Accurately measuring the color of the ocean on Earth and from space: uncertainties revisited and a report from the community-led spectral absorption workshop to update and revise the NASA Inherent Optical Properties Protocol.

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INTRODUCTION

The color of the ocean (apparent optical properties or AOPs) is determined by the spectral scattering and absorption of light by its dissolved and particulate constituents. The absorption and scattering properties of the water column are the so-called inherent optical properties (IOPs; Preisendorfer, 1976; Zaneveld et al. IOCCG Report Number 5). Total absorption is defined as absorption by the water itself ($a_w(\lambda)$), absorption by particles ($a_p(\lambda)$) and absorption by dissolved constituents ($a_g(\lambda)$) and can be described generally by the equation:

$$a(\lambda) = a_w(\lambda) + a_p(\lambda) + a_g(\lambda)$$

The particle absorption component can be further broken down to the absorption due to phytoplankton ($a_\varphi(\lambda)$) and non-algal particles (NAP; $a_d(\lambda)$):

$$a_p(\lambda) = a_\varphi(\lambda) + a_d(\lambda)$$

Particles in a dilute medium are difficult to measure in the laboratory. The quantitative filter technique (QFT) first developed by Yentsch (1962) and later modified by Mitchell (1990), circumvents this problem by concentrating the particles onto a filter pad and adjusting for pathlength (the ratio of volume filtered to clearance area of the filter). The algal particles and NAP can be de-convolved by measuring the samples in a spectrophotometer before and after solvent extraction of algal pigments (Kishino et al. 1985).

Currently there are three methods commonly used to measure the absorption of particles on a filter pad: the transmission method (T; e.g. Mitchell 1990; Roesler 1998), the transmission-reflectance method (T-R; Tassan and Ferarri 1995, 2002) and the Inside sphere method (IS; Rottgers and Gehnke 2012; Stramski and Reynolds (personal communication)). Each method requires a different spectrophotometric configuration and, therefore, brings its own uncertainties (see Figure 1). The configurations of the T-R and IS T-R methods reduce scattering error (loss of photons scattered from the filter pad and particles) theoretically producing a more accurate measurement (Tassan and Ferrarri 1995; Babin and Stramski, 2002; Rottgers and Gehnke 2012; Neukermans et al. 2014). Additionally, *in situ* measurements of particle absorption can be made with an ac-meter (WetLABS Inc.), introducing additional measurement uncertainty and complicating closure amongst measurements (see Figure 2).

Achieving closure and quantifying uncertainty amongst multiple methods for measuring the same parameter is challenging but important. Closure simply means obtaining the same value multiple ways. In ocean optics, closure is important to assess the accuracy and precision of *in situ* instruments measurements and model output, as well

as validating satellite-derived products. A failure to obtain successful closure between measurements and models could mean either the instruments, models or both are faulty.

Algorithms, such as QAA (Lee et al 2002), GSM (Maritorena et al. 2002), GIOP (Werdell et al. 2013), are used to retrieve IOPs from satellite remote sensing reflectances (R_{rs}). The general relationship between R_{rs} and IOPs is

$$R_{rs}(\lambda) \propto \frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)}$$

where $a(\lambda)$ is absorption and $b_b(\lambda)$ is backscatter (Sathyendranath and Platt 1997; Maritorena et al. 2002). As such, accurate in situ measurements of $a(\lambda)$ and $b_b(\lambda)$ are crucial for their development and validation. Satellite-derived IOPS have many applications including, but not limited to, deriving chlorophyll a (C_a; equivalent to phytoplankton abundance), particulate organic carbon, colored dissolved organic matter (cDOM), as well as modeling phytoplankton functional types and oceanic primary productivity.

Additionally, poor data quality can ultimately hinder validation of current and future satellite instruments. The NASA bio-Optical Marine Algorithm Data (NOMAD; Werdell and Bailey 2005) set is a compilation of high quality, *in situ*, geophysical data products collected throughout the global ocean. This publicly available data set is used by the OBPG for ocean color algorithm development and satellite product validation. We, the oceanographic community who contribute to this database, must ensure that any data we collect and distribute is as accurate as possible and is accompanied by quantified uncertainties.

In preparation for a community lead absorption workshop that took place at NASA Goddard Space Flight Center (to be discussed later), a comparison of absorption data was conducted using three different sources: standard transmission method, spectrophotometer equipped with integrating sphere and ac-s absorption measurements. The purpose of the comparison was to identify and quantify uncertainties associated with each of the methods. The uncertainty of the measurement can then be accounted for during validation of ocean color satellite derived products of absorption. Thus, the following presentation will 1) discuss the uncertainty associated with three common methods to measure absorption using three water types and 2) summarize the impending updates to the NASA protocols as discussed during the recent community-lead absorption workshop.

PART 1: CLOSURE

The challenge of attaining closure amongst methods lies in in the uncertainty associated within each filter pad measurement (See Figure 1). The sources of uncertainty include, but are not limited to:

1) **Sampling technique** (i.e., replicate samples): making sure sample bottle is homogenous i.e. well mixed prior to subsampling

2) **Filter to filter variability**: the filters themselves may have inconsistencies between lots.

3) **Variability in rotations**: can be caused by heterogeneous distribution of particles on the filter surface.

4) **Instrument drift:** defined as a change in performance of the instrument over a period of time.

5) **Configuration of spectrophotometer**: determines if the instrument is baselined with a filter pad (i.e. scattering and absorbance of filter can be automatically subtracted). Here, the analyst is assuming that a filter pad with particles on it doesn't change the way light is scattered from the filter.

6) **Null Correction**: a null correction is always applied to correct for scattering. As a consequence, one can never quantify spectral absorption in the NIR using the filter pad method because of the null correction and the underlying mechanism of the method.

7) **Pathlength amplification**: scattering of light by the filter pad and particles amplifies the photon pathlength and falsely increases the value of absorption. (Butler 1962; Bohren 1987)

Pathlength amplification can be corrected in the calculation of absorption by applying a correction factor (β). The β scales the absorption on the filter pad to absorption in suspension. Many βs have been determined empirically while at least two βs have also been derived analytically (Roesler 1998; Lohrenz 2000). The β has been empirically determined by using the ratio of filter pad optical density to the optical density derived from dilute (<0.3 optical density at 440 nm, single scattering regime) suspensions measured inside an integrating sphere. The source of these suspensions and filter pad samples are typically from cultures in order to get a sample thick enough for measurement (Roesler 1998). A power law or quadratic function and associated coefficients are calculated from a least squares regression, which can then be applied to field samples to derive the relationship between the two measurements. As such, these βs do not necessarily encompass all particle sizes and types encountered in the ocean. Consequently, the β is a major source of uncertainty for determining particle absorption coefficients by the filter pad methods because it can vary based on particle size, concentration and scattering properties (Roesler 1998; Naik and D'Sa 2012).

Another source of uncertainty exists when comparing particle absorption acquired from a filter pad and that acquired from using an ac-meter (see Figure 2). The QFT uses nominal 0.7 pore size fiberglass filters. Therefore, the fraction of particles <0.7 μm are lost from the absorption measurement. When attempting closure between particle absorption measured by the QFT and that from an ac-meter, it is important that the same pore-size filter is used for both. For instance, common procedure to measure absorption due to water is to use a 0.2 um filter cartridge on the inlet of the ac-meter. In this way, the 0.22-0.7 μm fraction is measured by the ac meter but not the QFT.

