REQUEST FOR A SPECIAL PROJECT 2021–2023

(request for extension of existing project)

MEMBER STATE: Ireland

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Project Title: Coupled Atmosphere Ocean Wave Forecasts for Ireland

Computer resources required for 2023-2025: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	9.9M	35M	35M
Accumulated data storage (total archive volume)[2]	(GB)	20TB	50TB	(will use national allocation)

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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** Project Extension Request **

The principal investigator has completed the following elements of the project to date: the two-way coupling between: (i) the ocean model (ROMS) and wave (WaveWatchIII) models and (ii) the atmospheric (Harmonie-Arome) and wave models.

In the next couple of months, the three-way coupling between all three models will be established with the basic verification tests to follow. The planned verification tests are listed in the original project's Extended Abstract below.

Following the development of such a prototype coupled atmosphere-wave-ocean model, it is essential to carry out thorough evaluation, tuning and verification of the model, in order to make the system operational for Ireland. This is to make sure that the system is robust, both scientifically and technically.

The testing of the coupled system will involve running month-long experiments for each season, as well for a wide range of case studies including winter storms, sea fog and other high impact weather. The simulations will be evaluated in comparison to observations over land and marine buoy data, as well as relevant satellite data. Inter-model comparison studies will be initiated where appropriate in cooperation with our international collaborators.

As in the case with all models, parameters in surface and upper-air physics parametrizations may require tuning. In addition, in some cases there is more than one choice of scheme so tests will be needed to optimise the choice e.g. the ECUME and ECUME6 in Harmonie-Arome, or physics schemes (ST3, ST4 and ST6) in WaveWatchIII. These and other schemes in all three models will have to be tested to ensure the choices are optimal.

Moreover, the optimisation of the computational cost is crucial when setting up an operational system. Therefore, various settings, such as time-stepping schemes, domain size, grid types etc., would have to be tested in order to reduce the computational costs without worsening the forecasts.

This atmosphere-ocean-wave system used operationally is needed in order to improve weather forecasts for Ireland, in particular high impact weather events, through improvements in near-surface parameters. In addition, the fully coupled system will be used to predict wave and tidal parameters, as well as near and off-shore winds. Such predictions are crucial given the need to increase Ireland's electricity generation from renewable sources and the fact that developments in these areas are expected to continue. The improvements to the wave and ocean parameters will also benefit tourism and recreational sectors, and will greatly contribute to the enhancement to coastal flooding and surge modelling and hence to the national warnings.

Extended abstract

1. Background

The first regional coupled atmosphere-ocean models were developed in the late 1990s with the primary purpose to improve weather forecasting and the prediction of extreme events (e.g., Bender et al., 1993; Gustafsson et al., 1998; Hodur, 1997; Xue et al., 2000). Coupled models typically outperform uncoupled models under extreme marine weather conditions and over the ocean (e.g., Aldrian et al., 2005; Bender & Ginis, 2000; Gröger et al., 2015; Lynn et al., 2015; Pullen et al., 2006; Seo et al. 2007A). For highly energetic phenomena, which are strongly controlled by air-sea interactions, the use of coupled atmosphere-ocean models appears therefore mandatory. For tropical cyclones, the use of coupled models is today already standard in research, forecasting, and climate assessments (e.g., Bender et al., 2010; Bernadet et al., 2015; Knutson et al., 2013).

Various other studies showed the improvements of coupled model simulations during high impact weather events, which are more dependent on ocean boundary conditions. Regional coupled models are also proven to provide a better representation for seasonal and intra-seasonal oscillations (Ratnam et al, 2009; Samala et al 2013). Olabarrieta et al, 2012 used the Coupled Ocean–Atmosphere–Wave–Sediment Transport (COAWST) coupled model to simulate hurricane Ida and Nor'Ida and demonstrated the improvement over uncoupled model systems. Zambon et al, 2014 have used the COAWST model for simulating hurricane Ivan and compared the results with WRF atmosphere-only model data. The results demonstrated a drastic improvement by the COAWST coupled model both in terms of ocean and atmosphere parameters during and after the hurricane. The, fully coupled COAWST modelling system was applied in Willapa Bay (Washington State) from 22 to 29 October 1998 that included a large storm event. To represent the interaction between waves and currents, the vortex-force method was used. Model results were well in agreement with water elevations, currents, and wave measurement observations (Olabarrieta et al, 2011). The COAWST forecasting system is operational in USGS (https://woodshole.er.usgs.gov/project-pages/cccp/public/COAWST.htm) to drive a predictive response of the physical system with the help of coupled model.

