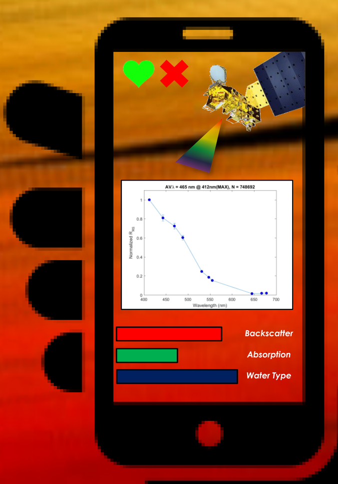

TINDER FOR THE OCEAN:

AN INTUITIVE, SIMPLE, AND EFFECTIVE SPECTRAL MATCHING ALGORITHM FOR OCEAN COLOR

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The Challenge

As we enter an era of satellite-based hyperspectral ocean color measurements, how can we better characterize the interactions between multiple, simultaneous dimensions (e.g. spatial-spectral-temporal variability and trends)? Here, we propose simple methodology to employ a universal, unsupervised classification system by which to summarize Remote Sensing Reflectance (R_{RS}) data with a quantitative and mappable output of spectral shape.

When analyzing large satellite data sets, it is challenging to represent and comprehend more than two dimensions of data at one time. Graphical representation of multi-spectral data are often represented as one of the following:

- *Multiple $R_{RS}(\lambda)$ scatter plot over region of interest (ROI)* [Spectral, Temporal, Spatial]
- ***One** $R_{RS}(\lambda)$ or product (chlor_a), mapped in 2 dimensions* [Spectral, Temporal, Spatial]
- *Δ time (animation), but only for **one** product/$R_{RS}(\lambda)$ at a time* [Spectral, Temporal, Spatial]
- *Multiple $R_{RS}(\lambda)$ from **one** pixel/ROI plotted over time* [Spectral, Temporal, Spatial]
- *Qualitative RGB image e.g. to "ID" coccolithophore blooms* [Spectral, Temporal, Spatial]

