The Cryosphere

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Supplement of

Diagnosing the decline in climatic mass balance of glaciers in Svalbard over 1957–2014

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S1 Meteorological measurements at Svalbard Airport

The 117 year long homogenized air temperature record after **?** from Svalbard airport is shown in Figure S1. Over the period all seasons has a positive trend with the largest warming during winter and lowest warming during summer. Summer temperature trend is not easily seen in Figure S1. Since 1976 daily meteorological measurements allow for estimating a common measure of glacier melt, yearly cumulative positive degree days (ΣPDD), which show a markedly increase over the last 40 years (Fig. S2).
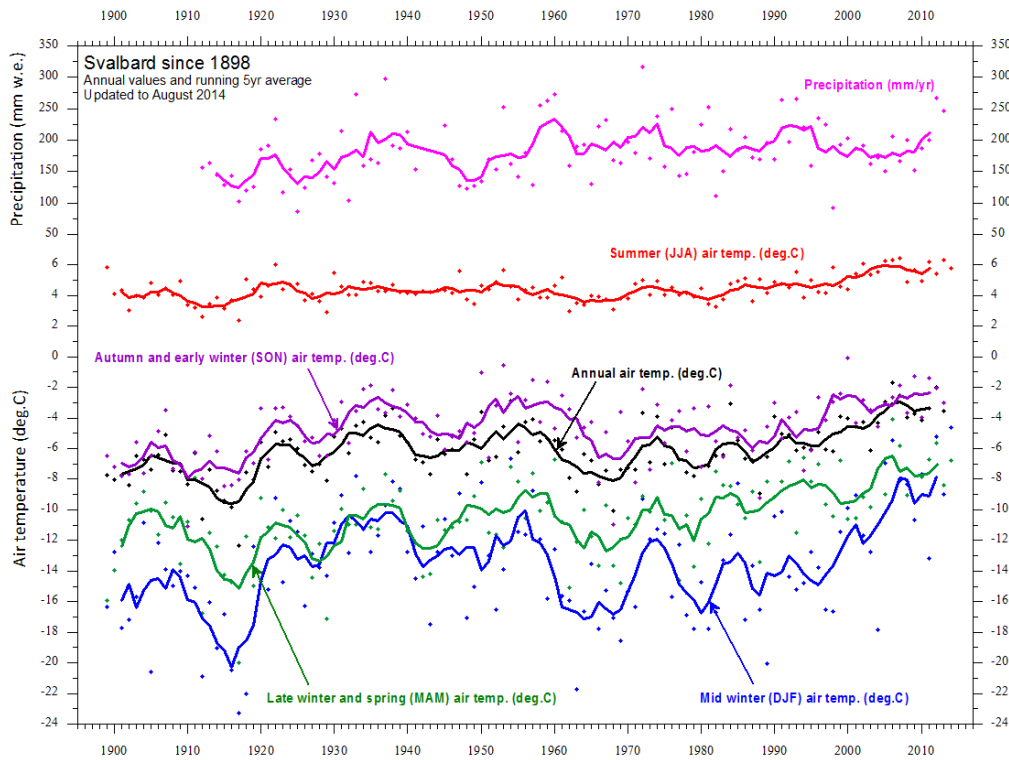

Figure S1. Air temperatures and precipitation at Svalbard Airport 1898-2014 from climate4you.com with data from eklima.no

