinguish between hail and no hail events
  - ✓ Reliability diagram – how well forecast probabilities correspond to the observed frequency of hail events
- 153 forecasts from 1 May to 30 September 2024
- The quantitative verification was done on the O640 grid, where presence of (very) large hail within 40 km of a gridpoint was counted as a positive event.

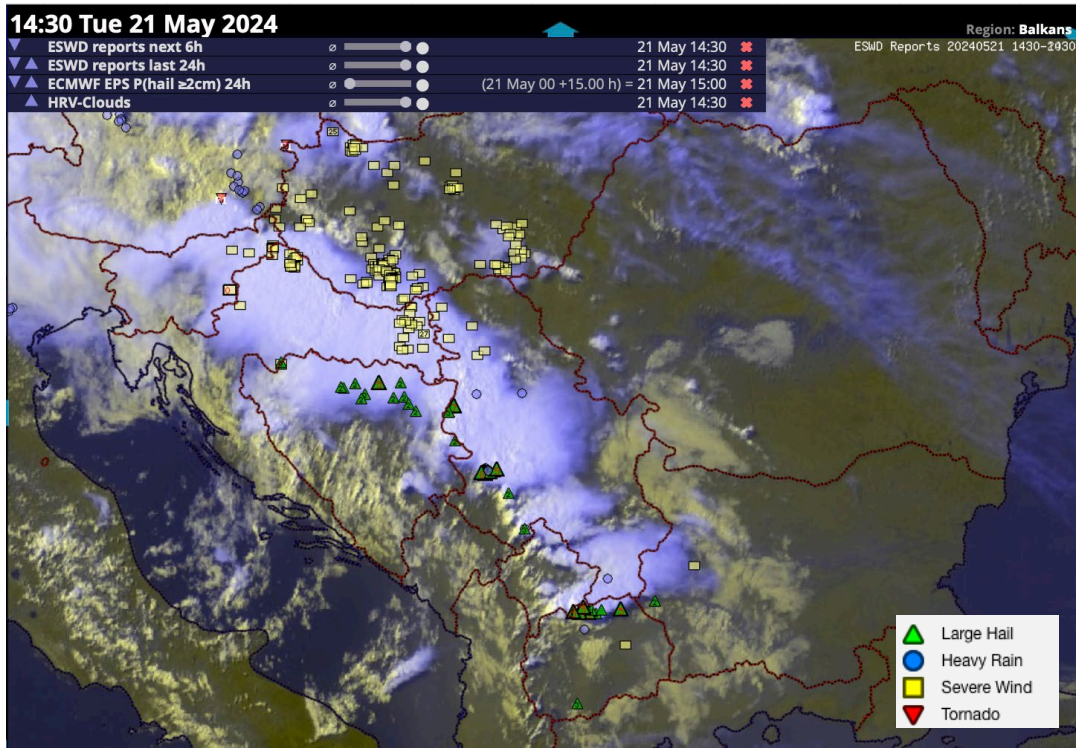
AR-CHaMo models for large and very large hail – skill assessment

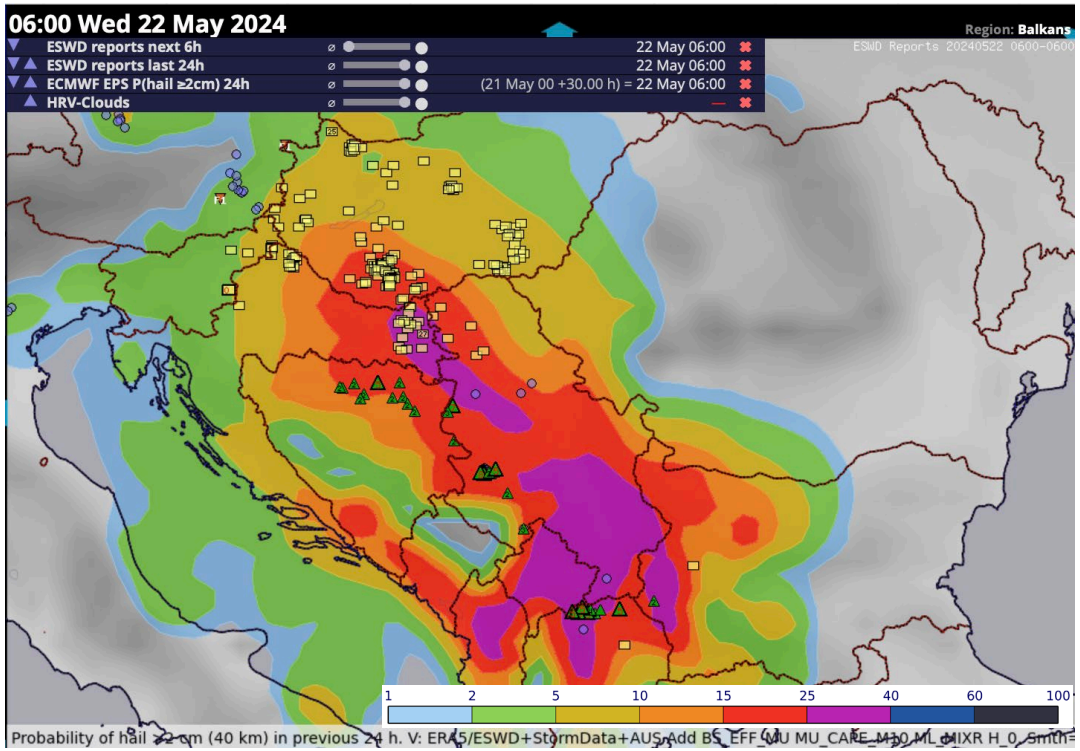


- ROC curves show a slightly better skill of very large hail vs large hail forecasts. High and almost constant skill up to T+84h dropping afterwards:
  - environments favorable for very large hail have lower environmental variability compared to smaller hail events that can be produced in a larger range of environments.
- Reliability diagrams:
  - forecasts overestimate hail occurrence – forecast probabilities higher than observed frequency;
  - overestimation grows with increasing lead time.