Closure between the QFT and the ac-s measurements of absorption was attempted by 1) comparing filter pad absorption measurements by two collection methods and three analytical techniques per method, and 2) comparing filter pad absorption to absorption measurements collected with an ac-s. Three different sample sets were used: coastal water, blue water and laboratory cultures. The filter pad samples were analyzed on either a standard spectrophotometer using the transmission method or using a 150 mm external integrating sphere. The ultimate goal is to quantify the uncertainty associated with the methods and data processing to achieve $a_p(\lambda)$.

METHODS

Sample sources

        Three sources of samples were used in the aforementioned multiple-method comparison:

        1) Filter pad measurements from blue water (See Figure 3; 10 sample sets). Only filter pad measurements were used for the comparisons.
        2) Filter pad and ac-s measurements from coastal water (See Figure 4; 10 sample sets).
        3) Filter pad and ac-s measurements from multiple dilutions of three different phytoplankton species (See Figure 5): *Thalassiosira weissflogii* (CCMP 1387) *Emiliania huxleyi* (CCMP 371) and *Nannochloris sp.* Dilution series: 100%, 42%, 20%, 10% and 5%. Cultures were diluted with filtered and sterilized seawater. Only the three lowest dilutions (20%, 10% and 5%) were processed through the ac-s.

For each sample source, duplicate filter pads were analyzed: one replicate filter was analyzed using the transmission method and the other with the integrating sphere.

Sampling technique

        Filter pad samples were collected by vacuum filtration (5-7 psi) onto combusted 25mm Whatman GFF filters using glass filter apparatus. Samples were stored in HistoPrep tissue capsules, flash frozen in liquid nitrogen and were placed in an -80° C freezer until analysis. These samples were measured with two spectrophotometers: a Cary 100 UV-Visible dual beam scanning spectrophotometer (250-800 nm) equipped with an integrating sphere (Labsphere DRA-CA-30, Agilent Technologies) and a Perkin Elmer Lambda 35 UV/Visual double beam spectrophotometer without an integrating sphere. For the culture experiment, fresh filter pad samples were used for the measurements.

Absorption measurements

        Transmission (T) measurements were performed following the protocol of Roesler (1998). Inside sphere measurements were performed using a 150 mm external integrating sphere (IS) and the protocol in Neukermans et al (2014). For both methods, scans were performed between 290-800 nm with a 2 nm Slit Band Width (SBW), and 240 nm per minute scan speed. For both filter pad methods, blank filters were soaked in 0.2 µm-filtered artificial seawater (ASW) for at least 30 minutes (Sunda et al. 2005). For sample analysis, three to four drops of artificial seawater were added to petri dish and the sample filter was placed biomass up onto the water droplet. The sample filter was allowed to thaw for 5 minutes before measurement. The petri dish was covered with the lid and foil to protect from the light.

        The total particulate and de-pigmented absorption coefficients were calculated using the following equation,

$$a_p = 2.303 \frac{A_{fp} OD_p}{V_f \beta}$$

where A_{fp} is the clearance area of the filter pad, V_f is the filter volume, β is the pathlength amplification correction for each method (see Table 1 for equations and abbreviations), and OD_p is the baseline-corrected absorbance (Roesler 1998; Mitchell et al. 2003).   For the T method, a_p and a_d were assumed to be zero at 750 nm or using the average absorbance between 750 and 800 nm was subtracted from the entire spectrum. A null correction was not applied to the absorption data from the IS method.

ac-s measurements
For the field samples, the ac-s was calibrated with ultrapure water using the method described in the ac Meter Protocol Document.   A mean of 3 days' calibrations was used to subtract the pure water offset. The ac-s profiles were made at each station, the sequence was one downcast from approximately 3 meters after soaking at 10 meters to degas, then an upcast with periodic time series at depths where bottles were being fired. Post processing began with merging the CTD with the ac-s by time stamp, adjusting for the time required for water to move from the intake to the center of the flow tube (1.5 seconds). Corrections for salinity, temperature, and instrument drift were made, using the equations of Sullivan et al. (2006). The absorption values were then corrected for scattering by baseline subtraction, using the values at 736 nm. For the laboratory experiment, each culture was fed through a funnel into the *a* and *c* tubes of the ac-s. For the dissolved fraction, the samples were prefiltered through a 0.2 μm filter and then fed to the ac-s.

RESULTS

Uncertainty analysis
        Uncertainty was calculated as the median, mean, and coefficient of variation of absorption from each method at the relevant satellite Ocean Color wavelengths of 412, 443, 490, 510, 555, and 670 nm. Median scatter plots (Figures 5-6) only show data for 443, 555 and 670 nm; however, the trends are similar for the other wavelengths. The median was chosen over mean values to avoid bias towards one method. An identity line (slope=1) is used to show when the individual absorption values from each method is closest or equal to the median value (Figures 5-6).
From this study, we saw that when only the filter pad measurements were considered (Figures 5a-5c):

- Absorption values from the Bricaud and Stramski (BrSB) method tended to be the lowest below the identity line in all water types.
- Absorption values from the Mitchell method tended to be the highest above the identity line.
- The Stramski and Rottgers methods fell on or close to identity line in most water types.
- Range of uncertainty of the filter pad methods alone was 7.8-58.6% for all six wavelengths (Table 2).
- Magnitude of uncertainty depended on absorption range and wavelength (Table 4).

- Absorption at 555 nm and 443 nm showed the highest uncertainty among all 6 wavelengths at 37.9% and 38.2%, respectively (Table 4).

When the ac-s absorption measurements were brought into consideration (Figures 6a-6c):
- ac-s measurements tended to fall on or slightly above the identity line
- The addition of ac-s data increased the uncertainty of the absorption measurements to 10.1-94.8%, with the highest uncertainty at 670 nm (Table 3).
- The largest uncertainty associated with all of the methods associated with low absorption values (Figure 7).
- Absorption at 555 nm and 443 nm showed the highest uncertainty among all 6 wavelengths at 45.3% and 42.7%, respectively (Table 5).
- Magnitude of uncertainty depended on absorption range and wavelength (Table 5).

DISCUSSION

Accurate *in situ* measurement of particle absorption is key to the validation and development of inverse models where remote sensing reflectance (R_{rs}) is used to derive IOPs (a and b_b). In particular, absorption can be partitioned to absorption by phytoplankton (a_{ph}) and nonliving particles. The parameter a_{ph}, is an important input vector for some phytoplankton functional type algorithms and can also be used to model primary productivity (Roesler and Perry 1995; Nair et al. 2008). Therefore, an understanding of measurement uncertainties is crucial and should be incorporated into algorithm and model development. Ignoring these uncertainties can result in poor algorithm and model performance.

The objectives of this study were to:
1. Communicate the nuances and complexities of methods for elucidating aquatic absorption
2. Understand the uncertainties within each method
3. Quantify the uncertainty related to choice of method when collecting and analyzing filter pad absorption samples.
4. Attempt closure between the filter pad methods and ac-s method for measuring absorption.

