REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: Ireland

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Project Title: Irish storms: a storyline approach to future post-tropical cyclones

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.	**N/A**	
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 X	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	30M		
Accumulated data storage (total archive volume)[2]	[GB]	20TB		

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]	n/a	n/a	n/a
Total memory	[GB]	n/a	n/a	n/a
Storage	[GB]	n/a	n/a	n/a

[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.

Number of vGPUs[3]	[#]	n/a	n/a	n/a

Continue overleaf.

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Extended abstract

Abstract/ Project Description

Storm events carry the potential for huge impacts on Ireland, and demand significant attention from Met Éireann's operational forecasting resources. Of particular interest are post-tropical cyclones (PTCs), such as Storms Ophelia and Lorenzo, which begin their life as hurricanes before undergoing extra-tropical transition and continuing their track as mid-latitude storms. Storm Ophelia was one of the most destructive windstorms to impact Ireland in recent years, leading to three casualties and total economic losses of US$100 million (Met Éireann Ophelia report, 2018; Topics Geo Munich Re, 2017).

Sainsbury et al. (2020) compared the climatologies of PTCs and mid-latitude cyclones (MLCs) in the North Atlantic and Europe extracted from the ERA5 reanalysis dataset, showing that PTCs constitute a disproportionately large fraction of high-intensity cyclones impacting Europe during hurricane season. They demonstrated that the fraction of PTCs impacting Northern Europe with storm force winds is approximately 10 times higher than for MLCs, although PTCs account for less than 1% of all such storms. In 2022, Sainsbury et al. (2022) extends its own earlier work by asking the question as to why some PTCs impact Europe. Using ERA5 reanalysis the authors investigate the conditions that lead to PTCs impact on Europe. The findings can be summarised as follows: tropical cyclones (TCs) that are more intense, and TCs that reintensify after extratropical transition (ET), are more likely to reach Europe.

With respect to climate change, recent research suggests a poleward and eastward extension of the hurricane genesis area as a result of rising SSTs (Zhao and Held, 2012; Murakami et al., 2012). This would imply an increased likelihood of PTCs impacting Northern Europe, a conclusion supported by recent modelling studies (Haarsma et al., 2013; Baatsen et al., 2015).

Notably, Knutson et al. (2020) published a review paper, where they combined results from many different TC studies. Authors find that "For TC intensity, 10 of 11 authors had at least medium-to-high confidence that the global average intensity will increase". Knutsons own opinion seems to be mixed: "A decrease of global TC frequency, and an increase in the global frequency (as opposed to proportion) of very intense (category 4–5) TCs.".

Later Hawkins (2023), supporting work of Sainsburry (2022), calls for more high-resolution simulations of the future TC and PTC. It becomes clear that even if there is no agreement in the decrease or increase of the frequency of PTC affecting Europe in the future climate, there is a definite agreement in the increase of the intensity of these events. The future projections show that the future storms that will hit Europe will have a higher destructive potential.

This avenue is explored in work by Cheung et al. (2023). Cheung et al look at the global increase in destructive potential of ET events in response to greenhouse warming. The results suggest an increase in the proportion of frequency of highly destructive transitioned TCs, together with a decrease in the total number of TCs, as a result of greenhouse warming. In summary, there are larger number or fraction of extra-tropical cyclones (ETCs) originated from the tropics with greater destructive potential under greenhouse warming. We can expect a greater impact from the transitioned TCs on the mid-latitude region due to human-induced global warming.

Work by Manning et al. (2023), demonstrates the added value of higher resolution simulations in their representation of extreme windstorms. Overall, higher resolution simulations improve the representation of windstorms, offering greater detail at the local scale which may provide better information for impact modelling, though large-scale projected changes in the assessed storm severity index are insensitive to the model resolutions in the simulations tested.

In general, we see that the question of future TC and PTC is still an area of active research. TCs, once they move to mid-latitudes (30◦ − 60◦) can undergo an ET. This ET can result in either decay or intensification of the cyclone, which in turn can bring intense rain, large waves, and hurricane strong winds. If TC does undergo an ET and becomes an extratropical cyclone ('ETC') it does tend to impact larger areas and thus larger populations.

