Observations at the West Florida Shelf Pressure Point: How the Pressure Point Affects both the Shelf and the Gulf of Mexico Loop Current.

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Abstract

Continental shelves come in varying widths. Very narrow shelves are readily impacted by the adjacent deep ocean, and tend to be rich in nutrients and highly productive. Very wide shelves are generally insulated from deep ocean influences, and may have nutrient deplete (or oligotrophic) zones.

Two factors are in play. The first is how far landward deep ocean influences may extend onto the shelf. The Rossby radius of deformation, the distance over which the pressure gradient and velocity adjusts to be in geostrophic balance, is a measure of this. For the West Florida Shelf (WFS), this distance is about 30 km. The second is how far seaward land influences extend onto the shelf, as may be seen in salinity fronts associated with fresh water drainage. For the WFS, these extend seaward by about 10-20 km.

Given a width that generally exceeds 120 km, much of the WFS lacks either direct deep ocean or land influences and hence is considered to be oligotrophic. But this begs the question: How can an oligotrophic shelf be so productive? The answer lies in the “Pressure Point,” the southwest corner of the WFS located near the Dry Tortugas.

In this webinar, we will explore how this special “Pressure Point” region impacts the WFS, affecting both its harmful algal blooms and fisheries ecology and, in turn, how the WFS impacts the Gulf of Mexico Loop Current’s ability to penetrate into the Gulf of Mexico.

Outline

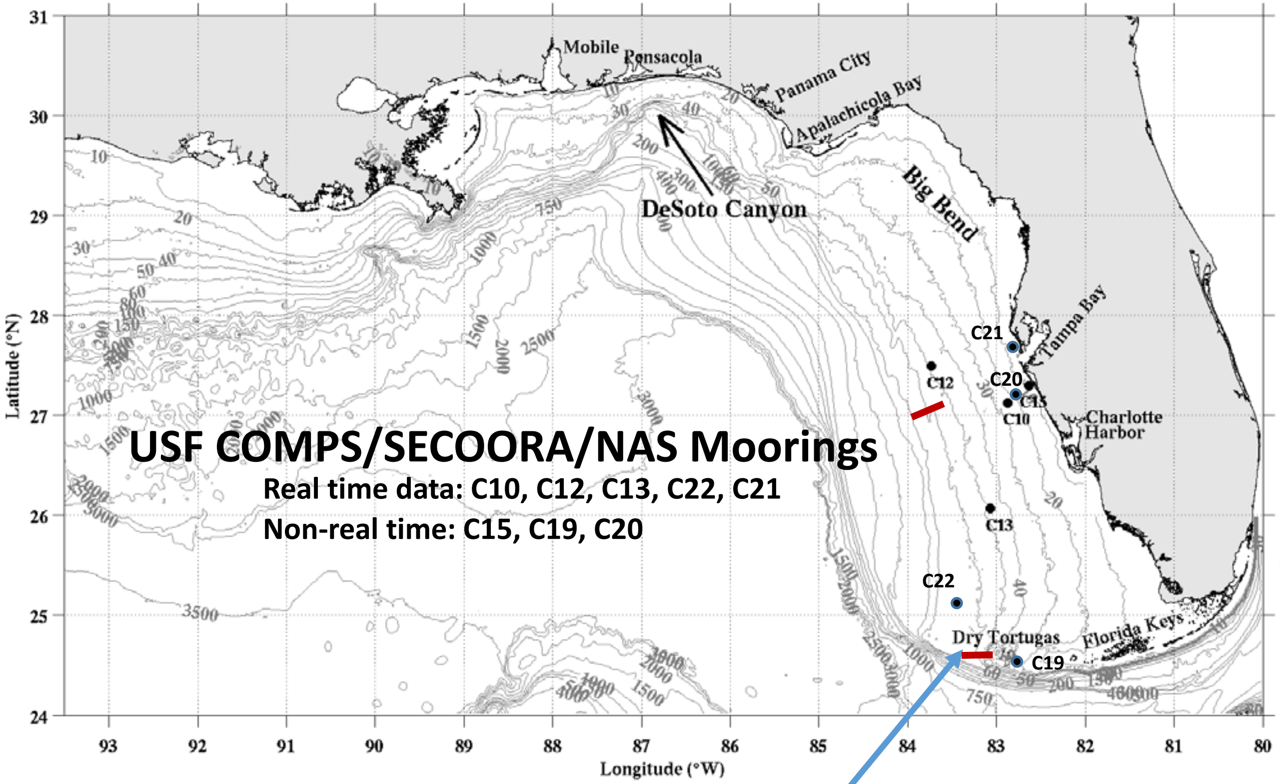
1. **WFS geometry and why the Pressure Point is important.**
2. **Observing and modeling tools.**
3. **Application to *Karenia brevis* red tide.**
4. **Determining origins and pathways of new, upwelled water**
5. **Application to gag grouper recruitment.**
6. **Application to the Gulf of Mexico Loop Current.**
7. **Initial results from the NASEM UGOS Pressure Point Mooring**

1. WFS Geometry and Pressure Point:

"To be oligotrophic, or not to be oligotrophic, that is the question."

So how does the shelf get its nutrients?

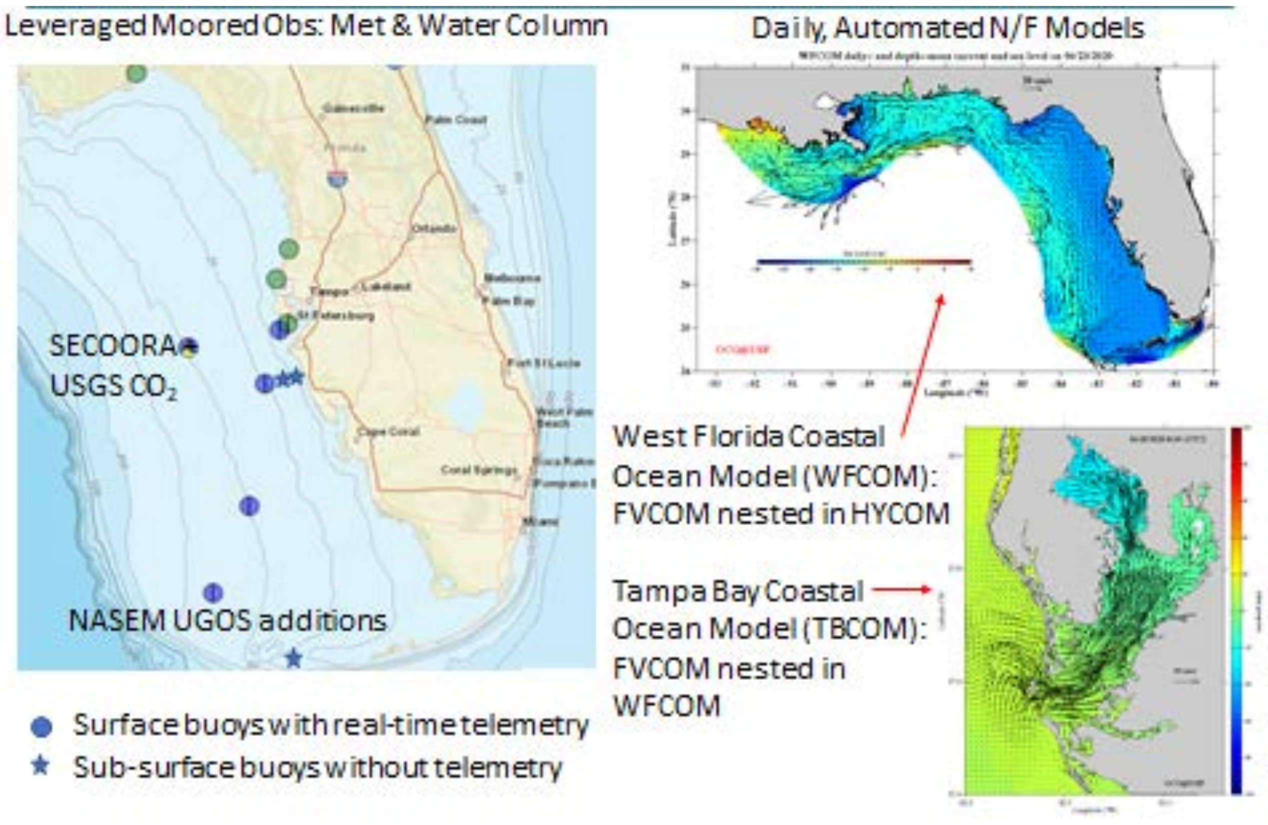
— 30 km, an approximate Rossby radius of deformation



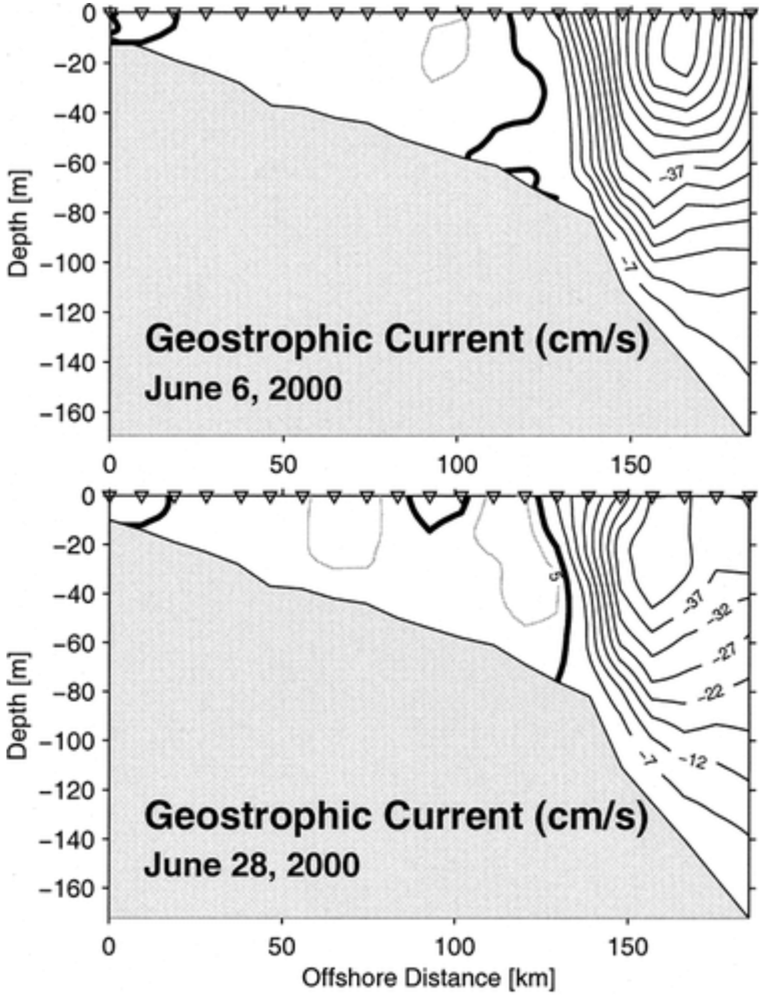
The WFS Pressure Point
Is critical in determining water properties.

2. Observing & Modeling Tools:

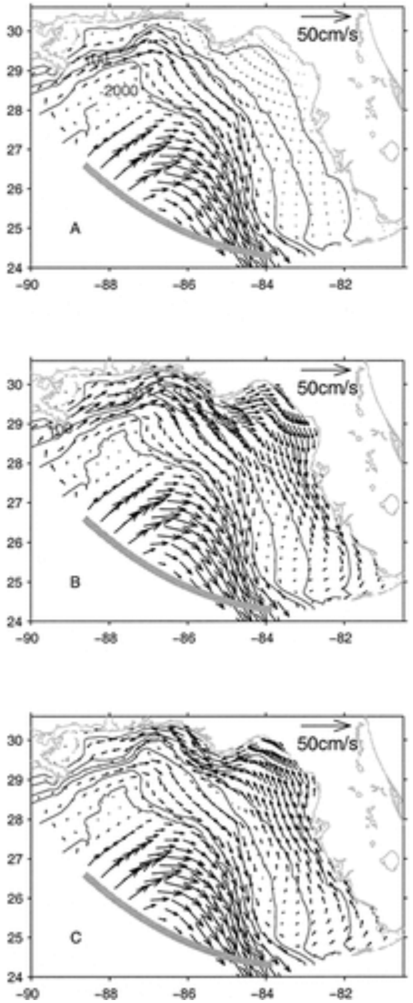
Our approach is to coordinate observations with models to determine how the WFS works



LC/WFS interaction case study occurring away from the PP

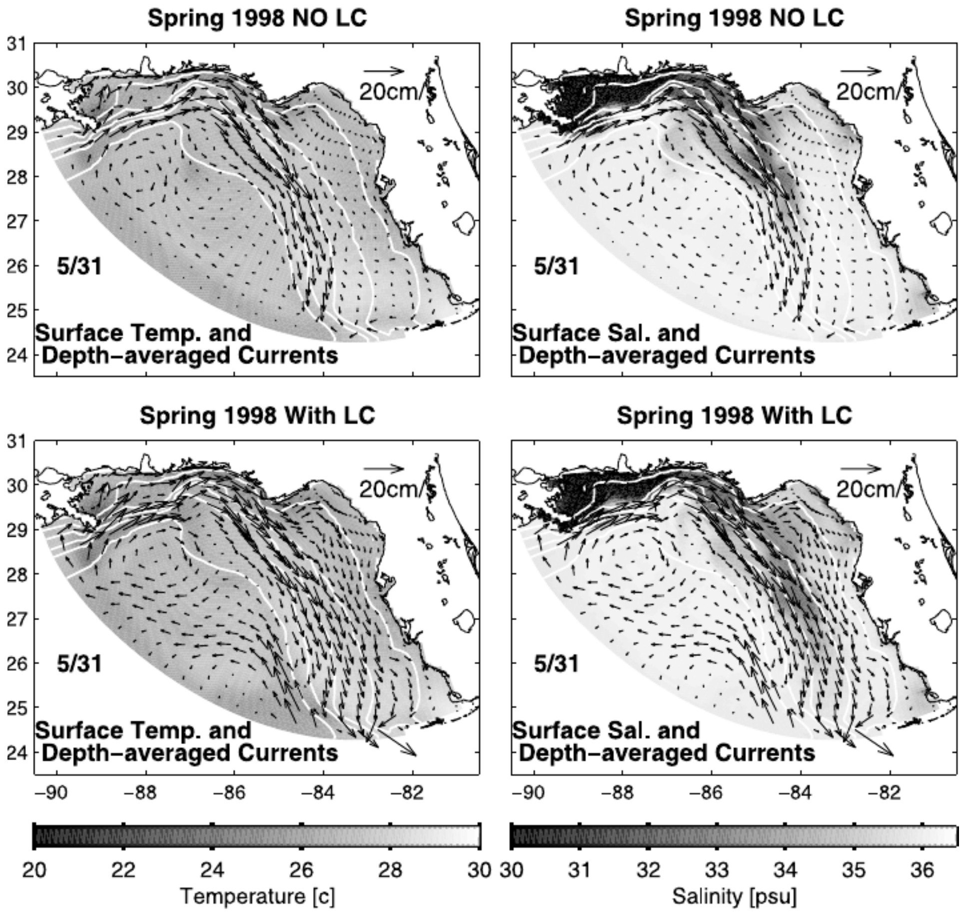


Geostrophic V from shipboard CTD



Simulated V with/without LC

LC/WFS interaction case study occurring at the PP



Note how the currents extend across the entire WFS with, whereas the currents over the inner shelf are nominally small without, the LC/PP interaction.

3. Application to *Karenia brevis* Red Tide

Knowns:

- Florida red tide, a bloom of the toxic dinoflagellate, *Karenia brevis*, is naturally occurring.
- It generally initiates offshore under oligotrophic (nutrient deplete) conditions.
- It generally manifests as a nuisance once transported to the coastline.
- Both the offshore conditions and transport are determined by the ocean circulation.

