Supplementary information

Glacier dynamics over the last quarter of a century at Jakobshavn Isbræ

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# Values of the ice sheet model (PISM) parameters

Table S1. Parameters of the ice sheet model that have been altered from the default PISM values during the regional equilibrium simulations

|  |  |  |
| --- | --- | --- |
| ﻿Symbol | Description | Value |
| *ESIA* | the flow enhancement factor for SIA | 1.2 |
| *ESSA* | the flow enhancement factor for SSA | 0.6 |
| *Fmelt* | parameter for subshelf melting [*m s-1*] | 10-3 |
| *Hcr* | ice thickness threshold [*m*] | 500 |
| *K* | proportionality constant for eigen calving [*ms*] | 1018 |
| *q* | the exponent of the pseudo-plastic basal resistance model | 0.3 |
| *δ* | the till effective fraction overburden | 0.02 |
| *ϕ* | the till fraction angle | ° |
| *ϕ min* | for bed elevations lower than 300 m below sea level [ ° ] | 15 |
| *ϕ max* | for bed elevations higher than 700 m above sea level [ ° ] | 40 |
| *T0* | temperature of the ocean water [°*C*] | -1.7 |
| *S0* | salinity of the ocean water under the ice shelves [*psu*] | 35 |

Table S2. Parameters of the ice sheet model that have been altered from the default PISM values during the forward simulations

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| --- | --- | --- | --- |
| ﻿Symbol | Description | Value | Range\* |
| *ESIA* | the flow enhancement factor for SIA | 1.2 | 1.0 - 1.3 |
| *ESSA* | the flow enhancement factor for SSA | 0.6 | - |
| *Fmelt* | parameter for subshelf melting [*m s-1*] | 5.05-1 | 10-3 - 5.05-1 |
| *Hcr* | ice thickness threshold [*m*] | 375 | 250 - 450 |
| *K* | proportionality constant for eigen calving [*ms*] | 218 | - |
| *q* | the exponent of the pseudo-plastic basal resistance model | 0.3 | 0.2 - 0.3 |
| *δ* | the till effective fraction overburden | 0.02 | 0.02-0.03 |
| *ϕ* | the till fraction angle\*\* | ° | - |
| *ϕ min* | for bed elevations lower than 300 m below sea level [ ° ] | 15 | - |
| *ϕ max* | for bed elevations higher than 700 m above sea level [ ° ] | 40 | - |
| *T0* | temperature of the ocean water [°*C*] | -1.7 | -1.3 - -1.9 |
| *S0* | salinity of the ocean water under the ice shelves [*psu*] | 35 | - |

\* Range (min/max values) for the parameters tested during the simulations;

\*\* The till fraction angle (*ϕ*) is computed as a piecewise-linear function of the bed elevation, with = 15° for bed elevations lower than 300 m below sea level, with = 40° for bed elevations higher than 700 m above sea level, and in between values with a linear change (see eq. 8 in The PISM Authors (2014)).

The PISM parameters are described in detail by The PISM Authors (2014), Winkelmann et al. (2011) and Aschwanden et al. (2013). We perform 50 simulations in which we vary different sets of parameters with focus on *ESIA, q, δ, Fmelt, Hcr, K* and *T0.*

From these simulations, we present in this paper the parameterization that best captures the full evolution of JI during the period 1990–2014: (i) in terms of observed versus modelled front positions for 1990-2014 and (ii) based on the correlation between observed and modelled mass changes during 1997-2014. While (i) is based on our visual interpretation, for (ii) we selected those simulations within a +/- 30 Gt threshold. We found 3 simulations to satisfy (i) and (ii). From these simulations, we choose only the one that captures the two accelerations from the observational record within a 1 year time frame difference and that has overall magnitudes similar with the observational record (i.e. the RMSE in point S1 is ~2236 m a-1; see also Fig. 3). It seems relevant to highlight that all the simulations are able to capture the two accelerations of JI within a 3 year time frame difference, but none of the simulations is able to simulate the 2012 speak in the observed velocities.

