Characterization of Water Reflectance Spectra Variability: Implications for Hyperspectral Remote Sensing in Estuary Waters

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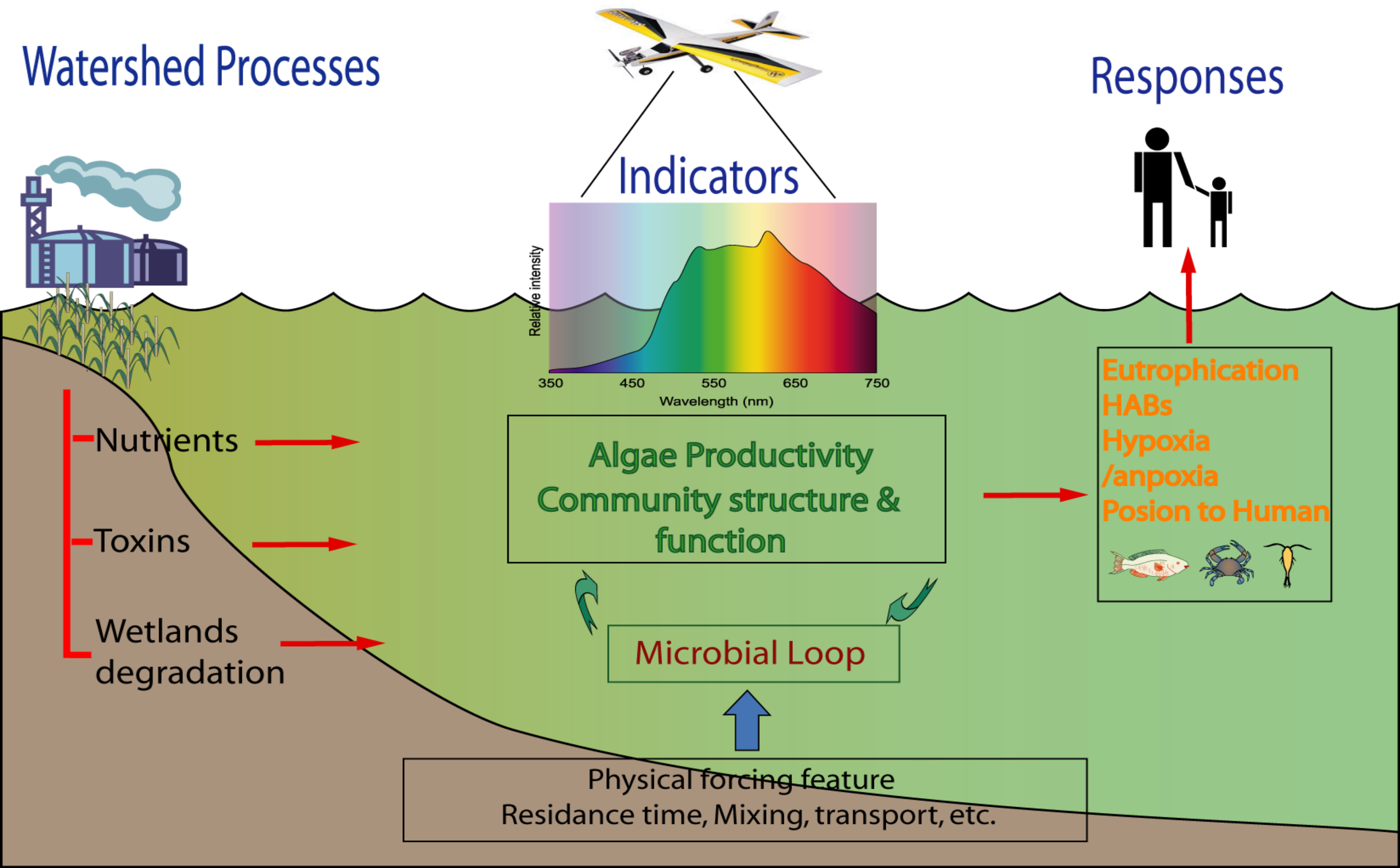
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

NSF

Presentation outline

- Review of remote sensing in case 2 water: problems and challenges.
- Introduction of NOAA supported Environmental Cooperative Science Center (ECSC)
- Study area, Methods and materials
- Results.
- Discussion and implication to water quality monitoring in coastal waters.
- On going and future works.

