U.S. ECoS

U.S. Eastern Continental Shelf Carbon Budget: Modeling, Data Assimilation, and Analysis

A project of the NASA Earth System Enterprise Interdisciplinary Science Program

E. Hofmann, M. Friedrichs, C. McClain, D. Haidvogel, J. Wilkin, C. Lee, A. Mannino, R. Najjar, J. O'Reilly, K. Fennel, J.-N. Druon, S. Seitzinger, S. Signorini, D. Pollard

Ocean Carbon and Biogeochemistry Gulf of Mexico Workshop
St. Petersburg, Florida
May 6-8, 2008

U.S. ECoS

Goal: To develop carbon budgets for the U.S. east coast continental shelf (Mid-Atlantic Bight and South Atlantic Bight)

Research Questions:

1. What are the relative carbon inputs to the MAB and SAB from terrestrial run-off and *in situ* biological processes?
2. What is the fate of DOC input to the continental shelf from estuarine and riverine systems?
3. What are the dominant food web pathways that control carbon cycling and flux in this region?
4. Are there fundamental differences in the manner in which carbon is cycled on the continental shelves of the MAB and SAB?
5. Is the carbon cycle of the MAB and SAB sensitive to climate change?

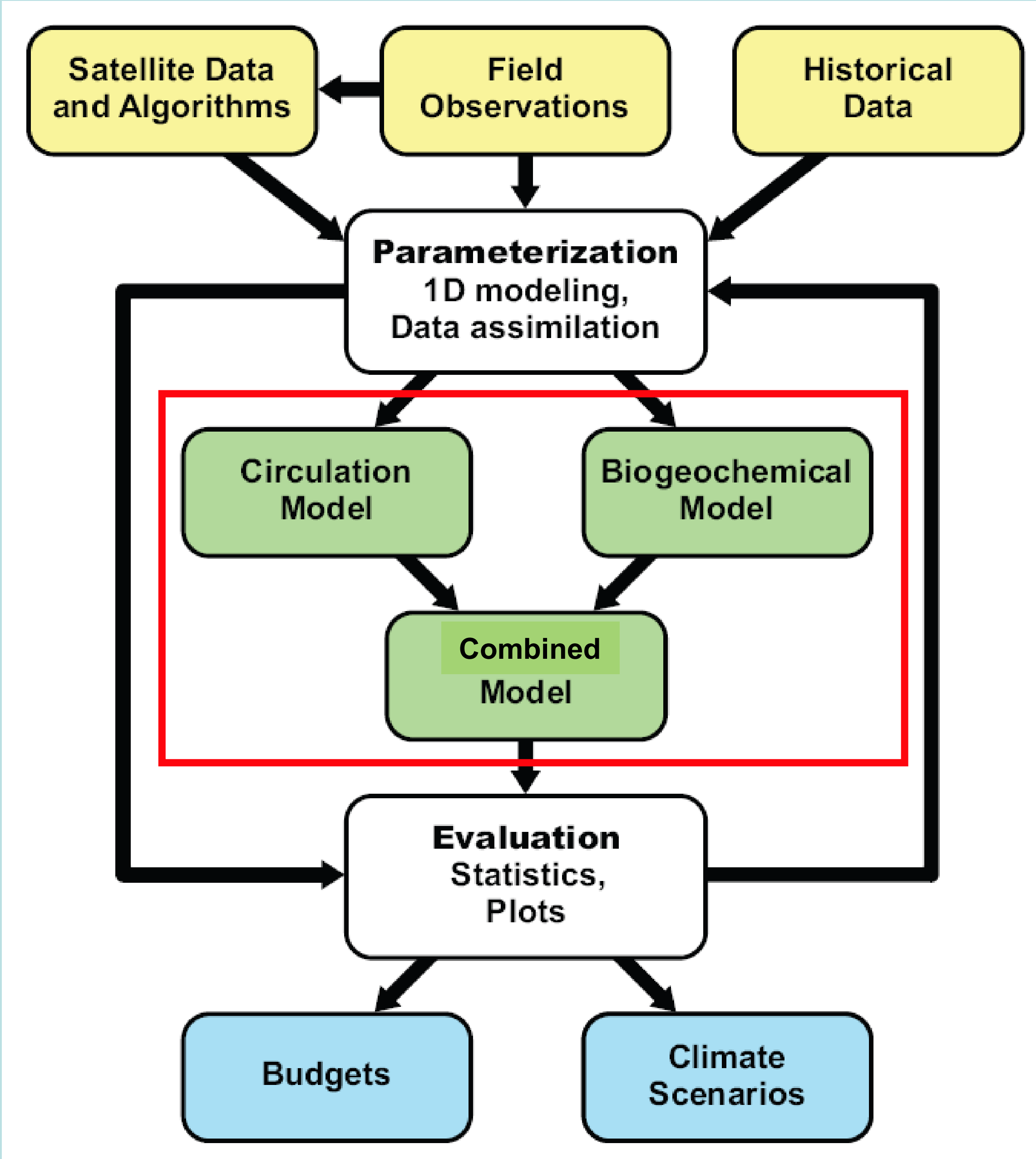
Project Structure

Personnel - 14 science investigators, 10 institutions

- Breadth of expertise - modelers and observationalists
- Multiple subgroups working in parallel with an overall focus on model-data comparisons

Parallelism coupled with frequent communication

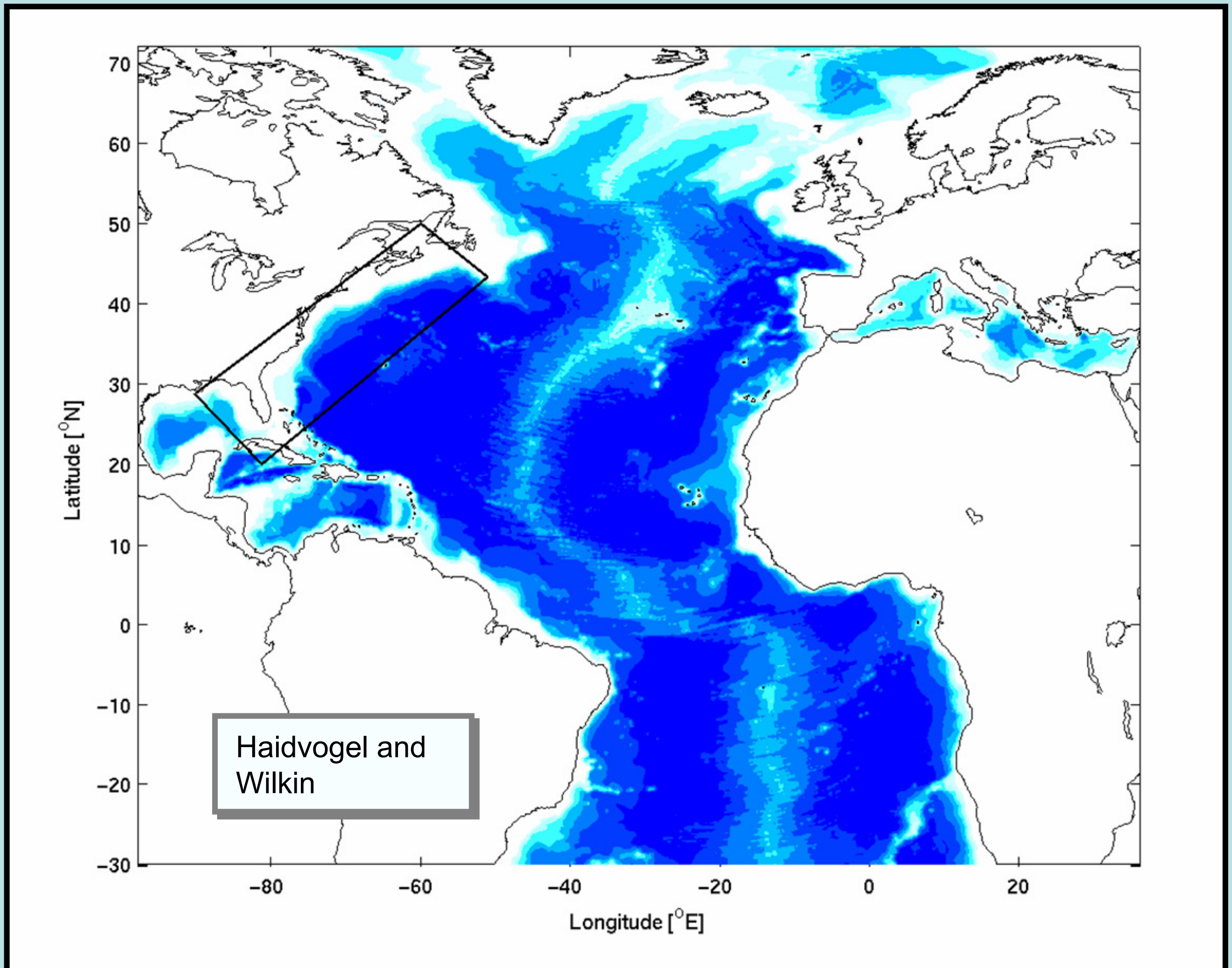
- Builds diversity



Hofmann *et al.* (2008)

Circulation Model

Northeast North American shelf model (NENA)



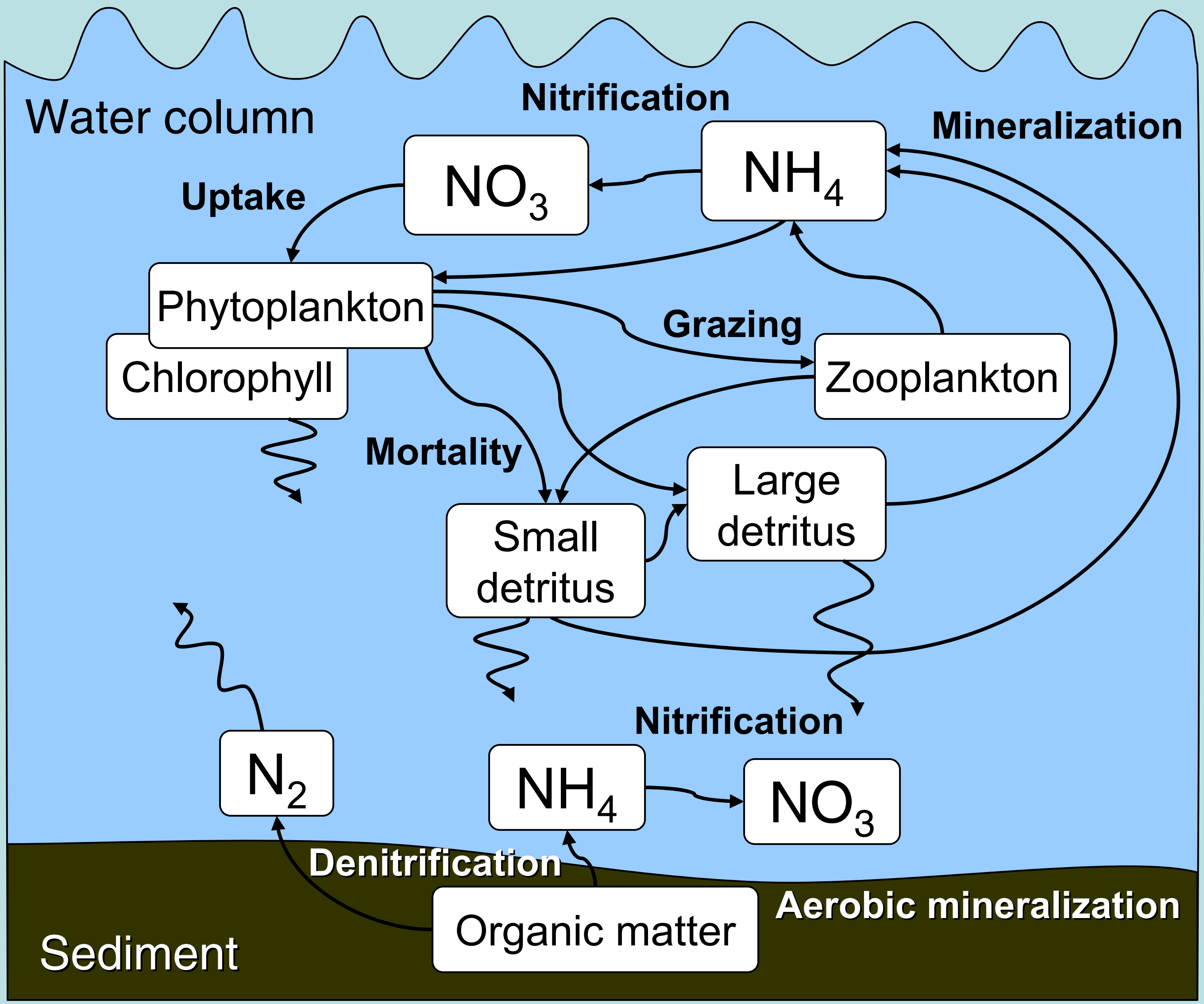
Based on ROMS
10 km horizontal resolution
30 vertical levels
Nested in HYCOM

