Supplementary material to "Self-sufficient seismic boxes for monitoring glacier seismology in Greenland"

Ana Nap, Fabian Walter, Martin P. Lüthi, Adrien Wehrlé

S1 GNSS results Gornergletscher

RINEX files acquired by the rover stations during the field campaign were processed in Post-Processed Kinematics (PPK) with Zermatt Swiss Positioning Service SWIPOS permanent base station (ZERM) using the RTKLIB GNSS processing software (Takasu and Yasuda, 2009) combining forward and backward assimilation of signal corrections. The configuration file containing all processing parameters is visible in the additional file S5. Once 3-dimensional positions were processed, retrievals associated with a standard deviation computed by RTKLIB higher than 3cm were considered as outliers and filtered out. A rolling linear regression on horizontal positions was then applied at a frequency of 3 hours and through a 3-hour window size in time. Surface velocities were finally computed using the distance and time between the first and last point of a given linear regression. On figure S1, envelopes correspond to the standard deviation around mean over a 30-minute and 6-hour rolling window for vertical position and horizontal velocity, respectively.

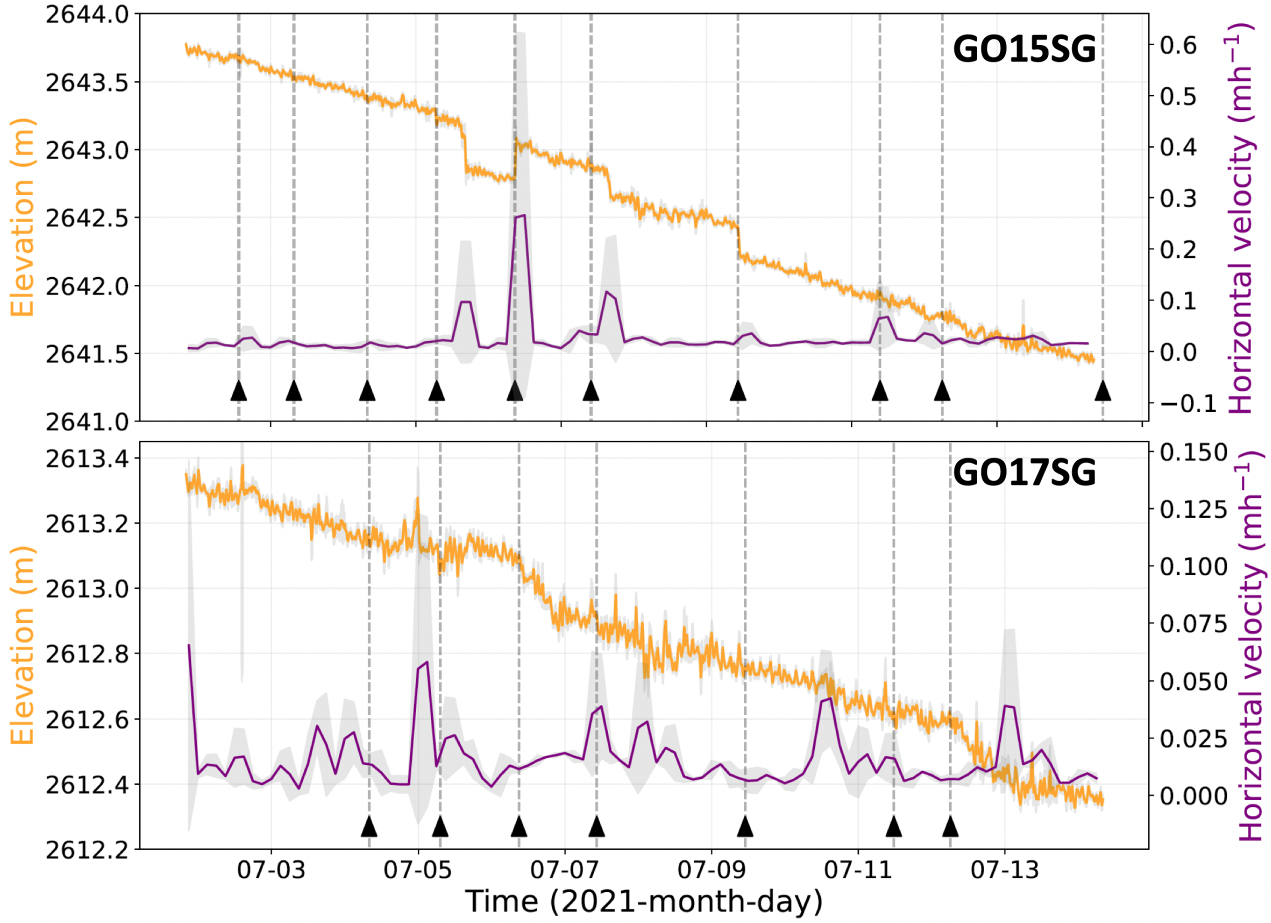

Figure S1: GNSS results for the SG-boxes GO15SG and GO17SG at Gornergletscher for the same consecutive period. The dashed lines and arrows indicate the visiting times at the sensors. Note the different scales for the horizontal velocity.

During the field test GO17SG was deployed for a shorter period than GO15SG, to allow for comparison between both GNSS records we only show the period in Figure S1 for which both GNSS receivers were running. The peaks in the velocity records correspond to tilt events or visiting times at which times the box was moved or experienced sliding. At those times the velocity does not represent the flow velocity of the glacier. The visiting times and tilt events can be found in Figure 5 of the main paper and Figure S2.

