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Atmospheric teleconnections between the Arctic and the Eastern Baltic Sea regions

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Abstract. The teleconnections between meteorological parameters of the Arctic and the Eastern Baltic Sea regions were analysed based on the NCEP-CFSR and ERA-Interim reanalysis data for 1979–2015. The Eastern Baltic Sea region was characterised by meteorological values at a testing point (TP) in Southern Estonia (~~58N, 26E~~58°N, 26°E). Temperature ~~and specific humidity~~ at the 1000 hPa level at the TP have a strong negative correlation with the Greenland sector (the region between 55–80°N and 20–80°W) during all seasons except summer. Significant teleconnections are present in temperature profiles from 1000 to 500 hPa. The strongest teleconnections between the same parameter at the Eastern Baltic Sea region and the Arctic are found in winter, but they are clearly affected by the Arctic Oscillation (AO) index. After removal of the AO index variability, correlations in winter were below ±0.5, while in other seasons there remained regions with strong ($|R|>0.5$, $p<0.002$) correlations. Strong correlations ($|R|>0.5$) are also present between different climate variables (sea-level pressure, specific humidity, wind speed) at the TP and different regions of the Arctic. ~~Temperature and wind speed at the 1000 hPa level in the Baltic Sea region have a significant positive correlation with sea ice concentration in Baffin Bay and in regions between the North Pole and Greenland during all seasons except summer.~~ These teleconnections cannot be explained ~~with the AO index variability.~~solely with the variability of circulation indices. The positive temperature anomaly of mild winter at the Greenland sector shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer. This evolution is present at 60°N and 65°N but is missing at higher latitudes. The most permanent lagged correlations in 1000 hPa temperature ~~are~~reveals that the temperature in summer at the TP ~~with~~ is strongly predestined by temperature in the ~~Baffin Bay region~~Greenland sector in the previous spring~~, winter and even autumn. At every season there are some regions in the Arctic that has strong teleconnections ($|R|>0.5$, $p<0.002$) with temperature, specific humidity, wind speed and air pressure in the Baltic Sea region. These relationships can be explained by the AO/NAO index variability only in~~ and winter.

1 Introduction

Over the past half a century, the Arctic has warmed at about twice the global rate (IPCC, 2014), a phenomenon called the Arctic Amplification~~.~~ (AA). At the same time, a significant decrease in sea ice extent has occurred in all calendar months since 1979 (Simmonds, 2015), which has been declared to have a leading role in recent ~~Arctic temperature amplification~~AA by some scientists (e.g. Screen and Simmonds, 2010; Francis and Vavrus, 2012). On the other hand, Perlwitz et al. (2015) ~~disconfirm~~disagree the common assumption that sea ice decline is primarily responsible for the amplified Arctic tropospheric warming. They found that from October to December, the main factors responsible for the Arctic deep tropospheric warming are: 1) the recent decadal fluctuations and 2) long-term changes in sea surface temperatures~~, both~~. These two factors are located outside the Arctic. According to Sato et al. (2014) warm southerly advection is favourable for retreating sea ice over the Barents Sea and warming of air aloft, whereas sea-ice decline would result in warming over the Barents Sea because of anomalous turbulent heat fluxes. Screen et al. (2012) found that sea ice concentration and sea surface temperature explain a large portion of the observed Arctic near-surface warming, whereas remote sea surface temperature changes explain the majority of observed warming aloft. As the energy budget of the Arctic is highly dependent on energy exchange with lower latitudes, then the changes in atmospheric and oceanic circulation play an important role in all kinds of heat conservation changes in the Arctic~~.~~ ~~Therefore, the~~, most prominently expressed in sea ice volume variations. The observed enhanced warming of the Arctic, referred to as the ~~Arctic amplification~~AA, is expected to be related to further changes that impact mid-latitudes and the rest of the world (Jung et al., 2015; Walsh, 2014).

These Arctic influences could be direct, as the advection of cold and dry air from over the ice-covered areas to the neighbouring territories, but it could also be through teleconnections – the large-scale patterns of high and low pressure systems and circulation anomalies that cover vast geographical areas and reflect the non-periodic oscillations of the climate system. Teleconnection as a term was first used by Ångström (1935). Wallace and Gutzler (1981) defined teleconnections as significant simultaneous correlations between the time series of meteorological parameters at widely separated points on the Earth; the essence of a teleconnection is that a climatic process may influence the Earth's system elsewhere (Liu and Alexander, 2007). Teleconnections between the Arctic and mid-latitude regions have been the focus of research for many years and several reviews about the Arctic sea ice impact on the global climate (Budikova, 2009; Vihma, 2014) or Eurasian climate (Gao et al., 2015) have been published. Budikova (2009) stated that the size of the response of the climate of remote regions to changes in the Arctic has been found to be linked linearly, but the forcing direction nonlinearly. Less ice in the Arctic results in a significant decrease in the speed of the westerlies and the intensities of storms poleward of 45°N (Budikova, 2009). Many studies suggest that the Arctic sea ice decline increases the probability for circulation patterns resembling the negative phase of the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) ~~indexes~~indices in winter (Vihma, 2014). However, there is a debate as to whether the reduction in the autumn Arctic sea-ice-induced negative AO/NAO index can persist into winter ~~(Gao et al., 2015). Some researchers~~and suggest that winter atmospheric circulation is more closely associated with changes in the winter Arctic sea ice (Gao et al., 2015). Several studies have demonstrated ~~the~~ relationships between warming and/or ice decline, and mid-latitude weather and climate extremes (Handorf et al., 2015; Coumou et al., 2014; Tang et al., 2013; ~~2014;~~ Petoukhov et al., 2013; Francis and Vavrus, 2012; Petoukhov and Semenov, 2010). Others have analysed whether these associations are statistically and/or physically robust (Hassanzadeh et al., 2014; Screen et al., 2014; Barnes et al., 2014; Screen and Simmonds, 2013, 2014; Barnes, 2013), while some investigations suggest that the apparent associations may have their origin, in part, in remote influences (Perlwitz et al., 2015; Sato et al., 2014; Peings and Magnusdottir, 2014; Screen et al., 2012; Petoukhov and Semenov, 2010).

~~The~~The relationship between the AA and weather extremes and/or persistent weather patterns in mid-latitudes are mostly explained with Arctic and North Atlantic anomalous circulation regimes, waviness and strength of jet stream (Vavrus et al., 2017; Francis and Skific, 2015; Overland et al., 2015; Barnes and Screen, 2015; Francis and Vavrus, 2015; Coumou et al., 2014; Tang et al., 2013; Petoukhov et al., 2013; Francis and Vavrus, 2012). Common supposition is that sea ice declines are primarily responsible for amplified Arctic tropospheric warming. This conjecture is central to a hypothesis in which Arctic sea ice loss forms the beginning link of a causal chain that includes weaker westerlies in mid-latitudes, more persistent and amplified mid-latitude waves, and more extreme weather (Perlwitz et al., 2015). On the other hand Sun et al. (2016) brought out that neither sea ice loss nor anthropogenic forcing overall yields the winter cold extremes and persistence in mid-latitudes. Arctic warming over the Barents and Kara Seas and its impacts on the mid-latitude circulations have been widely discussed (Dobricic et al., 2016; Semenov and Latif, 2015; Kug et al., 2015; Sato et al., 2014). Another particular regional warm core (Screen and Simmonds, 2010) is the East Siberian and Chukchi Seas, which is related to severe winters over North America (Kug et al., 2015; Lee et al., 2015). Screen and Simmonds (2010) brought out also the third particular regional warm core – northeast Canada and Greenland which has been less investigated. Wu et al., (2013) focused on winter sea ice concentration west of Greenland, including the Labrador Sea, Davis Strait, Baffin Bay, and Hudson Bay and found that winter sea ice concentration west of Greenland is a possible precursor for summer atmospheric circulation and rainfall anomalies over northern Eurasia. If we look at the regions in the mid-latitudes then potential Arctic teleconnections with Europe are less clear than with North America and Asia (Overland et al., 2015).

The Eastern Baltic Sea region features very variable weather conditions due to its location in the climatic transition zone between the North Atlantic and the Eurasian continent. The region is also close to the Arctic or even part of it (depending on defining the borderlines) and certainly has a direct Arctic influence. The weather in the region depends highly on the position of the polar front: it can be located northward as well as southward of the area. According to the Second Assessment of Climate Change for the Baltic Sea Basin (BACC II, 2015), significant changes have occurred in climate parameters, which could be associated to large-scale atmospheric circulation. Intensity of the zonal circulation, i.e. the westerlies, has increased during the cold period~~,~~ (NDJFM), especially in February and March. ~~There~~After 1980s there has been ~~an overall warming of~~significant temperature increase in the Baltic Sea region~~,~~ (BACC II, 2015), which has not been equal throughout a year~~, nor over the whole region~~. The highest increase in air temperature is typical for spring (MAM) season. Although a remarkable warming has been present also in winter (DJF), it is not significant due to a very high temporal variability (Jaagus, 2006). A tendency of increasing precipitation in winter and spring was detected in the Baltic Sea region during the latter half of the 20th century, possibly increasing the risk of extreme precipitation events. There is some evidence that the intensity of storm surges may have increased in some parts of the Baltic Sea in recent decades, and this has been attributed to long-term shifts in the tracks of some cyclone types rather than to a long-term change in the intensity of storminess~~.~~ (BACC II, 2015).

It is known that fluctuations of the climatological parameters in the Baltic Sea region are strongly affected by the atmospheric circulation variability described by the teleconnection indices of NAO and AO (BACC II, 2015). ~~But there~~There is no clear understanding about the reasons for the changes in these indices or climatic parameters in the Baltic Sea region in ~~last decades.~~most recent time. One of the reasons for incomplete understanding is the non-stationarity of the NAO spatial pattern and the temporal correlations (Lehmann et al., 2011; 2017). ~~On the other hand, it~~It is natural to assume that changes in the Arctic climate system have an effect on the Eastern Baltic Sea region and vice versa~~. Therefore, our~~ due to their close proximity. Our aim is to ~~find out~~clarify how ~~could~~ the climatic parameters in the Eastern Baltic Sea and Arctic regions ~~be~~are associated. Knowledge of such connections helps to define regions in the Arctic that could be with higher extent associated with the ~~specific geographic distribution of the resulting anomalies in surface~~Eastern Baltic region climate ~~parameters such as air temperature, precipitation or wind speed~~change.

Our analysis is designed as follows. We selected one grid point (the testing point TP) to represent the Eastern Baltic Sea region and to find~~ the~~ correlations between climate parameters at this point and in the Arctic cap to find the regions of mutual connections. Next, we calculate the partial correlations with various teleconnection indices as control factors to get rid of the known atmospheric circulation variability. To compare broad atmospheric circulation patterns, we calculate geopotential heights differences between cold and mild winters. Due to longer memory of non-atmospheric components of climate system we compute by season lagged correlations between climate parameters.

The objective of this paper is to indicate the relationships between meteorological parameters of the Arctic region and the TP. By tracking down the teleconnections between the rapidly changing Arctic region and the TP we can get valuable information about possible future trends in the Eastern Baltic Sea region even if the changes in both regions were caused by a third factor.

2 Data and methodology

We used monthly mean reanalysis data from the Climate Forecast System Reanalysis (CFSR) on a 0.5º×0.5º horizontal grids provided by the National Centers for Environmental Prediction (NCEP). For the period 1979–2010, 6-hourly data of CFSR version 1 ~~were used~~ (Saha et al., 2010) ~~and~~were used for ~~the period~~calculating monthly means and for 2011–2015, 6-hourly data of CFSR version 2 were used (Saha et al., 2014). For reproducibility, we repeated all calculations using ERA-Interim data

(Dee et al., 2011). Mostly, these two models showed very similar results. In this paper, only NCEP-CFSR results are shown, only disagreements between models are pointed out in the Results chapter. The following parameters were analysed: temperature at 1000, 850, 500 and 250 hPa level~~;~~, sea-level pressure (SLP), geopotential heights from 1000 hPa to 100 hPa, specific humidity and wind speed at 1000 hPa~~; sea-level pressure (SLP),~~ and sea ice concentration (SIC). Monthly means and seasonal means (DJF, MAM, JJA, SON~~, DJF~~) were calculated from the 6-hourly data. Monthly mean wind speed was calculated as a scalar average.

~~The following teleconnection indices – North Atlantic Oscillation (NAO), Arctic Oscillation (AO), East Atlantic Pattern (EA), Scandinavia Pattern (SCA), East Atlantic/West Russia Pattern (EA/WR), and Pacific Decadal Oscillation (PDO) were downloaded from the NOAA-CPC database (http://www.cpc.noaa.gov). The first two indices had the largest effect on the Arctic – Baltic Sea region atmospheric teleconnections and are investigated in more detail in this article.~~

The teleconnection indices we applied in our analyses were chosen according to the possible influence due to the geographical position of the centres of action of the teleconnection patterns over the North-Atlantic-Eurasian region. The following indices were chosen: 1) The North Atlantic Oscillation (NAO), which is the dominant mode of atmospheric variability in the North Atlantic sector throughout the year (Barnston and Livezey, 1987); 2) The Arctic Oscillation (AO), which is usually defined as the first EOF of the mean sea level pressure field in the Northern Hemisphere (Ambaum et al., 2001); 3) The Scandinavian Pattern (SCA), which consists of a primary circulation centre over Scandinavia, with two other weaker centres of action with the opposite sign, one over the north eastern Atlantic and the other over central Siberia to the southwest of Lake Baikal (Bueh and Nakamura, 2007); 4) The East Atlantic Pattern (EA), which consists of a north-south dipole of anomaly centres spanning the North Atlantic from east to west (Barnston and Livezey, 1987); 5) The East Atlantic/West Russia Pattern (EA/WR), which consists of four main anomaly centres: Europe, northern China, central North Atlantic and north of the Caspian Sea; 6) The Polar/ Eurasia Pattern (PEU) consists of height anomalies over the polar region, and opposite anomalies over northern China and Mongolia.; 7) Additionally, Pacific Decadal Oscillation (PDO), which is the dominant year-round pattern of monthly North Pacific sea surface temperature (SST) variability was included. Although its geographical centres are far from the Baltic Sea region, Uotila et al (2015) found that PDO correlated significantly with the ice concentration and temperature of Baltic Sea. All indices were downloaded from the NOAA-CPC database (http://www.cpc.noaa.gov).

We assume that because of a high spatial correlation between meteorological conditions in the ~~whole~~Eastern Baltic Sea region it is reasonable to choose one testing point (TP) that represents the ~~whole~~ region. Lehmann et al. (2011) used the same method by selecting Hamburg-Fuhlsbüttel to represent the temperature evolution of the Baltic Sea area as correlation coefficients for the seasonal mean air temperature between Hamburg and different sub-basins ranged from 0.8 to 0.9. We selected TP in Southern Estonia with coordinates 58°N, 26°E. The correlation coefficient for the seasonal mean air temperature at 1000 hPa and SLP (not shown) between the TP and different sub-basins of the Eastern Baltic Sea is mostly higher than 0.85 (~~Fig.~~Figure 1). The highest correlation is observed in winter and the lowest in summer.

We analysed the reanalysis data with the Grid Analysis and Display System (GrADS). We calculated linear correlation coefficients to reveal teleconnections between the Arctic region and the TP of the Eastern Baltic Sea region. In this paper we use only linear Pearson correlations, non-linear correlations are not included. We define the Arctic region here as the region northward of 55~~-~~°N. Larger region than usual (Arctic cap from polar circle or 70°N; July 10°C isotherm) helps to analyse results that lay partly outside the usually defined Arctic region. For correlations with the TP, the first correlation input was taken at the TP and the second in the Arctic region. ~~Two~~The lowest correlation ~~levels~~level in Figures ~~are ±0.17 and~~is ±0.32, representing~~ 68% and~~ 95% confidence levels of the correlations; only strong correlations |R|>0.5 (at least 99.8% confidence level) are discussed in this paper.

We used F-test to assess the significance of correlations. For comparison of averages, we used t-test assuming equal variances.

Detrending of seasonal time-series was done to ~~avoid~~ascertain that the correlations ~~to be~~are not caused by mutual trends in input variables~~.~~ using following formula:

$$Y_i = X_i - (k \cdot year + b - X_{average})$$ ~~.~~

Therefore, linear trends for each parameter at each grid point were calculated for each season and all correlations were calculated twice – at first using the regular and ~~later~~secondly the detrended data. Detrending ~~changed the correlations only slightly: differences between the areal averages~~did not change general patterns of correlations ~~were up to 0.02 in both directions. We show~~with TP, only ~~the~~negative correlation ~~coefficients~~ in the Greenland region intensified slightly. All discussed correlations of the regular data~~, but the detrended correlations~~ were also significant in ~~all discussed results~~analysis of detrended data. As we are exploring the connections that include long term climatic trends such as global warming, we present in this paper only correlations of the regular, not detrended data.

The next step in the analysis was to remove from the correlations the effect of atmospheric teleconnections which could be described by known teleconnection indices. For that purpose, partial correlations between ~~various~~selected atmospheric variables with the controlling effect of ~~AO~~the teleconnection indices were calculated~~.~~ as follows:

$$R_{AB|C} = \frac{R_{AB} - R_{AC} \cdot R_{BC}}{\sqrt{(1 - R_{AC}^2) \cdot (1 - R_{BC}^2)}}$$

Cold and mild winters were defined as years when the winter average temperature differed the whole period average more than one standard deviation at a geographical point in the Greenland sector (70°N, 60°W). Accordingly – cold winters were 1983, 1984, 1989, 1990, 1992 and 1993; mild winters were 1980, 1985, 1986, 2003, 2007, 2009, 2010 and 2011.

The last phase of the analysis was to calculate the lagged correlation coefficients with the purpose of revealing the possible delayed dependences between the atmospheric variables of the Arctic region and the TP. For the lagged correlation, the second parameter was taken by lag months earlier than the first parameter.

3 Results

3.1 Spatial correlations of climatic variables

Climatic variables at separate ~~gridpoints~~grid points are usually not independent, but correlations in space depend highly on the distance and climatic variables. For example, for temperature, the dependence in space stays significant for longer distances than for precipitation as the processes of their formation are different. But besides the short distance correlation of climatic parameters between the TP and the surrounding ~~gridpoints~~grid points, there are also vast areas far from the TP, still having significant correlations (~~Fig.~~Figure 2). The strongest correlations are detected in winter when temperature at the 1000 hPa level at the TP has a positive correlation over a ~~huge~~large area, covering nearly the whole northern Eurasia, with the maximum ($R>0.5$) in northern Europe, on the Eastern European Plain and Central Siberia. At the same time, an area of a strong negative correlation ($R<-0.5$) is found in the Greenland sector. Hereinafter, we define the Greenland sector as region~~.~~ between 55–80°N and 20–80°W. A similar correlation pattern, but of less magnitude, is also present ~~for~~in spring and autumn.~~ These patterns are very similar to the correlations between temperature and the AO index (Fig. 3).~~ The pattern of spatial correlation for temperature at the 1000 hPa level in summer is different. The area of positive correlation is much smaller than in winter, mostly covering only Europe, but a negative correlation is detected in the central Arctic and western Siberia~~ (Fig. 2).~~.

Specific humidity at the 1000 hPa level has a similar pattern of correlations as temperature at the same seasons. The largest differences are observed in Siberia in spring with about 20% higher correlation in temperature than in specific humidity. Wind speed at the 1000 hPa level at the TP has the highest correlation in winter, while the areas of a positive correlation in Europe and North Atlantic and of a negative correlation in the central Arctic and the Greenland sector are strictly ~~distinguished.~~distinct. During the other seasons the spatial correlation is much lower. ~~It~~There is~~ interesting that~~ a strong positive correlation in wind speed in summer~~ exists~~ between the TP and the Canadian Arctic Archipelago and the Bering Sea region. SLP at the TP has a significant negative correlation with SLP in ~~Greenland and at Baffin Bay region in summer and autumn (Fig. 2).~~the Greenland sector in autumn. Figure 2 using ERA-Interim data (not shown) gave very similar results. Detectable differences were found in Central Arctic in summer and autumn when correlations with temperature and specific humidity were slightly higher in ERA-Interim than NCEP-CFSR.

The Greenland sector showed most often significant correlations with the parameters of the Eastern Baltic Sea region. In Table 1 are given spatial average, minimum and maximum values of seasonal correlations between the TP and the Greenland sector. Strong negative correlation in the Greenland sector at 1000 hPa temperature in winter and spring decreases with altitude and turns even positive at 250 hPa (Table 1). Specific humidity at 1000 hPa shows quite similar values with temperature at the same level (Table 1). The correlation between wind speed at 1000 hPa at the TP and the Greenland sector is mostly negative in winter (Figure 2), reaching up to -0.72 (Table 1). Most significant correlation between SLP is present in autumn and summer (Figure 2, Table 1).

Climatic variables have close relationships between themselves. If there is a climatic change in one parameter, for example in temperature, then it causes changes also in other parameters connected with it, for example in ~~**3.2 Correlations between the teleconnection indices and climatic parameters**~~

~~Correlation~~ ice concentration. Similarly to correlations of the same climate variable at the TP and the Arctic (Figure 2), there are strong correlations (|R|>0.5) between different climate variables at the TP and the Greenland sector (Table 1). Correlation between the 1000 hPa temperature at the TP and SLP show expected results with a positive correlation in summer and negative in winter around the TP (not shown). Largest correlations with the Greenland sector are in winter when the correlation is averagely –0.39 and extremal values reach even to -0.73. Correlations with ice concentration have quite large extremal values reaching up to 0.71 in summer for wind speed and 0.64 in spring for temperature, but these correlations are significant only at narrow coastal areas around Greenland (not shown).

3.2 Impact of the teleconnection indices

To analyse the impact of the seven teleconnection indices given at Data paragraph, the average of partial correlations between 1000 hPa temperature at TP and the Greenland sector (55–80°N, 20–80°W) are shown for winter and spring in Table 2. The influence of teleconnection indices depends strongly on a season and on a parameter. Larger difference from regular correlation values means higher impact of the index. According to the definition – removing the impact may decrease but may also increase the correlation.

The first row of Table 2 shows the average of the regular Pearson correlation of temperature at 1000 hPa in the region. It has the most significant values during winter and spring. Also the impact of AO and NAO is most considerable during these seasons. Considering the correlation coefficients between seasonal mean temperature, specific humidity~~ and~~, wind speed at the 1000hPa level and SLP at the TP~~, and the NAO and AO indices are presented in Table 1. The highest values are found for both the NAO and AO indices in winter, where all the correlations are statistically significant. The~~ the AO indices have mostly ~~have~~ higher correlations~~, while correlations with temperature are significant in all seasons. Only~~ than the NAO indices, only SLP in summer and autumn has a significantly higher correlation with the NAO index~~.~~

~~Correlation maps between the seasonal mean values of the AO index and temperature, specific humidity and wind speed at the 1000hPa level, and SLP are presented in Fig. 3. There are patterns similar to Fig. 2, especially for temperature and specific humidity. The field of wind speed at the 1000 hPa level shows a diverse picture in both Figures. As it follows from the definition of the~~ (not shown). Hereafter mostly only AO index~~, there is a strong negative correlation between the AO~~ is analysed (and not NAO index~~ and SLP in the whole Arctic region in all seasons.~~).

