Ocean climate variability on the western Irish Shelf, an emerging time series.

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Abstract
In an attempt to fill the gap in long-term hydrographic measurements between the well-established sections off Iberia and in the Northern Rockall Trough, Ireland has initiated several standard oceanographic sections in southern Rockall Trough and on the western Irish shelf.

The continental shelf west of Ireland is exposed to the open Atlantic Ocean. Fresh water discharges from Irish rivers and those further afield (eg. Loire, Severn) interact with Eastern North Atlantic Water on the Irish shelf to produce the observed circulation pattern. Summer CTD measurements have been made along a section at 53° North on the western Irish shelf since 1999. A long-term gridded climatology is used to discern the mean conditions along this section and anomalies are calculated for the period.

Warmer conditions were observed along this section in 2003 and 2004, broadly consistent with other regions of the NW European shelf while cooler conditions were observed in 2001 and 2002. Salinity also exhibits strong inter-annual variability along this section depending on the timing and magnitude of discharges from Irish rivers and rivers in the UK and France. Fresh conditions observed in 2001, 2002 and 2005 are linked to strong discharges from the Loire and Shannon rivers.

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Introduction

The Western Irish Shelf is defined as the area of the continental shelf to the west of Ireland between latitudes 52° and 54° N extending westward to the 200m depth contour at the Irish shelf break (see Figure 1). Some work has focussed on the Western Irish Shelf in recent years to discern the dominant physical transport pathways and water column structure in the region. Hydrographic sections, current meter deployments and satellite-tracked drifter releases were undertaken by Nolan (2004) to observe the density structure of the water column in this region. While the presence of an Irish Shelf Front (ISF) had previously been discussed (Huang et al. 1988, Raine and Mc Mahon 1998) as a haline feature along the entire west coast of Ireland, the 2004 study showed that the key feature of the late Spring to Autumn circulation was the formation and persistence of bottom dominant fronts (Garrett and

Loder, 1981). These fronts form at the boundary between well-mixed waters inshore and stratified waters offshore. Mid-water flows of 20-25 cm s-1 have been observed on the western Irish Shelf and into the Celtic Sea (Fernand et al. 2006, Brown et al. 2003), flowing in a clockwise sense around the south and west coasts of Ireland.

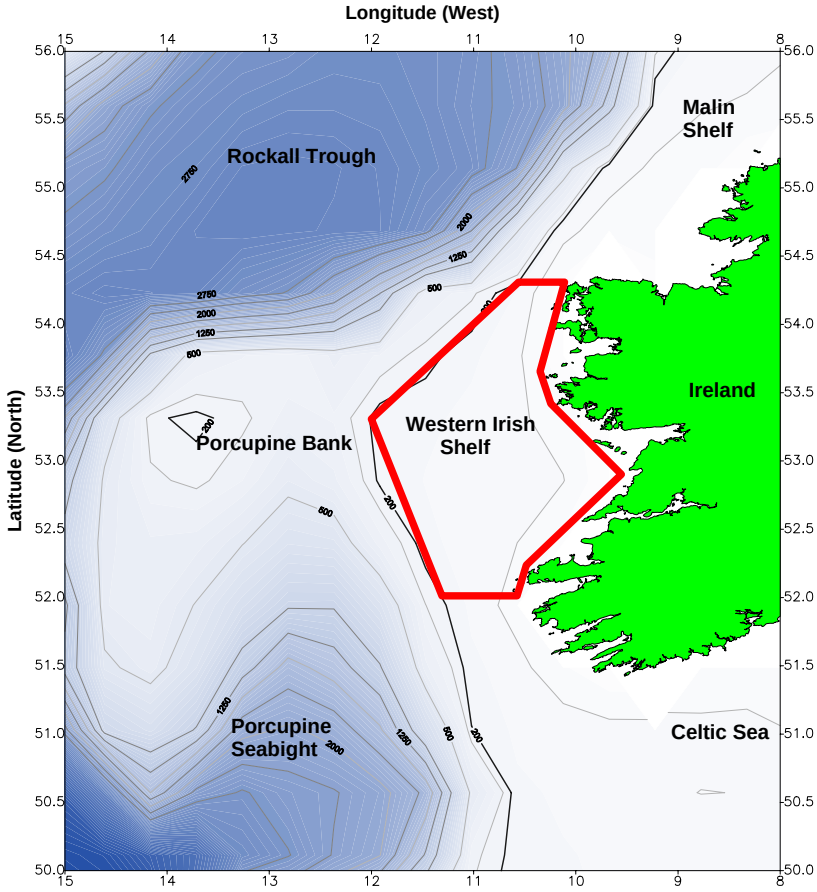


Figure 1 The sea area west of Ireland including the western Irish shelf (red polygon)

An interest in defining seasonal and interannual variability in the location and persistence of these fronts and increased Irish participation in the ICES Working Group on Oceanic Hydrography (WGOH) has led to the establishment of several standard sections to the south and west of Ireland that are repeated at least yearly.

