An Evaluation of Robotic Optical Carbon Analysis on Teflon Filter Media

Paige Presler-Jur, Prakash Doraiswamy, Lisa C. Greene, and Oki Hammond

RTI International

Neil Frank and Joann Rice

US EPA / OAQPS

Outline

- Background and Objectives
- Discussion of the Robotic Weighing System (RWS)
- Quality Assurance
  - Comparison of the RWS OT21 to Benchtop SootScan™ OT21
  - Sensitivity of filter blank used for light attenuation calculation
- Relationship of Light Attenuation and Thermal Elemental Carbon (EC) Analysis
- Future Work

Background

- Black carbon (BC) has been related to adverse human health and environmental effects.
- Predominant methods of analysis are labor intensive and/or expensive such as Thermal EC analysis of quartz filters or continuous instruments such as Aethalometers.
- Development of an inexpensive, nondestructive, fast, optical carbon analysis method to estimate BC would benefit air quality research.
- Ability to measure BC at a low cost on both archived and current filters would provide modelers and data end users with data for health and climate change effect research.

Objectives

- Evaluate the ability of the robotic weighing system to perform optical carbon analysis.
  - Comparison to the established benchtop optical carbon method
  - Evaluation of the relationship between optical carbon and thermal EC analyses
  - Preliminary investigation by season and region
- Verify robotic optical carbon analysis to illustrate its validity as a cost-effective means to:
  - Obtain a vast amount of BC data from archived filters
  - Maximize data collection for future samples with an efficient determination of both net gravimetric mass and BC on a single Teflon® filter

Instrumentation and Data Sets

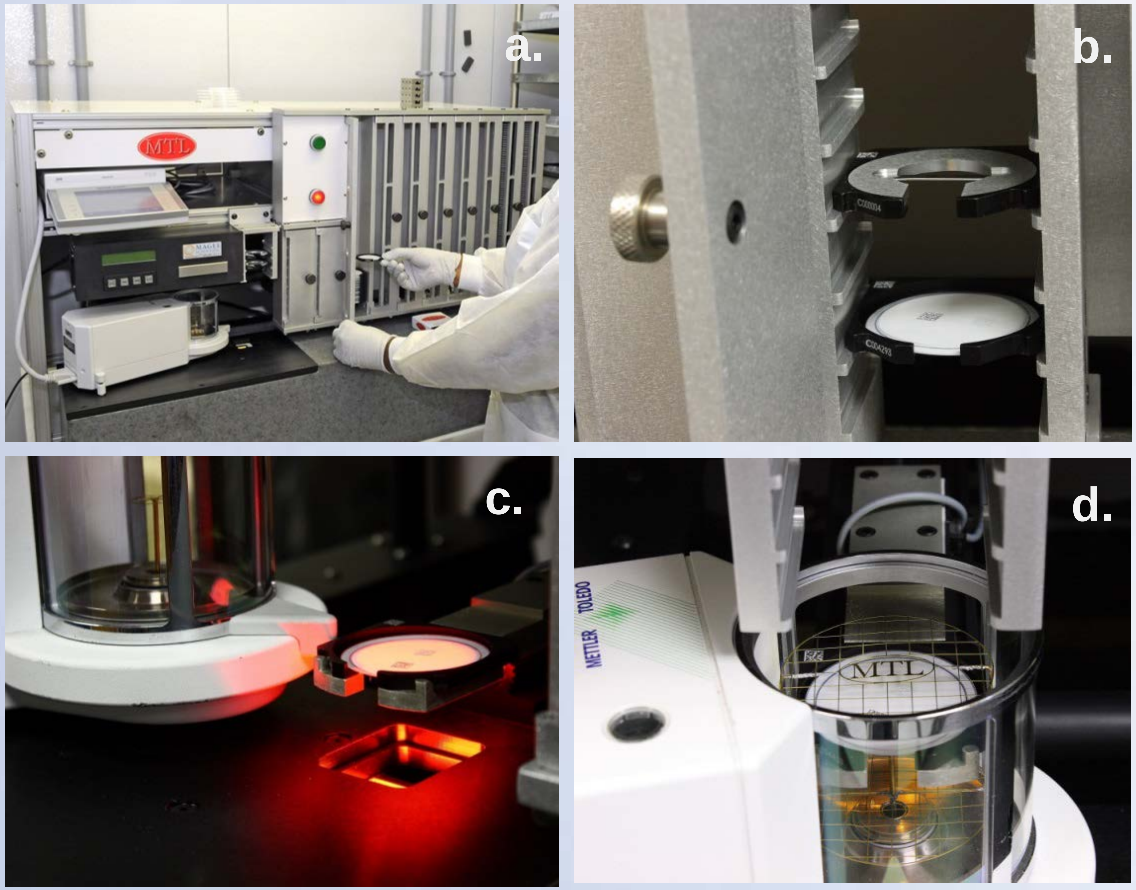
Instrumentation

- MTL Corporation AH-225 Precision Weighing System
  - Inline Magee SootScan™ Model OT21 Transmissometer
- Benchtop Magee SootScan™ Model OT21 Transmissometer

Data Sets

- Earlier measurements of CSN Teflon® filters performed in 2010 (sampled in 2007)
- Repetition of 2010 measurements on Benchtop and RWS OT21s in 2014
- New measurements of filters sampled in 2014 on both OT21s
- Corresponding quartz filters from the CSN analyzed by Thermal EC
  - STN Method (2007)
  - IMPROVE_A Method (2007 and 2014)
    - Thermal/optical reflectance (TOR) and transmittance (TOT) method

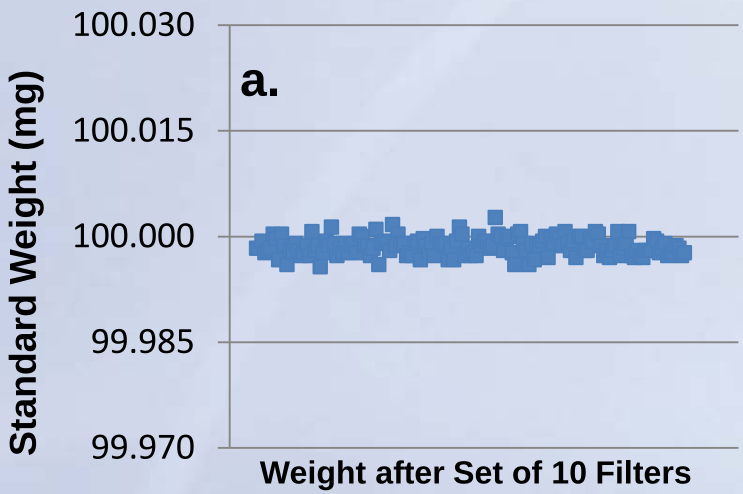
MTL Precision Weighing System AH-225

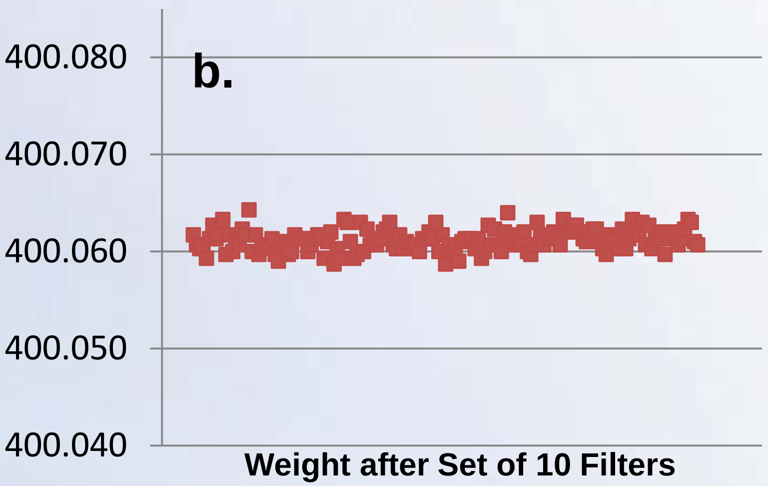


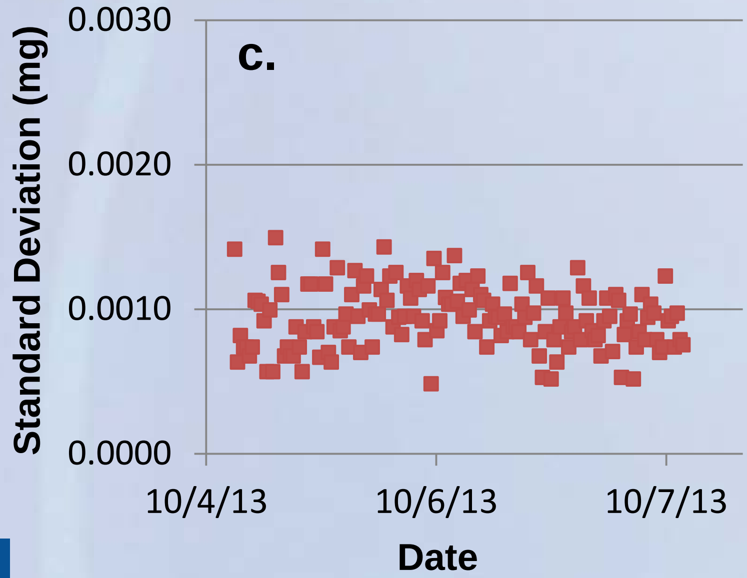
MTL AH-225 Precision Weighing System

Figures b-d provided by MTL Corporation

Repeatability for Continual Weighing







- Plots show variation in weight for groups of 10 filter weights for a single filter weighing continuously for a. 100 mg standard weight, b. 400 mg standard weight, c. standard deviation.
- Stability of standard weights indicate slight drift in standard deviation is due to filter media not instrument.

