Estimation of Light Attenuation from Brown Carbon using Filter Loading Adjusted Light Attenuation

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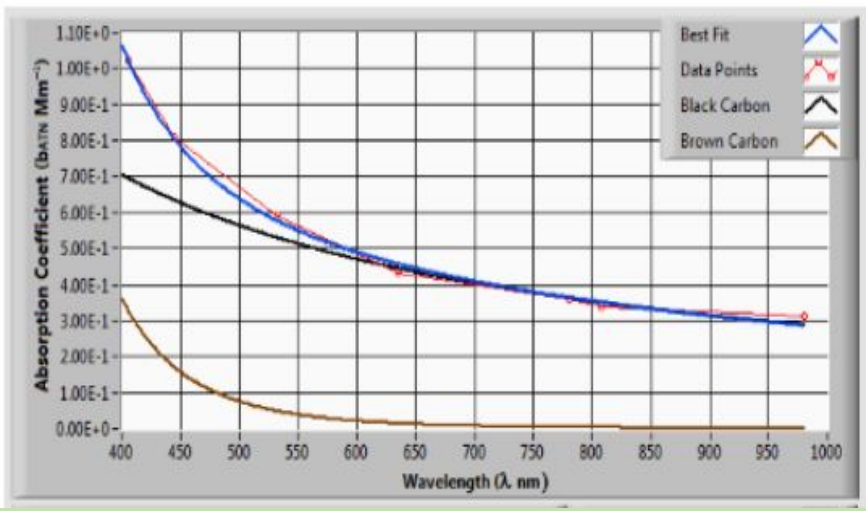
Introduction/Background

- Seven wavelength (λ) filter light attenuation is used to separate brown carbon (BrC) and black carbon (BC) for the IMPROVE and CSN samples[a]
- A reduced response in attenuation was found at higher EC concentrations
- Due to the inverse wavelength (λ) dependence of light attenuation on EC, the shorter λs (e.g., 405 nm) are more affected by the filter saturation effect
- Filter loading effects at shorter wavelengths alter the attribution of attenuation to BrC and BC

[a]Chow et al., 2018, *JAWMA*

Introduction/Background (cont'd)

- Separation of BrC from BC is based on two component modeling with a non-linear fit, assuming AAE[a] is unity for BC.
- The AAE is underestimated at higher EC due to the filter loading effect
- Empirical corrections for Aethalometer and other filter-based methods are used to account for the filter loading effects (Arnott et al., 2005; Collaud Coen et al., 2010; Virkula et al., 2010; and Weingartner et al., 2003)
- DRI Model 2015 carbon analyzer data from 2016-2017 (~60,000 samples) are empirically adjusted for filter loading effects and attenuation by BrC is re-calculated



Example of a screenshot of the DRI Model 2015 Multiwavelength thermal/optical carbon analyzer (Magee Scientific, Berkeley, CA) software for determination of BrC and BC light attenuation

AAE: Absorption Angstrom Exponent

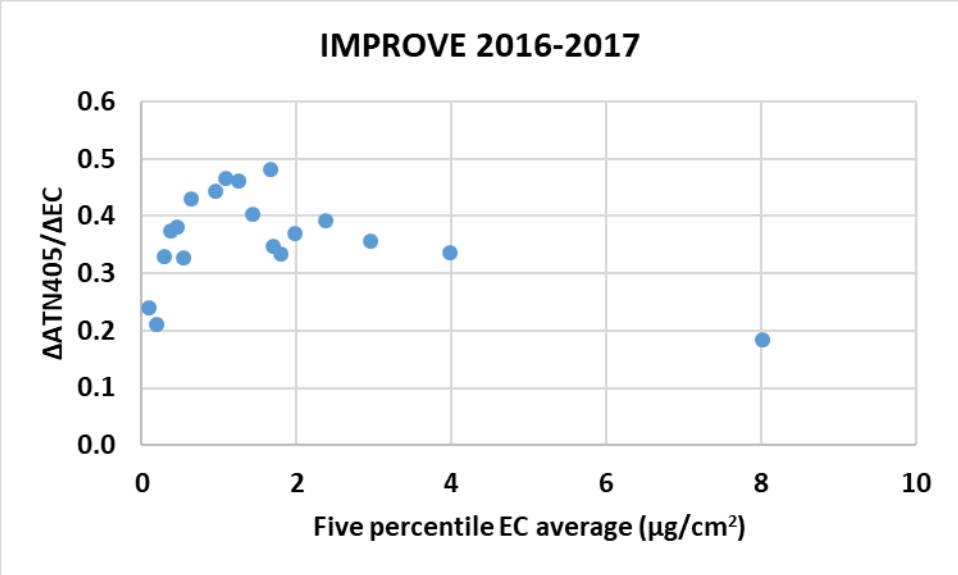
Any positive deviation from an AAE of 1 is attributed to BrC. If the AAE is <1, it is assumed that there is no BrC and all attenuation is from BC

Chow et al., 2018, *JAWMA*

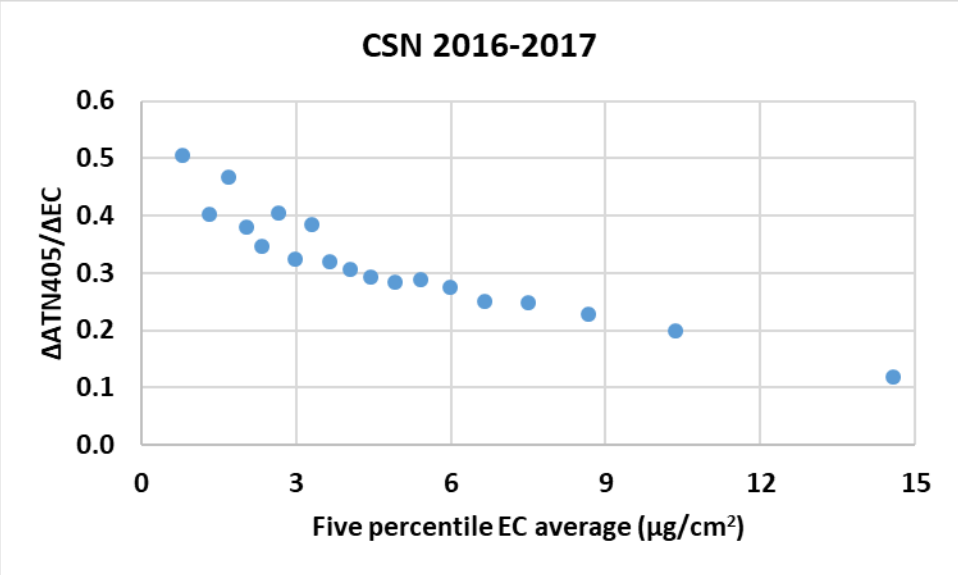
Methodology

- EC concentrations are expressed as area densities ($\mu g/cm^2$), not affected by filter size or flow rate.
- Average change in attenuation by EC is calculated for different ranges of EC filter loadings
- For threshold loadings where the response begins to decline, attenuation at each λ is adjusted upward assuming the responses should be the same as those at lower filter loadings
- Adjusted attenuation is then used to attribute total light attenuation between BrC and BC
- Light transmission through aerosol deposits on quartz-fiber filters overestimate $b_{abs}(\lambda)$ due to multiple scattering affects. This adjustment does not correct for filter scattering, but it allows for a better attribution of attenuation to BrC

Changes in ΔATN/ΔEC differ for IMPROVE and CSN samples



IMPROVE samples show an initial increase of ΔATN/ΔEC as EC increases, then decreases, perhaps due to lower EC concentrations with greater uncertainties



CSN samples show reduced ΔATN/ΔEC as EC increases, especially at EC >3 µg/cm^2

ΔATN= Avg $ATN_{5\text{-}10\%ile}$- Avg $ATN_{0\text{-}5\%ile}$, where percentiles are %iles of EC

ΔEC= Avg $EC_{5\text{-}10\%ile}$- Avg $EC_{0\text{-}5\%ile}$

Methodology (cont'd)

- Due to the stability of $\Delta ATN/\Delta EC$ for CSN samples, these EC loadings are used to develop adjusted ATN (λ)

- At each λ, the response of ATN to additional EC was assumed to be the same as the average response at EC loadings of 0-3 $\mu g/cm^2$

- For EC > 3 $\mu g/cm^2$, loading corrections were applied to 10.8% of IMPROVE data (2016-2018) and 64.7% of CSN data (2016-2017)