This paper considers results from a hydrographic section at 53° N conducted since 1999.

Methods

The research vessel Celtic Voyager was used to conduct Conductivity, Temperature, Depth (CTD) sections along 53° N each summer since 1999 (Figure 2). A Seabird Electronics SBE 9/11 CTD was used on all occasions to conduct profiles along the section with typical station spacing of 6 nautical miles. Following post-processing and calibration, the data are gridded and plotted using Matlab 7.1.

Comparison of the data with a long-term gridded climatology (World Ocean Database 2001 (WOD01)) is made to derive temperature and salinity anomalies from the long-

term mean. Data from various local and far-field rivers has been provided by ESB (River Shannon), HR Wallingford (River Severn) and the French Hydro database (River Loire).

Long-term sea surface temperature data is provided by the Irish Met Service (Met Eireann). A gridded subset of the ECMWF ERA40 meteorological data set is used to examine changes in wind conditions and storminess over the 1960-2000 period.

Results

The principle results presented herein detail the water column structure along a hydrographic section at latitude 53° N, shown in figure 2 below. The station at Malin Head (Ireland's northernmost point) from which the extended sea surface temperature record is presented, is also shown.

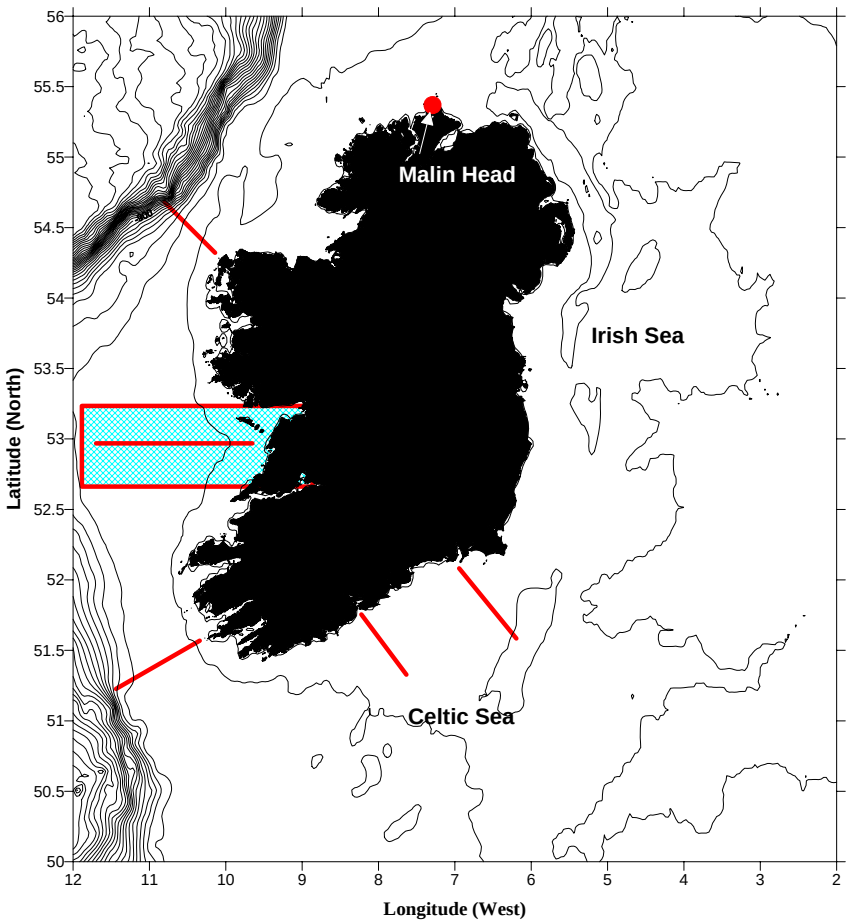


Figure 2 Shelf standard sections west of Ireland. The 53°N section is shown as a line within the blue box.

General structure along 53°N section

In June 2000 the section at 53° N received very detailed coverage with an average spacing between CTD stations of two nautical miles. These data are used to show the general structure along the section.

