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VARIABILITY AND CHANGES OF THE GROWING SEASON LENGTH AND FROST DAYS NUMBER IN RUSSIAN SUB-ARCTIC

ABSTRACT. Observational data from the Russian sub-Arctic stations are used to investigate long-term variability of the growing season length (GSL) and the number of frost days (FD) in 1949-2013. Consistent with the global warming pattern we find a trend-like increase (decrease) of GSL (FD) which is evident since early 1970th of the last century. These trend-like changes are best pronounced at Western stations (i.e. in European Russia and western Siberia) and they are essentially smaller to the East. Although we find some significant links to regional teleconnections (such as Scandinavian, East Atlantic and West Pacific teleconnections), in general our results imply rather weak impact of large scale atmospheric dynamics on interannual variability of GSL and FD. Further analysis of correlations between GSL and FD on the one side and snow cover on the other side revealed generally stronger links to snow cover compared to teleconnections. However, revealed links to regional atmospheric teleconnections and snow cover are significantly impacted by the linear trends. In general, our results imply that compared to large scale atmospheric dynamics impacting interannual variability, snow cover (being a result of wintertime synoptic activity) plays a more important role in decadal-interdecadal variations of GSL and FD in Russian sub-Arctic, which may have some value regarding predictability of the summer climate in the region.

KEY WORDS: Growing season, frost days, snow cover, teleconnections, northern Eurasia, climate variability and change

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INTRODUCTION

The growing season length (GSL) and number of frost days (FD) are among the most important climate indices (e.g., Zhang et al. 2011; Donat et al. 2013). Recent studies demonstrate increasing evidences of changes in air temperature and thus the GSL particularly in the Northern Hemisphere (Frich et al. 2002; Song et al. 2010). An increase in GSL have been noted in the late twentieth century through analysis of satellite data and phonological and meteorological observations (Linderholm 2006). The GSL variability appears as an important indicator of climate change. Myneni et al. (1997) showed that increases in the photosynthetic activity of terrestrial vegetation, as seen from satellite data, have been associated with increase of the GSL. IPCC (2013) affirms that the projected climate change will further increase GSL.

Thus, in some areas, such as high northern latitudes, an increased GSL along with a warmer climate might have a positive effect on crop production and possibly increase the harvests and seasonal yields.

The occurrence of freezing conditions is an integral element of a regional ecosystem processes, recreational activities and economy. Several studies revealed a clear trend towards fewer low temperature extremes in the late twentieth century over all continents (e.g., Horton et al. 2001; Kunkel et al. 2004). The global analysis of climate extreme indices by Frich et al. (2002) revealed the evidence of fewer frost days in much of the middle and high latitudes of the Northern Hemisphere during the second half of the twentieth century. Alexander et al. (2006) found significant decrease in the annual number of frost days over Western Europe and large parts of Russia during the period 1951-2003. Bartoly and Pongrácz (2007) detected a decreasing number of cold nights, severe cold days and frost days between 1961 and 2001.

It should be noted however that characteristics of interannual variability of GSL and FD vary significantly from region to region. Thus, a large degree of uncertainty remains regarding GSL and FD variability in such under sampled region as Russian sub-Arctic during recent decades, a time period characterized by the most intensive climate warming. Recently available observational data sets provide a good opportunity to address this issue.

In the present study we therefore aim to examine variability and changes in GSL and FD in Russian sub-Arctic and investigate possible mechanisms driving (or impacting) these variability and changes. The data used and the analysis methods are described in Materials and Methods section. The major results of undertaken analysis are presented and briefly discussed in Results and Discussion. Finally, major conclusions of the study are formulated in Conclusions section.

MATERIALS AND METHODS

In this study we use the growing season length (GSL) and number of frost days (FD) data for 1949-2013 which are calculated basing on Global Historical Climatology Network (GHCN) daily station dataset. Both GSL and FD are among the key climate indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI, e.g., Zhang et al. 2011). In essence GSL is an annual number of days between the first occurrence of 6 consecutive days with daily mean temperature exceeding 5ºC and first occurrence of 6 consecutive days with daily mean temperature below 5ºC. For the Northern Hemisphere this is calculated from January 1 to December 31. FD is annual number of days when minimum temperature is below 0ºC. These data are provided by the Climate Change Research Centre, University of New South Wales (e.g., Donat et al. 2013) and publicly available at www.climdex.org. Based on the criteria of time series length and absence of gaps, for our analysis, we selected 8 Russian sub-Arctic stations which are indicated in Fig. 1. It should be mentioned that, in general, Russian sub-Arctic is not well covered by observations (see e.g. Fig. 1 in Alexander et al. 2006). Nevertheless, the stations selected for present study, are relatively evenly distributed in west – east direction, though the number of stations in the eastern part of the region is obviously smaller.

