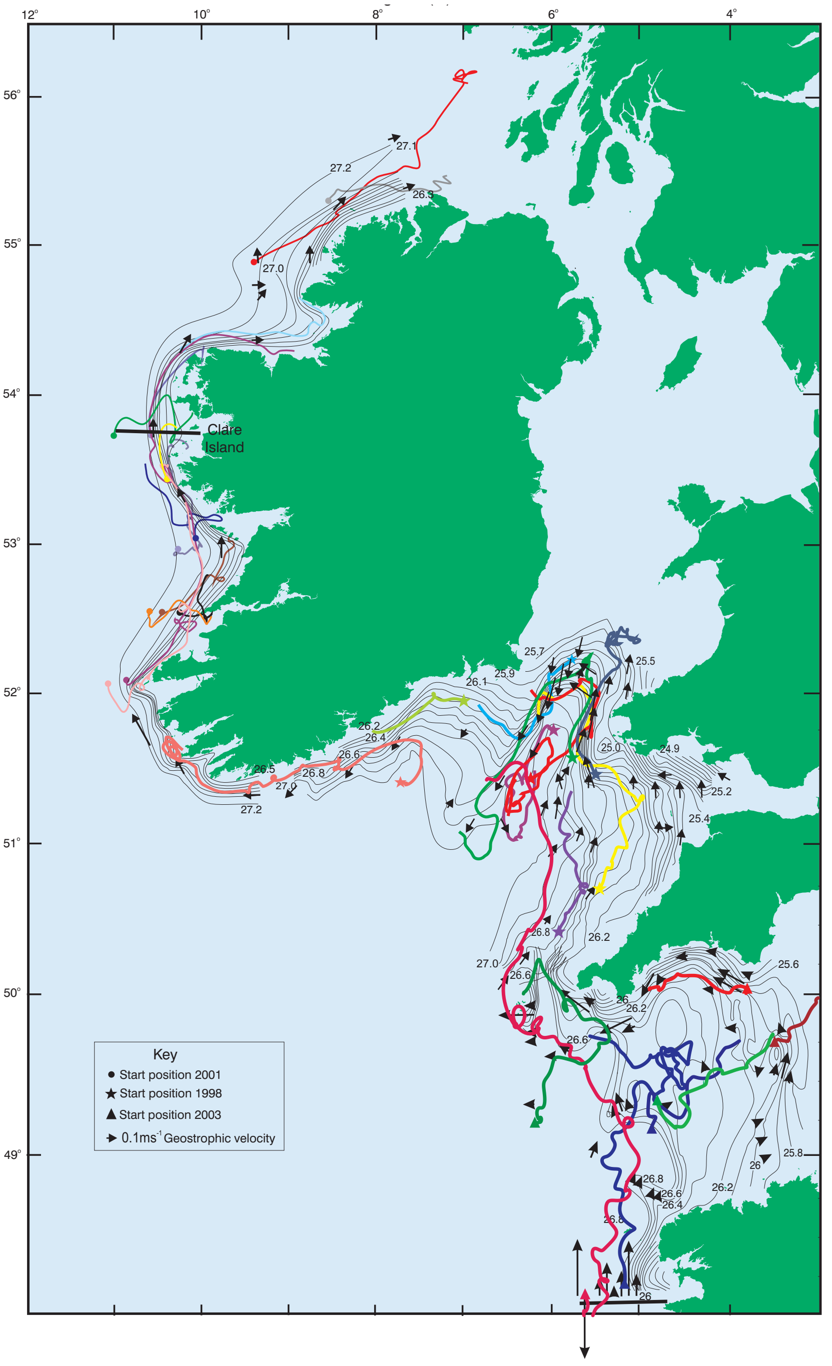
Understanding the UK's seas: marine pathways and oceanographic structure

As a contribution to the vision for clean, healthy, safe, productive and biologically diverse seas, key questions for this project were:

defra
Department for Environment Food and Rural Affairs

Cefas



Where are the major marine transport pathways?

Why are they there, and how are they driven?

