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A Study of Circulation in the North West Approaches Region

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A Study of Circulation in the North West Approaches Region

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Synopsis

- The mesoscale variability in the surface waters of the Faroe Bank Channel and Faroe-Shetland Channel has been investigated using a combination of drifter deployments; moored current meters; ship-borne observations; and satellite remote sensing.

- Both the mean flows and scales of variability in the Faroe Bank Channel are small.

- By contrast the Faroe-Shetland Channel is a highly dynamic region with large mesoscale meanders and eddies on the deep water side of the slope current.

- Meanders

i) up to 3 or 4 can appear at fixed intervals (c 60 km) downstream of the Wyville-Thomson ridge in the Faroe-Shetland Channel

ii) can extend across the channel from the Scottish side to the Faroese side

iii) have geostrophic current velocities of up to 0.75 m s^{-1} in their frontal regions

iv) seem to grow from instabilities along the deep water edge of the slope current that are mainly baroclinic

v) have timescales of the order one to two weeks.

- Eddies

i) are found throughout the Faroe-Shetland Channel in water over about 500 m deep

ii) are of the order of 50 km across

iii) have surface velocities of up to about 0.5 m s^{-1}

iv) often seem to be formed from the breakdown of meanders

v) can also be drawn into the Faroese side of the Faroe-Shetland Channel from the Iceland-Faroes Front

vi) are generally <u>not</u> formed at the junction of the Faroe Bank Channel and Faroe-Shetland Channel (i.e. upstream of present hydrocarbon operations).

- It is recommended that a climatology of the mesoscale variability in the Faroe-Shetland Channel be drawn up from historical satellite data.

CONTENTS

1. INTRODUCTION

This report describes the results of an investigation into some of the causes of the variability of currents in the Faroe-Shetland Channel (FSC). The work was conducted by the Centre for Applied Oceanography (CAO) at the University of Wales, Bangor (UWB) on behalf of HSE. The work was commenced in late December 1998 and the fieldwork completed in May 1999. The remaining time has been spent validating, analysing and interpreting the observations.

1.1 Objectives

The work is a continuation of an earlier project (Sherwin and Jeans, 1997) in which it was demonstrated that the FSC has large eddies and meanders of the slope current. This mesoscale variability contains strong currents that may have a detrimental impact on the safety of oil industry operations.

The present project was conceived with the objectives of:

a) characterising the interaction between the surface water masses at different locations in the FSC;
b) investigating the generation processes and location of mesoscale variability (with specific reference to eddies) in the FSC; and
c) attempting to address the issue of predictability of mesoscale variability.

The methodology involved making observations of oceanographic phenomena with ship-borne *in situ* oceanographic instrumentation; drifting satellite-tracked buoys; satellite remote sensing; and moored current velocity profilers. As a precursor, a literature review of mesoscale eddies on continental slopes was conducted.

1.2 Acknowledgements

Although HSE has been the instigator and substantial funder of this work, it could not have been carried out without significant material support from other parties. The Fisheries Research Services of the Marine Laboratory, Aberdeen, lead by Dr W. R.

Turrell, provided essential seatime and ship borne observation support on FRV Scotia, and scientific advice at no cost to the project; Dr P Miller of the Natural Environment Research Councils (NERC) Remote Sensing Data Analysis Service (RSDAS) made AVHRR images of the FSC available on their web site at no charge; and first Metoc Plc, Liphook, and subsequently Fugro-GEOS Ltd, Swindon, made uncharged office space available for Martin Williams to conduct his research. The support of these organisations is acknowledged with gratitude.

2. BACKGROUND

2.1 The previous study (MatSU/8807/3464).

An earlier investigation (Sherwin and Jeans, 1997), established the extent of mesoscale variability in the FSC, and observed some very large internal waves at its southern end. The internal wave research has not been followed up, but the reports' principal findings in relation to mesoscale variability were as follows:

A cold core cyclonic (anti-clockwise rotating) eddy was observed on the Shetland side of the channel near the Foinaven site. The diameter of the eddy was about 50 km and it had surface velocities of up to 0.5 m s^{-1}. Speeds in the slope current over the 300 m isobath increased from 0.5 to 0.7 m s^{-1}, where it was squeezed by the eddy.

