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).
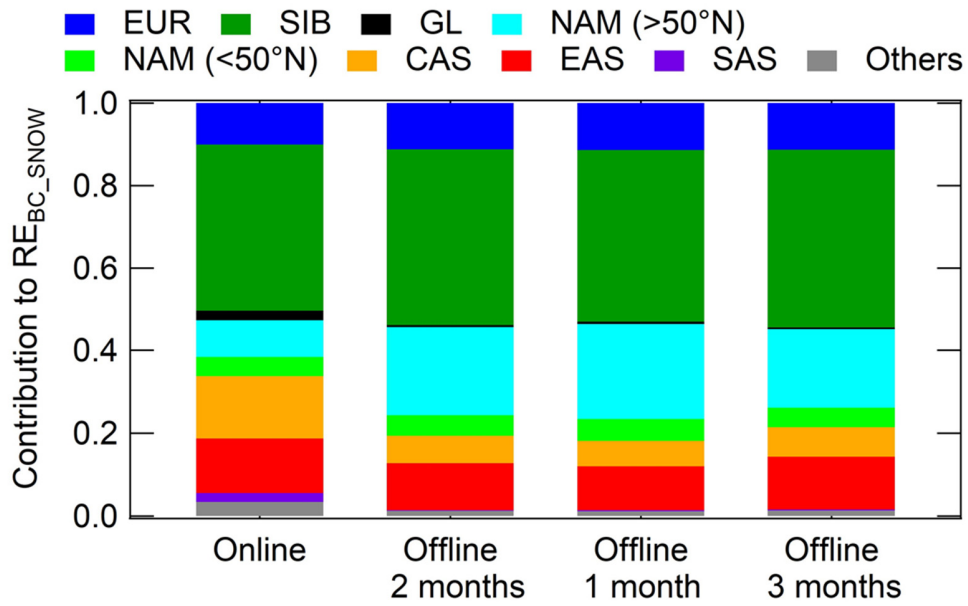
Figure S2. Source contributions to BC radiative effect at the snow surface (RE$_{BC\_SNOW}$) in the Arctic (>70°N) from the sum of all tags in the base simulation (Online) and from offline calculations using Eq. (1) (Offline). Offline calculations were performed for three cases that were weighted by BC deposition fluxes of different time periods (1 to 3 months).
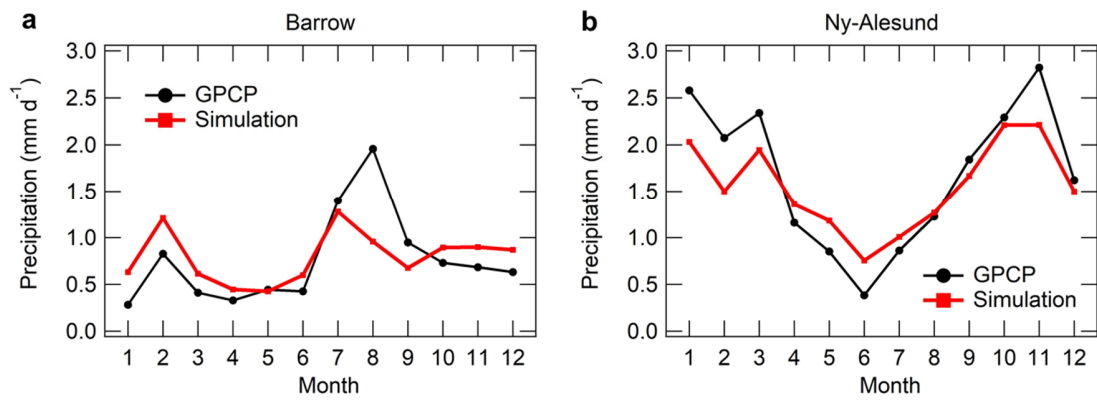
Figure S3. Observed and simulated precipitation rate at (a) Barrow and (b) Ny-Ålesund for 2009–2011. Observed data are derived from Global Precipitation Climatology Project (GPCP) monthly data (https://psl.noaa.gov/data/gridded/data.gpcp.html).