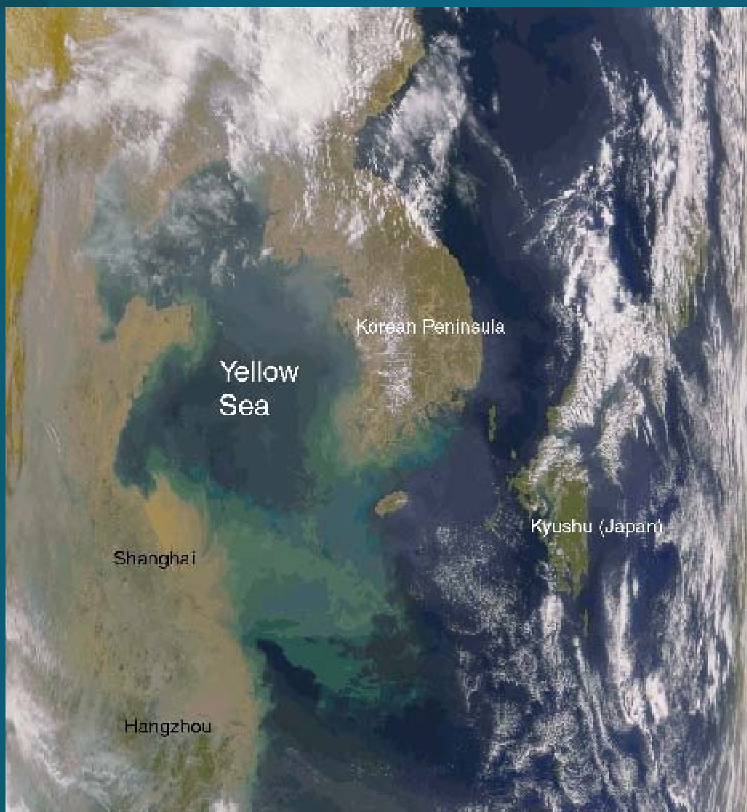
Remote sensing of estuarine ecosystem

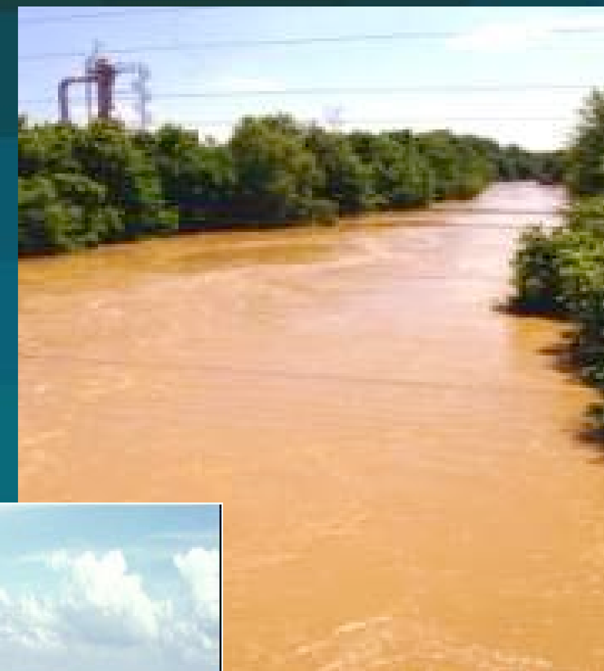


Challenges of remote sensing in Coastal Waters

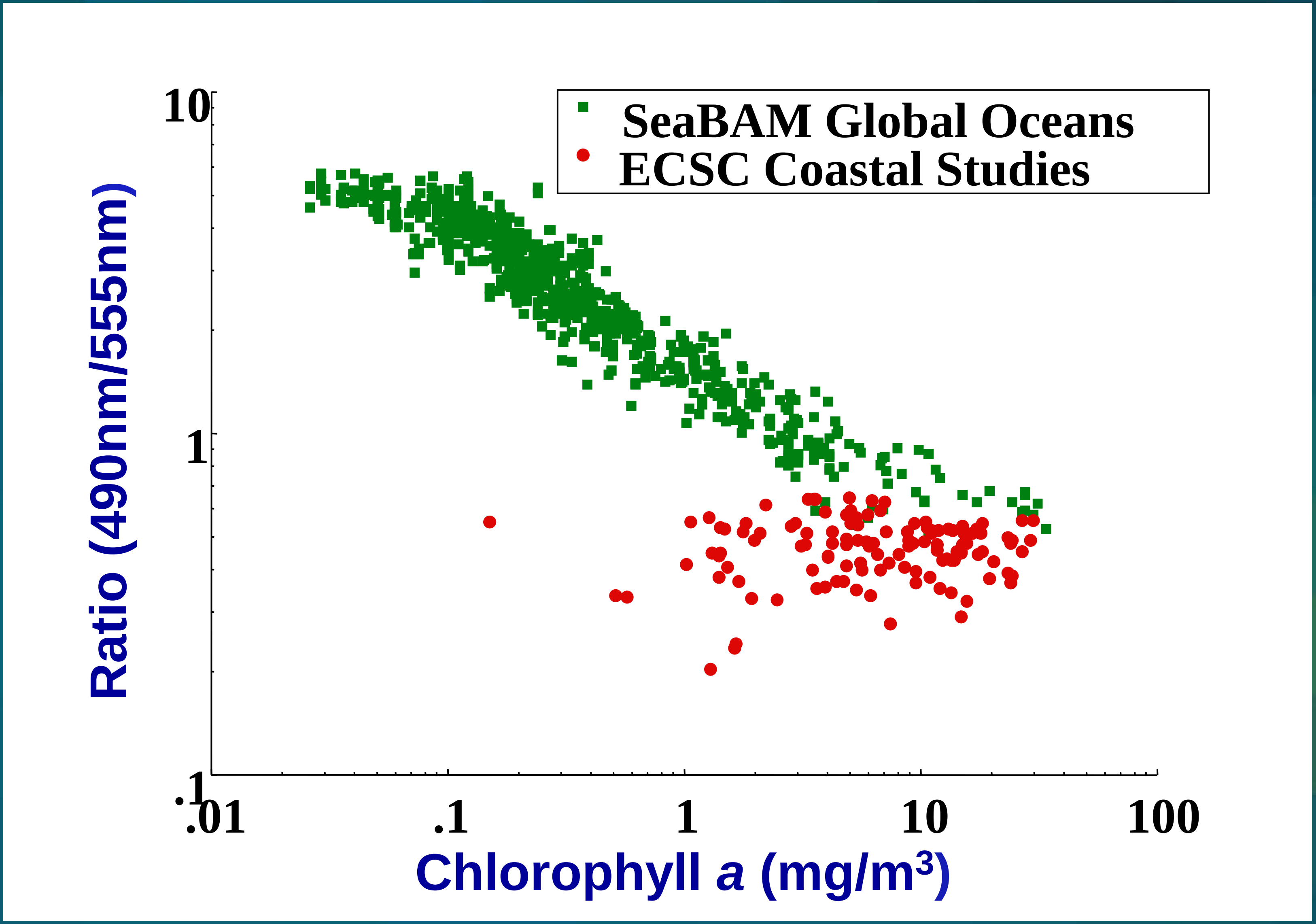
- Coastal waters are optically complex and the signal that a remote detector collects is a mixed signal including various water optically active constituents (Chla, TSS and CDOM) from different sources.
- Complex interaction among phytoplankton (chlorophyll), TSS and CDOM resulted in poor predictive ability in retrieval of various water quality proprieties in coastal waters.

