

Interagency Monitoring of Protected Visual Environments (IMPROVE): Semiannual Quality Assurance Report

Air Quality Research Center | University of California, Davis | April 30, 2019

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1. Introduction

The University of California Davis (UCD) Air Quality Research Center (AQRC) reviews quality assurance (QA) activities semiannually in this report series as a contract deliverable for the Interagency Monitoring of Protected Visual Environments (IMPROVE) program (contract #P15PC00384). The primary objectives of the series are to:

1. Provide the National Park Service (NPS) with graphics illustrating some of the comparisons used to evaluate the quality and consistency of measurements within the network.
2. Highlight observations that may give early indications of emerging trends, whether in atmospheric composition or measurement quality.
3. Serve as a record and tool for ongoing UCD QA efforts.

The graphics shown in this report are a small subset of the many QA evaluations that UCD performs on a routine basis. More finished analyses such as those available in data advisories are outside the scope of this report, which provides a snapshot of the network's internal consistency and recent trends.

Each network site has a sampler for collection of particulate matter on polytetrafluoroethylene (PTFE), nylon, and quartz filters. The IMPROVE sampler has four sampling modules:

- Module-A: Collection of fine particles with aerodynamic diameter less than 2.5 μm ($\text{PM}_{2.5}$) on polytetrafluoroethylene (PTFE) filters for gravimetric, x-ray fluorescence (XRF), and optical absorption by hybrid integrating plate/sphere (HIPS) analysis at UCD.
- Module-B: Collection of $\text{PM}_{2.5}$ on nylon filters for ion chromatography (IC) analysis at Research Triangle Institute (RTI) International.
- Module-C: Collection of $\text{PM}_{2.5}$ on quartz filters for thermal optical analysis (TOA) at Desert Research Institute (DRI).
- Module-D: Collection of particles with aerodynamic diameter less than 10 μm (PM_{10}) on PTFE filters for gravimetric analysis at UCD.

Additional information and detail regarding analytical and validation procedures can be found in the standard operation procedure (SOP) documents and Quality Assurance Project Plan (QAPP) available at the Colorado State University (CSU) Cooperative Institute for Research in the Atmosphere (CIRA) IMPROVE site at <http://vista.cira.colostate.edu/Improve/>.

Unless otherwise noted, data evaluated in this report cover sampling dates from January 1, 2018 through June 30, 2018.

2. Concentration-Level QC Checks

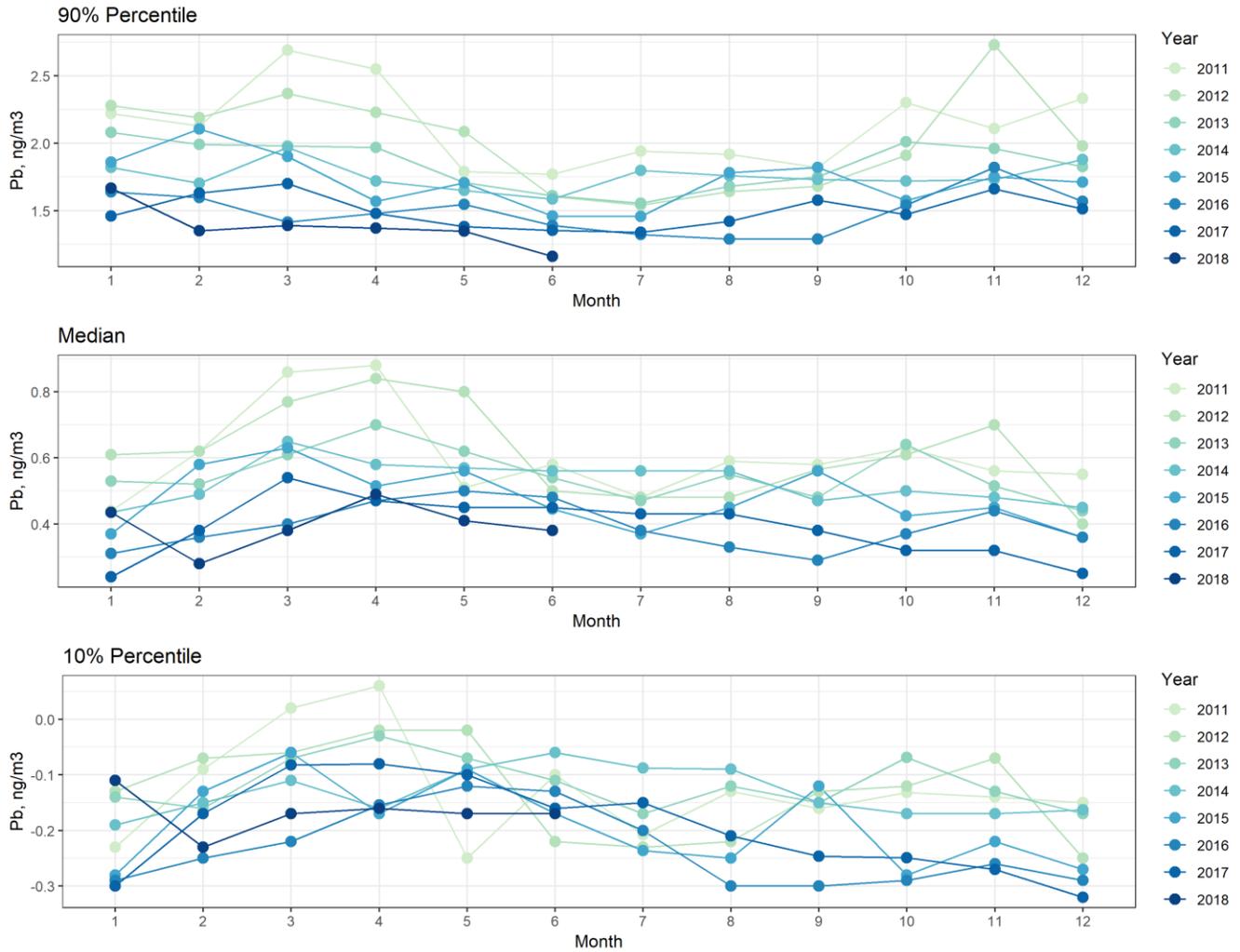
2.1 Comparison Across Years

Time series plots of network-scale statistics can reveal possible effects associated with changes in procedures, instrumentation, or sampling media in the analytical laboratories at DRI, RTI, and UCD. Interpretation of these plots is complicated by real atmospheric trends whose presence IMPROVE is intended to detect; these arise from intentional or adventitious changes in emissions, as well as inter-annual fluctuations in synoptic weather patterns.

Figures 1-8 show 90th percentile, median (50th percentile), and 10th percentile concentrations of select species, with seven years of historical network data (2011-2017) providing context for the six months currently under review (January through June 2018).

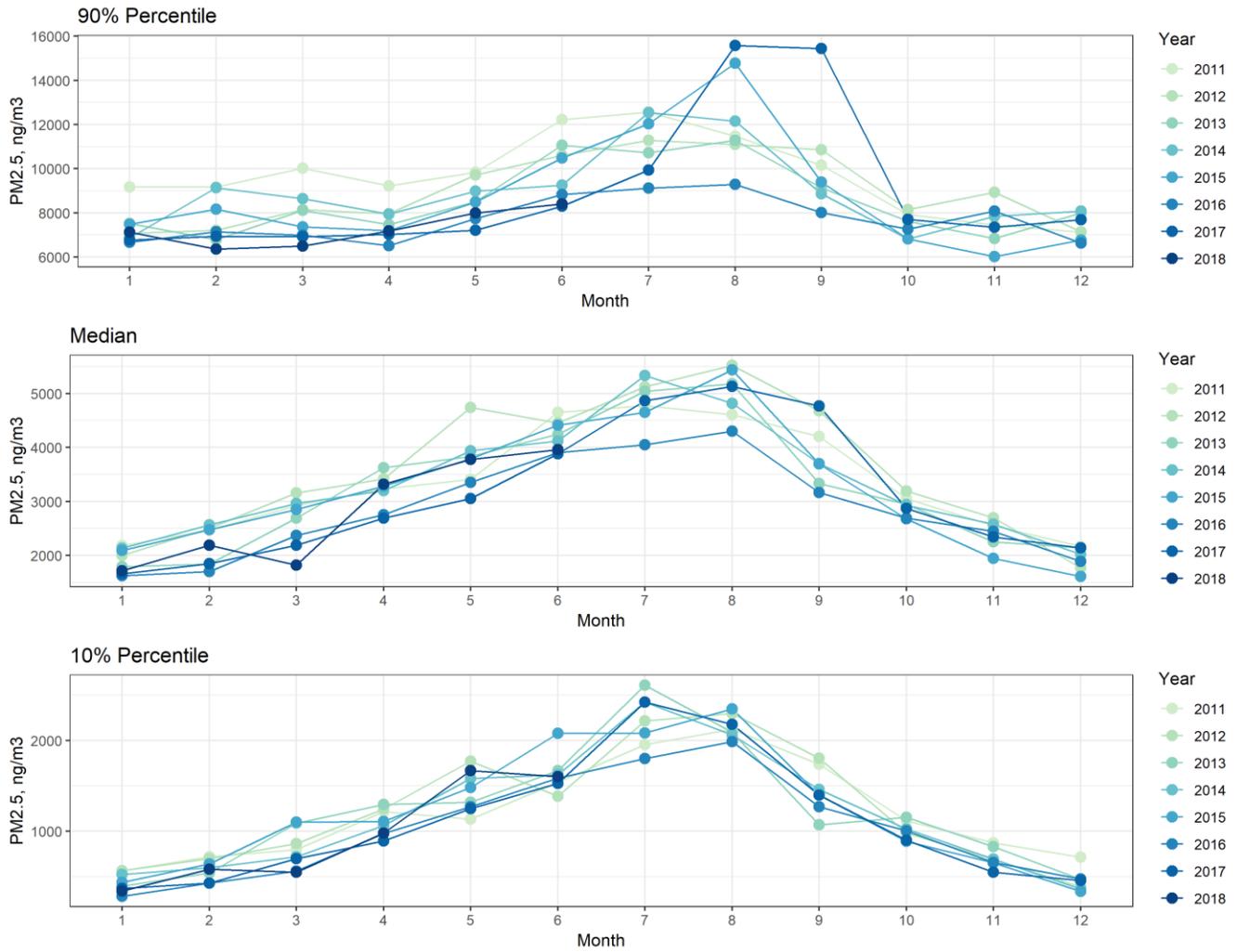
Concentrations of lead (Figure 1) during the first six months of 2018 were similar to observations from 2016 and 2017, and were generally lower relative to previous years.

Figure 1: Multi-year time series of network-wide lead (Pb) concentrations.



Median PM_{2.5} concentrations (Figure 2) during the first three months of 2018 were similar to those observed during 2016 and 2017; however during April and May 2018 PM_{2.5} concentrations were higher and in closer alignment with earlier years.

Figure 2: Multi-year time series of network-wide PM_{2.5} mass concentrations.



Corresponding with elevated $PM_{2.5}$ in April and May 2018, concentrations of soil (Figure 3) were also elevated, particularly during April 2018. Composite variable soil is calculated as,

$$SOIL = 2.2 * \max(Al,0) + 2.49 * \max(Si,0) + 1.63 * \max(Ca,0) + 2.42 * \max(Fe,0) + 1.94 * \max(Ti,0)$$

Thus, concentrations of soil elements (Al, Si, Ca, Fe, and Ti) were also elevated. Shown as an example is the multi-year time series for Si (Figure 4); concentrations during April 2018 – and to a lesser extent May 2018 – were elevated.

Figure 3: Multi-year time series of network-wide composite variable soil concentrations.

