nature climate change

SUPPLEMENTARY INFORMATION

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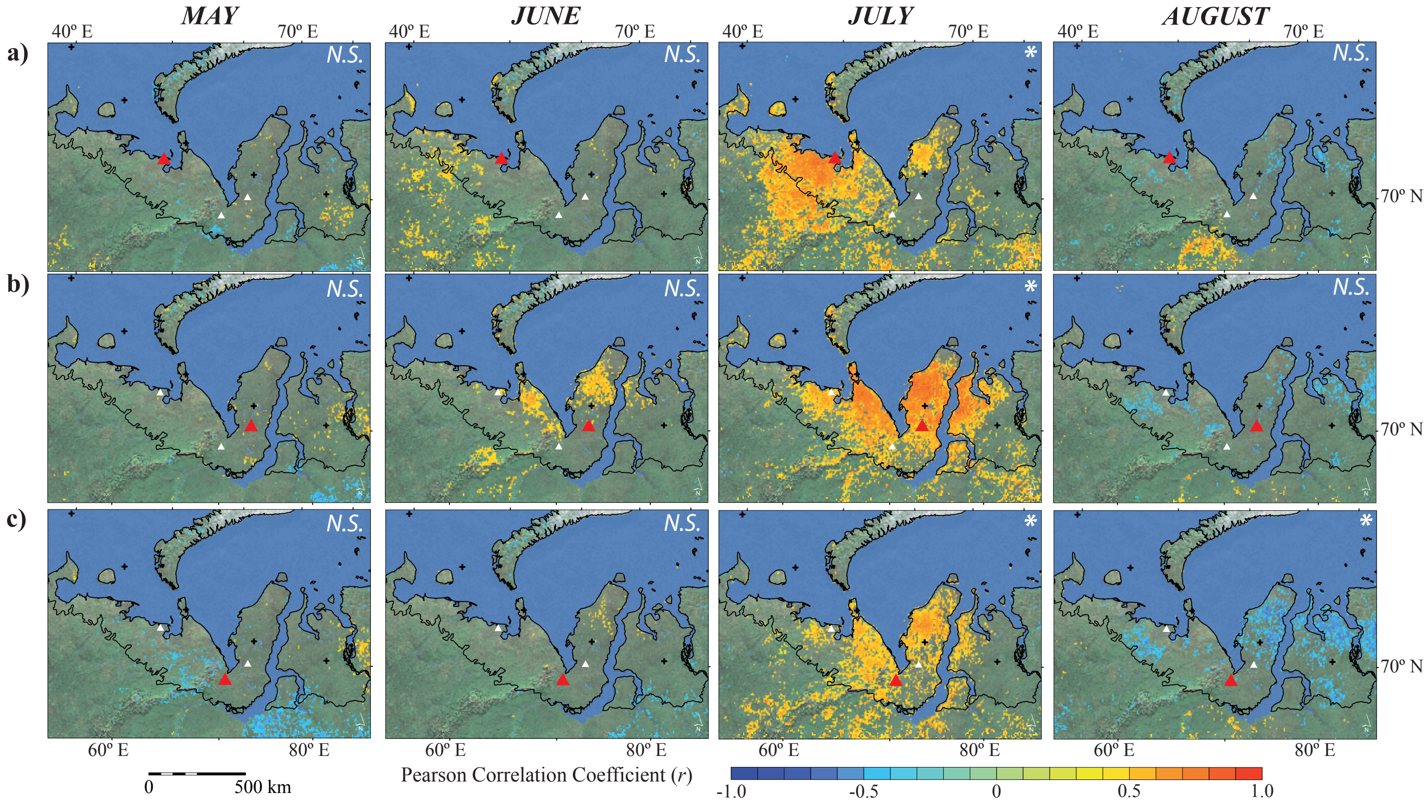
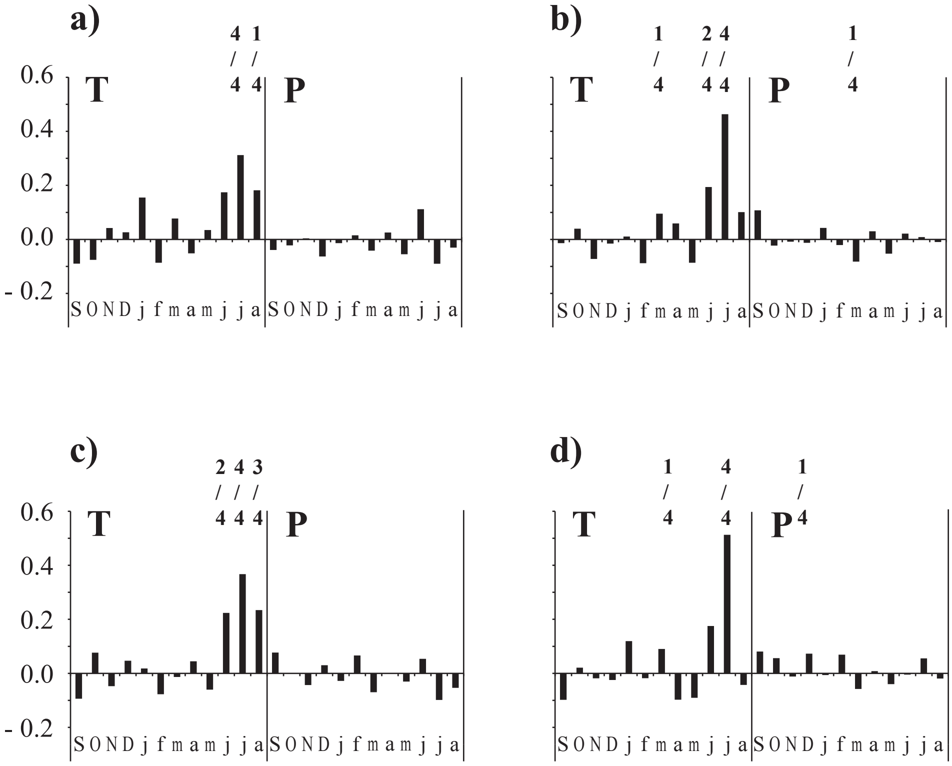