Challenges of remote sensing in Coastal Waters

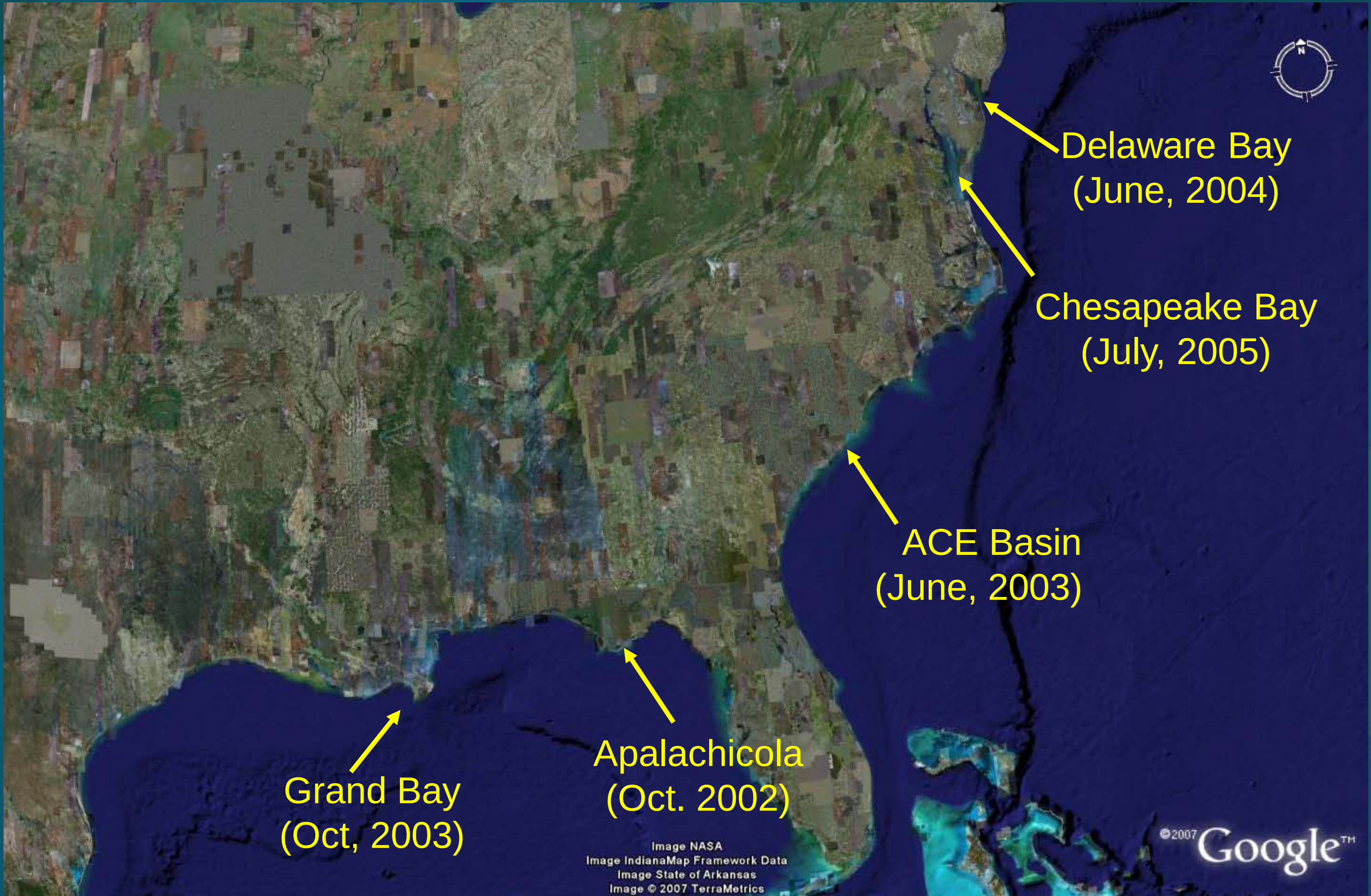




Poor predictive ability in retrieval of Chl *a* Concentration in coastal waters



Hyperspectral remote sensing missions
--- by NOAA supported Environmental Cooperative Science Center



NOAA Supported Environmental Cooperative Science Center (ECSC)

- The ECSC was established in 2001 as part of NOAA's Education Partnership Program to address ecological and coastal management issues at specific National Estuarine Research Reserves (NERR).

- Director: Dr. Larry Robinson

- ECSC Website:
- http://www.ecsc.famu.edu

The ECSC has four primary and interrelated goals:

- Increase the number of scientists, particularly from under-represented minority groups in the environmental, coastal, and oceanic sciences;
- Enhance the scientific understanding of human interactions with the coastal environment, particularly through integrated assessments in support of NOAA's place-based management;
- Improve the scientific bases for coastal resource management through applications on systems of interest to NOAA; and
- Facilitate community education and outreach relating to the function and significance of coastal ecosystems

NOAA ECSC Member Institutions and Affiliated Study Sites

Center Institution	*Partner National Estuarine Research Reserve or Sanctuary*
Florida A&M University	**Apalachicola Bay NERR**
Delaware State University	**Delaware NERR**
Jackson State University	**Grand Bay NERR**
Morgan State University	**Chesapeake Bay NERR**
Texas A&M University	**Mission-Aransas NERR**
University of Miami	**Florida Keys National Marine Sanctuary**
Creighton Univ / Univ of Nebraska	**Remote sensing projects with each ECSC school and NERR Partner**

Study area
Methods and materials

Study Area:
Hyperspectral remote sensing missions

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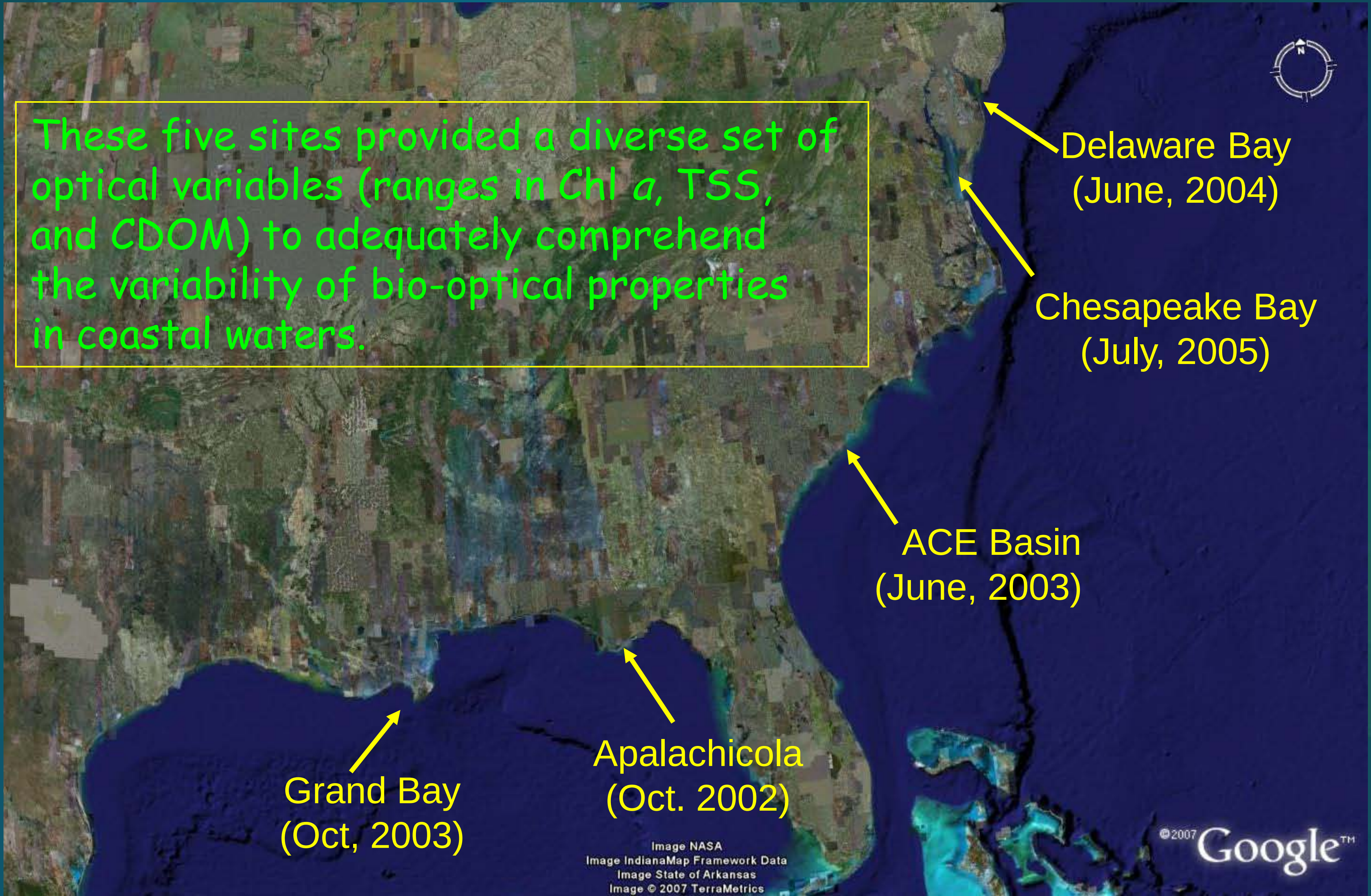
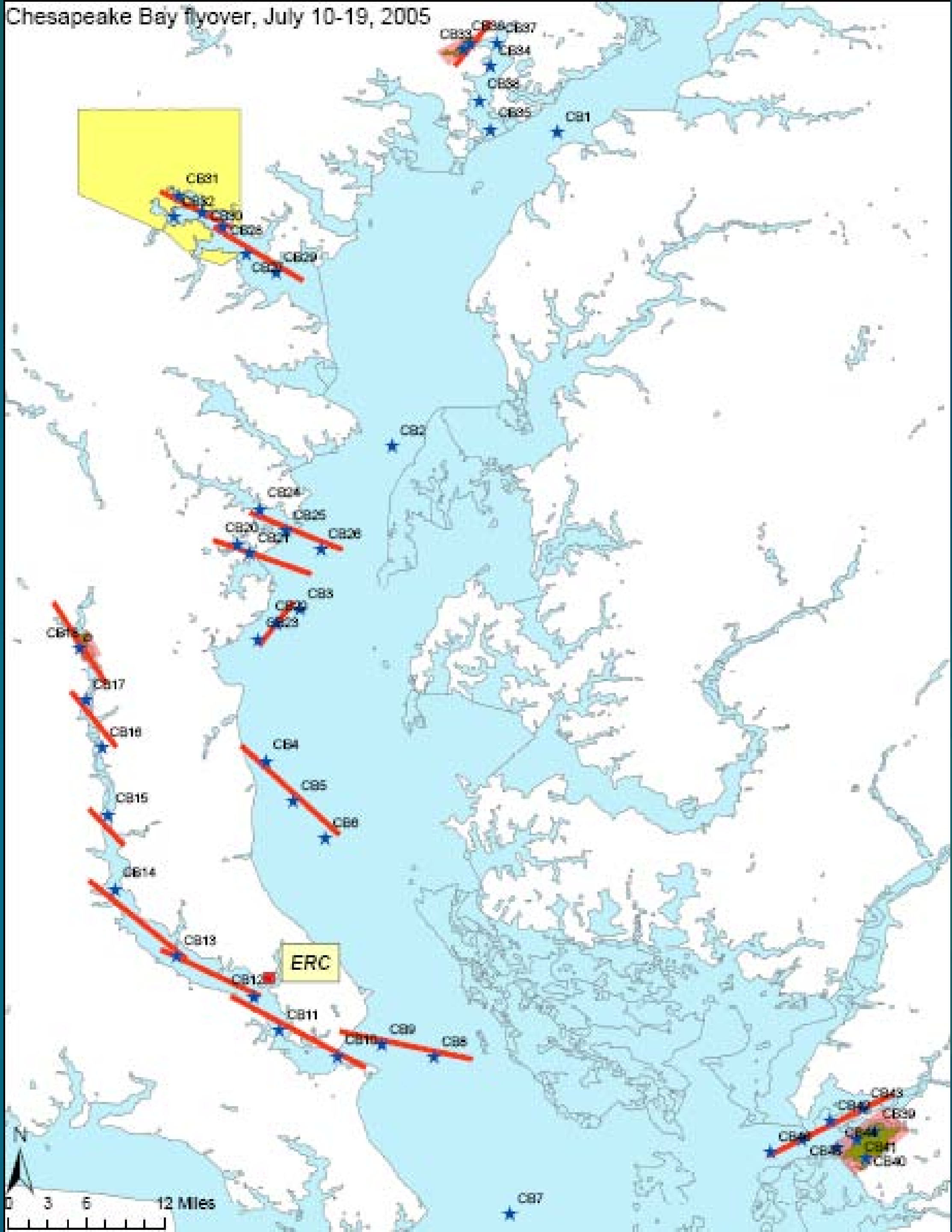
These five sites provided a diverse set of optical variables (ranges in Chl *a*, TSS, and CDOM) to adequately comprehend the variability of bio-optical properties in coastal waters.