S2 Noise levels and tilt time series

S2.1 GO17

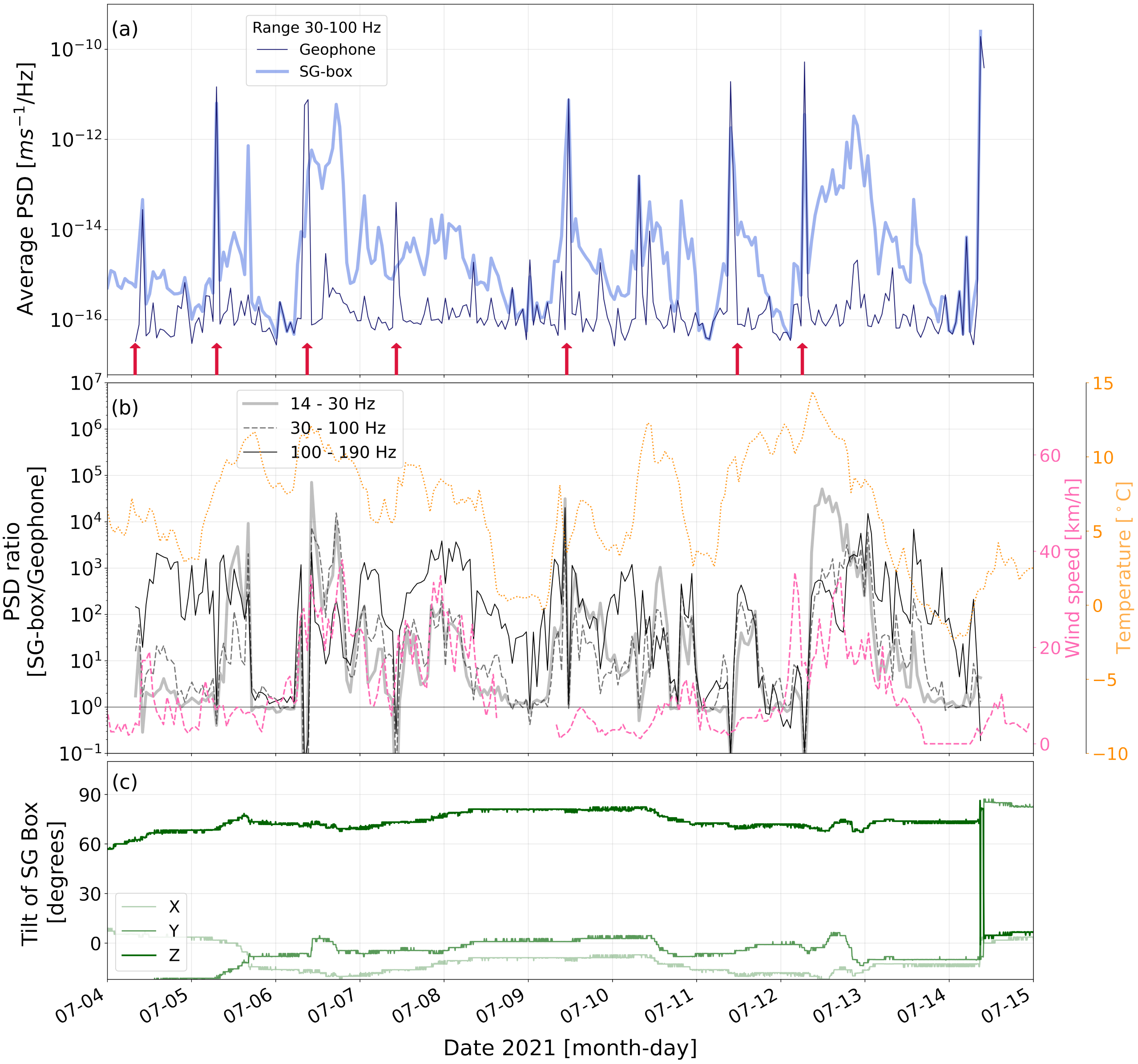

Figure S2: Noise levels and tilt time series of Station GO17. (a) Average power spectral density (PSD) of the SG-box and geophone in a frequency range of 30 to 100 Hz. The average PSD is computed by taking the average value of 60 minute windows in the spectrogram for a defined frequency range. The spectrograms used in the calculations have a window size of 5.12 seconds with 50% overlap. The red arrows indicate the maintenance visit times at the stations. (b) Ratio between average PSD of geophone and SG-box in three frequency windows: 14-30 Hz, 30-100 Hz and 100-190 Hz. Wind speed measured at the MeteoSwiss weather station at the Monte Rosa Hut is displayed in striped pink. A ratio of 1 (i.e. 10^0) corresponds to equal PSD levels of SG-box and geophone. (c) Tilt of three axis of the SG-box measured every 5 minutes by the MSR data logger accelerometer. The SG-box is exactly horizontal when X, Y and Z are 0, 0 and 90 degrees respectively.

