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Elemental and water-insoluble organic carbon in Svalbard snow: a synthesis of observations during 2007–2018

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Sampling site	Coordinates (DD° MM.MMM') Lat. N	Lon. E	Elev. (m a.s.l.)	Sampling date(s)	Snowpack depth (m)	Air T (°C)
Lomonosovfonna (LF)						
LF1	78° 37.977'	17° 04.600'	223	2016-04-10	0.27	-10.9
LF2*	78° 41.479'	17° 08.991'	523	2016-04-09	0.94	-5.8
LF3*	78° 49.438'	17° 26.085'	1193	2016-04-11	1.46	-24.0
Kongsvegen (KVG)						
KVG 1	78° 49.808'	12° 45.527'	226	2016-04-13	0.20	-13.9
KVG 1.5	78° 48.773'	12° 52.155'	326	2016-04-13	0.75	-13.9
KVG 2*	78° 46.830'	13° 09.206'	534	2016-04-11	1.62	-17.5
KVG3*	78° 45.335'	13° 20.178'	672	2016-04-12	2.24	-15.5
Holtedahlfonna (HDF)						
HDF1	78° 55.850'	13° 18.151'	570	2016-04-17	1.10	-14.5
HDF2*	79° 01.762'	12° 31.859'	718	2016-04-17	1.75	-14.2
HDF3*	79° 08.418'	12° 23.653'	1119	2016-04-15	2.34	-18.1
Werenskioldbreen (WSB)						
WSB1	77° 04.519'	15° 18.797'	166	2016-04-16	0.81	-9.2
WSB2	77° 04.312'	15° 26.435'	413	2016-04-16	1.10	-11.2
WSB3*	77° 05.539'	15° 29.362'	528	2016-04-18	3.30	-11.1
Hansbreen (HB)						
HB1	77° 02.917'	15° 38.313'	102	2016-04-25	1.02	-7.3
HB2	77° 04.959'	15° 38.362'	275	2016-04-25	1.69	-6.9
HB3*	77° 07.211'	15° 29.230'	396	2016-04-29	2.88	0.7
Austfonna (AF)						
AF1	79° 44.011'	22° 24.853'	336	2016-04-21	1.07	-13.5
AF2*	79° 46.014'	22° 49.485'	507	2016-04-23	1.56	-7.1
AF3*	79° 49.936'	24° 00.265'	785	2016-04-24	1.81	-14.7
Austre Lovénbreen (ALB)						
ALB1	78° 52.980'	12° 08.133'	195	2016-04-25	0.87	-3.7
ALB2	78° 53.318'	12° 09.552'	340	2016-04-25	1.16	-2.8
ALB3*	78° 51.645'	12° 11.222'	513	2016-04-20	1.61	-11.3

Table S1. Details of snowpit sites where samples were collected for EC and WIOC analyses during the Spring 2016 glacier survey. An asterisk (*) after the site code identifies snowpit sites for which the snowpack was simulated using the snowpack model (see section 2.4.2).

