# Analysis of the IMPROVE Equations for estimating light extinction

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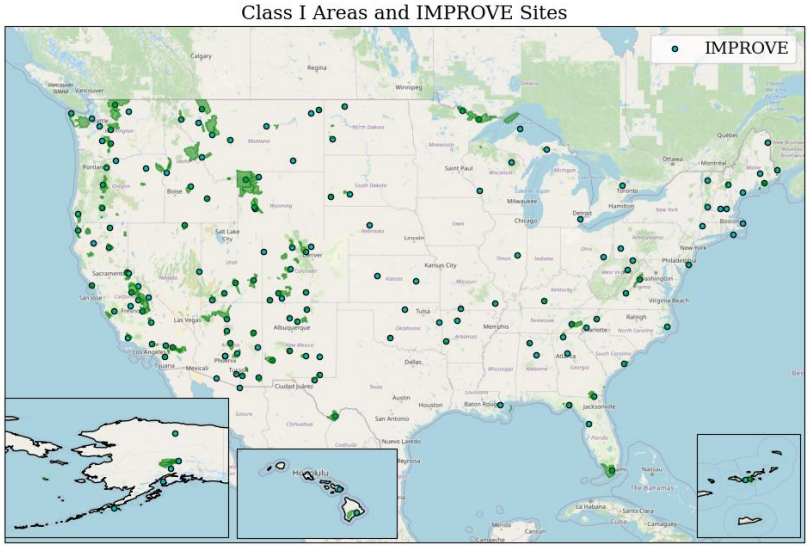
Connecting Models and Observations

# Visibility is calculated from composition measurements in the IMPROVE network




**Analyze filter measurements to calculate mass of:** Elemental carbon, organic mass, ammonium sulfate, ammonium nitrate, fine soil, sea salt and coarse mass

**Must also consider:** water uptake [*f(RH)*], mass extinction efficiencies

Particle Samplers

*Photo credit: Mackenzie Reed/NPS*

Nephelometers

*Photo credit: Mackenzie Reed/NPS*

Air Quality Webcams

# IMPROVE Equation 1

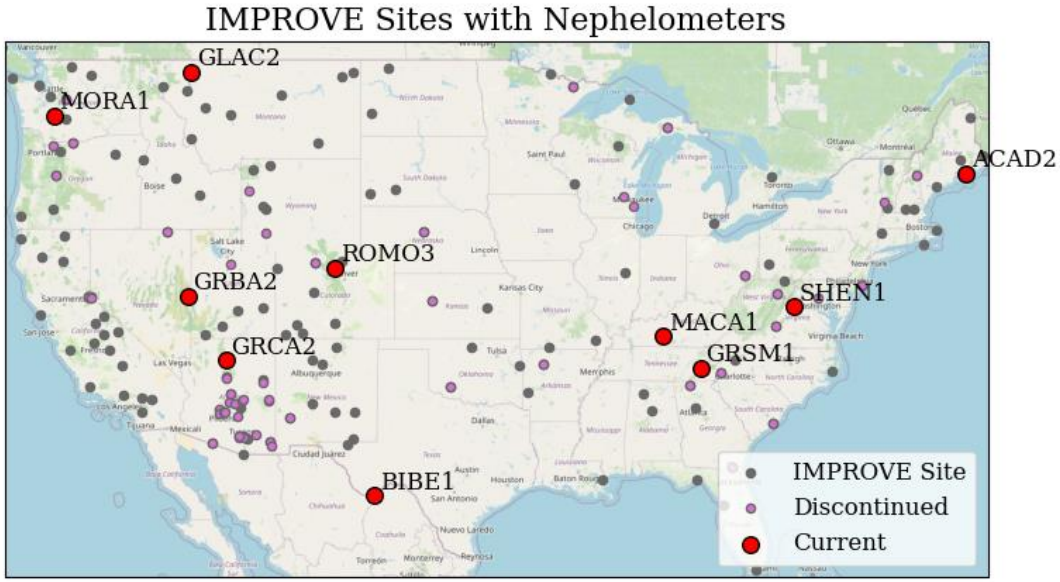
$$b_{ext} \approx 3 \times f(RH) \times [\textit{Ammonium Sulfate}] + 3 \times f(RH) \times [\textit{Ammonium Nitrate}] + 4 \times [\textit{Organic Mass}] + 10 \times [\textit{Elemental Carbon}] + 1 \times [\textit{Fine Soil}] + 0.6 \times [\textit{Coarse Mass}] + \textit{Rayleigh scattering}$$

Assumptions:

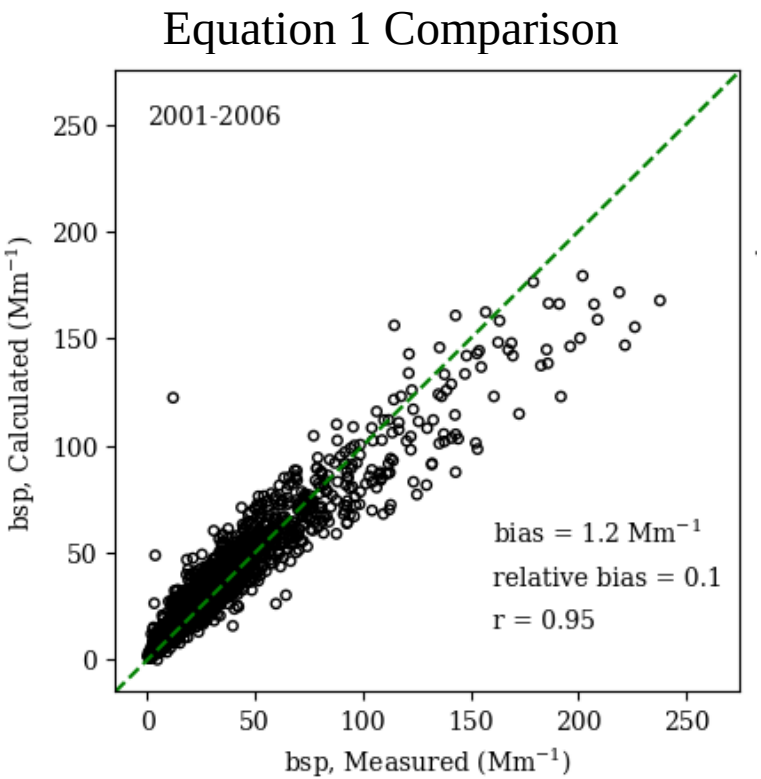
- No sea salt
- Externally Mixed
- Only ammonium sulfate and ammonium nitrate are hygroscopic (same curve)
- Size distribution for each component's extinction efficiency assumed the same regardless of mass concentration (constant value)
- Ratio of OM to OC ($R_{oc}$) is constant (1.4)
- Rayleigh scattering is 10 $Mm^{-1}$

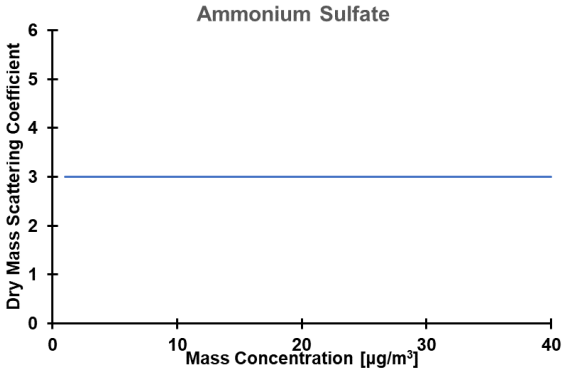
*(Malm et al., 1994)*

# Equation developed and evaluated using co-located nephelometer measurements



# Comparisons with nephelometer data suggested low bias at high concentration and high bias at low concentration



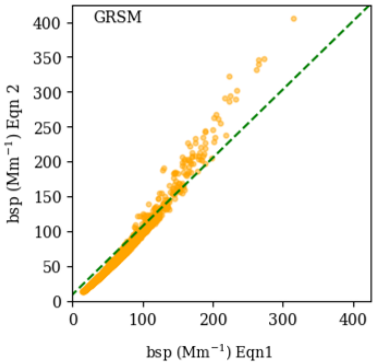



# IMPROVE Equation 2 (“split mode”)

$$b_{ext} \approx 2.2 \times fS(RH) \times [\textit{Small Ammonium Sulfate}] + 4.8 \times fL(RH) \times [\textit{Large Ammonium Sulfate}] +$$
$$2.4 \times fS(RH) \times [\textit{Small Ammonium Nitrate}] + 5.1 \times fL(RH) \times [\textit{Large Ammonium Nitrate}] +$$
$$2.8 \times [\textit{Small Organic Mass}] + 6.1 \times [\textit{Large Organic Mass}] +$$
$$10 \times [\textit{Elemental Carbon}] + 1 \times [\textit{Fine Soil}] + 1.7 \times fSS(RH) \times [\textit{Sea Salt}] +$$
$$0.6 \times [\textit{Coarse Mass}] + \textit{Rayleigh Scattering (Site Specific)} + 0.33 \times [\textit{NO2 (ppb)}]$$

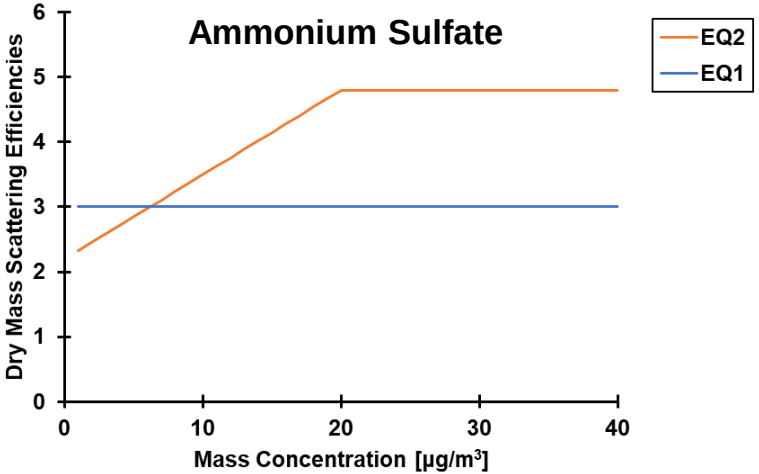
Assumptions:

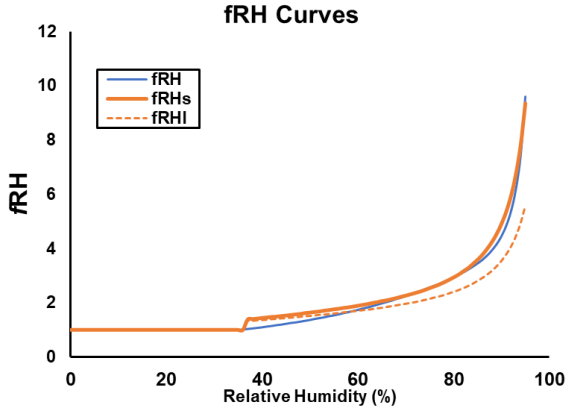
- Mass extinction efficiency changes with mass concentration
  - Large and small mode fractions
  - Not dependent on any other atmospheric conditions or processes
- Different water growth curves for small and large mode fractions
- OM is not hygroscopic
- Ratio of OM to OC ($R_{oc}$) is 1.8 (still constant)

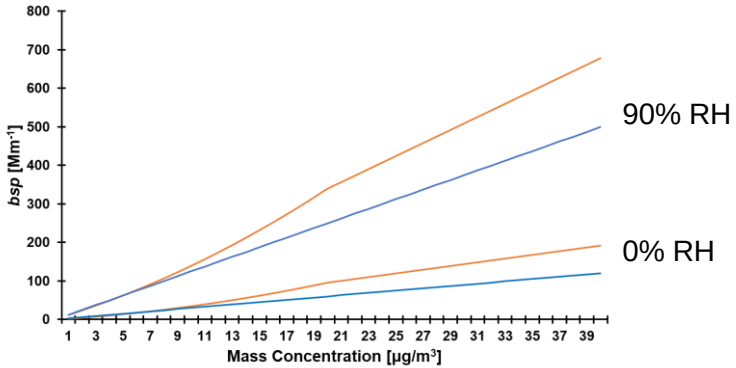



*(Pitchford et al., 2007)*

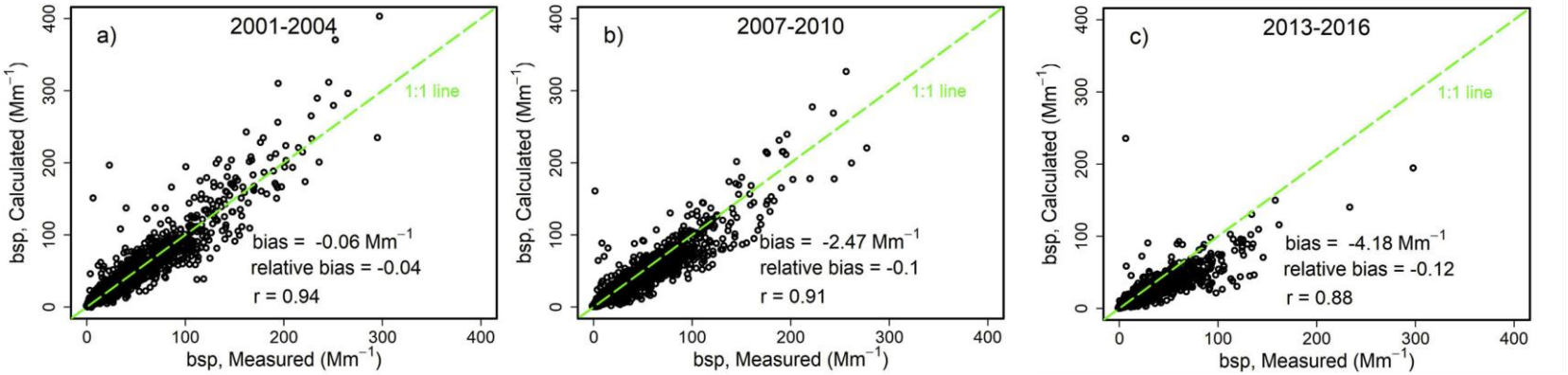
# Equation 2 adjusts scattering efficiencies by mass



# Agreement between measured and calculated (Equation 2) scattering has deviated over time




(*Prenni et al.*, 2019)

