I would like to thank both reviewers for the time and care they have taken with their reviews. I think responding to their comments and criticisms has improved the paper. In the following the reviewer comments are in italics and the responses are in standard font.

Reviewer 2.

This manuscript presents a concise and well-thought-out analysis of bass balance for a small but interesting piece of Humboldt Glacier. Although it does not try to solve the entire problem to ice-sheet mass balance, it contains a thorough and detailed analysis that would be a good model for other studies of the same type. I was happy with the way the material was presented, except for a piece of the analysis of the altimetry that I didn't understand, and that I think needs either more detail or a more convincing argument.

The section that I found problematic was the treatment of the mass balance for the high-elevation portion of the basin. Here, Dr. Gray writes: "Thirty-day height change data derived from all the CryoSat POCA data for basin 3 above 1300 m (Fig. 3) shows that there was a melt season height decrease in this area only in 2012, 2015 and 2019 (Fig.3B). As there is no evidence of run-off to lower elevations or of an associated change in speed, I ascribe these height changes predominantly to surface melt and sub-surface refreezing, i.e., firn densification, and reduce the volume loss using these values so that the mass loss can be estimated. The average summer height losses associated with densification (Fig. 3B) were 0.42±0.08 m (2012), 0.45±0.08 m (2015) and 0.4±0.08 m (2019) based on the 44,756 P OCA height results spanning the nine years and the area of basin 3 above 1300 m."

It seems to me that we should expect to see surface lowering during the summer. Even in an area of a glacier where the velocity is constant, for steady state the accumulation need only balance ice flow in the annual average. During the winter, we would expect to see accumulation in excess of that needed to balance ice flow and consequent surface rise, and during the summer, we would expect to see too little accumulation to balance ice flow, and consequent surface lowering. It seems that to assess the contributions of accumulation and densification to volume change we need external information. It maybe that the MAR data provide clues about this, and there's been some extra analysis that didn't make it into the manuscript, but I didn't see a strong argument for why all the surface lowering should be due to firn densification. Absent this argument, might it make more sense to remove the area upstream of 1300 m from the analysis? It seems that it's not the source of significant runoff.

I acknowledge that summer surface lowering in the accumulation zone need not be due solely to firn densification. Also, as the results show that the run-off originating from the area above 1300 m is minimal, the issue of the source of the summer height decrease in the accumulation zone in some years is not central to the contribution of the paper, and could be left out. Nevertheless, I would still like to include a rewritten section on the observed height change in the accumulation zone, and the possibility that in some years this could be indicative of firn densification. The expanded rewrite is now a little more speculative, but I hope still persuasive and useful to readers. Data from satellite altimeters, both optical and radar, represent a very direct way to track ice cap and ice sheet volume change but there is an issue in converting this to the more important mass change. Most papers using firn densification models to do this, e.g.

for radar altimetry; McMillan, M., et al. (2016), Geophys. Res. Lett., 43, 7002–7010. 2016, and for laser altimetry; Smith et al., Science, June 2020, Vol. 368, Issue 6496, pp. 1239-1242. But the results can only be as good as the reanalysis of the input weather data, which are very sparce for the large ice sheets. I think any approach which can contribute to this problem should be explored, especially a direct method using satellite data. Here the sequence of SAR imagery spanning the summer of 2019 (supporting material) shows conclusively that there was surface snow melt into the accumulation zone of the test area in this year. The record of yearly melt conditions over Greenland on the NSIDC web site also documents the unusual conditions in this area in the summers of 2012, 2015 and 2019. The unusually warm conditions for 2012 are well known. For summer 2015; (from http://nsidc.org/greenland-today/2015/11/), '….a surge in melting in late June and all of July as very warm conditions prevailed along the far northern and northwestern coast,…'. And for 2019, (from http://nsidc.org/greenland-today/2019/11/) ; '…(melting) was particularly intense along the northern edge of the ice sheet, where compared to the 1981 to 2010 average, melting occurred for an additional 35 days.'

The high temporal resolution (30-day) height change data for the 44,756 points in the upper accumulation part of the test area (Fig.3B) shows an overall height decrease from the fall of 2010 to the fall of 2019 of ~ 1.5 m with numerous small rises and dips. However, there are three relatively large height decreases of ~0.5 m, now marked with red arrows in the revised Fig.3B, which correspond to the melt seasons in 2012, 2015 and 2019. The height decreases could be associated with a relatively sudden change in ice speed but no such summer spike in speed has been observed at these elevations. Consequently, I think we can confidently associate these anomalous height decreases to the unusually warm summers in this area for these years. However, if surface melt did lead to the height decrease where did the water go? Again, I think the high-resolution SAR imagery helps show that there are none of the clues that one would normally associate with run-off to a lower elevation, e.g. surface streams, moulins or supra-glacial lakes. The suspicion then is that the water percolated downwards and ultimately became refrozen, thus leading to surface lowering and increased firn density of the near surface layer. If we assume that the height change reflects firn densification through surface melt and percolation, then calculating the volume change to mass change is now straightforward: The summer volume loss in this area does not represent a mass loss, and the summer dips in elevation in 2012, 2015 and 2019 can be discounted in calculating the mass losses.

