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Modeling Ocean Circulation and Biogeochemical Variability in the Southeast U.S. Coastal Ocean and Gulf of Mexico

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In collaboration with (in alphabetical order)

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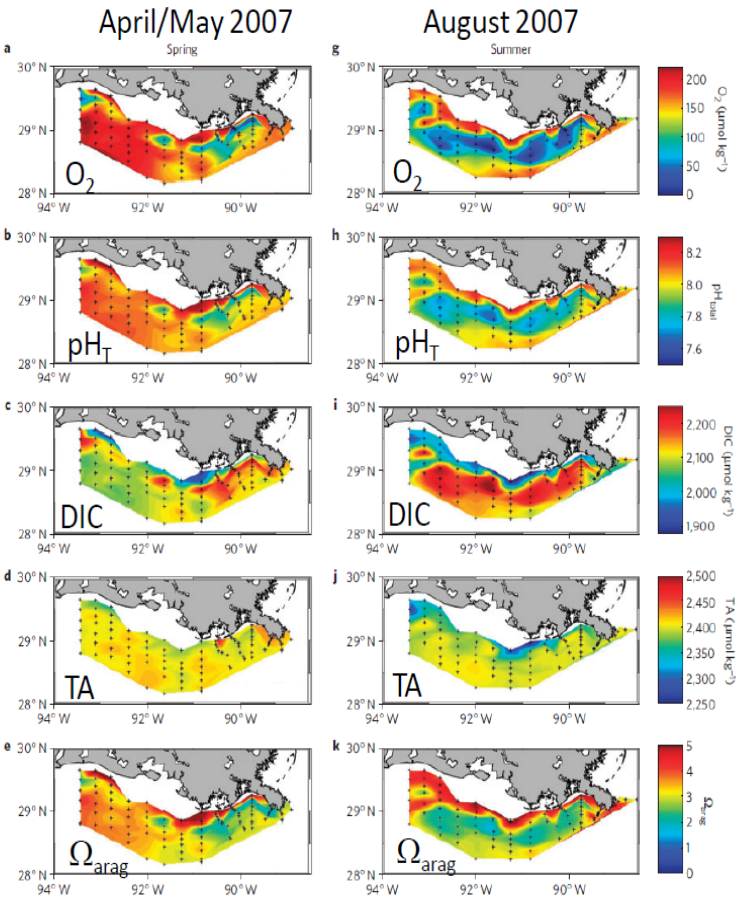
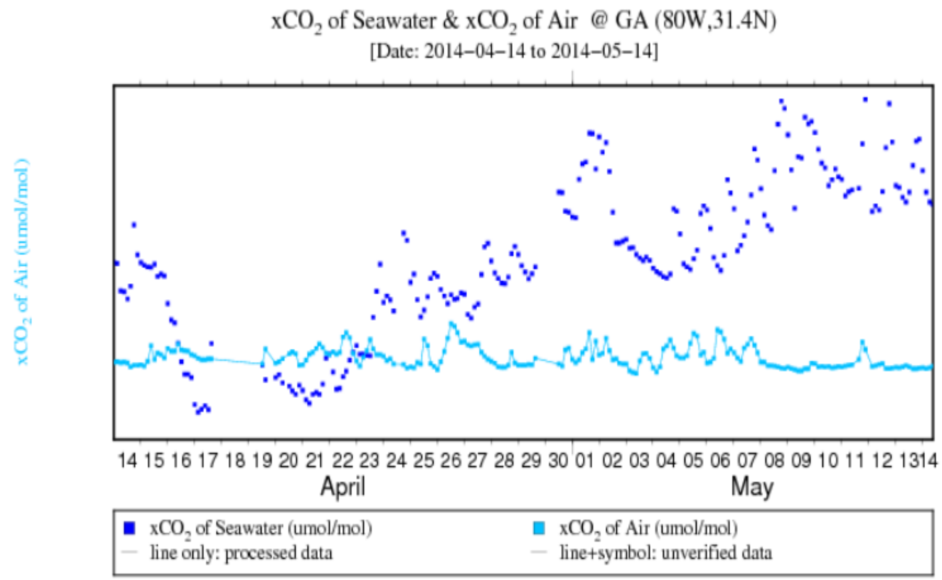
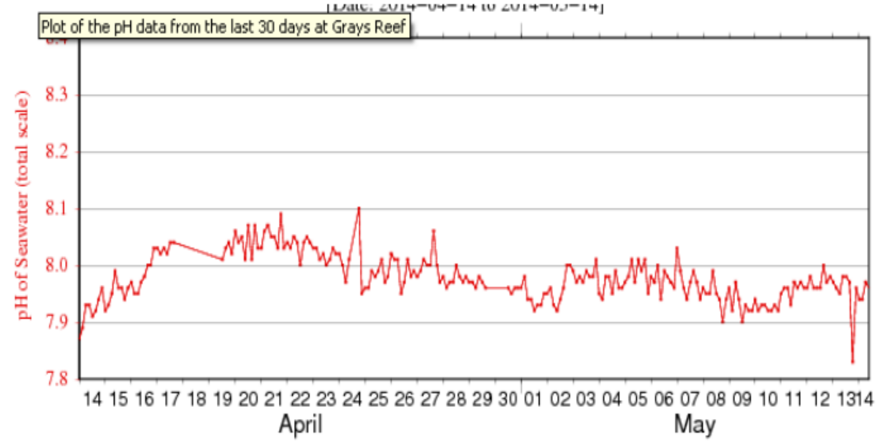
Significant variability from limited observations

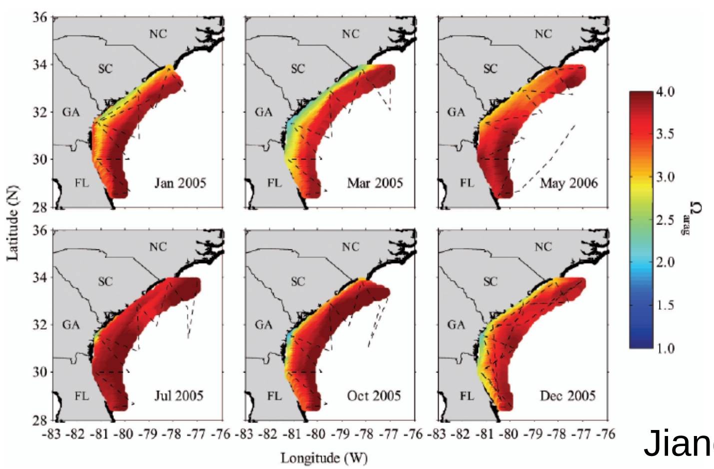


Cai et al. (2011)



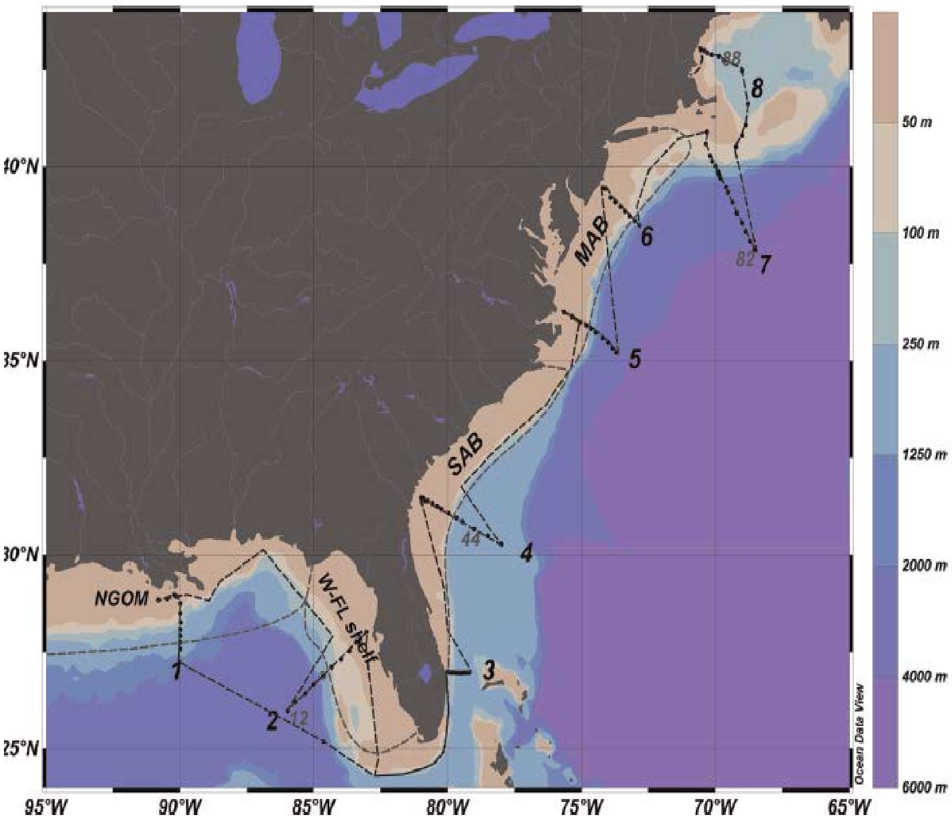
http://www.pmel.noaa.gov/co2/story/Grays+Reef



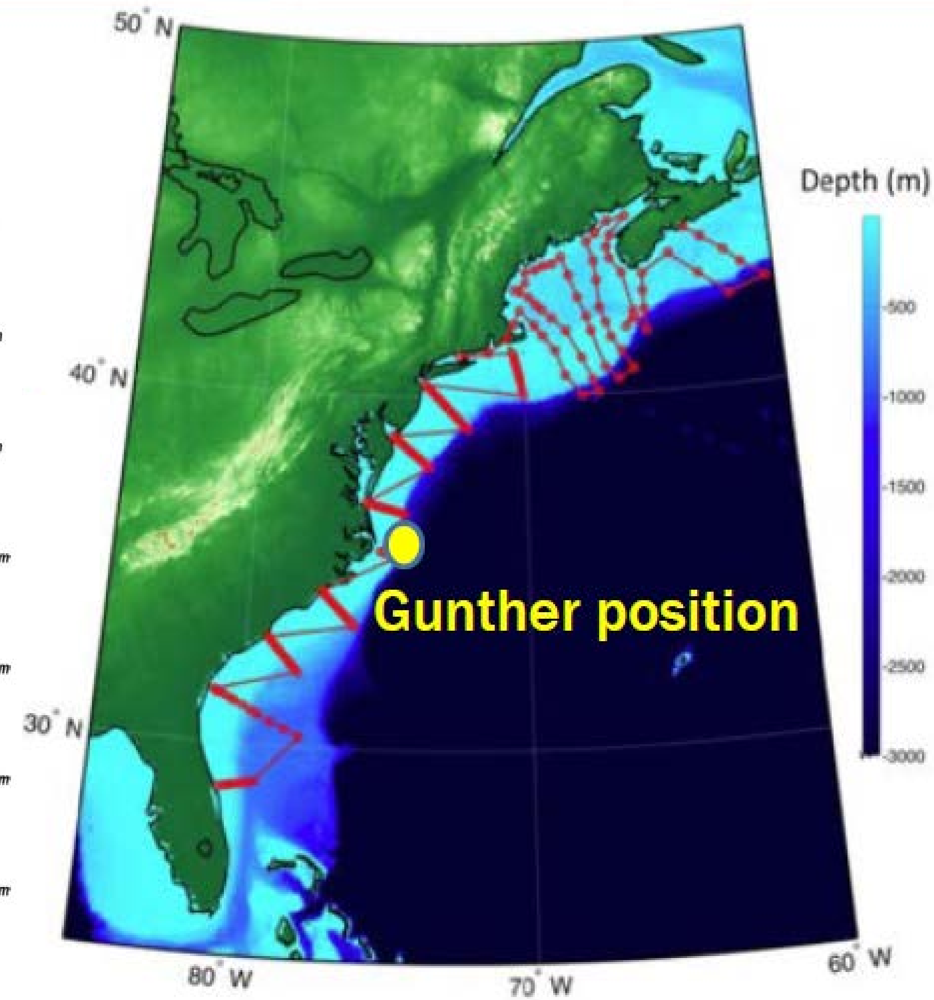


Jiang et al. (2010)

From Scott Noakes SOCAN talk



Wanninkhof et al. (2015)



From Libby Jewett's SOCAN talk

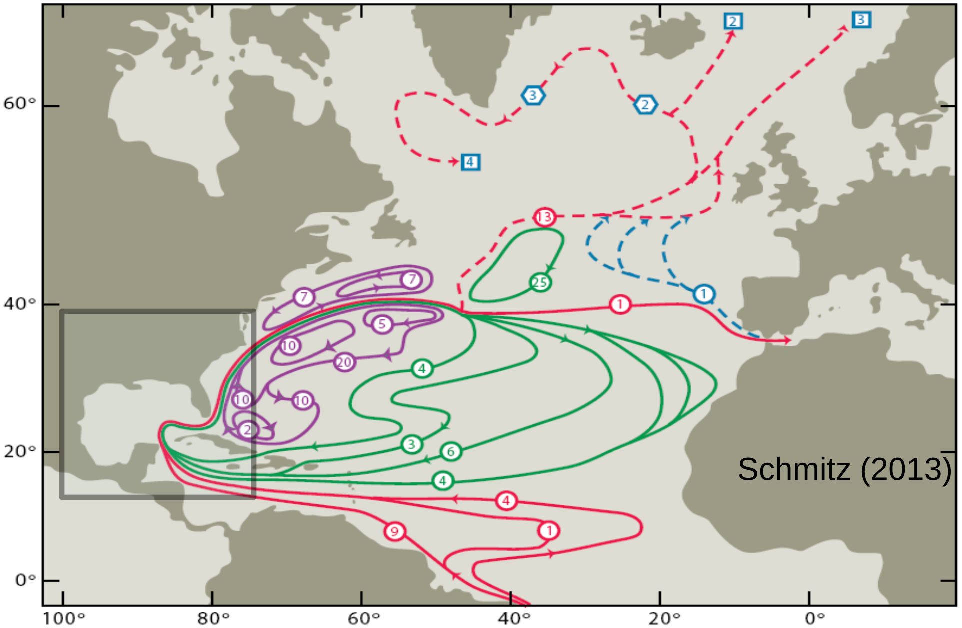
Goal: using coupled models for ocean state estimation to fill temporal and spatial gaps in observations, and to elucidate the underlying physical-biogeochemical dynamics that determine variability and long-term trend of our coastal marine ecosystem.

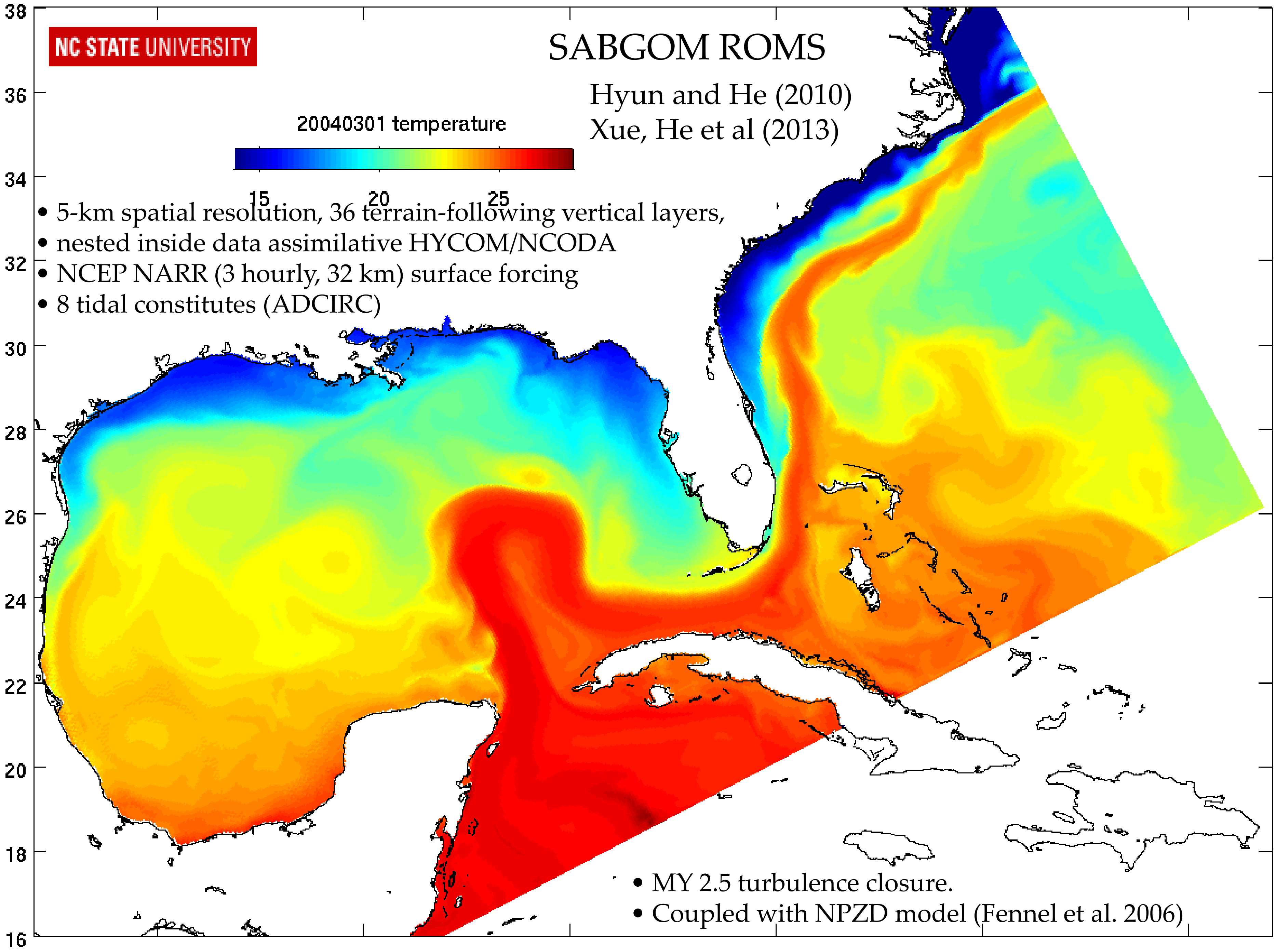
Outline

- Two coupled modeling systems
  - ❑ South Atlantic Bight and Gulf of Mexico (5 km)
  - ❑ NW Atlantic coastal ocean (7 km)

