Supplement of

Responses of Arctic Black Carbon and Surface Temperature to Multi-Region Emission Reductions: an HTAP2 Ensemble Modeling Study

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S1 Statistical metrics of the model evaluation

The statistical metrics in the present analysis include values of mean bias (MB), mean absolute error (MAE), normalized mean bias (NMB), normalized mean error (NME), and correlative coefficient (R). Detail equations of the above statistical metrics are shown as follows:

$$MB = \frac{1}{N}\sum_{i=1}^{N}(Cm\text{-}Co) \quad (1)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|Cm\text{-}Co| \quad (2)$$

$$NMB = \frac{\sum_{i=1}^{N}(Cm\text{-}Co)}{\sum_{i=1}^{N}Co}\times 100\% \quad (3)$$

$$NME = \frac{\sum_{i=1}^{N}|Cm\text{-}Co|}{\sum_{i=1}^{N}Co}\times 100\% \quad (4)$$

$$COR = \frac{\sum_{i=1}^{N}(Cm\text{-}\overline{Cm})(Co\text{-}\overline{Co})}{\sqrt{\sum_{i=1}^{N}(Cm\text{-}\overline{Cm})^2\sum_{i=1}^{N}(Co\text{-}\overline{Co})^2}} \quad (5)$$

Where:

Cm = The model–estimated concentration at station i, month j

Co = The observed concentration at station i, month j

$\overline{Cm}$ *= The average model–estimated concentration of all hours of all sites*

$\overline{Co}$ *= The average observed concentration of all hours of all sites*

N = The total numbers of hours of all sites for which the simulations are compared against observations

References

United States Environmental Protection Agency (U.S. EPA). Guidance on the use of models and other analyses for demonstrating attainment of air quality goals for ozone, $PM_{2.5}$, and regional haze. U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Air Quality Analysis Division Air Quality Modeling Group Research Triangle Park, NC. 2007.

U.S. EPA. Guidance on the Development, Evaluation, and Application of Environmental Models. Council for Regulatory Environmental Modeling U.S. Environmental Protection Agency Washington, DC. 2009.

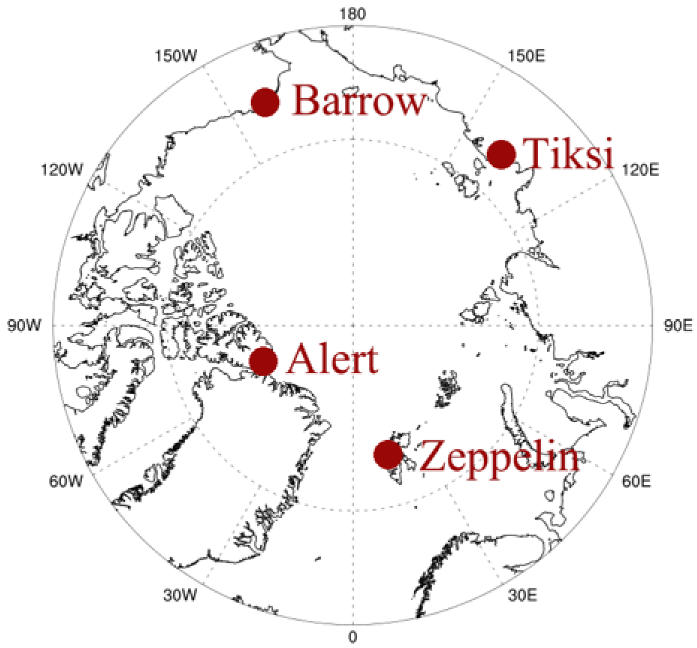


Figure S1 Four BC monitoring sites (Alert, Barrow, Tiksi, and Zeppelin) in the Arctic Circle.

Table S1 Comparison of the simulations of BC concentrations of participating models at **(a)** Alert, **(b)** Barrow, **(c)** Tiksi, and **(d)** Zeppelin in 2010.

