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A QUASI-SYNOPTIC SURVEY OF THE EUROPEAN CONTINENTAL SHELF EDGE DURING THE SEFOS PROJECT

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SUMMARY

Quasi-synoptic surveys of the European continental shelf edge have been conducted since the spring of 1994 by participants in the Shelf Edge Fisheries Oceanography Study (SEFOS). The purpose of the surveys is primarily to address questions concerning the eastern boundary current raised by fishery biologists, as the eastern boundary or slope current is intimately involved in the life history of many important European commercial fish species, such as mackerel, horse mackerel, blue whiting and hake. In all 21 sections were defined crossing the shelf edge from Portugal to Norway. The majority of these were occupied by a number of European laboratories between March and June 1994. Sections across the shelf edge have been used to examine the location and characteristics of the current in the different observational regions. Diagrams of t-S have been employed to describe the water masses involved in the slope current. Vertical and horizontal sections along the shelf have been constructed from the different across-shelf sections in order to examine the along-shelf variation of processes such as vertical and horizontal mixing in

the area of the current. While preliminary data are presented, data collection continues and final analysis has not yet been completed.

INTRODUCTION

The Shelf Edge Fisheries Oceanography Study (SEFOS) is a multi-disciplinary study of the interaction of physical processes at the shelf edge with commercially important fish species. It is a collaborative study involving 16 laboratories of nine European Countries (Table 1). The project has received funding from the European Community Agriculture and Agro-Industry, Including Fisheries (AAIR) research and technical development programme as a shared cost contract. The project coordinator is the Marine Laboratory Aberdeen. The funding commenced in January 1994 and will extend until December 1996.

1. Fish Species Associated with the Shelf Edge

The studies in SEFOS related to commercially important fish stocks are directed towards the following species: anchovy, hake, albacore and blue fin tuna, blue whiting, horse mackerel and mackerel. Many questions, relating fisheries biology to the physical and biological processes which occur at the shelf edge and particularly the Slope Current (SC), are being addressed during SEFOS.

It is believed, for example, that older adult anchovies are associated with the edge of the continental shelf especially during their spawning period in the spring. This may be linked to the increased biological productivity at the shelf edge. It is also thought that hake (*Merluccius*) spawn along the shelf edge in the Bay of Biscay area. Nothing is known about the subsequent larval drift and the effect of the SC, or the migration routes and timing of migration of the post-spawning adults. Albacore and blue fin tuna (*Thunnus thynnus*) both migrate to the Bay of Biscay and to the southwest of Ireland in the summer. It is believed that this is because their prey species concentrate at the shelf edge, but it is presently unclear why.

Adult blue whiting (*Micromesistius poutassou*) spawn at the shelf edge west of the UK in March and April each year. For management purposes they are split into two stocks, more for convenience than for any clear biological reason. It is believed that the eggs and larvae of the "northern" stock drift from the spawning grounds to nursery areas around Faroe, southern Iceland, in the Norwegian Trench and northwest of Norway. The SC will undoubtedly play a major role in this larval drift period. The existence of a separate "southern" stock has been suggested by numbers of young fish caught off Spain and Portugal; an area well separated from the main distributional area to the north. No separate spawning area has yet been identified for this stock.

Horse mackerel (*Trachurus)* is managed as three separate stocks ("North Sea", "western" and "southern"), again more for convenience than for any more direct reason. Spawning occurs all along the shelf edge from southern Portugal to the southwest of Ireland, with the peak in spawning occurring progressively later with increasing latitude. While there appears to be no geographical separation between "southern" and "western" spawning areas, there is a discontinuity between these and spawning grounds in the North Sea. The details of egg and larval drift are not yet known, although the SC must have profound effects upon this drift. Studies during SEFOS are being directed towards the stock separation issues, and will clarify advection during the planktonic stages of the species.

Mackerel (*Scomber scombrus*) is also presently managed as three separate stocks for convenience; "North Sea", "western" and "southern". Fish from the "western" and "southern" stocks spend much of their lives at, or close to, the shelf edge and spawn close to the 200 m contour. No investigations have yet revealed how the SC affects egg and larval drift following release at spawning. It is also not clear if the "western" and "southern" stocks have truly separate spawning areas; a question of some importance in relation to stock separation and management. Winter nursery areas are associated with the shelf edge, although young fish are also found in some inshore waters. Again there are no studies relating the juvenile fish distributions to the SC, either with respect to the effect the current may have on their distribution or why they gather there at all. After spawning, the adults migrate north along the 200 m contour, presumably employing the SC to move north more efficiently. At Tampen Bank northeast of Shetland the adult concentrations appear to split, with some entering the North Sea within the Norwegian Trench and the remainder moving north into the southern Norwegian Sea. After summer feeding they again begin to migrate, this time south back towards the spawning grounds but inshore from the northerly flowing SC.

Long term changes in the distribution of mackerel have been associated with oceanographic forcing. For example, between 1970 and 1981 the main summer distribution of adults lay inside the North Sea. A significant change occurred between 1982 and 1983 when the adult population appeared to spend the summer in the southern Norwegian Sea and between 1984 and 1985 the fish appeared to accumulate along the Norwegian coast. The reasons for these large shifts in summer distribution are not clearly known, but such changes have in the past been linked to hydrographic change (Walsh and Martin, 1986). Certainly many hypotheses remain to be tested and the subtle processes linking fish migration with the ocean environment will be examined during SEFOS.

2. **Fishery Investigations During SEFOS**

Combined acoustic, fishing and hydrographic studies are being undertaken to look at the pre-spawning migration of "western" mackerel north of Scotland, the post-spawning migration of the same stock in the Tampen Bank area, the migration of adult mackerel and horse mackerel north of Spain and west of Portugal and the migration of blue whiting offshore from the shelf edge. In addition tagging experiments have been performed in Spanish waters to study movements of hake, mackerel and horse mackerel and mackerel movements west of Ireland. Commercial catches are also being used to describe seasonal and annual changes in the distribution of all target species. Icthyoplankton has been studied west of the UK, concentrating on blue whiting and mackerel larvae, hake eggs and larvae north of Spain, blue whiting eggs and larvae on the Porcupine Bank.

THE SEFOS STANDARD SECTIONS

In addition to the more direct fishery measurements, hydrographic observations have also been obtained. From the outset of the project, hydrographers within SEFOS realised that it was possible to identify several periods when many research vessels equipped with CTDs were working at the shelf edge during the program, almost simultaneously.

Hence a set of 21 Standard Sections has been established (Fig. 1) which have been worked whenever possible by SEFOS cruises. The location of the Standard Sections have been determined after consulting many European oceanographic centres, and, where possible, existing Standard Sections have been incorporated into the scheme to ensure continuity with past data sets and current studies by non-SEFOS institutes. Data from the Standard Sections are still being collected, collated and calibrated. Inter-institution calibration is considered to be of great importance, and much effort is being taken to examine this aspect (eg Jorge da Silva *et al.*, 1995). Data from the Sections are being assembled at the Marine Laboratory Aberdeen, transformed into a single format and re-issued to participating institutes. Once collated the data set will provide unique, semi-synoptic views of the European shelf edge.

