

# Short Term Dynamics of a Harmful Algal Bloom in Monterey Bay

**Curtiss O. Davis**

**College of Oceanic and Atmospheric Sciences, Oregon  
State University, Corvallis, OR 97331, USA**

**[cdavis@coas.oregonstate.edu](mailto:cdavis@coas.oregonstate.edu)**

**541-737-5707**

**Special thanks to the COAST sponsor NOAA NESDIS and to Paul Bissett, Maria Kavanaugh, Ricardo Letelier, Bob Arnone, Z.-P. Lee, Heidi Sosik, Raphe Kudela and the entire COAST Monterey Bay Experiment Team**

# Presentation Outline

- **Background**
  - **The Coastal Ocean Applications and Science Team (COAST)**
  - **Coastal Waters Imaging System requirements**
    - **Spatial**
    - **Temporal**
    - **Spectral**
- **The September 2006 COAST Monterey Bay Experiment**
  - **Remote sensing data**
  - **In situ biological and optical data**
- **Assess the imaging requirements for this type of coastal environment**
  - **To detect the bloom**
  - **To understand bloom dynamics**
- **Discussion and Recommendations for a Coastal Waters Imaging System (CWIS)**

# The Coastal Ocean Applications and Science Team (COAST)

- The Coastal Ocean Applications and Science Team (COAST) was created in August 2004 to support NOAA to develop coastal ocean applications for a geostationary ocean color imager HES-CW:
  - **Mark Abbott**, Dean of the College of Oceanic and Atmospheric Sciences (COAS) at Oregon State University is the COAST team leader,
  - COAST activities are managed through the Cooperative Institute for Oceanographic Satellite Studies (CIOSS) a part of COAS, **Ted Strub**, Director
  - **Curtiss Davis**, Senior Research Professor at COAS, is the Executive Director of COAST.
  - Initial activity to evaluate HES-CW requirements and suggest improvements
  - Conducted Monterey Bay experiment during first year of funding.
- The Hyperspectral Environmental Suite including the Coastal Waters instrument (**HES-CW**) was dropped from **GOES-R** in **November 2006**.
- Here we report initial results from the Monterey Bay experiment
  - Use the airborne hyperspectral data to assess spatial, temporal and spectral sampling requirements for a **Coastal Waters Imaging System (CWIS)**.

# Risk Reduction Activities: Principal Roles of Co-Investigators

- **Curtiss Davis**, program management, calibration, atmospheric correction
- **Mark Abbott**, COAST Team Leader
- **Ricardo Letelier**, phytoplankton productivity and chlorophyll fluorescence, data management
- **Peter Strutton**, coastal carbon cycle, Harmful Algal Blooms (HABs)
- **Ted Strub**, CLOSS Director, coastal dynamics, links to IOOS

## COAST Participants:

- **Bob Arnone, NRL**, optical products, calibration, atmospheric correction, data management
  - **Paul Bissett, FERI**, optical products, data management
  - **Heidi Dierssen, U. Conn.**, benthic productivity
  - **Raphael Kudela, UCSC**, HABs, IOOS
  - **Steve Lohrenz, USM**, suspended sediments, HABs
  - **Oscar Schofield, Rutgers U.**, product validation, IOOS, coastal models
  - **Heidi Sosik, WHOI**, productivity and optics
  - **Ken Voss, U. Miami**, calibration, atmospheric correction, optics
- NOAA/STAR Menghua Wang**, atmospheric correction
- NOAA/STAR Mike Ondrusek**, calibration, MOBY
- NOAA/NOS Rick Stumpf**, HABs
- NOAA/NMFS Cara Wilson**, Ecosystem Management of Fisheries

# Monterey Bay September 3-16, 2006 Experiment Plan

- Goal to collect a data set that include all the key attributes of CWIS data:
  - Spectral coverage (.4 – 1.0  $\mu\text{m}$ )
  - High signal-to-noise ratio (>300:1 prefer 900:1, for ocean radiances)
  - High spatial resolution (<100 m, bin to 300 m)
  - **Hourly or better revisit**
- Monterey Bay has long-term physical, biological and optical monitoring
  - Links to data at <http://www.cencoos.org>
- COAST conducted Intensive effort for 2 weeks supplementing the standard data sets to assure that all essential parameters are measured
- Aircraft overflights for at least three clear days and one partially cloudy day (to evaluate cloud clearing) during the two week period.
  - High altitude to include 90% or more of the atmosphere
  - **30 min repeat flight lines** for up to 6 hours to provide a time series for models and to evaluate changes with time of day (illumination, phytoplankton physiology, etc.)
- All data to be processed and distributed over the Web for all users to test and evaluate algorithms and models <http://weogeo.coas.oregonstate.edu> .

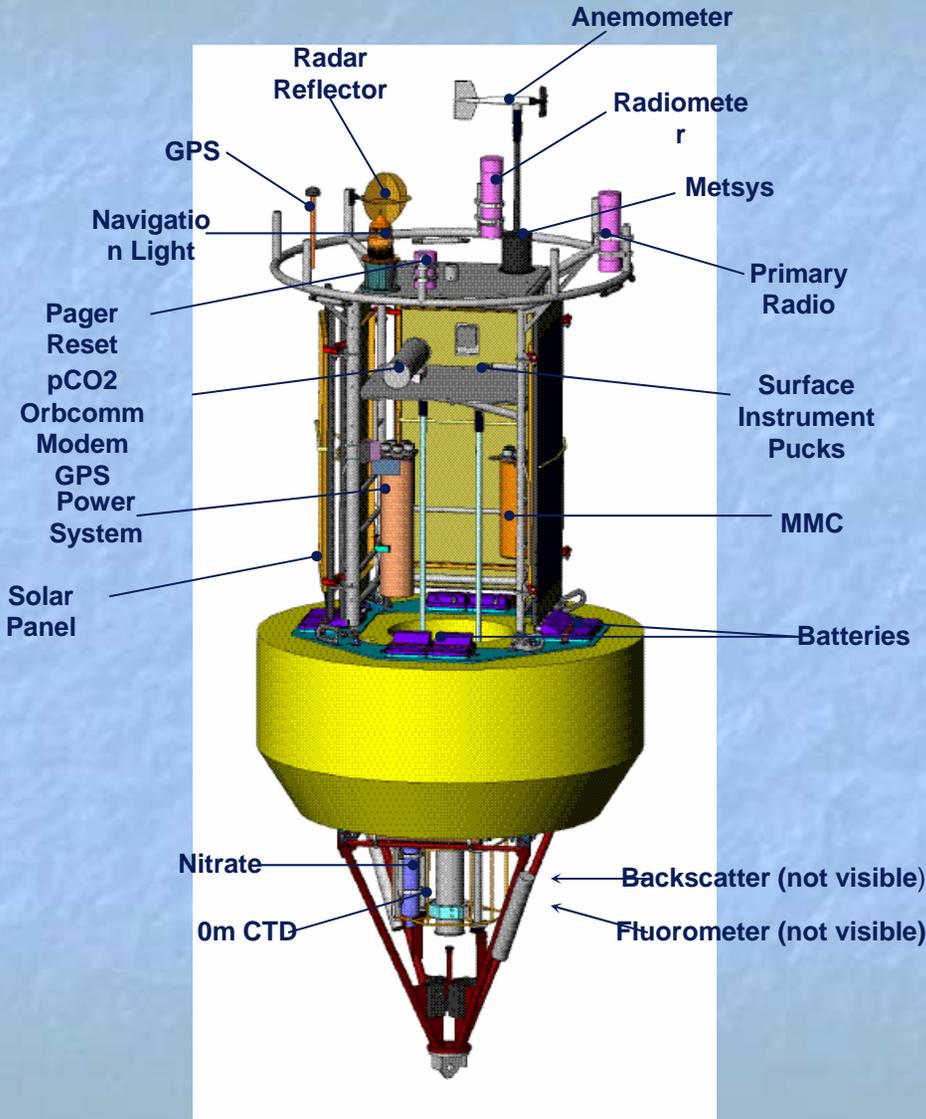
# SAMSON

## *Spectroscopic Aerial Mapping System with On-board Navigation*

- The Florida Environmental Research Institute (FERI) has developed a low-cost, robust HyperSpectral Imager, the Spectroscopic Aerial Mapper with On-board Navigation (SAMSON).
- SAMSON provides for a full HSI dataset 256 bands in the VNIR (3.5 nm resolution over 380 to 970 nm range) at 75 frames per second, with a SNR, stability, dynamic range, and calibration sufficient for dark target spectroscopy.
- Data sampled at 5 m GSD and binned to 10, 100, and 300 m to evaluate need for higher GSD.
  - Binned data will have SNR in excess of 1000:1 – noise can be added to simulate lower SNR data.



# Two Ships and long-term mooring available for Experiment



**MBARI M-0 mooring**



**R/V Shana Rae**



**R/V John H. Martin**

# Experiment Plan Sept 2006 Aircraft and Ship Schedules

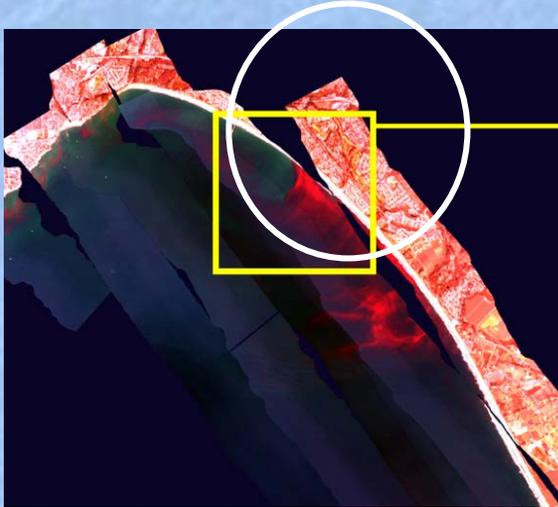
M	T	W	T	F	S	S
4 <b>Aircraft</b> Shana Rae John Martin	5 <b>Aircraft</b> Shana Rae John Martin	6 Shana Rae John Martin	7 Shana Rae John Martin	8 Shana Rae John Martin	9 Shana Rae	10
11 <b>Aircraft</b> John Martin	12 <b>Aircraft</b> John Martin	13	14	15 <b>Aircraft</b> John Martin	16	17
18	19	20	21	21	22	23

