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Quantifying sources of black carbon in western North America using observationally based analysis and an emission tagging technique in the Community Atmosphere Model

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Table S1: CAM5 monthly BC-in-snow-surface and BC-in-snow-column at 36 sites from December to March. ("N/A" means no snow in the model grid.)

Comparison pair i	BC-in-snow-surface (ng g^{-1})				BC-in-snow-column (ng g^{-1})			
	Dec	Jan	Feb	Mar	Dec	Jan	Feb	Mar
1	13	4	N/A	N/A	10	1	0	0
2	7	22	7	1	5	9	5	0
3	9	20	6	N/A	10	13	4	0
4	6	20	7	N/A	4	13	6	0
5	6	9	2	N/A	5	6	1	0
6	6	12	24	N/A	5	9	20	0
7	7	22	6	N/A	6	16	4	0
8	14	13	20	57	13	11	13	21
9	11	15	20	54	12	11	13	19
10	11	19	30	49	8	9	13	20
11	9	16	22	35	8	9	12	17
12	24	22	37	35	20	17	18	26
13	84	56	48	42	57	59	25	27
14	39	57	22	17	26	46	12	14
15	51	87	42	27	21	36	25	18
16	86	56	44	61	53	61	41	38
17	43	27	40	59	27	26	27	39
18	32	28	35	37	25	23	23	24
19	38	39	37	42	30	29	28	26
20	76	51	41	59	59	47	39	35
21	74	48	70	73	50	47	43	43
22	30	19	49	37	16	17	18	20
23	32	26	46	46	14	17	18	21
24	16	14	32	38	12	11	12	14
25	6	6	20	18	7	6	7	8
26	5	5	12	10	5	5	6	6
27	2	2	5	4	5	4	4	4
28	16	14	32	38	12	11	12	14
29	20	14	35	49	16	15	15	18
30	30	29	44	54	16	20	22	24
31	57	37	37	41	48	32	28	28
32	34	38	29	41	24	26	24	25
33	9	8	22	32	8	8	9	10
34	25	29	32	47	18	20	19	21
35	31	40	34	46	27	29	26	27
36	37	44	44	44	27	28	31	30

Table S2. PMF analysis results of Doherty et al. (2014), showing the estimated BC mass mixing ratio in snow attributed to soil, biomass burning and pollution (fossil fuel) sources.

Site	F_{SOIL}	F_{BB}	F_{FF}	C_{BC}^{est} (ng g^{-1})
2	-1.84	6.15	3.83	15.5
6	-1.84	4.76	-2.36	5.8
8	-1.7	6.25	6.06	13.3
9	-1.33	7.61	3.88	15.4
10	1.05	7.18	1.54	12.9
11	2.38	3.39	1.49	13.7
14	6.17	6.23	11.01	29.3
15	-0.41	5.32	5.21	9.6
15	0.61	4.56	12.85	45
16	-1.84	3.93	18.5	17.9
17	3.48	5.17	14.69	31.2
17	3.55	2.82	10.16	15.5
18	9.1	2.89	3.72	19.2
19	82.61	-0.93	-2.36	90.1
20	10.56	3.52	7.93	23.2
20	12.2	5.03	14.64	33.6
26	24.82	2.06	3.38	50.6
28	31.25	5.07	13.96	51.4
28	23.01	5.96	5.07	30.6
29	52.26	2.77	10.17	57.4
30	4.2	5.16	17.67	23.3
31	4.12	6.36	8.1	17.9
35	5.29	5.12	11.66	49.5
36	0.17	6	6.76	5.9
38	18.93	4.03	14.97	35.3
39	10.78	4.47	1.95	16.3
40	17.92	5.23	29.08	49.8
40	61.46	0.92	18.78	171.4
41	-0.37	3.32	27.09	34.9
43	14.86	4.55	29.31	38.4
44	28.23	6.14	53.19	84.4
45	3.31	4.05	9.11	11
46	8.21	3.65	23.8	28.5
47	12.94	4.34	8.44	26.9
49	2.53	5.71	4.28	8.3
49	5.44	6.88	19.58	36.1
50	0.19	5.92	4.66	8.3
50	2.57	6.18	16.76	27.3
52	17.29	8.26	9.84	27.5
53	-0.61	4.5	13.01	9.8

54	7.49	5.55	8.6	16.6
54	1.29	4.2	18.45	20.9
55	-1.52	4.39	9.52	14.4
57	3.93	0	12.91	26
58	4.53	1.81	5.9	15.1
59	4.49	5.21	22.03	18.4
60	-0.56	8.36	4.27	8.4
61	5.24	5.96	5.4	8
61	-1.84	2.93	21.86	26
62	-1.16	2.57	3.12	8.4
63	0.59	4.72	14.14	17
63	-0.43	5.26	8.35	12.3
64	2.82	4.62	11.68	21.5
65	5.96	4.98	17.19	17.5
66	2.67	4.59	13.83	25

Table S3: BC-in-snow-column concentrations from observations and the CAM5 simulation in Northwest USA and West Canada at 36 sites