The most comprehensive occupation of the Standard Sections occurred in the Spring of 1994. Table 2 summarises the initial occupations of the Standard Sections, although occupations continue by SEFOS and other cooperating research vessel cruises.

From the summaries of fish biology presented above it is clear that the dynamics of the SC are intimately linked with the survival, distribution and abundance of many commercially important fish species. Hence, during the analysis and interpretation of the data collected along the standard sections, SEFOS hydrographers will be focusing on questions posed by the fishery biologists in the project.

QUESTIONS POSED BY BIOLOGISTS

1. How Continuous is the Slope Current

The persistent current flowing along the edge of the continental shelf west of Britain may represent a continuous filament of transport, carrying water originating in Atlantic waters, to the south of the Celtic Sea, to the Northern Oceans (Ellett *et al.*, 1979). During its passage along the shelf edge, water from the Northeast Atlantic will become entrained into the SC and some exchange with waters on the shelf will occur. The continuity of the SC, and cross-shelf exchange obviously has great implications for the advection and dispersion of fish eggs and larvae.

Previous studies of the SC suggest that it is marked by a core of warm, saline water at the shelf break, which may reach the surface during the winter, but which is below the seasonal thermocline during the summer (Booth and Ellett, 1983). It is suggested that this core of water may be continually traced, at least from the shelf west of Ireland to the shelf edge north of Scotland (Dooley and Martin, 1969). The same water may be observed along the western edge of the Norwegian Trench and into the Skaggerak (Dooley and Martin, 1969). From a careful analysis of mixing of the different water types that make up the SC, Hill and Mitchelson-Jacob (in press) suggested that the current was continuous from the Porcupine Bank to the west of Scotland. A persistent slope current has also been examined further south, along the edge of the Celtic Sea by Pingree and Le Cann (1989), and this probably forms part of a continuous feature stretching along the entire northwest European shelf edge. Swallow *et al.* (1977) noted a northward flowing current off northern Spain and in the northern Bay of Biscay. Hence the SC may have origins much further south, explaining the observations of water originating in the Bay of Biscay in the upper waters of the Rockall Trough (Nansen, 1913; Ellett and Martin, 1973).

The data obtained from the SEFOS Standard Sections will be employed to examine the continuity of the SC, and the changes which occur to the temperature-salinity relationship of water found at the shelf edge at the different sections (eg Fig. 2).

During its passage along the shelf edge from the Bay of Biscay to the Norwegian Sea, the SC encounters several changes in topography. The slope along the edge of the Celtic Sea is one marked with deep submarine canyons, which themselves modify the current (Pingree and Le Cann, 1989). On entering the Rockall Trough the SC may split, partly flowing around the Porcupine Seabight and the Porcupine Bank, and partly crossing the Bank to the southwest and west of Ireland (Ellett *et al.*, 1986). It is in this area that the continuity of the SC from origins in the Bay of Biscay to the Norwegian Sea may be in most doubt (Ellett *et al.*, 1979).

Preliminary results from SEFOS Standard Sections on the Porcupine Bank have begun to suggest that indeed discontinuities in the SC may occur there, possibly related to the intrusion of offshore water branching in towards the shelf edge from the North Atlantic Drift (eg Fig. 3).

The next major topographic feature influencing the SC is the Wyville-Thomson Ridge at the entrance to the Faroe-Shetland Channel. Broad oceanic flow towards the northeast over the ridge is diverted towards the slope, possibly enhancing the SC there (Huthnance, 1986). Further north the SC appears to split around the area of the Tampen Bank at the entrance to the northern North Sea. Water above ocean depths of >300 m appears to continue to flow northeast into the Norwegian Sea, while water inshore from this enters the Norwegian Trench to flow south (Dooley and Martin, 1969). This pattern of circulation was confirmed by satellite tracked buoys released to the south of the Wyville-Thomson Ridge at the shelf edge (Booth and Meldrum, 1984). Three buoys travelled along the shelf edge at typical speeds of 15-24 cm s^{-1}, crossed the entrance to the Norwegian Trench and entered the Norwegian Sea, while one deployed further inshore entered the North Sea around Tampen Bank (Booth and Meldrum, 1984).

2. How Wide and Where is the Slope Current?

Details of the width and location of the main filament of transport is required in order to interpret fish behaviour, for example spawning locations, and larval distributions. Vertical sections of temperature and salinity obtained along the Standard Sections will be interpreted to provide details of the width and location of the core of the SC during SEFOS.

The SC is generally characterised by a narrow core of transport, persistently being observed over particular depth contours. However, estimates of the width and location of the current differ, with some evidence of short term and seasonal variability. In the Faroe-Shetland Channel north of Scotland the main transport towards the northeast appears to be above the 500 m contour (Dooley and Crease, 1978). To the northwest of the Hebrides, Turrell *et al.* (1992) found that a filament of maximum salinity lay above the 300 m contour, with observed current speeds increasing from above the 200 m contour (10 cm s^{-1}) to the 500 m contour (20 cm s^{-1}). They estimated that a 36 km wide section between the 160 m and 780 m contours accounted for almost all of the SC (1.8 Sv). Booth and Ellett (1983) estimate that a 10 km wide section of the current west of Scotland above the 500 m contour accounts for .5Sv of transport, possibly 30% of the SC transport there. From observations of temperature and salinity, Hill and Mitchelson-Jacob (in press) suggested the core of the SC was approximately 20 km wide west of Scotland, while using similar observations Dooley and Martin (1969) suggested the core of the SC lay above the 200-300 m contour from the west of Ireland to the north of Scotland. There is some evidence that to the west of Scotland the SC may broaden during the winter months, and also under the influence of southeasterly and easterly winds (Ellett *et al.*, 1986). Under such wind conditions the SC transport over deeper water may increase. Further south, at the edge of the Celtic Sea the SC was maximum between the 100-300 m contour (Pingree and Le Cann, 1989).

3. What are Typical Speeds Within the Slope Current?

Typical speeds within the SC are required in order to understand transport times along the shelf edge, and relate adult migration routes and swimming speeds to the SC. While the Standard Section results themselves will not yield information on speeds within the SC, associated deployments of recording current meters and ADCP measurements will.

Measuring the strength of the SC is not easy, however. Current meter observations are scarce, and the high fishing activity at the shelf edge often prevents successful mooring deployment. Speeds within the SC close to where it bifurcates around Tampen Bank have been estimated to be 16-30 cm s^{-1} (Dooley and Martin, 1969), which was confirmed by the satellite drogue buoys of Booth and Meldrum (1984). Dooley and Meinke (1981) estimated mean speeds within the SC north of Scotland of 20 cm s^{-1}. Turrell *et al.* (1992) observed stable (>95%) currents with monthly mean speeds of 13-20 cm s^{-1} flowing along the shelf edge to the northwest of the Hebrides.

To the west of Scotland, Booth and Ellett (1983) observed steady northward directed currents of 16 cm s^{-1} above the 700 m depth contour over a five month period (May-September). Further inshore at the 250 m contour weak (<10 cm s^{-1}) and variable currents were observed, with flow directed counter to the SC, towards the south, during the summer, but northwards during the winter. Offshore from the shelf edge, over depths of 2,000 m, Booth and Ellett (1983) observed strong (50 cm s^{-1}) currents which [illegible]creased with depth and exhibited significant long period (30 day) oscillations.

