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New stable isotope and dendrochronological studies of the 1000 years pine (*Pinus sylvestris L.*) tree-ring chronology at the upper timberline in the Khibiny Low Mountains, Kola Peninsula, North-Western Russia

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Introduction

A millennium-long (1138 years) tree-ring chronology for the central part of Kola Peninsula, first presented in this paper, is a result of continuing our dendroclimatological investigations on Kola Peninsula (Hiller et al., 2001; Boettger et al., 2002, 2003a, 2003b). Climatic influence on growth of trees (tree-ring width, wood density, stable isotope) in this area is high due to the geographical position of Khibiny Mountains. Pines exist there at the northern latitudinal boundary of their range, also limited by the mountain relief in the altitudinal distribution. The presented tree-ring chronology is the longest for Kola Peninsula and unique for Khibiny Mountains.

Study areas

Khibiny low mountains are located in the central part of Kola Peninsula, 150 km North of Polar Circle and at an elevation as high as 1100-1200 m a.s.l.

The climate refers to the cold-temperate type with strong Arctic and Atlantic oceans impact, resulting in long, moderately cold winters and cool, wet summers. The modern mean January temperature at the south-western margin of the Khibiny Mountains is about - 12ºC, while the mean July temperature is +13º C. Vegetative season lasts from May to September (60 - 80 days). The annual precipitation reaches 450 mm, 75-120 mm of which fall in the cold season within the study area (Jakovlev, 1961).

The Khibiny foothills are covered by northern taiga vegetation (spruce, pine and birch dominate). Forests grow up to 300-450 m a.s.l. depending on the slope exposure.

Geographical location of Khibiny Mountains makes a significant climatic effect on wood growth. On one hand, pines growing here are located near the northern latitudinal boundary of their distribution range, on the other hand, the mountain relief of Khibiny Mountains constitutes an altitudinal limitation for their growth.

Material

The collection of wood for constructing tree-ring chronologies consists mainly of Scots pine (*Pinus sylvestris* L.) samples. In total, 259 wood samples have been obtained, but only 19 of them refer to spruce (*Picea abies* L). Samples were taken at different altitudes as well as along the perimeter of Khibiny mountains where pine forests grew in the past (Fig. 1). Only at site 1 and 2 we collected spruce wood due to the absence of pines there.

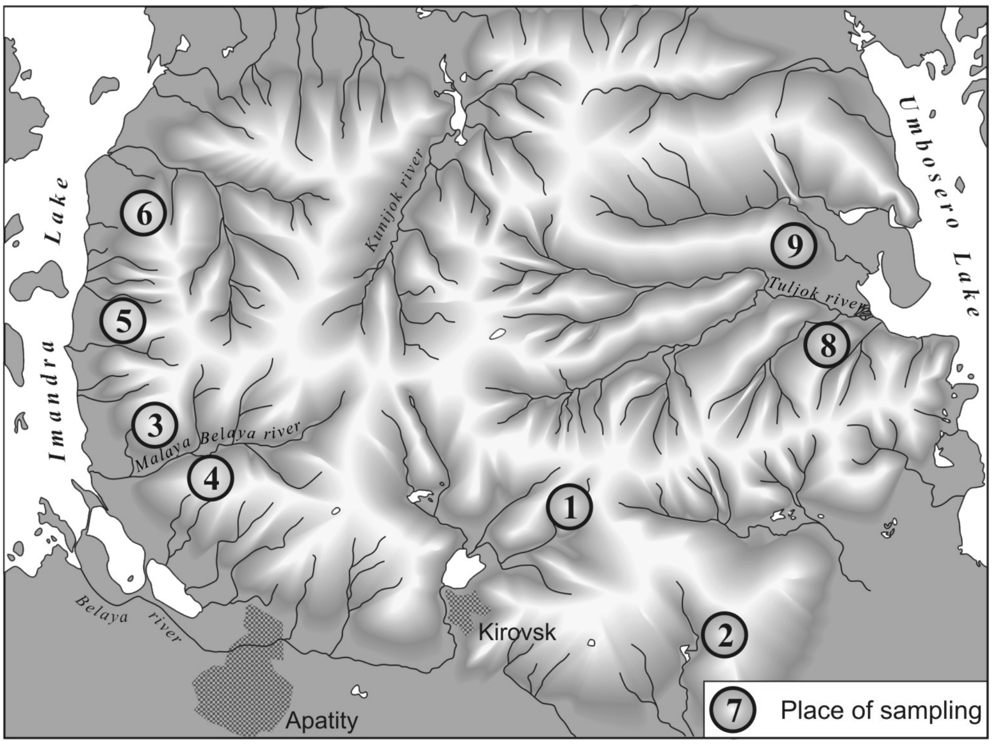

Figure 1: Map of Khibiny Mountains, showing the sampling sites.

