Spectral Classification of MODIS and VIIRS Water-Leaving Reflectance

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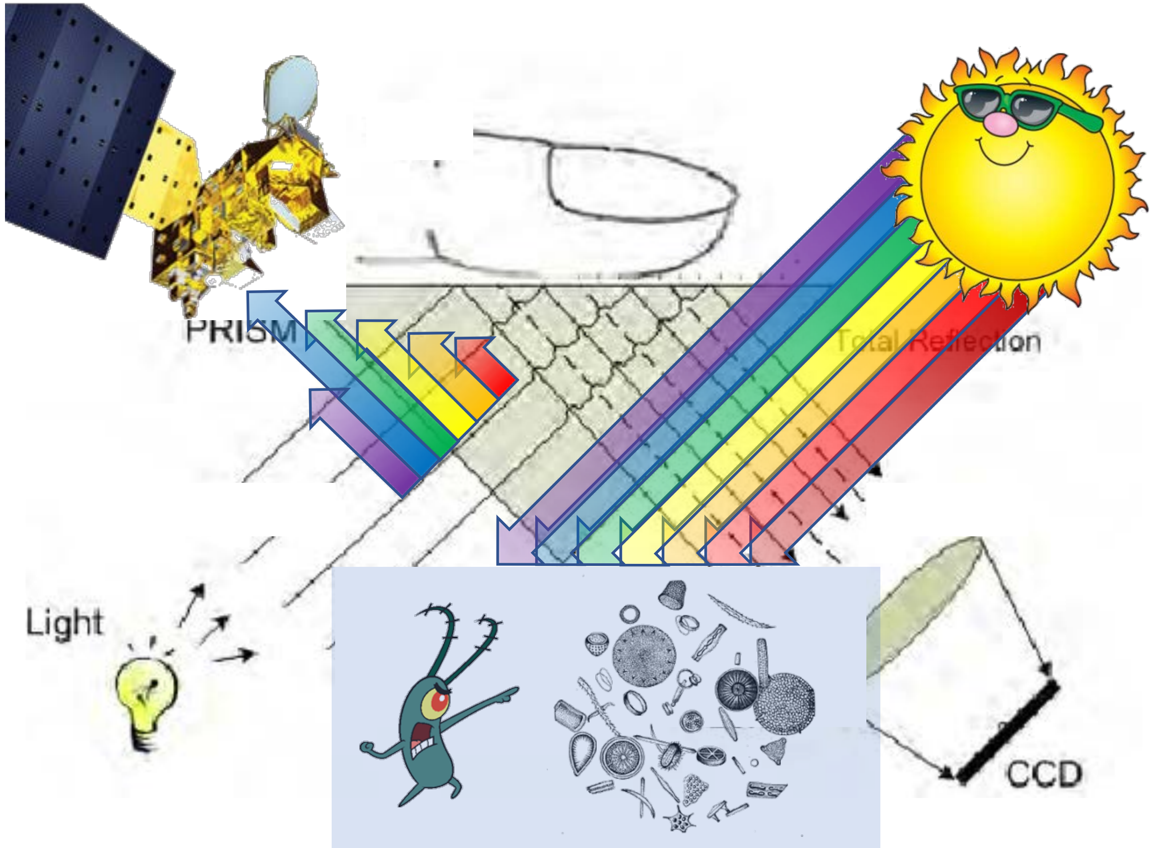
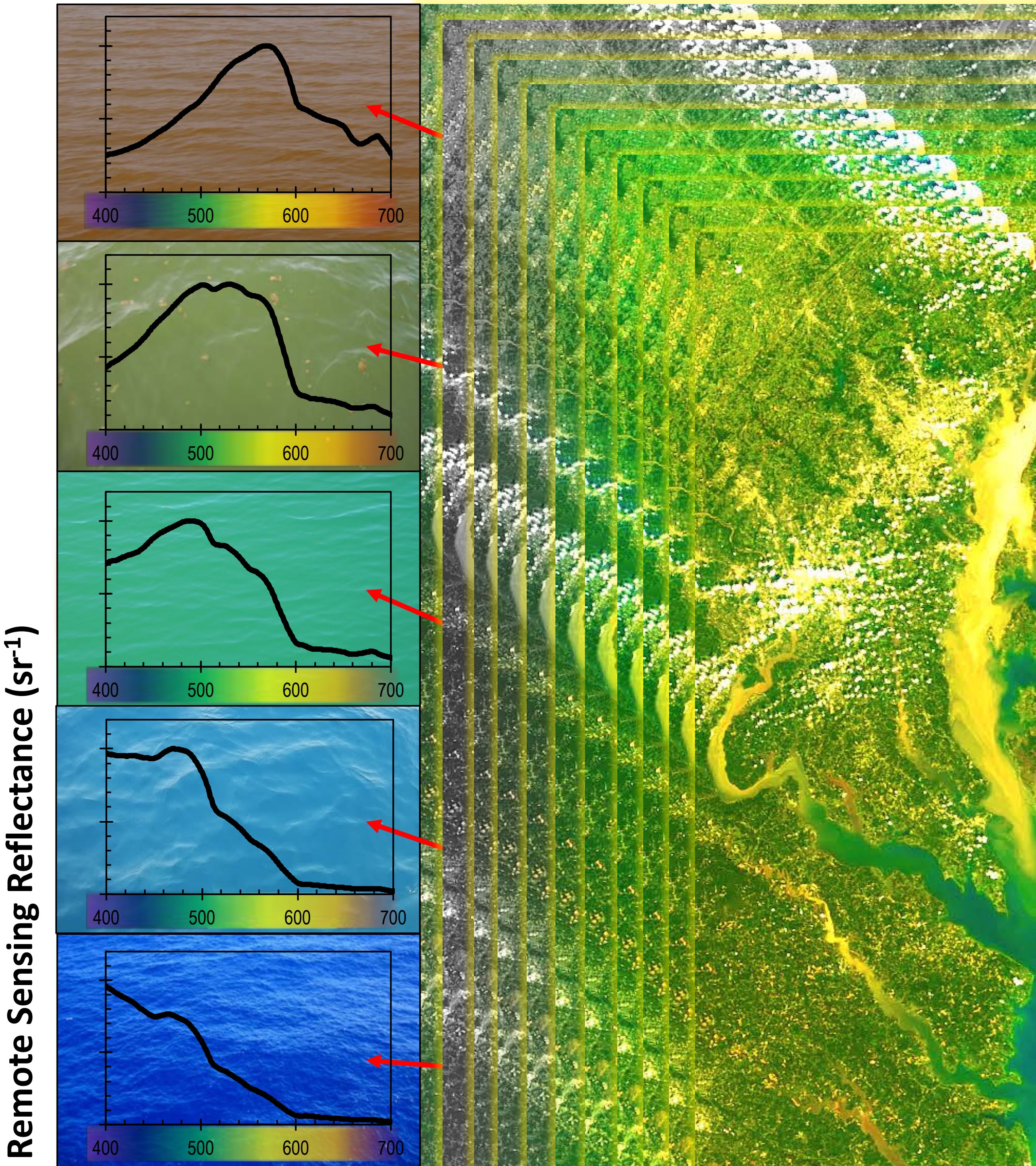
MODIS/VIIRS Science Team Meeting

College Park, MD

November 19, 2019

Optical "Fingerprints"





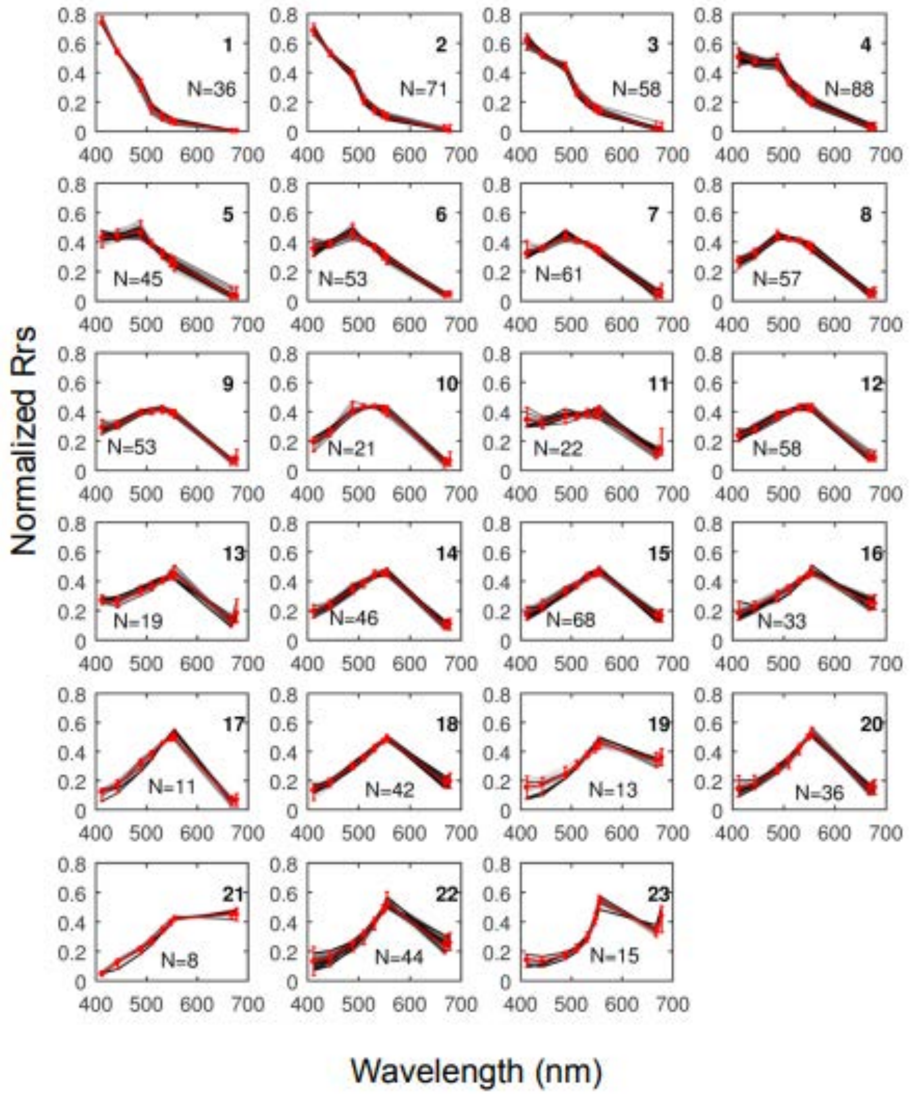
How can quantify and analyze the differences between multiple layers of spectral information within the context of a two-dimensional image?

Spectral Classification (abridged history)

- **Fuzzy c-means classification** (Moore et al. 2009, 2014, Eleveld et al. 2017)
- **Agglomerative Ward's linkage** (Lubac and Loisel 2007)
- **Iterative self-organizing data analysis technique** (Melin and Vantrepotte 2015)
- **Varimax-rotated Principal Component Analysis** (Avouris and Ortiz 2019)
- **Max-classification** (Ye et al. 2016)
- **K-means clustering** (Wei et al. 2016, Prasad and Agarwal 2016)
- **Chromaticity coordinates/Hue angle CIE** (Wernand et al. 2013)

