Optimal Sampling Spatial Scales in Coastal Waters: Considerations for GEO-Cape Mission Requirements

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Overview

- Consideration of relationships between key processes and their spatial scales in coastal waters
  - Classical studies of spatial scaling in coastal biological properties
    - Issues of ecological level (organization, trophic structure, landscape, canopy level, etc.) versus ecological field (biomass, population number density)
    - Scaling relationships of physical and biological processes
  - Approaches for considering optimal resolution in spatial observations
    - Spatial autocorrelation (Mackas, Moline)
    - Fractal analysis (Lovejoy)
    - PCA (Bissett et al.)
- Case studies
  - Mississippi River Plume
  - Gulf of Mexico HABs
  - CDOM and DOC Coastal Gradients in East Coast Estuary
- Conclusions and recommendations

Classical studies of spatial scales

- Classical work examining spatial structure in biological distributions, especially phytoplankton, reported strong coherence between physical and biological phenomena
  - Denman
  - Dickey
  - Steele
  - Powell and Steele
- However, a decoupling can occur between turbulence and biological fields attributable to ecological processes

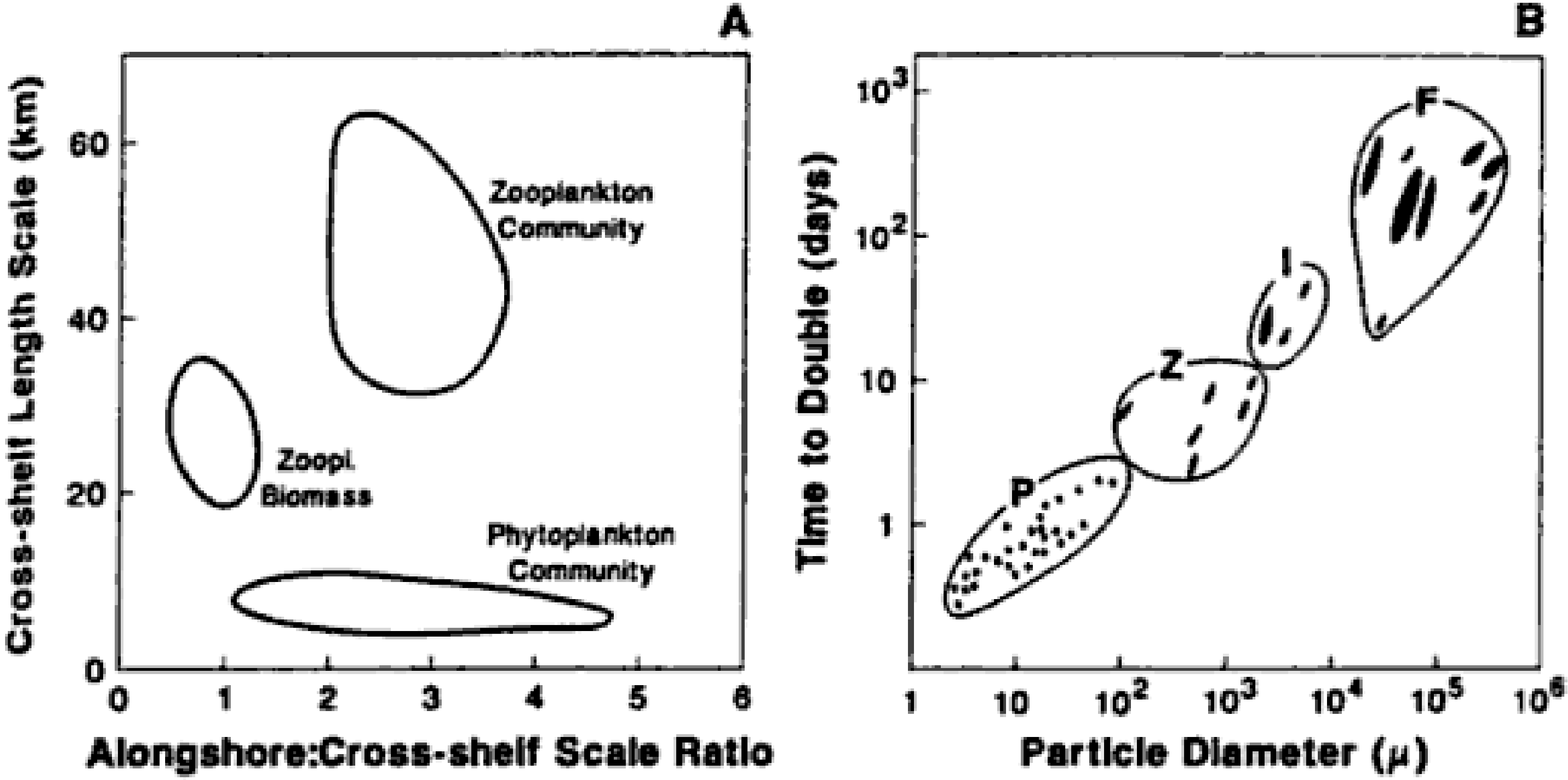


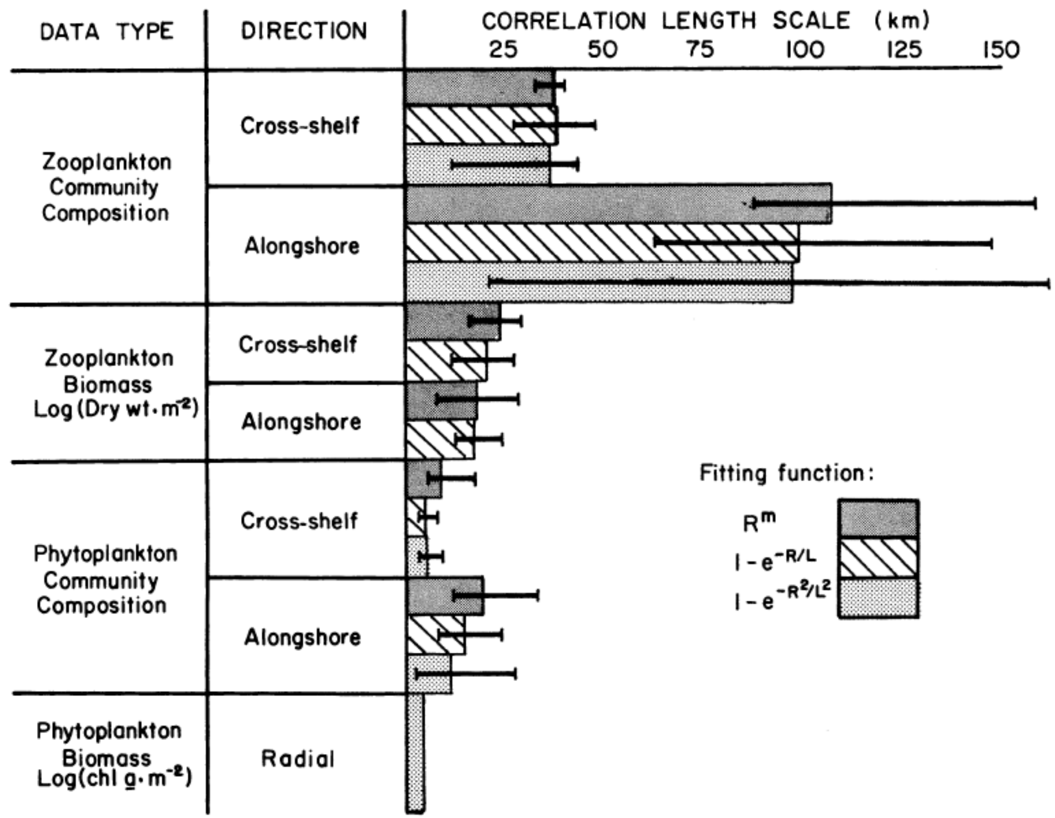
Figure 8-2. (A) 75% confidence regions for the scales of variability of zooplankton biomass, zooplankton community composition, and phytoplankton community composition along the coast of British Columbia. (After Mackas 1984.) (B) Doubling times versus particle size distributions for phytoplankton (P), zooplankton (Z), invertebrate carnivores or omnivores (I), and fish (F). (After Sheldon et al. 1972; and Steele, 1978, "Some Comments on Plankton Patches," in J. H. Steele, (ed.), *Spatial Patterns in Plankton Communities*, Plenum Press, New York. By permission of Plenum Press.)

From *Ecological Time-Series*, Powell and Steele, 1995

Correlation Length Scales for Different Biological Properties

Results from Mackas et al. (1984) based on Optical Plankton Counter and fluorescence surveys.

Phytoplankton biomass scales on the order of 4-7 km, however, sampling resolution was only ~1km!



