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Mixing in the Barents Sea Polar Front near Hopen in spring

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A B S T R A C T

Observations were made of hydrography, nutrients and shear microstructure in the water column across the Barents Sea Polar Front near Hopen. Profiles were collected in early May 2008 along a 125-km section extending from the Hopen Trench, across the front between the Arctic and Atlantic origin waters, and on toward the Spitsbergenbanken. Additionally a 10-h time series station was undertaken near the front. The Polar Front was identified near the 150 m isobath, coinciding with the 1 °C isotherm, with strong horizontal gradients in the temperature and salinity fields, which compensated in density. A second tidally-generated front with a strong horizontal density gradient was detected on the bank, dominated by salinity gradients due to ice melt. Biological activity was elevated between the two fronts. Nutrients were depleted in the euphotic zone where the chlorophyll concentrations were significantly enhanced relative to the stations on the warm side of the Polar Front and in the tidally mixed area. Below a turbulent surface layer, the water column on the warm side of the front was quiescent. Farther on the bank the turbulent boundary layers near the surface and seabed merged and the entire water column was turbulent. Energy arguments show that tidal straining together with stirring due to wind and tides can overcome the stratification induced by melting and heating, maintaining the tidal front. A mechanism is proposed whereby high nitrate concentrations on the warm side of the front are transported along the isopycnals onto the bank where tidal mixing then effectively mixes the nutrient-rich deep water upward, sustaining the phytoplankton bloom.

1. Introduction

The confluence of cold, low saline Polar waters of Arctic origin and warm, high saline waters of Atlantic origin in the Barents Sea forms the Barents Sea Polar Front (BSPF). The physical oceanographic conditions of the Barents Sea, including the main water masses and the circulation patterns contributing to the formation of BSPF, have been described in Loeng (1991) and Pfirman et al. (1994). The position of this thermohaline front is largely controlled by the topography (Gawarkiewicz and Plueddemann, 1995). The summertime conditions associated with the BSPF near Bear Island were described in Parsons et al. (1996). The surface expression of the front in summer tends to be dominated by a surface salinity gradient as a result of summer ice melt (Harris et al., 1998) and moves laterally on the order of 10 km associated with tidal oscillations. Beneath this shallow density front and the mixed layer, was a nearly barotropic, density compensating front with a moderate temperature gradient co-located with the 2 °C isotherm.

Frontal systems, owing to the different water masses, are home to transitions in physical and biogeochemical parameters as well as in the composition and productivity of species. Fronts are often associated with enhanced primary production (Le Fèvre, 1987) generally owing to vertical nutrient fluxes through enhanced mixing or upwelling (e.g. Allen et al., 2005). Fronts also are regions of high zooplankton and fish larvae concentrations (Franks, 1992; Munk et al., 2009) resulting in "hot-spots" of marine life (Belkin et al., 2009). Key ecosystem components and basic food web structure of the Barents Sea have been reviewed by Wassmann et al. (2006) and Loeng and Drinkwater (2007). The BSPF plays an important role as a faunal boundary separating boreal and arctic flora and fauna (Fossheim et al., 2006; Hassel, 1986; Owrid et al., 2000). In addition, certain fish species such as capelin (Gjøsæter, 1998), as well as marine mammals, have been associated with the Barents Sea Polar Front.

Cross-frontal transport and vertical mixing are essential to supply nutrients from the deeper parts of the water column to the euphotic zone, and given sufficient illumination, these processes might control the primary productivity. Cross-frontal exchange depends critically on frontal instability and relaxation of geostrophic constraints through friction (Huthnance, 1995). The very presence of a front suggests a local reduction in turbulent diffusivity as the density gradient suppresses mixing. Locally enhanced mixing rates, however, have been observed in frontal regions and in the marginal ice zone of the Barents Sea (Fer and Sundfjord, 2007; Sundfjord et al., 2007). Detailed knowledge of the mixing processes and reliable measurements of turbulent fluxes are necessary to quantify the rate at which nutrients become available for primary production. The International Polar Year (IPY) project

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entitled Norwegian Component of the Ecosystem Studies of Subarctic and Arctic Regions (NESSAR) focused on the physical and biological processes at the fronts separating the warmer Atlantic origin waters and the colder waters of Arctic origin in both the Norwegian and Barents Sea. In this study investigations of the dynamical frontal processes in the Barents Sea Polar Front near Hopen are reported with focus on mixing and utilizing microstructure measurements.

2. Measurements and data

Observations were made from the research vessel *Jan Mayen* between 24 April and 18 May 2008. The dataset reported here is a subset of the cruise data and includes vertical profiles of hydrography from a conductivity–temperature–depth (CTD, Sea-Bird Electronics SBE911+) package and of turbulence from 180 casts of a vertical microstructure profiler (MSS, ISW Wassermesstechnik, Germany). The CTD system consisted of the CTD sensors, a fluorometer (Aqua-III) and a SBE32 rosette with twelve 5-liter Niskin bottles. Nutrient samples were collected during the upcast at discrete depths from the water bottles on the rosette. Chloroform was added to the nutrient samples and the samples placed in a refrigerator on board the ship. Upon return to port, they were transported to the Institute of Marine Research in Bergen to undergo analyses for dissolved inorganic nutrients (nitrite, nitrate, phosphate and silicate) according to standard methods (Parsons et al., 1992) adapted to an auto-analyser (Rey et al., 2000).