(a) Alert

Parameters		CAMchem	CHASER_re1	CHASER_t106	GEOSCHEM	GOCART–v5	Oslo CTM3–v2
COR[a]	CAMchem	–	0.81	0.90	0.80	0.86	0.65
	CHASER_re1	0.81	–	0.94	0.61	0.70	0.86
	CHASER_t106	0.90	0.94	–	0.76	0.85	0.71
	GEOSCHEM	0.80	0.61	0.76	–	0.98	0.44
	GOCART–v5	0.86	0.70	0.85	0.98	–	0.48
	Oslo CTM3–v2	0.65	0.86	0.71	0.44	0.48	–
NMB[b] (%)	CAMchem	–	–92.99	–92.00	–74.12	–81.17	97.44
	CHASER_re1	1642.07	–	17.32	346.18	217.66	2785.04
	CHASER_t106	1457.24	–8.04	–	286.82	169.75	2682.54
	GEOSCHEM	370.56	–69.26	–65.84	–	–27.08	786.33
	GOCART–v5	562.46	–57.38	–53.44	40.04	–	1158.33
	Oslo CTM3–v2	–33.38	–96.10	–95.21	–82.90	–87.57	–
NME[c] (%)	CAMchem	–	92.99	92.00	74.12	81.17	106.21
	CHASER_re1	1642.07	–	27.85	346.18	217.66	2785.04
	CHASER_t106	1457.24	22.22	–	286.82	170.32	2682.54
	GEOSCHEM	370.56	69.26	65.84	–	27.08	786.33
	GOCART–v5	562.46	57.38	54.03	40.04	–	1158.33
	Oslo CTM3–v2	45.70	96.10	95.21	82.90	87.57	–
MB[d] (ng m^{-3})	CAMchem	–	–34.74	–33.87	–7.03	–11.63	1.07
	CHASER_re1	34.74	–	0.87	27.71	23.12	35.81
	CHASER_t106	33.87	–0.87	–	26.84	22.25	34.94
	GEOSCHEM	7.03	–27.71	–26.84	–	–4.59	8.10
	GOCART–v5	11.63	–23.12	–22.25	4.59	–	12.69
	Oslo CTM3–v2	–1.07	–35.81	–34.94	–8.10	–12.69	–
MAE[e] (ng m^{-3})	CAMchem	–	34.74	33.87	7.03	11.63	1.22
	CHASER_re1	34.74	–	9.29	27.71	23.12	35.81
	CHASER_t106	33.87	9.29	–	26.84	22.36	34.94
	GEOSCHEM	7.03	27.71	26.84	–	4.59	8.10
	GOCART–v5	11.63	23.12	22.36	4.59	–	12.69
	Oslo CTM3–v2	1.22	35.81	34.94	8.10	12.69	–

(b) Barrow

Parameters		CAMchem	CHASER_re1	CHASER_t106	GEOSCHEM	GOCART–v5	Oslo CTM3–v2
COR[a]	CAMchem	–	0.91	0.93	0.90	0.89	0.84