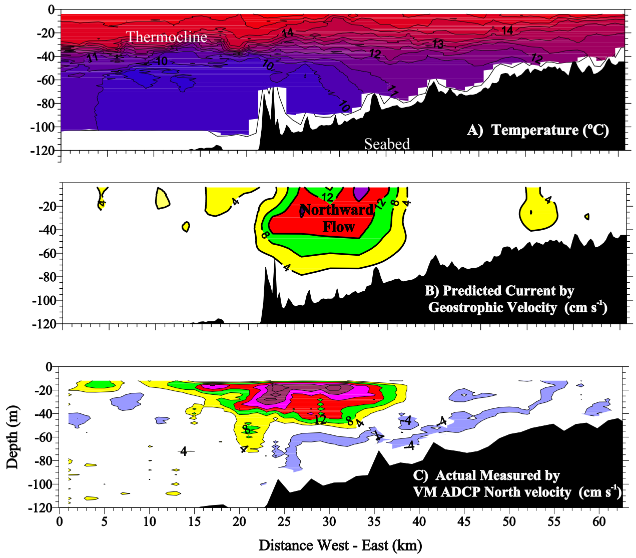
What is the role of pathways and oceanographic structure in the function of the UK shelf (shallow) seas.

Where?

From early summer (late May) to autumn (mid October), a continuous oceanographic pathway exists from the NW Brittany (Ushant), across the Western English Channel, south along the Cornish coast, around the Lizard Peninsula, along the N Cornish and Devon coasts, across St. Georges Channel, and then around the SW and W coasts of Ireland. These flows occur at the boundaries of the stratified regions and have significant magnitude, of ~0.1 – 0.2 x 10^6 m³/s. Such transport remains within its source eco-hydrodynamic region, and the pathway acts as a barrier to limit transport between neighbouring eco-hydrodynamic regions (e.g. stratified to mixed). For example, summer transport between the Celtic Sea and the Irish Sea is very limited, while there is strong transport across their boundary (St Georges Channel), There is thus limited potential for transport of plankton across these pathways, but high potential for transport along them of harmful species such as *Karenia mikimotoi.*

Northward transport from Brittany to Scotland. The combined pathway from the results of three field programs, with ARGOS drifter tracks overlain on the contours of bottom density. Each colour indicates a separate drifter track.

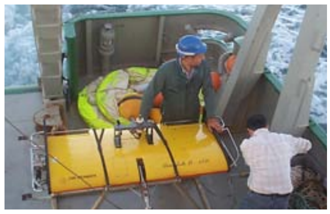
How?: The flows are driven by temperature differences



Section from Clare Island west of Ireland, showing: A) temperature structure, revealing the thermocline (maximum vertical temperature gradient) and the bottom front, (maximum horizontal gradient B) the speed of the inferred northward flow, estimated from the temperature data, C) the measured northward flow.

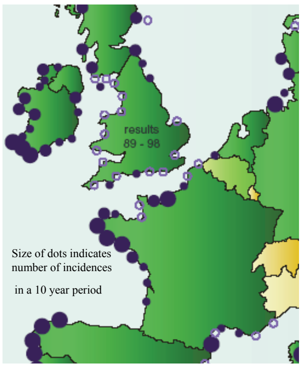
The density of water is primarily determined by temperature, when two different water masses are adjacent then the warmer will attempt to flow over the colder. However the rotation of the earth acts to deflect the flow to the right of the initial flow direction. Friction with the sea bed means that speeds near the bed are small, so that the fastest flows occur above the region where the bottom gradients in density (temperature) are strongest.

The towed undulating 'Scanfish' (yellow wing) measures continually temperature, salinity, fluorescence, light, and turbidity.

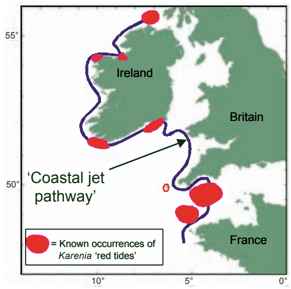


What is the role? Do Plankton use this pathway? Yes, many species including Harmful Algal Bloom (HABS) species are prevalent along these pathways

HABS come in various forms; some species produce massive blooms ('red tides', e.g. *Karenia mikimotoi*) and others are toxic at low concentrations (e.g. *Dinophysis*). Most occurrences of *Dinophysis* lie along the regional transport pathway, which provides favourable conditions for growth, primarily caused by strong stratification.