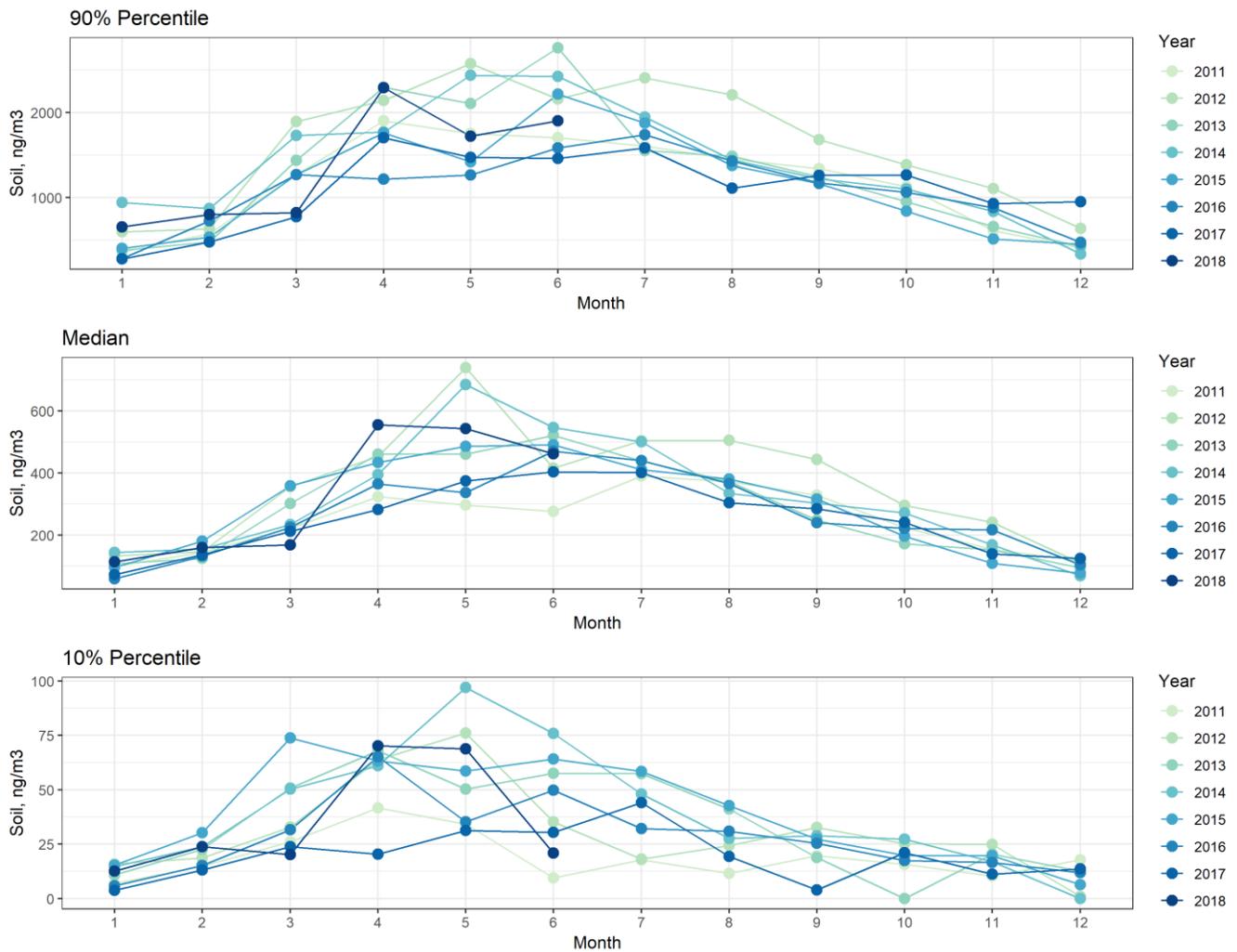
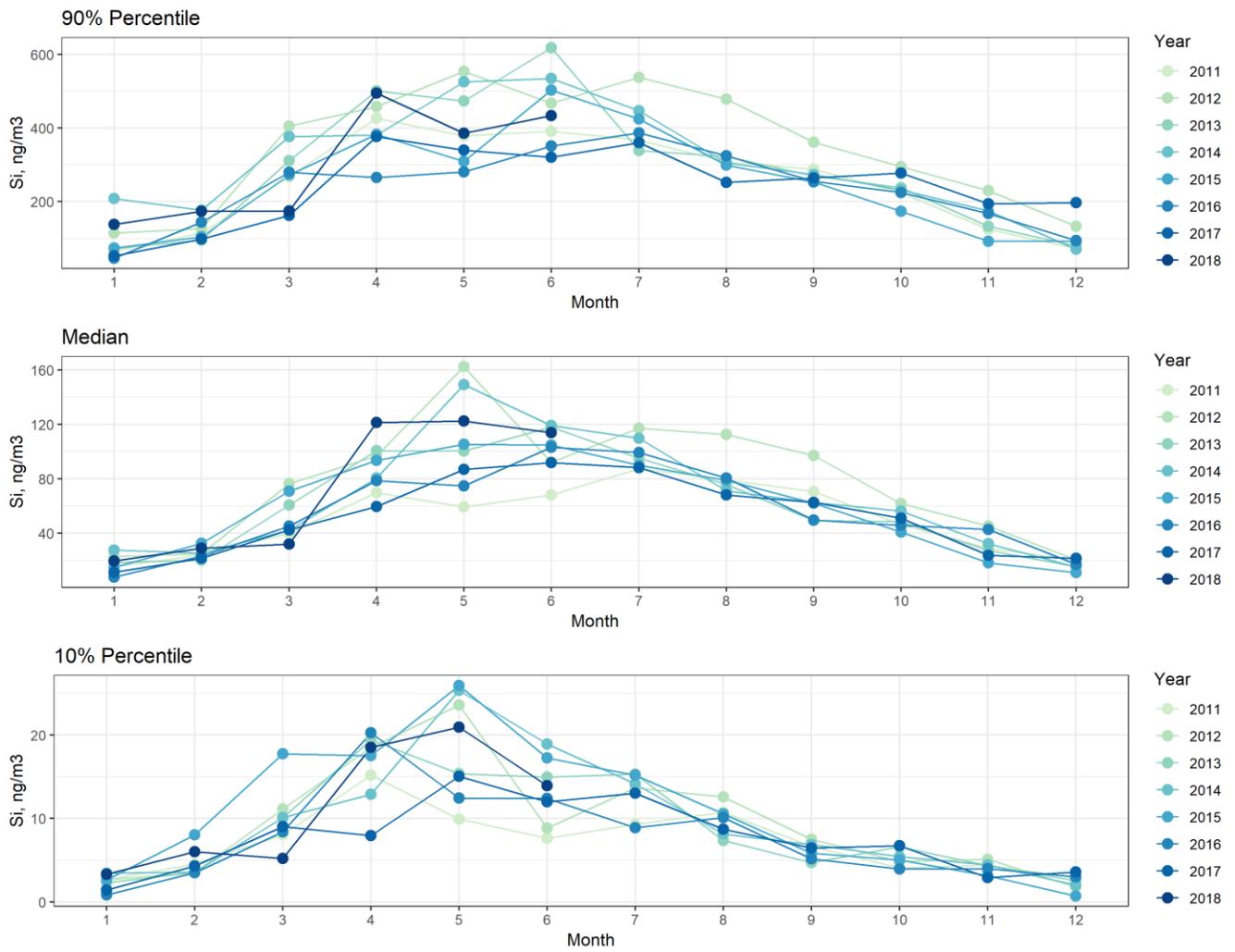


Figure 4: Multi-year time series of network-wide silica (Si) concentrations.



Measurements of organic carbon by reflectance (OCR) during the first six months of 2018 agree well with previous years (Figure 5). The 2018 elemental carbon by reflectance (ECR) concentrations (Figure 6) are generally high relative to previous years, particularly during March, April, and May.

Figure 5: Multi-year time series of network-wide organic carbon by reflectance (OCR) concentrations.

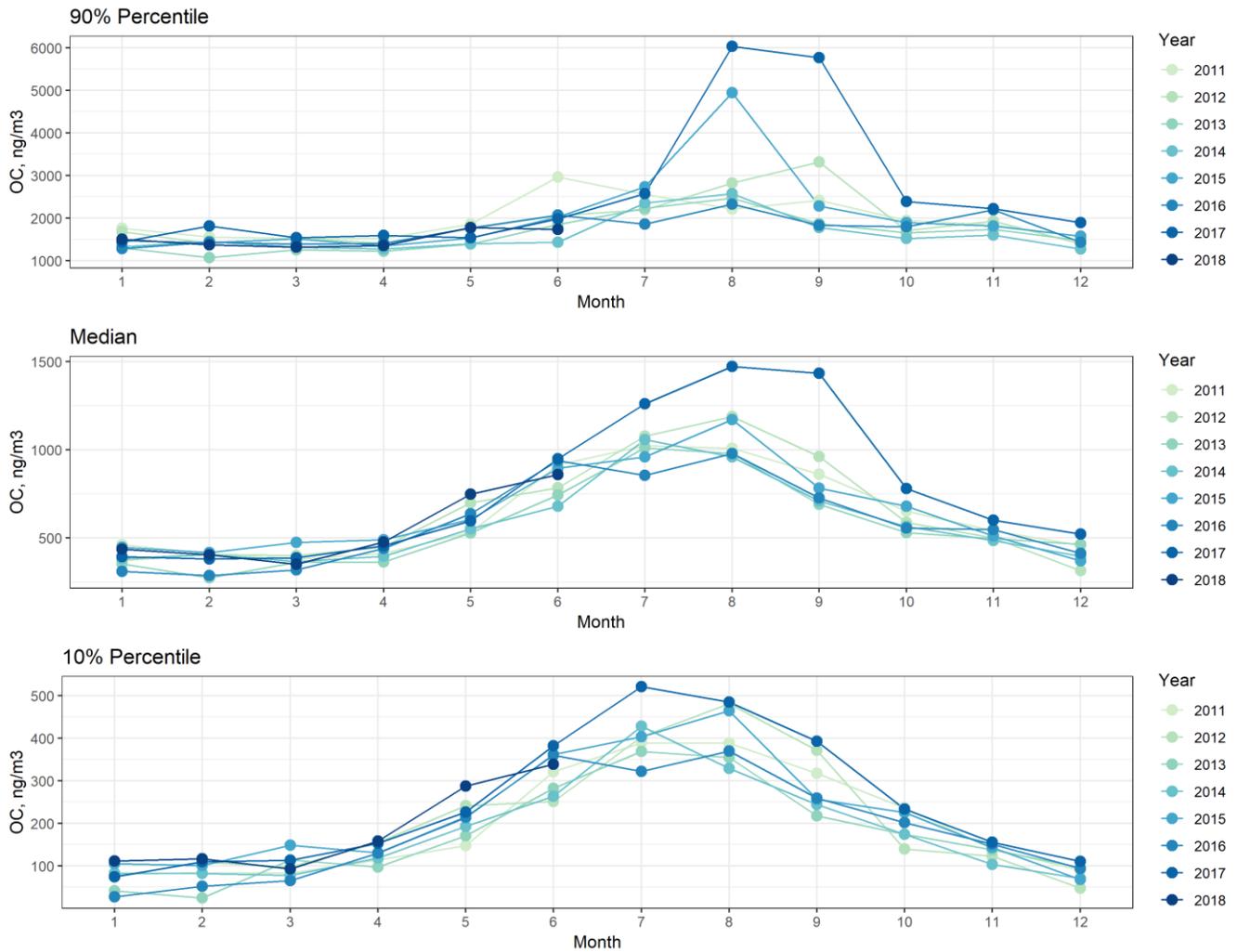
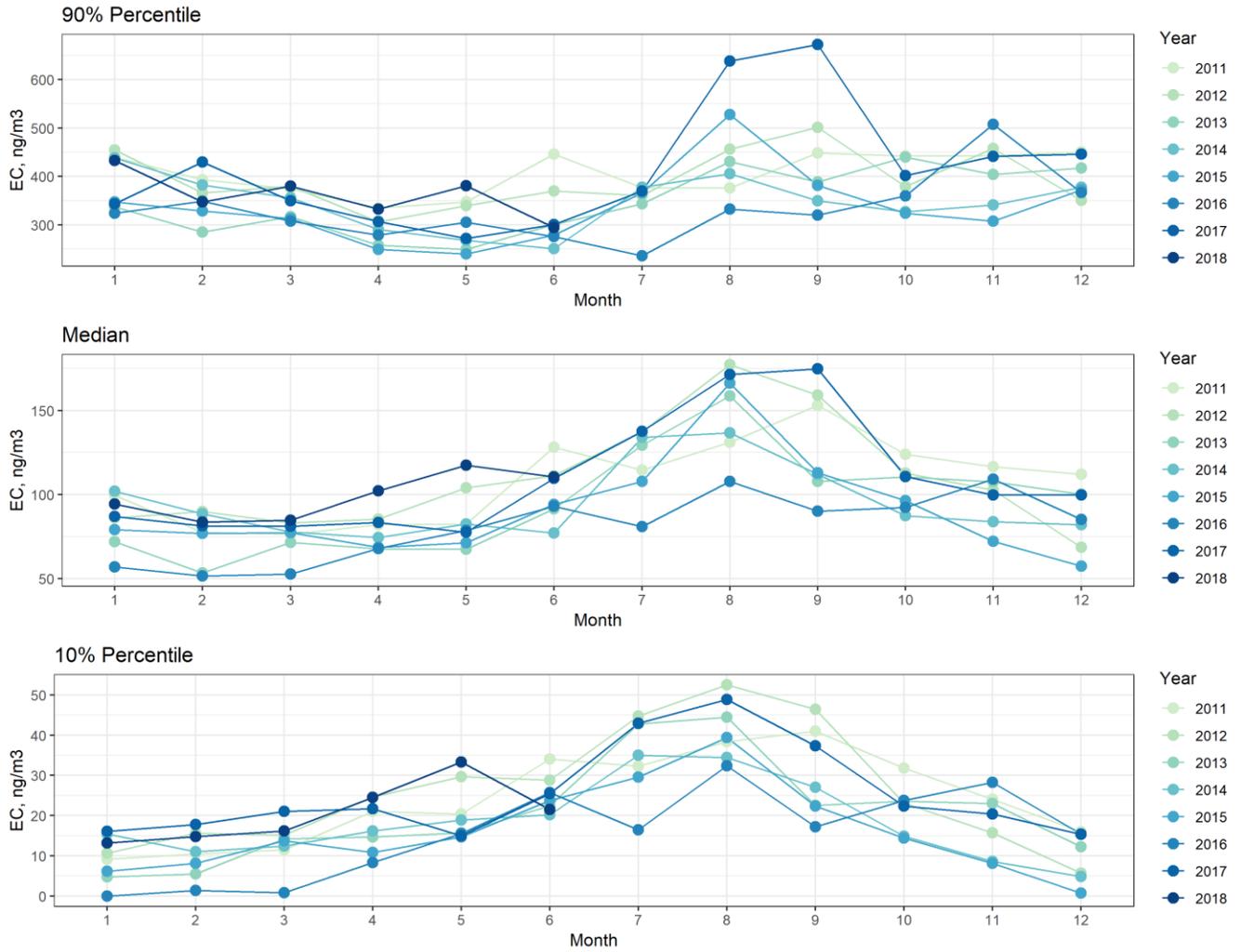
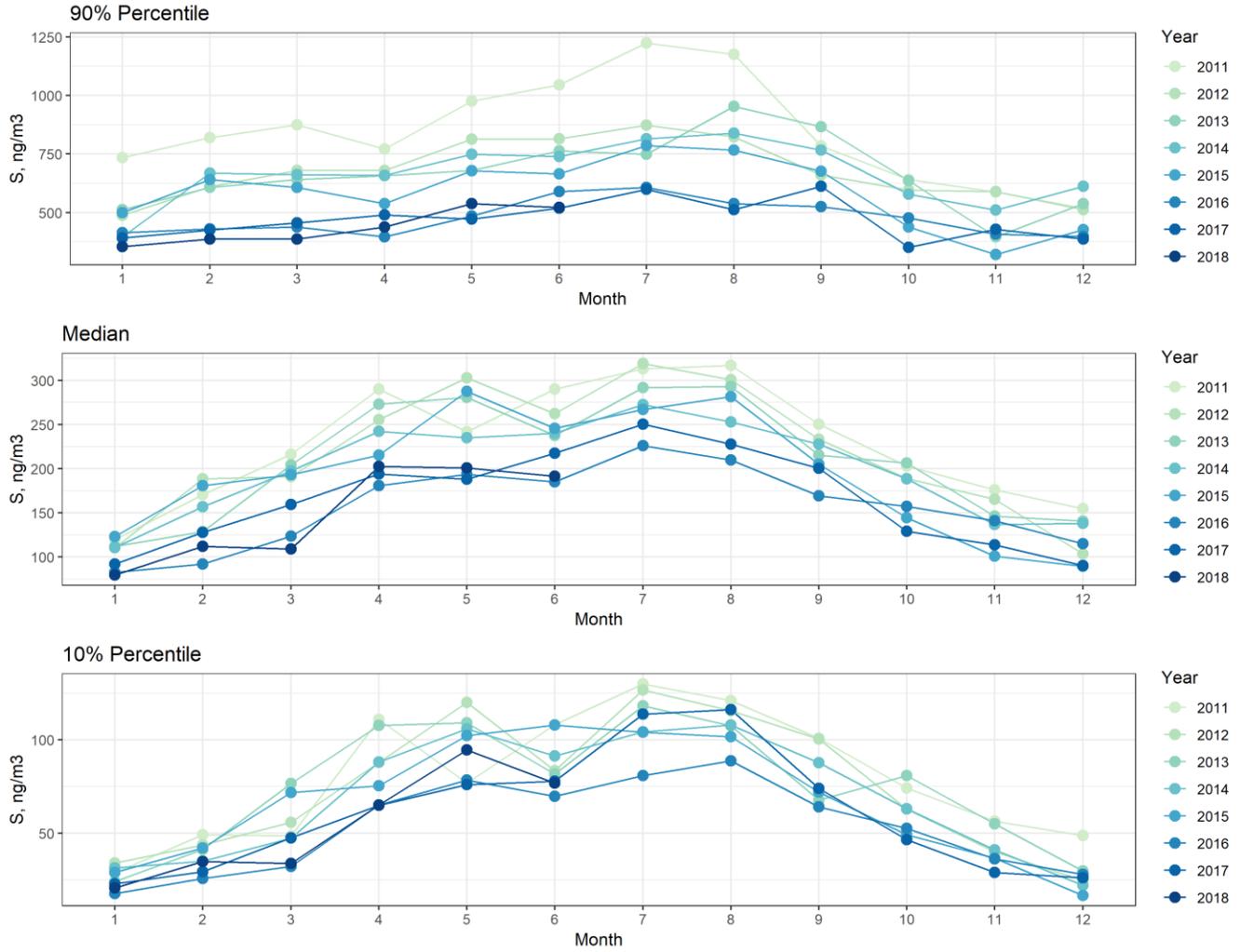


Figure 6: Multi-year time series of network-wide elemental carbon by reflectance (ECR) concentrations.