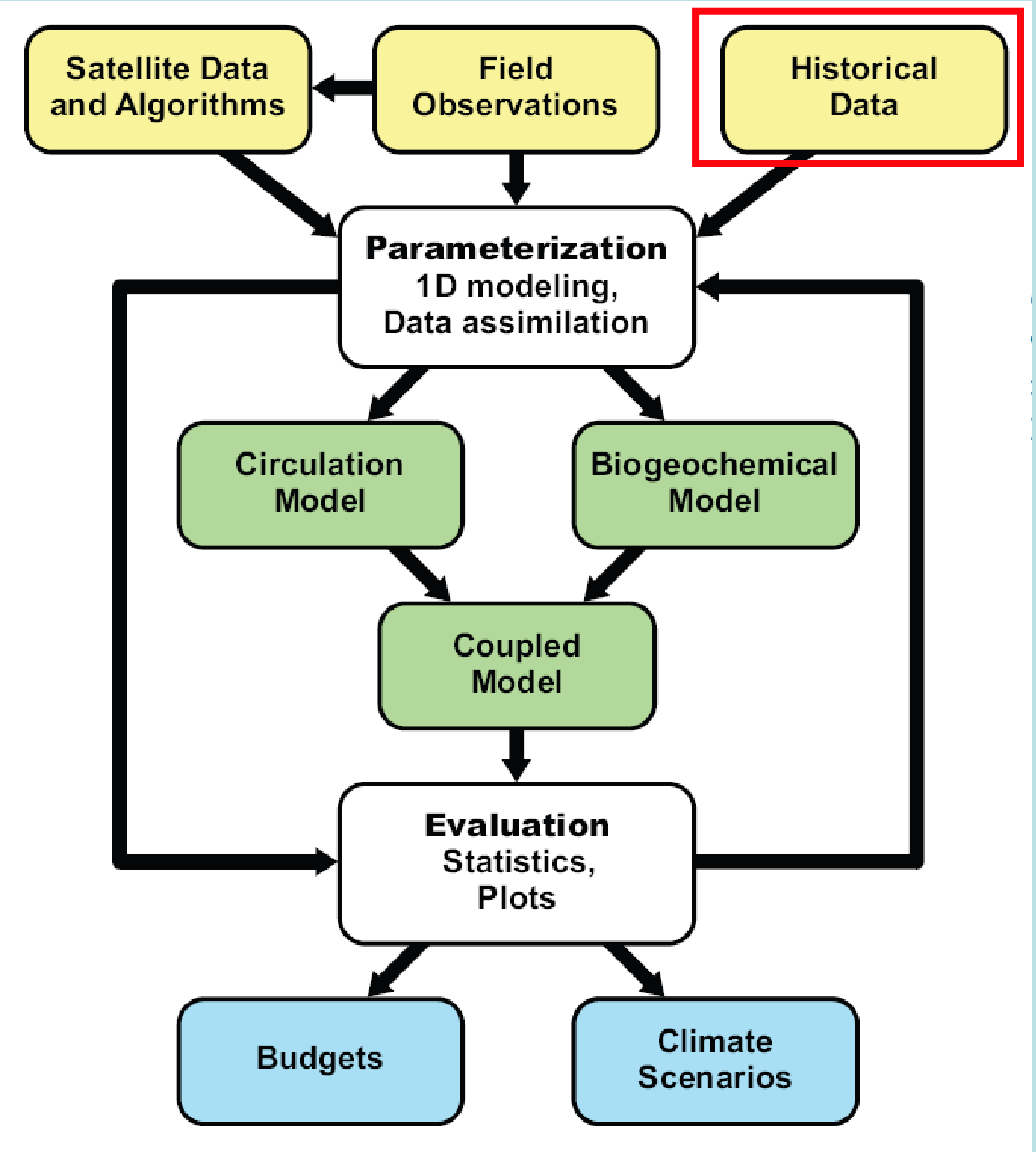
Schematic of Biogeochemical Model

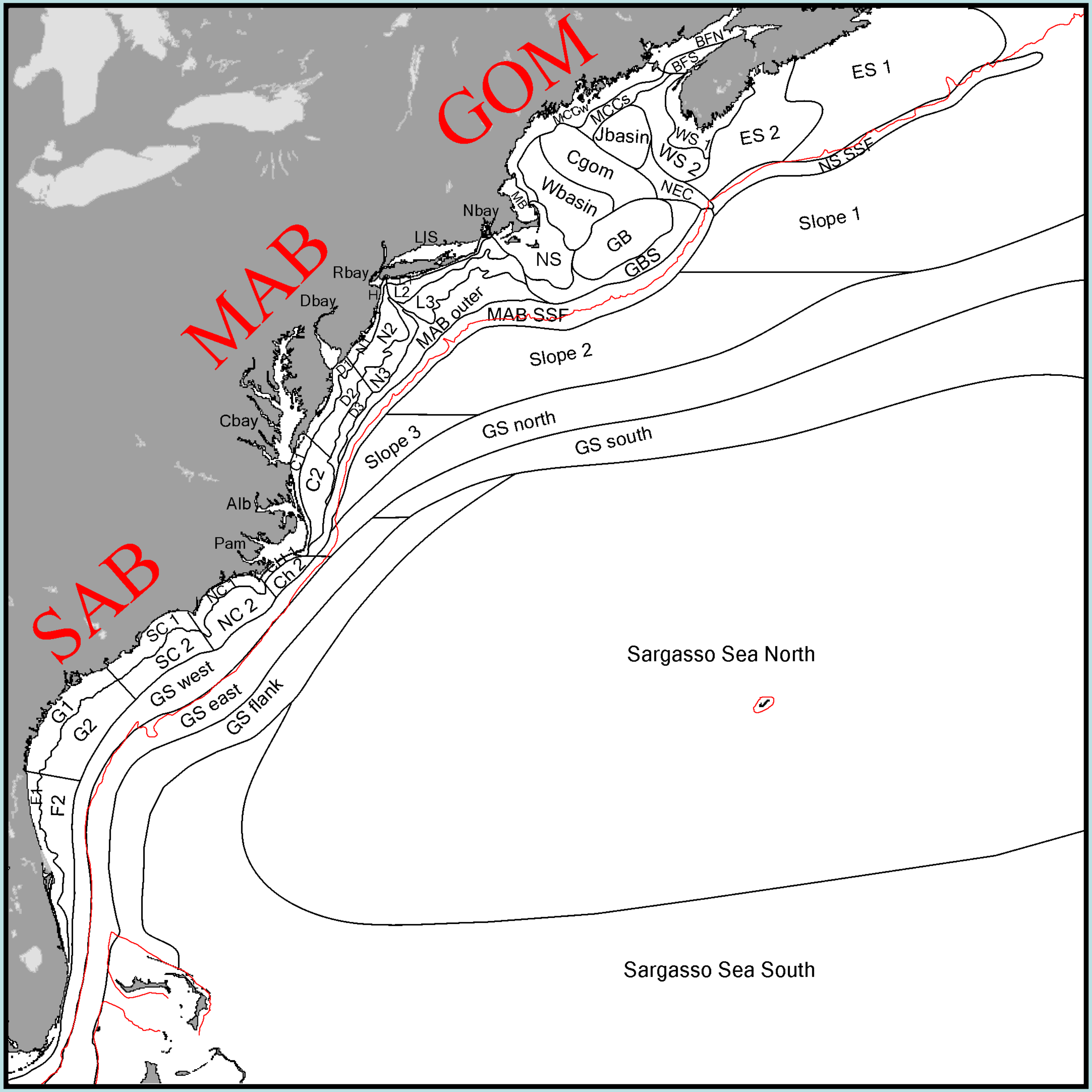
N shown here, but also includes C and O_2

Fennel et al. (2006)

Semi-labile DOM recently added




Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Coupled Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios



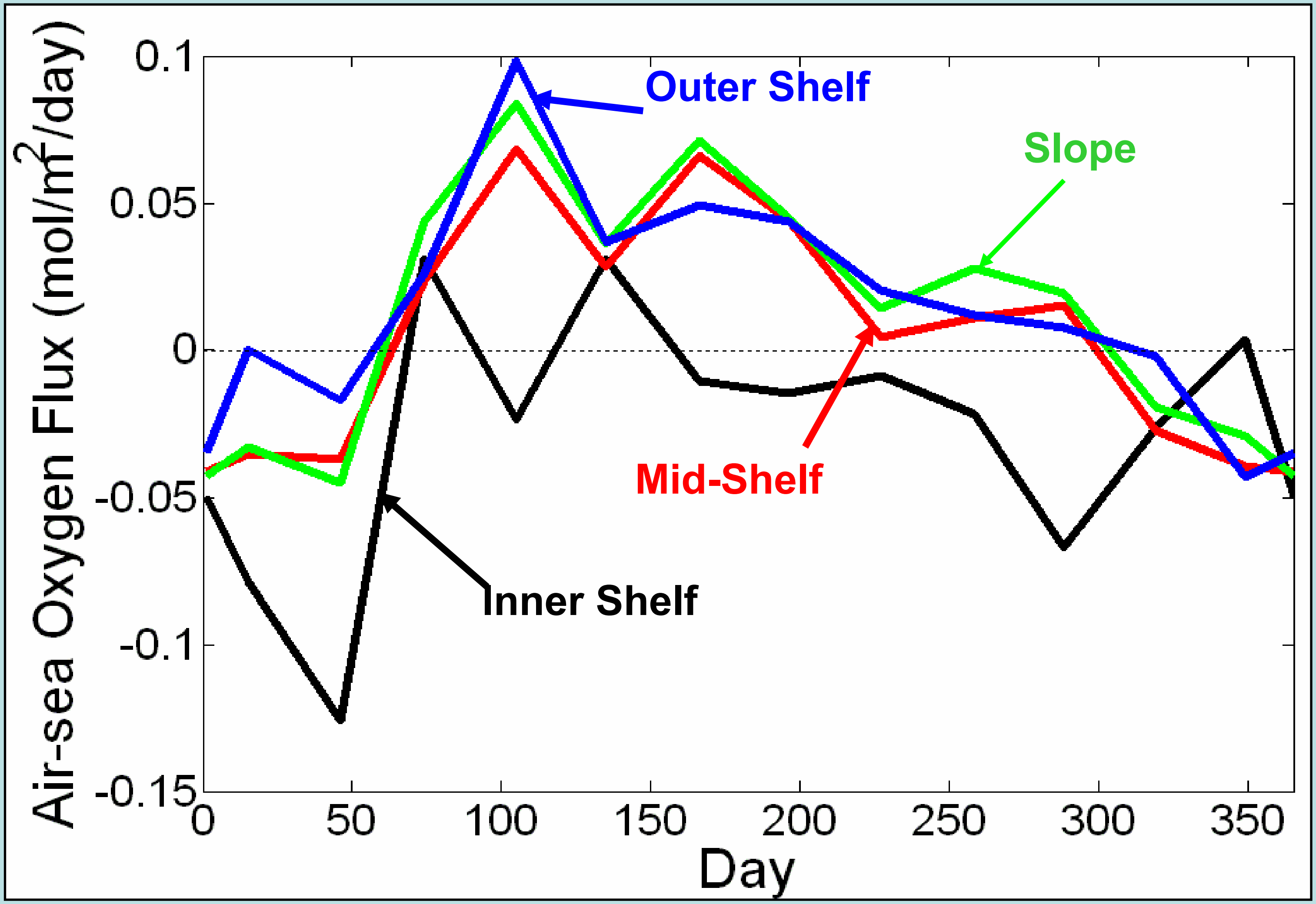
USECoS Study Region

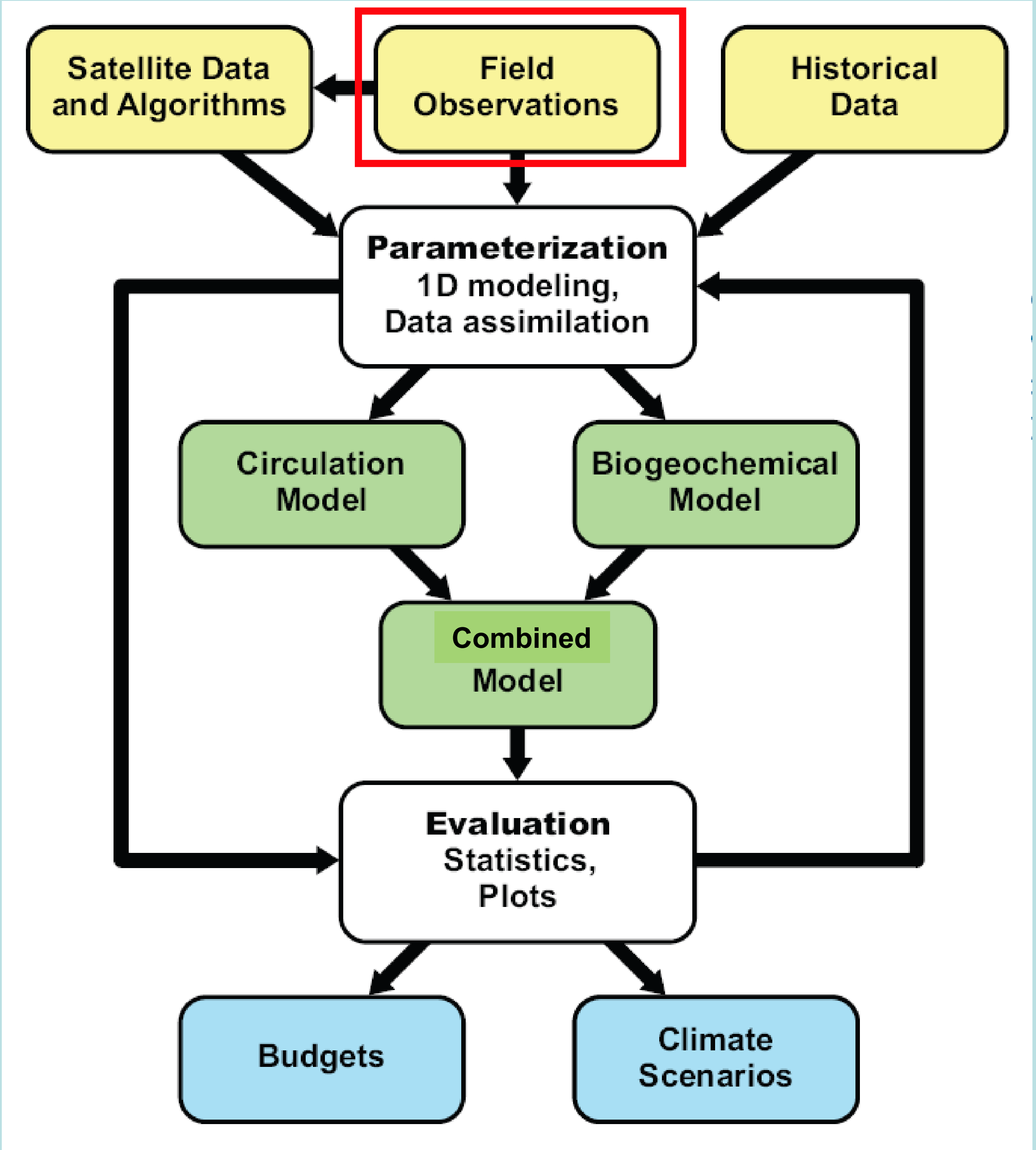
Fifty-two subregions

Profiles inshore of Sargasso:
460K T
110K S
20K O_2
(2005 WOD)

Hofmann *et al.* (2008)

