Journal of Marine Systems 130 (2014) 241–247

Contents lists available at ScienceDirect

Journal of Marine Systems

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

Bottom water formation as a primer for spring-blooms on Spitsbergenbanken?

Vidar S. Lien *, Bjørn Ådlandsvik

Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway
Bjerknes Centre for Climate Research, Bergen, Norway

ARTICLE INFO

Article history:
Received 28 April 2011
Received in revised form 22 November 2011
Accepted 23 November 2011
Available online 1 December 2011

Keywords:
Polar Front
Barents Sea
Numerical model
Biophysical processes
Spring-bloom dynamics

ABSTRACT

In a spring-bloom ecosystem such as the Barents Sea, the seasonal variations in sea ice and insolation play important roles for the seasonal stratification, which is a prerequisite for the spring-bloom to start. Here, we identify an additional mechanism which may contribute to the seasonal stratification on the Spitsbergenbanken slope: Dense bottom water formed through ice formation and subsequent brine rejection on the bank, is advected down the slope and stratifies the water column. Under certain circumstances, this may contribute to make the physical conditions favorable for the spring-bloom to start, and may potentially alter the timing of the spring-bloom locally. We utilize an eddy resolving numerical ocean model to study this mechanism, and discuss evidence from observations.

1. Introduction

In a spring-bloom ecosystem like the Barents Sea, the seasonal stratification determines the timing of the onset of the algal bloom (Sakshaug et al., 2009). During winter, the water column is homogenized through atmospheric cooling, salinization through ice freezing and subsequent brine rejection, and wind induced mixing. This brings nutrients from the deeper layers to the surface (Sakshaug et al., 2009). In the spring, an upper mixed layer is created through a decrease in the density at the surface, enabling phytoplankton to utilize the available nutrients given sufficient light, which gives rise to an intense algal bloom.

The seasonal stratification in the Barents Sea is dominated by two processes (Loeng, 1991): *i)* freshwater input from sea-ice melt which reduces the salinity, and *ii)* solar insolation which increases the temperature. The Polar Front, which separates the southern Barents Sea dominated by relatively warm and saline Atlantic water masses from the northern Barents Sea dominated by cold Polar water masses, also to a large degree determines the wintertime ice edge (Loeng, 1991). To the north of the Polar Front, the seasonal stratification starts when the ice starts to melt, and the bloom follows the retreating ice edge (Engelsen et al., 2002). In the Atlantic water masses to the south of the Polar Front, heating through solar insolation is the dominant process (Olsen et al., 2003). Hence, the timing of the bloom is different in Polar and Atlantic water masses.

Spitsbergenbanken is a highly productive area, and represents an important feeding area for fish species such as capelin (*Mallotus villosus*) (Loeng and Drinkwater, 2007), and also higher trophic levels, such as whales (Skern-Mauritzen et al., 2011). At the lower trophic levels, the interplay between phytoplankton growth and grazing zooplankton communities is important for the ecosystem to utilize the primary production. The timing of the spring-bloom is therefore important for the upward transfer of energy, and hence the annual variability in the pelagic biomass (Sakshaug et al., 2009).

Sverdrup (1953) hypothesized that the upper mixed layer must be shallower than a critical depth to sustain a net primary production. Hence, the mixed layer depth (MLD) is an indicator of whether the physical conditions are favorable for a spring-bloom to start. In addition to the two mechanisms contributing to the seasonal stratification in the Barents Sea, we propose a hypothesis that a third mechanism, under certain circumstances, may also contribute to the stratification needed to sustain an algal bloom. In regions with a large sea-ice production, water with a density higher than the surrounding water masses is formed through brine rejection. This process is common during winter on the banks in the Barents Sea (Midttun, 1985). Eventually, the dense water flows down the bank slope, creating or enhancing existing vertical density gradients. If the bottom depth is shallow enough, we hypothesize that the stratification created by the dense water has the potential to lift the MLD above the critical depth, and thereby make the conditions favorable for a spring-bloom to start.

On Spitsbergenbanken, all these prerequisites are met. The bank is ice covered in winter, while the proximity to the Polar Front keeps the lower slope ice-free throughout the year. Furthermore, the bottom depth is less than 50 m at the shallowest parts of the bank. The area

---

* Corresponding author at: Institute of Marine Research, P.O. Box 1870 Nordnes, 5817 Bergen, Norway. Tel.: +47 55 90 65 01.
E-mail address: vidar.lien@imr.no (V.S. Lien).

0924-7963/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmarsys.2011.11.018

is dominated by strong tidal currents (Kowalik and Proshutinsky, 1995), and the tidal mixing keeps the water column at the bank mixed from surface to bottom. This creates a tidal front around the bank approximately above the 60 m isobath, often referred to as the Summer Front (Loeng, 1991). On the southeastern slope, the topography controls the Polar Front (Johannessen and Foster, 1978) and during the survey in 2008 it was situated approximately above the 150 m isobath (Fer and Drinkwater, 2014–this issue). According to Sakshaug et al. (2009), the spring-bloom is closely connected to the fresh water input from melting sea ice in the region between these two fronts. However, this area is also shallow enough for the dense brine enriched water to create a stratification that may push the MLD above the critical depth.

