Predicting Marine Physical-Biogeochemical Variability in the Gulf of Mexico and Southeastern U.S. Shelf Seas

Ruoying He

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Ocean Observing and Modeling Group (OOMG)
North Carolina State University

In collaboration with (in alphabetical order)

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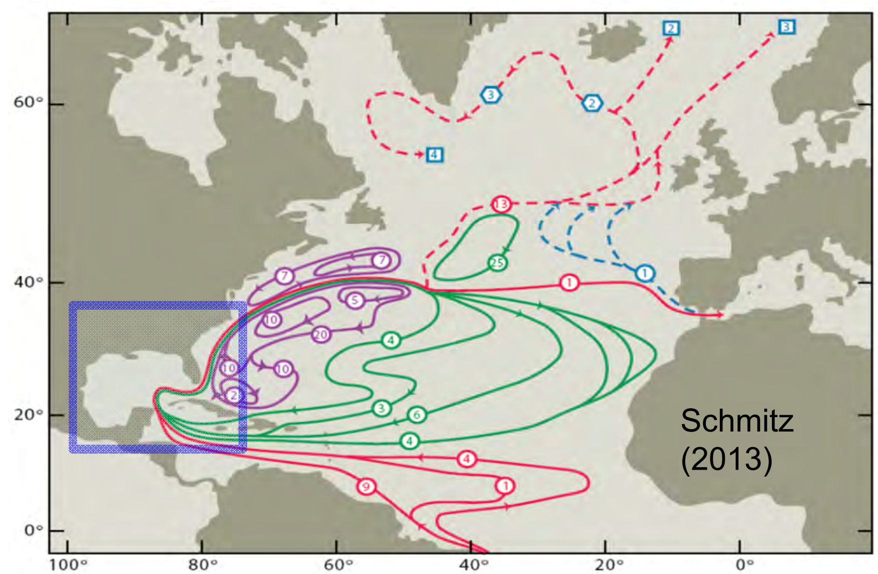
Powered by

Outline

- Some of the latest model developments
    - o Coupled modeling
    - o two-way nesting
    - o Ultra-high resolution wave modeling
    - o Data assimilation
- Case studies
    - o Gulf Stream meander
    - o Gulf of Mexico BGC study
- Summary



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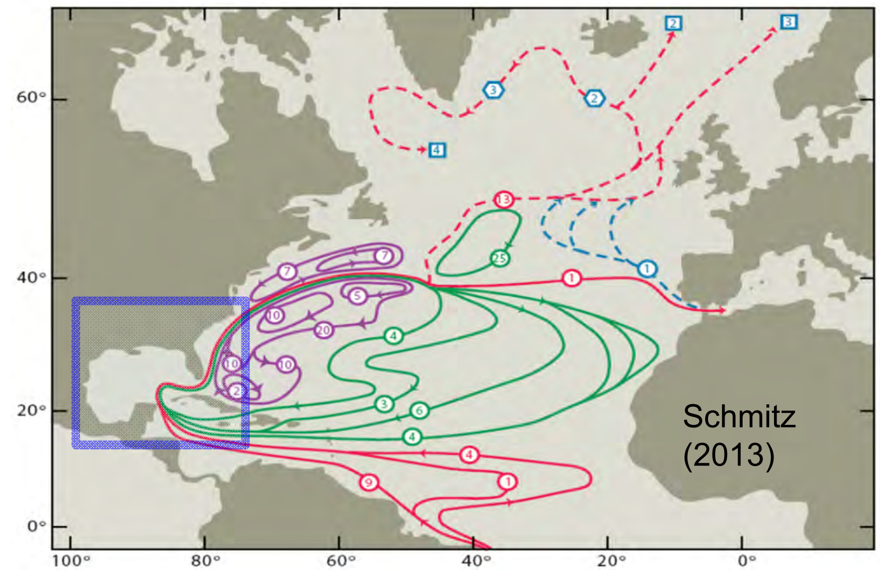

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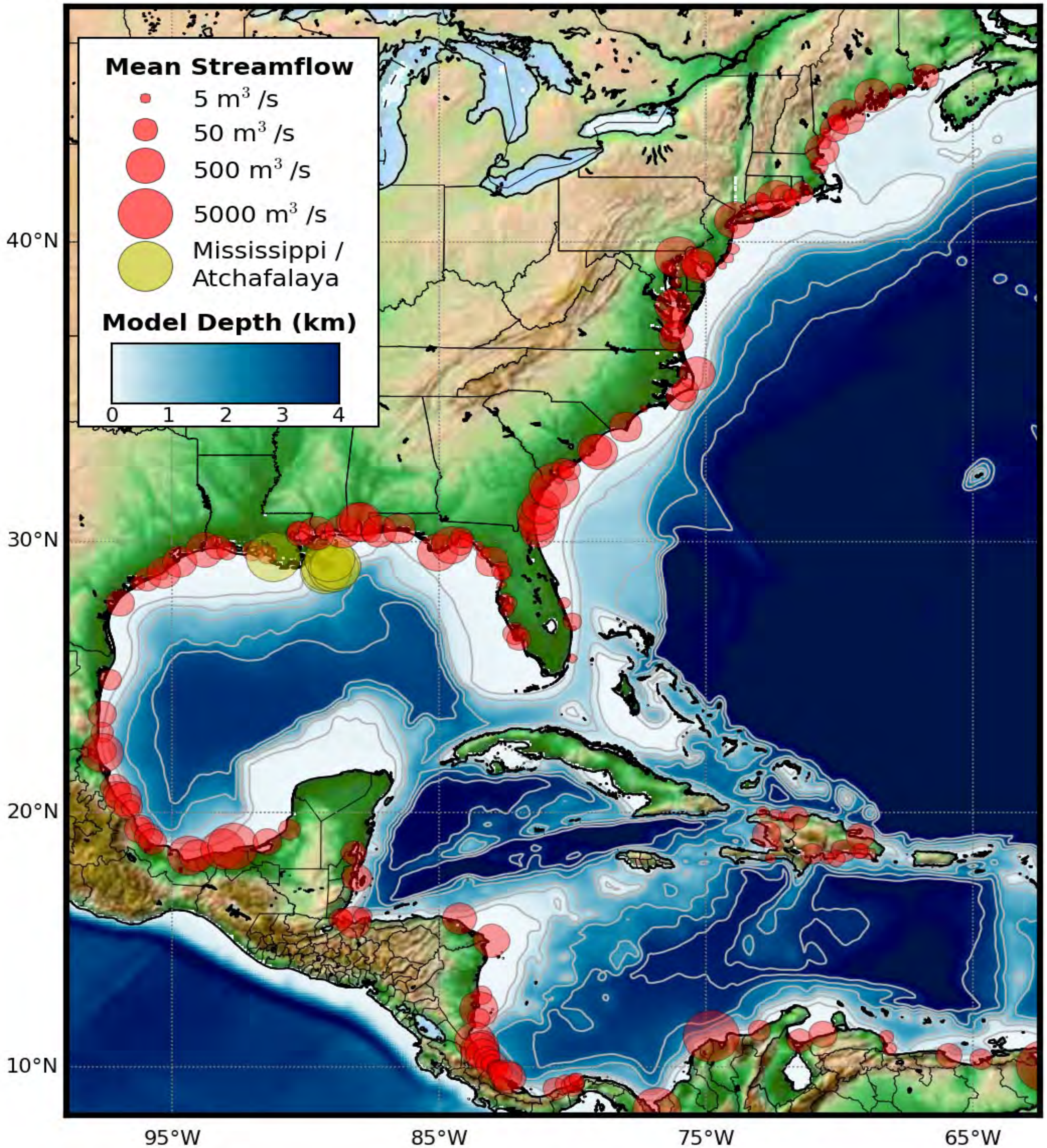
NW Atlantic Marine Environmental Prediction System

7-km resolution

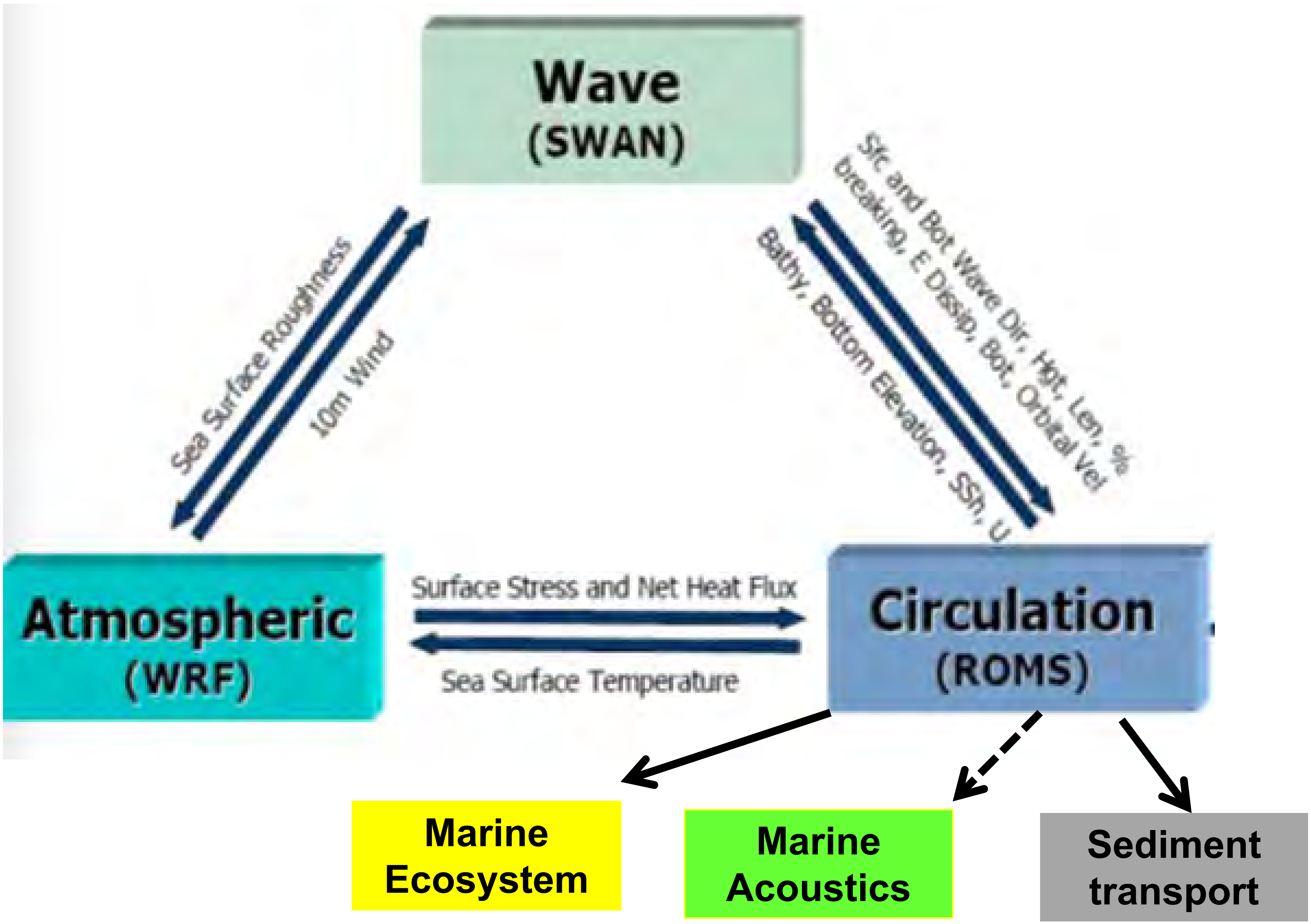
Considering 196 rivers In the region

Zeng and He (2016)

Yao, He, et al. (in review)



Marine Environment Coupled Modeling System



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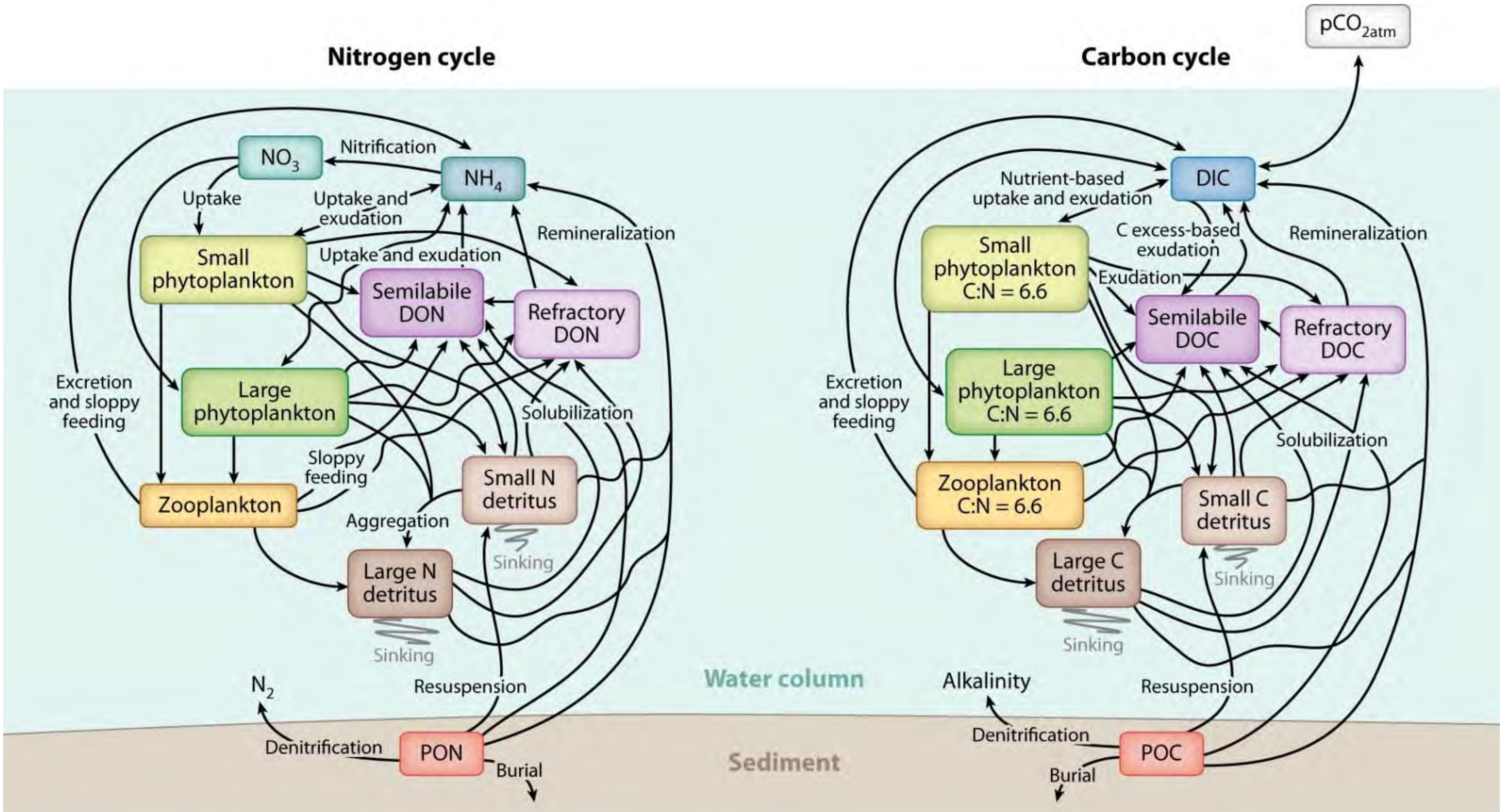
Marine biogeochemical model coupled with ocean circulation