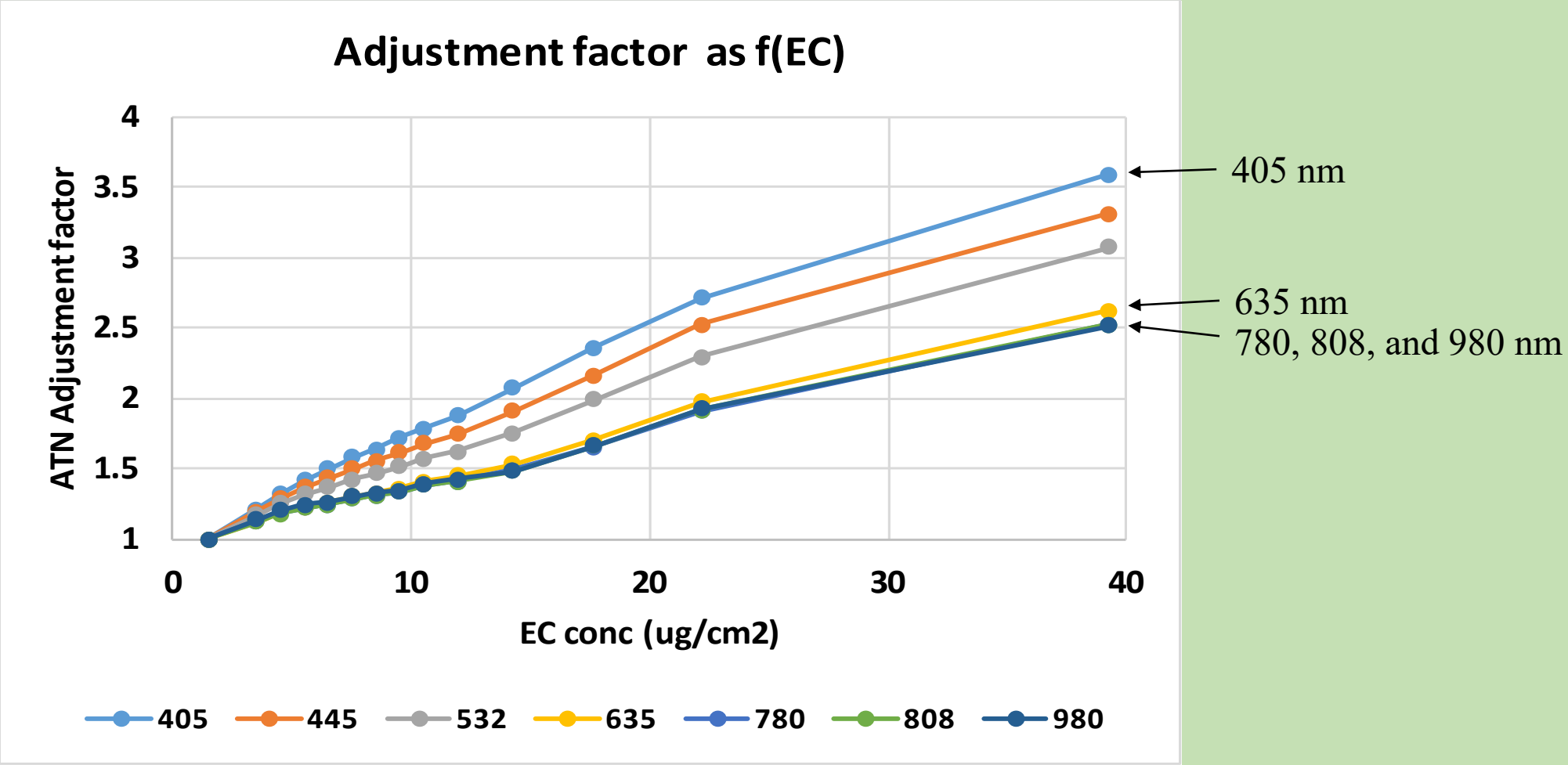
The adjustment factors for ATN (λ) increase with increased EC loadings

EC (μg/cm^2)	ATN_{405}	ATN_{445}	ATN_{532}	ATN_{635}	ATN_{780}	ATN_{808}	ATN_{980}
0-3	1	1	1	1	1	1	1
3-4	1.21	1.19	1.17	1.12	1.13	1.12	1.14
4-5	1.32	1.28	1.25	1.18	1.18	1.18	1.20
5-6	1.42	1.36	1.31	1.23	1.22	1.22	1.24
6-7	1.50	1.43	1.36	1.26	1.25	1.24	1.26
7-8	1.58	1.50	1.43	1.30	1.29	1.29	1.30
8-9	1.64	1.55	1.46	1.33	1.31	1.31	1.33
9-10	1.72	1.62	1.51	1.36	1.33	1.34	1.34
10-11	1.79	1.68	1.57	1.41	1.38	1.38	1.39
11-13	1.88	1.75	1.62	1.45	1.41	1.41	1.42
13-16	2.07	1.91	1.75	1.53	1.49	1.48	1.48
16-20	2.36	2.17	1.99	1.71	1.65	1.66	1.66
20-25	2.71	2.53	2.30	1.97	1.91	1.91	1.93
>25	3.60	3.31	3.07	2.62	2.53	2.53	2.51

Over 95% of samples have EC <10 μg/cm^2

High ATN (λ) adjustment factors at shorter λ, thus increasing the AAE and attributing more ATN to BrC

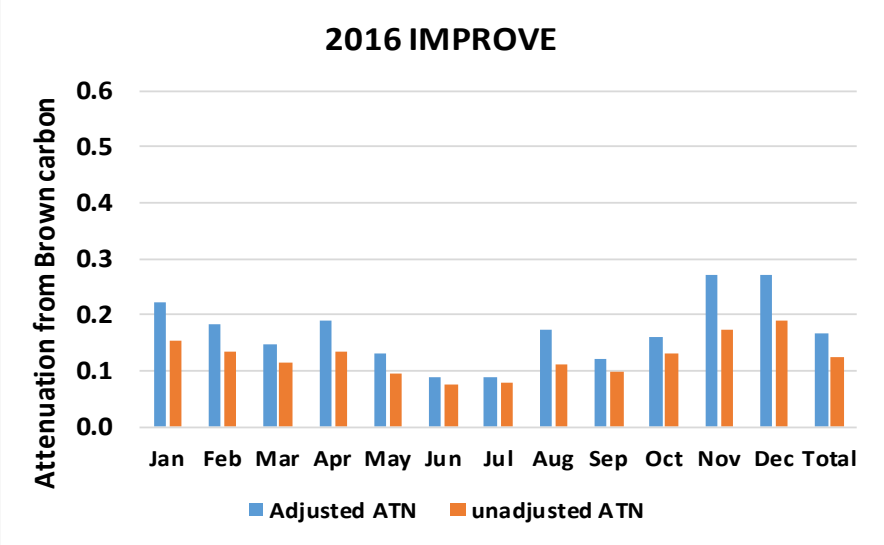
Adjustment factors are similar for wavelengths 635 nm and above

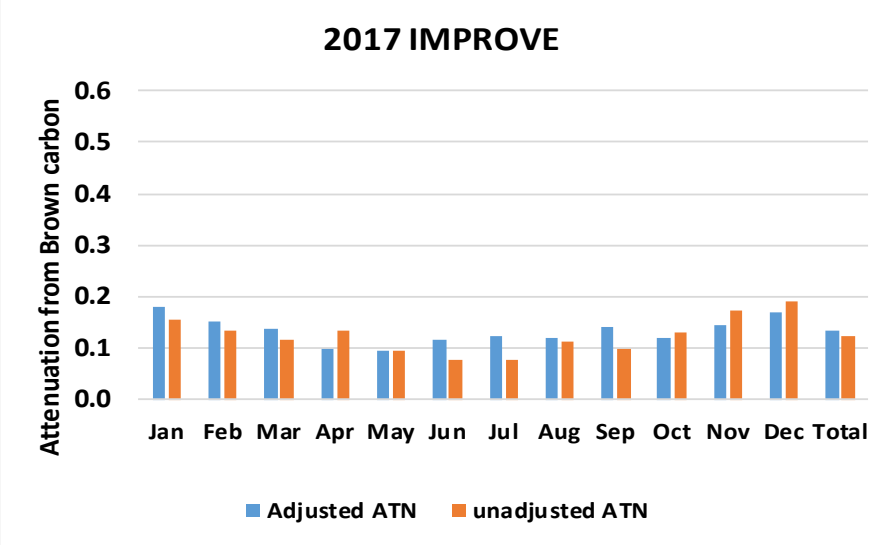


Note: ~95% of combined IMPROVE and CSN data have EC concentrations <10 ug/cm^2

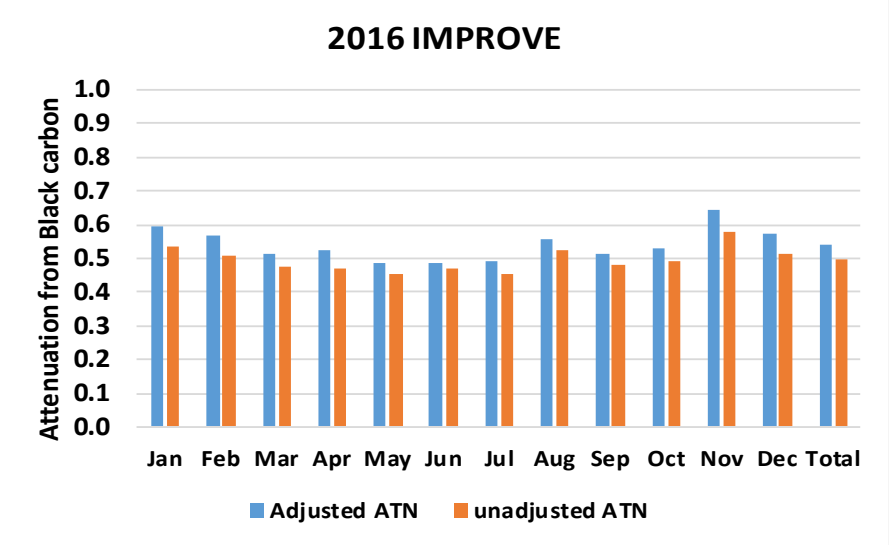
Higher attenuation adjustment for BrC than BC

