Annual Meeting 2022
4–9 September 2022, Bonn, Germany

SCREEN CAPTURE
WELCOME

Towards hail hazard estimation over Italy with a combination of high-resolution reanalysis proxies and overshooting top detections

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Why hail research?


Hailstorm near Asti, 27/07/2016

- Hail is one of the most hazardous perils related to deep convection
- Severe hailstorms are recurrent events in Europe especially in northern Italy
- As a consequence of anthropogenic warming, **hail severity and frequency** are expected to increase (Raupach et al. 2021)

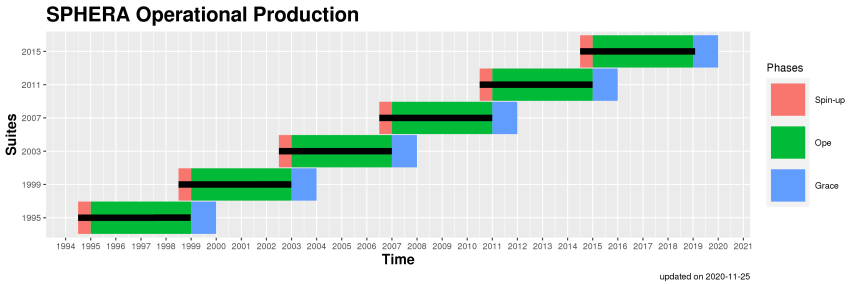
Limitations in hail representation:

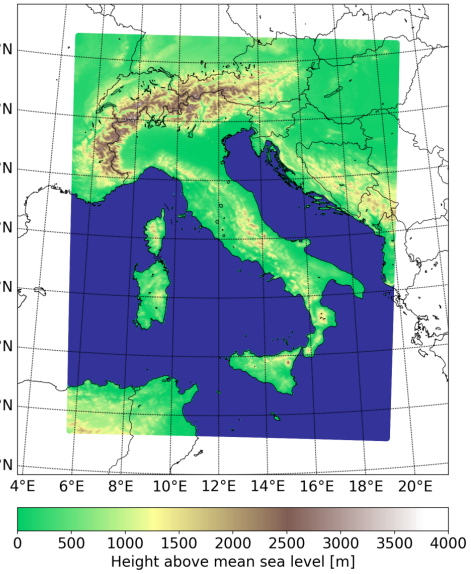
- Lack of homogeneous, continuous and complete observing system
- Inaccuracies of NWP simulations (physical parameterizations)


Hailstorm near Fidenza, 26/07/2021

SPHERA: High rEsolution regional ReAnalysis over Italy

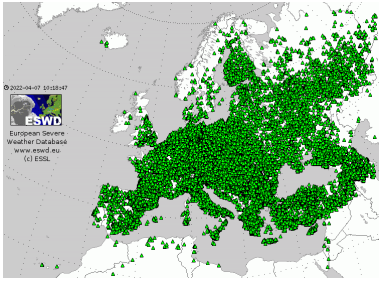
- SPHERA is a new regional reanalysis produced at the **convection-permitting** resolution of 2.2 km, covering Italy and the surrounding seas





- Downscaled from ERA5 (with ~31km horiz. res.), based on the model COSMO, and assimilating observations with a continuous nudging scheme, SPHERA covers 25 years (1995-2020) at hourly frequency
- **Objective**: estimate hailstorm frequency of occurrence by combining high-resolution reanalysis proxies with the available hail observations

Hailstorm observations



Hail observations:
direct and indirect

European Severe Weather Database (**ESWD**) from news, reports, spotters
Most extensive archive of hail reports in EU

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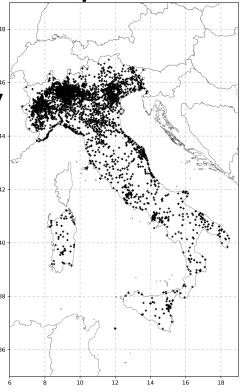
National insurance company claims dataset (**UNIPOL**) from hail-caused damage to cars, buildings and agriculture



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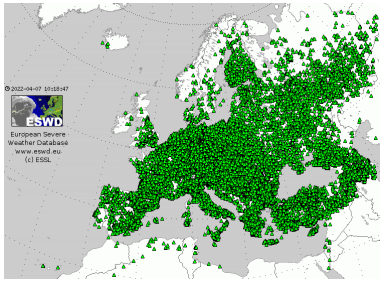