The suggestion of a seasonal counter current inshore from the main SC west of Scotland (Booth and Ellett, 1983) and possibly along the Celtic shelf edge (see below) is an interesting one. If such counter currents exist they may have considerable influence on egg and larval drift, and questions relating to stock separation issues.

4. What are the Interactions with Shelf Waters?

While many species spawn within the SC, or close to it, most juvenile fish must enter coastal waters in order to survive. Hence interactions between the SC and waters on the shelf are important for questions of larval survival. Cross-slope mixing will also affect the t-S relationship within the SC, and this will be examined using results from the Standard Sections.

The SC has important interactions with the waters on the European shelf, including the Celtic Sea, the Hebridean Sea and the North Sea. Water within the SC, mixing continually with water further offshore in the Northeast Atlantic, supplies the source water which inundates many parts of the continental shelf. It also to some extent dynamically isolates the shelf waters from processes occurring in the ocean (Huthnance, 1986; Pingree and Le Cann, 1989). The precise mechanisms whereby water is exchanged across the shelf edge onto the shelf are not yet fully understood.

West of Scotland little exchange may occur during the summer and autumn (Booth and Ellett, 1983). Water near the sea bed west of Scotland becomes isolated during the summer, and remains cool and dense until autumnal gales increase the mixing on the shelf (Edelsten *et al.*, 1976). It is this cold bottom water which may be partly responsible for the counter current observed inshore from the SC described above (Edelsten *et al.*, 1976), although wind forcing may also be important (Booth and Ellett, 1983).

Secondary, cross-shelf circulation is also important for egg and larval drift. Convergence towards the SC may concentrate eggs and larvae into the current, while divergence would disperse them away from the main transport. Certainly drogued drifting buoys appear to become entrapped within the SC for considerable periods of time.

There is some evidence that onshore flow occurs near the surface in the SC, with balancing offshore flow occurring near the sea bed (Pingree and Le Cann, 1989). To the north of Scotland Dooley *et al.* (1976) found evidence of a slow movement of water onto the shelf of 2 cm s^{-1}. This across-slope transport may supply the inflows of Atlantic water into the northern North Sea. They suggested the transport to be non-wind driven, dependent rather on advection as the result of periodic intrusions of oceanic water onto the slope.

5. What are the Dynamics of the Slope Current?

This question has important implications on the predictability of the SC. The dynamics of the SC must be understood before models of the current may be developed. Understanding the dynamics may alow us to understand or hindcast past variability in the SC and relate these changes to changes in the target fish populations.

It is believed the SC is predominantly non-wind driven (Huthnance, 1984, 1986). The increasing density in the Atlantic basin from south to north arising primarily from the equator-pole temperature difference, results in a southerly directed pressure gradient (from most dense towards least). In order to balance this gradient to maintain an equilibrium a surface slope develops, with the surface decreasing towards the north. As the density generated gradient is dependent upon the depth of water over which it operates, the gradients are greatest over ocean depths compared to shelf depths. Thus towards the north an increasing height difference occurs between the shelf waters and the oceanic waters (the surface of the shelf waters becoming increasingly higher with respect to that of the ocean). A geostrophically balanced poleward flow, increasing towards the north, then develops above the strip where shelf depths meet ocean depths; the shelf edge. The increasing transport is achieved by recruiting oceanic water into the SC (Pingree and Le Cann, 1989).

Observations appear to confirm that the dynamics of the SC are primarily non-wind driven. Examining observed currents above the shelf edge west of Scotland Booth and Ellett (1983) found a negligible contribution was made to the SC by non-linear interactions of the tide, which themselves may be enhanced at the shelf edge (Huthnance, 1986). Wind stress was insufficient to account for the observed currents, although it could account for flows observed inshore from the shelf edge. The local density gradients also failed to account for the observed flows.

Further south at the Celtic shelf edge Pingree and Le Cann (1989) examined the dynamics of the SC and inshore shelf circulation using observations and numerical modelling. On the shelf itself they found evidence for a variety of wind and non-wind driven circulations. A counter current inshore from the SC, similar to that observed further north by Booth and Ellett (1983), was evident, possibly driven by westerly winds. The SC itself appeared to be independent of the wind, characterised by strong and persistent along-slope flow. From the observations there appeared to be little vertical structure within the SC, hence the geostrophic estimates of transport described below may be of limited use.

A numerical model, driven by an internal north-south pressure gradient, reproduced the SC with speeds of typically 5 cm s^{-1} above the shelf edge in the Celtic Sea to 15 cm s^{-1} north of Scotland. The model failed to reproduce the inshore counter current on the Celtic Shelf, but did reproduce a reversal on the Malin Shelf. The model also suggested a convergence in the surface waters above the shelf edge. This might explain why drifting buoys, and fish larvae, become "trapped" within the SC for considerable lengths of time (Ellett *et al.*, 198[illegible]. The model suggested that to the north of Scotland approximately 30% of the transport within the SC was wind driven, while 70% was attributable to the meridional pressure gradients.

Results from the SEFOS Standard Sections will be employed to compare with the driving density fields and resultant predicted temperature and salinity fields of numerical hydrodynamic models of the SC. Thus they may add to our knowledge of the dynamics of the SC.

6. What is the Temporal Variability of the Slope Current?

The variability of the SC is important to the biology of the target fish species on a number of temporal scales. Short term variability may affect larval distributions and dispersion. Seasonal variability may determine spawning or migration timing and longer term variability may result in interannual changes in fish distributions, migrations and survival.

The SC does exhibit variability on a number of space and time scales. Owing to the difficulties involved in monitoring the SC with moored instrumentation the number of available observations decreases with increasing time periods.

Short Term Variability: Gould *et al.* (1985) noted significant short-period variability within the SC north of Scotland, over periods of typically four days. These were associated with wind events. Dooley and Meinke (1981) also noted extreme variability within the SC over these timescales, but could not relate them to wind events on all occasions. They ascribed some of the variability to the incursion of oceanic eddies into the shelf edge area. Dooley *et al.* (1976) concluded from a series of observations that currents along the slope were only increased by winds directed from the southwest with speeds of >15 ms^{-1} blowing for periods of more than three days.

Seasonal Variability: Gould *et al.* (1985), using an intensive year long deployment of current meter moorings across the SC to the northwest of Shetland, described a seasonal cycle of transport within the SC. Maximum flows occurred during the winter months (December-February) while minimum transport took place during the summer (June-August). The amplitude of the seasonal variation was about ±30% of the annual mean (Fig. 4a).

One commonly used estimate of current strength is the geostrophic method, where transport is calculated from an observed section of density across a current, such as those available along the SEFOS Standard Sections. One assumption this method requires is that the currents at a particular depth are known precisely. Often this is not the case, and a general assumption is that there is no flow at the sea bed in shallow seas, or at some selected depth in the ocean. Figure 4a shows the transport within the SC calculated using this method from SEFOS Standard Section Nos 18 and 19 obtained across the SC northwest of Shetland by the Marine Laboratory Aberdeen between 1970 and 1991. It is evident that the computed fluxes do not reproduce the observed seasonal cycle of Gould *et al.* (1985), nor are they of a similar magnitude (Fig. 4a).

