Remote Sensing of Chlorophyll *a* to Monitor Phytoplankton Community Changes (ECO MYP)

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AED Peer Review '07

US EPA ARCHIVE DOCUMENT

Agency Problem

Intense industrial, agricultural, recreational, and urban developmental activities have increased the magnitude and distribution of nutrients in the coastal environment. A frequent response of coastal systems to the addition of nutrients is an increase in phytoplankton biomass concentrations and primary production rates. Annually, hundreds of millions of dollars are spent by EPA and other Federal and State agencies on monitoring phytoplankton biomass in estuaries.

As an indicator of phytoplankton biomass in coastal and estuarine waters, the environmental monitoring community and governmental agencies routinely measure chlorophyll *a* concentrations in water samples. Usually, these efforts are focused within a limited geographic area and require time-consuming and expensive laboratory analyses. Passive remote sensing of coastal ocean and estuarine water color from multispectral and hyperspectral satellite and aircraft-based systems provides an opportunity to monitor coastal ecosystem condition at a variety of spatial and temporal scales.

Methods/Approach

- Goal 1: Determine chlorophyll *a* concentrations using multi- and hyper-spectral remote sensing of the color from approximately 30 southern New England estuaries and bays and coastal waters over seasonal cycles.

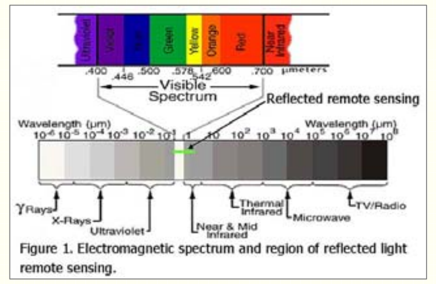
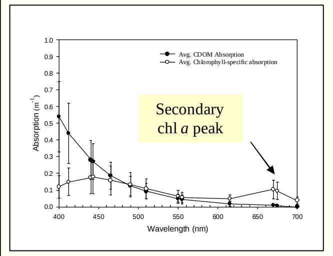


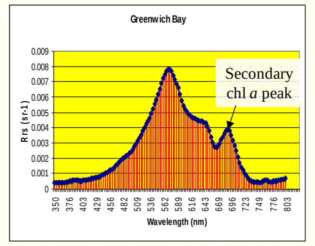
Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.

Approach: Using aircraft and satellite remote sensing data from the blue:green and red:near infrared portions of the visible spectrum offers the capability to estimate chlorophyll *a* concentrations at local and regional scales over long time periods.

- Goal 2: Reduce the variability of spectrally derived chlorophyll *a* concentrations for New England estuarine and coastal waters.



CDOM and phytoplankton absorption curves- Narragansett Bay (*Keith et al., 2002*)



Hyperspectral signature- Greenwich Bay, RI

Approach: Use the secondary chlorophyll *a* fluoresence peak in the red-NIR portion of the visible spectrum to derive a regional algorithm based on *in situ* hyperspectral data from Narragansett Bay, Rhode Island Sound, Buzzards Bay, and Long Island Sound and concurrently collected HPLC chlorophyll *a* concentrations.

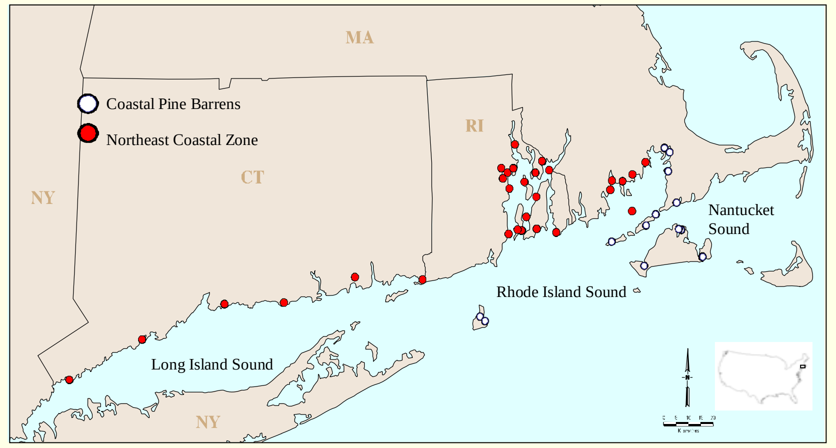
- Goal 3: Determine phytoplankton pigment composition from the hyperspectral signatures of New England estuarine and coastal waters. Phytoplankton may be diagnostic of estuarine conditions and responsive to changes in nutrient levels.

Approach: Accumulate hyperspectral signatures of various phytoplankton groups under controlled conditions to determine pigments present and confirm with water samples collected concurrently for HPLC pigment analysis.