Although the eddy could be seen moving north-eastward along the FSC, its source, frequency of occurrence and ultimate fate were all unknown. It was suggested that it may have originated from mixing near the Wyville-Thompson Ridge.

Speeds in the slope current ranged from about 0.5 m s^{-1} over the 300 m isobath to about 0.2 m s^{-1} over the 1000 m isobath. However, just north of the Shetlands the slope current was dramatically deflected across the channel to the Faroese side. Speeds in excess of 0.6 m s^{-1} were observed in the deflection.

The present study shows the relationship between these observations and demonstrates that they were not isolated events.

2.2 Literature Review

As a precursor to the fieldwork and subsequent data analysis, a study was made of the present state of knowledge about eddies on continental slopes (Williams, 2000).

Mesoscale eddies (eddies with diameters ranging from 10 to 100 km) are ubiquitous features of the world ocean, particularly in the vicinity of strong currents and/or large density differences. It is generally accepted that they derive their energy from two unstable sources: i) available kinetic energy in regions of large horizontal shear (barotropic instability) and ii) available potential energy in regions of sloping density surfaces (baroclinic instability). The concept of 'instability' is invoked to indicate that eddies evolve when a potentially unstable condition is perturbed and then grows catastrophically. An irregularity in topography (such as the Wyville-Thomson Ridge) would be one such source of perturbation.

Once formed mesoscale eddies tend to migrate. Those that are close to a sloping bottom will tend to move with shallow water on their right (in the northern hemisphere).

Ocean eddies can be long lasting and tend to preserve their original identity. Meddies (formed from the Mediterranean outflow at 1000 m) have been found throughout the tropical N. Atlantic. Warm core eddies in the Bay of Biscay can persist for several months. The Gulf Stream off the USA sheds both warm core and cold core eddies. Eddies are found throughout the NE Atlantic (on the Iceland-Faroes front, Norwegian Coastal current, and in the Rochall Trough and FSC). They are potentially very important in global budgets of the flux of salt and heat.

2.3 Interim Report

An interim report (Williams and Sherwin, 2000) was produced in March 2000. It contained a summary of the work up to that time and a copy of the literature review.

3. RESULTS

3.1 Introduction

The methodology and results of the project are described in full in a companion report (Williams and Sherwin, 2001). Figure 1 graphically summarises the results, the salient points of which are detailed below:

3.2 Bathymetry and Water Masses

The FSC is an oceanic channel, with maximum depths in excess of 1000 m, that lies between the shelves surrounding the Faroes (on the NW side) and the Shetlands (on the SE side). At its SW end the FSC is blocked by the Wyville-Thomson Ridge where it turns towards the NW leading to the smaller and shallower Faroe-Bank Channel (FBC).

The FSC is one of the main pathways for the exchange of heat between the Atlantic and Arctic Ocean. At the surface, warm North Atlantic Water (NAW) is drawn northward in a slope current on the Shetland side of the channel. Cooler Modified North Atlantic Water (MNAW) makes its way around the Faroes and into the FSC from its northern end. At lower depths cold water from the Norwegian Basin flows southward into the Atlantic via the FBC. Mesoscale variability in both the FBC and FSC is caused by interaction between these water masses (particularly the NAW and MNAW).

3.3 Observations

The fieldwork had the objective of defining and investigating the dynamics of the southern end of the FSC, with a view to determining whether mesoscale eddies were formed there. Ship borne observations were made between 29 April and 10 May 1999 and included: hydrographic surveys with a Conductivity Temperature Depth (CTD) sensor, a surface thermo-salinograph (TSR), and Expendable Bathythermographs (XBTS). The CTD and TSR data were calibrated by FRS using standard techniques. Velocity data were collected from 5 upward looking Acoustic Doppler Current Profilers (ADCP), which were deployed as part of the Nordic WOCE programme.