# Ship and Laboratory Measurements

Insitu instruments	Water measurement
<ul style="list-style-type: none"><li>- absorption scattering, acdom (ac9, acs)</li><li>- Backscattering (Hydroscat and Puck)</li><li>- CDOM (fluorescence, waveguide)</li><li>- CHL fluorescence</li><li>- Remote sensing reflectance (above, in-water)</li><li>- Diffuse attenuation coefficient – k(490,532)</li><li>- Lu(+). Radiance, ED+ irradiance (HTSRB)</li><li>- PAR (downwelling)</li><li>- Volume Scattering Function (spectral) (ECO-VSF)</li><li>- Radiance distribution – (NURADS)</li><li>- Particle Size (LISST) (forward scattering) (green)</li><li>- PC02 (underway)</li><li>- Phytoplankton communities (underway)</li><li>- CTD</li><li>- Aerosol optical depth –Microtops</li></ul>	<ul style="list-style-type: none"><li>-a(detrital) filterpad absorption</li><li>-a(cdom) (filterpad absorption)</li><li>-POM Particulate - organic</li><li>-PIM Particulate - inorganic</li><li>-SPM Suspended</li><li>-HPLC (pigments)</li><li>-CHL (Fluorescence)</li><li>- Nutrients</li><li>- Primary Production</li><li>- Fluorescence</li><li>- PC02</li><li>- Phytoplankton communities</li></ul>

# A red tide incubator in Monterey Bay?

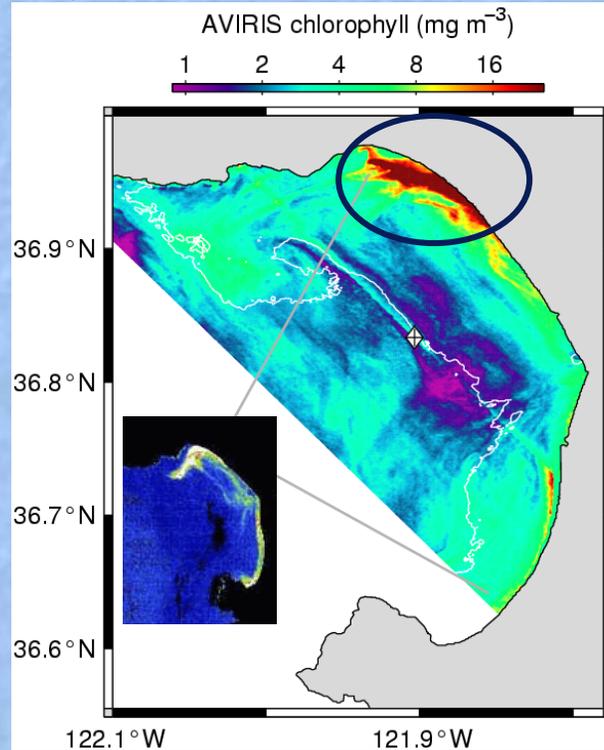
## 2002 red tide



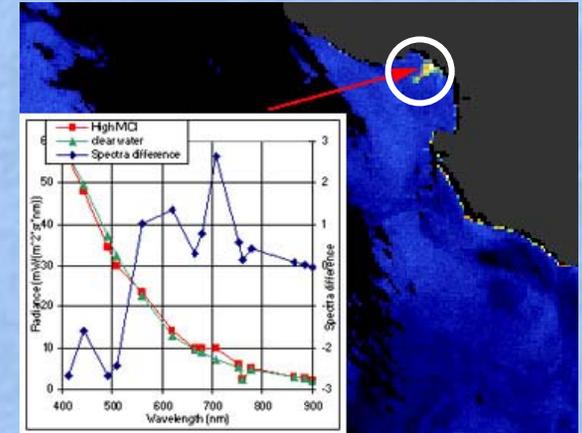
*Image from P. Bissett*

## 2004 red tide

*J. Ryan, MBARI, R. Kudela, UCSC*



## 2005 red tide



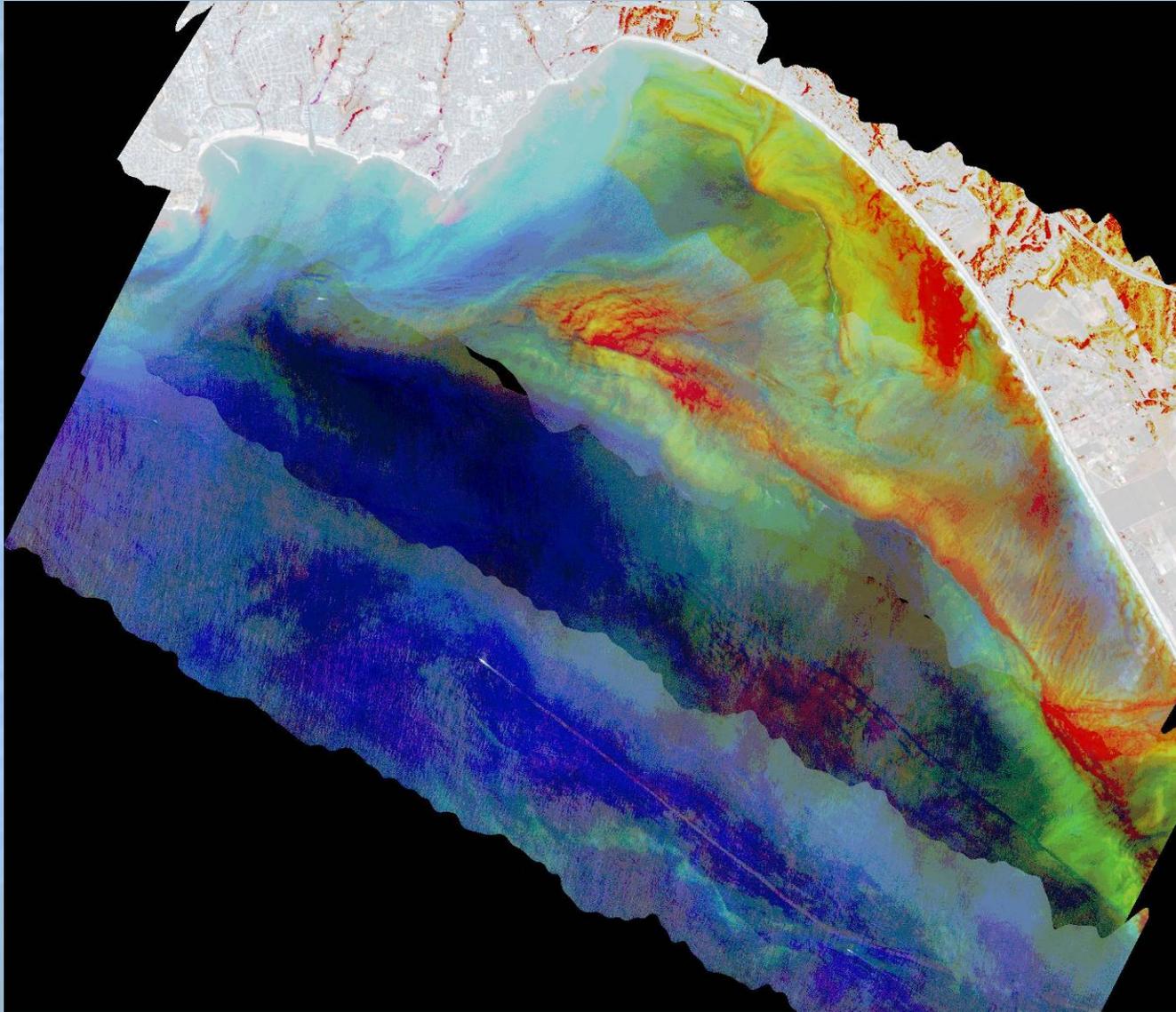
*MERIS satellite imagery, 9/17*

*J. Gower, IOS, Sidney BC*

Physical, chemical and biological influences in this region:

- In the upwelling shadow (stratification)
- Downstream of Elkhorn Slough plume (stratification, nutrients, dinoflagellate seed populations)

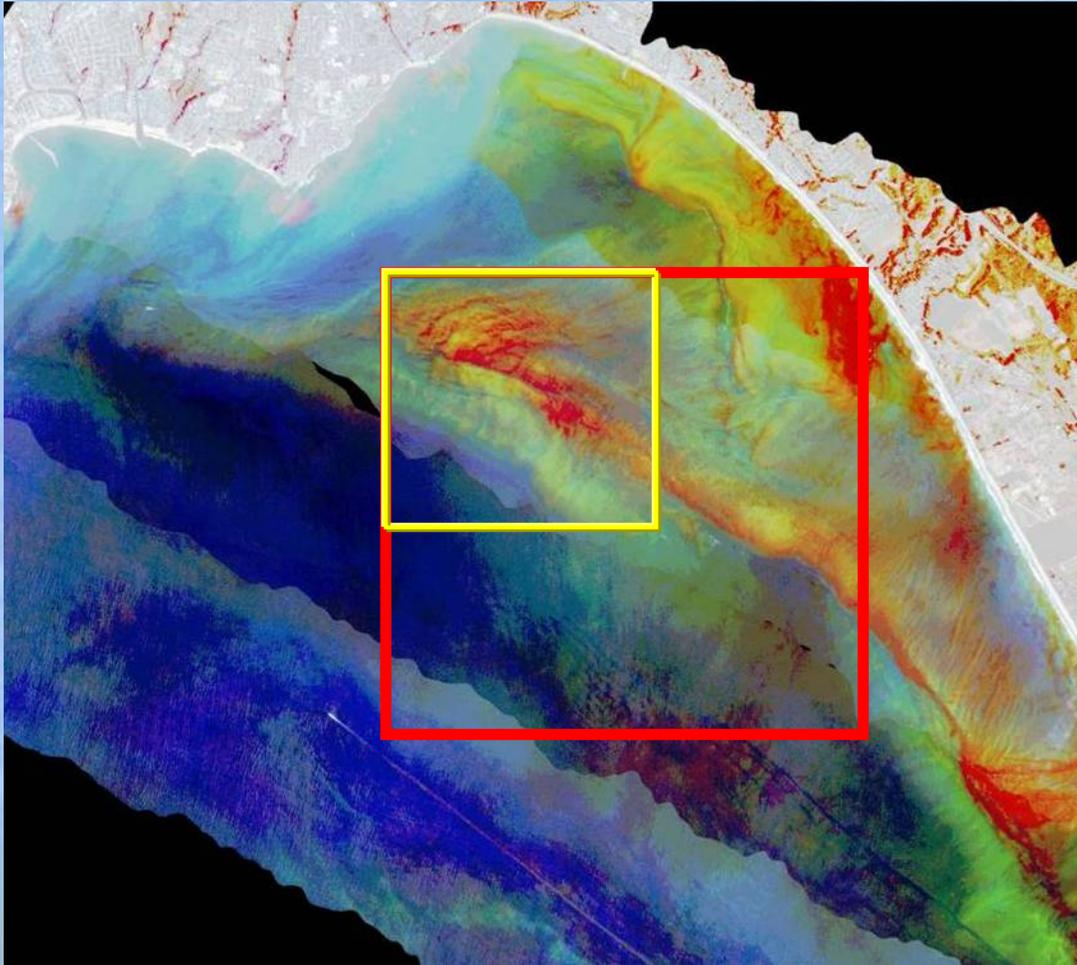
September 12, 2006  
Grid 03: 10:07 - 10:32



