SUPPLEMENTARY APPENDICES

Research Report 218

Estimating Model-Based Marginal Societal Health Benefits of Air Pollution Emission Reductions in the United States and Canada

Amir Hakami et al.

Appendix A: BPTs
Appendix B: Cobenefits

The Appendices were reviewed for spelling, grammar, and cross-references to the main report. They have not been formatted or fully edited by HEI. This document was reviewed by the HEI Review Committee.

Correspondence may be addressed to Dr. Amir Hakami, 3432 C.J. Mackenzie Building, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6 Canada; email: *amir.hakami@carleton.ca*.

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Appendix A: BPTs

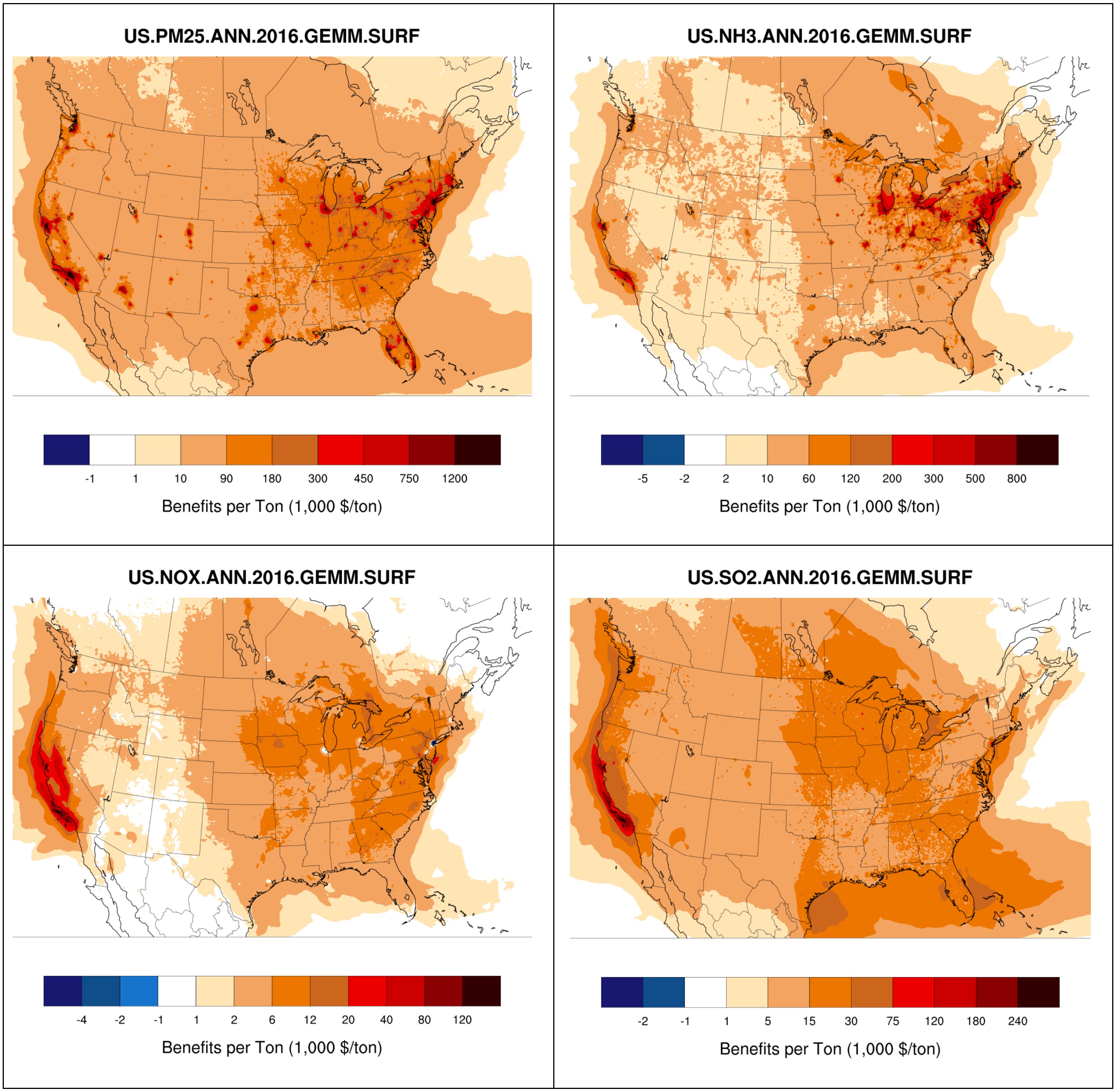

Figure A1. Annual BPT estimates, US, surface, GEMM CRF.

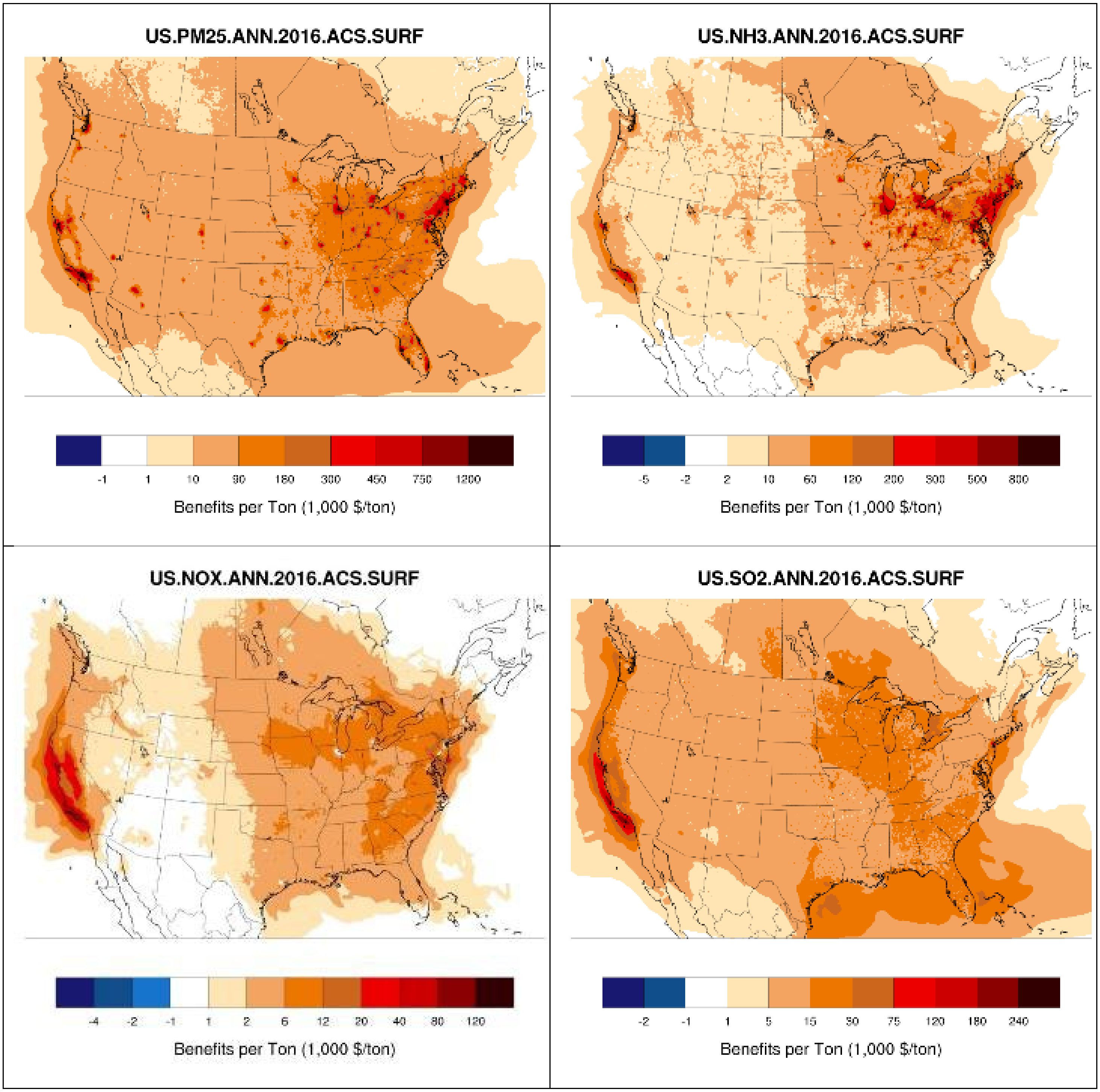

Figure A2. Annual BPT estimates, US, surface, ACS-09 CRF.

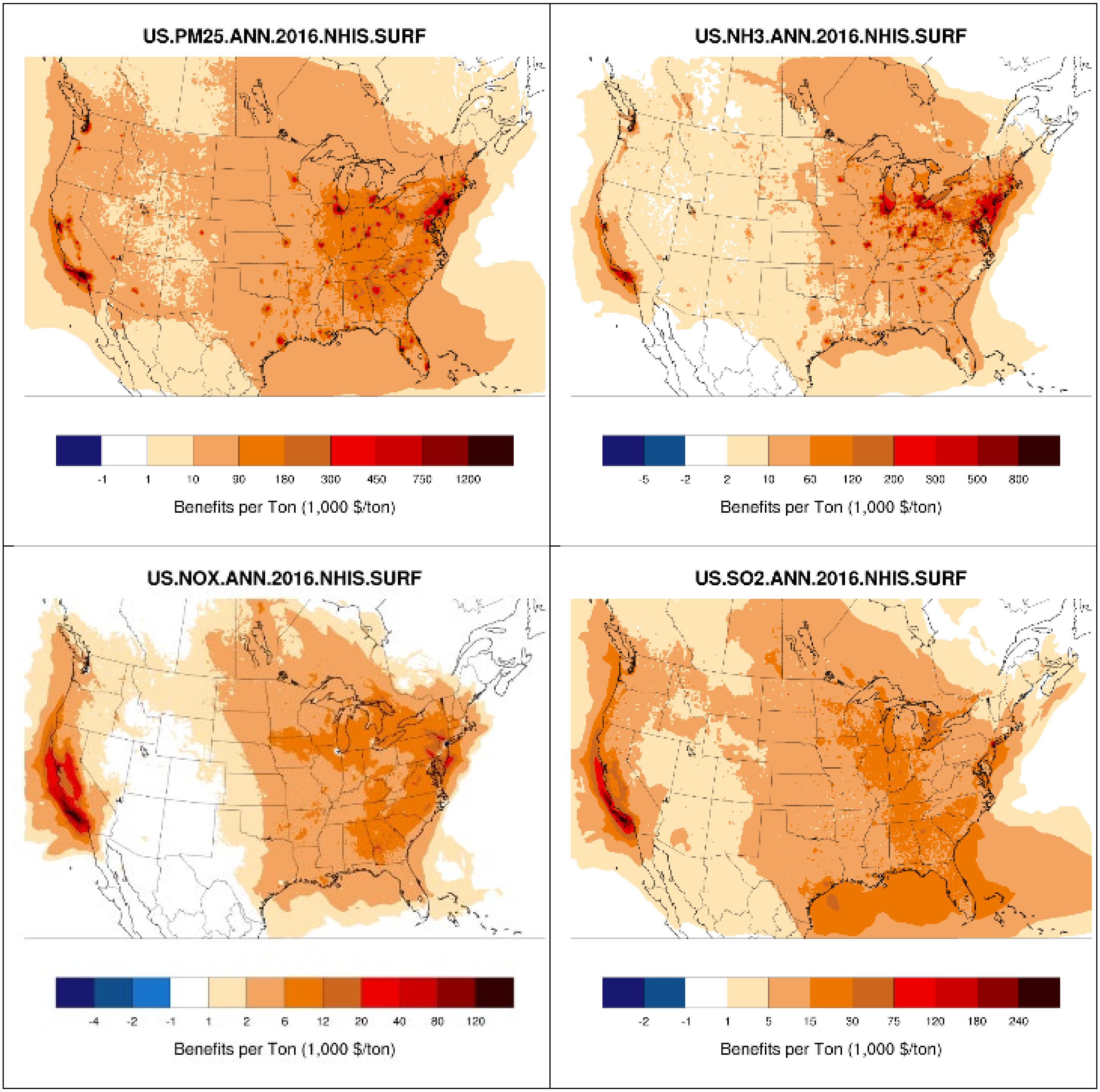

Figure A3. Annual BPT estimates, US, surface, NHIS CRF.

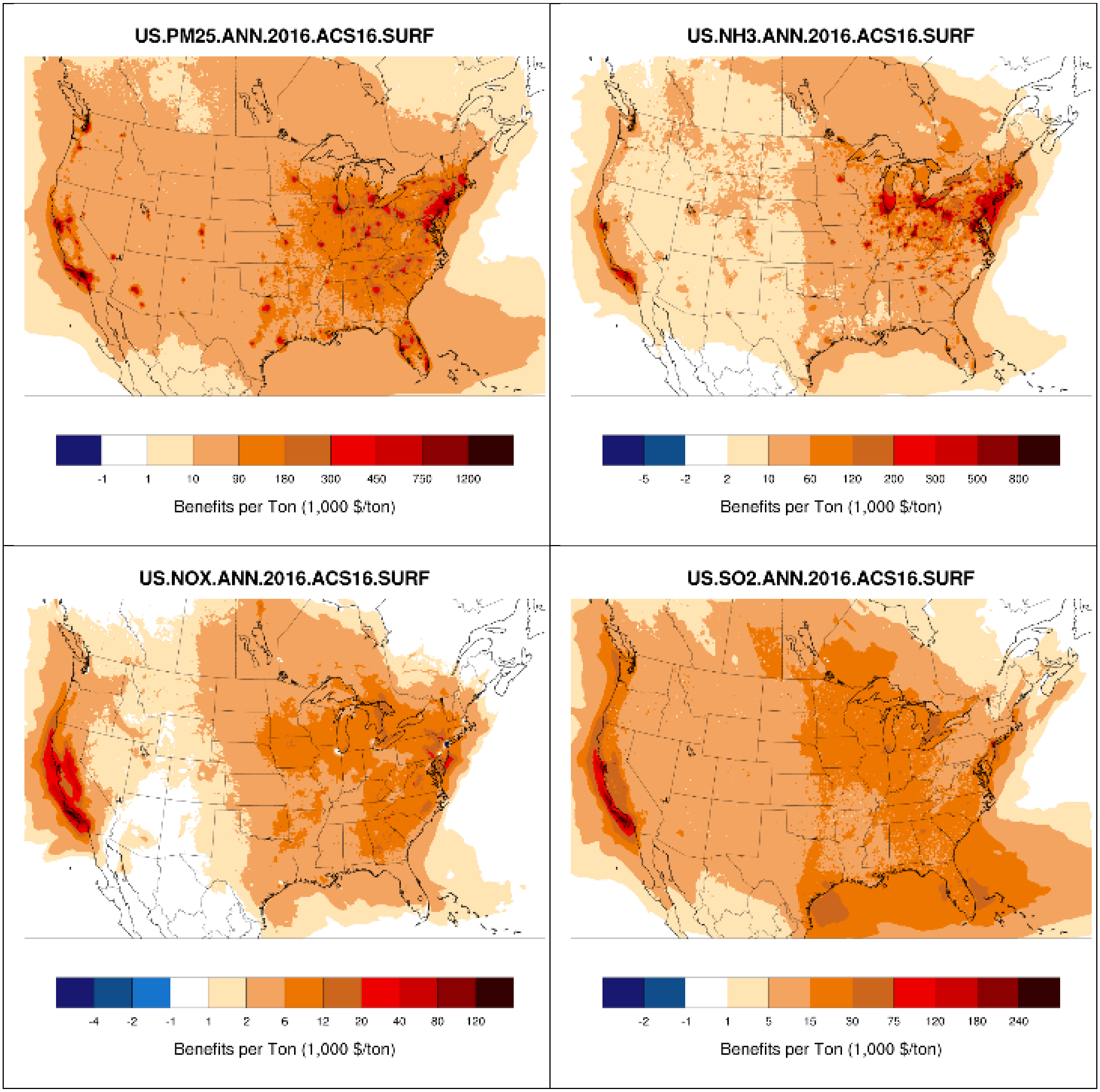

Figure A4. Annual BPT estimates, US, surface, ACS-16 CRF.

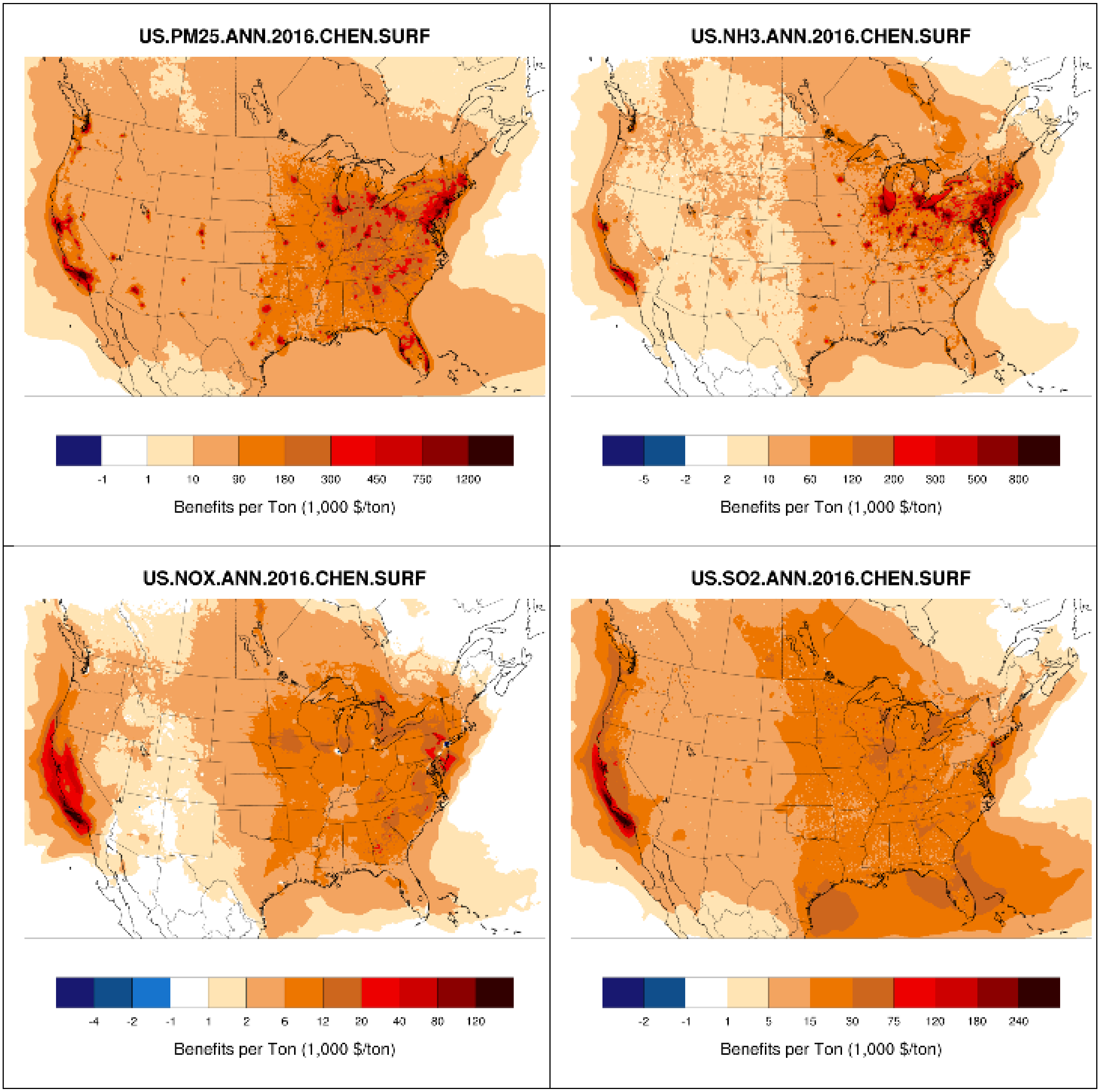

Figure A5. Annual BPT estimates, US, surface, CHEN CRF.

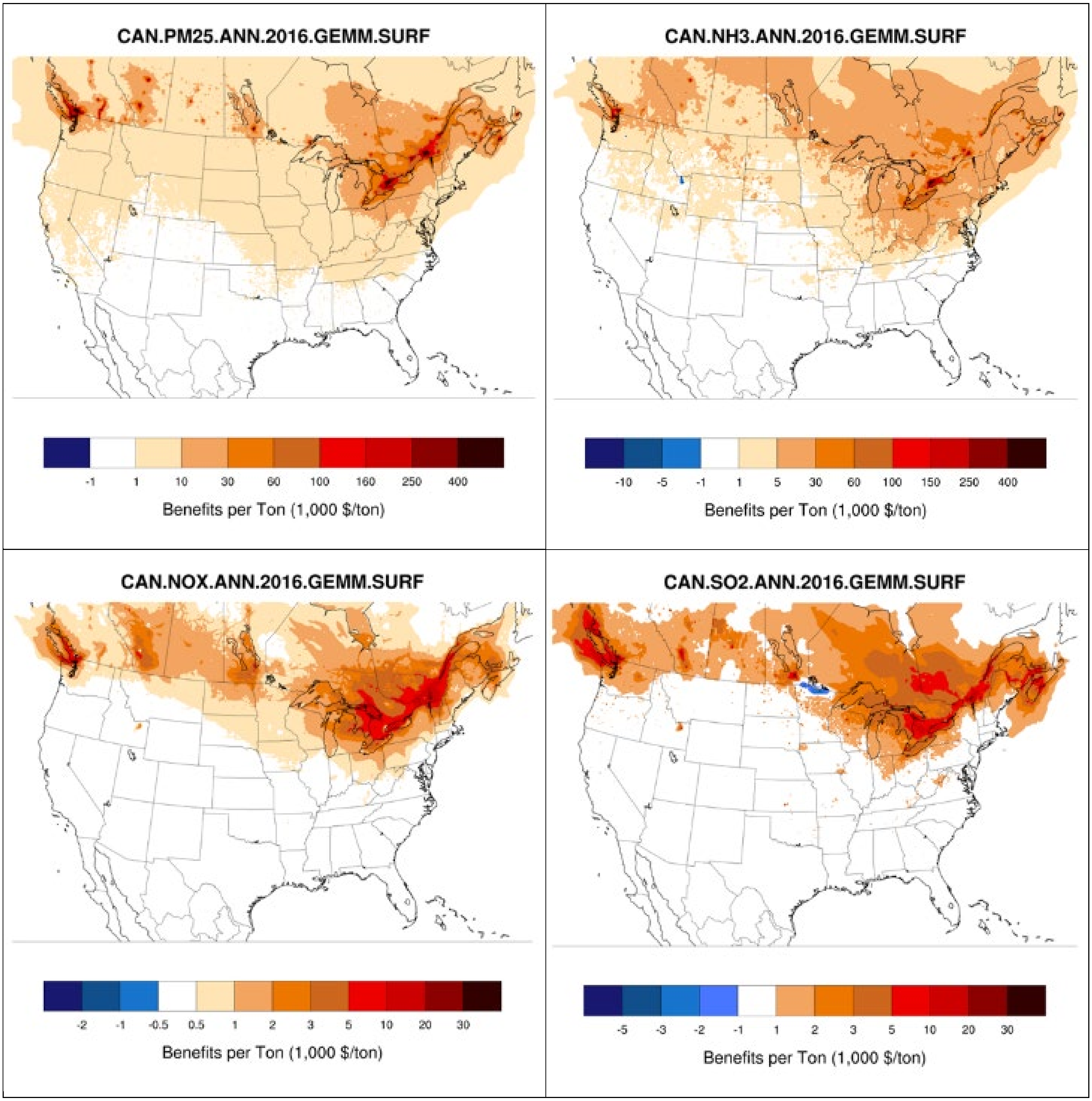

Figure A6. Annual BPT estimates, Canada, surface, GEMM CRF.

