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Recent Thickening of the Barents Sea Ice Cover

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Key Points:

- Upward Looking Sonar measurements in the Barents Sea show increased sea ice thickness during the last decade
- In an ice-ocean reanalysis (PIOMAS) the recent thickening is due to increased ice freezing, associated with lower ocean and air temperatures
- The long-term thickness trend is negative, meaning that despite recent thickening, ice is now much thinner than in the 1980s

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract The Arctic sea ice cover has decreased rapidly over the last few decades both in extent and thickness. Here we present multi-year (2013–2022) observations of sea ice thickness in the northwestern Barents Sea based on Upward Looking Sonar measurements and show that the winter sea ice has become thicker over the last decade. Sea ice thickness from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) reproduces both the observed variability and recent 10-year trend and shows that this thickening (0.24 m decade^{-1}) has not been seen since the 1990s. Using PIOMAS we find that the recent increase in sea ice thickness can be explained by increased sea ice freezing as a result of lower temperatures in the ocean and in the atmosphere. The recent thickening is set in the context of a long-term thinning trend, with PIOMAS showing much thinner ice now than in the 1980s.

Plain Language Summary The Arctic sea ice cover is becoming smaller and thinner due to global warming. We have measured sea ice thickness in the Barents Sea since 2013, and find that the ice thickness has increased since the measurements were initiated, contrary to what we would expect in a warming world. The Arctic sea ice cover can, however, increase for periods typically up to a decade due to natural climate variability. We find that increased sea ice formation due to lower ocean and air temperatures has caused the recent thickening of the ice cover. We also find that the Barents Sea ice thickness has decreased since the 1980s, and despite the recent thickening, the ice cover is much thinner now than it used to be.

1. Introduction

Since satellite observations began in the late 1970s, Arctic sea ice has gradually become less extensive (Comiso et al., 2017; Onarheim et al., 2018) and thinner (Kwok et al., 2009; Laxon et al., 2013). Whereas sea ice loss in the Arctic Ocean has been most pronounced in summer, a retreating sea ice edge is also observed in winter in the outer shelf seas, and in particular in the Barents Sea (Årthun et al., 2012; Onarheim & Årthun, 2017).

Despite the overall negative trend, sea ice extent in the Barents Sea is subject to large internal (natural) variability on interannual to decadal time scales (Bonan et al., 2021; Dörr et al., 2023; England et al., 2019). This variability results from changes in the inflow of warm Atlantic waters (Årthun et al., 2012; Docquier & Koenigk, 2021), atmospheric circulation anomalies and the associated heat and moisture transport (Liu et al., 2022; Woods & Caballero, 2016), and ice import from the Arctic Ocean (Efstathiou et al., 2022; Kwok, 2009).

Most studies on sea ice variability and loss in the Barents Sea have focused on sea ice area or extent, and have not considered changes in sea ice thickness. Sea ice thickness is a key high-latitude climate variable as changes are reflected in the Arctic energy balance (Kurtz et al., 2011; Labe, Peings, & Magnusdottir, 2018) and in the freshwater exchange between sea ice and ocean (Barton et al., 2018; Ellingsen et al., 2009; Serreze et al., 2006). Sea ice thickness changes can also have a significant impact on shipping activities (Smith & Stephenson, 2013) and on the design of offshore structures (ISO19906, 2019). Observing and understanding its temporal variability is therefore of large importance. Direct measurements of sea ice thickness in the Barents Sea are, however, sparse (Abrahamsen et al., 2006; Gerland et al., 2008; King et al., 2017).

Here, we document an observed thickening of the Barents Sea ice cover during the last decade (2013–2022) from Upward Looking Sonar (ULS) measurements. Using the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, J. Zhang & Rothrock, 2003) ice-ocean reanalysis we furthermore show that the recent thickening, acting as a deceleration of the long-term decline, can be explained by increased sea ice freezing related to lower oceanic and atmospheric temperatures.