PITFALLS

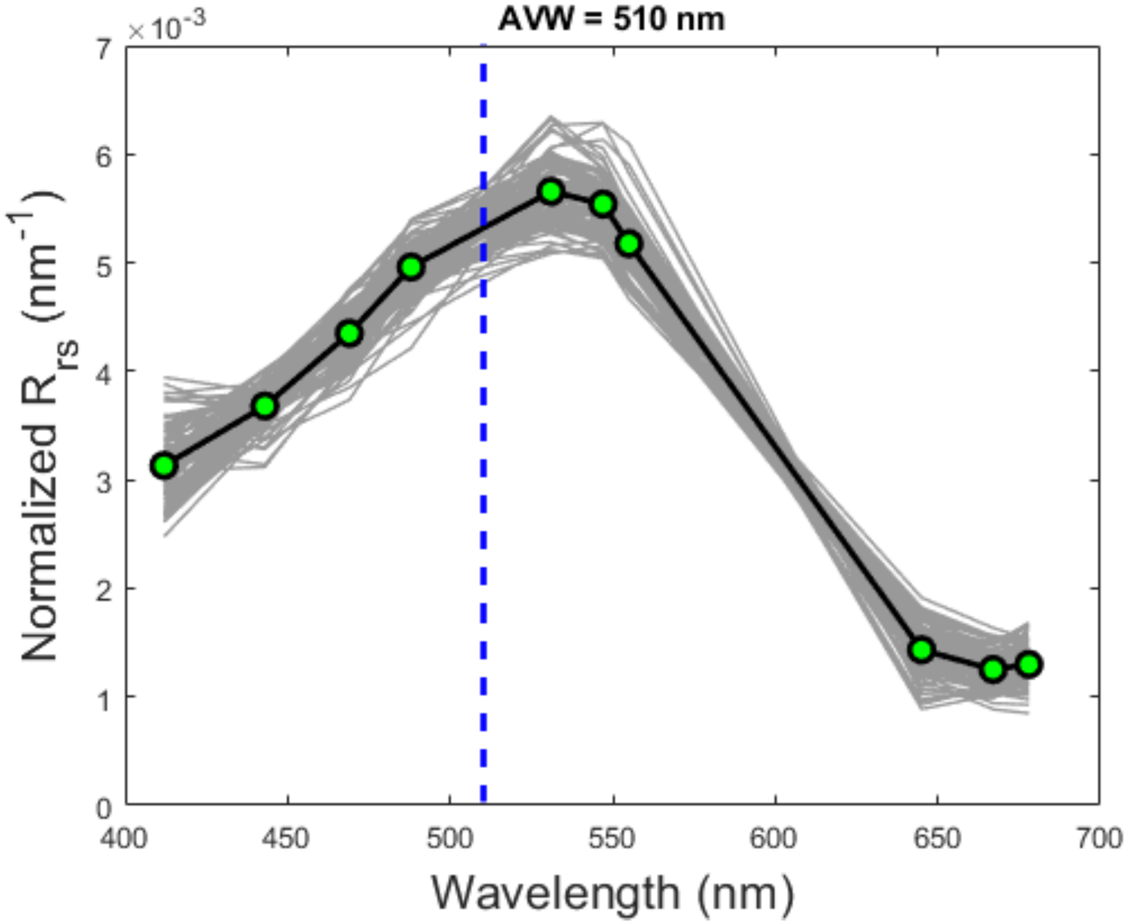
- Usually require training data sets (hard to come by)
- Often yield regionally-specific results, requires development
- Arbitrarily define number of clusters in some instances
- Exist in dimensionless space/not quantitative (Class A, B, C, etc.)
- May not incorporate the entirety of the $R_{rs}(\lambda)$ spectrum
- Challenging to interpret without some a priori knowledge of the data



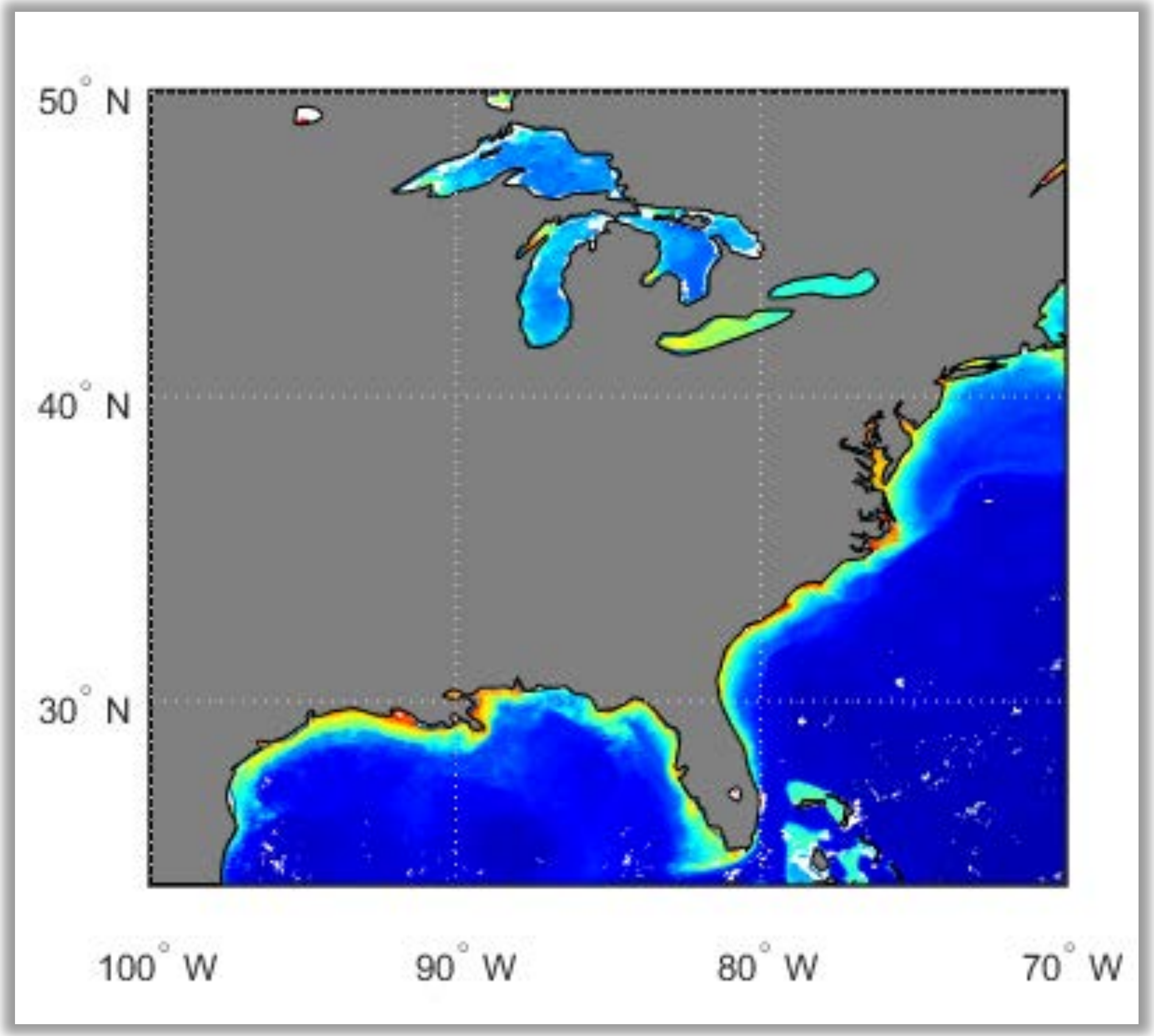
Apparent Visible Wavelength

$$AVW = \frac{\sum_{i=\lambda_1}^{\lambda_n} R_{RS}(\lambda_i)}{\sum_{i=\lambda_1}^{\lambda_n} \frac{R_{RS}(\lambda_i)}{\lambda_i}} = \left(\frac{\sum_{i=\lambda_1}^{\lambda_n} \lambda_i^{-1} R_{RS}(\lambda_i)}{\sum_{i=\lambda_1}^{\lambda_n} R_{RS}(\lambda_i)} \right)^{-1}$$

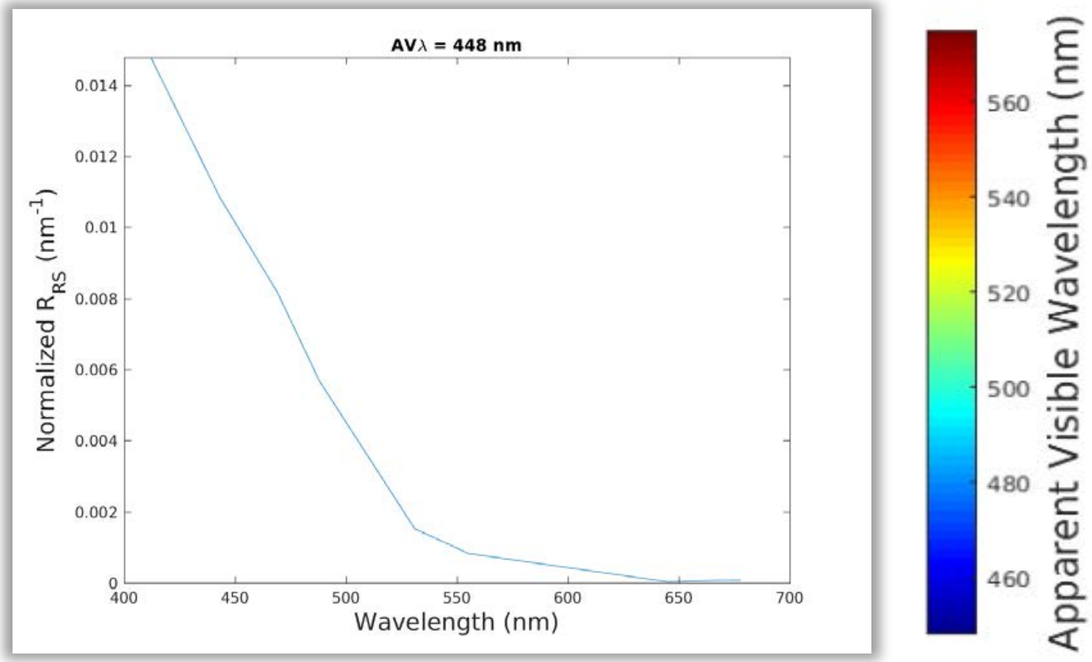
The weighted harmonic mean of the R_{RS} wavelengths, outputs an ***Apparent Visible Wavelength, AVW*** *(in units of nm). The derivation of the AVW is simply a first-order measure of the dominant color of the water, as determined by the weight that each measured channel contributes to the reflectance in the visible range of the spectrum.*

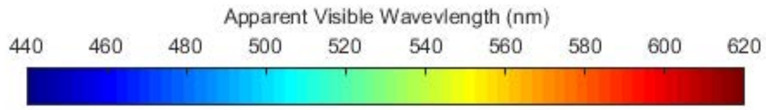


Apparent Visible Wavelength

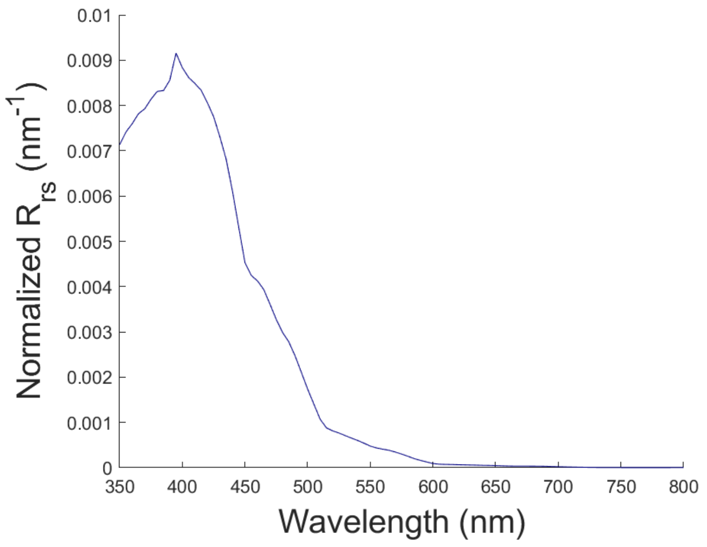


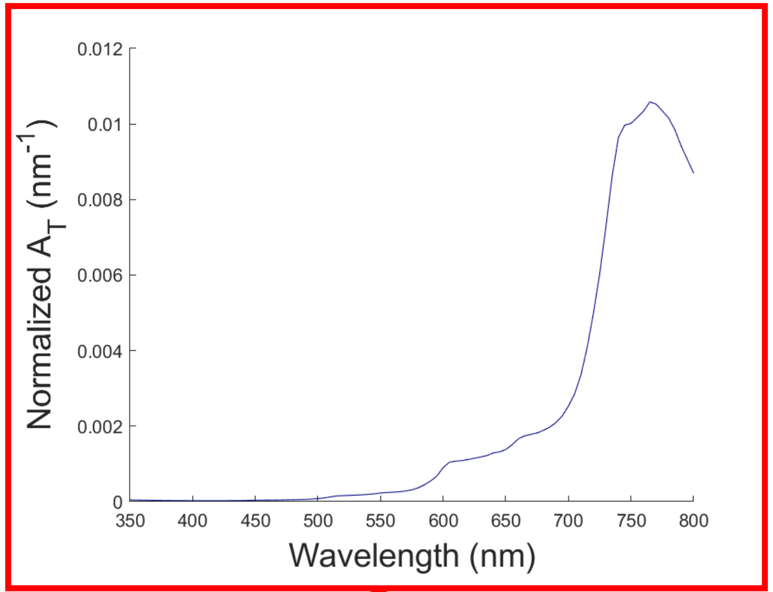
Every color on the map represents a different spectral shape. Constraining multiple layers (wavelengths) of multi-spectral $R_{rs}(\lambda)$ into one dimension is a simple and robust way for users to visualize and quantify trends in spectral $R_{rs}(\lambda)$ in terms of its apparent dominant color, which, inherently relates to a specific spectral shape and a unique combination of absorption and scattering properties.