Hofmann EE, et al. 2011.
Annu. Rev. Mar. Sci. 3:93–122

Fennel et al., 2006, 2011

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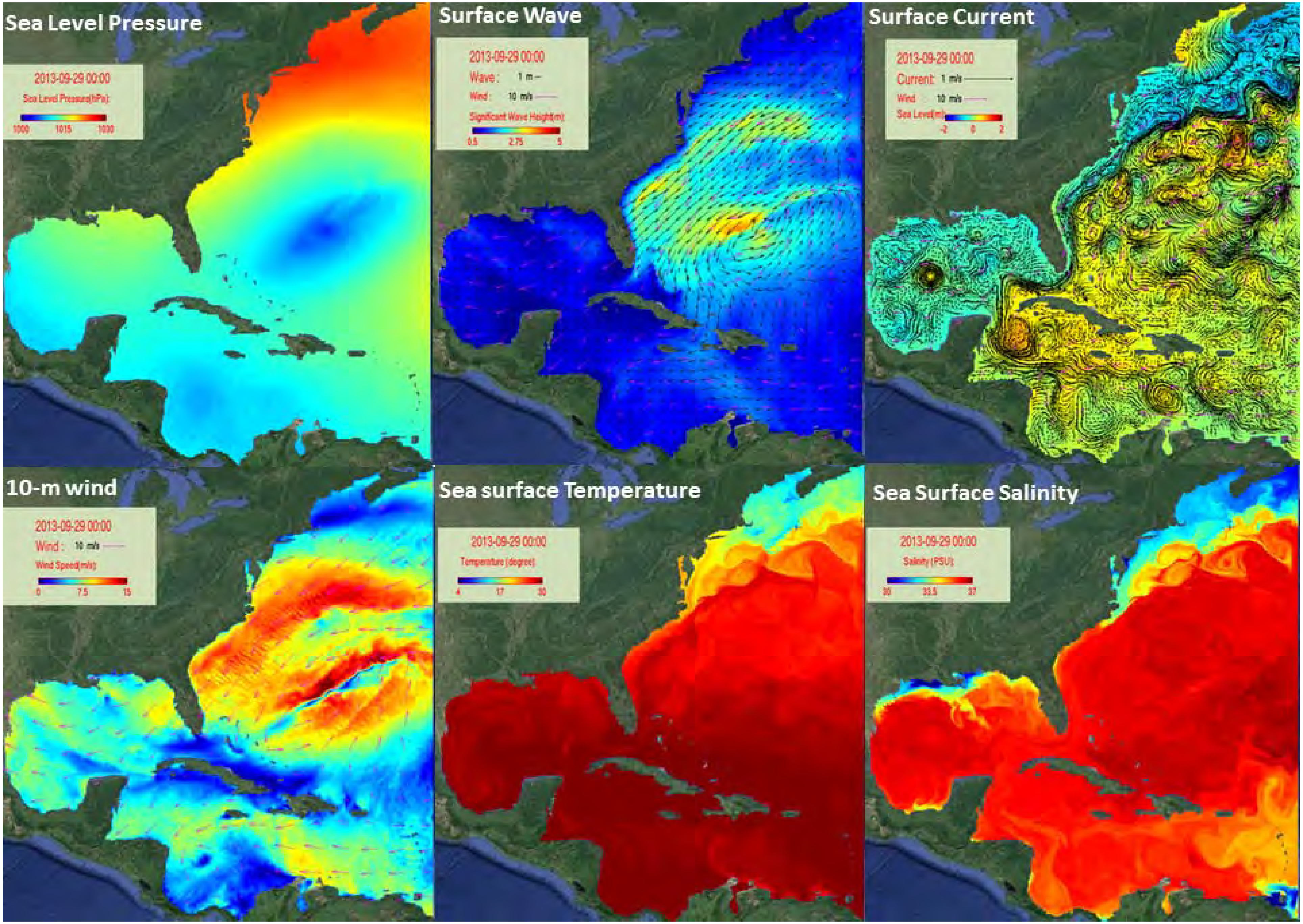
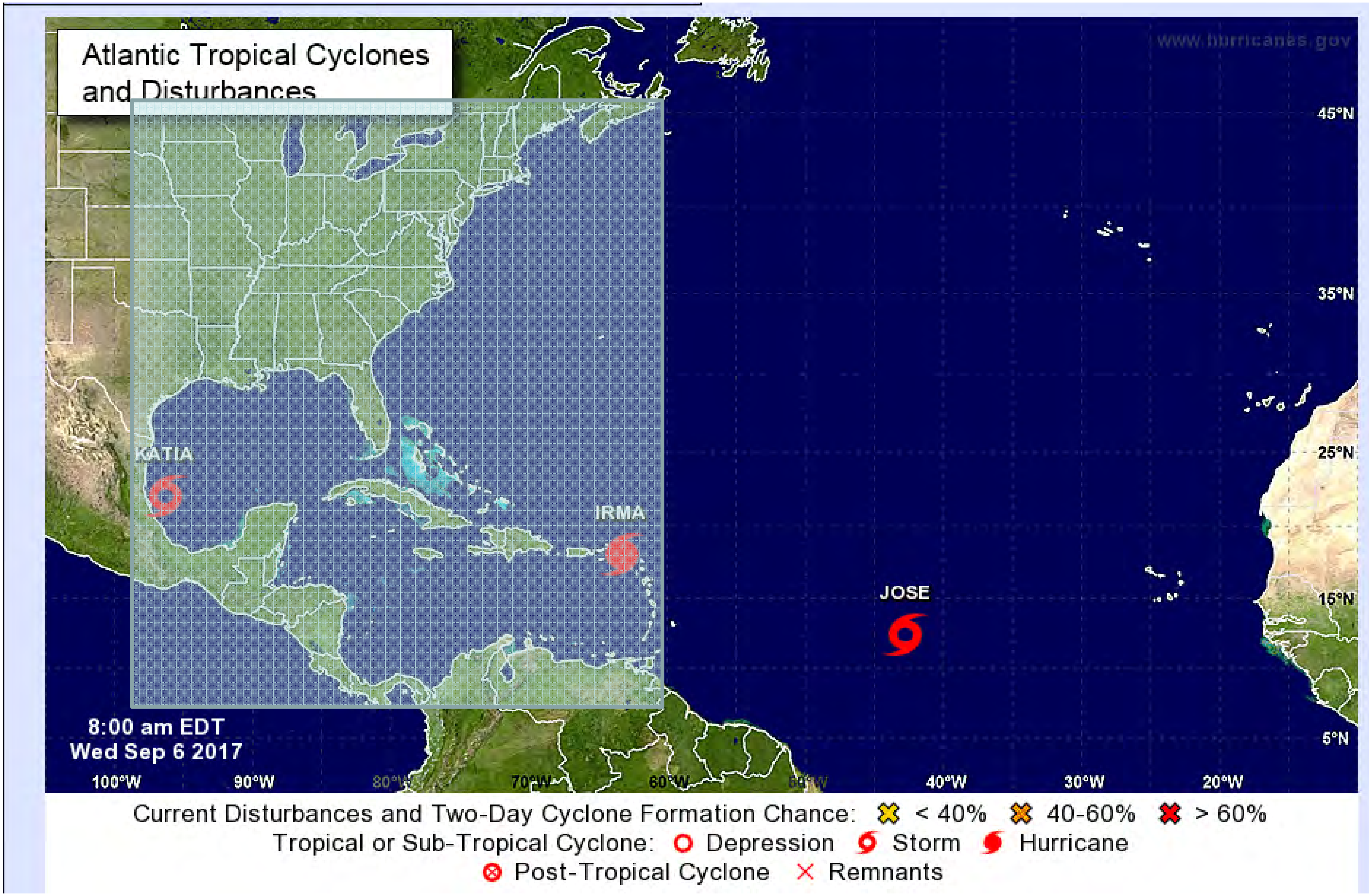
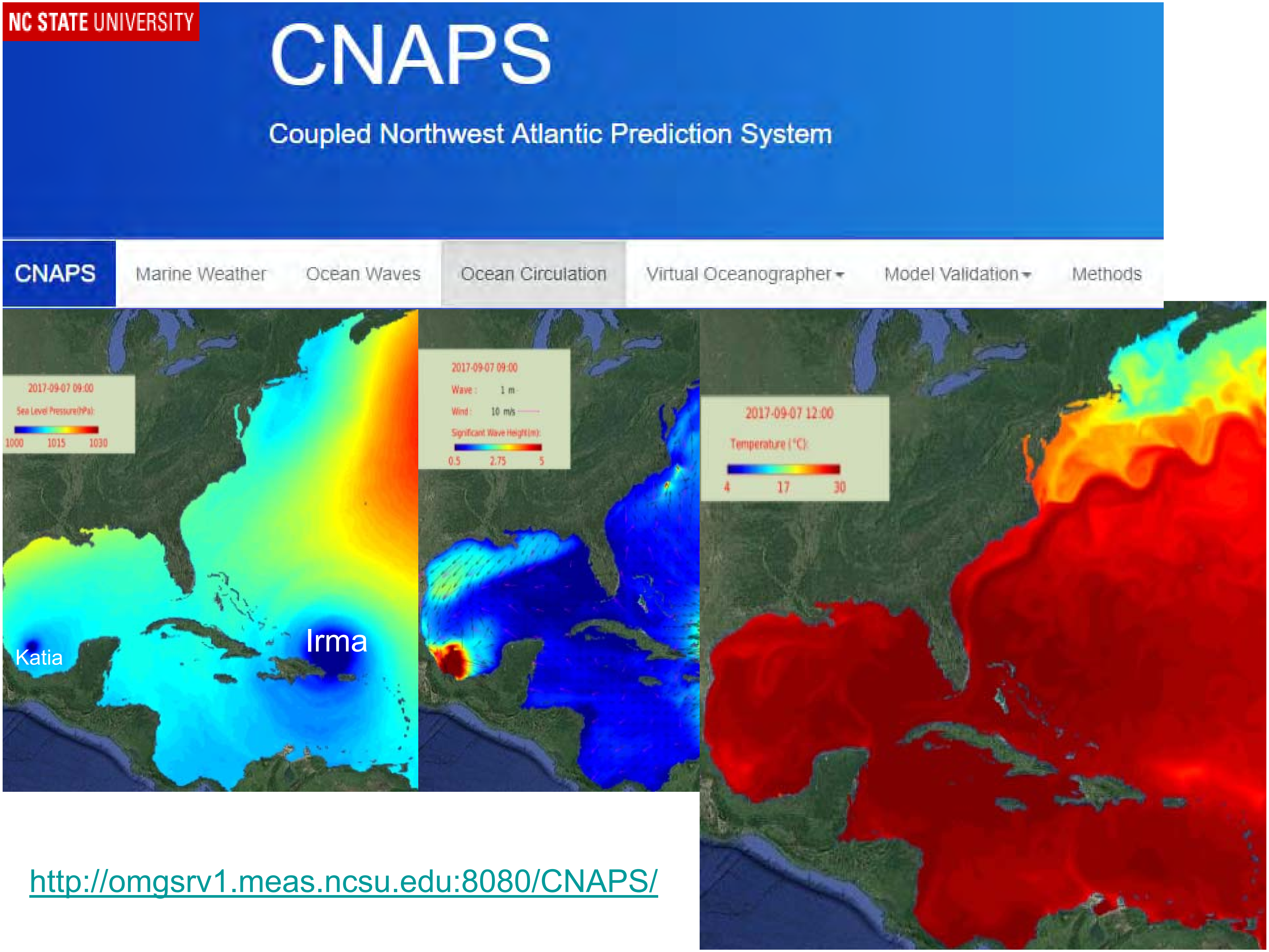
Coupled NW Atlantic Prediction System (CNAPS)



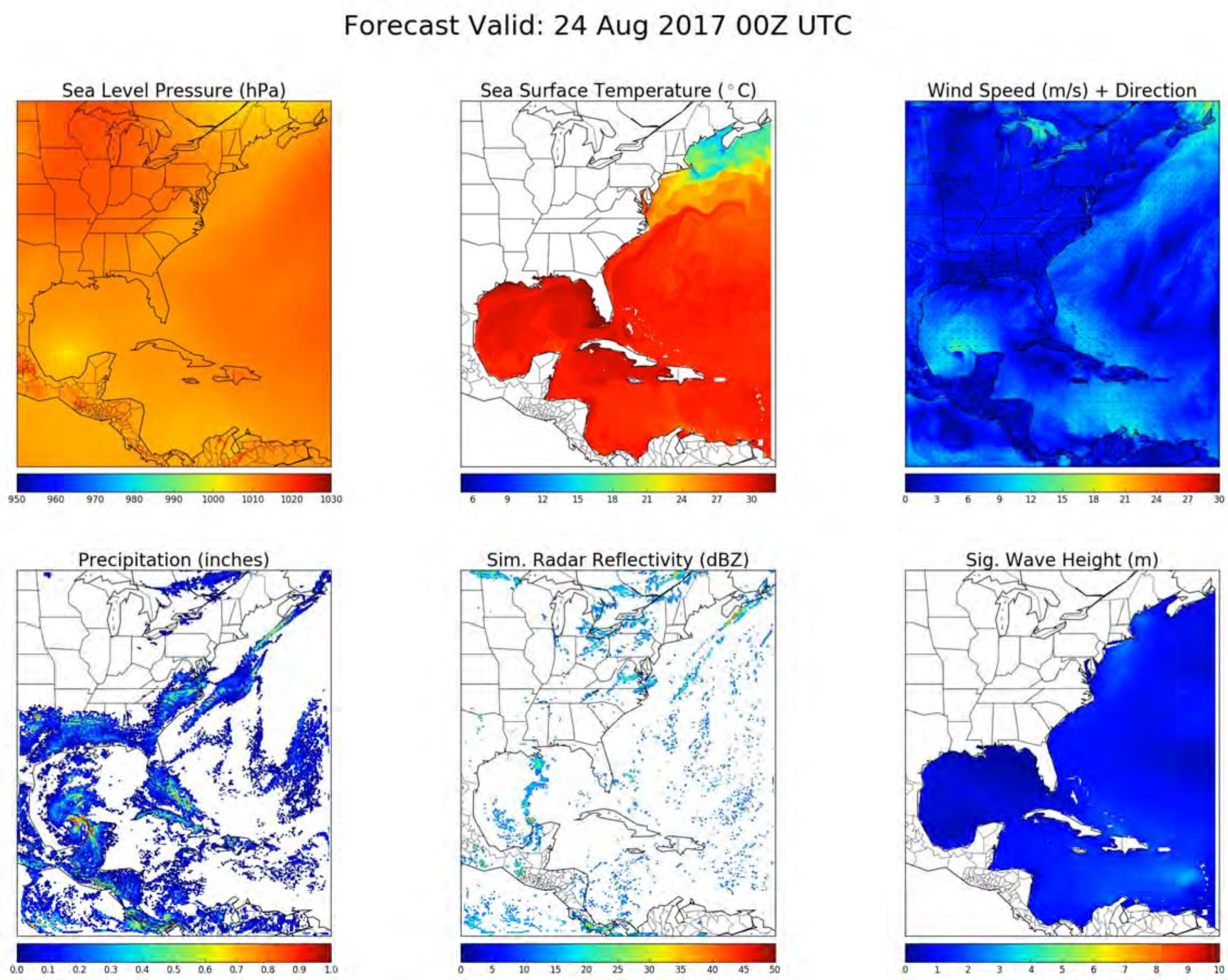
Hurricane Irma, Tropical Storm Katia, Jose