The use of the HARMONIE–AROME model is gradually extending beyond NWP to include more Earth system components and to longer time frames. Preliminary experiments in Norway have indicated that coupling HARMONIE–AROME with the wave model WAM is beneficial in that it reduces the systematic increase in near-surface wind bias for strong winds, which has been observed in verification against scatterometer data and buoys (Süld et al. 2015). For this reason, and for improved prediction of polar lows, a two-way coupling with WAM has been incorporated in model simulations over an Arctic domain used in operational forecasts by Met-Norway. ALADIN partners, in particular Météo-France and Croatia, have made progress: at

Météo-France by coupling AROME- France to the ocean model NEMO (Madec et al. 2015), using the OASIS coupler (Valcke 2013), which exists within SURFEX (Masson et al. 2013; Rainaud, 2015); in Croatia by implementing a two-way coupling between the ALADIN model on the atmosphere side, and an Adriatic setup of Princeton ocean model, POM (Blumberg and Mellor 1987), on the ocean side as described by Licer et al. (2016). Rasheed et al. 2017 have coupled HARMONIE uni- and bi-directionally with the stochastic wave model WAM. The coupled models were run over a period of 50 days and the resulting time series were compared against observational data from offshore platforms. Significant wave heights and offshore 10m wind magnitude were used for a quantitative validation. Based on the validation results, it can be concluded that bidirectional coupling is more accurate than the unidirectional coupled approach particularly for higher wind speeds and significant wave heights. The unidirectional coupled model configuration was found to overestimate both wind speed and wave height (Rasheed et al., 2017). The aim is to establish a three-way ocean-atmosphere-wave coupling system where the interaction between sea surface and ocean is included. This has been achieved using ALARO CMC, Princeton Ocean Model (POM) and WAM with OASIS coupler. The coupling is performed on the level of fluxes every time step with all three binaries running together in parallel. For this system, an extensive validation of atmosphere and ocean variables has been already performed for 2-way oceanatmosphere coupling (ALARO CMC, POM).

The wave model Wave Watch III (WW3) is forced with HARMONIE-AROME forecasted winds and an extensive verification was completed for three different physics schemes (ST3, ST4, and ST6) of WW3. Furthermore, WW3 is running operationally in three nested domain setups for Ireland. The WW3 wave model is running with HARMONIE forced hourly forecast winds in a one-way coupling configuration. In this case, WW3 does return not transfer any parameter to the HARMONIE model. The skill of the HARMONIE-AROME and WW3 coupled (atmospherewave) model is currently being tested to predict wave parameters and winds in Ireland. Recently, the proposed PI has implemented a two-way coupled (AROME-WW3) configuration by coupling the wave model WW3 via OASIS in cy43 of the HARMONIE-AROME configuration. The HARMONIE model shares 10m u and v components of wind with WW3 which in turn shares the Charnock coefficient with the HARMONIE model. This setup has been tested for the Irish region. The implementation, test runs, and validations are complete, and results show that the coupling HARMONIE-AROME (CY43, SURFEX8.0) with WW3 (using OASIS-MCT) has resulted in slightly improved results for wind speed and with very minor difference in wave height. This verification has been complete for February 2020. Figure 1 right panel shows rainfall comparisons from uncoupled and coupled model simulations for 18Z of 8th February 2020.

The Regional Ocean Modelling System (ROMS) is a free-surface, terrain-following, primitive equations ocean model widely used by the scientific community for a diverse range of applications (e.g., Haidvogel et al., 2000; Marchesiello et al., 2003; Peliz et al., 2003; Di Lorenzo, 2003; Dinniman et al., 2003; Budgell, 2005; Warner et al., 2005a, b; Wilkin et al., 2005). The algorithms that comprise ROMS computational nonlinear kernel are described in detail in Shchepetkin and McWilliams (2003, 2005), and the tangent linear and adjoint kernels and platforms are described in Moore et al. (2004). Initially, it was based on the S-coordinate Rutgers University Model (SCRUM) described by Song and Haidvogel (1994). ROMS was completely rewritten to improve both its numeric and efficiency in single and multi-threaded computer architectures. It also was expanded to include a variety of new features including high-order advection schemes; accurate pressure gradient algorithms; several subgrid-scale parameterizations; atmospheric, oceanic, and benthic boundary layers; biological modules; radiation boundary conditions; and data assimilation.

The PI is currently working on adding the ROMS ocean model to HAROMONIE-AROME-WW3 two-way coupled model, resulting in a fully Atmosphere-Ocean-Wave coupled system. Finally, this research will develop, validate and implement an operational coupled atmosphere-oceanwave forecasting system for Ireland. Furthermore, the research will involve short simulations and case studies using the coupled model to understand the coupled model response using different physics options. Detailed verifications will be carried out to validate the model results for applications in short-range forecasting.

