CLIMATE AND ENVIRONMENTAL CHANGES RECONSTRUCTED FROM TREE RINGS AND CAVE ICE

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ELTE TTK, FFI; MTA GKKI
2010

1. Introduction, Scopes

As instrumental meteorological series are available only for a relatively short time it makes difficult to study the long-term fluctuation of the climate system. If we want to know the natural variability of climate before the instrumental era then we need to look for sources having strong and stable physical/logical association with fluctuation of particular meteorological parameter. These surrogate data called proxy. By the aid of proxies past fluctuations of particular climatic characteristics can be reconstructed by good precision well before the instrumental era.

Climate reconstructions have been inferred from written evidences (KISS 1999, 2009, RÁCZ 1999, 2001, BARTHOLY et al. 2004, VADAS 2008) and plant phenology (PÉCZELY 1982, STREŠTIK & VERŐ 2000) in Hungary. The first studies recently were published about earth scientific methods like borehole temperature (BODRI & DÖVÉNYI 2004, BODRI et al. 2009) and stable isotopic and trace element composition of stalagmites (SIKLÓSY et al. 2009a, b).

The scope of the PhD research was to derive reconstructions of past climate and environmental changes using less known (at least in Hungary) proxies of earth sciences. Laminated materials were in the focus of the research as their lamination, per se, offer the potential of age determination by layer counting. The dissertation summarizes the major results achieved in studying tree rings and cave ice deposits. Tree rings are worldwide applied proxies however systematic dendroclimatological research has not made yet in Hungary before. The other studied environmental archive was cave ice. The exploration and exploitation of the potential environmental information captured in cave ice deposit is a pioneer work also in international level.

2. Materials

2.1. Tree rings

Living Swiss stone pines (*Pinus cembra*) were sampled following dendrochronological principles and conventions (COOK & KAIRIUKSTIS 1990, POPA 2004). From dead logs 8-10 cm thick disk samples were sawn. There were limited variations in the ecology and environment of the sampling area, ensuring the homogeneity of growth data. Samples surface were sanded and polished to enhance visibility of tree ring boundaries.

I have selected three healthy stone pine individuals for dendrochemical research from the site below the Rachitis Peak and an extra large (d=1 cm) increment core was extracted from each tree using a special increment borer. Special care was devoted to these samples during the whole process of sample treatment regarding the strict requirements of dendrochemisrty.

LINTAB equipment and TSAP 0.53 software (RINNTECH 2005) were used for measuring the annual ring widths with a precision of 0.01 mm, as well as for cross-dating the growth series by graphical comparison. The results were checked for missing ring and dating error using the COFECHA software (HOLMES 1983)

Archive wood density data originated from ITRDB database (NOAA 2009). A southern Carpathian timberline site (45.30N, 23.67E, 1650 m a.s.l.) near Novaci in the Parang Mts was selected for this study. The dataset contains 30 series of maximum and minimum density from 15 Norway spruce (*Picea abies*) (each tree represented by two series).

2.2. Data from cave ice

Drilling the ice block of Focul Viu Ice Cave and Bortig Ice Cave

Cave ice drilling was established by manual equipment the core bit was designed to attach to Ejkelkamp drill rods. A 7.6 m long ice core was extracted from the ice block of Focul Viu Ice Cave in November, 2001. The ice core was sliced into 2-8 cm long sub-samples. Altogether 299 sub-samples were collected, sealed into sterile plastic bags and transported to laboratory for analysis. Two ice cores (BA, BB) were extracted from the Bortig Ice Cave on 11 and 12 December, 2005. The BA drill penetrated to 205 cm ice and was sliced into 10 cm long sections. The BB drill reached 195 cm depth and was sliced into 2 cm long sections.

3. Analytical methods

3.1. Dendrochemical analysis

The elemental distribution in the tree-ring samples were measured using a laser ablation system (UP-213, New Wave Inc., Freemont, USA) coupled to an inductively coupled plasma mass spectrometer (ICPMS, Element2, Thermo Electron Corp., Bremen, Germany) in the Institute of Isotopes, HAS. Measured intensity values were corrected for the background signal. The background was measured prior to each measurement for approximately 30 s before starting the laser ablation. Each measured value was normalized by the corresponding ^{13}C intensity in order to correct for the possible different ablation efficiencies and wood density properties (BARRELET et al. 2006).

