Consistency of Long-term Elemental Carbon Trends from Thermal and Optical Measurements in the IMPROVE Network

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Supplementary Information

Table S1. Location, name, robust regression statistics, and Mann-Kendall trend (2000−2009) test results of EC and τ_R for 65 IMPROVE sites selected in this study.

Location			Robust Regression (Eq.[5])[¶]: $\begin{pmatrix} EC_- \\ EC_+ \end{pmatrix} = c_-\begin{pmatrix} I \\ I \end{pmatrix} + \Delta c\begin{pmatrix} 0 \\ I \end{pmatrix} + b_-\begin{pmatrix} \tau_{R-} \\ \tau_{R+} \end{pmatrix} + \Delta b\begin{pmatrix} 0 \\ \tau_{R+} \end{pmatrix}$								EC (μg m^{-3})				τ_R×A/V (Mm^{-1})[#]			
Regions	Code	Name	r	c_- (μg cm^{-2})	p (c_-)	Δc (μg cm^{-2})	p (Δc)	b_- (μg cm^{-2})	p (b_-)	Δb (μg cm^{-2})	p(Δb)	Med.(-)	Med.(+)	Sen's Slope (yr^{-1})	p	Med.(-)	Med.(+)	Sen's Slope (yr^{-1})	p
Northeast	NE1	MOOS1	0.91	-0.15±0.05	0.01	0.09±0.07	0.19	11.14±0.21	0.00	-1.11±0.34	**0.00**	0.20	0.14	-0.013	0.00	2.00	1.45	-0.105	0.00
	NE2	ACAD1	0.89	-0.12±0.05	0.02	0.01±0.07	0.84	10.72±0.23	0.00	-0.17±0.35	0.63	0.17	0.14	-0.009	0.00	1.71	1.42	-0.078	0.00
East Coast	E1	BRIG1	0.86	-0.95±0.14	0.00	0.71±0.18	**0.00**	15.29±0.38	0.00	-1.87±0.55	**0.00**	0.41	0.36	-0.018	0.00	3.44	2.73	-0.163	0.00
Urban	U1	WASH1	0.59	-1.59±0.62	0.01	4.76±0.78	**0.00**	19.38±1.10	0.00	-5.78±1.45	**0.00**	0.97	1.03	-0.013	0.01	5.83	4.89	-0.218	0.00
Appalachia	A1	JARI1	0.67	-0.39±0.30	0.20	0.53±0.38	0.16	14.06±0.70	0.00	-0.24±0.96	0.80	0.55	0.51	-0.019	0.00	4.15	3.50	-0.180	0.00
	A2	SIPS1	0.74	-0.19±0.20	0.34	0.40±0.26	0.12	12.76±0.52	0.00	-0.59±0.73	0.42	0.45	0.41	-0.021	0.00	3.81	3.06	-0.193	0.00
	A3	GRSM1	0.80	-0.18±0.14	0.19	0.32±0.18	0.07	12.41±0.42	0.00	-0.65±0.58	0.26	0.36	0.33	-0.016	0.00	3.24	2.54	-0.153	0.00
	A4	LIGO1	0.77	-0.27±0.15	0.08	0.32±0.20	0.11	12.97±0.49	0.00	-0.64±0.67	0.34	0.38	0.33	-0.014	0.00	3.00	2.46	-0.129	0.00
	A5	SHEN1	0.78	-0.17±0.12	0.16	0.19±0.16	0.23	12.25±0.42	0.00	-0.71±0.60	0.23	0.30	0.25	-0.013	0.00	2.68	2.12	-0.114	0.00
	A6	DOSO1	0.74	0.16±0.13	0.24	-0.01±0.17	0.96	10.43±0.45	0.00	0.06±0.62	0.92	0.33	0.25	-0.020	0.00	2.90	2.16	-0.149	0.00
Southeast	SE1	CHAS1	0.84	-0.74±0.17	0.00	0.42±0.22	0.05	13.62±0.42	0.00	-0.05±0.57	0.94	0.43	0.38	-0.019	0.00	3.84	2.92	-0.192	0.00
	SE2	OKEF1	0.89	-0.01±0.10	0.92	-0.07±0.13	0.57	11.41±0.28	0.00	0.66±0.42	0.12	0.33	0.28	-0.015	0.00	2.94	2.47	-0.121	0.00
	SE3	ROMA1	0.91	-0.63±0.10	0.00	0.26±0.13	**0.04**	13.76±0.27	0.00	-0.20±0.42	0.64	0.35	0.26	-0.019	0.00	3.16	2.27	-0.176	0.00
Boundary Waters	B1	SENE1	0.90	-0.09±0.06	0.14	-0.11±0.08	0.18	10.56±0.28	0.00	1.27±0.39	**0.00**	0.15	0.13	-0.007	0.00	1.58	1.28	-0.061	0.00