To investigate possible links between interannual variability of GSL and FD in Russian sub-Arctic and regional atmospheric circulation we use indices of the major teleconnection patterns that have been documented and described by Barnston and Livezey (1987). The patterns and indices were obtained by applying rotated principal component analysis (e.g., Hannachi et al. 2007) to standardized 500hPa height anomalies in the Northern Hemisphere. The teleconnection patterns used here include the North Atlantic (NAO), East Atlantic (EA), East Atlantic – West Russia (EAWR), Polar – Eurasia (POL), West Pacific (WP) and the Scandinavian (SCA) patterns. Their regularly updated indices, covering

Fig. 1. Russian sub-Arctic stations under analysis

the period 1950 – present, are available from the NOAA Climate Prediction Centre (CPC) website (www.cpc.ncep.noaa.gov/data/teledoc/telecontents. html). Further details on the teleconnection pattern calculation procedures can be found in Barnston and Livezey (1987) and at the CPC website. These indices have been curtailed to match the period of our analysis. To briefly examine possible impact of snow cover on the GSL and FD variability, we make use of the snow water equivalent (SWE) data from the GlobSnow dataset (Takala et al. 2011) which are satellite data provided on the grid with 25km spatial resolution.

Long-term linear trends of GSL and FD were estimated by least squares (e.g., Wilks 1995) at each station. Statistical significance of trend estimates was assessed according to a Student t-test (Bendat and Piersol 1966). Conventional correlation analysis has been applied to study links to teleconnection patterns and snow cover. In this study we consider simultaneous connections between GSL and FD and major teleconnection patterns as well as snow cover. According to the Student t-test (Bendat and Piersol 1966), the minimum significant correlation coefficient between the time series analyzed is 0.24 for the 5% significance level. Since the significance level of the correlation coefficient might be reduced if the time series are influenced by autocorrelation, the potential impact of autocorrelation on the estimation of significance of correlation coefficients has been examined. Significant autocorrelations have not been found in analyzed time series which is expected since each value is separated by 1 year. It should be emphasized that statistical methods used in this study imply that only linear relationships between analyzed variables are addressed.

RESULTS AND DISCUSSION

The time series of GSL and FD calculated for 8 Russian sub-Arctic stations are shown respectively at Fig. 2 and 3. Obviously, both GSL and FD vary significantly at interannual and decadal - interdecadal time scales. The major feature in GSL variability is an upward trend starting from the early 70-ties which is best pronounced at the more westerly located stations (Fig. 2). In particular, the largest trends are found in Vytegra and Pechora reflecting an increase in GSL of 8.0 and 8.3 days per decade respectively (Table 1). In contrast, respective trends in easterly located Suntar (2.6 day/decade) and Sejmchan (2.4 day/decade) are not statistically significant. It is worth noting that decadal scale GSL variations in earlier (i.e., before 70-ties) period are also better pronounced at western stations of Russian sub-Arctic (Fig. 2). Although these results (i.e., increase in GSL) are broadly consistent with the global warming trend and its recent intensification (e.g., Bindoff et al. 2013; IPCC 2013), it should be noted that this intensification began in late 70-ties, somewhat later than above described trends in GSL.

Contrasting to GSL, the major feature in FD variability is a downward trend also starting in early 70-ties and also better pronounced at the more westerly located stations (Fig. 3). Particularly, the largest negative trends of FD are found in Arhangelsk and Kotlas reflecting a decrease in FD of 6.6 and 6.0 days per decade respectively (Table 1). Again, similar to GSL, negative trends of FD at the easterly located stations are relatively small and statistically insignificant (Fig. 3). Note however, that at Sejmchan a strong negative trend (-7.9 day/decade) of FD is evident starting from late 80-ties (Fig. 3h). This might indicate a different (compared to more westerly located stations) origin of this downward trend of FD. Although GSL and FD basically characterize different seasons, it should be stressed that these climate indices are not completely independent and demonstrate statistically significant negative correlations varying from -0.49 (-0.46) at Sejmchan to -0.77 (-0.74) at Aleksandrovskoe. Note, correlations between respective de-trended time series (shown in parentheses) are only slightly smaller.