	CHASER_re1	0.91	–	0.98	0.82	0.79	0.81
	CHASER_t106	0.93	0.98	–	0.88	0.86	0.83
	GEOSCHEM	0.90	0.82	0.88	–	0.90	0.92
	GOCART–v5	0.89	0.79	0.86	0.90	–	0.71
	Oslo CTM3–v2	0.84	0.81	0.83	0.92	0.71	–
NMB[b] (%)	CAMchem	–	–75.42	–72.68	–3.89	–34.61	137.53
	CHASER_re1	399.17	–	13.85	310.46	188.49	854.96
	CHASER_t106	340.44	–11.12	–	257.15	151.11	756.02
	GEOSCHEM	49.47	–69.06	–65.51	–	–26.62	165.92
	GOCART–v5	99.71	–55.97	–51.42	45.54	–	305.41
	Oslo CTM3–v2	–38.57	–87.62	–85.81	–54.76	–66.86	–
NME[c] (%)	CAMchem	–	75.42	72.68	47.82	42.42	141.75
	CHASER_re1	399.17	–	15.01	310.46	190.71	854.96
	CHASER_t106	340.44	12.31	–	257.15	152.92	756.02
	GEOSCHEM	75.31	69.06	65.51	–	27.32	165.92
	GOCART–v5	105.96	58.53	53.45	46.22	–	305.41
	Oslo CTM3–v2	44.22	87.62	85.81	54.76	66.86	–
MB[d] (ng m^{-3})	CAMchem	–	–37.49	–32.90	–3.04	–11.02	8.27
	CHASER_re1	37.49	–	4.59	34.45	26.47	45.76
	CHASER_t106	32.90	–4.59	–	29.86	21.89	41.17
	GEOSCHEM	3.04	–34.45	–29.86	–	–7.98	11.31
	GOCART–v5	11.02	–26.47	–21.89	7.98	–	19.29
	Oslo CTM3–v2	–8.27	–45.76	–41.17	–11.31	–19.29	–
MAE[e] (ng m^{-3})	CAMchem	–	37.49	32.90	6.90	11.77	8.56
	CHASER_re1	37.49	–	5.72	34.45	28.24	45.76
	CHASER_t106	32.90	5.72	–	29.86	23.32	41.17
	GEOSCHEM	6.90	34.45	29.86	–	8.09	11.31
	GOCART–v5	11.77	28.24	23.32	8.09	–	19.29
	Oslo CTM3–v2	8.56	45.76	41.17	11.31	19.29	–

(c) Tiksi

Parameters		CAMchem	CHASER_re1	CHASER_t106	GEOSCHEM	GOCART–v5	Oslo CTM3–v2
COR[a]	CAMchem	–	0.45	0.59	0.47	0.33	0.54
	CHASER_re1	0.45	–	0.89	0.78	0.77	0.64
	CHASER_t106	0.59	0.89	–	0.72	0.60	0.74
	GEOSCHEM	0.47	0.78	0.72	–	0.93	0.87
	GOCART–v5	0.33	0.77	0.60	0.93	–	0.75
	Oslo CTM3–v2	0.54	0.64	0.74	0.87	0.75	–
NMB[b] (%)	CAMchem	–	–84.42	–83.61	–35.64	–46.60	11.07
	CHASER_re1	813.44	–	9.64	310.05	240.81	633.13
	CHASER_t106	750.90	–5.27	–	288.26	224.18	573.80

	GEOSCHEM	176.14	–70.09	–67.41	–	–10.18	98.37
	GOCART–v5	200.57	–67.11	–63.73	18.35	–	121.63
	Oslo CTM3–v2	37.84	–84.35	–83.37	–40.00	–50.66	–
NME[c] (%)	CAMchem	–	84.42	83.61	54.38	57.93	60.09
	CHASER_re1	813.44	–	18.18	310.05	240.81	633.13
	CHASER_t106	750.90	16.09	–	288.26	224.18	573.80
	GEOSCHEM	186.23	70.09	67.41	–	20.65	104.94
	GOCART–v5	209.03	67.11	63.73	26.28	–	121.63
	Oslo CTM3–v2	67.46	84.35	83.37	50.86	50.66	–
MB[d] (ng m^{-3})	CAMchem	–	–37.12	–35.47	–6.99	–7.66	0.12
	CHASER_re1	37.12	–	1.65	30.14	29.46	37.24
	CHASER_t106	35.47	–1.65	–	28.49	27.81	35.59
	GEOSCHEM	6.99	–30.14	–28.49	–	–0.68	7.10
	GOCART–v5	7.66	–29.46	–27.81	0.68	–	7.78
	Oslo CTM3–v2	–0.12	–37.24	–35.59	–7.10	–7.78	–
MAE[e] (ng m^{-3})	CAMchem	–	37.12	35.47	7.55	8.94	4.10
	CHASER_re1	37.12	–	7.55	30.14	29.46	37.24
	CHASER_t106	35.47	7.55	–	28.49	27.81	35.59
	GEOSCHEM	7.55	30.14	28.49	–	2.57	7.58
	GOCART–v5	8.94	29.46	27.81	2.57	–	7.78
	Oslo CTM3–v2	4.10	37.24	35.59	7.58	7.78	–