ROC curve and reliability diagram of the (very) large hail forecasts. The colors of the lines vary with the forecast lead time. The forecast times are labelled according to the start of the 24-hour period.

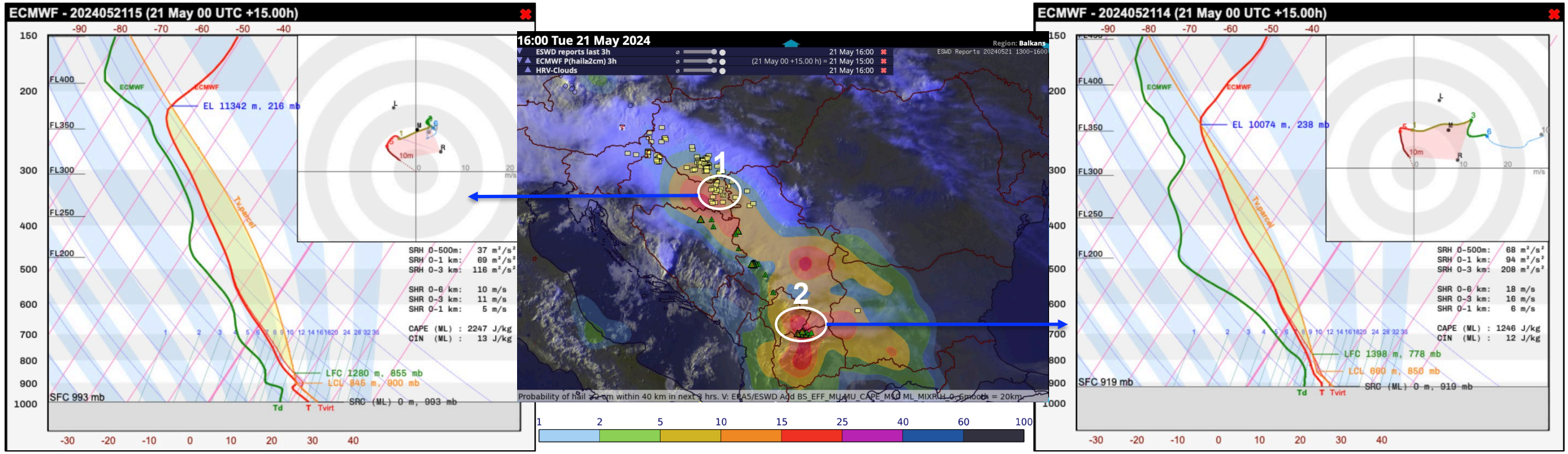
AR-CHaMo probabilities and convective mode





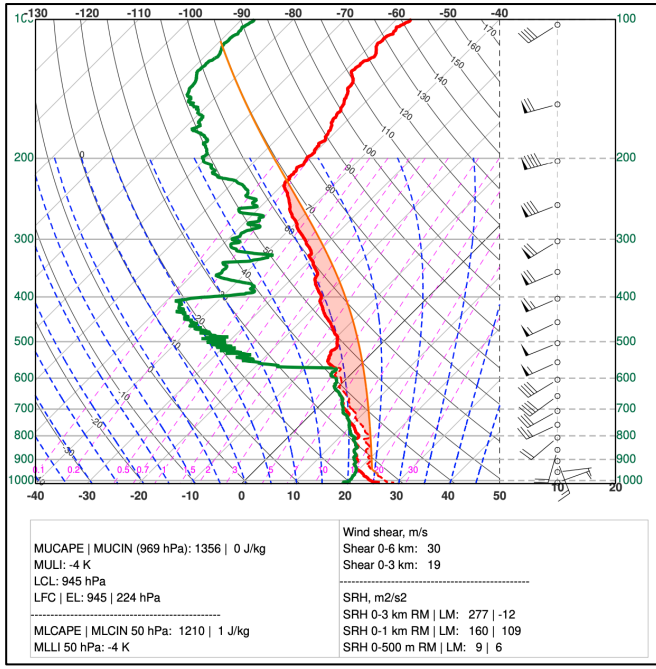
- On 21 May 2024, widespread storms occurred over large parts of southeastern Europe in a belt from southwestern Hungary and eastern Croatia through Serbia into North Macedonia.
- Large to very large hail occurred over the southern half of the area with the maximum hail diameter reaching 8 cm. No hail but widespread severe wind gusts occurred in the northern half of the area.
- High values of large hail probability covered the whole area including eastern Croatia and SW Hungary.