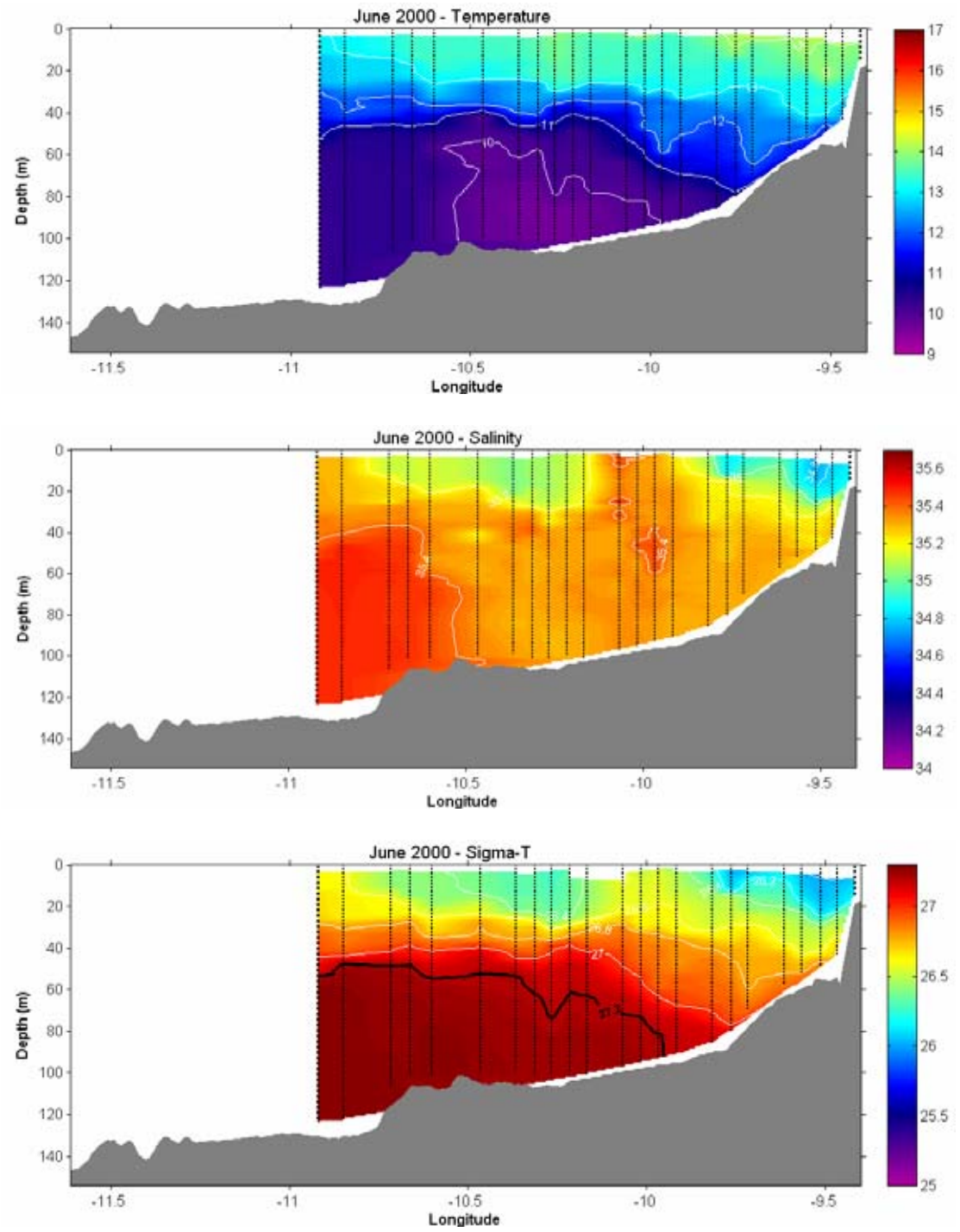


Figure 3 The 53°N section in June 2000 showing temperature (upper panel), salinity(middle panel) and density (lower panel).

The water column exhibits thermal stratification in the upper 40m of the water column . The stratified water overlies a relatively cold pool of water (<11°C) isolated below the seasonal thermocline (figure 3, upper panel). The salinity structure (figure 3, middle panel), shows the influence of river discharges in the coastal band from the

river Shannon. There is also a low salinity patch of water in the upper 30m of the water column offshore of the near coastal discharge. More saline water of Atlantic origin splits the two fresher patches in the upper water column and dominates the lower water column along much of the section. This deeper more saline water has the characteristics of Eastern North Atlantic Water (ENAW), (Harvey, 1982) and frequently encroaches this section from the Atlantic.

While salinity contributes to the observed density structure (figure 3, lower panel), it is primarily temperature that makes the strongest contribution to the density structure along 53°N. A band of water nearer the coast remains better-mixed compared to the water offshore which is strongly stratified and a gradient in density forms near the seabed between the mixed coastal water and the stratified water offshore. This results in the formation of a bottom dominant front (Garret and Loder, 1982) which drives a geostrophic flow from south to north through this section at mid-water depth. This front is a persistent feature of the circulation in both the Celtic Sea and along the western Irish shelf. It is important in transporting particles (eg. phytoplankton, pollutants) through this region (O'Boyle et al. 2001). Quantifying any variability in frontal location and strength is a key element in predicting Harmful Algal Blooms and recruitment to important sea fisheries.

Variability in freshwater fluxes

The 53°N section is influenced by fresh water inputs to the western Irish shelf both locally (eg. river Shannon) and from further afield (eg. river Severn and Loire) and by the encroachment of ENAW with a salinity typically >35.3 from the NE Atlantic ocean . It is the interplay of the ENAW with the coastal discharges (local and far-field) that establishes the hydrographic structure of this region.. Well established water gauging stations are established for many European rivers. From the historical records it is possible to establish how variability in the discharge from a particular source affects the western Irish shelf. Of particular interest is the timing of peak discharges from rivers.

