Continental Shelf Research 88 (2014) 171–184

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

The Faroe shelf circulation and its potential impact on the primary production

Till A.S. Rasmussen [a,*], Steffen M. Olsen [a], Bogi Hansen [b], Hjálmar Hátún [b], Karin M.H. Larsen [b]

[a] Danish Meteorological Institute, Lyngbyvej 100, Copenhagen, Denmark
[b] Faroe Marine Research Institute, P.O. Box 3051, FO-110 Tórshavn, Faroe Islands

ARTICLE INFO

Article history:
Received 17 September 2013
Received in revised form
9 June 2014
Accepted 25 July 2014
Available online 19 August 2014

Keywords:
Faroe shelf circulation
Modeling
HYCOM
Tidal front

ABSTRACT

The ecosystem on the Faroe shelf has been shown to be tightly controlled by the primary production. It has been suggested that the primary production is governed by the physical processes controlling this water mass. The objective of this study is to identify the physical control mechanisms that control this water mass, link these to the interannual variability of the chlorophyll content on the Faroe shelf and through this discuss the influence on the primary production. In order to achieve this, a 10 year hindcast (2000–2009) with a regional ocean circulation model has been set up for the focus area. Results are compared with measurements on the Faroe shelf.

The model reproduces the clockwise residual circulation around the Faroe Islands. The vertical velocity profile is validated using observations at a location west of the Islands. Observations show a logarithmic profile in the entire water column indicating a fully developed boundary layer. The modeled profile matches the observations in the bottom part of the water column, however the thickness of the bottom boundary layer is underestimated, which results in a constant profile in the upper part of the water column. As a consequence, the modeled velocity in the upper part of the water column is up to 20% lower than the observed velocity. The direction of the modeled velocity profile compares well with observations. The model realistically forms the partly isolated unique shelf water mass. Years with anomalously early and persistent modeled spring stratification correspond with years with a high on-shelf chlorophyll concentration.

An integration of the exchange across the 120 m isobath shows intense water mass exchange across this depth contour. The major part of this includes tidal shifting of the front between on-shelf and off-shelf waters and is associated with little effective water mass exchange. The result is a shelf water mass that is relatively isolated. The modeled net exchange is constituted by an on-shelf flow near the surface and an off-shelf flow near the bottom associated with the frictional boundary layer. This is confirmed by the tracer experiment. Both the tracer experiment and the exchange across the 120 m isobath indicate that there is spatial variability in the exchange of the shelf water.

The renewal rate of the shelf water mass during the spring bloom period is assessed by a set of passive tracer simulations. Using passive tracers, the time scale for the half-life is found to be between 30 and 40 days. This compares favorably with the time-scale based on the net, advected water mass exchange that yields 60–70 days, considering that this estimate neglects turbulent and diffusive exchange.

1. Introduction

The large scale surface circulation around the Faroe Islands is governed mainly by the presence of warm North Atlantic water. The relatively warm North Atlantic Current (Hansen and Østerhus, 2000) splits into two branches upstream of the Faroe Islands. These are the Shetland branch to the south and the Faroe Current (Hansen et al., 2003) to the north of the Faroes. The Faroe Current bifurcates northeast of the Faroes, with one branch continuing northeastwards towards Norway (Mork and Skagseth, 2010), and the other turning south into the Faroe-Shetland Channel where it merges with the Shetland branch.

A tongue of cold low-salinity East Icelandic water extends southeastwards towards the Faroe Current, establishing the so-called Iceland-Faroe Front (Pistek and Johnson, 1992) between the sub-arctic and the Atlantic water masses.

The Faroe shelf water mass is the water mass that is located on the shallow areas around the Faroe Islands, typically defined to be

* Corresponding author.
E-mail address: tar@dmi.dk (T.A.S. Rasmussen).

http://dx.doi.org/10.1016/j.csr.2014.07.014

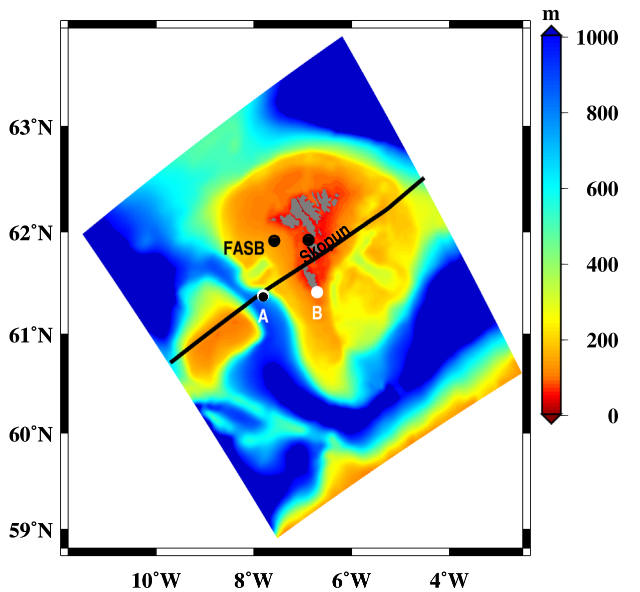

Fig. 1. Bathymetry around the Faroe Islands. The black line indicates the cross section where modeled data has been extracted. The white dot denoted A is the location where the modeled off-shelf data is extracted. Black dots are the data points where modeled and measured data are compared. The white dot, B, indicates the location of the measured data on the shelf south of the Faroe Islands.

within the 100 m depth contour, see Fig. 1. The shelf water mass is isolated from the surrounding water masses by a clockwise residual circulation, mainly generated by tidal rectification, that restricts the exchange (Larsen et al., 2008). Furthermore, the tidal currents mix the shelf water mass, which results in a fully mixed water column on the shallow parts of the shelf most of the year.

