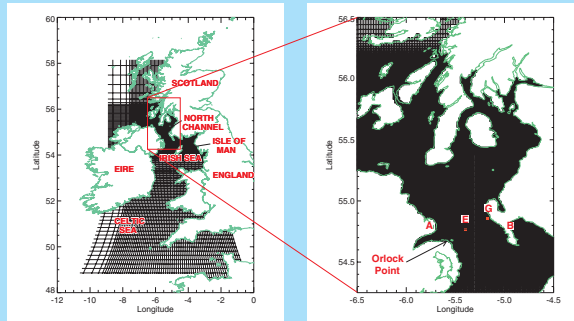


3-D CURVILINEAR MODELLING OF WIND-INDUCED FLOWS THROUGH THE NORTH CHANNEL OF THE IRISH SEA

by E.F. Young, J.N. Aldridge and J. Brown

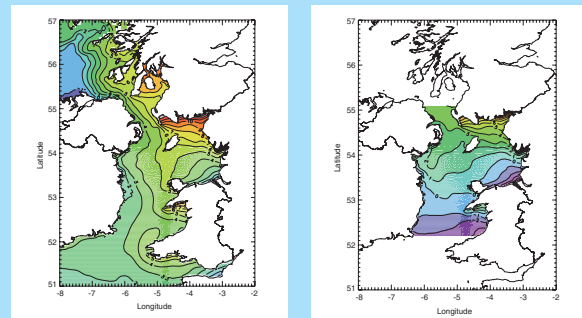
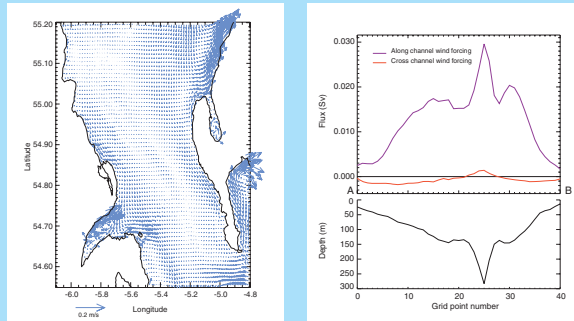
A 3-D non-orthogonal curvilinear model of the Celtic Sea, Irish Sea, North Channel and Malin Shelf has been applied to study the wind-induced dynamics of the region. The variable resolution of the grid provides an ideal solution to the problem of including the effects of far field forcing, whilst providing the appropriate fine resolution (of the order of 1 km) to resolve the complex local bathymetry and current structure of the North Channel. This novel approach is not only computationally efficient but, unlike the more common approach of nesting regular grids of varying resolution, avoids the problem of formulating suitable open boundary conditions for nested grids.

The finite difference grid of the curvilinear model (every fifth grid element; right), covers a sufficiently large geographical area to include far field forcing. The more detailed view (every grid element) highlights the fine resolution achieved in the North Channel region. For the purposes of this study, fine resolution (~1 km) bathymetry was digitised from Fair Sheets and Admiralty Charts supplied by the U.K. Hydrographic Office (Brown *et al.*, 1999). The numerical method used to solve the 3-D hydrodynamic equations was a mixed spectral-finite difference approach, described in detail by Davies (1980, 1987). The development and validation of the model for the two main tidal constituents (M_2 and S_2) is detailed in Young *et al.* (1999).



Simulations with constant winds

Simulations were intended to provide insight into how wind forcing (both local and far field) and the associated elevation gradients influence flows through the North Channel and the Irish Sea. Constant wind forcing of 10 m s^{-1} from a range of directions demonstrated an essentially linear model response, thus the response to any wind direction could be constructed from two orthogonal components. Wind-induced fluxes through the North Channel along section AB (above right figure) were greatest for an along channel wind (from 151° , 0.26 Sv; $1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$) and least for a cross channel wind (from 248° , -0.02 Sv), broadly in agreement with observations (Howarth, 1982; Brown & Gmitrowicz, 1995; Knight & Howarth, 1999). For an along channel wind, flows showed little cross channel variability. A cross channel wind produced much greater variability; although the surface currents were essentially uniform and eastward, the resulting weak pressure gradients in the North Channel drove a predominantly westward bottom flow with a weak north-westward flow along the centre of the channel. The resultant depth-mean flow (above left) is complex, with southward flow along the margins and northward flow along the centre of the channel. The predicted fluxes through section AB of the North Channel for along and cross channel winds (above right) illustrate the large differences in the magnitude and cross channel variability.



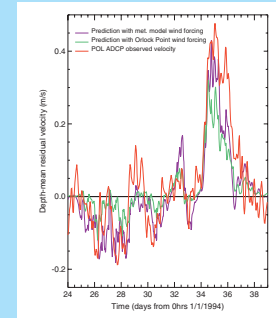
shown above (large grid left, small grid right). In addition to the considerable difference in the absolute elevations, the smaller grid predicts north-south elevation gradients in the western Irish Sea unlike the east-west gradients predicted with the large grid.

