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Contrasting source contributions of Arctic black carbon to atmospheric concentrations, deposition flux, and atmospheric and snow radiative effects

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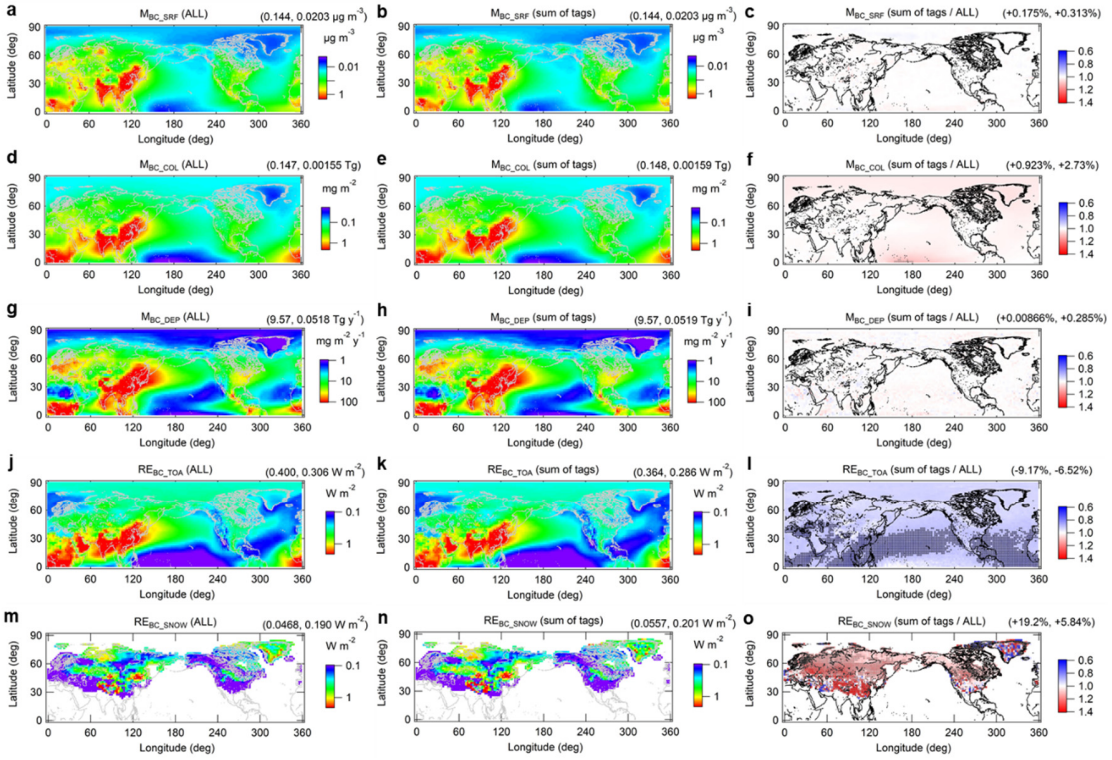

Figure S1. Spatial distributions of (a-c) surface BC mass concentrations (M_{BC_SRF}), (d-f) column BC mass concentrations (M_{BC_COL}), (g-i) BC deposition flux (M_{BC_DEP}), (j-l) BC radiative effect at the top of atmosphere (RE_{BC_TOA}), and (m-o) BC radiative effect at the snow surface (RE_{BC_SNOW}) in the Northern Hemisphere. The results of the base simulation (ALL) (a, d, g, j, and m), the sum of all tags consisting of 26 sources (b, e, h, k, and n), and their ratio (sum of tags / ALL) are shown for the five BC variables. The values in the parentheses show global-mean (left) and Arctic-mean (right) values of each BC variable (annual-mean). Grids where values differ by more than 10% between ALL and the sum of tags are indicated by black open circles (c, f, i, l, and o).