We further briefly examine possible links between GSL and FD variability and some regional teleconnections (Barnston and Livezey 1987). In general, correlations between GSL and FD time series and seasonally averaged indices of regional teleconnections are not very large although in

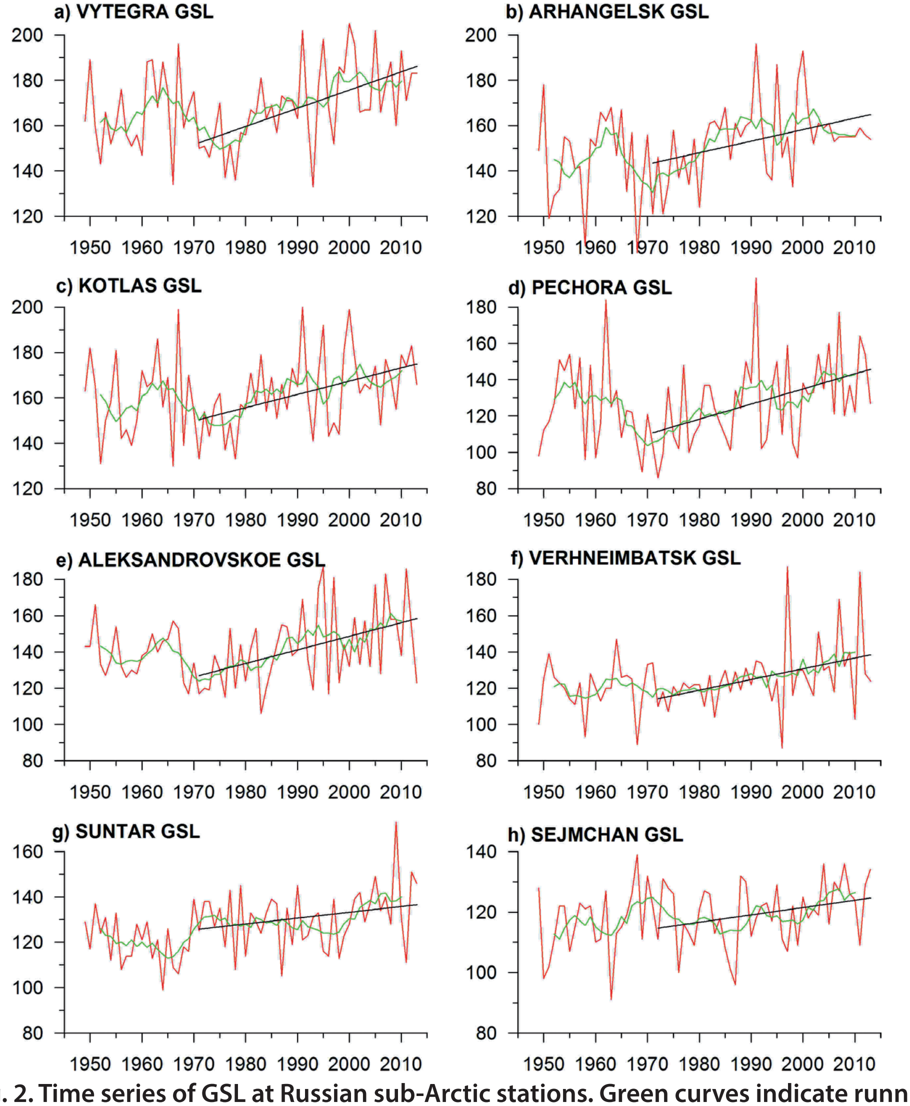

Fig. 2. Time series of GSL at Russian sub-Arctic stations. Green curves indicate running means (7-yr window). Black line indicates linear trend

many cases they are statistically significant at 5% significance level according to Student t-test (Bendat and Piersol 1966). Thus, we mention here only the largest among estimated correlations (Table 2). For GSL (i.e., for summer season) we found relatively large (-0.35) correlation between GSL at the most westerly located (see Fig. 1) Vytegra station and the SCA teleconnection index. Another relatively large (-0.37) detected correlation is that between GSL at the most easterly located Sejmchan station and the WP teleconnection index (Table 2). Note, we do not find large correlations for other stations located between Vytegra and Sejmchan. This basically means that interannual variability of GSL in Siberia is not impacted significantly by examined teleconnections that mostly active in the North Atlantic and Pacific sectors. For FD the largest correlations are found at Vytegra (-0.37) and Suntar (-0.38), in both cases with the EA teleconnection. At Suntar we also found relatively large (0.35) correlation between FD and the POL teleconnection.

