Supplementary Material

This supplement includes:

1-Gap filling of the maps of elevation difference

2-Time series of elevation changes of target glaciers

3-Floating-date and fixed-date geodetic mass balance

4-Temporally homogenized geodetic mass balance

5-Plots from the joint analysis of geodetic mass balance and climatic records

1 GAP FILLING OF THE MAPS OF ELEVATION DIFFERENCES

The gaps on the maps of difference between Digital Elevation Models (dDEMs) were filled using a mean elevation difference at each 100 m elevation bands, after excluding values larger than three times the Normalized Median Absolute Deviation (NMAD) of each analyzed band (e.g. Brun et al., 2017). In some cases, these gaps accounted for a significant percentage of the dDEM on the glacierized area analyzed (up to 40% in the dDEM of Snæfellsjökull, Figure S8). We established three categories of errors based on the area coverage of each band each elevation band for filling the entirety of the band: we assigned $\pm$1NMAD of the analyzed band if this contained 60%–80% grid points, $\pm$2NMAD for 40%–60% grid points and $\pm$3NMAD for elevation bands with less than 40% grid points.

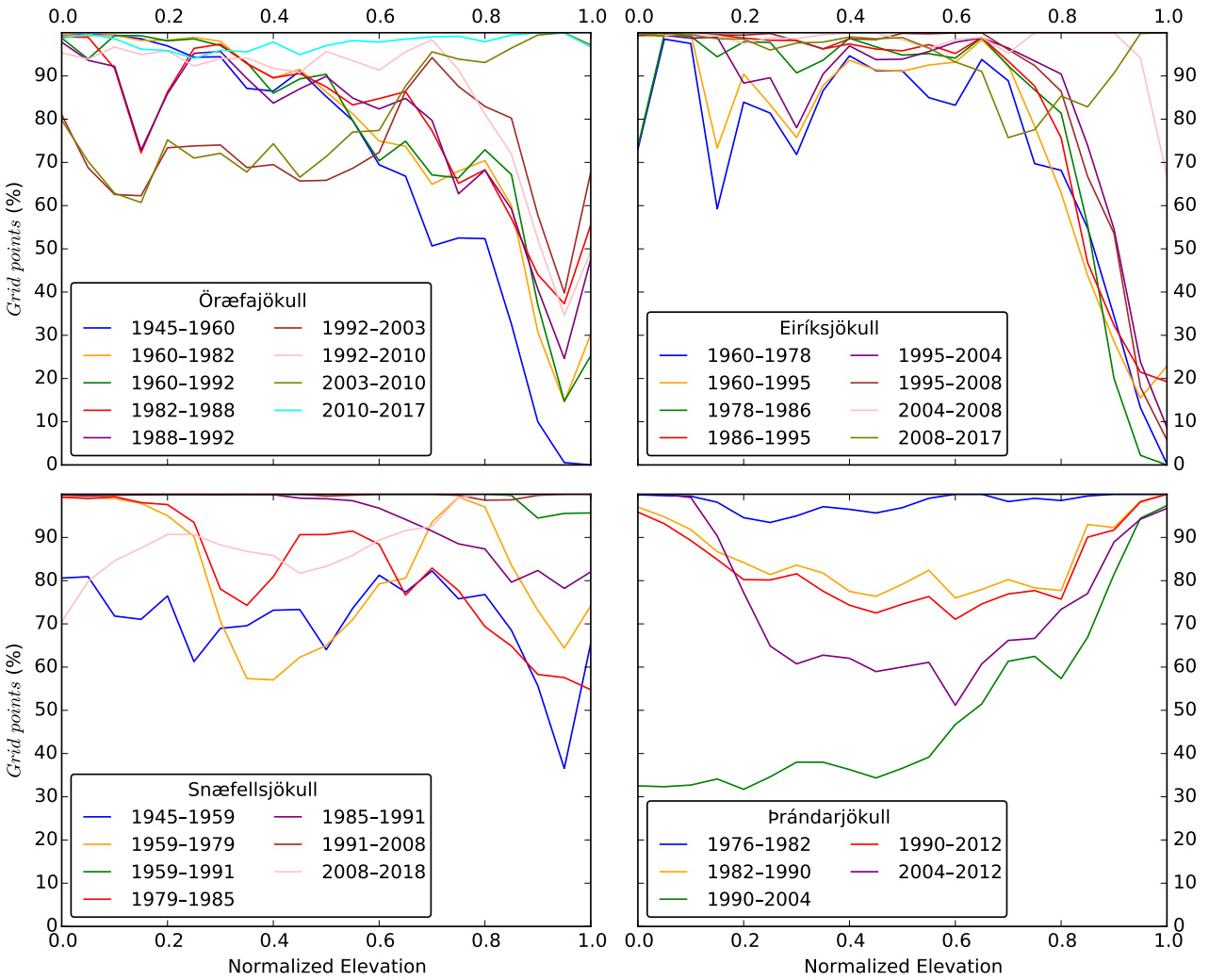

Figure S1. Area fraction of the dDEM on-glacier, at the four target areas with the largest data gaps, plotted versus the normalized elevation from lidar. Normalized elevation was calculated as $(z - z_{2.5})/(z_{97.5} - z_{2.5})$, where z is elevation and the sub-indexes indicate percentiles of the entire range of elevation

2 ELEVATION CHANGES OF INDIVIDUAL TARGET GLACIERS

In this section we show the elevation changes obtained for each target glacier analyzed. Similar maps can be found for Drangajökull (Magnússon et al., 2016) and Eyjafjallajökul (Belart et al., 2019).

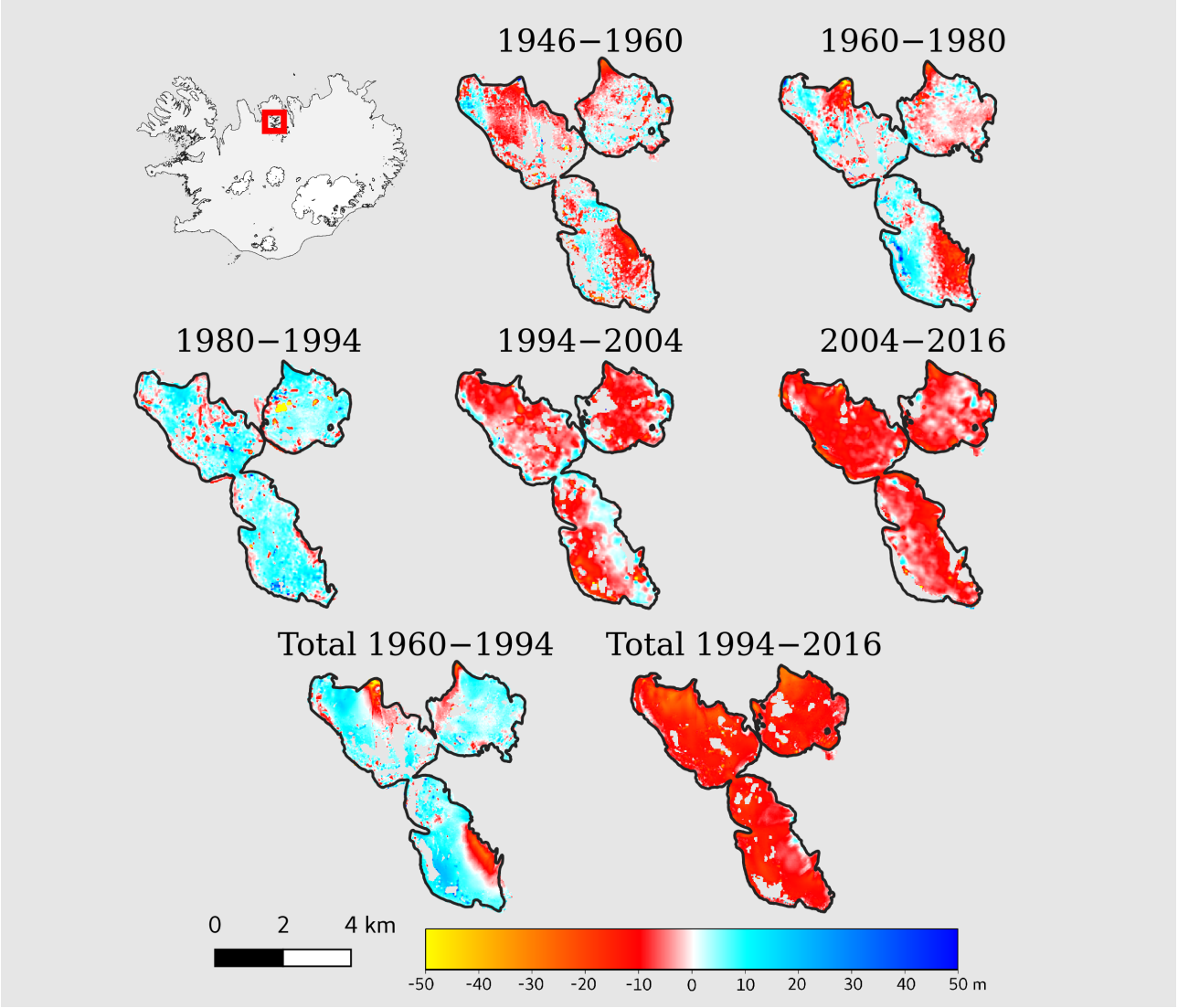

Figure S2. Elevation changes of Barkárdals- and Tungnahryggsjökull between 1946–1960, 1960–1980, 1980–1994, 1994–2004, 2004–2016 and for longer time periods: 1960–1994 and 1994–2016. Data voids are shown in grey.

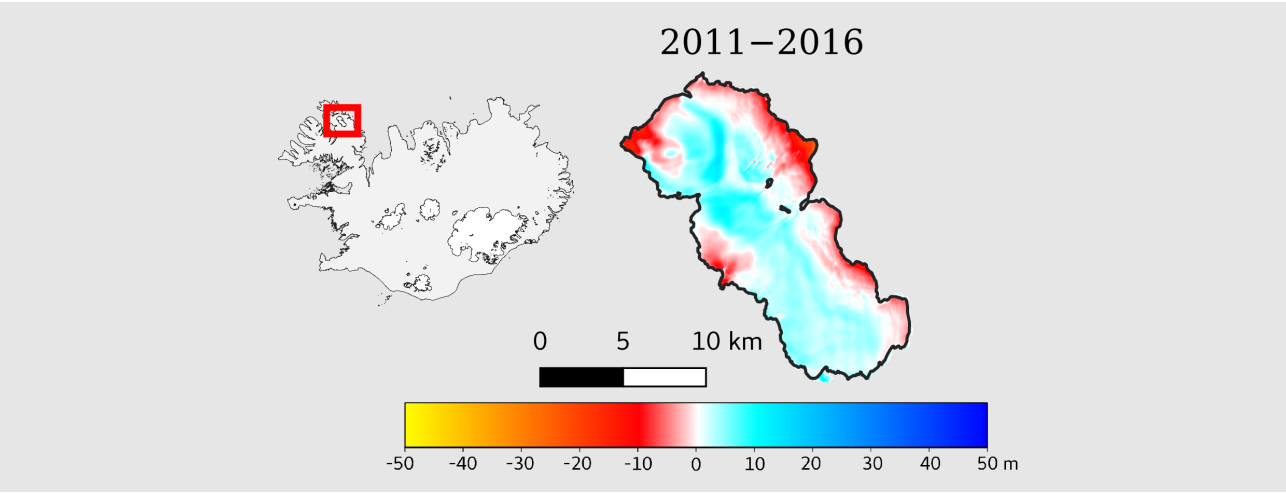

Figure S3. Elevation changes of Drangajökull in 2011–2016. The time series of elevation changes from 1946 to 2011 is shown in Magnússon et al. (2016).

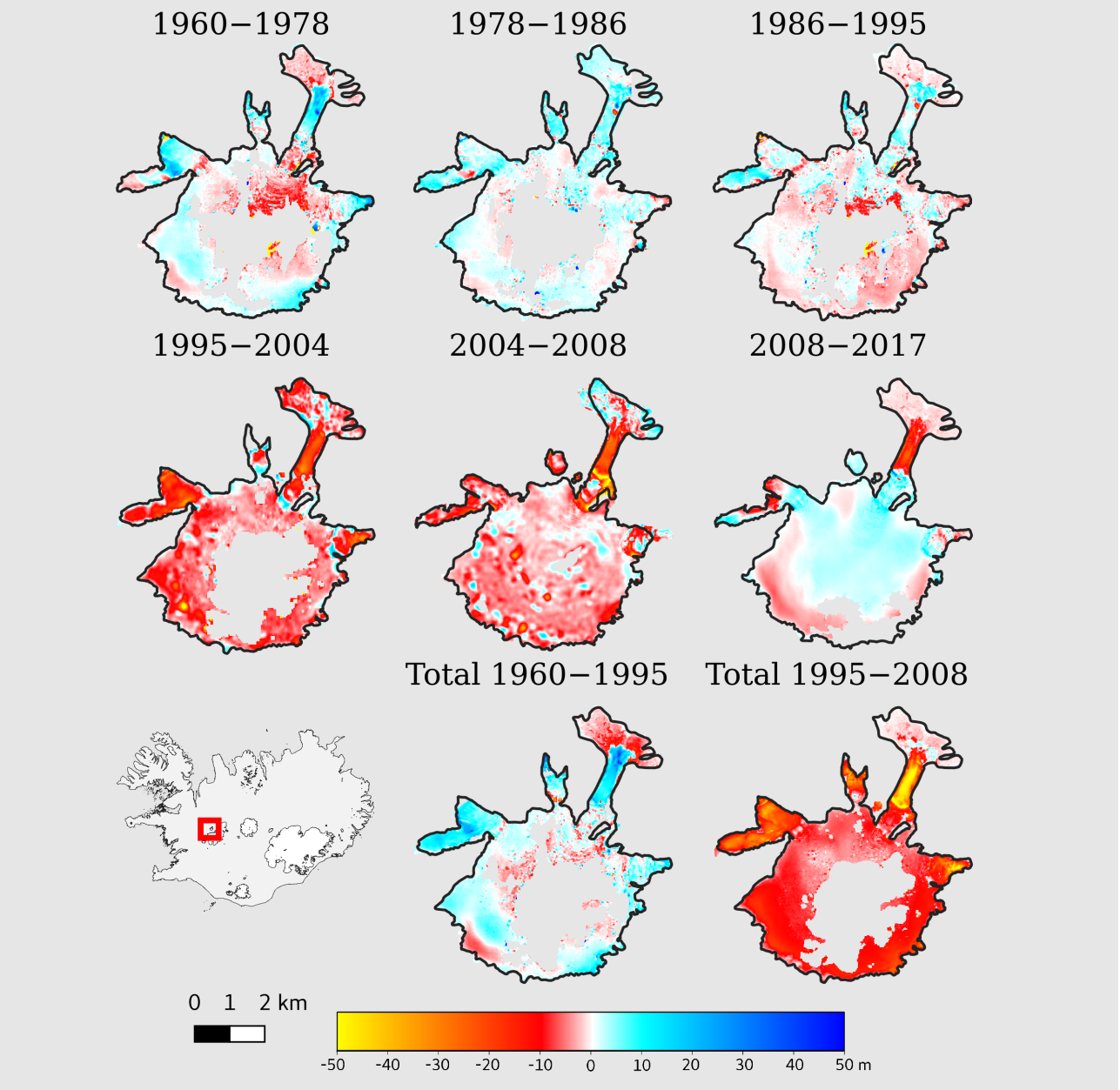

Figure S4. Elevation changes of Eiríksjökull between 1960–1978, 1978–1995, 1995-2004, 2004–2008, 2008–2017 and for longer time periods: 1960–1995 and 1995–2008. Data voids are shown in grey.