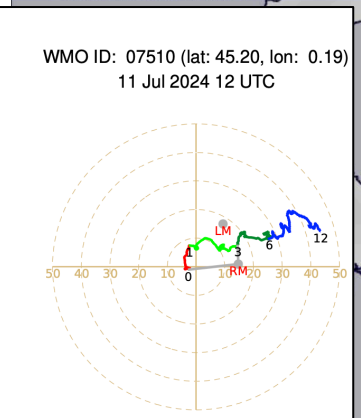
AR-CHaMo probabilities and convective mode



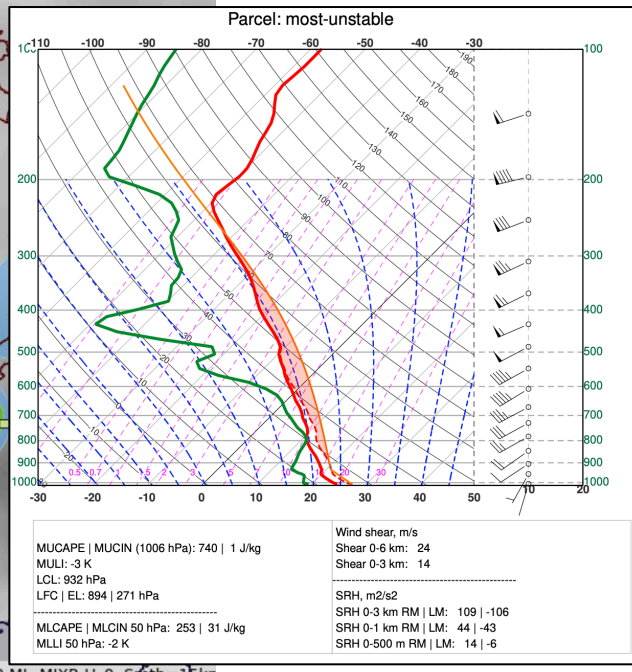
- CAPE above -10℃ is higher in area 1 than area 2 but wind shear was higher in 2 than in 1.
- Using the pre-convective environments alone, it is difficult to explain why one of the areas experienced only severe wind gusts, but no hail.
- Linear convective systems, which are major severe wind gust producers (Smith et al. 2012, Gatzen 2013, Smith et al. 2013, Surowiecki et al. 2024), form in similar pre-convective environments to supercells (Doswell and Evans, 2003, Thompson et al. 2012).

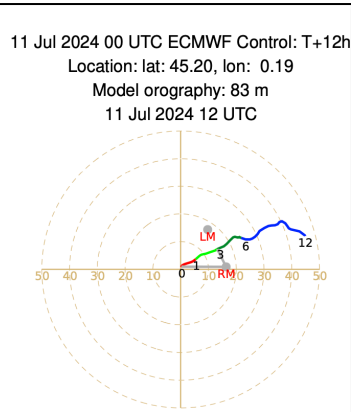
AR-CHaMo probabilities – a case of missed event





