

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

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36 Submitted to:

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38 Atmospheric Measurement Techniques Discussion
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40 April 15, 2012
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Supplementary Information

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45 **Table S-1.** Region, name, robust regression statistics, and Mann-Kendall trend (2000–2009) test results of EC and τ_R for 65
46 IMPROVE sites selected for this study.

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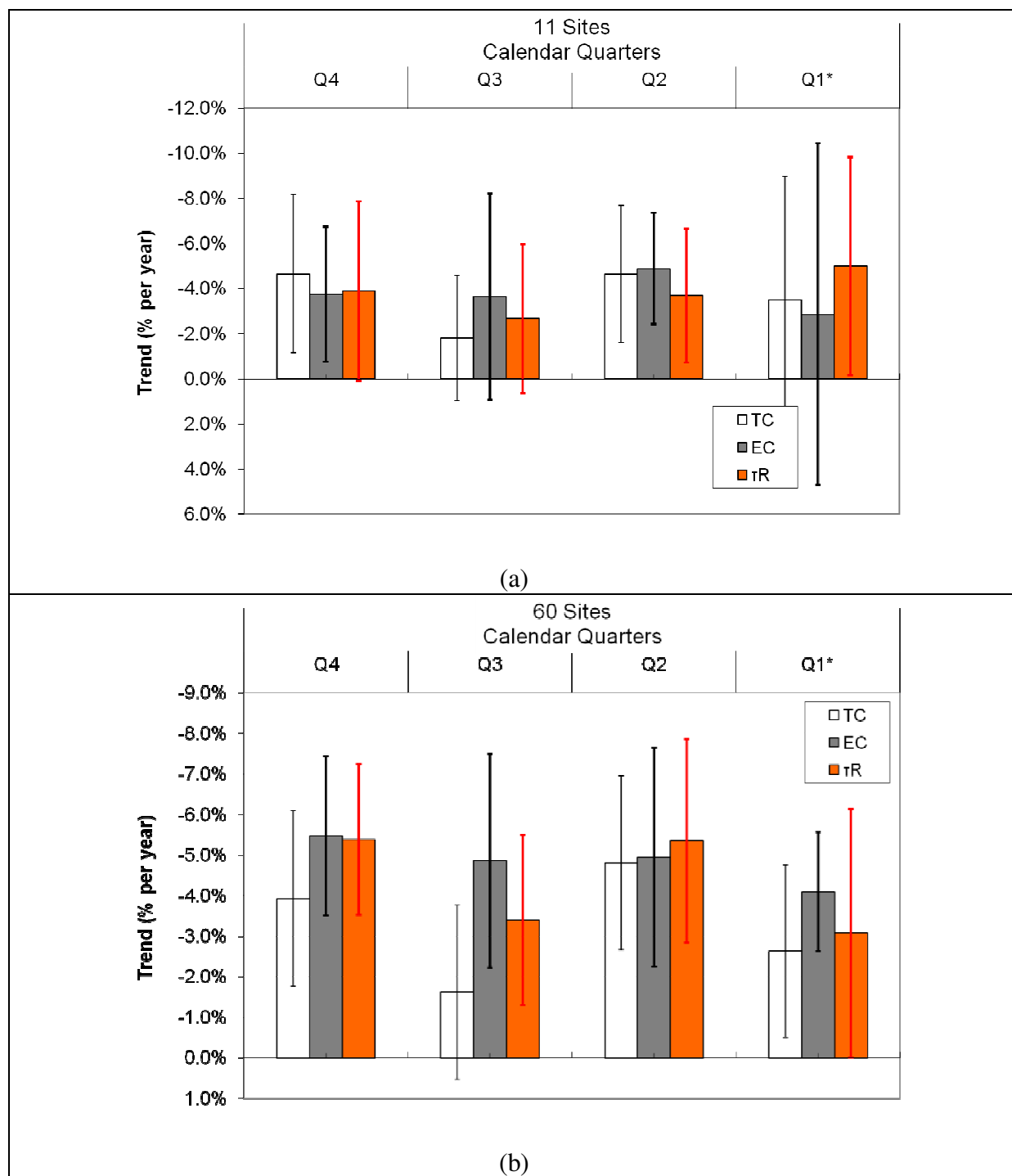
$$[\text{EC}]_t = c \begin{pmatrix} 1 \\ 1 \end{pmatrix} + \Delta c \begin{pmatrix} 0 \\ 1 \end{pmatrix} + b \begin{pmatrix} [\tau_R]_t \\ [\tau_R]_t \end{pmatrix} + \Delta b \begin{pmatrix} 0 \\ [\tau_R]_t \end{pmatrix}$$

Location		Robust Regression (Eq.[5]) η :										EC ($\mu\text{g}/\text{m}^3$)				$\tau_R \times A/V$ (Mm^{-1}) $\#$			
Regions	Code Name	r	c. ($\mu\text{g}/\text{cm}^2$)	p (c.)	Δc ($\mu\text{g}/\text{cm}^2$)	p (Δc)	b. ($\mu\text{g}/\text{cm}^2$)	p (b.)	Δb ($\mu\text{g}/\text{cm}^2$)	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 GRS A1	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 WHR11	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	

	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	COR11	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

48 ¶ For complete EC- τ_R pairs. c , b , and r are robust regression intercept, slope, and correlation coefficient, respectively. Subscripts - and + indicate
49 pre- and post 1/1/2005 data. Δc and Δb are changes in regression intercept and slope, respectively. p indicates the p-value of the regression
50 coefficients.

51 # 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,
52 respectively. Sen's slope and p values resulted from the M-K test.



53 **Figure S-1.** Total carbon (TC), elemental carbon (EC), and reflectance attenuation (τ_R) trends, by
 54 calendar quarter (Q1-Q4), for 2000–2009: (a) based on 11 IMPROVE sites and (b) based on 60
 55 IMPROVE sites. Trends were determined from ordinary linear regression of annual median
 56 values. Adapted from Watson et al. (2010).

57 **Reference**

58 Watson, J. G., J. C. Chow, and L.-W. A. Chen (2010), Long-term EC and reflectance trends in
59 IMPROVE laboratory data, presented at IMPROVE Carbon Issues and Trends
60 Workshop, Stevenson, WA, October 20, 2010.
61 http://vista.cira.colostate.edu/improve/Publications/Workshops/Carbon_Oct2010/Carbon
62 [Meeting2010.htm](http://vista.cira.colostate.edu/improve/Publications/Workshops/Carbon_Oct2010/Carbon)