REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: SPAIN

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Project Title: SEVERE CONVECTIVE WEATHER PHENOMENA AND CLIMATE CHANGE

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	SPESVALE	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2025	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:	**2025**	**2026**	**2027**
High Performance Computing Facility [SBU]	1200000	1200000	1200000
Accumulated data storage (total archive volume)[2] [GB]	10000	10000	10000

EWC resources required for project year:	**2025**	**2026**	**2027**
Number of vCPUs [#]			

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Total memory [GB]			
Storage [GB]			
Number of vGPUs[3] [#]			

Continue overleaf.

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Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 10,000,000 SBU should be more detailed (3-5 pages).

Thunderstorms and their associated phenomena (lightning, hail, wind or flash floods) have a great impact on human activities due to their destructive consequences (Martín et al., 2020; Taszarek et al., 2020). Europe is regularly threatened by severe thunderstorms (Dahl, 2006), causing considerable economic loss, having a social impact, and endangering aviation safety (Nisi et al., 2016; Mohr et al., 2017; Antonescu et al., 2017; Kunz et al., 2020).

Thunderstorm cells can be formed either in a discrete and isolated form or in large and organized systems, (e.g., squall lines). Three different thunderstorm types are defined by the US National Weather Service (NWS, 2019) based on their structure, organization and size: ordinary cell, multicell and supercell. Browning (1962) defines supercells as thunderstorms occurring in a significantly vertically sheared environment, which contains a deep and persistent mesocyclone, representing the most organized, severe and long-lasting form of isolated deep convection phenomena. These systems are linked to hail reports – including hail diameters larger than 5 cm – and EF2 tornadoes or higher (Quirantes et al., 2014; Blair et al., 2017). Supercells are common phenomena in spring and summer (Brooks et al., 2019), and can be detected through Doppler radar data to confirm the associated mesocyclone (Blair et al., 2011; Kahraman et al., 2017). Moreover, ground-based or satellite lightning detection systems can be useful as supporting information (Bedka et al., 2018; Galanaki et al., 2018).

Many hail cases with diameter larger than 5 cm are related to supercell thunderstorms (Blair et al., 2017; Kumjian & Lombardo, 2020). Supercells and hailstorms pose a recurrent threat over Europe (Dahl, 2006) resulting in substantial economic losses, societal impacts, and hazards to aviation safety (Antonescu et al., 2017; Kunz et al., 2020; Nisi et al., 2016; Púčik et al., 2019). There is growing evidence that the ongoing climate change is having a relevant impact on the frequency and intensity of severe convective events involving hail (Ashley et al., 2023; Battaglioli et al., 2023).

Climate change alters atmospheric circulation patterns (Herrera-Lormendez et al., 2023) and increases sea surface temperatures (SST), notably in the Mediterranean Sea (Pastor et al., 2020; Pastor & Khodayar, 2023), contributing to significant high-impact weather events (Ludwig et al., 2013; Meredith et al., 2015; González-Alemán et al., 2023). The increase in SST influences intensity and frequency of marine heatwaves (MHW). MHW, defined as a prolonged period of anomalously high SSTs, typically lasting five or more days (Hobday et al., 2016), leads to increases in low-level moisture. This can consequently contribute to greater potential instability that offsets expected reductions in deep-bulk wind shear on observed rawinsonde profiles (Taszarek, et al., 2021) expected in future climate scenarios (Lepore et al., 2021)—an important ingredient determining organization and severity of convective storms (Brooks et al., 2003; Del Genio et al., 2007; Muramatsu et al., 2016; Peters et al., 2019). In the western Mediterranean, MHWs significantly impact air temperature and summer precipitation (Serrano-Notivoli et al., 2023). Thus, the SST influence on localized convective hazards like tornadoes, giant hail, or severe wind gusts are gaining attention (Ashley et al., 2023; González-Alemán et al., 2023; Miglietta et al., 2017).

To properly characterize these and other severe convective phenomena with numerical simulations, it is typically required very high-resolution simulations, both temporally and spatially. Thanks to a previous special project (SPESVALE), this research team is working on simulating several mountain waves events in the Guadarrama range area and supercells in the Iberian Peninsula, with two well-known numerical weather prediction models, namely WRF-ARW and HARMONIE-AROME. These two models present different features, and therefore it is interesting to analyse how the severe convective phenomena are represented, considering their differences. With the current proposal, we aim to continue analysing this kind of events in the aforementioned zone. In addition to this, we would like to extend the study to focus on the influence of climate change on such events. For this purpose, we have used the pseudo-global warming approach (PGWA; Schär et al., 1996).

The HARMONIE-AROME Reference system is maintained on the ECMWF HPC platform. This Reference System includes code, scripts and some other useful tools which may be required to run and postprocess the deterministic model. The previous Special Project (SPESVALE) aimed to obtain very high-resolution simulations of different variables: wind speed, temperature, liquid water content and other derived relevant variables, so that the mountain waves can be properly characterized. On the other hand, for SPESVALE Special Project the WRF-ARW model was also implemented.

