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Climate of the past 1500 years as seen in cave ice core records from Romania (Eastern Europe)

A. Perşoiu (1), B.P. Onac (1,2), A.-V. Bojar (3), K. Holmgren (4), J. Wynn (1), and M. Hansson (4)

(1) Department of Geology, University of South Florida, Tampa, United States, (2) Department of Geology, Babeş-Bolyai University / Emil Racoviţă Institute of Speleology, Cluj, Romania, (3) Institute of Earth Science, Karl-Franzens University, Graz, Austria, (4) Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden

The study of recent climate changes has become of utmost importance especially over the past two decades, during which mean annual global temperature has increased to unprecedented values, with the cause of this rise being attributed mainly to anthropogenic emission of greenhouse gases. However, there is still a lack of consensus regarding the potential of the Holocene natural climate variability to produce rapid global temperature changes of a magnitude similar to the recent global warming. The so called medieval warm period (MWP) is often used to "prove" that climate can be as warm as today even without an anthropogenic impact. Proxy records of climate over the past millennium are restricted mainly to Western and Central Europe, being scarce in Eastern Europe, so that is difficult to asses the spatial extent of the European climatic change during this period. Here we present a detailed record of climatic change over the past 1500 years in Eastern Europe, using the stable isotopes of oxygen and hydrogen in cave ice as proxy for air temperature.

The study site is Scărişoara Ice Cave (Carpathian Mts., Romania), which hosts Earth's second largest cave ice block (~100.000 m^3, 22 m mean thickness), with a possible age of more than 2000 yrs. The ice deposit consists of a sequence of annually laminated layers, each layer containing a couplet of clear and sediment-rich (organic matter, calcite, soil, and pollen) ice layers.

Ice in the cave forms during two distinct periods: one in late autumn, and one lasting from winter through late spring. In autumn, a lake standing on the top of the ice block (formed by rainwater) freezes downward from the top to form a layer of stratified ice up to 15 cm thick ("lake ice"). Thin layers of ice form in winter and spring as seepage waters freeze, atop the autumn ice ("floor ice"). In summer, the upper part of the ice (mainly floor ice) melts and the resulting water drains away, so that the ice block is built up mainly from lake ice accumulated between late summer and early autumn.

In order to understand the relation between external climate and the stable isotopic composition of ice, a monitoring program has been initiated in the cave. Air temperature and precipitation amount were measured on an hourly basis inside and outside the cave. Ice and water from different settings inside the cave, as well as precipitations have been collected and analyzed for their isotopic composition.

Stable isotope data from one-year precipitation shows a positive correlation between $\delta^{18}O_{prec}$ and air temperature, with a slope of about 0.89‰*°C^{-1}. The Local Meteoric Water Line (LMWL) is defined by the equation $\delta^2H=8.14*\delta^{18}O+10.2$.

Analyses of presently forming ice have shown that the freezing process results in a succession of sub-layers of ice with decreasing δ-values from the top to the bottom. In order to obtain the isotopic composition of the initial water before freezing, we have first determined a "freezing slope" for each layer of ice, using the $\delta^{18}O$ and δ^2H values (in a similar way to meteoric water lines). This freezing slope is intersected with the LMWL, and the values of $\delta^{18}O$ and δ^2H at the intersection point are considered to reflect that of the total water in the ice layer before freezing. Measurements on modern ice have shown that the reconstructed and measured values are in good agreement, so this technique can be used to reconstruct the isotopic composition of waters affected by freezing.

This method has been used in the analysis of a 22.5 m-long ice core, extracted from the ice block in 2003. Two to fifteen samples have been recovered from each layer of ice for stable isotope measurements. ^{14}C measurements

on organic remains found between the ice layers enabled us to construct a depth-age model for the ice core. The ice accumulated since the middle of the 1^{st} millennium AD, but a series of melting events might have affected its continuity.

The stable isotope data spanning the past 1500 years clearly shows three main climatic events over this interval: the Dark Ages Cold Period (DACP), Medieval Warm Period (MWP) and the Little Ice Age (LIA). Accelerated melting over the last 6 decades has led to the loss of upper part of the ice block, so that the end of the LIA, as well as the recent warming, are not seen in the stable isotopic record. However, stable isotope measurements of recently deposited ice (2005-2008), yielded higher values than those from MWP, suggesting that the present day warming is unprecedented over the past millennium. Our results are in good agreement with previously published data for North Atlantic sea surface temperature, as well as land air temperatures in Western and Central Europe, indicating that climatic variability has been a general feature of mainland Europe over the past ca. 1500 years.