Recent Progress in Aircraft and Satellite Remote Sensing of Chesapeake Bay

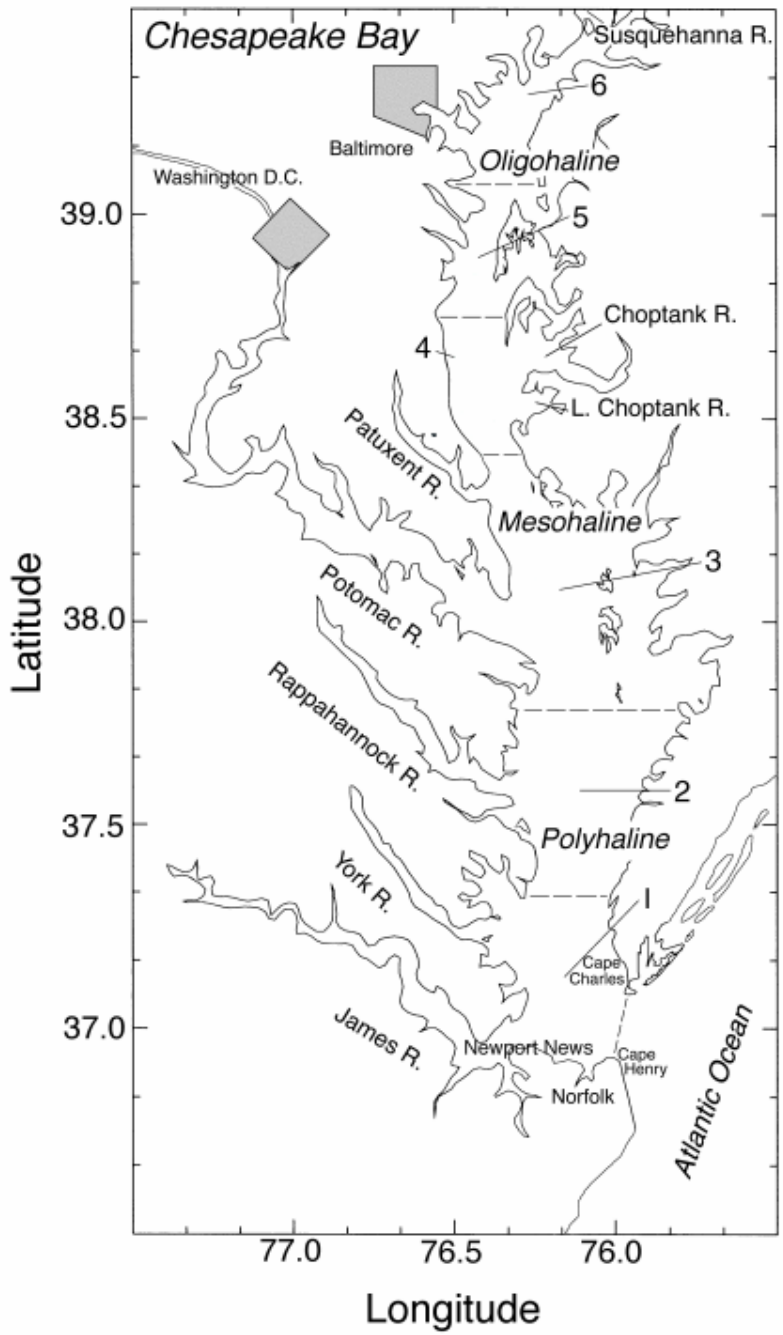
Horn Point Laboratory
and Maryland Sea Grant
University of Maryland
Center for Environmental Science

Integration and Application Network (IAN)
7 October 2004
Annapolis, Maryland

IAN Seminar - 7 Oct 2004

- Phytoplankton dynamics in Chesapeake Bay: background, historical perspective;
- Aircraft remote sensing of ocean color in Chesapeake Bay, 1989-2004 (http://www.cbrsp.org);
- Models of PP, derived products from ODAS/SAS II, III;
- Satellite missions (CZCS to SeaWiFS to MODIS): progress in retrieval of key properties in optically complex waters;
- Prospects for the future.

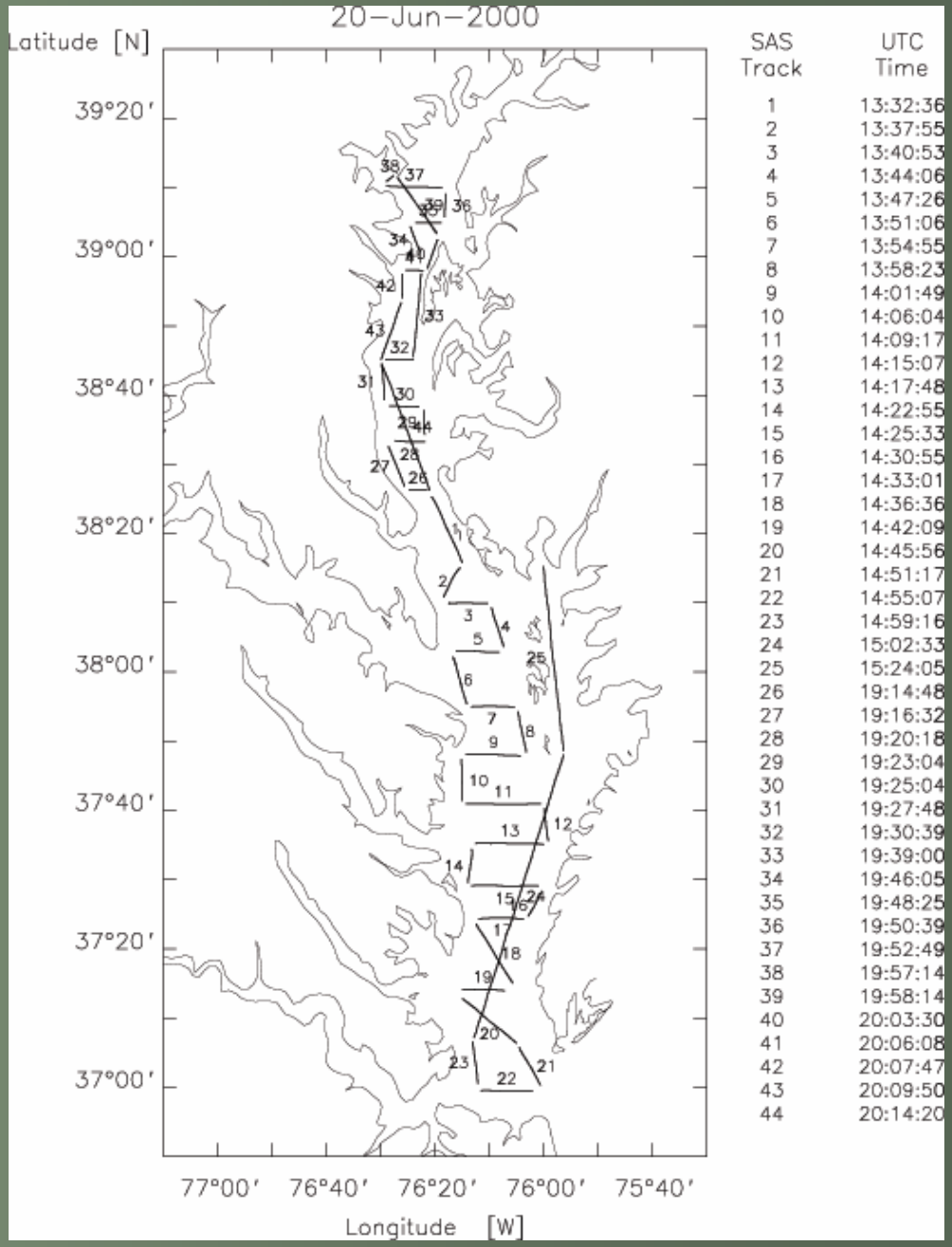
- Main stem is an estuary of the Susquehanna River;
- N-S gradients of salinity, turbidity, nutrients;
- Highest phytoplankton biomass in spring, mostly diatoms;
- Highest rates of primary productivity in summer, mixed floral composition;
- Strong interannual variability of biomass and primary productivity.



Oligohaline

Regions 5, 6 -
high turbidity, high nutrients

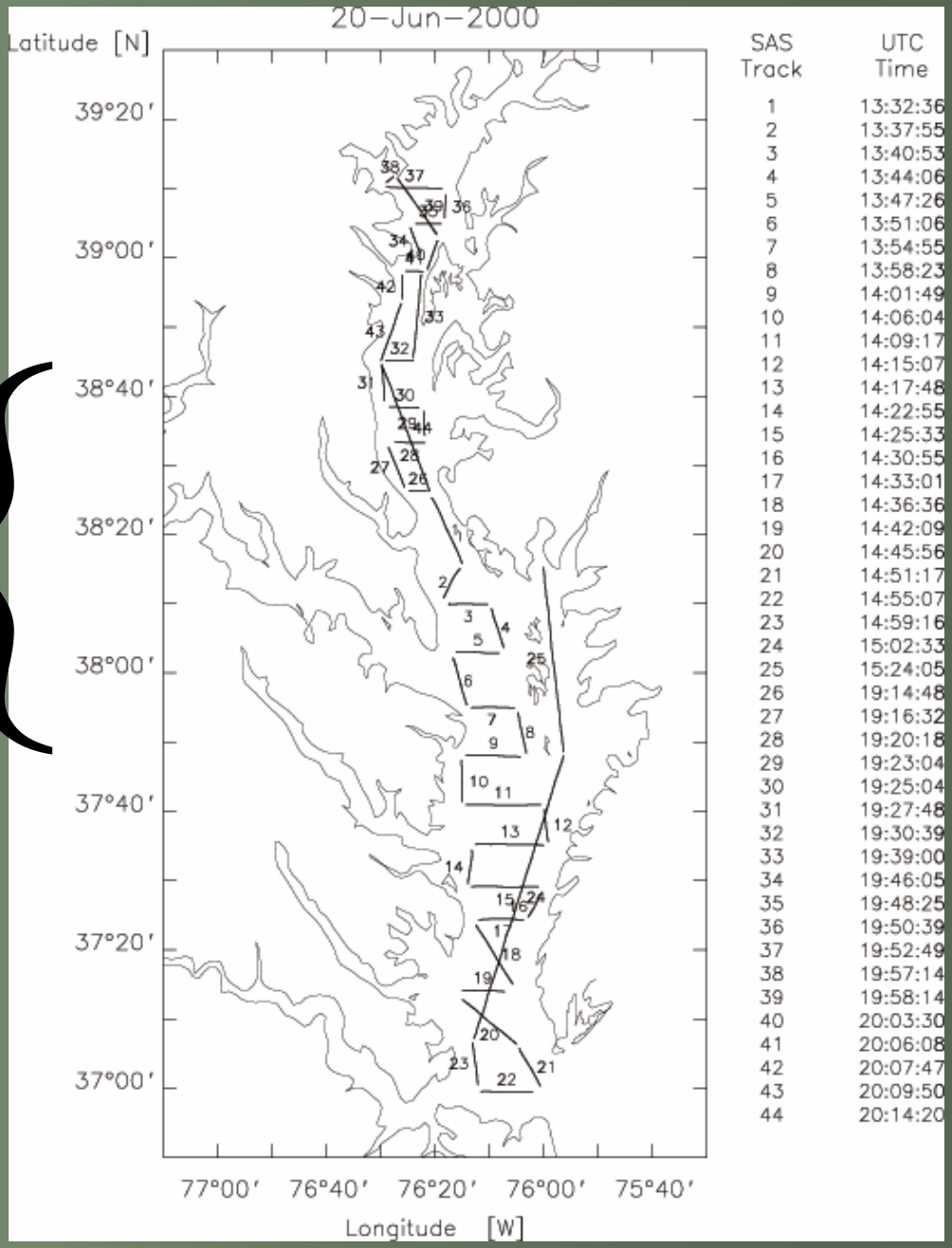
Light-limited in spring, Periodic dinoflagellate blooms in spring and summer



Regions 3, 4 -
lower turbidity,
high nutrients in spring,
N-limited in summer

Mesohaline

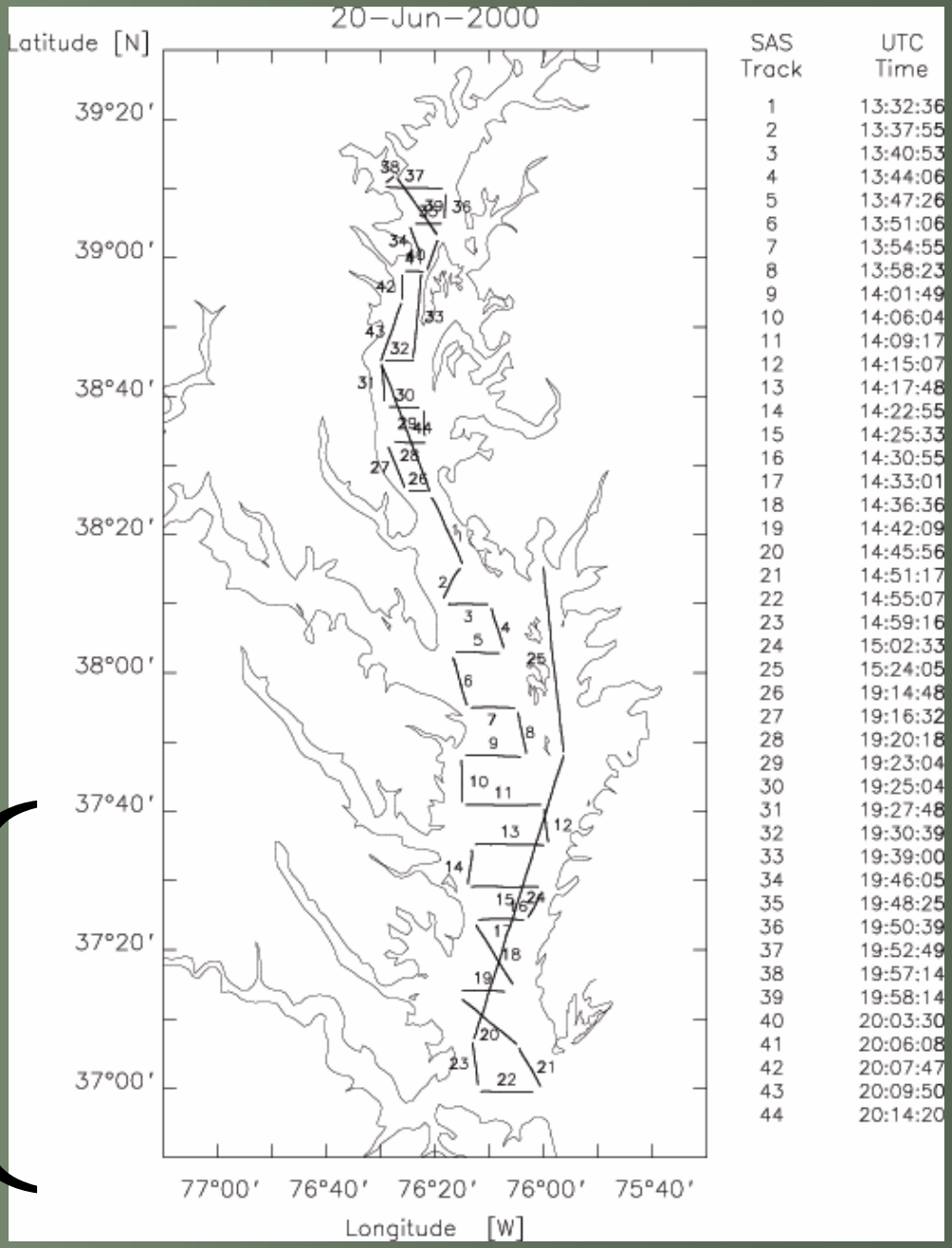
Large diatom blooms
in spring, highly variable
phytoplankton biomass
in summer



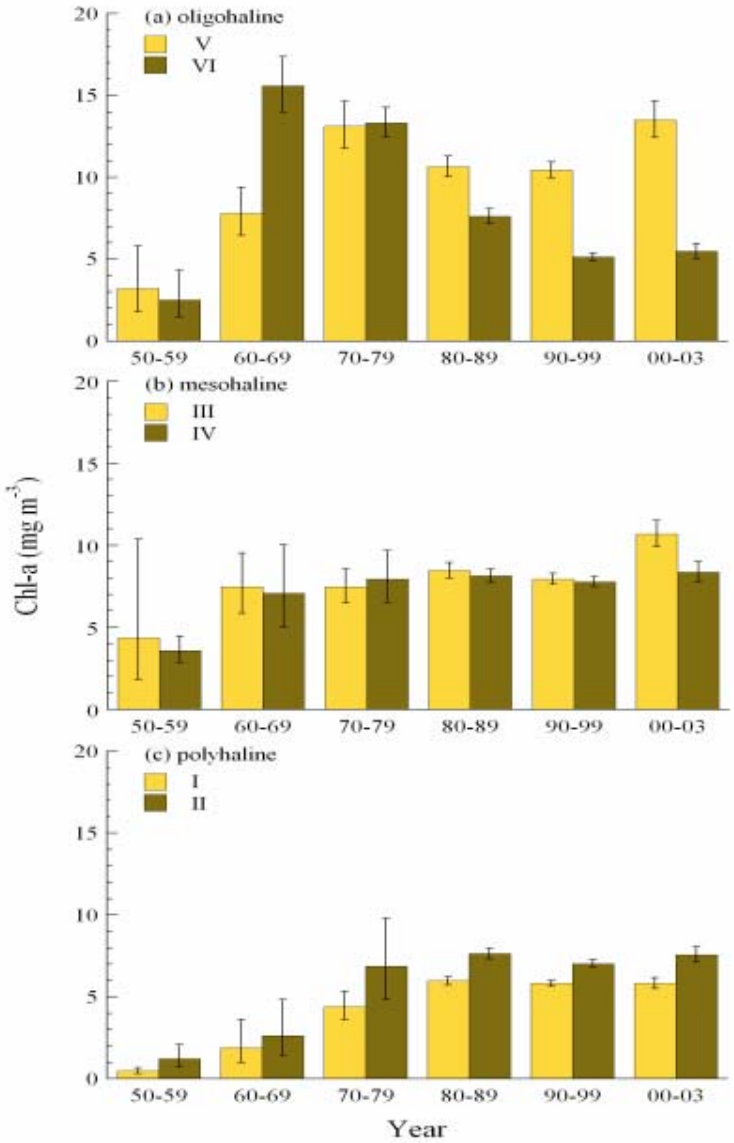
Regions 1, 2 -
lower turbidity (coastal),
high nutrients in spring,
N-limited in late-spring
and summer