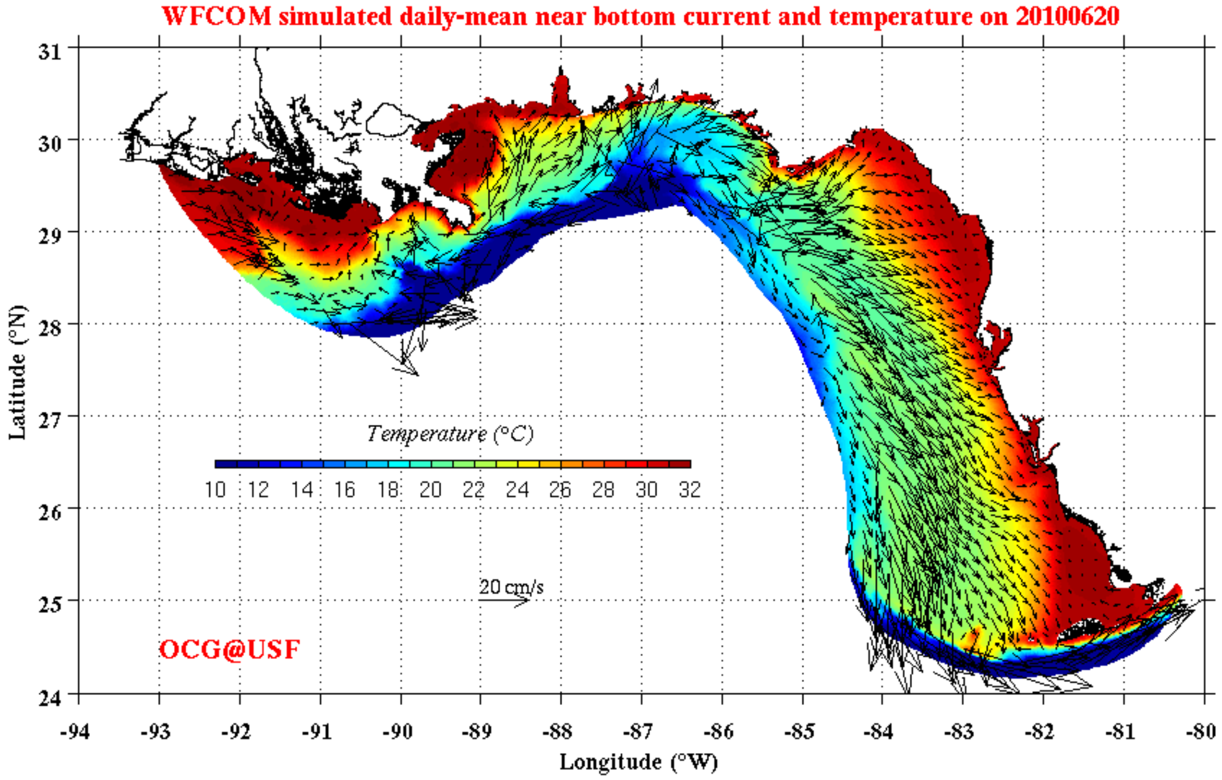
Unknowns:

- Do humans exacerbate *K. brevis* blooms?
- What terminates a *K. brevis* bloom?
- Might there be means for mitigation?

What to do about it:

- Support full water column observations across the entire west Florida continental shelf.
- Support necessary modeling and tracking.
- Conduct laboratory and microcosm mitigation experiments.
- Solve known human-made problems.
- Develop predictive schemes

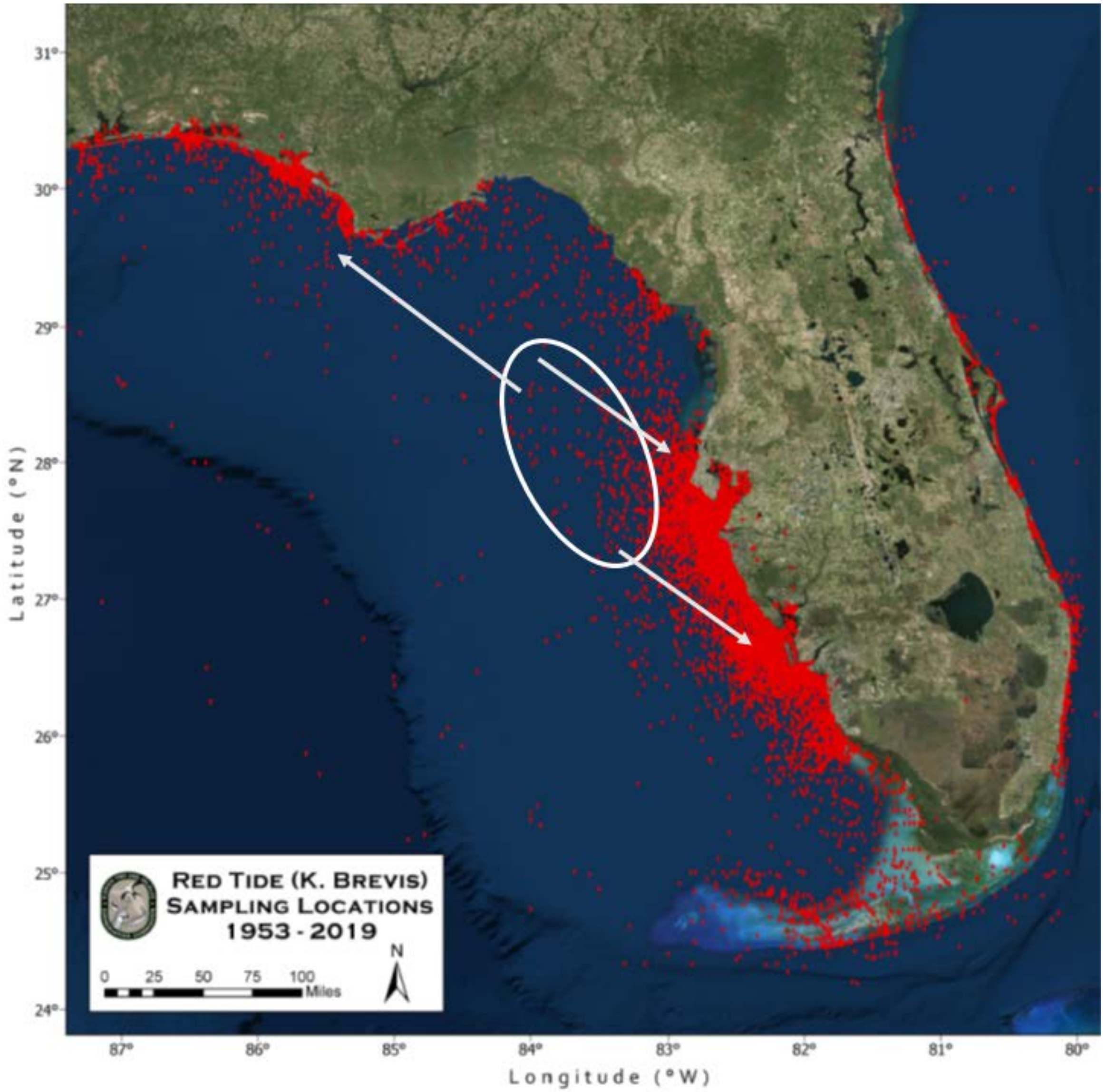
WFCOM Simulation of Near Bottom V and T for June 6, 2010



Whereas 2010 was a year when the WFS did not have a major red tide because of a protracted LC/PP interaction, it illustrates the pathway from mid-shelf to the shore that accounts for the spatial distribution of *K. brevis* on the WFS

K. brevis Cell Counts: 1953-2015

A spatial order exists for WFS ecology, implying offshore initiation and transport pathways to the coastline.



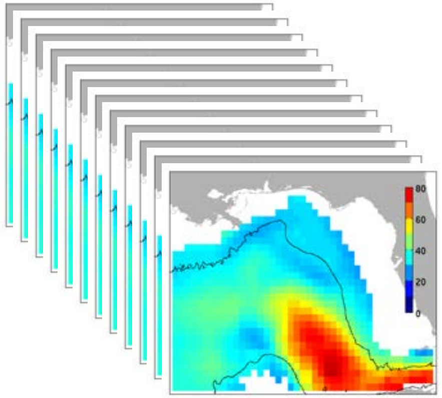
The Self-Organizing Map (SOM) as a Predictive Tool

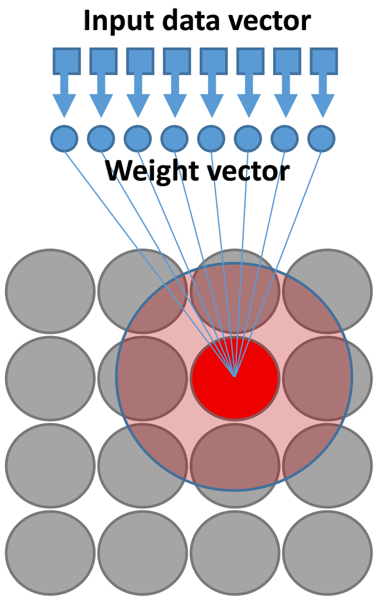
Rationale: If the occurrence or lack of a major red tide is related to LC interaction at the PP, then can we use pattern recognition to develop a predictive scheme?

Our premise is that oligotrophic conditions in the formative region during the spring to early summer bloom period will lead to a major red tide, and conversely.

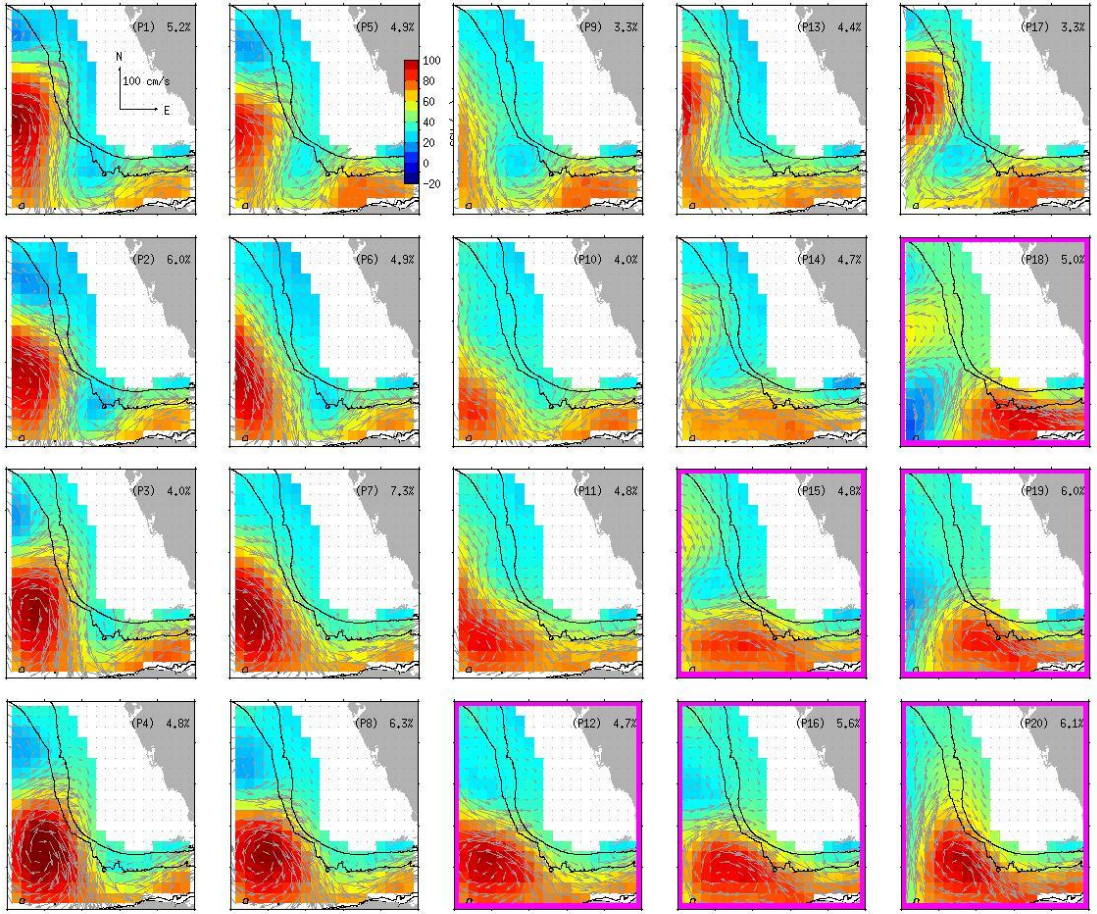
SOM

- Unsupervised learning neural network.
- Projects high-dimensional input data onto a low dimensional space (2D).
- Preserve the topology of the input data.
- Kohonen [1988, 2011].
- SOM MATLAB Toolbox [Vesanto et al., 2005].
- Richardson et al. [2003] introduce SOM to oceanography community.
- Liu & Weisberg [2005], SOM application to ocean current data analysis.
- Liu et al. [2006] SOM performance evaluation & parameter choices.

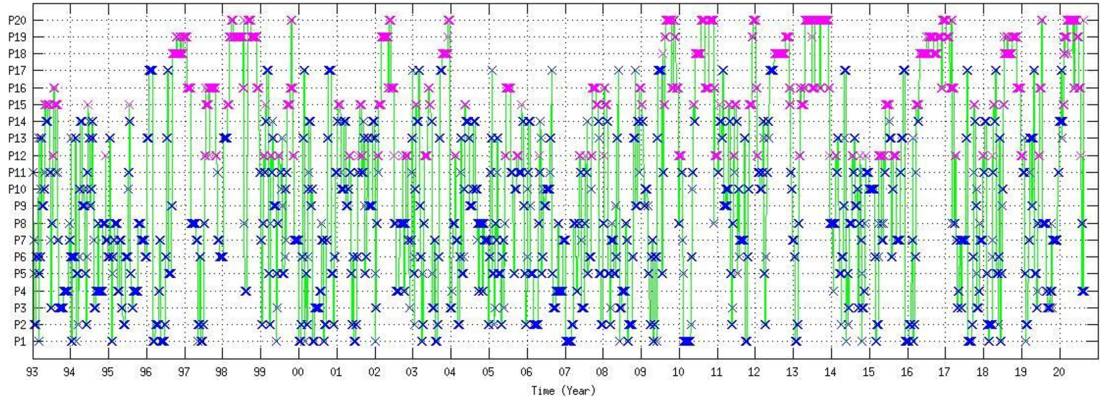




Characteristic LC patterns from 23 Years of Altimetry Data with a 4x5 SOM

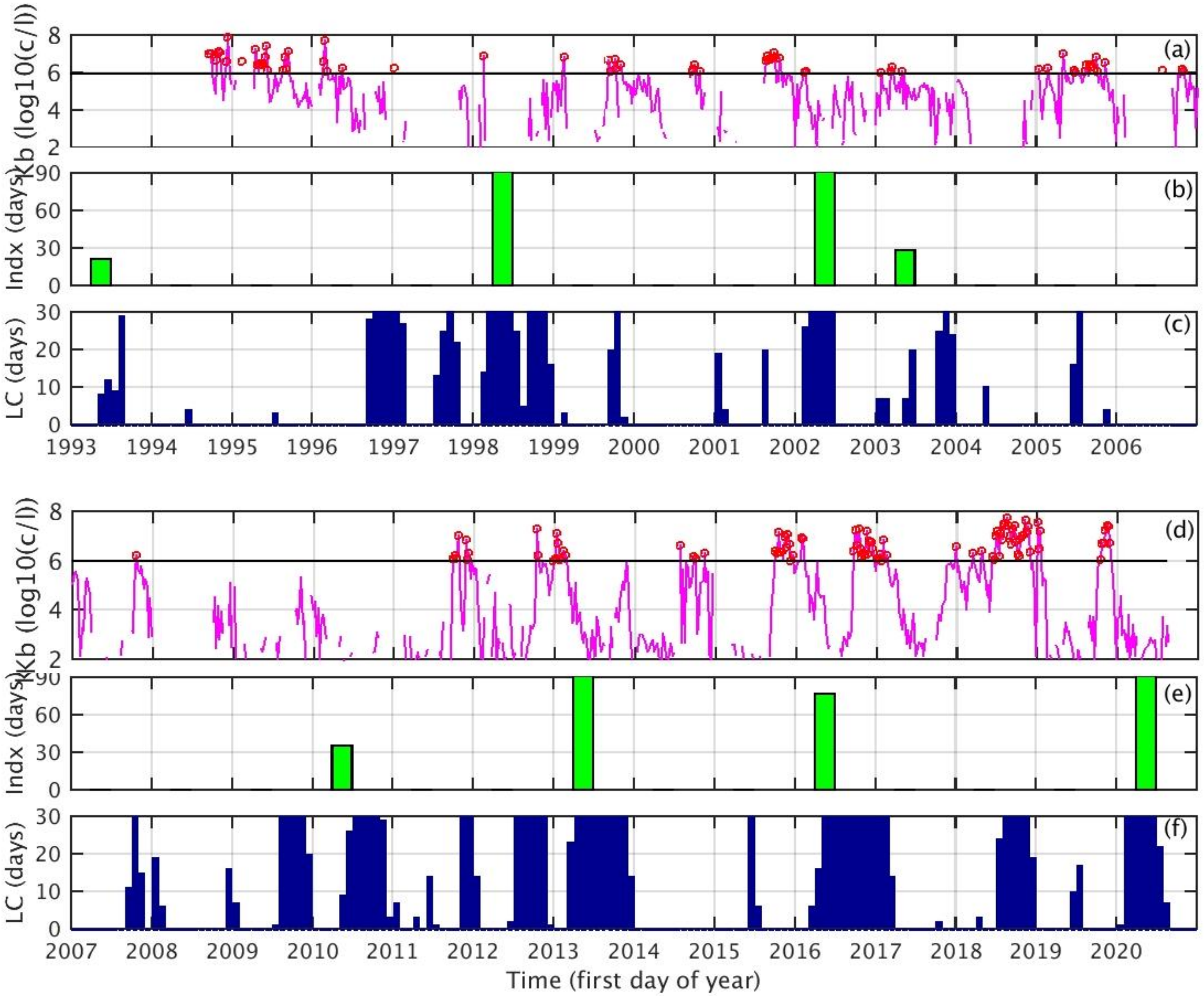


P15, P16, P18, P19, P20 highlighted In magenta are the ones identified as "pressure point" acting.



The Best Matching Unit (BMU) time series shows the evolution of these patterns over time.

