SUPPLEMENTAL MATERIAL

Impacts of global, regional, and sectoral black carbon emission reductions on surface air quality and human mortality

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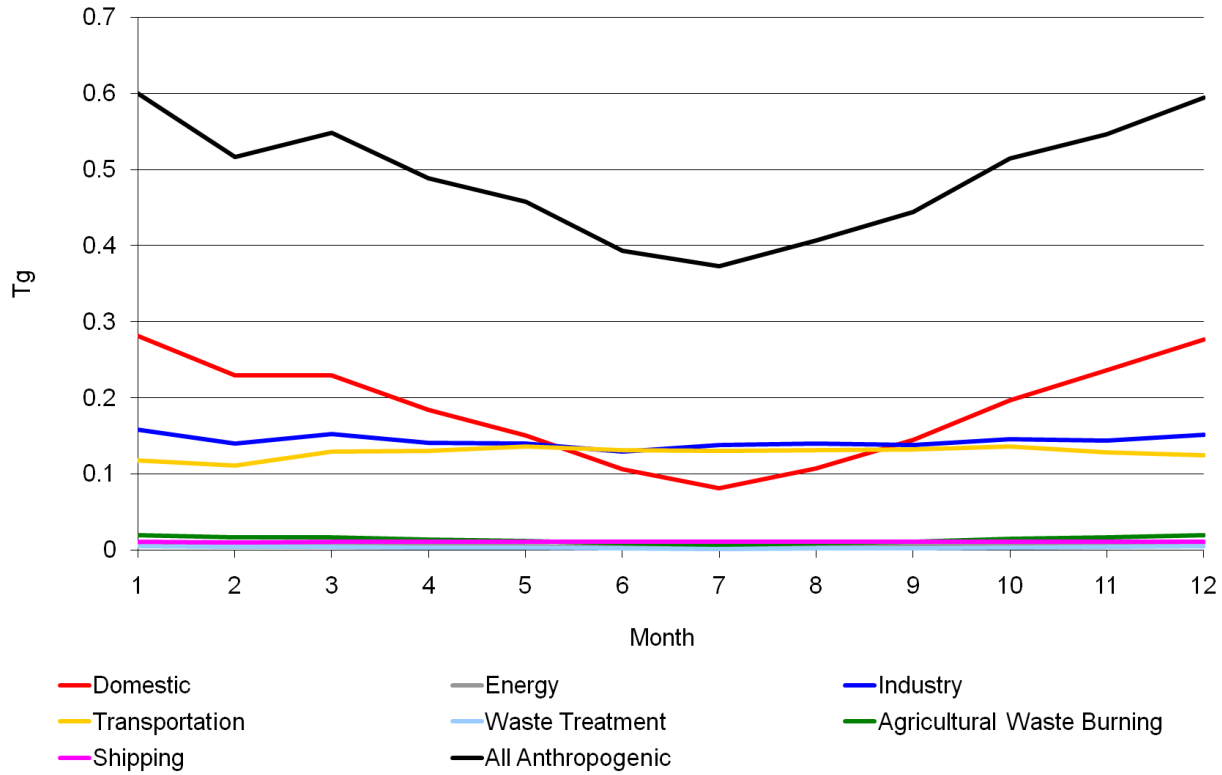


Fig. S1. Monthly variation of global BC emissions by sector, according to monthly variation of CO from RETRO inventory.

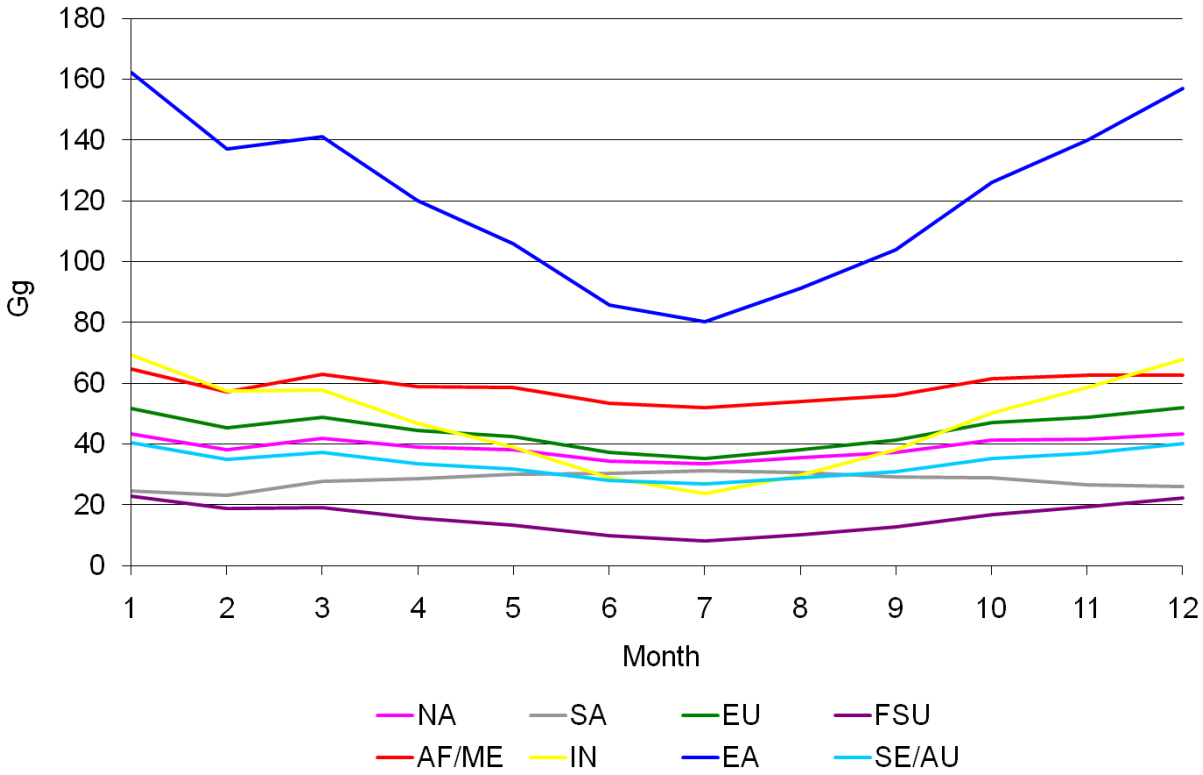


Fig. S2. Monthly anthropogenic BC emissions by region, according to monthly variation of CO from RETRO inventory.

Table S1. Total global emissions of relevant species for base case year 2002, in Tg(species)/year. NO_x ($NO+NO_2$) emissions are reported as NO.

Species	Emissions
BC	8.6
OC	41.2
NO_x	93.6
SO_2	149.5

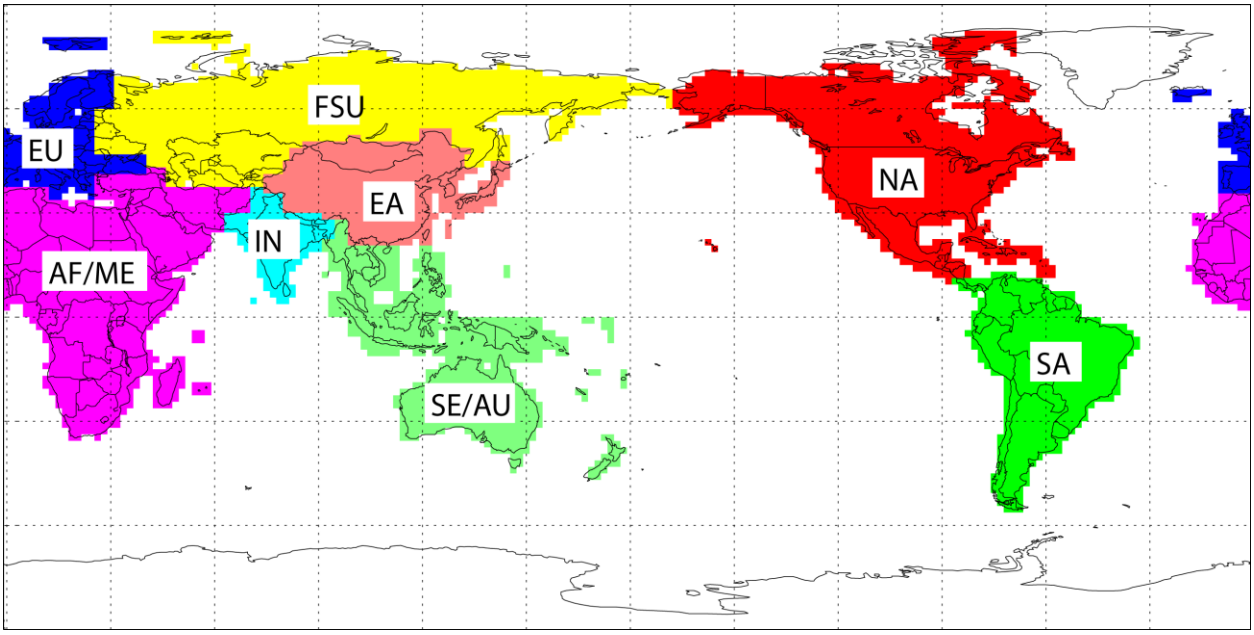


Fig. S3. Regional definitions, gridded to MOZART-4 grid.

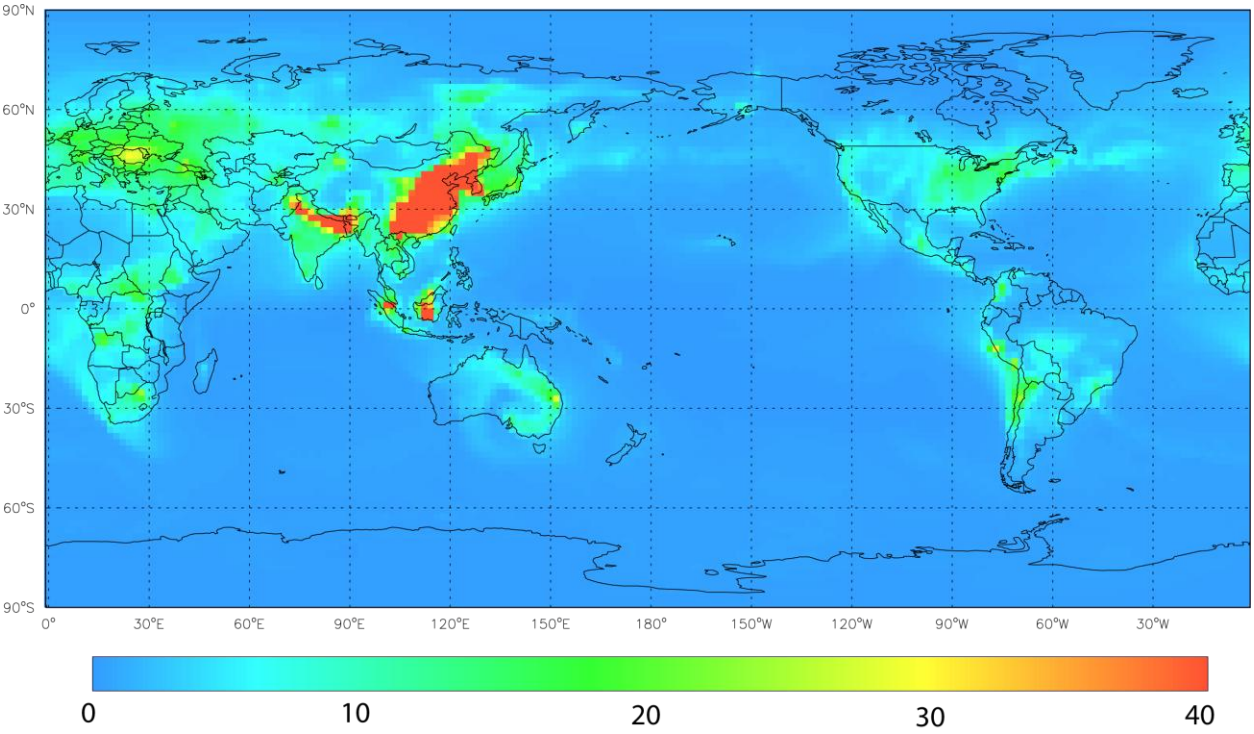


Fig. S4. Annual average concentration (μg/m^3) of total $PM_{2.5}$ for the 2002 base case