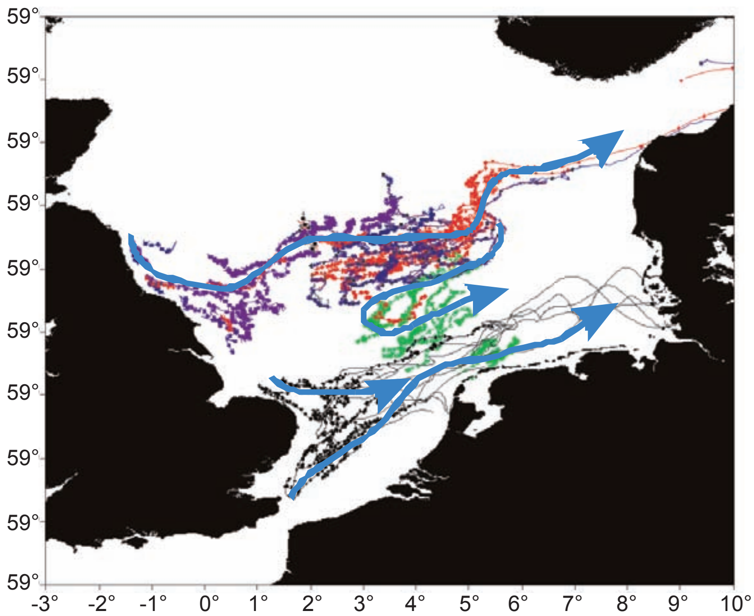


Incidence of Diarrheic Shell Fish Poisoning (DSP) due to the dinoflagellate Dinophysis.



Regular occurance of Red tides due to Karenia mikimotoi.

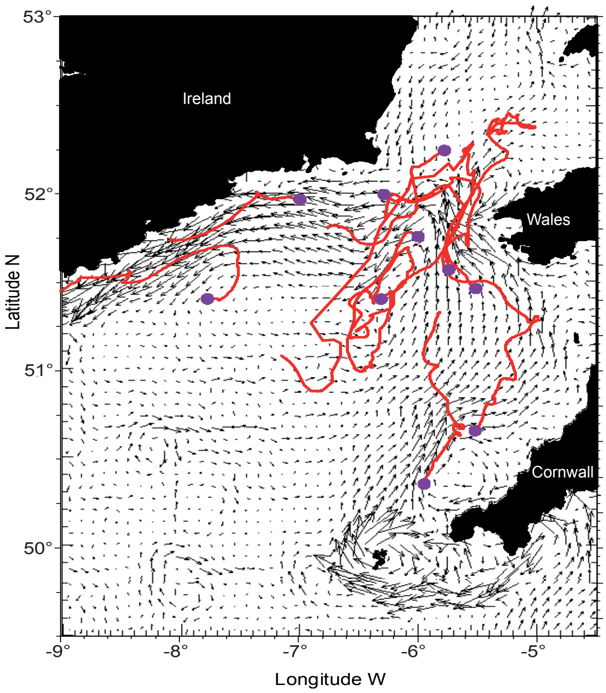
Where: Oceanographic pathways in the North Sea



In the North Sea, in summer, strong (12 cms^{-1}) organised flows exist from the NE English coast (i.e. North of the Flamborough front), past the northern edge of the Dogger Bank and NE to the Skaggerak. There are also strong flows (10 cms^{-1}) directed SW along the southern flank of the Dogger Bank. This flow continues anticlockwise around the edge of the stratified region at the south of the Oyster Grounds and in summer, acts to contribute to isolation of the bottom waters there. This isolation, coupled with the relatively shallow depth (and associated productivity), means that oxygen depletion is likely in the bottom waters.

Drifter tracks in the central and southern North Sea. Large blue arrows indicate the main pathways. Dots mark the daily positions.