MAB Sea-to-air oxygen flux



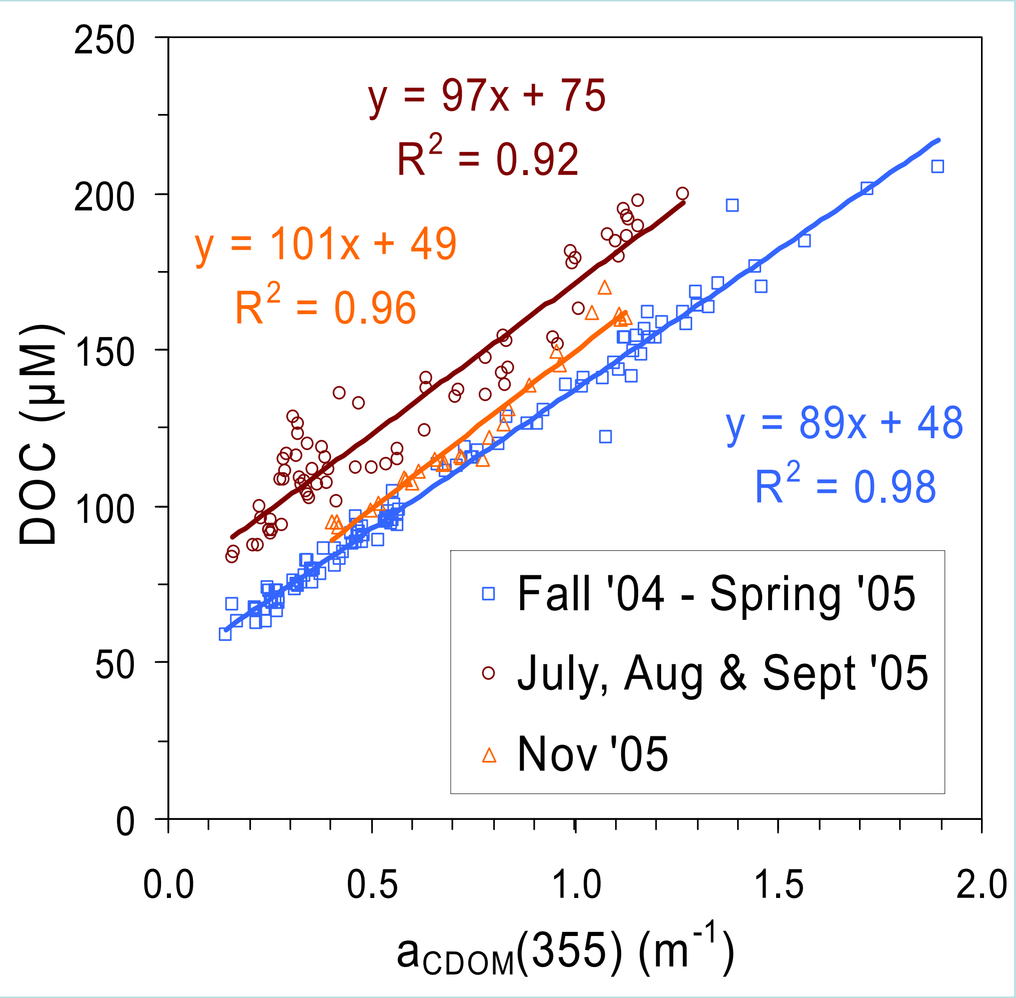


Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios

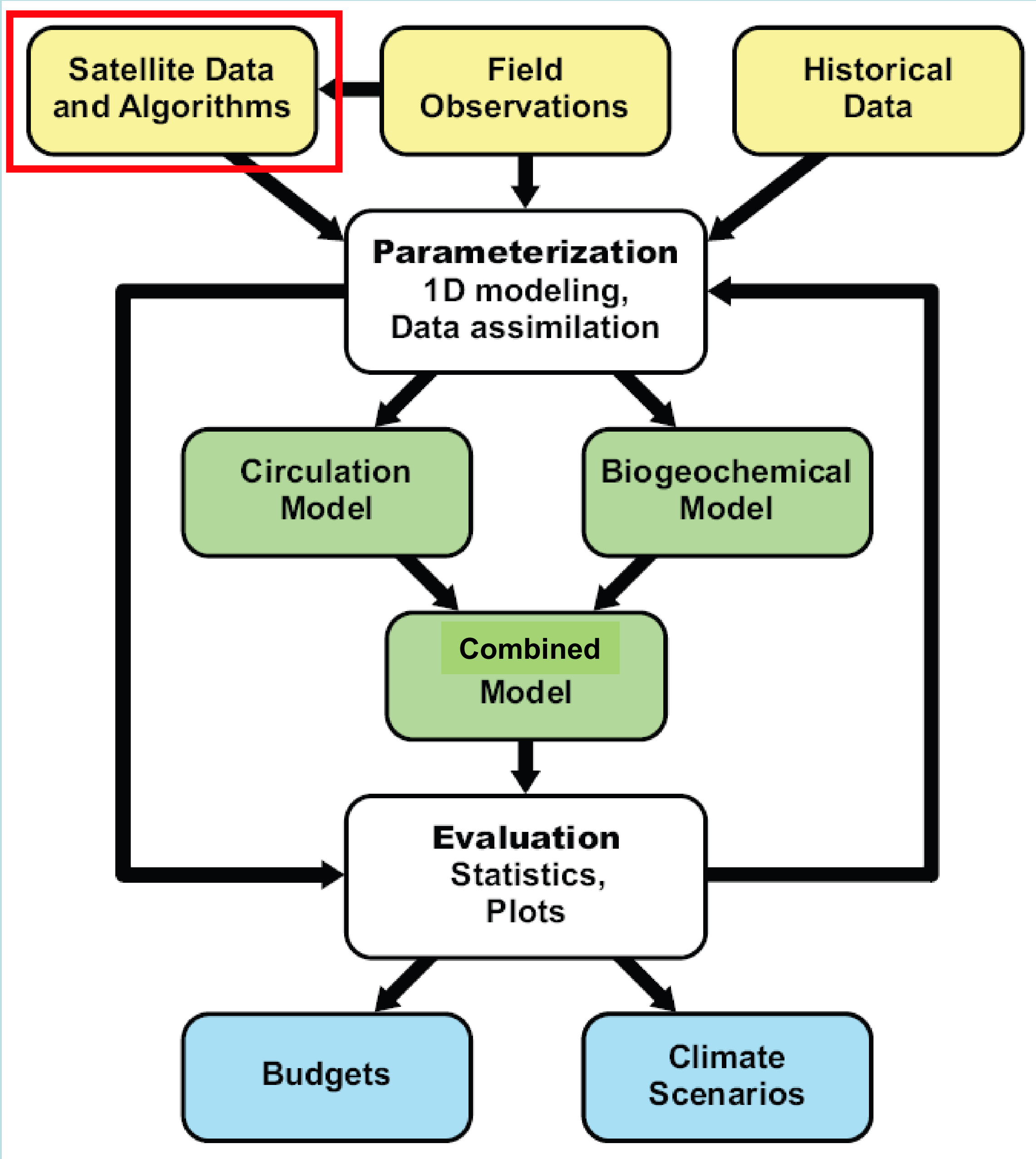
DOC & CDOM field measurements

From cruises in Southern MAB, including lower Chesapeake Bay.

Seasonal algorithms needed. Offset due to net community production of DOC and bleaching from spring to summer.

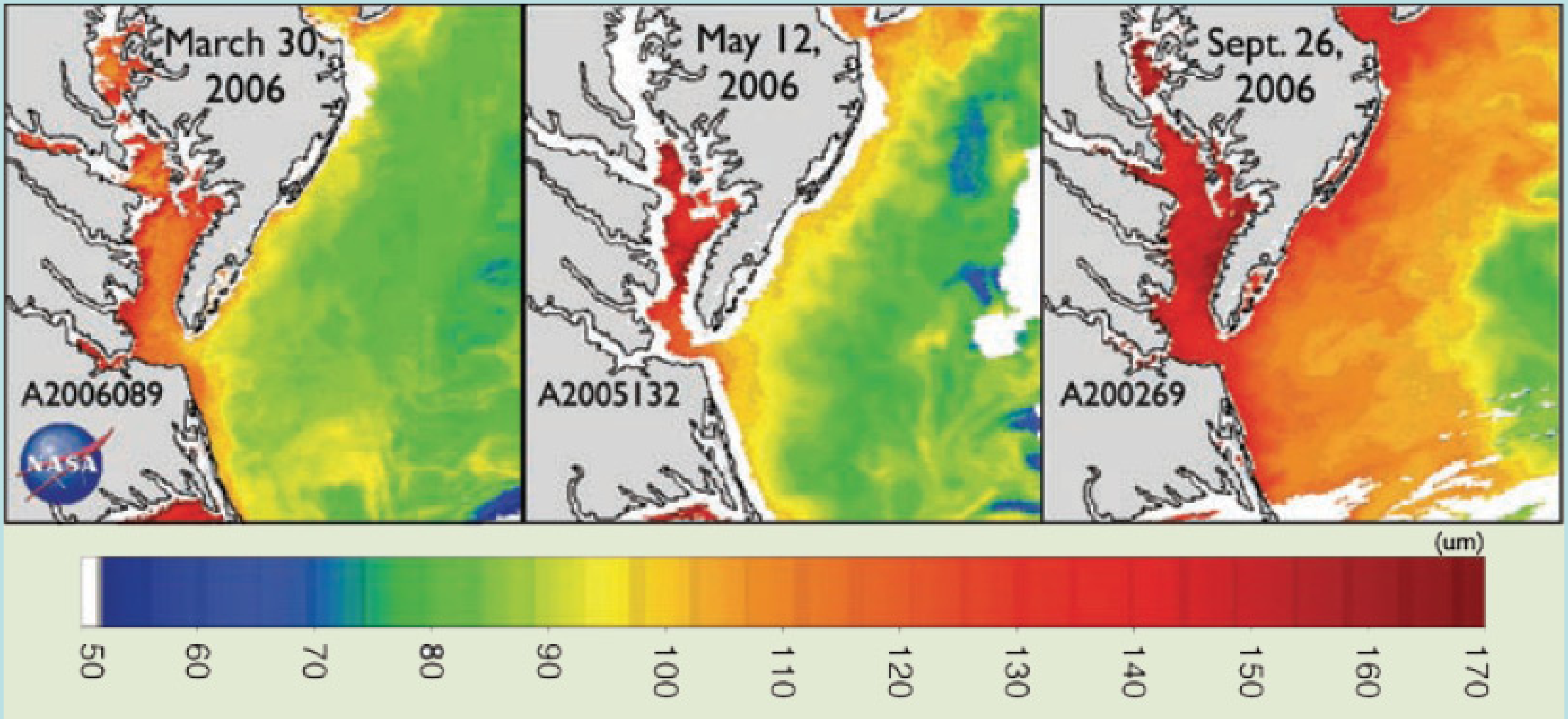


Mannino



Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios

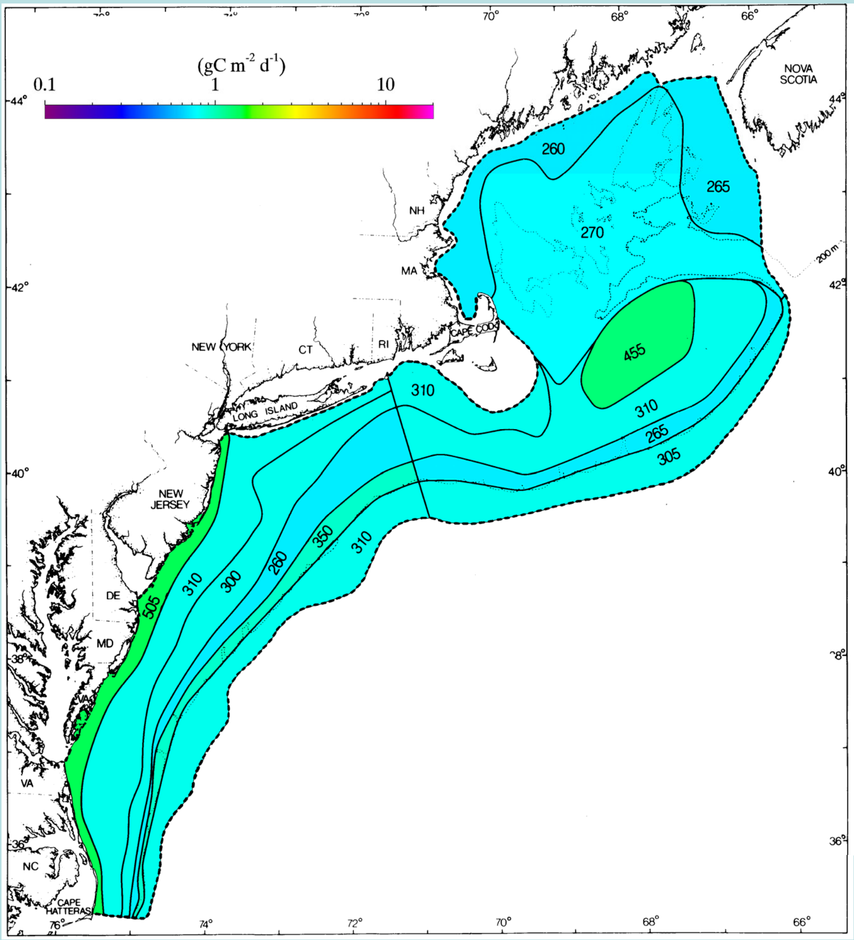
Space-based DOC estimates



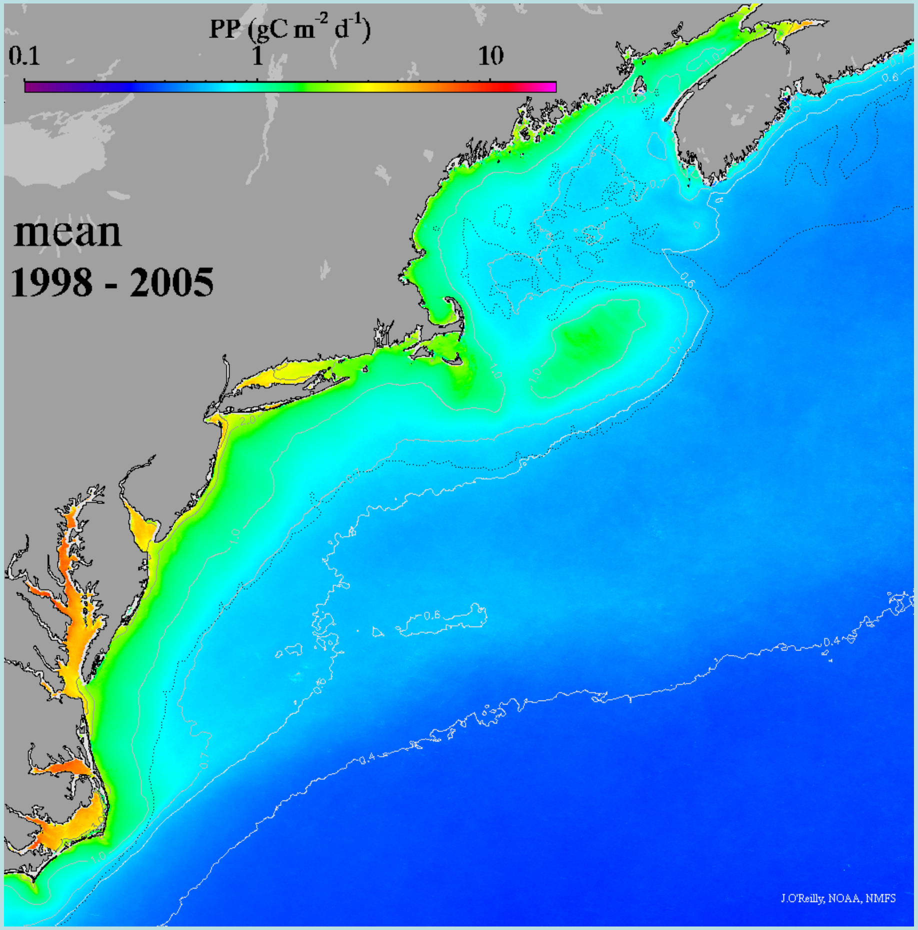
DOC concentration (μM)

Primary production

^{14}C-based from MARMAP program



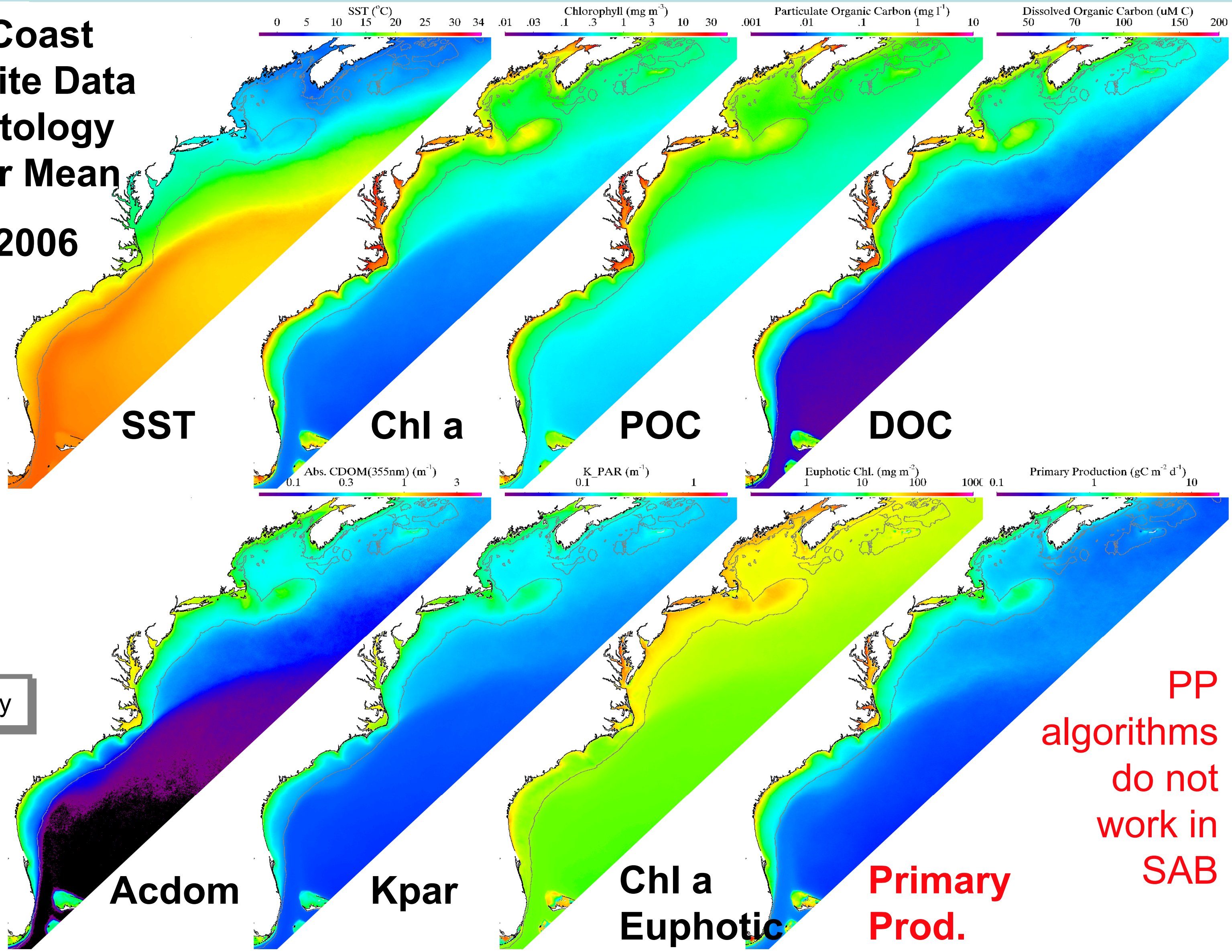
Satellite-based (VGPM2A)