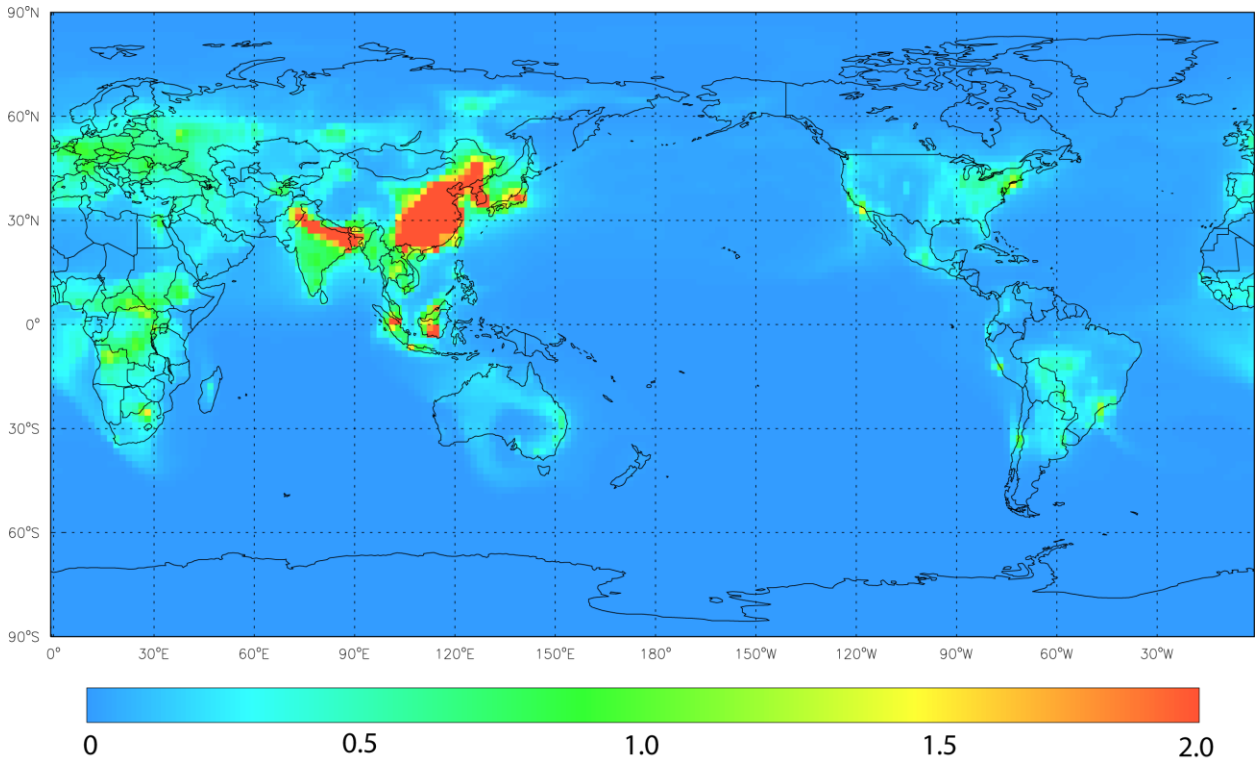


Fig. S5. As Fig. S4, but for BC

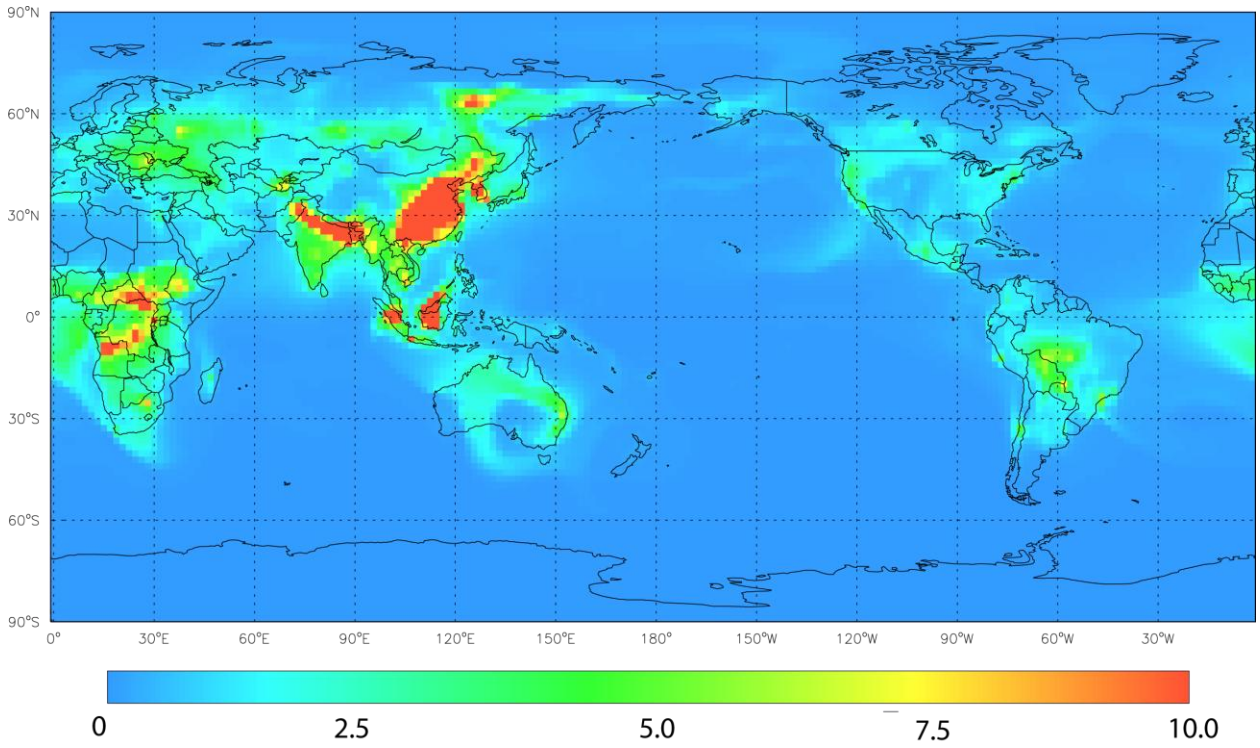


Fig. S6. As Fig. S4, but for OM (includes SOA)

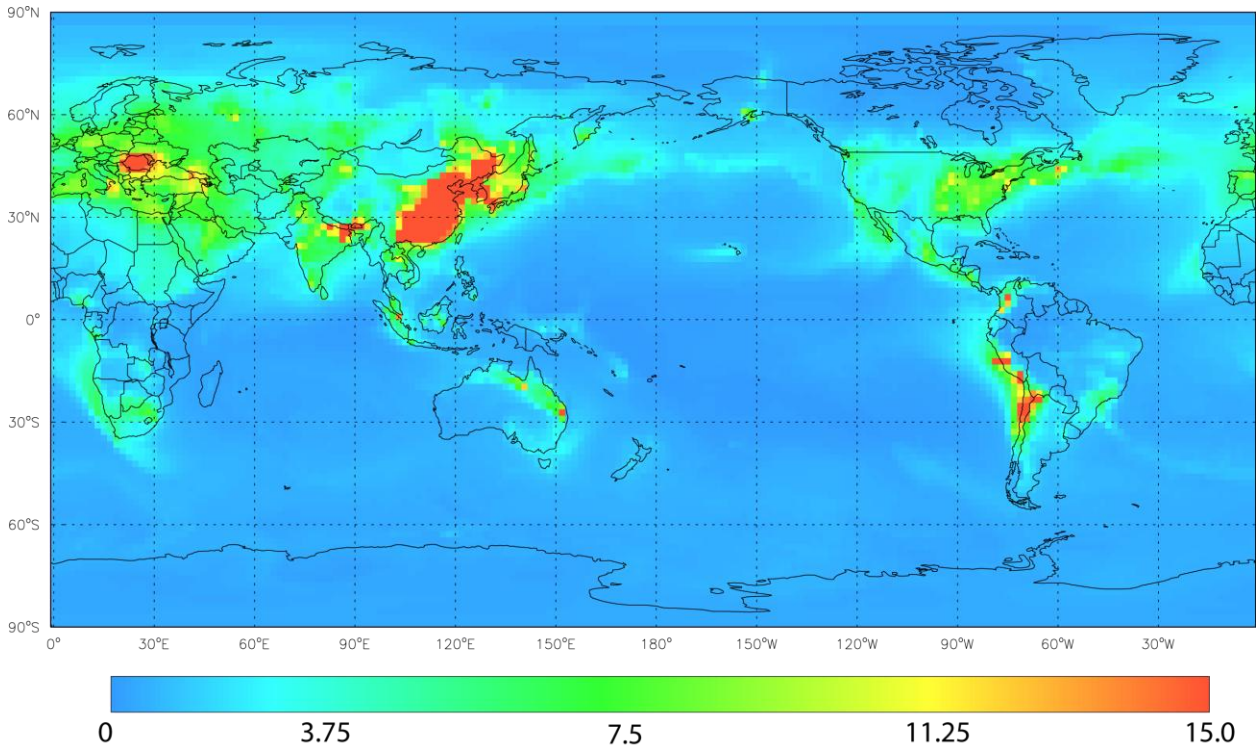


Fig. S7. As Fig. S4, but for SO_4

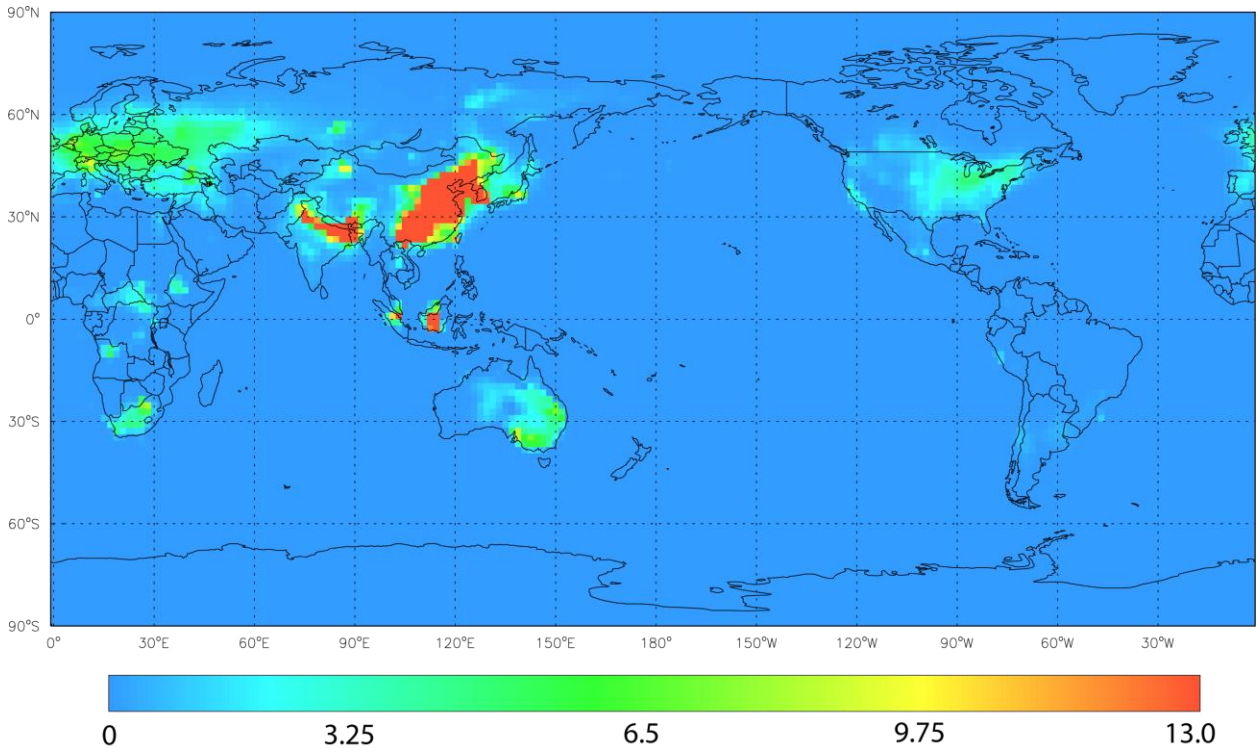
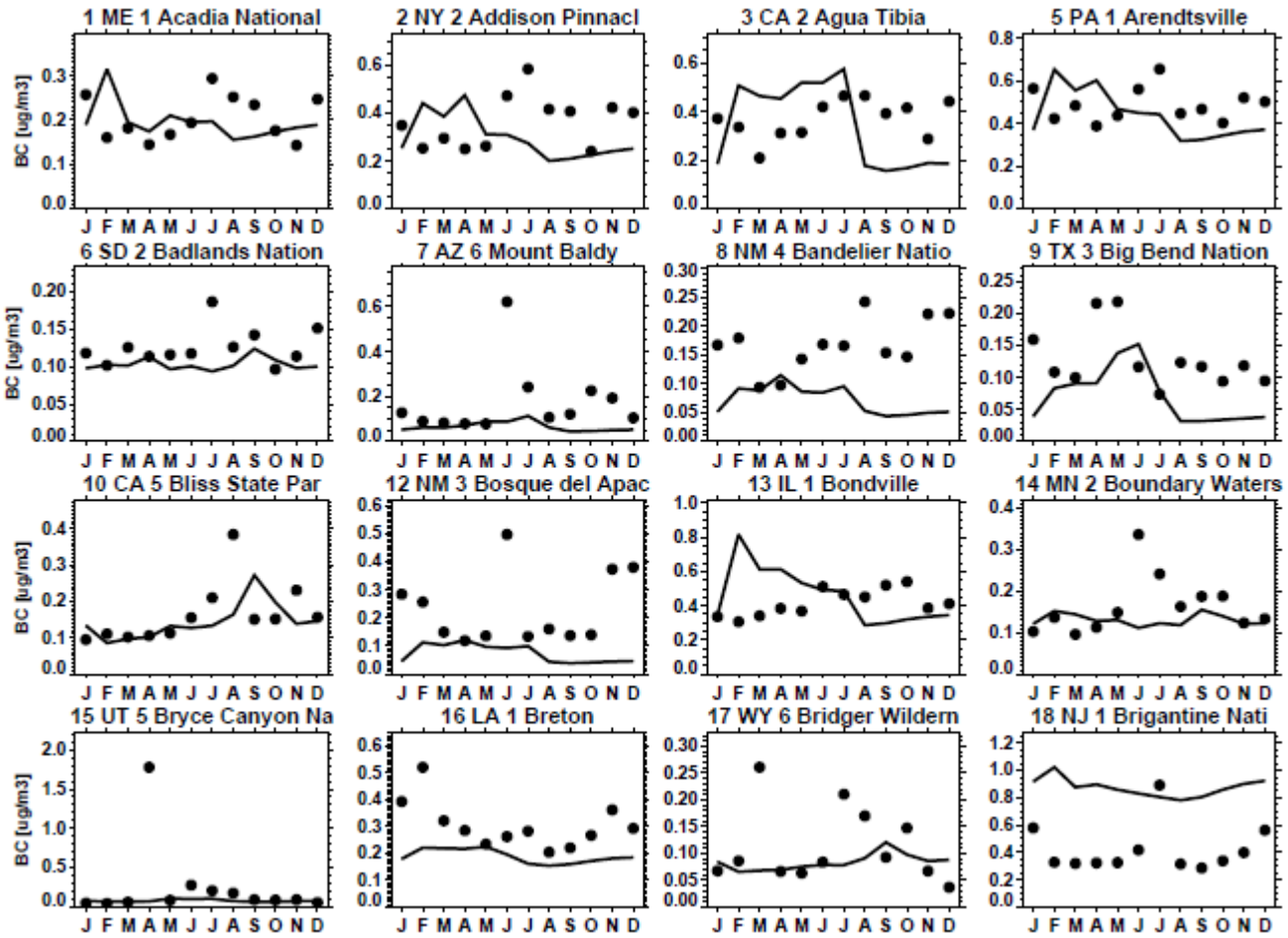


Fig. S8. As Fig. S4, but for NO_3

Table S2. Simulated simple and population-weighted regional average base case concentrations of BC, OM, SO_4, and NO_3 ($\mu g/m^3$). Total $PM_{2.5}$ values are given in Table 1.

