CIRCULATION OF THE WESTERN IRISH SEA

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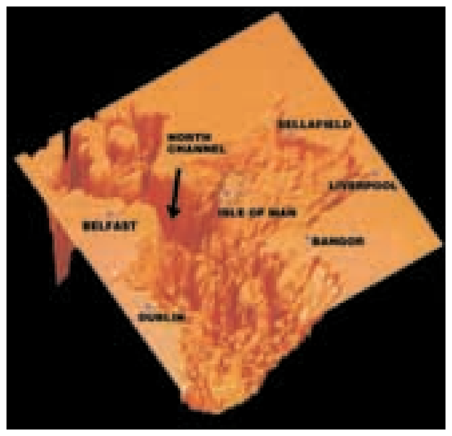
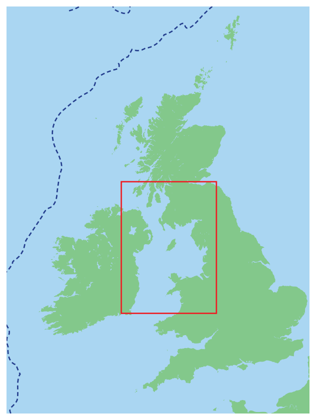
The circulation of the western Irish Sea has distinct seasonal regimes. During winter (October - April) the region is vertically mixed and residual circulation is largely dominated by wind forcing with a net long-term circulation weakly northward at 1 - 2 cm s^{-1}. A deep trough (> 100 m) extends along the length of the region and here tidal currents are exceptionally weak (< 30.0 cm s^{-1}) compared to the surrounding area where tidal amplitudes are of the order 100.0 cm s^{-1}. The combination of deep water and weak tides means the region stratifies during the spring and summer heating season (April - October) when there is insufficient tidally-generated turbulent energy to maintain vertical mixing against input of surface buoyancy. Until recently, conventional wisdom held that the mean summer circulation was also weak, with estimates that persistent cross frontal flows > 1 - 2 cm s^{-1} would displace tidal mixing fronts from their known fixed positions. The seasonal thermocline is located at 20 - 40 m and outcrops at the surface as a visible front. Isolated below is a dome of (cold) dense bottom water remaining from the previous winter. Significant baroclinic (density driven) circulations can be expected, and assuming the dome is static, the sloping density surfaces can only be maintained in geostrophic balance by cyclonic (anti-clockwise) surface layer flow.
A combination of observations, at high temporal and spatial resolution, and modelling have produced a remarkably detailed and consistent description of the circulation dynamics within the region. Data collected in 1994 and 1995 during mixed, stratified and transitionary stages demonstrates the dominance of density forcing in summer and wind forcing in winter.

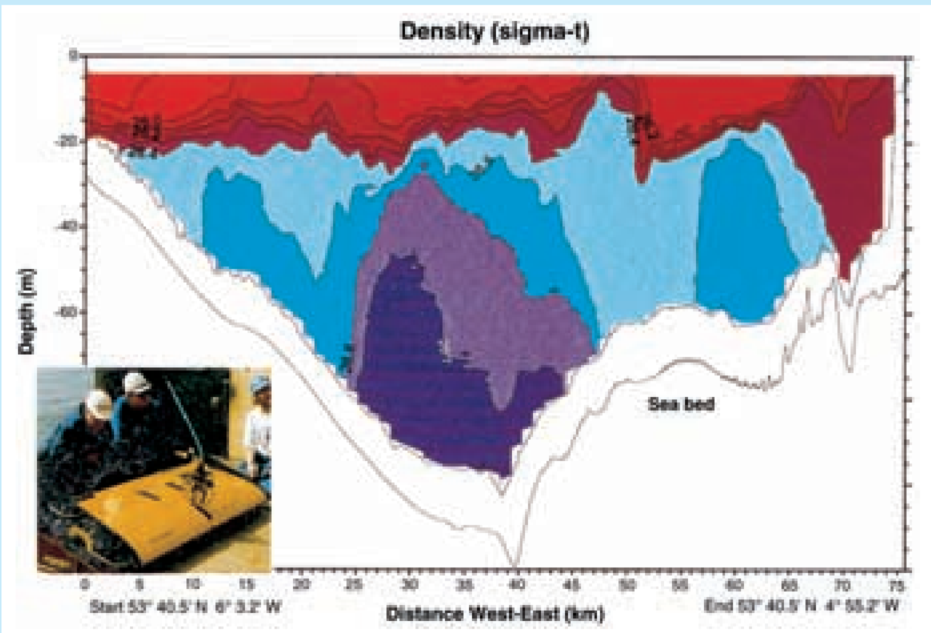
Irish Sea bathymetry

Relief map of the Irish Sea.West of the Isle of Man is the deep western Irish Sea basin, in which the low tidal energy regime helps maintain a deep muddy substrate.