WFS Red Tide Events and Pressure Point Forcing.



a&d: weekly averages of the highest 5 *K. brevis* cell counts (magenta lines), the black line indicating the major bloom threshold (10^6 cells/L) and red being cell counts exceeding this.

b&e: a "pressure point" forcing index (green bars), the cumulative days for which SOM patterns 15, 16, 18, 19 or 20 occurred in spring to early summer (4/1 to 6/30) for at least 7 days in each of at least two months.

d&f: the number of days for which patterns 15, 16, 18, 19 & 20 occurred in each month (blue bars).

Seasonal Hindcast Results Summary

No Major Bloom: 6/7 (2016 was the outlier)

Major Bloom: 16/20

Summary of Major *K. brevis* Blooms and Pressure Point Forcing

Year	Persistent offshore forcing during spring and early summer (√)	Major blooms (×)	No major fall bloom (√) or the earlier year bloom reduced in intensity (√*)	Outlier years (F)
1993	√		√	
1994		×		
1995		×		
1996		×		
1997			√*	F
1998	√		√*	
1999		×		
2000		×		
2001		×		
2002	√		√	
2003	√		√	
2004			√	F
2005		×		
2006		×		
2007		×		
2008			√	F
2009			√	F
2010	√		√	
2011		×		
2012		×		
2013	√		√*	
2014		×		
2015		×		
2016	√	×		F
2017		×		
2018		×		

Seasonal prediction:

No major bloom 6/7

Major bloom 15/19

21 out of 26 years followed the major bloom criteria defined herein.

22 out of 27 if we count 2019.

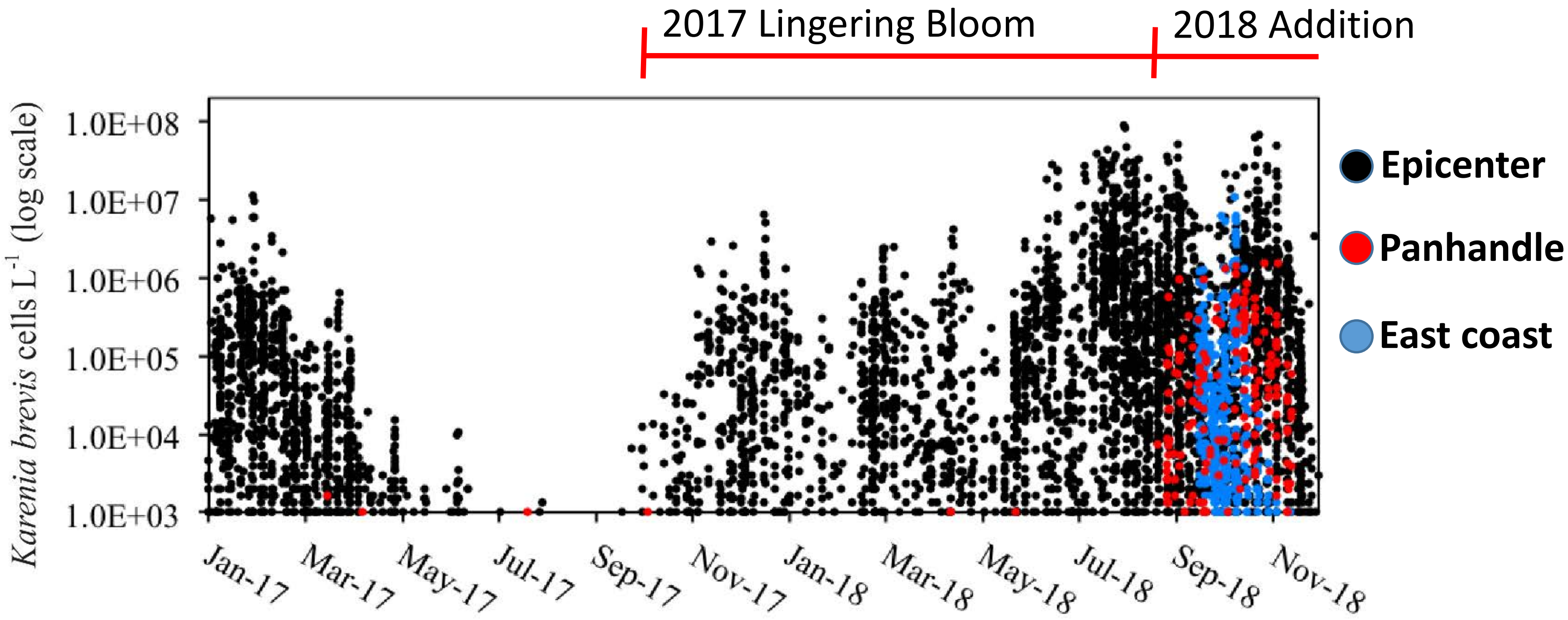
Caveat: This is an Occam's razor approach. Red tide is more complex!

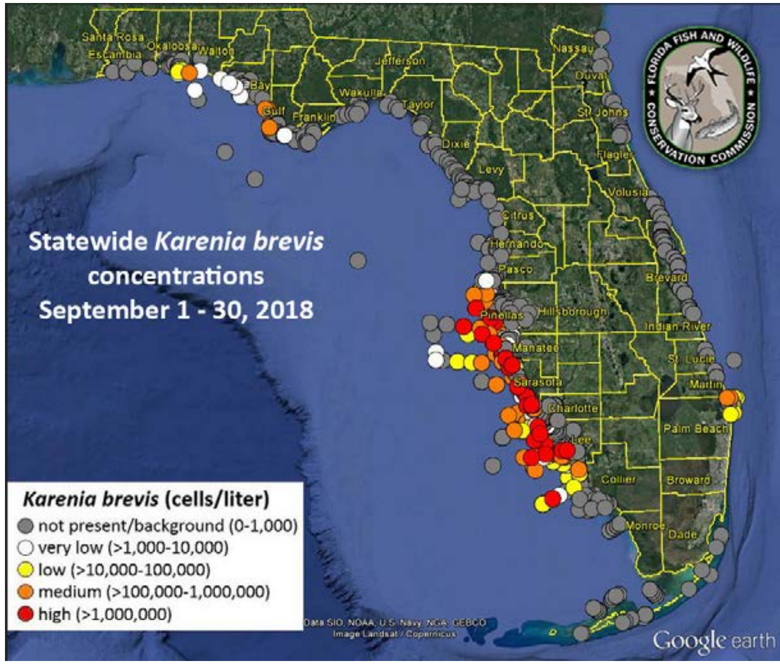
What Happened in 2018?

2018 may have rivaled 2005 as the worst of the recent *K. brevis* red tide blooms.
Two factors were in play:

1. **The 2017 bloom never dissipated, and it was particularly prevalent from Venice, FL southward.**
2. **Offshore conditions were conducive for a new bloom to form in spring through summer of 2018.**

The confluence of these two factors accounts for what we experienced. Might Lake Okeechobee releases exacerbate existing blooms? Good question, but lacking a definitive answer.

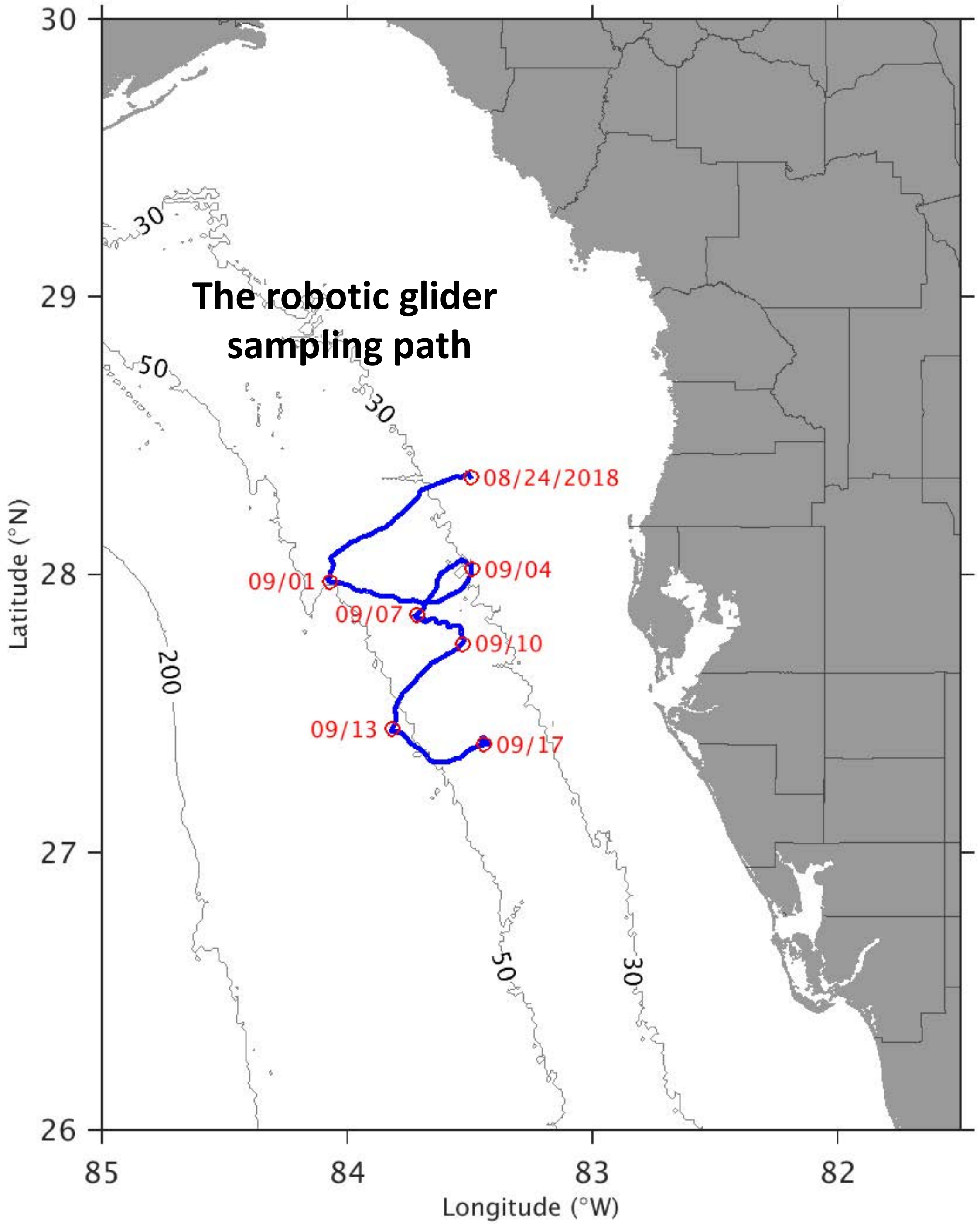




USF-CMS Responses

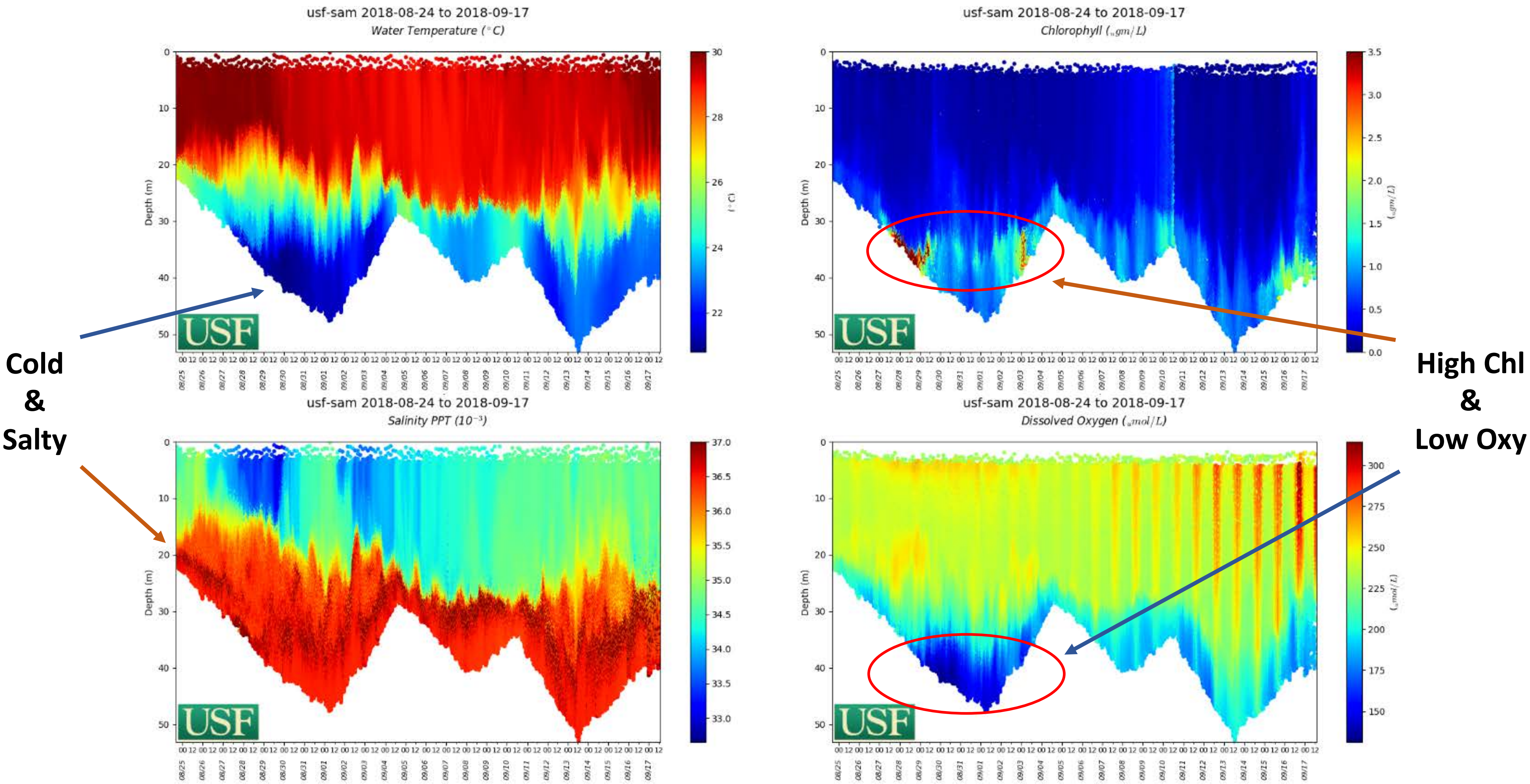
1. We deployed a robotic sampling device (a Webb Electronic Glider) from 8/24/18 to 9/17/18 to map water properties over the entire water column within the hypothesized *K. brevis* red tide initiation region.
2. We tracked the bloom using numerical circulation models.

The robotic glider



Water Properties Observed During the 8/24/18 to 9/17/18 Glider Mission

Note: 1) relatively cold, salty water near bottom indicative of an upwelling circulation, 2) elevated chlorophyll and reduced oxygen near bottom indicative of *K. brevis* with highest concentrations between the 30m-40m isobaths.



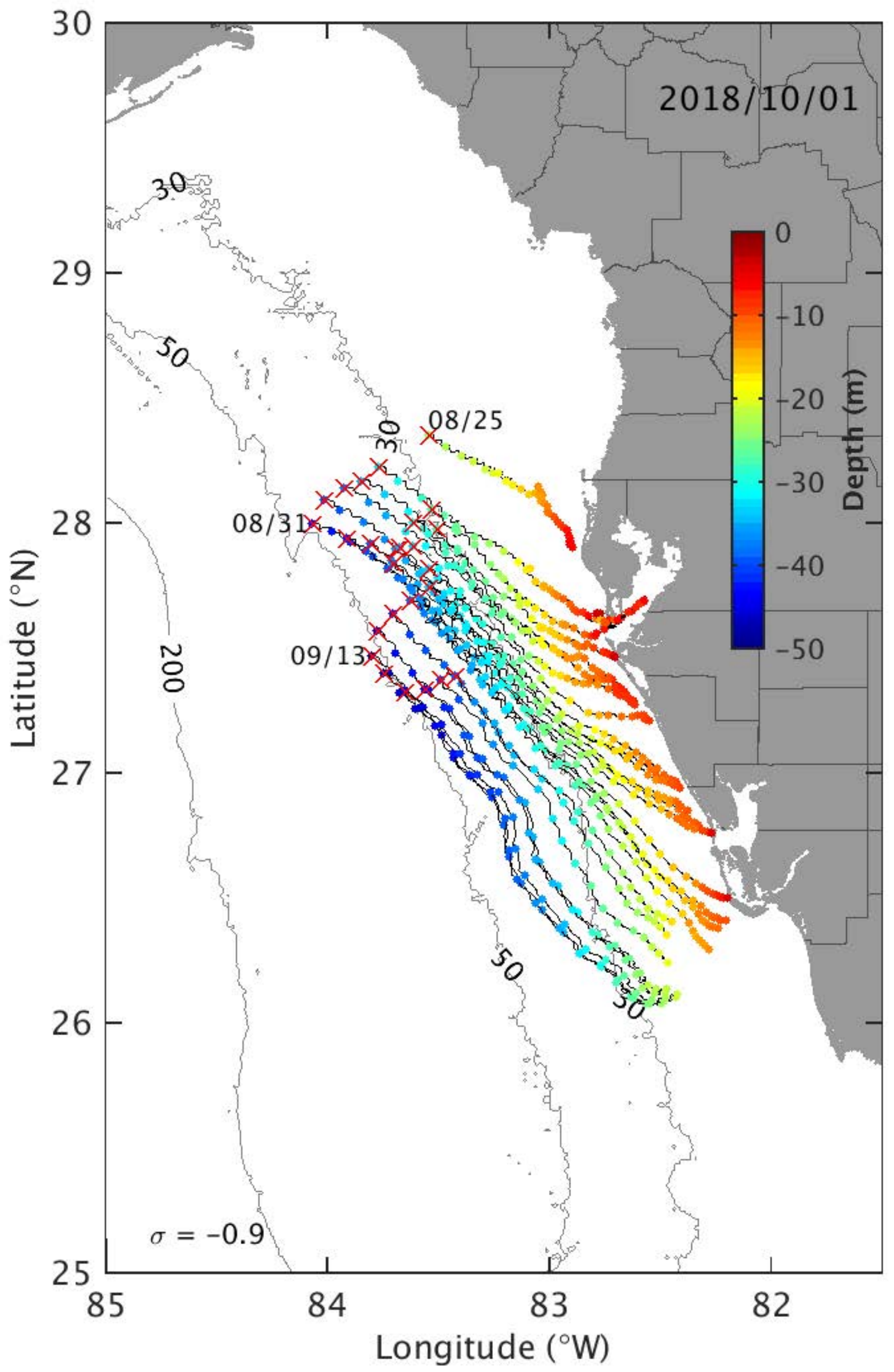
Transport to the Coastline

Given observations indicative of *K. brevis* red tide, where would these cells go if transported by the circulation?