Magee OT21 SootScan™ Transmissometer

- Analyzes filter media for BC content collected from both ambient and source applications
- Measures the IR (880 nm) and UV (370 nm) transmission of sample media
- Non-destructive and applicable for archived filters

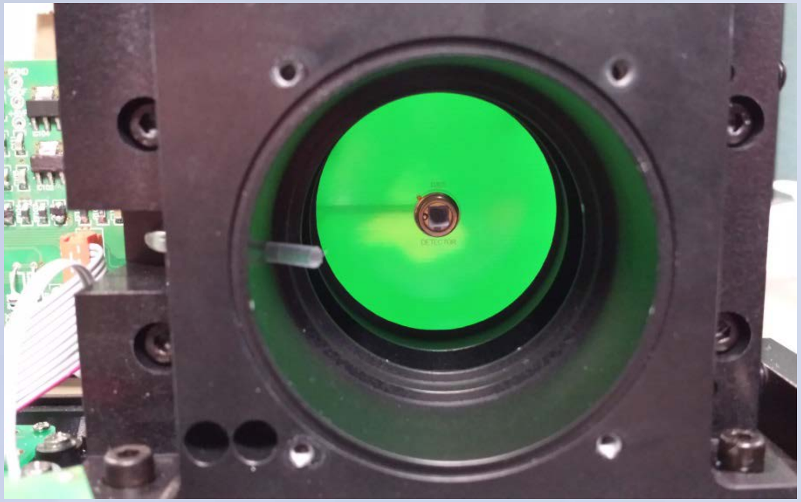
OT21 Distinction	Benchtop	RWS
Light Diffusion Media	T60 Filter Medium	GP47 Permanent Backing Filter
Analysis	Manual (1.5 min/filter required labor)	Automated
Neutral Density Filters	Available	In Development

Images provided by MTL Corporation

RWS OT21 SootScan™ Transmissometer

backing filter installed in the Magee filter holder

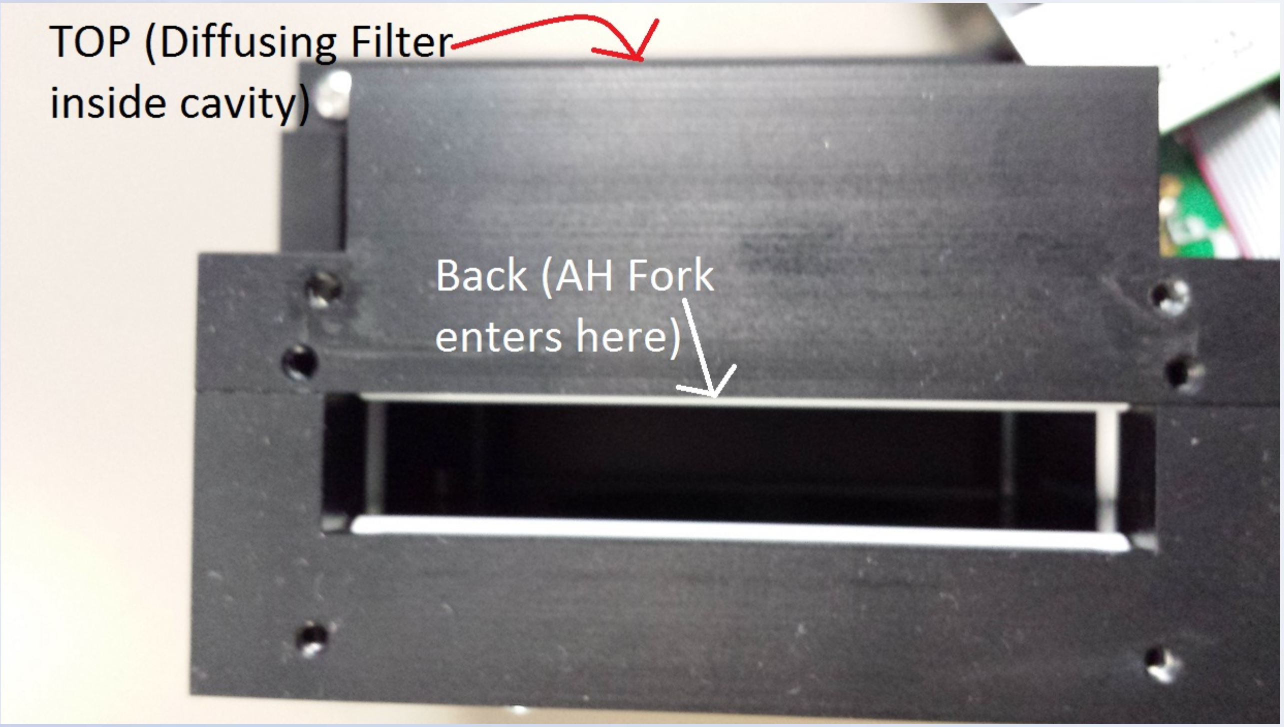
- The RWS Transmissometer is equipped with a GP47 glass filter with Teflon® coating as a permanent backing filter.
  - Borosilicate microfibers reinforced with woven glass cloth and bonded with PTFE



top view of the OT21 cavity without permanent backing filter

top view of the OT21 cavity with permanent backing filter

RWS OT21 SootScan™ Transmissometer

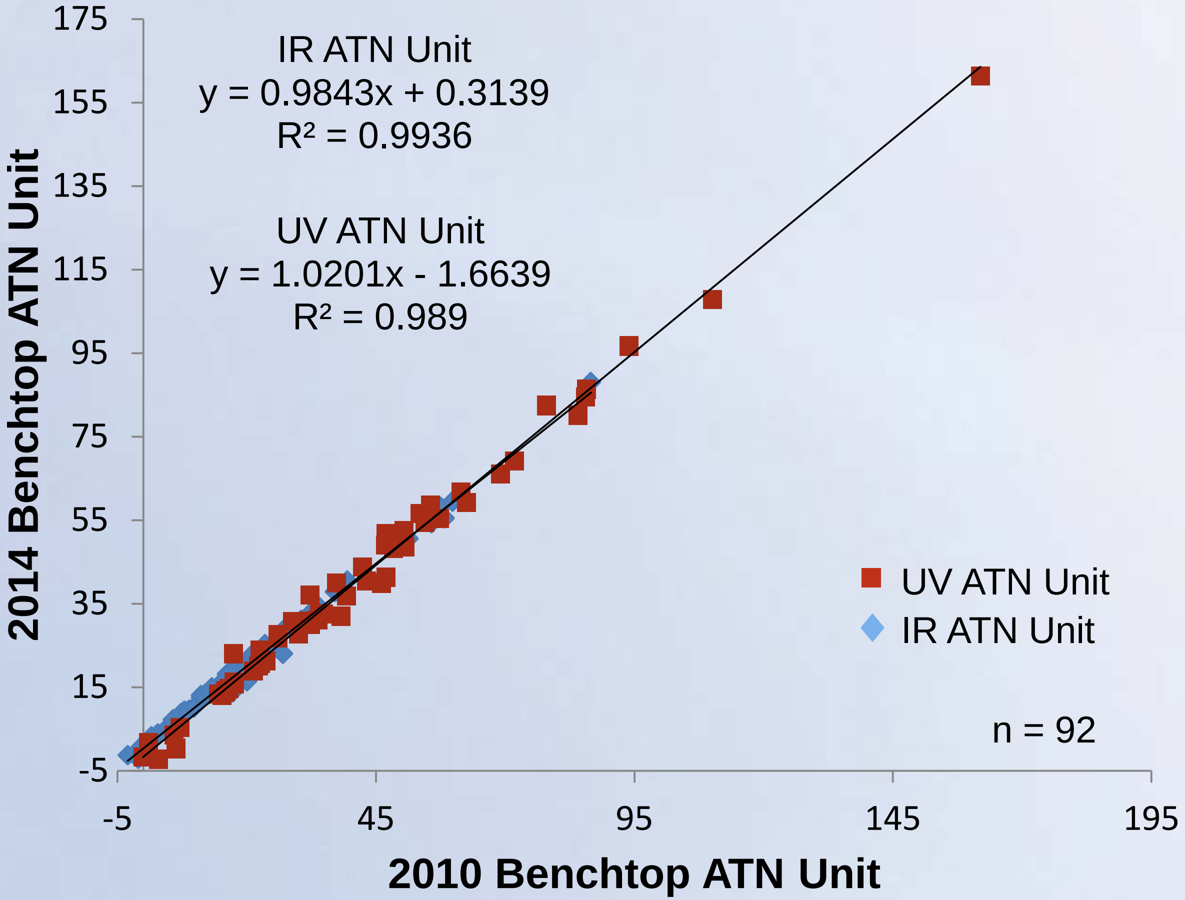


Back of the RWS Transmissometer illustrating the location of the diffusing filter inside the OT21 cavity and fork entrance