~~3.3 Spatial correlations between the same parameters without the effect of the AO and NAO indices~~

Partial correlations with the controlling factor AO index reduce the area with a statistically significant correlation around the TP in all parameters and in all seasons~~ (Fig. 4 in comparison with Fig. 2).~~. This effect on the remote areas depends on the season. In winter the effects of the AO indices on spatial correlations are the strongest, up to 0.5. In spring, the differences between partial correlations with the AO ~~or NAO~~ indices are ~~small~~below 0.2 in the whole region compared to the regular correlations between the TP and the Arctic. ~~Differences are below 0.2 in the whole region.~~ In summer and autumn, the differences are even smaller~~. The effects of the AO and NAO indices on spatial correlations are the strongest in winter, up to 0.5, while the AO index has a stronger controlling effect~~ than ~~the NAO index in all parameters. Partial correlation with the AO index as a controlling factor reduced the TP correlation (absolute value) with temperature and specific humidity in Central Siberia and the Baffin Bay region by 0.3–0.5, compared with the regular correlation. At the Gulf of Alaska, the difference exceeds by 0.3 as the regular correlation is negative there, but the partial correlation is positive~~in spring.

~~In~~ Partial correlation in temperature, removing the influence of the AO index, is below ±0.5 on all levels (1000, 850, 500 and 250 hPa) in winter, ~~the absolute values of partial correlations with the controlling factor the AO index are below 0.5 everywhere beyond the TP region,~~ though the regular correlations are the strongest~~.~~ (not shown). In other seasons, regions with stronger partial correlations than ±0.5 remain. ~~In temperature and specific humidity, there are strong positive partial correlations from spring to autumn in North-Eastern Siberia. In wind speed, there are still strong positive partial correlations in the Canadian Arctic Archipelago and the Bering Sea region.~~

~~Next, correlations in the higher atmosphere are investigated. Temperature correlations with the TP on four isobaric levels – 1000, 850, 500 and 250 hPa – are shown in Fig. 5. Generally, a spatial correlation decreases on higher levels and the area of significant correlation around the TP also decreases. The positive correlation in winter and spring in Central Siberia weakens with height and becomes a negative correlation at the 250 hPa level in winter. Partial correlation in temperature, removing the influence of the AO index, is below ±0.5 on all levels in winter (not shown).~~

In summer~~, there is a strong positive correlation with temperature in the Laptev Sea region on all levels below 250 hPa and in Canada on the above 850 hPa level. In autumn, correlation is strongly positive in the Kamchatka region below the 500 hPa level. In summer and autumn, the AO or NAO~~ and autumn, the AO indices have no significant influence on correlations on higher altitudes, similarly to the 1000 hPa level.

~~3.4 Spatial correlations between different parameters~~

The impact of other teleconnection indices than AO and NAO is much smaller. Among other indices the SCA index has the strongest impact in winter but very small impact during other seasons while in spring the partial correlation with the PEU index decreases the value of correlation coefficient the most (except AO and NAO). The average (regular) correlation coefficients between 1000 hPa temperature at TP and the Greenland sector during summer and autumn were only 0.15 and -0.02 respectively and are not discussed here.

3.3 Comparison of winters with low and high temperature

To compare broad atmospheric circulation patterns, we turn to the difference map of the geopotential heights of 500 hPa and temperature at 1000 hPa by subtracting the composites of cold winters (DJF) from those of mild winters (Figure 3). The large scale atmospheric circulation pattern in Figure 3 shows that the geopotential heights of 500 hPa are more than 100 gpm higher in mild winters than in cold ones. The maximum of this height anomaly is centred over the maximum of the 1000 hPa temperature difference. The whole column (up to 500 hPa) of the air in the Greenland sector is warmer than at cold years. Coming down to the lower surfaces (700 hPa, SLP, not shown), the maximum height anomaly is shifted to the east. Ensuing spring and summer also show positive values of the 1000 hPa temperature and the geopotential heights of 500 hPa in the Greenland sector (spring and summer in Figure 3). In autumn the positive anomaly of 1000 hPa temperature and geopotential heights of 500 hPa are present in Siberia.

Along the 60°W vertical slice the spring atmosphere exhibit baroclinic structure between about 60°N and 82°N due to negative height anomalies in the lower troposphere below the 850 hPa and with further higher the positive ones (spring in Figure 4). Similarly to Wu et al. (2013) the vertical distribution of spring height anomalies differs from that of the previous winter when height anomalies show dominantly quasi-barotropic structure. The annual evolution of 500 hPa height differences at 60°N shows that the positive temperature anomaly at the Greenland sector shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer (Figure 5). Also at 65°N the similar pattern is present (not shown), but at 70°N and 75°N this kind of signal propagation is missing. ERA-Interim has at 60°N similar patterns, but without considerable positive difference at the Greenland sector in winter (not shown).

3.4~~Climatic variables have close relationships between themselves. If there is a climatic change in one parameter, for example in temperature, then it causes changes also in other parameters connected with it, for example in snow cover. Similarly to correlations of the same climate variable at the TP and the Arctic (Fig. 1, 2 and 5), there are strong correlations (|*R*|>0.5) between different climate variables at the TP and the Arctic (Fig. 6). Correlation between the 1000 hPa temperature at the TP and SLP show the expected results with a positive correlation in summer and negative in winter. The largest areas of negative correlations, controlled by variations of the AO index (not shown) are present in winter and spring. In summer, the temperature at the TP is negatively correlated with SLP in Siberia and North America, while in autumn it is negatively correlated in the North Atlantic and positively correlated in the Canadian Arctic Archipelago.~~

~~Correlations between the temperature at the TP and wind speed at the 1000 hPa level in the whole Arctic have a negative correlation in winter above Greenland and the East Siberian Sea, but it is missing in the partial correlation with the controlling factor AO index (not shown). Correlation between the 1000 hPa temperature at the TP and sea ice concentration is positive around Greenland in spring, in the Central Arctic in summer and around Greenland and in the Canadian Basin in winter. Correlation between the 1000 hPa wind speed at the TP and ice concentration is negative in the Canadian Basin in summer and positive at the coastal areas of north-eastern Siberia in autumn and around Greenland in winter. Partial correlations between ice concentration and temperature or wind speed with the controlling factor AO index do not differ much from regular correlations even in winter.~~

~~3.5~~ **Teleconnection using lagged data**

There is a large inertia in the atmosphere causing lag effects. It means that ~~weather~~climatic conditions in a previous period can have an effect on the weather during the following weeks, months and seasons. For finding the effect of the previous seasons on weather conditions at the TP, lagged correlations were calculated for the 1000 hPa temperature (~~Fig. 7~~Figure 6). The results show that the previous winter season has a strong effect on temperature during the following ~~seasons.~~spring (lag=3) and summer (lag=6). At the same time, the winter mean temperature ~~is not~~has almost no dependent on weather conditions during the previous seasons~~.~~, there is only small region with strong negative correlation in the Taimyr region in the previous summer (lag=6).There is a strong (*R*>0.5) positive correlation between the 1000 hPa temperatures at the TP in spring and in Eurasia during the previous winter (lag~~ = 3 months). However, the~~=3). The spring temperature is not determined by the temperature of the previous autumn (lag=6) nor of the previous summer (lag=9). ~~This means that not only the TP, but the whole Eurasia average spring temperature is highly controlled by the previous winter average temperature, which is responsible for more than 25% of the variability.~~ Summer temperature at the TP has a strong positive correlation in the ~~Baffin Bay region~~Greenland sector with the previous spring (lag=3), winter (lag=6) and autumn (lag=9). Autumn temperature at the TP has a strong negative correlation with the ~~region between Greenland and Svalbard~~Fram Strait in the previous summer (lag=3~~). Winter temperature at the TP has a strong negative correlation in the~~) and Taimyr region in the previous ~~summer~~winter (lag=~~6~~9).

4 Discussion

There are vast areas in the Arctic far from the Eastern Baltic Sea region that show significant correlations with meteorological parameters at the TP. Temperature at the 1000 hPa level at the TP has a strong positive correlation (R>0.5) with the Eastern European Plain up to Central Siberia and a strong negative correlation with the Greenland ~~region~~sector during all seasons except summer (~~Fig.~~Figure 2). These patterns are similar to the correlations with the AO index (~~Fig. 3~~not shown) and are probably partly induced by the general circulation of the atmosphere. These correlations can be considered as an effect of stronger westerlies that carry relatively warm and moist air from the North Atlantic into Eurasia and, at the same time, cold and dry air from the central Arctic to Greenland and the Canadian Arctic Archipelago. As specific humidity and temperature are strongly coupled, specific humidity has a similar pattern of correlations as temperature. Warmer air can hold much more water vapour. The ~~exceptional~~reason why summer season ~~may be~~differs from other seasons maybe caused by a less effective large-scale circulation. Also, the circumstances are different in summertime: positive atmospheric energy budget, more specific humidity and clouds, the melting ice temperature is conserved by the melting energy of ice. Consequently, we assume that weather conditions in summer are more influenced by local factors, such as differences in local radiation and heat balances determined by local geographical peculiarities, and less affected by large-scale atmospheric circulation.

Partial correlation analyses were used as the control for the potential effects of different teleconnection indices on correlations between meteorological parameters at the TP and the Arctic. Partial correlations with the controlling factors of the AO and NAO indices had the strongest influence on the correlations between meteorological parameters between the TP and the Arctic region; other teleconnection indices had ~~smaller influence.~~much smaller influence. Budikova (2012) suggests that the AO and NAO are very closely related and the NAO is frequently referred to as a "local expression" of the AO as it dominates its structure in the Atlantic sector. Still, some scientists show different impact of NAO and AO to meteorological parameters and phenomenon. According to the review article by Bader et al. (2011), the NAO is the most important teleconnection index for investigating the impact of the Arctic sea-ice changes on teleconnection patterns. The study of Ambaum et al. (2001) suggests also that because of the physical background of the NAO ~~paradigm~~index it may be physically more relevant and robust for the Northern Hemisphere variability than is the AO ~~paradigm. On the other hand,~~index. Uotila et al. (2015) preferred NAO to AO analysing Baltic Sea ice conditions because of the centre of action that has more influence over the Baltic Sea ice conditions (Uotila et al., 2015). Thompson and Wallace (1998) declared that the AO index is actually more strongly coupled to the Eurasian winter surface air temperature than the NAO index. ~~We analysed different meteorological parameters, including~~Rinke et al. (2013) showed through the coupled regional climate model experiments that atmospheric large-scale circulation in a winter following a low September sea ice~~.~~ resemble a negative AO pattern. Our results ~~are more consistent with Thompson and Wallace~~ show that for the correlation coefficients between the Eastern Baltic Sea region~~,~~ and the Greenland sector the AO index had mostly ~~had~~ the highest ~~correlations~~impact in every season, only SLP in summer and autumn had a significantly stronger ~~correlation~~impact with the NAO index.

The strongest teleconnections between the same parameter at the Eastern Baltic Sea region and the Arctic region can be found in winter, but they are clearly affected by the AO index. After the removal of the influence of the AO index, the correlations were below 0.5 in winter, while in other seasons there remained regions with strong correlations. It means that climatic teleconnections, i.e. significant spatial correlations of climatic parameters between regions located long distance from each other, in winter are mostly caused by large-scale atmospheric circulation described with the AO index.

Among other teleconnection indices (except AO and NAO) the SCA index showed the largest impact between 1000 hPa temperature at TP and the Greenland sector during winter (Table 2). The SCA pattern has been shown to influence precipitation, temperatures, and cyclone activity across northern Europe and Eurasia (Moore et al., 2013; Bueh and Nakamura, 2007; Seierstad et al., 2007). Uotila et al. (2015) found that the PDO index has significant impact on the Baltic Sea ice concentration although physical mechanisms linking the Baltic Sea ice with PDO are not well known (Vihma et al., 2014). We investigated the correlation between 1000 hPa temperature at TP and the Greenland sector and removing the influence of PDO (by partial correlation) did not change the results much during any season. Removing the EA/WR index influenced the results even less although regionally the anomaly centres of the EA/WR Pattern include Europe and North Atlantic. Lim (2015) analysed the EA/WR (1979–2012) and found that the positive (negative) EA/WR is associated with a strong cooling (warming) over the Ural Mountains of northern Russia which is much more eastward from our TP.

The comparison of 700 hPa and 500 hPa geopotential height differences between mild and cold winters showed that 700 hPa geopotential height is shifted to the east. This could be due to warmer sea surface of the Northern Atlantic compared to the regions that lay to west of it. The positive temperature anomaly at 1000 hPa height shifts from the Greenland sector in winter towards east reaching to Scandinavia/Baltic Sea region in summer. This could be also followed by our lagged analyses which show that the summer temperature at TP has significant correlation with Greenland sector in winter (JJA; lag=6). By Wu et al. (2013) proposed mechanism, that associates the summer atmospheric circulation anomalies in the northern Eurasia with the previous winter ice conditions west of Greenland, supports our results.

5 Conclusions

Rapid warming and reduction of sea ice is going on in the Arctic. In this article, the relations between meteorological parameters of the Arctic region and the Eastern Baltic Sea region are investigated, using the NCEP-CFSR and ERA-Interim reanalysis data for 1979–2015. The Eastern Baltic Sea region is characterized by meteorological values at the testing point (TP) in southern Estonia (~~58N, 26E). To avoid false correlations, only the results that were present in both the regular and the detrended data were discussed.~~

58°N, 26°E). There are vast areas in the Arctic, far from the Eastern Baltic Sea region, that show significant correlations with climatological parameters at the TP. The most ~~spectacular~~important findings about the Arctic teleconnections with the Eastern Baltic Sea region are as follows:

- The strongest teleconnections between the same parameter in the Eastern Baltic Sea region and the Arctic are in winter, but they are clearly affected by the Arctic Oscillation index (AO index). After removal of the AO index variability, correlations in winter were below 0.5, while in other seasons strong (|*R*|>0.5) correlations mostly remain.
- Strong teleconnections are present in temperature profiles from 1000 to ~~250~~500 hPa. Similarly to the 1000 hPa level, teleconnections on higher levels are connected with the AO index variability in winter.
- Strong teleconnections are present between different climate variables at the TP and the Arctic. Temperature and wind speed at the 1000 hPa level in the Eastern Baltic Sea region have in all seasons strong teleconnections with the sea ice concentration in some regions of the Arctic Ocean. These teleconnections cannot be explained solely with the ~~AO index~~climate indices variability.
- The annual evolution of 500 hPa height differences (between mild and cold winter in the Greenland sector) at 60°N shows that the positive temperature anomaly during winter shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer. Also at 65°N the similar pattern is present. At higher latitudes (70 and 75°N) this kind of signal propagation is missing.

- In all seasons there are strong teleconnections in temperature at 1000 hPa at the TP with some Arctic regions from the previous seasons. The most permanent lagged correlations in 1000 hPa temperature are in summer at the TP with the ~~Baffin Bay region~~Greenland sector in the previous spring, winter and even autumn.

In conclusion, at every season there are some regions in the Arctic that has strong teleconnection ($|R|$>0.5, p ~~<~~ ≤0.002) with temperature, SLP, specific humidity, and wind speed ~~and air pressure~~ in the Eastern Baltic Sea region. These relationships can be explained by the AO~~/NAO~~ index variability only in winter. In other seasons there has to be other influencing factors. ~~Also,~~The positive temperature anomaly evolution of 500 hPa height differences from the ~~previous season's weather~~Greenland sector in ~~some Arctic regions has a statistically strong effect on the~~ winter to Baltic Sea region~~. Results~~ in summer is present at 60°N and 65°N meridian and missing at higher latitudes. The lagged correlation in 1000 hPa temperature in summer at the TP supports the results of temperature evolution. The results of this study are valuable for selecting regions in the Arctic that have statistically the largest effect on climate in the Eastern Baltic Sea region.

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References

Ambaum, M. H. P., Hoskins, B. J., Stephenson, D. B.: Arctic Oscillation or North Atlantic Oscillation?, J CLIMATE, 14, 3495–3507, DOI: http://dx.doi.org/10.1175/1520-0442(2001)014<3495:AOONAO>2.0.CO;2, 2001.

Ångström, A.: Teleconnections of Climatic Changes in Present Time, Geografiska Annaler, 17, 242~~-~~–258, DOI: 10.2307/519964, 1935.

BACC II Author Team~~.~~: Second Assessment of Climate Change for the Baltic Sea Basin. Springer Open. 501 p. ISBN: 978-3-319-16005-4 (Print) 978-3-319-16006-1 (Online), 2015.

Bader, J., Mesquita, M.D.S., Hodges, K.I., Keenlyside, N., Østerhus, S., Miles, M.: A review on Northern Hemisphere sea-ice, storminess and the North Atlantic Oscillaion: Observations and projected changes, ATMOS RES, 101:809-834, 2011.

Barnes, E. A. and Screen, J. A.: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?, WIRES CLIM CHANGE, 6: 277–286. doi:10.1002/wcc.337, 2015.

Barnes, E. A., Etienne, D.S., Giacomo, M., and Woollings, T.: Exploring recent trends in Northern Hemisphere blocking, GEOPHYS RES LETT, 41, doi: 10.1002/2013GL058745, 2014.

Barnes, Elizabeth A.: Revisiting the evidence linking Arctic Amplification to extreme weather in midlatitudes, GEOPHYS RES LETT, 40, doi:10.1002.grl.50880, 2013.

Barnston, A. G., and Livezey, R.E.: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns, MON WEATHER REV, 115, 1083-1126, 1987.

Budikova, D.: Northern Hemisphere Climate Variability: Character, Forcing Mechanisms, and Significance of the North Atlantic ⁄Arctic Oscillation, Geography Compass 6/7: 401–422, 10.1111/j.1749-8198.2012.00498.x, 2012.

Budikova, D.: Role of Arctic Sea Ice in Global Atmospheric Circulation: A review, GLOBAL PLANET CHANGE, 68, ~~Pages~~ 149–163, doi:10.1016/j.gloplacha.2009.04.001, 2009.

Bueh, C. and Nakamura, H.: Scandinavian pattern and its climatic impact, Q J ROY METEOR SOC. 133: 2117 – 2131, DOI: 10.1002/qj.173, 2007.

Coumou, D., Petoukhov, V., Rahmstorf, S., Petri, S., and Schellnhuber, H.J.: Quasi-resonant circulation regimes and hemispheric synchronization of extreme weather in boreal summer. P NATL ACAD SCI USA, 111, 12331–6, doi: 10.1073/pnas.1412797111, 2014.

Dee, D. P., et al.: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Q. J. R. Meteorol. Soc., 137, 553–597, doi:10.1002/qj.828, 2011.

Dobricic, S., Vignati, E., and Russo, S.: Large-Scale Atmospheric Warming in Winter and the Arctic Sea Ice Retreat, J CLIMATE, 29, 2869–2888, doi: 10.1175/JCLI-D-15-0417.1, 2016.

Francis, J. A. and Vavrus, S.J.: Evidence for a wavier jet stream in response to rapid Arctic warming, ENVIRON RES LETT, 10 014005, 2015.

Francis, J.A. and Skific N.: Evidence linking rapid Arctic warming to mid-latitude weather patterns. Philosophical transactions of the Royal Society A, 373, doi:10.1098/rsta.2014.0170, 2015.

Francis, J.A., and Vavrus, S.J.: Evidence linking Arctic amplification to extreme weather in mid-latitudes, GEOPHYS RES

LETT, 39, L06801, doi: 10.1029/2012GL051000, 2012.

Gao, Y., Sun, J., Li, F., He, S., Sandven, S., Yan, Q., Zhang, Z., Lohmann, K., Keenlyside, N., Furevik, T., Suo, L.: Arctic sea ice and Eurasian climate: A review, ADV ATMOS SCI, 32, ~~pp~~ 92~~-~~–114, doi:10.1007/s00376-014-0009-6, 2015.

Handorf, D., Jaiser, R., Dethloff, K., Rinke, A., and Cohen, J.: Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections, GEOPHYS RES LETT, 42, 2367–2377. doi: 10.1002/2015GL063203, 2015.

Hassanzadeh, P., Kuang, Z., and B. F. Farrell: Responses of midlatitude blocks and wave amplitude to changes in the meridional temperature gradient in an idealized dry GCM, GEOPHYS RES LETT, 41, 5223–5232, doi:10.1002/2014GL060764, 2014.

IPCC, Pachauri, R. K. et al.: Climate Change, Geneva, Switzerland, 151 pp (Print), https://www.ipcc.ch/report/ar5/syr/ (Online), 2014.

Jaagus, J.: Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation, THEOR APPL CLIMATOL, 83, 77–88, DOI: 10.1007/s00704-005-0161-0, 2006.

Jung, T. et al.: Polar lower-latitude linkages and their role in weather and climate prediction, BULL AM METEOROL SOC 96, ES197–ES200, 2015.

Kug, J.S., Joeng, J.H., Jang, Y.S., Kim, B.M., Folland, C.K., Min, S.K., Son, S.W.: Two distinct influences of Arctic warming on cold winters over North America and East Asia, NAT GEOSCI, 8, 759–762, doi:10.1038/ngeo2517, 2015.

Lee, M.-Y., Hong, C.-C. and Hsu, H.-H.: Compounding effects of warm sea surface temperature and reduced sea ice on the extreme circulation over the extratropical North Pacific and North America during the 2013–2014 boreal winter, GEOPHYS RES LETT, 42: 1612–1618. doi: 10.1002/2014GL062956, 2015.

Lehmann, A., Getzlaff, K., and Harlaß, J.: Detailed assessment of climate variability of the Baltic Sea area for the period 1958-2009~~.~~, CLIM RES, 46~~. pp.~~, 185~~-~~–196~~.~~, doi: 10.3354/cr00876, 2011.

Lehmann, A., Hoflich, K; Post, P., Myrberg, K.: Pathways of deep cyclones associated with large volume changes (LVCs) and major Baltic inflows (MBIs), J MARINE SYST, 167, 11~~-~~–18, DOI: 10.1016/j.jmarsys.2016.10.014, 2017.

Lim, Y.K.: The East Atlantic/West Russia (EA/WR) teleconnection in the North Atlantic: climate impact and relation to Rossby wave propagation, CLIM DYNAM, 44: 3211. doi:10.1007/s00382-014-2381-4, 2015.

Liu, Z., and Alexander, M.: Atmospheric bridge, oceanic tunnel, and global climate teleconnections, Reviews in Geophysics, 45, 2, doi:10.1029/2005RG000172, 2007.

Moore, G.W.K., Renfrew, I.A., Pickart, R.: Multi-decadal mobility of the North Atlantic Oscillation. J CLIMATE. 26 : 2453–2466, DOI:10.1175/JCLI-D-12-00023.1, 2013.

Overland, J., Francis, J.A., Hall, R., Hanna, E., Kim, S.J., Vihma, T.: The melting Arctic and mid-latitude weather patterns: are they connected?, J CLIMATE, . doi:10.1175/JCLI-D-14-00822.1, 2015.