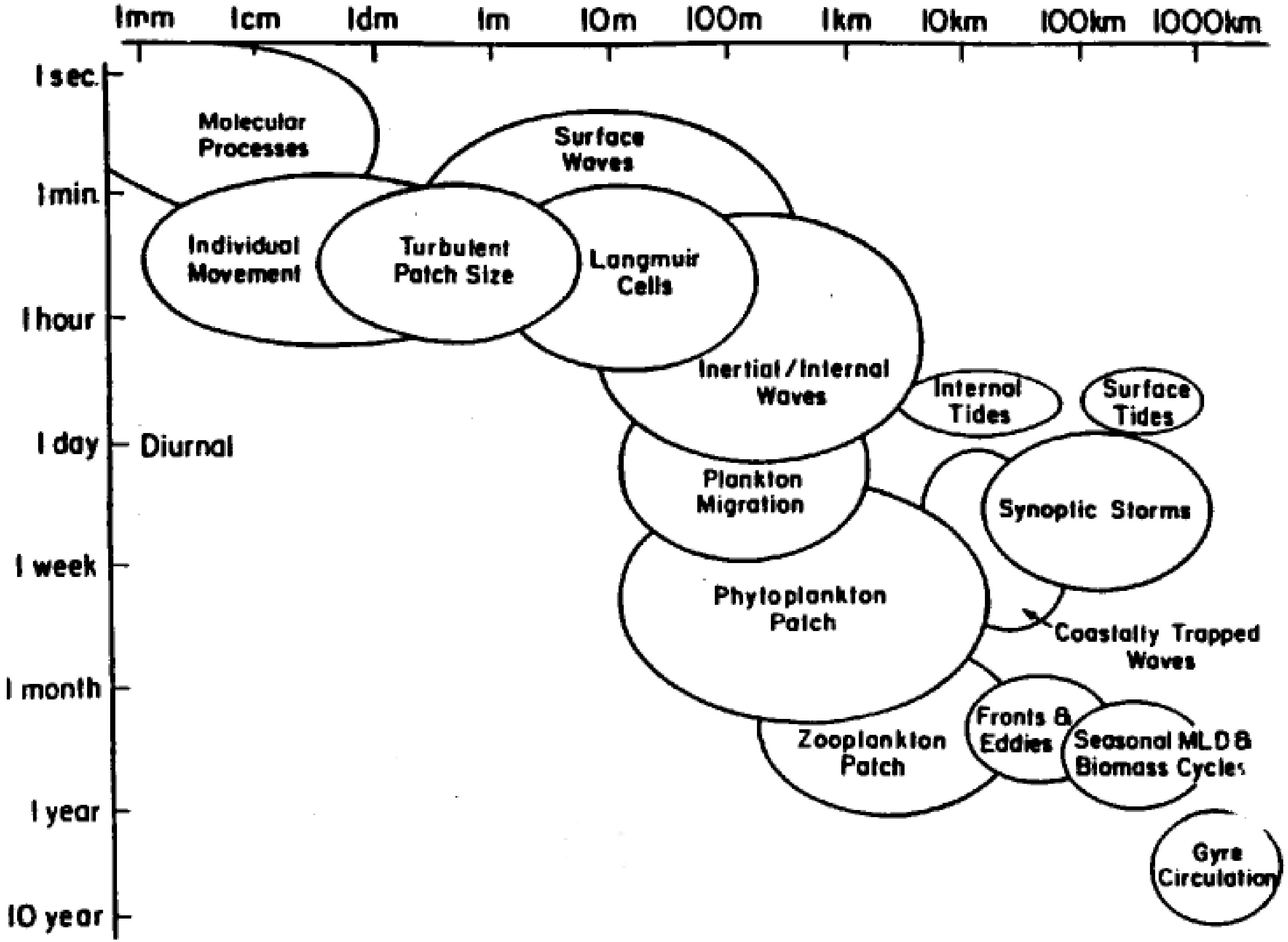
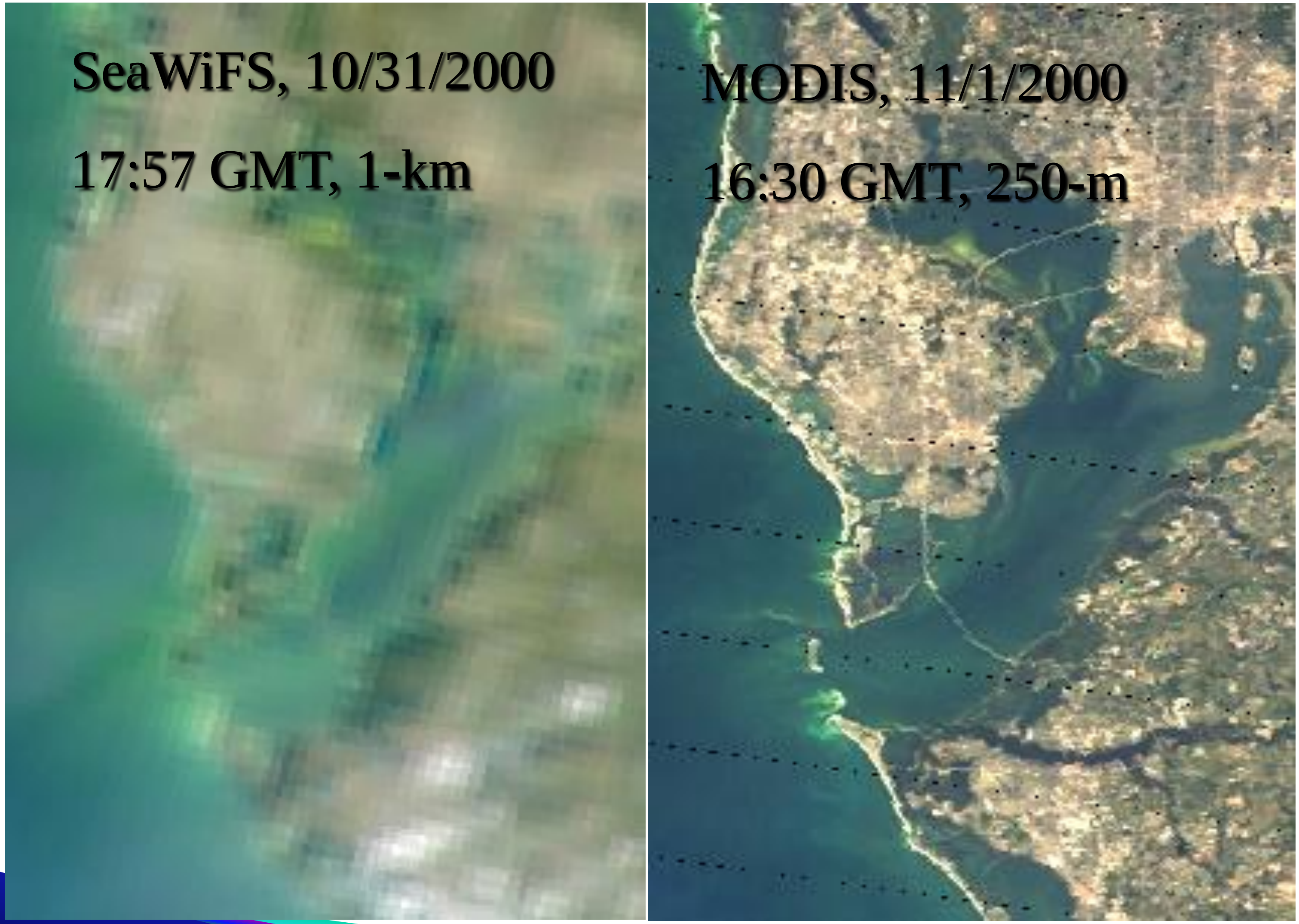