- Thoughts on path forward

- Summary





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SABGOM ROMS
Hyun and He (2010)
Xue, He et al (2013)
20040301 temperature
15
20
25
• 5-km spatial resolution, 36 terrain-following vertical layers,
• nested inside data assimilative HYCOM/NCODA
• NCEP NARR (3 hourly, 32 km) surface forcing
• 8 tidal constitutes (ADCIRC)
• MY 2.5 turbulence closure.
• Coupled with NPZD model (Fennel et al. 2006)
38
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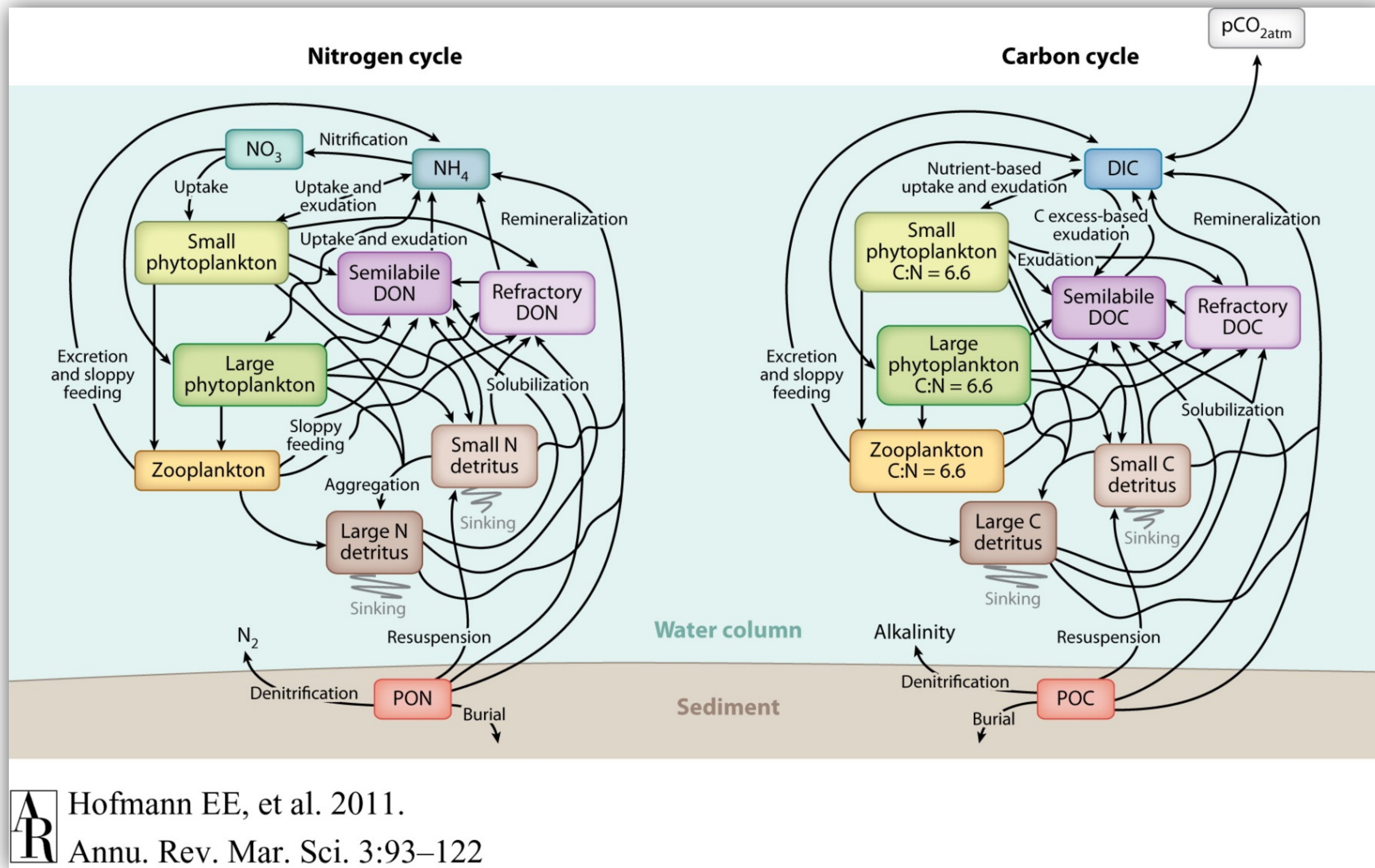
Biogeochemical Model:



Fennel et al., 2006, 2011

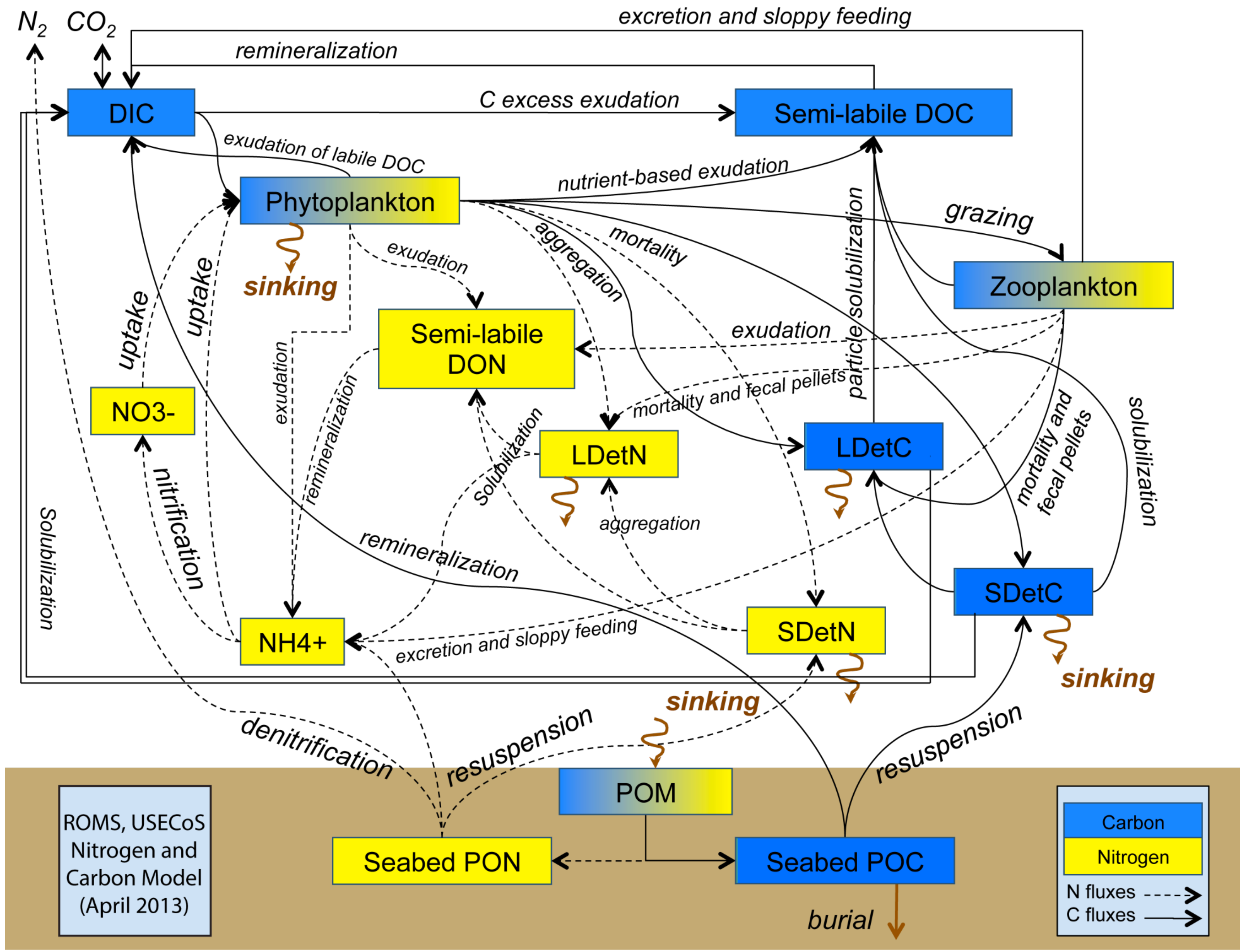


Figure courtesy, J. Wilkin and A. Tabatabai

Fennel et al., 2006, Fennel et al., 2009, Hoffman et al., 2011

Biogeochemical Model Setup

- **Initial & Boundary Conditions:**
  - NO3: NODC (Levitus) World Ocean Atlas 2009;
  - Alkalinity and DIC (*Lee et al., 2000 and 2006*);
- **63 River Forcing (38 US rivers USGS):**
  - Runoff, NO3, NH4, Alkalinity, DIC
  - USGS observations used for 38 U.S. rivers
  - Climatology (*Milliman and Farnsworth, 2011)* for 23 Mexico and 2 Cuba rivers

Multi-year Hindcast covering 2003-2010

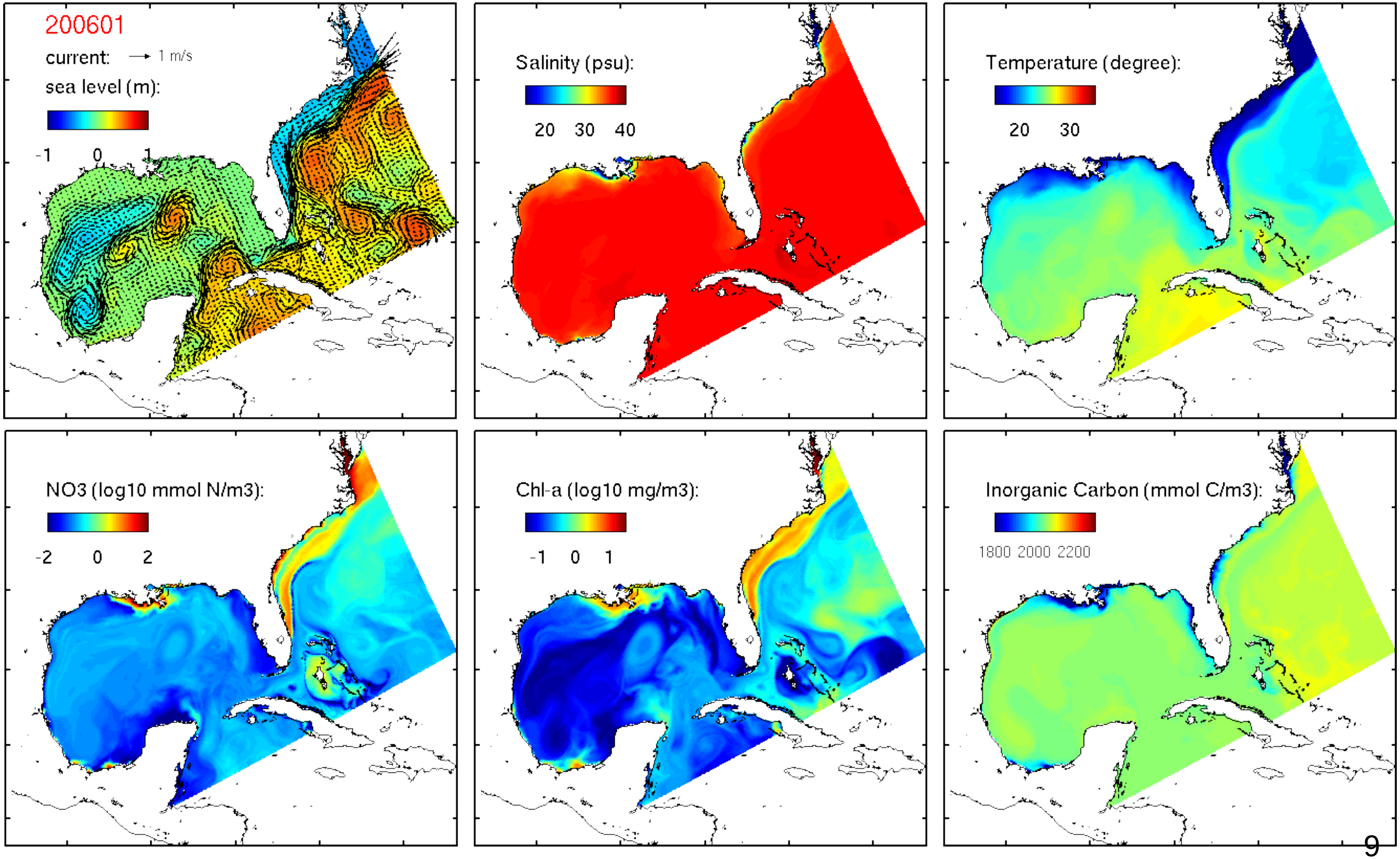
(NO_3, NH_4, Primary Production, Chl-a, Phytoplankton, Zooplankton, TIC, Alkalinity, pCO2, CO2-airsea, Oxygen)

Xue, Z., R. He, K. Fennel, W. J. Cai, S. Lohrenz, and C. Hopkinson (2013), Modeling ocean circulation and biogeochemical variability in the Gulf of Mexico, *Biogeosciences*, 10, 7219-7234.

Xue, Z., R. He, K. Fennel. W.-J. Cai, S. Lohrenz, W.-J. Huang, and H. Tian (2014) Modeling pCO2 variability in the Gulf of Mexico, *Biogeosciencs Discuss*, 11, 12673-12695.

Results

SSH, SST, SSS, NO_3, Chl-a, and Inorganic Carbon



Validations: Physical Model

coastal sea level anomaly

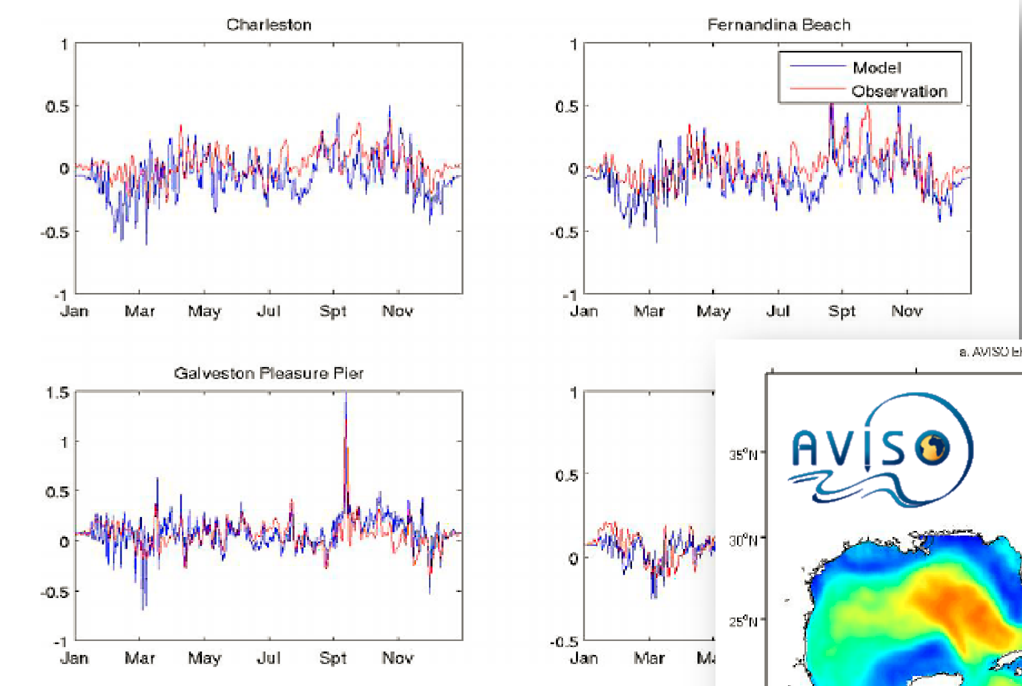
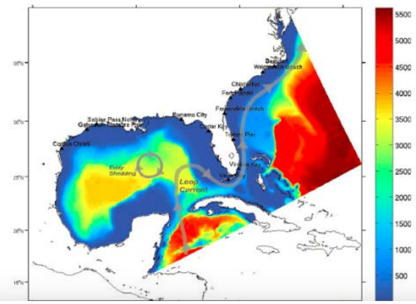
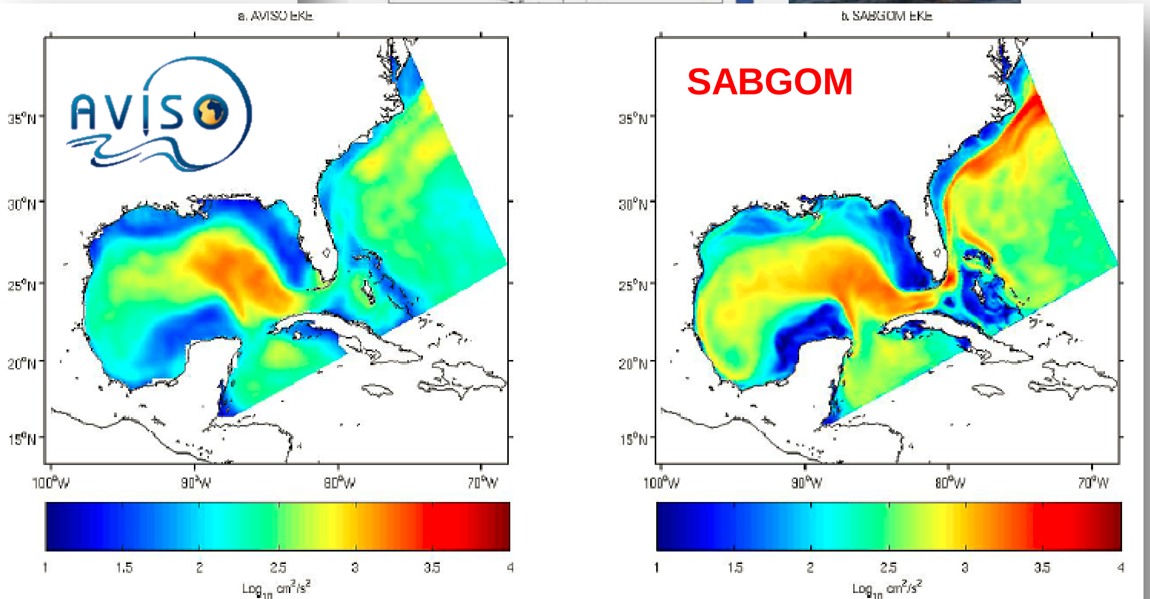


Fig. 3. Comparisons between observed and simu
series at four tidal stations in 2008.

