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The impact of winds and sea surface temperatures on the Barents Sea ice extent, a statistical approach

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ABSTRACT

An analysis was made of the processes controlling the incidence of sea ice in the Barents Sea for the period 1979–2010. The influence of atmospheric circulation and ocean temperature on the interannual variability of sea-ice extent (SIE) in the Barents Sea was investigated using sea-ice concentrations obtained from passive microwave satellite imagery, sea surface temperatures (SSTs), and NCEP–NCAR sea level pressure (SLP) data. Data from April and September were analysed, the months when SIE in the Barents Sea is respectively at its maximum and minimum. The strongest negative correlations (−0.65 to −0.77) were found between the SIE in the Barents Sea and SST in the regions most influenced by Atlantic Water. The patterns of distribution of correlation coefficients between interannual variability of SIE in the Barents Sea and SLP over the Nordic Seas and Siberia showed two well-defined SLP zones: one with a high positive correlation (0.60 to 0.65) over the Norwegian and Greenland seas, and a zone with high negative correlation (−0.60 to −0.63) in the area of western Siberia. We conclude that winds induced by changes in SLP gradient between these zones affect both the redistribution of sea ice and the advection of heat into the Barents Sea.

1. Introduction

The Barents Sea plays a crucial role for regional economies and local communities. Owing to the inflow of warm Atlantic Water, the Barents Sea has high biological production compared to other Arctic marginal seas (Helland-Hansen and Nansen, 1909; Loeng, 1989; Loeng et al., 2005). The spring bloom of phytoplankton can start as early as April or May close to the ice edge, where freshwater from the melting ice forms a stable layer on top of the sea water (Loeng and Drinkwater, 2007; Olsen et al., 2003). In addition to the fishing industry, large reserves of oil and gas have been found in the Barents Sea, and it is an important route for fishing, trade and navy vessels. All human activity in this area is affected by the climate and its variability.

Sea ice is one of the most important components of the Barents Sea climate system. The ice distribution in the Barents Sea is influenced by both the Atlantic and the Arctic Oceans. Two opposing currents determine the sea-ice cover, ice-edge configuration and ice concentration in the Barents Sea. In the northwestern Barents Sea a predominantly cold arctic current passes to the southwest along the Svalbard Archipelago, extending south to Bear Island. On the other hand, the southwestern and eastern Barents Sea are influenced by the warm current coming from the Norwegian Sea through the Barents Sea opening (e.g. Årthun et al., 2012; Helland-Hansen and Nansen, 1909; Loeng, 1991; Loeng and Drinkwater, 2007; Skagseth et al., 2008, 2011). The development and interaction of these two ocean currents have a significant impact on the sea-ice distribution in the Barents Sea (Ådlandsvik and Loeng, 1991; Gammelsrød et al., 2009; Vinje, 1998, 2001). This interaction occurs mainly in the Polar Front Zone, which separates Polar and Atlantic Waters. In the western region the position of the Polar Front is strongly influenced by bottom topography (Gawarkiewicz and Plueddemann, 1995; Harris et al., 1998; Loeng and Drinkwater, 2007; Parsons et al., 1996) and in the east it is more variable and depends on the strength of the Atlantic water inflow (Loeng, 1991; Loeng and Drinkwater, 2007).

The southwestern Barents Sea remains ice free year-round due to the inflow of warm Norwegian Atlantic Current (Skagseth et al., 2008, 2011), and in September, the entire Barents Sea is more or less ice free. There are three main water masses in the Barents Sea: (1) warm, saline Atlantic Water from the Norwegian Atlantic Current (temperature > 3 °C, salinity > 35), (2) cold Arctic Water from the north (temperature < 0 °C, salinity < 34.8), and (3) warm, but relatively fresh coastal water (temperature > 3 °C, salinity < 34.7). As one of the two gateways for Atlantic Water into the Arctic, the Barents Sea plays an important role in the development of the hydrography of the Arctic Ocean. Thermo-hydrodynamic processes in this region are important both in terms of the transformation of Atlantic Water on its transit through the Barents Sea en route to the Arctic and in maintaining the cold halocline layer in the Arctic Ocean (Ingvaldsen et al., 2002, 2004; Loeng, 1991; Loeng et al., 1997; Schauer et al., 2002; Skagseth et al., 2008).

Most of the sea ice in the Barents Sea is formed locally (Vinje, 1998, 2001; Vinje and Kvambekk, 1991) but a significant fraction is imported from adjacent regions of the Arctic Basin through the straits

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between Svalbard and Novaya Zemlya (Pavlov and Pavlova, 2008; Pavlov et al., 2004). This ice flux is directed into the Barents Sea throughout the year with a maximum in the winter (March–April) and values close to zero in the summer (August–September) (Kwok, 2009; Kwok et al., 2005). Hence, the Barents Sea ice cover has a strong seasonal variability. The largest SIE in the Barents Sea occurs in March or April. In May the ice begins to recede and in September the SIE reaches its minimum. In October or November the freezing process begins again (Koç et al., 2007).

In contrast to the other marginal Arctic seas, a significant part of the Barents Sea is free of ice during the entire year. The area near the southwestern coast of the Barents Sea does not freeze in the winter because of the inflow of warm Atlantic Water.

During anomalously warm years, the sea becomes completely ice-free in August and September while in anomalously cold years, the ice cover in these months can be 15–30% of the Barents Sea area, with the sea ice located mainly in the northern regions. At the end of the coldest winters more than 80% of the sea area is covered by highly compacted sea ice. During especially warm winters, the maximum SIE in April does not exceed 55–60% (Loeng and Drinkwater, 2007; Parkinson and Cavalieri, 2002, 2008; Parkinson et al., 1999).

