Influence of the stratospheric polar vortex on the Barents Sea ice extent in early 2012

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Abstract. A significant decrease in the sea ice extent in the Barents Sea was observed in February 2012 due to a large increase in Arctic surface temperature. In early January 2012 a sudden stratospheric warming occurred simultaneously with a stratospheric polar vortex displacement. Based on the ERA-Interim reanalysis data, we show that the displacement of the stratospheric polar vortex led to a perturbation and splitting of the tropospheric polar vortex. An inflow of warm air masses into the polar region, mainly over the Barents Sea, occurred during the splitting of the tropospheric vortex, which resulted in an increase in Arctic surface temperature and a decrease in the sea ice extent.

1. Introduction
Stratospheric polar vortices usually form in autumn, reach peak intensity in mid-winter, and decay from late winter to spring [1]. The dynamics of the polar vortices plays an important role in the stratospheric ozone distribution, the movement of air masses in the polar stratosphere, and the change in the stratospheric temperature over the polar region [2]. The area and extent of the stratospheric ozone depletion over the polar region depend on the polar vortex strength and persistence in spring [3]. The polar vortices act as containment vessels and prevent the inflow of warm and ozone-rich air masses from the midlatitude stratosphere into the polar region [4, 5]. At the same time, polar stratospheric clouds (PSCs) form at extremely low temperatures (lower than −78 °C) inside the polar vortex. Heterogeneous reactions, releasing photochemically active molecular chlorine, occur on and in PSC particles [6]. The stratospheric ozone depletion over the polar region is a result of catalytic cycles involving chlorine species in the presence of weak solar radiation from late winter to spring [7].

One of the most prominent features of the Arctic polar vortex is its large interannual variability associated with the frequency of occurrence of sudden stratospheric warmings (SSWs) [8]. The SSWs are characterized by a sudden increase in the latitudinal mean temperature poleward from 60° latitude at the 10 hPa level (~ 30 km) or below. Such temperature increase occurs during the breaking and dissipation of westward propagating planetary waves, which weaken or reverse the eastward zonal flow (i.e. the stratospheric polar vortex) and induce heat by adiabatic processes [8]. The SSWs are divided into major and minor ones [9]. A strong displacement of the polar vortex occurs during minor SSWs, whereas major SSWs are often accompanied by the polar vortex splitting or even its breakdown.

Displacement, splitting, and breakdown of the polar vortex usually develop from the middle stratosphere to the lower stratosphere [10]. Most studies on this subject focus on the stratospheric effects of the polar vortex dynamics, such as changes in the gas and aerosol composition of the polar
stratosphere [9, 11, 12] and its temperature fluctuations [13, 14]. The aim of this study is to investigate the influence of the stratospheric polar vortex displacement which occurred during a SSW on January 12, 2012 on the tropospheric polar vortex dynamics and its effects on the Arctic surface temperature and sea ice extent.

2. Data and methods
The data on the zonal wind and temperature for 30°–90° N on the 50 and 500 hPa pressure surfaces and the temperature data for 60°–90° N on the 1000 hPa pressure surface were retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=pl/) [15]. The monthly mean values of the sea ice extent over the Barents Sea were taken from the National Snow and Ice Data Center (NSIDC, http://nsidc.org) [16].

To explore the dynamics of the Arctic polar vortices we obtained 38-year monthly climatological means of the zonal wind and temperature for 30°–90° N on the 50 and 500 hPa pressure surfaces over 1979–2016. To analyze variations of the Arctic surface temperature from January to March 2012 we obtained a 38-year climatological mean seasonal cycle of the air temperature for 60°–90° N on the 1000 hPa pressure surface over 1979–2016 with standard deviations (σ). The climatological mean and standard deviations were smoothed by a 15-point fast Fourier transform (FFT) filter.

3. Results
3.1. Stratospheric and tropospheric polar vortices
The polar vortex is a large-scale cyclone located over the polar region. The strong polar vortex leads to a temperature decrease inside the vortex and prevents the inflow of air masses into the polar region. The stratospheric polar vortex exists from autumn to spring and extends from the tropopause to the stratopause [2]. The tropospheric polar vortex extends from the ground to the upper troposphere and exists all year. Figure 1 shows 38-year monthly climatological means (1979–2016) of the zonal wind and temperature at the 50 and 500 hPa pressure levels (~ 20 and 5 km) over the Arctic from October to March obtained using the ERA-Interim reanalysis. As seen in Figure 1, the tropospheric polar vortex is larger than the stratospheric one, has lower velocities of the zonal wind and a more curved trajectory of the zonal flow (which forms the vortex edge). The tropospheric polar vortex usually strengthens from autumn to spring during the existence of the stratospheric vortex [10]. The splitting of the stratospheric polar vortex occurring under the influence of vertically propagating planetary Rossby waves can appear in the dynamics of the tropospheric vortex [17].

