Blooms in the lower Chesapeake Bay: hot spots and hot times

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Photo by Ryan Morse

Lower James River

- Salty triblets
- Over the last 20 years, bloom forming dinoflagellates have become increasingly abundant in the tidal rivers of lower Chesapeake Bay.[2]
- They have been linked with eutrophication and anthropogenic perturbations
- Specific species occur with regular seasonality (hot times), yet nutrient concentrations and physical parameters are highly variable on timescales ranging from minutes to years.
- Most often sampling of blooms only occurs after a bloom is visibly discoloring the water so we can only speculate as to the cause of bloom initiation

2. Burchardt and Marshall 2004,

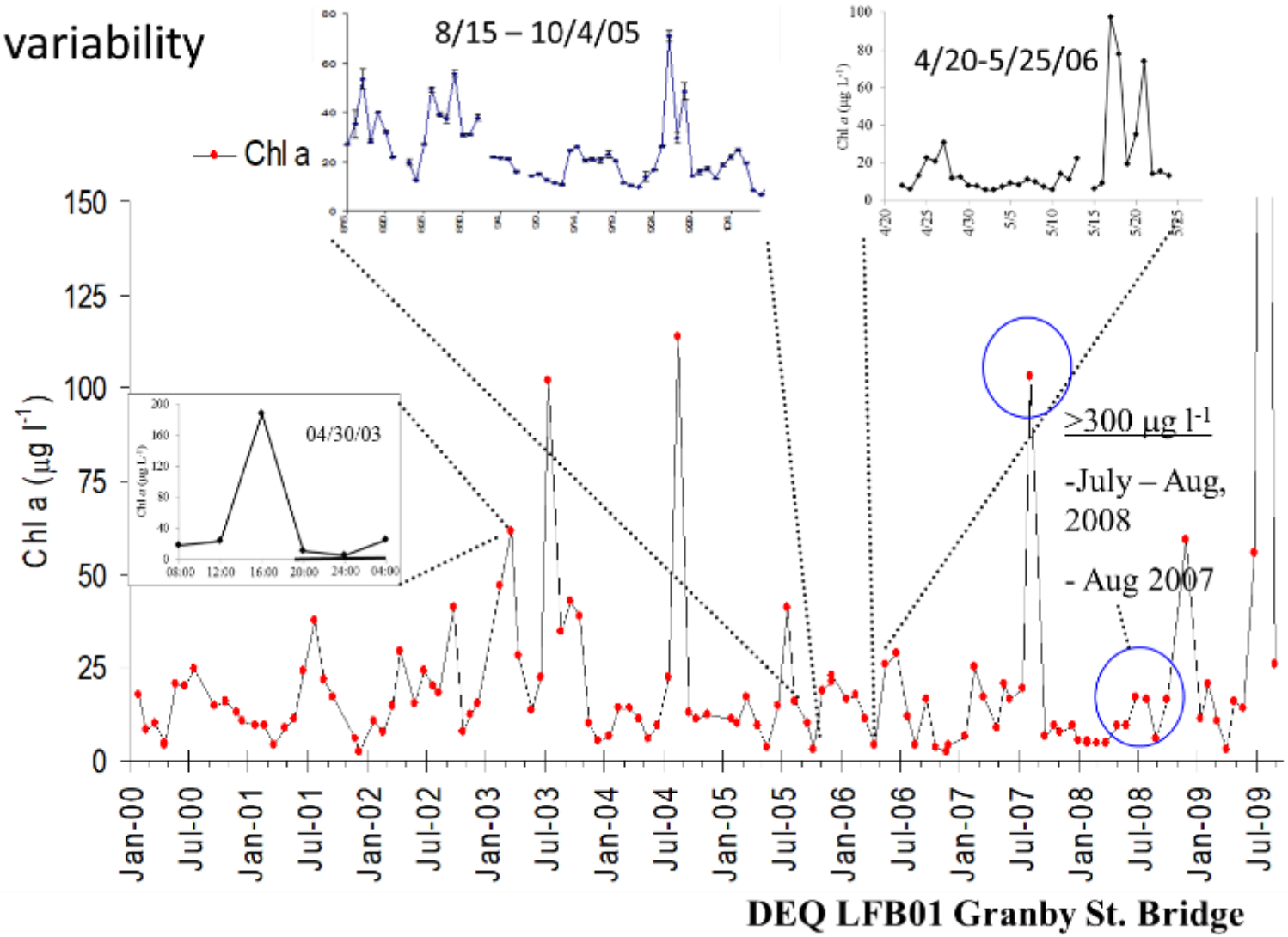
Blooms can be spectacular

Cells can reach densities
10’s of thousands per mL

Take home points

- Initiation of blooms in hotspots followed by “incubation” and transport
- Sediment connection is key
- Coastal flooding inputs can be substantial but are currently unquantified - climate change link

Timescales of variability



Potentially harmful blooms of *Cochlodinium polykrikoides* and *Alexandrium monilatum* in Virginia waters from 1994 – 2014.