Sampling site	Coordinates (DD° MM.MMM') Lat. N	Lon. E	Elev. (m a.s.l.)	Sampling dates(s)	Sampled depth (cm)
Midtre Lovénbreen (MLB)					
Stake 10 (Top)	78° 52.242'	11° 59.016'	403	2017-04-12	0-5
Stake 7 (Middle)	78° 52.590'	12° 01.836'	297	2017-04-12	0-3
Stake 2 (Bottom)	78° 53.604'	12° 03.696'	87	2017-04-12	0-2
Stake 10 (Top)	78° 52.242'	11° 59.016'	403	2017-05-04	0-3
Stake 7 (Middle)	78° 52.590'	12° 01.836'	297	2017-05-04	0-2
Vestre Brøggerbreen (VBG)					
Bottom	78° 54.708'	11° 44.040'	139	2017-04-09	0-5
Middle	78° 54.234'	11° 39.480'	355	2017-04-11	0-2
Top	78° 53.694'	11° 39.816'	450	2017-04-12	0-2
Bottom	78° 54.708'	11° 44.040'	139	2017-04-12	0-2
Waypoint	78° 54.300'	11° 41.202'	300	2017-04-16	0-8
Edithbreen (EBR)					
Top	78° 51.180'	11° 11.094'	625	2017-04-13	0-2
Middle	78° 51.276'	11° 45.000'	425	2017-04-13	0-2
Top	78° 51.180'	11° 11.094'	625	2017-04-13	0-2
Holtedahlfonna (HDF)					
Stake 4	78° 58.667'	13° 28.098'	642	2017-04-11	3-4
Stake 6	79° 01.762'	13° 31.861'	718	2017-04-11	0-3
Kongsvegen (KVG)					
Stake 8 (Top)	78° 45.334'	13° 20.178'	672	2017-04-02	0-5
Stake 6	78° 46.683'	13° 09.206'	534	2017-04-02	0-5
Stake 4	78° 48.167'	12° 57.520'	395	2017-04-02	0-5
Stake 2 (Bottom)	78° 49.808'	12° 45.527'	226	2017-04-02	0-5
Moraine	78° 51.843'	12° 29.460'	3	2017-04-02	0-12
Stake 8 (Top)	78° 45.334'	13° 20.178'	672	2017-04-13	2-4
Stake 6	78° 46.683'	13° 09.206'	534	2017-04-13	0-2
Stake 4	78° 48.167'	12° 57.520'	395	2017-04-13	2-3
Stake 2 (Bottom)	78° 49.808'	12° 45.527'	226	2017-04-13	0-6
Stake 6	78° 46.683'	13° 20.178'	534	2017-05-05	2-6
Stake 6	78° 46.683'	13° 09.206'	534	2017-05-05	0-7

Table S2. Details of sites where surface snow samples were collected for EC and WIOC analyses during the Spring 2017 glacier survey in northwestern Spitsbergen.

Location	Lat. N	Long. E	Alt. (m.a.s.l.)	Operated by
Hansbreen	77° 02.90'	15° 38.16'	178	University of Silesia
Werenskioldbreen	77° 04.32'	15° 26.40'	358	University of Silesia
Lomonosovfonna	78° 44.39'	17° 19.87'	685	Uppsala & Utrecht Universities
Kongsvegen	78° 46.82'	13° 09.61'	534	Norwegian Polar Institute (NPI)
Holtedalfonna	78° 59.00'	13° 36.99'	692	Norwegian Polar Institute (NPI)
Austfonna	79° 43.97'	22° 25.01'	369	University of Oslo & NPI

Table S3. Automated Weather Stations (AWS) from which supporting data were obtained for this study.

Site (*landscape type)*	Year(s) of sampling	Thermal protocol	Data source
Summit, central Greenland *(glacier)*	2005	NIOSH 5040	Hagler et al. (2007)
Svalbard: Holtedahlfonna (*glacier*)	2006 to 2014	EUSAAR-2	Ruppel et al. (2017)
Svalbard *(glaciers, sea ice, tundra)*	2007	NIOSH 5040	Forsström et al. (2009)
Svalbard *(glaciers, sea ice, tundra)*	2008	NIOSH 5040	Aamaas et al. (2011)
Svalbard *(glaciers, sea ice, tundra)*	2007 to 2009	EUSAAR-2	Forsström et al. (2013)
Northern Scandinavia *(forest, treeline, tundra)*	2007 to 2009	EUSAAR-2	Forsström et al. (2013)
Northern Sweden *(glacier)*	2009 to 2011	EUSAAR-2	Ingvander et al. (2013)
Northern Sweden *(rural, forested/tundra)*	2017	EUSAAR-2	Unpublished data, Table S5
Northern Finland *(rural, forest)*	2009 to 2011	NIOSH 5040	Meinander et al. (2013)
Northern Finland *(rural, forest)*	2010	NIOSH 5040	Svensson et al. (2013)
Northern Finland rural, *(forest)*	2013 to 2016	EUSAAR-2	Svensson et al. (2018)
NW Siberia and NW Russia *(rural, forest, tundra)*	2014 to 2016	EUSARR-2	Evangeliou et al. (2018)
St. Elias Mountains, Yukon, Canada *(glacier)*	2016	EUSAAR-2	Unpublished data, Table S5

Table S4. Details of the C_{snow}^{EC} data presented on **Fig. 10**. Methodological details are given in these publications: NIOSH 5040: Birch (2003); EUSAAR-2: Cavalli et al. (2010). The C_{snow}^{EC} measured by the NIOSH 5040 protocol were multiplied by a factor of 2, as in Forsström et al. (2013). The C_{snow}^{EC} measurements made by Aamas et al. (2011) near Longyearbyen were excluded because of local pollution of the snow cover by coal dust (Khan et al., 2017). Five samples with C_{snow}^{EC} > 140 ng g^{-1} taken in Russian towns (Tomsk, Archangelsk) were also excluded from the dataset by Evangeliou et al. (2018).