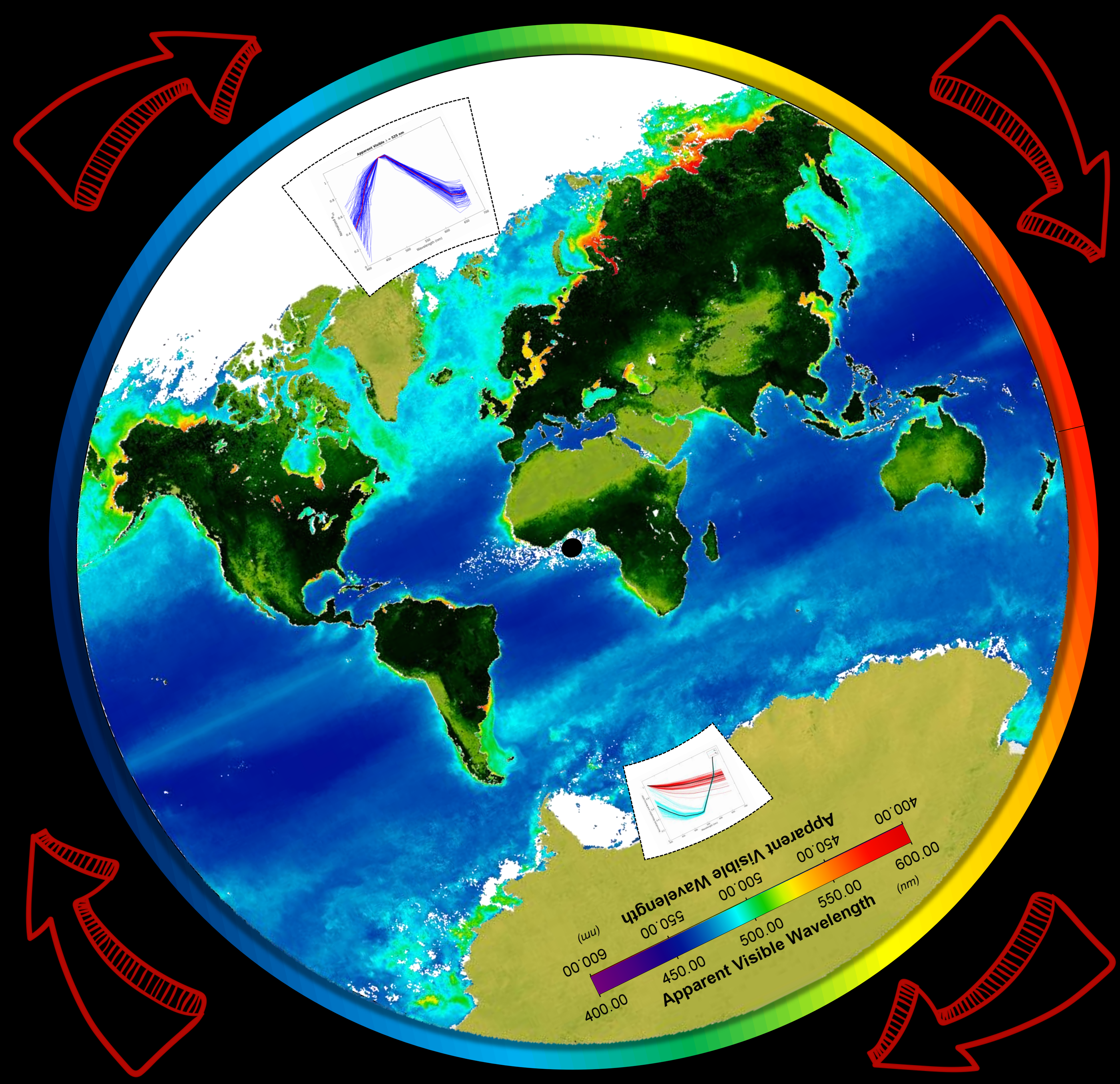
GOAL: If we can utilize a spectral classification algorithm to reliably define the full spectrum of $R_{RS}(\lambda)$ in terms of a single number, this affords the opportunity to examine trends of spectral shape in the spatial and temporal domain.

Finding Your Spectral Match

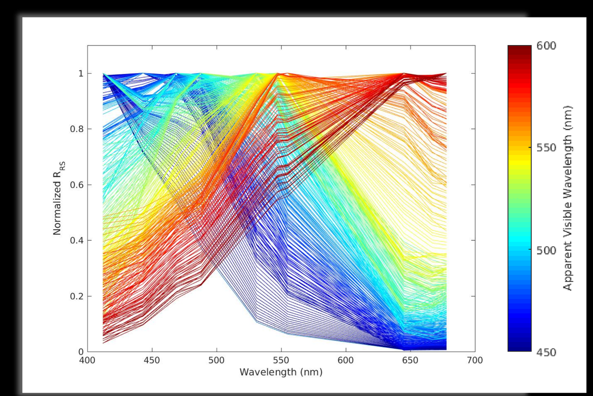
Defining a specific optical water "type" implicitly assumes that different regions can present similar optical characteristics of marine components (A_T + B_B), which translate into similar R_{RS}. The process of spectral classification is not unique (see Moore et al. 2001, Wernand et al. 2013, Melin and Vantrepotte 2015, Wei et al. 2016, Ye et al. 2016), but these techniques often require training data sets, and/or yields dimensionless, regionally specific results. Here, we cluster spectral data using a simple weighted average of the R_{RS} wavelengths, constrained by the relative intensity of each channel, outputting an Apparent Visible Wavelength (AVW), in units of nm.

