Geostationary Ocean Color Observations: A NOAA Perspective

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IOCCG Geostationary Working Group
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NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

Overview

- NOAA Ocean Color Needs, Activities and Requirements
  - ⇒ Ocean and Coastal Ecosystem Interests & Observing Needs
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  - ⇒ Operational Specifications for Satellite Ocean Color Measurement
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- Future Directions

NOAA Ocean and Coastal Ecosystem Interests & Observing Needs

- In the United States it is the responsibility of the National Oceanographic and Atmospheric Administration (NOAA) to:
  - help manage society's use of ocean and coastal ecosystems
  - sustain natural resources
  - sustain ecosystem health and services
  - protect public health under several legislative & executive mandates, e.g. *The Coastal Zone Management Act*
    Coral Reef Protection Executive Order/Coral Reef Conservation Act
    The Clean Water Act
    The Harmful Algal Bloom and Hypoxia Research & Control Act
    The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act
    The Marine Mammal Protection Act
    The National Coastal Monitoring Act
    The National Marine Sanctuaries Act
- Satellite ocean color data, products and imagery are important sources of information to help fulfill these mandates, to meet other needs, and to optimize use and protection of coastal and ocean resources.
- However, there are significant gaps in existing and planned capabilities.

NOAA Ocean and Coastal Ecosystem Interests & Observing Needs

Coastal applications that a Geostationary Imager could potentially support:

- Monitor and assess water quality and clarity
- Detect, monitor, and predict the location and/or impacts of hazardous materials, conditions such as harmful algal blooms, oil/sewage spills, urban/stormwater runoff, hypoxia/anoxia, eutrophication et al.
- Appraise health of shallow water corals and other coastal habitats; improve habitat mapping and characterization
- Enhance the development and implementation of new and improved products for fisheries and integrated ecosystem assessments
- Better understand the habitat used by large pelagic animals that are tracked with electronic tags, including describing longer term trends
- Quantify the response of marine ecosystems to both short-term events and climate variability/change (e.g., ocean warming, acidification)
- Assess variability in phytoplankton biomass and productivity and associated forcing for an improved understanding of coastal carbon cycle
- Initialize, evaluate and validate output of coupled ocean-ecosystem models
- Direct research cruises based on real time ocean features and habitat
- Track dynamic ocean features

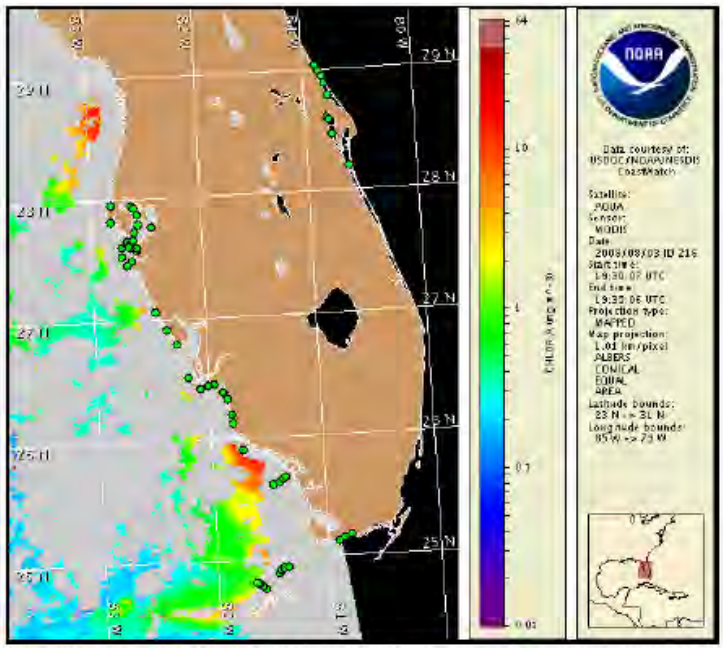
Some examples of ocean color research, applications & operational use

Harmful Algal Blooms – Operational Monitoring and Forecasting

Gulf of Mexico: South Florida

Gulf of Mexico Harmful Algal Bloom Bulletin

Region: South Florida
4 August 2008
NOAA Ocean Service
NOAA Satellites and Information Service
Last bulletin: July 28, 2008



Satellite chlorophyll image with possible HAB areas shown by red polygon(s). Cell concentration sampling data from July 25 to 31 shown as red (high), orange (medium), yellow (low b), brown (low a), blue(very low b), purple (very low a), pink (present), and green (not present). For a list of cell count data providers and a key to the cell concentration categories, please see the HABFS bulletin guide:
http://www.csc.noaa.gov/crs/habf/habfs_bulletin_guide.pdf

Please note the following restrictions on all SeaWiFS imagery derived from CoastWatch.

1. Data are restricted to civil marine applications only; i.e. federal, state, and local government use/distribution is permitted.
2. Image products may be published in newspapers. Any other publishing arrangements must receive GeoEye approval via the CoastWatch Program.

Conditions Report

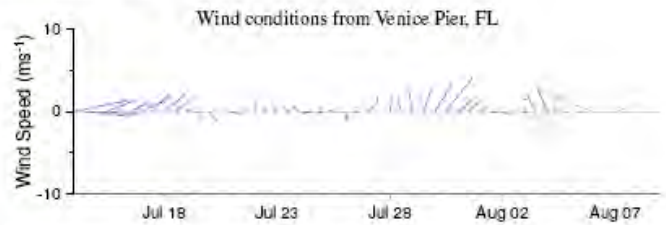
There is currently no indication of a harmful algal bloom at the coast in southwest Florida. No impacts are expected alongshore southwest Florida today through Sunday, August 10.

Analysis

There is currently no indication of a harmful algal bloom at the coast in southwest Florida. No *Karenia brevis* was found in samples collected last week between Pinellas County and the Florida Keys (FWRI, MML, SCHD; 7/30-8/1). Cloud cover has obscured recent satellite imagery, limiting analysis. Imagery from July 31 continued to show patches of elevated to high chlorophyll alongshore SW Florida due to confirmed non-harmful algae. Dead fish have been reported in the upper Tampa Bay, but are not due to *K. brevis* (FWRI, 08/01). Upwelling conditions are possible through Wednesday, August 6, however bloom formation alongshore is unlikely. No impacts are expected along the coast through Sunday, August 10.

Please note that SeaWiFS imagery is temporarily unavailable for display on this bulletin due to technical difficulties; MODIS imagery is shown on pages 1 and 2 of this bulletin.

Fenstermacher, Fisher



Wind speed and direction are averaged over 12 hours from buoy measurements. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

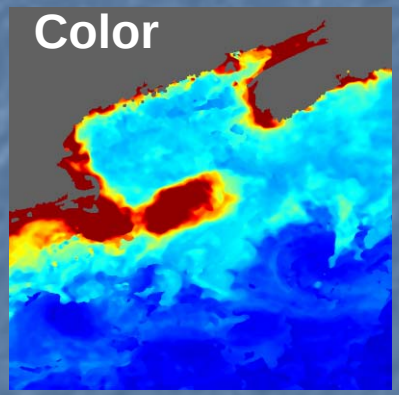
Wind Analysis

SW Florida: Southeast to easterly winds today through Wednesday, with onshore winds in the afternoon (5-10 kns; 3-5 m/s). Southwesterlies Thursday and Friday (5-10 kns; 3-5 m/s)

To see previous bulletins and forecasts for other Harmful Algal Bloom Bulletin regions, visit the NOAA CoastWatch bulletin archive: http://coastwatch.noaa.gov/hab/bulletins_ns.htm

NOAA/NOS - http://coastwatch.noaa.gov/hab/bulletins_ms.htm

Integrated Ecosystem Assessments: Right Whale Forecast



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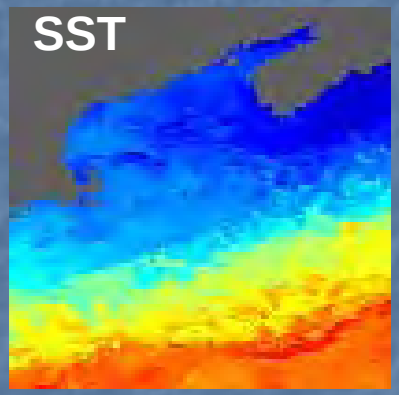