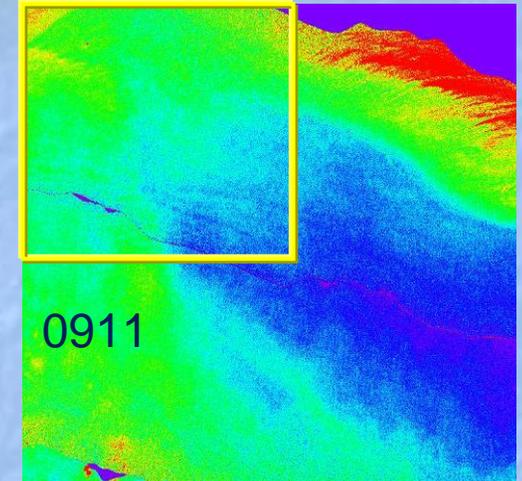
Primary species *Akashiwo sanguinea*

FERI SAMSON data

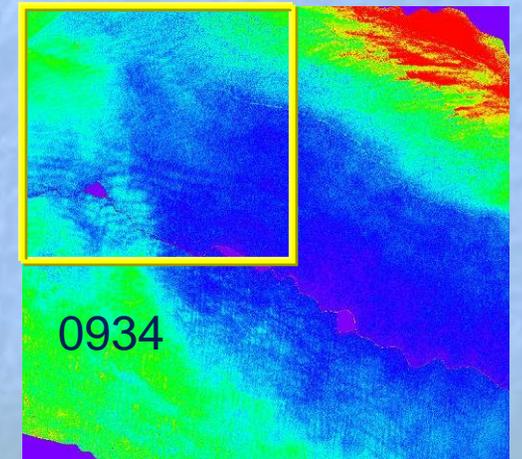
# Bloom disappears on the 15th



Sept 12, 2006, 1007



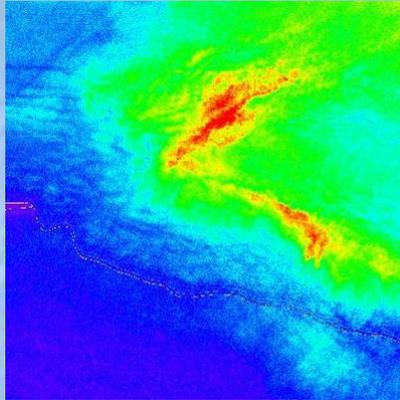
0911



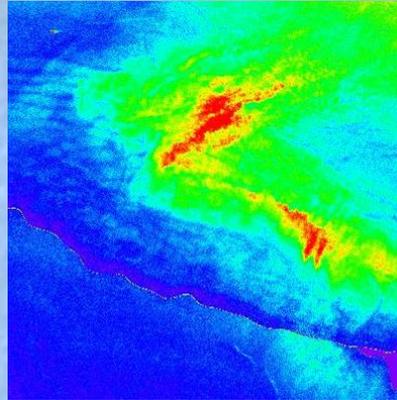
0934

Sept 15, 2006: No bloom images by Maria Kavanaugh

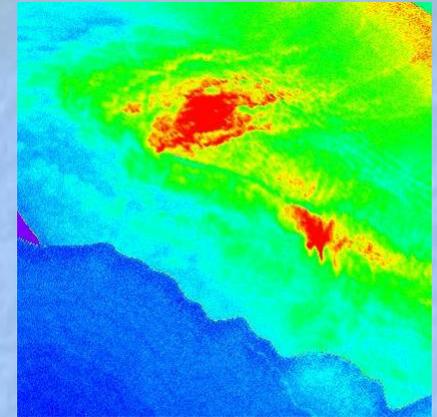
# September 12, 2006 Time sequence of 710 nm: Diurnal migration of the bloom?



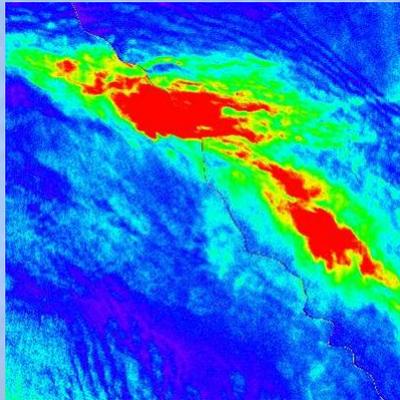
0908



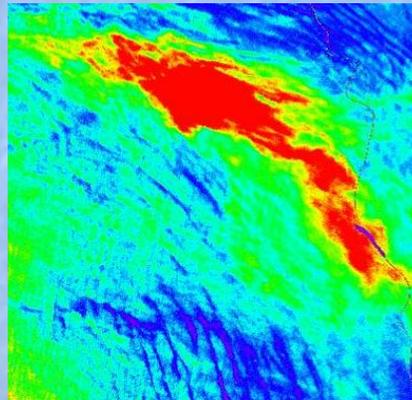
0938



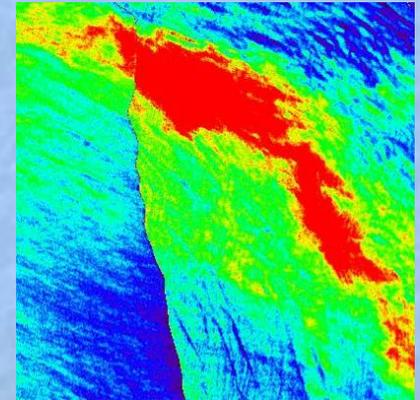
1006



1124



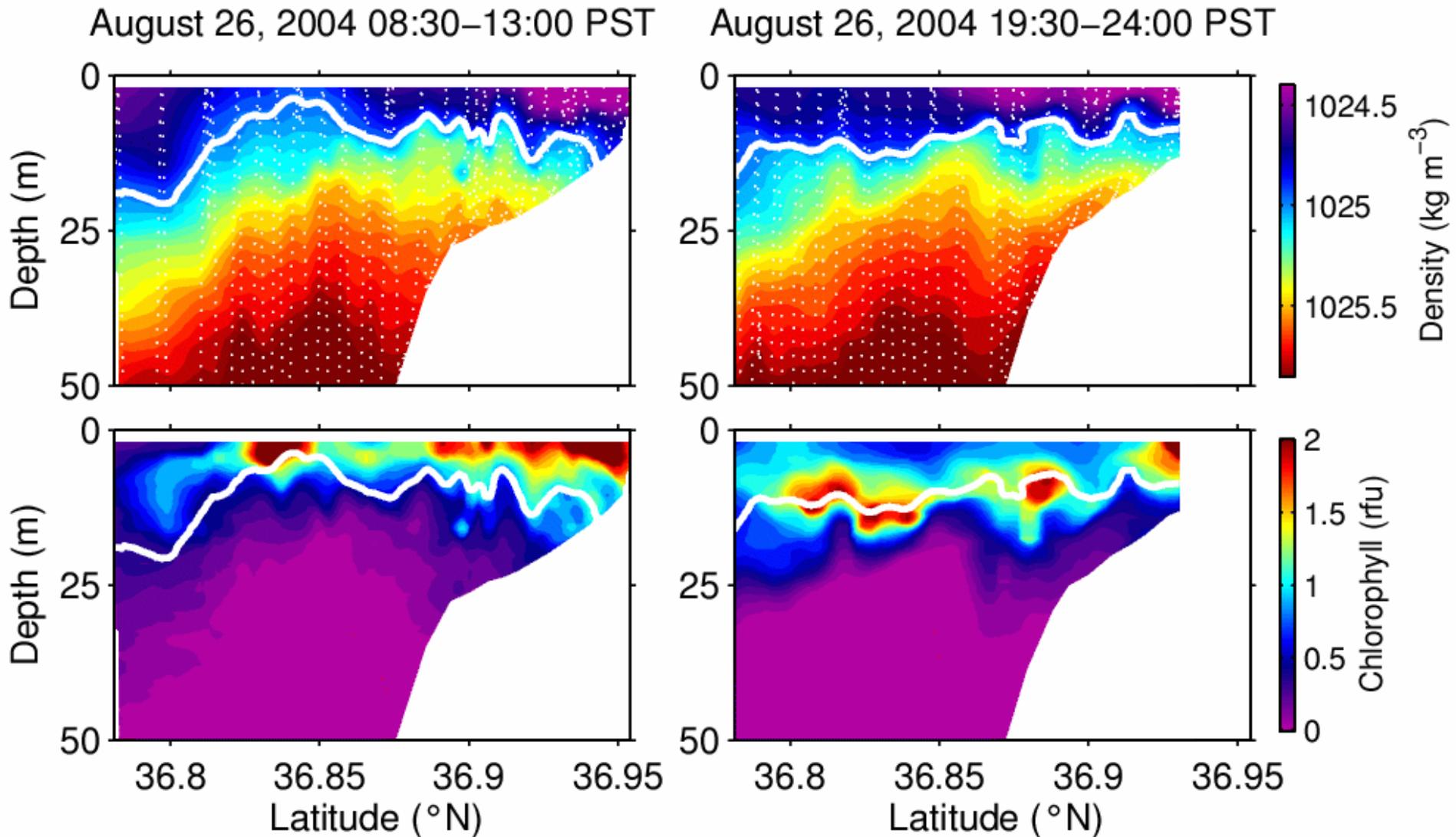
1204



1238

images by Maria Kavanaugh

# Dinoflagellates migrate vertically (downward at night). Unique Signature in HES-CW data.



The white contour is the same reference isopycnal in each figure (R. Kudela, UCSC)

# Scales of Patchiness Analysis Approach

We calculated the lagged distance and semivariance values using “Queen’s move” pixel pairs. Queen’s move calculates the squared difference over all pairs of pixels in the image in all eight directions.