Image provided by MTL Corporation

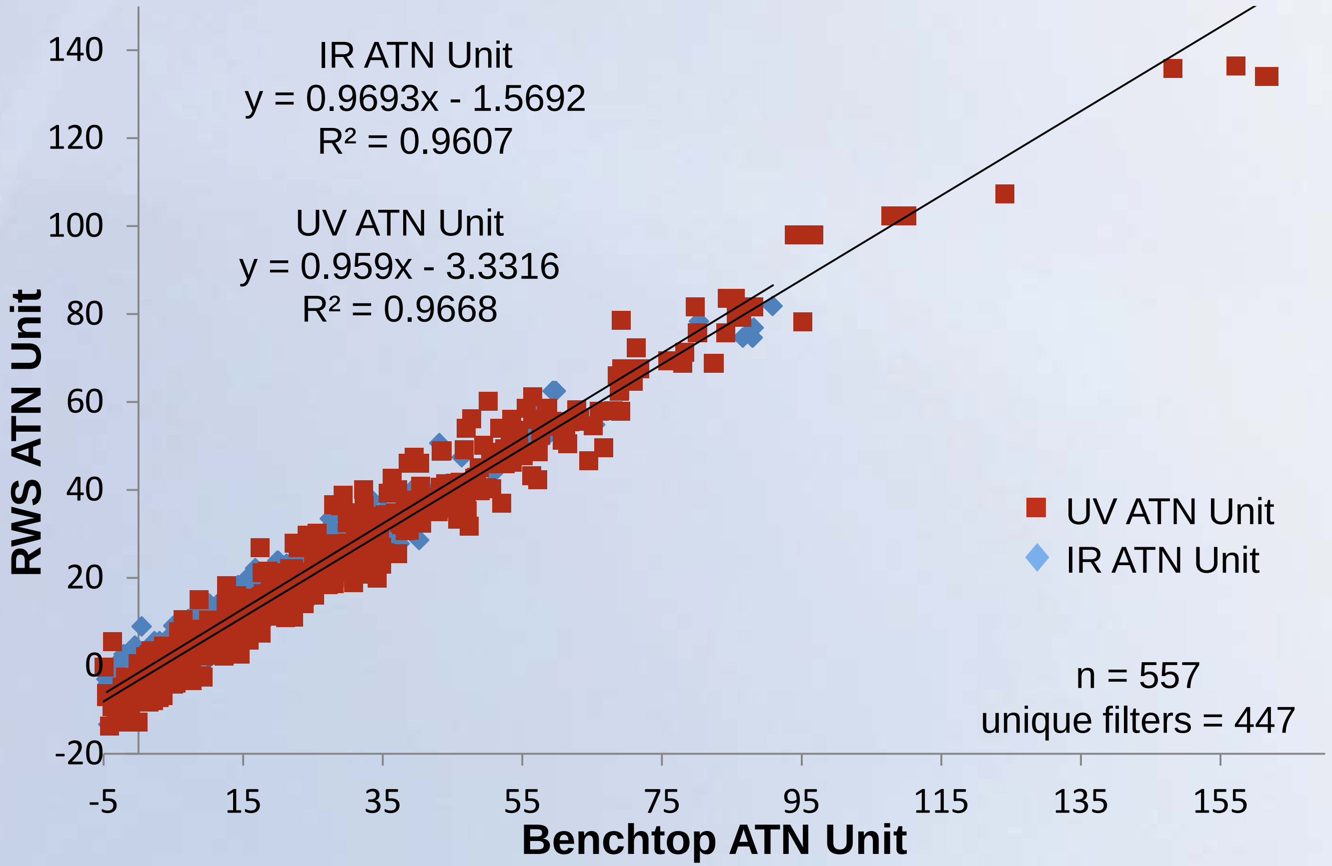
Benchtop OT21 Analysis Comparison

- Comparison between the Benchtop OT21 measurements analyzed in 2010 and in 2014



Comparison between OT21 SootScan Transmissometers

- Comparison between the RWS OT21 analyzed in 2014 and Benchtop OT21 measurements analyzed in 2010 and in 2014



Comparison to Thermal EC Analyses

- Light absorption is approximated by the light attenuation (b_{att}) from PM deposited on the filter surface.

$$b_{att} = \text{Area } (m^2)/\text{Volume } (m^3) * LN(I_0/I)$$

I_0 = transmission through a blank filter

I = transmission through an exposed filter

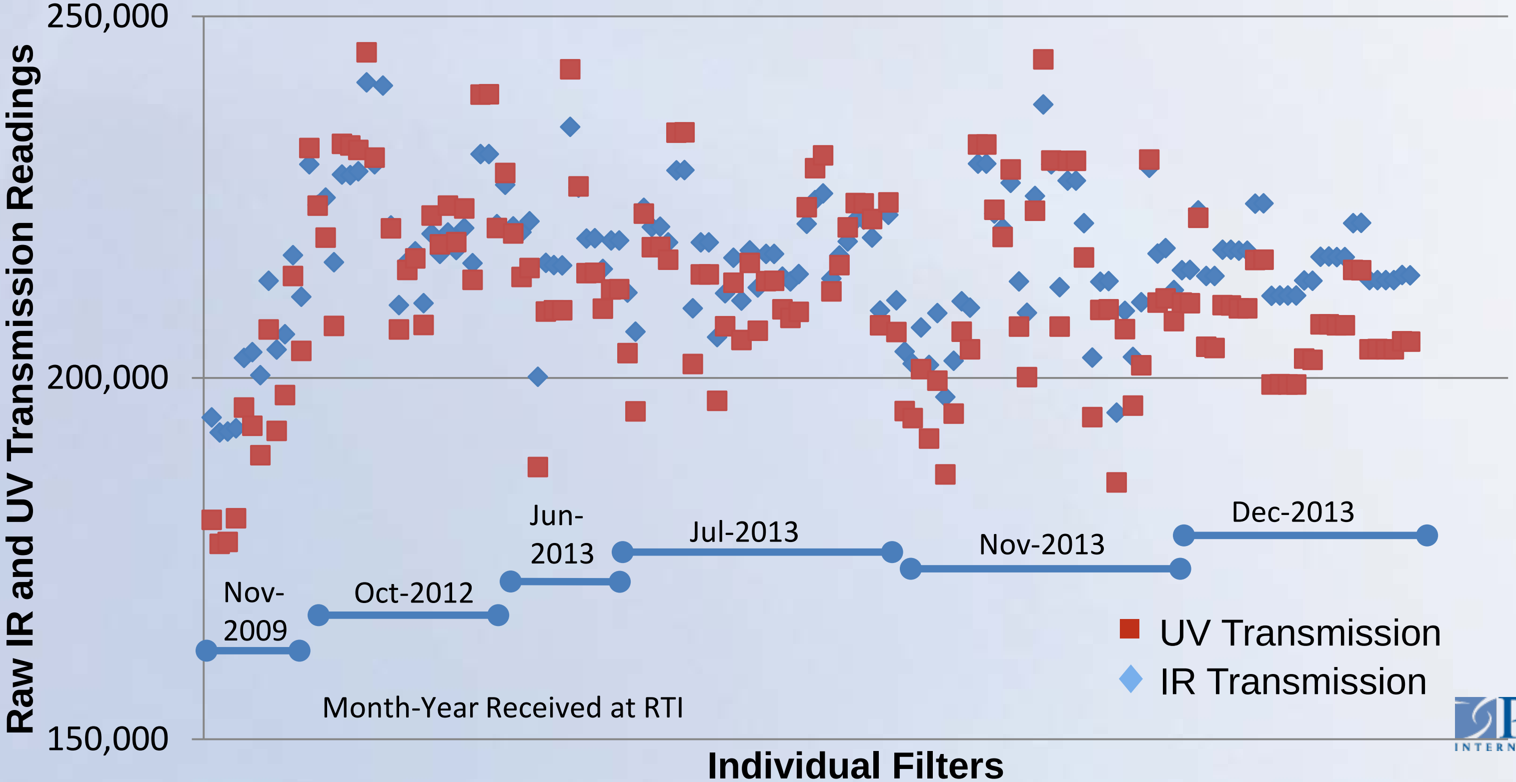
- The BC concentration (µg/m^3) of the PM is calculated with the mass absorption efficiency ($\sigma_{att}[\lambda]$ (m^2/g)).

$$[BC] = b_{att}\,(Mm^{-1})/\sigma_{att}[\lambda]\,(m^2/g)$$

- A linear regression scatter plot of the EC by thermal analysis and optical carbon b_{att} can empirically derive the $\sigma_{att}[\lambda]$ (m^2/g). $\sigma_{att}[\lambda]$ (m^2/g) is the slope of the least-squares regression analysis.