# 2 Observed ice mass change

We estimate the rate of ice volume change using 1997–2014 NASA’s Airborn Topographic Mapper (ATM) flights (Krabill, 2014) derived altimetry, supplemented with Ice, Cloud and land Elevation Satellite (ICESat) data (Zwally et al., 2012) for 2003–2009 and Land, Vegetation and Ice Sensor (LVIS) data (Blair and Hofton 2012) for 2007–2012, CryoSat-2 data (Wouters et al., 2015) for 2010–2014, and European Remote-Sensing Satellite (ERS-2) data during 1997-2003. ATM flight lines in the JI region between 1993 and 1996 cover only a minor transect, and are therefore not used. The procedure for deriving ice surface elevation changes is identical to Khan et al. (2013) and is similar to the method used by, for example, Ewert et al. (2012) and Smith et al. (2009). However, ice surface elevation changes from cryostat-2 data were derived as described by Wouters et al. (2015) and Helm et al. (2014). We convert the volume loss rate into a mass loss rate and take firn compaction into account as described by Kuipers Munneke et al. (2015). Further, corrections are made for bedrock movement caused by elastic uplift from present-day mass changes (Khan et al., 2010) and long-term past ice mass changes, Glacial Isostatic Adjustment (GIA), (Peltier, 2004). Table 3 shows the ice mass change rates in Gt a-1 during 1997-2014.

Table 2. Estimated ice mass change rates in Gt a-1 from airborne and satellite laser altimetry for 1997– 2014

|  |  |
| --- | --- |
| ﻿Time span | Mass change [Gt a-1] |
| 1997–2003 | -5.9 ± 2.7 |
| 2003–2006 | -10.4 ± 1.4 |
| 2006–2009 | -18.7 ± 1.2 |
| 2009–2012 | -27.4 ± 1.6 |
| 2012–2014 | -33.1 ± 2.2 |

# 3 Modeled and observed elastic uplift due to mass changes from JI

We assess the mass change from the regional 3-D outlet glacier model by comparing predicted and observed bedrock displacements. We predict displacements by convolving mass change from the regional 3-D outlet glacier model with the Green’s function for vertical displacements for the Preliminary Reference Earth Model (Dziewonski and Anderson, 1981) (see Fig. 4 solid black curve).

We compare predicted bedrock displacements with observed displacements from Global Positioning System (GPS) time series at four sites located between 5 and 150 km from the front of JI. To estimate site coordinates from GPS measurements, we follow the procedure of Khan et al. (2010). Fig. 5 (blue curve) shows observed GPS time series of monthly average vertical bedrock displacements caused by the Earth’s elastic response to seasonal ice mass variability. To focus on elastic displacements caused by present-day mass variability of the JI, we remove bedrock displacements due to ice mass loss outside JI using load estimates from satellite altimetry (Nielsen et al., 2013) and we remove GIA based on the deglaciation history ICE-5G (VM2 L90) version 1.3 estimated by W. R. Peltier.

# 4 ATM data 1997-1998

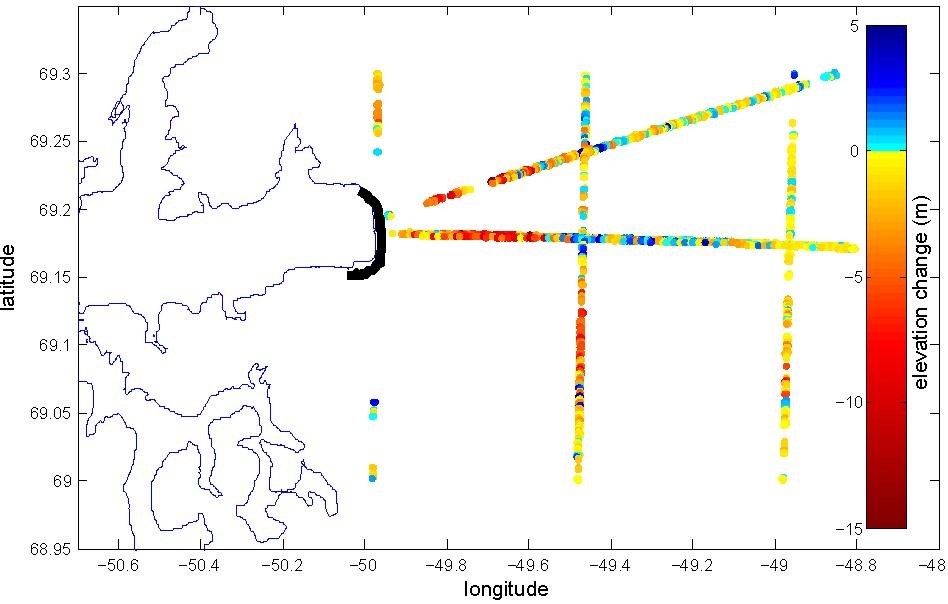


Figure S1. Elevation change from NASA’s ATM flights during 1997-1998 at Jakobshavn Isbræ. The thick black line denotes the JI terminus position in 1998. The red and orange circles denote thinning during 1997-1998 both on the northern and southern tributary of JI.