	BC		OM		SO_4		NO_3	
Region	Simple Average	Population-weighted Average	Simple Average	Population-weighted Average	Simple Average	Population-weighted Average	Simple Average	Population-weighted Average
NA	0.11	0.36	0.76	1.54	2.26	5.07	0.41	1.32
SA	0.15	0.31	1.36	1.75	2.28	3.84	0.05	0.13
EU	0.36	0.54	1.41	1.86	5.86	7.20	2.14	3.79
FSU	0.17	0.45	1.64	3.27	3.31	6.11	0.74	2.47
AF/ME	0.26	0.39	2.09	2.99	2.68	3.31	0.30	0.53
IN	0.99	1.75	6.33	11.32	5.66	8.08	6.31	15.14
EA	1.28	3.46	5.61	14.35	10.45	21.70	10.65	30.64
SE/AU	0.23	0.66	2.19	4.81	1.62	3.06	0.78	1.02
World	0.10	1.46	0.68	7.42	1.52	9.39	0.45	11.43


1 ME 1 Acadia National
2 NY 2 Addison Pinnacl
3 CA 2 Agua Tibia
5 PA 1 Arendtsville
6 SD 2 Badlands Nation
7 AZ 6 Mount Baldy
8 NM 4 Bandelier Natio
9 TX 3 Big Bend Nation
10 CA 5 Bliss State Par
12 NM 3 Bosque del Apac
13 IL 1 Bondville
14 MN 2 Boundary Waters
15 UT 5 Bryce Canyon Na
16 LA 1 Breton
17 WY 6 Bridger Wildern
18 NJ 1 Brigantine Nati
BC [ug/m3]
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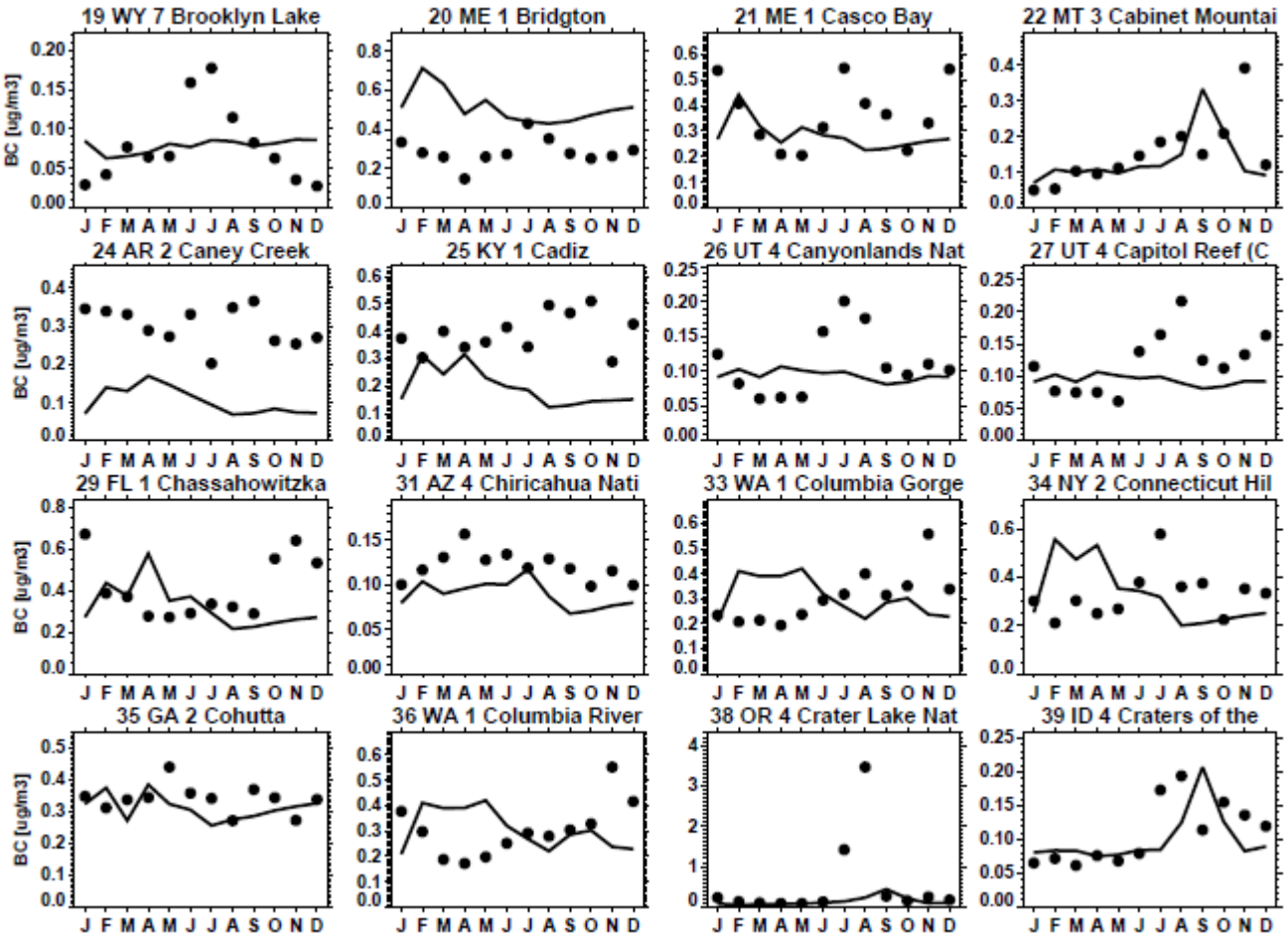
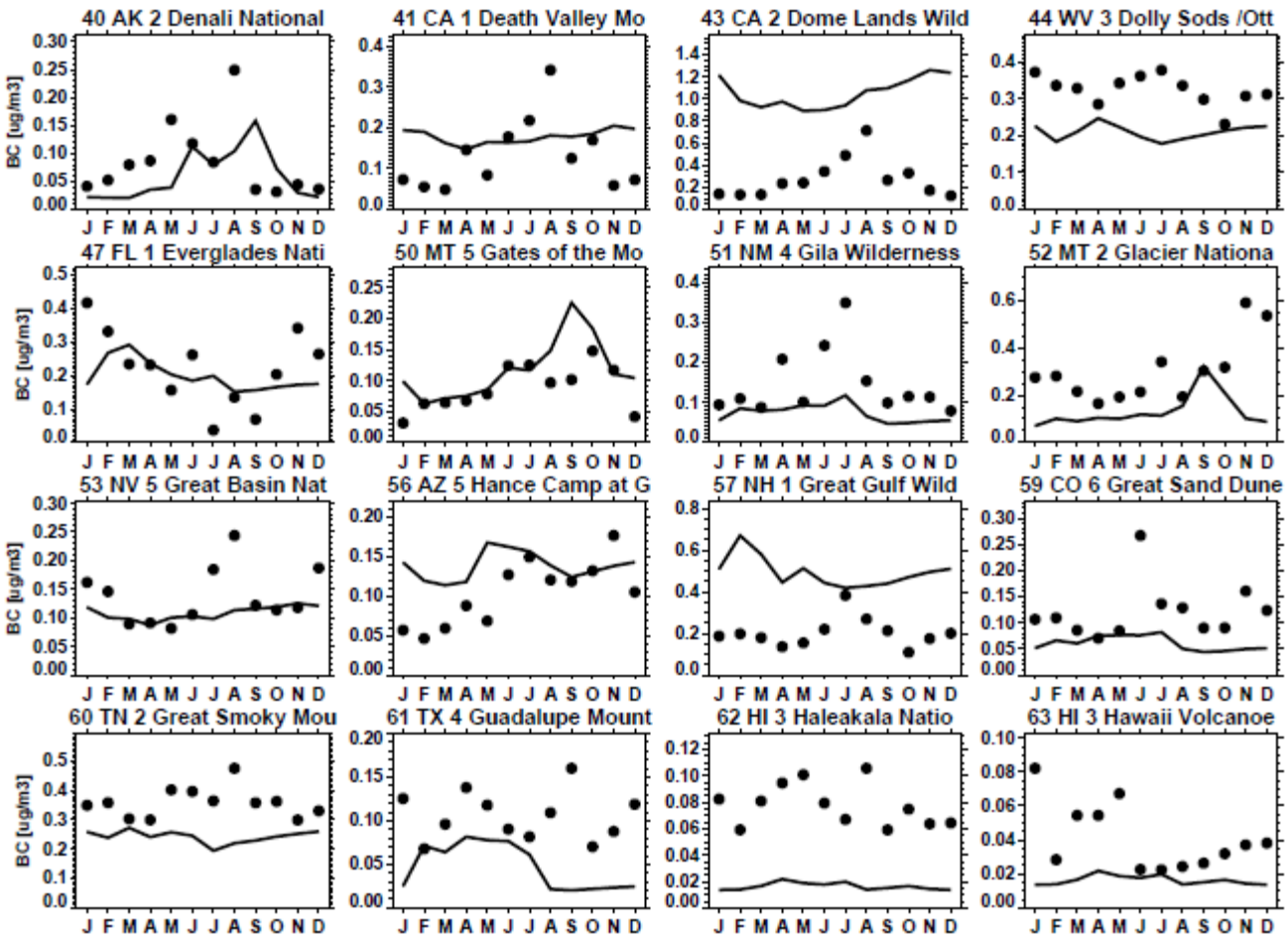
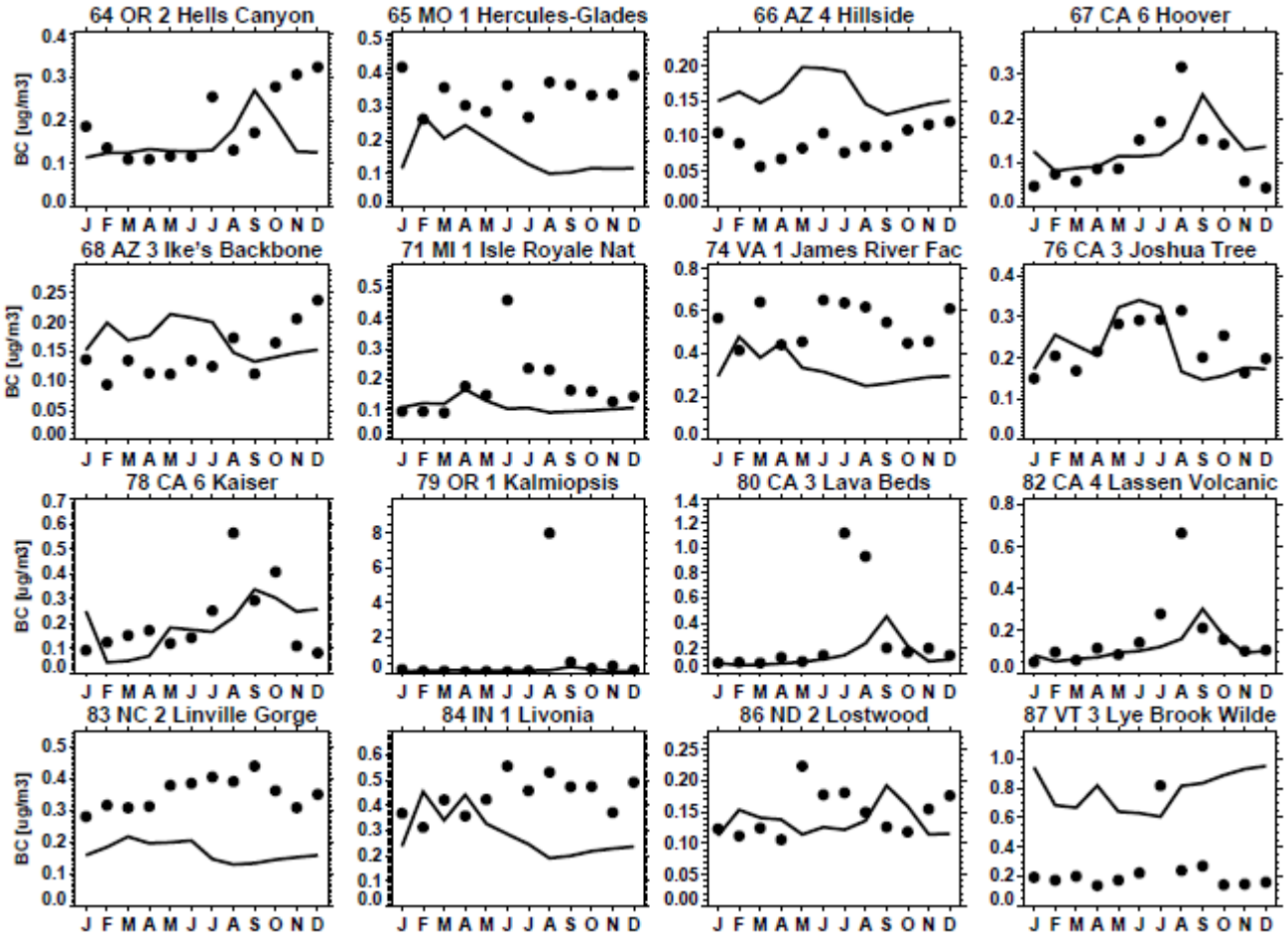
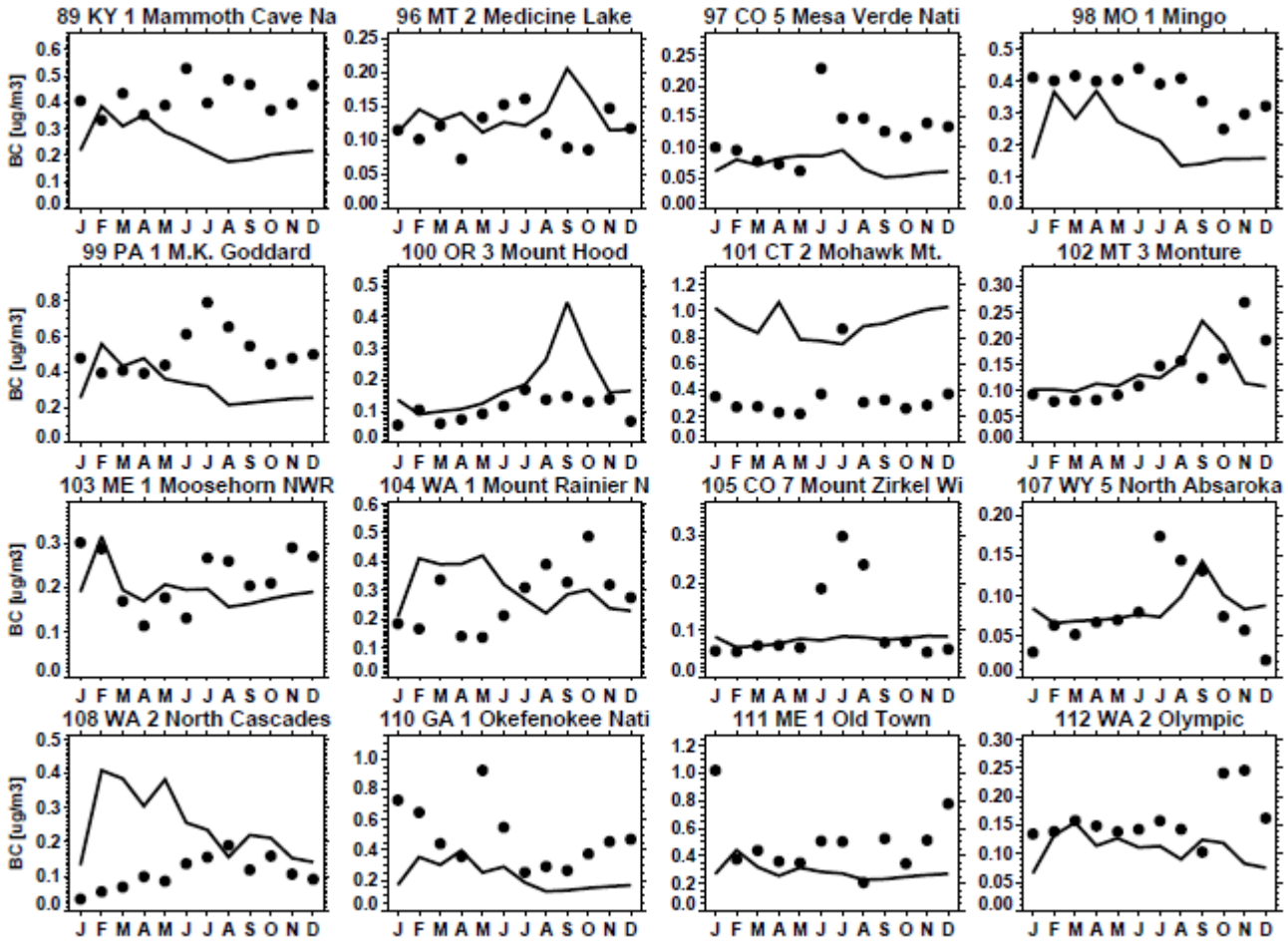

