Quantifying uncertainties in phytoplankton absorption coefficients for accurate validation of the PACE ocean color sensor: moving towards satellite retrieved phytoplankton functional types (PFTs)

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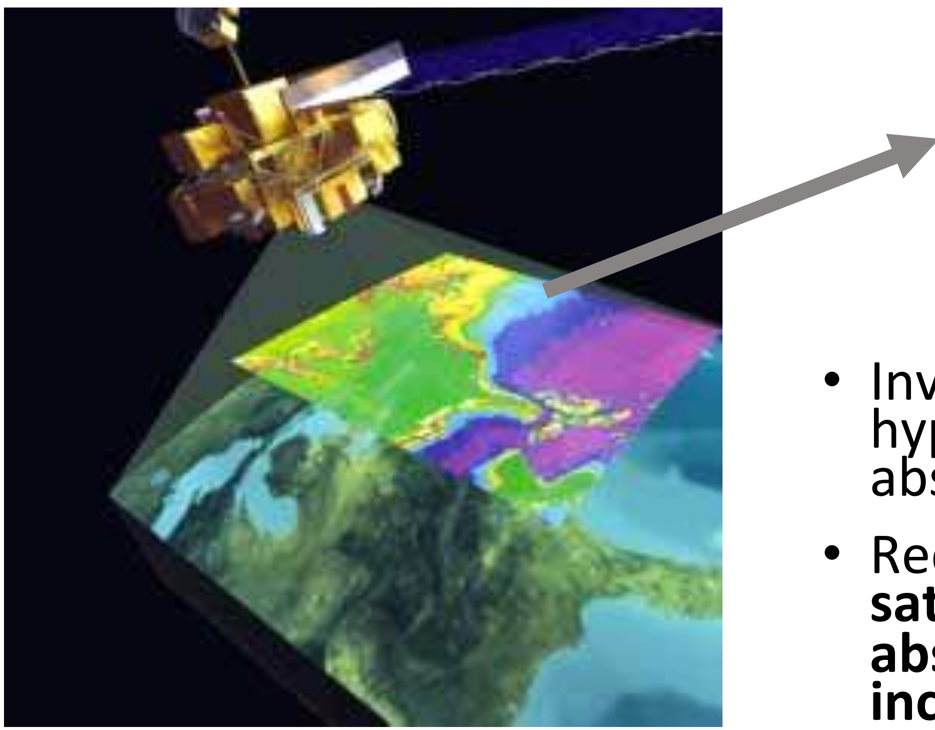
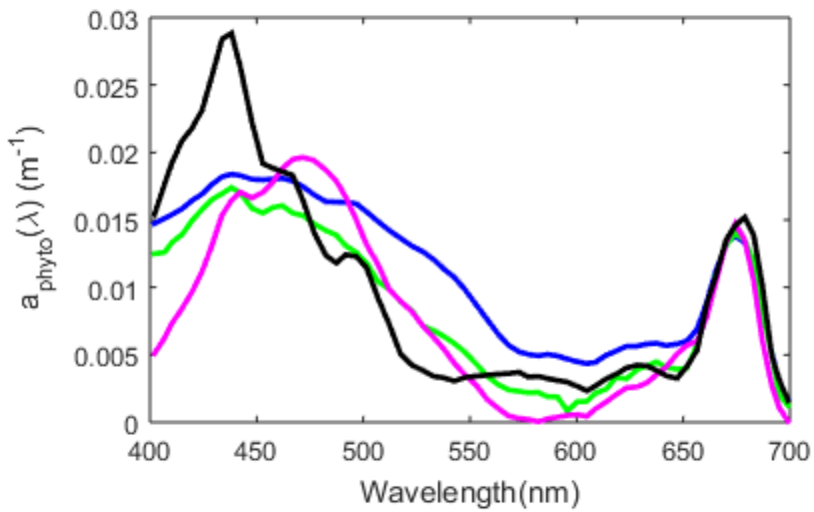
PACE – ST 2017

One of the PACE objectives is to support the estimation of IOPs in general and specifically optically-based Phytoplankton Functional Types



http://wamis.meraka.org.za/modis-basics

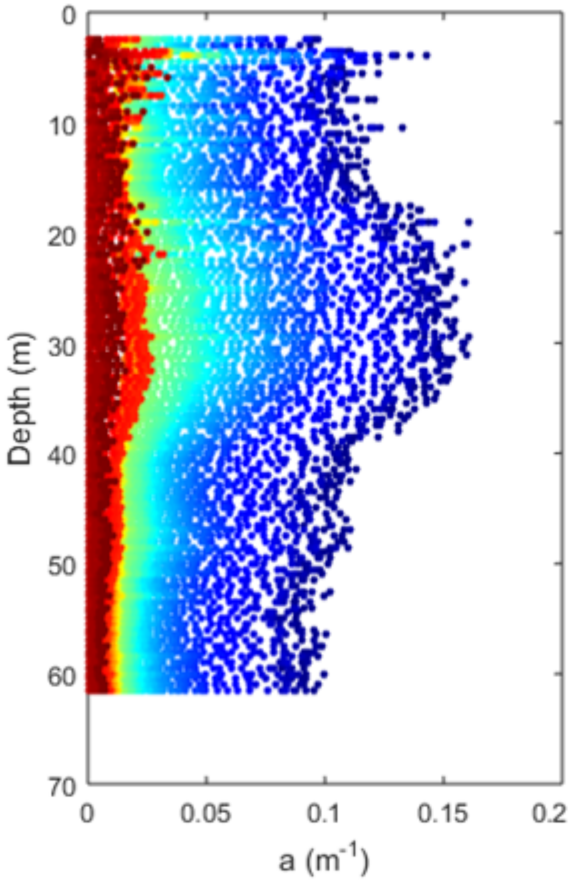


- Invert ocean color signal to retrieve hyperspectral phytoplankton absorption coefficients
- Requires capability to **validate satellite-derived phytoplankton absorption with in situ observations including uncertainties**

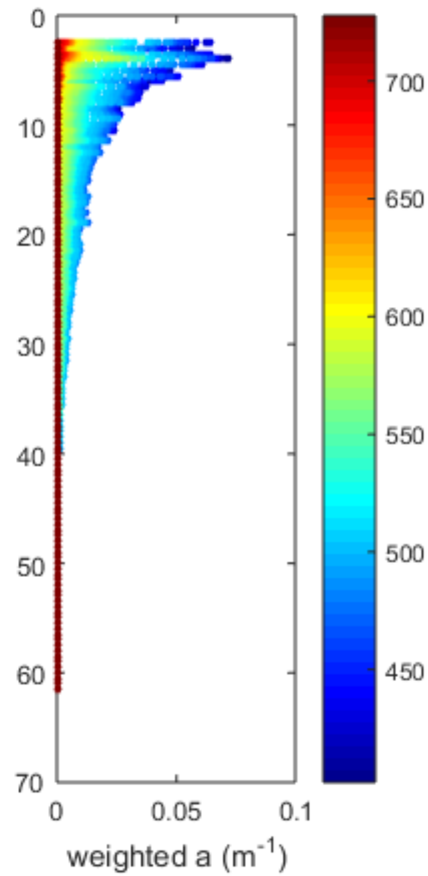
Steps to construct a validation data set for $a_{sat}(\lambda)$
1a. Exponentially weighted $a_{insitu}(\lambda)$