	B2	ISLE1	0.92	-0.16±0.04	0.00	-0.03±0.05	0.64	10.97±0.21	0.00	0.35±0.30	0.25	0.14	0.10	-0.007	0.00	1.42	1.08	-0.054	0.00
	B3	VOYA1	0.89	-0.03±0.05	0.51	-0.09±0.06	0.12	10.19±0.24	0.00	0.49±0.36	0.17	0.15	0.11	-0.008	0.00	1.51	1.15	-0.063	0.00
Ohio River Valley	O1	MACA1	0.75	0.28±0.18	0.12	-0.04±0.22	0.85	10.70±0.48	0.00	1.03±0.64	0.11	0.44	0.39	-0.016	0.00	3.70	2.96	-0.164	0.00
Mid South	MS1	UPBU1	0.85	-0.13±0.10	0.17	0.12±0.12	0.35	11.31±0.34	0.00	1.07±0.48	**0.02**	0.28	0.26	-0.010	0.00	2.66	2.12	-0.115	0.00
	MS2	CACR1	0.86	0.15±0.09	0.10	-0.19±0.11	0.10	10.37±0.31	0.00	1.52±0.43	**0.00**	0.30	0.26	-0.013	0.00	2.79	2.12	-0.134	0.00
Northern Great Plains	NP1	WICA1	0.85	0.05±0.11	0.64	-0.09±0.14	0.52	8.94±0.66	0.00	0.07±0.85	0.93	0.13	0.10	-0.006	0.00	1.41	1.20	-0.045	0.00
	NP2	THRO1	0.84	-0.04±0.05	0.51	0.10±0.07	0.16	9.25±0.27	0.00	-0.55±0.37	0.14	0.16	0.14	-0.006	0.00	1.74	1.57	-0.053	0.00
	NP3	LOST1	0.86	-0.08±0.05	0.10	0.16±0.07	**0.02**	10.01±0.23	0.00	-1.56±0.38	**0.00**	0.15	0.13	-0.005	0.00	1.58	1.42	-0.035	0.00
	NP4	MELA1	0.86	-0.06±0.04	0.17	0.07±0.05	0.18	9.54±0.25	0.00	-0.72±0.34	**0.04**	0.12	0.11	-0.005	0.00	1.39	1.18	-0.038	0.00
	NP5	BADL1	0.85	0.00±0.04	0.97	-0.01±0.05	0.87	9.18±0.25	0.00	-0.49±0.36	0.17	0.14	0.09	-0.009	0.00	1.43	1.10	-0.074	0.00
	NP6	ULBE1	0.94	-0.15±0.03	0.00	0.09±0.04	**0.01**	10.76±0.18	0.00	-1.15±0.27	**0.00**	0.10	0.08	-0.006	0.00	1.16	0.89	-0.047	0.00
West Texas	W1	BIBE1	0.84	0.03±0.04	0.44	-0.01±0.06	0.88	8.61±0.25	0.00	-0.04±0.35	0.91	0.12	0.12	-0.004	0.00	1.38	1.27	-0.032	0.00
	W2	GUMO1	0.75	0.02±0.04	0.58	0.09±0.06	0.11	7.85±0.29	0.00	-0.53±0.41	0.20	0.11	0.10	-0.003	0.00	1.32	1.20	-0.028	0.00
Central Rockies	CR1	ROMO2	0.93	-0.12±0.03	0.00	0.01±0.04	0.72	10.14±0.16	0.00	-1.02±0.24	**0.00**	0.12	0.09	-0.007	0.00	1.36	1.05	-0.050	0.00
	CR2	GRSA1	0.86	-0.02±0.03	0.49	0.07±0.05	0.14	9.07±0.23	0.00	-0.91±0.33	**0.01**	0.10	0.09	-0.003	0.00	1.14	1.06	-0.018	0.00
	CR3	WHRI1	0.82	-0.01±0.03	0.70	-0.06±0.05	0.20	7.91±0.23	0.00	0.03±0.35	0.92	0.08	0.07	-0.004	0.00	1.10	0.97	-0.027	0.00
Colorado Plateau	CP1	BRCA1	0.92	-0.09±0.05	0.07	-0.06±0.07	0.37	9.25±0.28	0.00	0.23±0.45	0.60	0.11	0.08	-0.005	0.00	1.21	0.98	-0.037	0.00
	CP2	BAND1	0.82	0.01±0.05	0.90	0.11±0.07	0.10	9.11±0.25	0.00	-0.86±0.40	**0.03**	0.14	0.12	-0.006	0.00	1.53	1.29	-0.057	0.00
	CP3	HANC1	0.91	-0.01±0.05	0.86	-0.20±0.06	**0.00**	8.25±0.33	0.00	1.37±0.43	**0.00**	0.10	0.08	-0.003	0.00	1.17	1.08	-0.018	0.01
	CP4	WEMI1	0.82	-0.01±0.05	0.91	0.00±0.06	0.96	8.23±0.27	0.00	-0.20±0.36	0.58	0.14	0.11	-0.007	0.00	1.66	1.28	-0.068	0.00