19 WY 7 Brooklyn Lake
20 ME 1 Bridgton
21 ME 1 Casco Bay
22 MT 3 Cabinet Mountai
24 AR 2 Caney Creek
25 KY 1 Cadiz
26 UT 4 Canyonlands Nat
27 UT 4 Capitol Reef (C
29 FL 1 Chassahowitzka
31 AZ 4 Chiricahua Nati
33 WA 1 Columbia Gorge
34 NY 2 Connecticut Hil
35 GA 2 Cohutta
36 WA 1 Columbia River
38 OR 4 Crater Lake Nat
39 ID 4 Craters of the
BC [ug/m3]
J F M A M J J A S O N D


40 AK 2 Denali National
41 CA 1 Death Valley Mo
43 CA 2 Dome Lands Wild
44 WV 3 Dolly Sods /Ott
47 FL 1 Everglades Nati
50 MT 5 Gates of the Mo
51 NM 4 Gila Wilderness
52 MT 2 Glacier Nationa
53 NV 5 Great Basin Nat
56 AZ 5 Hance Camp at G
57 NH 1 Great Gulf Wild
59 CO 6 Great Sand Dune
60 TN 2 Great Smoky Mou
61 TX 4 Guadalupe Mount
62 HI 3 Haleakala Natio
63 HI 3 Hawaii Volcanoe
BC [ug/m3]
J F M A M J J A S O N D


64 OR 2 Hells Canyon
65 MO 1 Hercules-Glades
66 AZ 4 Hillside
67 CA 6 Hoover
68 AZ 3 Ike's Backbone
71 MI 1 Isle Royale Nat
74 VA 1 James River Fac
76 CA 3 Joshua Tree
78 CA 6 Kaiser
79 OR 1 Kalmiopsis
80 CA 3 Lava Beds
82 CA 4 Lassen Volcanic
83 NC 2 Linville Gorge
84 IN 1 Livonia
86 ND 2 Lostwood
87 VT 3 Lye Brook Wilde
BC [ug/m3]
J F M A M J J A S O N D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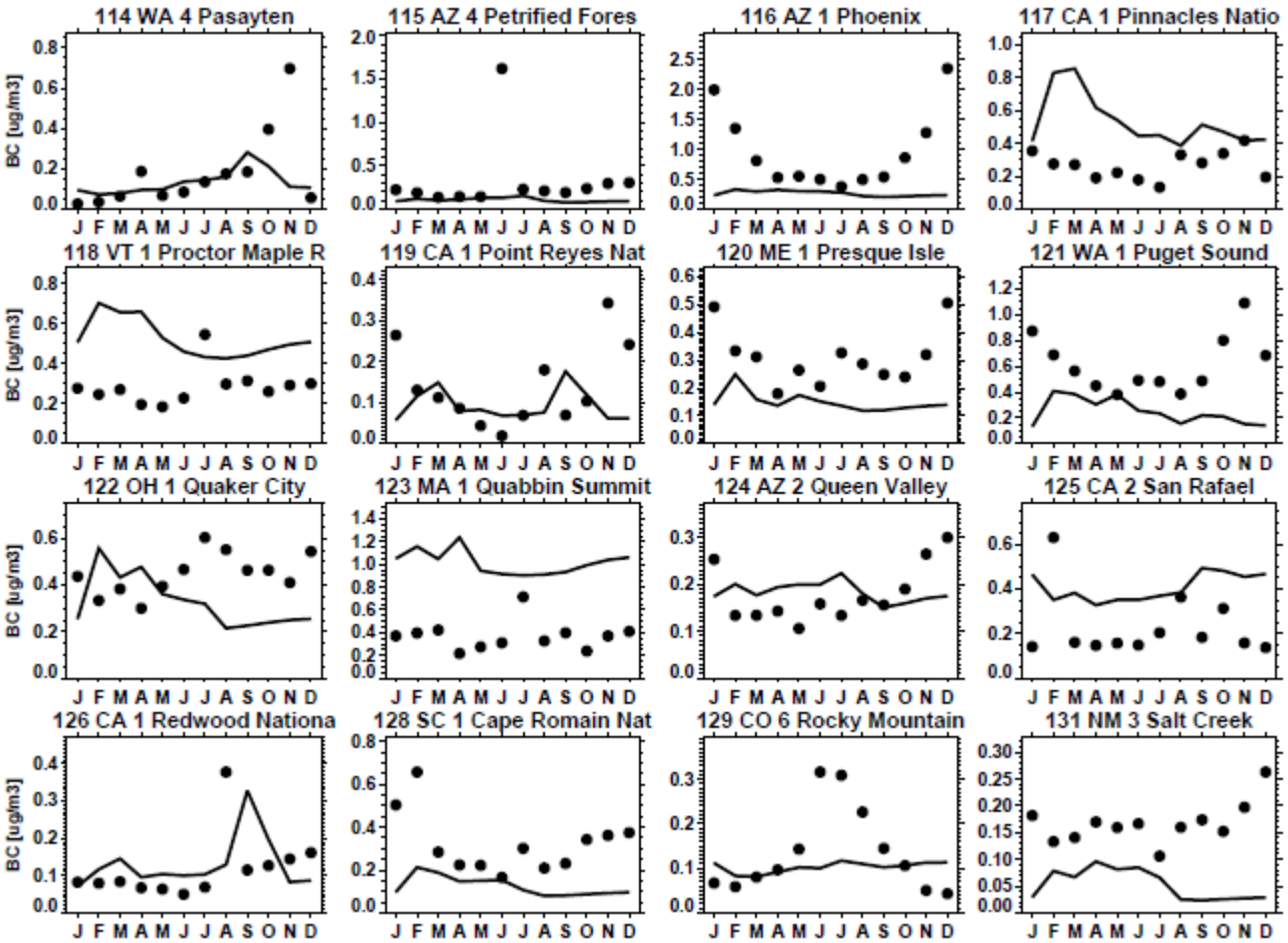
96 MT 2 Medicine Lake
97 CO 5 Mesa Verde Nati
98 MO 1 Mingo
99 PA 1 M.K. Goddard
100 OR 3 Mount Hood
101 CT 2 Mohawk Mt.
102 MT 3 Monture
103 ME 1 Moosehorn NWR
104 WA 1 Mount Rainier N
105 CO 7 Mount Zirkel Wi
107 WY 5 North Absaroka
108 WA 2 North Cascades
110 GA 1 Okefenokee Nati
111 ME 1 Old Town
112 WA 2 Olympic
BC [ug/m3]
J F M A M J J A S O N D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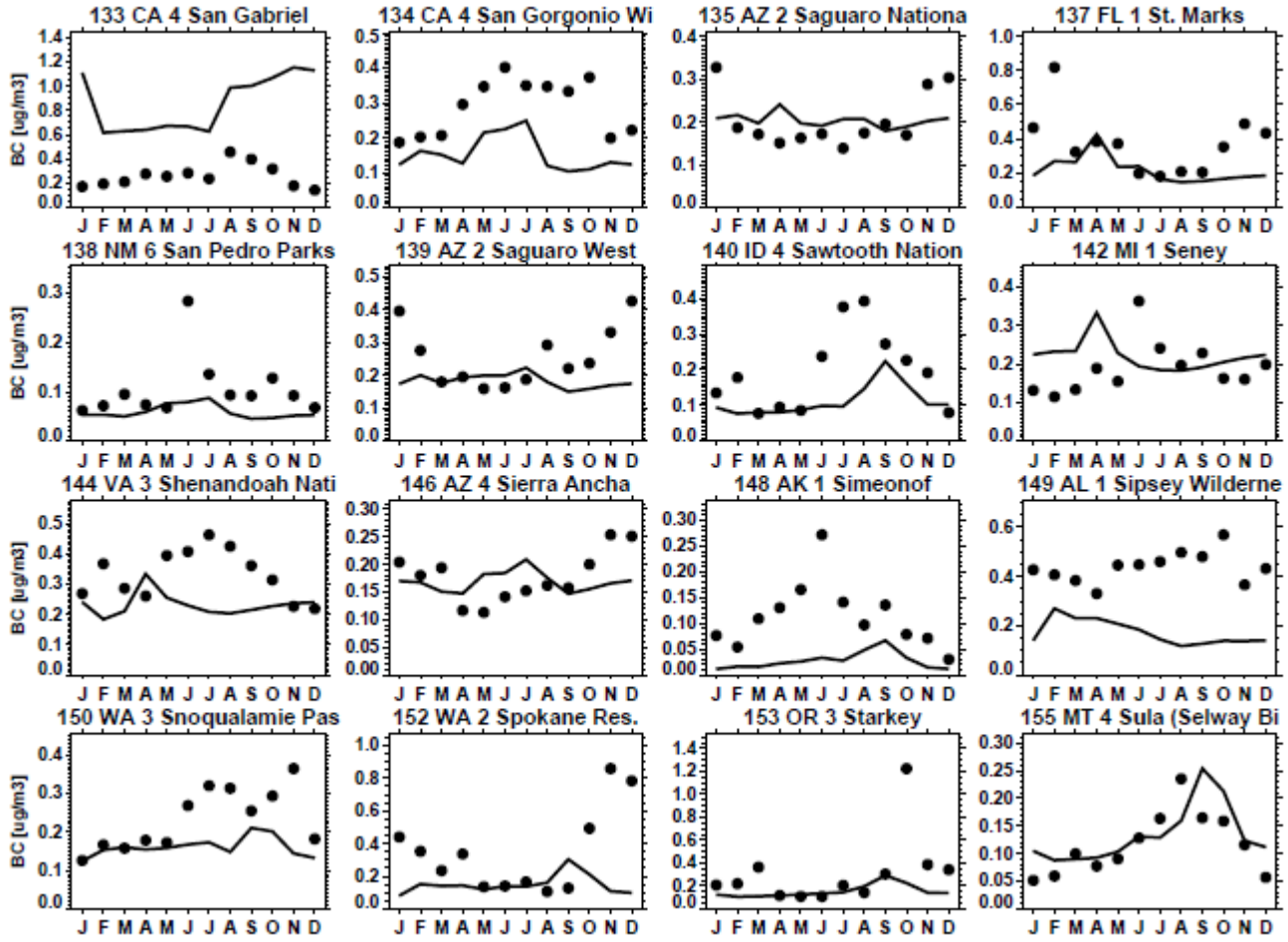
115 AZ 4 Petrified Fores
116 AZ 1 Phoenix
117 CA 1 Pinnacles Natio
118 VT 1 Proctor Maple R
119 CA 1 Point Reyes Nat
120 ME 1 Presque Isle
121 WA 1 Puget Sound
122 OH 1 Quaker City
123 MA 1 Quabbin Summit
124 AZ 2 Queen Valley
125 CA 2 San Rafael
126 CA 1 Redwood Nationa
128 SC 1 Cape Romain Nat
129 CO 6 Rocky Mountain
131 NM 3 Salt Creek
BC [ug/m3]
J F M A M J J A S O N D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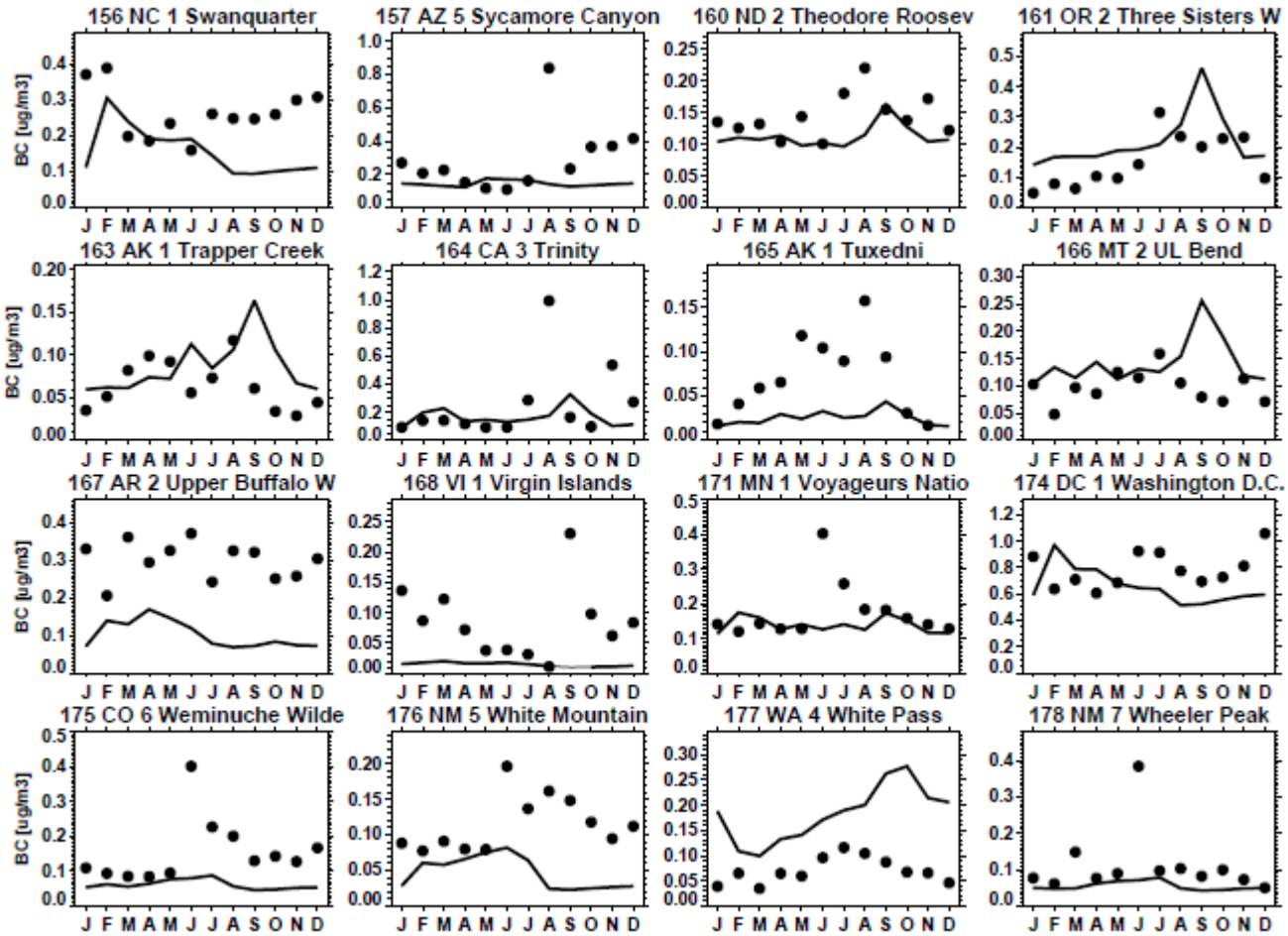
134 CA 4 San Gorgonio Wi
135 AZ 2 Saguaro Nationa
137 FL 1 St. Marks
138 NM 6 San Pedro Parks
139 AZ 2 Saguaro West
140 ID 4 Sawtooth Nation
142 MI 1 Seney
144 VA 3 Shenandoah Nati
146 AZ 4 Sierra Ancha
148 AK 1 Simeonof
149 AL 1 Sipsey Wilderne
150 WA 3 Snoqualamie Pas
152 WA 2 Spokane Res.
153 OR 3 Starkey
155 MT 4 Sula (Selway Bi
BC [ug/m3]
J F M A M J J A S O N D