Sea-ice conditions in the seas of the European sector of the Arctic are influenced by the large-scale atmospheric circulation and ocean currents and their interannual variability (see e.g. Zhang et al., 2000, 2008). However, local air temperature and wind also play a discernible role in determining sea-ice conditions in this area (Abrahamsen et al., 2006; Dmitrenko et al., 2009; Francis and Hunter, 2007; Schauer et al., 2002; Wu et al., 2004). In particular, the local wind can redistribute the sea ice, changing its concentration and affecting ice fluxes through the northern straits of the Barents Sea, leading to significant changes of SIE (Ådlandsvik and Loeng, 1991; Ingvaldsen et al., 2004; Kimura and Wakatsuchi, 2000; Schlichtholz, 2011; Schlichtholz and Houssais, 2011).

The Barents Sea SIE is also characterized by a large interannual variability. The decline in sea-ice concentration and sea-ice cover in the Arctic is widely cited (e.g. Comiso, 2002, 2012; Comiso et al., 2008; Parkinson and Cavalieri, 2002, 2008; Stroeve et al., 2007) and many studies have shown that the most dramatic changes have taken place in the Russian Arctic, in particular in the Barents Sea (see e.g. Francis and Hunter, 2007; Gammelsrød et al., 2009; Ikeda, 1990; Kvingedal, 2005; Overland and Wang, 2007; Rodrigues, 2008, 2009; Sorteberg and Kvingedal, 2006). For example, Ikeda (1990) compared SIE variability in different parts of the Arctic Ocean for 1950s–1980s and showed that on the decadal time scale, SIE variability in the region of the Barents and Kara seas is similar to the Arctic as a whole, but the character of the interannual variability of SIE in these two regions can differ. For example, Fig. 1 shows the interannual variability of the SIE in April for the Arctic Ocean and Barents Sea. It is clear that maxima and minima of SIE do not always occur in the same years for these two areas.

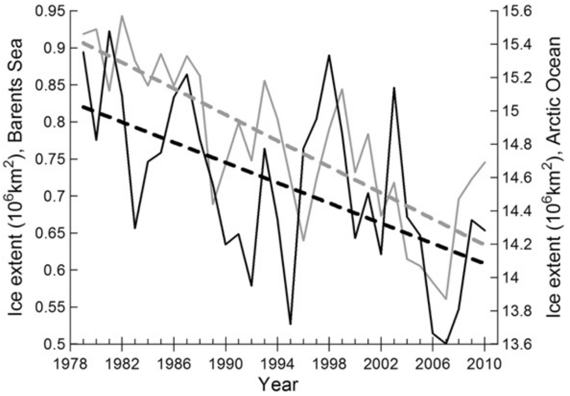

Fig. 1. Interannual variability of SIE in the Arctic Ocean (gray line) and in the Barents Sea (black line) for April. Dashed lines-trends.

The aim of this study was to investigate how atmospheric circulation and ocean temperature influence the interannual variability of SIE in the Barents Sea.

2. Data and method

We have used the following data:

1) Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave Imager (SSM/I) daily and monthly mean sea-ice concentrations from satellite, gridded with a spatial resolution of 25 × 25 km, for the period 1979–2010 (Cavalieri et al., 1996, updated yearly; Meier et al., 2006, updated quarterly) were obtained from the National Snow and Ice Data Center (NSIDC). For details see http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.gd.html.
   SIE was calculated as the total area of all cells with sea-ice concentrations greater than 15%.
2) Monthly mean SLP data, gridded with spatial resolution of 5° latitude and longitude, for the period 1979–2010 were obtained from the Research Data Archive (RDA), which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds010.1.
3) Monthly SST data, gridded with spatial resolution of 2° latitude–longitude, for the period 1979–2010 were obtained from the NOAA National Climatic Data Center (NCDC) dataset (Smith and Reynolds, 2003, 2004; Smith et al., 2008), see http://www.ncdc.noaa.gov/ersst/.

SIE in the Barents Sea was calculated in a box bounded by latitudes 72°N and 82°N and longitudes 20°E and 60°E (Fig. 2). SLP and SST data were interpolated onto a domain (as a part of EASE-Grid projection, see http://nsidc.org/data/ease/ease_grid.html) that includes the Barents Sea and a large surrounding area (Fig. 2).

Our approach was to find the areas where the SLP and SST have the largest impact on the SIE variability in the Barents Sea. We calculated correlation coefficients between SIE (in the Barents Sea) and both SLP (in a large area around the Barents Sea) and SST (in the Nordic Seas) for each point of their grids. We then analysed the distribution of these correlation coefficients in April and September during the years 1979–2010. We also analysed the patterns of the SLP and SST distributions for individual years of maximum and minimum ice cover.

3. Results and discussion

The time series of SIE in the Barents Sea in April (when the extent tends to be a maximum) for 1979–2010 shows four distinct years with above-normal SIE (1981, 1987, 1998 and 2003) and four distinct years with below-normal SIE (1983, 1992, 1995 and 2007) (Fig. 3, upper panel). The interannual variability of SIE is large, except for the periods 1992–1995 and 1998–2003. For September there are also four years with large SIE (1982, 1989, 1993 and 2003) and six years with low SIE (1979, 1984, 1996, 2001, 2004 and 2007). SIE minima after 1996 are not followed by sharp increases (Fig. 3, lower panel). After 2004, the amplitude of interannual fluctuation is smaller than in previous years. The maximum (minimum) SIE during April occurred in 1981 (2007) and for September in 1982 (2001). The main feature of the SIE in the Barents Sea is a clear negative trend (see Fig. 3). Based on a least-squares linear regression, the rates of decadal decrease in April and September were −8.1% and −11.9%, respectively.