Peings, Y. and Magnusdottir, G.: Response of the wintertime northern hemisphere atmospheric circulation to current and projected arctic sea ice decline: a numerical study with CAM5, J CLIMATE, 27:244–264. doi:10.1175/JCLI-D-13-00272.1, 2014.

~~Petoukhov, V., Rahmstorf, S., Petri, S., and Schellnhube, H.J.: Quasiresonant amplification of planetary waves and recent Northern hemisphere weather extremes, P NATL ACAD SCI USA, 110, 5336–5341, doi: doi: 10.1073/pnas.1222000110, 2013.~~

Perlwitz, J., Hoerling, M., Dole, R.: Arctic Tropospheric Warming: Causes and Linkages to Lower Latitudes, J CLIMATE, 28, 2154–2167~~.~~, doi: http://dx.doi.org/10.1175/JCLI-D-14-00095.1, 2015.

Petoukhov, V., and Semenov, V. A.: A link between reduced Barents-Kara sea ice and cold winter extremes over northern continents, J GEOPHYS RES, 115, D21111, doi: 10.1029/2009JD013568, 2010.

~~Saha, Suranjana, and Coauthors: The NCEP Climate Forecast System Reanalysis, Bulletin of the American Meteorological Society, 91, 1015.1057, doi: 10.1175/2010BAMS3001.1, 2010.~~

Petoukhov, V., Rahmstorf, S., Petri, S., and Schellnhube, H.J.: Quasiresonant amplification of planetary waves and recent Northern hemisphere weather extremes, P NATL ACAD SCI USA, 110, 5336–5341, doi: 10.1073/pnas.1222000110, 2013.

Rinke, A., Dethloff, K., Dorn, W., Handorf, D., and Moore, J.C.: Simulated Arctic atmospheric feedbacks associated with late summer sea ice anomalies, J GEOPHYS RES-ATMOS, 118, 7698–7714, doi:10.1002/jgrd.50584, 2013.

Saha, Suranjana and Coauthors: The NCEP Climate Forecast System Version 2, J CLIMATE, 27, 2185–2208, doi: http://dx.doi.org/10.1175/JCLI-D-12-00823.1, 2014.

Saha, Suranjana, and Coauthors: The NCEP Climate Forecast System Reanalysis, Bulletin of the American Meteorological Society, 91, 1015–1057, doi: 10.1175/2010BAMS3001.1, 2010.

Sato, K., Inoue, J., and Watanab, M.: Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter, ENVIRON RES LETT, 9, 084009, 8pp, doi:10.1088/1748-9326/9/8/084009, 2014.

Screen, J. A. and Simmonds, I.: The central role of diminishing sea ice in recent Arctic temperature amplification, NATURE, 464, 1334–1337, DOI: 10.1038/nature09051, 2010.

Screen, J. A., and Simmonds, I.: Exploring links between Arctic amplification and mid-latitude weather, GEOPHYS RES LETT, 40, 959–964, doi:10.1002/grl.50174, 2013.

Screen, J. A., Deser, C., and Simmonds, I.: Local and remote controls on observed Arctic warming, GEOPHYS RES LETT, 39, L10709, DOI: 10.1029/2012GL051598, 2012.

~~Screen, J. A.,~~Screen, J.A. and Simmonds, I.: Amplified mid-latitude planetary waves favour particular regional weather extremes, NAT CLIM CHANGE, 4, 704-709, 2014.

Screen, J.A., Deser, C., Simmonds, I., and Tomas, R.: Atmospheric impacts of Arctic sea-ice loss, 1979-2009: Separating forced change from atmospheric internal variability, CLIM DYNAM, 43, 333-344, 2014.

Seierstad, I.A., Stephenson, D.B., and Kvamsto, N.G.: How useful are teleconnection patterns for explaining variability in extratropical storminess? Tellus, 59A, 170–181, 2007.

Semenov, V. A. and Latif, M.: Nonlinear winter atmospheric circulation response to Arctic sea ice concentration anomalies for different periods during 1966–2012, ENVIRON RES LETT, 10 (5). 054020. DOI 10.1088/1748-9326/10/5/054020, 2015.

~~and Simmonds, I.: The central role of diminishing sea ice in recent Arctic temperature amplification, NATURE, 464, 1334–1337, DOI: 10.1038/nature09051, 2010.~~

Simmonds, I.: Comparing and contrasting the behaviour of Arctic and Antarctic sea ice over the 35-year period 1979–2013, ANN GLACIOL, 56, 18–28, doi: https://doi.org/10.3189/2015AoG69A909, 2015.

Sun, L., Perlwitz, J., and Hoerling, M.: What caused the recent “Warm Arctic, Cold Continents” trend pattern in winter temperatures?, GEOPHYS RES LETT, 43, 5345–5352, doi:10.1002/2016GL069024, 2016.

Tang, Q., Zhang, X., Yang, X., and Francis, J.A.: Cold winter extremes in northern continents linked to Arctic sea ice loss, ENVIRON RES LETT, 8, 014036, doi: 10.1088/1748-9326/8/1/014036, 2013.

Thompson, D. W. J~~.,~~. and Wallace, J. M.: The Arctic Oscillation ~~isgnature~~signature in the wintertime geopotential height and temperature fields, GEOPHYS RES LETT, 25, 1297~~-~~–1300, 1998.

Uotila, P., Vihma, T., and Haapala, J.: Atmospheric and oceanic conditions and the extremely mild Baltic Sea ice winter 2014/15, GEOPHYS RES LETT, doi:10.1002/2015GL064901, 2015.

Vavrus, S., F. Wang, J. E. Martin, J. A. Francis, Y. Peings, and Cattiaux, J.: Changes in North American atmospheric circulation and extreme weather: Influence of Arctic amplification and Northern Hemisphere snow cover, J CLIMATE, **30**, 4317–4333, doi:https://doi.org/10.1175/JCLI-D-16-0762.1, 2017.

Vihma, T., Cheng, B., and Uotila, P.: Linkages between Arctic sea ice cover, large-scale atmospheric circulation, and weather and ice conditions in the Gulf of Bothnia, Baltic Sea, Advances in Polar Science, 25(4), 289-299, doi: 10.13679/j.advps.2014.4.00289, 2014.

Vihma, T.: Effects of Arctic Sea Ice Decline on Weather and Climate: A Review, SURV GEOPHYS, 35, 1175–1214, doi: 10.1007/s10712-014-9284-0, 2014.

~~Walsh, J. E.: Intensified warming of the Arctic: Causes and impacts on middle latitudes, GLOBAL PLANET CHANGE, 117, 52–63, doi: 10.1016/j.gloplacha.2014.03.003, 2014.~~

Wallace, J.M., and Gutzler, D.S.: Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter, MON WEATHER REV, 109, 784–812, doi: http://dx.doi.org/10.1175/1520-0493(1981)109<0784:TITGHF>2.0.CO;2, 1981.

Walsh, J. E.: Intensified warming of the Arctic: Causes and impacts on middle latitudes, GLOBAL PLANET CHANGE, 117, 52–63, doi: 10.1016/j.gloplacha.2014.03.003, 2014.

~~Vihma, T.: Effects of Arctic Sea Ice Decline on Weather and Climate: A Review, SURV GEOPHYS, 35, 1175–1214, doi: 10.1007/s10712-014-9284-0, 2014.~~

~~**Table 1. Correlation coefficients between seasonal mean NAO and AO indices and meteorological parameters in the Baltic Sea region testing point (TP): temperature (t1000), specific humidity (q1000) and wind speed (s1000) at 1000 hPa and sea-level pressure (SLP). Statistically significant values (*p*<0.05) are marked with bold.**~~

~~**NAO**~~ ~~**AO**~~

Wu, B. Y., Zhang, R. H., D'Arrigo, R. et al.: On the Relationship between winter sea ice and summer atmospheric circulation over Eurasia, J CLIMATE, 26:5523-5536, doi:10.1175/JCLI-D-12- 00524.1, 2013.

Table 1. Areal average, minimum and maximum of seasonal correlations between VAR1 at TP and VAR2 at the Greenland sector (20–80°W, 55–80°N).

		AVERAGE				MINIMUM				MAXIMUM			
VAR1	**VAR2**	**DJF**	**MAM**	**JJA**	**SON**	**DJF**	**MAM**	**JJA**	**SON**	**DJF**	**MAM**	**JJA**	**SON**
t1000	**t1000**	-0.~~31~~	41	-0.~~38~~23	0.15	~~0.70~~		~~0.47~~	~~0.35~~	~~0.34~~	~~0.76~~		
~~**q1000**~~	~~0.01~~	~~0.10~~	~~0.08~~	~~**0.71**~~		-0.02	-0.~~09~~	~~**0.32**~~	~~**0.80**~~				
~~**s1000**~~	~~**0.34**~~	~~0.27~~	~~0.06~~	~~**0.73**~~		~~**0.57**~~	~~0.13~~	~~0.22~~	~~**0.82**~~				
~~**SLP**~~	~~0.15~~	~~**0.52**~~	~~**0.37**~~63	-0.51	-0.22	-0.49	0.03	0.21	0.44	0.49			
t850	**t850**	-0.41	-0.26	0.09	-0.02	-0.63	-0.46	-0.19	-0.34	0.08	0.06	0.34	0.48
t500	**t500**	-0.32	-0.19	0.24	0.00	-0.52	-0.51	0.02	-0.20	0.09	0.15	0.49	0.40
t250	**t250**	0.31	0.20	-0.02	0.00	0.08	0.02	-0.36	-0.29	0.55	0.39	0.41	0.28
q1000	**q1000**	-0.44	-0.20	0.28	-0.04	-0.65	-0.50	-0.19	-0.53	0.11	0.09	0.62	0.45
s1000	**s1000**	-0.11	0.02	0.05	0.01	-0.72	-0.58	-0.47	-0.36	0.77	0.67	0.75	0.42
SLP	**SLP**	0.15	-0.12	-0.25	-0.36	-0.25	-0.30	-0.43	-0.54	0.51	0.33	-0.16	-0.13
t1000	**SLP**	-0.39	-0.27	-0.23	0.03	-0.73	-0.50	-0.42	-0.45	0.35	0.11	-0.02	0.51
t1000	**s1000**	-0.15	-0.03	-0.02	-0.03	-0.67	-0.54	-0.42	-0.65	0.65	0.48	0.38	0.43
t1000	**icec**	0.17	0.11	-0.07	0.01	-0.26	-0.34	-0.62	-0.41	0.61	0.64	0.41	0.48
s1000	**icec**	0.19	0.06	~~-0.48~~0.03		0.16	-0.28	-0.67	-0.36	-0.24	0.63	0.63	0.71
	0.59												

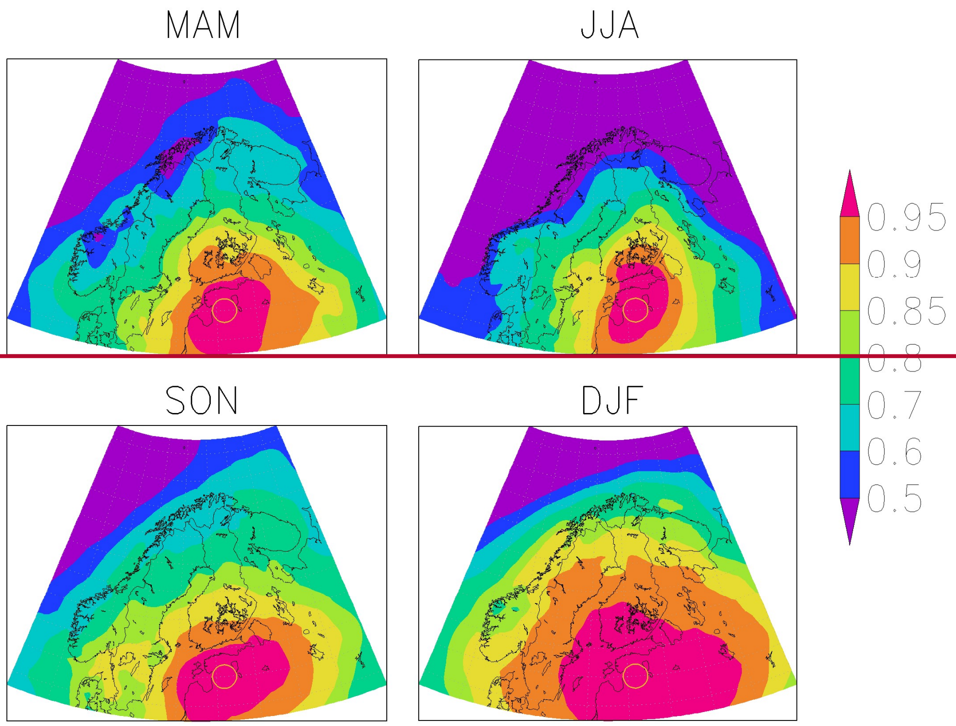


Table 2. Areal average of seasonal (winter and spring) partial correlations between 1000 hPa temperature at TP and the Greenland sector (20-80°W; 55–80°N) using different teleconnection indices as controlling factors.

index	**DJF**	**MAM**
reg. correl.	-0.41	-0.23
AO	-0.07	-0.10
NAO	-0.10	-0.11
PDO	-0.45	-0.26
CAI	-0.41	-0.21
PEU	-0.42	-0.18
EA	-0.43	-0.27
EA/WR	-0.41	-0.22
SCA	-0.25	-0.23

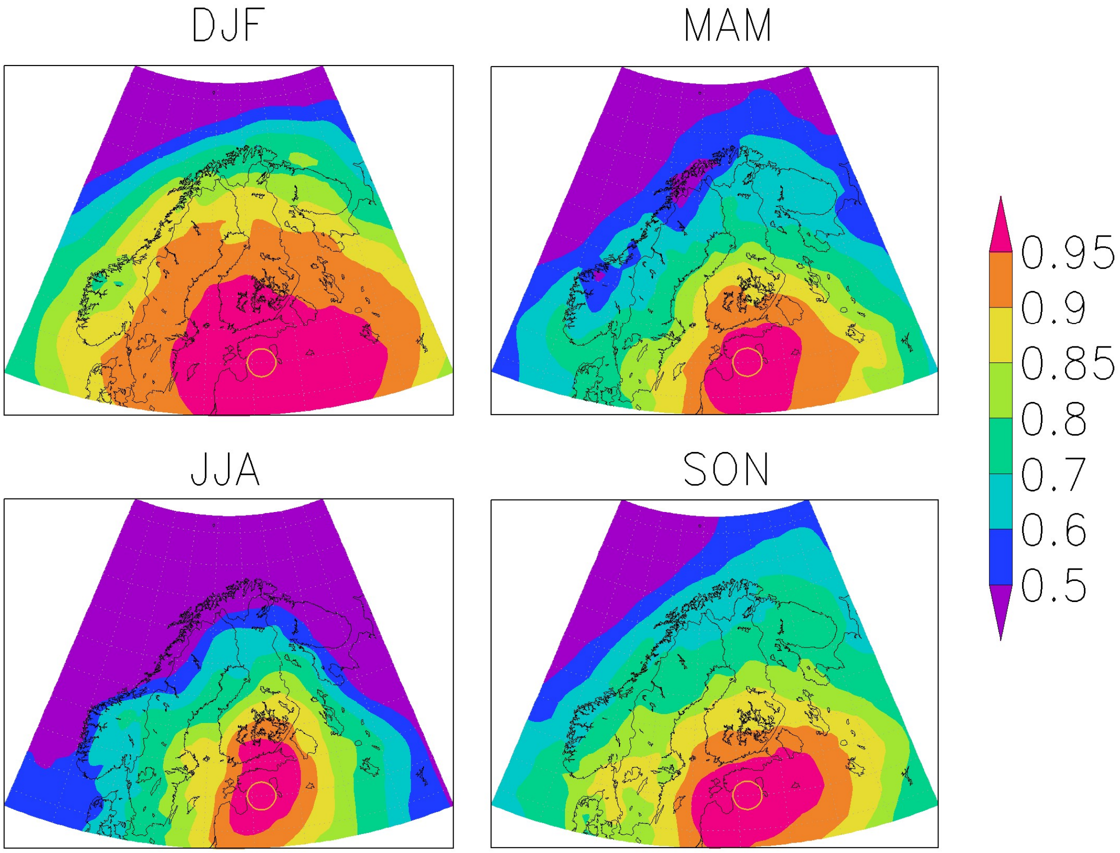
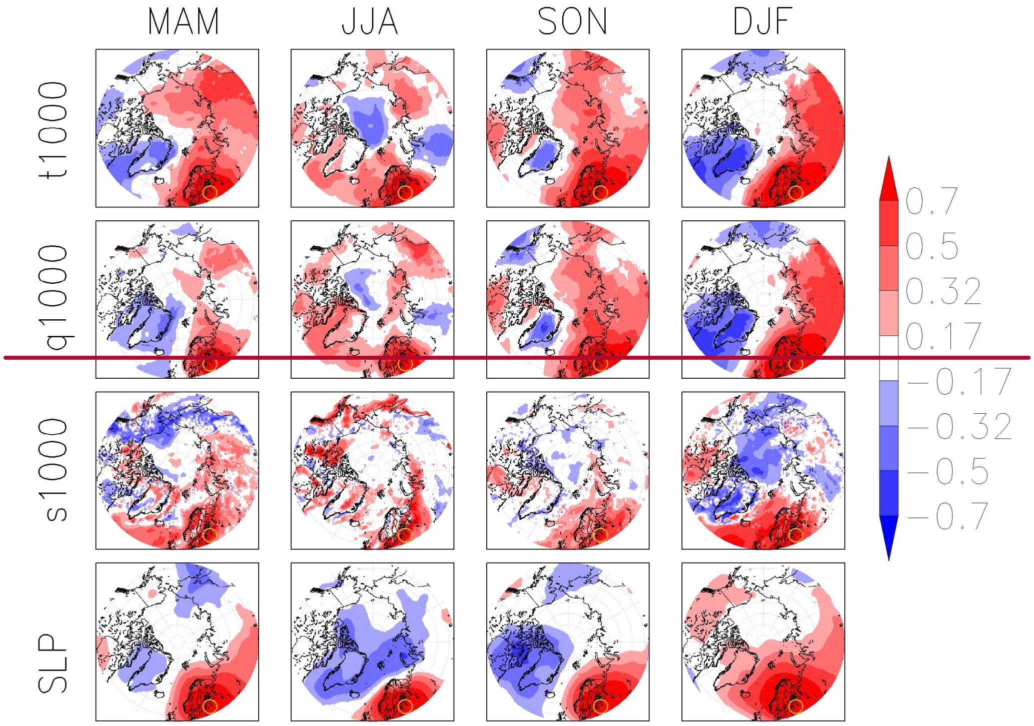


Figure 1~~.~~: Correlation maps of air temperature on 1000 hPa level for the testing point in the Baltic Sea region.



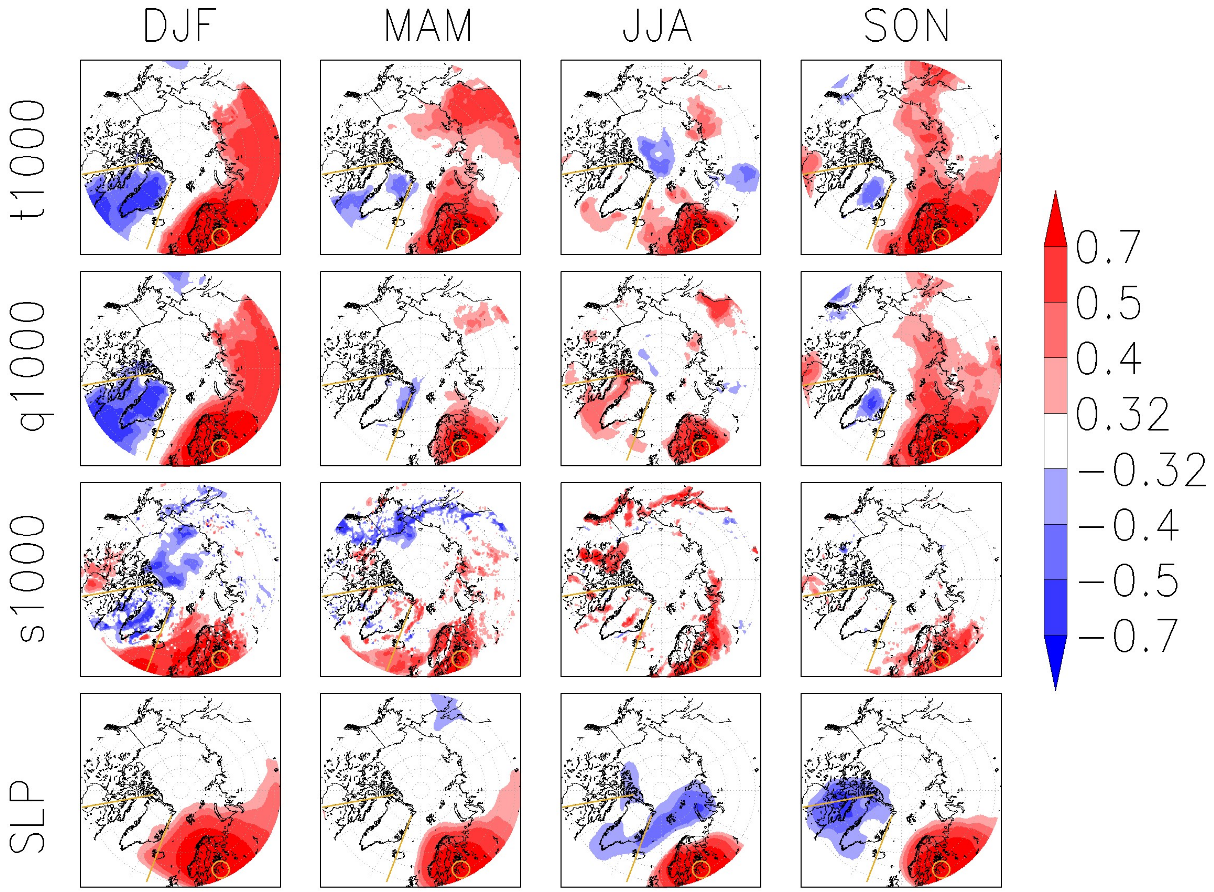
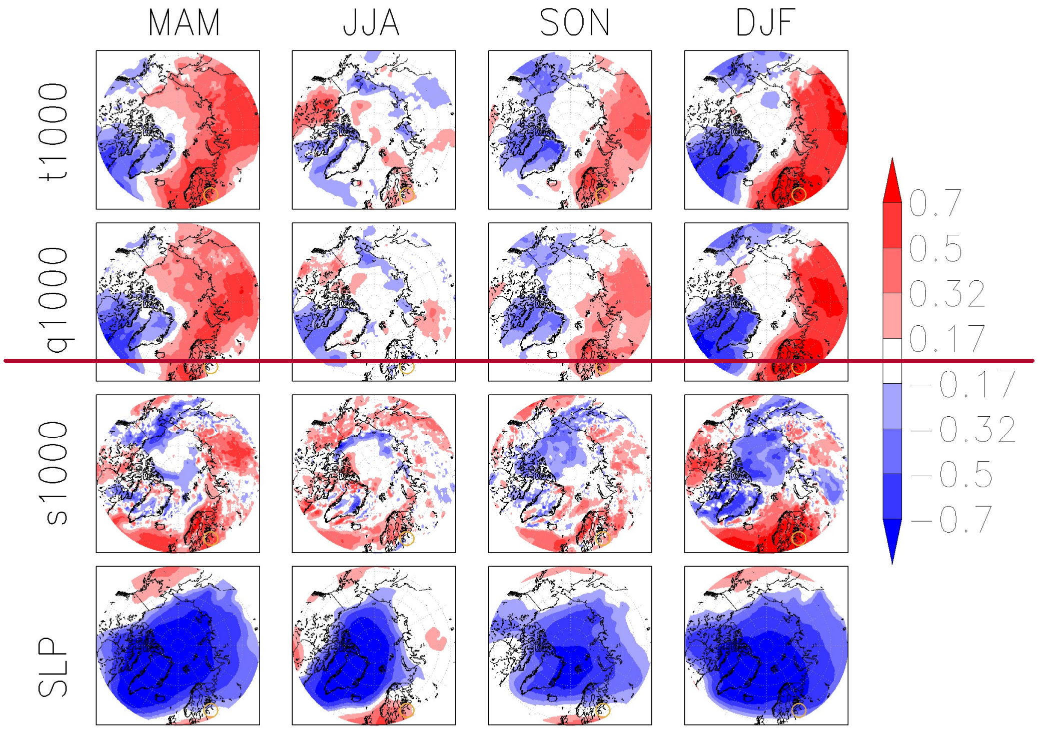


Figure 2~~.~~: Correlation maps between seasonal mean 1000 hPa temperature (t1000), specific humidity (q1000), wind speed (s1000) and SLP measured at the TP (the yellow circle) and in the whole Arctic region. Columns represent seasons, shading ~~levels ±0.17~~

~~and~~level ±0.32 represent correlation significance at the confidence ~~levels 68% and~~level 95%. The Greenland sector (20 – 80°W, 55 – 80°N) borders are marked with two yellow lines.



