# Exploring uncertainty in future hail trends: A comparison of proxy-based and diagnostic approaches using convection-permitting climate simulations over Europe

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## 1 Introduction

Hail observations are limited and hail is normally not explicitly simulated in climate models.Thus studies have used hail proxies – hail estimates based on environmental conditions such as convective available potential energy (CAPE), convective inhibition (CIN), vertical wind shear and freezing level height (HZERO) – to estimate hail occurrence.

Examples of hail damage to buildings and cars.
Pictures: keystone

However, varying datasets and methods lead to different climatologies and climate change signals from hail proxies, showing the need for a systematic comparison[e.g. 1,2,3,4,5,6,7,8].
In this study, we apply various hail proxies to a common dataset from a climate simulation including the online HAILCAST hail diagnostic (see below) to explore:

**How do hail climatologies and climate change signals based on hail proxies compare to HAILCAST?**

## 2 COSMO climate simulations and HAILCAST

**11-year present-day and future climate simulations using COSMO 6.0[7,9]**

- 2.2 km grid spacing
- 1-moment graupel schemes with online HAILCAST[10] hail diagnostic providing 5-min maximum hail diameter
- Present day: 2011-2021, driven by ERA5 reanalysis
- Future: 2011-2021 + 3°C global warming using PGW approach[11] (applied to sea-surface temperature,surface skin temperature, temperature, horizontal winds, relative humidity, and geopotential height)
- Setup tested and explored in previous case-study and seasonal simulations[12,13]

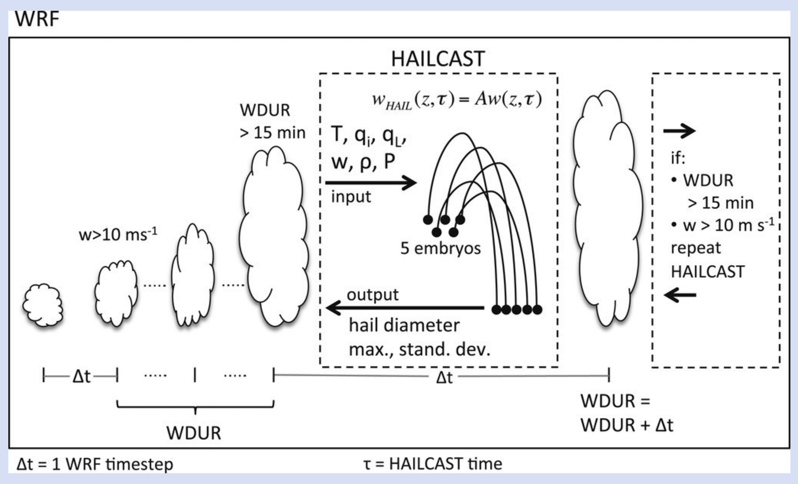



**Figure 1**
Conceptual model of the online hail diagnostic HAILCAST. Figure from Adams-Selin and Ziegler (2016)

## 3 COSMO-HAILCAST simulation

**Climatology**

- Hail hot spot in Po valley, eastern Spain, middle-eastern Europe, and eastern Mediterranean Sea

**Climate change signal**

- Decrease in southwestern Europe
- Increase over and to the north of the Alps, northeastern Europe and eastern Mediterranean

Based on online diagnostic (HAILCAST) that estimates maximum hail size in a single climate simulation.