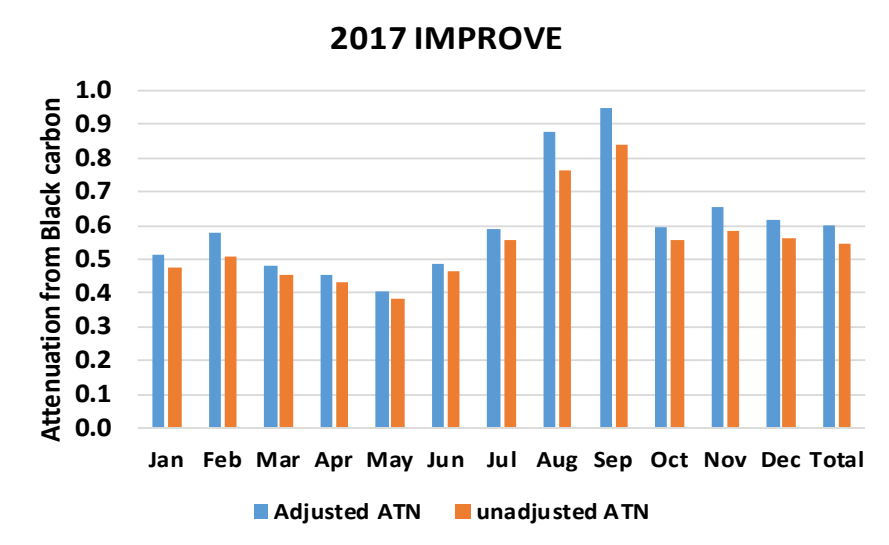
BrC





BC

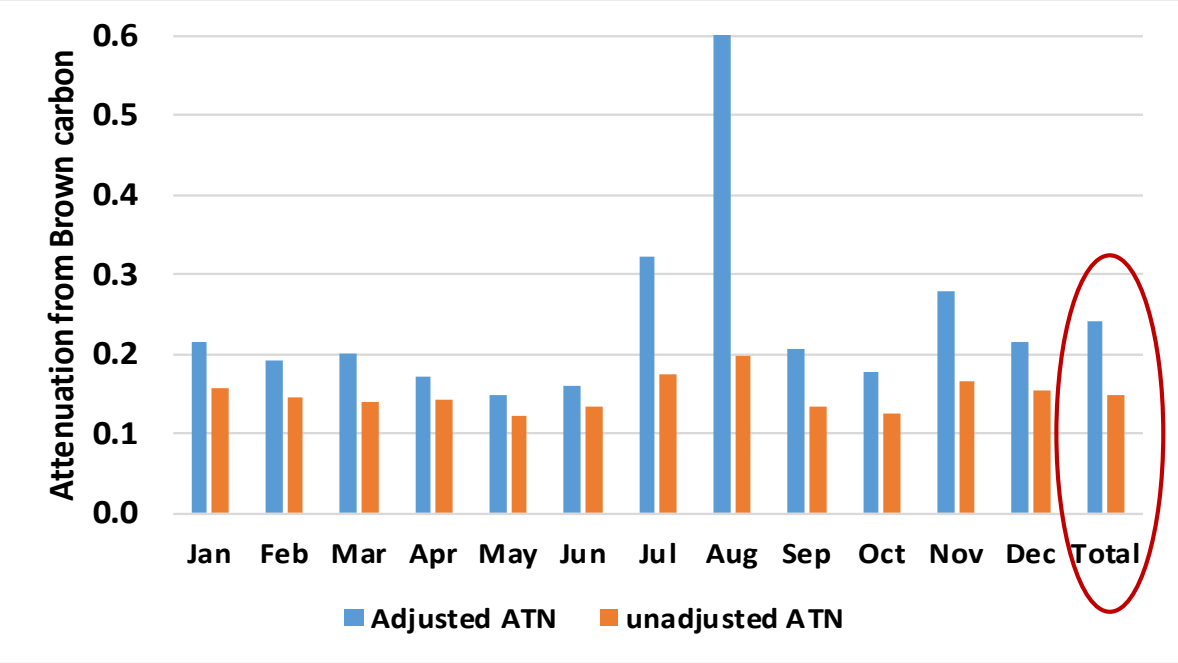




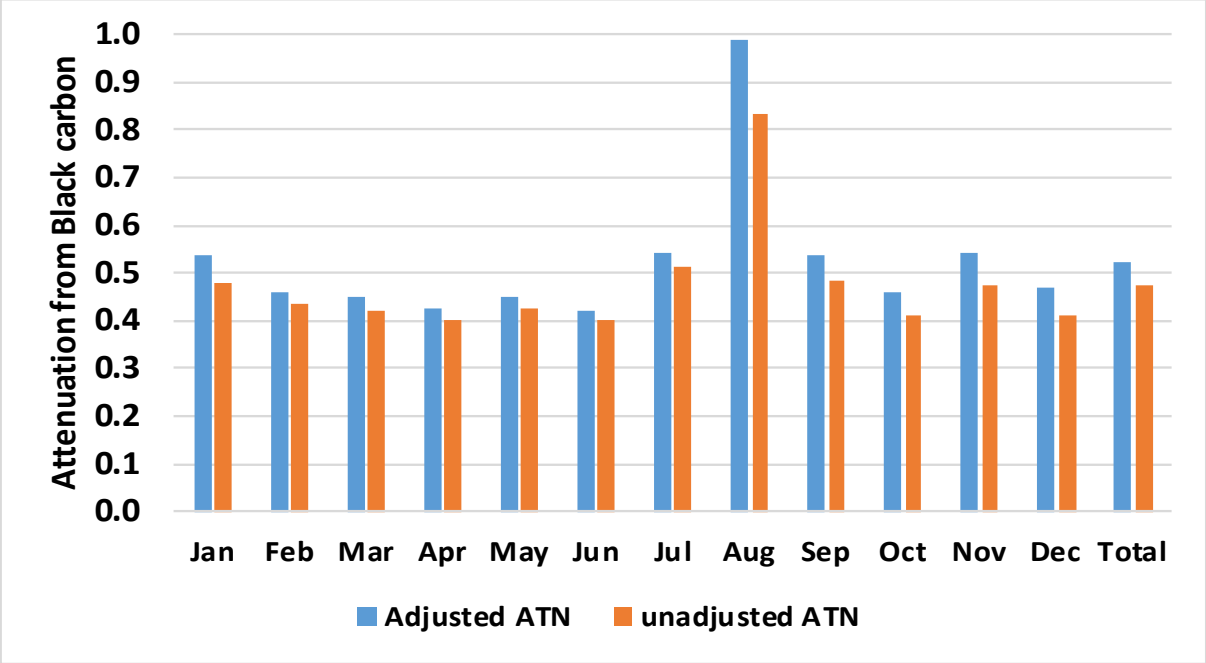
After attenuation adjustment, ATN_{405} increased ~62% for BrC and ~10% for BC, on average

(2018 IMPROVE)

BrC



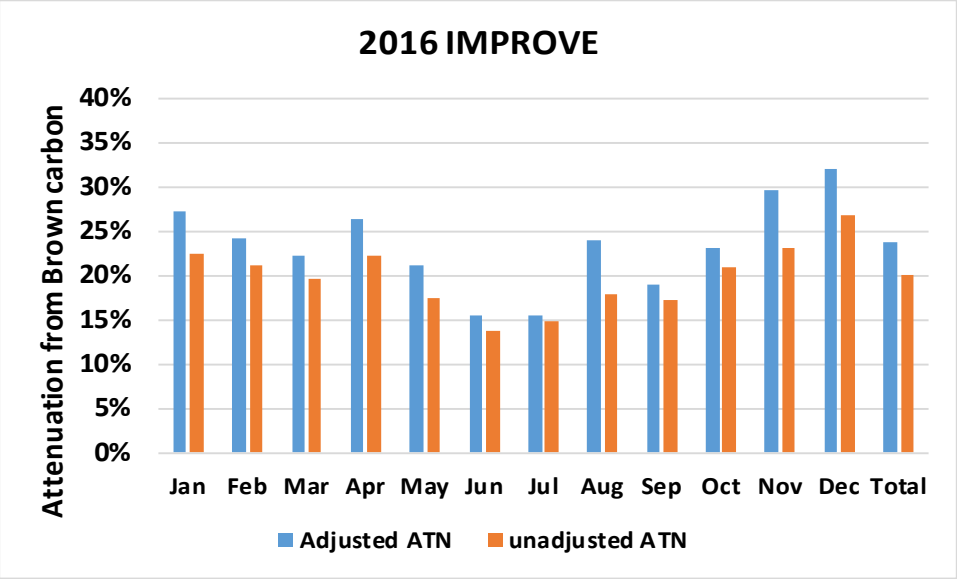
BC

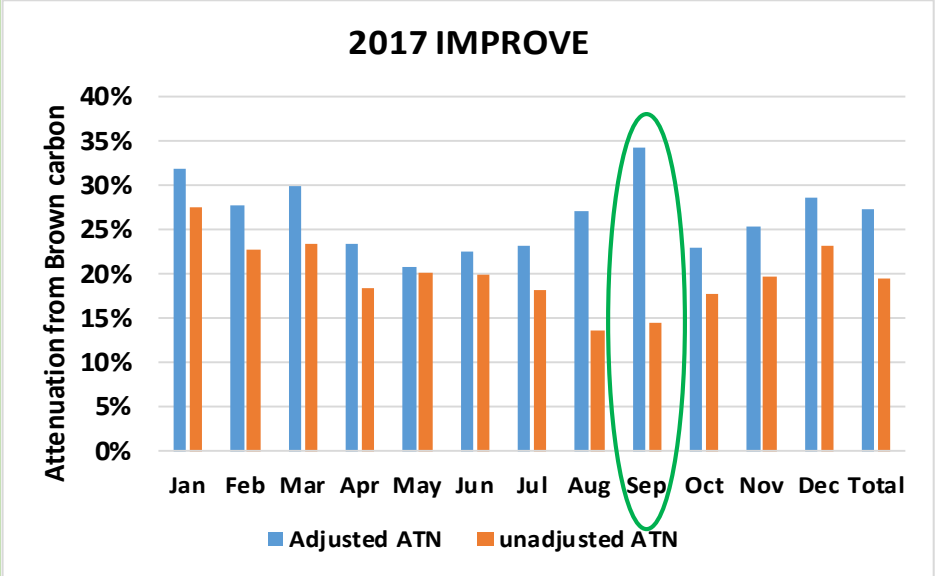


Average total attenuation increased 23%, with 64% from ATN_{BrC} and 36% from ATN_{BC}.
ATN_{405} by BrC increased from 24% (unadjusted) to 31.6% (adjusted)