(d) Zeppelin

Parameters		CAMchem	CHASER_re1	CHASER_t106	GEOSCHEM	GOCART–v5	Oslo CTM3–v2
COR[a]	CAMchem	–	0.72	0.63	0.88	0.93	0.57
	CHASER_re1	0.72	–	0.90	0.51	0.72	0.61
	CHASER_t106	0.63	0.90	–	0.47	0.60	0.58
	GEOSCHEM	0.88	0.51	0.47	–	0.92	0.57
	GOCART–v5	0.93	0.72	0.60	0.92	–	0.76
	Oslo CTM3–v2	0.57	0.61	0.58	0.57	0.76	–
NMB[b] (%)	CAMchem	–	–89.52	–89.08	–66.10	–77.05	61.88
	CHASER_re1	1116.80	–	6.58	310.46	167.04	1389.68
	CHASER_t106	1093.77	–2.16	–	292.67	161.46	1382.26
	GEOSCHEM	230.01	–65.56	–64.95	–	–29.68	408.70
	GOCART–v5	378.64	–53.57	–51.37	50.21	–	520.07
	Oslo CTM3–v2	44.23	–87.53	–87.20	–58.64	–73.17	–
NME[c] (%)	CAMchem	–	89.52	89.08	66.10	77.05	108.27
	CHASER_re1	1116.80	–	17.38	310.46	167.04	1389.68
	CHASER_t106	1093.77	14.60	–	292.67	161.46	1382.26
	GEOSCHEM	230.01	65.56	64.95	–	32.28	408.70
	GOCART–v5	378.64	53.57	51.37	52.47	–	520.07

	Oslo CTM3–v2	81.19	87.53	87.20	58.64	73.17	–
MB[d] (ng m^{-3})	CAMchem	–	–27.11	–26.25	–6.81	–10.72	–0.48
	CHASER_re1	27.11	–	0.86	20.30	16.40	26.63
	CHASER_t106	26.25	–0.86	–	19.44	15.53	25.77
	GEOSCHEM	6.81	–20.30	–19.44	–	–3.91	6.33
	GOCART–v5	10.72	–16.40	–15.53	3.91	–	10.24
	Oslo CTM3–v2	0.48	–26.63	–25.77	–6.33	–10.24	–
MAE[e] (ng m^{-3})	CAMchem	–	27.11	26.25	6.81	10.72	1.84
	CHASER_re1	27.11	–	3.86	20.30	16.40	26.63
	CHASER_t106	26.25	3.86	–	19.44	15.53	25.77
	GEOSCHEM	6.81	20.30	19.44	–	4.27	6.33
	GOCART–v5	10.72	16.40	15.53	4.27	–	10.24
	Oslo CTM3–v2	1.84	26.63	25.77	6.33	10.24	–

[a] Correlative coefficient. [b] Normalized mean bias. [c] Normalized mean error. [d] Mean bias. [e] Mean absolute error.

