Supplement Information

Unexpected performance improvements of nitrogen dioxide and ozone sensors by including carbon monoxide sensor signal

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Table S1. Federal Reference Method/Federal Equivalent Method equipment lists at all six cities

City	Site ID	Pollutant	Model	Principle	Method Reference ID
Atlanta, GA	13-089-0002[1]	CO	Thermo Scientific 48i-TLE	Infrared absorption	RFCA-0981-054
		NO_2	Thermo Scientific 42i	Chemiluminescence	RFNA-1289-074
		O_3	Thermo Scientific 49i	UV absorption	EQOA-0880-047
New York City, NY	36-081-0124[2]	CO	Teledyne API 300EU	Infrared absorption	RFCA-1093-093
		NO_2	Thermo Scientific 42i	Chemiluminescence	RFNA-1289-074
		O_3	Teledyne API T400	UV absorption	EQOA-0992-087
Phoenix, AZ	04-013-9997[3]	CO	Teledyne API 300EU	Infrared absorption	RFCA-1093-093
		NO_2	Teledyne API T500U	Cavity Attenuated Phase Shift	EQNA-0514-212
		O_3	Teledyne API T400	UV absorption	EQOA-0992-087
Portland, OR	41-051-0080[4]	CO	Teledyne API T300	Infrared absorption	RFCA-1093-093
		NO_2	Teledyne API T500U	Cavity Attenuated Phase Shift	EQNA-0514-212
		O_3	Teledyne API T400	UV absorption	EQOA-0992-087
RiverSide, CA	06-065-8005[5]	CO	Horiba APMA 360	Infrared absorption	RFCA-0895-106
		NO_2	Thermo Scientific 42i	Chemiluminescence	RFNA-1289-074
		O_3	Teledyne API 400E	UV absorption	EQOA-0992-087
Sacramento, CA	06-067-0010[5]	CO		N/A	
		NO_2	Teledyne API 200 EU/501	Chemiluminescence	RFNA-1194-099
		O_3	Teledyne API 400E	UV absorption	EQOA-0992-087

[1]See Georgia Ambient Air Monitoring Plan for details: https://airgeorgia.org/networkplans.html
[2]See New York State Monitoring Network Plan for details: https://www.dec.ny.gov/chemical/8406.html#Plan
[3]See Maricopa County Air Monitoring Network Plan for details: https://www.maricopa.gov/1669/Air-Monitoring-Network-Plans-and-Assessm
[4]See Oregon Annual Ambient Criteria Pollutant Air Monitoring Network Plan for details: https://www.oregon.gov/deq/aq/Pages/Air-Quality-Monitoring.aspx
[5]See California Annual Monitoring Network Report (https://ww2.arb.ca.gov/our-work/programs/ambient-air-monitoring-regulatory/annual-monitoring-network-report) and Quality Assurance Air Monitoring Site (https://ww2.arb.ca.gov/applications/quality-assurance-air-monitoring-site-search-1) for details

Table S2. Sensor performance (RMSE) at corresponding cities, without CO data

Pollutant		Portland	Atlanta	Riverside	Sacramento	New York	Phoenix
NO_2	Linear	3.48	4.29	4.39	5.99	4.37	7.51
	Polynomial	2.78	4.19	4.56	5.09	3.74	6.66
	RF	2.72	3.16	3.75	3.91	3.43	5.46
O_3	Linear	7.84	7.8	5.65	10.18	10.32	9.77
	Polynomial	7.66	8.29	6.6	10.68	10.62	10.44
	RF	5.70	6.68	5.14	6.85	9.28	8.31
CO	Linear	0.04	0.07	0.07		0.03	0.06
	Polynomial	0.04	0.07	0.07	N/A	0.03	0.05
	RF	0.03	0.04	0.03		0.02	0.05

RF = Random Forest

Table S3. Sensor performance (RMSE) at corresponding cities, with CO data introduced as an independent variable. Data shown in parentheses are changes of RMSE when CO data were included.