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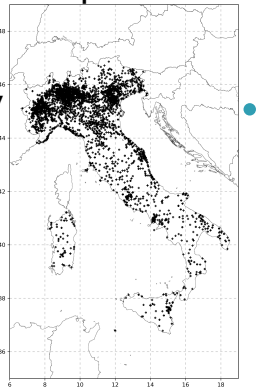
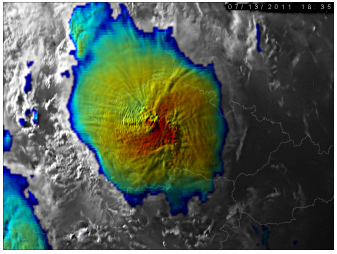


Overshooting Tops (OT):

- Convective cloud intrusions atop updrafts in lower stratosphere
- Indicate very strong convection



- Probabilistic detection of cold pixels in IR satellite imagery of Meteosat (MSG) SEVIRI cloud top temp. scans



Numerical proxies for hail

⇒ coupled with numerical proxies related to ***hail-favouring environments***

SPHERA dynamic/ thermodynamic conv. indices

Key ingredients for hailstorm occurrence in convective environments

Atmospheric instability and low-level moisture:

- **K index:**

$$K = (T_{850hPa} - T_{500hPa}) + Td_{850hPa} - (T_{700hPa} - Td_{700hPa})$$

- **Surface lifted index (SLI):**

$$SLI = T_{500hPa_{environment}} - T_{500hPa_{parcel}}$$

- **CAPE:** convective available potential energy in its Most Unstable (MU) formulation

Sufficiently low **freezing level height** H0

Presence of a sufficiently strong vertical wind shear:

- **Deep layer shear (DLS):** change in wind speed with altitude between surface and ~6km above:

$$|\overrightarrow{DLS}| = |\vec{v}_{500hPa} - \vec{v}_{10m}|$$

Definition of the OT-filter

Approach: retain the OTs linked to hail by filtering out the occurrences not related to hailing convective environments as described by reanalysis proxies

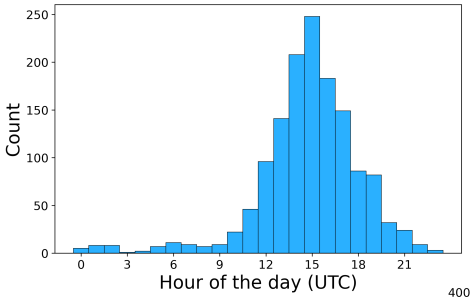
Design of the filter:

- Spatio-temporal neighbourhood window for OT-reanalysis matching:
  - *Spatial match*: **70km** (0.63°x0.63°) around each OT detection
  - *Temporal match*: **0-3 hours** temporal window preceding each OT
- Extract the parameters maximum (for CAPE, K, DLS) or minimum (for H0 and SLI) within the spatio-temporal window
- *Thresholds definition*: values to be fulfilled to describe hailstorm conditions:
  - Same spatio-temporal matching applied to the **ESWD-based** reanalysis parameters distributions
  - Limits defined as n^{th} percentiles of the distributions

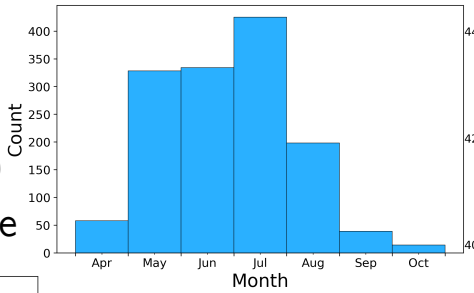
Analysis details:

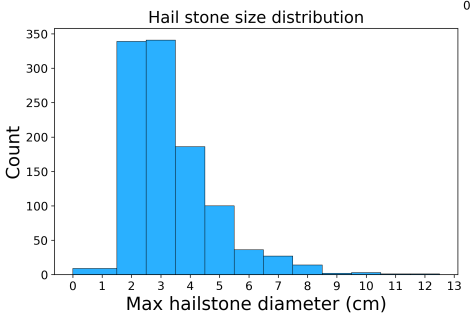
- Period of investigation: 2016-2018, extended summer (Apr-Oct)
- Spatial domain: SPHERA domain (6-19°E, 35-49°N)