Northwest USA			West Canada		
Comparison pair *i*	$\overline{C_{obs}^{i}}$ (ng g^{-1})	$\overline{C_{mod}^{i}}$ (ng g^{-1})	Comparison pair *i*	$\overline{C_{obs}^{i}}$ (ng g^{-1})	$\overline{C_{mod}^{i}}$ (ng g^{-1})
1	8	1	21	39	44
2	15	7	22	36	18
3	25	8	23	18	19
4	31	9	24	18	13
5	29	3	25	15	7
6	52	15	26	19	6
7	78	10	27	7	4
8	88	15	28	11	13
9	62	14	29	12	16
10	45	14	30	21	22
11	35	13	31	22	29
12	28	20	32	16	25
13	34	37	33	15	9
14	17	24	34	13	20
15	19	26	35	21	27
16	18	47	36	22	30
17	73	30	mean±SD	19±8	19±11
18	110	23			
19	37	28			
20	67	40			
mean±SD	44±28	19±13			

Table S4. Fractional contributions from tagged source regions and sectors (BB and FF) to BC deposition (multiplied by snow cover fraction for the consideration of calculating BC-in-snow radiative forcing) over the two receptor regions, Northwest USA and West Canada, from the CAM5 simulation.

Source region	**Northwest USA**		**West Canada**	
	BB (%)	FF (%)	BB (%)	FF (%)
ARC	0.0	0.0	0.0	0.1
WCA	1.4	9.3	9.1	56.6
ECA	0.0	0.0	0.0	0.1
NWU	3.7	24.8	1.6	7.5
NEU	2.0	23.1	0.4	5.0
SWU	1.8	9.8	0.1	0.6
SEU	0.3	1.8	0.0	0.1
LAM	0.1	0.4	0.0	0.1
ERCA	0.0	0.3	0.1	0.5
AFME	1.4	0.6	1.0	0.5
EAS	3.6	7.6	3.2	7.3
SAS	3.6	1.5	2.7	1.2
SEA	1.5	0.2	1.1	0.1
PAN	0.0	0.0	0.0	0.0
ROW	0.0	1.0	0.0	1.2

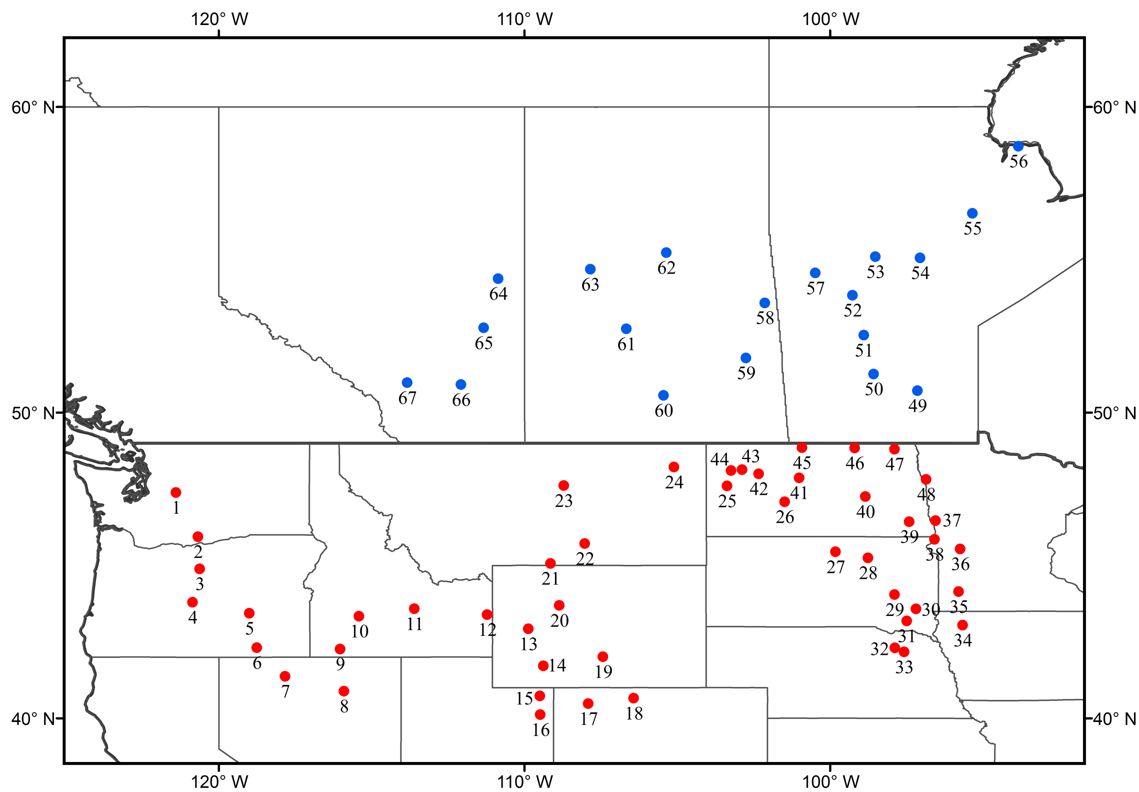

Fig. S1. Map of the 67 sampling site locations for the January-March of 2013 large-area survey of BC in snow across Western North America conducted by Doherty et al. (2014). Red dots mark sites in the region we term here "Northwest USA", and blue dots are in our "West Canada" region.