From this comparison we saw that the variability of all samples measured using the T-R IS method was small and consistent across all samples types (values were closest to the Identity Line), illustrating that scattering errors were indeed minimized with this method. The Mitchell and BrSB βs performed consistently higher and lower, respectively, than the median absorption values. The larger uncertainty observed at 555 nm across all methods could be attributed to the low absorption at that waveband and to the scattering differences between the reference and sample filters, which are amplified on applying the beta correction factor to the absorbance spectra of the samples. Additionally, some of the uncertainty associated with the ac-s data may be attributed to low signal and/or data analysis technique. For instance, I used an average absorption for each sample depth +/- 1 m. Another analysis technique may be employed to improve accuracy and decrease uncertainties.

The uncertainties inherent within each method cannot be completely avoided but may be minimized by:

1) Using the same lot of filters for sample collection and analysis
2) Making sure the sample bottle is well mixed before filtering
3) Collecting replicates and filtering the same volume for replicates
4) During sample analysis, monitoring the instrument with blank filter scans and air scans to account for instrument.
5) Using the same filter pore size for QFT and ac-meter data collection. The increase in uncertainty when the ac-s measurements were included may be caused by the filter type mismatch between the two methods. Earlier in this document, we mentioned that using a 0.2um filter for ac-meter measurements while using a 0.7 nominal pore size filter for the QFT measurements creates a deficit in absorption between the two methods. The effect of this discrepancy may be dependent on water type i.e., mostly in case-1 waters where most phytoplankton cells are small.

The most important point we want to make is to quantify uncertainties and report those uncertainties when submitting any data to NASA OBPG.

PART TWO: THE ABSORPTION WORKSHOP

INTRODUCTION

The "NASA Ocean Optics Protocols for Satellite Ocean Color Validation" are community-vetted protocols that were first synthesized as part of the Sensor Intercomparison and Merger for Biological and Interdisciplinary Studies (SIMBIOS). This standard set of protocols, when followed explicitly, provides community-wide measurement consistency and accuracy that are necessary for minimizing measurement and data processing errors in multi-mission satellite algorithm development and validation. The protocols are living documents with topics separated into different volumes so each could be revised independently as standards and technology improve over time. However, the last revision to the protocols was in 2003 and, as such, they are due for an update. One of the overarching goals of the NASA Ocean Ecology Laboratory Field Support Group (FSG) is the revision and distribution of community-vetted protocols for in situ data collection, processing and analysis. To this end, the NASA FSG hosted an absorption workshop June 11-13, 2014 at NASA Goddard Space Flight Center that brought together an international collaboration of spectral absorption experts to produce the ultimate deliverable: a revised version of the Inherent Optical Properties Protocol (Revision 4, Vol. IV, 2003) that includes both liquid and filter pad techniques for measuring $a_p(\lambda)$.

THE WORKSHOP

The workshop participants (Table 6) focused on spectral particle absorption ($a_p(\lambda)$) and updating the protocols used to separate $a_p(\lambda)$ into its individual components $a_\varphi(\lambda)$ and $a_d(\lambda)$. Each chapter of the 2003 protocol was assessed and updates, additions and reorganization of the protocol were addressed where necessary. A subset of the

participants presented their expertise, updates to current methods and introduced new methods that have been developed since the publication of the last protocol.

1) Collin Roesler: Transmission Method
2) Eurico D'Sa: QFT measurements with an Ultrapath (Ultrapath QFT Measurement)
3) Dariusz Stramski and Rick Reynolds: Spectrophotometric measurements of particulate absorption coefficient with center-mounted samples in the integrating sphere
4) Rüdiger Röttgers: PSICAM measurements of particulate absorption in seawater
5) Mike Twardowski: ac device absorption measurements
6) Emmanuel Boss: Underway and Mooring sampling methods
7) Chris Proctor: SeaBASS Validation: Absorption
8) Aimee Neeley: Methods Unite: a method intercomparison

Of particular interest was to include methods and instrumentation that were developed after the publication of the 2003 protocol. Here, only a summary of the updates will be addressed. The rest of the updates will be available in the updated protocol to be released December 2014/January 2015.

INSTRUMENT UPDATES

1) IS method: filter pad absorption samples are placed in the center of a Spectralon-coated 150 mm cavity. The sphere is part of a diffuse reflection accessory that houses it's own detector. The purpose of using the sphere is that it reduces the scattering error, i.e. the light that is lost when it is scatter within and out of the filter fibers.
2) PSICAM- Point Source integrating-cavity absorption meter (Kirk 1997; Rottgers and Doerffer, 2007): the cavity is made of a white, highly reflective material that reduces scattering errors. A central, diffuse light source is contained within the sphere. The effective pathlength of photons within the sphere is very long, increasing measurement sensitivity.
3) ac-s: The ac-s is a hyperspectral absorption and attenuation meter. It employs dual 25-cm pathlength flow cells. The light source is a collimated beam from a tungsten lamp, which passes through a linear variable filter. The absorption side has a reflecting tube and a large area diffuse detector, whereas the attenuation side has a non-reflective tube and a collimated detector. The instrument provides an 80+ wavelength output from approximately 400–730 nm with approximately 4 nm steps.

PROTOCOL UPDATES

1) *Sample collection*
A subset of blanks should be collected coincident with field samples and treat them as samples. It was suggested that 100 ml of ultrapure water should be filtered through the samples to remove potential contamination. Then the filter

should be soaked in 0.2 μm filtered seawater and stored the same as the samples. These blanks should be measured and treated through the extraction process during sample analysis. Roesler (1998) hypothesized that if the same amount of water is filtered through the blank filter as through the sample filter, β can be assumed to be 2.0 (Kirk 1997). Additionally, filtering volumes should result in range of optical density 0.1 to 0.4 absorbance units.

2) *Satellite validation*

Knowledge of the structure of the water column helps scientists in the field make good choices about what depths and how many samples to take water measurements. Approximately 90% of the light they measure comes from the first optical depth. Therefore, if the water column isn't homogeneous (e.g. if there is a subsurface C_a maximum within the first optical depth), then satellite validation requires multiple in-water measurements to be as accurate as possible. Post-measurement calculations (e.g. the optical-weighting calculations) are ideally made using attenuation coefficients derived from field measurements (coincident or relatively-coincident optics measurements; Chris Proctor, pers. comm. and Werdell and Bailey 2005).

Therefore, it has been recommended that in order to successfully sample for satellite validation, it must meet the following criteria:

1. Ideally sampling for filter pad analysis should occur coincident with optics measurements
2. The researcher should sample at multiple depths particularly in the first optical depth in order to characterize what the satellite 'sees'

3) *Deployment Strategies*

With increasing use of underway sampling and moorings to augment our repository of *in situ* data, particularly important for satellite validation, the addition of optics instrumentation has become attractive. However, biofouling, detector drift and degradation of the light sources are legitimate concerns for long-term deployment. Some strategies have been developed to counteract these issues (Slade et al. 2010) and will be further described in the protocol.

4) *Reporting Guidelines*

The participants proposed to generate a community log sheet to be included in the data submission to streamline uniformity. When submitting to SeaBASS include good documentation on data processing methods. Also provide optical density data with other metadata, such as volume filtered, so that the data can be reprocessed by the NASA OBPG if warranted.