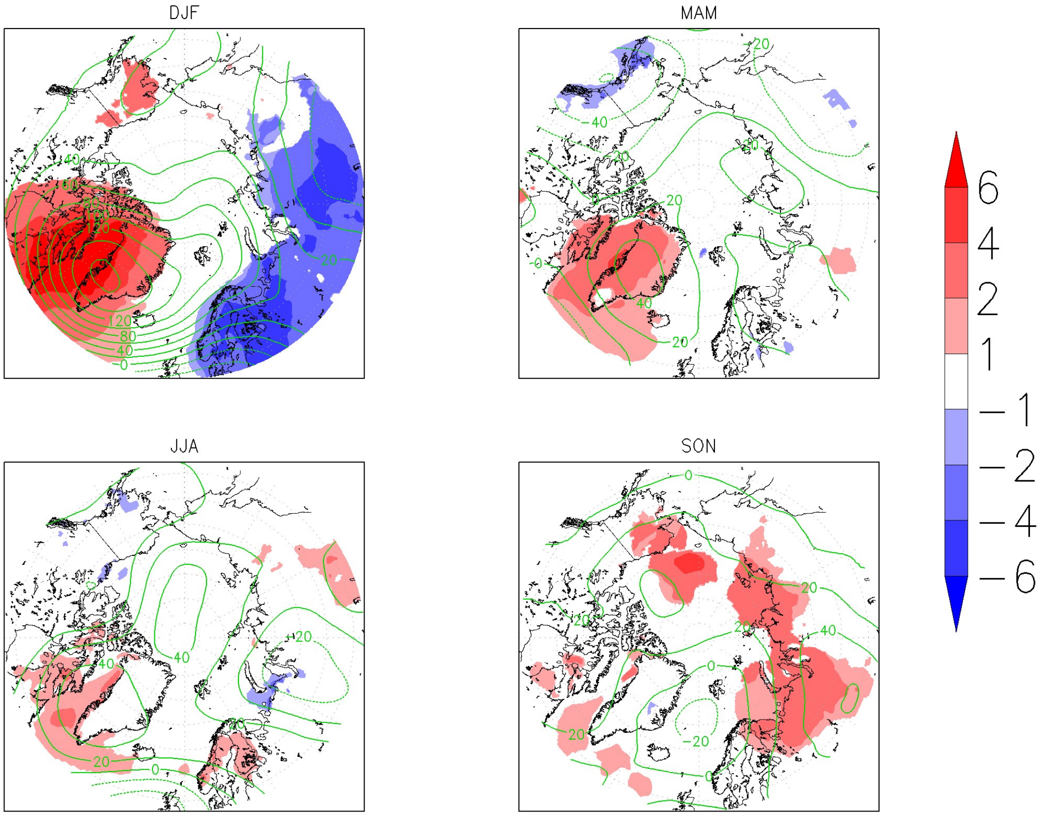


Figure 3. ~~Correlation~~Seasonal difference maps ~~of seasonal mean AO index~~(years with ~~1000 hPa~~mild winters minus years with cold winters) in air temperature ~~(t1000), specific humidity (q1000), wind speed (s1000)~~at 1000 hPa level (shading with confidence level of 95%), and ~~SLP. Columns~~geopotential height at 500hPa level (contours).

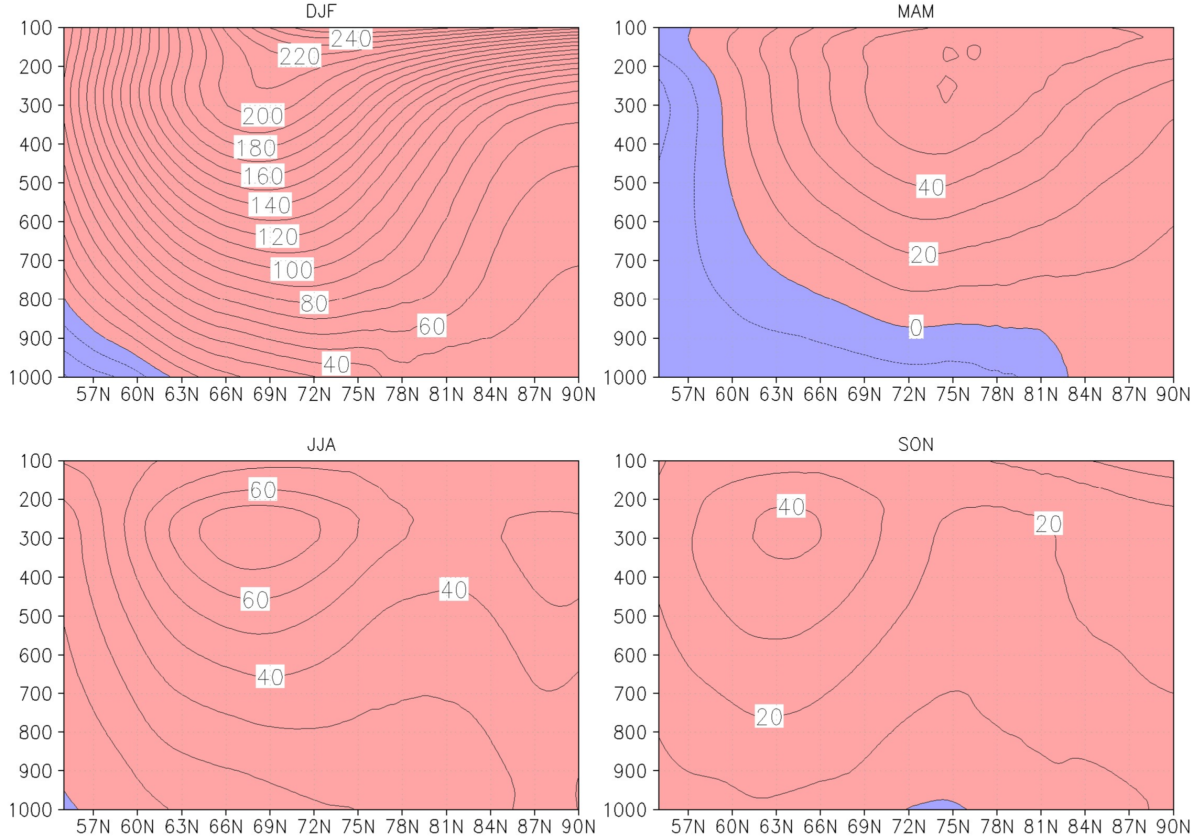
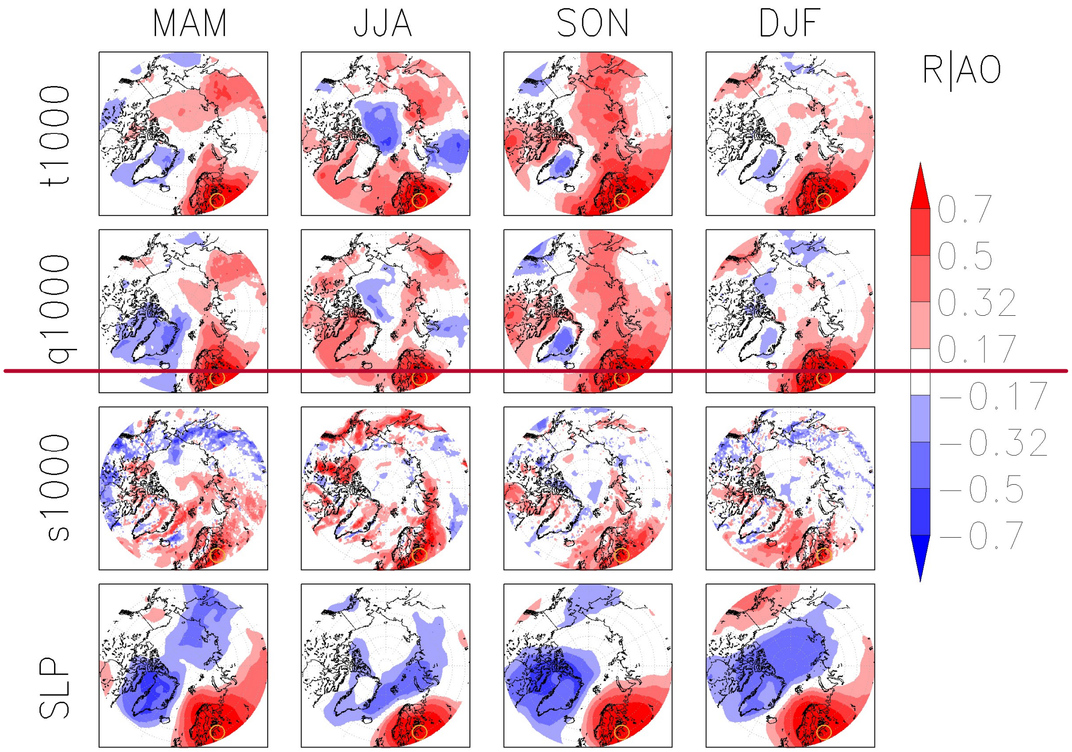


Figure 4. Differences in the mean geopotential heights between mild and cold winters along the 60W vertical slice. Contour intervals are 10 gpm; blue represent ~~seasons, shading levels ±0.17 and ±0.32 represent correlation significance at the confidence levels 68%~~negative height differences and ~~95%.~~red positive height differences.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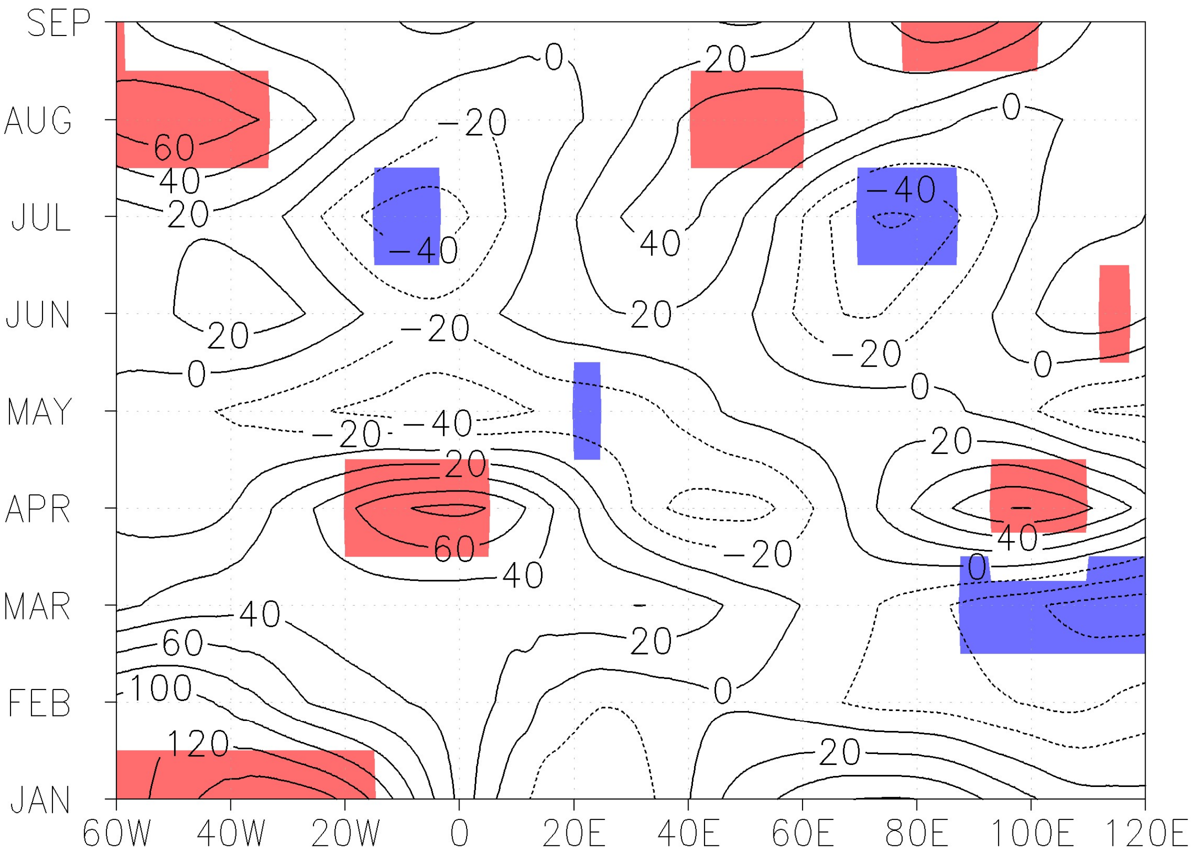
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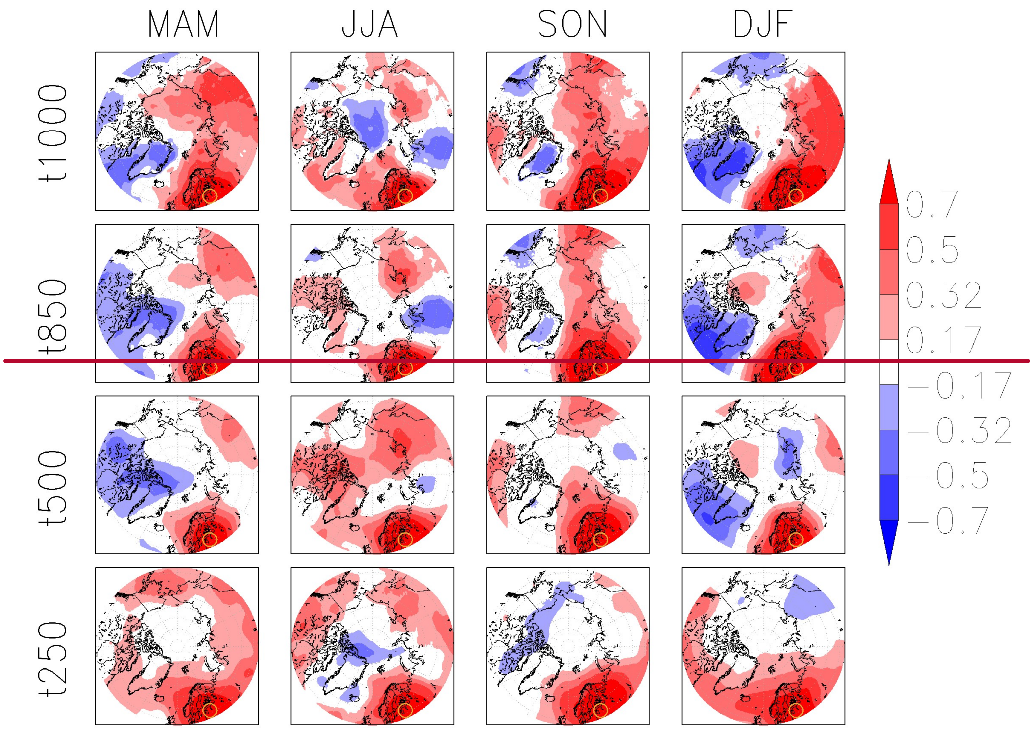
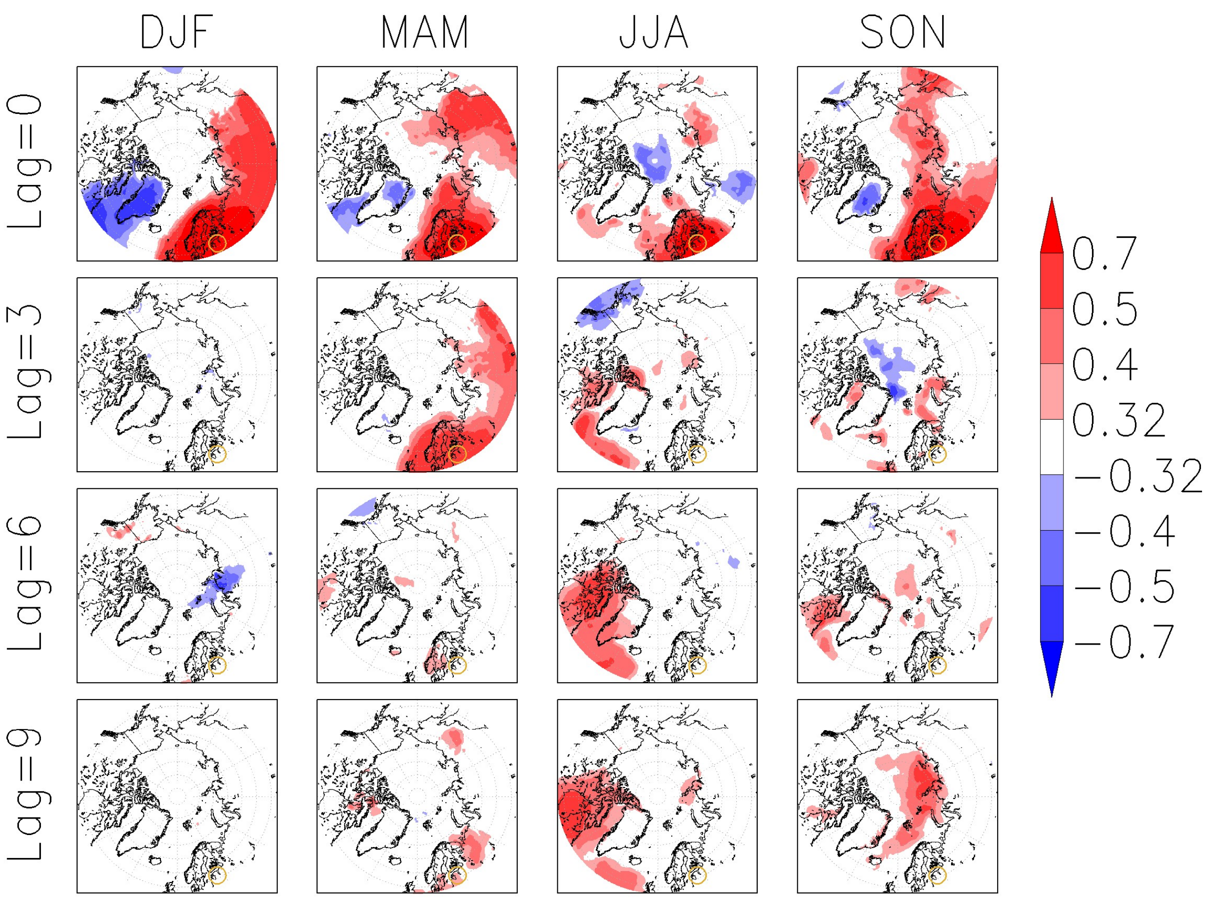
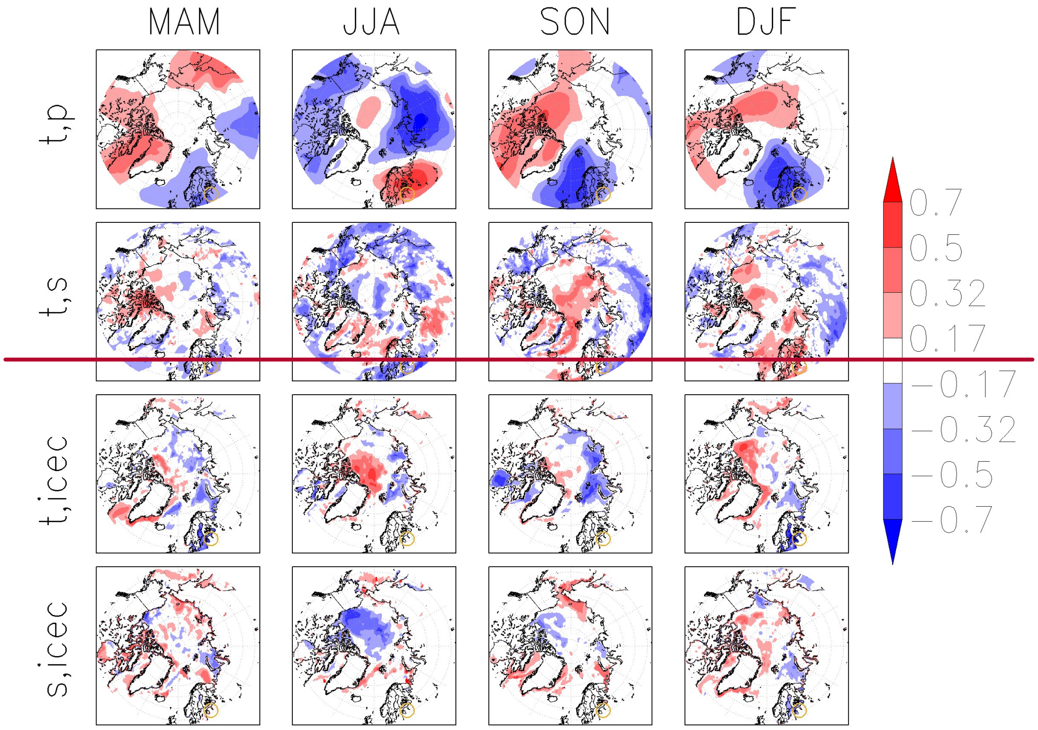
Figure 5. ~~Figure 4. Partial correlation maps between seasonal mean 1000 hPa temperature (t1000), specific humidity (q1000), wind speed (s1000) and SLP measured at the TP (the yellow circle) and in the whole Arctic region while the controlling factor is the AO index. Columns represent seasons, shading levels ±0.17 and ±0.32 represent correlation significance at the confidence levels 68% and 95%.~~



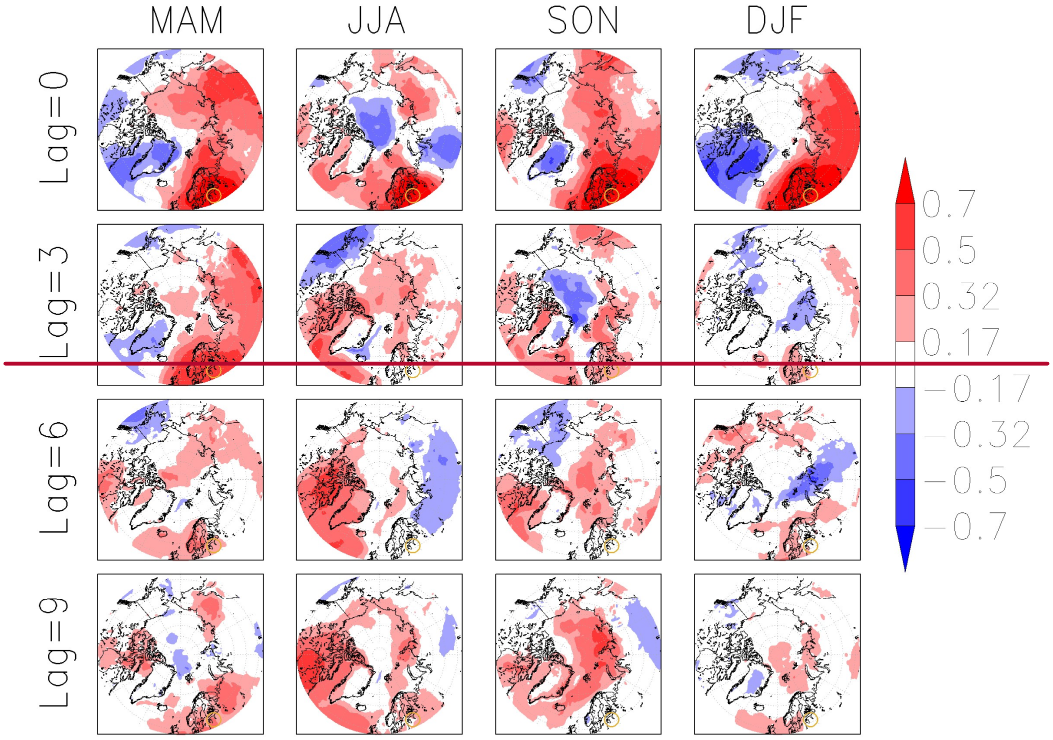
Evolution of 500-hPa height differences between mild and cold winters at 60N; red and blue shading indicates differences at the 95% significance levels for positive and negative height, respectively.