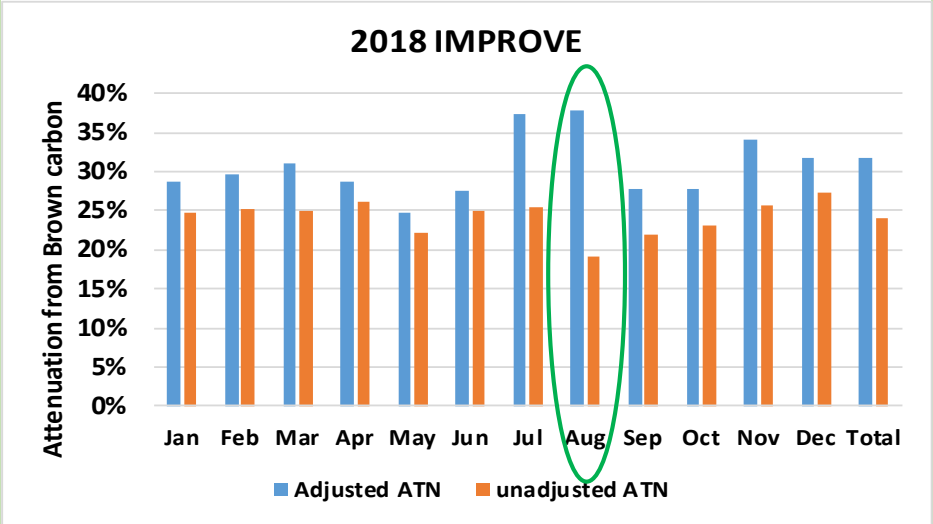
Filter loading corrections alter seasonal patterns from highest BrC attenuation in winter to summer

(2017 and 2018)



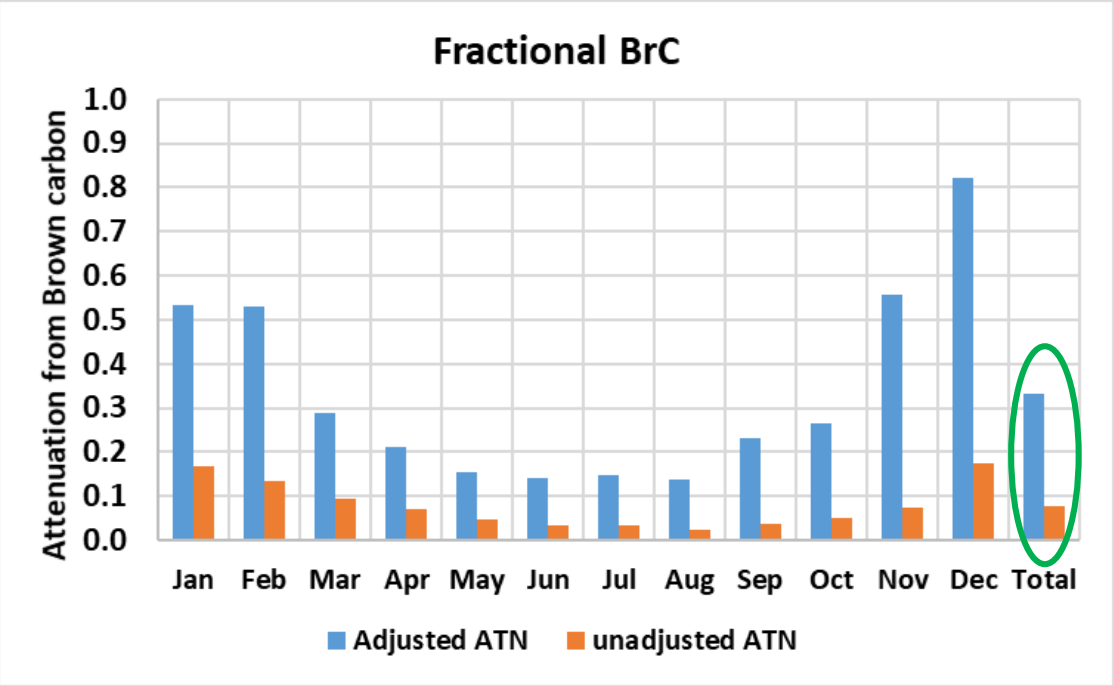


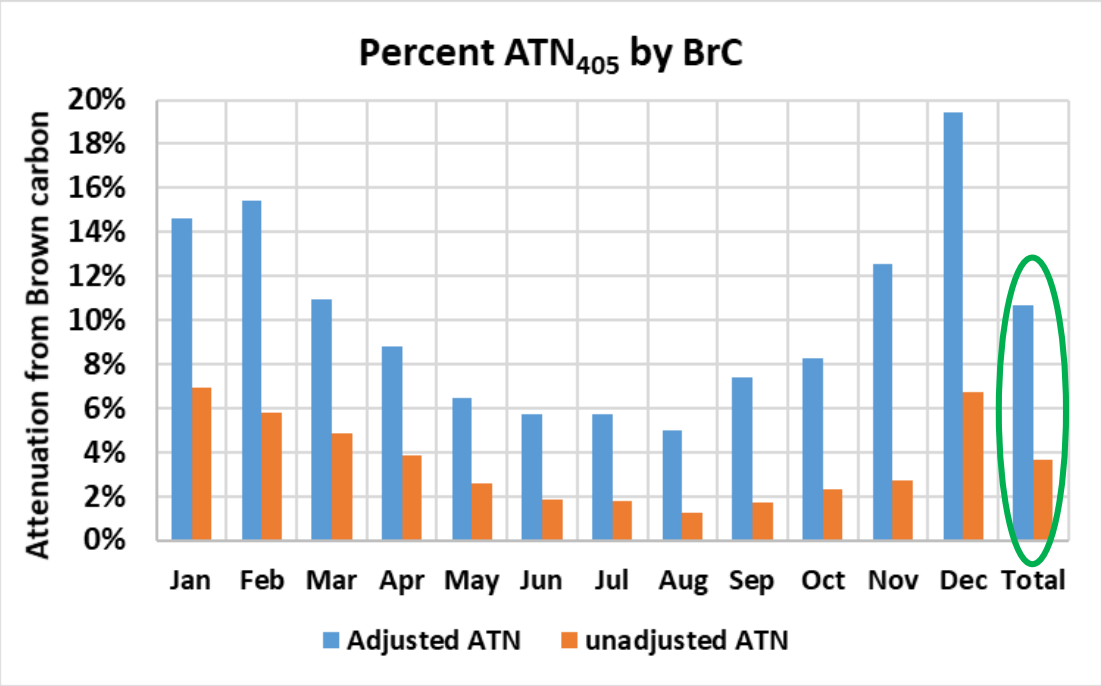
August 2018 shows the lowest $\%ATN_{405}$ by BrC for the unadjusted data but the highest after adjustment



Average attenuation due to BrC for CSN samples increases by three fold (323%) after loading adjustment

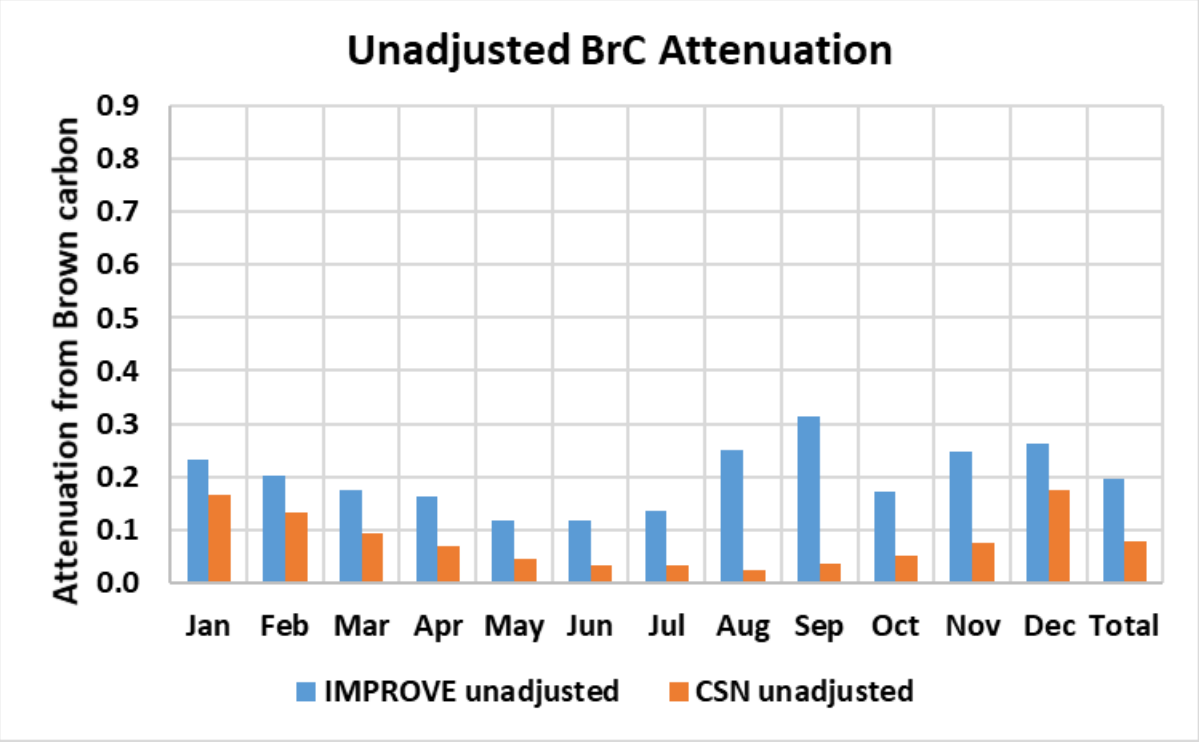
(CSN 2016-2017)