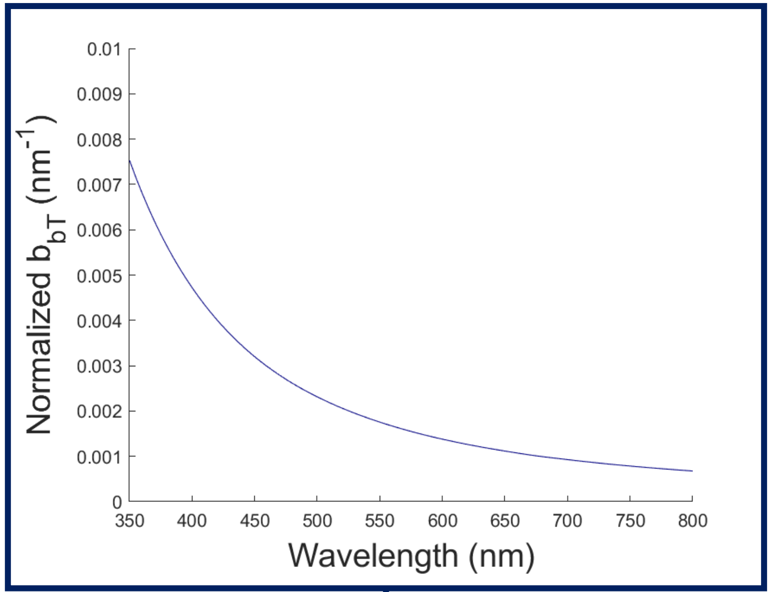




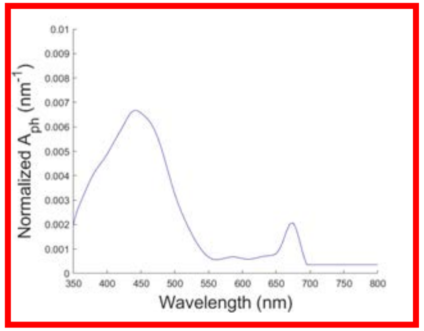
IOCCG Synthetic Dataset sorted according to Apparent Visible Wavelength

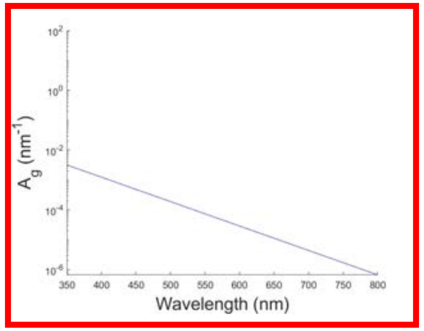


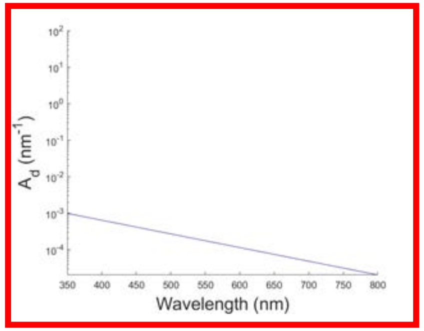




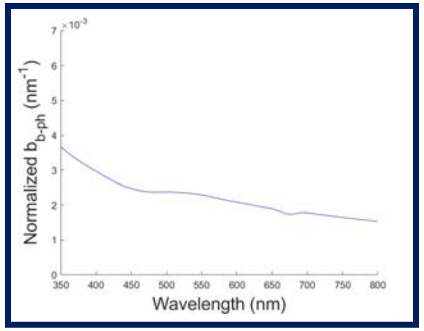
Absorption components (Phytoplankton, Detrital Matter, CDOM)

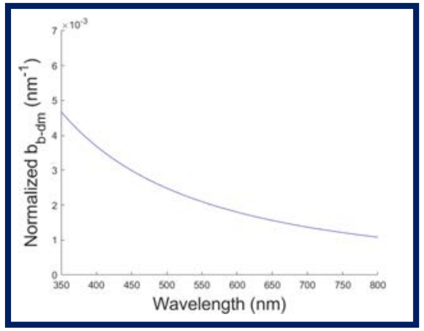






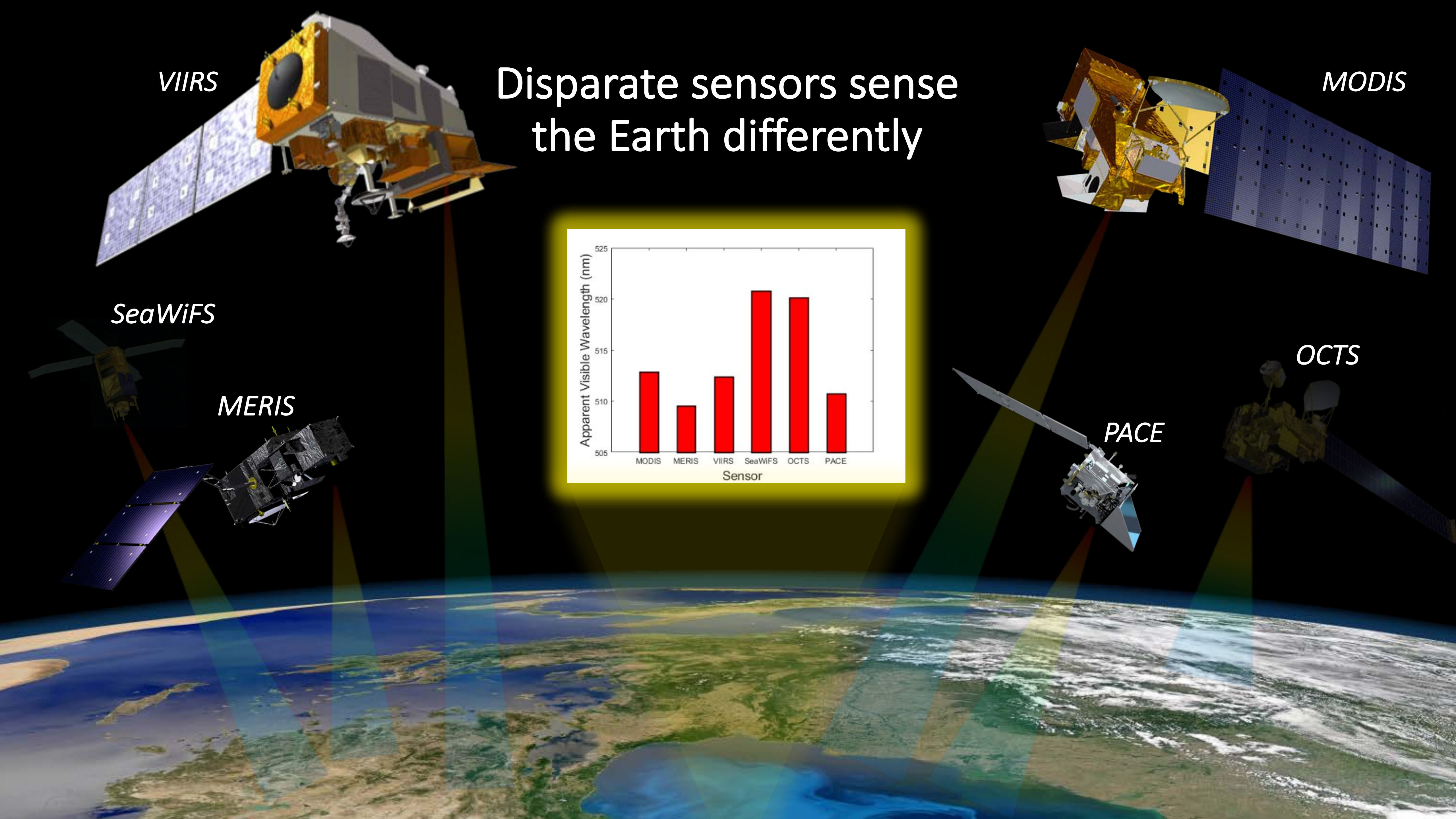
Backscatter components (Phytoplankton, Detrital Matter)





Similar $R_{rs}(\lambda)$ spectral shapes tend to converge along the AVW gradient, ultimately constrained by the finite amount of combinations of absorption and backscatter found in the natural world that create a particular $R_{rs}(\lambda)$ spectrum with an identical balance point.

Disparate sensors sense the Earth differently

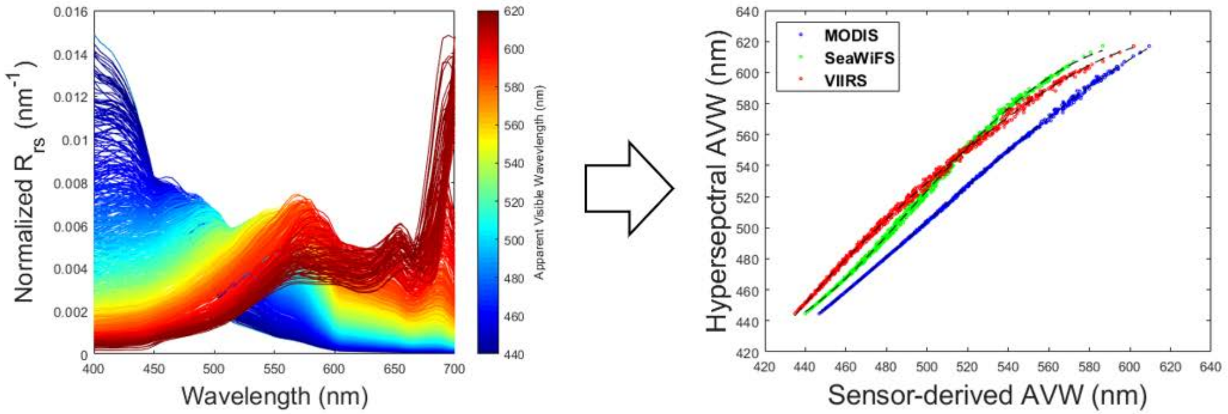


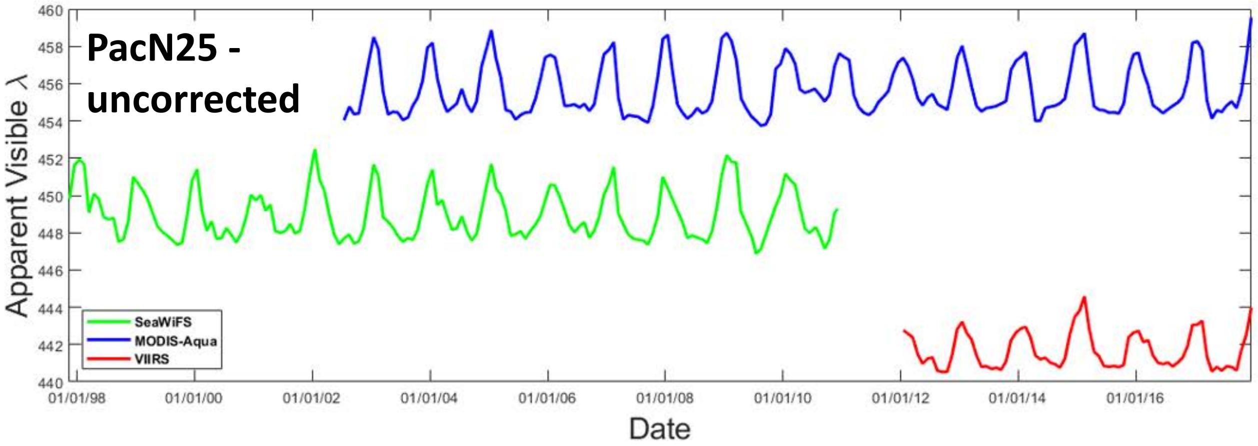
Deriving continuity in spectral shape from heritage sensors of disparate resolutions

