

1 Supplementary Material

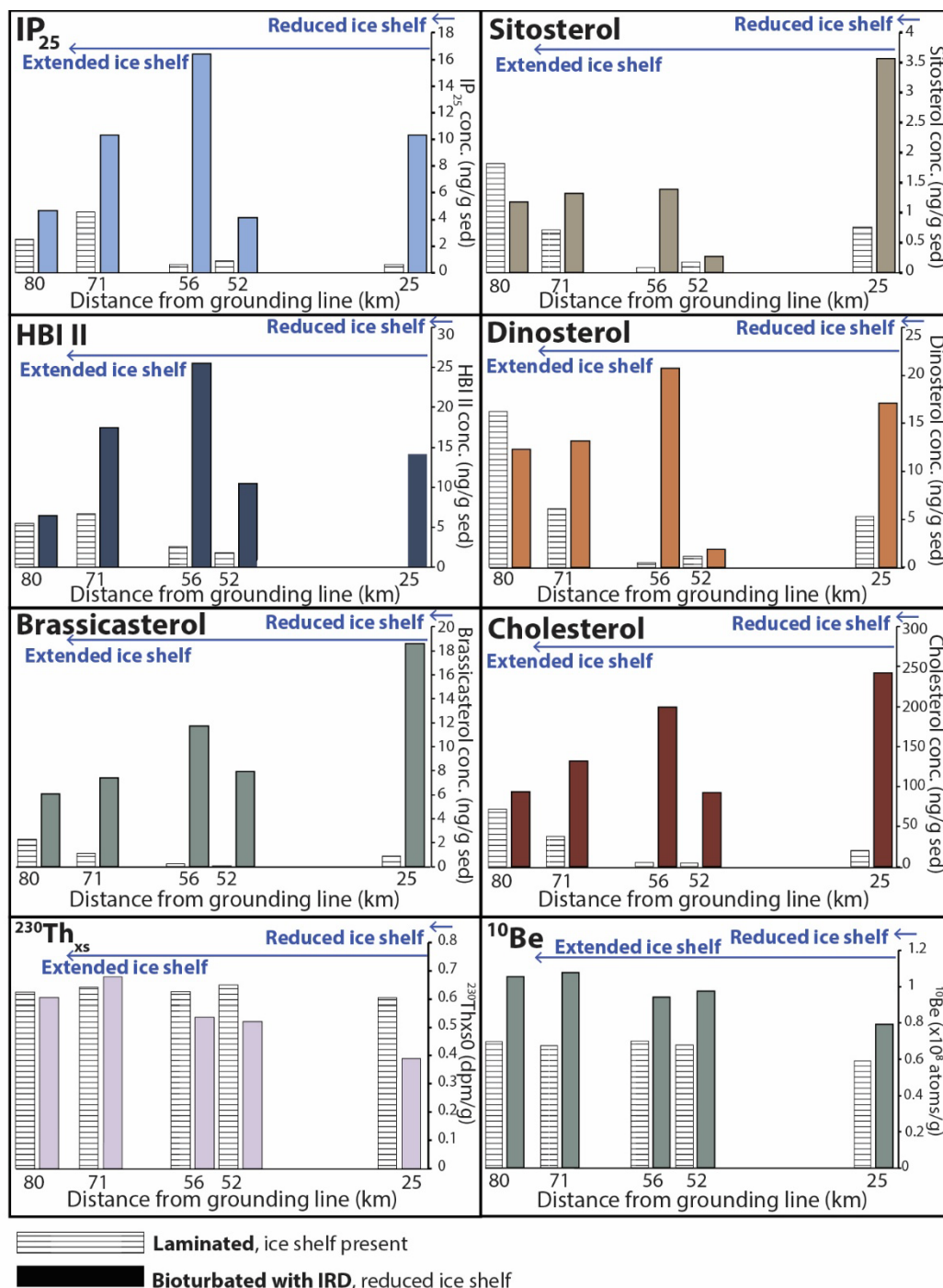