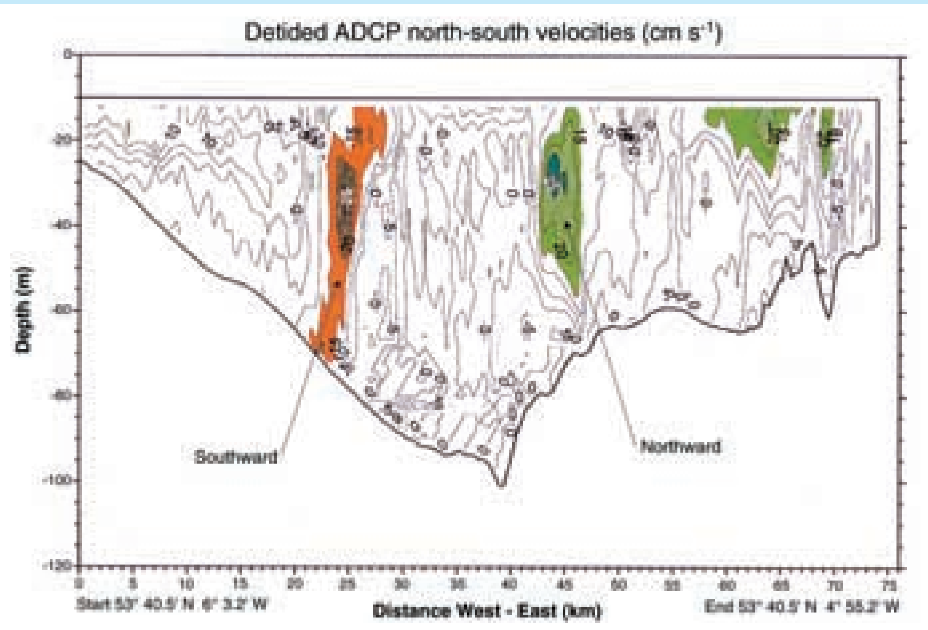




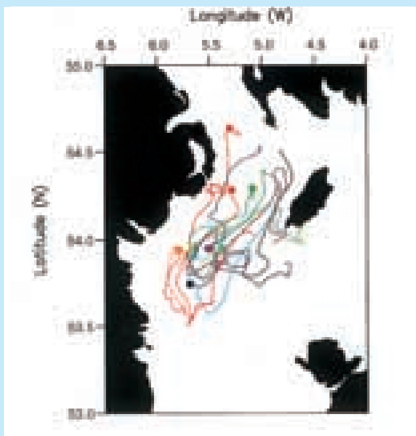
Density & velocity structure

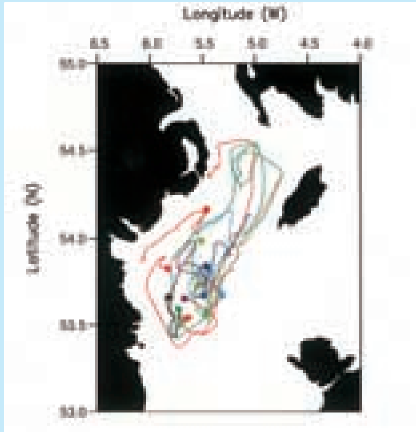


A west-east σ_t (kg m^{-3}) section (19 June 1994; above) obtained using Scanfish (a towed undulating vehicle with CTD; inset) illustrates the mixed surface layer, a strong temperature dominated pycnocline and the emergence of the isopycnals to the east marking the western Irish Sea front observed in satellite imagery. In the deep central basin is a dome of dense (cold) bottom water. A corresponding ADCP (153.5 kHz broad band acoustic Doppler current profiler) velocity section (below) provides convincing evidence that the dome is static, with intense southward and northward flowing cores associated with the western and eastern flanks, respectively. The sections are derived from raw data on a horizontal resolution of order 400 m.