156 NC 1 Swanquarter
157 AZ 5 Sycamore Canyon
160 ND 2 Theodore Roosev
161 OR 2 Three Sisters W
163 AK 1 Trapper Creek
164 CA 3 Trinity
165 AK 1 Tuxedni
166 MT 2 UL Bend
167 AR 2 Upper Buffalo W
168 VI 1 Virgin Islands
171 MN 1 Voyageurs Natio
174 DC 1 Washington D.C.
175 CO 6 Weminuche Wilde
176 NM 5 White Mountain
177 WA 4 White Pass
178 NM 7 Wheeler Peak
BC [ug/m3]
J F M A M J J A S O N D

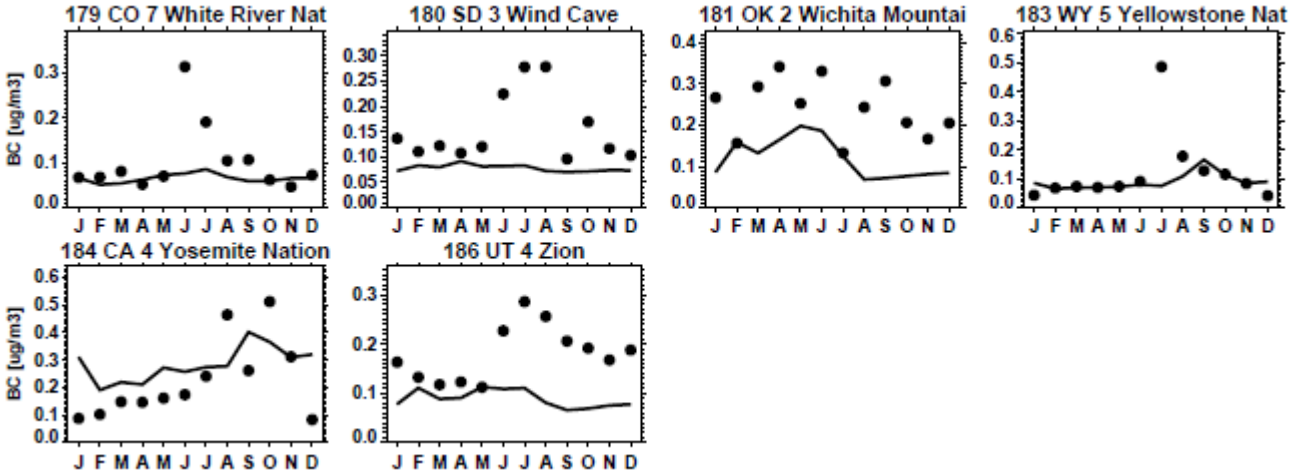


Figure S9. Comparison of simulated (solid lines) monthly average surface BC concentrations (μg/m^3) with the IMPROVE surface monitoring network (dots) for remote locations in the US (average of 2002 and 2003). Station identifying information can be found at http://vista.cira.colostate.edu/IMPROVE/.

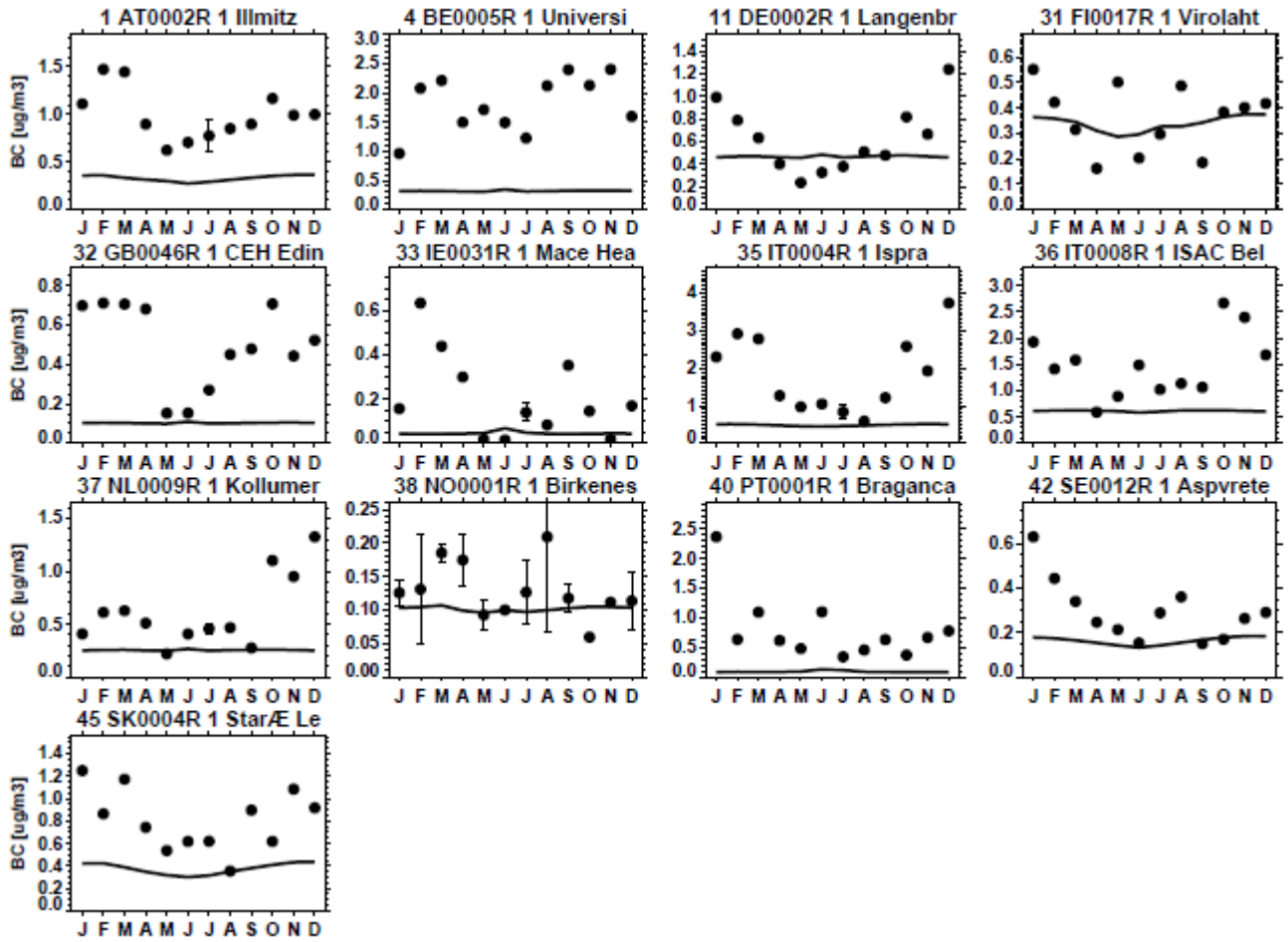


Figure S10. Comparison of simulated (solid lines) monthly average surface BC concentrations (μg/m^3) with observations from the EMEP surface monitoring network (dots) for remote locations in Europe (average for July 2002 to June 2003). Station identifying information can be found at http://www.emep.int/.