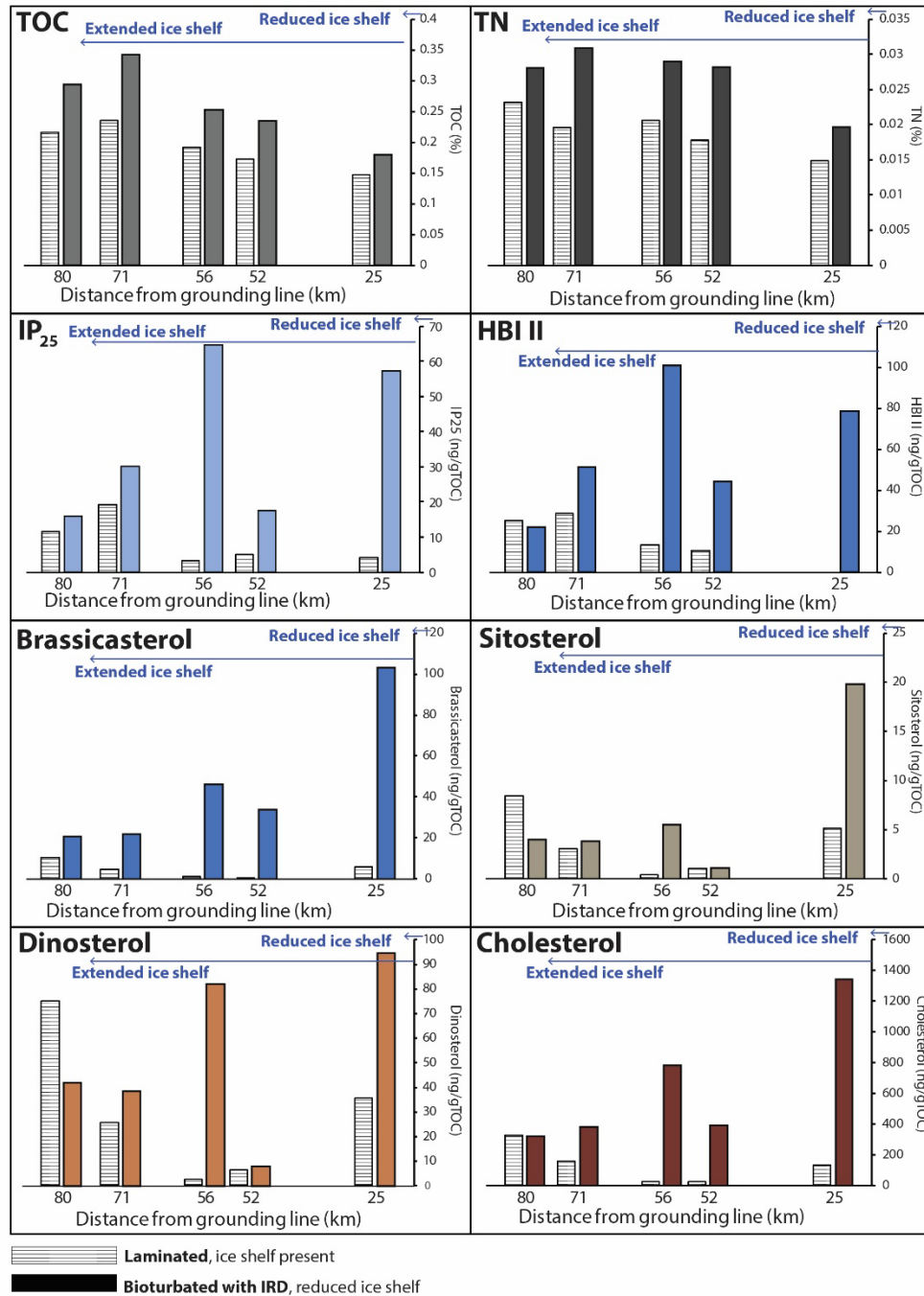