Variation in Blank Filter Batches

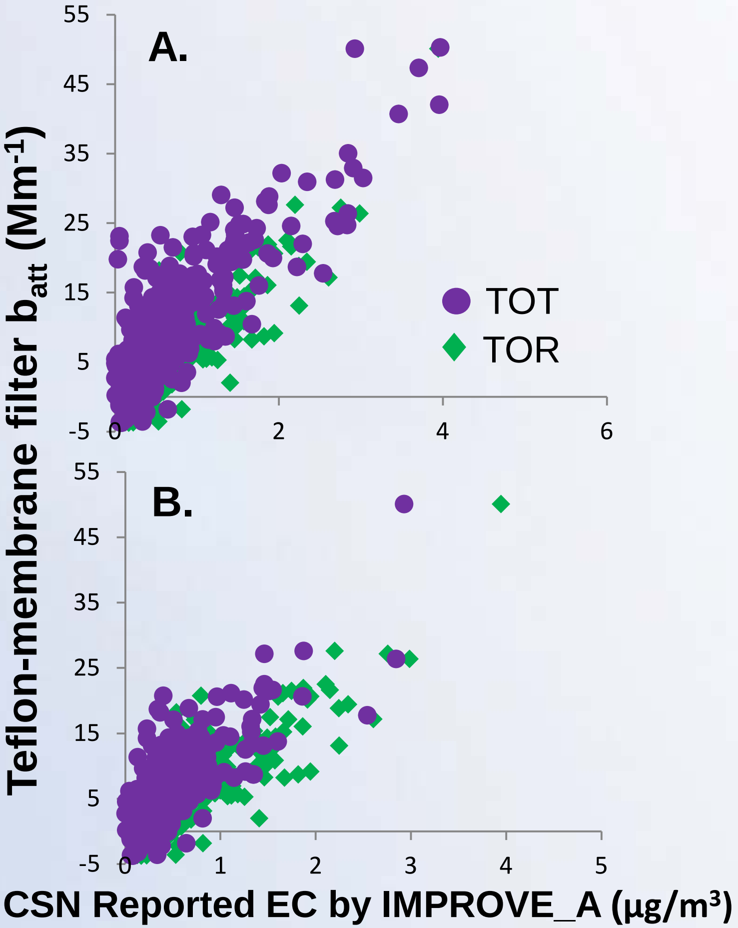
- Blank filters are used to measure initial transmittance, I_0.
- IR and UV transmission readings of blank filters are compared by receipt date at RTI.
- Results indicate that transmission values can vary by lot or over time. When possible, blank filters from the same time period should be used.



Elemental Carbon by IMPROVE_A Method Compared to the RWS Light Attenuation

- EC by IMPROVE_A TOR and TOT was compared to the RWS light attenuation.
  - **A.**: RWS I_0 was the **blank filter** analyzed with the exposed filters.
  - **B.**: RWS I_0 was the **average of blank filters** from batch blank test.

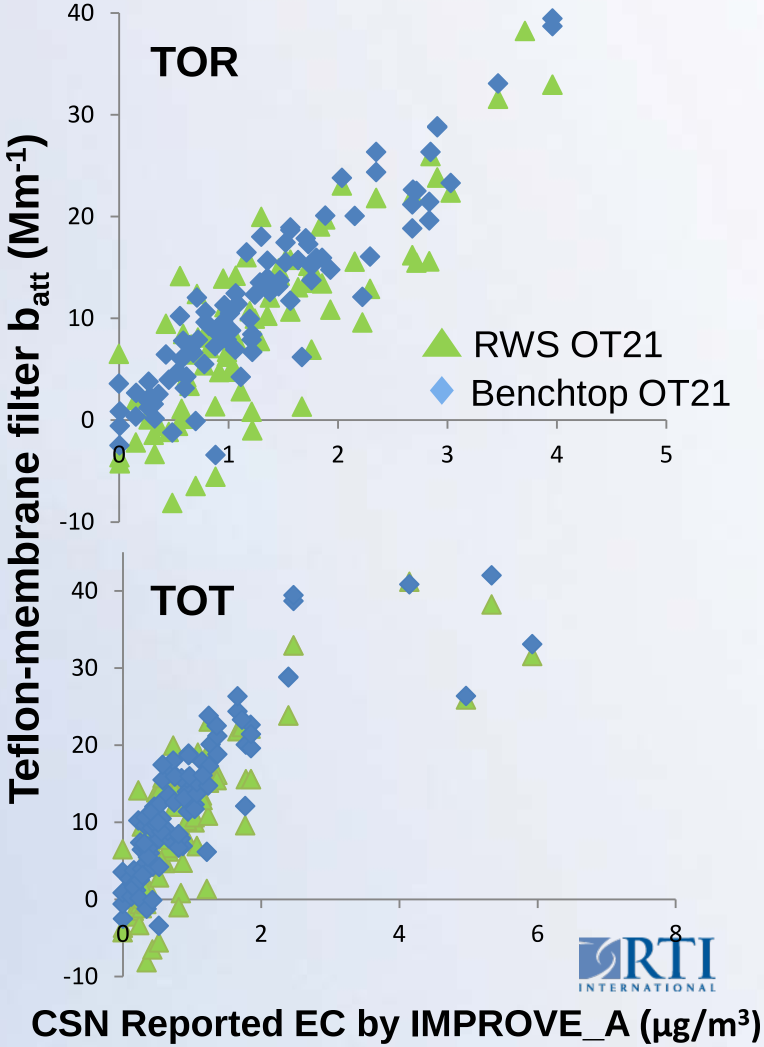
EC by IMPROVE_A Type	Slope $\sigma_{att}[\lambda]$ (m^2/g)	Intercept	r^2	Count (n)
TOR – A	10.3	0.51	0.67	370
TOR – B	9.42	0.27	0.67	370
TOT – A	11.1	2.24	0.70	370
TOT - B	11.6	1.27	0.58	370