Ground-truthing stations in the Chesapeake Bay flyover



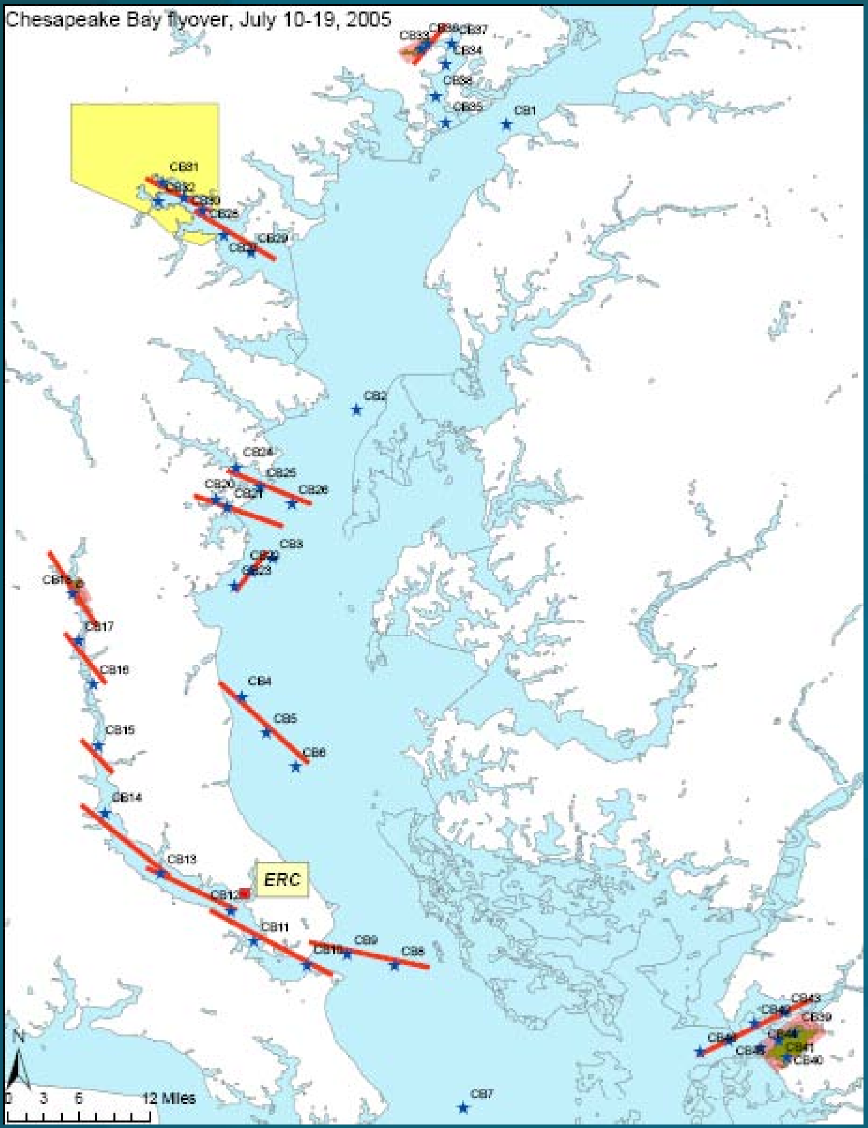
Field spectrometry

- Reflectance (R) is measured using a pair of Ocean Optics USB 2000 spectrometers
- Light brought to instruments with pair of fiber optic cables. Downwelling (E_d) and Upwelling (L_w) Cables
- $R = L_w / E_d$

Other measurements of optically active constituents (OACs)

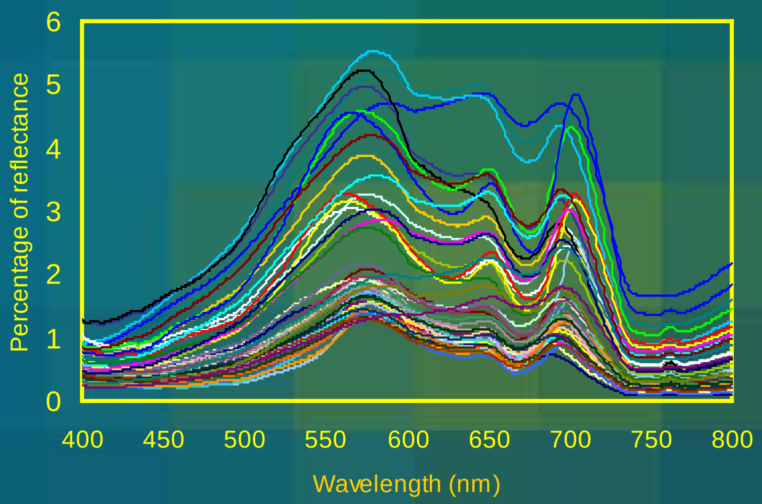
- Chl *a* was extracted using 90% acetone and measured with a Spectronic Genesys II spectrophotometer.
- Total suspended solids analysis was performed by filtering water samples on pre-weighed filters, which were then placed in a drying oven at 70°C for 24 hours and reweighed.
- The CDOM absorbance was measured in quartz cuvettes (10 cm path length) at 40 nm intervals between 320 nm and 580 nm using the Genysis II Spectrophotometer.