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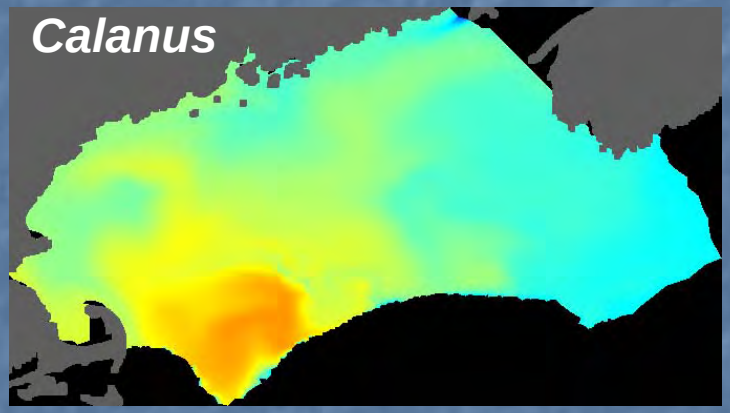

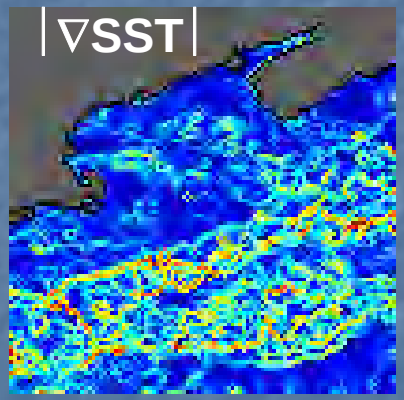

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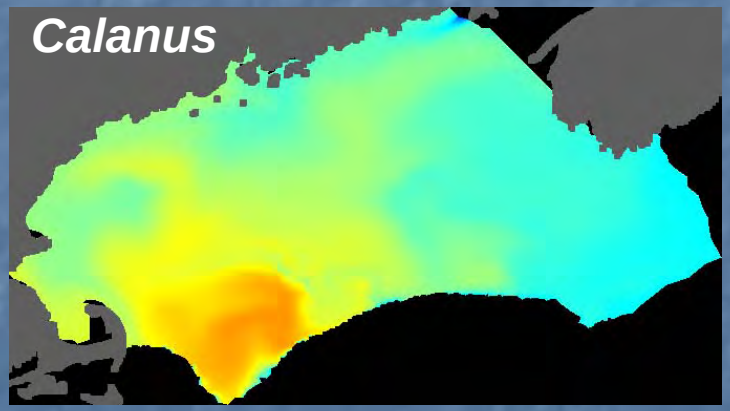

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Whale feeding areas

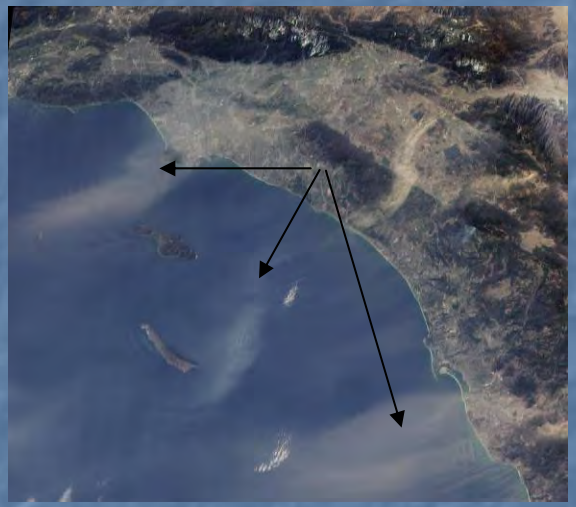
Biggest source of mortality to highly endangered (<400 left) Right Whales is ship strikes. Ability to predict their location will help NOAA minimize ship traffic in those regions.

Pershing and Monger, Cornell University, funded by NASA/NOAA

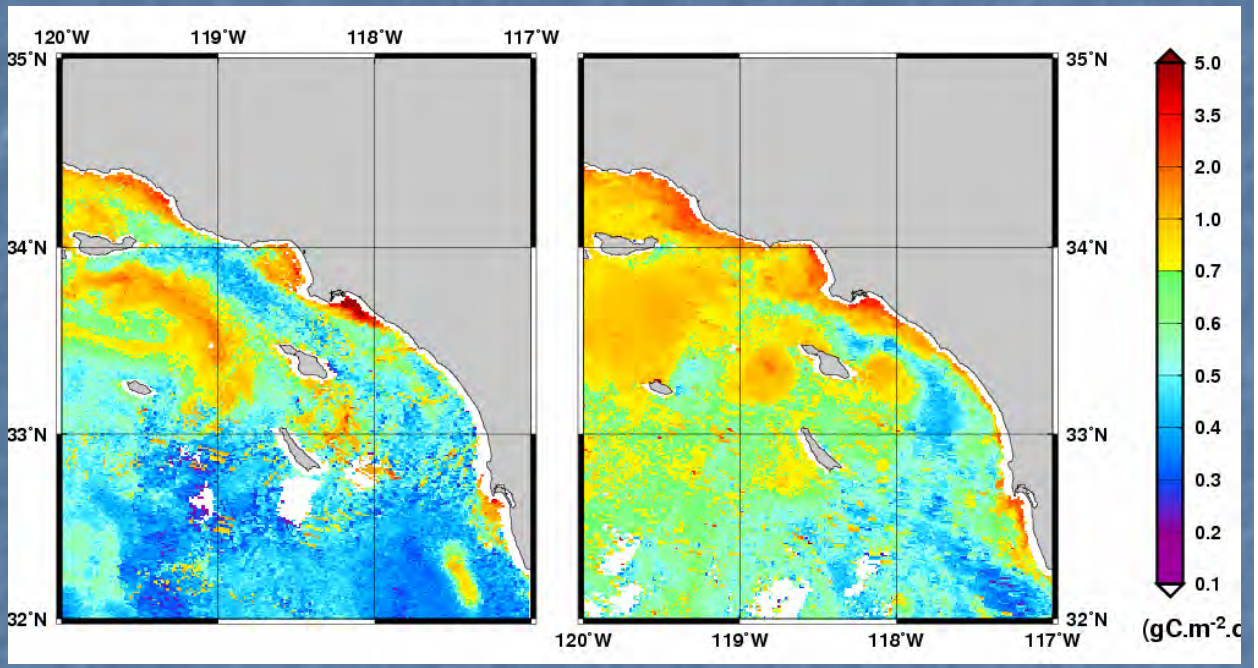
www.geo.cornell.edu/whales

Santa Ana Winds off Southern California

Strong, seasonal offshore winds from inland deserts transport nutrient-laden dust and air pollutants into coastal zones - can impact primary productivity (potentially through both chemical and physical forcing) and carbon cycling



NASA/MISR - 9 February 2002



NASA/MISR - 27 November 2003

- Primary-productivity composites (1 km SeaWiFS and AVHRR data; before (left panel; 2-4 Jan 2001) and after (right panel; 13-16 Jan 2001) a Santa Ana wind event on 8 Jan 2001.
- Important to consider aeolian inputs relative to those from upwelling, runoff, sewage et al. inputs.

(DiGiacomo et al., In Preparation)

NOAA ocean color requirements

NOAA Operational Specifications for Satellite Ocean Color Measurement

Nominal Threshold Channel Center Wavelength (um)	Nominal Threshold Resolution (um)	Nominal Threshold Signal to Noise	Nominal GOAL Channel Center Wavelength (um)	Nominal GOAL Resolution (um)	Nominal Goal Signal to Noise
0.412	0.02	300 to 1 all channels	0.345	0.02	900 to 1 all channels
0.443	0.02		0.380	0.02	
0.490	0.02		0.407 through 0.987	0.01	
0.510	0.02		0.570	0.05	
0.555	0.02		1.000	0.04	
0.580	0.02		1.240	0.03	
0.620	0.02		1.380	0.03	
0.645	0.01		1.640	0.03	
0.667	0.01		2.130	0.05	
0.678	0.01		11.200 (2 km)	0.8	
0.709	0.01		12.300 (2 km)	1	
0.750	0.02	Nominal Threshold Horiz. Resolution: 300 m; 3 hr refresh rate			Nominal Goal Horiz. Resolution:30 m except for LW IR channels; 1 hr refresh rate
0.865	0.02				
1.240	0.03				
1.640	0.03				
2.130	0.05				

Based on threshold and objective requirements for coastal ocean color as documented in NATIONAL OCEAN SERVICE Environmental Satellite Requirements DRAFT February 8, 2005, with later review and endorsement by members of the coastal Ocean Applications and Science Team. Some updates made August 2008, including adding SWIR bands to threshold.