Pollutant		Portland	Atlanta	Riverside	Sacramento	New York	Phoenix
	Linear	2.99(-0.49)	3.92(-0.37)	3.25(-1.14)	4.89(-1.1)	4.07(-0.3)	5.32(-2.19)
NO_2	Polynomial	2.69(-0.09)	3.93(-0.26)	3.66(-0.9)	4.92(-0.17)	4.21(0.47)	5.72(-0.94)
	RF	2.52(-0.2)	2.76(-0.4)	2.94(-0.81)	2.37(-1.54)	3.04(-0.39)	3.35(-2.11)
	Linear	6.02(-1.82)	7.34(-0.46)	5.54(-0.11)	7.02(-3.16)	6.4(-3.92)	6.98(-2.79)
O_3	Polynomial	6.4(-1.26)	8.62(0.33)	6.96(0.36)	7.8(-2.88)	7.43(-3.19)	7.92(-2.52)
	RF	3.42(-2.28)	6.17(-0.51)	4.97(-0.17)	3.96(-2.89)	5.14(-4.14)	4.51(-3.8)

RF = Random Forest

Table S4. Parameters of all calibration models at six sites

		Linear	Polynomial	RF (Tree depth)
CO	PTL	Cp=0.014Sp-0.002T-0.0001RH-5.19	Cp=2.65e-8Sp3-1.38e-6T3+1e-8RH3-1.49	6
	ATL	Cp=0.009Sp-0.009T-0.002RH-3.07	Cp=1.86e-8Sp3+6.22e-7T3+8.12e-8RH3-1	6
	RAV	Cp=0.006Sp+0.002T+0.0008RH-2.13	Cp=1.29e-8Sp3+1.49e-6T3+1.24e-7RH3-0.71	6
	SAC		N/A	
	NYC	Cp=0.014Sp-0.002T-0.0004RH-5.41	Cp=2.96e-8Sp3-1.54e-6T3-1.8e-8RH3-1.49	4
	PHX	Cp=0.014Sp-0.0006T-0.0008RH-5.41	Cp=2.69e-8Sp3+1.04e-6T3-2.79e-9RH3-1.4	4
NO2 (w/o CO)	PTL	Cp=0.109Sp+0.05T-0.136RH-82.19	Cp=4.44e-8Sp3+0.001T3-3.53e-6RH3-26.80	5
	ATL	Cp=0.009Sp-0.72T-0.154RH+31.73	Cp=7.56e-9Sp3-0.0001T3-3.38e-6RH3+7.68	6
	RAV	Cp=-0.003Sp-0.986T-0.231RH+52.38	Cp=8.89e-10Sp3-0.0001T3-2.7e-6RH3+12.71	6
	SAC	Cp=0.126Sp+0.464T-0.15RH-98.90	Cp=4.43e-8Sp3+0.0004T3-1.06e-5RH3-19.96	5
	NYC	Cp=0.115Sp+0.33T-0.17RH-90.8	Cp=3.64e-8Sp3+0.001T3-8.56e-6RH3-19.24	6
	PHX	Cp=0.036Sp-0.16T-0.135RH-5.12	Cp=1.77e-8Sp3-9.44e-5T3-1.09e-5RH3+5.14	4
NO2 (w CO)	PTL	Cp=0.253CO+0.078Sp+0.011T-0.102RH-155.09	Cp=2.88e-7CO+3.71e-8Sp3+0.0008T3-3.17e-6RH3-38.73	5
	ATL	Cp=-0.202CO+0.003Sp-0.644T-0.139RH-48.17	Cp=3.43e-7CO+4.75e-9Sp3-0.0001T3-3.55e-6RH3-13.50	6
	RAV	Cp=0.4CO-0.023Sp-1.04T-0.179RH-91.60	Cp=7.26e-7CO-6e-9Sp3-0.0001T3+2.32e-6RH3-29.65	6
	SAC	Cp=0.256CO+0.07Sp+0.18T-0.12RH+147.88	Cp=2.57e-7CO+3.33e-8Sp3+0.0003T3-8.9e-6RH3-28.10	5
	NYC	Cp=0.364CO+0.088Sp+0.127T-0.141RH-205.43	Cp=2.68e-7CO+3.33e-8Sp3+0.0008T3-8.18e-6RH3-31.97	6
	PHX	Cp=0.307CO+0.019Sp-0.007T-0.133RH-118.37	Cp=4.6e-7CO+1.1e-8Sp3-8.82e-5T3-0.128RH3-16.52	4
O3 (w/o CO)	PTL	Cp=0.121Sp+0.545T-0.289RH-92.78	Cp=3.42e-8Sp3+0.0027T3-9.93e-6RH3-22.63	6
	ATL	Cp=0.026Sp+0.669T-0.662RH+21.28	Cp=5.57e-9Sp3+0.0006T3-2.88e-5RH3+12.69	4
	RAV	Cp=0.021Sp+4.71T+0.39RH-134.42	Cp=3.76e-9Sp3+0.0011T3-2.66e-5RH3+10.09	4
	SAC	Cp=0.014Sp+1.45T-0.186RH-11.03	Cp=1.26e-9Sp3+0.0013T3-1.08e-5RH3+11.31	5
	NYC	Cp=0.022Sp+0.72T-0.23RH+10.9	Cp=5.3e-9Sp3+0.002T3-1.36e-5RH3+21.86	4
	PHX	Cp=-9.8e-4Sp+1.16T-0.205RH+14.25	Cp=-8.85e-10Sp3+0.001T3-1.35e-5RH3+16.34	6