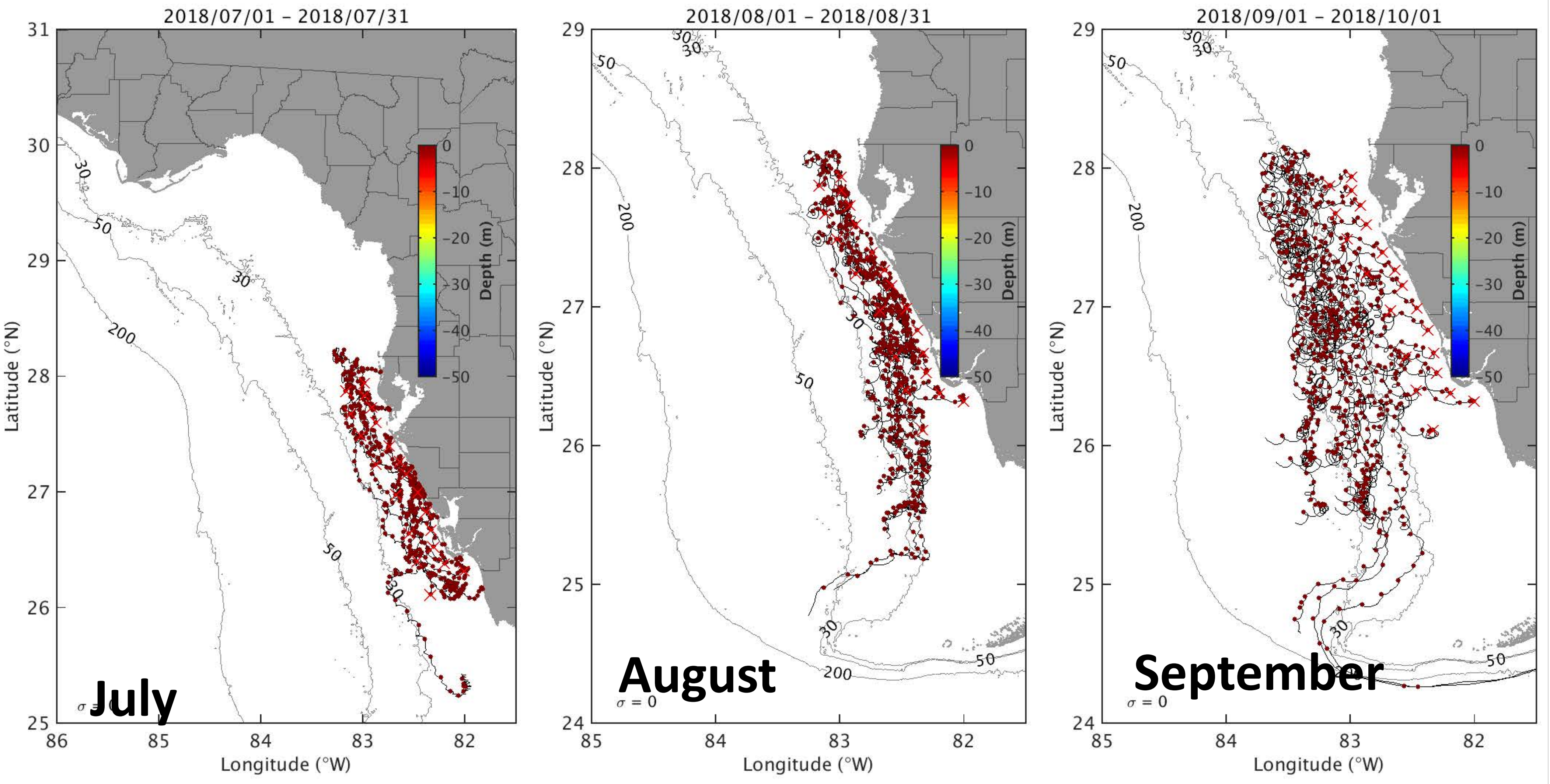
We applied our West Florida Coastal Ocean Model (WFCOM) to track simulated particles in 3-D. Beginning near bottom when the glider was at each of the X designated locations, the colored lines are the particle trajectories and depths ending on 10/1/18. All of the near bottom particles approached the coastline from northern Pinellas County to Lee County, consistent with the mid-shelf initiation hypothesis.

While not shown we also tracked particles from higher in the water column to the Panhandle coast (as influenced by TS Gordon) and from the west coast to the east coast.

Thus *K. brevis* red tide from the hypothesized initiation region accounts for the simultaneous occurrence in 2018 of blooms on Florida's west, Panhandle and east coasts.

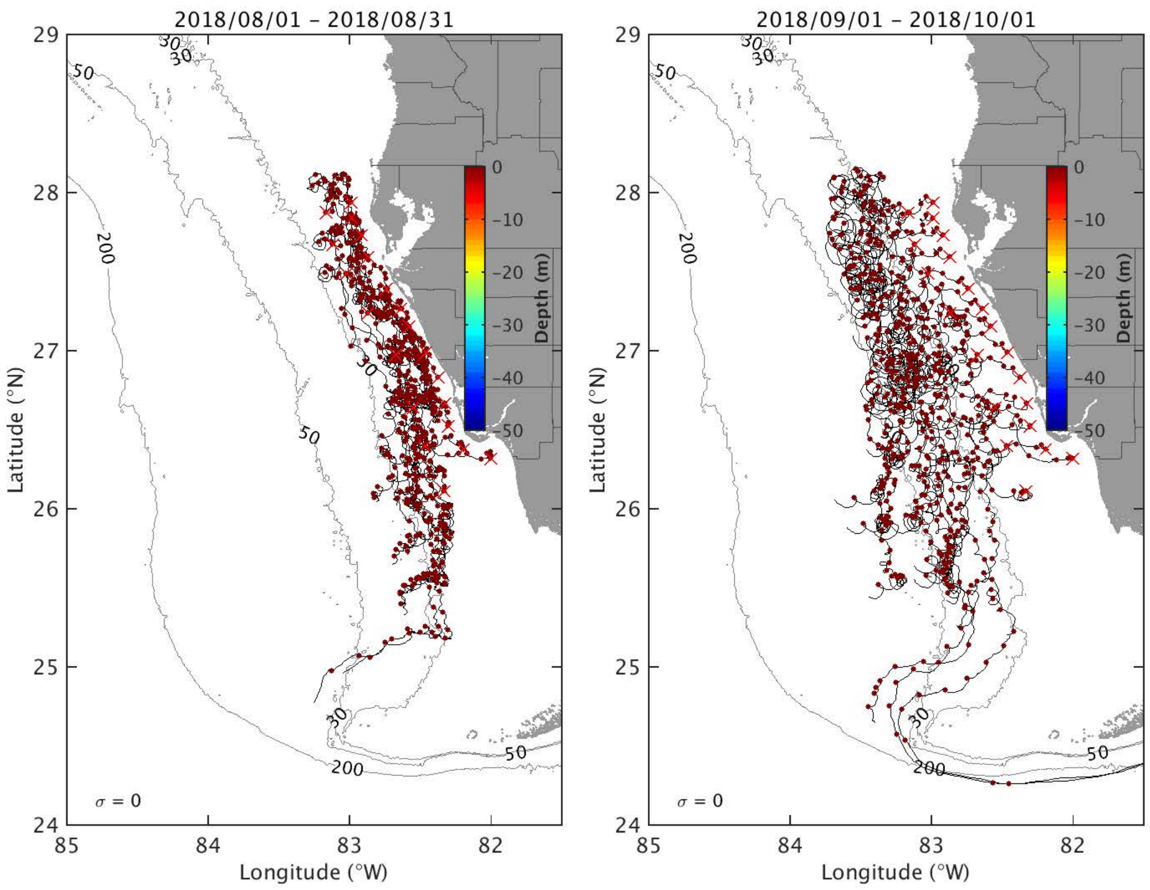


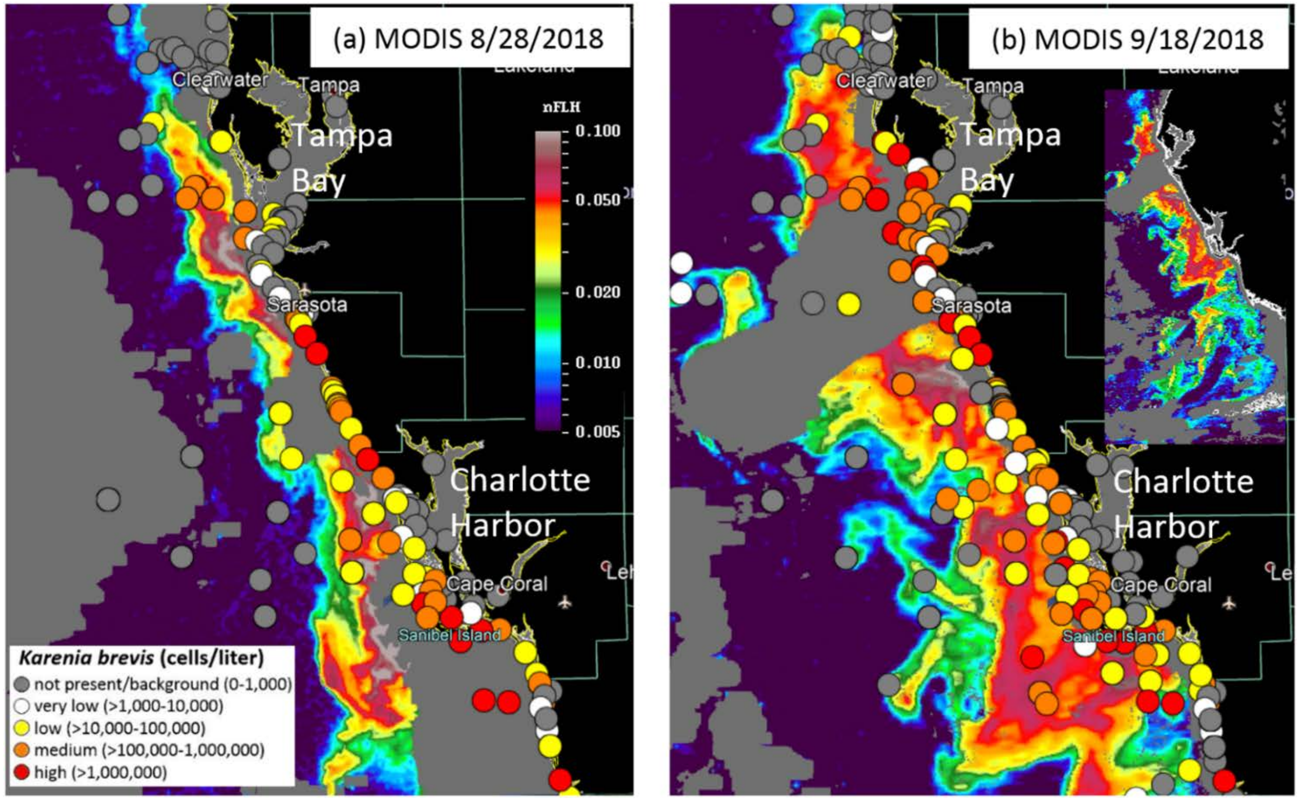
Near Shore Surface Layer Particle Trajectories for Successive Months



Note the offshore displacements in September 2018 and the subsequent finding of *K. brevis* on Florida's east coast. The east coast bloom originated in the west coast epicenter region as did the *K. brevis* observed on Florida's Panhandle coast.

WFCOM Particle Tracking Veracity Assessment





The increase in offshore particle extents on 9/18, relative to 8/28, was due to strong easterly winds.

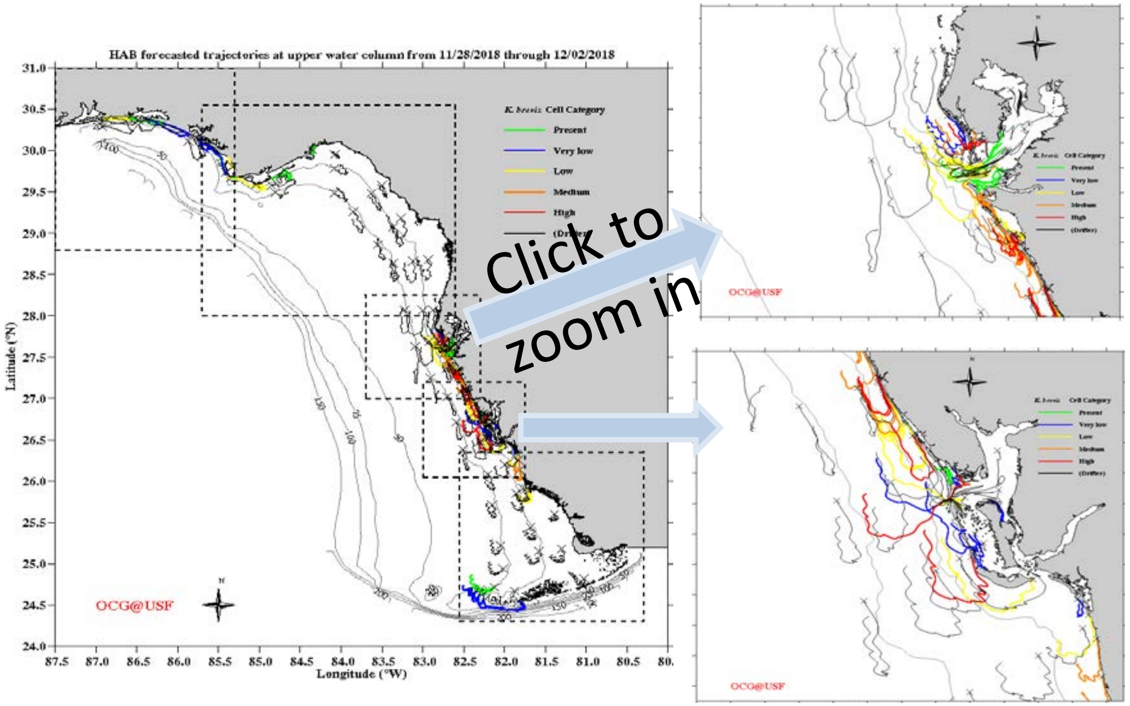
This same increase in the offshore particle extents on 9/18, relative to 8/28 were observed in both MODIS fluorescence line height algal bloom index (C. Hu) and in the overlaid *K. brevis cell* concentrations determined by FWRI water sample microscopy (K Hubbard).

Seasonal and Short-term (4.5-day) Forecasting by the USF-CMS/FWC-FWRI Collaboration for the Prediction of Red tide (CPR).

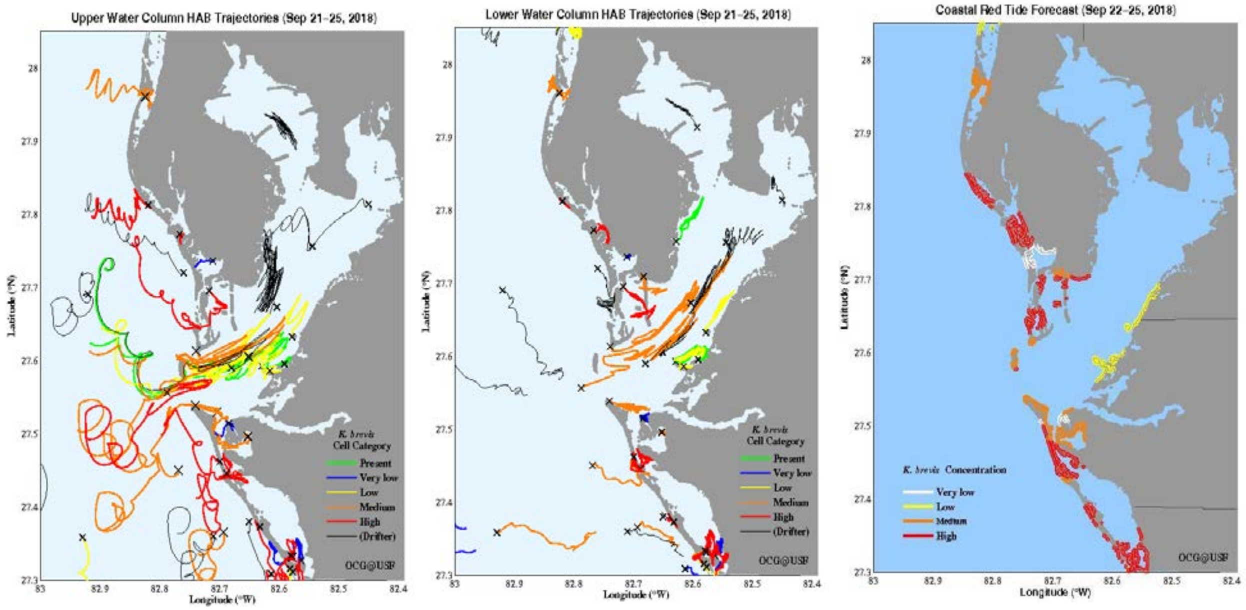
Seasonal: Based on mid-shelf nutrient conditions determined by the circulation.