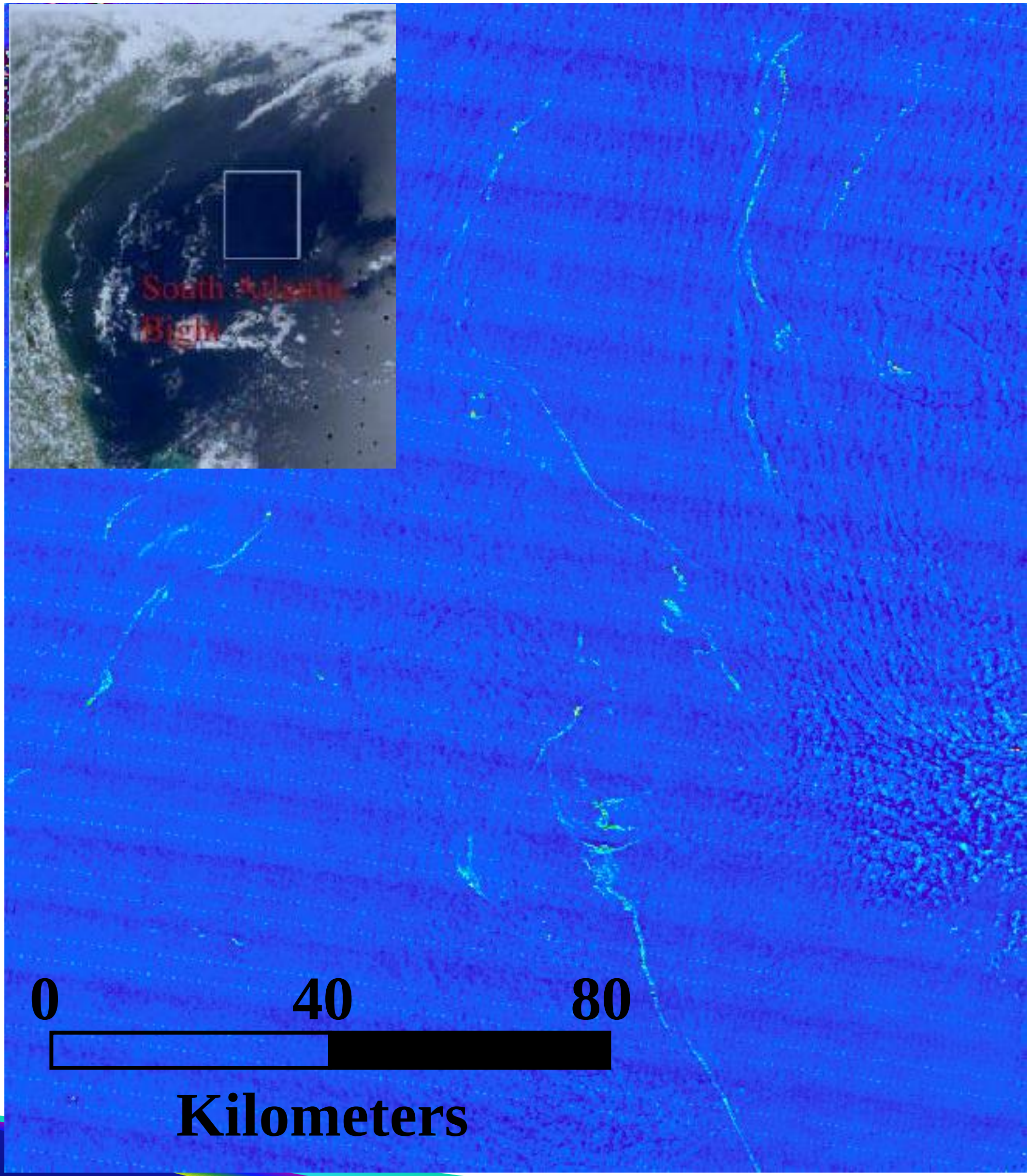
Fig. 1. Relevant time and space scales characteristic of biological and physical processes in the upper ocean (Dickey, 1991).

Spatial Resolution: Tampa Bay viewed by SeaWiFS and MODIS



Chuanmin Hu, USF

Surface Floating *Sargassum*



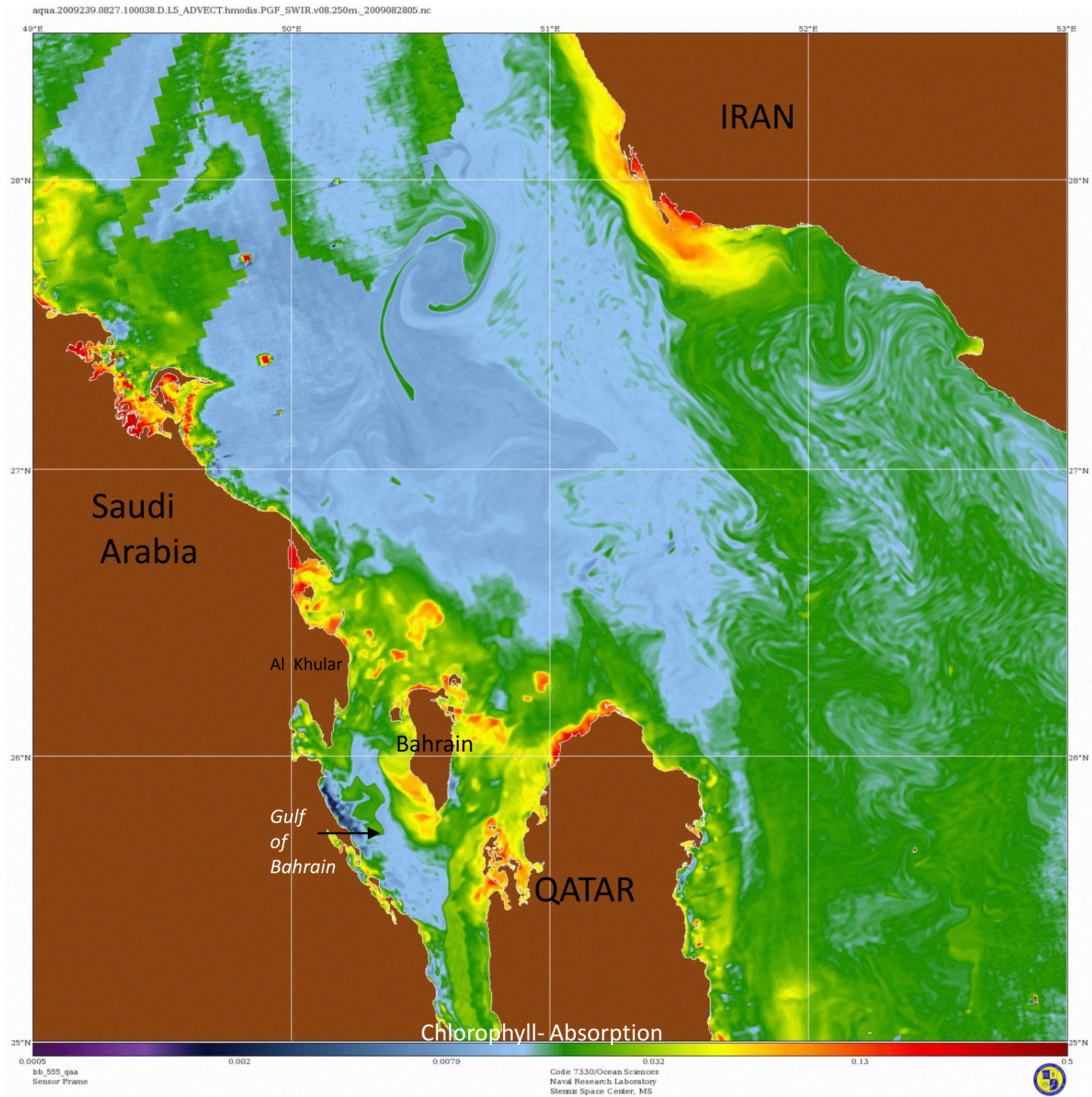
Optical Forecast – "Surface Only"

Day 239
Aug 27, 2009

MODIS – AQUA
250 m
Hourly updates
48 hour
0000 – 0048

RELO – NCOM
High resolution

250 m

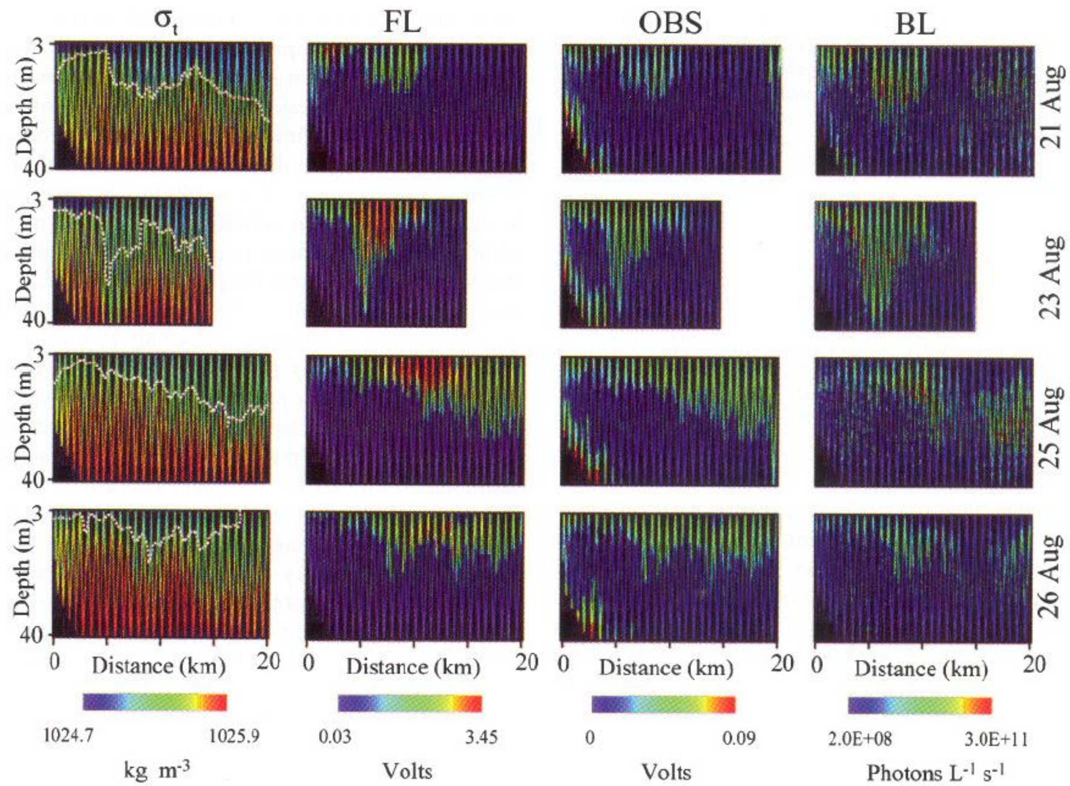


Horizontal length scales from Autonomous Underwater Vehicle Observations

Results from Moline et al. (2005).