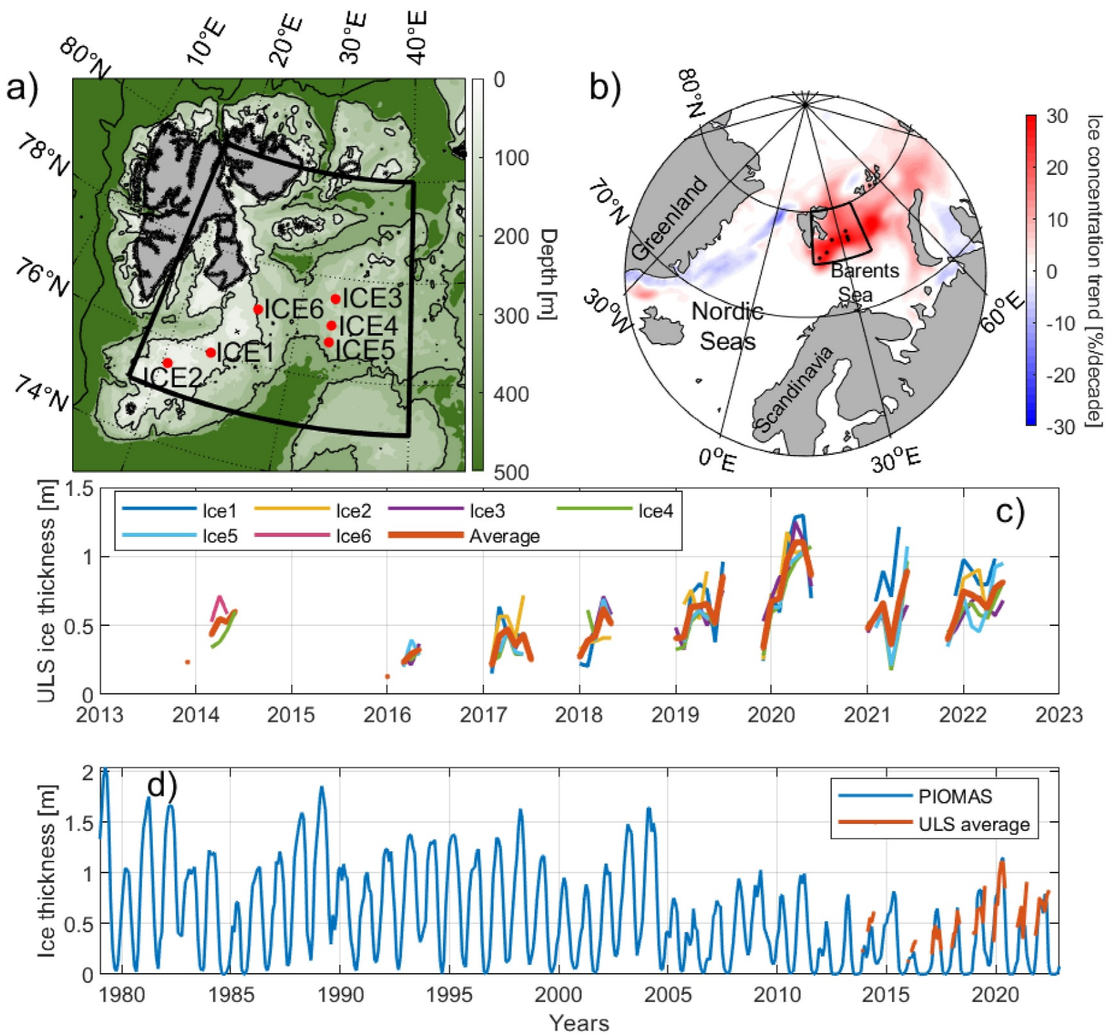

Figure 1. (a) Map of the northwestern Barents Sea showing the locations of the six Upward Looking Sonar (ULS) moorings (red dots) and ocean bathymetry (color). The black box shows the area the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) data are averaged over. (b) Winter sea ice concentration trend during the recent decade (2013–2022) from PIOMAS, including the mooring locations and the area the PIOMAS ice thickness data are averaged over. (c) Observed monthly sea ice thickness at the six ULS locations, and (d) monthly ice thickness in the northwestern Barents Sea from PIOMAS (blue) and the average ice thickness from the ULS moorings (red).

2. Data and Methods

This paper combines in situ observations and output from an ice-ocean reanalysis product in order to examine changes in Barents Sea ice thickness over the last four decades, with emphasis on decadal variability and trends. Atmospheric and oceanic data are assessed to understand the driving mechanisms. As the Barents Sea is predominantly ice free in summer, we mainly focus on the winter season. Winter is defined as November–April, which typically corresponds to the freezing season. All variables are calculated as averages over the winter season (based on monthly means), the indicated year denoting the winter-mean that ends in the respective year (e.g., 2022 represents November 2021 to April 2022). Linear trends are calculated using the least squares method, and significance tested with the modified Mann-Kendall trend test for autocorrelated data (Hamed & Rao, 1998).