Bordeaux
OBS

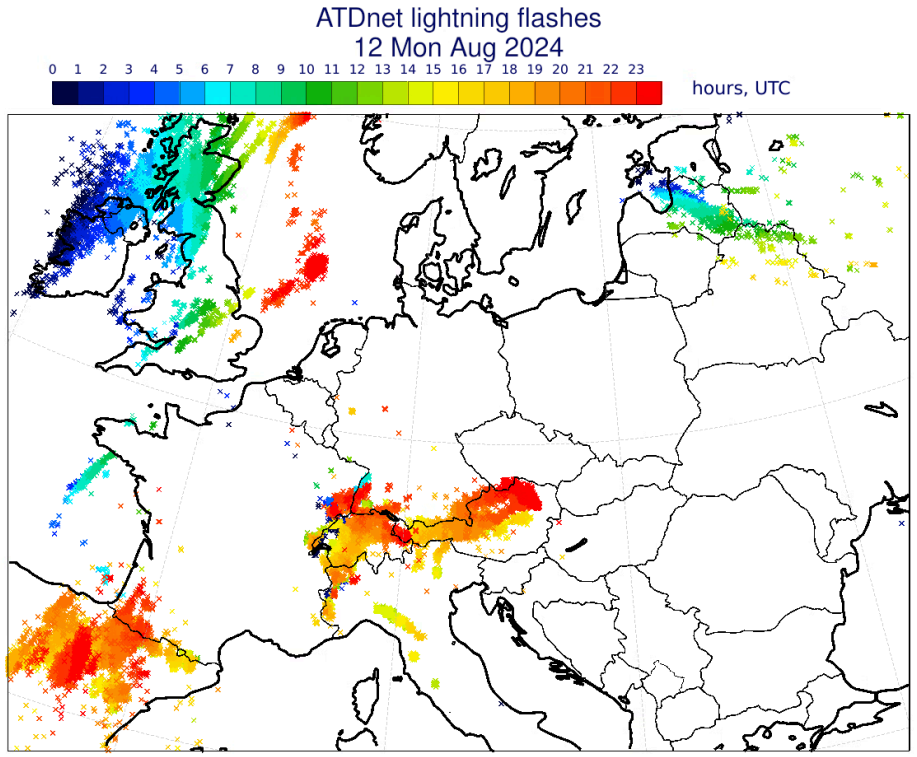


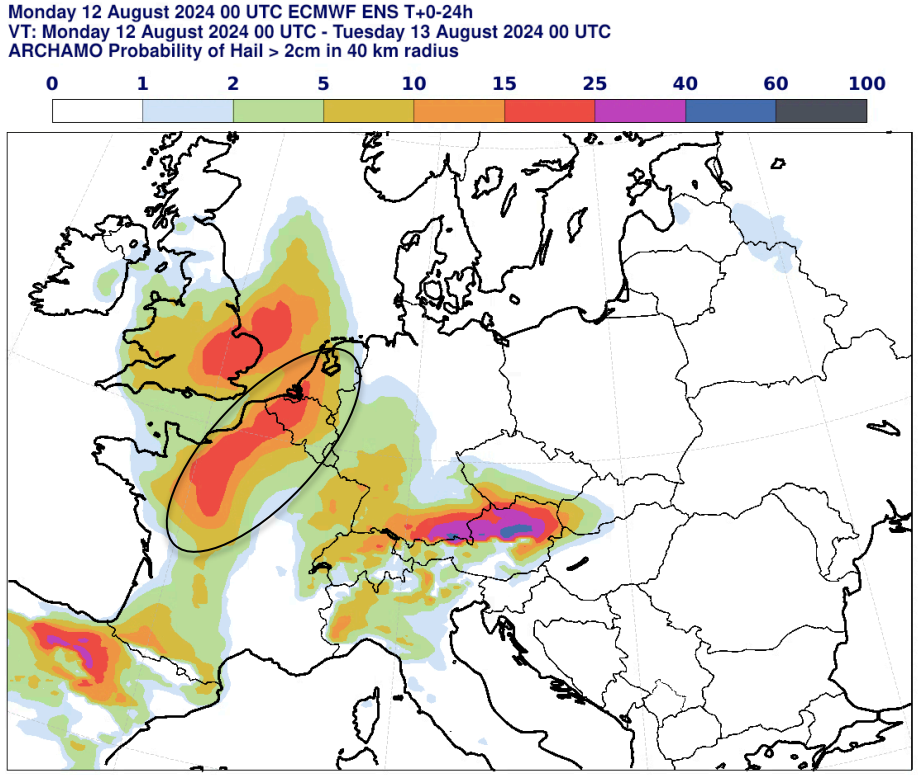


Bordeaux
12h Forecast

- Low probabilities of large and very large hail where it was observed.
- Reason1 for low probabilities: Underestimation of MUCAPE in the forecast.
- Reason2 for low probabilities: a dry layer between 650 and 400 hPa. Latest research show that the average relative humidity of a shallower layer between 1 and 4 km AGL is a more skillful predictor of lightning than that of a layer between 850 and 500 hPa used in the lightning model.

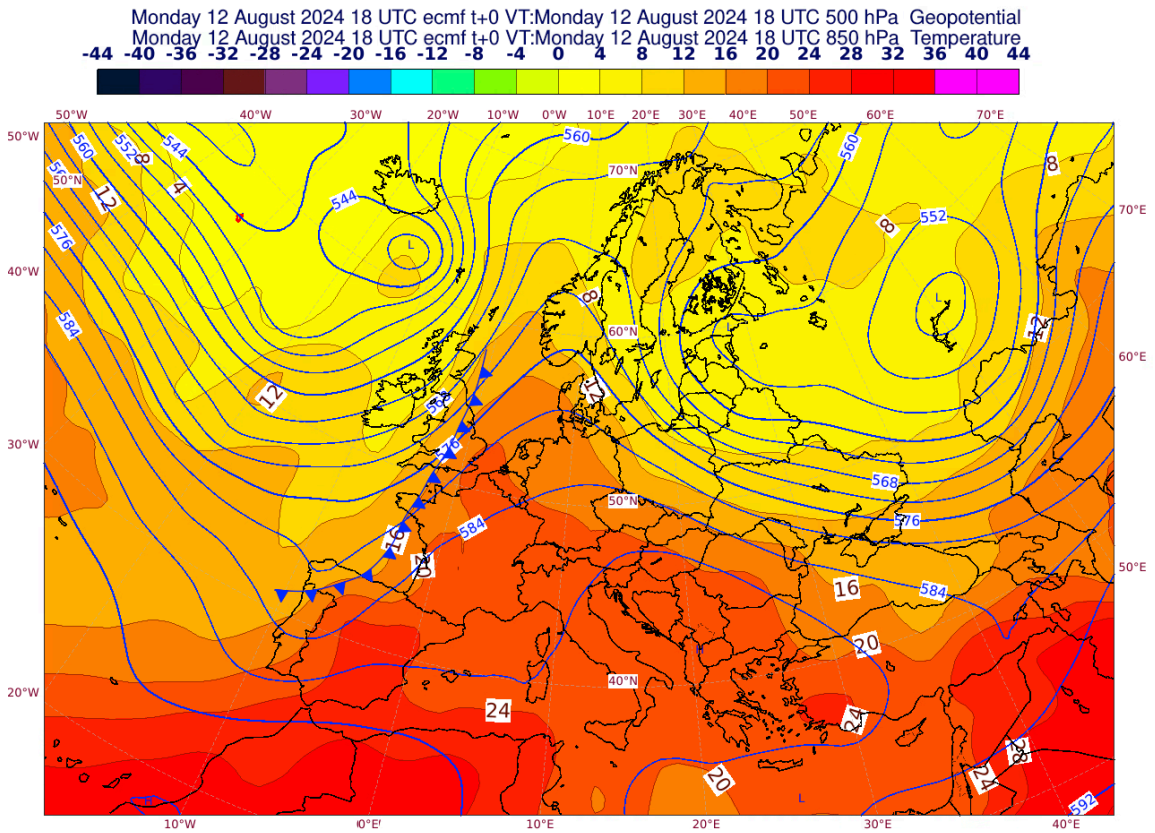
AR-CHaMo probabilities – a false alarm case