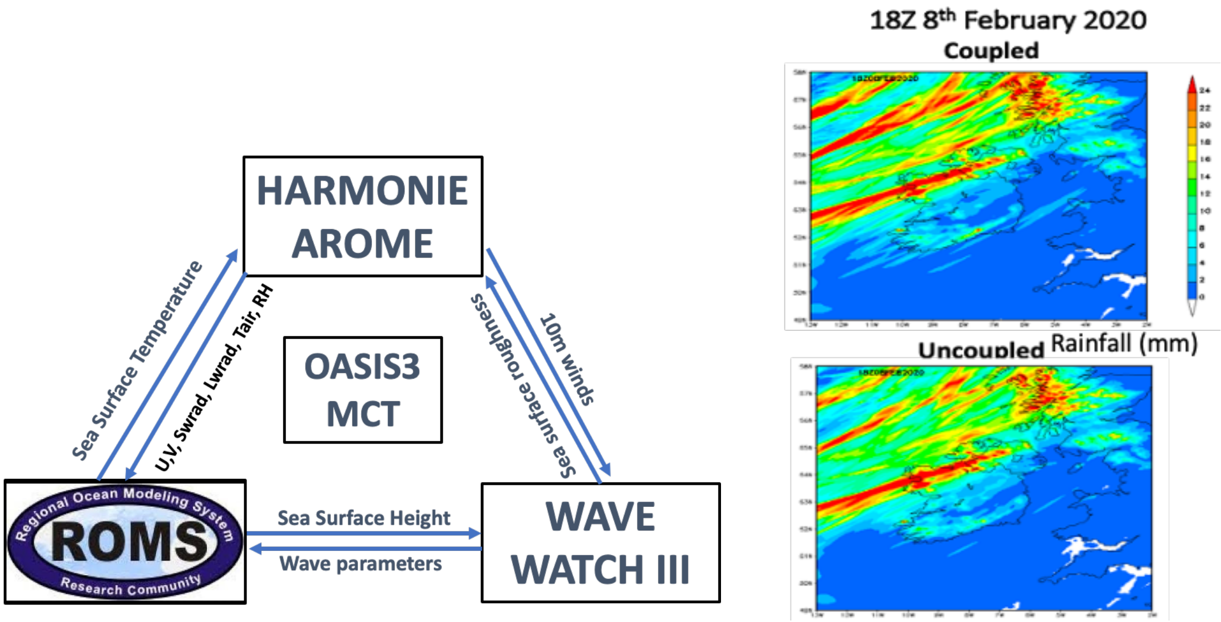

Figure 1: Flow diagram for fully coupled model (left panel); Rainfall comparison from Harmonie-AROME (uncoupled) with Harmonie-AROME-WW3 coupled model (right panel).

2. SBU Justification for Various Experiments:

For the year 2022:

The PI will develop and test the coupled models using the "IRELAND150" domain, which is a toy domain with (50X50) grids.

Once model development is complete, verification runs will be carried out on the IRELAND25 domain (540X500 grids) with the same grid resolution for the WW3 model. Harmonie has 65 vertical levels. The ROMS model is run with 758X574 grid resolution and 16 vertical levels. This fully coupled model for Ireland25 domain will be tested rigorously for different initial time periods, and coupling configurations (e.g. one-way, two-way and fully coupled). Verification of exchange parameters during and after the coupling will be performed. Validation experiments will be run for every six hours forecast, with initial and boundary conditions updated every 3-hours (as with operational mode). Based on the PI's current coupling simulations on cca, it is estimated that development and test run of this coupled model will require 9.9M SBUs.

The requested resource of 9.9 MSBUs is expected to be spent as follows:

• Development and testing of fully coupled model using IRELAND150 domain: ~3.9 MSBUs.

• Testing fully coupled model with various continuation simulations of (stand alone and coupled code): ~ 6 MSBUs

• With this experience, it is expected to use 256 cores for HARMONIE, WW3 and ROMS with total 768 cores for fully coupled model.

• ~100,000 SBUs will be used for serial jobs such as pre-processing boundary data and testing.

Justification for the year 2022:

The Harmonie-WW3-ROMS coupled model will be fully validated by running multiple forecasts on the Ireland25 domain and comparing the results with observations. This fully coupled model will be run for 30 days (ensuring that extreme weather event days are included) along with all three standalone models (Harmonie, WW3 and ROMS) for inter-comparison of model results. These runs will investigate the stability of the coupled model. During the second half of 2022, the operational domain (IRELAND25_090) will be tested in semioperational mode for real-time verification with the present forecast model. It is estimated that the above simulations will require approximately 35.0 MSBUs on the Atos Sequana XH2000 HPCF machine.

The requested resource of 35.0 MSBUs are expected to be used as follows:

• Simulating fully coupled model with Ireland25 domain for 30 days: ~15 MSBUs.

• Simulating all three standalone models (Harmonie, WW3 and ROMS) for the same time period with same initial conditions: ~10MSBUs.

• Situation of ocean-atmosphere-wave coupled model with operational domain Irland25_090 to verify with operational results ~ 10 MSBUs.