2.1. Upward Looking Sonar (ULS) Measurements

Regular ice draft measurements from moored ULS instruments in the northwestern Barents Sea have been collected since 2013 (Figure 1a). The moorings are typically recovered and redeployed in October. For the winter 2013/2014, moorings are located at the two locations ICE4 and ICE6, and for the winters from 2015/2016 to 2021/2022, moorings are located at the five locations ICE1-ICE5. The instruments are of type IPS5 by ASL

Environmental Sciences, and measure sea ice draft at 1 s intervals (Fissel et al., 2008). The data are processed by Fugro data scientists using their in-house software routines following the recommendations of the instrument manufacturers (Hansen et al., 2013; Melling et al., 1995), including screening of erroneous records and sound speed corrections. Wave action and the propagation of bubbles downwards from white capping of waves lead to uncertainties in the measured ice draft values. Periods flagged as influenced by waves are therefore removed from the analyses, and the monthly mean values considered herein represent the mean of valid ice records only (i.e., periods with ice only; a comparison between daily and monthly data is provided in Figure S1 in Supporting Information S1). We refer to Hansen et al. (2023) for a more detailed description of the data set and data processing. Following Fukamachi et al. (2017), the ice draft measurements are multiplied by 1.1 to estimate sea ice thickness.

The moorings are also equipped with SBE37 SM MicroCat CTD (conductivity, temperature, depth) sensors (Hansen et al., 2023). The most shallow moorings (i.e., ICE1 and ICE2) have sensors at approximately 50 m depth (near the seabed), and the deeper moorings (ICE3-ICE6) have instruments at 80–100 m depth. Here, we consider winter means based on the 2-min temperature measurements.

2.2. PIOMAS

Monthly sea ice thickness (model variable *heff*) from the PIOMAS version 2.1 (J. Zhang & Rothrock, 2003) is available since 1978 on a generalized curvilinear coordinate system. The horizontal resolution is approximately 25 km in the Barents Sea. Please see Schweiger et al. (2011) and references therein for a detailed description of the model setup.

PIOMAS has been evaluated thoroughly against observations of sea ice thickness, volume (Labe, Magnusdottir, & Stern, 2018; Laxon et al., 2013; Schweiger et al., 2011; Stroeve et al., 2014; Wang et al., 2016), and ice motion (Selyuzhenok et al., 2020; J. Zhang et al., 2012) and found to perform well. PIOMAS typically overestimates the thickness of thin sea ice and underestimates the thickness of thick sea ice, but the spatial patterns and trends in sea ice thickness are realistically reproduced (Schweiger et al., 2011). The spatial pattern of winter sea ice thickness trends (Figure S2 in Supporting Information S1) and sea ice concentration trends (Figure S3 in Supporting Information S1) in PIOMAS during the recent decade (2013–2022) closely compares with Cryosat-2 (Hendricks & Ricker, 2020) and SMMR and SSM/I-SSMIS (NSIDC, Stroeve & Meier, 2018), respectively. The PIOMAS ice thickness is the mean thickness of sea ice in a grid cell including open water (often called effective ice thickness). Ice thickness values from PIOMAS are therefore not directly comparable to the IPS measured ice thickness (which is a point measurement and the mean of periods with ice only). Figure 1d, however, shows that PIOMAS reproduces both the observed variability and trend very well.

Using PIOMAS allows us to quantify the dynamic and thermodynamic contributions to sea ice thickness changes (Labe, Peings, & Magnusdottir, 2018; Ricker et al., 2021). The dynamic contribution is the sea ice thickness flux convergence (model variable *advect*, units in m s^{-1}) and the thermodynamic contribution is the sea ice production (freezing and melting; model variable *iceprod*, m s^{-1}). To compare with ice thickness changes in winter (as obtained directly from PIOMAS, *heff*), we integrate the thermodynamic and dynamic terms from November to April. To represent the northwestern Barents Sea and the region covered by the moorings, the PIOMAS data are averaged over the region 75°–80°N, 18°–40°E (Figure 1a). To exclude areas of extensive open water in the analysis, grid points with ice concentration below 30% are removed from the analysis when examining the drivers of sea ice thickness change.

2.3. Atmospheric and Oceanic Data

To assess changes in atmospheric temperature (at 2 m and at 850 hPa), sea level pressure, surface (10-m) winds, geopotential height, and surface heat fluxes we calculate winter means from the ERA5 reanalysis (Hersbach et al., 2020). Heat fluxes from ERA5 generally compare well to observations in Arctic and sub-Arctic seas (Graham et al., 2019), although the biases are larger in the marginal ice zone (Renfrew et al., 2021). In addition to temperatures from the ULS moorings, we use observed Atlantic water temperature from the southwestern Barents Sea (71.5°–73.5°N, 20°E), often referred to as the Barents Sea Opening (BSO). The BSO section has been sampled since 1977 by the Institute of Marine Research, Norway. The temperatures are annual averages typically based on six surveys per year and are averages between 50 and 200 m (Ingvaldsen et al., 2004).

