Two-year record of triple-isotope composition of daily precipitation at two contrasting sites in central Europe

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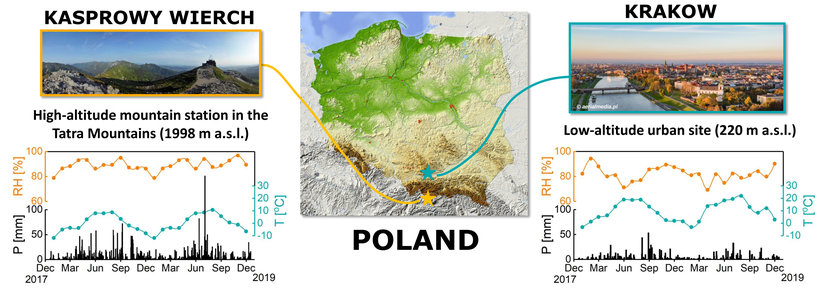
INTRODUCTION

Better understanding of factors controlling stable isotope composition of precipitation on various temporal and spatial scales under present-day climate is a necessary step towards more efficient utilisation of water isotope records preserved in diverse environmental archives for reconstruction of past climatic and environmental changes, and to investigate the response of the hydrological cycle to progressing global warming.

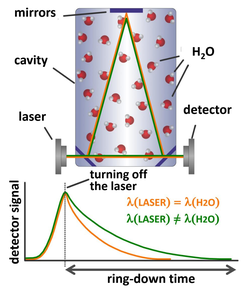
The IAEA/WMO Global Network of Isotopes in Precipitation (GNIP) played a central role in characterizing spatial and temporal variability of δ^2H and $\delta^{18}O$ of precipitation on the global scale [1]. Precipitation samples analyzed in the framework of GNIP represent cumulative monthly precipitation. It is an open question to which extent this monthly weighted averages faithfully represent physical conditions accompanying formation of individual rainfall events. Another question, which needs to be addressed in sufficient detail, is the link between the origin and rainout history of air masses and isotopic signatures of precipitation recorded on the continents.

A two-year record of triple-isotope composition (δ^2H, $\delta^{18}O$, $\delta^{17}O$, d-excess, $\Delta^{17}O$) of daily precipitation collected during 2017 and 2018 at two contrasting locations in southern Poland is presented. The Krakow station is a low-altitude urban site whereas Krasprowy Wierch is a high-altitude mountain station situated in the Tatra Mountains (1998 m a.s.l.).

STATIONS



METHODS



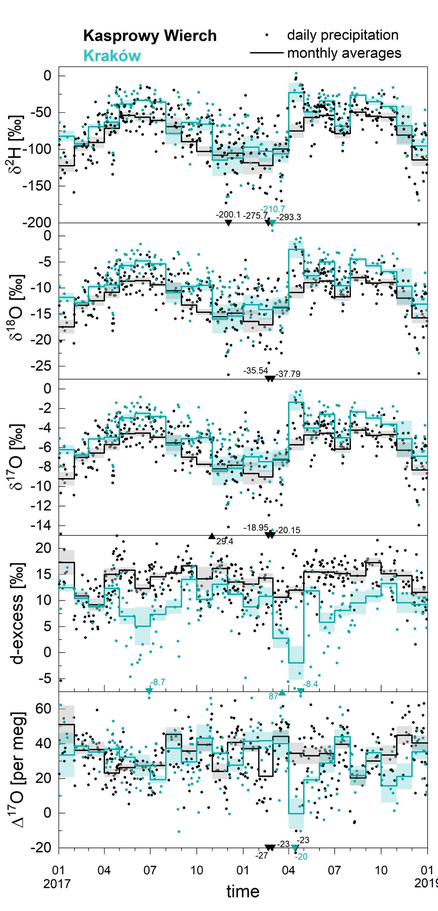
Althogether, 591 samples of daily precipitation were analysed (184 for Krakow and 407 for Kasprowy Wierch). Isotope analyses of daily precipitation were conducted with the aid of Picarro L2140-*i* laser spectrometer [2].

Picarro L2140-*i* measures the rate of decay (ring-down time) of a laser beam after the laser has been switched off. The laser beam is confined in an optical cavity filled with the sample being analysed (water vapor). If the beam frequency matches the absorption frequency of the given type of isotope water molecule, absorption of light occurs, inducing more rapid reduction of the signal. Consequently, the higher the concentration of the beam-absorbing molecules, the shorter is the ring-down time.



