REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: Ireland

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Project Title:

Future Weather: An Investigation of Storm Scenarios for Ireland

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ___________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2022	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024:
(To make changes to an existing project please submit an amended version of the original form.)

		2022	**2023**	**2024**
High Performance Computing Facility	(SBU)	10M	24M	
Accumulated data storage (total archive volume)[2]	(GB)	10TB	20TB	

Continue overleaf

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.

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Extended abstract

Background

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).

Recently, 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. 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).

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 extra-tropical 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.

Preliminary technical tests were 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 +2 degree perturbation added to the SSTs (Fig. 1, below). The present and "future" simulations have slight differences, but single experiments such as this are not sufficient to draw any conclusions. The aim of this project is a more thorough investigation.

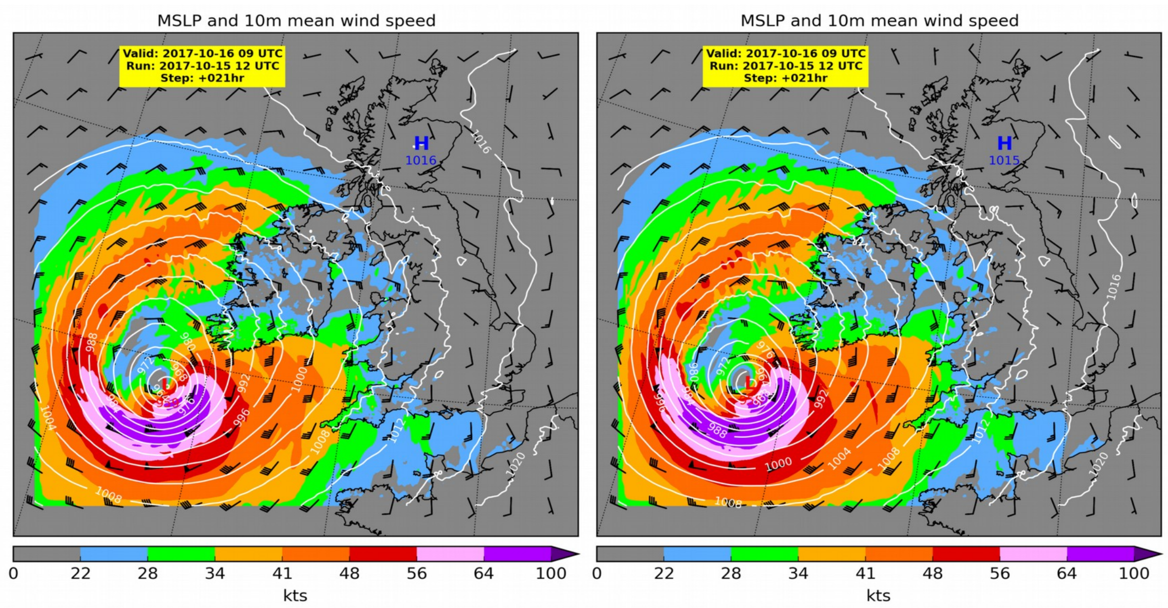

Figure 1: Forecasted MSLP and 10m wind during Storm Ophelia. Present conditions (left) and "future" using perturbed SSTs (right)

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. We will begin by selecting historical storm tracks of interest, such as Storms Ophelia and Lorenzo, thereby constraining the role of large-scale dynamics, and focus on the thermodynamic aspects of such storms. We will first optimize the model setup for the selected storms by varying the model domain, the spin-up time needed to reach an acceptable equilibrium and the forecast lead time, and compare the simulation output with observations.

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.

We will first focus on the present-day climate and begin by constructing a monthly Atlantic SST climatology for the period 2000-2020 ranging from the Mean Development Region (MDR) to the North Atlantic. For each track timestep, the average SST anomaly within a fixed radius will be computed and subsequently averaged along the track. A similar calculation will be performed using historical monthly SST values. This will enable the construction of a probability distribution of such values, from which corresponding likelihood estimates may be calculated, as well as providing a climatologically-constrained range of SSTs to inform our PGW sensitivity tests.