Figure S1 shows thinning during 1997 to 1998. The red circles denote major thinning of ~10 m during 1997-1998 both on the northern and southern tributary of JI.

# 5 Evolution of the main driver variables for the atmosphere and the ocean during 1990-2014

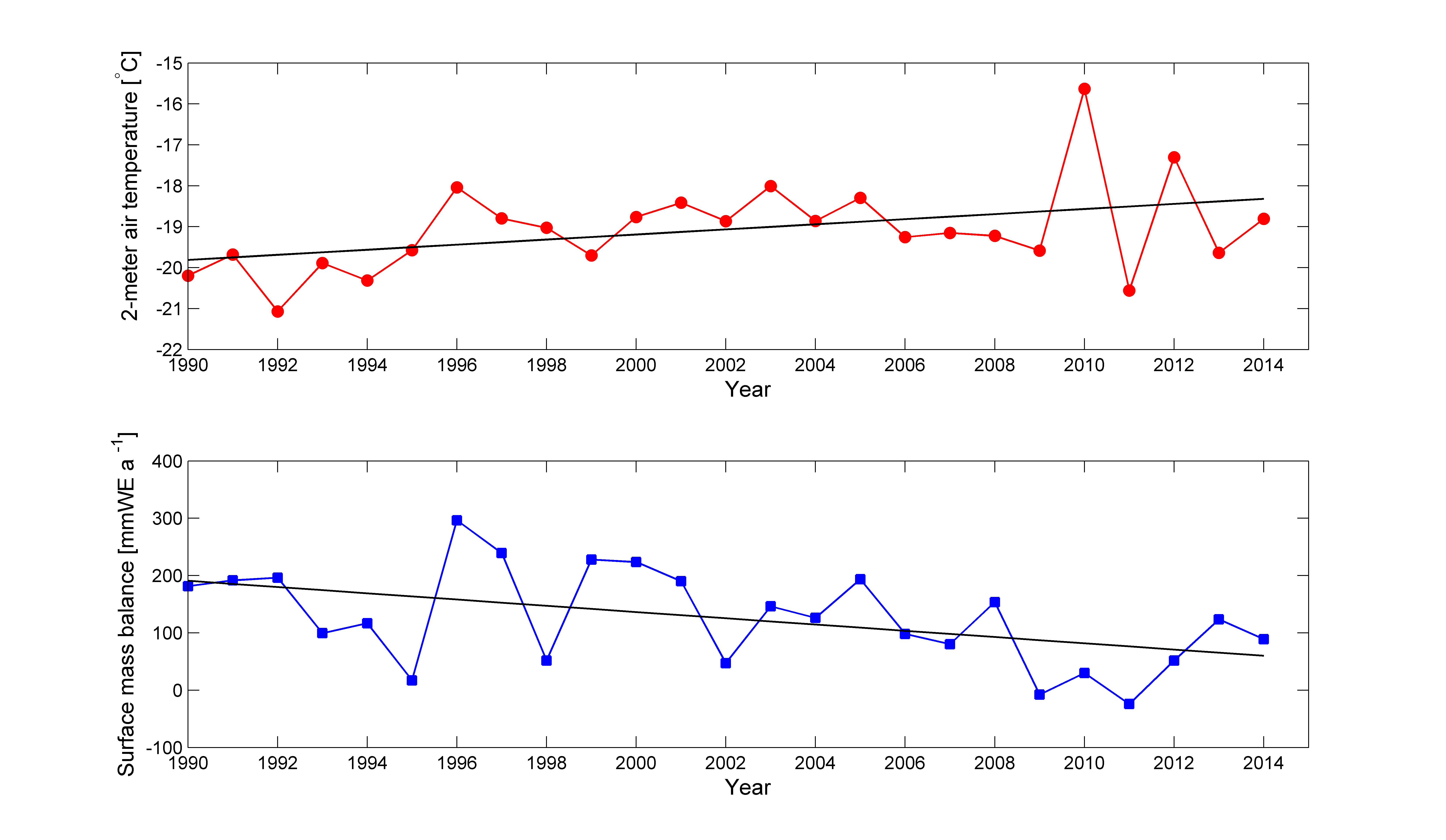
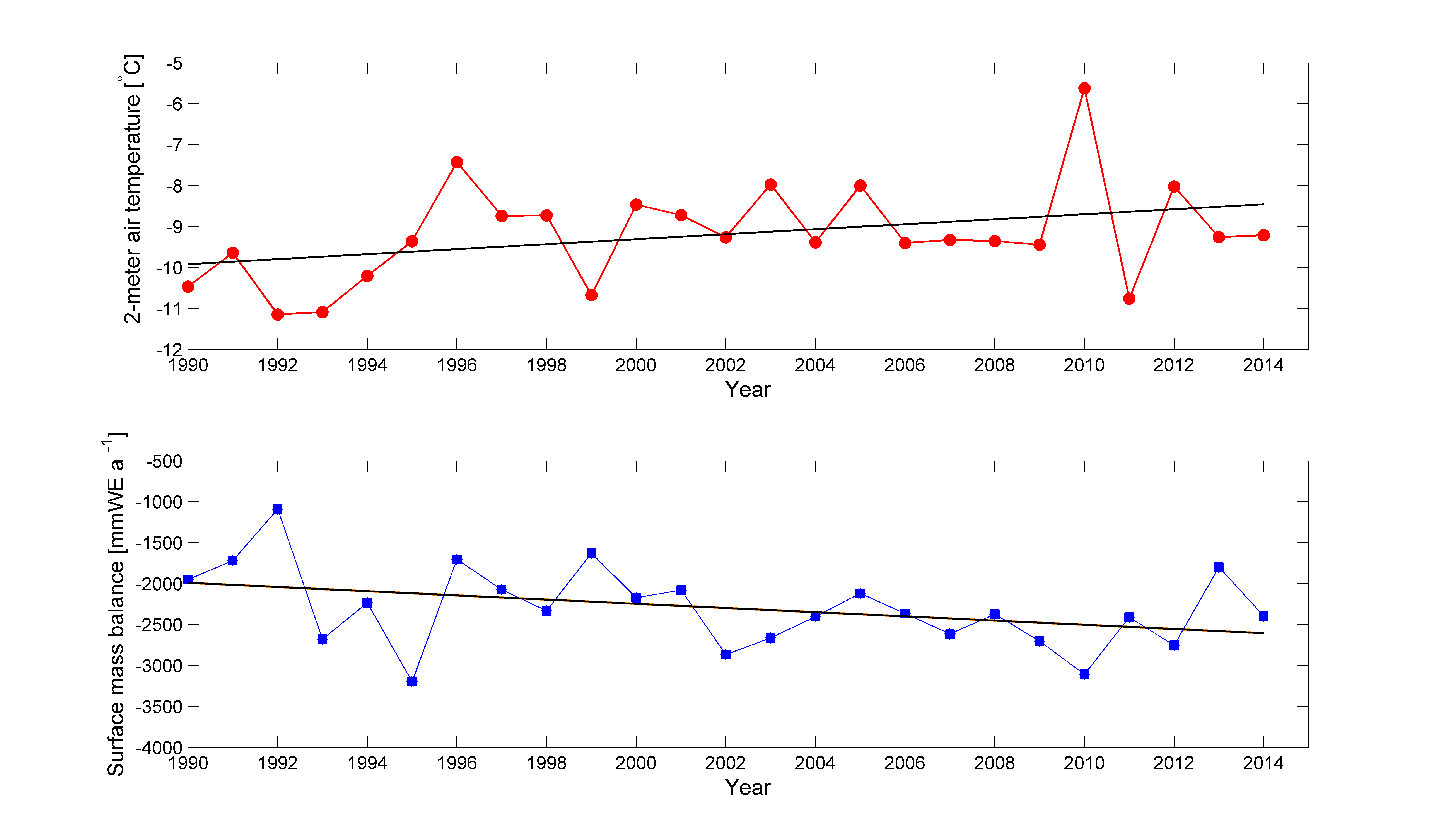


Figure S2. Mean annual 2-meter air temperature [°C] and surface mass balance [mmWE a-1] with their respective trend lines (black line)during the period 1990-2014 for the computational domain shown in Fig. 1B (red border polygon).



# Figure S3. Mean annual 2-meter air temperature [°C] and surface mass balance [mmWE a-1] (near the 2014 JIs terminus) with their respective trend lines (black line) for the period 1990-2014.

Figures S2 and S3 denote the mean annual 2-meter air temperature and surface mass balance (SMB) for the computational domain shown in Fig. 1B and near the 2014 JIs terminus (as calculated based on RACMO 2.3 (Noël et al., 2015)). The data suggest an overall increase in temperature and a decrease in SMB. The decrease in SMB is most significant near the terminus. Overall 1996, 2010 and 2012 are characterized by higher mean annual temperatures.

For the simulations that best captures the full evolution of JI during the period 1990–2014, the ocean temperature (T0) is set to a constant value of -1.7 °C (see sec. 2.1.3 and Table S2).

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