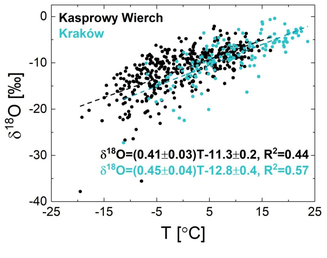
RESULTS

TIME SERIES OF ISOTOPE DATA



SEASONAL EFFECT

δ^2H, $\delta^{18}O$ and $\delta^{17}O$ values measured in daily precipitation samples reveal expected distinct seasonality, with a maximum of heavy isotope content during summer and a minimum during winter. This seasonality stems from seasonally varying thermal contrast between major source regions of atmospheric moisture (Atlantic Ocean) and the centre of the European continent, where both stations collecting daily precipitation are located [3]. Enhanced thermal contrast during winter time (temperature of the moisture source remains relatively constant whereas the continent cools down) leads to larger average rainout of the moist air masses and reduced heavy isotope content of precipitation. In addition, the evapo-transpiration flux returning to the atmosphere isotopically heavy water vapour, is largely missing during winter time thus enhancing the heavy isotope depletion of precipitation collected during this time of a year [4]. Consequently, δ^2H, $\delta^{18}O$ and $\delta^{17}O$ of daily precipitation correlate well with daily air temperatures measured at both sites.

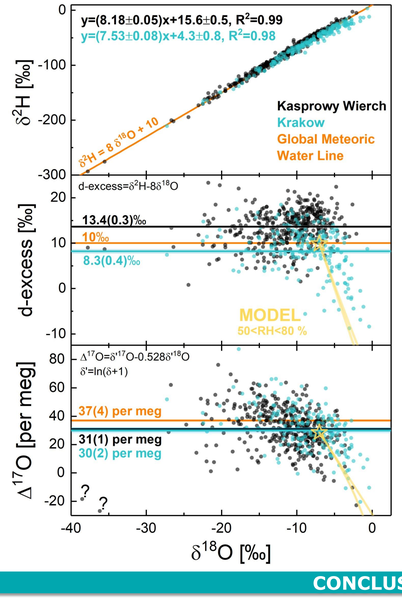


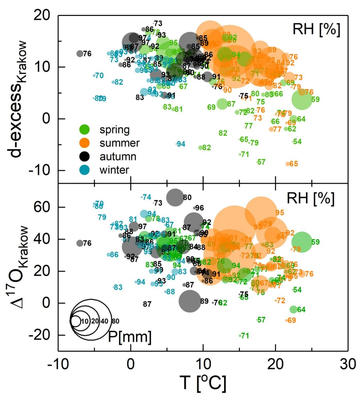
Distinctly lower δ values measured for Kasprowy Wierch samples, when compared to those recorded in Krakow (the mean differences being $\Delta\delta^2H_{KR\text{-}KW}$=47.0‰, $\Delta\delta^{18}O_{KR\text{-}KW}$=2.70, $\Delta\delta^{17}O_{KR\text{-}KW}$=1.43), reflect mainly large difference in the altitude of both sites (ca. 1770 m).

CORRELATIONS OF ISOTOPE & METEO DATA

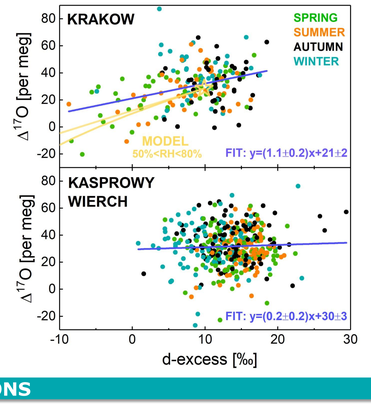
The Local Meteoric Water Lines for both sites differ substantially: mean d-excess value for Kasprowy Wierch equals approximately 14‰, to be compared with ca. 8‰ for Krakow. The $\Delta^{17}O$ values measured at both sites range from ca. -20 to 80 per meg, with the mean values of 30(2) (Krakow) and 31(1) per meg (Kasprowy Wierch).

Reduction of d-excess and $\Delta^{17}O$ values with increasing $\delta^{18}O$, apparent in Krakow data, can be explained by partial evaporation of raindrops on their way from the cloud-base level to the ground. This decreasing trend is consistent with the model results (yellow trend lines in the figures). Partial evaporation of raindrops is favored by meteorological conditions, i.e. higher air temperatures and lower relative humidities prevailing during summer. As the Kasprowy Wierch station is located at the height of the mean cloud base, partial evaporation of raindrops is largely absent, and the d-excess and $\Delta^{17}O$ values are not correlated.



