Review/comment on :

Reanalysis of a ten year record (2004-2013) of seasonal mass balances at Langenferner / Vedretta Lunga, Ortler-Alps, Italy

by S. P. Galos and co-authors,
submitted to The Cryosphere, tc-2016-286

E. Thibert, Grenoble (France) – 8 February 2017.

General comment

S. P. Galos and co-authors provide a data reanalysis scheme applied to a ten year record (2004 to 2013) of seasonal mass balance at Langenferner glacier in the European Alps.

The approach involves homogenization of available point values and reconstruction of missing data for years and locations without measurement by the application of a process-based model constrained by snow line observations. Point mass balances are then extrapolated to the overall glacier surface to quantify the glacier-wide balance help to different extrapolation techniques and recourse of topographic data. The 2 reconstructed seasonal series differ notably from the original records. The new annual mass balance series is compared to long-term volume changes determined from airborne laser-scanning data in a rigorous error analysis and following the framework proposed by Zemp and others (2013). The authors find good agreement between those determinations, the residual discrepancy being explainable by the natural scattering of the data. These favourable results are to confer a significant confidence in the correctness of the re-analysed glacier-wide mass balance times-series of Langenferner glacier.

The paper employs advanced methods of mass balance computations, and geo-statistical inferences. The paper is clear, well organized, and properly focuses the scope of the journal. I think this paper is to be welcomed also as a new appropriation from the glaciological community of the guidance proposed 4 years ago by Zemp and others (2013).

I have two main questions regarding the model tuning for point balances, and the spatial/temporal pattern of balances:

1°) I find the calibration of the accumulation rather weakly constrained on how the precipitation scaling factors $\Gamma_{i,a}$ are allowed to vary spatially (from stake-to-stake) and with time (from year-to-year). In the present formulation, Γ is allowed to account for any deviation from the observed precipitations at all stakes and independently from what happens at other stakes. The authors mention on line 25 that the spatial pattern of $\Gamma_{i,a}$ is reasonable regarding terrain curvature and wind effects. Analysing Figure 5, it seems also that some stakes systematically have lower Γ (stakes no. 21 or 25) and on some years all stakes deviates accordingly up (2009, 2011) or down (2010, 2004). Can the authors provide a colour coded map of the mean spatial structure of Γ between 2004 and 2013 which could sustain this? Therefore one should expect a much more constrained formulation in Equation (2) when it comes to tune the model at individual stakes. Maybe the authors could reformulate Γ as $\Gamma_{i,a} = \gamma_i \, \gamma_a$., fitting 2 uncorrelated functions holding spatial and times dependencies of accumulation, and accounting for systematic deviations at some locations (γ_i) and on some years (γ_a).

2°) Figure 6 shows that the altitudinal profiles of balance and the way they change over time somewhat follow the time-space decomposition proposed by Rasmussen (2004) or Kuhn (1984): $b(z,t)=f(z)+\delta b(t)$.
In search of this, the authors could test if there is strong correlation between readings at the individual stakes. This feature also suggests that Lliboutry's model should work on the data set. A 10-year time series is just long enough and eminently suitable to test Lliboutry's linear model. I would therefore encourage to possibly test this analysis all the more that it could provide estimates for missing values of point balances in the accumulation area at the beginning of the record. Moreover these estimates would be free from any meteorological or glacier-to-climate assumption and safeguards the reconstructed series for an independent and unbiased analysis with climate drivers.

Here follow some detailed questions, comments, suggestions, and indications of minor typos in the paper. Please consider them in the same positive way in which they are proposed.

Substantive comments
P1-L1. You could mention that both uncertainties (scattering) and incorrectness (biases) affect calculations.

P1-L11. Annual values for mass balance refer to changes per unit of time (rate) and should here and throughout the manuscript expressed per year (yr^{-1}). Although there is not uniformity of units regarding specific mass balance (per unit of area), the authors could use the convenient, numerically equivalent and more meaningful mm w.e. or, alternatively, the SI unit m w.e. instead of kgm^{-2}.

P1-L19. Don't you think that a more direct (physically-based) driver is rather the surface energy balance?