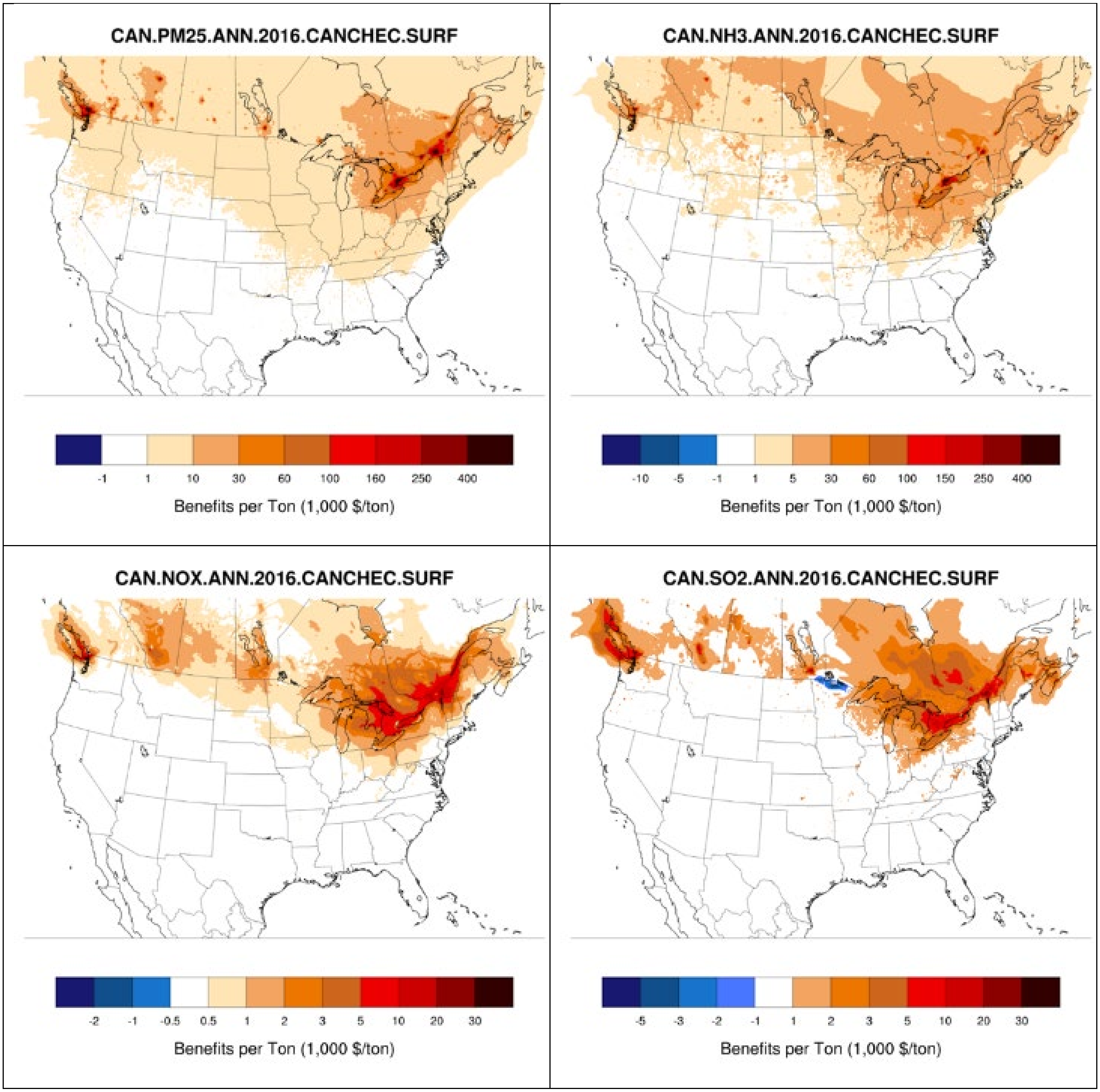

Figure A7. Annual BPT estimates, Canada, surface, CanCHEC CRF. (Zhao et al. [In press])

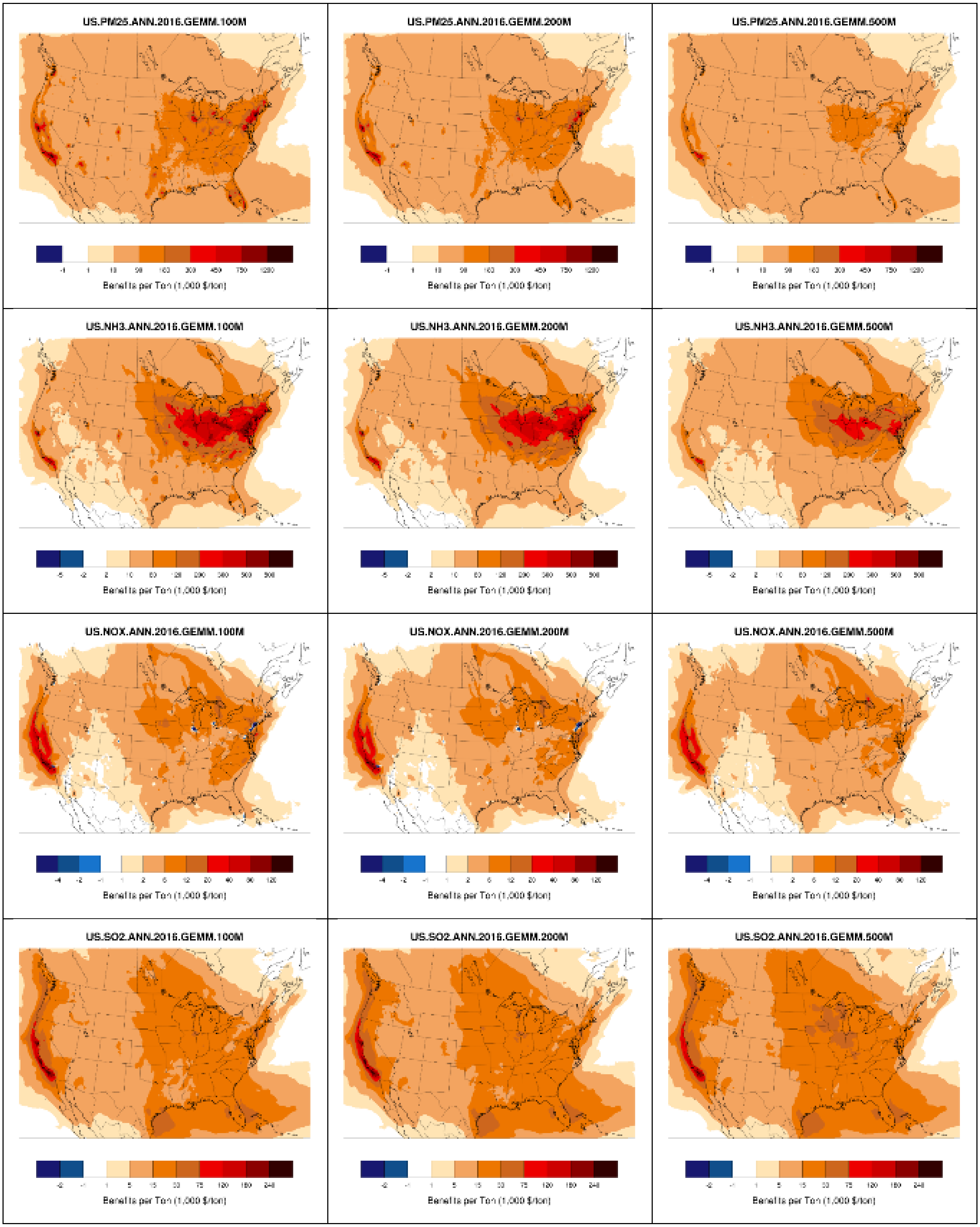

Figure A8. BPTs for elevated sources at 100m, 200m, and 500m elevation (columns 1, 2, and 3, respectively), US, GEMM CRF. (Zhao et al. [In press])

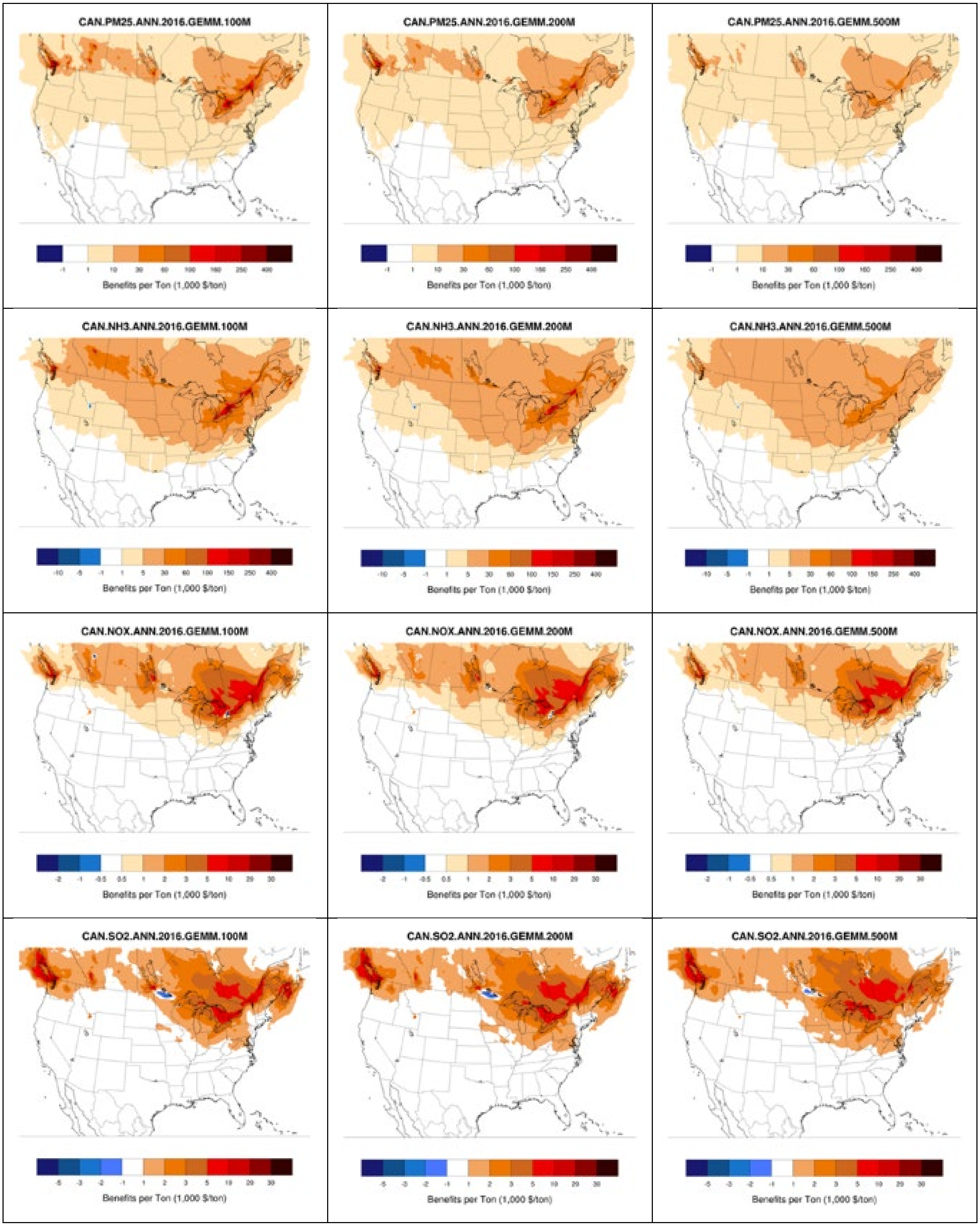

Figure A9. BPTs for elevated sources at 100m, 200m, and 500m elevation, (columns 1, 2, and 3, respectively), Canada, GEMM CRF. (Zhao et al. [In press])

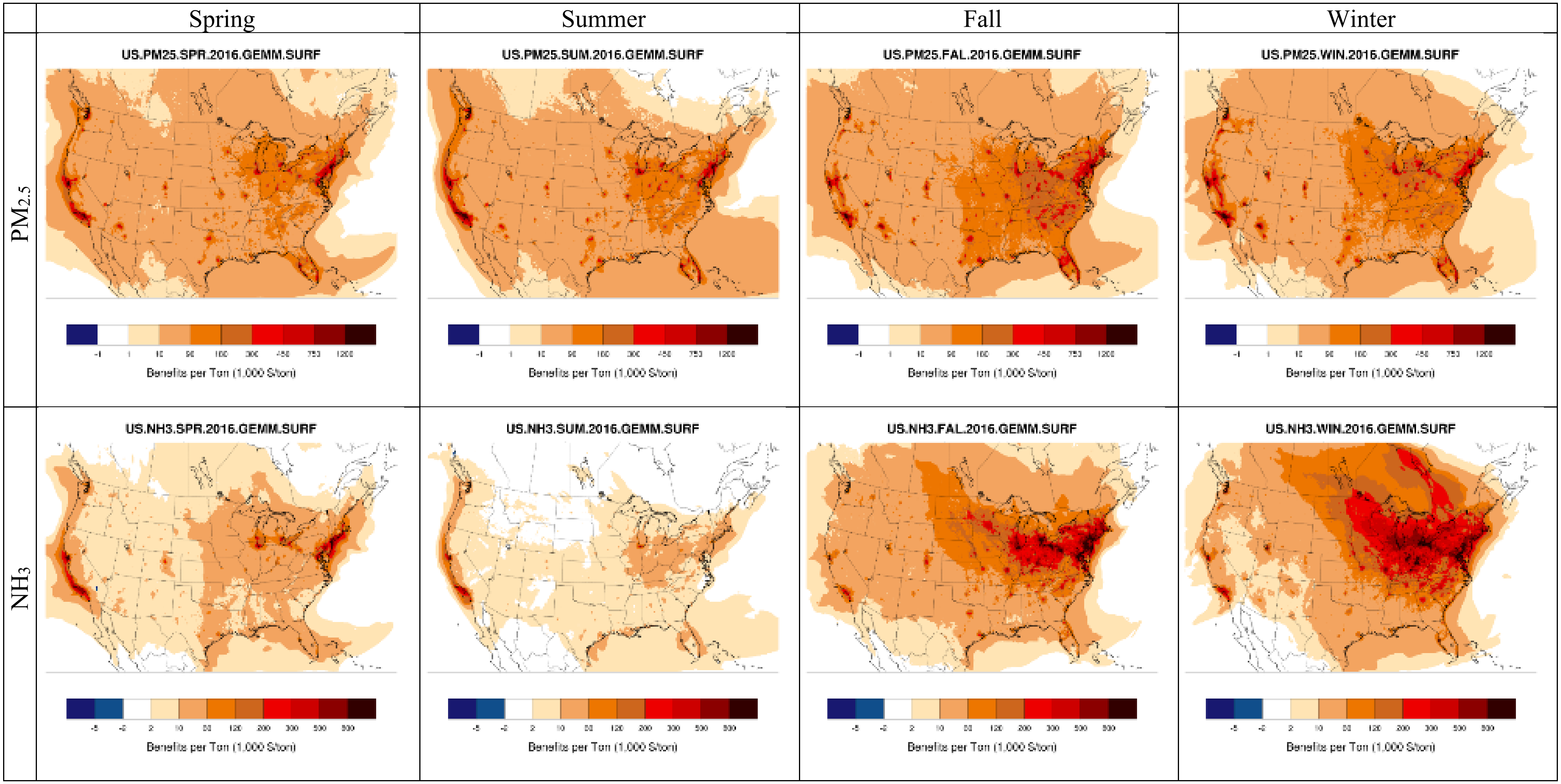

Figure A10. Seasonal variation in BPTs, US, surface, GEMM CRF (*continues next page*).

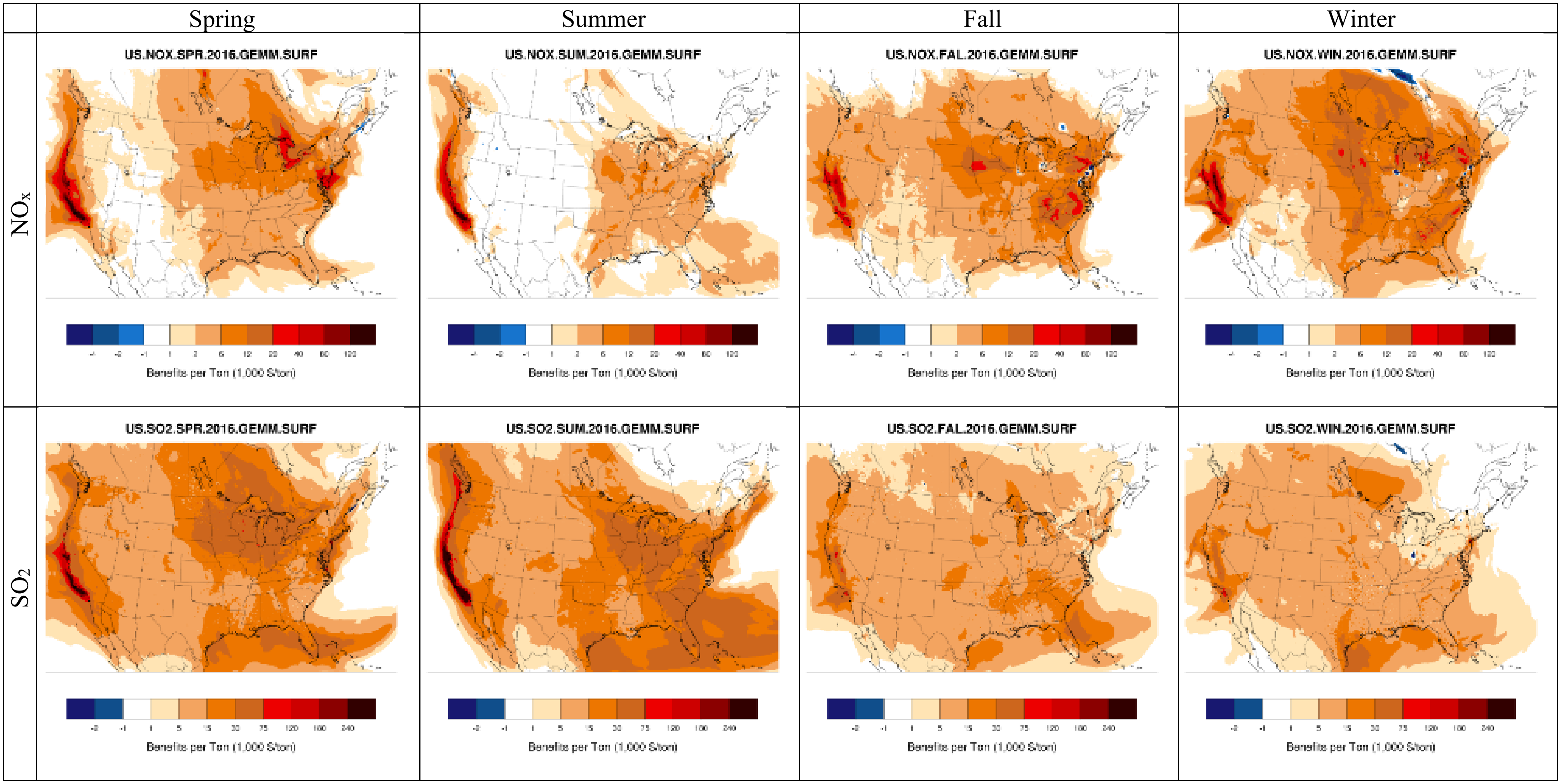

Figure A10 (*continued*). Seasonal variation in BPTs, US, surface, GEMM CRF.

