Review of '**Ice speed of a Greenlandic tidewater glacier modulated by tide, melt, and rain**' by Sugiyama et al., for *The Cryosphere*

Summary

This manuscript investigates the short-term drivers of speed variability at Bowdoin Glacier, a medium sized outlet glacier in Greenland, using three deployed GPS receivers during six summers from 2013-2019. 3D ice motion is compared to tidal fluctuations and AWS-recorded near-surface air temperature and precipitation. Units were deployed at approximately the same location each year and oriented along flow with one unit nearest the terminus, and the third ~4 km inland. The study finds that glacier speeds responded both diurnally (melt-driven signal) and semi-diurnally (tide-modulated), though the later forcing decayed in influence with increasing distances from the front. Rain-driven acceleration was also detected in some years, though inconsistently across years, which is attributed to the subglacial drainage system evolution and dependency on the state of the subglacial system when precipitation events occur. Tidal influence was strongest near the front, and most pronounced once the terminus is believed to be at or near flotation heights. Most interestingly, this study shows that the 2 inland GPS receivers record uplift during periods (up to multi-day) of acceleration on the order of several centimeters, which is linked to the physical separation of the glacier from the bed as pressurized subglacial drainage systems form.

The manuscript is well written and arranged in a comprehensive and logical structure, with appropriate figures that complement the main results in the text. The study presents important results for understanding drivers and response times of dynamic outlet glaciers and evolving subglacial systems and offers valuable in situ observations that capture processes that occur at higher frequency than can be captured by most remote sensing studies. This manuscript is therefore nearly suitable for publication in TC in its current form, but I find there to be two topics that warrant further analysis/discussion in the main text, mainly: context on the position and phase of the terminus throughout the study period and (2) more figures that describe how key variables (such as lag time and coefficients of temp/speed relationships) vary between years and any trends that were observed. These themes are discussed below in the 'Main', followed by minor comments and requests for clarification.

Main

Terminus change: Some general description of Bowdoin's terminus change are provided in the background, but it would be beneficial to include more information on terminus change during the study period, especially because variations in distance-to-front is found to be an important component on varying responses to tidal impacts between sites 1, 2 and 3. Similarly to the phase of tidal change, the phase of terminus change (whether advancing of retreating), and distance from the nearest GPS receiver (unit 1) each year, and the range in that distance over the seasonal study window, are all important variables that may lend more context to various signals detected during the 2013-2019 period. While I believe the terminus remained relatively stable after 2013 as compared to the large retreat in the preceding years, the interannual variability in when advance/retreat occurs (if any) would still be important to address in this manuscript.

Interannual changes in key variables:
A main strength of this manuscript over previously published studies at this glacier is the extended 2013-2019 study period, which enables the authors to investigate trends and interannual variability in key characteristics of ice flow. While the ‘stacking” approach across multiple years was necessary to conduct the fast fourier transform and identify the dominant frequency components, multiyear mean values (such as shown in Figure 4) exclude potentially informative information on how seasonality and characteristics of low have evolved over time. For example, the temperature-max speed lag time of 2 hours was only provided for GPS3, and using a mean result from stacked daily values. It would be useful to understand how this lag compared across years at GPS3, or even compared to lag time at GPS2. Another recommendation on this theme would be to provide corresponding text in the main manuscript that describes the relationships seen in the scatter plots (which include all years superimposed). The plots by themselves are not super informative, and difficult to discern how correlations vary (or remain consistent) across years.

<u>Minor</u>
Request for more clarity: Were 2013, 2014 and 2017 the only years where precipitation was recorded during the study period?

Scatter-plots (for example, in figure 9): Consider using a colormap that avoids very similar colors. It is difficult to discern the years shown in light blue and darker blue (2013 and 2019).

Line 80:
Consider replacing “continuous” with “multi-year year series”.

Request for additional citation: I think some of the introductory discussion on subglacial hydrology is light on citations, particularly for more recent work. Should also include citations for discussion on tidal force balance at the calving front. (lines 35-42, and again supporting citations in lines 72-80). There are some important citations used later in the discussion of results on subglacial hydrology that could be incorporated again in the earlier introduction/background.

Request for additional clarity: I found some of the detrending methods description confusing. For example, in some places the text uses “detrended” to refer to, what I believe, is simply the time series with the seasonal mean subtracted. In Figure 5, 2019 speeds certainly show a “trend” over the July period, though the mean is zero. However, I assume this detrending approach (where a seasonal acceleration or deceleration may be present) is a different approach used to the “stacking” described, where a mean diurnal speed is computed. Can you please provide more clarity on these methods?

Line 170 – how is *significant* acceleration defined here? Based on a threshold rate of change?