Comments by reviewer 2

The original comments were in a PDF and have been copied here (in black). Answers are provided in blue.

Line 56-58: How is this model different from the model being used in this manuscript? Since this is the most recent model, please point out the detailed differences including assumptions and pros and cons of each approach.

Advantages include the combination of thermodynamics and firn modelling with the aquifer modelling in Miller et al (2023), and includes procedures to model unsaturated and saturated flow, a process that is missing in our approach. SUTRA-Ice is only tested on a 2D, flowline case of the Helheim glacier with constant recharge rates. Our simulation is 3D, tested and calibrated against three years of observations and including a 'downscaled' meteorological forcing to simulate surface melt, firn conditions and the behaviour of the aquifer over time.

We will add to L 57: 'The model SUTRA-ICE is comprehensive: it contains water flow through the unsaturated zone as well as water movement within the saturated zone. Freeze-thaw cycles are modelled, so a winter freeze of (a part of) the modelled PFA is represented. The model is tested on a 2D flowline of the Helheim glacier, with constant recharge rates. 3D flow and realistic meltwater input from a (downscaled) climate or energy balance model is missing.'

Fig 1: add ice edge boundary to this figure so the reader has a better sense of glacier setting. Also, make sure the colors of the rectangles match the caption and the years 2015 and 2016 do not appear in the text. Change 'next paragraph' to 'below'

We will remove the years 2015 and 2016, both from the figure as from the caption. We will change the colormap to make it easier to distinguish between height contours. We do not deem it necessary to add glacier outlines to this graph, because in this study we do not refer to or use data from individual glaciers.

Line 111: Explain this in more detail. Are there any density vs depth measurements available?

Yes, snow pits have been dug at this location, to which the EBFM is tuned, see Van Pelt et al. (2019). We then use a density profile of the EBFM close to the location of the measurements to calculate the dielectric constant for firn snow, which we use to calculate the velocity of the radar wave in the firn. We then use this velocity of the radar wave to turn the TWTT to the reflective surface that is semi-automatically picked to a depth to the water table. We will change Ln 111 – 114 to:

'The raw GPR data was minimally processed with zero-time adjustment and a low-pass filter (300 MHz cut-off frequency). An example radargram is shown in Figure 2. The water table is picked from a radargram shown in Figure 2 semi-automatically: first, the reflective surface of the water table is manually found in a single data point. Then, a tracing algorithm is used to track that reflective surface through adjacent points. This results in the two-way travel times (TWTT) per datapoint. Then, the velocity of the radar wave in the firn is used to calculate the distance to the water table from the surface. For this, the dielectric constant of firn is required, which is calculated according to Eq 1 from Kovacs et al (1995) where ρf is the density of the firn layer and ρw the density of water:

The density of the firn at the location of the observations is obtained from the Energy Balance Firn Model (EBFM; Van Pelt et al, 2019), of which a description is given in the next section.'

Line 123: please give more details

We will rephrase this to:
' … which has previously been calibrated and validated against stake measurements, weather station data and observed density profiles from shallow firn cores. For more details, we refer to Van Pelt et al (2019).'

Line 140: is there a term that describes the density changes due to melt/freeze events?

Yes, the second F/dZ term in Eq 4. You can choose what unit for F to use, in the manuscript we used kg m^{-2} s^{-1}, so we needed to divide by the layer thickness dZ. We will just use F in kg m^{-3} s^{-1} as the density increase through refreezing.
We will add to Line 140: and F is the refreezing rate (in kg m^{-3} s^{-1}) and remove dZ from the equation.

Line 219: can you quantify the difference?

Thanks for this suggestion. However, we rather do not use the GPS measurements of the surface height. We will leave the GPR observations in terms of 'depth below the surface', and transform LPFAM data, which is typically in height above sea level with the DEM from Melvaer et al (2014) to a depth below the surface. We will change Ln 211 – 2019 to:

'LPFAM output gives the elevation of the water table in meters above sea level (m a.s.l.). The raw observational data gives instead water table depth below the surface. We use the Digital Elevation Model (DEM) of Svalbard referred to as the Terrengmodel S0 with a resolution of 5 meters from ‚Melvær et al. (2014) re-gridded to the model grid of the LPFAM as the firn surface. We then use the re-gridded DEM to subtract our modelled water table height above sea level, to obtain modelled water table depths in m a.s.l.'

Table 2: Can you estimate the uncertainty in this?

Thanks for this suggestion. We will add to Line 292:

'There are uncertainties in the observed water table depth shown in this study. The system specific uncertainty (related to the sampling frequency, the cable length, and the GPR used is small and about ±0.02 meters. The largest source of uncertainty stems from the calculation of the velocity of the radar wave, which is calculated using a modelled density profile of the firn. When changing the firn density arbitrarily with ±10%, this resulted in a spread of ±0.21 m in calculated water table depths. The uncertainty arising from digitizing the water table, quantified by doing cross analysis of double-measured points during the same field season, results in ±0.03 m.

Fig 7: should this be blue?

Yes, thanks for spotting. We will change this.

Ln 354: Sentiel-1 may also be helpful and could potentially identify buried crevasses since C-band SAR can penetrate some snow covered surfaces

This is a great suggestion. We will add Sentinel 1 to our discussion and look for more prove on the existence of crevasses.

Ln 355: or potentially lakes depending upon local topography

We will add 'or meltwater lakes, if the surface topography allows for it'

Melvær, Y., Aas, H., and Skoglund, A.: Terrengmodell Svalbard (S0 Terrengmodell), Norwegian Polar Institute, 465, 2014.