- Satellite sees (spectrally) exponentially-weighted absorption

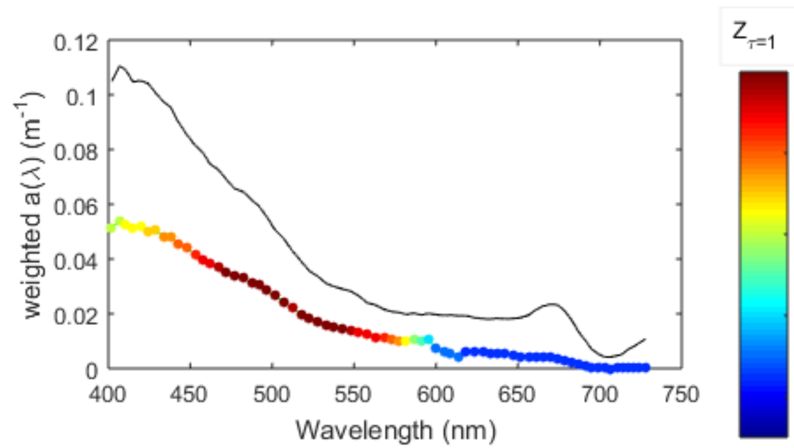
Depth Profile
Measured absorption



Depth Profile
Weighted absorption



a_{sat} requires depth weighted absorption spectra not discrete



Objective: Quantify uncertainties in deriving hyperspectral satellite-detected absorption

Stepwise approach
Step 1b. In situ hyperspectral absorption

- In situ sensors don't have the full capabilities to provide validation for PACE absorption products
    - acs - hyperspectral, but no UV and has unquantified scattering errors
    - ICAM - 9 wavelengths, 1 UV, "no" scattering error
    - a-sphere - hyperspectral but poorly constrained drift/baseline
- Validation requires merging the best of each sensor
- One approach is to quantify scattering error in acs/ac9
    - Use Integrating sphere in spectrophotometer to determine scattering correction and extrapolate to UV
    - Use ICAM to determine scattering correction and extrapolate to UV

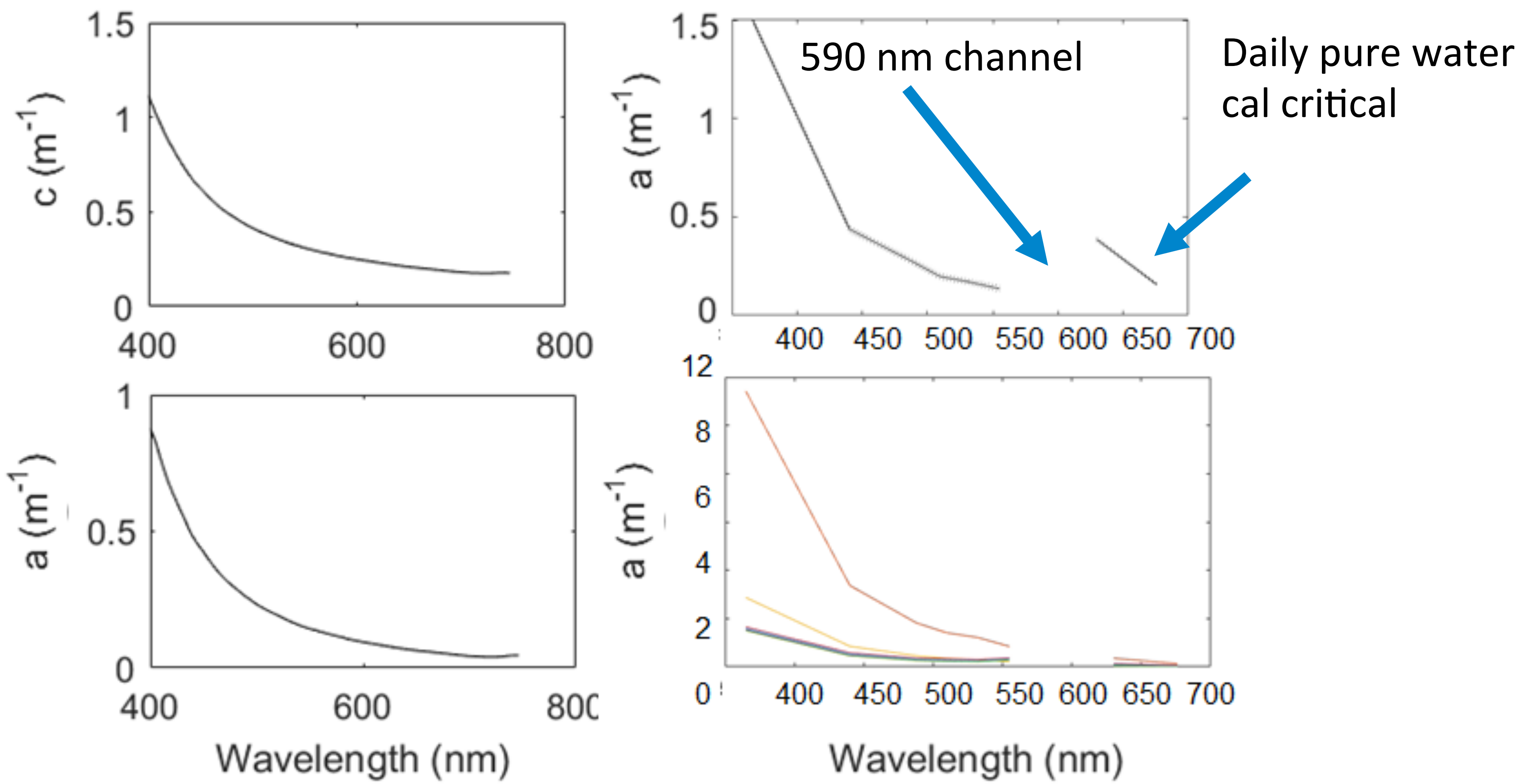
Objective 1b

Can the ICAM provide a pathway to expand absorption to the UV and provide scattering corrections for acs?

- Progress to date
  - **Laboratory experiments** on acs and ICAM
    - CDOM dilution series, additions of 50 μm beads (Duke Scientific)
    - Phytoplankton culture dilution series
  - **Field experiments** with acs and ICAM
    - January 2016 Boussole
    - January 9-13 2017 closure experiments
      - Multiple acs, ac9, ICAM
      - Gershun radiometry
      - 1 psicam
      - Filter pads (Integrating sphere – 3 Pis)