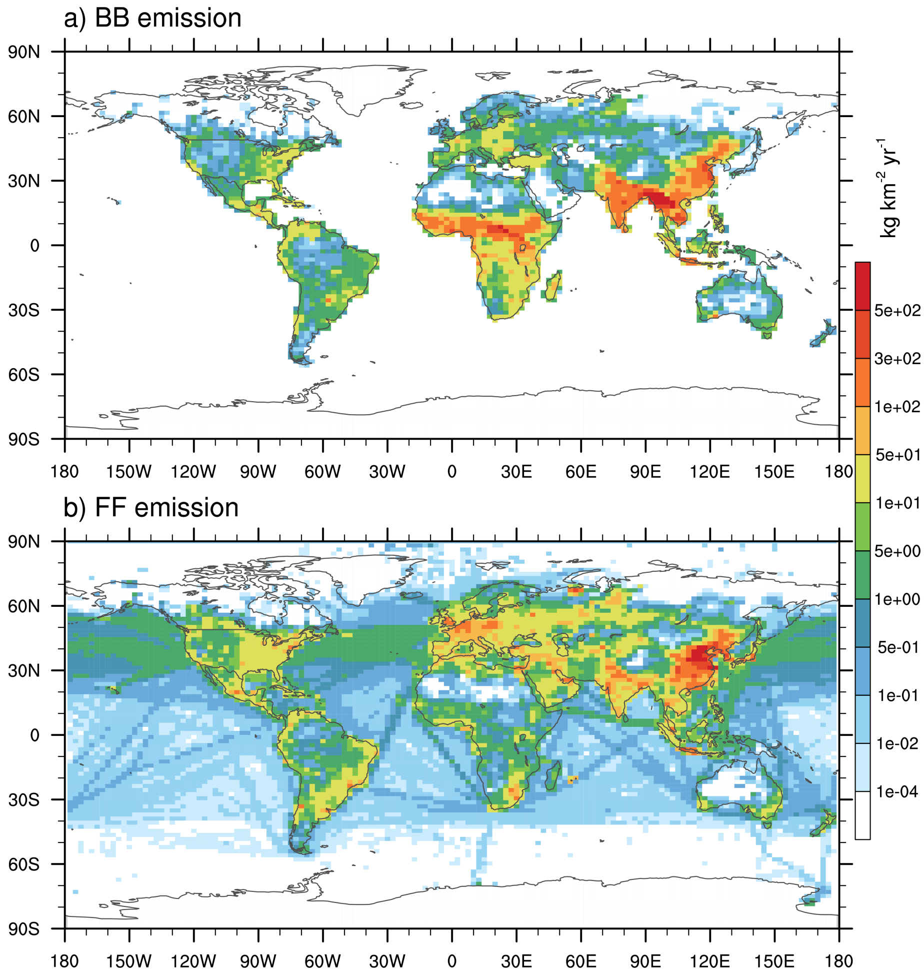

Fig. S2. Global distribution of JFM mean BC emissions (kg km^{-2} yr^{-1}) from the (a) BB and (b) FF sectors for the emission inventory of year 2010 used in this study.

