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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Footprints of climate in groundwater and precipitation" *by* A. Liebminger et al.

A. Liebminger et al.

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We want to thank the Referee for his very detailed review of our paper and the critical and stimulating comments he provided. In this reply we are concentrating on the most relevant issues raised by the Referee, of course we will keep also into account all the other comments if we are allowed to submit a revised version of the paper.

First of all we agree with the Referee that the paper is indeed very short. The paper has been designed as a short scientific letter supposed to be a valuable addition to a recent paper about correlations of stable isotopes in Austrian precipitation with climatic (meteorological) parameters (Liebminger et al., 2006a; referred to as JGR-paper by the Referee). Because of this intention a lot of basic information has been omitted in the text of the present paper, however we agree that it would be more easy to follow the logic of the manuscript if some well-established concepts such as the amount effect or deuterium excess are mentioned in the manuscript. Therefore we will include the missing essential information in the revised paper and provide more references in order to follow the suggestion of the reviewer.

The Referee reflected on four items of our study identified as interesting observations, in particular:

1) Temporal trends of δ18O in Vienna drinking water are related to a weighted mean of precipitation data from the recharge area (Wildalpen) nd to temperature.

2) The δ18O variations in precipitation at Wildalpen are correlated with the winter NAO index, and anticorrelated with the local snow/precipitation ratio and relative humidity.

3) A comparison between a mountain and nearby valley station shows the effect of sub-cloud evaporation on the stable isotope composition of precipitation.

4) The importance of sub-cloud evaporation apparently has increased over the past 30 years and is related to the precipitation amount.

The Referee considered points 2 and 4 to be at least partly new whereas point 1 has been qualified to present nothing unexpected. From our point of view the essential thing about point 1 is not the relation of drinking (ground) water to precipitation and temperature but that the δ18O pattern in this unique (because covering 30 consecutive years) data set of Vienna drinking water can only be explained with precipitation data from the winter months! This is especially important because if the data set is analyzed according to the concept of groundwater being generally reflected by annual mean precipitation (as mentioned in the introduction section; cf. Clark and Fritz; 1997) the information about climate impacts as pointed out in the paper will be lost. On the other hand the fact that this δ18O pattern is primarily based on winter data allows to draw the main conclusion that groundwater is bearing climate information which is just more than temperature (because influences of NAO, relative humidity and snow to precipitation ratio are discussed for winter precipitation in the recharge area governing the groundwater data presented). We also cannot fully agree with the Referee's comment that claiming the novelty of this conclusion might be unjustified. In the literature available to us we could not find anything deviating from the common concept of stable isotopes in precipitation being influenced by temperature. Also the study of Rademacher et al., 2002 which has been referenced by the Referee (page S101; (7)) is only dealing with possible impacts of temperature. However, although we tried to make the approach of scrutinizing the exclusiveness of temperature regarding the impact on stable isotopes in precipitation the central message of our paper, we feel that we have to emphasize more on that.

As mentioned by the Referee the comparison between Patscherkofel and the nearby valley station of Innsbruck (point 3) has already been shown in a previous paper of us. However, point 3 was not intended to be a major observation in this paper. Moreover it should only be one piece within our argumentation showing the effect of sub-cloud evaporation on the stable isotope composition of precipitation as well as the examples of δ18O/δD. As mentioned by the Referee the amount effect of stable isotopes together with it's explanation (sub clod evaporation) is rather observed at tropical stations than at mid latitude stations (page S100; (6)), therefore it seems quite necessary to point out as many items as possible to underline our conclusion of sub-cloud evaporation playing also a major role in governing the final isotopic composition of Austrian precipitation. Furthermore point 3 also covers the observation of point 4 which has been found to be of special interest by the Referee.

Response to specific comments:

(1)As mentioned above the central message of the paper is the coexistence of several influences governing the isotopic pattern in precipitation and groundwater (see also the cartoon given as supplement). We never claimed that the idea of sub cloud evaporation is new but until now we have not found another detailed description of interactions between several climatic parameters which we claimed to show for the first time. However we agree with the Referee that the statement of explaining the whole variance of stable isotopes not explained by temperature might lead to far. We will revise this

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sentence.

(2)The concept of groundwater being generally reflected by annual mean precipitation is widely used as it gives a good approximation in many investigations where a detailed analysis is not feasible or possible. Since we did not use this concept within our study we agree that it is confusing to find it referenced in the introduction section. Nevertheless the concept plays a role for our conclusion (see general response above) and therefore we will mention it in the context of the explanation given above. The part in the introduction section will be replaced by a review of the methods used for calculation of the input function.

Using monthly δ18O values from precipitation sampled at Wildalpen which is the recharge area for Vienna drinking water an input function was calculated according to Maloszweski and Zuber (1996) defined as follows:

δin(t) = δbar + [αiPi(δi - δbar)]/Σ(αiPi/n)

where δbar is the mean input which must be equal to the mean output of monthly δ18O values and n is the number of months for which the observations are available, Pi is the amount of monthly precipitation, δi the isotope composition and αi is the recharge factor which is representative for the amount of recharge in the sense that α = 0 means that no recharge takes place while α = 1 indicates that all water is recharged. Since only a summer/winter recharge as proposed by Grabczak et al. (1984) does not account for the variations in evapotranspiration and water availability a sinusoidal function was suggested to give a more realistic adjustment (McGuire et al., 2002):

αi = 0.9cos$^4(\omega$t + Φ) + 0.07

Φ is the phase lag in radians between precipitation and recharge, t is the calendar time and ω the angular frequency. Values for Φ and ω have been chosen to be 150 and π/340 respectively. The calculation of the input function was carried out in order to show that the typical pattern of the groundwater (peak in the beginning 1990ies) is reflected also in the precipitation input when weighted according to higher impact of winter precipitation. An output (i.e. mean residence time MRT) has not been calculated since it is hard to apply a model for the pathways of drinking water !