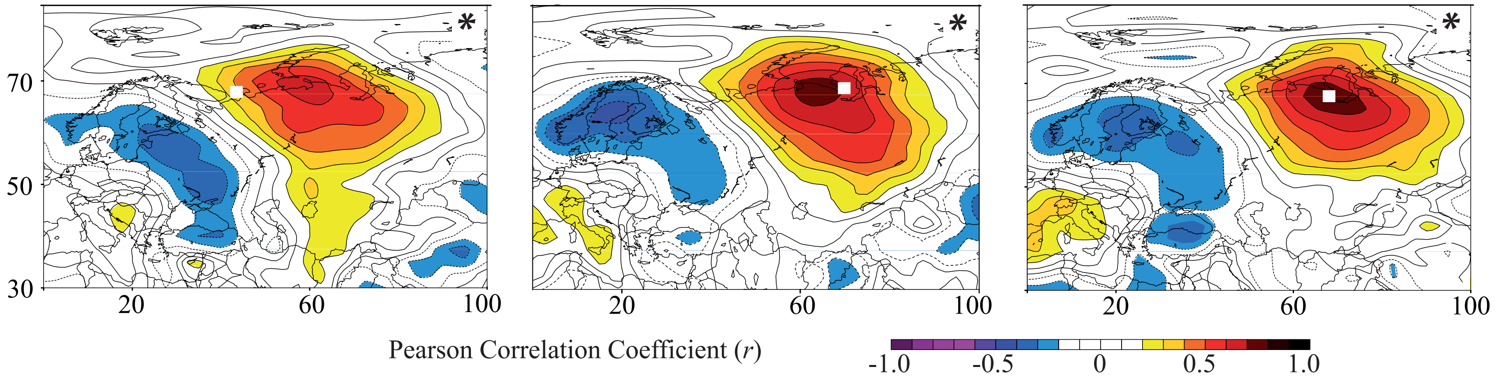
Eurasian Arctic greening reveals teleconnections and the potential for structurally novel ecosystems