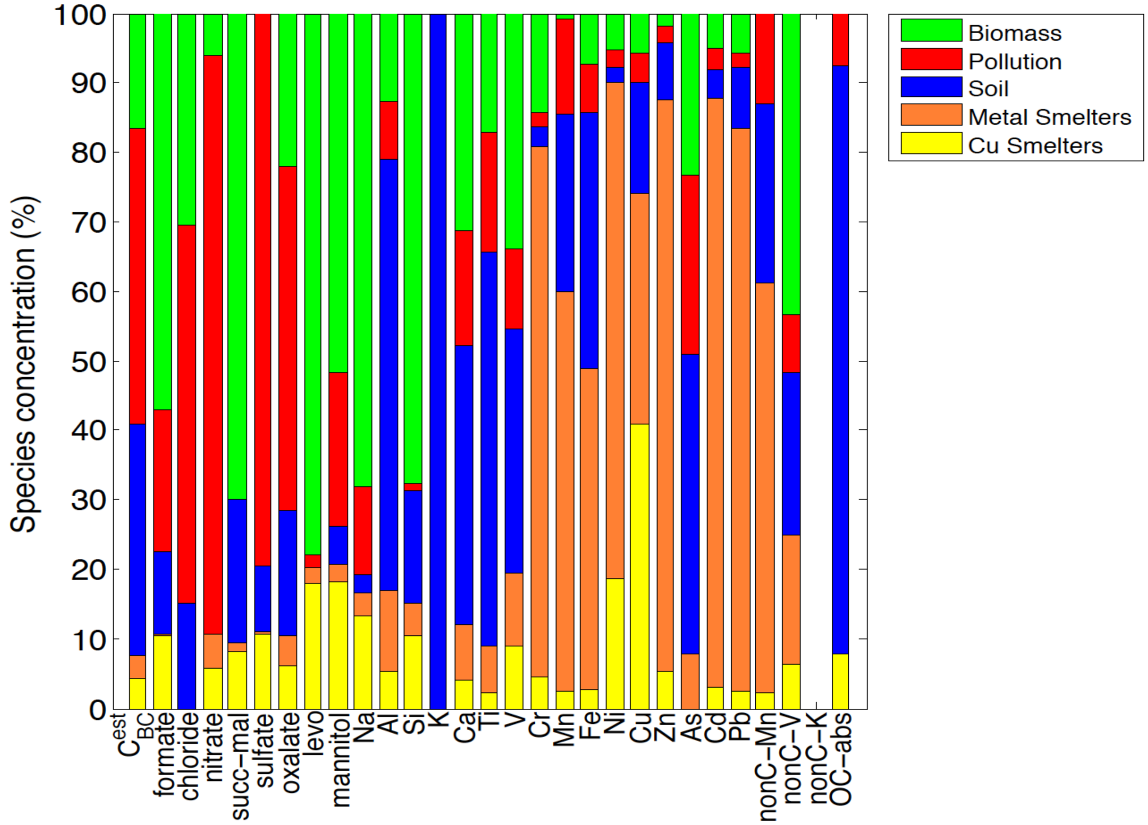

Fig. S3. Chemical "fingerprints" of the five factors that account for variations in estimated snow BC mixing ratios (C_{BC}^{est} from ISSW analysis in Doherty et al., 2014), and the fraction of BC attributable to the five factors across all sites. The three fingerprints accounting for variations in BC were identified as being associated with pollution (red), soil (blue), and biomass burning (green). Non-crustal sources of Mn, V and K are shown as nonC-Mn, nonC-V and nonC-K. OC-abs indicates the 470-700nm absorption due to organic components of the particles, as determined by Dang and Hegg (2014) via serial extractions of sample filters. All other constituents are measured by chemical analysis (Doherty et al. 2014), where "levo" denotes levoglucosan and "succ-mal" the sum of succinate and malate.

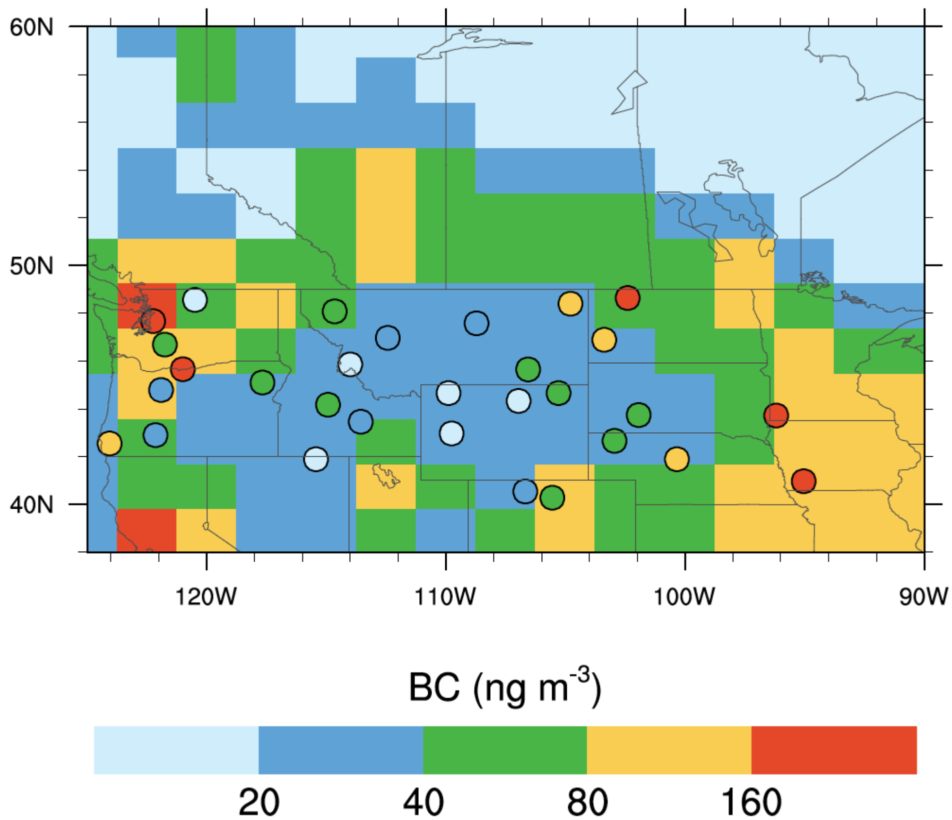

Fig. S4. Spatial distributions of JFM mean near-surface atmospheric BC concentrations (ng m^{-3}) from the CAM5 simulation (colored grid-boxes) and from the IMPROVE network observations (color circles with black outlines).