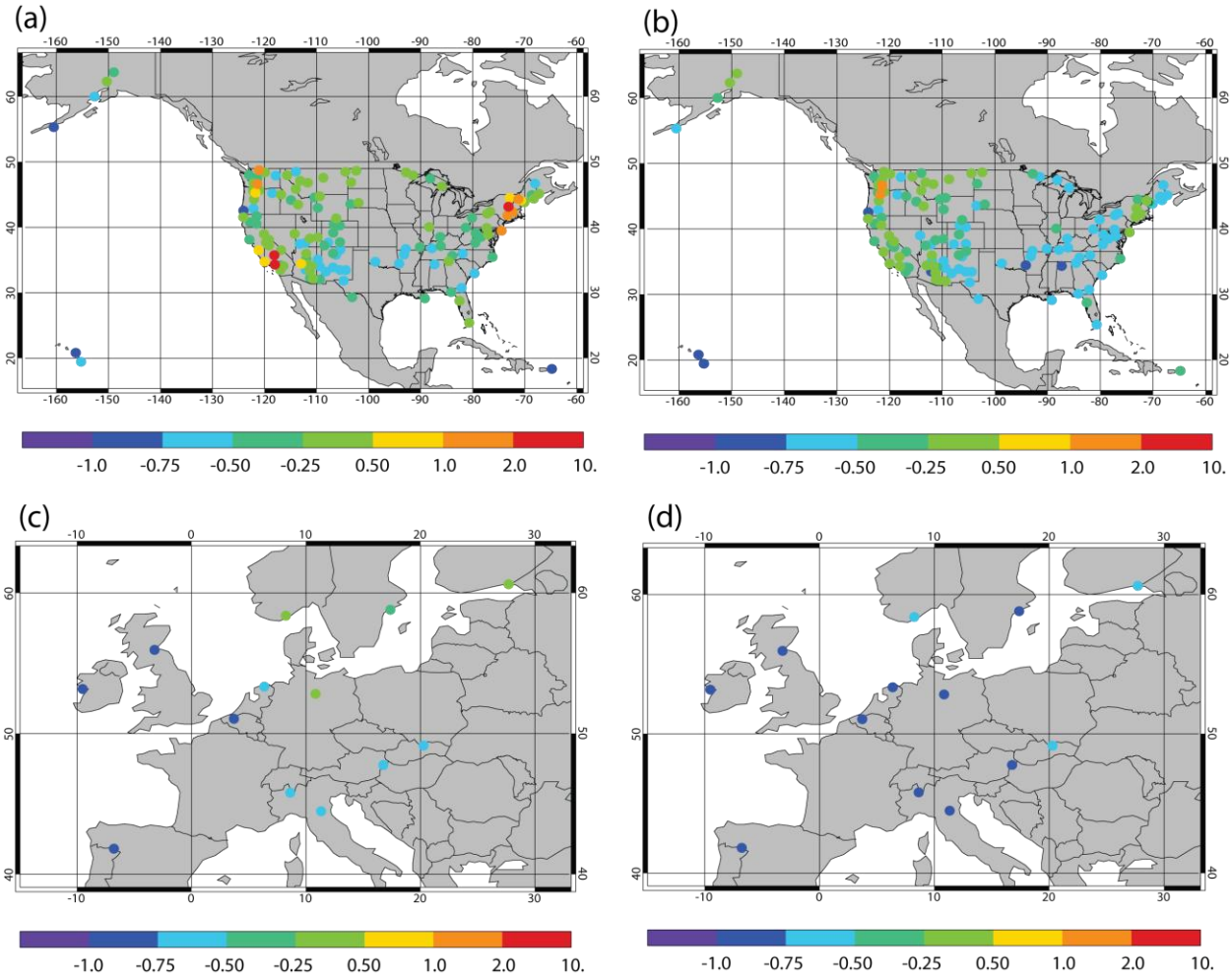


Fig. S11. As Fig. 3, but plotted on a spatial map to show a comparison of modeled and measured concentrations [(modeled-observed)/observed] in μg/m^3.

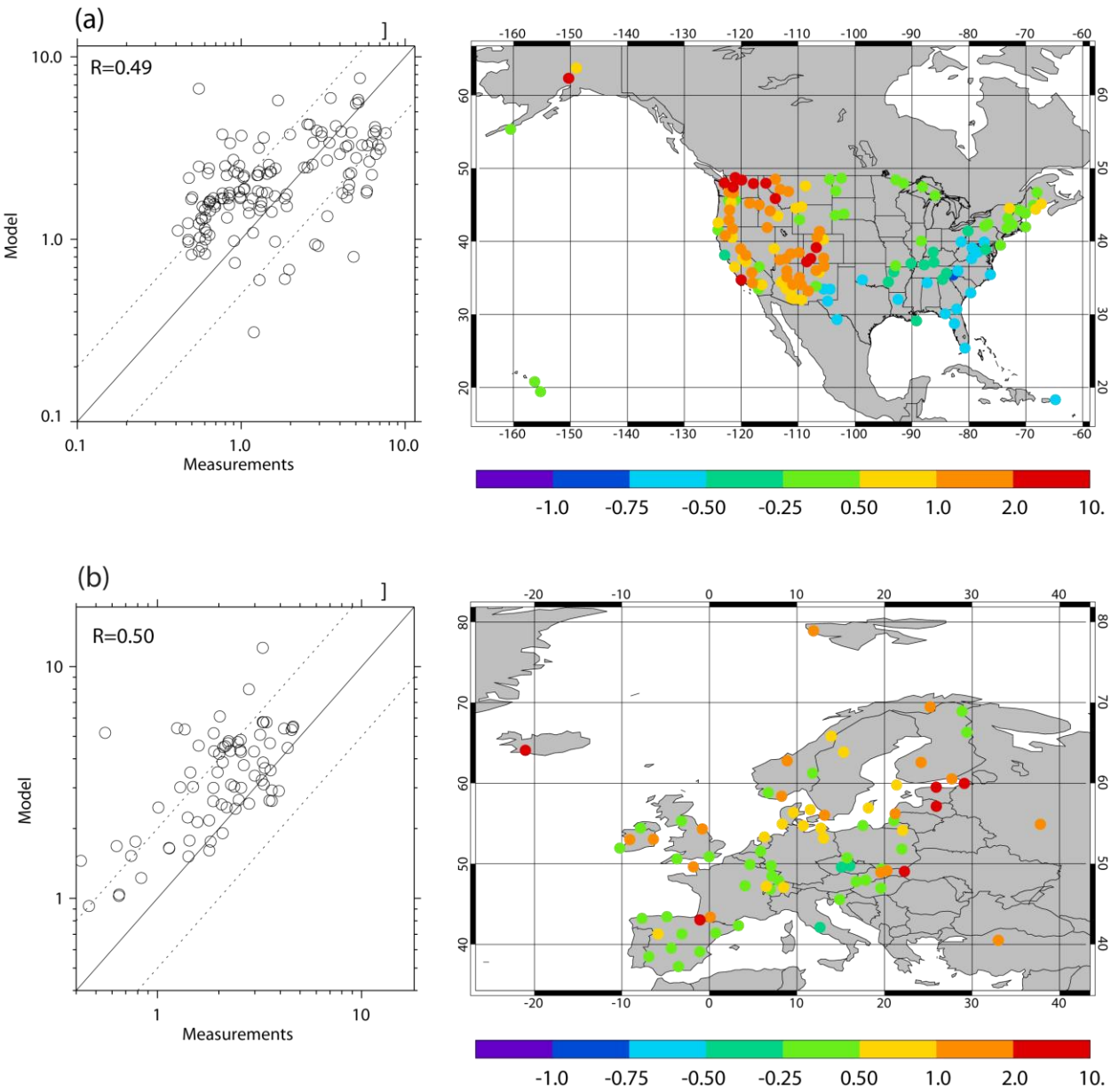


Fig. S12. Comparison of simulated annual average surface SO_4 concentrations with the IMPROVE surface monitoring network for remote locations in the United States and with the EMEP surface monitoring network for Europe (average 2002-2003). The panels on the right show a comparison of modeled and measured concentrations [(modeled-observed)/observed] in $\mu g/m^3$.

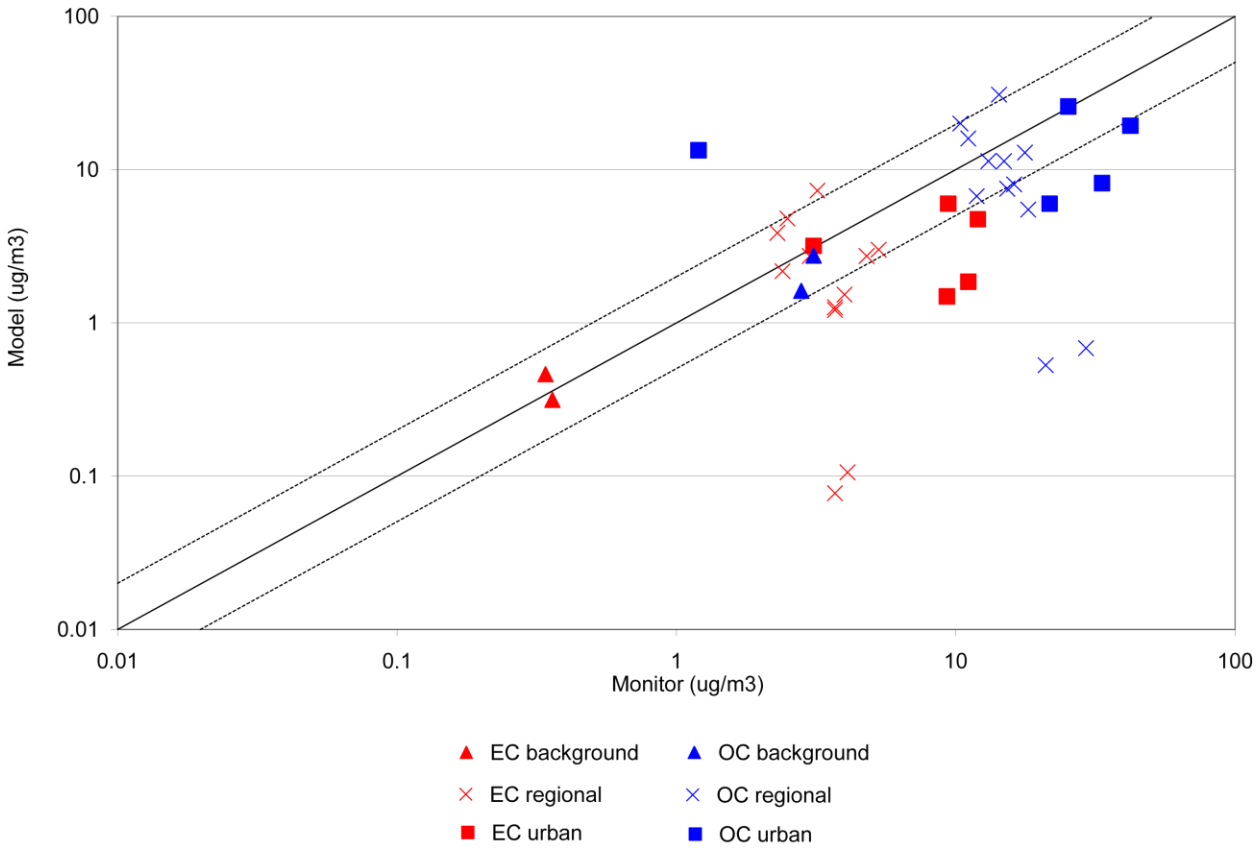


Fig. S13. Comparison of modeled annual average (2002) BC and OC with observed annual average EC and OC at 15 sites in China in 2006 (Zhang et al., 2009).

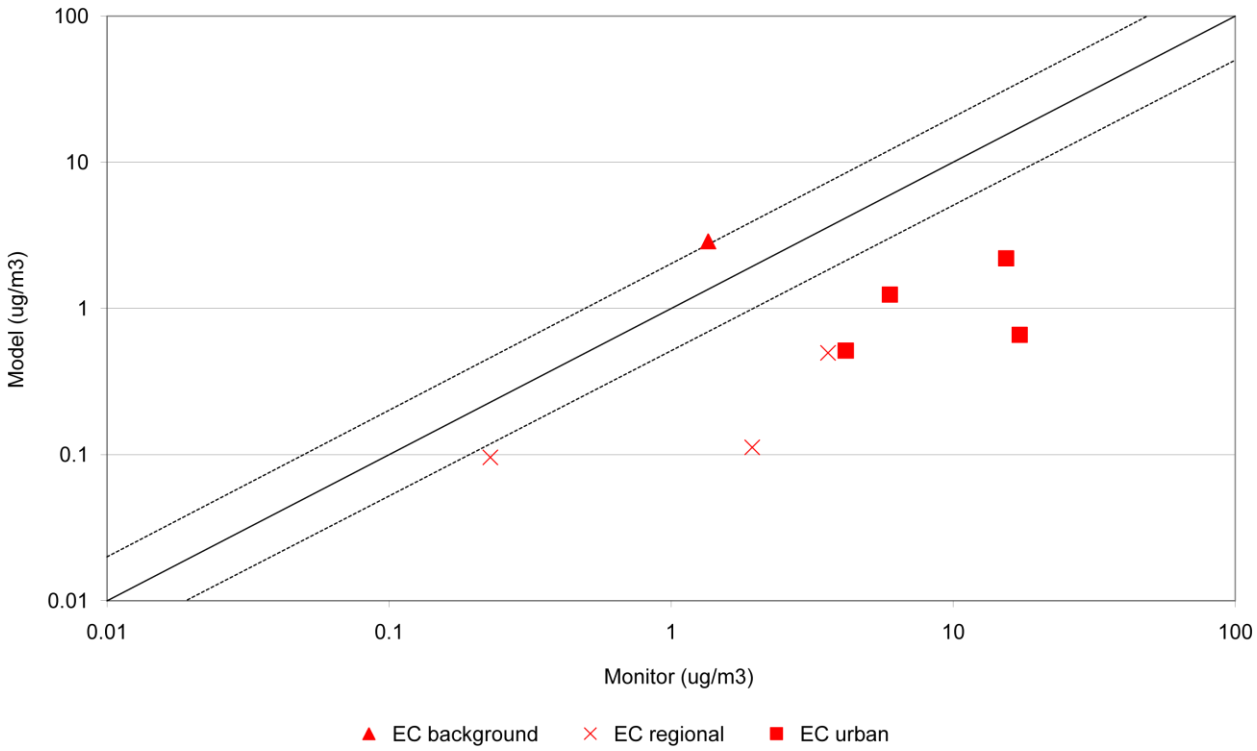


Fig. S14. Comparison of modeled annual average BC (2002) with observed EC in India for the pre-monsoon season (average January-May) at eight sites in India in 2006 (Beegum et al., 2009).