Data were fit to a Generalized Additive Model and smoothed using a loess smoothing function.

Sensors included CTD, optical backscatter (OBS), chlorophyll fluorescence (FL) , and bioluminescence (BL).



Horizontal length scales from Autonomous Underwater Vehicle Observations

Moline et al. (2005).

Lengths scales based on variogram analyses ranged from the 50-300 m.

TABLE 2. Horizontal length scales calculated for density (σ_t), optical backscatter (OBS), fluorescence (FL), and bioluminescence (BL). Values are shown in meters for the upper and lower layers of the water column separated by the maximum density gradient as shown in Fig. 7.

Date	σ_t	OBS	FL	BL
Upper layer				
21 Aug	48	209	367	201
23 Aug	69	89	99	55
25 Aug	48	176	153	103
26 Aug	28	124	64	98
Lower layer				
21 Aug	204	155	274	166
23 Aug	154	126	218	76
25 Aug	193	230	181	69
26 Aug	230	189	184	75

Fractal Analysis

- Fractal analyses of chlorophyll fluorescence reveal break in scaling at ~100 m (characteristic planktoscale) (Lovejoy et al., 2001)
- Variability at all scales (Lovejoy et al., 2000)
- Remote sensing algorithms are strongly scale/resolution dependent

Bissett et al.: Approach

- Hyperspectral dataset
  - PHILLS 2 during the 2001 HyCODE LEO-15
  - Spectral data at 9 m resolution
  - Length scales determined by PCA analysis of spectral properties and comparative analysis of relationships of covariance to random noise levels

Bissett

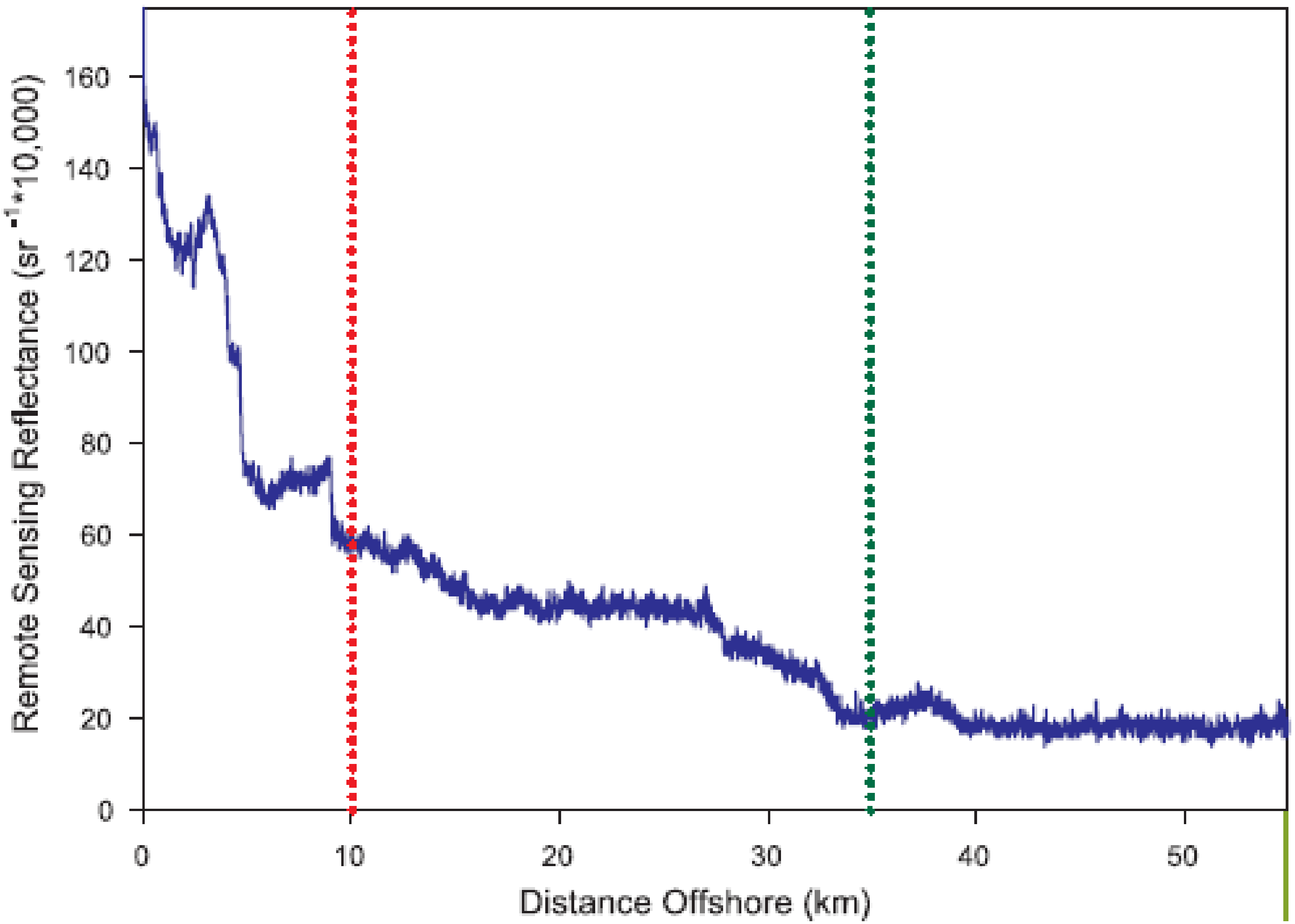


Figure 3. The Simulated SeaWiFS Band 5 R_{rs} values (sr^{-1}*10,000) along the sampling line transect as shown in Figure 1. The vertical green and red lines denote the respective locations of offshore and inshore regions of interest from which the variance threshold for the GSD analysis was determined.