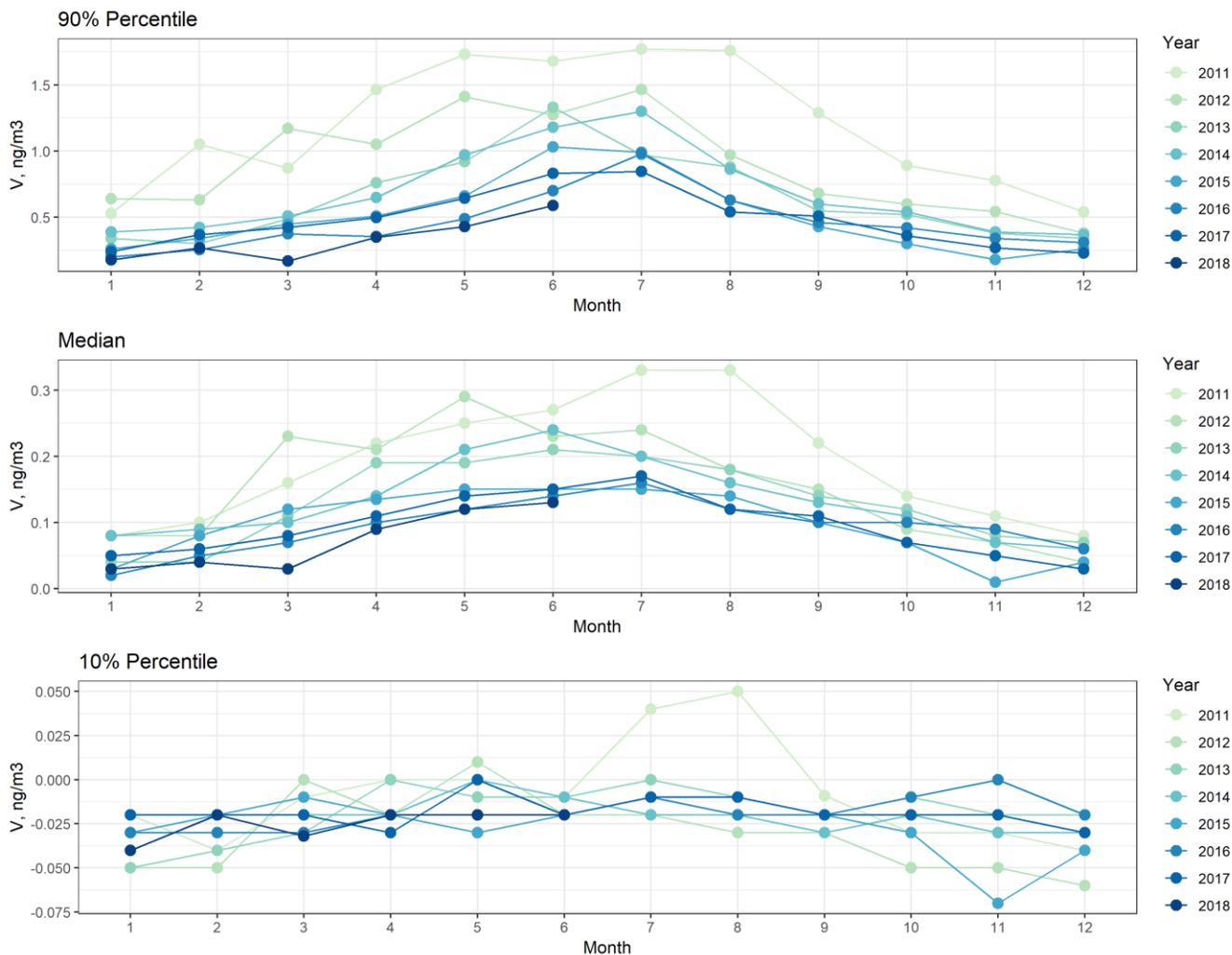
Similar to 2016 and 2017, sulfur concentrations generally continue to be low (Figure 7), and relatively stable since 2016.

Figure 7: Multi-year time series of network-wide sulfur (S) concentrations.



Concentrations of vanadium (Figure 8) continue to be low similar to observations from 2015, 2016, and 2017, with concentrations during March 2018 lower at the median and 90th percentile than the previous seven years. These observations are likely a continuation of lower concentrations observed corresponding with regulations on international shipping emissions implemented in January 2015 (Spada et al, 2018).

Figure 8: Multi-year time series of network-wide vanadium (V) concentrations.



2.2 Comparisons Between Modules

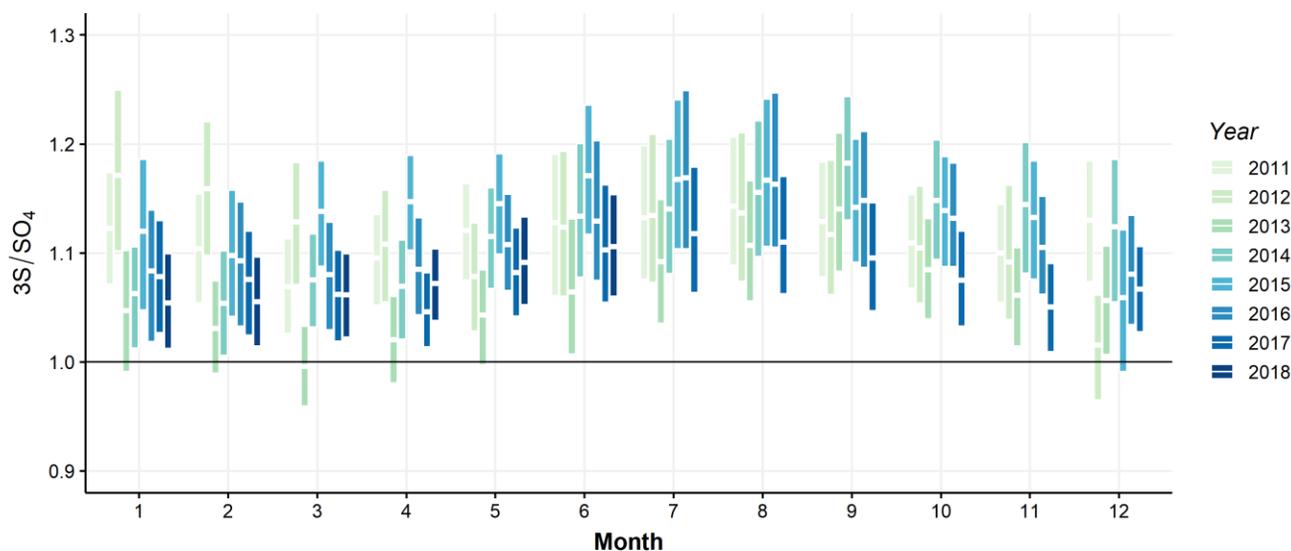
The following graphs compare two independent measures of aerosol properties that are expected to correlate. Graphs presented in this section explore variations in the correlations, which can result from real atmospheric and anthropogenic events or analytical and sampling issues.

2.2.1 Sulfur versus Sulfate

PTFE filters collected from the A-Module are analyzed for elemental sulfur using XRF, and nylon filters collected from the B-Module are analyzed for sulfate (SO₄) using IC. The molecular

weight of SO₄ (96 g/mol) is three times the atomic weight of S (32 g/mol), so the concentration ratio (3×S)/SO₄ should be one if all particulate sulfur is present as water-soluble sulfate. In practice, real measurements routinely yield a ratio greater than one (Figure 9), suggesting the presence of some sulfur in a non-water soluble form of sulfate or in a chemical compound other than sulfate.

Figure 9: Multi-year time series of network-wide (3×S)/SO₄ ratios. Bars show 25th to 75th percentile range, middle line indicates median.



2.2.2 PM_{2.5} versus Reconstructed Mass (RCM)

PTFE filters from the A-Module are analyzed gravimetrically (i.e., weighed before and after sample collection) to determine PM_{2.5} mass. Gravimetric data are compared to reconstructed mass (RCM), where the RCM composite variable is estimated from chemical speciation measurements. The formulas used to estimate the mass contributions from various chemical species are taken from *UCD IMPROVE SOP 351, Data Processing and Validation*. In the simple case where valid measurements are available for all needed variables, reconstructed mass is the following sum:

$$\text{RCM} = (4.125 \times \text{S}) + (1.29 \times \text{NO}_3^-) + (1.8 \times \text{OCR}) + (\text{ECR}) + \\ (2.2 \times \text{Al} + 2.49 \times \text{Si} + 1.63 \times \text{Ca} + 2.42 \times \text{Fe} + 1.94 \times \text{Ti}) + (1.8 \times \text{chloride})$$

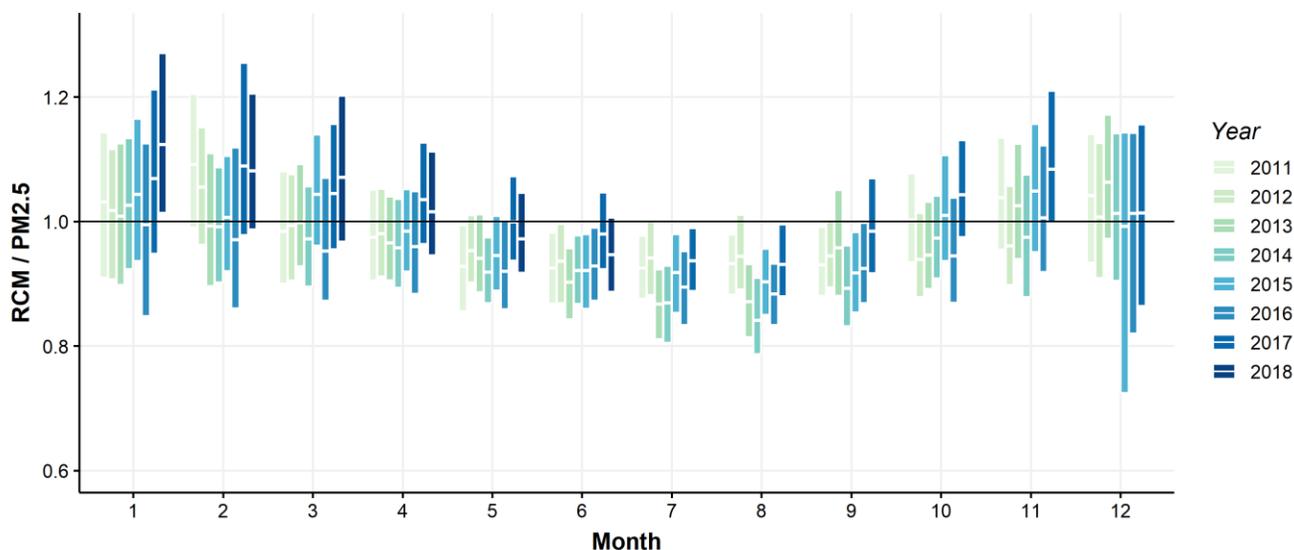
The parenthesized components represent the mass contributions from, in order, ammonium sulfate, ammonium nitrate, organic compounds, elemental carbon, soil, and sea salt.

If the RCM completely captures and accurately estimates the different mass components, the RCM/PM_{2.5} ratio is expected to be near one. In practice, the RCM/PM_{2.5} ratio exhibits some seasonal variability (Figure 10). The lowest ratios appear during the summer months when hygroscopic sulfates are most abundant, potentially contributing retained water to gravimetric PM_{2.5} and when organic carbon is most oxidized, potentially resulting in an organic carbon mass

multiplier larger than the 1.8 value used in the RCM equation. Unbound water is not accounted for by any of the RCM terms. Conversely, the highest ratios appear during the winter months when peak levels of ammonium nitrate are captured on the retentive nylon filter. Some of this thermally unstable RCM may volatilize from the inert PTFE filter before it can be weighed to determine $PM_{2.5}$.

The RCM/ $PM_{2.5}$ ratios during January and March 2018 are higher than those reported during the previous seven years; other months during early 2018 are also high, though in closer alignment to the 2017 observations. As suggested in previous reports, elevated 2017 and 2018 RCM/ $PM_{2.5}$ ratios could indicate changing organic carbon character. Additionally, water retained on the filter and a weighing environment with unstable relative humidity could be contributing factors.