We will also study the role of diabatic heating processes in the initial intensification and post-tropical re-intensification of such storms, taking our lead from similar previous studies (Wernli et al., 2002, Fink et al., 2012, Rantanen et al., 2020). Rantanen et al. (2020) focused on Storm Ophelia, demonstrating that diabatic heating was the dominant forcing in both the tropical and extra-tropical phases, as well as calculating the diabatic heating contributions from different model parameterizations. We will follow this approach, creating an ensemble of varying model parameterizations combined with PGW perturbations for each historical case study.

For future weather studies, we will take input from the recent EC-Earth CMIP6 simulations. EC-Earth has a known cold bias (Haarsma et al., 2020), which can adversely impact the evolution and peak intensity of simulated tropical cyclones (Walsh et al., 2016). As a result, we will not study PTCs in the model output data directly. Rather, we will follow the PGW approach taken by recent similar tropical cyclone studies (Lackmann, 2015, Gutmann et al., 2018, Chen et al., 2020) and simulate the historical tracks selected for a range of perturbed fields, including SST, 2-m air temperature, surface and soil temperatures, and air temperature at all vertical levels. 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.

We will compare the present-day climate (2000-2020) to a range of past and future climates, including the pre-industrial period (1880-1900), the near-term future climate (2040-2060) and the end-of-century climate (2080-2100). For the future climate periods we will consider two future scenarios, namely SSP2-4.5 and SSP5-8.5, taking input from the recent EC-Earth global CMIP6 simulations.

For each combination of time period and SSP scenario we will construct climatologies of the PGW fields listed, which will inform our PGW perturbations. Prescribed forcings computed relative to the present-day climate will be applied and a combined PGW and physics reforecast ensemble computed, as per the present-day studies. This will have the effect of negating the EC-Earth model biases, assuming such biases are constant in time. The future and past storm ensembles will be compared with the present-day ensemble to assess the effects of climate change.

As well as providing the necessary input to compute the relevant PGW perturbations, the EC-Earth CMIP6 data also contains additional PTCs. These additional tracks offer the possibility of expanding the PTC ensemble beyond the small number of historical PTCs available to us. We will apply a cyclone identification and tracking algorithm to first identify these tracks, followed by repeating the same ensemble-generating procedure as outlined for the future and past ensembles.

Justification of Computational Resources Requested

Cycle 43 is the latest version of HARMONIE-AROME and 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 guided by the climate model runs 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. 1, a domain size of 540x500 grid-points in the horizontal with 2.5km spacing, 65 vertical levels, and a time-step of 75s has typically been used. Based on experience, a 24-hour simulation costs approximately 1.7 kSBU, where options such as quadratic or cubic spectral truncations can be used to save costs and time.

For simulating the track and, in particular, the transition phase of the PTC, a longer simulation on a much larger domain is required. As an upper bound estimate, we consider a 4-day run on a 1800x2300 domain, an example shown below in Fig. 2. The best track positions for Ophelia and Lorenzo are shown in Figs. 3 and 4 respectively.

These extra factors scale up the cost of a single simulation to approximately 100 kSBU. While this is a large increase, it represents a good opportunity to explore the dynamics of these storms at high resolution.

Figure 2: domain boundaries for the 540x500 domain (orange) and 1800x2300 domain (red)