O3 (w CO)	PTL	Cp=-0.56CO+0.088Sp+0.32T-0.27RH+167.89	Cp=-1.01e-6CO+2.64e-8Sp3+0.0021T3-9.44e-6RH3+53.18	6
	ATL	Cp=-0.3CO+0.034Sp+0.64T-0.62RH+130.34	Cp=-5.87e-7CO+6.86e-9Sp3+0.0005T3-3e-5RH3+50.85	4
	RAV	Cp=-0.138CO+0.024Sp+4.47T+0.34RH-74.42	Cp=-6.31e-7CO+4.94e-9Sp3+0.001T3-2.78e-5RH3+51.25	4
	SAC	Cp=-0.35CO+0.038Sp+1.12T-0.152RH+109.38	Cp=-6.52e-7CO+9.21e-9Sp3+0.001T3-1.22e-5RH3+46.43	5
	NYC	Cp=-1.11CO+0.029Sp+0.923T-0.129RH+427.19	Cp=-2.17e-6CO+6.9e-9Sp3+0.0023T3-8.06e-6RH3+144.1	4
	PHX	Cp=-0.35CO+0.003Sp+0.661T-0.171RH+161.36	Cp=-6.67e-7CO+9.5e-10Sp3+0.0008T3-1.17e-5RH3+62.15	6

Table S5. Results of NO_2 and O_3 LCAQ sensors tested by AQ-SPEC (only electrochemical type sensors are included, data retrieved on March 5th, 2022)

Make (Model)	Pollutant	Field R^2
APIS	NO_2	0.30 to 0.44
	O_3	0.73 to 0.83
AQMesh (v4.0)	NO_2	0.0 to 0.46
	O_3	0.46 to 0.83
AQMesh (v5.1)	NO_2	0.49 to 0.54
	O_3	0.62 to 0.74
Igienair (Zaack AQI)	NO_2	0.53 to 0.58
	O_3	0.0
Kunak	NO_2	0.24 to 0.32
	O_3	0.86 to 0.88
Magnasci SRL	NO_2	0.00 to 0.05
	O_3	0.00 to 0.08
Oizom (Polludrone Smart)	NO_2	0.002 to 0.03
	O_3	0.14 to 0.23
Perkin Elmer (ELM)	NO_2	0.0
	O_3	0.89 to 0.96
Spec Sensors	NO_2	0.0 to 0.16
	O_3	0.0 to 0.24
Vaisala (AQT410) Ver. 1.11	NO_2	0.0
	O_3	0.40 to 0.58
Vaisala (AQT410) Ver. 1.15	NO_2	0.43 to 0.61
	O_3	0.66 to 0.82