Large diatom blooms
in spring for years of
High freshwater flow,
highly variable phyto-
plankton biomass
in summer

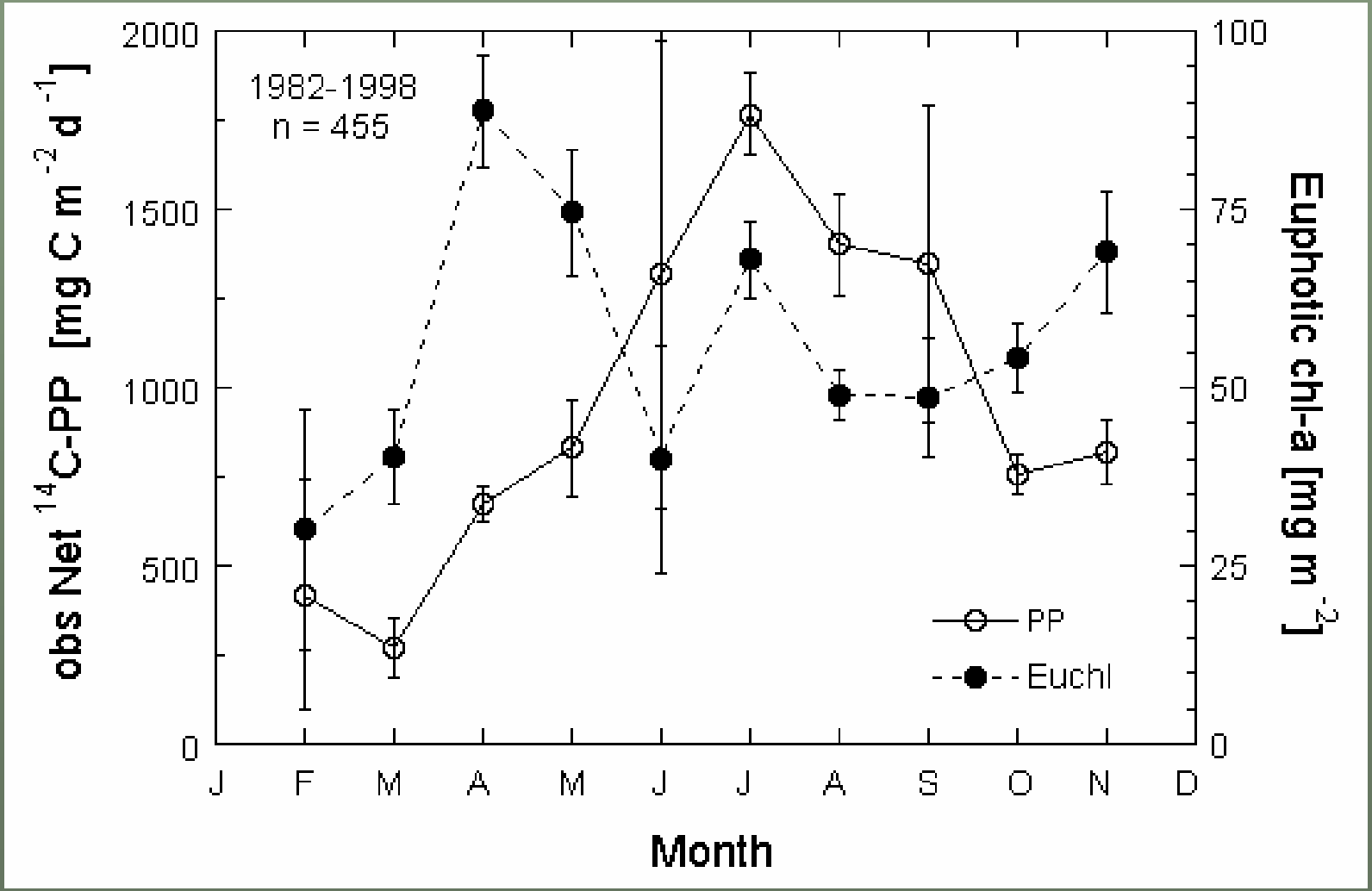
Polyhaline



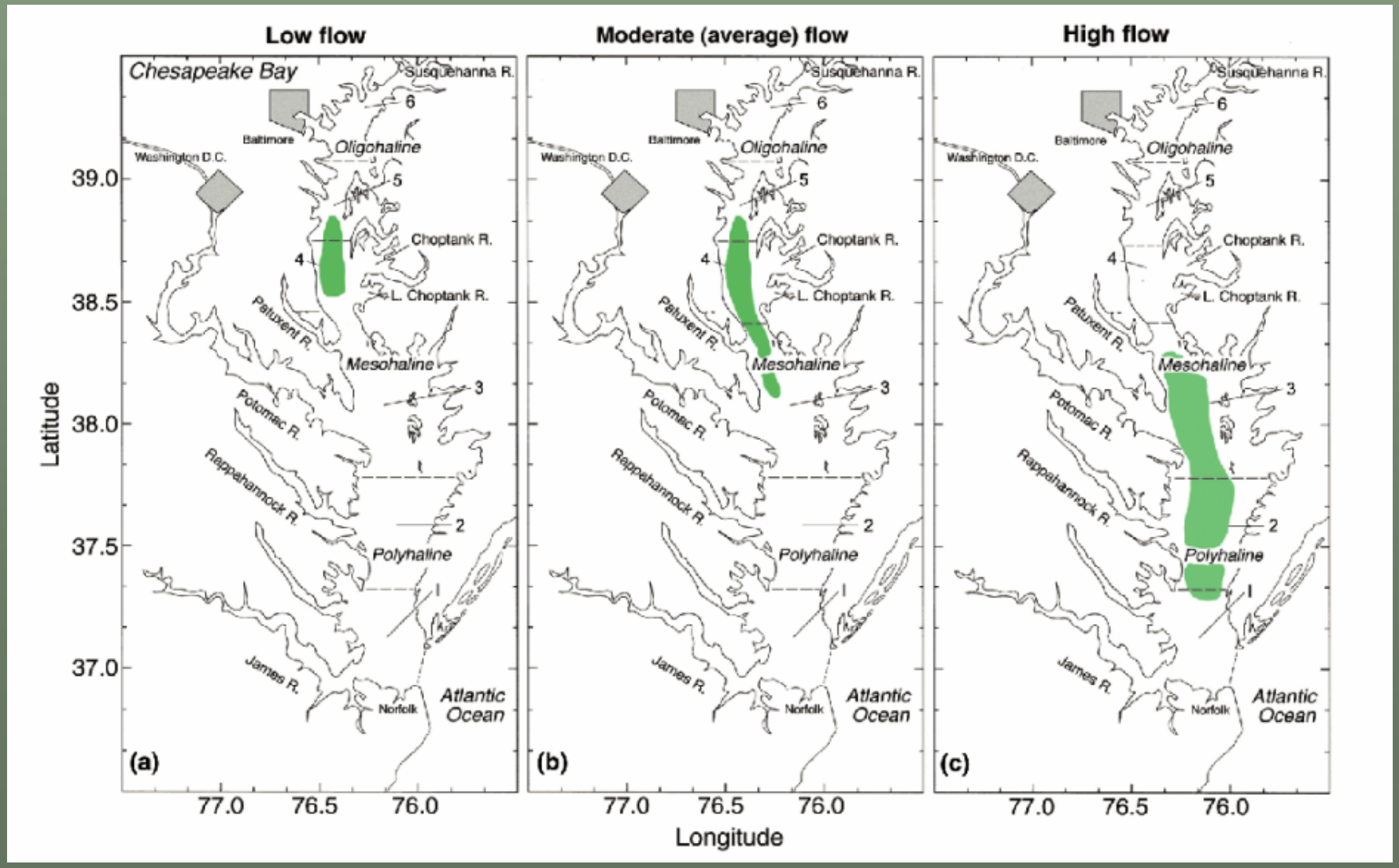
Historical changes of annual, average chl-a by region since the 1950s

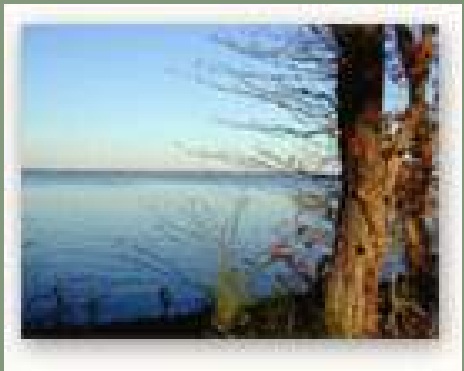


Annual cycles of net PP and euphotic-layer chl-a from long-term shipboard observations



Effect of freshwater flow from the Susquehanna R. on the magnitude and position of the spring diatom bloom





Chesapeake Bay Remote Sensing Program

http://www.cbrsp.org

History of Program

- Started in 1988 with NASA Ocean Data Acquisition System (ODAS) on test flights in collaboration with NASA, NOAA and CBP;

- Spring-summer flight series began in 1989; spring-fall flight series began in 1990 and now extends through October, 2004;

- Initial goal was to better define spatial and temporal extent of the winter-spring diatom and summer dinoflagellate blooms;

- Developed regional algorithms using a combination of aircraft and shipboard data to retrieve surface chlorophyll (chl-a), temperature (SST) and integrated, water-column chl-a as a measure of phytoplankton biomass;

- Introduced SAS II in 1995 and SAS III in 1997, replacing ODAS with more capable instruments (more bands in UV, VIS, NIR)

History of Program, cont'd

- Web page (*http://www.cbrsp.org*) launched in spring 2001 containing complete imagery from ODAS, SAS II and SAS III flights on the main stem Bay for 1989-2004, the Choptank and Patuxent Rivers in 1999-2001, and these same rivers in a new series for 2004-2005.

The "Beaver"

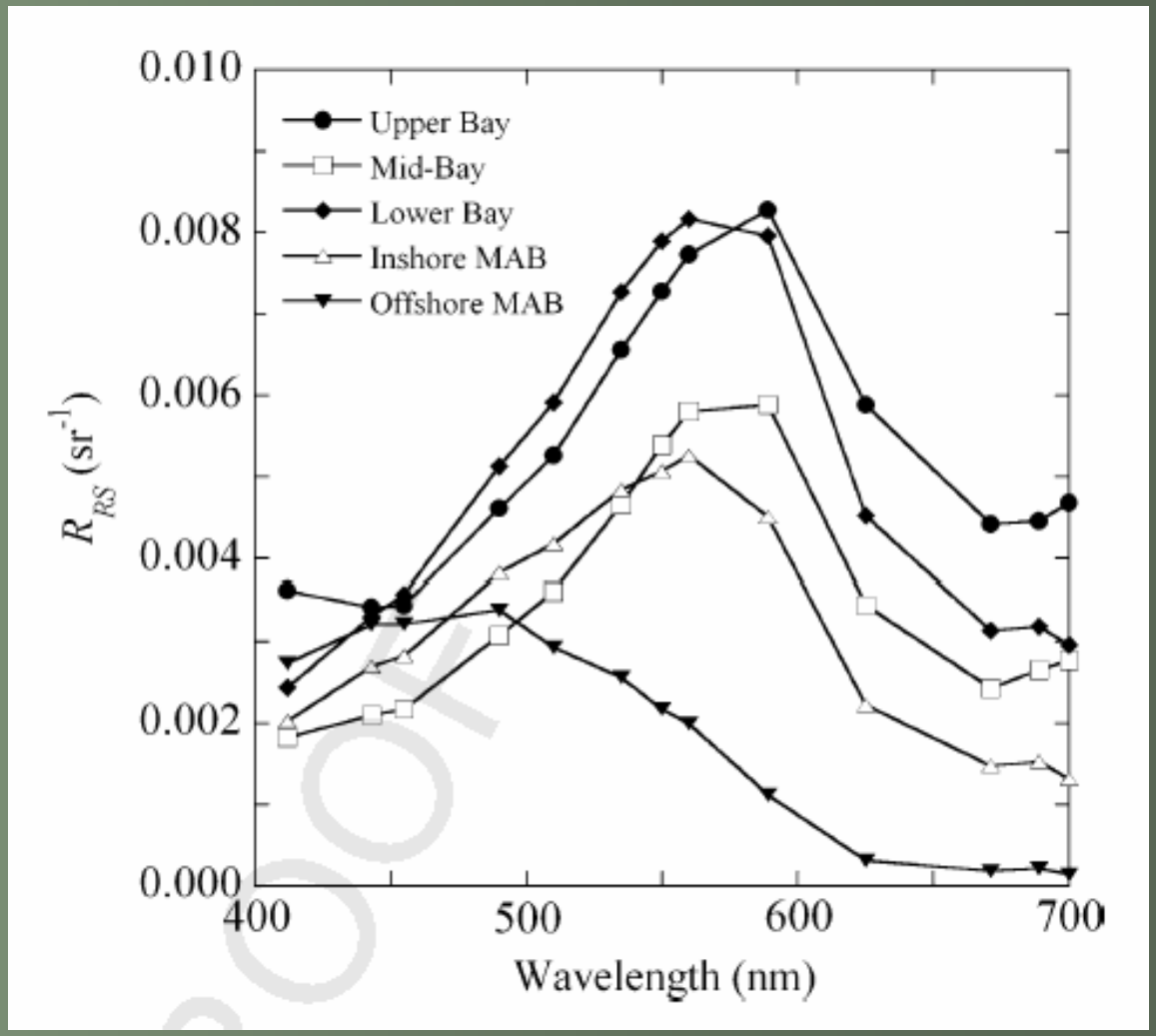
Aircraft

Main stem Bay

Tributaries

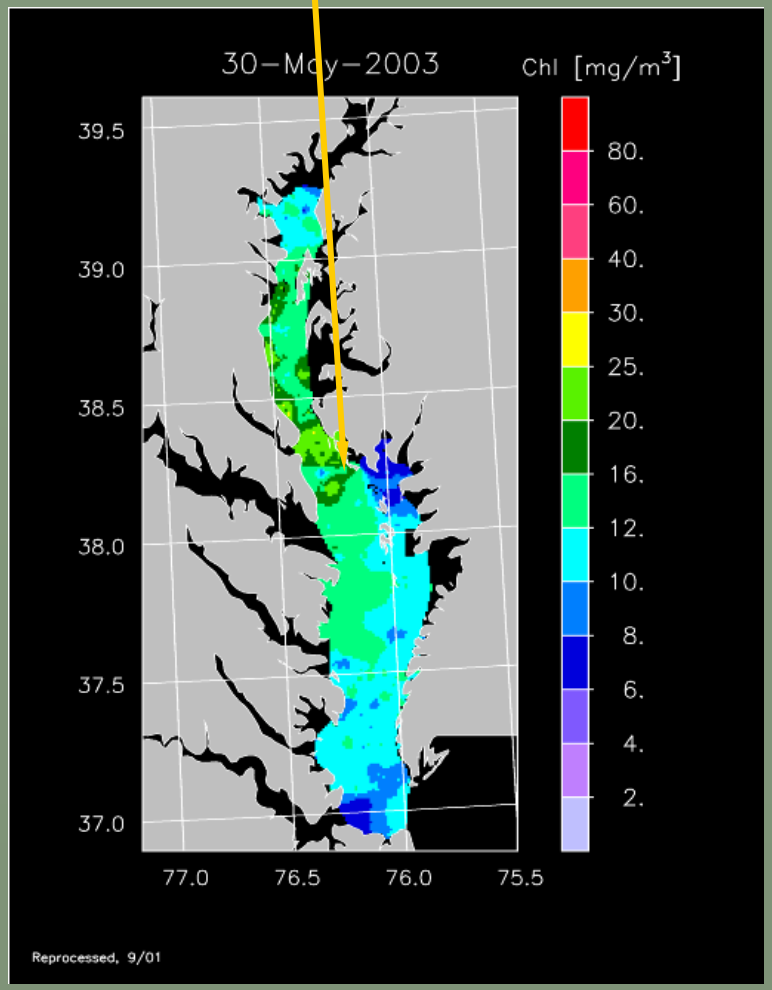
R_{RS} spectra for Chesapeake Bay and the MAB

Principle under-lying retrievals of chl-a and other properties is change in shape of R_{RS} spectra

