Low-altitude of Svalbard drives large mass loss changes

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1. Introduction

Svalbard ice caps represent 6% of the world's land ice outside polar ice sheets, and would rise global sea-level by 1-2 cm if totally melted. Compared to other Arctic ice masses, Svalbard glaciers are **low-elevated** with a maximum area **below 450 m**, i.e. hypsometry peak (Fig.1b), and experience summer melt that consistently exceeds winter snowfall. Meltwater **refreezing** in firn covering the accumulation zones **is crucial** to mitigate **runoff mass loss** (Fig.1a).

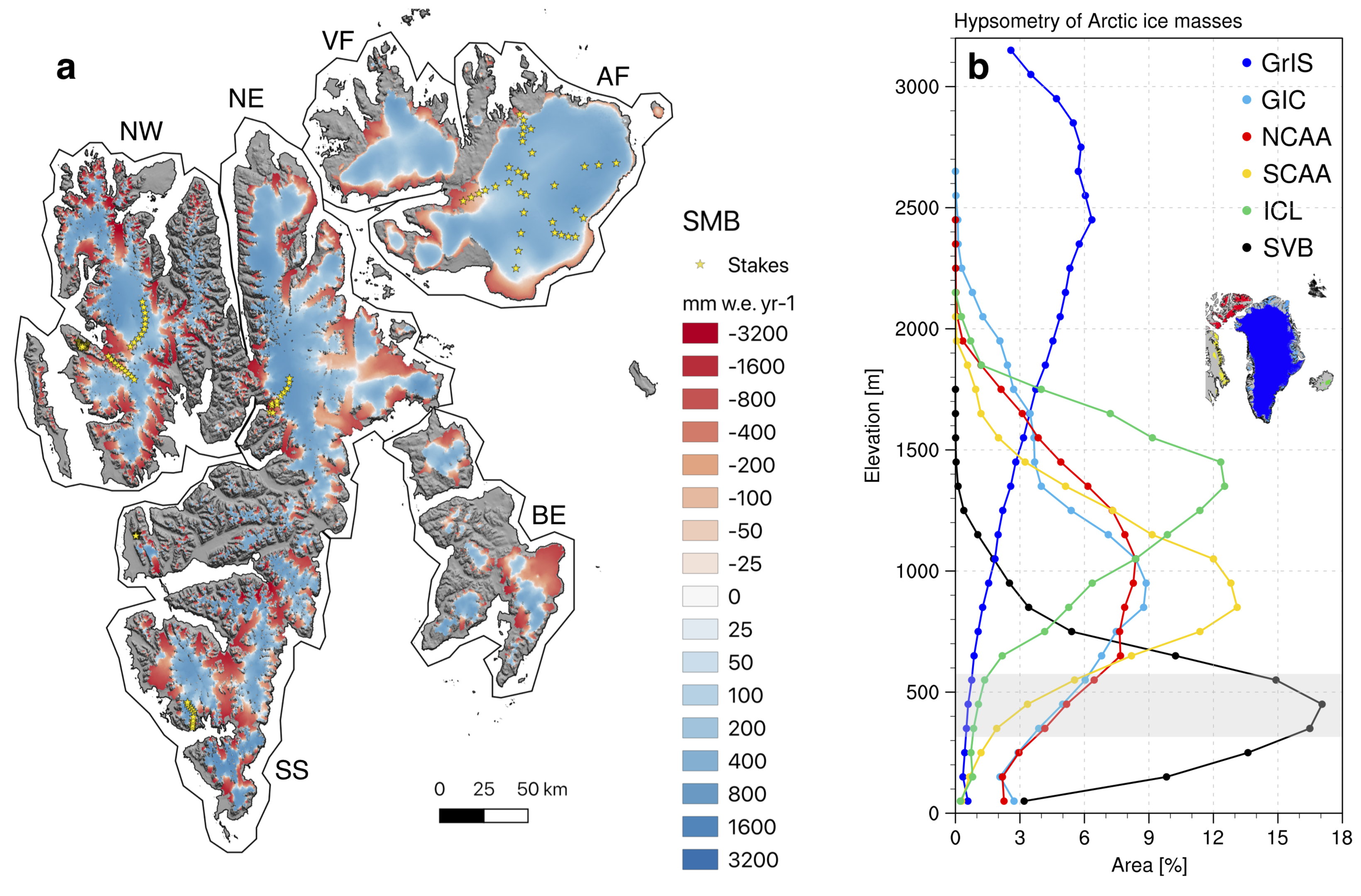

Fig. 1: **a** *Annual mean downscaled surface mass balance (SMB) at 500 m spatial resolution for the period 1958-2018.* **b** *Hypsometry of six Arctic ice masses, namely Svalbard (SVB), Iceland (ICL), North and South Canadian Arctic Archipelago (NCAA and SCAA), Greenland ice sheet (GrIS) and peripheral glaciers and ice caps (GIC). The grey shade highlights the hypsometry peak at 450 m.*