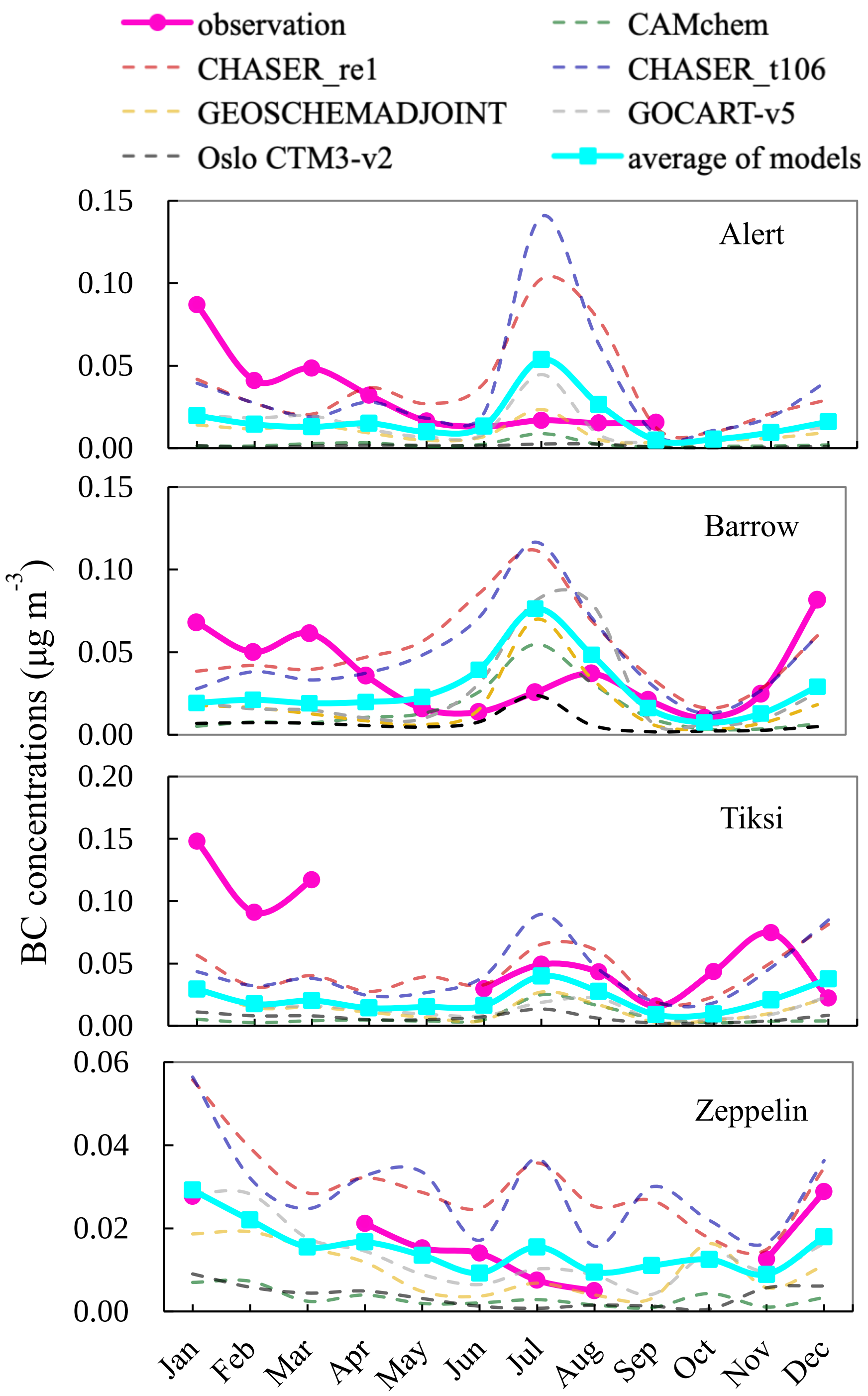


Figure S2 Temporal variations in simulated and observed BC concentrations near surface at Alert, Barrow, Tiks, and Zeppelin in 2010.