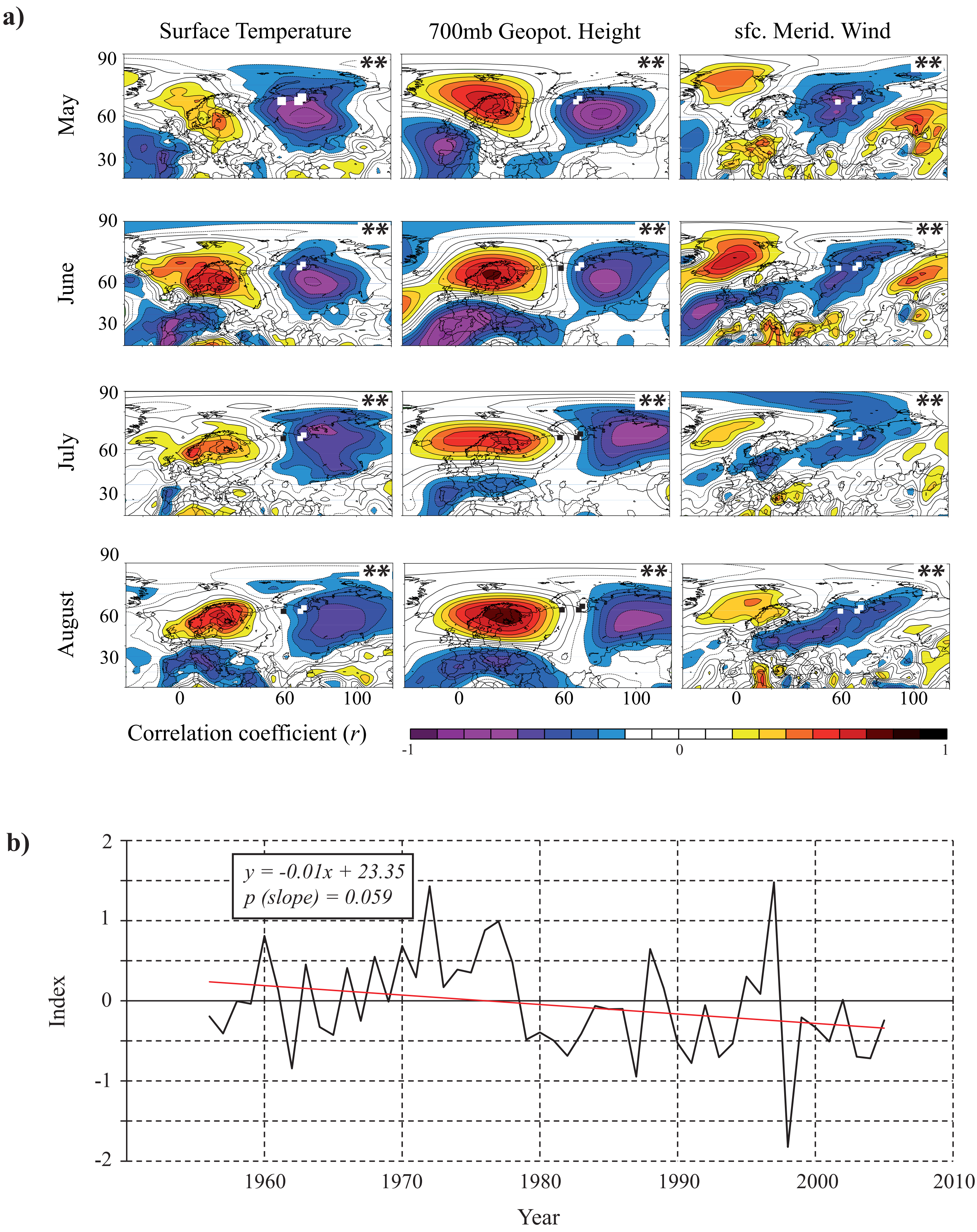
Supplementary Figure 1. Monthly Pearson correlation coefficients (*r*) between NDVI[11] and shrub ring-width chronologies. Sites are depicted as filled triangles. Large red triangle shows the location of the site of chronology used in each computation. Period is 1982-2005, for which there is NDVI data. **a)** Varandei (*Salix lanata*); *b)* Yuribei River (*Salix lanata*); **c)** Laborovaya (*Alnus fruticosa*). Only significant ($p<0.05$) correlations are shown. Field significance, accounting for multiplicity[36], is shown in the upper part of each panel as: *: $p < 0.05$; N.S.: non-significant. Note the short period over which correlations are widespread (July). Biweekly correlations, not shown in here for brevity, show even higher values for the second half of June and the first half of July. Note as well that the correlation between *Alnus* ring-width chronology in Laborovaya and distant highly productive areas to the north and west is higher than that to proximal sandy low-productivity areas to the east.