• The PI will be saving the above two sets of data for detailed verification with point locations and spatial data. It is estimated that will be require ~50TB of disk space. 3.

Justification for the year 2023:

Continue the testing with a focus on case studies (e.g. A recent tsunami event in West Cork) and fine tuning the models in preparation for possible operational use.

3. Benefits of the Project

This research will lead to Harmonie-ROMS-WW3 coupled model and implementation of the system in operational mode. Such a coupled forecast system will be a first for Ireland will have important implications for short-range weather, ocean state and wave energy forecasting system. In particular, the coupled system is expected to provide more accurate forecasts of extreme events such as flooding and storms. The improved forecasts will provide a direct benefit to Irish society which is increasingly vulnerable to the impact of weather due to both climate change and increasing urbanisation. Weather-related hazards such as flooding and wildfires have the potential to cause personal injury or loss of life, and to damage property, infrastructure and the environment. The improved forecasts resulting from the proposed project will allow planners, policy makers and emergency services to make informed decisions based on accurate and robust weather forecasts.

Forecasts of ocean and wave conditions are important to all who live, work or travel on or near sea and ocean, and the economic impact is significant for end-users in harbour and coastal monitoring, dredging, offshore design and operations, wave and wind energy, maritime traffic control and the Navy. For example, improved forecasts of strong waves/storms will yield direct economic benefits by providing information to sea transportation and port management (if strong wave conditions are forecasted, ships can slow down and save on fuel, instead of waiting outside of the harbour) and there is additional economic benefit in providing improved knowledge of wave environments for facilities situated near coasts. There is also indirect economic benefit in defining the wave resource for optimal implementation of wave energy parks to provide alternative electricity sources. The societal benefits of improved ocean/wave forecasting include improving safety conditions for ocean workers, reduced loss of life, public access to better wave forecasts for recreational activities and enhanced environmental protection.

4. References

• Madec, G.: NEMO ocean engine (version 3.3), Tech. Rep. 27, Note du Pole de modélisation, Institute Pierre-Simon Laplace (IPSL), France, 2011 McGrath, R., Nishimura, E., Nolan, P., Semmler, T., Sweeney, C. and Wang, S., 2005: Climate Change: Regional Climate Model Predictions for Ireland. Environmental Protection Agency.

• Olabarrieta M, et al. (2011) Wave–current interaction in Willapa Bay. J Geophys Res. 116, C12014. doi:10.1029/2011JC007387

• Olabarrieta M, et al. (2012) Ocean–atmosphere dynamics during Hurricane Ida and Nor’Ida: an application of the coupled ocean–atmosphere–wave– sediment transport (COAWST) modeling system. Ocean M. 43–44:112–137.

• Ratnam JV et al., (2008): Simulation of the Indian monsoon using the RegCM3-ROMS regional coupled model, Climate dynamics, 33,119-139

• Ratnam JV et al. (2009) Simulation of the Indian monsoon using the RegCM3–ROMS regional coupled model. Clim Dyn. doi:10.1007/s00382-008-0433- 3

• Regional Climate modelling and Ai-Sea Coupling by Corinna Schrum (2017) Oxford Research Encyclopaedia of Climate Science.

• Samala BK, et al., (2013) Study of the Indian summer monsoon using WRF-ROMS regional coupled model simulations, Atmospheric Science Letters, 14:20-27.

• Seo H, et al., (2006) The Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model, with Applications in the Eastern Pacific Sector, Journal of Climate, 20, 381-402.

• Sikiric M.D. et al., (2013) Coupling of the Regional Ocean Modelling System (ROMS) and Wind Wave Model, Ocean Modelling, 72, 59-73.

• Warner J.C. et al., (2010), Development of a Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modelling system, Ocean modelling, 35, 230-244

• Süld, J.K., et al. (2015). Mesoscale numerical modelling of met-ocean interactions. Energy Procedia, 80, 433–441. doi: https://doi.org/10.1016/j.egypro.2015.11.447

• Valcke, S., Craig, T., and Coquart, L.: OASIS3-MCT User Guide, OASIS3-MCT 2.0, Technical Report, TR/CMGC/15/38, No. 1875, CERFACS/CNRS SUC URA, Toulouse, France, 2013

• Warner, J. C., B. Armstrong, R. He, and J. B. Zambon (2010), Development of a Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System, Ocean Modelling, 35(3), 230–244,

• Zappa G et al. (2013). A multimodel assessment of future projections of North Atlantic and European extratropical cyclones in the CMIP5 climate models. J. Clim. 26:5846–5862, doi: 10.1175/JCLI-D-12-00573.1.

• Zambon, J. B., R. He, and J. C. Warner (2014), Investigation of hurricane Ivan using the coupled ocean-atmosphere-wave-sediment transport (COAWST) model, Ocean Dynamics, 64(11), 1535-1554