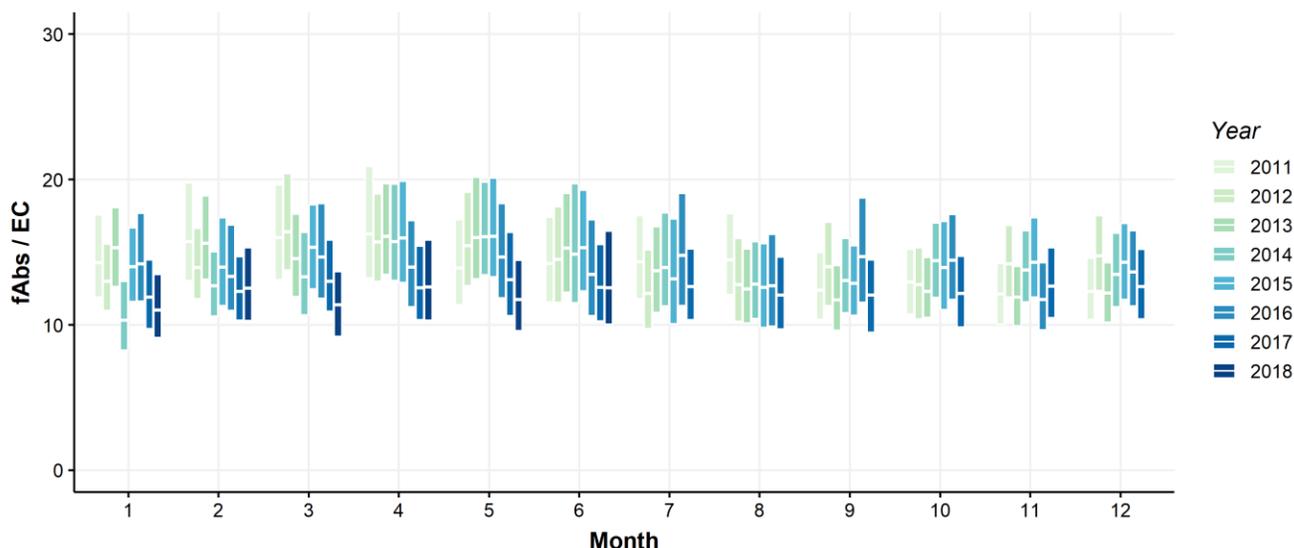
Figure 10: Multi-year time series of network-wide RCMN/ $PM_{2.5}$ ratios. Bars show 25th to 75th percentile range, middle line indicates median.



2.2.3 Optical Absorption versus Elemental Carbon

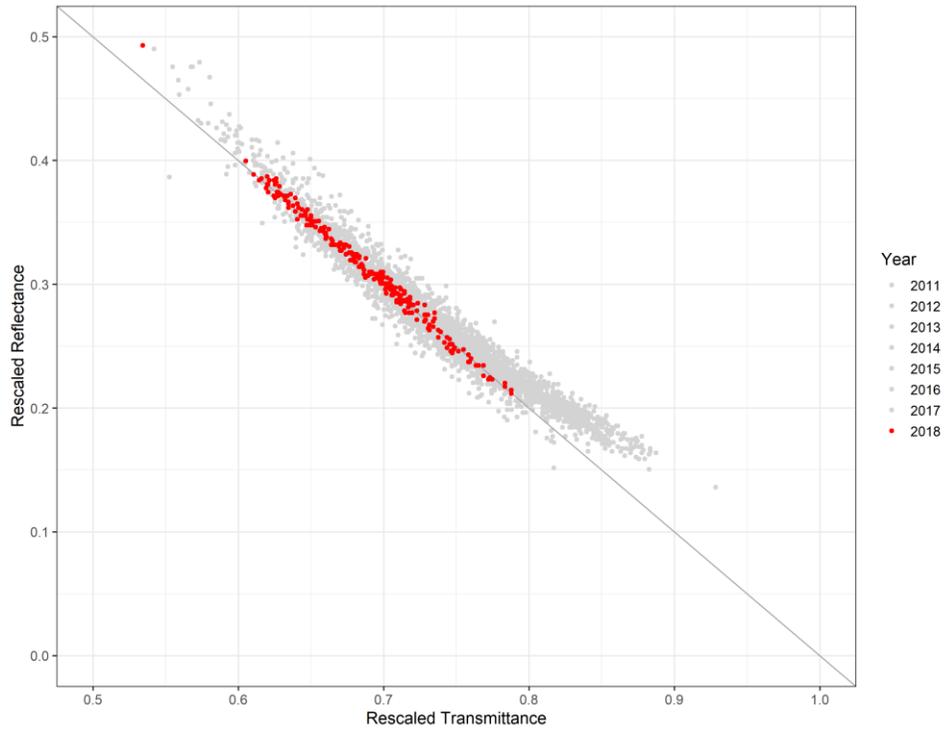
The hybrid integrating plate/sphere (HIPS) instrument measures optical absorption, allowing for calculation of absorption coefficients (fAbs, where units are Mm^{-1}) from A-Module PTFE filters. Absorption coefficients are expected to correlate with C-Module elemental carbon (ECR, where units are $\mu g/m^3$) measured by thermal optical reflectance (TOR). The fAbs/ECR ratio (with units m^2/g) exhibits seasonal variability with lower ratios during the summer months, corresponding with higher concentrations of ECR (Figure 11). Ratios during the first six months of 2018 are low relative to the previous seven years, particularly March and May, which could be driven by high ECR values noted in Figure 6.

Figure 11: Multi-year time series of network-wide fAbs/ECR ratios, where fAbs is in Mm^{-1} and elemental carbon by reflectance (ECR) is in $\mu\text{g}/\text{m}^3$. Bars show 25th to 75th percentile range, middle line indicates median.



As mentioned in the previous IMPROVE Semiannual Quality Assurance Report (October 12, 2018) and documented in a data advisory (available at the CSU CIRA IMPROVE site at <http://vista.cira.colostate.edu/Improve/data-advisories/>), in April 2018 the HIPS integrating sphere was changed from the legacy 2-inch Spectraflex-coated sphere described in White et al. (2016) to a newer 4-inch Spectralon sphere from the same manufacturer, and the laser was replaced. A calibration was performed following the April 2018 instrument upgrades; samples collected January 2017 through February 2018 were analyzed under this calibration. Additionally, in November 2018 a new detector was installed and the instrument was subsequently recalibrated; samples collected beginning March 2018 were analyzed under this calibration. A scatter plot of HIPS reflectance and transmittance shows good performance on 2018 field blanks collected January through June 2018 and analyzed under both calibration regimes (Figure 12). Early investigation suggests that recalibration in November 2018 (impacting samples collected March 2018 onward) may have introduced a 5% positive bias in sample values; this is being further explored through a multiyear reanalysis project.

Figure 12: Calibration of HIPS showing rescaled reflectance and transmittance for network-wide samples collected January 1, 2018 through June 30, 2018 (red points) relative to previous years (2011-2017; gray points).



2.3 Comparisons Between Collocated Samples

Select IMPROVE network sites have collocated modules, where duplicate samples are collected and analyzed using the same analytical protocols. Differences between the resulting data provide a measure of the total uncertainty associated with filter substrates, sampling and handling in the field, and laboratory analysis. Collocated precision is reported as fractional uncertainty.

Fractional uncertainty (f) is calculated from the scaled relative differences (SRD) between the collocated sample pairs. Beginning with data from samples collected January 2018, fractional uncertainties are determined using the most recent two years of data from collocated measurements. If the count of collocated pairs over the two year period is less than 60, a value of 0.25 is adopted as f .

$$\text{Scaled Relative Difference (SRD)} = \frac{(\text{collocated} - \text{routine}) / \sqrt{2}}{(\text{collocated} + \text{routine}) / 2}$$

$$\text{Fractional Uncertainty (f)} = \frac{(\text{84th percentile of SRD}) - (\text{16th percentile of SRD})}{2}$$

The scaled relative differences are $\pm\sqrt{2}$ when one of the two measurements is zero, and vary between these limits at concentrations close to the detection limit. They generally decrease with increasing concentration and are expected to converge to a distribution representative of multiplicative measurement error when the concentration is well above the detection limit (Figure 13, elements; Figure 14, mass; Figure 15, ions; Figure 16, carbon; Figure 17, optical

absorption). Note that this convergence is not observed for species that are rarely measured above the MDL.

Figure 13: Scaled relative difference for element measurements at sites with collocated modules across the IMPROVE network (January through June 2018). Dotted vertical lines indicate method detection limits.

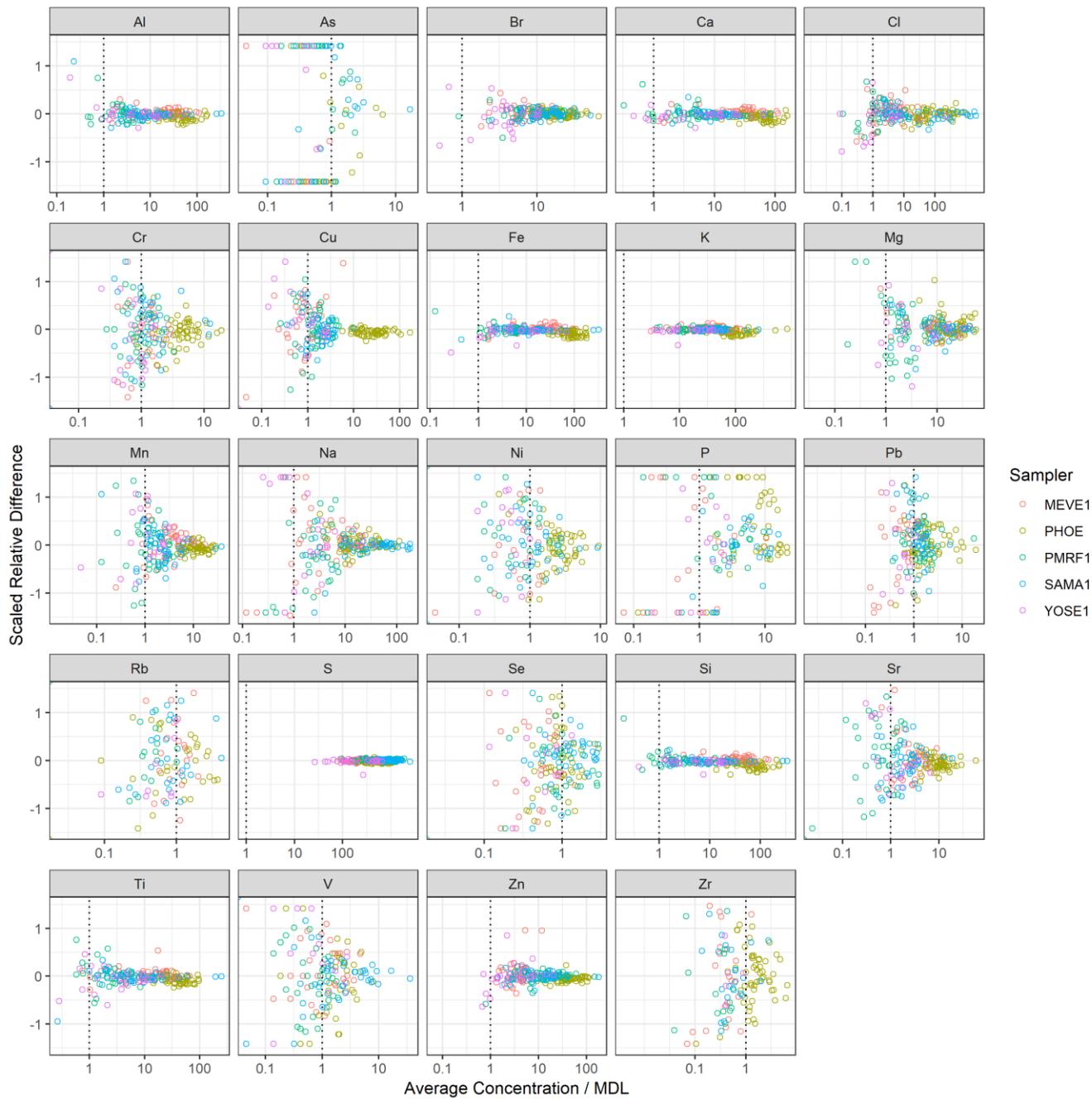


Figure 14: Scaled relative difference for PM₁₀ and PM_{2.5} at sites with collocated modules across the IMPROVE network (January through June 2018). Dotted vertical lines indicate method detection limits.

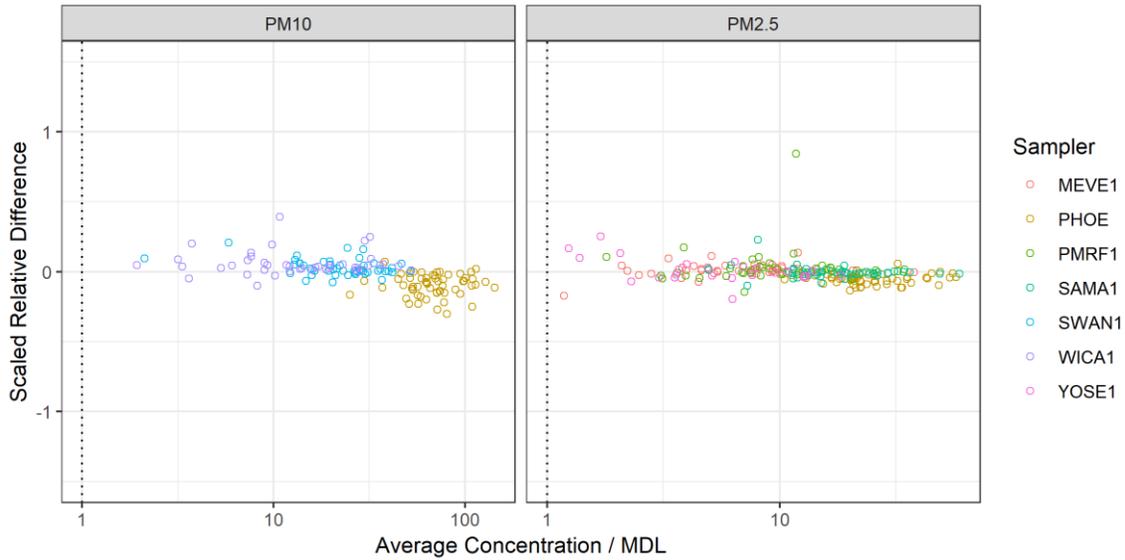


Figure 15: Scaled relative difference for ions measurements at sites with collocated modules across the IMPROVE network (January through June 2018). Dotted vertical lines indicate method detection limits.