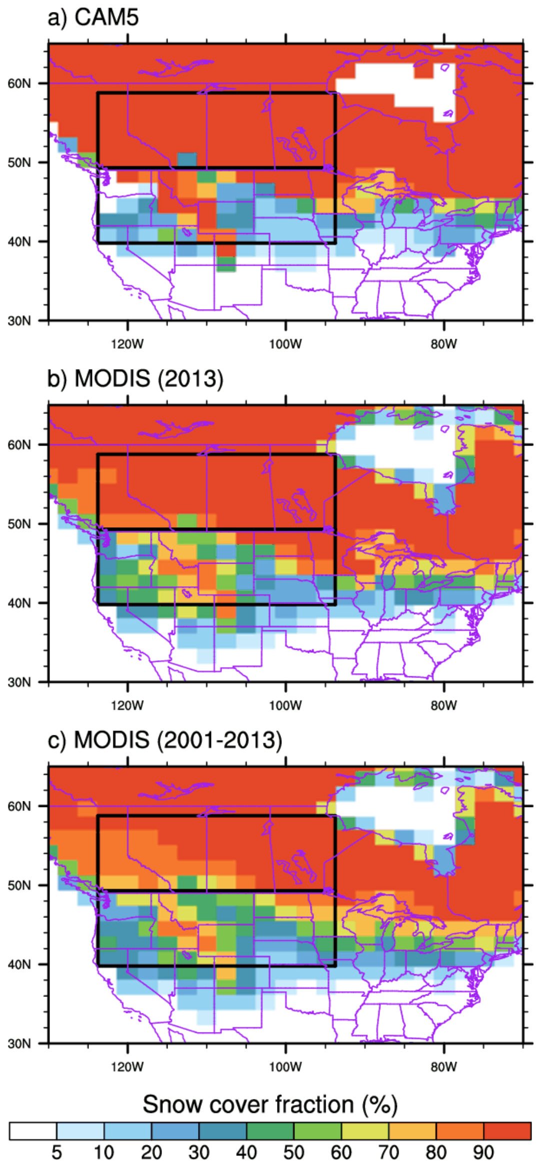

Fig. S5. JFM mean snow cover fraction (SCF) from (a) the CAM5 simulation for year 2013, (b) MODIS retrievals (Hall et al., 2006) for year 2013 and (c) MODIS multi-year (2001−2013) average. The thick black boxes outline two receptor regions, Northwest USA (39.8−49.3° N, 93.75−123.75° W) and West Canada (49.3−58.8° N, 93.75−123.75° W). The JFM mean SCF for CAM5 is 50% over Northwest USA and 99% over West Canada, similar to the MODIS retrieved SCFs of 58% and 96%, respectively. The mean MODIS SCF (±standard deviation) for January, Feburary and March of 13 years (a total of 39 samples) is 50%±19% over the Northwest USA and 90%±16% over West Canada. The standard deviation of the MODIS SCF indicates intra-seasonal and inter-annual variations during 2001-2013 for the given regions.