~~Figure 5.~~ ~~Correlation maps between seasonal mean temperature on the 1000 hPa, 850 hPa, 500 hPa and 250 hPa levels measured at the TP (the yellow circle) and in the whole Arctic region. Columns represent seasons, shading levels ±0.17 and ±0.32 represent correlation significance at the confidence levels 68% and 95%.~~



~~**Figure 6. Correlation maps between seasonal mean values measured at the TP (the yellow circle) and in the whole Arctic region. 1. row: temperature on the 1000 hPa level at the TP and SLP; 2. row: temperature on the 1000 hPa level at the TP and wind speed on the 1000 hPa; 3. row: temperature on the 1000 hPa level at the TP and sea ice concentration; 4. row: wind speed on the 1000 hPa level at the TP and sea ice concentration. Columns represent seasons, shading levels ±0.17 and ±0.32 represent correlation significance at the confidence levels 68% and 95%.**~~



~~Figure 7.~~Figure 6: Lagged correlation maps between the TP (the yellow circle) and Arctic 1000 hPa temperature: 1. row: lag is 0 months (no lag); 2. row: lag is 3 months; 3. row: lag is 6 months; 4. row: lag is 9 months. Columns represent seasons, shading ~~levels ±0.17 and~~level ±0.32 represent correlation significance at confidence ~~levels 68% and~~level 95%.

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ANSWERS TO REFEREES 1 – 4:

Answers to the referee 1 23-Jun-2017

Thank you very much for your competent and creative comments. Please find below your comments repeated again and our answers. With the help of your advices, we have prepared a new version of our manuscript.

Main comments:

1.a) More literature research should have been done to discuss on physical mechanisms behind statistically identified teleconnections. This discussion should include how AO/NAO are dependent, and therefore to some degree redundant, and the role of PDO, SCA, and PEU. For example, some studies (cf. Vihma et al. 2014; Uotila et al. 2015) have found that PDO and SCA, in addition to AO/NAO, are important for the northern Baltic Sea temperature and for the maximum Baltic sea-ice extent. This appears to contradict the author's argument that only AO/NAO are important circulation modes in the Baltic Sea region.

To avoid the redundancy, after the first comparison with AO and NAO, we concentrate our subsequent analysis on AO only, which shows in our analysis larger impact than NAO. In discussion paragraph we added some discussion about the AO and the NAO dependency (based on Wallace, 2000; Budikova, 2012) and emphasised that although some investigations (Uotila et al., 2015; Ambaum et al., 2001; Bader et al., 2011) have been brought out that NAO is much more relevant and robust for the Northern Hemisphere variability than is the AO, still, we found like some other authors before us (Rinke et al., 2013; Balmaseda et al., 2010; Thompson and Wallace, 1998) that AO has larger impact to the teleconnections between the Artic and the mid-latitudes.

Our study and studies mentioned by the referee are investigating different connections. Vihma et al (2014) and Uotila et al (2015) investigated variability in the Baltic Sea region. We concentrated on the analysis of the teleconnection between the Eastern Baltic Sea region and the Arctic region. So, PDO and SCA are influencing more the Baltic Sea region variability than the Arctic and the Baltic Sea region covariability.

To expose the role of different teleconnection indices we reorganized the analysis of teleconnection indices as follows (based on the suggestions of our referees):

we explained our choices of indices based on geographical position of the centres of action of the teleconnection patterns in data paragraph (see the segment 1 beneath);

to show the impact of teleconnection indices we replaced the figure 4 (and left out the figure 3) with a table which contains the average of partial correlations of all relevant teleconnection indices between 1000 hPa temperature at TP and the Baffin Bay-Greenland region (20 – 80W; 55 – 80N). The region was chosen due to the results of analysis where this region showed most often significant correlation with the parameters of the Eastern Baltic Sea region. The first row shows the average of the regular Pearson correlation of 1000 hPa in the region. It has the most significant values during winter and spring. During these seasons is also the impact of AO and NAO most considerable. See the table 1 below;

we added to our discussion paragraph a new segment about the role of teleconnection indices, based on our analysis and literature: Uotila et al, 2015; Lim, 2015; Comas-Bru and McDermott, 2014; Vihma et al., 2014; Moore et al., 2013.

Segment 1 of new version:
"The teleconnection indices we applied in our analyses were chosen according to the possible influence due to the geographical position of the centres of action of the teleconnection patterns over the North-Atlantic-Eurasian region. The following indices were chosen: 1) The North Atlantic Oscillation (NAO), which is the dominant mode of atmospheric variability in the North Atlantic sector throughout the year

(Barnston and Livezey, 1987); 2) The Arctic Oscillation (AO), which is usually defined as the first EOF of the mean sea level pressure field in the Northern Hemisphere (Ambaum et al., 2001); 3) The Scandinavian Pattern (SCA), which consists of a primary circulation centre over Scandinavia, with two other weaker centres of action with the opposite sign, one over the north eastern Atlantic and the other over central Siberia to the southwest of Lake Baikal (Bueh and Nakamura, 2007); 4) The East Atlantic Pattern (EA), which consists of a north-south dipole of anomaly centres spanning the North Atlantic from east to west (Barnston and Livezey, 1987); 5) The East Atlantic/West Russia Pattern (EA/WR), which consists of four main anomaly centres: Europe, northern China, central North Atlantic and north of the Caspian Sea; 6) The Polar/ Eurasia Pattern (PEU) consists of height anomalies over the polar region, and opposite anomalies over northern China and Mongolia.; 7) Additionally, Pacific Decadel Oscillation (PDO), which is the dominant year-round pattern of monthly North Pacific sea surface temperature (SST) variability was included. Although its geographical centres are far from the Baltic Sea region, Uotila et al (2015) found that PDO correlated significantly with the ice concentration and temperature of Baltic Sea. All indices were downloaded from the NOAA-CPC database (http://www.cpc.noaa.gov)."

Table 1. *The partial correlations of teleconnection indices between 1000 hPa temperature at TP and the Baffin Bay-Greenland region (20-80W; 55 – 80). Smaller (than regular) values show higher impact of the index.*

index	**DJF**	**MAM**	**JJA**	**SON**
reg. correl.	*-0.41*	*-0.23*	*0.15*	*-0.02*
AO	**-0.07**	**-0.10**	0.19	0.08
NAO	**-0.10**	**-0.11**	0.23	0.04
PDO	-0.45	-0.26	0.06	-0.11
CAI	-0.41	-0.21	0.15	-0.01
PEU	-0.42	-0.18	0.19	-0.02
EA	-0.43	-0.27	0.06	0
EA/WR	-0.41	-0.22	0.12	-0.12
SCA	-0.25	-0.23	0.21	-0.01

1.b) Also, there are studies identifying possible physical mechanisms behind teleconnections. For example, Wu et al. (2013) found a linkage between the winter Baffin Bay sea-ice anomaly and northern European atmospheric circulation. Such discussion on mechanisms would assist the authors to find out which of the numerous correlation associations are likely to be physically sensible. Finally, by adding such a discussion the manuscript would better address the "Dynamics of the Earth system" subject area of the ESD journal.

We added to the Introduction paragraph the following segment to summarise possible physical mechanisms behind teleconnection (Segment 2):

Segment 2 of new version:

"The relationship between AA and weather extremes and/or persistent weather patterns in mid-latitudes are mostly explained with Arctic and North Atlantic anomalous circulation regimes, waviness and strength of jet stream (Vavrus et al., 2017; Francis and Skific, 2015; Overland et al., 2015; Barnes and Screen, 2015; Francis and Vavrus, 2015; Coumou et al., 2014; Tang et al., 2013; Petoukhov et al., 2013; Francis and Vavrus, 2012). Common supposition is that sea ice declines are primarily responsible for amplified Arctic tropospheric warming. This conjecture is central to a hypothesis in which Arctic sea ice loss forms the beginning link of a causal chain that includes weaker westerlies in mid latitudes, more persistent and amplified mid latitude waves, and more extreme weather (Perlwitz et al., 2015). On the other hand Sun et al. (2016) brought out that neither sea ice loss nor anthropogenic forcing overall yield the winter cold extremes and persistence in mid-latitudes. Arctic warming over the Barents–Kara Seas and its impacts on the mid-latitude circulations have been widely discussed (Jung et al., 2017; Dobricic et al., 2016; Semenov and Latif, 2015; Kug et al., 2015; Sato et al., 2014). Another particular regional warm core (Screen and Simmonds, 2010) is East Siberian–Chukchi Seas which is related to severe winters over North America (Kug et al., 2015; Lee et al., 2015). Screen and Simmonds (2010) brought out also the third particular regional warm core – northeast Canada and Greenland which has been less investigated. Wu et al., (2013) focused on winter SIC west of Greenland, including the Labrador Sea, Davis Strait, Baffin Bay, and Hudson Bay and found that winter SIC west of Greenland is a possible precursor for summer atmospheric circulation and rainfall anomalies over northern Eurasia. If we look at the regions in mid-latitudes then potential Arctic connections in Europe are less clear then with North America and Asia (Overland et al., 2015)."

To have a more focused paper we reduced the number of parameters, for that we made a general table of correlations with all our parameters and then chose only 3 for subsequent analysis: temperature, SLP and we added geopotential heights. We separated cold and warm winters (based on Baffin Bay region), similar to Sato et al, (2014); and added following analysis to reveal possible physical mechanisms why the Baltic Sea and the BB winters are in opposite phase relying on 1000 hPa temperature. We look atmospheric circulation differences using SLP, 700 hPa and 500 hPa geopotential height differences between warm and cold winters. We added also a cross-section of geopotential heights (up to 100 hPa) along the 60W vertical slice and plots of annual evolution of 500-hPa height differences at 60N, 70N and 75N (similar to Wu et al., 2013). See figures below:

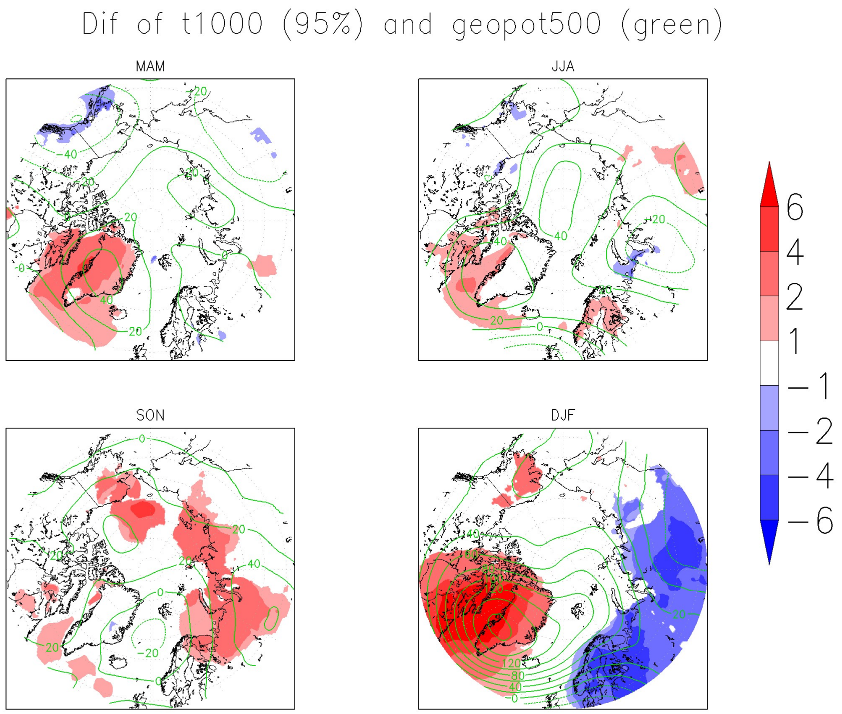


Figure 1. Seasonal difference maps (years with mild winters years with cold winters) in air temperature at 1000 hPa level (shading with confidence level of 95%), and (b) geopotential height at 500hPa level (contours).

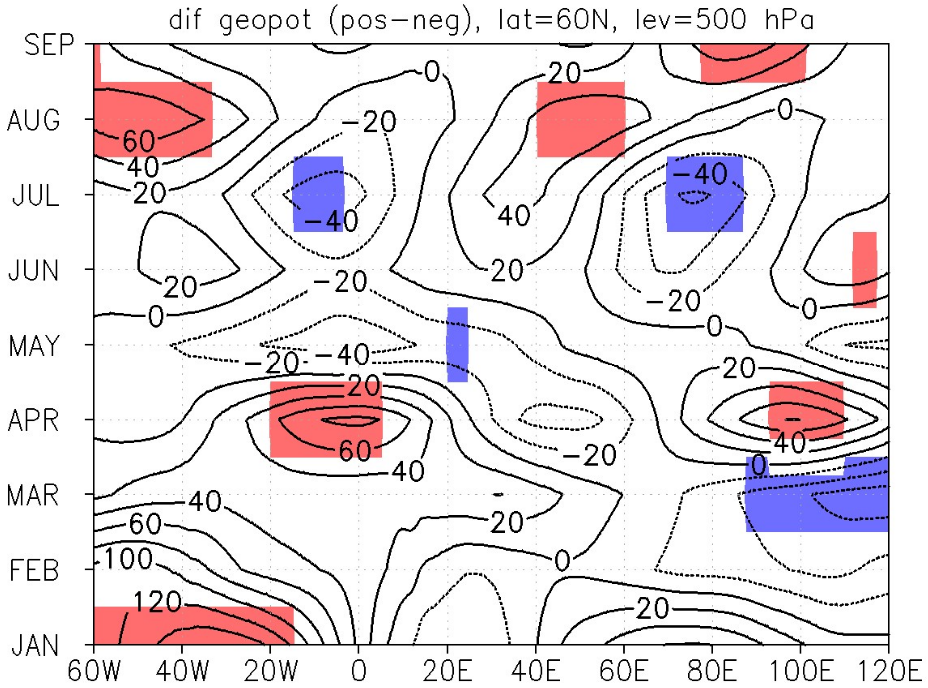


Figure 2. Evolution of 500-hPa height differences between mild and cold winters at 60N; red and blue shading indicates differences at the 95% significance levels for positive and negative height, respectively.

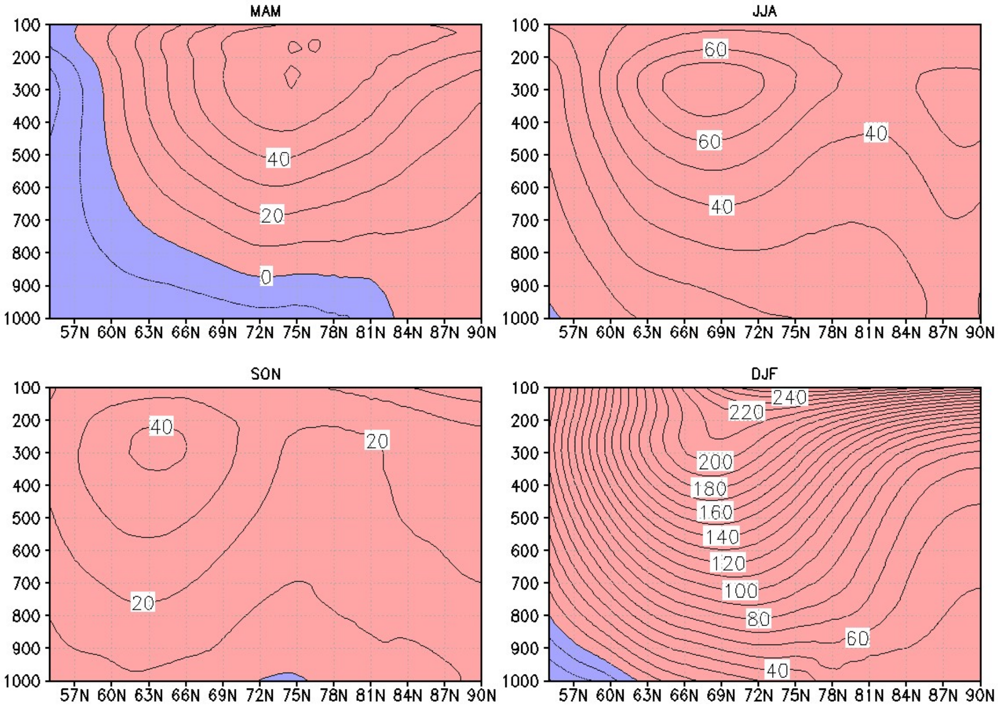


Figure 3. Differences in the mean heights between mild and cold winters along the 60W vertical slice. Contour intervals are 10 gpm; blue represent negative height differences and red positive height differences.

In discussion paragraph we added:

The large scale atmospheric circulation pattern in Figure 1 shows that the geopotential heights of 500 hPa are more than 100 gpm higher in mild winters than in cold ones, and the maximum of this height anomaly is centred over the maximum of the 1000 hPa temperature difference. It means that the whole column (up to 500 hPa) of the air in the Baffin Bay region is warmer than at cold years. Coming down to the lower surfaces (700 hPa, not shown), the maximum height anomaly is shifted to the east, what could be due to warmer sea surface of the Northern Atlantic compared to the regions that lay to west of it. The positive temperature anomaly (with the 500-hPa height anomalies) shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer (Figure 2). By Wu et al (2013) proposed mechanism, that associates the summer atmospheric circulation anomalies in the northern Eurasia with the previous winter ice conditions west of Greenland, supports our idea.
Figure 3 exhibit baroclinic structure of spring atmosphere north of 55N due to positive height anomalies in the lower troposphere below the 850 hPa and with further higher the negative ones. Similarly to Wu et al (2013) the vertical distribution of spring height anomalies differs from that of the previous winter when height anomalies show dominantly quasi-barotropic structure (not shown). With regression analysis they show the validity of their hypothesis of eastward propagation of the 500 hPa height anomalies. The same could be followed from Figure 2, where the evolution of 500 hPa height differences between mild and cold winters at 60 N is presented. Also at 65 N the similar pattern is present. At higher latitudes (70N and 75 N) this kind of signal propagation is missing.

2) Title is misleading. TP is a location in Southern Estonia and is not representing the entire Baltic Sea region. I base this claim on findings of previous studies mentioned above. I suggest to change the title to ’Atmospheric teleconnections between the Arctic and Southern Estonia’.

We generally agree with the reviewer. One point is not representative for the whole Baltic Sea region. But the representativeness depends very much on spatial autocorrelation of the studied parameter. To reduce the number of correlations we made a general table with all our parameters and then chose only 3 for subsequent analysis (temperature, SLP and we added height of geopotentials). According to Figure 1 in our manuscript and figure 4 in this document (see the figure 4 below) we presume that TP represents well the Eastern Baltic Sea region. Therefore we renamed the title as the 'Atmospheric teleconnections between the Arctic and the Eastern Baltic Sea regions'.

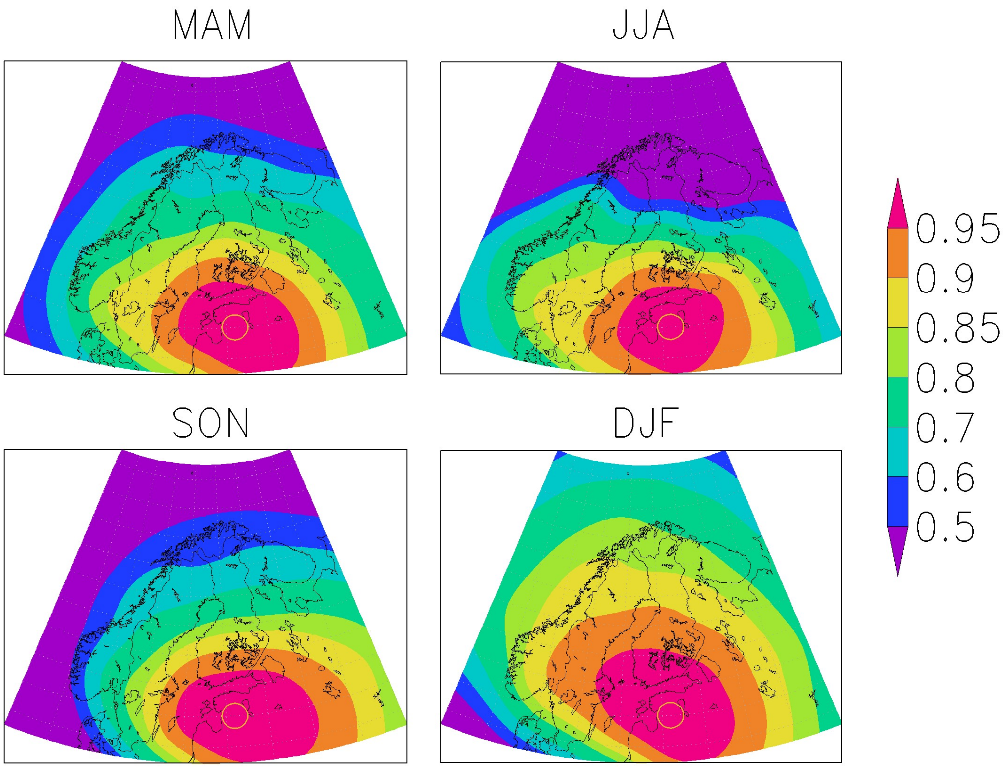


Figure 4. Correlation maps of SLP for the testing point in the Eastern Baltic Sea region.

