Author Response to RC2

General author response: We would like to thank the reviewer for their thoughtful and constructive comments. Here, we provide our responses to all comments, and we explain the revisions that we plan to make to the manuscript. Along with the specific changes outlined in the responses below, we have also made a change from using the GIMP DEM to using the ArcticDEM as our reference ice sheet surface, in response to a comment made by Reviewer 1. This allows for a better representation of the current ice sheet, as the reference elevations are closer in time with the ICESat-2 observations, and has significantly reduced many glaciers' individual mean dH error values for each point seen in the plots (Figure 1, Supplementary Material Figures).

Main comments:

Detrending data:

I wonder if it is useful or appropriate to detrend such short time series, especially at glaciers with only one year of data. This approach can completely alter the characteristics of the seasonal pattern and/or the magnitude of change in a given season (see for example, thinning from Autumn 2019 to Spring 2020 at Nansen glacier in the raw time series as opposed to thickening shown over the same period in the detrended time series).

Author Response: We agree with the reviewer that care should be taken when using a short time series to estimate a trend. What we have found, however, is that the impact of removing the trend is very limited for this dataset (more information below). Because our goal is to classify seasonal change, we have chosen to keep the detrended measurements as the focus in the main text. However, we will add a paragraph to the discussion section to discuss the implications of removing the trend and the impact on our classifications.

Part of our reasoning for keeping the detrended measurements as the focus of the paper is that the impact of detrending the data on our seasonality classifications is limited to just 5 out of 37 glaciers when using ArcticDEM (new plots will be provided in the revised manuscript). In other words, 5 glaciers would change classifications if we were to use the dynamic thickness change time series without the trend removed (i.e., comparing the purple and orange curves in the supplementary figures for glaciers 2, 16, 27, 32, and 47). This is also true for the classifications in the initial submission of the paper, which used the GIMP DEM as the reference ice sheet surface height. Four glaciers (IDs 16, 47, 93, 150) would have changed classifications if we had used the dynamic thickness change without the trend removed (see supplementary figures in our first submission). Nevertheless, we will add to our discussion the caveat that the interpretation of seasonal changes of these glaciers is sensitive to the way in which a trend is estimated and removed. The fact that our classification of most glaciers is unaffected by the trend shows that the dynamic thickness changes that these glaciers undergo from season to season are larger in magnitude than their annual trend and we will add this as a point of discussion, as well.

Timing and description of thickness change:

I think the timing of seasonal thickness change can be presented in a way that is more intuitive. Based on Figure 1 and the supporting text, a given seasonal change is defined by the change from the previous season to the current (for example, an increase in thickness from spring to summer is described as "summer thickening" – as in Figure 1c). However, this description could be misleading to readers. For example, an elevation increase between mid-March (spring) to mid-June (summer) would be considered summer thickening in the text, even though the time over which the change occurred is primarily spring months (April and May).

Instead, I suggest one of two alternatives:
(1) I think it would be more accurate to describe the timing of thickness change by the season that corresponds to the midpoint between two observations. For example, thickening observed between mid-June and mid-September would be centered on early August, or "summer thickening" (as opposed to autumn thickening due to a September end point).

(2) The second alternative is to change the language surrounding seasonal change throughout the manuscript. Rather than describing a pattern as one with "summer thickening," describe the glacier as one that "thickened from spring to summer."

Author Response: We agree with the comment that the language we used to describe the timing of change may be ambiguous and we will change the language using the reviewer's second suggested alternative throughout the manuscript. Each point in our plots in Figure 1 shows the mean surface elevation change, as referenced to the initial point. Thus, seasonal surface elevation change is the difference between one point and the next. We will make it clearer that our interpretation and classifications are based on the difference from season to season, rather than at each point individually.