2. Recent mass loss onset

Before 1985, Svalbard remained in **approximate mass balance**: SMB = glacial discharge. **After 1985**, a persistent SMB decline starts the **mass loss**, with a short **hiatus** in **2005-2012** (Fig.5a). Since 1985, Svalbard has contributed **1 mm** to **sea level rise** (Fig.2).

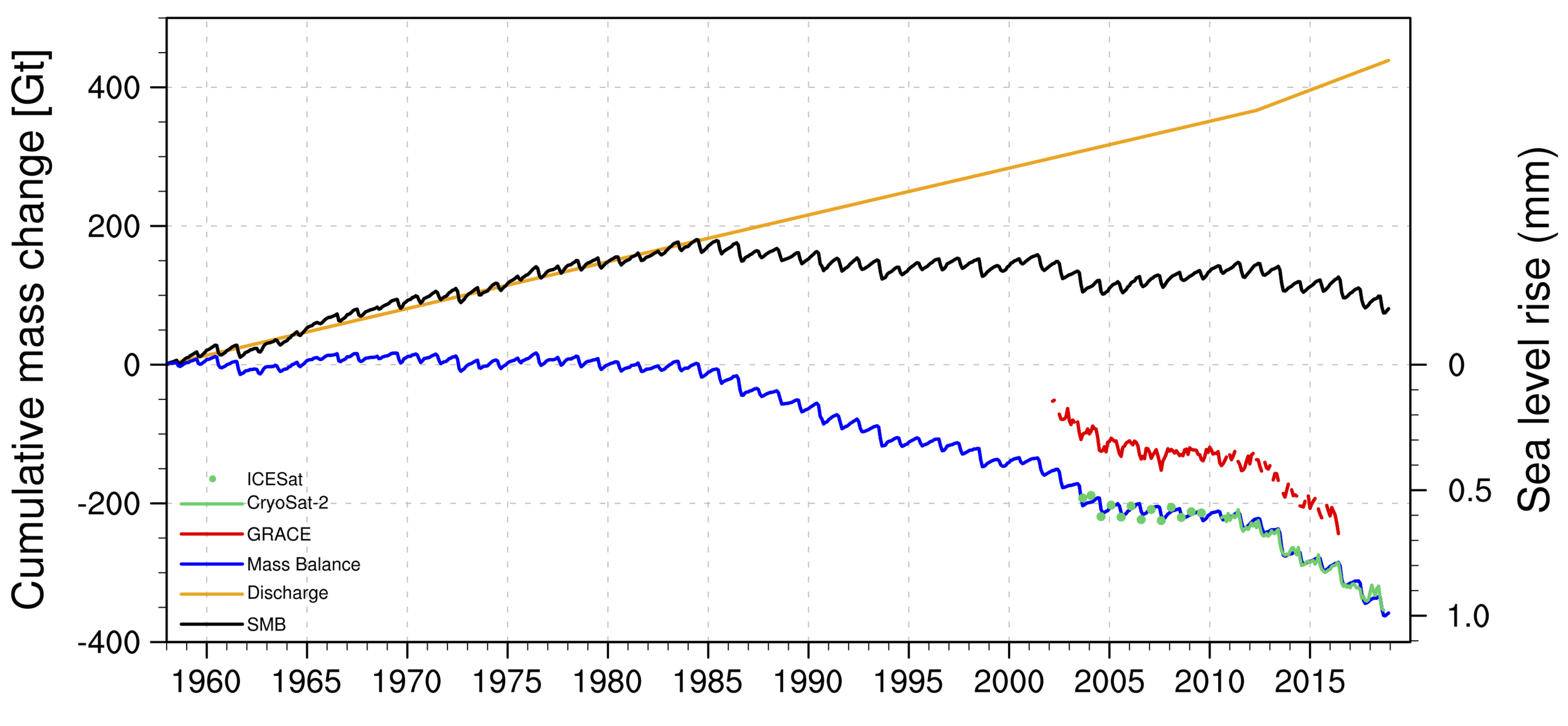

Fig. 2: *Time series of monthly cumulative SMB (black), glacial discharge (orange) and mass balance (MB = SMB minus discharge; blue) for the period 1958-2018. Mass change derived from GRACE (red; 2002-2016), ICESat (green dots; 2003-2009) and CryoSat-2 (green line; 2010-2018) are also shown.*

3. Post-1985 ablation zone expansion

Before 1985, glaciers were sustained as firn retained 54% of melt in accumulation zones above **350 m** (Fig. 3a). **After 1985**, the firn line moved to **450 m** (Fig.3b), i.e. hypsometry peak, causing a rapid ablation zone expansion (Fig.3c). The melt increase reduces the firn refreezing capacity (40%), **enhancing runoff** at all elevations.

