# Implementation of a combined wave and current modelling system

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## *Introduction*

The Proudman Oceanographic Laboratory (POL) conducts research into the dynamics of the ocean. Its expertise has traditionally been in marine physics, studying the processes of tides, sea level, and shelf sea circulation. One of the important tools is the use of numerical modelling, which complements other strengths in observation systems. In recent years POL has tackled more interdisciplinary problems, moving towards the ultimate goal of a fully integrated biological-chemical-physical system, with a coupled atmosphere-ocean-geosphere model. A previous article in this newsletter described the coupled physics-ecosystem model (Holt et al, 2002).

Wave prediction is needed for ship routing, offshore operations and coastal engineering and waves are also important in various processes. The ocean-atmosphere coupling is through the surface wave field. Accurate air-sea fluxes are critical for weather and climate change modelling. The impact of climate change on coastal communities is partly due to possible changes in coastal wave climate and its effect on coastal erosion and flooding (Wolf et al., 2002a). In shallow water waves penetrate to the sea bed and are important in the re-suspension and transport of sediment. In order to properly model waves, currents, air-sea fluxes of momentum, heat and gas exchange and sediment transport in the sea, a coupled wave-current model is one necessary part of the model system. The detailed mechanisms of turbulence (which are affected by waves) must be incorporated into hydrodynamic models and are still to a great extent unknown. Practical solutions such as bulk parameterisations may fail in the very areas where they are most critical e.g. in momentum flux when waves are not in equilibrium with the wind.

Earlier work on wave-current interaction in the Irish Sea showed the feasibility of the coupling of wave and hydrodynamic models but the computational cost was very high (Wolf et al., 2002b). It was therefore necessary to develop an implementation of the fully-coupled model on a parallel computer. The coupling is two-way, i.e. the currents affect the waves and the waves affect the currents. Here we describe the physics, the numerical solutions required and some results of the coupled model for the Irish Sea (Figure 1), where the complicated bathymetry and topographic features (i.e. headlands and shoals) produce tidal and wind-driven currents that exceed 3m/s in some locations. It is exposed to the SW with swell waves from the NE Atlantic, where some of the largest waves outside the Southern Ocean can be found. The Irish Sea is also noted for short choppy seas generated locally by winter storms.

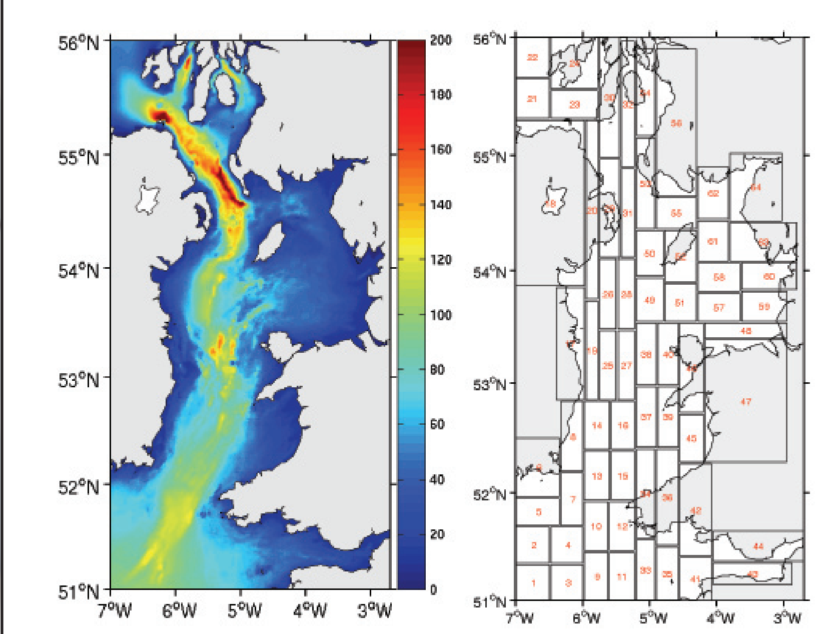


Figure 1: Bathymetry (in metres) of the Irish Sea (left). Partitioning scheme for parallel processing (right).

## *Details of wave-current coupling*

The effects of current and depth refraction of waves by the changing water levels and currents, and the coupling between waves and currents in the surface and bottom stress terms are included. The wave-current interaction module allows the synchronous exchange of information between POL3DB (the component of POLCOMS which computes the 3-D baroclinic current field) and the spectral wave model ProWAM, which is a modified version of the WAM model (Komen et al., 1994). In this implementation ProWAM works as a module of POLCOMS, so the wave model uses the same bathymetry and wind information supplied to the hydrodynamic model. The different time-steps used by the models are independent but, as the wave model is embedded in the baroclinic step of POL3DB, the ProWAM time-step must be an integer multiple of the POL3DB baroclinic time step. The wave model consists of propagation and source terms (such as wind input and dissipation). The source terms are integrated on a longer time step than propagation. An example of the time stepping in the coupled system is presented in Figure 2.