Coastal Observing Requirements – Ocean Color

	PARAMETER	HOR. RES	HR MIN	OBS. CYCLE	OC MIN	AVAIL	AVAIL MIN	ACCURACY	ACC. MIN
BIOLOGICAL/BIOGEOCHEMICAL OBSERVATIONS	Phytoplankton pigments (e.g., chl-a)	100 m	500 m	1 h	2 h	1 h	3 h	20%	30%
	Total suspended matter	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Coloured dissolved organic matter	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Optical properties (includes PAR)	100 m	500 m	1 h	2 h	1 h	3 h	10%	20%
	Chlorophyll fluorescence	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Aerosol properties (includes AOT)	100 m	500 m	1 h	2 h	1 h	3 h	10%	20%
	Nutrients	10 km	100 km	1 d	1 mo	1 d	7 d	10%	30%
	O_2 and pCO_2	10 km	100 km	1 d	1 mo	1 d	7 d	10%	30%
	Slicks/films (sea surface roughness)	25 m	50 m	3 h	2 d	1 h	3 h	50 m	100 m

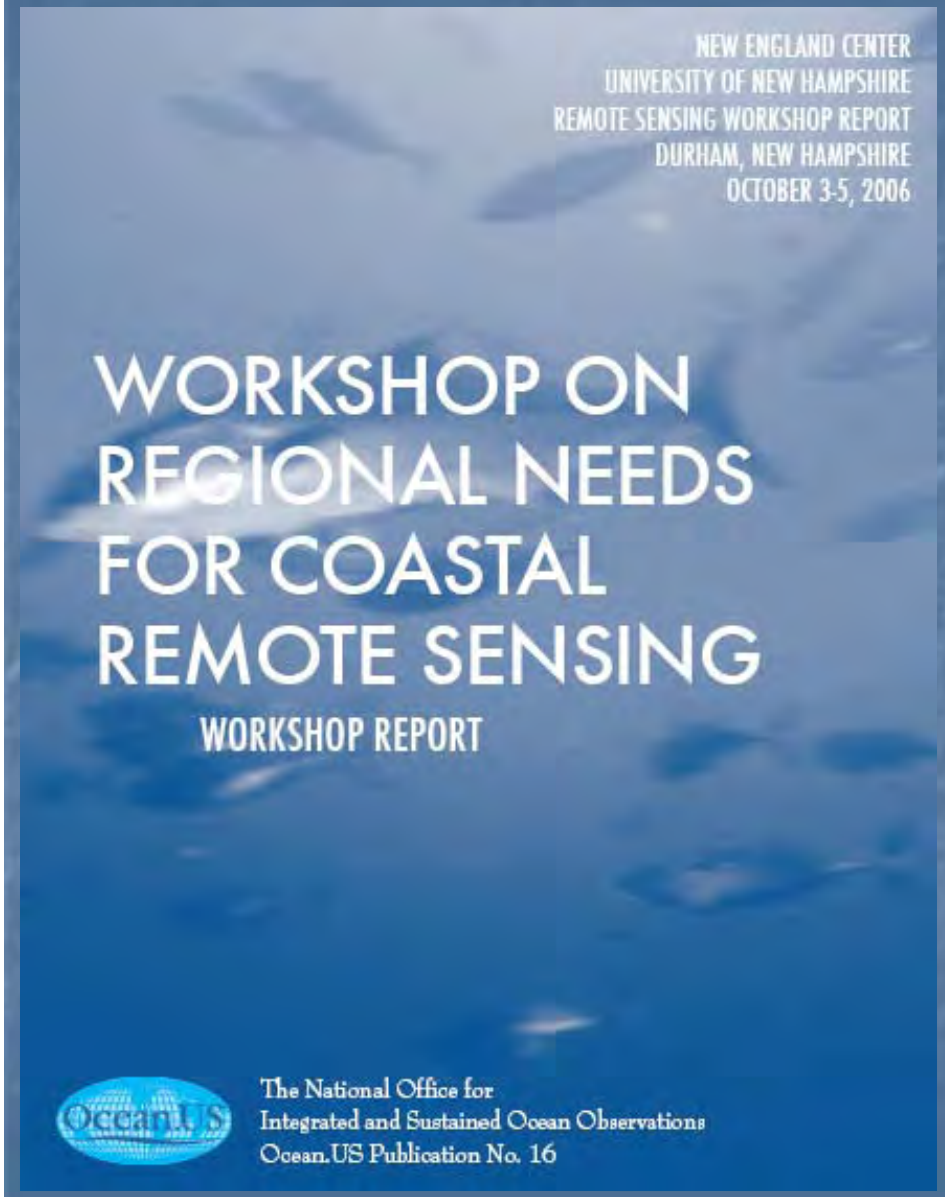
PROVIDE	Geostationary, hyperspectral visible spectral radiance (i.e., ocean colour) data for coastal waters
	Higher resolution/improved coverage for ocean vector winds & sea surface height
	High spatial and spectral resolution capacity to assess changes in coral reef & other terres-trial and aquatic habitats (e.g., estuaries)
	Ocean surface current observations and river discharge in coastal regions
	InSAR measurements for coastal subsidence and erosion
IMPROVE	Calibration/validation of measurements in coastal regions
	Data management infrastructure (near-real-time delivery; climate data records)
SUPPORT	Development of an integrated COastal Data Assimilation System
	Adaptive, coordinated remote and *in situ* sampling

IGOS Coastal Theme Report, 2006

Common needs & gaps vis-à-vis existing and planned capabilities:

- Existing global observing assets generally provide *inadequate* **spatial, temporal and spectral resolution.**
- Some observations needed for coastal users not presently made from space; as such, data often sparse/spotty.

Coastal Observing Requirements – Ocean Color



- Synoptic sub-diurnal temporal revisits on the order of 3 hours or ideally more frequently – i.e. hourly or better, for observing dynamic coastal regions and rapidly evolving and/or ephemeral ocean events:
    - resolve Coastal processes and phenomena influenced by tides and other factors
    - mitigate data losses due to cloud cover.

- Spatial resolution of ~100-300 m – necessary for broad, frequent synoptic observations of the U.S. EEZ; an order of magnitude increase in resolution, i.e., ~10-30 m, is required to effectively study and monitor aquatic ecosystems & habitats at the land-sea interface, particularly small bays, estuaries, mangroves, kelp and sea grass beds.

- As a minimum standard, coastal ocean color sensors should have a band-set similar to MERIS, including fluorescence bands as well as including UV and SWIR bands (the latter for improved atmospheric corrections); hyperspectral imaging capabilities are optimal.

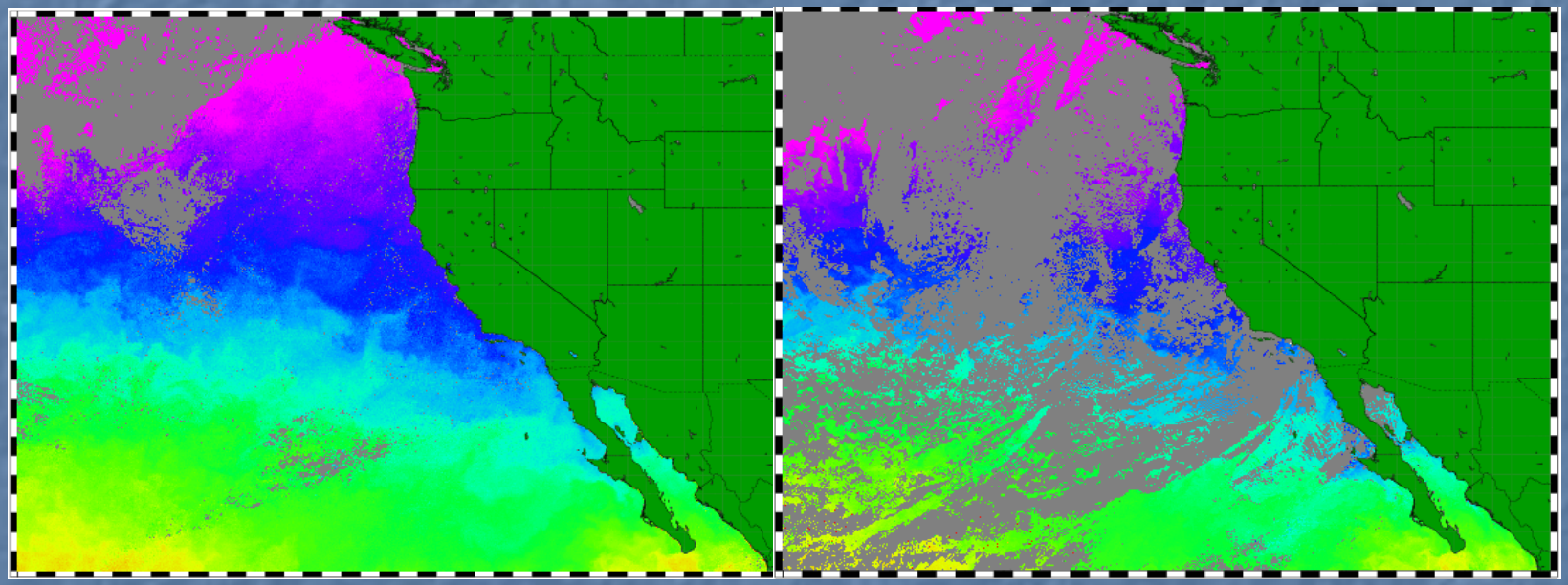
Need for improved resolution

Need for Improved Temporal Resolution

- Once-per-day frequency limits the utility of coastal area observations; multiple looks/revisits per day will help significantly mitigate this problem.
- Cloud cover can be a significant problem, particularly in highly variable coastal regions, and can result in vast areas with little or no coverage.
- More frequent ocean color observations are also required to resolve diurnal and tidal cycle effects associated with currents, winds et al.
- More frequent sampling is also required to track dynamic features, e.g., water masses containing harmful algal blooms, urban/stormwater runoff, and oil/sewage spills, as well as help examine vertical migration.
- More frequent sampling also aids in the development of ecosystem models to support the management of marine sanctuaries and protected areas, provide hazard warnings, and improve management of fisheries using the Essential Fish Habitat approach for key commercial and sport fish stocks.