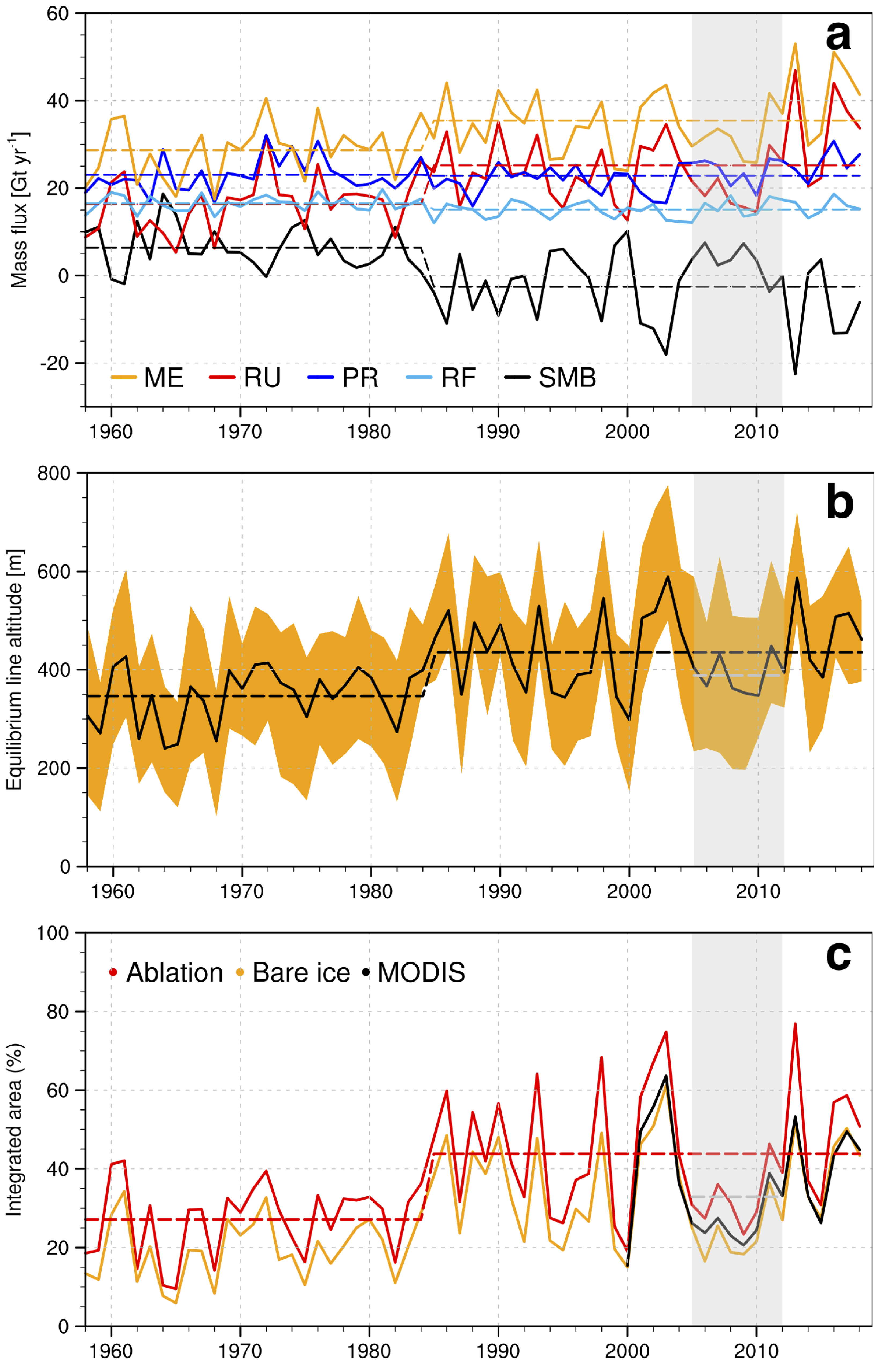

Fig. 3: **a** *Time series of annual SMB (black) and components for the period 1958-2018: melt (ME; orange), runoff (RU; red), precipitation (PR; blue) and refreezing (RF; cyan).* **b** *Evolution of the equilibrium line altitude (ELA; SMB = 0) over Svalbard (black) and individual sectors (orange band).* **c** *Time series of modelled ablation zone area (red), modelled (orange) and observed (black; MODIS) bare ice area as a fraction of the total Svalbard land ice area (%).*