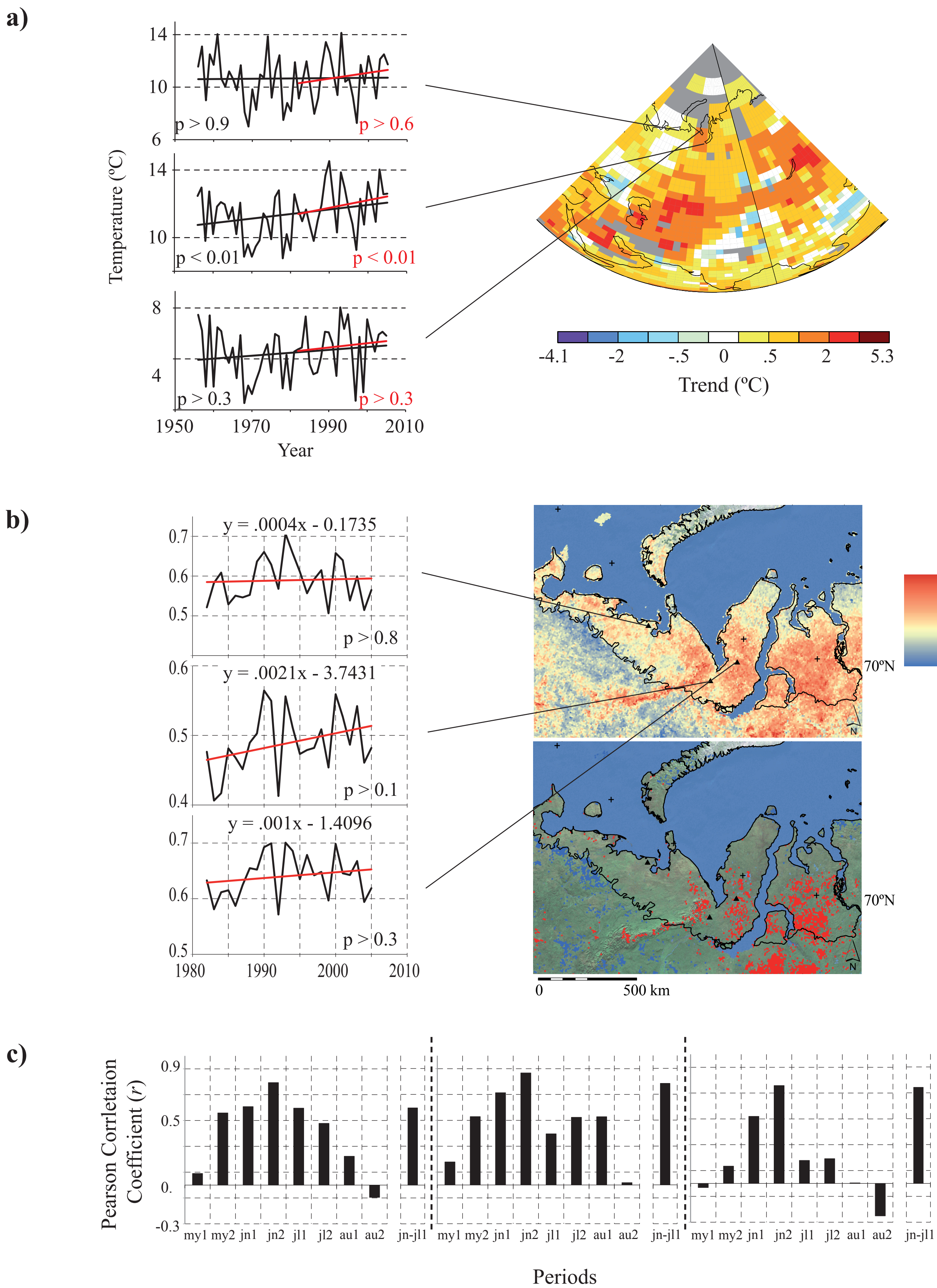
Supplementary Figure 2. Averaged response function coefficients for residual ring width chronology *vs.* monthly temperature (left, **T**) and precipitation (right, **P**) over four meteorological stations within distances up to 400 km for: **a)** Varandei (*Salix lanata*); **b)** Yuribei River (*Salix lanata*); **c)** Laborovaya (*Salix lanata*); **d)** Laborovaya (*Alnus fruticosa*). Response function coefficients calculated separately for each meteorological station (not shown) resulted in the same overall pattern. Analyses were performed from September of the year prior to the growing season to August of the growing season year for the period 1961–2005 for which there is available **T** and **P** monthly meteorological data. Months abbreviated with capital letters correspond to the year previous to the growing season. Positive (negative) coefficients indicate positive (negative) ring-width *vs.* climate relationships. Fractions in the upper part of the plot indicate the number of times the response coefficients were found significant ($P<0.05$); for example, 4/4 in July T means that the relationship between ring-width and July T was found significant when analyzed against four out of the four climate records used. No fraction is displayed when no significant coefficients were found.