Why and how: using models to understand the system



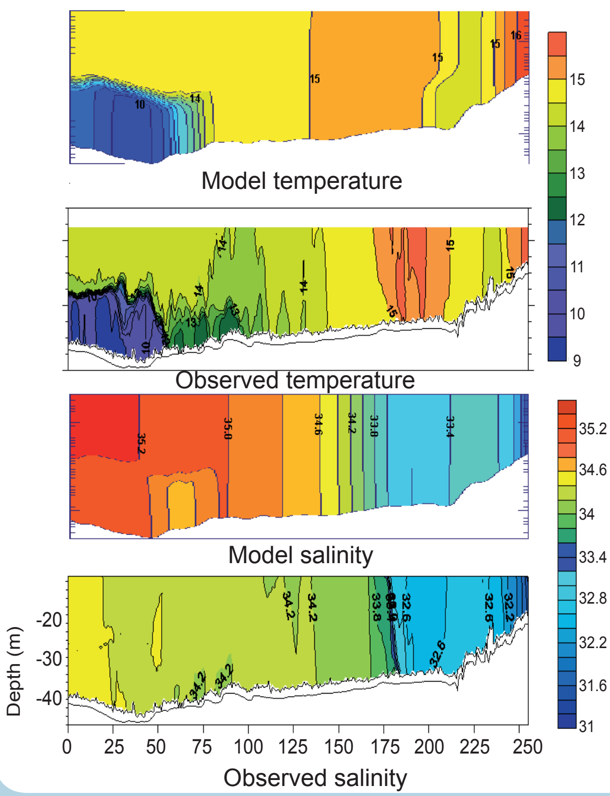
Measured water movement (red lines) and modelled flow (black arrows) for the Celtic Sea in July 1998. The model replicates well the observed flow from the Cornish coast north to the Gower Peninsula, and west across St Georges Channel towards the SE coast of Ireland. Density (temperature) gradients at the bed are responsible for over 90% of this flow (Young et al., 2004).

Drifters like this one, with an orange surface marker and a large 'sock' beneath, are tracked by satellite to map water movements.

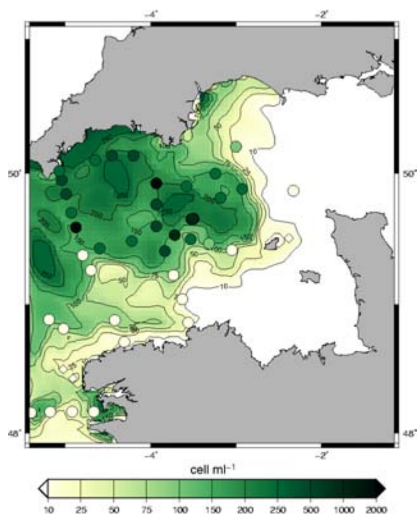
How good are models

Good – Most modern 3-D baroclinic models, which include density, replicate measured surface and bottom temperatures typically to better than 0.5°C (1 SD) which is sufficiently accurate for the simulation of many ecological processes. Principle features of the flow fields in the Celtic and North seas are well replicated by the Cefas models (as do many other models).

Room for improvement – Many models, (Cefas GETM, POLCOMS, COHERENS) indicate that freshwater inputs are underestimated, for example, in the German Bight, where although the horizontal structure is well replicated, the modelled absolute values of salinity are too high.



Observation and model comparison



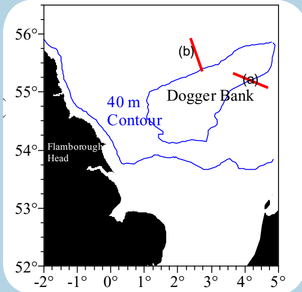
Observation versus Model comparison. Contours of Karenia modelled by Ifremer, with dots of observed values from Cefas/ Irish survey. Results indicate that the bloom is due to the strength of stratification and reduction in mixing, rather than supply of nutrients (van Houtte Brunier et al., 2006).

What is the role: Structure of the North Sea. Why is there high primary productivity plant growth?

In summer, the central and northern North Sea become thermally stratified, because the surface water warms up more than the bed. In contrast, due to the strong tides the southern North Sea remains well mixed. New estimates indicate that in the whole of the North Sea, 38% of the growth of new phytoplankton (plankton that utilise sunlight to grow) occurs in summer along the thin boundary at the base of the warm surface waters, the 'thermocline'. Growth is concentrated here because of favourable interactions between sunlight, the supply of nutrients, tides and shape of seabed. Also, phytoplankton growth is sustained here for a much longer period than occurs in the spring (the 'spring bloom') and so forms a reliable food source to support organisms further up the food web. The phytoplankton growth is at depth, so is not visible from satellite observations.