3.2. Stratospheric polar vortex displacement and tropospheric polar vortex splitting in early 2012
The SSW which occurred on January 12, 2012 [11] was accompanied by the stratospheric polar vortex displacement, preceding the weakening and breakdown of the vortex. Figure 2 shows the monthly means of the zonal wind and temperature at the 50 and 500 hPa pressure levels over the Arctic from October 2011 to March 2012 retrieved from the ERA-Interim reanalysis. In December 2011 the stratospheric polar vortex was strong and centered over the pole. The displacement and subsequent breakdown of the stratospheric polar vortex were observed in January 2012: it is almost not manifested in the zonal wind distributions for February and March (Figure 2). The changes in the dynamics of the stratospheric vortex appeared in the perturbation of the tropospheric polar vortex in January and its short-term splitting, in February (Figure 2), then the tropospheric vortex recovered in March.
Figure 1. Monthly climatological means of zonal wind and temperature at 50 and 500 hPa pressure levels over the Arctic from October to March over 1979–2016.
Figure 2. Monthly means of zonal wind and temperature at 50 and 500 hPa pressure levels over the Arctic from October 2011 to March 2012.

Figure 3 shows the zonal wind and temperature distributions at the 50 and 500 hPa pressure levels over the Arctic from January to February 2012 retrieved from the ERA-Interim reanalysis. As seen in Figure 3, both the stratospheric and tropospheric polar vortices appear clearly in the zonal wind and temperature distributions in early January. The displacement and elongation of the stratospheric polar vortex were observed on January 12, resulting in the perturbation of the tropospheric polar vortex. The tropospheric vortex splitting occurred in early February. The Beaufort and Barents Seas appeared to be located outside the tropospheric vortex (Figure 3). The Beaufort Sea was covered with cold air masses
of the polar vortex in a few days. The Barents Sea was located outside the tropospheric vortex during February 2012. The inflow of warm air masses in the troposphere over the Barents Sea led to an increase in the surface temperature and a decrease in the sea ice extent over the Barents Sea.

![Figure 3. Zonal wind and temperature distributions at 50 and 500 hPa pressure levels over the Arctic from January to February 2012.](image)

3.3. Arctic surface temperature and Barents Sea ice extent in early 2012

Figure 4 shows the time series of the air temperature for 60°–90° N at the 1000 hPa pressure level from January to March 2012 compared to its 38-year climatological mean seasonal cycle over 1979–2016 with ±1 standard deviations. The time series and seasonal cycle are retrieved from the ERA-Interim reanalysis. As seen in Figure 4, an increase in the Arctic surface temperatures was observed in
the second half of January and then from 6 to 26 February. Thus, it occurred a few days after the stratospheric polar vortex displacement in January, during the tropospheric vortex perturbation, and then in February during the splitting of the tropospheric vortex. In early 2012 the monthly mean surface temperature $T_s$ reached $-17.1$ °C and $-16.7$ °C in January and February, respectively, in comparison with the 38-year monthly mean values for January $T_s = -20.0\pm2.0$ °C and February $T_s = -19.8\pm2.3$ °C.

![Figure 4](image)

**Figure 4.** Time series of temperature for 60°–90° N at 1000 hPa pressure level from January to March 2012 (red line) and 1979–2016 climatological means (green line) with ±1 standard deviations (green areas).

The main inflow of warm air masses into the polar troposphere was observed over the Barents Sea during the perturbation and splitting of the tropospheric polar vortex in January and February 2012 (Figure 3). Figure 5 shows the time series of the monthly mean sea ice extent over the Barents Sea from February 1979 to 2018 retrieved from the NSIDC dataset. As seen in Figure 5, one of the minimum values of the sea ice extent over the Barents Sea for 1979–2018 was observed in February 2012 and reached $3.9\times10^5$ km$^2$.

![Figure 5](image)

**Figure 5.** Time series of February mean sea ice extent over the Barents Sea from 1979 to 2018.
The dynamics of the tropospheric polar vortex plays an important role in the movement of air masses in the polar troposphere and the temperature variations over the polar region [10]. The incursions of cold polar air into the middle latitudes (cold air outbreaks) resulting in extreme negative anomalies of the surface air temperature occur due to a change in the polar vortex edge [18–21]. The Arctic sea ice extent is also influenced by the tropospheric polar vortex, especially in winter when the surface temperature significantly decreases under the conditions of vortex strengthening [22, 23]. Some papers [24, 25] investigated the effect of regional cyclone activity on the Arctic sea ice extent in winter. Overland and Wang in [22] showed an increase in the Arctic surface temperature in the winter of 2015/2016 as a result of splitting of the tropospheric polar vortex.

4. Conclusions
In this study we showed that a stratospheric polar vortex displacement occurring under the influence of vertically propagating planetary Rossby waves can lead to a splitting of the tropospheric polar vortex resulting in an increase in Arctic surface temperature. The displacement and subsequent breakdown of the stratospheric polar vortex were observed during a SSW which occurred in January 2012 and appeared, firstly, in a perturbation and splitting of the tropospheric polar vortex and, secondly, in a large increase in Arctic surface temperature in January and February 2012. As a result, a significant decrease in the sea ice extent in the Barents Sea was observed in February 2012.

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