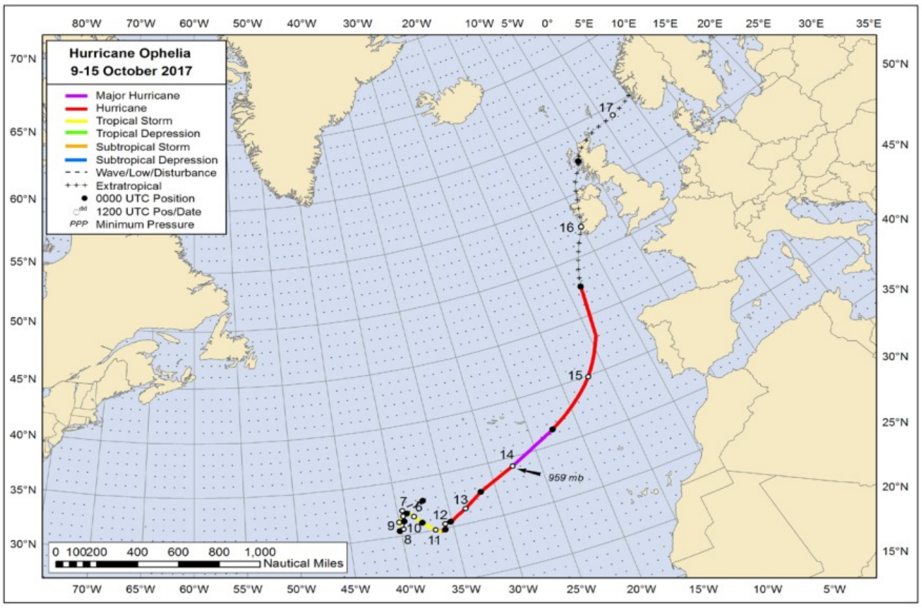

Figure 3: Best track positions for Hurricane Ophelia, 9–15 October 2017, NOAA.

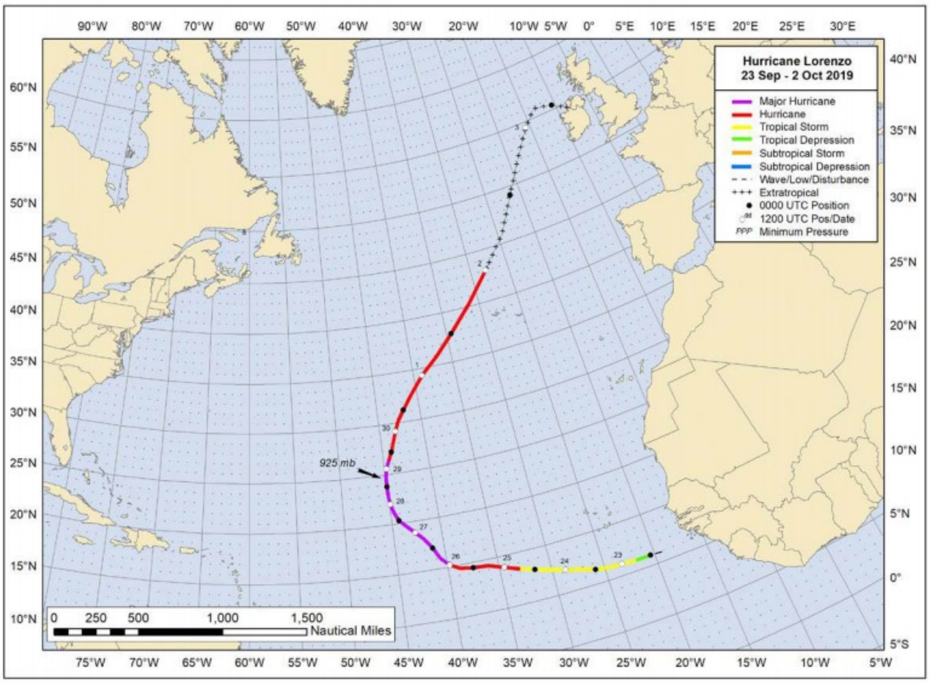

Figure 4: Best track positions for Hurricane Lorenzo 23 September–2 October 2019, NOAA

Year One:

For the PGW approach, in year one of the project we will take 5 different scenarios of simple SST perturbations, and consider 10-member physics ensembles, for two the historical Storms Ophelia and Lorenzo. yields a cost of: 100 kSBU x 5 x 10 x 2 = 10 MSBU

Year Two:

In year two, the simple SST perturbations will be replaced by those from 6 scenarios: pre-industrial past, present, and near and far future informed by EC-Earth simulations under two SSP scenarios each.

Allowing for the two historical storms, and two “future” storms from EC-Earth output, we get a total cost of: 100 kSBU x 6 x 10 x 4 = 24 MSBU.

Overall Project Cost:

Adding the costs from both years yields a total project cost of: 10 + 24 MSBU = 34 MSBU

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