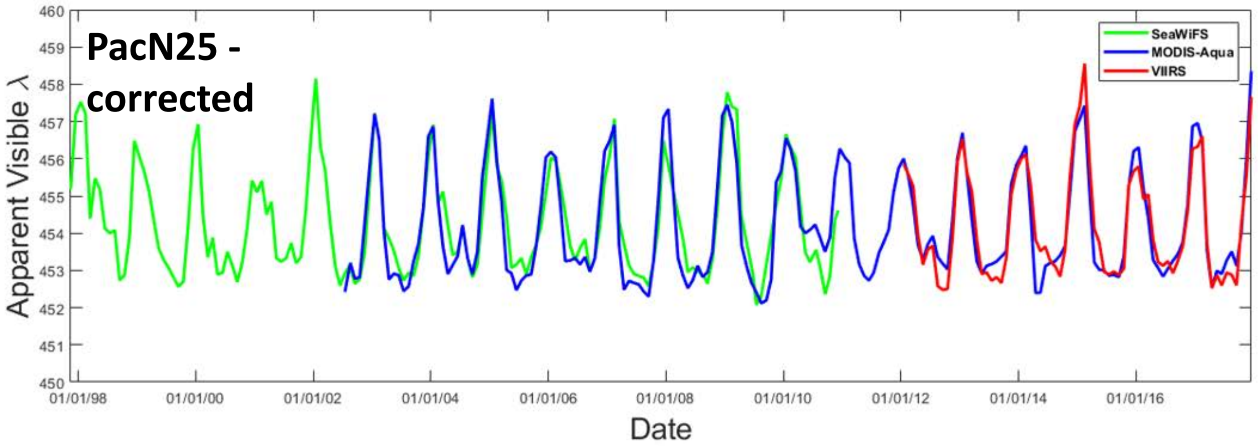
1) *$R_{rs}(\lambda)$ from each heritage sensor (SeaWiFS, MODIS-Aqua, and VIIRS) is reconstructed from the 720 IOCCG hyperspectral $R_{rs}(\lambda)$, using the Relative Spectral Response (RSR) functions for each sensor.*

2) *The AVW is calculated for hyperspectral data (only 400-700 nm, for compatibility), and compared to AVW from each sensor.*

3) *3rd or 4th polynomial fits are retained and applied to satellite data, enabling the analysis of comparable AVW values.*

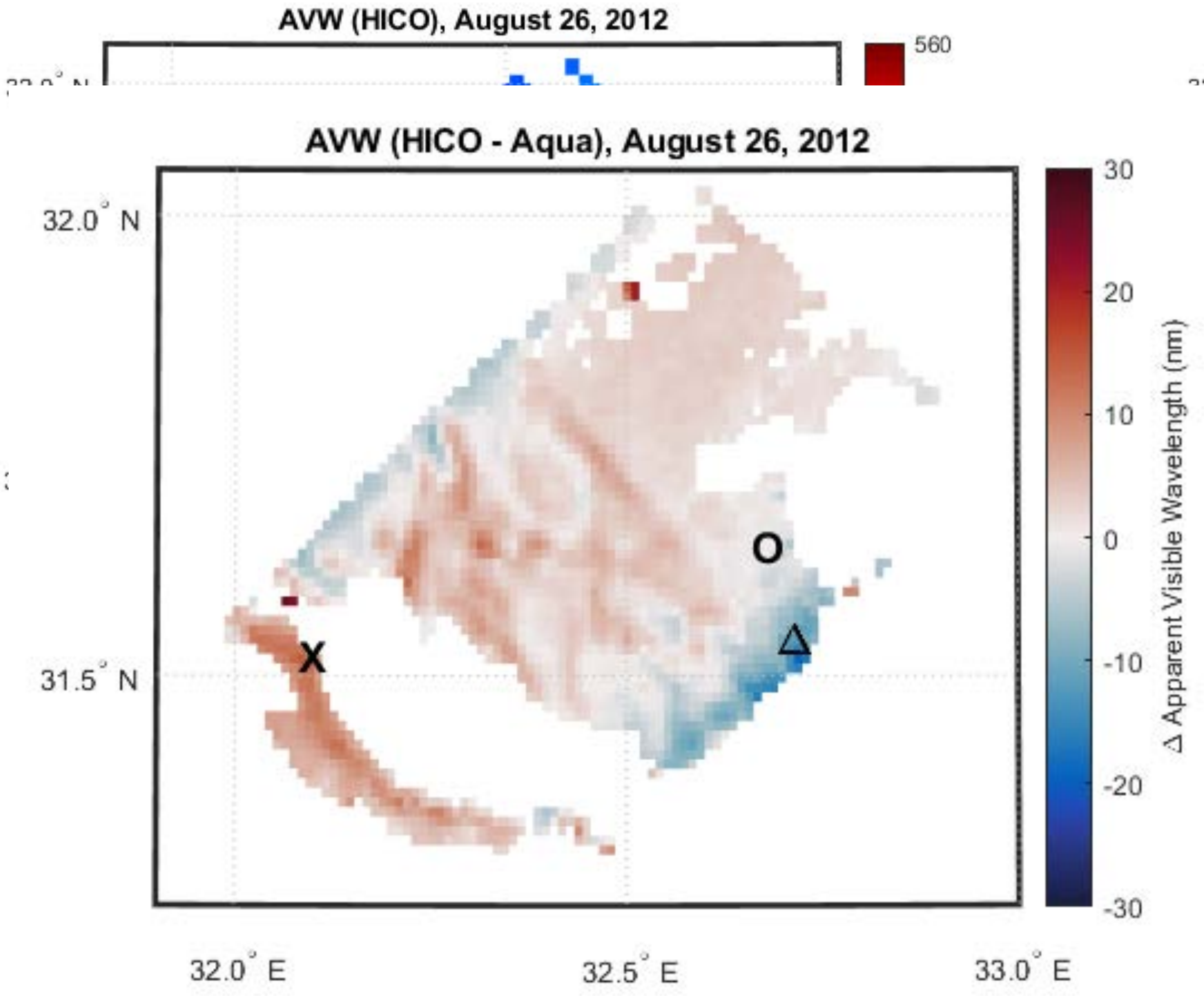




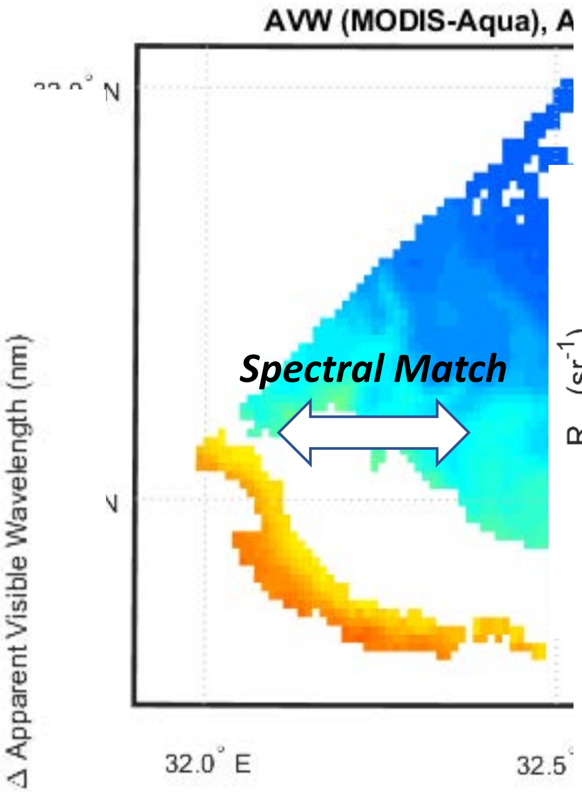


Sanity Check → test on independent Hyperspectra

The dimensionality reduction of spectral information can be used to easily match up where spectral information agrees/disagrees



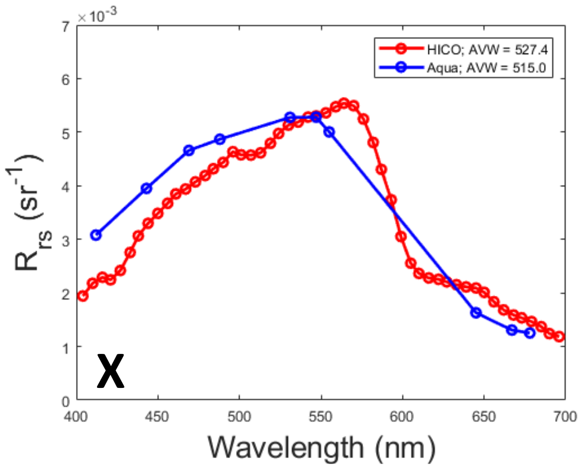
HICO is red-shifted

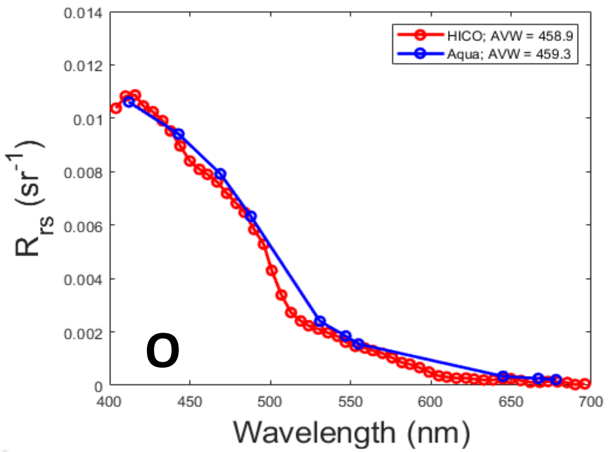


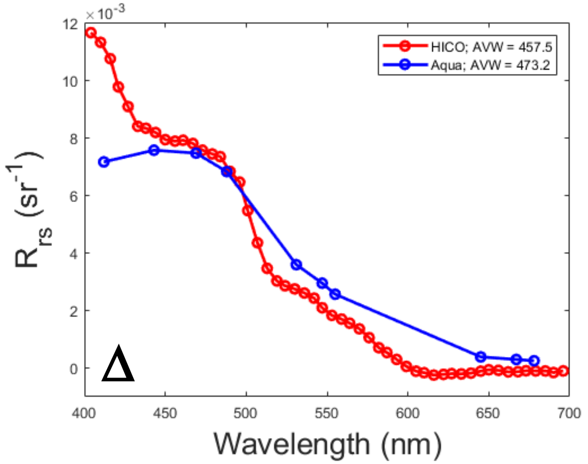
Spectral Match

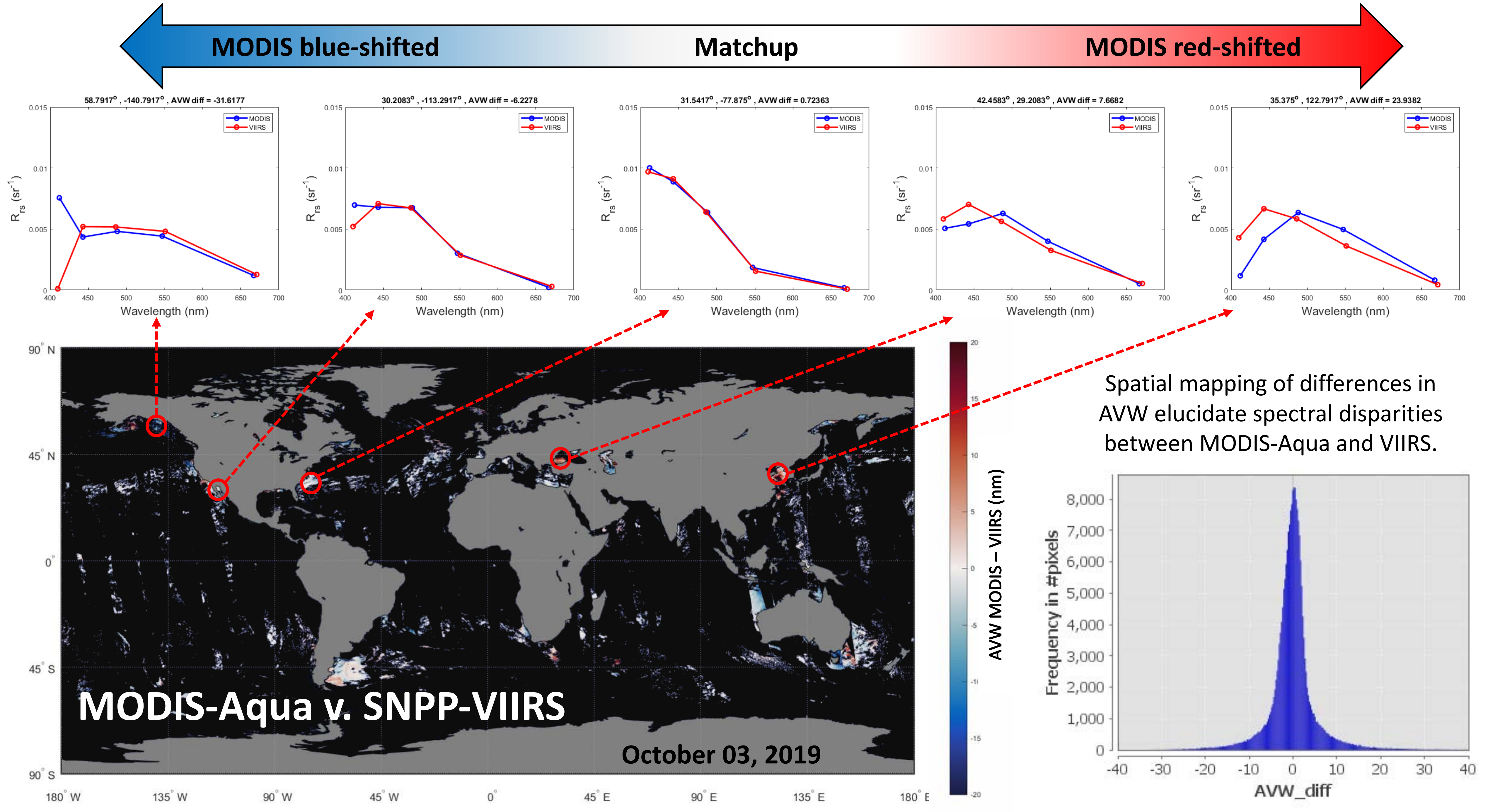
HICO is blue-shifted

…es look similar. …the two should …spectral shape.



