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Reply on RC2

Dylan J. Irvine et al.

Author comment on "Depth to water table correction for initial carbon-14 activities in groundwater mean residence time estimation" by Dylan J. Irvine et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-276-AC2, 2021

Anonymous Referee #2

General comments

This paper uses literature values of unsaturated zone ^{14}C activities to develop a depth to water (DTW) correction for initial ^{14}C values for groundwater dating. Not all previous studies have assumed that the unsaturated zone is in equilibrium with the atmosphere, but many have. In these cases, the correction indicated by the equation can be substantial (corrected mean residence times (MRTs) can be thousands of years younger than the uncorrected MRTs). These effects are well known, as attested by the 14 studies used to develop the DTW correction, but the contribution here is the development of the correction equation, which will be easy and useful for others to adopt.

Response: Thank you for the comments. Yes, our goal was to bring the findings from the unsaturated zones together and generalise them, thereby presenting simple to apply approaches to account for this specific process in the unsaturated zone in the estimation of mean residence times of groundwater.

We address your additional comments below.

Logically, the DTW in the recharge area has the most relevance to the correction required, not the DTW where the sample was collected. Using the DTW from the sample location (as in this paper) is a compromise made for convenience.

Response: As the referee highlights, the selection of water levels in the wells was made for convenience. We note that Marina Gillon raised this point in her comments also.

As the focus of the manuscript is on the presentation of the method (with a demonstration), we feel that this approach is appropriate. To highlight that the DTW in the recharge zone may be of more importance, we will add the following to the end of Section 2.2 (Saturated zone data collation):

It is likely that the DTW in the recharge zone is more relevant. One approach could have been to determine DTW from spatially mapped water levels (e.g. Wood et al., 2017). Nonetheless, the simple approach to estimate DTW from the sampled wells allows for a demonstration of the methods outlined here.

We will also further discuss the implications of using DTW from a sample well, relative to the recharge zone (where the water table is expected to be closer to the surface):

The example applications presented here used the DTW at the sampling well was used to estimate the 14Ci values. These DTW values are likely greater than the DTW at the recharge zone, at the time of recharge, leading to minor over-corrections of 14Ci values from Eqs. 2-4. For example, for Well ID 7022-128 (Sample ID = 16, Clgw = 13.35 pmC, DTW = 27.47 m, see Table S3) the MRT using Eq. 2 was 13,180 y. If the DTW was assumed to be 5 m shallower (22.47 m), the MRT increased to 13,880 y (700 y, or ~5%). Given that Eqs. 2-4 are straightforward to implement, the impact of uncertainty on the DTW could be easily investigated.

The paper makes the implicit assumption that only the residence time in the saturated zone is of interest. Time spent passing through the unsaturated zone in the recharge zone presumably is assumed to be negligible or of no interest (which of these is not specified as this issue is not mentioned in the paper).

Response: It is true that groundwater recharge is not instantaneous. However, the timescales of infiltration through the unsaturated zone is likely to be a few weeks to a few years, which is short relative to the several thousand-year time frame of 14C residence times that are typical of many aquifers. We will note this in the revised version.

The authors have adopted a very simplified MRT estimation procedure, which they label "conventional". It is hardly conventional, since it ignores (1) the recent history of ^{14}C activity in the atmosphere due to nuclear weapons testing (instead they assume a uniform atmospheric activity), (2) the input of ^{14}C-free carbon from the aquifer matrix (i.e. they assume q = 1), and (3) groundwater dispersion producing a distribution of residence times in the sample (in effect assuming piston flow). I think it could be described better as "simplified". However, as an exercise to illustrate the application of the correction equation it is reasonable.

Response: The use of the term 'conventional' to describe the assumptions highlighted by the referee is commonplace in hydrogeology. To address this comment, we will insert the phrase "so-called" into the first description of conventional ages and add an additional reference to clarify our use of 'conventional' in this context. The relevant sentence in paragraph two of the introduction would read:

This approach yields so-called conventional radiocarbon ages in years Before Present (BP) where 1950 AD = 0 years BP (Clark and Fritz. 1997; Plummer and Glynn, 2013; Cartwright et al., 2020).

The paper is well organised and succinct, but possibly too succinct in parts making it unnecessarily difficult to understand. (e.g. The caption of Fig. 6 is very unhelpful. The symbol A_0 from the caption is not used in the text.)

Response: We will replace A0 with Ciq (to be consistent with the text). To ensure that the purpose of Figure 6 is clear, we will clarify and expand the caption to:

Figure 6: Maximum difference in calculated MRT (y) where Ciq on the x-axis is used, relative to the case where it is assumed to be 100 pmC. Secondary x-axis shows indicative water depths that correspond to 14Ciq values shown on the lower x-axis according to Eq. 2.

However, the paper is generally clearly written with few technical or detail corrections needed. It is suitable for the journal and has no unnecessary or overlong sections. The references are appropriate. The data set is sufficient to support the discussion and

conclusions. Title and abstract are satisfactory. I think the paper should be published after minor revision.

Response: We thank the refereefor their comments on our manuscript.

Specific comments

L124-125. Not sure what this sentence means. "However, owing to the relatively small sample size, the data was included in the fitting process independent of the year in which it was collected." Does this mean that no account was taken of the actual ^{14}C input function?

Response: The reviewer is correct. The paragraph in question identifies difficulties in accurately estimating what the actual ^{14}C input function might be (i.e. it will differ from atmospheric concentrations). Thus, our fitting process did not account for the year that the sample was collected in. We will update the final sentence to read as:

Owing to the abovementioned complexities, the sample date was not taken into account in the fitting process.

L134-139. I would like to see the simplifying assumptions in itemised form (1, 2, 3)

Response: This change can be made to the manuscript.

We thank the anonymous referee for their comments.