Poor comparison between such estimated currents at the shelf edge and actually observed currents has been noted before. Dooley and Meinke (1981) compared geostrophically calculated flows with observed currents and found little similarity. In fact the current strength near the sea bed may be little different from that near the surface, as the current is driven by the pressure gradient caused by the ocean-shelf sea surface height difference, and hence is barotropic in nature (Dooley and Meinke, 1981; Pingree and Le Cann, 1989). Dooley and Crease (1978) found that slope currents could be twice those predicted by geostrophic calculations, which appears to be confirmed by the present estimates (Fig. 4a). The large scatter within a single month may have been cause by interannual variability. However, as can be seen in Figure 4b, computed transport from sections performed during the same month and year often bear little relation.

The seasonal variability of the potential driving mechanisms of the SC may be examined. Both the meridional temperature difference (Fig. 5a) and wind stress (Fig. 5b) demonstrate a similar seasonal pattern to that of the observed transport (Fig. 4a), with minima occurring during the summer (June). The wind stress reaches a maximum during the winter (December-January) while the temperature gradient exhibits an autumn maximum (September-October).

Interannual Variability: No direct current meter observations exist that permit an examination of interannual variability of the SC. The errors associated with the estimates of transport using the geostrophic method (Fig. 4b) are too great to allow interannual trends to be discerned. However, there may be evidence of interannual variability in the driving mechanisms. The meridional temperature gradient (Fig. 6a) appears to have been reduced during the period 1970-1978, compared to 1979-1990. The early period corresponds to what is now known as the Great Salinity Anomaly (Dickson *et al.*, 1988) when environmental conditions throughout the northeast Atlantic altered, and the circulation of the shelf seas around the UK may have also have been reduced in strength (Corten, 1990; Turrell, 1992). This period was certainly associated with great biological changes, paricularly in North Sea herring and sandeel abundance (Corten, 1990; Turrell, 1992) and western mackerel distribution (Walsh and Martin, 1986).

Examination of the wind stress directed from the four quadrants reveals little coherent interannual change. One event is obvious, however, with extremely strong southwesterly winds during 1983. Closer examination of the data reveals that southwesterly wind strengths were particularly abnormal during the months of January, March, July and October that year. As 30% of the SC may indeed be wind driven, and respond greatest to southwesterly winds, north of Scotland (Pingree and Le Cann, 1989), and that the shelf circulation itself has an optimum response for a southwesterly wind, circulation at the shelf edge and on the shelf may have been particularly strong that year. Turrell and

Shelton (1993), from an examination of sea surface temperatures around Britain, have suggested that the years 1921/22, 1958/60 and 1989/90 were marked by particularly strong slope transport, again owing to changes in the driving mechanisms as described above.

Again, results from the SEFOS Standard Sections, particularly in conjunction with results from the numerical models being developed within the project, will be examined to determine the seasonality of the structure and composition of the SC. It is hoped that sufficient data may be obtained to examine inter-annual differences which occur during the three year period of SEFOS.

CONCLUSIONS

While not originally planned as part of the SEFOS project, 21 Standard Sections have been selected to be occupied whenever possible by participating SEFOS research cruises equipped with CTDs. Surveys of these Standard Sections are generating a unique data series, with approximately simultaneous sections across the Slope Current (SC) at different locations along the European shelf edge from Iberia to Norway. The most comprehensive coverage of the SC occurred in the spring of 1994, but surveys continue and further quasi-synoptic views will be possible. While only preliminary results are available, it is clear that the Standard Sections will provide invaluable support for the fishery studies being undertaken during SEFOS.

Results from the Standard Sections will be employed to address questions posed by the biologists such as where is the SC, how wide is it and how does it vary along the shelf edge ? Standard techniques such as vertical and horizontal sections of physical parameters and tS diagrams will be employed. Additional questions about the dynamics of the SC, the transports within it and their variability can be addressed by combining results from the Standard Sections with numerical models being developed within SEFOS. In addition comparison of Standard Section data with vessel mounted ADCP observations, and incorporation of techniques such as inverse methods may overcome the inherent limitations of the geostrophic method in determining transports within the SC.

The SEFOS Standard Sections, and their position within SEFOS, constitute a regional GOOS. They cross disciplinary and political boundaries to monitor a regional scale feature of ocean circulation and relate this to the health of the oceans as represented by several commercially important fish species. The Standard Sections provide a future method to monitor decadal change in the oceans and link modelling to monitoring studies. The value of the Standard Sections increases as more institutes and principal scientists adopt them as part of their own cruises and studies.

Finally, it is clear that the SC plays a fundamental role in the biology of many fish species, whose life cycles have evolved to account for the physics of the Slope Current. Oceanographers only recognised the existence of the SC in the 1970s (eg Swallow *et al.*, 1977). Hence it is again demonstrated that physical oceanographers may learn a great deal from fish and fish biology, hence the importance of interdisciplinary studies as promulgated by ICES.

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TABLE 1

SEFOS participants

Eire	Department of Marine, Fisheries Research Centre, Dublin
	Martin Ryan Marine Science Institute, University College Galway
Faroe	Fisheries Research Institute, Thorshavn
France	IFREMER - Centre de Nantes
	Centre de Geostatistique, Ecole de Mines de Paris
Germany	BAH - Biologishes Anstalt Helgoland
Netherlands	RIVO - Netherlands Insitute for Fisheries Investigations
Norway	IMR - Institute of Marine Research, Bergen
Portugal	IPIMAR - Instituto Portugues de Investigacao Maritima, Lisbon
	IH - Instituo Hidrografico, Lisbon
Spain	AZTI/SIO - Instituto de Investigacion y tecnologia para la Oceanografia, Basque Country
	IEO - Instituto Espanol de Oceanografia, Vigo
UK	SOAFD - Marine Laboratory Aberdeen
	PML - Plymouth Marine Laboratory
	DML - Dunstaffnage Marine Laboratory, Oban
	SAHFOS - Sir Alister Hardy Foundation for Ocean Science, Plymouth

TABLE 2

Summary of the occupation of the SEFOS Standard Sections during 1994

Lab	Start date	Section	Stations			Observations
			Number	Occupied	Total	
IMR	05 01 94	20a	(9)		23	Section done at different latitude (not worked up yet)
IMR	28 03 94	13	26	1-19	19	No observations over slope offshore of Porcupine
IMR	18 04 94	21	17	1-17	17	
IMR	18 05 94	17	10	1-10	10	
IMR	19 05 94	18	14	1-14	14	
IMR	20 05 94	19	14	1-14	14	
IMR	19 07 94	20a	(9)		18	Section done at different latitude (not worked up yet)
MLA	03 04 94	17	10	1-10	10	April observations employed Nansen bottles due to CTD breakdown
MLA	05 04 94	18	14	1-14	14	
MLA	06 04 94	19	14	2-14	13	
MLA	22 09 94	17	10	1-10	10	
MLA	23 09 94	18	14	1,3,5-14	12	Clear observation of front between Atlantic inflow and Norwegian Sea outflow in September
MLA	24 09 94	19	14	1-14	14	
MLA	26 09 94	20	9	1-9	9	Section not worked up yet
MLA	14 12 94	18	14		8	
MLA	16 12 94	20	9		7	December 1994 and January 1995 observations still to be analysed
MLA	16 01 95	19	14		9	
DML	15 03 94	16	7	0-3,5,7,9	7	
DML	03 05 94	16	7	7,9	2	May observations combined in one single section
DML	08 05 94	16	7	0-5	6	
DML	16 08 94	16	7	0-7,8-9	10	