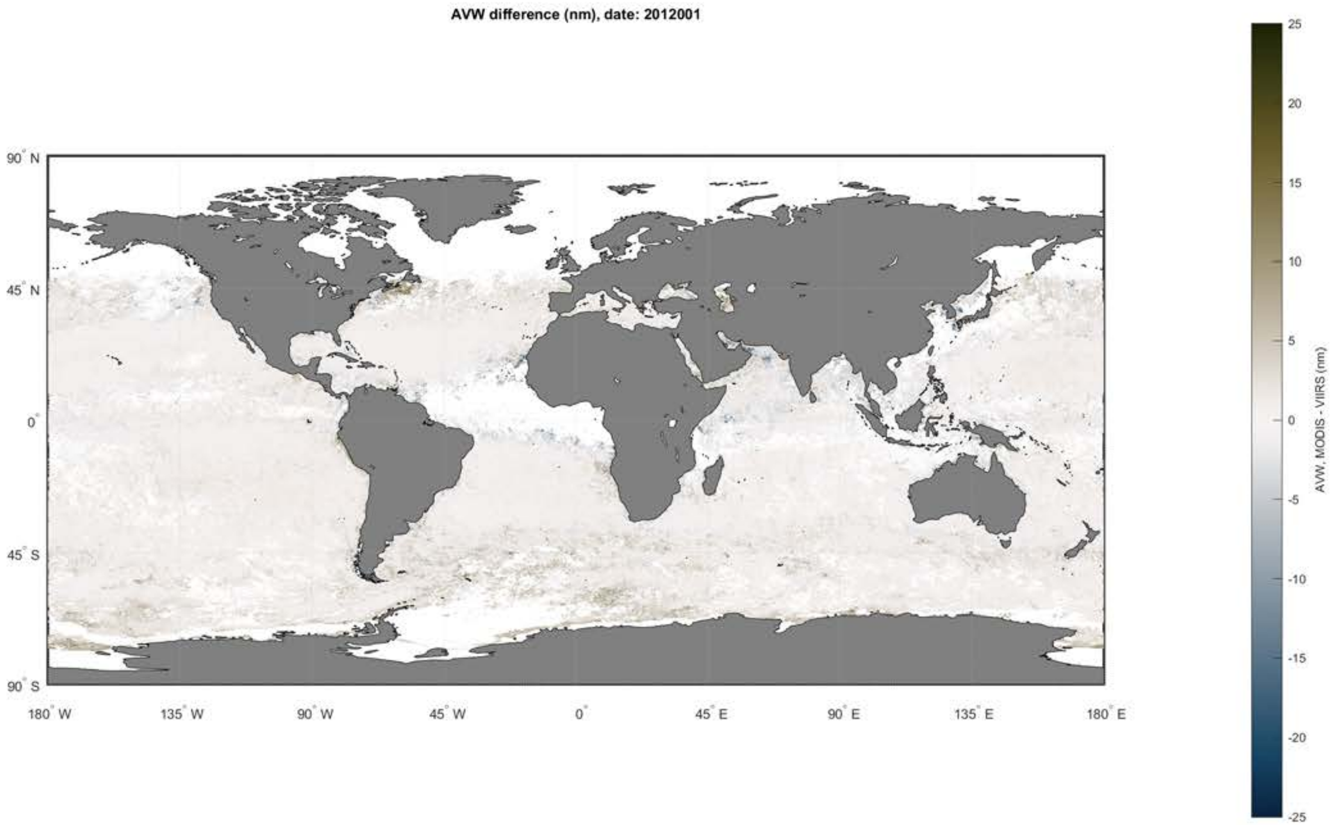


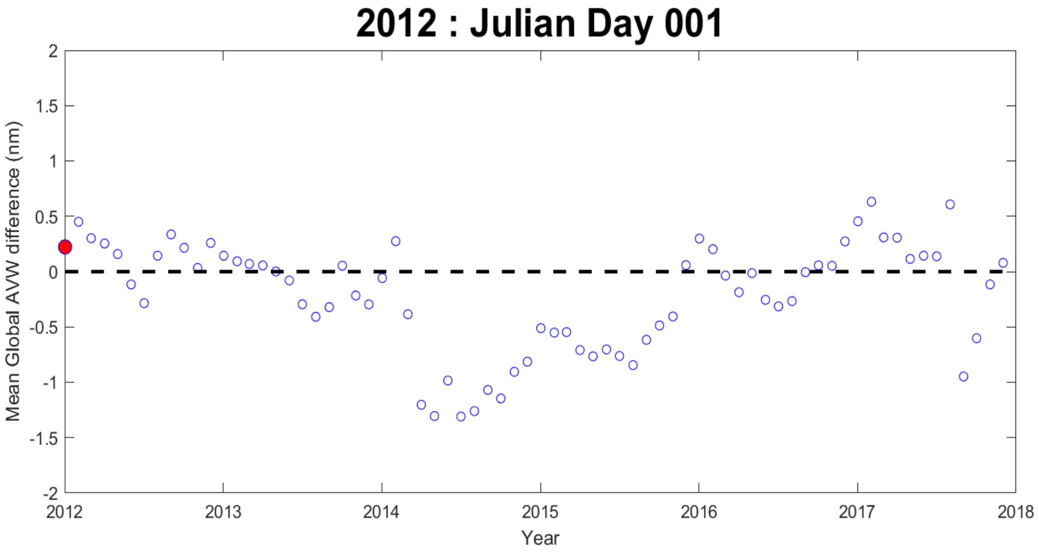


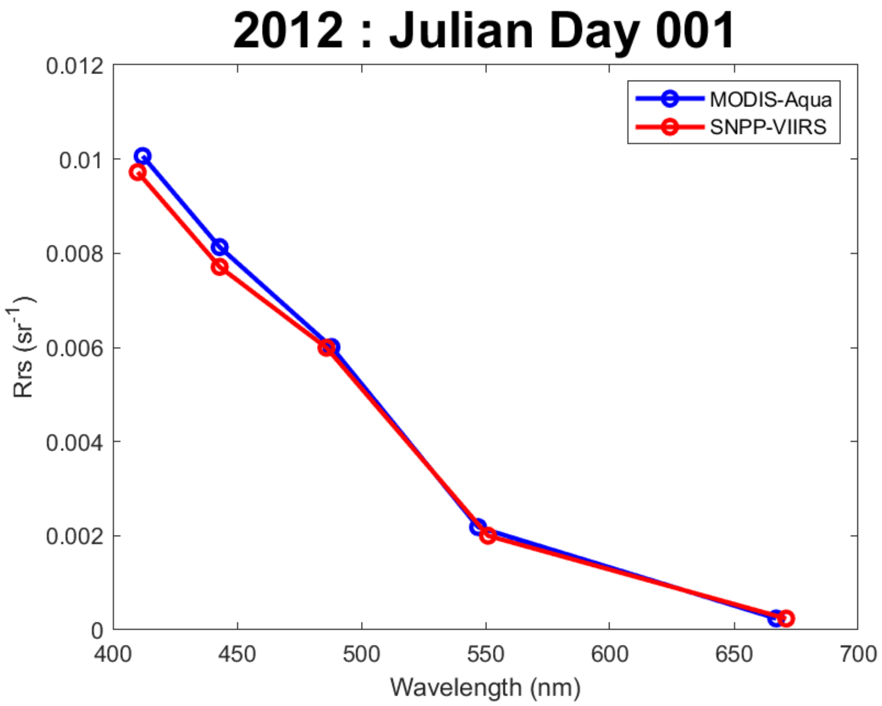


MODIS blue-shifted
Matchup
MODIS red-shifted
58.7917°, -140.7917°, AVW diff = -31.6177
30.2083°, -113.2917°, AVW diff = -6.2278
31.5417°, -77.875°, AVW diff = 0.72363
42.4583°, 29.2083°, AVW diff = 7.6682
35.375°, 122.7917°, AVW diff = 23.9382
MODIS
VIIRS
R_{rs} (sr^{-1})
Wavelength (nm)
Spatial mapping of differences in AVW elucidate spectral disparities between MODIS-Aqua and VIIRS.
AVW MODIS – VIIRS (nm)
Frequency in #pixels
AVW_diff
MODIS-Aqua v. SNPP-VIIRS
October 03, 2019