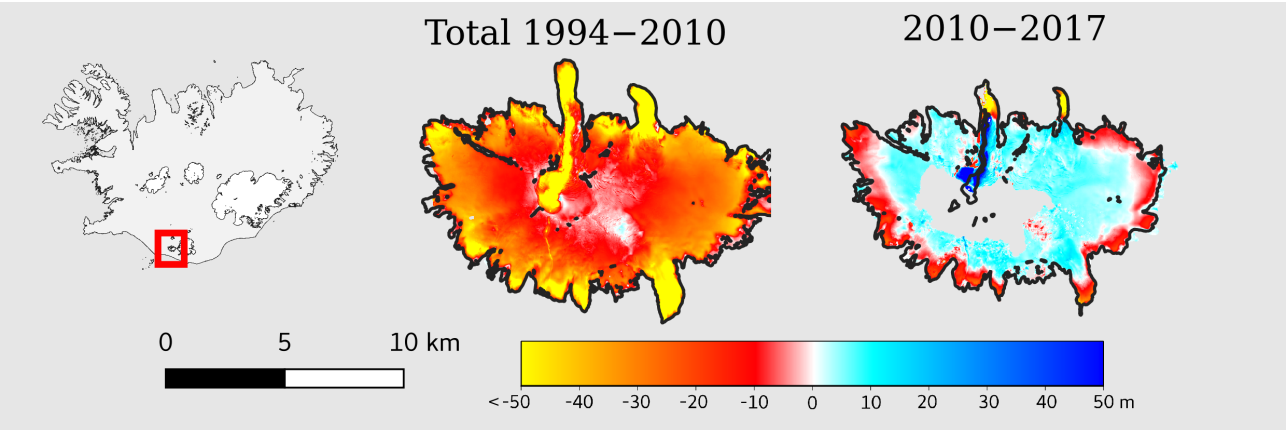

Figure S5. Elevation changes of Eyjafjallajökull in 2010–2017 and for the longer period 1994–2010. Data voids are shown in grey. The time series of elevation changes from 1945 to 2010 and the longer period 1960–1994 are shown in Belart et al. (2019).

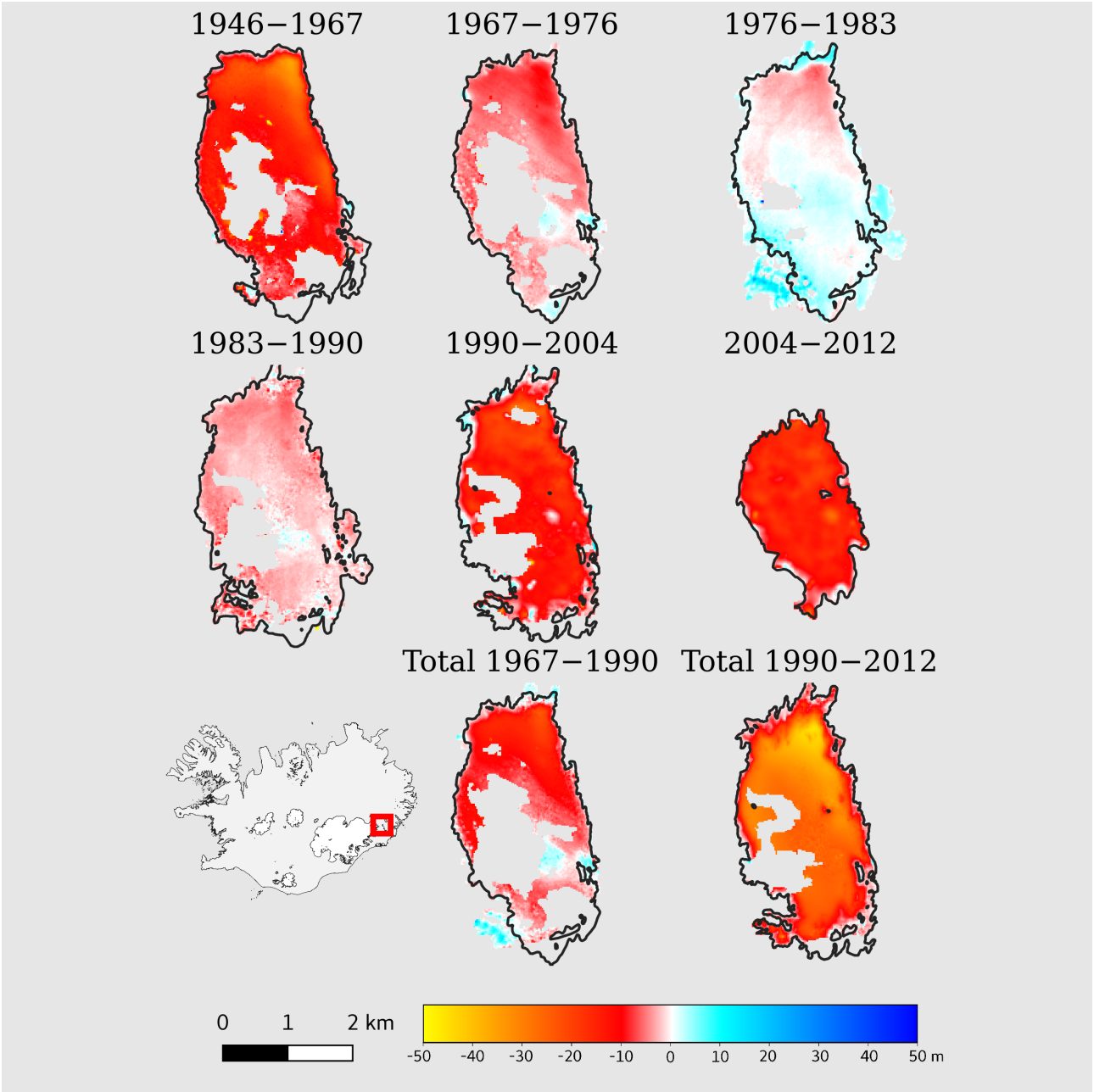

Figure S6. Elevation changes of Hofsjökull Eystri between 1946–1967, 1967–1976, 1976–1984, 1983–1990, 1990–2004, 2004–2012 and for longer time periods: 1967–1990 and 1990–2012. Data voids are shown in grey.

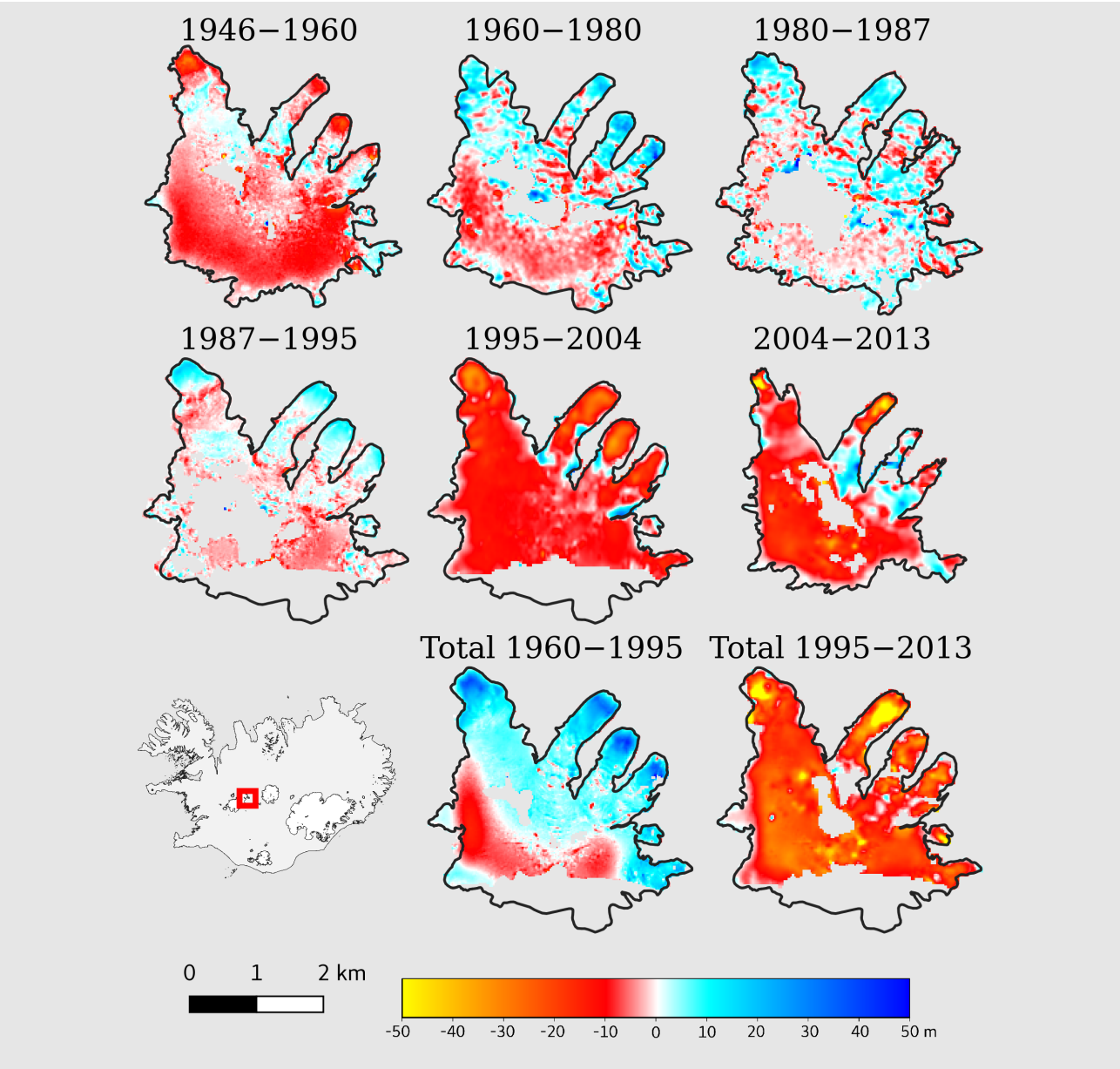

Figure S7. Elevation changes of Hrútfell between 1946–1960, 1960–1980, 1980–1987, 1987–1995, 1995–2004, 2004–2013 and for longer time periods: 1960–1995 and 1995–2013. Data voids are shown in grey.

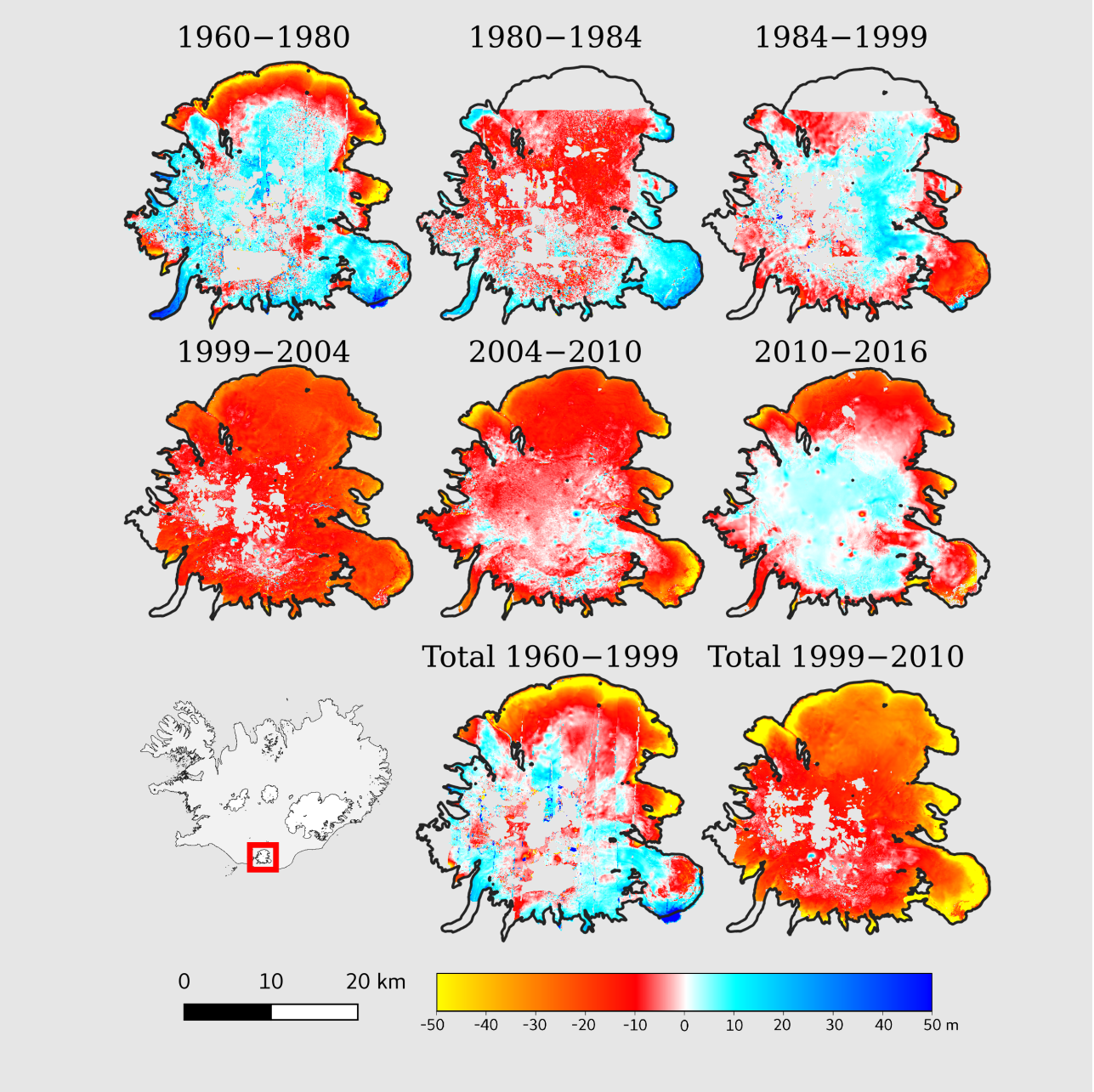

Figure S8. Elevation changes of Mýrdalsjökull between 1960–1980, 1980–1984, 1984–1999, 1999–2004, 2004–2010, 2010–2016 and for longer time periods: 1960–1999 and 1999–2010. Data voids are shown in grey.