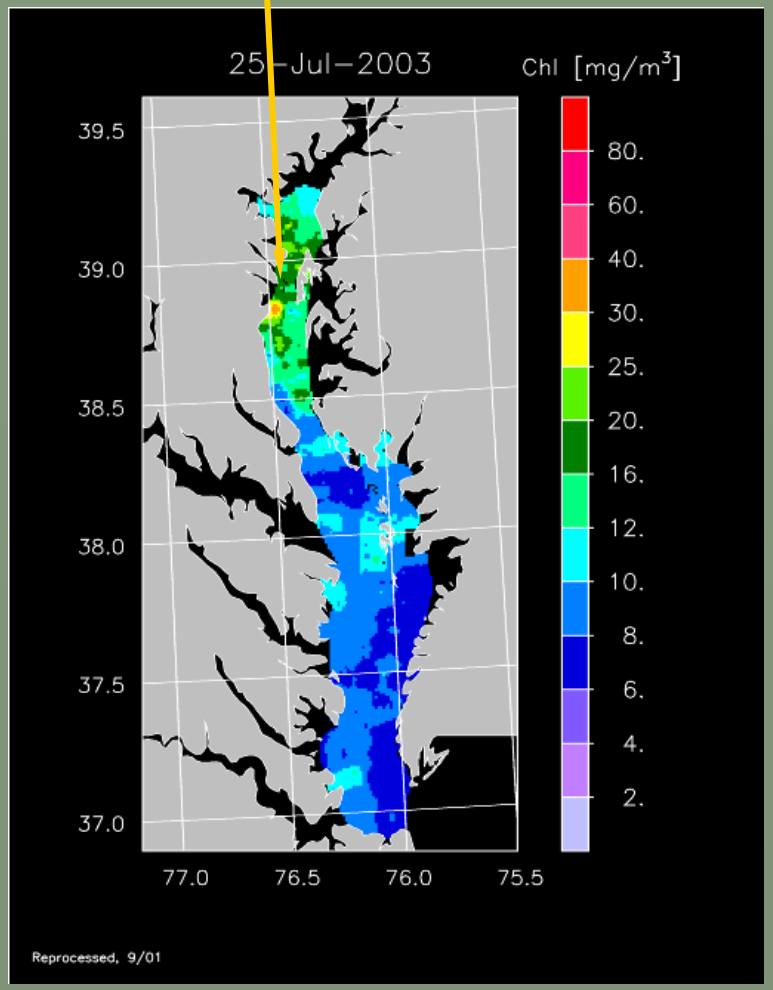


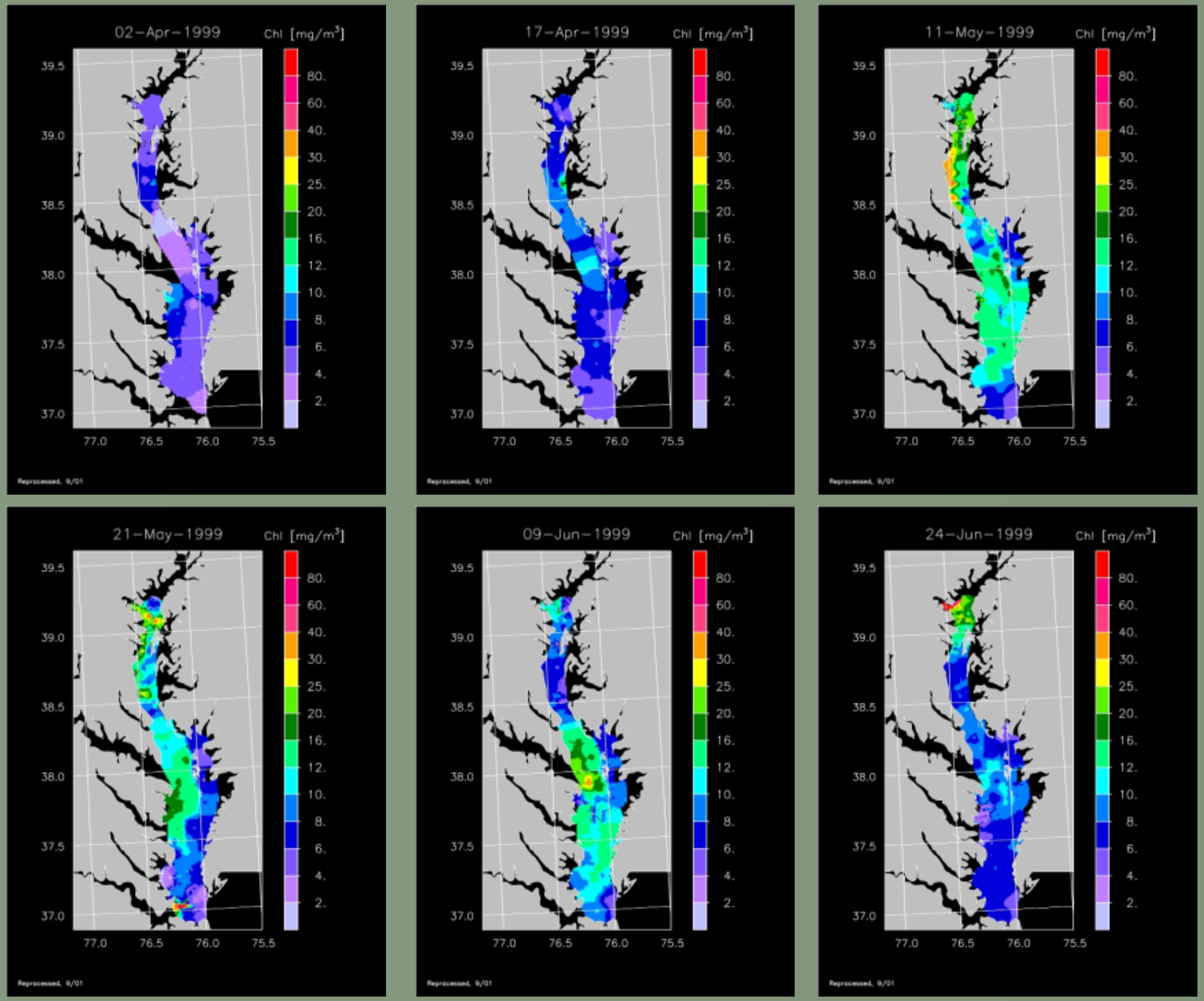
Seasonal variability

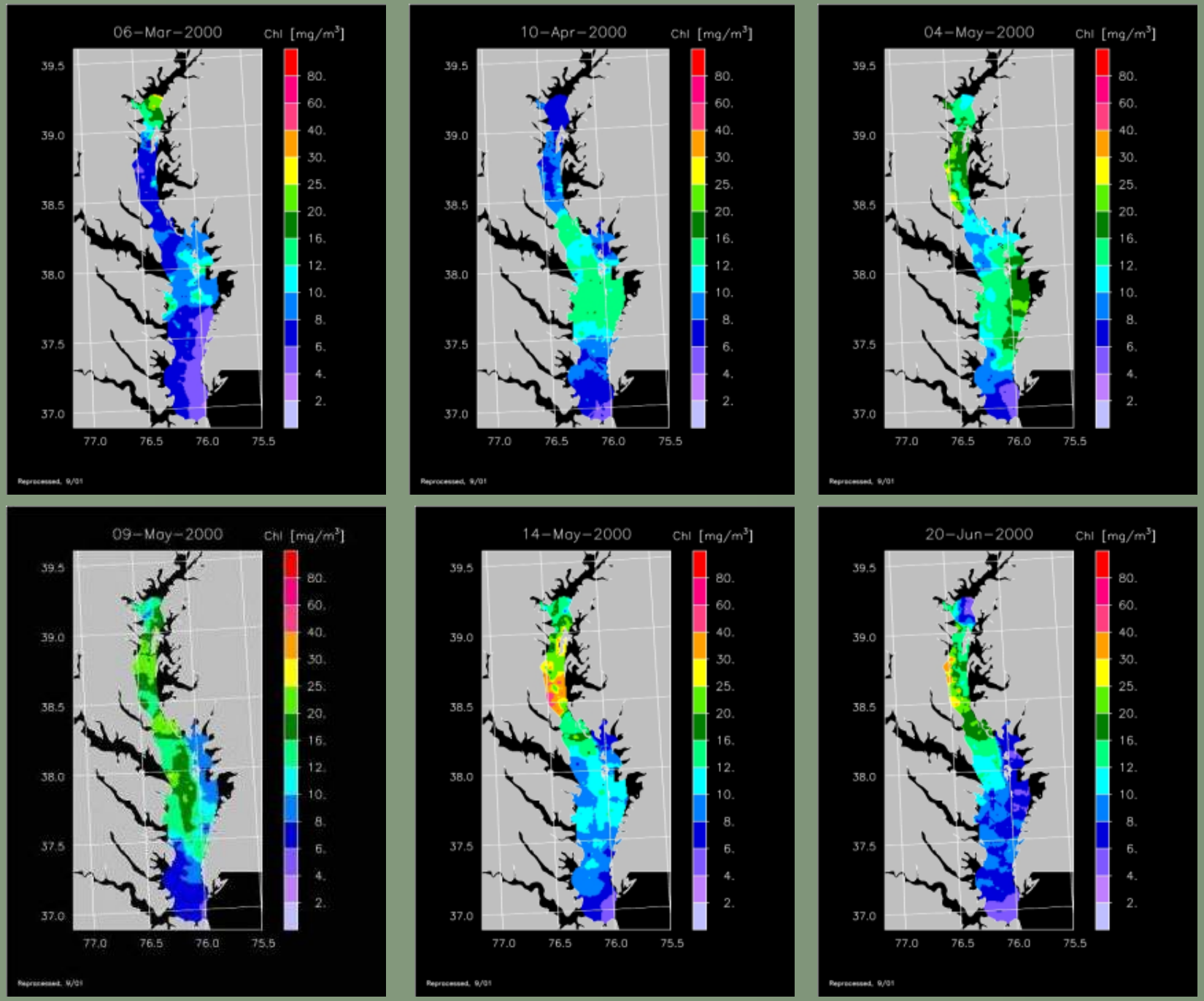
Spring diatom bloom



Summer dinoflagellate bloom




02-Apr-1999
17-Apr-1999
11-May-1999
21-May-1999
09-Jun-1999
24-Jun-1999
Chl [mg/m3]
80.
60.
40.
30.
25.
20.
16.
12.
10.
8.
6.
4.
2.
39.5
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
75.5
Reprocessed, 9/01


06-Mar-2000
10-Apr-2000
04-May-2000
09-May-2000
14-May-2000
20-Jun-2000
Chl [mg/m3]
80.
60.
40.
30.
25.
20.
16.
12.
10.
8.
6.
4.
2.
39.5
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
75.5
Reprocessed, 9/01

Analytical steps

Data sources:

Aircraft ocean color and SST, EPA/CBP monitoring data 1989-2001

~300 flights

PP computations:

Apply depth-integrated models (DIMs) for CB to remotely sensed data

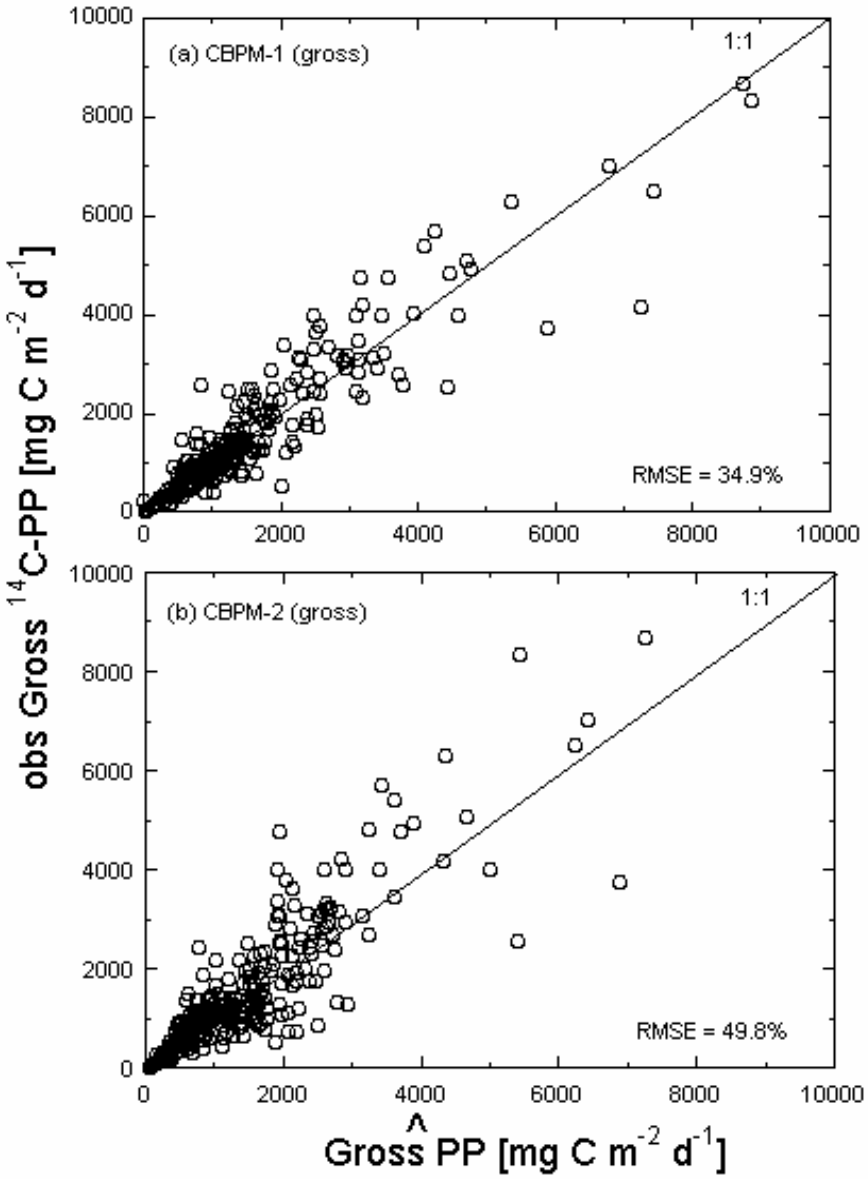
64 cruises

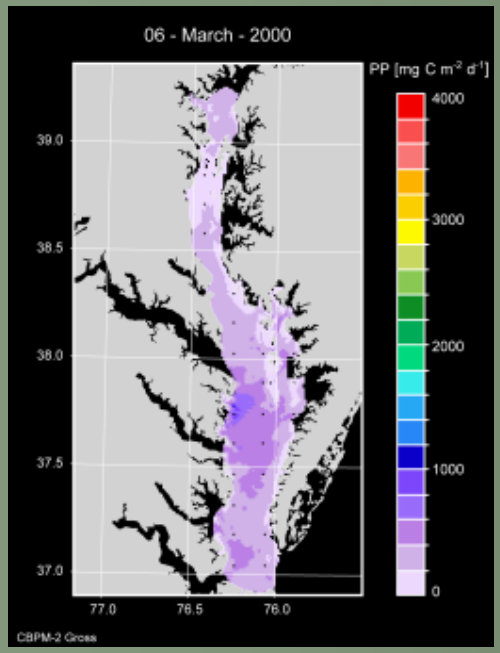
PP time-series for main stem CB

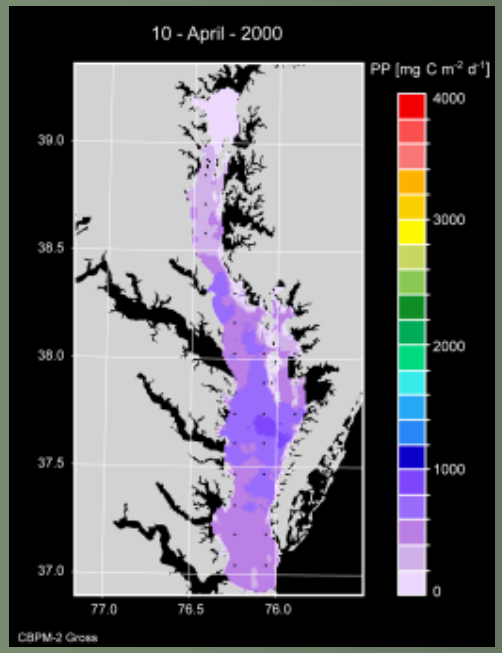
LOESS and MLR models using simple input variables

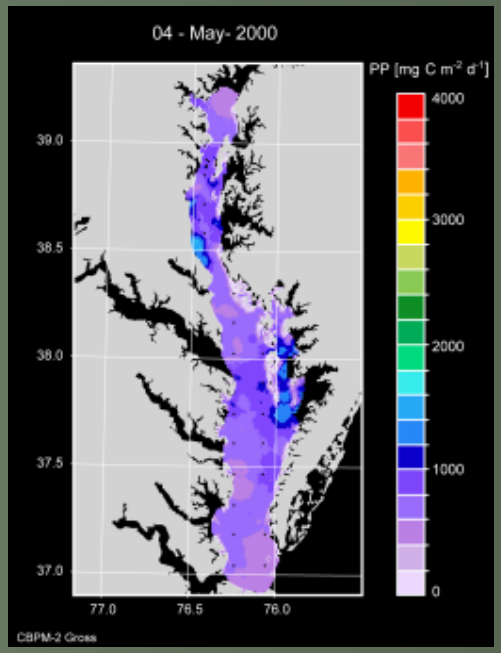
CBPM-1 and CBPM-2 recoveries of gross PP for LMER TIES data, 1995-98. CBPM models are multiple regression DIMs in log-space, using common variables for this lineage of models, such as chl-a, E_0, Z_p, SST. CBPM-1 requires a physio-logical input, P^B_{opt}, CBPM-2 embeds a model of P^B_{opt} in CBPM-1.