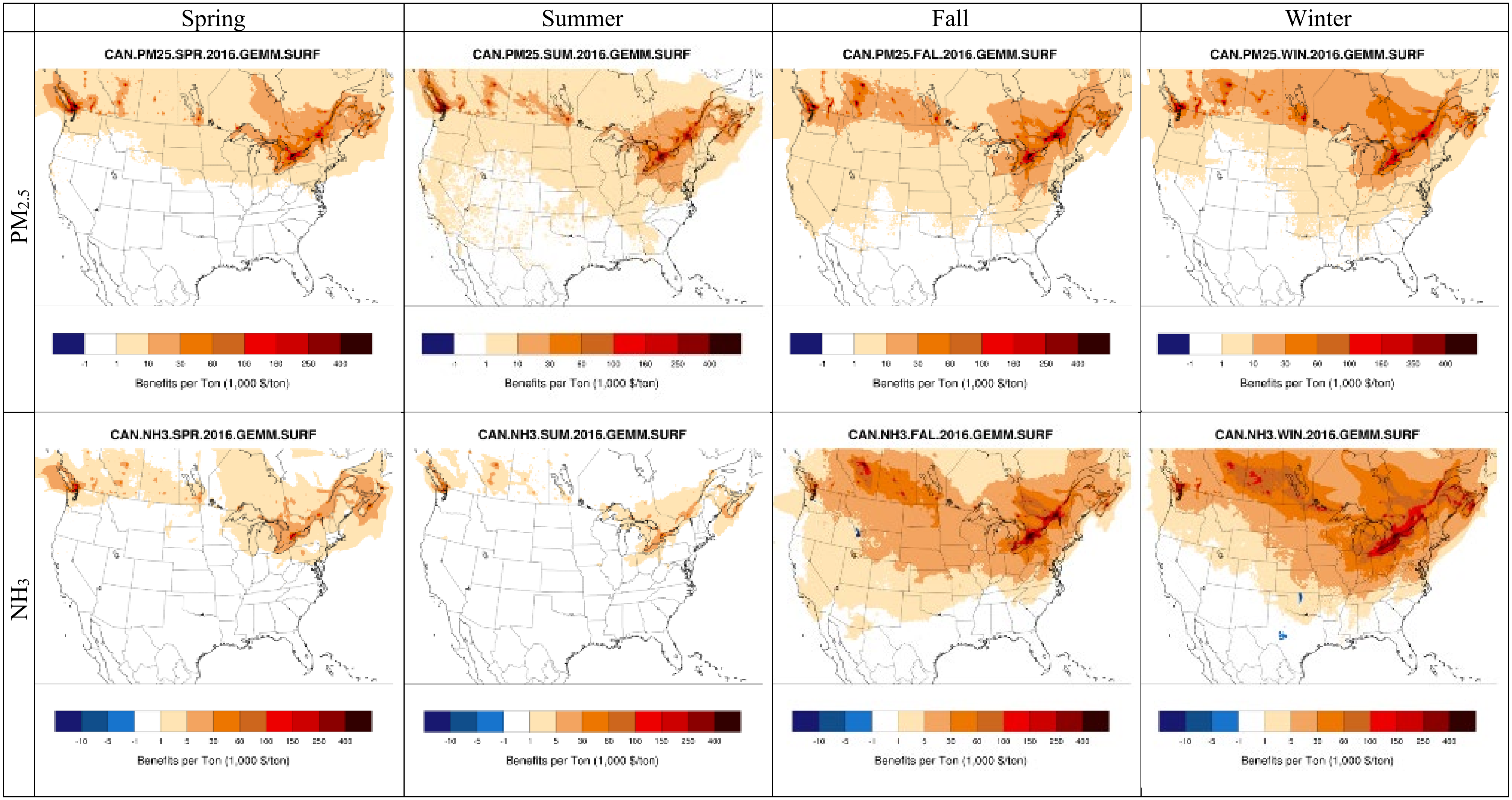

Figure A11. Seasonal variation in BPTs, Canada, surface, GEMM CRF (*continues next page*).

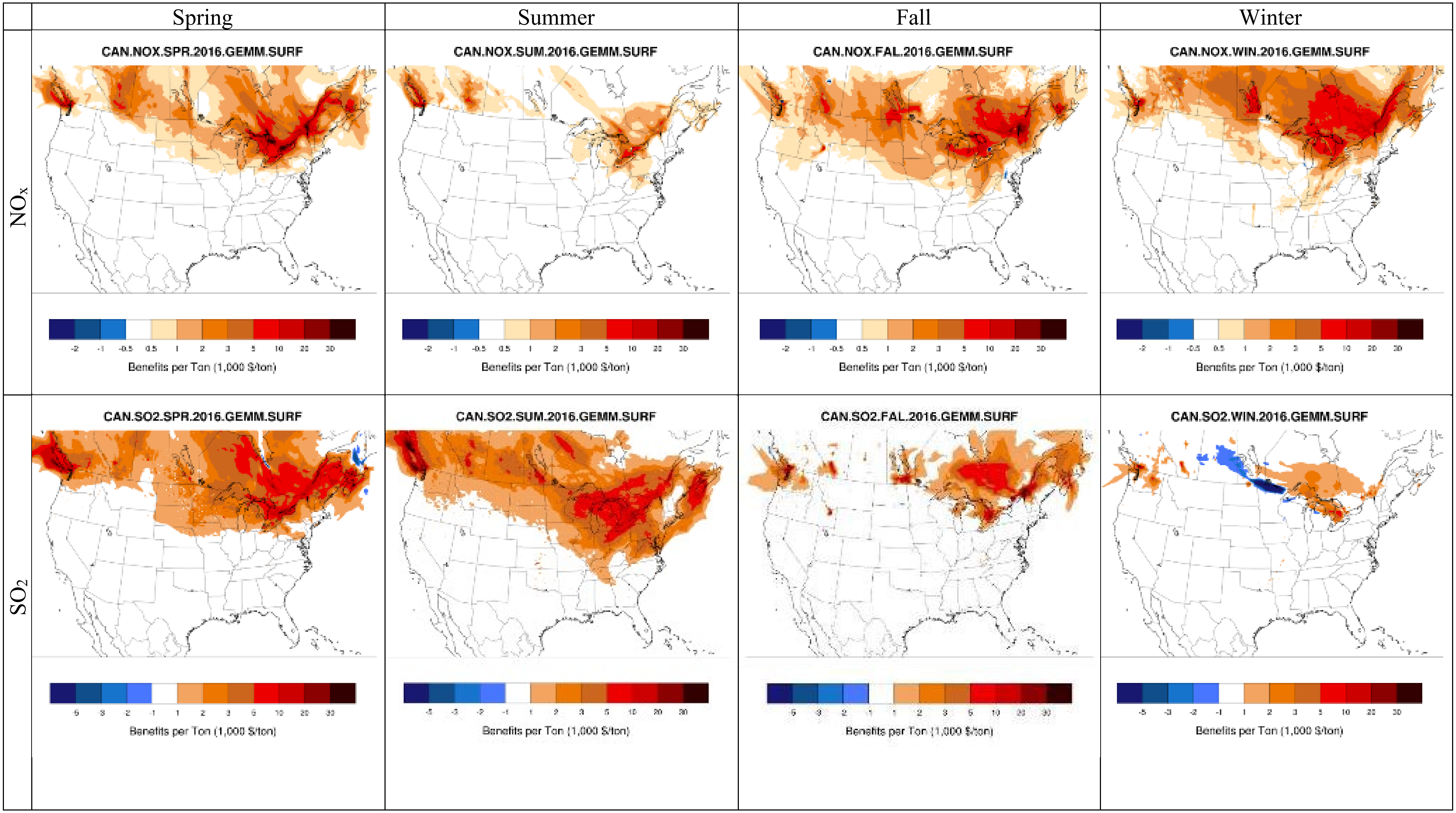

Figure A11 (*continued*). Seasonal variation in BPTs, Canada, surface, GEMM CRF.

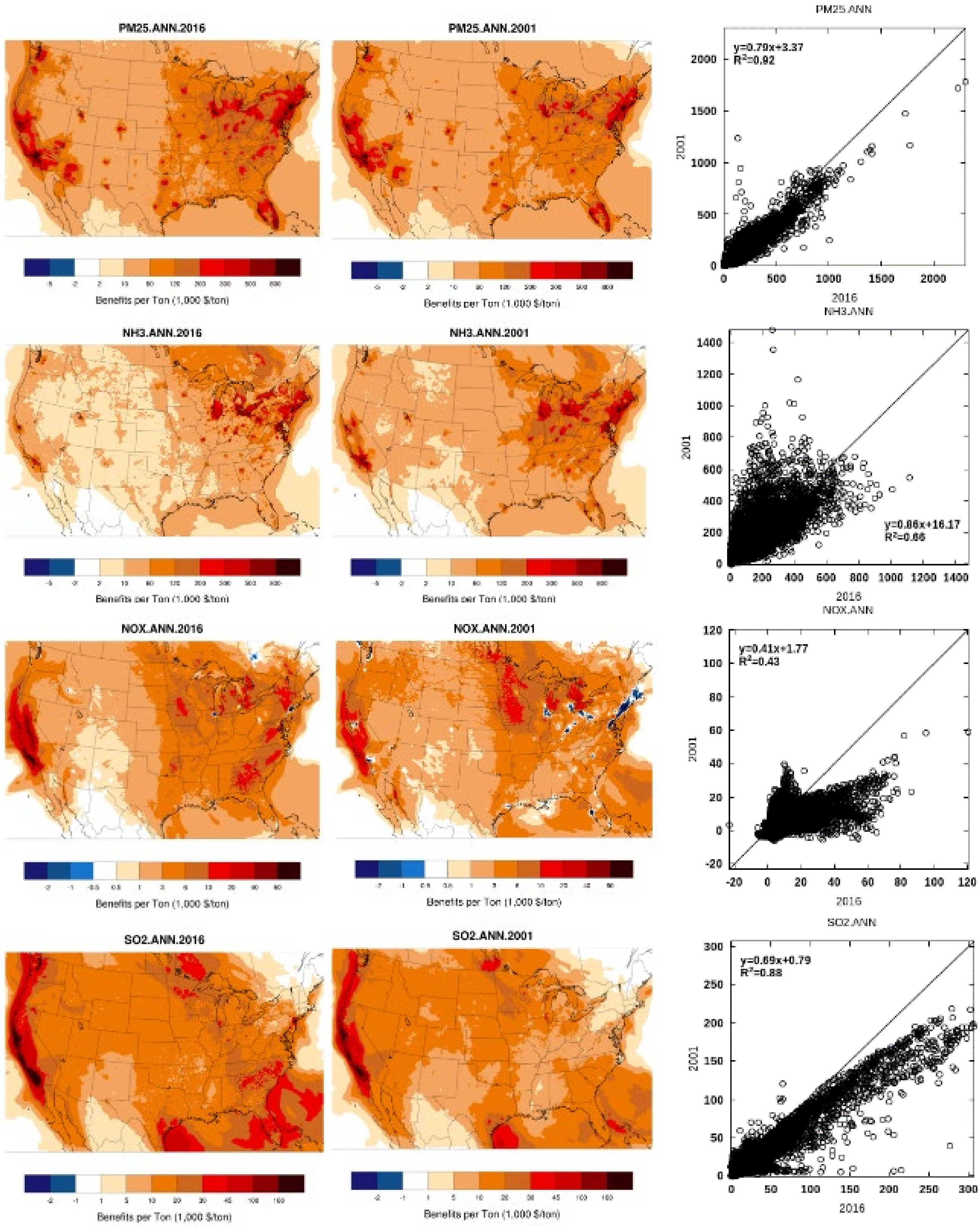

Figure A12. Comparison of BPTs for 2016 and 2001 inventories. Annual estimated BPTs are constructed from winter and summer simulations. Adjoint forcing terms for 2001 BPTs are adjusted based on concentrations in episodic simulations to better reflect the 2001 episode.

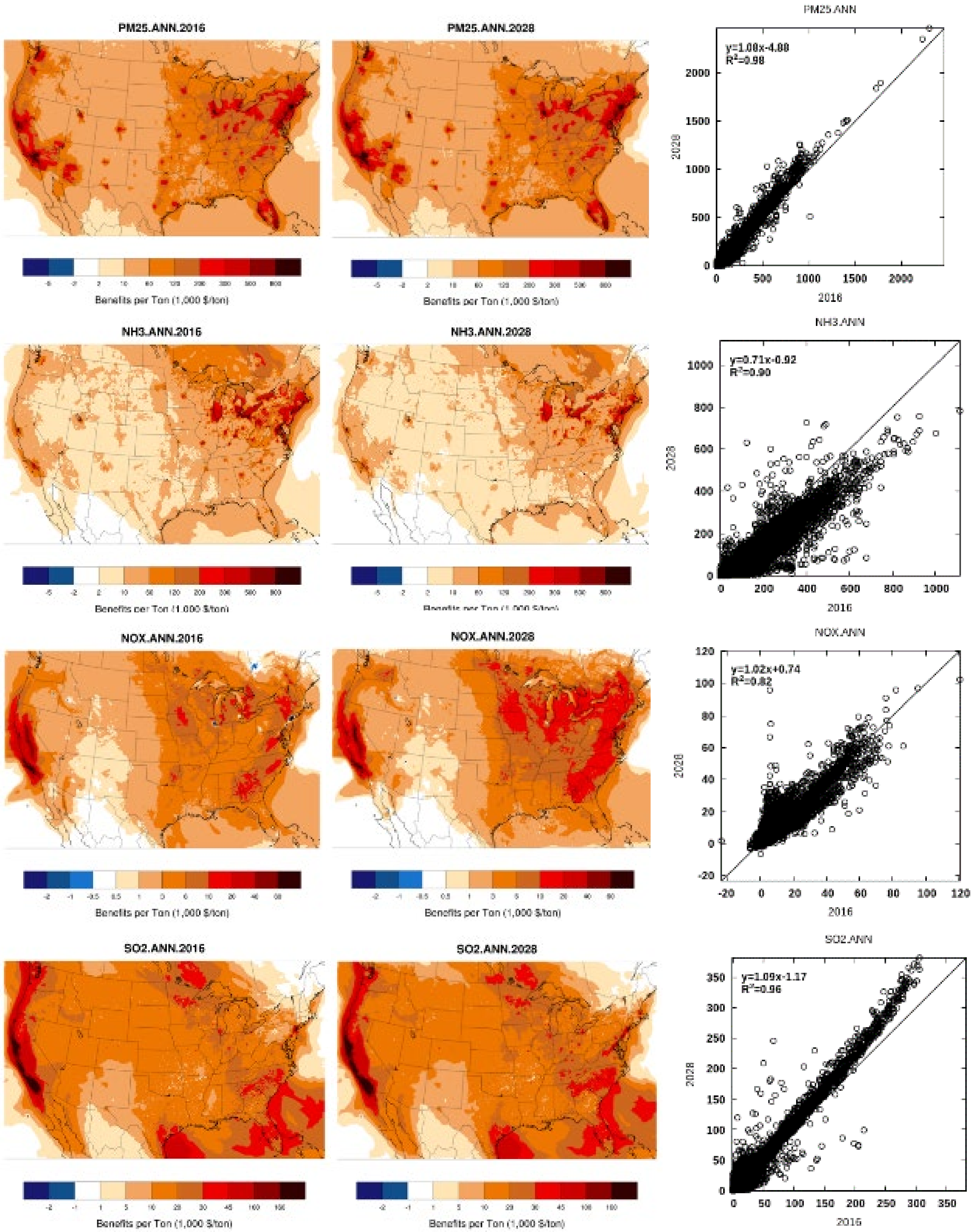

Figure A13. Comparison of BPTs for 2016 and 2028 inventories. Annual estimated BPTs are constructed from winter and summer simulations. Adjoint forcing terms for 2028 BPTs are adjusted based on concentrations in episodic simulations to better reflect the 2028 episode.

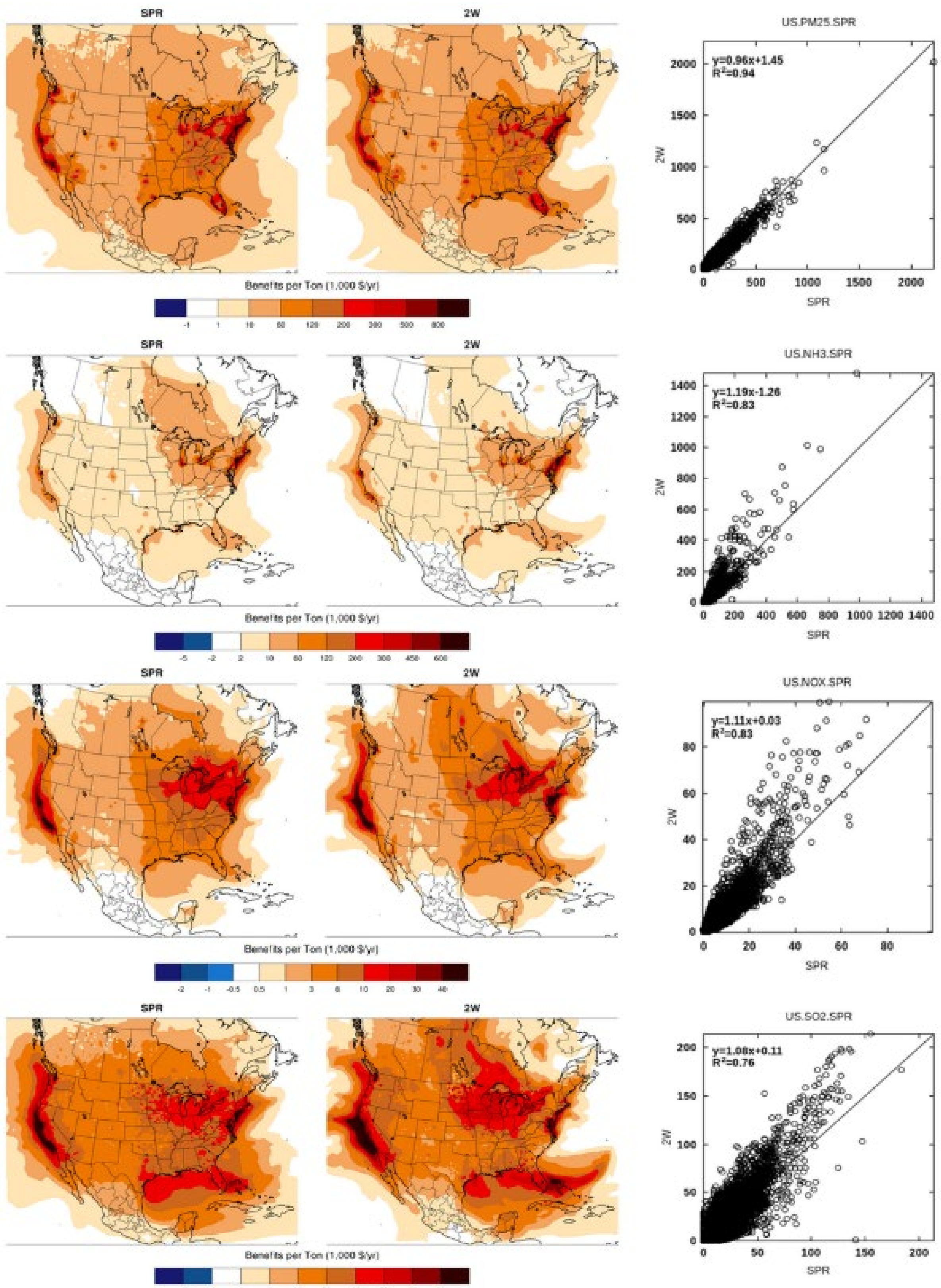

Figure A14. Episode selection uncertainty in BPTs, US, spring, GEMM CRF.

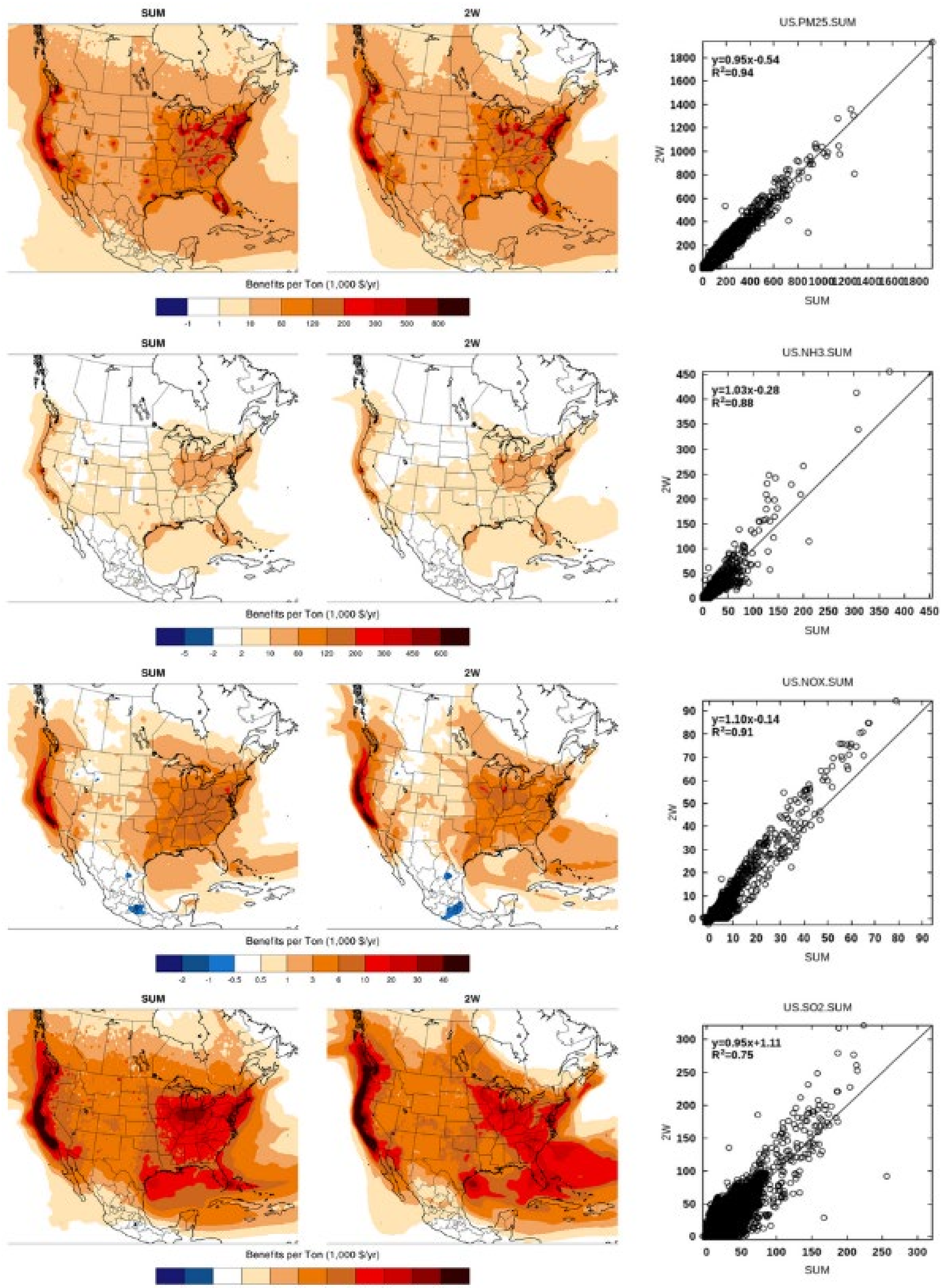

Figure A15. Episode selection uncertainty in BPTs, US, summer, GEMM CRF.

