Response to reviewers 2

Each of the reviewer's comment are included and the response and altered section from the manuscript below in italic.

Rev. 1

First af all, the authors answered to all the comments made by the reviewers. I thank them. They reformulated many paragraphs of the paper. In particular, the sensitivity analysis is now much clearer. Moreover, they added a discussion about the validity of the assumptions made to apply their methodology.

That is the reason why, to my mind, this paper is now acceptable.

I have only some minor remarks:

- line 31: firm instead of firn?
Changed to firn

- line 77: Jougnot et al. 2012 does not appear in the reference list
Reference has been added

Jougnot, D., Linde, N., Revil, A., Doussan, C.: Derivation of soil-specific streaming potential electrical parameters from hydrodynamic characteristics of partially saturated soils, Vadose Zone J. 11. doi:10.2136/vzj2011.0086, 2012.

- line 114: longitudinal (i.e., in the direction of the slope) instead of lateral?
The term lateral was removed and the sentence not reads;

'It was therefore our aim to characterise bulk meltwater fluxes in inclined snowpacks at two glaciers in Valais, Switzerland, measuring all relevant snow pack attributes for ground truth.'

- line 242: Albert et al. 1998 does not appear in the reference list
Reference has been added

Albert, M., and Krajeski, G.: A fast, physically based point snowmelt model for use in distributed applications, Hydrol. Processes, 12, 1809–1824, doi:10.1002/(SICI)1099-1085(199808/09)12:10/11<1809: AID-HYP696>3.0.CO;2-5, 1998.

- line 293 (equation 8): define what is the pzc (isoelectric point)
Pzc is point of zero charge, this has been added to the text and the sentence prior to equation 8 now reads;

'The zeta potential is principally a function of pH and electrical conductivity and the combined dependency of the zeta potential on EC (sw), meltwater pH (pHw) and the meltwater pH at the point of zero charge (pHw (pzc)) can be expressed as'

- line 519: Jouniaux et al. 2009 does not appear in the text

Jouniaux et al. 2009 has been removed from the text

- line 537: the year (2007) is missing
The year has been added and the reference now reads;

Linde, N., Revil, A., Bolève, A., Dagès, C., Castermant, J., Susli, B. and Voltz, M.: Estimation of the water table throughout a catchment using self-potential and piezometric data in a Bayesian framework, J. of Hydrol. 334, 88-98, doi: 10.1016/j.jhydrol.2006.09.027, 2007.

- line 589 (Table 1): since the uncertainty range is deduced from the sensitivity range, maybe *place the sensitivity column before the uncertainty column*
The columns have been swapped over, see below;

Measured / estimated parameters	***Best estimate***	***Sensitivity range***	***Uncertainty range***
Self-potential (V)	*Variable*	*± 20%*	*± 40%*
Discharge Q ($m^3 s^{-1}$)	*Variable*	*Q ± 20%*	*Q ± 40%*
Electrical conductivity σ_w ($S m^{-1}$)	*5×10^{-6}*	*$\sigma_w \pm 5 \times 10^{-7}$*	*10^{-7} –10^{-4}*
Zeta potential ζ (V)	*-1×10^{-5}*	*$\zeta \pm 50\%$*	*$10^{-4} – 10^{-6}$*
Permeability from;			
Grain diameter d (m)	*0.00175*	*d ± 0.0005*	*d ± 0.001*
Density ρ ($kg m^3$)	*555.5*	*ρ ± 70*	*ρ ± 140*
Cross sectional area from;			
Width w (m)	*12.5*	*w ± 5*	*w ± 10*
Depth dp (m)	*1.45*	*dp ± 0.2*	*dp ± 1*

- line 594 (caption of Figure 1): say somewhere the size of the SP grid (in order to have a scale)
The size of the SP grid has been included in the caption, which now reads;

Figure 1: (a) Example survey set up, SP grid 25x25m. Insert left show the location of both fieldsites. Insert right illustrates the self-potential survey design; to provide each self-potential data value, a profile of 25 data points (P1, P2, etc.) was collected (Line 1, Line 2, etc.), perpendicular to assumed bulk water flow.

<u>Rev. 2</u>

The authors have done a nice job revising this manuscript. Overall, it is much improved, and the new conclusions section helps pulls the manuscript together. It should be published, addressing a few minor last issues.

The results of the sensitivity analysis are interesting. In particular, the authors note: “Despite our consideration of extreme potential error bounds, calculated uncertainties in liquid water

contents are restricted to a relatively small range (~ 20 % for large assumed uncertainty in the zeta potential, and ~ 3 – 4 % otherwise)"—if this is the case, then the downside of such "robustness" might be: who needs a measurement? Could we not just guess a field value and do a calculation and be close to the truth? I suppose the variation in impacts associated with the zeta potential would be the crux as noted in the conclusions, but perhaps the other result is just that the rest of our measurements aren't important. Do I misunderstand? I feel like this part of the paper still isn't as clear as it could be.