Location	Coordinates (DD° MM.MMM') Latitude	Longitude	Alt. (m)	Year	Month	Day	C_{snow}^{EC} (ng g^{-1})	Depth (cm)	*n*
Northern Sweden *(Rural, forested or remote sites)*									
Gällivare	N 67° 09.187'	E 20° 43.379'	326	2014	4	4	29.9	98	2
Abisko	N 68° 21.818'	E 18° 45.751'	427	2014	4	5	22.6	75	1
Arvidsjaur	N 65° 34.427'	E 19° 13.344'	390	2014	4	6	35.5	64	2
Jokkmokk	N 66° 36.340'	E 19° 46.756'	272	2014	4	6	29.4	69	2
Puoltisvaara	N 67° 26.294'	E 21° 06.075'	383	2014	4	6	22.2	70	2
Lycksele	N 64° 36.248'	E 18° 43.652'	268	2014	4	7	52.4	65	2
Svartberget	N 64° 15.354'	E 19° 47.041'	258	2014	4	7	44.9	78	2
SW Yukon, Canada *(Core drilled on mountain icefield on 15 May, 2016. Years shown are estimates)*									
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2016			10.4	0-150	3
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2015			3.3	150-350	3
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2014			3.4	350-700	7
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2013			2.9	700-1000	6
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2012			3.8	1000-1200	6
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2011			3.3	1200-1500	5
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2010			3.4	1550-1650	4
Eclipse Icefield	N 60° 50.088'	W 139° 49.746'	3020	2009			1.5	1650-1720	1

Table S5. Previously unpublished data on C_{snow}^{EC} from Sweden and the Yukon, used for comparison on **Fig. 10**. These data were collected during reconnaissance surveys in 2014 and 2016, and were handled and analyzed by the same methods and protocols described for the Spring 2016 glacier survey in Svalbard. The samples from Sweden were recovered with assistance from M. Syk and J. Vollmer, Uppsala University, and the Eclipse Icefield core by K. Kreutz, University of Maine, USA.