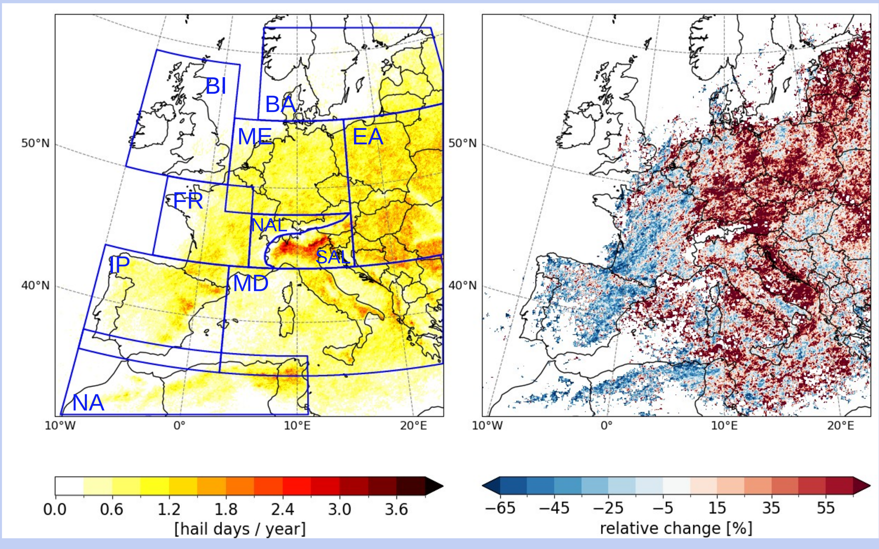



**Figure 2** Mean annual hail frequency (days/year with diameter ≥ 12.5 mm) during the period 2011–2021 and relative changes between PGW and CTRL based on HAILCAST. For visualisation, a 1-sigma smoothing was applied to fields.
Subdomains (used in Fig. 4,5, and 7) are shown in blue outlines (AL=NAL+SAL, MDS is the sea area of MD, and MDL the land area of MD).