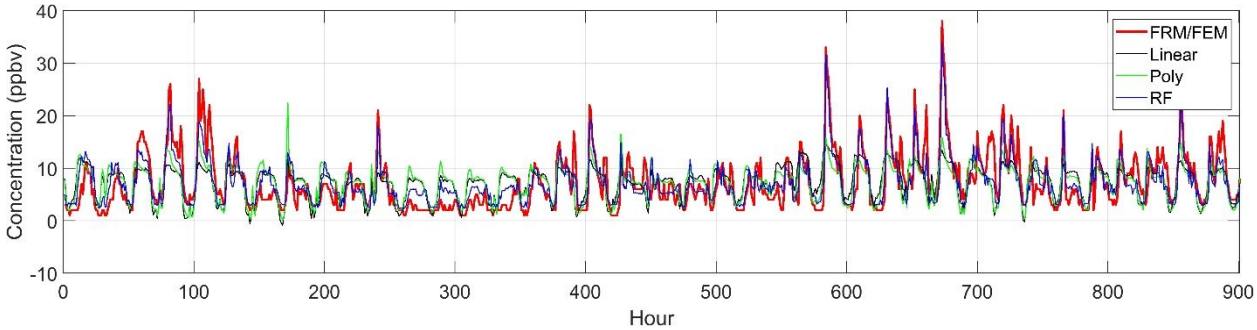

Figure S1. Time-series plot of hourly NO_2 concentrations at Atlanta as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

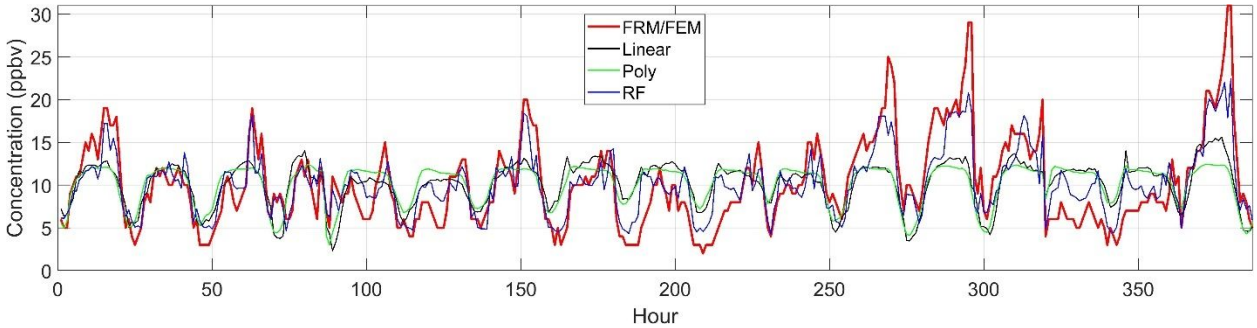

Figure S2. Time-series plot of hourly NO_2 concentrations at Riverside as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

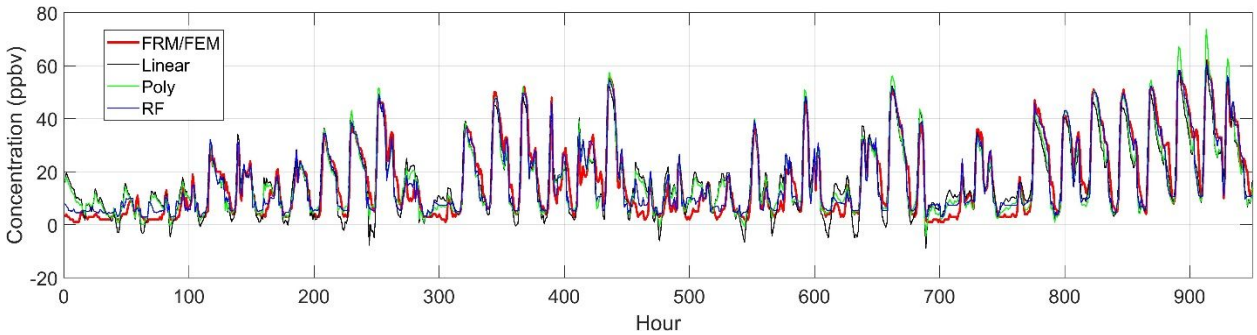

Figure S3. Time-series plot of hourly NO_2 concentrations at Sacramento as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