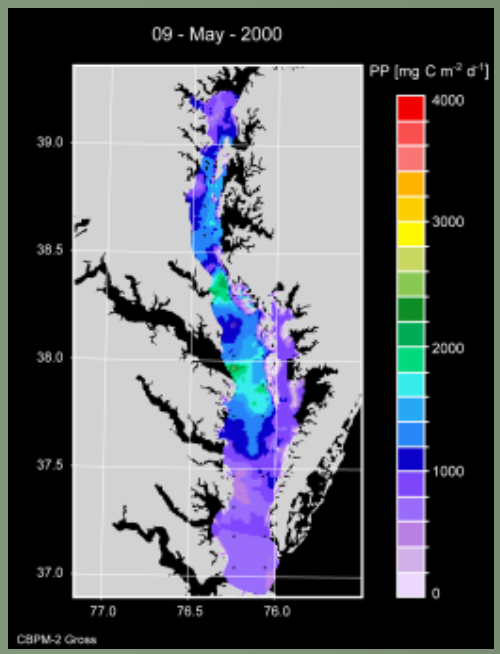
from Harding *et al.*, 2002 *Estuar. Coastal Shelf Sci.*

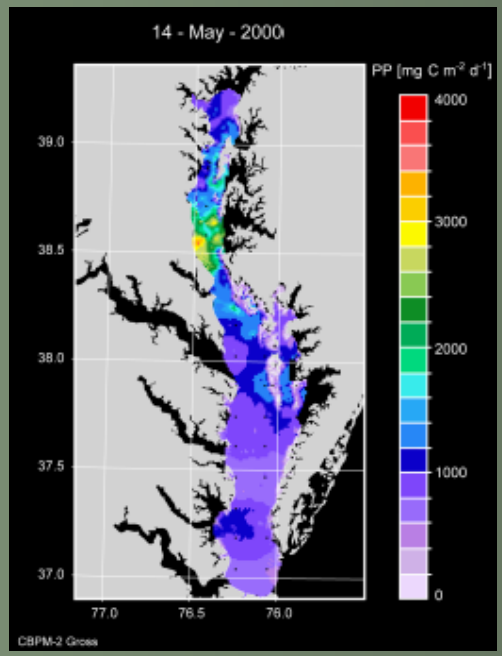


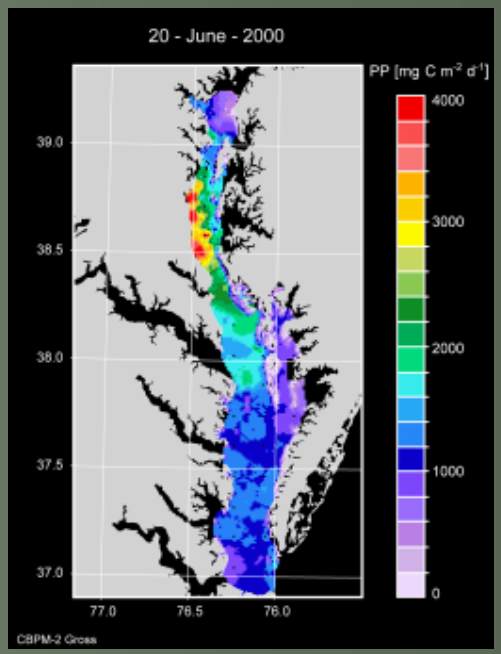

06 - March - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross

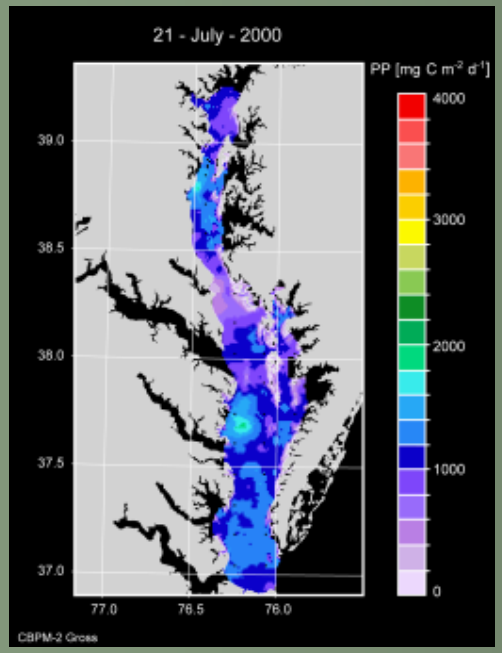

10 - April - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross

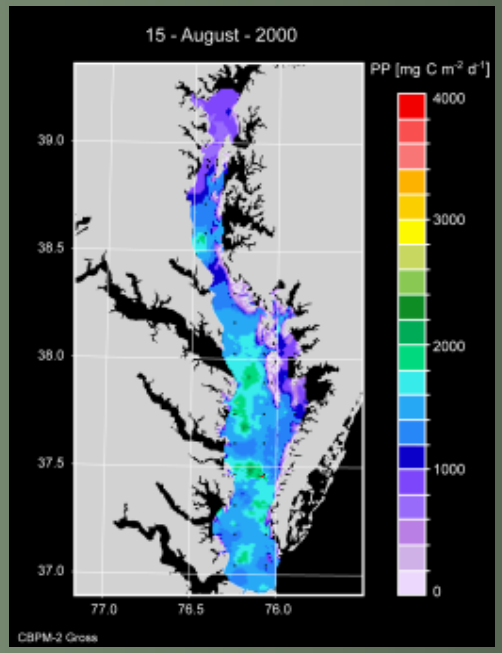

04 - May- 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross

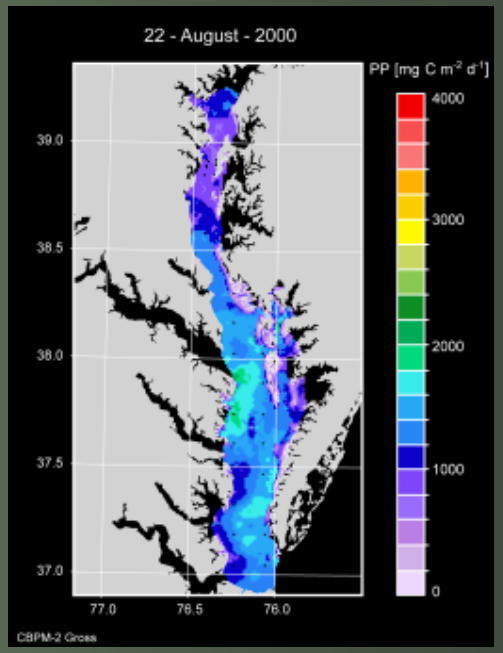

09 - May - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


14 - May - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


20 - June - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


21 - July - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


15 - August - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


22 - August - 2000
PP [mg C m-2 d-1]
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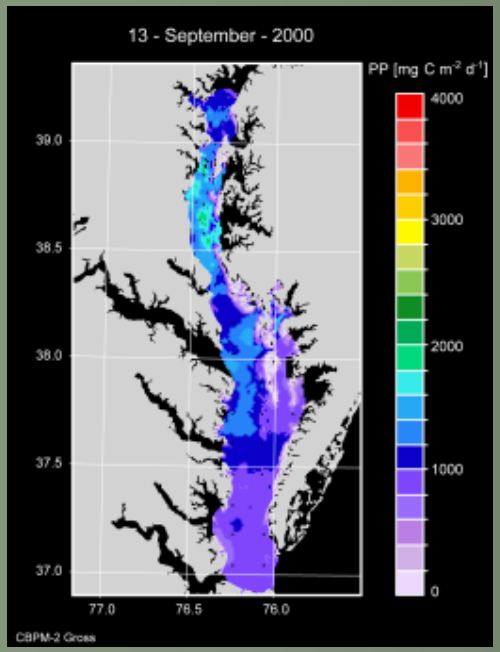
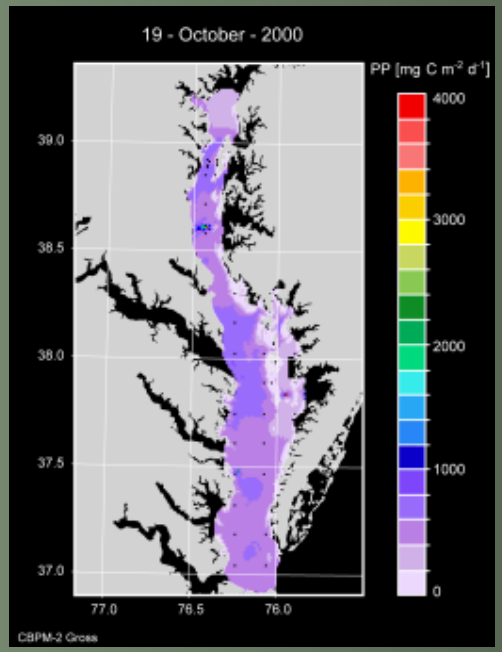
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


13 - September - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


19 - October - 2000
PP [mg C m-2 d-1]
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2000
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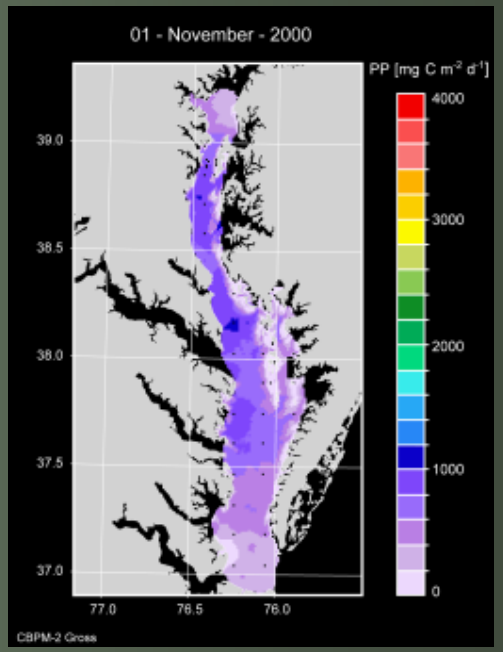
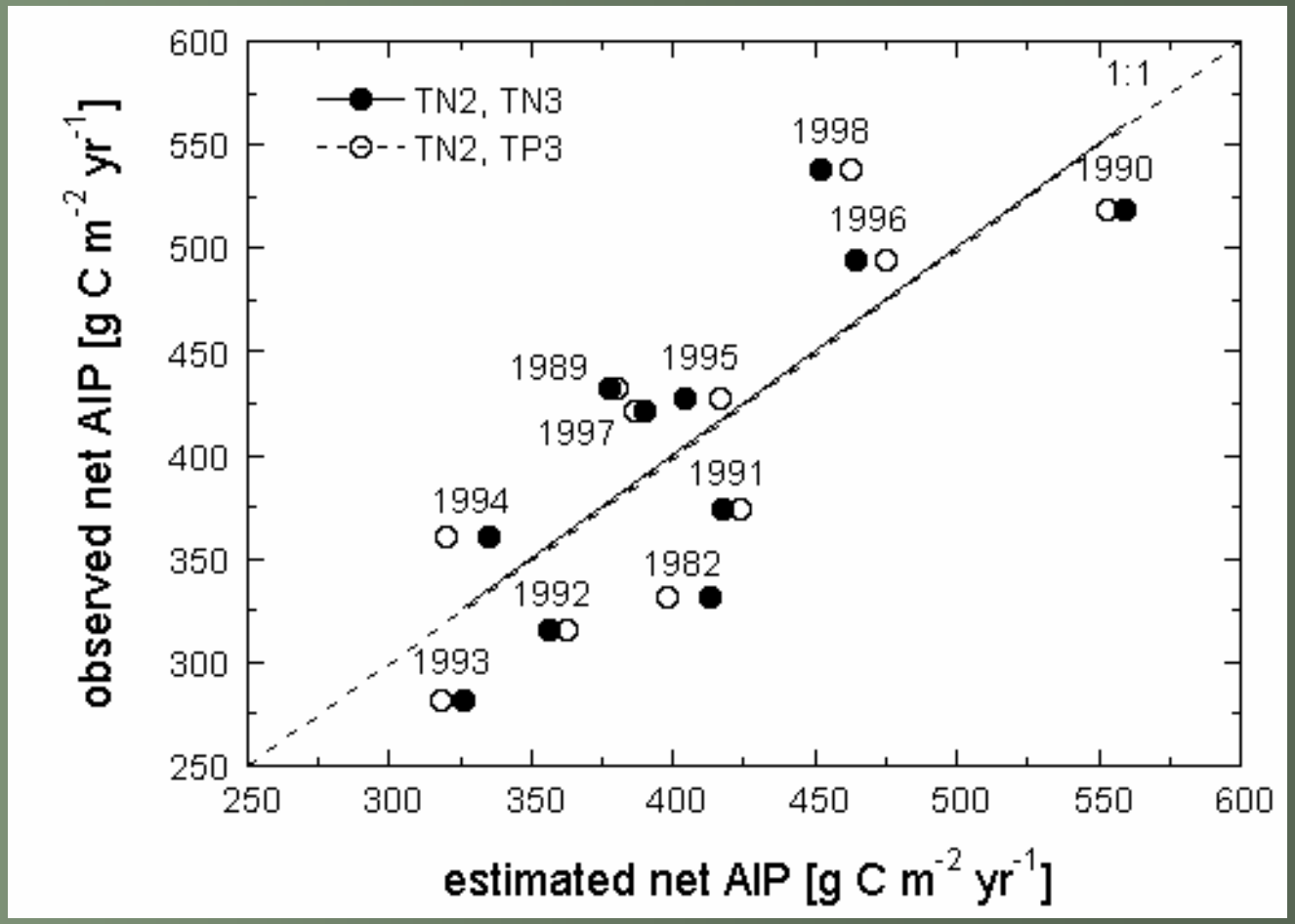
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross


01 - November - 2000
PP [mg C m-2 d-1]
4000
3000
2000
1000
0
39.0
38.5
38.0
37.5
37.0
77.0
76.5
76.0
CBPM-2 Gross

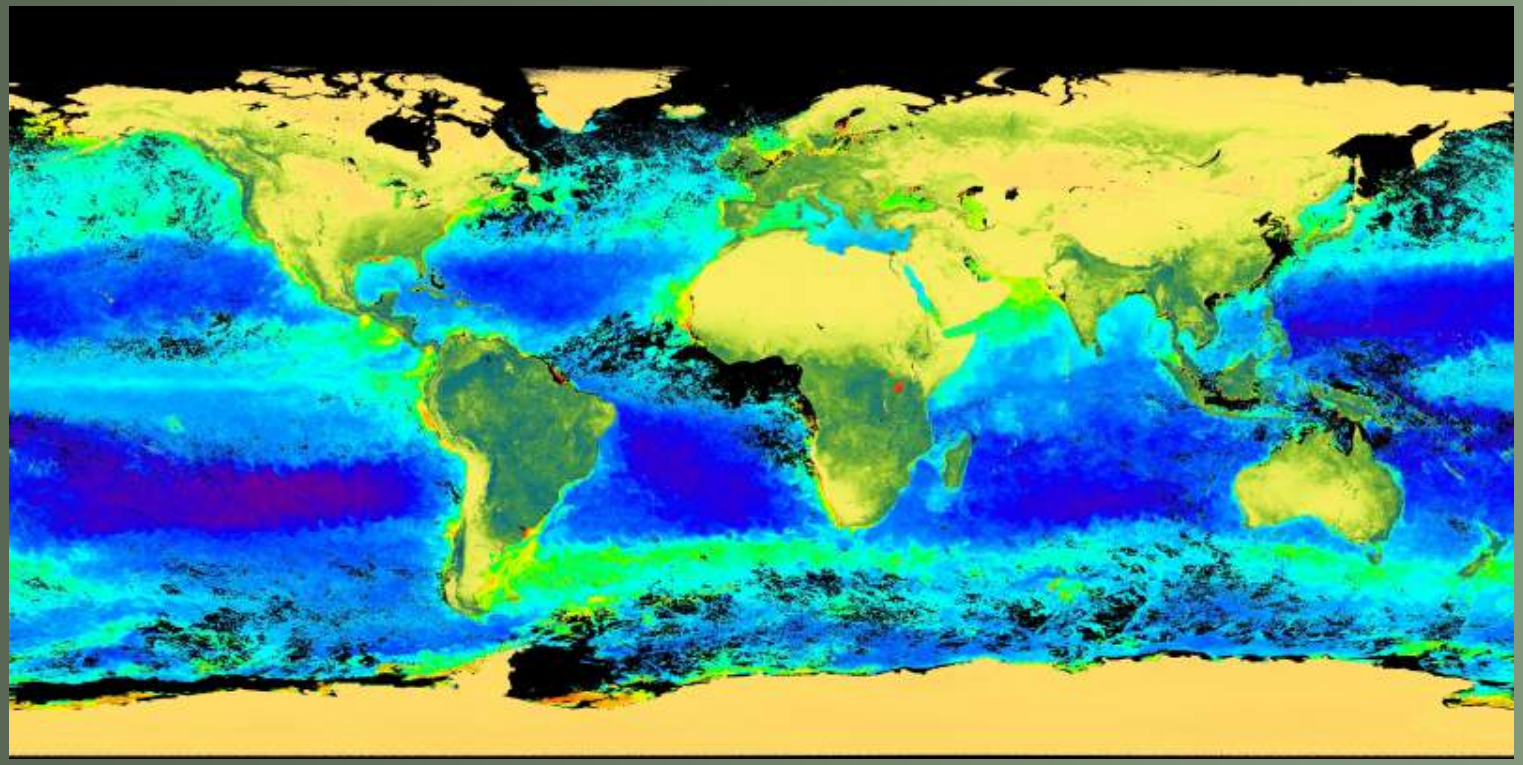
Model estimates of AIP using winter-spring TN and TP loadings

TN2: Feb
TP3: Mar

$R^2 = 0.623$

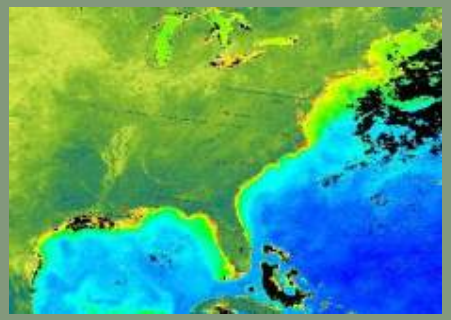


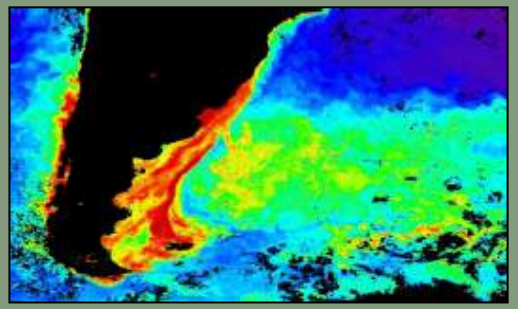
SeaWiFS - Sea-viewing Wide Field-of-view Sensor

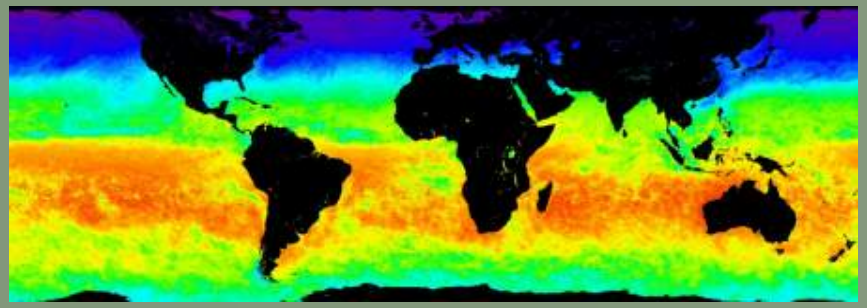


SeaWiFS products are obtained from the NASA's Goddard Space Flight Center for research and education