http://omgsrv1.meas.ncsu.edu:8080/CNAPS/

Hurricane Harvey



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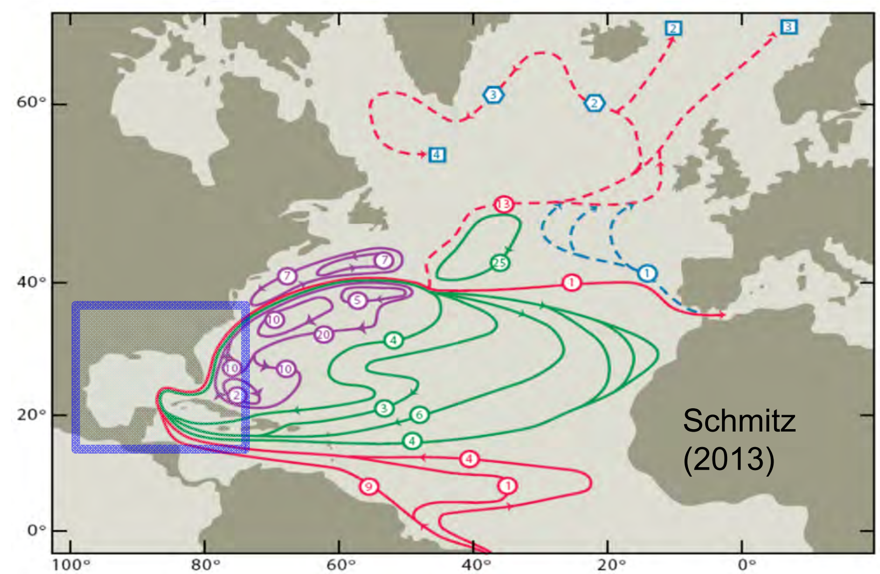
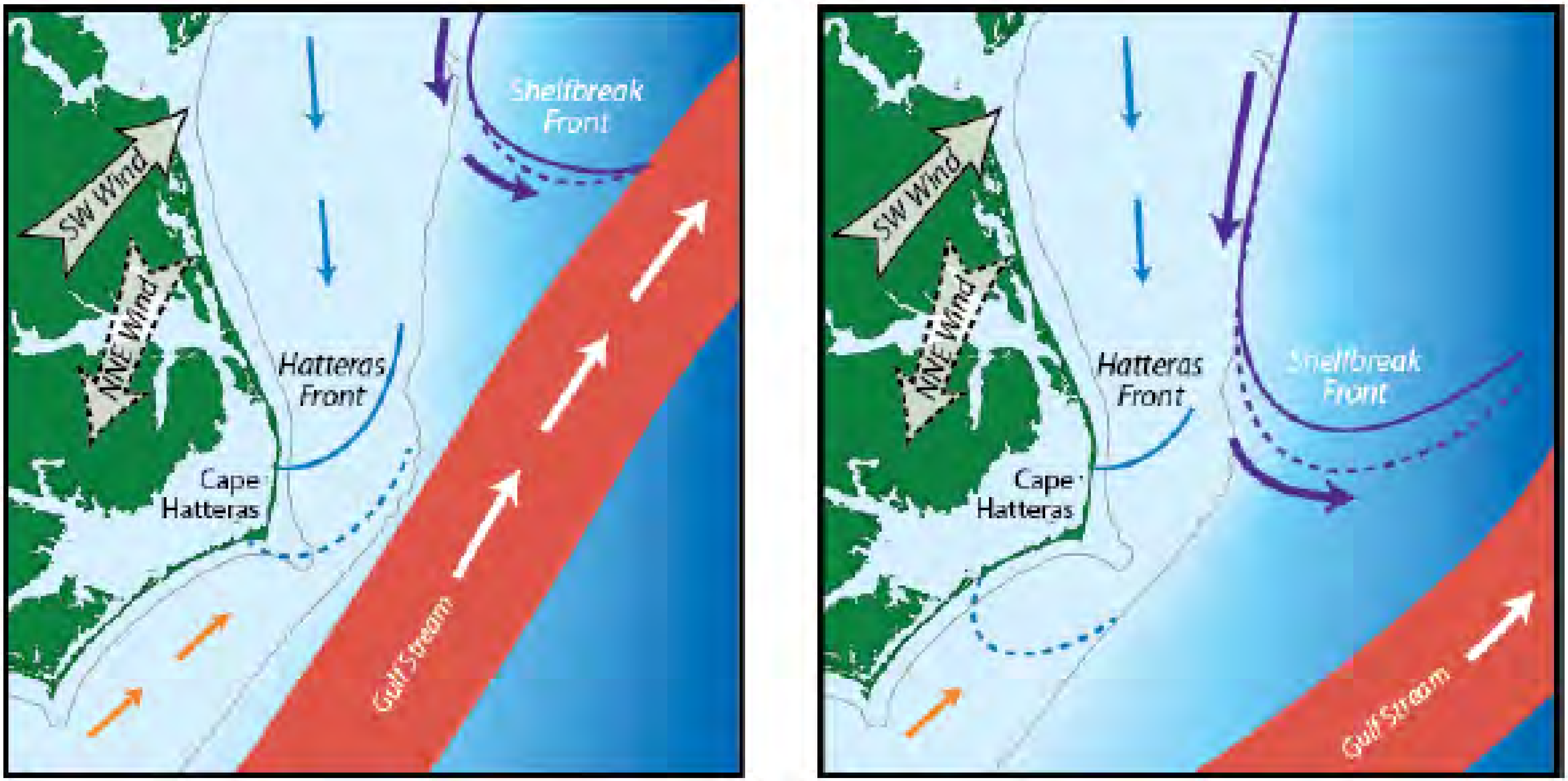
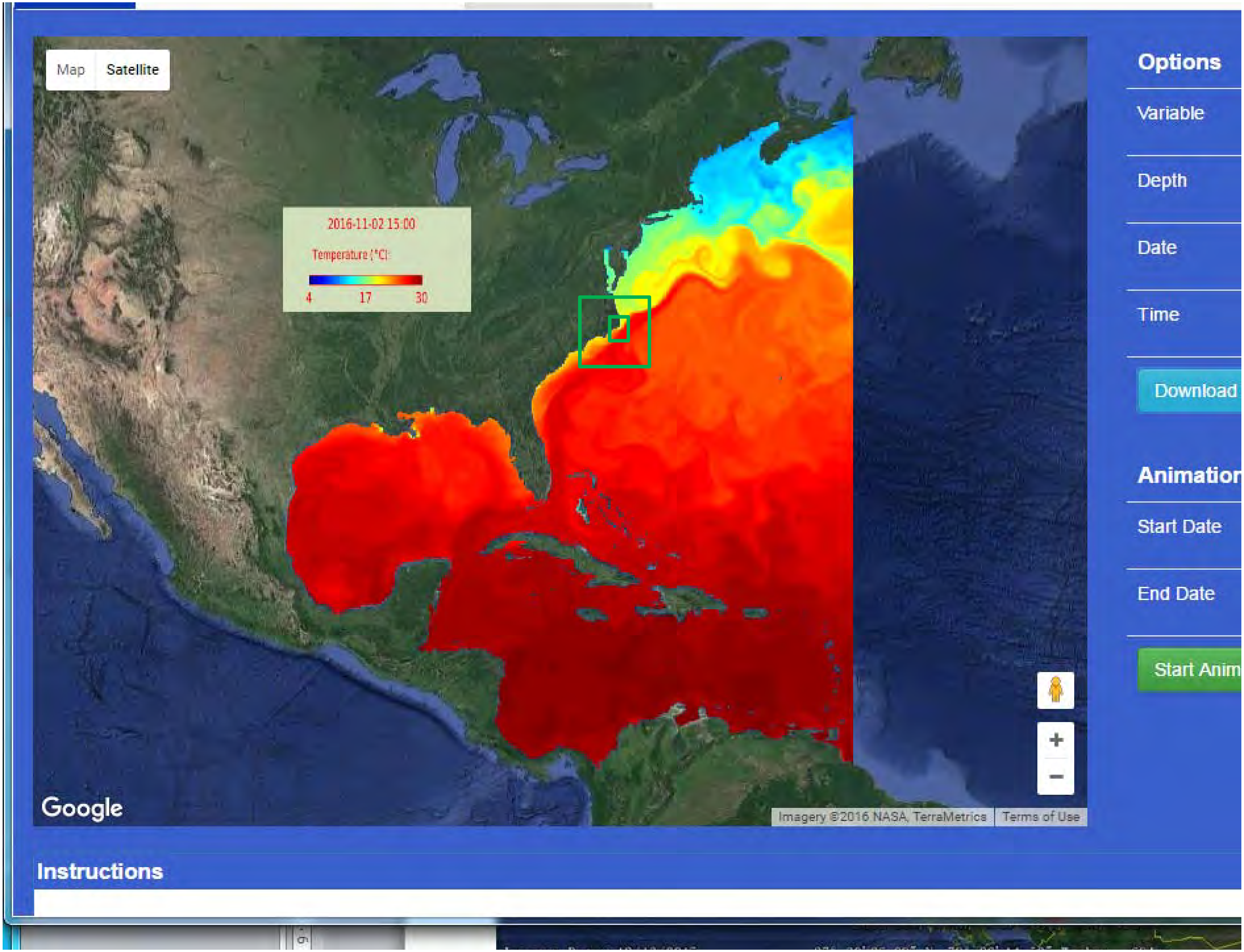
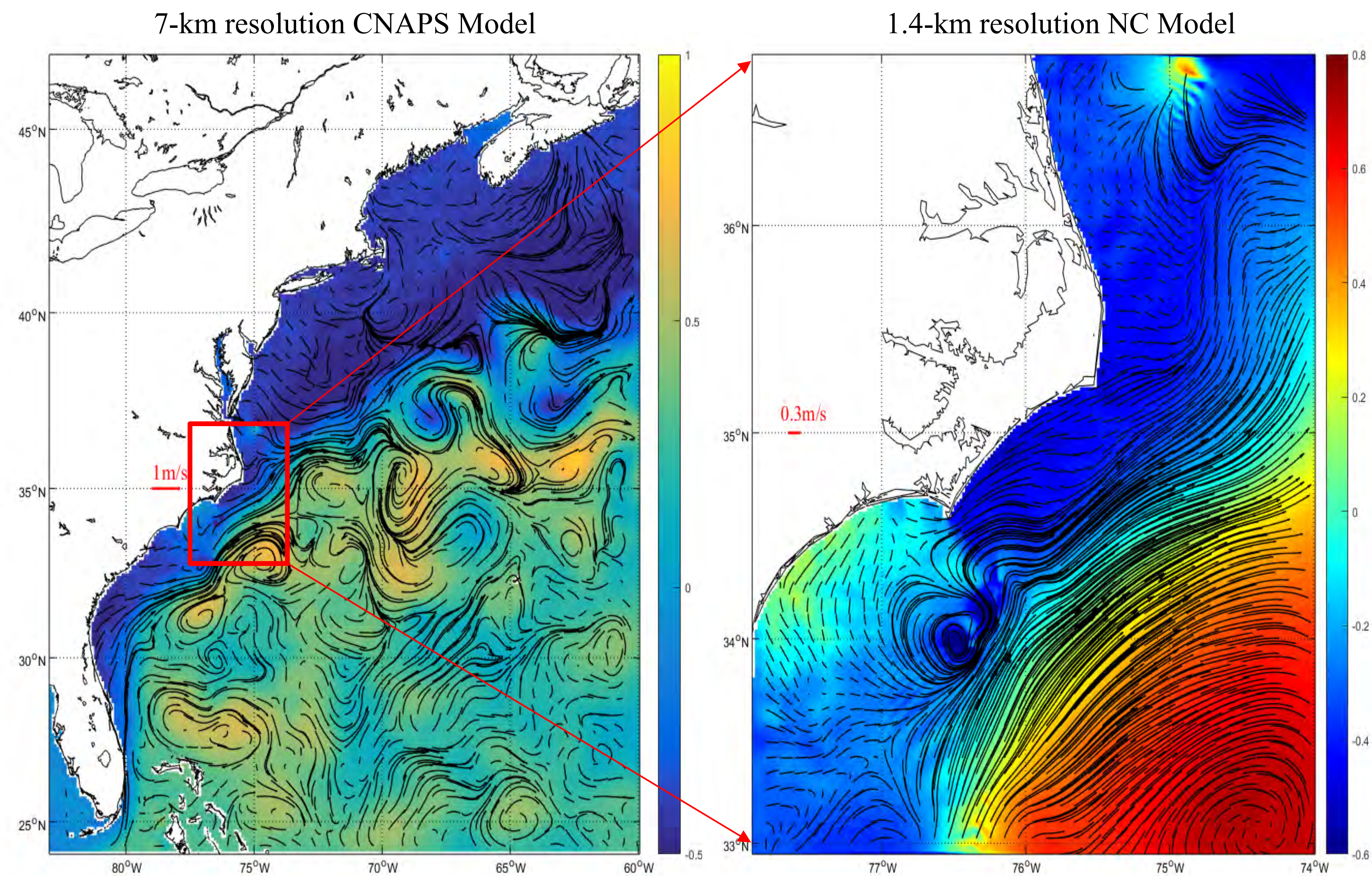


PEACH Field Campaign: April 2017-October 2018




Map
Satellite
2016-11-02 15:00
Temperature (°C):
4
17
30
Google
Imagery ©2016 NASA, TerraMetrics
Terms of Use
Options
Variable
Depth
Date
Time
Download
Animation
Start Date
End Date
Start Anim
Instructions



7-km resolution CNAPS Model
1.4-km resolution NC Model
1m/s
0.3m/s
45°N
40°N
35°N
30°N
25°N
80°W
75°W
70°W
65°W
60°W
36°N
35°N
34°N
33°N
77°W
76°W
75°W
74°W

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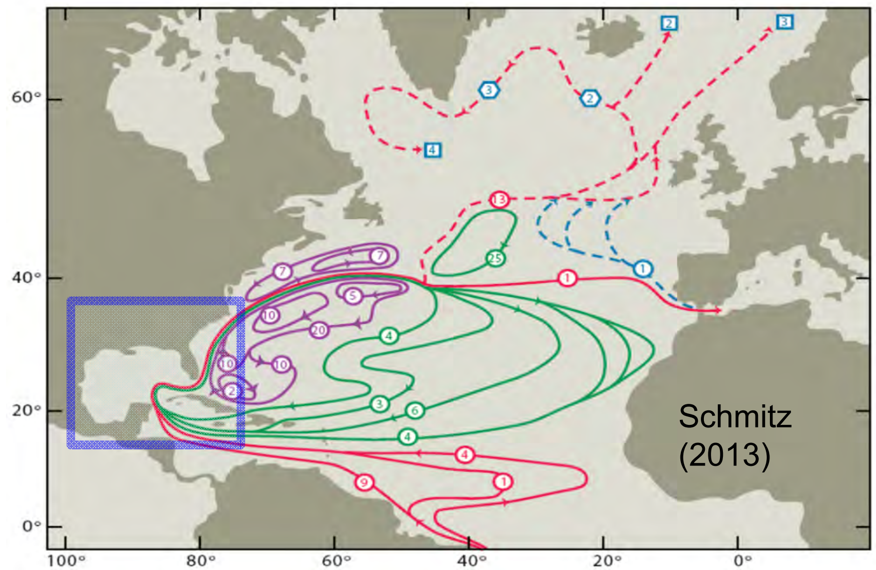
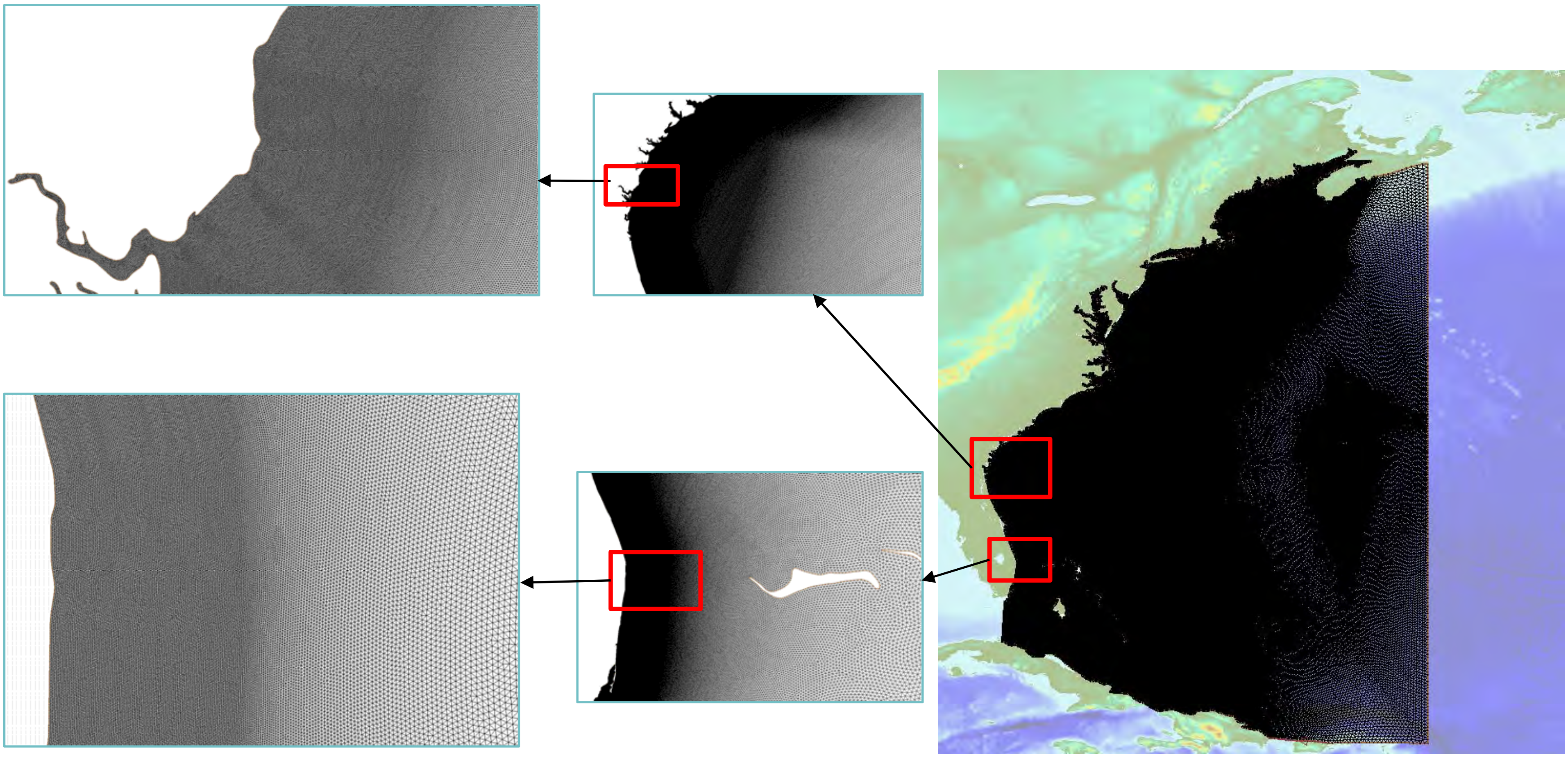
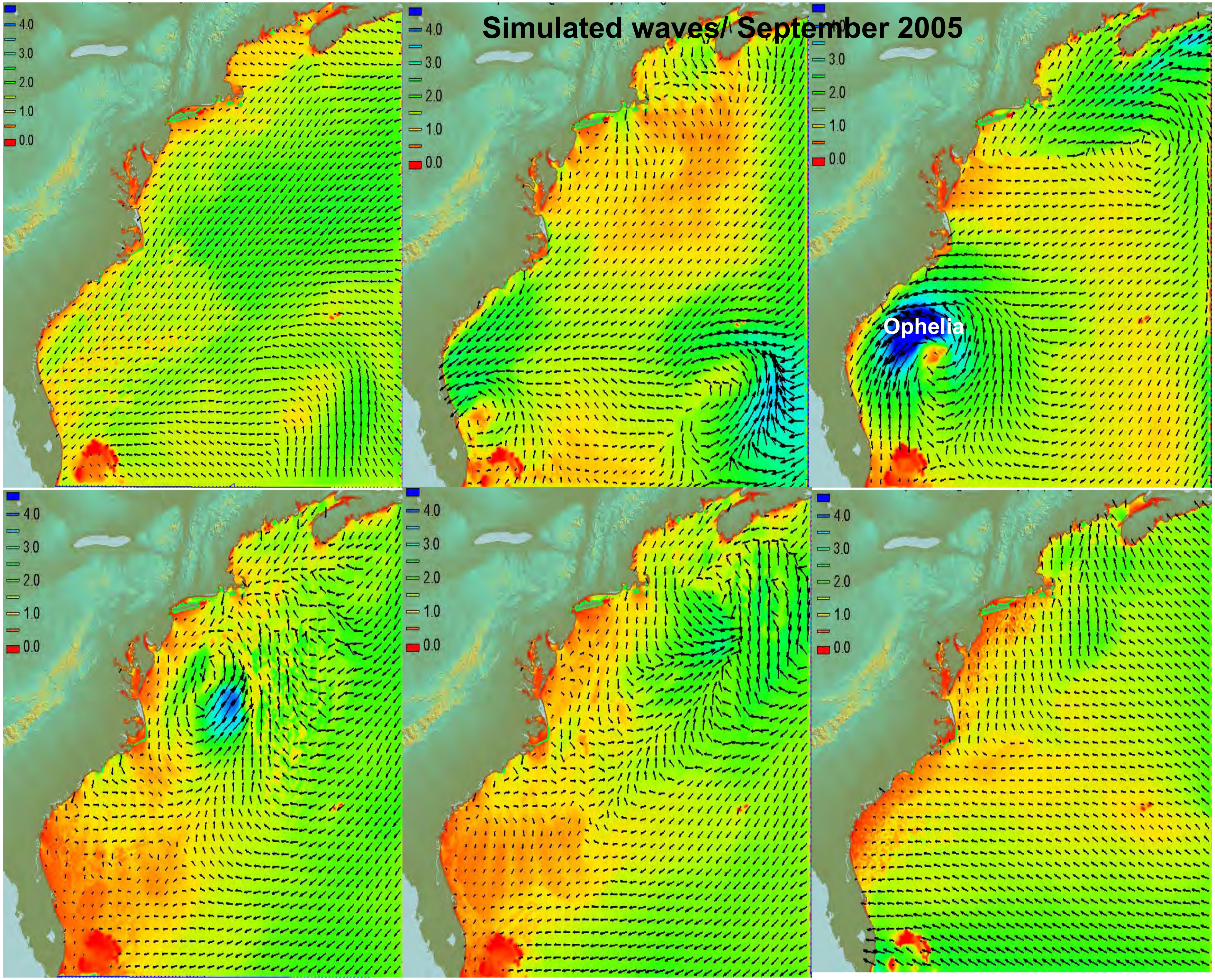


