

## ***Interactive comment on “A two thousand year annual record of snow accumulation rates for Law Dome, East Antarctica” by J. Roberts et al.***

**Anonymous Referee #2**

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Summary: The manuscript presents a reconstruction of the accumulation history for the last 2000 years at Law Dome in Antarctica, from the analysis of annual layer thickness. The major difficulty with this method is to correct the layer thicknesses from thinning from ice flow. The authors present here two classical approaches to this problem, and clearly state the shortcomings of each method and the associated uncertainty in the long-term trend. They find that there is no significant long-term trend in the accumulation record, which is in agreement with other studies in Antarctica. They also find a clear 30-year period through the dataset, which they relate to the IPO or the zonal wave 3 EOF of 500hPa geopotential height, suggesting that the variability in accumulation is driven by large scale atmospheric forcing, a conclusion also shared by

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other studies (e.g. Frezzotti et al, TC, 2013).

This work presents solid science, using well-established methods. It is clearly written, and the figures are also well made. It provides an important new dataset, which will likely be a benchmark for the community, and certainly deserved prompt publication. However, the uncertainty estimation could be improved. I offer two suggestions regarding the uncertainty in the flow correction, and the quantification of the spatial variability of the layer thickness data. The discussion could also be clarified, and it would be interesting to add a discussion of the covariance of accumulation and  $\delta^{18}\text{O}$  of water, which is not present in the paper.

General comments :

- flow thinning correction The Authors present two strategies for correcting the annual layer thicknesses for flow thinning, but both of these approaches have strong assumptions (for instance of a steady state accumulation rate), and it is difficult to understand exactly what the limitation of these approaches are, and what the impact on the accumulation trend is. To refine this problem, I suggest that the authors do a monte-carlo type calculation of the thinning function, changing the driving parameters (mean accumulation rate,  $C$ ,  $p$ ,  $z_0$ ) for each of the model by one or two standard deviation, and produce a suite of accumulation time series, which they can use to 1) calculate the uncertainty in the accumulation history 2) calculate the uncertainty on the Holocene trend, and estimate pre quantitatively whether they can actually resolve the existence of the trend. In particular, I am curious on the impact of assuming a constant accumulation rate. What if the accum rate was 10% larger, 10% smaller? How would it change the strain rate and inferred accumulation history?

- Timescale I understand that the timescale has been determined in other publications, but I think that it would be useful to test the accuracy of the timescale by giving the age of a few prominent volcanoes, and compare with their published date. This would be an independent constraint on the accuracy of the layer counting

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- Spatial variability of the layer thickness You have several cores. In the periods of overlap, how well do the layer thicknesses match between cores? I think it would be useful to add a paragraph on this in Section 2, and a plot showing the layer thickness for several cores. You mention the good overlap in  $\delta^{18}\text{O}$ , but it would be interesting to comment on the overlap on layer thicknesses.

- correlation between accumulation and temperature In Antarctica, both accumulation and temperature are often inferred from  $\delta^{18}\text{O}$ , with the underlying assumption that temperature and accumulation are correlated by the Clausius-Clapeyron equation. You have independent information about both, and it would be interesting to comment on the correlation between them, and study the time variations of this correlation (correlation on year to year timescale, versus decadal timescales, versus centennial...). Furthermore, a correlation between  $\delta^{18}\text{O}$  and accumulation might lead you to say a few words about the dominant circulation patterns that bring moist air to the site.

- spatial coherence Page 4481, the authors suggest that there is a large spatial coherence of accumulation. Could they validate this model result by comparing their record with other records of snow accumulation? for instance Dome C, Vostok, D47, D67, and the ITASE sections. There is also a major difference between figure 11 a and b in Droning Maud land, and perhaps the authors could test using ice core data whether they see significant correlation between Law Dome and DML accumulation. Many of the DML cores are archived on Pangaea.de

Specific comments:

P4470-L22-23: used "suitable" twice. Perhaps remove one of them

L25-26, very long sentence, and...and.. difficult to read, consider rephrasing

p4471, L2 : reference weather station data

L7: add (0.68m/y) after high snow accumulation.

P4472: L18 : is it 1841\_1887 or 1841-1987? Did you make a stack of cores, or just  
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splice them?