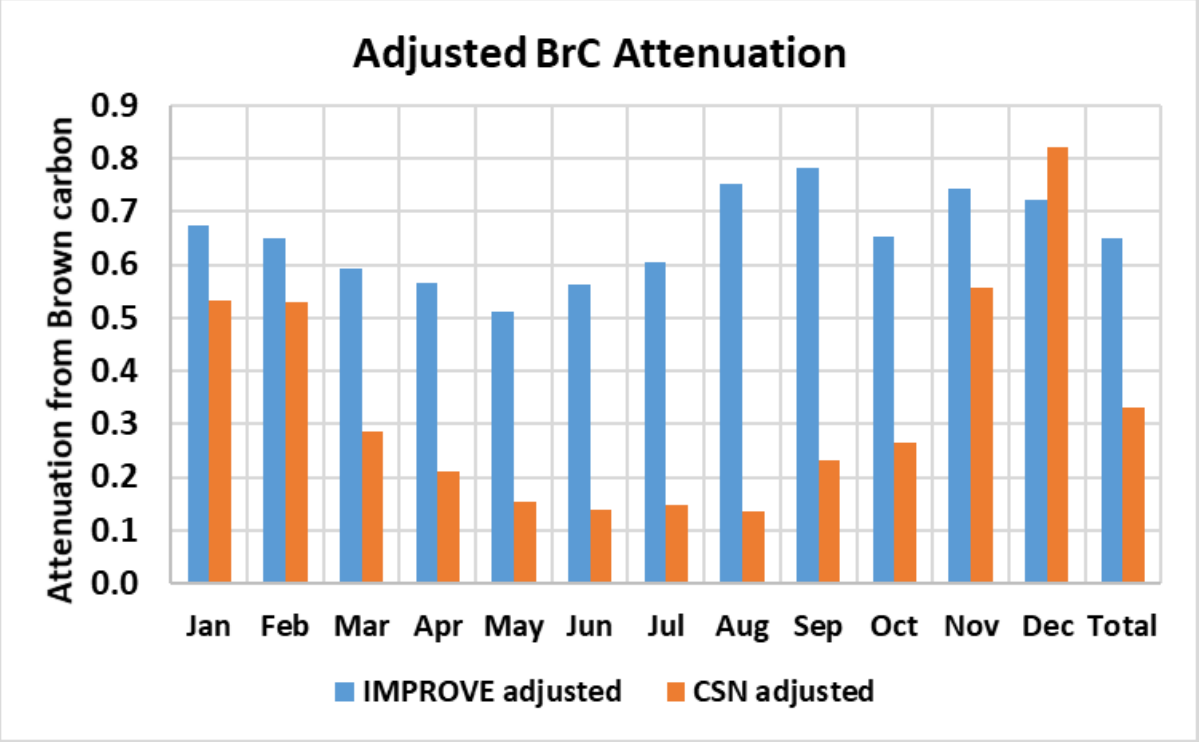




Percent of attenuation due to BrC increased from 3.6 to 10.7 % for CSN

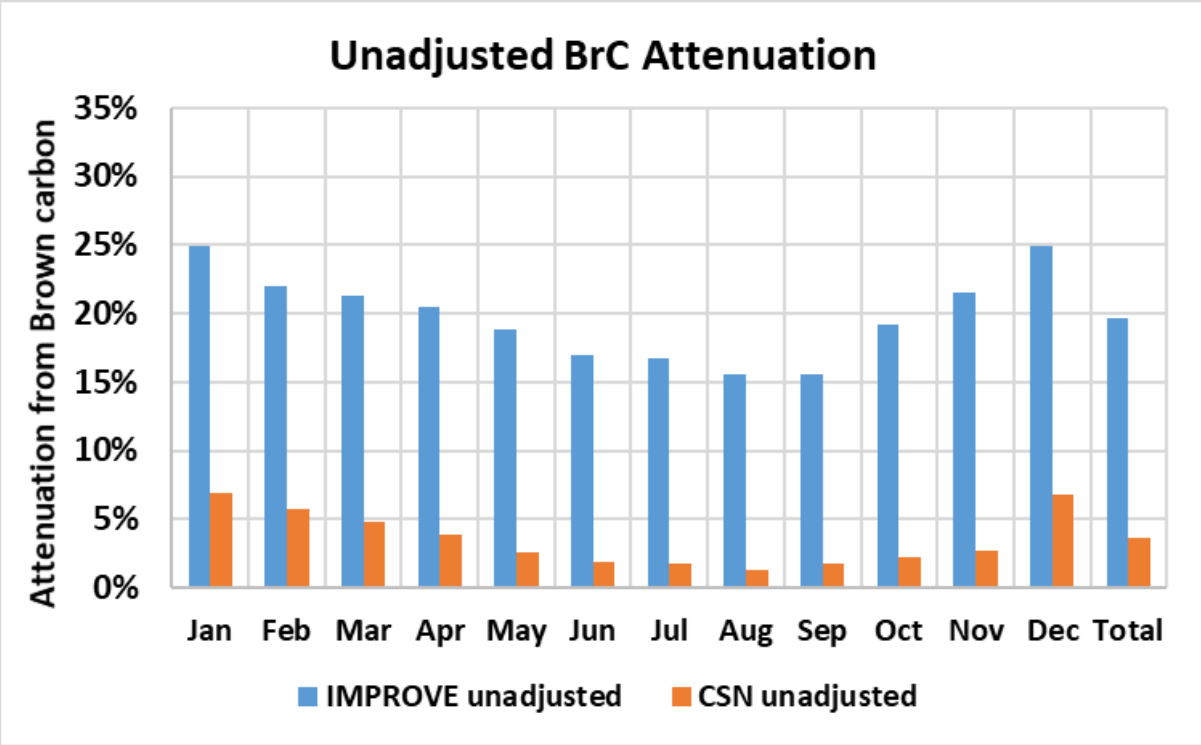
BrC attenuations are higher for IMPROVE than for CSN samples, but the % difference is less after filter loading adjustment

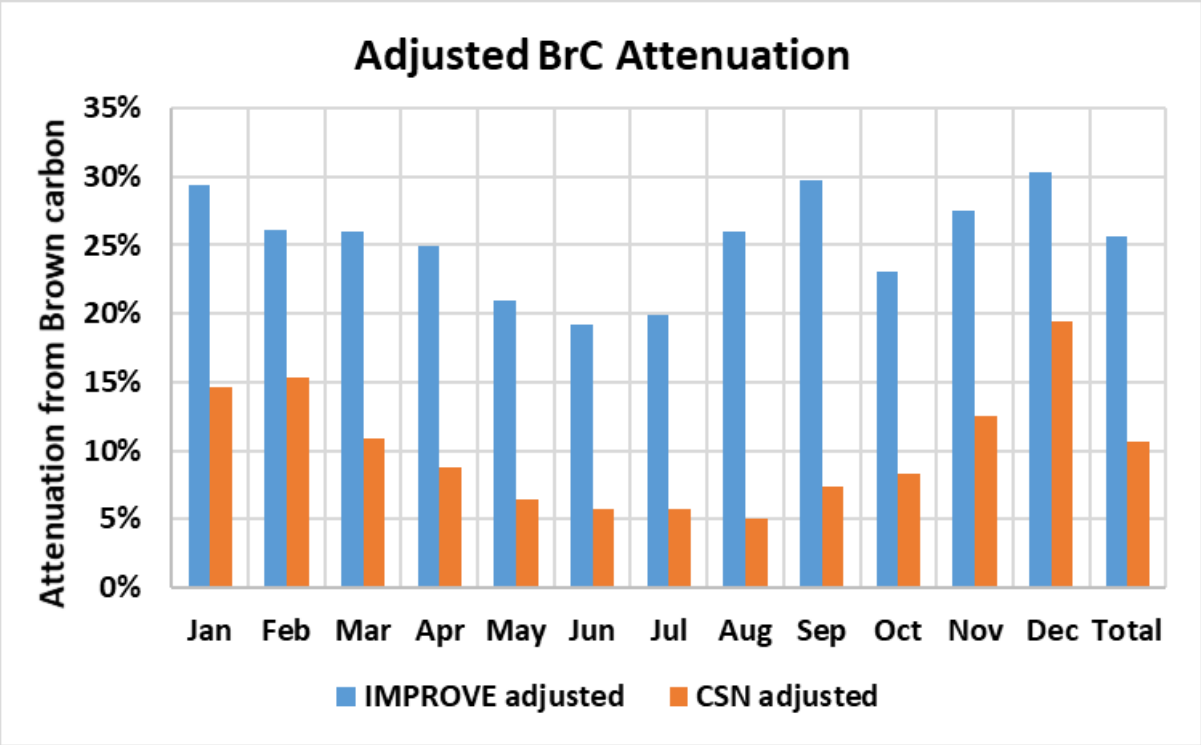




Higher percent BrC attenuation for IMPROVE than CSN

(IMPROVE and CSN, 2016-2017)