DOE: East coast wave energy resource assessment

- Unstructured SWAN model (200 m resolution)
- Extensive validation against buoy observations
- 31 years wind hindcast (1979-2009)




Simulated waves/ September 2005
Ophelia
4.0
3.0
2.0
1.0
0.0

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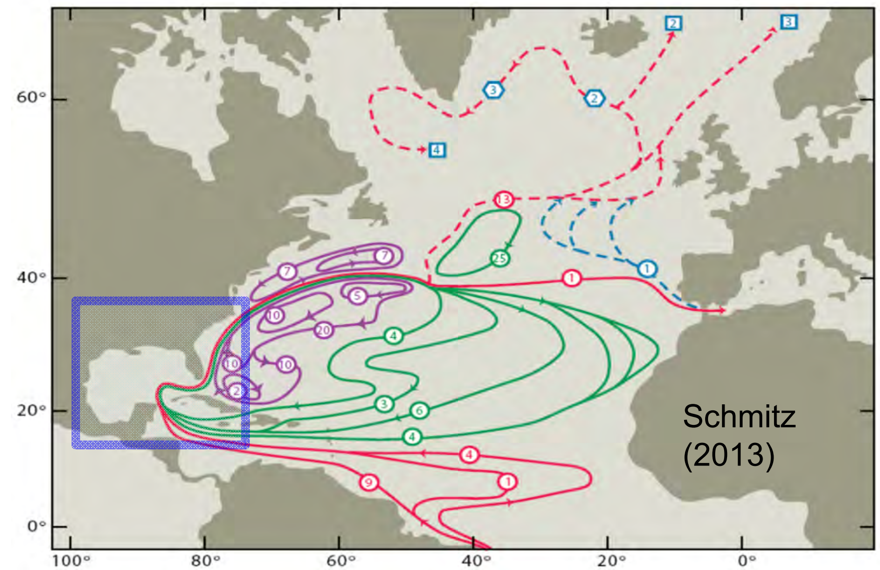
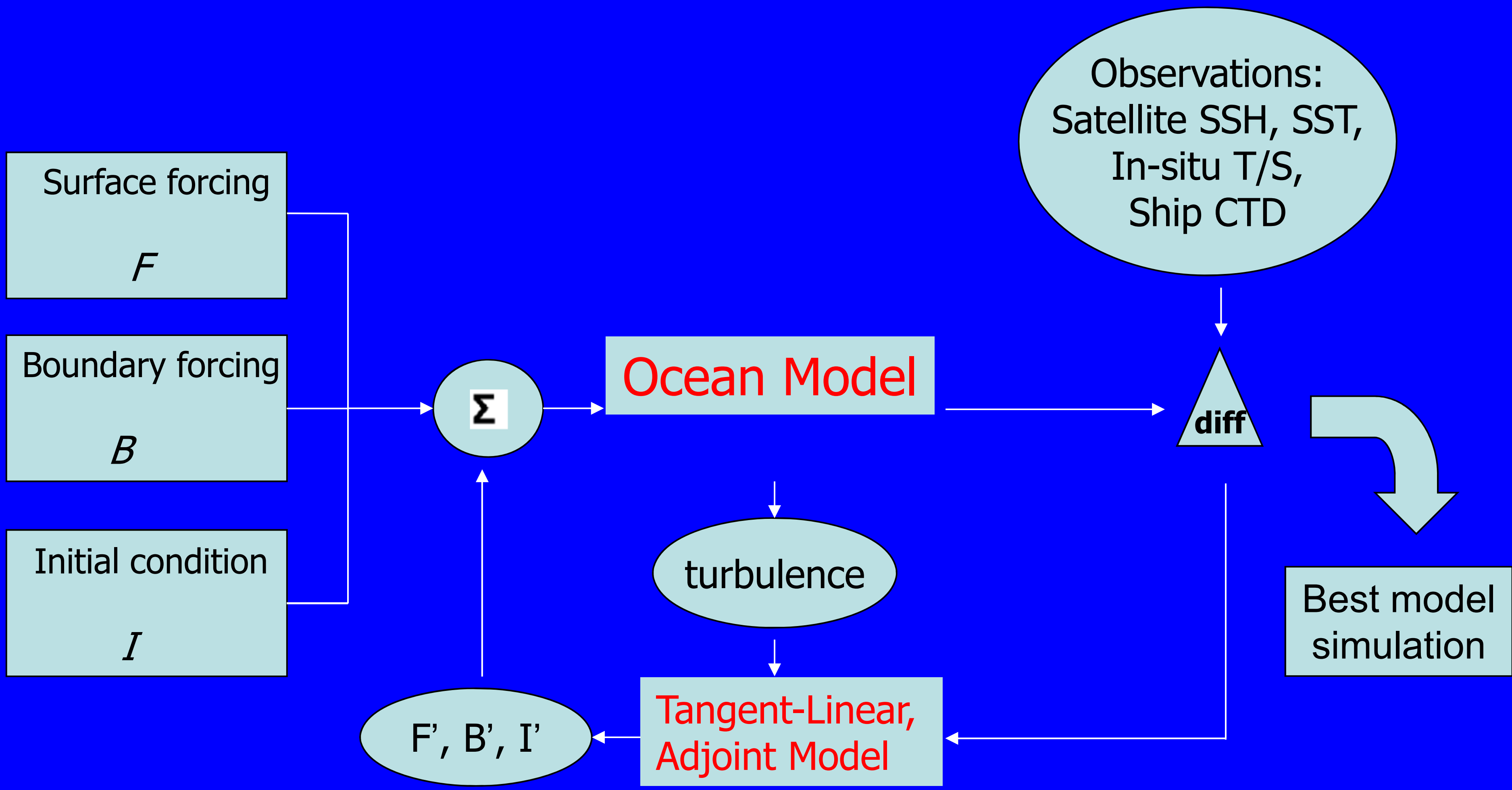


- **4-D Variational (4DVAR) data assimilation**
- **Adjoint Sensitivity Analysis**



Mooer et al. (2011); Chen, He et al. (2014); Li, He, McGillicuddy (2014); Zeng and He (2016)

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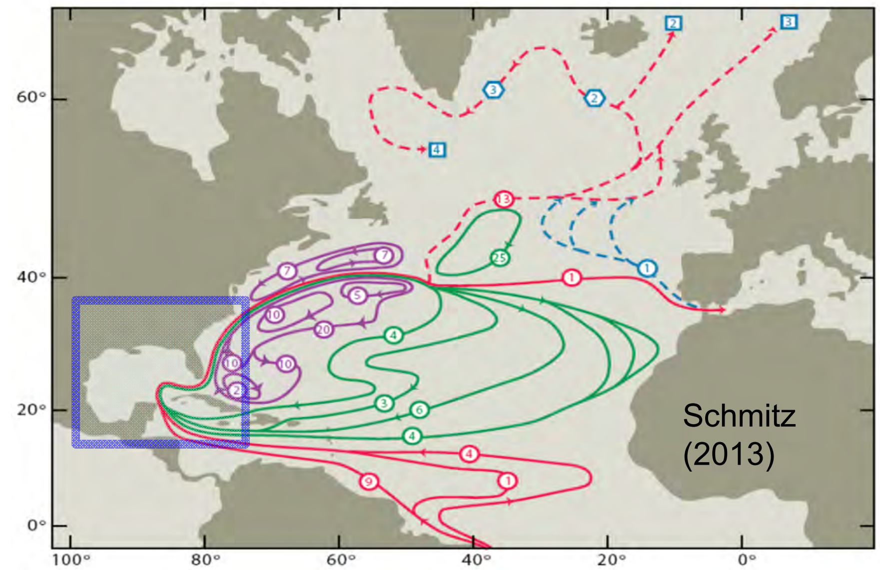


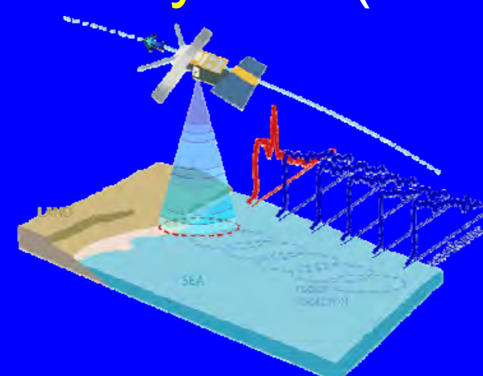
- Summary

Q1: How does the GS change its position in the SAB?

FIG. 173. — FRANKLIN'S CHART OF THE GULF STREAM.

- Data

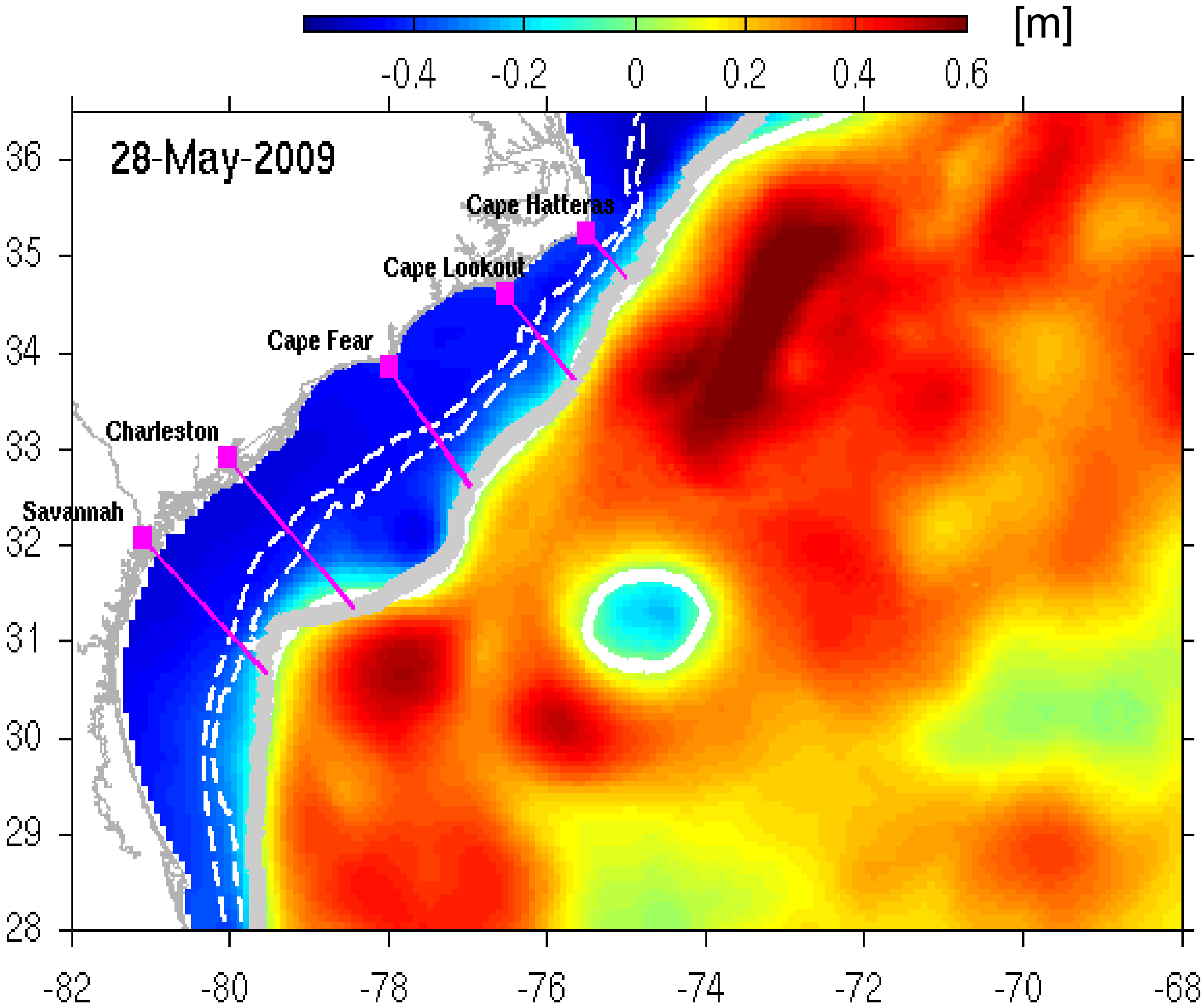
Daily Sea Surface Height (SSH) field over 13 years (2003-2015) from satellite Altimetry.