3. Observed Sea Ice Thickness Variability and Change

The ULS measurements show that the northwestern Barents Sea is ice free in summer and fall and has a winter sea ice thickness of approximately 0.5 m between 2013 and 2022 (Figure 1c). There are relatively small spatial variations in mean sea ice thickness between the different measurement sites, although there is a tendency that the measured thicknesses on Spitsbergenbanken (moorings ICE1, ICE2, and ICE6) exceed those on Storbanken (moorings ICE3, ICE4, and ICE5; Figure 1c). Variability and trends are nevertheless similar. The observations show that from 2016 to 2020 the maximum monthly ice thickness increased from 0.3 to 1.1 m. The ice thickness is slightly smaller in 2021 and 2022 compared to 2020, but still has maximum values exceeding 0.8 m. The length of the ice covered season has also increased since 2014, and the winter season 2021/2022 shows the presence of sea ice in each month from November to June. In contrast, sea ice is only present in 4 months during the winter 2015/2016. The recent increase in winter sea ice thickness in the Barents Sea is concurrent with increasing satellite-observed sea ice concentration (Figure S3 in Supporting Information S1), revealing a thicker and more extensive Barents Sea ice cover in recent years (Figure 1).

The observed increase in winter sea ice thickness in the Barents Sea during 2013–2022 is well captured by PIOMAS (Figure 1d). Next, we will therefore use PIOMAS to put the recent trend into a longer perspective and to assess the drivers of the recent thickening.

4. Long-Term Sea Ice Thickness Variability and Change: 1978–2022

PIOMAS shows clear seasonal and interannual variability in Barents Sea ice thickness since 1978 (Figure 1d). The observed variability, including the record low ice thickness in 2016 and high ice thickness in 2020, is reproduced very well. According to PIOMAS, the winter ice thickness has increased by 0.24 m over the last decade (2013–2022; trend significant at 95% confidence level; Table S1 in Supporting Information S1). There is, however, an overall thinning of the ice cover since the late 1970s; the winter ice thickness has decreased by 0.18 m decade^{-1}, and as a result is almost 1 m thinner now than it used to be (Figure 2a). The long-term trend based on PIOMAS is larger but in general agreement with previous observations of seasonal fast ice from the western Barents Sea (close to Hopen Island) that showed a trend of −0.11 m decade^{-1} between 1966 and 2007 (Gerland et al., 2008). The mean thickness and interannual variability in PIOMAS also show reasonably good agreement with the observations of Gerland et al. (2008) (Figure S4 in Supporting Information S1). The recent decadal (2013–2022) increase in sea ice thickness in PIOMAS is not unique over the 40-year record, but it has not been seen since the mid-1990s (Figure 2d). The decadal trends have consistently been negative since the mid-1990s except for the most recent years, resulting in a long-term thinning of the ice cover (Figure 2a). We note that positive trends with comparable magnitude to the recent thickening have occurred on shorter, sub-decadal, time scales.

5. Mechanisms of Recent Sea Ice Thickening

Changes in sea ice thickness can be a result of changes in either thermodynamics (freezing and melting) or dynamics (advection and divergence) (Methods, Holland et al., 2014). To understand what drives the variability and trends in the Barents Sea ice thickness, and specifically the recent increase (2013–2022), we thus use PIOMAS to examine the relative contributions from dynamic and thermodynamic forcing. The thermodynamic term is positive for sea ice freezing (i.e., sea ice gain) and negative for sea ice melting (i.e., sea ice loss). The dynamic term is also positive (negative) for sea ice gain (loss).

First, we examine the impact from dynamic changes. This term is, in general, positive since 1980 (Figure 2b) and thus mainly contributes to increased sea ice thickness in the northwestern Barents Sea. The dynamic term shows large interannual variability and a negative long-term trend since the 1980s. There is, however, no positive trend during the last decade. Changes in ice dynamics are thus not the primary cause for the recent observed increase in ice thickness.