Short-term: Based on observations (FWC-FWRI) and two different circulation models (USF-CMS): the West Florida Coastal Ocean Model (WFCOM) and the Tampa Bay Coastal Ocean Model (TBCOM)

WFCOM for the entire West Florida Shelf



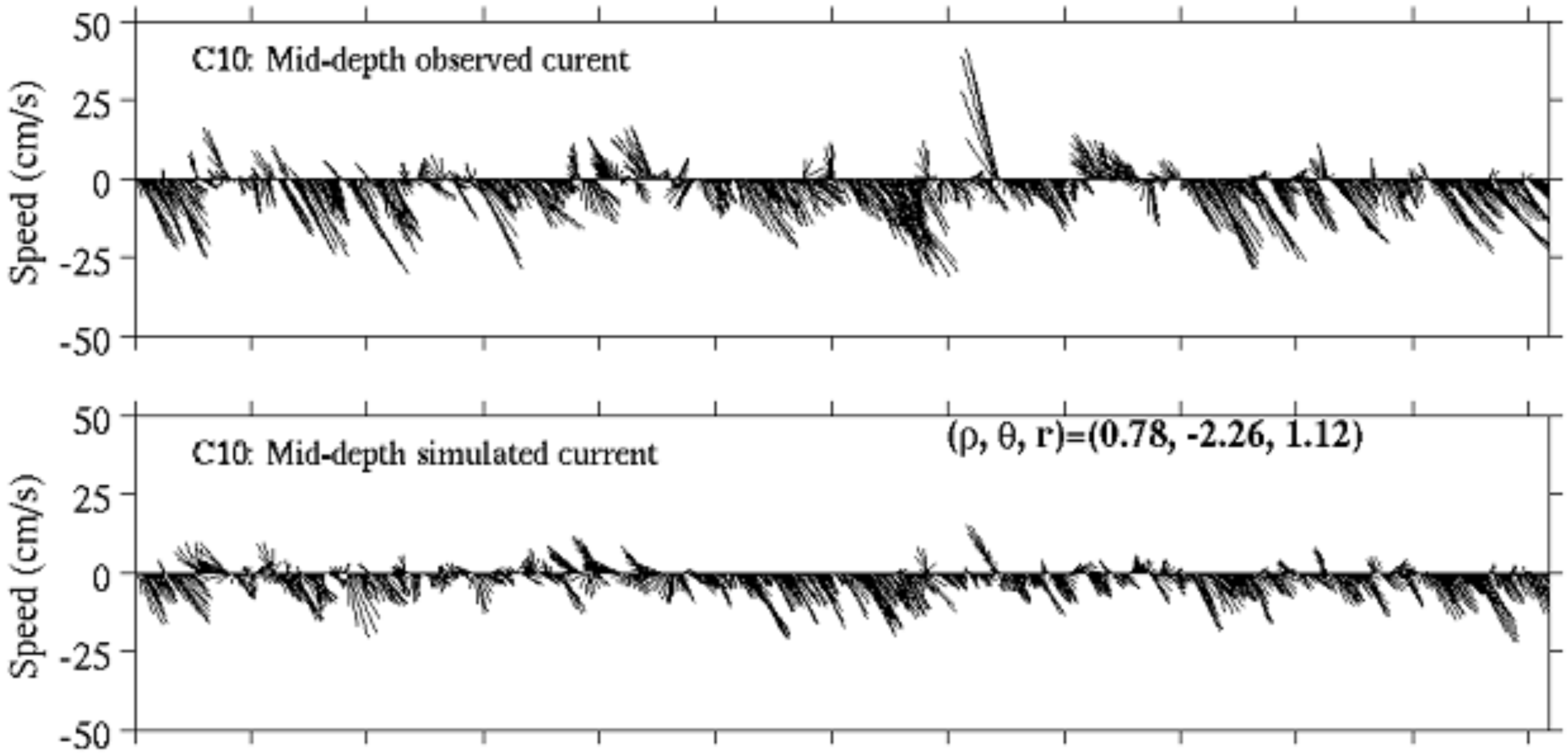
TBCOM for Tampa Bay

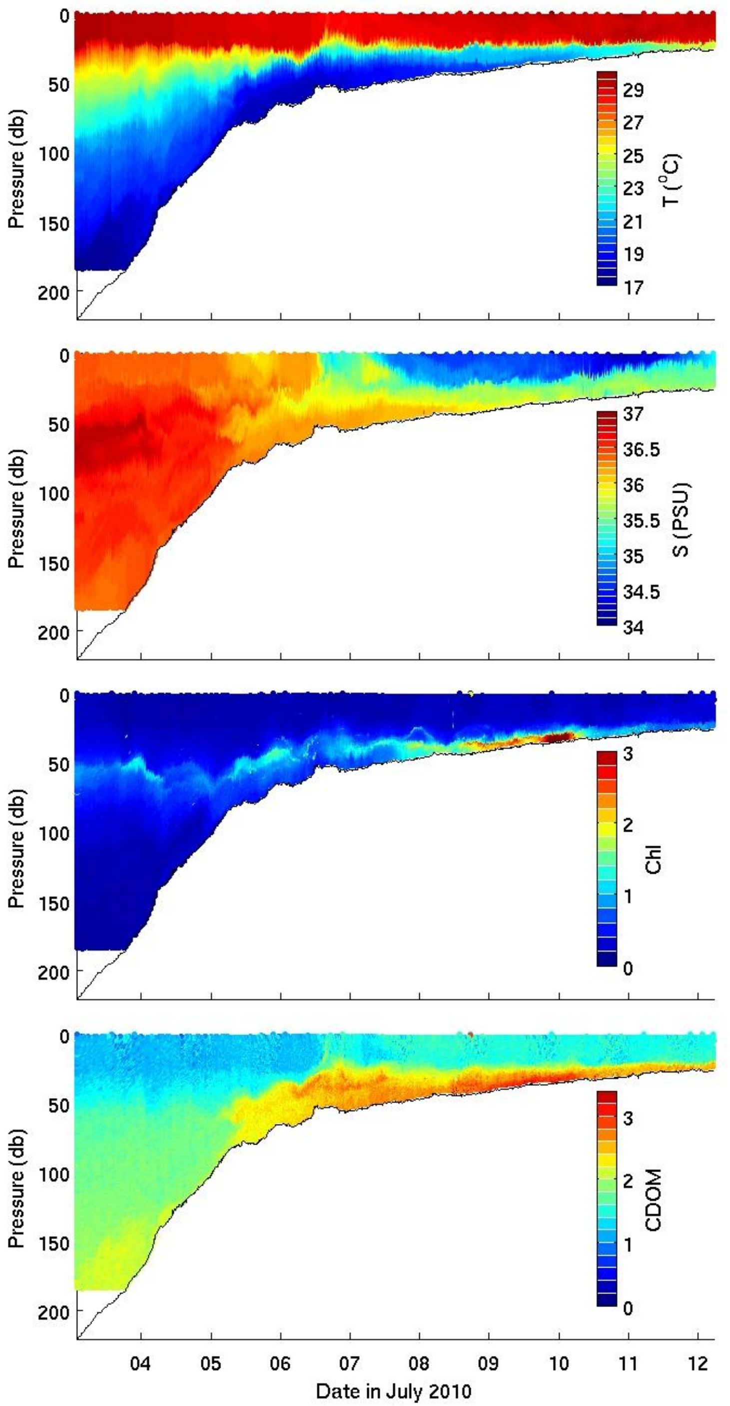


http://ocgweb.marine.usf.edu/hab_tracking/

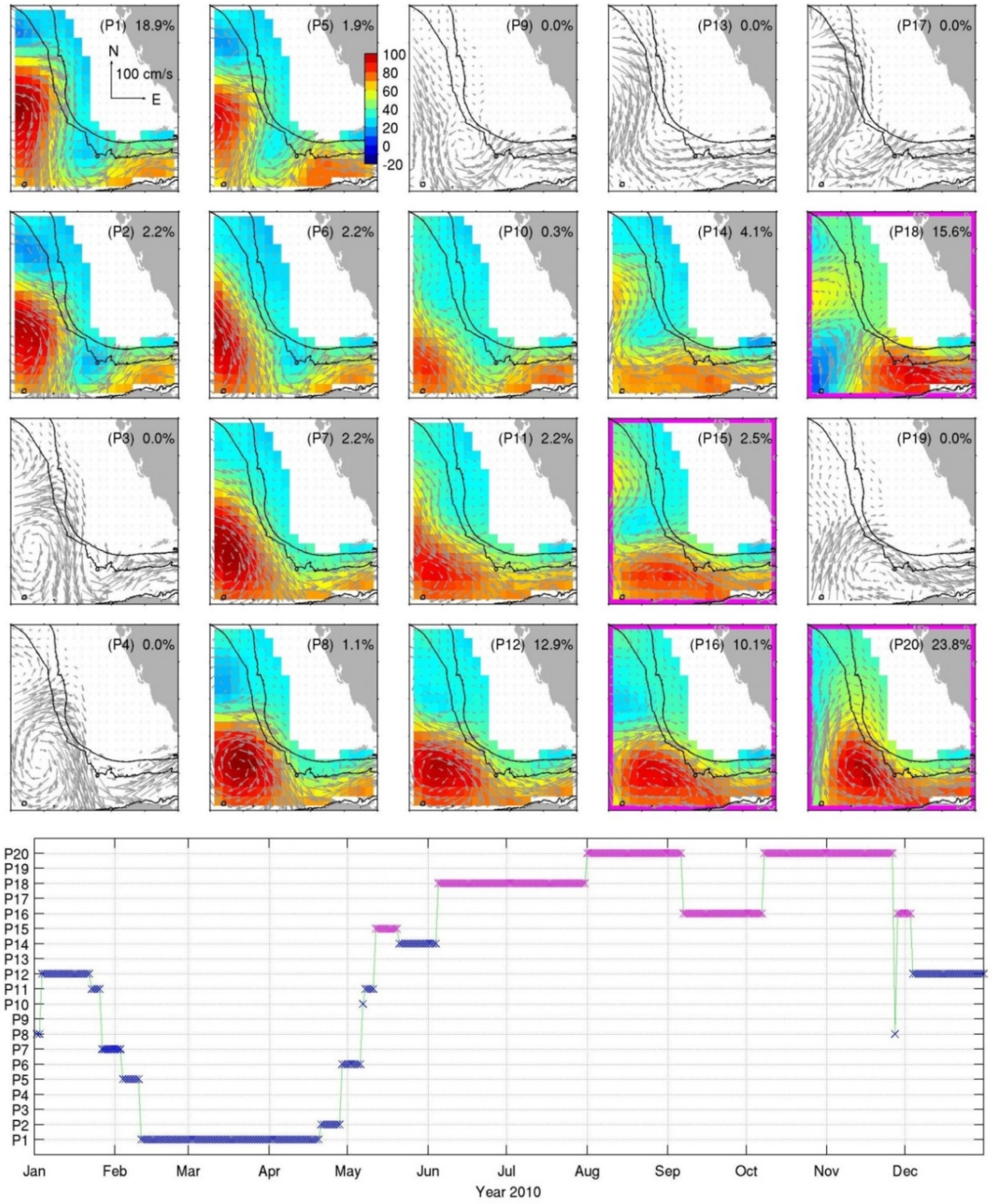
4. Given that Loop Current/Pressure Point interactions result in new, deeper ocean water being upwelled onto the WFS, what are new water origins and pathways and hence their state properties?

2010, a protracted upwelling year (mid-May-December) in which WFCOM simulations agree with observations and glider data show the upwelled water, provides for a good case study.





Characteristic LC Patterns from Altimetry for 2010

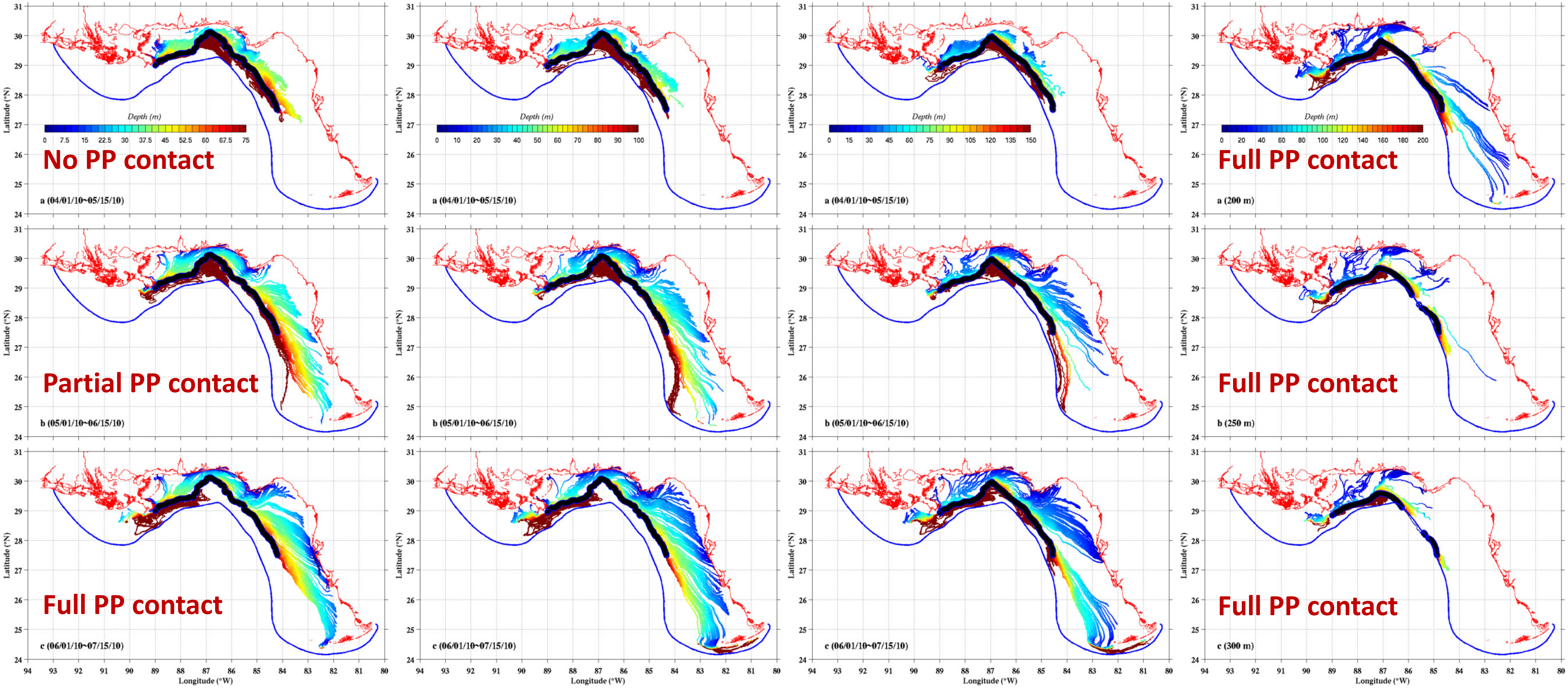


All of the patterns occurring in 2010 are shown in color and the "pressure point" patterns are further highlighted in magenta.

The BMU) time series shows a prolonged period of pressure point contact.

45-day Trajectories for Particles on the 75, 100, 150, 200, 250, 300m isobaths.