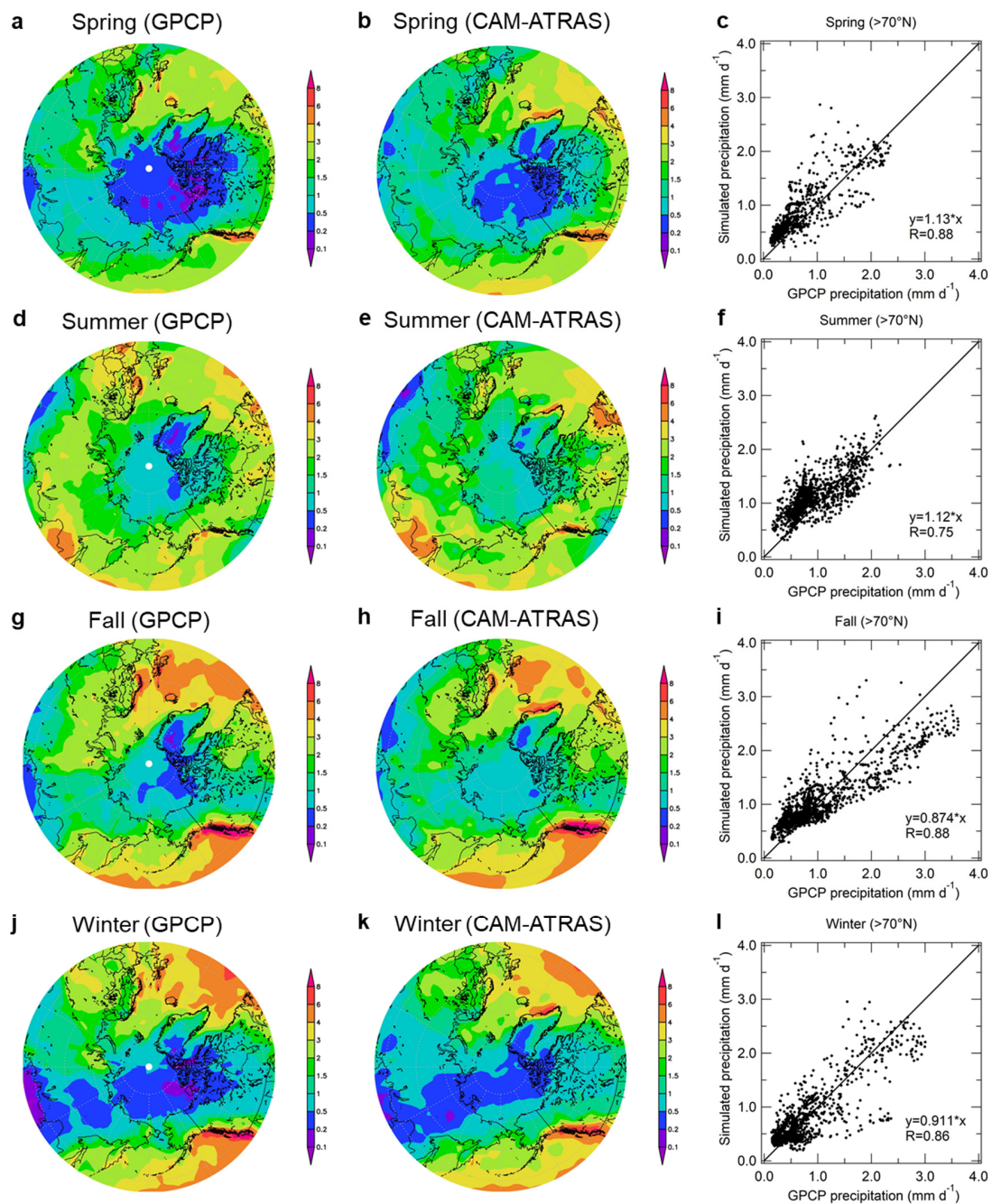
Figure S4. (a, d, g, and j) Observed (GPCP) and (b, e, h, and k) simulated (CAM-ATRAS) precipitation rate (mm d-1) at high latitudes in the Northern Hemisphere in (a–b) spring (March–May), (d–e) summer (June–August), (g–h) fall (September–November), and (j–k) winter (December–February) for 2009–2011. (c, f, i, and l) scatterplots between observed and simulated precipitation rate. Seasonal averages for 2009–2011 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.