Lab	Start date	Section	Stations			Observations
			Number	Occupied	Total	
UCG	12 04 94	15a	(10)	(1-7)	10	Different sect orientation and st separation; poor coverage of slope area
IfM	03 05 94	12	17	1-17	17	
IfM	09 05 94	13	26	5,6,8,10-25	19	N flow had to be inferred inshore of first station
IfM	13 05 94	14	18	2-18	17	N flow also probably present inshore of first station
IEO	16 03 94	10a	(13)	(1,3,5-8,9/10,10/11)	12	4 pairs of st nearly coincident; N flow not observed
IEO	20 03 94	9a	(12)	(3,1,4-8,10)	8	Shelf not covered; N flow prob also beyond last st
IEO	15 03 94	7a	(15)	(1-9,10/11,11/12,13,14)	12	Cold eddy detected but poorly covered (large st sep)
IEO	10 04 94	5a	(17)	5,8-16	11	N flow barely contained within section limits
IEO	08 04 94	4	14	3-11	9	N flow probably present beyond last station
IPIMAR	28 04 94	3	14	3,6,8/9/,10/11	5	Continental slope area not adequately observed in sections 1-3 due to a very large station separation (*ca* 18 km)
IPIMAR	02 05 94	2	14	5/6,8,9/10,11,12/13	5	
IPIMAR	08 05 94	1	15	4,7,8/9,10/11	4	
IH	27 11 94	6	15	1-15	15	
IH	28 11 94	5	17	1-6,8-17	16	
IH	30 11 94	4	14	1-14	14	
IH	02 12 94	3	14	1-14	14	
IH	05 12 94	2	14	1-18	18	Sections 1 and 2 prolonged to allow observation of zonal flow off the coastal boundary layer
IH	07 12 94	1	15	1-19	19	

Figure 1 Location of the 21 SEFOS Standard Sections.

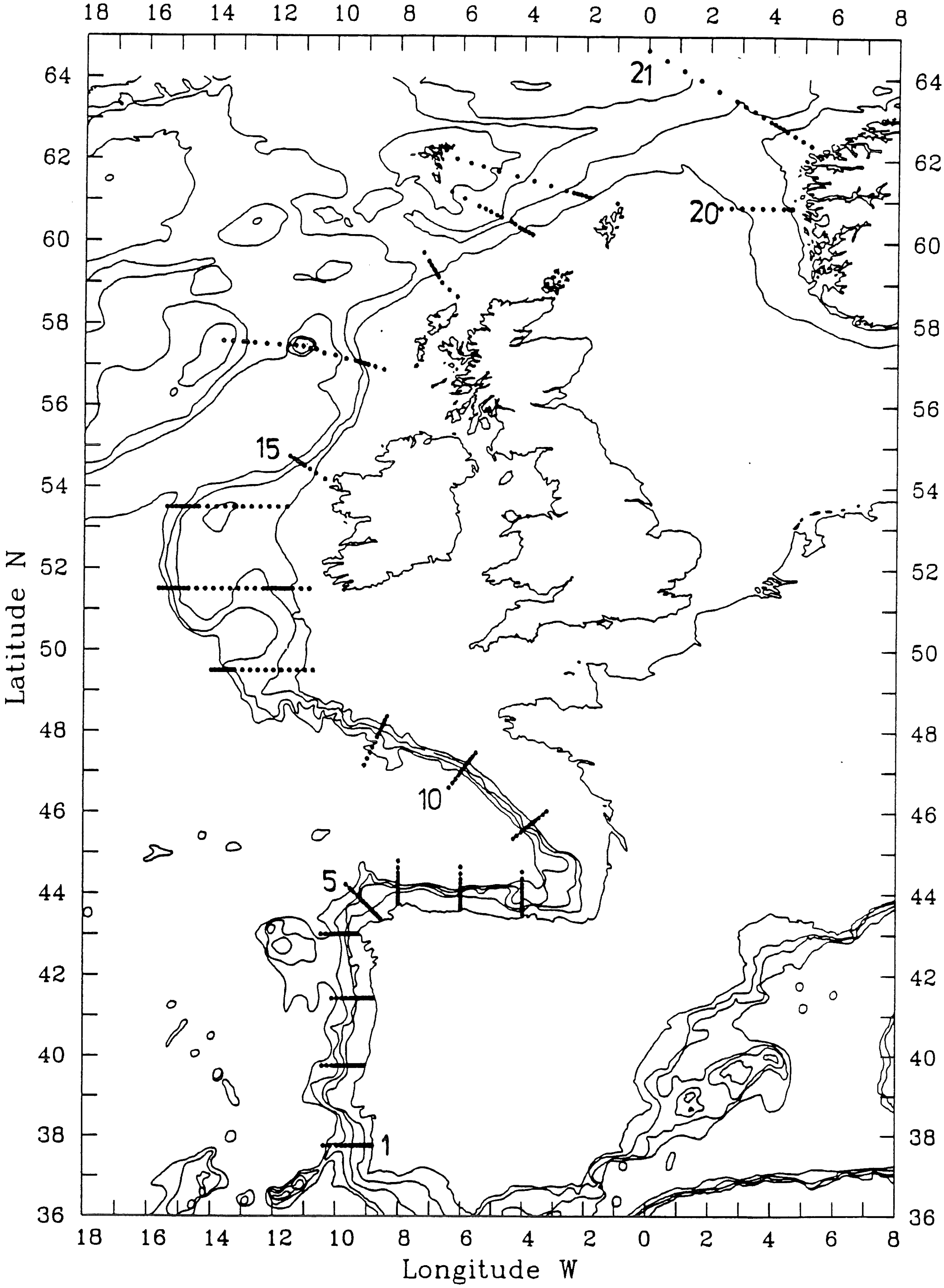


Figure 2 Example of a tS diagram developed from CTD data obtained at the 21 SEFOS Standard Sections along the shelf edge from Portugal to Norway in the spring of 1994.