Satellite Data Climatologies

East Coast Satellite Data Climatology 9-Year Mean

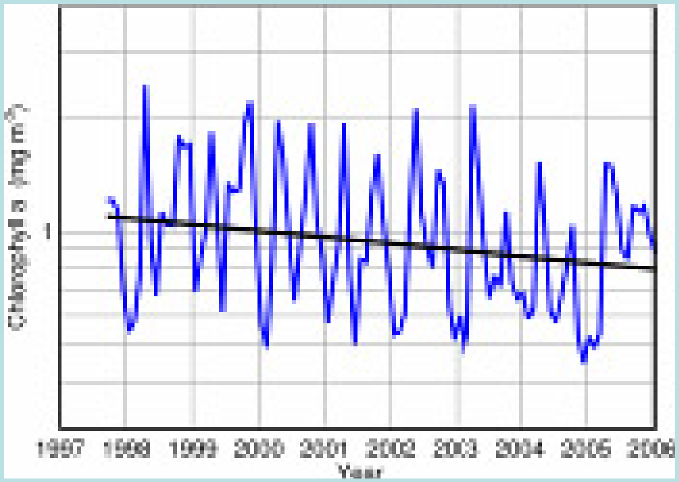
1998-2006

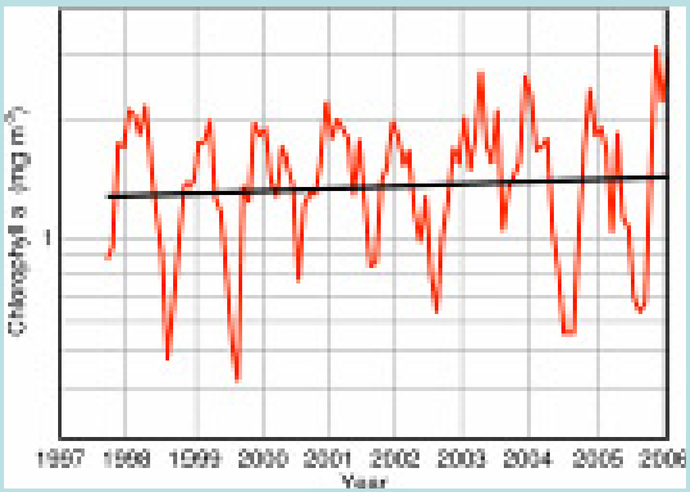


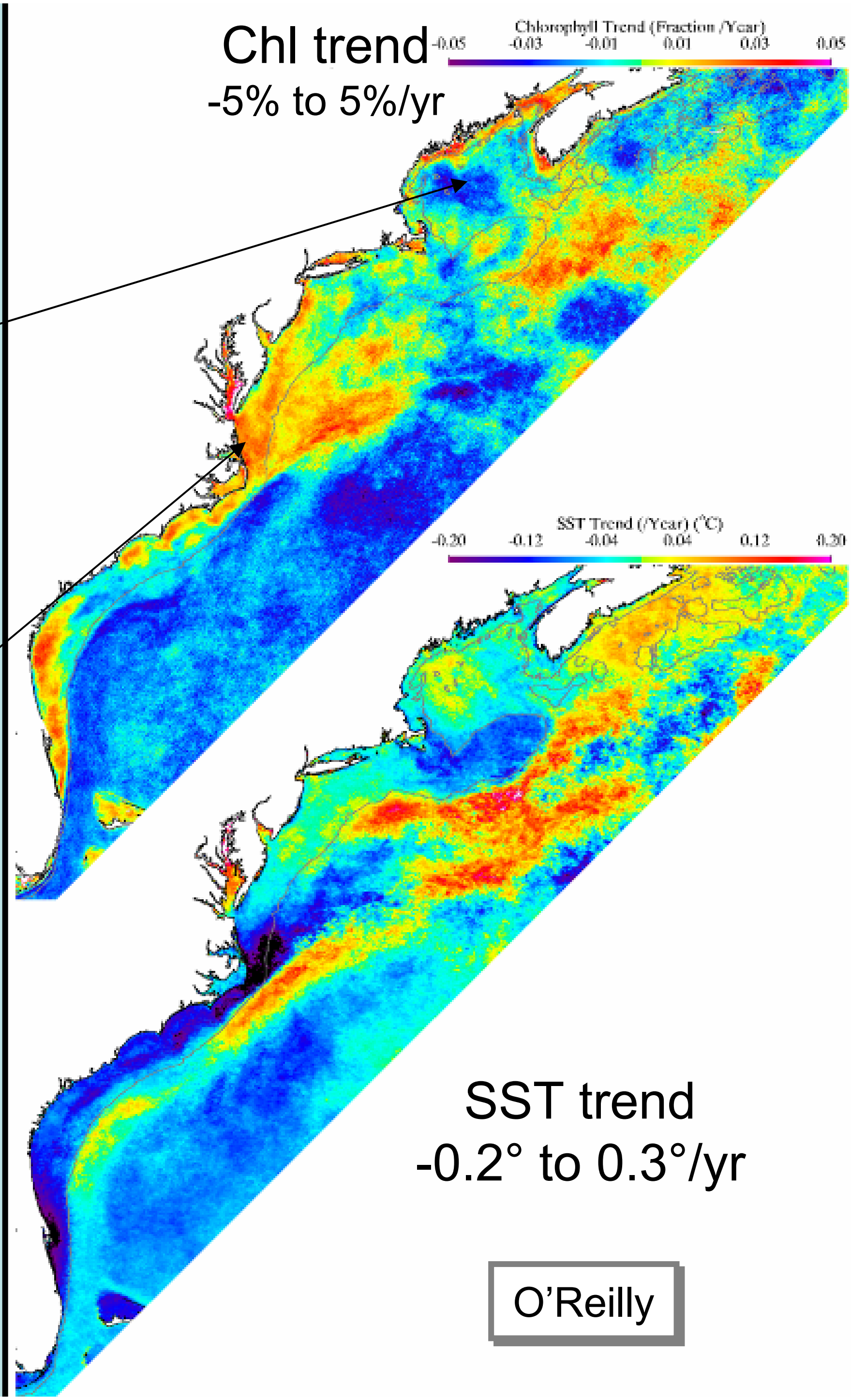
O'Reilly

PP algorithms do not work in SAB

Long Term Trends 1998-2006

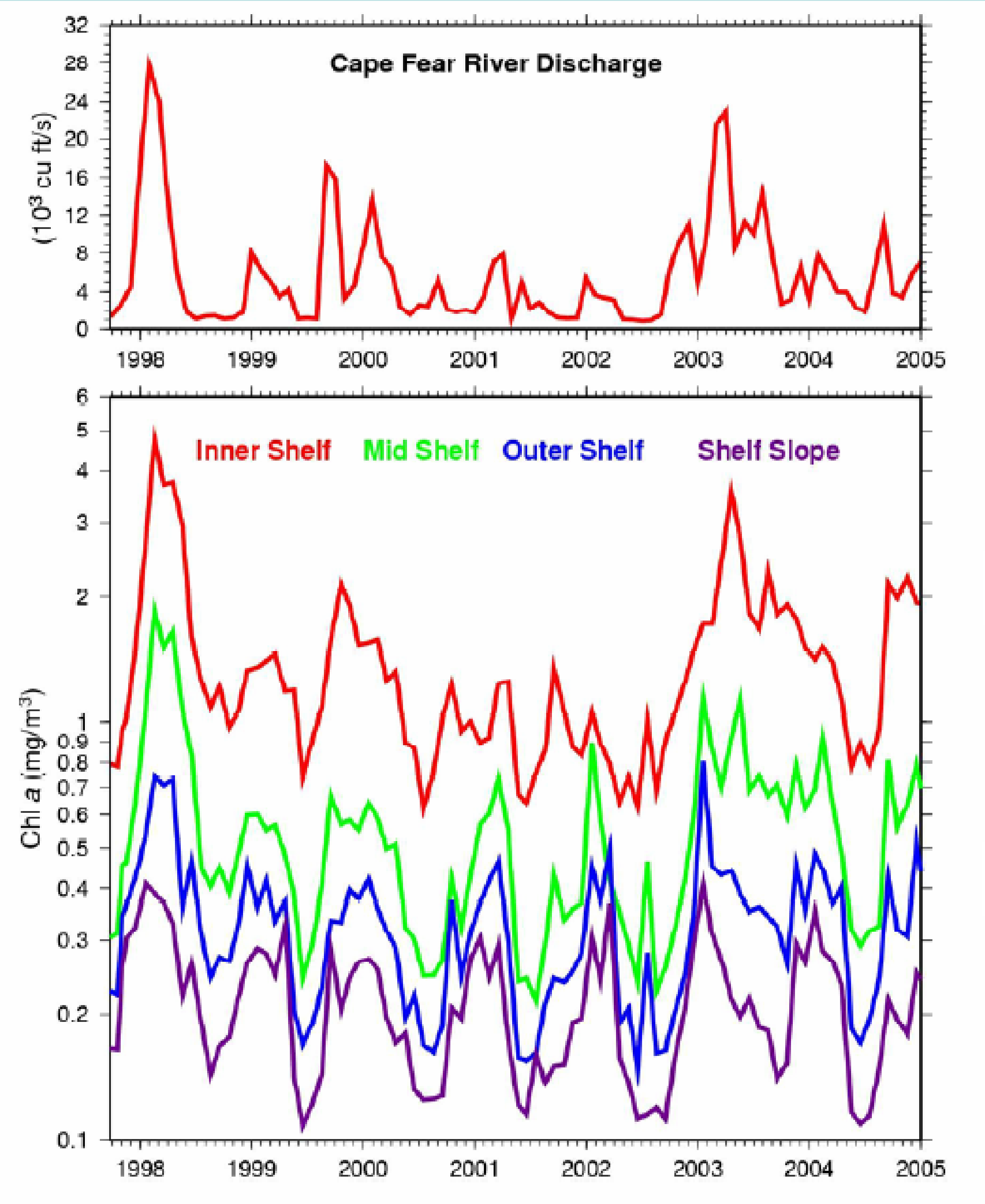






O'Reilly

SAB Chlorophyll dynamics



Correlation with discharge

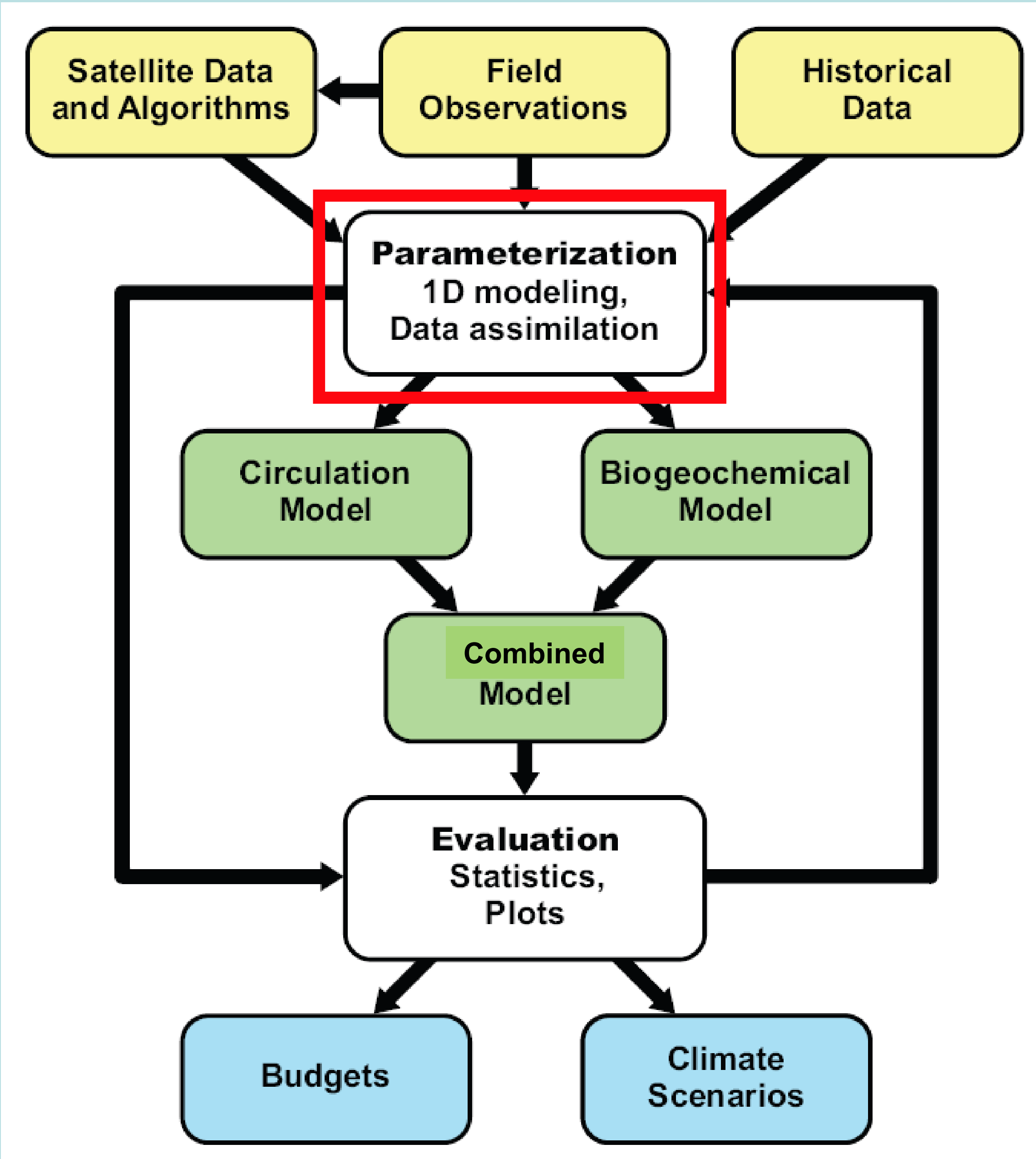
0.84

0.73

0.60

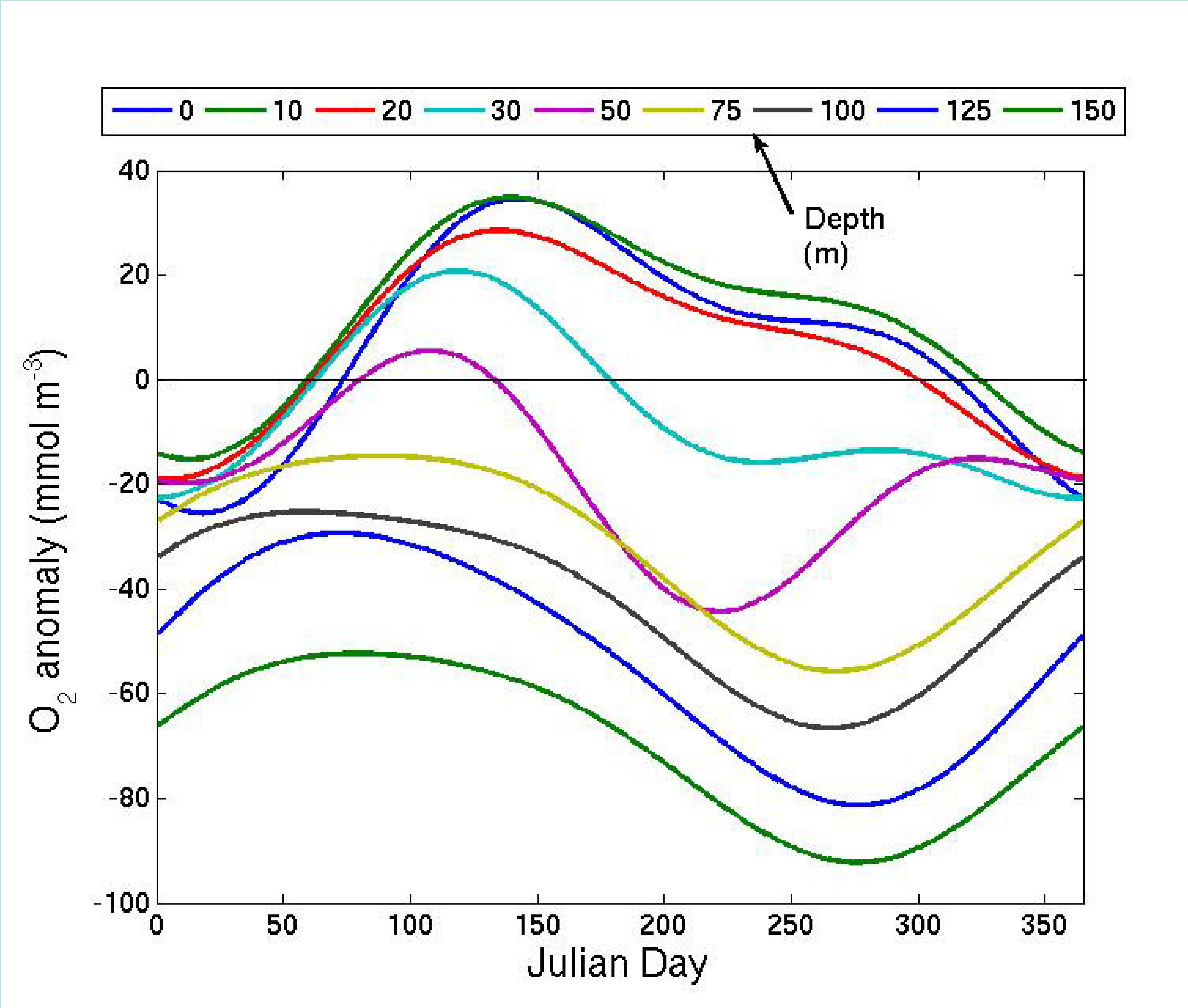
0.53

Signorini and McClain (2006, 2007)