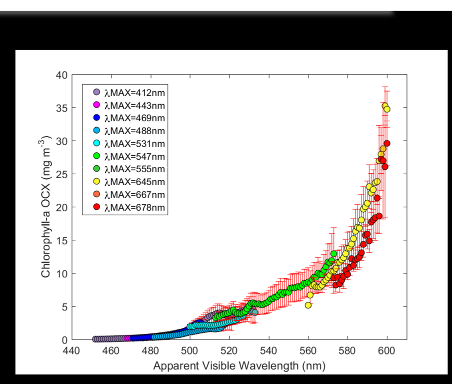
$$AVW(\lambda_{MAX}) = \frac{\sum_{\lambda=400}^{700} \lambda R_{RS}(\lambda)}{\sum_{\lambda=400}^{700} R_{RS}(\lambda)}$$

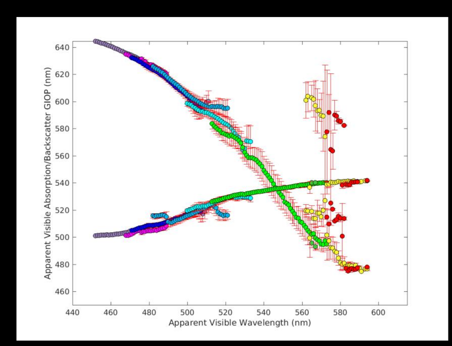
SPIN THE GLOBE TO EXAMINE MODIS-AQUA SPECTRAL MATCHES AND UNCERTAINTY



Instead of classifying water types in discrete segments, the AVW quantifies R_{RS} spectral shape as a continuous function of the centroid. Of course, there can be more than a single unique solution to each spectral cluster (e.g. 2 or 3 spectral shapes can have the same AVW value. However, in normalizing the AVW according to the wavelength of maximum reflectance (λ_{max}) these solutions retain a mostly unique quality. Having $R_{RS}(\lambda)$ constrained to one dimension enables the comparison of spectral shape in relation to bio-geochemical parameters. Using the same methodology, we can also define the apparent "color" of absorption and backscattering spectra, thus enabling the investigation of how R_{RS} directly relates to the inherent optical properties.