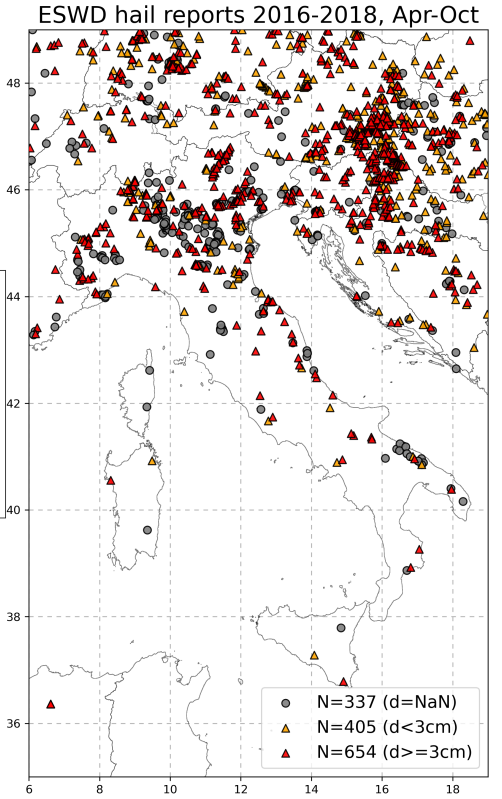
ESWD hail reports dataset



- Total of 1386 reports QC0+ (i.e. quality controlled), with 1059 having info on hail size

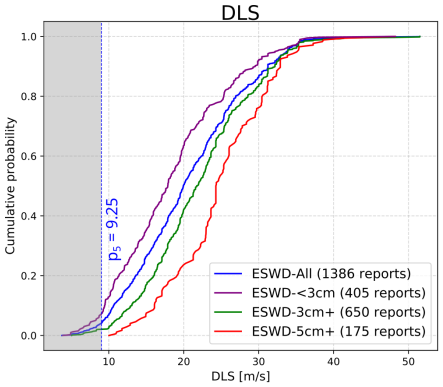


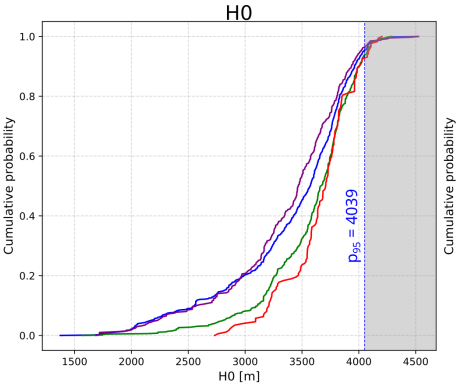


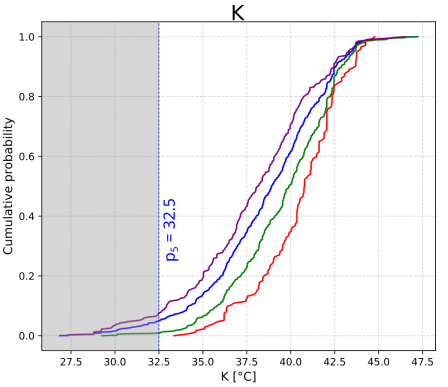


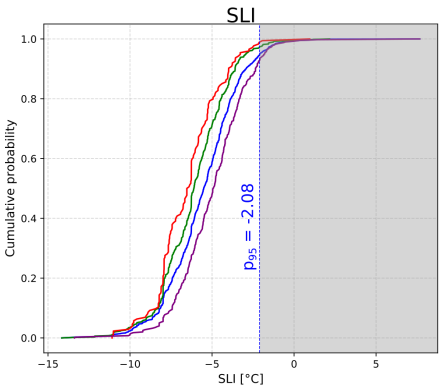
Definition of the OT-filter:

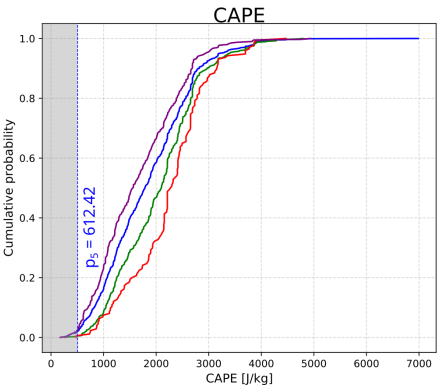
CDF of SPHERA parameters in presence of ESWD hail reports











VARIABLE	Threshold (5/95%)
DLS	$> p_5 = 9.25$ m/s
H0	$< p_{95} = 4039$ m
K	$> p_5 = 32.5$ °C
SLI	$< p_{95} = -2.08$ °C
CAPE	$> p_5 = 618.42$ J/kg