In the case of future climate modelling studies, while current state-of-the-art simulations have a high degree of skill in modelling tropical cyclone frequency and geographical distribution (Walsh et al., 2016), much higher resolution modelling is needed to accurately model peak intensity and extratropical re-intensification (Haarsma, 2021; Haarsma et al., 2016). This implies the need for either high-resolution GCM modelling or alternatively downscaling coarser GCM output to selected regions using high-resolution RCMs. Both approaches are computationally expensive and can introduce biases which need to be carefully handled.

Additionally, a multi-model ensemble approach is often taken to ensure that statistically robust statements can be made in relation to climate change. It has been argued that this approach is effective for the global, thermodynamic aspects of climate change, but less effective for local, dynamical aspects, such as the location and strength of mid-latitude storm tracks (Shepherd, 2019). It has recently been proposed that a so-called "storyline" or "tales of future weather" approach provides an alternative, complementary approach, whereby physically self-consistent simulations of past events, or of plausible future events or pathways are constructed (Sillmann et al., 2021; Hazeleger et al., 2015).

In this framework, high-resolution NWP models are used to simulate phenomena of interest in a hypothetical, but physically plausible, climate setting. For example, Attema et al. (2014) ran the HARMONIE-AROME model at 2.5 km resolution with idealised boundary forcings to investigate the precipitation response to warmer, more humid climates. Magnusson et al. (2014) carried out simulations of Hurricane Sandy with the IFS model and modified sea surface temperatures (SST), showing increased intensity in terms of minimum pressure, wind-speeds and precipitation. Trenberth et al. (2015) discuss how this approach can give more meaningful insight on attribution of extreme events to climate change.

Some tests were already carried out at Met Éireann following Attema et al. (2014), in which Storm Ophelia was simulated with HARMONIE-AROME driven by IFS boundary conditions modified with a -1, +1, +2, +3, and +4 degree perturbation added to the SSTs and air temperatures. In addition, tests with HARMONIE CLIMATE ('HCLIM') driven by ERA5 boundary conditions modified with the same perturbations as above were completed. These tests were conducted on large domains (see figures 1 and 2) ensuring that all stages of storm development were captured.