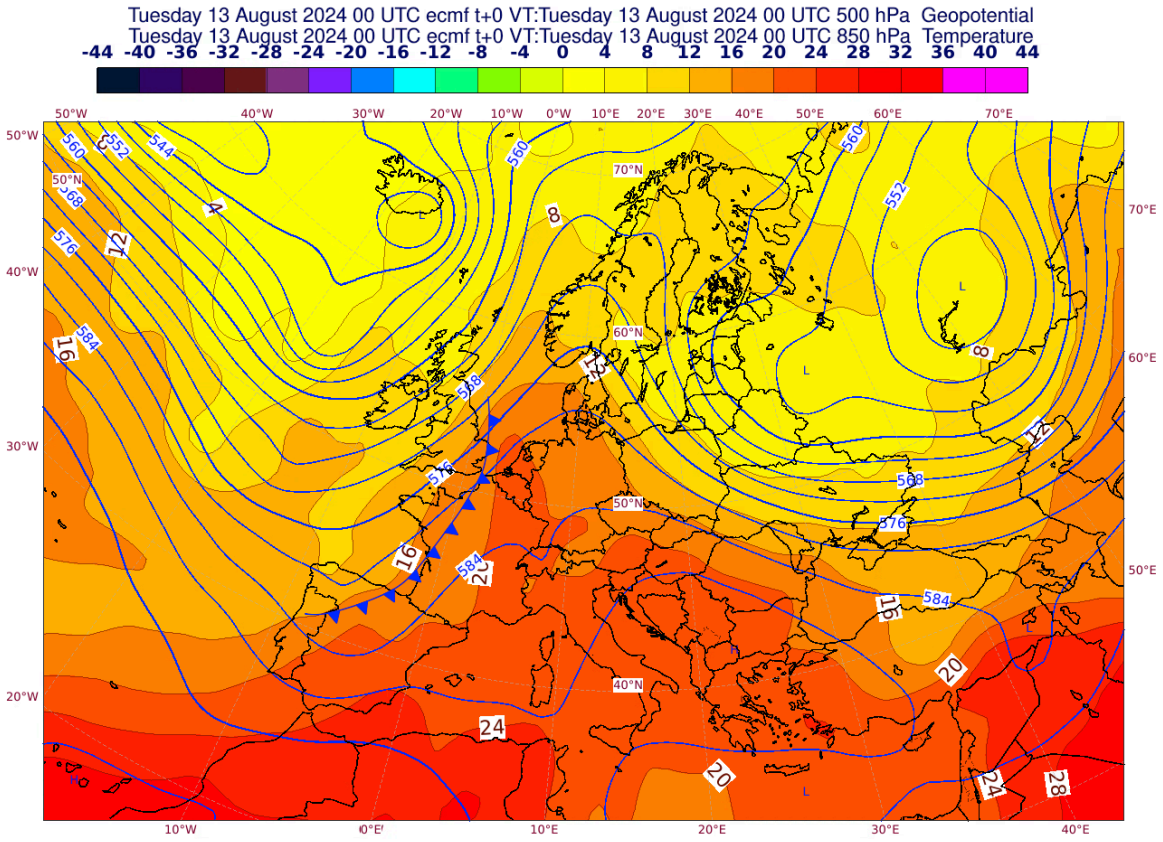




- High probabilities of large hail over NW France and Belgium.
- No storms in the area. No convection was initiated.

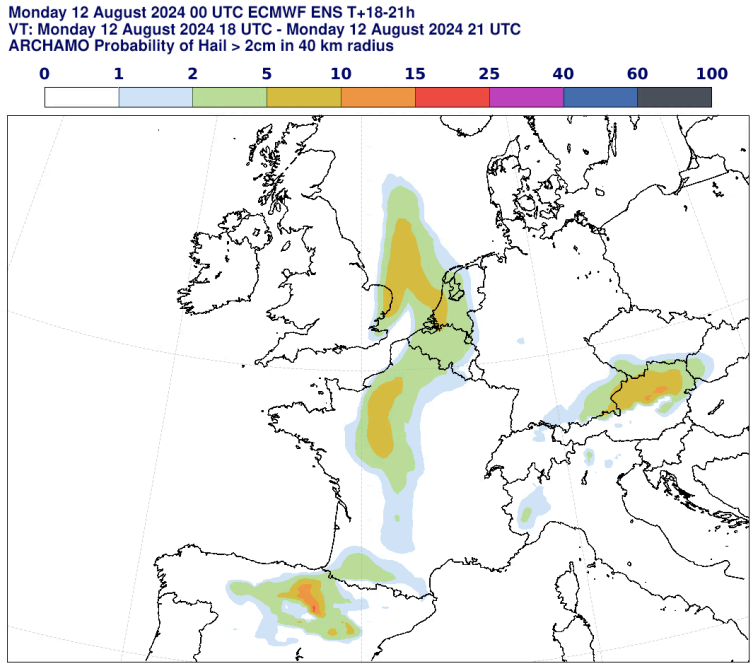
AR-CHaMo probabilities – a false alarm case

