

Water Isotopes ($^2\text{H}/^{18}\text{O}$) and Climate Change

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Abstract

Precipitation water of meteorological station (11) and river water of monitoring station (6) with long-term (1973-2014) monthly $\delta^{18}\text{O}$ -measurements all over Austria show a mean increase of 0.8 and 1.0 ‰ (SMOW), respectively. The mean increase of air-temperature in these meteorological stations is 1.7 °C during these 41 years. The ratio of $\delta^{18}\text{O}$ -increase in precipitation water (‰ SMOW) to air-temperature increase (°C) is in the range of 0.5 and 0.6 respectively. As this ratio is similar to the ratio obtained in each single meteorological station, irrespective of its position on a mountain or in a valley, shows that temperature is the dominant fractionation factor of $\delta^{18}\text{O}$ in precipitation and river water and its decadal increase of 0.2 to 0.25 ‰ is caused by climate change during this period. In addition, simultaneous enhanced increase of $\delta^{18}\text{O}$ and air-temperature during 1980-1990 and 2001-2006 in many stations supports this assumption. This continuous change in $\delta^{18}\text{O}$ in precipitation and rivers show that long term monitoring data are important and contemporaneous data must be used to trace a water cycle.

Introduction

The isotopic ratios of hydrogen and oxygen in water ($^2\text{H}/^1\text{H}$ and $^{18}\text{O}/^{16}\text{O}$) are important tools to characterise waters and their cycles. This starts in the atmosphere as rain or snow, continues in the surface water and ends in shallow as well as in deep groundwater.

The fractionation of Water Isotopes ($^2\text{H}/^{18}\text{O}$) is dependent on the source of the humidity, the distance of transport in the air and the temperature of the area receiving the precipitation. If the source of the precipitation and the transport conditions stay more or less constant, the water isotopes can give you information about the yearly/seasonal mean temperature of an area and the long term (decadal) change of these temperatures (Kralik et al., 2003; Fröhlich et al., 2008). For areas with continuous measurements in precipitation and surface water prediction of the isotope composition of the water and the temperature in the past and in the future, allow to estimate climate variabilities and the potential impact on water resources and mitigation activities (Kralik et al. 2015a and b).

To monitor these changes 11 meteorological stations and 6 river stations of the Austrian Network of Isotopes in Precipitation (ANIP 2017) with monthly water isotope data were investigated for trends over the last 40 years and compared with air temperature measurements. In some alpine areas in Europe the mean air temperatures changed up to 2 °C (Auer et al., 2007). The aim of the Austrian Network for Isotopes in Precipitation (ANIP) is to provide input data for hydrological and hydrogeological investigations and a data-base for climatological changes and trends in sensitive Alpine areas.

To evaluate the impact of climate change on the $\delta^{18}\text{O}$ composition in waters of the hydrological cycle data of long term precipitation stations (>40 years) were compiled and compared with mean air-temperature changes.

Austrian Network of Isotopes in Precipitation and Surface waters (ANIP)

The selected meteorological and hydrological stations at the rivers are all on Austrian Territory in the centre of Europe between 9° - 16° E and 46.1 – 48.2 N (Fig. 1). The altitude of the stations ranges from 198 m in Vienna up to 2164 m on the top of the Villacher Alpe in the Southern Calcareous Alps. The Austrian Network for Isotopes in Precipitation (ANIP) started in 1972. Some stations (e.g. Vienna) have already been sampled since the 1960s (IAEA/WMO, 2017). The network runs in the framework of the Austrian water quality monitoring program. Fifty-six precipitation and 16 surface water stations are presently sampled all over Austria. From the total of 72 monitored stations 17 are selected due to their long monitoring periods of 37 – 41 years. The mean yearly sum of precipitation varies between 600 and 2000 mm. The local climate ranges from cold alpine to humid moderate, which results in mean air temperatures between 1 and 11 °C.

Methods

The precipitation is collected daily in ombrometers (500 cm²) in meteorological stations and mixed to monthly samples. The surface waters were collected as monthly grab samples. For this statistical interpretation, approx. 7,500 analyses of oxygen-18 have been made by the Austrian Institute of Technology (AIT; predecessor: Arsenal research) and Helmholtz Centre Munich (predecessor: Institut für Radiohydrometrie der Gesellschaft für Strahlenforschung). The measurements were performed up to 2010 using isotope mass spectrometers equipped with automatic equilibration lines. Since then nearly all measurements were done by laser-spectroscopy (CRDS – System). All results are reported as relative abundance ($\delta^2\text{H}$ and $\delta^{18}\text{O}$, respectively) of the isotopes ^2H and ^{18}O in permille (‰) with respect to the international standard VSMOW (Vienna Standard Mean Ocean Water). The accuracy of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ measurements is better than < 1.0 ‰ and < 0.1 ‰, respectively.