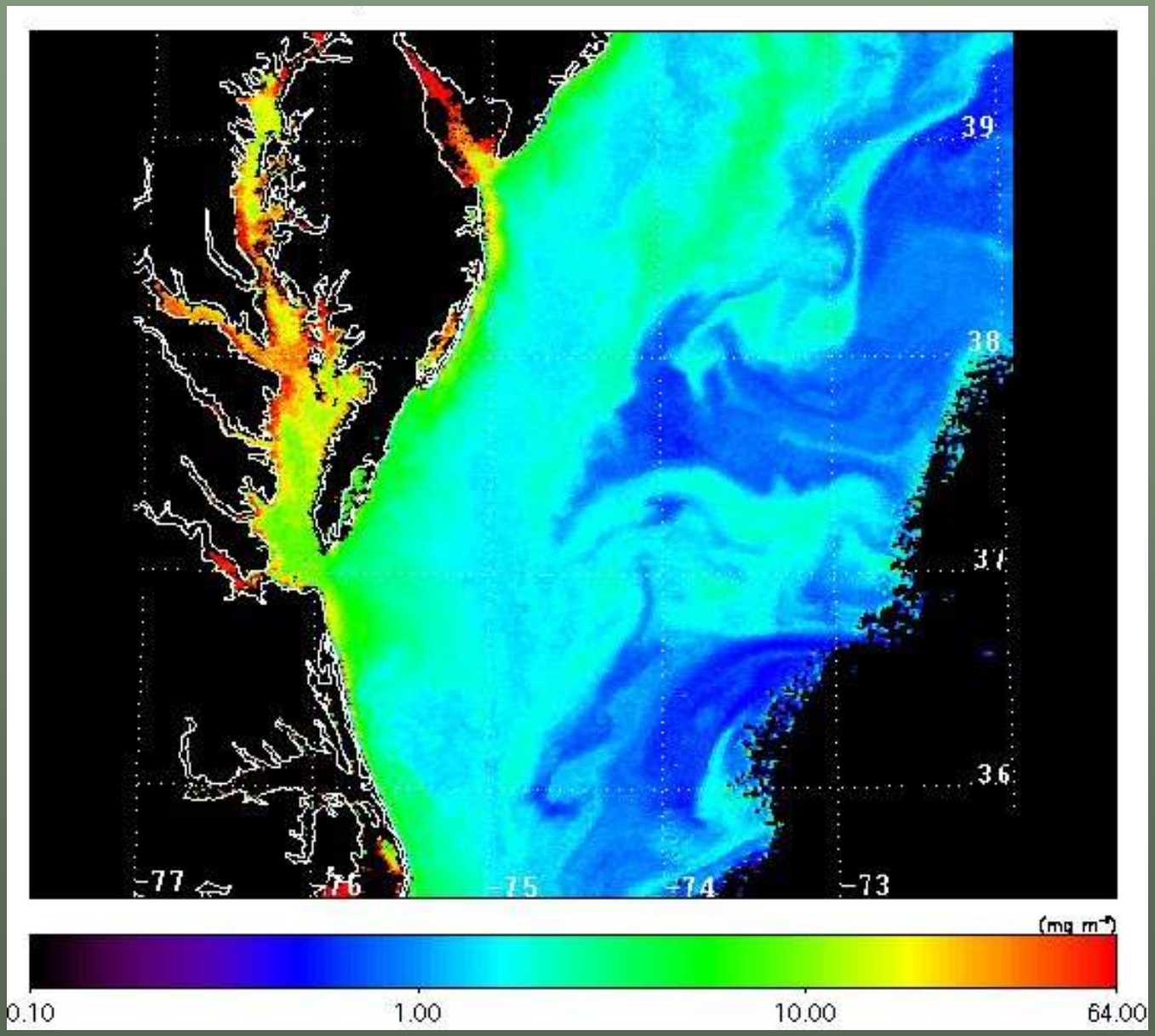
- Standard Products
  - Water leaving radiances (6 bands)
  - Chlorophyll concentration
  - Diff. attenuation at 490 nm
  - Aerosol opt. thickness at 865 nm
- Evaluation Products
  - Vegetation Index
  - Cloud depth and cloud fraction
  - Colored dissolved matter/detritus
  - PAR
  - Aerosol Index
- Other Products
  - True color



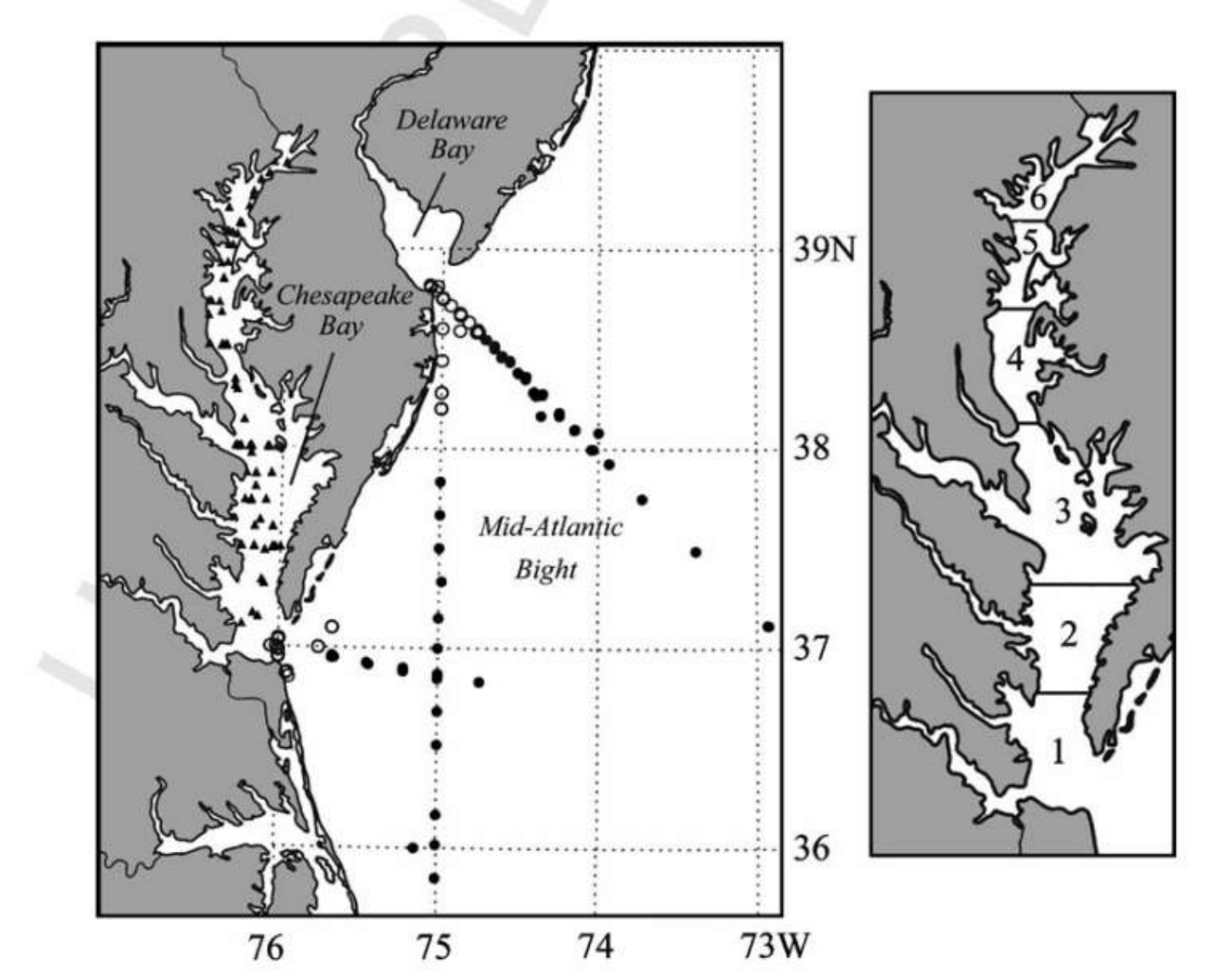




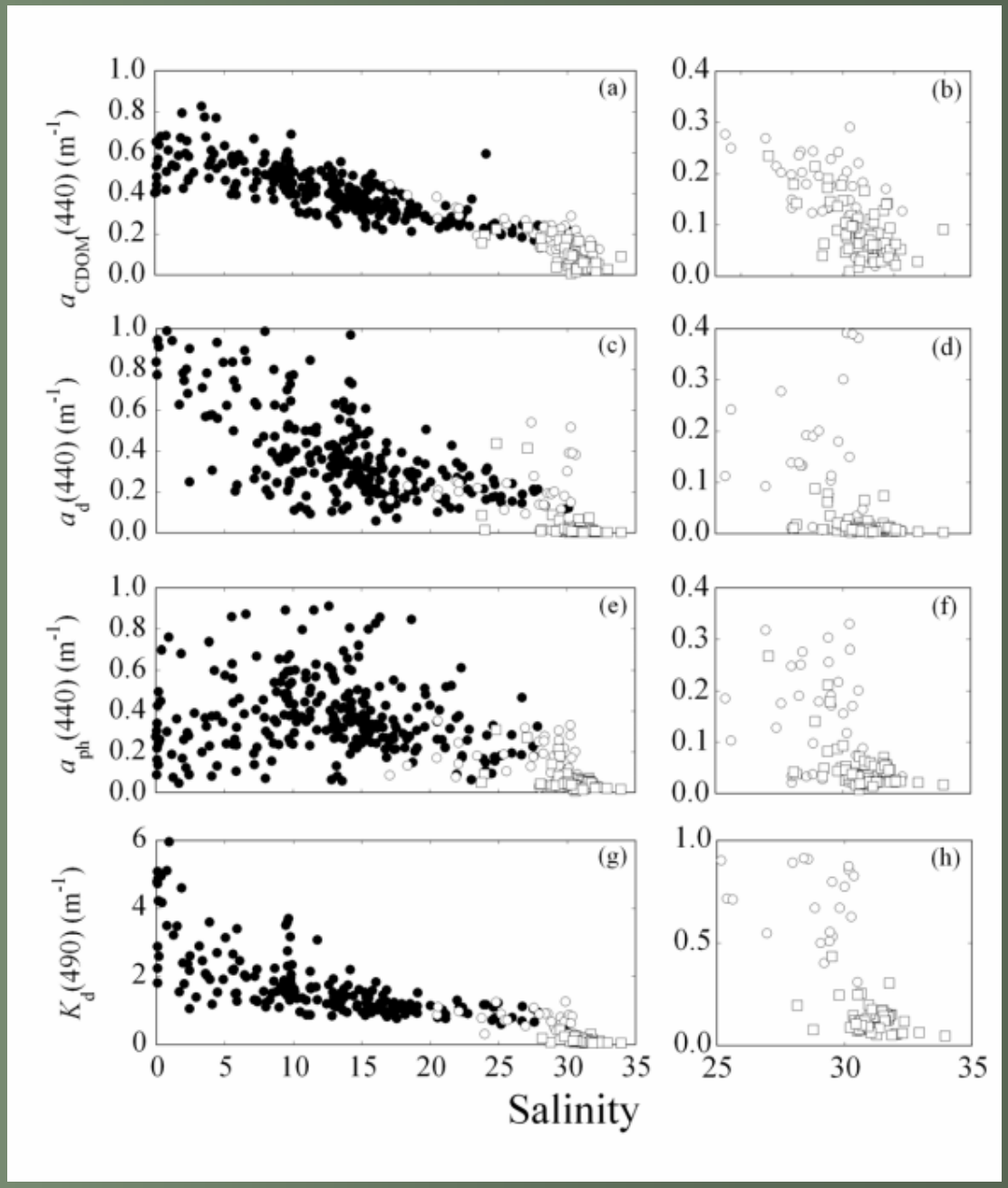
SeaWiFS chl-a (mg m^{-3}), 12 April 1998



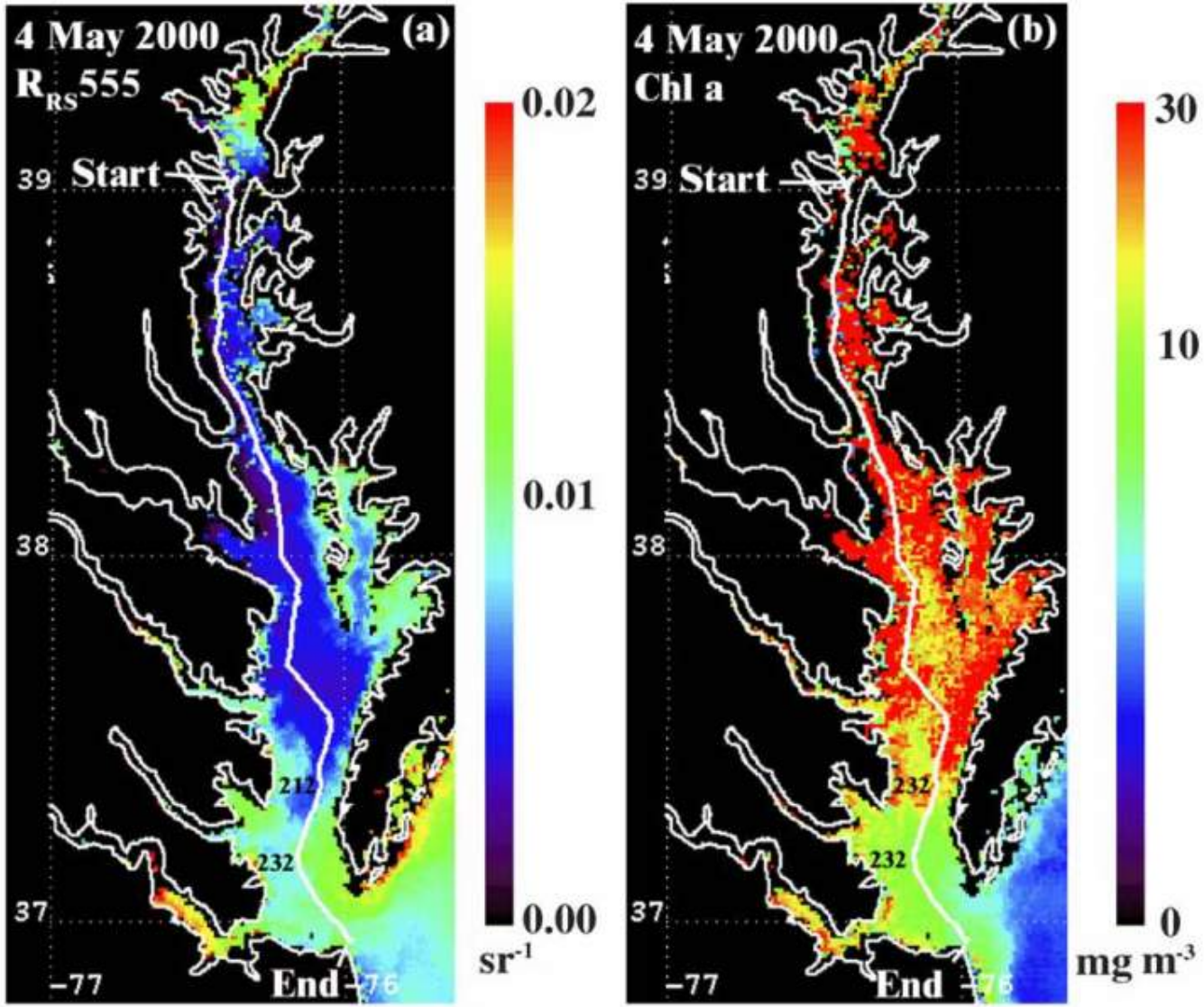
Station locations for bio-optical sampling in Chesapeake Bay and the Mid-Atlantic Bight



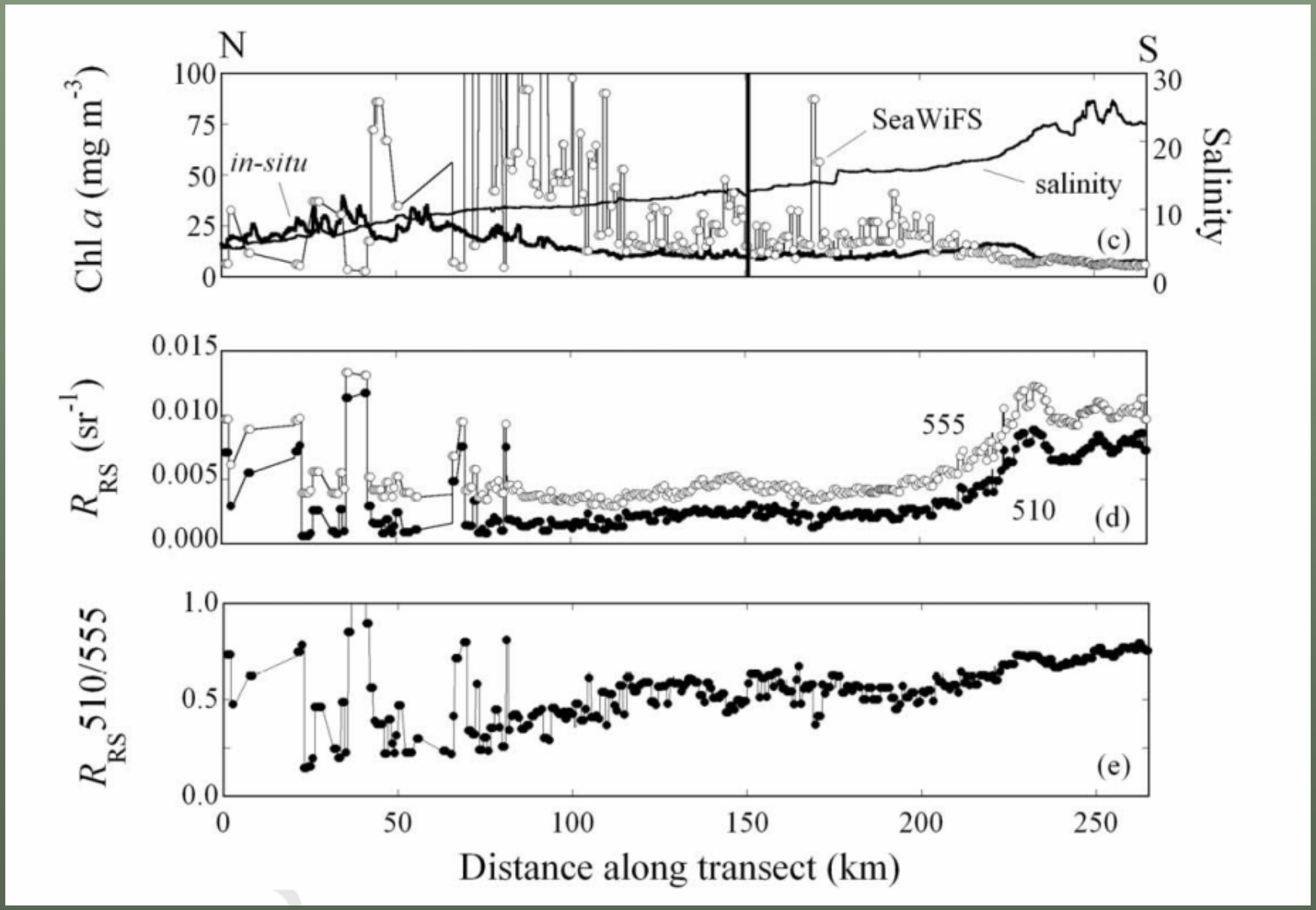
Bio-optical properties in Chesapeake Bay and the MAB, 1996-2000