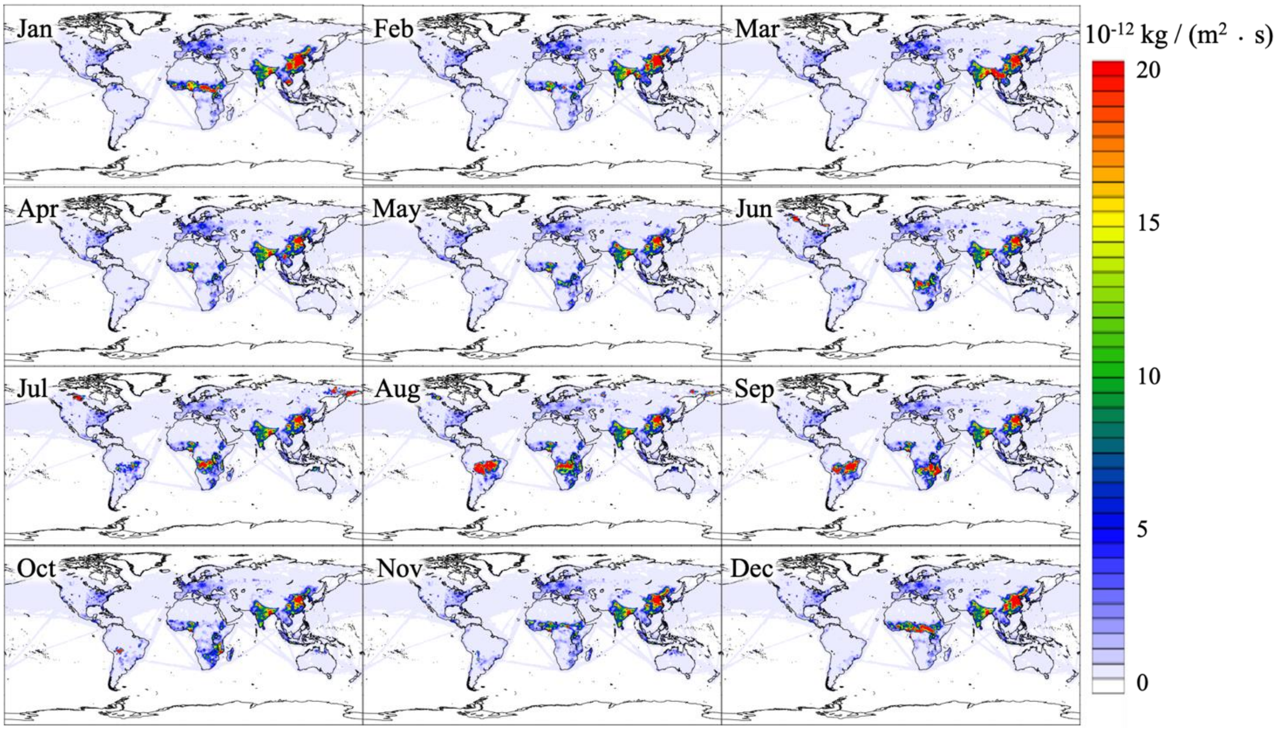


Figure S3. Spatial distribution of monthly BC emissions in 2010.