For a given wavelength, the nugget, sill, and range was determined by plotting the semivariance  $g(h)$ , over distance between pixel pairs,  $h$ . For the spherical model of saturating semivariance,  $g(h)$ , with increased distance,  $h$ , the equation for a theoretical semivariogram is as follows:

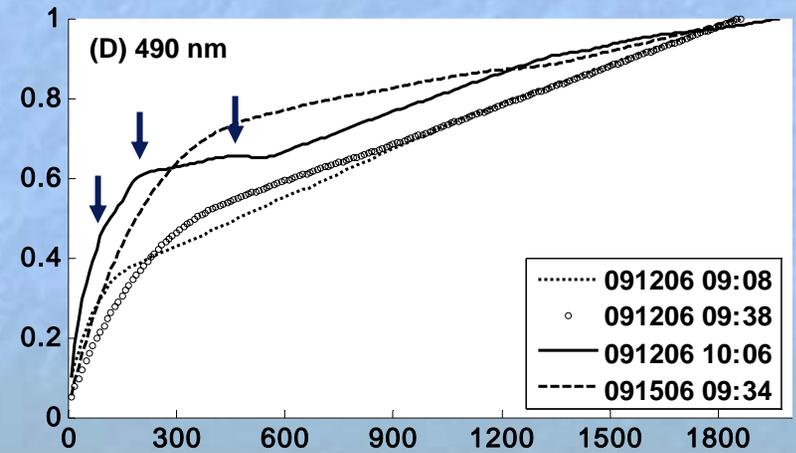
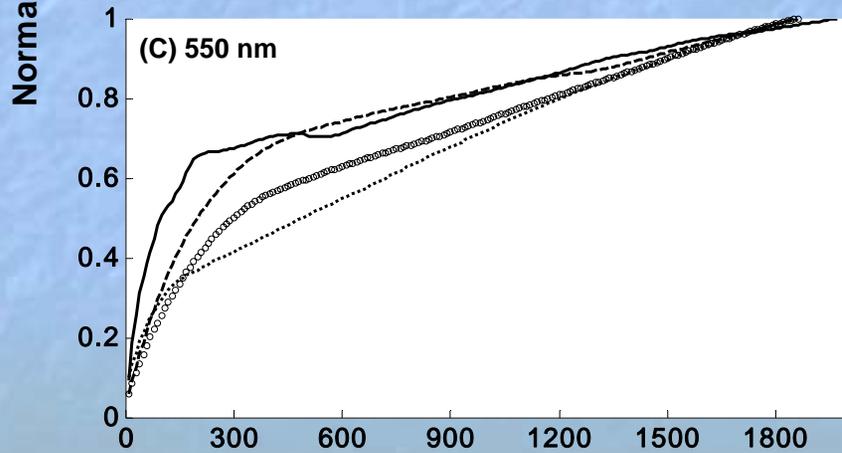
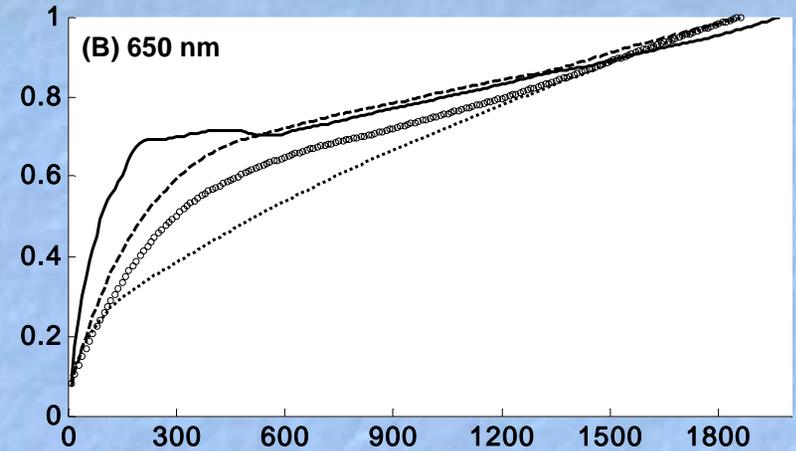
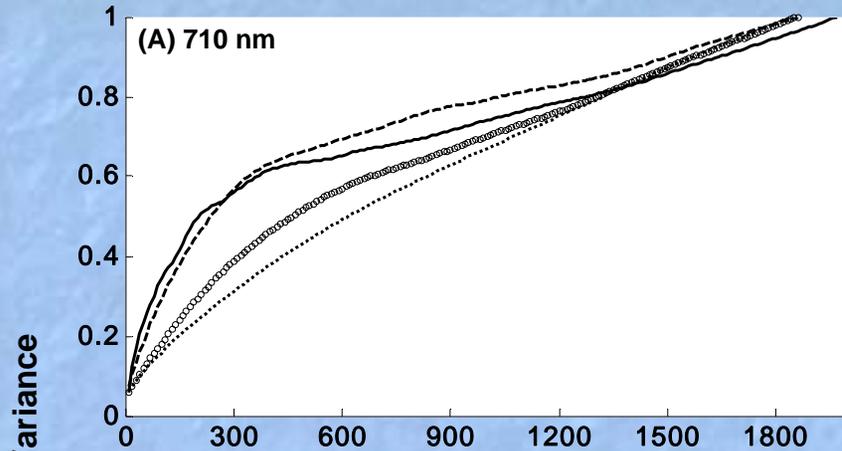
$$g(h) = c_0 + c_1[(3h/2a) - 0.5(h/a)^3]$$

The non-zero intercept or nugget of the variogram,  $c_0$ , determines the degree of unresolved variability; for sensor comparison it can represent the degree to which the particular pixel size captures the underlying phenomenon.

The range,  $a$ , of a semivariogram determines how quickly the underlying variability reaches a global maximum. Finally the sill,  $c_1$ , determines the total variance resolved in the image. Equations based on real data may exhibit much more complex behavior than a theoretical spherical model and multiple nodes often apparent at distances less than saturation.

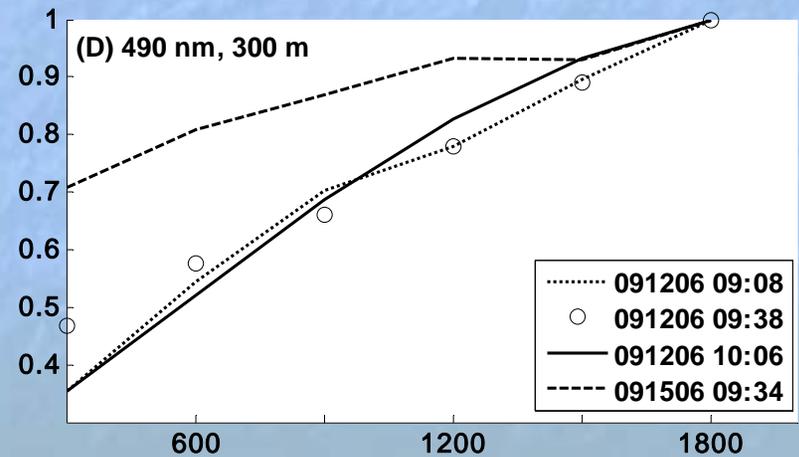
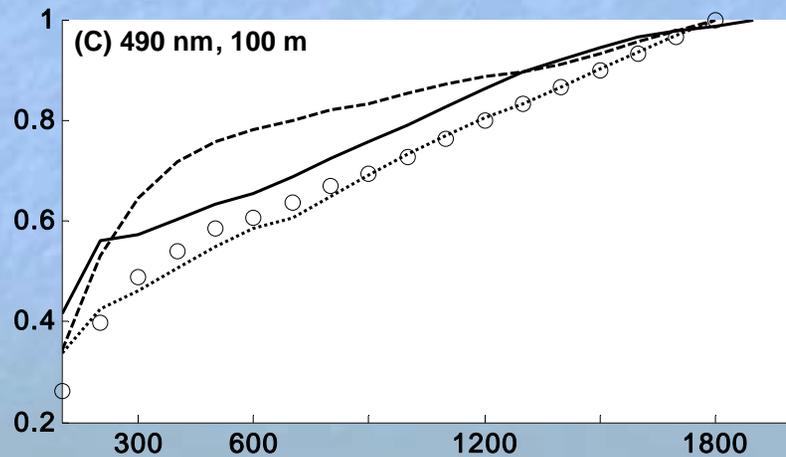
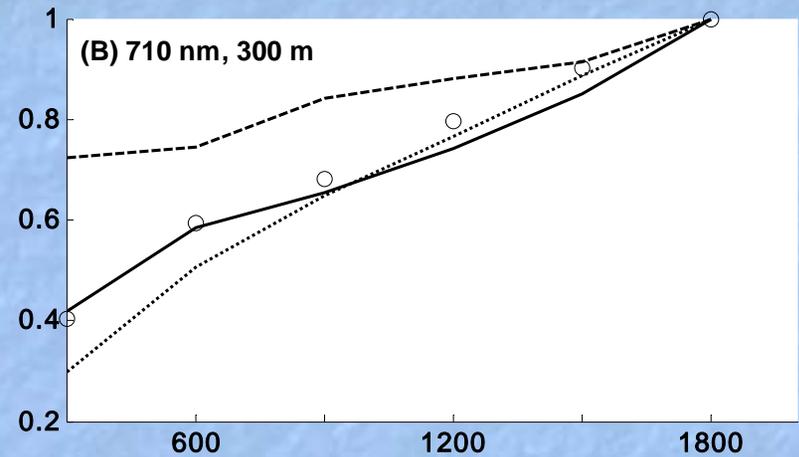
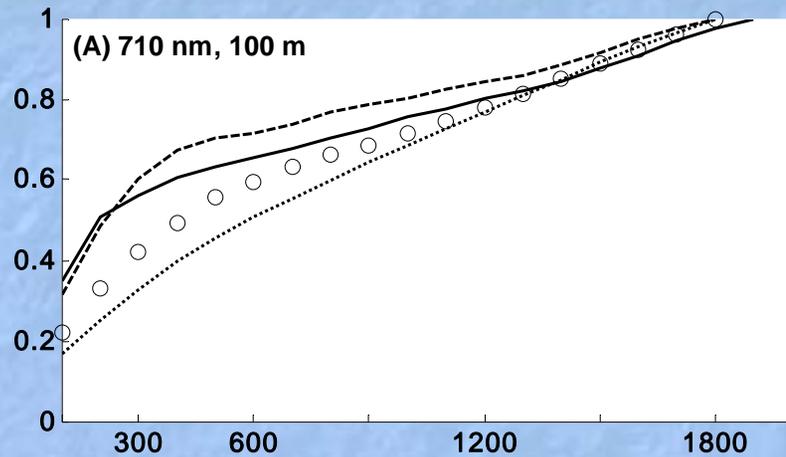
For our experiment, we compared the nugget, ranges and nodes across spatial and spectral bins sizes for data collected on two dates, 09/12/06 and 09/15/06.