Fig. 1. Austrian borders (red line) in the centre of Europe. The blue arrow shows the main precipitation source from NW (North Atlantic). The yellow arrow shows the second important precipitation source from the SW (Mediterranean) influencing mainly the southern part of Austria.

Tests to check the significance of linear trends the Mann-Kendall-Test were applied on all data sets. Due to its high quality and outlier resistance, the frequently in hydrological studies used Mann Kendall-Test was selected (Hirsch and Slack, 1984; Libiseller and Grimvall, 2002). The statistic Z follows the standard normal distribution. At a 5 % significance level, the null hypothesis of no trend is rejected if $Z > 1.96$. A positive value of Z denotes an increasing trend, and the opposite corresponds to a decreasing trend.

Results

All long-term precipitation stations show a mean temperature increase of 1.7 °C (1.3-2.4 °C) between 1973 – 2014. This is a temperature increase of 0.42 °C (0.3-0.5 °C) per decade. All precipitation except of one (Villacher Alpe) show an annually precipitation weighted $\delta^{18}\text{O}$ increase of 0.79 ‰ (0.3-1.8 ‰) and a decadal change of 0.19 (0.1-0.5 ‰) of the same stations (Fig. 2).

The waters of Austria's major rivers, including the river Danube, increase in $\delta^{18}\text{O}$ by 0.97 ‰ (0.6-1.3 ‰) between 1973-2014 demonstrating a decadal rise of 0.24 ‰ (0.16-0.31 ‰; Fig. 3).

The correlation between the monthly $\delta^{18}\text{O}$ -values and the mean monthly air-temperatures in the period f 1973-2014 in all meteorological stations allows to calculate a mean $\delta^{18}\text{O}$ -increase of 0.6 ‰ (0.59-0.77 ‰) per °C air-temperature. The coefficient of determination r^2 ranges between 0.5-0.8.

Over the same period the yearly sum of precipitation (mean: 637-1853 mm) increased slightly (1-6% per decade) in all stations except one.

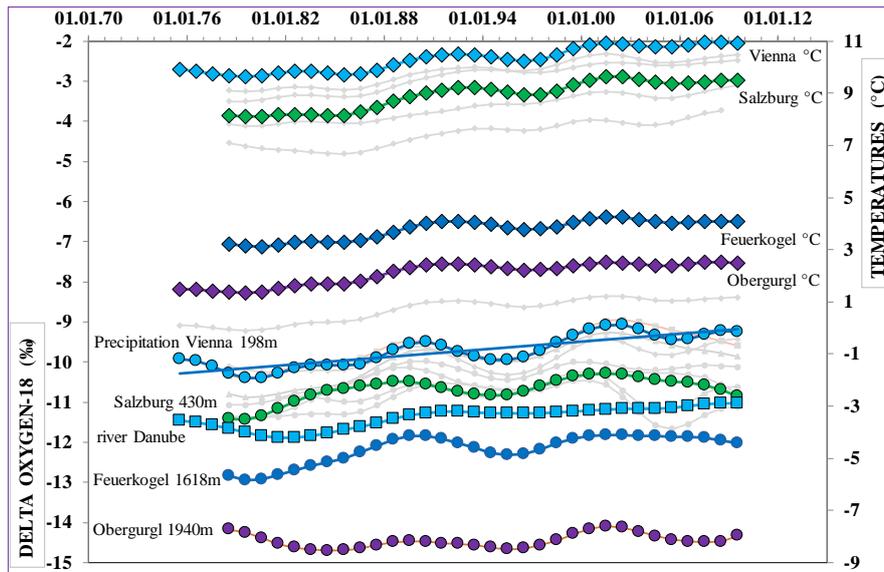


Fig. 2. Smoothed (Gaussian filter) yearly mean air-temperatures (above; temperature right scale) and smoothed yearly mean $\delta^{18}\text{O}$ -values (below; left scale) of selected meteorological stations and the Danube river station in Vienna. For clarity, the rest of the stations are shown as grey lines in the background. Many stations show an enhanced increase of temperature and $\delta^{18}\text{O}$ -values between 1980-1990 and 1996-2001.