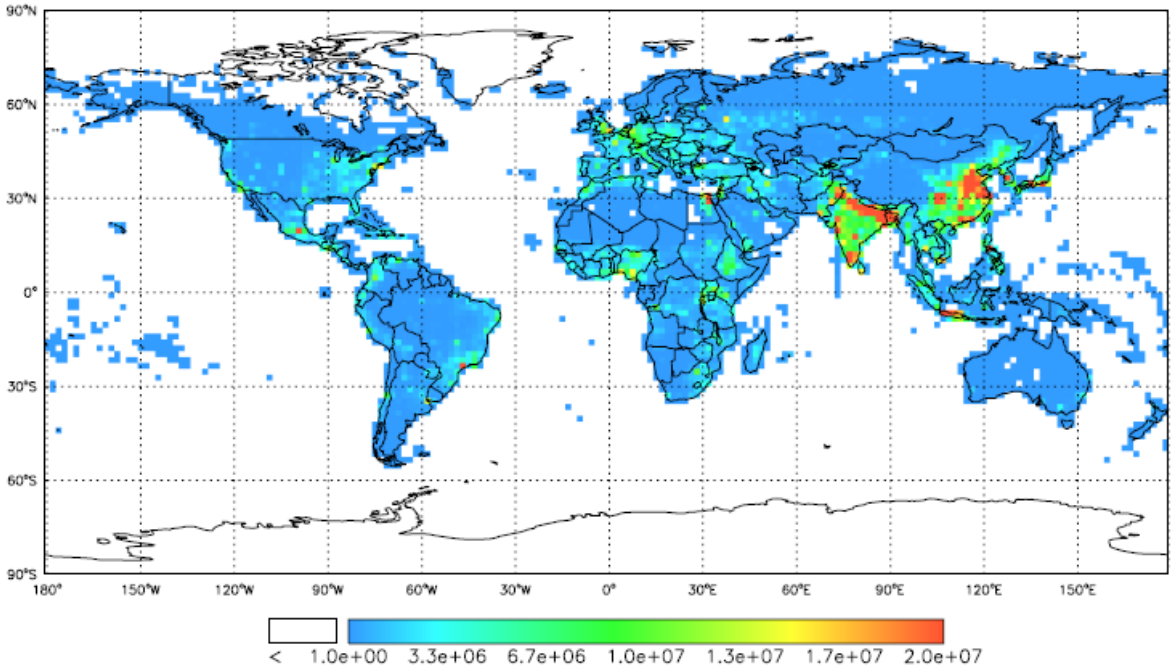


Fig. S15. 2006 population from Landscan database (Oak Ridge National Laboratory, 2008) aggregated to MOZART-4 grid.

Table S3. Population aged 30 and older, baseline total (for all population), cardiopulmonary (for the population ≥30), and lung cancer (for the population ≥30) mortality rates, and simulated simple and population-weighted average $PM_{2.5}$ concentrations ($\mu g/m^3$) for the 2002 base case, for each region.

Region	Population 30+	Baseline Mortality Rates (% per year) All-cause	Cardio-pulmonary (30+)	Lung Cancer (30+)	Base Case $PM_{2.5}$ Concentration Range ($\mu g/m^3$)
NA	2.70E+08	0.723	0.488	0.072	0.32 - 17.82
SA	1.50E+08	0.615	0.500	0.024	0.64 - 28.63
EU	3.46E+08	1.000	0.735	0.061	1.08 - 29.87
FSU	1.66E+08	1.514	1.421	0.055	0.57 - 27.49
AF/ME	3.59E+08	1.206	0.746	0.014	0.40 - 23.71
IN	5.87E+08	0.919	0.835	0.026	1.69 - 185.36
EA	8.03E+08	0.741	0.679	0.046	2.26 - 233.65
SE/AU	2.61E+08	0.599	0.490	0.040	0.11 - 86.89
World	2.94E+09	0.858	0.676	0.038	0.10 - 233.65

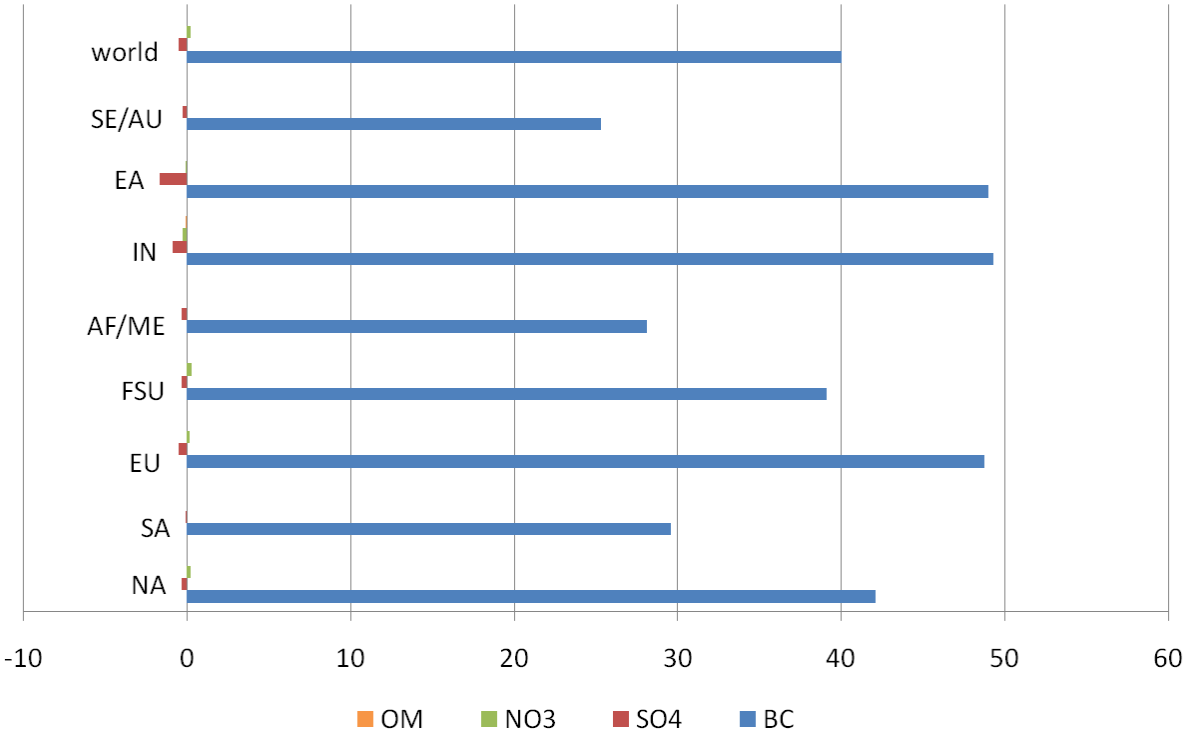


Fig. S16. Percentage reduction in annual average concentrations (ng/m^3) of $PM_{2.5}$ species for halving global anthropogenic BC emissions relative to the base case. Negative values indicate increases.

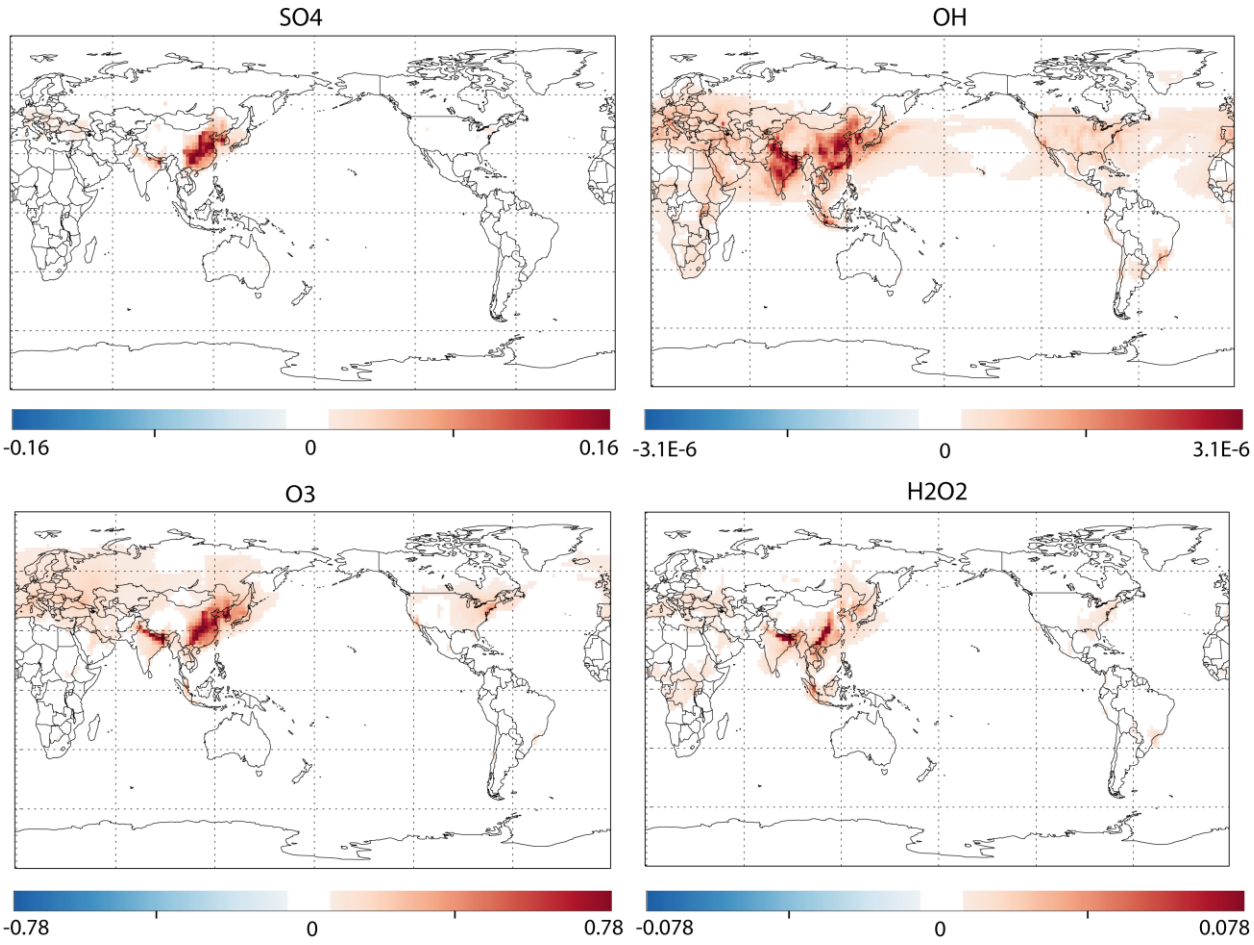


Fig. S17. Change in annual average surface SO_4, OH, O_3, and H_2O_2 concentrations (ppb) for halving global anthropogenic BC emissions relative to the base case. Negative values indicate increases.

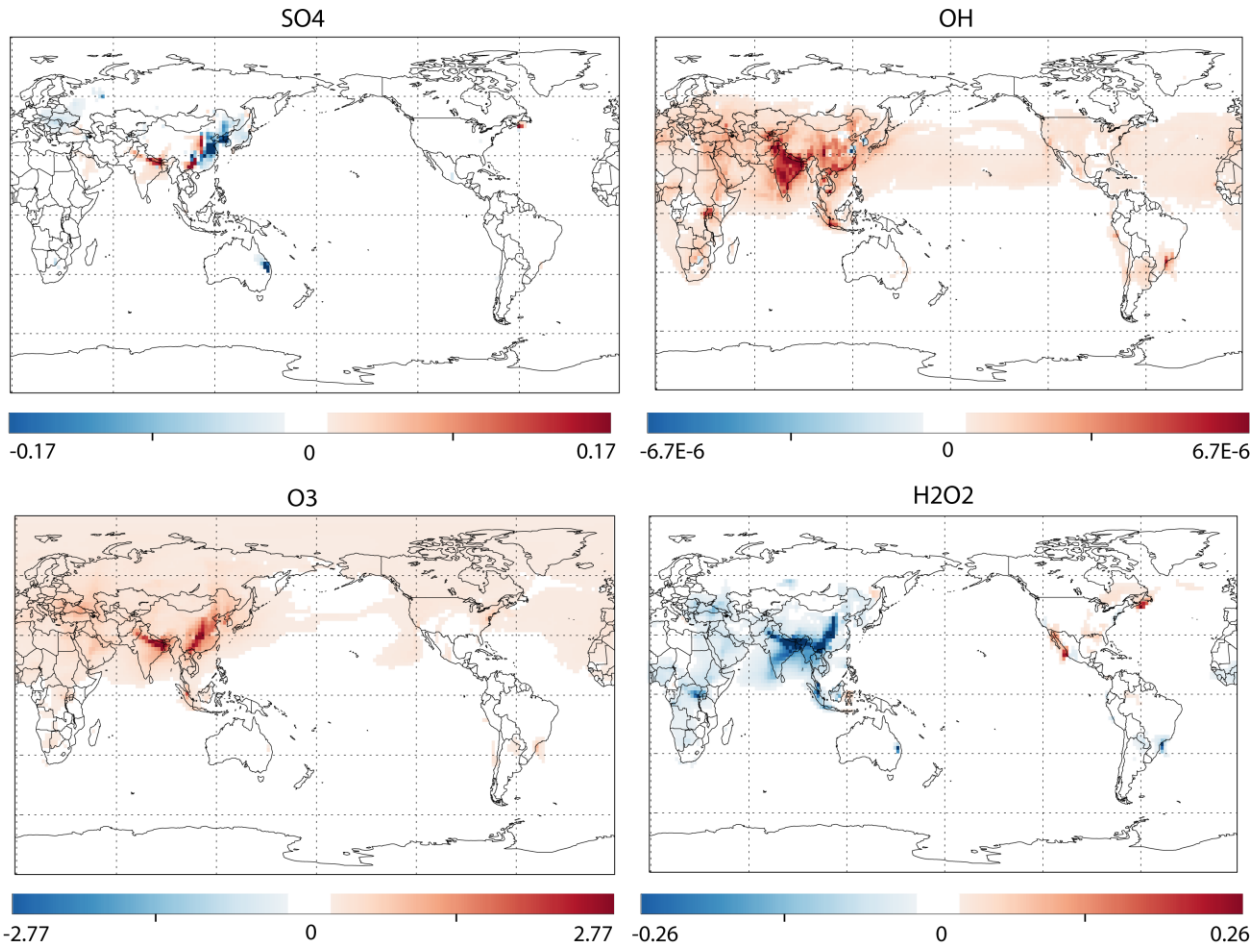


Fig. S18. As Fig. S17 but for halving global anthropogenic BC+OC emissions.