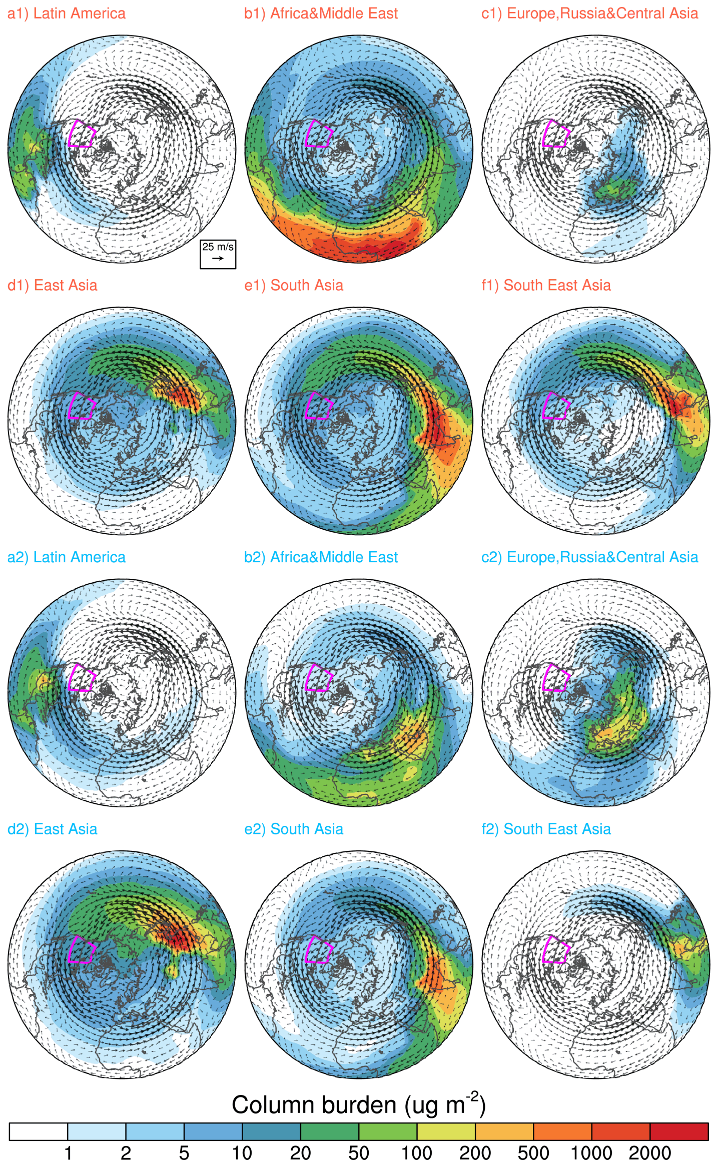

Fig. S6. Spatial distributions of the JFM mean BC total column burden (in μg m^{-2}, colors), originating from the BB (a1−f1) and the FF (a2−f2) sectors in six tagged source regions that are distant from the receptor region of interest, Western North America (39.8−58.8° N, 93.75−123.75° W), which is marked with magenta outline.

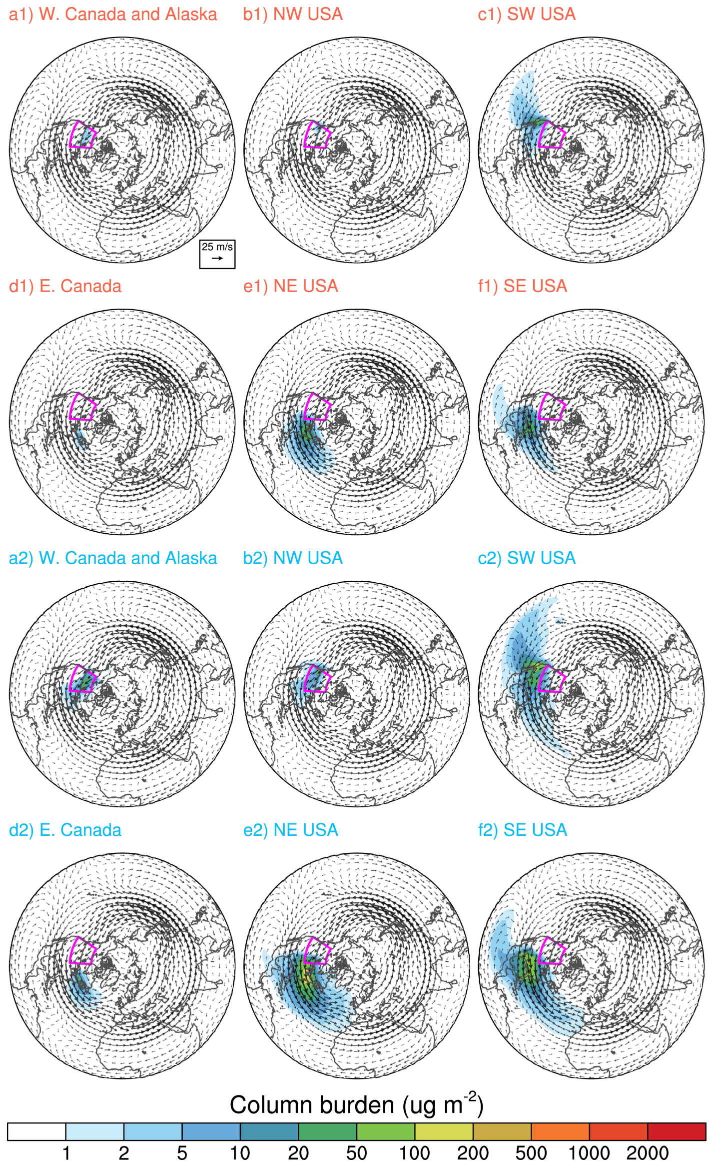

Fig. S7. Same as Fig. S6 but for six local source regions within North America.