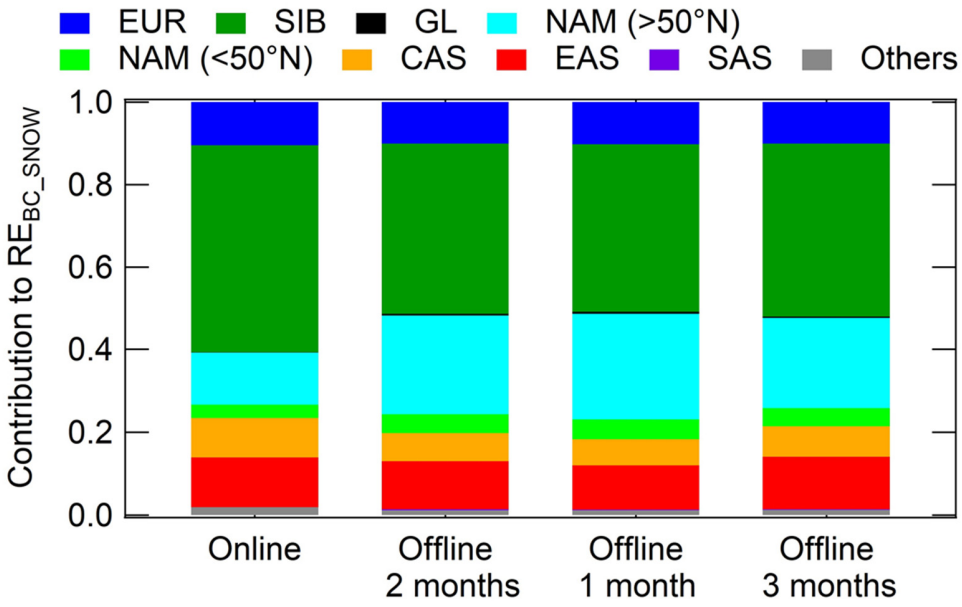

Figure S2. Source contributions to BC radiative effect at the snow surface (RE_{BC_SNOW}) in the Arctic (>70°N) from the sum of all tags in the 13 simulations (Online) and from offline calculations using Eq. (1) (Offline). Offline calculations were performed for three cases that were weighted by BC deposition fluxes of different time periods (1 to 3 months).

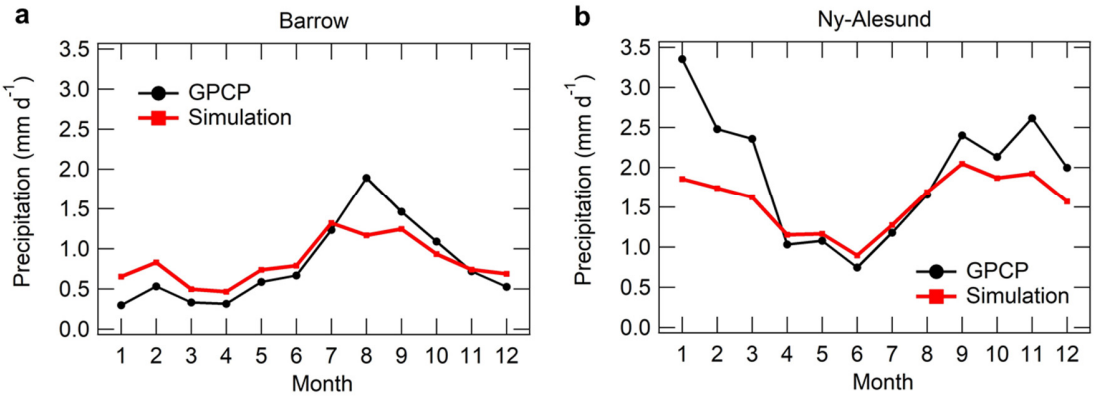

Figure S3. Observed and simulated precipitation rate at (a) Barrow and (b) Ny-Ålesund for 2009–2015. Observed data are derived from Global Precipitation Climatology Project (GPCP) monthly data (https://psl.noaa.gov/data/gridded/data.gpcp.html).