Figure 1 HARMONIE-AROME domain used for Ophelia simulations

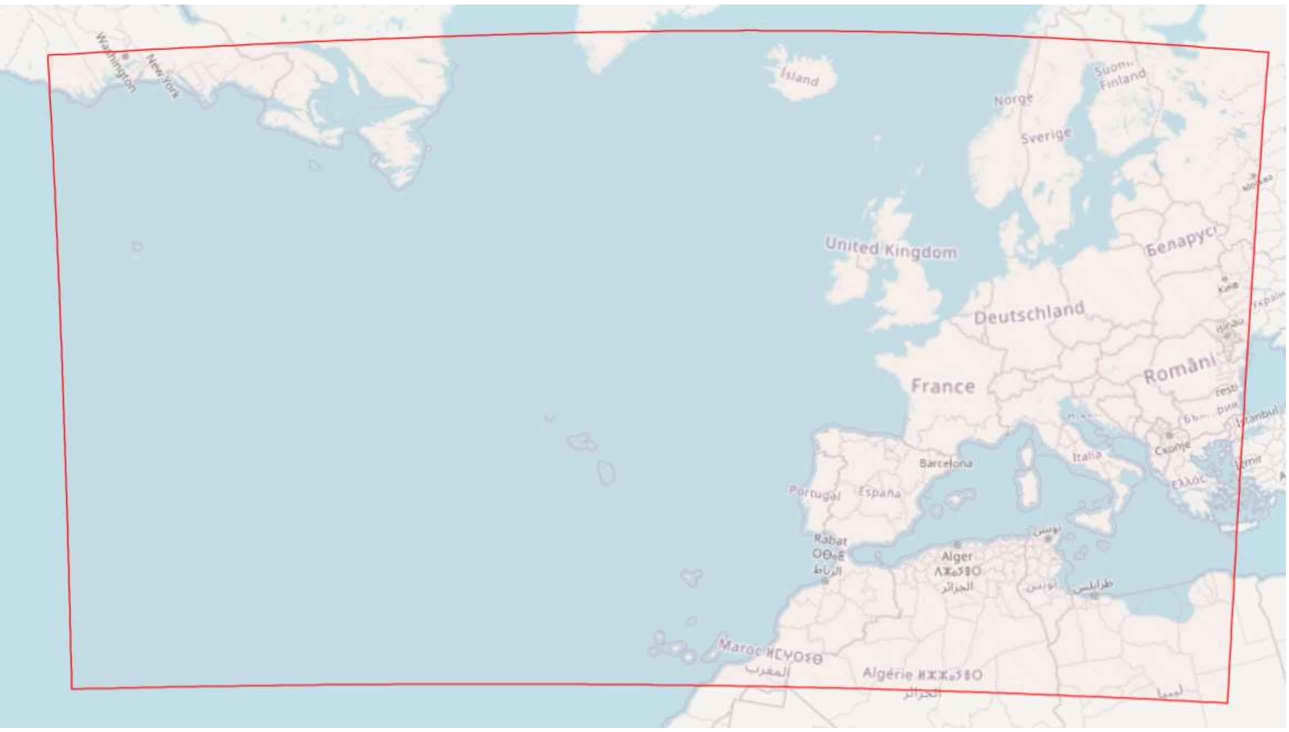

Figure 2 HCLIM domain used for Ophelia simulations.

The present and “future” simulations have visible differences, in track (figure 3) and minimum pressure (figure 4) but single experiments such as this are not sufficient to draw any conclusions. The aim of this project is a more thorough investigation.