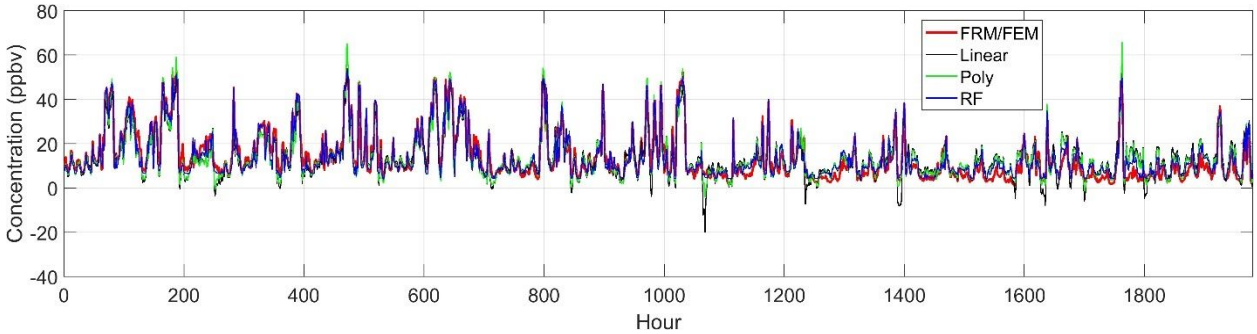

Figure S4. Time-series plot of hourly NO_2 concentrations at New York City as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

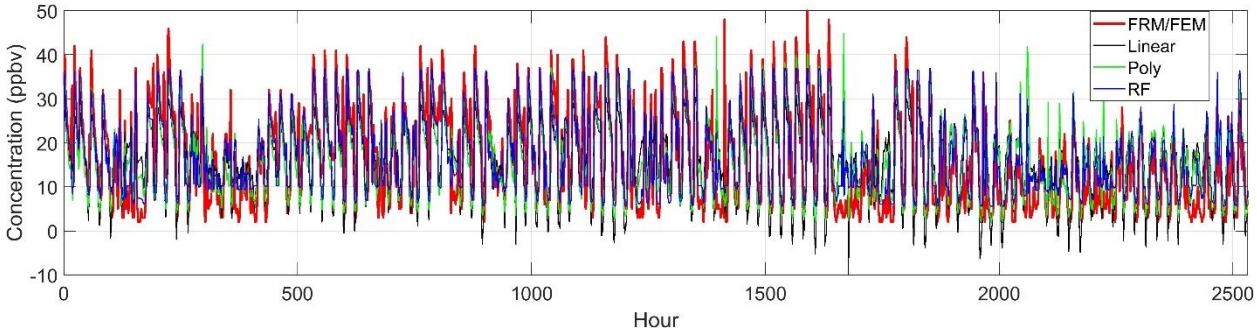

Figure S5. Time-series plot of hourly NO_2 concentrations at Phoenix as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

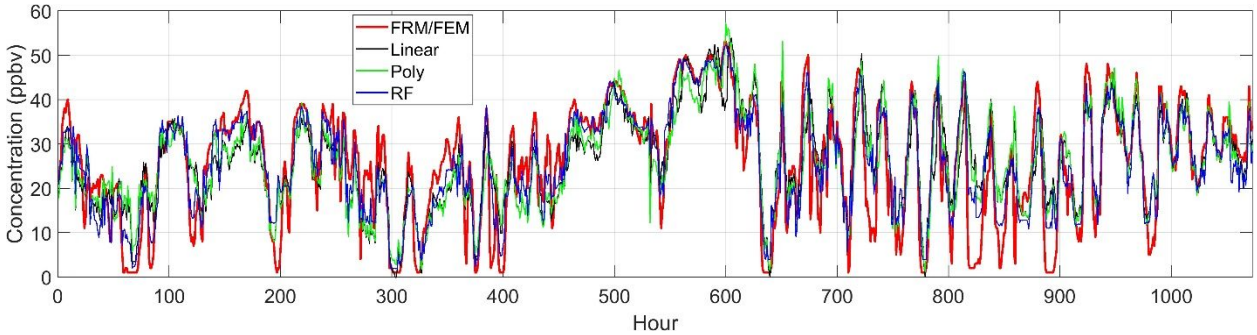

Figure S6. Time-series plot of hourly O_3 concentrations at Portland as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