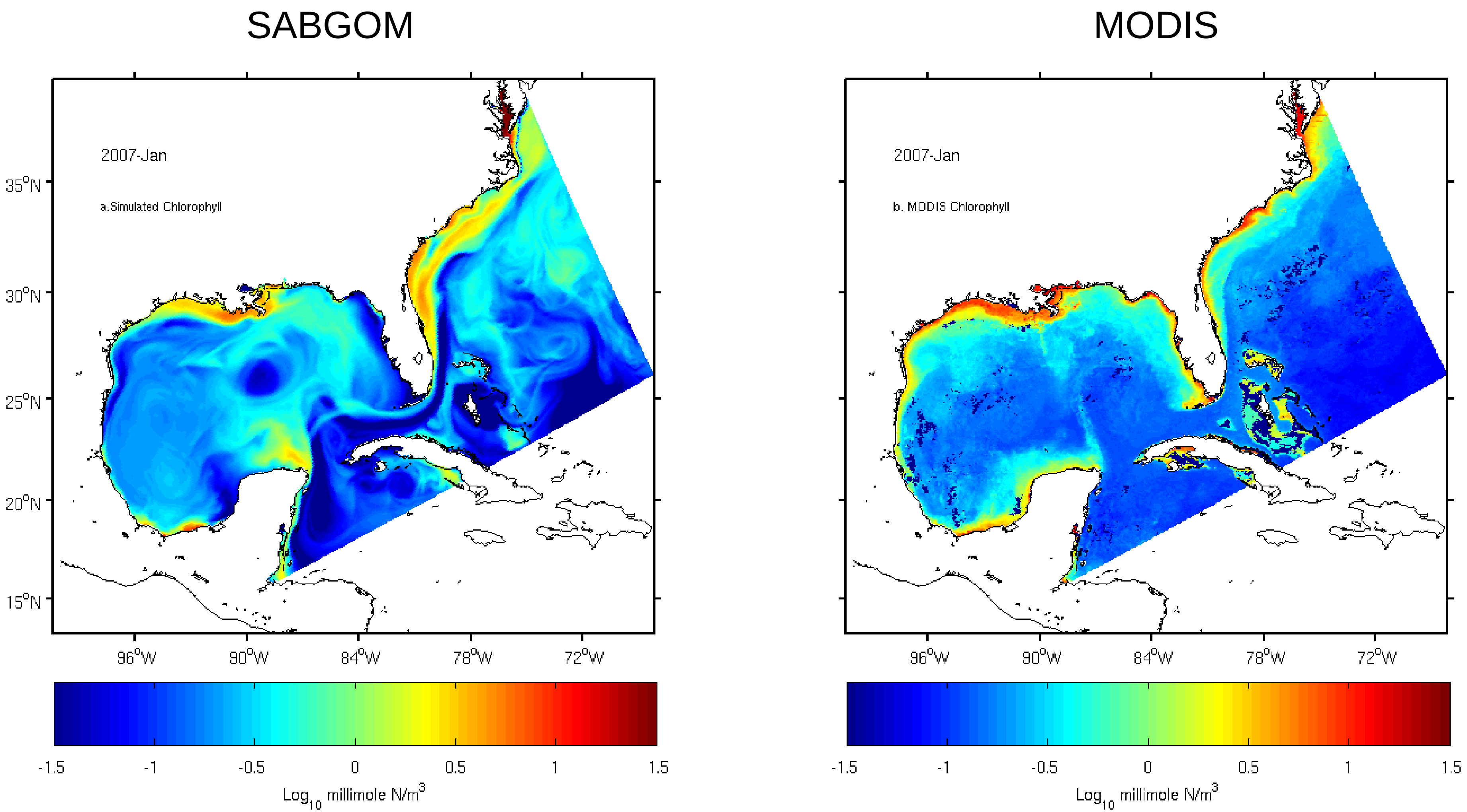




Eddy Kinetic Energy

Fig. 5. Comparison of 7 yr (2004–2010) mean eddy kinetic energy calculated based on **(a)** AVISO SSH observation and **(b)** SABGOM model simulated SSH.

Monthly Surface Chl-a Comparison

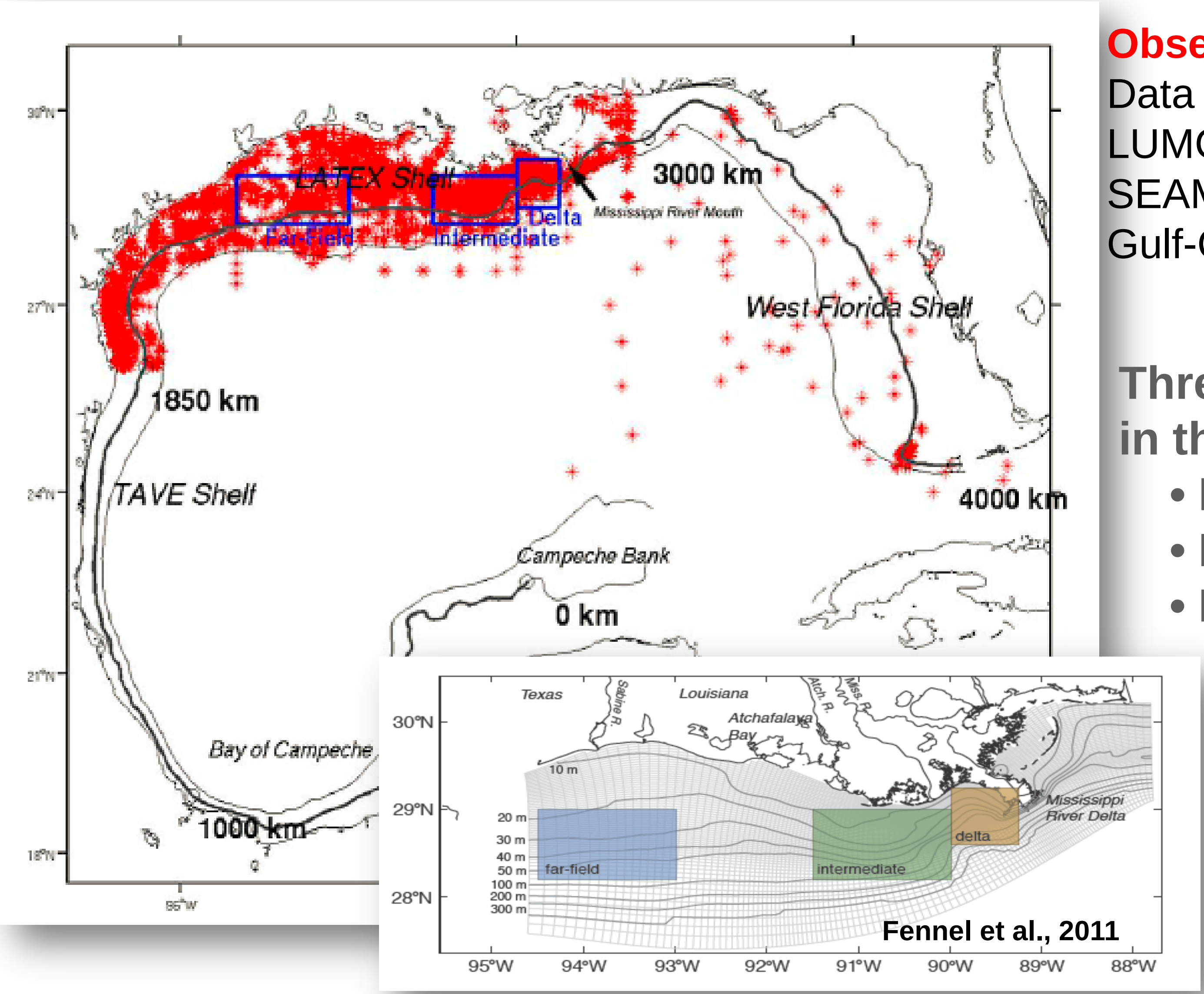


Other variables: NO_3, NH_4, Primary Production, Phytoplankton, Zooplankton, TIC, Alkalinity, pCO2, CO2-airsea, Oxygen

Xue, Z., R. He, K. Fennel, W. J. Cai, S. Lohrenz, and C. Hopkinson (2013), Modeling ocean circulation and biogeochemical variability in the Gulf of Mexico, *Biogeosciences*, 10, 7219-7234.

Validations: biogeochemical model

ship survey physical-biogeochemical data (2003-2010)



Fennel et al., 2011

Observations (n > 9000)

Data Source:
LUMCON, EPA, MCH, SEAMAP, Gulf-Carbon, and MMAGMIX

Three sub-regions in the northern GOM

- **Delta**
- **Intermediate**
- **Far-Field**

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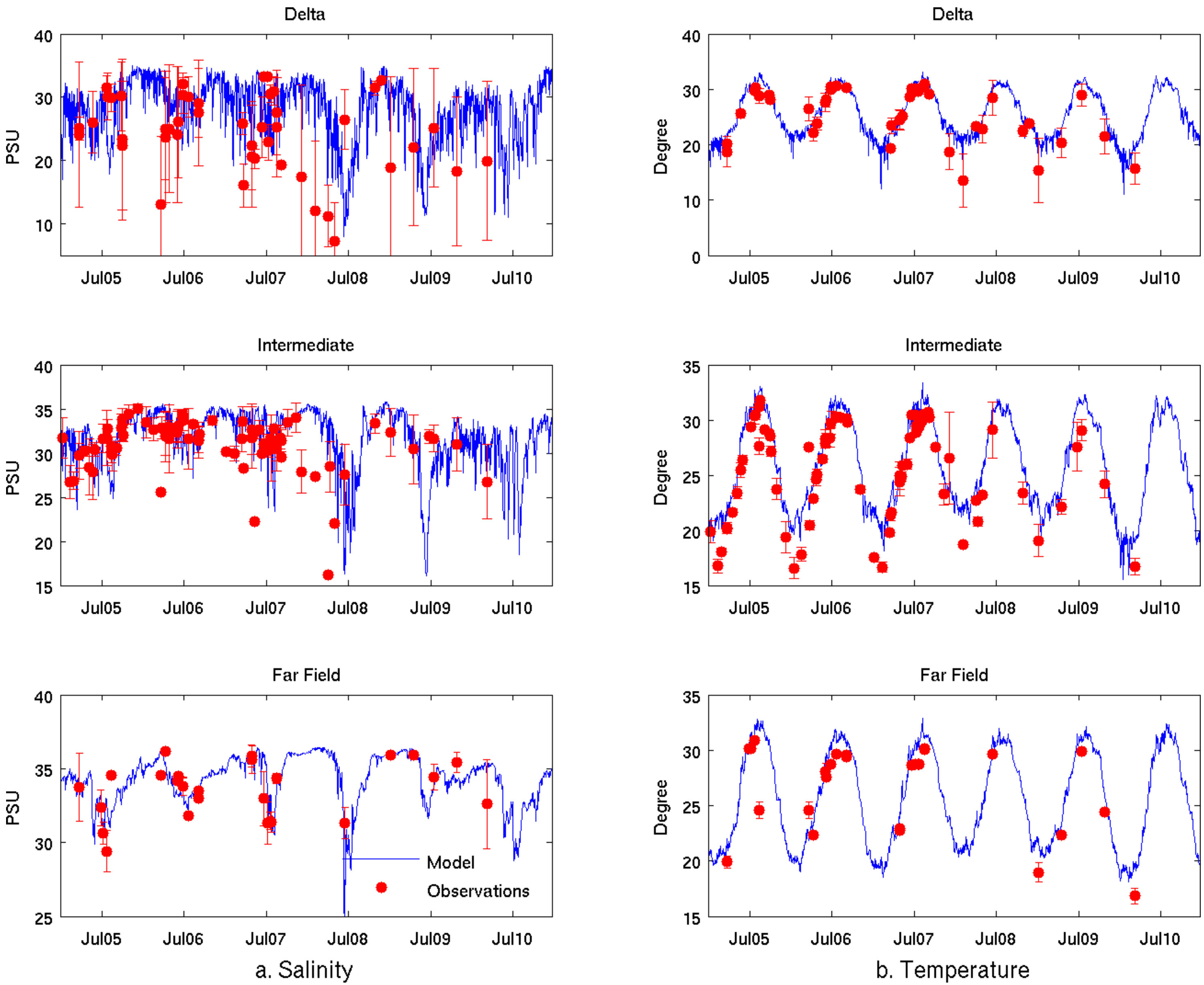
Validations (cont'd)

