Freshwater lenses as archives for climate history - insights from depth-specific age dating and stable water isotope analysis, Langeoog Island, Germany

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ABSTRACT

The age stratification of groundwater contained in a freshwater lens of Langeoog Island, Germany, was reconstructed based on depth-specific sampling and the tritium helium dating method. The vertical distribution of groundwater ages is spatially strongly variable. This is an effect of the variable land use and the resulting differences in groundwater recharge. Dune valleys contribute significantly more groundwater recharge per area than dune tops and up to four times more than other land uses such as forests and urban areas. The fresh groundwater shows a distinct decrease of stable isotope ratios with increasing depths. This mirrors an evolution of the climatic conditions at the time of recharge. Combined with dating of groundwater, this pattern could be matched to observed climate data, which show a distinct air temperature increase during the last 50 years.

INTRODUCTION

Langeoog is a barrier island of about 20 km² size, located off the North German coast, in the intertidal Wadden Sea. Water supply for population and tourists relies on the extraction of groundwater from one of three freshwater lenses. The lenses are recharged only by rainfall.

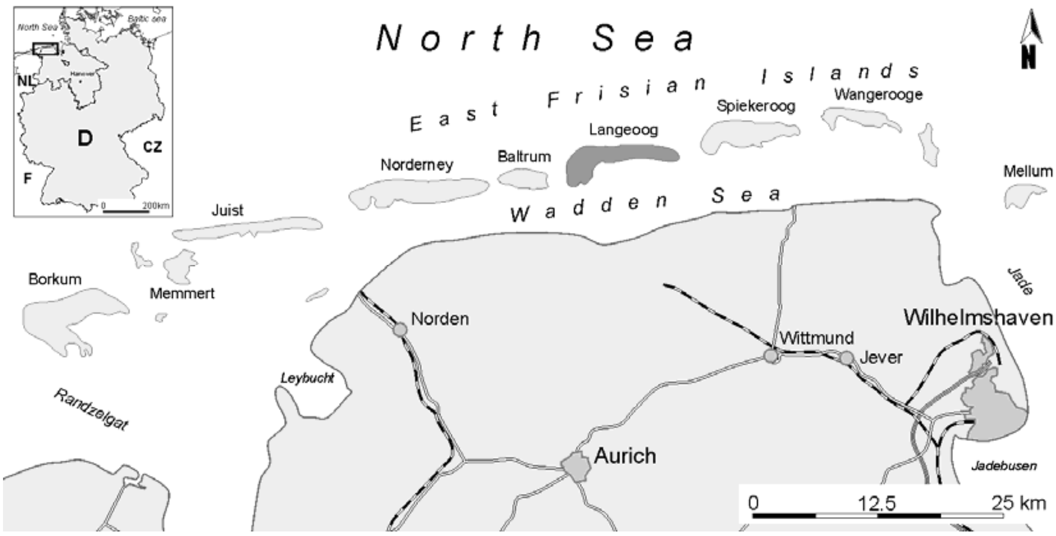

Figure 1. Location map.

METHODS

Several multi-level observation wells with short (1 to 2 m) screens allowed the depth-specific sampling of groundwater. Stable water isotope ratios δ^2H and $\delta^{18}O$ were analyzed after vaporization on a PICARRO L2120-i laser cavity ring-down apparatus against Vienna Standard Mean Ocean Water (VSMOW). Tritium and dissolved noble gases were analyzed at the Institute for Environmental Physics at Bremen University (Sültenfuß et al., 2009).

RESULTS

The freshwater lens as climate archive

The fresh groundwater samples generally show a decrease of stable water isotope ratios with increasing depths. Groundwater ages also increase with depth (Fig. 2). These patterns mirror an evolution of the climatic conditions over time. The freshwater column contains a climate archive which reflects e.g. temperature changes during the last decades. Combined with age dating of groundwater, this pattern could be matched successfully to air temperature records from the neighboring island of Spiekeroog (Fig. 3).