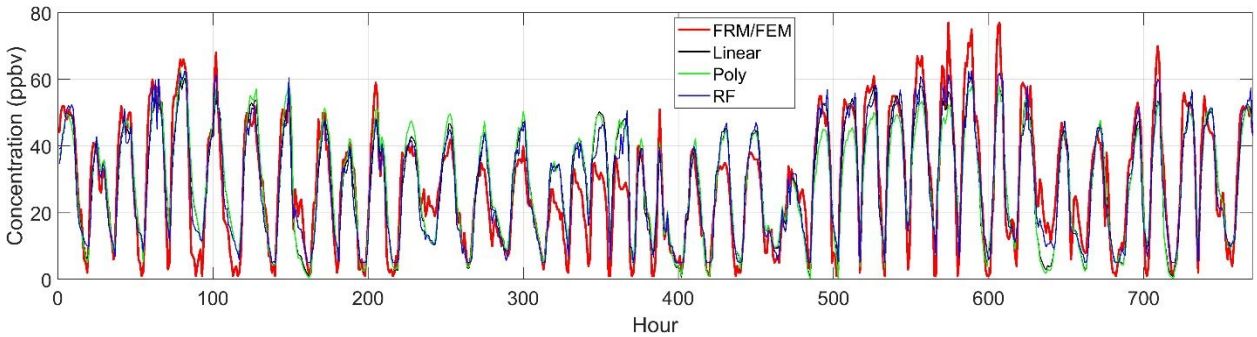

Figure S7. Time-series plot of hourly O_3 concentrations at Atlanta as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

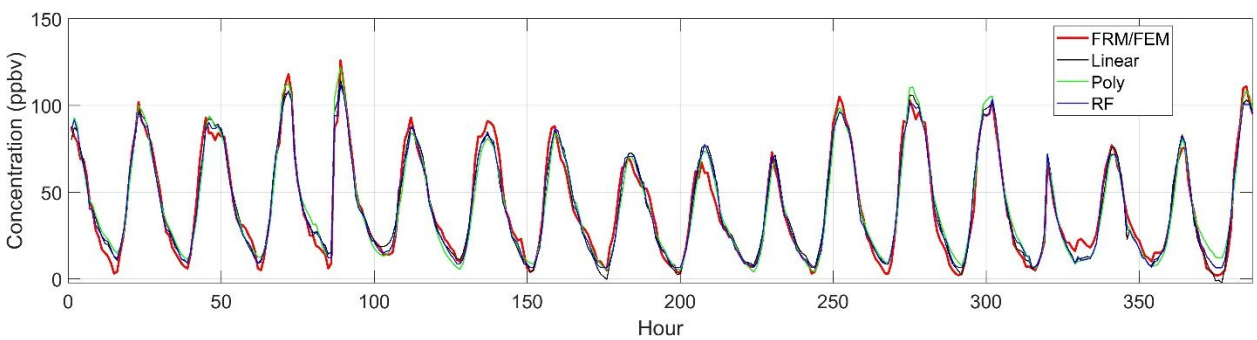

Figure S8. Time-series plot of hourly O_3 concentrations at Riverside as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