Research Goals

- Goal 1: Determine chlorophyll *a* concentrations using multi- and hyper-spectral remote sensing of the color from approximately 30 southern New England estuaries and bays and coastal waters over seasonal cycles.
- Goal 2: Reduce the variability of spectrally derived chlorophyll *a* concentrations (and other water quality indicators) for New England estuarine and coastal waters.
- Goal 3: Determine phytoplankton pigment composition from the hyperspectral signatures of New England estuarine and coastal waters. Phytoplankton may be diagnostic of estuarine conditions and responsive to changes in nutrient levels.

Cessna Skymaster equipped with Satlantic Inc. remote sensing system



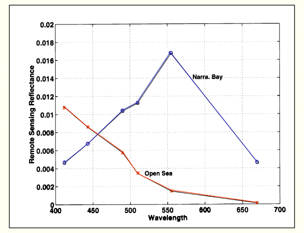
Coastal and estuarine systems surveyed in support of the EMAP/National Coastal Assessment Program and NHEERL Nutrient Effects Program

Reference:

Keith, D.J., J.A. Yoder, and S.A. Freeman (2002). Spatial and Temporal Distribution of Coloured Dissolved Organic Matter (CDOM) in Narragansett Bay, Rhode Island: Implications for Phytoplankton in Coastal Waters. *Estuarine, Coastal and Shelf Science*, **55**, 705-717

Results

- Goal 1: Using aircraft multispectral remote sensing, aerial surveys of the southern New England coast were conducted on a monthly basis during Summer/Fall 2002 and 2004 – Spring 2005. These data were processed to retrieve chlorophyll *a* concentrations using the NASA Ocean Color 4, version 4 algorithm.

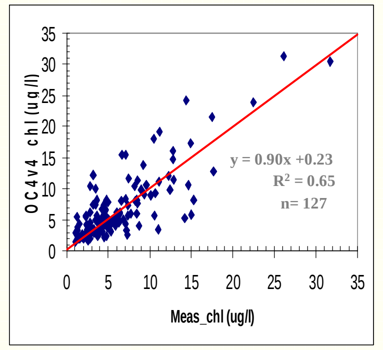


General multispectral signal of coastal and ocean waters

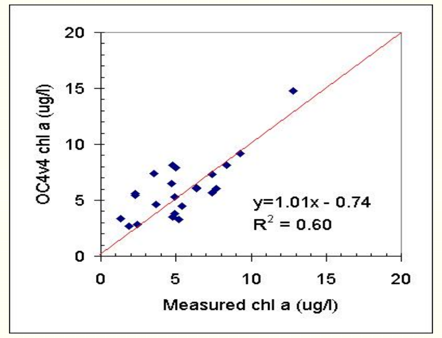
Comparison of chlorophyll *a* concentrations derived from the OC4v4 Model vs. Fluorometrically determined chlorophyll concentrations

$$OC4v4\ Chl\ a\ (ug/l) = 10^{(0.366 - 3.067R + 1.930R^2 + 0.649R^3 - 1.532R^4)}$$

where $R = \log_{10}(R_{rs}443/R_{rs}555 > R_{rs}490/R_{rs}555 > R_{rs}510/R_{rs}555)$



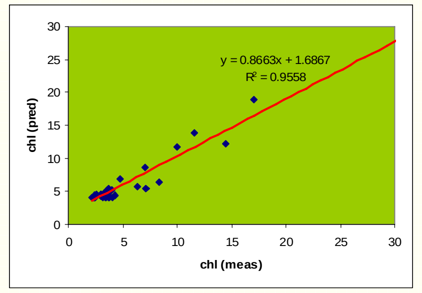
In situ spectral data from Narragansett Bay



Aircraft multispectral data from Narragansett Bay sampling stations

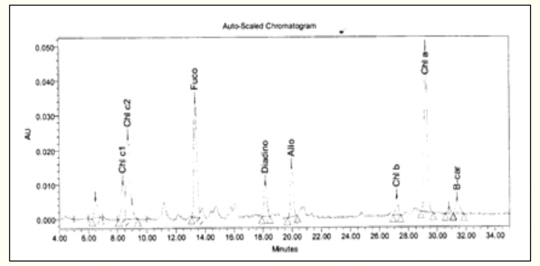
Using aircraft hyperspectral remote, aerial surveys of the southern New England coast have been conducted montrhly beginning in Fall 2005 and continue to the present.

- Goal 2: Using the hyperpspectral signature of local waters, a regional algorithm (HYPERCHLOR) was created to retrieve chlorophyll *a* concentrations from coastal and estuarine water color. Using HYPERCHLOR, the variability in estimating chlorophyll concentrations from spectral data has been reduced from approximately 40% to approximately 5%. The HYPERCHLOR model is described in *Keith (in review). The Determination of Chlorophyll a Concentrations in southern New England Estuarine and Coastal Waters Using the Red/Near–Infrared Band Ratio Approach* submitted to Remote Sensing of Environment.