2012 – 2018 MODIS-Aqua v. SNPP-VIIRS differences in spectral shape

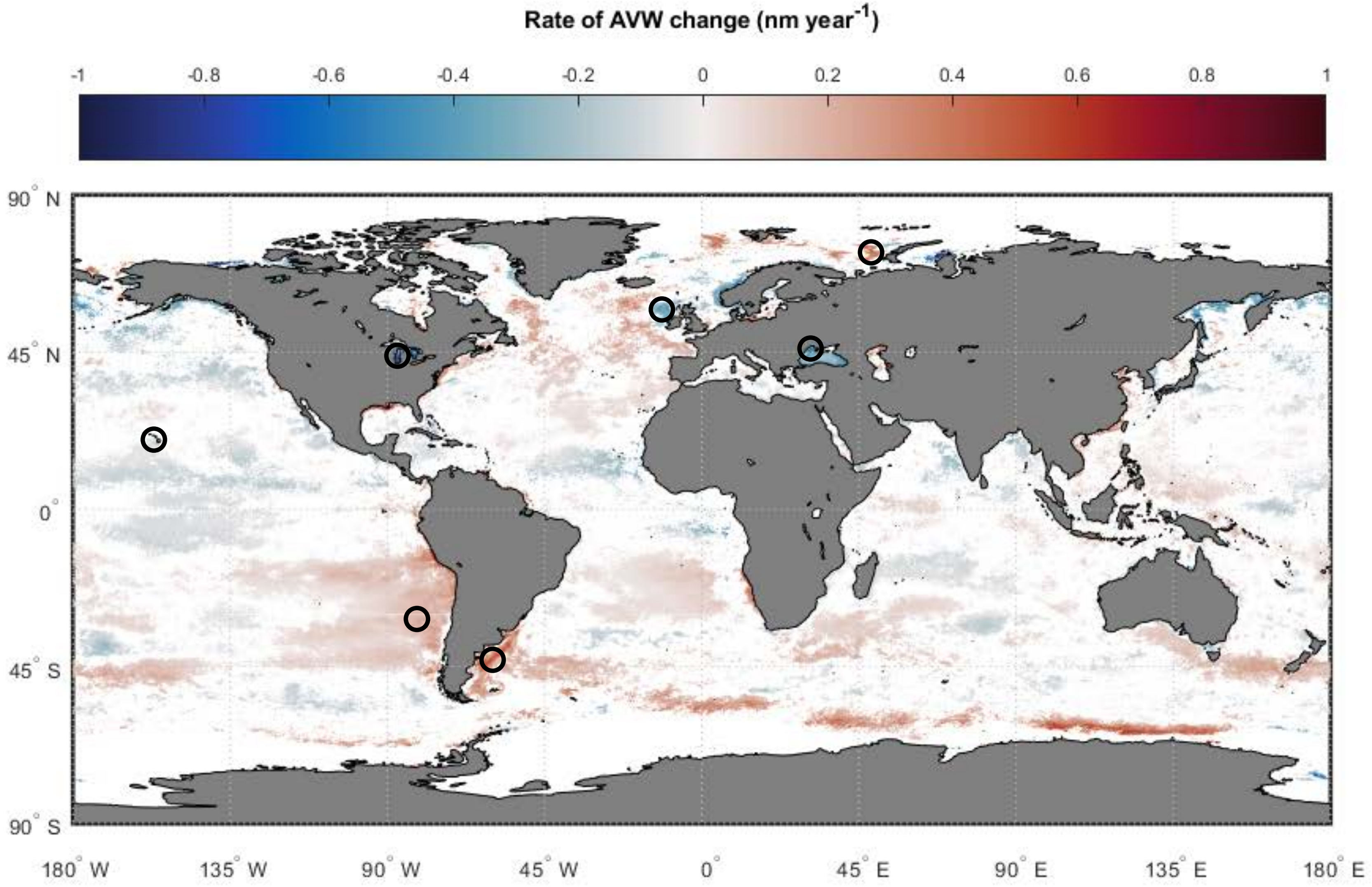


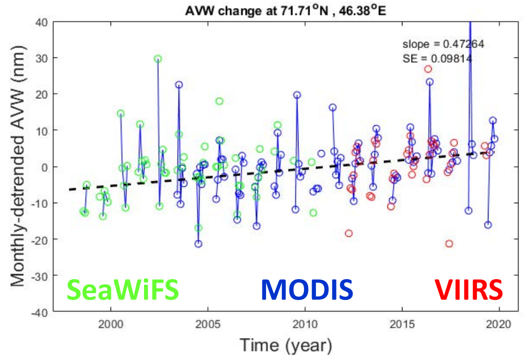


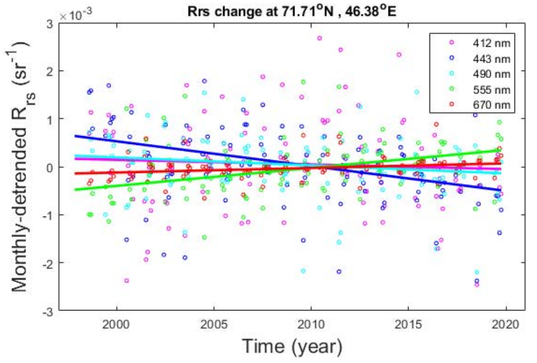


A monthly time series of the differences in spectral shape (AVW) will episodically shift lower, manifested as a blue-shift in MODIS-Aqua $R_{rs}(\lambda)$ relative to SNPP-VIIRS.

Elucidating spectral shifts over time (SeaWiFS → MODIS/VIIRS → PACE)



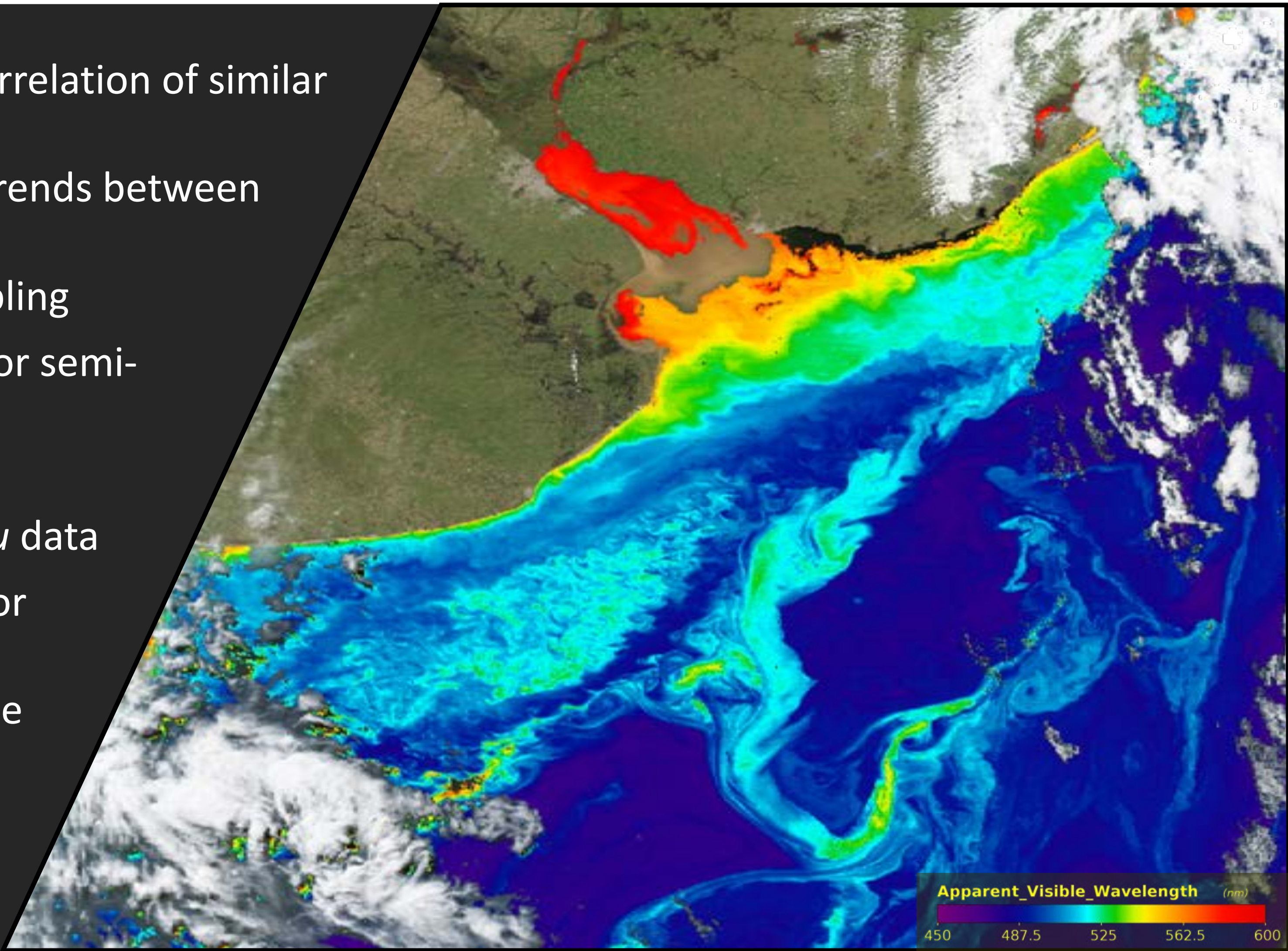




Robust Linear regression/time of AVW enables the examination of spectral shift in $R_{rs}(\lambda)$ over time

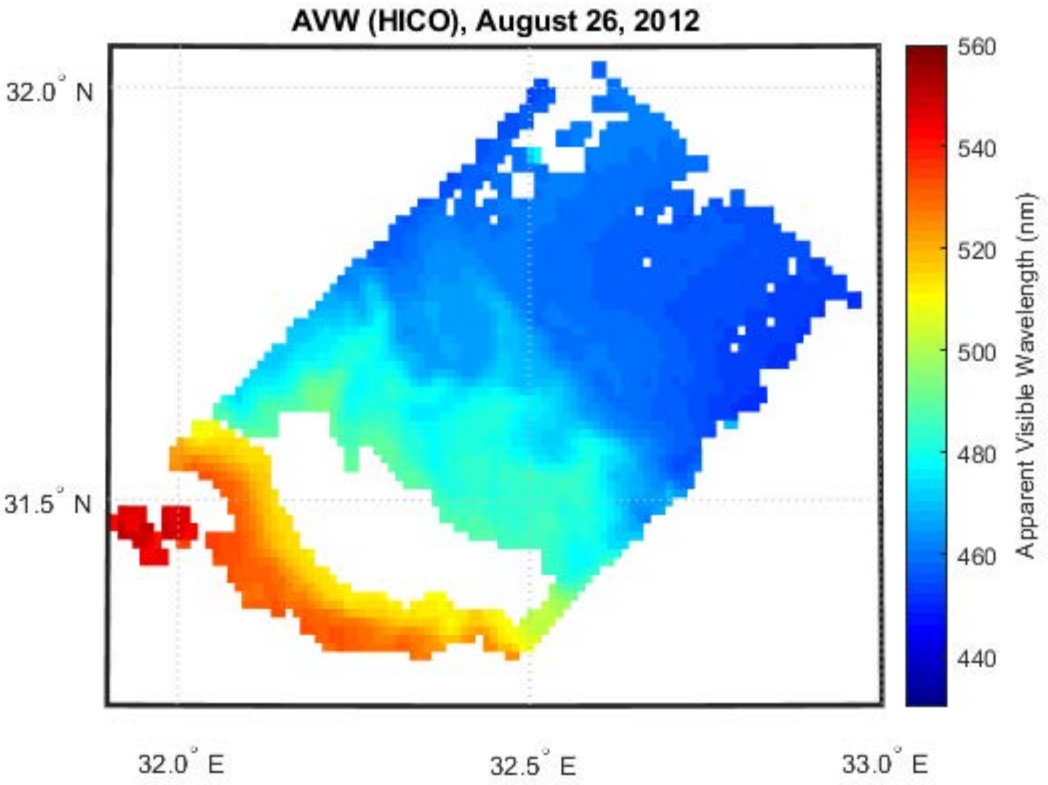
Applications

- Identification of optical water types (OWT), correlation of similar water types on global scales
- Global spectral matching function to analyze trends between disparate sensors.
- Analysis of spectral variance for targeted sampling
- Potential improvements to parameterization for semi-analytical inversions
- A useful climatological metric of change
- Useful for display of multi/hyperspectral *in situ* data
- Implementation of decision tree approaches for algorithm development
- Quality control check of algorithm performance (e.g. erratic spectral shapes)
- When used in tandem with other biophysical parameters, PFT and/or water-type distinction