S2.2 GO18

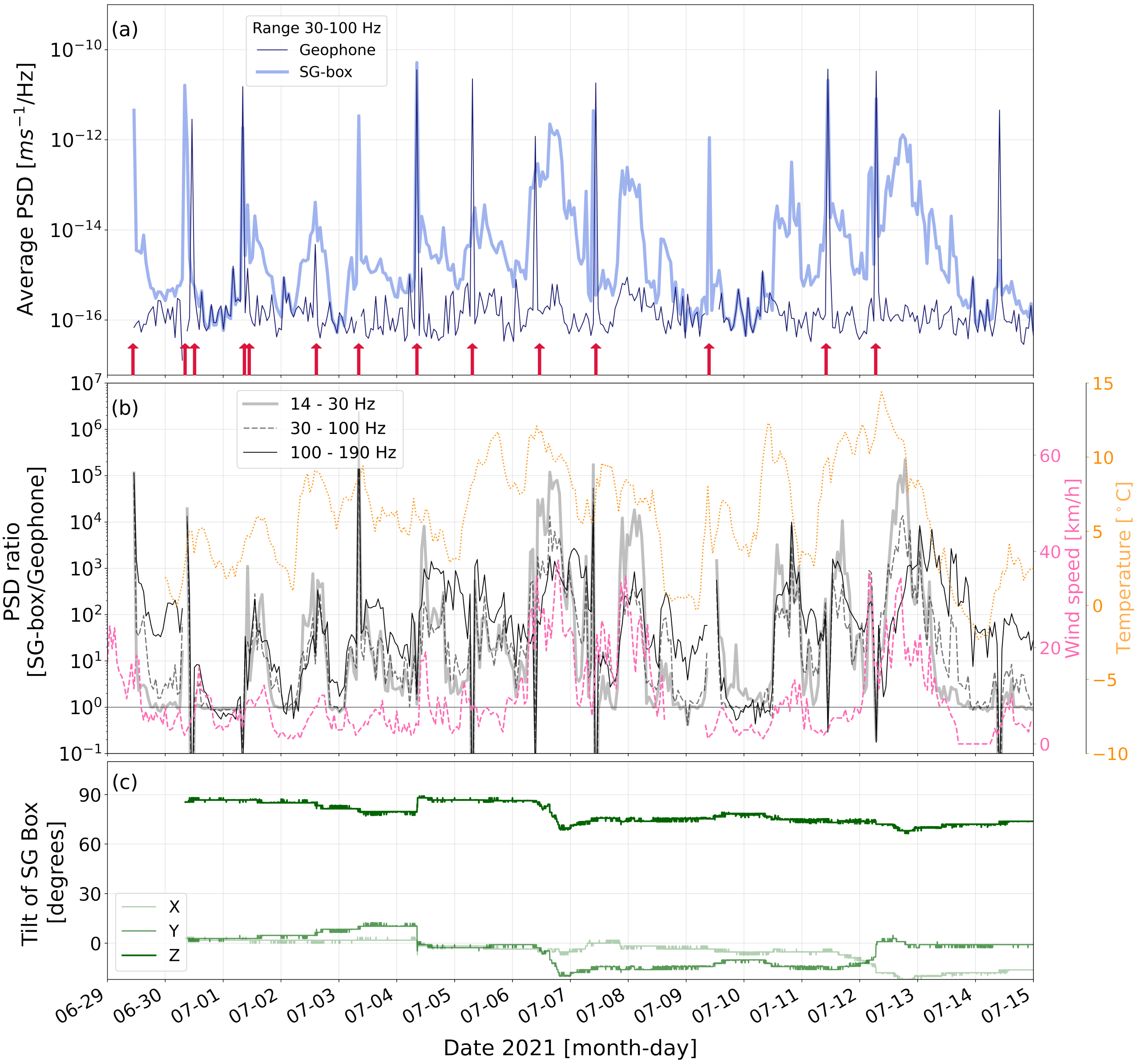

Figure S3: Noise levels and tilt time series of Station GO18. (a) Average power spectral density (PSD) of the SG-box and geophone in a frequency range of 30 to 100 Hz. The average PSD is computed by taking the average value of 60 minute windows in the spectrogram for a defined frequency range. The spectrograms used in the calculations have a window size of 5.12 seconds with 50% overlap. The red arrows indicate the maintenance visit times at the stations. (b) Ratio between average PSD of geophone and SG-box in three frequency windows: 14-30 Hz, 30-100 Hz and 100-190 Hz. Wind speed measured at the MeteoSwiss weather station at the Monte Rosa Hut is displayed in striped pink. A ratio of 1 (i.e. 10^0) corresponds to equal PSD levels of SG-box and geophone. (c) Tilt of three axis of the SG-box measured every 5 minutes by the MSR logger accelerometer. The SG-box is exactly horizontal when X, Y and Z are 0, 0 and 90 degrees respectively.

