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Diurnal tides on the Barents Sea continental slope

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ABSTRACT

Measurements of diurnal tides over the continental slope between the Norwegian Sea and the Barents Sea shelf are presented. Numerical 3D simulations, in agreement with field data, show strong cross-slope velocities and large vertical displacements of the interface between Atlantic Water and intermediate water over the slope. The striking correspondence between the prominent observed and modeled diurnal oscillations gives confidence that this is well represented by the model. This variability, interpreted as tidally induced diurnal period topographic waves, is confined to the diverging topography of the continental slope west of Tromsøflaket. The model results reveal highly variable magnitudes of the oscillations and the cross shelf currents in time, related to variable strength of the background flow, the Norwegian Atlantic Current. We suggest that the diurnal topographic wave can be an effective mechanism for cross slope exchange between the Norwegian Sea and the Barents Sea shelf, and important for benthic and pelagic biological processes on the shelf and slope.

1. Introduction

The ocean circulation in the Nordic Seas is characterized by topographic steering (Helland-Hansen and Nansen, 1909), with the Norwegian Atlantic Current (NAC) carrying warm Atlantic Water (AW) northwards along the Norwegian continental shelf break. Over the continental shelf slope the AW occupies the upper ~600 m of the water column, and below this the colder and less saline intermediate water (IW) is found. Norwegian coastal water (NCW) flows northwards along the coast and over the continental shelf as the Norwegian coastal current (NCC). The vertical and horizontal extent of the NCC varies seasonally, and the front between the NCW and AW is characterized by eddies and meanders (Ikeda et al., 1989; Johannessen et al., 1989). At Tromsøflaket, a bank area at the entrance to the Barents Sea (Fig. 1), the NAC splits into two branches, one flowing eastwards into to the Barents Sea, and the other northwards to Spitsbergen and the Fram Strait (Furevik, 1998, 2001).

There is great interest in understanding the local ocean dynamics and the interaction between the water masses in the Tromsøflaket area to explain the transport mechanisms of plankton (such as fish eggs and *Calanus finmarchicus*) into the Barents Sea (Aksnes and Blindheim, 1996; Edvardsen et al., 2003), the observed distribution of benthic species on the continental shelf and slope (Buhl-Mortensen et al., 2012), and sediment distribution on the seabed (Bøe et al., 2013; King et al., 2014). Previous model studies have shown that the interaction between tides and topography produce topographic waves along the continental slope off Northern Norway (Ommundsen and Gjevik, 2000) and that diurnal components are enhanced at Tromsøflaket (Kowalik and Proshutinsky, 1995). Such waves could initiate large excursions of the interface between AW and intermediate water due to interaction with the sloping bottom. Diurnal topographic waves have been observed both in the Arctic (Hunkins, 1986; Padman et al., 1992), and in the Antarctic (Middleton et al., 1997; Padman et al., 2009). However, observations confirming such variability have so far been lacking for the Northern Norwegian continental margin.

In this paper we present high resolution time series of measured temperature, salinity and currents near the sea bed resolving the diurnal tides on the Tromsøflaket slope. We support the interpretation of these data using simulations with a high-resolution ocean circulation model. We show that the model reproduces the key features of the observations well, and use the model results to discuss the regional differences connected to the bottom slope. In a companion paper (Bøe et al., 2014), these model fields are integrated with geological data to explain the generation and development of sandwaves on the continental slope.

2. Methods

2.1. Numerical modeling

We used an extended version of the 800 m grid model NorKyst800 developed by the Institute of Marine Research (IMR),