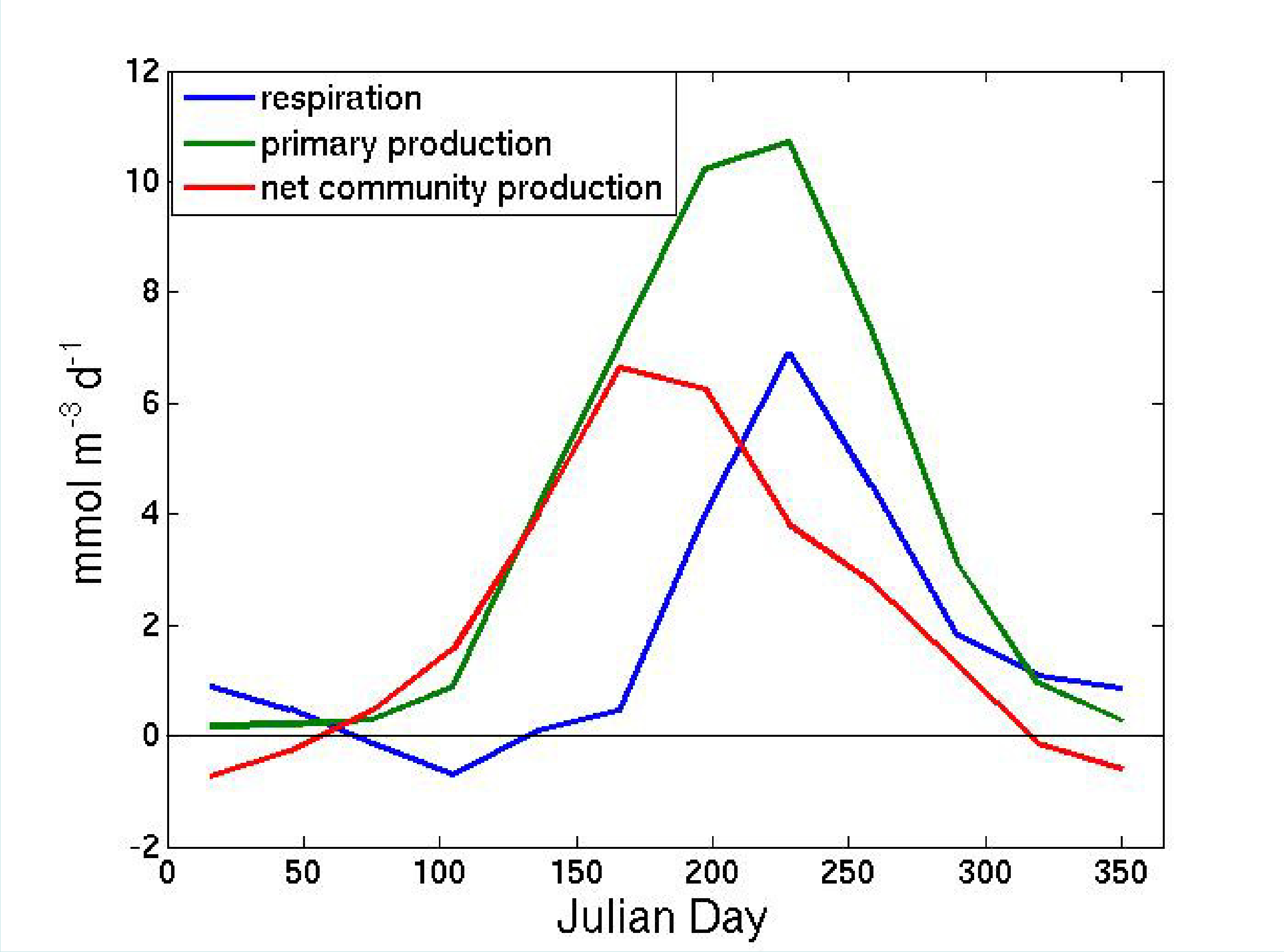


Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios

Central Gulf of Maine O_2 anomaly climatology



$$H \frac{d\Delta[O_2]_{ml}}{dt} = PP_I - R_I - F_S + F_B + E$$



Annual, integrated mixed layer budget (mol O_2 m^{-2}):

PP = 19.4

R = 13.6

NCP = 5.8

NCP ÷ *PP* = 0.30

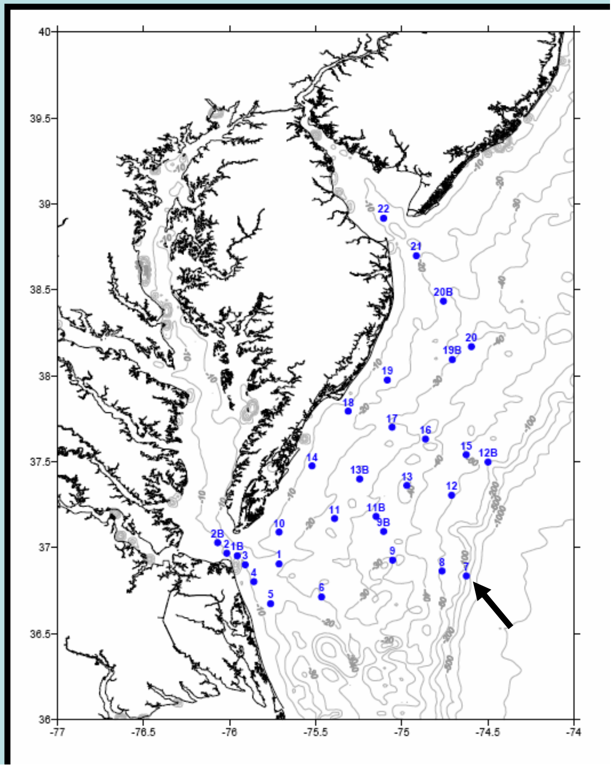
Data assimilation framework: 1D implementation

Approach:

1-D physics + horizontal advection terms from 3D model
Same biogeochemical model as is running in 3D;
reproduces 3D model results very well
Assimilate ocean color or *in situ* data (variational adjoint method)
for optimization of biogeochemical parameters
(e.g. max. growth rate; C:chl ratio)
Runs quickly

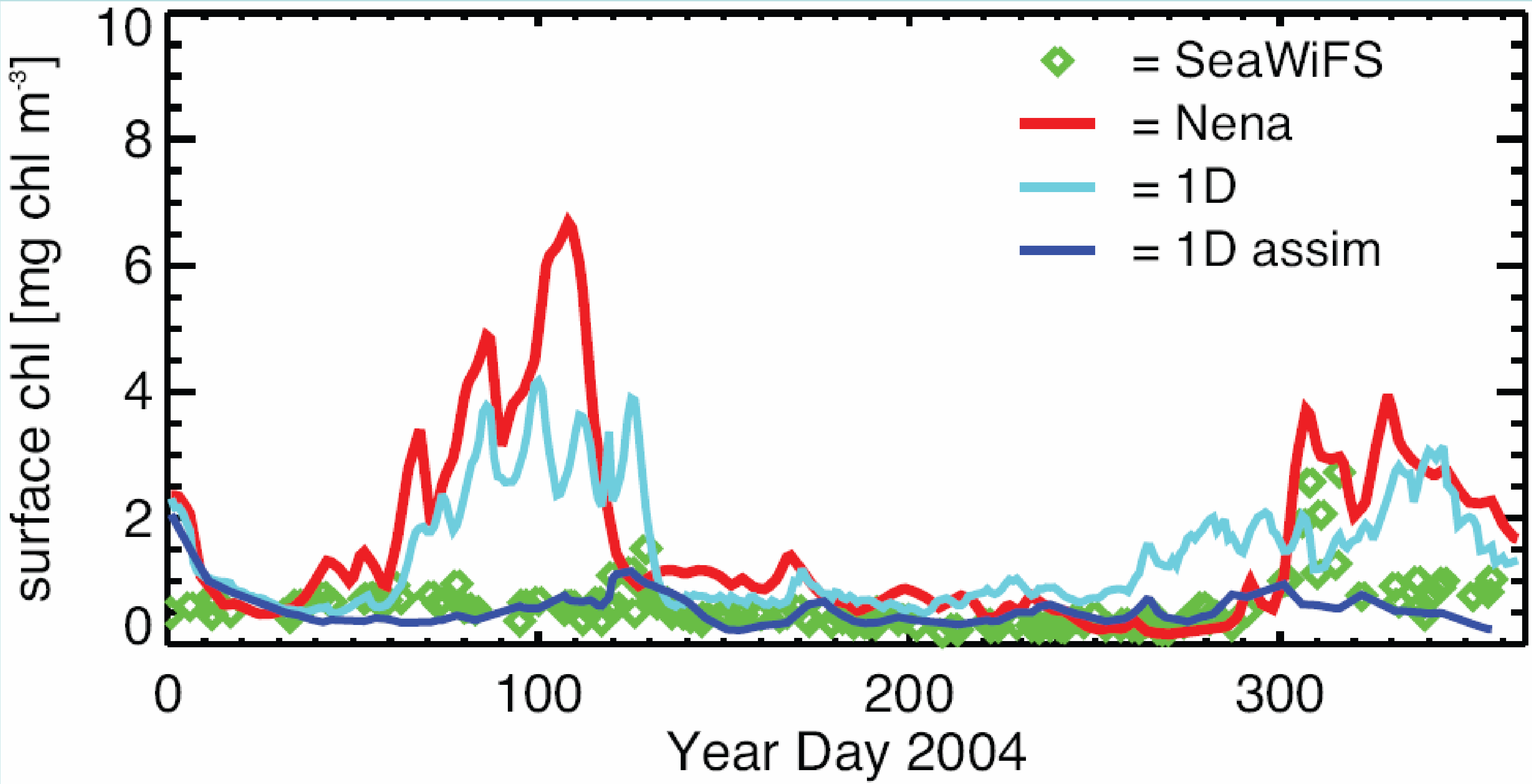
Goals:

Test new parameterizations and formulations
Perform parameter sensitivity/optimization
analyses
Quantitatively assess optimal model-data fit
via cost function



Friedrichs et al.

Impact of parameter optimization



SeaWiFS Assimilation Results

The variational adjoint method of data assimilation can be used to improve the model-data comparison:

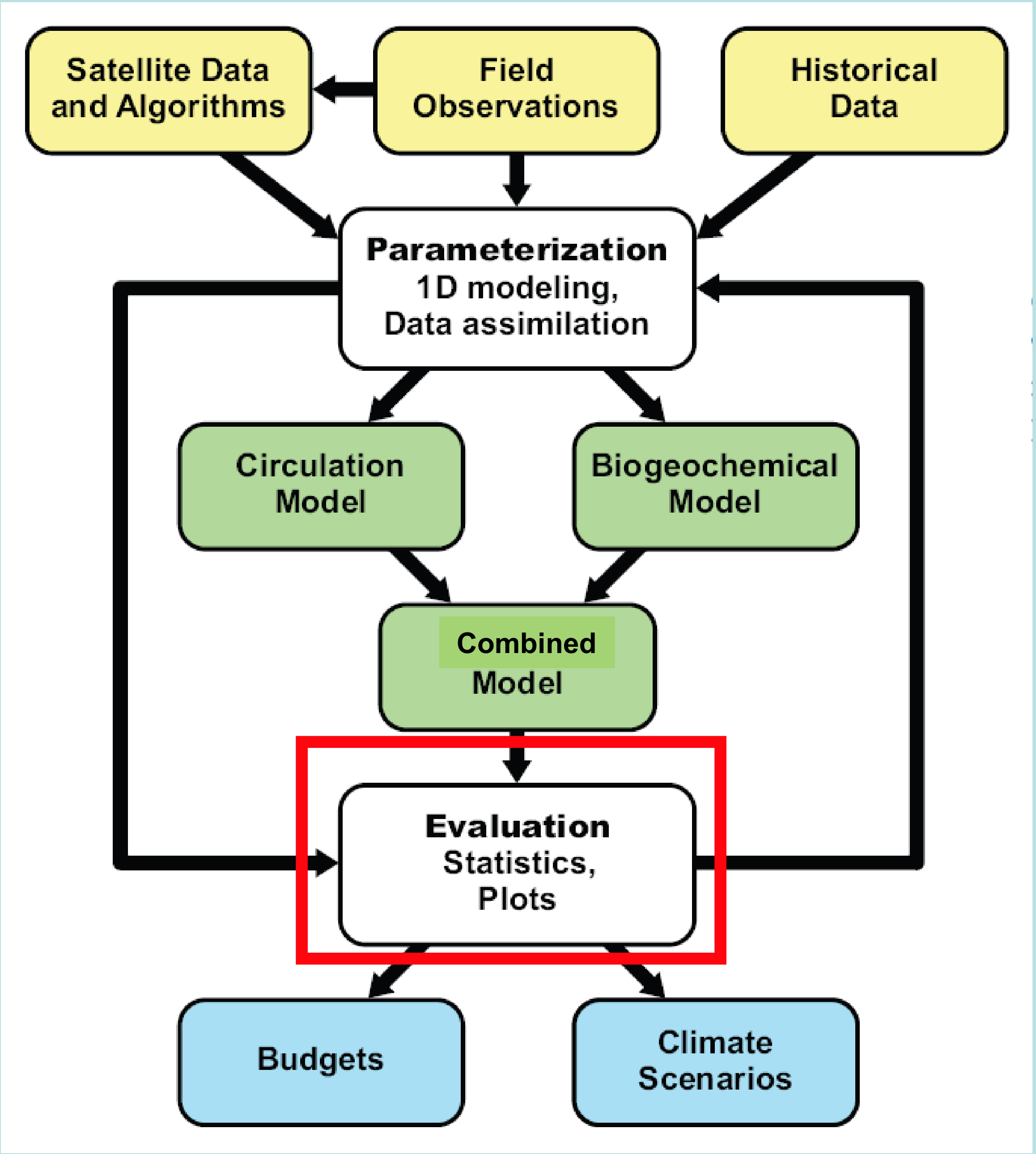
→ max growth rate [d^{-1}]