The thermodynamic part is decomposed into a freezing term and a melting term, in which the freezing clearly dominates (Figure 2c). The sea ice freezing shows pronounced interannual to decadal variability, which corresponds well to the ice thickness variability ($r = 0.75$). Consistent with the long-term decrease in sea ice thickness, there is a strong reduction in sea ice freezing since the 1980s. Considering the recent decade, however, the thermodynamic ice production has increased at magnitudes comparable to the thickness increase. There is

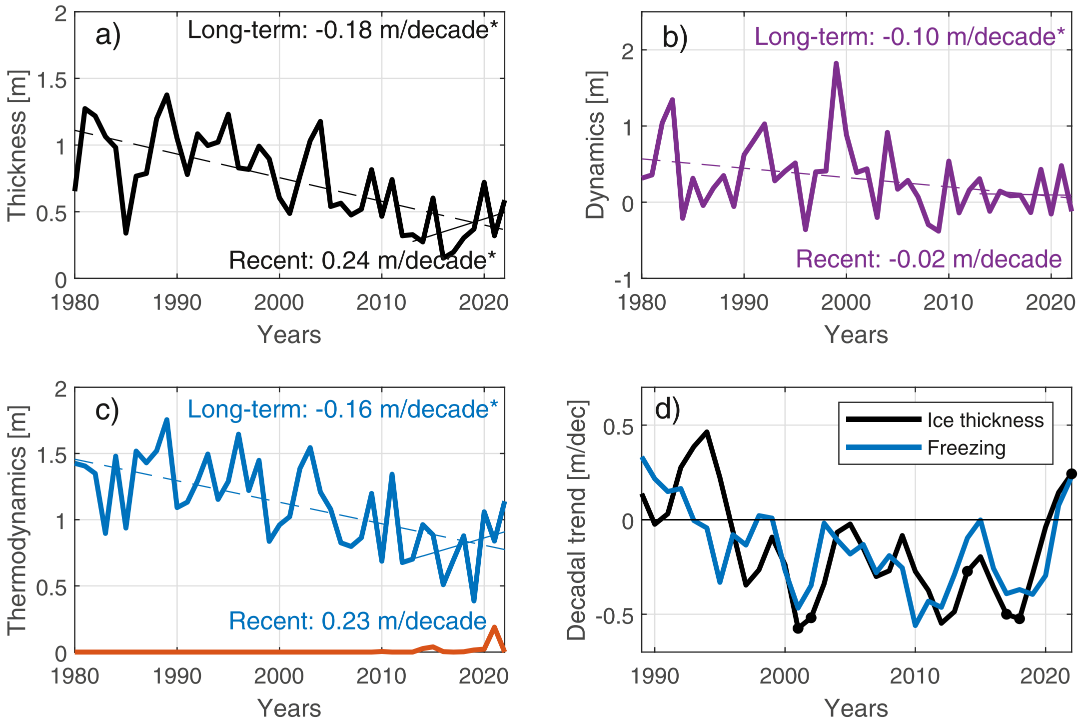

Figure 2. (a) Winter sea ice thickness, (b) dynamics (i.e., ice thickness flux convergence), (c) thermodynamics separated into sea ice freezing (blue) and melting (red), and (d) decadal trends in winter sea ice thickness (black) and in sea ice freezing (blue). The decadal trends are plotted at the last year of the 10-year period, for example, the last point shows the trend for the 2013–2022 period. Significant trends (95% confidence level; p-values provided in Figure S5 in Supporting Information S1) in ice thickness are marked with black dots. In panels (a–c) the long-term trends (1980–2022, dashed lines) and recent trends (2013–2022, solid thin lines) are shown and quantified in each panel (* indicating significant trends; see also Table S1 in Supporting Information S1). All data from Pan-Arctic Ice Ocean Modeling and Assimilation System.

generally no sea ice melt during winter (Figure 2c), but summer melting has increased during the last decade (0.39 m decade^{-1}). Note that the magnitude of the trend in sea ice thickness is not expected to exactly match the trends in the forcing terms. For example, the trend in winter ice thickness can also be influenced by thicker ice being present at the end of autumn (before November) as a result of either anomalous thermodynamic or dynamic thickness changes.

The recent thickening of the Barents Sea ice cover thus seems to be mainly due to enhanced freezing. Increased sea ice production can be a result of changes in either oceanic and/or atmospheric temperatures. The former can be assessed using the temperature measurements from the ULS moorings. These show a decrease in temperature since 2016 (Figure 3a), consistent with the increased sea ice freezing in PIOMAS. To put these temperature changes into a longer and larger perspective we also include observations of Atlantic water temperatures from the BSO. In agreement with the ULS measurements, BSO temperatures also show a negative trend over the last decade (Figure 3a).

The reduced ocean temperatures can be translated into changes in winter ice growth (Δh_i) by Steele et al. (2008):

$$\Delta h_i = \rho_w c \Delta T_z / \rho_i L_i,$$

where ΔT is the temperature change (integrated over layer thickness z), c is the heat capacity of seawater, ρ_w and ρ_i are the density of seawater and sea ice, respectively, and L_i is the latent heat of fusion. Assuming that the cooling of inflowing Atlantic waters of 0.4°C (Figure 3a) takes place over the upper 50–70 m (winter mixed layer depths in the northern Barents Sea, Shu et al., 2021) yields a sea ice thickening of 32–40 cm, which is the right order of magnitude compared to the thickening in PIOMAS (24 cm). Colder waters will also contribute to an earlier freeze-up in fall as less heat needs to be extracted before ice can form (Steele et al., 2008).