S3 Waveform quality: horizontal components

S3.1 East-West

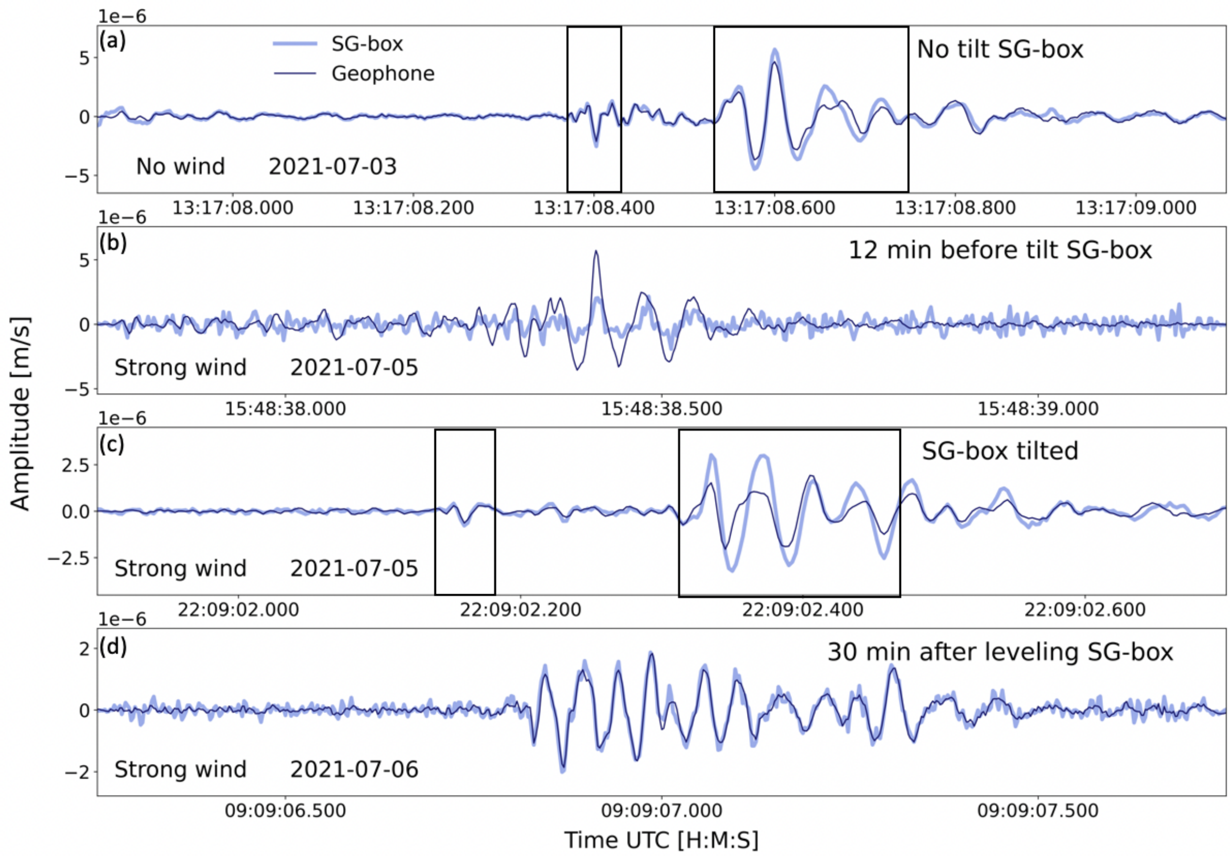

Figure S4: Example of match between SG-box and geophone for selected icequake events before, during and after extreme tilt of SG-box at station GO15. Here the horizontal East-West component is shown and the data are bandpass filtered between 14 and 190 Hz. East direction is positive amplitudes, West direction is negative amplitudes. The tilt occurred between approximately 16:00UTC on 2021-07-05 and 09:00UTC the next day. The measured tilt can be found in the section Waveform quality, Figure 6 in the main paper. (a) No tilt on 2021-07-03 with no wind. (b) 12 minutes before tilt occurred on 2021-07-05. (c) During tilt of SG-box on 2021-07-05. (d) 30 minutes after placing the SG-box in a horizontal position again.