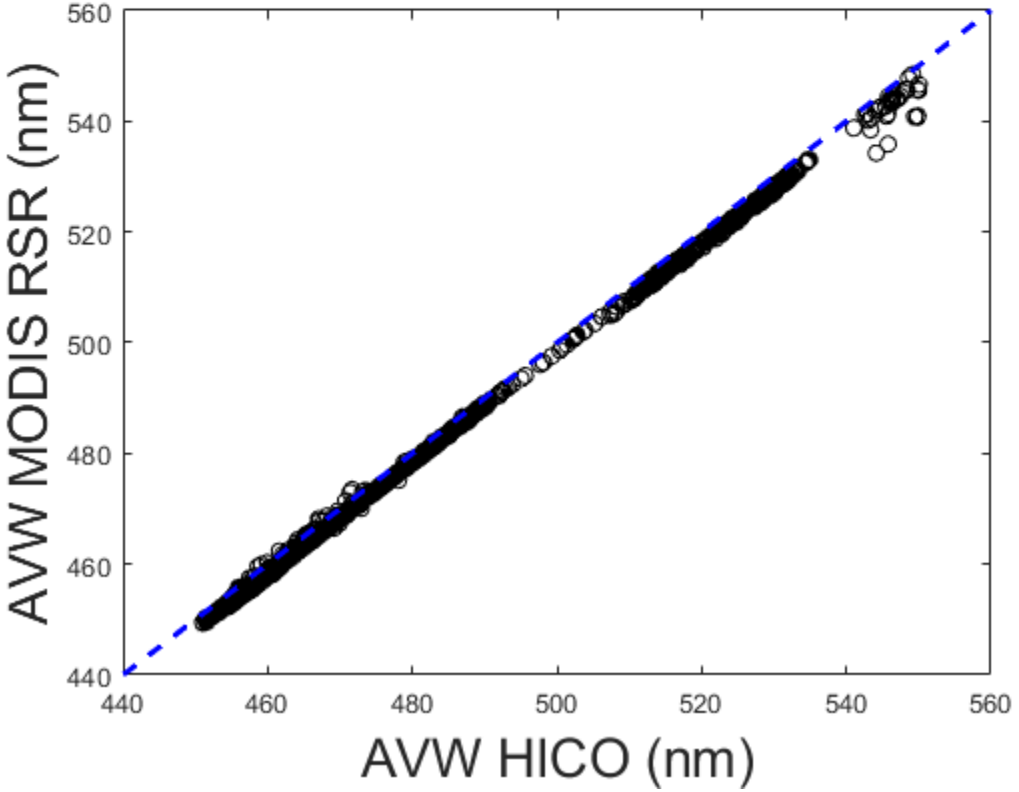


Extras

Sanity Check → test on independent Hyperspectral dataset

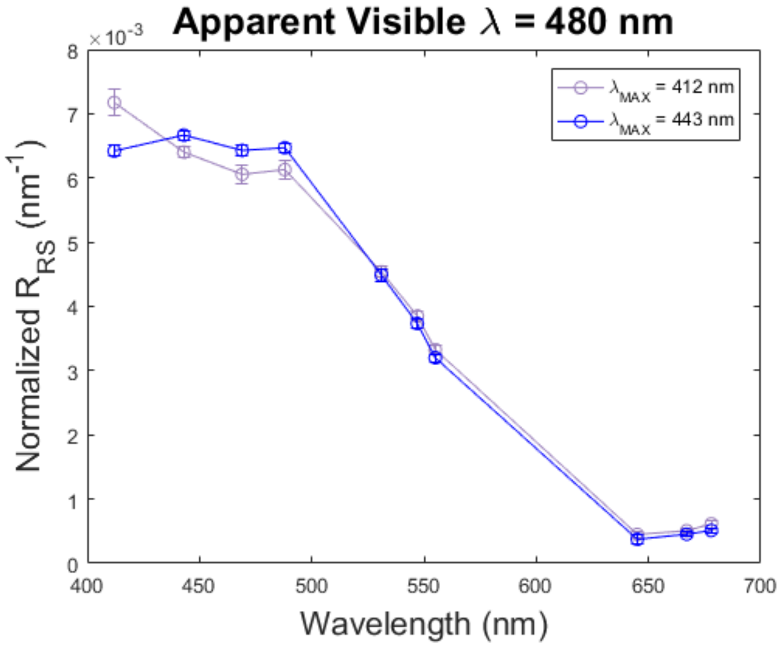


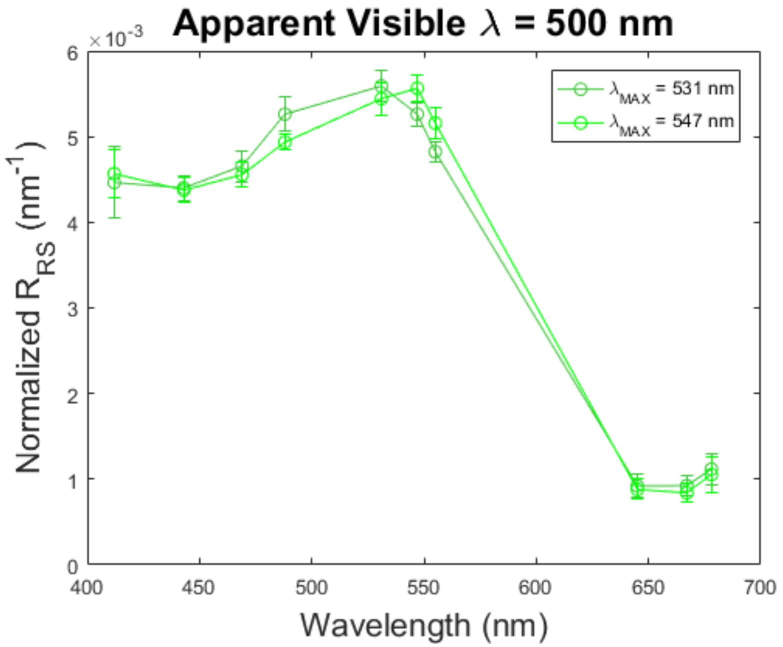
*A hypothetical AVW for MODIS is calculated from **HICO** data, by applying MODIS RSRs. This serves as an independent check on the quality of the polynomials.*

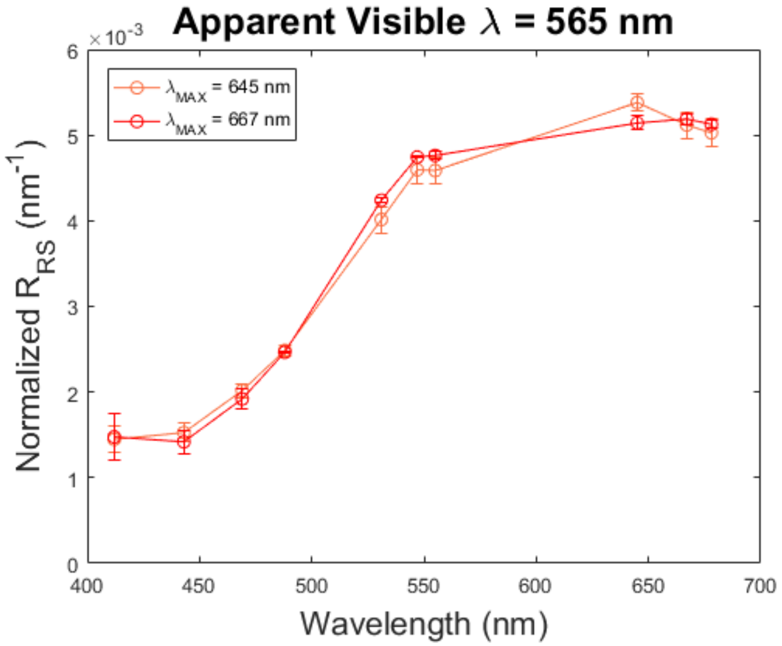


Since the values are vary similar, we should be able to directly compare an actual MODIS image to a HICO image to examine spectral shifts relative to one another.

Uncertainty in *AVW* to represent spectral shape can lead to Type II, but not Type I errors

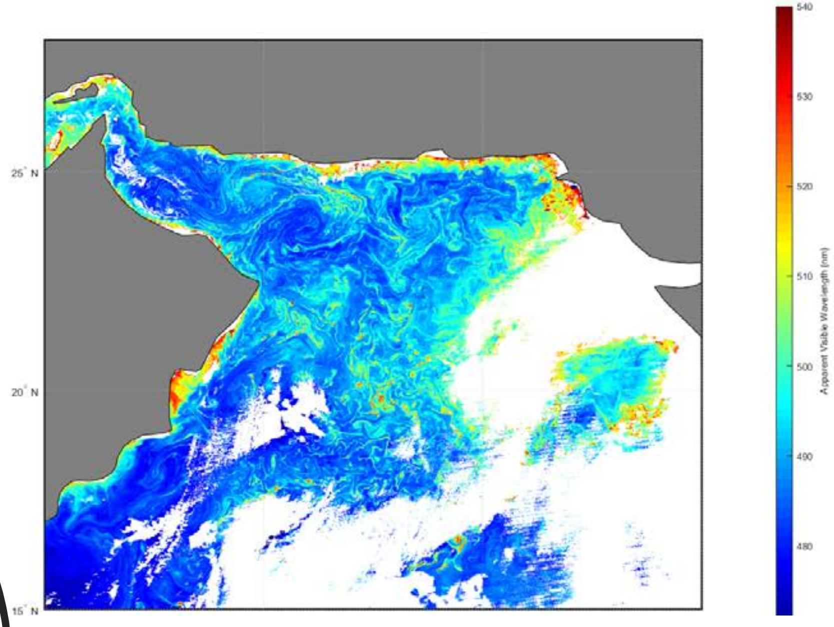


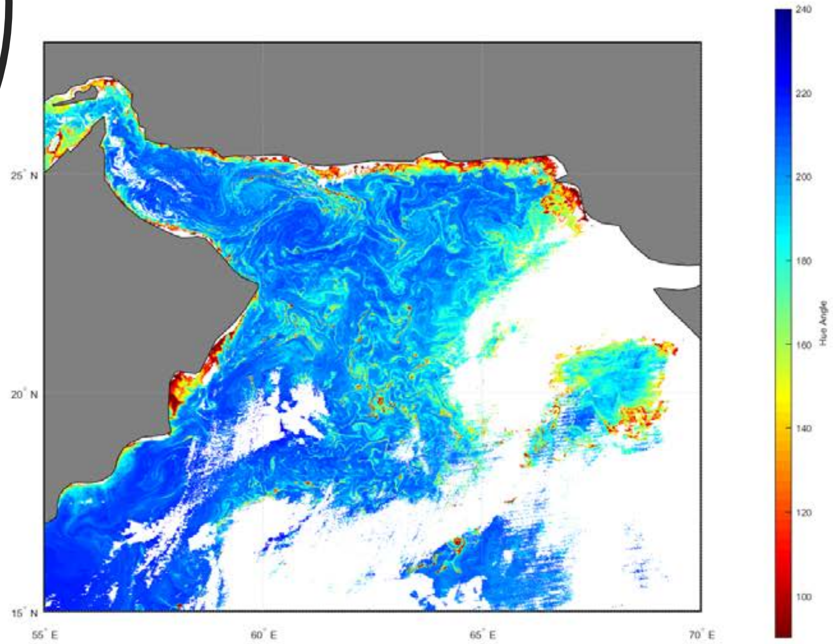


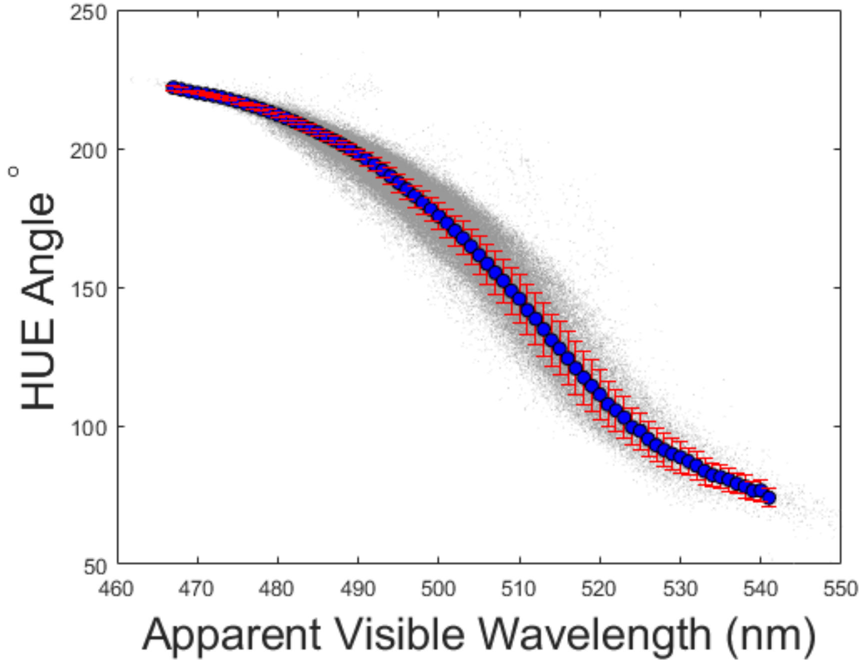


One further step of classification by the wavelength of maximum reflectance (λ_{max}) can help alleviate Type II errors and further reduce uncertainty by a factor of 5.