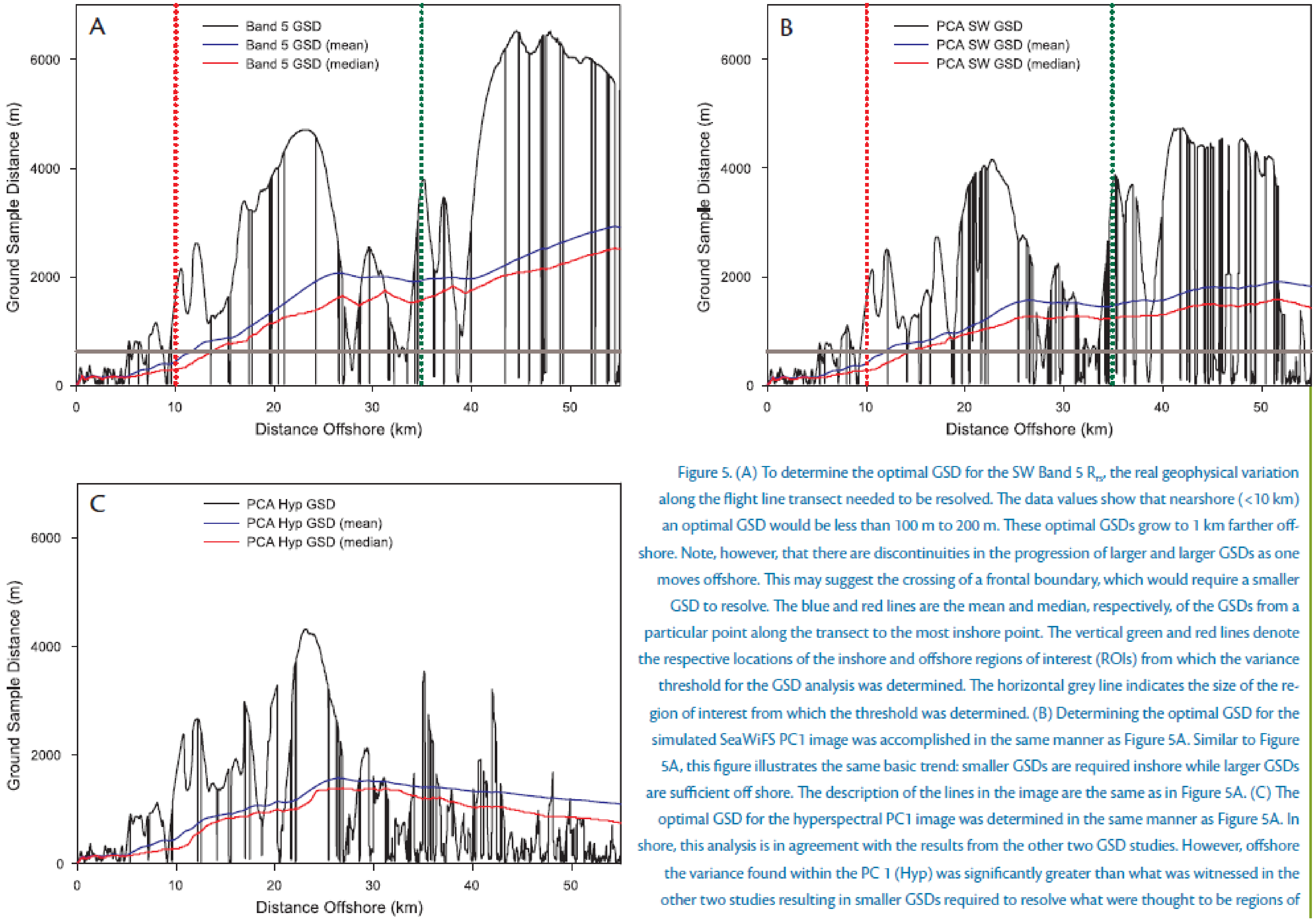


Figure 5. (A) To determine the optimal GSD for the SW Band 5 R_{rs}, the real geophysical variation along the flight line transect needed to be resolved. The data values show that nearshore (<10 km) an optimal GSD would be less than 100 m to 200 m. These optimal GSDs grow to 1 km farther offshore. Note, however, that there are discontinuities in the progression of larger and larger GSDs as one moves offshore. This may suggest the crossing of a frontal boundary, which would require a smaller GSD to resolve. The blue and red lines are the mean and median, respectively, of the GSDs from a particular point along the transect to the most inshore point. The vertical green and red lines denote the respective locations of the inshore and offshore regions of interest (ROIs) from which the variance threshold for the GSD analysis was determined. The horizontal grey line indicates the size of the region of interest from which the threshold was determined. (B) Determining the optimal GSD for the simulated SeaWiFS PC1 image was accomplished in the same manner as Figure 5A. Similar to Figure 5A, this figure illustrates the same basic trend: smaller GSDs are required inshore while larger GSDs are sufficient off shore. The description of the lines in the image are the same as in Figure 5A. (C) The optimal GSD for the hyperspectral PC1 image was determined in the same manner as Figure 5A. In shore, this analysis is in agreement with the results from the other two GSD studies. However, offshore the variance found within the PC 1 (Hyp) was significantly greater than what was witnessed in the other two studies resulting in smaller GSDs required to resolve what were thought to be regions of

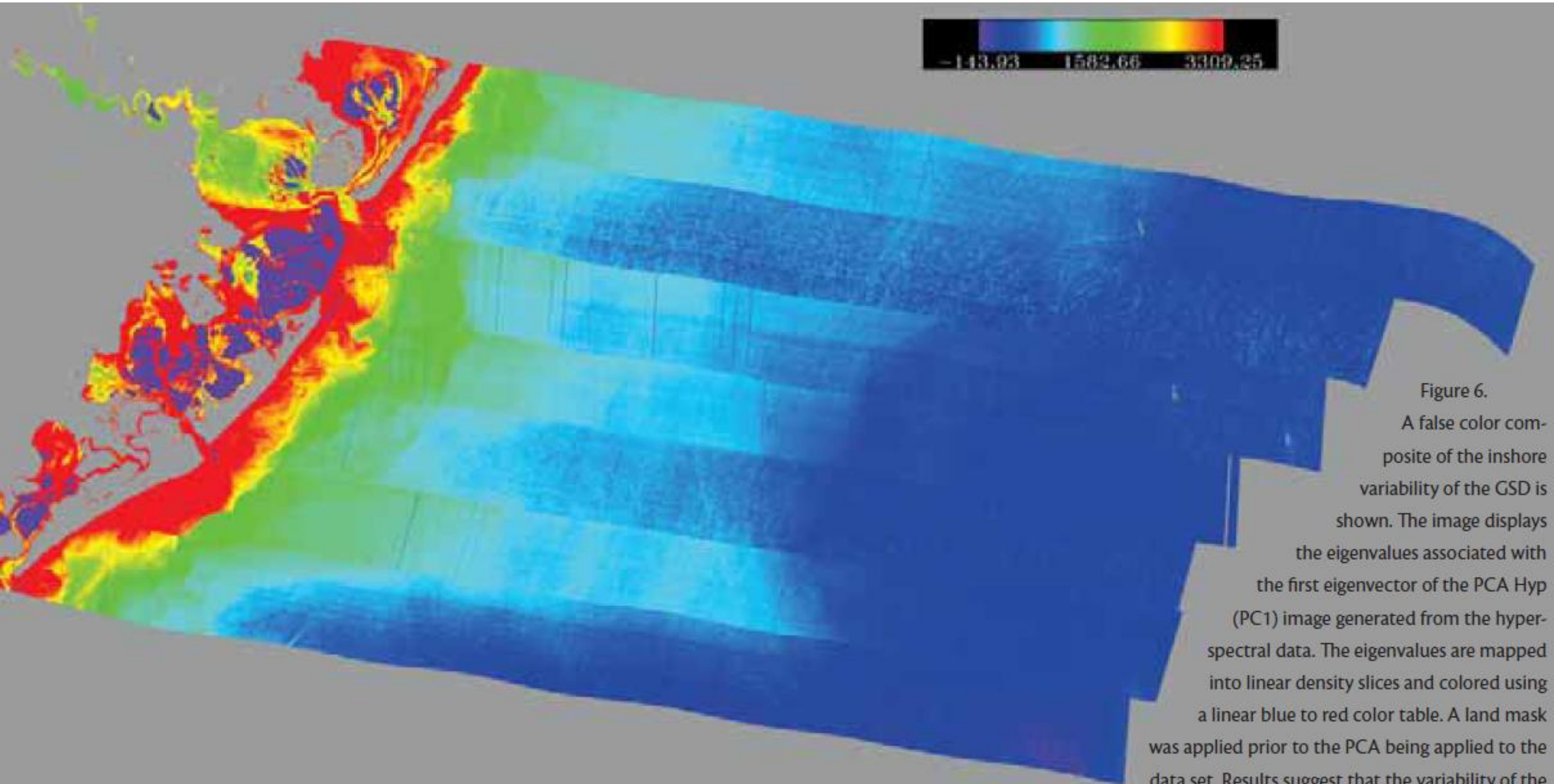


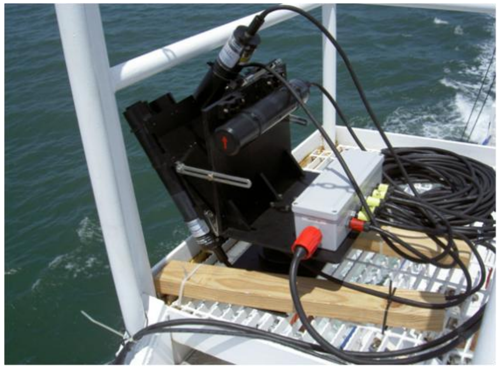
Figure 6.
A false color composite of the inshore variability of the GSD is shown. The image displays the eigenvalues associated with the first eigenvector of the PCA Hyp (PC1) image generated from the hyperspectral data. The eigenvalues are mapped into linear density slices and colored using a linear blue to red color table. A land mask was applied prior to the PCA being applied to the data set. Results suggest that the variability of the water color is greater as one approaches the shore.

