## **Supplementary Material for**

Panyushkina, I. P., Shishov, V. V., Grachev, A. M., Knorre, A. A., Kirdyanov, A. V., Leavitt, S. W., Vaganov, E. A., Chebykin, E. P., Zhuchenko, N. A., Hughes, M. K., 2016. Trends in elemental concentrations of tree rings from the Siberian Arctic. *Tree-Ring Research* 72:67–77.

Fig. S1. Schematic diagram describing methodological approach used in this study to detect the changes in variance behavior of normalized element concentrations measured in tree rings.

A) Sampled trees and their overlaps: line represents a span of a wood specimen from sampled tree, and shaded area shows the tree sapwood (*ca.* 20-25 outer rings with functioning vascular tissue) that is present in two tree groups around the 1890s and 1990s.

B) Measured element concentrations: subsampled tree rings with 5-year or 10-year groups (grey blocks marked as T1, T2, T3, T4, T5) from available trees (horizontal rows of grey blocks) for which 26 different element concentrations were measured. Overall, we measured 351 concentration values of each studied element from the tree samples as shown in this example for Ca and K concentrations.

C) Normalization of element concentration measurements: the raw element measurements of each tree-ring series were normalized to their mean and standard deviation (Z-score). Then their Z-scores were averaged for corresponding time intervals. The normalized time series were considered for further statistical analysis.

D) Cluster analysis: 26 averaged Z-score element series were categorized with cross-correlation into clusters. The Methods describes details of the cluster analysis.

E) Principal Component analysis: element time series pooled by the clusters were further classified with factor analysis. The PCA identified 2-4 principal components for each cluster.



**Fig. S2**. Raw measurements of element concentrations of tree rings from 1300 to 2000. The plot line is the average of measurements from different wood samples, and error bars show two standard deviations of the average values. X-axis is element concentration in ppb ( $\mu$ g/kg) referenced to the mass of initially dry wood sample prior to adding acid treatment. The chemical concentrations of Li, B, Na, Mg, Al, Si, P, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Rb, Sr, Zr, Ag, Cd, Sn, I, Ba, Pb and Bi were measured on an Agilent 7500 quadrupole Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Detailed description of analytical methods used for the element concentration measurement and value calibration was published in Grachev *et al.* (2013). Notice that statistical analysis of element concentration variance was performed with normalized time series - Z-scores of element concentrations.





**Fig. S3**. Examination of pathways for SO<sub>2</sub> transport from the Norilsk Nickel complex (star) into the studied area (triangle) simulated with Dispersal HYSPLIT 4.8 model (Draxler RR and Rolph GD 2013 HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website <a href="http://ready.arl.noaa.gov/HYSPLIT.php">http://ready.arl.noaa.gov/HYSPLIT.php</a> NOAA Air Resources Lab Silver Spring MD). Example of concentration (A) and deposition (B) of daily sulfur dioxide emission along a 48-hour dispersal pathway as calculated for May 13, 1991. Annual value of SO<sub>2</sub> emission in 1991 was 2397 thousand tons, which is *ca*. 6 million kg day<sup>-1</sup> on average (EPR 2010). The tallest smelting smokestack in 1991was 300 m. Norilsk elevation is about 180 m a.s.l. Note that the background concentration of SO<sub>2</sub> in the Russian Arctic is on average 1 μg m<sup>-3</sup> (AMAP 2006). The modeled daily concentration in the Russian Arctic. The modeling indicates a 12-hour transport of emissions to the studied site, on average.





**Fig. S4.** Tree-ring width chronology of larch from the Taymyr region (Naurzbaev and Vaganov 2000) that includes the tree specimens from this study as well. Variability of the tree-ring indices corresponds to June and July temperature. Red dotted line shows mean June –July temperature observations from Khatanga weather station for the interval 1934-2000. Thick black line is a 20-year low-pass filter average of tree-ring indices. The plot shows the reduced tree-ring width growth during the Little Ice Age and the increased growth since mid-1850 prompted by the Common Era warming.



## **REFERENCES CITED**

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- A. A. Knorre, M. K. Hughes, and M. M. Naurzbaev, 2013. Methodology for development of a 600-year treering multi-element record for larch from the Taymyr Peninsula, Russia. *Journal of Siberian Federal University-Biology* 5(1):61–72.
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