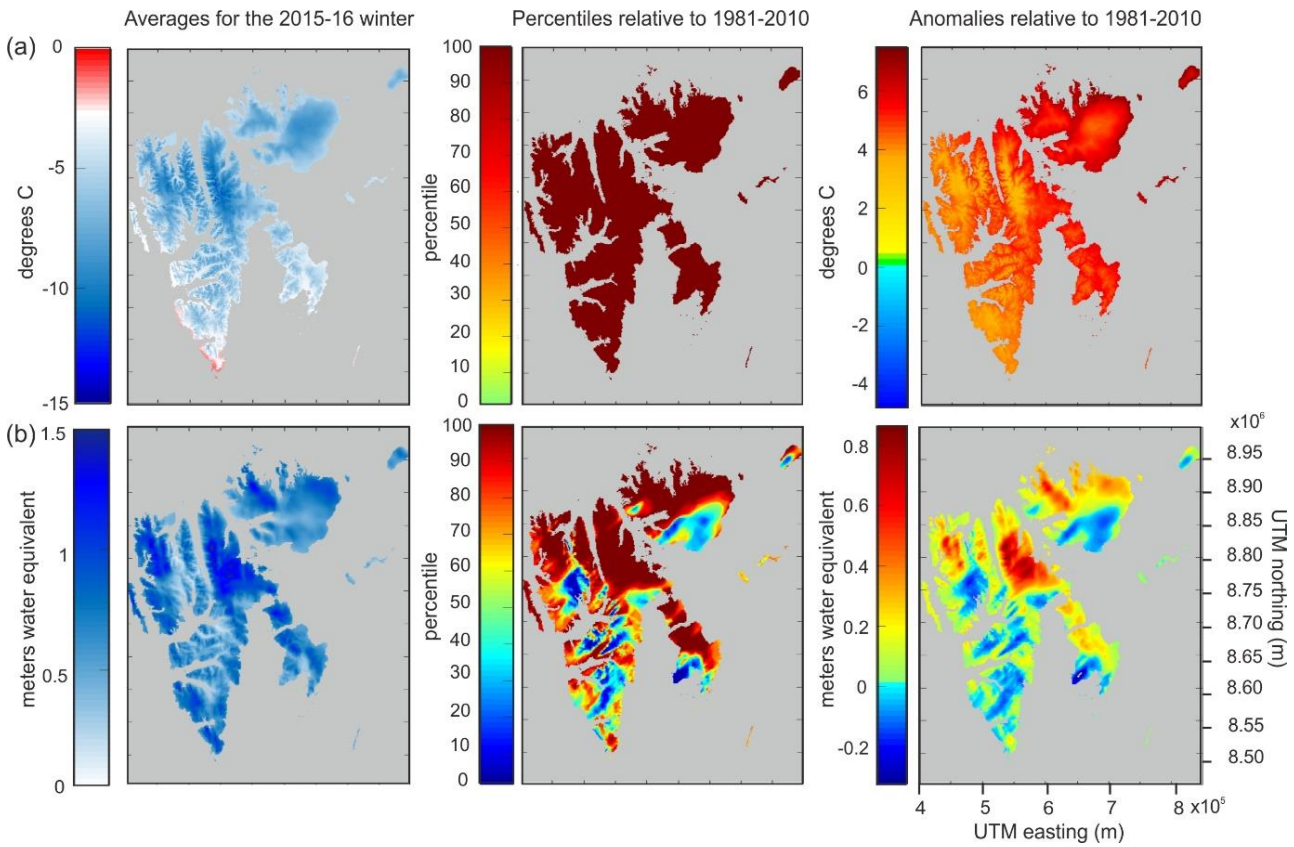

Fig. S1. Comparison of (a) mean surface temperatures and (b) total precipitation (snow + rainfall) over Svalbard during the winter 2015–16 (1 Oct 2015 to 30 April 2016) from gridded ERA Interim reanalysis data fields. Left: Mean winter temperature or total precipitation across the archipelago. Center: Percentile ranking for the winter 2015–16, when compared to the cumulative probability distributions of these conditions during the 30-year climatological reference period 1981–2010. Right: Mean anomalies of temperature or total precipitation in the winter 2015–16 when compared to the climatology of the 1981–2010 period.

Fig. S2. Southward-looking perspective view over part of Brøgger Peninsula, northwestern Spitsbergen, showing the snow sampling sites in this area in relation to Ny-Ålesund and the Zeppelin Observatory. The elevation of some high peaks (m a.s.l.) is shown to provide a vertical scale reference. Image generated with the online mapping service of the Norwegian Polar Institute (https://toposvalbard.npolar.no/)