A station location map is shown in Fig. 1. The sampling was made along a line extending from the Hopen Trench in about 250 m depth, across the BSPF, and on toward the shallow Spitsbergenbanken (Spitsbergen Bank) southwest of Hopen. The line was approximately 125 km long oriented along 145° from due East (i.e. −55°T), approximately perpendicular to the orientation of the 100 m isobath. Although we did not undertake a spatial survey of the hydrography in the region, we assume that the position of the BSPF is guided by the topography (Gawarkiewicz and Plueddemann, 1995) and interpret the orientation of the transect as the cross-front direction. The occupation time of stations with respect to the tides and the spring-neap cycle is shown in Fig. 2. The sampling was undertaken during spring tides and in transition to neaps. Sea ice was present on top of Spitsbergenbanken during the cruise; however, the tendency was for a gradual reduction in the amount of ice over the duration of the study.

Section A (the main sampling line) was occupied twice; in the first run, indicated by A0 in Fig. 2, the shipboard CTD was deployed at selected stations where nutrients were also sampled. In the second run, indicated by A, station spacing was denser and the microstructure profiler was deployed following the shipboard CTD at each station. Upon completing the A section, a time series station (TS) was occupied for about 10 h at a site in the vicinity of the BSPF with a depth of approximately 150 m.

The MSS was equipped with accurate CTD sensors, a fast response thermistor (FP07) and a pair of microstructure airfoil shear probes used in measuring the viscous dissipation rate of turbulent kinetic energy per unit mass (ε, dissipation rate hereafter). High resolution temperature gradients were also sampled from the FP07. Data from all channels were sampled during the downcast at 1024 Hz at a typical profiling speed of 0.6–0.7 m s^{-1}. The MSS was deployed along Section A and as a time series close to the front (station TS) (Fig. 1). Profiles of temperature and salinity measured by MSS were averaged in 10-cm vertical bins; turbulent variables were derived for 1-m vertical bins. Turbulence is inherently intermittent and averaging increases the statistical reliability of the results. We therefore chose a sampling strategy where we collected 3 (Section A) to 5 (station TS) continuous repeat casts at each station. All profiles presented in this study are ensemble averages (isobaric) of the repeat casts.

Salinity data from the shipboard CTD were calibrated using water samples collected at the bottom of the CTD cast from Niskin bottles attached to the rosette. The corrected CTD profiles were then compared to the MSS-derived salinity. Using all MSS-SBE CTD profile pairs close in

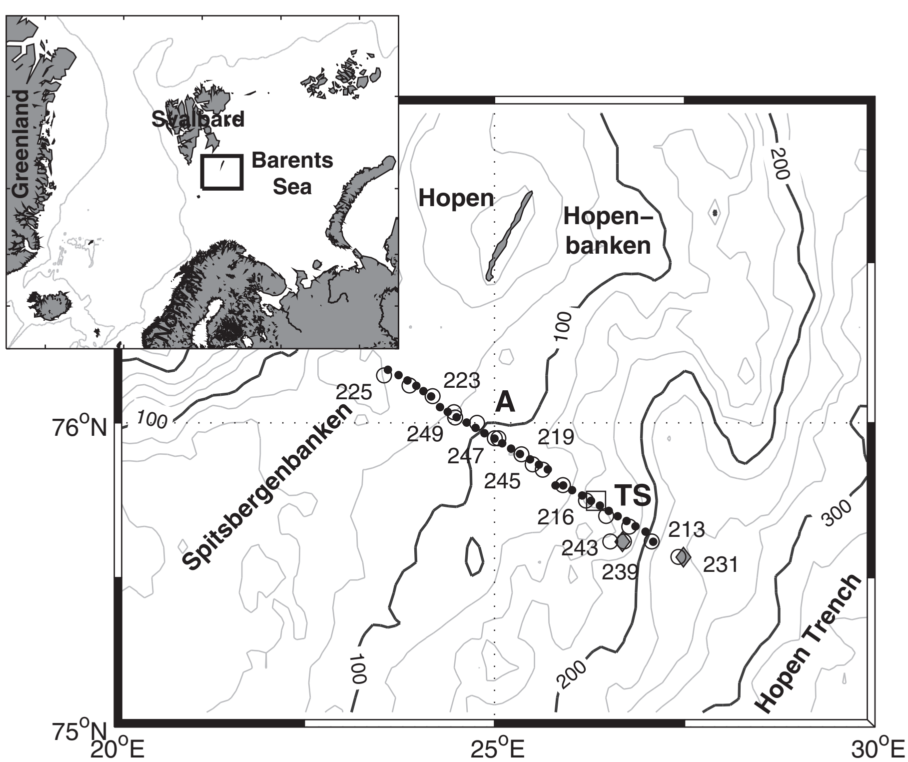

Fig. 1. Location map of the study region together with the place names and the positions of the stations. Bathymetric contours are drawn at 25 m intervals. The inset identifies the region (box) in the Barents Sea shown in detail and the 1000-m isobath (gray). Microstructure profiles were collected along section A (dots), at the time series station TS (square) and at stations 231 and 239, marked by diamonds, occupied prior to section A. Shipboard CTD measurements were made at each station of section A, and also during an earlier occupation of the section (A0) with coarser station spacing (open circles). Nutrient sampling was conducted at all stations indicated by circles.