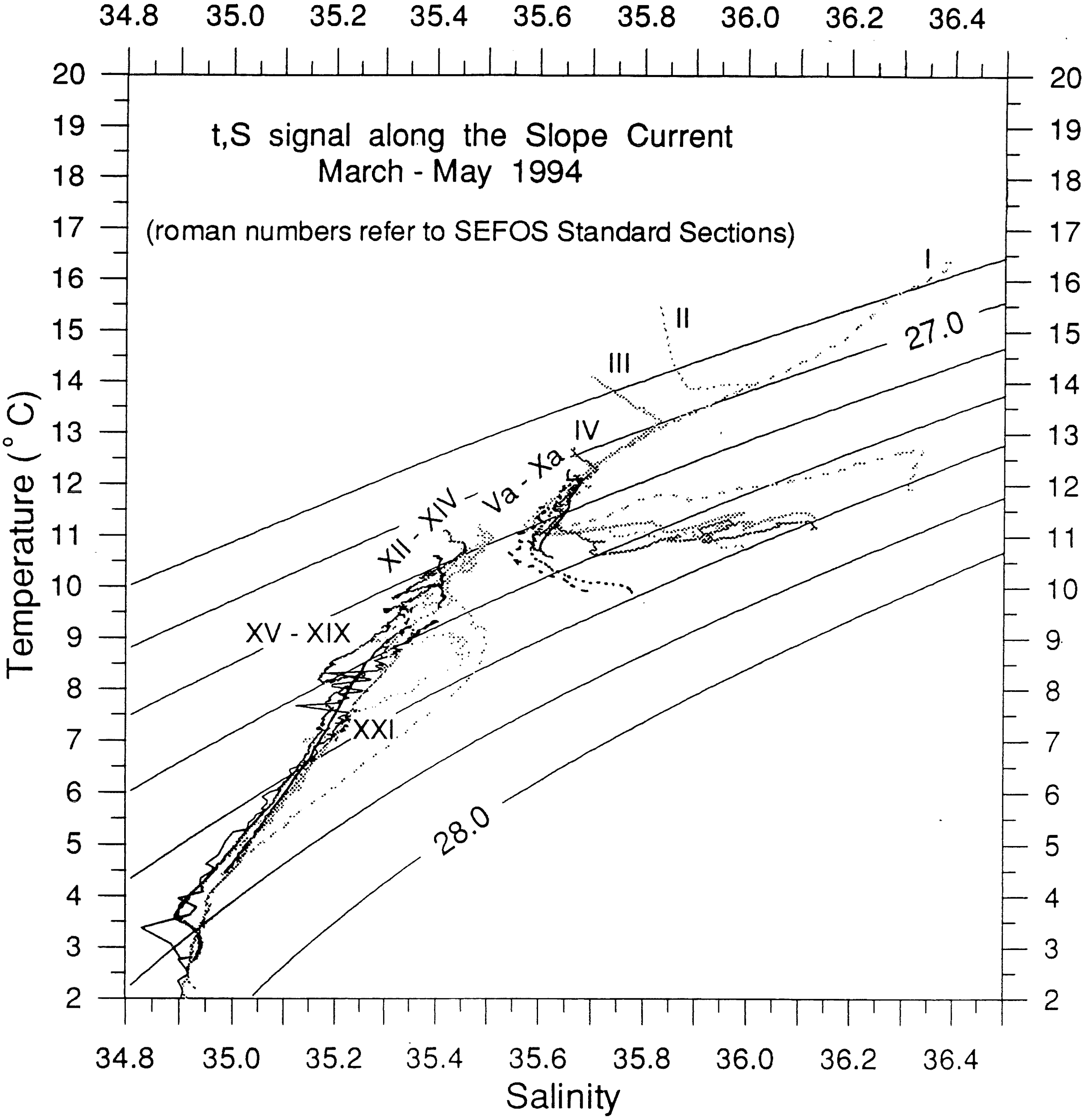
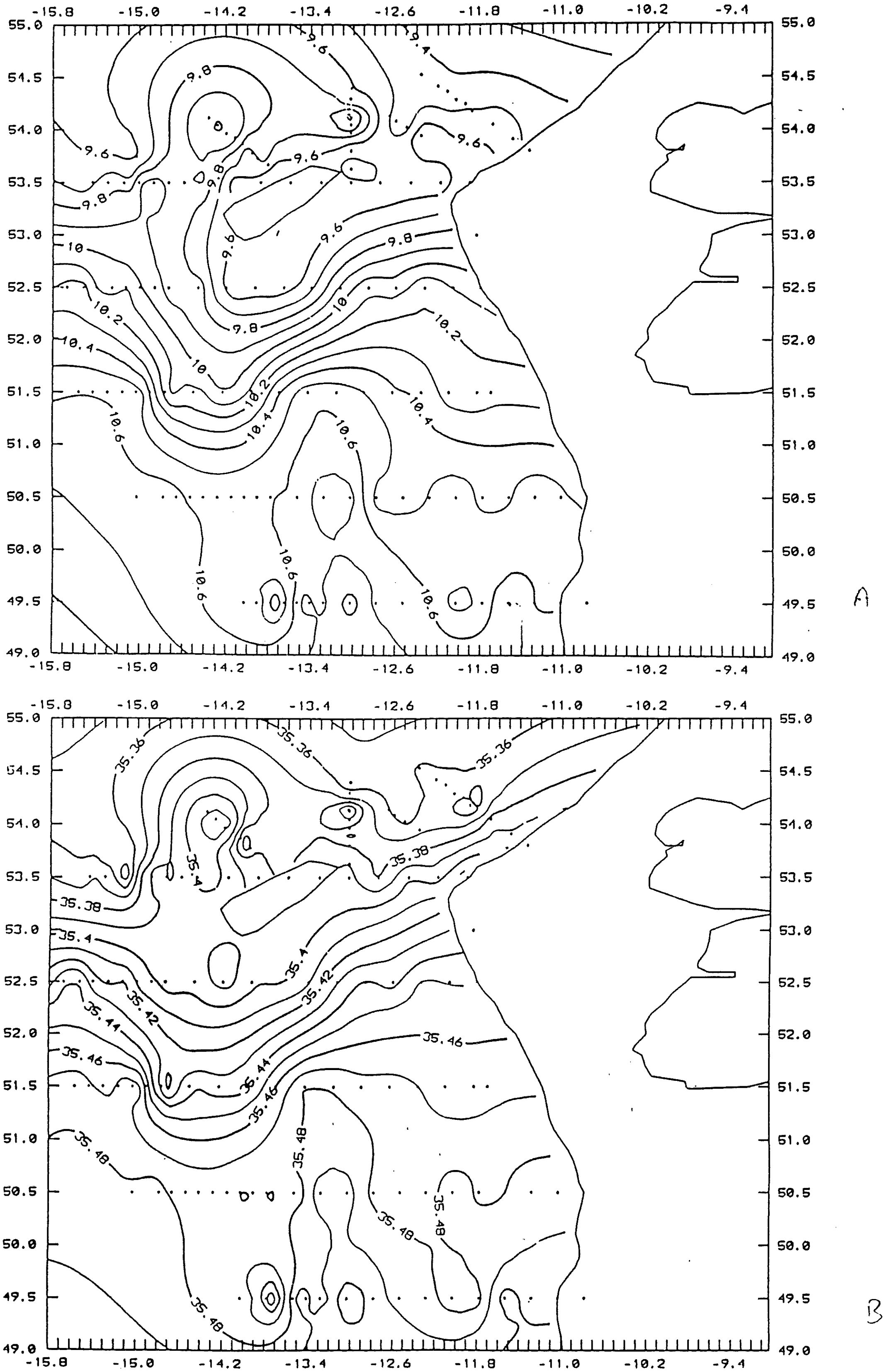


Figure 3 **Example of horizontal sections of physical properties along a selected pressure level through the Porcupine Bank SEFOS Standard Sections. Such horizontal distributions will be examined for all quasi-synoptic surveys of the shelf edge.**



Horizontal distribution of pot. temperature [°C] (A) and salinity [psu] (B) along the 200 db niveau (V144-1)

Figure 4 Computed northeastwards directed geostrophic transports through SEFOS Standard Sections 18 and 19 (Fig. 1). Data from stations between 150 m and 1,000 m have been employed (53 km wide section). A level of no motion of 550 m has been selected (Dooley and Meinke, 1981). a) Monthly observed transports. Also shown is the seasonal cycle of transport as measured by Gould *et al.* 1985 using a line of recording current meters deployed between 300-1,000 m (58 km wide section). b) Interannual values.