# Should we update the IMPROVE Equation?

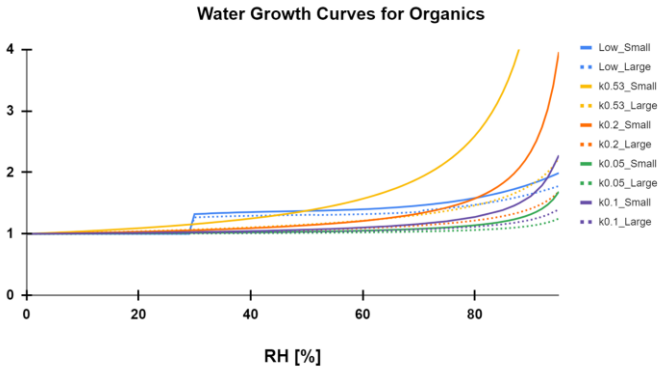
1. Add in “new” science: OM  hygroscopicity, seasonality in OM:OC ratio
2. Do we need to update the mass extinction efficiencies and fRH curves?
3. Do we need to keep Equation 2 (or return to Equation 1 with updates)?

# How does this impact RHR metrics?

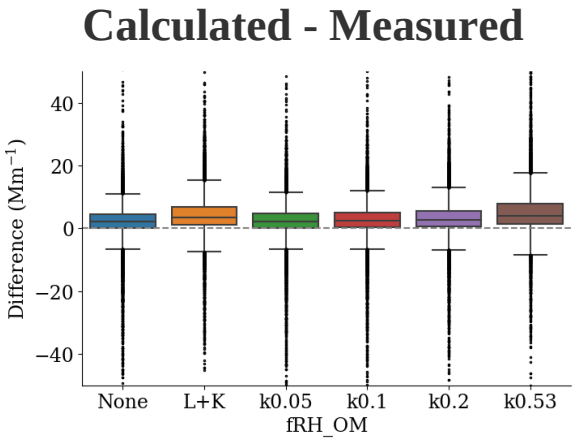
# Adding water growth curves for organics

Suggested in *Lowenthal and Kumar* (2016)

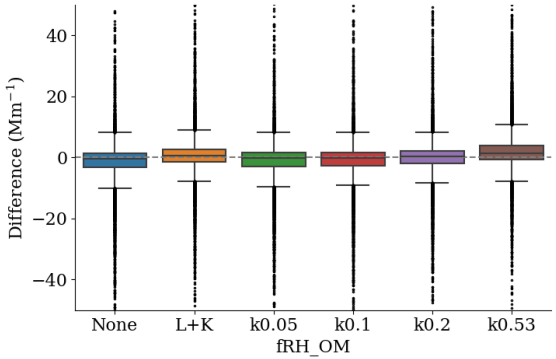
Tested 4 different water growth curves calculated (cr. *J. Hand*) for a specific size distribution and different kappa values: 0.05, 0.1, 0.2, 0.53




**Equation 1**



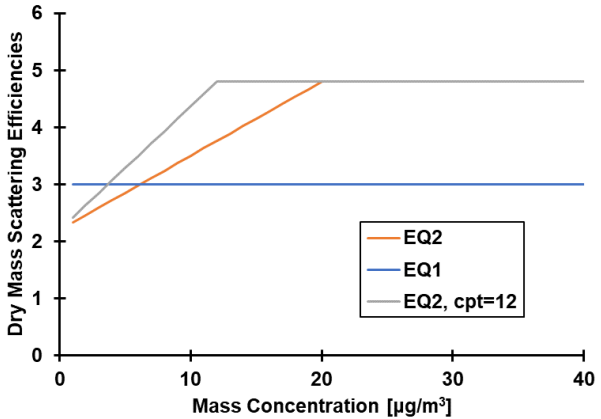

**Equation 2**

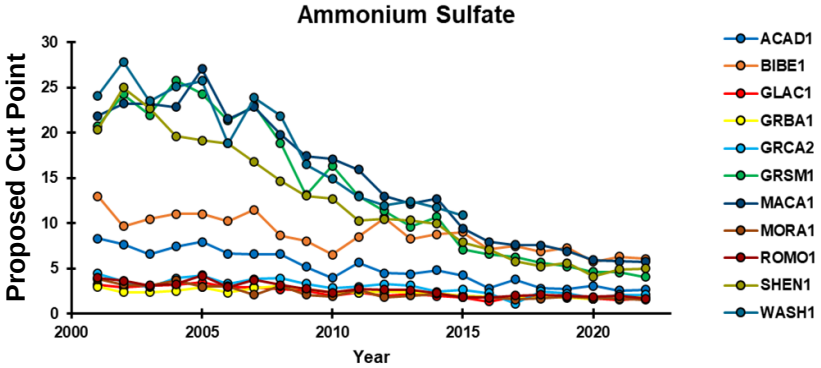


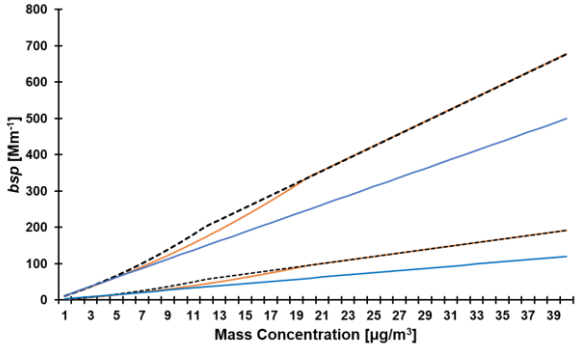
# Adjusting Mass Extinction Efficiencies