Average primary productivity, integrated over the entire water column (mg of Chl/m²/day) for different regions along a transect north of the Dogger Bank (line b). SML = surface mixed layer, CM = deep chlorophyll maximum and BML = bottom mixed layer.

Area Type	Entire Water Column	SML	CM	BML
	mg of Chl/m²/day	%	%	%
Stratified (N)	741	35.1	57.8	7.1
Frontal (~40 m contour)	1015	44.8	-	55.2
Bank (S)	456	38.1	-	61.9

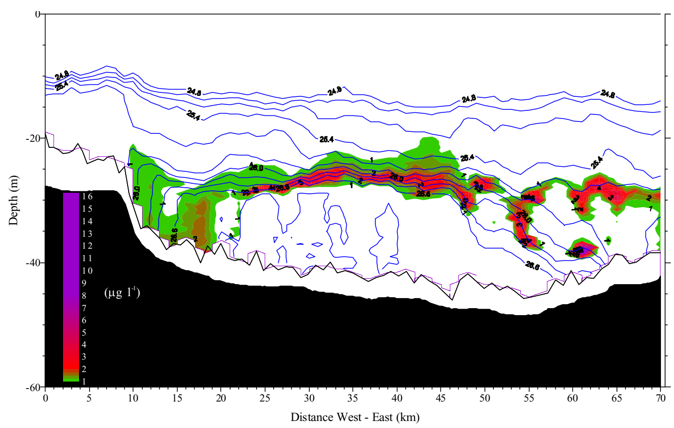


This project has demonstrated that in the stratified regions, many nutrients, such as nitrates and ammonia, are used up very quickly in summer, and are recycled within the system very rapidly (Weston *et al.*, 2005). Recycling times are ~7 days in much of the warm surface waters, and as rapid as ~1 day along the thermocline itself. As a result, even though the summer transport pathways are long and fast, the direct transport of dissolved nutrients from the NE English coast to the central and southern N. Sea is unlikely.

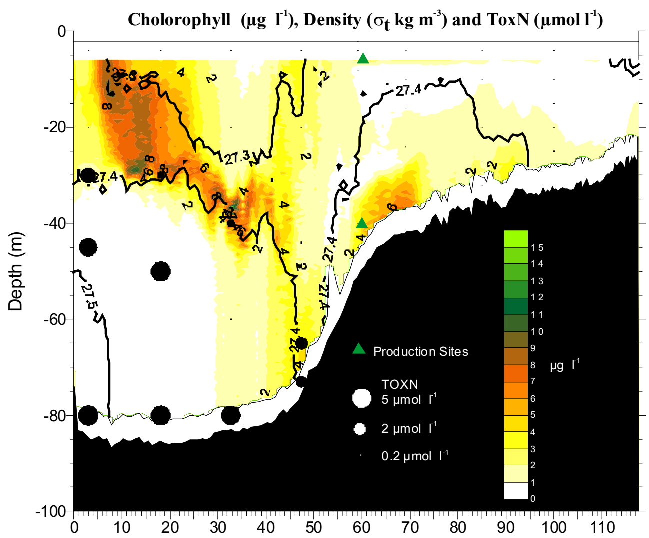
Away from these summer pathways, nutrient transport is much slower, for example, in the stratified regions, most nutrient transport is probably as particles, and the transport mechanisms are relatively weak and slow. In contrast, in well-mixed regions, the cycling of nutrients is much slower (Weston *et al.*, 2004) so that significant transport of dissolved nutrients can occur, even where net flows are weak.

Nitrate 'turnover times' (days) for in situ concentrations and for a standard concentration of NO_3 of 5 mmol/m³, for the southern N. Sea (well mixed) and north of the Dogger Bank (stratified)

	August
Well-mixed waters - *In situ* concentrations	13 ± 17
NO_3 at 5 mmol/m³	
Well-mixed waters	100 ± 54
Stratified waters - Surface	7 ± 14
Stratified waters - Chlorophyll max.	< 1



Chlorophyll (µg/l) and density (σt kg/m³) for a section across the Oyster Ground (line a) in August 2001. Note the three layer system and high levels of productivity at the base of the second layer. Here, in contrast to the diatom-rich spring bloom, the productivity at depth consists mostly of dinoflagellates, which thrive in relatively stable, low-energy environments.