Figure 4a. Monthly slope transports

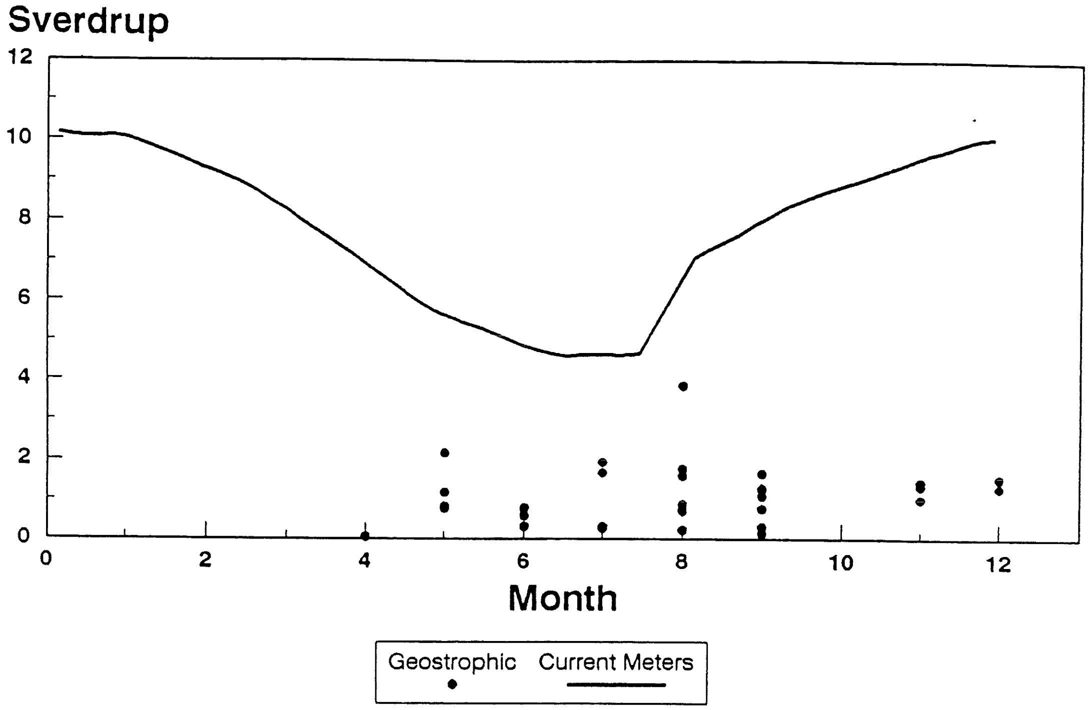


Figure 4b. Interannual slope transports

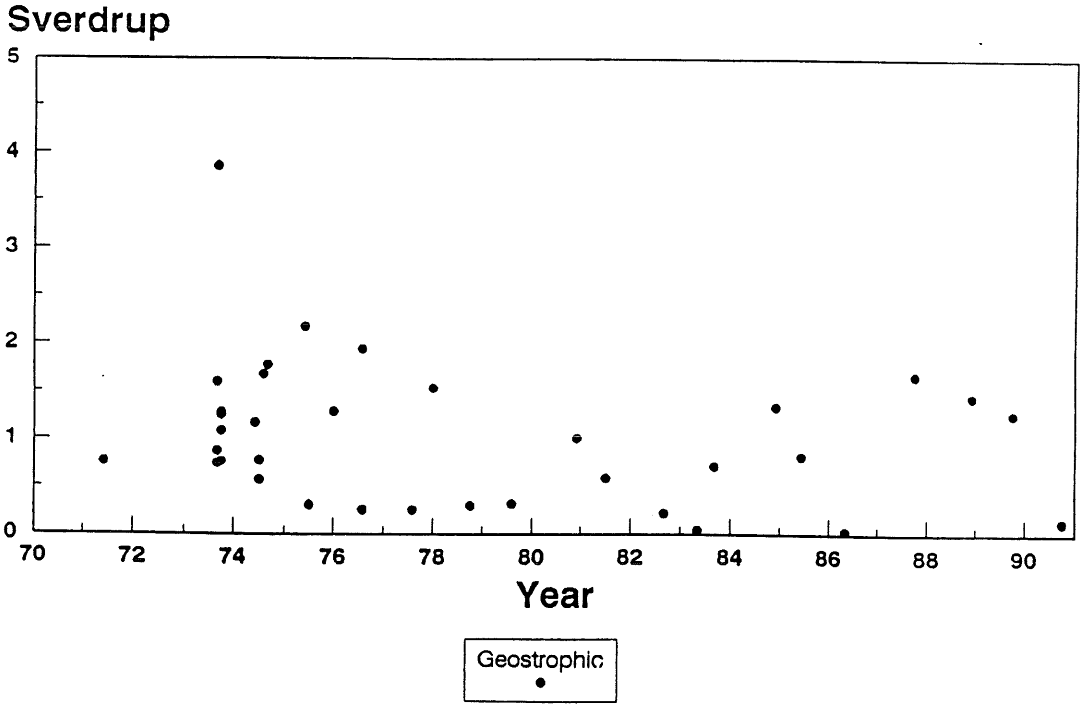


Figure 5 Seasonal variability in the potential driving mechanisms of the Slope Current (SC). a) the north-south temperature difference as calculated from monthly mean sea surface temperatures obtained in 5° x 5° bins centred at 62.5°N 2.5°W (Norwegian Sea) and 42.5°N 12.5°W (North Portugal) over the period 1951-1980. b) Monthly mean wind stress calculated from wind speed and direction as observed at Kirkwall (Orkney) at 0900 each day between 1970-1990.