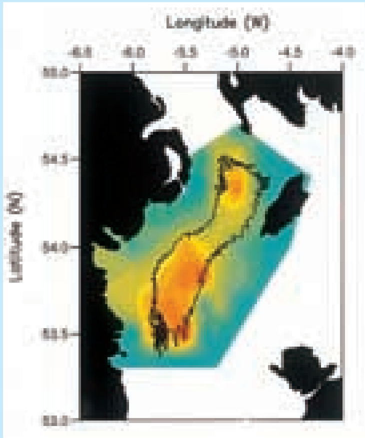


Regional Circulation

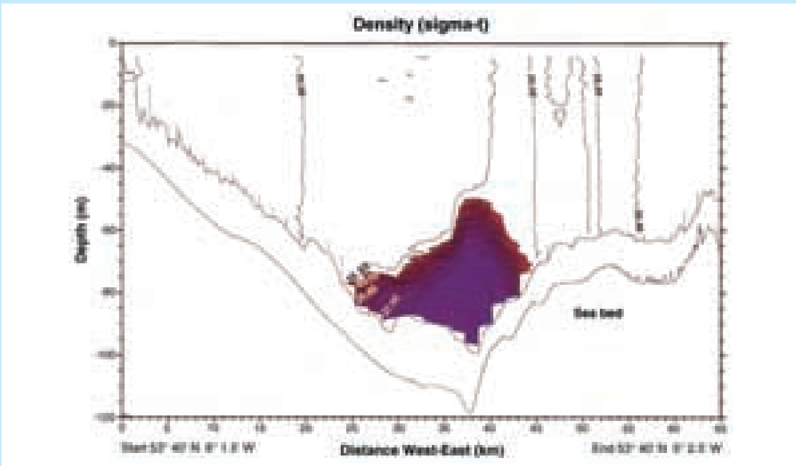


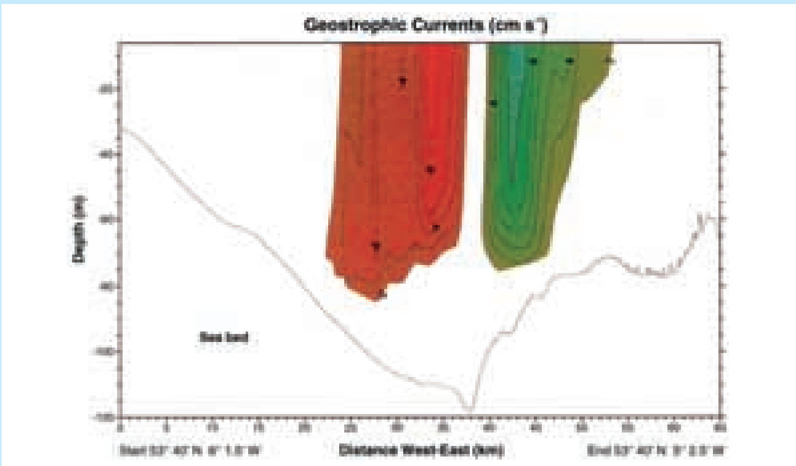


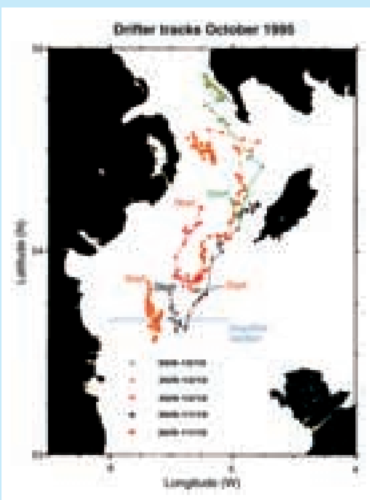
At the beginning of the heating cycle, salinity contributes to stratification and essentially mirrors temperature, particularly in the coastal zone. During this period (5 - 31 May 1995) the tidally filtered trajectories of 12 drifters, with holey sock drogues centred at 23 m, largely described a cyclonic circulation (upper left). With heating, density gradients sharpen and the intensified circulation becomes less 'leaky', as illustrated in a composite of 12 drifter trajectories (21 June - 17 August 1995; upper right). Solid circles represent release positions. The unfiltered trajectory of a drifter (21 June - 15 August 1995) superimposed on the potential energy anomaly field (ø), a measure of stratification, derived from a CTD grid (15 August) illustrates the strong correspondence between drifter track and ø (left). After 13 days of negligible movement (south west corner) the drifter travelled 340 km in 42 days, averaging 9 cm s^{-1}. Drifters circulate about the entire region and/or about either ø centre.



Autumnal Transition

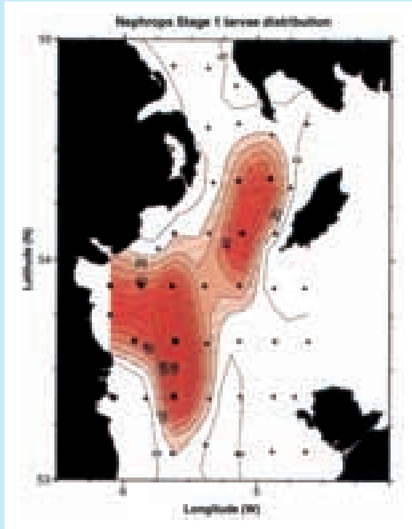


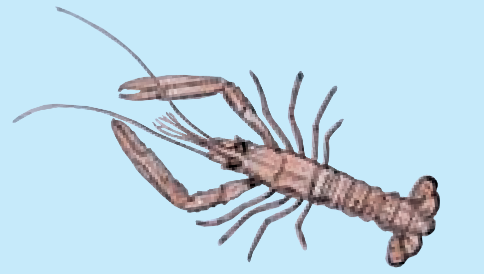




A Scanfish section (5 October 1995) during the autumnal transition to mixed conditions demonstrates the σ_t field (upper) after erosion of the surface thermocline. Dependent on meteorological conditions, the residual dome may last up to a month. The associated geostrophic velocities (middle) emphasise the crucial role of bottom fronts in determining circulation (red south flowing; green north flowing). Drifters deployed (30 September - 13 October) described a cyclonic circulation (left) almost in disregard of the strong winds. Conversely, the trajectories of a limited number of drifters during winter mixed conditions showed no evidence for cyclonic motion and were strongly influenced by wind.