Elemental Carbon by IMPROVE_A Method Compared to OT21 Light Attenuation

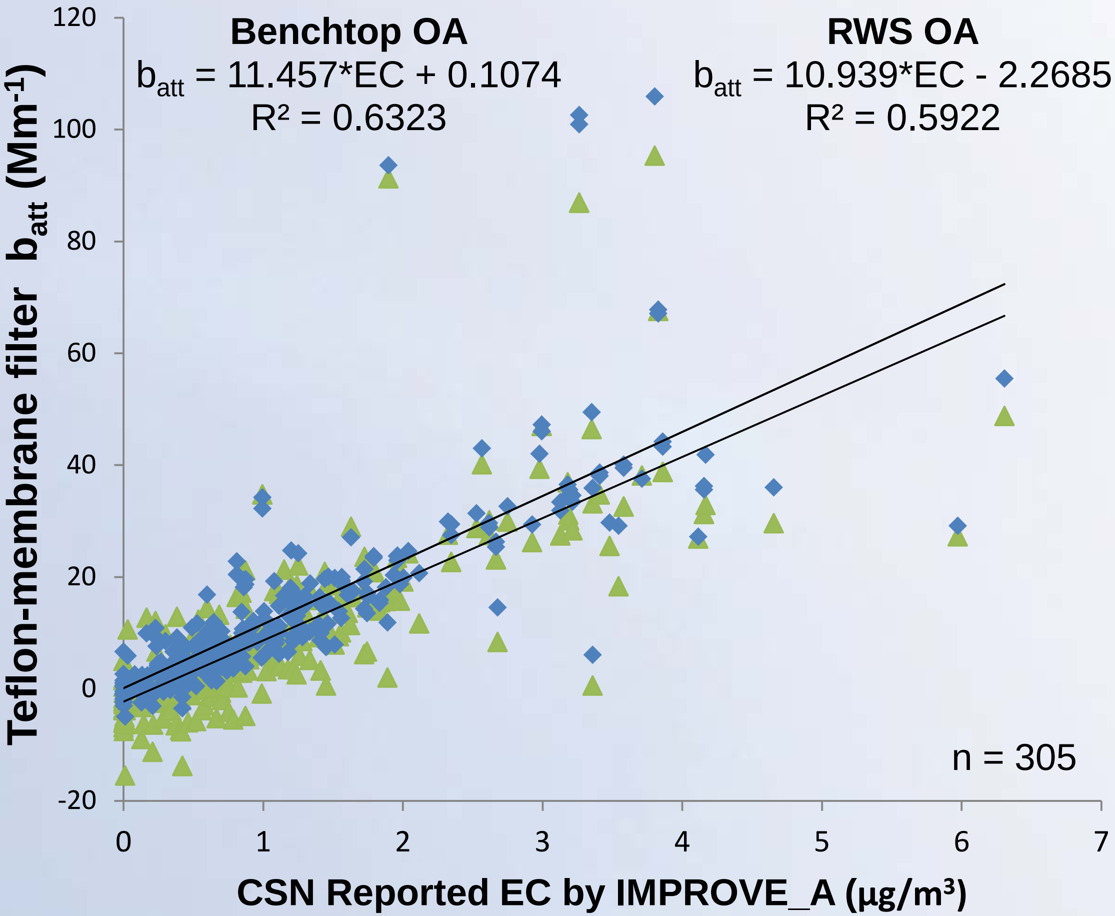
- EC by IMPROVE_A TOR and TOT was compared to the OT21 light attenuation.
  - **TOR.**: EC by IMPROVE_A TOR
  - **TOT.**: EC by IMPROVE_A TOT

OT21 – TOR or TOT	Slope $\sigma_{att}[\lambda]$ (m^2/g)	Intercept	r^2	Count (n)
RWS – TOR	8.71	1.87	0.73	95
Benchtop – TOR	9.34	0.30	0.87	95
RWS – TOT	7.27	3.09	0.60	95
Benchtop – TOT	7.58	5.20	0.68	95



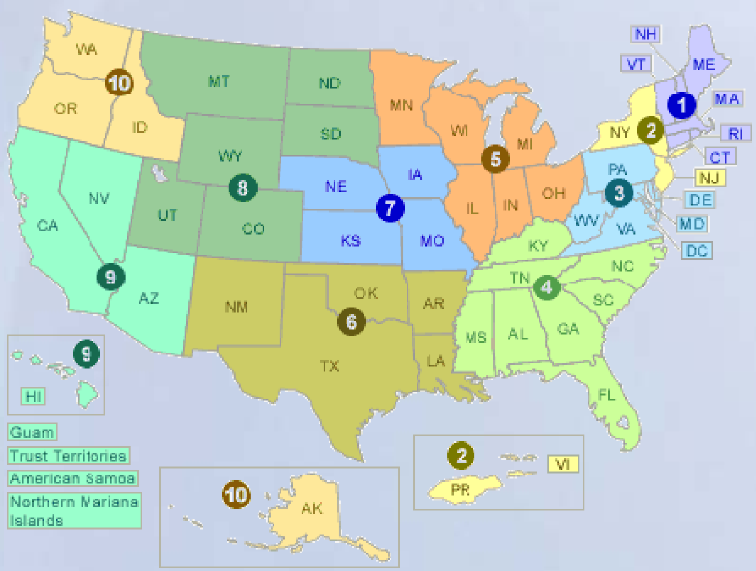
EC by STN Method compared to OT21 SootScan Transmissometers

- EC by STN method was compared to light attenuation measured on the RWS and Benchtop.
- b_{att} was comparable to filters measured by IMPROVE_A method.



Future Data Analysis

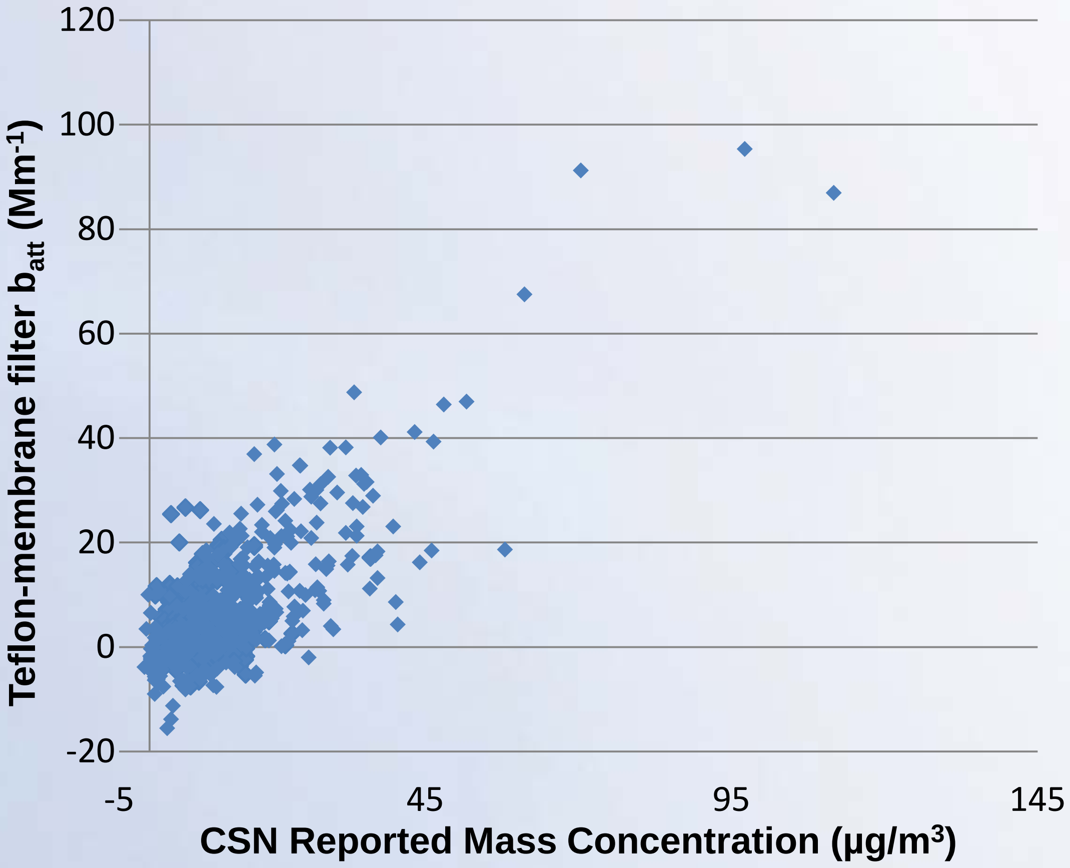
- Understanding the relationship of the net mass loading on the optical carbon analysis
- Comparing the b_{att} and thermal carbon analysis as a function of
  - seasonal variation
  - EPA regions
  - Regional Planning Organizations



Images from epa.gov

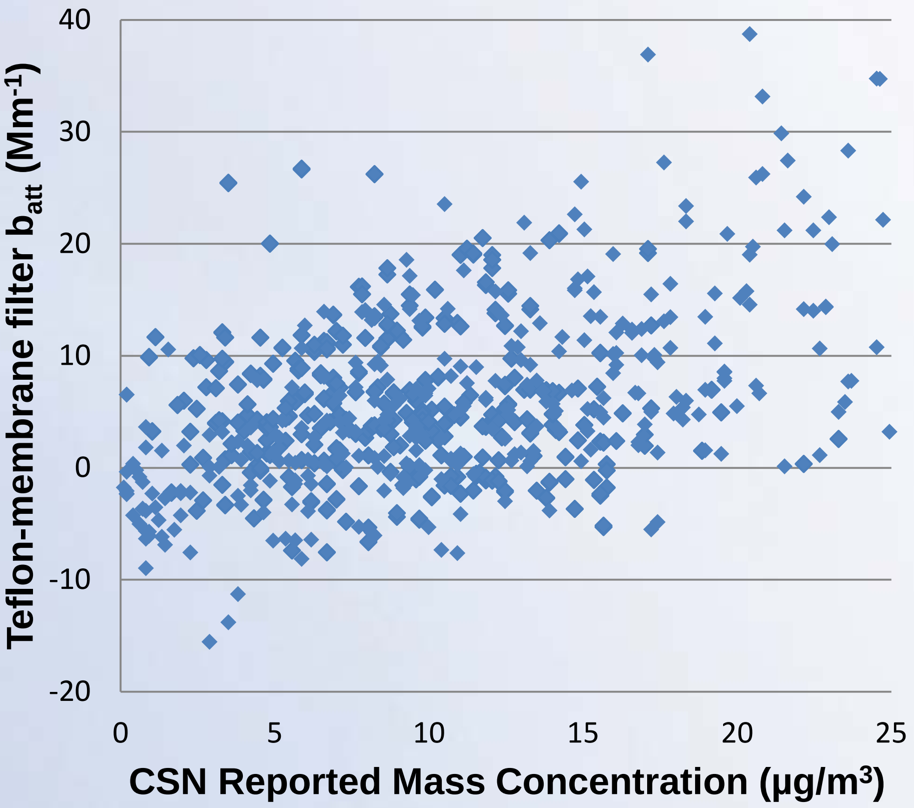
RWS Light Attenuation as a Function of Mass Concentration

- Light attenuation as a function of the Mass Concentration of the Teflon filter shows a possible plateau at higher concentrations.
- Further investigation is needed to evaluate the limit of the capability of the optical absorption method at high net mass loadings.



