Forecasting Large Hail using Logistic Models and the ECMWF Ensemble Reforecasts

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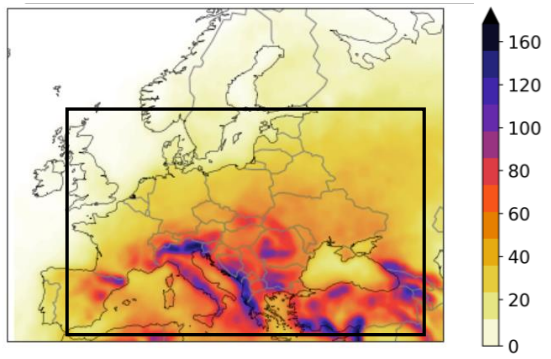
Additive Regressive Hail Model (AR_{hail}) development

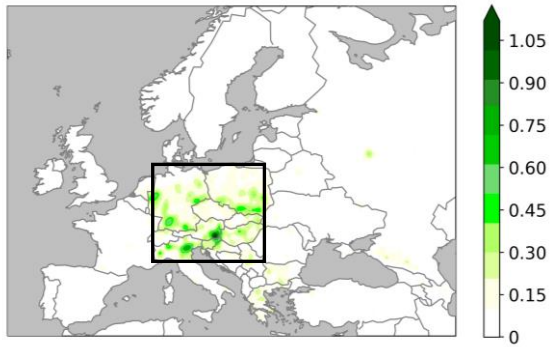
Training data

2008-2020 - Europe

Lightning



Hail ≥ 2cm

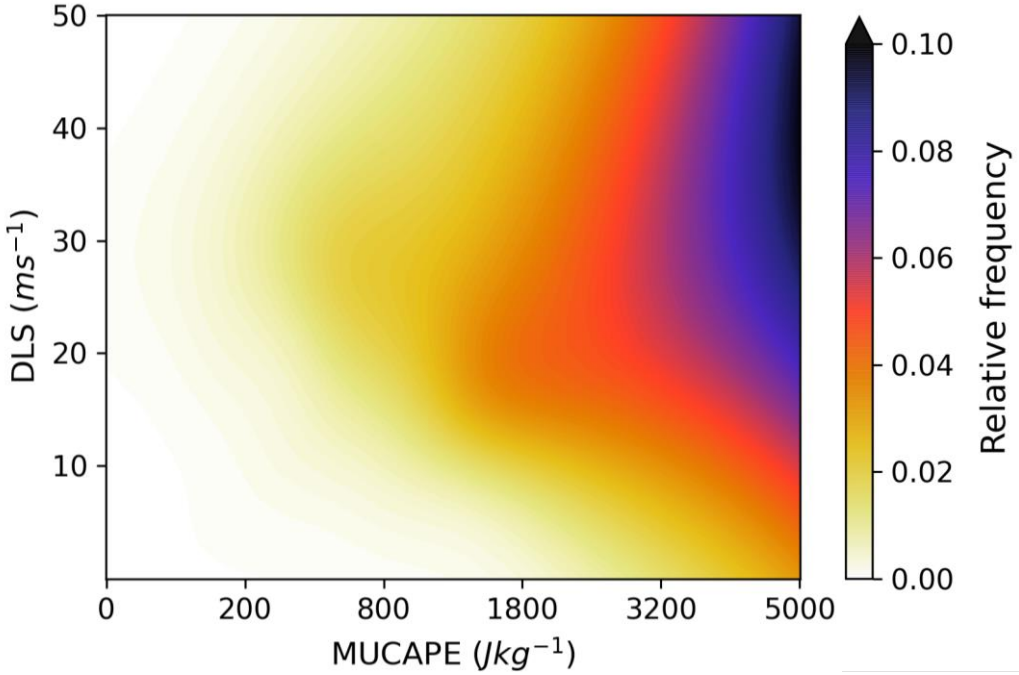


ERA5 reanalysis

$$AR_{hail}$$

$$P_{hail} = P_{storm} \times P_{hail|storm}$$

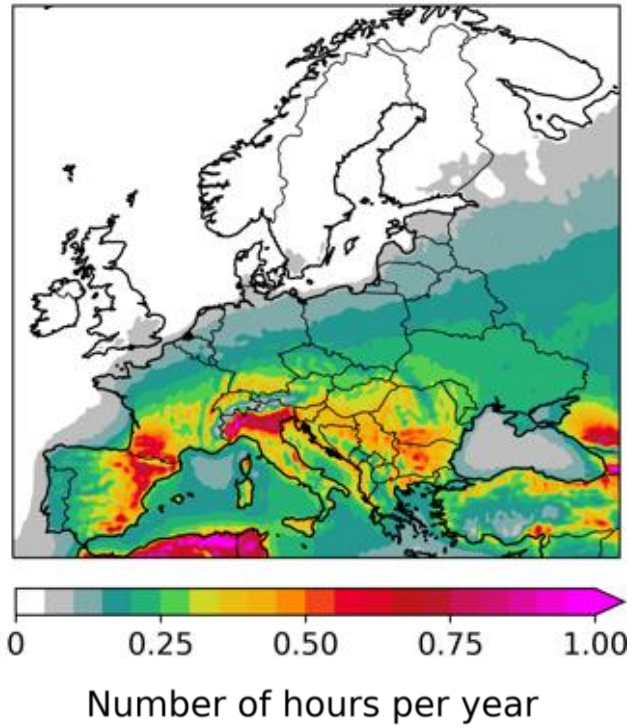
Fraction of environments with hail ≥ 2 cm ***(modelled)***