Lowenthal and Kumar (2016) suggest that the cut point between the two modes should be lowered

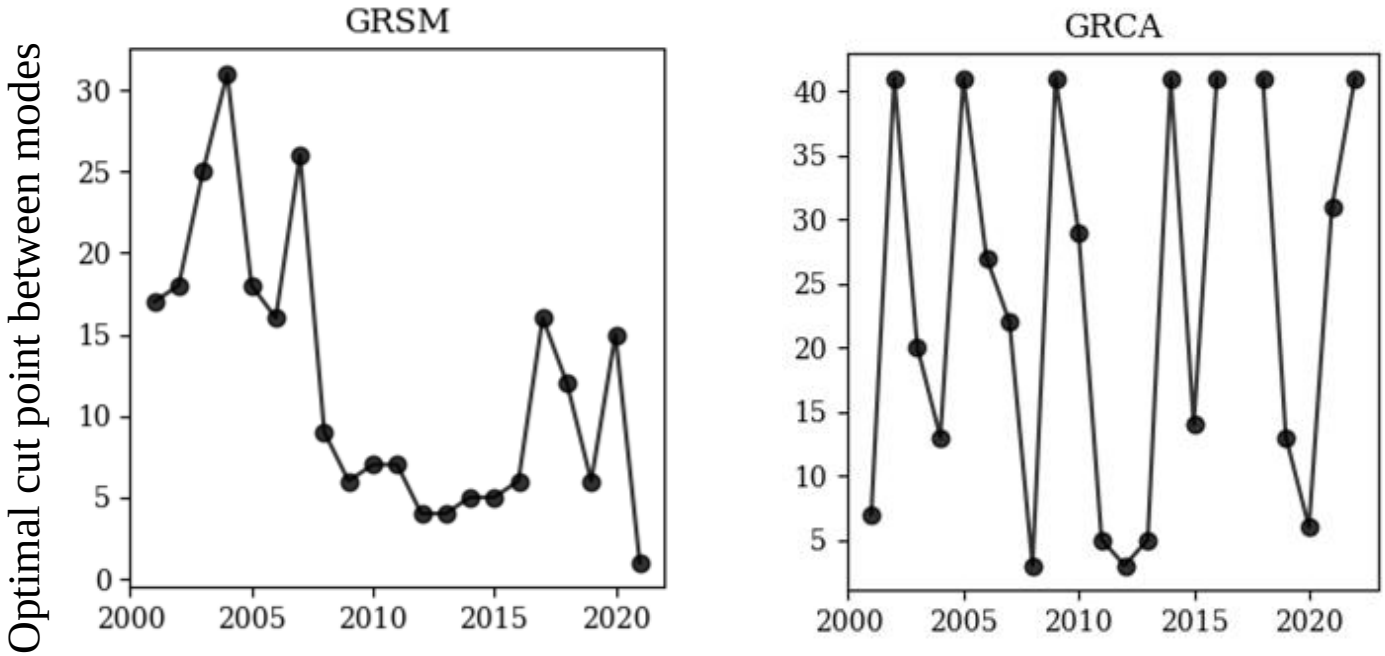
Prenni et al. (2019) suggest that the cut point between the two modes should be a function of the mass concentration at each site for each year.