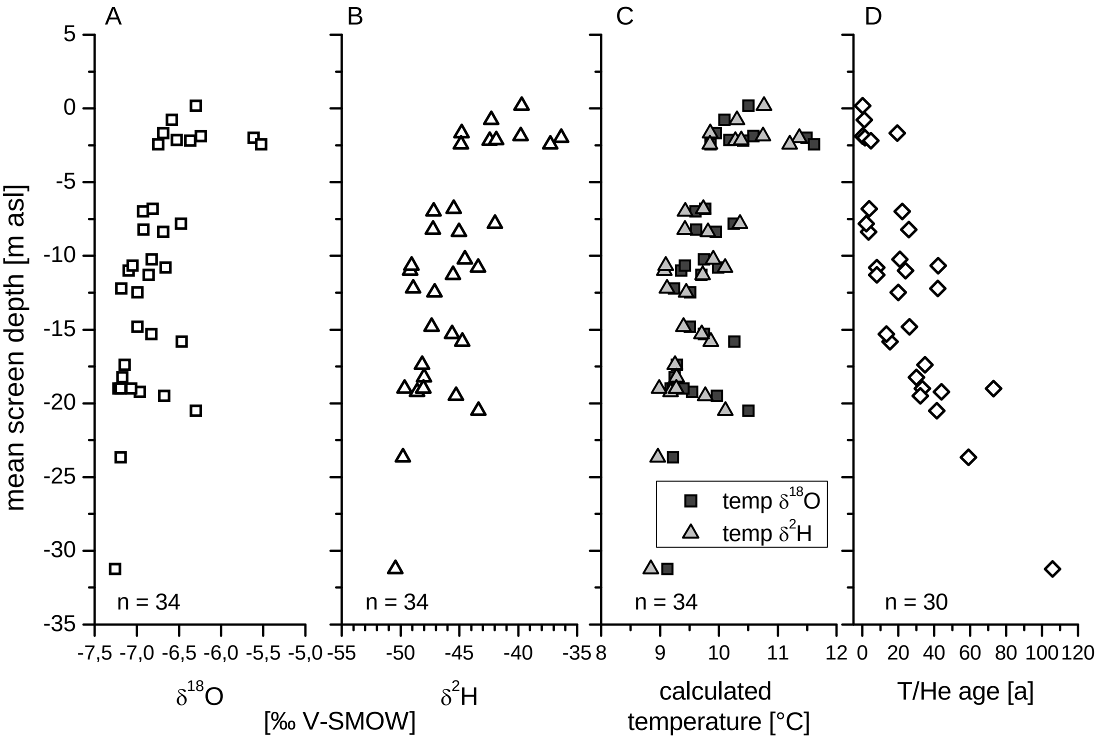

Figure 2. Stable water isotope ratios (A) $\delta^{18}O$, (B) δ^2H, (C) recharge temperatures after Dansgaard (1964), and (D) tritium helium age, as a function of screen depth.