Application

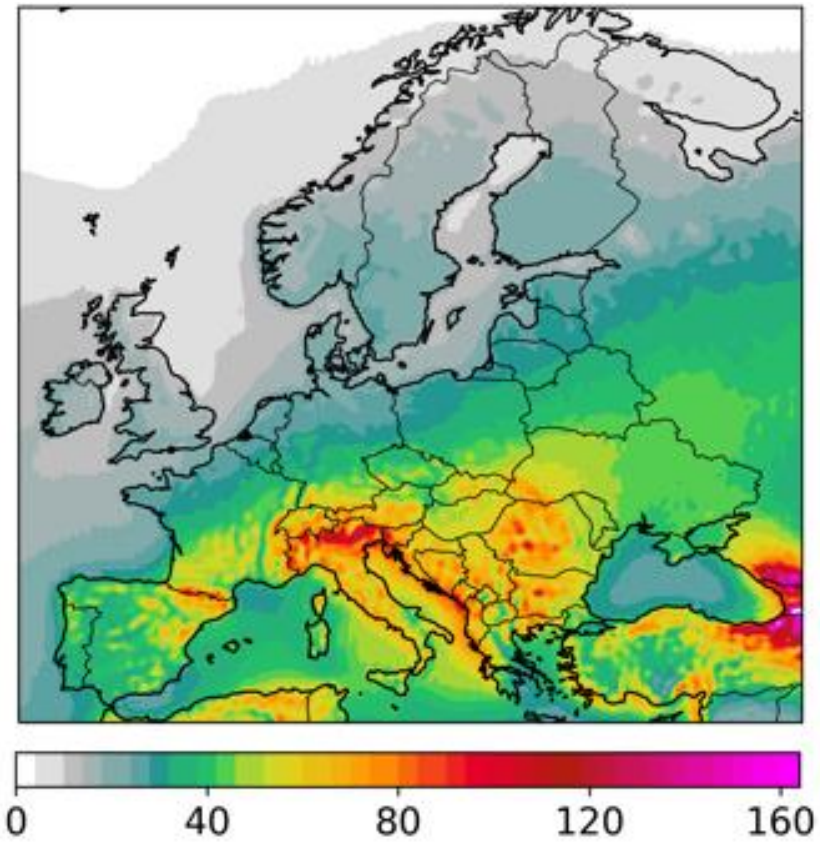
1950-2021 – All Europe

Modelled *climatology of hail ≥ 2 cm (1950-2021)*



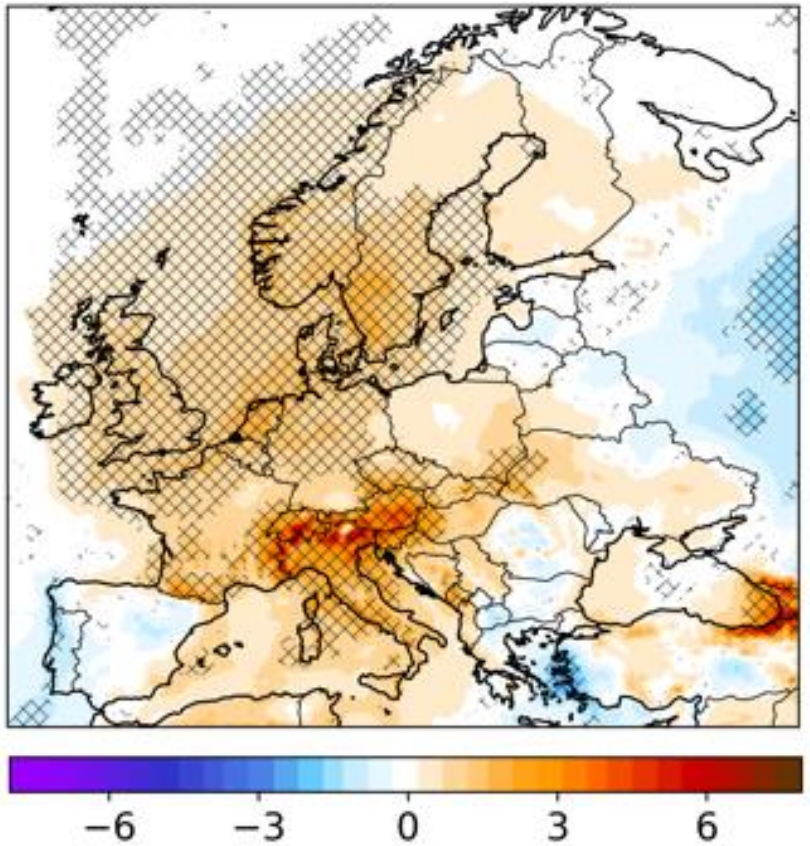
Lightning climatology and trends (1950-2021)

Annual Mean



Number of hours per year

Decadal trend



Change in number of hours per decade

Lightning model predictors

Most Unstable Lifted Index

Relative Humidity 500-850 hPa

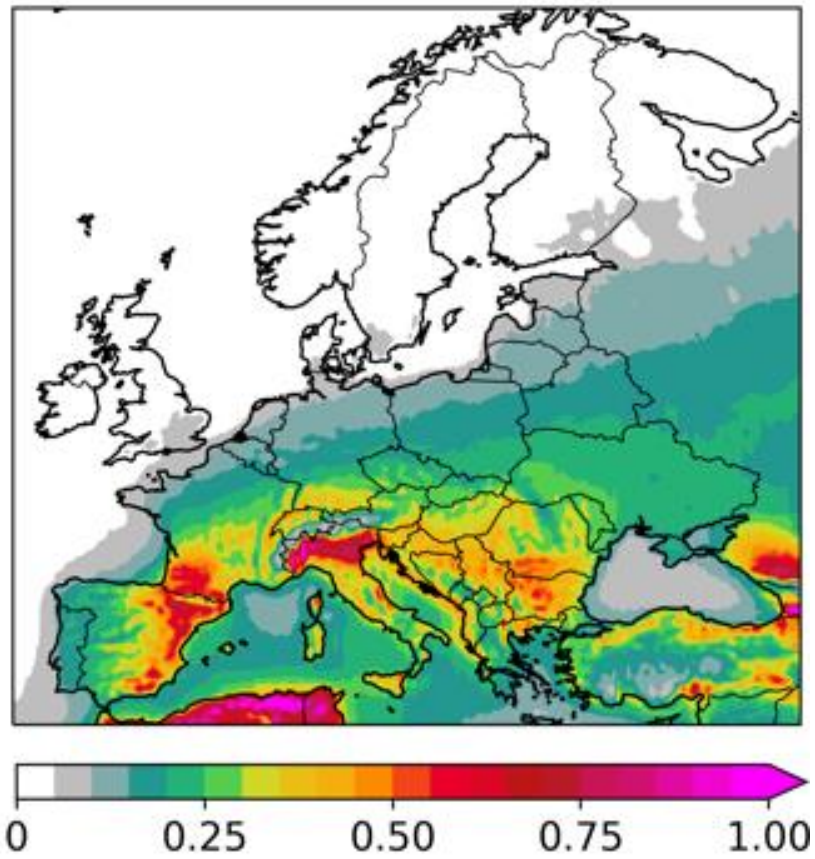
Convective Precipitation

Most Unstable Mixing Ratio

Land Sea mask

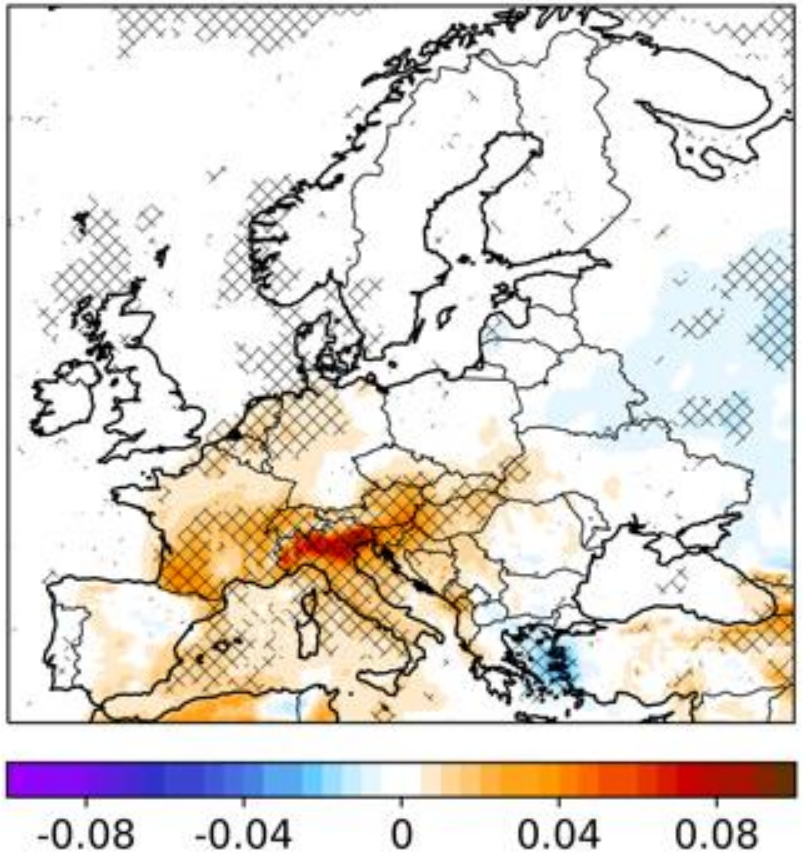
Large hail climatology and trends (1950-2021)

Annual Mean



Number of hours per year

Decadal trend



Change in number of hours per decade

Large hail model predictors

Most Unstable CAPE above -10°C

Effective Most Unstable Bulk Shear

Most Unstable Mixing Ratio

Height of 0°C isotherm

Model adaptation to reforecasts

1. Adapt predictors

*1. **ERA5 based** - Most Unstable CAPE above -10°C isotherm*
*1. **Reforecasts** - Most Unstable CAPE*

*2. **ERA5 based** – Effective Most Unstable Bulk Shear*
*2. **Reforecasts** – Deep Layer Shear*

*3. **ERA5 based** – Most Unstable Mixing Ratio*
*3. **Reforecasts** – Specific humidity at 925 hPa*

2. Develop simplified models

Lightning model

1. *Most Unstable CAPE*
2. *Relative Humidity 500-850 hPa*
3. *Convective precipitation (to be included)*