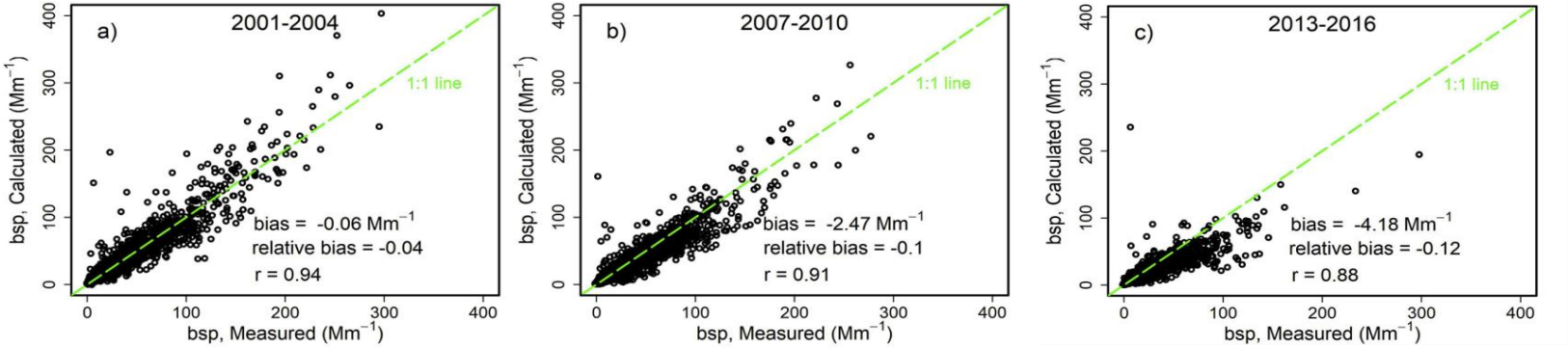



# We can also optimize to determine how to adjust the mass extinction efficiency

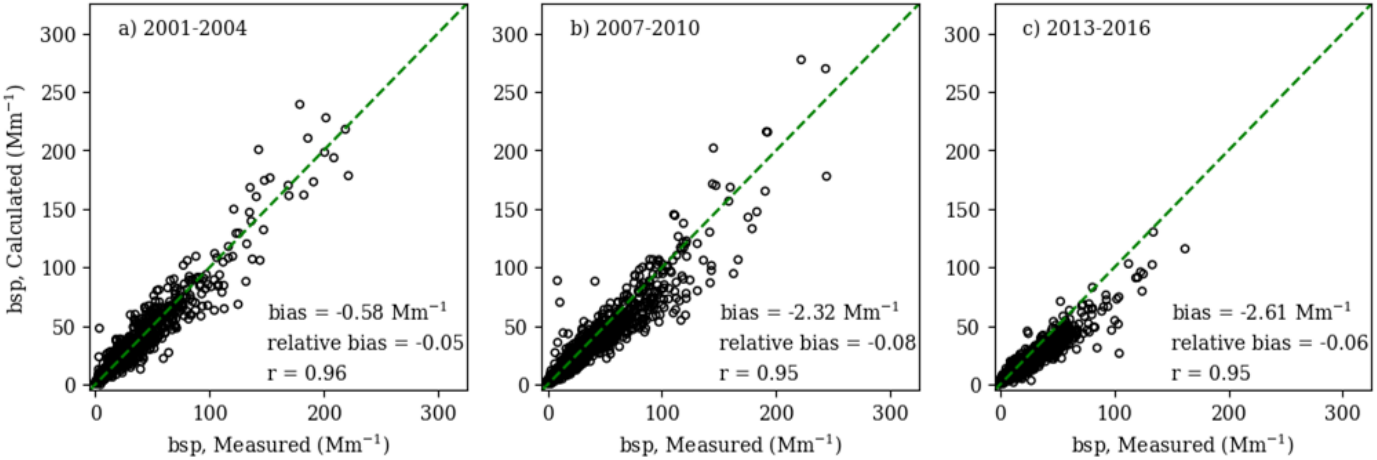



However, we are really reliant on the quality of the nephelometer data.

# Removing poorly calibrated nephelometer data reduces the trend in the bias.

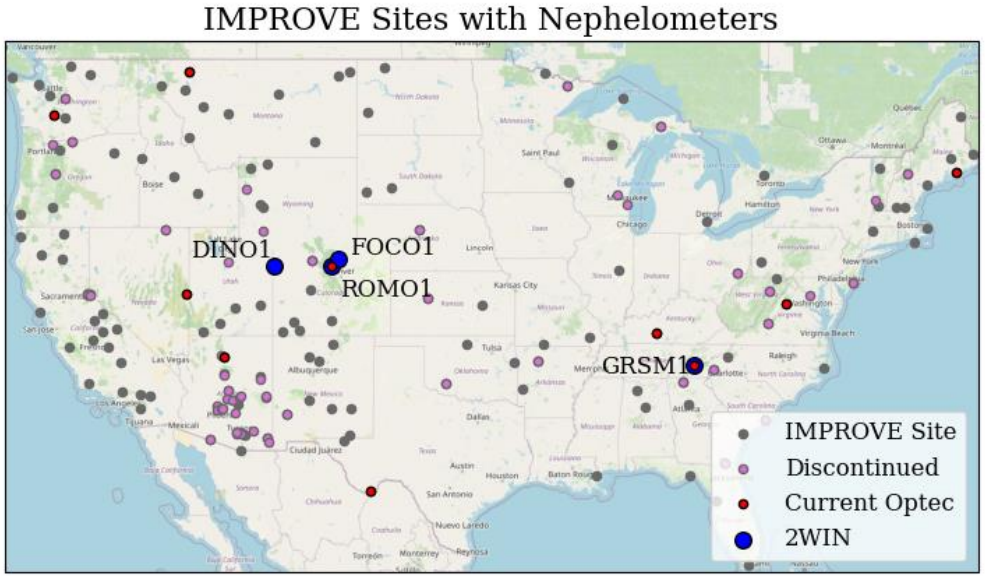



(*Prenni et al.*, 2019)