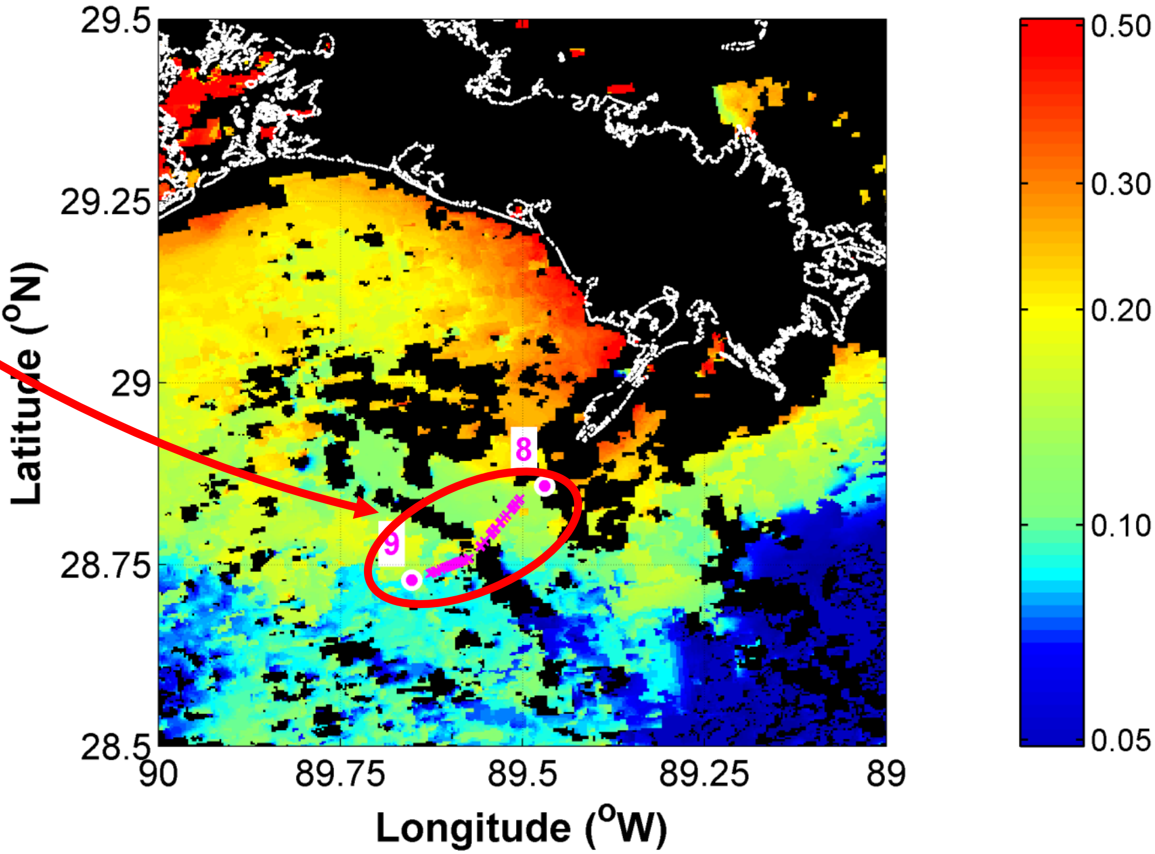
Bissett et al.: Conclusions

- Ground Sample Distance of 50-200 m between 1-10 km of shore
- Smaller scales may be needed within 1 km
- Offshore there is a difference in optimal GSD depending on whether multispectral or hyperspectral dataset is used
  - Multispectral suggests 1 km may be adequate
  - Hyperspectral suggests higher resolution may be necessary (features not apparent in multispectral)

Underway Hyperspectral Radiometry Observations in the Gulf of Mexico

Transect from near the mouth of the Mississippi River out to shelf water during October 2005

