Eddy Resolved Coupled Physics-Ecosystem Modelling in the Irish Sea

Jason Holt, Roger Proctor ~ Proudman Oceanographic Laboratory
Mike Ashworth ~ CLRC, Daresbury
Icarus Allen, Jerry Blackford ~ Plymouth Marine Laboratory

Among the marine science and management community there is intense interest in how the ecosystems of the shallow seas of the continental shelves are controlled by the physical environment in which they exist. Some of the principle ideas have long been established: tides, wind driven currents and river plumes transport nutrients from the land and the open ocean into coastal waters where rapid production of plankton occurs in spring blooms. In shallow waters these are controlled by the turbidity of the water limiting light levels. In deeper waters, where tidal currents are weaker, blooms occur when seasonal heating reduces mixing near the surface; mixing which would otherwise carry photosynthesizing plankton out of the illuminated region. The plankton produced by the bloom enters a complicated biogeochemical web, much of which is being explored by biological processes studies. But it is only recently, with the advent of sophisticated ecosystem and hydrodynamic models, and massively parallel computers, that the environment at the first few levels of the food chain can be explored in its entirety. Here we examine how coupling two such models at high resolution in four dimensions predicts a rich and complicated behaviour with a strong resemblances to reality.

The Irish Sea presents an ideal location for developing and testing coupled physics-ecosystem models. It is a semi-enclosed sea with a wide range of physical and biogeochemical regimes: the tides propagate inwards from both channels resulting in weak tides and seasonal stratification in the west and very strong tides in the Eastern Irish Sea; nutrient input is both from rivers and from oceanic sources; and the ecosystem is not dominated by a single plankton or zooplankton species. A computationally efficient 3-dimensional coastal-ocean modelling system (POLCOMS, www.pol.ac.uk/home/research/polcoms) has been developed and this acts as 'host' to the ecosystem dynamics. A full description of the hydrodynamic model can be found in Holt and James 2001 (J. Geophys. Res. 106 C7 14015-14034). The structure of the modelling system allows different ecosystem formulations to be explored in an identical physical environment, and this article focuses on one such model: the European Regional Seas Ecosystem Model (ERSEM), developed through a 6 year EU funded project involving 8 institutes in 4 countries is probably the most comprehensive model of its type (see Baretta et al, 1995 , Neth. J Sea Res., 33, (3/4), 233-246). This system has been applied at eddy-resolving lengthscales (~1.5 km) to the Irish Sea in a model domain nested within a hierarchy of models covering the whole of the North West European Continental Shelf.

The whole system has about 2×10^7 inter-related degrees of freedom that are stepped forwards in time, with typically a 20 minute time step. Modelling seasonal and multiyear periods is therefore a computational challenge of the highest order. The system uses domain decomposition to partition a sea area between the processors available at run time and message passing (MPI) is used to communicate the model variables between the processors as required by the equations of motion. As figure 1 shows, the performance of the system scales excellently with the number of processors on the Origin 3000, GREEN, whereas there is a degradation of performance with more than 96 processors on TURING (the CRAY T3E-1200E). This is using

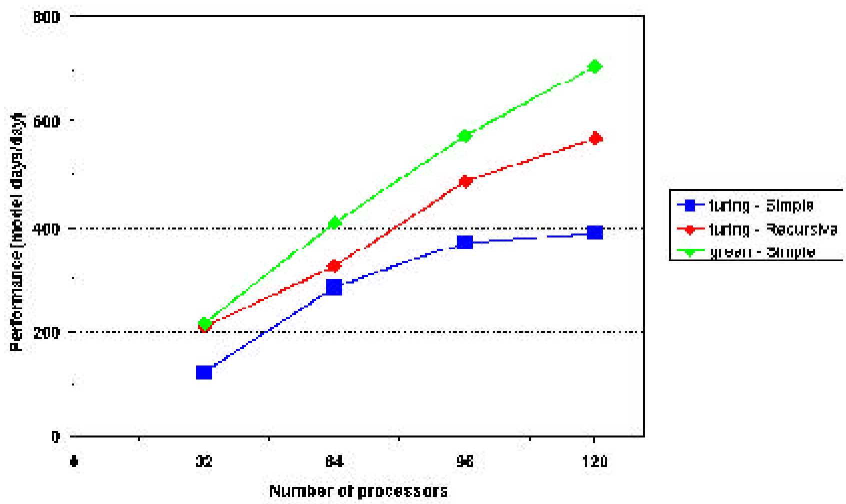

Figure 1: Model performance on Turing with simple and recursive partitioning and on Green with simple partitioning.

simple partitioning, whereby the model domain is divided into equal area boxes with no account as to whether they contain land or sea (about 50% of the domain in these tests is land). If a recursive algorithm, which divides the domain so each processor has a similar load, is used then both performance and scaling are significantly improved.

Model results from a simulation of 1995 show that during the onset of seasonal stratification the weak frontal regions are unstable, resulting in substantial eddy activity (figure 2). This transports water from the well-mixed regions, which are nutrient rich, into the regions where a spring bloom has already occurred and hence are nutrient depleted (figure 3). This provides a new source of nutrients to the phytoplankton in this region and there is enhanced production along the front (figure 4).