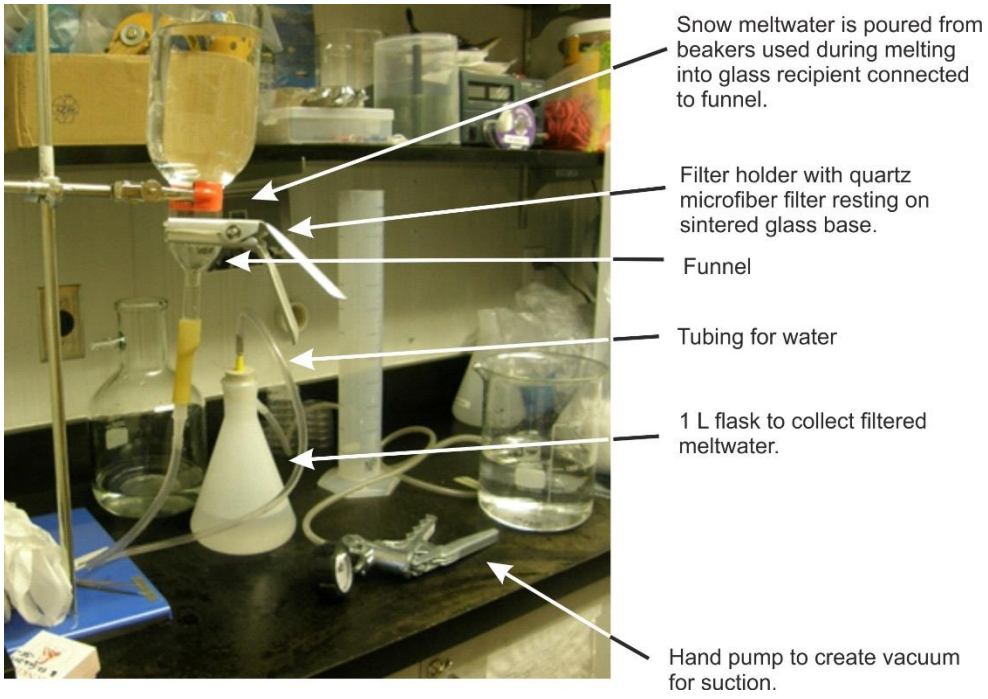

Fig. S3. Filtration apparatus used in the preparation of filters analyzed for EC and WIOC.

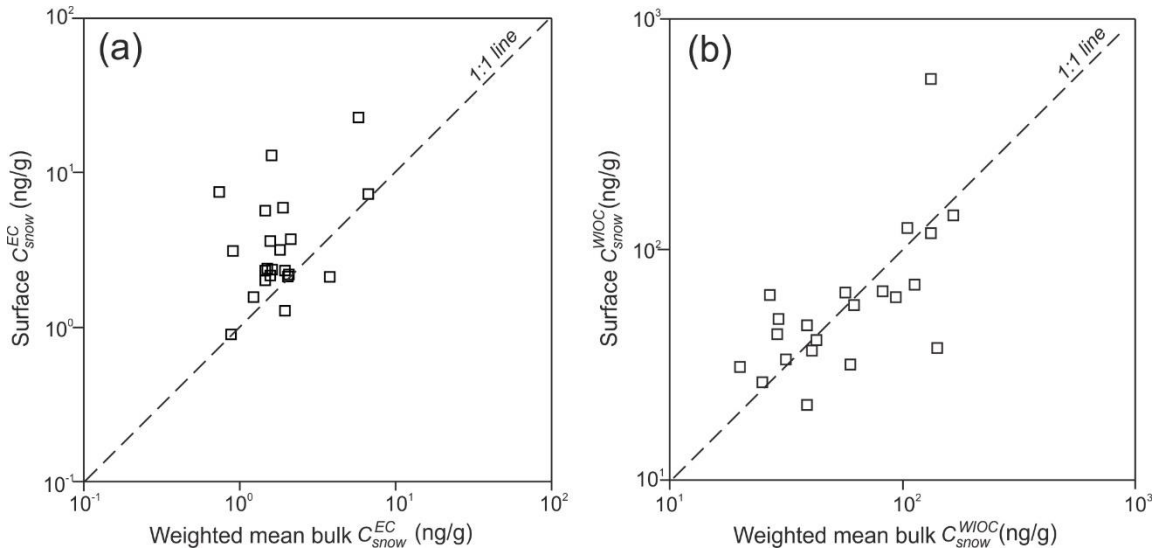

Fig. S4. (a) C_{snow}^{EC} and (b) C_{snow}^{WIOC} in surface layers vs. bulk snow on Svalbard glaciers sampled in Spring 2016.