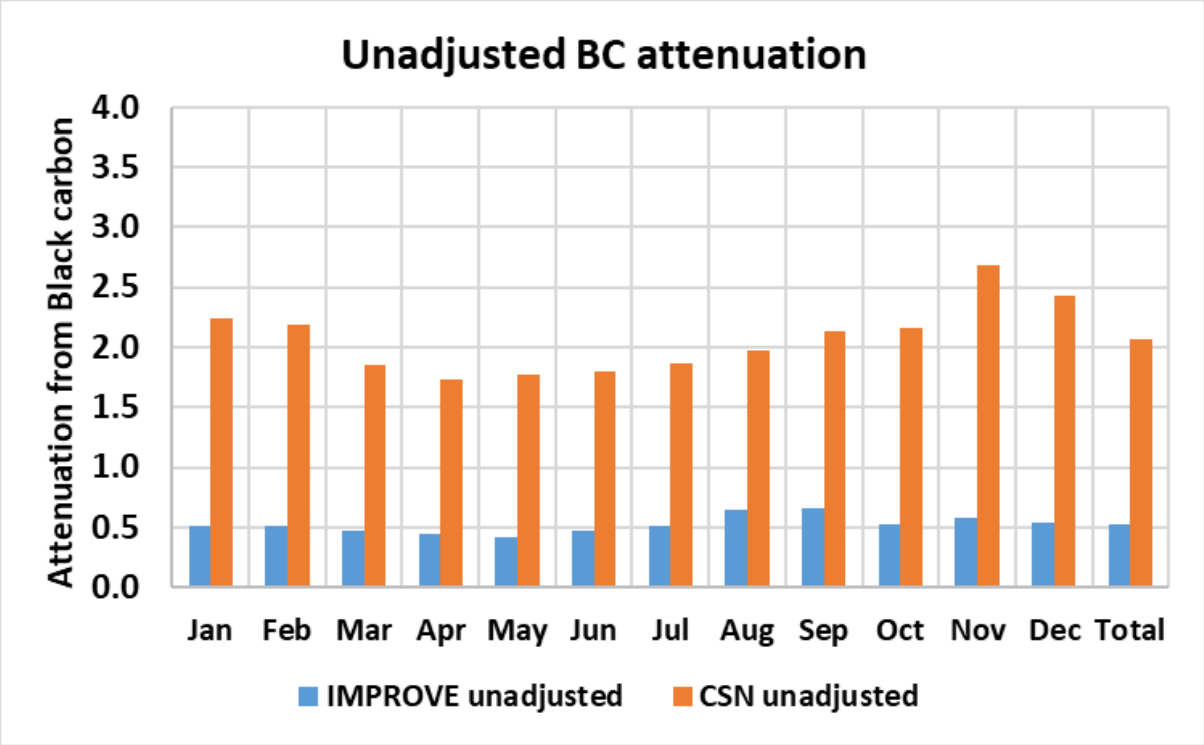


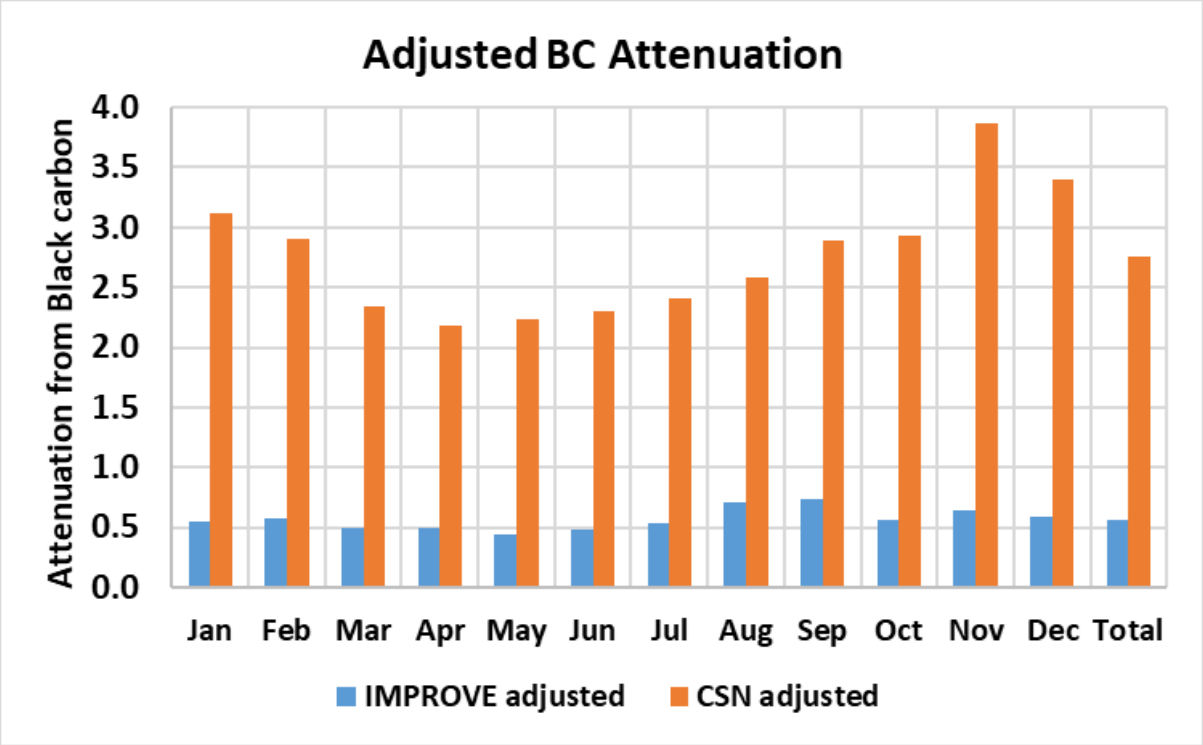


After filter loading adjustment, less difference in attribution of ATN_{405} to BrC are found between networks

BC attenuation for CSN is four to five times higher than IMPROVE

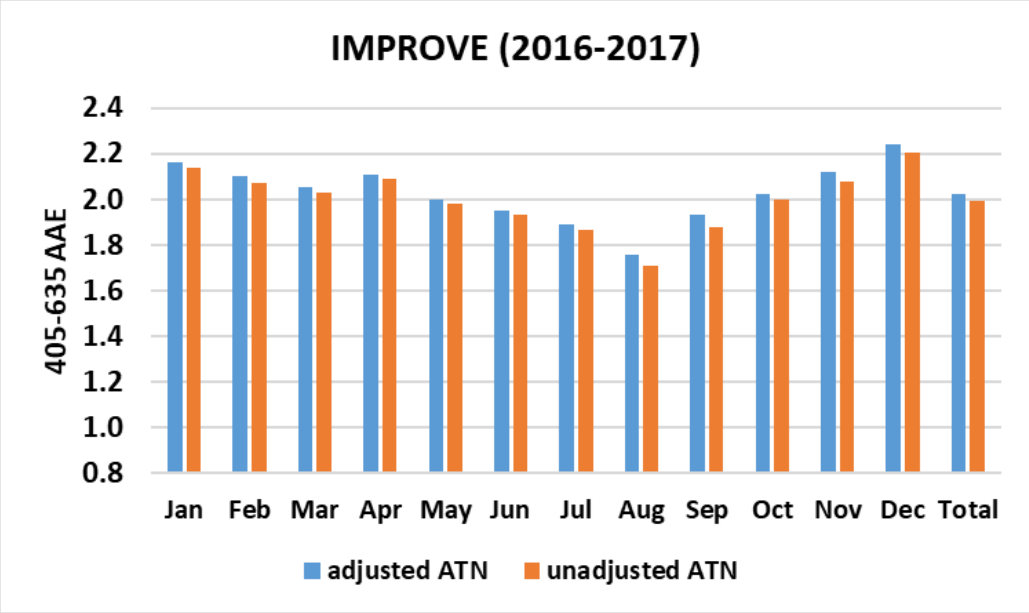
(IMPROVE and CSN 2016-2017)

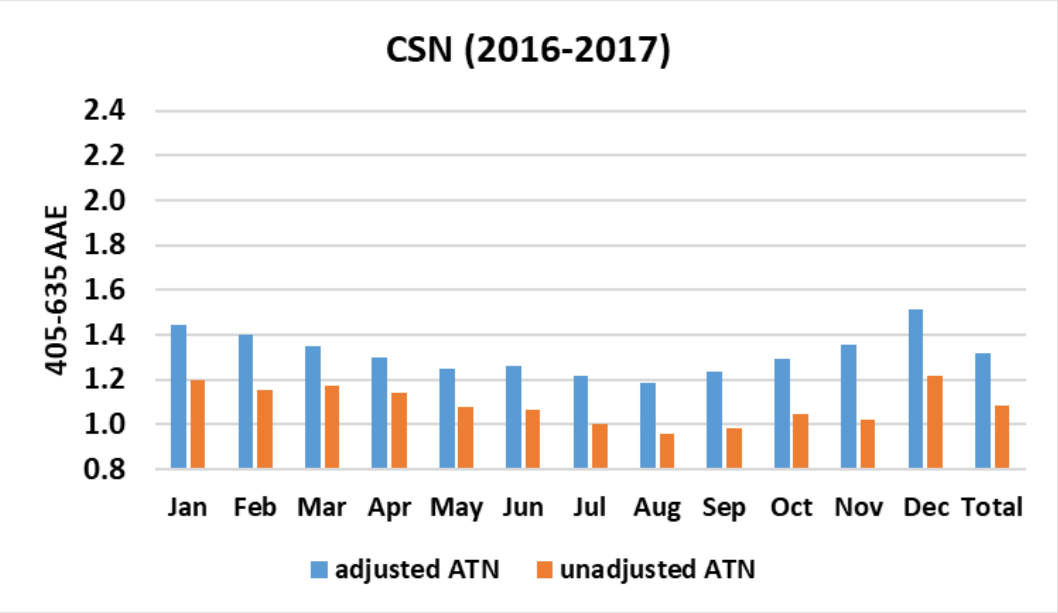




$$ATN_{\lambda} = ln\left(\frac{FT_{\lambda,f}}{FT_{\lambda,i}}\right)$$

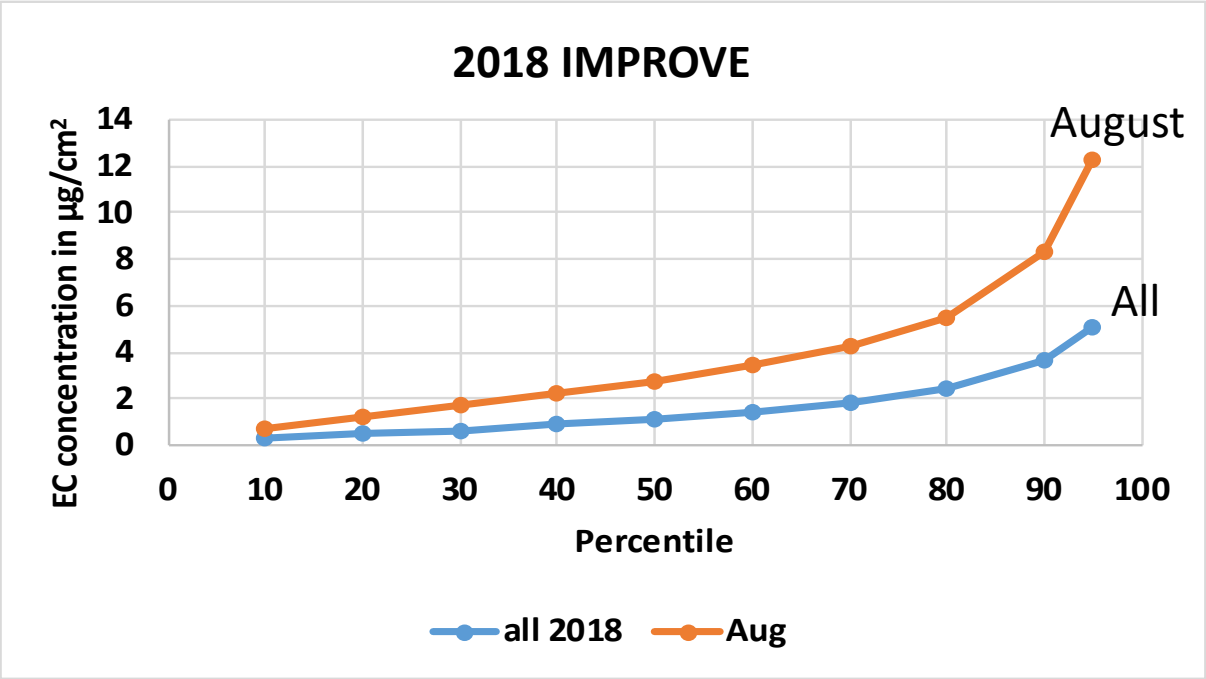
Changes in AAE after filter loading adjustment is more apparent for CSN samples