Results of the reanalysis-based OT-filtering:

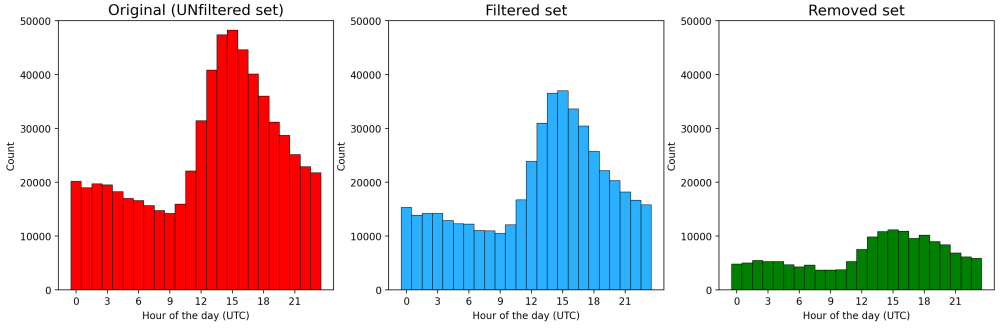
- Over the whole SPHERA domain:

YEAR	OT UNFILTERED set	OT FILTERED set	OT REMOVED set
2016	171.947	126.599 (73.6%)	45.348 (26.4%)
2017	189.613	143.468 (75.7%)	46.145 (24.3%)
2018	270.840	198.823 (73.4%)	72.017 (26.6%)
2016-2018	632.400	468.890 (74.1%)	163.510 (25.9%)

- Only over LAND (i.e. 62% of the whole OT dataset):

YEAR	OT UNFILTERED set	OT FILTERED set	OT REMOVED set
2016	106.094	75.568 (71.2%)	30.526 (28.8%)
2017	133.634	100.892 (75.5%)	32.742 (24.5%)
2018	152.012	106.579 (70.1%)	45.433 (29.9%)
2016-2018	391.740	283.039 (72.3%)	108.701 (27.7%)

OT set vs hour of the day (2016-2018)



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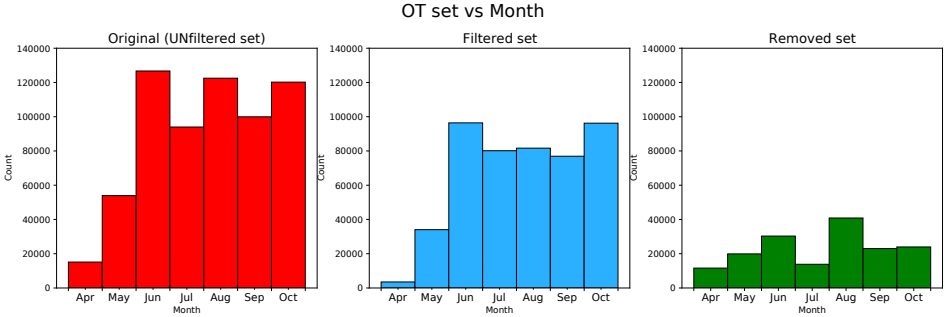