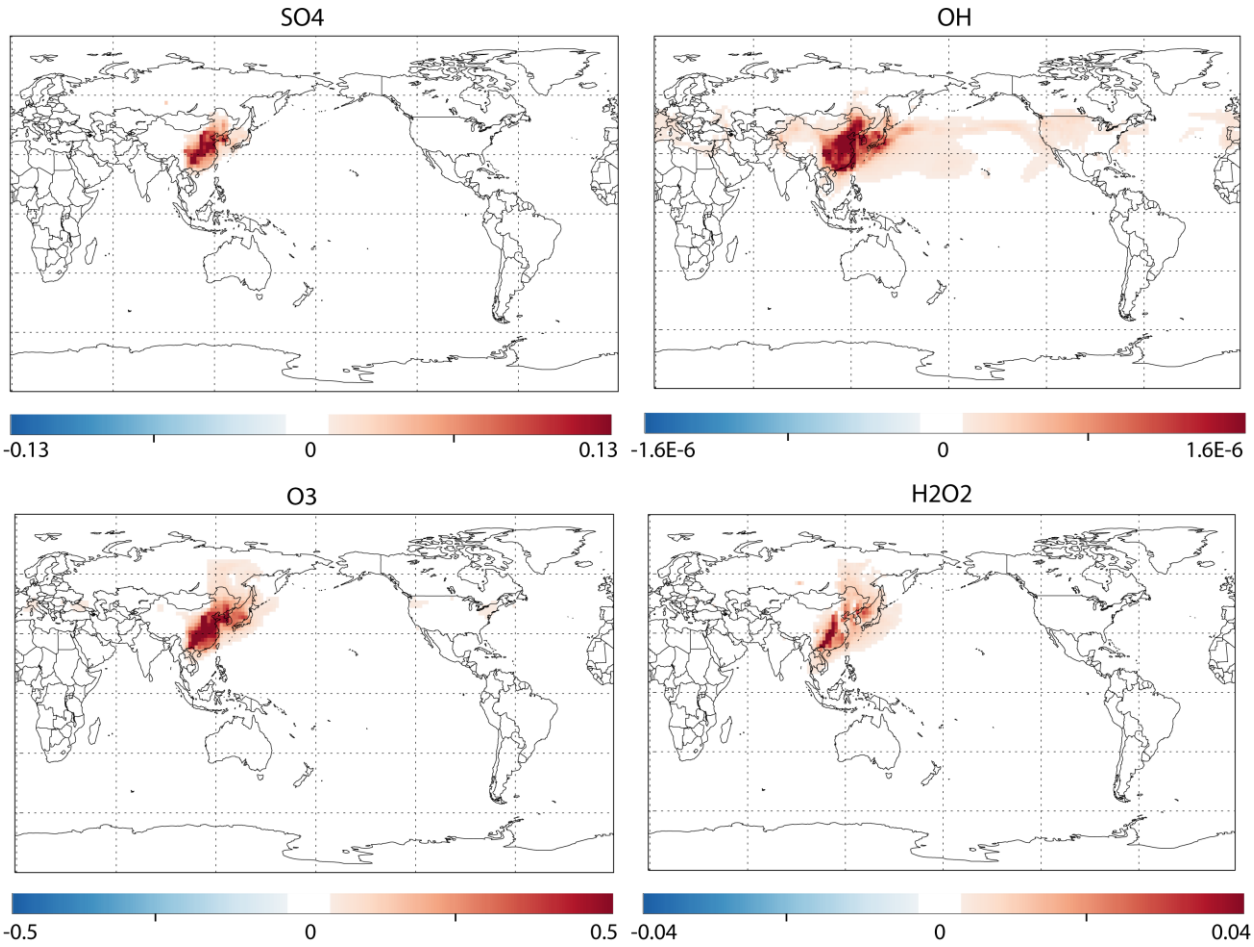


Fig. S19. As Fig. S17 but for halving anthropogenic BC emissions in EA only.

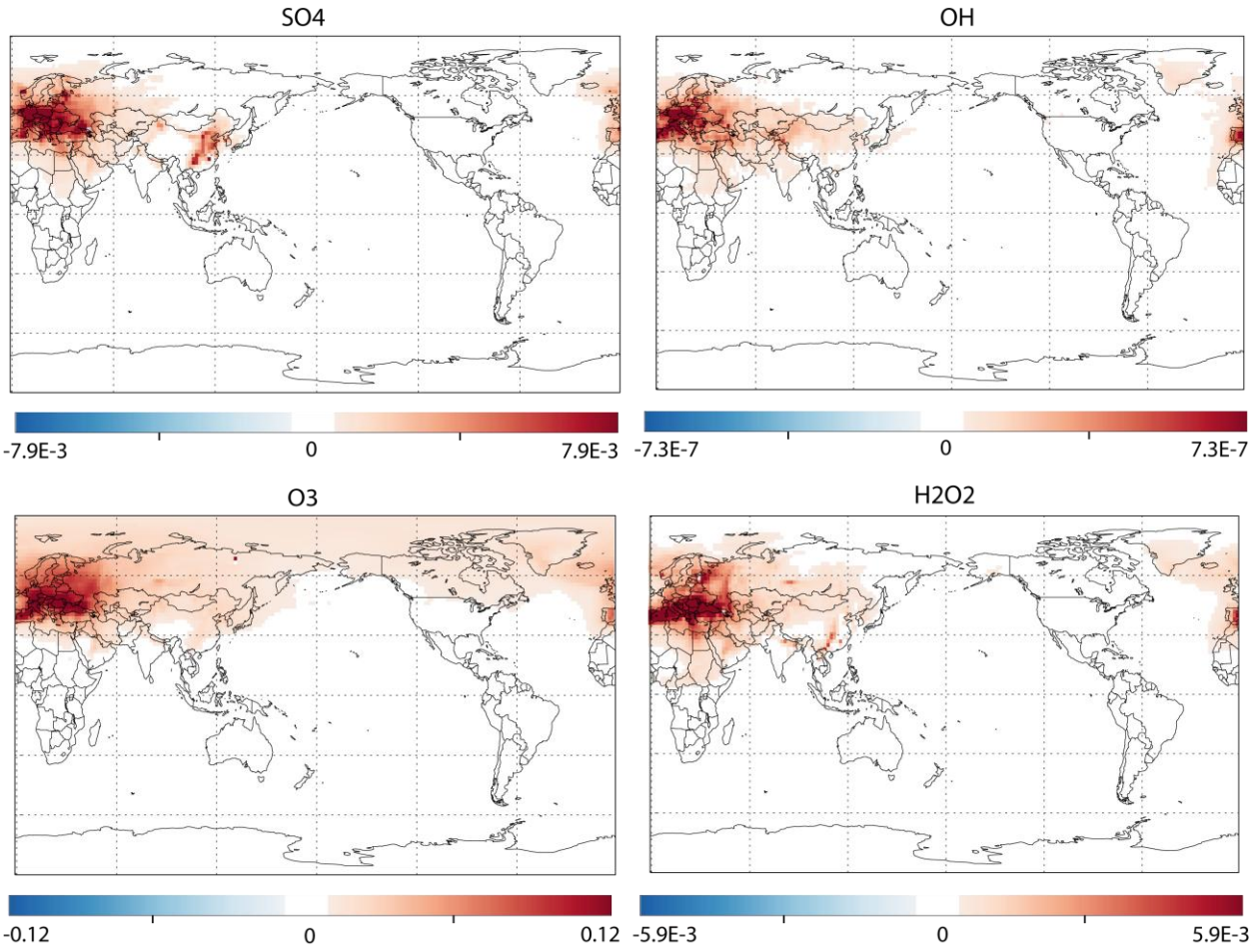


Fig. S20. As Fig. S17 but for halving anthropogenic BC emissions in EU only.

To isolate the impact of emissions in the United States (US), we compare the impact of halving BC emissions in the entire North America region (includes Canada and Mexico) versus halving emissions in the US only. Halving NA emissions reduces $PM_{2.5}$ in that region by 151 ng/m^3 and avoids 4,000 (95% CI, 3,000-5,000) annual premature deaths (12 per Gg BC reduced), 91% of which occur within the US. Compared with halving BC emissions in the US only, halving all NA emissions causes 12% more avoided deaths in NA and 1.6% more in the US, mostly in the Northeast and California near national borders (Fig. S21).

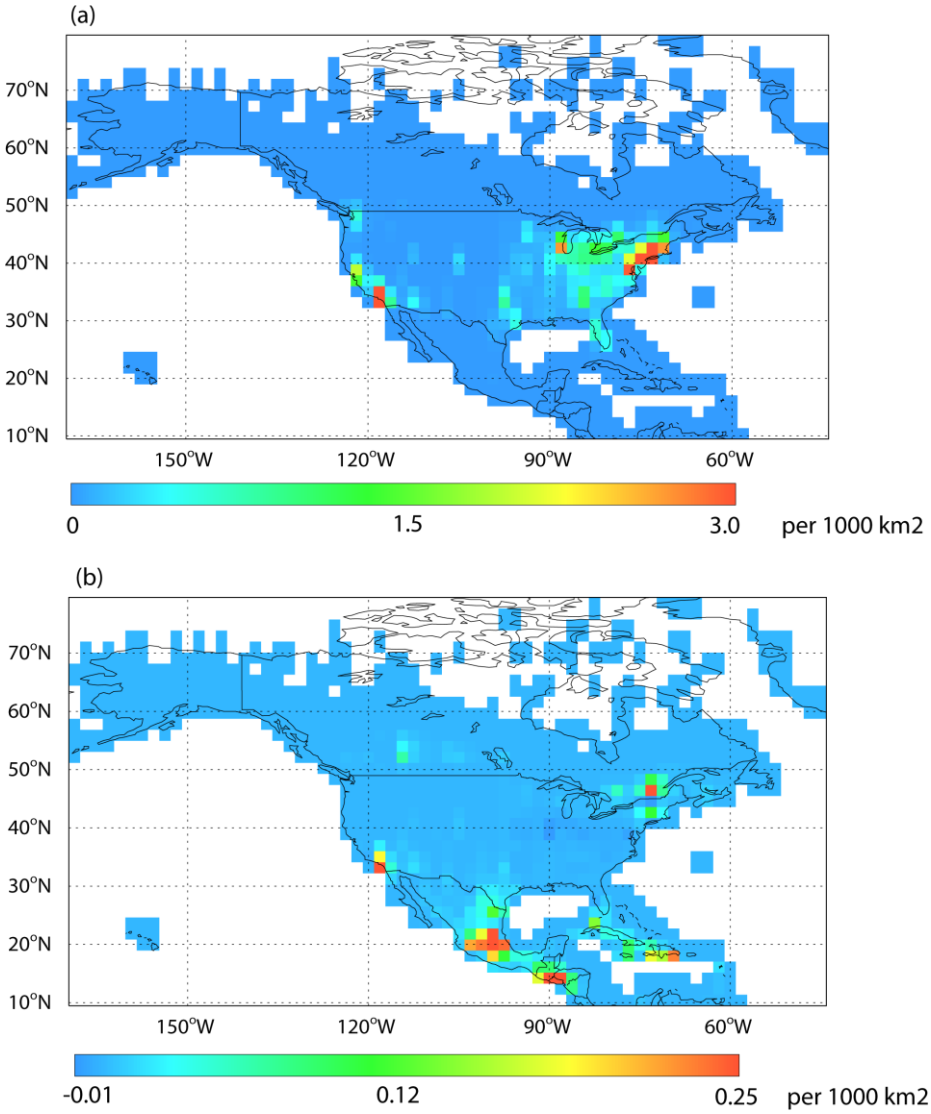


Fig. S21. (a) Avoided premature deaths from halving US anthropogenic BC emissions relative to the base case, and (b) difference in avoided deaths from halving BC emissions in NA vs. the US only (NA reduction minus US reduction).

References

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Oak Ridge National Laboratory: LandScan Global Population Database 2006, available at: http://www.ornl.gov/sci/landscan/index.html, 2008.

Zhang, X. Y., Wang, Y. Q., Zhang, X. C., Guo, W., and Gong, S. L.: Carbonaceous aerosol composition over various regions of China during 2006, J. Geophys. Res., 113, D14111, doi:10.1029/2007JD009525, 2008.