Comparison ICAM and acs

CDOM Experiment



Comparison ICAM and acs

CDOM Experiment

- acs and ICAM comparison

Dilution 1

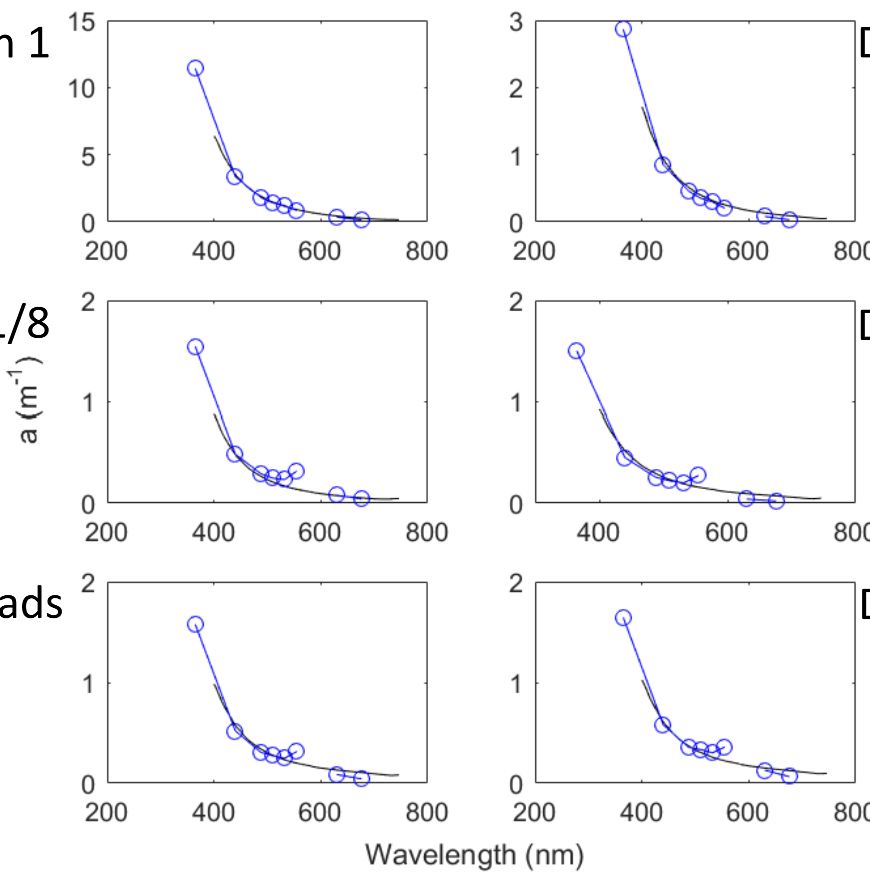
Dilution 1/4

Dilution 1/8

Dilution 1/8 +beads

Dilution 1/8 + 2*beads

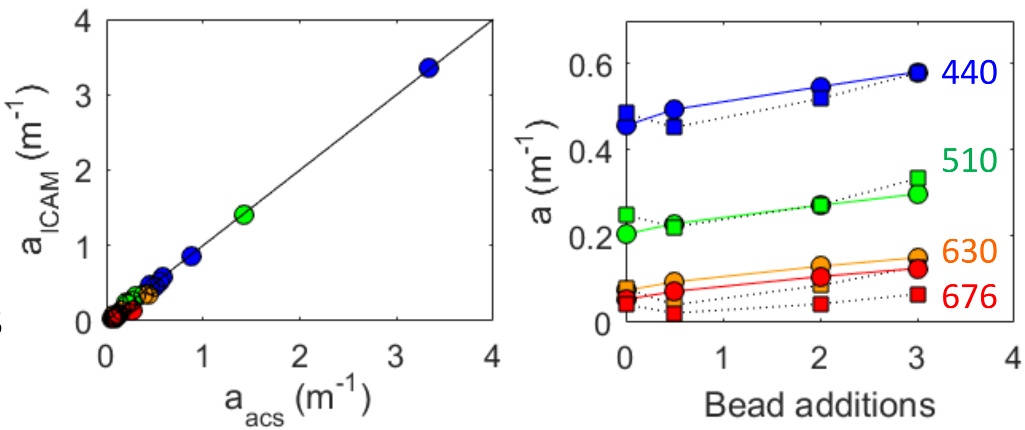
Dilution 1/8 + 3*beads



Comparison ICAM and acs

CDOM Experiment

- Water calibrated, acs temperature corrected
  - Comparable values
  - Scales with bead additions



Comparison ICAM and acs

CDOM Experiment

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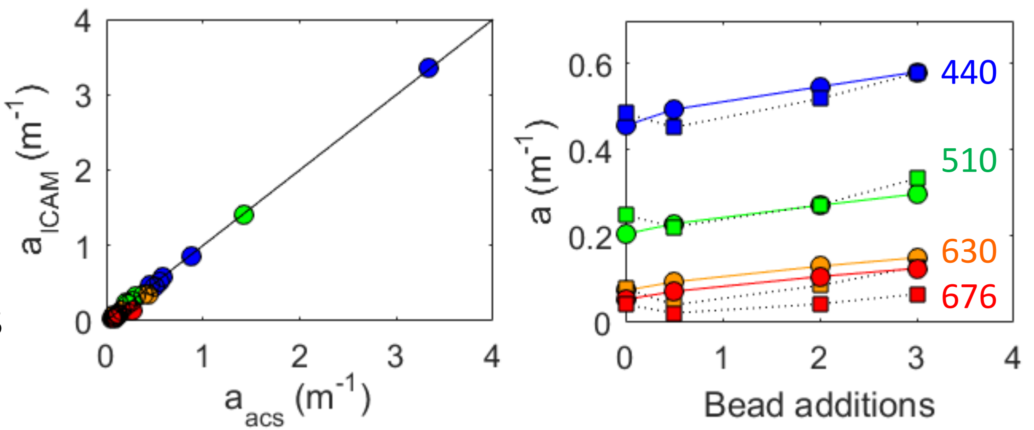
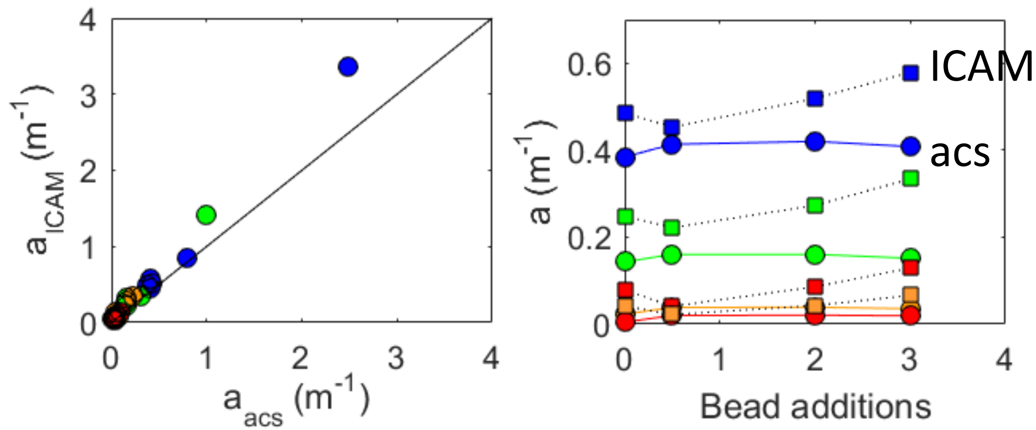
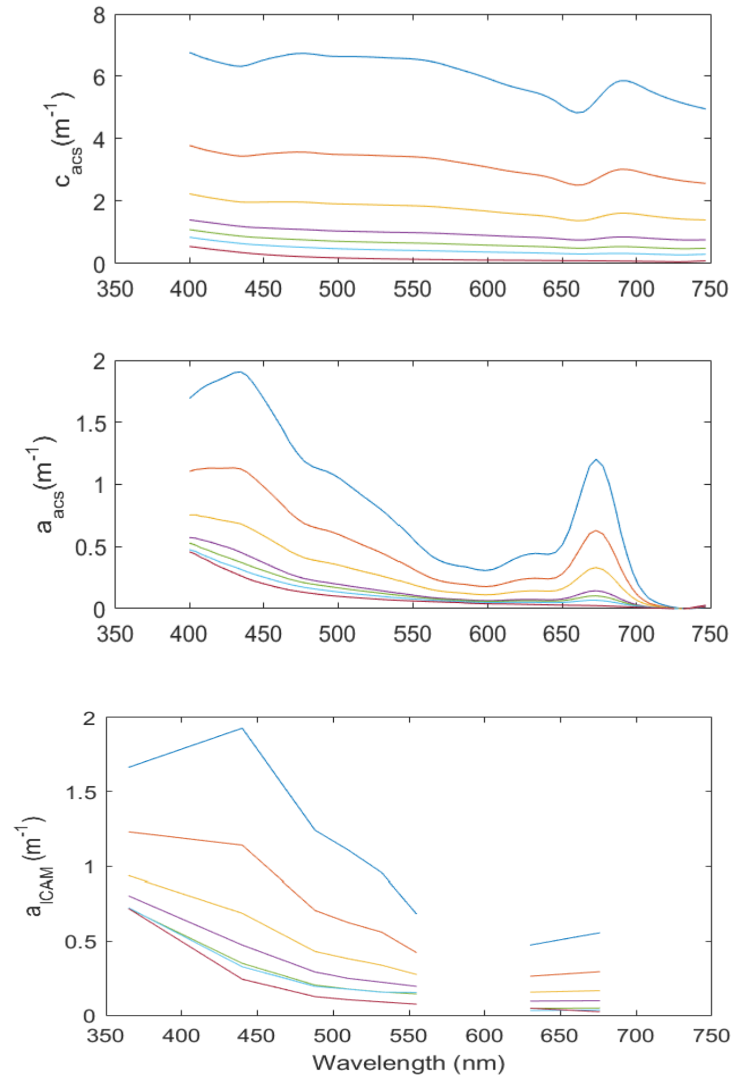