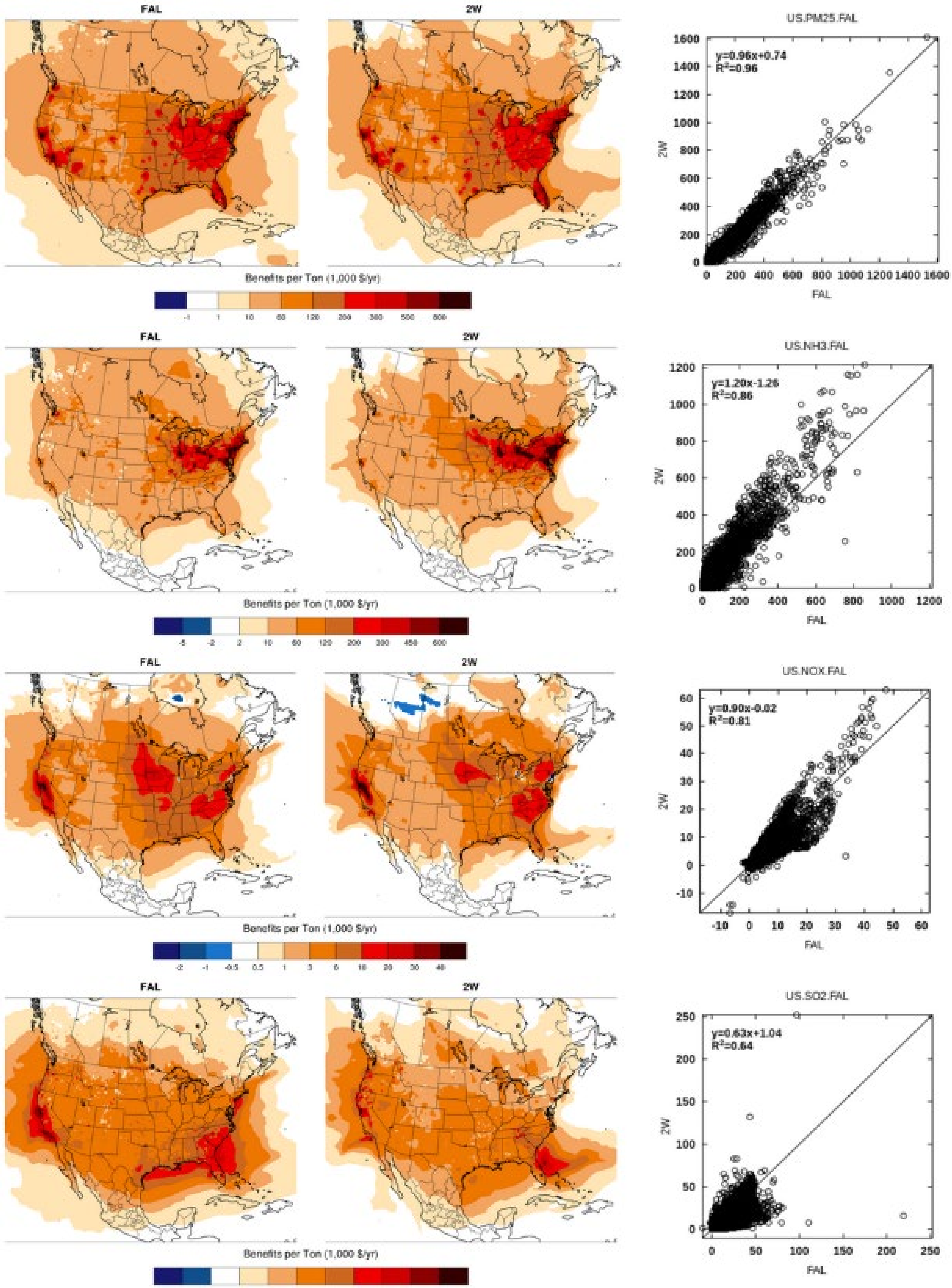

Figure A16. Episode selection uncertainty in BPTs, US, fall, GEMM CRF.

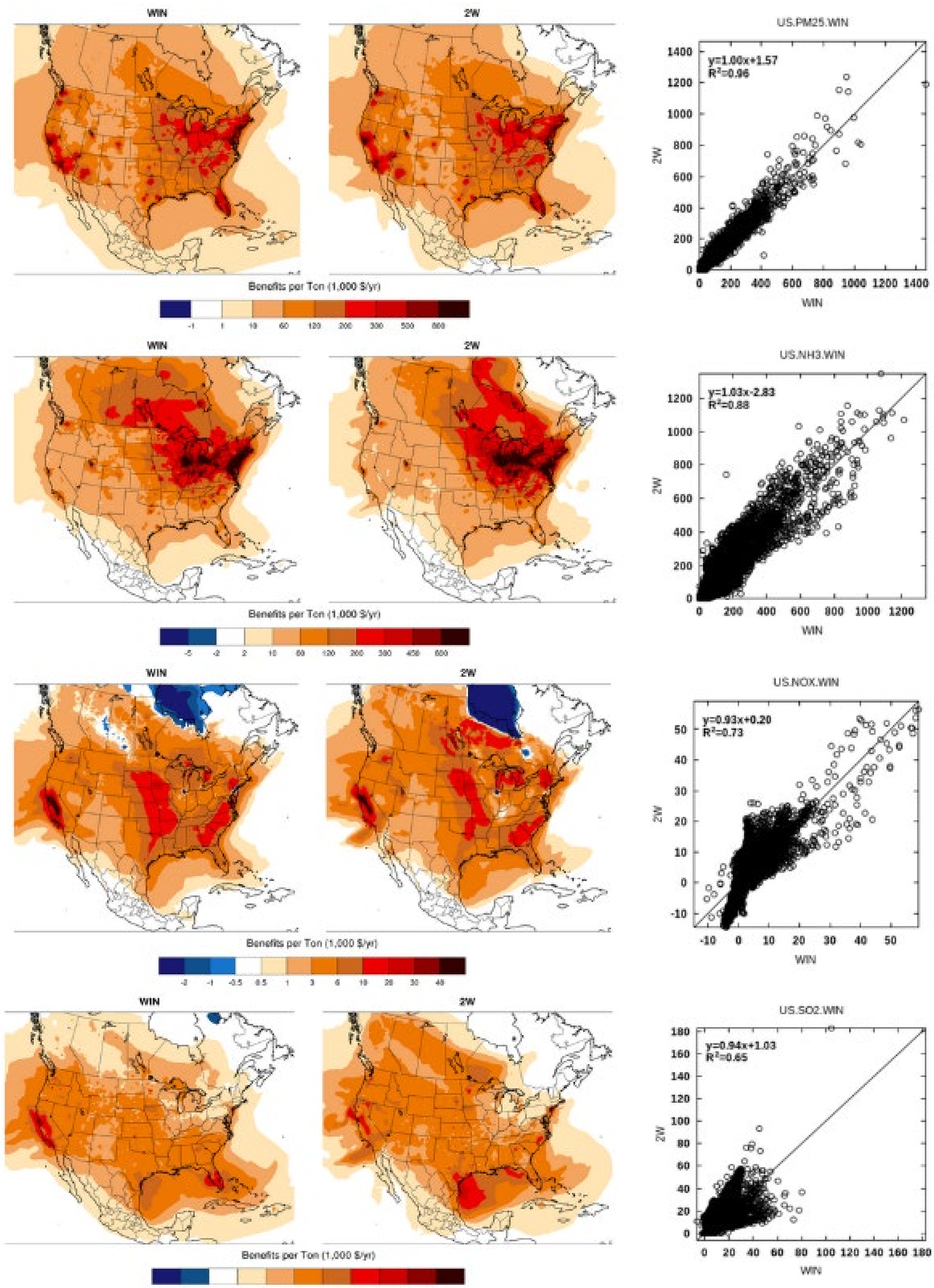

Figure A17: Episode selection uncertainty in BPTs, US, winter, GEMM CRF.

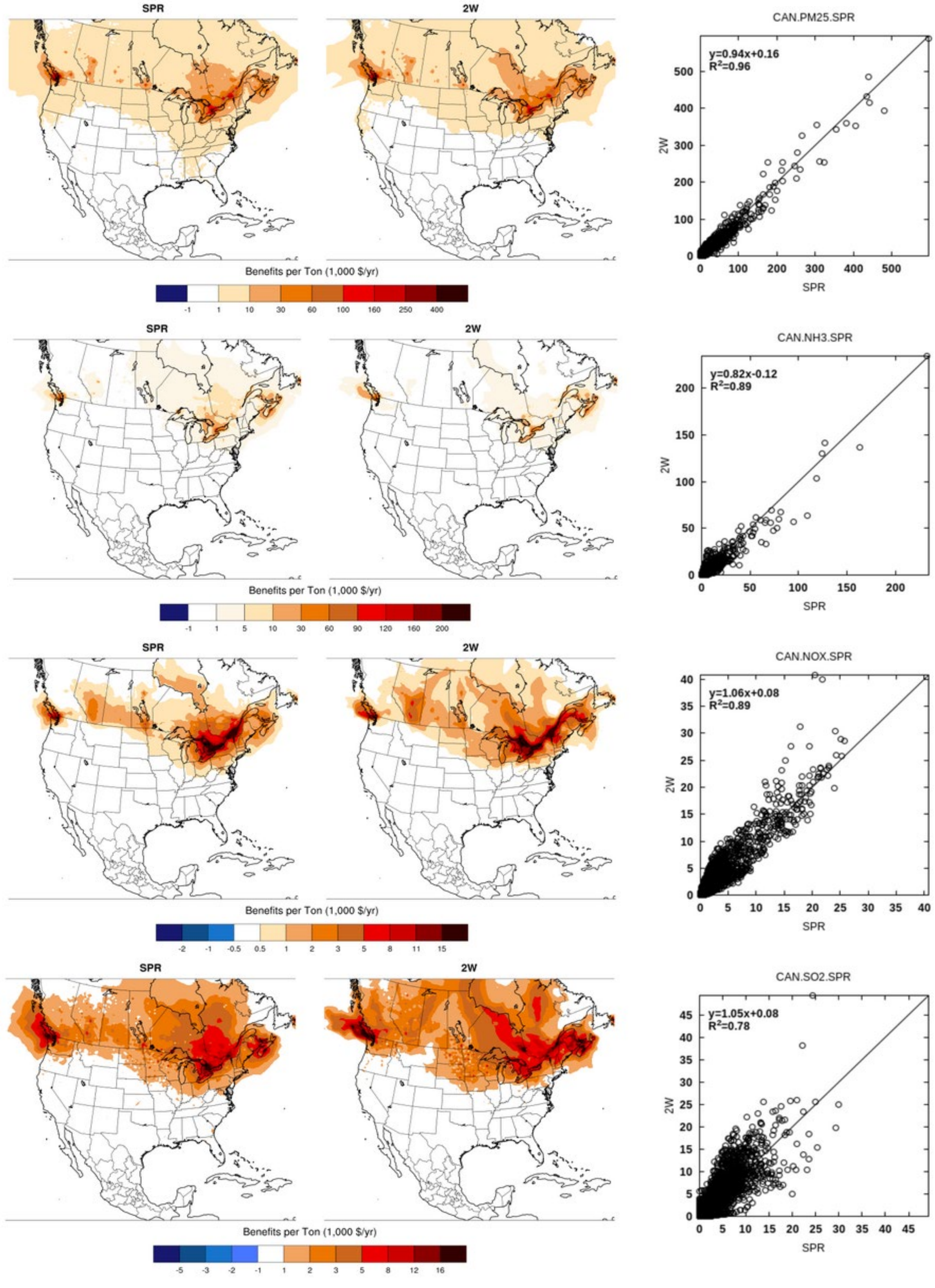

Figure A18. Episode selection uncertainty in BPTs, Canada, spring, GEMM CRF.

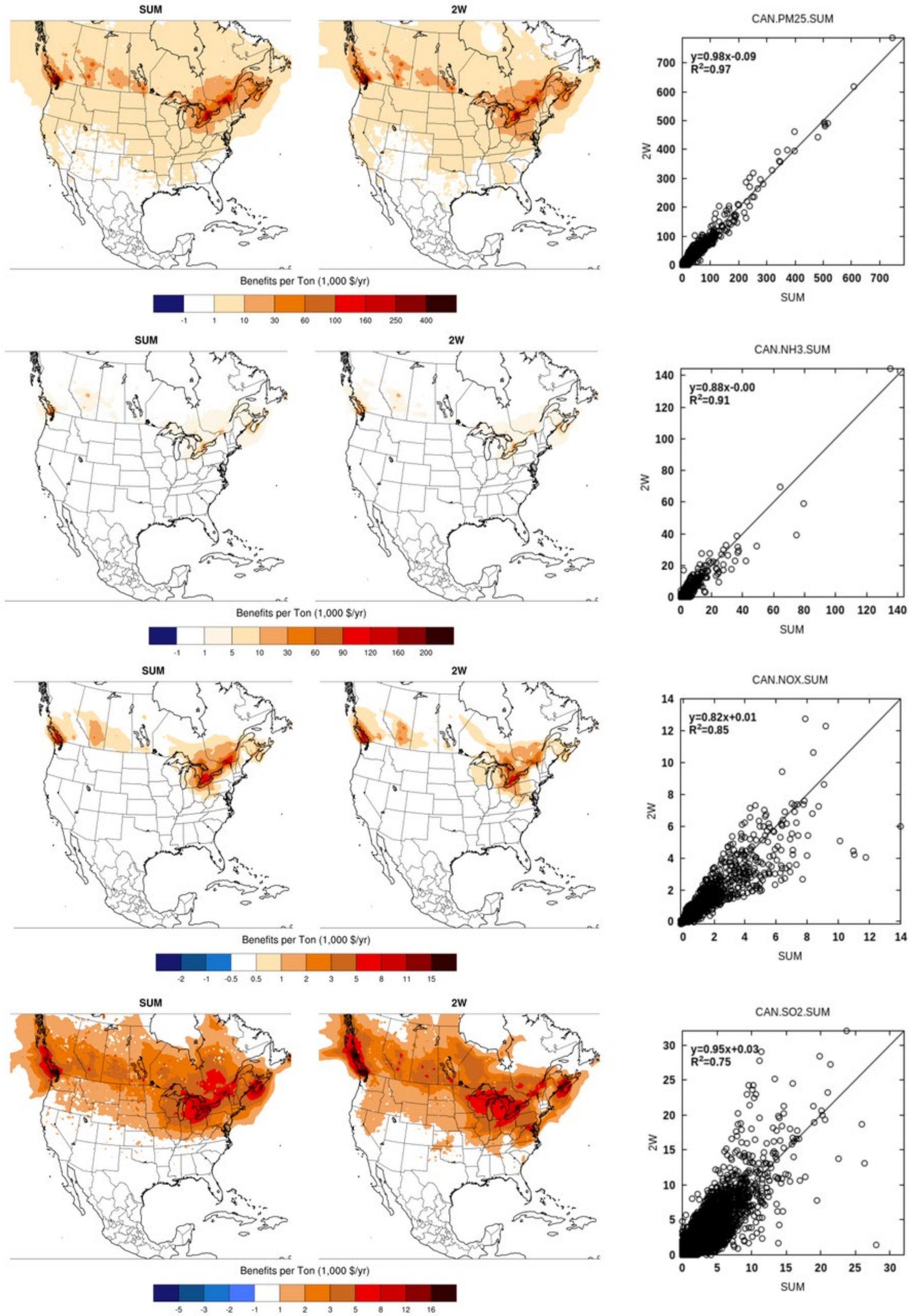

Figure A19. Episode selection uncertainty in BPTs, Canada, summer, GEMM CRF.

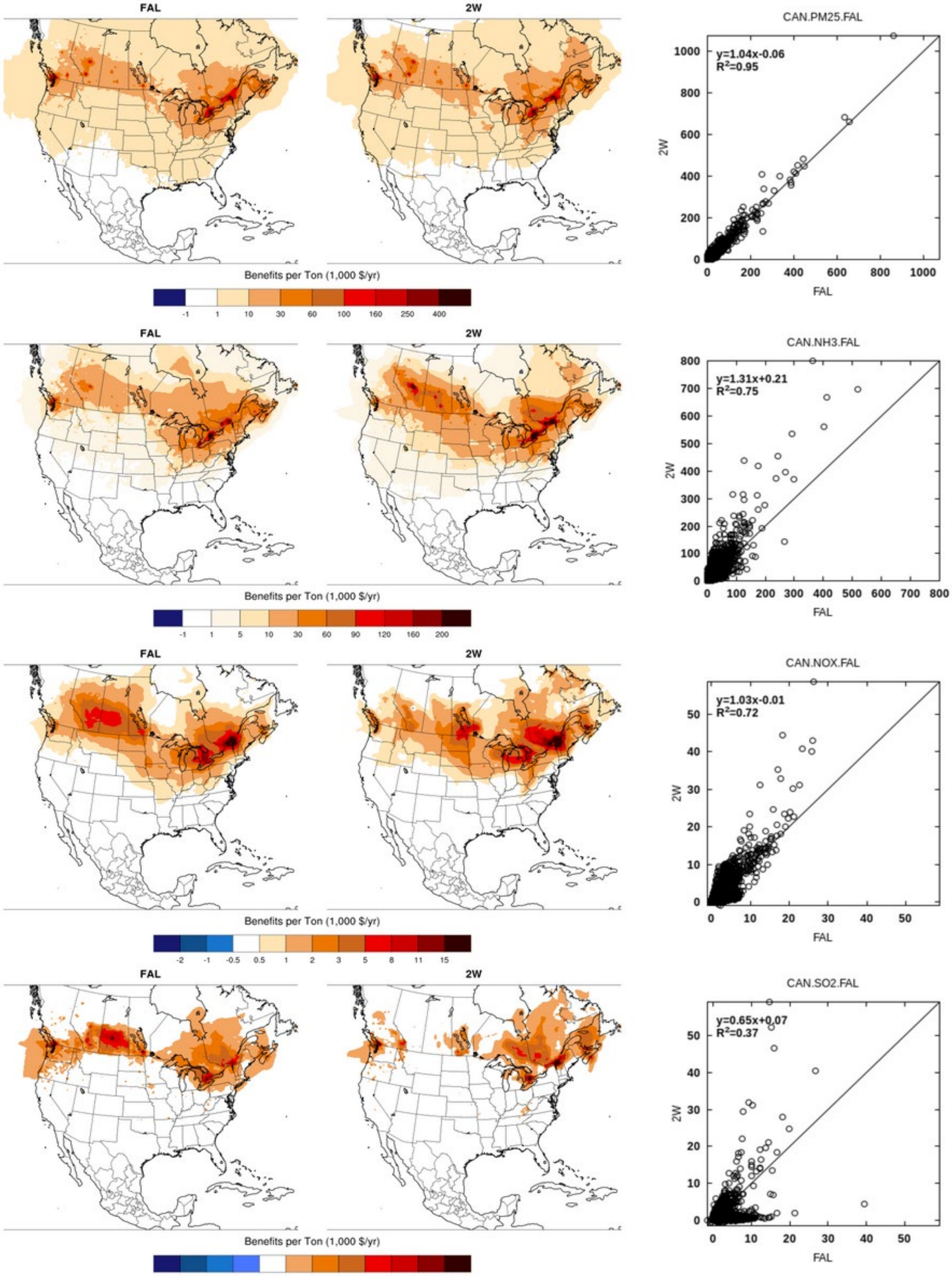

Figure A20. Episode selection uncertainty in BPTs, Canada, fall, GEMM CRF.

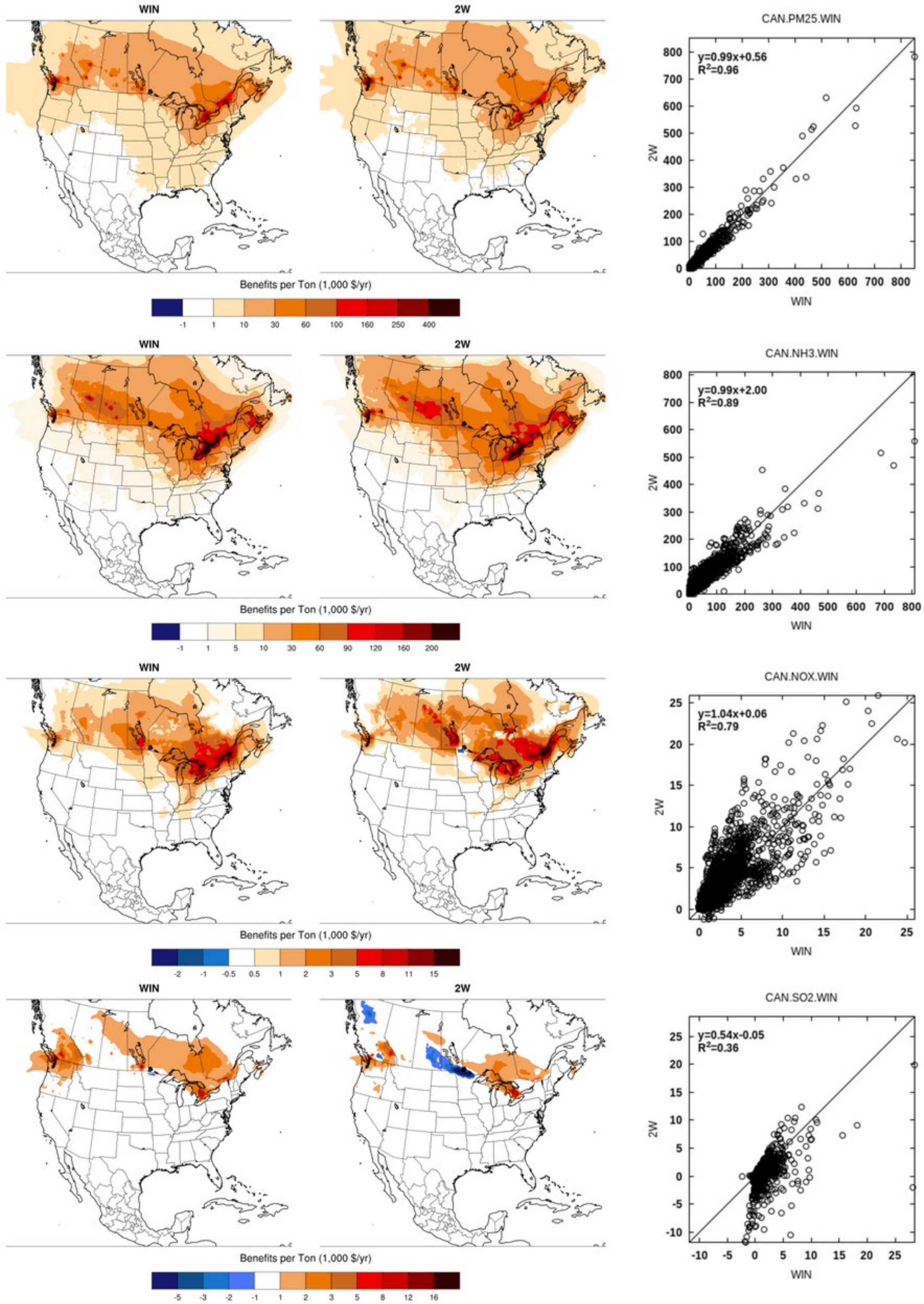

Figure A21. Episode selection uncertainty in BPTs, Canada, winter, GEMM CRF.