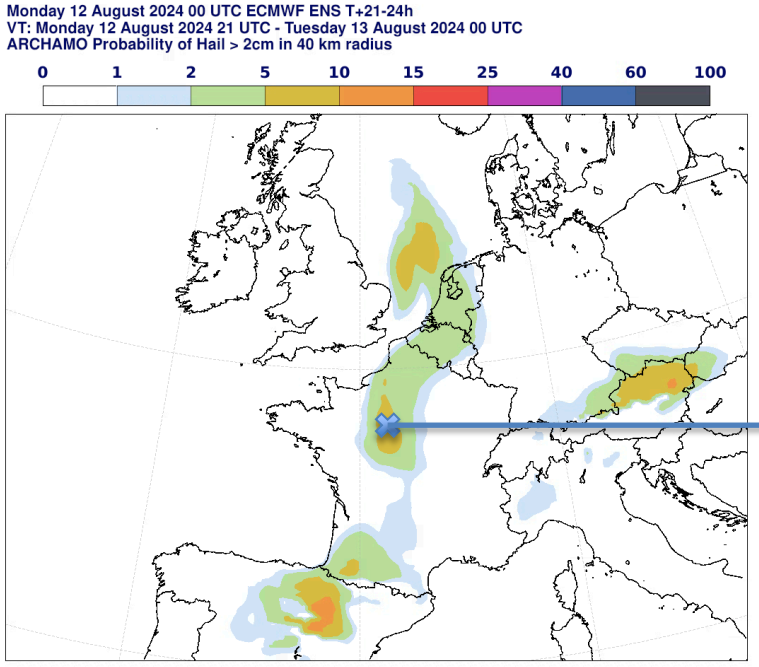


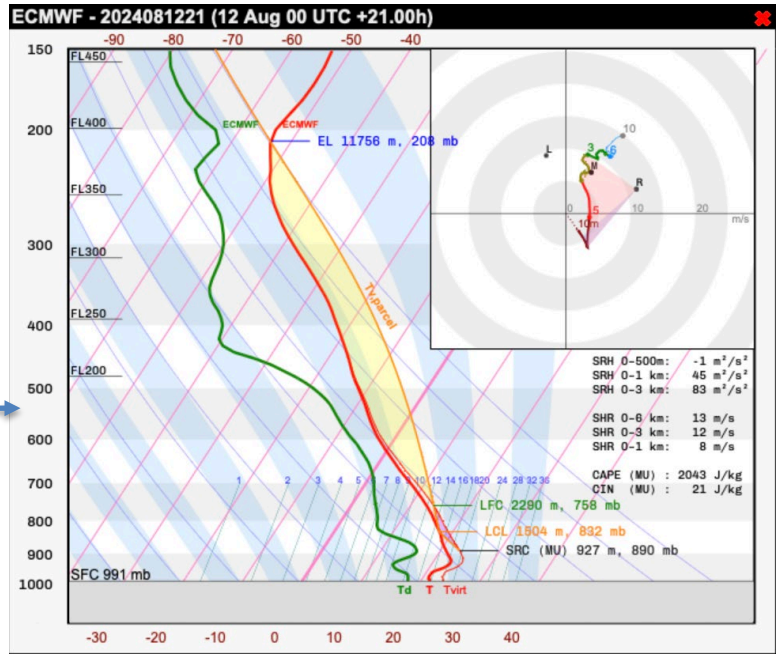


- A cold from from the west approaching NW France and Belgium in evening and night hours.
- Ahead of the cold front – moist, unstable airmass with MUCAPE over 1000 J/kg and moderate values of DLS.