Living trees

Three (minimum two) cores were taken from each living tree in different directions. The sample sites embraced foothills up to the upper timberline and were collected at 50 m altitudinal interval. Not less than 10-15 trees were studied in each location.

Dead trees

The samples from dead trees were taken in form of discs. Wood remains were found at an elevation of 250-450 m a.s.l. It is noteworthy that 49 samples were obtained from dead trees, found at an elevation of 100 -140 m above the present tree line.

Results and discussion

Construction of the chronology

All samples were exposed to a preliminary preparation in the laboratory. Cores from living trees were prepared using a razor along the horizontal axis of the trunk. Slabs from dead trees we cleaned by razor for three or four radii. We measured tree-ring widths to the nearest

0.01 mm, and the data were stored in computer files using TSAP standard tree-ring measurement software system. Obtained data were used for graphs of absolute tree-ring growth of every radius for each sample. Then all tree radii were averaged to produce an individual chronology for each sample. The next step was cross-dating of individual chronologies (Briffa *at al*., 1990). To remove the age trend that can obscure the climatic influences on tree-ring growth, a special method known as standardization or indication of absolutely dated chronologies was used (Cook *at al*., 1990). As a result a tree-ring chronology more than 1000 years long has been constructed (fig. 2).

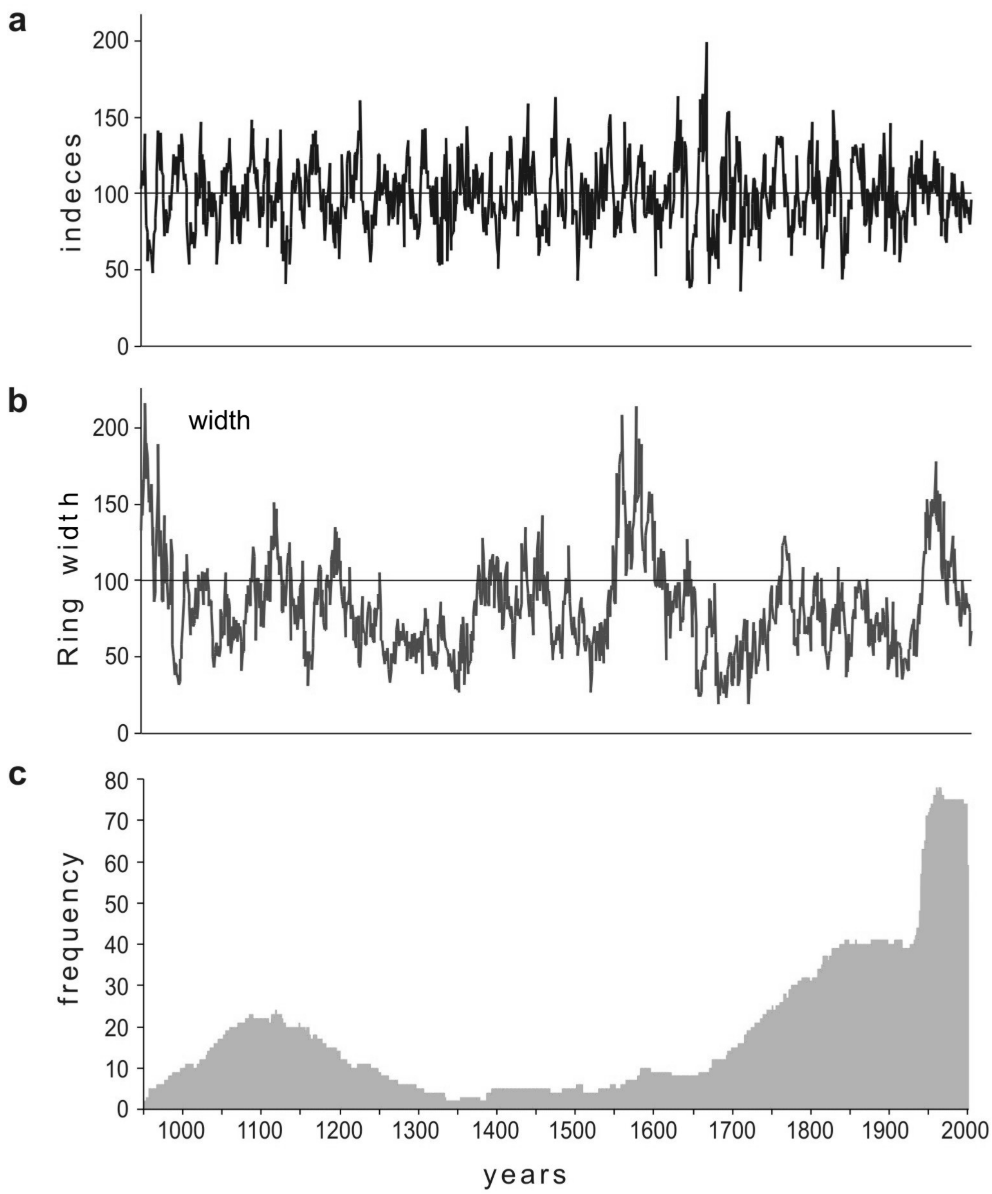

Figure 2: Tree-ring chronology for Khibiny Mountains. (a) Standardized data, (b) raw data, (c) sample depth.

