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Atmospheric circulation shifts during the Younger Dryas in Western Europe

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The hydrological cycle constitutes a significant unknown variable in the prediction of the effects of climate change on regional climate patterns. Lake Meerfelder Maar (MFM) in Western Germany is a key archive due to its continuous annual varved sediment record, including tephra layers, which results in a highly precise age model. Previous studies have emphasized the record's sensitivity to climatic changes. High-resolution well-dated records, such as MFM, provide a better understanding of the timing and the underlying mechanisms of past climatic changes on a regional scale.

Here we present a high-resolution record of paleohydrological changes during the Younger Dryas cold episode (YD) from MFM, based on changes in the hydrogen isotope composition (δ^2H) of aquatic macrophyte (nC$_{23}$ alkane) and higher plant derived lipid biomarkers (nC$_{25}$, nC$_{27}$, nC$_{29}$alkanes).

The δ^2H values of the n-alkanes record large and rapid shifts to more negative values at the onset of the Younger Dryas. Based on the modern relationship of δ^2H of precipitation and temperature (ca. 2‰°C) in the investigated area, the assumed temperature decrease of about 6 – 7°C during the YD cannot fully account for the observed isotopic shift of up to 60‰ which thus must be due to combined changes in temperature, increased snowmelt and changes in the moisture source and/or transportation pathway.

δD values of the nC$_{23}$ alkane, interpreted as representative of the isotopic composition of lake water and hence precipitation, showed a synchronous decrease of about 30‰ with the onset of cooling in the Northern hemisphere at 12.85 ka BP. At 12.68 ka, when the ice core records indicate that Northern hemisphere temperatures had reached the minimum values, a further decrease of 30‰ in n-alkane δD values occurred over 100 years. The onset of this additional decrease is synchronous with a prominent shift in varve deposition in MFM. This reflects increasing storminess due to a southward shift of the North Atlantic storm track as well as a major shift in regional vegetation marking the biostratigraphic onset of the YD. Our isotopic data suggest that after relatively stable hydrological conditions until 12.1 ka two major oscillations, characterized by centennial excursions to more positive δD values, occurred. We interpret these oscillations as northward shifts in the Westerlies' storm track, i.e. closer to its current position, due to a decline in N-Atlantic sea ice cover. At 11.65 ka a threshold in the volume and position of N-Atlantic Sea ice cover was passed, marking the end of the YD in MFM (as well as NGRIP), and the storm track returned to a more northerly position.

Our data show the potential of lipid biomarker D/H ratios to resolve short-term hydrological changes with unprecedented detail. We demonstrate that the YD in Western Europe was accompanied by rapid changes in moisture source/ transportation-pathway taking place on 50-100 year timescales, stressing the importance of atmospheric phenomena for regional effects of climate change. Our results emphasize that global or hemispheric temperature changes can result in rapid perturbations of the water cycle on regional spatial scales.