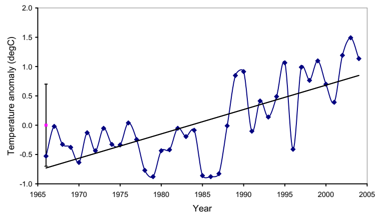


Section from North of the Dogger Bank (line b) 28th April 2005, showing high productivity at the surface and subsurface, with high concentrations of available nutrients in the deep waters beneath the pycnocline (thermocline).

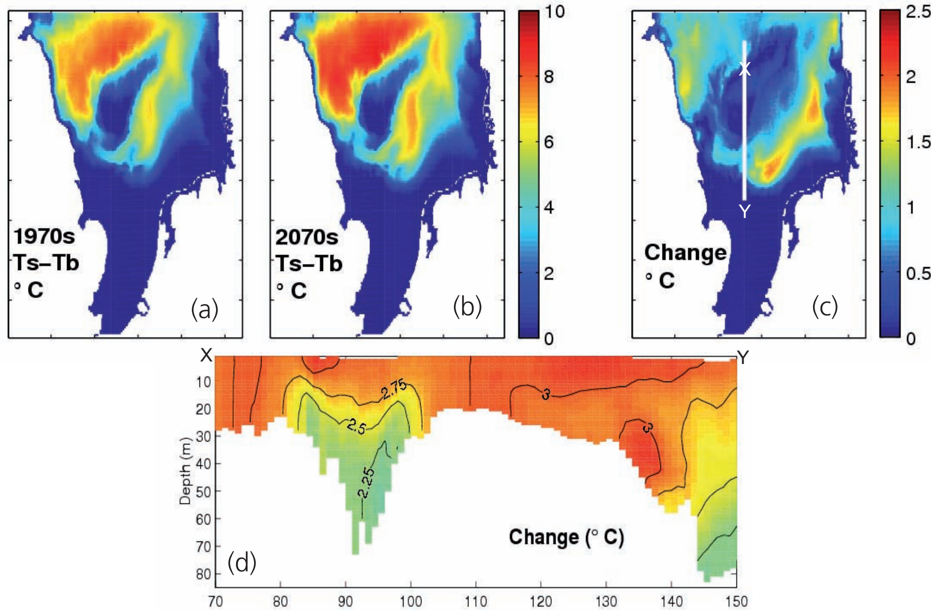
As early as mid April, productivity at depth can be greater than at the surface. Productivity experiments from one pair of stations demonstrate that the greatest productivity occurs at depths of ~40 m.

The future: some potential impacts of climate change on the UK shelf seas

Plankton are the base of the marine food web, and in UK waters, seasonal stratification is a key factor controlling the timing, location and nature of the growth of plankton. In a few decades from now, summer stratification in areas of the North and Celtic Seas could last up to 40 days longer, as well as being stronger (by about 1-2°C) so that more plankton will be produced. These changes are likely to be greatest at the boundaries between stratified and well-mixed waters, such as in St Georges Channel in the Celtic sea and in the southern N. Sea.

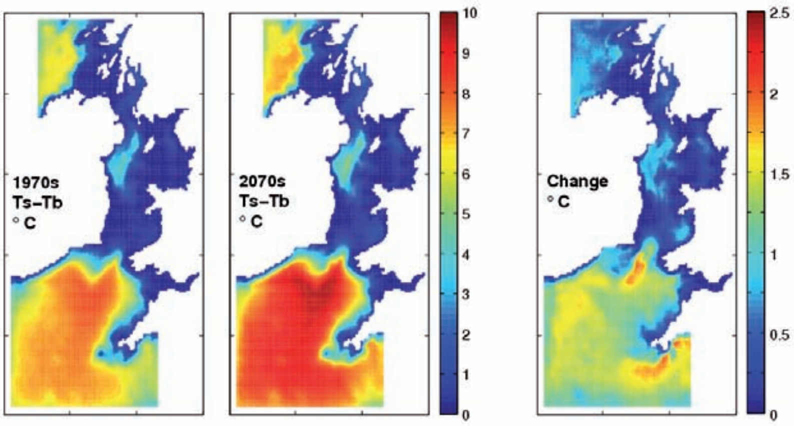


An example of changing temperature in UK coastal waters. Observations of annual mean sea temperature anomaly since 1966 at Southwold (source, UK Coastal Temperature Network). There has been a 1.5°C rise over this 40-year period, with regular inter-annual changes of 0.5-1.5°C. Note also the 'shifts in state' which occurred around 1988. Error bar on left-most point indicates the standard deviation of the dataset presented.