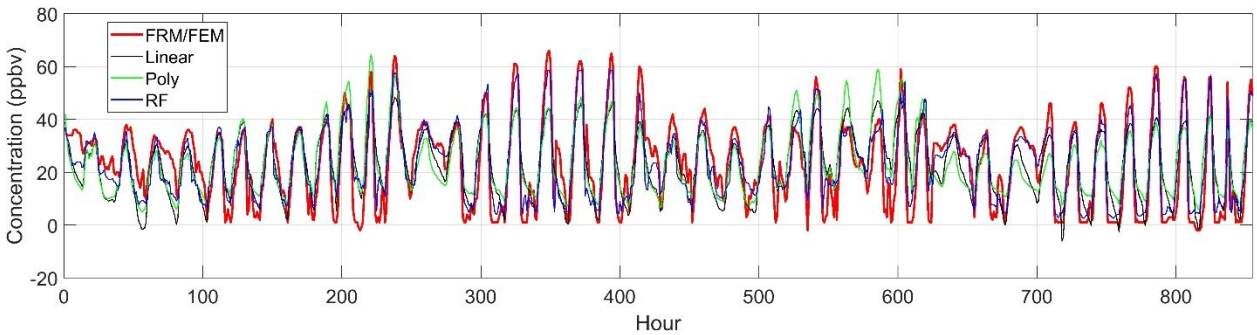

Figure S9. Time-series plot of hourly O_3 concentrations at Sacramento as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

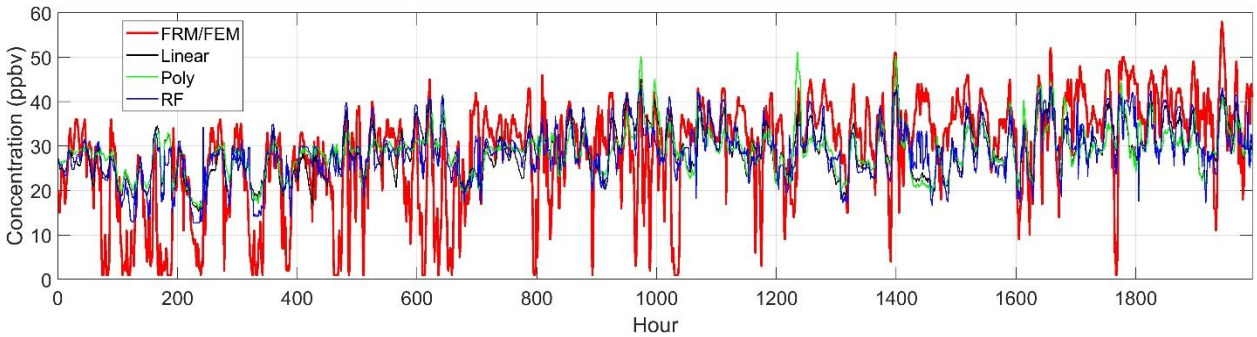

Figure S10. Time-series plot of hourly O_3 concentrations at New York City as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration

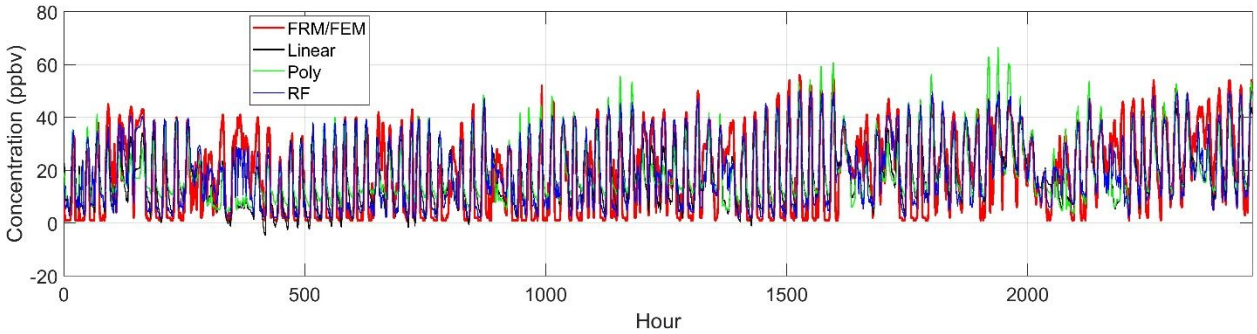

Figure S11. Time-series plot of hourly O_3 concentrations at Phoenix as collected by FRM/FEM equipment, and from low-cost sensors with linear, polynomial, and random forest calibration