One effect of the separation of water masses is an ecosystem that differs from the surrounding waters (Debes et al., 2008). The marine ecosystem on the Faroe shelf has been shown to be tightly controlled by the primary production during the spring bloom with sandeel, economically important demersal fish stocks as well as seabirds clearly linked to the intensity of the spring bloom (Gaard et al., 2002). The spring bloom has been monitored since the early 1990s (Gaard et al., 1998) and is found to have huge interannual variability. A complete explanation for these variations has not been demonstrated, but it has been suggested (Eliasen et al., 2005; Hansen et al., 2005) that physical processes on the shelf, including circulation and cross-shelf exchanges, are the main controlling mechanism of the spring bloom.

A 2D diagnostic ring model has been described by Eliasen et al. (2005) and Larsen et al. (2009). This simplified model study of the Faroe shelf waters established an effective exchange rate of ~75 days between the shelf water and the off-shelf water based on the temperature variation and the heat flux from the atmosphere. Their model gave a reasonable salinity variation across the shelf, but it was unable to replicate abrupt changes seen in the observations.

In order to investigate the physical properties of the water masses and the circulation on the Faroe Island shelf, a high resolution (~1 km) physical 3D ocean model has been set up and a hindcast has been conducted for the period from 2000 to 2009. The results from this hindcast are compared with observations of temperature, salinity and currents on the shelf and the ability of the model to explain the observed physical properties and variations are discussed.

Section 2 describes the model setup, and Section 3 describes the observations. Section 4 follows with a brief description of comparisons of modeled and observed temperature, salinity and velocities. After this, Section 5 describes the modeled circulation, properties on a cross section (salinity, temperatures and velocities), the exchange of water masses between the shelf and the open ocean, and the results from a passive tracer experiment. Finally, Section 6 discusses the performance of the model and to what extent it helps explain the processes that control the primary production on the Faroe shelf.

2. Model description

The model is a slightly modified version of HYCOM (HYbrid Coordinate Ocean Model) v2.2.18 (Chassignet et al., 2007; Bleck, 2002). HYCOM exploits a hybrid coordinate system that is isopycnal in the open, stratified ocean, but smoothly reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or unstratified seas. This results in a z-level model on the Faroe shelf. The vertical mixing is defined by the KPP scheme (Large et al., 1994).

The oceanographic boundary conditions are provided by a hindcast archive from the Danish Meteorological Institute, which covers the Arctic and the North Atlantic Ocean. The horizontal resolution of the oceanic boundary conditions is approximately 10 km in both directions. The body tides are described with eight tidal constituents, namely Q1, K2, P1, N2, O1, K1, S2 and M2. The hindcast covers the period from the beginning of 2000 to the end of 2009. An average of the temperature and the velocities at 100 m depth for the year 2007 can be seen in Fig. 2.

The high resolution regional model is based on the same model that is used for the oceanographic boundary conditions. The horizontal grid size ranges from 750 m to 1300 m and the resolution is highest near the Faroe Islands. This model setup has 340 grid points in the southwest/northeast direction and 400 grid points in the southeast/northwest direction. 32 vertical layers have been used for this regional setup. 14 layers are present at the 100 m contour. The bathymetry is extracted from ETOPO1 (Amante and Eakins, 2009) combined with measurements conducted by the Faroe Marine Research Institute (FAMRI) and the coast guard (Simonsen et al., 2002).

In order to resolve the external tides, the boundary conditions are based on a linear interpolation between hourly snapshots. The barotropic velocities are prescribed on the boundary along with the sea surface height, whereas the baroclinic velocities, the temperature and the salinity are prescribed by a relaxation towards the boundary conditions on the outermost 10 grid points.

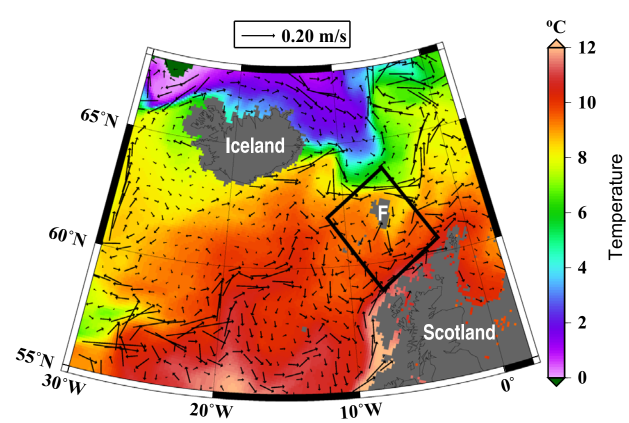

Fig. 2. The 2007 averaged temperature (colors) and velocities (arrows) at depths of 100 m around the Faroe Islands. The data has been extracted from the North Atlantic hindcast simulation that serves as boundary conditions. F denotes the Faroe Islands.The black square shows the location of the nested domain. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)