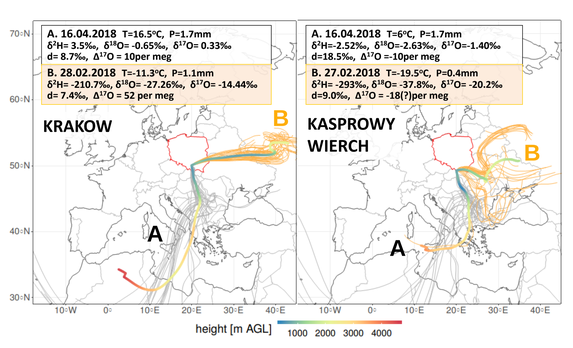


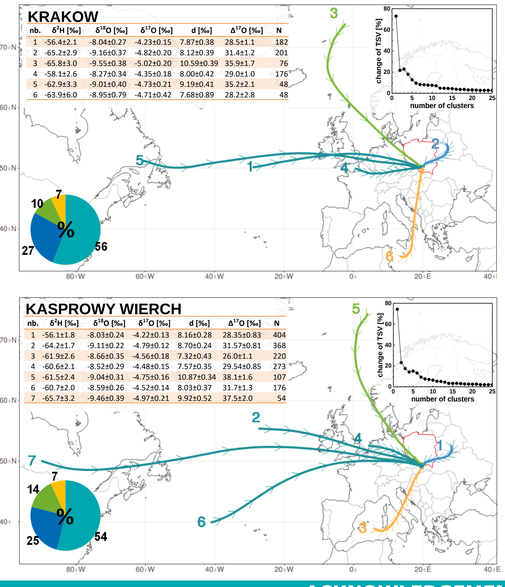
To quantify the isotopic evolution of raindrops below the cloud-base level, simplified model was adopted which assumes partial evaporation of raindrops to unsaturated atmosphere with constant isotopic compostion of ambient moisture and constant turbulence parameter (n=0.5). The yellow lines are bracketing the expected changes for two selected values of relative humidity: 80% and 50% .



BACKWARD TRAJECTORY & CLUSTER ANALYSIS

To link the observed triple isotope composition of daily precipitation collected at Kasprowy Wierch and Krakow stations, backward trajectory analysis of the moist air masses precipitating at those sites during 2017-2018 was performed for extreme isotope values recorded there. 96-hour backward trajectories were calculated using HYSPLIT modelling framework [5], with NCAR reanalysis data used as driving meteorological field. Ensembles of trajectories and the mean trajectory were calculated for each of the analysed precipitation events.





Cluster analysis of the entire dataset available for both stations was performed [6]. The analysis yields dominating directions (clusters) of moist air masses bringing precipitation to Kasprowy Wierch and Krakow stations.

As shown in the accompanying figures, similar structure of clusters and associated mean 96-hour trajectories was obtained for both stations. The dominating circulation component at both sites is westerly circulation (56% and 54% of all analysed trajectories, for Krakow and Kasprowy Wierch, respectively). This westerly component consists of 3 (Krakow) and 4 (Kasprowy Wierch) clusters, represented by mean trajectories of different length.

Cluster representing N-W and N air masses arriving from northern high latitudes is present at both stations. It has similar share in the total budget of the analysed trajectories: 10% (Krakow) and 14% (Kasprowy Wierch).

Southerly circulation is poorly represented (7% in both cases). The mean trajectories originate over central and western Mediterranean pointing to possible influence of this source of moisture.

Clusters represented by "blue" mean trajectories (27% for Krakow and 25% for Kasprowy Wierch) comprise trajectories which originate in relative vicinity of the collection sites and cover broad spectrum of directions.

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CONCLUSIONS

- Triple-isotope composition of daily precipitation collected at two sites located in southern Poland revealed expected distinct seasonality of the isotope signals, with mean slopes of isotope/temperature relationships equal (3.3±0.3)‰/°C, (0.43±0.04)‰/°C and (0.22±0.02)‰/°C, for δ^2H, $\delta^{18}O$ and $\delta^{17}O$, respectively.
- The secondary parameters, d-excess and $\Delta^{17}O$, point to partial evaporation of raindrops below the cloud-base level as important parameter modifying isotopic composition of daily precipitation at Krakow station.
- Cluster analysis reveals similar origin of moist air masses arriving at Krakow and Kasprowy Wierch stations, with dominating influence of westerly circulation.

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