Figure 4 shows the discharges from the river Loire in France, the Severn in the UK and the river Shannon in Ireland. The Loire contributes approximately 5 times the volume of freshwater to the NW European shelf than the river Shannon. There are differences in the timing of large discharges from all 3 rivers, related to the precise tracking of atmospheric depressions and the associated rainfall into particular river catchments. In order to demonstrate the effect of local and far-field freshwater inputs to the 53°N section we focus on data in 2001 and 2002.

In August 2001 there is a minimal influence of ENAW (salinity >35.3) on the section (figure 5). The section exhibits a negative salinity anomaly (figure 5, lower panel) throughout the entire water column reflecting in our view the influence of the strong Spring peak discharges from the Loire river (>6,000 x 10^6 m3 s-1) in early 2001. The peak discharges from the Severn and Shannon leading into 2001 occurred much earlier in the year (November 2000-January 2001) and have most likely been advected through the 53°N section by August 2001.

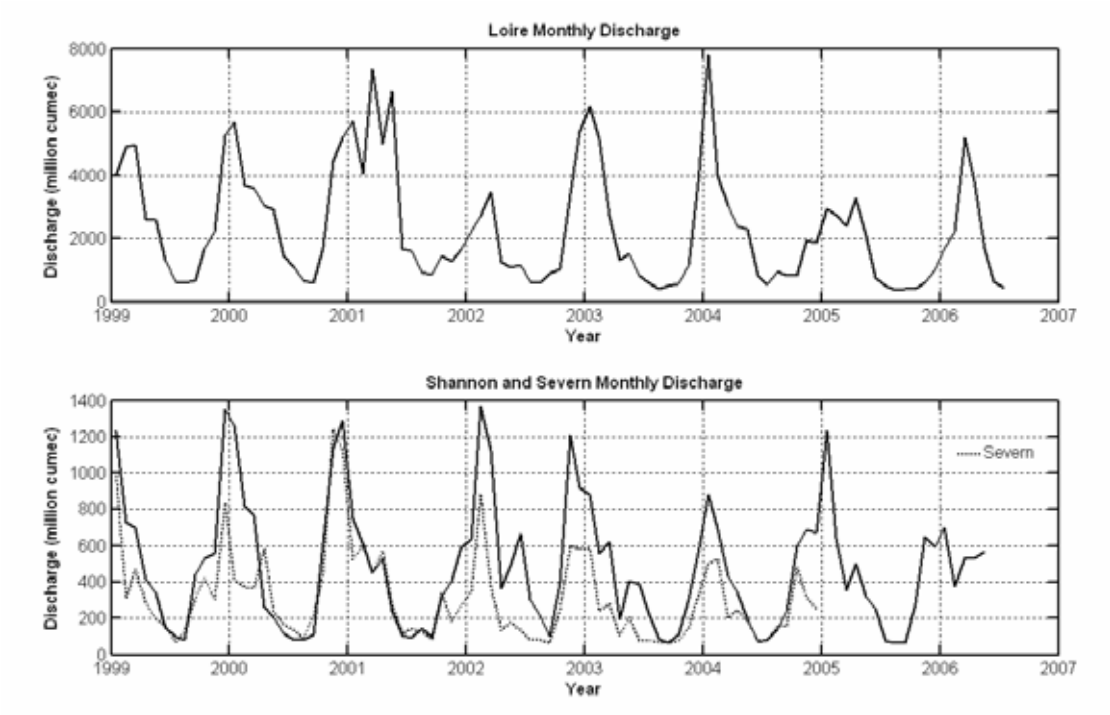
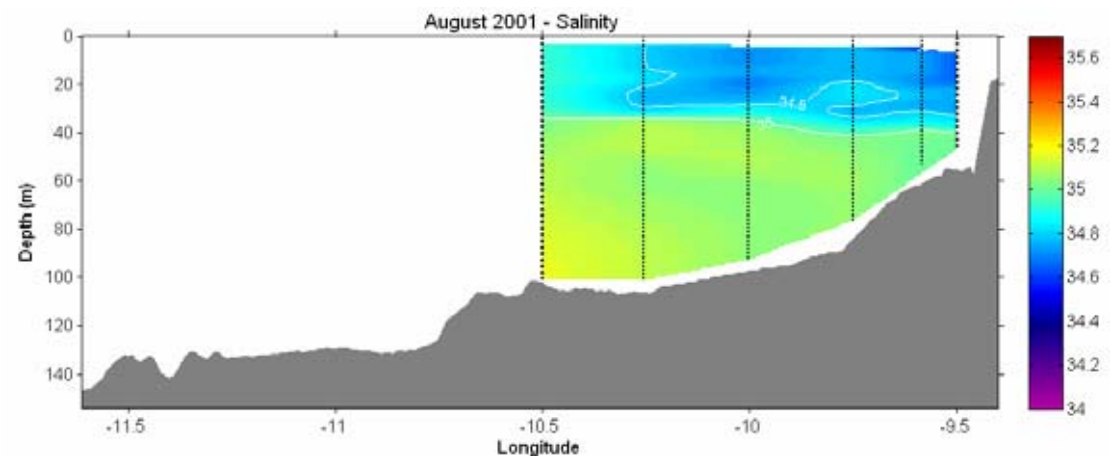


Figure 4 Discharges from rivers affecting the western Irish Shelf, river Loire (upper panel) and rivers Shannon and Severn (lower panel). Note different scales on Y axes.