Figure 5a. North-south temperature difference

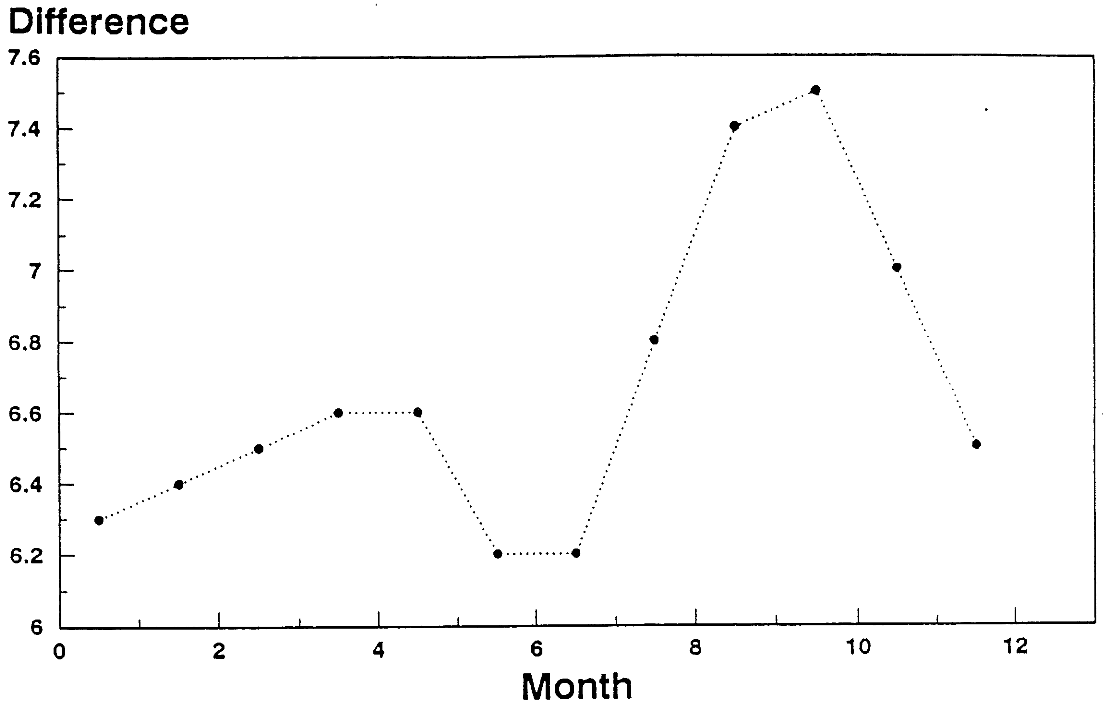


Figure 5b. Wind stress

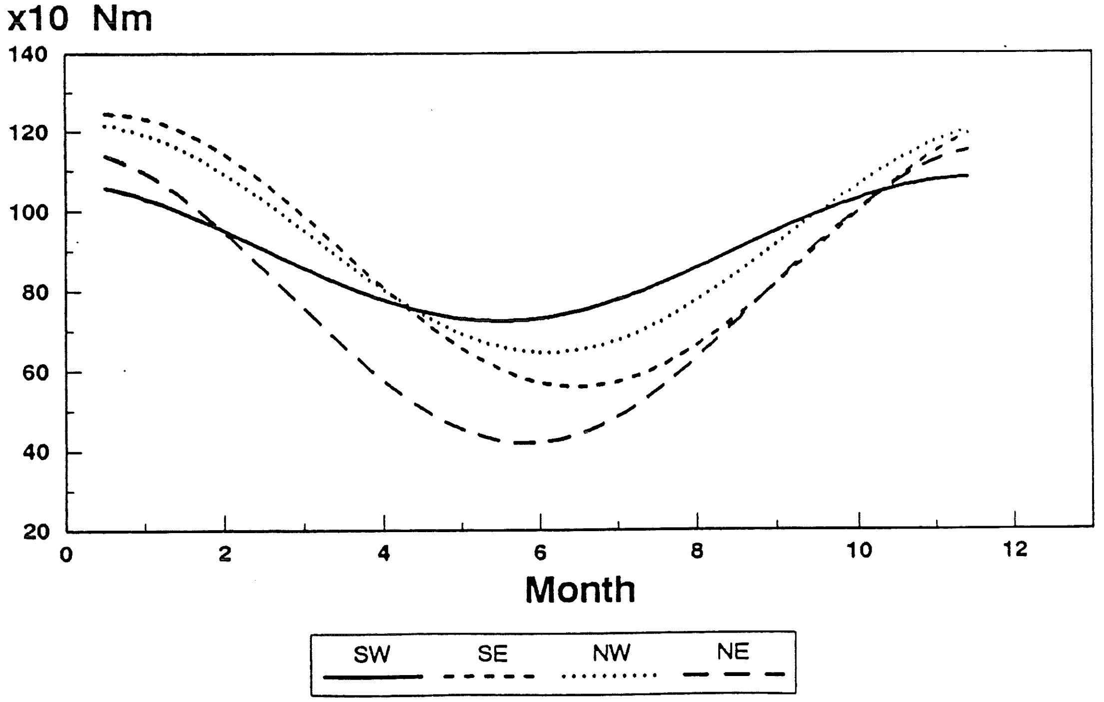


Figure 6 Interannual variation of potential driving mechanisms of the Slope Current (SC). a) North-South temperature difference during the month of February using the data employed in Figure 5a. b) Annual mean wind stress at Kirkwall.

Figure 6a. North-south temperature difference

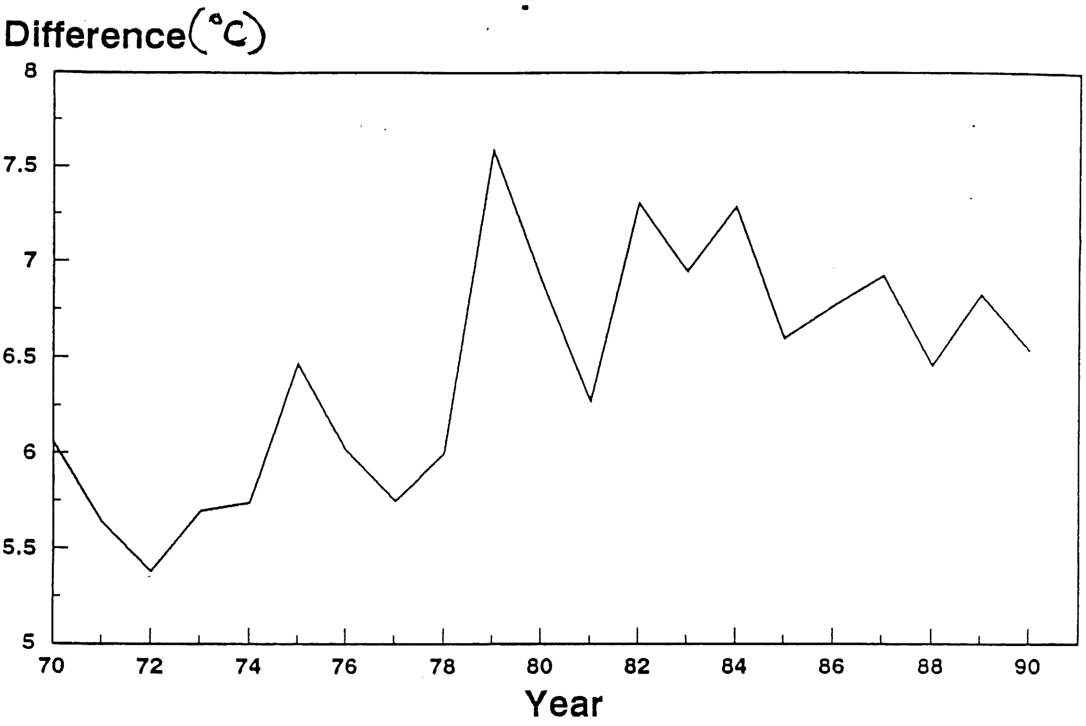


Figure 6b. Wind stress