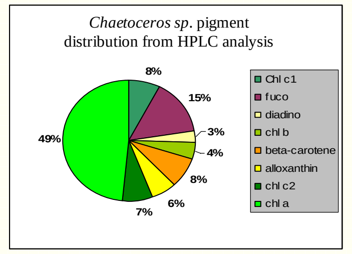


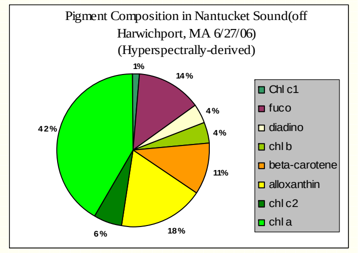
Scatter plot of chlorophyll *a* concentrations predicted using HYPERCHLOR and HPLC derived chlorophyll *a* concentrations.

- Goal 3: Since 2006, we have conducted four experiments using laboratory cultured phytoplankton. The hyperspectral signatures of these groups were collected under controlled conditions and water samples were collected concurrently for High Perfomance Liquid Chromatography (HPLC) pigment analysis. Derivative analysis was applied to the hyperspectral signatures from each experiment. Using the spectral data and HPLC data, regression analysis has resulted in several algorithms which estimate the concentration of several diagnostic pigments.



HPLC Chromatogram showing spectral peaks for several pigments





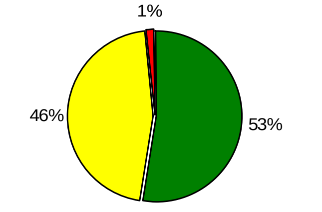
Impacts and Outcomes

- The primary impact of incorporating aircraft and space-based remote sensing into the routine monitoring of surface waters in estuarine, coastal ocean, and lacustrine environments is that EMAP, the EPA Office of Water , and University of New Hampshire/EPA Region 1 Lakes Program will be able to accurately characterize the ecological condition of entire aquatic systems, making synoptic comparisons among coastal or lake systems possible.
- Significant financial savings to the Agency will be realized as analytical costs are reduced because the need to process hundreds of surface water samples for selected indicators (e.g., water clarity, salinity, turbidity) will be eliminated.
- Environmental condition assessments could be conducted at a variety of spatial scales (local, regional, and global) over variable time scales (monthly, seasonally, and annually) and cover more temporal scope and geographic breath than do present reports.
- Additionally, this research is increasing data accuracy as variability in chlorophyll *a* as well as data from other indicators will be reduced.
- An important outcome of distinguishing phytoplankton groups based on their spectrally–derived pigment composition, especially those groups associated with Harmful Algal Blooms (HABs), is the potential for creating a remote sensing-based early warning system for HAB detection.
- A better understanding of the dynamics of watershed impact on coastal systems will occur from exploring relationships between changes in phytoplankton community structure (based on remotely sensed pigment distribution) and nutrient input to estuaries and coastal waters along southern New England.

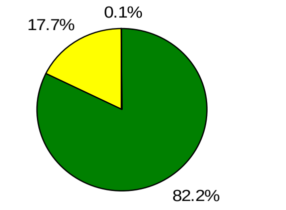
Future Directions

- Continue to derive EMAP/NCA/OW indicators of surface water quality when possible from multispectral and hyperspectral aircraft and satellite signatures and use them to conduct site-specific and regional scale condition assessments on monthly to annual time scales.

Sippican Harbor (MA) Chlorophyll *a* condition based NCA Criteria- 10 Jan 2006



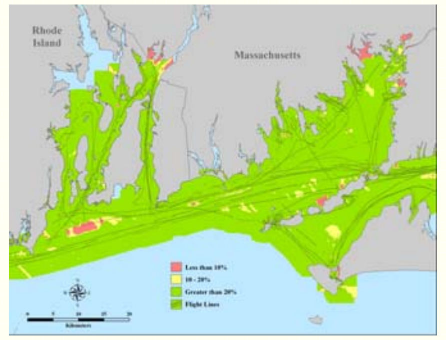
2006 Southern New England Chlorophyll *a* Condition Based on NCA Criteria



EMAP/NCA Criteria for Chlorophyll Condition

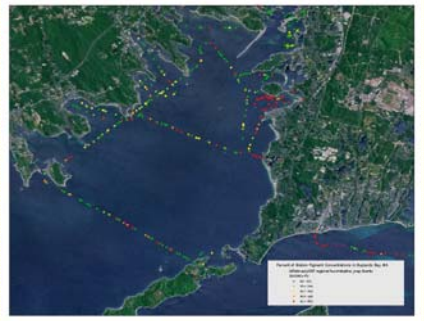
Good	< 5 ug/l
Fair	5 to 20 ug/l
Poor	> 20 ug/l

- Map the geographic distribution of selected EMAP/NCA/OW surface water indicators (e.g. water clarity) on time scales of interest.



Water clarity based on % photosynthetically available radiation at 1 meter depth (Composited from aircraft multispectral data from March – December 2005)

- Map the geographic and temporal distribution of phytoplankton groups based on pigment composition derived from aircraft-based hyperspectral remote sensing.



EPA Atlantic Ecology Division Narragansett, Rhode Island