# Resolving Spatial Patterns at 10 m GSD



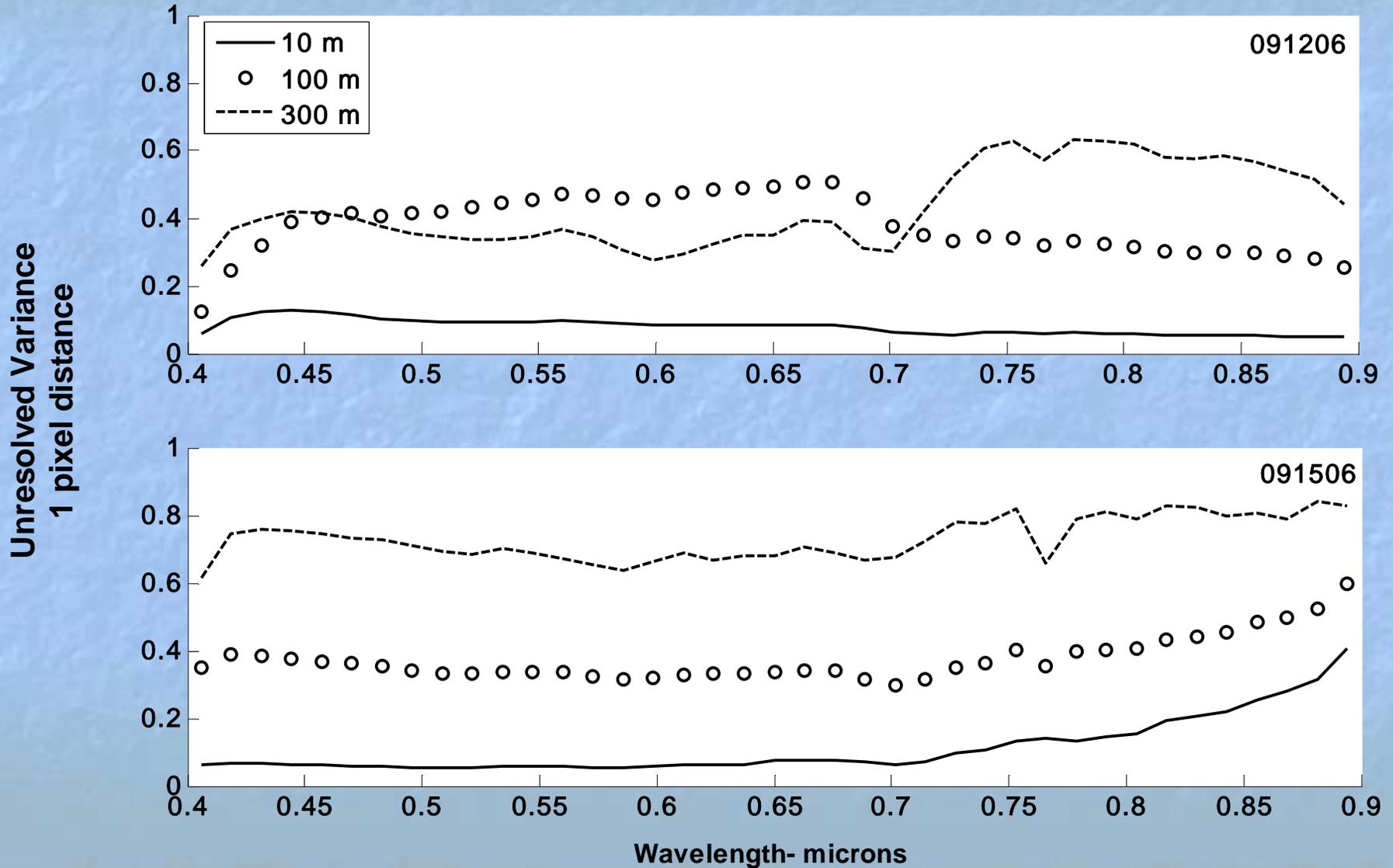
Distance- meters

# Comparing 10, 100 and 300 m GSD



Distance - meters

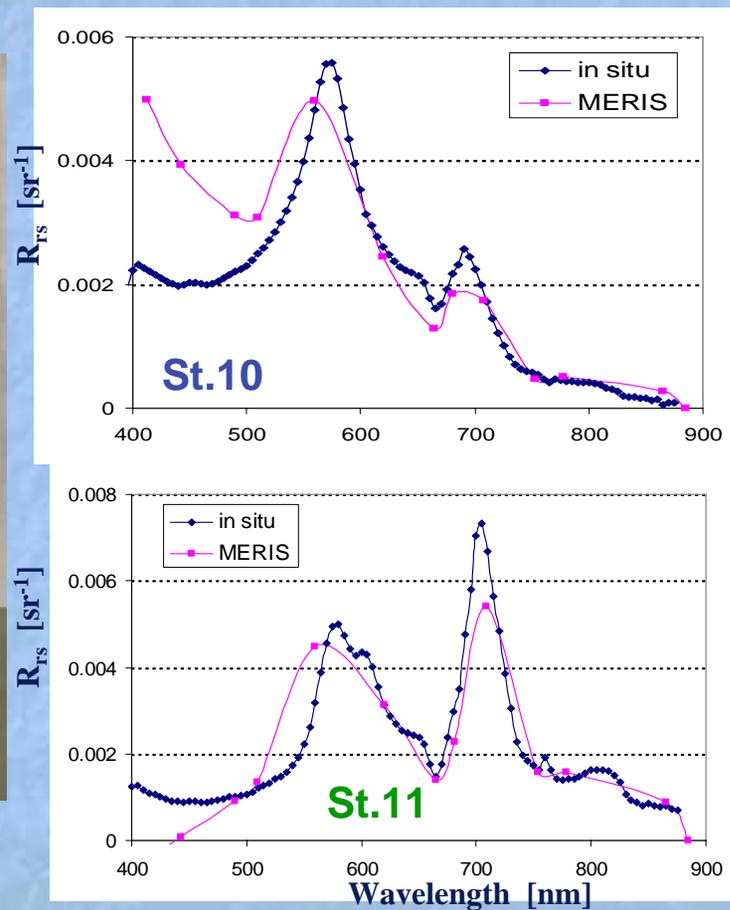
# Spectral Wavelength and Pixel size dependence



# MERIS remote sensing reflectance ( $R_{rs}$ ) compared with in situ measurements



[Chl] was  $\sim 500 \text{ mg/m}^3$ .



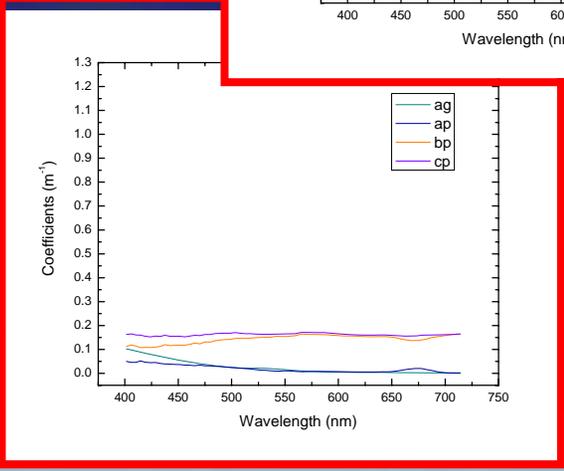
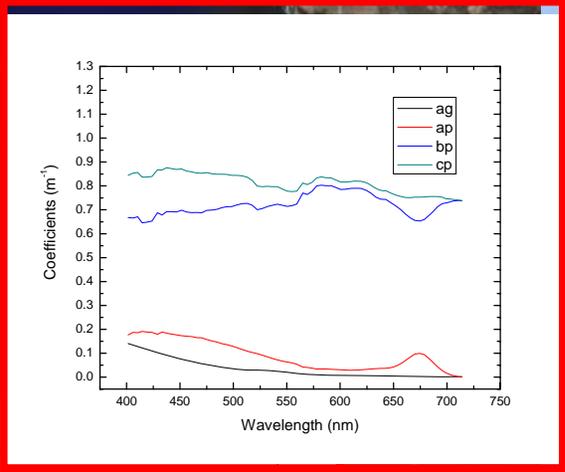
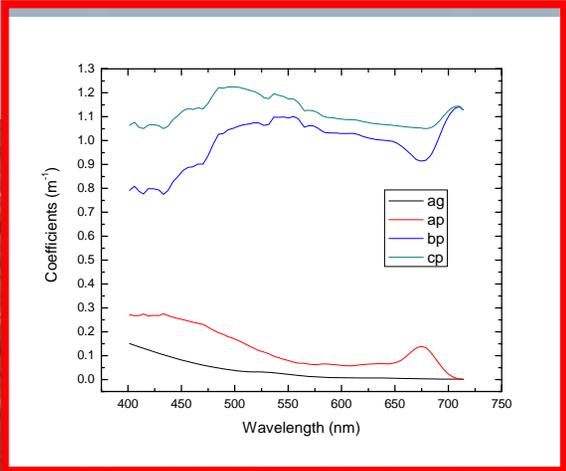
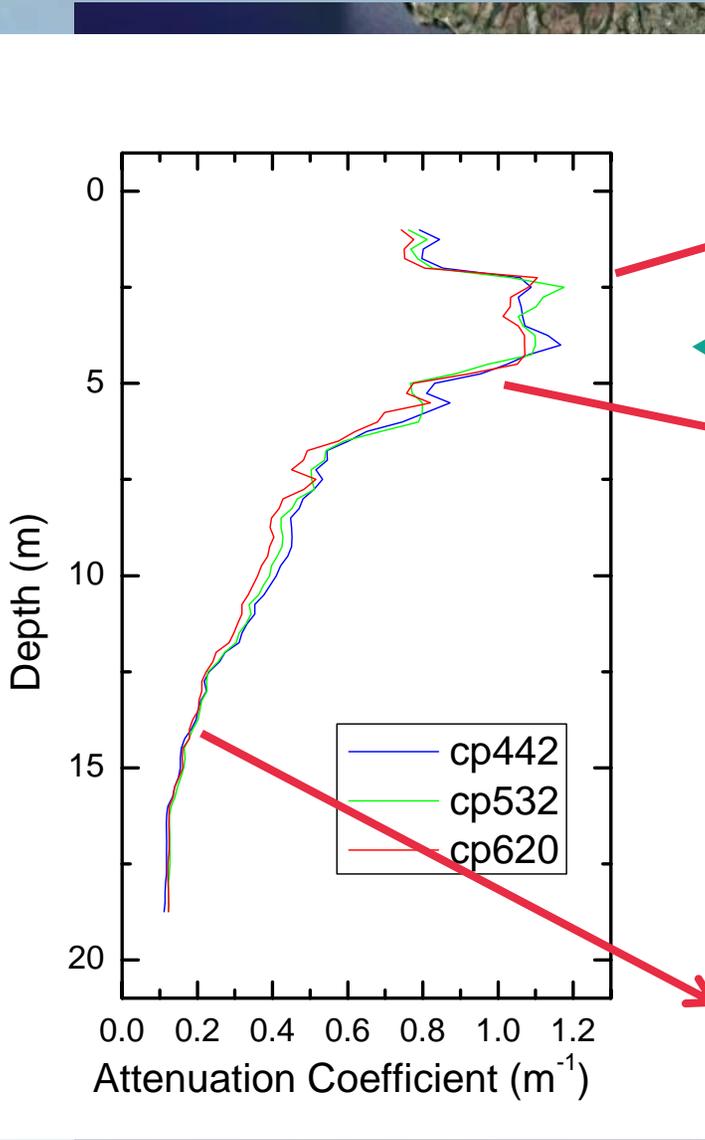
Data from Z.-P. Lee, NRLSSC