Supplementary Figure 3. Pearson correlation coefficients between surface gridded temperatures from the Reanalysis project[33] and ring-width chronologies. Correlations are computed between chronologies and the growing season period for which significant response function coefficients were found. That is, from left to right, July-August (Varandei, *Salix lanata*), June-July (Yuribei, *Salix lanata*), and July (Laborovaya, *Alnus fruticosa*). Site locations are shown as white filled squares. Only significant ($p<0.05$) correlations are shown. Field significance, accounting for multiplicity[36], is shown in the upper part of each panel as: *: $p < 0.05$.

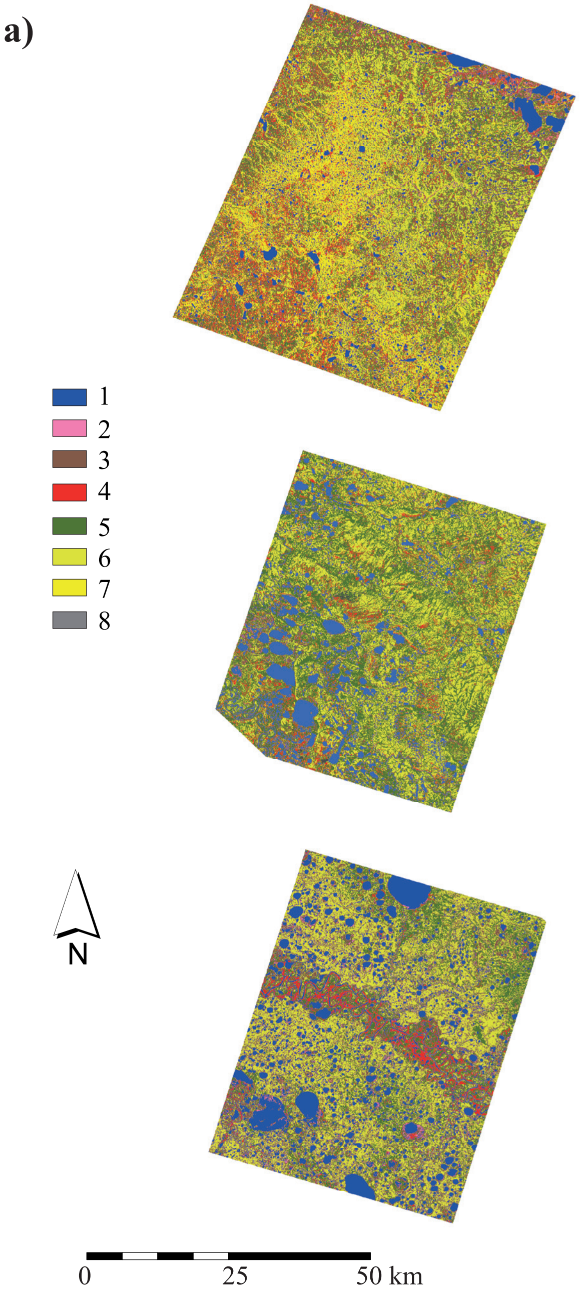


Supplementary Figure 4. a) Monthly Pearson correlation coefficient between the Scandinavian Index and Surface Temperature (**left column**), 700 mb geopotential height (**centre column**), and surface meridional wind (**right column**) for May, June, July, and August. The position of the study sites is shown as filled squares. Field significance, accounting for multiplicity[36], is shown in the upper part of each panel as: **: $p < 0.01$. Note that a negative summer Scandinavian Index enhances warm air advection onto **NWET** due to the position persistent mid-tropospheric air masses, which implies warmer temperatures. **b)** Yearly time series of summer (defined as June to July average) Scandinavian Index. Red line depicts a linear regression performed to the time series. Inset box shows the linear regression equation and the p-value associated with the slope of the regression. Note a generalized negative trend for the summer Scandinavian Index during the study period.



Supplementary Figure 5. a) Left: Yearly June to August mean temperature for Naryan Mar (**upper**), Salekhard (**middle**) and Marre Sale (**lower**), each being the closest meteorological station to each of the study sites with available long term records. Period 1956-2005 (i.e. common length of the shurb ring-width chronologies). Linear trends for the whole period (**black**) and for the period with available NDVI data (i.e. 1982-2005; **red**) are shown. Significance of the slope coefficient is also depicted. **Right:** Spatially explicit mean temperature trends for the same period and season, obtained from GISS Surface Temperature Analysis of the NASA (http://data.giss.nasa.gov/gistemp/). Note a summer temperature increase of 1-2ºC over 50 years in southern and central Yamal, and 0.2º-1ºC west of the Ural mountains. **b) Left:** Yearly June to August NDVI averaged over an area 50 km * 50 km centred over each of the three study sites (**Supplementary Figure 6**), for Varandei (**upper**), Laborovaya (**middle**) and Yuribei River (**lower**). Period 1982-2005. **Right:** spatially explicit linear trends of NDVI for the same period (**upper**). Only significantly positive (**red**) and negative (**blue**) trends are shown in the **lower** picture. Note the overall greening pattern, albeit mostly significant in the eastern part of **NWET**, in agreement with overall temperature patterns in the area. **c)** Pearson correlation coefficient between monthly temperature and 15-day NDVI averages for an area 50 km * 50 km centred over each of the three study sites, for Varandei (**left**), Laborovaya (**middle**) and Yuribei River (**right**). Note that the peak of correlation occurs in the second half of June, and that the correlation between the temperature of June and the NDVI of the first half of July is generally very high.

a)