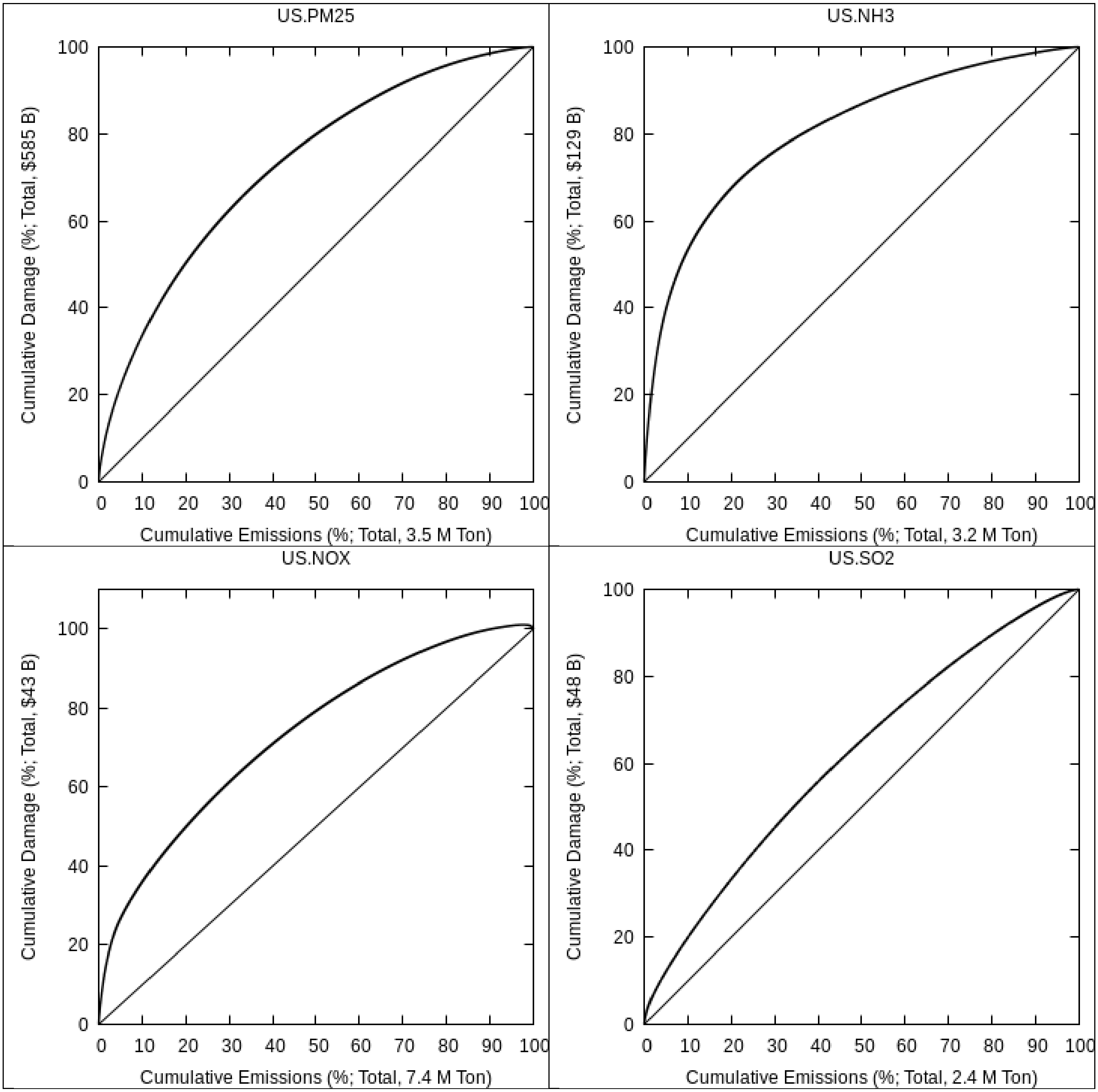

Figure A22. Lorenz curves for the US display the extent of disparity in health burden of emissions across the two countries. The vertical and horizontal axes show cumulative burden and cumulative emission fractions, respectively.

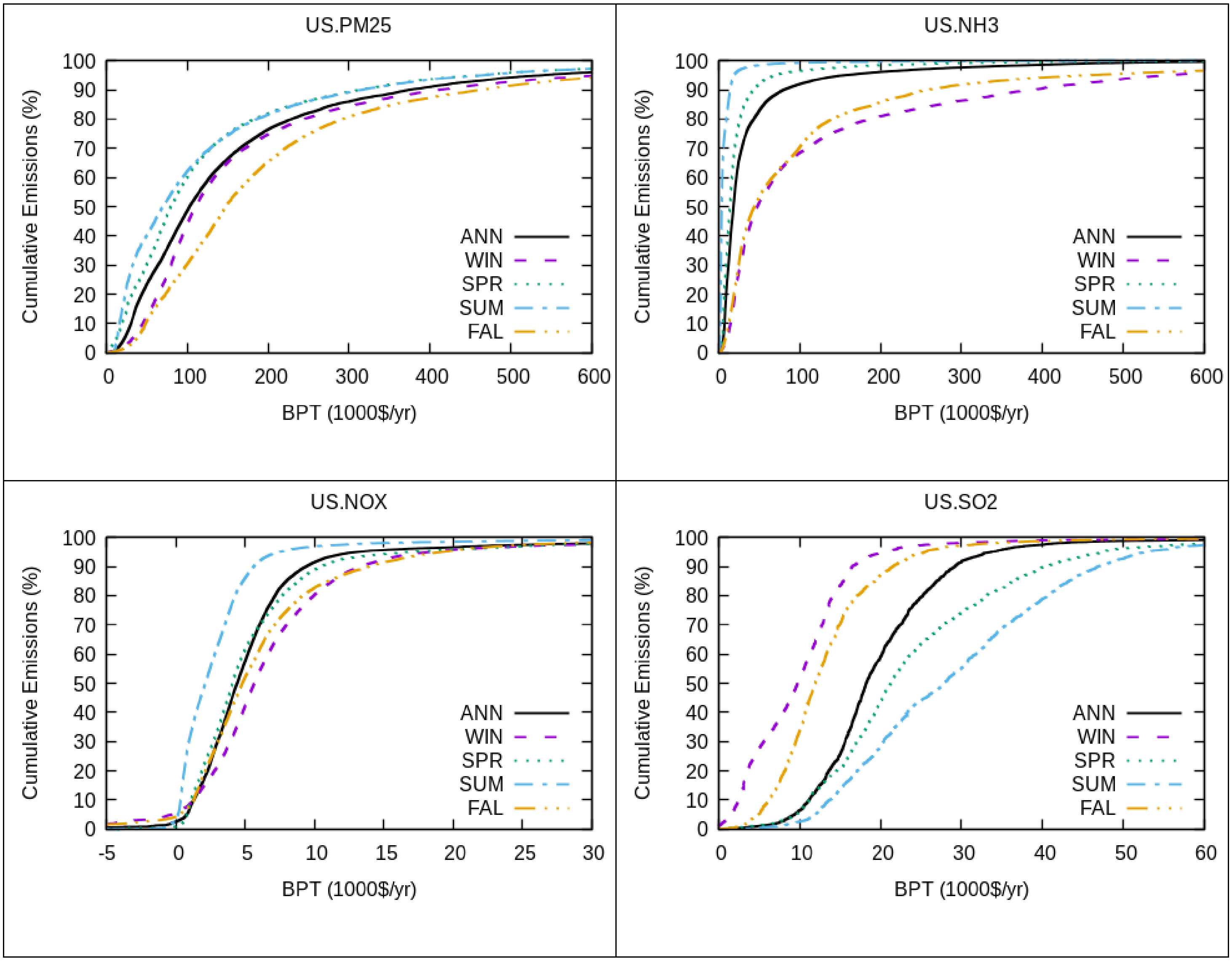

Figure A23. Cumulative distribution function for annual and seasonal BPT estimates in the US, all emissions, GEMM CRF.

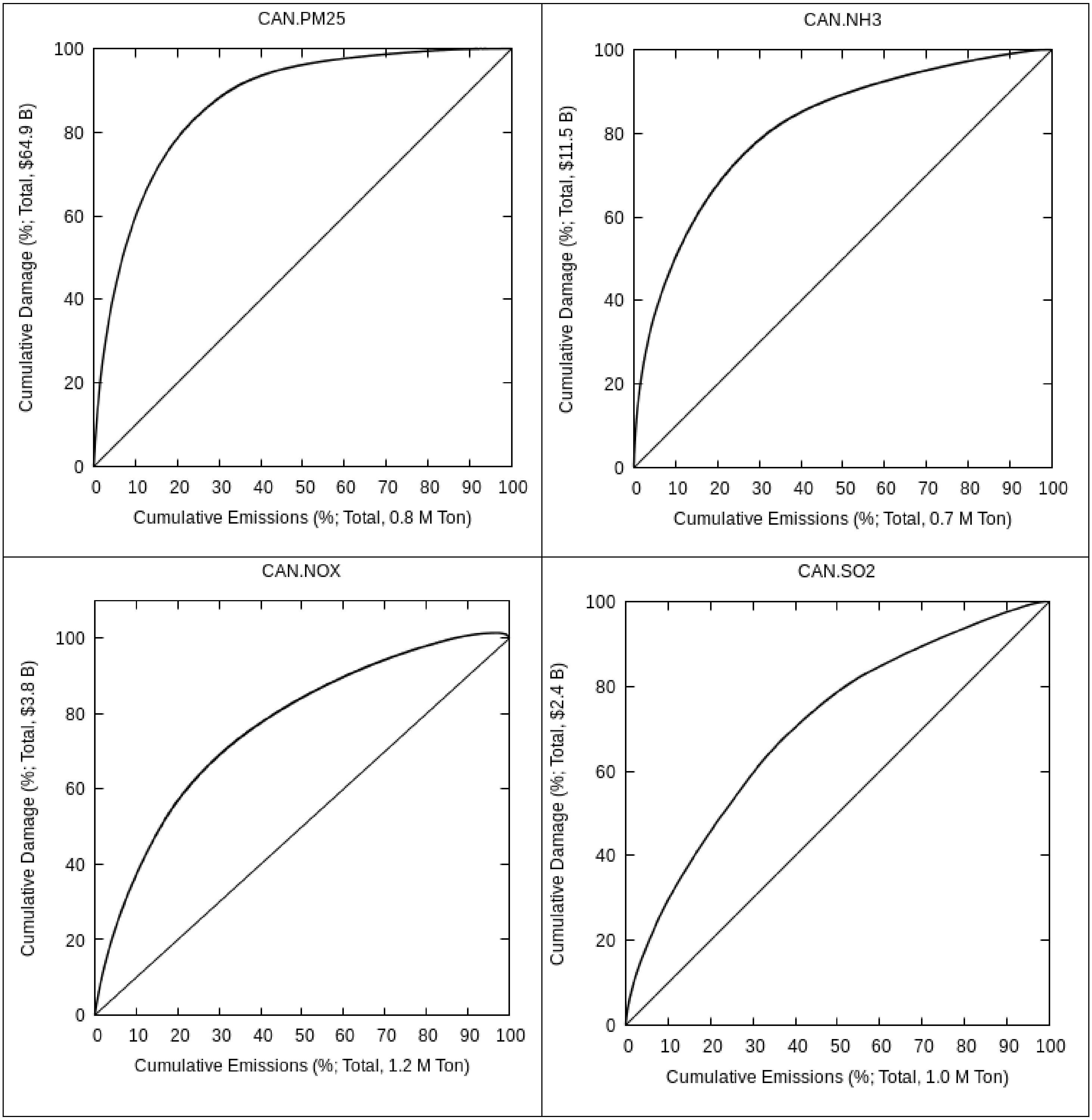

Figure A24. Lorenz curves for Canada display the extent of disparity in health burden of emissions across the two countries. The vertical and horizontal axes show cumulative burden and cumulative emission fractions, respectively.

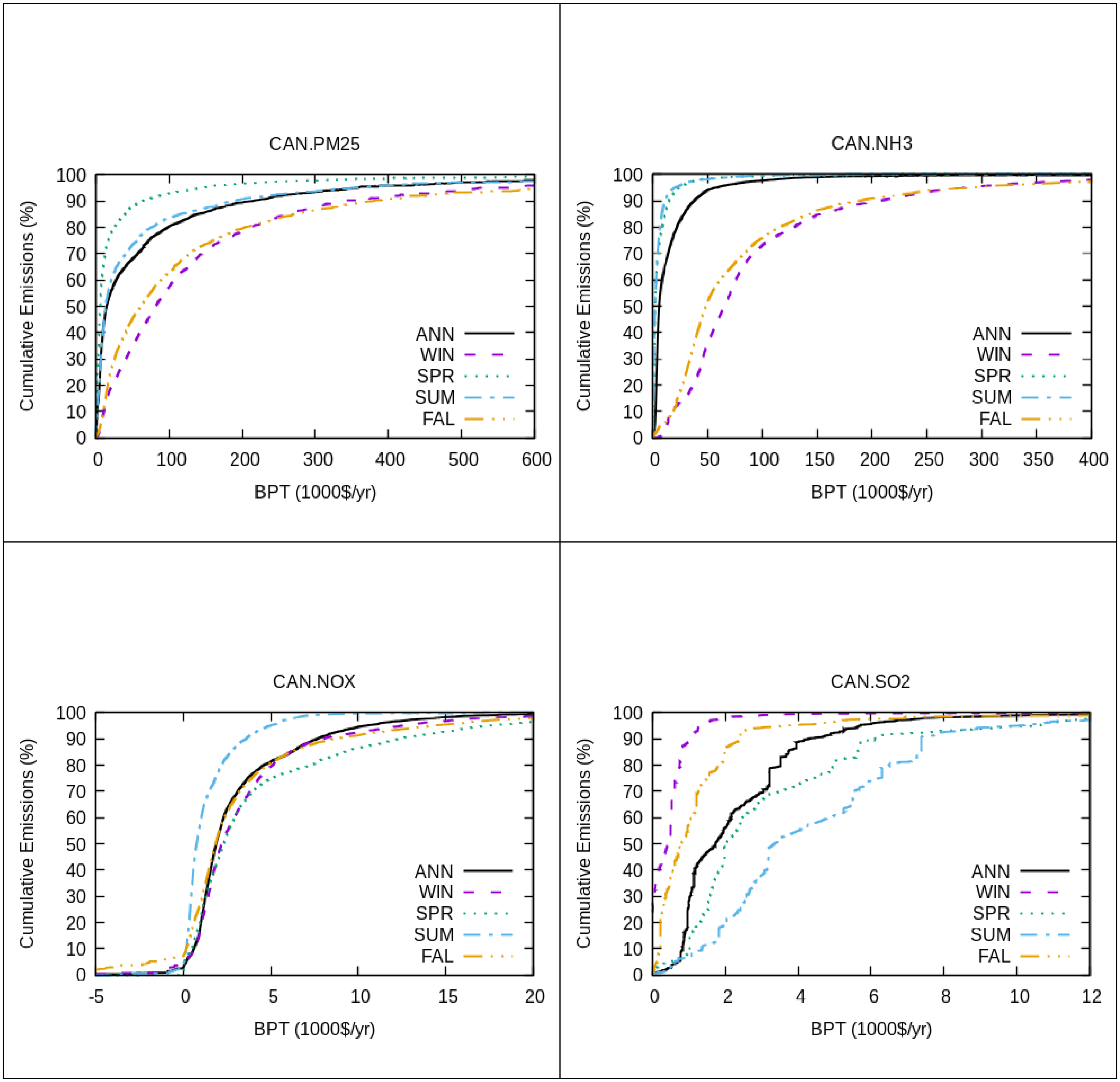

Figure A25. Cumulative distribution function for annual and seasonal BPT estimates in Canada, all emissions, GEMM CRF.

Appendix B: Cobenefits

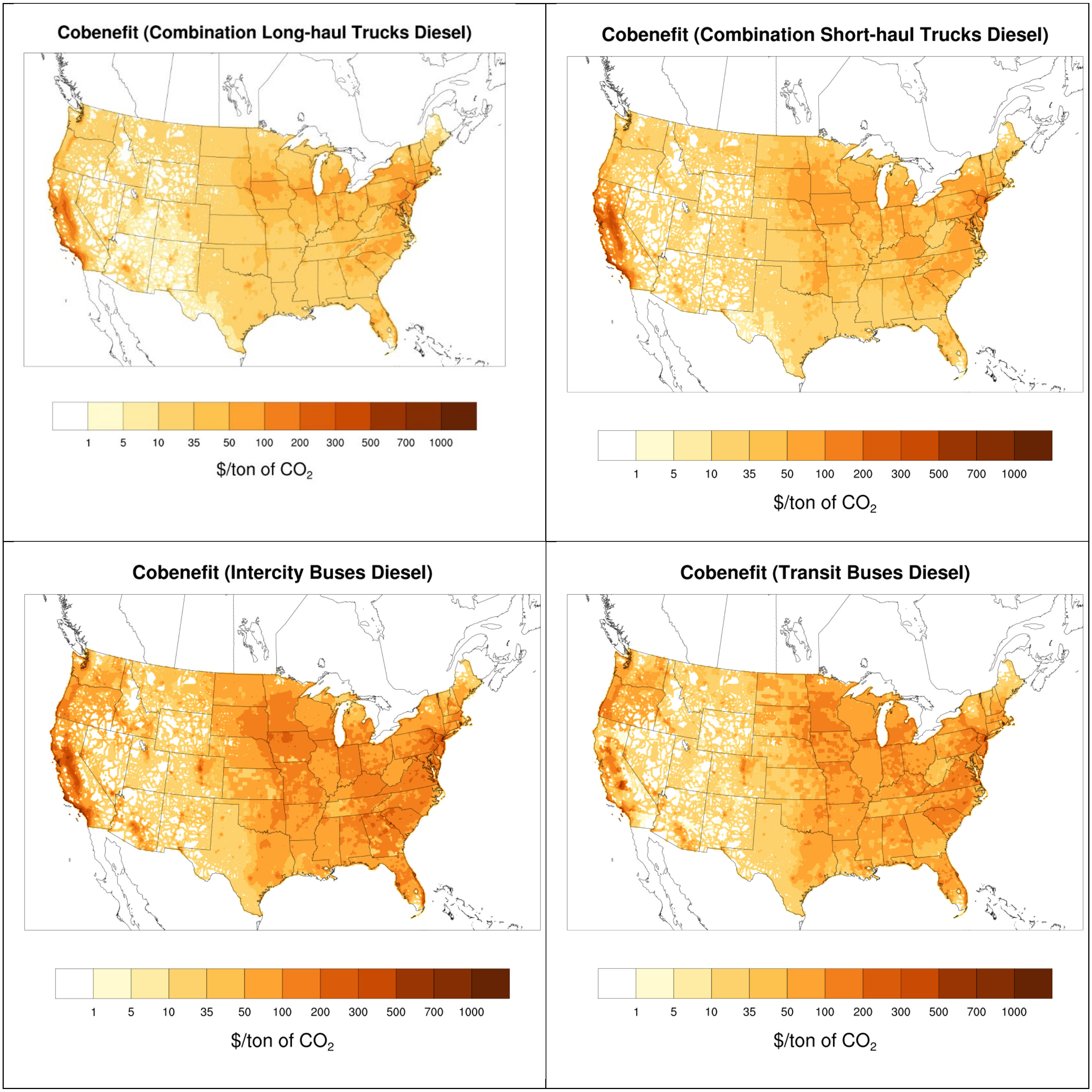

Figure B1. Cobenefits for subsectors of on-road diesel vehicles (*continues next page*).

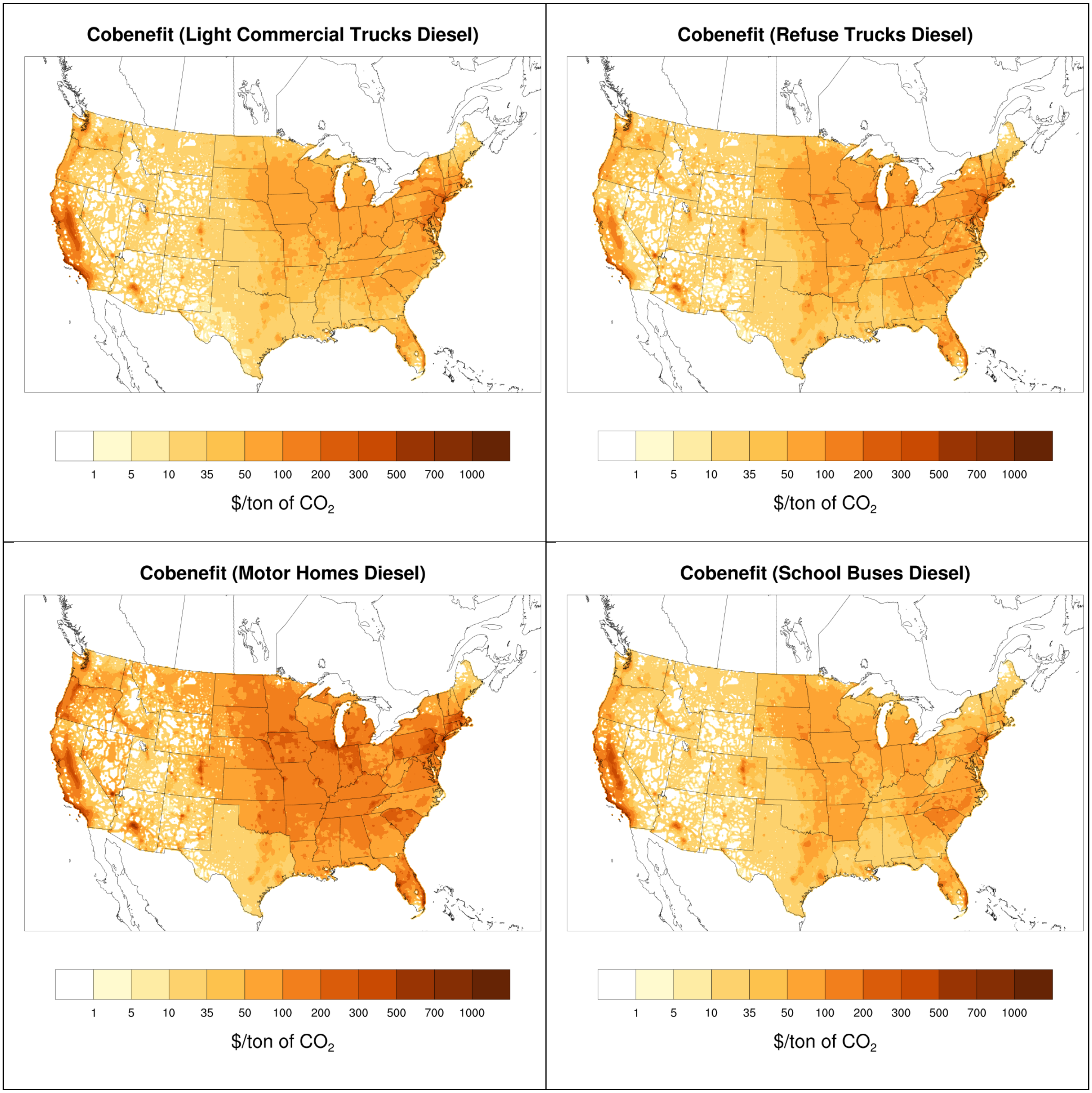

Figure B1 (*continued*). Cobenefits for subsectors of on-road diesel vehicles (*continues next page*).