75m | **100m** | **150m** | **200, 250, 300m**

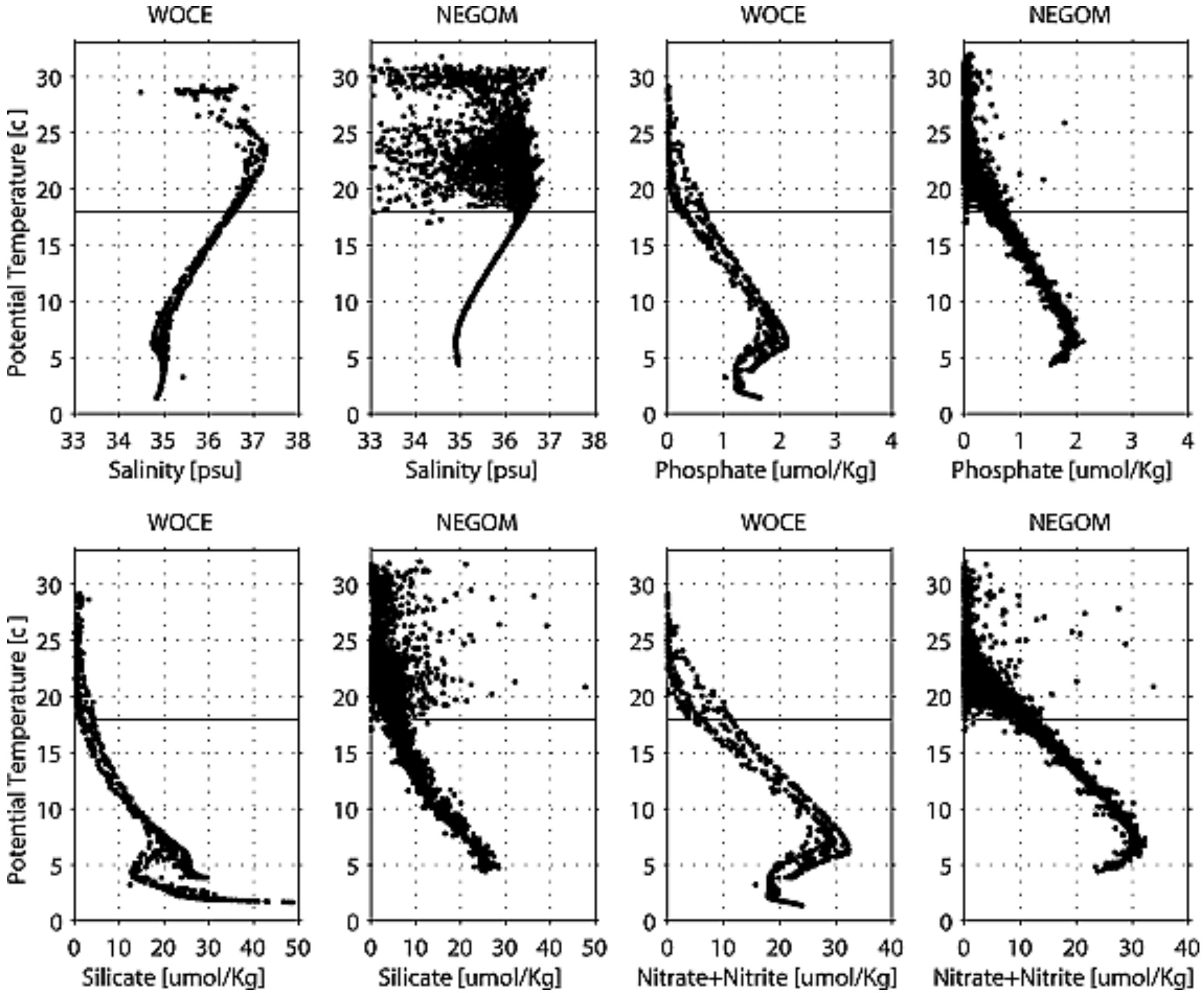


Conclusion: The origin for new upwelled water onto the WFS is from the upper slope from the shelf break (~75m isobaths) to 200m, and the pathway is the bottom Ekman layer.

Upper Shelf Slope Water Properties

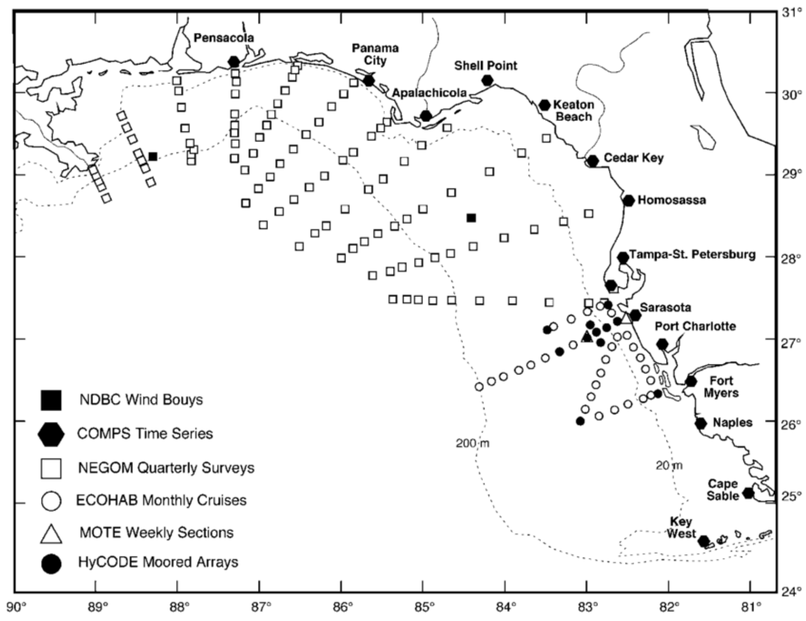
NEGOM: TAMU MMS hydrographic survey of the northeastern GOM, 1998-1999

WOCE hydrographic section A22 (subsampled from 11N and 25N)

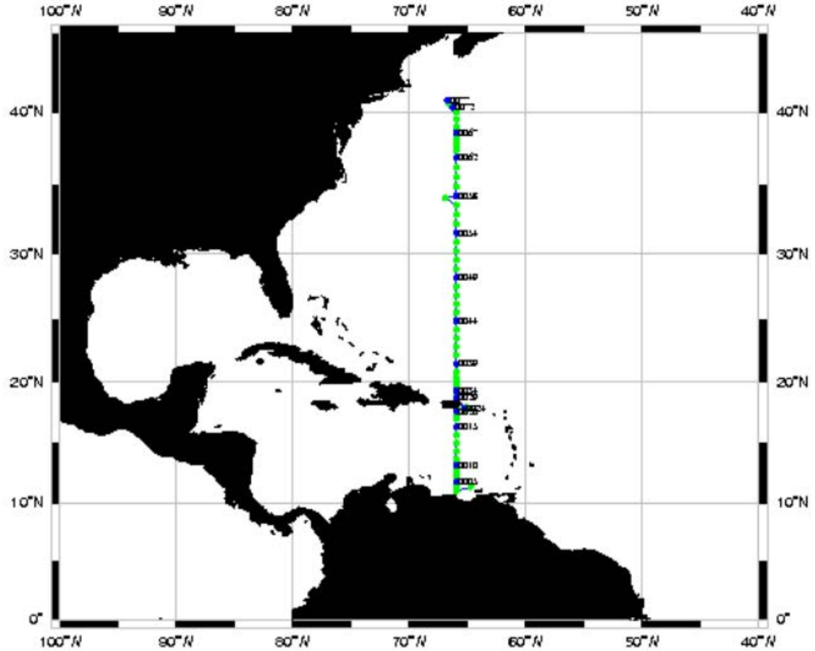


Nutrients begin to increase with T below 19 deg. as seen along the upper slope below the region of light penetration.

NEGOM +

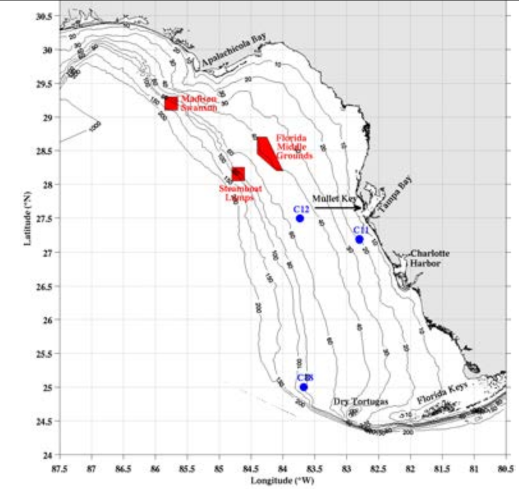


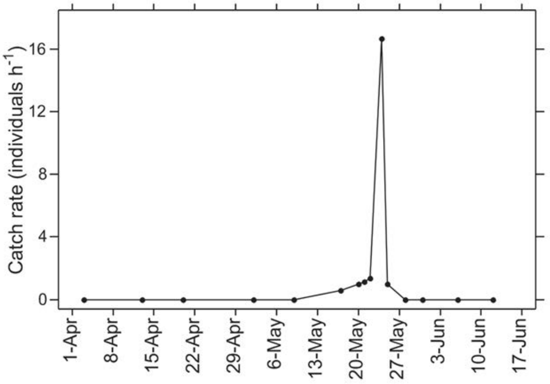
WOCE A22

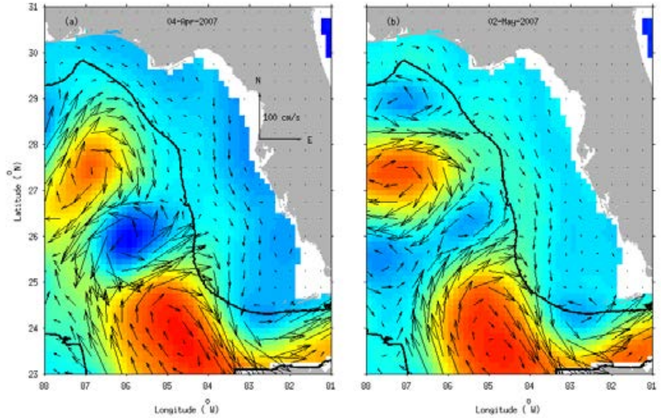


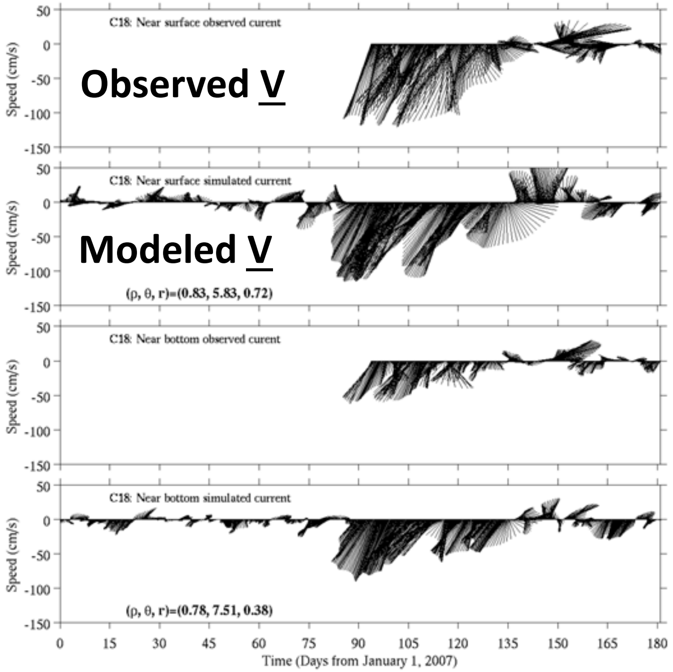
5. Application to the Gag Grouper Conundrum

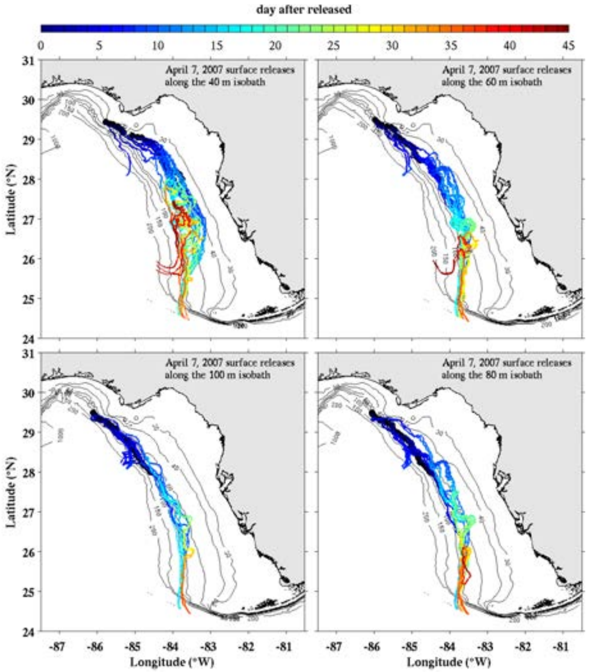
Gag, a major recreational and commercial reef fish, spawn offshore in winter-spring months, and the juveniles settle along the shore. The spawning to settlement transport mechanisms were a mystery.



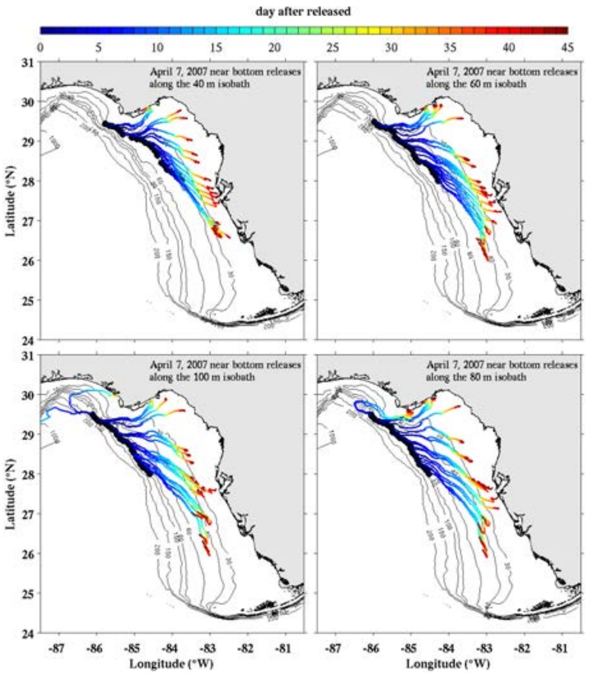








Surface trajectories do not result in settlement



Bottom trajectories do result in settlement

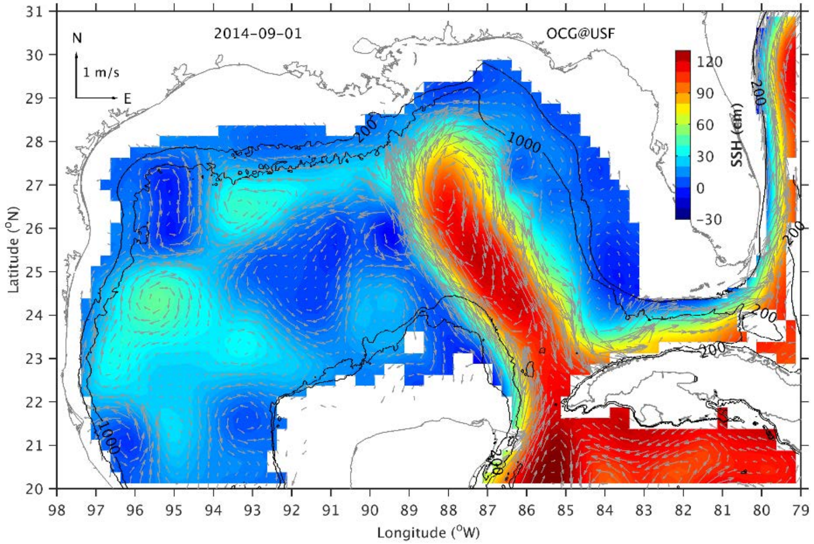
Conclusion: Gag recruitment (and likely other species) is facilitated by pressure point contact during spawning. Thus, the LC plays a major role in WFS ecology by determining nutrient conditions and by transporting fish larvae. In other words the circulation physics largely impacts the biology, and the pressure point is critical to this.

6. Application to the Gulf of Mexico Loop Current

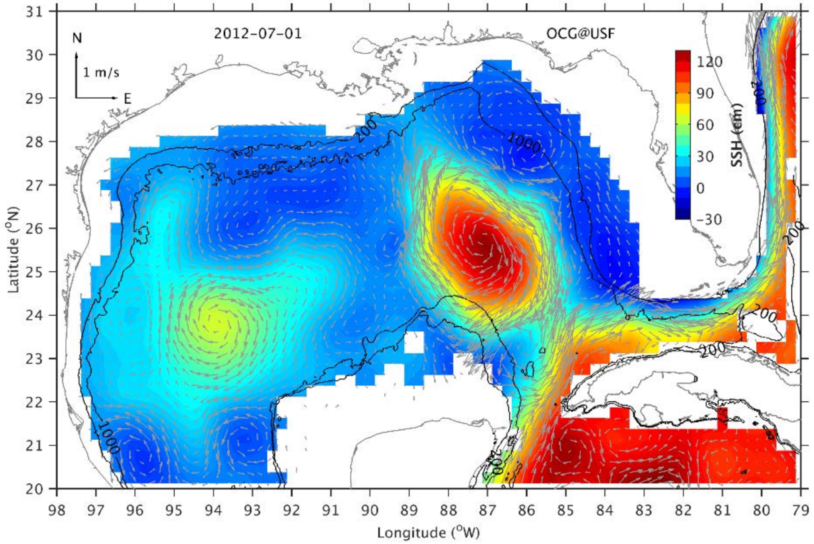
Given that Loop Current via Pressure Point interaction profoundly influences WFS water properties (and hence every aspect of WFS ecology), it is natural to ask: Does the WFS also profoundly influence the Loop Current?