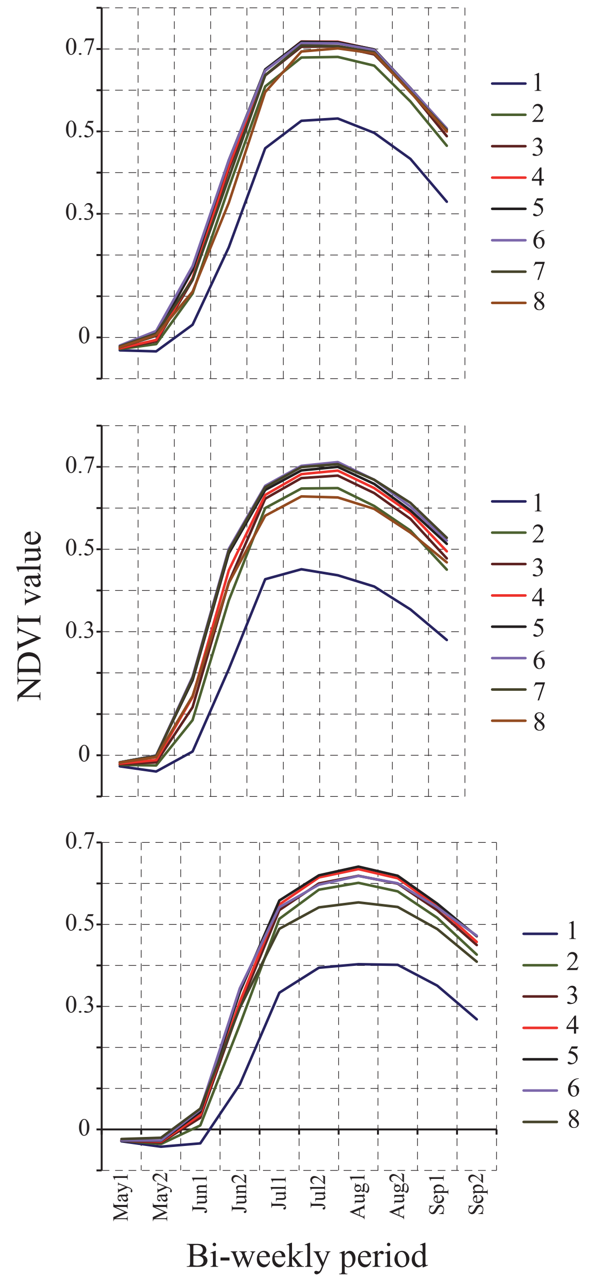
b)

	1	2	3	4	5	6	7	8
1	1.000							
2	0.928	1.000						
3	0.874	0.991	1.000					
4	0.876	0.989	0.997	1.000				
5	0.869	0.985	0.992	0.990	1.000			
6	0.829	0.959	0.972	0.970	0.992	1.000		
7	0.860	0.962	0.962	0.966	0.984	0.987	1.000	
8	0.782	0.880	0.884	0.891	0.920	0.937	0.968	1.000

	1	2	3	4	5	6	7	8
1	1.000							
2	0.896	1.000						
3	0.792	0.977	1.000					
4	0.713	0.940	0.990	1.000				
5	0.523	0.802	0.902	0.951	1.000			
6	0.491	0.775	0.881	0.936	0.999	1.000		
7	0.496	0.789	0.891	0.941	0.988	0.989	1.000	
8	0.697	0.883	0.932	0.948	0.935	0.923	0.935	1.000

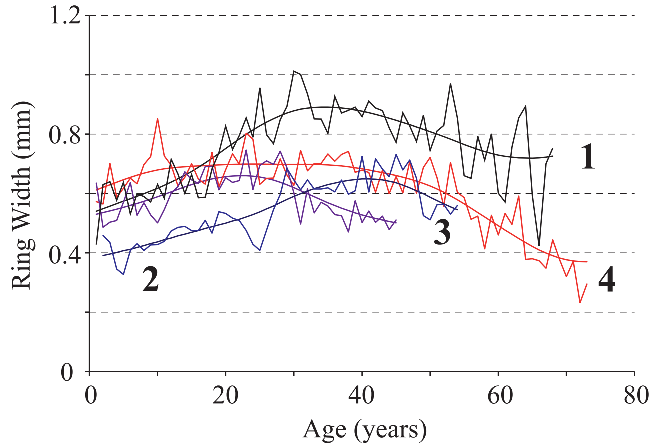
	1	2	3	4	5	6	8
1	1.000						
2	0.866	1.000					
3	0.797	0.986	1.000				
4	0.774	0.980	0.999	1.000			
5	0.747	0.969	0.996	0.999	1.000		
6	0.715	0.953	0.990	0.994	0.998	1.000	
8	0.836	0.979	0.990	0.986	0.980	0.973	1.000

c)