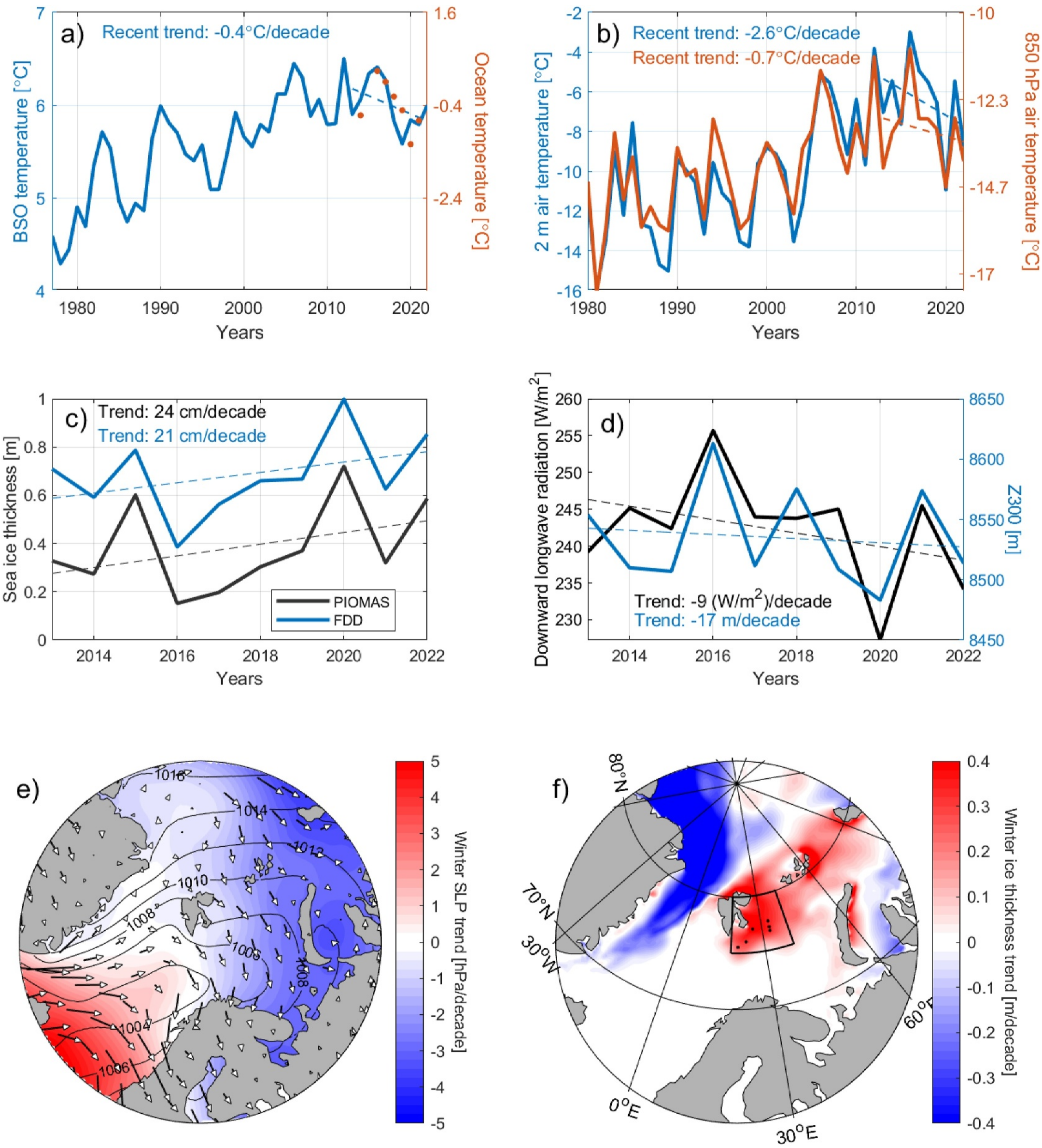

Figure 3. (a) Observed Atlantic water temperature in the Barents Sea Opening (blue) and mean winter ocean temperature from the moorings (red dots), (b) air temperature at 2 m (blue) and 850 hPa (red, ERA5), (c) sea ice thickness from Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) (black) and calculated from the freezing degree day model (blue) for the recent decade (2013–2022), (d) downward longwave radiation (black; 75°–80°N, 18°–40°E) and 300 hPa geopotential height (Z300; blue; 65°–85°N, 20°–100°E; Liu et al., 2022), and (e) the trend in winter sea level pressure (SLP, color) and surface winds (arrows) for the recent decade. Contours show mean winter SLP for 1978–2022. (f) The trend in winter sea ice thickness for the recent decade from PIOMAS. In panels (a–d) trends for the recent decade are quantified and shown by thin dashed lines.