RWS Light Attenuation as a Function of Mass Concentration

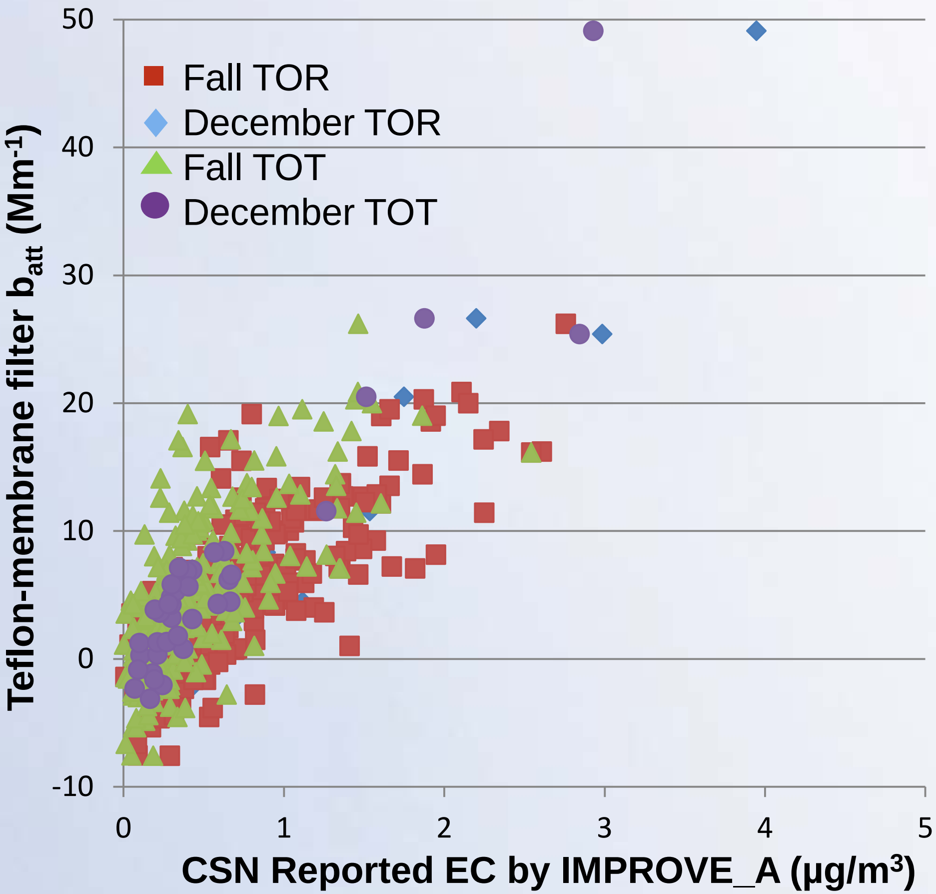
- A focused look at the low mass concentrations illustrates increased possibility of negative light attenuation.
- This further illustrates the importance of blank filter at low net mass loadings.
- RWS provides the capability of looking at a large number of filters with minimal labor time to further understand this variance.



Seasonal Variation of Light Attenuation as a Function of EC by IMPROVE_A Method

- Seasonal variation of the Teflon filter light attenuation as a function of EC by IMPROVE_A method for filters sampled in 2014

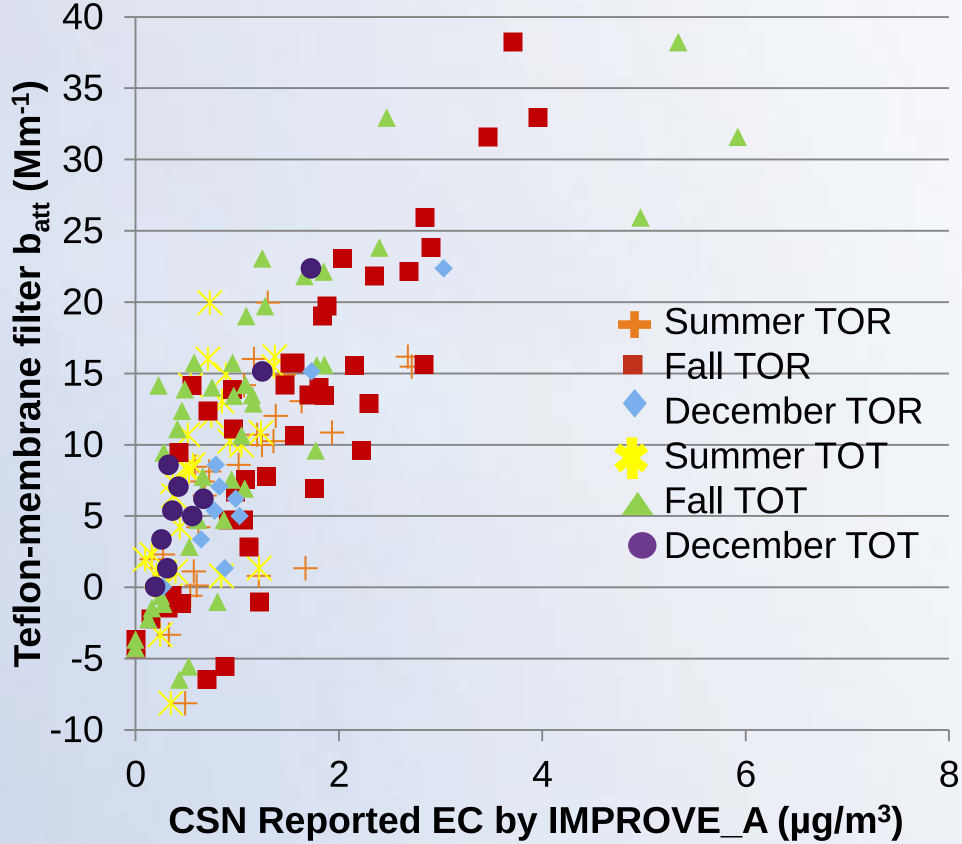
Season	Slope ($\sigma_{att}[\lambda]$, m^2/g)	Intercept	r^2	Count (n)
Fall – TOR	8.61	1.14	0.60	252
December – TOR	12.0	3.41	0.91	37
Fall – TOT	10.8	0.26	0.47	252
December – TOT	13.6	1.44	0.88	37



Seasonal Variation of Light Attenuation as a Function of EC by IMPROVE_A Method

- Seasonal variation of b_{att} as a function of EC by IMPROVE_A method for filters sampled in 2007