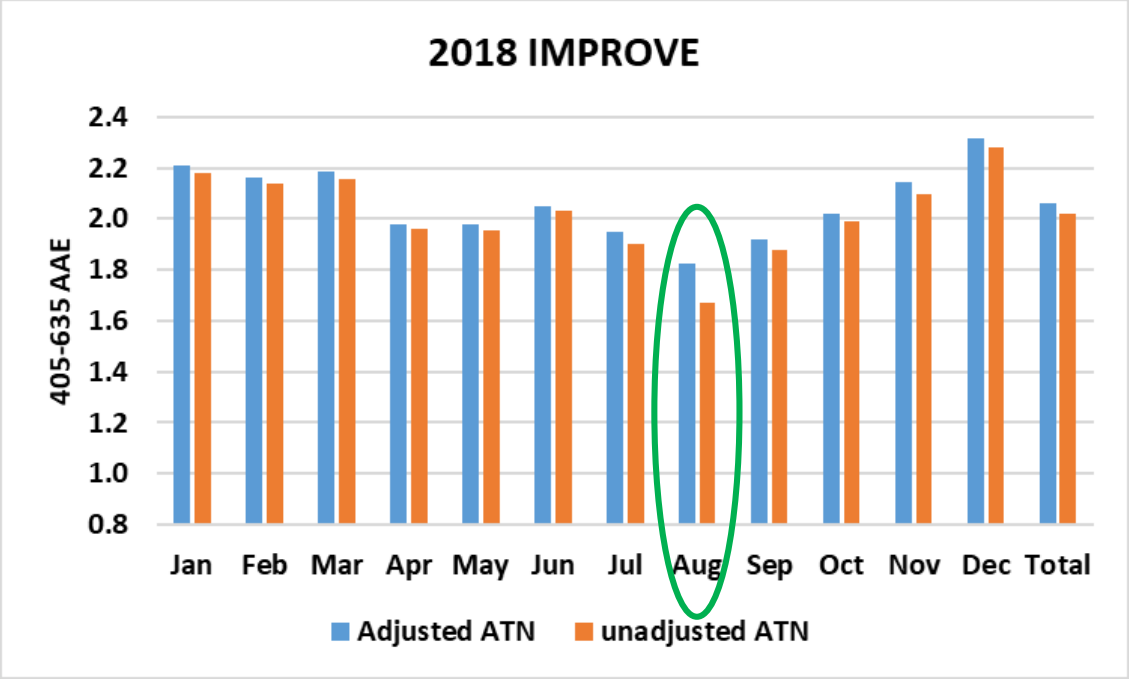




- $\frac{b_{ATN}(\lambda_1)}{b_{ATN}(\lambda_2)} = \left(\frac{\lambda_1}{\lambda_2}\right)^{-AAE}$
- AAE: Absorption Angstrom Exponent, a parameter to characterize λ dependence of light absorption
- Monthly average 405-635 nm AAE changes significantly for CSN after filter loading adjustment (ranges from 0.96-1.22 before adjustment to 1.19-1.51 after adjustment)
- Little AAE changes in IMPROVE AAEs because most EC levels are below the adjustment threshold of 3 μg/cm^2

Increase in AAE after loading adjustment is only apparent for August, 2018 samples



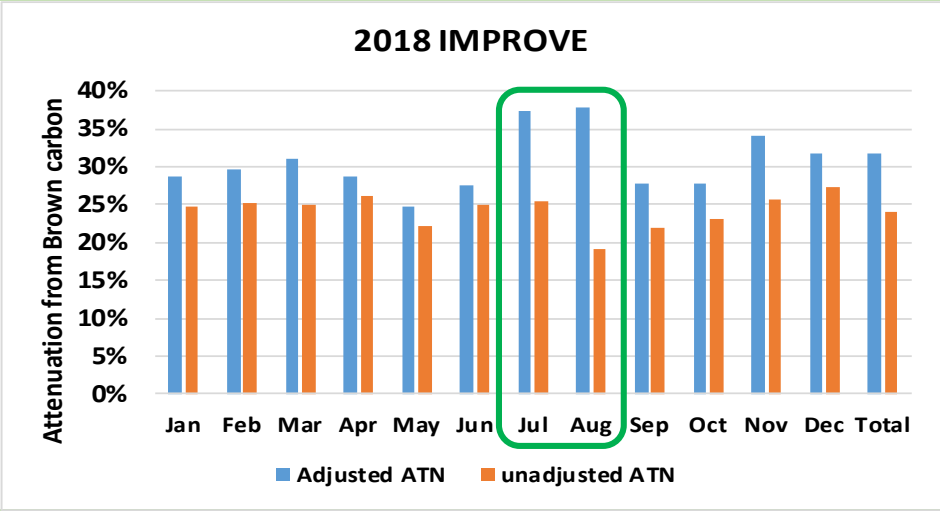


August 2018 has a greater percent of samples subjected for adjustments to ATN (nearly 50%). High EC values cause loading effects that artificially reduces AAEs, resulting in little attribution to BrC.

Forest fires result in elevated BrC light attenuation

(Summer, 2018)

- Elevated BrC light attenuation was found during August 2018 after filter loading adjustment
- Sites with especially high BrC ATN included locations in California (YOSE, LAVO, TRIN, and LABE), Oregon (CRLA), and Washington (PASA and WHPA).
- The Ferguson Fire (CA, 97K acres) affected Yosemite National Park (YOSE).



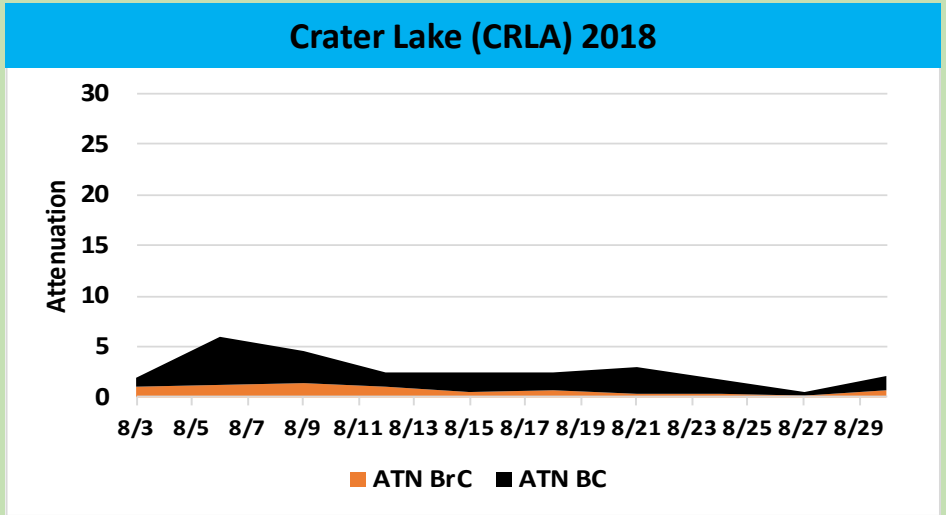
- Active fires in Mendocino Complex (CA, 459K acres), Carr Fire (CA, 230K acres), and the Klondike Fire (OR, 175K acres) contributed to BrC at the Northern California and Southern Oregon IMPROVE sites. The Hirz Fire (CA, 46K acres) was near the Trinity Alps Wilderness (TRIN site).
- The Miriam Fire (WA) only burned 5400 acres but was in very close proximity to the White Pass site (WHPA,WA).

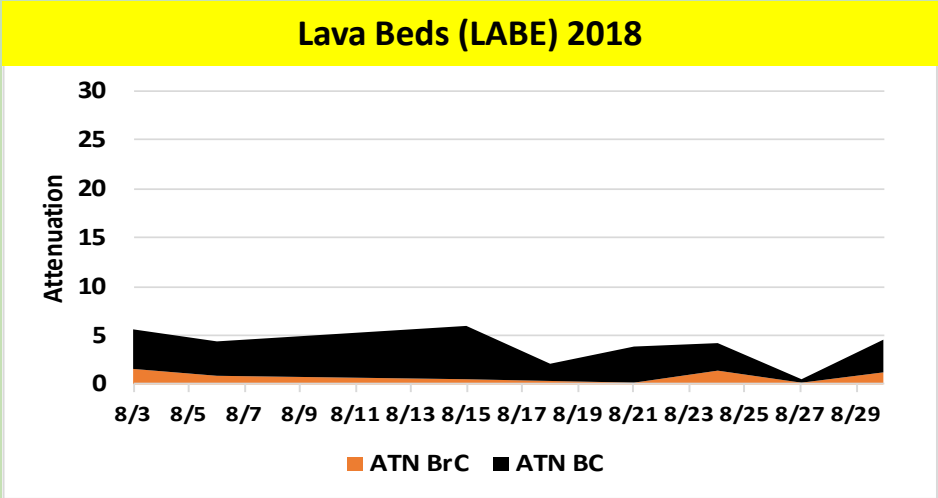
CRLA: Crater Lake; LABE: Lava Beds; LAVO: Lassen Volcanic; PASA: Pasayten; TRIN: Trinity National Forest; WHPA: White Pass; YOSE: Yosemite National Park

Attenuations increase considerably after filter loading adjustments for Crater Lake (CRLA, OR) and Lava Beds (LABE,CA) samples