The Spanish Supercell Data set (Martín et al., 2021) and the European Severe Weather Database (ESWD; Dotzek et al., 2009) observations are here used to analyze a climatological background and uniqueness of the Gerona giant hail event. The Spanish Supercell Data set (Calvo-Sancho et al., 2022; Martín et al., 2021) encompasses the period from 2011 to 2022 with a total of 286 documented supercell observations. The data set includes Supporting Information S1 to the events whenever available, such as hail diameter or tornado intensity. For the purposes of this study, only hail with a diameter larger than 5 cm is considered. In total, 57 large hail reports from the Spanish Supercell Data set are evaluated. The ESWD is Europe's main severe weather reports data set (Dotzek et al., 2009). This data set uses quality control (QC) classes to assess the accuracy and reliability of reports. For this study, only hail reports with a highly reliable status of QC1 (report confirmed by a reliable source) and QC2 (scientific case study) were included in the analysis. Only hailstones larger than 5 cm are considered for the period from 1940 to 2022 across continental Spain and the Balearic Islands. In total, 99 large hail reports from ESWD are included in this work.

Calvo-Sancho et al. (2022) characterized and compared the environments of supercell hail and supercell non-hail events in Spain from 2011 to 2020 (Figure 1). Different atmospheric variables were retrieved from the ERA5 reanalysis to obtain the synoptic patterns and composite soundings at the formation time of the supercells. Thermodynamic and kinematic parameters related to convective environments were also calculated and compared between supercell hail and non-hail events. A similar approach will be done in the upcoming studies we aim to perform.

Moreover, Martín et al. (2024) analysed a severe hailstorm that occurred in Spain on 30 August 2022, caused material and human damage, including one fatality due to giant hailstones up to 12 cm in diameter (Figure 2). By applying a pseudo-global warming approach, they evaluated how a simultaneous marine heatwave (and anthropogenic climate change) affected a unique environment conductive to such giant hailstones. The main results showed that the supercell development was influenced by an unprecedented amount of convective available energy, with significant contributions from thermodynamic factors. Numerical simulations where the marine heatwave was not present showed a notable reduction in the hail-favourable environments, related mainly to modifications in thermodynamic environment. Moreover, the simulations indicated that the environment in a preindustrial-like climate would be less favourable for convective hazards and thus the hailstorm event would likely not have been as severe as the observed one, being possible to perform a novel attribution of such kind.

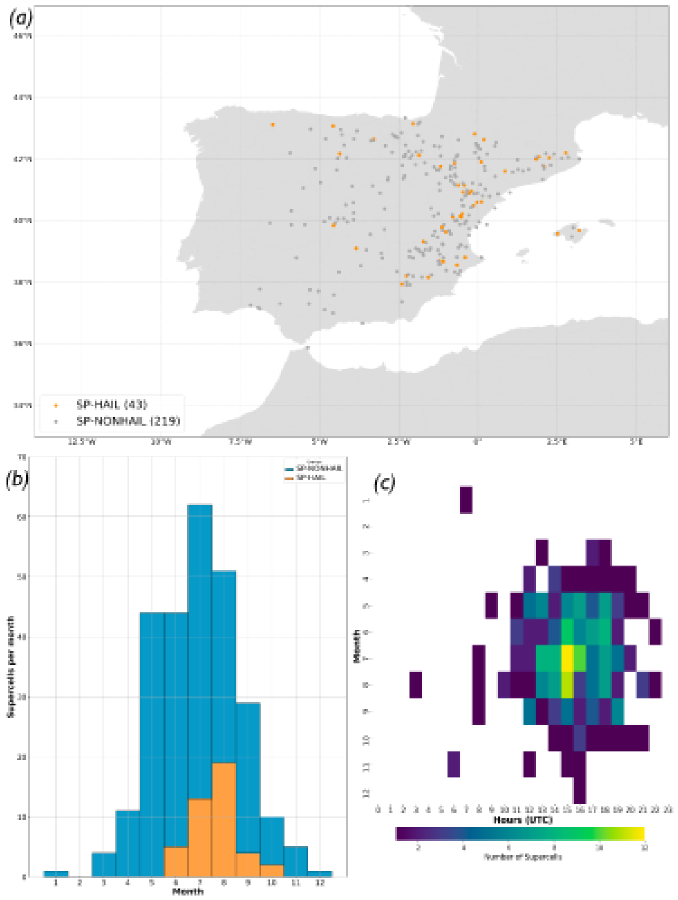

Figure 1: (a) Location of the dataset events (SP-HAIL and SP-NONHAIL events) from 2011 to 2020 in Spain. (b) Monthly supercell distribution. (c) Hourly supercell distribution (UTC).

The Pseudo-Global Warming Approach (PGWA) added a climate perturbation signal to the reference conditions for the period of interest (Schär et al., 1996; Brogli et al., 2023). The PGWA was applied to analyse the anthropogenic climate change (ACC) signal contribution to the giant hail development associated with the supercell, considering the pre-industrial period and SSP5-8.5 simulations from the CMIP6 climate models. To apply the PGWA, several prognostic variables from ERA5 initial and boundary conditions were modified.