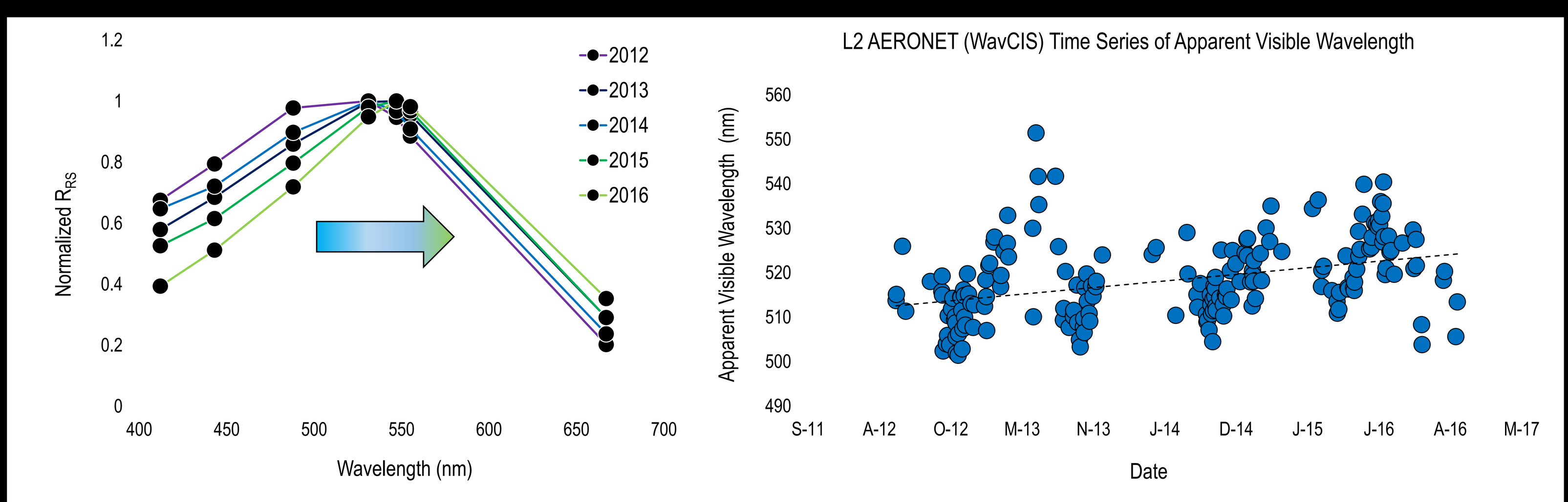




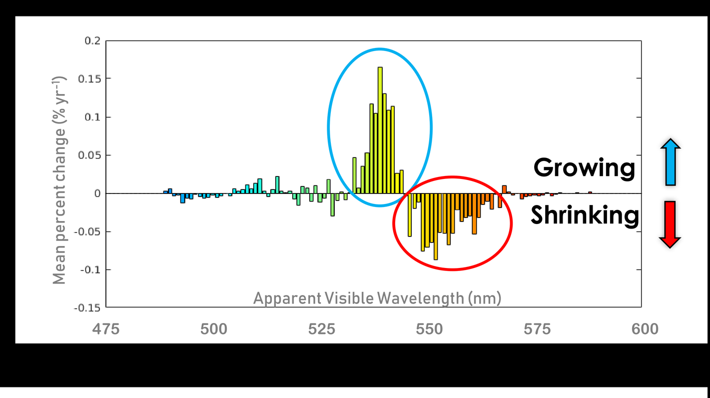


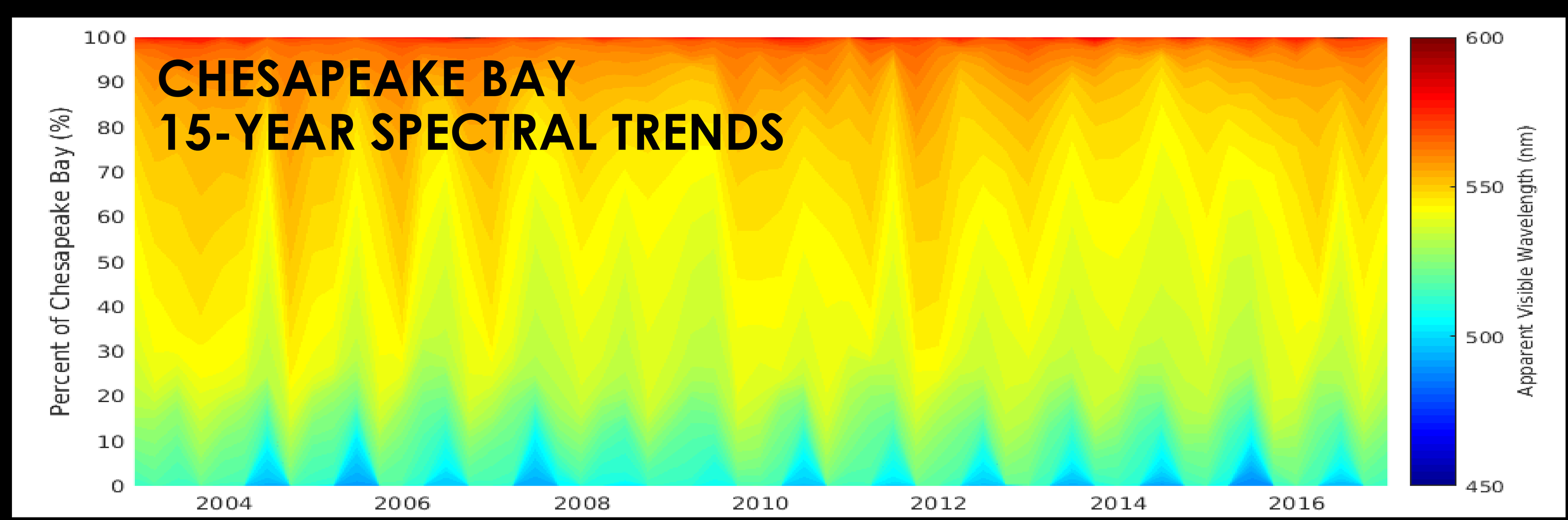
Changes in Spectral Shape Over Time and Space

A time-series of the WavCIS (AERONET-OC) platform in Gulf of Mexico shows a "greening" trend in AVW, and is corroborated by examining the green shift in the average $R_{RS}(\lambda)$ spectrum over each year. While the trend itself may be a short-term artifact (including temporal sampling bias), the sensitivity of AVW to detect changes in spectral shape demonstrates the utility in examining and quantifying integrated $R_{RS}(\lambda)$ trends over time and space. Without an integrated picture of $R_{RS}(\lambda)$, it is difficult to discern these trends using a single wavelength.