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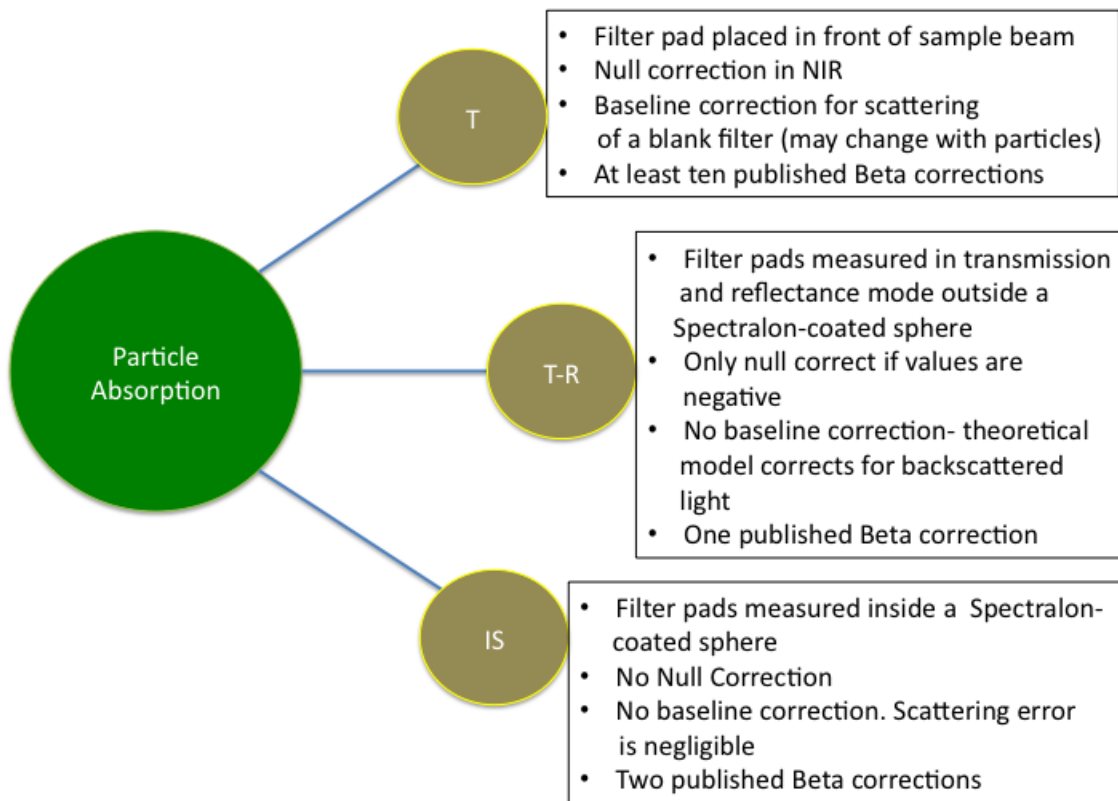
Figure 1: Schematic of uncertainties inherent between the three filter pad techniques for measuring absorption.
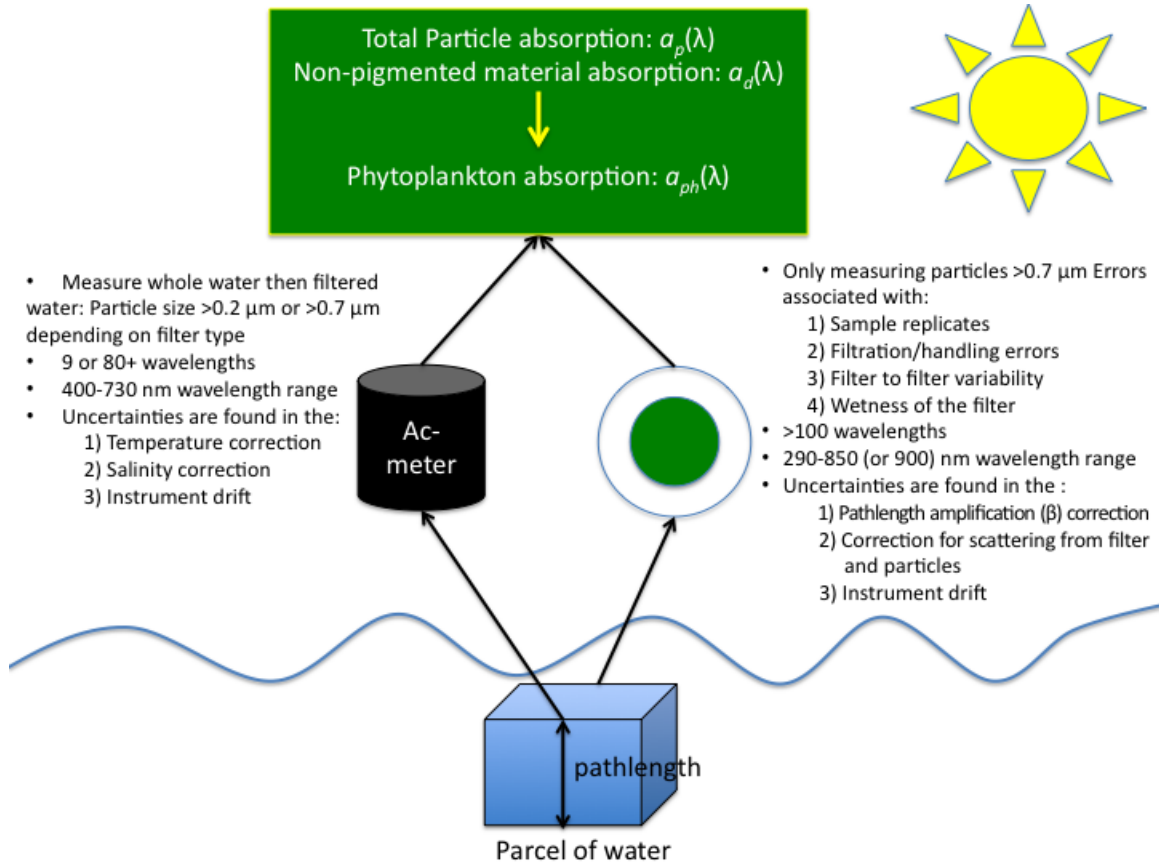
Figure 2: Uncertainties of the filter pad absorption measurements versus absorption measurements made with an ac-meter.
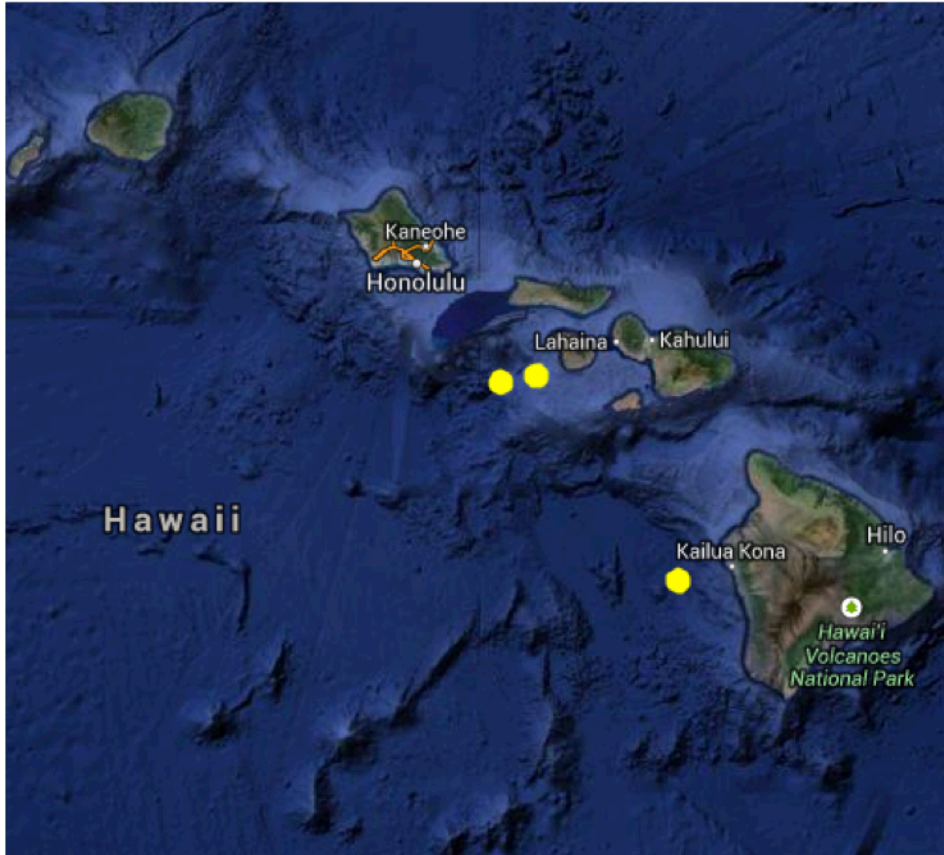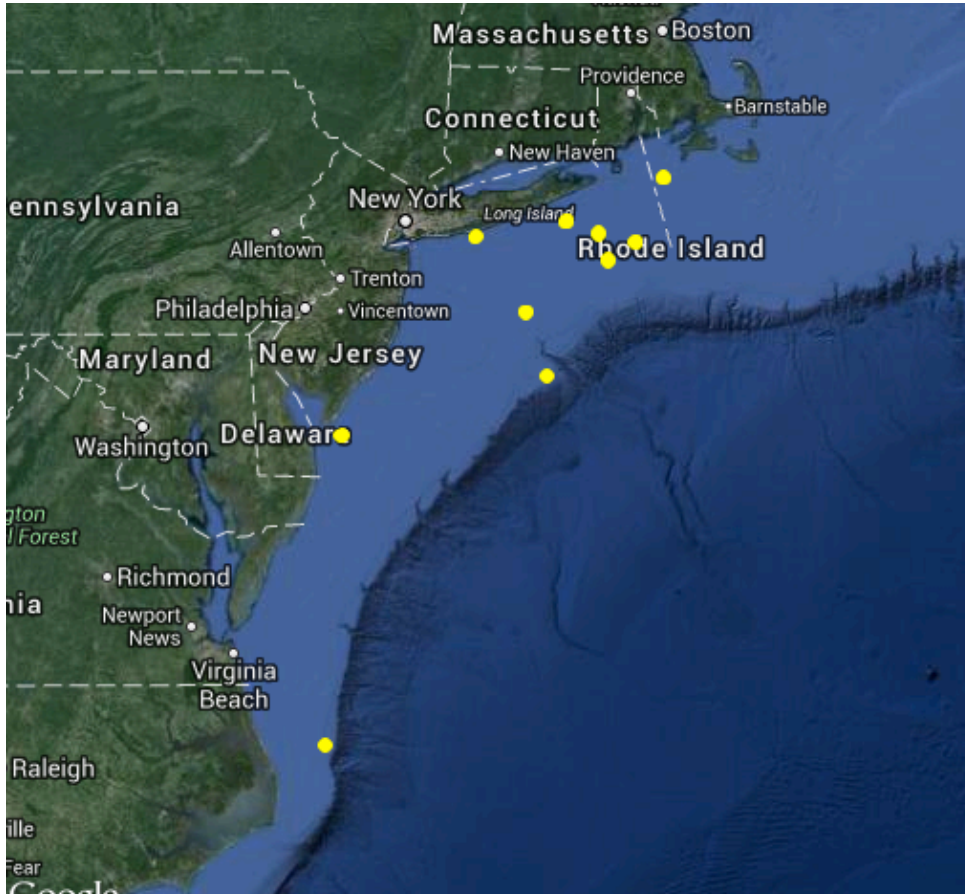
Figure 3. Locations of the "Blue Water" samples