It is obvious that considered correlations might be impacted by the linear trends revealed in original time series of GSL and FD

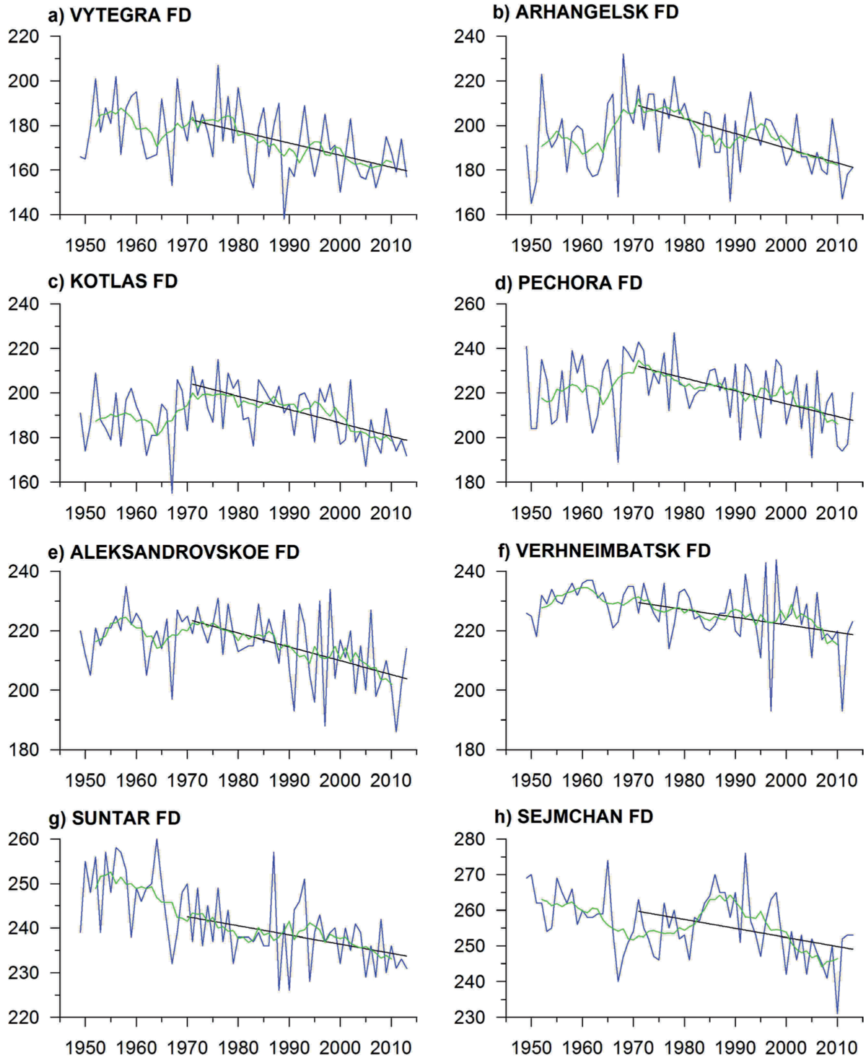

Fig. 3. Time series of FD at Russian sub-Arctic stations. Green curves indicate running means (7-yr window). Black line indicates linear trend

Table 1. Linear trends (in days per decade) in growing season length (GSL) and frost days (FD) number at Russian sub-Arctic stations for 1971-2013. The trends that statistically significant at 5% level are shown in *italics*

	VYT	ARH	KOT	PEC	ALE	VER	SUN	SEJ
GSL	*8.0*	*5.1*	*5.8*	*8.3*	*7.4*	*5.9*	2.6	2.4
FD	*-5.4*	*-6.6*	*-6.0*	*-5.7*	*-4.6*	*-2.6*	-2.1	-2.5