- Method

We tracked the Gulf Stream (GS) front in the South-Atlantic Bight (SAB) based on the maximum SSH gradient, and computed daily nearest cross-shore distance between GS and coastline

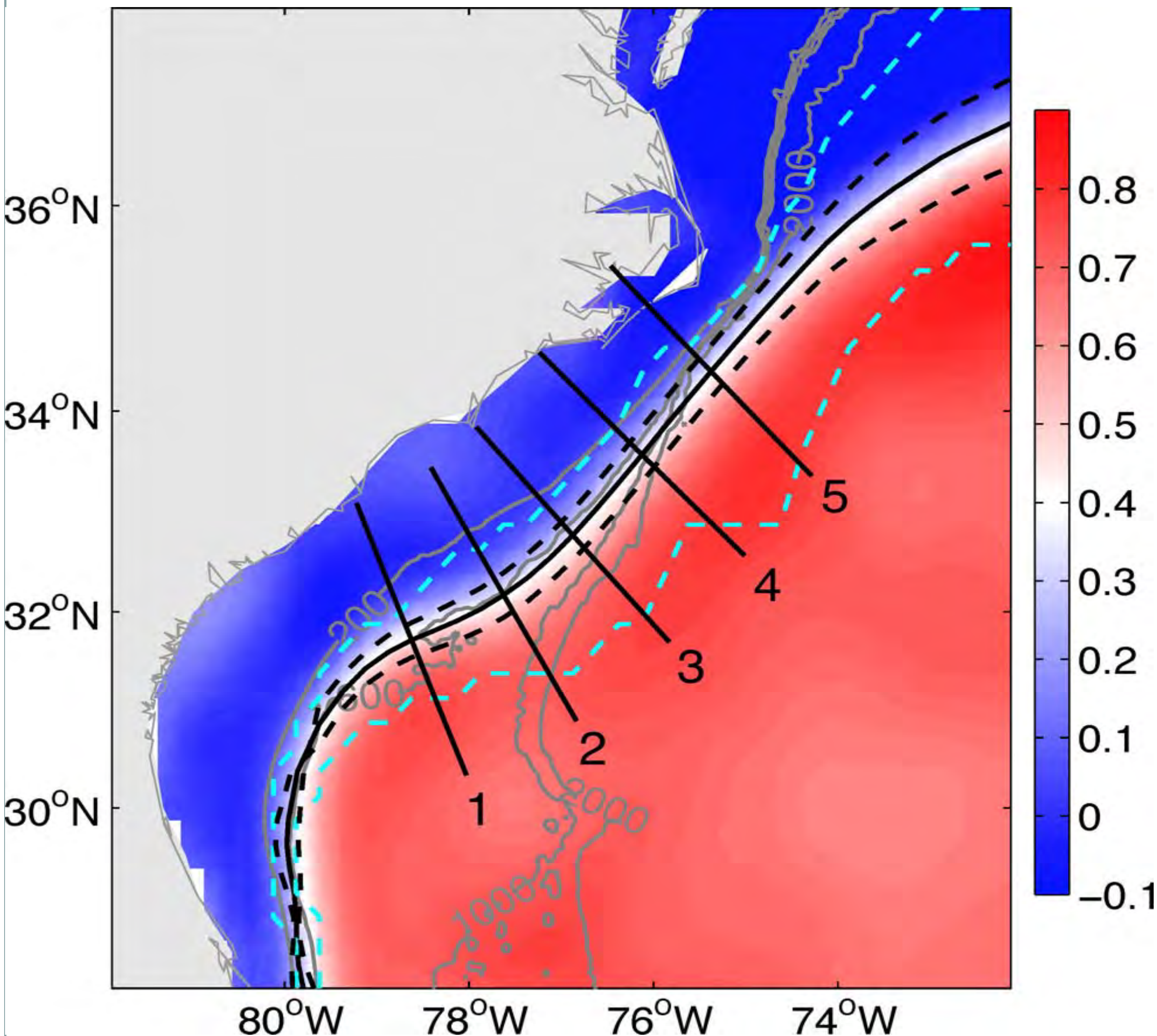
Daily position of GS and cross-shelf distance



Pink: Cross-shelf distance of GS to the 5 coastal sites.

Gray: GS locations based on the maximum SSH gradient.

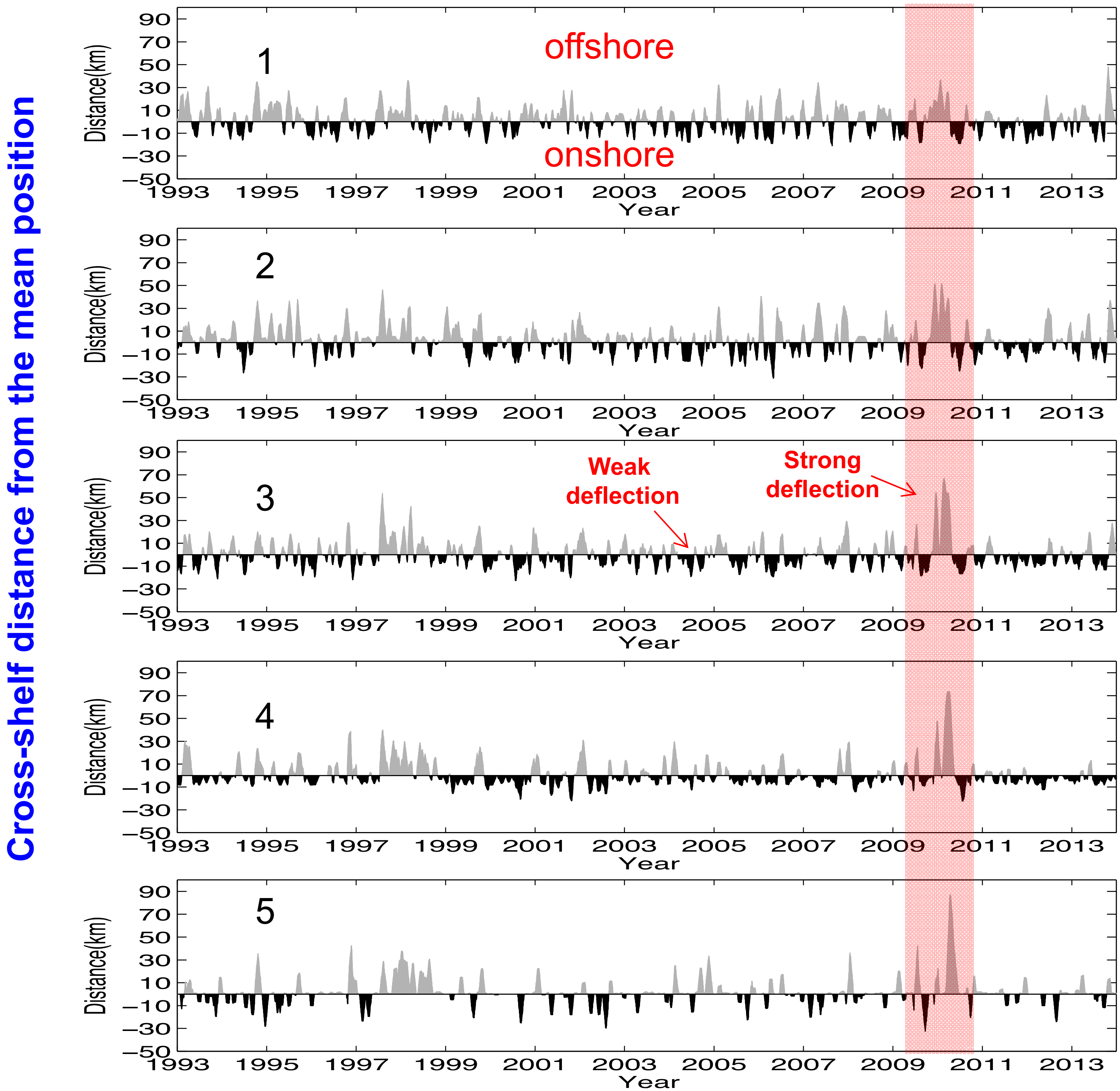
Mean SSH (unit: m) during 2003-2015



- Black solid line: **Mean GS front** at the largest SSH gradient.

- Gray dashed lines: **Mean GS+STD; Mean GS-STD**.

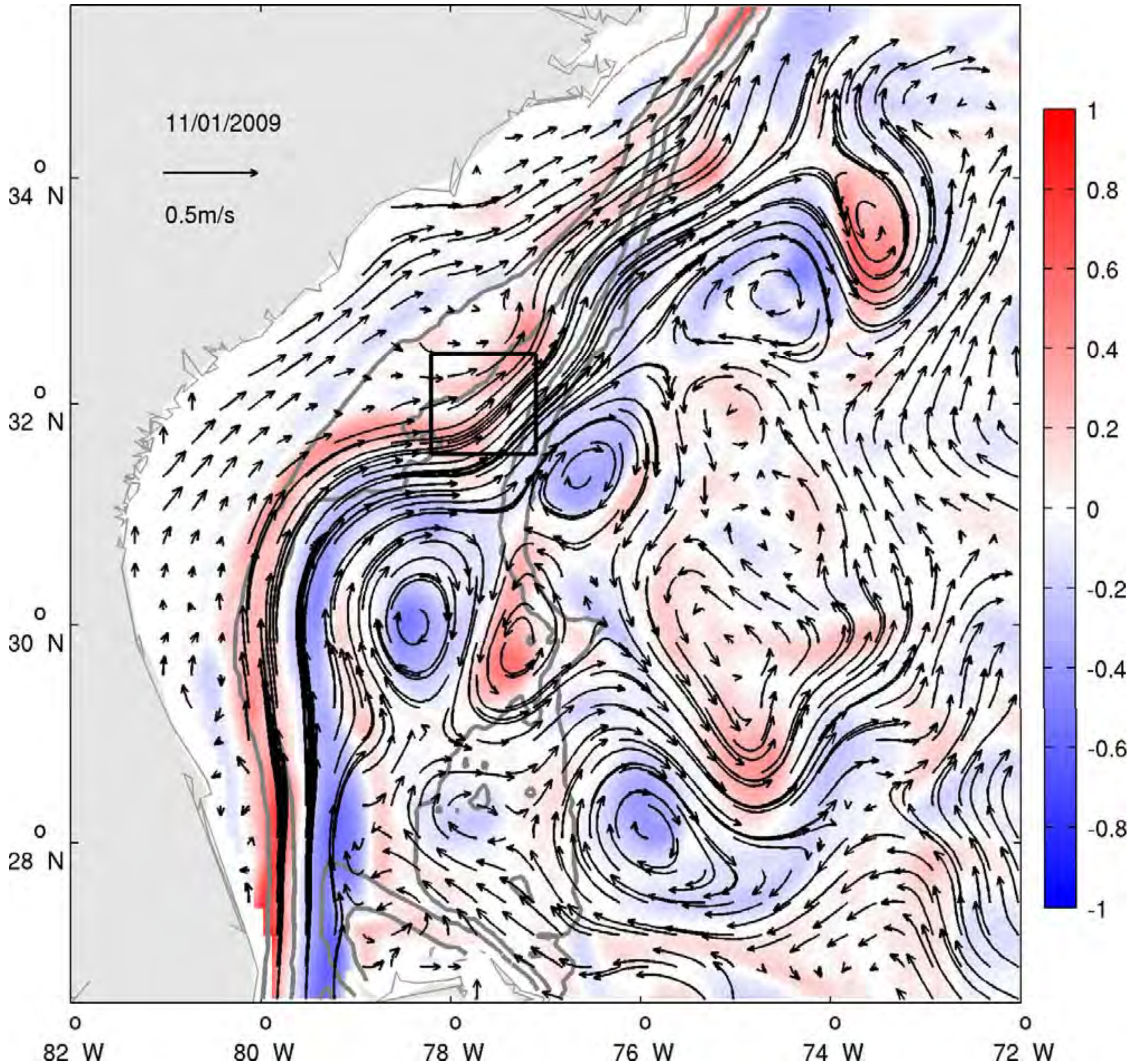
- Cyan dashed line: **Envelop of GS**



The Strongest Deflection Happened in:

Nov 2009 - Mar 2010

Simulated Surface Velocity and Relative Vorticity/f (color-shading) in Nov 2009

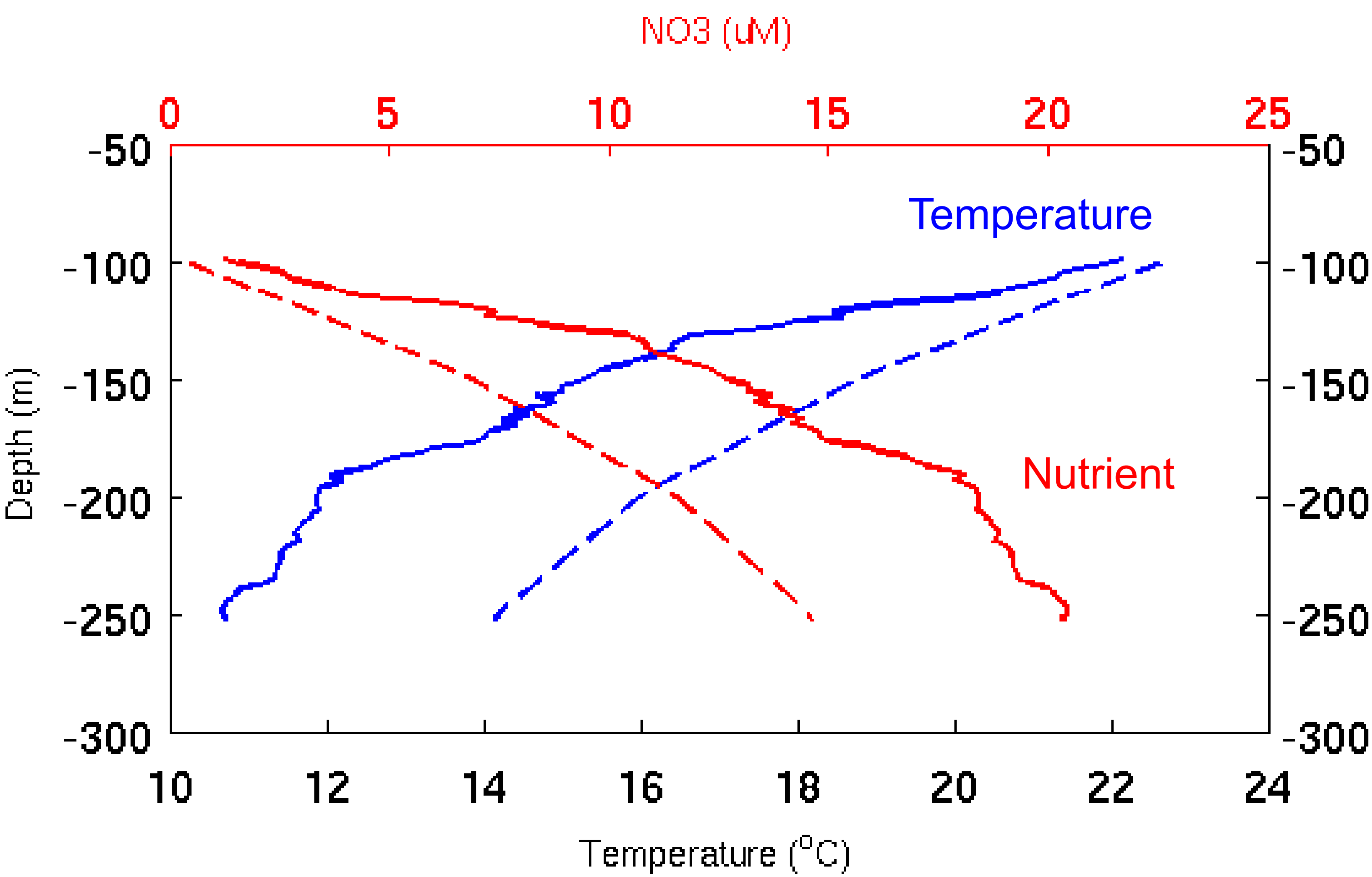


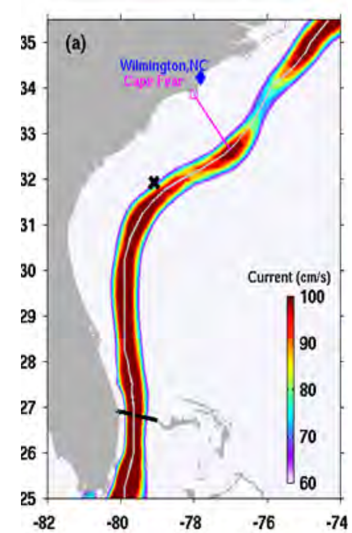
Can we trace and quantify the perturbation(s) that lead to this large offshore deflection?