The surface air temperature over the northwestern Barents Sea during winter has also cooled by 2.6°C during the recent decade (Figure 3b). To assess the potential impact on thermodynamic ice growth we calculate the change in sea ice thickness as a function of the freezing-degree days (F) (King et al., 2017; Lebedev, 1938):

$$h_i = 1.33F^{0.58}/100,$$

where $F = \int (T_f - T_a)dt$, T_a is the daily surface air temperature, and T_f is the freezing temperature of seawater. Although snow depth is not explicitly expressed in this equation, it describes ice growth under average snow conditions in the eastern Arctic Ocean. The integration of F, which is performed for each ERA5 grid point within our domain of interest, starts at the first occurrence of sea ice at each location. In addition to T_a, the number of freezing degree days is thus also directly related to the start of the freezing season, which, as argued above, is impacted by the temperature of the upper ocean in fall. Over the recent decade (2013–2022), changes in freezing degree days correspond to a sea ice thickening of 21 cm (Figure 3c).

It should be noted that surface air temperature is both a driver and a response to sea ice changes. A more extensive ice cover could lead to lower air temperatures through anomalous turbulent heat fluxes (Olonscheck et al., 2019; Screen et al., 2012), making it difficult to quantify the role of surface air temperature in driving changes in sea ice thickness. The temperature at 850 hPa (T850) is above the boundary layer and, hence, less affected by sea ice. T850 also shows a cooling in winter over the recent decade (0.7°C) and is highly correlated with 2-m air temperature ($r = 0.92$, Figure 3b).

Further insight into the role of atmospheric forcing in the recent thickening of the Barents Sea ice cover can be obtained by calculating the surface energy budget (SEB), that is, the sum of net shortwave and longwave radiation, and sensible and latent heat fluxes (neglecting heat conduction through the ice, e.g., Boisvert et al., 2016). During winter in the northwestern Barents Sea, the SEB is negative (surface heat loss; Figure S6 in Supporting Information S1), favoring ice formation. Since the 1980s, the SEB shows a trend toward more surface heat loss (-9 W m^{-2} decade^{-1}). During the recent decade, however, surface heat loss has decreased (15 W m^{-2} decade^{-1}).

In line with previous studies (Hegyi & Taylor, 2017; Kim et al., 2019; Liu et al., 2022), there is a high correlation between T_a and the downward longwave radiation (LW_d; Figure 3d); $r = 0.98$ (1980–2022; same for clear-sky LW_d). The source of changes in LW_d, and the role of local and remote processes, is, however, debated (summarized in e.g., Boeke & Taylor, 2018). Some studies (e.g., Alexeev et al., 2017; Kim et al., 2019) argue that sea ice loss and the associated anomalous turbulent heat fluxes warm the lower troposphere and increase LW_d which further increases sea ice loss (and vice versa for an increased sea ice cover). In this (local) mechanism, a role for ocean temperature or winds in driving sea ice changes is implied.

In contrast, other studies have concluded that changes in LW_d are driven by poleward atmospheric water vapor transport, often termed atmospheric rivers (e.g., Liu et al., 2022; Woods & Caballero, 2016; P. Zhang et al., 2023). Liu et al. (2022) argued that variable heat and moisture transport into the Barents Sea is captured by a geopotential height index, representing anticyclonic atmospheric circulation anomalies. Consistent with a thickening ice cover, this index shows a negative trend over the recent decade (Figure 3d), which would correspond to reduced heat and moisture transport and less LW_d (Liu et al., 2022). The latter is consistent with that observed over the recent decade (Figure 3d) and thus supports an important role for atmospheric circulation anomalies in driving the recent sea ice thickening. The trends in atmospheric circulation (sea level pressure), characterized by a weakening of the cyclonic atmospheric circulation over the Nordic Seas (i.e., the Norwegian, Iceland, and Greenland seas; Figure 3e), are however also associated with reduced flow of Atlantic water toward the Barents Sea (Muilwijk et al., 2019; Skagseth et al., 2008) and, as a consequence, decreased ocean temperatures in the Barents Sea (Figure 3a) and further upstream (Årthun et al., 2021; Polyakov et al., 2023).