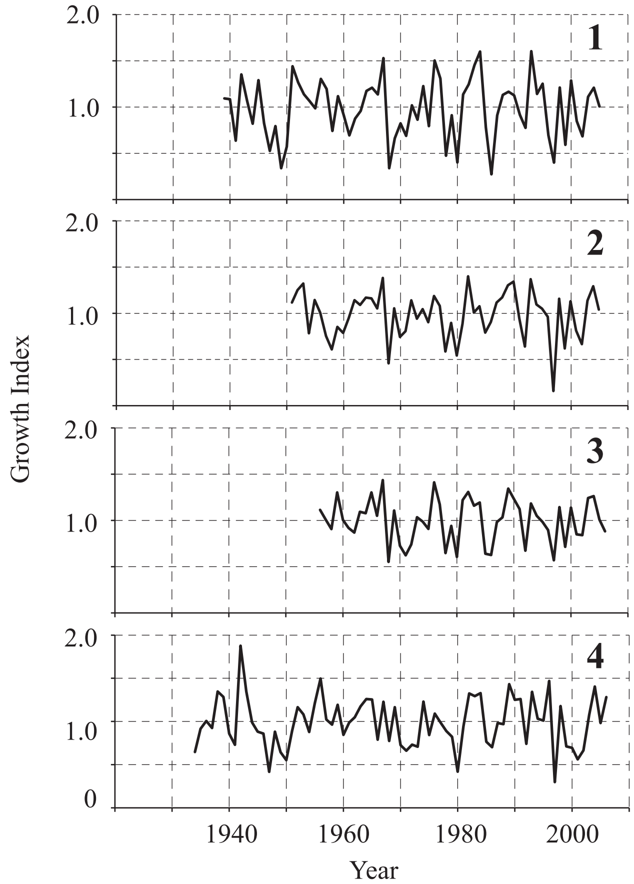


Supplementary Figure 6. a) Land cover classification of a 50 km x 50 km area around Varandei (**upper**), Laborovaya (**middle**) and Yuribei River (**lower**), based on MODIS 30 m resolution imagery and intensive ground truthing. **1**: water, **2**: wet peatland, **3**: peatland with mixed *Salix* and *Betula*, **4**: tall shrubs (*Salix*, plus *Alnus* in Laborovaya), **5**: dwarf shrubs, moist biotope, **6**: dwarf shrubs, dry biotope (*Empetrum* and *Betula*), **7**: Dwarf shrubs, dry biotope, undetermined, **8**: Barren. **b)** Pearson correlation tables between yearly time-integrated NDVI (defined as the sum of biweekly values above 0.05 from May to September) time series for each land cover class. Time period: 2000-2010. Note the overall high correlations among all land cover types, except for water. Numbers are described in **a)**. **c)** Seasonal biweekly NDVI values for each study region (as in **a)**). Numbers are described in **a)**. Note the high and overall similar NDVI values for dwarf and tall shrubs.

a)



b)



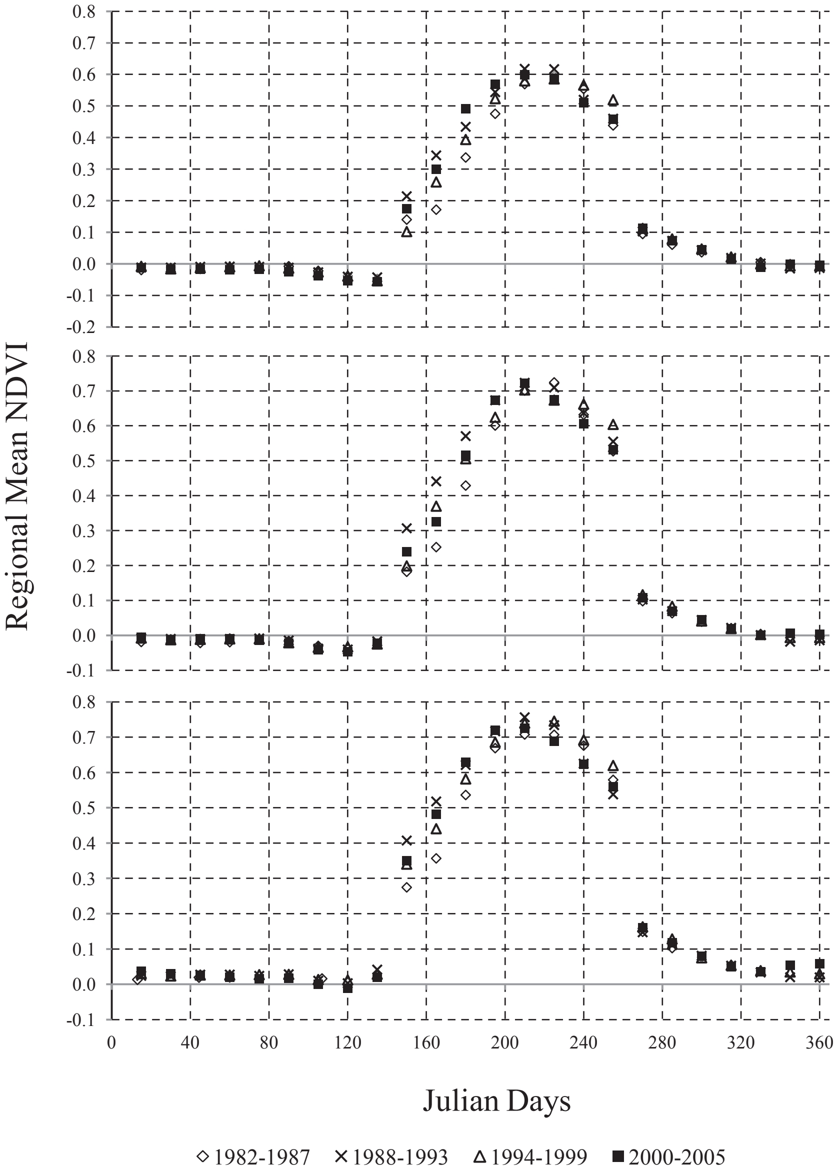
c)