SSS SST



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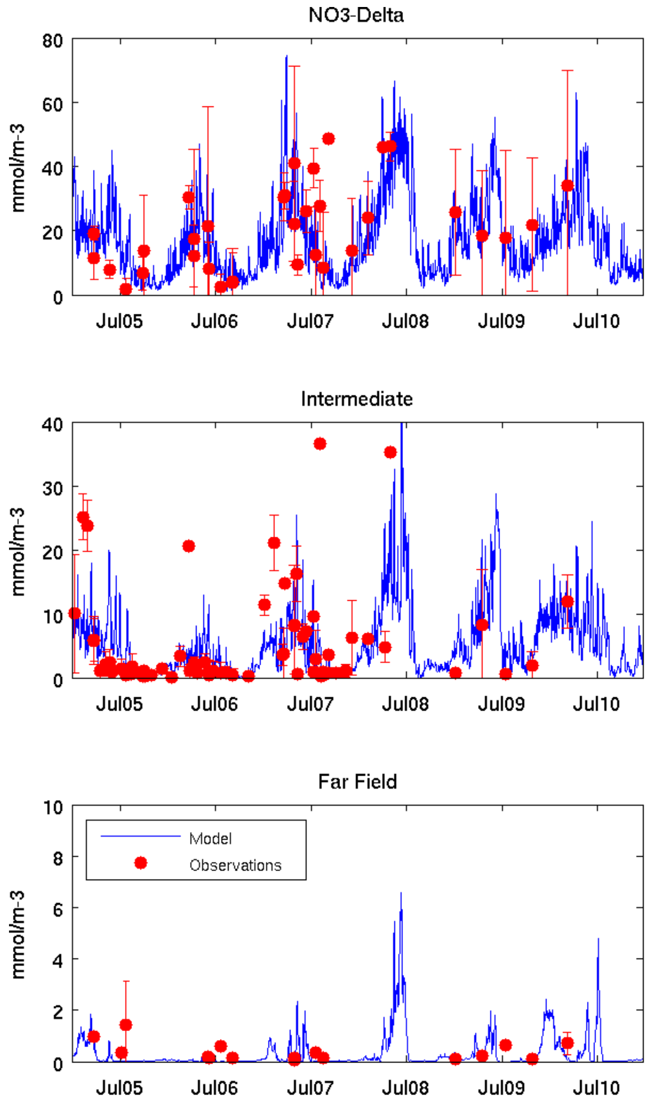
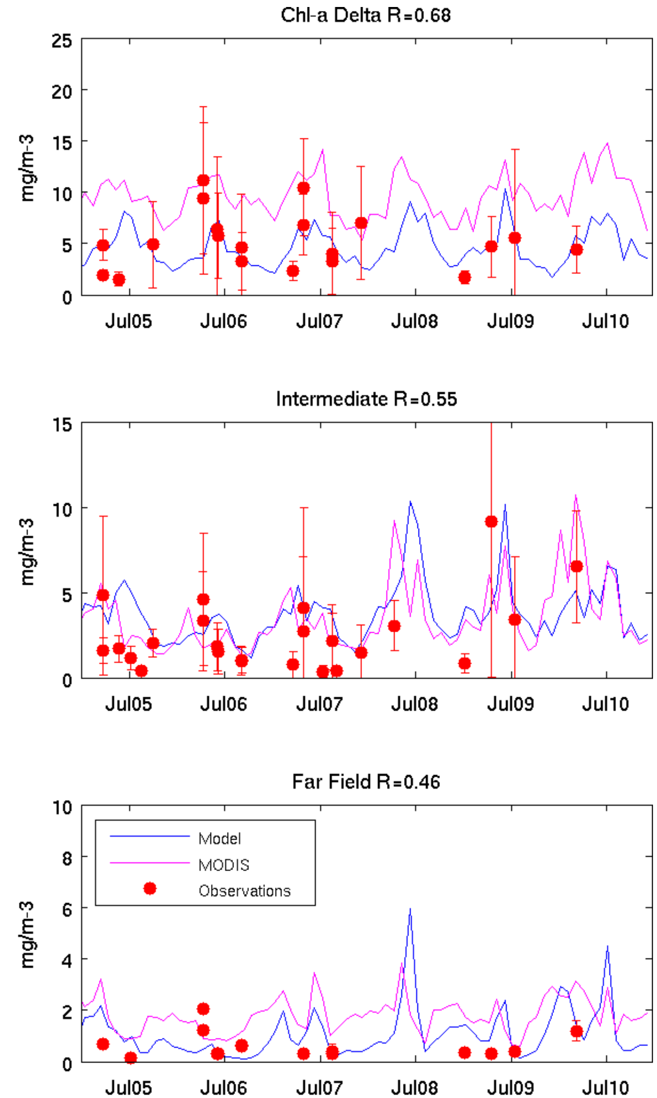
Validations (cont'd)

NO3 Chl-a



a. NO3



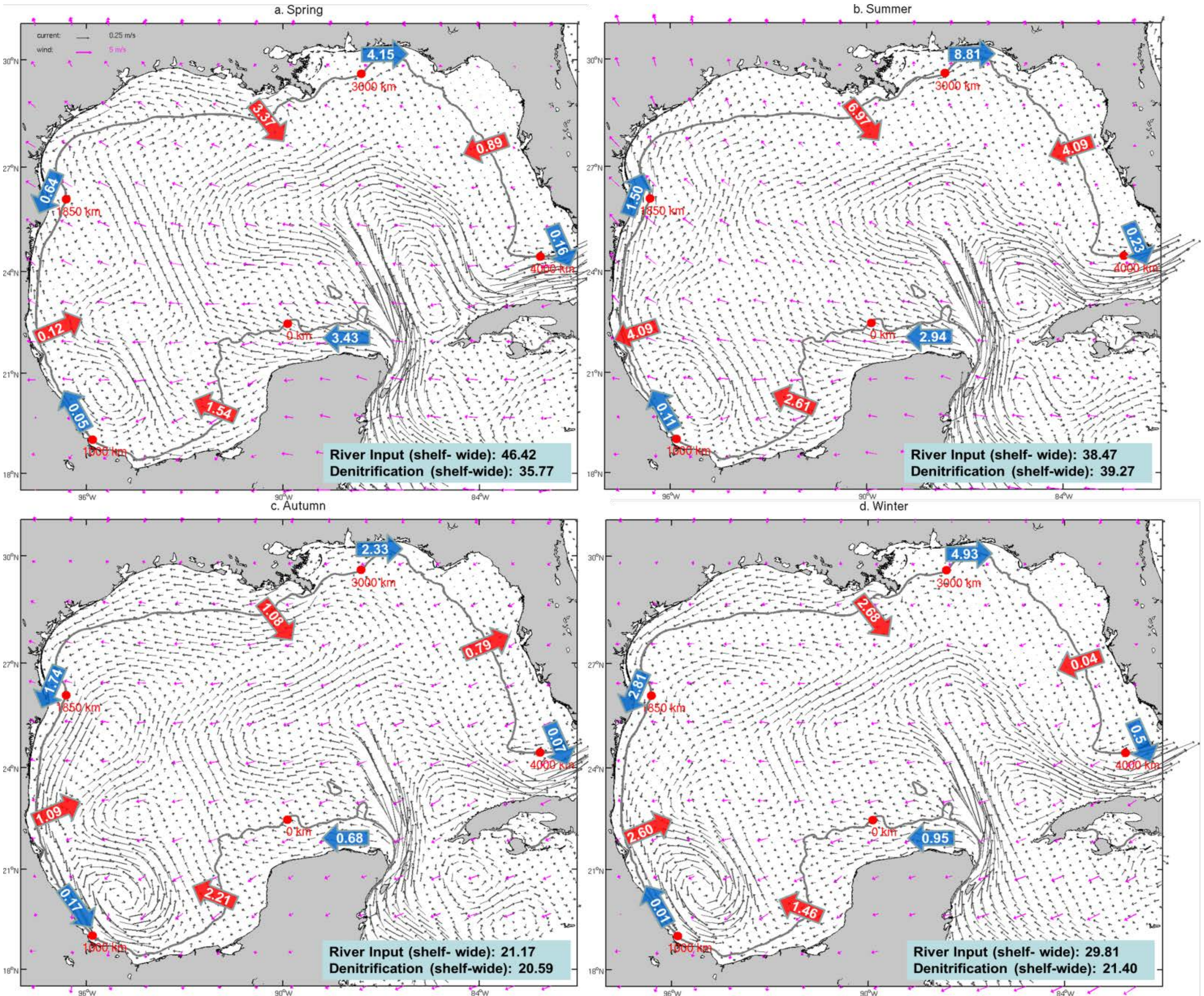
b. Chlorophyll

Analysis (cont'd):

long-term seasonal mean of along-, across-shelf DIN/PON transport

Spring

Summer



Fall

Winter

Analysis (cont'd): GOM Shelf-wide DIN/PON budget

Table 1. River, cross-shelf (at 50 m isobath), along-shelf, and denitrification budget in the inner shelf

Annual Nutrient Budget (10^9 mol N yr^{-1})		Shelf				
		Bay of Campeche	Tamaulipas-Veracruz	Louisiana-Texas	West Florida	Shelf-Wide
River Input		12.42	1.83	108.86	12.76	135.87
Cross-shelf*	DIN	-1.4	1.28	-10.23	-0.14	-10.49
	PON	-6.43	-1.04	-2.87	-4.1	-14.44
Along-shelf**	DIN	0.97	2.52	-13.05	10.23	0.67
	PON	7.03	1.15	-10.68	9.02	6.34
Denitrification***		-12.85	-6.25	-73.66	-24.27	-117.04

** for cross-shelf DIN/PON transport, +: onshore, -: offshore;** for along-shelf DIN/PON transport, +: net gain, -: net lose*
**** denitrification budgets are presented in negative values as a nitrogen removal process*

- The GoM shelf receives **142.88 × 10^9 mol N** annually, the majority of which was input by **local rivers**.
- On an annual basis the DIN input is largely balanced by 1) the removal through **denitrification** (equivalent of **~80%** of DIN input) and 2) offshore exports (equivalent of **~17%** of DIN input).

Carbon Cycle cont'd

pCO2 water seasonality

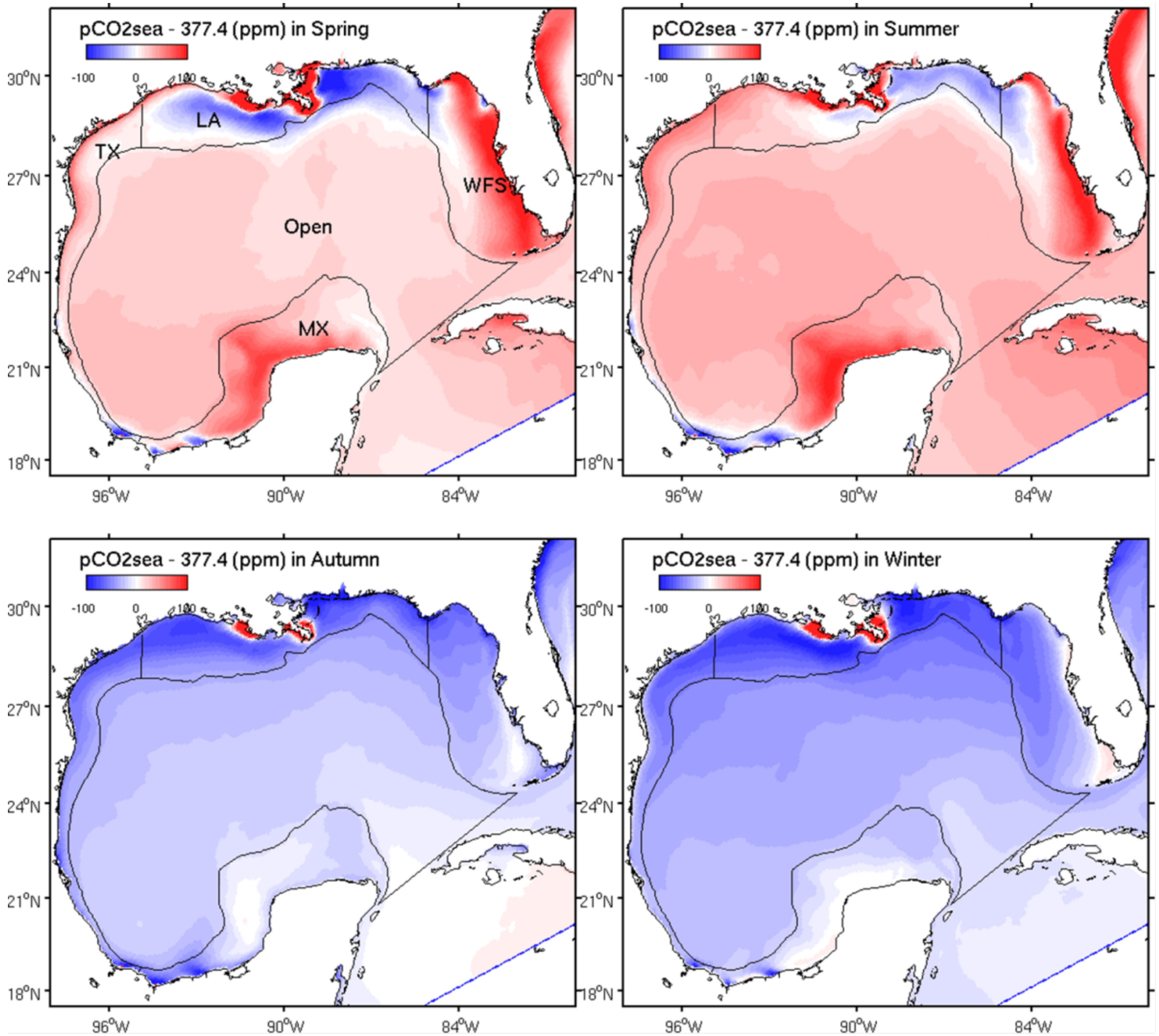
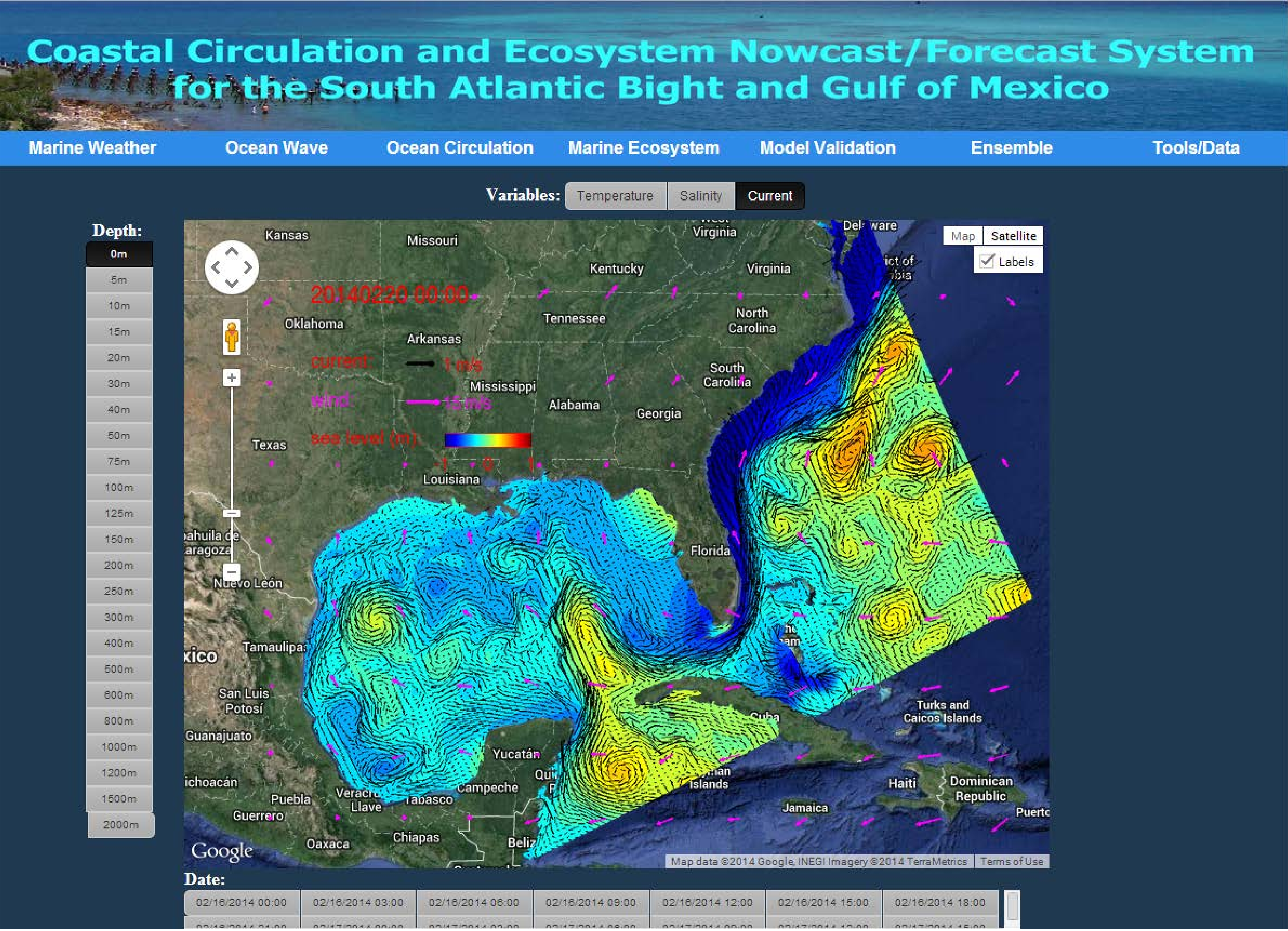


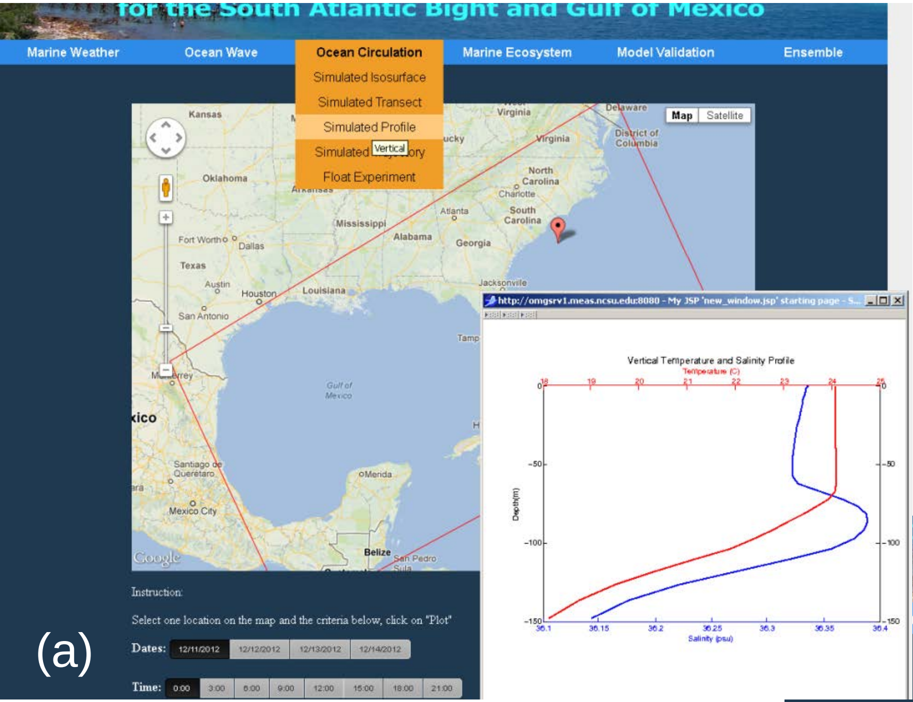
Fig 4 Model simulated ΔpCO2 (2005-2010 mean) in the Gulf during a) spring, b) summer, c) fall, and d) winter months.

