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First geodetic mass balance estimate of the bulk of the South Shetland Islands ice caps

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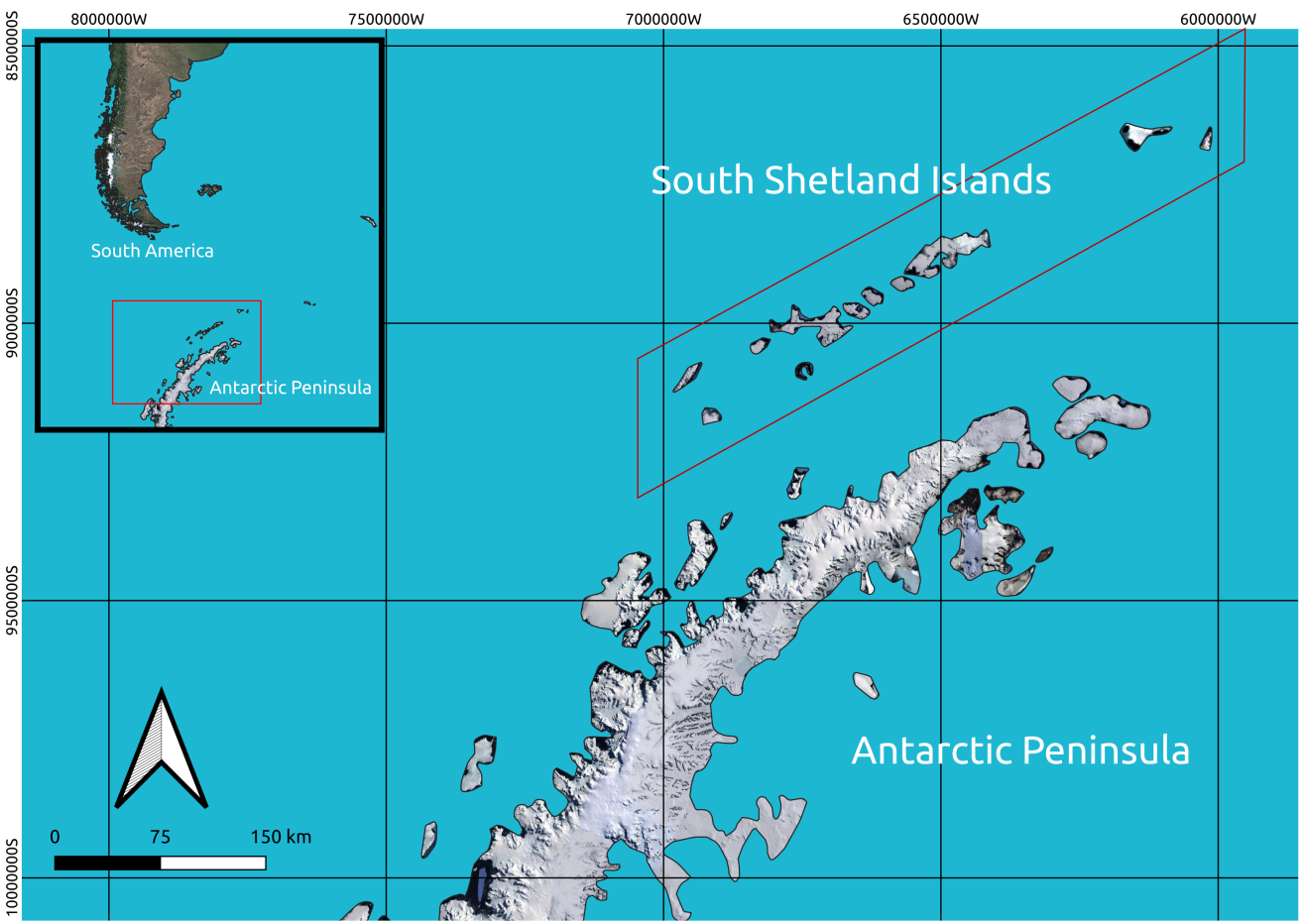
Introduction

Carrasco et al. (2021) identified two breaking points on the near-surface air temperature (nSAT) trend in the 1978-2020 period. The first in 1998/1999 from a warming to a cooling trend. The second, dated in the mid-2010s, indicates the reverse, meaning the end of the warming pause and a return to the warming trend. This changes are expected to have had an impact on the cryosphere in the AP region. In this context, the understanding of how the ice caps respond to different environmental drivers is crucial to understand, predict, and mitigate the climate change effects.