a priori: μ_0 = 1.0 → optimal: μ_0 = 0.38 ± 0.20

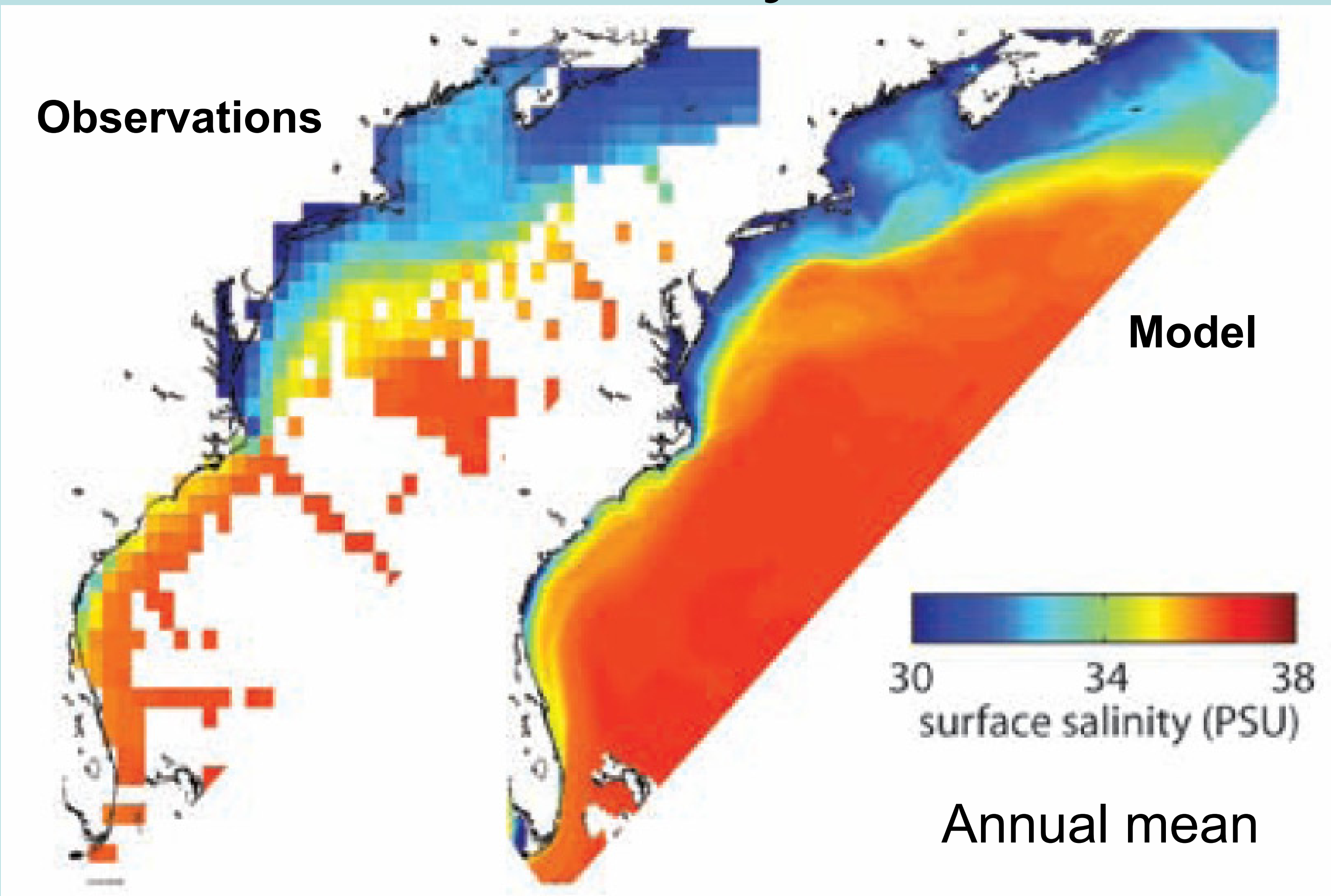
→ max Chl:C ratio [mgChl mgC^{-1}]

a priori: Chl2C = 0.0535 → optimal: Chl2C = 0.030 ± 0.009

Data assimilation is used as an approach for improving model structure

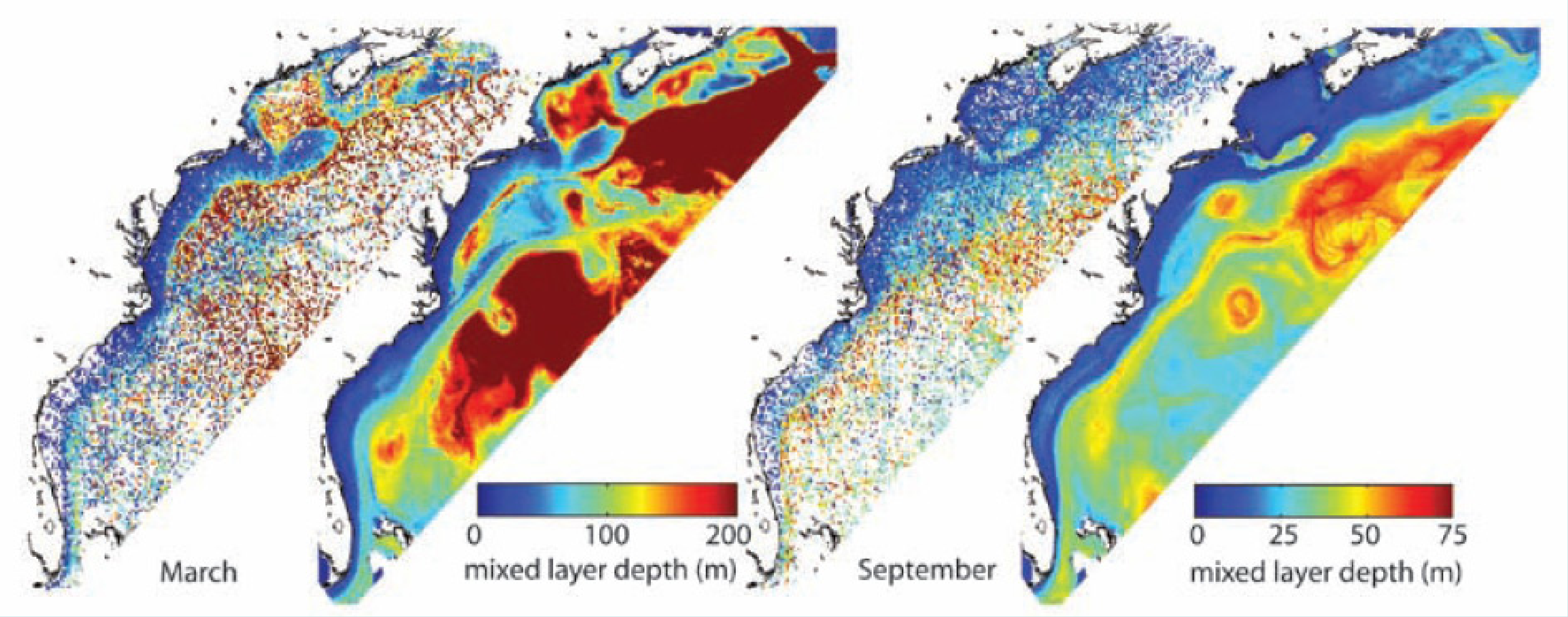

Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios

Evaluation of model physics—salinity



Evaluation of model physics—mixed layer depth

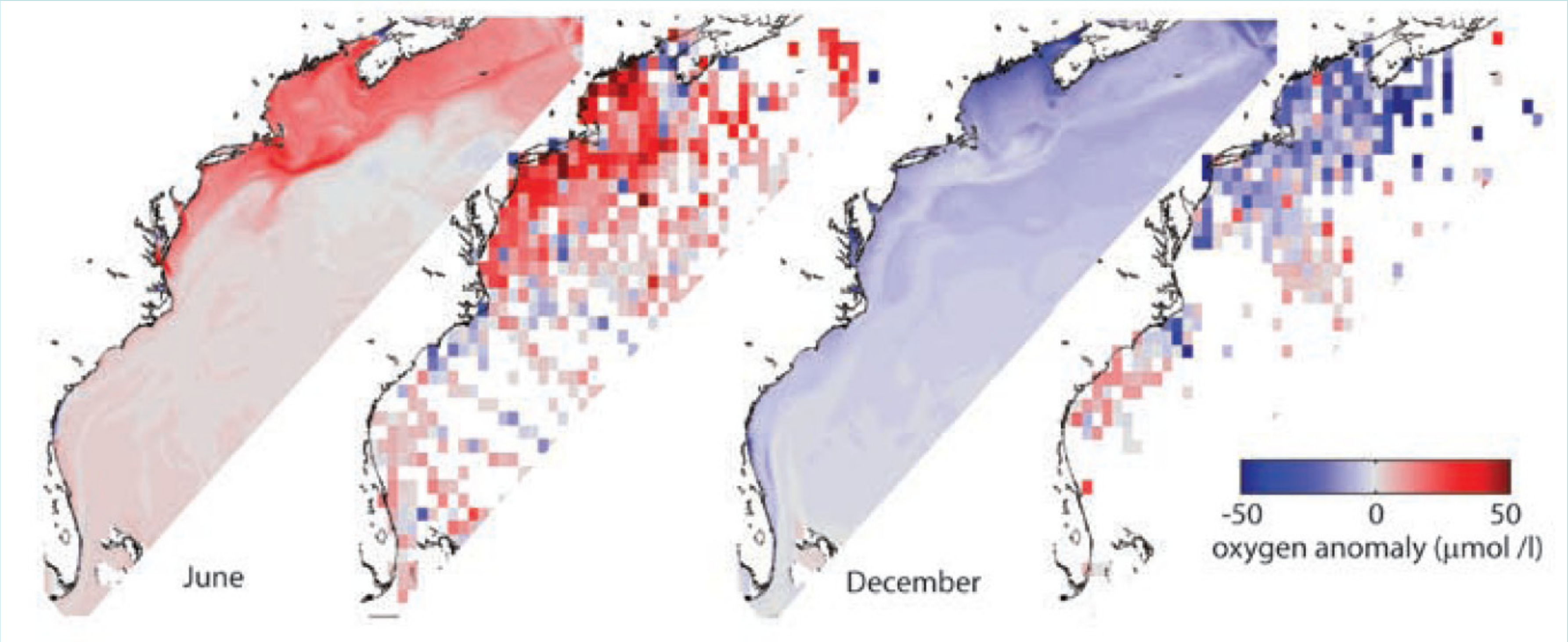
Observations **Model** **Observations** **Model**



March **September**

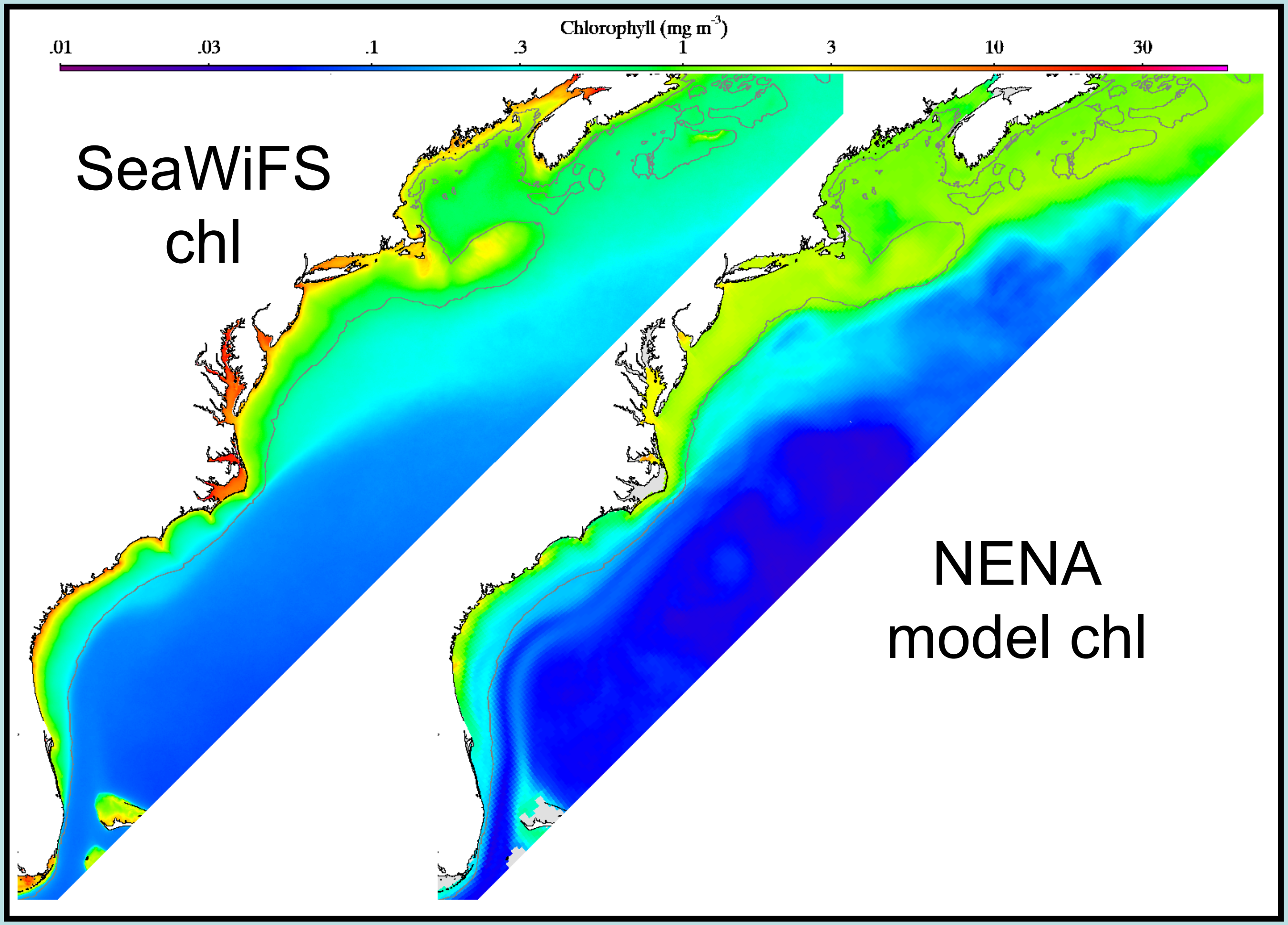
Evaluation of model biogeochemistry—oxygen anomaly

Model **Observations** **Model** **Observations**



June **December**

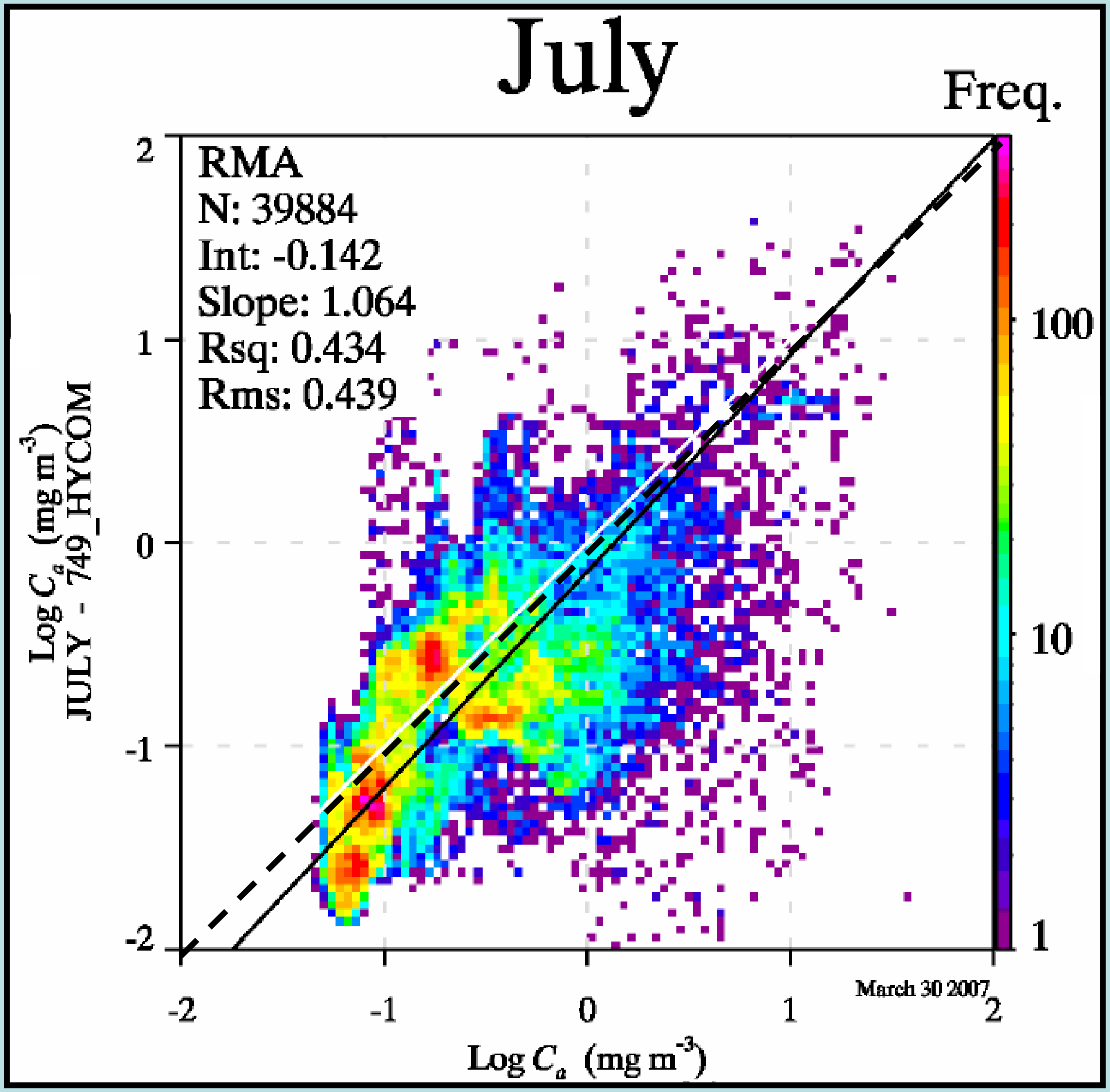
Qualitative model-data comparisons are not enough!