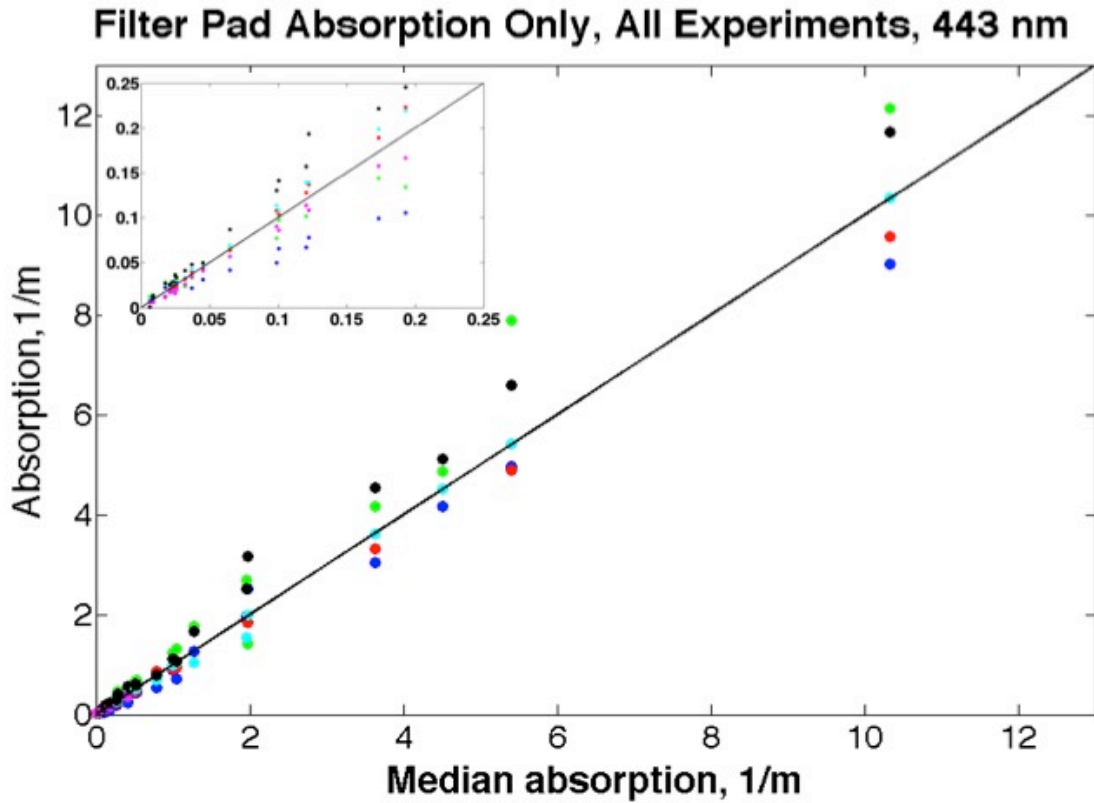Figure 4: Locations of the "Coastal Water" samples.