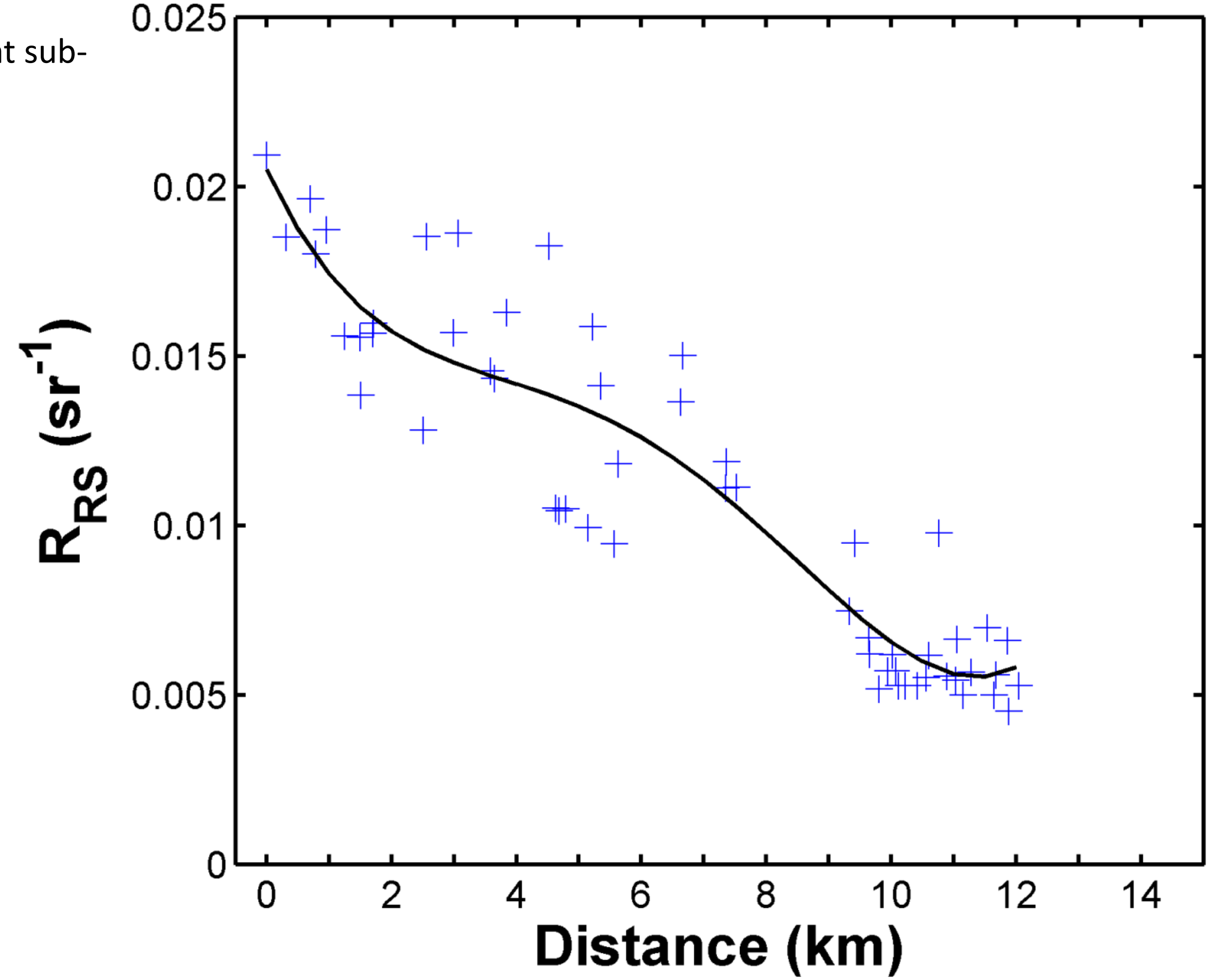




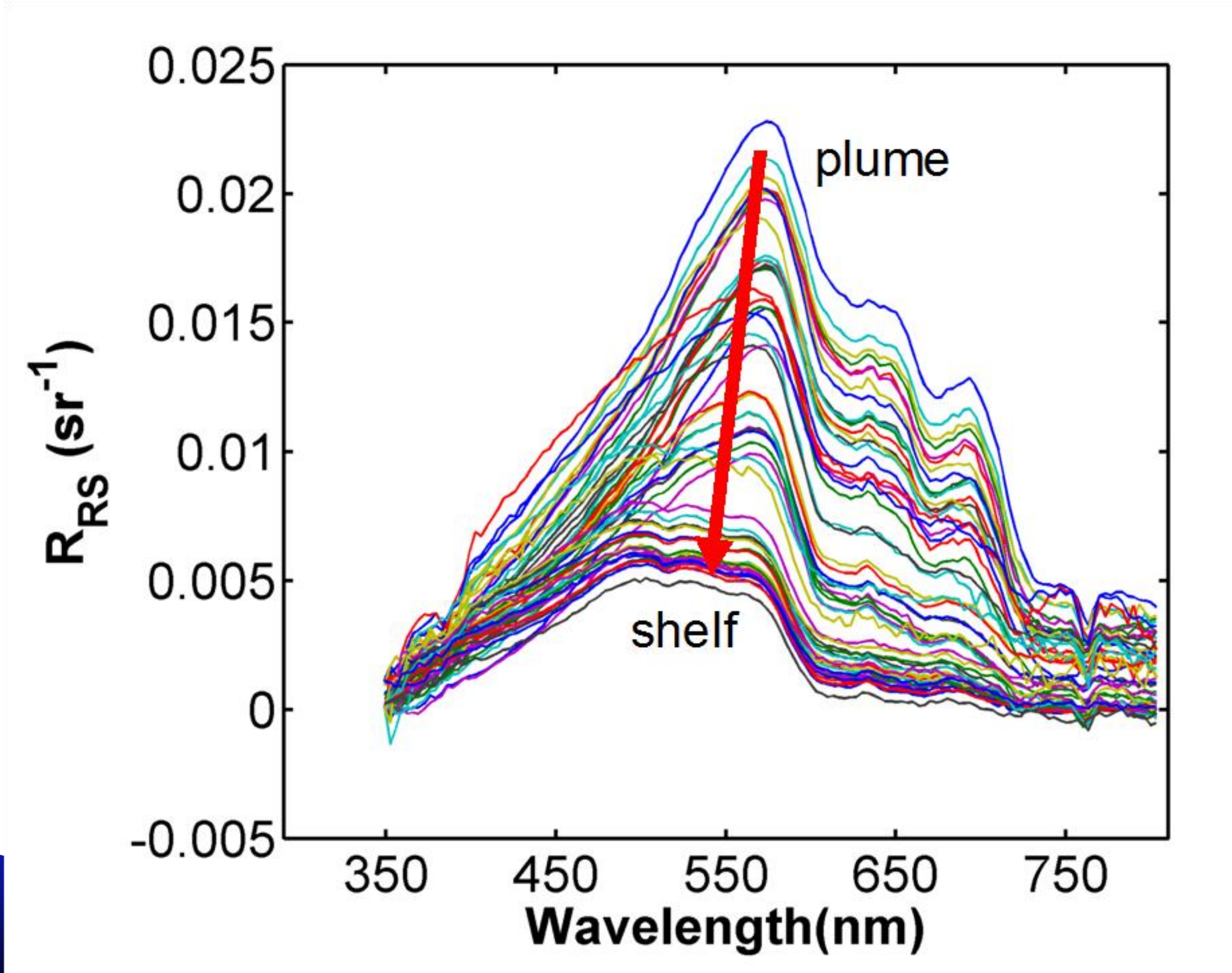
Lohrenz et al., 2009, IEEE Proceedings

Remote Sensing Reflectance at 550 nm Along Transect

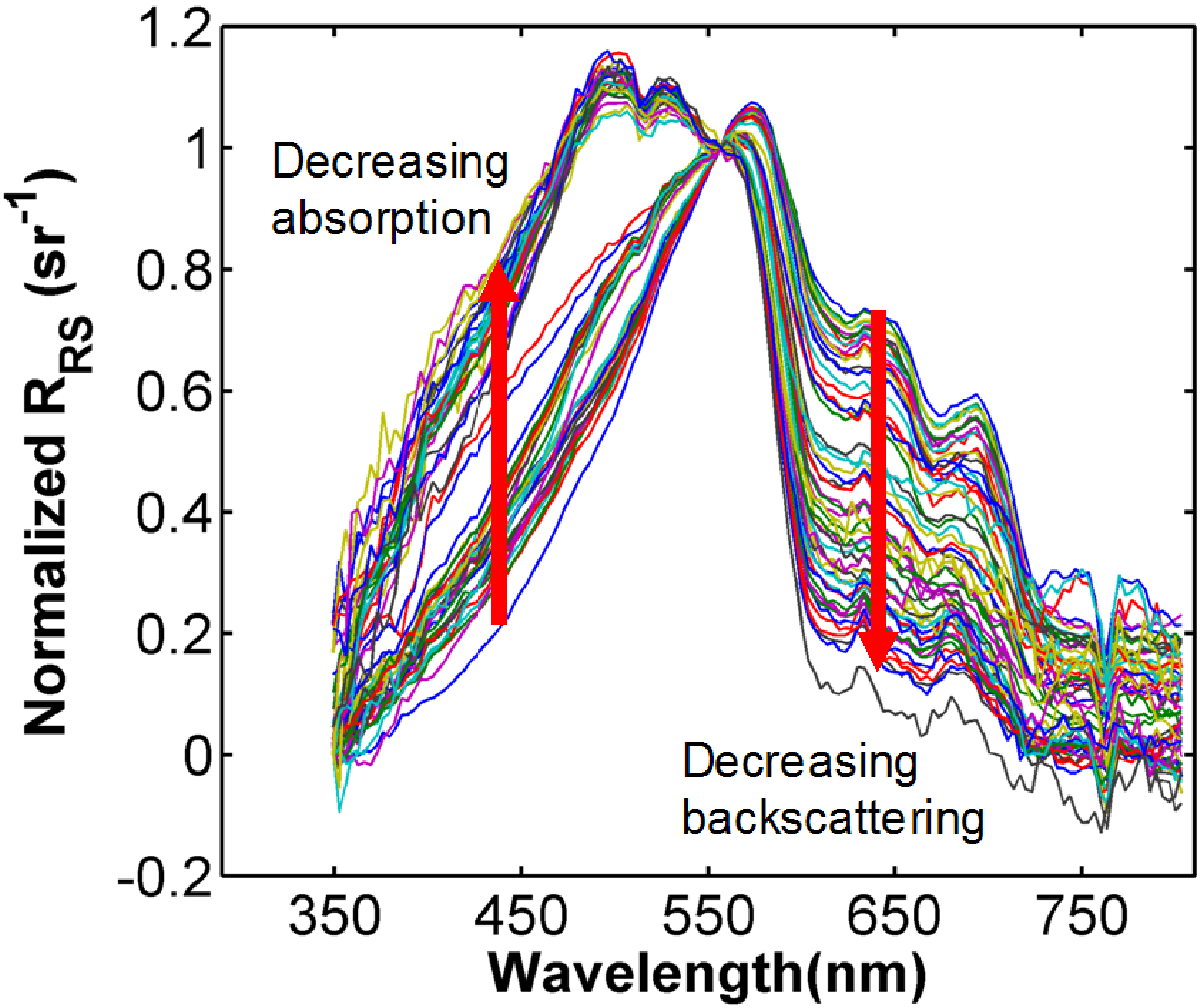
Course sampling resolution , but significant variability is evident at sub-kilometer scales.