Table 2. Correlations between GSL and FD and indices of regional teleconnections. Correlations for de-trended time series are presented in parentheses. Correlations that statistically significant at 5% level are shown in *italics*

GSL	
VYTEGRA - SCA	*-0.35 (-0.30)*
SEJMCHAN - WP	*-0.37 (-0.29)*
FD	
VYTEGRA - EA	*-0.37* (-0.19)
SUNTAR - EA	*-0.38* (-0.11)
SUNTAR - POL	*0.35* (0.13)

(Fig. 2 and 3). To examine the role of linear trends, we removed the trends from original time series, and estimated correlations for de-trended time series. As expected, correlations for de-trended time series are generally lower than those for original time series (Table 2). It is important to note that correlations for de-trended GSL time series are only slightly smaller and remain statistically significant. In contrast, correlations for de-trended FD time series are very small and statistically insignificant. Thus, the trends revealed in time series of GSL and FD do indeed impact detected links to regional teleconnections, and this impact is stronger for FD time series.

Finally, we investigate links to SWE, which is the key characteristic of snow cover. To do this we examine correlations between GSL and FD indices at each station and gridded SWE field in northern Eurasia. As a general tendency, we note that for each station the largest correlations to SWE are detected (not shown) in the end of cold season, in March-April, when seasonal snow accumulation is the largest. This result is physically reasonable since anomalously large (small) snow cover at the end of cold season favors longer (shorter) winter season and thus, negative (positive) anomalies of GSL and opposite anomalies of FD. Another principal result is that correlations to SWE (especially in the nearby regions) are generally larger than above considered correlations to regional teleconnections. This implies relative importance of the local processes in interannual variability of GSL and FD in Russian sub-Arctic. As illustration in Fig. 4 we show some of the obtained correlation patterns. Rather high and significant negative correlations between GSL at Pechora station and SWE in April are revealed over extensive region of northern European Russia and western Siberia (Fig. 4a). As expected, the largest (reaching -0.6) correlations are detected in the area close to the station. Somewhat similar correlation pattern is obtained for GSL at Aleksandrovskoe (Fig. 4b), however, the correlations are generally larger and the region of largest correlations is more extensive. This might indicate increasing role of local interactions in more continental climate. Correlation pattern for FD at Arhangelsk reveals an extensive region of significant positive correlations over northern European Russia and northern part of western Siberia (Fig. 4c), which generally suggest that positive (negative) SWE anomalies result in increased (decreased) FD number. Very large (exceeding 0.7) positive correlations to SWE in northeastern part of Eurasia are also found for FD at Sejmchan station (Fig. 4d). We further examine links between de-trended time series of GSL, FD and SWE. As seen from Fig. 5, obtained correlation patterns differ significantly from respective patterns for original time series (Fig. 4). Correlations are not only significantly smaller (e.g. correlations between FD at Arhangelsk and SWE over northern part of western Siberia, Fig. 5c), but in many cases (regions) change sign. For example, large positive correlations between FD at Sejmchan and SWE detected in delta of the Ob river (Obskaya guba) and in Kolyma region (eastern Siberia, Fig. 4d), after de-trending change sign and become negative ones (Fig. 5d).

Thus, overall our results imply rather tight links between GSL and FD at Russian sub-Arctic stations and regional snow cover variations. These links, however, are