Temporal Resolution Comparison

Increased temporal resolution will greatly increase data coverage in persistently cloudy areas

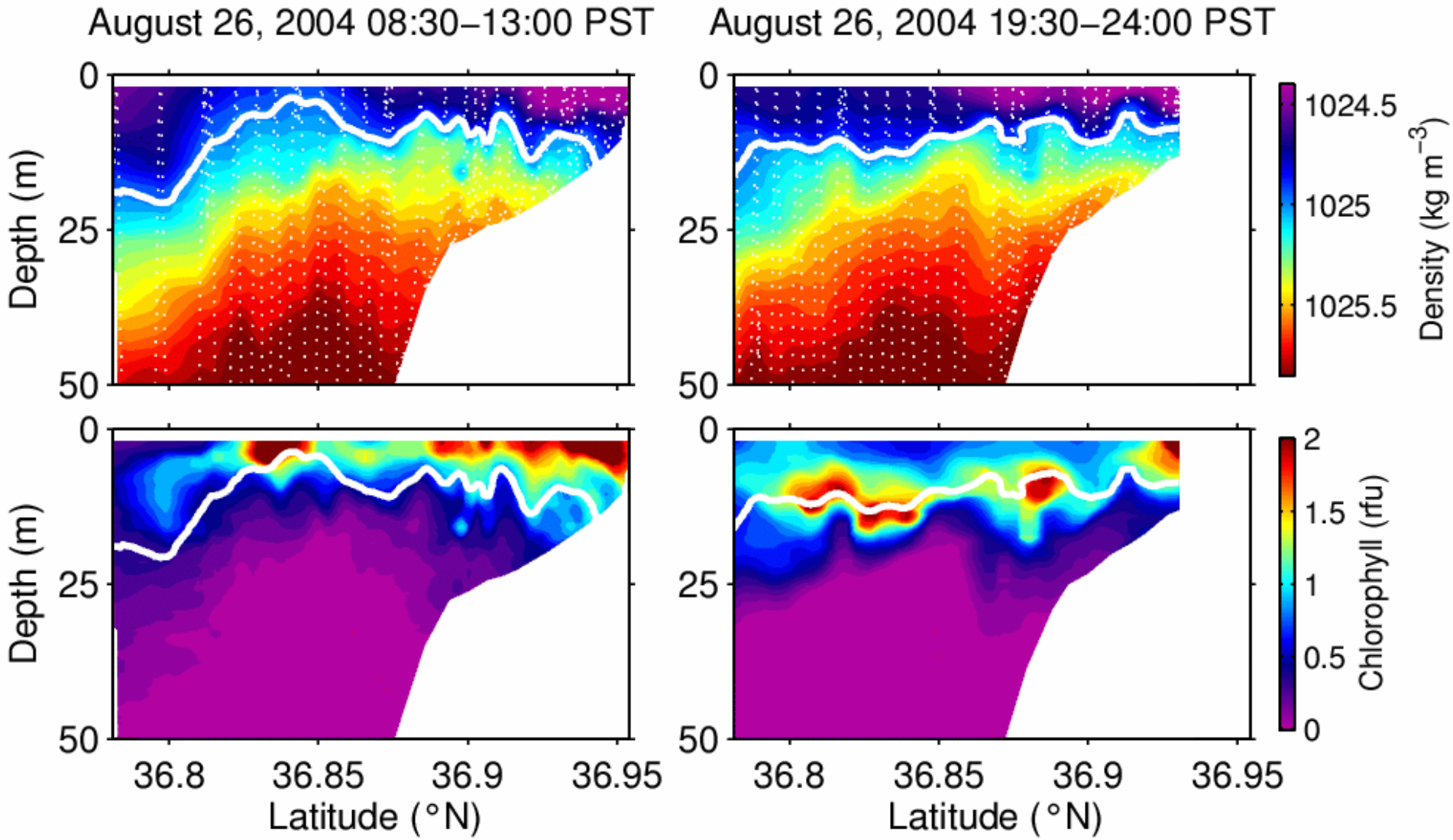


3 day composite of GOES SST

3 day composite of AVHRR SST

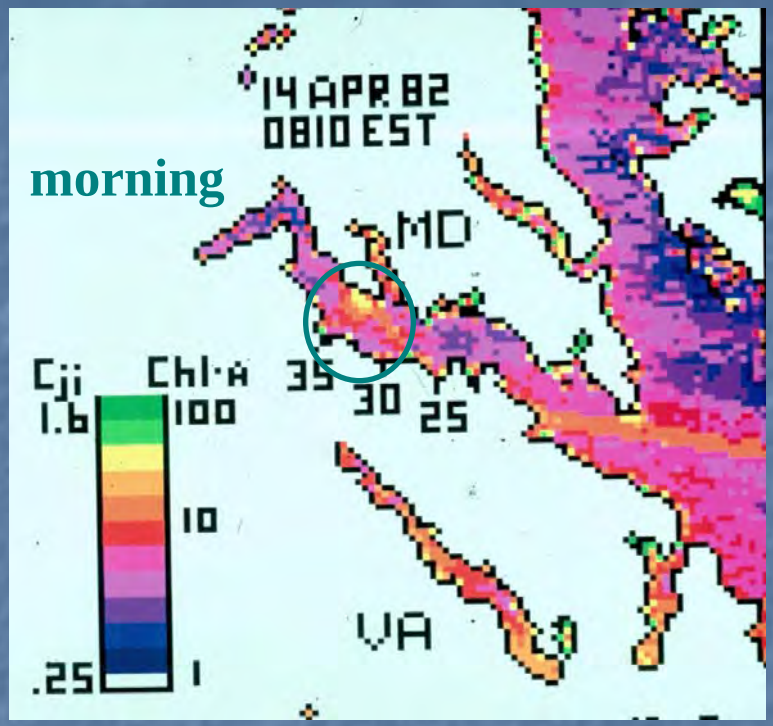
Images courtesy of NOAA CoastWatch, West Coast node at ERD

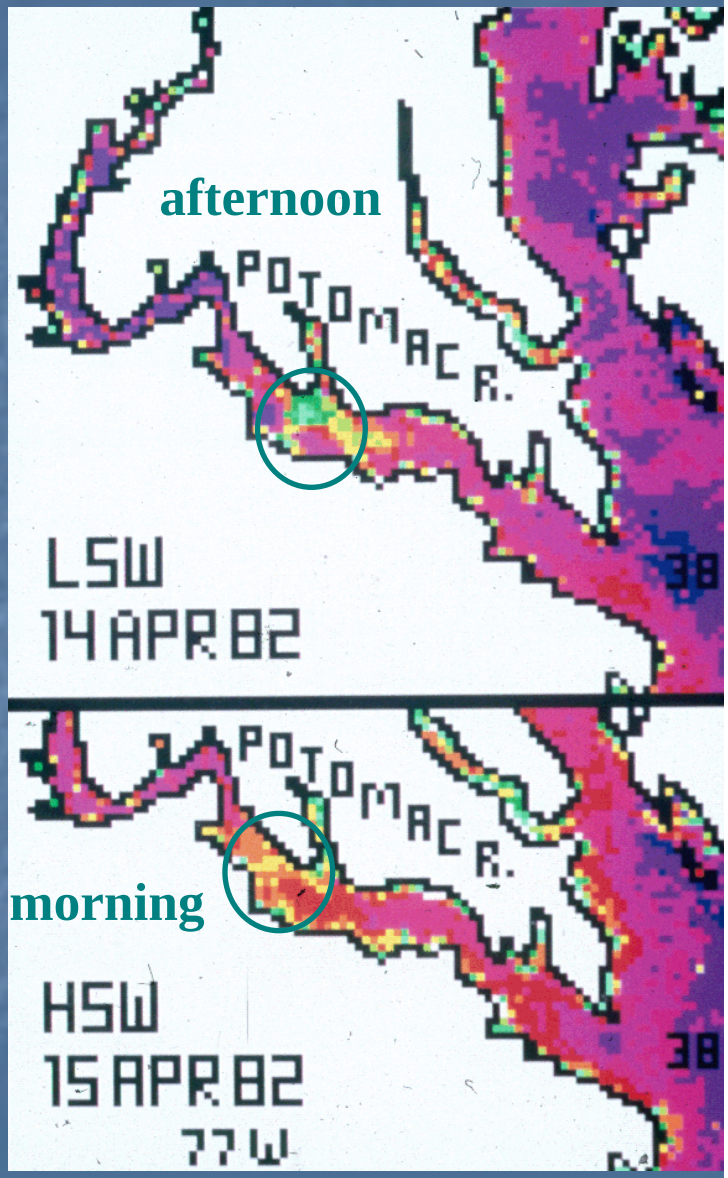
Dinoflagellates migrate vertically (downward at night).