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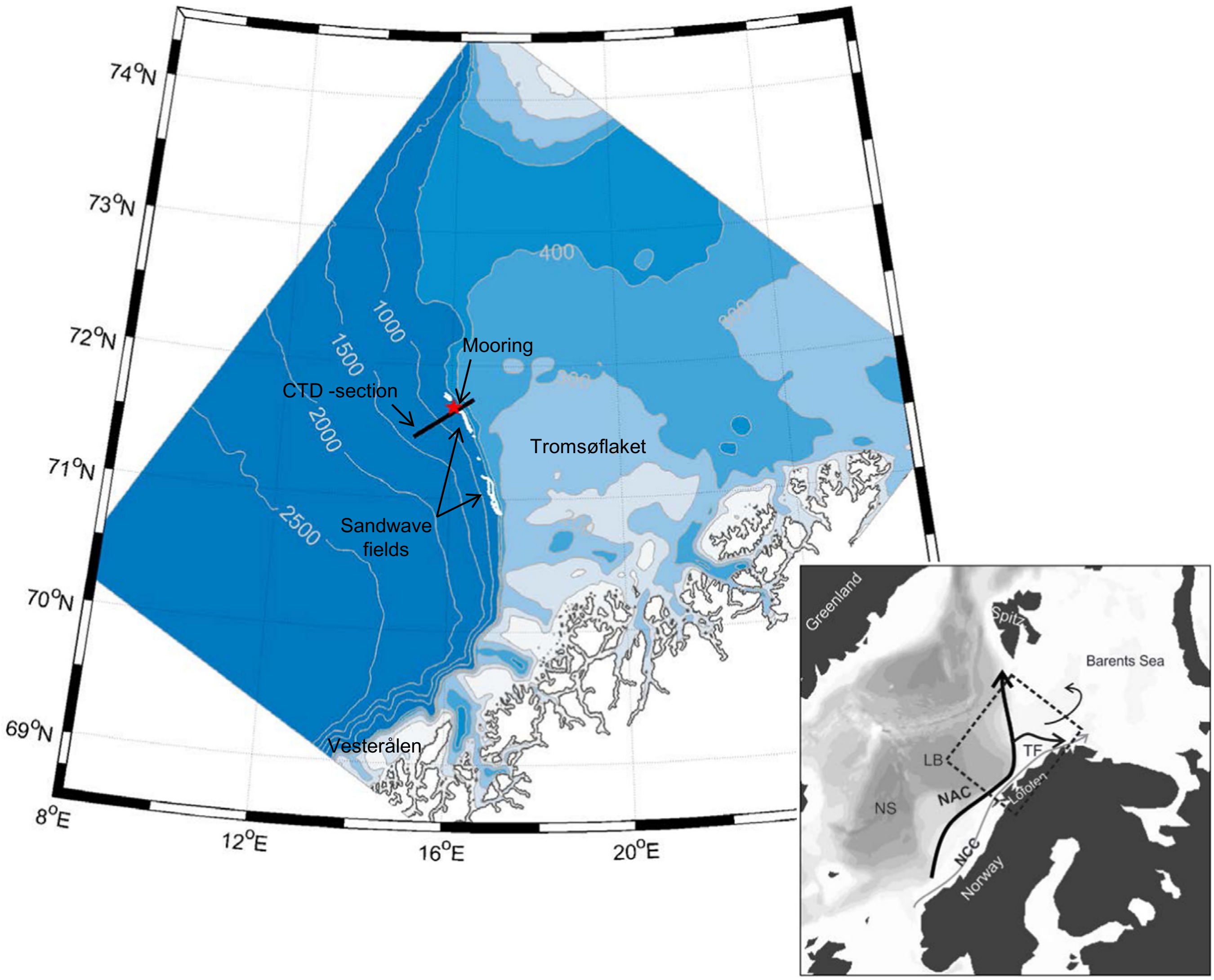

Fig. 1. Bathymetric map of the model domain (left), which is marked with a stipled rectangle in the map of the Nordic Seas (right). NAC: North Atlantic Current, NCC: Norwegian coastal current, NS: Norwegian Basin, LB: Lofoten Basin, TF: Tromsøflaket, Spitz.: Spitsbergen. The red star indicates the position of the current meter mooring, and the black line shows the CTD transect. Isobaths are drawn for depths 100, 200, 300, 400, 500, 1000, 1500, 2000 and 2500 m. The white contours between 70.5 and 72°N marks the positions of the sandwave fields described in Bøe et al. (2014). The coastline is drawn with black contours.

Norwegian Institute for Water Research (NIVA) and Norwegian Meteorological Institute (MET) (Albretsen et al., 2011). NorKyst800 is based on the public domain Regional Ocean Modeling System (ROMS, Haidvogel et al., 2008; Shchepetkin and McWilliams, 2005), which is a 3D free-surface, hydrostatic, primitive equation ocean model using terrain-following *s*-coordinates in the vertical. Our model covered the area shown in

Fig. 1, with 681×611 grid cells in the horizontal, each of size $800\ \text{m} \times 800\ \text{m}$, and 35 terrain-following levels in the vertical. The model was run for 2012 with three months preceding spin up time. Lateral boundary conditions were obtained from the archive of MET's Nordic4km simulation (http://thredds.met.no), and included daily mean currents, salinity and temperature at depths 0, 5, 10, 20, 30, 50, 100, 200, 500 and 1000 m, in addition to surface height. Tidal forcing was based on a global inverse barotropic model of ocean tides (TPXO7.2), including eight primary harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1) of semidiurnal and diurnal frequencies, two long period (Mf, Mm) and three nonlinear (M4, MS4, MN4) constituents. River runoff was based on estimated discharge data from the Norwegian Water Resources and Energy Directorate (NVE) (Beldring et al., 2003), and atmospheric forcing from ERA-interim (http://www.ecmwf.int/ research/era/do/get/era-interim). See Albretsen et al. (2011) for further details about the forcing. The vertical configuration of the model layers and grid resolution were adapted to the original vertical transformation in ROMS and the stretching function by Song and Haidvogel (1994), see Fig. 2. The bottom stress computed in our model application applies a quadratic bottom friction formulation with a drag coefficient equal to 3×10^{-3} and bottom roughness equal to 0. The baroclinic time step used was 1 min, and the barotropic time step was 1 s. Output fields of all variables from the model were saved every hour.

2.2. Field measurements

A current meter mooring was deployed on the slope off Tromsøflaket at depth 630 m in the period 19 March–23 April, 2012 (Fig. 1). The mooring was equipped with one Aanderaa Seaguard current meter and two sensors measuring temperature, salinity and pressure (Seabird Microcat CTD, SBE37). See Table 1 for mooring details and measuring depths. During the recovery cruise 27–30 April, 2012 the shelf and slope were surveyed along a