Due to the seasonal ice cover, observations from the Spitsbergenbanken slope in winter and spring are scarce. We therefore utilize an eddy resolving numerical ocean model to test our proposed hypothesis. By combining observations with the model results, we will address the question whether dense water production on the bank can create a stratification which is strong and shallow enough to sustain an algal bloom.

2. Data and methods

2.1. Observational data

Measurements of Conductivity, Temperature, and Depth (CTD) are used in the evaluation of the model results. A total of 138 CTD-stations were obtained from 28th of April to 16th of May 2008, as a part of the International Polar Year project Norwegian component of the Ecosystem Studies of Sub-Arctic and Arctic Regions (NESSAR). The sampling was concentrated along a section across the Spitsbergenbanken slope southeast of Hopen (Fig. 1).

To get a better spatial evaluation of the modeled hydrography, a gridded dataset of temperature and salinity at standard depths in the Barents Sea (Sigrid Lind, pers. comm.) for the winter (February–March–April) and summer (August–September–October) seasons was used. Due to better data coverage in summer, the August to October values were used in the comparison between modeled and observed hydrography, and the model results were interpolated onto the same grid.

Satellite-derived (AMSR-E) daily sea-ice concentration (Spreen et al., 2008), were used to evaluate the sea-ice distribution in the model by interpolating the modeled sea-ice concentration onto the observational grid within a box covering Spitsbergenbanken (Fig. 1). Monthly averages of satellite based observations of chlorophyll-*a* for the different years were obtained from the SeaWiFs project (O'Reilly et al., 1998).

2.2. Mixed layer depth and critical depth

There are several ways of estimating the MLD (Thomson and Fine, 2003). In this study, we apply the threshold method (Peters et al., 1989), where the MLD is defined as the depth z at which the potential density difference $\Delta\sigma_\Theta(z)=\sigma_\Theta(z)-\sigma_\Theta(z_0)$ between the surface z_0 and the depth z exceeds a specified threshold value. In this study, we use the value $\Delta\sigma_\Theta=0.03$ kg m^{-3}. However, reducing the value slightly to $\Delta\sigma_\Theta=0.01$ kg m^{-3} did not alter our conclusions.

The critical depth is estimated as the depth where phytoplankton production and respiration balances using algorithms from the model system NORWECOM (Skogen et al., 1995). Respiration is temperature dependent, while production is a function of temperature and available light. Light at the surface is modeled using the formulation by Skartveit and Olseth (1986, 1987), using daynumber and latitude only as input while the cloud cover is set to zero. Light in the water column is modeled without including the effect from self-shading. Thus, the estimate is valid for a situation prior to the spring bloom, which is sufficient for our purpose.

2.3. Model description

We utilize the three-dimensional baroclinic ocean general circulation model Regional Ocean Modeling System (ROMS), which uses normalized, terrain-following sigma-coordinates in the vertical (Haidvogel et al., 2008; Shchepetkin and McWilliams, 2005). Furthermore, the model has been coupled with a dynamic-thermodynamic sea-ice module (Budgell, 2005). We have applied 40 sigma levels in the vertical, with vertical stretching that allows for enhanced resolution in the surface and bottom boundary layers. The horizontal resolution is 800 by 800 m, and based on the CTD-measurements, the internal Rossby-radius is estimated to be in the range 1–2 km. Thus, mesoscale dynamics with a spatial scale close to the internal radius

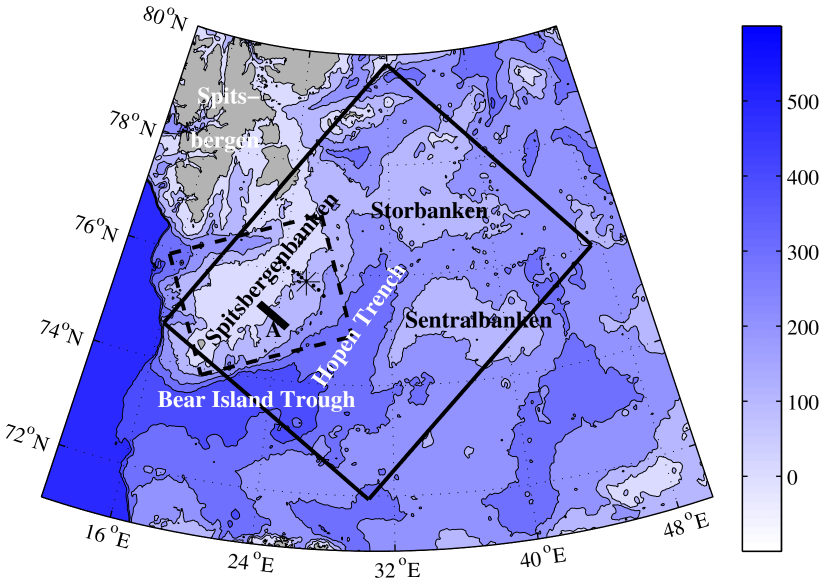

Fig. 1. Bathymetric map of the western Barents Sea. Colors denote bottom depth in meters and contour interval is 100 m. Large rectangle shows the model domain, while the broken lines show the Spitsbergenbanken box. Black dots show station positions. Station 7 is marked by a star.