There are some studies on the South Shetland Islands (SSI) regarding regional glacier dynamics (e.g. Osmanoglu et al., 2013, 2014; da Rosa et al., 2020), but they are sparse both temporally and spatially.

In many regions, Geodetic Mass Balance (GMB) studies have been undertaken to obtain mass change of wide glacierized areas (e.g. Braun et al., 2019; Seehaus et al., 2019a, 2019b; Sommer et al., 2020). We have done this for the SSI, bringing wider spatial and temporal coverage.

Study site and objective



We adapted and applied the GMB technique to provide an estimate of mass balance the SSI as complete as possible. Due to their steep relief (resulting in shadows and layovers), Smith and Clarence islands were excluded from the calculation. Nor the GMB of Elephant Island was calculated, due to lack of a good reference DEM. Our final coverage of the glacierized area on the SSI was 73%.

Methods

The methodology to obtain geodetic mass balances is structured into 4 main steps (Braun et al., 2019; Seehaus et al., 2019b; Sommer et al., 2020):

DEM generation: DEMs from 2013/2014 and 2017 were generated from TanDEM-X data using a reference DEM for each island. We collected data within the period between May and November (wintertime) to avoid differences in radar penetration.

DEM co-registration: In order to compute high quality GMBs, horizontal or vertical shifts between the subsequent DEMs should be minimal. For this reason, a co-registration over stable ground (ice-free areas) of the generated DEMs was carried out.

Height change calculation: We then subtracted the DEMs from distinct periods, getting a height change (Δh), and divided it by the time difference between the periods (Δt), resulting in the elevation change rate ($\Delta h/\Delta t$).

Mass change computation: To calculate the geodetic mass balance rates ($\Delta M/\Delta t$), we integrated the elevation change rate over the glacierized areas and multiplied the resulting volume change rate by a volume to mass conversion factor (Cogley et al., 2011; Huss, 2013).

Results

In what follows, Figure 1 shows the **spatial distribution of GMB across the SSI**. The area of green and red circles is proportional to the mass gained or lost (assuming ρ_{ice} = 850 kg m^{-3}), respectively. The blue circle represents the only island with virtually no change in GMB. The total mass change rate for the archipelago is of **-131 ± 0.014 Mt a^{-1}**.

Although Livingston presents important losses in some particular areas, the island is the most important positive contributor to the mass change in SSI, with 135 Mt a^{-1} and a mean elevation change rate of 0.246 m a^{-1}. Deception is the other island with positive mass change, of 9 Mt a^{-1}, and a mean elevation change rate of 0.314 m a^{-1}. Greenwich has virtually neutral mass balance (0 Mt a^{-1}). Low, Nelson, and Snow islands present similar mass change rates, of -85, -60, and -68 Mt a^{-1}, respectively. Low and Nelson have spatially homogeneous losses with elevation change rates of -0.800 m a^{-1} and -0.493 m a^{-1}, respectively. Differently, Snow has an important loss on the Southeast part partially balanced by gain on the opposite Northwest part with a mean mass change rate of -0.731 m a^{-1}. Finally, King George Island has little changes in almost all areas, except in King George Bay with important losses, being the reason for the overall negative -53 Mt a^{-1} mass change on the island, with mean elevation change rate of -0.066 m a^{-1}.