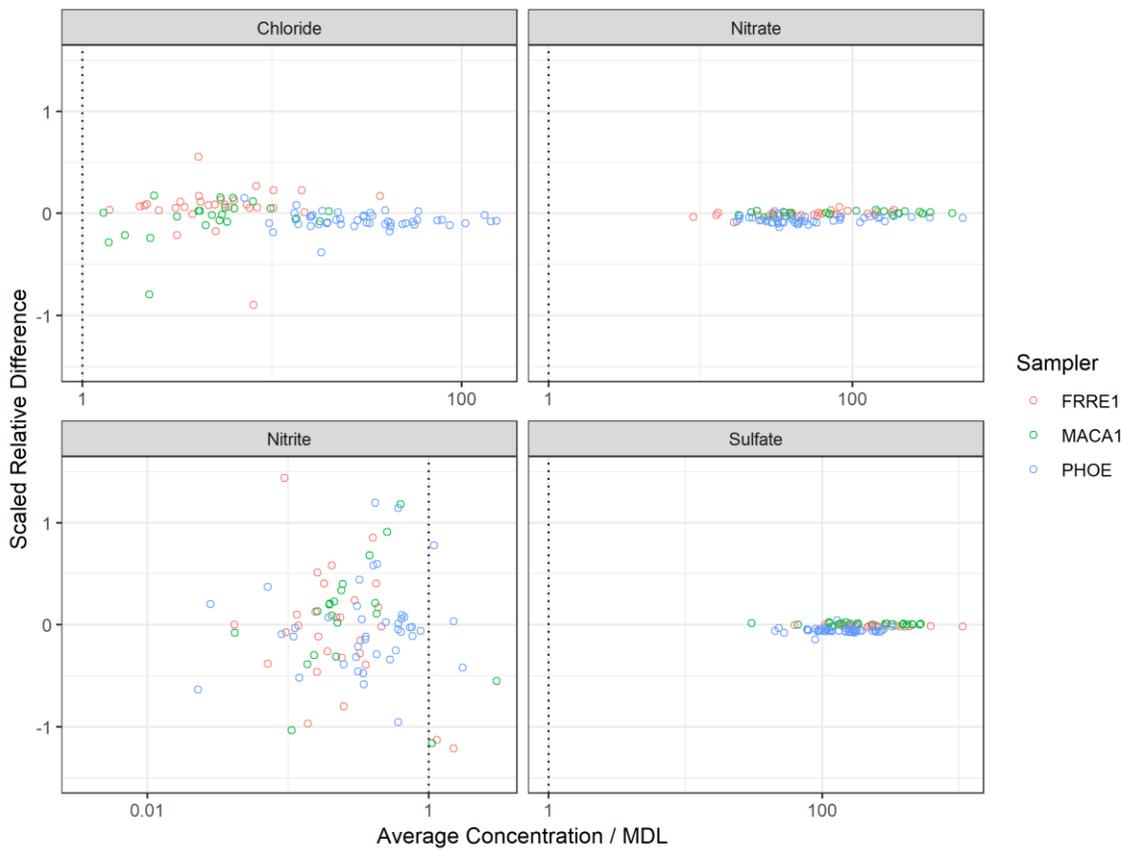


Figure 16: Scaled relative difference for carbon measurements at sites with collocated modules across the IMPROVE network (January through June 2018). Elemental carbon by reflectance (ECR) fractions are indicated as (1) through (3), organic carbon by reflectance (OCR) fractions are indicated as (1) through (4), TR indicates measurement by reflectance, and TT indicates measurement by transmittance. Dotted vertical lines indicate method detection limits.

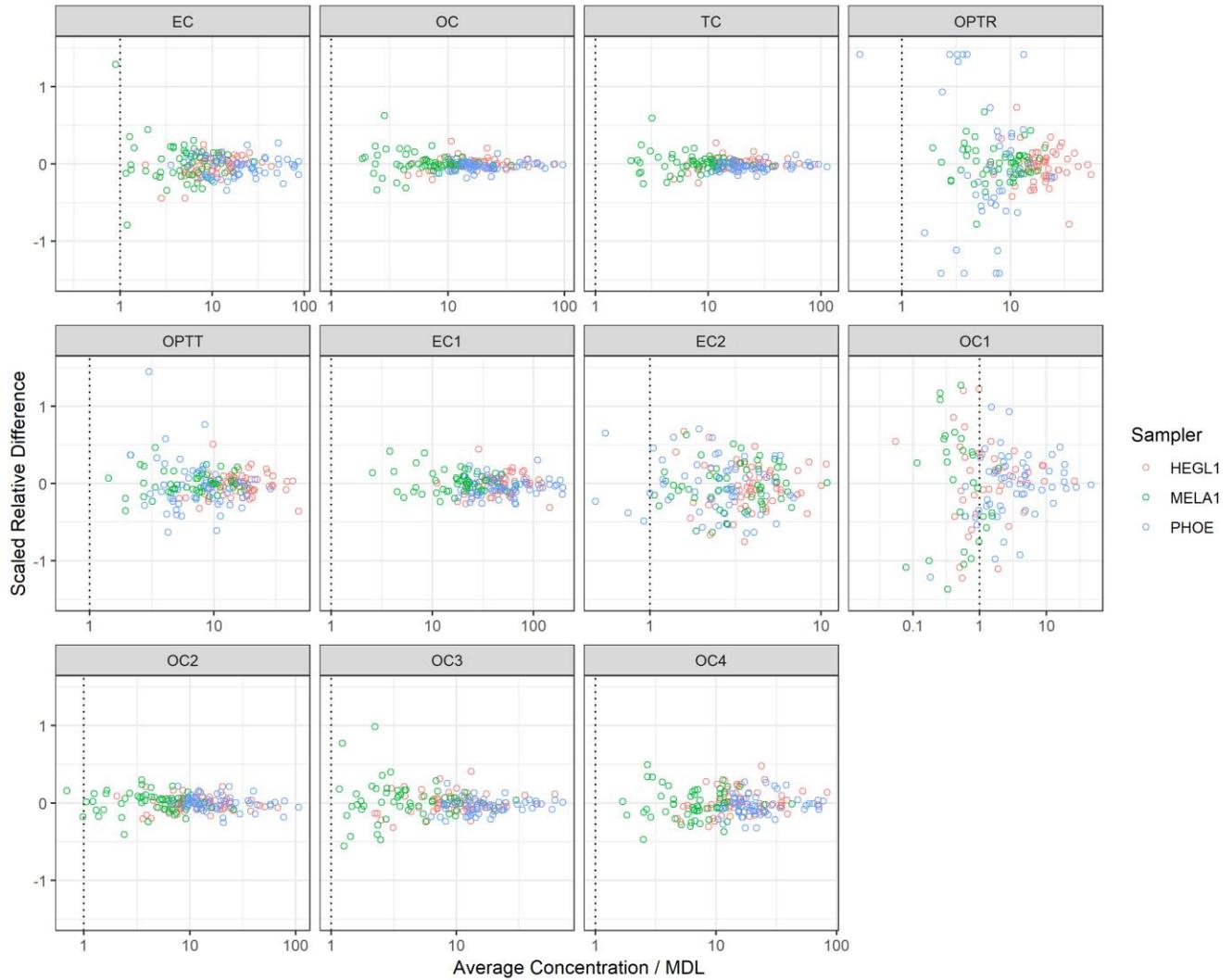
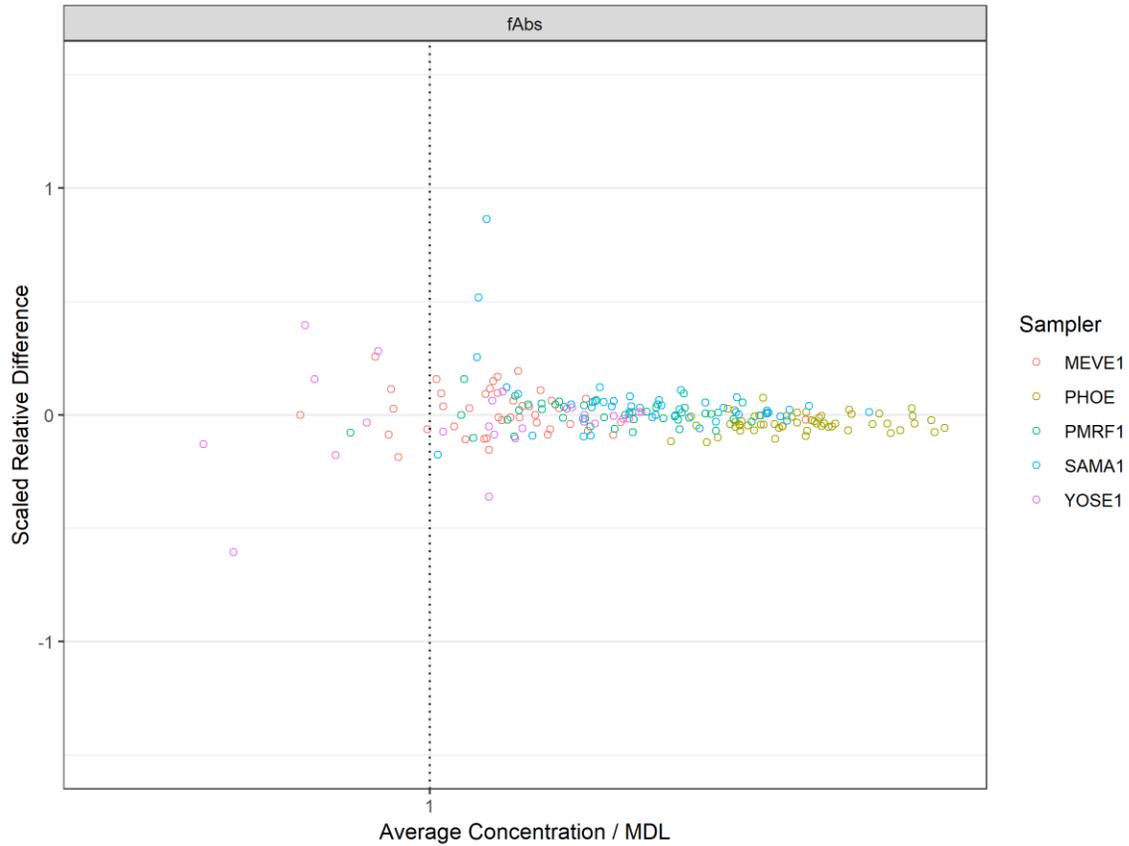


Figure 17: Scaled relative difference for optical absorption measurements at sites with collocated modules across the IMPROVE network (January through June 2018). Dotted vertical line indicates method detection limit.



As noted in past reports, the collocated comparisons for elements (particularly soil elements: Al, Si, Ca, Fe, and Ti) and mass ($PM_{2.5}$ and PM_{10}) at the Phoenix, AZ site (PHOE) have historically had poor agreement. This issue has been previously explored and is possibly related to a highly localized source of dust (i.e., a dog run at the neighboring house). Interestingly, the 2018 collocated comparisons show much better agreement at PHOE for the soil elements, particularly relative to 2016 and 2017; Fe is shown in Figure 18 as an example. However, while the 2018 $PM_{2.5}$ mass shows improved agreement (Figure 19), the poor agreement for PM_{10} persists (Figure 20).

Figure 18: Scaled relative difference for iron (Fe) at sites with collocated modules across the IMPROVE network, January through June for 2011 through 2018. Dotted vertical lines indicate method detection limits. The Phoenix, AZ (PHOE) site is shown in black.

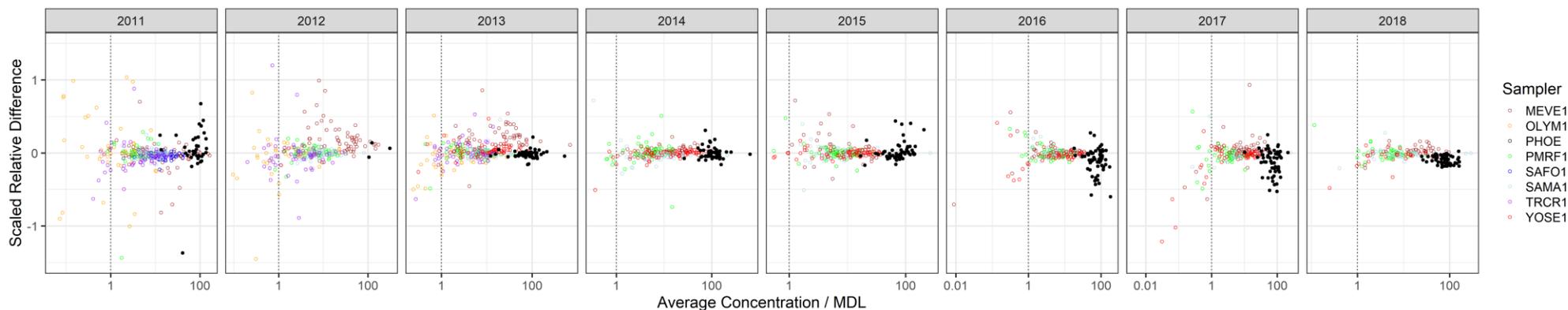


Figure 19: Scaled relative difference for PM_{2.5} mass at sites with collocated modules across the IMPROVE network, January through June for 2011 through 2018. Dotted vertical lines indicate method detection limits. The Phoenix, AZ (PHOE) site is shown in black.

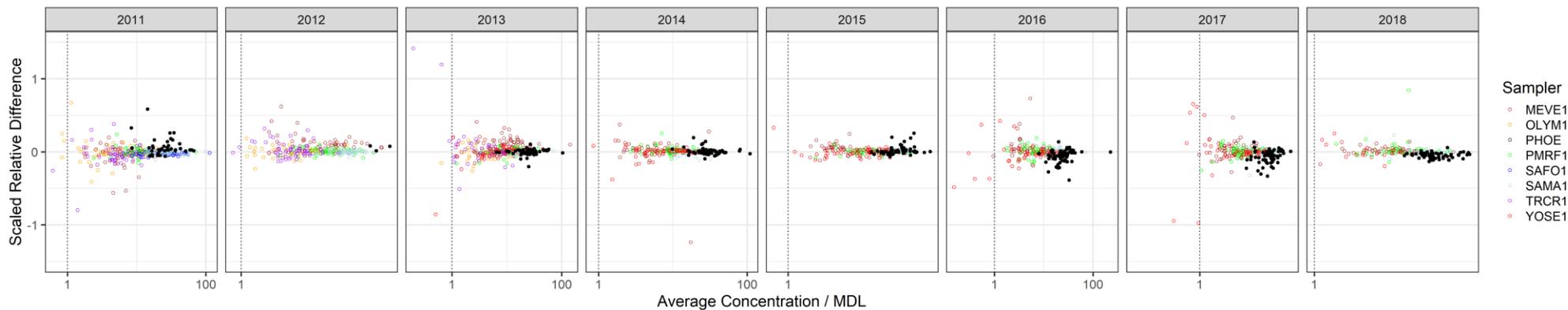
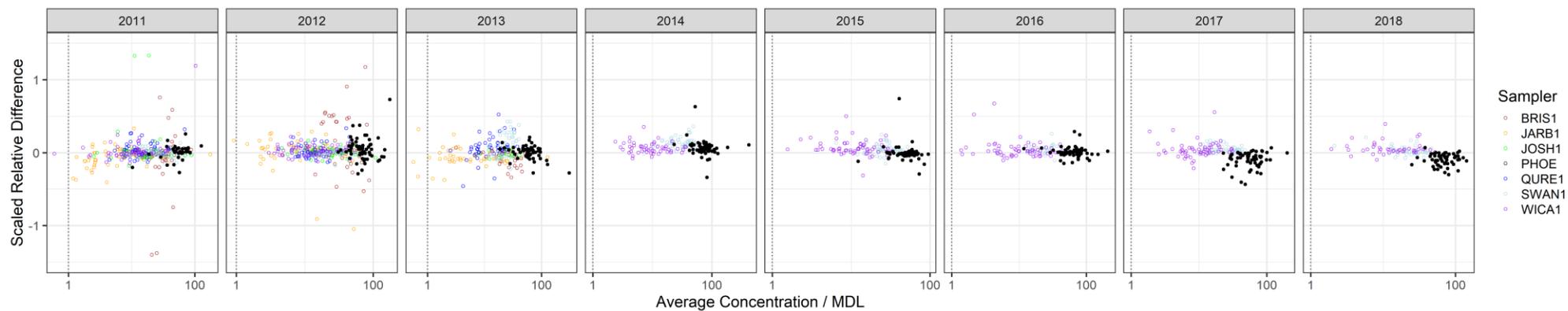


Figure 20: Scaled relative difference for PM₁₀ mass at sites with collocated modules across the IMPROVE network, January through June for 2011 through 2018. Dotted vertical lines indicate method detection limits. The Phoenix, AZ (PHOE) site is shown in black.