	Code	Name	r	*c*. (μg cm^{-2})	p (*c*.)	Δ*c* (μg cm^{-2})	p (Δ*c*)	*b*. (μg cm^{-2})	p (*b*.)	Δ*b* (μg cm^{-2})	p(Δ*b*)	Med.(-)	Med.(+)	Sen's Slope (yr^{-1})	p	Med.(-)	Med.(+)	Sen's Slope (yr^{-1})	p
	CP5	MEVE1	0.88	-0.04±0.03	0.24	0.03±0.05	0.45	8.51±0.20	0.00	-0.74±0.32	**0.02**	0.11	0.08	-0.006	0.00	1.30	1.05	-0.046	0.00
	CP6	CANY1	0.81	0.09±0.04	0.02	-0.11±0.05	**0.02**	7.29±0.25	0.00	0.44±0.35	0.21	0.10	0.08	-0.005	0.00	1.21	1.01	-0.037	0.00
Southern Arizona	SA1	CHIR1	0.81	0.06±0.03	0.09	-0.01±0.05	0.85	7.50±0.23	0.00	-0.70±0.34	**0.04**	0.11	0.08	-0.007	0.00	1.35	1.10	-0.053	0.00
Mogollon Plateau	MP1	SYCA1	0.82	-0.06±0.09	0.53	-0.03±0.11	0.79	10.46±0.36	0.00	0.62±0.49	0.20	0.23	0.22	-0.004	0.02	2.30	2.01	-0.049	0.00
	MP2	IKBA1	0.84	-0.07±0.05	0.13	0.09±0.06	0.16	8.93±0.26	0.00	-0.50±0.35	0.15	0.14	0.12	-0.006	0.00	1.64	1.42	-0.055	0.00
	MP3	BALD1	0.91	-0.12±0.04	0.00	0.00±0.05	0.95	9.74±0.21	0.00	0.28±0.36	0.44	0.11	0.10	-0.004	0.00	1.28	1.11	-0.040	0.00
Northern Rockies	NR1	GLAC1	0.89	-0.67±0.14	0.00	0.71±0.19	**0.00**	14.54±0.43	0.00	-2.57±0.66	**0.00**	0.30	0.29	-0.010	0.00	2.84	2.32	-0.099	0.00
	NR2	MONT1	0.95	-0.27±0.04	0.00	0.03±0.06	0.63	12.99±0.22	0.00	-0.34±0.33	0.31	0.12	0.09	-0.006	0.00	1.18	0.98	-0.044	0.00
	NR3	CABI1	0.93	-0.23±0.06	0.00	0.03±0.08	0.66	13.18±0.32	0.00	-1.59±0.52	**0.00**	0.13	0.09	-0.008	0.00	1.19	1.01	-0.047	0.00
	NR4	BRID1	0.89	-0.01±0.03	0.80	-0.14±0.04	**0.00**	8.17±0.19	0.00	1.26±0.28	**0.00**	**0.09**	0.06	-0.006	0.00	1.07	0.79	-0.042	0.00
Great Basin	G1	GRBA1	0.87	0.09±0.04	0.01	-0.19±0.05	**0.00**	7.84±0.25	0.00	1.21±0.33	**0.00**	0.11	0.07	-0.009	0.00	1.29	0.85	-0.074	0.00
Southern California	SC1	SAGO1	0.89	-0.32±0.10	0.00	0.06±0.12	0.63	11.29±0.30	0.00	0.10±0.39	0.79	0.31	0.21	-0.019	0.00	3.08	2.11	-0.178	0.00
	SC2	JOSH1	0.90	-0.16±0.06	0.01	0.02±0.08	0.82	9.93±0.21	0.00	-0.15±0.30	0.62	0.23	0.17	-0.012	0.00	2.46	1.87	-0.121	0.00
Death Valley	D1	DEVA1	0.91	-0.08±0.03	0.02	-0.12±0.04	**0.01**	8.60±0.19	0.00	0.83±0.27	**0.00**	0.12	0.08	-0.008	0.00	1.58	1.09	-0.072	0.00
Hell's Canyon	H1	STAR1	0.94	-0.17±0.04	0.00	-0.11±0.06	0.06	12.14±0.20	0.00	0.43±0.32	0.18	0.16	0.10	-0.014	0.00	1.58	1.00	-0.087	0.00