L24: "shows good replication" : show us, be quantitative about this statement. Perhaps plot it. (even if the plot ends up in the supplement)

P4473 : L5: dating error : consider giving age of large volcanic events to back up your layer count (see general comment)

P4474 : equation 2 : consider using the notations of Cuffey and Patterson :  $\lambda$  for layer thickness instead of  $z$ , which people like to use for depth, like you did for equation 1

L14 : "this method assumes that there is no long term trend in accumulation rate", then at the end of page 4478, you seem to deduct that you have no trend. It's not clear to me whether the statement of line 14 applies to subsequent section on vertical strain rate calculation. Consider adding a sentence here to remove the ambiguity.

P4475, L6 : I'm not convinced that it is appropriate to use the standard error rather than the std deviation : the std error is the error on the mean, and this is probably why you used it, but the std deviation informs you on the spread of the values around this mean, and perhaps it is more informative, when you want later to assume that the accumulation is near constant.

L7: how did you infer the uncertainty in the vertical strain rate?

L20 : "temperature at the base below the freezing point", please include a citation to justify your statement.

P4476, equation 3 : introduce a citation to justify the equation.

P4477: Consider adding subsection titles to the discussion. I suggest: 1) strain rate model 2) Accumulation history, before the paragraph starting at line 22, p4478 3) Spatial variability, before the paragraph starting at line 18 p 4480

p4478, L21 : use  $\text{m yr}^{-1}$  or  $\text{m a}^{-1}$  rather than  $\text{m yr}^{-1}$  ie

P4479: l5-6 :vocabulary overly technical. It would be much easier just to show the distribution in a plot, and eventually, overlay a classical distribution fitting your dataset, or a Gaussian distribution to highlight the skewness/long tail.

P4480, l7 : do you expect the noise of a sastruggi passing over the site to be periodic? I am surprised by your statement, because with 0.68m/year correspond to more than 2m of snow per year, and sastruggi are not necessarily that large, so I am not sure whether you can justify a 2.5 year period as being due to dune migration, unless you can quote a paper giving a quantitative assessment of speed and amplitude of dune migration in a high accumulation site like Law Dome. However, perhaps that the presence of sastruggi adds significant noise to your accumulation record at annual resolution, which is something that you should be able to document with repeat cores, as I mentioned in the general comment section. When we have a noisy record, we usually resort to averaging to increase the signal to noise ratio. In ice cores, we can average spatially, by making a composite of many cores, or temporally; by taking the temporal mean over a number of years, so that in the mean, the signal emerges. You have a lot of cores, and perhaps a number of snow pits also, and it would be useful for you to quantify the depositional noise (spatial standard deviation of the nb of meters of snowfall per year over a certain area). This way, once you know the depositional noise, you can derive how much temporal averaging you would need to do to have a decent signal to noise ratio, and not try to interpret wiggles inside of the 1 or 2 sigma envelope of the depositional noise.

L11: Correlation with the IPO. It would be useful to make a plot of your accumulation record with other climate variables of interest, that you discuss in the current paragraph: the IPO, ERA interim and RACMO-ANT reanalyses for the site, zonal wave 3, and perhaps the accumulation rate history at other sites that you expect to find significant correlation or anti-correlation (see my comment about spatial coherence in the major comment section).

L12-17 : This point about the low frequency power is hard to address because it is  
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linked with the assumptions in your methods. I think that it belongs more to the beginning of the discussion, when you discuss the two methods.

L25 : discussion of the reanalyses. I am a bit skeptical of reanalyses products in Antarctica, when the constraints are so weak. For instance, Nicolas and Bromwich, JCLim 2014 showed that for temperature, the different reanalyses products were vastly different, and the spatial patterns described in the reanalyses were conflicting, and not supported by data (see their Figure 7). When you find a good correlation between reanalyses and snow accumulation, is it because Law Dome data are incorporated in the reanalyses?

Figure 1 : make the figure a little more zoomed out, so that we can clearly see the independence with the main Antarctic Plateau.

Figure 2 could go in the online supplement if you have too many figures

Figure 3 : merge it with Fig 6

Figure 7 and 8 could go into the online supplement if you have too many figures

Figure 10 : why did you choose to do this rather than use wavelets?

I suggest you add 2 figures 1) showing overlapping records to assess the significance of all these wiggles 2) Showing your reconstruction with other variables of interest (SOI, IPO, other records. ...)

Overall the figures are very clear and readable. It is easy to understand the point behind each one of them.

References: Please add: Frezzotti, M., Scarchilli, C., Becagli, S., Proposito, M., and Urbini, S.: A synthesis of the Antarctic surface mass balance during the last 800 yr, *The Cryosphere*, 7, 303-319, doi:10.5194/tc-7-303-2013, 2013.

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