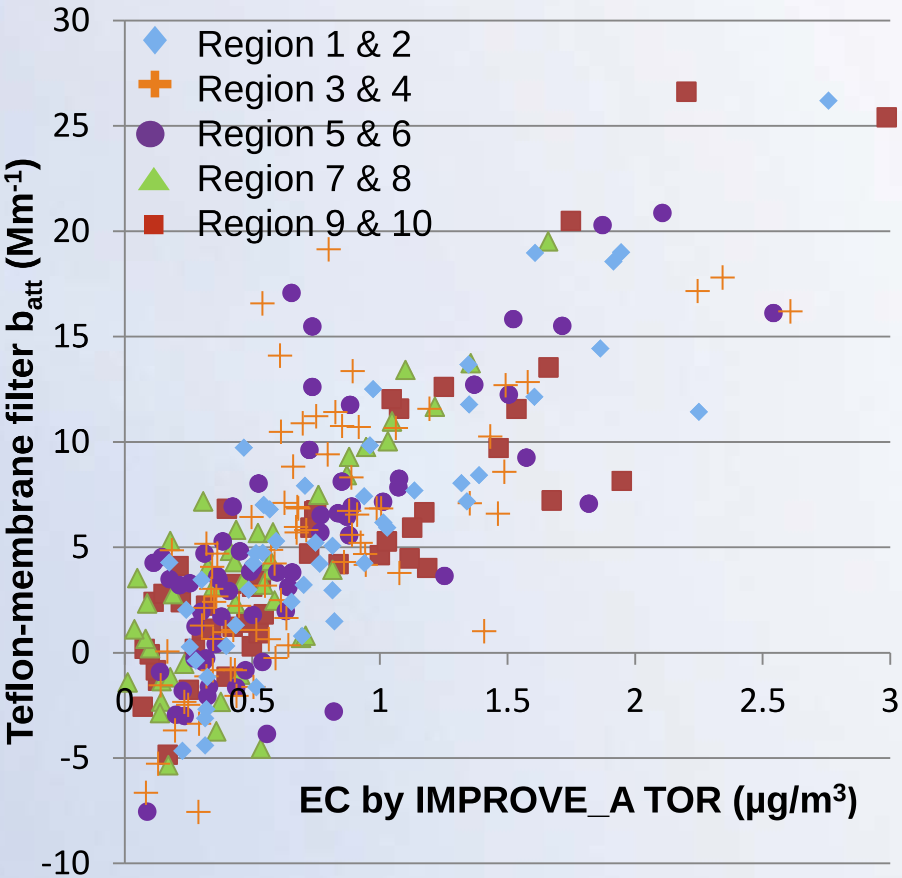
Season	Slope $\sigma_{att}[\lambda]$ (m^2/g)	Intercept	r^2	Count (n)
Summer – TOR	8.91	1.97	0.73	29
Fall – TOR	9.02	2.12	0.74	43
December – TOR	8.51	1.48	0.88	10
Summer – TOT	9.95	0.90	0.65	29
Fall – TOT	6.13	4.14	0.59	43
December – TOT	12.68	0.24	0.89	10



EPA Regional Variation of b_{att} as a Function of EC by IMPROVE_A TOR

- Variation between EPA regions of b_{att} as a function of EC by IMPROVE_A method for filters sampled in 2014

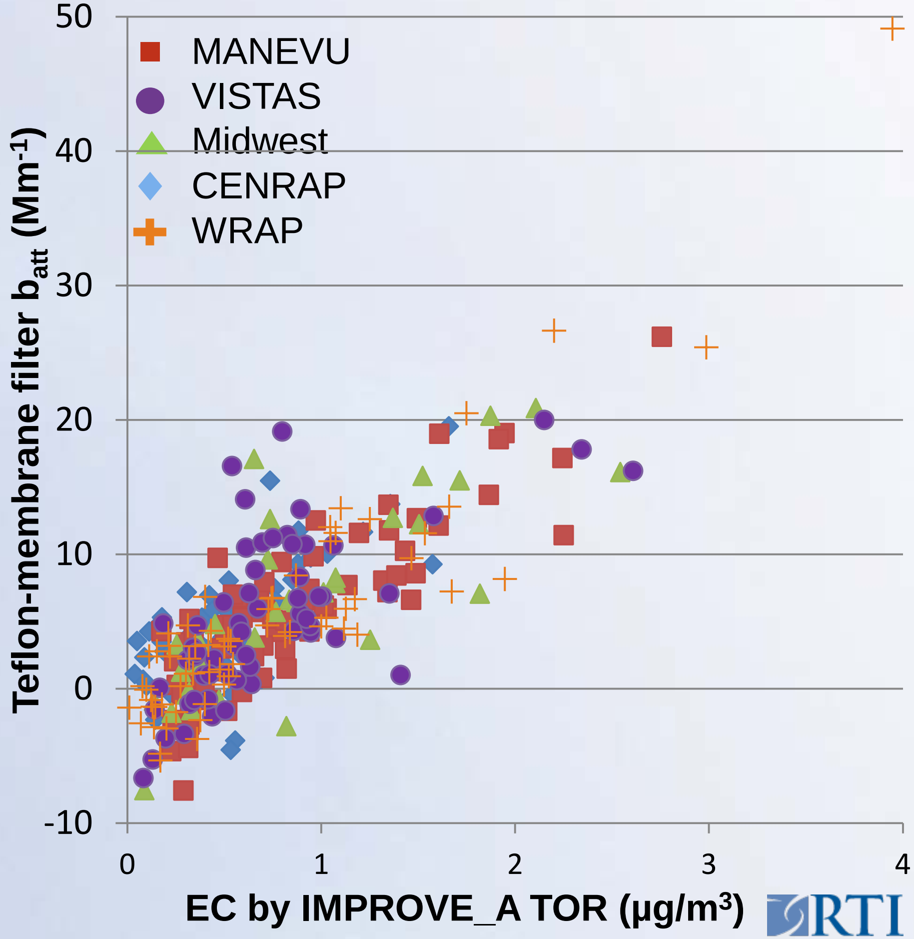
EPA Regions	Slope $\sigma_{att}[\lambda]$ (m^2/g)	Intercept	r^2	Count (n)
1 & 2	9.53	2.27	0.75	49
3 & 4	8.20	0.90	0.48	80
5 & 6	8.60	0.94	0.56	65
7 & 8	11.14	1.94	0.67	47
9 & 10	10.57	2.78	0.84	48



Regional Planning Organization Variation of b_{att} as a Function of EC by IMPROVE_A TOR

- Variation between Regional Planning Organizations (RPO) of b_{att} as a function of EC by IMPROVE_A method for filters sampled in 2014

RPO	Slope $\sigma_{att}[\lambda]$ (m^2/g)	Intercept	r^2	Count (n)
MANE-VU	9.38	2.25	0.74	70
VISTAS	8.29	0.68	0.46	42
Midwest	9.05	1.62	0.64	46
CENRAP	8.96	0.53	0.47	38
WRAP	10.70	2.81	0.83	59



Conclusions and Next Steps

Conclusions

- Robotic system shows excellent agreement with the Benchtop OT21.
- Relationship between thermal EC and RWS b_{att} provides σ_{att} comparable to RTI and EPA Benchtop OT21s and ranges observed in literature.
- Ability of the RWS to measure optical carbon at a high throughput makes it a valuable, cost-effective tool for
  - black carbon and gravimetric analysis as part of routine network sampling.
  - black carbon analysis of filters archived as part of the CSN, FRM, and other network activities.

Next Steps

- Further investigation of the relationship of optical carbon analysis to
  - mass concentration
  - seasonal variation
  - regional variability
- Development of neutral density filters for RWS
- Analysis of reference materials produced by RTI

Acknowledgements

- Linda Andrews
- Ed Rickman
- Wayne Winstead
- Eric Poitras
- Cindi Salmons

- Project was funded by RTI International.