AR-CHaMo probabilities – a false alarm case

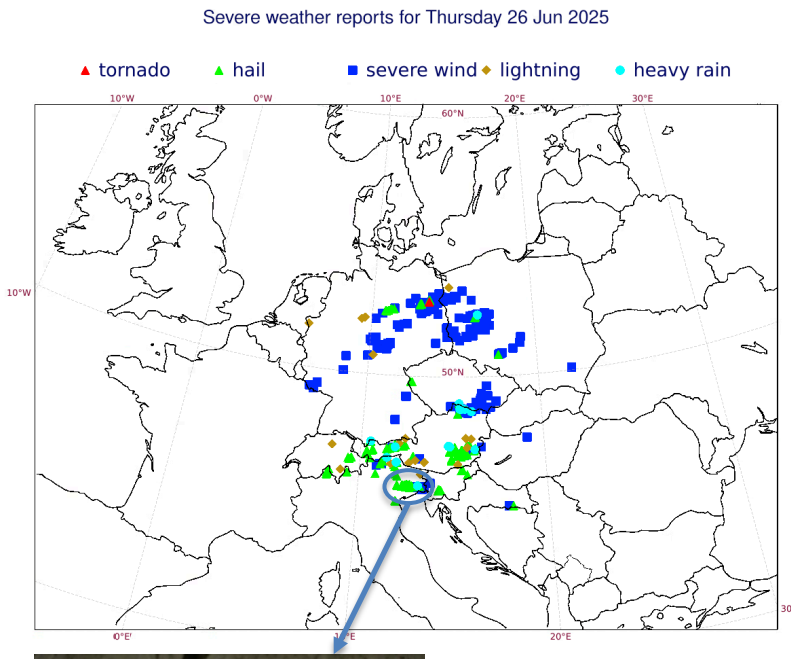


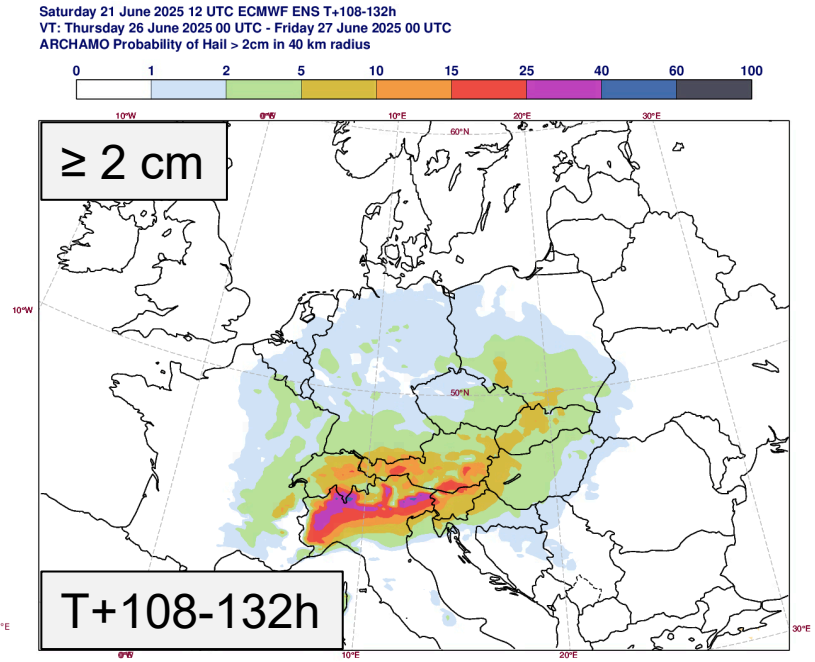


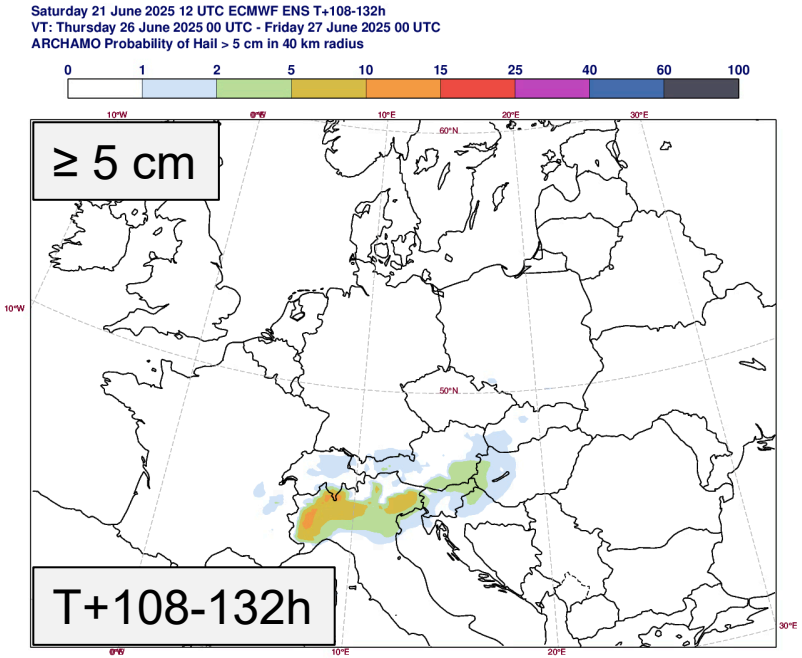


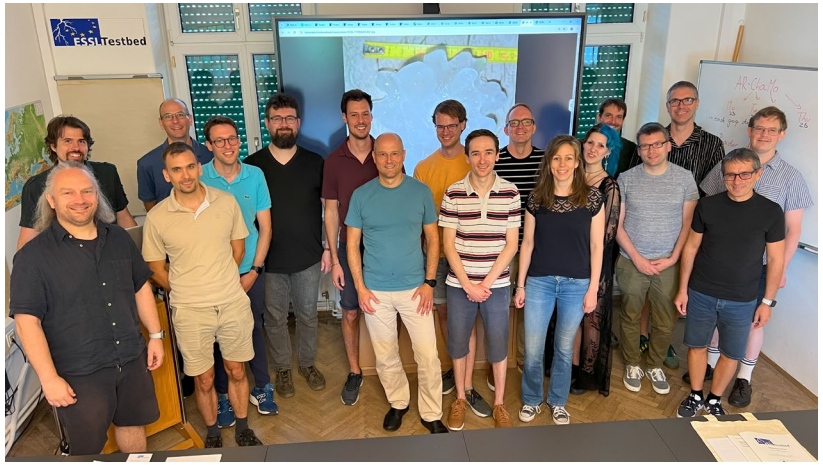
- High 24h probabilities of large hail were due to a long period with relatively high probabilities of large hail.
- Probabilities increased in the evening hours. ECMWF kept low probabilities of rainfall which hinted that convective initiation could be a problem.
- Initiation failure could be caused by the lack of a deep enough mesoscale lift along the cold front to reach the LFC for the elevated storms.