The rewritten part of the text in the results section is added below for convenience…

The cumulative net run-off for the three basins (Fig. 2D) is estimated based on the ice flux difference between input and output, the accumulation and the net change in basin mass, as described in section 2.4 above. By the Fall of 2019, the cumulative run-off for basin 2 is comparable to that for the larger basin 3. As the larger basin contains the smaller one, the run-off from the larger basin cannot be less than the smaller one implying that most of the run-off originates from below gate 3 in all years. However, when converting the yearly volume change to mass change in the accumulation zone care should be taken to account for changing summer weather conditions and the impact this may have on firn compaction and therefore, near surface density.

Firn densification models can be used to improve the volume to mass change estimation, e.g. McMillan, et al. (2016) and Smith et al., (2020), but the results can only be as good as the reanalysis of the input weather data, which are very sparce for the large ice sheets. Here, a straightforward correction has been carried for three years when anomalous height decreases were observed for the summers of 2012, 2015 and 2019. Figure 3 shows the positions of 44,756 height estimates above 1300 m in basin 3, and Fig. 3B shows the average height change sampled at 30-day intervals from the Fall of 2010 to the Fall of 2019. The three red arrows indicate the anomalous height decreases in the summers of 2012, 2015 and 2019. In an idealized situation, the surface height would not change for an ice sheet in equilibrium, and the slow snow accumulation would be balanced by the slow downslope movement of the ice. However, the detected height change data can be affected by temporal changes in accumulation, downslope ice speed and near surface conditions including summer firn densification. A sequence of Sentinel SAR imagery spanning the summer of 2019 (see the supporting material) shows that there was surface snow melt extending up into the accumulation zone of the test area in this year. The NSIDC 'Greenland Ice Sheet Today' web site documents the melt conditions over Greenland and the unusual conditions in this area in the summers of 2012, 2015 and 2019. The unusually warm conditions for 2012 are well known. For the summer 2015; (from http://nsidc.org/greenland-today/2015/11/), '….a surge in melting in late June and all of July as very warm conditions prevailed along the far northern and north-western coast,…'. And for 2019, from http://nsidc.org/greenland-today/2019/11/ ; '…(melting) was particularly intense along the northern edge of the ice sheet, where compared to the 1981 to 2010 average, melting occurred for an additional 35 days'. Consequently, the anomalous height decreases in this area can be linked to the unusually warm summers in 2012, 2015 and 2019. While the height decreases could be due to a relatively sudden change in downstream ice speed no such summer spike in speed has been observed at these elevations. As there are none of the clues that one would normally associate with run-off to a lower elevation, e.g. surface streams or supra-glacial lakes, the most likely explanation for these three summer height decreases is surface melting, percolation of the melt water and subsurface refreezing. When calculating the volume change to mass change I assume, therefore, that the height losses of 0.42 ±0.08 m (2012), 0.45 ±0.08 m (2015) and 0.4 ±0.08 m (2019) were due to firn densification and I correct the yearly volume change accordingly. The error associated with this assumption is hard to evaluate but an additional error of ±10 cm has been included to account for unknown biases in the height data (section 3.2 below).

My other comments are editorial.

Line 18: Should give an example of the use of the model, not just a reference to the model.

The Fettweis 2017 reference does show how the model is used… ('Reconstructions of the 1900–2015 Greenland ice sheet surface mass balance using the regional climate MAR model')

Line 20: "height when" -> "height with radar altimeters when"

Phrase added.

Line 37: small -> weak

This part was rewritten…

For example, when the height and height change of the surface of supra-glacial lakes were mapped using CryoSat swath mode data (Gray et al., 2017), the relatively flat lake provided a strong reflecting surface so that the returns from the lake dominated over any range-ambiguous regions. Consequently, the differential phase reflected the cross-track look angle for the supra-glacial lake and allowed accurate geocoding and height estimation of the lake.

Line 38: "to the supra-glacial" -> "for the supra-glacial"

Changed, as above

Line 38: add "of the lake" after "estimation"

Done.

Line 39: "By using" -> By selecting

Changed.

Line 43: This paragraph needs an introductory sentence that summarizes the method and helps provide some context for the trade off between patch size and accuracy

An introductory sentence has been added…

In calculating ice height and temporal height change we need to be able to change both the area over which the change will be measured and also the time interval between average height estimates. There is a trade-off…

Line 43: "data is" -> "data are"

Fixed.

Line 47: rather than saying that the size of the window can be increased, say that you increased it (otherwise it's ambiguous what was done in the study).

Fixed.

Line 51: add comma after "this period"

Done.

Line 52: add comma after "369 days"

Done.

Line 53: add comma between "next" and "many

Done.

Line 55: "year-to-year work" -> "year-to-year differences"

Changed.

Line 57: "has provided" -> "provides

Changed.

Line 58: add comma after moderate

Comma added.

Line 61: “samping is 2.4 km” -> “bin spacing is increased to 2. .4 km.

Changed.

Line 66: “good weather data” -> “accurate weather data”

Changed.

Line 74: change-> vary

Changed.

Line 103: thickness and speed should both be plural.

Corrected.

143-144: “are available as mm” -> “are provided in units of mm”

Yes, corrected.

144: I think the units are most likely mm water equivalent (not per square meter). This is numerically the same as kg / mˆ2.

As above

145: “at 150 m” -> “on a 150-m grid”

Changed.

164: “is less” -> “are fewer

165: “less than that” -> “smaller than those”

164 and 165 Fixed, as suggested.

166: add comma after “four gates”

Done,

173: comma after “balance”

Done.

208: delete quotes around 30-day

That sentence has gone in the rewrite.

235: issue->question

Data availability: Need to provide a source for the MAR accumulation data.

The link to the ftp site has been added to the data availability section.