Modelled change in thermal conditions in the North Sea: a) September stratification (temperature difference between surface and bottom waters, Ts-Tb, °C) for a (1970s) climate and b) for 100 years further forward (2070s). The model uses weather conditions predicted by the Hadley Centre for a climate under a medium high emissions scenario (SRES-A2). c) The change in stratification, where positive values indicate enhanced stratification. d) Cross-section X –Y shows the September temperature difference.

The Celtic Seas

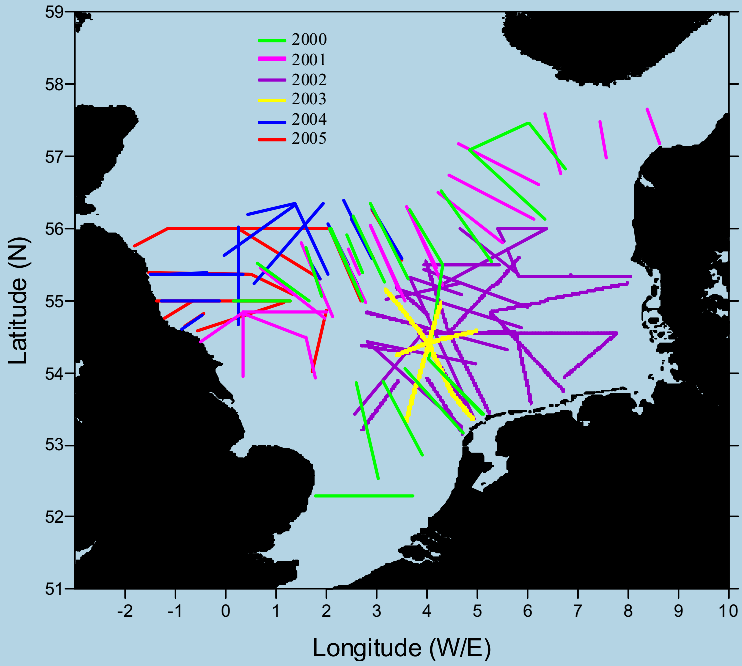


Modelled change in thermal conditions in the Irish and Celtic Seas, for August (see figure caption above). Enhanced stratification results in an increase in oceanographic stability, which enhances the potential for large blooms of certain harmful algal species (HABs). Stratification may last 10-30 days longer, which might increase the total amount of plankton growth in the western Irish Sea. Combined with this region's relative isolated character, this may lead to more incidences of low oxygen concentrations in waters near the sea bed. The western Irish Sea has a significant Norway Lobster fishery (Nephrops norvegicus), and while adults can cope with a wide range of environmental variation (except severe oxygen depletion <2 mg/l) juveniles may die at relatively mild levels of oxygen depletion (< 5 mg/l), so that this fishery will probably be at increased risk.

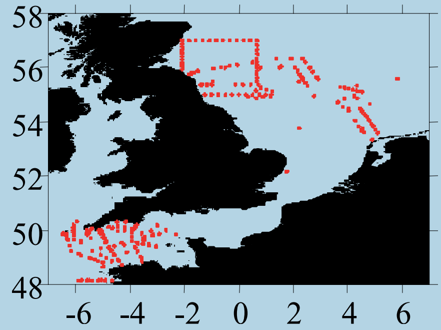
Data collected and publications

Results from the Defra funded project - Towards a consensus concerning the extent, strength and persistence of pathways governing the fate of contaminants and nutrient dynamics, AE1225.

High resolution CTD - Sections (scanfish)
Showing coverage from 2000–2005



Position of CTDs



Summary

In the North Sea 13000 km of scanfish towed undulating CTD, including calibrated Fluorescence, Turbidity and Light. 404 CTD Profiles 15 ADCP Moorings, 7 Thermistor chain moorings, 58 Argos Buoy deployments and 20 cores.