S2 Glacier masks

Figure S3 shows the glacier coverage at three epochs, 1930-60s, 1990s, and 2000s, (**?**). Regional glacier area for the applied temporally evolving glacier mask, which was is derived by interpolation of the **?** inventory, is shown in Figure S4. For some locations like Kvitøya, glacier coverage is only available for the last epoch and the glacier area is constant for the entire period. This approach assume linear glacier retreat or advance between the epochs and no changes are assumed
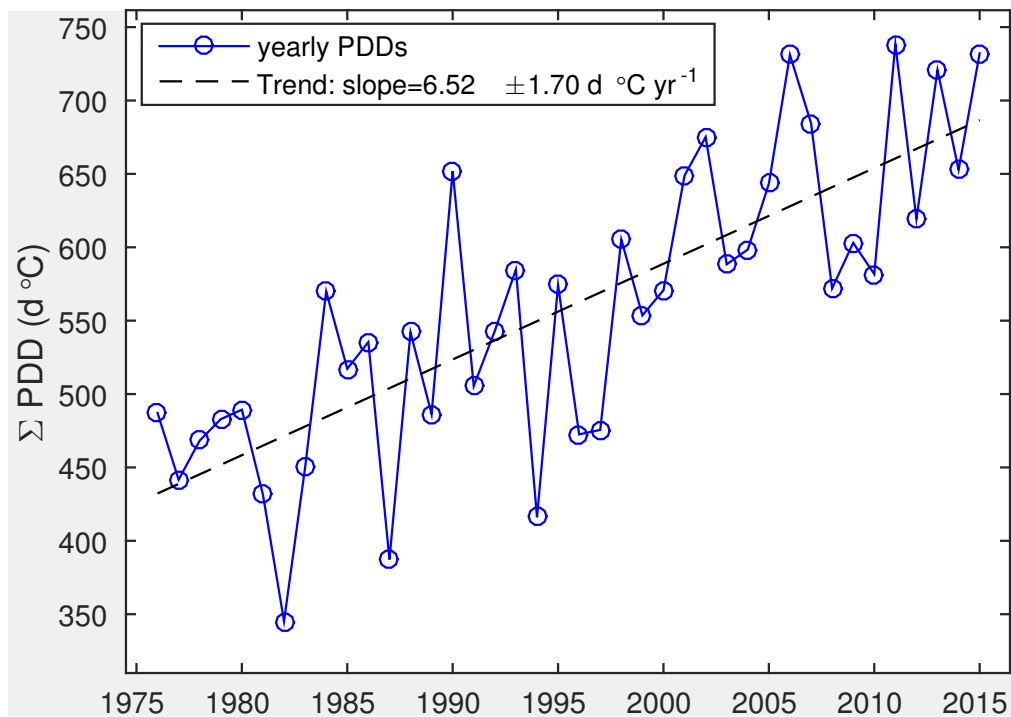
Figure S2. Accumulated positive degree days from Svalbard airport 1976-2015. Data from eklima.no

after the 2000s epoch. Representation of glacier tongue retreats are somewhat unrealistic, since they
15 disintegrate rather than displaying a frontal retreat.

S3   MODIS

Figure S5 shows MODIS-derived average over 2003-13 for: minimum summer (lower 5th percent)
albedo and mean annual clear-sky skin surface temperatures.