Figure 1: Biomarker and inorganic proxy results for marine sediment cores shown with distance from the modern grounding line for bioturbated units with IRD (reduced ice shelf; shaded in black colours) and laminated units (extended ice shelf; shaded in black horizontal lines) for concentrations of: IP₂₅, HBI II, brassicasterol, sitosterol, dinosterol, cholesterol, ²³⁰Th_{xs} and ¹⁰Be. Distance from the grounding line is scaled accordingly on the x-axis. The extent of the Petermann Ice Shelf in its extended and reduced state is marked (blue arrows) according to Reilly et al., 2019.



10 **Figure 2:** Total organic carbon (TOC) and total nitrogen (TN) shown (top panel) with biomarker data normalised to TOC shown in the other panels: IP₂₅, HBI II, brassicasterol, sitosterol, dinosterol, cholesterol. Distance from the grounding line is scaled accordingly on the x-axis. The extent of the Petermann Ice Shelf in its extended and reduced state is marked (blue arrows) according to Reilly et al., 2019.

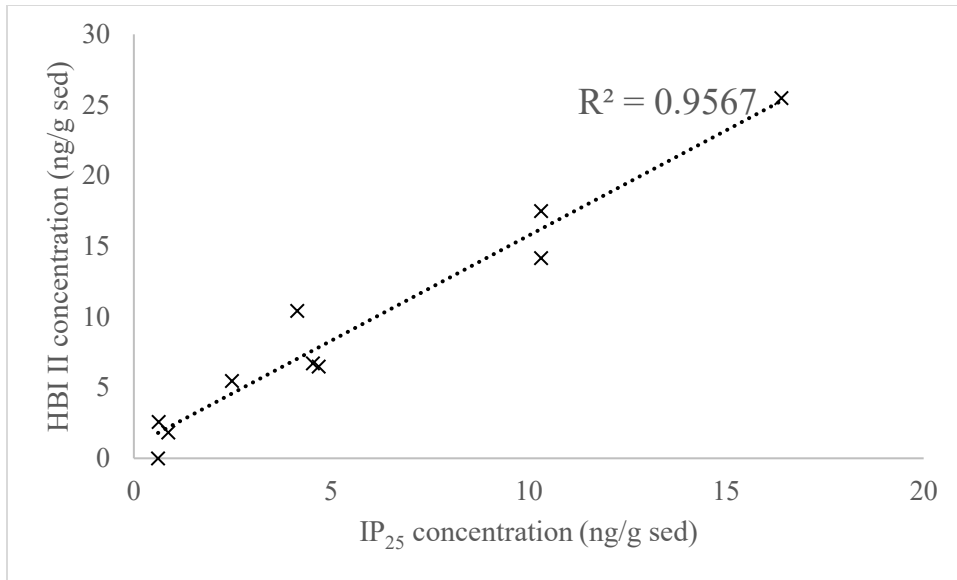


Figure 3: IP₂₅ vs HBI II concentrations for all sites in this study. The R² value is displayed.

P_BIP₂₅ index

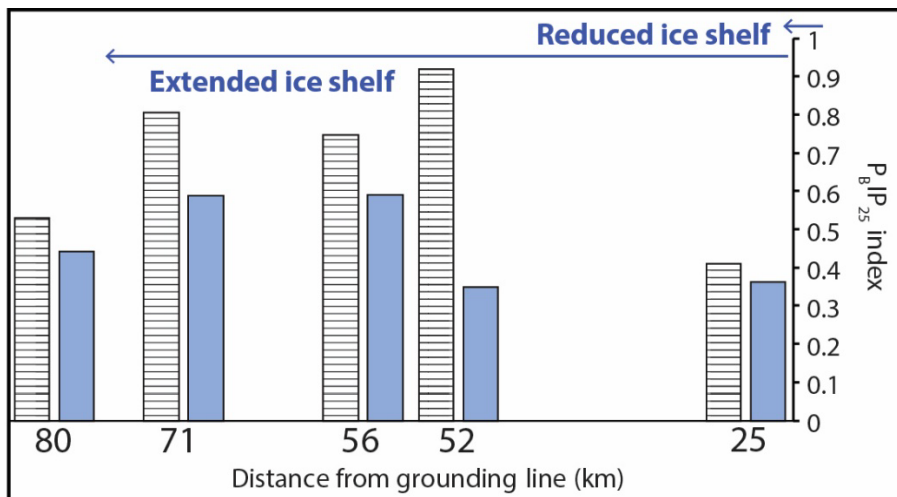
The PIP₂₅ index was calculated using the following Eq. (1) (Müller et al., 2011):

$$PIP_{25} = \frac{IP_{25}}{(IP_{25} + (\text{phytoplankton marker} * c))} \quad (1)$$

Where c is the balance factor, Eq. (2):

$$c = \frac{\text{mean } IP_{25} \text{ concentration}}{\text{mean phytoplankton biomarker concentration}} \quad (2)$$

Brassicasterol was used as the phytoplankton sterol (P_BIP₂₅ index).