We need to assess model skill **quantitatively**

Model-data Fusion to Assess Skill

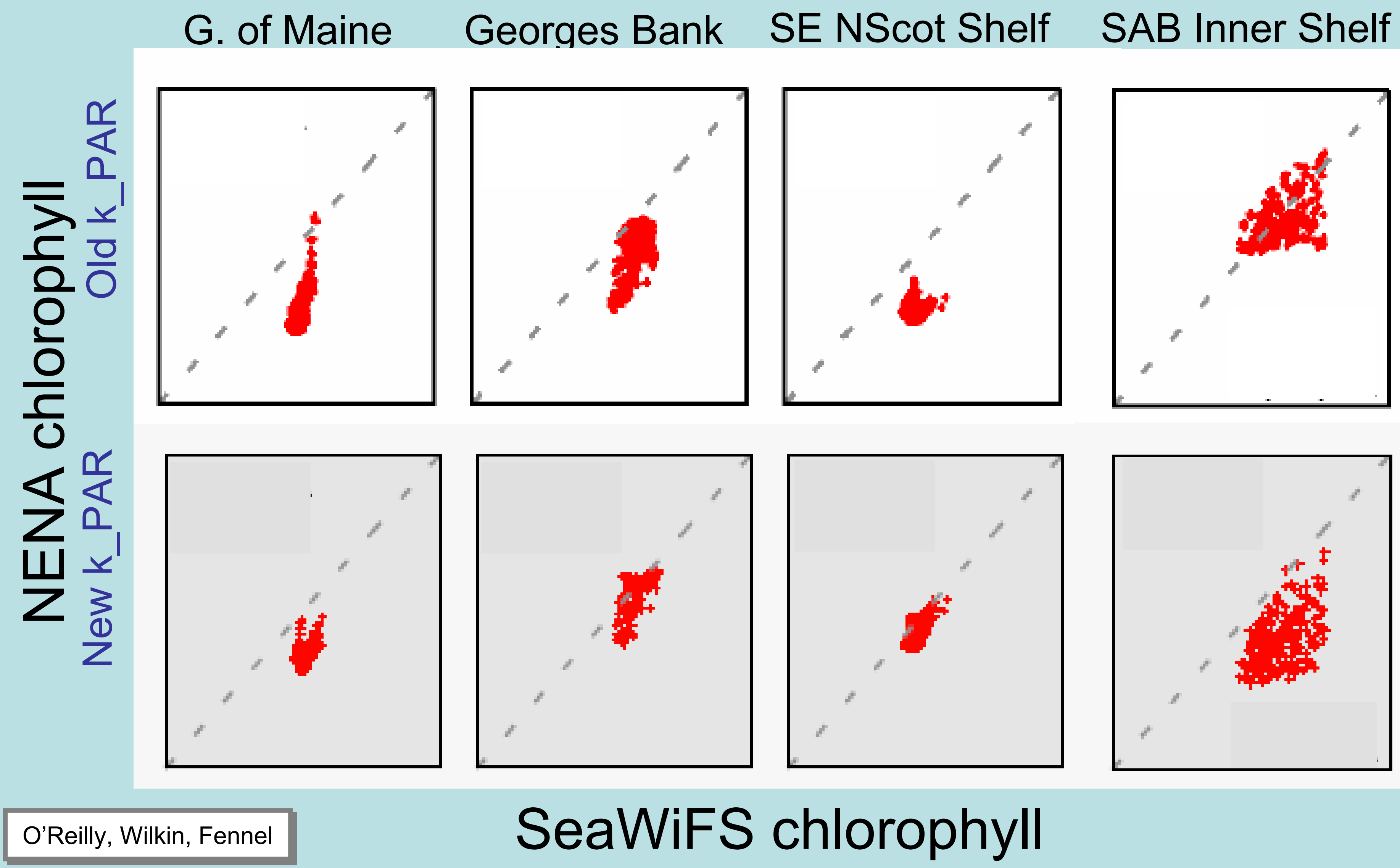
NENA model chlorophyll



SeaWiFS chlorophyll

O'Reilly, Wilkin, Fennel

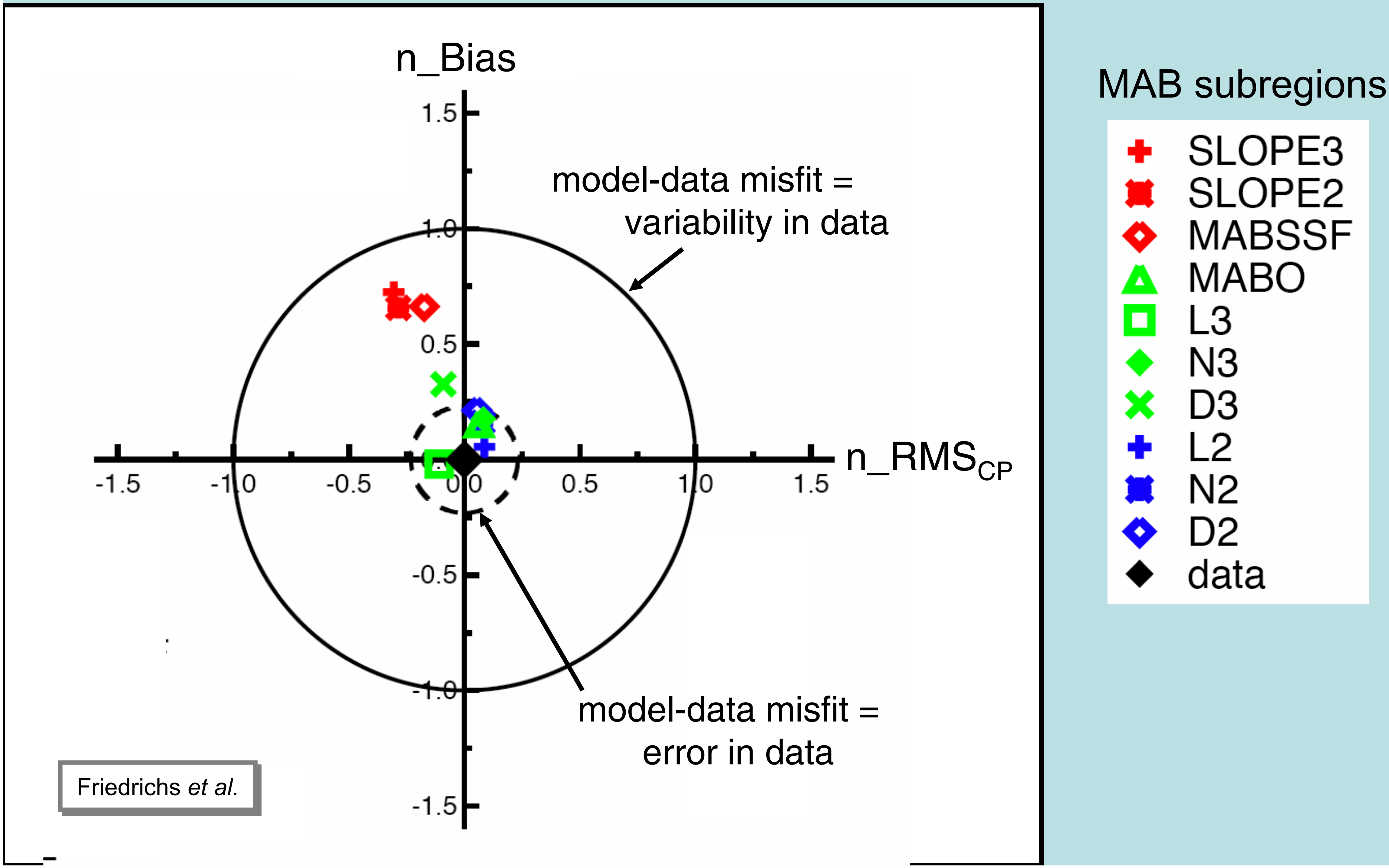
Quantitative comparison by region with parameterization refinement