Results

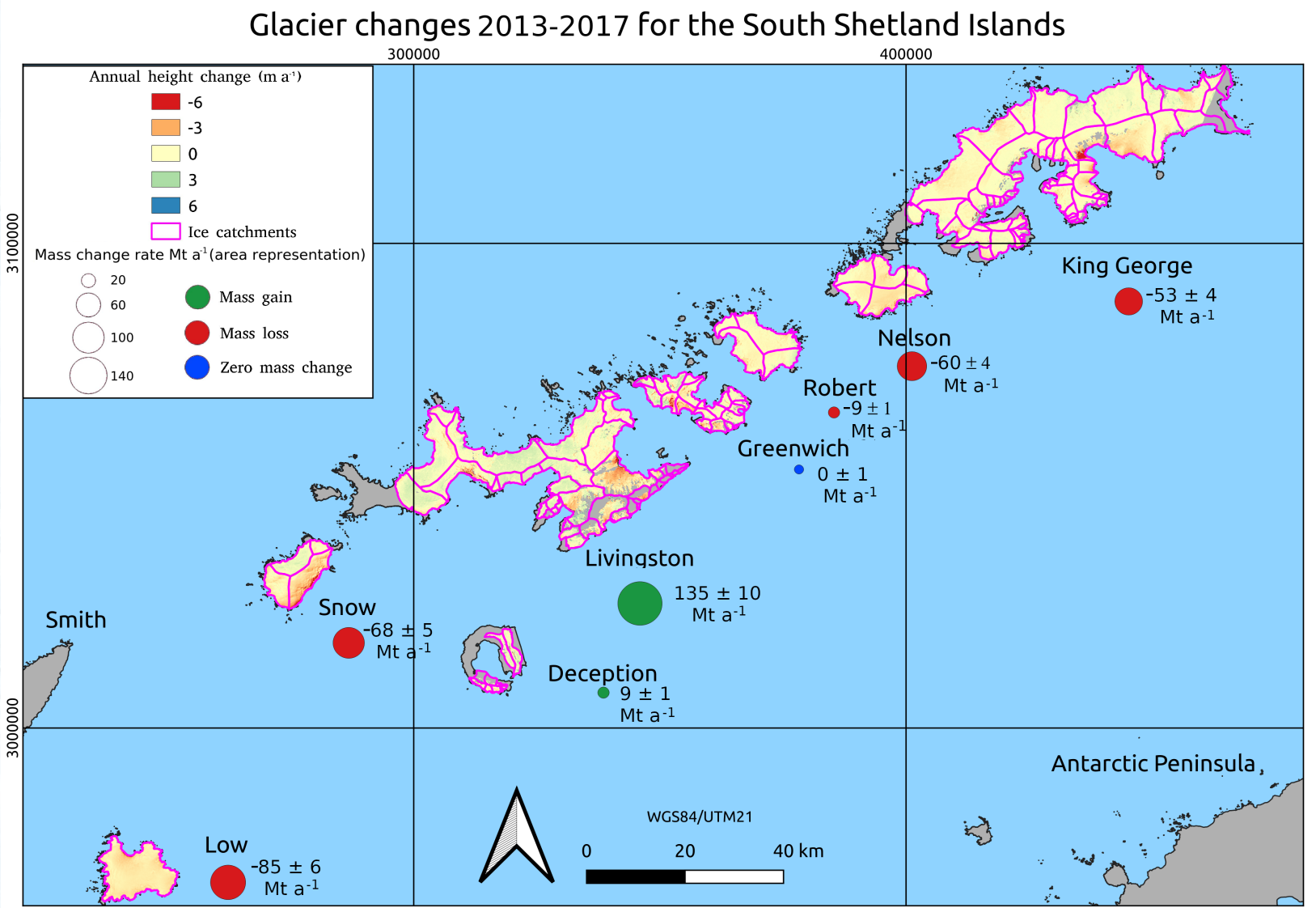


Figure 1

Results

Figure 2 shows the **Hypsometric distribution of computed** (red bars) **and total** (light blue bars) **glacier area** of the individual islands and the South Shetland archipelago. Blue dots represent the mean elevation change (Δh/Δt) in each elevation interval. Error bars represent the Normalized Median Absolute Deviation (NMAD) of the Δh/Δt of each hypsometric bin. Grey areas indicate the lower and upper 2% quantile of the total glacier area distribution. The dark green dashed line represents the mean elevation of each island. Areas with slope higher than 50º were masked out. The grey dashed line is the mean elevation change rate of each island and the blue dashed line is the zero elevation change.

The area of the study site filtered out is 4.5% of the total measured area. In Figure 2, some elevation bins have strong deviations from the mean dh/dt value of the corresponding island, but they are located within the lower and upper 2% quantiles of the total glacier measured area, not contributing significantly to the mean calculation. This can be seen in the bins above 700 m a.s.l. on the whole SSI results.