25 **Figure 4: The PbIP₂₅ index for reduced ice shelf (solid colour) and extended ice shelf environment (horizontal lines).**

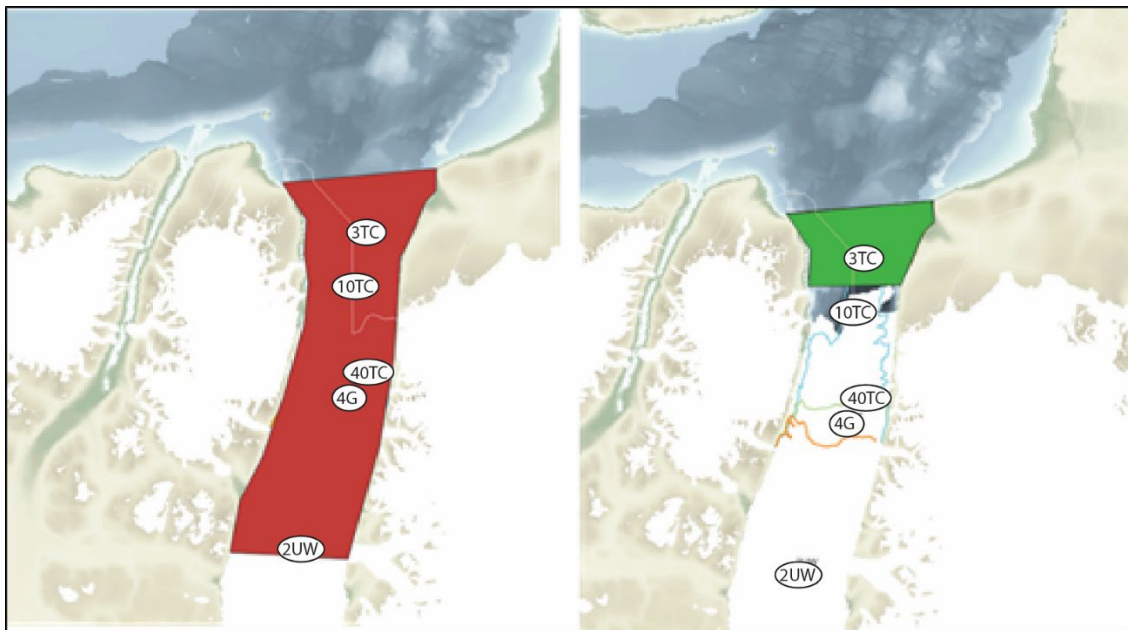
Estimates of ¹⁰Be delivery to Petermann Fjord

Atmospheric deposition

- Flux of ¹⁰Be= 522962.48 atoms/cm²/year (79.5256° N, 61.8750° E) = **5.23 · 10⁵ atoms/cm²/year** (Heikkilä et al., 2015). *Global average flux is 1.09 · 10⁶ atoms/cm²/year*
- 30 • Area of fjord exposed (expanded)= 289 km² = **2.89 · 10¹² cm²**
- Area of fjord exposed (reduced)= 1208 km² = **1.208 · 10¹³ cm²**

Flux of atoms to fjord (reduced ice shelf) = 1.208 × 10¹³ cm² · 5.23 · 10⁵ atoms/cm²/year = **6.37 · 10¹⁸ atoms/year**

Flux of atoms to fjord (expanded ice shelf) = 2.89 × 10¹² cm² · 5.23 × 10⁵ atoms/cm²/year = **1.51 · 10¹⁸ atoms/year**



35 **Figure 3: Estimates of the area of Petermann Fjord in the reduced (left) and extended (right) ice shelf configuration. Analysis undertaken in QGIS.**

Basal and subglacial melt

- Concentration of ¹⁰Be in Greenland ice sheet = **~1.5 · 10⁴ atoms/g ice** (Yiou et al., 1997)
- Density of ice= **0.9 g/cm³**
- 40 • Basal melt = 257 m³/s = **8.1 · 10⁹ m³/year = 8.1 · 10¹⁵ cm³/year** (Washam et al., 2018)
- Subglacial runoff = **110 m³/s = 3.47 × 10¹² cm³/yr** (Washam et al., 2020)