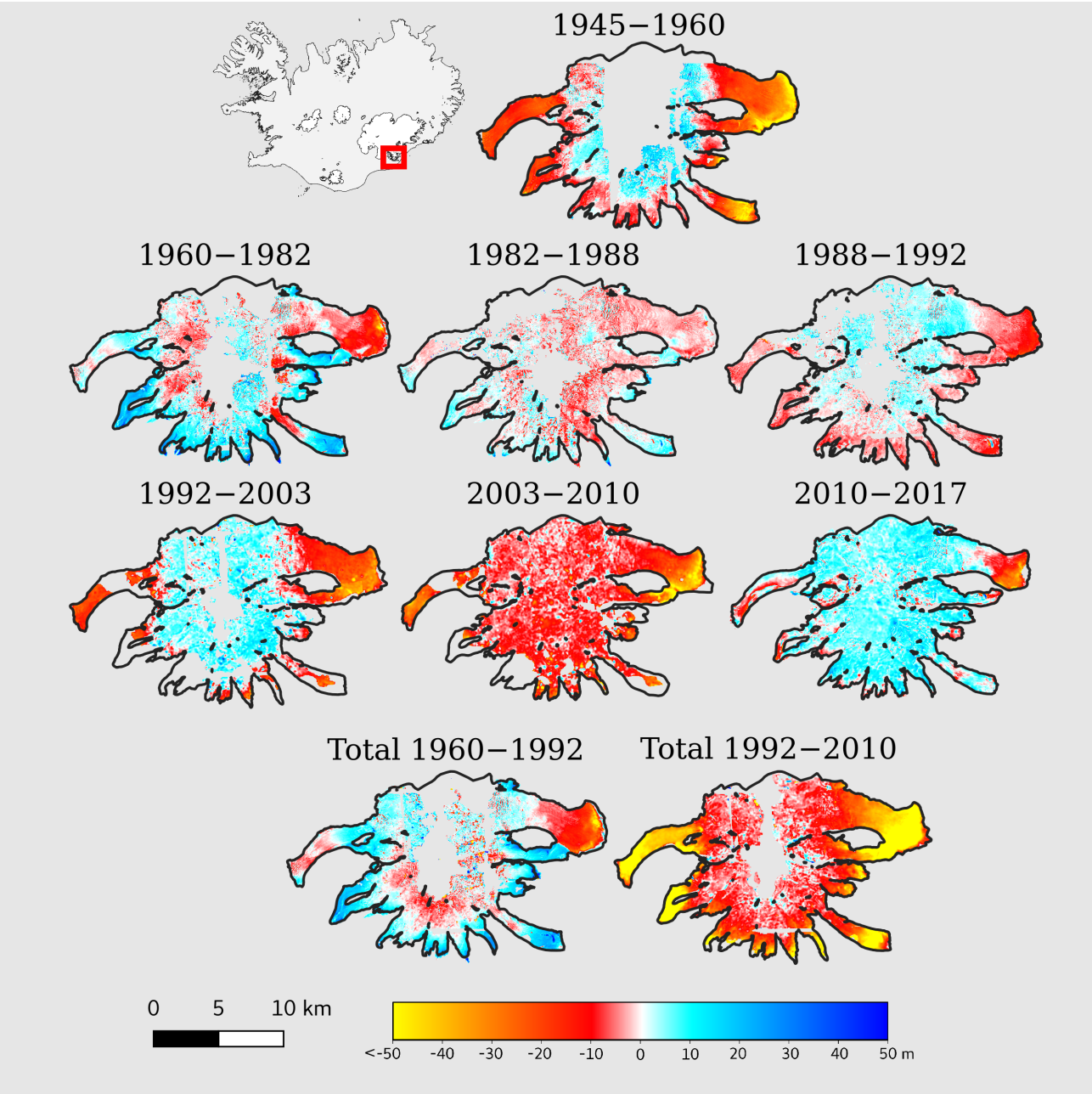

Figure S9. Elevation changes of Öræfajökull between 1945–1960, 1960–1982, 1982–1988, 1988–1992, 1992–2003, 2003–2010, 2010–2017 and for longer time periods: 1960–1992 and 1992–2010. Data voids are shown in grey.

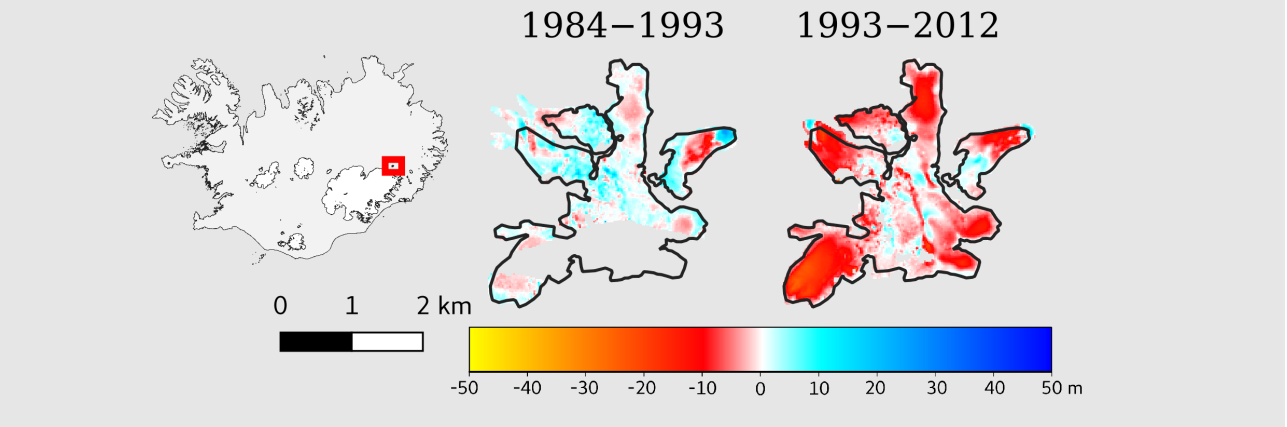

Figure S10. Elevation changes of Snæfell between 1984–1993, 1993–2012. Data voids are shown in grey.

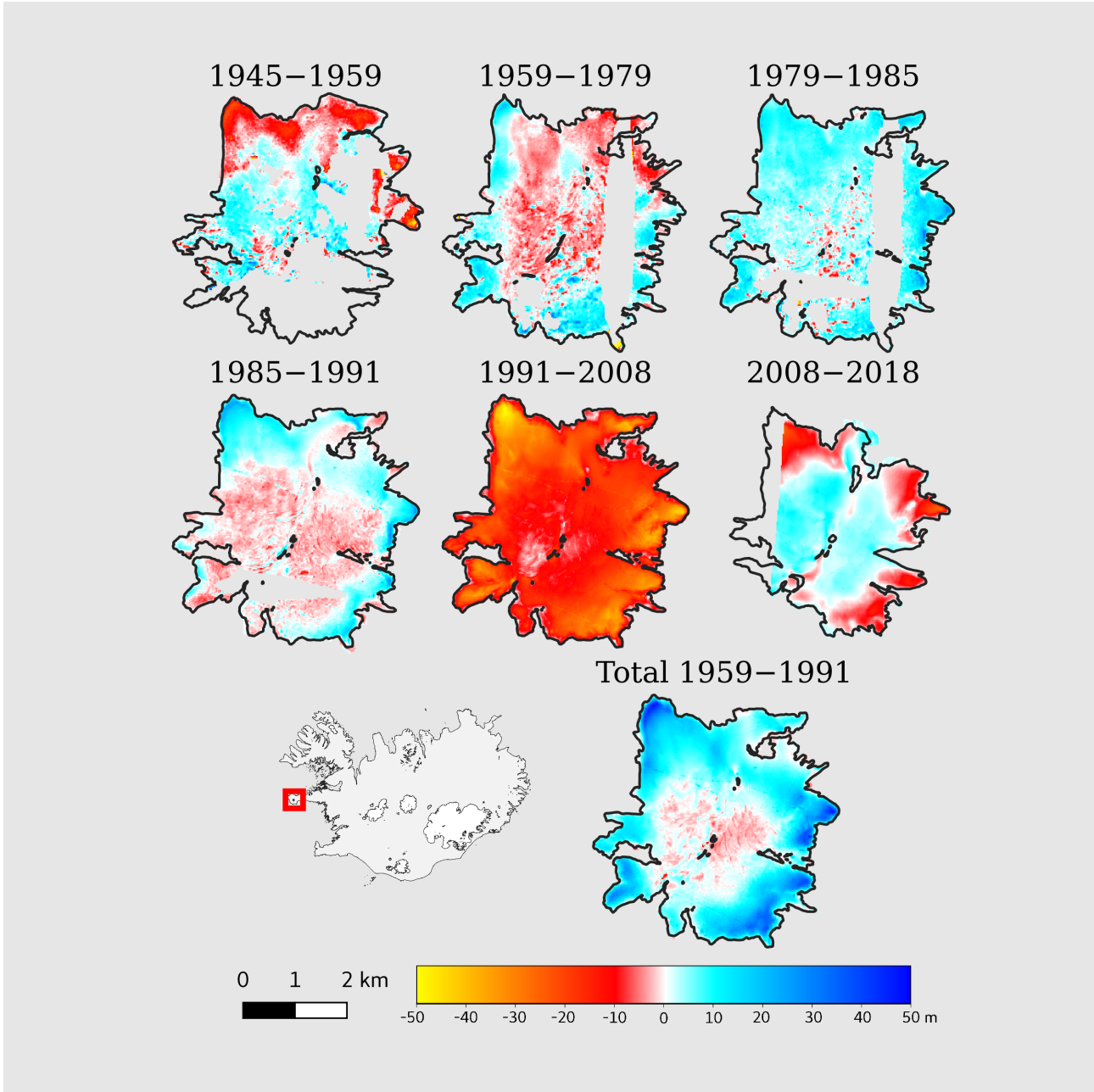

Figure S11. Elevation changes of Snæfellsjökull between 1945–1959, 1959–1979, 1979–1985, 1985–1991, 1991–2008, 2008–2018 and for a longer time period: 1959–1991. Data voids are shown in grey.

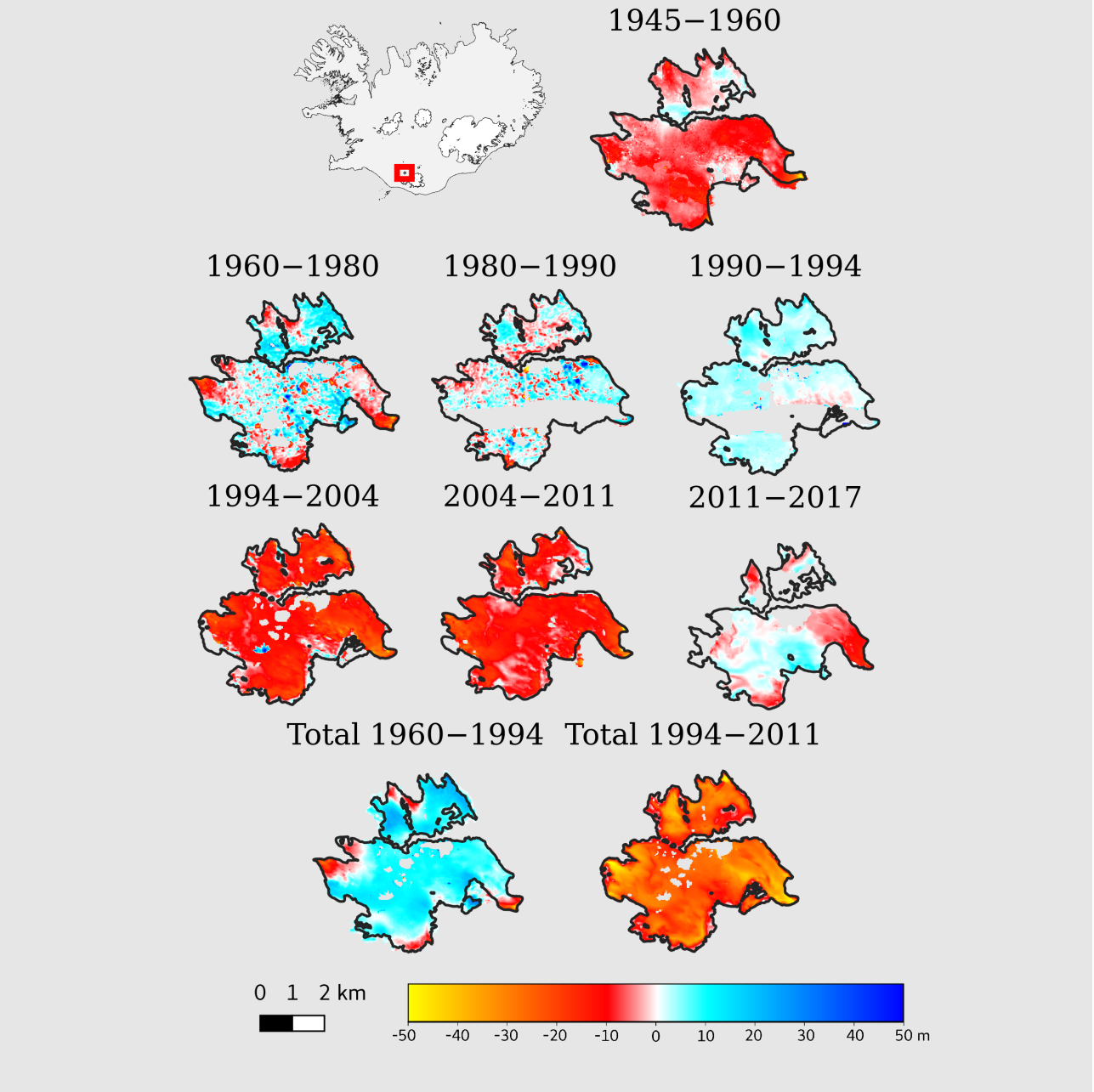

Figure S12. Elevation changes of Tindfjallajökull between 1945–1960, 1960–1980, 1980–1994, 1994–2004, 2004–2011, 2011–2017 and for longer time periods: 1960–1994 and 1994–2011. Data voids are shown in grey.