3) Results section needs to be more focussed, now the large number of details confuses the reader. As a result, the reader is left wondering which correlation links are important which are not. Here, a summary table listing the most significant and physically relevant linkages would help the reader. Such a table would then support discussion.

To reduce the number of correlations we made a general table with all our parameters and then chose only 3 for subsequent analysis (temperature, SLP and we added height of geopotentials). We took the maximum value of the correlation between the Baffin Bay region and the testing point in the East Baltic Sea region during one season.

4) The analysis is based on only one reanalysis, although it is known that reanalyses have significant biases in the Arctic. To ensure the robustness of results, would be good to check main results with another reanalysis. I was also wondering why CFSR was picked of all available products? I suggest carrying out the analysis with an ECMWF one, such as ERA-Interim.

We repeated all the analysis with ERA-Interim. The results were resembled sufficiently in main points, although there were some discrepancies during summer season in the Central Arctic region. The dissimilarities are mentioned in the manuscript.

5) Methods have not been adequately explained. In particular, the partial correlation method needs to be explained and a reference to literature added.

We have used only well-known statistical methods in our analyses. For partial correlation, we could cite for example H. Cramer, Mathematical methods of statistics, Princeton Mathematical Series, no. 9. (Princeton University Press, Prinston, 1946), but it is in most statistical textbooks anyway. Still, we added formulas we used to the manuscript:

Detrending: $Y_i = X_i - (k \cdot year + b - X_{average})$.

Partial correlation: $R_{AB|C} = \dfrac{R_{AB} - R_{AC} \cdot R_{BC}}{\sqrt{(1 - R_{AC}{}^2) \cdot (1 - R_{BC}{}^2)}}$

6) Statistical terminology is misleading at places. For example, I would not say that correlation is strong when r is 0.5-0.7. Such a correlation range explains only 25-50% of variance.

By the meaning of "how much one parameter variance is controlled by the other one", 25-50% is indeed not very strong. At the same time, by the meaning of "how certain we can be that there is connection between two parameters", the probabilities for 0.5 and 0.7 are 99.8% and 99.998% correspondingly, that is quite strong. Even correlations exceeding ±0.32 are significant at 95% confidence level, so for correlation above ±0.5 we needed stronger name than "significant".

7) Although the manuscript is generally clearly written, some sentences are difficult to understand (please see minor comments for details).

We improved our manuscript as suggested in minor comments:

- lines 27-28. mention what could be the mechanism linking the Arctic to the outside Arctic environment. For example, does the air advection from mid-latitudes to the Arctic change?

We added the assumption about southerly warm advection based on Sato et al., 2014.

- line 32. 'all kinds of heat conservation changes' is obscure, be more specific.

As the energy budget of the Arctic is highly dependent on energy exchange with lower latitudes, then the changes in atmospheric and oceanic circulation play an important role in all kinds of heat conservation changes in the Arctic, most prominently expressed in sea ice volume variations.

- lines 33-34. I found this argument rather weak. So far, it has been very difficult to show that the observed Arctic warming has actually had impact on mid-latitutes.

We added a segment to our Introduction to reveal the background of Arctic – mid latitude linkages (Segment 3) and to summarise possible physical mechanisms behind teleconnections (Segment 2).

Segment 3

"Several studies have demonstrated relationships between warming and/or ice decline, and mid-latitude weather and climate extremes (Handorf et al., 2015; Coumou et al., 2014; Tang et al., 2013; Petoukhov et al., 2013; Francis and Vavrus, 2012; Petoukhov and Semenov, 2010). Others have analysed whether these associations are statistically and/or physically robust (Hassanzadeh et al., 2014; Screen et al 2014; Barnes et al 2014; Screen and Simmonds 2013, 2014; Barnes 2013), while some investigations suggest that the apparent associations may have their origin, in part, in remote influences (Perlwitz et al., 2015; Sato et al., 2014; Peings and Magnusdottir 2014; Screen et al., 2012; Petoukhov and Semenov 2010)."

- line 36. 'patterns of high pressure'?

Actually we meant by the 'large-scale patterns of pressure anomalies' both high and low pressures. To be clearer we replaced the phrase as follows: 'large scale patterns of high and low pressure'.

- line 69. 'One of the reasons for incomplete understanding ...'

Corrected

- line 71. '... vice versa due to their close proximity.'

Corrected

- line 71. Where does 'Therefore' point to?

Therefore may-be redundant in this sentence and we decided to remove it.

- line 100. Which correlation coefficient? Spearman?

We use through the work only Pearson correlation, we have clarified this in the manuscript.

- line 102. Why was the Arctic defined as north of 55N. Why not north of the Arctic circle?

We added a sentence: "We define the Arctic region here as the region northward of 55 N. Larger region than usual (Arctic cap from polar circle or 70N; July 10 °C isotherm) helps to analyse results that lay partly outside the usually defined Arctic region."

- lines 155-160. When explaining your correlation findings, it would help if figure subpanels are cited more frequently to specifically indicate where you see the regions. Some geographic regions mentioned are rather local and many readers may not know where they are (e.g. the Gulf of Alaska).

We added citations of figures.

- line 156. 'the AO index as the controlling factor', better?

Corrected

- line 171. 'change in one parameter due to climate change'?

We added to the brackets (e.g. due to climate change).

- line 176. '... partial correlations, controlled ...'

Corrected

- line 180. I can't find negative correlation in winter above Greenland and the East Siberian Sea in Figure 6.

Thank you for pointing this out. There has been really some misunderstanding and the sentence is incorrect. We deleted this statement.

- line 184. Positive correlation around Greenland in winter looks rather weak and not clear.

It is indeed quite weak so we deleted this statement.

- line 188. Change to ’It means that climatic conditions’. Weather is chaotic with no memory beyond two weeks.

Corrected

-line190-191. This sentence is unclear. Do you mean’... during the following spring?’

We added ...’during the following spring and summer’... to clarify the sentence.

- line 195. How can you say that ’whole Eurasian average spring temperature is highly controlled’ based on your analysis?

Our idea based on both lag=0 and lag=3 strong correlation between TP and Eurasia in spring. We tested this by changing the TP in several locations in Eurasia and it turned out that this statement is incorrect, so we deleted it.

- line 198. You can call the region between Greenland and Svalbard the Fram Strait.

Corrected.

- line 209-210. I don’t understand this sentence.

We rephrase the sentence as follows:
The reason why summer season differs from other seasons may-be caused by a less effective large-scale circulation.

- line 220-221. What do you mean by ’AO/NAO paradigm’?

We rephrase the sentence as follows:
The study of Ambaum et al. (2001) suggests also that because of the physical background of NAO, it may be more relevant and robust for the Northern Hemisphere variability than is the AO.

- line 253. ’previous season’s climate conditions’.

Corrected

- Table 1. Add information on the sample size, N=36?

Corrected

Thank you once more for your trouble and professionalism!

Sincerely yours,

Liisi Jakobson
Erko Jakobson
Piia Post

Jaak Jaagus

985

References (If we use in our answers references that were already given in our article then we will not give the reference here again):

- Bader, J., Mesquita, M.D.S., Hodges, K.I., Keenlyside, N., Østerhus, S., Miles, M.: A review on Northern Hemisphere sea-ice, storminess and the North Atlantic Oscillaion: Observations and projected changes, ATMOS RES, 101:809-834, 2011.
- Balmaseda, M. A., Ferranti, L., Molteni, F. and Palmer, T. N.: Impact of 2007 and 2008 Arctic ice anomalies on the atmospheric circulation: Implications for long-range predictions, Q J ROY METEOR SOC, 136: 1655–1664. doi:10.1002/qj.661, 2010.
- Barnes, E. A. and Screen, J. A.: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?, WIRES CLIM CHANGE, 6: 277–286. doi:10.1002/wcc.337, 2015.
- Barnes, E. A., Etienne, D.S., Giacomo, M., and Woollings, T.: Exploring recent trends in Northern Hemisphere blocking, GEOPHYS RES LETT, 41, doi: 10.1002/2013GL058745, 2014.
- Barnes, Elizabeth A.: Revisiting the evidence linking Arctic Amplification to extreme weather in midlatitudes, GEOPHYS RES LETT, 40, doi:10.1002.grl.50880, 2013.
- Barnston, A. G., and Livezey, R.E.: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns, MON WEATHER REV, 115, 1083-1126, 1987.
- Budikova, D.: Northern Hemisphere Climate Variability: Character, Forcing Mechanisms, and Significance of the North Atlantic⁄Arctic Oscillation, Geography Compass 6/7: 401–422, 10.1111/j.1749-8198.2012.00498.x, 2012.
- Bueh, C. and Nakamura, H.: Scandinavian pattern and its climatic impact, Q J ROY METEOR SOC. 133: 2117 – 2131, DOI: 10.1002/qj.173, 2007.
- Comas-Bru, L. and McDermott, F.: Impacts of the EA and SCA patterns on the European twentieth century NAO–winter climate relationship. Q J ROY METEOR SOC, 140: 354–363. doi:10.1002/qj.2158, 2014.
- Cramer, H.: Mathematical methods of statistics, Princeton Mathematical Series, no. 9. Princeton University Press, Prinston, 1946.
- Dobricic, S., Vignati, E., and Russo, S.: Large-Scale Atmospheric Warming in Winter and the Arctic Sea Ice Retreat, J CLIMATE, 29, 2869–2888, doi: 10.1175/JCLI-D-15-0417.1, 2016.
- Francis, J. A. and Vavrus, S.J.: Evidence for a wavier jet stream in response to rapid Arctic warming, ENVIRON RES LETT, 10 014005, 2015.
- Francis, J.A. and Skific N.: Evidence linking rapid Arctic warming to mid-latitude weather patterns. Philosophical transactions of the Royal Society A, 373, doi:10.1098/rsta.2014.0170, 2015.
- Handorf, D., R. Jaiser, K. Dethloff, A. Rinke, and J. Cohen: Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections, GEOPHYS RES LETT, 42, 2367–2377. doi: 10.1002/2015GL063203, 2015.
- Hassanzadeh, P., Kuang, Z., and B. F. Farrell: Responses of midlatitude blocks and wave amplitude to changes in the meridional temperature gradient in an idealized dry GCM, GEOPHYS RES LETT, 41, 5223–5232, doi:10.1002/2014GL060764, 2014.
- Kug, J.S., Joeng, J.H., Jang, Y.S., Kim, B.M., Folland, C.K., Min, S.K., Son, S.W.: Two distinct influences of Arctic warming on cold winters over North America and East Asia, NAT GEOSCI, 8, 759–762, doi:10.1038/ngeo2517, 2015.
- Lee, M.-Y., Hong, C.-C. and Hsu, H.-H.: Compounding effects of warm sea surface temperature and reduced sea ice on the extreme circulation over the extratropical North Pacific and North America during the 2013–2014 boreal winter, GEOPHYS RES LETT, 42: 1612–1618. doi: 10.1002/2014GL062956, 2015.
- Lim, Y.K.: The East Atlantic/West Russia (EA/WR) teleconnection in the North Atlantic: climate impact and relation to Rossby wave propagation, CLIM DYNAM, 44: 3211. doi:10.1007/s00382-014-2381-4, 2015.
- Moore, G.W.K., Renfrew, I.A., Pickart, R.: Multi-decadal mobility of the North Atlantic Oscillation. J CLIMATE. 26 : 2453–2466, DOI:10.1175/JCLI-D-12-00023.1, 2013.
- Overland, J., Francis, J.A., Hall, R., Hanna, E., Kim, S.J., Vihma, T.: The melting Arctic and midlatitude weather patterns: are they connected?, J CLIMATE, . doi:10.1175/JCLI-D-14-00822.1, 2015.

- Peings, Y. and Magnusdottir, G.: Response of the wintertime northern hemisphere atmospheric circulation to current and projected arctic sea ice decline: a numerical study with CAM5, J CLIMATE, 27:244–264. doi:10.1175/JCLI-D-13-00272.1, 2014.
- Rinke, A., Dethloff, K., Dorn, W., Handorf, D., and Moore, J.C.: Simulated Arctic atmospheric feedbacks associated with late summer sea ice anomalies, J GEOPHYS RES-ATMOS, 118, 7698–7714, doi:10.1002/jgrd.50584, 2013.
- Sato, K., Inoue, J., and Watanab, M.: Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter, ENVIRON RES LETT, 9, 084009, 8pp, doi:10.1088/1748-9326/9/8/084009, 2014.
- Screen, J. A., and I. Simmonds (2013), Exploring links between Arctic amplification and mid-latitude weather, GEOPHYS RES LETT, 40, 959–964, doi:10.1002/grl.50174, 2013.
- Screen, J.A. and Simmonds, I.: Amplified mid-latitude planetary waves favour particular regional weather extremes, NAT CLIM CHANGE, 4, 704-709, 2014.
- Screen, J.A. and Simmonds, I.: Increasing fall-winter energy loss from the Arctic Ocean and its role in Arctic temperature amplification, GEOPHYS RES LETT, 37, L16707, doi:10.1029/2010GL044136, 2010.
- Screen, J.A., Deser, C., and Simmonds, I.: Local and remote controls on observed Arctic warming, GEOPHYS RES LETT, 39, L10709, doi:10.1029/2012GL051598, 2012.
- Screen, J.A., Deser, C., Simmonds, I., and Tomas, R.: Atmospheric impacts of Arctic sea-ice loss, 1979-2009: Separating forced change from atmospheric internal variability, CLIM DYNAM, 43, 333-344, 2014.
- Semenov, V. A. and Latif, M.: Nonlinear winter atmospheric circulation response to Arctic sea ice concentration anomalies for different periods during 1966–2012, ENVIRON RES LETT, 10 (5). 054020. DOI 10.1088/1748-9326/10/5/054020, 2015.
- Sun, L., Perlwitz, J., and Hoerling, M.: What caused the recent “Warm Arctic, Cold Continents” trend pattern in winter temperatures?, GEOPHYS RES LETT, 43, 5345–5352, doi:10.1002/2016GL069024, 2016.
- Uotila, P., Vihma, T., and Haapala, J.: Atmospheric and oceanic conditions and the extremely mild Baltic Sea ice winter 2014/15, GEOPHYS RES LETT, doi:10.1002/2015GL064901, 2015.
- Vihma, T., Cheng, B., and Uotila, P.: Linkages between Arctic sea ice cover, large-scale atmospheric circulation, and weather and ice conditions in the Gulf of Bothnia, Baltic Sea, Advances in Polar Science, 25(4), 289-299, doi: 10.13679/j.advps.2014.4.00289, 2014.
- Wallace, J. M.: North atlantic oscillatiodannular mode: Two paradigms—one phenomenon, Q J ROY METEOR SOC, 126, 564, 791-805, DOI: 10.1002/qj.49712656402, 2000.
- Wu, B. Y., Zhang, R. H., D’Arrigo, R. et al.: On the Relationship between winter sea ice and summer atmospheric circulation over Eurasia, J CLIMATE, 26:5523-5536, doi:10.1175/JCLI-D-12-00524.1, 2013.

Answers to the referee 2

23-Jun-2017

Thank you very much for your competent and creative comments. Please find below your comments repeated again and our answers. With the help of your advices, we have prepared a new version of our manuscript.

General Comments:

1. The thrust of the paper implies that the presence of statistical correlation implies causation, which is not the case. It is important for the authors to further explore the identified relationships by placing them in a climatological context and examining various potential atmospheric processes that may help explain the correlation results.

To have a more focused paper we reduced the number of parameters, for that we made a general table of correlations with all our parameters and then chose only 3 for subsequent analysis: temperature, SLP and we added geopotential heights. We separated cold and warm winters (based on Baffin Bay region), similar to Sato et al, (2014); and added following analysis to reveal possible physical mechanisms why the Baltic Sea and the BB winters are in opposite phase relying on 1000 hPa temperature. We look atmospheric circulation differences using SLP, 700 hPa and 500 hPa geopotential height differences between warm and cold winters. We added also a cross-section of geopotential heights (up to 100 hPa) along the 60W vertical slice and plots of annual evolution of 500-hPa height differences at 60N, 70N and 75N (similar to Wu et al., 2013). See figures below:

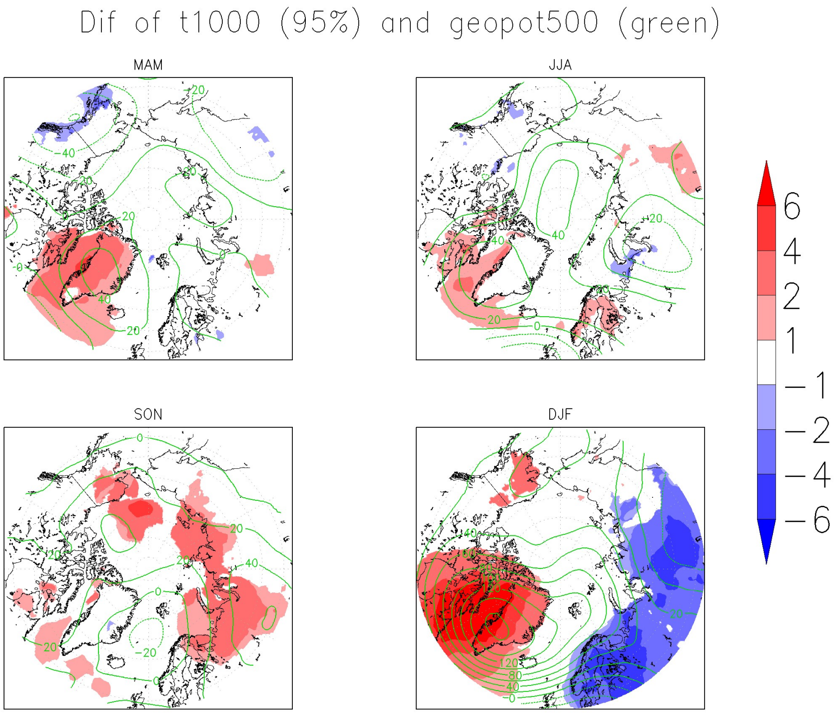


Figure 1. Seasonal difference maps (years with mild winters years with cold winters) in air temperature at 1000 hPa level (shading with confidence level of 95%), and (b) geopotential height at 500hPa level (contours).

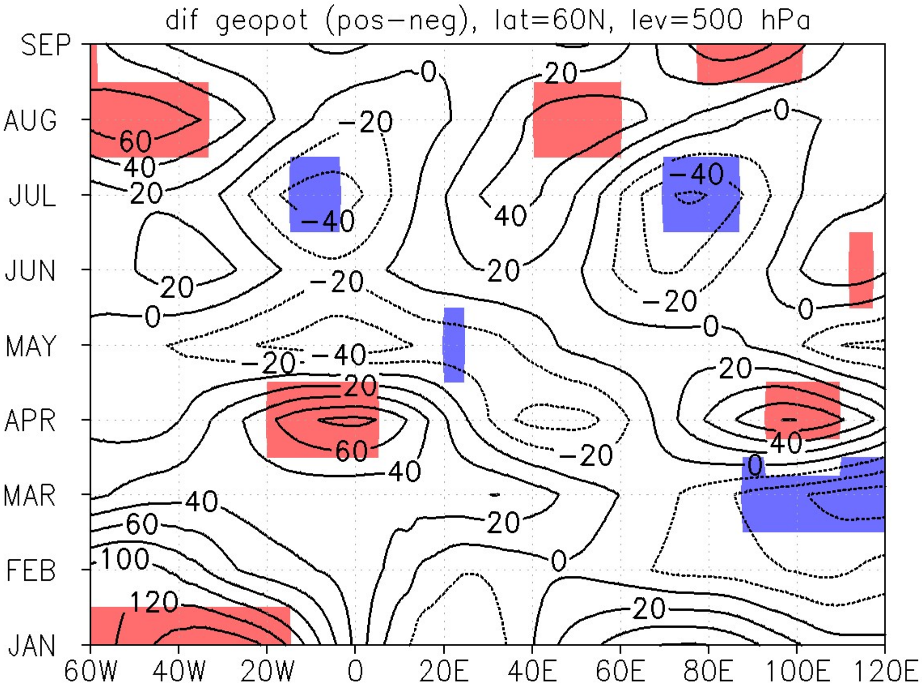


Figure 2. Evolution of 500-hPa height differences between mild and cold winters at 60N; red and blue shading indicates differences at the 95% significance levels for positive and negative height, respectively.

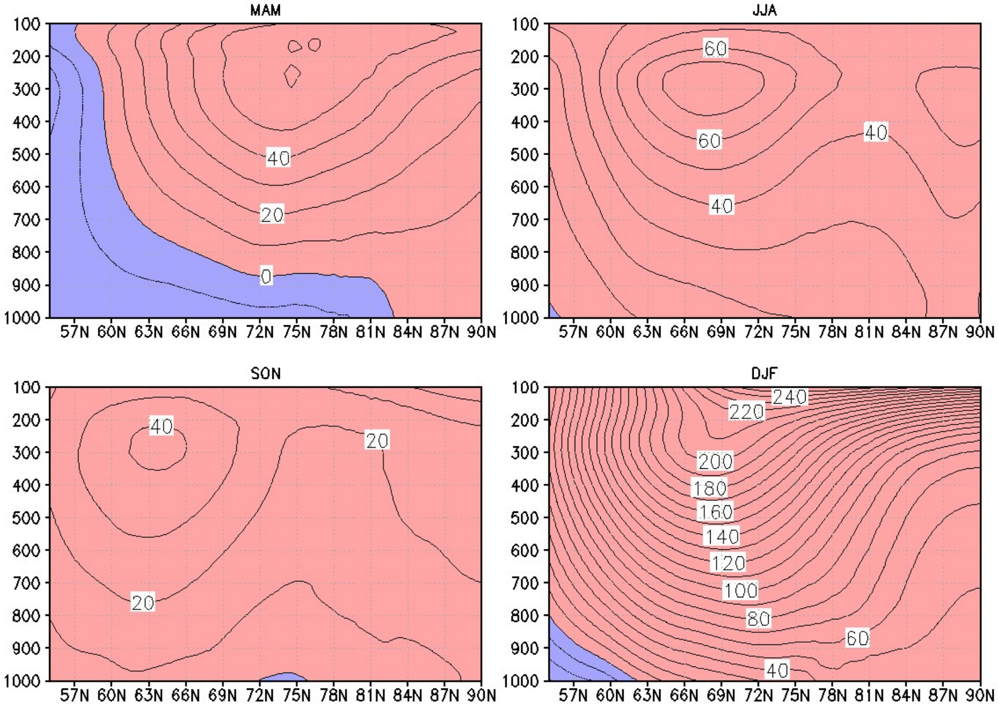


Figure 3. Differences in the mean heights between mild and cold winters along the 60W vertical slice. Contour intervals are 10 gpm; blue represent negative height differences and red positive height differences.