The white contour is the same reference isopycnal in each figure (MBARI)

Vertical Migration, example with *Heterocapsa*



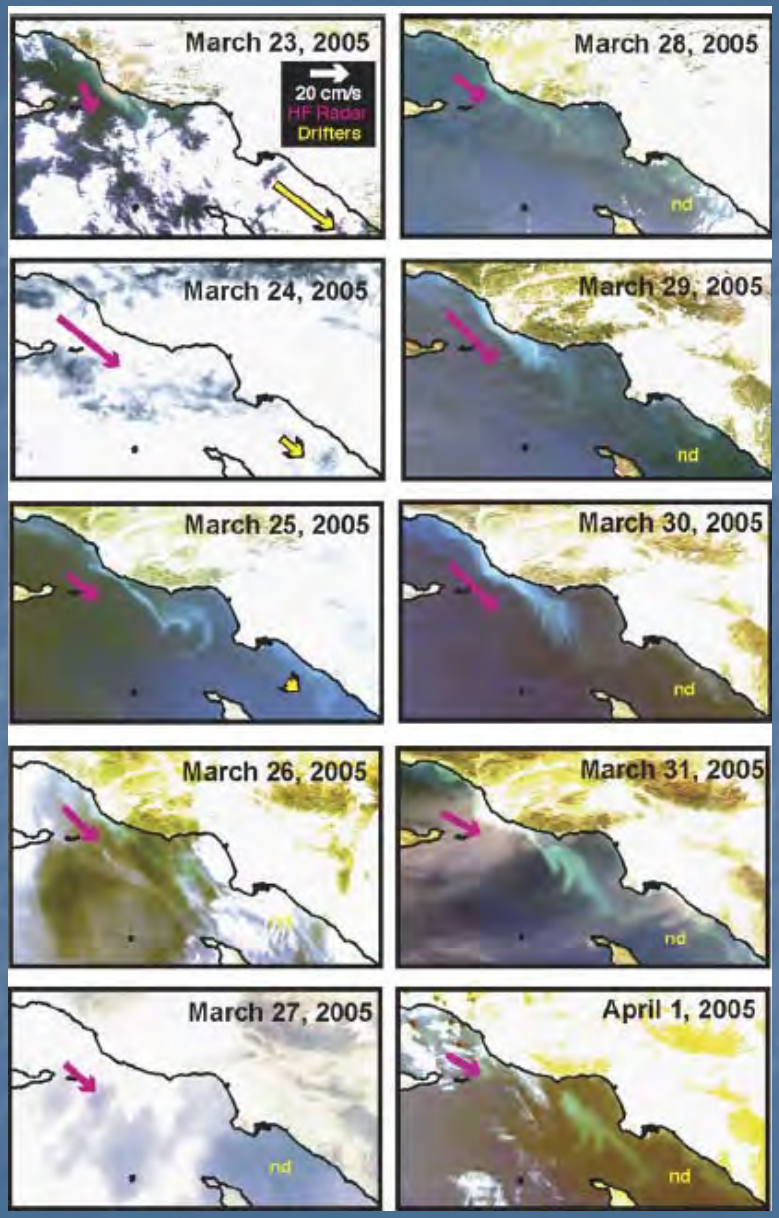


Annual bloom, dinoflagellate (not toxic) in Chesapeake Bay

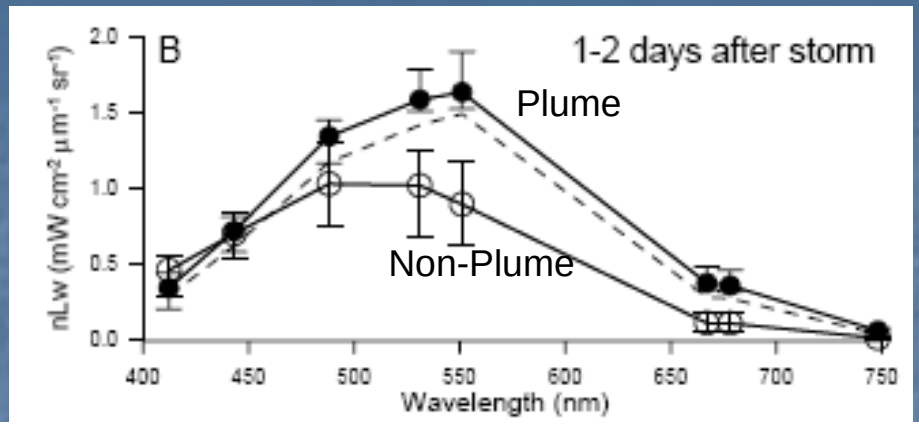
w/Shipboard validation

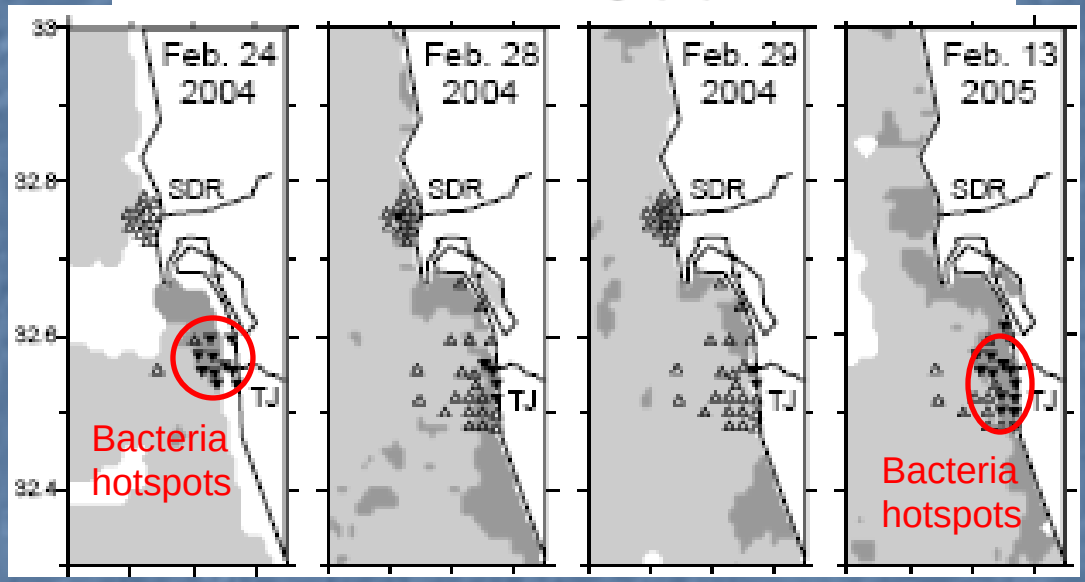
Tyler and Stumpf, RSE 1988

Satellite Observations of Stormwater Runoff Plumes



Warrick et al., CSR, 2007





Nezlin et al., ECSS, 2008

- Runoff plumes are dynamic, episodic features, and can move 20-40 km/day
- Cloud cover limits their observation

