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Faroe Shelf Water

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ABSTRACT

Faroe Shelf Water (FSW) is the water mass that occupies the shallow parts of the Faroe Shelf, surrounding the Faroe Islands (62°N, 7°W). Intensive tidal mixing induces a high degree of homogeneity and the circulation system allows a partial isolation from surrounding waters. This water mass, therefore, supports a unique ecosystem of great importance for commercial fish stocks and studies have shown a clear dependence of the ecosystem on the physical processes that maintain this system and control the exchange between the FSW and the off-shelf waters. In order to identify and quantify these processes, a large observational dataset has been analysed and related to alternative theories. From this analysis, the extent and properties of the FSW have been quantified and the degree of stratification explained in terms of the Simpson–Hunter theory. The residual clockwise circulation system, which is responsible for the partial isolation from off-shelf waters, is shown to be mainly generated by tidal rectification. The typical exchange rate of water between the FSW and the off-shelf regimes has been determined by the use of simple models based on the heat and the salt budgets but the actual exchange rate is found to vary considerably in time and space. These results support earlier suggestions that this exchange is the main limiting factor for the phytoplankton spring bloom on the Faroe Shelf and that variations in exchange rate are responsible for the large inter-annual variation in spring bloom timing and intensity. The observations indicate that the on-shelf/off-shelf exchange intensity is not symmetrically distributed around the shelf, but rather concentrated around the narrow southern tip of the Faroe Shelf, where off-shelf waters during intensive exchange events may be imported all the way to the shore.

1. Introduction

Faroe Shelf Water (FSW) (Hansen et al., 1998) is the relatively homogeneous water mass on the shallow parts of the Faroe Shelf (Fig. 1), which generally differs from off-shelf waters due to a partial isolation (Fig. 2). Biologically, the FSW is of great importance, since it serves as a nursing ground for several commercially important fish stocks. The FSW supports a separate and relatively simple ecosystem (Gaard et al., 2002) and the recruitment and mean weight of cod and haddock on the Faroe Plateau correlate remarkably well with the primary production on the Faroe Shelf (Gaard et al., 2002; Steingrund and Gaard, 2005). But the primary production (and thus also higher trophic levels) is seen to have a high interannual variability (Gaard, 2003).

Because of the key location at the main gateway between the North Atlantic and the Nordic Seas, a large number of expeditions have taken place in the area, but most of them have focused on the off-shelf circulation (e.g. overflow 1960 and 1973). A few of the early expeditions, however, have been made partly on the Shelf and have observed the different properties of the FSW and the off-shelf water (Knudsen, 1905, 1911; Ellet and Debrah, 1974). Since the Faroese Fisheries Laboratory (FFL) began systematic CTD observations in the early 1980s, a large number of profiles have been added to the hydrographic database of the Faroe Shelf. Also, the FFL, mainly during the late 1970s and the 1980s, carried out current measurements on the Shelf and has established coastal monitoring stations. Thus, there is a considerable amount of data available on the properties and behaviour of the FSW.

In the literature, the FSW is generally referred to as a homogeneous water mass (Hansen et al., 1998) surrounded by a shelf front, which acts like a barrier and, to a variable degree, isolates the FSW from the off-shelf waters (Larsen, 2003; Eliasen et al., 2005; Hansen et al., 2005), thus creating the basis for a separate ecosystem. A more quantitative treatment of the FSW homogeneity is missing, however, as well as a better understanding of the exchange between the FSW and off-shelf water. In spite of its evident biological importance, there has been no detailed presentation of the FSW, except for the rather brief and qualitative overview in Hansen et al. (1998). And, much of the existing documentation is in the "grey literature" that is not readily available.

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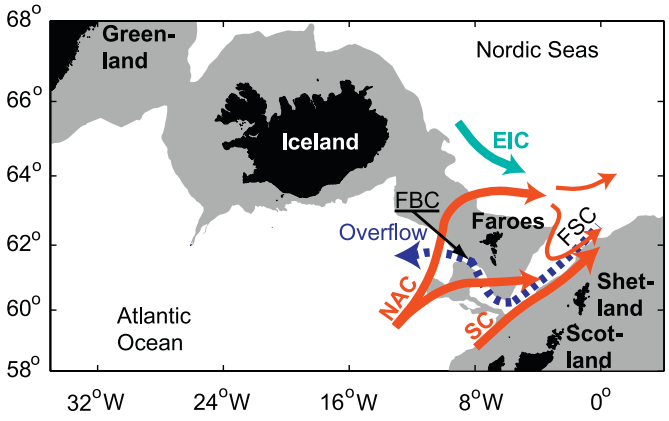

Fig. 1. The topography of the Northern North Atlantic, showing the Greenland–Scotland Ridge and the Atlantic Ocean and the Nordic Seas to the south and to the north of the ridge, respectively. Grey areas are shallower than 750 m. Red arrows indicate surface flow of warm Atlantic water carried by the North Atlantic Current (NAC) and the Slope Current (SC). Continuous blue arrow indicates surface flow of the East Icelandic Current (EIC). Dotted blue arrow indicates cold overflow water from the Nordic Seas flowing through the Faroe Shetland Channel (FSC) and the Faroe Bank Channel (FBC) to the Atlantic Ocean (deeper layers). Based on Hansen et al. (1998).