Eight satellite tracked drifters, with drogues set at 100 m, were deployed and tracked until they either crossed the 0º W line or stopped transmitting. The last position was fixed on 30 July 1999. Eulerian current profiles were measured between 6 May and 6 June 1999 at 5 points across the channel by moored Acoustic Doppler Current Profilers (ADCPs). Maps of sea surface temperature were obtained from NOAA orbiting satellites and anomalies in the height of the sea surface and were derived from altimeters carried on the Topex-Poseidon and European Remote Sensing (ERS) satellites.

3.4 Data Processing

The drifter positions, which are contaminated with fix errors as well as high frequency processes such as tides, were despiked and interpolated onto a regular grid (in time) and then smoothed to remove periods in excess of 30 h. Tests were conducted to ensure that the drifter movement was consistent with the drogue being attached.

Bad data in the Nordic WOCE ADCP observations were replaced with interpolated values, and the data smoothed in the same way as the drifter positions.

3.5 Observations in the Faroe Bank Channel

An initial CTD and XBT survey was conducted between 28 and 30 April 1999 at the southern end of the FSC, where it meets the FBC. A tongue of relatively cool and fresh water (with the signature of MNAW) appeared to protrude across the FBC from the Faroes Shelf. However, there appeared to be little evidence of eddies or instabilities being created in the front between this water and the surrounding NAW. Geostrophic velocity calculations suggest that at 100 m there was a weak (0.1 m s^{-1}) NW flow over the Faroes Shelf, with stronger SE currents (up to 0.7 m s^{-1}) in the centre of the FBC and NW currents over the Wyville-Thomson Ridge.

Eight drifters were released on 1 May over the area covered by the hydrographic survey. Of these drifters 3 remained in the FBC, 2 entered the FSC but returned to the FBC and 3 entered the FSC and did not return. Although in the end nearly all the drifters left the region via the FSC, some remained in the FBC for nearly two months. The tracks revealed that, overall, velocities in the FBC tend to be less than 0.5 m s^{-1} and, furthermore, flushing of the surface waters is weak particularly close to the Faroes Bank where small eddies tend to persist for long periods.

3.6 Observations in the Faroe-Shetland Channel

Throughout May and June 1999, the deep water side of the slope current was convoluted in a series of huge meanders, which took NAW to between 50 and 100 km away from the Shetland slope. On 19 May there appeared to have been about five loops spaced fairly evenly about 60 km apart along the FSC, with the first also about 60 km from the Wyville-Thomson Ridge. The drifters moved around these meanders with speeds that sometimes exceeded 0.7 m s^{-1} (Fig.1). The meanders were not permanent features, though - over time they grew and subsequently decayed - and there was also evidence that the NAW could become attached to the Shetland slope at times.

Because the drifters escaped the FBC at fairly regular intervals over a period of nearly two months, it has been possible to derive an idea of the frequency and persistence of the dynamics

The pattern of circulation on the Faroese side of the FSC from the drifters is complex. Overall there appears to have been a slow migration of MNAW into the channel from the north, but this movement was sometimes cut off by meanders of the NAW and punctuated by large mesoscale eddies that may have interacted with the meanders.

From the spectra of the NWOCE current meters the meanders appear as peaks in the 5 and, particularly, 10 day frequency bands. Although most of this energy is found in the upper 300 m of the water column, there is nevertheless a significant equivalent enhancement of energy below 600 m. The meanders are sufficiently large that they also have a sea-surface elevation expression – analysis of a satellite borne altimeter suggested that the fastest currents in the meanders were about 0.4 m s^{-1}, which is close to (but about half) that observed by the drifters.

3.7 Analysis of the Faroe-Shetland Channel meanders

The scales of the meanders have been compared with theoretical and laboratory work, although in fact there have been very few such studies. Theoretical work involves simple parameterisations of what is essentially a very complicated structure. Although the predictions are sensitive to the choice of parameterisation, the scales of the meanders are consistent with instability theory. Theory suggests that the wavelength of a meander will increase as the meander extends into deeper water. On theoretical grounds it is estimated that the ratio of the barotropic over the baroclinic contribution to the instability is about 0.15.