Large hail model

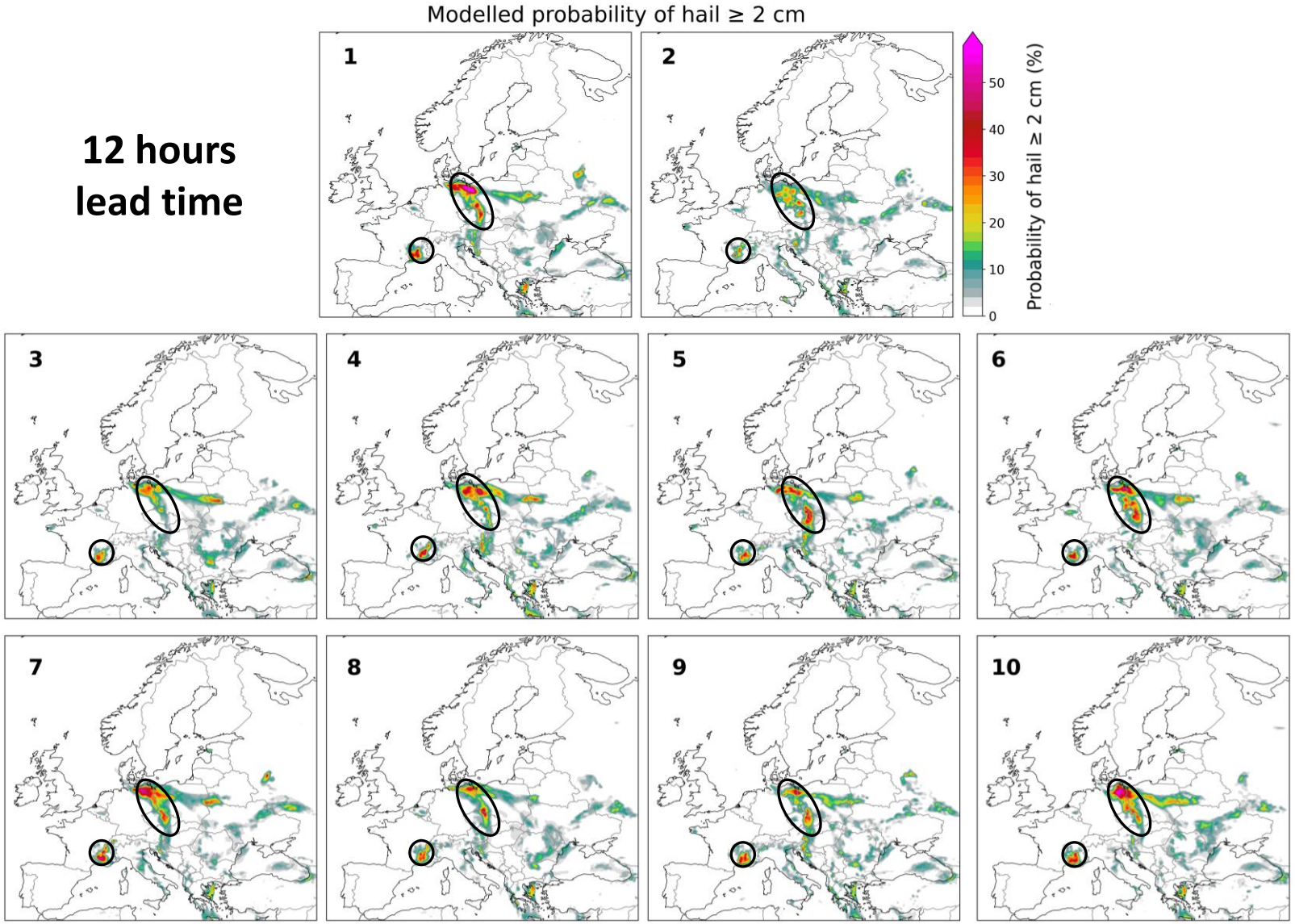
1. *Most Unstable CAPE*
2. *Deep Layer Shear*
3. *Specific humidity at 925 hPa*
4. *Height of 0°C isotherm*

3. Apply to reforecasts

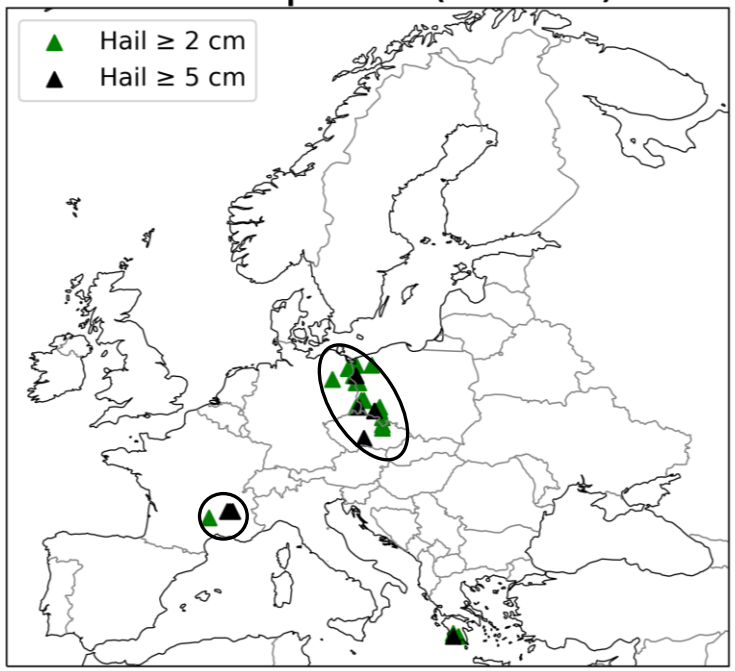
Hail forecasts from 2008 to 2019
10 ensemble members
lead times from 12 to 228 hours

Ensemble Hail Forecasts per lead time – 15th June 2019

12 hours lead time

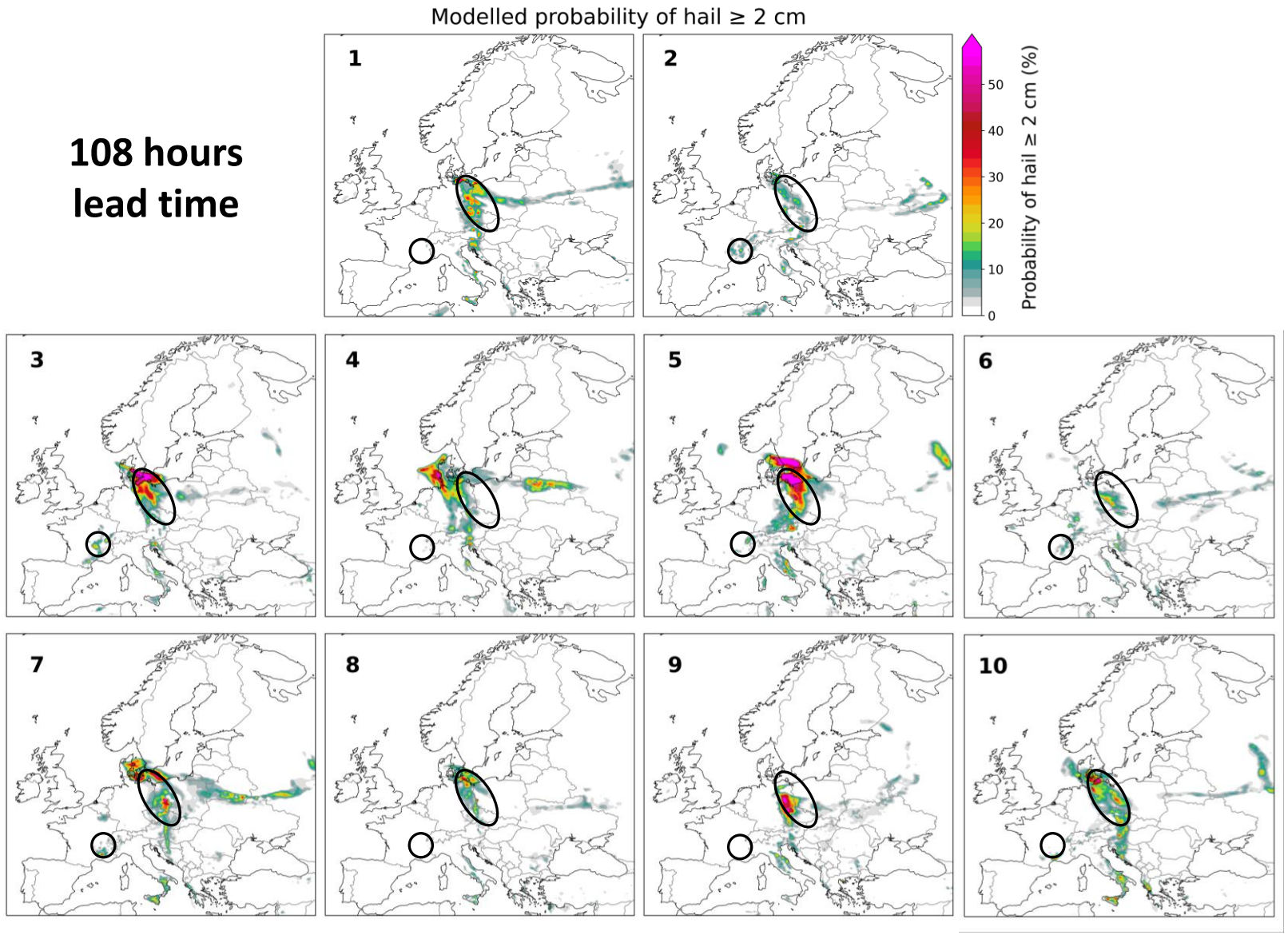


Hail reports (*ESWD*)