In discussion paragraph we added:

The large scale atmospheric circulation pattern in Figure 1 shows that the geopotential heights of 500 hPa are more than 100 gpm higher in mild winters than in cold ones, and the maximum of this height anomaly is centred over the maximum of the 1000 hPa temperature difference. It means that the whole column (up to 500 hPa) of the air in the Baffin Bay region is warmer than at cold years. Coming down to the lower surfaces (700 hPa, not shown), the maximum height anomaly is shifted to the east, what could be due to warmer sea surface of the Northern Atlantic compared to the regions that lay to west of it. The positive temperature anomaly (with the 500-hPa height anomalies) shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer (Figure 2). By Wu et al (2013) proposed mechanism, that associates the summer atmospheric circulation anomalies in the northern Eurasia with the previous winter ice conditions west of Greenland, supports our idea.

Figure 3 exhibit baroclinic structure of spring atmosphere north of 55N due to positive height anomalies in the lower troposphere below the 850 hPa and with further higher the negative ones. Similarly to Wu et al (2013) the vertical distribution of spring height anomalies differs from that of the previous winter when height anomalies show dominantly quasi-barotropic structure (not shown). With regression analysis they show the validity of their hypothesis of eastward propagation of the 500 hPa height anomalies. The same could be followed from Figure 2, where the evolution of 500 hPa height differences between mild and cold winters at 60 N is presented. Also at 65 N the similar pattern is present. At higher latitudes (70N and 75 N) this kind of signal propagation is missing.

2. The authors present a great amount of results that need to be better interpreted, synthesized and placed in to a climatological/ atmospheric context supported by existing literature.

To reduce the number of correlations we made a general table with all our parameters and then chose only 3 for subsequent analysis (temperature, SLP and we added height of geopotentials). We made extra analyses and supported our results with existing literature (see previous answer).

3. The authors use simple linear correlation analyses to explore atmospheric teleconnections. I assume that they are speaking of the Pearson Correlation Coefficient. I have some concerns about this given that the areas of concern are in middle-to-high latitudes where teleconnections are known to be of non-linear nature. Also, the correlation method is applied to climate parameters such as wind and specific humidity that may not be normally distributed and significantly influence the results.

We added the word "Pearson" to clarify which correlation we use in the manuscript. Teleconnections (like most physical processes) can often have non-linear nature, but until the process real relation functions are unknown, linear estimates are the most reasonable ones. We added to the text: "in this paper we use only linear correlations, non-linear correlations are not included".

To be statistically correct, our methods indeed assume normal distributions for all inputs. Still, as we are seeking not exact numbers but rather general patters, small violation of normal distribution assumptions should not have considerable effect. Also – as we use mostly seasonal mean values – central limit theorem also gives us credit to assume that our data is at least in some extent normally distributed.

4. The entire Baltic Sea region is represented by one single station located in southern Estonia (TP). The authors claim that the information provided in Figure 1 (i.e., Correlations between air temperatures at this location with locations across the greater Baltic Sea region during various season) shows that TP's climate represents the climate of the greater region very well. This may be the case for surface temperature, but I strongly doubt that same would hold true for the other variables such as wind

characteristics. This can be seen in Figure 2 for JJA, for instance.

We reduced the parameters of analysis. Temperature at 1000 hPa, SLP and geopotential heights at 700 hPa and 500 hPa are analysed. For SLP we prepared a similar figure as for temperature in manuscript (see below Figure 4).
To be more precise we renamed our title as the 'Atmospheric teleconnections between the Arctic and the Eastern Baltic Sea regions'.

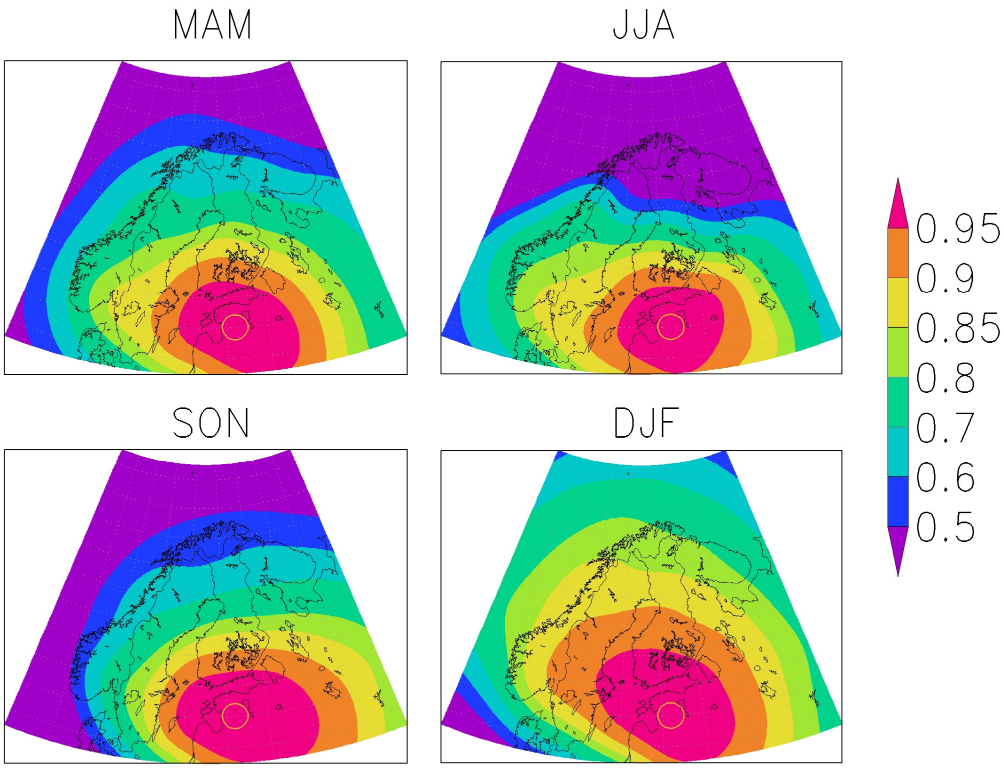


Figure 4. Correlation maps of SLP for the testing point in the Eastern Baltic Sea region.

5. For their analyses, the authors chose four atmospheric variables including air temperature, specific humidity, wind speed, and sea level pressure. Why did they choose these variables and not just sea level pressure, or the more typical 700 hPa geopotential heights for exploring atmospheric teleconnections?

We have left out specific humidity and wind speed and have added 700 hPa and 500 hPa geopotential heights.

6. What methods were used to remove the trends from the data?

For detrending, firstly we calculated linear trend (k) and intercept (b) for each parameter every season in every grid point. Using these parameters linear detrending was done also for each parameter every season in every grid point:
$Y_i = X_i - (k \cdot year + b - X_{average})$.
We added the formula with explanations in the manuscript.

7. What methods were used to assess statistical significance?

We used F-test for testing the significance of correlations. For comparison of averages (difference between warm and cold winters, was not included in the previous version), we used t-test assuming equal variances.

$$F = \frac{(N-2)\cdot R^2}{1-R^2}$$

8. The overall manuscript is clearly written baring some oddities in grammar and general use of the English language. I would recommend a more careful proof-reading of the revised manuscript. Some (not all) recommendations are included below.

Specific Comments:

Line 90: The authors mention several atmospheric teleconnections including the AO, NAO, PDO, SCA, EA, and EA/WR but do not explain what each of these are and on what basis they were included in the conversation. They also do not explain why most these were discounted up front and not addressed again even in the discussion section.

To expose the role of different teleconnection indices we reorganized the analysis of teleconnection indices as follows (based on the suggestions of our referees):

we explained our choices of indices based on geographical position of the centres of action of the teleconnection patterns in data paragraph (see the segment 1 beneath);

we added to Results paragraph the table about the influence of teleconnection indices to correlations between the Baffin Bay region and the Eastern Baltic Sea region (see the table 1 below);

we added the analysis of PEU and found that the strength of influence is larger than all other teleconnection indices except much more larger impact of AO and NAO (see table 1);

we added to our discussion paragraph a new segment about the role of teleconnection indices, the possible reasons why other indices showed much less impact than AO and NAO indices, based on literature: Uotila et al, 2015; Lim, 2015; Comas-Bru and McDermott, 2014; Vihma et al., 2014; Moore et al., 2013.

Table 1. *The partial correlations of teleconnection indices between 1000 hPa temperature at TP and the Baffin Bay-Greenland region (20-80W; 55 – 80). Smaller (than regular) values show higher impact of the index.*

index	DJF	MAM	JJA	SON
regular	*-0.41*	*-0.23*	*0.15*	*-0.02*
AO	**-0.07**	**-0.10**	0.19	0.08
NAO	**-0.10**	**-0.11**	0.23	0.04
PDO	-0.45	-0.26	0.06	-0.11
CAI	-0.41	-0.21	0.15	-0.01
PEU	-0.42	-0.18	0.19	-0.02

EA	-0.43	-0.27	0.06	0
EA/WR	-0.41	-0.22	0.12	-0.12
SCA	-0.25	-0.23	0.21	-0.01

Segment 1 of new version:

"The teleconnection indices we applied in our analyses were chosen according to the possible influence due to the geographical position of the centres of action of the teleconnection patterns over the North-Atlantic-Eurasian region. The following indices were chosen: 1) The North Atlantic Oscillation (NAO), which is the dominant mode of atmospheric variability in the North Atlantic sector throughout the year (Barnston and Livezey, 1987); 2) The Arctic Oscillation (AO), which is usually defined as the first EOF of the mean sea level pressure field in the Northern Hemisphere (Ambaum et al., 2001); 3) The Scandinavian Pattern (SCA), which consists of a primary circulation centre over Scandinavia, with two other weaker centres of action with the opposite sign, one over the north eastern Atlantic and the other over central Siberia to the southwest of Lake Baikal (Bueh and Nakamura, 2007); 4) The East Atlantic Pattern (EA), which consists of a north-south dipole of anomaly centres spanning the North Atlantic from east to west (Barnston and Livezey, 1987); 5) The East Atlantic/West Russia Pattern (EA/WR), which consists of four main anomaly centres: Europe, northern China, central North Atlantic and north of the Caspian Sea; 6) The Polar/ Eurasia Pattern (PEU) consists of height anomalies over the polar region, and opposite anomalies over northern China and Mongolia.; 7) Additionally, Pacific Decadel Oscillation (PDO), which is the dominant year-round pattern of monthly North Pacific sea surface temperature (SST) variability was included. Although its geographical centres are far from the Baltic Sea region, Uotila et al (2015) found that PDO correlated significantly with the ice concentration and temperature of Baltic Sea. All indices were downloaded from the NOAA-CPC database (http://www.cpc.noaa.gov)."

Line 105: The authors mention that they detrended the seasonal time series "to avoid the correlations to be caused by mutual trends in input variables." They also claim that the detrended and original correlation results were very similar. For this reason, they only show correlation results from "regular data". The results surprise me (i.e., similar correlations from original and detrended data), especially given the large recent temporal trends in many of the variables that are explored (i.e.,temperature)in the high latitudes of the northern hemisphere. It is also important to note that the conclusions regarding teleconnections that one can reach from the original series versus detrended series may be different. Are the authors exploring the connections that include long term climatic trends such as global warming, or are they interested in understanding the relationships as they may exist independently of such trends?

Thank you especially for the last sentence, it ended our hesitations should we present results with or without trend. In the upgraded version, we show only results without detrending, to focus connections that are present in our world that is influenced by global climate change trends. We include discussion about detrended data to clarify that presented correlations are not because of trends. Our sentence "differences between the areal averages of correlations were up to 0.02 in both directions" is indeed a bit misleading, as there are small regions where the difference is larger than 0.4, we replaced it with "detrending did not change general patterns of correlations with TP, only intensified negative correlation in the Greenland region ".

Line191: The authors claim that"...,the winter mean temperature is not dependent on weather conditions during the previous seasons." But on line 199 they proceed to make the following claim: "Winter temperature at the TP has a strong negative correlation in the Taimyr region in the previous summer." To me, these statements seem to contradict themselves.

Thank you for asking, there was indeed conflict between these sentences. We upgraded the text as follows: " At the same time, the winter mean temperature has almost no dependent on weather conditions during the previous seasons, there is only small region with strong negative correlation in the Taimyr region in the previous summer (lag=6).

Line 235: The authors state that "To avoid false correlations, only the results that were present in both the regular and the detrended data were discussed." I am not sure what is meant by "false correlations". Like I mentioned earlier, detrended data for instance, may hold a different story, not a false story.

You are correct, we just remove this sentence (we explained reasons two comments above).

Line 25: find another word for "disconfirm"

We replaced "disconfirm" with "disagree".

Line 26-27: It is not clear what "both" is referring to in the sentence starting with "They found that from...."

We changed the sentence as follows: "They found that from October to December, the main factors responsible for the Arctic deep tropospheric warming are: 1) the recent decadal fluctuations and 2) long-term changes in sea surface temperatures. These two factors are located outside the Arctic."

Line 33: "Arctic amplification" should be Arctic Amplification

Corrected

Line 67: It is not customary for sentences to begin with "But"

We changed the sentence as follows:

There is no clear understanding about the reasons for the changes in these indices or climatic parameters in the Baltic Sea region in most recent time.

Line 68: I would suggest replacing "last decades" with most recent?

Corrected.

Line 71: Rework the sentences starting with "Therefore, our aim is to....

We changed the segment as follows: "Our aim is to clarify how the climatic parameters in the Eastern Baltic Sea and Arctic regions are associated. Knowledge of such connections helps to define regions in the Arctic that could be with higher extent associated with the Baltic region climate change."

Line 123: Replace the word "huge" with large

Corrected

Line 132: Can the word “distinguished” be replaced with different or distinct?

Replaced with distinct.

Thank you once more,

Sincerely yours,

Liisi Jakobson
Erko Jakobson
Piia Post
Jaak Jaagus

References (If we use in our answers references that were already given in our article then we will not give the reference here again):

- Barnston, A. G., and Livezey, R.E.: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns, MON WEATHER REV, 115, 1083-1126, 1987.
- Bueh, C. and Nakamura, H.: Scandinavian pattern and its climatic impact, Q J ROY METEOR SOC. 133: 2117 – 2131, DOI: 10.1002/qj.173, 2007.
- Comas-Bru, L. and McDermott, F.: Impacts of the EA and SCA patterns on the European twentieth century NAO–winter climate relationship. Q J ROY METEOR SOC, 140: 354–363. doi:10.1002/qj.2158, 2014.
- Lim, Y.K.: The East Atlantic/West Russia (EA/WR) teleconnection in the North Atlantic: climate impact and relation to Rossby wave propagation, CLIM DYNAM, 44: 3211. doi:10.1007/s00382-014-2381-4, 2015.
- Moore, G.W.K., Renfrew, I.A., Pickart, R.: Multi-decadal mobility of the North Atlantic Oscillation. J CLIMATE. 26 : 2453–2466, DOI:10.1175/JCLI-D-12-00023.1, 2013.
- Sato, K., Inoue, J., and Watanab, M.: Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter, ENVIRON RES LETT, 9, 084009, 8pp, doi:10.1088/1748-9326/9/8/084009, 2014.
- Uotila, P., Vihma, T., and Haapala, J.: Atmospheric and oceanic conditions and the extremely mild Baltic Sea ice winter 2014/15, GEOPHYS RES LETT, doi:10.1002/2015GL064901, 2015.
- Vihma, T., Cheng, B., and Uotila, P.: Linkages between Arctic sea ice cover, large-scale atmospheric circulation, and weather and ice conditions in the Gulf of Bothnia, Baltic Sea, Advances in Polar Science, 25(4), 289-299, doi: 10.13679/j.advps.2014.4.00289, 2014.
- Wu, B. Y., Zhang, R. H., D'Arrigo, R. et al.: On the Relationship between winter sea ice and summer atmospheric circulation over Eurasia, J CLIMATE, 26:5523-5536, doi:10.1175/JCLI-D-12- 00524.1, 2013.

Answers to the referee 3

23-Jun-2017

Thank you very much for time dedicated to our manuscript. Please find below your comments repeated again, and our answers. With the help of your advices, we have prepared a restructured, rebalanced and easier readable version of our manuscript.

General comments:

1. The background of Arctic-midlatitude linkages and possible physical relationships between Arctic climate change and midlatitude weather and climate and the role of atmospheric teleconnections has to be described more detailed and sound.

We added the following segment to summarise possible physical mechanisms behind teleconnection and to reveal the background of Arctic - mid latitude linkages to our Introducion (the first sentence was also in the previous version):

“Several studies have demonstrated relationships between warming and/or ice decline, and mid-latitude weather and climate extremes (Handorf et al., 2015; Coumou et al., 2014; Tang et al., 2013; Petoukhov et al., 2013; Francis and Vavrus, 2012; Petoukhov and Semenov, 2010). Others have analysed whether these associations are statistically and/or physically robust (Hassanzadeh et al., 2014; Screen et al 2014; Barnes et al 2014; Screen and Simmonds 2013, 2014; Barnes 2013), while some investigations suggest that the apparent associations may have their origin, in part, in remote influences (Perlwitz et al., 2015; Sato et al., 2014; Peings and Magnusdottir 2014; Screen et al., 2012; Petoukhov and Semenov 2010).”
The relationship between AA and weather extremes and/or persistent weather patterns in mid-latitudes are mostly explained with Arctic and North Atlantic anomalous circulation regimes, waviness and strength of jet stream (Vavrus et al., 2017; Francis and Skific, 2015; Overland et al., 2015; Barnes and Screen, 2015; Francis and Vavrus, 2015; Coumou et al., 2014; Tang et al., 2013; Petoukhov et al., 2013; Francis and Vavrus, 2012). Common supposition is that sea ice declines are primarily responsible for amplified Arctic tropospheric warming. This conjecture is central to a hypothesis in which Arctic sea ice loss forms the beginning link of a causal chain that includes weaker westerlies in mid latitudes, more persistent and amplified mid latitude waves, and more extreme weather (Perlwitz et al., 2015). On the other hand Sun et al. (2016) brought out that neither sea ice loss nor anthropogenic forcing overall yield the winter cold extremes and persistence in mid-latitudes. Arctic warming over the Barents–Kara Seas and its impacts on the mid-latitude circulations have been widely discussed (Dobricic et al., 2016; Semenov and Latif, 2015; Kug et al., 2015; Sato et al., 2014). Another particular regional warm core (Screen and Simmonds, 2010) is East Siberian–Chukchi Seas which is related to severe winters over North America (Kug et al., 2015; Lee et al., 2015). Screen and Simmonds (2010) brought out also the third particular regional warm core – northeast Canada and Greenland which has been less investigated. Wu et al., (2013) focused on winter SIC west of Greenland, including the Labrador Sea, Davis Strait, Baffin Bay, and Hudson Bay and found that winter SIC west of Greenland is a possible precursor for summer atmospheric circulation and rainfall anomalies over northern Eurasia. If we look at the regions in mid-latitudes then potential Arctic connections in Europe are less clear then with North America and Asia (Overland et al., 2015).

2. All analysis are based on linear correlation analysis. To make inferences about correlations, the test of the Nullhypothesis of no correlation has been performed only. I think, this need to be expanded by, at least, including non-parametric approaches not relying on normally distribution, taking into account the reduction of degrees of freedom due to autocorrelation and also

by estimating the confidence intervals of the correlation coefficients. Furthermore, Wallace and Gutzler (1981) introduced a stronger criterion than that of statistical significance to make inferences about teleconnections, namely reproducibility, which should be used here, too. Furthermore, the authors have to be careful not to overstate the results of the simple correlation analyses and have to be aware that correlation does not mean causation.

We agree, that our real data may not fulfil all condition thoroughly that are preconditions for linear correlations, especially linearity and normality. Still, as we are seeking not exact numbers but rather general patters, small violation of normal distribution assumptions should not have considerable effect. Also – as we use mostly seasonal mean values – central limit theorem also gives us credit to assume that the data is at least in some extent normally distributed.
We agree, that correlation does not mean causation always as covariability between two different data can happen without reason. Still, we discuss in the paper only correlations that are larger than ±0.5. For two random 37-elements dataset there is possibility to have such big correlation 0.2%, so only 2 cases of 1000.
For reproducibility, we run over all calculations using ERA-interim data, and saw that these two models show similar correlation patterns. We believe that our results using linear correlations are sufficiently confidential for our conclusions even without suggested Wallace and Gutzler (1981) method that would demand totally new calculations.

3. Having in mind the position of the centers of action of the teleconnection patterns over the North-Atlantic-Eurasian region, I suggest to include the analysis of statistical relationships with the Scandinavian and East Atlantic/West Russia patterns.

We added explanations (also for Scandinavian and East Atlantic/West Russia patterns) our choices of indices based on geographical position of the centres of action of the teleconnection patterns in data paragraph (see the segment 1 beneath);

Segment 1:
"The teleconnection indices we applied in our analyses were chosen according to the possible influence due to the geographical position of the centres of action of the teleconnection patterns over the North-Atlantic-Eurasian region. The following indices were chosen: 1) The North Atlantic Oscillation (NAO), which is the dominant mode of atmospheric variability in the North Atlantic sector throughout the year (Barnston and Livezey, 1987); 2) The Arctic Oscillation (AO), which is usually defined as the first EOF of the mean sea level pressure field in the Northern Hemisphere (Ambaum et al., 2001); 3) The Scandinavian Pattern (SCA), which consists of a primary circulation centre over Scandinavia, with two other weaker centres of action with the opposite sign, one over the north eastern Atlantic and the other over central Siberia to the southwest of Lake Baikal (Bueh and Nakamura, 2007); 4) The East Atlantic Pattern (EA), which consists of a north-south dipole of anomaly centres spanning the North Atlantic from east to west (Barnston and Livezey, 1987); 5) The East Atlantic/West Russia Pattern (EA/WR), which consists of four main anomaly centres: Europe, northern China, central North Atlantic and north of the Caspian Sea; 6) The Polar/ Eurasia Pattern (PEU) consists of height anomalies over the polar region, and opposite anomalies over northern China and Mongolia.; 7) Additionally, Pacific Decadel Oscillation (PDO), which is the dominant year-round pattern of monthly North Pacific sea surface temperature (SST) variability was included. Although its geographical centres are far from the Baltic Sea region, Uotila et al (2015) found that PDO correlated significantly with the ice concentration and temperature of Baltic Sea. All indices were downloaded from the NOAA-CPC database (http://www.cpc.noaa.gov)."