Sierra Nevada	SN1	SEQU1	0.86	-0.19±0.11	0.10	0.18±0.15	0.21	12.15±0.32	0.00	0.05±0.46	0.91	0.40	0.32	-0.020	0.00	3.46	2.40	-0.179	0.00
	SN2	YOSE1	0.94	-0.30±0.05	0.00	0.09±0.07	0.16	12.42±0.19	0.00	-0.95±0.32	**0.00**	0.18	0.14	-0.007	0.00	1.87	1.41	-0.070	0.00
	SN3	BLIS1	0.89	-0.09±0.05	0.09	-0.16±0.07	**0.02**	10.03±0.28	0.00	1.32±0.38	**0.00**	0.14	0.11	-0.007	0.00	1.63	1.23	-0.060	0.00
Columbia River Gorge	CG1	CORI1	0.82	-0.44±0.12	0.00	0.22±0.16	0.17	12.34±0.40	0.00	-0.38±0.54	0.48	0.31	0.26	-0.011	0.00	2.93	2.32	-0.113	0.00
California Coast	CC1	PINN1	0.86	-0.39±0.08	0.00	0.18±0.11	0.09	11.04±0.29	0.00	-0.66±0.41	0.11	0.24	0.18	-0.015	0.00	2.55	1.92	-0.148	0.00
Northwest	NW1	MORA1	0.95	-0.19±0.04	0.00	-0.07±0.06	0.23	11.19±0.17	0.00	0.76±0.24	**0.00**	0.21	0.16	-0.010	0.00	2.11	1.61	-0.083	0.00
	NW2	SNPA1	0.91	-0.36±0.06	0.00	0.01±0.08	0.90	11.25±0.22	0.00	-0.29±0.33	0.38	0.21	0.16	-0.011	0.00	2.27	1.70	-0.092	0.00
	NW3	NOCA1	0.94	-0.10±0.03	0.00	-0.07±0.04	0.09	10.44±0.19	0.00	-0.05±0.33	0.88	0.10	0.06	-0.005	0.00	1.04	0.85	-0.034	0.00
	NW4	WHPA1	0.91	-0.05±0.02	0.04	-0.17±0.03	**0.00**	9.03±0.19	0.00	1.29±0.28	**0.00**	0.07	0.04	-0.004	0.00	0.85	0.75	-0.011	0.05
Oregon & Northern California	ON1	KALM1	0.91	-0.30±0.07	0.00	0.07±0.10	0.51	12.17±0.35	0.00	-0.60±0.54	0.26	0.14	0.11	-0.007	0.00	1.48	1.16	-0.057	0.00
	ON2	CRLA1	0.95	-0.32±0.04	0.00	0.06±0.06	0.30	11.40±0.18	0.00	-0.74±0.31	**0.02**	0.13	0.09	-0.006	0.00	1.47	1.18	-0.055	0.00
	ON3	LABE1	0.93	-0.18±0.04	0.00	-0.02±0.05	0.69	11.44±0.19	0.00	0.00±0.31	1.00	0.13	0.10	-0.006	0.00	1.33	1.02	-0.041	0.00
	ON4	THSI1	0.96	-0.10±0.03	0.00	-0.16±0.04	**0.00**	10.62±0.14	0.00	1.45±0.21	**0.00**	0.13	0.08	-0.007	0.00	1.35	0.92	-0.050	0.00
	ON5	MOHO1	0.94	-0.09±0.03	0.00	-0.20±0.04	**0.00**	9.28±0.15	0.00	1.74±0.25	**0.00**	0.09	0.06	-0.006	0.00	1.09	0.85	-0.044	0.00
	ON6	REDW1	0.95	-0.17±0.02	0.00	0.03±0.03	0.29	9.76±0.14	0.00	-2.16±0.21	**0.00**	0.08	0.05	-0.005	0.00	1.01	0.82	-0.036	0.00
Alaska	AK1	DENA1	0.96	-0.24±0.02	0.00	0.16±0.03	**0.00**	11.41±0.13	0.00	-4.81±0.27	**0.00**	0.06	0.04	-0.004	0.00	0.82	0.67	-0.021	0.00