S3.2 North-South

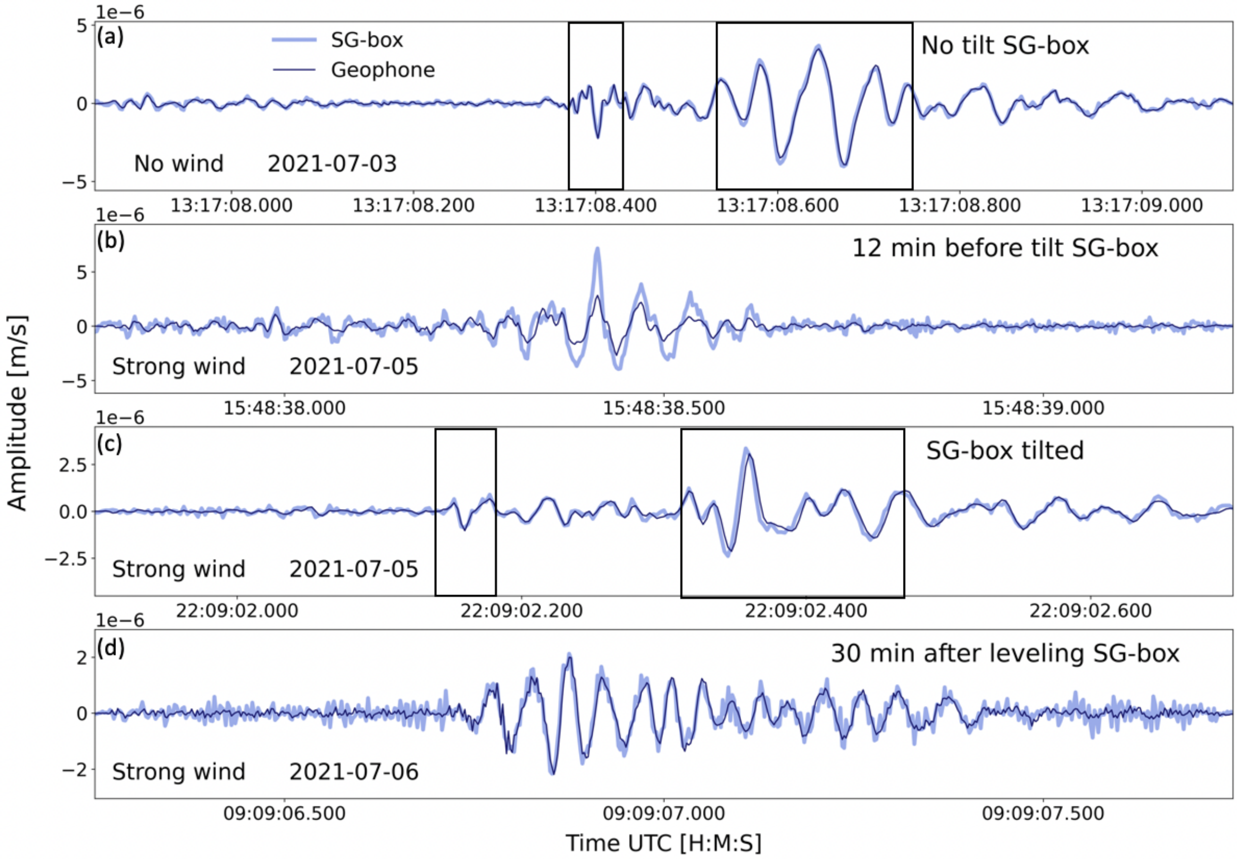

Figure S5: Example of match between SG-box and geophone for selected icequake events before, during and after extreme tilt of SG-box at station GO15. Here the horizontal North-South component is shown and the data are bandpass filtered between 14 and 190 Hz. North direction is positive amplitudes, South direction is negative amplitudes. The tilt occurred between approximately 16:00UTC on 2021-07-05 and 09:00UTC the next day. The measured tilt can be found in the section Waveform quality, Figure 6 in the main paper. (a) No tilt on 2021-07-03 with no wind. (b) 12 minutes before tilt occurred on 2021-07-05. (c) During tilt of SG-box on 2021-07-05. (d) 30 minutes after placing the SG-box in a horizontal position again.