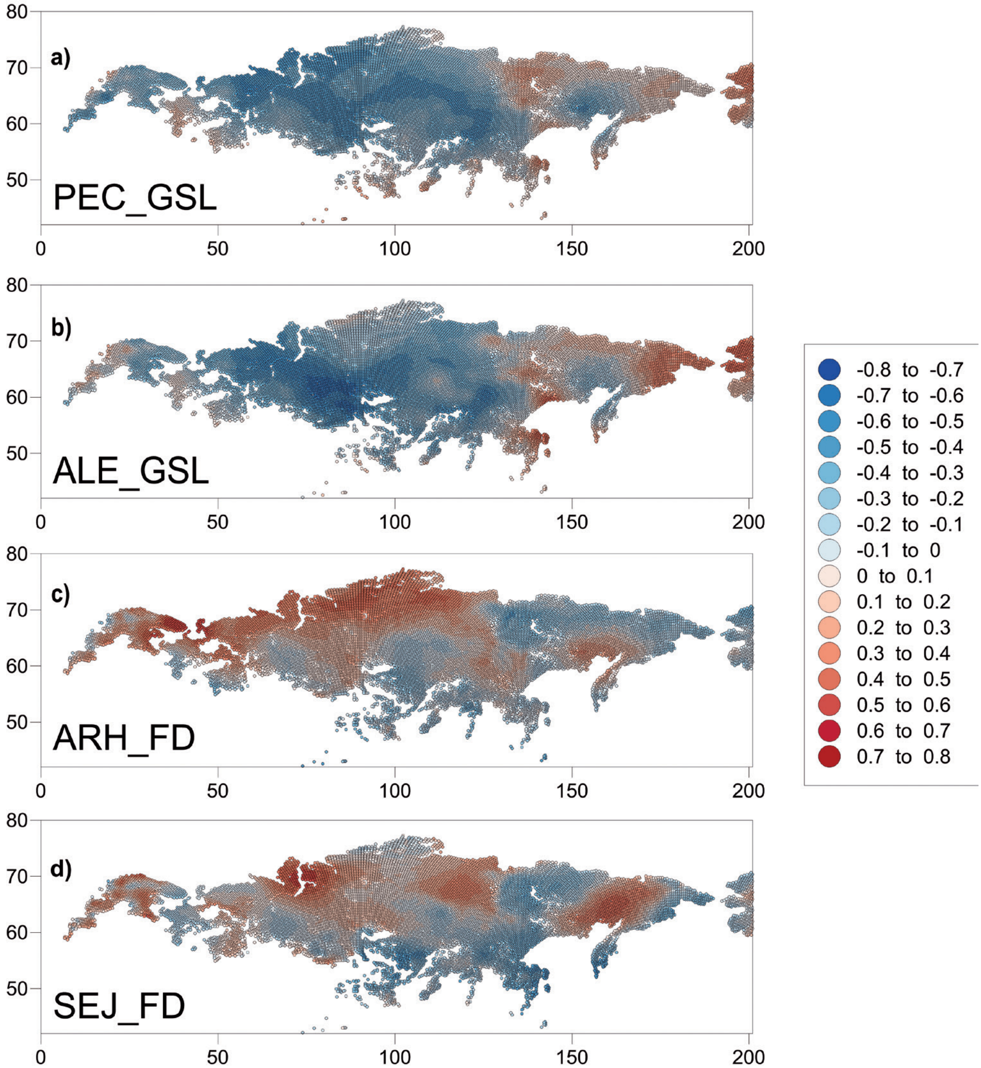

Fig. 4. Correlations between SWE in April and GSL at Pechora (a), GSL at Aleksandrovskoe (b), FD at Arhangelsk (c) and FD at Sejmchan (d). Red (blue) color indicates positive (negative) correlations