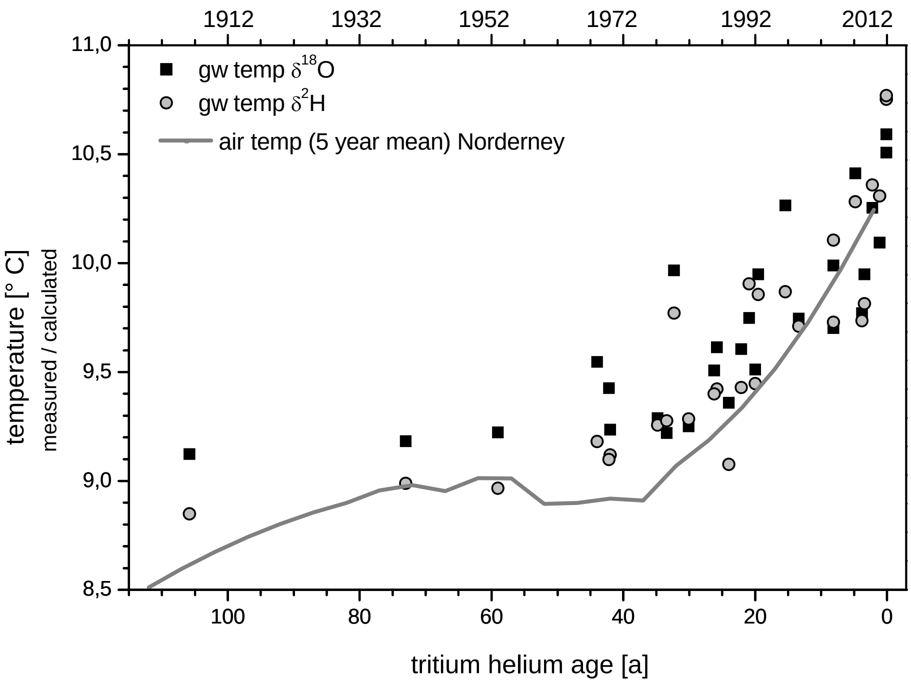

Figure 3. Comparison of measured air temperatures from Norderney and groundwater temperatures from Langeoog calculated after Dansgaard (1964).

Age stratification as indicator of spatially inhomogeneous groundwater recharge

The age stratification of the freshwater lenses currently in use was investigated using depth-specific sampling and tritium helium age dating (Fig. 4). It shows an increase of age with depth, with age layers successively becoming thinner due to ongoing exfiltration at the sides.

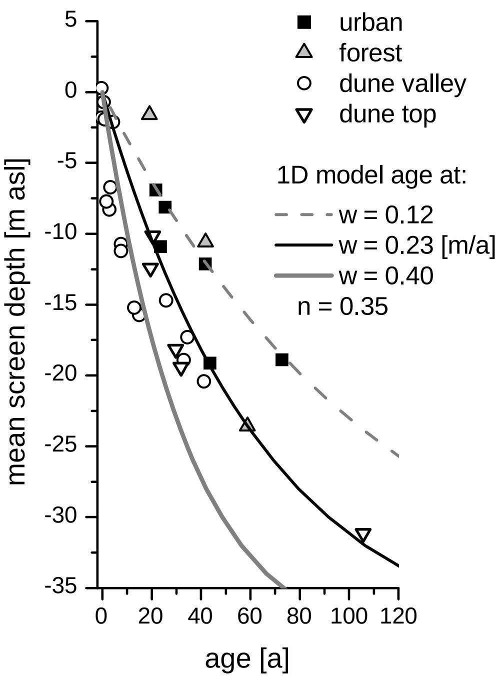

Figure 4. Measured tritium helium groundwater ages as function of mean screen depth compared to 1D age models after Vogel (1967, 1970). w = recharge rate, n = porosity.

The observed stratification is strongly affected by variations in land use and the resulting differences in recharge rates. Dune valleys contribute almost twice as much groundwater recharge per area than urban zones and forests. Infiltration at dune tops is significantly lower than in the valleys, probably due to repellency of the dry sand. Not only is the thickness of the individual age layers thinner under areas receiving less recharge compared to dune valleys but this might also affect the total thickness (or interface depth) of the freshwater lens. If the area of an individual type of land use is sufficiently large, the thickness (or interface depth) may differ from an adjacent area of different land use and recharge rate.

DISCUSSION AND CONCLUSIONS

The combination of depth-specific age-dating of groundwater with hydochemical and stable water isotope analysis gives a good insight into the internal dynamics of freshwater lenses. The age stratification is a function of the groundwater recharge rate which is strongly influenced by the type of land use. Dune valleys act as collectors of groundwater recharge and contribute more than any other type of land use. Two dimensional analytical models of age stratification which assume a homogeneous recharge (e.g. Greskowiak et al. 2013) cannot explain the age distributions encountered on Langeoog.

Variations of the stable isotope ratios of groundwater over depth can indicate changing climatic conditions over time. Freshwater lenses may thus preserve a climate archive. Islands are especially useful as climate archives, since the proximity to the ocean dampens the influence of temperature extremes, altitude effects are absent, and the system size is small. The reach of this approach is limited by the diminishing thickness of age layers with depth and the range of the chosen dating technique.

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