S4 Greenland deployment

S4.1 Overview map

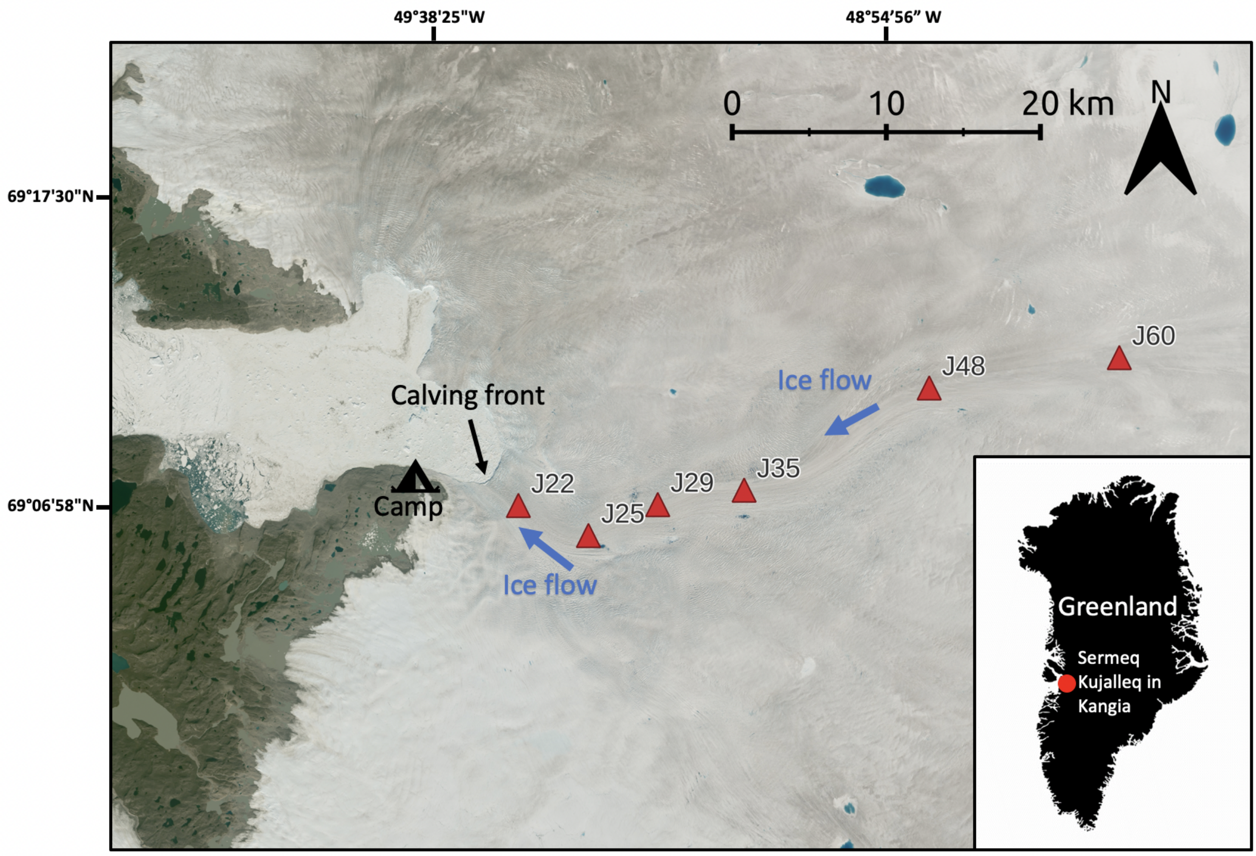

Figure S6: Overview of SG-box deployment at Sermeq Kujalleq in Kangia in 2021. The red triangles are all singular SG-boxes that were deployed for a period of 7 days, 28^{th} of July until the 4^{th} of August. At J60 the SG-box was co-located with a weather station. The correlation of the PSD of the SG-box at J60 and the weather station can be found in the Discussion section of the paper. (Source orthoimage: imagico.de maps)

S4.2 GNSS results

For the GNSS results of the deployment in Greenland in 2021 the same processing has been applied as for the GNSS results plotted in Figure S1. The base station for this deployment was located close to the camp (see Fig. S6).