	1	2	3	4
1	1			
2	0.739	1		
3	0.598	0.661	1	
4	0.632	0.754	0.701	1

	1	2	3	4
1	1			
2	0.826	1		
3	0.639	0.734	1	
4	0.743	0.774	0.701	1

Supplementary Figure 7. a) Average absolute growth age-dependent measurements (mm) for Varandei (*Salix lanata*, **1**); Yuribei River (*Salix lanata*, **2**); Laborovaya (*Salix lanata*, **3**); and Laborovaya (*Alnus fruticosa*, **4**). Note the higher average growth of *Salix lanata* in Varandei than in Laborovaya. **b)** Standard chronologies for **1**, **2**, **3**, and **4**. **c)** Cross-correlations between chronologies for residual (**upper**) and standard (**lower**) chronologies. Note the high inter-series correlations.

a)



b)

	Pooled NDVI n=48 StdDev	***Pooled temperature n=24 StdDev***
May-June	0.0667	1.8546
September	0.0356	1.7107
p (T-Test)	0.0009	0.5523

Supplementary Figure 8. a) Interannual changes in seasonality of NDVI, averaged from an area ~ 250 km^2 centred around Varandei (**upper**), Yuribei River (**middle**) and Laborovaya (**lower**), for successive 6-year periods from 1982 to 2005. Note the high variability in NDVI values at the beginning of the growing season and the synchronous and sharp NDVI drop marking the start of leave senescence by mid-September. **b)** Pooled standard deviation of NDVI (measured from the three study areas) and temperature (taken from the three closest meteorological stations to the study sites, i.e. Naryan-Mar for Varandei, Salekhard for Laborovaya, and Marre-Sale for Yuribei) for the periods comprising the start of the growing season (May and June) and the end of the growing season (September), as defined by the NDVI patterns shown in **a)**. The two-tailed *p-value* associated with a Student's t-test between the two periods for both NDVI and temperature is shown in the lower row. Note that the much higher variability of NDVI at the start than at the end of the growing season is not matched by the pattern in temperature.

RAW DATA

	Time span	nc(ns)	rg(SD)	t(SD)	r
1	1921-2005	117(39)	0.756 (0.160)	52 (13)	0.745
2	1911-2009	81 (27)	0.479 (0.149)	60 (14)	0.616
3	1934-2006	87 (29)	0.541 (0.105)	47 (13)	0.575
4	1896-2006	72 (24)	0.578 (0.150)	61 (17)	0.672

STANDARD CHRONOLOGY

	MS	SD	r1	EPS > 85% since	EPS 1956-2005 (Minimum Common Period)
1	0.414	0.359	0.049	1939	0.98
2	0.341	0.294	0.019	1951	0.94
3	0.272	0.234	0.029	1956	0.93
4	0.372	0.33	0.049	1934	0.95

RESIDUAL CHRONOLOGY

	MS	SD
1	0.366	0.324
2	0.325	0.27
3	0.267	0.215
4	0.366	0.308

Supplementary Table 1. Ring-width chronology statistics for **1)** Varandei (*Salix lanata*); **2)** Yuribei River (*Salix lanata*); **3)** Laborovaya (*Salix lanata*); and **4)** Laborovaya (*Alnus fruticosa*). **EPS**, Expressed Population Signal; **nc**, number of cores; **ns**, number of shrub individuals; **rg**, mean radial growth (mm); **SD**, standard deviation; **t**, mean series length (years); **r**, mean correlation between individual and mean chronology; **MS**, mean sensitivity; **r1**, first-order autocorrelation. Note the high quality of the chronologies as measured by EPS over the common period 1956-2005.