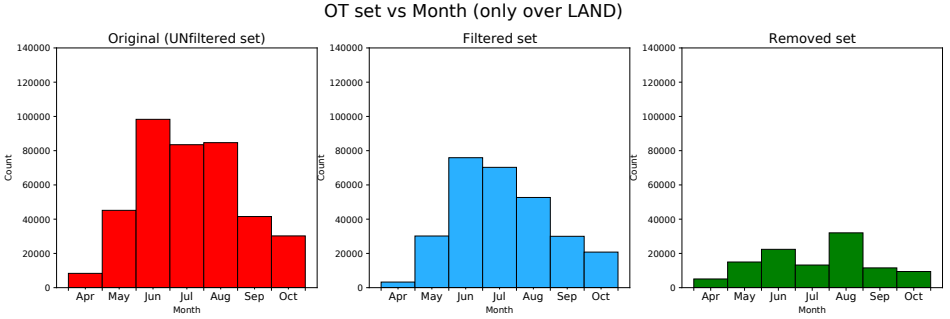

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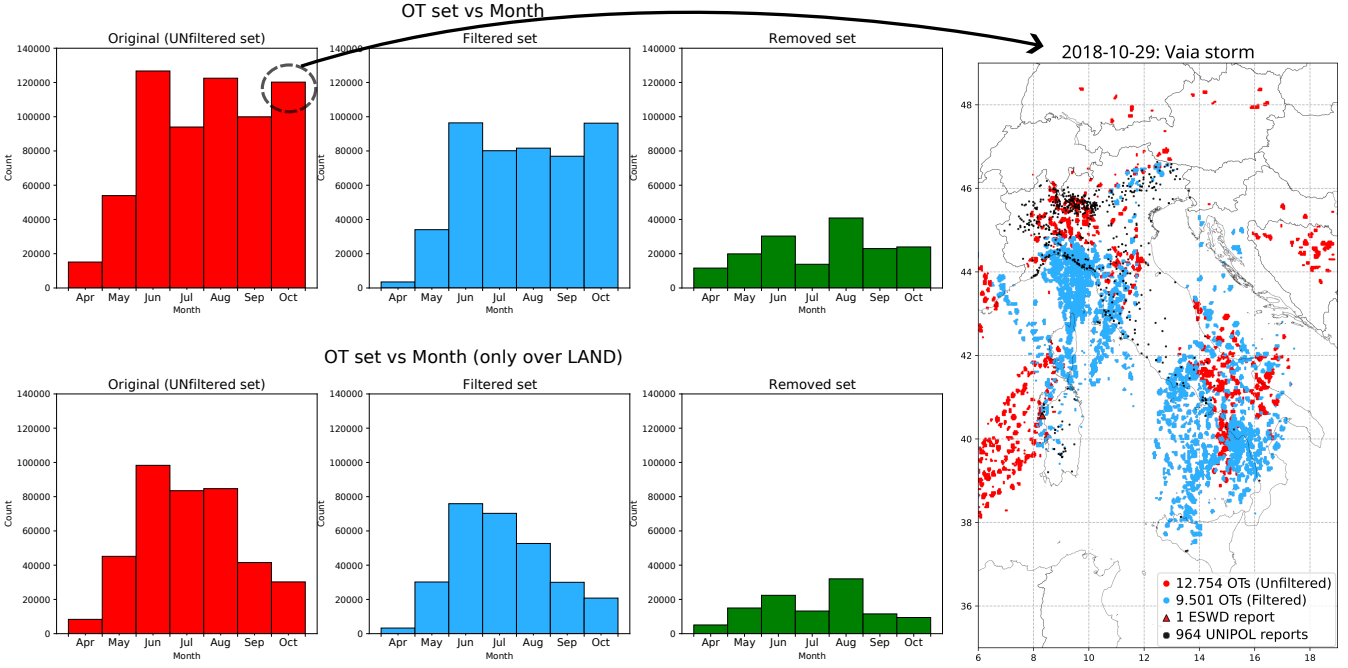

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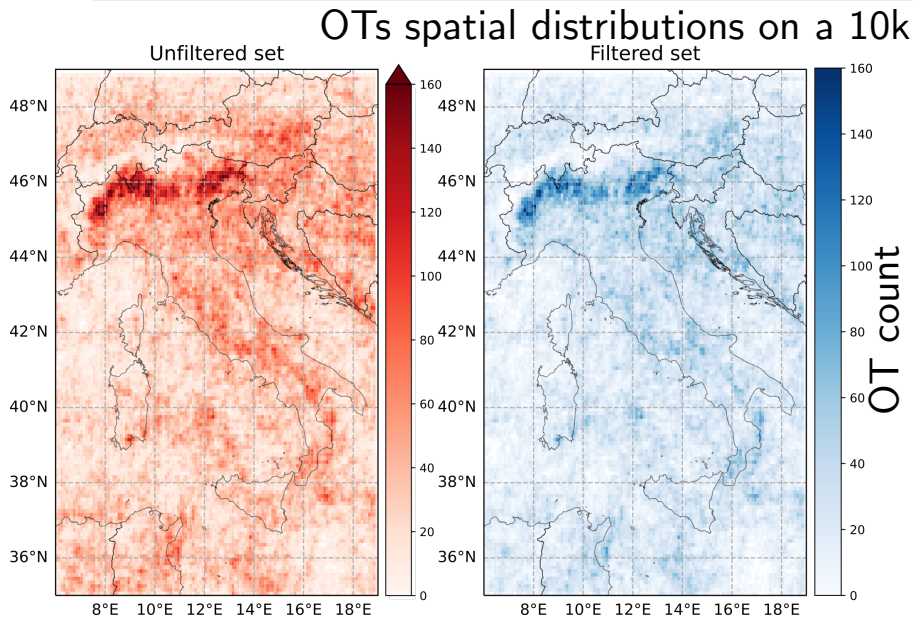

In absolute terms: filter most effective in central-eastern pre-Alpine/Alpine areas, along the Apennines and in northern Algeria (Aurès mountains).