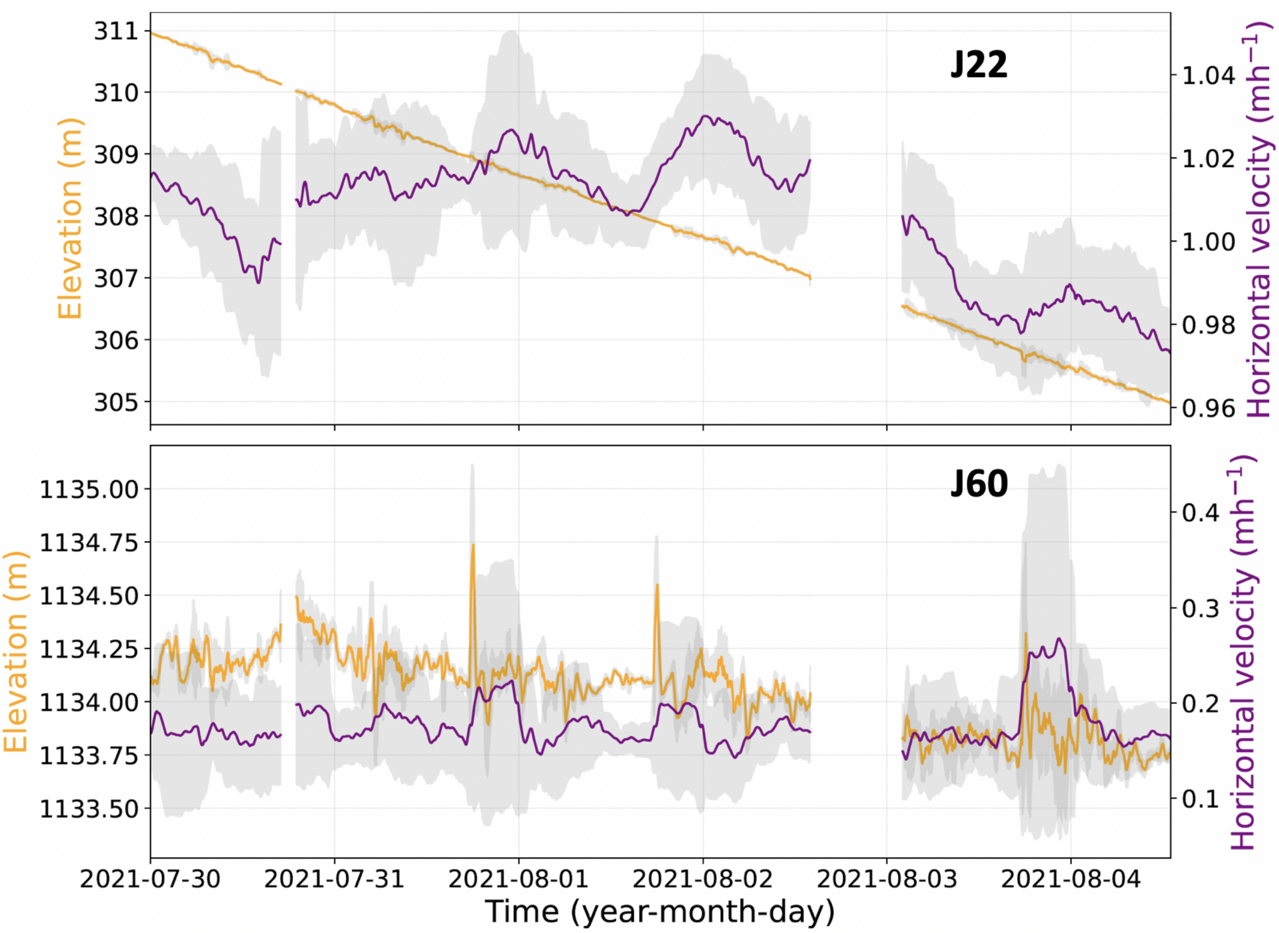

Figure S7: GNSS results for the SG-boxes at J22 and J60 (see map in Fig. S6). Surface velocities are shown in purple and elevation change is shown in yellow. As J60 is located further away from the base station the velocities for this station are generally less accurate than for J22 which was located closer to the base station. The base station was located close to camp. Note the different y-axis scales for the horizontal velocities and the elevation. The glacier flows faster closer to the calving front than more upstream, but there is less elevation decrease at the calving front (see fig. S6).

References

Takasu, T. and Yasuda, A. (2009). Development of the low-cost rtk-gps receiver with an open source program package rtklib. In *International symposium on GPS/GNSS*, volume 1. International Convention Center Jeju Korea.