Diversity of optically active constituents (OACs)



Chl a range: 1.26 - 235.6 ug/L
TSS range: 5.93 - 113.19 mg/L
CDOM absorption at 440nm: 0.1 - 21.8

Reflectance spectra



Research Objectives

- Characterize the general variability of the *in situ* water reflectance spectra R(λ)
- Explore the mechanism of how optically active constituents in coastal waters could influence the variability of reflectance spectra.
- and Provide a framework for hyperspectral remote sensing of water quality in optically complex coastal environments

Statistical Method - Principal component analysis (PCA)

- PCA analysis was used for assessing the variance structure of spectral measurements
- Reflectance values R(λ) from 400 -800 nm derived from Ocean Optics USB2000 were included, and were further normalized to 10 nm interval
- So each spectrum in the PCA represented a vector, with 40 elements, which can be treated as an observation of a 40 dimensional stochastic variable at different wavelengths.
- The reflectance R(λ) dataset (matrix) can thus be thought as *n* observations, where *n* is the number of the reflectance spectrum (151) obtained from ground-truthing stations.

Results

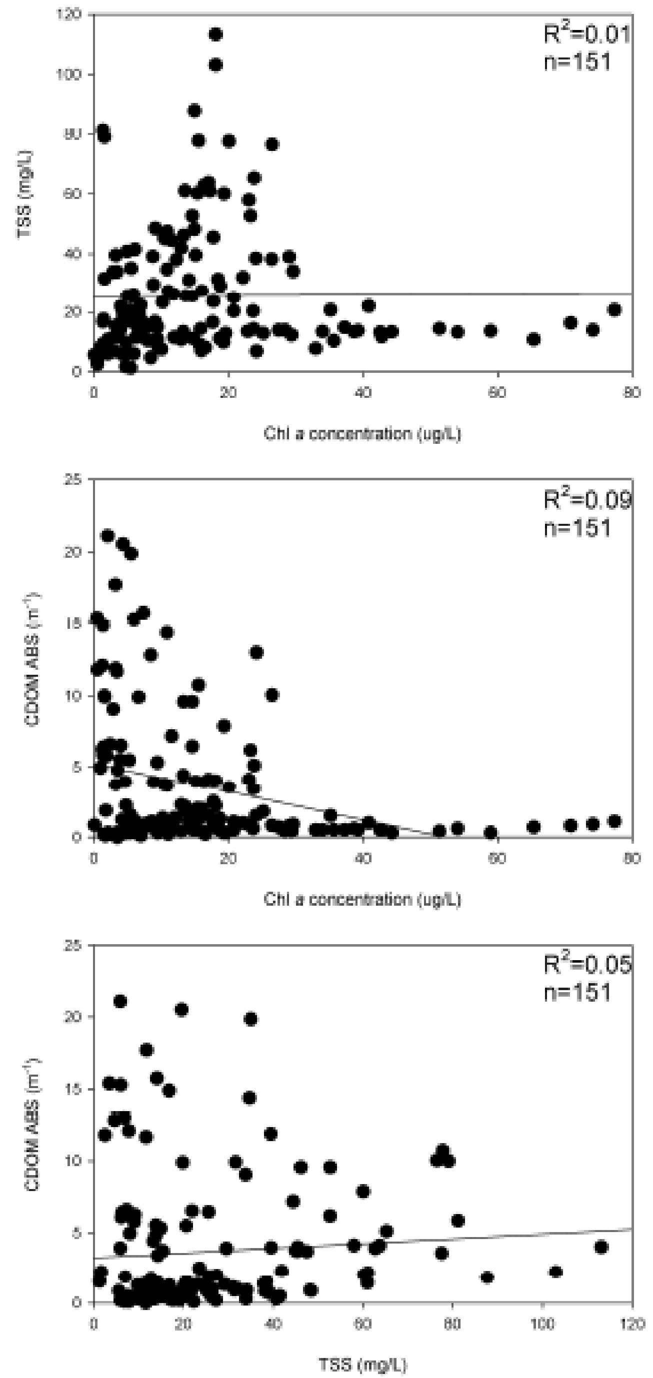
Water parameters of discrete water samples (n=151).

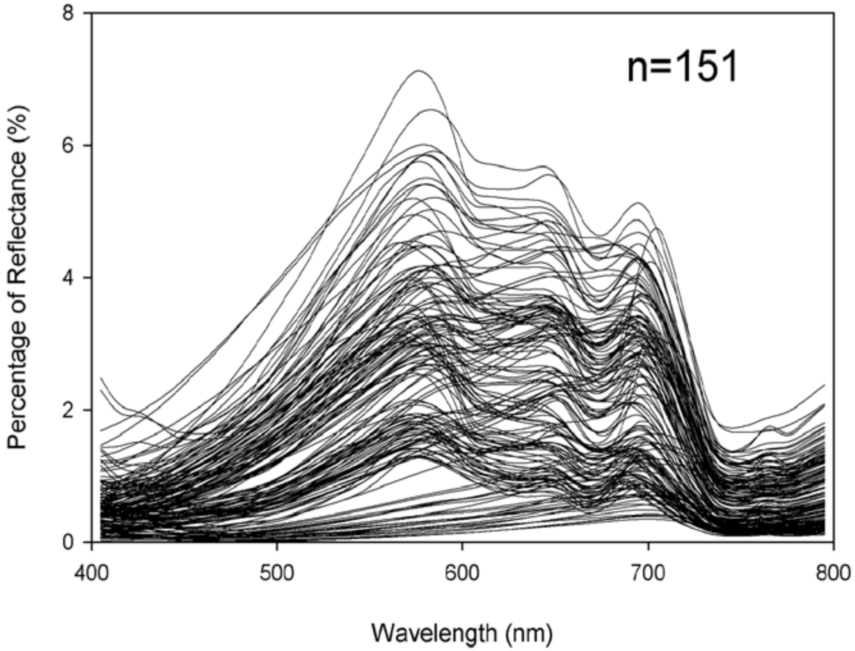
Parameters	Minimum	Maximum	Mean	Standard deviation
Salinity, pus	0.0	32.0	12.4	9.34
Temp, °C	9.7	31.3	26.0	5.04
Depth, m	0.9	25.0	5.5	4.24
Secchi depth, m	0.2	2.2	0.8	0.45
Chl a, µg/L	0.2	77.4	15.6	15.12
TSS, mg/L	1.3	113.2	25.6	21.26
ABS440, m^{-1}	0.2	21.1	3.7	4.72

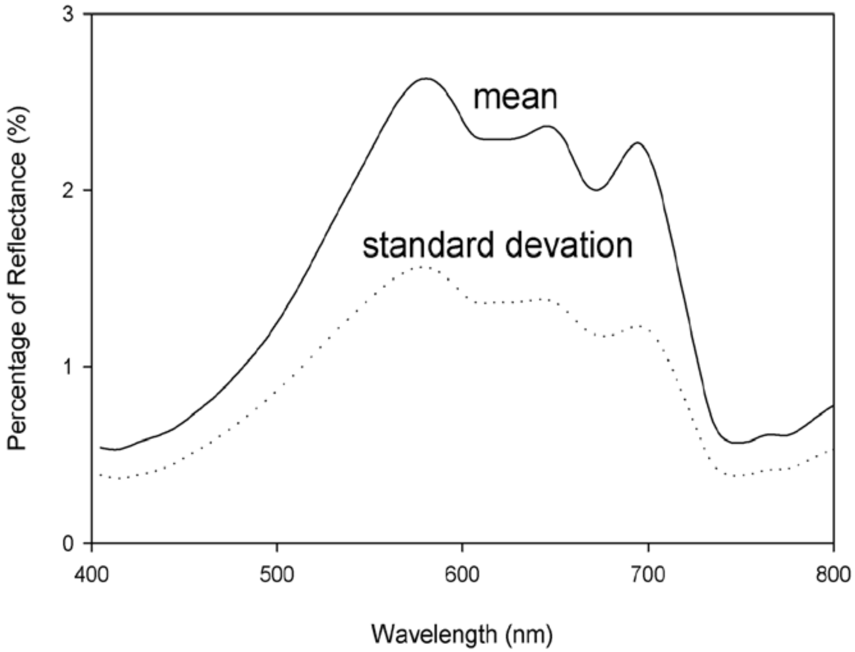
Correlation analysis suggests that Chl *a*, TSS, and CDOM are not related to each other.

TSS and CDOM do not co-vary with Chl *a* concentration, and exhibit a complex origin.

The phytoplankton biomass (chl *a*) was not the only driver controlling the water optical properties.





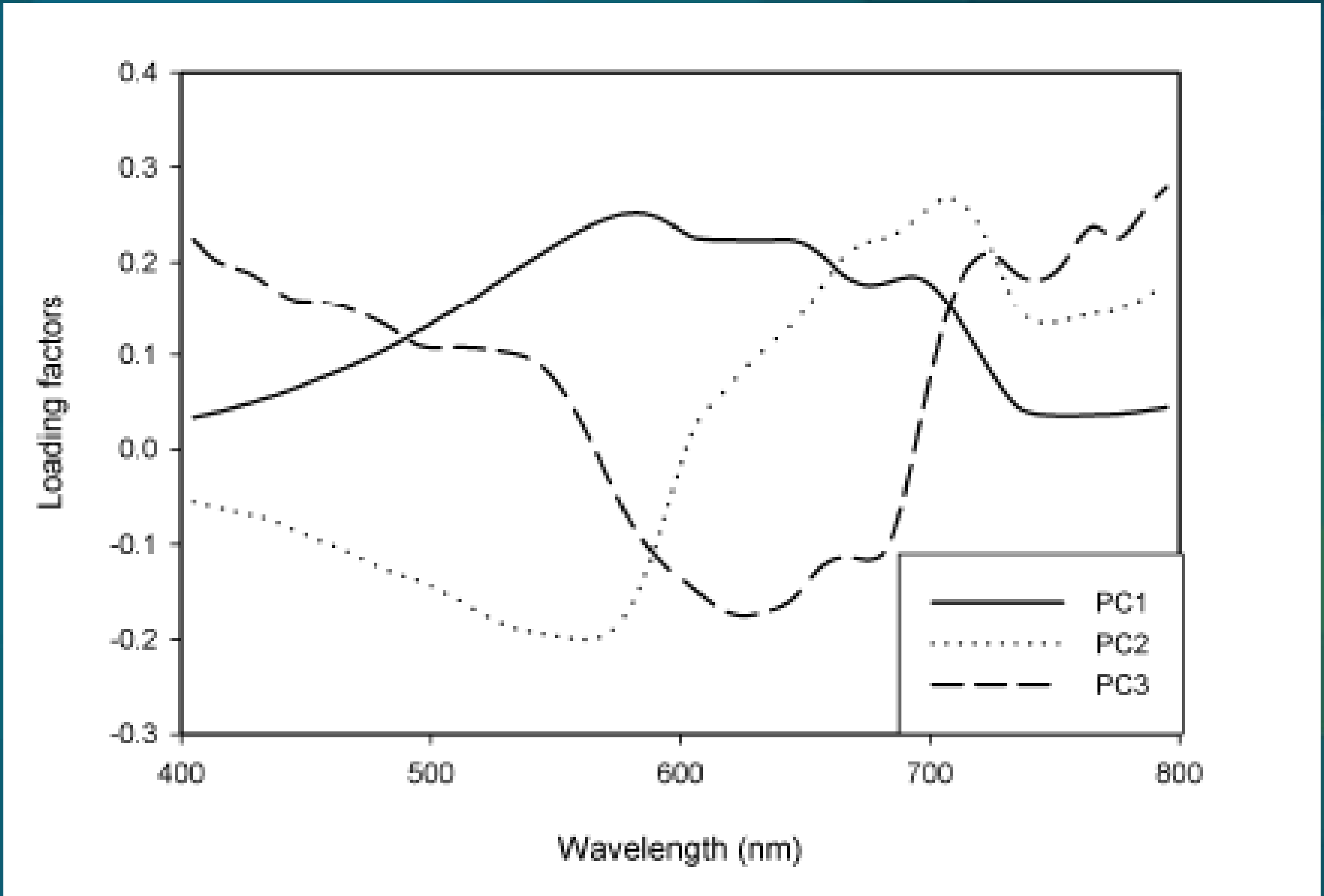


High degree of variation in magnitude and shape

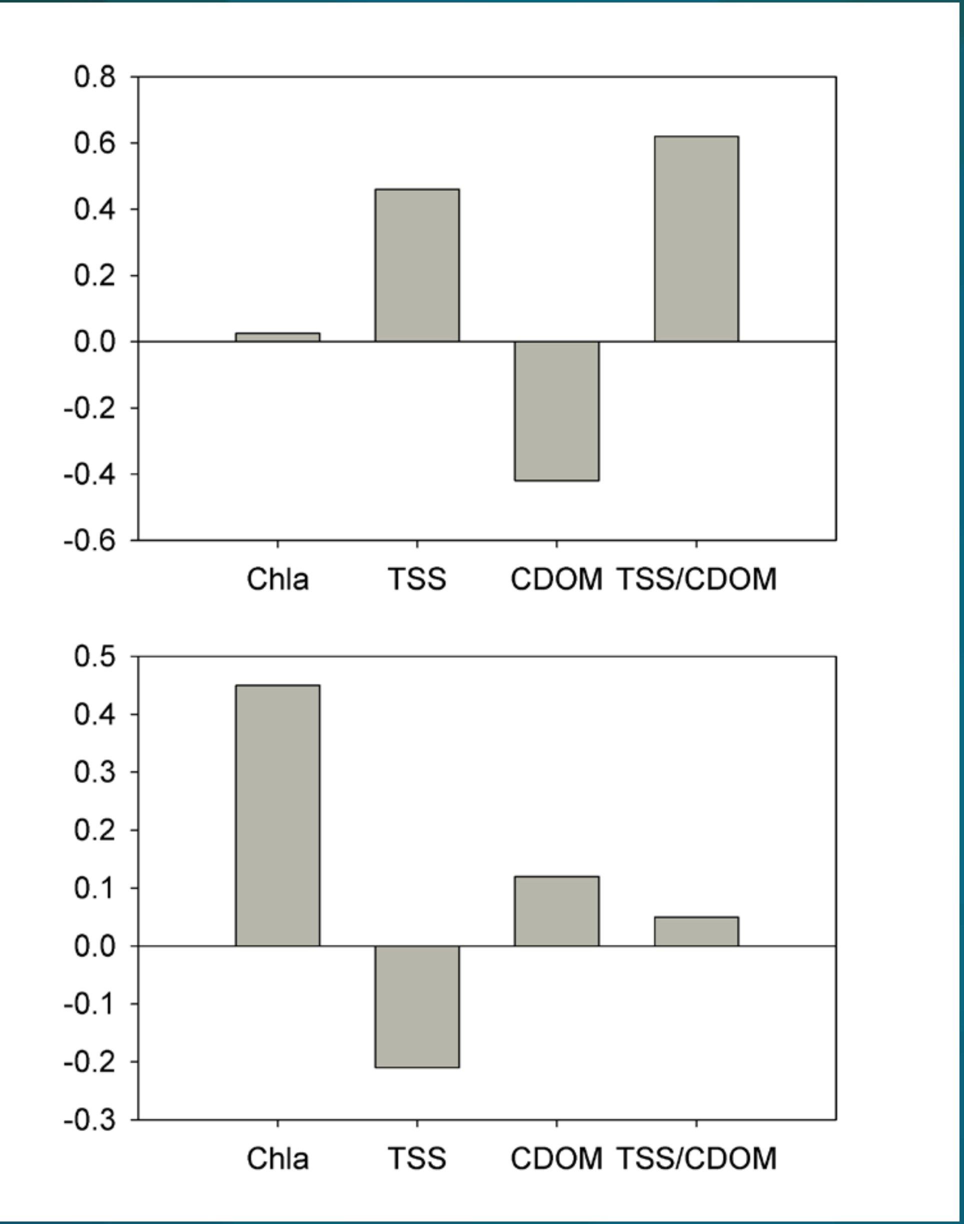
Common spectral pattern:

•Reflectance R(λ) at blue spectral region is low, and with a small variability compared to the green and red spectral regions.
•One reflectance peak around 570 nm
•Second peak was observed at red/NIR spectral range around 695 nm

The loading factors of the first three principal components



Correlation between the principal component scores and the water bio-optical parameters



For PC1:

Positive with TSS, however, also negative with CDOM.

For PC2:

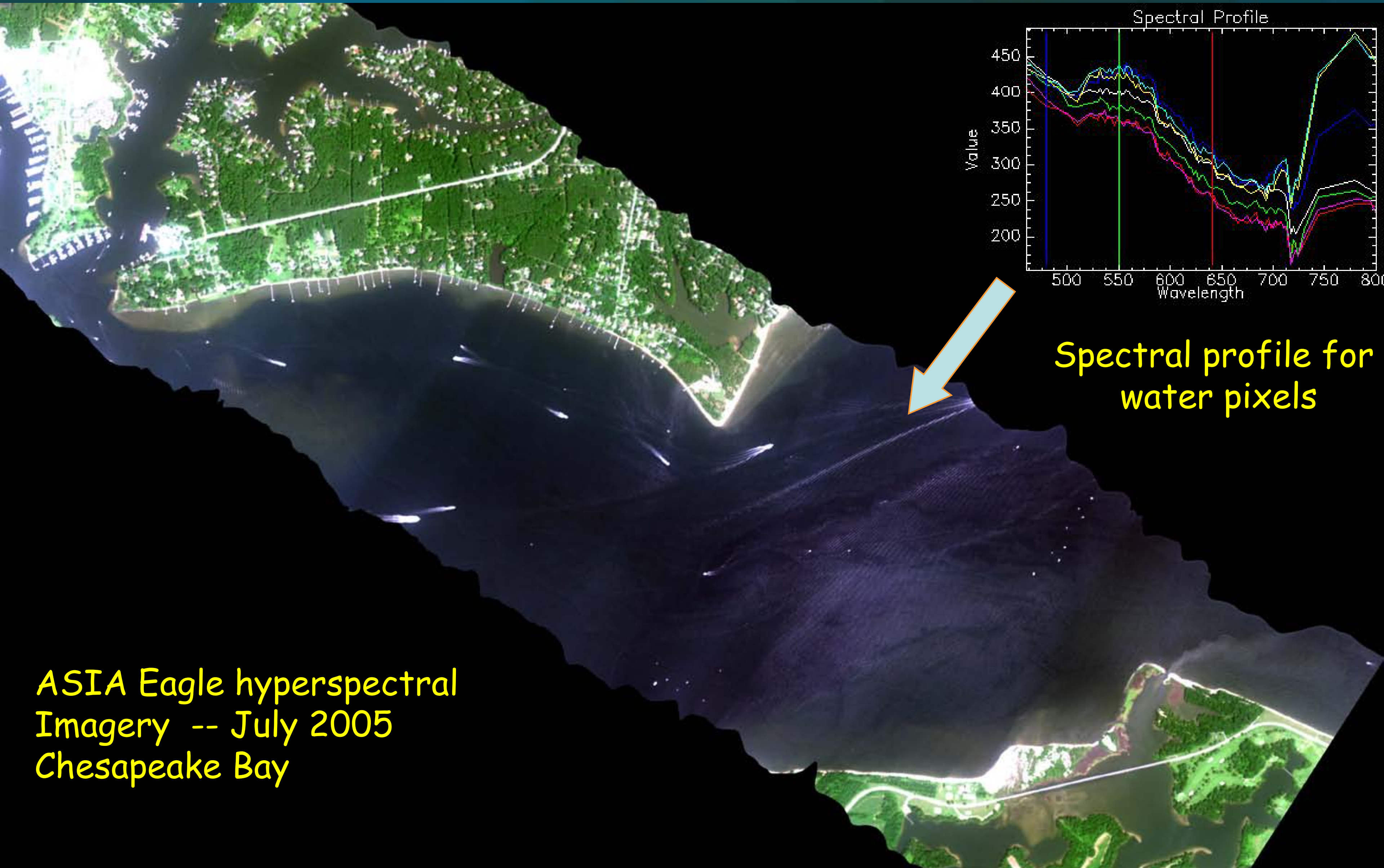
Positive with Chl a, and does not show a relationship with TSS, or CDOM.

Conclusions

- Reflectance spectra demonstrate a high degree of variation in magnitude and shape over the visible and NIR spectral regions due to complex mixtures of optically active constituents with high spatial and temporal variability.
- PCA analysis showed that more than 93% of the total variance of $R(\lambda)$ can be explained by the first two principal components.
- PC1 is considered to represent the overall backscattering effect of water optical constituents, both TSS and CDOM should be included in the interpretation of PC1, especially at blue and green spectral regions.
- PC2 is considered to represent the absorption process that is mainly regulated by phytoplankton pigment at red and NIR spectral regions.

Implications

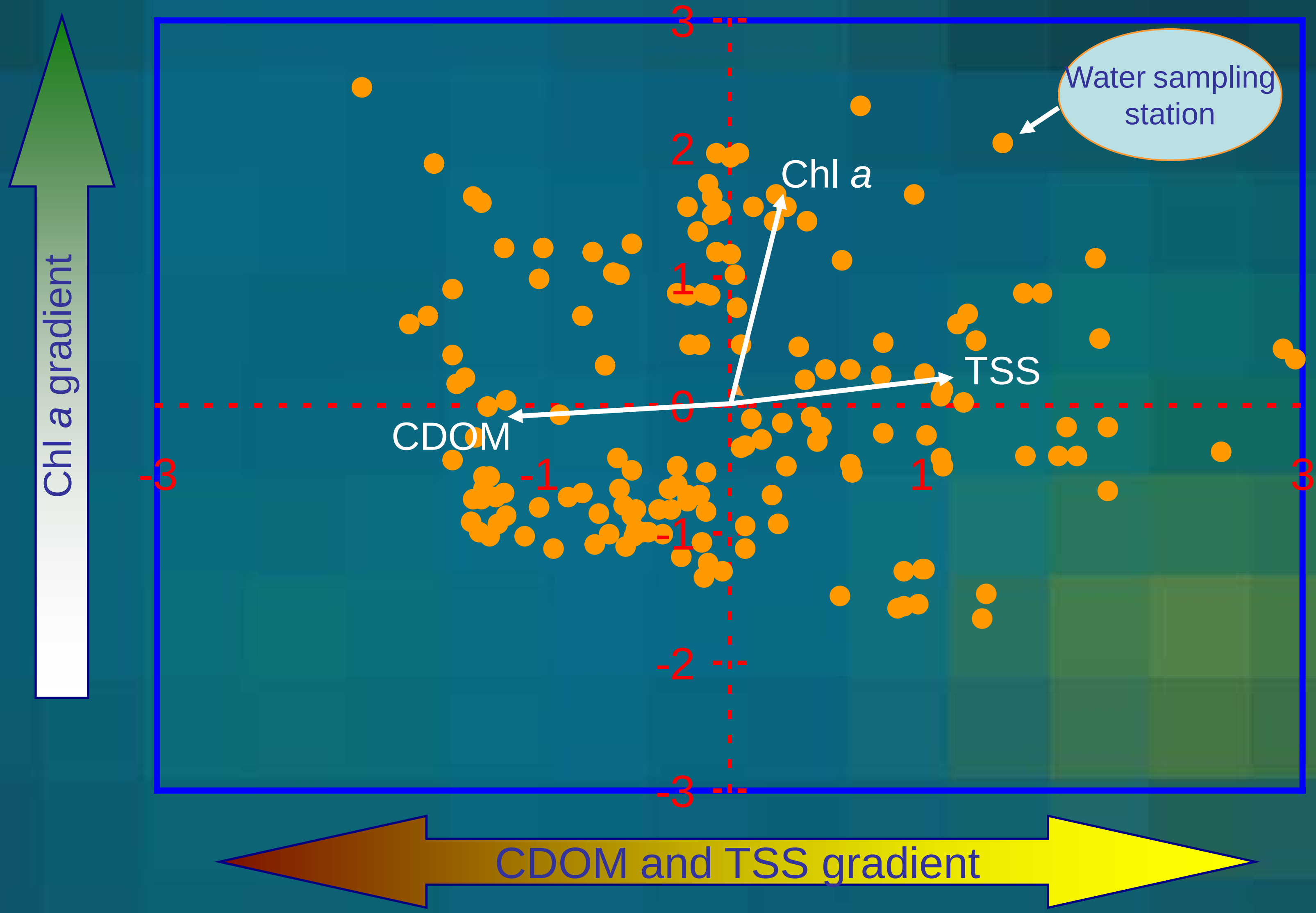
Hyperspectral aerial imagery



Spectral profile for water pixels

ASIA Eagle hyperspectral Imagery -- July 2005 Chesapeake Bay

A Framework – water quality monitoring in estuarine waters by remote sensing

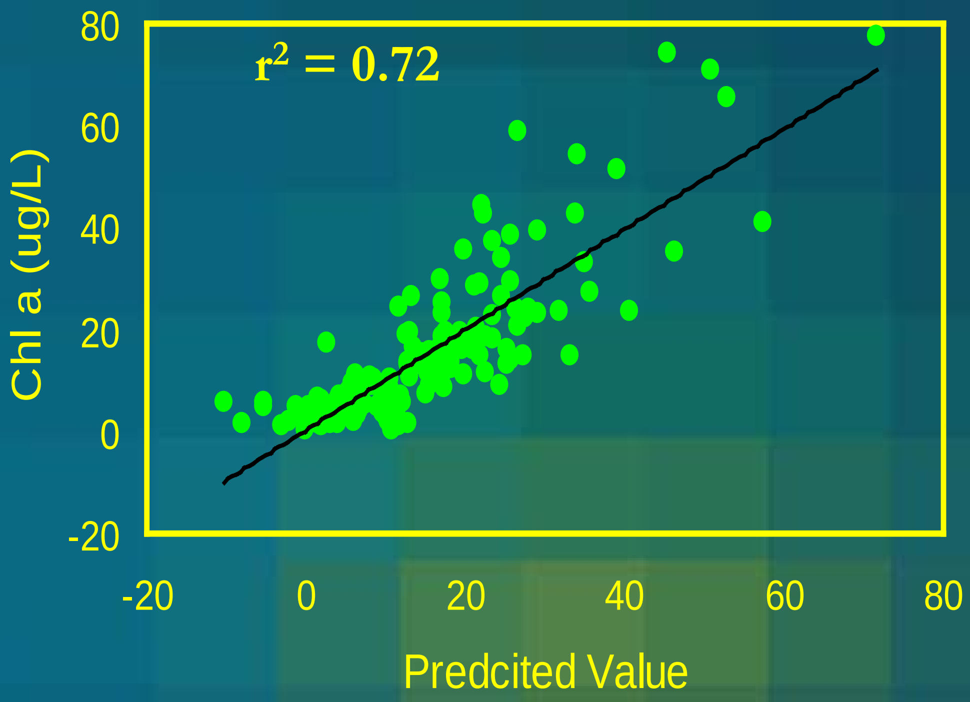


Multiple linear regression for chl *a* retrieval

Chl *a* concentration can be estimated by using three spectral bands at red and NIR spectral range:

Chl *a* = $-24.5R_{675} + 58.3R_{705} - 51.4R_{775}$

This regression can explain about 72% of the variability for chl *a* concentration across a wide geographic regions.



On going and future study:

HABs detection in estuarine waters

- Collect the reflectance spectra for three groups of phytoplankton (diatom, dinoflagellates, and blue-green algae) associated with algal blooms in the Chesapeake Bay region in pure culture conditions.

- Analyze the spectra by higher derivative analysis and by using spectral analysis tools in ENVI to determine spectral features for identification of algal groups, and develop algorithms based upon the spectral features to identify the three groups of phytoplankton.

- Validate the algorithms in the field algal bloom conditions.

Morgan State University Estuarine Research Center

State-of-the art facility is designed to increase the understanding of coastal ecosystems so that they may be properly managed and protected.

http://www.morgan.edu/erc/index.html

Fleet of research vessels.
Range of research laboratories, and teaching laboratory.
Researches include plankton ecology, remote sensing,
Monitoring of Power Plants for EPA Compliance, etc.
Active Environmental Education Program.