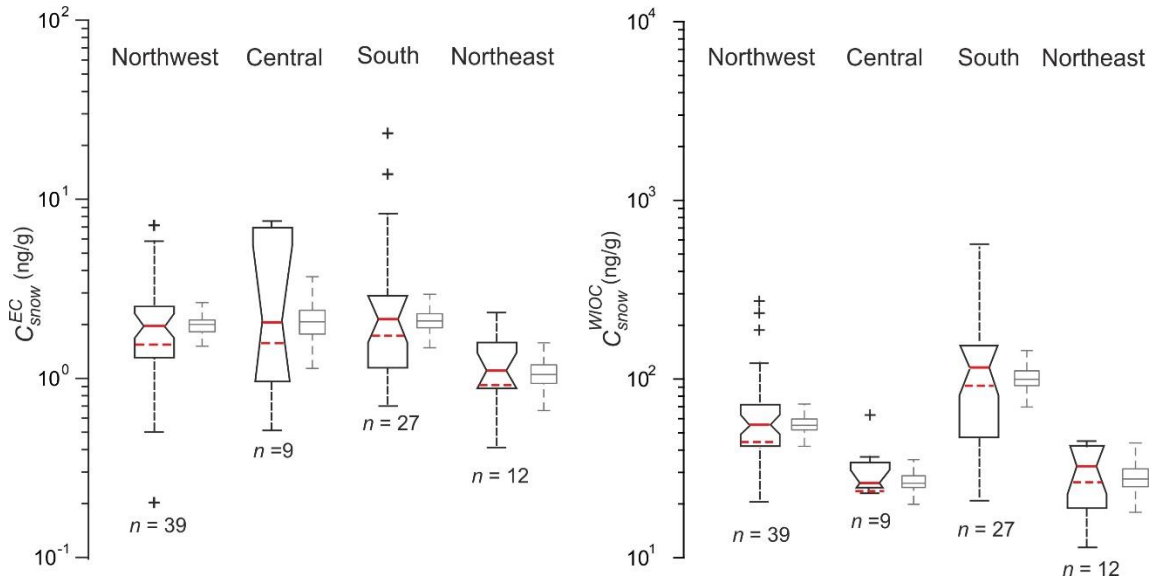

Fig. S5. Estimates of the uncertainty in median C_{snow}^{EC} (left) and C_{snow}^{WIOC} (right) in Svalbard snow collected on glaciers during the Spring 2016 survey. The large box-whisker plots are distributions of the measured C_{snow}^{EC} and C_{snow}^{WIOC} in snow across various geographic sectors of Svalbard, as in **Fig. 3**. The small grey box-plots beside each group of observations show the possible spread in the estimates of the group medians (solid red lines) that arise from the methodological errors in the TOT method described in section 2.2.2., based on a Monte Carlo simulation (500 realisations). When the possible effect of filtration undercatch (range 18-35 %, median 22 %) is also included, the estimates of all group medians are lower (dashed red lines), but the relative uncertainties are unchanged.

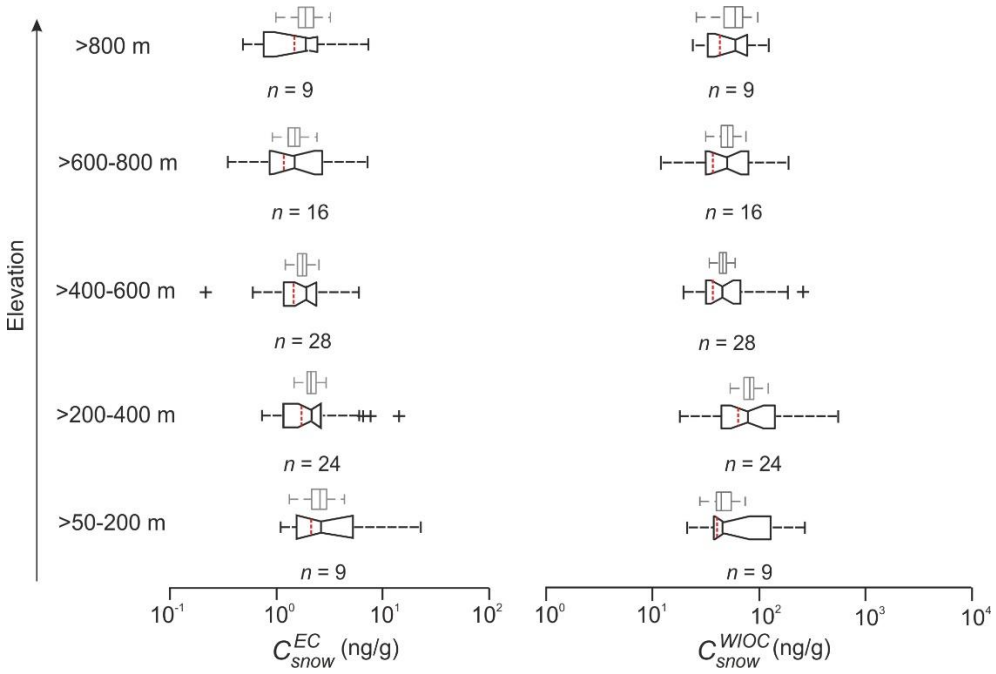

Fig. S6. As in **Fig. S5**, but for C_{snow}^{EC} and C_{snow}^{WIOC} in snow binned by elevation (from **Fig. 4**).