3.2. Stable isotope analysis

Stable oxygen and hydrogen isotope measurements were carried out at the Institute for Geochemical Research, HAS. Stable isotope compositions are expressed in the conventional delta notation:

$\delta^{18}O$ or $\delta D = (R-R_{std})/R_{std} * 1000$ [‰]$_{VSMOW}$,

where R and R_{std} are $^{18}O/^{16}O$ or $^{2}H/^{1}H$ ratios in the sample and the standard (Vienna Standard Mean Sea Water: VSMOW), respectively. Raw isotopic data were converted to by two-point linear normalization to the reference scale (PAUL et al. 2007).

3.2. Tritium in BA and BB ice cores

Tritium activities were measured by a Wallac 1220 Quantulus (Perkin Elmer) ultra low-level liquid scintillation spectrometer at the Institute of Nuclear Research (ATOMKI).

4. Methods of Standardizations

4.1. Standardization of Stone pine ring width data

In order to preserve also the low-frequency variability during the standardization procedure of Stone pine data, the Regional Curve Standardization (RCS) (ESPER et al. 2003) technique was adopted. Detrended series was averaged by biweigth robust mean (COOK 1985). Variance was adjusted to changing replication (OSBORN et al. 1997, FRANK et al. 2007). Steps of standardization were established using the ARSTAN software (COOK & KRUSIC 2006).

4.2. Standardization of dendrochemical data

I have worked out a novel two-stage procedure to standardize the relative sulphur intensity of the three analysed stone pine samples (KERN et al. 2009b). Firstly, heartwood values were ratioed to the mean of the longest common overlapping period covered by each heartwood section. Secondly, data related to sapwood rings were standardized. Finally separately standardized sections were spliced.

4.3. Standardization of wood density data

The biological trend of wood density can optimally be approximated by linear model (BRÄKER 1981). The density indices were calculated for each series for each year as ratio of raw density data and the predicted value of the fitted linear model. The stand average was calculated from individual indices as biweight robust mean (COOK 1985) both for maximum (MXD) and minimum (MND) density. The variance of MXD and MND were adjusted to changing sample depth (OSBORN et al. 1997, FRANK et al. 2007b). ARSTAN software (COOK & KRUSIC 2006) was used in standardization and index calculation.

5. Reconstruction methods

5.1. Ring width indices and temperature reconstruction

I have assessed the relationship between the ring width index and the mean monthly/multimonthly surface temperature by correlation analysis. Results indicated the highest potential for reconstruction of past fluctuations of July-August mean temperature. To avoid the loss of natural amplitude rescaling technique was adopted (ESPER et al. 2005).

5.2. Maximum, minimum density and reconstructed temperature

Similarly, I have assessed the relationship between the radiodensitometric parameters (MXD and MND) and the mean monthly/multimonthly surface temperature by correlation analysis. Two calibration trials were calculated using these density data. Firstly, MXD was calibrated against MJJAS mean temperature. Secondly, combination of MXD and MND was calibrated against the JJAS mean temperature. Bilinear regression and scaling was applied to combine the individual density indices.

5.3. $\delta^{18}O$ of cave ice

The stable isotopic composition of local precipitation and surface air temperature were monitored between 17 September, 2005 and 17 January, 2008. I have approximated the $\delta^{18}O$-T relationship by linear regression from the dataset and used in calculation for the full year and also for the winter half year calibration trials.

6. Theses

1. The stone pine ring width chronology covers 994-2005 period. By this spanned 1011 year length the longest established tree ring chronology of the Carpathian Region until today. We, together with my Colleague, have shown that the fluctuations of radial increments are reliable proxy for the Jul y-August mean temperature. The relationship between tree ring indices and July-August mean temperature is better in the low-frequency domain so it suggests higher potential for reconstruction of decadal-centennial scale temperature changes.
2. The ring width fluctuation portrays changes of summer temperature over the major part of the 20^{th} century but the chronology presents significantly larger rings from 1965 to 1986 than corresponding summer temperatures can explain. I have presented dendrochemical data providing clear evidences that sulphur content in the tree rings grown during the main phase of nearby sulphur exploitation is also anomalously elevated. I have argued that degraded temperature sensitivity likely due to the nitrogen fertilizer residues co-deposited with S-rich dust ejected from the mine after explosions.