- acs scattering corrected
  - a_{ICAM}>a_{acs}
  - acs independent of bead addition



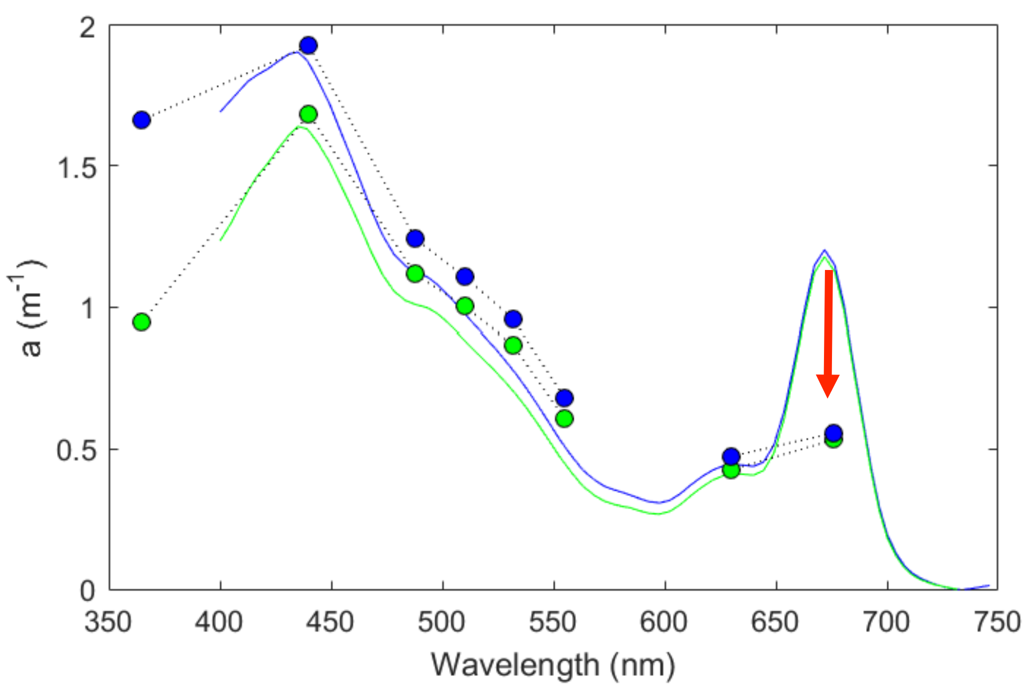
Comparison ICAM and acs

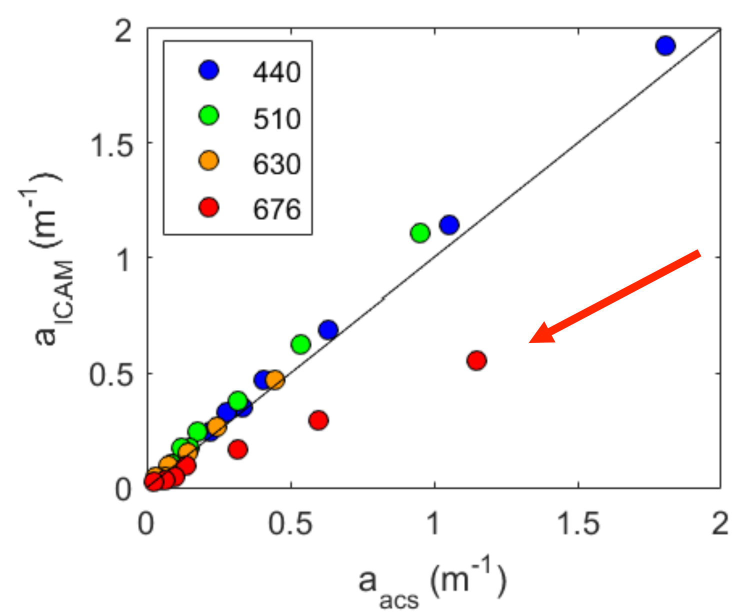
Phytoplankton Experiment



Comparison ICAM and acs
Phytoplankton Experiment

- acs and ICAM comparison with phytoplankton culture
  - ICAM overestimates acs by 5 to 14% ±3 to 11% ($r^2>0.99$, $p<10^{-6}$) at all wavelengths
  - But underestimates acs(676) by 55% ±3% ($r^2>0.99$, $p<10^{-6}$)
  - Is fluorescence causing the underestimation?





Summary of acs and ICAM Comparison

- Wavelength range and resolution
  - acs ~80 channels, 400 to 750 nm (3 nm but requires unsmoothing)
  - ICAM 9 channels, 365 to 676 nm (bandwidth not reported)
- Data processing and corrections
  - Pure water correction
  - Temperature and salinity correction (acs published protocol)
  - Scattering correction (acs uses beam attenuation)
- Data rates
  - acs 6 Hz
  - ICAM 1 Hz (now 0.5 to 0.2 Hz)
- Uncertainties
  - ICAM exhibits sensitivity to particle scattering but does not have sufficient wavelength range for developing even a null correction minimally
  - ICAM 676 nm channel significantly underestimates the red chlorophyll absorption peak by >50%
- In situ closure experiment conducted last week will investigate whether these are systematic issues

Stepwise approach
Step 2. Discrete analysis of phytoplankton absorption

- Samples are concentrated on glass fiber filters
  - Increases signal to noise
  - Removes CDOM from analysis
  - Separation of phytoplankton from other particulates
  - But there are scattering losses and pathlength amplification
- Improved spectrophotometric configuration
  - Samples center-mounted in integrating sphere (IS)
  - Mitigates scattering losses
  - Reduces uncertainty in pathlength amplification

Objective: Quantify uncertainties in estimating phytoplankton absorption coefficients on discrete samples

Objective 2

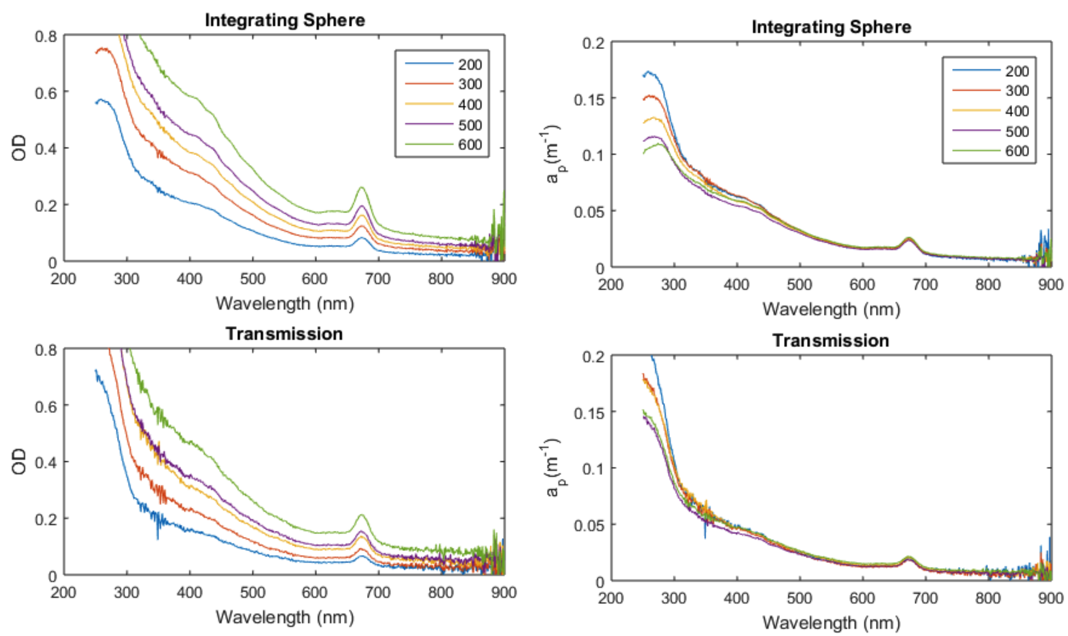
Quantify uncertainties in estimating phytoplankton absorption coefficients on discrete samples