Zeng and He (2016)

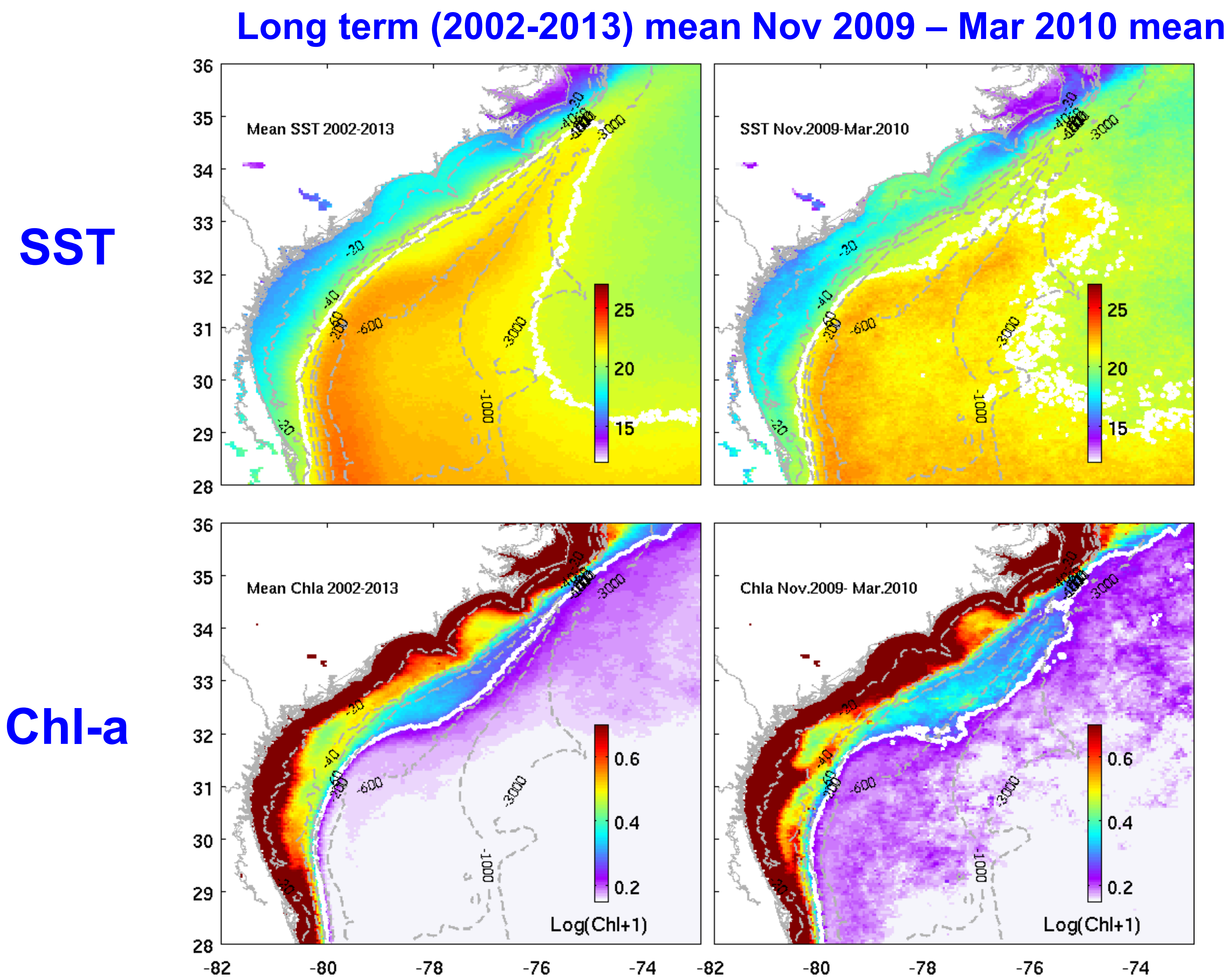
Q2: What is the impact of this large GS deflection on the regional marine ecosystem?

Comparisons between observed temperature and nutrient profiles in **Nov 2009 (solid)** and their respective long term means (dashed, from NODC)

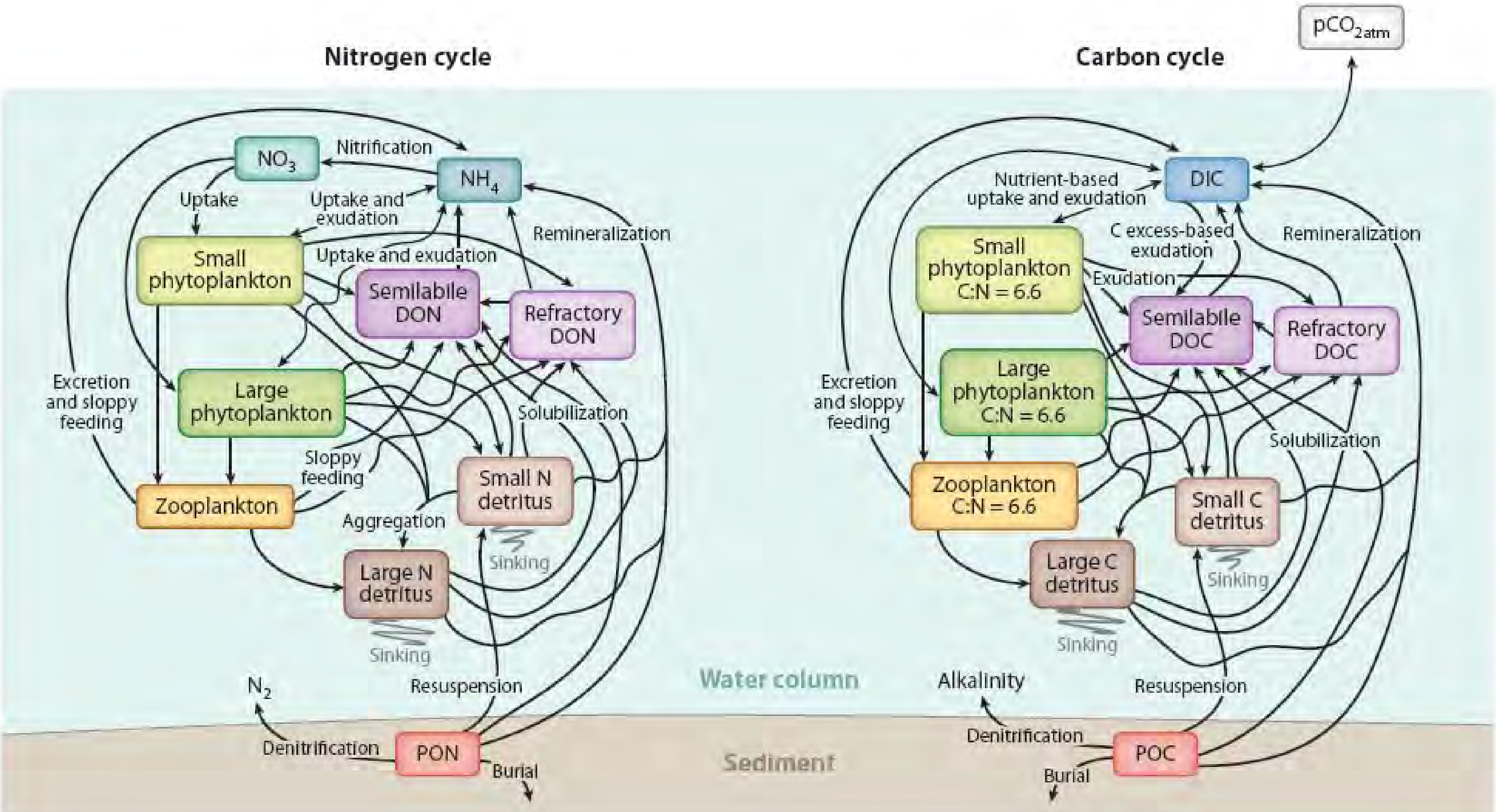


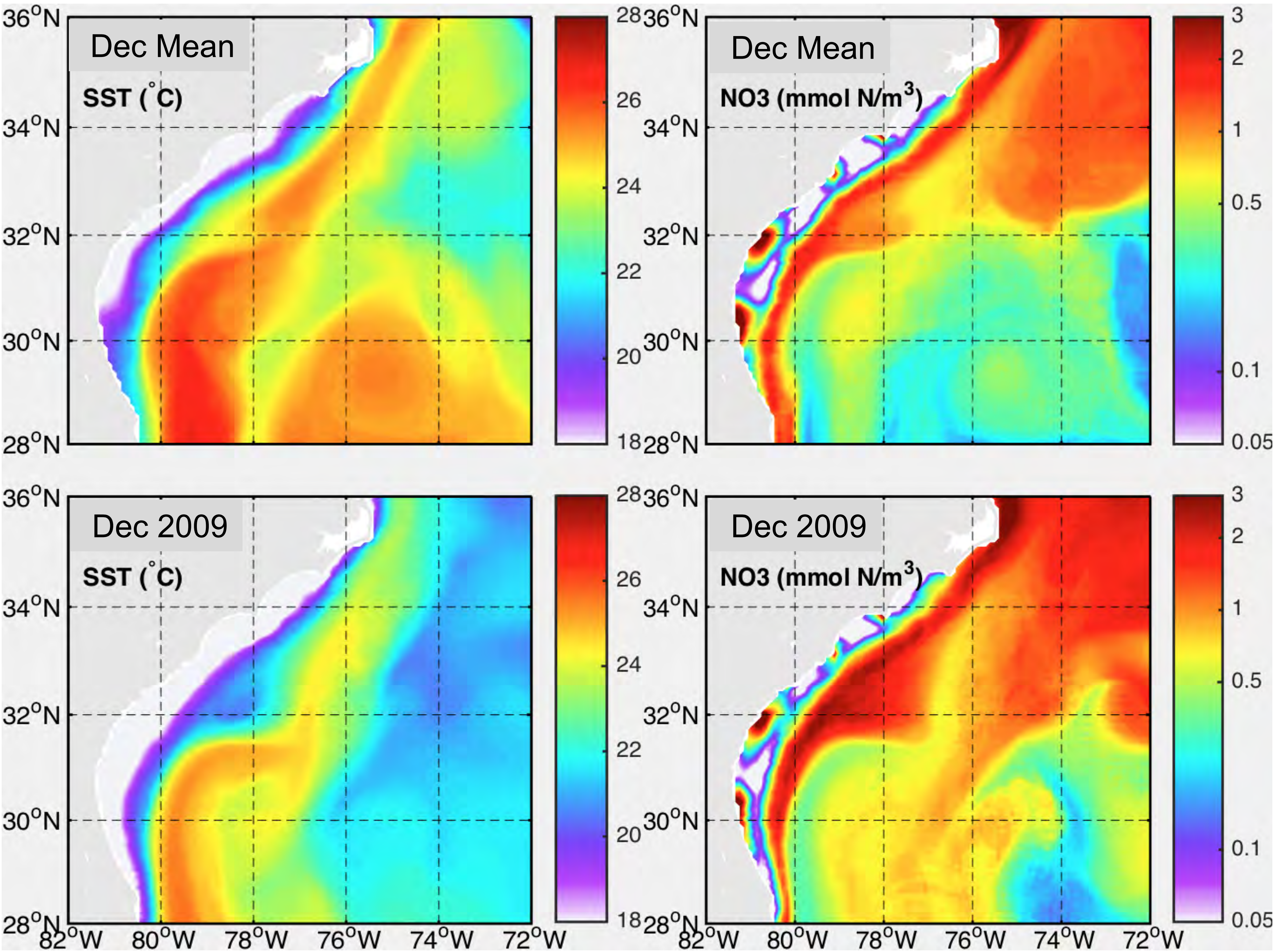


Comparisons of SST & ocean color



Coupled physical-biogeochemical modeling





Dec Mean
SST (°C)
Dec Mean
NO3 (mmol N/m³)
Dec 2009
SST (°C)
Dec 2009
NO3 (mmol N/m³)
36°N
34°N
32°N
30°N
28°N
82°W
80°W
78°W
76°W
74°W
72°W
28
26
24
22
20
18
3
2
1
0.5
0.1
0.05

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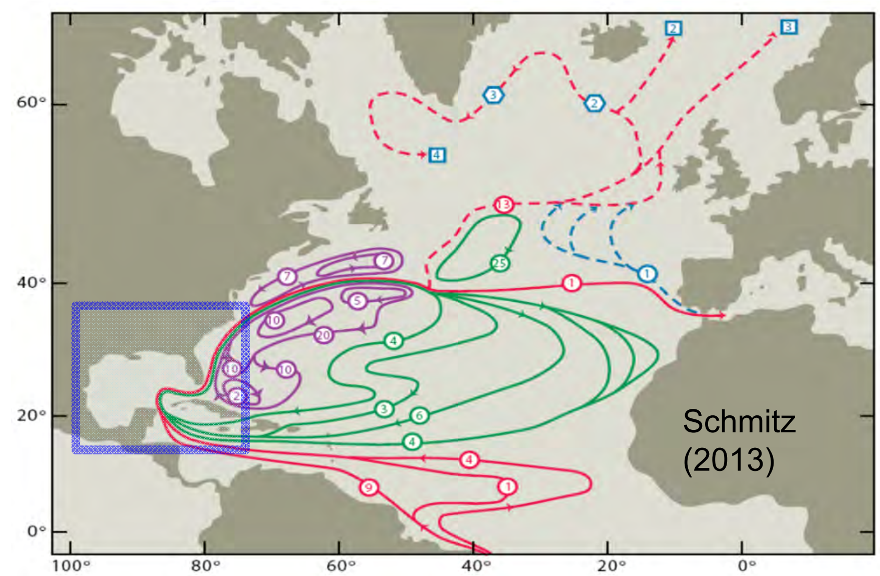
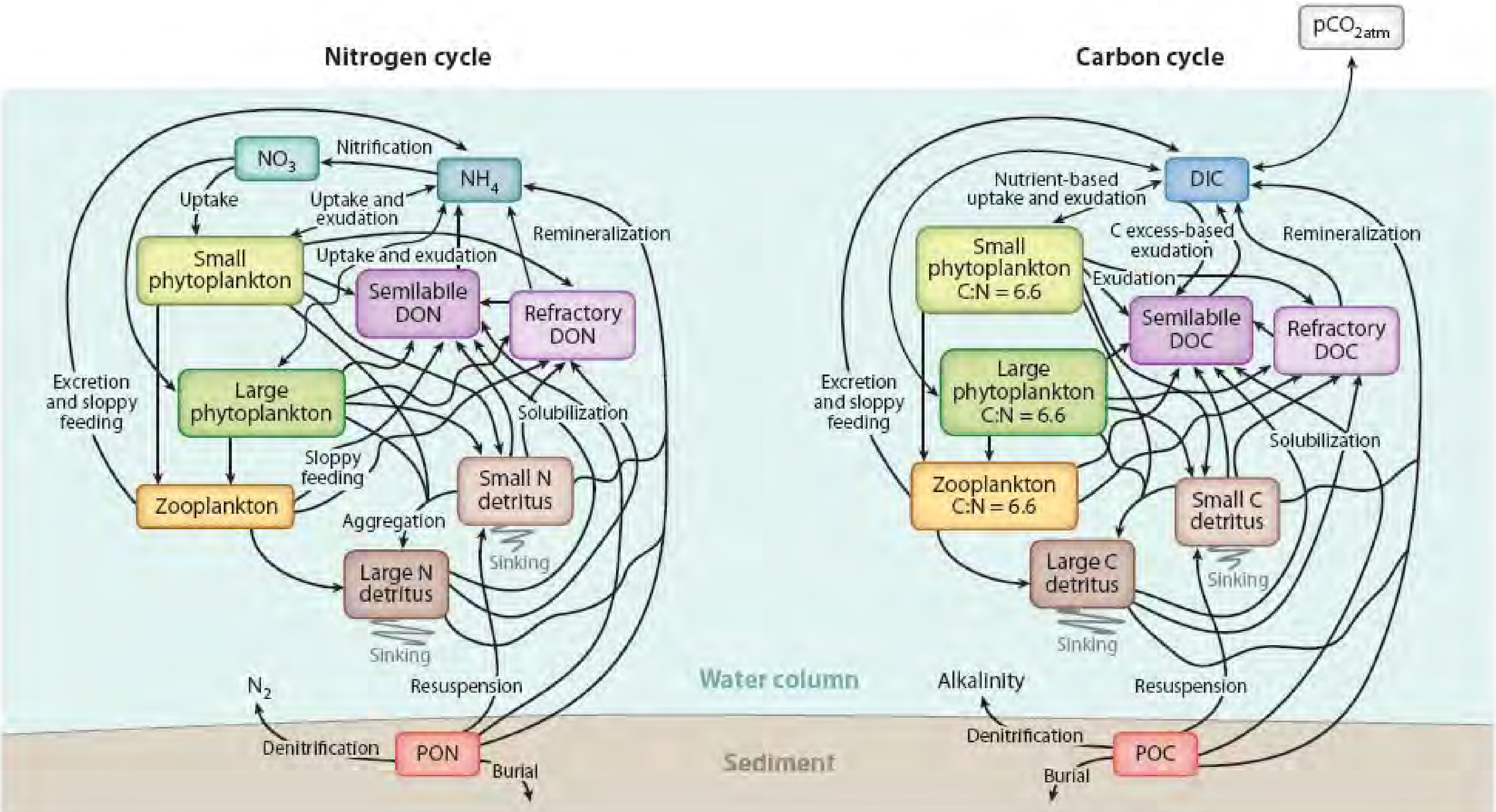