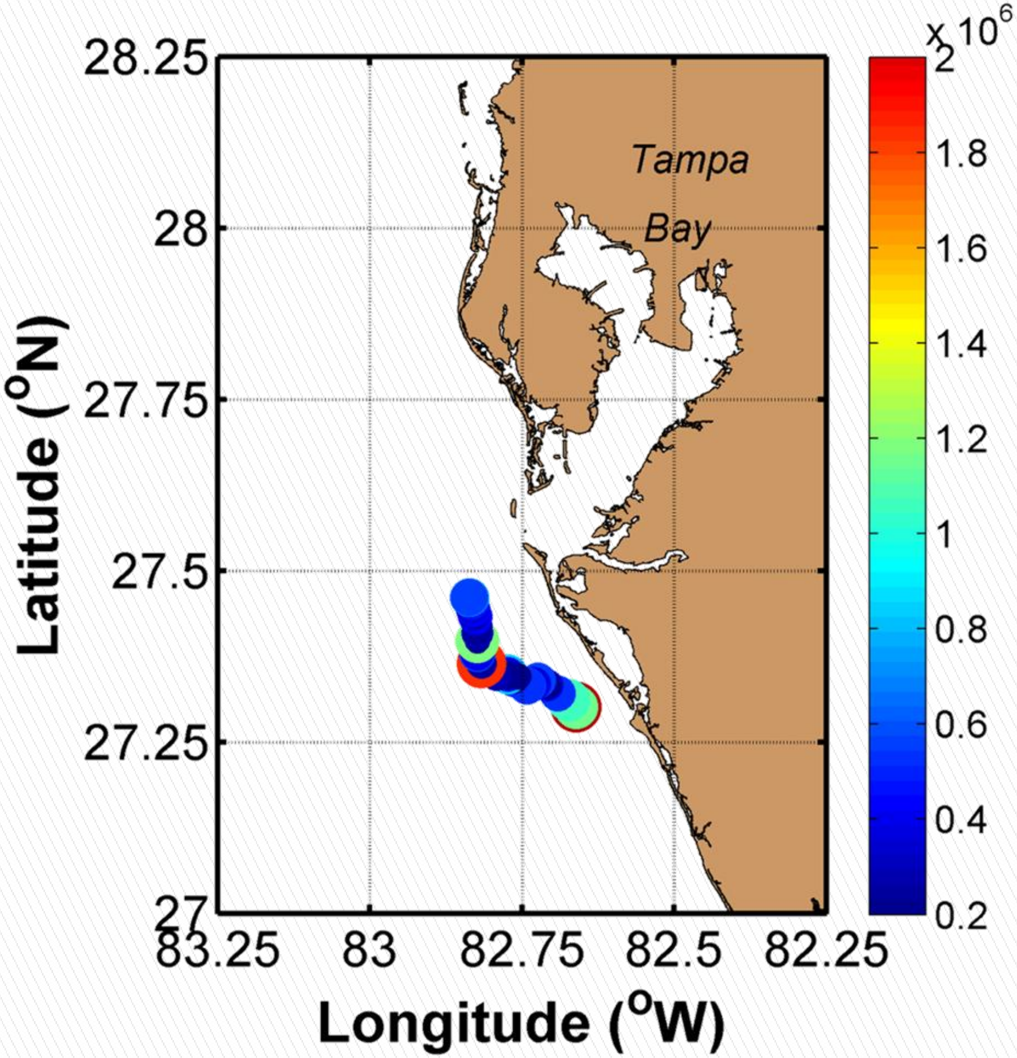


Plume-shelf transition in reflectance signatures



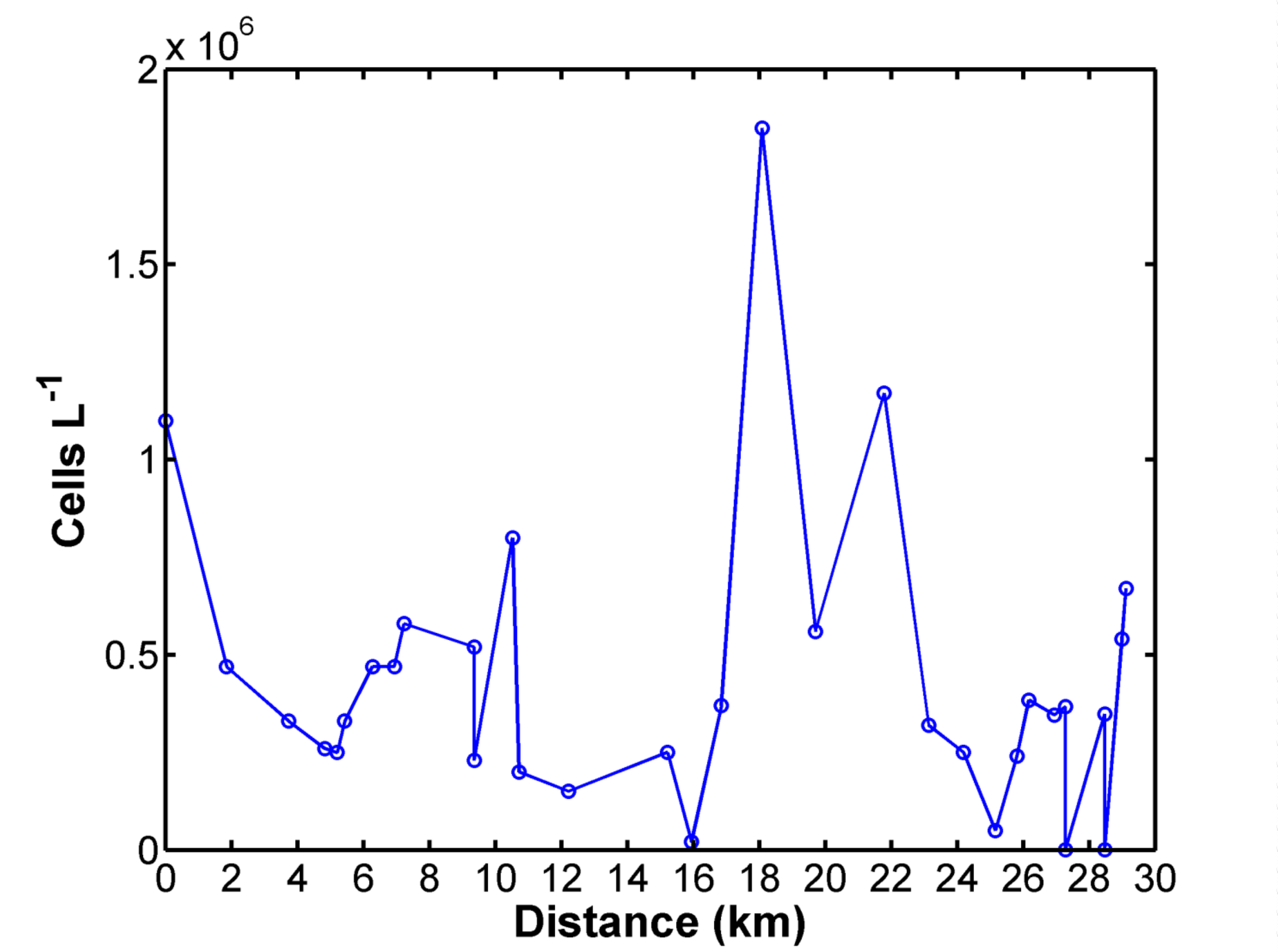
Normalization to 555 nm reveals distinct water mass types





Karenia brevis concentrations (cells per during October 2001 off Tampa Bay tracked using Lagrangian drifter

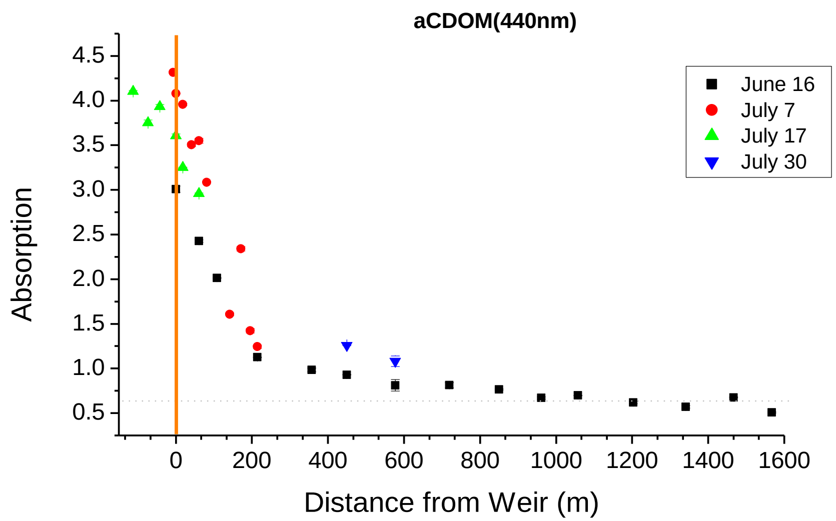
MODIS Aqua true color image from 24 October 2001.

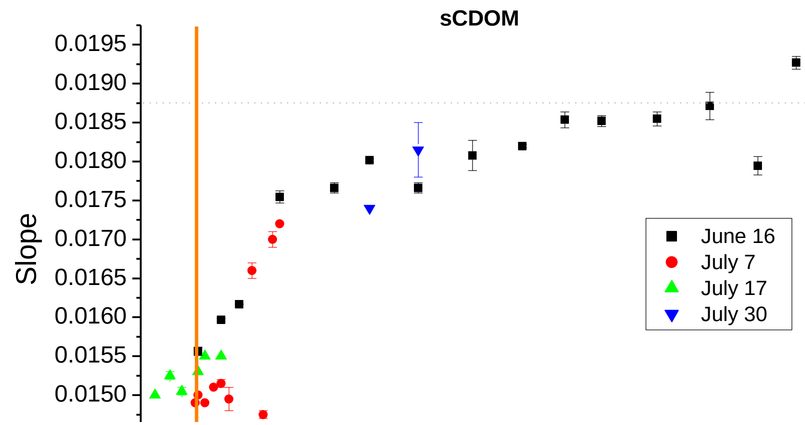


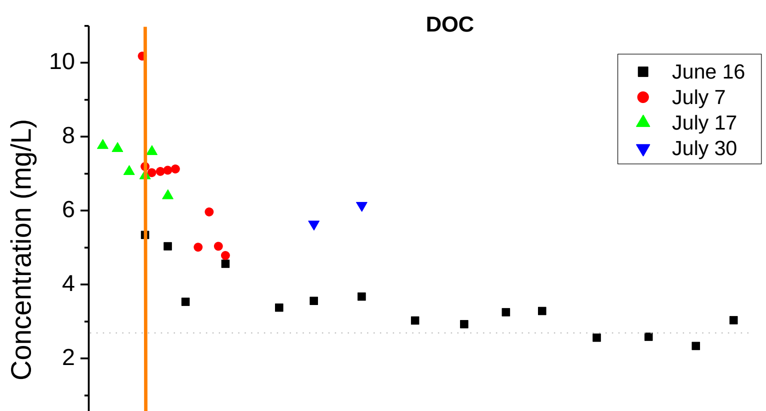
K. brevis cell counts versus distance

Concentrations along drift track during October 2001 show sub-kilometer scale variability

Diurnal and Spatial Variability in DOC, Chl-a, and CDOM in coastal waters







Spatial Variability in CDOM and DOC at the Kirkpatrick Marsh

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Conclusions

- Different analyses point towards optimal horizontal sampling scales of 50 – 300 m in coastal waters
- Variability occurs at all scales
- Scale dependence of algorithms requires consideration with the advent of improved resolution sensors