SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021
Project Title:	Coupled Atmosphere Ocean Wave Forecasts for Ireland
Computer Project Account:	spiesama
Principal Investigator(s):	Basanta Kumar Samala
Affiliation:	ICHEC, NUIG
Name of ECMWF scientist(s) collaborating to the project (if applicable)	…… ……
Start date of the project:	June 2021
Expected end date:	June 2026

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	9900000		35000000	
Data storage capacity	(Gbytes)	20000		50000	

Summary of project objectives (10 lines max)

The research goal of the project is to develop a regional coupled weather forecasting system (Ocean-Atmosphere-Wave) for Ireland. To begin with, a detailed literature survey was completed, and a report generated. The report conclusions recommended using the HARMONIE-AROME (Atmosphere), ROMS (Ocean) and WW3 (Wave) models are as components of a coupled model with the OASIS3-MCT coupler used to exchange required parameters among these models during runtime. The aim of this project is to develop, validate and implement an operational, fully coupled atmosphere-ocean-wave forecasting system for Ireland. The proposed coupled forecasting system will be the first such system developed for Ireland. This coupled forecasting model will provide improved weather forecasts, as well as integrated solar, wind (onshore and offshore) and wave energy forecasting system which would significantly benefit the renewable energy sector. This research will involve short simulations and case studies using the coupled model to understand the coupled model response to different physics options in ocean and wave model specific to Ireland observations. A detailed verification of the model results for applications in short-range forecasting will be emphasized.

Summary of problems encountered (10 lines max)

PI has worked on model development and implementation with WRF (atmosphere), ROMS (ocean) and WW3 and SWAN (wave) models and COAWST (coupled) model. PI had no experience with Harmonie atmosphere model and OASIS3-MCT coupler, that took ample time for the project. PI was new to ecgate system configuration and ecflow job submission system. Few other problems were to estimate the number of SBUs required for the particular year. As this project involves with development of coupled model, if the model development delayed due to various reasons, then the planned simulations will be delayed. Furthermore, test runs with a smaller domain size won't take much SBUs but with real time fully coupled model runs will require good number of SBUs. This may be one of the reasons for underused of SBUs during reported year. The other problems like technical problems or disk space problems were solved using ecmwf system support team, with Paul Dando and others.

Summary of plans for the continuation of the project (10 lines max)

The PI has developed and implemented HARMONIE-WW3 (atmosphere-wave) two-way coupled model for Ireland on the ecgate cluster at ECMWF, where both models exchange respective parameters in the assigned time steps. The present model domain, as well as the initial and boundary conditions are the same as the operational run by Met Eireann. The Harmonie-WW3 coupled code runs with a single domain wave model set-up and uses ECMWF-WAM wave spectral boundary conditions. The PI has done an extensive verification of different physics scheme of WW3 wave model for wave height parameter for Irish seas. The PI has completed a detailed verification of stand-alone model vs HARMONIE-WW3 coupled model to check the benefits of coupling with the same as operational 2.5km Irish domain. Currently PI is integrating ROMS ocean model in Harmonie-WW3 coupled model to make a three way fully coupled model (atmosphere-ocean-wave). The plan for this project is to make a fully coupled model and test the model for it's operational run. Furthermore, to identify the benefits of using regional coupled model as compared to its standalone counterpart. This verification will include different seasons of the year and high weather events. The model runs will be two sets of runs one without coupling and other with coupling.

List of publications/reports from the project with complete references

- Attended online project progress meetings with Met Éireann on a regular basis.
- The PI attended the Hirlam NWP surface working week from time to time every year. PI is presenting his work in this meeting to a wider community of Hirlam and Accord.

- The PI is actively participating in the ESM coupling group of the HCLIM NWP modelling system. The PI shares his ideas, experiences, difficulties, and future plans for developing a full phase earth system coupled model with the proper documentation and test cases.
- PI is in regular touch with Met Norway and the Swedish Meteorological and Hydrological Institute (SMHI) during the coupled model development.
- PI has submitted annual report to SEAI, Dublin.

Summary of results

Overview: The research goal of the project is to develop a coupled model (Ocean-Atmosphere-Wave) for Ireland. To begin with, a detailed literature survey was completed, and a report generated. The report conclusions recommended using the HARMONIE-AROME (Atmosphere)- ROMS (Ocean)- WW3 (Wave) models as components of a coupled model with the OASIS3-MCT coupler to exchange required parameters among these models during runtime. The PI has set-up the WW3 wave model for Ireland with three nested domains and forced with HARMONIE-AROME operational run winds. WW3 runs operationally and generates wave forecasts for 54 hours every day at 00GMT. Furthermore, the PI has run WW3 wave model for one month (February 2020) with three different physics schemes for day1 (0-23 hours) and day2 (24-48 hours) forecast. These different forecasts were verified with the available observational data from wave buoys located around the coasts of Ireland. In addition, a two-way coupled model consisting of HAMONIE-AROME and WW3 has been developed and implemented and a detailed verification with the available observations and its stand-alone counterparts has been completed. Efforts are currently ongoing to couple the ROMS ocean model to the current set up of the atmosphere-wave coupled model.