[¶]For complete (non-missing) EC-τ_R pairs. *c*, *b*, and r are robust regression intercept, slope, and correlation coefficient, respectively. Subscripts - and + indicate pre- and post 1/1/2005 data. Δ*c* and Δ*b* are changes in regression intercept and slope, respectively. p indicates the p-value of the regression coefficients; $p < 0.05$ are marked in bold.

[#]A and V are nominal filter area (3.53 cm^2) and sample volume (32.7 m^3). Med.(-) and Med.(+) are median values before and after the upgrade, respectively. Sen's slope and p values result from the M-K test.

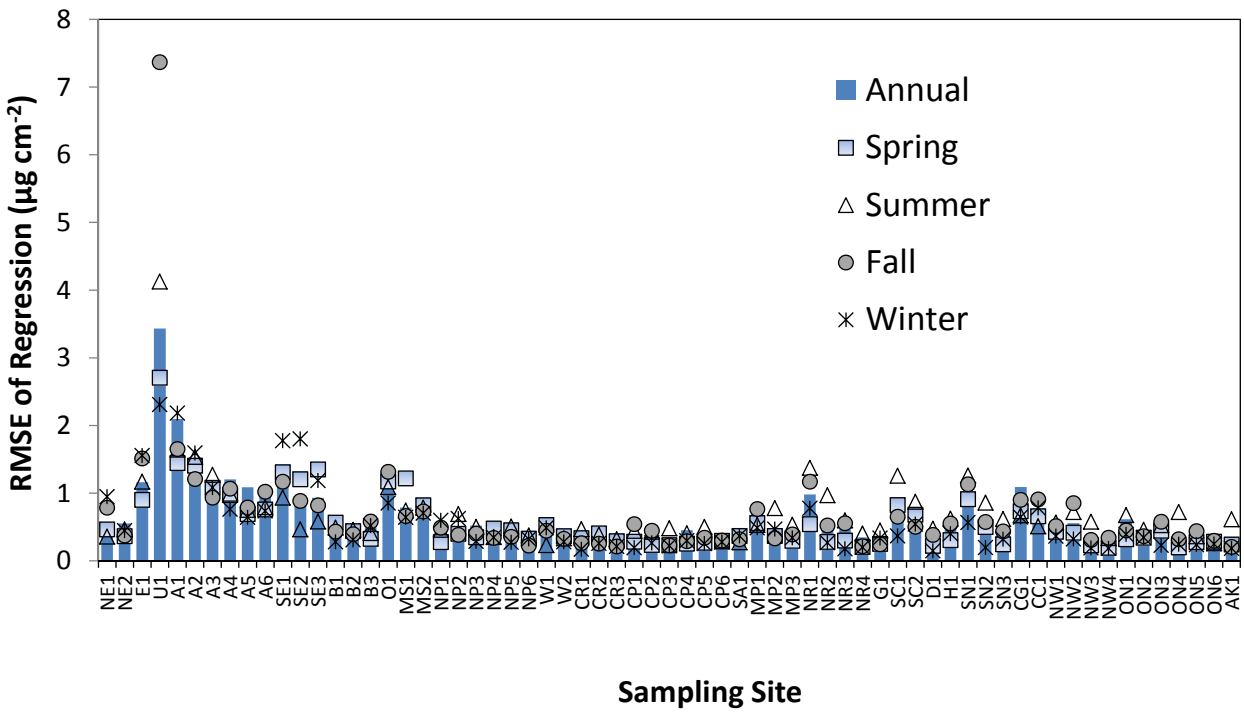
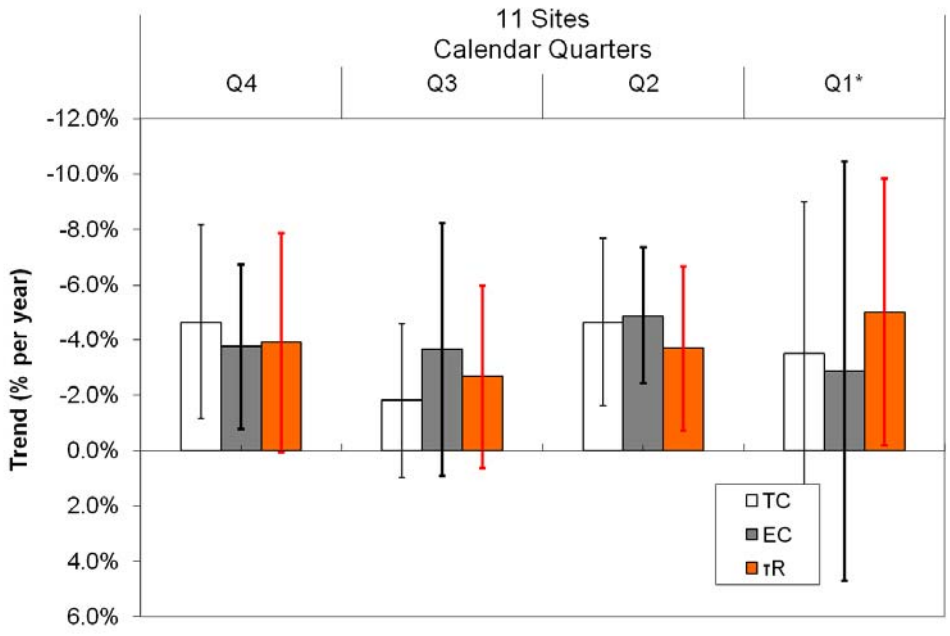