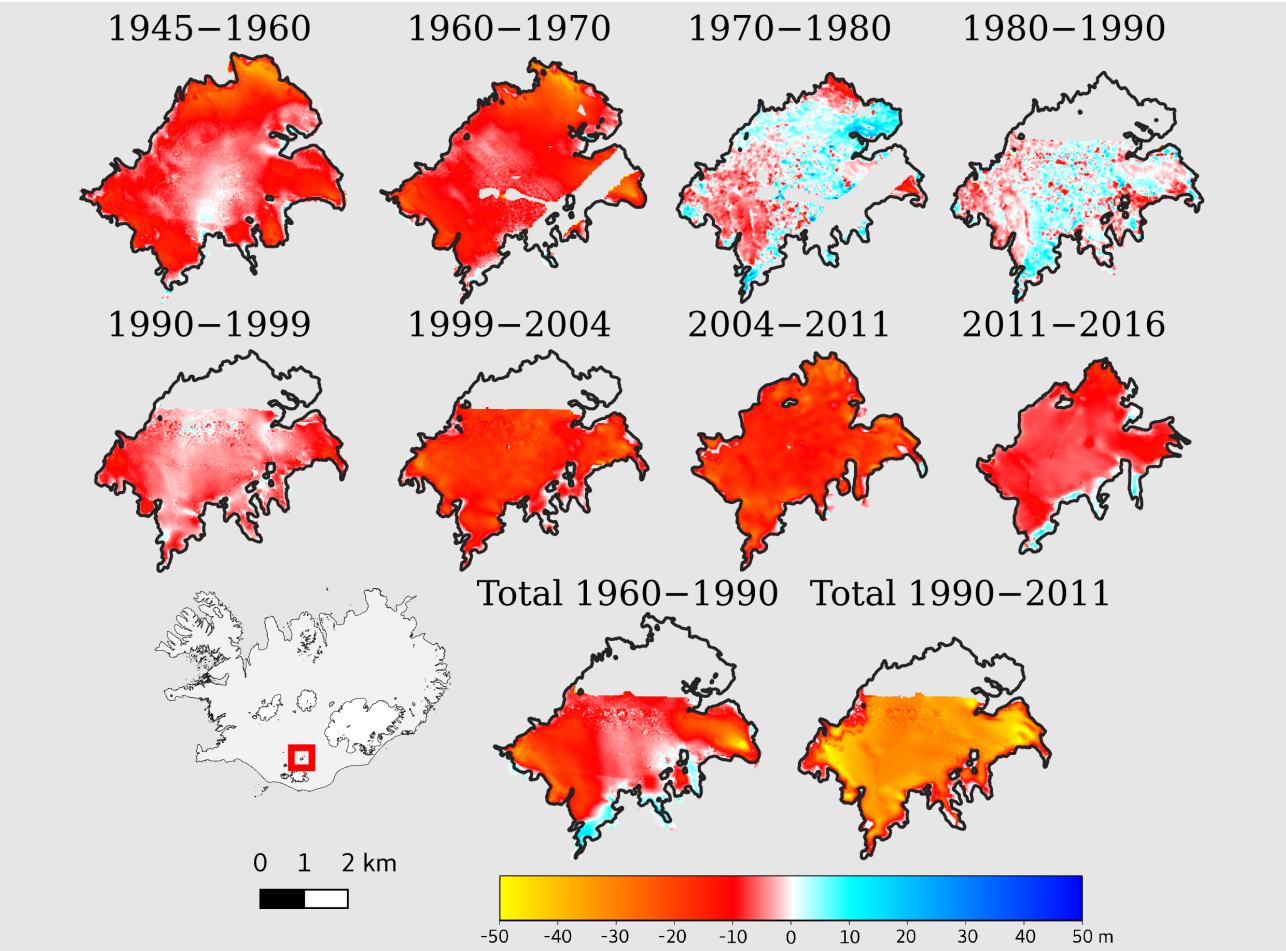

Figure S13. Elevation changes of Torfajökull between 1945–1960, 1960–1970, 1970–1980, 1980–1990, 1990–1999, 1999–2004, 2004–2011, 2011–2016 and for longer time periods: 1960–1990 and 1990–2011. Data voids are shown in grey.

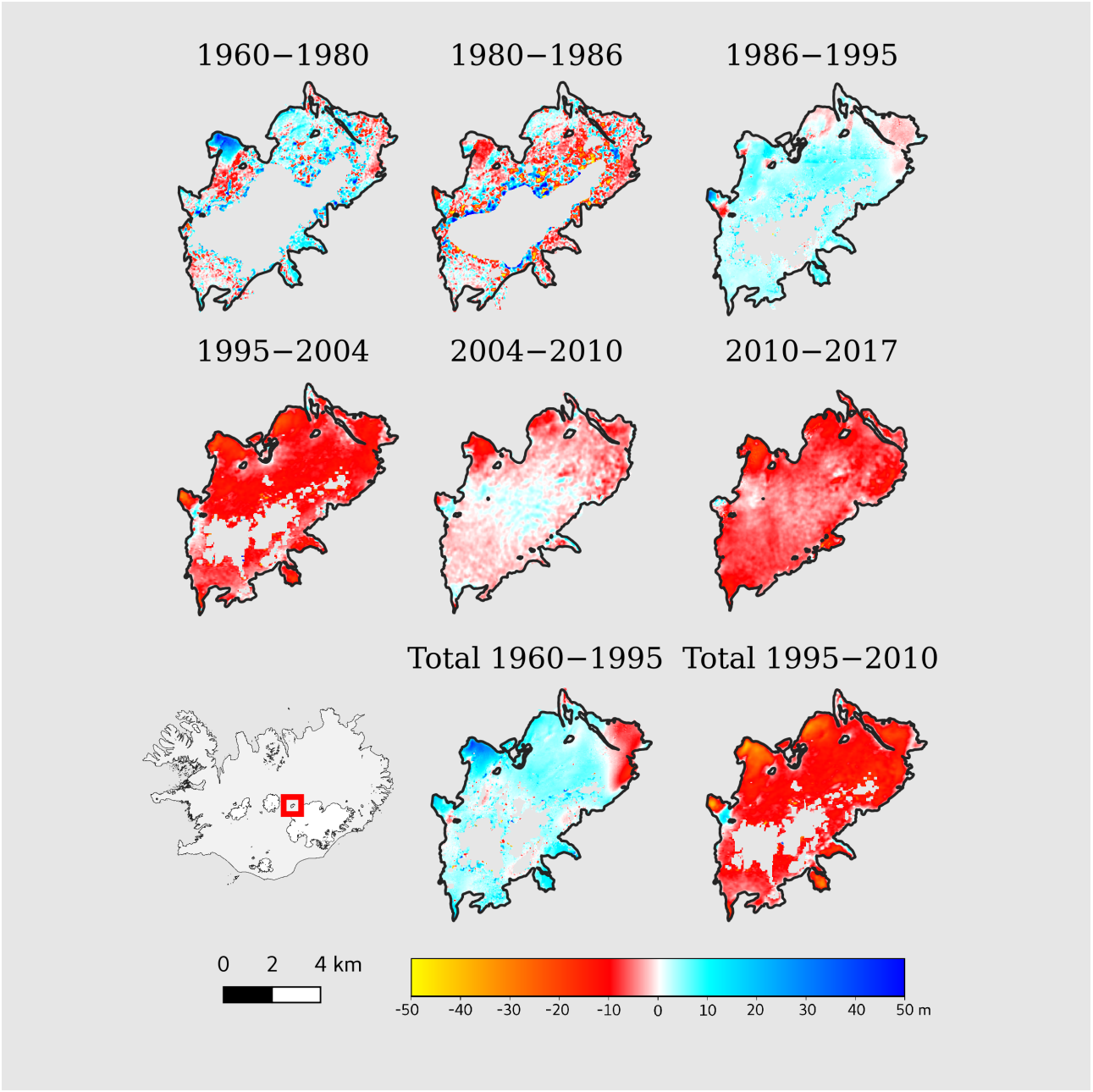

Figure S14. Elevation changes of Tungnafellsjökull between 1960–1980, 1980–1986, 1986–1995, 1995–2004, 2004–2010, 2010–2017 and for longer time periods: 1960–1995 and 1995–2010. Data voids are shown in grey.

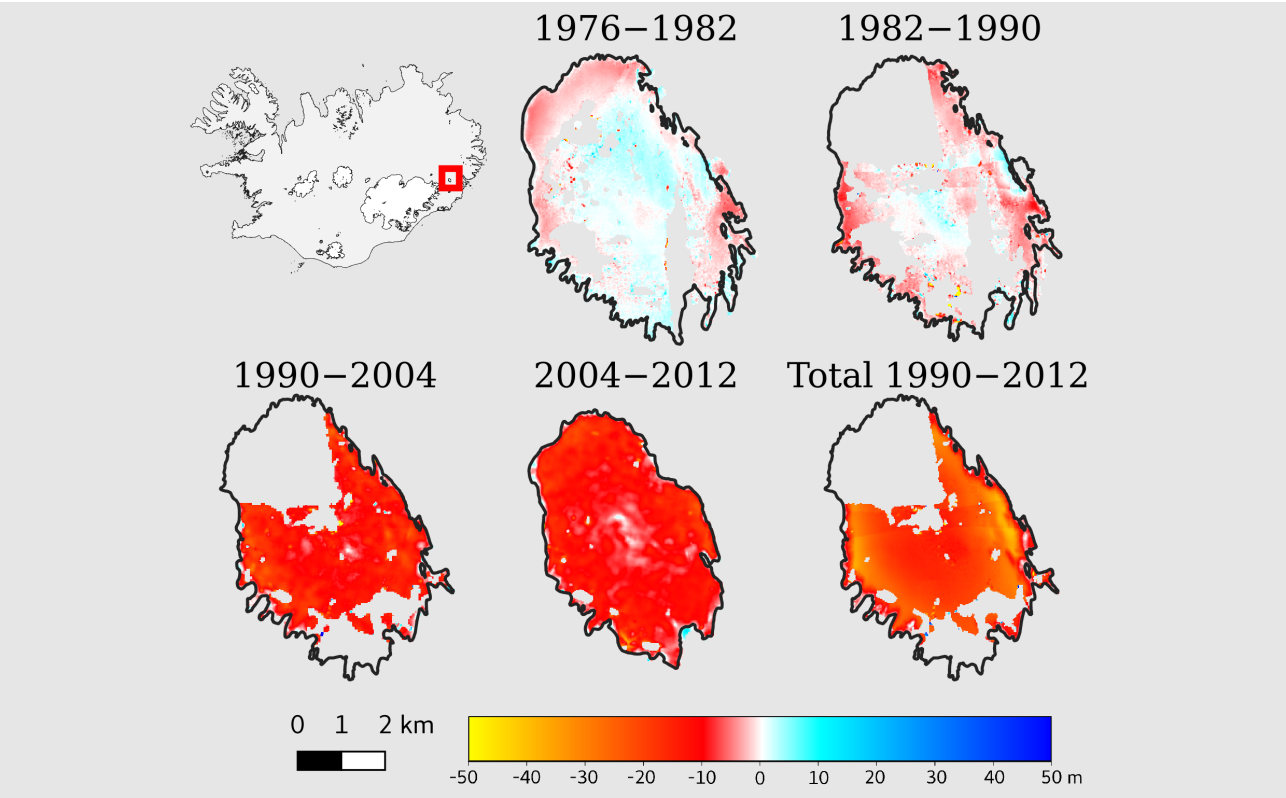

Figure S15. Elevation changes of Þrándarjökull between 1976–1982, 1982–1990, 1990–2004, 2004–2012 and for a longer time period: 1990–1912. Data voids are shown in grey.

3 TABULATED GEODETIC MASS BALANCE

Table S1. List of the geodetic mass balance calculated, in m w.e. a^{-1}, using the floating-date system ($\dot{B}$) and the fixed-date system (end of season, $\dot{B}_{EOS}$). Bar: Barkárdals- and Tungnahryggsjökull. Dra: Drangajökull. Eir: Eiríksjökull. Eyj: Eyjafjallajökull. Hof: Hofsjökull Eystri. Hrú: Hrútfell. Mýr: Mýrdalsjökull. Öræ: Öræfajökull. Snæ: Snæfell. Snj: Snæfellsjökull. Tin: Tindfjallajökull. Tor: Torfajökull. Tun: Tungnafellsjökull. Þrá: Þrándarjökull.