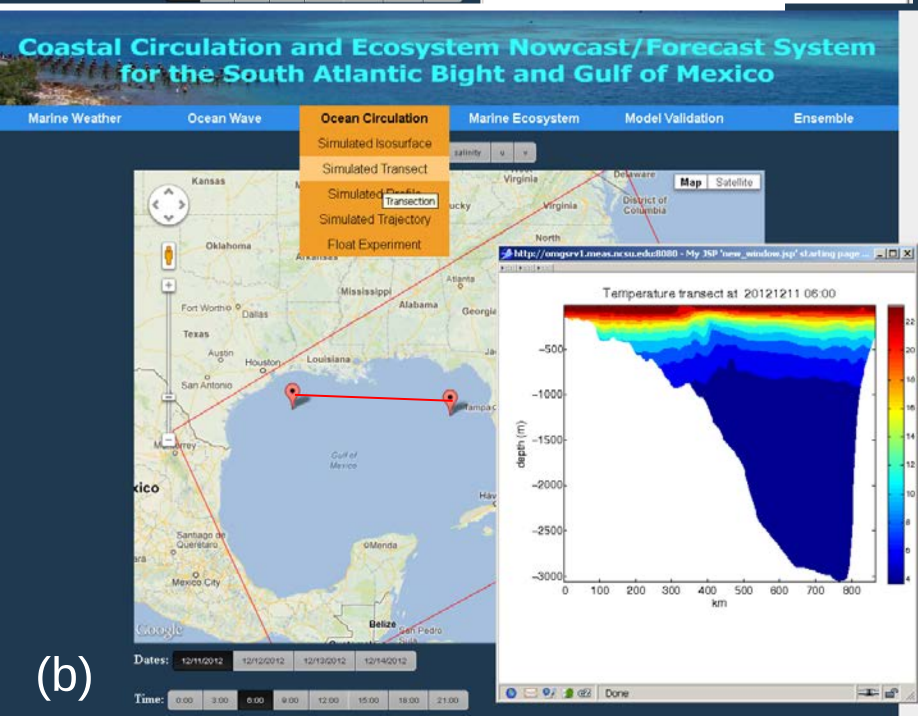


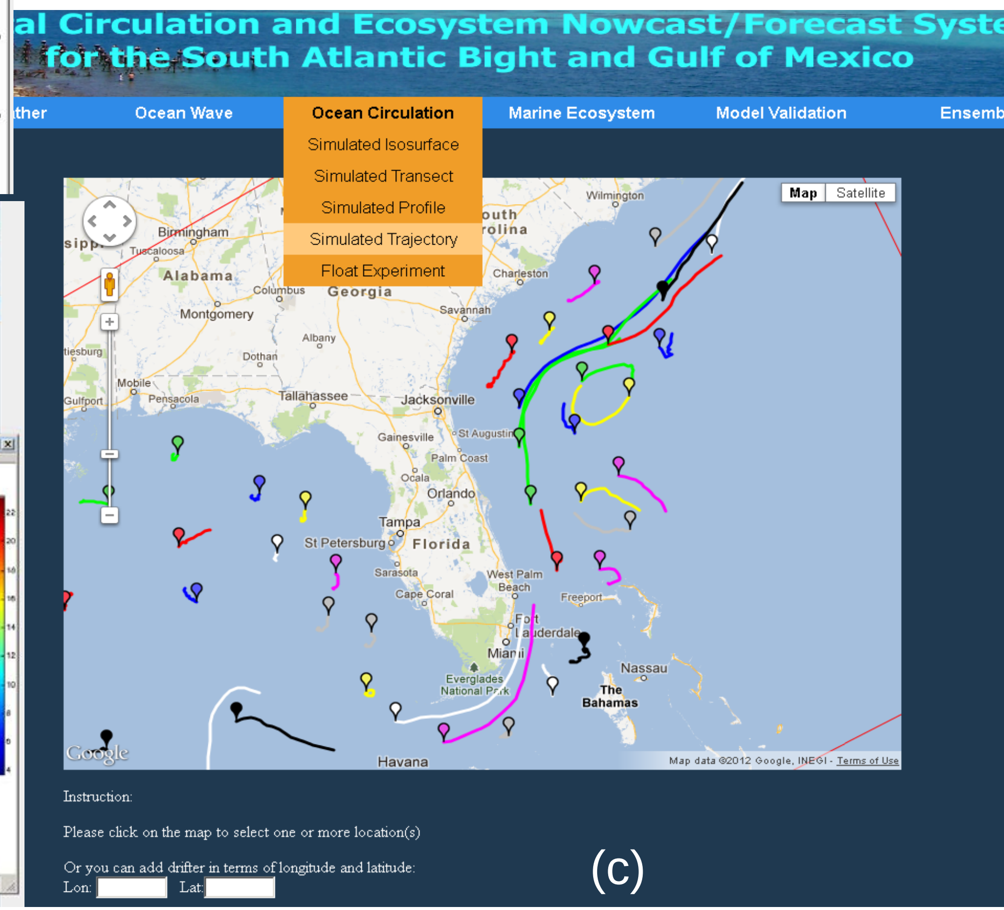
SABGM website: http://omgsrv1.meas.ncsu.edu:8080/ocean-circulation

Online user-defined functions

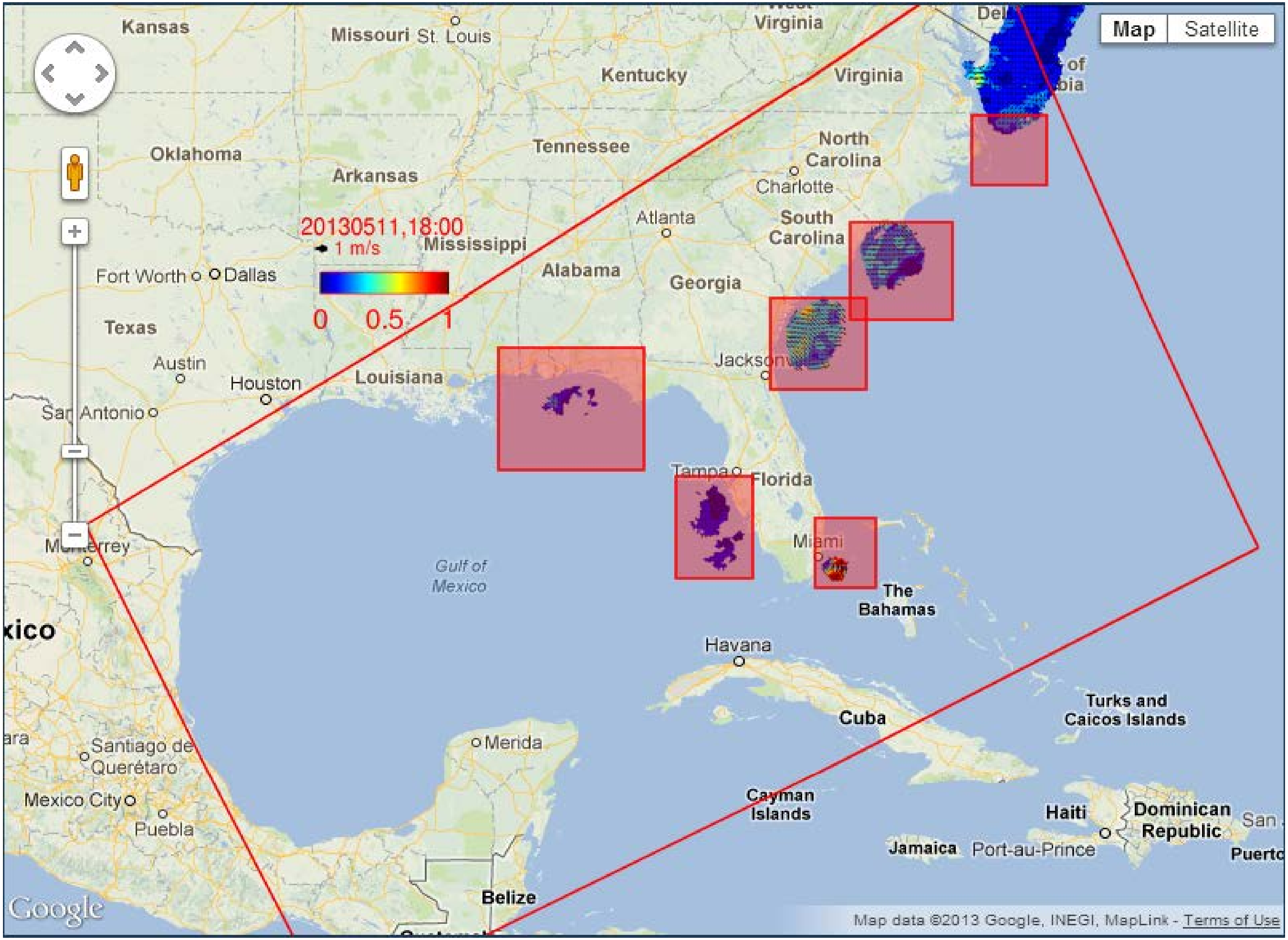
a) virtual mooring profile (T/S/V)
b) virtual transect (T/S/V)
c) 84-hour virtual drifter trajectory



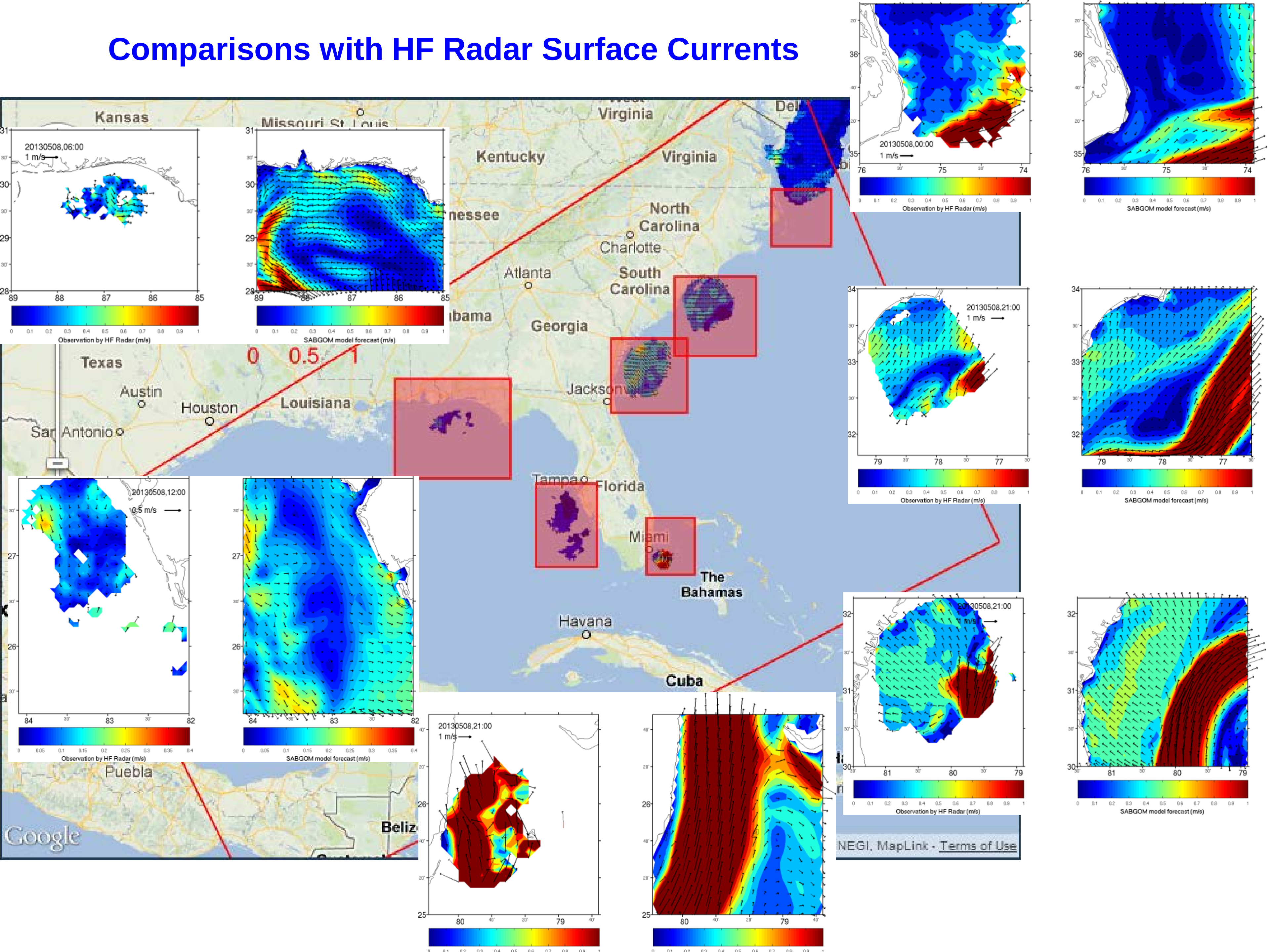




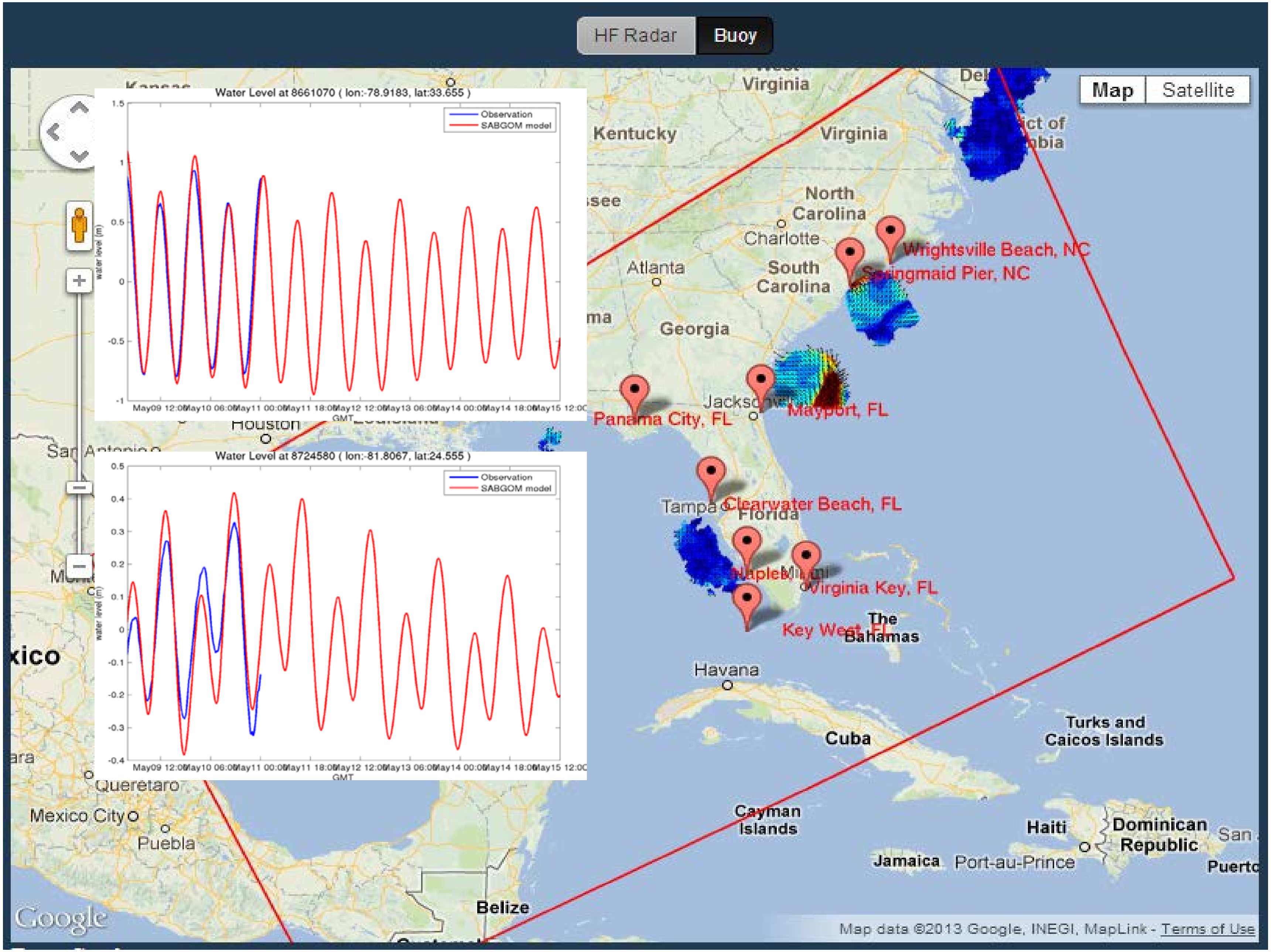
Online Skill Assessment: Comparisons with HF Radar Surface Currents