## Bucket Sample in the Bloom



# In-water Optics Data for typical Bay water

Bob Arnone, Alan Weidemann and Deric Gray, NRLSSC

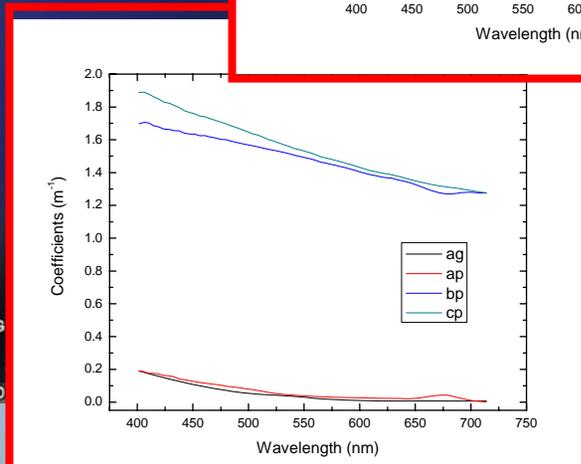
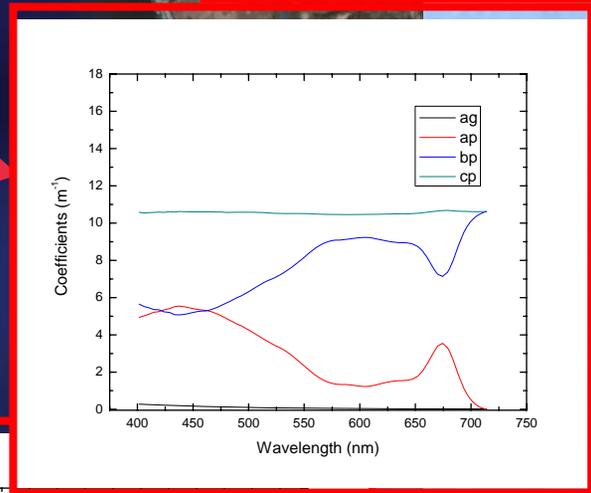
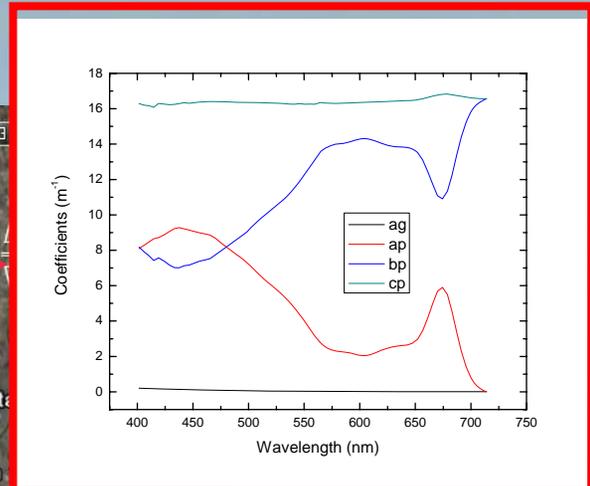
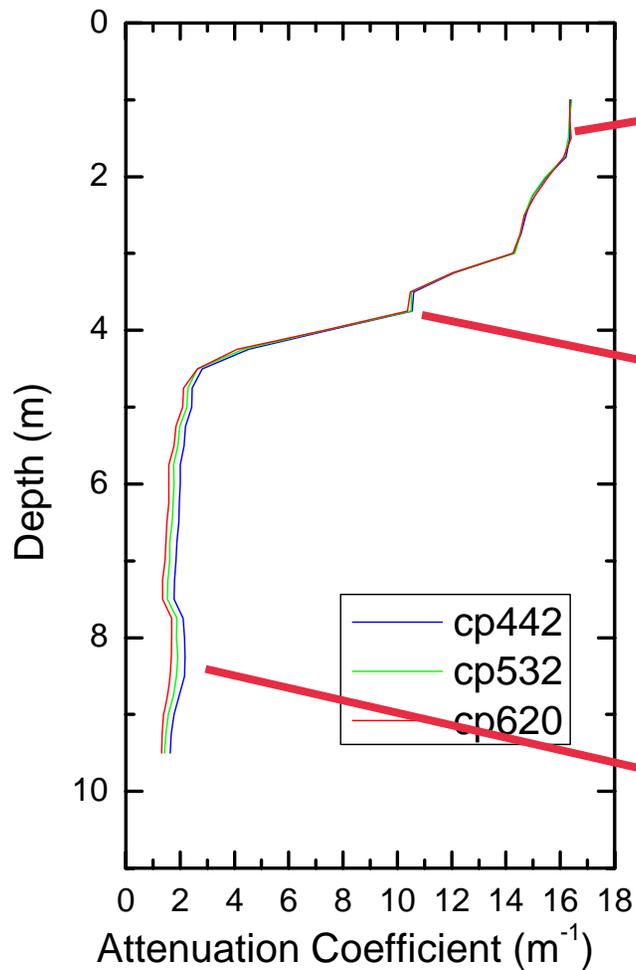
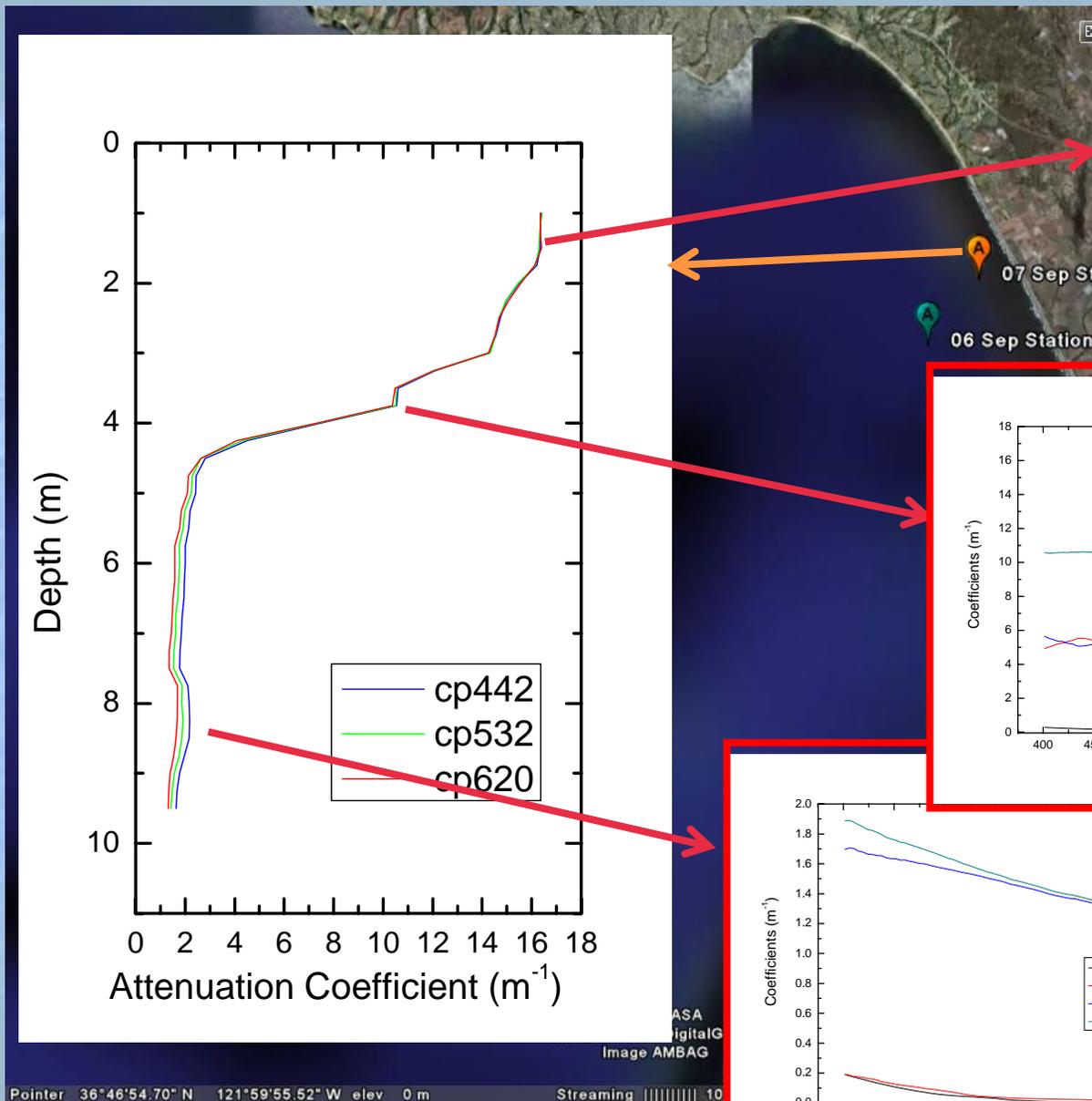