## 4 CAPE-CIN-shear- HZERO climatology

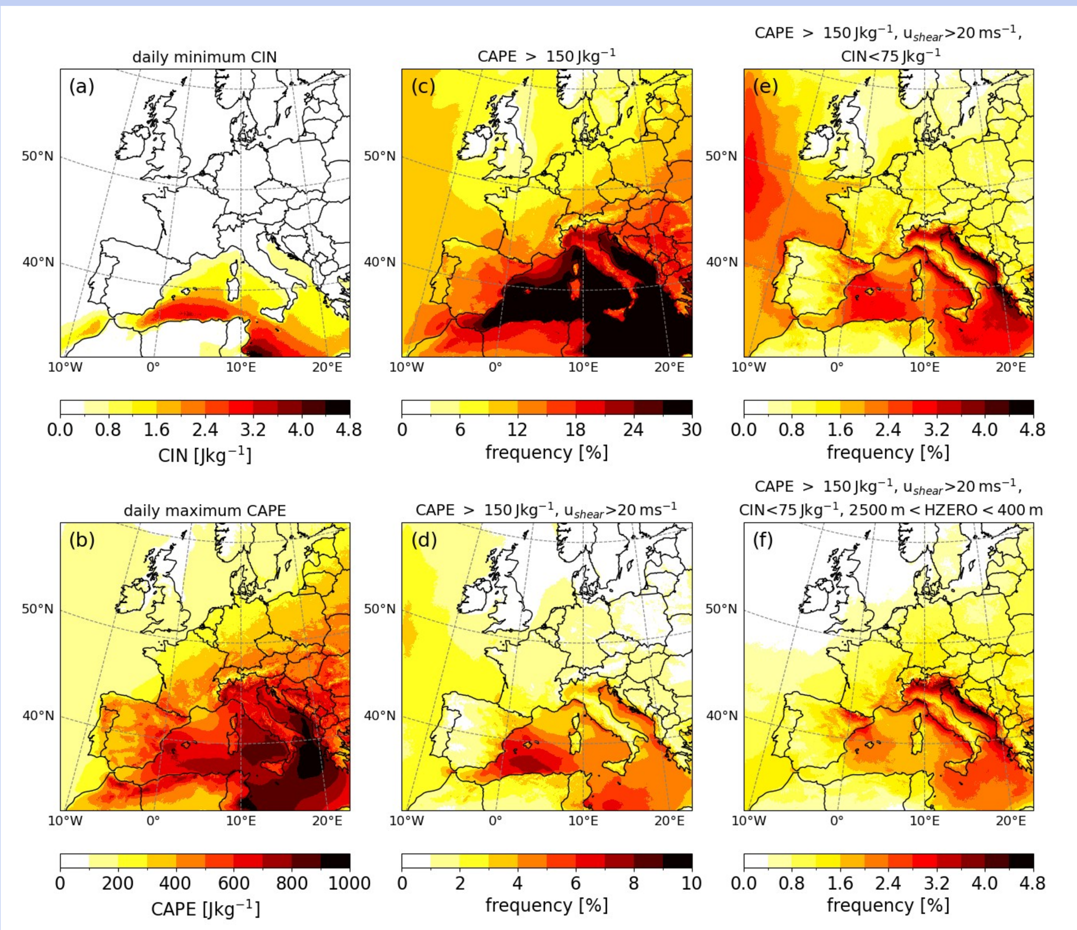



**Figure 3**
Mean of
(a-b) daily minimum CIN and daily maximum CAPE
(c-f) frequency of hours exceeding thresholds of CAPE, 925-500hPa wind shear, CIN and freezing level height (HZERO)
during convective season (April-November) in the period 2011–2021.

- Offline threshold-based hail proxies applied to same climate simulation as HAILCAST output, thresholds based on variable distributions in pre-storm environment

→see poster on hail and supercell proxy stationarity P5: ECSS2025-43

- CIN limiting in Mediterranean regions, CAPE in northern part of domain, HZERO influences north-south gradient
- Overestimation of hail days and hail hours for many hail proxies compared to HAILCAST
- Highest Pearson's correlation factor (>0.8) between haildays per subdomain for CAPE150-CIN25-SHEAR10 (first column in Fig. 4)

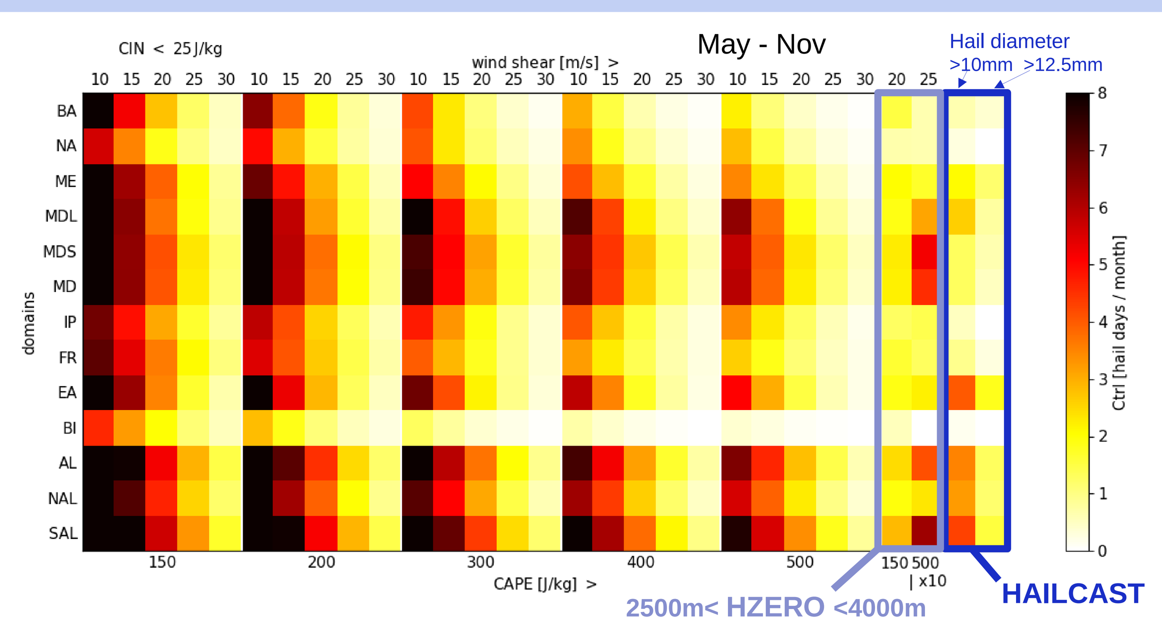



**Figure 4** Mean hail climatology (for the months May-November) in the period 2011-2021 for subdomains and different threshold-based hail proxies.
All proxies use a CIN threshold <25J/kg, except for forth-last column where CIN<75J/kg. The freezing level height (2500 - 4000m) is only included in the columns labeled with HZERO. The last two columns show the HAILCAST climatologies for hail diameter >10mm and >12.5mm.
The last three columns are multiplied by a factor of 10 for visualisation.