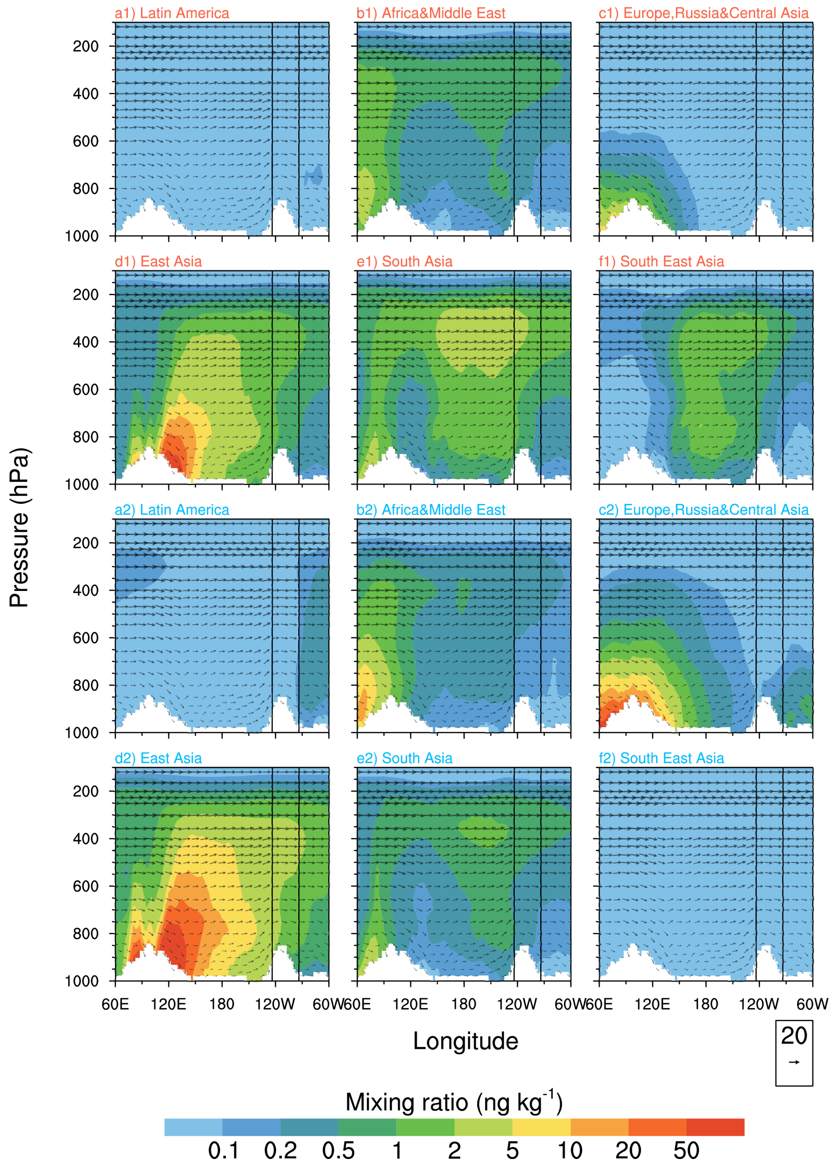

Fig. S8. Longitude-height cross-section of JFM mean BC mass mixing ratios (in ng kg^{-1}, colors) over the latitude band 39.8−58.8° N, originating from the BB (a1−f1) and the FF (a2−f2) sectors in six tagged source regions that are distant from the receptor region. The longitudinal boundaries of Western North America (93.75−123.75° W) are marked with black vertical lines.