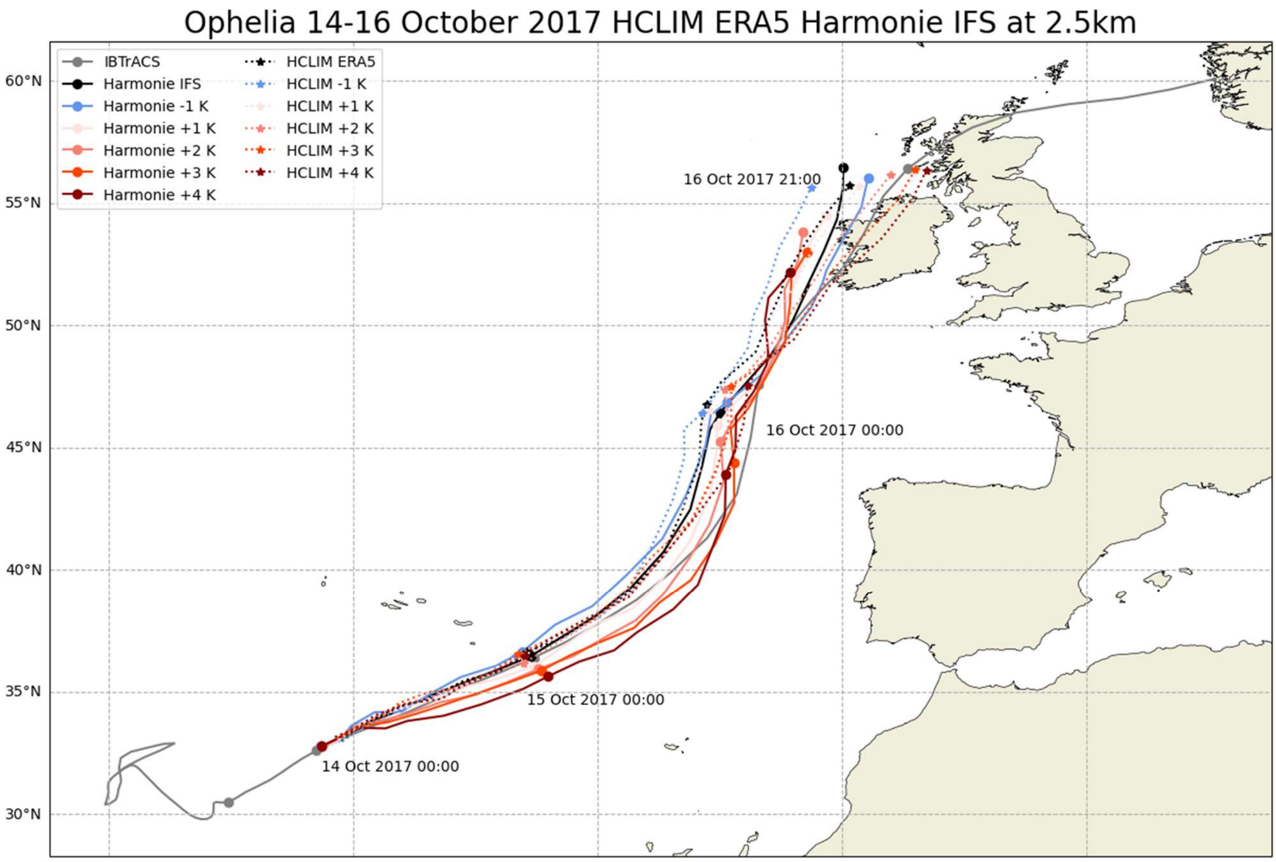

Figure 3 Different tracks of Ophelia dependent on the temperature perturbations.