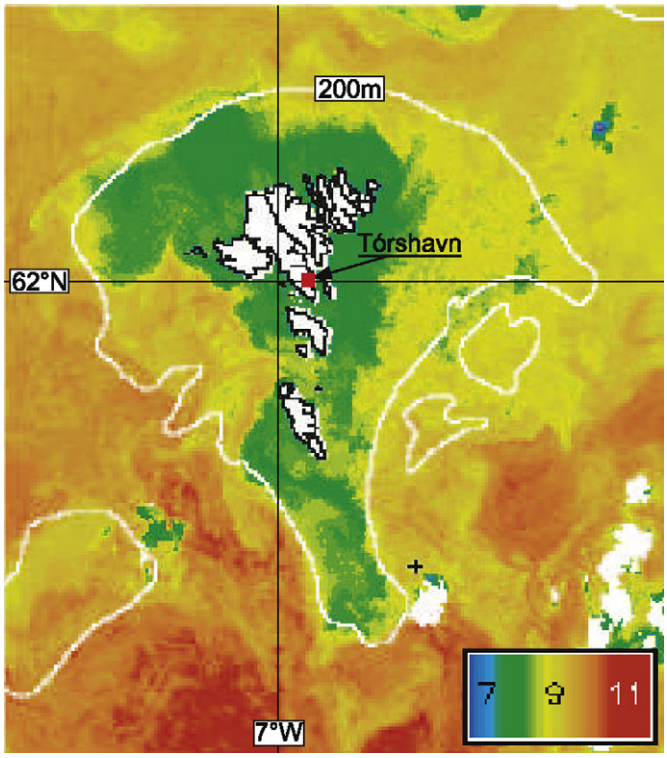

Fig. 2. Sea surface temperature around the Faroe Islands on 18 April 2003 from infrared satellite imagery. A temperature scale based on general algorithms of SST is shown in the lower right corner (in °C). The location of Tórshavn is indicated by the red square. Satellite data were received and processed by Dr. Peter Miller at the NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS) at Dundee University and Plymouth Marine Laboratory (www.neodaas.ac.uk).

The aim of this paper is therefore twofold. Firstly, we wish to present a detailed overview of the FSW that can serve as a reference source for future physical and biological studies. Secondly, we wish to address a number of questions that are of special importance to biological problems:

- How homogeneous is the FSW vertically and horizontally?
- What are the mechanisms that generate the FSW homogeneity and its separation from the off-shelf waters?
- What is the exchange rate between FSW and off-shelf waters, how does it vary in time, and what processes contribute to it?

In the following, a description of the area and surrounding waters is first given and data material and methods are presented. To investigate the homogeneity of the FSW, an analysis of vertical homogeneity in density and horizontal homogeneity in temperature and salinity are performed, based on CTD and coastal station data. The tidal currents on the Shelf are investigated using a tidal analysis of moored current meter data and the structure, variation and origin of the residual currents around the islands are investigated. Finally, an estimate of the exchange rate between FSW and off-shelf water is given and a possible exchange process is discussed.

2. Area description

2.1. Topography

The Greenland–Scotland Ridge separates the North Atlantic Ocean from the Nordic Seas, and on this ridge the Faroe Islands are situated between Iceland and Scotland (Fig. 1). The Faroe Shelf area (Fig. 2) is considered to extend to the 200 m depth contour (Hansen, 2000; Larsen, 2003); between 0 m and 200 m the area is 20 000 km^2. The 200 m contour roughly describes a triangle with a long and narrow corner pointing to the south. The width of the Shelf is thus variable, being narrowest east of the southernmost island and widest in the northwestern direction where the Iceland–Faroe Ridge encounters the Faroe Plateau.

Almost everywhere around the Faroe Plateau, the bottom depth exceeds 1000 m except for the shallowest parts of the Faroe Bank Channel west of the Plateau and the Iceland–Faroe Ridge area to the northwest.

The Faroe Islands are 18 islands separated by fjords and sounds. Current speeds on the Shelf are typically on the order of 1 m s^{-1}, but may in the sounds between the islands be several meters per second (Simonsen, 1999). In the fjords, the current speeds generally are smaller and typical maximum values here are between 0.2 and 0.3 m s^{-1} (Larsen, 1999).

2.2. Large-scale circulation

In the upper layers, three major currents influence the Faroe region: the North Atlantic Current, the Slope Current and the East Icelandic Current (Fig. 1). The North Atlantic Current enters the region from the southwest and sends branches both north of and south of the islands (Hansen et al., 1998). Together these branches embrace the Faroe Shelf area, which finds itself completely surrounded by the warm and saline water of the North Atlantic Current. Water from the other two currents seems only occasionally to penetrate onto the Shelf.

In the deeper layers, cold and dense overflow water from the Nordic Seas continuously flows equator wards through the Faroe Shetland Channel and the Faroe Bank Channel and more variably crosses the Iceland–Faroe Ridge. The Faroe Plateau is, therefore, almost completely surrounded by cold overflow water from around 500 m and deeper (Hansen and Østerhus, 2000).

2.3. Atmospheric forcing

The climate on the Faroe Islands is greatly influenced by the passing of frequent low-pressure systems, which have a main track close to the islands from a southwesterly direction. According to the climatological standard normals, 1961–1990