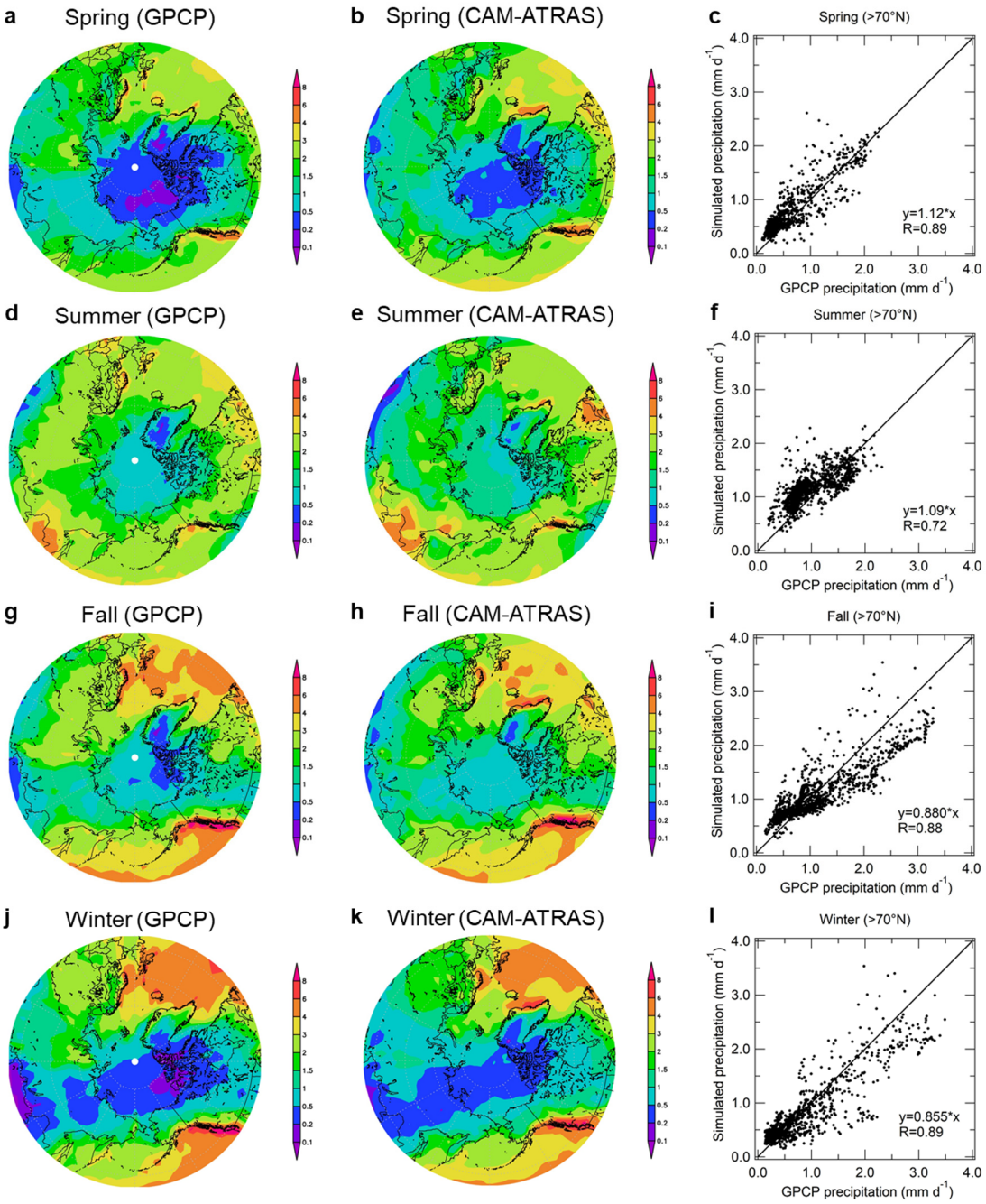

Figure S4. (a, d, g, and j) Observed (GPCP) and (b, e, h, and k) simulated (CAM-ATRAS) precipitation rate (mm d^{-1}) at high latitudes in the Northern Hemisphere in (a–b) spring (March–May), (d–e) summer (June–August), (g–h) fall (September–November), and (j–k) winter (December–February) for 2009–2015. (c, f, i, and l) scatterplots between observed and simulated precipitation rate. Seasonal averages for 2009–2015 are shown for all model grids north of 70°N. The values in the lower right show the slope of the fitting and correlation coefficient.