Major Collaborations

The Marine Institute for Ireland provided the *RV Celtic Voyager*, for work off the west coast of Ireland.
The Martin Ryan Institute, Galway, Ireland.
Climatic Research Unit, UEA.
School of Environmental Sciences UEA.
Ifremer, Brest, France.
Department of Earth Sciences, University of Liverpool.
Royal Netherlands Institute for Sea Research - NIOZ, Texel, The Netherlands.
British Oceanographic Data Centre

Selected publications derived from this project

i) Peer-Reviewed Journals

Aldridge J. N., in press, Simple analytical results for bedload transport due to tides. Proc. Roy. Geological Soc.

Aldridge J.N., submitted, On the mechanisms for net tidal transport of suspended sediment. Continental Shelf Research.

Brown, J., Carillo, L., Fernand, L., Horsburgh, K.J., Hill, A.E. and Young, E.F., 2003. Observations of the physical structure and seasonal jet-like circulation of the Celtic Sea and St. George's Channel of the Irish Sea. Continental Shelf Research, 23, 533 - 561

Brown, J., Fernand, L., Horsburgh, K.J., Hill, A.E. and Read, J.W., 2001. PSP on the east coast of the UK in relation to seasonal density-driven circulation. Journal of Plankton Research, 23, 105 - 116.

Carillo, L., Souza, A., Hill, A.E., Brown. J., Fernand, L and Candela, J., 2004, De-tiding ADCP data in a highly variable shelf sea: The Celtic Sea. Journal of Atmosphere and Oceanic Technology, 22, 84- 97.

Eaton, D.R. Brown, J. Addison, J.T. Milligan, S.P. and Fernand L.J.,2003, Edible crab (*Cancer pagurus*) larvae surveys off the east coast of England: implications for stock structure. Journal of Fisheries Research, 1-3, 191-199

Fernand, L. Nolan, G.D. Brown, J, Raine, R., Chambers, C.E., Dye. S.R and White, M., in press, The Irish coastal current: a seasonal jet-like circulation. Continental Shelf Research.

Kelly-Gerreyn, B.A., Hydes, D.J. Fernand, L.J. Jégou, A.M. Lazure, P. and Puillat, I., in press, Low salinity intrusions in the western English Channel and possible consequences for biological production. Continental Shelf Research.

Vanhoutte-Brunier, A Fernand, L., Menesgun, A., Lyons, S., Gohin, F. and P. Cugier (submitted) Modelling the *Karenia mikimotoi* bloom that occurred in the western English Channel during summer 2003. Journal of Ecological Modelling.

Weston, K, Fernand, L, Mills, D.K, Delahunty R. and J. Brown, 2005, Primary production in the deep chlorophyll maximum of the northern North Sea. Journal of Plankton Research, 27, 909 - 922.

Weston, K, Jickells, T.R, Fernand L. and Parker E.R. 2004 Nitrogen cycling in the southern North Sea: consequences for total nitrogen transport. Estuarine, Coastal and Shelf Science, 59, 559 – 573.

Young, E.F., J. Brown, J.N. Aldridge, K.J. Horsburgh and L. Fernand 2004 Development and Application of a Three-Dimensional Baroclinic Model to the Study of the Seasonal Circulation in the Celtic Sea Continental Shelf Research 24, 13 – 36.

ii) Book Chapters and Theses

Larcombe, P., in press . Continental Shelf Systems. In: Environmental Sedimentology. Eds. Perry, C. & Taylor, K . Blackwell Scientific Press.

Nolan, G., 2004, Observations of the seasonality in hydrography and current structure on the western Irish Shelf. PhD Thesis, University of Galway, Ireland, 198pp.

Van-Houtte Brunier, A., in prep., Modelling the life history of *Karenia mikimotoi* with comparison to observation. PhD Thesis, Ifremer.

Lyons., S., in prep., The relationship between the physical structure and the phytoplankton dynamics in the Celtic Seas. PhD Thesis, University of Galway.

Badin G., in prep., Cross-frontal eddy transfer between well-mixed and stratified waters. PhD Thesis, University of Liverpool.