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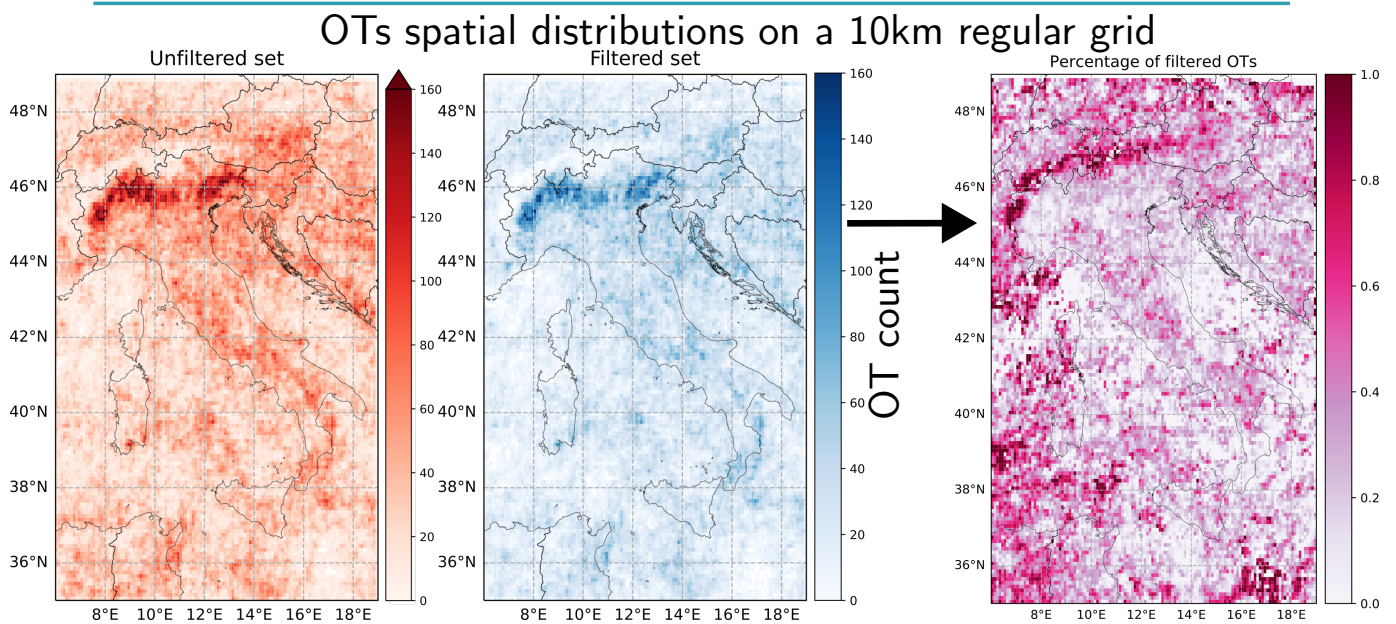

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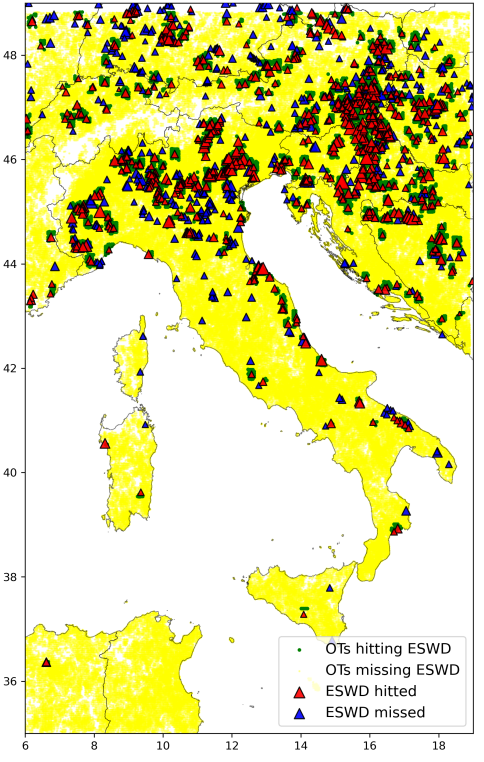
In relative terms: almost 100% OTs removed along the Alpine arc, ~60% in S-Ger/Aus, lowest removal (<20%) in Po valley and Adriatic/Thyrrenian seas