Progress to date

- Transfer function between transmission mode and integrating sphere measurements

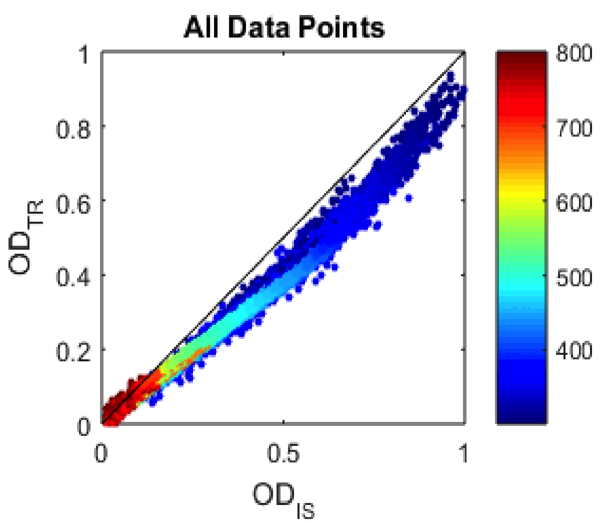
- Reduce uncertainty and increase accuracy of historical filter pad absorption data

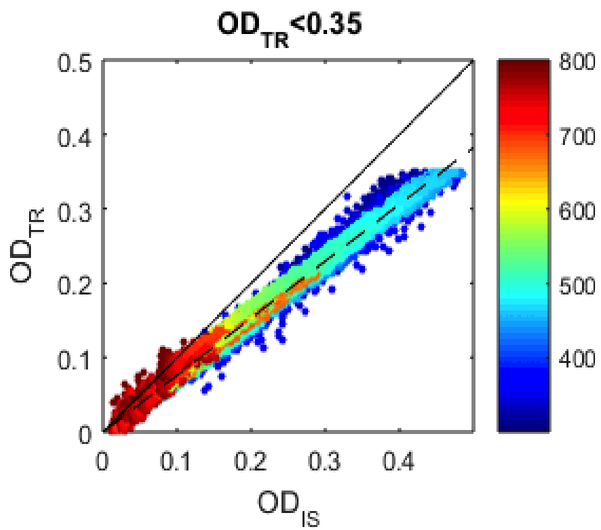
- Range of filter loading
- Field/lab samples

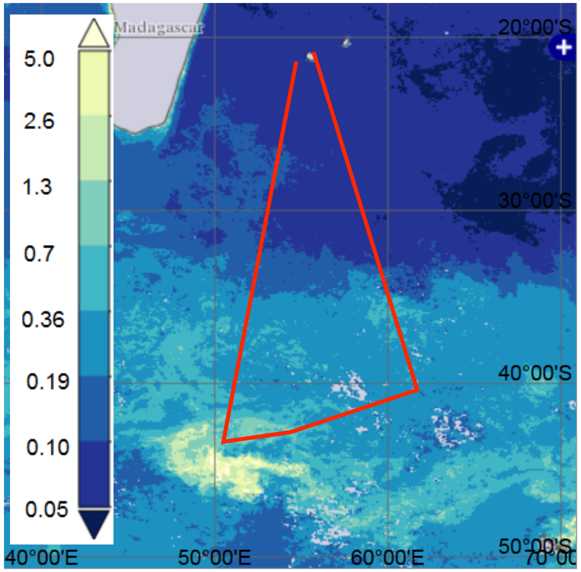


Transfer function between transmission mode and integrating sphere measurements

- (left) Results for 30 samples (n>14,000) over the entire spectrum
- (right) restricting observations OD<0.35 (%T mode)
- dotted is the best fit linear model
  $OD_{IS} = 1.29 * OD_{TR} + 0.00205$
- Tested with data from SOCLIM (La Réunion-Kerguelen 10/2016)



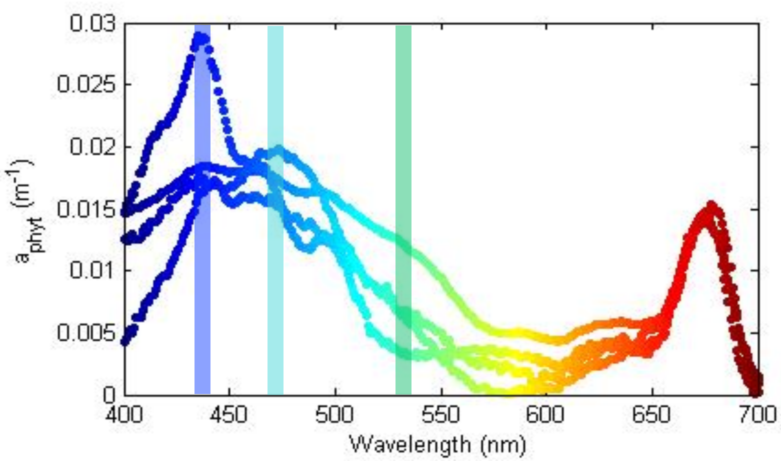




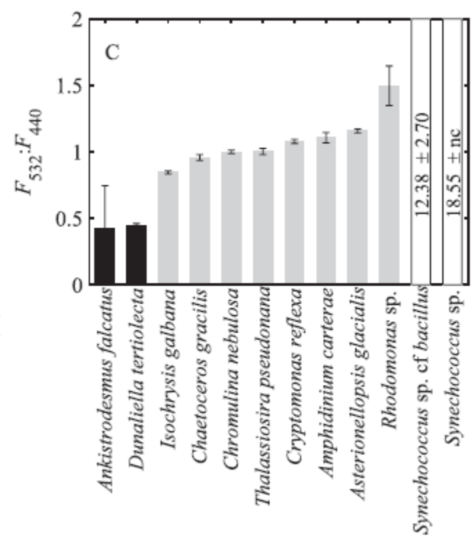
Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

- Some Validation Platforms (floats, moorings) not optimal for ac meter deployments (e.g. size, power, data, biofouling)
- To increase opportunities for validation, small, low power optical sensors are ***also*** needed
- Multichannel fluorometers (3X1M) provide means for discerning absorption ratios and pigmentation (*Proctor and Roesler 2010; Thibodeau et al. 2014*)



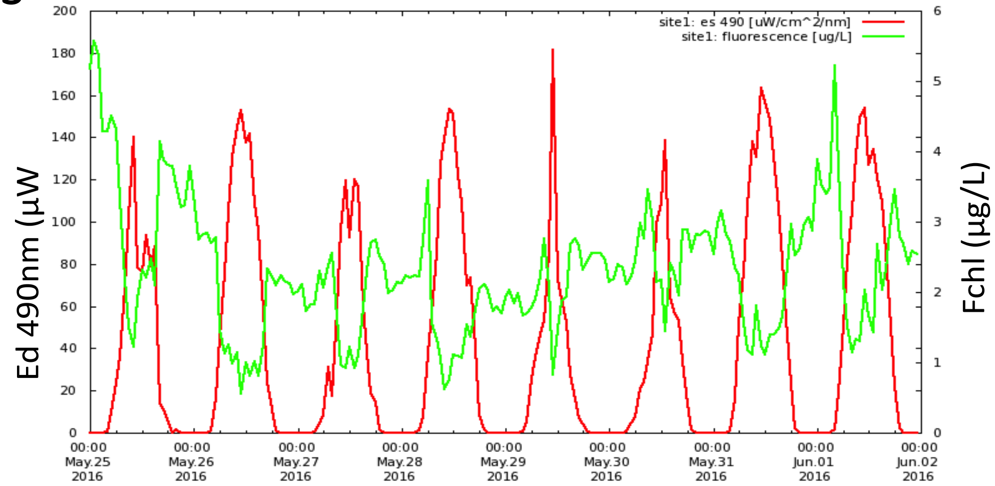
🡐 Fluorescence is proxy for absorption
🡒 Fluorescence ratios are proxies for pigment composition