Coupled physical-biogeochemical modeling



Model simulated pCO2 water seasonality

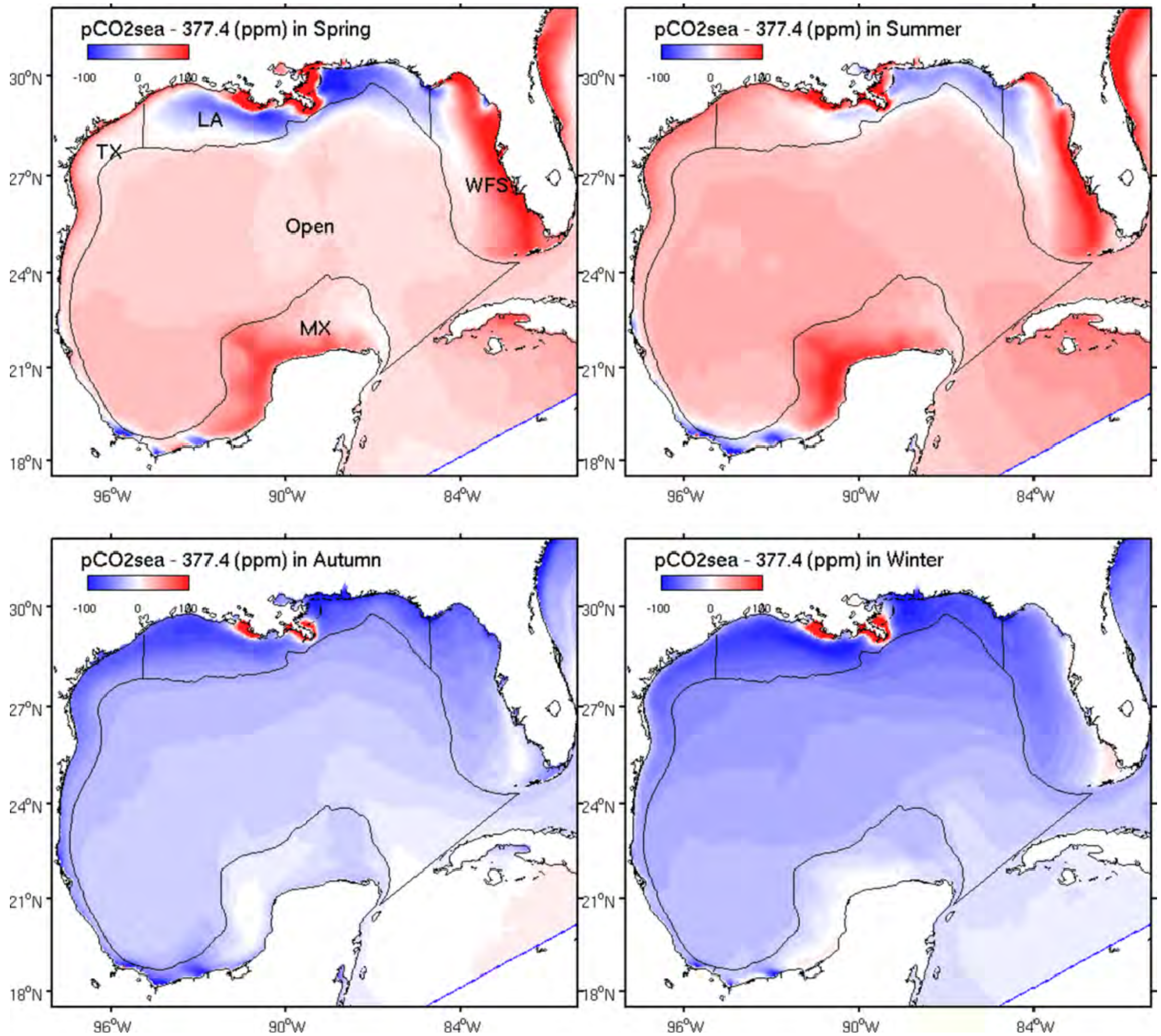
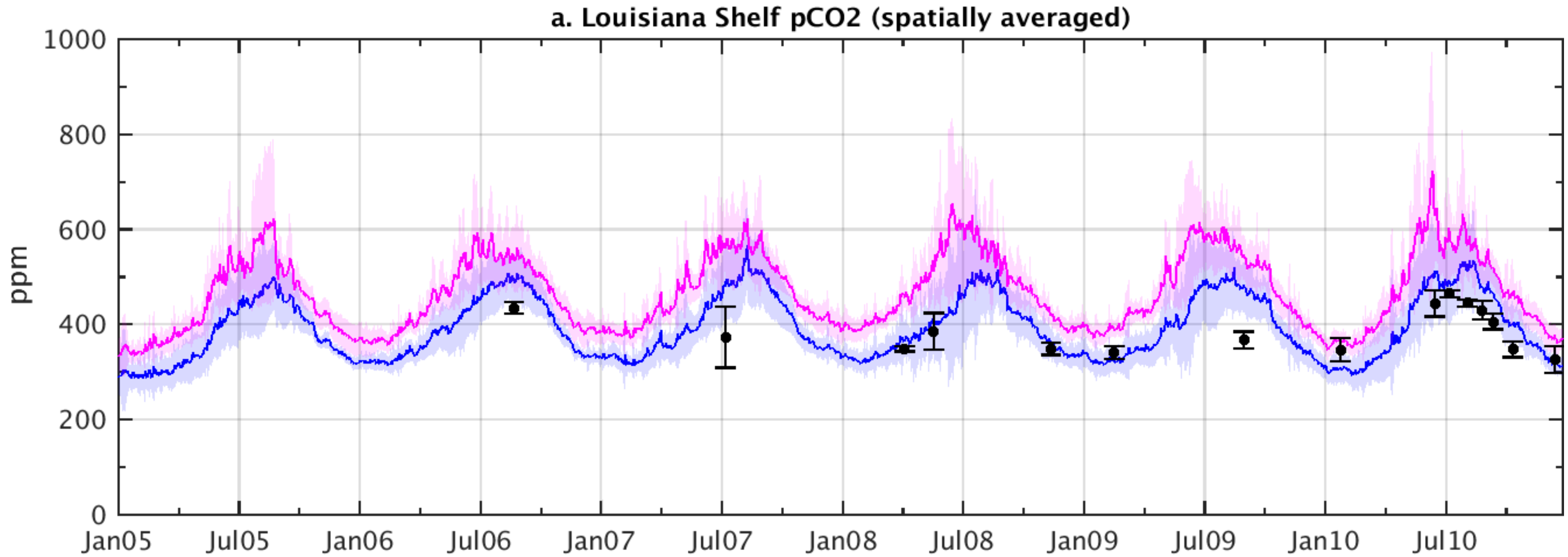


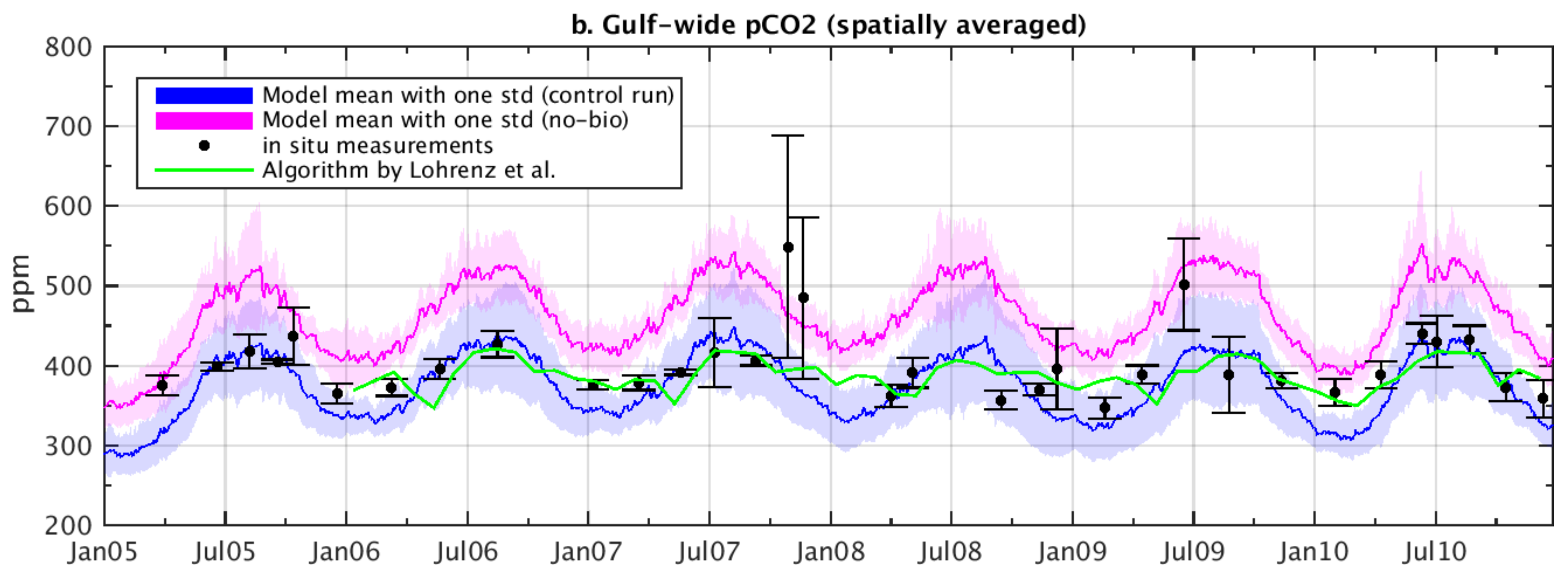
Fig 4 Model simulated ΔpCO2 (2005-2010 mean) in the Gulf during a) spring, b) summer, c) fall, and d) winter months.

Xue, Z., R. He, K. Fennel, W.J. Cai, S. Lohrenz, W.J. Huang, H. Tian, W. Ren, and Z. Zang (2016):

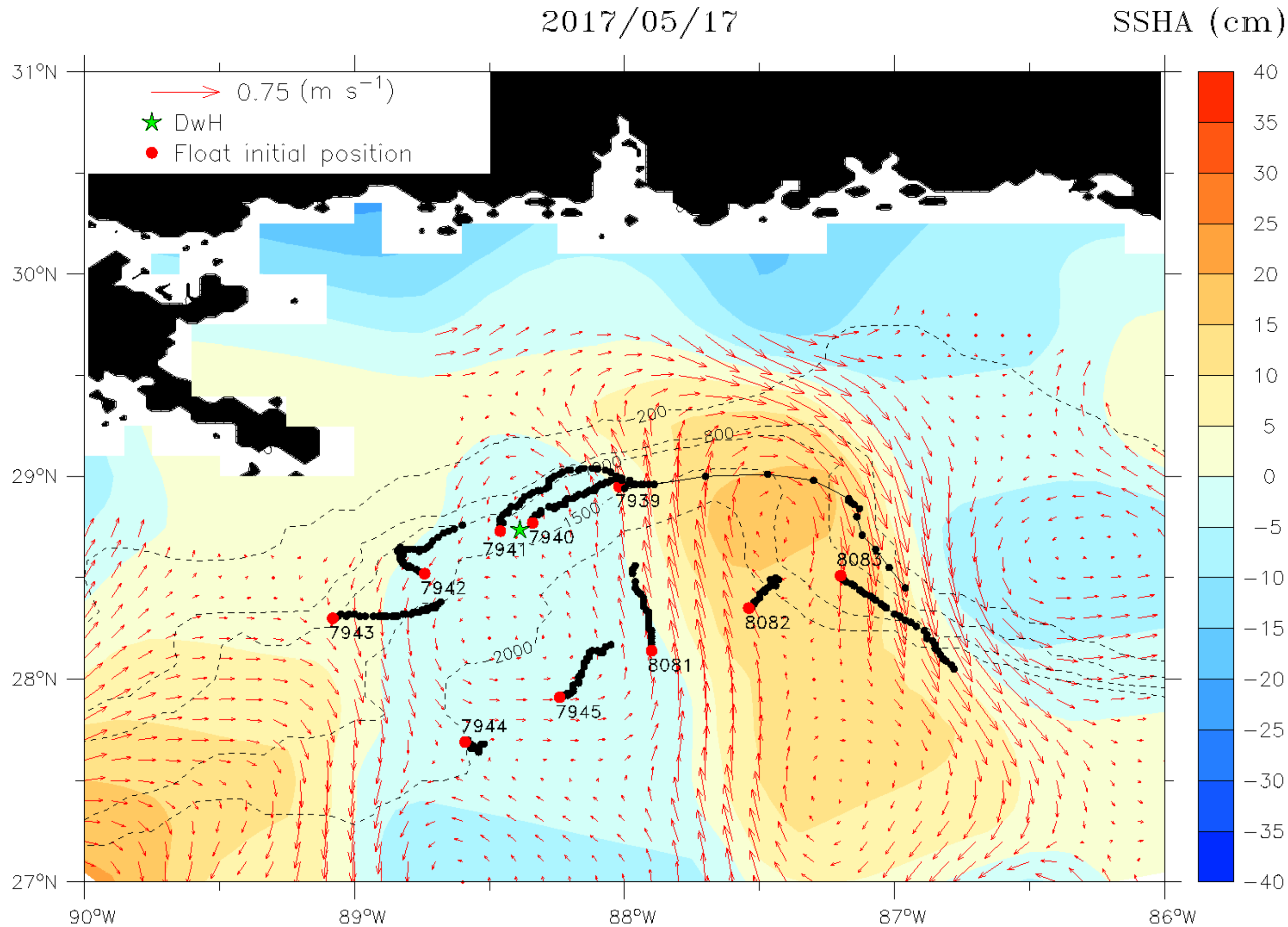
Modeling *p*CO_2 variability in the Gulf of Mexico, *Biogeosciences*, 13, 4359-4377

Gulf of Mexico pCO_2: Model, Satellite and In Situ





2017 Northern Gulf of Mexico Deployment (10 APEX-EM floats)

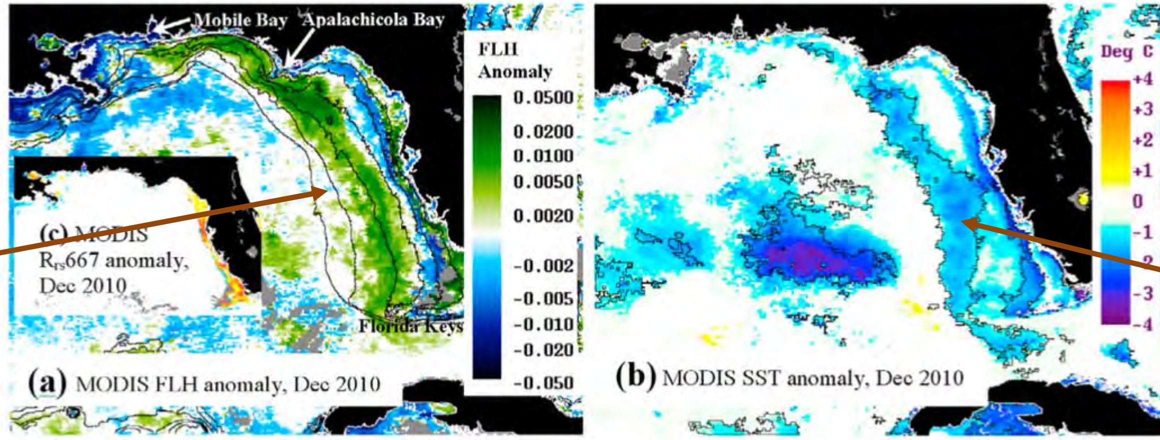


Vectors are altimeter-based surface geostrophic currents from absolute sea surface height

Nick Shay (U. Miami)