The Loop Current has three basic states:

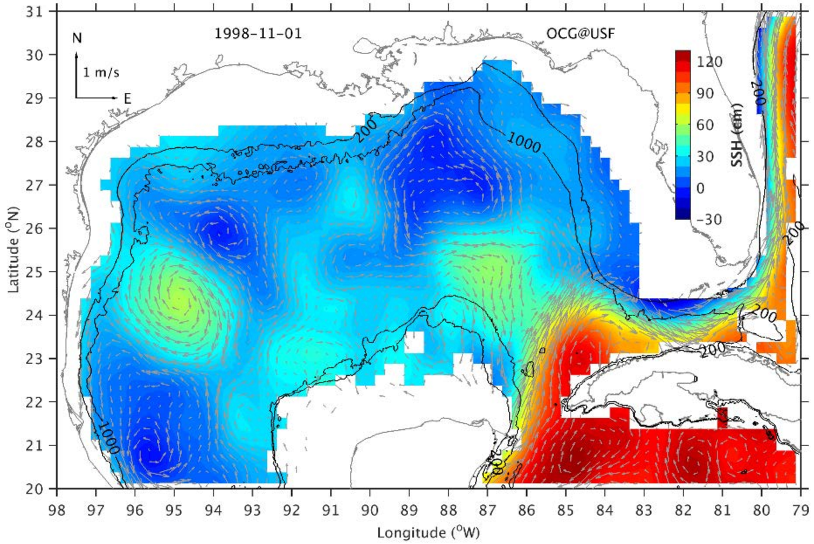
Extended



Eddy Shedding



Retracted



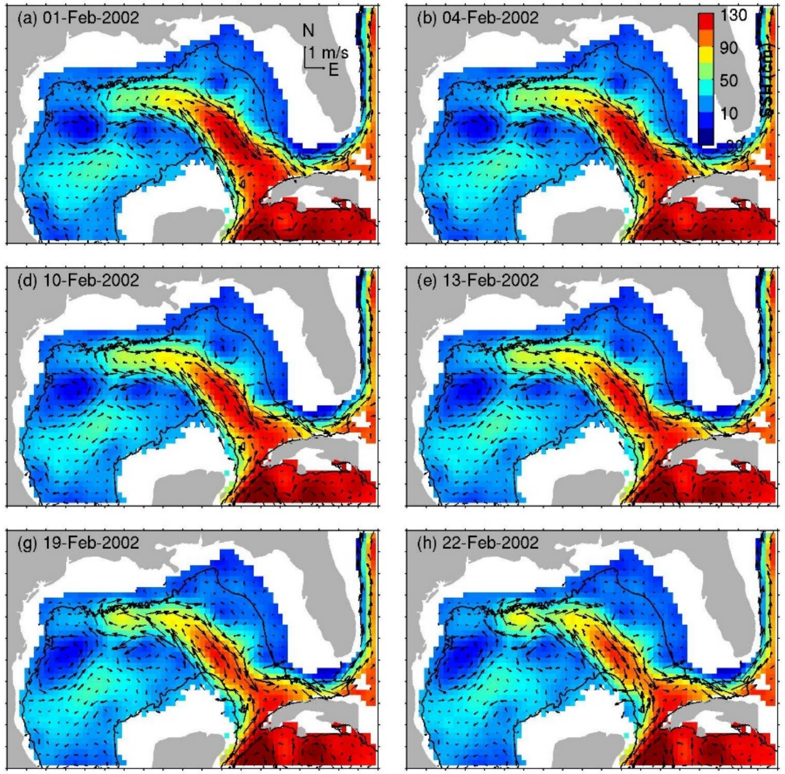
The overarching science question regarding for the Gulf of Mexico Loop Current is: What determines the transitions between these three states?

It is hypothesized that the WFS, by virtue of Pressure Point interaction, serves to anchor the Loop Current in its retracted state. Penetration back into the GOM requires that this anchor be released.

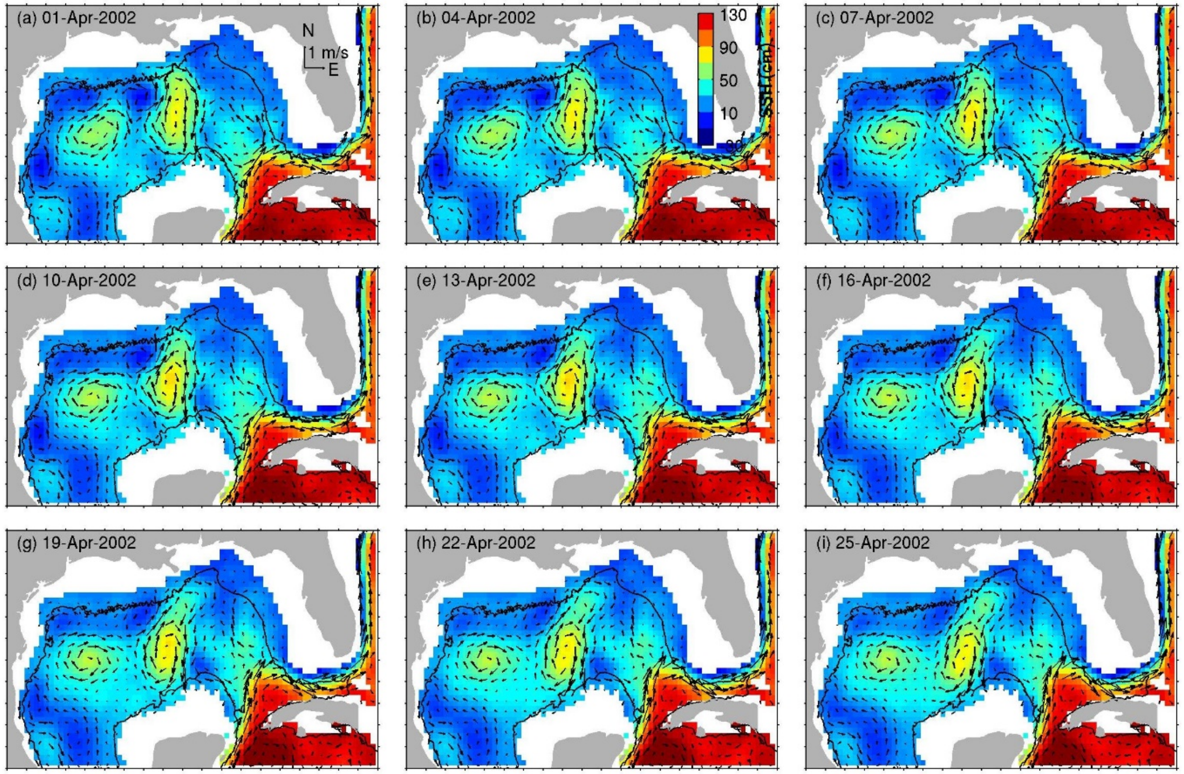
Once in the extended state, instability can result in eddy shedding and retraction.

Transitions from extended to retracted states can occur rapidly.

February 2002

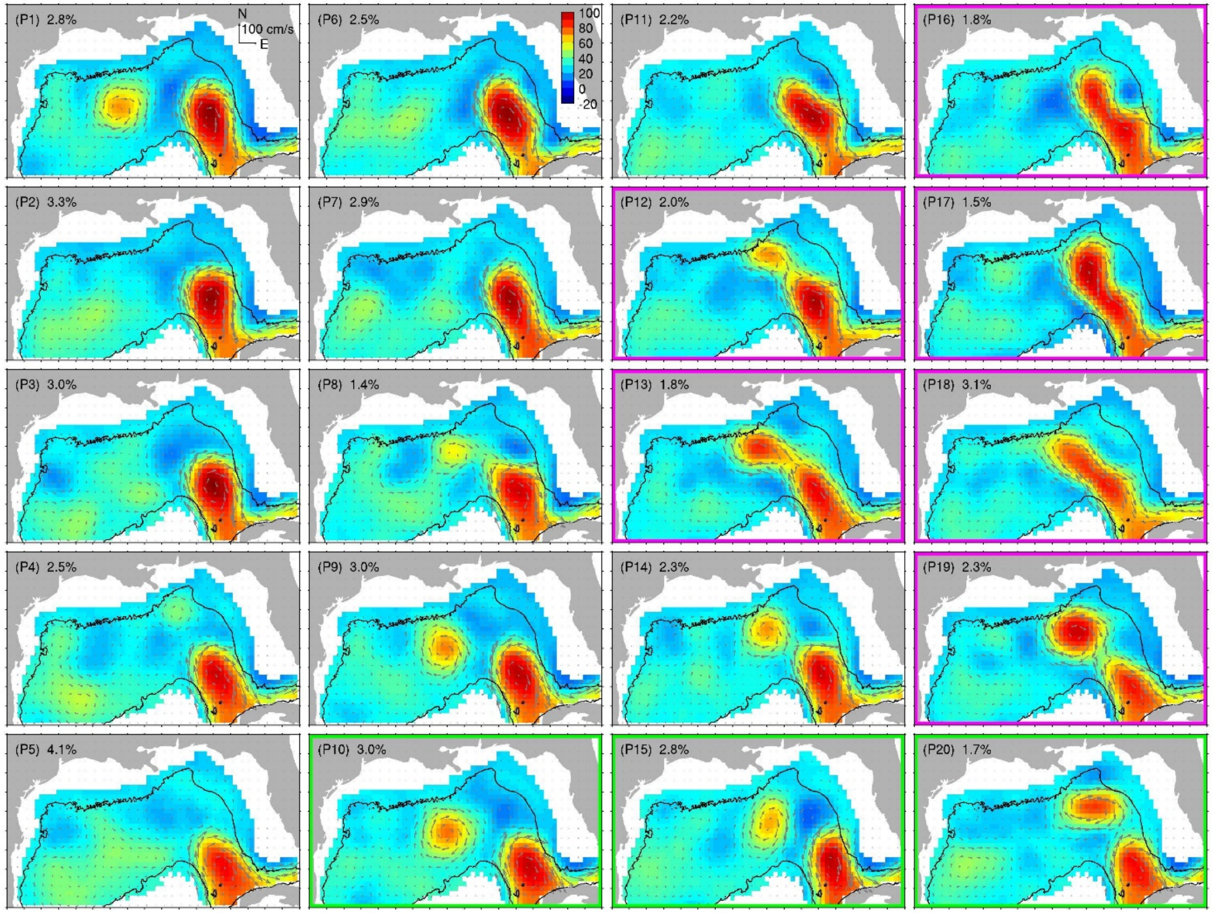


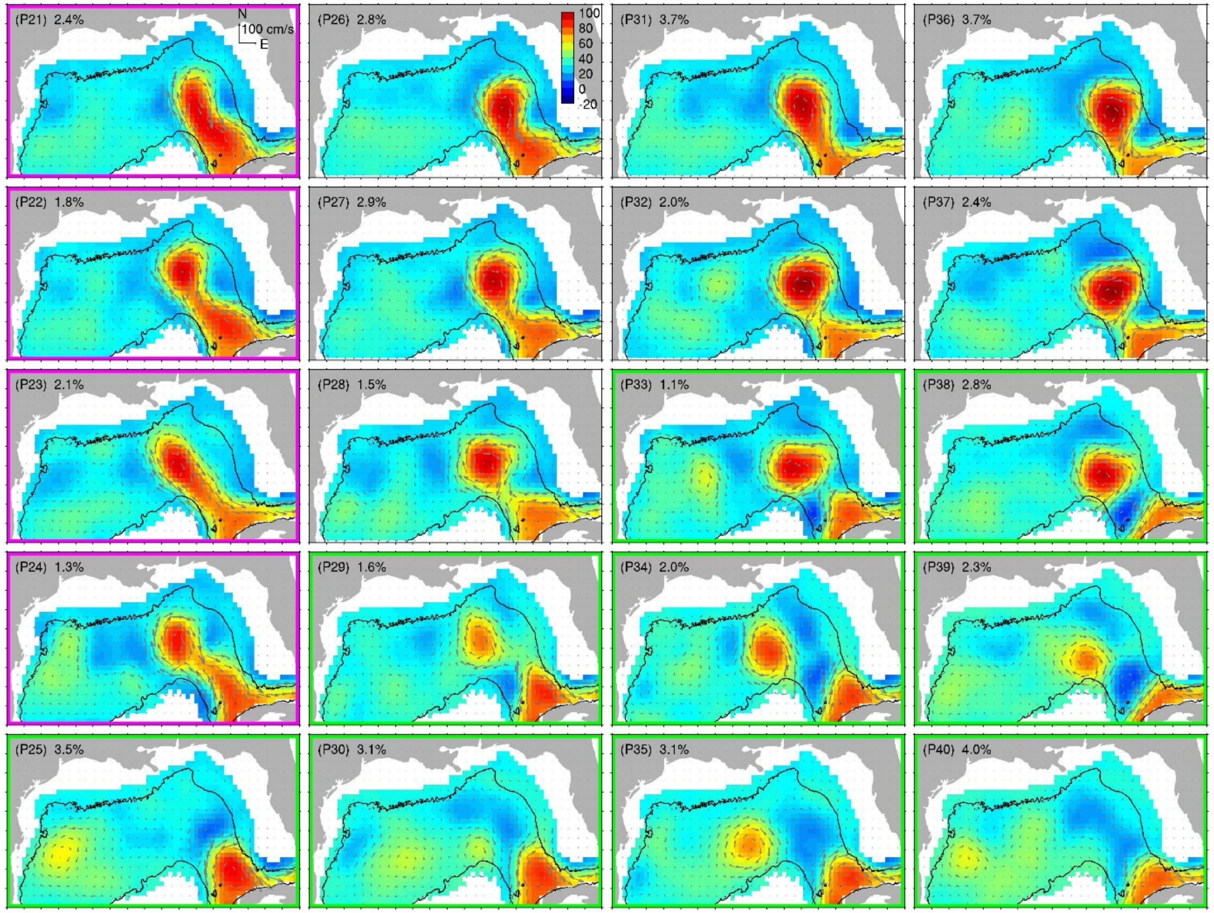
April 2002



Patterns using a 40 neuron SOM applied to SSH and Geostrophic V

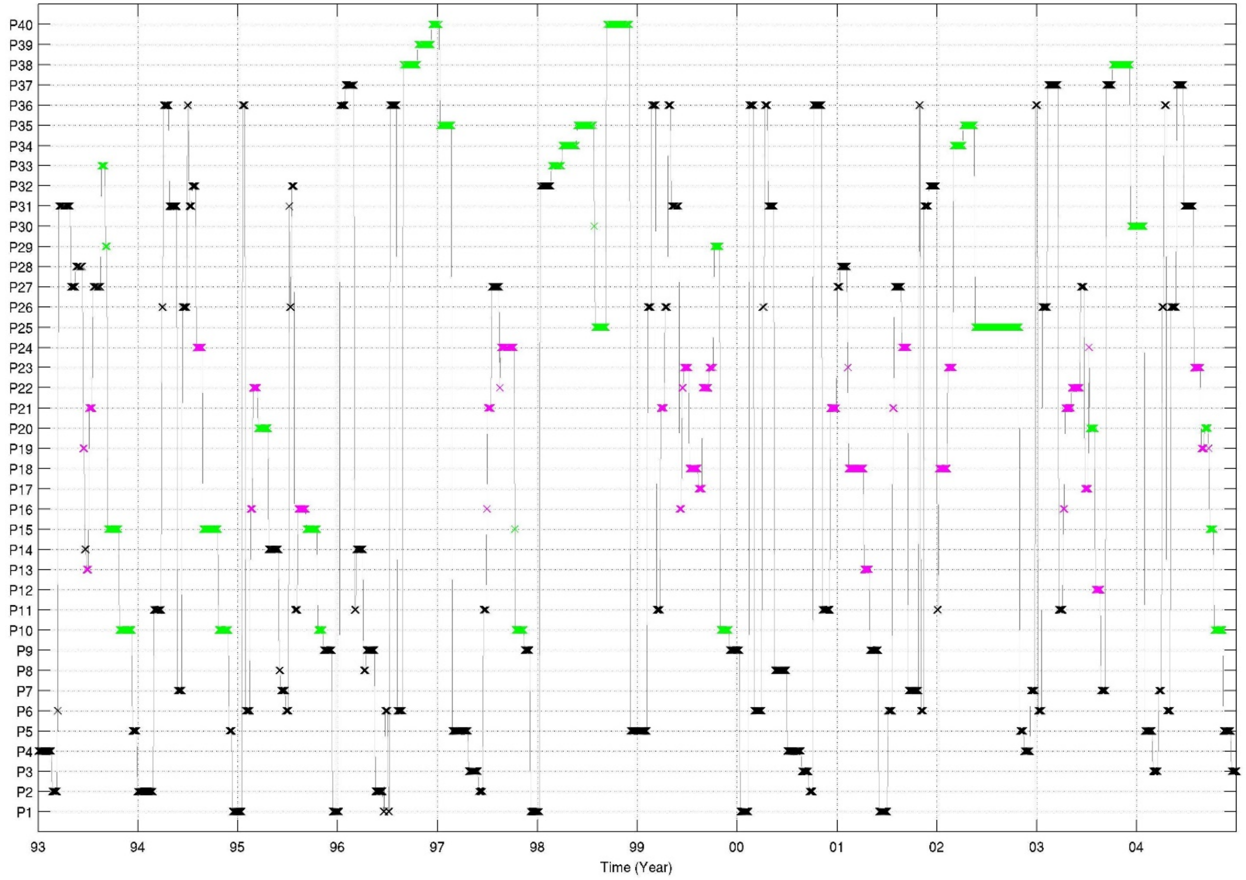
Magenta highlights denote extended patterns; Green highlights denote retracted, pressure point contact patterns