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

- Problems linking in situ fluorescence observations with remote sensing observations due to Non-Photochemical Quenching (NPQ)
- Remote sensing requires daytime validation and unquenched fluorescence occurs at nighttime
- Particularly problematic for tidally impacted coastal environments

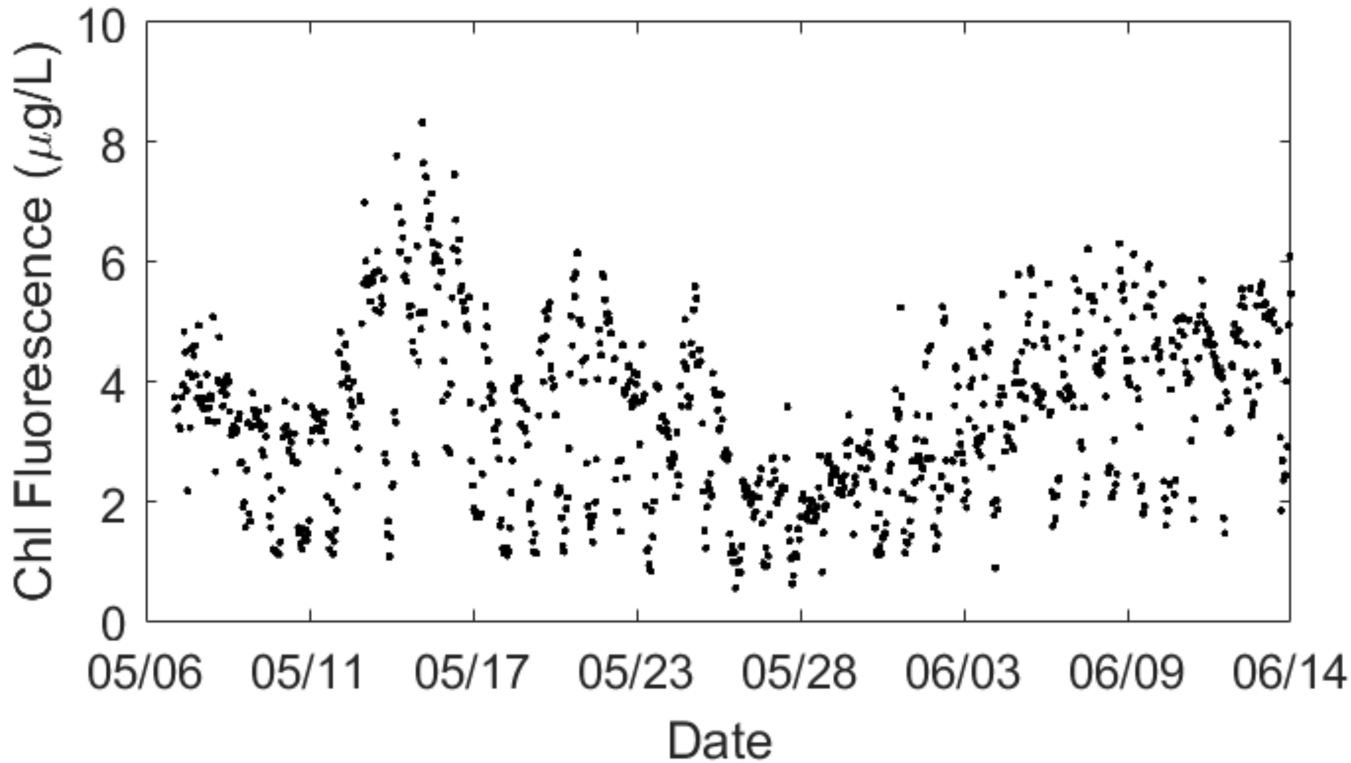


May 25 – June 2, 2016

Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

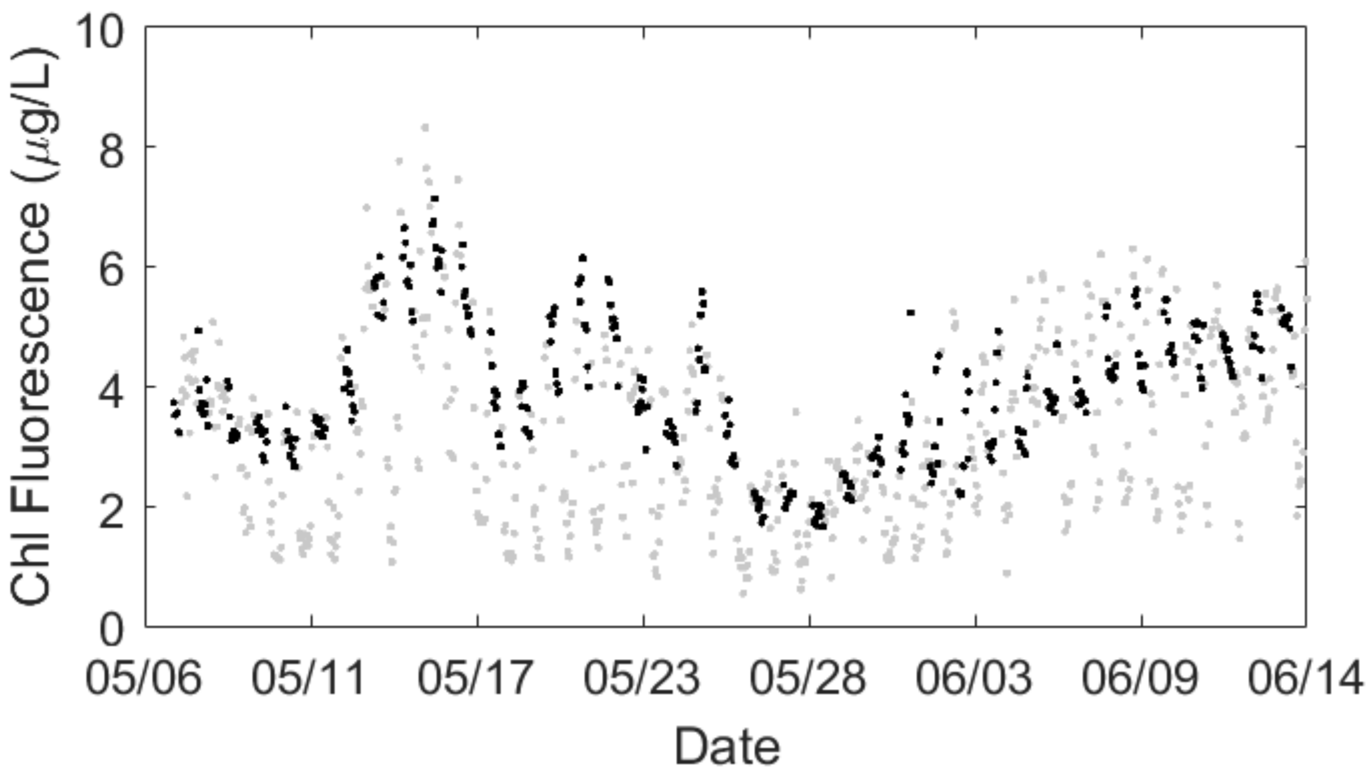
- Start with hourly fluorescence observations