Radiocarbon dating

The dendrochronological dating was supported by ^{14}C dating of selected wood fragments (Hiller et al., 2001). All the data are given in conventional ^{14}C years BP. Quoted errors (1s) include uncertainties in conventional ^{14}C dates and were calibrated using the INTCAL 98 calibration program (Stuiver at al., 1998). According to determinations, ^{14}C dates well correspond to the dendrochronological dating, though some samples lay out of the ideal position (fig. 3).

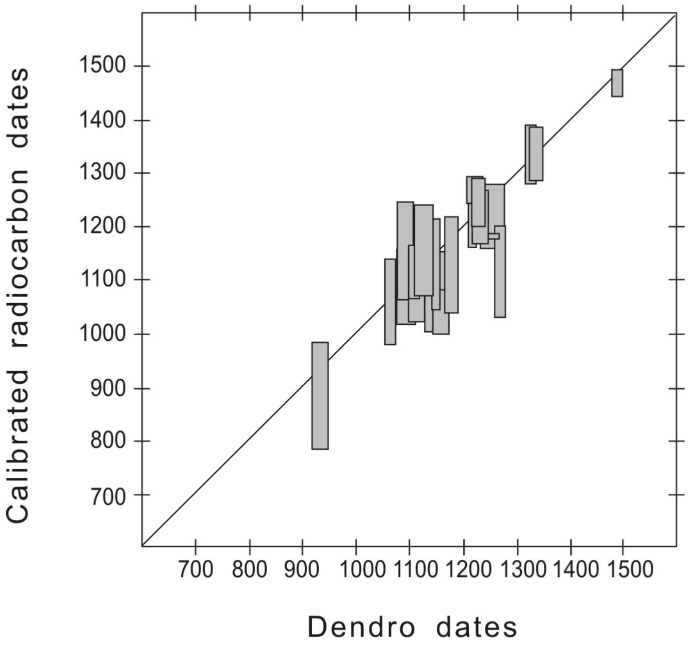

Figure 3: Comparison of dendrochronological age and corresponding calibrated ^{14}C age of the samples. Each box represents one sample. The width represents the number of rings in the sample, and the height represents the radiocarbon date of the sample.

Stable isotopes

10 increment cores of living pines were measured for stable isotope composition of carbon and oxygen in cellulose of their tree rings with annual resolution. The mean $\delta^{13}C$ values from three cores of young pine trees (where climatic signal is most pronounced) correlate significantly with the average temperatures of July and August (r= 0.71). Carbon isotopes and ring-width seem to have quite similar climatic information for this site (Fig. 4a,b). Much less pronounced correlation was found between the $\delta^{13}C$ values and the precipitation sums for summer months.

The carbon and oxygen isotope values from both living and fossil trees correlated positively with each other (r=0.78; n=93). Probably, the isotope ratios in the period of wood formation depend on varying humidity conditions (Saurer et al., 1997). Short summer in Khibiny is characterized by relatively low humidity.