UCD IMPROVE SOP 351, Data Processing and Validation documents the calculation of scaled relative difference and fractional uncertainty. Fractional uncertainty for the 2018 IMPROVE data is calculated using data from collocated samples collected 2016-2017 (Table 1).

Table 1: Fractional uncertainty calculated from collocated samples collected 2013-2016 (reported for 2017 IMPROVE data) and 2016-2017 (reported for 2018 IMPROVE data).

Species	Fractional Uncertainty, 2013-2016	Fractional Uncertainty, 2016-2017
Chloride	0.08	0.08
Nitrite	0.25	0.25
Nitrate	0.04	0.04
Sulfate	0.02	0.02
Organic Carbon (OCR)	0.09	0.08
Elemental Carbon (ECR)	0.14	0.14
Total Carbon	0.08	0.07
Organic Carbon (OCR1)	0.26	0.23
Organic Carbon (OCR2)	0.13	0.11
Organic Carbon (OCR3)	0.13	0.13
Organic Carbon (OCR4)	0.13	0.13
Organic Pyrolyzed (OPR)	0.16	0.20
Elemental Carbon (ECR1)	0.10	0.11
Elemental Carbon (ECR2)	0.18	0.19
Elemental Carbon (ECR3)	0.25	0.25
Na	0.14	0.14
Mg	0.15	0.15
Al	0.08	0.08
Si	0.07	0.06
P	0.23	0.27
S	0.02	0.02
Cl	0.17	0.14
K	0.04	0.03
Ca	0.06	0.06
Ti	0.09	0.09
V	0.16	0.17
Cr	0.17	0.15
Mn	0.13	0.14
Fe	0.06	0.05
Ni	0.20	0.13
Cu	0.09	0.13
Zn	0.07	0.08
As	0.25	0.25
Se	0.25	0.25
Br	0.11	0.10
Rb	0.25	0.25
Sr	0.13	0.13
Zr	0.25	0.25
Pb	0.16	0.14
PM _{2.5}	0.03	0.04
PM ₁₀	0.07	0.07
fAbs	0.06	0.06

3. Analytical QC Checks

3.1 Replicate versus Routine

Analytical precision is evaluated by comparing data from replicate and routine analyses, where the replicate analysis is a second analysis performed on the same sample. Reliable laboratory measurements should be repeatable with good precision. Analytical precision includes only the uncertainties associated with the laboratory handling and analysis, and is used internally at UCD as a QC tool.

Comparison between routine and replicate data are presented as scaled relative difference (SRD).

$$\text{Scaled Relative Difference (SRD)} = \frac{(\text{replicate} - \text{routine}) / \sqrt{2}}{(\text{replicate} + \text{routine}) / 2}$$

The scaled relative differences are $\pm\sqrt{2}$ when one of the two measurements is zero and vary between these limits at concentrations close to the detection limit. They generally decrease with increasing concentration and are expected to converge to a distribution representative of analytical measurement error when the concentration is well above the detection limit (Figure 21 and Figure 22). Note that this convergence is not observed for species that are rarely measured above the MDL.

As shown in Figure 22, replicate and routine analyses performed on the same analyzer (Figure 22; green points) show better agreement for the OCR and ECR fractions than those performed on different analyzers (Figure 22; red points).

Replicate XRF analyses are not performed on the routine IMPROVE samples. Rather, long-term reanalyses are performed to assess both the short- and long-term stability of the XRF measurements as described in *UCD IMPROVE SOP 301, XRF Analysis*.

Figure 21: Scaled relative difference for replicate and routine ion analyses, January through June 2018.

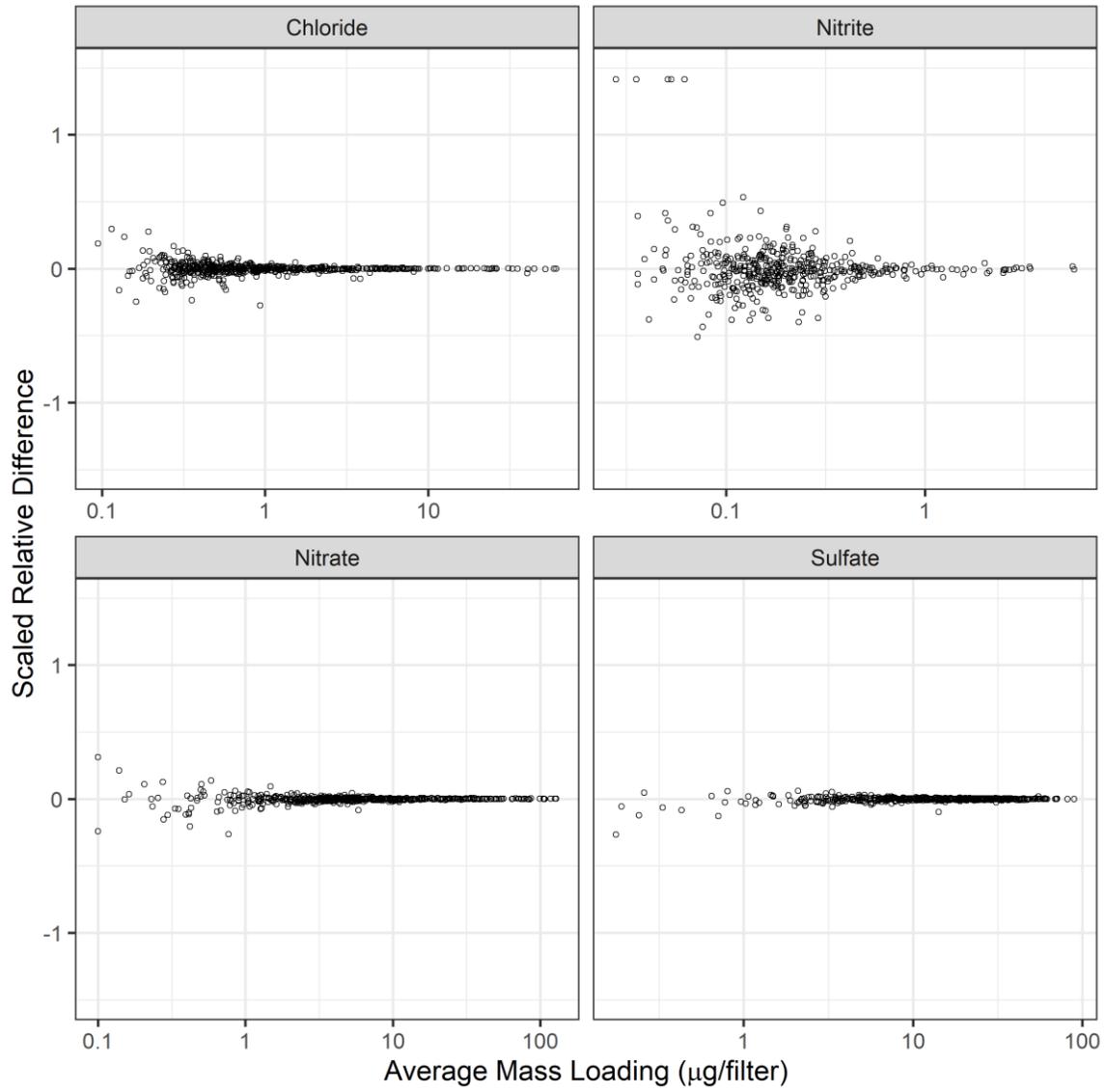
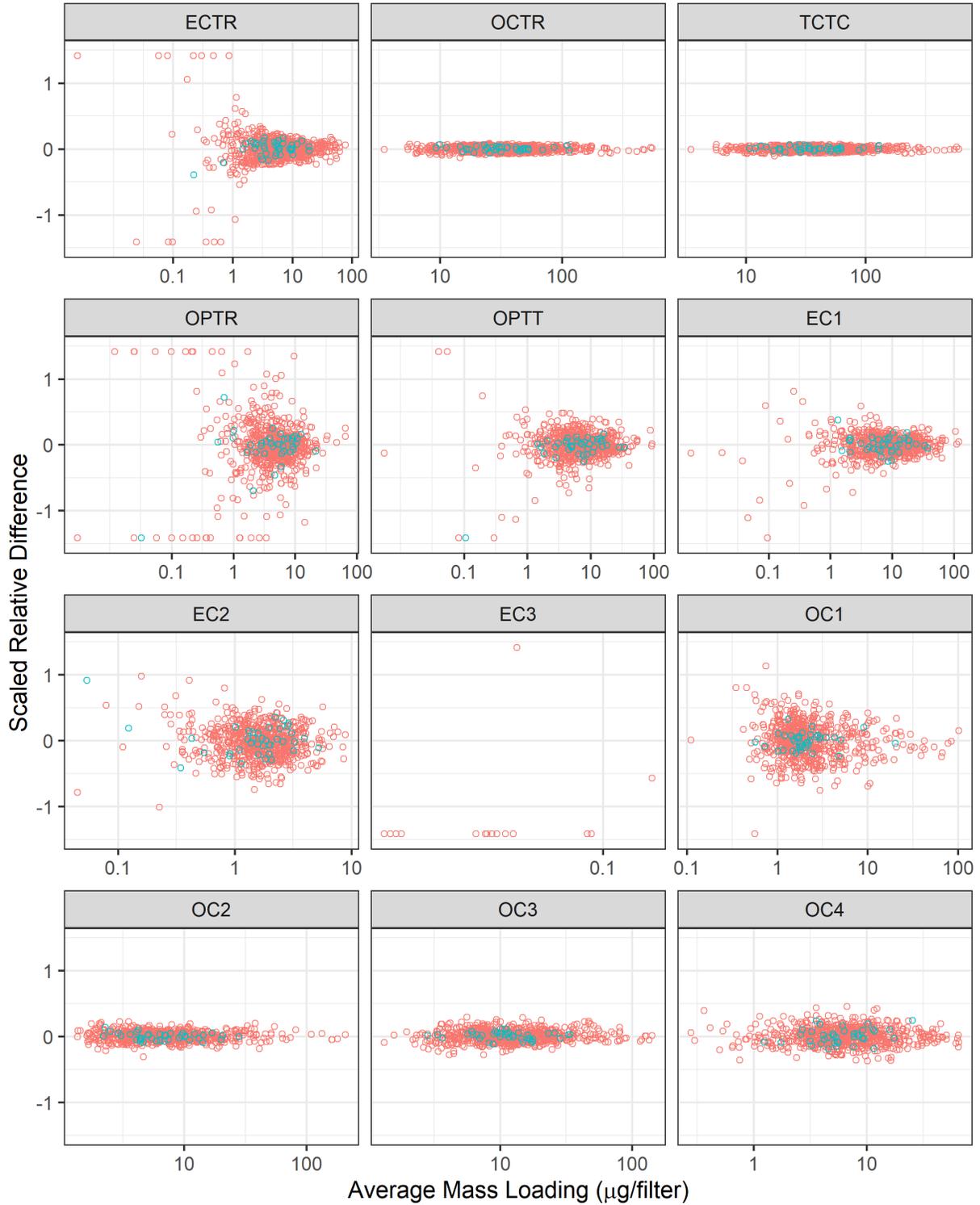


Figure 22: Scaled relative difference for replicate and routine carbon analyses, January through June 2018. Analyses performed by the same analyzer are shown in green, and those by different analyzers are shown in red. Elemental carbon by reflectance (ECR) fractions are indicated as (1) through (3), organic carbon by reflectance (OCR) fractions are indicated as (1) through (4), TR indicates measurement by reflectance, and TT indicates measurement by transmittance.



3.2 Blanks

Lab blanks and field blanks are handled and analyzed in the laboratory using the same process as sampled filters. Lab blanks are only handled in a laboratory environment and have the least opportunity for mishandling and contamination. Field blanks are collected at sampling sites across the network by exposing filters to the same conditions and handling that a sampled filter experiences but without pulling air through the filter. Considering that field blanks capture artifacts from both field and laboratory processes, it is expected that field blank mass loadings will be generally higher than lab blanks.

Field blanks are an integral part of the QC process, and analysis results enable artifact correction of sampled filters as part of the concentration calculation. Artifacts result from contamination in the filter material or handling and analysis.

Nylon filters are received from the manufacturer in lots that typically last one year. Acceptance criteria are established to evaluate background concentrations for each new lot of filters, however, there can be substantial variability in ion species across different lots (Figures 23-25). Transition to new lots occurs over a period of weeks; thus the shift in field blank concentrations gradually manifest over time rather than abruptly.

As noted in previous reports, a known contamination issue occurred at the RTI laboratory during summer 2017, and evidence of the event are seen in both the chloride (Figure 23) and sulfate (Figure 25) field blank time series. An earlier contamination issue in 2011 from lack of refrigeration is also observed in the chloride field blank time series (Figure 23). This issue was resolved with implementation of sample refrigeration beginning early 2011, and corresponds with a decrease in intermittent high chloride field blank concentrations; UCD prepared a data advisory with further detail, <http://vista.cira.colostate.edu/Improve/data-advisories/> (posted 3/2019).

Figure 23: Time series of chloride measured on nylon filter field (FB) and lab (LB) blanks. Red vertical lines indicate lot transition, January 1, 2011 through July 31, 2018.