R_{RS} and chl-a retrievals from SeaWiFS (OC4v.4)



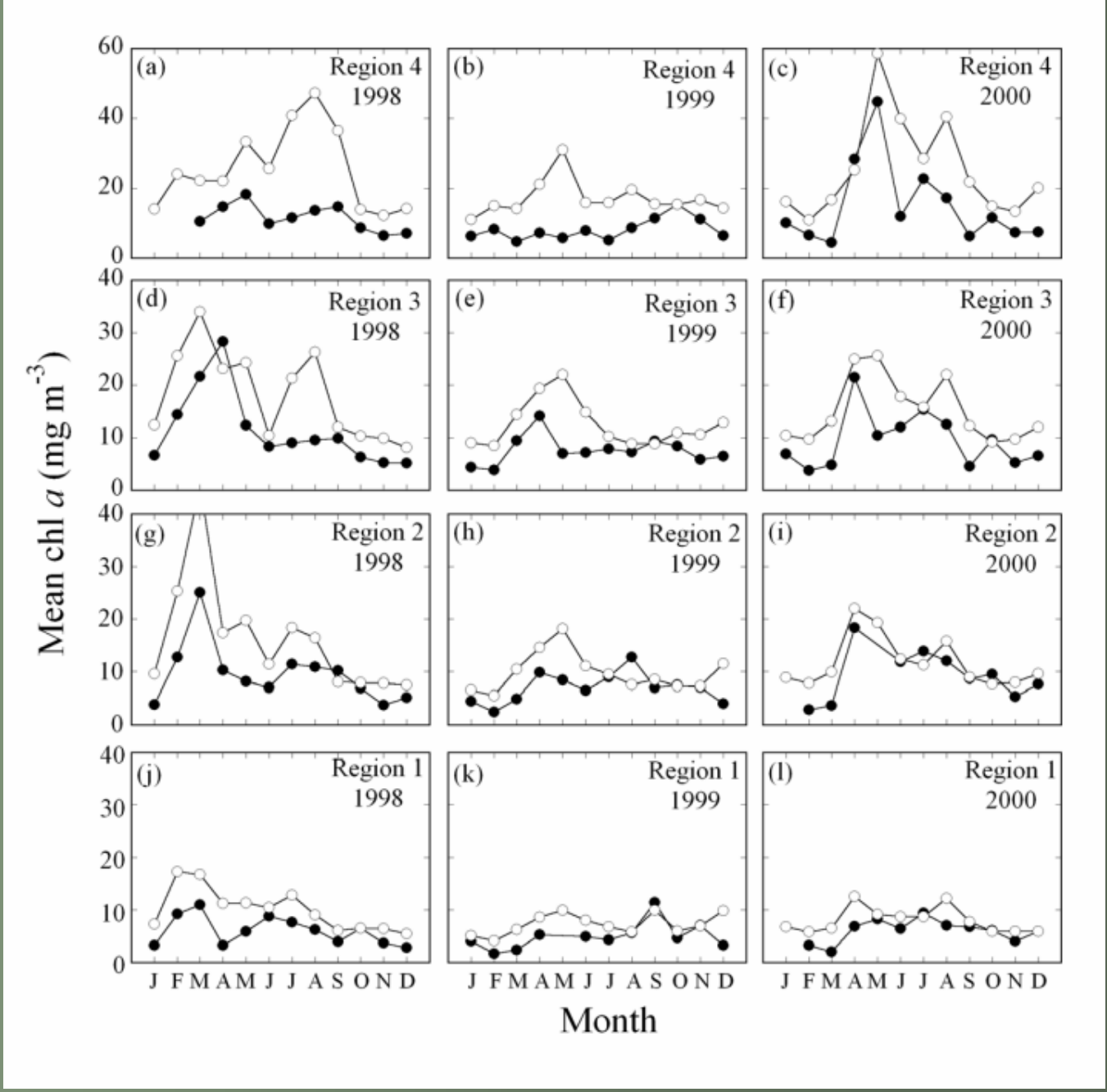
Chl-a, R_{RS} (510, 555 nm), and R_{RS} 510/555 for image



Time-series of chl-a for regions 1-4 in the Bay

open circles: SeaWiFS

closed circles: *in-situ*

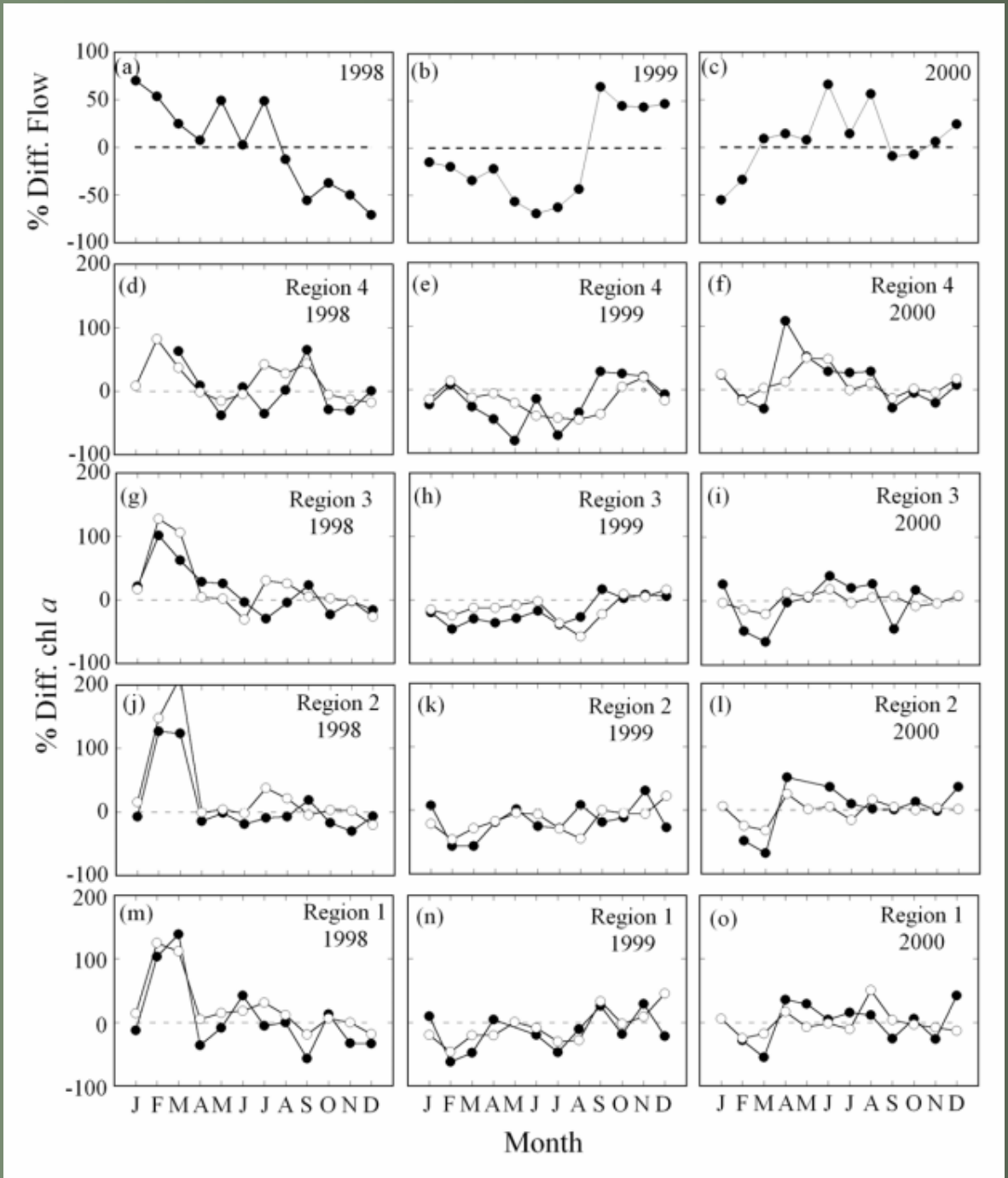


Deviations[1] of flow and SeaWiFS chl-a for regions 1-4 in the Bay, 1998-2000

open circles: SeaWiFS

closed circles: *in-situ*

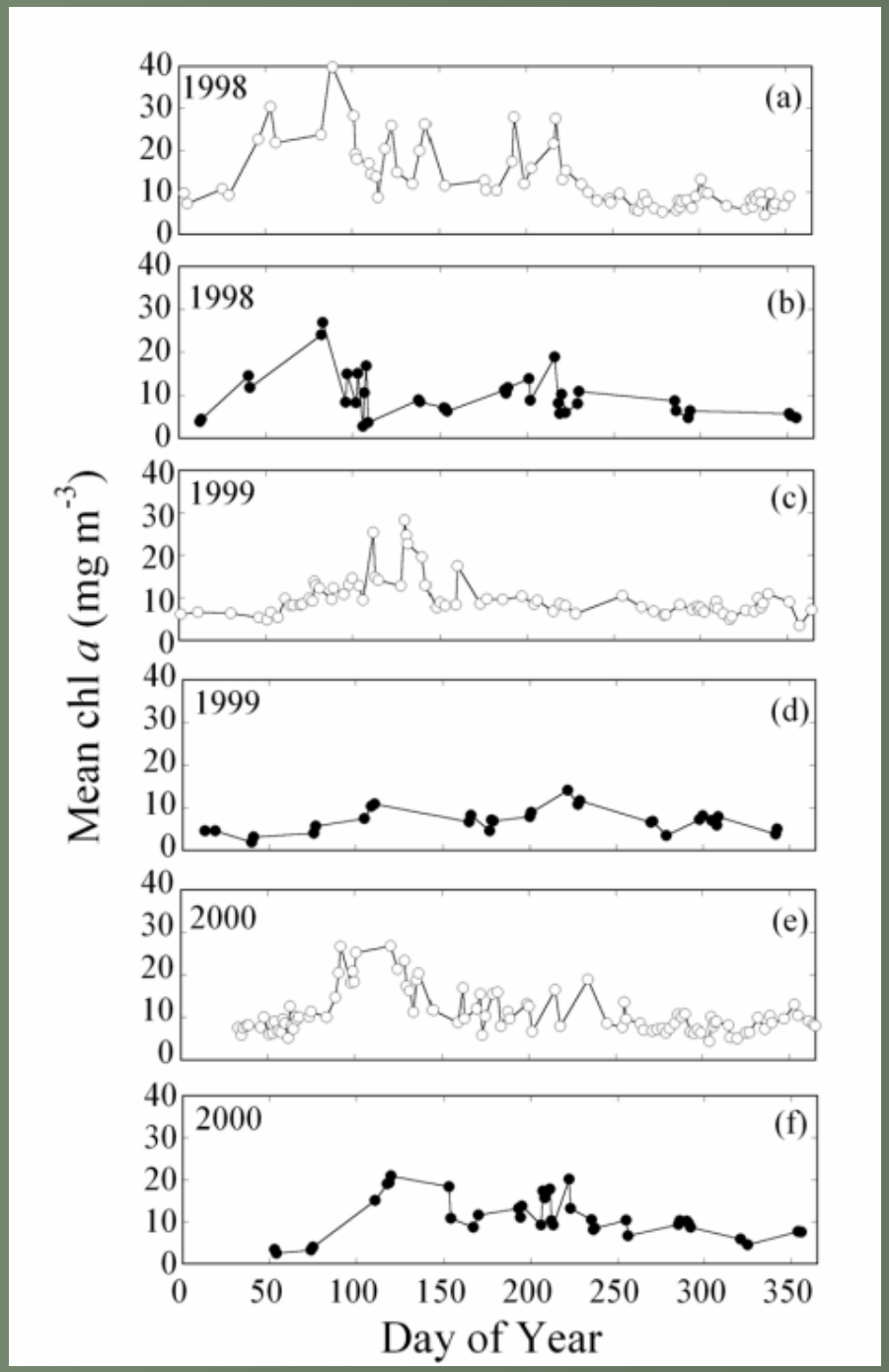
[1] Based on 3-year means



Time-series of SeaWiFS and *in-situ* chl-a for region 2 in the Bay, 1998-2000

open circles: SeaWiFS

closed circles: *in-situ*

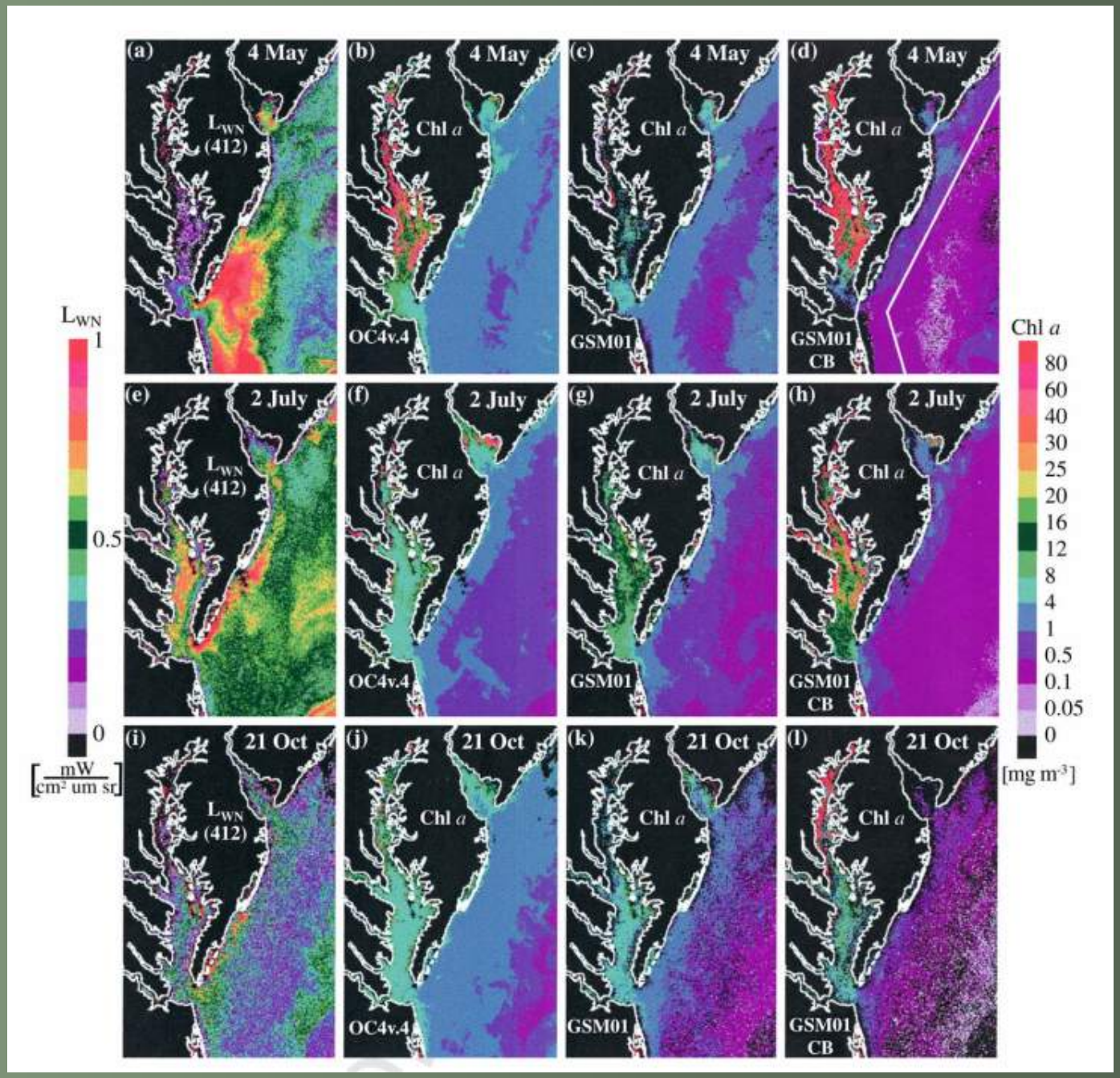


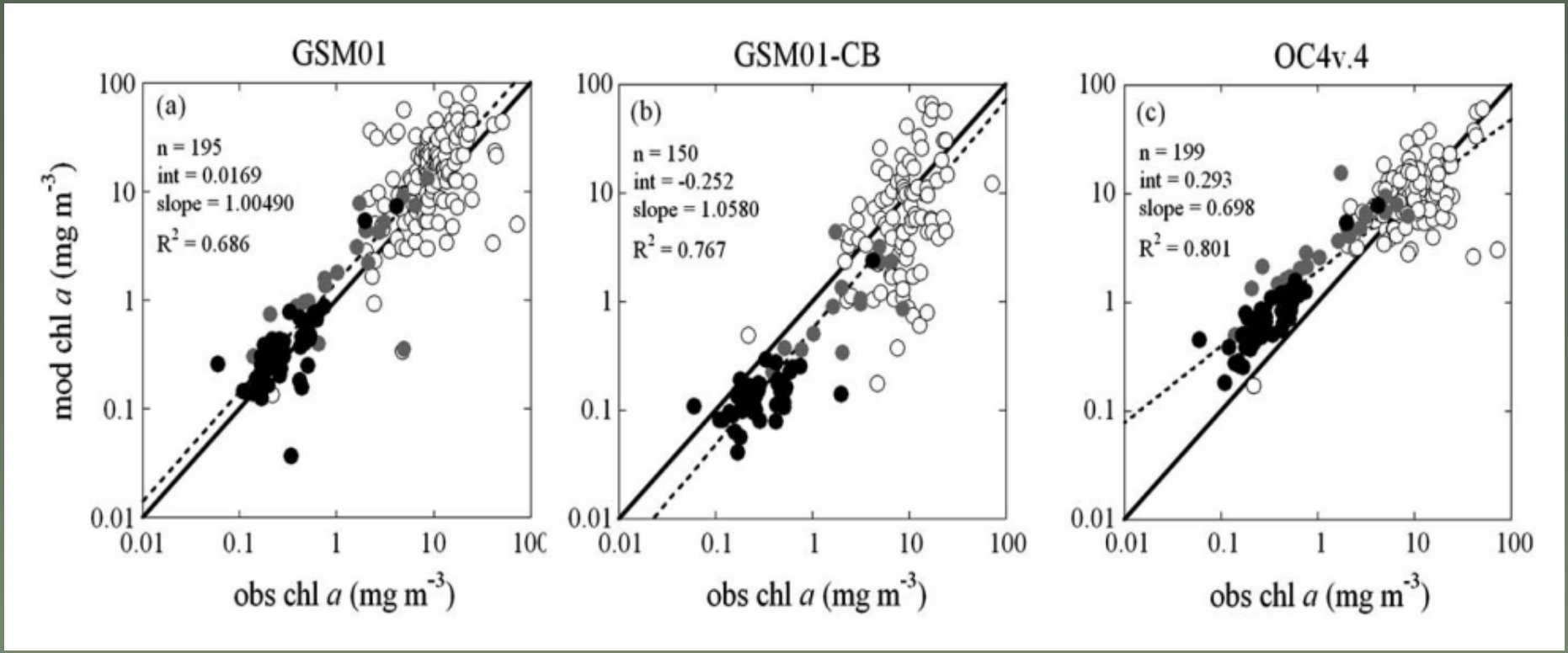
Basis of the semi-analytic model developed by Maritorena *et al.* (2002) - inversion of the the Gordon *et al.* (1988) model relating water-leaving radiances (L_{WN}) to inherent optical properties (absorption, backscattering coefficients):

$$L_{\mathrm{WN}}(\lambda) = \frac{tF_0(\lambda)}{n_{\mathrm{w}}^2} \sum_{i=1}^{2} \times g_i \left(\frac{b_{\mathrm{bw}}(\lambda) + b_{\mathrm{bp}}(\lambda)}{b_{\mathrm{bw}}(\lambda) + b_{\mathrm{bp}}(\lambda) + a_{\mathrm{w}}(\lambda) + a_{\mathrm{ph}}(\lambda) + a_{\mathrm{cdm}}(\lambda)} \right)^i \quad (1)$$

where λ refers to SeaWiFS radiances (412, 443, 490, 510, 555, 670 nm), t is the air-sea transmission factor, $F_0(\lambda)$ is extraterrestrial solar irradiance, n_w is index of refraction of water, and g_i are modeled terms derived from Monte Carlo simulations. Andrea Magnuson (Post-doctoral Fellow)