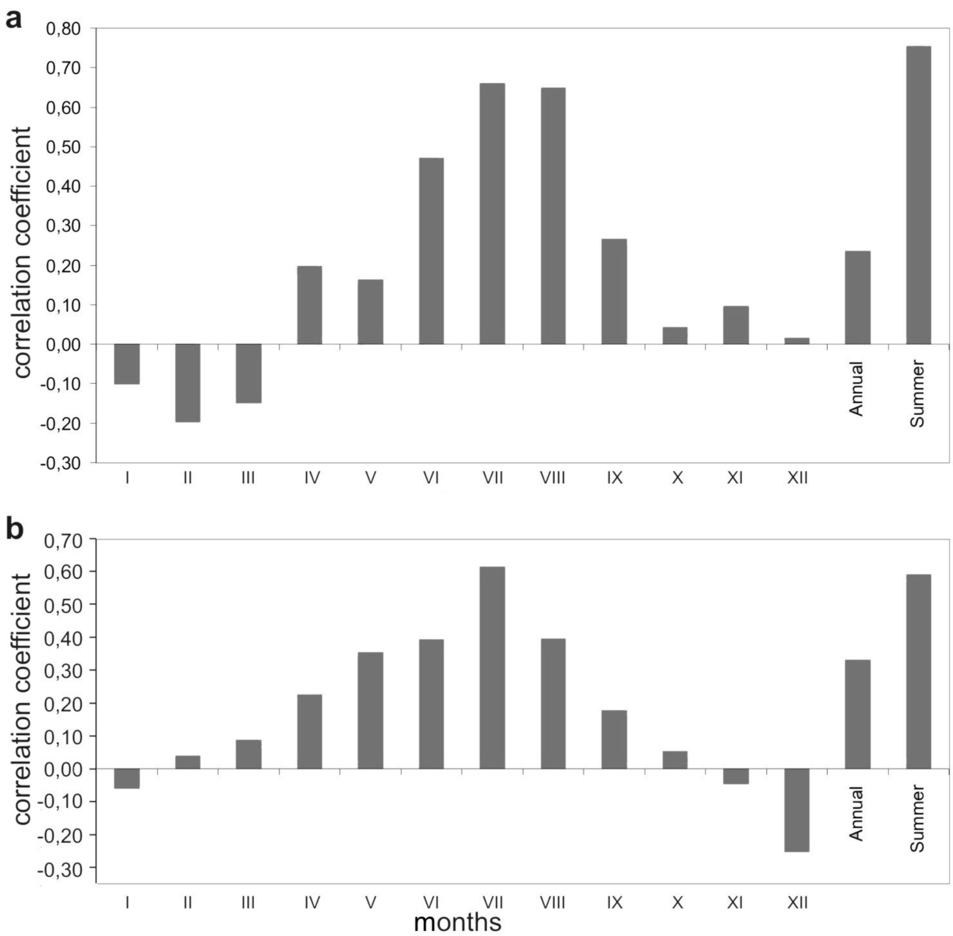

Figure 4: Relationship between air temperature and carbon isotopic composition (a) and tree-ring width (b)

Our results show that tree-ring width could increase and reduce within approximately 50 years. Only during 17th and first half of 18th centuries (about 150 years) the tree-ring growth was lower than its average value for the whole millennium. This longest period of tree "mortality" and low tree-ring growth rate can be identified as a main phase of Little Ice Age (LIA) in the study area. A considerable increase of tree-ring width occurred in the end of 9th and first decades of 10th centuries, the time interval can be attributed to the beginning of Medieval Warm Period (MWP). During the subsequent periods some oscillations of tree growth rate lasting several decades were recognized.

However, some insight into the MWP duration can be derived from the data about fluctuations of the tree-line in the given region. Samples of wood, discovered above the contemporary tree-line, serve as related proxies (Fig. 5). The highest location of this group of samples was 140 m higher than the modern pine-tree-line. This means that at that time the upper timber line was at least 140 m higher than now.