Basal melt + subglacial runoff = 367 m³/s = 1.16 · 10¹⁶ cm³/yr

$$\text{Mass lost per year} = 1.16 \cdot 10^{16} \text{ cm}^3/\text{yr} \cdot 0.9 \text{ g/cm}^3 = 1.042 \cdot 10^{16} \text{ g/yr}$$

$$^{10}\text{Be atoms/yr} = 1.042 \cdot 10^{16} \text{ g/yr} \cdot 1.5 \cdot 10^4 \text{ atoms/g ice} = \underline{\underline{1.56 \cdot 10^{20} \text{ atoms/yr}}}$$

45 **Lateral advection**

- ^{10}Be in Arctic sea water at ~ 1000 m water depth = **500 atoms/g** (Frank et al., 2009)
- Inflow of AW towards glacier = **$3.03 \cdot 10^6 \text{ m}^3/\text{s}$**
- Density of AW = **$27.9 \text{ kg/m}^3 = 27,900 \text{ g/m}^3$**

$$^{10}\text{Be per m}^3 \text{ of AW} = 500 \text{ atoms/g} \cdot 27,900 \text{ g/m}^3 = \mathbf{1.395 \cdot 10^7 \text{ atoms/m}^3}$$

$$50 \quad \text{Annual volume of AW inflow} = 3.03 \cdot 10^6 \text{ m}^3/\text{s} \cdot 31,536,000 \text{ s/yr} = \mathbf{9.56 \cdot 10^{13} \text{ m}^3/\text{yr}}$$

$$^{10}\text{Be inflow per year} = 1.395 \cdot 10^7 \text{ atoms/m}^3 \cdot 9.56 \cdot 10^{13} \text{ m}^3/\text{yr} = \underline{\underline{\mathbf{1.33 \cdot 10^{21} \text{ atoms/yr (in 2015)}}}}$$

References

- 55 Frank, M., Porcelli, D., Andersson, P., Baskaran, M., Björk, G., Kubik, P.W., Hattendorf, B., Guenther, D., 2009. The dissolved Beryllium isotope composition of the Arctic Ocean. *Geochimica et Cosmochimica Acta* 73, 6114–6133. <https://doi.org/10.1016/j.gca.2009.07.010>
- Heikkilä, U., Von Blanckenburg, F., Heikkilä, U., 2015. The global distribution of Holocene meteoric ^{10}Be fluxes from atmospheric models. Distribution maps for terrestrial Earths surface applications. <https://doi.org/10.5880/GFZ.3.4.2015.001>
- 60 Müller, J., Wagner, A., Fahl, K., Stein, R., Prange, M., Lohmann, G., 2011. Towards quantitative sea ice reconstructions in the northern North Atlantic: A combined biomarker and numerical modelling approach. *Earth and Planetary Science Letters* 306, 137–148. <https://doi.org/10.1016/j.epsl.2011.04.011>
- Washam, P., Münchow, A., Nicholls, K.W., 2018. A Decade of Ocean Changes Impacting the Ice Shelf of Petermann Gletscher, Greenland. <https://doi.org/10.1175/JPO-D-17-0181.1>
- 65 Washam, P., Nicholls, K.W., Münchow, A., Padman, L., 2020. Tidal Modulation of Buoyant Flow and Basal Melt Beneath Petermann Gletscher Ice Shelf, Greenland. <https://doi.org/10.1029/2020JC016427>
- Wilson, N.J., Straneo, F., 2015. Water exchange between the continental shelf and the cavity beneath Nioghalvfjærdsbræ (79 North Glacier). *Geophysical Research Letters* 42, 7648–7654. <https://doi.org/https://doi.org/10.1002/2015GL064944>
- 70 Yiou, F., Raisbeck, G.M., Baumgartner, S., Beer, J., Hammer, C., Johnsen, S., Jouzel, J., Kubik, P.W., Lestringuez, J., Stievenard, M., Suter, M., Yiou, P., 1997. Beryllium 10 in the Greenland Ice Core Project ice core at Summit, Greenland. *Journal of Geophysical Research: Oceans* 102, 26783–26794. <https://doi.org/10.1029/97JC01265>