Comparison of chl-a from OC4v.4 and semi-analytic models - GSM01 and GSM01-CB

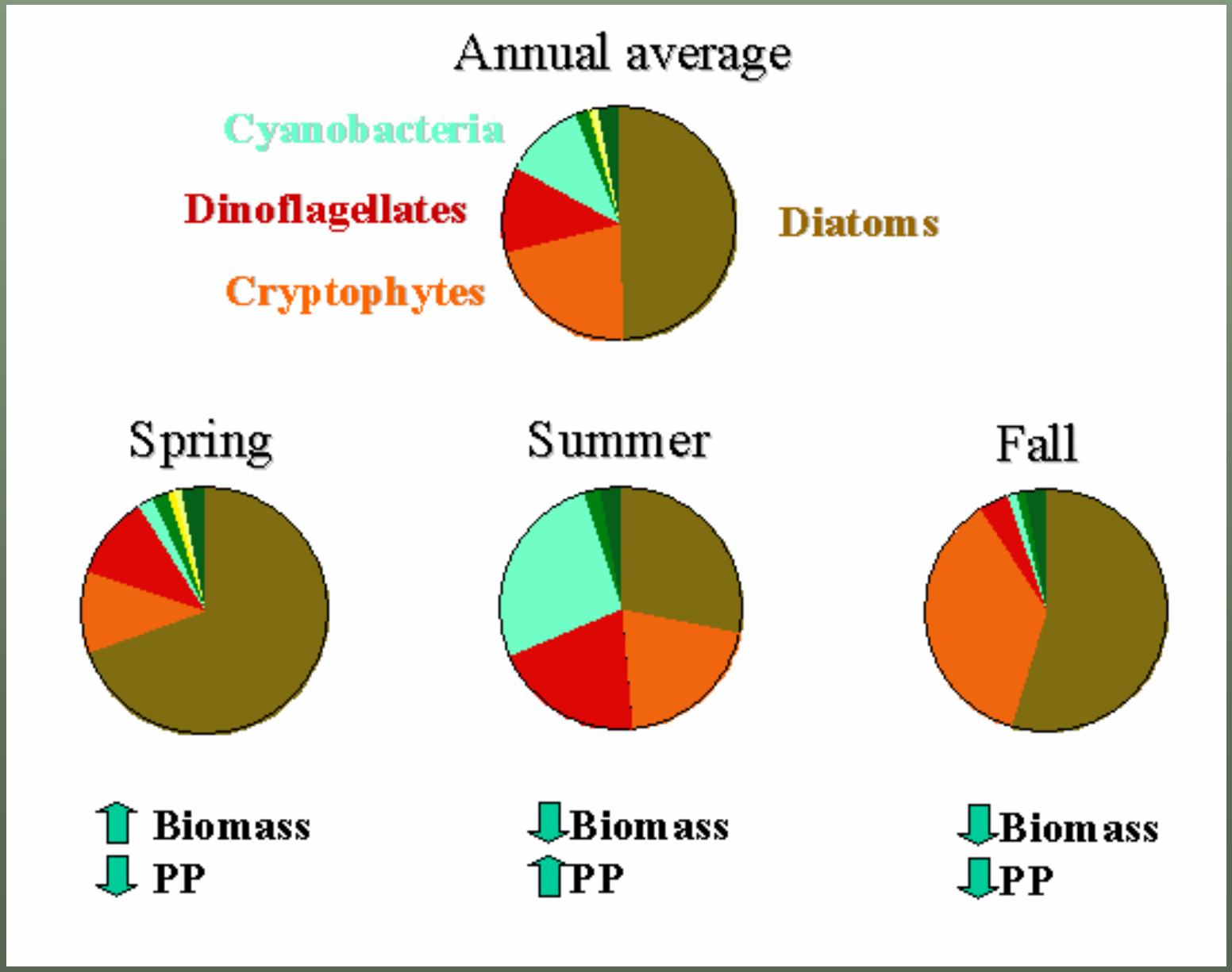




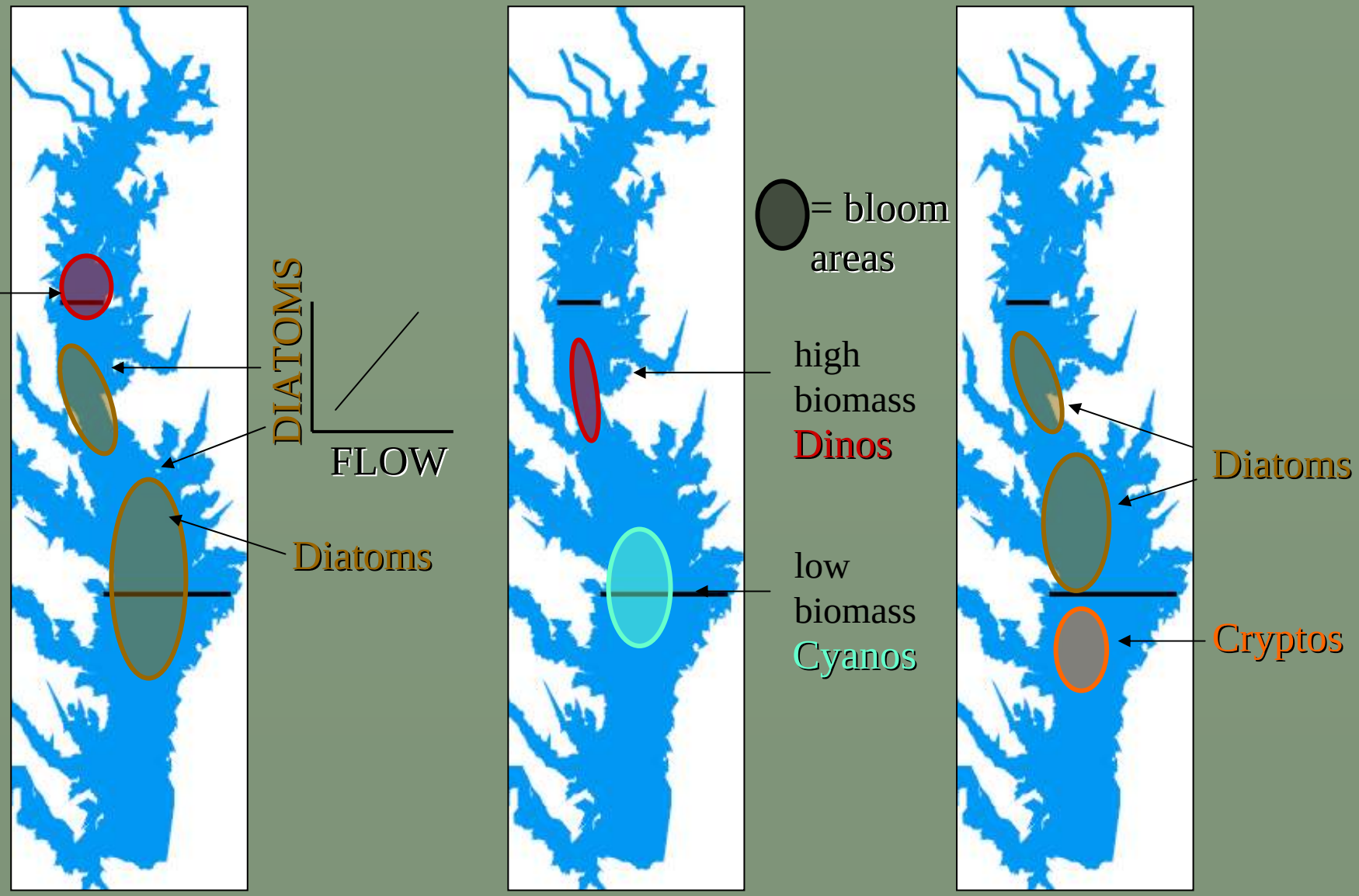
Comparison of chl-a from semi-analytic models and OC4v.4 in Chesapeake Bay and the MAB

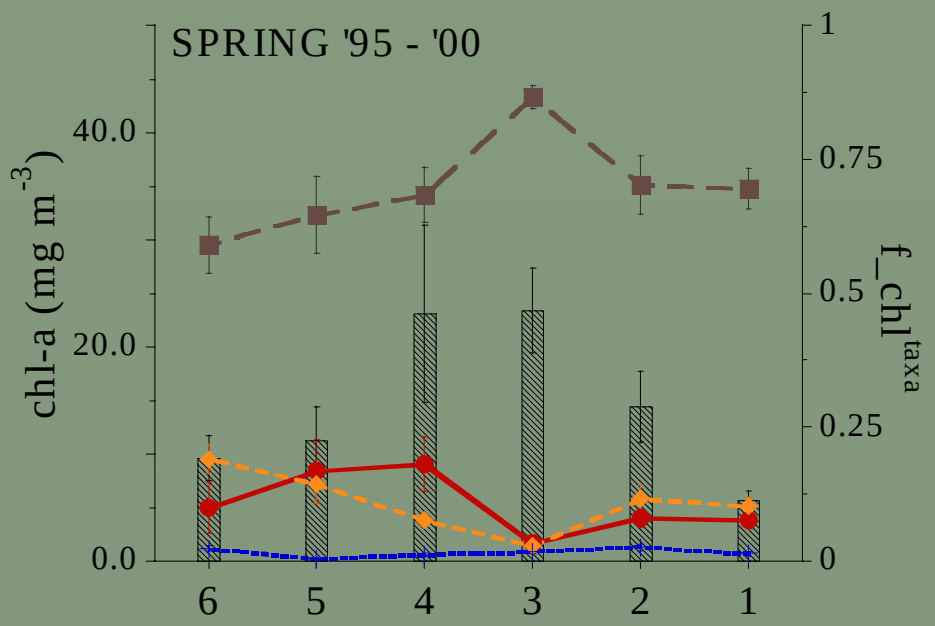
closed black circles: offshore MAB
closed gray circles: inshore MAB
open circles: Chesapeake Bay

Long-term averages of floral composition, biomass, and PP (1995-2000): Jason Adolf (Postdoctoral Fellow)

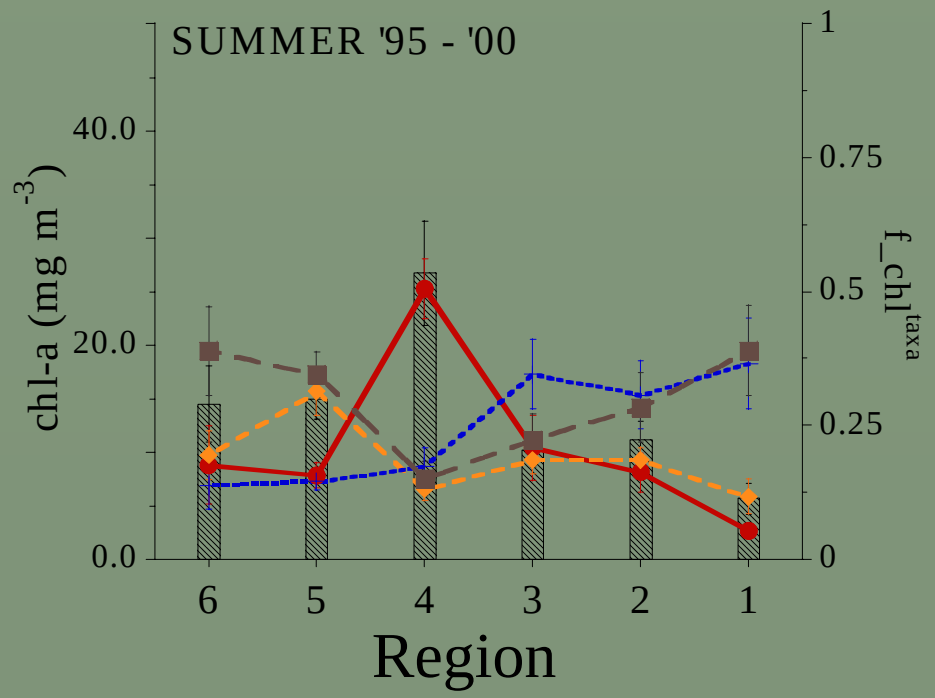


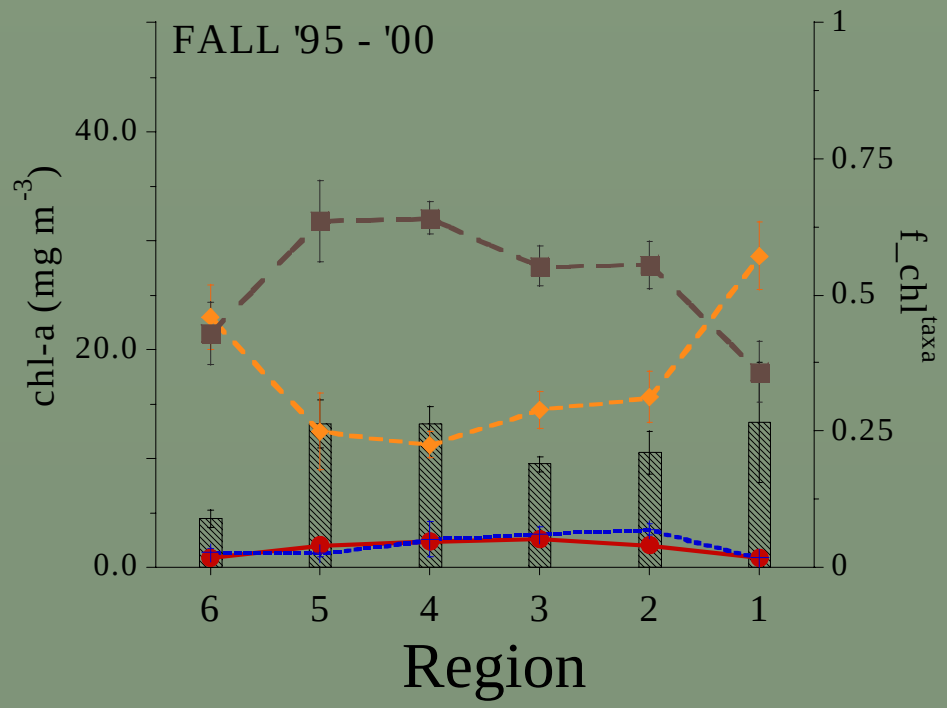
Conceptual model of floral and biomass distributions