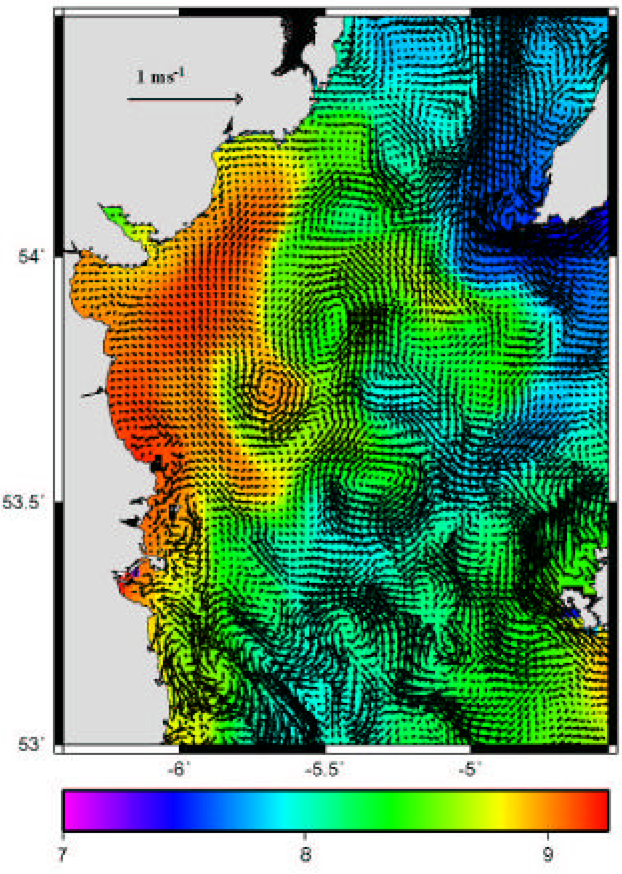

Figure 2: The surface temperature (°C) and Currents on 24th April 1995).

It is only with resolution of these scales that the details of the interaction of primary production and the hydrodynamics become apparent. As well as primary production this work particularly focuses on the next level up in the food chain, zooplankton. These are a major food source for many commercially important fish species, so understanding how they interact with their physical environment, for example why production rates in the North and Irish Seas are so different, is crucial to fisheries management.

This work has been conducted in collaboration with researchers at CLRC Daresbury Laboratory, Plymouth Marine Laboratory and Southampton Oceanography Centre as part of the NERC Marine Productivity Thematic program.

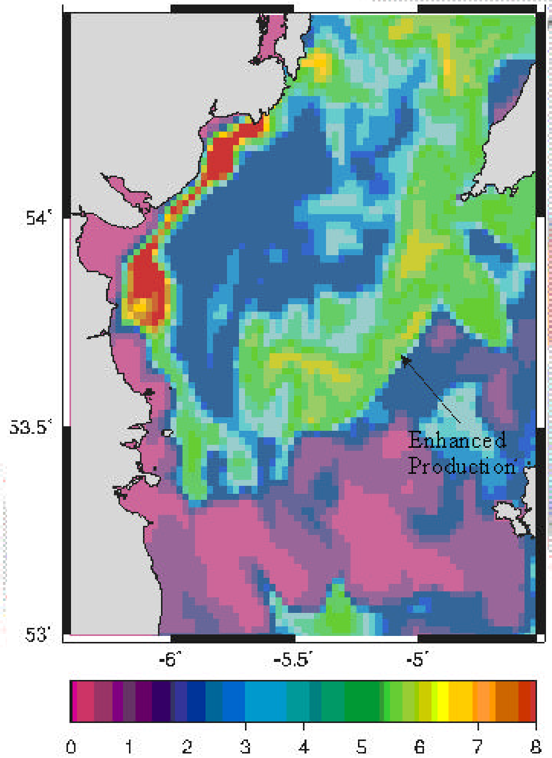

Figure 3: Surface Nitrate (mmol N m^{-3})

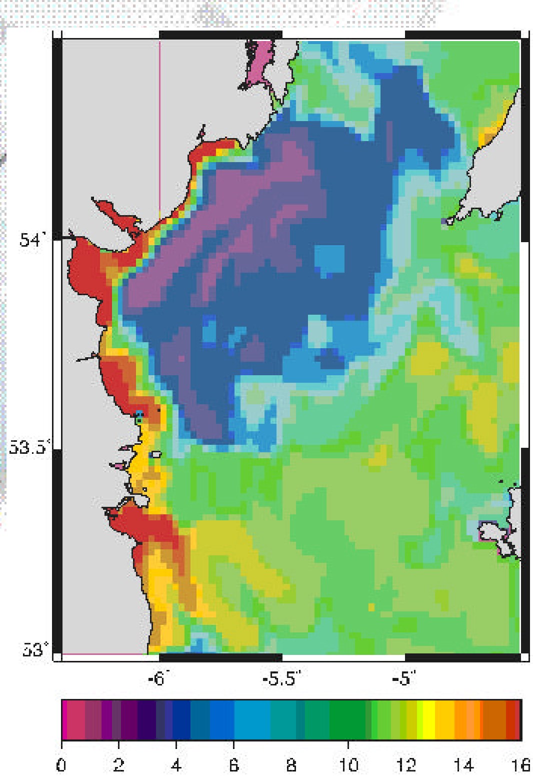

Figure 4: Surface Chlorophyll (mg chl-A m^{-3})