4. Firn response to warming

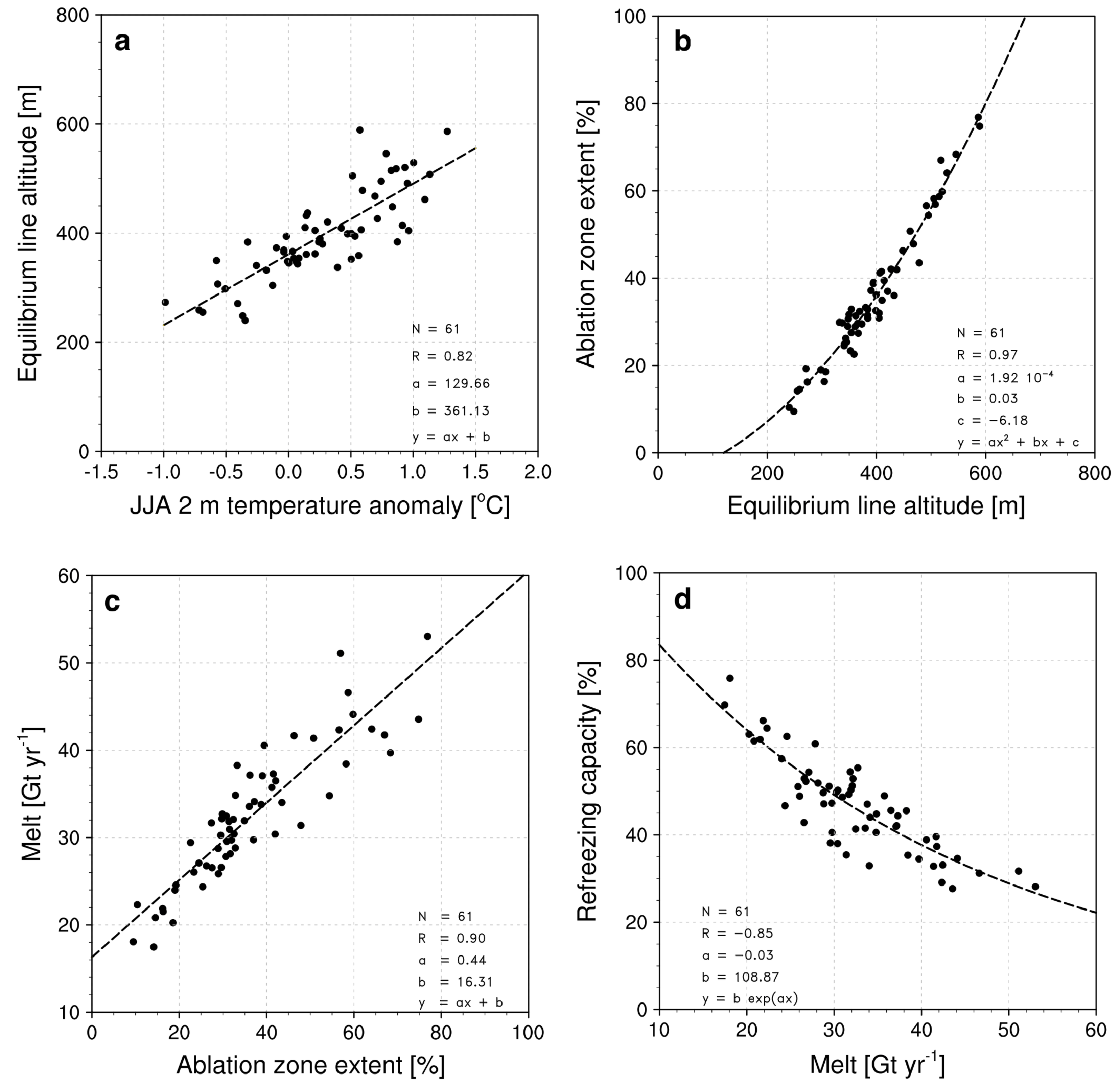

Fig. 4: *Correlation between* **a** *surface warming and firn retreat;* **b** *firn retreat and ablation zone expansion;* **c** *ablation zone expansion and melt increase, and* **d** *melt increase and refreezing capacity decline.*

5. Take home message

As **firn** oscillates around the hypsometry peak, a modest **warming** triggers fast ablation zone expansion and refreezing decline (Fig.4). In summer **2013**, the ablation zone even covered 77% of the glaciers area (Fig.5b), **doubling runoff** compared to previous years (Fig.5a). **Future firn retreat** will inevitably **amplify mass loss**.