4. The analysis should be extended by including other reanalysis. The authors themselves are experts in evaluating reanalysis data over the Arctic (Jakobson, E., et al, GRL, 2012). The same issue has been studied by Lindsay et al., JC, 2014). Based on these evaluations I suggest, that at least ERA-Interim should be studied for comparison.

We repeated the analysis with ERA-Interim. The results were resembled sufficiently in main points in the study region, although there we some discrepancies during summer season in the Central Arctic region. The dissimilarities are mentioned in the manuscript.

Specific comments:

(1) Check the spelling of ’Arctic Amplification’ throughout the manuscript.

Corrected

(2) Check the spelling of ’indices’ throughout the manuscript.

Corrected

(3) L57: What is meant by ’cold period’

We added the explanation to the brackets: (NDJFM).

(4) L59: ’overall warming. Over which period?

We added a period and a reference as follows:

After 1980s there has been significant temperature increase in the Baltic Sea region (BACC II, 2015).

(5) L62-65: Please, give references for these statements.

We added the reference (BACC II, 2015).

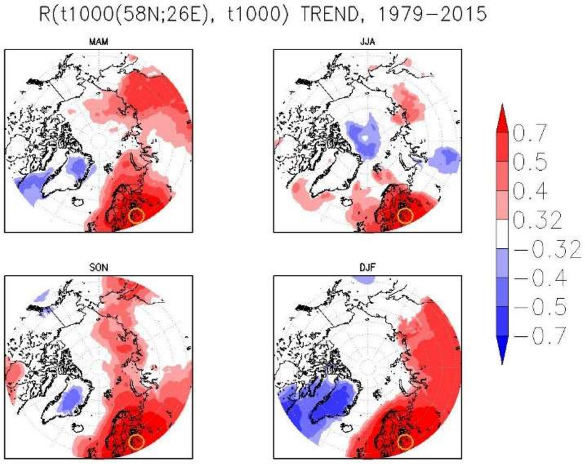
(6) L69: reference Lehmann et al., 2011 is not included in the list of references.

Corrected

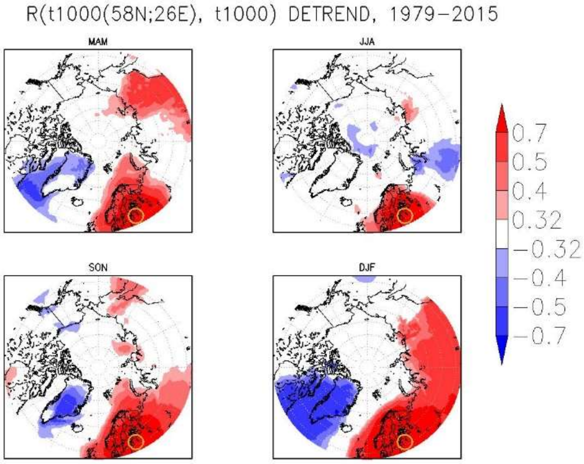
(7) L107-108: I have some doubts, that detrending changes the correlations only slightly given only an area averaged value. I would like to see the correlation maps instead.

Here are temperature at 1000 hPa seasonal correlations: first without detrending, second after detrending and third is first figure minus second one. Without trends in temperature, negative correlations with TP would be slightly stronger in Greenland-Labrador area. Our sentence "differences between the areal averages of correlations were up to 0.02 in both directions" is indeed a bit misleading, we replaced it with "detrending did not change general patterns of correlations with TP, only intensified negative correlation in the Greenland region ".

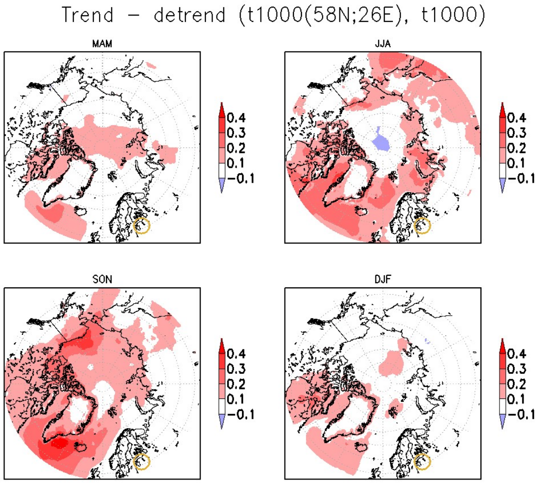
In the upgraded version, we show only results without detrending, to focus connections that are present in our world that is influenced by global climate change trends.



R(t1000(58N;26E), t1000) TREND, 1979–2015



R(t1000(58N;26E), t1000) DETREND, 1979–2015



Trend – detrend (t1000(58N;26E), t1000)

(8) Throughout the manuscript, do not call a correlation coefficient of 0.5 as strong, it explains only 25% of variance.

By the meaning of "how much one parameter variance is controlled by the other one", 25-50% is indeed not very strong. At the same time, by the meaning of "how certain we can be that there is connection between two parameters", the probabilities for 0.5 and 0.7 are 99.8% and 99.998% correspondingly, that is quite strong. Even correlations exceeding ±0.32 are significant *at 95% confidence level, so for correlation above ±0.5 we needed stronger name than "significant".*

(9) L237: Though I think the results of the study are valuable, they are not very surprising nor spectacular. Please, be more cautious with your formulation.

We tried to be more cautious with our formulations and replaced "spectacular" with "important".

(10) Fig.2 to 6: Do not include the shading levels below the 95% significance level.

We initially added 68% shading level to mark regions with still quite high possibility for the connections. We upgraded the new version to have first shading level at 95% as you suggested.

Thank you once more for your trouble!

Sincerely yours,

Liisi Jakobson
Erko Jakobson
Piia Post
Jaak Jaagus

References (If we use in our answers references that are already given in our article then we will not give the reference here again):

- Barnes, E. A. and Screen, J. A.: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?, WIRES CLIM CHANGE, 6: 277–286. doi:10.1002/wcc.337, 2015.
- Barnes, E. A., Etienne, D.S., Giacomo, M., and Woollings, T.: Exploring recent trends in Northern Hemisphere blocking, GEOPHYS RES LETT, 41, doi: 10.1002/2013GL058745, 2014.
- Barnes, Elizabeth A.: Revisiting the evidence linking Arctic Amplification to extreme weather in midlatitudes, GEOPHYS RES LETT, 40, doi:10.1002.grl.50880, 2013.
- Barnston, A. G., and Livezey, R.E.: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns, MON WEATHER REV, 115, 1083-1126, 1987.
- Bueh, C. and Nakamura, H.: Scandinavian pattern and its climatic impact, Q J ROY METEOR SOC. 133: 2117 – 2131, DOI: 10.1002/qj.173, 2007.
- Dobricic, S., Vignati, E., and Russo, S.: Large-Scale Atmospheric Warming in Winter and the Arctic Sea Ice Retreat, J CLIMATE, 29, 2869–2888, doi: 10.1175/JCLI-D-15-0417.1, 2016.
- Francis, J. A. and Vavrus, S.J.: Evidence for a wavier jet stream in response to rapid Arctic warming, ENVIRON RES LETT, 10 014005, 2015.
- Francis, J.A. and Skific N.: Evidence linking rapid Arctic warming to mid-latitude weather patterns. Philosophical transactions of the Royal Society A, 373, doi:10.1098/rsta.2014.0170, 2015.
- Handorf, D., R. Jaiser, K. Dethloff, A. Rinke, and J. Cohen: Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections, GEOPHYS RES LETT, 42, 2367–2377. doi: 10.1002/2015GL063203, 2015.
- Hassanzadeh, P., Kuang, Z., and B. F. Farrell: Responses of midlatitude blocks and wave amplitude to changes in the meridional temperature gradient in an idealized dry GCM, GEOPHYS RES LETT, 41, 5223–5232, doi:10.1002/2014GL060764, 2014.
- Kug, J.S., Joeng, J.H., Jang, Y.S., Kim, B.M., Folland, C.K., Min, S.K., Son, S.W.: Two distinct influences of Arctic warming on cold winters over North America and East Asia, NAT GEOSCI, 8, 759–762, doi:10.1038/ngeo2517, 2015.
- Lee, M.-Y., Hong, C.-C. and Hsu, H.-H.: Compounding effects of warm sea surface temperature and reduced sea ice on the extreme circulation over the extratropical North Pacific and North America during the 2013–2014 boreal winter, GEOPHYS RES LETT, 42: 1612–1618. doi: 10.1002/2014GL062956, 2015.
- Overland, J., Francis, J.A., Hall, R., Hanna, E., Kim, S.J., Vihma, T.: The melting Arctic and mid-latitude weather patterns: are they connected?, J CLIMATE, . doi:10.1175/JCLI-D-14-00822.1, 2015.
- Peings, Y. and Magnusdottir, G.: Response of the wintertime northern hemisphere atmospheric circulation to current and projected arctic sea ice decline: a numerical study with CAM5, J CLIMATE, 27:244–264. doi:10.1175/JCLI-D-13-00272.1, 2014.
- Sato, K., Inoue, J., and Watanab, M.: Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter, ENVIRON RES LETT, 9, 084009, 8pp, doi:10.1088/1748-9326/9/8/084009, 2014.
- Screen, J. A., and I. Simmonds (2013), Exploring links between Arctic amplification and mid-latitude weather, GEOPHYS RES LETT, 40, 959–964, doi:10.1002/grl.50174, 2013.
- Screen, J.A. and Simmonds, I.: Amplified mid-latitude planetary waves favour particular regional weather extremes, NAT CLIM CHANGE, 4, 704-709, 2014.
- Screen, J.A., Deser, C., and Simmonds, I.: Local and remote controls on observed Arctic warming, GEOPHYS RES LETT, 39, L10709, doi:10.1029/2012GL051598, 2012.
- Screen, J.A., Deser, C., Simmonds, I., and Tomas, R.: Atmospheric impacts of Arctic sea-ice loss, 1979-2009:

Separating forced change from atmospheric internal variability, CLIM DYNAM, 43, 333-344, 2014.

- Semenov, V. A. and Latif, M.: Nonlinear winter atmospheric circulation response to Arctic sea ice concentration anomalies for different periods during 1966–2012, ENVIRON RES LETT, 10 (5). 054020. DOI 10.1088/1748-9326/10/5/054020, 2015.
- Sun, L., Perlwitz, J., and Hoerling, M.: What caused the recent "Warm Arctic, Cold Continents" trend pattern in winter temperatures?, GEOPHYS RES LETT, 43, 5345–5352, doi:10.1002/2016GL069024, 2016.
- Uotila, P., Vihma, T., and Haapala, J.: Atmospheric and oceanic conditions and the extremely mild Baltic Sea ice winter 2014/15, GEOPHYS RES LETT, doi:10.1002/2015GL064901, 2015.
- Wallace, J.M. and Gutzler, D.S.: Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter, Monthly Weather Review, 109, 784-812, https://doi.org/10.1175/1520-0493(1981)109<0784:TITGHF>2.0.CO;2, 1981.
- Wu, B. Y., Zhang, R. H., D'Arrigo, R. et al.: On the Relationship between winter sea ice and summer atmospheric circulation over Eurasia, J CLIMATE, 26:5523-5536, doi:10.1175/JCLI-D-12- 00524.1, 2013.

Answers to the referee 4

23-Jun-2017

Thank you very much for your comments. Please find below your comments repeated again and our answers. With the help of your advices, we have prepared a new version of our manuscript.

a) The authors mostly describe results based on linear correlation analysis but provide little physical interpretations.

To have a more focused paper we reduced the number of parameters, for that we made a general table of correlations with all our parameters and then chose only 3 for subsequent analysis: temperature, SLP and we added geopotential heights. We separated cold and warm winters (based on Baffin Bay region), similar to Sato et al, (2014); and added following analysis to reveal possible physical mechanisms why the Baltic Sea and the BB winters are in opposite phase relying on 1000 hPa temperature. We look atmospheric circulation differences using SLP, 700 hPa and 500 hPa geopotential height differences between warm and cold winters. We added also a cross-section of geopotential heights (up to 100 hPa) along the 60W vertical slice and plots of annual evolution of 500-hPa height differences at 60N, 70N and 75N (similar to Wu et al., 2013). See figures below:

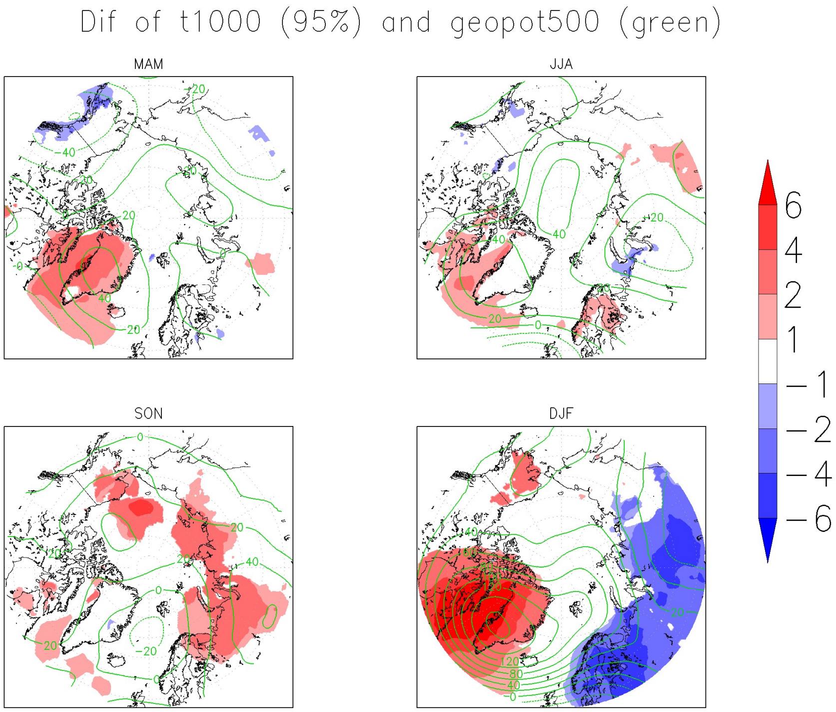


Figure 1. Seasonal difference maps (years with mild winters years with cold winters) in air temperature at 1000 hPa level (shading with confidence level of 95%), and (b) geopotential height at 500hPa level (contours).

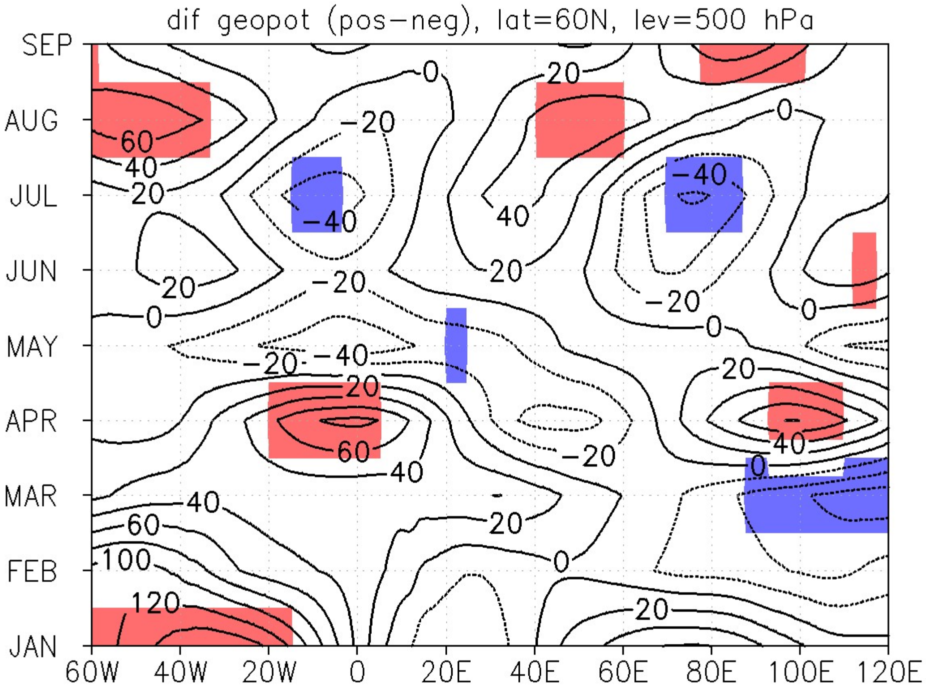


Figure 2. Evolution of 500-hPa height differences between mild and cold winters at 60N; red and blue shading indicates differences at the 95% significance levels for positive and negative height, respectively.

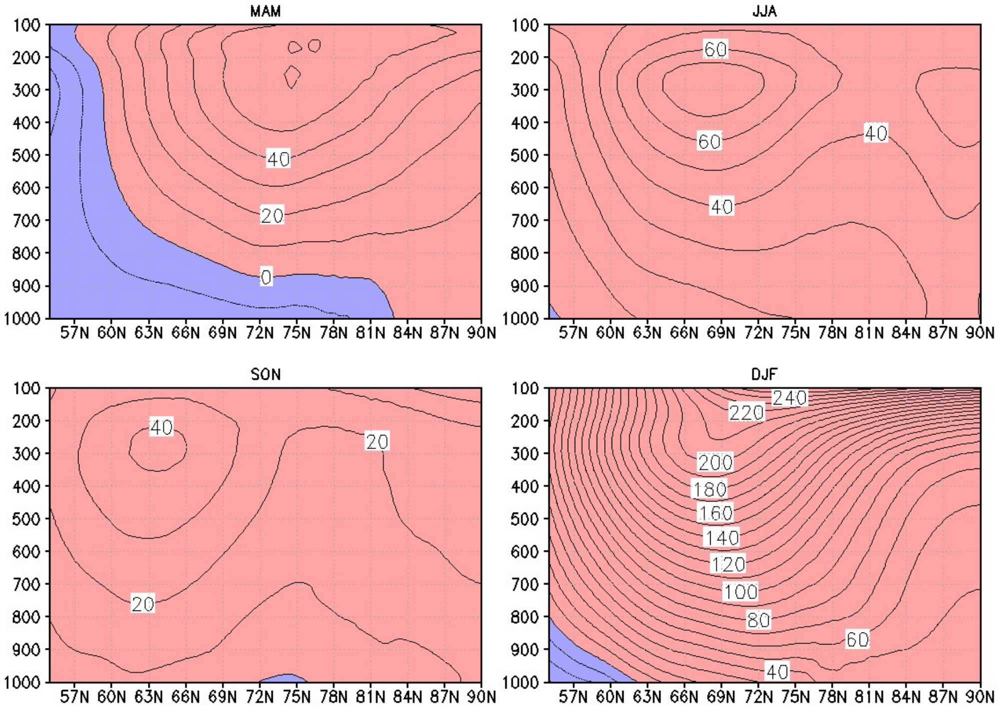


Figure 3. Differences in the mean heights between mild and cold winters along the 60W vertical slice. Contour intervals are 10 gpm; blue represent negative height differences and red positive height differences.

In discussion paragraph we added:

The large scale atmospheric circulation pattern in Figure 1 shows that the geopotential heights of 500 hPa are more than 100 gpm higher in mild winters than in cold ones, and the maximum of this height anomaly is centred over the maximum of the 1000 hPa temperature difference. It means that the whole column (up to 500 hPa) of the air in the Baffin Bay region is warmer than at cold years. Coming down to the lower surfaces (700 hPa, not shown), the maximum height anomaly is shifted to the east, what could be due to warmer sea surface of the Northern Atlantic compared to the regions that lay to west of it. The positive temperature anomaly (with the 500-hPa height anomalies) shifts towards east during the next seasons, reaching to Scandinavia/Baltic Sea region in summer (Figure 2). By Wu et al (2013) proposed mechanism, that associates the summer atmospheric circulation anomalies in the northern Eurasia with the previous winter ice conditions west of Greenland, supports our idea.

Figure 3 exhibit baroclinic structure of spring atmosphere north of 55N due to positive height anomalies in the lower troposphere below the 850 hPa and with further higher the negative ones. Similarly to Wu et al (2013) the vertical distribution of spring height anomalies differs from that of the previous winter when height anomalies show dominantly quasi-barotropic structure (not shown). With regression analysis they show the validity of their hypothesis of eastward propagation of the 500 hPa height anomalies. The same could be followed from Figure 2, where the evolution of 500 hPa height differences between mild and cold winters at 60 N is presented. Also at 65 N the similar pattern is present. At higher latitudes (70N and 75 N) this kind of signal propagation is missing.

b) Also I would like the authors to be more specific regarding novel findings in the manuscript.

We rewrote our Conclusions and besides results that assure (e.g. the strongest teleconnections are present in winter; temperature has strong negative correlation) or contradict (e.g. which has more impact NAO or AO) with results in literature. We added results that we considered to be new:

Although the East Baltic Sea region is downstream from North Atlantic and Greenland – Baffin Bay region is upstream, after removing the general atmospheric circulation influence (we used NAO and AO indices) there still remained significant correlations between parameters of Baffin Bay region and the East Baltic Sea region, except winter.

We showed correlation coefficients between parameters of the Baffin Bay region and the East Baltic Sea region, which was the first time precisely for this region. We hope there will be revealed more physical mechanisms than we were able to reveal this time. This could help long period climate forecast to be more precise in the Eastern Baltic Sea region.

c) Regarding the lagged correlations it would be nice to see how the authors connect their study to those discussing the persistence effect, such as Kolstad et al. (2015).

Kolstad et al. (2015) investigated the persistence of European surface temperature and found that once the persistent weather patterns appear (e.g. temperature anomalies of at least one standard deviation above or below climatology in a month), then the persistence is observed irrespective of the data source or driving mechanisms, and the temperature itself is a more skilful predictor of the temperatures one month ahead. We concentrated on the analysis of the teleconnection between the Eastern Baltic Sea region and the Arctic region. The analysis of the temperature persistence of one region was beyond our scope.

d) Also I found the maps in the figures are too small and they are very difficult to analyse. Some of them mostly repeat each other. For example q1000 and t1000 show very similar patterns. I wonder if it is possible to reduce the number of maps.

We improved figures quality and left out wind speed at 1000 hPa (which is possible to assume from the geopotential heights) and specific humidity at 1000 hPa (which is very similar to temperature at 1000 hPa) to avoid redundancy.

e) Technical comment: the paper by Lehmann et al., 2011 is referred to in the text but not listed in the literature section.

Corrected.

The references you suggested are added to introduction, data and discussion paragraphs .

Thank you once more for your trouble!

Sincerely yours,

Liisi Jakobson
Erko Jakobson
Piia Post
Jaak Jaagus

References

- Kolstad, E.W., Sobolowski, S.P., and Scaife, A.A.: Intraseasonal persistence of European surface temperatures, J CLIMATE, 28:5365–5374. doi:10.1175/JCLI-D-15-0053.1, 2015.
- Sato, K., Inoue, J., and Watanab, M.: Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter, ENVIRON RES LETT, 9, 084009, 8pp, doi:10.1088/1748-9326/9/8/084009, 2014.
- Wu, B. Y., Zhang, R. H., D'Arrigo, R. et al.: On the Relationship between winter sea ice and summer atmospheric circulation over Eurasia, J CLIMATE, 26:5523-5536, doi:10.1175/JCLI-D-12- 00524.1, 2013.