



Comparison of a spatio-temporal speleothem-based reconstruction of late Holocene climate variability to the timing of cultural developments

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Speleothems are considered as a valuable continental climate archive. Their $\delta^{18}\text{O}$ records provide information onto past changes of the atmospheric circulation accompanied by changes in surface air temperature and precipitation. During the last decades European speleothem studies have assembled a European speleothem network (including numerous speleothem $\delta^{18}\text{O}$ records) that allow now not only to picture past climate variability in time but also in space. In particular the climate variability of the last 4.5 ka was investigated by these studies. This allows the comparison of the speleothem-based reconstructed palaeoclimate with the timings of the rise and fall of ancient civilisations in this period – including the Dark Ages.

Here we evaluate a compilation of 10 speleothem $\delta^{18}\text{O}$ records covering the last 4.5 ka using a Monte Carlo based Principal Component Analysis (MC-PCA) that accounts for uncertainties in individual speleothem age models and for the different and varying temporal resolutions of each speleothem $\delta^{18}\text{O}$ record. Our MC-PCA approach allows not only the identification of temporally coherent changes in $\delta^{18}\text{O}$ records, i.e. the common signal in all investigated speleothem $\delta^{18}\text{O}$ records, but it also facilitates their depiction and evaluation spatially. The speleothem $\delta^{18}\text{O}$ records are spanning almost the entire European continent ranging from the western Margin of the European continent to Northern Turkey and from Northern Italy to Norway. For the MC-PCA analysis the 4.5 ka are divided into eight 1ka long time windows that overlap the subsequent time window by 500 years to allow a comparison of the spatio-temporal evolution of the common signal. For every single time window we derive a common mode of climate variability of all speleothem $\delta^{18}\text{O}$ records as well as its spatial extent. This allows us to compare the rise and fall of ancient civilisations, like the Hittite and the Roman Empire, with our reconstructed spatio-temporal record.