S4   Calibration

20 Table S1 list relevant parameters employed in the model and how the respective values are deter-
mined. Only four parameters were determined during the calibration. Expert judgment are values
based on one or more of the following: 1) from a pre-calibration step with many more than the 4 pa-
rameters, to aid the parameter choice in the next calibration exercise; 2) from fitting to observations,
where direct comparison where possible; 3) from a mixture of values found in the literature.
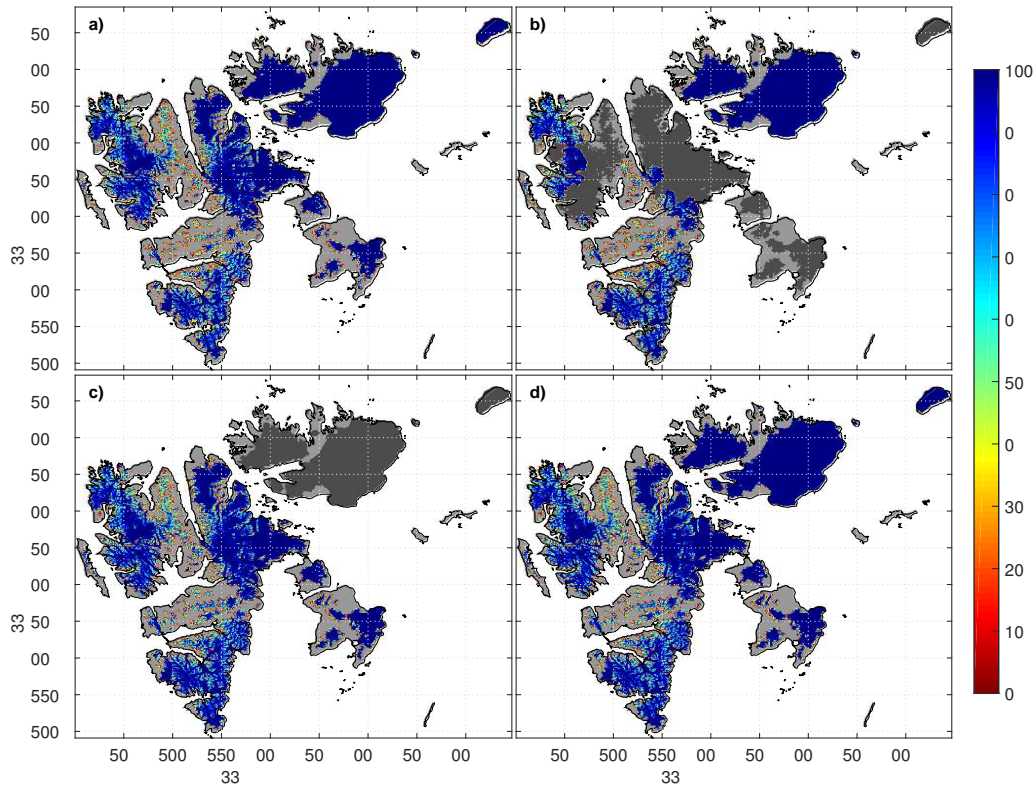
Figure S3. Fractional glacier cover (%) on 1000m DEM: a) 2000s, b) 1990s, c) 1930s/60s and d) reference mask
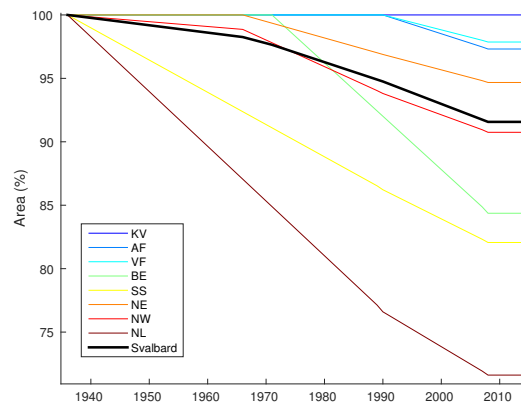

Figure S4. Glacier area evolution for Svalbard and it's regions in percent from the first data acquisition in 1936 and onwards constructed from the multi-temporal glacier inventory (**?**).
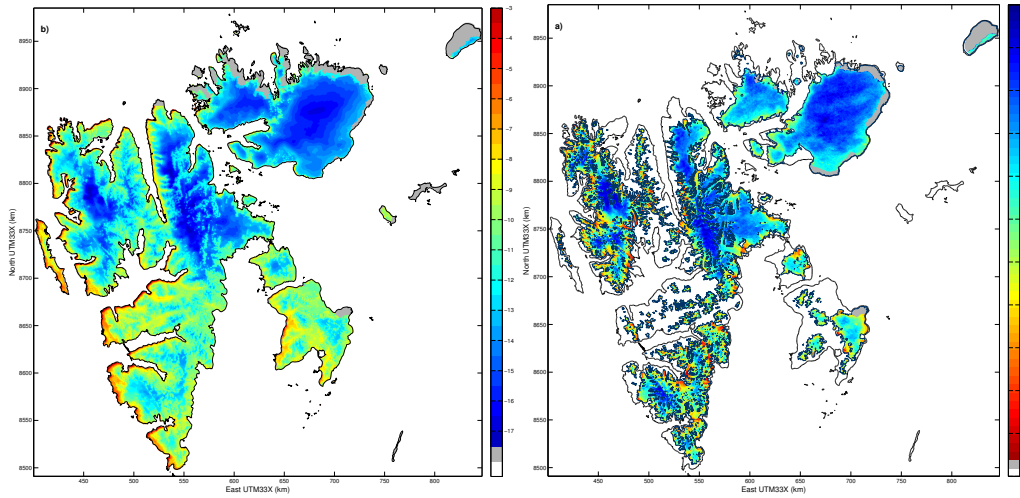
Figure S5. a) Mean annual clear-sky skin surface temperatures from MODIS over 2003-2013. b) Minimum (lower 5th percentile) summer albedo averaged over 2003-2013 derived from MODIS. Missing data (in gray) are caused by erroneous landmask in MODIS.