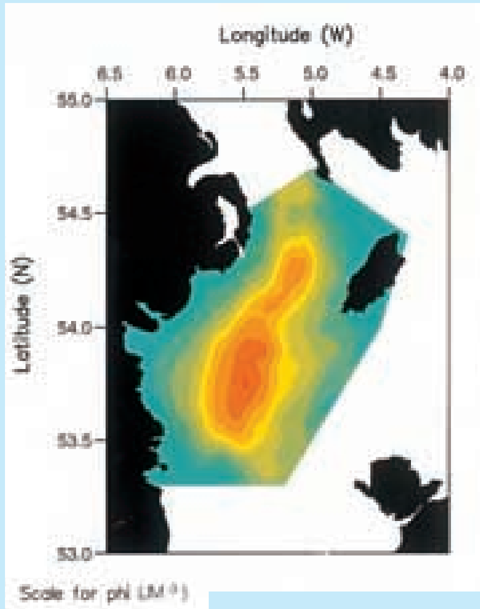
Retention

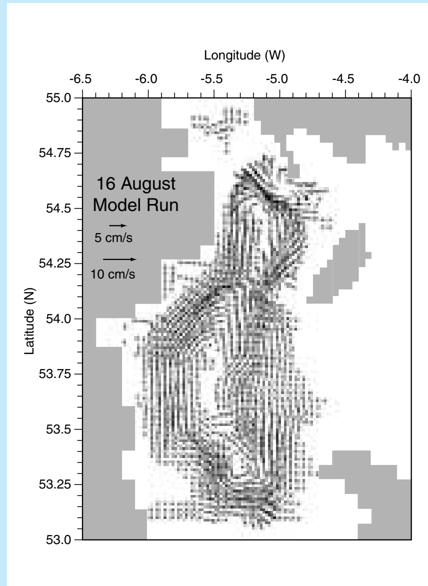




The isolated muddy substrate below the stratification is inhabited by Nephrops norvegicus (Dublin Bay prawn), a fishery worth £14.5m to the fishermen (1992 prices). In spring, larvae are released to the water column, spending 50 - 60 days in the plankton and confined to the upper 45 m. Subsequently, they must settle on the mud patch to survive. Larvae numbers correspond strongly to ø. Shown (left) are Stage I zoea (sampled by High Speed Tow Net; 16-19 May 1995) and an adult (right). The larvae can be considered to represent the distribution of contaminants if released in the area. Distribution of fish larvae show similar patterns.

Modelling





Organised baroclinic flows such as the gyre represent a challenge to numerical models. A fine resolution (3 km), semi-implicit version of the Princeton Ocean Model (Blumberg & Mellor, 1987) was developed for the Irish Sea, and it has reproduced the essential features of the seasonal circulation.
The model was forced with M_2 and S_2 tidal constituents at its open boundaries, and observed hourly winds and solar heating from 1995. The left-hand diagram shows the modelled stratification (ø) in mid-July; the spatial pattern and strength agree well with observations. The right-hand diagram shows residual currents from the model (i.e. after removal of the tide and wind-driven components) greater than 2 cm s^{-1} for 16 August 1995. The currents have been taken at a model level corresponding to the drogue depth of the drifters. The spatial extent of the gyre and the multiple recirculation paths are reproduced. Mean modelled residual current around the gyre was 8 cm s^{-1} with a maximum of 18 cm s^{-1} to the west of the Isle of Man, the latter equating to the mean drifter speed at this location.

Management implications

A sound knowledge of circulation is necessary for sensible and informed management of coastal seas and the balancing of competing demands. For example, the western Irish Sea is an important spawning ground for fisheries, yet historically the region has been viewed as a convenient dumping ground: munitions in the North Channel, sewage sludge in Liverpool Bay and the North Channel and radionuclides from the Sellafield nuclear reprocessing. Recently oil and gas extraction has become important and leisure demands are increasing.

The recent recognition of the gyre circulation emphasises that our understanding of coastal transport processes is far from complete. Here, progress has been made through improved technology together with the application of realistic models, which for the first time replicate the water column structure and circulation. Such an approach will form a key environmental management tool.

Further Reading:

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