## 5 Hail proxy seasonal cycle

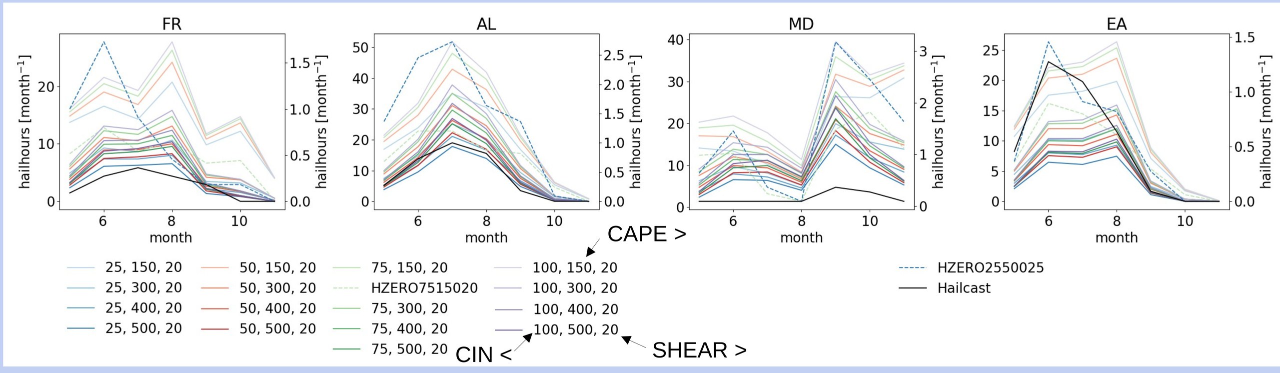
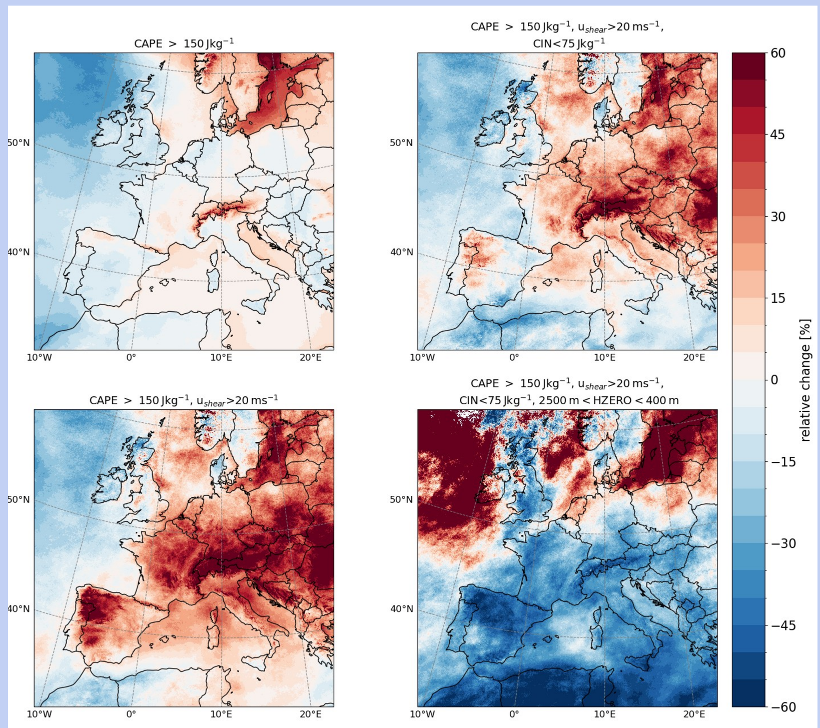



**Figure 5** Mean seasonal cycles of hail hours of selected subdomains for the period 2011-2021. HZERO denotes proxies including the freezing level height (2500 – 4000m) as a constraint. HZERO2550025 and Hailcast (>10mm hail diameter) are shown on the right-hand axis.

"CAPE500-CIN25-SHEAR25-HZERO25004000" proxy similar range as HAILCAST, but tends to overestimate hail occurrence in spring

## 6 Hail proxy climate change signal

**Figure 6** Relative changes in number of hours exceeding environmental thresholds of CAPE, CIN, vertical wind shear and freezing level height between the PGW and CTRL simulation during the convective season (April – Nov).