Need for Improved Spatial Resolution

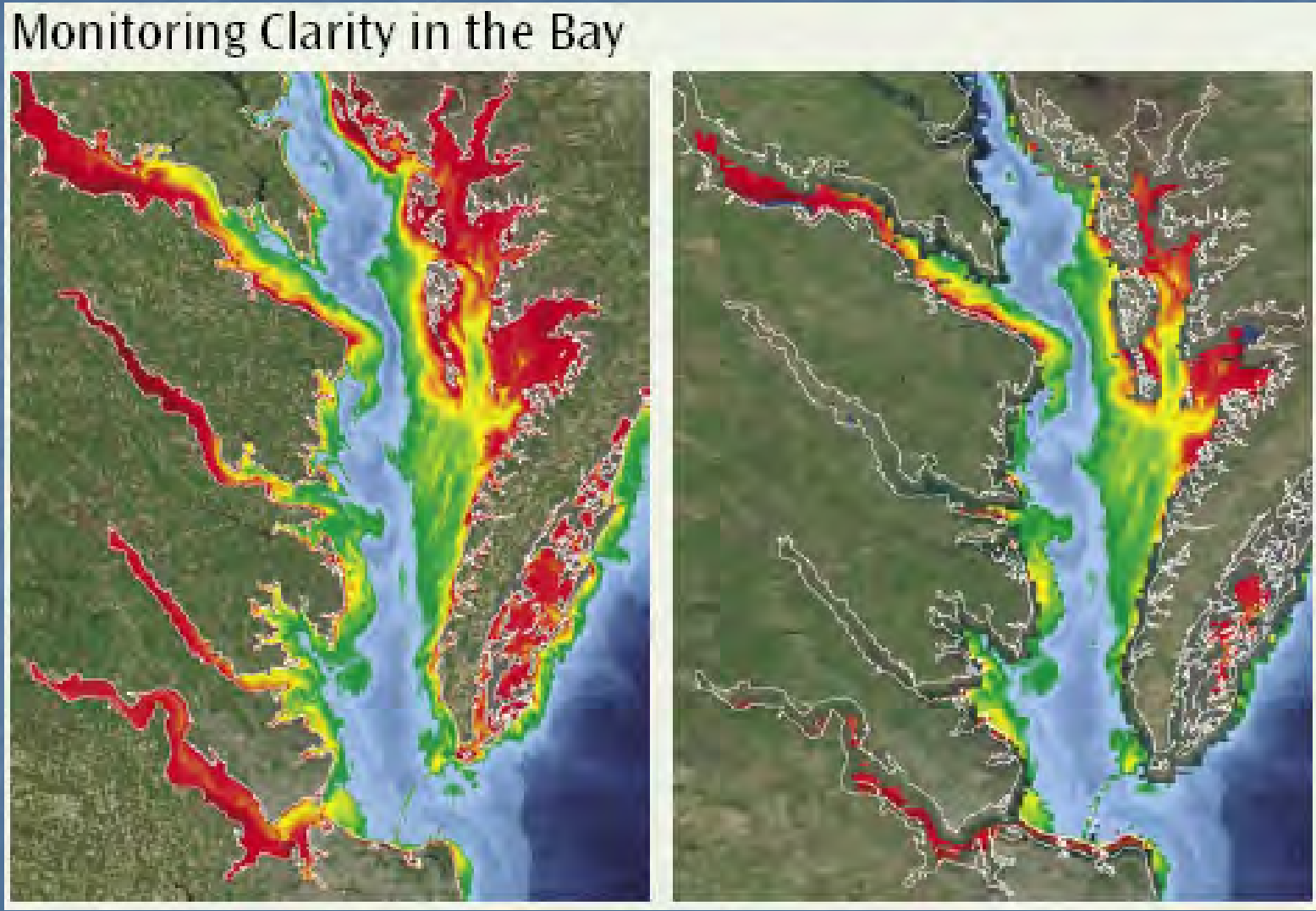
- The complex U. S. coastline requires higher resolution than 1 km to successfully image many sounds, bays and estuaries; higher spatial resolution sensors of ~300 meters (or better) can provide significantly improved observations for many areas that are currently poorly resolved.

- For example, such higher spatial resolution will provide a new capability for monitoring over 100 significant estuaries (per U.S. National Estuarine Eutrophication Report) and provide sufficient information on complex coastal areas like the Chesapeake Bay, Puget Sound and the Florida Keys.

- Higher spatial resolution ocean color satellite data will also improve tracking of small-scale ocean features and processes (e.g., eddies) that can influence migration, feeding, spawning, and recruitment of commercially important fish populations and many protected species.

- It will also help improve water quality monitoring & assessments by enhancing detection of (harmful) algal blooms, urban/storm runoff (can contain pollutants and pathogens), and other dynamic phenomena and processes of interest.

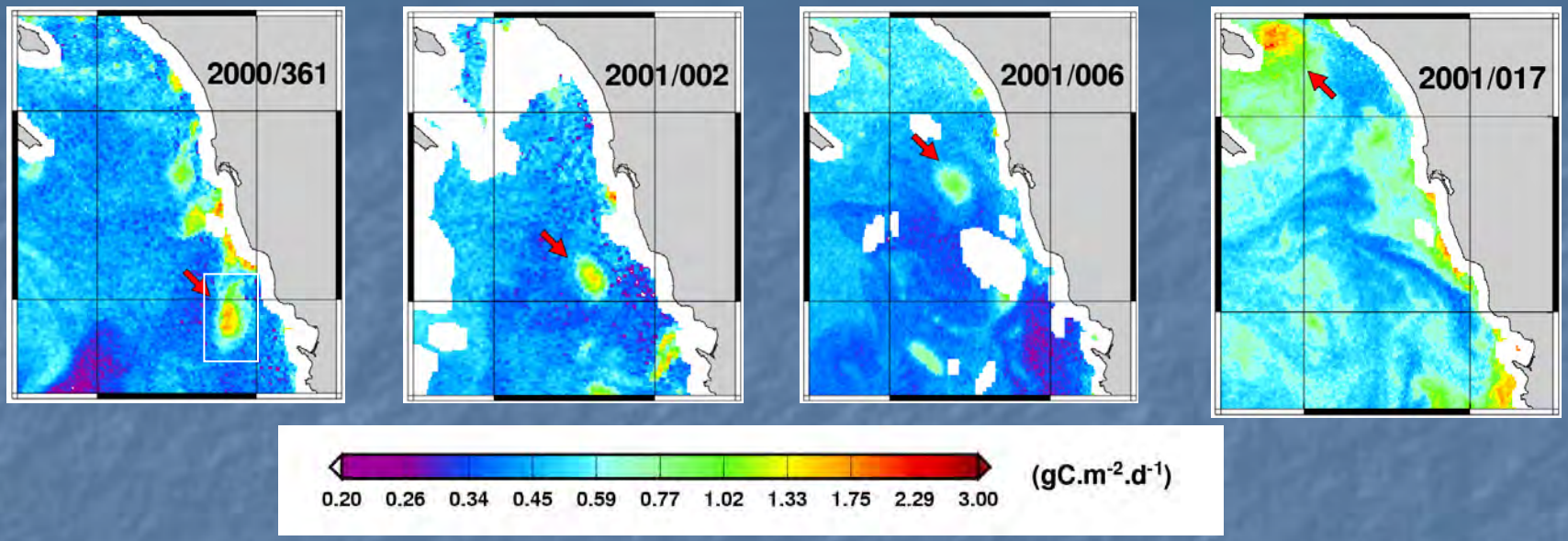
Higher spatial resolution crucial for monitoring of complex coastal waters