Relatedly, the vales plotted in Figure 1 are somewhat challenging to interpret. My understanding is that dH is first derived by comparing ICESat-2 values to those from GIMP DEM, and then the dH time series is shifted so that the first data point (typically in winter) has a value of zero (see the purple dynamic time series in the Supplement). These time series are then detrended, with some examples representative of each seasonal pattern appearing in Figure 1. Due to the detrending, the resulting series then start with a positive or negative wintertime value that is somewhat meaningless. Without carefully reading the methods and cross-referencing the Supplementary figures, I would incorrectly interpret a negative wintertime value to represent wintertime dynamic thinning. In this case, the values themselves are unimportant, but rather it is the change between seasonal values that has meaning. I would suggest shifting the time series to begin at zero post-detrending and changing the y-axis label to read "Relative dynamic thickness change". If the authors elect to forego detrending altogether as I suggest above, a sentence can be added to the figure caption here to describe how values are relative to the initial time series surface. Alternatively, a secondary y-axis could be added to each figure that shows the derivative of thickness change values, or the change between each season.

Author Response: We agree that the way in which we plotted the data may be unclear and, to address this comment, we will make the following changes:

1. Shift the detrended time series such that the first point is at zero
2. Change the y-axis label of our plots to "relative dynamic seasonal thickness change (m)"
3. Add a sentence to the figure caption to describe that each value is relative to the first value in the time series
4. Clarify the language in the manuscript to state that our classifications are based on the changes from season to season, rather than at each point individually

On excluding seasonal changes greater than 25 meters:
Some justification for the 25m-magnitude seasonal change cutoff, which is used to exclude several glaciers from the analysis, is warranted.
Sub-annual thickness changes of similar magnitude have been discussed in the literature (for example, up to 50 m at Jakobshavn in Joughin et al., 2020 and 19 m at Helheim in Bevan et al., 2015).

Joughin, I., E. Shean, D., E. Smith, B. and Floricioiu, D.: A decade of variability on Jakobshavn Isbræ: Ocean temperatures pace speed through influence on mélange rigidity, Cryosphere, 14(1), 211–227, doi:10.5194/tc-14-211-2020, 2020.
Bevan, S. L., Luckman, A., Khan, S. A. and Murray, T.: Seasonal dynamic thinning at Helheim Glacier, Earth Planet. Sci. Lett., 415, 47–53, doi:10.1016/j.epsl.2015.01.031, 2015.:

Author Response: We agree with the reviewer's comment and we will change our threshold to 50 m and we will cite Joughin et al. (2020) as the largest observed seasonal thickness change to date. We note, however, that this change will not add any previously excluded glaciers from our analysis because the excluded glaciers had magnitudes of dynamic thickness changes of over 75 m from season to season. Nevertheless, we will change our threshold to be consistent with previous literature.

Glacier speed vs seasonal dynamic change pattern, beginning on line 160
Velocity values are taken straight from Rignot and Mouginot 2012, which is cited, but these velocity figures are now ~1 decade older than the ICESat-2 elevation data used in this study. Was a regression performed to conclude a weak relationship mentioned in line 160, or rather a more qualitative assessment? These things considered, I'm not sure this paragraph/analysis adds much to the study as is probably best omitted.

Author Response: Please see our response to the next comment, which addresses this comment as well.

If velocity and dynamic thickness changes are more closely examined in future work, I'd suggest using the seasonal range in glacier speed (perhaps as a % of annual mean speed) as a more appropriate metric to compare against dynamic thickness change patterns. For example, I would hypothesize that glaciers with larger seasonal ranges in velocity to have seasonal thickness patterns that are less sensitive to SMB, due to a larger dynamic thickness change component.

Author Response: We agree that the qualitative assessment of the velocity values added little to the manuscript and we will remove it. Our ultimate goal, beyond the scope of this study, is to compare seasonal dynamic thickness changes with seasonal velocity changes. But we feel that this would be better left for future work that can take advantage of additional ICESat-2 measurements over the next several years, which can provide data for glaciers that we were unable to classify. In this Brief Communication, our goal is to present initial observations of thickness changes as observed by ICESat-2 as well as one potential method for quantifying these changes.