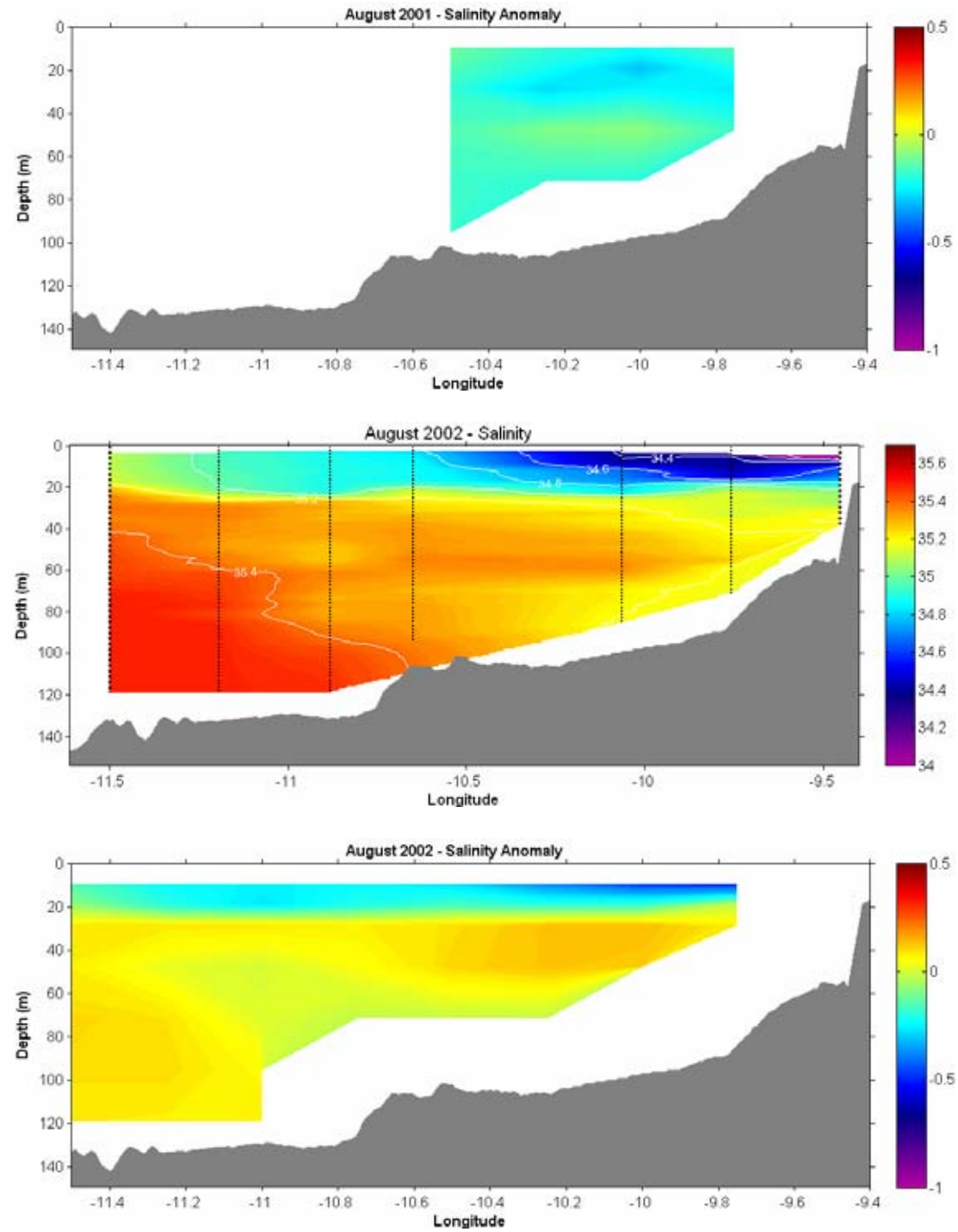


Figure 5 Salinity structure and anomalies along 53°N in 2001 (upper 2 panels) and 2002 (lower 2 panels)

In August 2002 a band of fresher water is present in the upper 30m of the 53°N section (figure 5). ENAW encroaches below the halocline in this case. The effect of this is to have a negative salinity anomaly in the upper layers and a positive anomaly in the lower layers. There was a strong Spring discharge (February-March 2002) from the river Shannon in 2002 and a relatively weak discharge from the Loire during the same period. This salinity structure reflects more the local influence of the river

Shannon as a buoyant plume of low salinity water in the upper water column and not the influence of rivers further afield in this case.