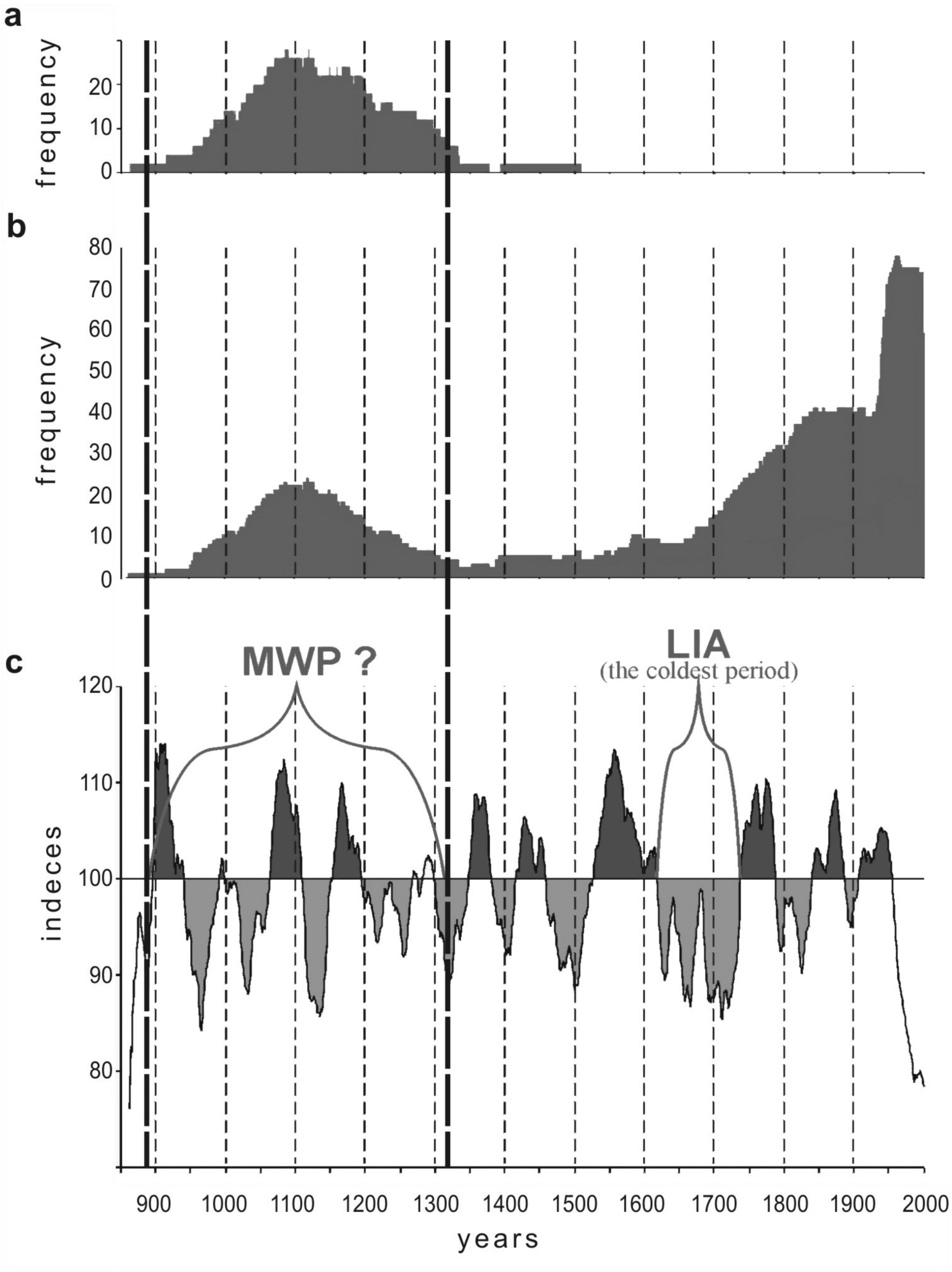

Figure 5: (a) Sample depth of samples above modern tree-line. (b) The same for all samples. (c) annual ring-width variability filtered with 50-year running mean.

Dendrochronological dating of the samples showed that they had grown there mainly from the end of 9th to the middle of 14th centuries that corresponds to the general assumption about timing of the MWP.

Important feature of the presented tree-ring chronology is a strongly pronounced trend to reduced tree-ring growth in the second part of the 20th century, characterized by the so called modern global warming. Furthermore, instrumental records from weather stations in Khibiny foothills with a long period of observation (from 1924) suggest a tendency to cooling since the end of 1930s.

Conclusions

(1) The presented tree-ring chronology for Khibiny Mountains enables us to conclude that dynamics of carbon isotope content and tree-ring growth correlate with climate changes.
(2) Climatic changes during the last millennium, influencing annual tree-ring growth, are identified as short-term (decadal scale) oscillations.
(3) The main chronological subdivisions of Late Holocene in Khibiny area had specific regional features being rather smoothly pronounced in contrast to Central Europe.

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