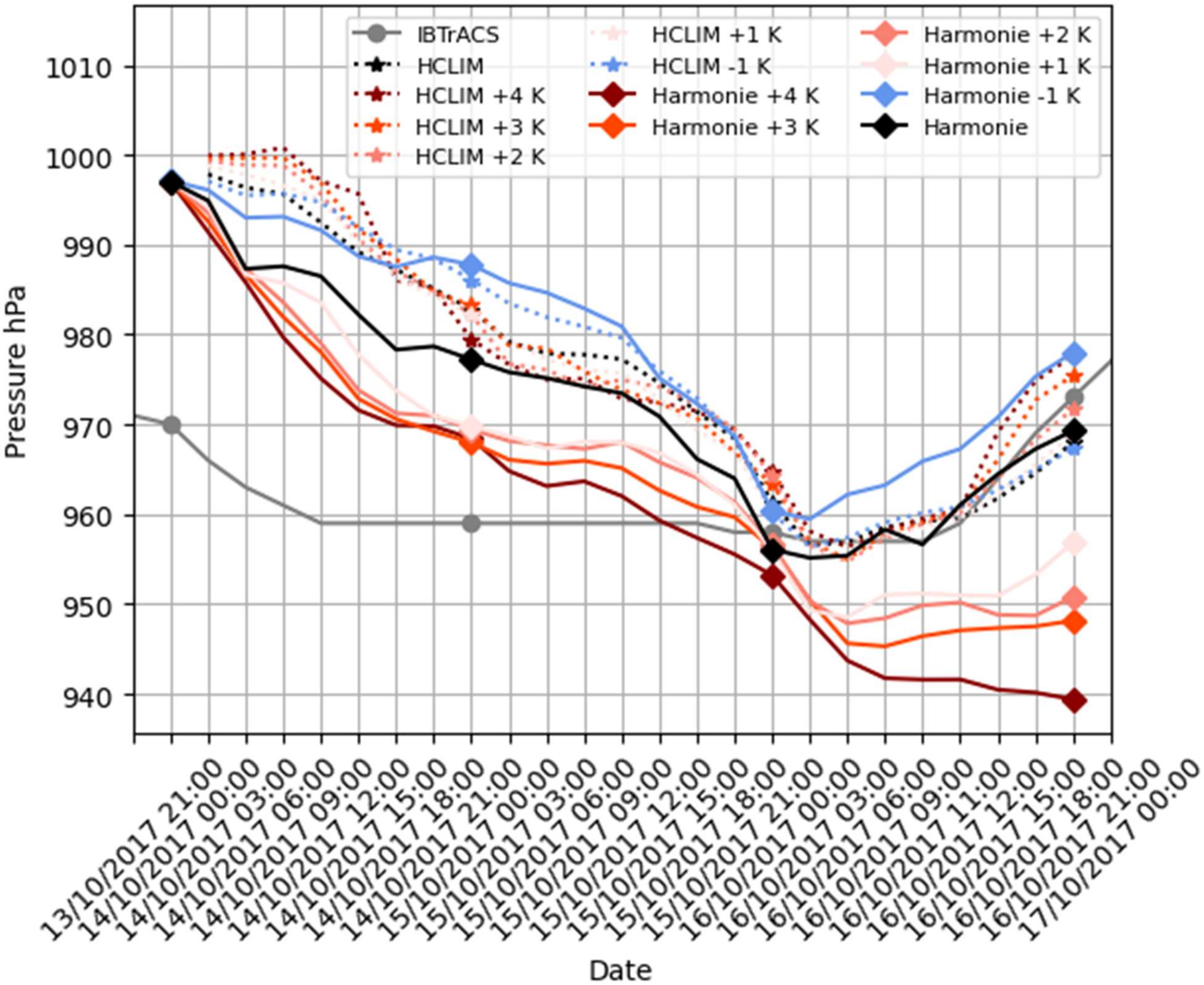

Figure 4 Difference in minimum pressure depending on the temperature perturbations.

Scientific plan

We will use the "future weather" framework to investigate the effect of a warming climate on extreme post-tropical storms impacting Ireland. The project will take its cue from Lackmann (2015), paraphrasing his key question as: if the synoptic pattern accompanying Ophelia, or similar storms, had occurred in the past or if it were to repeat in the future, how would these storms differ in response to climate change?

The HARMONIE-AROME model (Bengtsson et al., 2017) is used at an operational resolution of 2.5km at Met Éireann for NWP guidance, and this will be used throughout the project for simulations of storm events.

The historical storm tracks of interest were chosen based on the severity and impact. The storms desired for the study are Storms Ophelia (2017), Lorenzo (2019), Ernesto (2018), Helene (2006), Lili (1996), Debbie (1961), Edna (1953). Time and resource permitting, it would be beneficial to investigate storm of different origin, such as Darwin (2014) Barra (2021), Eunice (2022) and others.

The optimization process of the model was already completed on the example of Ophelia (model domain, the spin-up time, forecast lead time), these steps will be repeated for each storm of interest.

The influence of Atlantic SSTs on the development of PTCs is of particular interest. We will study the sensitivity of these storms to variations in SSTs by replicating the "pseudo global warming" (PGW) approach (Meredith et al., 2015a&b, Magnusson et al., 2014). For the storm tracks of interest, we will modify the input boundary IFS Atlantic SSTs before running HARMONIE with the optimized model setup. We will study the effects of these changes on key aspects of PTCs, such as intensification rate, peak intensity, and associated wind-speeds and precipitation. Same approach will be applied to HCLIM with ERA5 boundaries.

In addition to SST perturbations, air temperature perturbations will be included. Since humidity is a great factor also, the additional experiments will include humidity perturbations.

We will follow this approach, creating an ensemble of varying model parameterizations combined with PGW perturbations for each historical case study. Broadening the scope of the study from a focus on SSTs only will facilitate more realistic simulations by accounting for the warming affects associated with the additional fields.

Justification of the computer resources requested

We will use Cycle 43 version of HARMONIE-AROME which is now in operations at Met Éireann. This will be used throughout for the storm simulations, representing the main computational overhead of the project. In addition to the SST perturbations discussed above, the ensemble configuration of HARMONIE-AROME will be employed, specifically the Stochastic Physics Perturbations (SPP), in order to explore the spread in the simulations.

For tests like those shown in Fig. 3, a domain size of 1152x1728 grid-points in the horizontal with 2.5km spacing, 65 vertical levels, and a time-step of 50s has typically been used. Based on experience, a 72-hour simulation costs approximately 55 kSBU, where options such as quadratic or cubic spectral truncations can be used to save costs and time.

Setting the cost of a single simulation to approximately 75 kSBU.

During the project, we will take 6 different scenarios of simple SST, air temperature and humidity perturbations, and consider 10-member physics ensembles, for the six storms. Yields a cost of: 75 kSBU x 6 x 10 x 6 = 27 MSBU

Overall Project Cost:

Adding the costs yields a total project cost of: 27 MSBU. If possible, we would round it up to 30 MSBU, as additional tests are required during each storm setup.

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