Anomalies along 53°N (1999-2006)

The data for the 53°N section have been compared with the relatively coarse WOD01 climatology to generate anomalies in both temperature and salinity over the 1999-2006 period (figure 6).

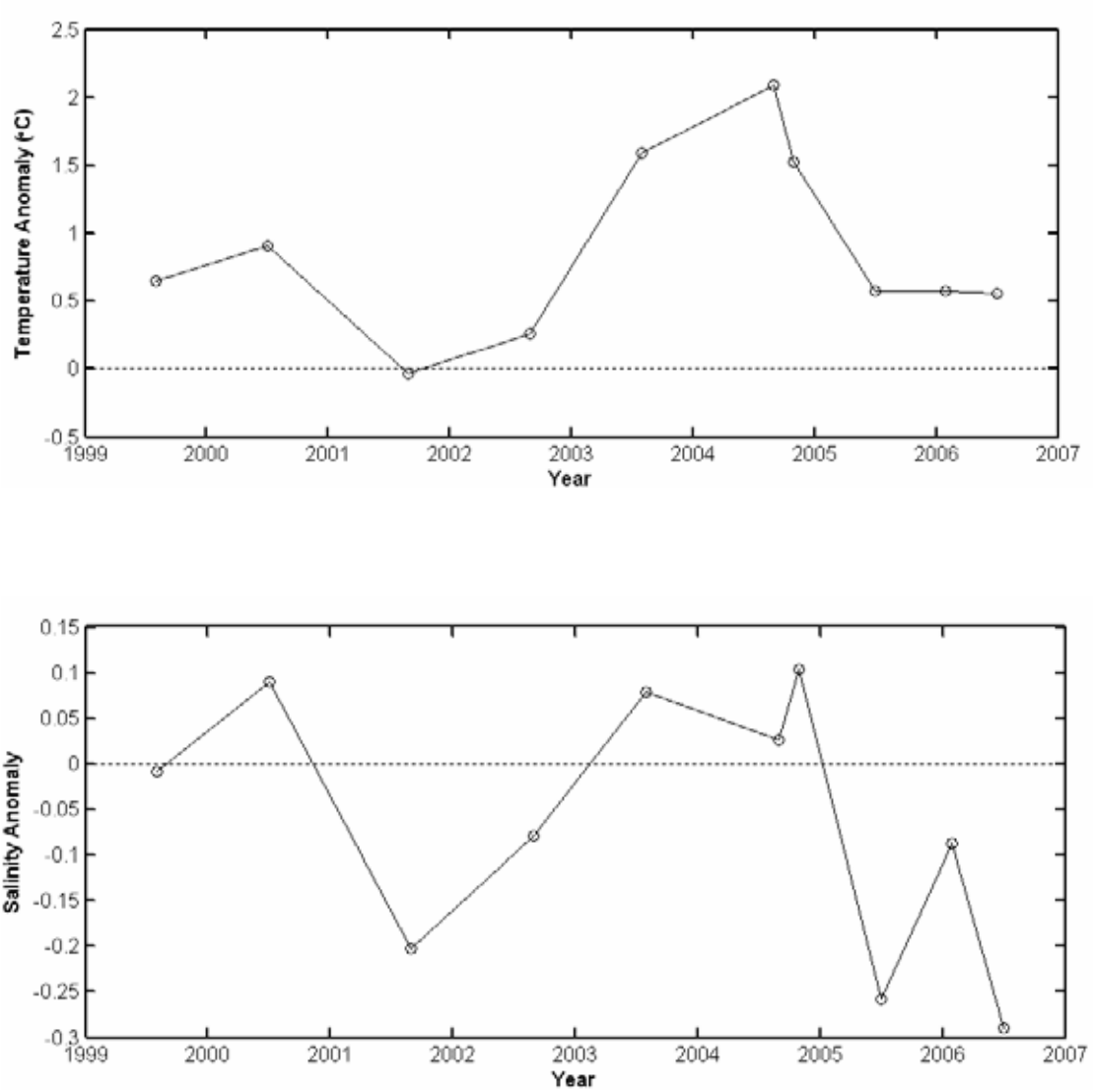


Figure 6 Anomalies in temperature (upper panel) and salinity (lower panel) for the 53°N section (1999-2006)

In all years since 1999 (except 2001) the 53°N section has exhibited positive anomalies in temperature of between 0.2°C and 2°C. In 2001, the temperature anomaly from the long-term climatology was zero. Years with lower temperature anomalies seem to co-incide with years of strongly negative salinity anomalies (eg. 2001 and 2005, 2006) perhaps reflecting the limited influence of ENAW on the section in those years as the section is dominated by coastal discharges from the Loire and Shannon.