Figure 5a: Median absorption versus absorption by each filter pad method for all experiments at 443 nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2.
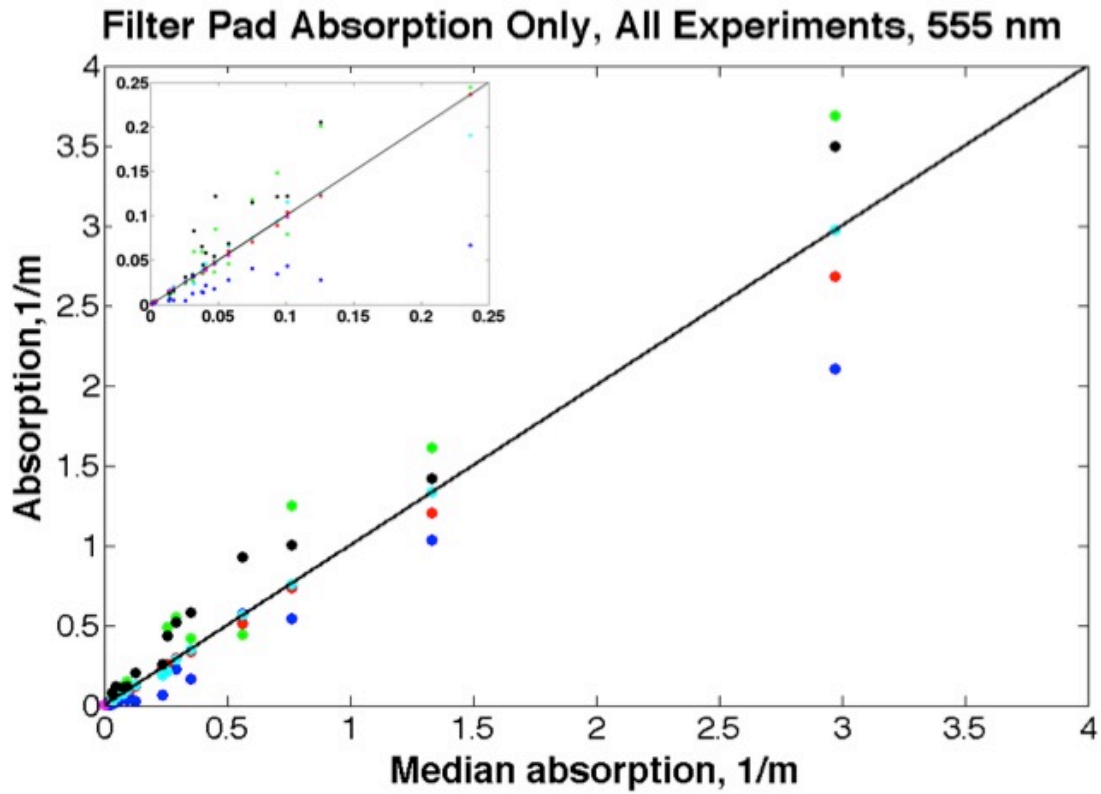
Figure 5b: Median absorption versus absorption by each filter pad method for all experiments at 555nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2.
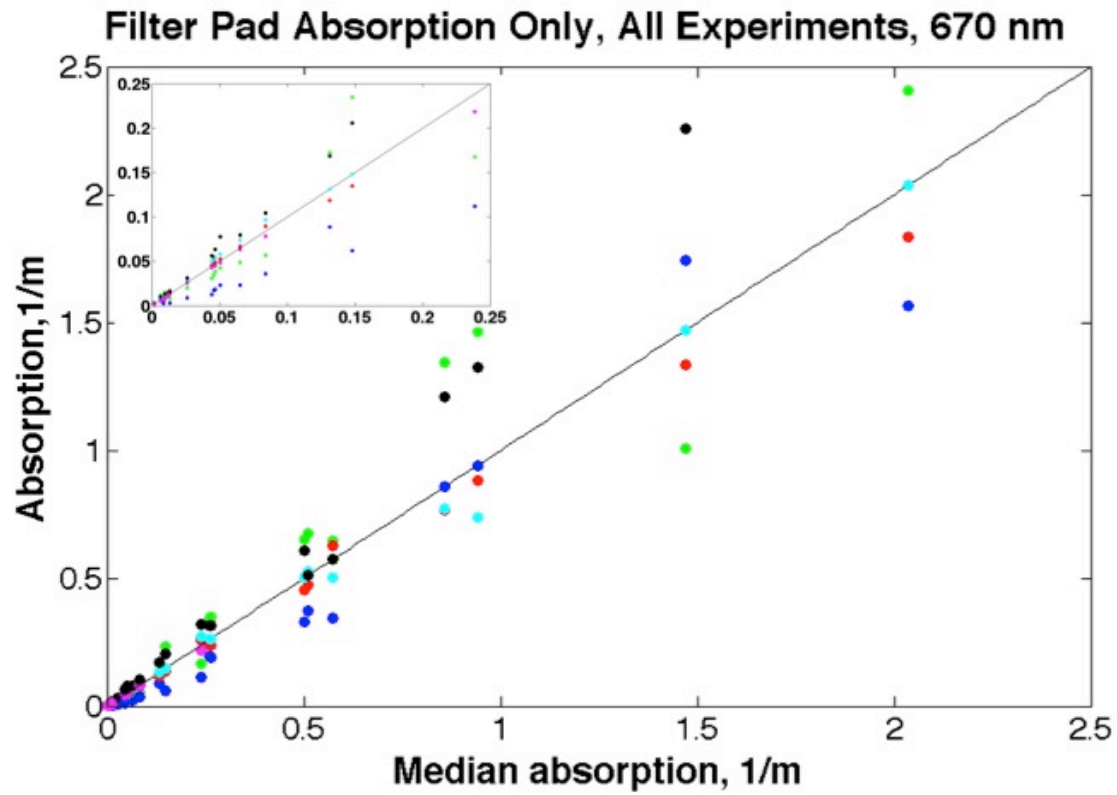
Figure 6c: Median absorption versus absorption by each filter pad method for all experiments at 670 nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2.
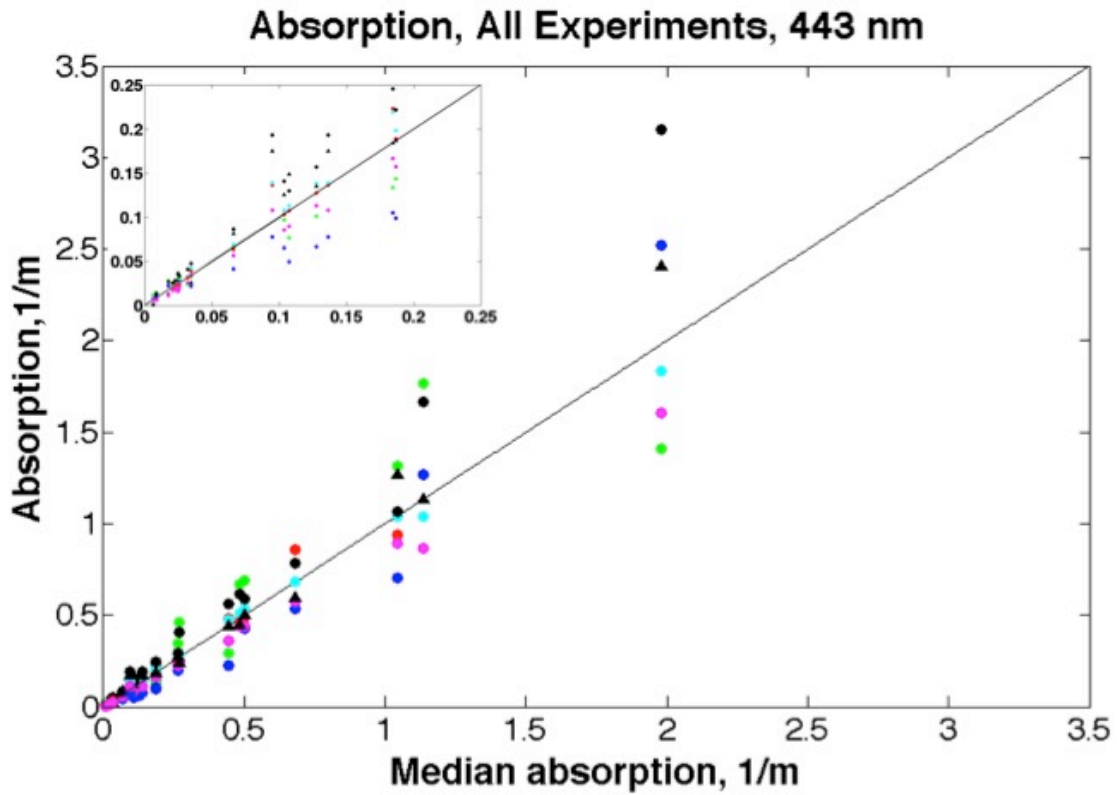
Figure 6a: Median absorption versus absorption by each method for all experiments at 443 nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2 Black Δs represent ac-s measurements.