AVW v.
Hue Angle

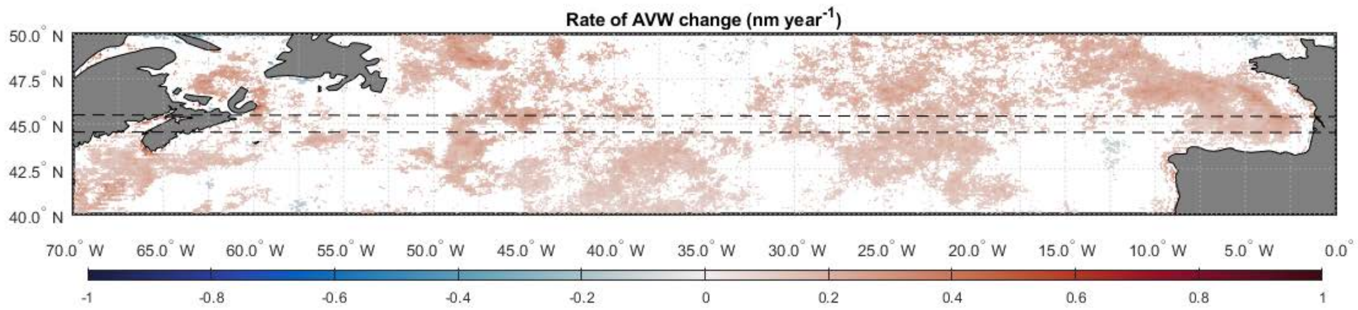


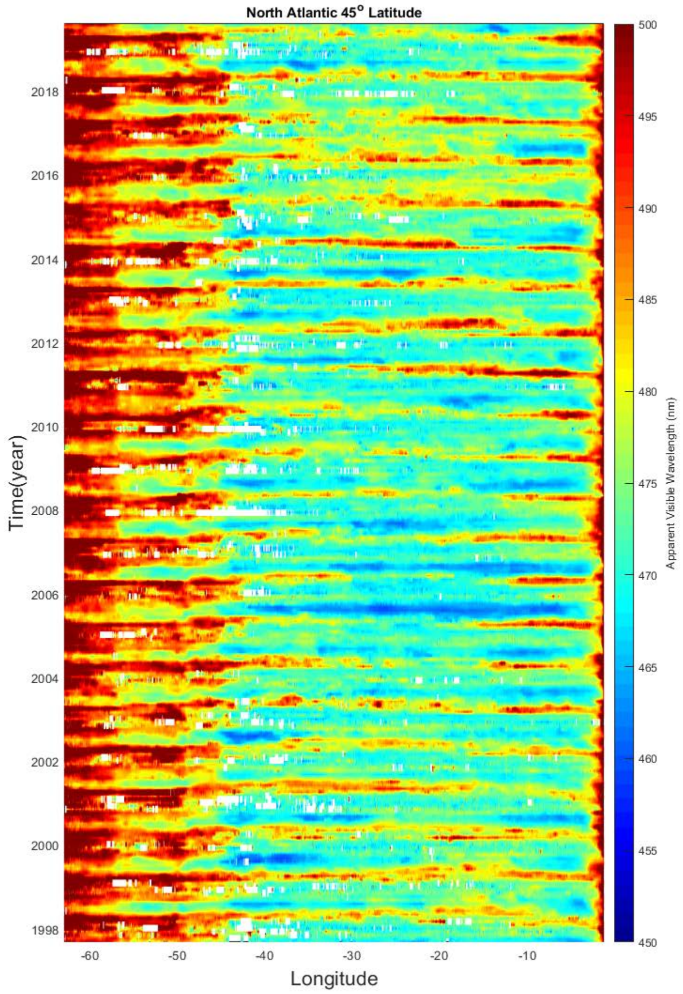


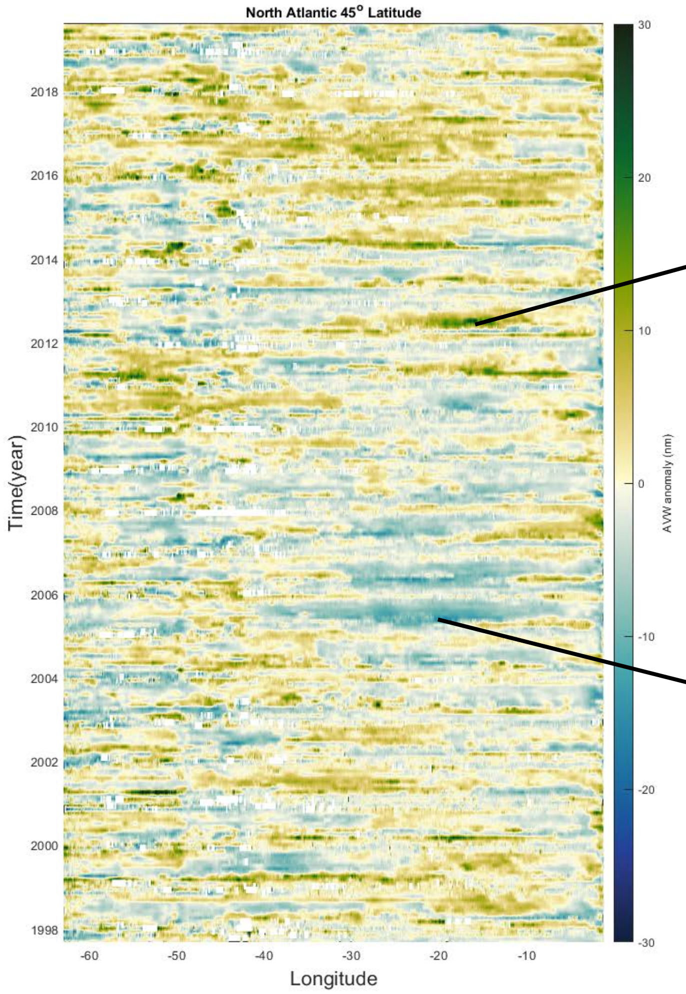


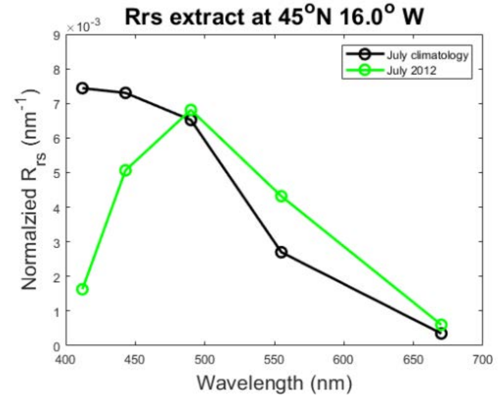
On average, each 1-nm increment of AVW has a mean absolute deviation of 3.09 hue angle degrees. The disparities between the two are likely a function of the RSR of the human eye not being sensitive to far blue/far red portions of the spectrum.

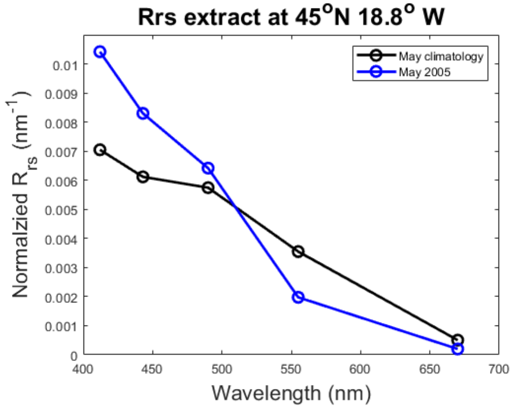
Hovmöller diagrams can lend enhanced insight into the spatio-temporal distribution of $R_{rs}(\lambda)$.











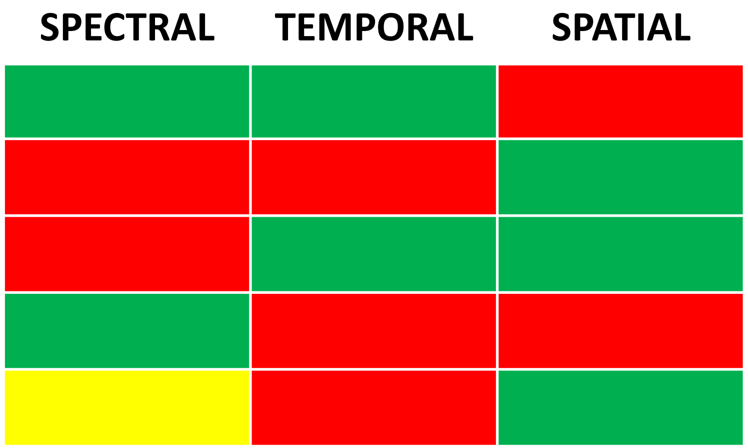
Potential Discards

The challenge:

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 spectral data:

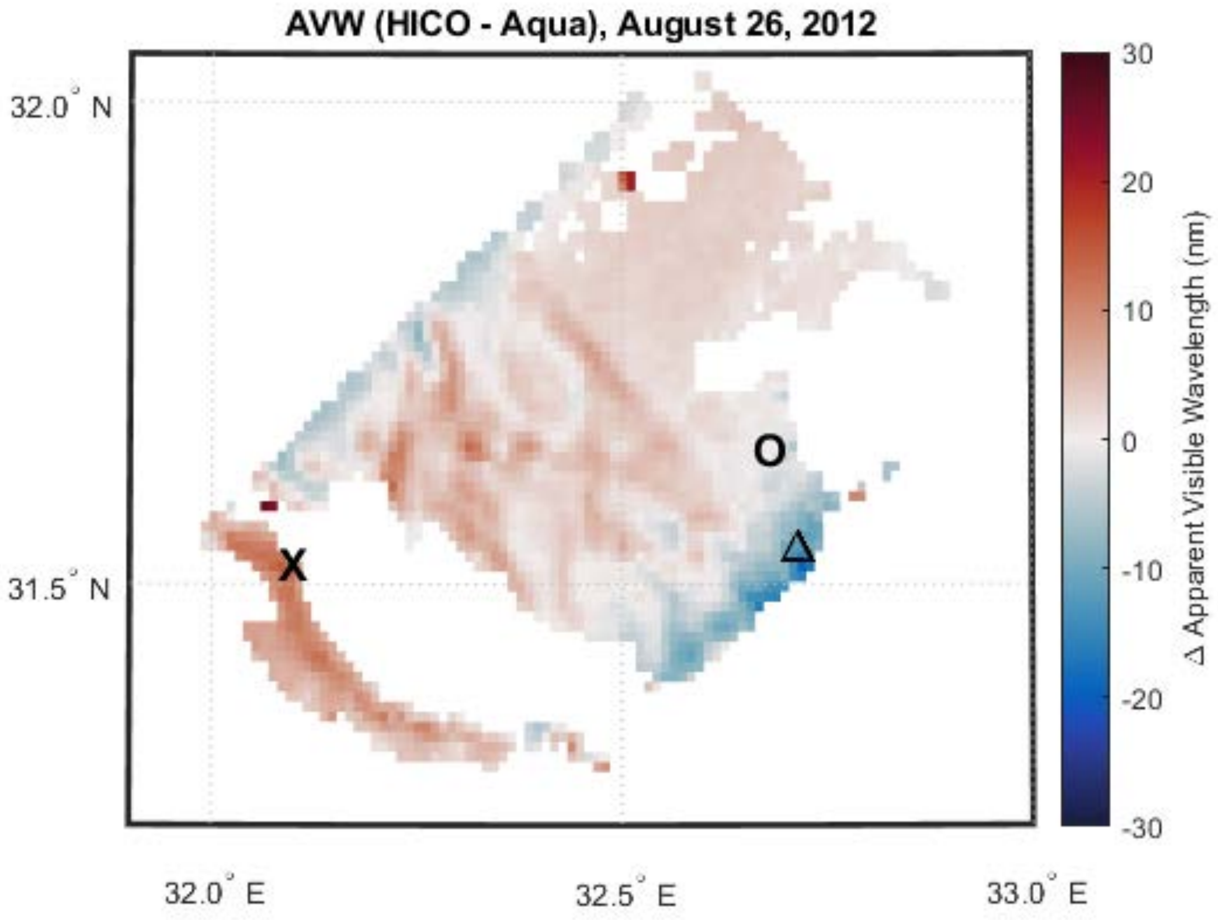
- *Multiple $R_{RS}(\lambda)$ from* ***one*** *pixel/ROI plotted over time*
- ***One*** *$R_{RS}(\lambda)$ or product (chlor_a), mapped in 2 dimensions*
- *Δ time (animation), but only for* ***one*** *product/λ at a time*
- *Multiple $R_{RS}(\lambda)$ scatter plot over region of interest*
- *RGB image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



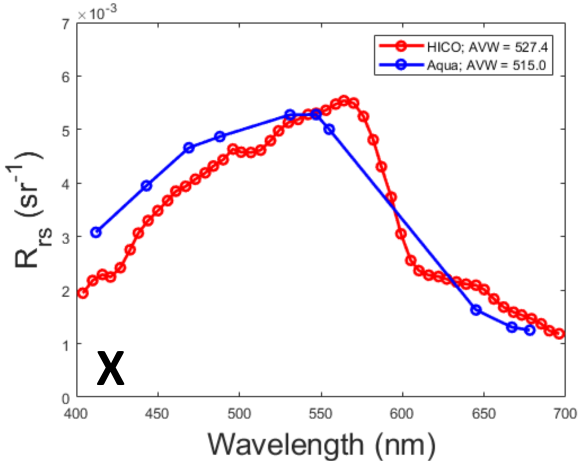
How can quantify and analyze the differences between multiple layers of spectral information within the context of a two-dimensional image?

Good news, it's been done…

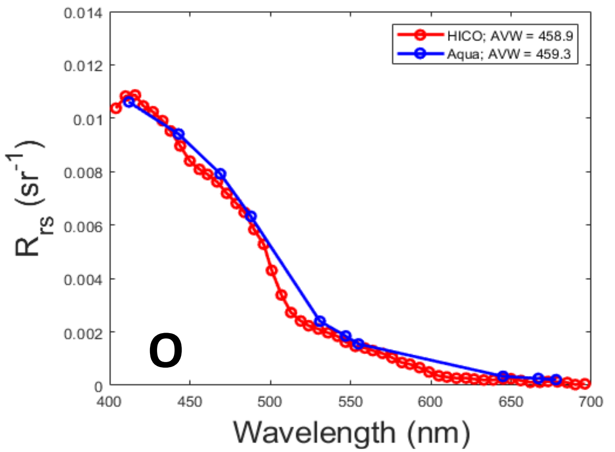
The dimensionality reduction of spectral information can be used to easily match up where spectral information agrees/disagrees



HICO is red-shifted



Spectral Match



HICO is blue-shifted