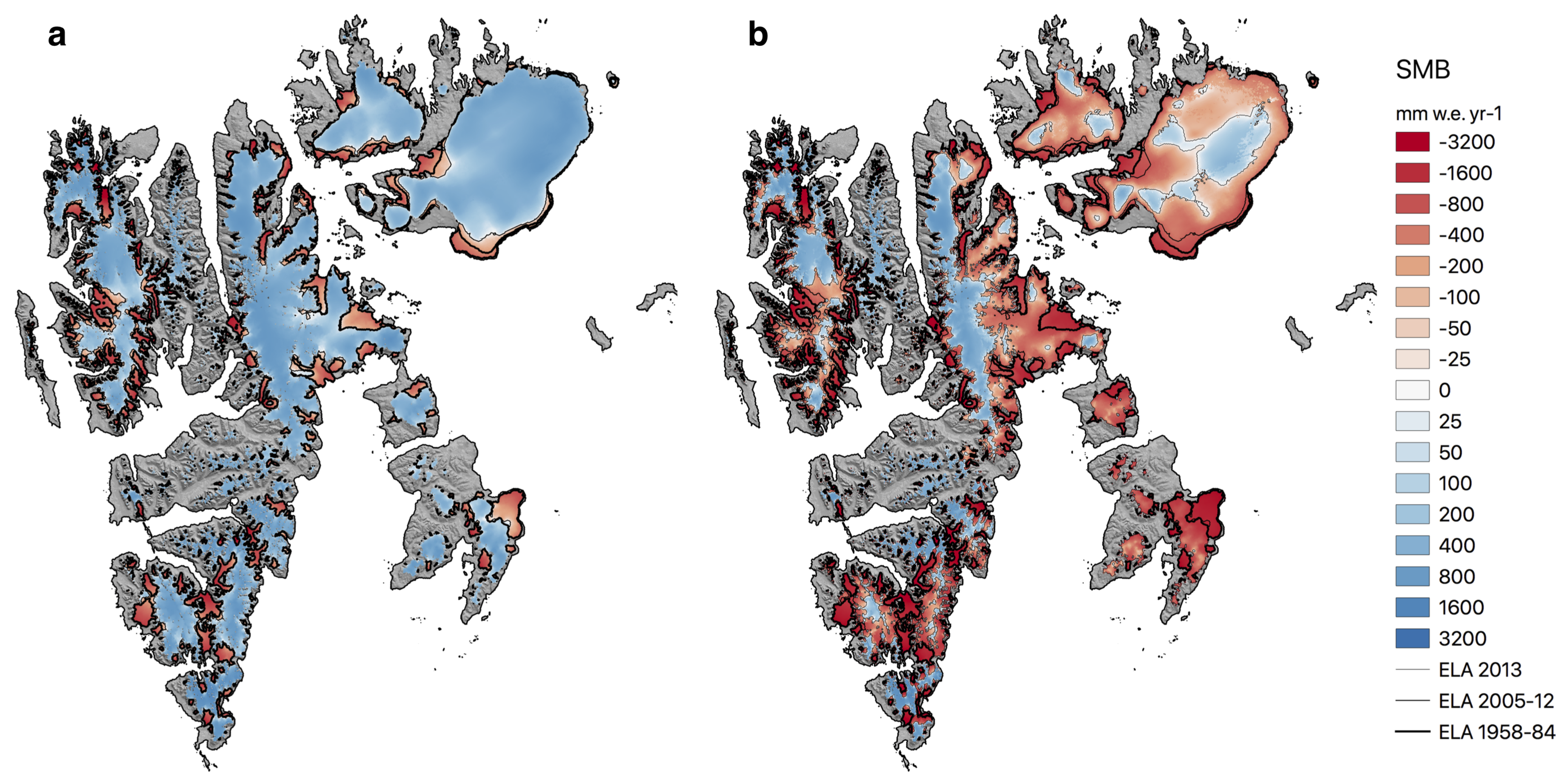

Fig. 5: *Annual mean SMB for* **a** *the colder period 2005-2012, and* **b** *the warm year of 2013 highlighting the fast ablation zone expansion when firn retreats to 590 m, well above the hypsometry peak at 450 m.*