P3-L21. Again please express rate units per year (yr^{-1}).

P4-L10. You mean that these stakes couldn't be measured any longer?

P4-L26. Please use when relevant "glacier-wide balance" terminology to fit Cogley et al. (2010) glossary.

P5-L24. A bit more needs to be say on how single out definitely areas outside the glacier subject to elevation loss (erosion in moraine terrain) and area on the glacier subject to reduce ablation (thick debris)?

P7-L19. A 10-year time series is just long enough to test Lliboutry's linear model as the spatial terms generally converge to steady values over this time scale.

P8-L15. At which spatial scale does ERA-Interim provides time series for atmospheric pressure?

P8-L26 to P9L8. How ranges the pre-calibrated scaling factor Γ_0 compared to the altitudinal gradient of precipitations?

P9-L10 to 28. As mentioned above, the calibration is very weakly constrained on how $\Gamma_{i,a}$ is allowed to vary spatially and with time and one should expect a much more constrained formulation in Equation (2). Please refer to my general comment ahead.

P10-L29. I suspect a 1x1m resolution grid to be an oversampled interpolation. Considering 250 kg m^{-2} contour-lines and analysing Figures 4 and 6 suggests that just 4 to 5 contour-lines should cover the altitude range [3125-3375 m] over nearly 1 km in the accumulation area. Which means that a 100x100 m would be the right sampling scale adopting a maximum of 2 grid cells between contour-lines.

P11-L25. Don't you think it should be better to adjust field data to preserve the independency of the geodetic balance as a reference control?

P13-L15. Looks like my comment on P5-L24 on how single out areas outside the glacier subject to erosion and area on the glacier subject to low ablation.

P15-L5. Here and in section 4.2, I am not sure if 3 levels of subsections are worth.

P14-Equation 14. Here you assume errors to be uncorrelated to combine them quadraticaly. To some extent, this general formulation from Zemp et al. (2013) does not account that errors at a point and errors associated to the spatial integration are combined through weighting coefficients in the spatial averaging. Make here an explicit referral to the supplement S2.1 where details can be found about error calculations.

P16-L12. Unit kg m^{-2} yr^{-1}?

P17-L5. How do you think your re-analysis model will perform in case of systematic positive balances over few years? Would you have to recalibrate it? Or to reformulated the approach?

P17-L8. Title section 5.2: Mean (specific) glacier-wide annual balance
Specific means per unit area, not averaged at the glacier scale.

P17-L9. Can you estimate the spatial variability of the mass balance at the glacier scale from the five different extrapolation methods? And for winter and summer balance as well?

P17-L20. Biases units kg m^{-2} yr^{-1}?

P20-L10. It would be helpful to remind the reader that you did not correct for such internal processes.

Tables
Table 4. Legend. Remove "s" after δ.

Figures
Figure 6. I don't find where the main text refers to Figure 6

Figure 7. I suggest to add the 1:1 line and the fitted line with the equation terms providing intercept (bias) and slope.

Figure 10. Is it possible to plot error bars (one sigma) on cumulative balances.

References

Cogley, J. G., Hock, R., Rasmussen, L. A., Arendt, A. A., Bauder, A., Braithwaite, R. J., Jansson, P., Kaser, G., Möller, M., Nicholson, L., and Zemp, M.: Glossary of Glacier Mass Balance and Related Terms, IHP-VII Technical Documents in Hydrology No. 86, IACS Contribution No. 2, UNESCO-IHP, Paris, 2010.

Kuhn, M. (1984), Mass budget imbalances as criterion for a climatic classification of glaciers, *Geogr. Ann.,* 66A, 229– 238.

Rasmussen, L.A. 2004. Altitude variation of glacier mass balance in Scandinavia. *Geophys. Res. Lett.,* 31(13), L13401. (10.1029/2004GL020273.)

Supplement
In the main text of the paper, provide much more explicit referrals to the supplement when needed.

Stylistic/flaw/typos
P5-L5. The "glacier" surface energy balance, not glacial

P9-L14. Therefore

P12-L6. Therefore

P20-L12. Point to be deleted after "shown"

P21-L33. Add a space bar "52 kgm^{-2} for winter"