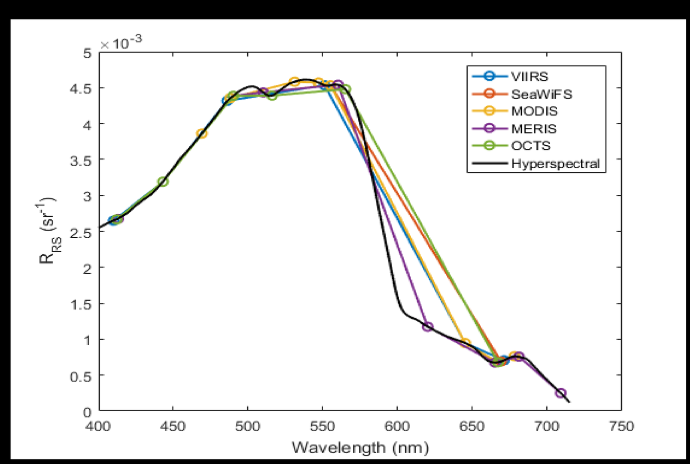
Here we examine the spectral-spatial-temporal variability of the Chesapeake Bay over 15 years of the MODIS-Aqua time-series. Preliminary results suggest a subtle shift in spectral shape. It should be noted that no discernable trend was found at the MOBY site over the same time frame.

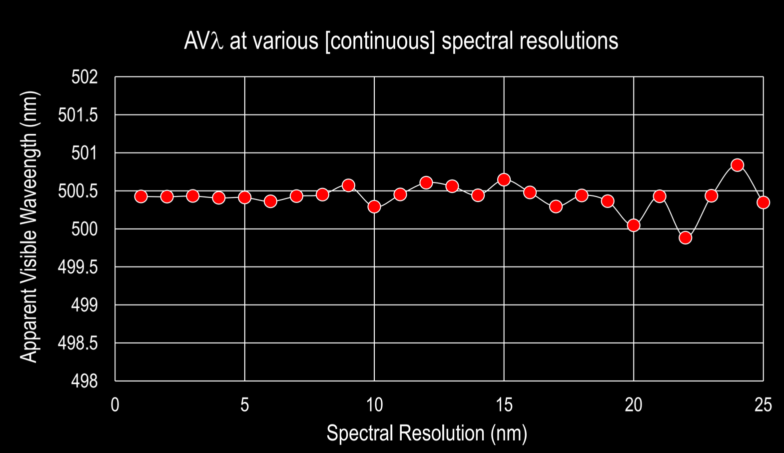




Hyperspectral Data Helps

Note that different heritage satellite sensors will inherently yield different spectral "shapes" when detecting the same water mass, due to the bias in band-center location (upper-right). This precludes the analysis of multi-sensor climatological trends in spectral shape without applying a correction (gain) factor, which would introduce further uncertainty. However, with continuously placed band centers, a simulation of spectral resolutions ranging from 1-25 nm yields nearly the same results for overall spectral shape (bottom-right).





Potential Applications

- Simple and intuitive identification of optical water types
- Phytoplankton functional type distinction with iterations
- Analysis of spectral variance for targeted sampling
- Potential improvements to semi-analytical inversions
- A useful climatological metric of change in color
- Correlation of similar water types on global scales
- Functional display of multi/hyperspectral *in situ* data
- Implementation of decision tree approaches for algorithm development
- Quality control check of algorithm performance (erratic spectral shapes)

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