"Green river" in the Gulf of Mexico

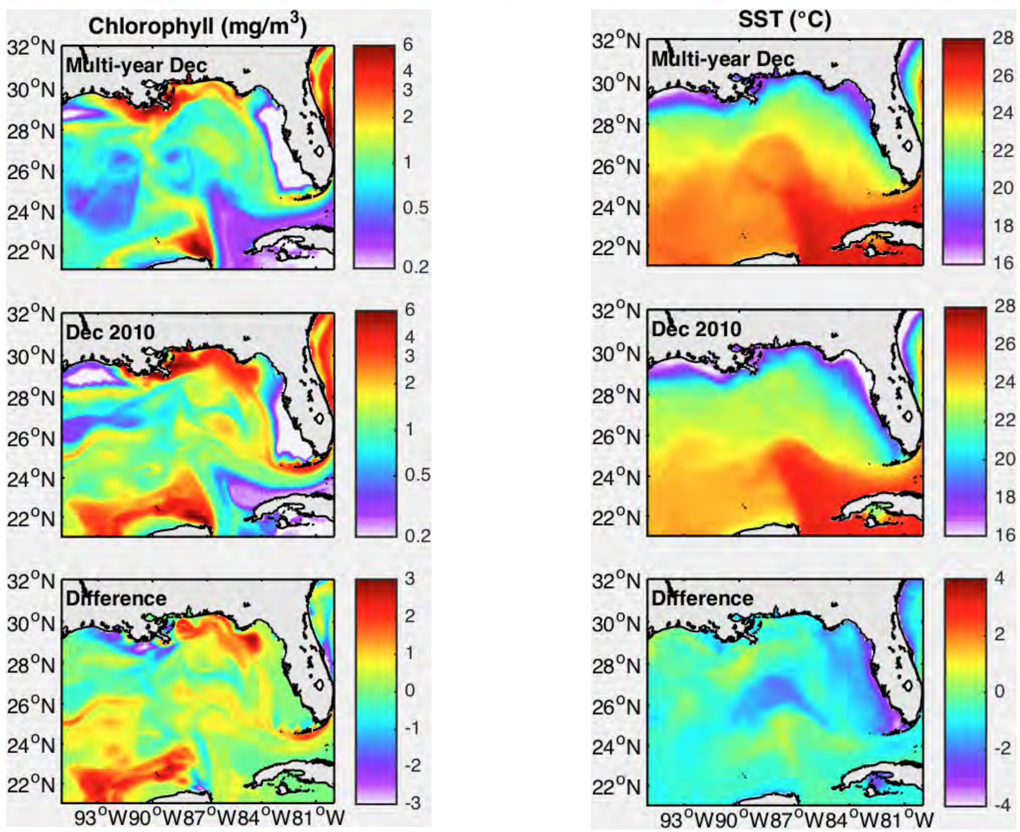
Higher FLH



Lower SST

Hu et al.(2011)

Coupled Model Simulation results



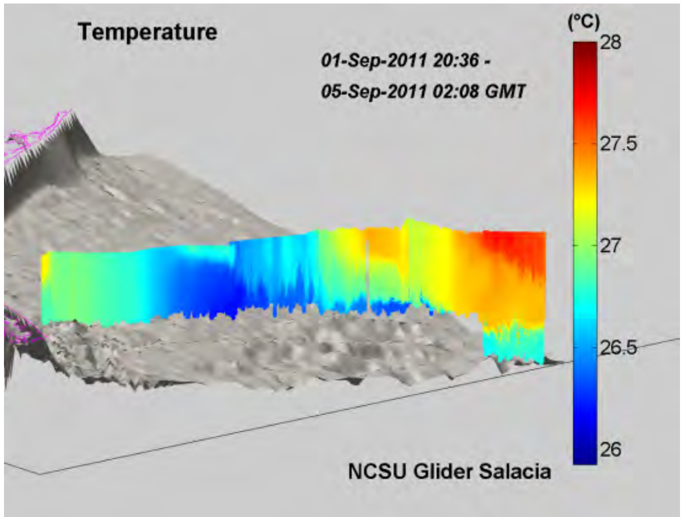
Some thoughts on path forward..

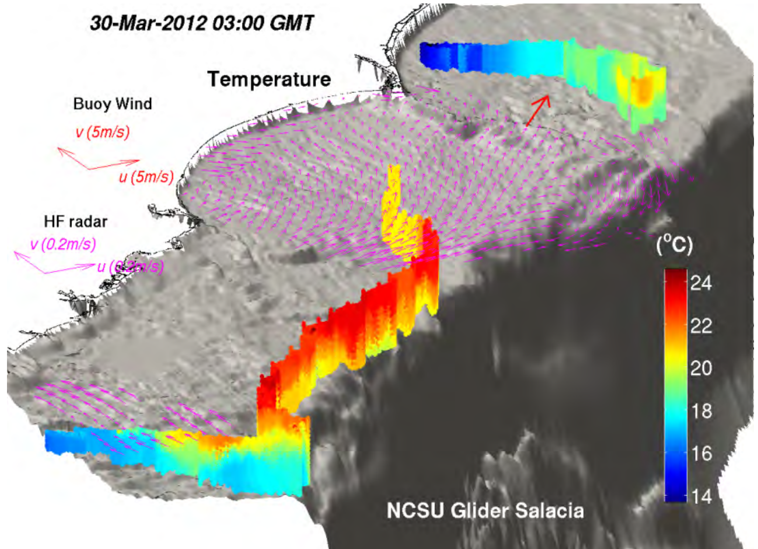
- Understanding the coastal ocean response to climate change effects require us to first define the intrinsic variability on seasonal to inter-annual time scale;

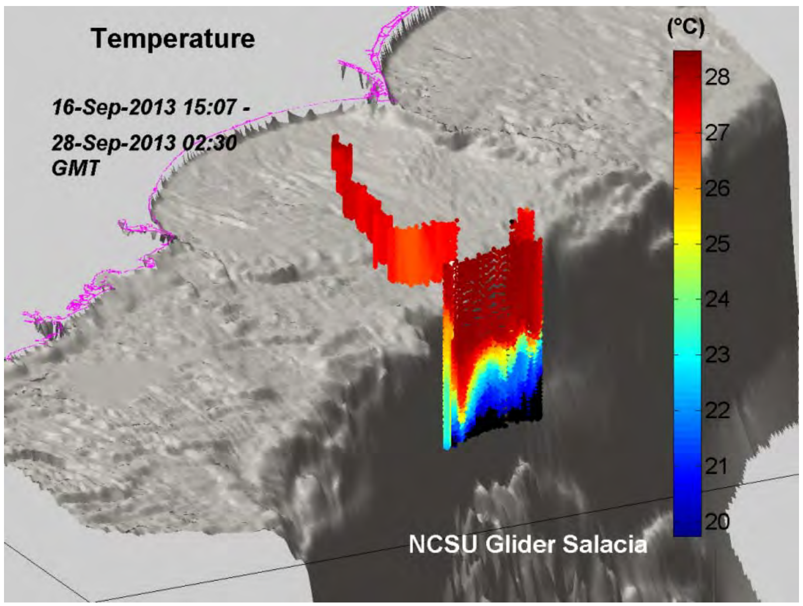
- Strong couplings in land-ocean-atmosphere, and between physics and biogeochemistry in coastal ocean need to be carefully quantified;

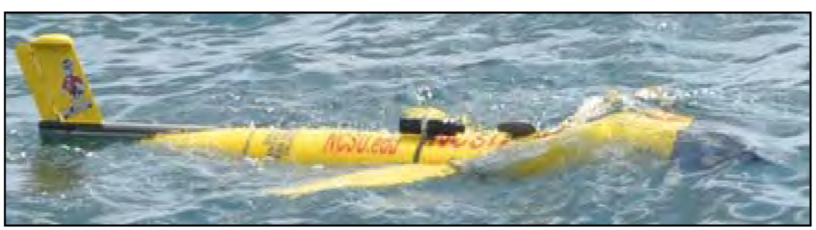
- Coupled physical-biogeochemical model with multi-scale nesting capability can provide a valuable tool to understand and forecast variability of the coastal ocean.

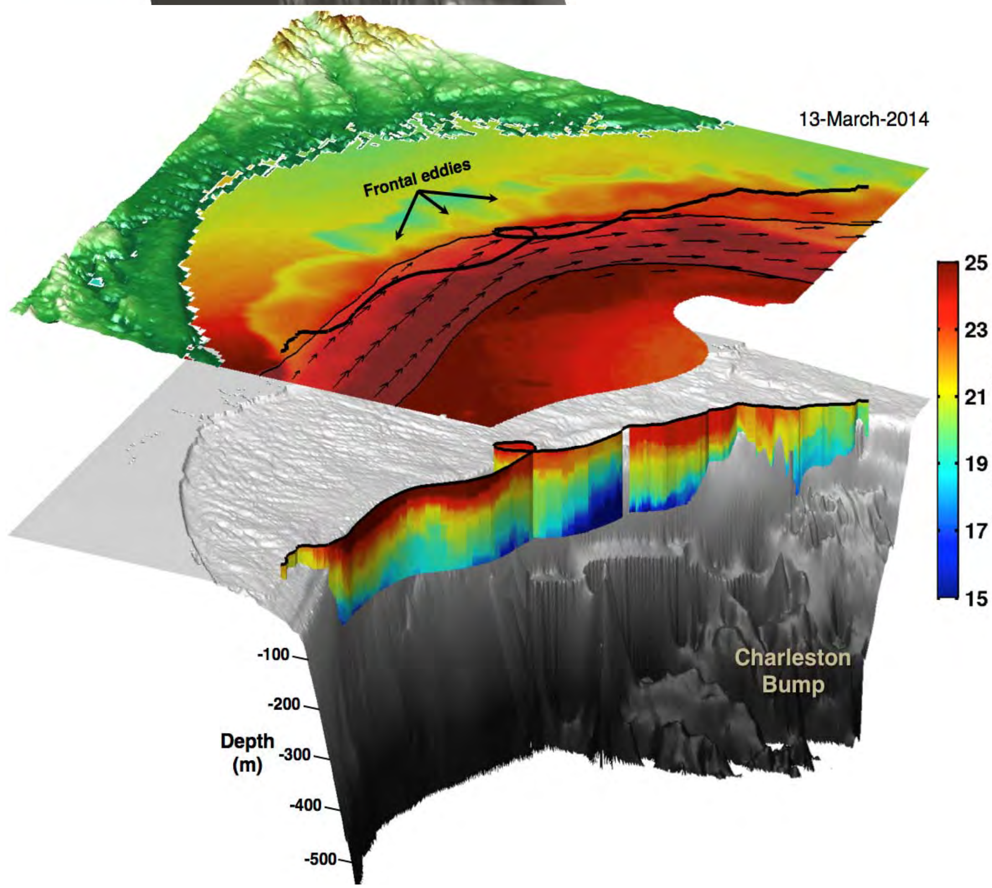
- Deterministic predictions of the coastal circulation and ecosystem dynamics will clearly require refined models, advanced observational infrastructure together with sophisticated techniques for data assimilation.


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

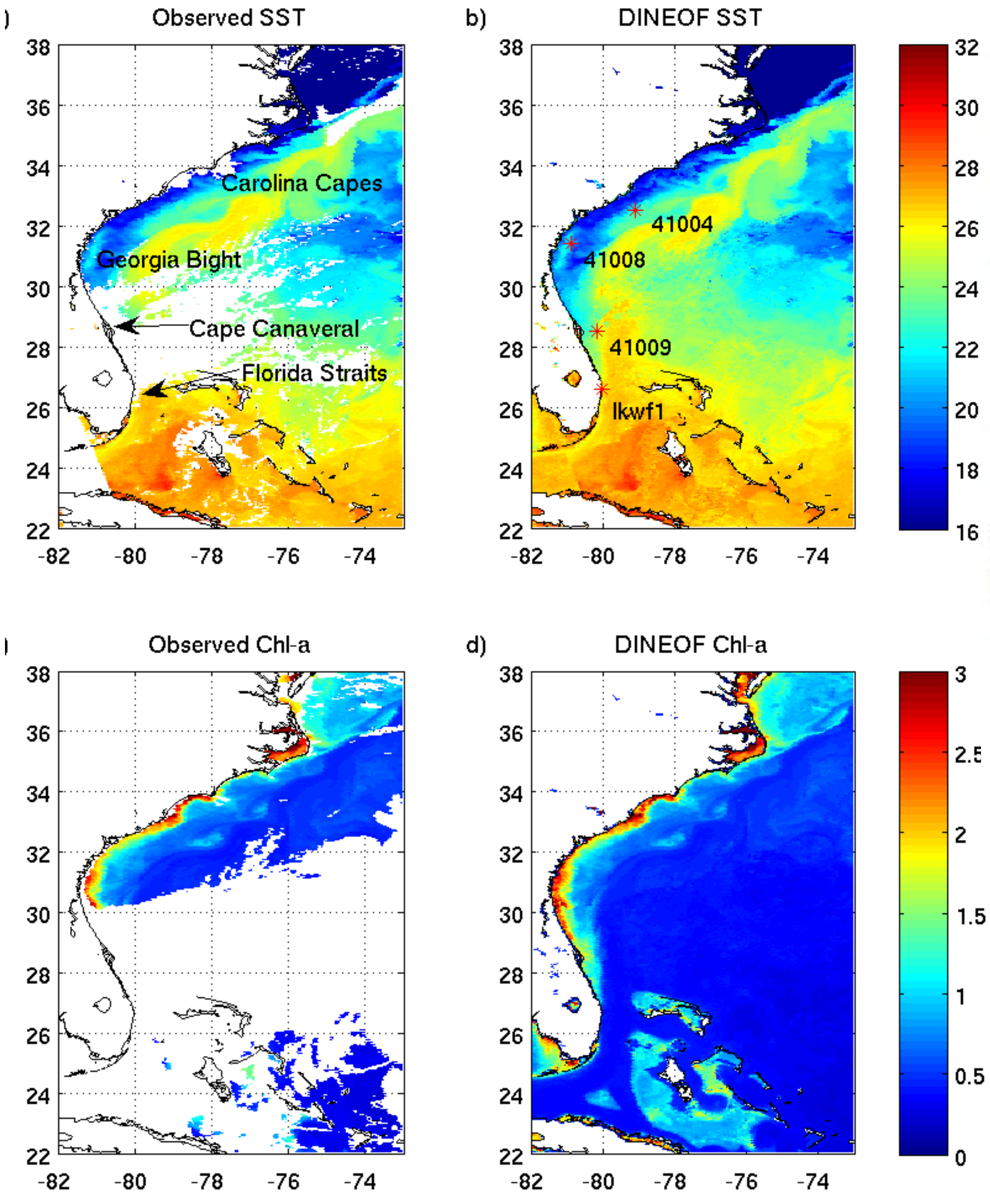

30-Mar-2012 03:00 GMT
Temperature
Buoy Wind
v (5m/s)
u (5m/s)
HF radar
v (0.2m/s)
(°C)
24
22
20
18
16
14
NCSU Glider Salacia

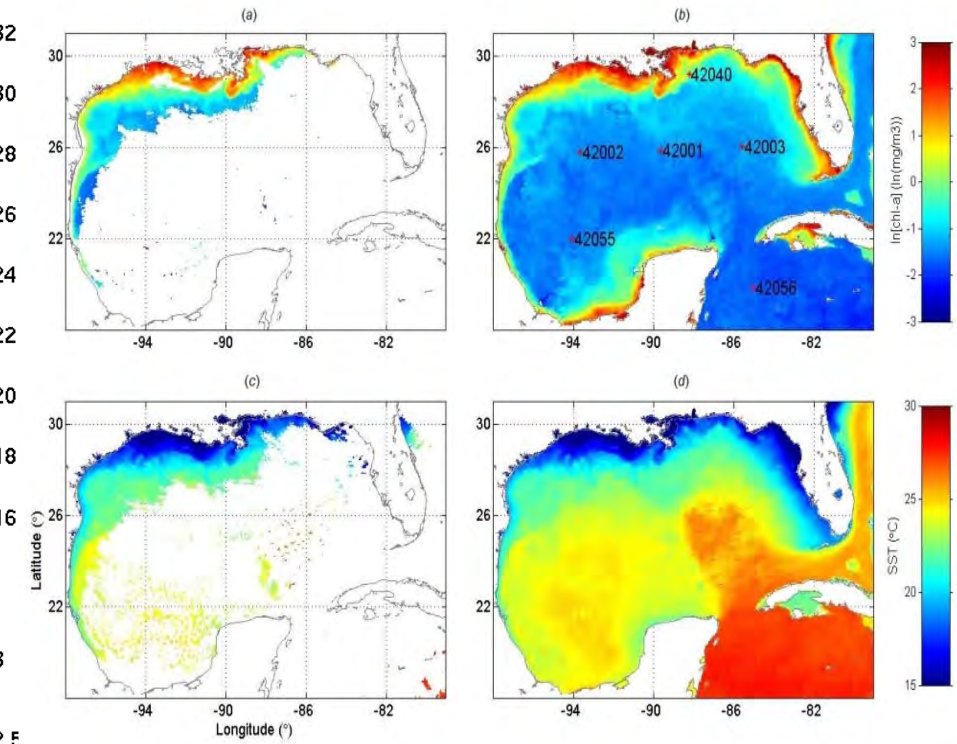

Temperature
16-Sep-2013 15:07 -
28-Sep-2013 02:30
GMT
(°C)
28
27
26
25
24
23
22
21
20
NCSU Glider Salacia




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

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)

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Summary

- Marine Environmental Hindcast, Nowcast Forecast System for 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 2008
- 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 :

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

Point of contact: Dr. Ruoying He
email: rhe@ncsu.edu tel: 919-513-0249

- **Group website: http://go.ncsu.edu/oomg**
- **NW Atlantic site: http://omgsrv1.meas.ncsu.edu:8080/CNAPS**