Comparisons with HF Radar Surface Currents



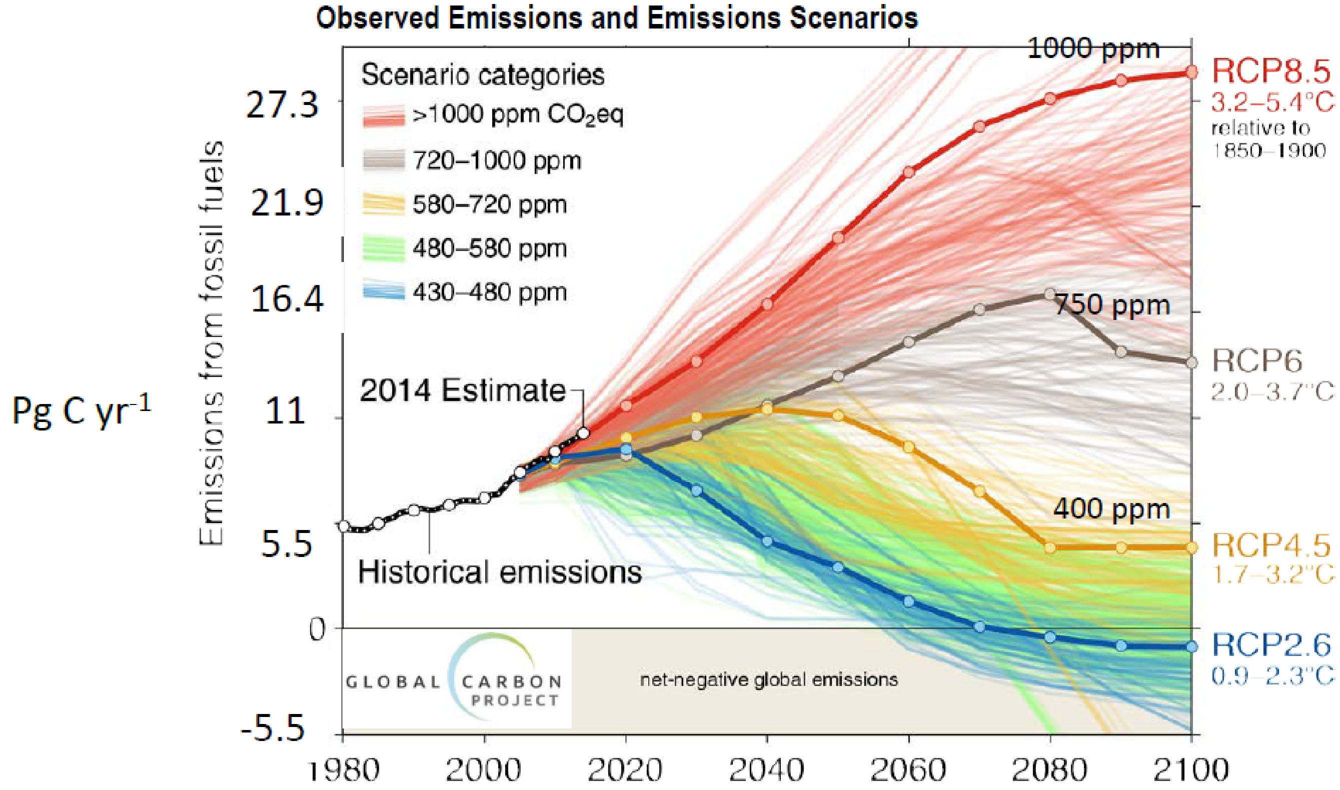
Online Skill Assessment: Comparisons with NOS Sea Level Observations



From Rick Wanninkhof SOCAN talk on March 10:

The Global Carbon Cycle: Uncertainties in modeling the future

Inherent uncertainties in connection between radiative forcing and CO_2

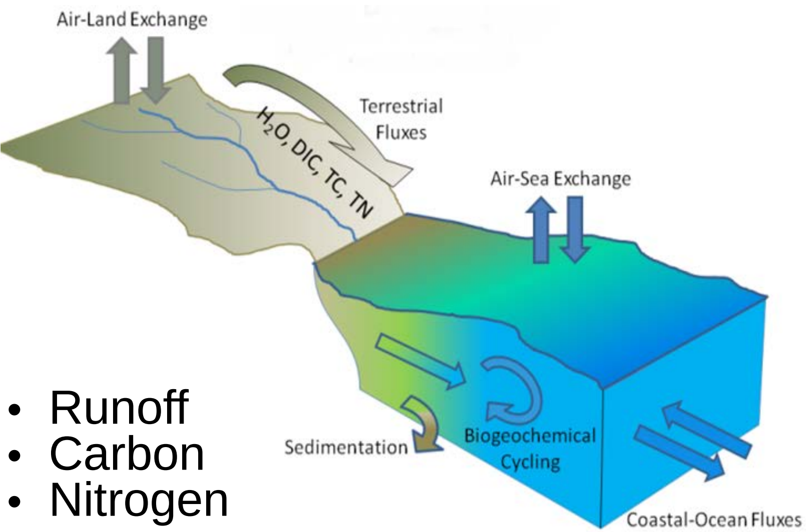


- ➢Emissions are on track for 3.2–5.4°C "likely" increase in temperature above pre-industrial
- ➢Large and sustained mitigation is required to keep below 2°C

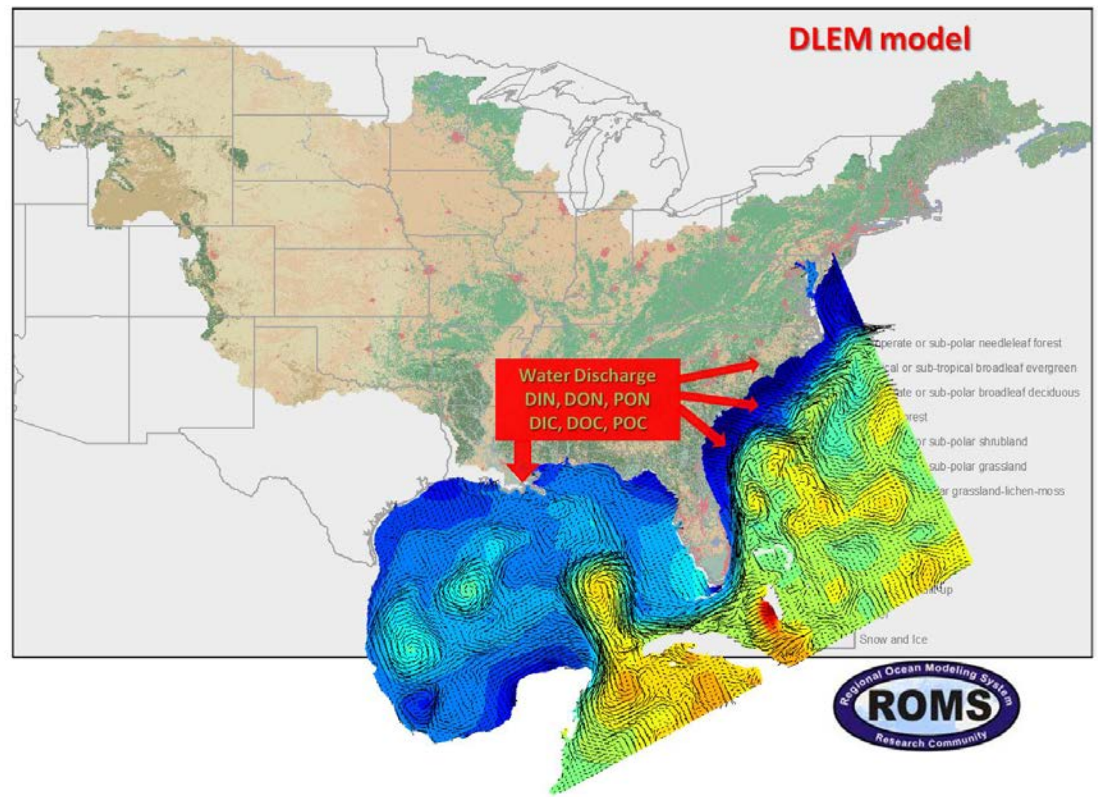
Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014

Coupling Land with Ocean



- Runoff
- Carbon
- Nitrogen



Assessing Impacts of Climate and Land Use Change on Terrestrial-Ocean Fluxes of Carbon and Nutrients and Their Cycling in Coastal Ecosystems

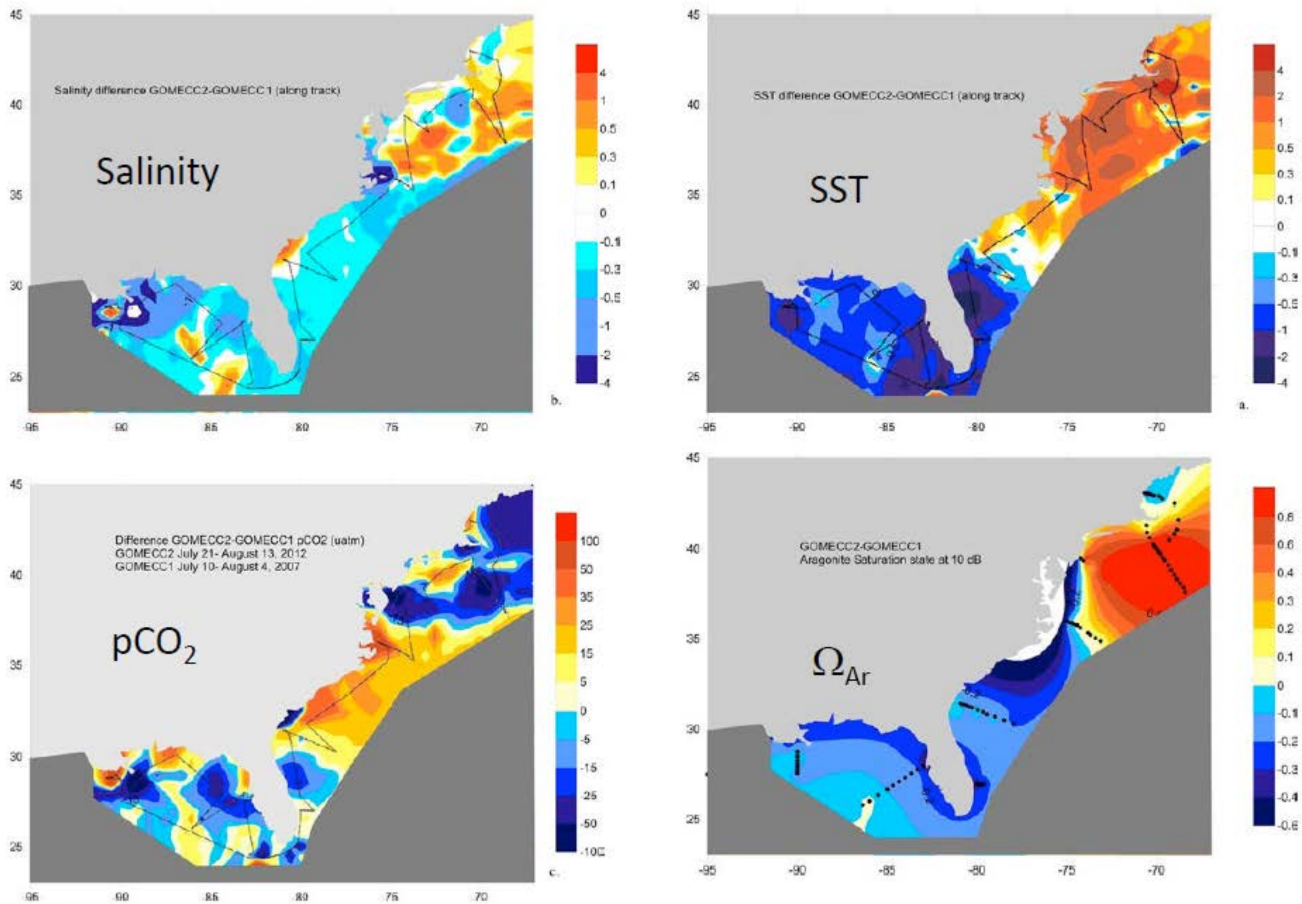
Past, Present, Future

UMass Dartmouth | AUBURN UNIVERSITY | NC STATE UNIVERSITY | UNIVERSITY OF DELAWARE

From Rick Wanninkhof SOCAN talk on March 10:

Changes in surface waters GOMECC region from 2007 to 2012

Changes in pCO_2, SST and SSS in surface waters GOMECC region



SOCAN
Southeast Ocean and Coastal Acidification Network

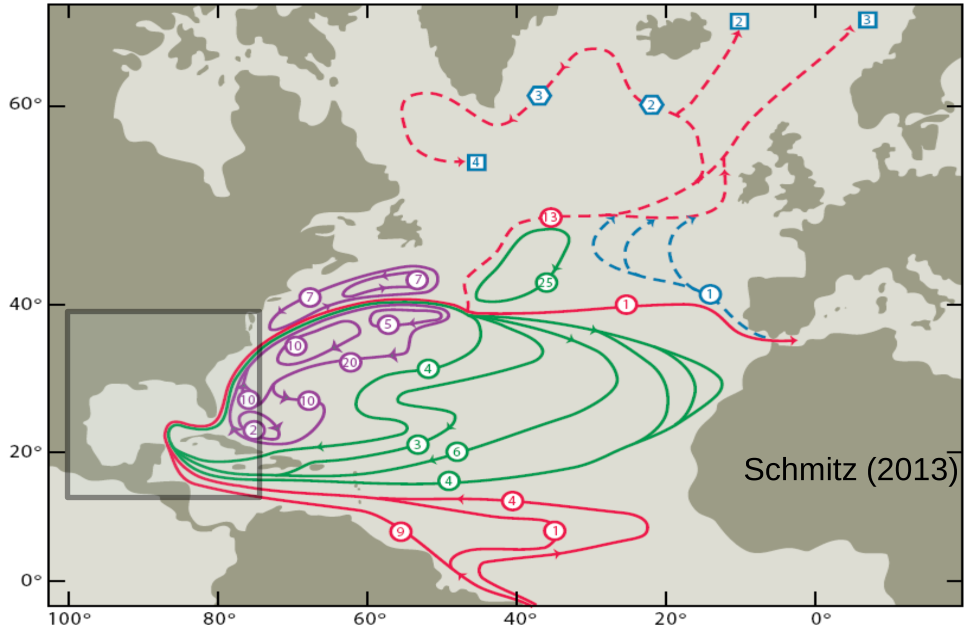
GOMECC-2 –GOMECC1 : Blue-GOMECC1 higher
Red :GOMECC2 higher

Outline

- Two coupled modeling systems
  - ❑ South Atlantic Bight and Gulf of Mexico (5 km)
  - ❑ **NW Atlantic coastal ocean (7 km)**

- Thoughts on path forward

- Summary



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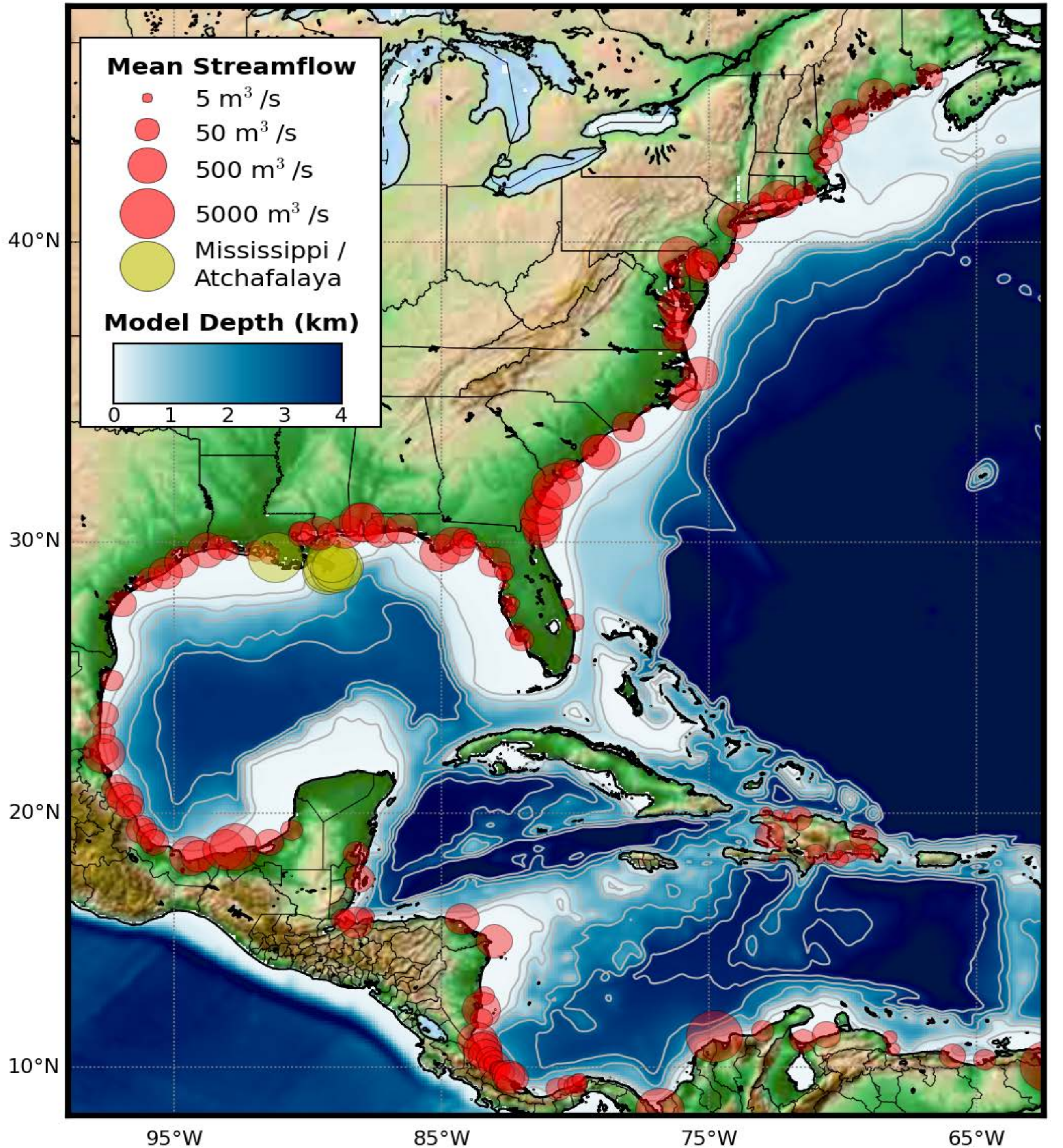
NW Atlantic Marine Environmental Prediction System

