Estimation and calibration of the water isotope differential diffusion length in ice core records
tc-2014-208

Author response to the review of Anonymous Referee #1

We'd like to thank the Referee for the comments and suggestions for improvement of our manuscript. Below we restate the Referee's report in bold and answer each comment directly below.

This is a substantial paper with a number of important points to make about the information that can be obtained about past climate from ice core isotope records. However, it is quite difficult for the non-expert reader to follow the arguments being made and gain a clear picture of the results. This is perhaps because the authors are very familiar with their material and do not want to state the obvious. Nevertheless I think it would be useful to add a little more explanation, especially since this paper will be of interest to ice core chemists as well as mathematical physicists. The authors might care to consider the following points:

- **The theory section in this paper begins with an equation describing the mathematics of diffusion in ice given by Johnsen (1977), also used in a later paper Johnsen et al. (2000) which extends the analysis to firn. The derivation of this equation is not given in these papers, but appears to be as follows:**
  Express the change in the concentration of an isotope as

$$d\delta = \frac{\partial \delta}{\partial t}dt + \frac{\partial \delta}{\partial z}dz \tag{1}$$

where z is a particle-following depth coordinate and t is time. From the continuity equation and Fick's Law

$$\frac{\partial \delta}{\partial t} = D(t)\frac{\partial^2 \delta}{\partial z^2} \tag{2}$$

and by definition

$$\dot{\epsilon}_z(t) = -\frac{1}{z}\frac{dz}{dt} \tag{3}$$

Hence

$$\frac{d\delta}{dt} = D(t)\frac{\partial^2 \delta}{\partial z^2} - \dot{\epsilon}_z(t)z\frac{\partial \delta}{\partial z} \tag{4}$$

Is this correct? Should "∂" or "d" be used on the L.H.S of equation (1) in the paper?

This is correct. We will add this for completeness. We use ∂ since δ is a function of both t and z.

- **Johnsen et al (2000) and the authors (p. 936 l.7) suggest that the second term on the R.H.S. of equation 4 should be neglected for firn because $\dot{\epsilon}_z(t) = 0$ or is negligible. But the vertical strain rate in firn is not negligible, so this is very confusing. Does the second term vanish because in snow vertical compression is achieved without horizontal transport and consequent loss of isotopes?**

  We do not neglect the vertical strain rate in equation 4 (equation (1) in the manuscript). Only for the calculation of the diffusion length σ we neglect thinning due to ice flow initially (eq (7) p 936). This is corrected for afterwards as outlined (p 936, lines 9-13). The effect of thinning as a result of densification on the diffusion length is accounted for by calculating the increase in diffusion length in ice equivalents (see the term $\left(\frac{\rho}{\rho_{ice}}\right)^2$ in equation (7)). We will mention this explicitly in the revised manuscript.

- **As far as I can work out, the correlation method of determining the differential diffusion length defined by the equation**

  $$\sigma^2 = \sigma_{18}^2 - \sigma_2^2 \qquad (5)$$

  consists of taking the series which results from the (unknown) squared diffusion length σ_2^2 and producing a set of new series using different values of $\sigma_{2,add}^2$. These are then compared to the series which results from the (unknown) squared diffusion length σ_{18}^2. At the point of maximum correlation of two series it is assumed that

  $$\sigma_2^2 + \sigma_{2,add}^2 \approx \sigma_{18}^2 \qquad (6)$$

  and hence the value of $\sigma_{2,add}^2$ at maximum correlation is a good estimate for σ^2. It would be helpful to state this explicitly at some stage.

This is correct. (Note that we use $\Delta\sigma^2$ and not σ^2 for the differential diffusion length.) We will rewrite the text from p 942, line 25 to p 943, line 3 to state this more clearly.