Two parameters that may be important in the onset of the meanders are the width of the slope current, and the magnitude of vertical shear. It is not clear at this stage what role these factors play, if any. However, it is noted, from those satellite and drifter observations that have been examined to date, that when meanders form their spacing seems to be fairly constant from one event to another. The distance of the first meander from the Wyville-Thomson Ridge (about 50 - 60 km) is consistent with theory, and it is speculated that the meanders may be set up by flow over the ridge.

Finally, it is suggested that some of the mesoscale eddies found in the FSC are formed when the meanders grow very large. The patterns created by cyclonic eddies being generated in wave tank experiments seem to be very similar to those observed in some AVHRR images.

4 CONCLUSIONS

This study has analysed *in-situ* observations from surface drifters, fixed station survey data, and satellite measurements, and revealed much information about the dynamics of the Faroese Channels, particularly the FSC.

The measurements have characterised the nature of baroclinically unstable slope current meanders in the FSC, with a wavelength of 50 - 60 km, and shown that they play a fundamental role in the circulation of the upper layers. During their development the meanders transport NAW across the FSC and onto the Faroes slope, possibly on a time scale of 1 to 2 weeks. They thus appear to have a direct affect on the exchange of water between the FBC and the FSC and on the recirculation of upper and intermediate waters within the FSC. In addition, the meanders generate mesoscale eddies along the deep water side of the slope current, which are then able to propagate north-eastwards along the Scottish slope. It has been suggested that eddies are responsible for elevated current velocities measured at fixed locations in the FSC, but this study has shown that the meanders themselves are also associated with strong currents (~ 0.75 m s^{-1}) that flow around their edges. Interaction between the meanders and the surface waters on the Faroes side of the FSC results in cyclonic mesoscale eddies being formed upstream of each meander.

The drifters showed that the meanders impose time and length scales on the surface variability of the FSC that are much greater than those seen in the FBC, which by contrast is broadly sub-mesoscale in nature with little net through flow. The exchange of surface waters between the two channels, appears to be regulated by both the meanders and the intrusion of cool Faroes shelf water into the confluence region of the Faroese Channels. This intrusion constitutes a frontal zone that is better defined at 300 m than near the surface and is a persistent feature extending over a variable horizontal area. It influences the circulation in the southern FBC by maintaining density currents that occur across the FBC. However, there was no evidence that this frontal zone sheds eddies, as has been suggested elsewhere. Furthermore, no eddies were observed propagating into the FSC from the south, and the size of any such structures are unlikely to be as large as the mesoscale features observed there.

Further work is required to investigate the time scales and periodicity of the meanders, and the role of the Wyville-Thomson Ridge in their formation. Such work would help HSE determine the probability of extreme current events in the UK sector of the FSC, and thereby to evaluate the risk they pose. Water movement in the FSC forms part of a much larger North Atlantic circulation that contributes to the climate of Northern Europe. Many climate change scenarios involve the breakdown of this circulation, but it is not known how climate change will affect mesoscale variability in the FSC, and hence the safety of hydrocarbon operations.

The importance of satellite measurements has been established, and the opportunity exists to develop a comprehensive meander and eddy climatology through the judicious use of altimeter data and AVHRR imagery. A 'tool' of this nature would also assist with numerical model verification and with the development of a prediction capability for mesoscale variability and associated strong currents.