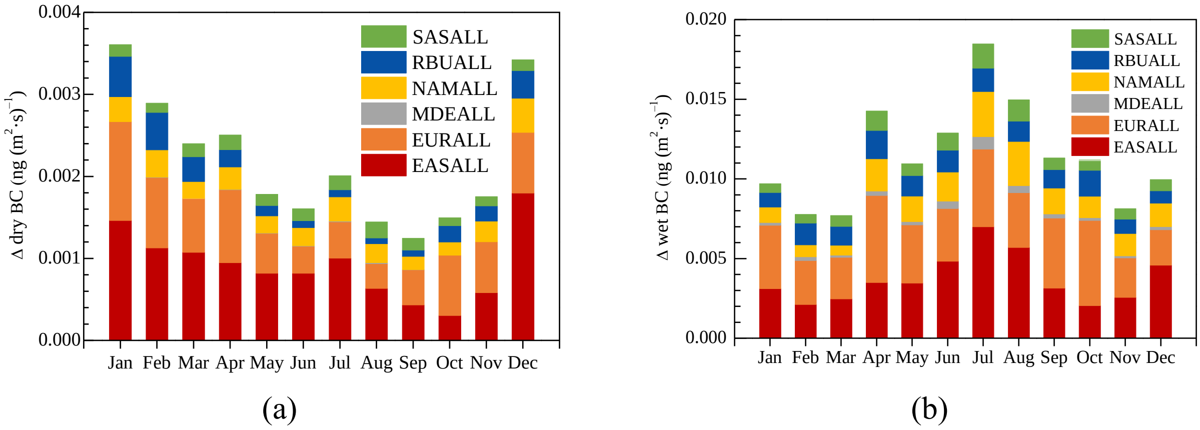
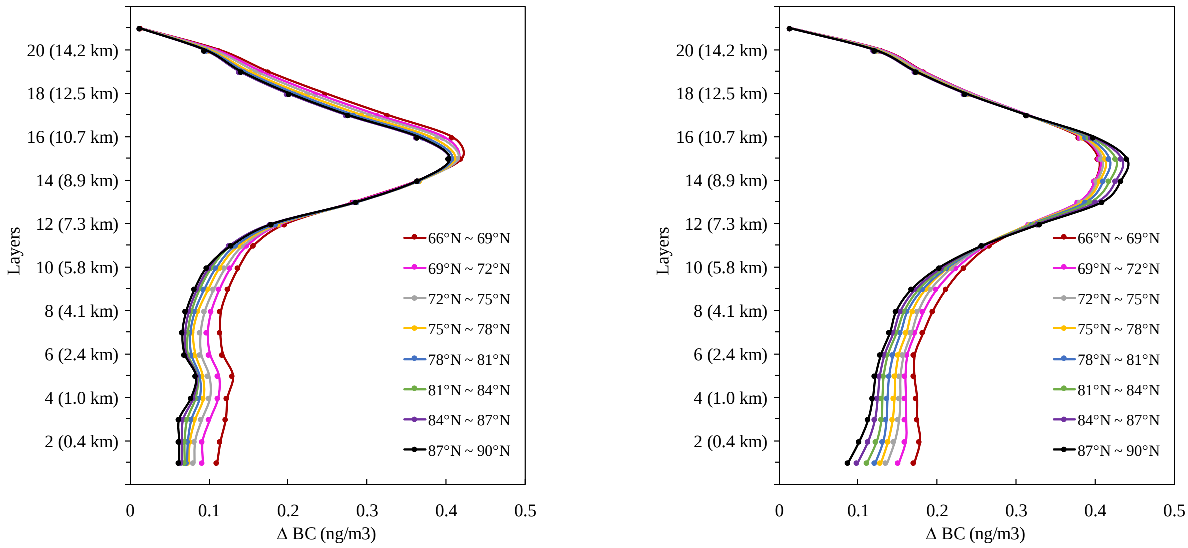


Figure S4. Monthly mean reduced (a) dry and (b) wet depositions of the near surface Arctic BC due to 20% emission reductions of six source regions in 2010.

Table S2 The vertical stratification unified according to the pressure of CHASER_re1

The unified layers of this study		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Pressure (kPa)		> 99.5	97–99.5	92–97	85–92	78–85	68–78	60–68	52–60	45–52	39–45	34–39	30–34	26–30	23–26	20–23	17–20	15–17	13–15	11.5–13	10–11.5	<10
The original layers of participating models	CAMchem	1	2–3	4–6	7–11	12–14	15–18	19–20	21–22	23–34	25–26	27	28	29	–[a]	30	31	32	33	34	35	36–56
	CHASER_re1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21–32
	CHASER_t106	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21–32
	GEOSCHEM	1–2	3	4–7	8–11	12–15	16–19	20–21	22–23	24–25	26	27	28	29	30	31	32	33	–[a]	34	35	36–47
	GOCART–v5	1	2–3	4–6	7–11	12–14	15–18	19–20	21–22	23–34	25–26	27	28	29	–[a]	30	31	32	33	34	35	36–72
	OsloCTM3–v2	1–2	3–5	6–9	10–12	13, 14	15–17	18–19	20–21	22–23	24	25–26	27	28	29	30–31	32	33	34	34–35	35	36–60

[a] There was no pressure in CAMchem, GEOSCHEM, and GOCART–v5 corresponding to the pressure range of 23–26, 13–15, and 23–26 kPa in CHASER_re1, respectively. The BC concentrations were calculated from the average of concentrations of two adjacent layers.



(a) (b)

Figure S5 Contributions of 20 emission perturbation in SAS to BC concentrations of Arctic in different latitude bands varies with altitude in **(a)** summer and **(b)** winter in 2010.