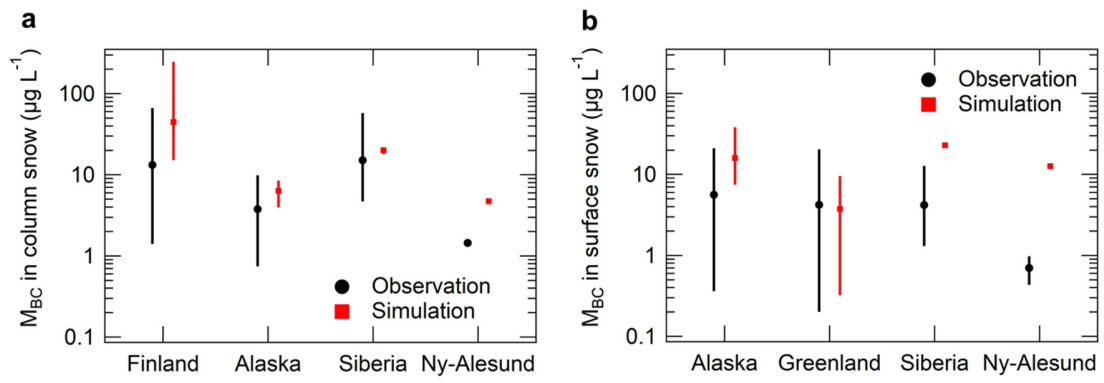
Figure S5. Observed (black) and simulated (red) BC mass concentrations (M_{BC}) (a) in the total column of snowpack and (b) in surface snow. Averages (circles and squares) and maximum–minimum ranges (vertical lines) are shown for individual regions of snow samplings.
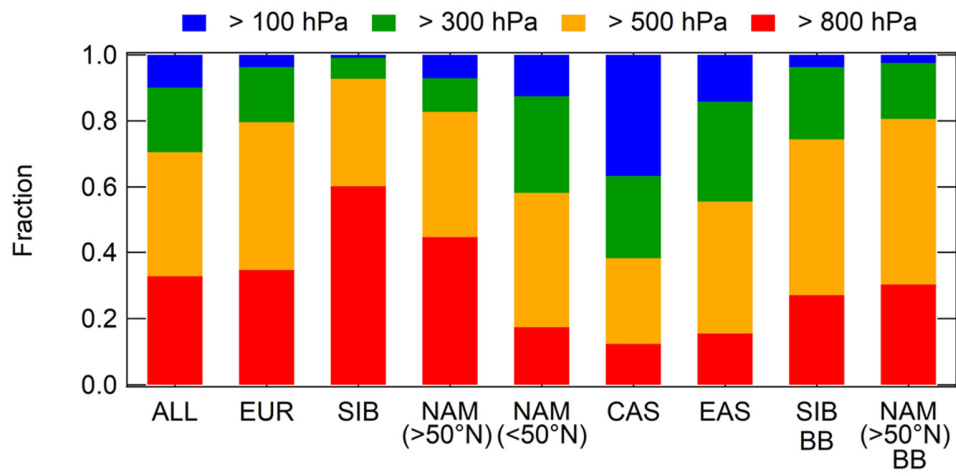
Figure S6. The altitude fraction of BC mass for each source in the Arctic. The altitudes are divided into four categories: 100–300 hPa (blue), 300–500 hPa (green), 500–800 hPa (orange), and 800 hPa to the surface (red).