Salinity anomalies along 53°N range from –0.3 to +0.1 psu over the period. The freshest years were 2001, 2005 and 2006. In 2000, 2003 and 2004 ENAW has a stronger influence on the salinity structure and positive anomalies in salinity from the long-term climatology are the result.

Sea surface temperature at Malin Head (1960-2005)

A long-term sea surface temperature data set has been maintained at Malin Head since 1958. Temporal variability in sampling frequency ranges from hourly to daily over the period. The results presented herein are daily averages of sea surface temperature at the station (figure 7).

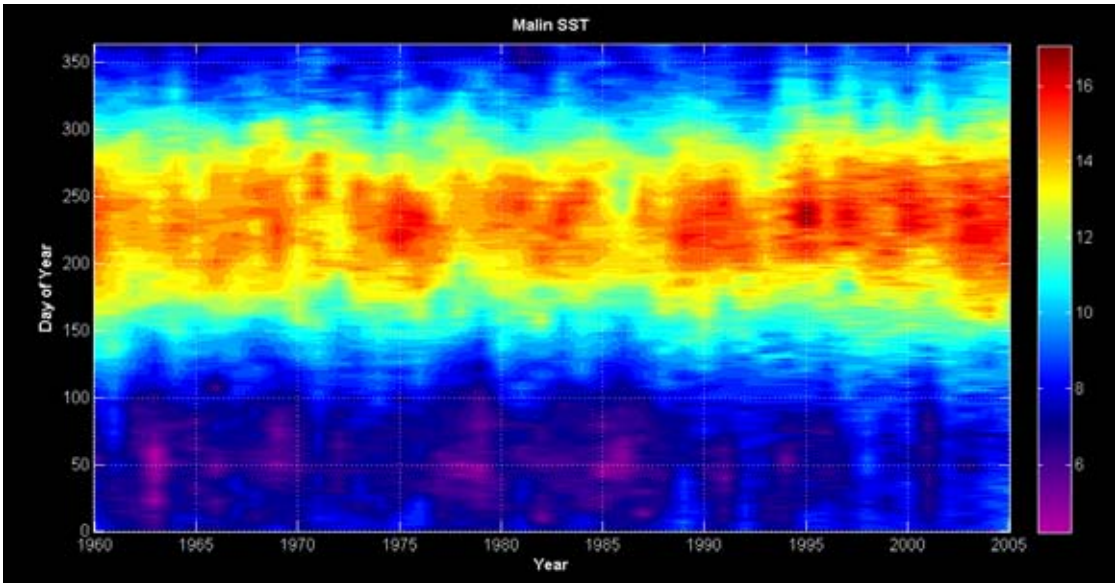


Figure 7 Sea surface temperature from Malin Head (Ireland) 1960-2005, x axis is year while y axis is year day (0-365).

One of the noteworthy points in this data set is the presence of colder winter SST values in the early part of the record with values between 4°C and 6°C. Where these lower temperatures are observed in winter there is a less pronounced heating season in summer of that year. This is particularly apparent in 1963, 1978, and 1985-86. This can be considered in relation to storminess over the period of the record. Figure 8 depicts the wind speeds over the northern part of Ireland since 1960. Red colours relate to wind speeds exceeding 30 knots while weak wind speeds are coloured blue and purple. Stormy conditions in February and March are apparent in 1963, 1978 and 1985-86 concurrent with the lower winter SST values.

Winter temperatures are typically >6°C since 1990 and summer temperatures are more pronounced in that period also. This seems to correspond with a period of decreased storminess in this data since 1990.