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

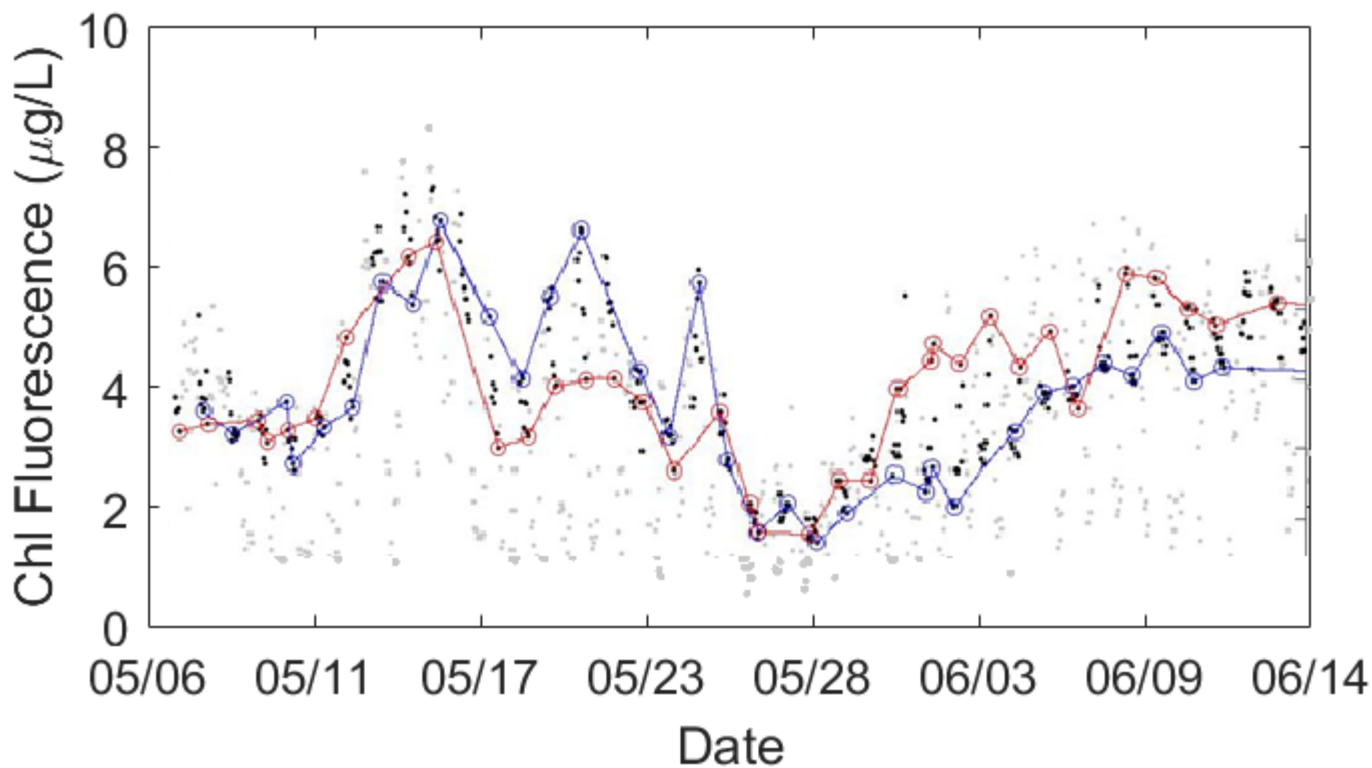
- Remove NPQ-impacted observations (grey)



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

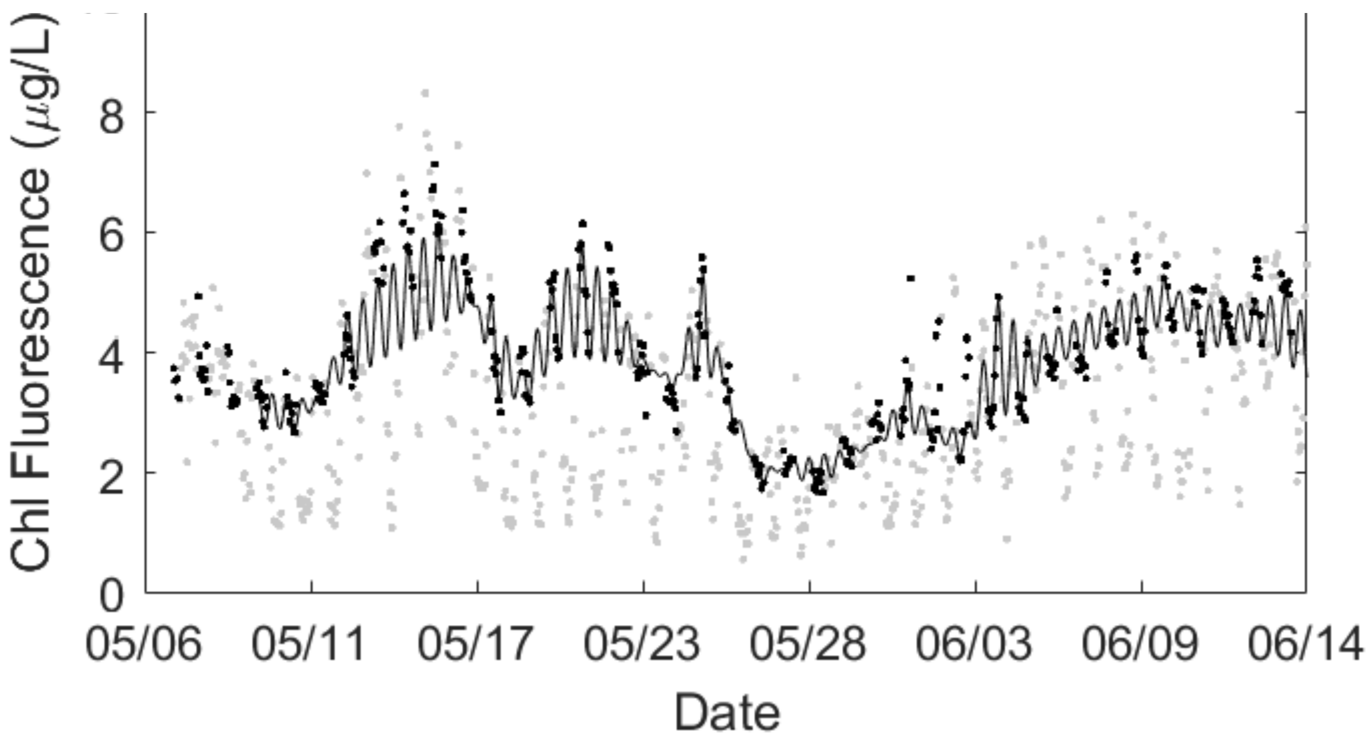
- Use tide proxy (ADCP currents or Salinity) to identify hours of high (blue) and low (red) tide *during non-NPQ times*