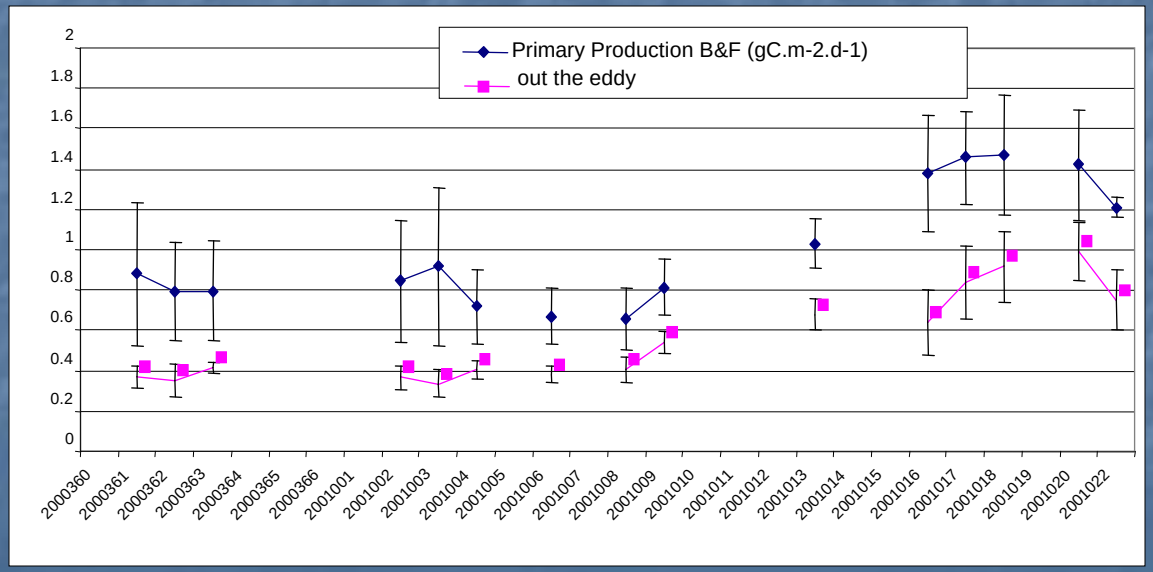


MODIS (250 m) **MODIS (1 km)**

Courtesy Bob Arnone, NRL

Biological Impact of Small-Scale Eddies

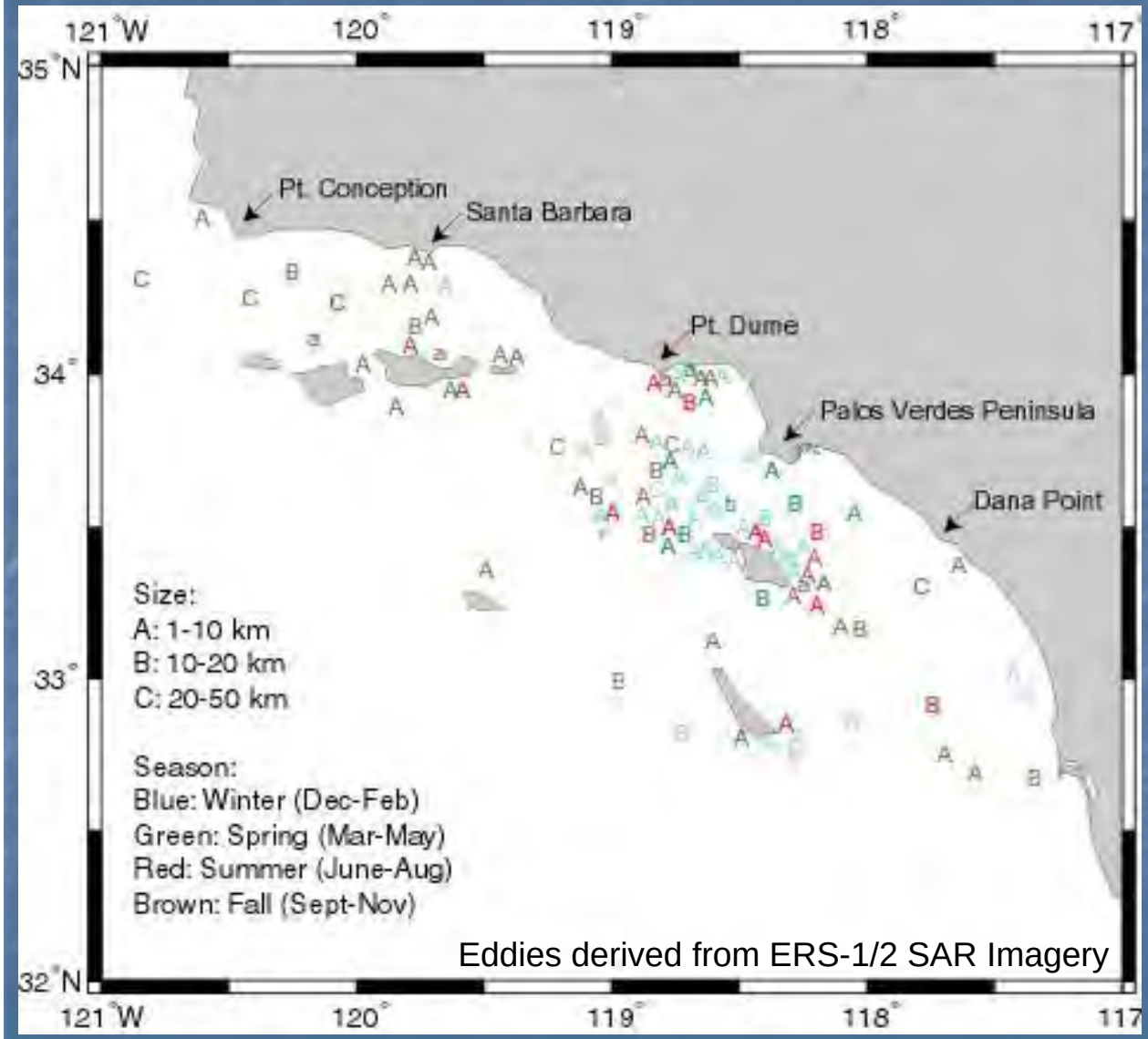




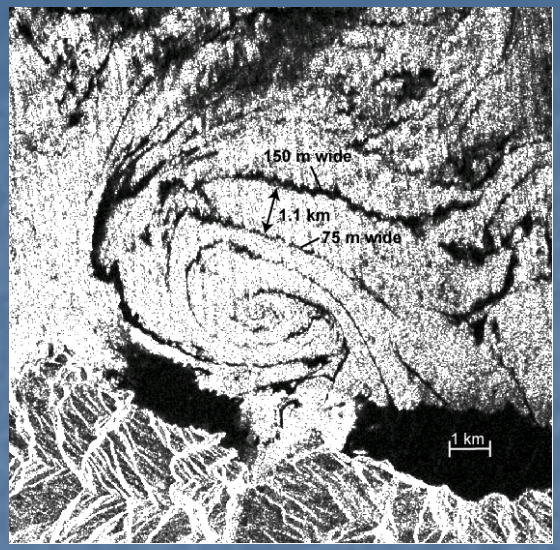
- Primary production was significantly higher within the eddy over its 27-day lifetime, representing an 80% increase over the background rate of primary productivity, presumably resulting from elevated upwelled/entrained nutrients.

Bosc et al., submitted

Small-Scale Coastal Eddies



Eddies derived from ERS-1/2 SAR Imagery



Eddies of this type are quite common in dynamic coastal regions, and are relatively small (frequently < 20 km), ephemeral and episodic, and can have significant ecosystem impacts. (e.g., DiGiacomo & Holt, 2001; Caldeira et al., 2005)