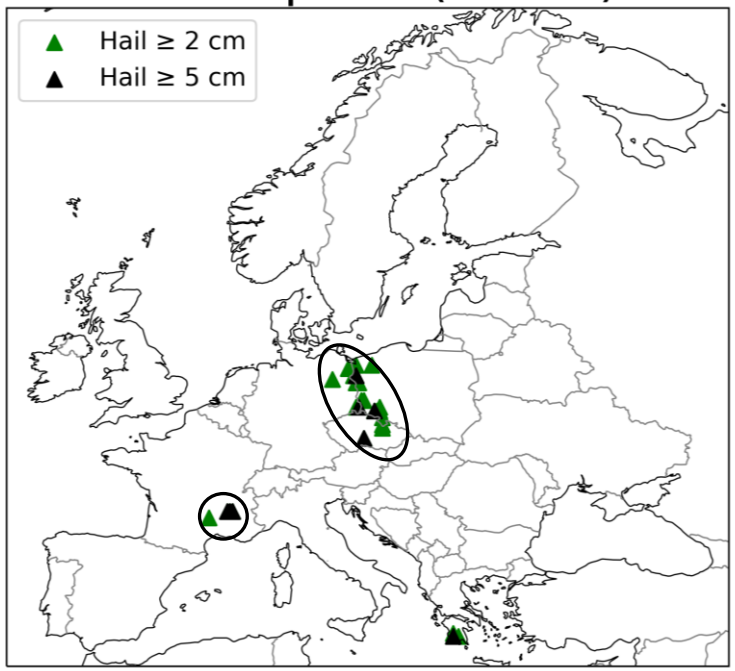


Ensemble Hail Forecasts per lead time – 15th June 2019

108 hours lead time

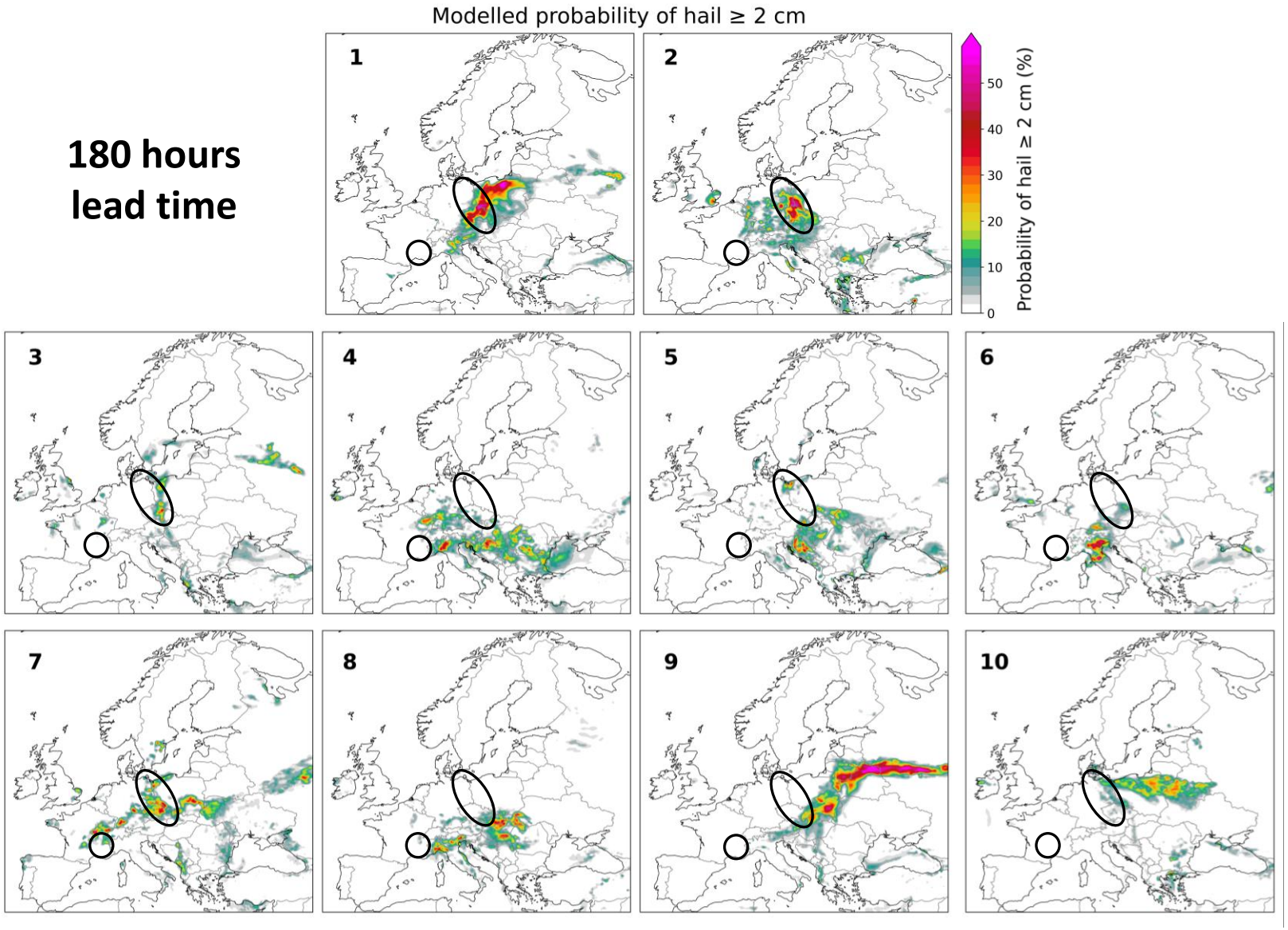


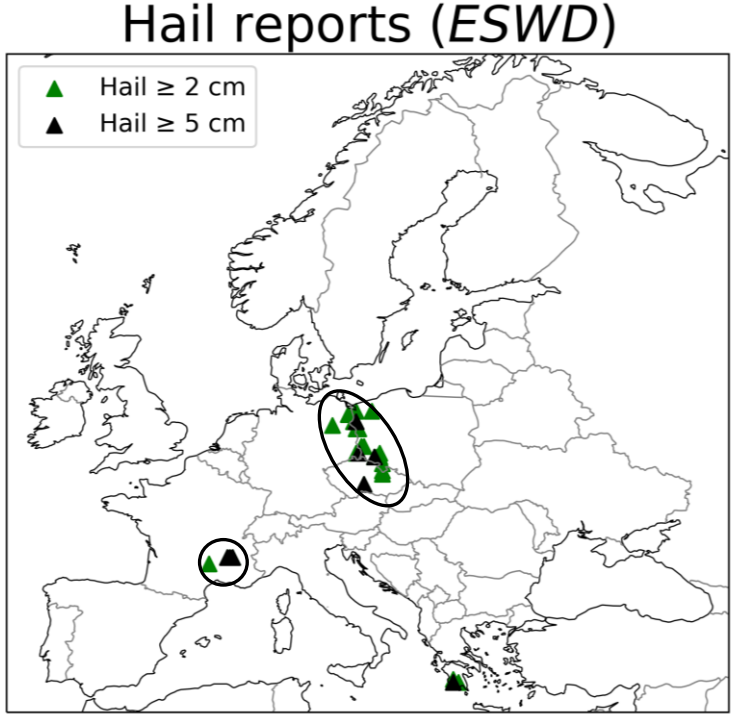
Hail reports (*ESWD*)



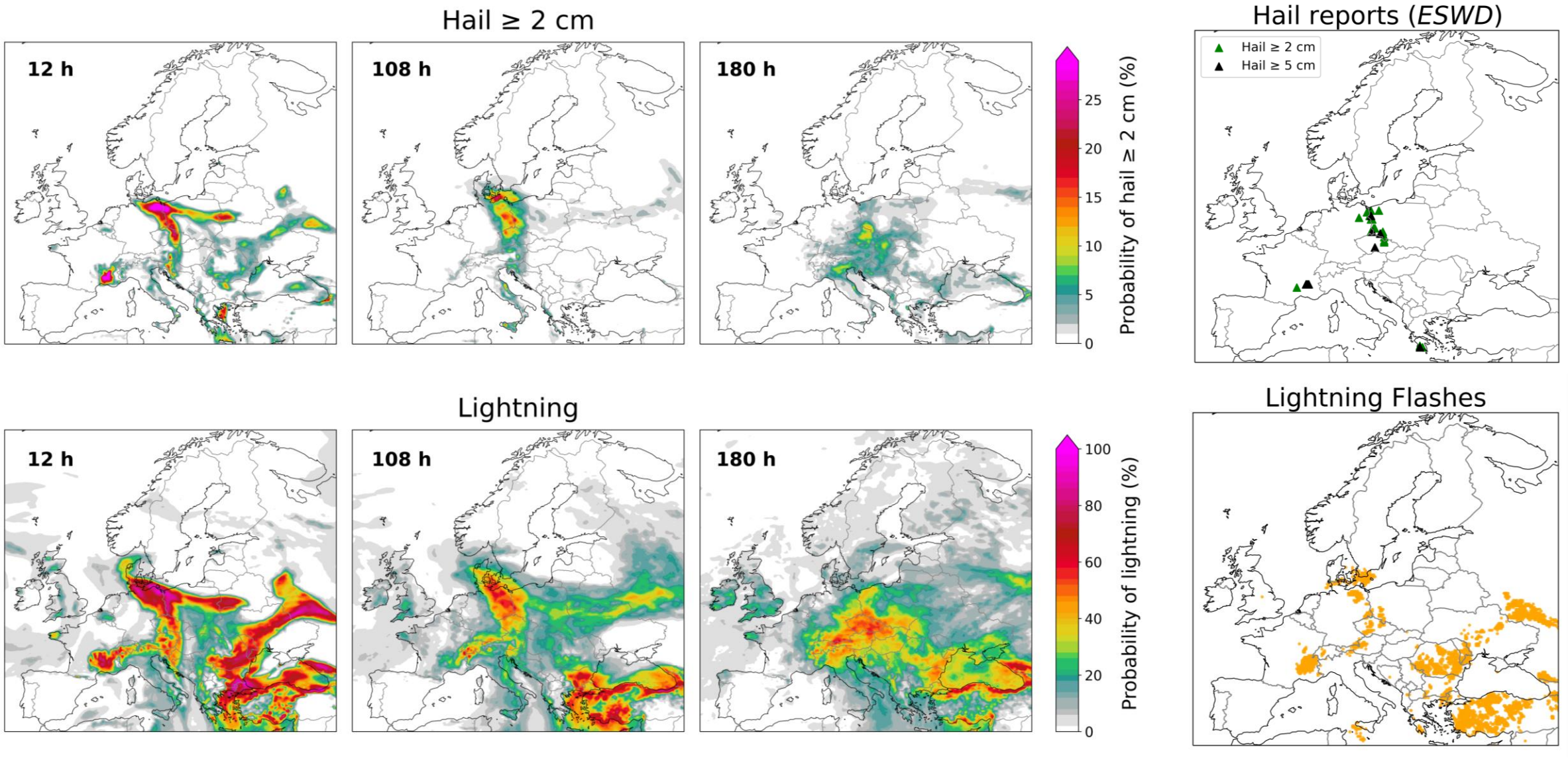
Ensemble Hail Forecasts per lead time – 15th June 2019

180 hours lead time



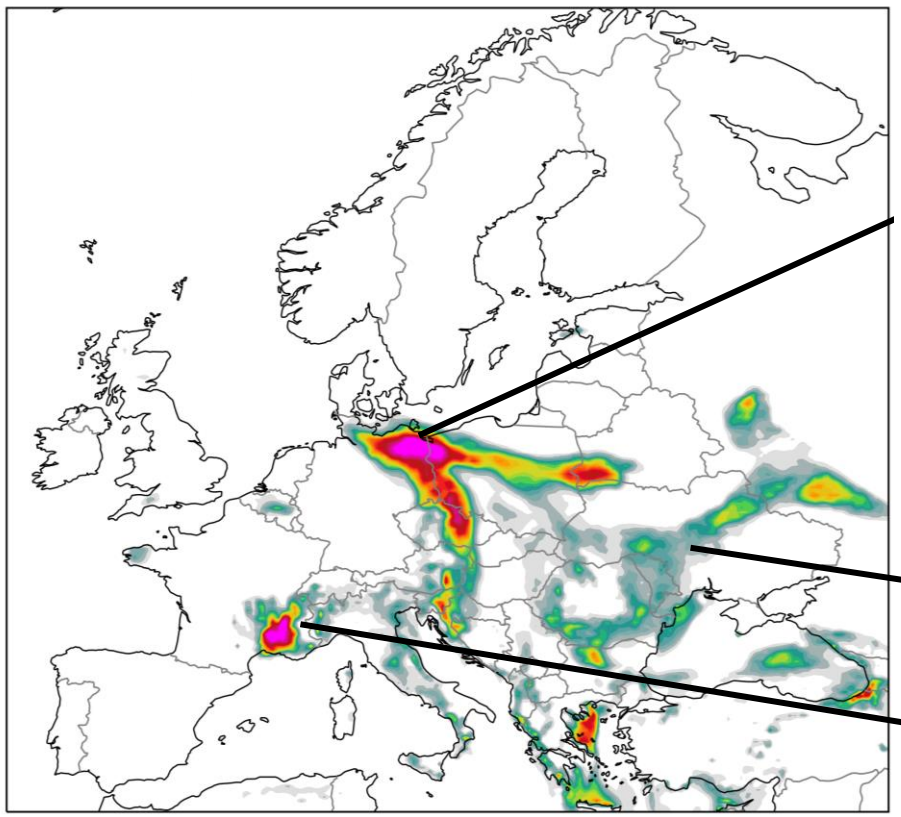


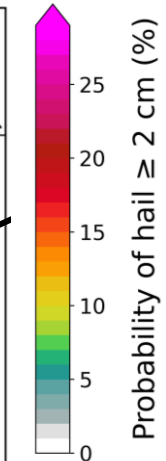
Ensemble Mean Forecasts per lead time – 15th June 2019



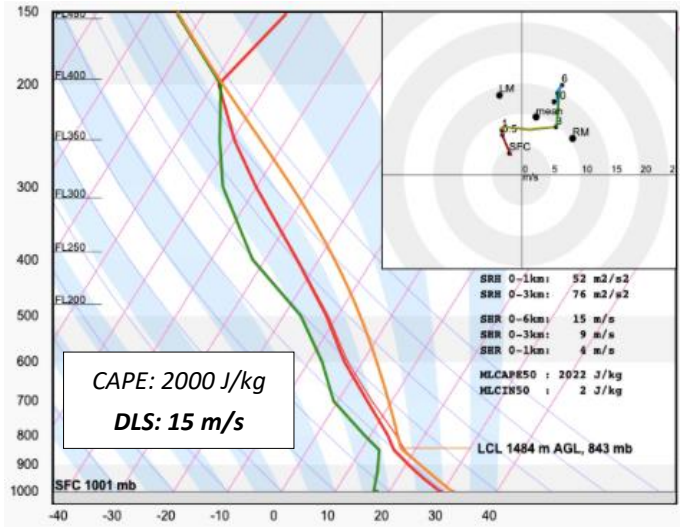
Hail forecast and convective environment

12 hours Hail Ensemble Mean Forecast

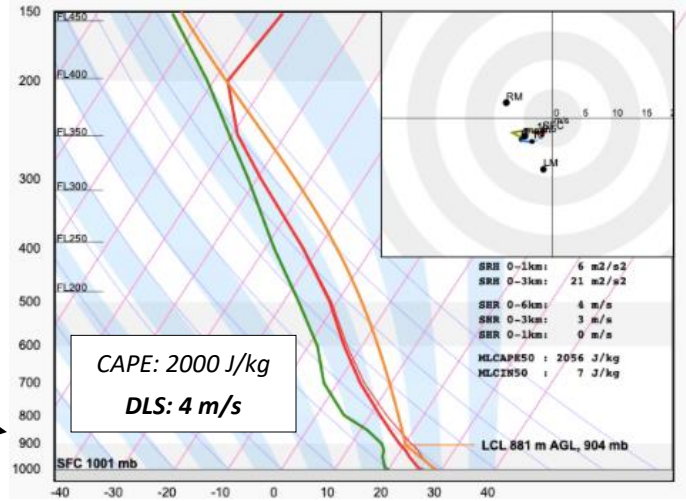




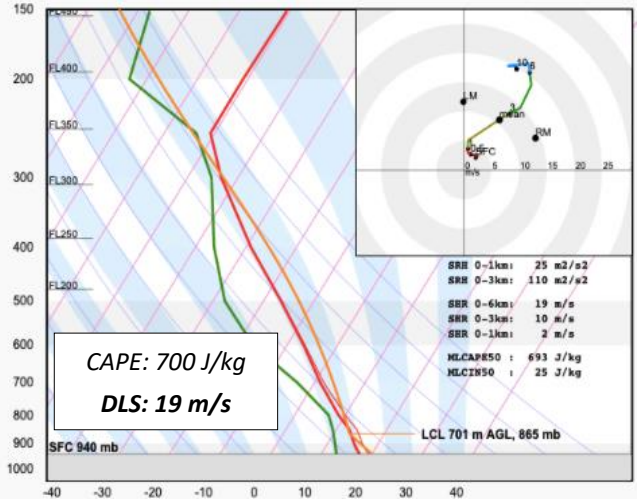
Hail



No Hail

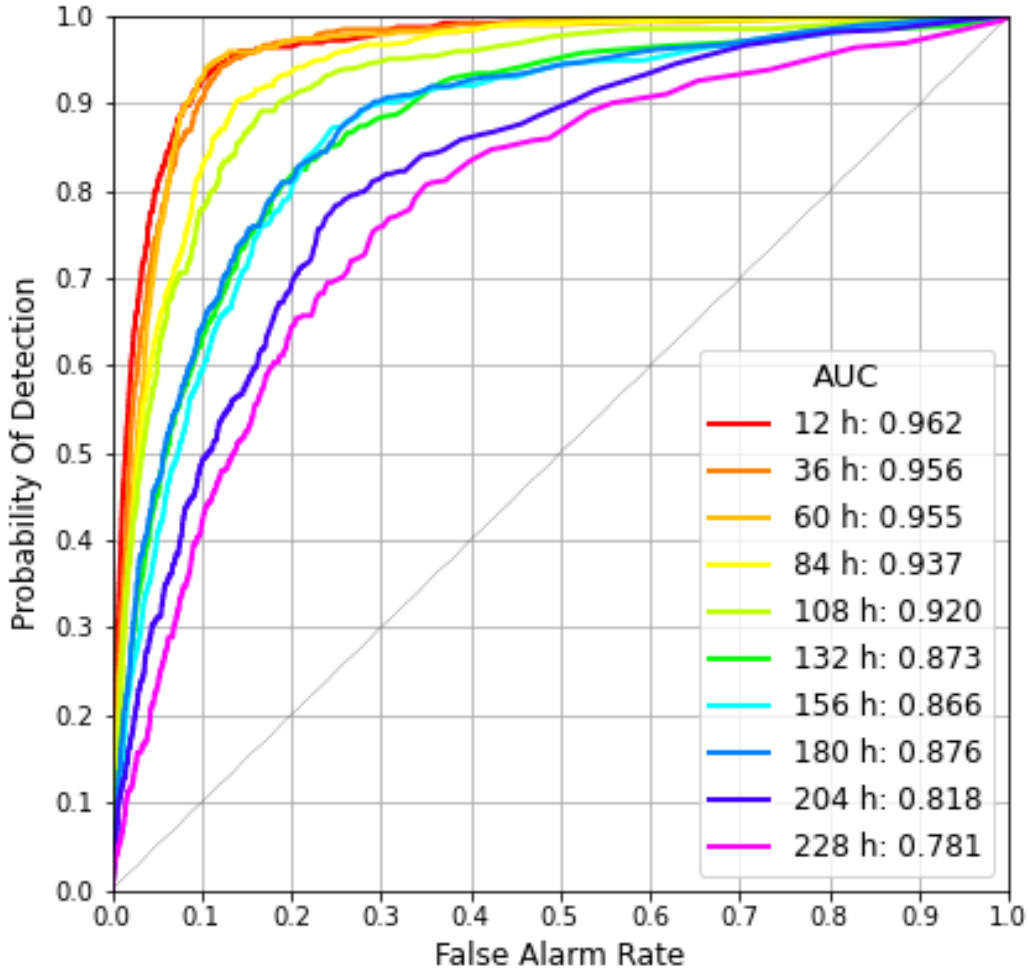


Hail

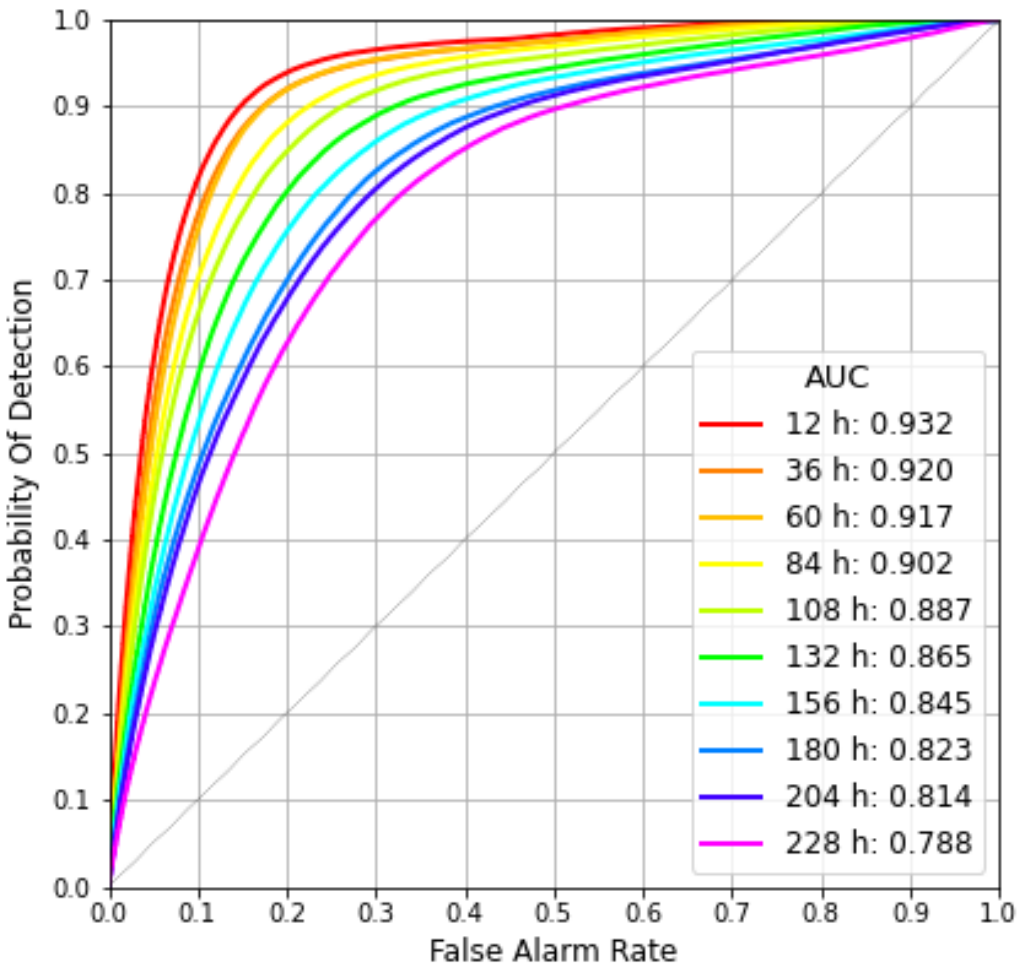


Model evaluation per lead time

Hail model - ROC curve per forecast lead time

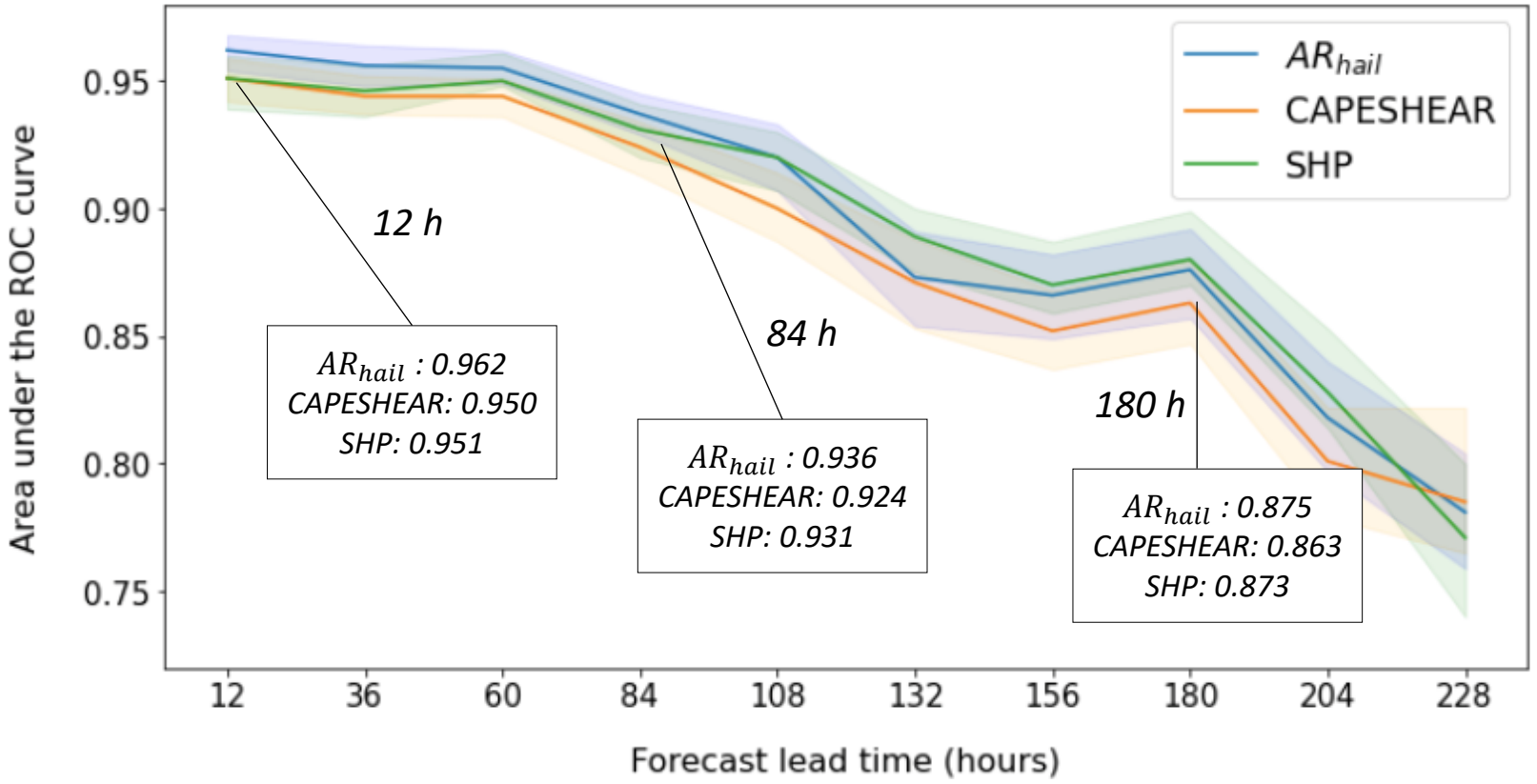


Lightning model - ROC curve per forecast lead time



Comparison with hail composite parameters

AR_{hail}, CAPESHEAR and Significant Hail Parameter (SHP) performance depending on forecast lead time



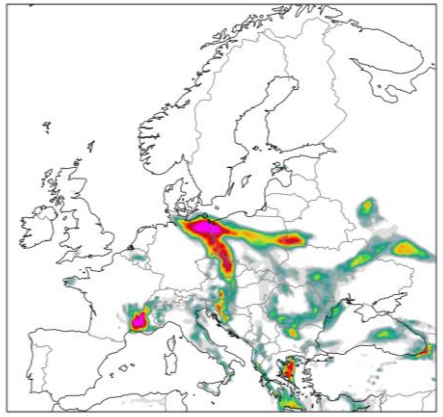
AR_{hail} outperforms existing parameters

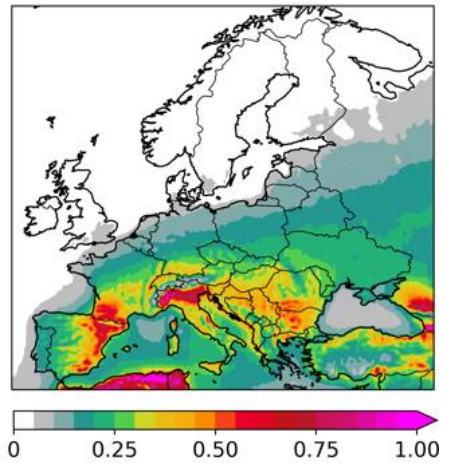
*Better than **CAPESHEAR** at all lead times.*

*Better than **SHP** at short ranges (up to 84 hours).*

Conclusion and future work

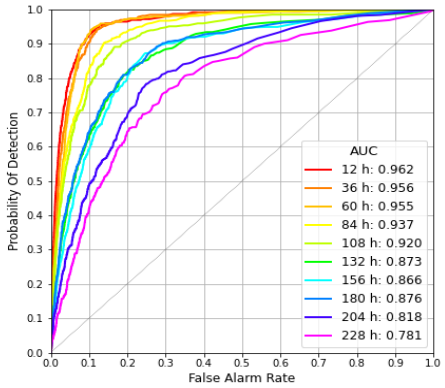
- Large hail and lightning models **accurately reproduce the climatological distribution.**





- Models adapted to reforecasts **provide skillful hail predictions up to 5 days in advance.**

- AR_{hail} **outperforms existing parameters** for hail forecasting.



Future work

1. Development of **very large hail ($\geq$ 5 cm) and convective wind models.**
2. Inclusion of **convective precipitation in the lightning model** and **comparison with IFS lightning diagnostic.**
3. Application **of full ERA5 hail model** to the ECMWF Ensemble Prediction System.

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Model selection

Evaluation metrics

- Deviance Explained
- Bayesian Information Criterion (BIC)

- Parameters are split in **three main categories.**
- Best thermodynamic and shear parameters build the 2D model:

Best Thermo + **Best Shear** → 2D model

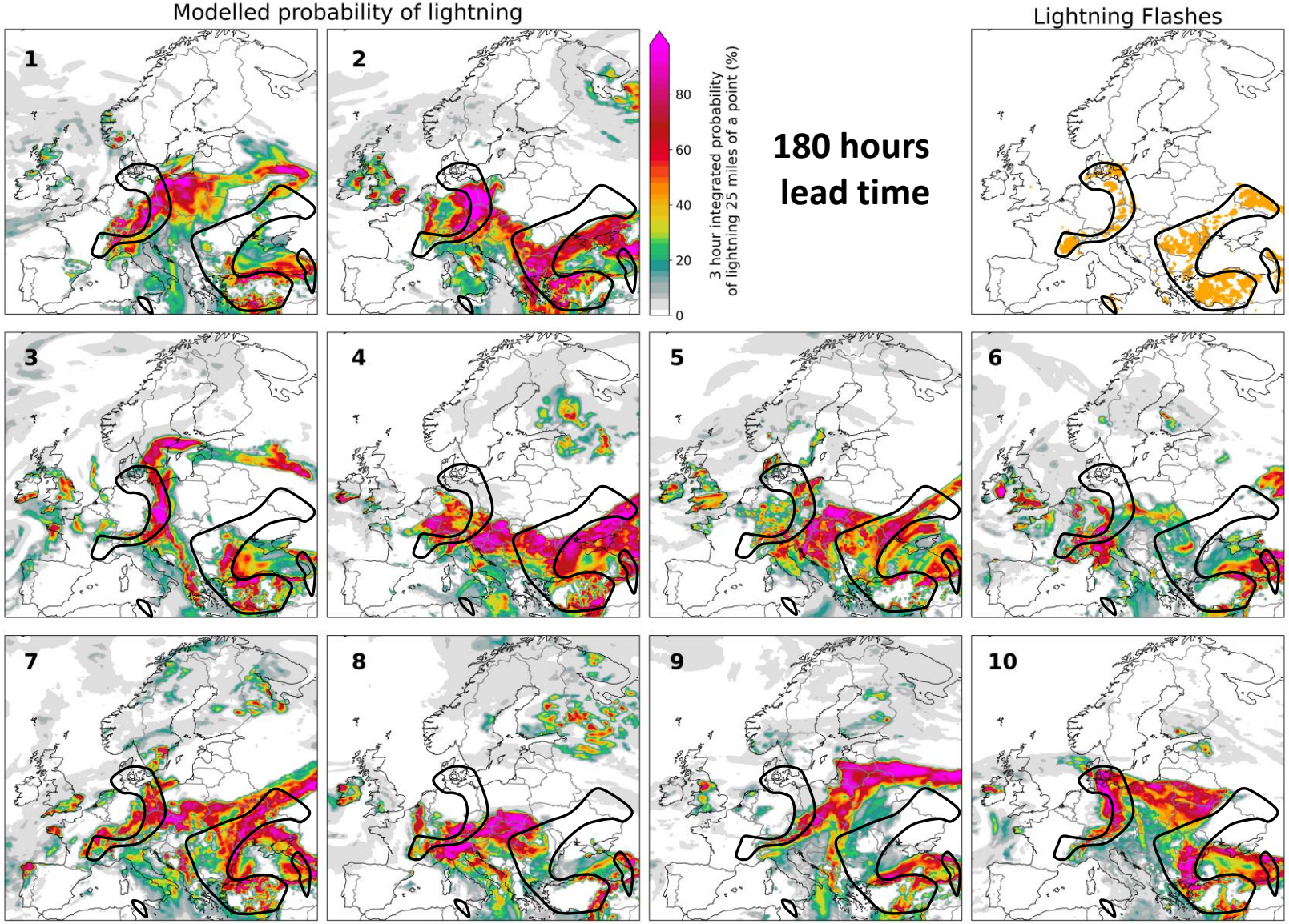
Best Thermo	Best shear	Best other
$MU\ CAPE$	BS_{06}	LCL_{height}
$ML\ CAPE$	BS_{08}	LFC_{height}
$SB\ CAPE$	BS_{16}	$0°_{height}$
$MU\ CAPE_{HGL}$	BS_{HGL}	$Wb\ 0°_{height}$
$MU\ CAPE_{-10°C}$	$EFF\ BS_{MU}$	SRH_{03}
LI	$EFF\ BS_{ML}$	$MIXR_{ML}$
LR_{36km}	$EFF\ BS_{SB}$	$Convective\ depth$
LR_{24km}	$BS_{-10°C}$	…
…	…	

- Starting from the 2D model, 10 **other** parameters are tested. The **parameter adding the most skill** to the original is chosen to **build a 3D model**

Best Thermo + **Best Shear** + **Best Other** → 3D model

Best Thermo + **Best Shear** + **Best Other** + **Best Other –1** → 4D model *(Until the model overfits)*

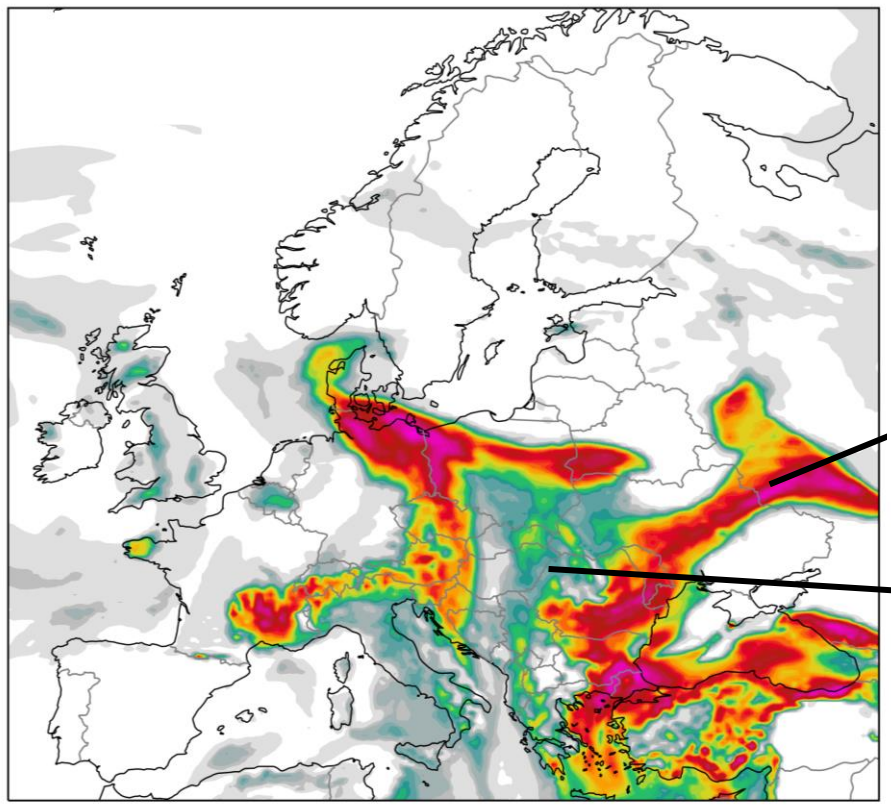
Ensemble Lightning Forecasts per lead time – 15th June 2019



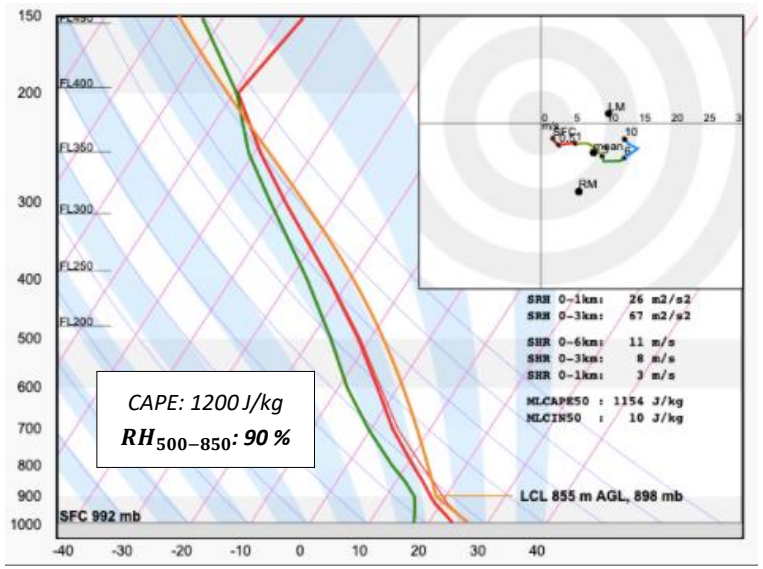
- **High probabilities** along the Polish-German border and SE France, and most of Eastern Europe.
- **Overestimation over the Black Sea –** inclusion of convective precipitation could help.
- **Good agreement between ensemble members at 12 hours** lead time.
- The **ensemble spread increases strongly already at 108 hours**, uncertainty on the location of the frontal boundary in Eastern Europe.

Lightning forecast and convective environment

12 hours Lightning Ensemble mean forecast



Lightning



No lightning

Too dry