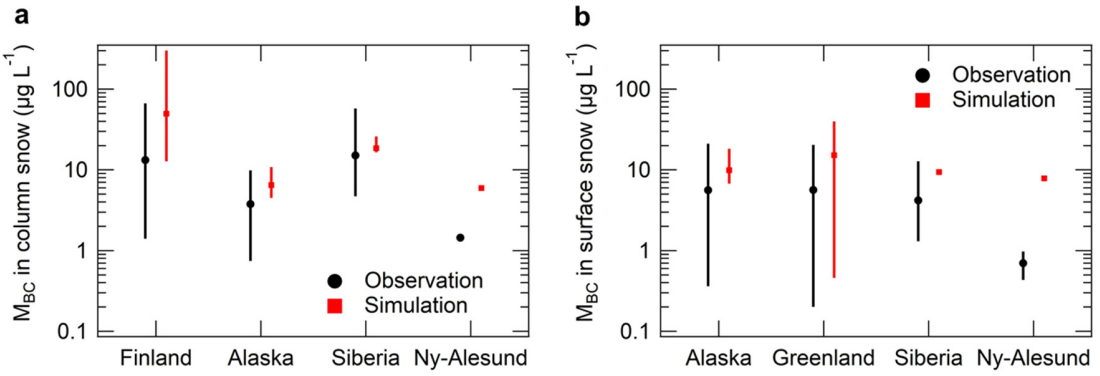

Figure S5. Observed (black) and simulated (red) BC mass concentrations (M_{BC}) (a) in the total column of snowpack and (b) in surface snow. Averages (circles and squares) and maximum–minimum ranges (vertical lines) are shown for individual regions of snow samplings.

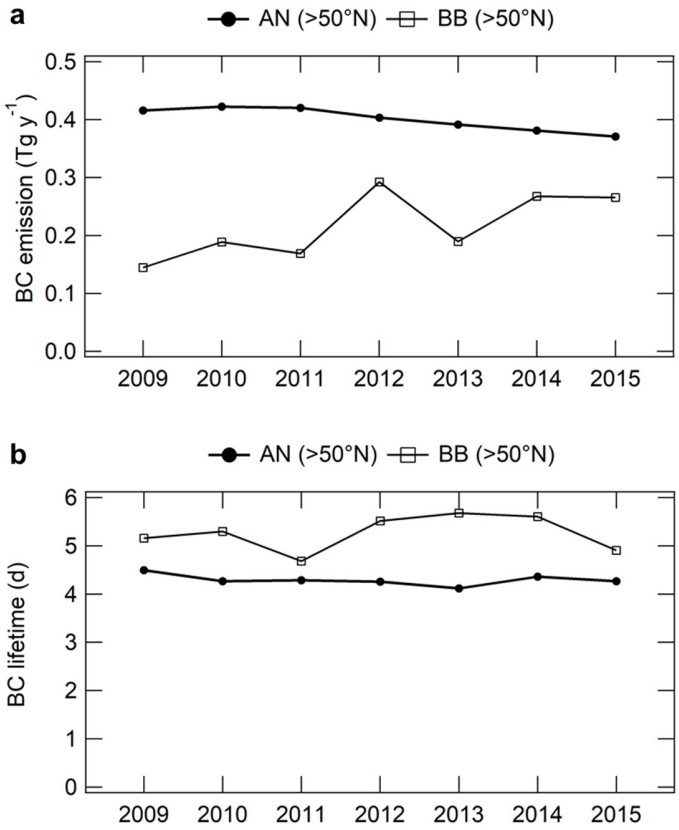

Figure S6. Year-to-year variations in (a) emissions and (b) lifetime of anthropogenic (closed circles) and biomass burning (open squares) BC north of 50°N. Lifetimes were defined by the ratio of BC deposition flux to atmospheric BC loading north of 50°N.