#	t_1	t_2	$\dot{B}$	$\dot{B}_{EOS}$	#	t_1	t_2	$\dot{B}$	$\dot{B}_{EOS}$
Bar	1946	1960	–0.16±0.10	–0.20±0.10	Snæ	25/08/1984	25/08/1993	0.09±0.16	0.06±0.16
Bar	1960	1980	–0.02±0.05	–0.01±0.05	Snæ	25/08/1993	12/07/2012	–0.22±0.02	–0.29±0.04
Bar	1960	1994	0.07±0.02	0.06±0.03	Snj	16/09/1945	27/07/1959	0.05±0.24	–0.07±0.24
Bar	1980	1994	0.19±0.05	0.14±0.06	Snj	27/07/1959	22/07/1979	0.02±0.05	0.01±0.07
Bar	1994	2004	–0.44±0.08	–0.45±0.10	Snj	27/07/1959	19/07/1991	0.21±0.02	0.18±0.04
Bar	1994	2016	–0.47±0.03	–0.43±0.04	Snj	22/07/1979	13/08/1985	0.69±0.15	0.84±0.21
Bar	2004	2016	–0.59±0.07	–0.49±0.08	Snj	13/08/1985	19/07/1991	0.13±0.05	–0.15±0.17
Dra	20/07/2011	05/07/2016	0.18±0.02	0.00±0.30	Snj	19/07/1991	02/09/2008	–1.02±0.08	–0.88±0.09
Eir	18/08/1960	05/09/1978	–0.02±0.10	0.01±0.10	Snj	02/09/2008	17/07/2018	0.01±0.05	–0.13±0.10
Eir	18/08/1960	24/08/1995	0.03±0.05	0.04±0.05	Tin	30/08/1945	05/08/1960	–0.36±0.12	–0.47±0.13
Eir	05/09/1978	15/08/1986	0.13±0.19	0.12±0.20	Tin	05/08/1960	10/09/1978	0.01±0.01	0.09±0.04
Eir	15/08/1986	24/08/1995	–0.01±0.17	–0.03±0.18	Tin	05/08/1960	22/08/1980	0.09±0.06	0.14±0.07
Eir	24/08/1995	19/08/2004	–0.55±0.17	–0.55±0.18	Tin	05/08/1960	12/08/1994	0.18±0.02	0.20±0.03
Eir	24/08/1995	02/09/2008	–0.62±0.11	–0.60±0.11	Tin	10/09/1978	09/04/1990	0.27±0.07	0.29±0.07
Eir	19/08/2004	02/09/2008	–0.95±0.19	–0.88±0.22	Tin	22/08/1980	09/04/1990	0.06±0.15	0.12±0.16
Eir	02/09/2008	10/07/2017	0.03±0.02	–0.26±0.10	Tin	09/04/1990	12/08/1994	0.54±0.15	0.31±0.19
Eyj	06/08/1994	10/08/2010	–1.51±0.11	–1.44±0.11	Tin	12/08/1994	05/10/2004	–1.09±0.14	–1.00±0.15
Eyj	10/08/2010	10/08/2017	0.26±0.15	–0.14±0.20	Tin	12/08/1994	09/08/2011	–1.26±0.09	–1.27±0.10
Hof	13/10/1946	30/09/1967	–0.49±0.08	–0.51±0.08	Tin	05/10/2004	09/08/2011	–1.45±0.19	–1.63±0.21
Hof	30/09/1967	26/08/1976	–0.34±0.12	–0.35±0.13	Tin	09/08/2011	11/07/2017	–0.15±0.08	–0.45±0.20
Hof	30/09/1967	02/08/1990	–0.22±0.13	–0.26±0.13	Tor	14/10/1945	13/08/1960	–0.54±0.13	–0.63±0.14
Hof	26/08/1976	27/07/1983	0.11±0.04	–0.06±0.12	Tor	13/09/1960	03/09/1970	–0.95±0.25	–0.83±0.26
Hof	27/07/1983	02/08/1990	–0.31±0.05	–0.26±0.14	Tor	13/09/1960	04/09/1990	–0.30±0.10	–0.26±0.10
Hof	02/08/1990	08/10/2004	–0.78±0.08	–0.66±0.09	Tor	03/09/1970	09/08/1979	0.21±0.19	0.14±0.19
Hof	02/08/1990	03/08/2012	–0.90±0.07	–0.85±0.08	Tor	03/09/1970	22/08/1980	0.01±0.18	–0.03±0.18
Hof	08/10/2004	03/08/2012	–1.49±0.15	–1.60±0.17	Tor	09/08/1979	04/09/1990	–0.10±0.09	–0.03±0.10
Hrú	13/10/1946	08/08/1960	–0.27±0.11	–0.36±0.11	Tor	22/08/1980	04/09/1990	–0.05±0.12	0.00±0.13
Hrú	08/08/1960	22/08/1980	0.01±0.08	0.04±0.09	Tor	04/09/1990	05/08/1999	–0.43±0.15	–0.58±0.17
Hrú	08/08/1960	24/08/1995	0.09±0.04	0.11±0.04	Tor	04/09/1990	08/08/2011	–1.21±0.12	–1.26±0.12
Hrú	22/08/1980	05/08/1987	0.09±0.15	0.02±0.19	Tor	05/08/1999	05/10/2004	–2.56±0.43	–2.23±0.44
Hrú	05/08/1987	24/08/1995	–0.10±0.22	–0.06±0.24	Tor	05/10/2004	08/08/2011	–2.07±0.20	–2.27±0.23
Hrú	24/08/1995	19/08/2004	–1.02±0.10	–1.01±0.11	Tor	08/08/2011	18/09/2016	–1.23±0.09	–0.91±0.14
Hrú	24/08/1995	01/08/2013	–1.03±0.17	–1.02±0.17	Tun	12/08/1960	22/08/1980	0.13±0.24	0.15±0.24
Hrú	19/08/2004	01/08/2013	–0.78±0.11	–0.76±0.13	Tun	12/08/1960	24/08/1995	0.08±0.02	0.09±0.03
Mýr	13/08/1960	22/08/1980	–0.04±0.06	0.01±0.07	Tun	22/08/1980	18/08/1986	–0.20±0.63	–0.18±0.63
Mýr	13/08/1960	05/08/1999	–0.12±0.02	–0.11±0.03	Tun	18/08/1986	24/08/1995	0.23±0.14	0.23±0.15
Mýr	22/08/1980	04/09/1984	–0.57±0.36	–0.40±0.39	Tun	24/08/1995	14/08/2004	–0.83±0.12	–0.86±0.13
Mýr	04/09/1984	05/08/1999	–0.10±0.10	–0.19±0.11	Tun	24/08/1995	06/06/2010	–0.56±0.07	–0.78±0.11
Mýr	05/08/1999	05/10/2004	–2.64±0.21	–2.40±0.25	Tun	14/08/2004	06/06/2010	–0.26±0.05	–0.80±0.23
Mýr	05/08/1999	08/08/2010	–1.65±0.12	–1.71±0.16	Tun	06/06/2010	15/10/2017	–0.87±0.09	–0.31±0.20
Mýr	05/10/2004	08/08/2010	–1.42±0.10	–1.74±0.17	Þrá	26/08/1976	01/08/1982	0.02±0.08	0.04±0.14
Mýr	08/08/2010	19/09/2016	–0.63±0.05	–0.30±0.12	Þrá	01/08/1982	02/08/1990	–0.16±0.23	–0.26±0.25
Öræ	30/08/1945	23/08/1960	–0.25±0.22	–0.31±0.23	Þrá	02/08/1990	08/10/2004	–0.71±0.20	–0.61±0.20
Öræ	23/08/1960	20/08/1982	0.10±0.10	0.16±0.10	Þrá	02/08/1990	03/08/2012	–0.71±0.16	–0.67±0.17
Öræ	23/08/1960	27/07/1992	0.06±0.06	0.06±0.07	Þrá	08/10/2004	03/08/2012	–1.24±0.12	–1.31±0.14
Öræ	20/08/1982	22/08/1988	–0.12±0.27	–0.30±0.29					
Öræ	22/08/1988	27/07/1992	–0.04±0.32	–0.02±0.42					
Öræ	27/07/1992	06/08/2003	–0.16±0.17	–0.21±0.20					
Öræ	27/07/1992	13/09/2010	–0.87±0.07	–0.84±0.09					
Öræ	06/08/2003	13/09/2010	–1.28±0.16	–1.10±0.19					
Öræ	13/09/2010	16/08/2017	0.44±0.07	0.25±0.10					

4 TEMPORALLY HOMOGENIZED GEODETIC MASS BALANCE

Table S2. List of the geodetic mass balance temporally homogenized and associated uncertainties, in m w.e. a^{-1}.*The mass balance of Barkárdals– and Túngnahryggsjökull, Drangajökull, Hofsjökull Eystri and Hrútfell is presented without temporal homogenization for the period 1945–1960, since the is no climate data available at the time of their earliest survey, in 1946.

	$\dot{B}^{1960}_{1945}$*	$\dot{B}^{1980}_{1960}$	$\dot{B}^{1994}_{1980}$	$\dot{B}^{2004}_{1994}$	$\dot{B}^{2010}_{2004}$	$\dot{B}^{2017}_{2010}$
Barkárdals– and Túngnahryggsjökull	–0.20±0.10	–0.01±0.05	0.14±0.06	–0.45±0.10	–0.56±0.22	–0.48±0.19
Drangajökull	–0.66±0.17	–0.08±0.09	0.27±0.14	–0.67±0.11	–0.51±0.19	–0.10±0.32
Eiríksjökull	N/A	0.02±0.11	0.04±0.27	–0.50±0.18	–0.90±0.25	–0.06±0.15
Eyjafjallajökull	–0.45±0.12	0.38±0.07	0.48±0.41	–1.74±0.37	–0.89±0.43	–0.14±0.20
Hofsjökull Eystri	–0.57±0.13	–0.35±0.19	–0.08±0.17	–0.93±0.13	–1.73±0.21	N/A
Hrútfell	–0.36±0.11	0.04±0.09	0.03±0.30	–0.93±0.12	–0.91±0.20	N/A
Mýrdalsjökull	N/A	0.01±0.07	0.03±0.41	–1.69±0.27	–1.74±0.17	–0.32±0.14
Öræfajökull	–0.31±0.23	0.11±0.11	0.03±0.52	–0.53±0.22	–0.98±0.21	0.25±0.10
Snæfellsjökull	–0.18±0.24	0.05±0.08	0.59±0.28	–1.60±0.16	–0.65±0.20	0.09±0.16
Tindfjallajökull	–0.47±0.13	0.14±0.07	0.17±0.25	–1.00±0.15	–2.11±0.23	–0.21±0.22
Torfajökull	–0.63±0.14	–0.43±0.32	–0.12±0.15	–1.47±0.48	–2.66±0.24	–0.78±0.17
Tungnafellsjökull	N/A	0.15±0.24	0.03±0.65	–0.72±0.14	–0.80±0.23	–0.31±0.20
Þrándarjökull	N/A	N/A	–0.10±0.31	–0.89±0.23	–1.42±0.18	N/A

5 PLOTS FROM THE JOINT ANALYSIS OF GEODETIC MASS BALANCE AND CLIMATIC RECORDS

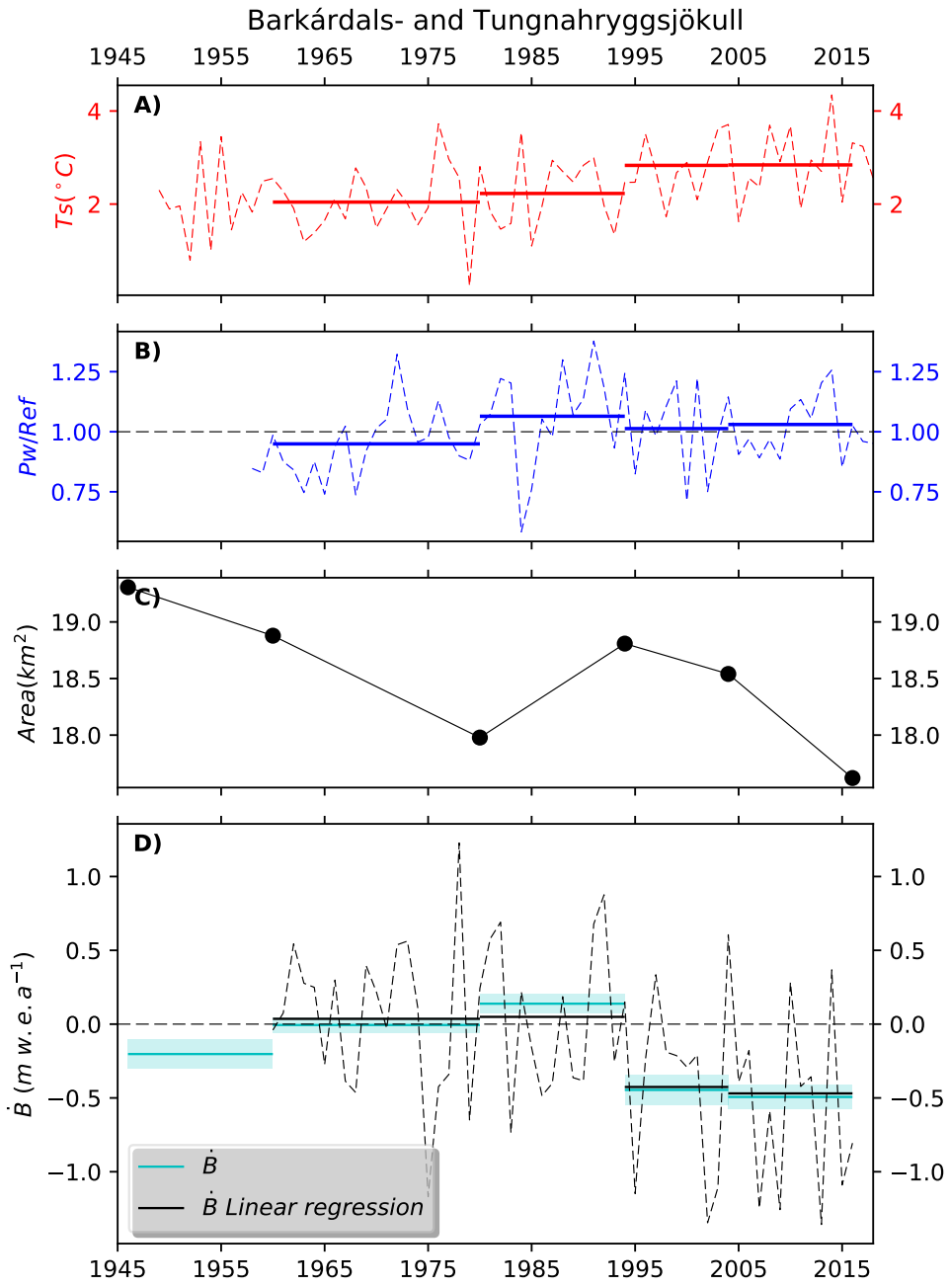

Figure S16. Barkárdals- and Tungnahryggsjökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1946–2016. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