It is true that in some cases measurement of the additional snow and meltwater characteristics may not be vital to the estimation of liquid water content using the self-potential technique, particularly when the measurements have small variability but we cannot just guess a field measurement. Having the all of the additional measurements provides confidence in determining the maturity (or immaturity) of the snowpack and therefore robustness of the liquid water content estimation. The data we present are the result of the first field tests for mature snowpacks, conditions will be different in space and time affecting the characteristics we measure and their impact on the estimation. In addition, the snow and particularly meltwater characteristics are important measurements in improving our understanding of the zeta potential. It is also important to clarify that it is the LWC uncertainty bounds that are small, not absolute values of LWC – the latter are spatially and temporally highly variable and necessitate a field measurement. The conclusion states (L430-35);

'Future work must ascertain to what extent longer-term monitoring studies are affected by the preferential elution of ions and the associated impacts on meltwater pH, EC and thus the zeta potential. Even if such effects were found to be of concern, meltwater EC and pH are readily monitored in-situ with automated probes and could be measured alongside self-potential data at a calibration location, and subsequently be assimilated in snow models.'

Ultimately we would like to characterise LWC over significant spatial areas, and there is obviously a limit to the spatial distribution and density of possible electrode placement. The robustness of the estimation means that in practice we can make SP measurements at several points within the area of interest, and then make reliable interpolations between measurements in space and time. The following sentence was added to the conclusion (L435-39);

'*Being able to characterise LWC over significant spatial areas is limited to the spatial distribution and density of possible electrode placement. However, the robustness of the estimation means that in practice SP measurements at several points within the area of interest can in the future make reliable interpolations between measurements in space and time.*'

I'm also not sure how to place a reference electrode where no streaming potential exists. How do you find this place? I appreciate that it is "elaborate" but some elaboration would be useful to the readers of this paper.
The location criteria and the emplacement are described in section 2 (lines 139-42), which reads;

All self-potential measurements were taken as differential readings relative to the reference electrode, minimizing streaming, electrochemical and thermal potentials at the latter by grounding them outside the survey areas at the top of a local topographic high point (Fig.

1a), submerged in a glass jar, open at the top and filled with water-saturated local media (Kulessa et al., 2003a). The jar was then buried upright ~1 m deep to avoid exposure to surface temperature variations.

This description has now been referred to in the conclusion, the sentence now reads;

The latter is unknown in our field feasibility study, although our method of emplacing the reference electrode is elaborate and designed to eliminate, or at least minimise, any streaming potentials at the reference electrode (see Section 2).

Because the conclusions section is wholly new, I have a few comments/questions:

Line 441: the authors talk about the "scaling factor"—it would be good to note what that is again here.
The scaling factor referred to here is the right hand side of equation 4, this is now stated in the text and the sentence reads;

The scaling factor (right side of equation (4)) depends principally on the liquid water content of the snowpack, its permeability and the water chemistry (Kulessa et al., 2012).

Line 461: "overestimation of pore diameter" — citation needed.

Schneebeli and Sokratov (2004) show that for higher density snow samples (>490 kg m^{-3}) grain diameter is an overestimation of pore diameter. At our test sites average snow density is 564 kg m^{-3} and therefore higher than the threshold proposed by these authors. We can therefore expect grain diameter to be an overestimation of pore diameter at our study sites, as stipulated. The sentence now reads;

'In porous media such as snow L corresponds to the average pore diameter, and in the absence of direct evidence is assumed to be equal to grain size. Where snow is denser than ~ 490 kg m^{-3}, such as that at our study sites (average ~ 564 kg m^{-3}), grain size is expected to be larger than pore diameter (Schneebeli and Sokratov, 2004). This assumption is therefore likely an overestimation of pore diameter.

Line 463: Re = 50.7—is this really good to three significant figures?
The sentence now reads;

For the respective snow properties and their uncertainties reported in Table 1 values of Re between < 1 and 51 are obtained, with a best estimate of Re ≈ 1.1.

Line 474: Was there an inversion here that I missed? It seems like there are just basic calculations done on raw data—did I miss something fundamental here?
We were referring to the simplest case 'inversion', the inference of material properties from geophysical measurements, using some constative relationship. To avoid any confusion this has been changed and the sentence now reads;

'We have also shown that the estimation of snow properties, such as liquid water content, from self-potential data is insensitive to the area of snowpack contributing meltwater flow to the measured signals.'