S5   Regional Refreezing and Thermal regime

Figure S6 and S7 shows yearly amount of refreezing and 15 m temperatures with altitude resolved regionally. All regions show nearly the same response regarding thermal regime for the period 1957-2014, thus occurring at different elevation. The main features are: 1) warming of the cold ice in the ablation area; 2) cooling of the the area around ELA, which climb increase as firn area shrinks with the increasingly negative B_{clim}; 3) warming of the cold firn area which existed until 1975, when nearly all firn became temperate.

Table S1. Overview on parameters and parameterization employed in the model and their origin.

| Process	Parameter	Symbol	Value	Source
Turbulent fluxes	Roughness lengths of momentum	zo_{ice} (mm)	0.18	Calibration
		zo_{snow} (mm)	0.06	Calibration
	Roughness length heat/moist	$zo_{T/q}$ (mm)	see	**?**
Albedo	Ice	α_{ice} (−)	0.30	Calibration
	Firn/ min snow	α_{firn} (−)	0.62	Calibration
	New snow	α_{snow} (−)	0.85	Expert judgment
	Slush	α_{slush} (−)	0.55	Expert judgment
	Superimposed ice	α_{SI} (−)	0.67	Expert judgment
	Water	α_{water} (−)	0.15	**?**
	Slush	α_{slush} (−)	xx	Expert judgment
	Aging wet snow	t^*_{wet} (d)	5	Expert judgment
	Aging dry snow 0°C	$t^*_{dry(0°C)}$ (d)	15	Expert judgment
	Aging cold snow -10°C	$t^*_{dry(-10°C)}$ (d)	100	Expert judgment
	Depth scale snow	d^* (cm)	3	**?**
	Depth scale water	w^* (cm)	30	**?**
Long wave radiation	Emissivity	ϵ (−)	0.99	**?**
Heat conductivity	Ice conductivity	a (W m^{-1} K^{-1})	2.3	Expert judgment
(**?**)	Exponent	b (−)	2.35	Expert judgment
Runoff	timescales	$\tau_{steep}, \tau_{1°}, \tau_{0°}$, Factor	see	**?**
Precipitation	Rain/snow threshold	$T_{rain/snow}$ (°C)	1.5	Expert judgment
Fresh snow density	Density	ρ_{fsn} (kg m^{-3})	300	Expert Judgment
Densification				**?**
Irreducible water content				**?**
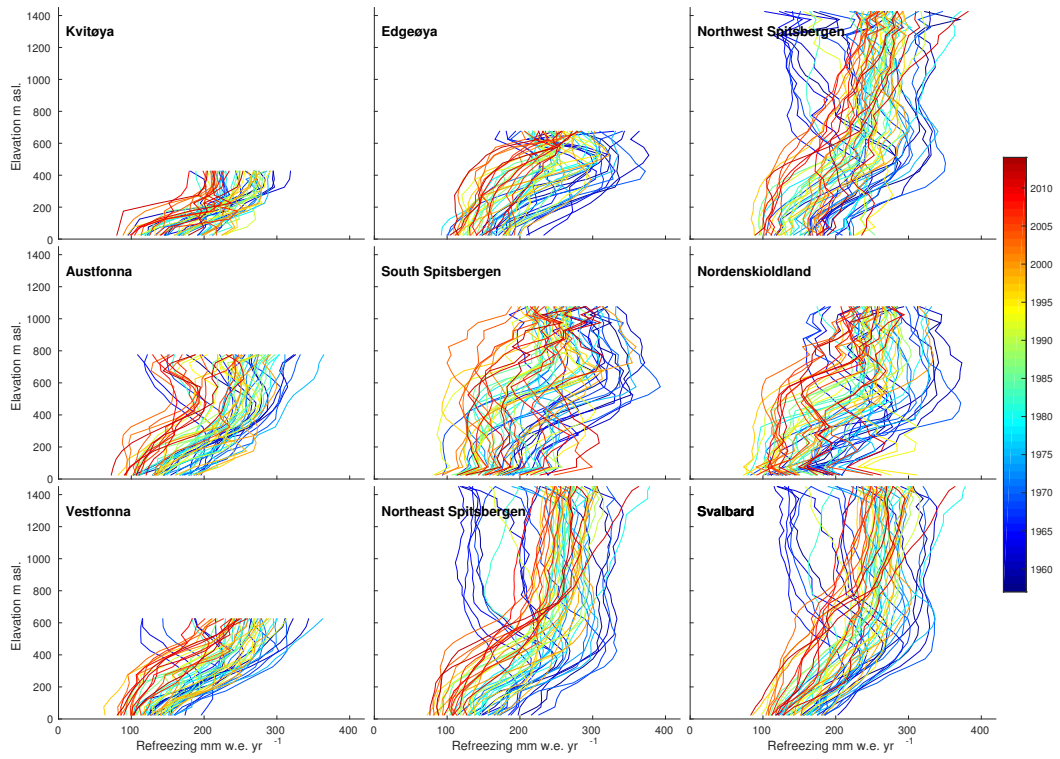
Figure S6. Refreezing averaged over 50 m altitude intervals for Svalbard and for 8 regions, for each year from 1957 (blue) to 2014 (red).
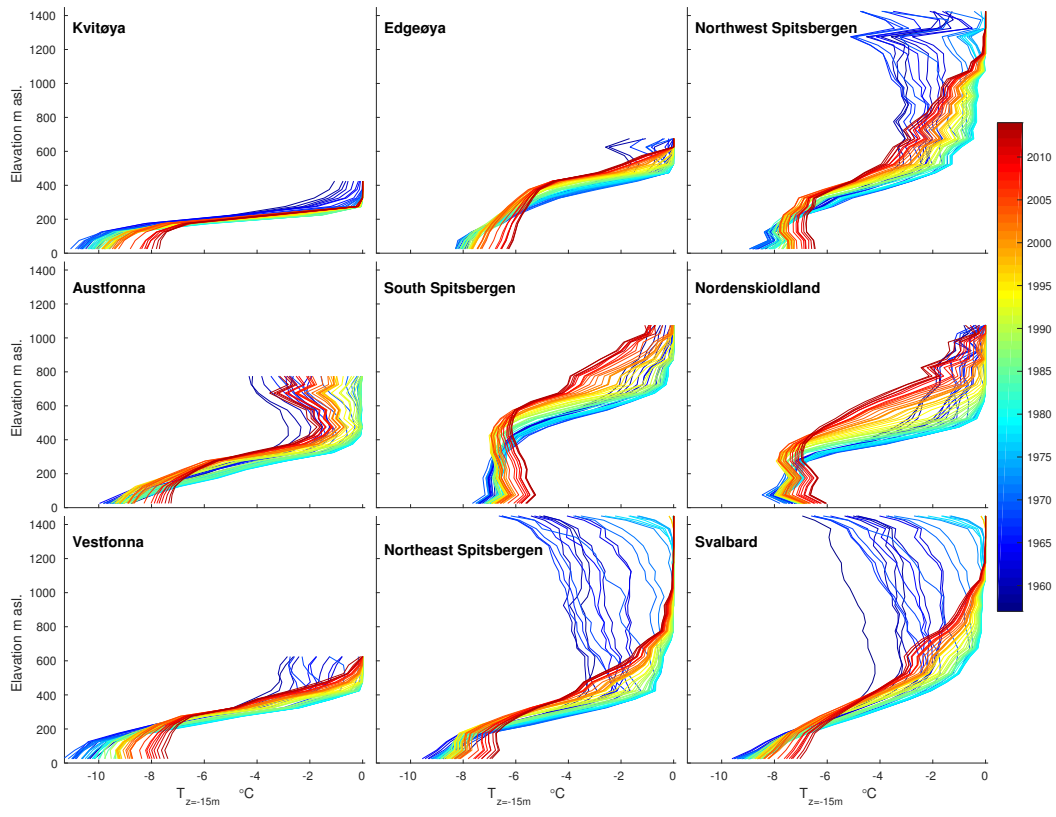
Figure S7. Subsurface temperatures at 15 m depth averaged over 50 m altitude intervals for Svalbard and for 8 regions, for each year from 1957 (blue) to 2014 (red).