Figure 6b: Median absorption versus absorption by each method for all experiments at 555 nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2 Black Δs represent ac-s measurements.
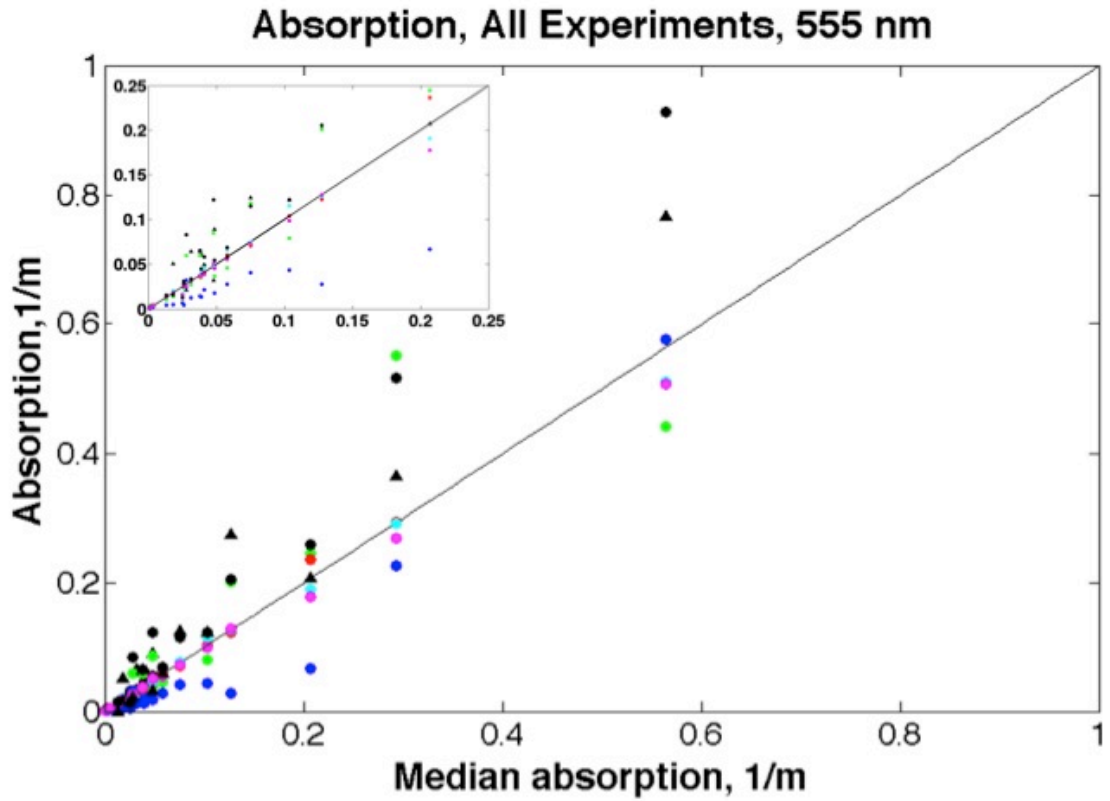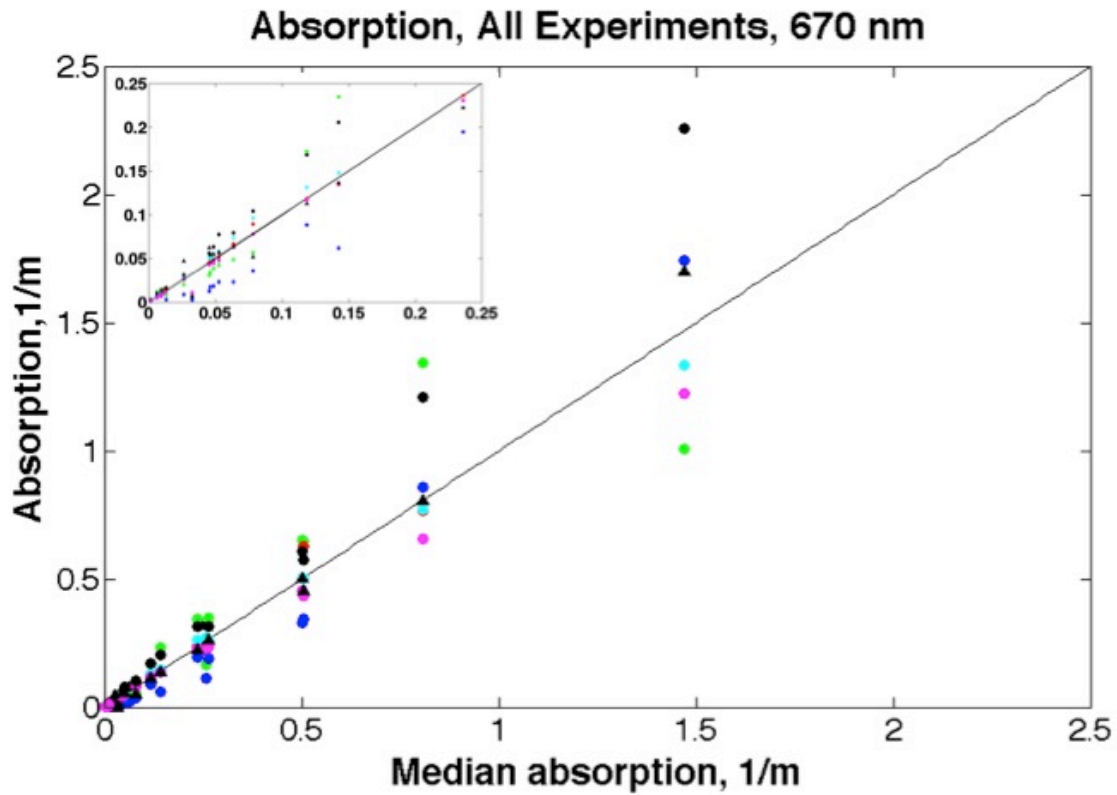
Figure 6c: Median absorption versus absorption by each method for all experiments at 670 nm. Circles represent Roesler, BrSB, Mitchell, Stramski, Rottgers, and Rottgers B2 Black Δs represent ac-s measurements.
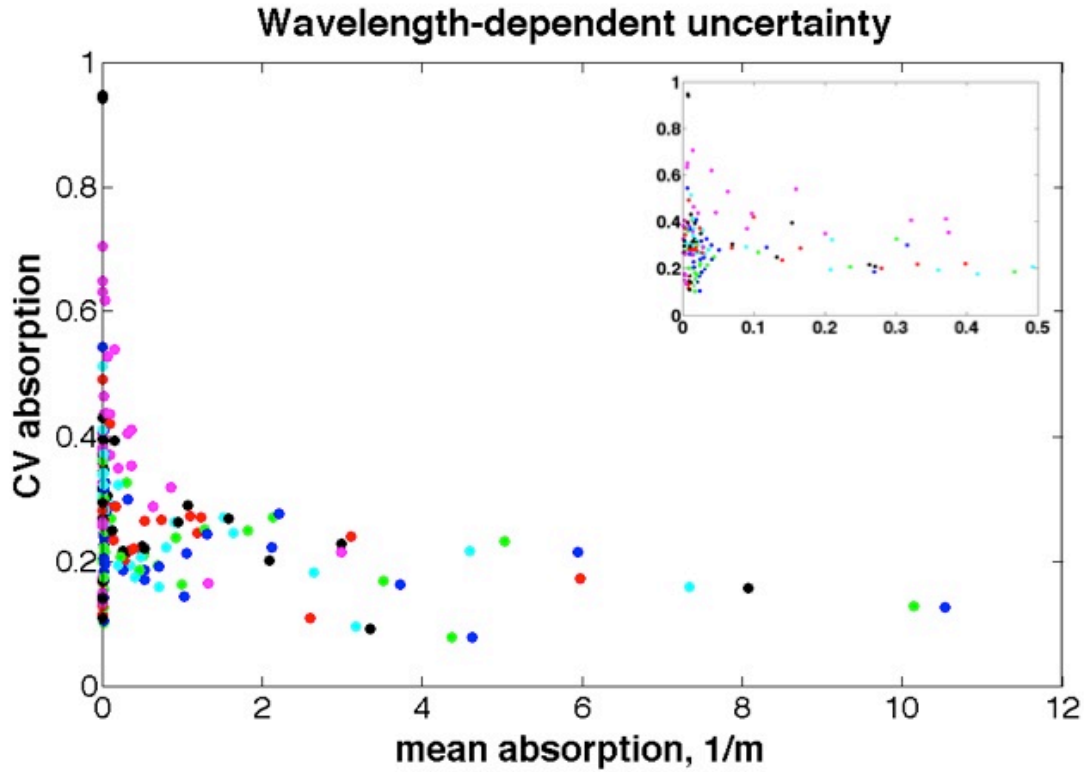
Figure 7: Uncertainty of all methods based on wavelengths: 412 443, 490, 510, 555, and 670 nm.

