Available online at www.sciencedirect.com

SCIENCE DIRECT®

Continental Shelf Research 25 (2005) 1541–1560

CONTINENTAL SHELF RESEARCH

www.elsevier.com/locate/csr

Circulation and shelf–ocean interaction off North Norway

Jofrid Skarðhamar[a,*], Harald Svendsen[b]

[a]Akvaplan-niva AS, Polar Environmental Centre, N-9296 Tromsø, Norway
[b]Geophysical Institute, University of Bergen, Allégt. 70, N-5007 Bergen, Norway

Received 19 April 2004; received in revised form 7 April 2005; accepted 11 April 2005
Available online 17 June 2005

Abstract

The narrow continental shelf off Troms has a complex topography with deep trenches separating shallow banks. The front between Atlantic Water (AW) and Norwegian Coastal Water (NCW) is found near the shelf break and the currents in the area are topographically steered by the shelf slope. We have investigated the combined effects of topography, seasonal stratification, wind and tides on circulation and shelf–ocean interaction using field measurements and numerical simulations of hydrography and currents. Comparisons between simulation results and field measurements show that the model behaves realistically in terms of the distribution of NCW and general circulation. Effects of wind, tides and topography on the currents are shown to be strongly dependent on the stratification, which shows large seasonal variations in the area. Topographical effects on surface circulation are weakened when stratification increases. During stratified conditions winds have a strong impact on surface circulation and shelf–ocean exchange, and the wind direction is crucial for drift paths and residence times for particles (e.g. plankton) in the shelf area. When stratification is weak, tidal effects combined with topographic steering dominate the circulation.

Keywords: Shelf dynamics; Coastal currents; Upwelling; Bottom topographic effects; Numerical model; Tides; North Norwegian shelf

1. Introduction

Shelf areas typically have steep topography that traps currents along the shelf slope thus creating bio-geographic boundaries and fronts that appear to have high primary production relative to surrounding regions (Holligan, 1981; Franks, 1992). Also apparent is the often high zooplankton and fish production of shelf/frontal zones (Brander and Hurley, 1992). The shelf area outside Troms, which is the focus area of this study, hosts large and commercially important fisheries. In 1999 approximately 70 000 tonnes of cod and herring were landed from the area extending from Lofoten to Malangsgrunnen and west of Tromsøflaket (Anonymous, 2002). In addition, there were substantial catches of capelin in this region. For

*Corresponding author. Tel.: +47 77750316;
fax: +47 77750301.
E-mail addresses: jsk@akvaplan.niva.no (J. Skarðhamar), harald.svendsen@gfi.uib.no (H. Svendsen).

0278-4343/$ - see front matter
doi:10.1016/j.csr.2005.04.007

several decades fluctuations in geophysical parameters (temperature, vertical stability, etc.) have been used to explain variable plankton production and fish abundance (see e.g. Parsons, 1975; Parsons and Lalli, 1988; Ådlandsvik and Sundby, 1994; Svendsen et al., 1995; Ådlandsvik et al., 2004). Somewhat less focus has been put on the potential effects of variability in medium and large-scale circulation patterns on marine biomass redistribution, fish recruitment conditions and migration patterns (Lear and Green, 1984; Franks and Anderson, 1992). The shelf area off Troms is important for studying population dynamics of *Calanus finmarchicus,* as this is a key area for the advection of Atlantic zooplankton into the Barents Sea (Edvardsen et al., 2003; Halvorsen and Tande, 1999).

The main water masses along the Norwegian coast are of coastal and Atlantic origin. Runoff from the European continent into the North Sea, from the Baltic into Kattegat, and from rivers and fjords along the Norwegian coast contribute to the northward buoyancy-driven flow named the Norwegian Coastal Current (NCC). NCC consists of relatively cold and low salinity water termed Norwegian Coastal Water (NCW). The North Atlantic Current (NAC), containing Atlantic Water (AW) is characterised by salinities above 35 (Helland-Hansen and Nansen, 1909), and flows into the Nordic Seas between Iceland and Shetland. The main part of the NAC continues along the Norwegian continental shelf slope as the Norwegian Atlantic Current (NWAC), advecting relatively warm and saline water northwards. At Tromsøflaket the NWAC splits into two branches; one continues northwards to Spitsbergen along the shelf slope of the western Barents Sea, the other heads eastwards into the Barents Sea (see e.g. Helland-Hansen and Nansen, 1909; Hopkins, 1991; Simonsen and Haugan, 1996; Furevik, 2001).

The main water masses found on the shelf and shelf-slope area off the North Norwegian coast are NCW and AW. NCW has salinity less than 35 (Sundby, 1984), and stretches like a wedge out over the shelf edge merging with AW. Norwegian Sea Deep Water (NSDW), with salinity less than 34.95 and temperature less than 0 °C, fills the Lofoten basin below about 800 m. The temperature of AW and NCW, and the salinity of NCW, change with the season, while both temperature and salinity of NSDW are relatively constant throughout the year. According to Sundby (1976) the NCW is broad and shallow (50 m) during summer and narrow and deep (200 m) during winter. This seasonal change in the lateral extent of the coastal water is related to the changes in stability caused by seasonal variation in runoff and strength of vertical diffusion (Haakstad, 1977). It is additionally affected by the influence of Ekman drift caused by the monsoon-like variation pattern of the prevailing wind direction along the coast (Sætre et al., 1988). The dominating wind directions are from the southwest in winter and the northeast in summer, with usually considerably stronger winds in winter than in summer (Børresen, 1987; Hopkins, 1991). Storms may induce considerable transport of water in the upper layers in other directions than that of the prevailing wind (Sundby, 1976). The changing stratification of NCW affects the speed of the current as indicated by direct measurements (Eide, 1978); these show the mean currents to be strongest in the autumn (September–December). The greatest current velocities are typically found near the shelf break (Sundby, 1976). It is expected that turbulence related to strong shear flows in this area and formation of eddies in the front and over banks or seamounts are the main energy sources for mixing of AW and NCW. The tide propagates as a Kelvin wave northwards along the Norwegian coast, dominated by the semi-diurnal component (M2). According to Moe et al. (2002) and Ommundsen and Gjevik (2000), the amplitude of M2 decreases over the narrow shelf north of Lofoten, and the diurnal current component (K1) increases due to shelf wave resonance.

In this paper, the results from an investigation carried out in the shelf area between Andenes (69°20′N) and Tromsøflaket (71–72°N), the narrowest part of the Norwegian continental shelf, are presented (Fig. 1). The width of the shelf, defined here as areas shallower than 200 m, varies from less than 10 km near Andenes to 60 km at Nordvestbanken (Fig. 1). The shelf slope is steep (~15°) with depths increasing from 200 to 1000 m