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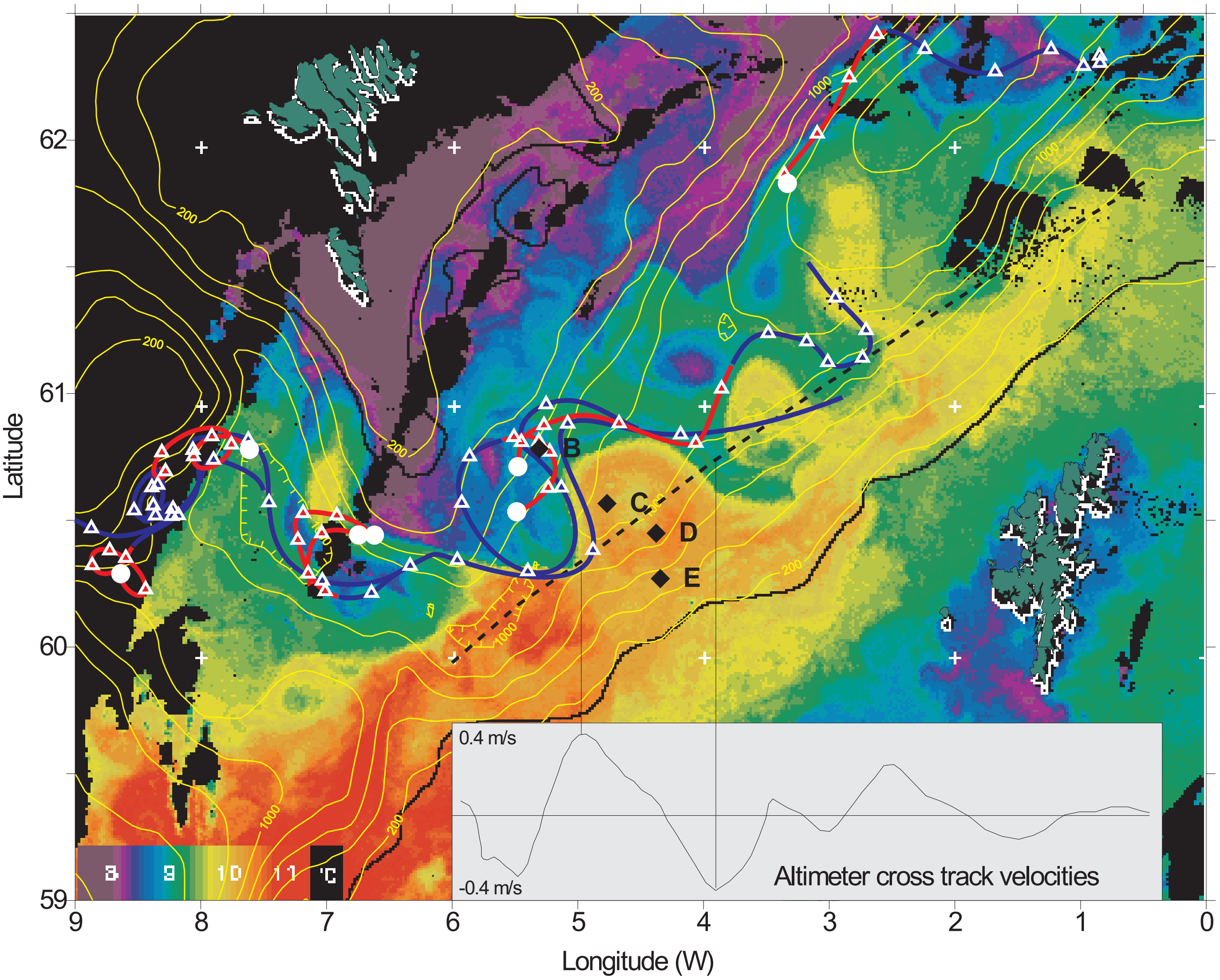

Figure 1. AVHRR SST image at 0423 h on 19 May 1999. Large meanders of the slope current can be seen in the FSC with the drifters travelling at up to 0.75 m/s. To the SW of the Faroes the drifters moved slowly, with little net movement. The smoothed drifter tracks from 15 to 25 May are coloured red before the satellite overpass and blue after it. A white dot marks the start and triangles indicate 0000 h every day. Also shown at the positions of the Nordic WOCE bottom mounted ADCP stations, B to E. The black dashed line is the track of the Topex/Poseidon altimeter on 20 May, and the panel shows the cross track geostrophic velocities.

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