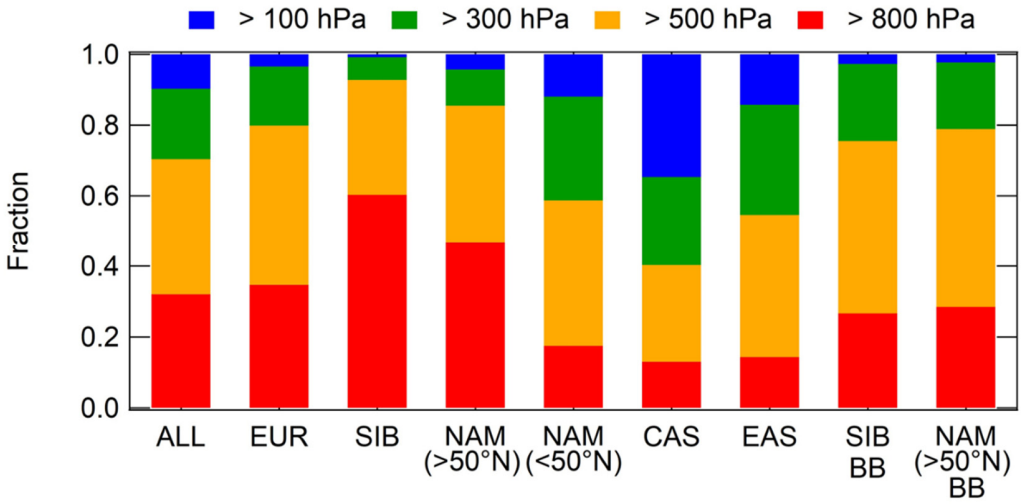

Figure S7. The altitude fraction of BC mass for each source in the Arctic. The altitudes are divided into four categories: 100–300 hPa (blue), 300–500 hPa (green), 500–800 hPa (orange), and 800 hPa to the surface (red).

Table S1. Inter-annual variability of BC source contributions in the Arctic (>70°N)

Region [a]	Source [b]	$M_{BC\ SRF}$ [c]	$M_{BC\ COL}$ [c]	$M_{BC\ DEP}$ [c]	$RE_{BC\ TOA}$ [c]	$RE_{BC\ SNOW}$ [c]
		ng m^{-3}	Gg	Gg y^{-1}	W m^{-2}	W m^{-2}
ALL	AN	17−22	1.2−1.5	30−38	0.19−0.24	0.11−0.15
	BB	0.73−1.7	0.22−0.35	8.9−28	0.056−0.12	0.040−0.086
		%	%	%	%	%
EUR	AN	9.0−14	11−15	10−20	6.9−10	7.4−14
SIB	AN	61−71	22−29	25−43	11−17	26−36
SIB	BB	1.5−6.4	4.3−16	9.6−36	7.1−25	5.6−19
NAM (>50°N)	AN	3.8−5.5	1.8−2.1	1.6−2.3	1.3−1.8	2.9−3.8
NAM (>50°N)	BB	0.92−5.2	2.8−14	4.5−22	4.2−27	7.7−31
NAM (<50°N)	AN	1.5−2.1	4.2−5.9	1.4−2.6	3.3−6.1	2.8−5.2
NAM (<50°N)	BB	0.040−0.099	0.20−0.53	0.13−0.34	0.24−1.0	0.19−0.99
CAS1	AN	0.10−0.15	1.2−1.6	0.31−0.45	1.7−2.5	0.40−0.71
CAS2	AN	0.17−0.29	2.9−4.0	0.62−1.0	3.7−6.3	0.73−1.2
CAS3	AN	1.4−2.0	4.1−4.9	2.1−3.8	4.1−5.4	2.1−4.6
CAS4	AN	1.0−1.7	3.8−4.4	1.5−2.7	3.8−5.3	1.4−2.0
EAS1	AN	0.57−0.89	3.9−5.3	1.1−1.6	4.4−6.5	1.4−2.0
EAS2	AN	3.3−6.0	15−19	5.6−8.2	16−23	7.7−12
EAS2	BB	0.037−0.15	0.22−1.0	0.081−0.37	0.31−2.0	0.12−1.2
Others	AN	0.53−0.72	1.6−2.3	0.68−1.2	1.7−2.6	1.0−1.5

[a] EUR: Europe, SIB: Siberia, GL: Greenland, NAM: North America, CAS: Central Asia, EAS: East Asia, SAS: Southeast Asia. These regions are defined in Fig. 1.

[b] AN: Anthropogenic (fossil fuel + biofuel), BB: Biomass burning.

[c] Maximum-minimum ranges of annual-mean source contributions. Values are shown only for regions/sources where their contributions are greater than 1%.