COMPLETED PROJECT CASE STUDY

HIGH-RESOLUTION OCEAN MODELLING FOR NORTHERN SCOTLAND AND THE SHETLAND ISLES

PARTNERS

Scottish Association for Marine Science (SAMS) | Scottish Sea Farms | Scotland's Rural College (SRUC)

PROJECT LEADS

Prof. Keith Davidson, Dr Dmitry Aleynik, Ralph Bickerdike, and Dr Annette Boerlage

BACKGROUND

The waters around northern Scotland and the Shetland Isles are among the most dynamic and productive marine environments in Europe. They support a thriving aquaculture industry, including finfish farming and shellfish cultivation, which is central to the rural economy. However, the sector faces significant challenges from marine environmental hazards. Harmful algal blooms (HABs), extreme weather, and complex circulation patterns can all jeopardise fish health, shellfish safety, and wider coastal ecosystems.

Predicting these events requires robust, high-resolution modelling of atmospheric, tidal, and oceanographic processes. Traditional operational models such as the Met Office's AMM15, which operates on a 1.5 km grid, are valuable at large scales but insufficient for resolving local circulation features around complex coastlines, like those in Shetland. Such coarse models cannot adequately capture small-scale hydrodynamic processes that drive HAB dispersal, nor can they reliably inform farm-level management decisions.

To address this gap, the Scottish Association for Marine Science (SAMS), in collaboration with industry and academic partners, has advanced a new generation of regional coastal models. Building on the success of the West Scotland Coastal Ocean Modelling System (WeStCOMS) from previous research funded by the Sustainable Aquaculture Innovation Centre (SAIC), the SAIC-funded High-Resolution Shetland project developed the North Scotland Coast Ocean Modelling System (NORSCOMS). This system extends high-resolution forecasting to the northern mainland, Orkney, and Shetland, providing a step-change in Scotland's capacity to anticipate and respond to marine hazards.

For aquaculture, the implications are direct and substantial. In Shetland, where project partner Scottish Sea Farms (SSF) operates numerous farms, the ability to anticipate HAB dispersal at the farm scale could safeguard turnover by at least £1 million annually. The system also benefits shellfish growers, with Shetland producing 75% of Scotland's rope-grown mussels. Improved HAB prediction enhances regulatory oversight by Food Standards Scotland, reducing the risk of biotoxin contamination.

AIMS

The primary objective of this project was to establish a fully operational high-resolution modelling framework, NORSCOMS-WRF-FVCOM, capable of delivering near-real-time hindcasts and short-term (five-day) forecasts of hydrodynamic conditions in the seas between Cape Wrath, the Pentland Firth, Orkney, and Shetland.

Specific objectives included:

1. Developing an advanced model using realistic atmospheric forcing conditions from the Weather Research and Forecasting (WRF) model;
2. Designing a continuous data acquisition system for tides, salinity, temperature, and currents with a temporal resolution of 1–3 hours and a horizontal resolution of ~2 km;
3. Building and optimising a Finite Volume Coastal Ocean Model (FVCOM) domain for the northern Scottish shelf, capable of producing operational forecasts within 24 hours.

PROJECT OVERVIEW

ATMOSPHERIC MODELLING

To capture the influence of weather on the seas around northern Scotland and Shetland, the research team used the Weather Research and Forecasting (WRF) model. This system is widely applied in both research and operational forecasting, and in this case was configured to resolve fine-scale wind and rainfall patterns.

Such detail is essential in a region where mountains, fjords, and narrow straits can amplify or redirect winds, driving local changes in sea circulation.

The model was set up with three nested grids: a broad outer domain at 18 km resolution, a mid-range domain at 6 km, and a fine inner domain at 2 km resolution covering western and northern Scotland and the Shetland Isles. This structure allowed the model to 'zoom in' progressively, ensuring that small-scale features of the coastline were represented while still being informed by large-scale weather systems.

Boundary information for the model was based on the U.S. National Centers for Environmental Prediction (NCEP) Global Forecast System, updated every three hours at 0.25° grid. To improve accuracy at the sea surface, the model also incorporated high-resolution (1 km) satellite data on sea surface temperature from JPL-NASA.

The system now runs weekly on SAMS' computing cluster, producing both hindcasts (covering the previous week) and five-day forecasts. These outputs provide the necessary atmospheric forcing for the ocean model, ensuring that wind, temperature, and rainfall conditions are represented as realistically as possible.

OPEN BOUNDARY FORCING

To make the model realistic, accurate information is necessary at the boundaries, where the model domain connects to the wider sea. For tides, researchers used well-established global datasets that combine satellite measurements with long-term records, capturing the 11 main tidal components responsible for over 96% of water level changes in the region. Previous experience showed these inputs match well with observations, even in narrow lochs.

Temperature and salinity data were provided by European and U.S. ocean monitoring systems (Copernicus and NOAA/NASA), which produce regular forecasts and include satellite observations of sea surface height and temperature. This ensured the model started with reliable conditions and was continuously updated.

Freshwater input from rivers was also included. Instead of relying on long-term averages, river flow was calculated directly from rainfall predicted by the atmospheric model. Each river's response to rainfall was adjusted depending on the size and location of its catchment, as well as seasonal effects like evaporation. This approach makes the model much more responsive to real weather patterns, capturing year-to-year variability that can influence coastal conditions. In total, 455 rivers and tributaries were included, based on data from the Scottish Environment Protection Agency (SEPA).

FVCOM COASTAL OCEAN MODELLING

The core of the system is the Finite Volume Coastal Ocean Model (FVCOM), which is well-suited to areas with complex coastlines and irregular seabed features. Unlike models that use evenly spaced grids, FVCOM uses a flexible mesh of triangular elements that can be refined where more detail is needed, such as narrow channels, aquaculture sites, or busy coastal areas, while remaining coarser offshore.