**Filtered (no updates)**

# NPS is replacing the Optec NGN with Ambilabs 2WIN Nephelometers



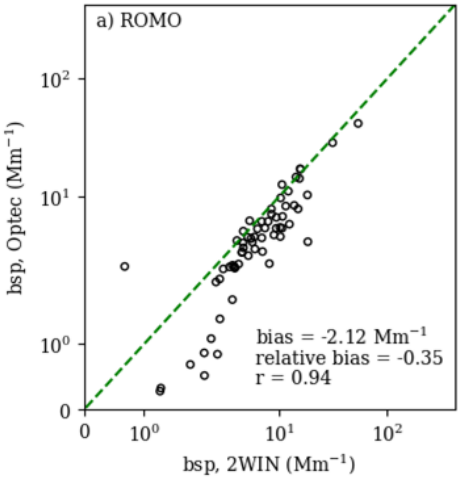

Optec

2WIN

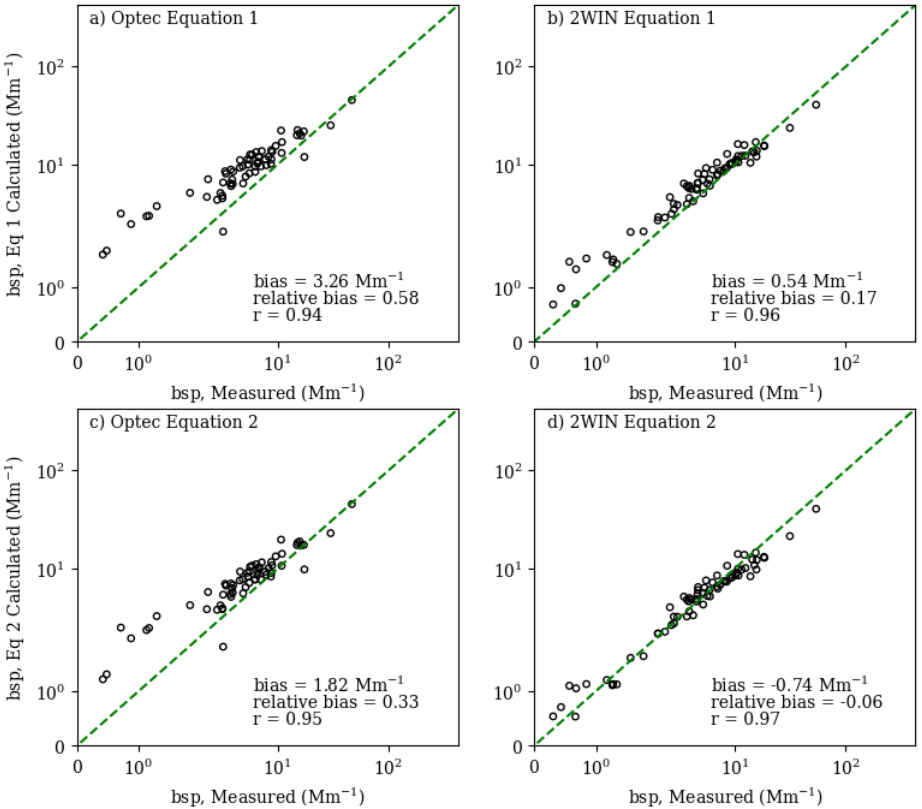
# Comparing co-located 2WIN and Optec at ROMO

## Daily comparison

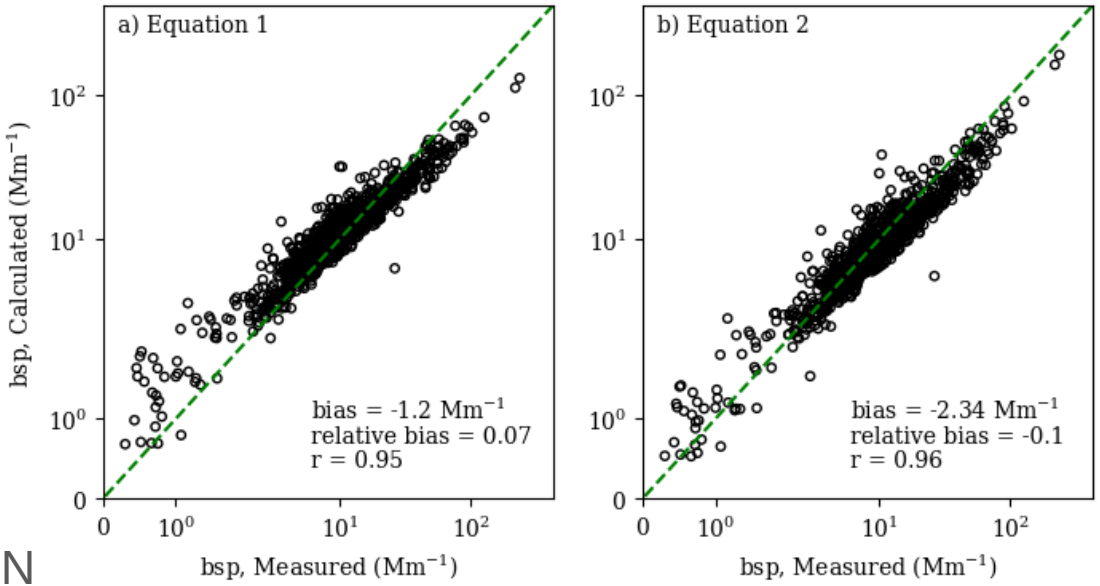
($bsp_{optec}$ - $bsp_{coarse}$)