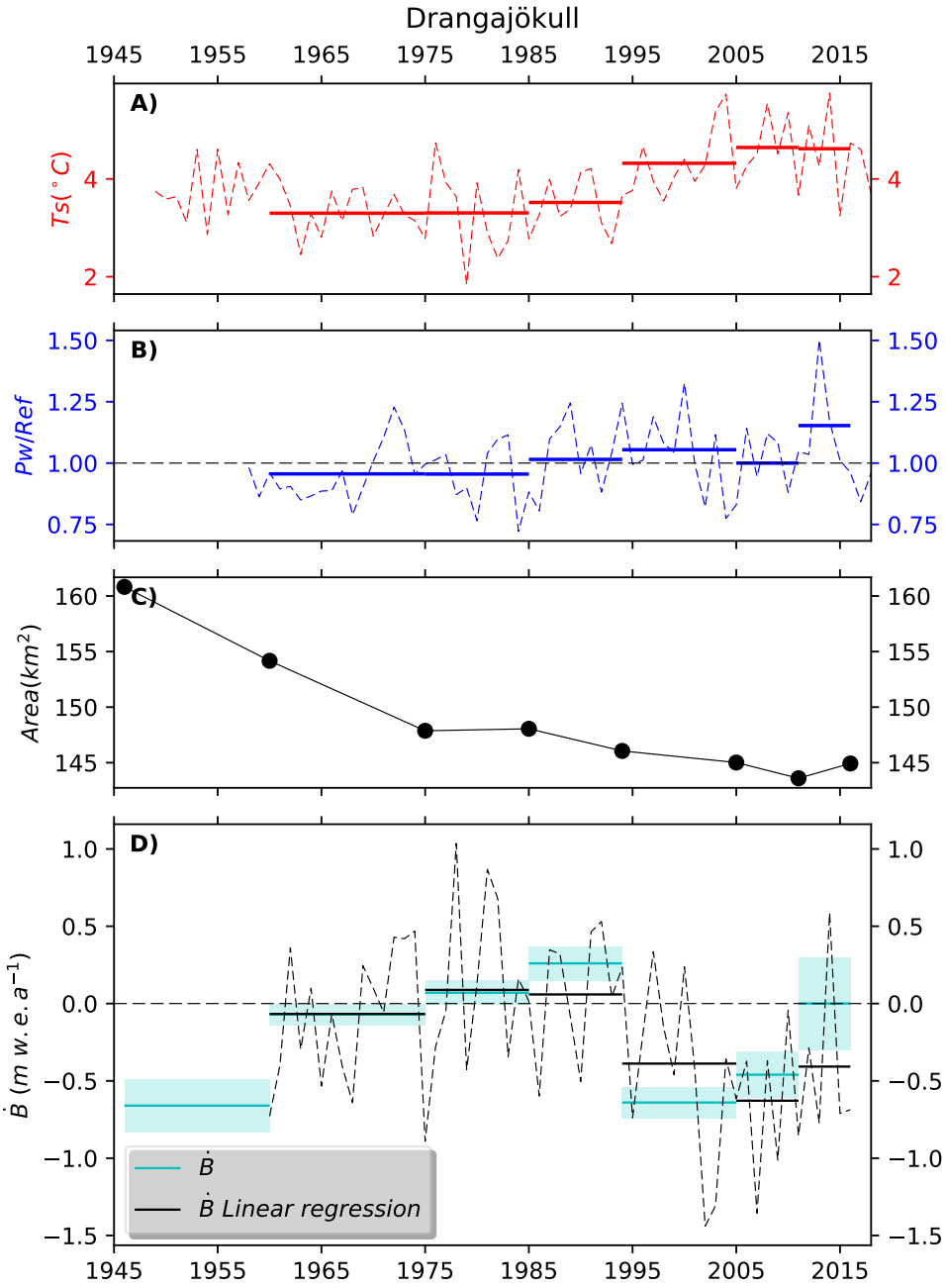

Figure S17. Drangajökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1946–2016. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

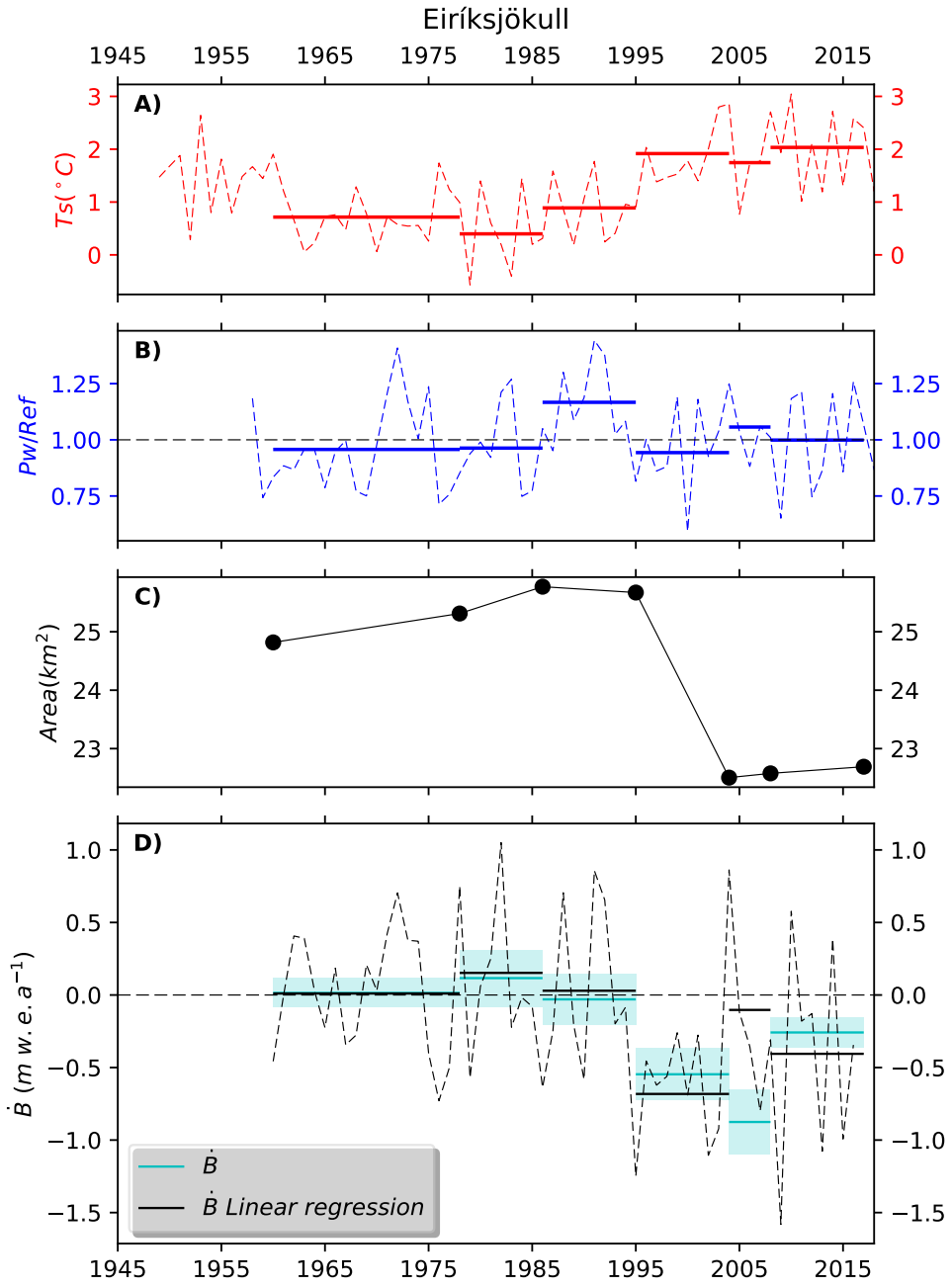

Figure S18. Eiríksjökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1960–2017. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

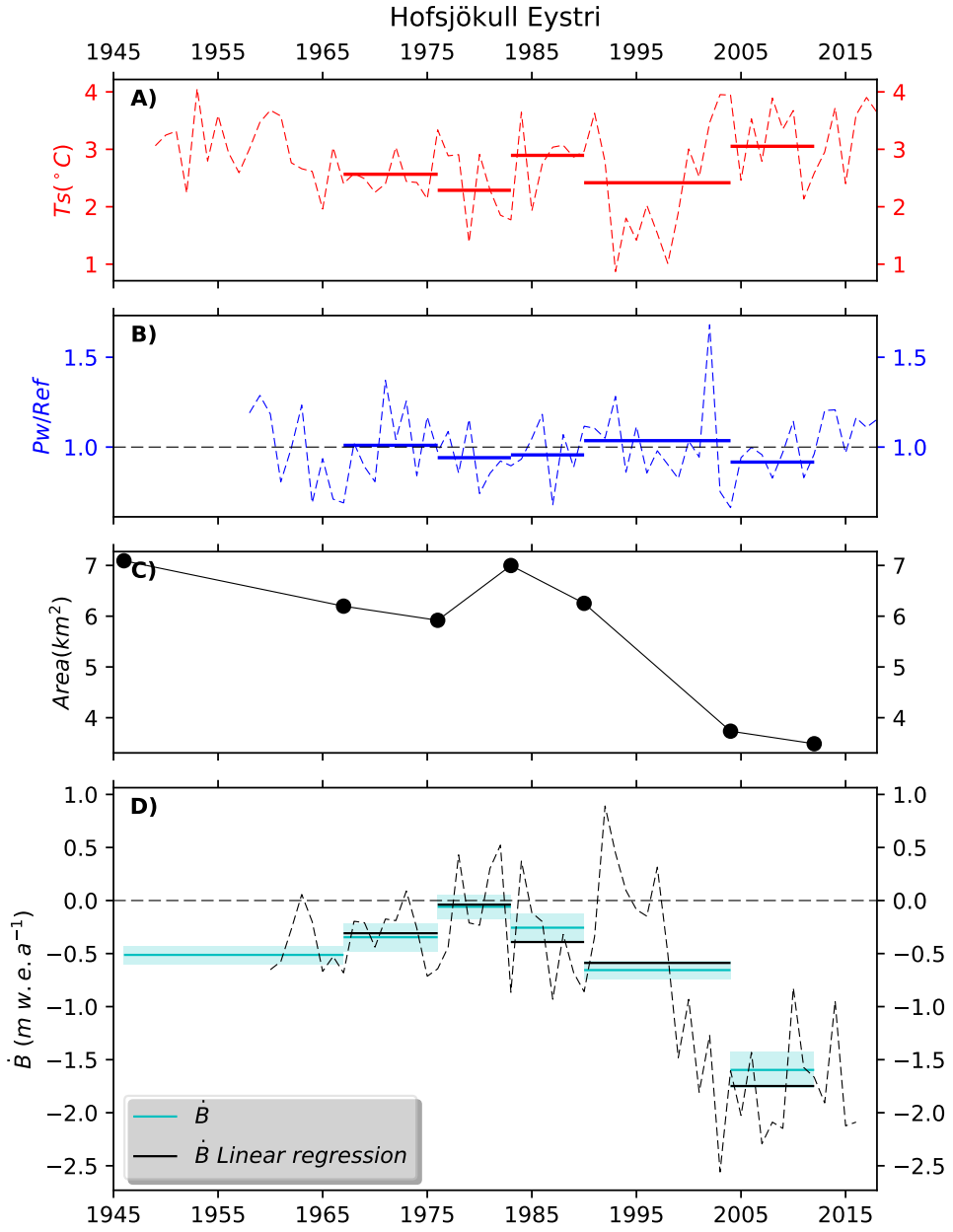

Figure S19. Hofsjökull Eystri. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1946–2012. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

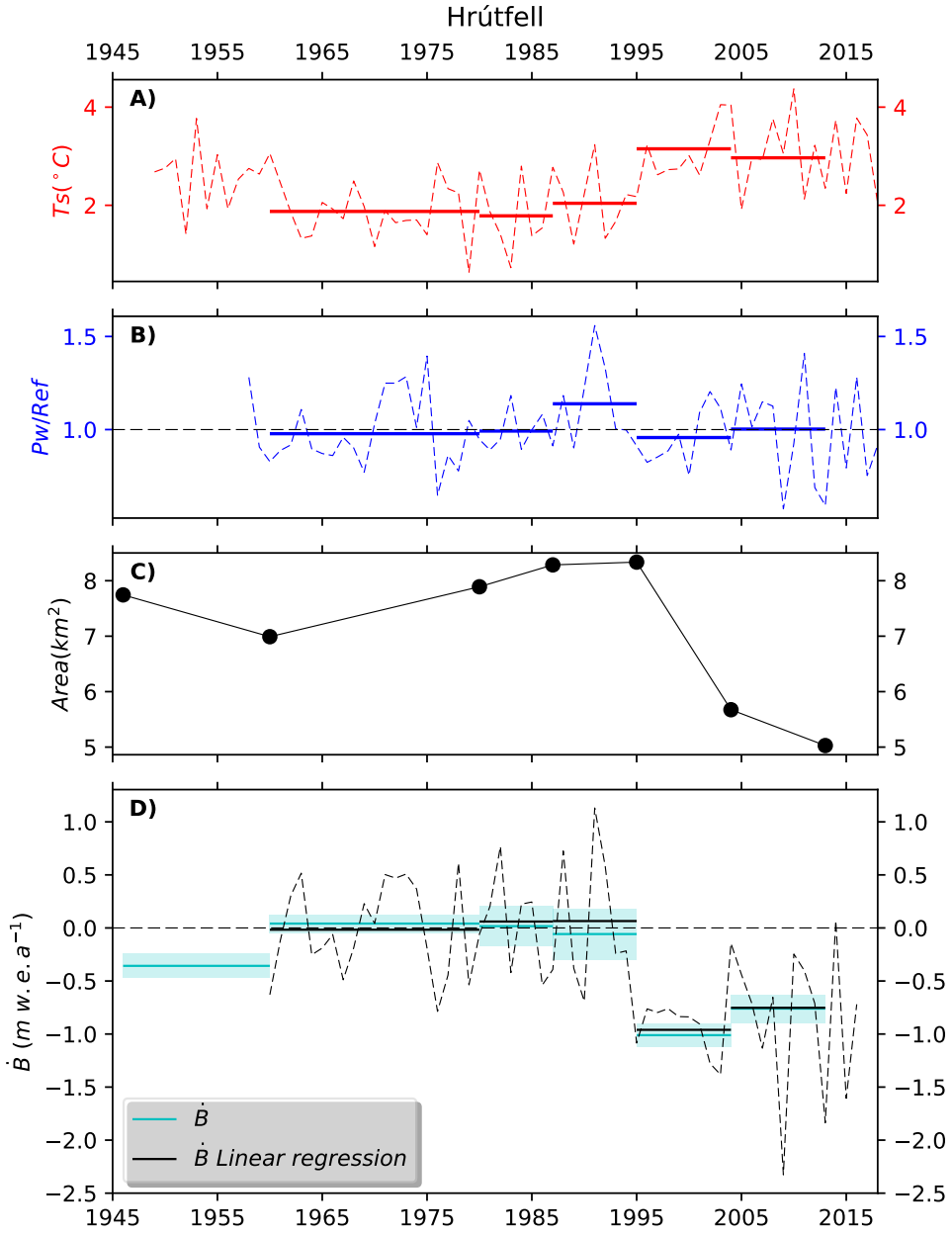

Figure S20. Hrútfell. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1946–2013. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