Validation against ESWD dataset (2016-2018)

- Considered only OTs over land (that can be validated!)
- Temporal window for matching: ± **1.5h**
- Spatial window for matching: **25km**

	Unfilt. OTs	Filtered OTs
ESWD reports sample	1386	
HITTED ESWD reports	969 69.9%	871 62.8%
% ESWD reports lost	**-7.1%**	
OTs sample (Land)	391.740	283.039
OTs HITTING ESWD rep	9.356 2.39%	7.928 2.80%
% FiltOTs gain on Unfilt	**+0.41%**	



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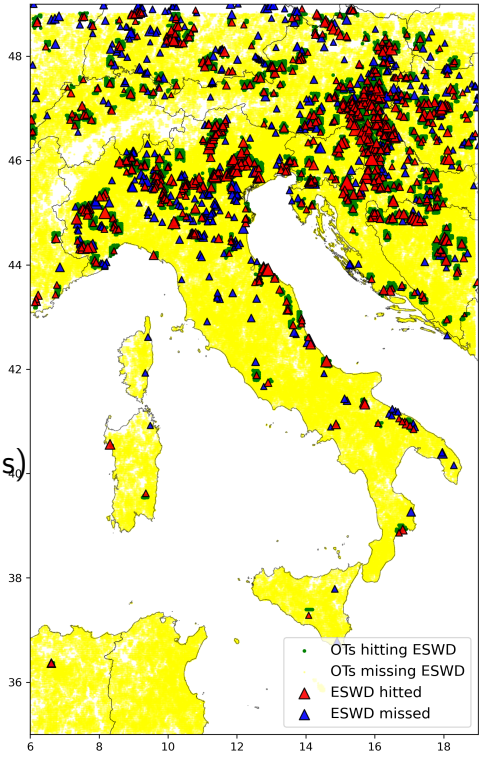
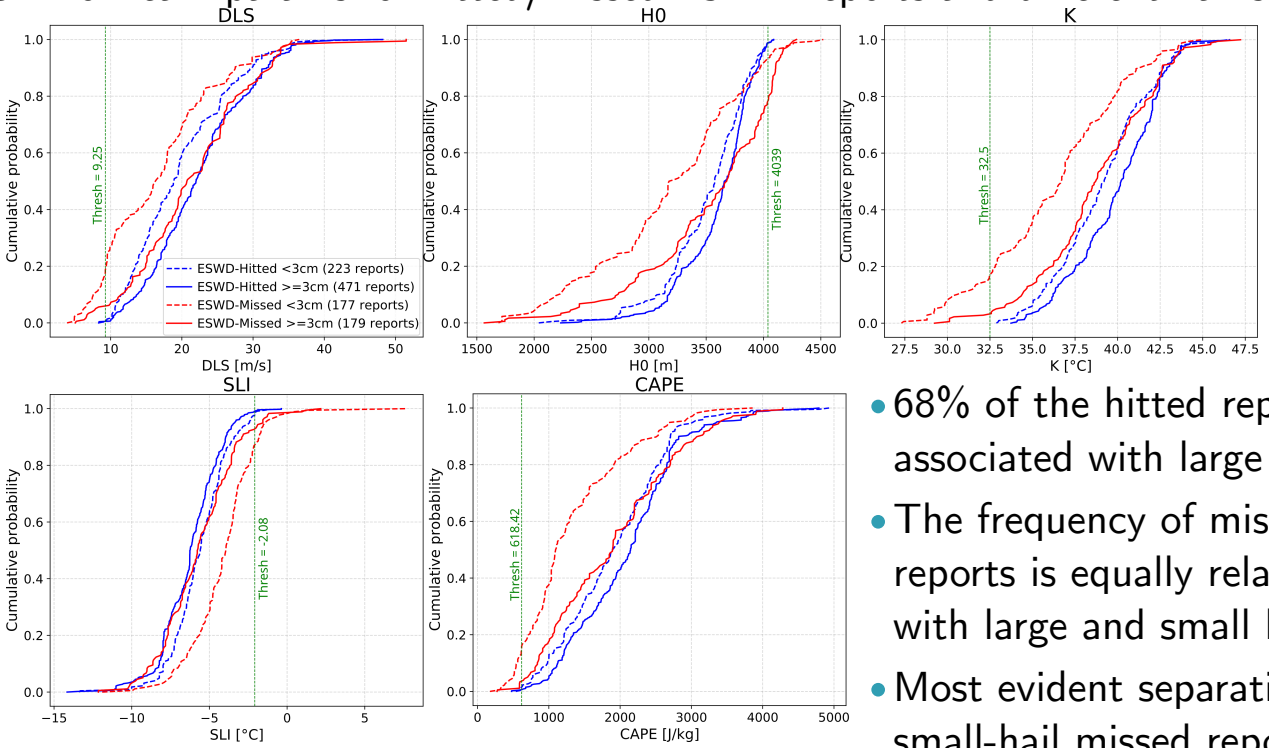
- Comparison with Punge et al. 2017: (EU domain, old OT detection method, 2004-2014, ERA-Interim reanalysis)