Optec generally underestimates scattering compared to 2WIN

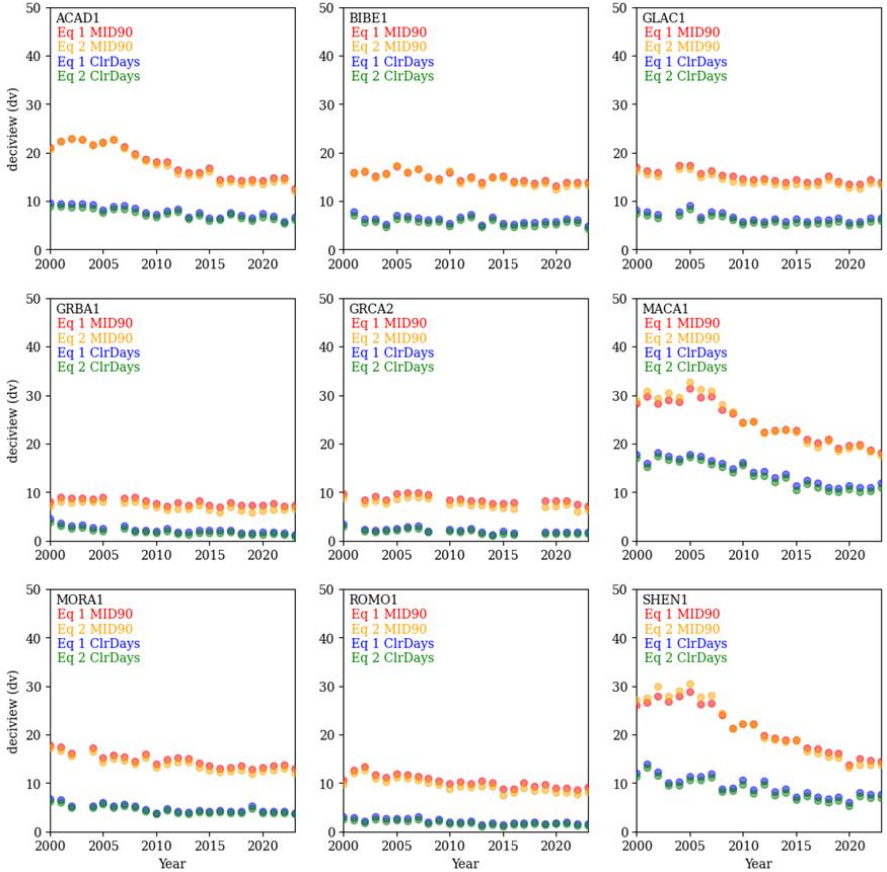


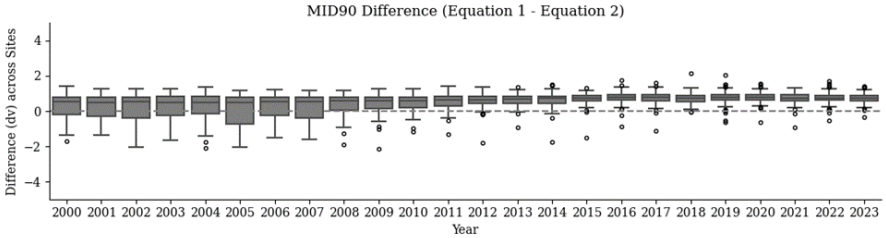
# 2WIN (& better filtered Optec) nephelometer data may suggest that Equation 2 is not substantially better than Equation 1

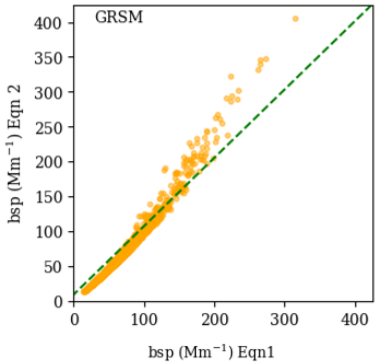



2WIN

# Impacts on trends in Regional Haze Rule metrics




Note, we use climatological fRH curves for the RHR

# Ongoing Work

- The Equation could use an official update that includes more current knowledge (ie, seasonal $R_{oc}$, water growth for organics, updating mass extinction coefficients).

- Part of the discrepancy between Equation 2 calculated scattering and measurement data appears to be due to the Optec nephelometers which are being replaced.

- Further data from 2WIN should confirm necessary updates to the equation.