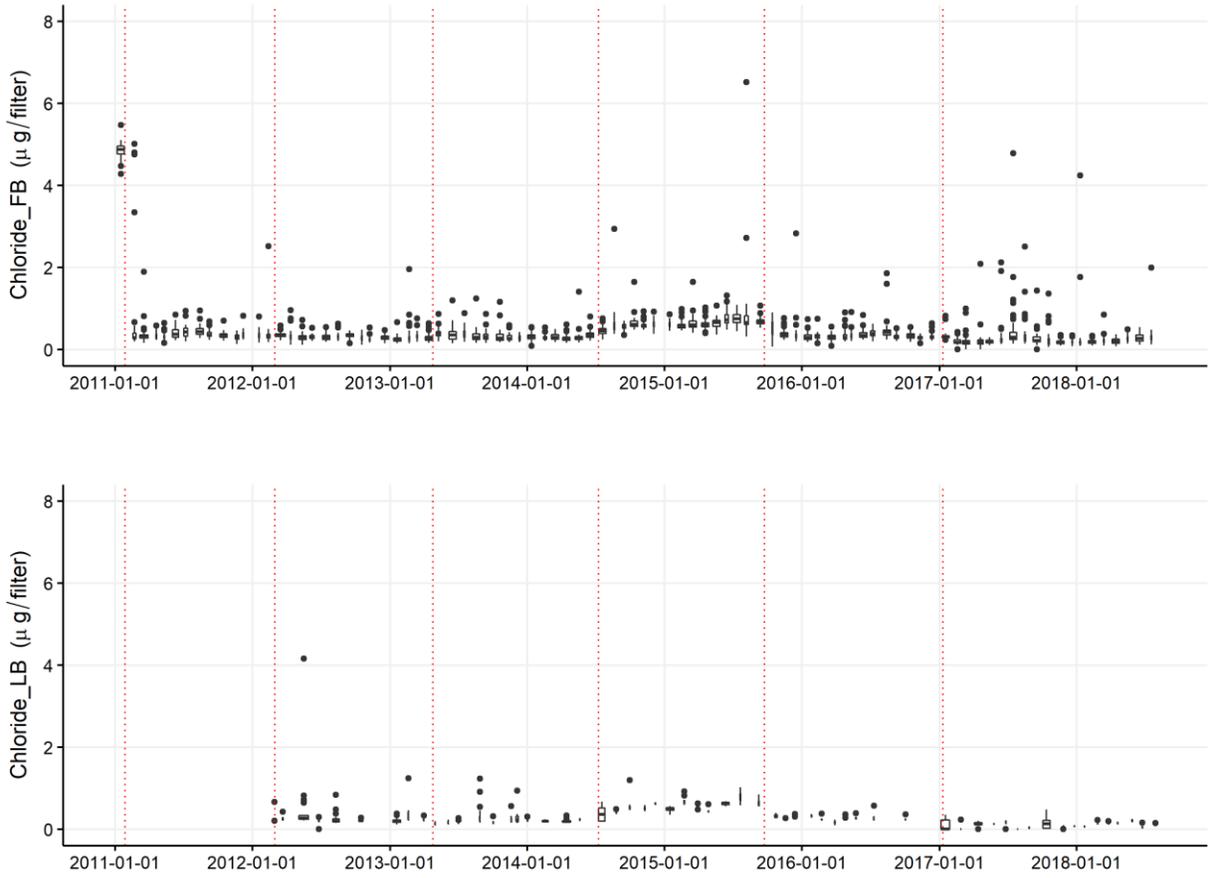


Figure 24: Time series of nitrate on nylon filter field (FB) and lab (LB) blanks. Red vertical lines indicate lot transition, January 1, 2011 through July 31, 2018.

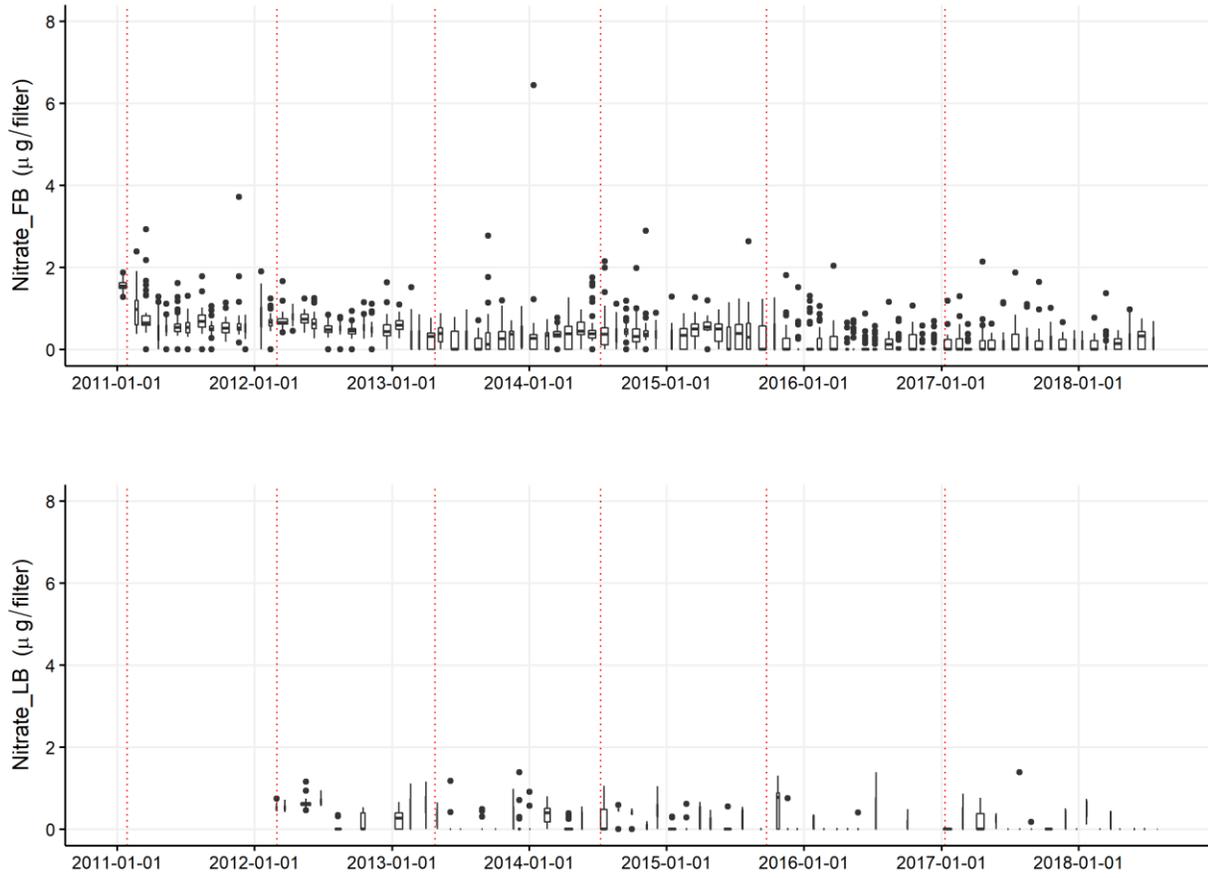
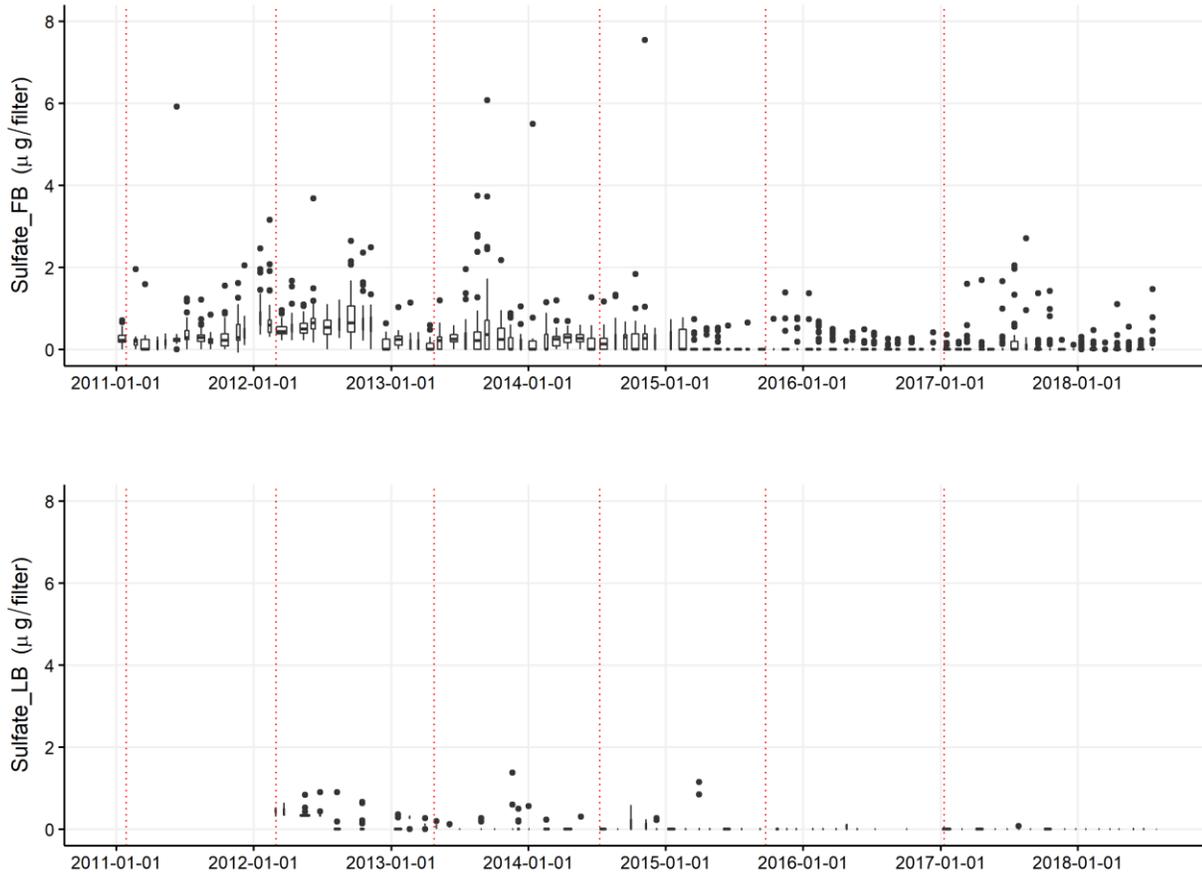
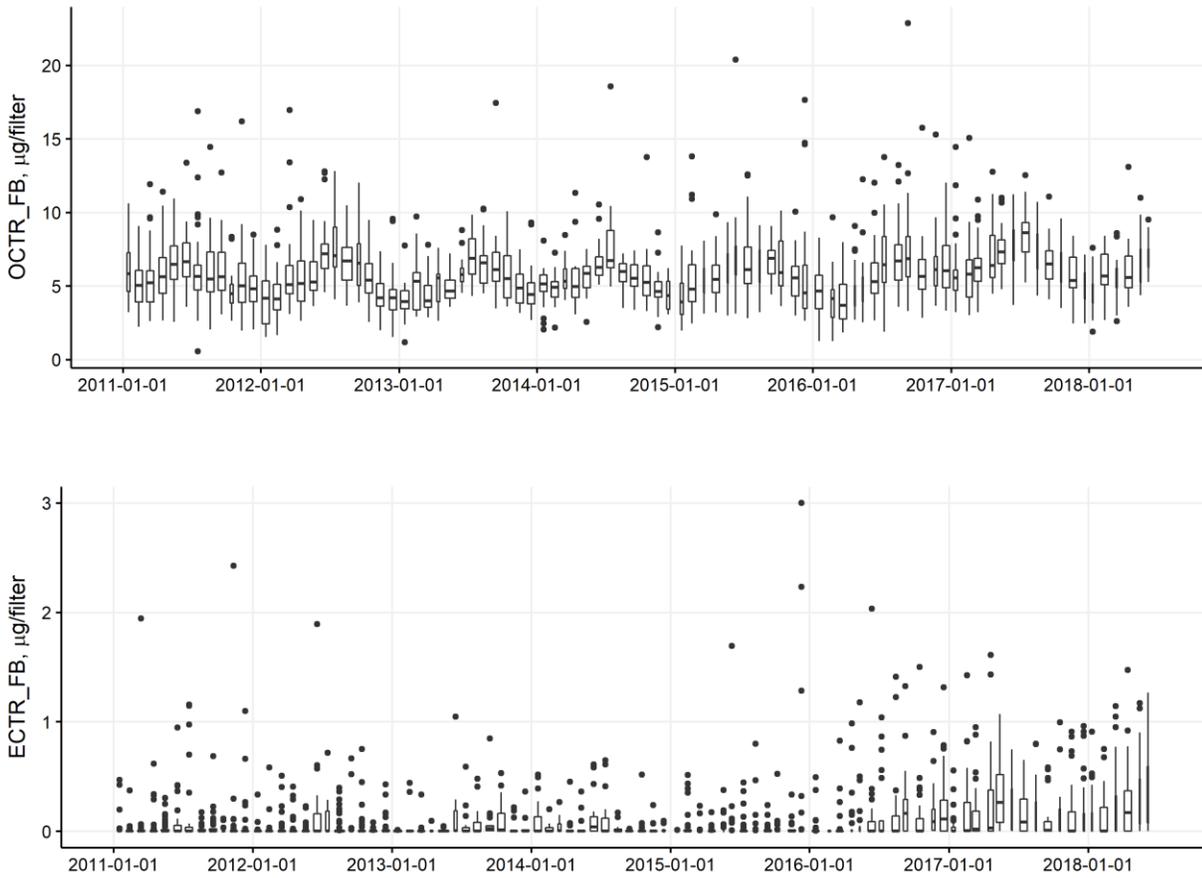


Figure 25: Time series of sulfate on nylon filter field (FB) and lab (LB) blanks. Red vertical lines indicate lot transition, January 1, 2011 through July 31, 2018.