The context:

Wave forecast operational: Wave Watch III wave model runs every day by using HARMONIE-AROME atmospheric model 00Z run provides 10 metre wind speed and direction as hourly forecast for the upcoming 54 hours. Every day, plots are generated for Significant Wave Height (SWH) and wave direction from the post-processed output of WW3 and are automatically transferred to a server for guidance to forecasters. The details of the system configuration, model domain, bathymetry and initial conditions were discussed in the annual report. To make this forecast more accurate and usable for forecasters, the PI has completed extensive verifications by selecting different physics schemes of the WW3 wave model, i.e., ST3, ST4 and ST4 (https://github.com/NOAA-EMC/WW3/wiki/Manual).

Wave height verification: In this study, Significant Wave Height (SWH) was used for verification purposes of the mdel forecast with observations. SWH is the average wave height, from trough to crest, of the highest one-third of the waves and this parameter is widely used for model validation.

The model was run to forecast 54 hours for each day from 1st February to 29th February 2020 and three physics schemes were tested in order to find optimal set up for the Irish domain. These three physics schemes are : “ST4 (Ardhuin et al., 2010) correction reduces the wind input for high frequencies and high winds, ST3 (ECWAM) takes into account a stronger gustiness in unstable atmospheric conditions, and ST6 (Rogers et al. 2012 & Zieger et al. 2015) includes wind input source terms, and sink terms due to negative wind input, white capping dissipation and wave-turbulence interactions (swell dissipation)”. The detailed description of these schemes is available in Wave Watch III technical note (https://github.com/NOAA-EMC/WW3/wiki/Manual). In addition, the model was run with multi nested domains (12km,

2.5km and 1.2km). In order to validate the model settings, the comparison was done between: (i) three domains of varied resolution, (ii) two different forecasts: Day-1 (first 24 hours) and Day-2 (second 24 hours, i.e., 24-48 hours) from the 54-hour forecast and (iii) three physics schemes. Different settings, times and domains were compared and validated using SWH parameter. SWH from the model was compared with SWH measurements obtained from quality-controlled Met Éireann marine wave buoy data for every respective hour for eight locations.

The time period chosen for the verification was chosen in order to capture a few anomalous weather events with strong winds and rain. These weather events have been observed from 7-10/02/2020, 12-13/02/2020 and 15/02/2020. Radar plot for 24 hours from 08/02/2020 is shown as an example in Figure 1 top-right panel. The eight buoy locations are shown in Figure 1 top-left panel: three buoys are near the east coast (i.e. Dublin, M2, and M5), one buoy is the South (Kinsale) and the other four buoys are near the west coast (i.e. BerthB, SmartB, M4 and Ballybunion). For all these buoy locations, hourly observations were matched with hourly forecast of all three physics schemes (ST3, ST4 and ST6), for Day-1 (first 24 hours) and Day-2 (second 24 hours) forecast and three domains (d01 – 12 km, d02 – 2.5 km and d03 – 1.2 km). The timeseries of the observed (black line) and modelled (coloured lines) SWH (in meters) is shown for the verification period from Galway Bay location in the bottom panel of Figure 1. For this location we can see a very good agreement between the one-way coupled model and the observational data. Similar plots, as well as box plots and verification statistics (e.g., RMSE, Standard Deviation, Mean Error) were calculated for each individual location. The results show that Day-2 forecast is nearly as good as Day-1 forecast. The higher resolution inner domain forecasts are slightly better (d03) than the low-resolution outer domains (d01 and d02). From the three physics schemes, ST4 physics scheme is performing well consistently for all range of wave heights and buoys. Top-middle panel of Figure 1 shows scatter plot of SWH (m) hourly observations (x-axis) versus ST3, ST4, and ST6 forecasts (y-axis) for February 2020. From this plot we can clearly see that ST4 is outperforming the other schemes by having the highest correlation with the observational data compared to ST3 and ST6 schemes. From the results we can see that the model does not capture some of the high wave events (>8m). It is important to note that, the one-way coupled model underestimates wave height at the M4 buoy, in particular the higher wave height observed days.

Harmonie is more complex model compared to WW3 with more complicated routines and schemes involved, hence WW3 configuration is integrated into Harmonie scripts not the other way round. The Harmonie-WW3 two-way coupled model setup has been recently completed and the required Ireland domain setup has been implemented. In a coupled model, the air-sea interactions occur at the ocean surface in real-time. To develop this coupled model, the SURFEX model was used. SURFEX is the surface modelling platform composed of various physical models for natural land surface, urbanised areas, lakes, and oceans (https://www.umr-cnrm.fr/surfex/IMG/pdf/surface_assimilation_in_harmonie.pdf). SURFEX interacts with OASIS3-MCT to exchange coupling parameters between Harmonie and WW3. The first step was to compile the OASIS library along with all models by modifying the Harmonie compilation scripts. The paths and libraries of OASIS are included in the corresponding variables from the models. On the first compilation of the code a remapping file is generated which guides the parameters from one model to another by taking care of different model grids. Every model makes calls to OASIS functions like send and receive to couple the various fields at the required timestep. *Prep* is the program which generates the initial surface files. SURFEX routines and namelist files are modified to include WW3 routines in the coupled model. The *Config* file of Harmonie has the control switches for coupling periodicity, restart file writing, and one-way model run. Harmonie shares 10 meter u- and v- components of the wind and WW3 takes as input and returns the Charnock coefficient to/from the Harmonie model.