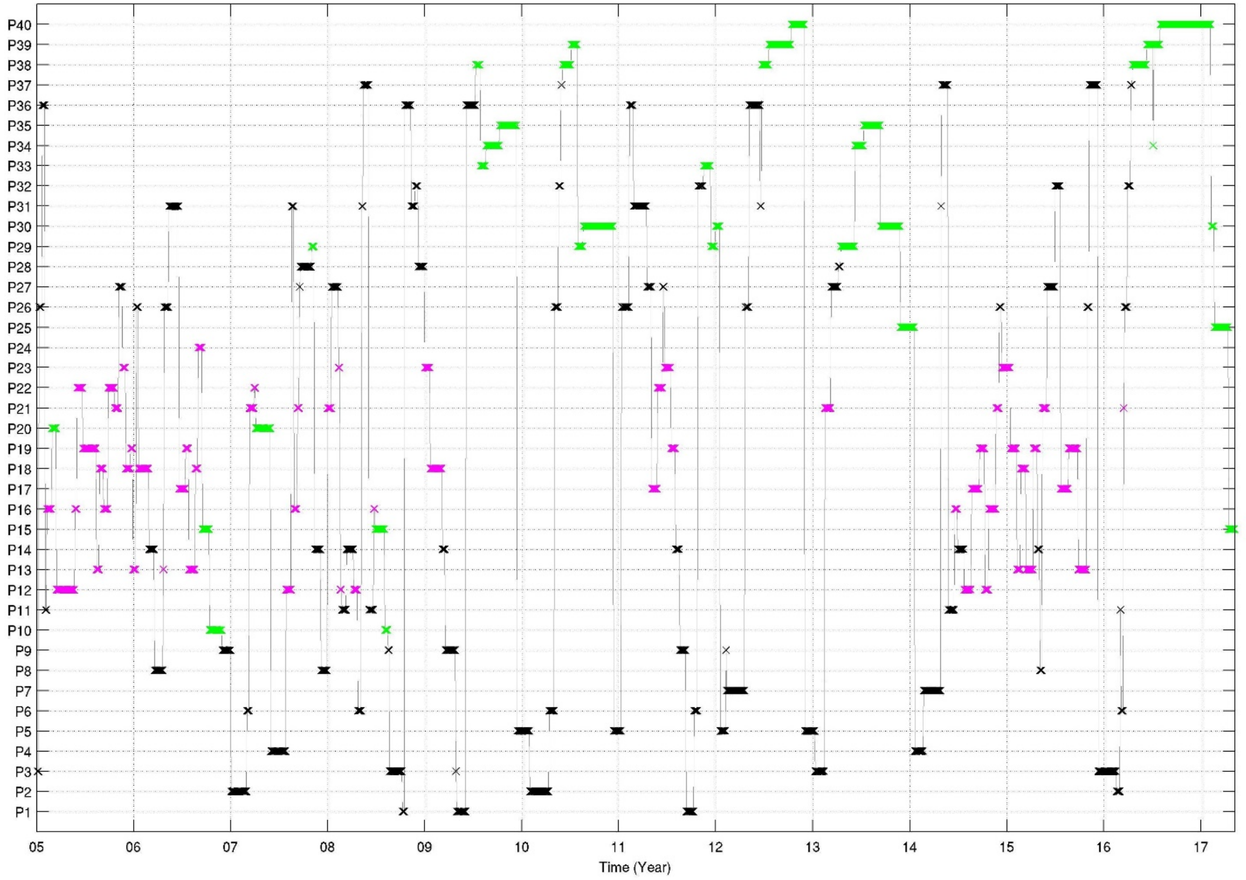




Best Matching Units for the 40 neuron SOM shows the transitions between the various patterns

Green highlighted (pressure point) patterns tend to cluster and last for several months, sometimes longer - why?





The physics argument is as follows:

By setting the entire WFS in an upwelling favorable motion there are rates of work by bottom friction, W_τ, and buoyancy, W_b, by lifting colder, saltier (and hence denser) water onto and across the shelf.

$$W_\tau = \iint \boldsymbol{\tau} \cdot \boldsymbol{V} dA \sim 2.0 \text{ GW.}$$

$$W_B = [\iiint \Delta\rho gz dz dx dy]/\Delta t \sim 1.6 \text{ GW.}$$

Combined, these exceed the rate of work required to move the Loop Current into the GOM against the ambient fluid, W_{LC}.

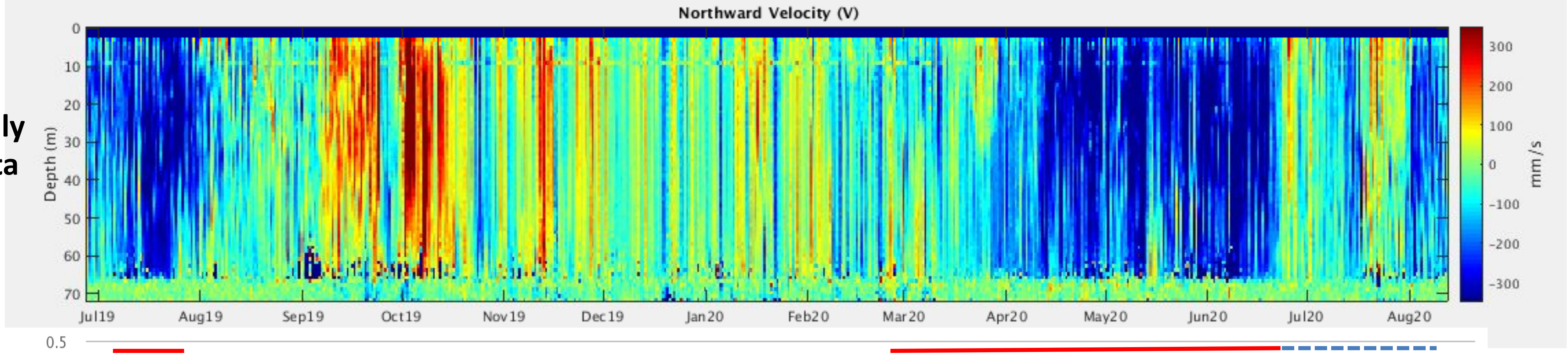
$$W_{LC} = \iiint \boldsymbol{Va} \cdot \nabla P \partial x \partial y \partial z \sim 2.9 \text{ GW.}$$

where *Va* is the rate of advance of the Loop Current into the Gulf of Mexico.

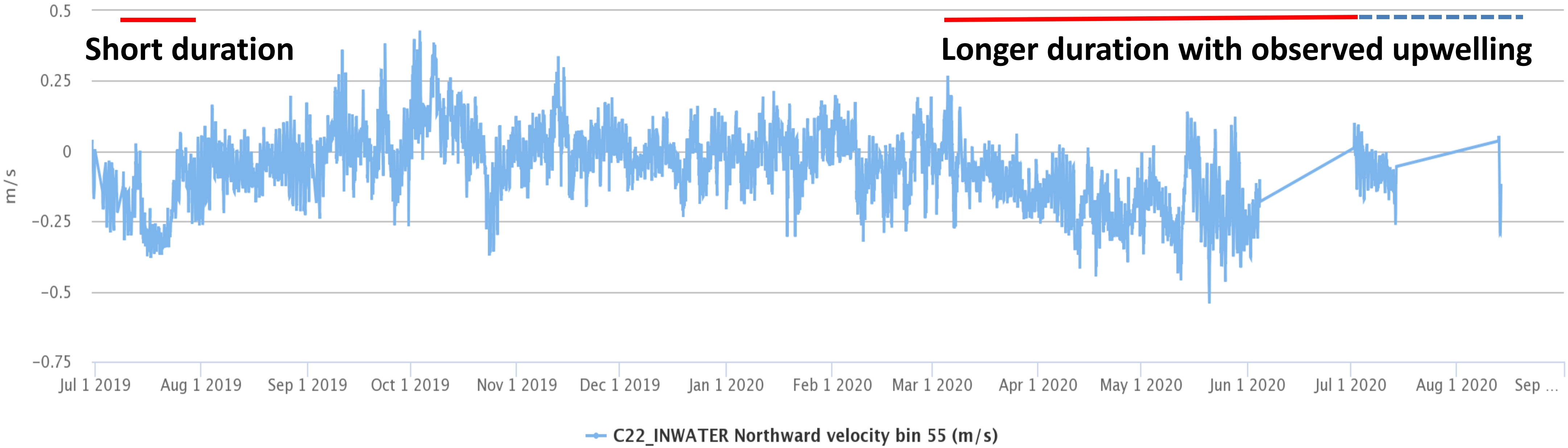
Initial results from the NASEM UGOS Pressure Point Mooring.

COMPS/NASEM UGOS mooring C22, with near real time telemetry of surface met and water column V, was deployed in June 2019 to the northwest of the Dry Tortugas, along with a bottom mounted ADCP in the cut between the Dry Tortugas and Rebecca Shoals. Recovery and redeployment was in August 2020.

Raw internally recorded data

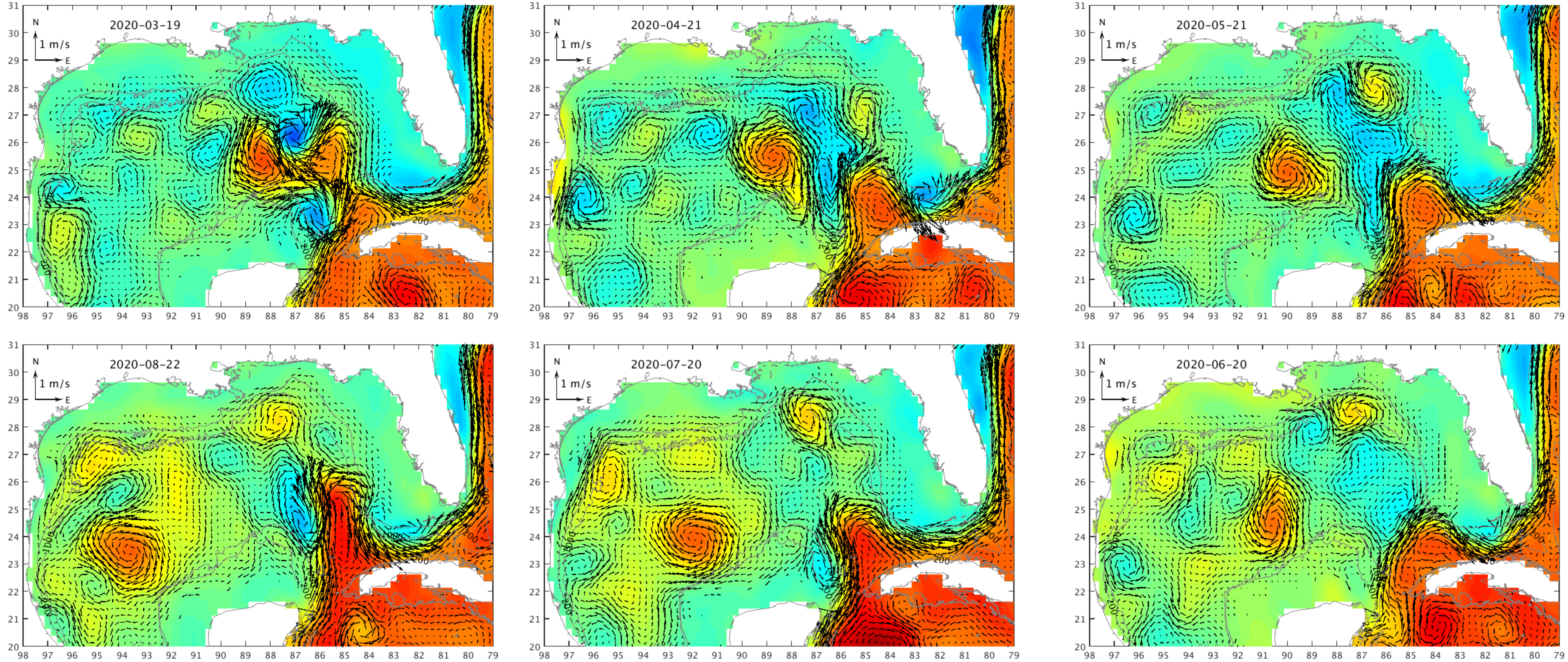


Real time data at ~59m



Altimetry and Geostrophic V Analyses

These show the LC/PP interaction evolution. However, there remain observations that are unaccounted for by altimetry. Thus, in situ observations remain important because of the limited altimetry coverage relative to the complex LC geometry. Snapshots at 1 mo. intervals (clockwise from 3/19/20 to 8/22/20) are given below. The LC was on the PP for about 4 mos before beginning to move back into the GOM.



Concluding Remarks:

- "To be oligotrophic or not to be oligotrophic, that is the question." We owe such insight to Shakespeare.
- WFS water properties are largely controlled by the circulation, which is why the ocean physics are of paramount importance to shelf ecology.
- Examples were provided regarding *K. brevis* red tide and gag grouper recruitment.
- Whether or not new inorganic nutrients are upwelled onto the shelf depends upon Loop Current interactions with the southwest corner of the WFS, referred to as the Pressure Point.
- Prolonged Pressure Point interaction results in upper shelf waters (primarily from the shelf break to 200m depth) being transported across the shelf break and the toward the shore within the bottom Ekman layer.
- This transport pathway explains why the region between the Tampa Bay and Charlotte Harbor estuaries is the epicenter for red tide and also such a productive fisheries region. Such spatial organization to shelf ecology is largely owing to the circulation.
- By virtue of setting the entire WFS in motion, Loop Current contact at the Pressure Point also exerts a control on the Loop Current itself, inhibiting penetration back into the Gulf of Mexico until such time as the Pressure Point contact is broken.
- The WFS is now fortunate to have a real-time Pressure Point Mooring as part of the NASEM Understanding Gulf Ocean Systems (UGOS) program, whose primary science questions include what controls the penetration, eddy shedding and retraction of the Loop Current, questions that have eluded the community for some 48 years after Reid's seminal 1972 paper.
- Given the Pressure Point mooring results from its first year, we are now in a position to speculate on whether or not a major red tide event will occur this year. Using an Occam's razor scheme that has worked well (primarily in hindcast) for 21 out of 26 years for which joint altimetry/red tide data exist (maybe 22 out of 27 if we count the short lived and localized 2019 event), in this year of COVID-19 and plentiful hurricanes, we may be spared a major red tide.

Some CMS-OCG Related Publications:

He, R & R.H. Weisberg (2003). A Loop Current intrusion case study on the West Florida Shelf. *J. Phys. Oceanogr.,* 33, 465-477.

Weisberg, R.H. & R. He (2003). Local and deep-ocean forcing contributions to anomalous water properties on the West Florida Shelf. *J. Geophys. Res.,* 108, C6, 15, doi:10.1029/2002JC001407

Weisberg, R.H., L. Zheng and Y. Liu (2015). Basic tenets for coastal ocean ecosystems monitoring, in *Coastal Ocean Observing Systems*, Y. Liu, H. Kerkering and R.H. Weisberg, eds., Elsevier, London, ISBN: 978-0-12-802022-7, 461pp.

Weisberg, R.H., Zheng, L., Liu, Y., Lembke, C., Lenes, J.M., Walsh, J.J. (2014). Why a red tide was not observed on the West Florida Continental Shelf in 2010, *Harmful Algae*, 38, 119-126, doi:10.1016/j.hal.2014.04.010.

Liu, Y., R.H. Weisberg, R.H., Lenes, J., Zheng, L., Hubbard, K., Walsh, J.J. (2016). Offshore forcing on the west Florida shelf "pressure point" and its upwelling influence on harmful algal blooms, *J. Geophys Res. - Oceans,* doi:10.1002/2016JC011938Y.

Weisberg, R.H., Zheng, L., Liu, Y., Corcoran, A., Lembke, C., Hu, C., Lenes, J. Walsh, J. (2016). Karenia brevis blooms on the west Florida shelf: A comparative study of the robust 2012 bloom and the nearly null 2013 event, *Cont. Shelf Res*., 120, 106-121, doi:10.1016/j.csr.2016.03.011.

Weisberg, R.H., Zheng, L.Y., Liu, Y. (2016). West Florida shelf upwelling: origins and pathways, *J. Geophys. Res. - Oceans*, 121, 5672-5681, doi:10.1002/2015JC011384.

Weisberg, R.H. and Y. Liu (2017), On the Loop current penetration into the Gulf of Mexico, Journal of Geophysical Research: Oceans, 122, 9679-9694, doi: 10.1002/2017JC013330, https://doi.org/10.1002/2017JC013330.

Weisberg, R.H., Y. Liu, C. Lembke, C. Hu, K. Hubbard, M. Garrett (2019), The Coastal Ocean Circulation Influence on the 2018 West Florida Shelf K. brevis Red Tide Bloom, *J. Geophys. Res. - Oceans*, 124, doi:10.1029/2018JC014887.

Publications by my group are accessible at: http://ocgweb.marine.usf.edu/pubs.html