The importance of adequate representation of far field effects on wind-induced flows was investigated by comparing the above with results obtained using a smaller model grid of similar spatial coverage to conventional Irish Sea models. Whilst cross-channel fluxes were similar (0.02 Sv compared to -0.02 Sv), along channel fluxes were markedly different (0.07 Sv compared to 0.26 Sv). This difference is due to a combination of the reduced geographical coverage of the smaller grid and the proximity of the open boundaries to the area of interest (the North Channel). These affect the development and orientation of the pressure gradients, which influence the magnitude and direction of the predicted fluxes. This is clearly demonstrated by comparing the wind-induced surface elevations for an along-channel wind

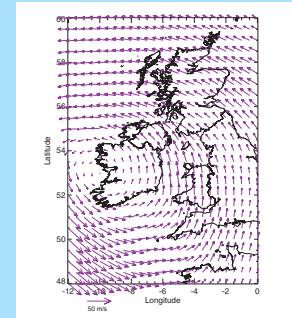
Simulations with dynamic winds

Whilst uniform winds have generally been used to study the wind-induced dynamics of the Irish Sea, they are unrepresentative of real conditions. Dynamic winds, using three-hourly surface wind fields obtained from the U.K. Met. Office, were applied to two periods in 1994. January-February corresponded to a significant outflow event when ADCP (acoustic Doppler current profiler) observations were available (Knight, 1995). A second period in September coincided with an observational program undertaken by CEFAS in the North Channel.

i) January-February 1994; a 'big event'

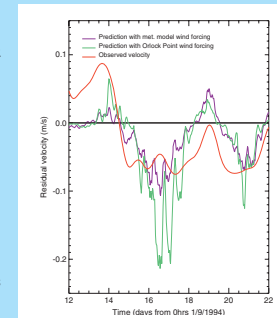


The northward component of the depth-mean flow recorded by the ADCP (site E) for 24 January to 8 February is shown to the left. Strong along-channel winds associated with a low-pressure system centred over the west coast of Ireland on the 3-4 February (right) generated northward currents of nearly 0.5 m s^{-1} . The northward depth-mean currents from the large area curvilinear model are in good agreement with the observations. The simulation was repeated using a non-spatially varying wind field from Orlock Point. Although the general trends were predicted, the extremes of the observed currents were not. Differences in the far field forcing due to spatial variability in the wind field evidently play an important role in forcing flow.



ii) September 1994

Observed northward residual velocities at current meter G, an Aandera deployed 56 m above the sea bed in 75 m of water, for 12-22 September 1994, are shown to the right. The predicted wind-induced residual currents at a depth of 19 m using the spatially varying Met. Office model wind forcing generally agree well with the observed currents. The simulation using Orlock Point wind forcing shows some significant differences with the observations, in particular the prediction of a southward flow of approximately 0.2 m s^{-1} on the 16-17 September, much stronger than the observed flow of about 0.06 m s^{-1} . During this period the observed north-westerly winds at Orlock Point were much stronger than those predicted by the model and those observed on the Isle of Man, suggesting that observed winds at Orlock Point were a localised event. This again emphasises the importance of appropriate representation of far field effects in numerical models.



iii) How significant was the 'big event'?

Whilst the February event was large, in terms of the flushing of the Irish Sea it is important to place it in the context of average conditions. The mean northward flux for February was 0.23 Sv, but neglecting the 3-4 February the flux was still 0.16 Sv. The total volume flux for water passing through the North Channel from the Irish Sea in February, including the tidal residual flux of 0.023 Sv (Young *et al.*, 1999), was $6.1 \times 10^{11} \text{ m}^3$. This approximates to 25% of the volume of the Irish Sea, of which 34% passed through on 3-4 February. Thus, while short term wind events generate significant strong fluxes through the North Channel of the Irish Sea, prolonged periods of along channel winds such as those observed throughout February 1994 are more significant for the longer term flushing of the Irish Sea.

Summary

The Irish Sea receives radioactive discharge from a nuclear reprocessing plant and material from the industrialised and densely populated northwest of England. Knowledge of the factors influencing the flow dynamics and flushing of the Irish Sea through the North Channel is essential for an understanding of the fate of Irish Sea contaminants and recruitment to fisheries. However, the harsh tidal regime in the North Channel region, with tidal flows approaching 1.5 m s^{-1} , makes direct observations difficult. Consequently, to understand the region, data have been combined with numerical simulations. The approach described here resolves the local detail of the circulation, incorporates the far field forcing and is computationally efficient.

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