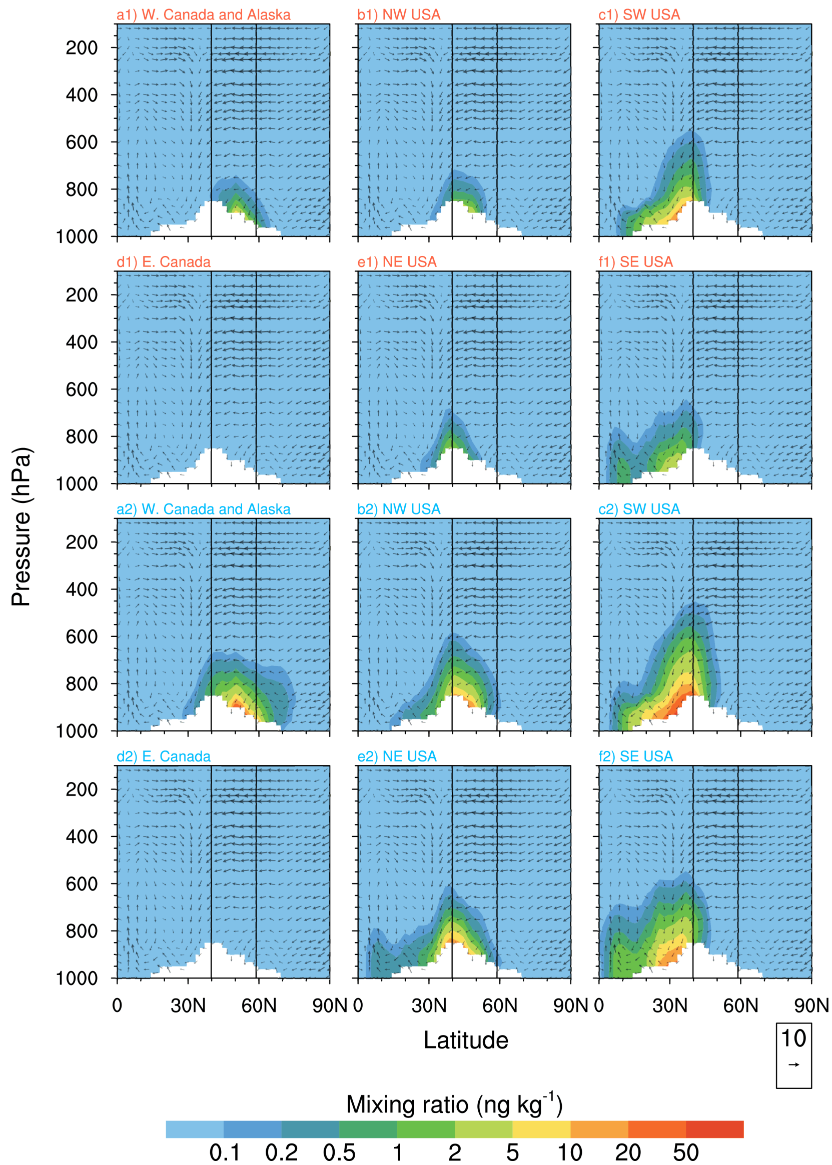

Fig. S9. Latitude-height cross-section of JFM mean BC mass mixing ratios (in ng kg^{-1}, colors) over the longitude band 93.75−123.75° W, originating from the BB (a1−f1) and the FF (a2−f2) sectors in six tagged local source regions. The latitudinal boundaries of Western North America (39.8−58.8° N) are marked with black vertical lines.

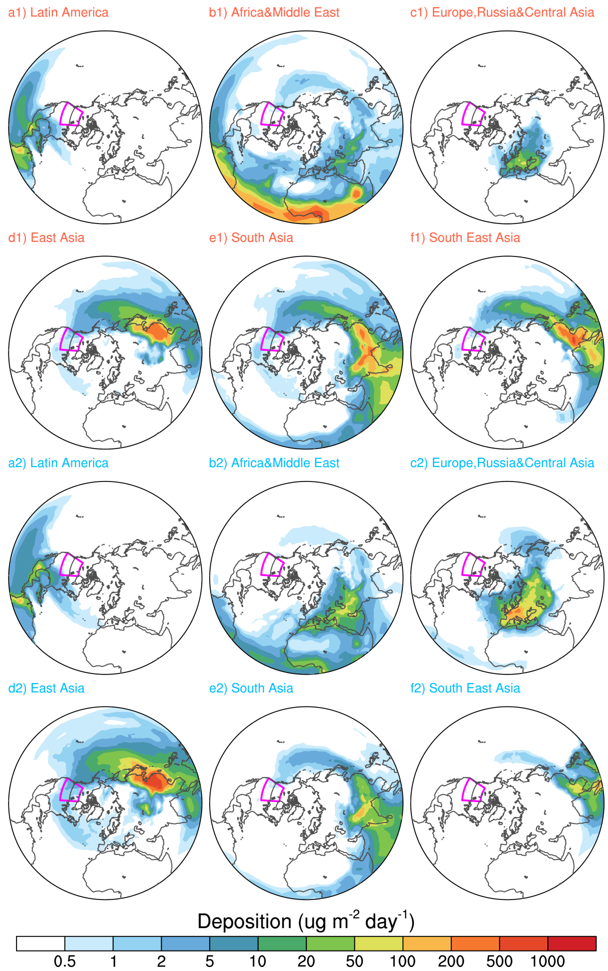

Fig. S10. Same as Fig. S6 but for BC deposition.

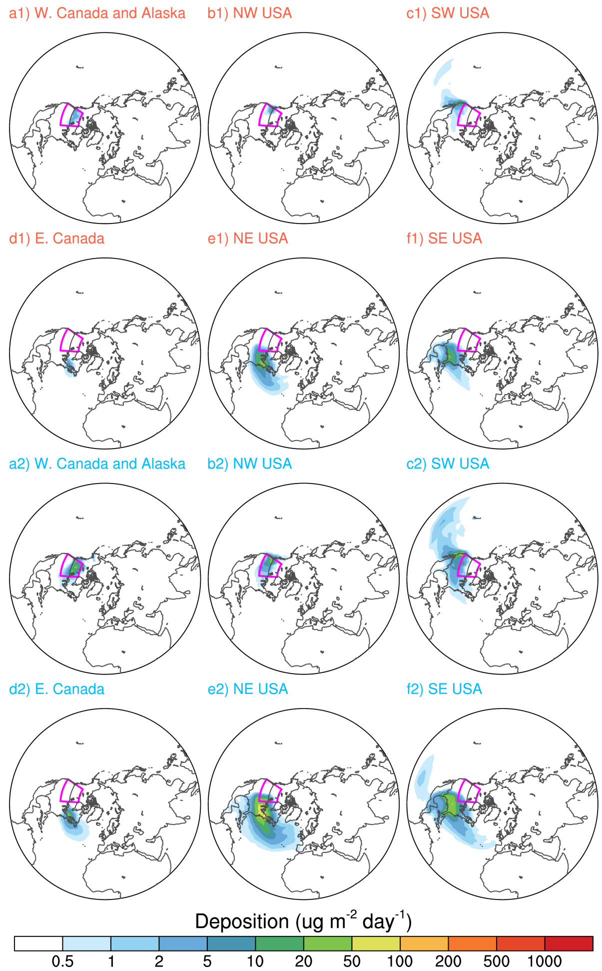

Fig. S11. Same as Fig. S7 but for BC deposition.

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