- Different future changes in hail occurrence from online HAILCAST simulations and hail proxies
- Difference between HAILCAST and simple hail proxies differs for climatology and climate change signals
- Highest Pearson's correlation factor (~0.8) in subdomain trends is seen between HAILCAST (>12.5mm) and hail proxies with wind shear = 20 m/s (exlcuding HZERO)

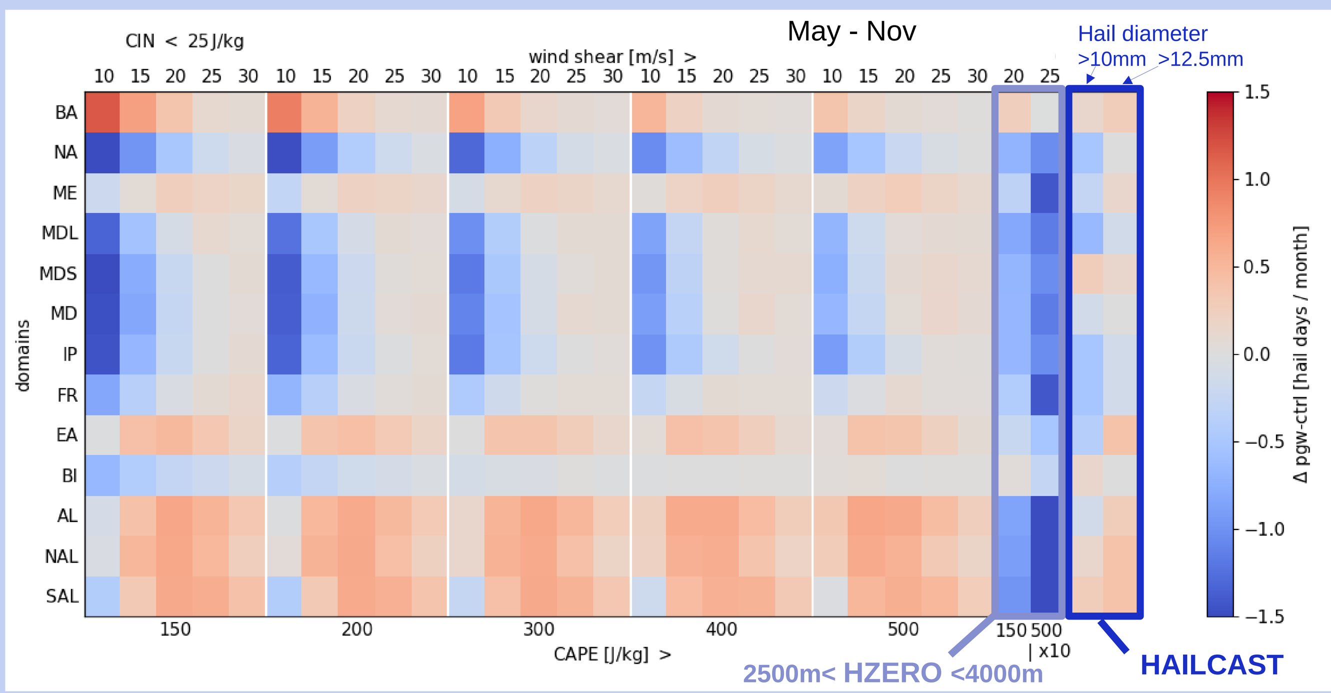



**Figure 7** Mean absolute changes of haildays in subdomains for various hail proxies (see Figure 4) and HAILCAST between the PGW and CTRL simulation from May – Nov.

## 7 Conclusions and Outlook

**Conclusions**

- HAILCAST climatology and climate change signal hardly reproduced by simple proxies based on environmental thresholds.
- Strong differences between proxies and HAILCAST regarding the strength and sign of the trends.

**Outlook**

- Determine environments representative for hail initiation based on hail cell tracking and investigate sensitivity of hail environments to climate change (see P5 ECSS2025-43).
- Derive hail climatologies and changes based on more elaborate hail proxies[2,3,4] using the COSMO climate simulation outputs.

**References**

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