	Unfilt. OTs	Filtered OTs
ESWD reports sample	12.282 (2.475 QC1+)	
HITTED ESWD reports	997 40.3%	983 39.7%
% ESWD reports lost	**-0.6%**	
OTs sample	696.135	542.137
OTs HITTING ESWD rep	4.664 0.67%	4.554 0.84%
% FiltOTs gain on Unfilt	**+0.17%**	



Validation against ESWD dataset (2016-2018)

CDF of rean. params for hitted/missed ESWD reports and different hail sizes



- 68% of the hitted reports associated with large hail
- The frequency of missed reports is equally related with large and small hail
- Most evident separation: small-hail missed reports

Conclusions and future outlook

- The high-resolution reanalysis-based OT-filter has the potential to enable distinction between hailing and non-hailing convective conditions
- Spatio-temporal distribution over 3 years is in agreement with other recent European/national hail climatologies (Punge 2014, Baldi 2014, Torralba 2022)
- To get robust estimates longer time series are needed!
- A comparison with a coarser-reanalysis filtering (e.g. ERA5) could help identifying the importance of the convection-permitting resolution in the description of hail-prone environmental conditions

References:

- Baldi, M., et al. "*Hail occurrence in Italy: Towards a national database and climatology.*" Atmospheric research 138 (2014)
- Punge, H. J., et al. "*Hail frequency estimation across Europe based on a combination of overshooting top detections and the ERA-INTERIM reanalysis.*" Atmospheric Research 198 (2017)
- Punge, H. J., et al. "*A new physically based stochastic event catalog for hail in Europe.*" Natural Hazards 73.3 (2014)
- Raupach, T. H., et al. "*The effects of climate change on hailstorms.*" Nature reviews earth & environment 2.3 (2021)
- Torralba, V., et al. "*Modelling Hail Hazard Over Italy with Era5 Large-Scale Variables.*" Available at SSRN 4115213.

Thank you for your attention!

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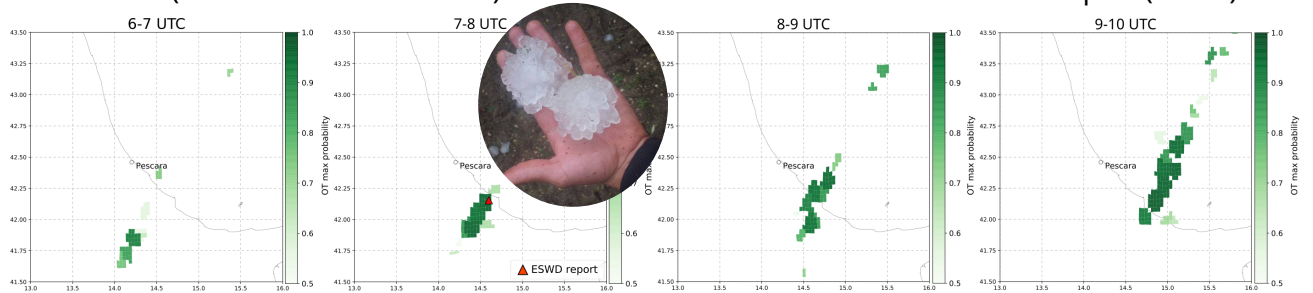
Example: hailstorm near Chieti (IT) on 15th Oct 2016

Hailfall (with max. 7cm diameter) recorded at 7.30 UTC: OT detections + hail report (ESWD)



To be coupled with reanalysis proxies describing hail-favouring convective conditions:

