# Remote Sensing of Coastal Waters


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# Improved Retrievals of Coastal Water Properties – Main Topics

## Bio-Optical Properties – Surface Reflections – Atmopsheric Impacts – Satellite Sensors

- **Non-traditional Red/NIR algorithms for Improved Retrievals of Coastal water properties**
- **Chlorophyll Fluorescence as a Function of Chlorophyll and other Water Parameters from Field Measurements & Simulation**
- **Harmful Algal Bloom Retrieval Algorithms**
- **Polarization properties of ocean and coastal waters**
- **Development of advanced atmospheric correction models**
- **Development of Coastal Observation Platform in LIS**
- **Hydrodynamic modeling for coastal waters**
- **Future plans and topics of study**

# Relevance to NOAA's mission and the strategic plan

The work in this thrust area is in line with NOAA goals to conserve, protect, manage, and restore living marine resources and coastal and ocean resources is critical to the health of the U.S. economy, and to Restore, and Manage the Use of Coastal and Ocean Resources Through an Ecosystem Approach to Management. The work is also in keeping with NOAA strategies that address end to end processes that cover monitoring and observing the land, sea, atmosphere, and space to create an observational and data collection network that tracks Earth's changing systems, and assess and predict the changes of natural systems and provide information about the future.

## Relevance to NOAA Line Office (i.e., National Weather Service, National Ocean Service) strategic plan

The work falls within NOAA-NESDIS mandates through (NODC) and (NCDDC) to manage uses of ecosystems by applying scientifically sound observations, assessments, and research findings and supports the NOAA-NESDIS algorithm development strategy for improved coastal water retrieval; and within NOAA-NOS mandates to perform coastal monitoring and observations through measurements of physical, chemical, biological and meteorological phenomena affecting the marine environment.

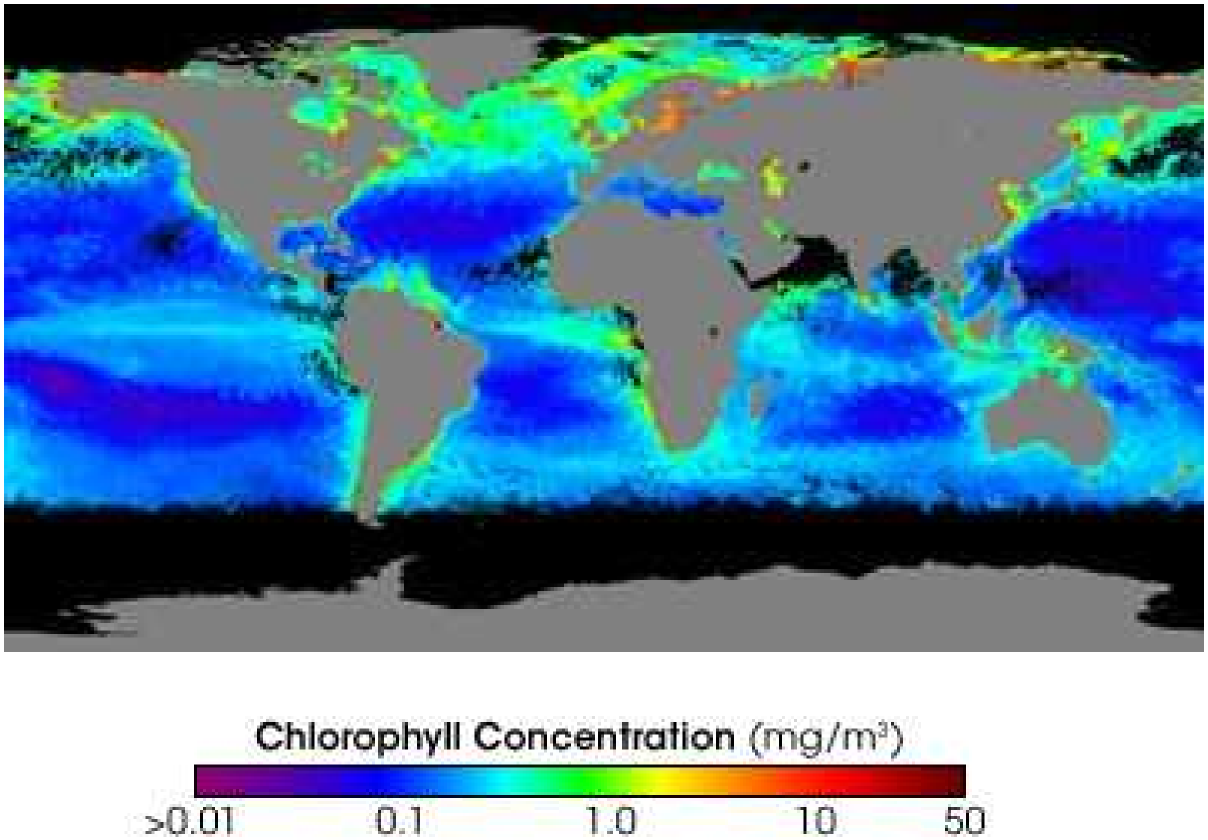
# Remote Sensing of Coastal Waters

- ***City College of NY and University of Puerto Rico Mayaguez***
- ***5 Faculty Members***
- ***1 Researcher***
- ***8 Graduate Students***
- ***6 Undergraduate Students***

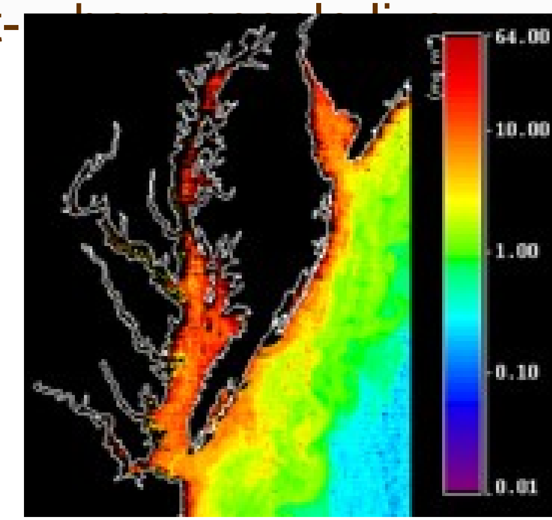
# Chlorophyll Global and Regional Maps

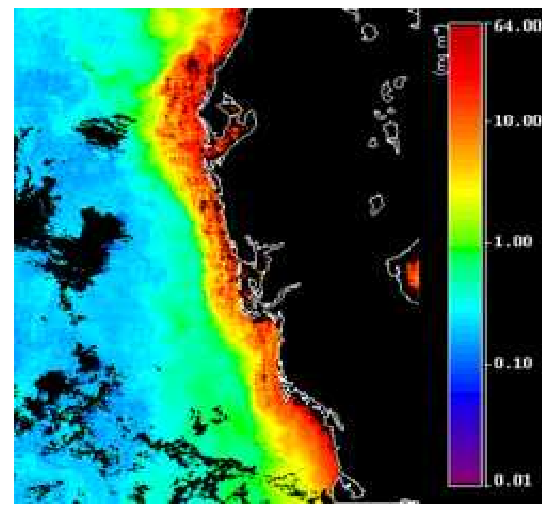
Marker for Ocean Health,Anthropogenic & Climate Change Impacts

Coastal water retrievals difficult, but important-




SeaWiFS, July 2006

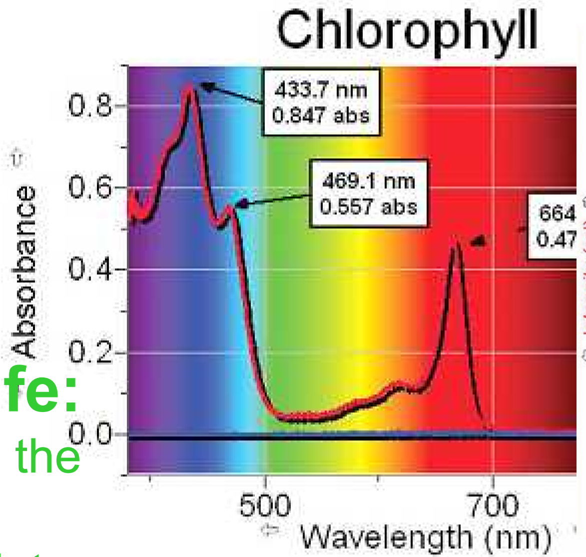


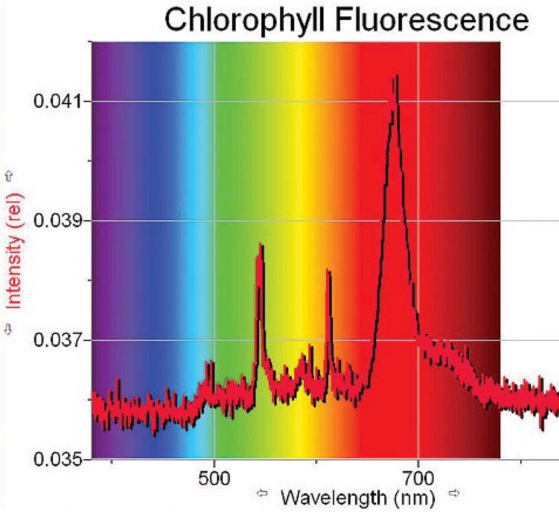




MODIS, NE and Florida coasts

# Remote Sensing of Coastal Waters

RS of water areas provides an efficient way of monitoring water quality, biomass in the ocean, sediment plumes, spatial and temporal scales of the water structures, sea surface temperature, etc.

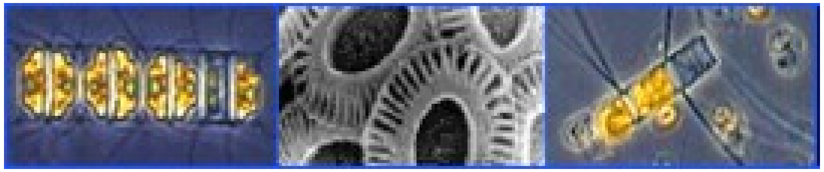



## Phytoplankton are a very important part of ocean life:

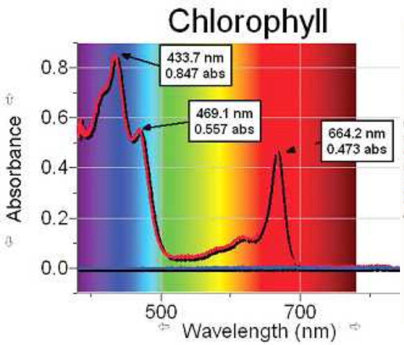
- Phytoplankton are the first link in the food chain.
- Phytoplankton convert nutrients into plant material through photosynthesis and convert carbon dioxide from sea water into organic carbon and oxygen as a by-product

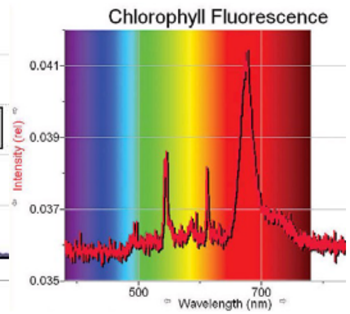
**Amount of phytoplankton in the ocean can be traced by the concentration of the optically active pigment** chlorophyll [Chl]

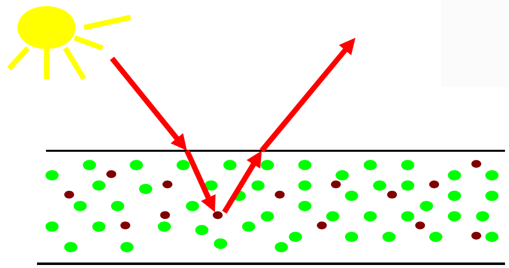


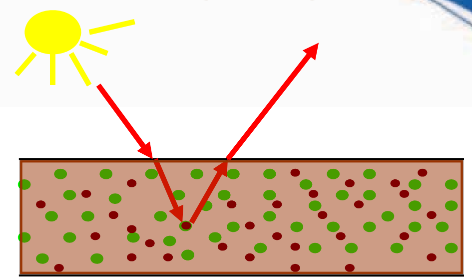
Chlorophyll fluorescence is an indicator of Chl concentration and an important characteristic of photosynthetic processes

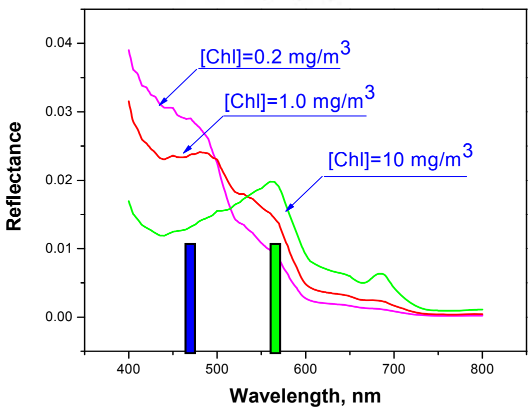
# Open ocean and coastal waters

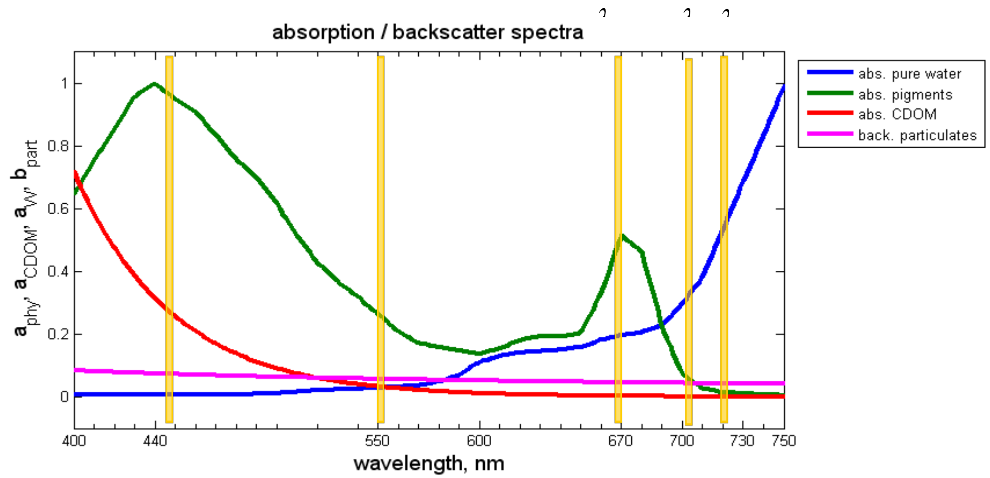


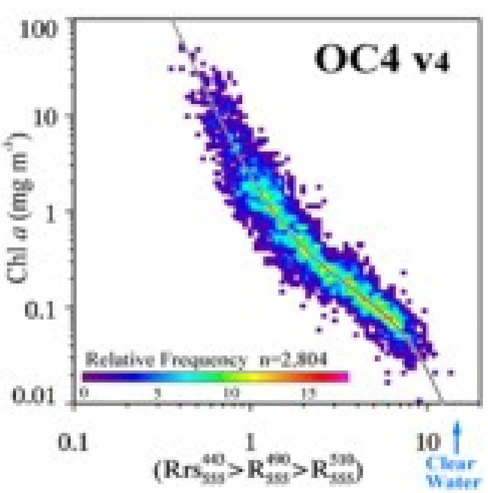



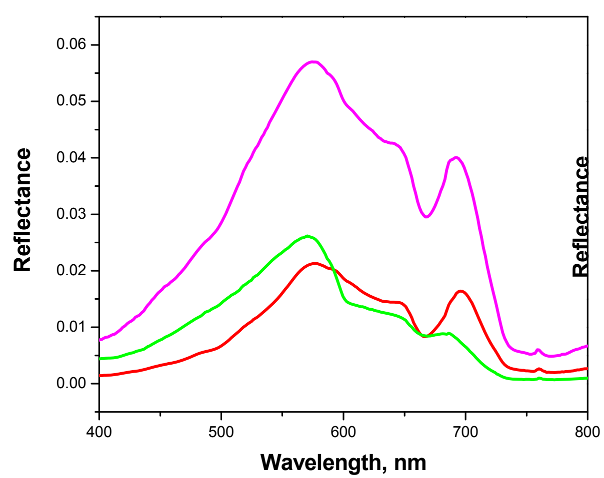



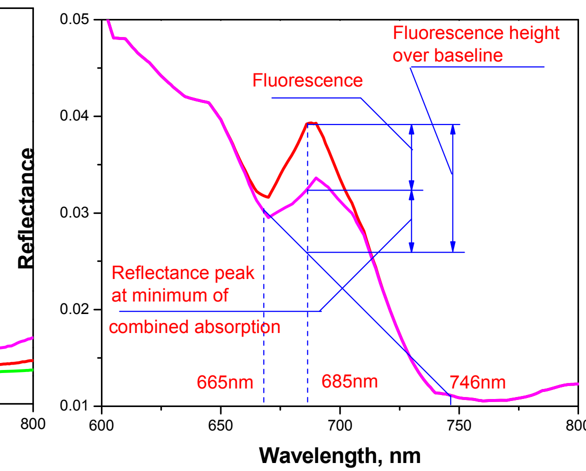




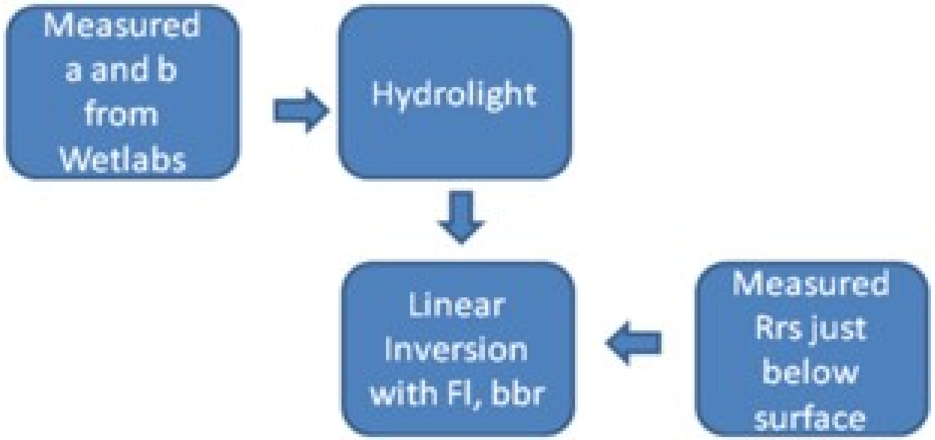
# Field Measurements

| Physical properties | ↔ | Optical properties | ↔ | Reflectance spectra | ↔ | Satellite sensor data |
|---|---|---|---|---|---|---|

Instrumentation:

- WET Labs package: absorption, attenuation, scattering, backscattering, Chl concentrations, CDOM fluorescence, temperature, salinity,
- LISST for particle size distribution
- Hyperspectral profiler (Satlantic) and GER spectroradiometer for water reflectance measurements above and below water surface
- Polarization components detection
- Water sampling (Chl, TSS and mineral concentrations, CDOM absorption)

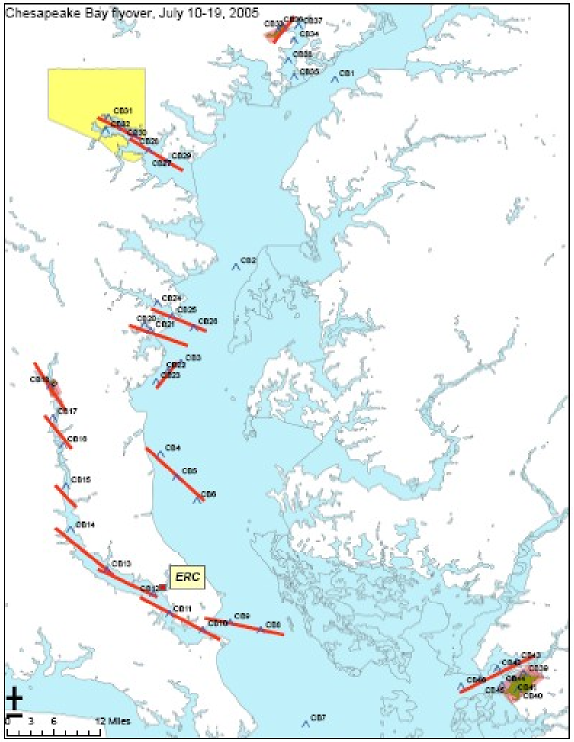

# Closure between measured IOP and AOP under various ocean conditions



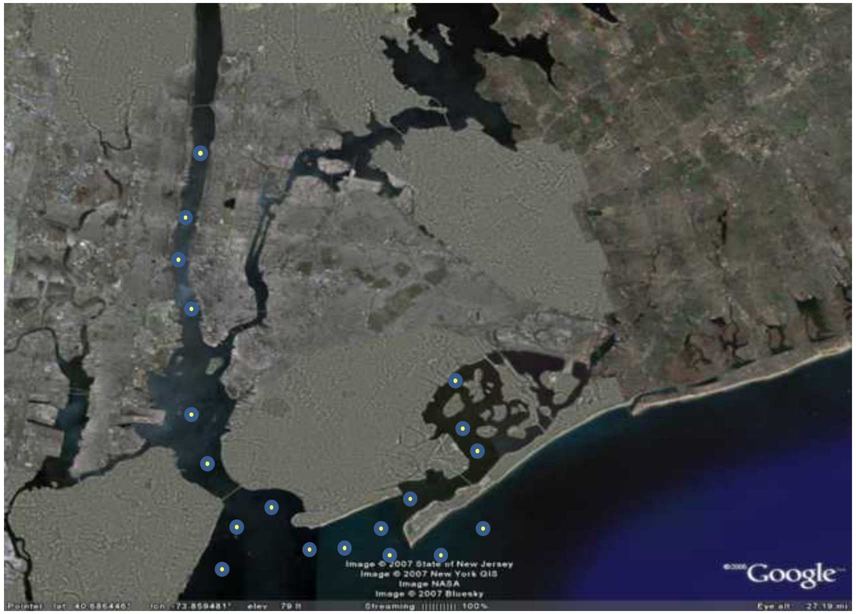

Assumptions:

1. Backscattering ratio is wavelength independent
2. The spectral shape of $R_{rs}$ mainly depends on a and b while the amplitude is proportional to backscattering ratio

# Areas of field campaigns








Areas of study:

Chesapeake Bay (2005), Georgia waters near Sapelo Island (2006), Long Island Sound, Peconic Bay NY Harbor, Hudson River (2004-2009), Sandy Hook, NJ (2008-09), Norfolk, VA (2009) Puerto Rico (2004-09)

# Field measurements

NJ cruise, R/V Connecticut, 2008

NY Harbor 2007-09

Our partners – other teams:

Florida A&M University, Fl;
Creighton University, NE;
University of Nebraska, NE,
NRL, SSC
NASA – GSFC, LARC
WET Labs Inc
University of Connecticut
Old Dominion University, VA
University of Texas
Texas A&M University

Norfolk, VA 2009 – validation of CALIPSO and Glory missions

# Calibration and Lab Measurements

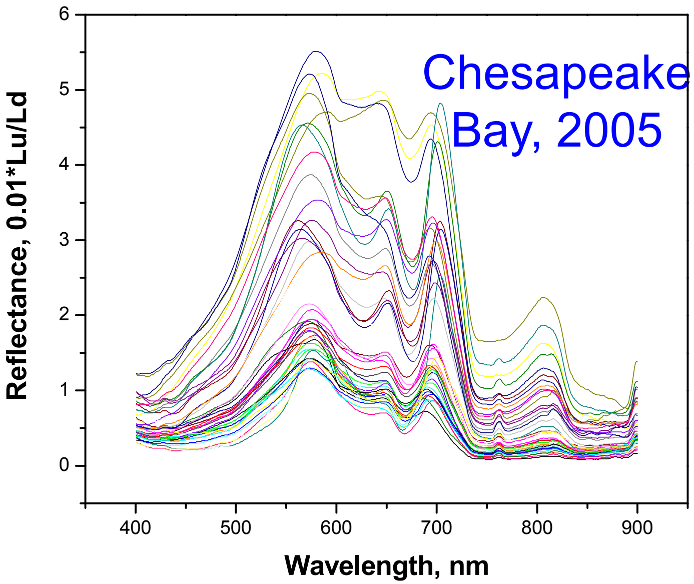
For irradiance sensors LI-COR 1800-02 calibration standard

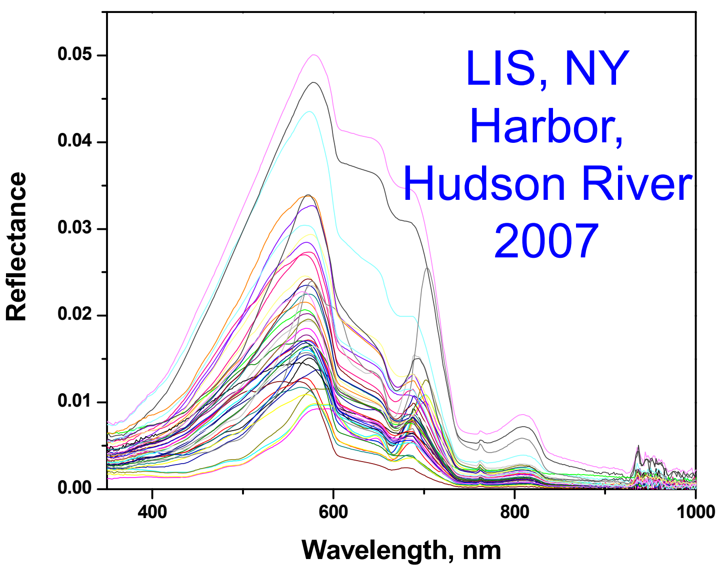
For radiance sensors OL 455 integrating sphere calibration standard

Perkin Elmer Lambda 19 UV/Vis Spectrometer for [Chl] and sample absorption spectra

Perkin Elmer Fluorescence Spectrometer LS 50 for excitation-emission matrix of CDOM

# Variability of water parameters in field measurements



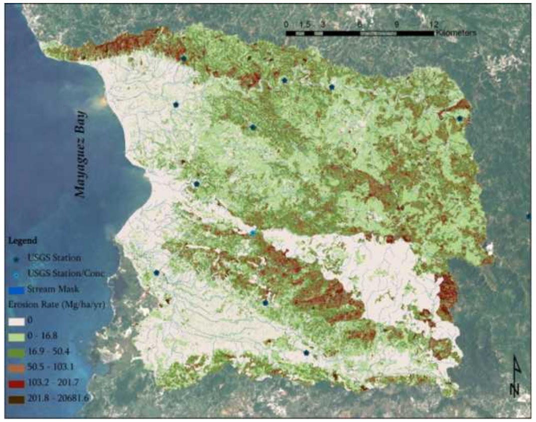




| Chl | Abs 400 | TSS |
|---|---|---|
| µg/l | $m^{-1}$ | mg/l |
| 9.1-354.2 | 1.41-10.8 | 7-64.8 |

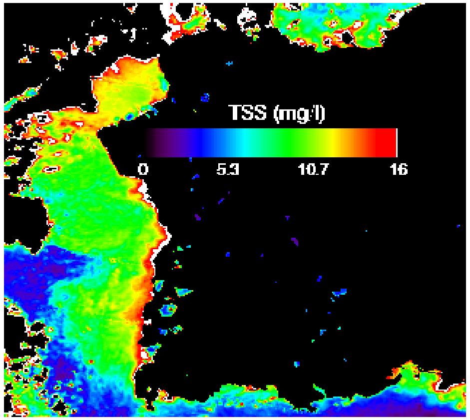
| Chl | Abs 400 | TSS |
|---|---|---|
| µg/l | $m^{-1}$ | mg/l |
| 1.9-106 | 0.47-3.73 | 1.7-43.2 |

# Remote Sensing and Biogeo-optical Properties Of Mayaguez Bay, F.Gilbes, PI, UPRM-Department of Geology

- Evaluation of MODIS data continued to fine-tuning the algorithm to estimate total suspended sediments (TSS).
- Analyses with the GIS based model continued to estimate soil erosion and sediment load to the Mayagüez Bay and compare it with same estimations derived from MODIS data.
- Composition and grain size distribution of TSS are being analyzed to determine their role in the optical properties of the water.
- A laboratory procedure was tested to extract the minerals from the sediments and measure their Remote Sensing Reflectance (Rrs).




**Soil Erosion Rates for study area as determined with GIS. These results were compared with MODIS data by Vilmaliz Rodriguez, graduate student from Geology.**




**Example of TSS as measured with MODIS and using one of the tested algorithms.**

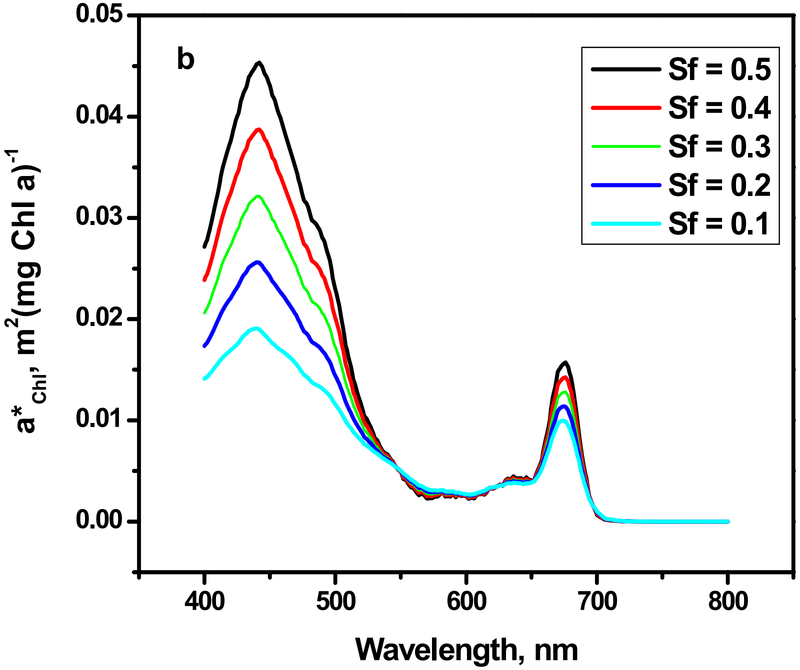
# Red/NIR algorithms for Improved Retrievals of Coastal water properties

SPIE 2005-09, Sea Technology, 2007,
Optics in Natural Waters, 2009

# To Examine Impact of Coastal Waters on NIR Retrievals used Datasets Simulated by Hydrolight Radiative Transfer Program

Several datasets, 500 reflectances each were simulated using HYDROLIGHT with and without fluorescence with 1 nm resolution (similar to IOCCG database – Lee) for typical conditions of coastal waters [Chl] =1-100 mg/m$^3$, CDOM absorption $a_y(400)$ = 0 -5 m$^{-1}$, various Chl absorption spectra

Datasets: 1 - $C_{nap}$ = 0 -1 mg/l   2 - $C_{nap}$= 1 – 10 mg/l   3 - $C_{nap}$= 10 – 100 mg/l

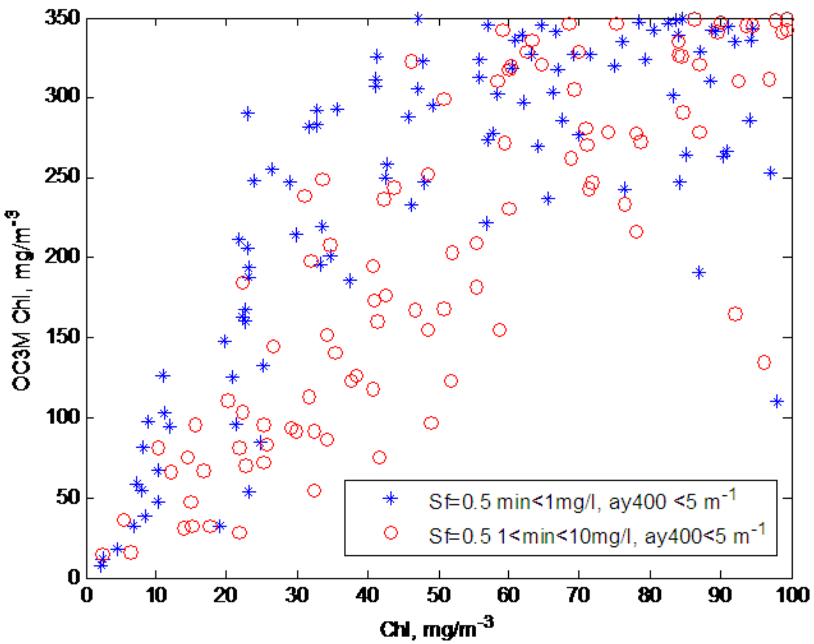


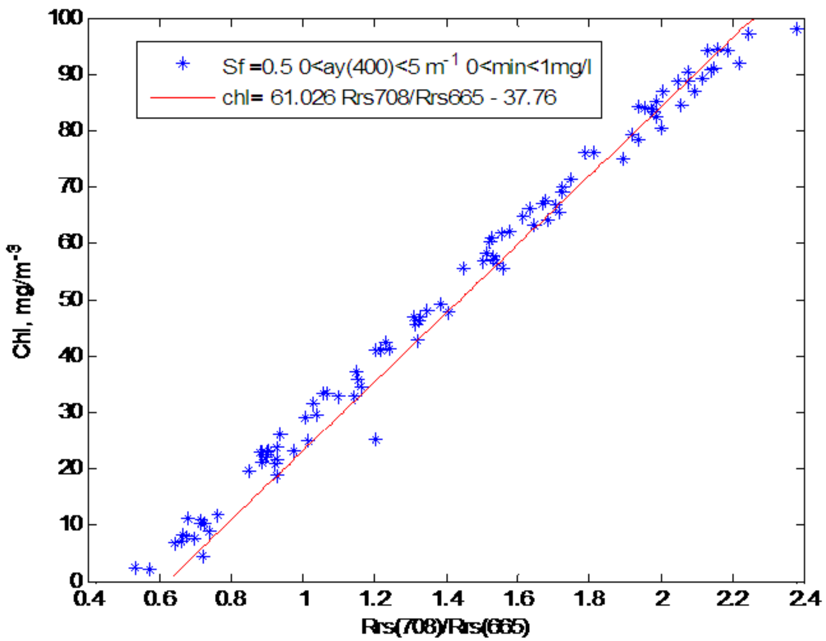

Specific Chl absorption: combination of pico- and micro-plankton spectra with several weighting factors – Ciotti et al., 2002

$$a^*_{chl}(\lambda) = S_f \cdot a^*_{pico}(\lambda) + (1 - S_f) \cdot a^*_{micro}(\lambda)$$

$$a_{chl}(\lambda) = a^*_{chl}(\lambda) * [Chl]$$

# Blue-green and NIR Chl algorithms



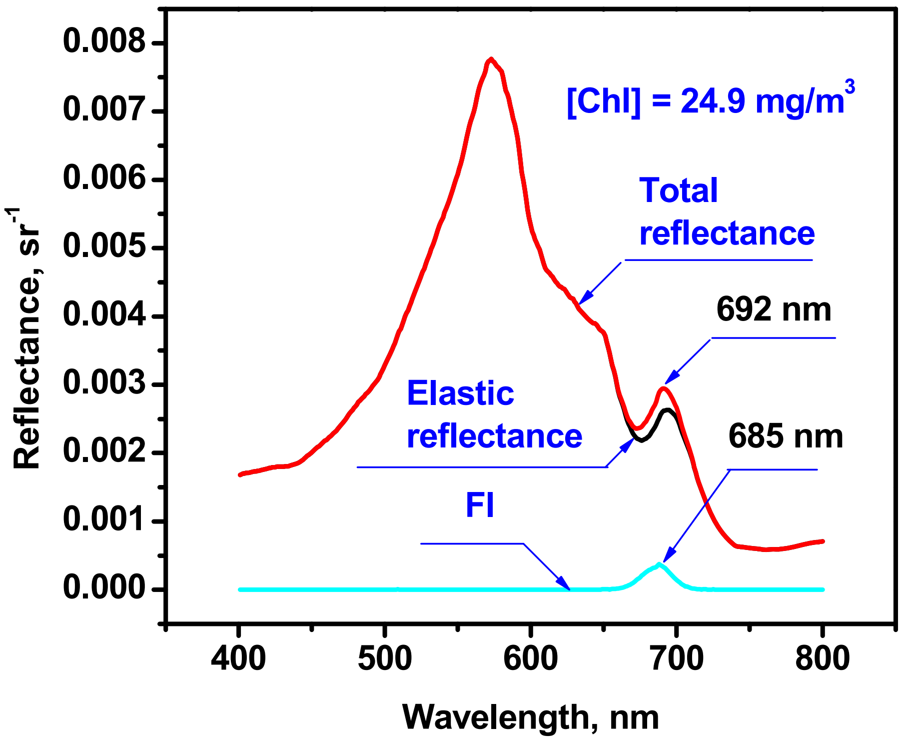

Blue-green algorithms are extremely inaccurate in coastal waters, expected errors 100-300%

On the other hand, Rrs(708)/ Rrs(665) was found to be extremely stable for various water conditions: algorithm developed from MERIS reflectance data and in-situ Chl almost perfectly matches independently Hydrolight simulated data

# Chlorophyll Fluorescence as a Function of Chlorophyll and other Water Parameters from Field Measurements & Simulation

Optics Comm., 2004, Appl. Optics, 2006, Opt. Express, 2007, Opt. Express(2), 2008

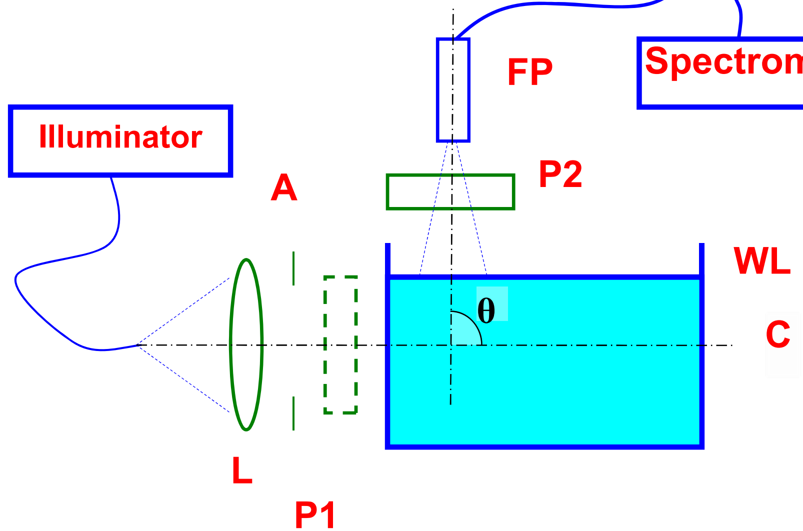
# Total reflectance, components: elastic and fluorescence components

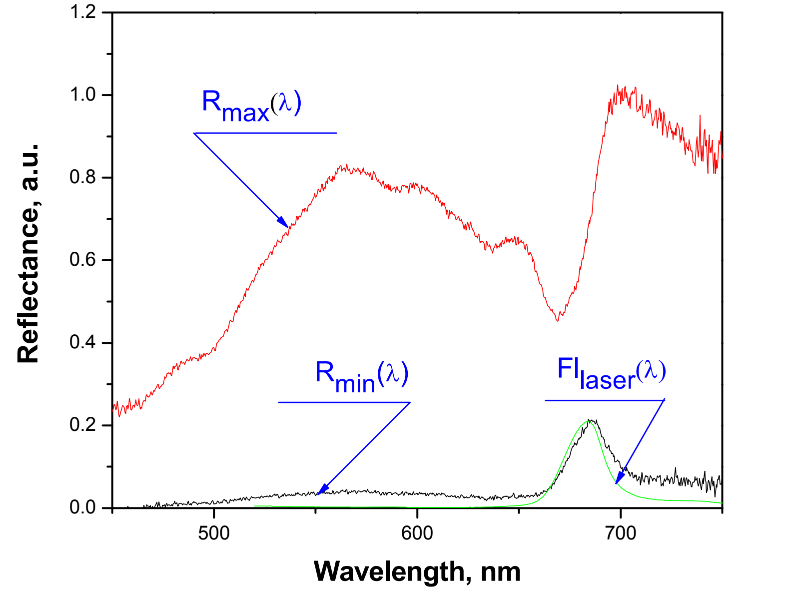



NIR peak on reflectance spectra is a good indicator of the [Chl] but it also has the fluorescence component on top of elastic reflectance which adds significant uncertainty

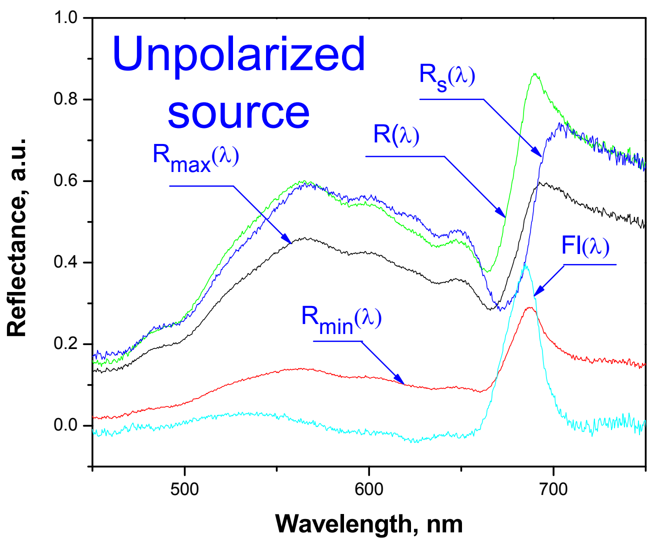
**NIR algorithms will be more accurate if the fluorescence is properly isolated or quantified**

# First Experiments on Polarization discrimination technique for the separation of fluorescence and elastic scattering (Patented) precurser to present hyperspectral Stokes Polarimeter

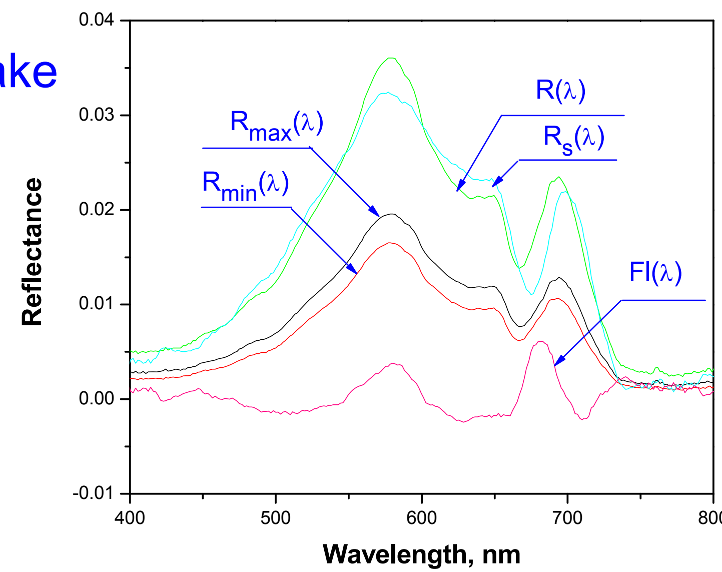



L – lens, FP – fiber probe, A – aperture, P1, P2 – polarizers, C – cuvette with algae, WL – water level.




Chesapeake Bay



# Why is fluorescence signal important?

- **It is related to chlorophyll concentration**
- **It can be used for the estimation of the fluorescence quantum yield and photosynthetic properties**
- **It is useful in detection of algal blooms**

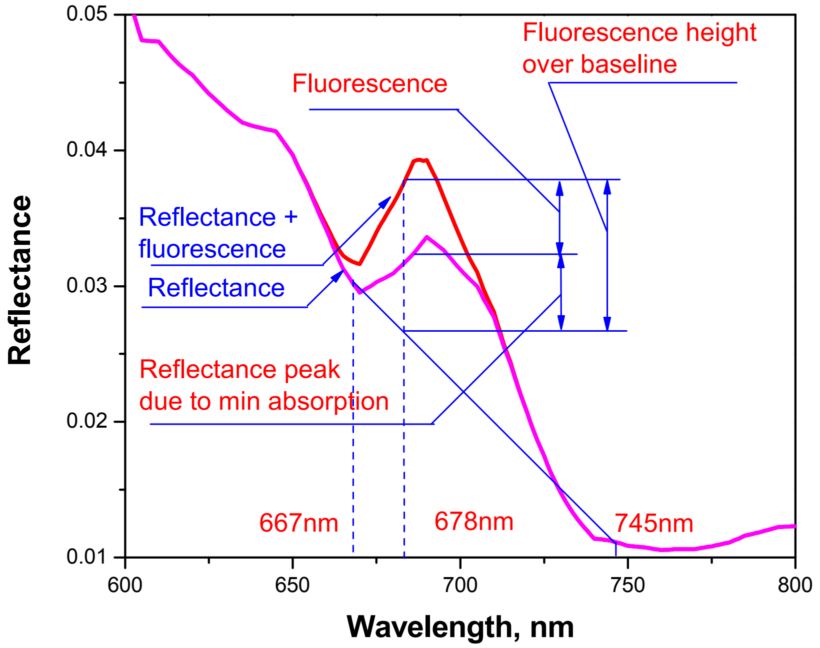
Fl ~ [Chl] ?

Fl ≈ FLH ???

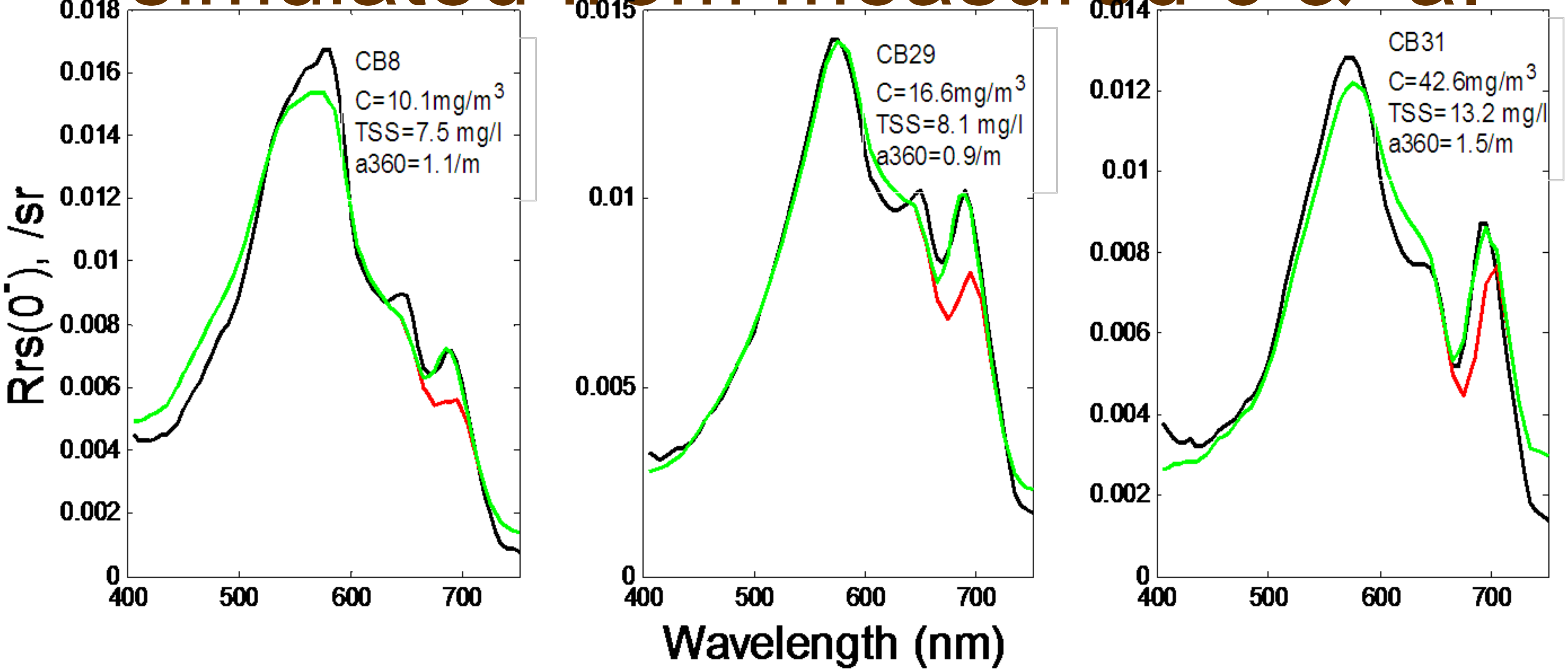
Is fluorescence quantum yield almost 100 fold range (0.1-9%) real?

What is the contribution of the fluorescence to the total reflectance in NIR?

How the fluorescence magnitude changes with the water composition?



# Typical total and elastic reflectances, measured & simulated from measured c & a.



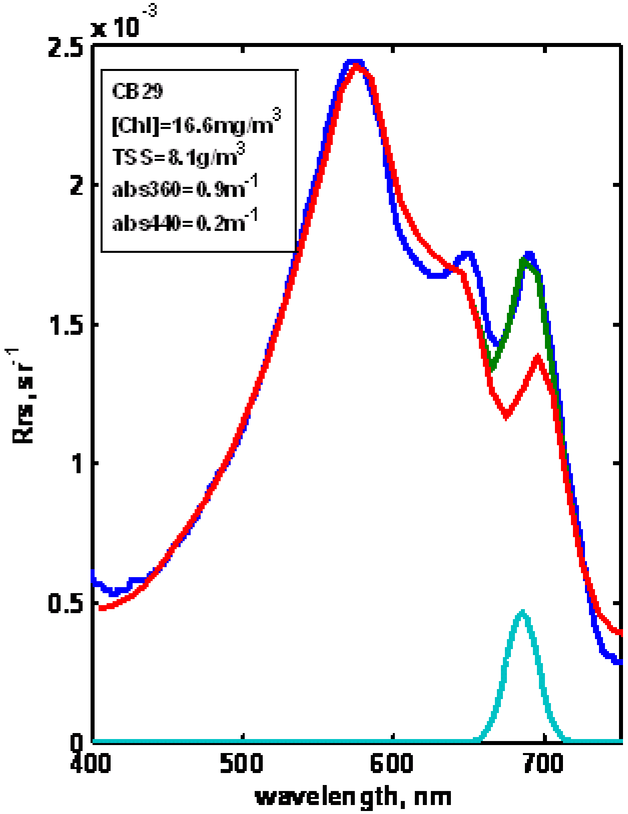

Black – measured, green – total fitted, red – elastic, simulated from measured c and a

Total reflectances were measured below water

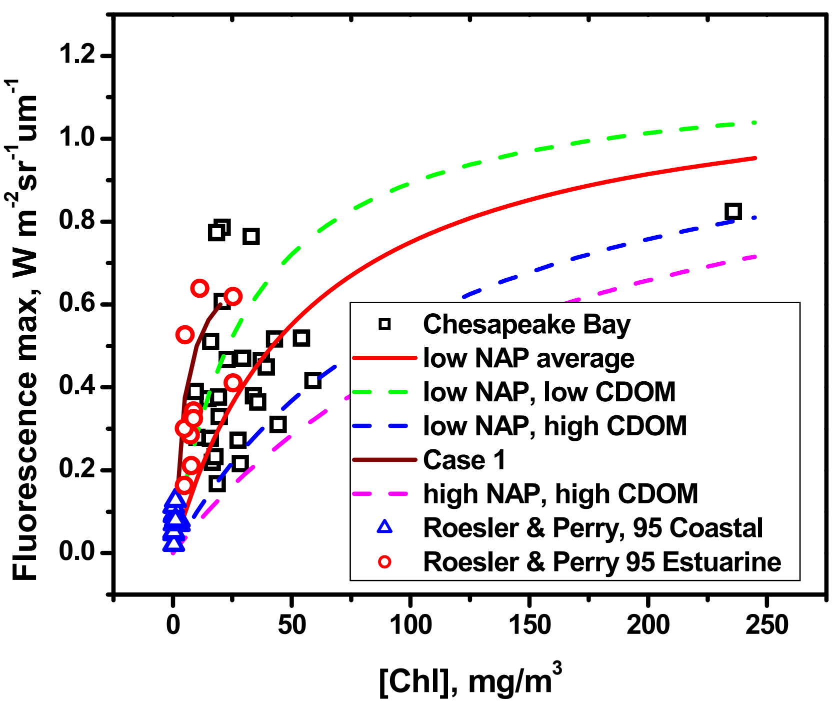
Elastic reflectances were simulated by Hydrolight from IOP

# Fluorescence as a function of [Chl] and other water parameters from field measurements and simulations for varying conditions

$$Fl = 0.0375[Chl]/(1+0.32\,a_y(400)+0.01C_{nap}+0.032\,[Chl])$$

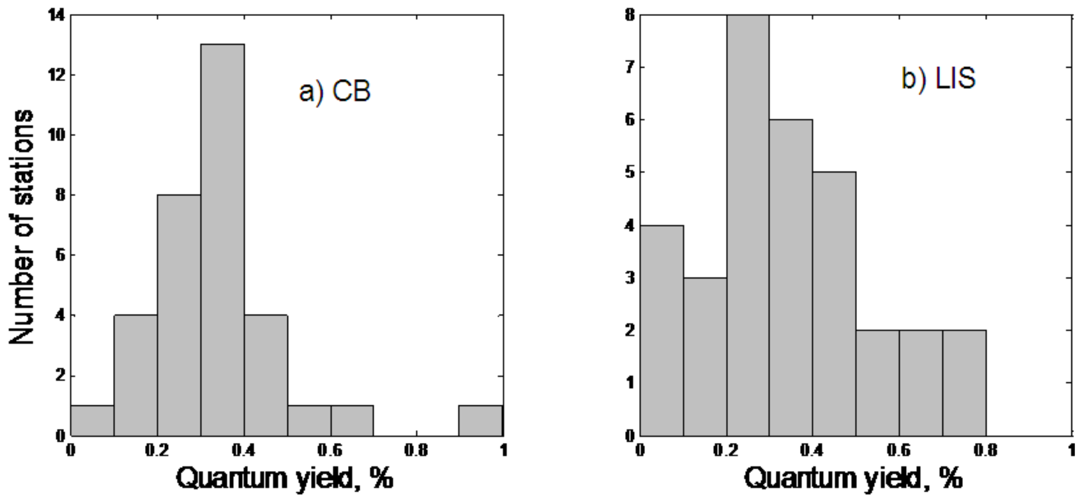


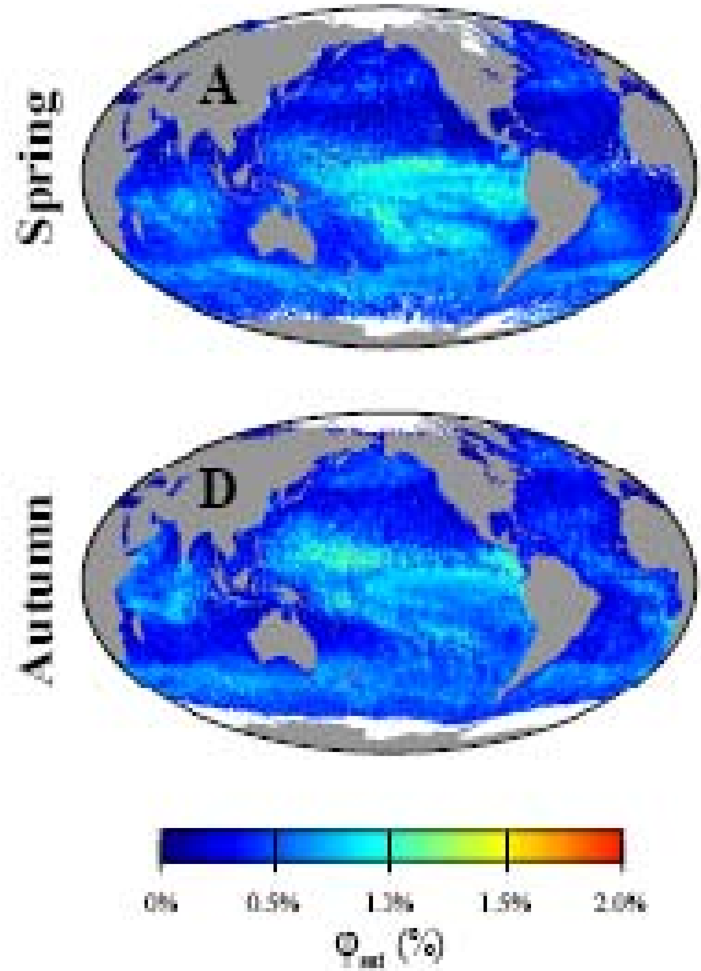

Typical fluorescence regimes




Based on the field data and radiative transfer simulations we parameterized Chl fluorescence component for coastal waters

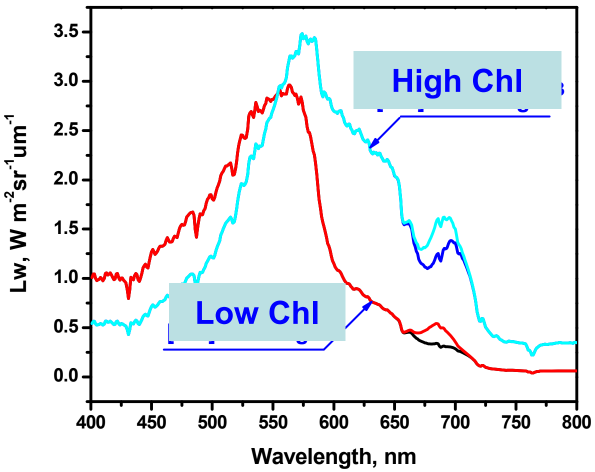
# Distribution of the fluorescence quantum yield values for two coastal areas of study



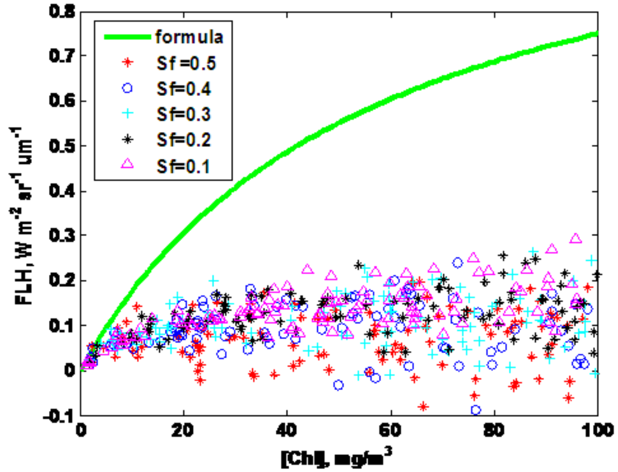




Mean values are around 0.3-0.5% which is in a good agreement with other authors estimations (Behrenfeld et al.) on the global scale for the open ocean

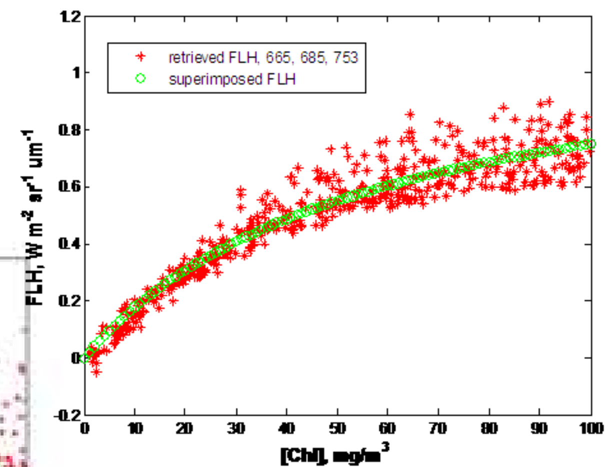
# Indicates potential improvements for Coastal Fluorescence Height Algorithms

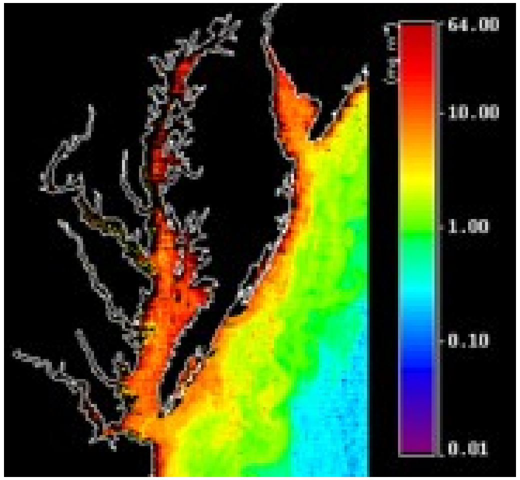



MODIS: 667, 678, 748 nm

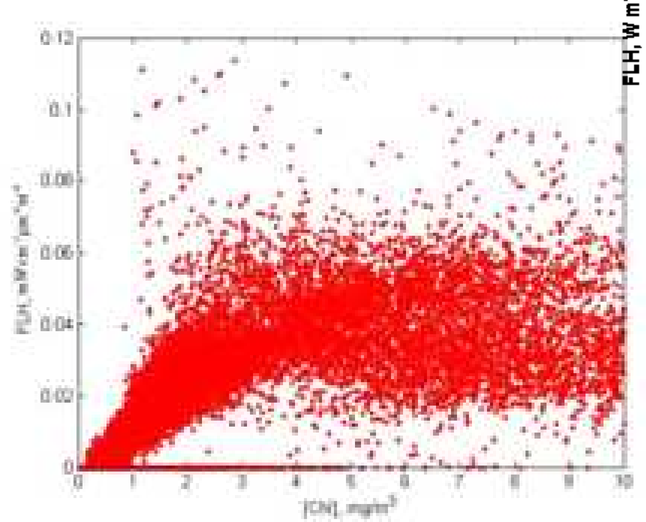



Simulated FLH response




[Chl] map for Chesapeake Bay



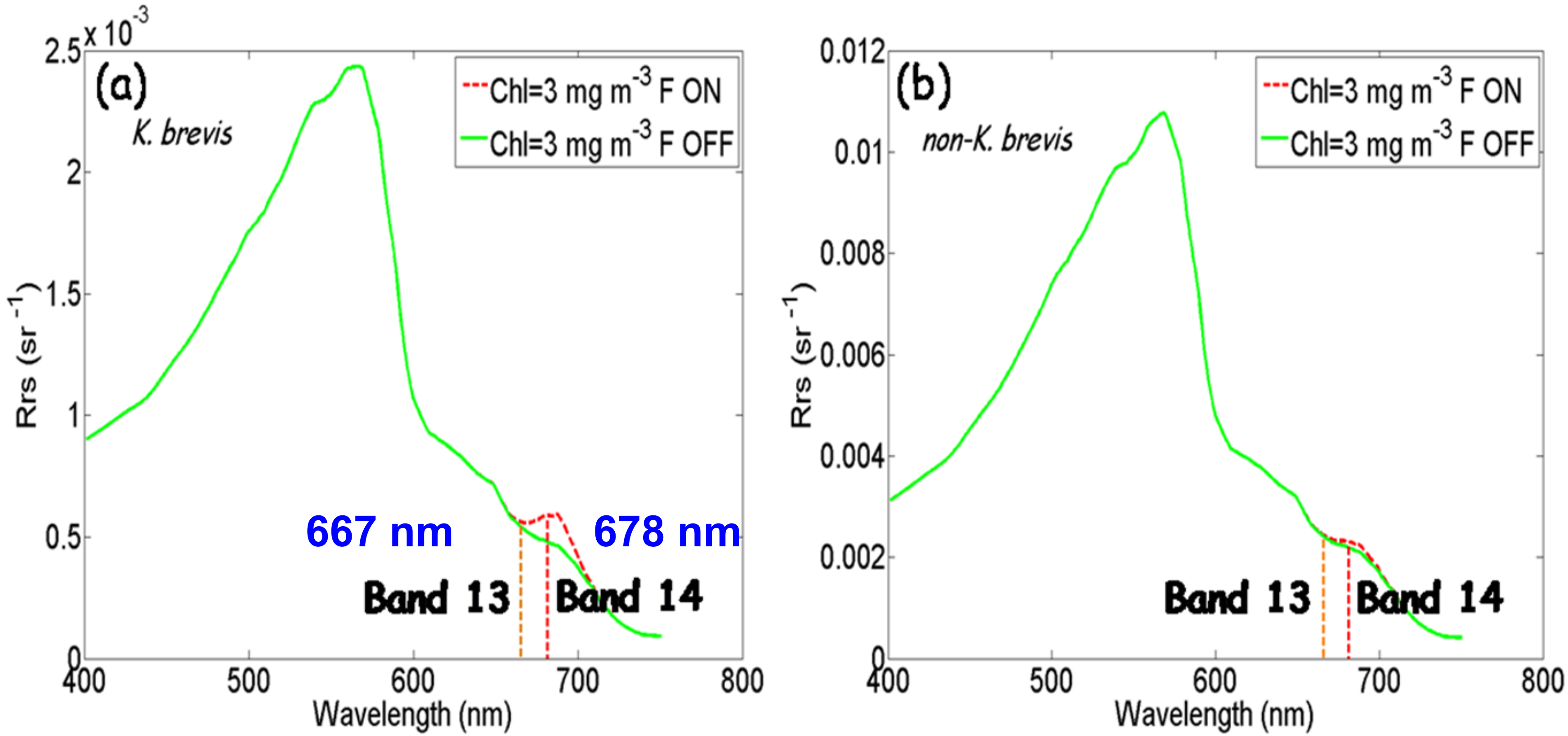
Satellite retrieval using MODIS FLH algorithm

665, 685, 753 nm – improvement with modified central band

# Harmful Algal Bloom Retrieval Algorithms

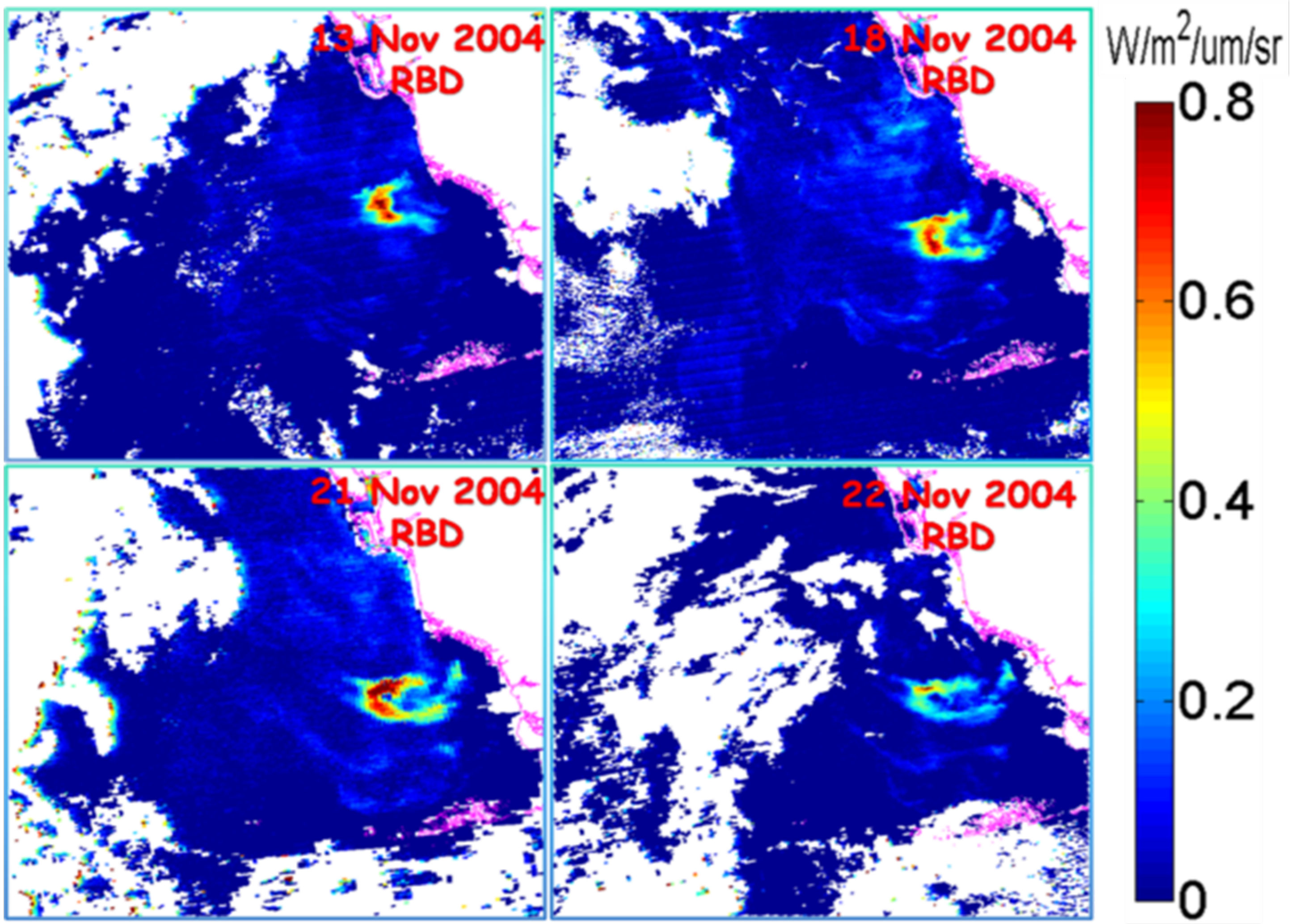
AMS, AGU, SPIE 2009, Opt. Express, 2009

# RBD Detection of Karenia Brevis blooms using NIR bands

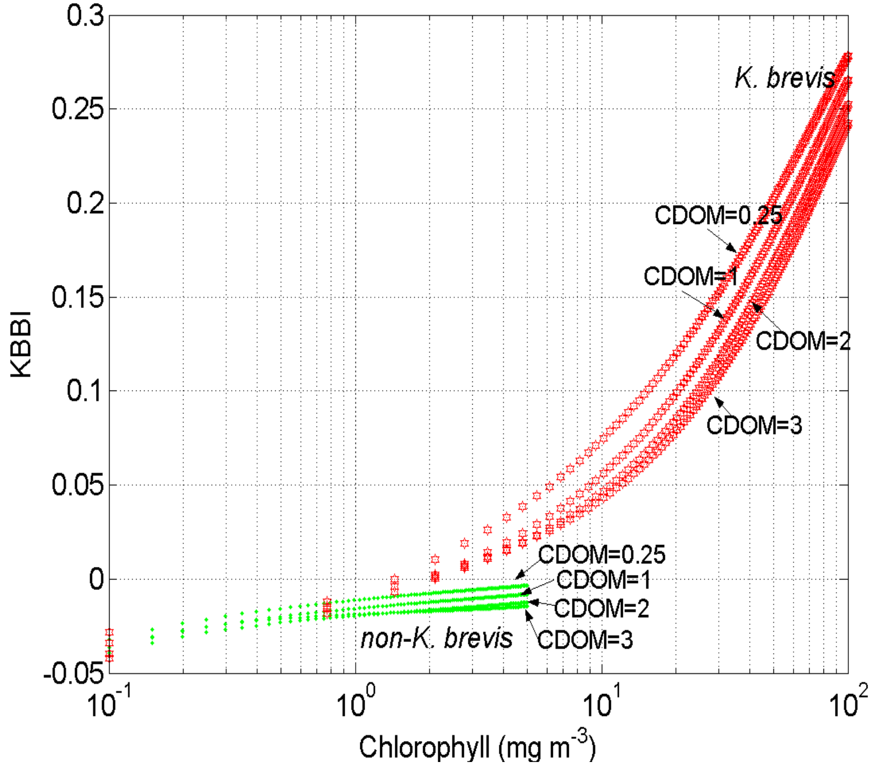


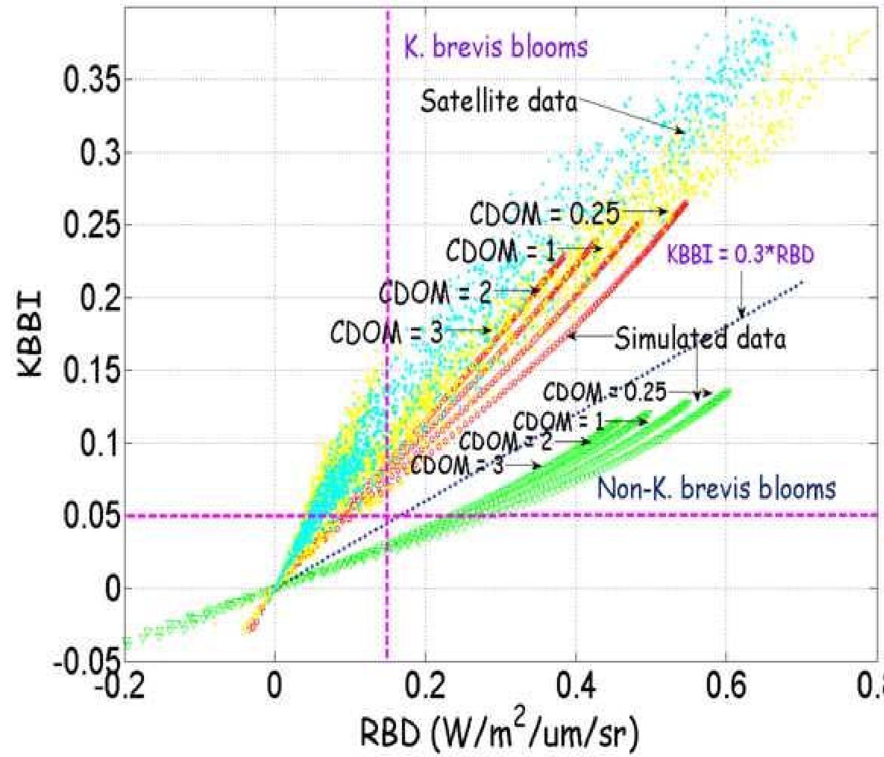

Because of the large particle sizes Karenia Brevis backscattering is lower than for other types of algae and fluorescence is more pronounced. And because differences in adjacent spectral bands used atmospheric correction impacts minimized

# Progression of K. Brevis bloom using MODIS RBD



# Classification of *K. brevis* with KBBI

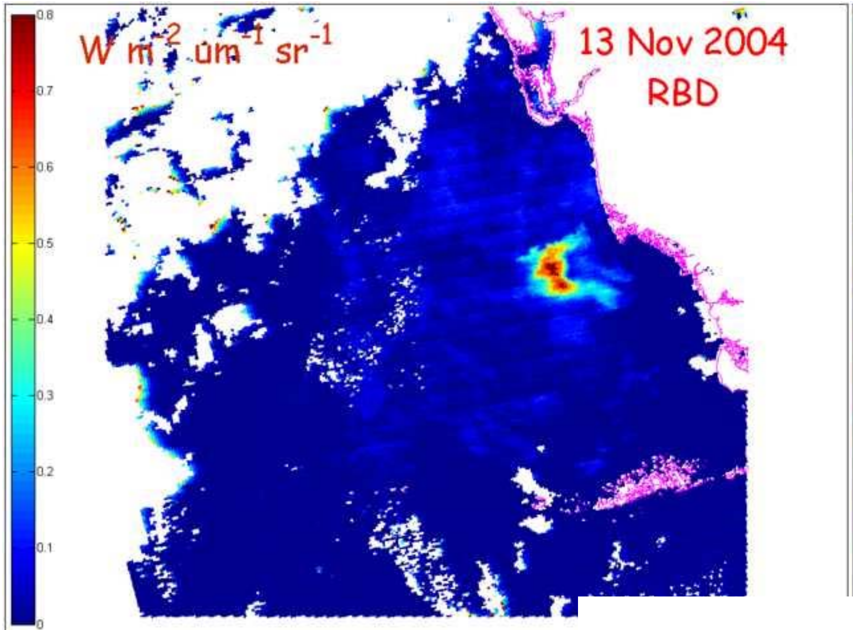


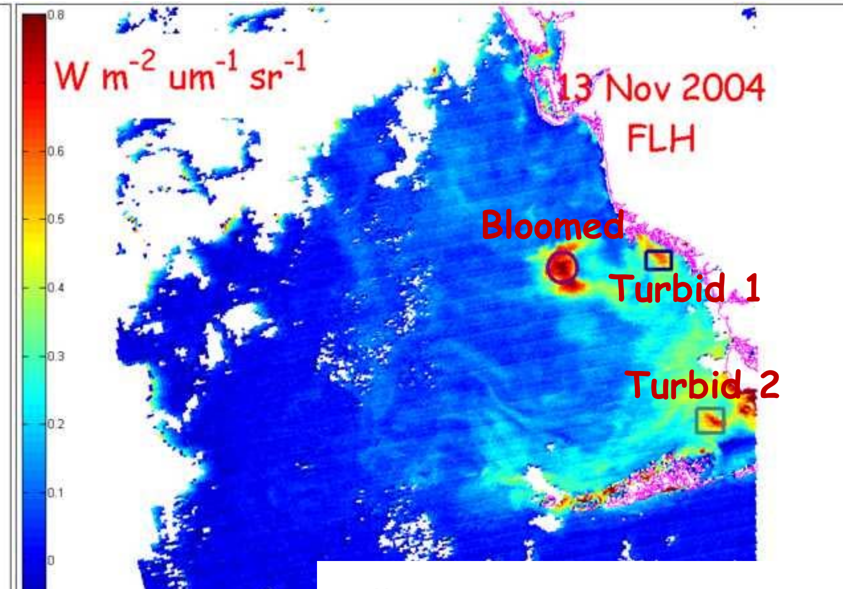




Particulate backscattering for *K. brevis* and non-*K. brevis* blooms are modeled based on the cell concentrations of *K. brevis* according to [Cannizzaro et. al 2004]

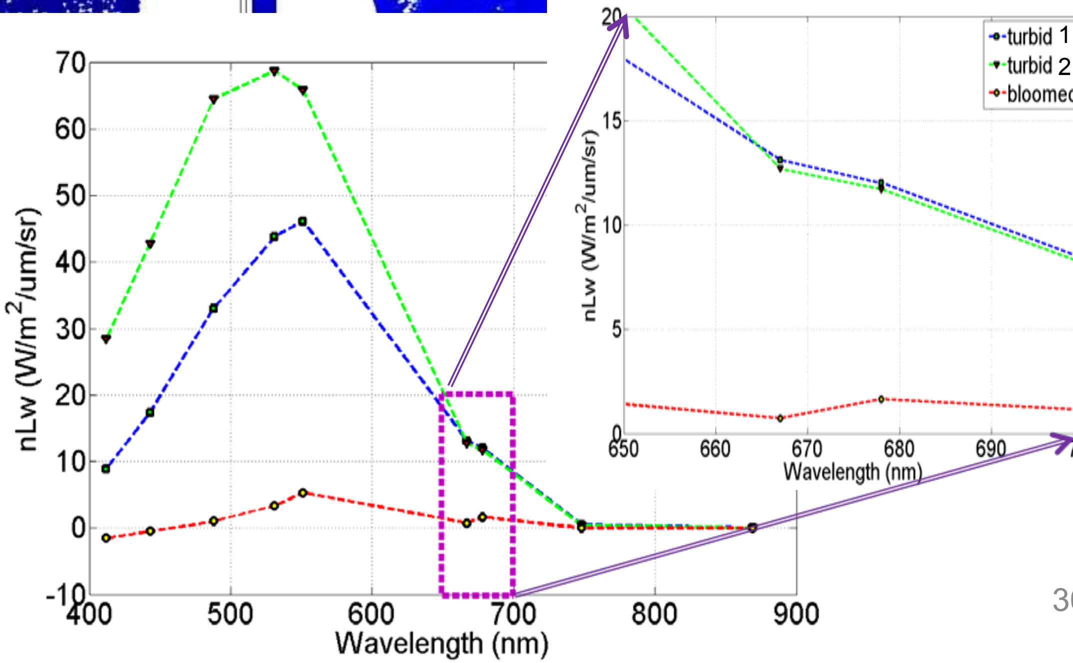
*K. brevis* simulated according to [Cannizzaro et. al 2004] and non-K. brevis simulated using standard bio-optical model assuming background concentration of NAP = 2 mg/l.
Chlorophyll ranges between 1 and 100 mg/m^3

# RBD vs. FLH



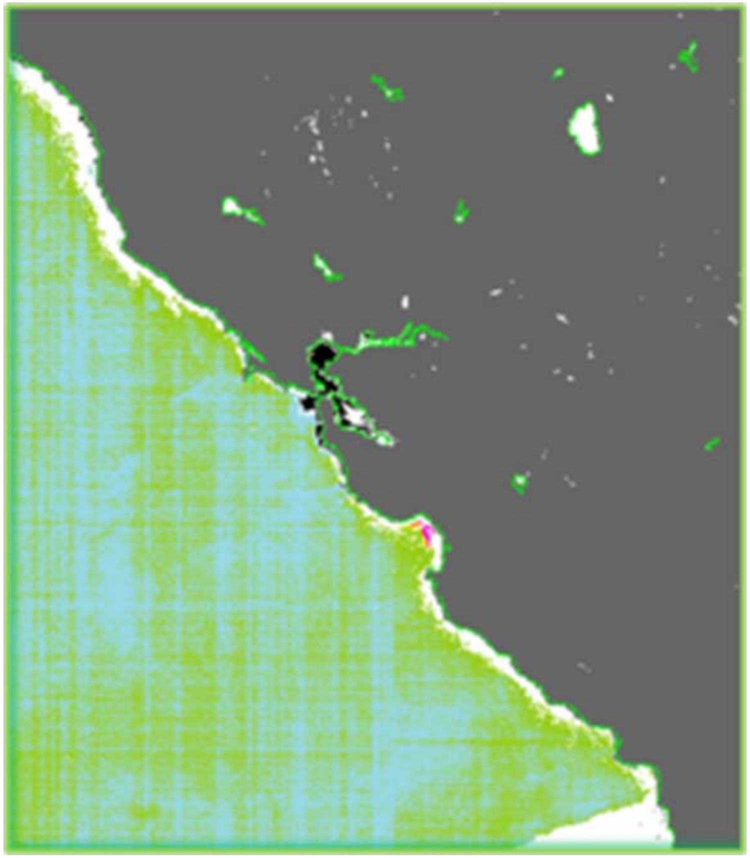




FLH alone cannot discriminate between bloomed waters and highly scattering waters. However, both the RBD or KBBI could easily distinguish between the two types of waters: since they both result in negative values in the highly scattering waters and positive values in the bloomed waters.

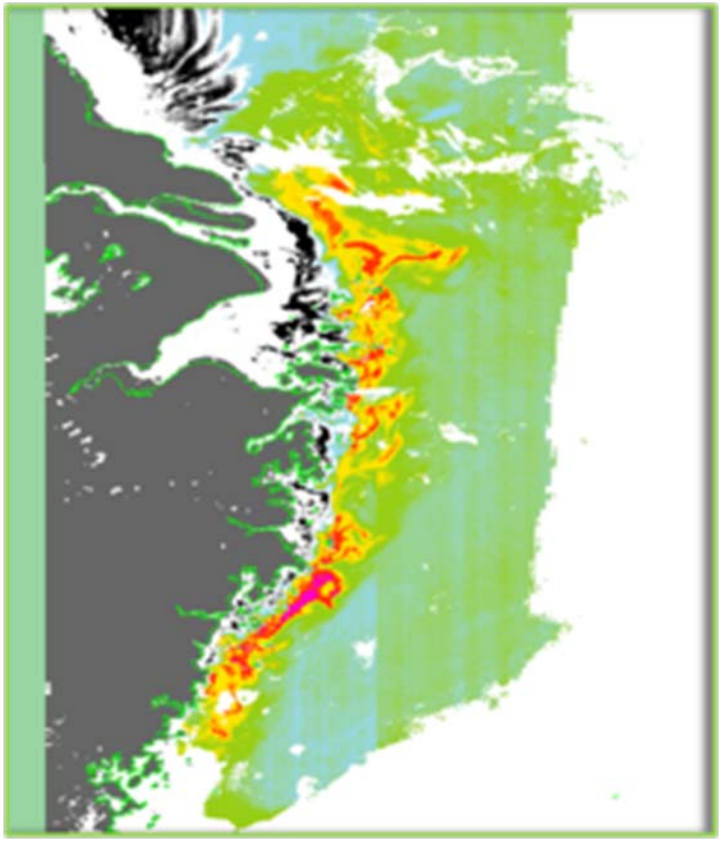


# Red Tide Detection with RBD Technique

**Monterey Bay Nov 3 2007**



**East China Sea 4 June 2005**



# Polarization properties of ocean and coastal waters

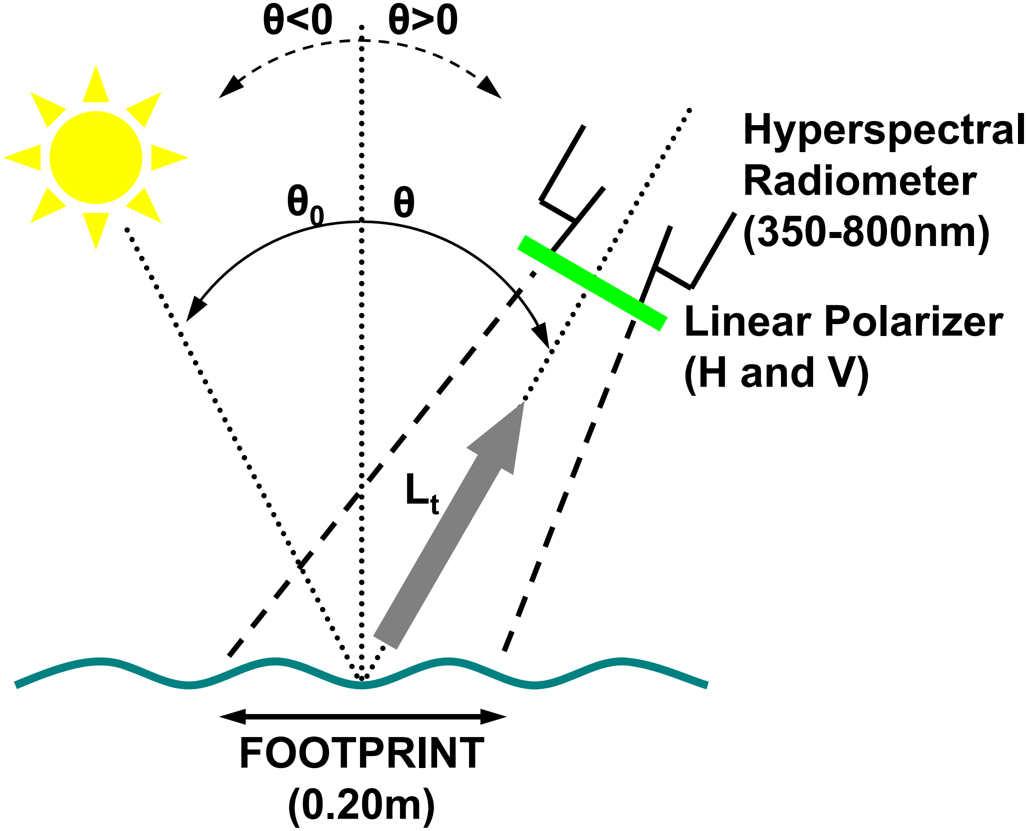
Applied Optics, 2006, Optics Express, 2008

# Why do we need polarization characteristics of water?

- The absorption of organic (non-chlorophyll) particles and mineral (inorganic) particles is exponential, similar to the absorption of CDOM – separation is problematic
- Organic particles have relative (to water) index of refraction 1.06-1.08, minerals 1.12-1.25, CDOM does not scatter
- Particle size distribution is an important factor of particulate scattering and backscattering
- Polarization characteristics depend on both: index of refraction and particle size distribution and that’s why they can be useful in retrieval !!!
- They are also useful in the separation of fluorescence and elastic components, in the improvement of the underwater vision, in the interpretation of ocean lidar signals
- It is important to determine contribution of atmosphere and air-water interface to the total degree of polarization

# Polarization measurements above water

Shipborne above-water angularly resolved measurements of the polarized components were taken in the Hudson River (Summer 2007 Campaign)




Geometry of observation of the instrument

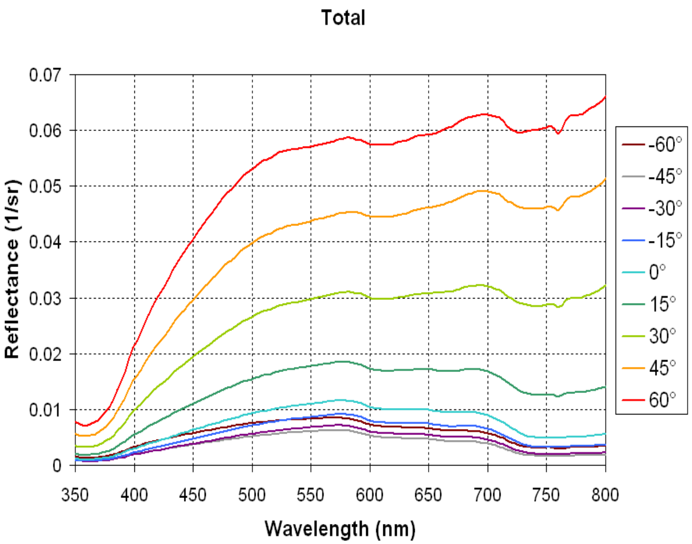
The radiometer was rotated up to 70° (5° steps) either side of nadir viewing

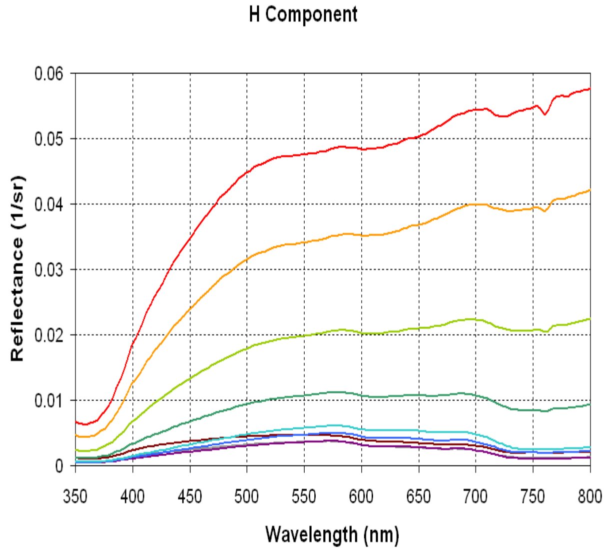
The scanning system was mounted at the extremity of the back deck of the boat (~1m above water)

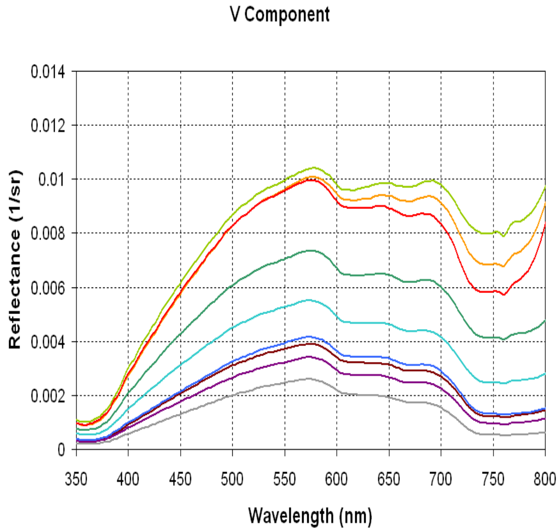
Simultaneous measurement of downwelling spectral irradiance ($E_d$)

# Optical characterization

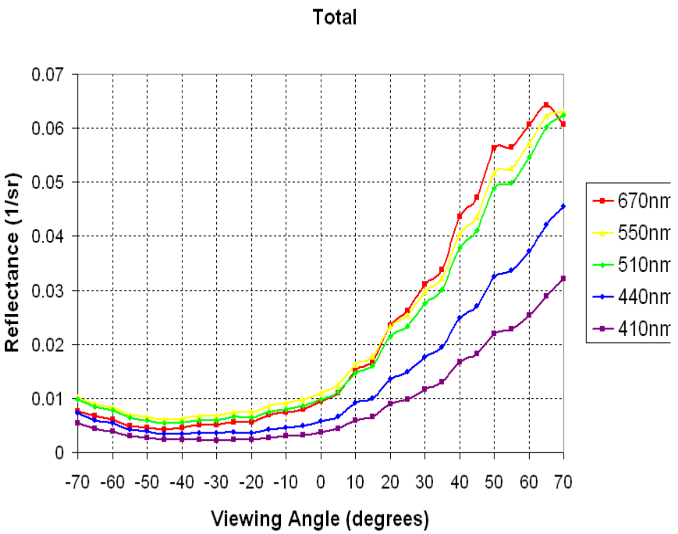
## - Spectral dependence: Station 3

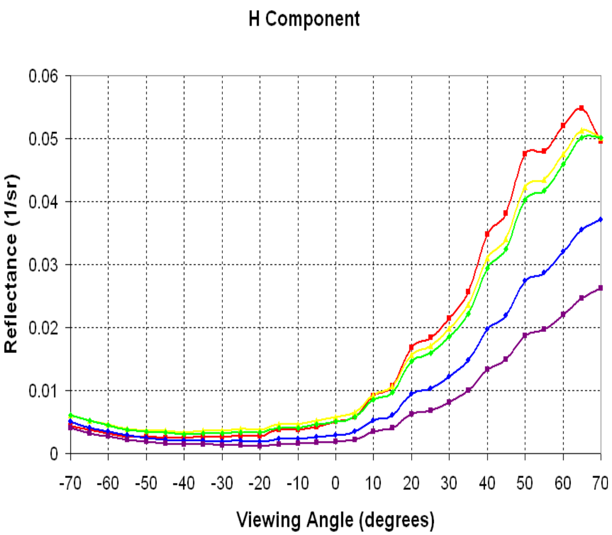


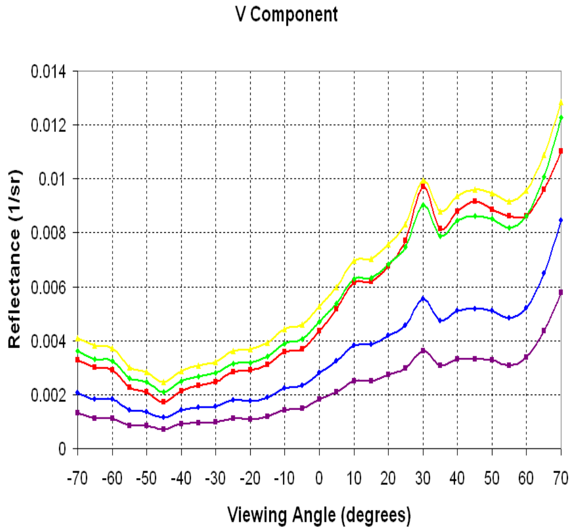




## - Angular dependence: Station 3

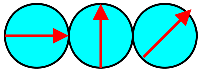


# New Sensor Development

- Under-water angularly resolved measurements of the polarization components:



- Polarizers (0°, 90°, 45°) are attached to three hyperspectral radiance sensors (Satlantic):

ADV: simultaneous measurements

no need to manually switch polarizer position

- A step electric motor allows for a full rotation of the radiometers to change the angle automatically:

ADV: faster and convenient measurements

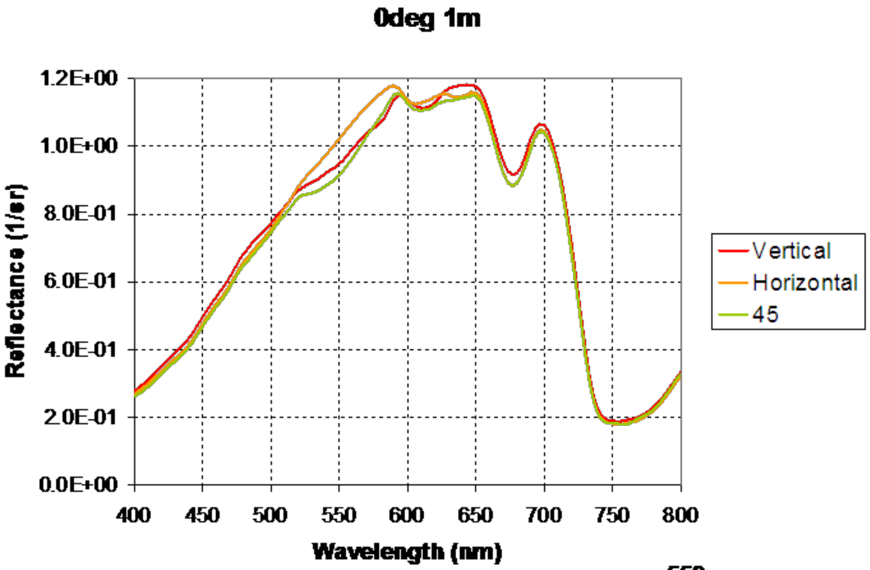
more accurate determination of the angular position

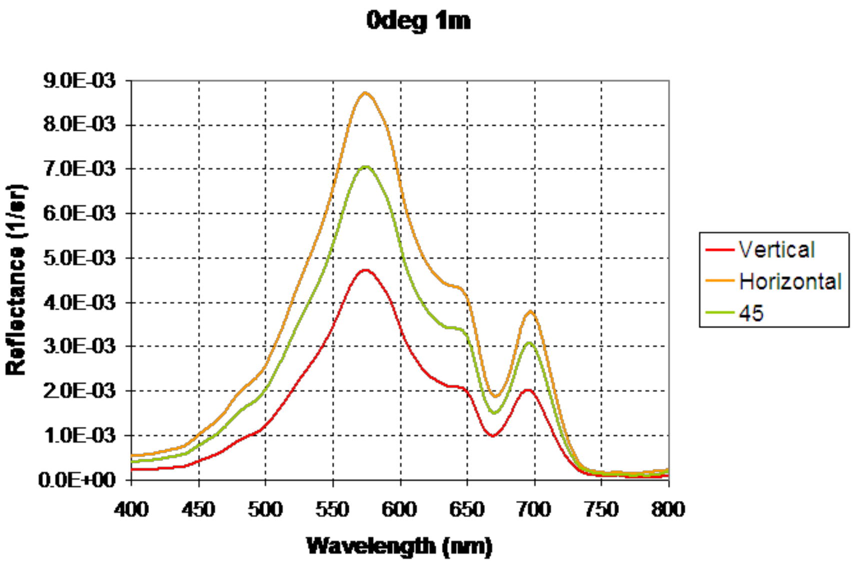
**Simultaneous measurement of downwelling spectral irradiance (*Ed*)**

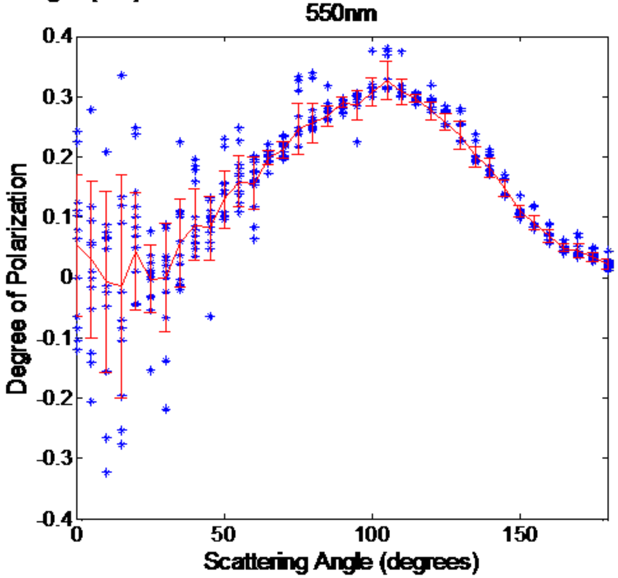
# Accuracy of measurements

Radiances at scat. angle 0 deg

at 90 deg

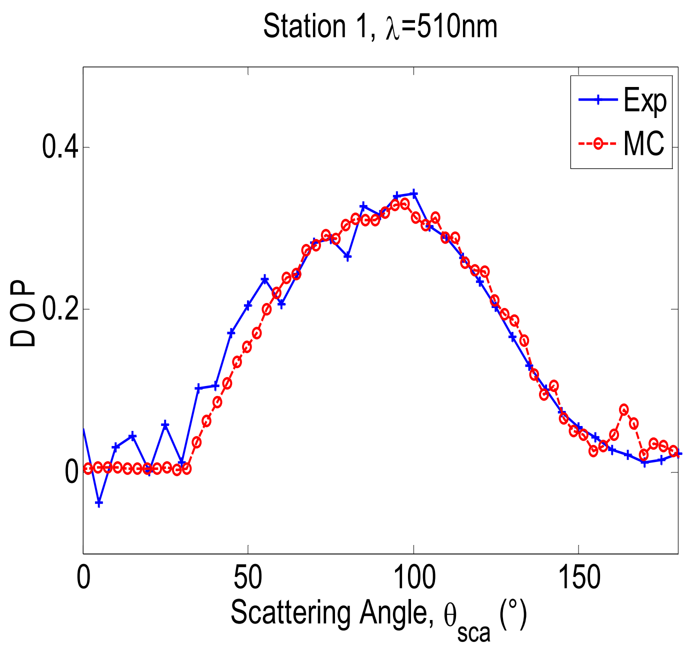


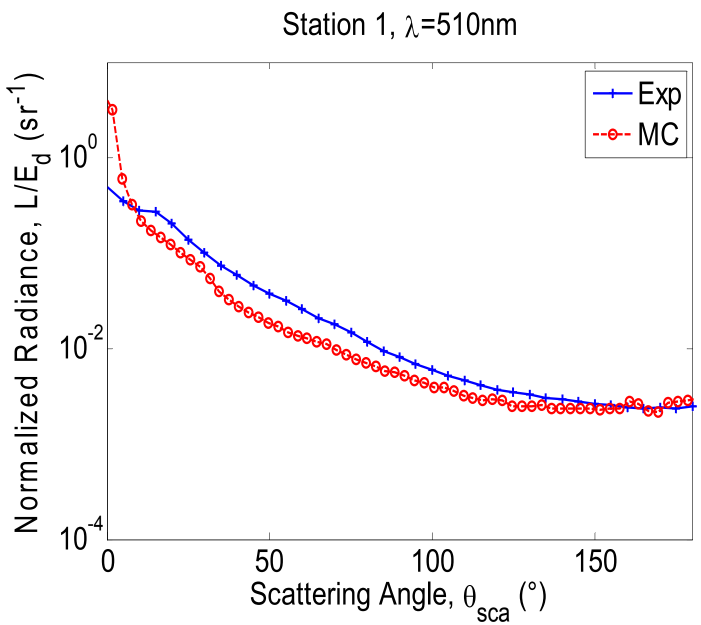




Variability of degree of polarization as a function of scattering angle

# Comparison of measured and simulated underwater degree of polarization and radiance distributions

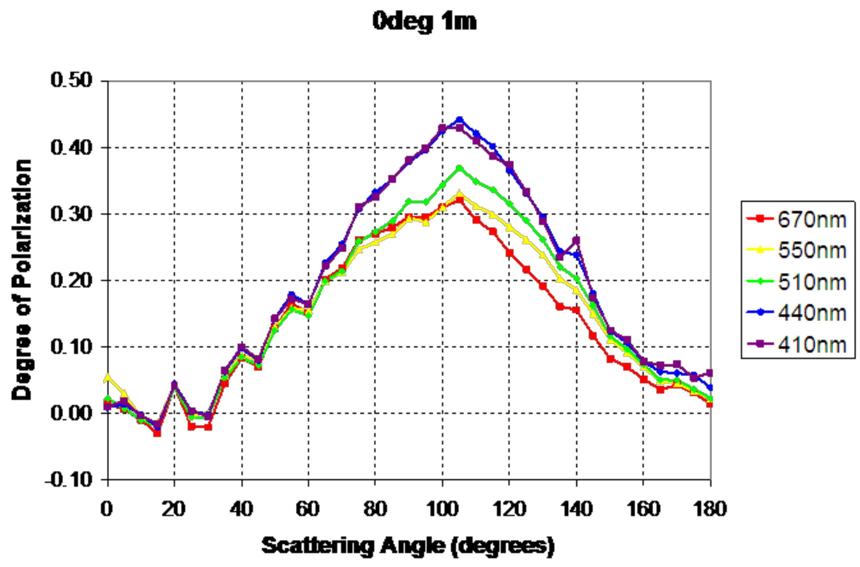


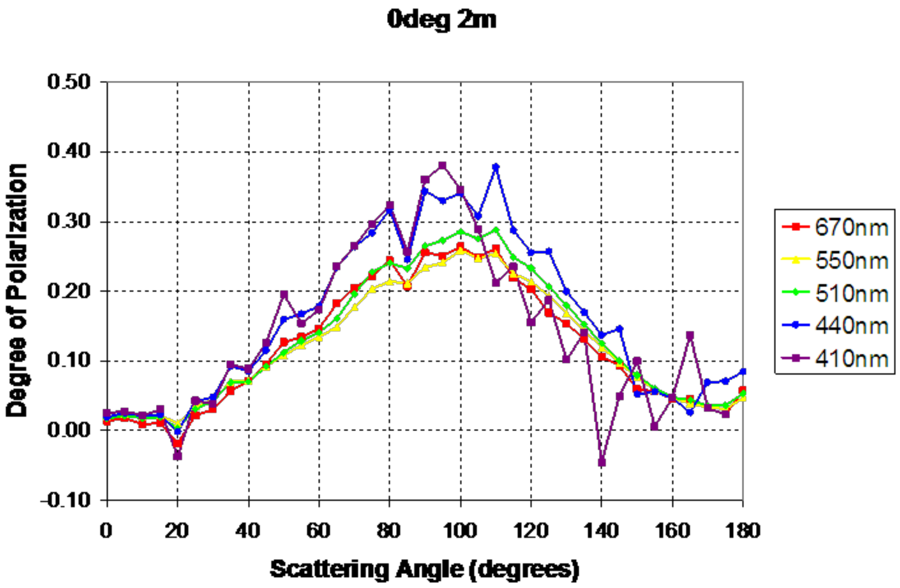




New Jersey Coast, summer 2008

Polarization characteristics can be also studied from the platform

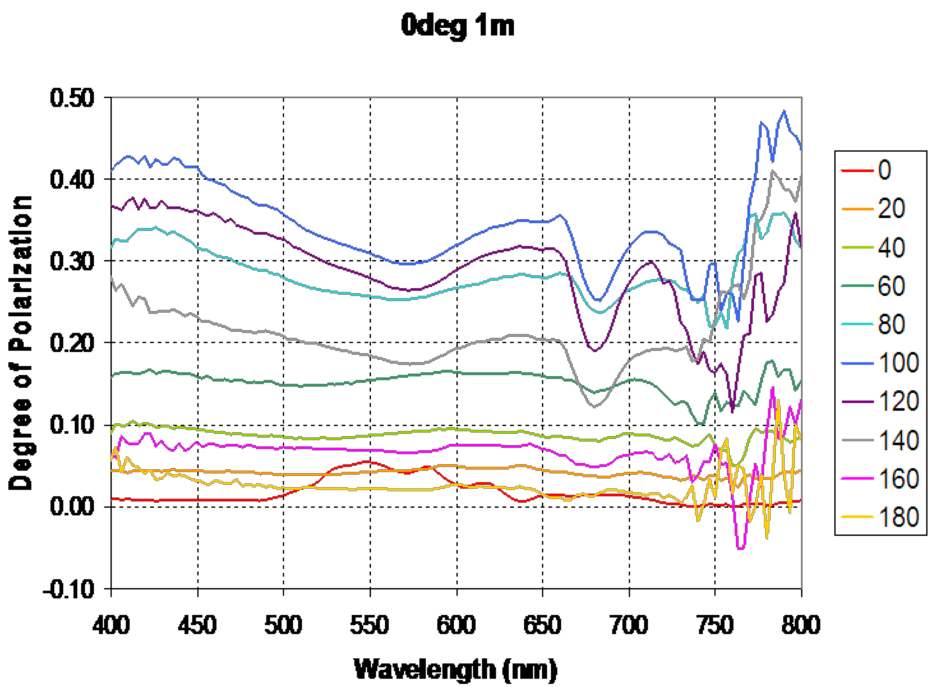
# Degree of polarization as a function of scattering angle for various wavelengths and two depths (marina)

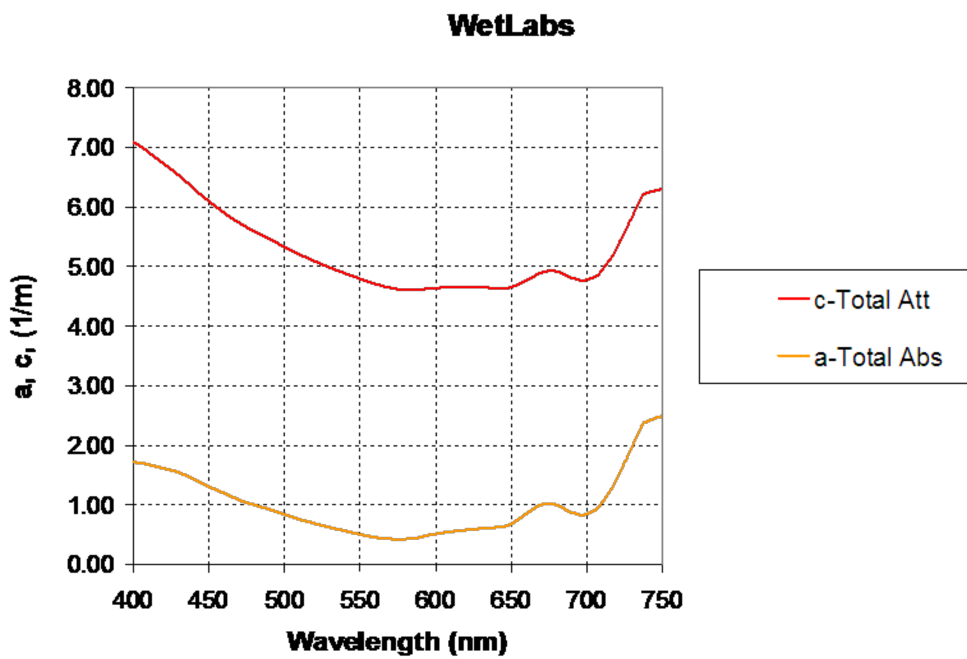



Decrease of DOP with depth due to the multiple scattering

# Degree of polarization as a function of wavelength




Degree of polarization generally follows total absorption trend; multiple scattering decreases with absorption increase.

Fluorescence is an additional depolarizing factor

# Examining Impact of Atmopsheric Corrections on Coastal Ocean Color Retrievals

- Retrieving water signal in coastal areas is complicated by several factors
  - turbid waters which make dark pixel approximations invalid. Use SWIR algorithm (Wang et al.)
  - Complex aerosols which are not completely represented by global based LUT’s.
- Past efforts - Explore whether in areas with high CDOM absorption (like Chesapeake Bay), we can use the 412nm channel  as an extra atmosphere constraint which when combined with atmosphere estimates in the long wave channels, improves water leaving radiances.
- Some success seen in improving retrieval for highly absorbing cases  but observed correlations of optical thickness and water leaving radiances show solution is not always an improvement.

# Difficulties/ Current Efforts

- Assuming a single mean water leaving signal clearly introduces statistical biasing which is probably only partially reduced by including SWIR band information.
- Algorithm clearly not reasonable for most waters since it requires high CDOM absorption.
- Algorithm requires three-channel optimization over regional atmosphere LUT. Hard to make operational.
- Current efforts - Can we try to estimate 412 water leaving signal using estimators (i.e bio-optical Stumpf et al, NN etc)
- Instead of solving for Atmosphere contribution directly, can we clean up errors using post-processing correction (like Stumpf's absorbing aerosol correction scheme ?)

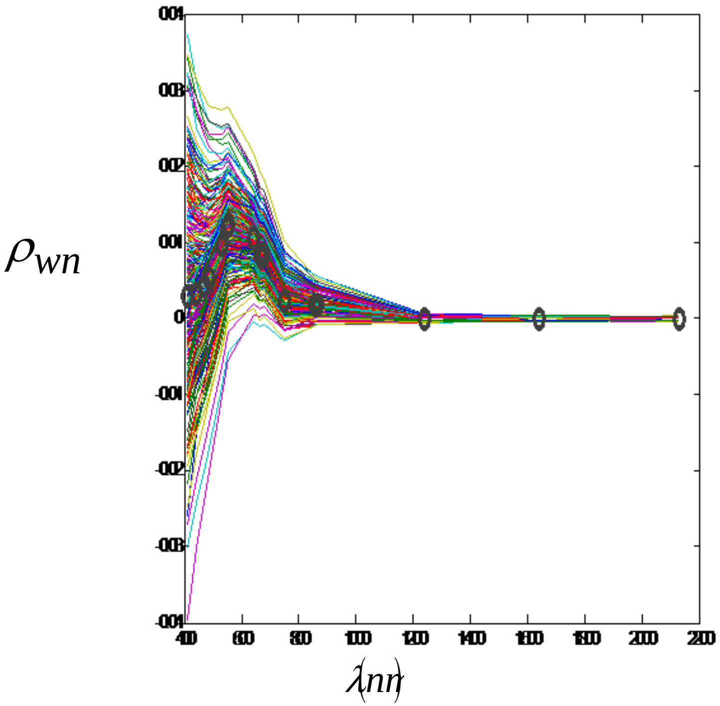
# Current Results

- Post Processing approach  using 412nm estimator requires an adjustment in the spectral correction factor (between 3-4) then that assumed by Stumpf et al (between 6-8)
- A Neural Network approach to estimating 412nm (trained using channels 490, 510, 555, 670)  based on insitu global measurements seems to be a much better estimator than the bio-optical one with correlation factor  R^2 ~ .6 compared to bio-optical estimator  factor R^2 ~ .35
- High correlation requires inclusion of the 490 nm channel.

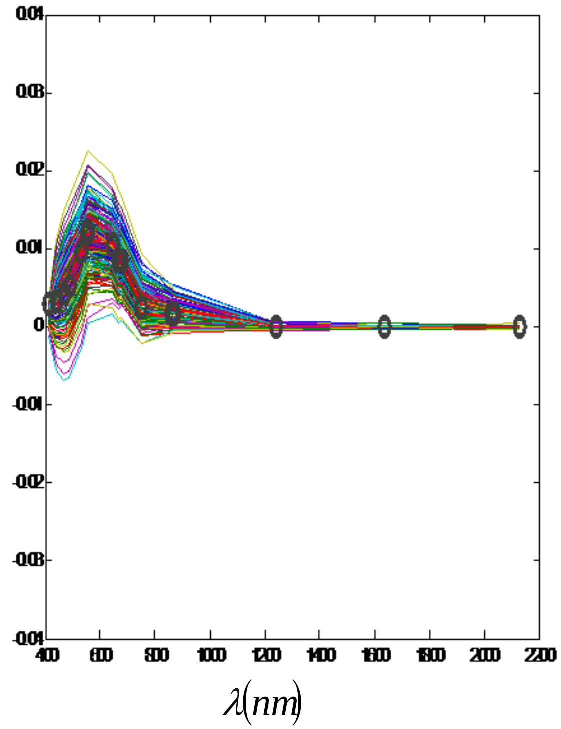
# Optimizing spectral correction factor

## Water leaving signals (443nm) with AERONET Ref Atmospheres (NYC)inverted using SeaDAS atmospheres

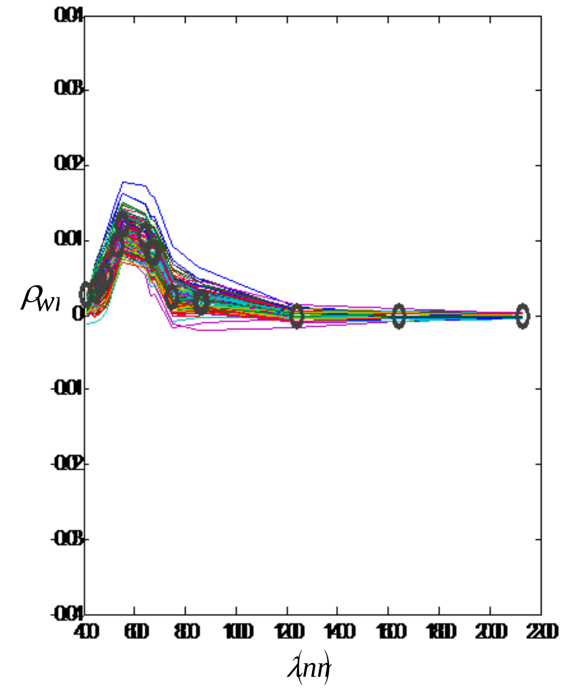
No post-processing correction




N=6 power exponent correction
Stumpf Power Law correction




N=3 power exponent correction
Based on optimization over AERONET Atmospheres.



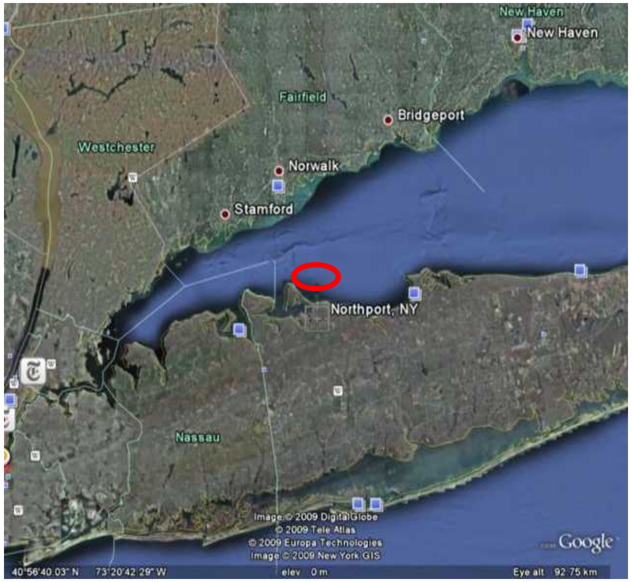

Note improvements seen both for highly absorbing aerosol models pushing Solution negative as well as high angstrom aerosol models which SeaDAS Model atmospheres would underestimate.

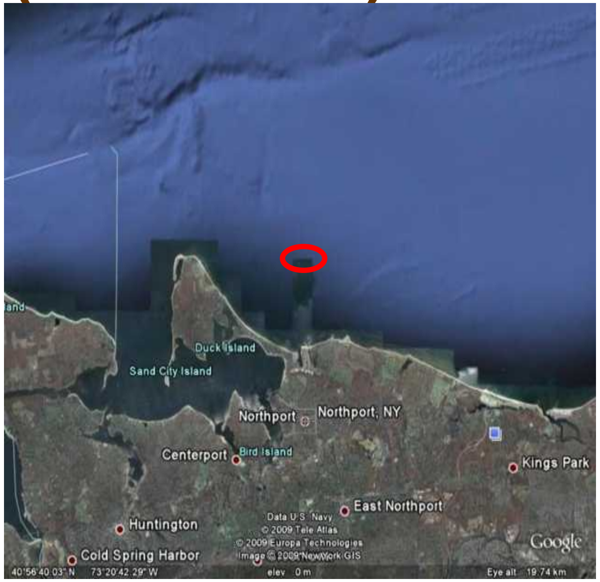
# Future Directions

- Test these post-processing algorithms on current LISCO Sea-PRISM Ocean Observing Site.
- Develop together with NASA-GISS efficient Radiative Transfer codes to ingest aerosol vertical structure to improve retrieval for absorbing aerosols.

# Development of Coastal Observation Platform in LIS

# Long Island Sound Coastal Observatory (LISCO)

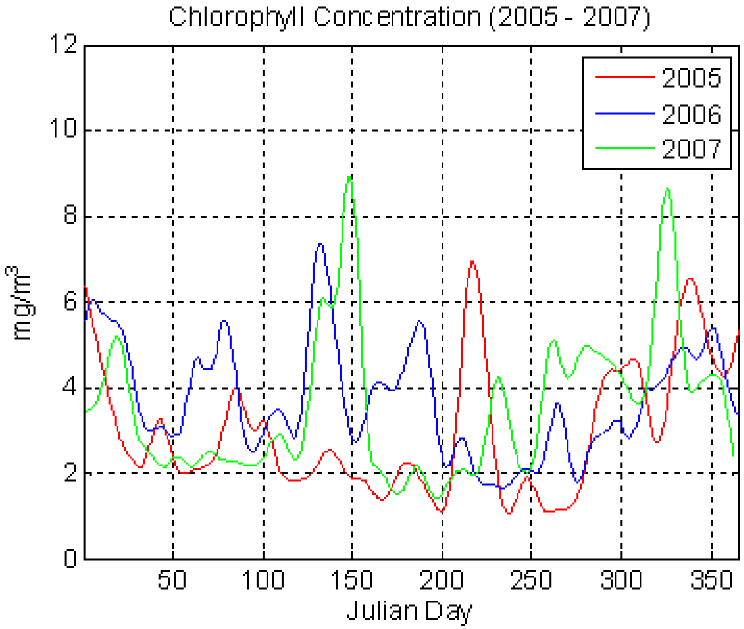


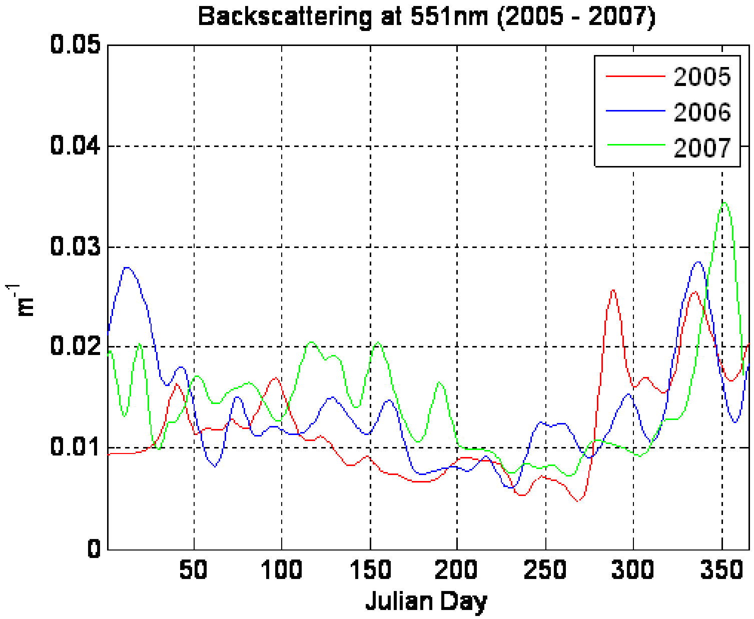



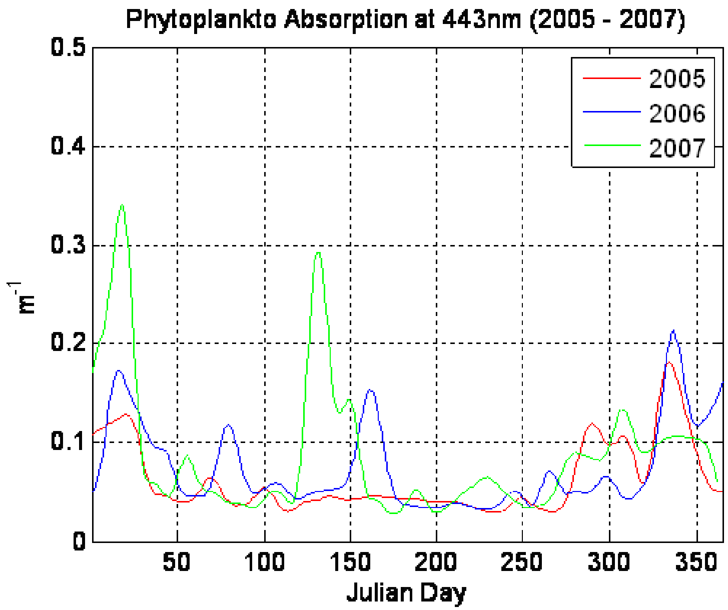


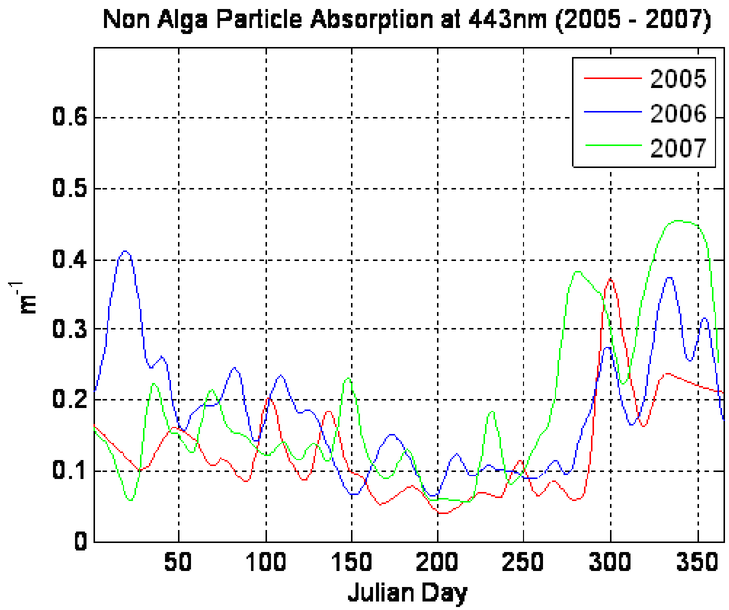
With SeaPRISM installed close to the western corner it will be operational for the most time of the day (90 deg to the Sun position)

# Water quality in the area of platform

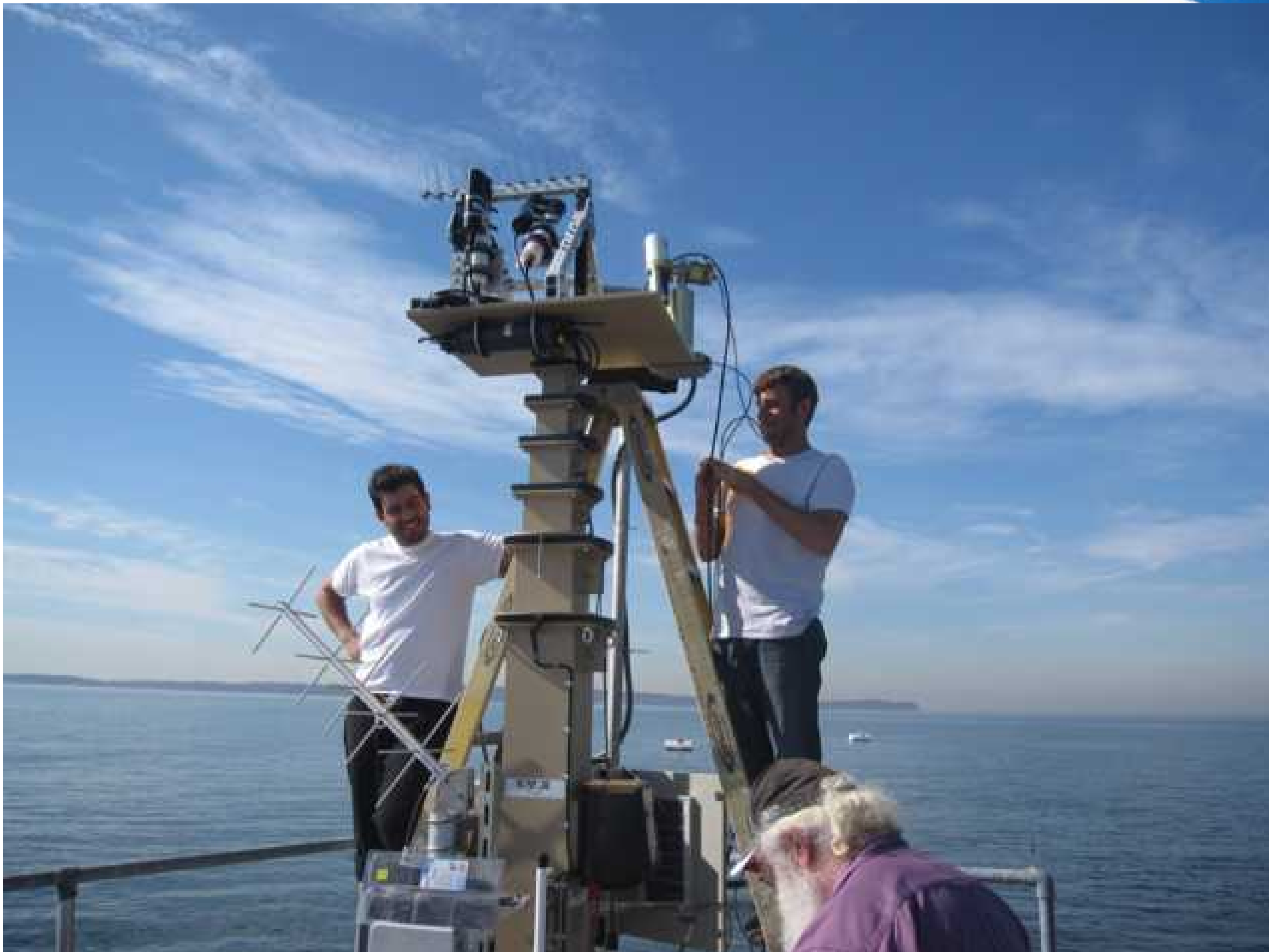


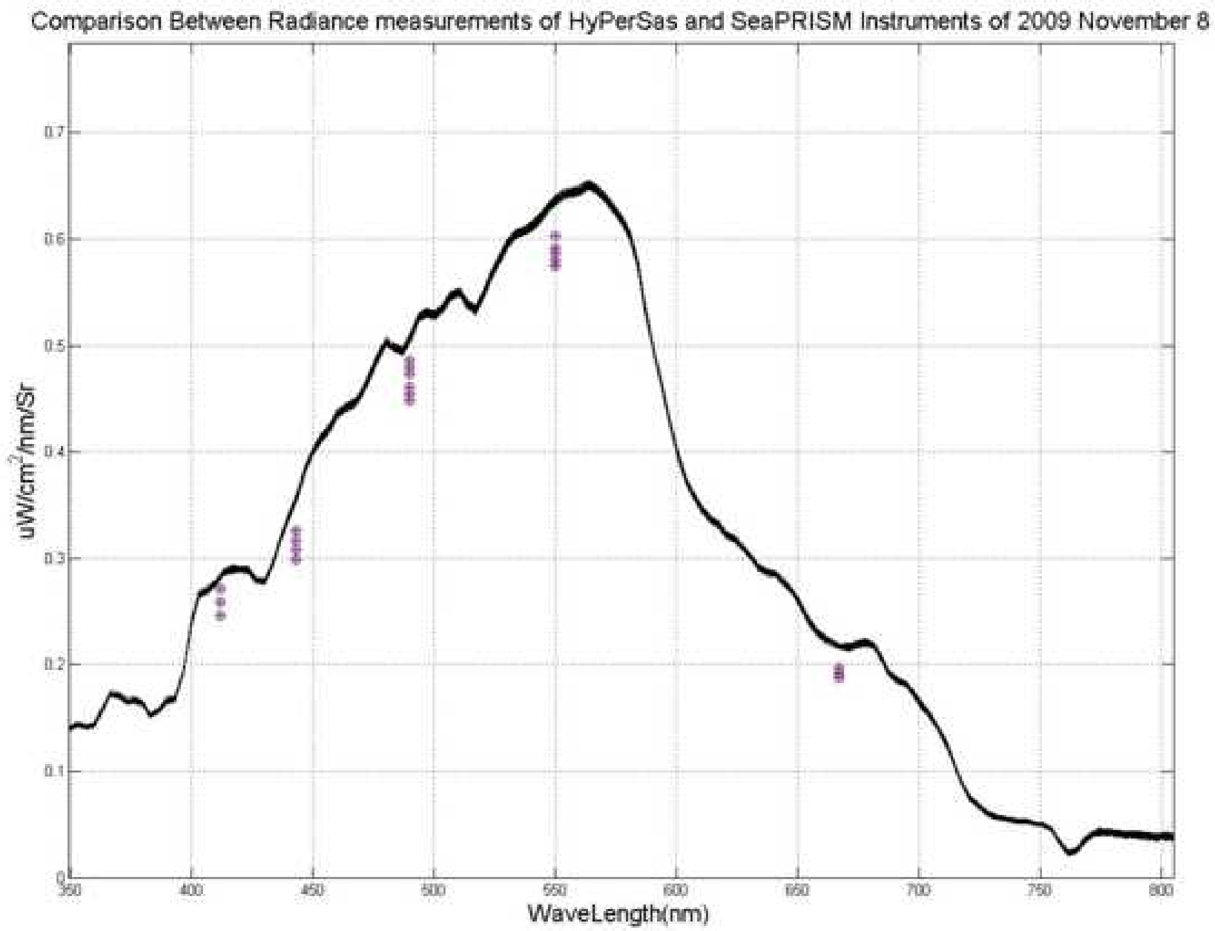



# HyperSAS instrument to be modified in the future also for hyperspectral polarimetric platform measurements



# Comparison of HyperSAS and SeaPRISM measurements, November 8, 2009

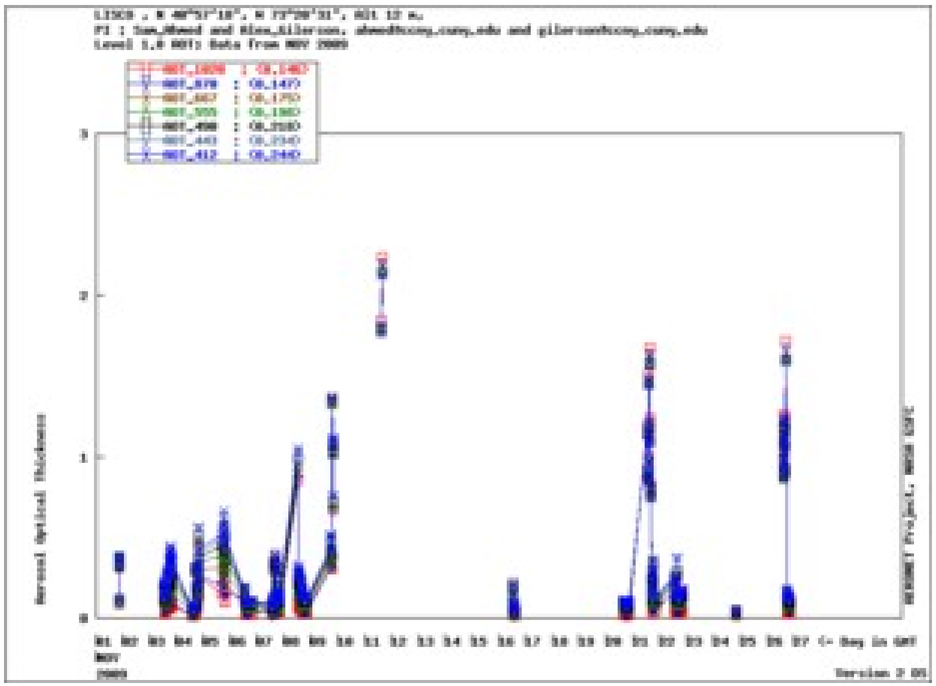


GODDARD SPACE FLIGHT CENTER

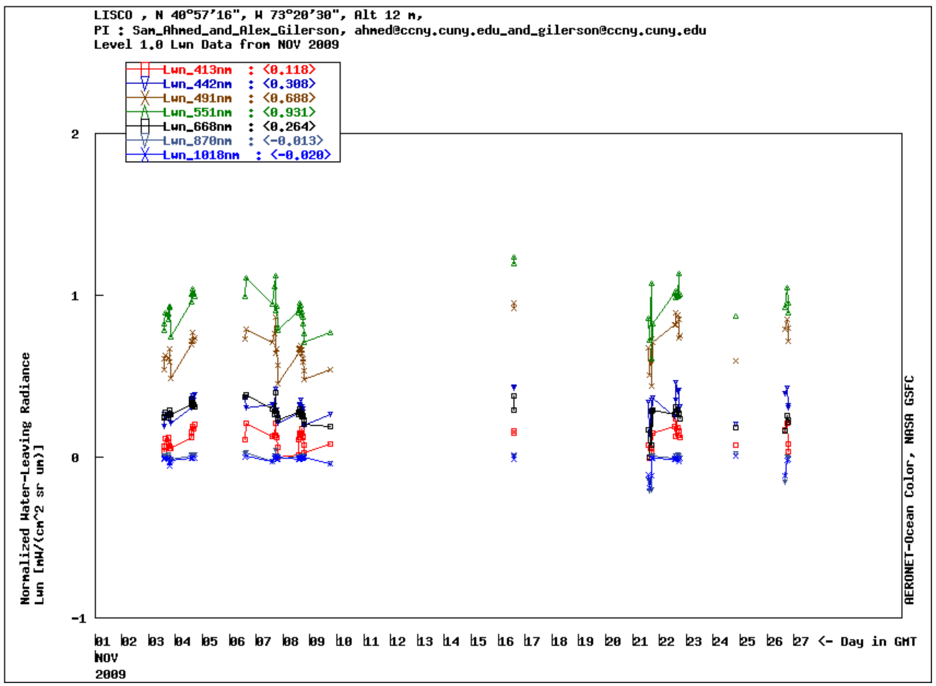
NOAA|CREST

# AERONET

## AEROSOL ROBOTIC NETWORK



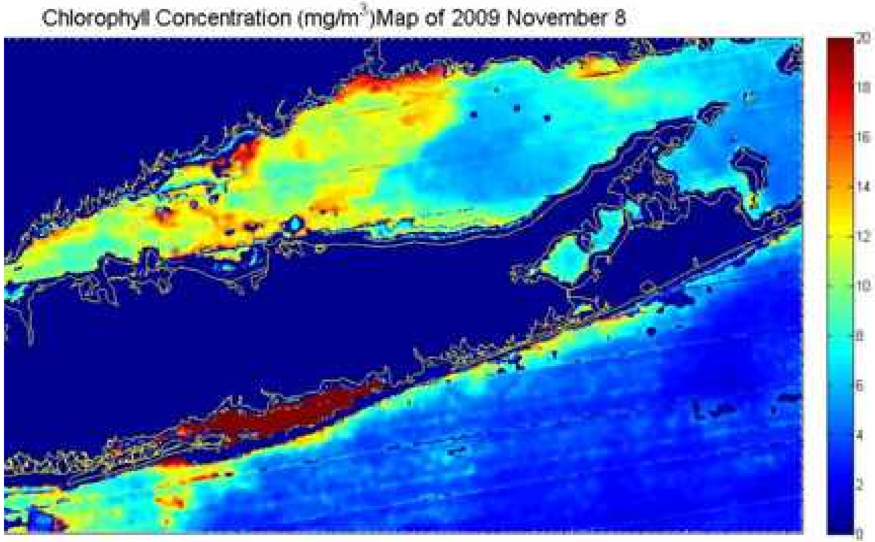
Aerosol Optical Thickness from LISCO site for Nov 2009




Water Leaving Radiance from LISCO site for Nov 2009

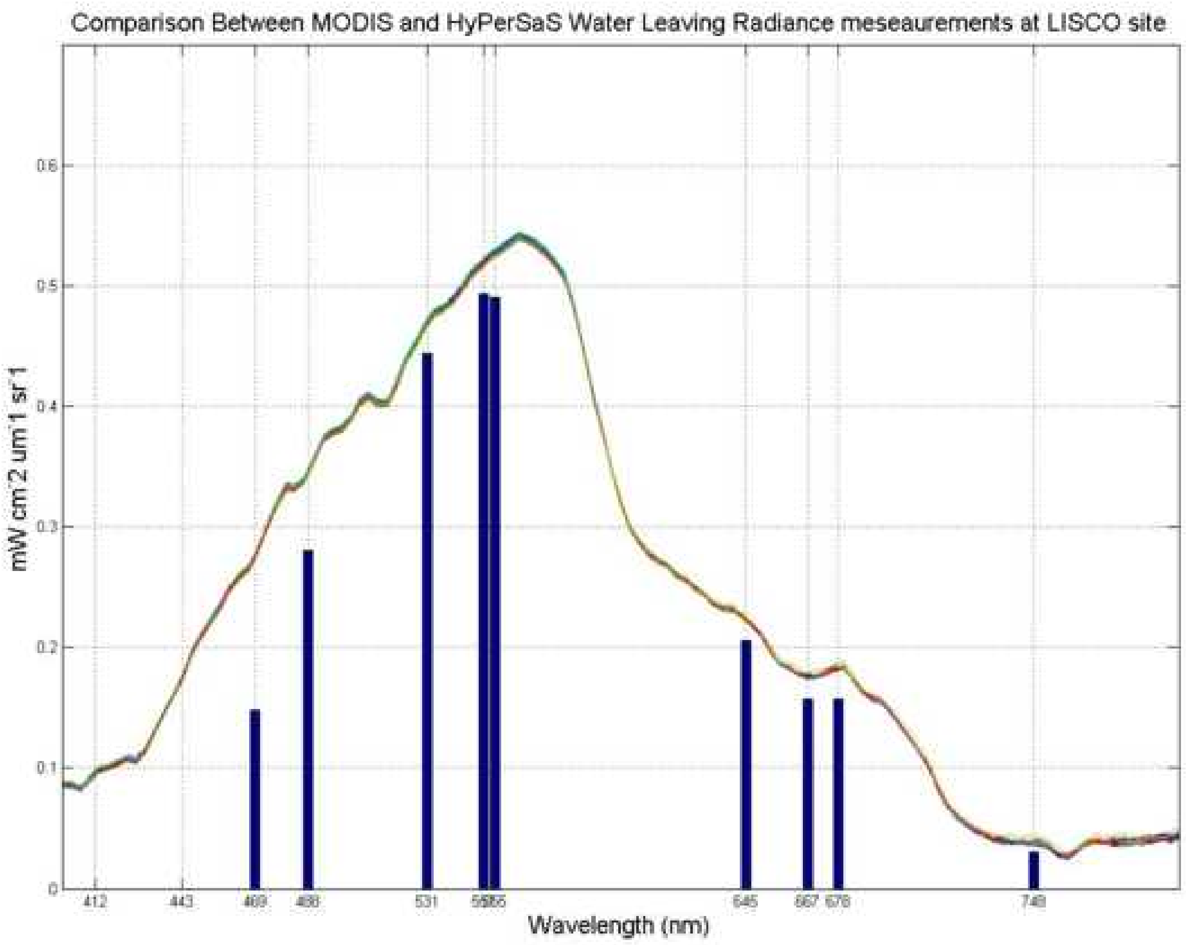
# Satellite imagery for Long Island Sound


MODIS Aqua 250 m true color composite image, November 8, 2009




MODIS Aqua map of chlorophyll concentration, November 8, 2009

# Comparison between HyperSAS and MODIS water leaving radiances at LISCO site

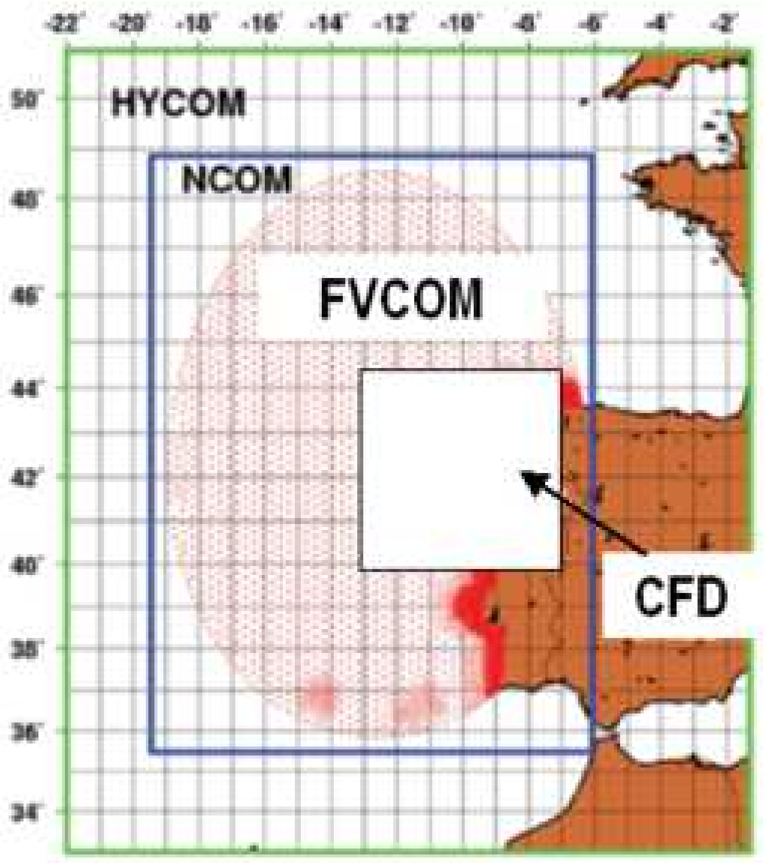


# Hydrodynamic modeling for coastal waters

# Coupling CFD and Coastal Models

Coupling Strategies

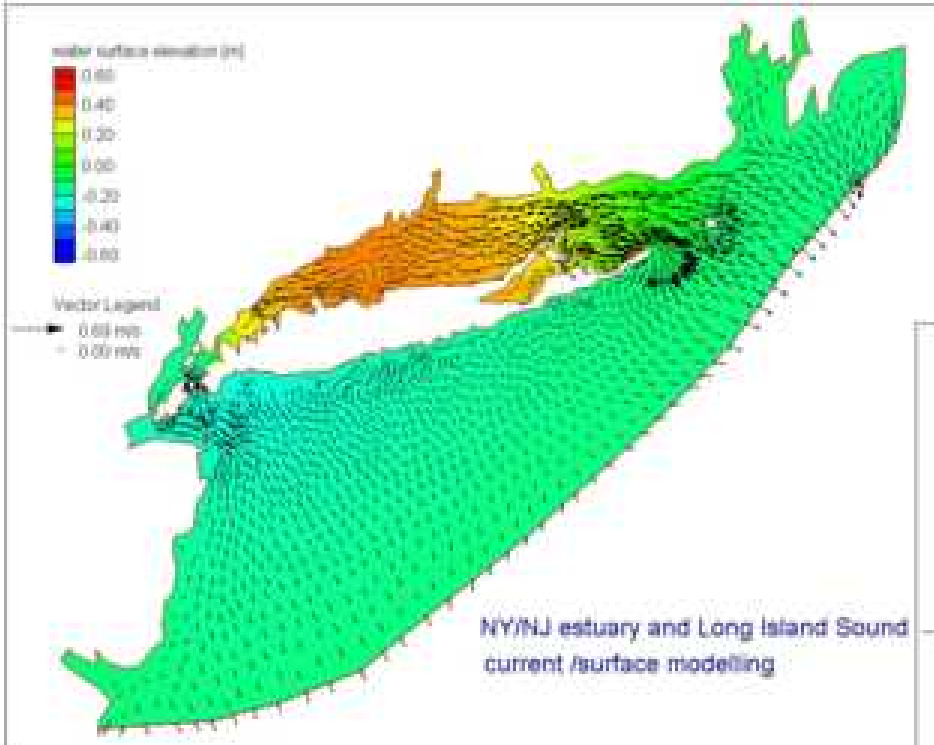
- CFD model and coastal model (FVCOM) are coupled together
- CFD is used to resolve fine scale flows, and coastal model is used to capture large scale background flows
- Chimera overset girds
- Two-way coupling

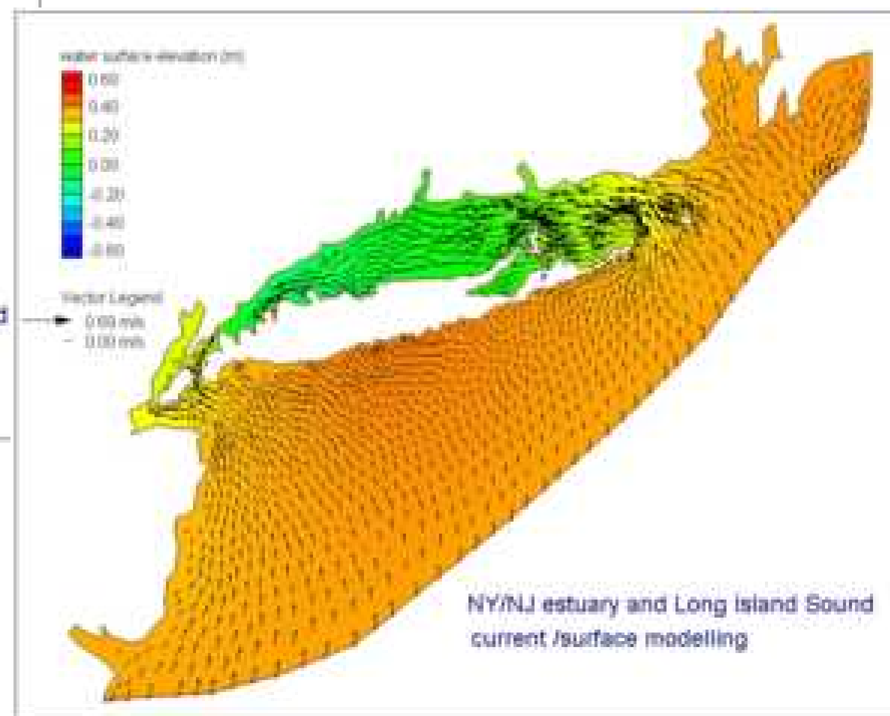


# Coastal Flow Modeling for NY/NJ Estuary --- Mesh

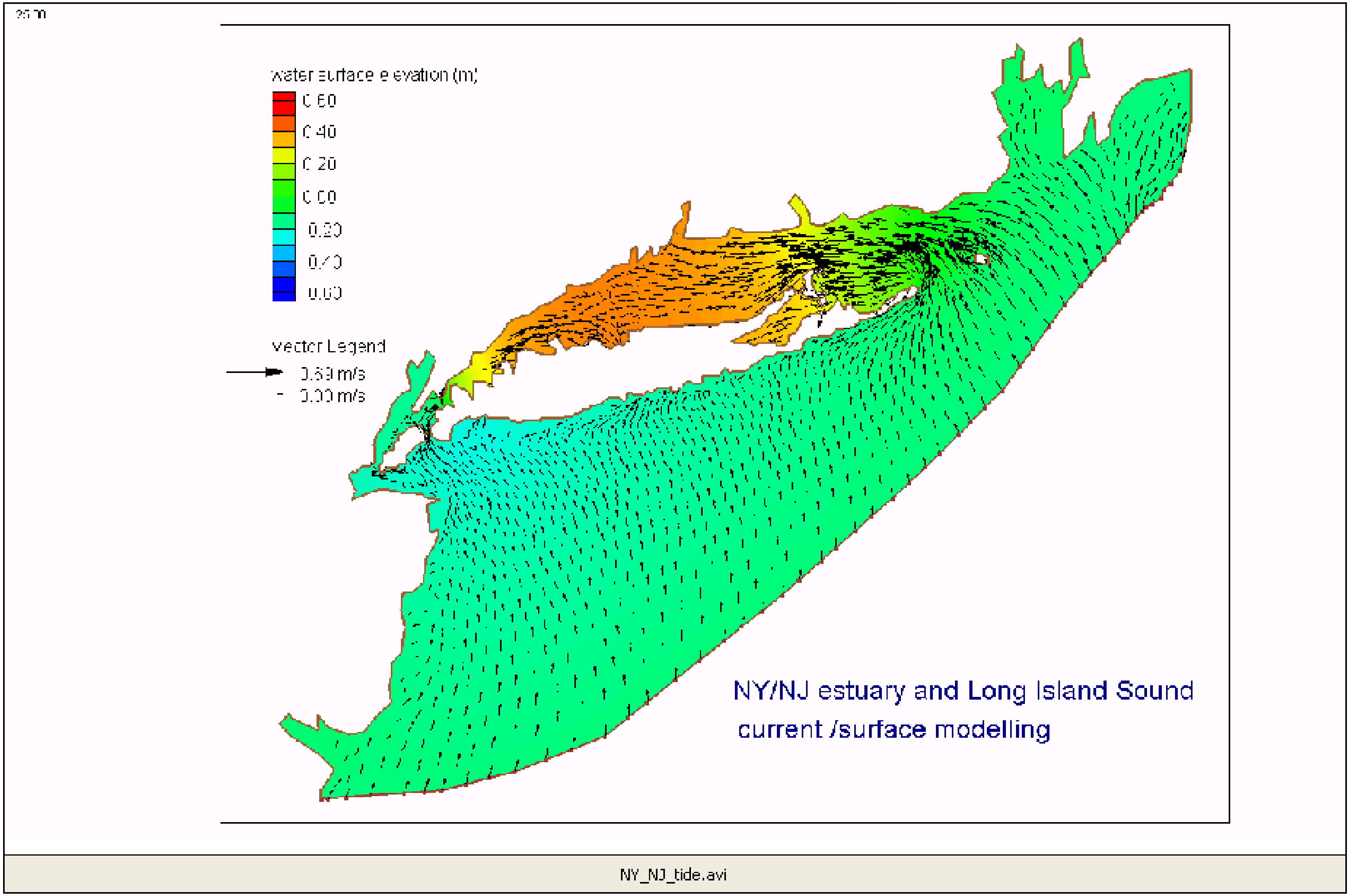
# Coastal Flow Modeling for NY/NJ Estuary --- Solutions

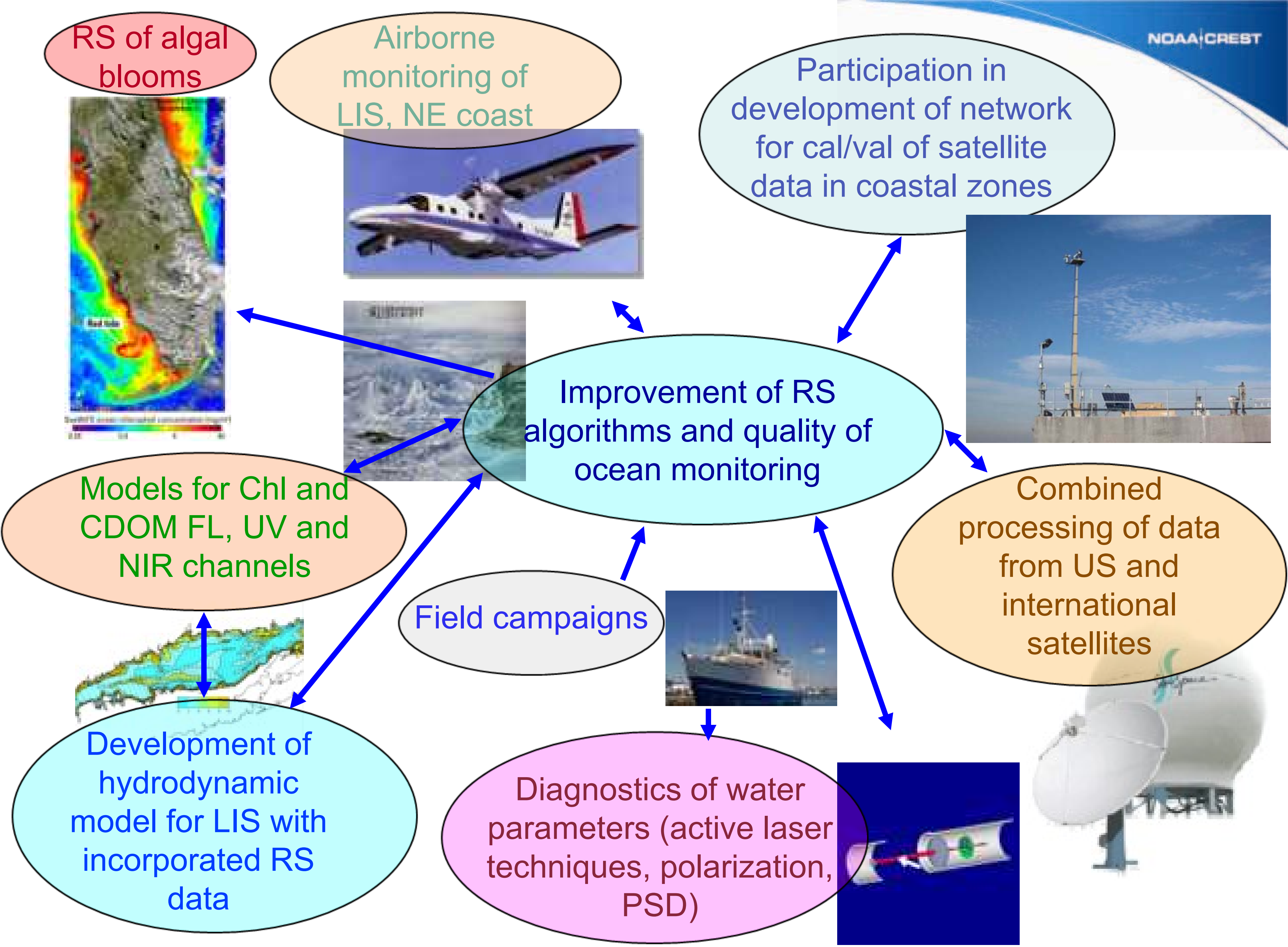
flood tide




ebb tide


Vector Legend
NY/NJ estuary and Long Island Sound
current /surface modelling
NY_NJ_tide.avi


NOAA CREST
RS of algal blooms
Airborne monitoring of LIS, NE coast
Participation in development of network for cal/val of satellite data in coastal zones
Improvement of RS algorithms and quality of ocean monitoring
Models for Chl and CDOM FL, UV and NIR channels
Combined processing of data from US and international satellites
Field campaigns
Development of hydrodynamic model for LIS with incorporated RS data
Diagnostics of water parameters (active laser techniques, polarization, PSD)

# Future plans

- Improvement of IOP retrieval algorithms based on hyperspectral, UV, NIR and polarization data
- Studies of inland waters
- Algorithms for the detection and prediction of algal blooms
- Cal/val efforts for NPOESS, HICO, current and future US and international satellites
- Development of advanced atmospheric correction models based on LISCO and AERONET data, lidar measurements.
- Incorporation of satellite data into hydrodynamic models
- Land-ocean interactions and their impact on ocean extreme events

# Publications

## Journal papers

- R. Amin, J. Zhou, A. Gilerson, B. Gross, F. Moshary, and S. Ahmed, “Novel optical techniques for detecting and classifying toxic dinoflagellate Karenia brevis blooms using satellite imagery,” Optics Express, 17, 9126 – 9144, 2009.
- A. Tonizzo, J. Zhou, A. Gilerson, M. Twardowski, D. Gray, R. Arnone, B. Gross, F. Moshary, and S. Ahmed, "Polarized light in coastal waters: hyperspectral and multiangular analysis," Optics Express, 17, 5666–5683, 2009.
- J. Zhou, A. Gilerson, I. Ioannou, S. Hlaing, J. Schalles, B. Gross, F. Moshary, S. Ahmed, “Retrieving quantum yield of sun-induced chlorophyll fluorescence near surface from hyperspectral in-situ measurement in productive water,” Optics Express, 16, 17468-17483, 2008.
- M. Oo, M. Vargas, A. Gilerson, B. Gross, F. Moshary, S. Ahmed, “Improved robustness of atmospheric correction for highly productive coastal waters using the SWIR retrieval algorithm together with water leaving reflectance constraints at 412nm”, Applied Optics, 47, 3846-3859, 2008.
- A. Gilerson, J. Zhou, S. Hlaing, I. Ioannou, B. Gross, F. Moshary, and S. Ahmed, “Fluorescence Component in the Reflectance Spectra from Coastal Waters. II. Performance of retrieval algorithms,” Optics Express, 16, 2446-2460, 2008
- A. Gilerson, J. Zhou, S. Hlaing, I. Ioannou, J. Schalles, B. Gross, F. Moshary, S. Ahmed, “Fluorescence component in the reflectance spectra from coastal waters. Dependence on water composition,” Optics Express, 15, 15702-15721, 2007.
- A. Gilerson, J. Zhou, R. Fortich, "Particulate Scattering in Coastal Waters: Chesapeake Bay Study", Sea Technology, 48, No. 9, 2007.
- J.Zhou, F. Moshary, B. Gross, S. Ahmed, “Particle size and refractive index retrieval from the backscattering spectrum of white light using the Twomey iterative method: simulation and experiment,” Applied Optics, 45, 6876-6885, 2006.
- A. Gilerson, .J Zhou, M. Oo, J. Chowdhary, B. Gross, F. Moshary, and S. Ahmed “Retrieval of fluorescence from reflectance spectra of algae in sea water through polarization discrimination: modeling and experiments”, Applied Optics, 45, No 22, 5568-5581, 2006.
- S. Ahmed, A.Gilerson, A.Gill, B.M. Gross, F.Moshary, J.Zhou . Separation of Fluorescence and Elastic Scattering from Algae in Seawater Using Polarization Discrimination, Optics Communications, Vol 235/1-3 pp 23-30, 2004.

# Publications

## Conference proceedings

- A.Gilerson, A. Gitelson, V.P. Budak, J. Zhou, I. Ioannou, and S. Ahmed, “Remote estimation of chlorophyll-a in coastal waters using red and near infrared spectral regions,” Current problems in optics of natural waters, St-Petersburg, Russia, Sept. 2009.
- V.P. Budak, S.V. Korkin, A.A. Gilerson, A. Tonizzo, S.A. Ahmed, "Spatial distribution of the degree of polarization of light scattered inside the depth of the ocean," Current problems in optics of natural waters, St-Petersburg, Russia, Sept. 2009.
- R. Amin, A. Gilerson, B. M. Gross, F. Moshary, S. A. Ahmed, "MODIS and MERIS detection of dinoflagellate blooms using the RBD technique," Proc. of SPIE 7473, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2009.
- A. Tonizzo, J. Zhou, A. Gilerson, J. Chowdhary, B.M. Gross, F. Moshary, S. A. Ahmed, "Multiangular hyperspectral investigation of polarized light in case 2 waters," Proc. of SPIE 7473, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2009.
- I. Ioannou, J. Zhou, A. Gilerson, B. M. Gross, F. Moshary, S. A. Ahmed, "New algorithm for MODIS chlorophyll fluorescence line height retrieval: performance and comparison with the current product," Proc. of SPIE 7473, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2009.
- M. Vargas, B. M. Gross, J. Zhou, A. Gilerson, F. Moshary, S. A. Ahmed, “Assessment of 412-nm bio-optical reflectance estimator for use in atmospheric correction,” Ocean Remote Sensing: Methods and Applications, Proc. of SPIE 7459, 2009.
- I. Ioannou, J. Zhou, A. Gilerson, B. Gross, F. Moshary, S. Ahmed, "Inversion of inherent optical properties of water using artificial neural network techniques for coastal water," Ocean Remote Sensing: Methods and Applications, Proc. of SPIE 7459, 2009.
- J. Zhou, A. Tonizzo, I. Ioannou,S. Hlaing, A. Gilerson, B. Gross, F. Moshary, S. Ahmed, "Evaluation of solar stimulated CDOM fluorescence and its impact on the closure of remote sensing reflectance," Ocean Remote Sensing: Methods and Applications, Proc. of SPIE 7459, 2009.
- R. Amin, A. Gilerson, J. Zhou, B. Gross, F. Moshary, and S. Ahmed, “ Impacts of atmospheric corrections on algal bloom detection techniques,” 89th AMS Annual Meeting, Phoenix, AZ, 11-15 January, 2009.

# Publications

## Conference proceedings (cont)

- A. Gilerson, J. Zhou, S. Hlaing, I. Ioannou, B. Gross, F. Moshary, S. Ahmed, "Improved Fluorescence Modeling and Retrieval in Coastal Zones," Proc. of Ocean Optics, XIX, Italy, October, 5-10, 2008.
- R. Amin, J. Zhou, A. Gilerson, B. Gross, F. Moshary and S. Ahmed, "Use of MODIS ocean color imagery for improved detection and monitoring of Karenia brevis blooms in the Gulf of Mexico," Proc. of Ocean Optics, XIX, Italy, October, 5-10, 2008.
- A. Tonizzo, J. Zhou, A. Gilerson, T. Iijima, M. Twardowski, D. Gray, R. Arnone, B. Gross, F. Moshary, S. Ahmed,"Polarization measurements in coastal waters using hyperspectral multi-angular sensor," Proc. of Ocean Optics, XIX, Italy, October, 5-10, 2008.
- R. Amin, J. Zhou, A. Gilerson, B. Gross, F. Moshary and S. Ahmed,"Detection of Karenia Brevis Harmful Algal Blooms in the West Florida Shelf using Red Bands of MERIS Imagery," Proc. of Ocean 08 MTS IEEE Conference, Quebec, Canada, Sept. 08.
- S. Ahmed, A. Gilerson, J. Zhou, R. Dyer, S. Hlaing, I. Ioannou, B. Gross, F. Moshary,"Untangling the Make-up of the NIR Reflectance Peak in Coastal Waters and its Impact on Remote Sensing Retrievals of [Chl] and Fluorescence Height Algorithms," Proc. of SPIE 7105, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2008.
- A. Gilerson , A. Tonizzo, J. Zhou, R. Dyer, J. Chowdhary, B. Gross, F. Moshary and S. Ahmed,"Characterization of multi-angular hyperspectral polarized reflectance from coastal waters, " Proc. of SPIE 7105, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2008.
- S. Hlaing, R. Dyer, J. Borrero, J. Zhou, A. Gilerson, B. Gross, F. Moshary, S. Ahmed,"Validation of MODIS FLH algorithm using satellite imagery," Proc. of IEEE 2008 International Geoscience and Remote Sensing Simposium (IGARSS 2008), Boston, MA, July 2008.
- I. Ioannou, N. Steiner, J. Zhou, A. Gilerson, B. Gross, F. Moshary, S. Ahmed,"Application of UV and NIR bands for the advanced IOP retrieval algorithms in coastal waters," Proc. of IEEE 2008 International Geoscience and Remote Sensing Simposium (IGARSS 2008), Boston, MA, July 2008.
- A. Tonizzo, R. Dyer, R. Fortich, J. Zhou, A. Gilerson, J. Chowdhary, B. Gross, F. Moshary and S. Ahmed, "Multi-angular multi-spectral polarized reflectance from coastal waters for the separation of water organic and inorganic particulate components," Proc. of IEEE 2008 International Geoscience and Remote Sensing Simposium (IGARSS 2008), Boston, MA, July 2008.
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- S. Ahmed, A. Tonizzo, A. Gilerson, J. Zhou, B. Gross, F. Moshary, “Development of a hyperspectral sensor for multi-angular measurements of polarized reflectance from coastal waters,” ISSSR Conference, Hoboken, NJ, June 2008.
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