Pointer 36°46'54.70" N 121°59'55.52" W elev 0 m Stream

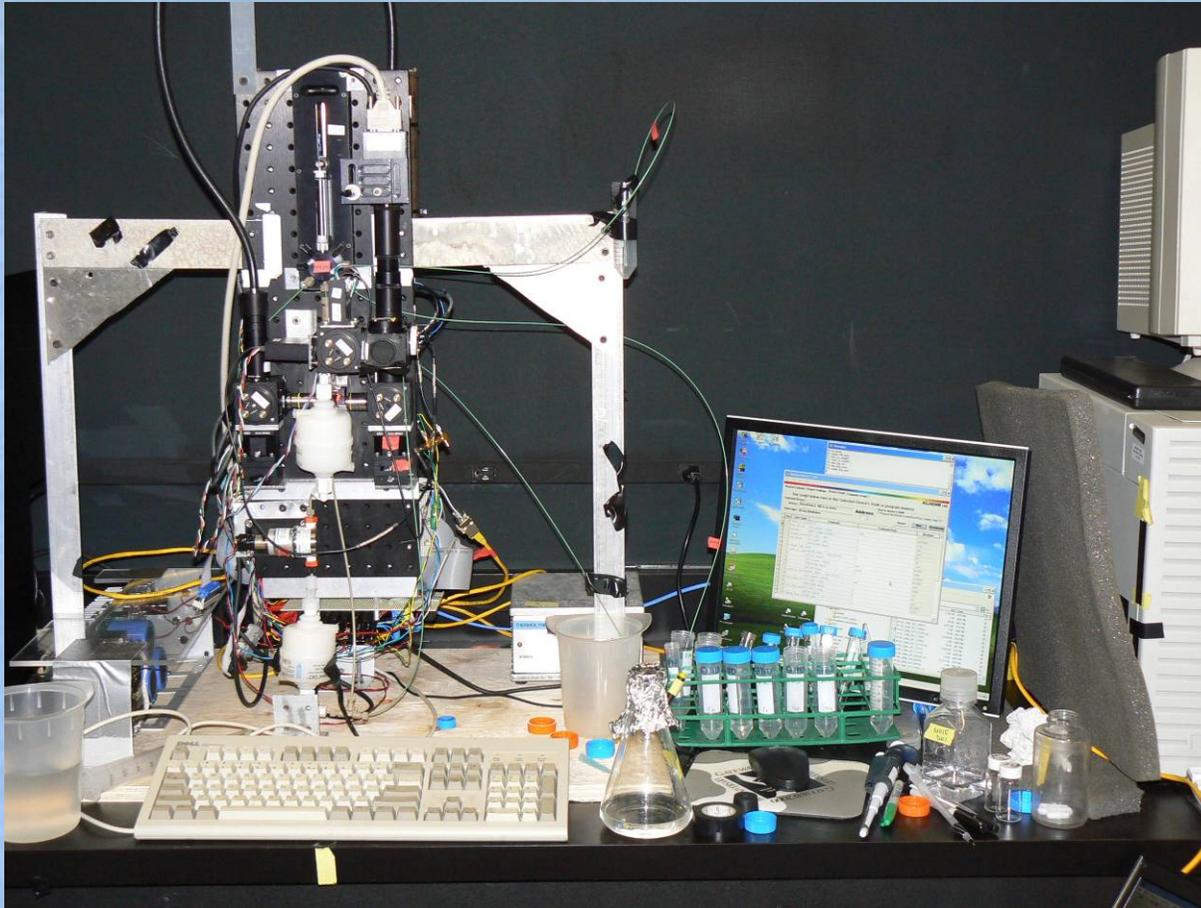
007 Google™ Eye alt 45.89 km

# In-water Optics Data for the Bloom

Bob Arnone, Alan Weidemann and Deric Gray, NRLSSC

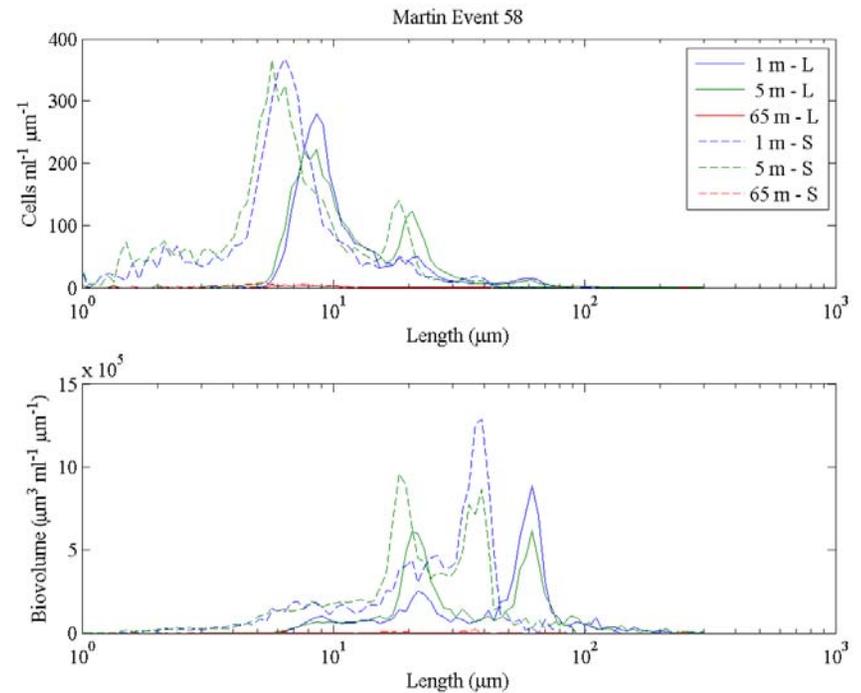
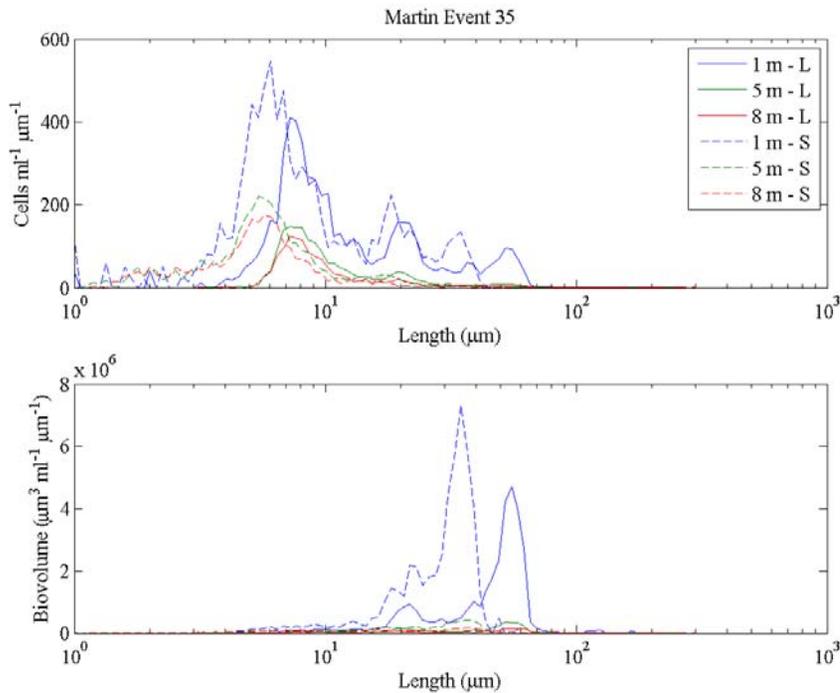