The analysis of the temperature data within this paragraph corresponds to the δ18O data of precipitation sampled at Wildalpen for summer and winter months respectively. In the revised version of the manuscript the commented part of the text will be reformulated to deserve an easier understanding. As mentioned in the caption of figure 2 all presented data is averaged for winter months December to March following the above described central approach of the paper. Again this information will also be included into the text of the manuscript.

(3)We completely agree with the Referee about the point of the groundwater section which is that the isotopic variations seen in the groundwater essentially reflect those of the winter precipitation, which in turn are related to NAO and other climatic parameters. We also appreciate his suggestions to discuss first the patterns in the precipitation and their relationship with the winter NAO index and afterwards to show that this winter signal is still visible in the Vienna drinking water.

(4)We agree that a previous review of our JGR - paper will definitely improve the understanding of the commented paragraph. In the JGR - paper we compared sample stations located within different landscape profiles. From this comparison it became obvious that sub - cloud evaporation is most important at inter mountain valley stations and at large basins because of high cloud to base distances. While at the former landscape profile air masses arrive due to surrounding mountains at a high level above the ground, convective movement of clouds due to higher temperatures is prevailing at the latter one. Relative humidity which is mainly responsible for sub cloud evaporation is therefore of increased importance at these landscapes, whereas it's influence is lowered at locations in front of orographic barriers where enhanced precipitation amounts are occurring, leading to a faster saturation of the ambient air during a precipitation event, thus limiting the effect of evaporation on the falling rain drop.

We also agree with the Referee that the sentence beginning on line 11 is also difficult to interpret and might be misleading. What is actually meant by “Considering a lower relative humidity at these winter days with rain ...”, is that relative humidity as well as S/P - ratio is in antiphase with δ18O in winter precipitation of Wildalpen. Therefore it can be assumed that a low relative humidity corresponds to a higher amount of rain within the precipitation. Since evaporation of falling snow flakes due to the low molecular diffusion rates in ice can be neglected (Siegenthaler and Oeschger; 1980) as well as with high relative humidity prevailing, this assumption from above nicely fits to the observation of sub- cloud evaporation being relevant at days with rain and lower relative humidity.

(5)The following sentence where δ18O trends of different sample stations are compared is also criticized by the Referee because of possible misinterpretation. We will revise this sentence in order to make clear, that there are two quite different situations, with the one issue in common, that the observed trends can not be explained by temperature alone. The first situation is characterized by two stations (Innsbruck and Patscherkofel) located very close to each other but showing quite different trends for δ18O (Fig. 3a). We will provide a additional figure which shows that this difference can not be attributed to temperature because there is almost no difference in the annual temperature trends of Innsbruck and Patscherkofel, whereas the slope of δ18O for Patscherkofel is almost the same as for temperature. In general no difference regarding the temperature trends between Austrian mountain and valley stations has been observed (Auer et al., 2001). Since 1850 there has been an increase in annual mean temperature of 1.8 °C at high and low elevations.

From the trends in Fig. 3a it can also be seen that the δ18O difference between the valley station Innsbruck (577 m a.s.l.) and the mountain station Patscherkofel (2245 m a.s.l.) has increased over the last 30 years. The second situation is characterized by two sample stations (Kufstein and Weyregg) located in the same landscape profile (Northern hill slopes of the Alps, both at 500 m a.s.l.) but in more than 150 km distance. Despite the large distance the δ18O trends for these two locations are quite

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the same. The remarkable δ18O offset of almost 2 permill between the two locations (Fig. 3b) can again not be explained by temperature because at both locations there are almost the same temperatures prevailing (cf. Liebminger et al., 2006a).

Together with the trends of the δ18O /δD - trends both examples can be interpreted as indicators for increased importance of sub - cloud evaporation which can be explained by a decrease in relative humidity. Formayer et al. (2001)showed that besides the well known increase of temperature there in only one parameter showing a very significant trend in Austria within the last 30 years: the decrease of relative humidity! The influence of changes in the source of air moisture as mentioned by the Referee has not been examined, because one of the key messages from the JGR - paper is that most of the variation within the isotopic composition of alpine precipitation is “home made”.

(6)As indicated by the Referee a reference of the amount effect would be appreciable. We agree and will follow the Referee’s suggestion. The example of the amount effect for Vienna precipitation is scrutinized by the Referee since most examples for the amount effect given in literature are from the tropical area. However, from the data for amount of precipitation and δ18O presented in Fig. 4a (which are averaged for winter months December to March as it is in line with the papers main thrust) it can easily be seen that smaller precipitation amounts are prevailing at times with higher δ18O values and vice versa which again fits to the concept of the amount effect. We will reformulate the commented sentence in order to make clear what kind of data is used for this example.

(7)A response to this comment was already given in the general response at the beginning of this authors comment (see above).

We completely agree with the essence of all the Referee comments we did not explicitly discuss above. All the minor and major remarks will be addressed if we are encouraged to revise the paper.

Additional References: Auer, I., Böhm, R., Schöner, W., (2001). Austrian long-term

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