7-km resolution

Yao, He, et al. (2015)

Considering 196 rivers In the region



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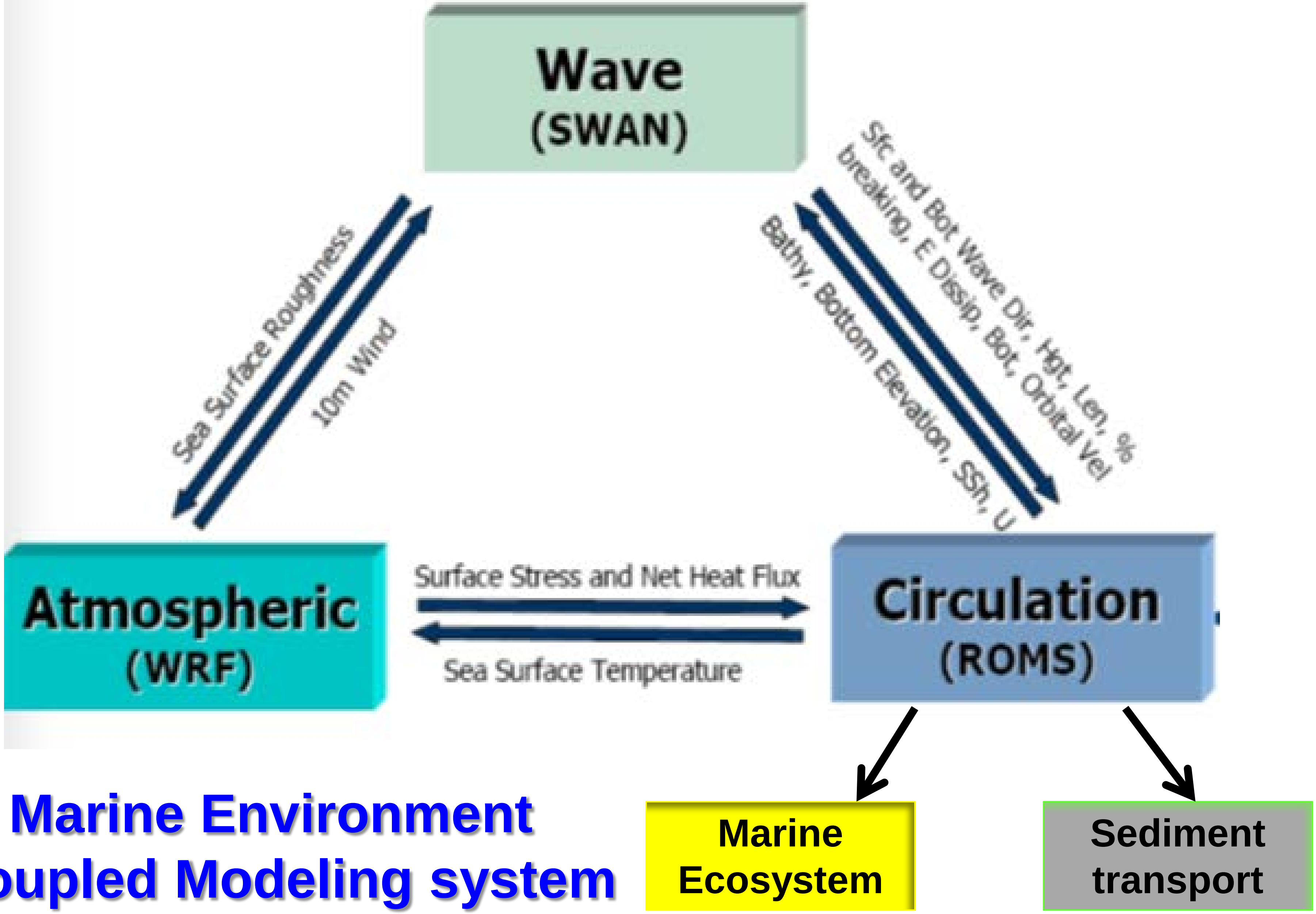
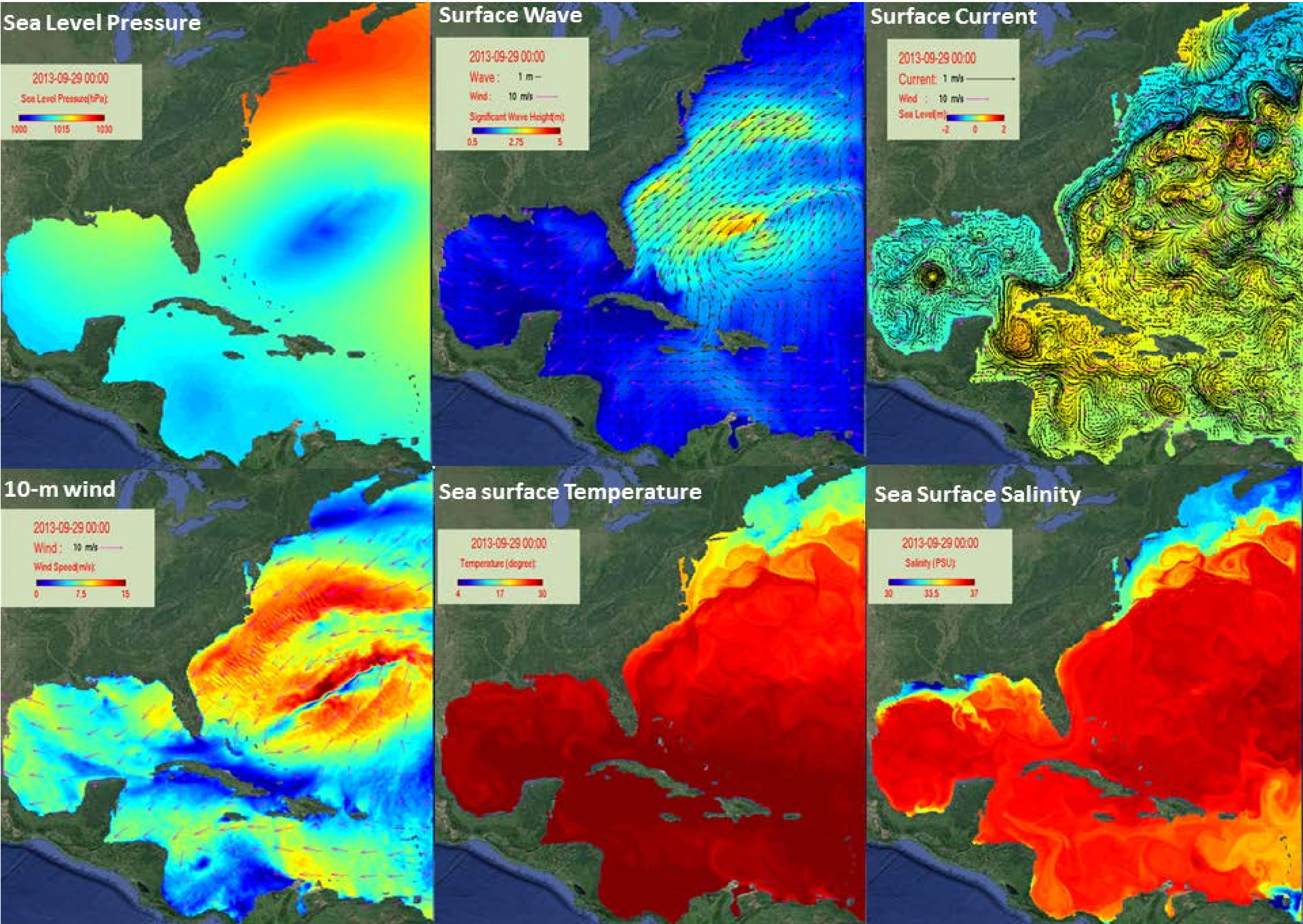


Marine Environment Coupled Modeling system

NW Atlantic Marine Environmental Prediction



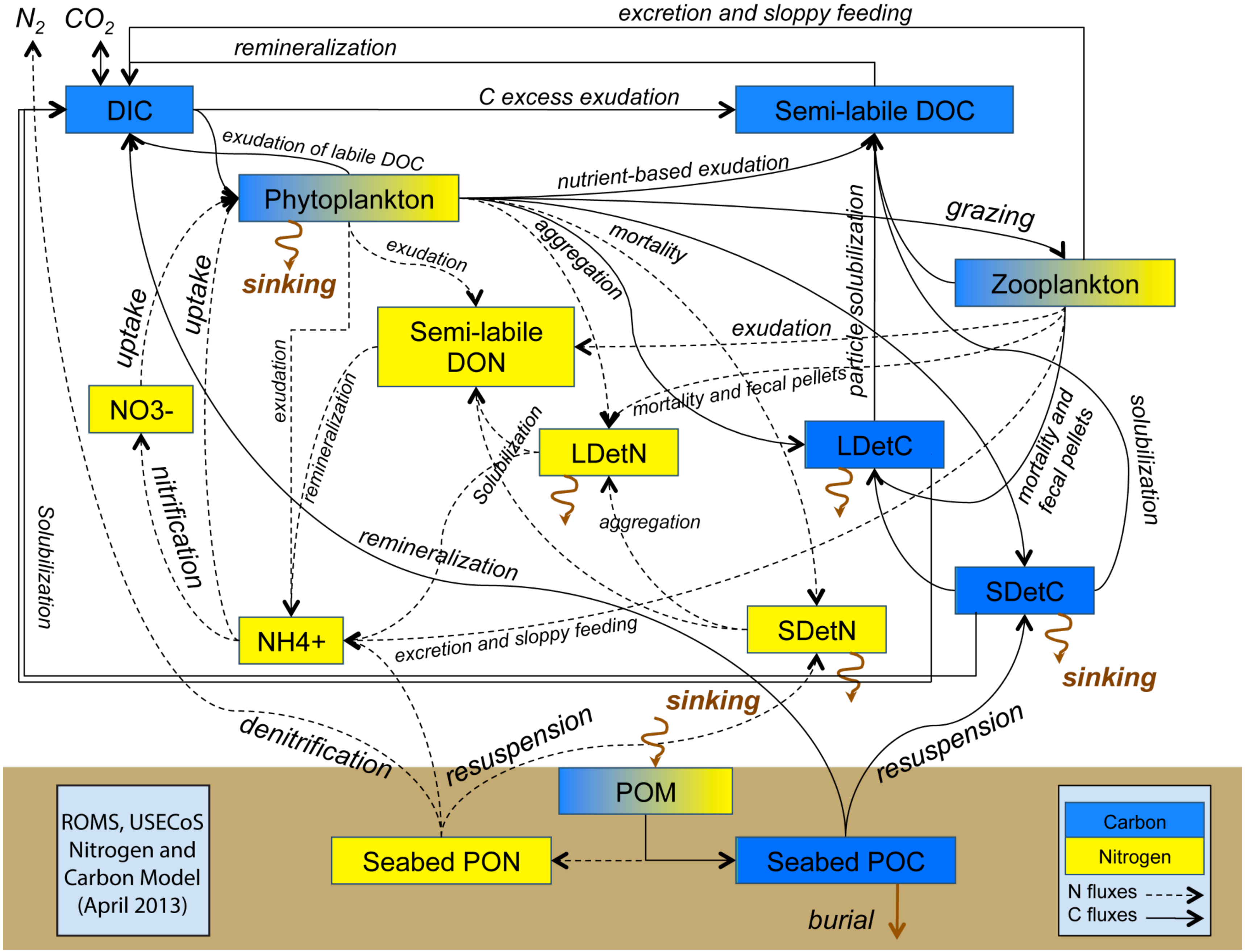


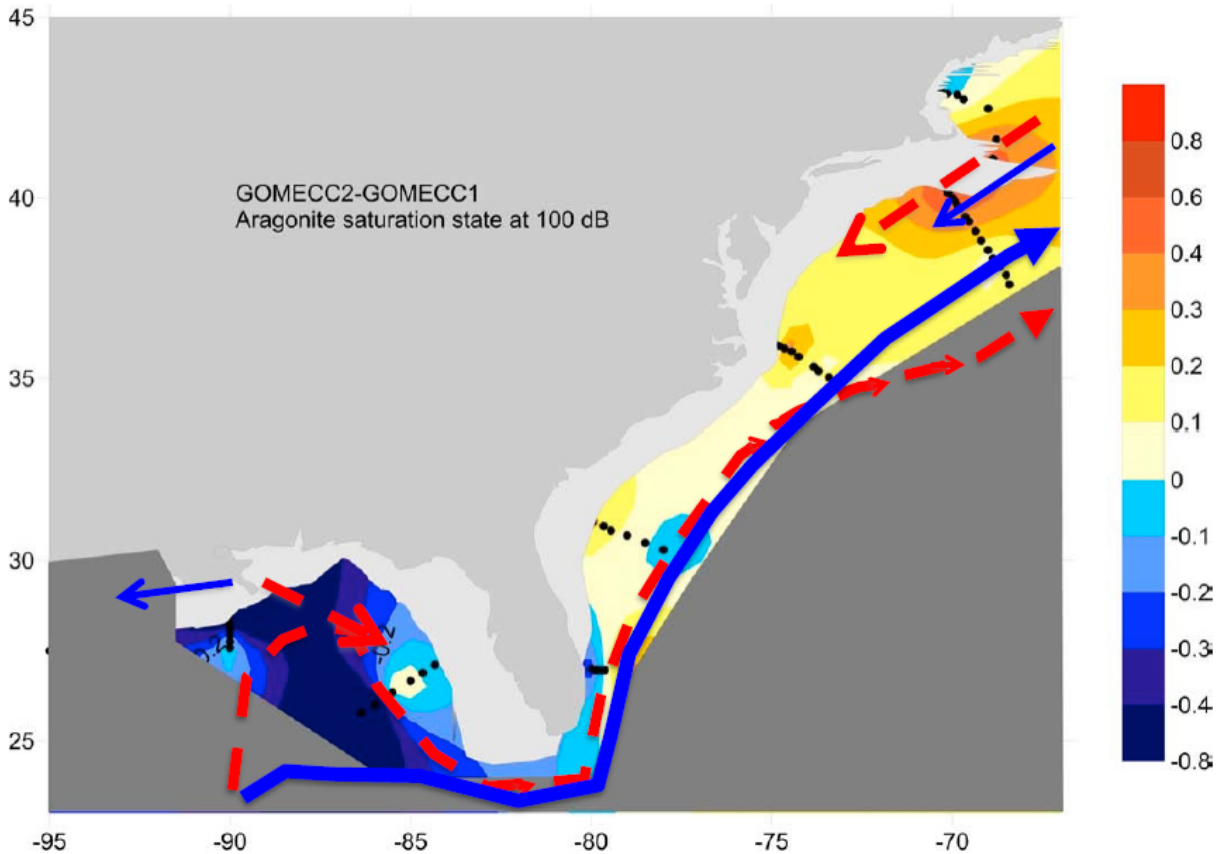
Figure courtesy, J. Wilkin and A. Tabatabai

Fennel et al., 2006, Fennel et al., 2009, Hoffman et al., 2011

From Rick Wanninkhof SOCAN talk on March 10:

Changes in Ω_{Ar} (100-m) GOMECC region from 2007 to 2012

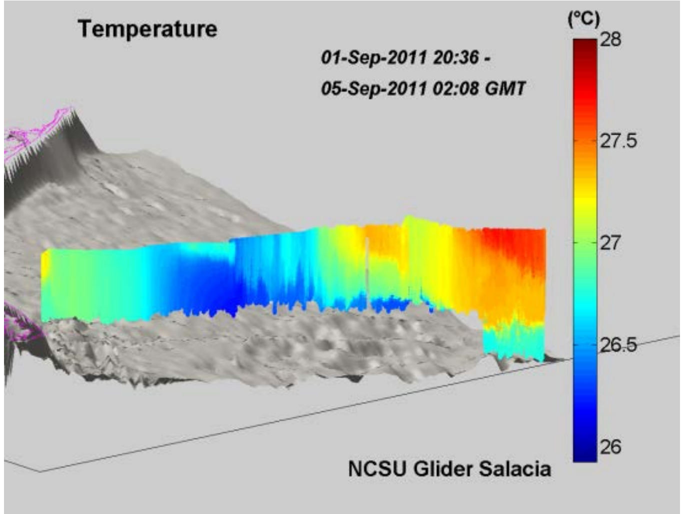
Changing currents cause large changes in Ω_{Ar}

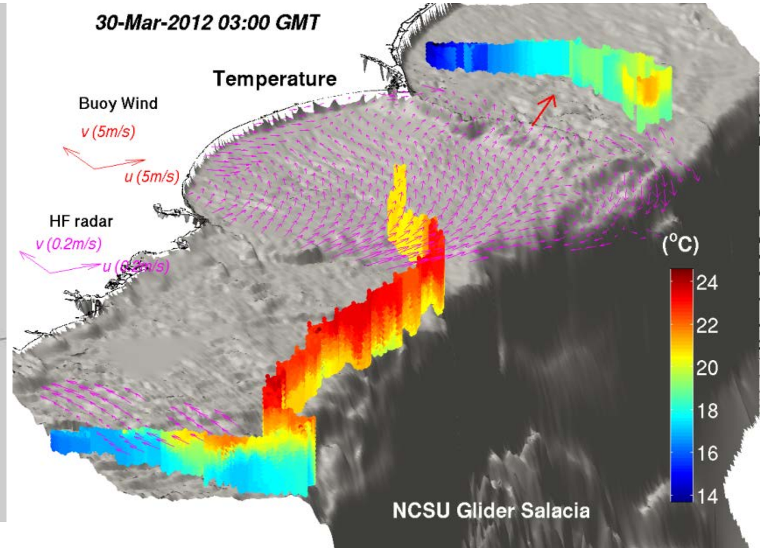


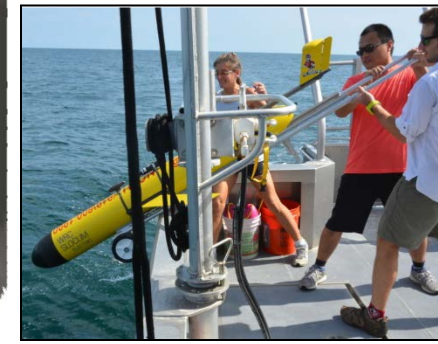
Summer 2007 (GOMECC-1: Strong Loop Current;MARS along WFl shelf; Strong Labrador Coastal current

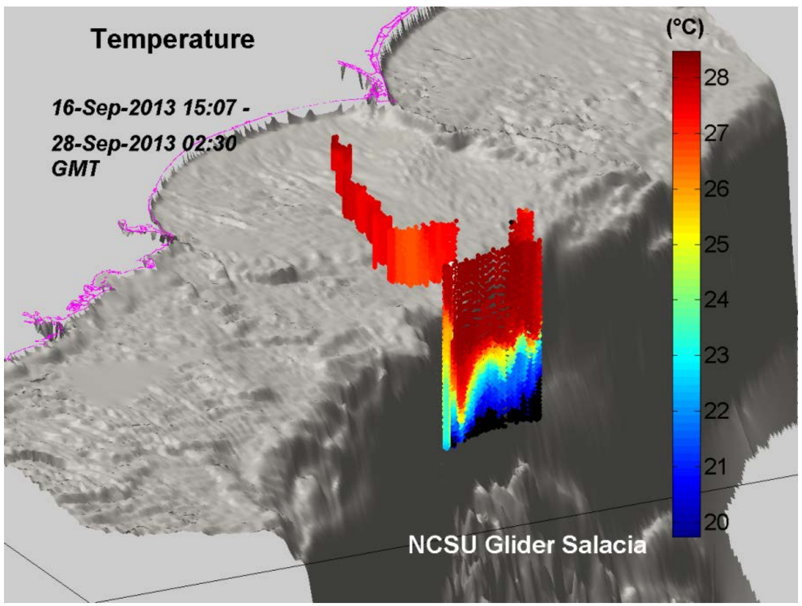
Summer 2012 (GOMECC-2: Weak Loop Current;MARS Westward; Weak Labrador Coastal current

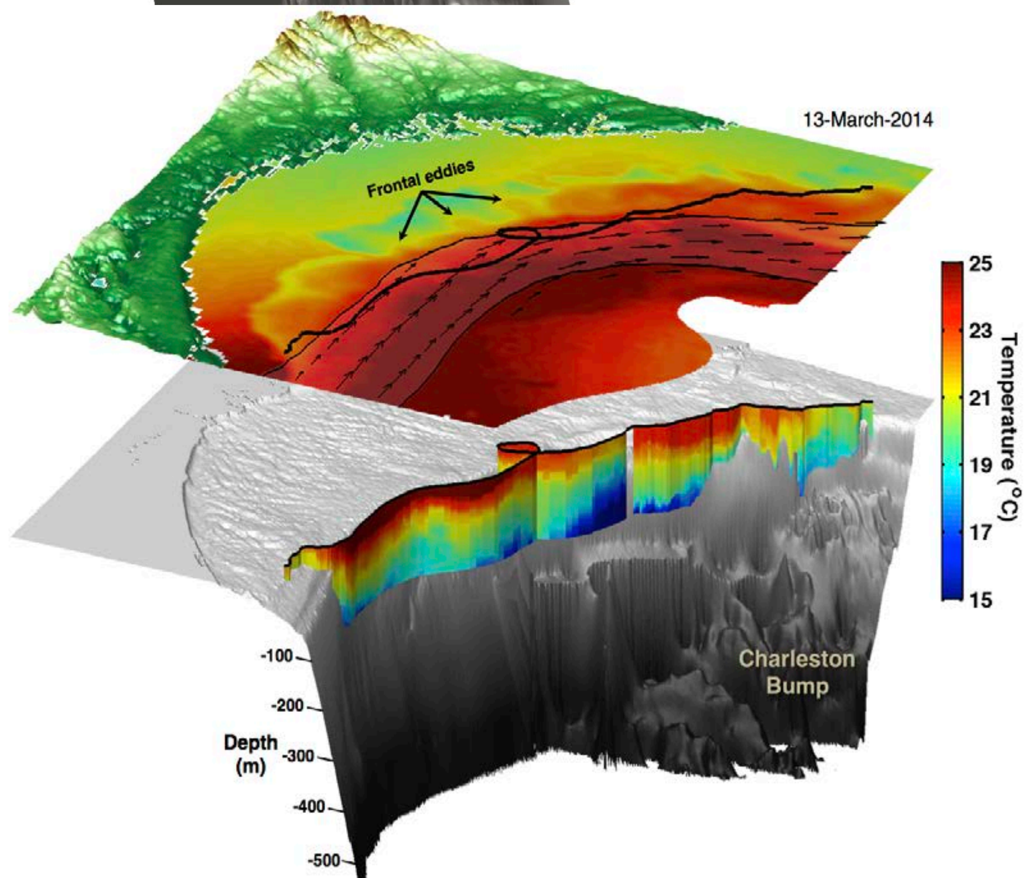
SOCAN
Southeast Ocean and Coastal Acidification Network

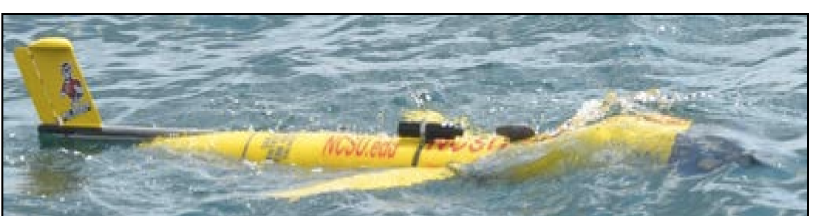

Temperature
01-Sep-2011 20:36 -
05-Sep-2011 02:08 GMT
(°C)
28
27.5
27
26.5
26
NCSU Glider Salacia


30-Mar-2012 03:00 GMT
Temperature
Buoy Wind
v (5m/s)
u (5m/s)
HF radar
v (0.2m/s)
u (0.2m/s)
(°C)
24
22
20
18
16
14
NCSU Glider Salacia

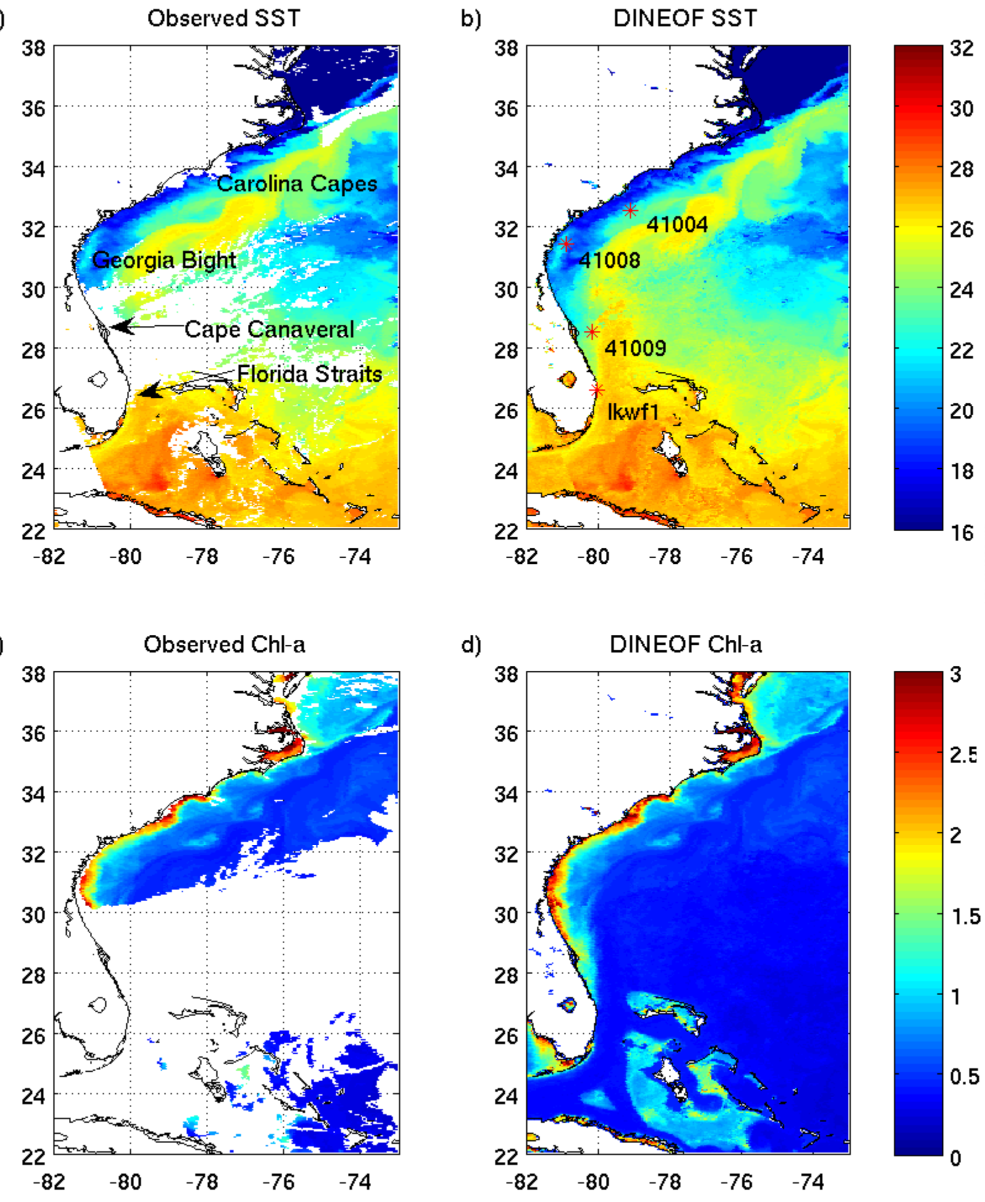


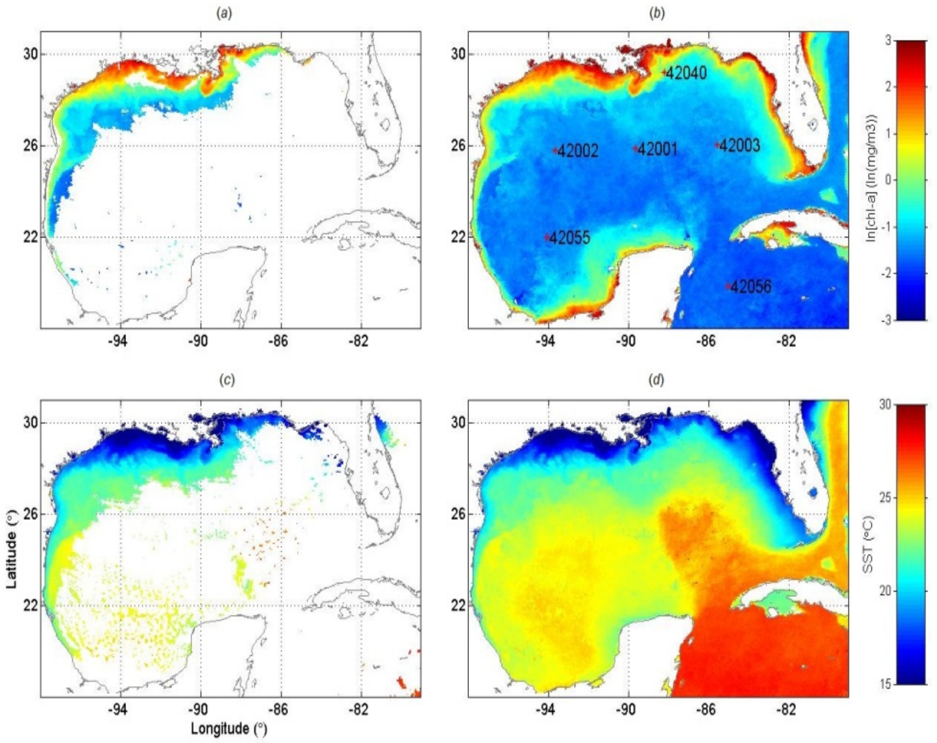

Temperature
16-Sep-2013 15:07 -
28-Sep-2013 02:30
GMT
(°C)
28
27
26
25
24
23
22
21
20
NCSU Glider Salacia


13-March-2014
Frontal eddies
25
23
21
19
17
15
Temperature (°C)
-100
-200
-300
-400
-500
Depth
(m)
Charleston
Bump



EOF based Daily Cloud–free SST and Chl-a reanalysis





Period: 11 years (2003- 2013)

Miles, Moore and He (2009);
Miles and He (2010);
Zhao and He (2012)
Shropshire, Li and He (2014)

Some thoughts on path forward..

- Understanding the coastal ocean response to climate change effects require us to first define the intrinsic variability on seasonal to interannual time scale;

- Strong couplings in land-ocean-atmosphere, and between physics, biology, geology in coastal ocean need to be carefully quantified;

- Coupled physical-biogeochemical model nested inside climate model scenarios can provides a valuable tool to forecast climate impact on the coastal ocean.

- Deterministic predictions of the coastal circulation and ecosystem dynamics will clearly require refined models, advanced observational infrastructure together with sophisticated techniques for data assimilation.

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Summary

- Marine Environmental Hindcast, Nowcast Forecast System for 1) the Gulf of Mexico and South Atlantic Bight and 2) NW Atlantic Ocean
  - 3-dimensional baroclinic ocean circulation (T/S/V/sea level)
  - ocean wave (height and direction)
  - marine meteorology (U10, SLP, air temp, etc)
  - marine ecosystem (NO_3, NH_4, phytoplankton, Zooplankton, TIC, Alkalinity, pCO2, Oxygen)
  - Hindcast solution available since 2003

- Value added product
  - online model skill assessment
  - online user defined virtual mooring, virtual transect, virtual drifter trajectory simulations
  - model ensembles and data assimilation
  - seasonal forecast and regional downscaling of climate scenarios

- Glider based hydrography and marine species observations
  - in situ, subsurface, AUV and acoustic technology

- Cloud-free satellite data reanalysis
  - daily SST and chl-a data since 2003

Marine Ecosystem Forecasting Service:

- Ocean Acidification
- Fishery/coral habitat/ species distribution
- Hypoxia
- Harmful Algal Bloom

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- **Group website: http://go.ncsu.edu/oomg**
- **SABGOM site: http://omgsrv1.meas.ncsu.edu:8080/ocean-circulation**
- **NW Atlantic site: http://omgsrv1.meas.ncsu.edu:8080/ocean-circulation2**