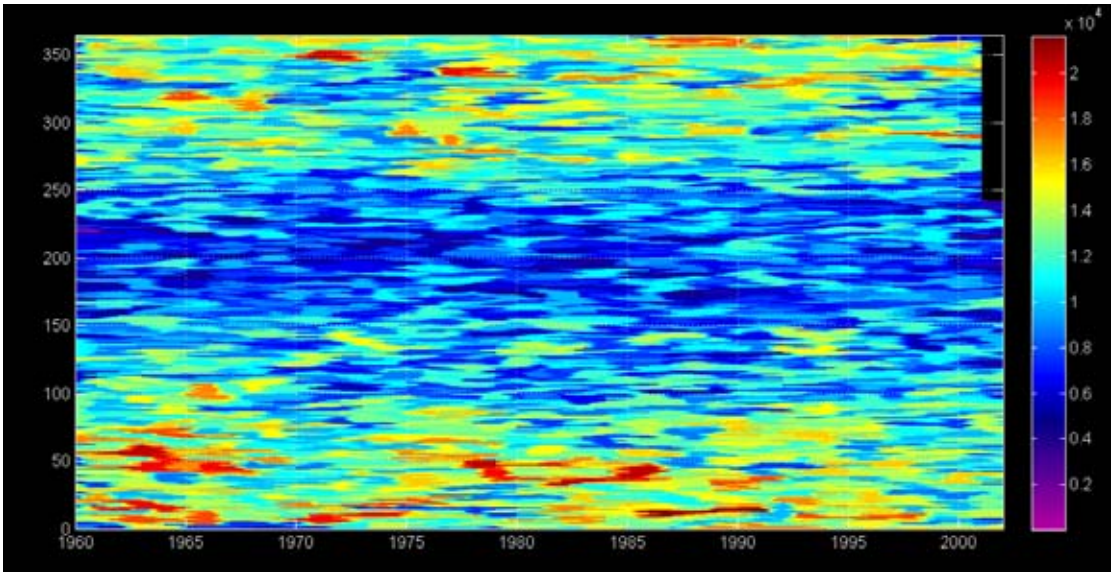


Figure 8 Wind speed for a grid covering the northern part of Ireland (1960-2002). Red colours indicate stormy conditions, blue colours indicate calm conditions.

Consideration has been given to the sea surface temperature anomaly at Malin Head over the 1960-2006 period. The anomaly is expressed relative to the 1961-1990 average and is shown in figure 9 below.

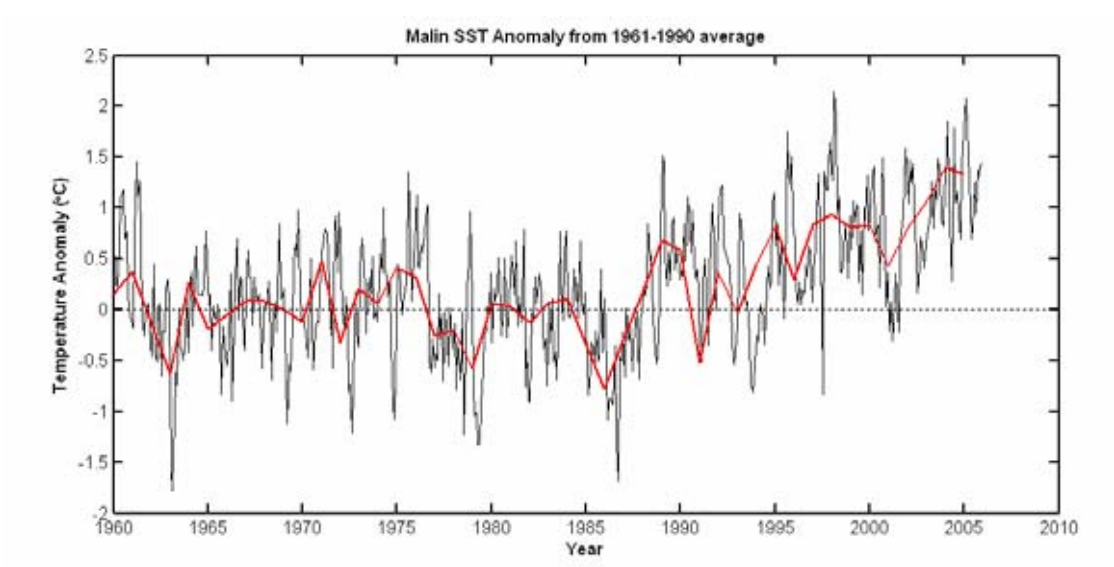


Figure 9 Sea surface temperature anomaly at Malin Head (1960-2005)

There is considerable variability in the anomaly both on a monthly and yearly basis but a trend towards sustained positive temperature anomalies from 1990 is apparent. Interestingly the temperature anomaly record at Malin seems to mirror that observed at 53°N in the period between 1999 and 2006 with both records showing smaller temperature anomalies in 2002 and post 2005.

Conclusions

The section at 53°N exhibits considerable oceanographic variability inter-annually. The location of bottom dominant fronts in this region consequently exhibit a similar variability. Table 1 shows the summer position of the 27.2 isopycnal along 53°N from 1999-2006.

Table 1 Variability in the location of bottom front from year to year (red shows furthest west, blue shows furthest east.

Year	Longitude of 27.2 isopycnal
1999	10.1W
2000	**9.95W**
2001	10.25W
2002	**10.75W**
2003	>10.6W
2004	10.25W
2005	>10.4W
2006	10.2W

The longitudal position of the strongest frontal gradient varies from year to year from being relatively close to the Irish coast (2000) to being relatively far offshore (as in 2002). The difference in frontal location from year to year can be 20-48km and has implications for the fate of harmful algae and contaminant transport on the western Irish shelf. There may however by considerable variability on much shorter time scales (weeks to months).

This shelf section will continue to be monitored on a yearly basis but it is hoped to deploy moored current meter and temperature, salinity arrays in the region to look at shorter-term variability along 53°N in the coming years.

The apparent link between storminess and lower SST and a reduced summer heating cycle in summer at Malin Head in winter has been presented. Whether this is a straightforward relationship whereby increased wind speeds cause an increase in rainfall and an input of cold run-off from Irish rivers to this site in winter is not conclusive. It would be useful to collect salinity data from Malin Head also to establish the precise nature of these interactions.

Acknowledgements

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