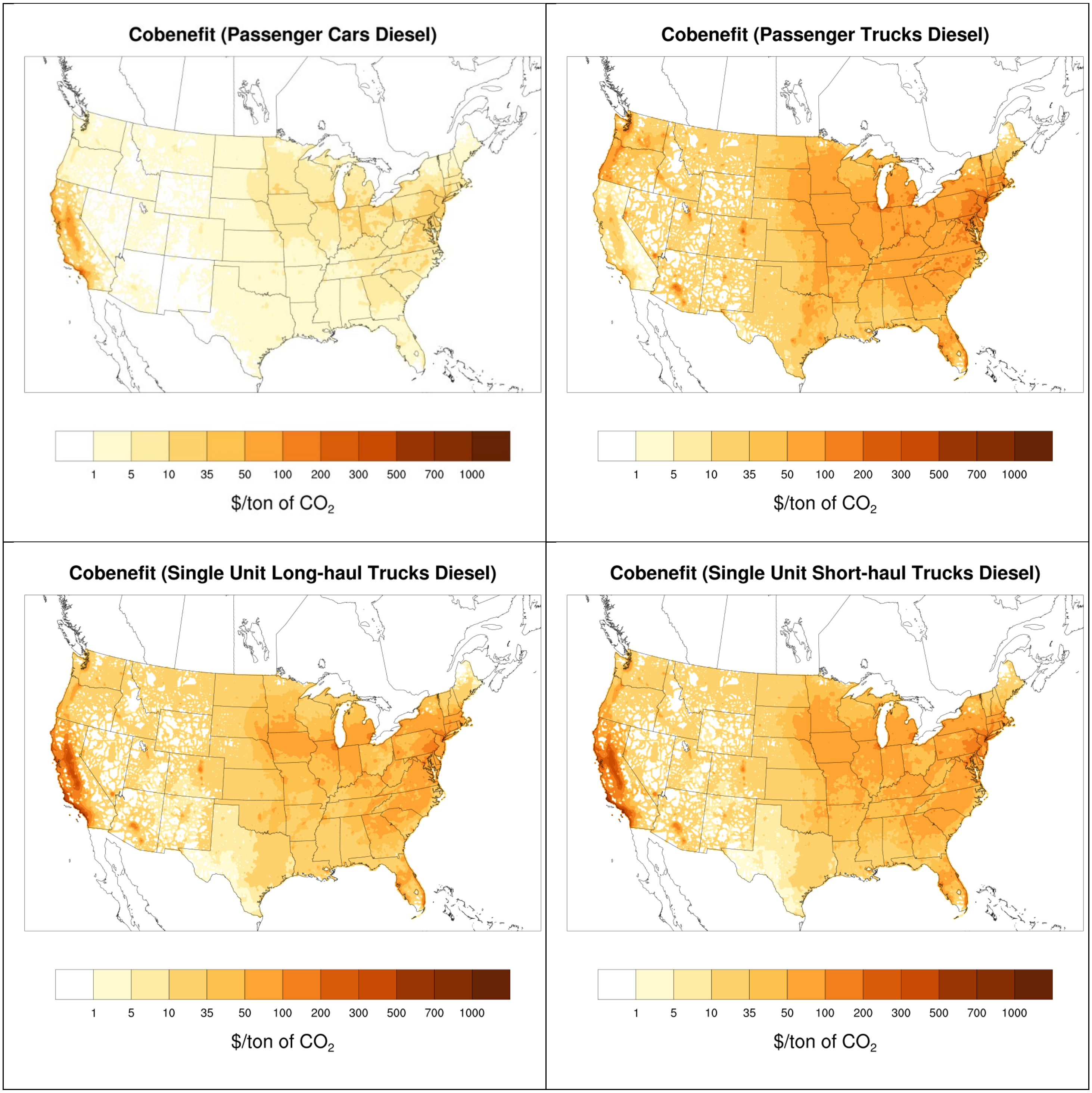

Figure B1 (*continued*). Cobenefits for subsectors of on-road diesel vehicles.

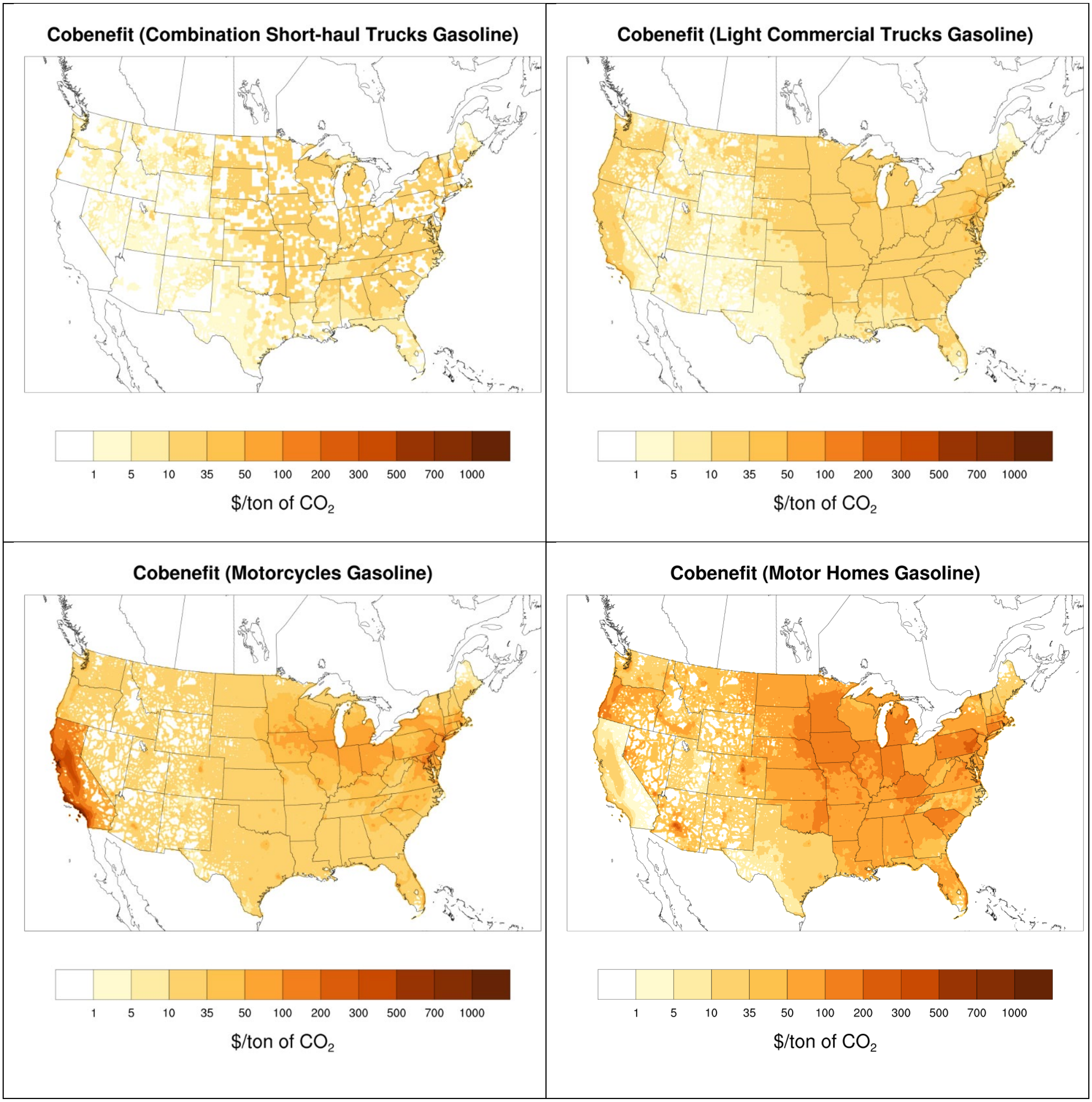

Figure B2. Cobenefits for subsectors of on-road gasoline vehicles (*continues next page*).

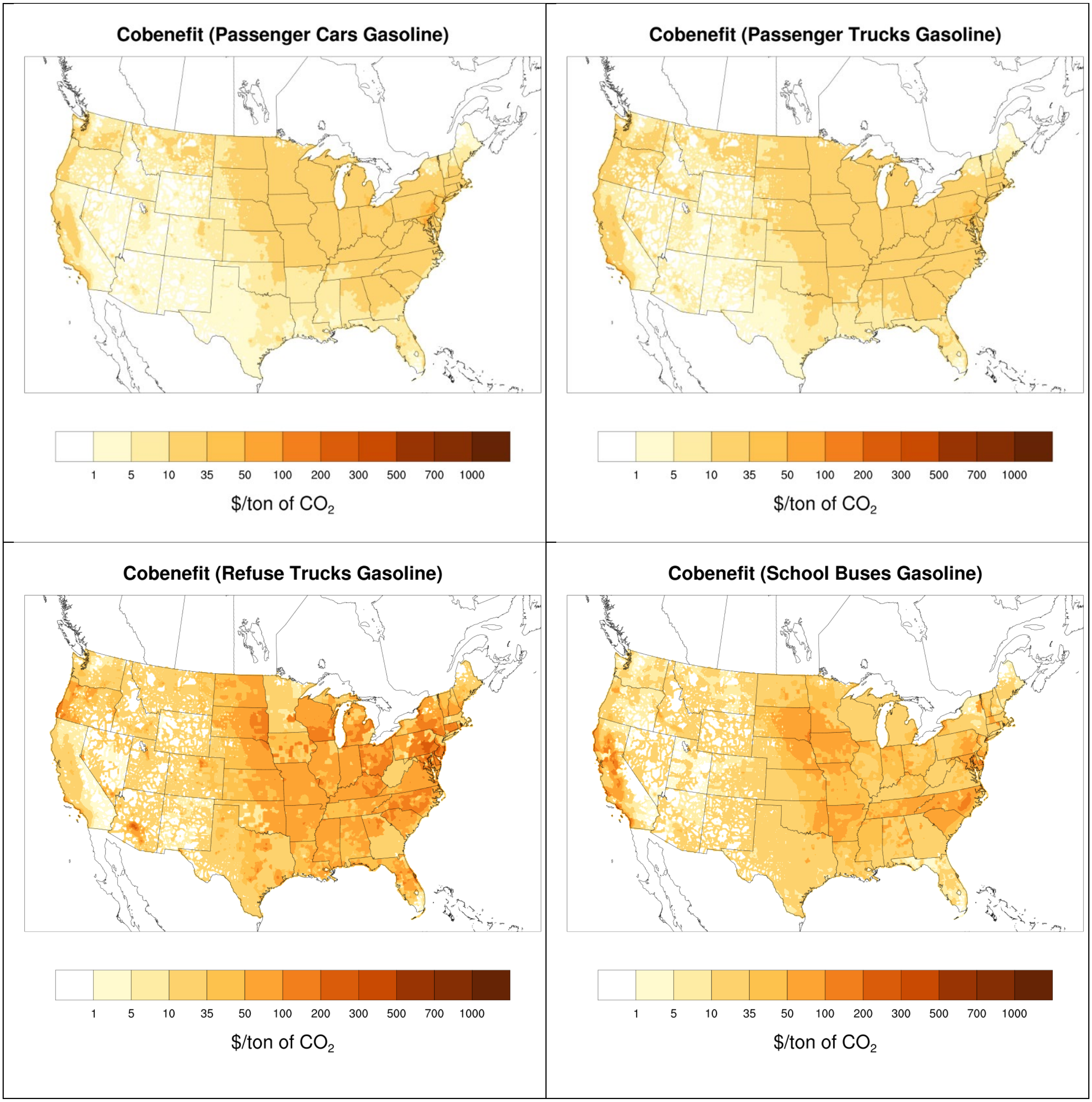

Figure B2 (continued). Cobenefits for subsectors of on-road gasoline vehicles (*continues next page*).

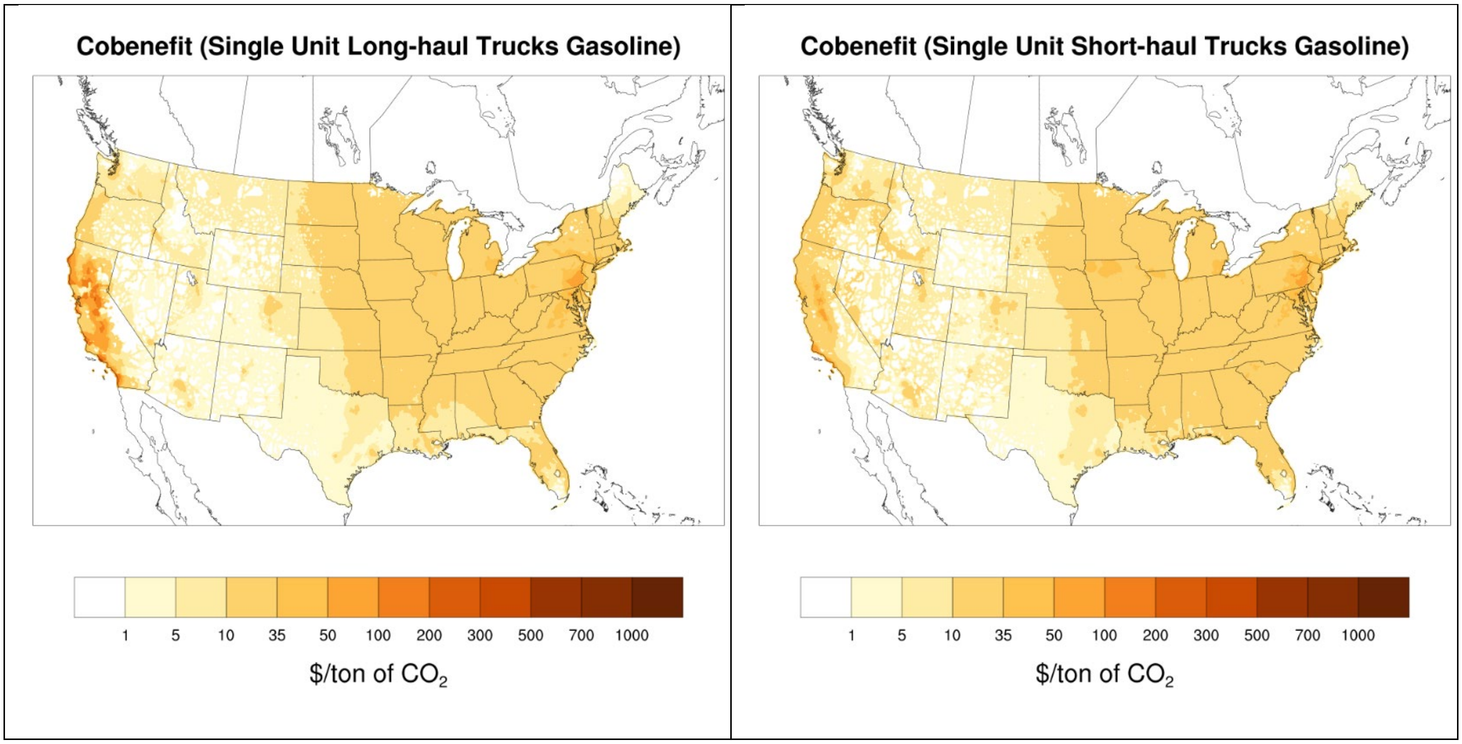

Figure B2 (*continued*). Cobenefits for subsectors of on-road gasoline vehicles.

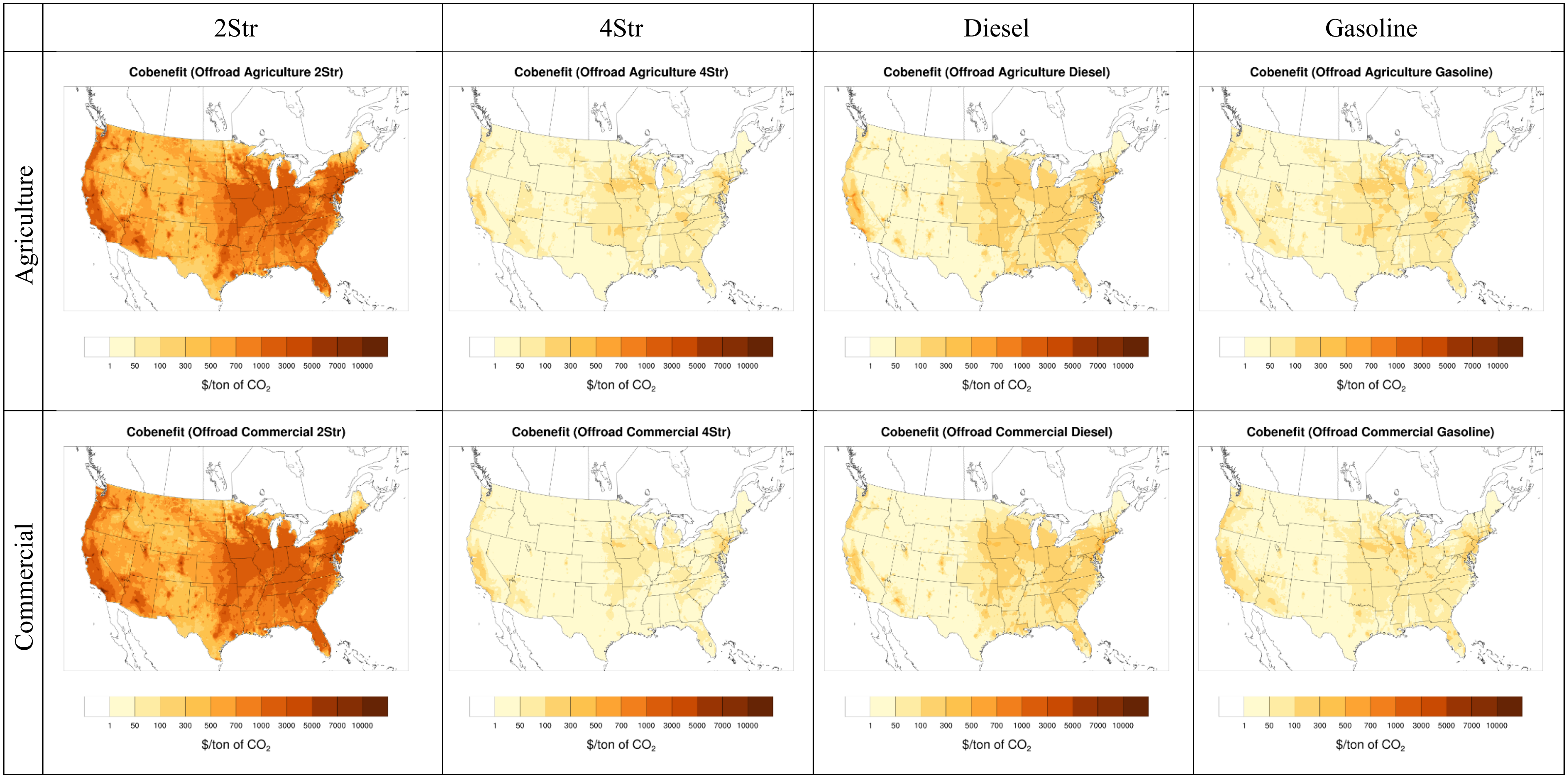

Figure B3. Cobenefits for 2-stroke and 4-stroke, gasoline, and diesel off-road engines in the US (*continues next page*).

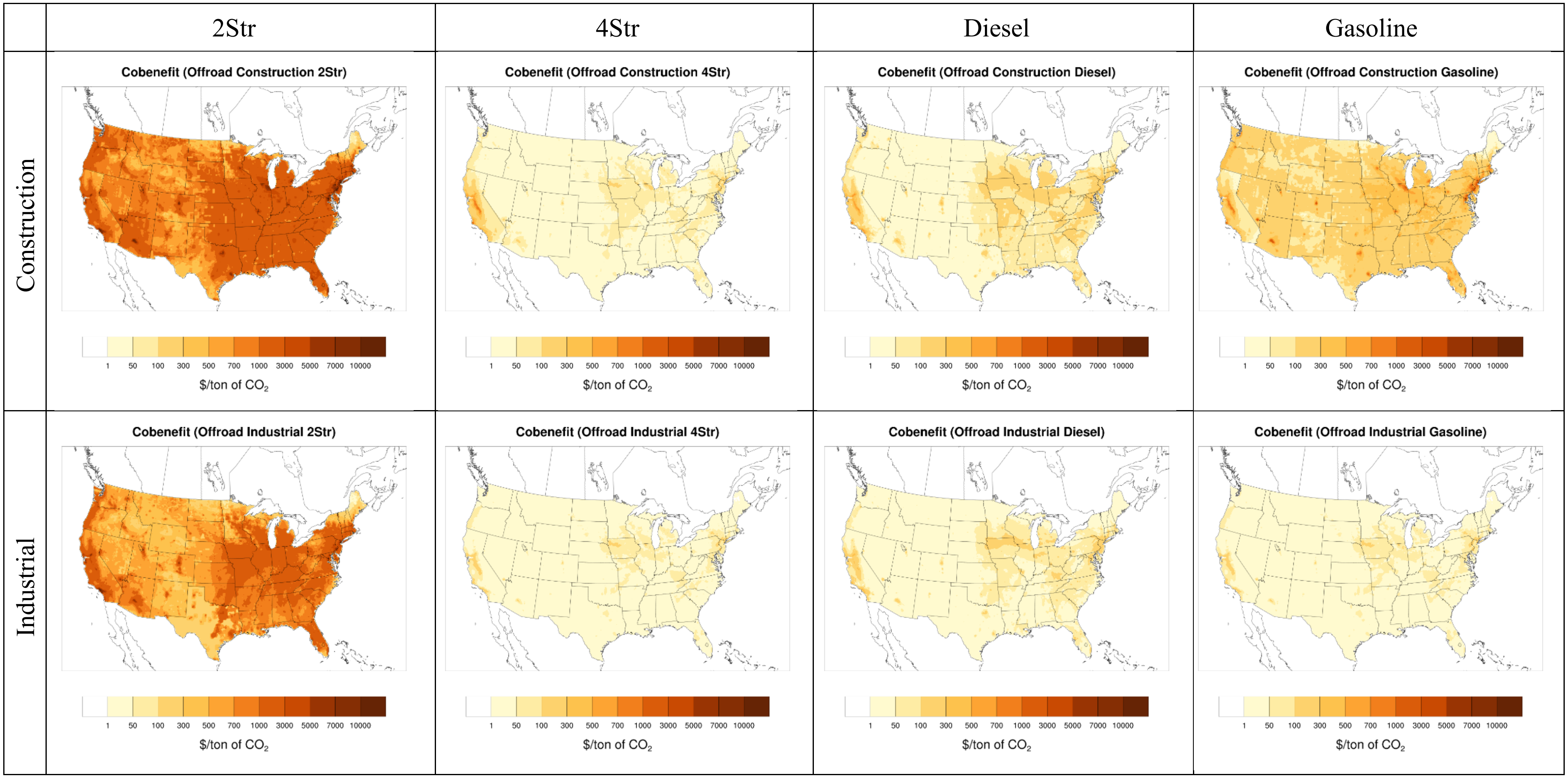

Figure B3 (*continued*). Cobenefits for 2-stroke and 4-stroke, gasoline, and diesel off-road engines in the US (*continues next page*).