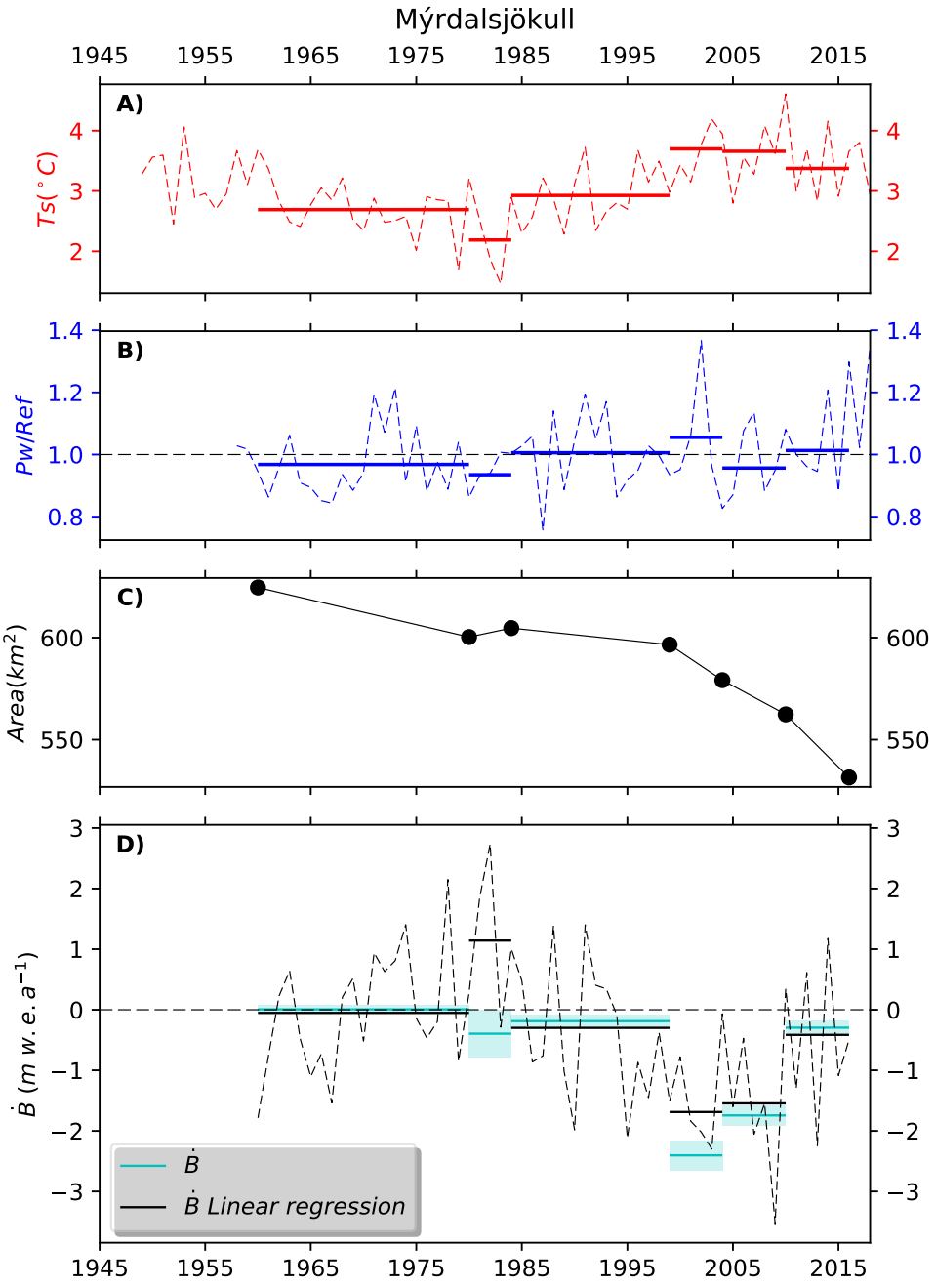

Figure S21. Mýrdalsjökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1960–2016. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

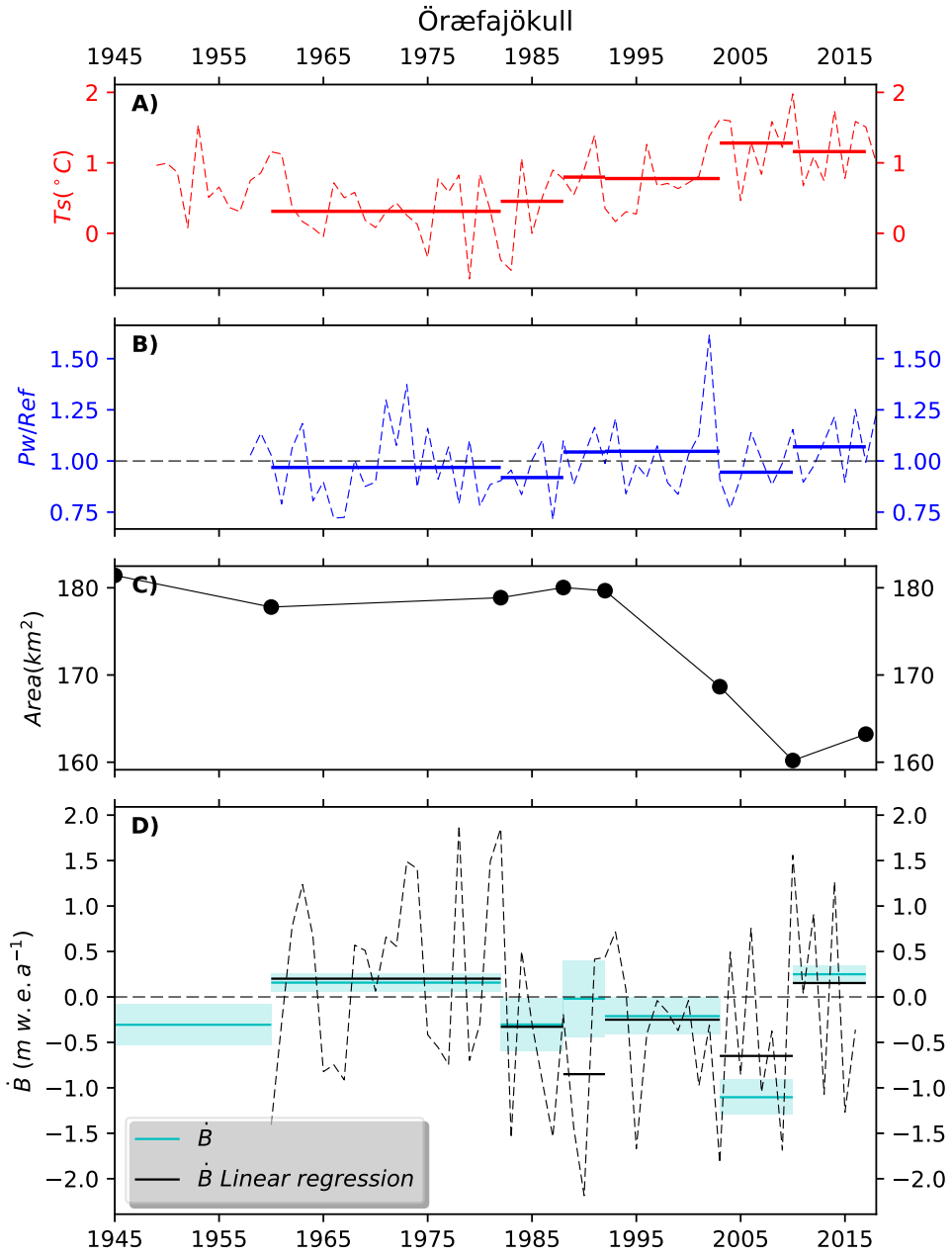

Figure S22. Öræfajökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1945–2017. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

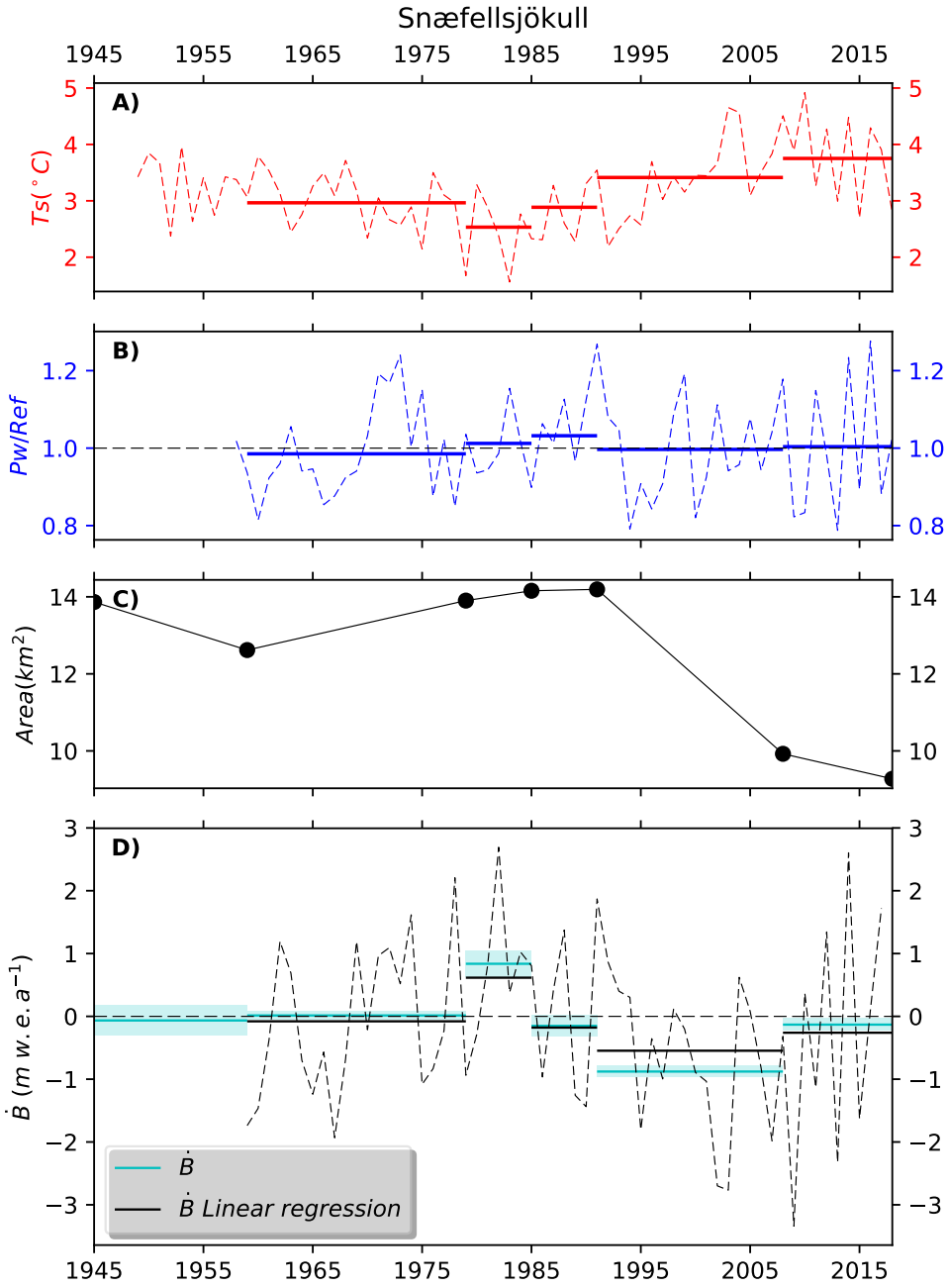

Figure S23. Snæfellsjökull. **A**: Temperature in 1949–2018. **B**: Normalized precipitation in 1957–2018. **C**: Area changes, 1945–2018. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

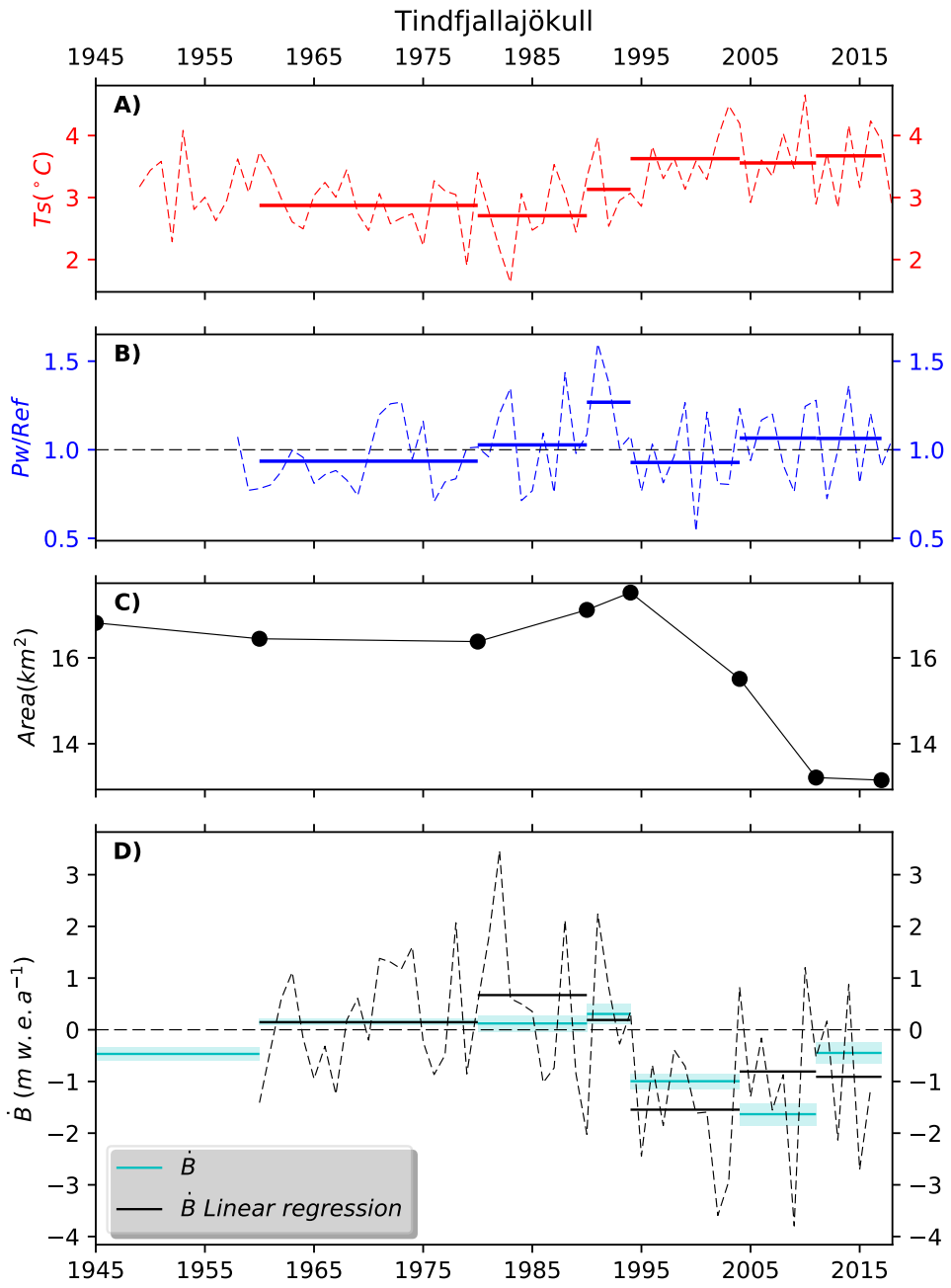

Figure S24. Tindfjallajökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1945–2017. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