Severe convective case – 26 June 2025 (see also the poster)



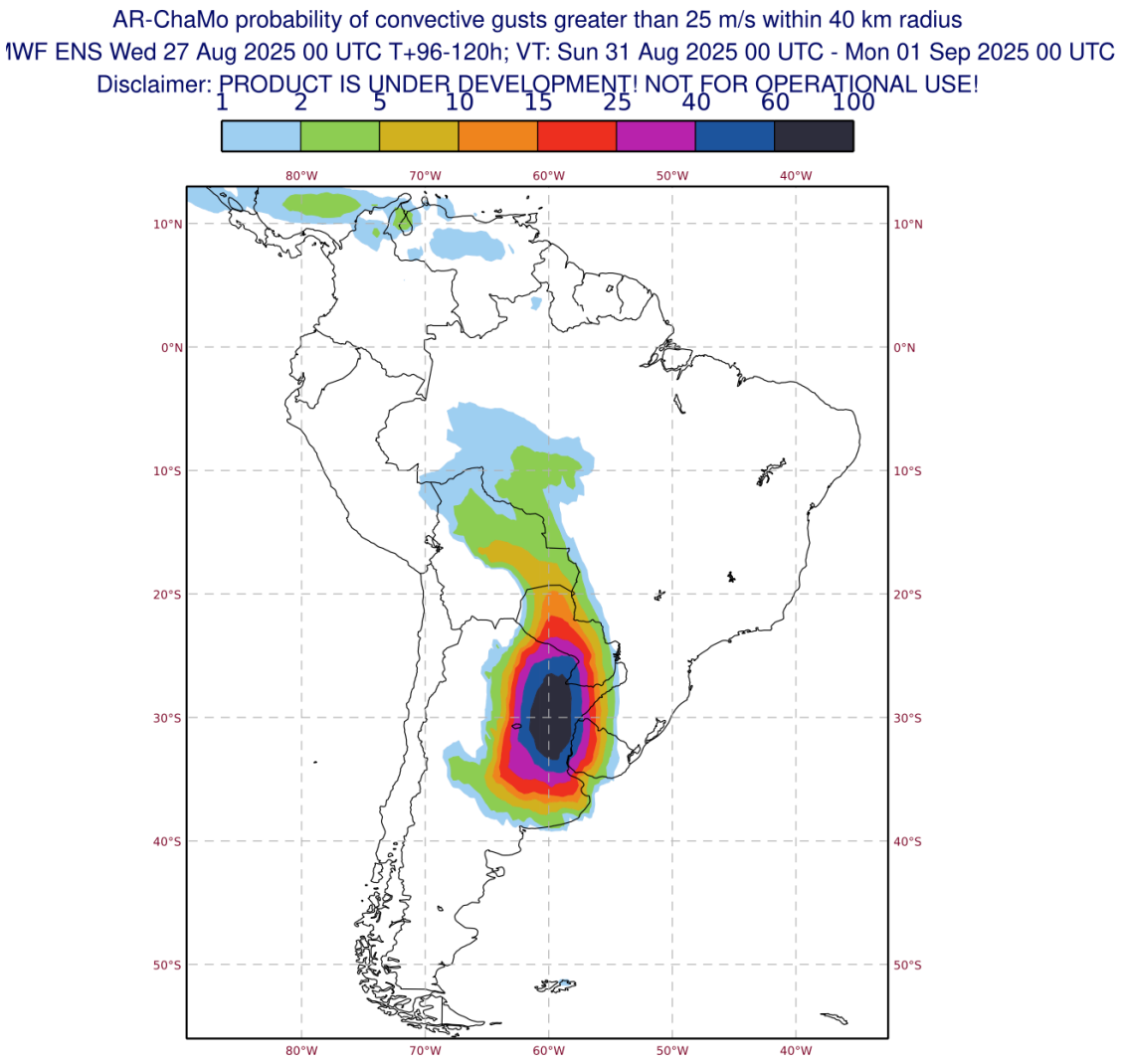






- Large (2-5 cm) and very large (over 5 cm) hail around the Alps, severe wind gusts further north.
- Max. hailstone size – 12 cm over NE Italy.
- AR-CHaMo probabilistic forecasts of large and very large hail highlighted the Alpine region well in advance.

Ongoing work



- Improvements in the lightning model would improve other AR-CHaMo models:
  - ✓ Increasing training dataset by extending the training period to more recent years
  - ✓ Including CIN as a predictor
- Improving AR-CHaMo wind model:
  - ✓ Significant increase in wind reports used for training (not only wind reports where wind speed measurement is present)
  - ✓ Testing more predictors (probabilities are very sensitive to the low-level (1-3 km) mean wind
  - ✓ Including more datasets from other regions (e.g. South America)

Predictors for the Lightning model (original set):

- ✓ Most unstable LI;
- ✓ Most unstable mixing ratio
- ✓ Mean RH 850-500 hPa
- ✓ Convective precipitation
- ✓ Land-sea mask