The Harmonie-WW3 coupled model has been completed and tested in forecast mode. Forecasts are generated for six hours from 00 to 21 GMT every three hours. Furthermore, the coupled model can be run in stand-alone mode (HARMONIE-AROME) by switching off WW3 and two_way_couple as *NO* option. The Coupled model (HARMONIE-WW3) and stand-alone models (HARMONIE and WW3) are run for 29days of February 2020 and a detailed validation completed. From this validation results suggest an improvement by coupled model in terms of spatial plots. Importantly the high biases from uncoupled model reduced in coupled model.

Key results and outcomes:

- A detailed wave height verification of the one-way coupled model was completed; Observational data was compared with the model output; WW3 model set up was tested using three different physics schemes, three different domains and two different forecasts (Day-1 – first 24 hours and Day-2 - last 24 hours) .
- HARMONIE-WW3 two way coupled model with the parameters being exchanged in real-time was completed; Winds (10m) from HARMONIE-AROME are passed to WW3 and in return the induced stress (Charnock parameter) is passed from WW3 to HARMONIE-AROME.
- The two-way coupled atmosphere-wave model was forecasted and validated with observations and uncoupled model counterpart.

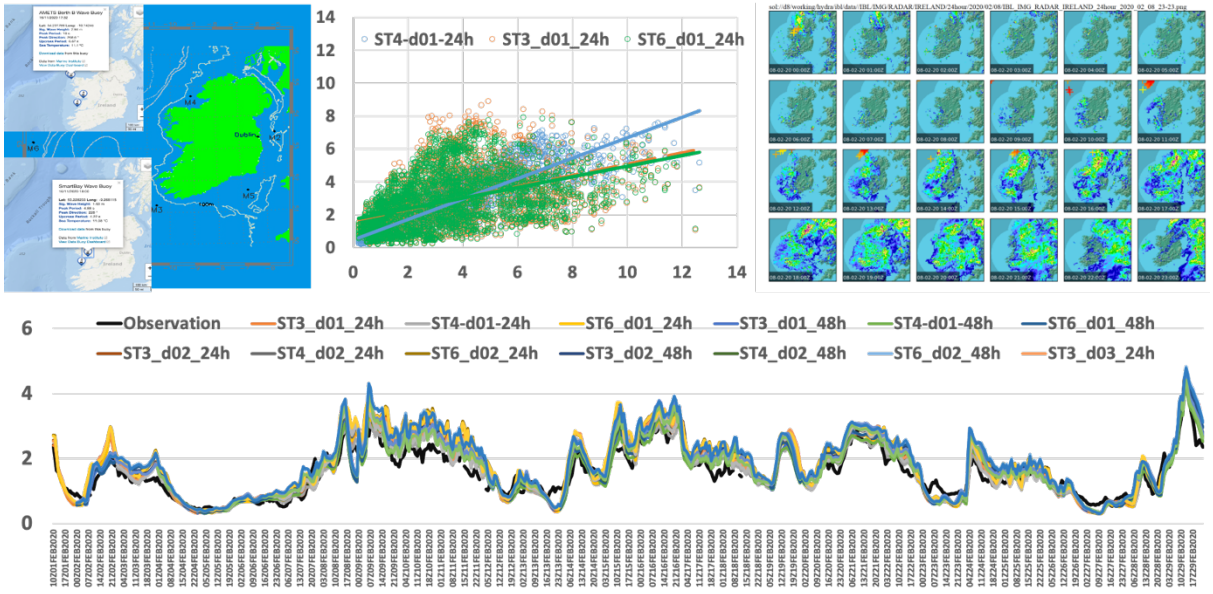

Figure 1: Locations of the eight wave buoys (left top panel); Observed SWH (x-axis) versus SWH from 12km domain and Day-1 forecast model output (y-axis) for the month of February 2020: 3 physics schemes are shown as ST4 (blue), ST3 (orange) and ST6 (green). ; 24-hours of radar images from 8th February (right top panel); Timeseries of SWH (m) from 1st February 2020 until 29 February 2020 for Galway Bay location (bottom panel); Black line represent observational data and different colour schemes represent different model set up (ST3, ST4 and ST6 – physics schemes, d01 – 12km domain, d02 – 2.5km domain and d03 – 1.2km domain, 24h – Day-1 forecast, 48h- Day-2 forecast).