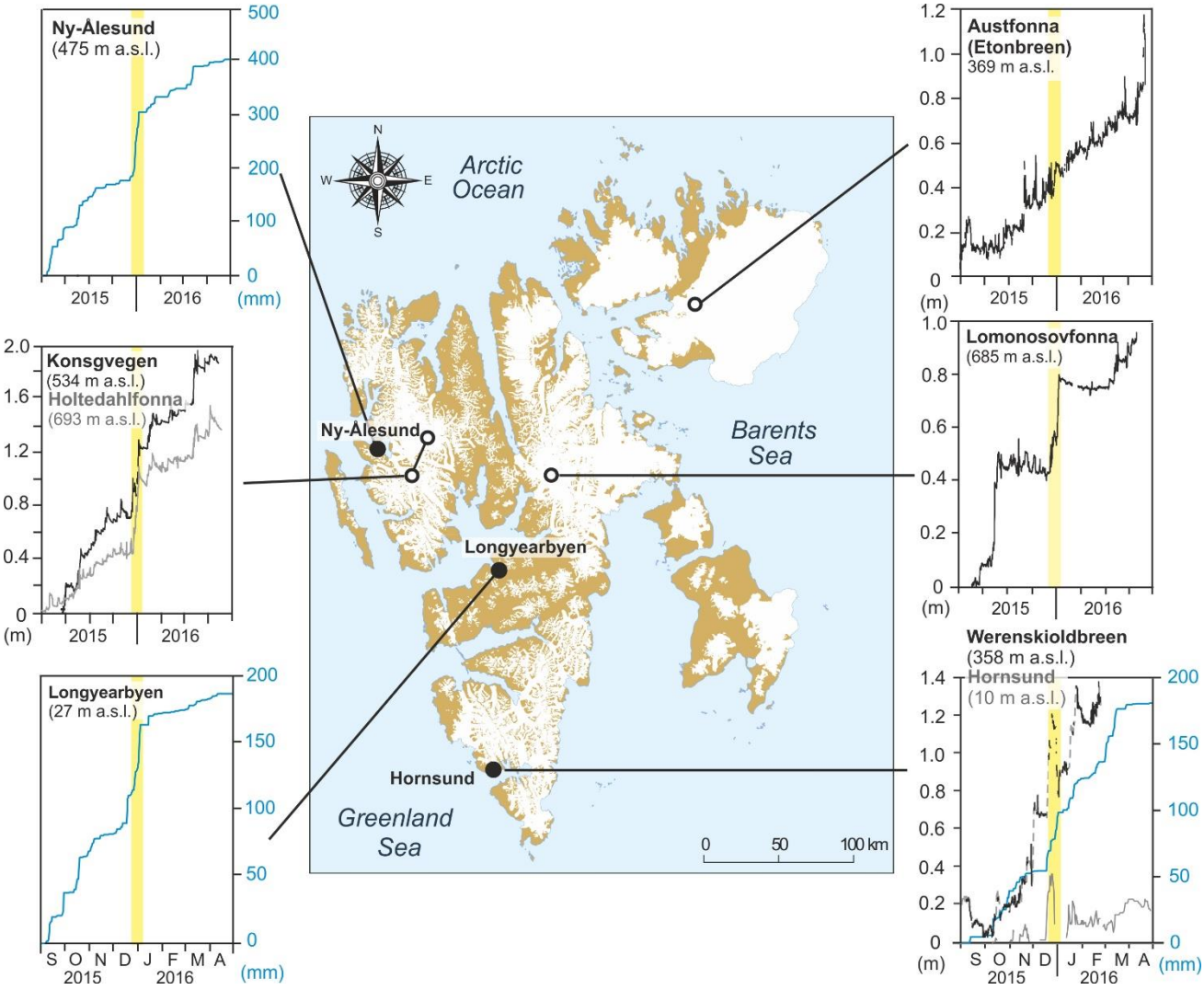

Fig. S7. The signature of the late December 2015 snowstorm (highlighted) across Svalbard. Black/grey: Changes in snowpack thickness or relative surface height (left-hand scale, in m); Blue: cumulative precipitation (right-hand scale, in mm w.e.). Data from glaciers come from the automated weather stations (**Table S3**), while other data are from weather stations at Longyearbyen, the airport in Ny-Ålesund, and from the Polish Polar Station Hornsund.

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