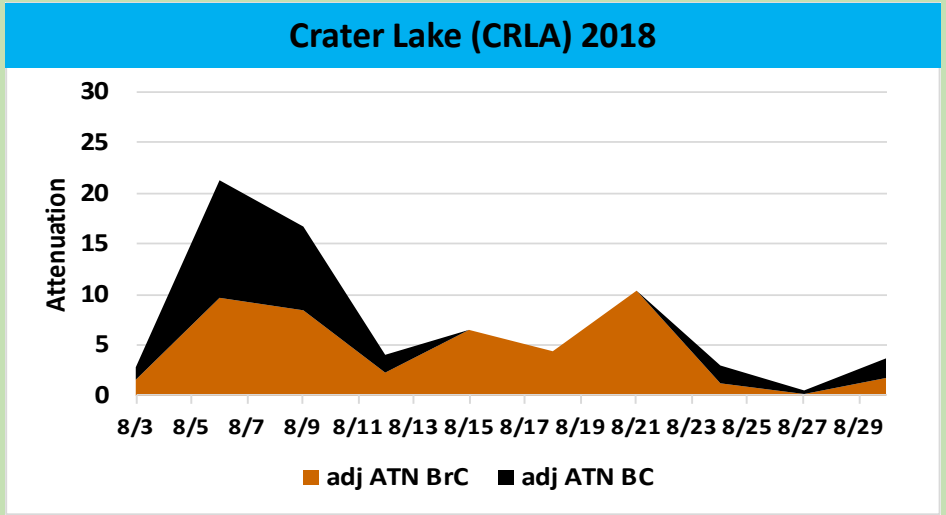
(It shifts from predominantly BC to BrC attenuation)

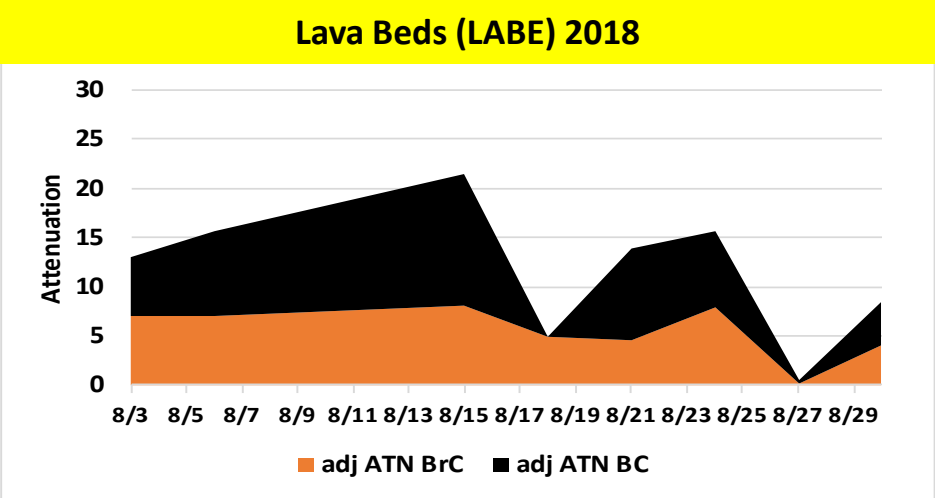
Unadjusted





Adjusted



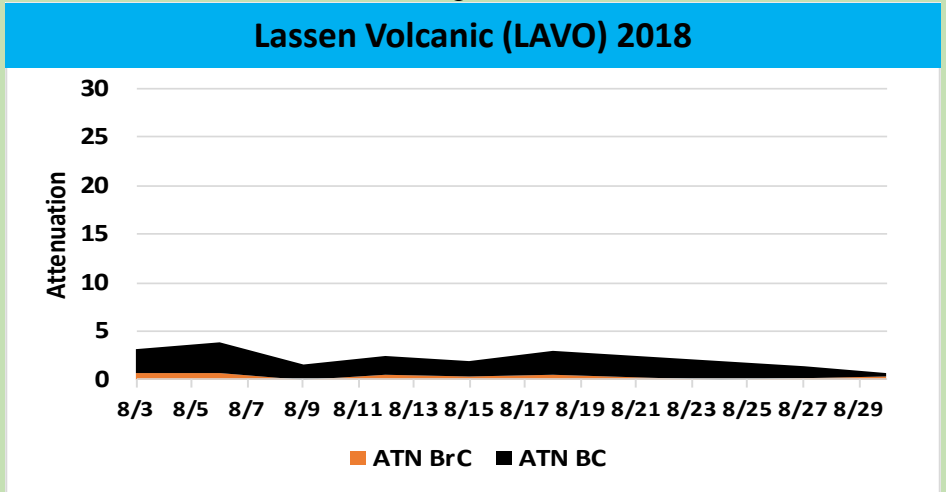


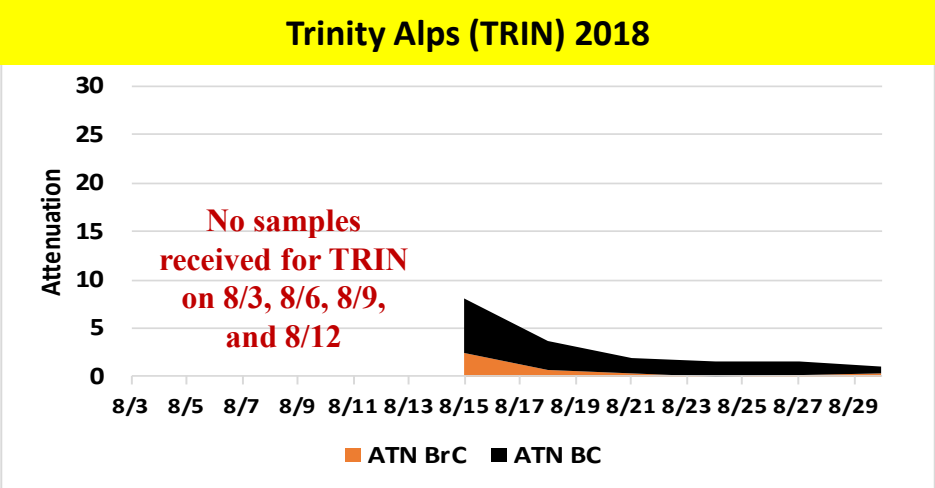
$$ATN_{\lambda} = ln\left(\frac{FT_{\lambda,f}}{FT_{\lambda,i}}\right)$$

Attenuation increases considerably after filter loading adjustment for Lassen Volcanic (LAVO, CA) and Trinity Alps (TRIN, CA) samples

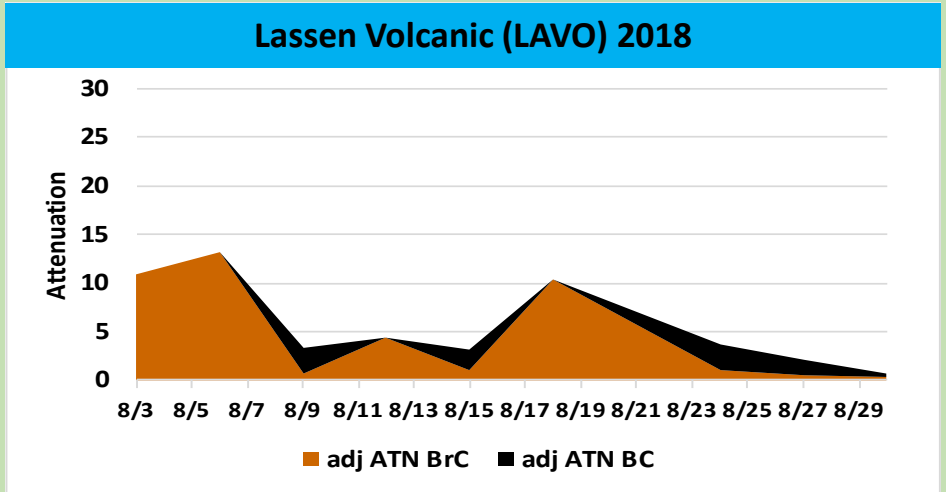
(It shifts from predominantly BC to BrC attenuation)

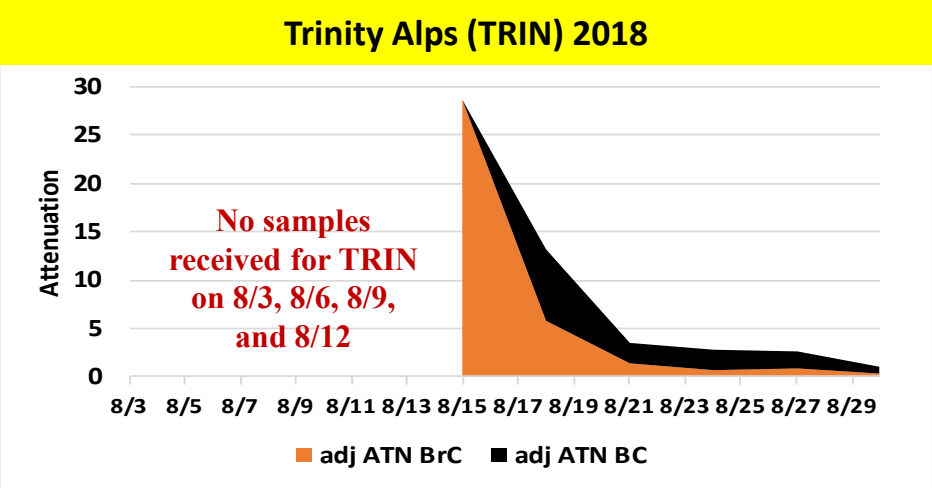
Unadjusted





Adjusted





$$ATN_{\lambda} = ln\left(\frac{FT_{\lambda,f}}{FT_{\lambda,i}}\right)$$

Summary

- A simple method is developed to adjust attenuation based on filter loading levels applied to EC concentrations > 3 $\mu g/cm^2$
- Attenuation decreases at moderate and high EC filter loadings
- Filter loading has greater effects at short λ, causing AAE underestimation, and resulting in less attribution to BrC
- Loading adjustment was applied to ~10% of 2016-2018 IMPROVE and ~67% of 2016-2017 CSN data.
- Periods with smoke impacts show dramatic increases in light attenuation from BrC after filter loading adjustment