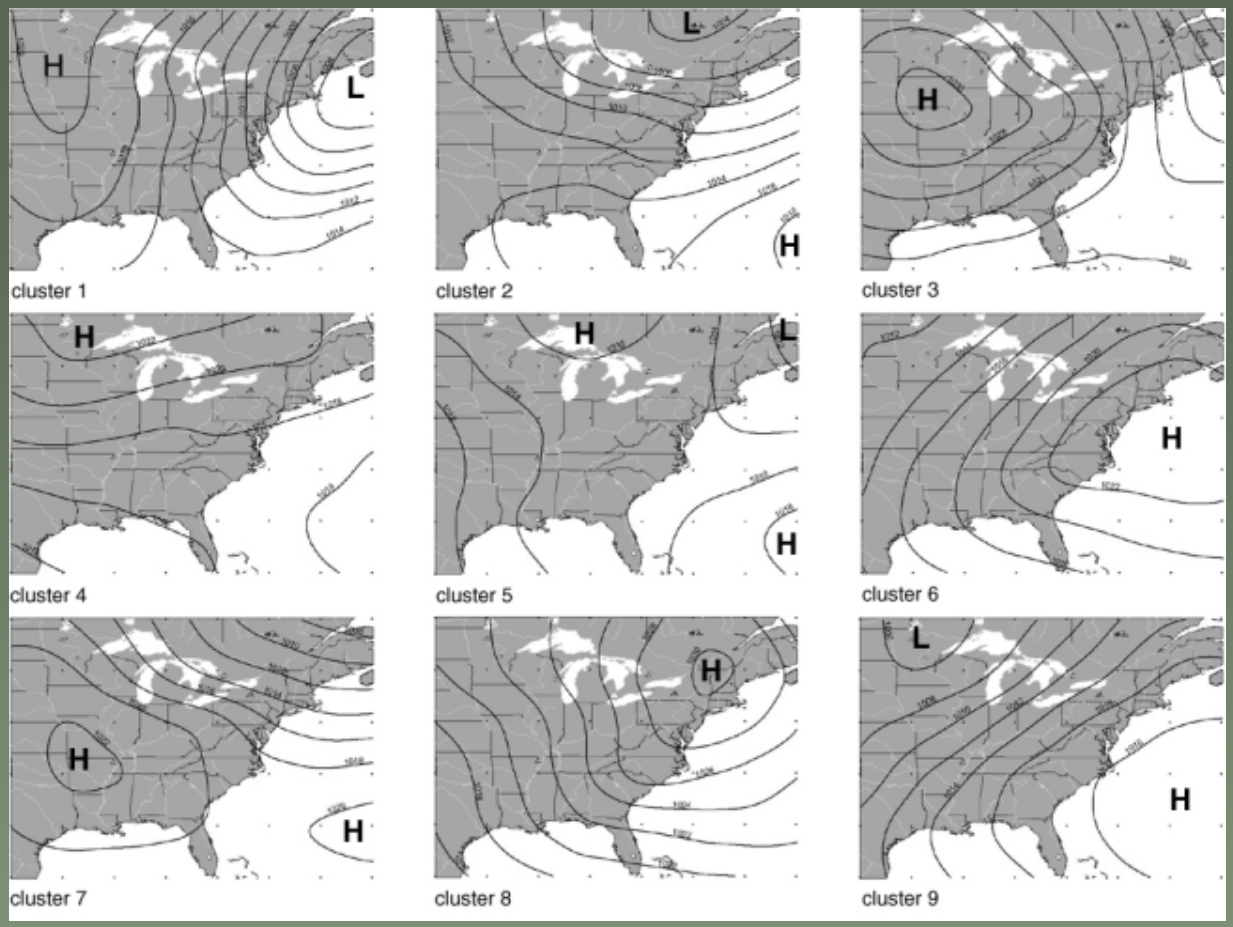


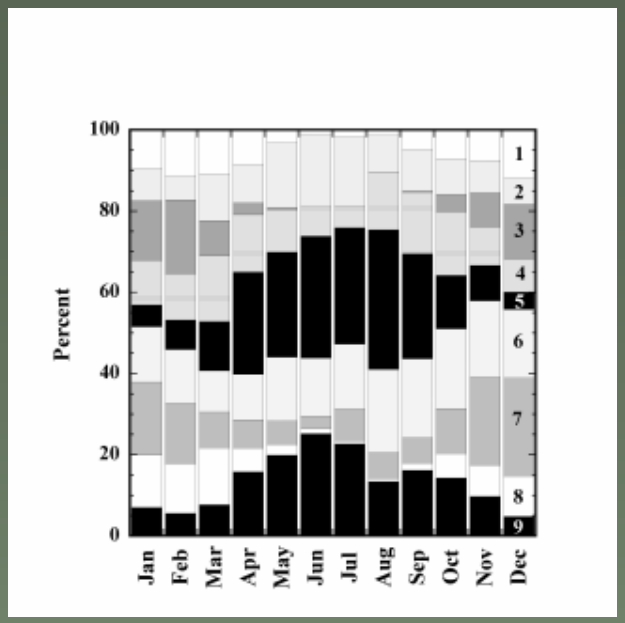


Diatoms
Dinoflagellates
Cryptophytes
Cyanobacteria



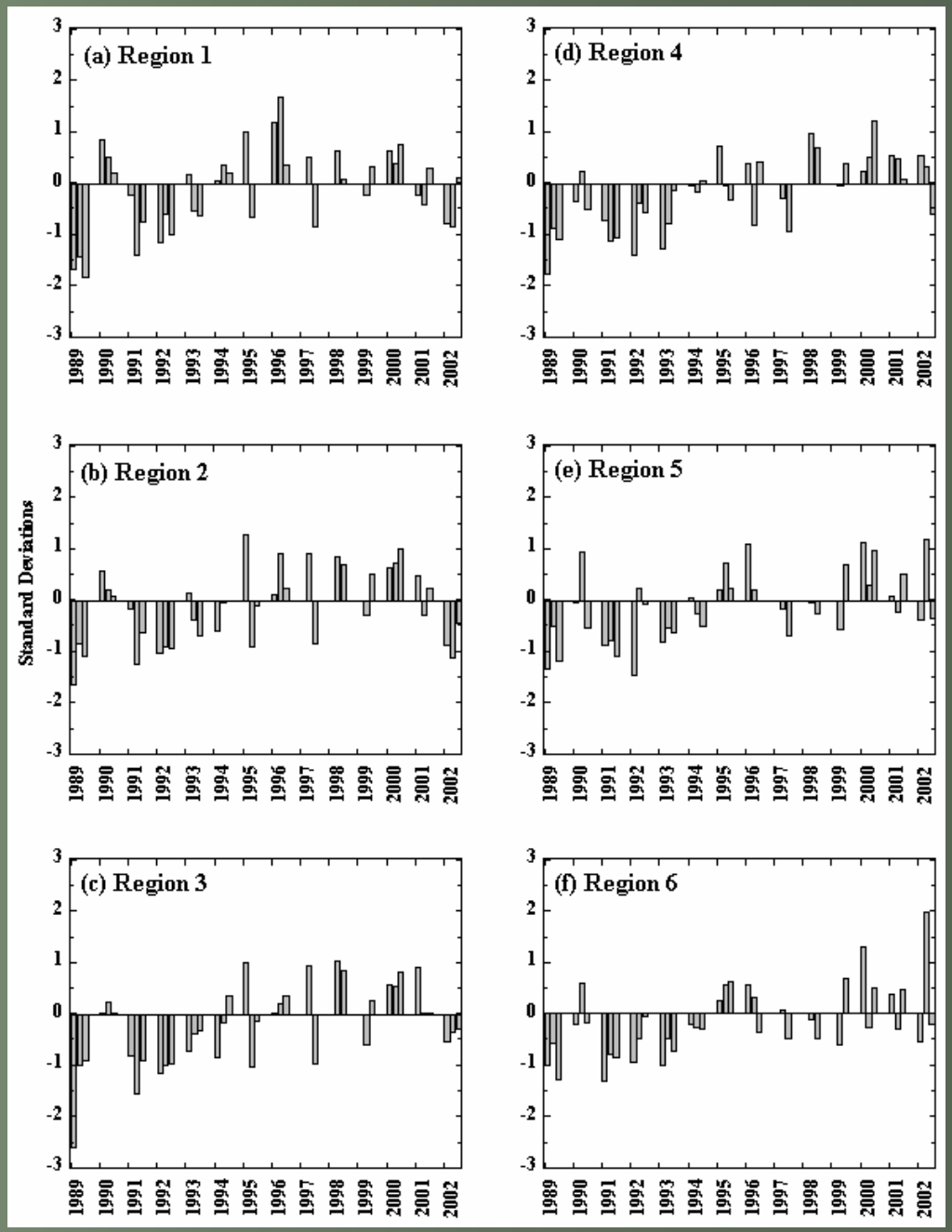




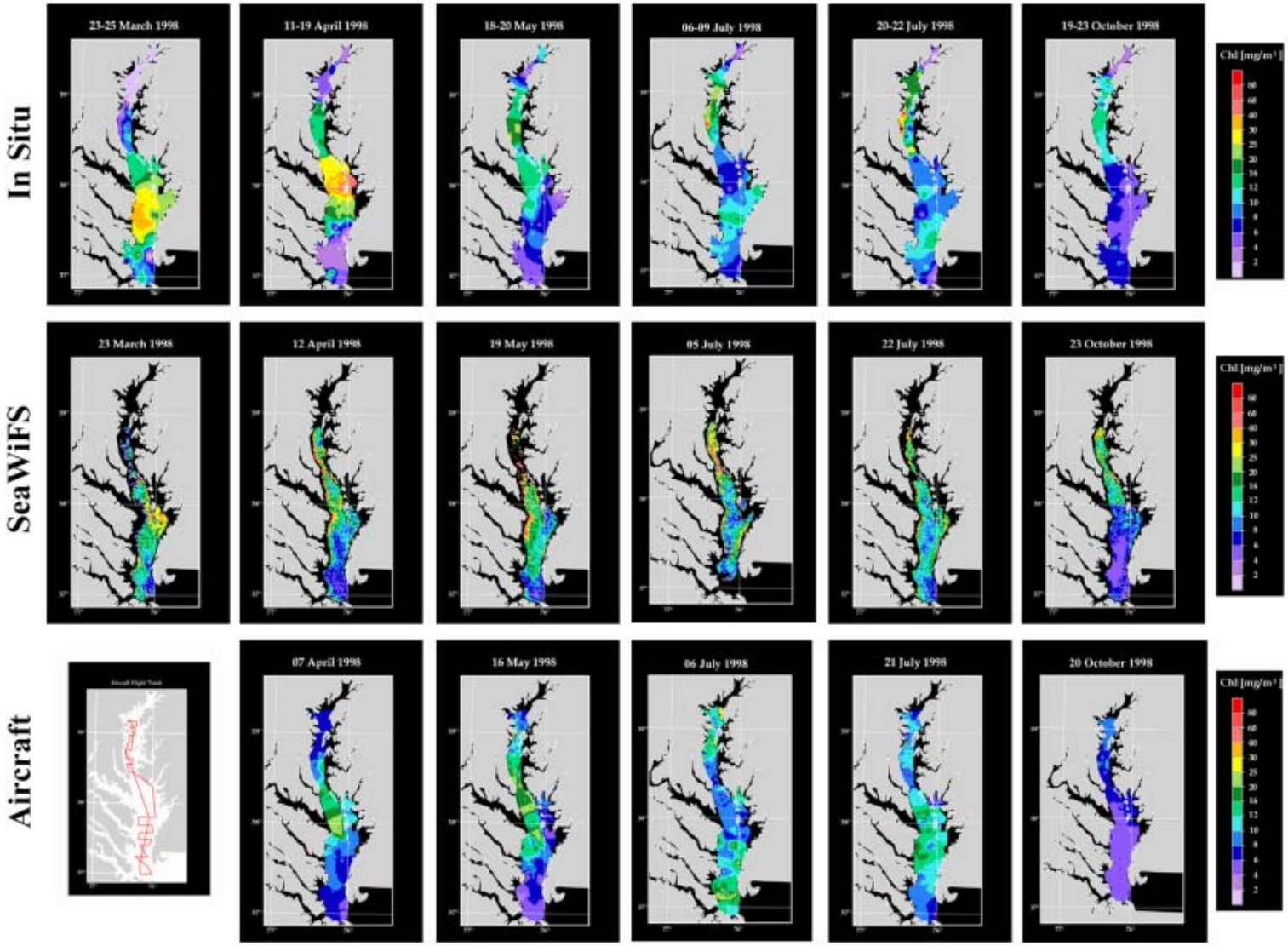


Synoptic climatology: the classification of predominant climate patterns based on sea-level pressure to link seasonal and interannual variability of chl-a and PP to climate: Dave Miller (Ph.D. Candidate)

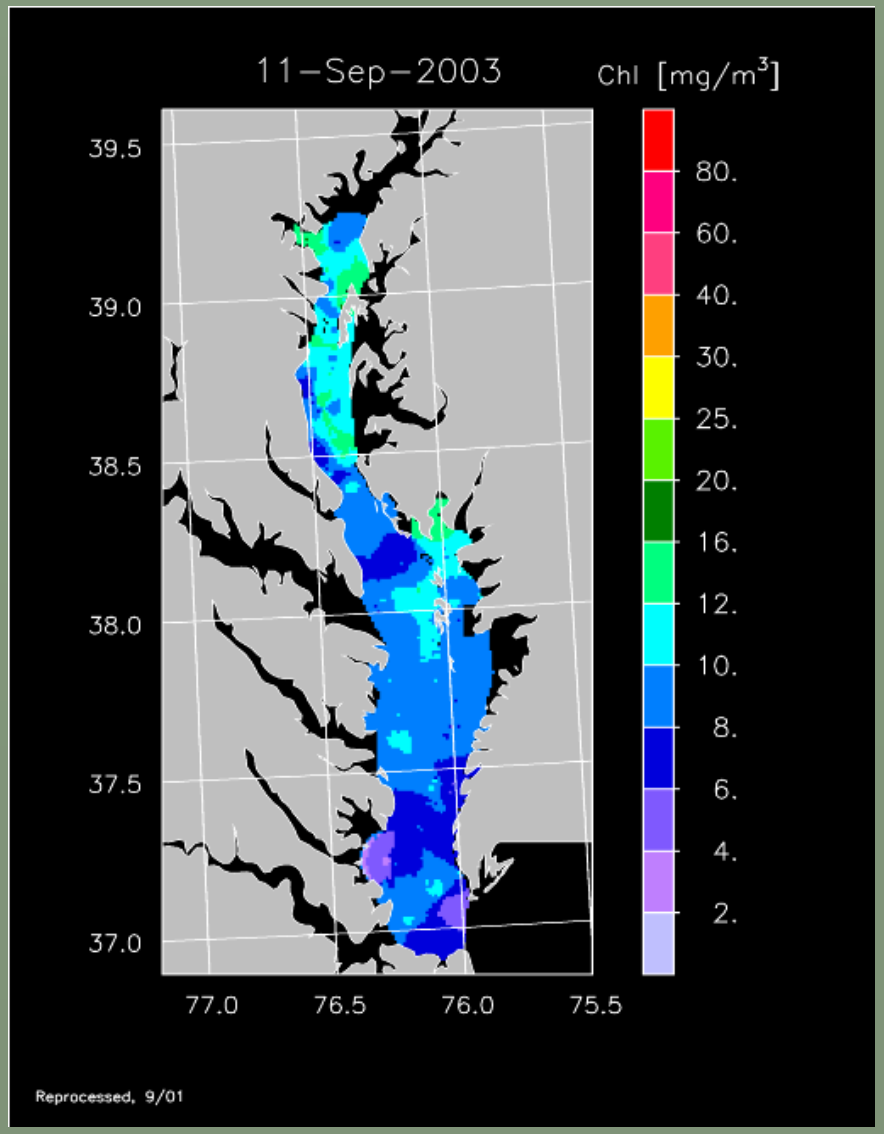
Annual chl-a anomalies from long-term regional means (1989-02)

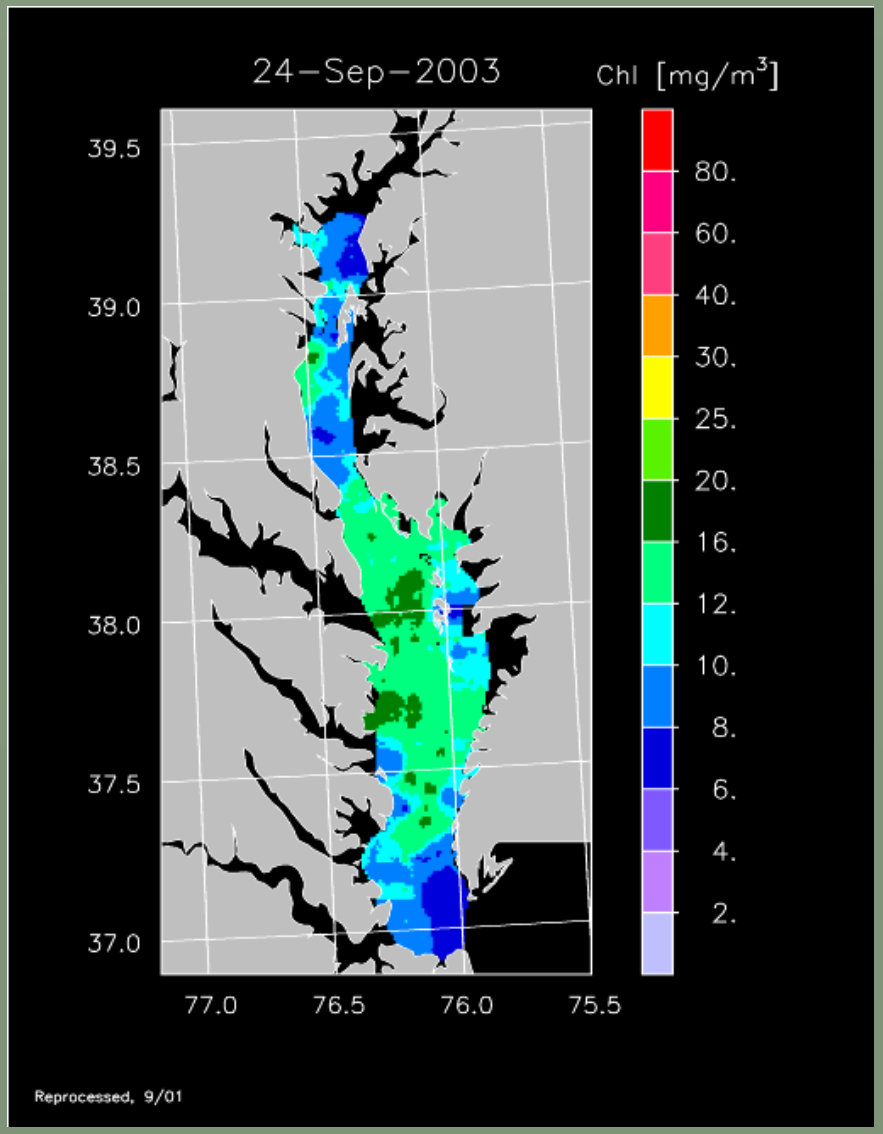


Comparison of shipboard, satellite and aircraft retrievals of chl-a for matching dates in 1998



Pre- and post- Isabel flights, Sept 2003





Summary

1. Spatial and temporal variability of phytoplankton biomass and primary productivity are strongly expressed in Chesapeake Bay;

2. Forecasts of key ecosystem properties such as primary productivity require data of high resolution for years of contrasting forcing by freshwater flow and other independent variables to capture this variability;

3. Remotely sensed observations of ocean color and temperature by CBRSP provide data sufficient to model the annual cycle of primary productivity to support these forecasts;

4. Several expressions of phytoplankton dynamics are driven by a common set of drivers, providing a basis to develop forecasts that include floral composition;

5. Synoptic climatology links continental-scale weather to precipitation, freshwater flow, and ecosystem responses, adding to our predictive capabilities.

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'Remote sensing' along the Hana coast, Maui