A similar approach will be implemented in the next phase of our research, where we will apply the PGWA strategy to a wider range of severe convective weather phenomena that have had significant impacts on populations. This next phase will focus on events such as tornadoes, hailstorms, and intense thunderstorm outbreaks, which pose substantial risks to human life, property, and infrastructure. By utilizing the PGWA strategy, we will modify historical weather event data to reflect future climate conditions, enabling us to simulate and analysed how these severe weather phenomena may change as the climate continues to warm. This approach will help us to identify potential trends and patterns in the frequency, intensity, and spatial distribution of these extreme events under different climate scenarios.

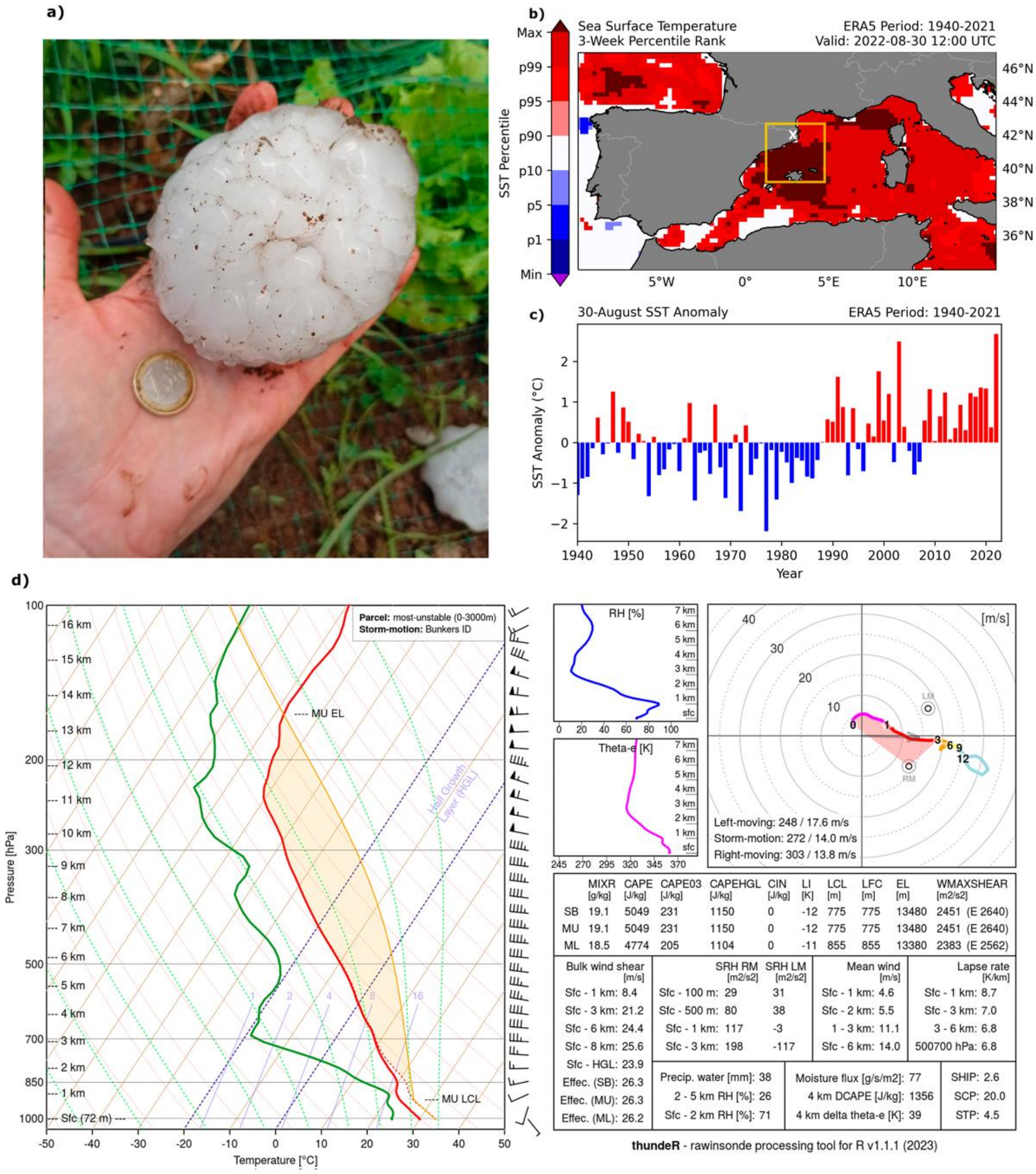

Figure 2. (a) Photography of a hailstone collected on 30 August 2022, in Forallac (Girona province). Source: x.com/Morgana_50. (b) Western Mediterranean SST 3-week percentile rank of 30 August 2022, for the period 1940–2021 derived from ERA5 reanalysis. The white cross indicates the location of the giant hail event, and the yellow square indicates the area where the SST anomaly is calculated. (c) Time series of SST anomalies averaged over the yellow square area and period in (b). (d) Skew-t profile and hodograph for a Forallac's proximity profile derived from ERA5 reanalysis for 30 August 2022, 16:00 UTC, 42°00’N, 003°00’E.

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