Results

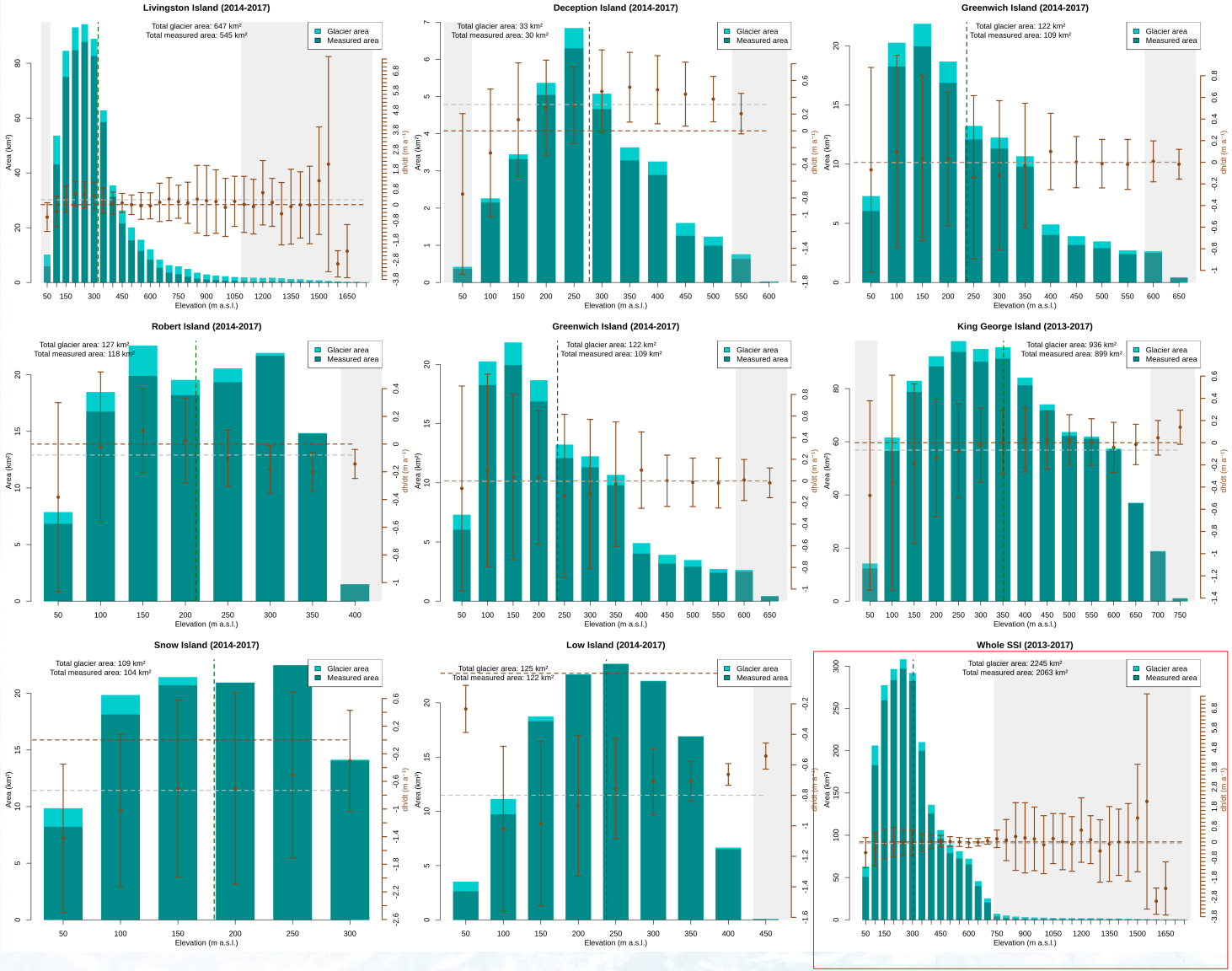


Figure 2

Results

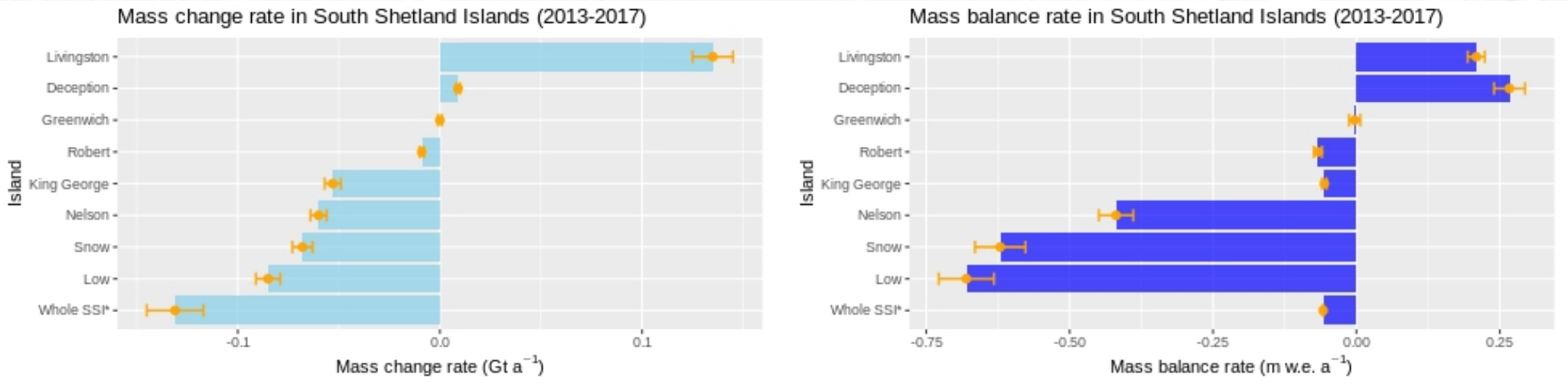


Figure 3: Mass change and mass balance rate graphs of the studied islands as well as the whole SSI. Error bars represent the uncertainty of the GMB calculation. Uncertainty is calculated using the Normalized Median Absolute Deviation (NMAD).

* South Shetland Islands calculation.

Results

Island	Observation period	Total glacier area (km²)	Area covered (%)	Mean elevation change (m a^{-1})	Volume change rate (km³ a^{-1})	Mass change rate considering ρ_{ice} = 850 kg/m³ (Gt a^{-1})	Mass change rate considering ρ_{ice} = 900 kg/m³ (Gt a^{-1})	Mass balance rate considering ρ_{ice} = 850 kg/m³ (m w.e. a^{-1})	Mass balance rate considering ρ_{ice} = 900 kg/m³ (m w.e. a^{-1})
Livingston	2014-2017	647.296	89.8	0.246 ± 0.004	0.159 ± 0.003	0.135 ± 0.010	0.143 ± 0.010	0.209 ± 0.015	0.221 ± 0.015
Deception	2014-2017	33.852	97.2	0.314 ± 0.021	0.011 ± 0.001	0.009 ± 0.001	0.010 ± 0.001	0.267 ± 0.027	0.283 ± 0.028
Greenwich	2014-2017	122.703	96.5	-0.003 ± 0.012	0.000 ± 0.001	0.000 ± 0.001	0.000 ± 0.001	-0.003 ± 0.01	-0.003 ± 0.011