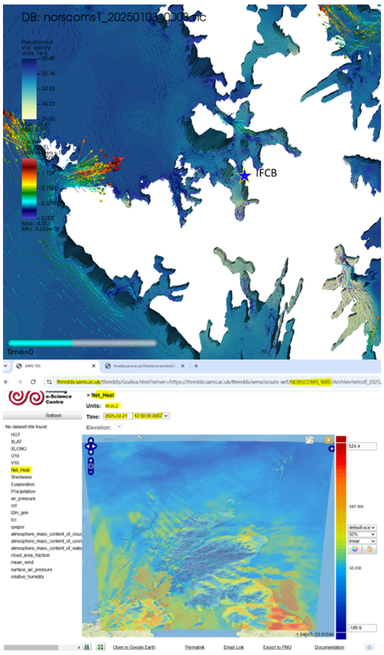
For northern Scotland and Shetland, the model mesh included 73,393 nodes in the vertices of 129,935 triangular elements. Resolution ranged from 2–3 km offshore to as fine as 30 metres near coastlines and farm sites, ensuring that small-scale hydrodynamic processes were properly represented. The vertical structure of the water was divided into 15 layers, allowing the model to capture seasonal stratification and mixing.

Model bathymetry data derived from detailed digital atlases and multibeam surveys, carefully smoothed to prevent instabilities in the model. Depths in the domain ranged from shallow coastal waters to over 350 metres near the shelf break. Physical processes such as vertical turbulence, horizontal diffusion, and bottom friction were represented using widely accepted parameterisations.

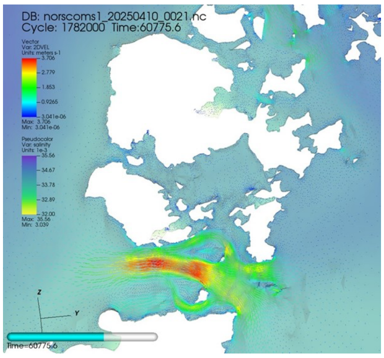
The model was initialised using Copernicus datasets, with sea surface temperature adjusted using satellite data when necessary. Weekly runs were carried out on high-performance computers, each five-day forecast requiring around 20 hours of computing time. These runs provided realistic simulations of currents, tides, and water properties across the region.

RESULTS

All three core objectives of the High-Resolution Shetland project were successfully achieved. The NORSCOMS-WRF-FVCOM system now delivers operational hindcasts and forecasts of circulation around northern Scotland and Shetland, with outputs disseminated openly via the SAMS THREDDS server. The atmospheric model is fully operational, generating weekly five-day forecasts at 2 km resolution. Open boundary forcing has been automated, and river discharges are now dynamically modelled rather than based on static climatology.



NORSCOMS-FVCOM: a) screenshot of the surface velocity m·s-1and the sea surface salinity (g·kg-1) at 12:00 UTC, on the 3rd of January 2025, near Magnus Bay, Shetlands; IFCB location shown with a star.



NORSCOMS-FVCOM: b) the surface velocity m·s-1and the sea surface salinity (g·kg-1) at 14:00 UTC, on the 10th of April 2025 in Pentland Firth (between Orkney and the Scottish mainland)

IMPACT

The development of NORSCOMS provides a long-term enhancement to Scotland's capacity to respond to marine environmental hazards. By integrating northern waters into the HABreports.org early warning system, the project strengthens national resilience to HAB events.

Open access dissemination through the SAMS THREDDS server ensures wide availability of model outputs for industry, regulators, and researchers.

The project brought about the creation of a new oceanographic model with extensive benefits, and the improved knowledge and standardisation of methodology is a highly valuable result of this work.

In addition, the improved power of the predictive model for the Shetland Isles can be used for other applications and will be a valuable legacy. The MATLAB, Python and R-packages for model output visualisation, processing and analysis will outlive the project and are available for use by interested individuals anywhere in the world.

Beyond HABs, the modelling framework supports evaluation of sea lice dispersal, jellyfish transport, and waterborne pollutants, offering broader benefits across aquaculture and coastal management. The fine-resolution circulation fields also inform site selection, helping minimise connectivity between farms and reducing epidemiological risk.

The integration with SRUC's epidemiological models provides an important advance in fish health management. Linking hydrodynamic predictions to gill health outcomes, for example, enables more proactive responses to environmental stressors, enhancing survivability and supporting welfare.

Scientifically, the project advances the state of coastal ocean modelling, incorporating the latest atmospheric and hydrodynamic codes, high-resolution bathymetry, and robust forcing datasets. The modelling infrastructure developed under the High-Resolution Shetland project lays a foundation for Scotland to remain at the forefront of predictive aquaculture science and coastal hazard management.

The potential of this project to have far-reaching impacts across a whole range of marine sectors – such as ecological studies, environmental impact assessments, offshore energy applications, licensing, sea lice regulation, and technology development – should not be underestimated.

FURTHER RESEARCH

This work prepares the ground for new functionalities in the utilisation of NORSCOMS environmental predictions and modelling of gill health in the North Sea.

Furthermore, the project is continuing with the support of SAIC's 'Call 5' funding. This will allow the team to continue delivering risk assessments until the end of 2025. It will also refine the IFCB deployment system to include its deployment from an autonomously operated winch, which will allow profiling of the water column, while the proof of concept and mechanics tests were performed in August 2025. It will also enable the extension of the project's plankton monitoring to micro-jellyfish through the development of a Holocam/AI-based system in collaboration with the University of Aberdeen.