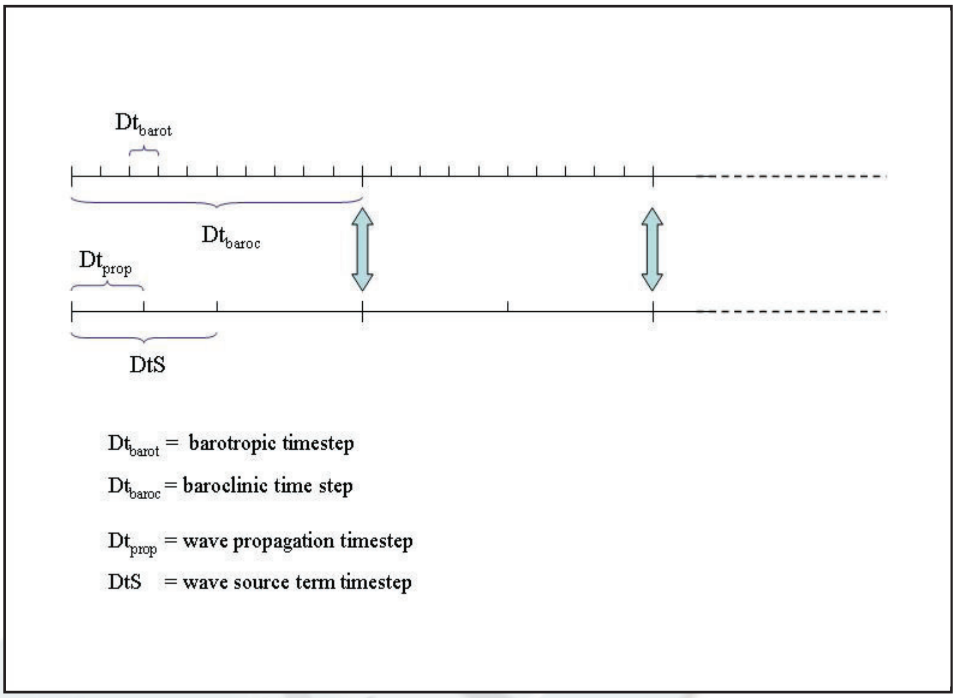


Figure 2: Time stepping in the wave-current interaction module.

## *Parallelisation and Optimisation*

The propagation terms require more work in implementing a parallel code than the source terms since the way in which the code is parallelised is to distribute the spatial grid over the processors. The source terms, however, are local to each grid-point. The area partitioning is shown in Figure 1. The strong current gradients in some areas enhance the spectral variability of the wave field so the use of even smaller time steps for the solution of the source terms becomes necessary. The wave-current interaction module is already an expensive sub-model of POLCOMS. Normally, using the wave module increases the computation time in a factor 20 with respect to the standard POLCOMS system. For the Irish Sea the system must be set up in such a way that the coupled system uses 40 times more computer time than the standard POLCOMS implementation. Performance improvements were made by reducing repeated calculations, correct loop nest ordering and reducing the number of temporary arrays. These serial optimisations of the ProWAM part of the code resulted in an improvement of an order of magnitude in run time whilst maintaining the high scalability of the code, results from Newton are provided in Figure 3.

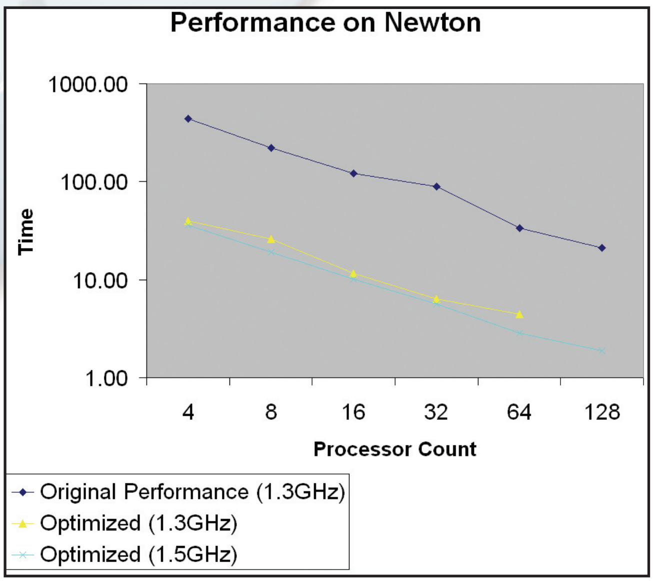


Figure 3: Wallclock time of the parallel code over a range of processor counts for the original code on Newton's 1.3GHz processors, the optimised code on Newton's 1.3GHz processors and the optimised code on Newton's 1.5GHz processors. The log scale shows the order of magnitude difference between the run times whilst maintaining the same level of scalability.