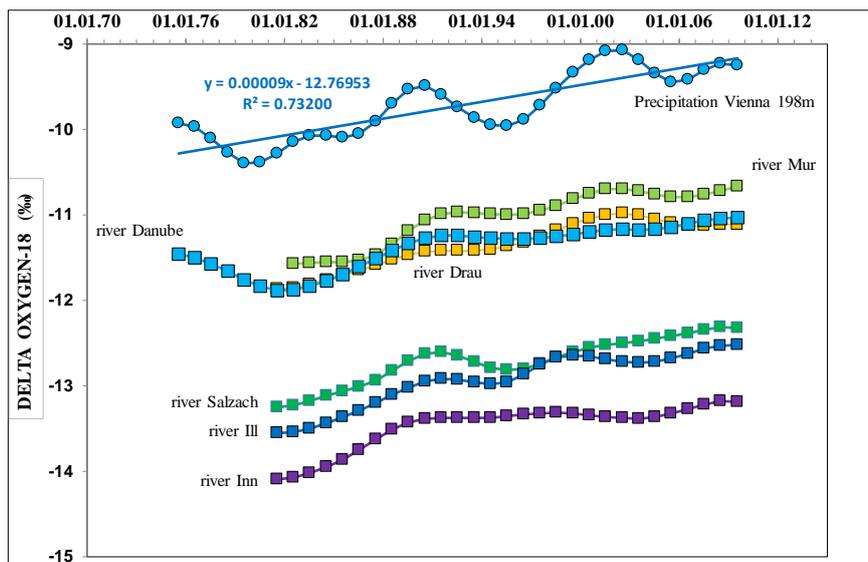


Fig. 3. Smoothed yearly mean $\delta^{18}\text{O}$ -values (Gaussian filter) of selected river stations and for comparison the meteorological station in Vienna. All stations show an enhanced increase of temperature and $\delta^{18}\text{O}$ -values between 1980-1990 and some between 1996-2001 as well.

Discussion

The evaluation of trends of meteorological or geochemical data is always difficult and often depends on the selected period and is normally based on a too small number of data. Despite these risks the evaluations are quite essential for the interpretation of hydrological and geochemical data as well as the prediction of future developments.

Austria is in the favourable situation to have many long-term isotope data in monthly precipitation samples and river waters in a globally relative small area (72 per approx. 80,000 km²). On the other hand, the meteorological situation is complicated by the Alpine relief and the weather divide along the main Alpine crest. The dominating source of precipitation is from the NW the North Atlantic, but frequently precipitation comes from the Mediterranean (Fig. 1) showing a slightly different isotopic signature (similar altitudes show approx. 1 ‰ higher $\delta^{18}\text{O}$ values).

Although each meteorological station can show its peculiar climatic conditions, ten of eleven meteorological stations show a significant increase in $\delta^{18}\text{O}$ -values over the period of 41 years (1973-2014). In the river stations which integrate large recharge areas of 1,300-10,400 km² all $\delta^{18}\text{O}$ -values of river waters show an increase during the same period. The mean increase in the meteorological stations is in the same range as in the river stations 0.79 to 0.97 ‰, respectively (Fig. 3).

In the same period (1973-2014), the mean air-temperature increases by 1.6 °C (1.3-2.0 °C) in all meteorological stations. The correlation of monthly air-temperatures and $\delta^{18}\text{O}$ values of the precipitation of all stations indicate a mean increase in $\delta^{18}\text{O}$ of 0.6 ‰ (0.59-0.64 ‰) per 1 °C. As mentioned in the introduction, the $\delta^{18}\text{O}$ -values in the precipitation depend on other factors as well than just the air-temperature. However, the coefficients of determination r^2 of the correlation of $\delta^{18}\text{O}$ -values in precipitation and air-temperatures are in all stations in the range of 0.5-0.8. Therefore, the assumption that the increase of $\delta^{18}\text{O}$ -values is triggered mainly by the increase of air-temperature in the Austrian meteorological stations and the recharge areas of the investigated rivers.

In addition, the periodic enhanced air-temperature increase in 1980-1990 and 1996-2001 is visible in the $\delta^{18}\text{O}$ -values of most precipitation and river waters. The reasons for this periodic accelerated temperature increase and decrease are presently unknown.

In conclusion, the tendency of an increase of the air-temperature and $\delta^{18}\text{O}$ -values in precipitation and river waters of 0.4 °C and 0.2 ‰ $\delta^{18}\text{O}$ -values per decade is most likely a consequence of climate change. This supports the necessity to continuously monitor the precipitation input not only for climatic research, but also for hydrogeological investigations. A once established input (precipitation or surface water) baseline cannot be extrapolated over many years or decades.

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