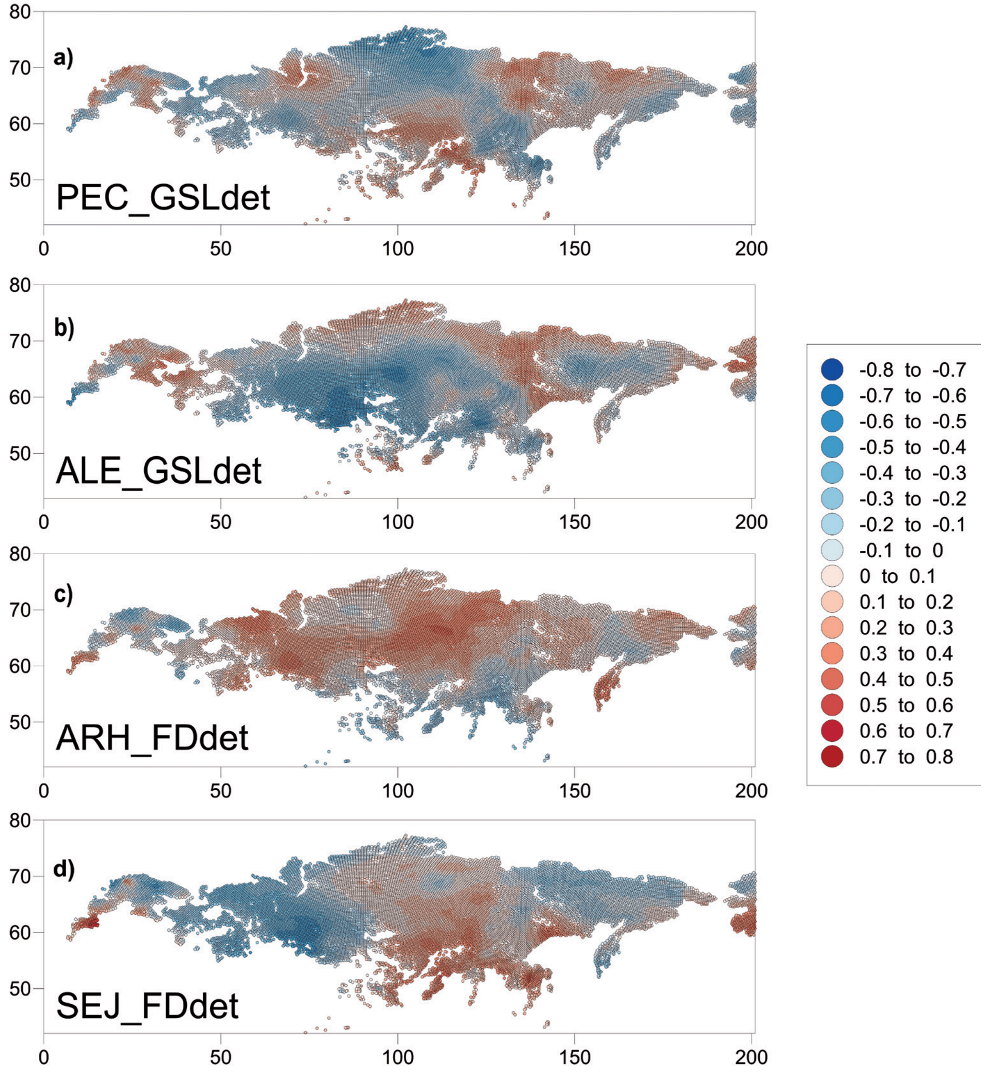

Fig. 5. Same as Fig. 4, but for de-trended time series

strongly impacted by linear trends revealed during recent decades. This is indeed indicative of differing character of interactions between considered parameters at different (i.e. interannual versus deacadal-interdecadal) time scales. Although impact of atmospheric dynamics (expressed by teleconnections) on GSL and FD is generally weaker (compared to snow cover), it should be stressed that it acts on the shorter (i.e. interannual) time scale while impact of snow cover is more pronounced at decadal-interdecadal time scales.

CONCLUSIONS

This study is an investigation of interannual variability of GSL and FD in Russian sub-Arctic in 1949-2013. We find significant upward and downward trends in GSL and FD respectively. Though these trends are broadly consistent with the global warming trend (e.g., Bindoff et al. 2013; IPCC 2013), it should be stressed that detected trends in GSL and FD are evident only since early 70-ties. Before that, at some stations even opposite trends can be observed. It is also important to emphasize that detected trends in GSL and

FD are stronger and more significant at western stations compared to easterly located stations.

Regarding interannual variability, we found rather moderate impact of the SCA teleconnection on GSL variability at Vytegra, and an impact of the WP teleconnection on GSL at Sejmchan station. During winter the EA teleconnection impacts FD variability at Vytegra and Suntar. Thus, GSL and FD variability at majority of considered stations (particularly in Siberia) is not significantly influenced by regional teleconnections (Barnston and Livezey 1987). Moreover, even significant correlations to teleconnections are impacted by linear trends. This impact is particularly strong for FD time series (Table 2).

We also explored links between GSL and FD variability at selected Russian sub-Arctic stations and snow cover (characterized by SWE) variations in northern Eurasia. While we leave in depth analysis of these links for the further study, it should be stressed that the present analysis reveals generally stronger links to SWE than that to teleconnections. As expected the largest correlations to SWE are detected in the areas around respective stations. Altogether these results imply that compared to large scale atmospheric dynamics (characterized by teleconnections) which impacts (in some regions) GSL and FD on interannual time scale, snow cover formed by winter synoptic activity, plays a more important role in longer-term (i.e., decadal-interdecadal) variability of GSL and FD in Russian sub-Arctic. Both links to regional teleconnections and links to SWE are greatly impacted by detected linear trends. In this regard, a detailed analysis of such links at different time scales is needed, and will be undertaken in our further studies.

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