Minor comments:
Line 63
Change "average ice discharges" to "average ice velocities"

Author Response: We will make this change.

Courtrauld, a slow-moving glacier, is reported as having one of the largest total dynamic thickness changes of ~20m. Do the authors have a suggestion for why this could be possible?

Author Response: The large thickness changes we measured on Courtauld Gletsjer were due to errors in the GIMP DEM in this region. In response to a comment from Reviewer 1, we have changed our ice sheet surface elevation reference dataset to ArcticDEM. By making this switch, the errors for Courtrauld have been eliminated and we are now measuring ~2-3 m of dynamic thickness changes per season. This update will be reflected in the revisions to the manuscript.

This leads me to a related point: while fully incorporating terminus change data from CALFIN might be outside the scope of this paper, it would be useful to note how significant front change plays a role at glaciers with the largest observed change. For example, Courtauld (#150) is a relatively small glacier – did it undergo a rapid retreat and readvance to account for such a large ~20 m dynamic thinning over the 2-year observational period noted above?

Author Response: We agree with the reviewer, however, based on currently published data from the CALFIN and TermPicks (Goliber et al., 2021) datasets, glacier centerlines are only recorded until mid-2019 which does not provide enough overlap with the ICESat-2 observations. If additional CALFIN data can be provided by the creators, we will add measurements of terminus position change along glacier centerlines for one glacier from each of our seven categories. We feel that a comprehensive comparison of terminus position changes with our measurements of dynamic thickness changes for all glaciers is outside of the scope of this Brief Communication because this kind of analysis would benefit from additional years of data collected by ICESat-2. Nevertheless, if the data is available, we plan to show terminus position changes of seven glaciers, one representing each different type of seasonal pattern. This will serve as a qualitative exploration of whether seasonal thickness changes are related to terminus motion. We are in the process of investigating which seven glaciers have sufficient terminus position data in the recently released TermPicks dataset and we may or may not choose Courtauld, specifically.

Reference:

Goliber, S., Black, T., Catania, G., Lea, J. M., Olsen, H., Cheng, D., Bevan, S., Bjørk, A., Bunce, C., Brough, S., Carr, J. R., Cowton, T., Gardner, A., Fahrner, D., Hill, E., Joughin, I., Korsgaard, N., Luckman, A., Moon, T., Murray, T., Sole, A., Wood, M., and Zhang, E.: TermPicks: A century of Greenland glacier terminus data for use in machine learning applications, The Cryosphere Discuss. [preprint], https://doi.org/10.5194/tc-2021-311, in review, 2021.

On Figure 2

Glacier 34 is classified as having summer thinning (defined in the manuscript as having a decrease between spring and summer in the detrended time series) in 2019, but this is not supported by the figure in the Supplement, which shows thickening in the detrended time series.

Author Response: The x-axis of the plot for Illullip Sermia in Supplementary Material had a mistake, where every value was shifted by one season, giving the appearance of a different categorization. This will be corrected in the new Supplementary Material, and it will correctly correspond with summer thinning.

Line 191: "Our results reveal little regional coherency in seasonal dynamic thickness change patterns, indicating that atmospheric circulation patterns are not the likely driver of differences in patterns among glaciers"

Was this a hypothesis in the study? What are the mechanisms that could potentially link atmospheric circulation to the dynamic thickness change (SMB removed) over such short time scales?

Author Response: We will add a discussion of the links between atmospheric circulation and dynamic thickness change to the introduction to better contextualize this section of the manuscript.

Consider adding a citation to the recent paper with updated velocity classifications to the intro:

Vijay, S., King, M., Howat, I., Solgaard, A., Khan, S., & Noël, B. (2021). Greenland ice-sheet wide glacier
classification based on two distinct seasonal ice velocity behaviors. Journal of Glaciology, 1-8. doi:10.1017/jog.2021.89

Author Response: The citation will be added to the text.