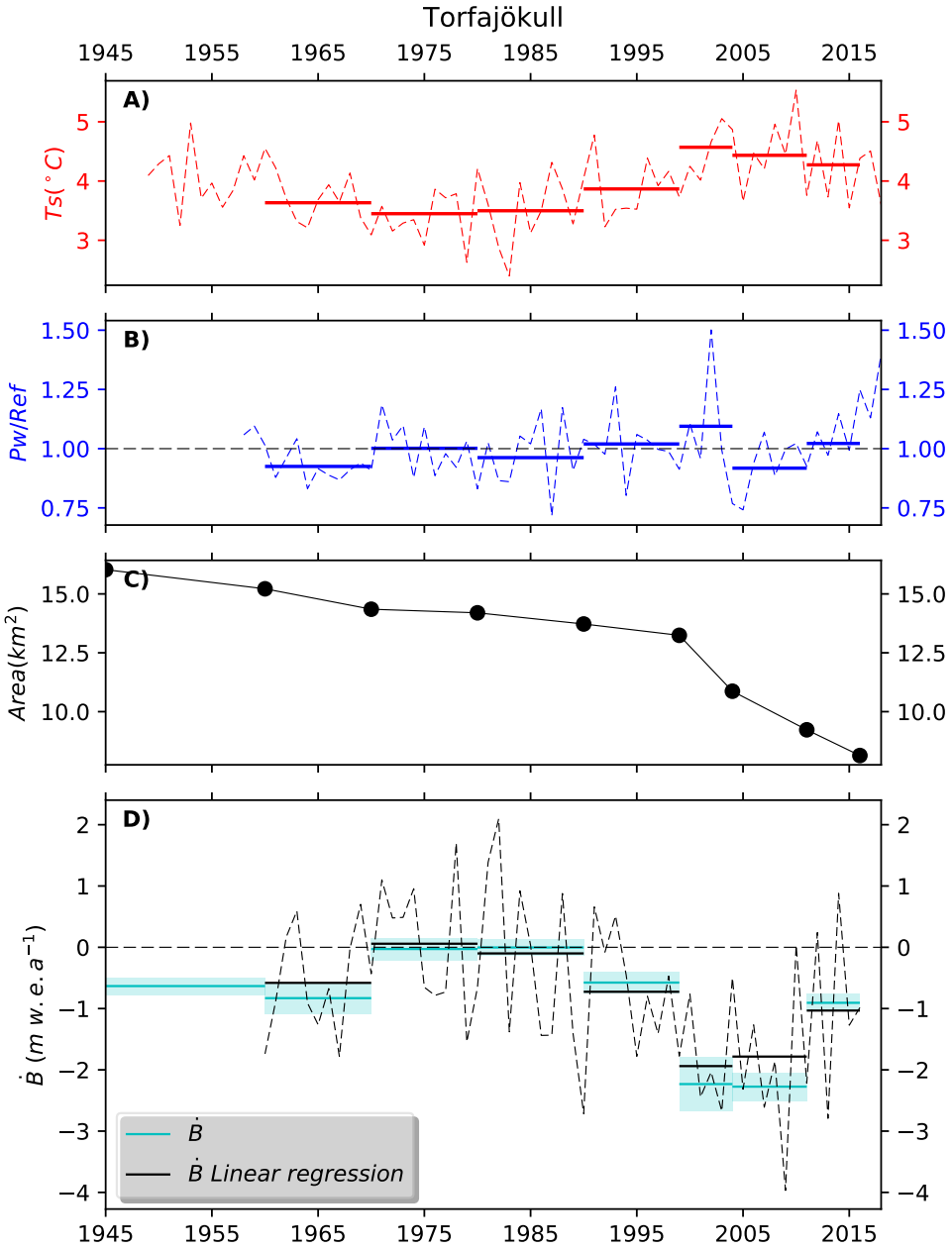

Figure S25. Torfajökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1945–2016. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

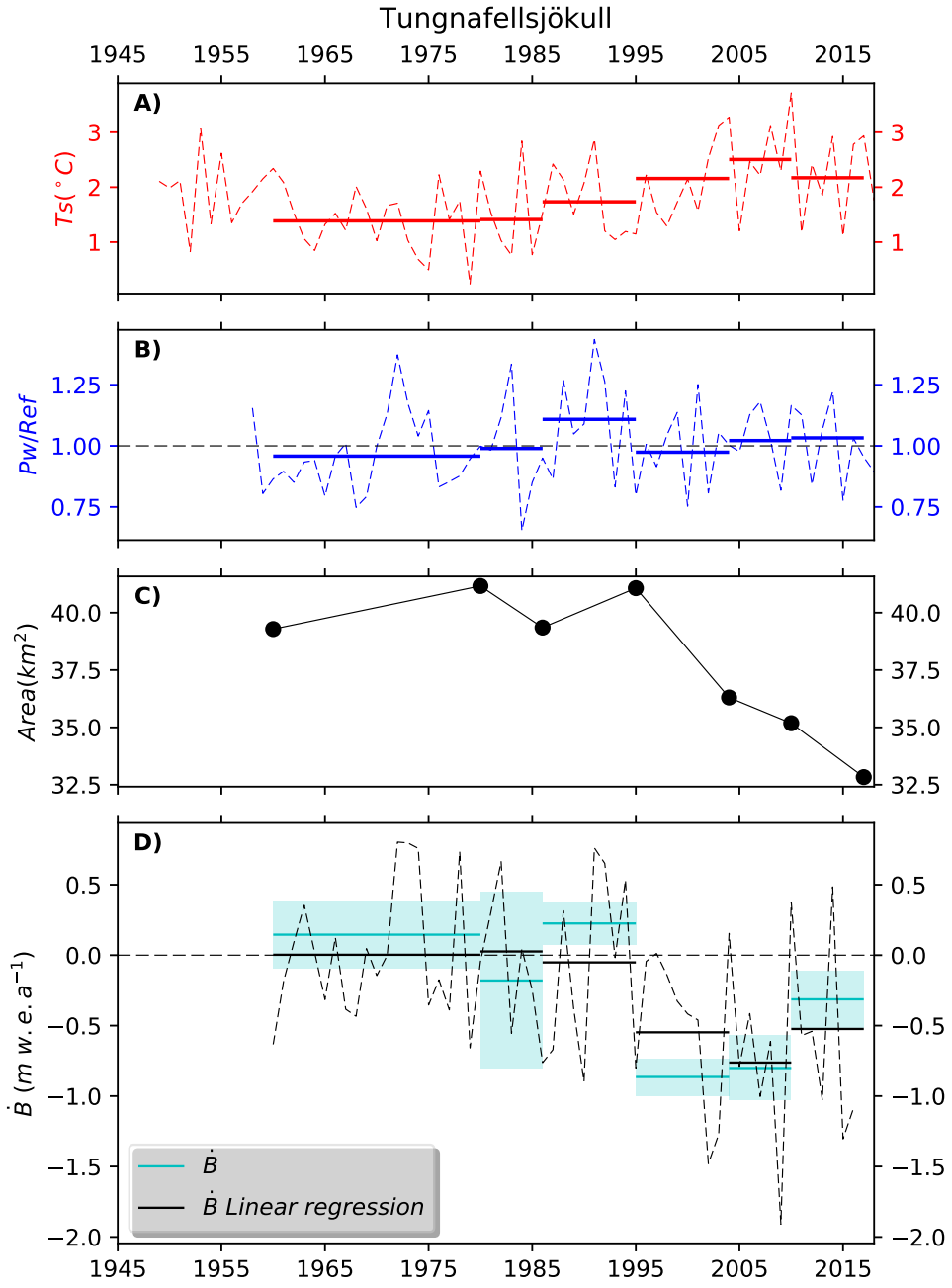

Figure S26. Túngnafellsjökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1960–2017. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

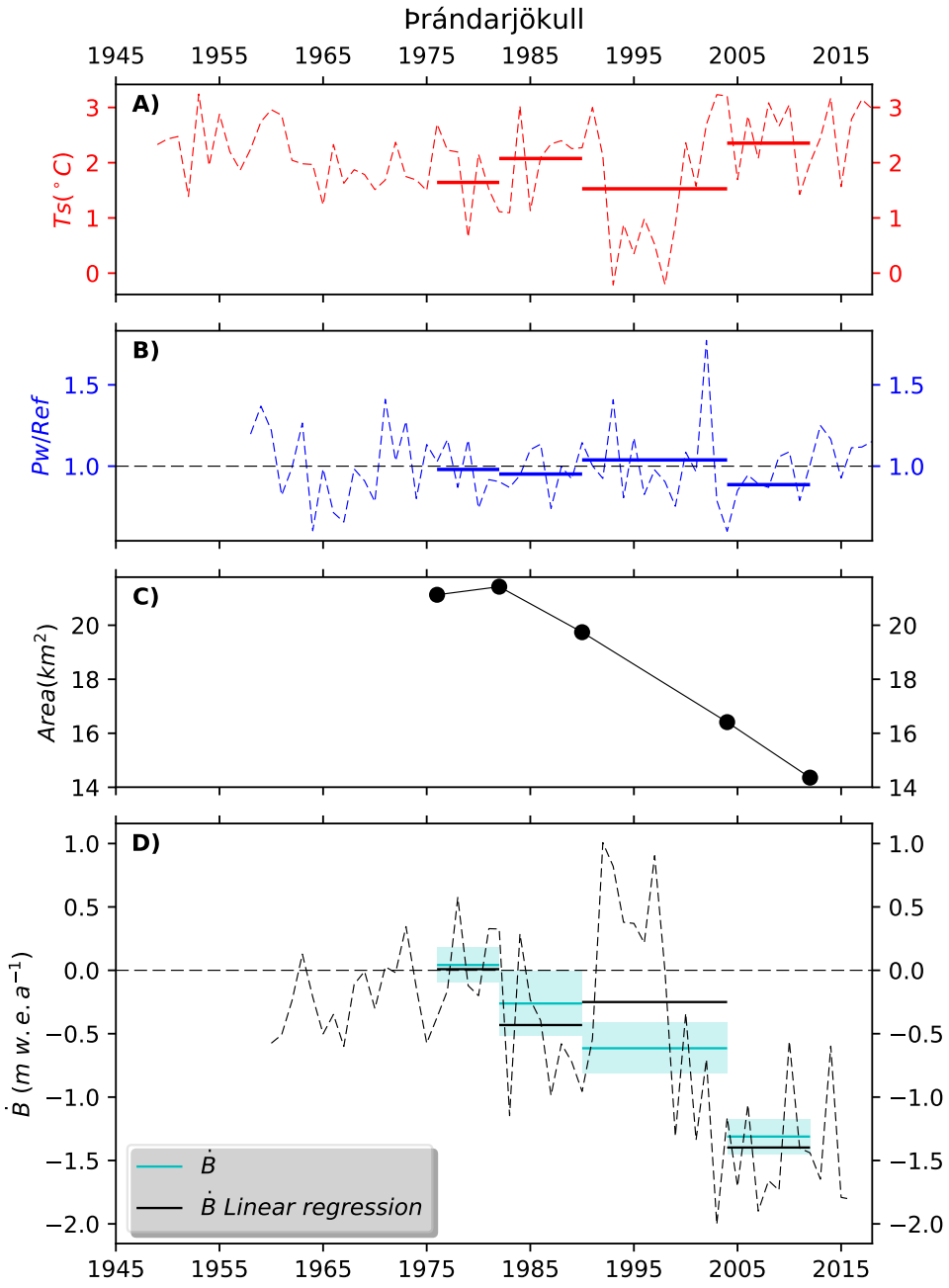

Figure S27. Þrándarjökull. **A**: Temperature in 1949–2017. **B**: Normalized precipitation in 1957–2017. **C**: Area changes, 1976–2012. **D**: Measured and predicted geodetic mass balance, as well as annual mass balance.

REFERENCES

Belart, J. M. C., Magnússon, E., Berthier, E., Pálsson, F., Aðalgeirsdóttir, G., and Jóhannesson, T. (2019). The geodetic mass balance of Eyjafjallajökull ice cap for 1945–2014: processing guidelines and relation to climate. *Journal of Glaciology* 65, 395–409. doi:10.1017/jog.2019.16

Brun, F., Berthier, E., Wagnon, P., Kääb, A., and Treichler, D. (2017). A spatially resolved estimate of High Mountain Asia glacier mass balances from 2000 to 2016. *Nature Geoscience* 10, 668. doi:10.1038/ngeo2999

Magnússon, E., Belart, J., Pálsson, F., Ágústsson, H., and Crochet, P. (2016). Geodetic mass balance record with rigorous uncertainty estimates deduced from aerial photographs and lidar data – Case study from Drangajökull ice cap, NW Iceland. *The Cryosphere* 10, 159–177. doi:10.5194/tc-10-159-2016