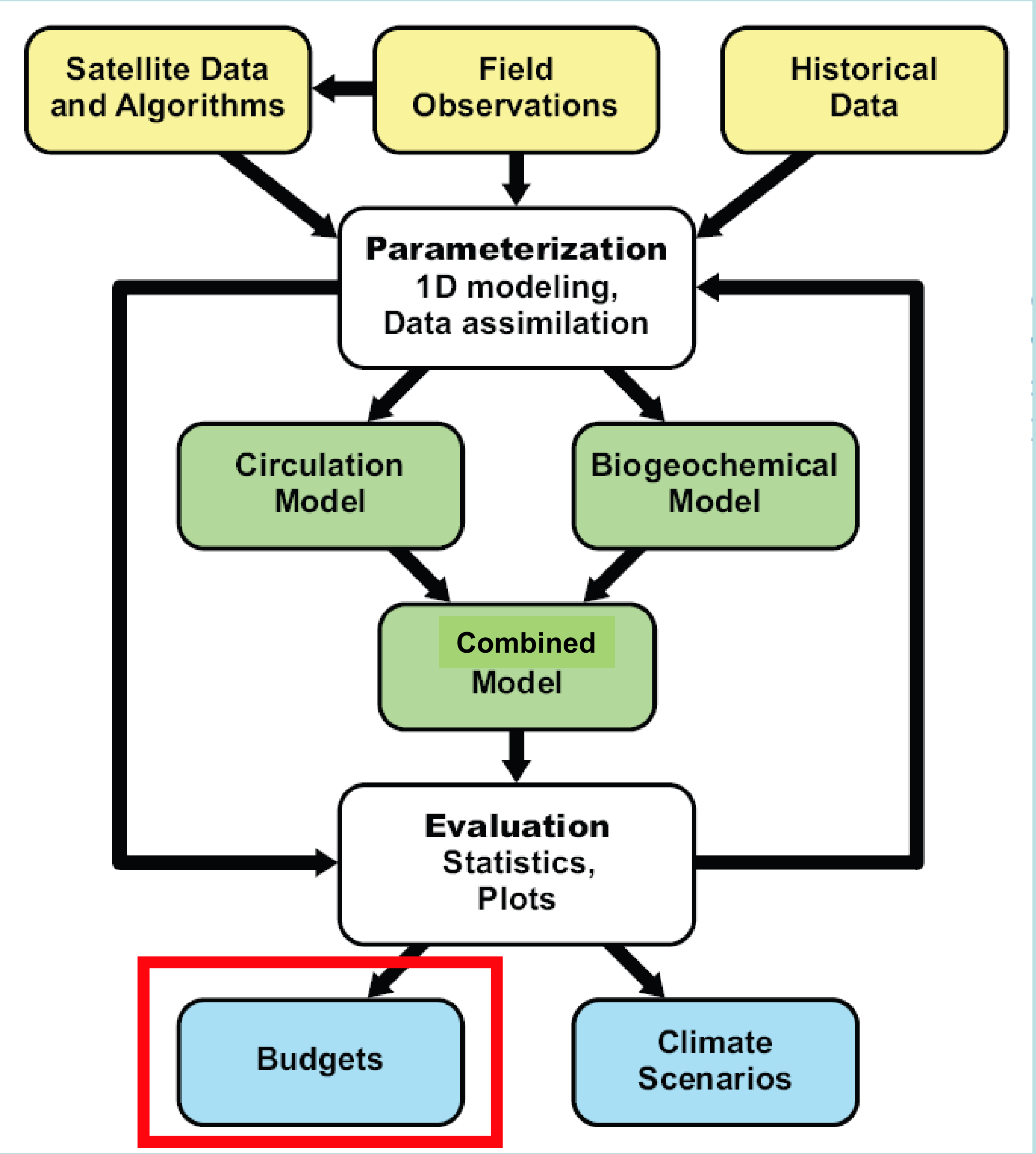


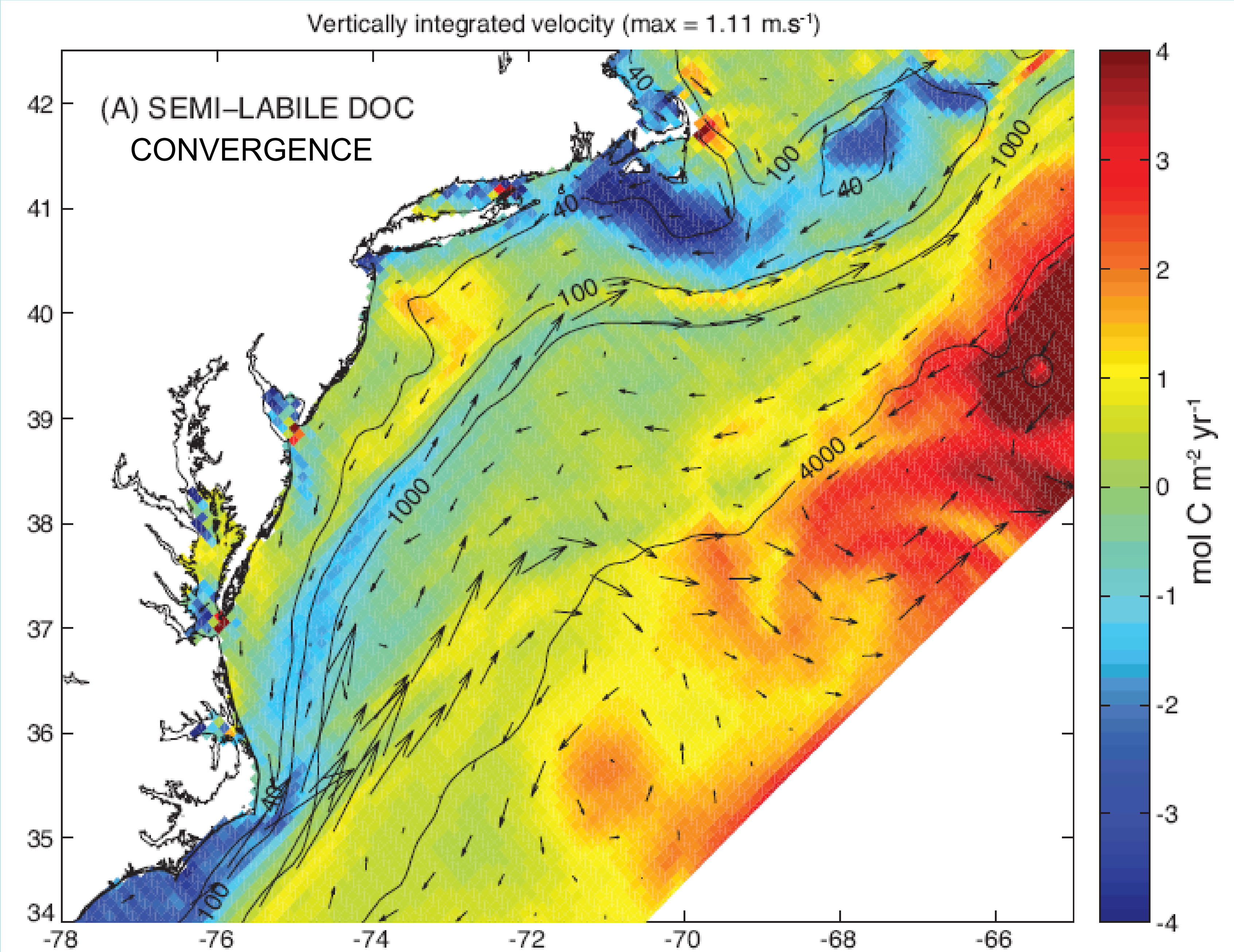
O'Reilly, Wilkin, Fennel

Normalized Target diagram for SST

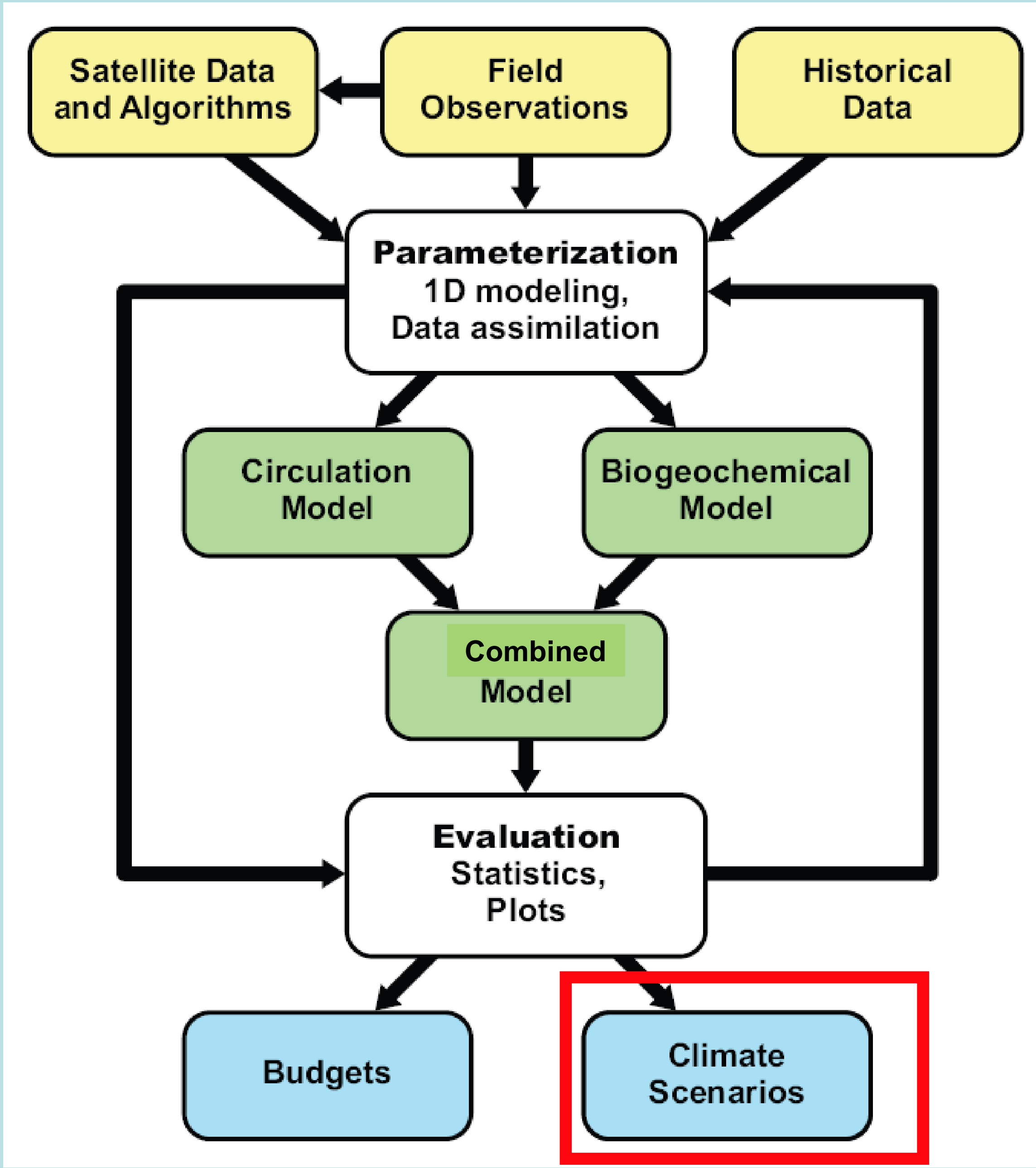
Misfits of means and variability




Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios


Vertically integrated velocity (max = 1.11 m.s-1)
(A) SEMI–LABILE DOC
CONVERGENCE
mol C m-2 yr-1
42
41
40
39
38
37
36
35
34
-78
-76
-74
-72
-70
-68
-66
4
3
2
1
0
-1
-2
-3
-4
40
100
1000
4000

Druon et al.


Satellite Data and Algorithms
Field Observations
Historical Data
Parameterization
1D modeling,
Data assimilation
Circulation Model
Biogeochemical Model
Combined Model
Evaluation
Statistics,
Plots
Budgets
Climate Scenarios

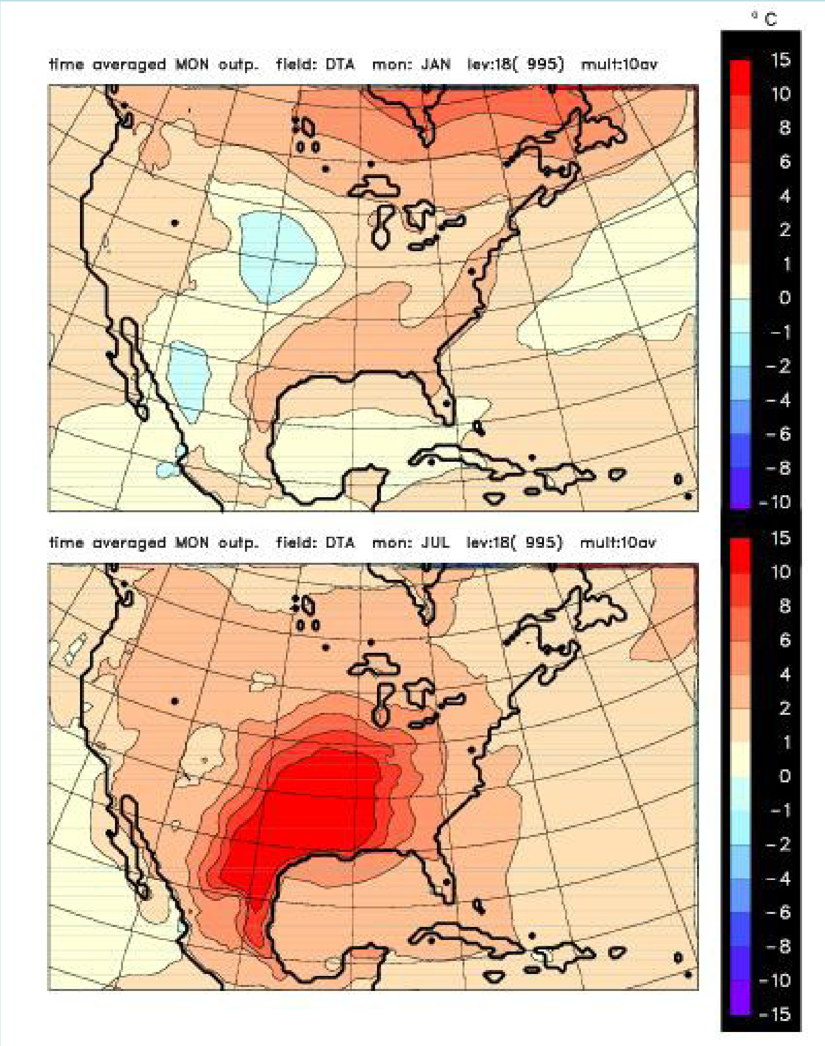
Changes over 21st century

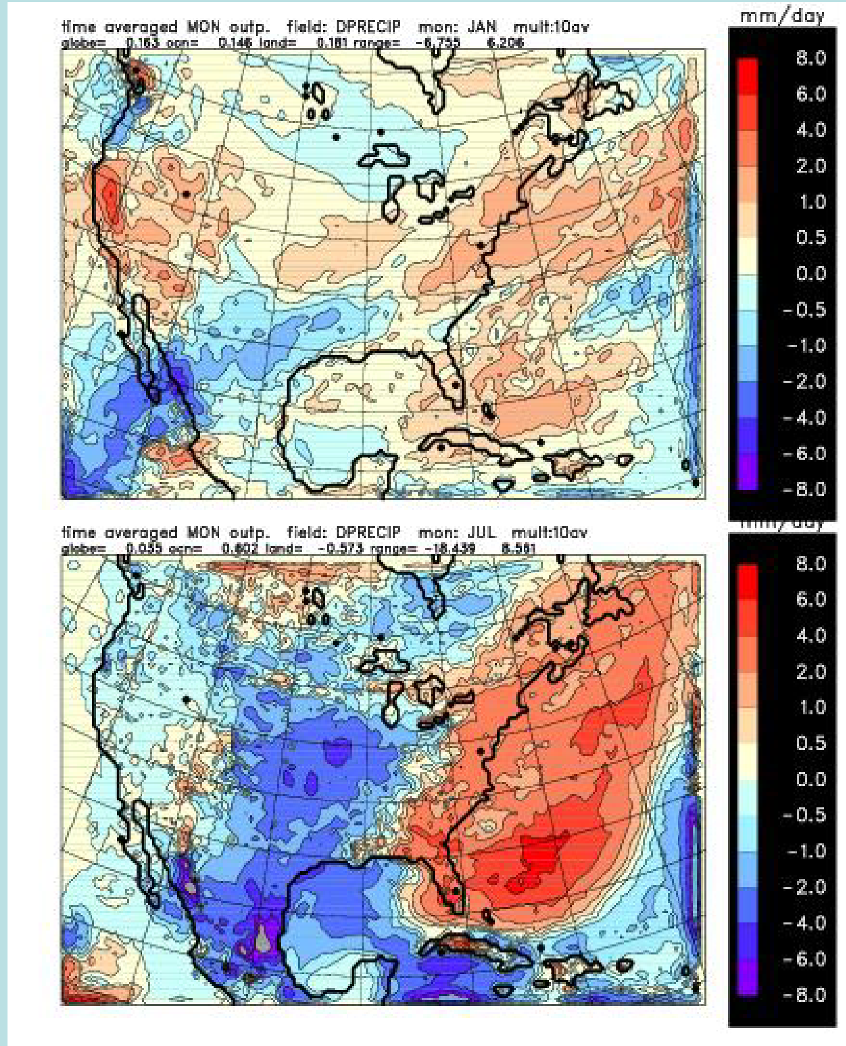
ΔTemperature [15 to -15ºC]

ΔPrecipitation [8 to -8 mm/d]

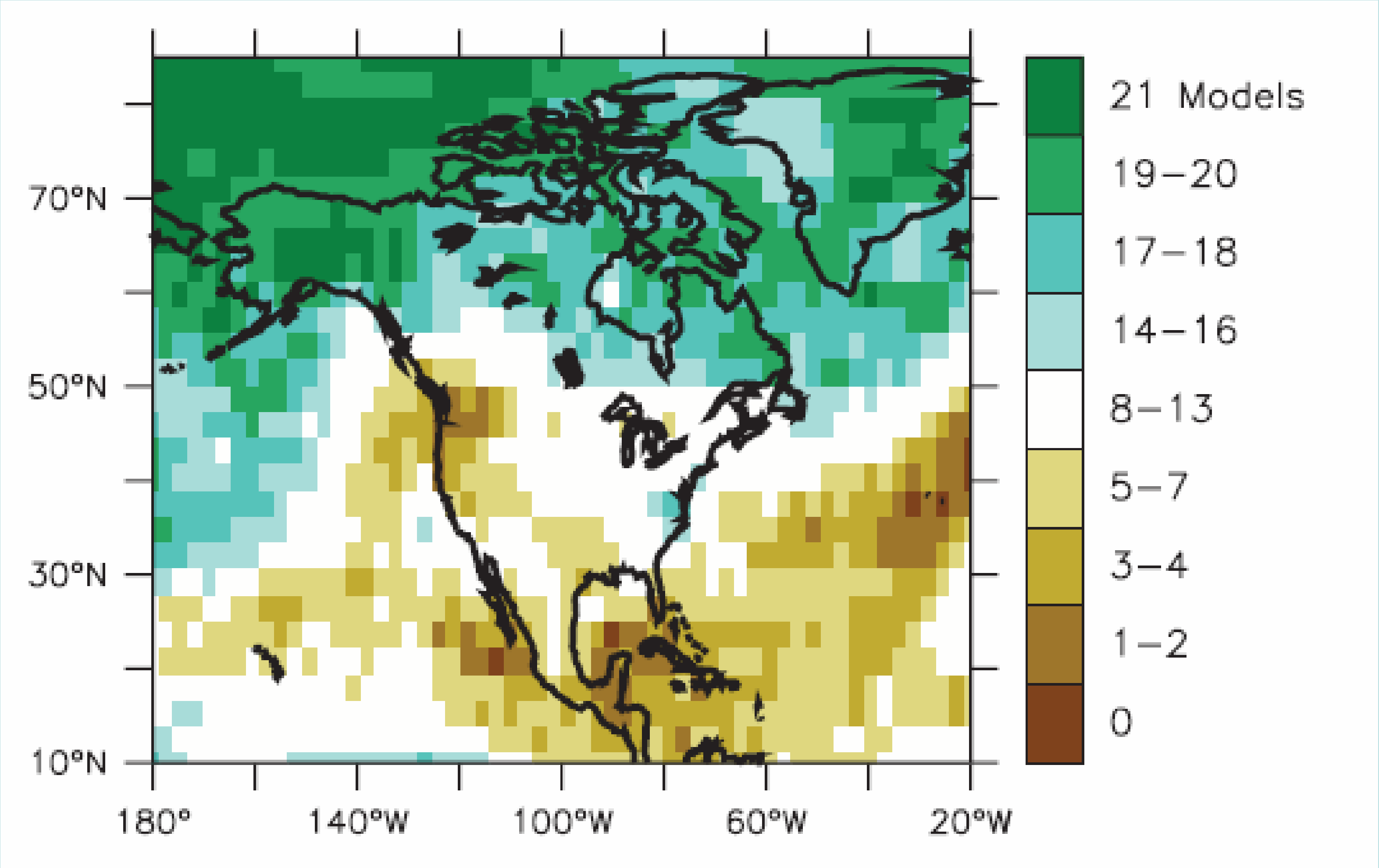
January

July





Number of models that predict an increase in summer precipitation



Christensen *et al.* (2007). A1B scenario, 1980-1999 to 2080-2099

Closing Remarks

U.S. ECoS Goal: To increase our understanding of carbon cycling in U.S. east coast continental shelf waters

- Integration of modeling and data analysis from outset is critical to addressing project goal
- Extensive collaboration of observationalists and modelers—more progress results than each component working independently
- Model advancement requires quantitative skill assessment coupled with data synthesis

Closing Remarks

- Interdisciplinary team focused on a single coupled circulation-biogeochemical is an effective way to address complex issues, such as carbon cycling in marine ecosystems
- Single model forces the team to resolve issues and reconcile differences of opinion—end product is stronger

Thank you

References

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. M. Rueda, L. Mearns, C. G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton (2007), Regional climate projections, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon, et al., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fennel, K., J. Wilkin, J. Levin, J. Moisan, J. O'Reilly, and D. Haidvogel (2006), Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget, Global Biogeochemical Cycles, 20, GB3007, doi:10.1029/2005GB002456.

Hofmann, E., J.-N. Druon, K. Fennel, M. Friedrichs, D. Haidvogel, C. Lee, A. Mannino, C. McClain, R. Najjar, J. O'Reilly, D. Pollard, M. Previdi, S. Seitzinger, J. Siewert, S. Signorini, and J. Wilkin (2008), Eastern US Continental Shelf carbon budget: Integrating models, data assimilation, and analysis, Oceanography, 21, 86-104.

Signorini, S. R., and C. McClain (2006), Remote versus local forcing of chlorophyll variability in the South Atlantic Bight, NASA Tech. Memo., 2006–214145.

Signorini, S. R., and C. R. McClain (2007), Large-scale forcing impact on biomass variability in the South Atlantic Bight, Geophysical Research Letters, 34, L21605, doi:10.1029/2007GL031121.