Need for Improved Spectral Resolution/Coverage

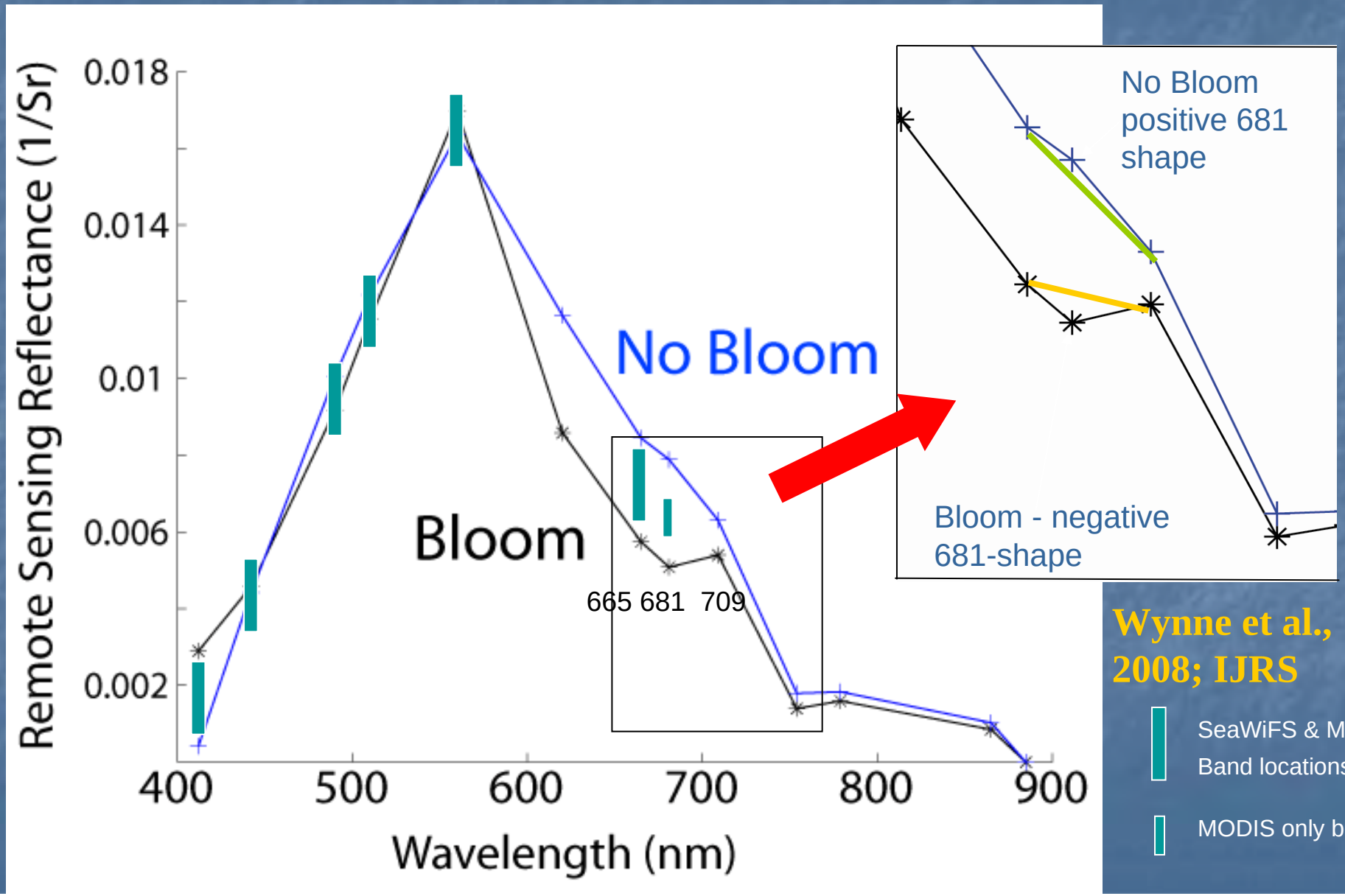
- River runoff, suspended sediments, colored dissolved organic matter, large phytoplankton blooms and bottom reflectance in shallow water all add to the optical complexity of coastal waters.
- Most current and planned sensors do not measure light in enough different wavelengths to optimize separation of components in optically complex waters, and none provide enough bands for optimal atmospheric correction.
- Bands in the infrared (IR) and shortwave infrared (SWIR) can improve atmospheric correction.
- Additional bands in the red-near-infrared can aid phytoplankton identification.
- Additional ultraviolet (UV) bands show potential for improving atmospheric correction and phytoplankton discrimination.
- Higher spectral resolution (narrower/more bands) & greater spectral coverage, from UV to SWIR with suitable SNR, will allow for improved discrimination of aquatic and atmospheric optical constituents and enable new and improved products for better environmental assessments and monitoring.

Cyanobacteria

Landsat “true color”

Lake Erie, courtesy OhioView

Spectral shape around "red edge" MERIS



Wynne et al., 2008; IJRS

SeaWiFS & MODIS Band locations

MODIS only band

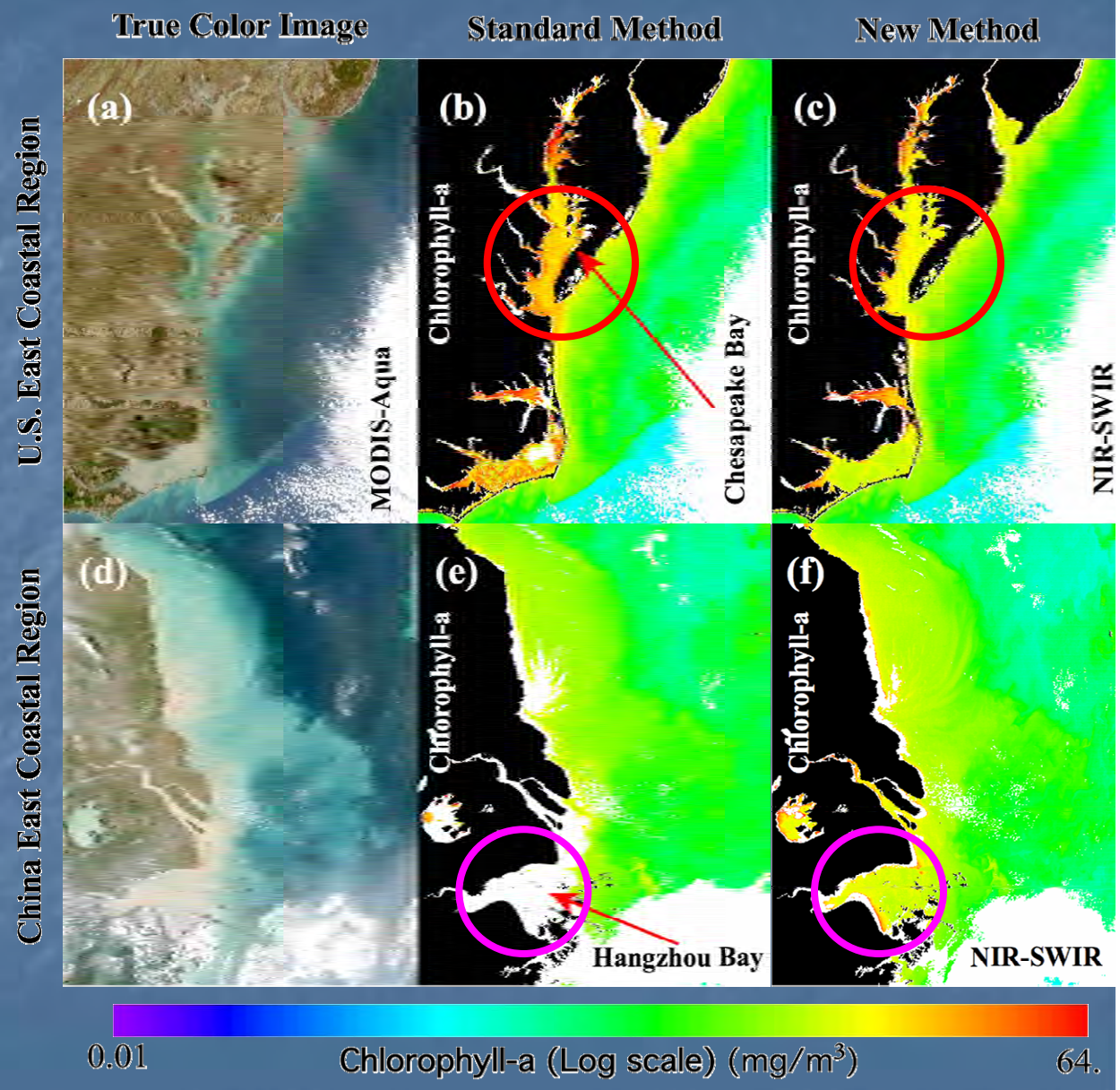
Utility of SWIR Bands in Turbid Coastal Waters

Comparison:

MODIS-derived chl-a using existing standard as well as new method using NIR-SWIR algorithm (Wang & Shi, 2007)

US East Coast (panels a-c)
China East Coast (panels d-f)

Significance: MODIS-derived chlorophyll-a data are significantly improved using the new atmospheric correction techniques for turbid coastal waters, e.g. Chesapeake & Hanzhou Bays.



Also see Wang, 2007; Wang et al., 2007 et al.

Expanded Future OC Applications & Operations

- Creation of habitat suitability maps - establishing boundaries of marine sanctuaries; managing commercially and recreationally important living marine resources; directing *in situ* sampling efforts, and locating targeted organisms such as Harmful Algal Blooms (HABs).

- Ecological prediction - forecasting year-class survival or growth rate of a species based on the timing of the spring phytoplankton bloom; initialising and validating results of numerical ecological models; improving ecological forecasts through data assimilation; and nowcasting or forecasting the fate and transport of pollutants and pathogens.

- Extended use for climate change and impact assessments - to better estimate the spatio-temporal distribution of the air-sea CO2 flux and ocean acidification, especially in the coastal zone where riverine inputs and productive filaments can degrade the accuracy of estimates based only on sea surface temperature and scatterometer-derived wind speeds; providing data on the long term changes of surface biomass in response to climate change and other human activities.

(IOCCG Report #7: Why Ocean Colour?)

Summary & Future Directions

- NOAA is presently utilizing NASA and commercial ocean color observations (MODIS-Aqua, SeaWiFS) on an operational basis supporting various user needs; MERIS chl-a data will become operational in early 2009 via NOAA CoastWatch.

- Continuation of the ongoing successful efforts to transition ocean color R&D capabilities into applications/operations is crucial to meet NOAA goals.

- Spatial resolution of 300 m or better, temporal revisits on the order of 1 to 3 hours, and enhanced spectral coverage/resolution are required for a variety of coastal applications.

- A constellation of geostationary ocean color imagers would be desirable to provide broader global coverage.

- Geostationary ocean color observations would be of great interest to NOAA scientists/users and would provide enhanced support for numerous research, applications, & operational activities.