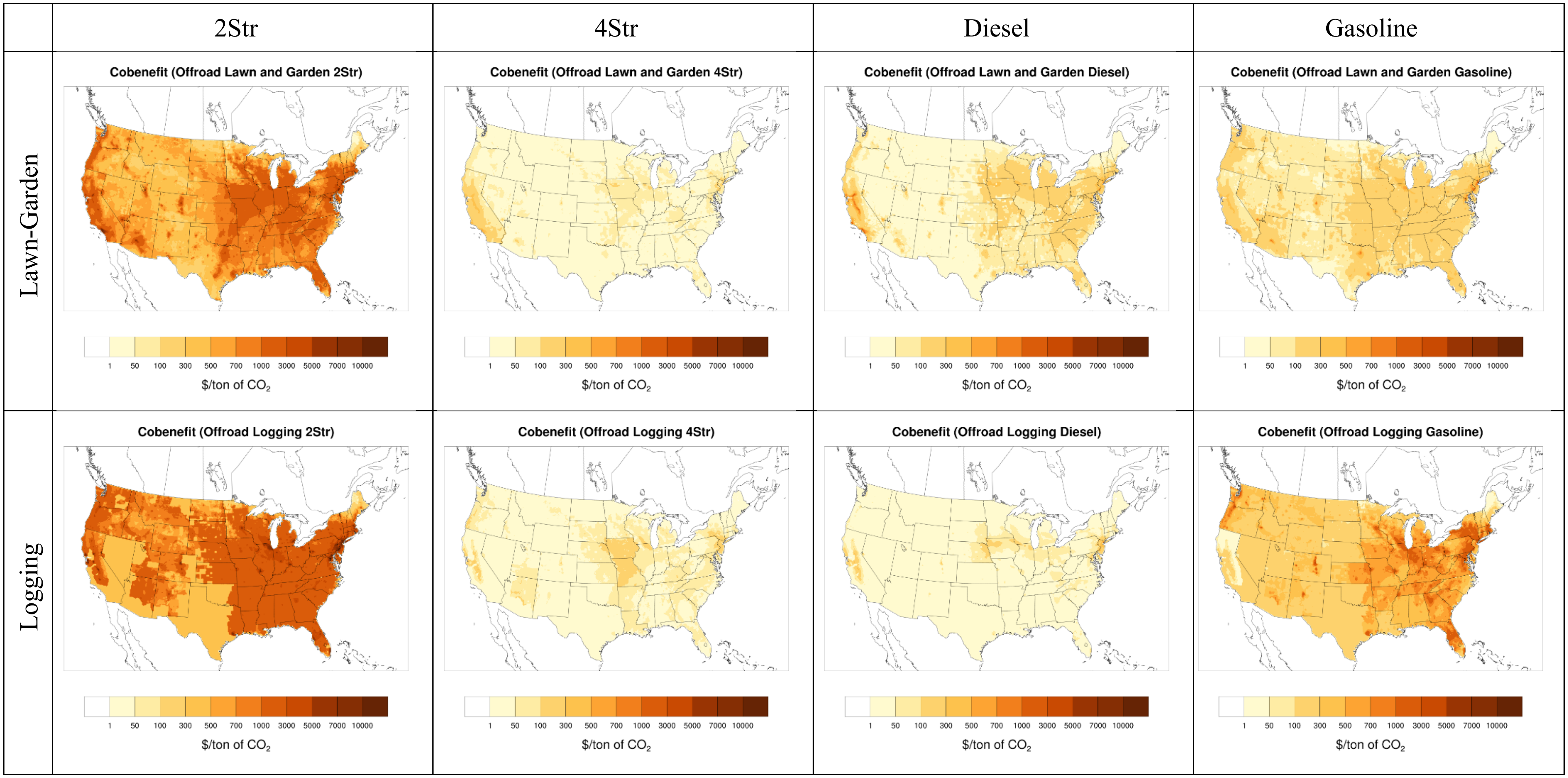

Figure B3 (*continued*). Cobenefits for 2-stroke and 4-stroke, gasoline, and diesel off-road engines in the US (*continues next page*).

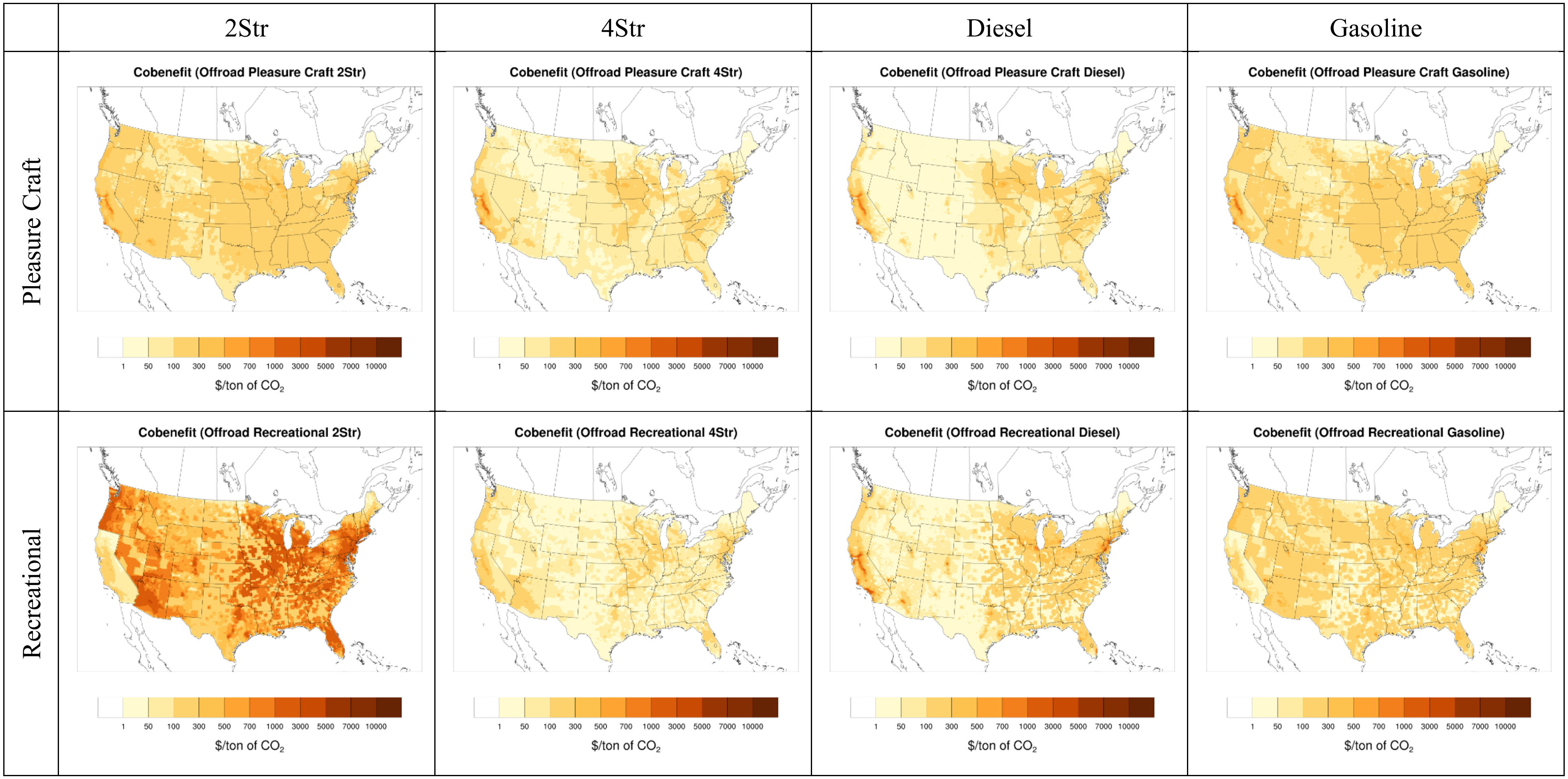

Figure B3 (*continued*). Cobenefits for 2-stroke and 4-stroke, gasoline, and diesel off-road engines in the US

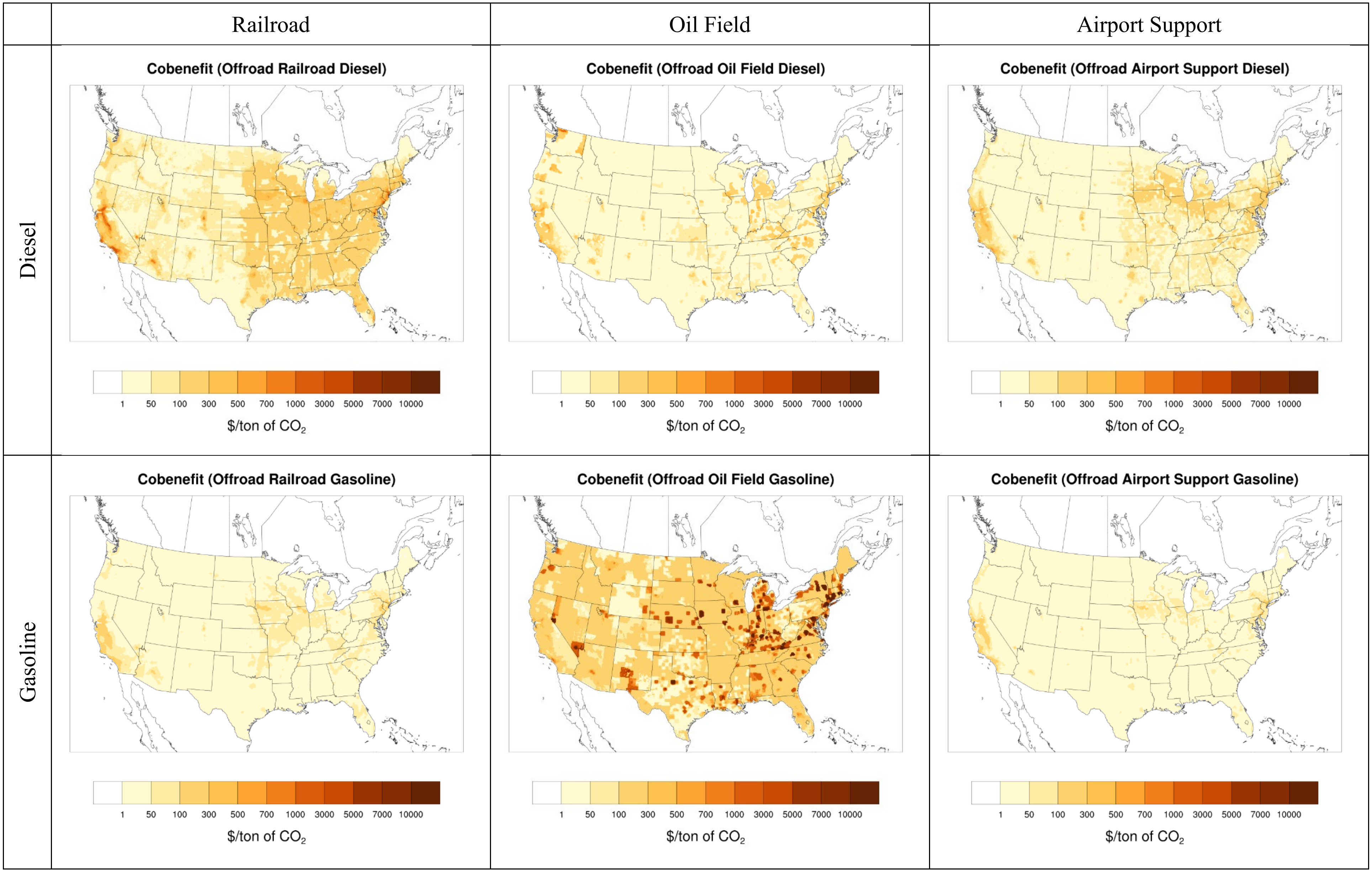

Figure B4. Cobenefits for gasoline and diesel off-road engines in railroad, oilfield, and airport support subsectors of off-road engines in the US

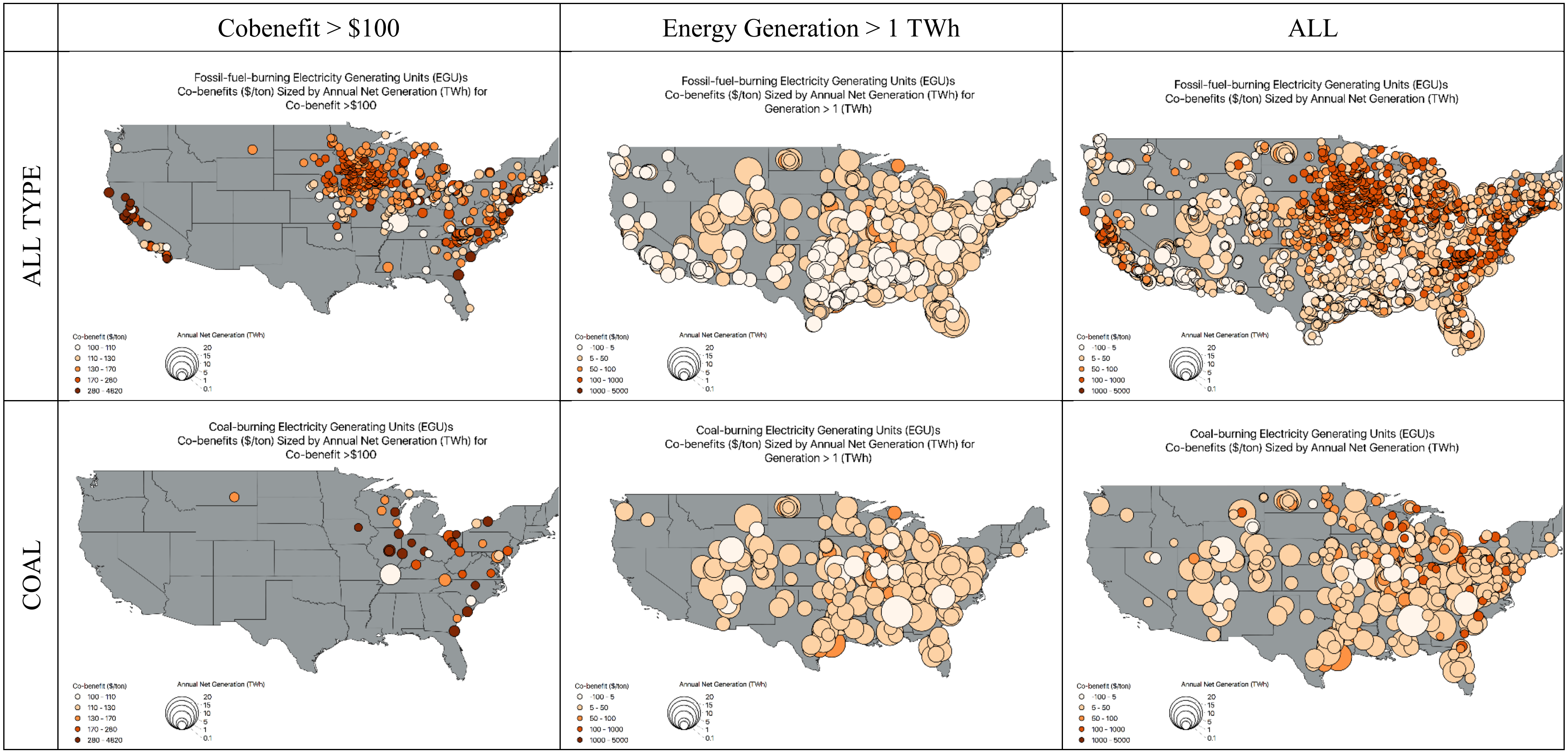

Figure B5. Cobenefits for thermal electricity generation in the US from coal, natural gas, and other fuels (*continues next page*).

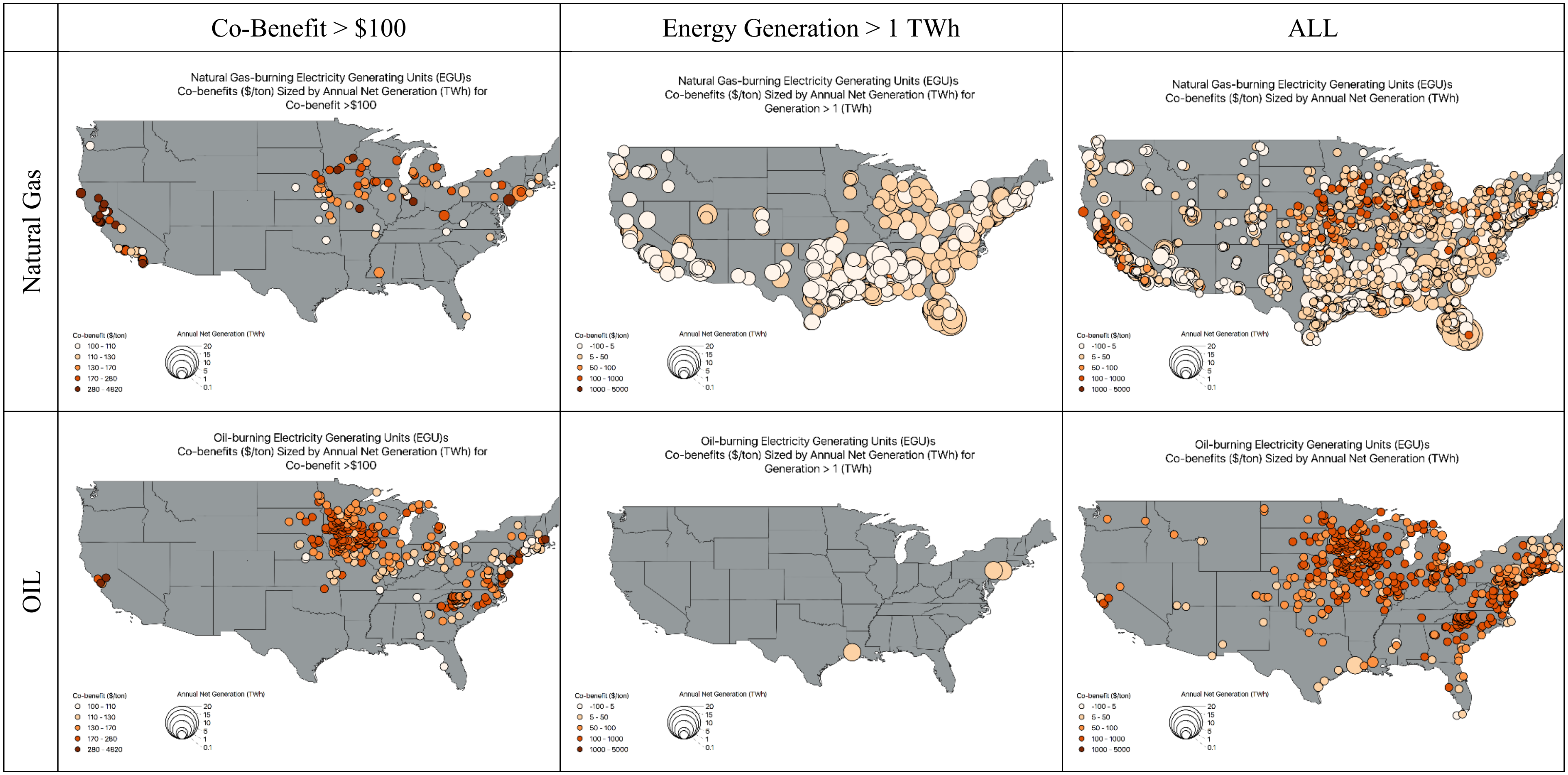

Figure B5 (*continued*). Cobenefits for thermal electricity generation in the US from coal, natural gas, and other fuels.