In summary, we find based on PIOMAS that thermodynamic forcing (rather than dynamics) is the main driver of the recent thickening of the Barents Sea ice cover. Decreasing temperatures in both the atmosphere and the ocean, working in tandem to increase sea ice growth, are consistent with large-scale atmospheric circulation anomalies modulating the poleward transport of heat in the ocean and in the atmosphere.

6. Discussion and Conclusions

Based on a combination of direct measurements and an ice-ocean reanalysis (PIOMAS), we find that the winter sea ice thickness and concentration have increased in the Barents Sea during the last decade. Such an increase in sea ice thickness has not been seen since the 1990s. We furthermore find that anomalous freezing as a result of decreased oceanic and atmospheric temperatures can explain the recent thickening. We emphasize that, despite the recent thickening of the Barents Sea ice cover, the sea ice thickness has gradually decreased since the 1980s. As thinner sea ice is more sensitive to changes in atmospheric and oceanic temperature (Ricker et al., 2021), strong thermodynamically forced trends in sea ice thickness could become more common in a thinning Arctic sea ice cover. Such internally driven multi-annual to decadal trends could lead to an intermittent reversal of the long-term decrease of sea ice thickness, as observed during the recent decade, but also to an accelerated loss of the sea ice (e.g., Dörr et al., 2023).

In agreement with our results, a recent study by Polyakov et al. (2023) showed that there has been a decrease in the decline of pan-Arctic summer sea ice extent and thickness during the last years. PIOMAS also shows that the thickening of the winter ice cover during the last decade is not restricted to the northwestern Barents Sea. The winter sea ice thickness has increased over the entire Barents-Kara Seas region (Figure 3f) and in large parts of the Pacific-Arctic (Figure S2 in Supporting Information S1). In contrast, the ice cover has thinned substantially north and east of Greenland. Decreased sea ice thickness in Fram Strait is consistent with observations (Sumata et al., 2023). In further agreement with our results, the mechanism for the recent decline in summer sea ice loss was suggested to be changes in the large-scale atmospheric circulation over the Arctic Ocean that alters both ocean circulation and the transport of sea ice within and out of the Arctic (Polyakov et al., 2023).

Results from PIOMAS indicate that the recent trend in atmospheric circulation has impacted the thickness of the Barents Sea ice cover through thermodynamic effects, and not through the advection of sea ice (i.e., dynamics). The latter result is somewhat in contrast to other studies that have found a more important role for dynamical forcing. Dethloff et al. (2022), for example, found that the anomalously thick winter sea ice in the Barents Sea in 2020 (Figure 2a) was driven by both low-temperature anomalies and atmospherically driven sea ice transport. On the other hand, Yi et al. (2023) found, based on a sea ice concentration budget, that increased winter sea ice growth in recent decades is dominated by thermodynamic ice growth in most parts of the Arctic seasonal ice zone. A direct comparison of these studies is, however, difficult, as the relative importance of dynamics and thermodynamics depends on both the time scale (trend length) and region considered. Our results are furthermore based on PIOMAS, which is an ice-ocean reanalysis with inherent uncertainties and biases that could potentially influence the relative roles of dynamic and thermodynamic contributions to sea ice thickness changes (e.g., by underestimating regional sea ice advection). We reiterate, however, that PIOMAS has been evaluated thoroughly against observations of sea ice thickness and advection and found to perform well (Schweiger et al., 2011; Selyuzhenok et al., 2020; J. Zhang et al., 2012).

Our analysis has predominantly focused on the recent decadal trend (2013–2022). A detailed analysis for previous decadal trends (including the thickening ice cover in the 1990s) is not presented here. The relative roles of dynamic and thermodynamic forcing can differ for individual decadal trends (Rieke et al., 2023). Comparing all decadal trends since the 1980s nevertheless shows that the importance of sea ice freezing in driving thickness changes is not restricted to the recent decade (Figure 2d).

Our results highlight the importance of natural variability in the Arctic climate system, and in the Barents Sea in particular. As natural variability is the main source of uncertainty in projections of winter sea ice in the Barents Sea over the next few decades (Bonan et al., 2021), understanding the causes and impacts of natural variability is critical for many sectors of business and society (Emmerson & Lahn, 2012).

Data Availability Statement

ULS and temperature measurements are available at Onarheim et al. (2024). PIOMAS version 2.1 model output is available at Polar Science Center (2023). ERA5 data are available at Hersbach et al. (2020). Time series of Atlantic water temperature are available at Gonzalez-Pola et al. (2022). Cryosat-2 data are available at Hendricks and Ricker (2020). Sea ice concentration data are from Stroeve and Meier (2018). Measurements of sea ice thickness from Hopen Island are from Gerland et al. (2022).

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