3. I have shown by evaluating spatial correlation maps that the new multicentennial summer temperature reconstruction situated out of the field of the existing similar European reconstructions. In addition its spatial relevance field is largely well separated from their one covering the Carpathians and the Northern Balkan regions.
4. I have found the strongest positive relationship between MXD and August (r=0.46) and September (r=0.38) air temperature and MND record showed clear and significant negative response to June (r=-0.30) and July (r=-0.44) mean air temperature. This significant MND response to climate is a novel result.
5. I have shown that a biproxy reconstruction combining information of maximum and minimum densities doubtless improve the precision of the derived temperature reconstruction.
6. The presented tritium concentration data of Bortig Ice Cave highlighted that if a subsurface ice body is accumulated dominantly from unaltered atmospheric precipitation, and long-term melting has not erased a significant part of the twentieth-century ice deposition, then tritium concentration data gained from cave ice can be applied a, to precise dating of the past ~60 years of ice deposit; b, in a retrospective evaluation of local tritium fallout history.
7. I have argued that $\delta^{18}O$ record derived from a 7.6 m long ice core extracted from the perennial ice block of Focul Viu Ice Cave can be regarded as a proxy of the mean surface air temperature of the winter-half year (T_w). The $\delta^{18}O$-T_w relationship has been established after ~3 years of monitoring of local precipitation. Using this $\delta^{18}O$-T_w relationship a reconstruction of T_w has been derived from the stable oxygen isotopic composition of the cave ice core by semicentennial resolution for the past 2000 years and by bidecadal resolution for the past Millennium.

7. Conclusions

7.1. Methodological perspectives

The significant response of minimum earlywood density to climate is a novel result as traditionally this densitometric parameter was regarded not to carry any meaningful climatic signal. This novel approach suggests a potential methodological improvement in radiodensitometric dendroclimatology.

The most important methodological message of the presented results in the case of cave, I think, is that the results demonstrate that ice cores from cave ice can preserve environmental information by comparable fidelity like polar sites. It means that cave ice can provide even more reliable glaciochemical records of past low and mid latitude surface ice bodies (pl. HE et al. 2001, HOU & QIN 2002, THOMPSON 1980) where water vapour diffusion and melt water percolation smooth or erase any environmental signal.

7.2. The main results related to the millennial climate history of the Carpathian Basin

- A strong summer warming took place in the Calimani Mts since the late-1970s. The reached level of summer mean temperature is unprecedented in the ~850 year-long context. However the dynamics of warming, and the decadal amplitude of the observed temperature rise is not exceptional.

- Contrary winter temperatures relatively smoothly rise through since 1900 through the whole 20th century. Compared the warmest pre-instrumental decade and the recent conditions to the late-19th century the difference indicate that recent decades are the mildest winters of the last Millennium in the Carpathian Basin.

- The coldest summers prevailed between 1810 and 1820 while the harshest winters prevailed between 1680 and 1700 over the Carpathian Region.

- For the Carpathian Basin three major sub-periods can be distinguished during the Little Ice Age (LIA) the well-known cold period of the global millennial climate history. Gradually decreasing winter temperatures and fluctuating but dominantly cool summer temperatures characterized the 1370-1700 interval. The thermal conditions ameliorated during the 18th century when both summers and winters showed elevated mean temperatures comparable to the mid-20th century conditions. The regional thermal conditions seem to decline again in the 19th century.

- Preceding the LIA for the winter half year the milder period of Medieval Climate Anomaly (MCA) is detected and dated between 800 and 1260 AD. The mildest winters of the MCA is reconstructed for the 1220-40 period, however probably even milder winters prevailed for decades in the first half of the 9th century.

Acknowledgement

I would like to say special thanks to dr. IONEL POPA (ICAS) for his generous offer and allowed me to use also his data in the case study of 2. chapter. I would like to acknowledge dr. MOLNÁR MIHÁLY (MTA-ATOMKI) for tritium activity measurement , dr. PALCSU LÁSZLÓ (MTA- ATOMKI) for the precipitation stable isotope data from Debrecen and AUREL PERSOIU (USF) for the stable isotopic data for precipitation at Scarisoara, for the surface temperature dataset and for the many stimulating discussions. Many thanks to dr. FÓRIZS ISTVÁN (MTA-GKKI) for the essential help in interpretation of stable isotopic data. I would like to say thanks to the Supervisors for the many valuable advice during the preparation of the dissertation. Special thanks to dr. KÁZMÉR MIKLÓS due to his continuous motivation and help to participate of conferences and international courses.

The research was funded by the „Dendrokronológia geológiai és paleoklimatológiai alkalmazásokkal" (OTKA T43666) and „Környezettörténet éves felbontással" (OTKA K67583) projects. Cross border cooperation was supported by the „Az elmúlt öt évszázad környezetváltozásának tér- és időbeli változatossága a Kárpát-Pannon Térségben" RO-37/05 bilateral cooperation contract.

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