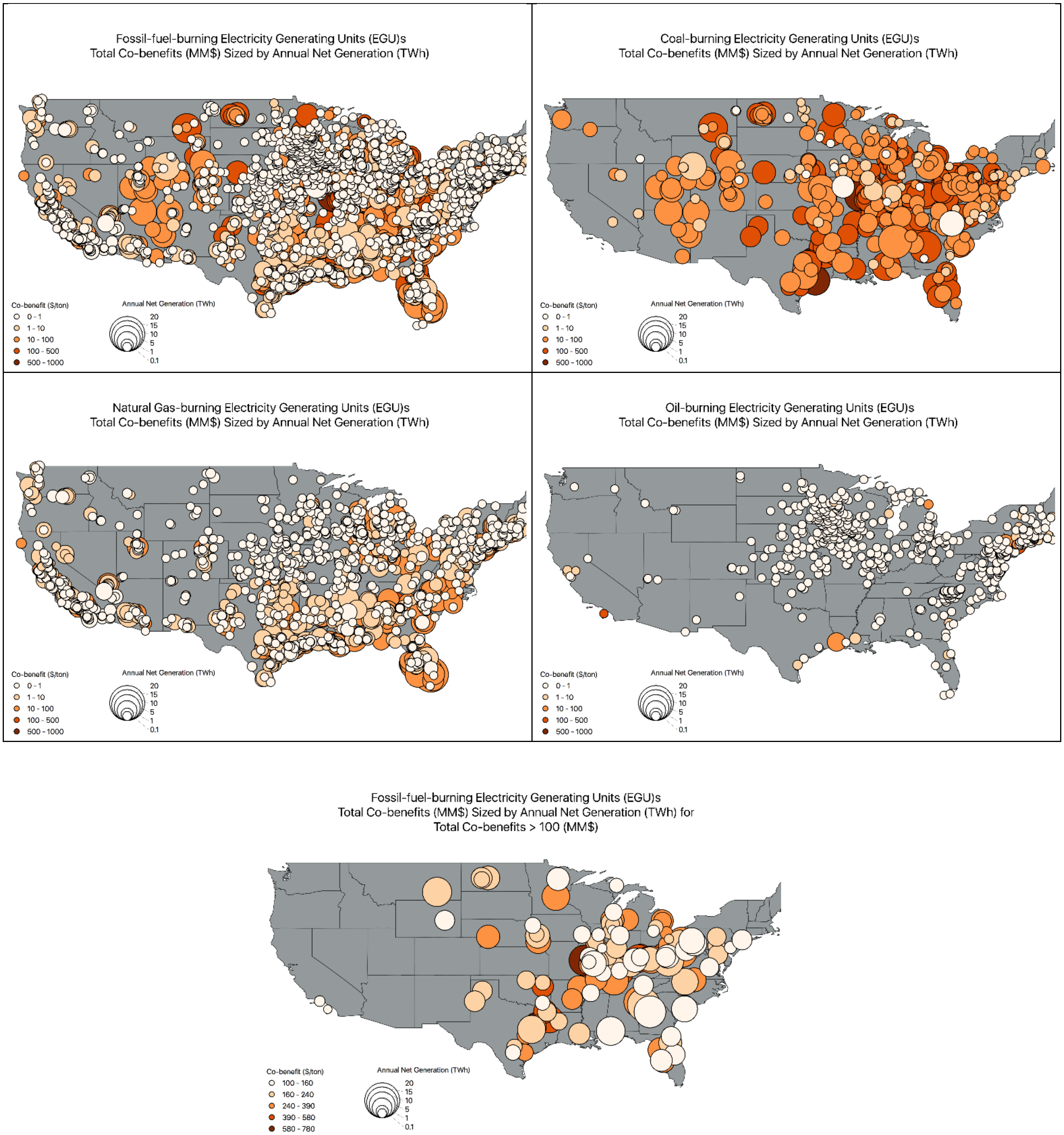

Figure B6. Total burden estimates for thermal electricity generation in the US from coal, natural gas, and other fuels.

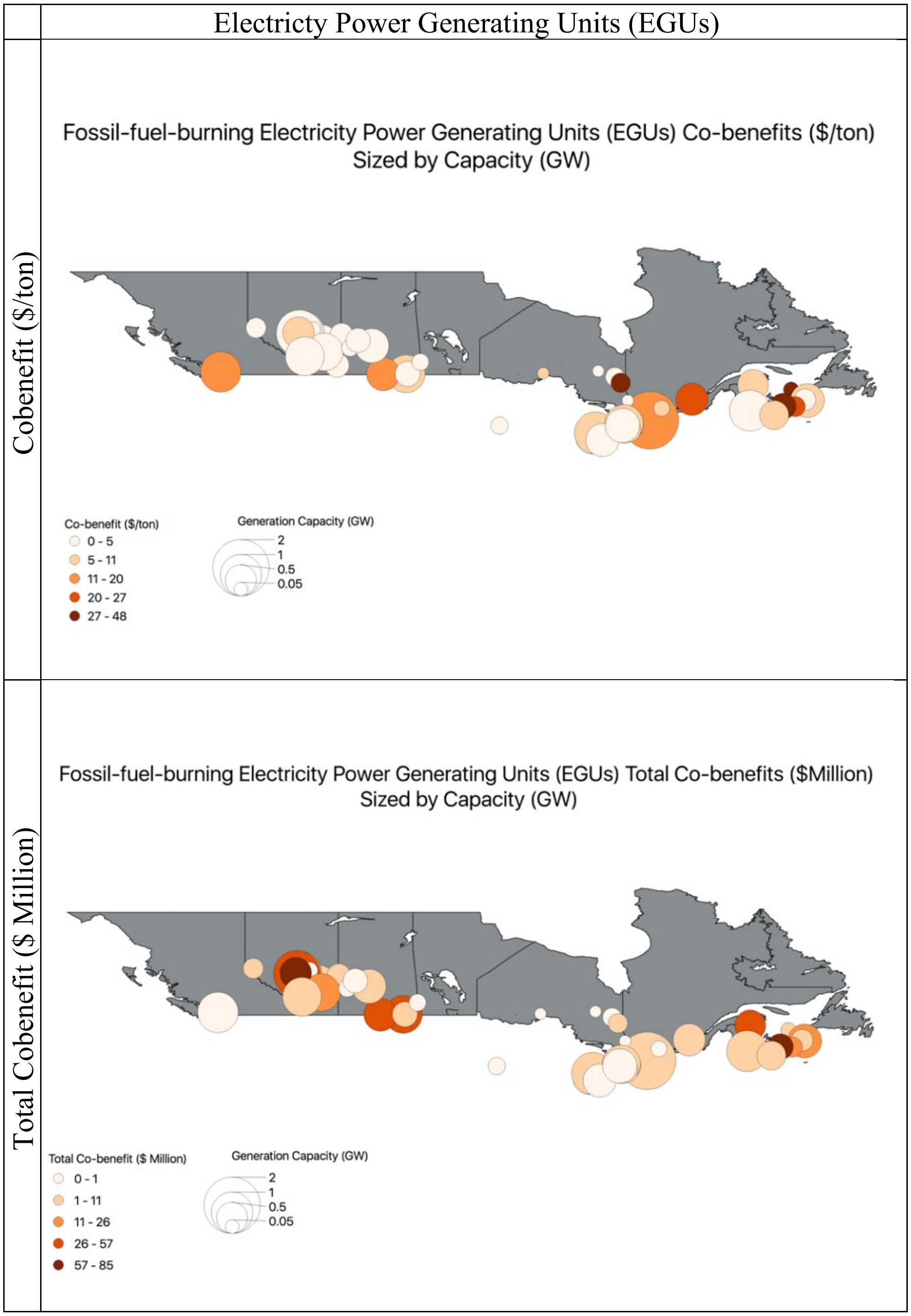

Figure B7. Cobenefits (top) and total burden (bottom) from thermal electricity generation in Canada.

Table B1. Cobenefits and per-vehicle burden of **diesel school buses** in major US cities for different vintages. Numbers are based on 2016 national MOVES simulations. Number of vehicles in each vintage year in the county are shown parenthetically.

City	Cobenefit ($/ton-$CO_2$)					Per-vehicle damage ($/year)				
	1998	2002	2008	2012	2016	1998	2002	2008	2012	2016
Baltimore	354	325	40	47	25	3107 (10)	3435 (18)	508 (25)	741 (19)	414 (36)
Boston	431	428	23	41	15	3912 (10)	4431 (19)	292 (26)	637 (20)	246 (37)
Buffalo	379	330	42	44	19	3419 (19)	3320 (37)	511 (51)	668 (39)	312 (72)
Chicago	607	603	39	63	28	5481 (79)	6215 (150)	485 (209)	978 (160)	463 (295)
Dallas-Fort Worth	181	167	14	18	7	1573 (65)	1652 (124)	169 (172)	265 (132)	101 (243)
Denver	249	242	16	24	9	2130 (15)	2401 (28)	183 (39)	349 (30)	137 (54)
Detroit	362	350	27	39	18	3266 (39)	3613 (74)	336 (104)	607 (79)	293 (146)
Houston	141	128	12	15	6	1239 (108)	1291 (205)	148 (285)	222 (218)	91 (402)
Las Vegas	385	380	17	31	8	3422 (43)	3838 (82)	199 (114)	475 (87)	123 (160)
Los Angeles	1522	1252	180	165	61	13484 (220)	12651 (418)	2204 (582)	2537 (445)	998 (820)
Memphis	262	208	37	34	15	2360 (49)	2168 (92)	466 (129)	520 (98)	247 (181)
Miami	445	445	17	36	9	3964 (48)	4587 (90)	208 (126)	558 (96)	149 (177)
Minneapolis	472	424	47	52	23	4090 (55)	4175 (105)	553 (146)	778 (112)	361 (206)
New York	1093	1116	37	90	26	10211 (8)	11301 (16)	460 (22)	1371 (17)	422 (31)
Orlando	470	431	37	44	16	3824 (10)	4004 (19)	422 (26)	639 (20)	247 (37)
Philadelphia	604	582	43	62	26	5389 (14)	6071 (26)	539 (36)	960 (28)	427 (51)
Phoenix	285	283	11	23	5	2521 (94)	2890 (177)	131 (247)	343 (189)	83 (348)
Raleigh-Durham	209	170	29	27	13	1868 (26)	1749 (49)	359 (68)	414 (52)	203 (96)
Salt Lake City	137	125	12	15	6	1221 (24)	1259 (46)	146 (64)	216 (49)	90 (90)
San Diego	388	308	52	45	19	3303 (155)	2999 (294)	616 (409)	671 (313)	301 (576)
San Francisco	686	543	95	85	35	12042 (9)	11619 (16)	2392 (23)	2718 (17)	1187 (32)
Seattle	214	211	12	19	7	1877 (45)	2102 (86)	135 (120)	289 (92)	106 (169)
Washington	221	189	32	33	18	1904 (4)	2023 (7)	443 (9)	547 (7)	318 (13)

Table B2. Cobenefits and per-vehicle burden of **diesel combination short-haul trucks** in major US cities for different vintages. Numbers are based on 2016 national MOVES simulations. Number of vehicles in each vintage year in the county are shown parenthetically.

City	Cobenefit (\$/ton-CO_2)					Per-vehicle damage (\$/year)				
	1998	2002	2008	2012	2016	1998	2002	2008	2012	2016
Baltimore	354	328	43	39	34	5150 (27)	10937 (20)	3535 (19)	4710 (40)	4046 (42)
Boston	434	422	26	27	25	6578 (26)	14102 (20)	2151 (19)	3297 (40)	2920 (42)
Buffalo	378	339	48	39	32	5445 (58)	10943 (44)	3957 (41)	4603 (87)	3638 (92)
Chicago	595	578	40	43	40	8702 (227)	19083 (171)	3325 (162)	5180 (342)	4711 (360)
Dallas-Fort Worth	177	164	17	14	12	2539 (201)	5297 (152)	1335 (143)	1630 (303)	1317 (319)
Denver	241	231	17	17	15	3499 (44)	7596 (33)	1367 (32)	1923 (67)	1661 (70)
Detroit	356	340	29	29	26	5220 (113)	11146 (86)	2392 (81)	3434 (171)	3025 (180)
Houston	139	128	15	12	10	2016 (322)	4165 (244)	1155 (230)	1402 (487)	1131 (512)
Las Vegas	378	365	20	20	17	5514 (127)	11990 (96)	1636 (91)	2336 (193)	1978 (203)
Los Angeles	1535	1329	220	160	121	22272 (657)	43373 (497)	18105 (469)	19188 (993)	14156 (1045)
Memphis	268	229	45	34	26	3940 (137)	7593 (103)	3706 (98)	4076 (206)	3059 (217)
Miami	440	429	21	22	20	6457 (136)	14136 (103)	1683 (97)	2602 (206)	2267 (217)
Minneapolis	462	421	53	43	36	6627 (173)	13576 (131)	4229 (124)	5097 (262)	4167 (275)
New York	1071	1059	42	50	48	15606 (24)	34979 (18)	3429 (17)	6086 (36)	5593 (38)
Orlando	447	413	42	34	29	6289 (35)	12824 (27)	3344 (25)	3961 (53)	3242 (56)
Philadelphia	600	572	47	45	40	8764 (39)	19110 (29)	3864 (28)	5528 (58)	4694 (62)
Phoenix	280	272	14	14	12	4075 (274)	8875 (208)	1081 (196)	1618 (414)	1384 (436)
Raleigh-Durham	213	184	34	26	21	3128 (73)	6088 (55)	2828 (52)	3156 (110)	2413 (116)
Salt Lake City	135	125	14	12	10	1973 (71)	4061 (54)	1140 (51)	1383 (108)	1119 (113)
San Diego	388	330	62	44	34	5533 (499)	10573 (377)	5003 (356)	5191 (754)	3897 (793)
San Francisco	707	602	117	86	65	100539 (5)	30265 (24)	18635 (18)	44961 (17)	16491 (36)
Seattle	206	199	13	13	12	2963 (139)	6459 (105)	1012 (99)	1489 (210)	1308 (221)
Washington	233	209	37	32	27	3640 (8)	7367 (6)	3058 (6)	4074 (12)	3200 (13)

Table B3. Cobenefits and per-vehicle burden of **diesel single-unit short-haul trucks** in major US cities for different vintages. Numbers are based on 2016 national MOVES simulations. Number of vehicles in each vintage year in the county are shown parenthetically.

City	Cobenefit ($/ton-$CO_2$)					Per-vehicle damage ($/year)				
	1998	2002	2008	2012	2016	1998	2002	2008	2012	2016
Baltimore	402	365	48	43	29	2592 (95)	3998 (187)	1030 (288)	1039 (280)	766 (388)
Boston	512	480	29	28	15	3355 (96)	5326 (189)	616 (291)	682 (283)	388 (393)
Buffalo	416	366	46	38	22	2595 (192)	3897 (379)	964 (583)	910 (567)	565 (787)
Chicago	714	670	51	48	30	4537 (791)	7252 (1560)	1061 (2403)	1155 (2335)	776 (3242)
Dallas-Fort Worth	202	183	16	13	7	1229 (671)	1907 (1322)	318 (2038)	309 (1980)	166 (2748)
Denver	287	265	18	17	9	1766 (149)	2799 (294)	371 (453)	389 (440)	217 (611)
Detroit	420	389	34	31	20	2655 (393)	4192 (776)	711 (1195)	746 (1161)	500 (1612)
Houston	157	141	14	12	6	974 (1095)	1497 (2158)	280 (3326)	271 (3232)	155 (4486)
Las Vegas	451	420	19	18	6	2820 (425)	4485 (837)	385 (1290)	425 (1254)	154 (1740)
Los Angeles	1615	1373	186	142	71	10034 (2222)	14598 (4381)	3862 (6751)	3432 (6559)	1820 (9106)
Memphis	276	232	40	32	18	1775 (479)	2528 (945)	845 (1457)	770 (1415)	472 (1965)
Miami	526	493	20	20	8	3338 (473)	5329 (932)	421 (1436)	483 (1396)	184 (1938)
Minneapolis	521	465	53	43	26	3140 (571)	4825 (1126)	1070 (1735)	1018 (1686)	636 (2340)
New York	1304	1235	48	50	22	8278 (83)	13332 (164)	1008 (253)	1221 (245)	553 (341)
Orlando	520	467	41	33	17	2918 (102)	4611 (200)	795 (309)	750 (300)	402 (416)
Philadelphia	701	649	52	47	28	4485 (137)	7081 (269)	1093 (415)	1147 (403)	713 (560)
Phoenix	335	313	13	12	4	2100 (931)	3346 (1836)	254 (2829)	289 (2748)	94 (3815)
Raleigh-Durham	223	189	32	25	15	1423 (255)	2056 (503)	661 (776)	609 (754)	384 (1046)
Salt Lake City	153	138	14	12	7	957 (241)	1469 (475)	278 (732)	271 (711)	156 (987)
San Diego	402	336	55	41	23	2388 (1595)	3451 (3145)	1102 (4847)	954 (4709)	552 (6537)
San Francisco	723	604	100	79	43	9277 (86)	25934 (86)	6579 (169)	3751 (260)	3117 (253)
Seattle	248	232	14	13	7	1520 (457)	2432 (901)	279 (1389)	303 (1349)	163 (1873)
Washington	246	217	37	33	23	1780 (32)	2568 (64)	843 (98)	849 (96)	620 (133)

Table B4. Cobenefits and per-vehicle burden of **diesel refuse trucks** in major US cities for different vintages. Numbers are based on 2016 national MOVES simulations. Number of vehicles in each vintage year in the county are shown parenthetically.

City	Cobenefit ($/ton-$CO_2$)					Per-vehicle damage ($/year)				
	1998	2002	2008	2012	2016	1998	2002	2008	2012	2016
Baltimore	393	368	43	33	25	8512 (1)	9313 (3)	1460 (2)	1673 (2)	2047 (1)
Boston	495	480	25	17	12	10907 (1)	12387 (3)	856 (2)	867 (2)	933 (1)
Buffalo	414	377	48	33	22	8881 (2)	11354 (5)	2165 (3)	2237 (3)	1200 (3)
Chicago	677	658	40	30	23	15188 (8)	19754 (21)	1713 (13)	1765 (14)	1266 (12)
Dallas-Fort Worth	196	183	16	11	7	4189 (7)	5355 (18)	686 (11)	611 (12)	370 (10)
Denver	272	261	17	11	8	4544 (2)	7668 (4)	864 (2)	574 (3)	455 (2)
Detroit	402	385	29	21	16	8941 (4)	10954 (11)	1338 (6)	1259 (7)	877 (6)
Houston	154	143	14	10	6	3153 (12)	4120 (30)	597 (18)	539 (20)	329 (17)
Las Vegas	432	417	19	11	6	10254 (4)	12672 (11)	796 (7)	595 (8)	321 (6)
Los Angeles	1651	1457	218	142	86	34271 (24)	42522 (60)	9573 (36)	8187 (41)	4922 (33)
Memphis	286	250	45	32	21	6232 (5)	7336 (13)	1927 (8)	1786 (9)	1193 (7)
Miami	504	491	19	11	6	10763 (5)	14165 (13)	785 (8)	600 (9)	317 (7)
Minneapolis	508	468	52	36	24	10723 (6)	13031 (16)	2305 (9)	1928 (11)	1291 (9)
New York	1231	1212	38	23	14	23202 (1)	40142 (2)	2226 (1)	997 (2)	945 (1)
Orlando	493	458	41	26	17	10662 (1)	11639 (3)	1398 (2)	1306 (2)	678 (2)
Philadelphia	677	648	46	33	23	21058 (1)	17704 (4)	2261 (2)	1592 (3)	1342 (2)
Phoenix	320	311	12	7	4	6683 (10)	9126 (25)	531 (15)	386 (17)	174 (14)
Raleigh-Durham	229	201	34	24	16	4416 (3)	5851 (7)	1560 (4)	1310 (5)	870 (4)
Salt Lake City	150	140	14	10	6	2707 (3)	3790 (7)	586 (4)	589 (4)	306 (4)
San Diego	414	357	62	40	26	8535 (17)	10259 (43)	2638 (26)	2292 (29)	1409 (24)
San Francisco	753	654	117	81	51	29406 (1)	44877 (2)	14404 (1)	7402 (2)	7462 (1)
Seattle	234	227	12	8	6	4750 (5)	6740 (12)	542 (7)	465 (8)	281 (7)
Washington	253	230	37	29	21	1944 (0)	6204 (1)	894 (1)	1045 (1)	608 (0)

Table B5. Cobenefits and per-vehicle burden of **gasoline passenger trucks** in major US cities for different vintages. Numbers are based on 2016 national MOVES simulations. Number of vehicles in each vintage year in the county are shown parenthetically.

City	Cobenefit ($/ton-$CO_2$)					Per-vehicle damage ($/year)				
	1998	2002	2008	2012	2016	1998	2002	2008	2012	2016
Baltimore	147	52	37	34	39	666 (3385)	295 (6003)	243 (5970)	227 (5280)	244 (9950)
Boston	77	31	22	22	25	351 (3462)	175 (6139)	145 (6106)	144 (5400)	157 (10176)
Buffalo	107	40	21	20	22	481 (6552)	221 (11620)	138 (11557)	127 (10220)	137 (19259)
Chicago	154	57	41	40	46	691 (27866)	319 (49420)	271 (49151)	261 (43467)	284 (81911)
Dallas-Fort Worth	37	13	8	7	8	164 (22908)	72 (40627)	47 (40406)	43 (35733)	45 (67337)
Denver	46	19	11	11	13	203 (5136)	101 (9109)	71 (9060)	70 (8012)	76 (15098)
Detroit	101	38	26	25	29	451 (13804)	215 (24481)	168 (24347)	163 (21532)	178 (40575)
Houston	32	12	7	6	7	144 (37859)	64 (67143)	42 (66777)	39 (59055)	40 (111285)
Las Vegas	38	19	10	10	11	171 (14455)	106 (25636)	61 (25496)	63 (22548)	68 (42490)
Los Angeles	337	85	36	32	35	1487 (76589)	470 (135831)	233 (135092)	205 (119469)	209 (225132)
Memphis	94	32	15	14	15	421 (16956)	177 (30072)	99 (29909)	87 (26450)	91 (49843)
Miami	39	18	10	10	11	181 (16607)	102 (29453)	66 (29293)	66 (25905)	68 (48816)
Minneapolis	149	52	30	28	32	658 (19320)	288 (34264)	193 (34078)	181 (30137)	194 (56791)
New York	134	58	40	41	47	603 (2924)	328 (5185)	260 (5157)	266 (4561)	289 (8594)
Orlando	89	34	18	16	18	380 (3060)	182 (5428)	108 (5398)	101 (4774)	106 (8996)
Philadelphia	129	49	33	32	37	580 (4849)	276 (8599)	219 (8552)	211 (7563)	228 (14252)
Phoenix	25	11	5	5	6	116 (32159)	61 (57034)	34 (56724)	34 (50164)	34 (94531)
Raleigh-Durham	70	25	13	11	13	311 (9012)	139 (15983)	82 (15896)	72 (14058)	76 (26491)
Salt Lake City	36	13	7	7	8	157 (8288)	72 (14699)	46 (14619)	44 (12928)	47 (24363)
San Diego	86	22	11	10	10	373 (52663)	119 (93398)	66 (92889)	58 (82148)	60 (154801)
San Francisco	199	51	24	22	24	1790 (3049)	570 (5408)	318 (5378)	283 (4756)	296 (8963)
Seattle	35	14	10	9	11	154 (15422)	78 (27351)	59 (27202)	59 (24056)	63 (45332)
Washington	106	37	24	22	24	497 (1246)	217 (2209)	161 (2197)	147 (1943)	156 (3662)