TABLES

Table 1: Equations for β used in the comparisons. OD is baseline corrected optical density.

T Method	Equation	Abbreviation
Mitchell (1990)	$(0.392+(0.655\ OD(\lambda))^{-1}$	Mitchell
Roesler (1998)	$\beta = 2$	Roesler
Bricaud and Stramski (1990)	$1.63 \times (OD(\lambda)^{-0.22})$	BrSB
IS Method		
Stramski and Reynolds (2014)	$3.0927 \times (OD(\lambda)^{-0.0877})$	Stramski
Röttgers and Genhke (2012)	$6.475 \times OD(\lambda)^2 - 6.474 \times OD(\lambda) + 4.765$	Röttgers
Röttgers and Genhke (2012)	4.5 (when $OD(\lambda) < 0.1$)	RöttgersB2

Table 2: Uncertainties (%CV) for filter pad measurements.

Filter Pad						
	412nm	443nm	490nm	510nm	555nm	670nm
Min	7.8	7.8	9.5	10.9	13.3	9.1
Max	40.9	54.3	51.3	41.7	58.6	47.2
Mean	22.9	24.3	28.1	25.8	33.1	27.9

Table 3: Uncertainties (%CV) for all measurements including ac-s.

All methods						
	412nm	443nm	490nm	510nm	555nm	670nm
Min	10.1	10.4	17.5	11.5	13.3	10.9
Max	40.9	54.3	51.3	49.1	70.5	94.8
Mean	23.7	25.6	30.5	28	37	31.9

Table 4: Absorption range, mean absorption and %CV for all samples, each wavelength, filter pad methods, only

Absorption Range	CV 412	Mean absorption	CV 443	Mean absorption	CV 490	Mean absorption	CV 510	Mean absorption	CV 555	Mean absorption	CV 670	Mean absorption
0-.01	30.6	0.008 ± 0.001	38.2	0.009 ± 0.001	30.5	0.007 ± 0.002	24.9	0.007 ± 0.002	27.5	0.004 ± 0.003	29.2	0.006 ± 0.003
0.01-0.05	21.9	0.0233 ± 0.010	22.8	0.027 ± 0.008	33.2	0.020 ± 0.008	26.6	0.019 ± 0.006	37.9	0.025 ± 0.014	30.2	0.016 ± 0.005
>0.05	21.8	2.050 ± 2.648	21.6	2.081 ± 2.770	22.9	1.580 ± 2.00	26.2	1.128 ± 1.576	37.0	0.619 ± 0.834	25.8	1.419 ± 2.052

Table 5: Absorption range, mean absorption and %CV for all samples, each wavelength, all methods.

Absorption Range	CV 412	mean absorption	CV 443	mean absorption	CV 490	mean absorption	CV 510	mean absorption	CV 555	mean absorption	CV 670	mean absorption
0-0.01	33.6	0.008 ± 0.0006	42.7	0.009 ± 0.002	34.9	0.005 ± 0.0005	24.6	0.007 ± 0.003	24.4	0.002 ± 0.001	23.9	0.006 ± 0.003
0.01-0.05	20.5	0.021 ± 0.008	22.3	0.026 ± 0.005	36.8	0.0194 ± 0.010	34.2	0.0316 ± 0.017	45.3	0.033 ± 0.013	29.3	0.027 ± 0.017
>0.05	23.5	0.465 ± 0.544	24.2	0.491 ± 0.571	25.8	0.366 ± 0.403	28.0	0.302 ± 0.345	42.4	0.209 ± 0.200	27.8	0.401± 0.456

Table 6: NASA Goddard Absorption Workshop Participants. Those with a * indicate that they were not able to attend the workshop but will participate in editing the updated protocol.

Participants	Affiliation
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