Robert	2014-2017	127.429	99.7	-0.079 ± 0.006	-0.010 ± 0.001	-0.009 ± 0.001	-0.009 ± 0.001	-0.067 ± 0.007	-0.071 ± 0.007
King George	2013-2017	936.36	98.9	-0.066 ± 0.001	-0.062 ± 0.001	-0.053 ± 0.004	-0.056 ± 0.004	-0.056 ± 0.004	-0.060 ± 0.004
Nelson	2014-2017	142.214	99.9	-0.493 ± 0.003	-0.070 ± 0.000	-0.060 ± 0.004	-0.063 ± 0.004	-0.419 ± 0.03	-0.444 ± 0.030
Snow	2014-2017	109.093	99.2	-0.731 ± 0.006	-0.080 ± 0.001	-0.068 ± 0.005	-0.072 ± 0.005	-0.621 ± 0.044	-0.658 ± 0.044
Low	2014-2017	125.135	99.7	-0.800 ± 0.003	-0.100 ± 0.001	-0.085 ± 0.006	-0.090 ± 0.006	-0.680 ± 0.048	-0.720 ± 0.048
Whole SSI*	2013-2017	2244.082	96.3	-0.068 ± 0.004	-0.152 ± 0.004	-0.131 ± 0.014	-0.137 ± 0.014	-0.058 ± 0.001	-0.061 ± 0.002

Table 1: Elevation change, volume change, mass change, and mass balance rates (GMB) for the individual studied islands as well as for the whole SSI. Mass balance change rate is presented in meter of water equivalent per year.

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THANK YOU

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