Figure S1. Scatter around the best-fit line (Eq. [5] in the manuscript), by site and by season, compared to that for site-specific annual (year-round) data. Scatter is evaluated through the root-mean-square-error (RMSE) between the measured and predicted dependent variable (i.e., EC). See Table S1 for definitions of site code. Seasonal segregation does not usually reduce scatter around the best-fit lines.

(a)



(b)

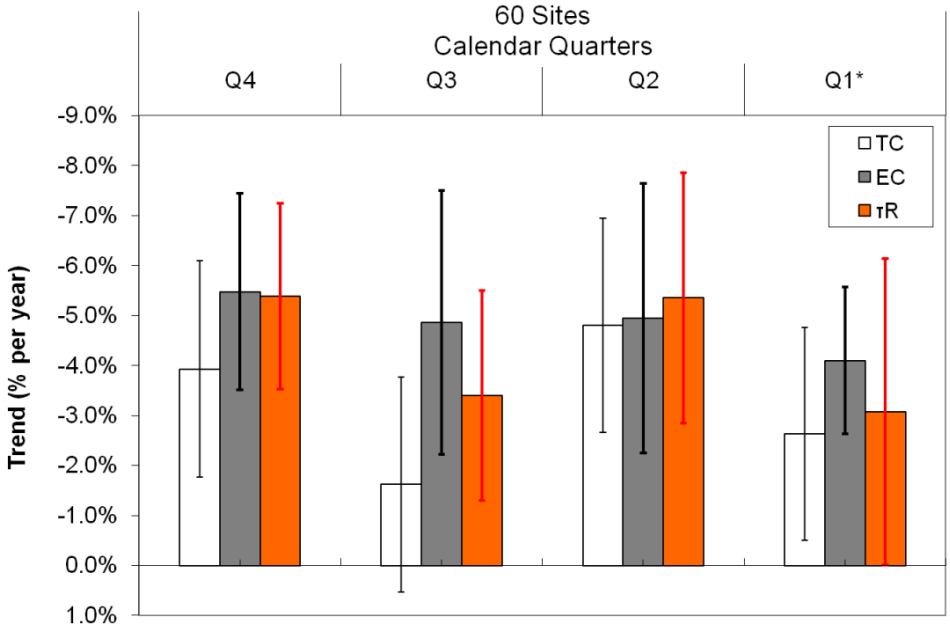


Figure S2. Total carbon (TC), elemental carbon (EC), and reflectance attenuation (τ_R) trends, by calendar quarter (Q1-Q4), for 2000−2009: (a) based on top 11 IMPROVE sites and (b) based on top 60 IMPROVE sites with respect to data recovery. Trends were determined from ordinary linear regression of annual median values. Adapted from Watson et al. (2010).

Reference

Watson, J. G., J. C. Chow, and L.-W. A. Chen (2010), Long-term EC and reflectance trends in IMPROVE laboratory data, presented at IMPROVE Carbon Issues and Trends Workshop, Stevenson, WA, October 20, 2010. http://vista.cira.colostate.edu/improve/Publications/Workshops/Carbon_Oct2010/CarbonMeeting2010.htm (last accessed on September 24, 2012)