- MTL Corporation
  - Joel Englund
- Magee Scientific
  - Tony Hansen

More Information

Paige Presler-Jur

Research Environmental Scientist

919.541.6813

pjur@rti.org

Prakash Doraiswamy

Research Environmental Scientist

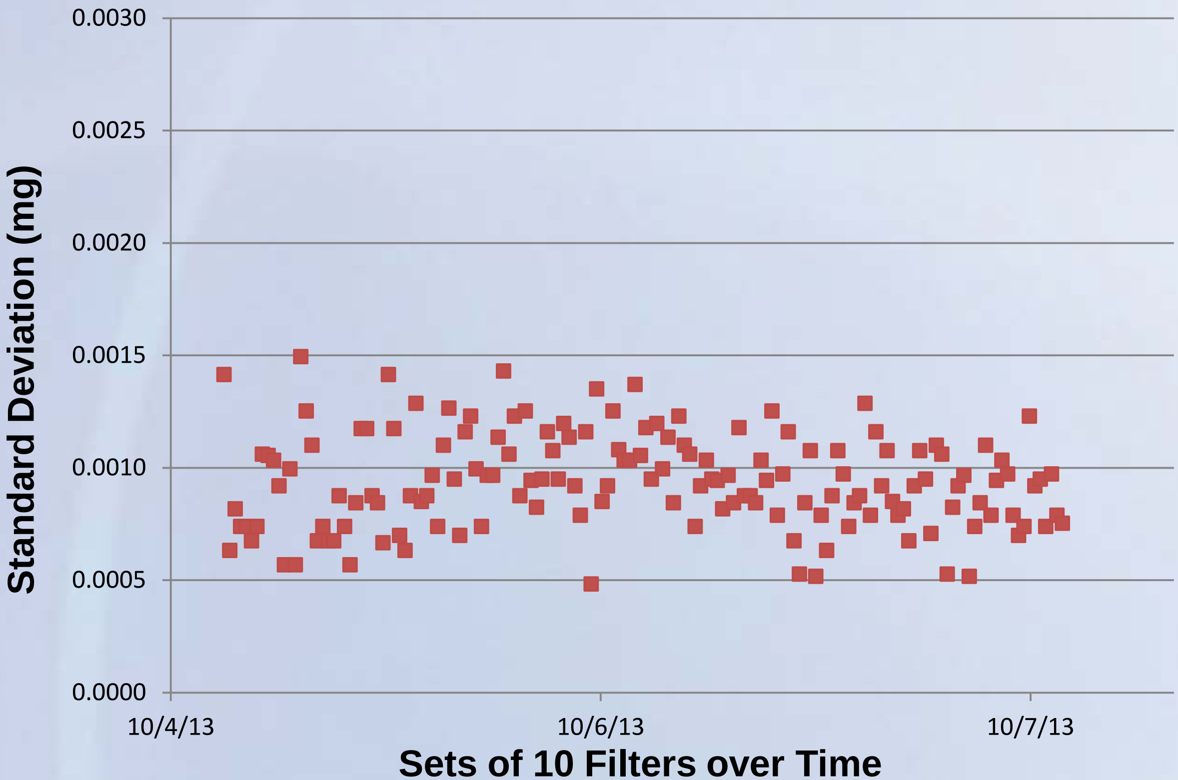
919.990.8648

pdoraiswamy@rti.org

Extra Slides

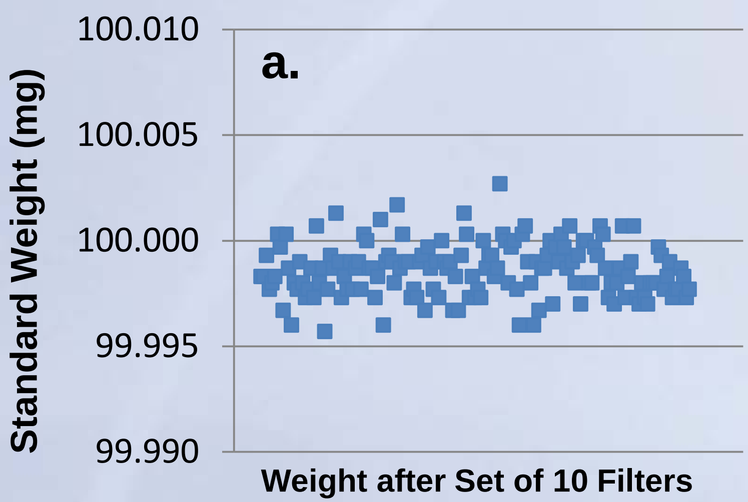
Repeatability for Continual Weighing

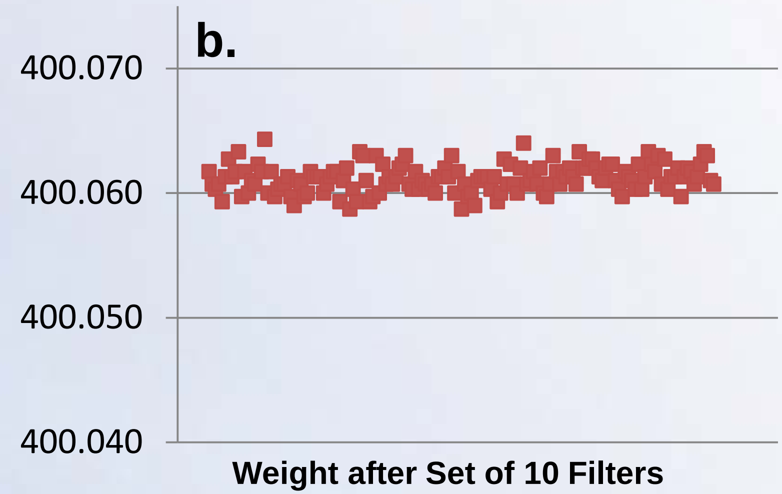
- Analysis of a single filter weighed over a three-day period showed collection of filter weights by AH-225 to have a high level of precision.

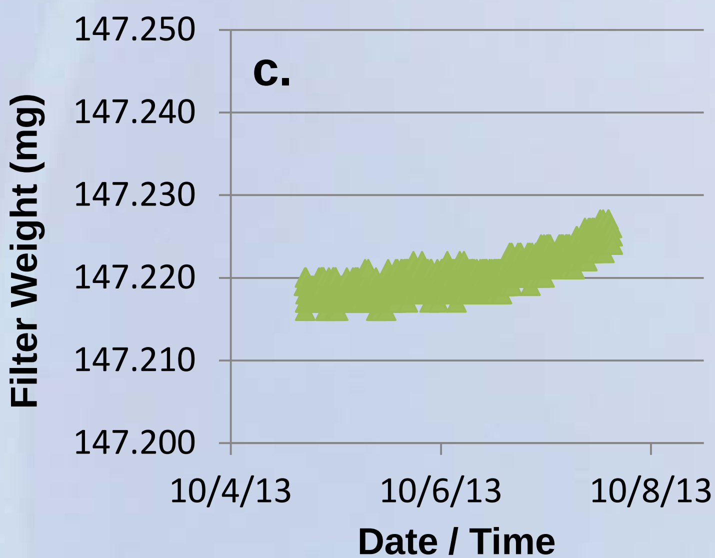


- Standard Deviation for groups of 10 filter weights for a single filter weighing continuously. Sets of 10 were divided by the weighing of standard weights.

Repeatability for Continual Weighing





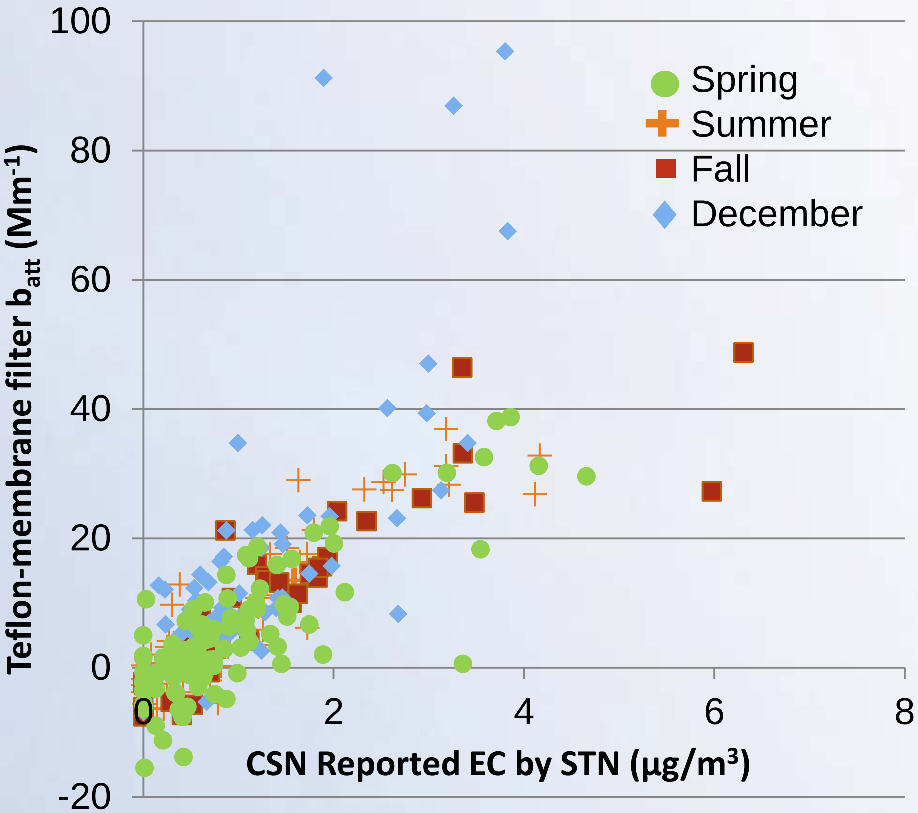


- Variation in weight of a. 100 mg Standard Weight, b. 400 mg Standard Weight, c. Filter Weight for single filter repetitions.
- Stability of standard weights indicate drift is due to filter media not instrument.

Seasonal Variation of Light Attenuation as a function of EC by STN Method

- Seasonal variation of b_{att} as a function of EC by STN method for filters sampled in 2007

Season	Slope ($\sigma_{att}[\lambda]$, m^2/g)	Intercept	r^2	Count (n)
Spring	8.53	2.89	0.66	92
Summer	10.03	2.12	0.81	67
Fall	8.24	1.03	0.76	42
December	16.80	4.21	0.59	70



EPA Regional Variation of b_{att} as a function of EC by IMPROVE_A TOT

- Variation between EPA Regions of b_{att} as a function of EC by IMPROVE_A method. Filters sampled in 2014.

EPA Regions	Slope ($\sigma_{att}[\lambda]$, m^2/g)	Intercept	r^2	Count (n)
1 & 2	10.67	0.56	0.65	49
3 & 4	12.68	0.19	0.41	80
5 & 6	9.20	1.23	0.38	65
7 & 8	16.12	1.37	0.61	47
9 & 10	13.05	2.17	0.84	48