## Heidi M. Sosik: Imaging Flow CytoBot



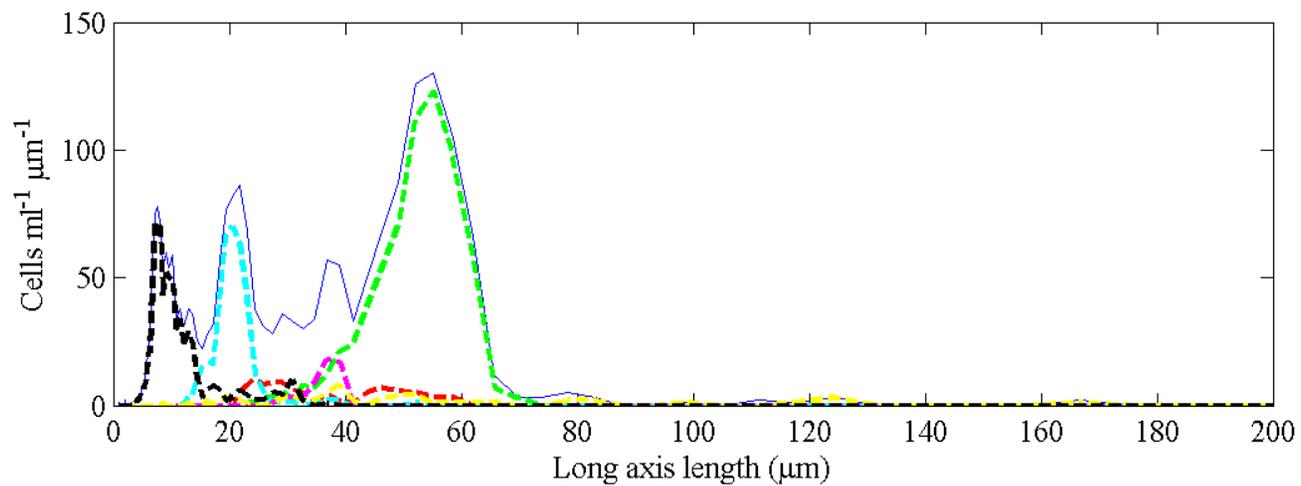
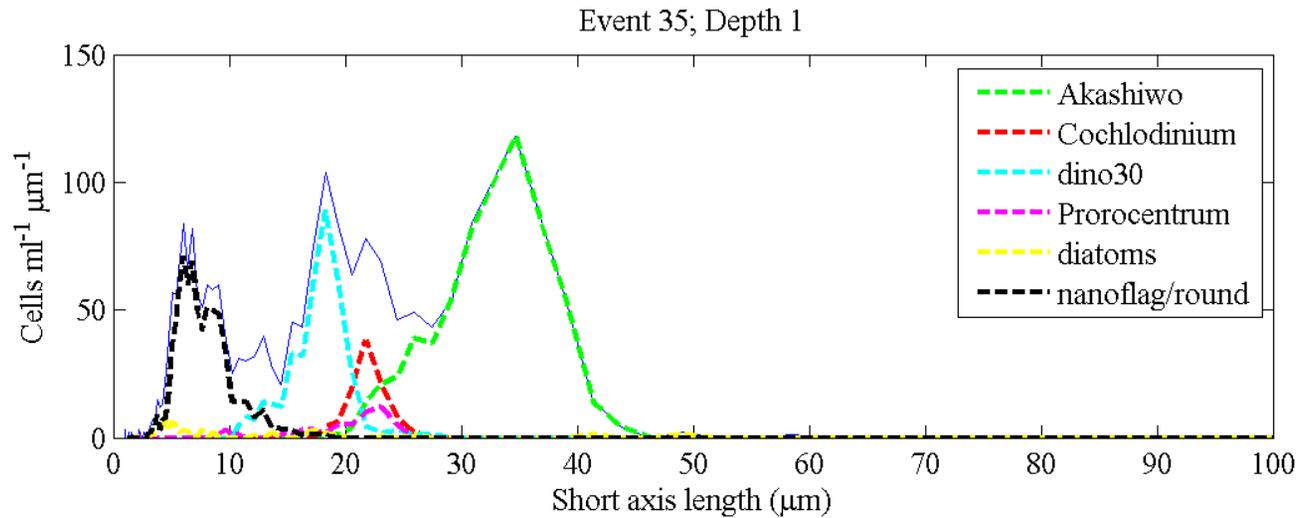
Automated taxonomic classification of phytoplankton sampled with imaging in-flow cytometry, Heidi M. Sosik and Robert J. Olson, *Limnol. Oceanogr. Methods* (2007) 5:204-216

# Example Data

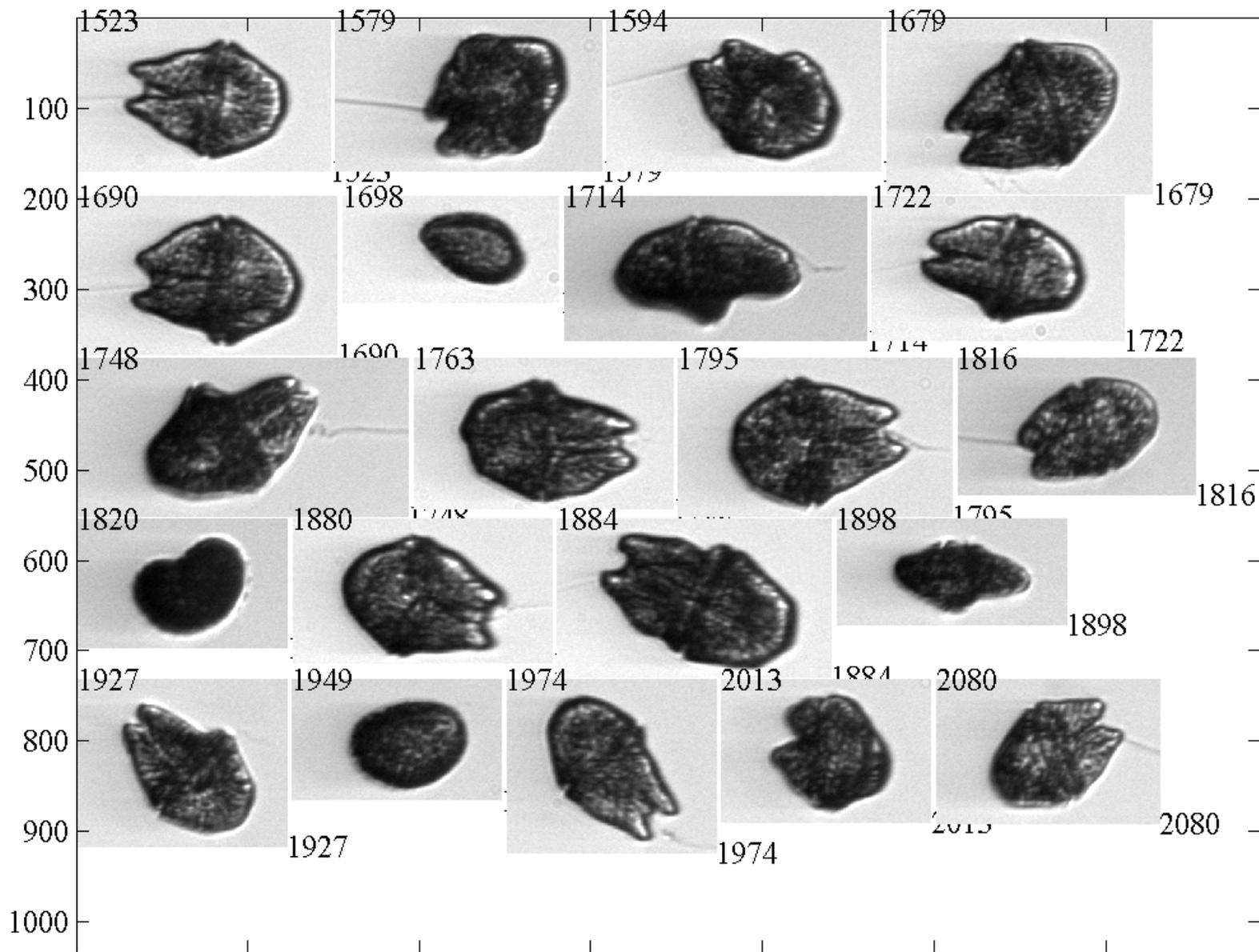


- Each particle is imaged (using fluorescence as a trigger--likely underestimates small cells) for Long and Short axis
- Heidi calculates biovolume based on cylindrical equivalent

# Data are classified to group



Akashiwo



# Monterey Bay Experiment Summary

- **Monterey Bay experiment conducted Sept 3-15, 2006.**
  - **Mid-summer foggy conditions persisted until the last day of the experiment limiting remote sensing opportunities.**
- **Collected SAMSON Airborne hyperspectral data on Sept 4, 5, 11, 12, and 15.**
- **Ship data was collected on those dates and additional measurements were made on cloudy days.**
- **Exceptional data set for characterization of the HAB biology, optics and remote sensing characteristics.**
- **A dry cold front passed through the area September 15<sup>th</sup> thoroughly disrupting the HAB.**
- **Initial analysis of SAMSON data binned to 10 m, 100 m and 300 m. The 10 m data resolved the HAB patches, binned to 100 m was adequate for most features while 300 m data missed surface HAB patches on the 12<sup>th</sup> and the general scale of patchiness on the 15<sup>th</sup> (Davis et al. 2007, Proceedings of the SPIE).**
- **Initial analysis of spectral sampling (Z-P Lee, NRLSSC, not shown) indicates that MERIS channels adequate for sampling this environment.**

# Monterey Bay Experiment Papers in Progress

- **Biology and Dynamics of a Harmful Algal bloom in Monterey Bay, CA (Raphe Kudela, Francisco Chavez, Ricardo Letelier, Heidi Sosik, and Maria Kavanaugh)**
- **Remote Sensing of a Harmful Algal Bloom in Monterey Bay, CA (Raphe Kudela, Bob Arnone, Zhong-Ping Lee, Deric, Curtiss Davis, Paul Bissett, Dave Kohler, and Marcos Montes)**
- **Remote Sensing Requirements for the Coastal Ocean (Curtiss Davis, Paul Bissett, Dave Kohler, Marcos Montes, Bob Arnone, Victor Klemas, Pete Strutton, Maria Kavanaugh, and Zhong-Ping Lee)**
- **Optical characterization of the water masses of Monterey Bay (Alan Weidemann, Bob Arnone, Rick Reynolds, Deric Gray, Alex Chekalyuk, Vanessa Wright, Ken Voss, Heidi Sosik, and Raphe Kudela)**
- **Separating the optical components associated with a Harmful Algal Bloom using in-situ and remote sensing optical properties. (Alex Chekalyuk, Zhong-Ping Lee, Sherry Palacios, and Curtiss Davis)**

# Recommendations for a Coastal Waters Imaging System (CWIS)

- Based on this and earlier studies the recommended sampling characteristics for a Coastal Waters Imaging System (CWIS) are:
  - Spatial sampling 300 m with a goal of 100 m
  - Sampling frequency every 3 hours with a goal of hourly
  - MERIS channels with a goal of hyperspectral covering 380 to 1000 nm plus a channel at 1240 nm for atmospheric correction for optically shallow or turbid waters.
- We will continue analysis of the Monterey Bay data set and broaden our analysis to include data from the New Jersey Coast (LEO-15) and the Florida coast including Florida Bay (PHILLS and Hyperion Data).
- NOAA recognizes the need for a CWIS to meet it's coastal management requirements but there are currently no US plans to build a CWIS.
- South Korea is currently building a Geostationary Ocean Color Imager (GOCI) for the COMS-1 satellite scheduled to be launched in 2009
  - For information go to:  
[http://directory.eoportal.org/pres\\_COMS1CommunicationOceanandMeteorologicalSatellite1.html](http://directory.eoportal.org/pres_COMS1CommunicationOceanandMeteorologicalSatellite1.html)