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

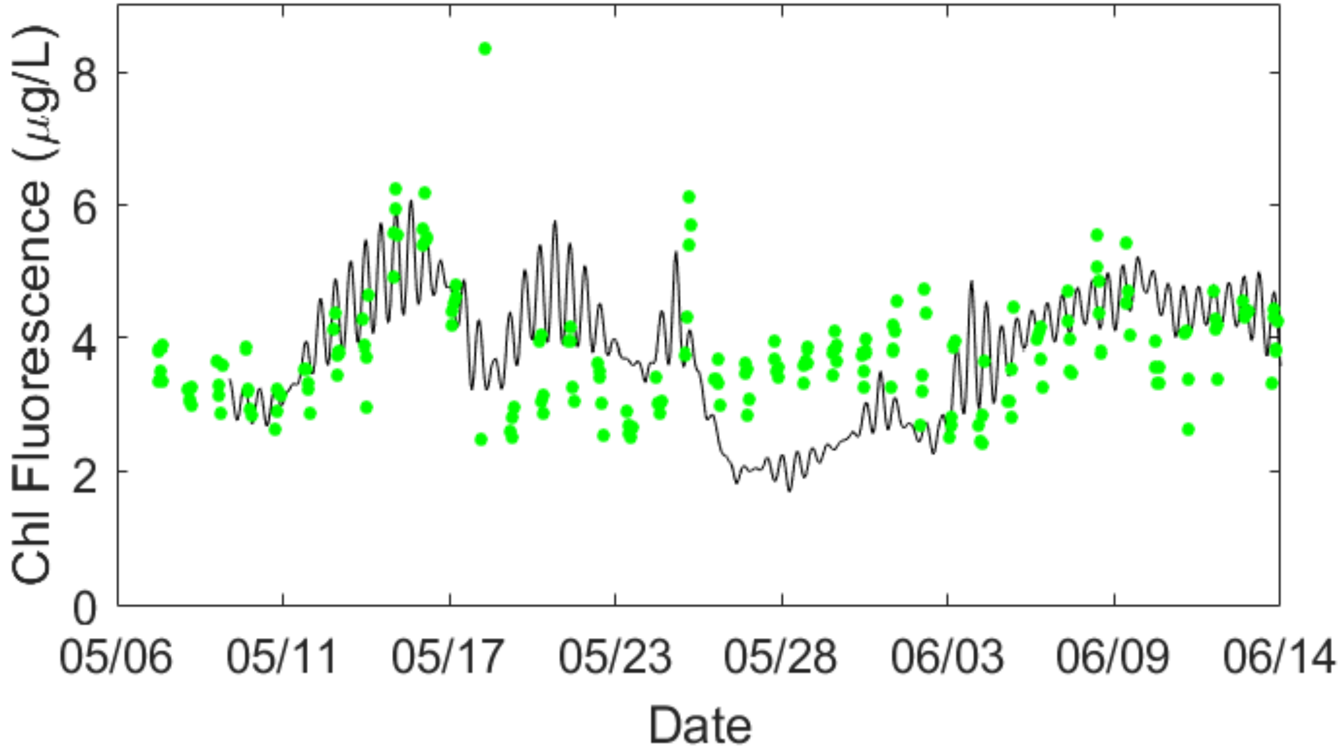
- Interpolate daily tidal excursions in non-NPQ fluorescence between high and low tide envelope to estimate the non-quenched calibrated fluorescence at the mooring that would be observed every hour



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

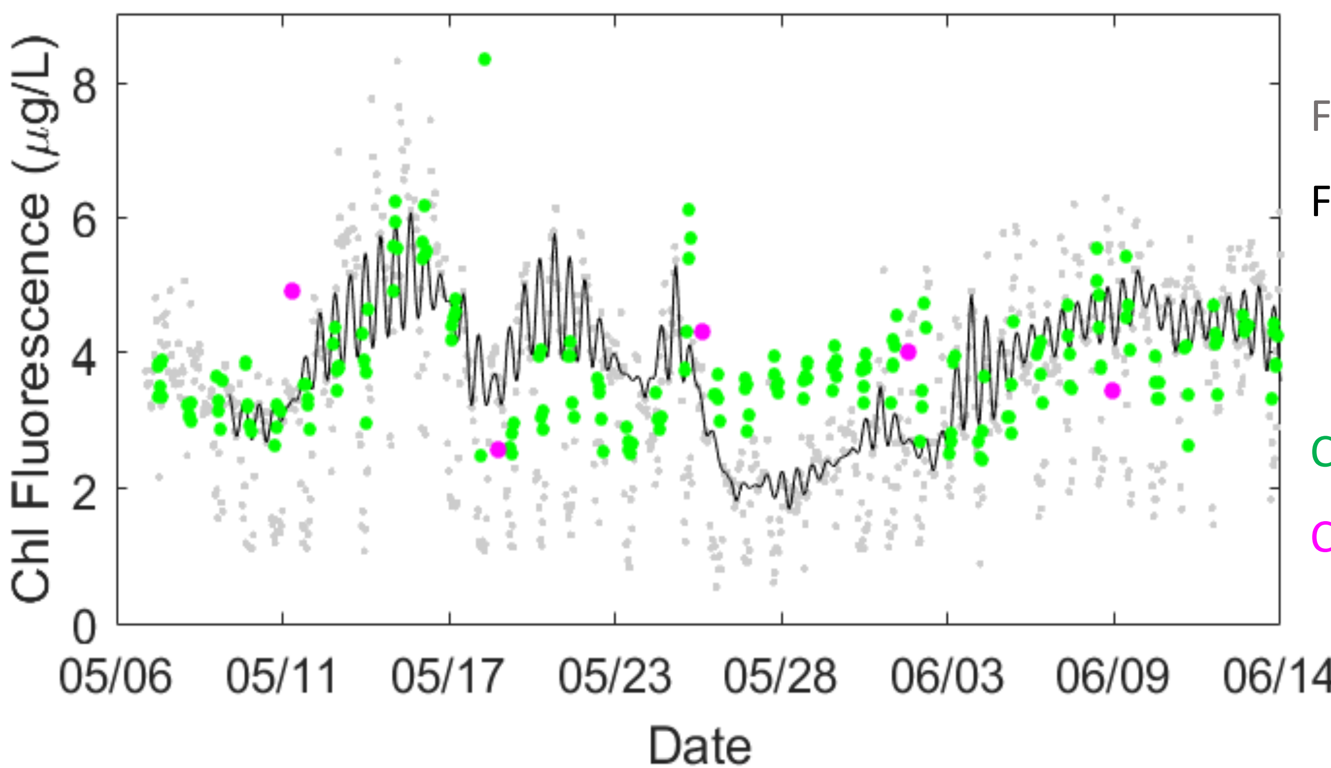
- Improved matchup between hourly in situ calibrated chlorophyll fluorescence time series (black line) and radiometric chlorophyll concentration (green symbols)



Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

- Now variability between Chl_{sat} and Chl_{insitu} can be examined from the perspective of ***natural variability in fluorescence per chl***



F_{chl} raw

F_{chl}

Tidally corrected

NPQ removed

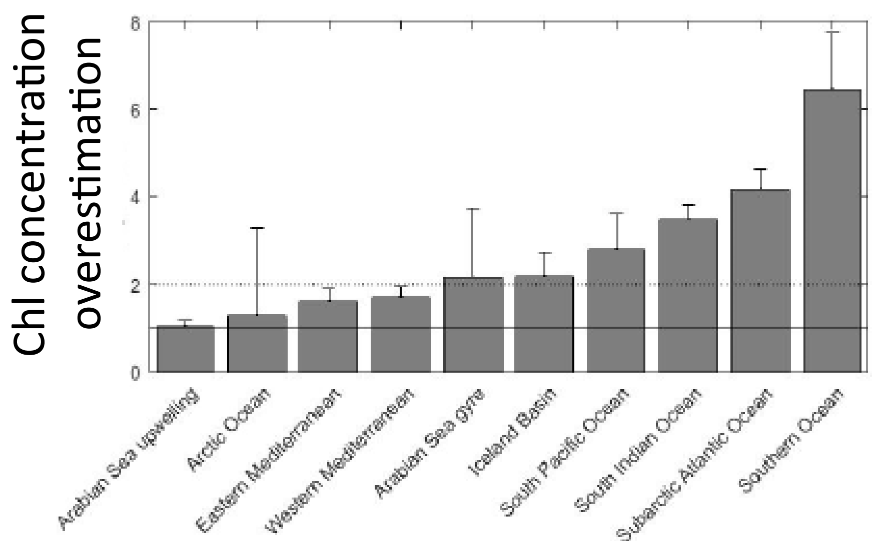
Chl_{sat}

$Chl_{extracted}$

Objective 3

Discerning absorption-based phytoplankton functional types from multispectral fluorescence

- Natural variations in the fluorescence per chl (calibration slope) are well documented
- WETLabs calibration overestimates in situ chl with a global bias of 2 but local biases of over 6 in some regions



Challenges of and recommendations for absolute calibration of in situ fluorometers for assessing global phytoplankton distributions
Roesler et al 2017 accepted to Limnology and Oceanography Methods


Thank you