## *Results for Irish Sea*

The performance of the system is assessed in the Irish Sea, with a high spatial resolution of about 1:85km. In order to incorporate swell (remotely generated waves) coming from the Atlantic, a coarser resolution wave model, which includes part of the northeast Atlantic Ocean (NEA), was used. The open boundary conditions for the hydrodynamic model were generated by an implementation of POLCOMS for the northwest European continental shelf. The wind forcing is provided by six-hourly, 1-degree resolution, ECMWF ERA40 reanalysis surface winds and atmospheric pressure, for the period from 02/02/1997 to 16/02/1997.

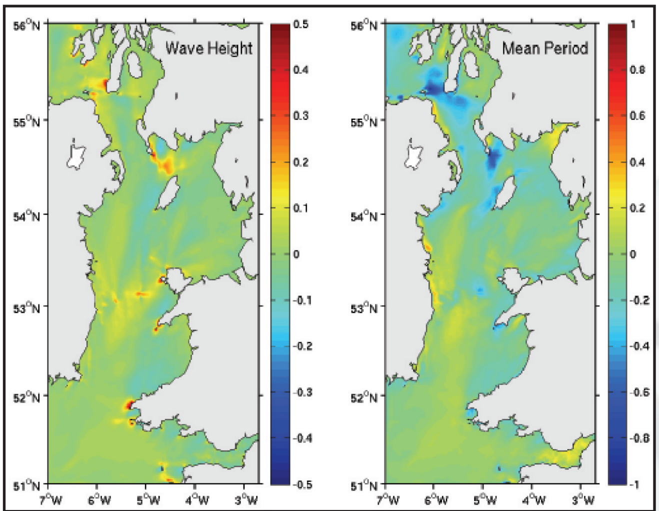


Figure 4: Daily mean differences (coupled minus uncoupled) of wave height (in m) and mean wave period (in seconds) corresponding to the 11/02/1997.

## *Conclusions*

Results indicate that the effect of currents on the waves (e.g. modulations of wave height and mean period) can be significant in the Irish Sea area (see Figure 4). Larger effects are observed around headlands and shoals, where the magnitude and shear of currents are large. The effect of waves on currents is also evident around headlands and shoals (Figure 5). During stormy periods, differences in the daily mean current speed are mainly caused by the wave-dependent surface stress. The effect of the combined wave-current bottom shear stress is confined to coastal areas.

The model is now running in an optimum environment which will facilitate further development. This will include the effect of current shear; radiation stress which generates long-shore currents and set-up in the coastal zone and continuing improvements to the other source terms in the wave model. We are also working on collecting sufficient data to validate and test the model.

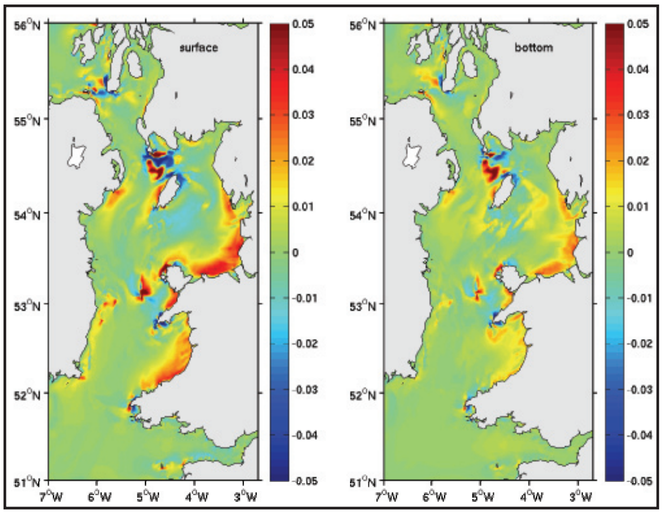


Figure 5: Daily mean differences (coupled minus uncoupled) of currents at the surface (left panel) and the bottom (right panel) (m/s) for the 11/02/1997.

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