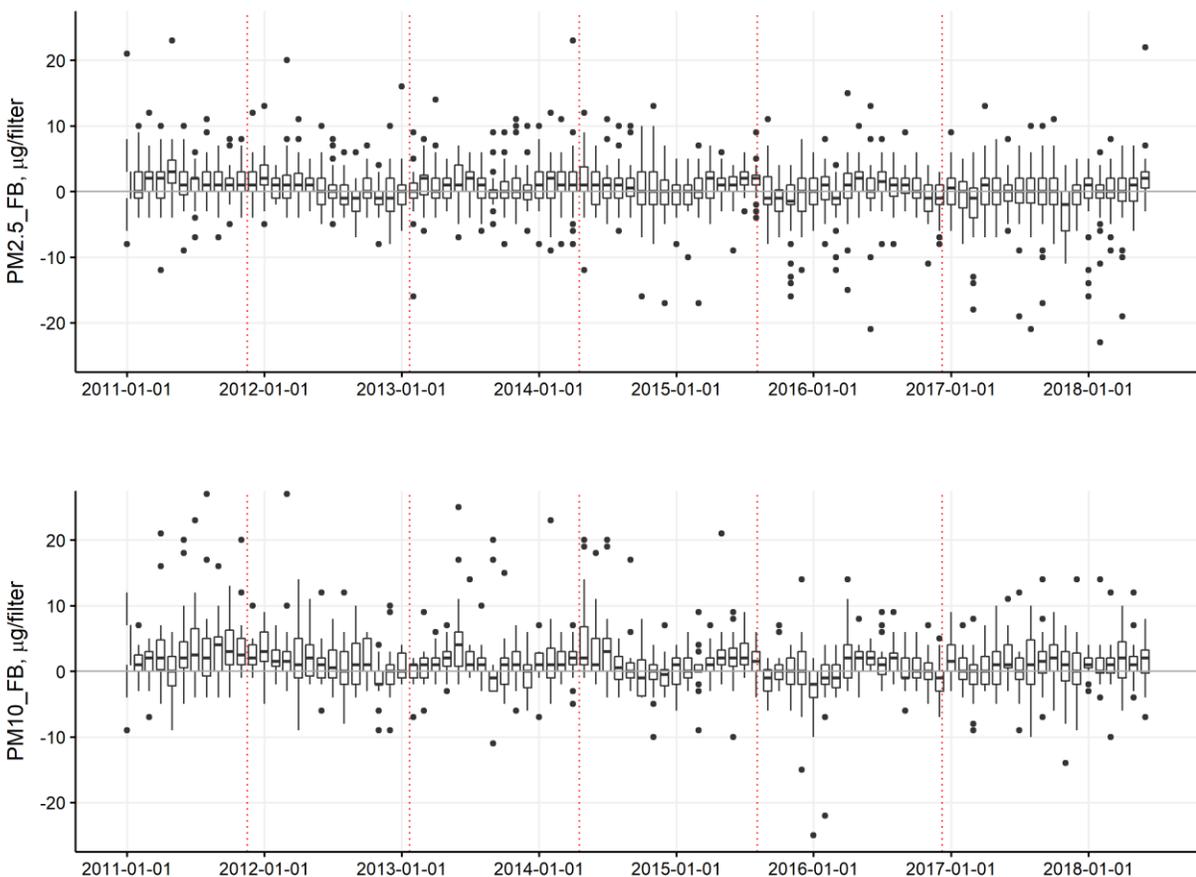
Quartz filters are pre-fired by DRI. Quartz filter field blanks typically have low concentrations of elemental carbon by reflectance (ECR). In occasional cases the median field blank ECR concentration is greater than zero and an artifact correction is applied; this has been more frequent since mid-2016 (Figures 26, bottom panel). Conversely, higher field blank concentrations are observed for organic carbon by reflectance (OCR), with the highest values during summer months often over 5 µg/filter (Figures 26, top panel).

Figure 26: Time series of organic carbon by reflectance (OCR; top) and elemental carbon by reflectance (ECR; bottom) on quartz filter field blanks, January 1, 2011 through June 30, 2018.



PTFE filter field blanks from the A-module (fine particles, $PM_{2.5}$) and D-module (coarse particles, PM_{10}) are gravimetrically analyzed to monitor contamination levels and balance stability (Figure 27).

Figure 27: Time series of PM_{2.5} and PM₁₀ on PTFE filter field blanks, January 1, 2011 through June 30, 2018.



Field blanks are used for calculation of method detection limits (MDLs) reported for each species. Prior to 2018, MDLs for ions and carbon species were calculated as $2 \times$ the standard deviation of the field blank loadings, using a minimum of three field blanks collected in the sampling month for each filter type. Beginning with samples collected January 2018, UCD harmonized the MDL calculation for ions and carbon species to be 95th percentile minus median of the field blank loadings, using 50 field blanks collected in and closest to the sampling month for each filter type. The MDL calculation for elements was not changed, and is calculated as 95th percentile minus median of field blank loadings, using 35 field blanks (see *UCD IMPROVE SOP 351, Data Processing and Validation*). It is anticipated that this calculation change for ions and carbon species will stabilize the MDLs, making them less susceptible to influence from field blank outliers. Table 2 summarizes the MDLs, listing average MDLs calculated for 2017 data for comparison with average MDLs calculated for data from the first six months of 2018.

Table 2: Average method detection limits (MDLs) and percentage of reported data above the MDLs calculated for 2017 data and January through June 2018 data.

Species	2017		2018 (January – June)	
	Average MDL (ng/m ³)	% Above MDL	Average MDL (ng/m ³)	% Above MDL
Chloride	15.25	55	4.25	87
Nitrite	30.13	7	18.92	11
Nitrate	15.39	98	10.79	99
Sulfate	13.84	100	3.88	100
Organic Carbon (OCR)	110.22	94	76.02	96
Elemental Carbon (ECR)	15.63	93	22.78	88
Total Carbon	117.81	95	82.71	97
Organic Carbon (OCR1)	36.96	24	27.19	29
Organic Carbon (OCR2)	35.88	83	20.02	91
Organic Carbon (OCR3)	59.81	89	37.47	92
Organic Carbon (OCR4)	31.37	94	16.41	97
Organic Pyrolyzed (OPR)	10.77	94	15.05	93
Elemental Carbon (ECR1)	10.04	98	10.19	98
Elemental Carbon (ECR2)	12.31	94	16.07	84
Elemental Carbon (ECR3)	9.23	0	4.58	0
Na	4.44	79	4.33	84
Mg	2.61	79	2.70	83
Al	4.05	91	3.73	92
Si	7.31	90	6.25	93
P	0.22	34	0.22	31
S	0.42	100	0.38	100
Cl	0.41	84	0.44	86
K	1.16	99	1.08	99
Ca	2.63	93	2.61	94
Ti	0.40	82	0.34	87
V	0.12	41	0.11	35
Cr	0.11	33	0.11	40
Mn	0.33	66	0.33	68
Fe	2.56	92	1.98	95
Ni	0.11	25	0.11	26
Cu	0.22	54	0.22	53
Zn	0.23	90	0.22	92
As	0.22	18	0.22	16
Se	0.22	27	0.22	27
Br	0.14	96	0.15	96
Rb	0.24	15	0.23	18
Sr	0.23	47	0.22	57
Zr	1.32	7	1.30	6
Pb	0.65	34	0.65	34
PM _{2.5}	306.26	97	306.86	97
PM ₁₀	416.49	98	418.19	98
fAbs	0.35	85	0.35	82

4. Documentation

Current standard operations procedures (SOPs) are available at:

<http://vista.cira.colostate.edu/Improve/>

<http://airquality.crocker.ucdavis.edu/improve/standard-operating-procedures-sop/>

Table 3: Summary of upcoming project documentation deliverables.

Deliverable	Upcoming Delivery Date
SOPs and TI documents	June 15, 2019*
Quarterly Site Status Report	May 15, 2019 (2019 Q1) August 15, 2019 (2019 Q2)
Semiannual Quality Assurance Report (June - December 2018 data)	October 30, 2019

* Previously listed as January 30, 2019. Date has been revised to allow time for conversion of documents to meet Section 508 standards for accessibility.

5. Site Maintenance Summary

5.1 Summary of Repair Items Sent

UCD maintains and repairs samplers at each IMPROVE site. The UCD Field Group works closely with site operators to address maintenance and repair issues to ensure continuous operation and sample collection at the sites. UCD maintains an inventory of sampler components for shipment to the sites on short notice. Table 4 summarizes the equipment shipped to sites for sampler repairs, July 1, 2018 through December 30, 2018.

Table 4: Summary of major repair items shipped to IMPROVE sites, 7/1/2018 through 12/30/2018.

Item	Quantity	Sites
Controller	31	AGTI1 (x2), BALD1, BIRM1, BOLA1, BRIG1 (x2), BRIS1, BYIS1, CABI1, CACR1, CAPI1, CHAS1, FRRE1, GUMO1, LASU2, MEAD1, MEVE1, NOAB1, NOCA1, NOGA1, PHOE5, PRIS1, QUCI1, SACR1, SAGU1, SAPE1, SHEN1, SHRO1 (x2), UPBU1
Pump	69	ACAD1 (x3), AGTI1, BADL1, BOND1 (x2), BOWA1 (x3), BRIG1, CACR1, CAPI1 (x2), CEBL1 (x2), CHAS1 (x2), DINO1, EVER1, FCPC1, FLTO1, FRRE1, GRR11, HAVO1, HOOV1, JARI1, LAVO1, LOND1, LOST1, LTCC1, MAKA1, MAVI1, MEAD1, MEVE1, MOMO1, MONT1, MOOS1, OKEF1, OWVL1 (x2), PHOE5 (x2), PINN1 (x2), PMRF1, PORE1, PRIS1, PUSO1, RAFA1 (x2), REDW1 (x2), ROMA1, ROMO1, SACR1, SAPE1, SAWT1 (x4), SULA1, THRO1 (x3), THSI1, VILA1, ZICA1 (x2)
Electronic boxes	51	ACAD1, AGTI1 (x3), BAND1 (x2), BIRM1, BOAP1, BOND1 (x2), BOWA1, BRIG1 (x3), BRIS1 (x2), CAVE1, CHIR1, COHU1, CRMO1 (x2), DOME1, EVER1 (x2), FCPC1, FLTO1 (x2), GRR11, HEGL1, HOOV1, LASU2 (x4), MEAD1 (x2), MOHO1, NOAB1, NOCA1, OKEF1 (x2), OWVL1, PUSO1, SHEN1, SHRO1, SIPS1, STIL1, SYCA2, TALL1, VILA1 (x2)
Module Cable	10	AGTI1, BIRM1, CRMO1, DOME1, EGBE1, LASU2, SAPE1, SHEN1, SHRO1, STIL1
Relay Box	1	VILA1
Sierra PM ₁₀ Inlet	1	BLIS1
PM _{2.5} Inlet Cap	0	
Flow Check Kits	1	STIL1
Module	3	GICL1, SHRO1, STIL1

5.2 Field Audits

CSU CIRA performs field audits at IMPROVE sites to measure and evaluate sampler flow. Results are reported to the UCD Field Group, and issues are addressed during site visits and through coordination with site operators. Table 5 summarizes the field audits that CSU CIRA performed July 1, 2018 through December 30, 2018.

Table 5: CSU CIRA field audits 7/1/2018 through 12/30/2018.

2018 Site Audits (July - December)					
July	August	September	October	November	December
	LASU2	VILA1	VILA1		
	WHRI1	WICA1	MONT1		
		GRR11	SULA1		
		FCPC1	SAWT1		
		SENE1	CRMO1		
		ISLE1	MOZI1		
		BOWA1	LASU2		
		VOYA2			
		BADL1			
		LOST1			
		THRO1			
		FOPE1			
		ULBE1			
		GAMO1			
		GRSA1			
		MEVE1			
		FLTO1			
		SHMI1			
		WEMI1			

5.3 Summary of Site Visits

The UCD Field Group visits IMPROVE network sites biennially to provide routine maintenance and cleaning. Sites are occasionally visited more frequently to address emergency issues. Table 6 summarizes the visits that UCD performed July 1, 2018 through December 30, 2018.

UCD has developed and is currently deploying new sampler controllers. Between July 1, 2018 and December 30, 2018 UCD installed 46 new controllers (Table 6). As of December 30, 2018 there were a total of 77 new controllers installed across the network. Prior to new controller installation, availability of internet access is evaluated at each site, and in cases where it is not available a hot spot device is installed. Sites with new controllers are monitored in real time by UCD technicians, allowing faster follow up and recovery in cases where samples are being lost or equipment has failed.

Table 6: UC Davis field visits to IMPROVE sites, 7/1/2018 through 12/30/2018.

Site Name	Date Visited	Repair Notes	Improvements Requested
COR11	7/10/2018	Installed new controller.	
MORA1	7/11/2018	Installed new controller.	
FRES1	7/11/2018	Temporarily relocated shed for foundation rebuild.	
OLYM1	7/12/2018	Installed new controller.	
MAKA2	7/13/2018	Installed new controller.	
PUSO1	7/14/2018	Installed new controller.	
NOCA1	7/16/2018	Installed new controller.	
PASA1	7/17/2018	Installed new controller.	
SNPA1	7/18/2018	Installed new controller. Installed grip tape on roof.	Needs roof access anchor.
WHPA1	7/19/2018	Installed new controller.	
MOHO1	7/20/2018	Installed new controller.	Needs roof access anchor.
CEBL1	7/24/2018	Installed new controller.	
TALL1	7/25/2018	Installed new controller.	
WIMO1	7/26/2018	Installed new controller.	Needs roof access hatch or other fall safety solution.
STIL1	7/27/2018	Installed new controller.	
UPBU1	7/28/2018	Installed new controller.	
HEGL1	7/29/2018	Installed new controller.	
CACR1	7/30/2018	Installed new controller.	
BRIS1	8/1/2018	Installed new controller.	Needs major shed repair.
BOLA1	8/10/2018	Installed new controller.	
BRID1	8/11/2018	Installed new controller.	
YELL2	8/13/2018	Installed new controller.	
NOAB1	8/14/2018	Installed new controller. Resized D-Stack roof hole.	
ULBE1	8/15/2018	Installed new controller.	
GAMO1	8/16/2018	Installed new controller.	
MONT1	8/17/2018	Installed new controller.	
FLAT1	8/18/2018	Installed new controller. Replaced manifold.	
CAB11	8/20/2018	Installed new controller.	
GLAC1	8/21/2018	Relocated site. Installed new controller.	
LOND1	8/27/2018	Installed new controller.	
PACK1	8/28/2018	Installed new controller.	
LYEB1	8/29/2018	Installed new controller.	
MOMO1	8/30/2018	Installed new controller.	
CACO1	8/31/2018	Installed new controller.	Needs outlet and wiring replacement and breaker inspection.
MAVI1	9/1/2018	Installed new controller.	
BRIG1	9/4/2018	Installed new controller.	Needs more frequent inlet inspection; spiderwebs.
CABA1	9/12/2018	Installed new controller.	
ACAD1	9/13/2018	Installed new controller.	
MOOS1	9/15/2018	Installed new controller.	
PENO1	9/16/2018	Installed new controller.	
GRGU1	9/17/2018	Installed new controller.	
PRIS1	9/18/2018	Installed new controller.	
PMRF1	9/18/2018	Installed new controller.	
KAIS1	9/18/2018	Installed new controller.	
SEQU1	9/19/2018	Installed new controller.	
DOME1	9/20/2018	Installed new controller.	Roof shingles need to be replaced and/or maintained.
TOOL1	11/8/2018	Site setup. Installed new controller.	Needs better roof and power setup.

6. References

Spada, N.J., Cheng, X., White, W.H., Hyslop, N.P. (2018). Decreasing Vanadium Footprint of Bunker Fuel Emissions. *Environmental Science & Technology*, 52 (20): 11528-11534.

White, W.H., Trzepla, K., Hyslop, N.P., Schichtel, B.A. (2016). A critical review of filter transmittance measurements for aerosol light absorption, and *de novo* calibration for a decade of monitoring on PTFE membranes. *Aerosol Science and Technology*, 50 (9), 984-1002.