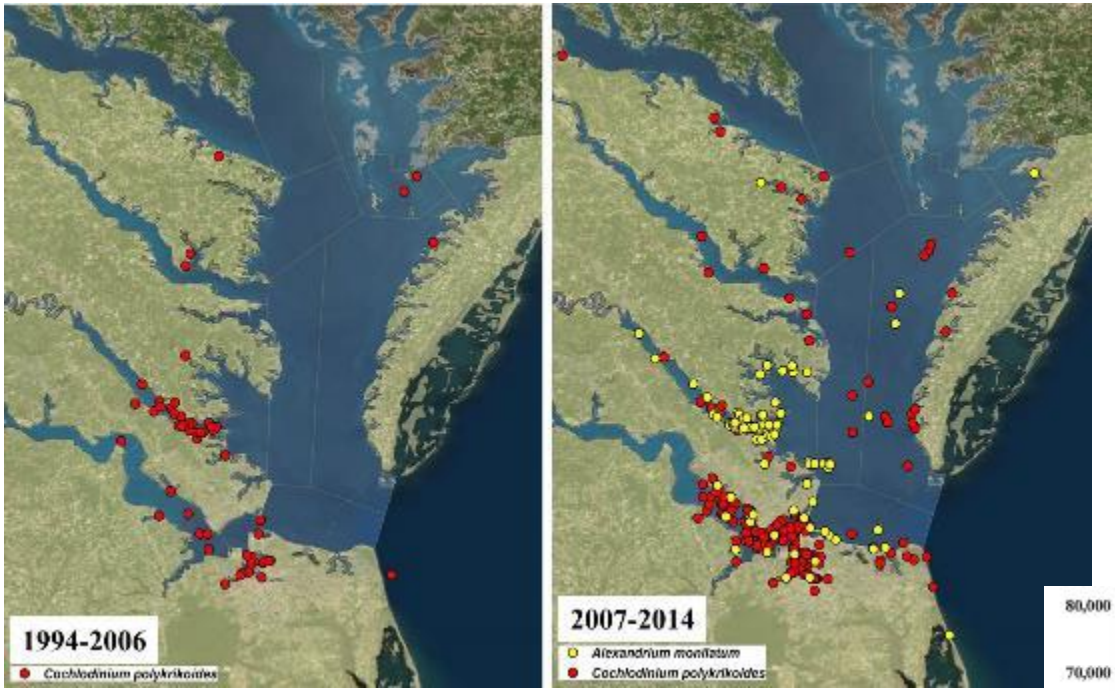
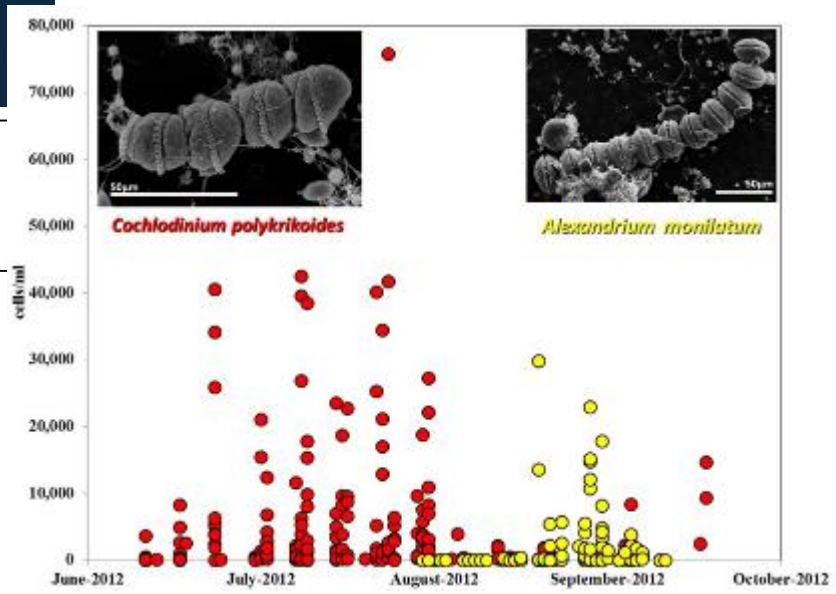


Figure 1. Maps of observed *Cochlodinium polykrikoides* blooms from 1994-1996 (left panel) and *C. polykrikoides* (red circles) and *Alexandrium monilatum* (yellow circles) blooms from 2007-2014.

In recent years, *Alexandrium* blooms have emerged after *Cochlodinium* as temperatures cool.



From Todd Egerton

The Virginian-Pilot

This algae caused a blue stir

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each-based
nance unit

sers, dozens of
panies face scrutiny
state regulators

Kleiner
n-Pilot

e has recommended
ily banning Virginia
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, several of its execu-
affiliated companies

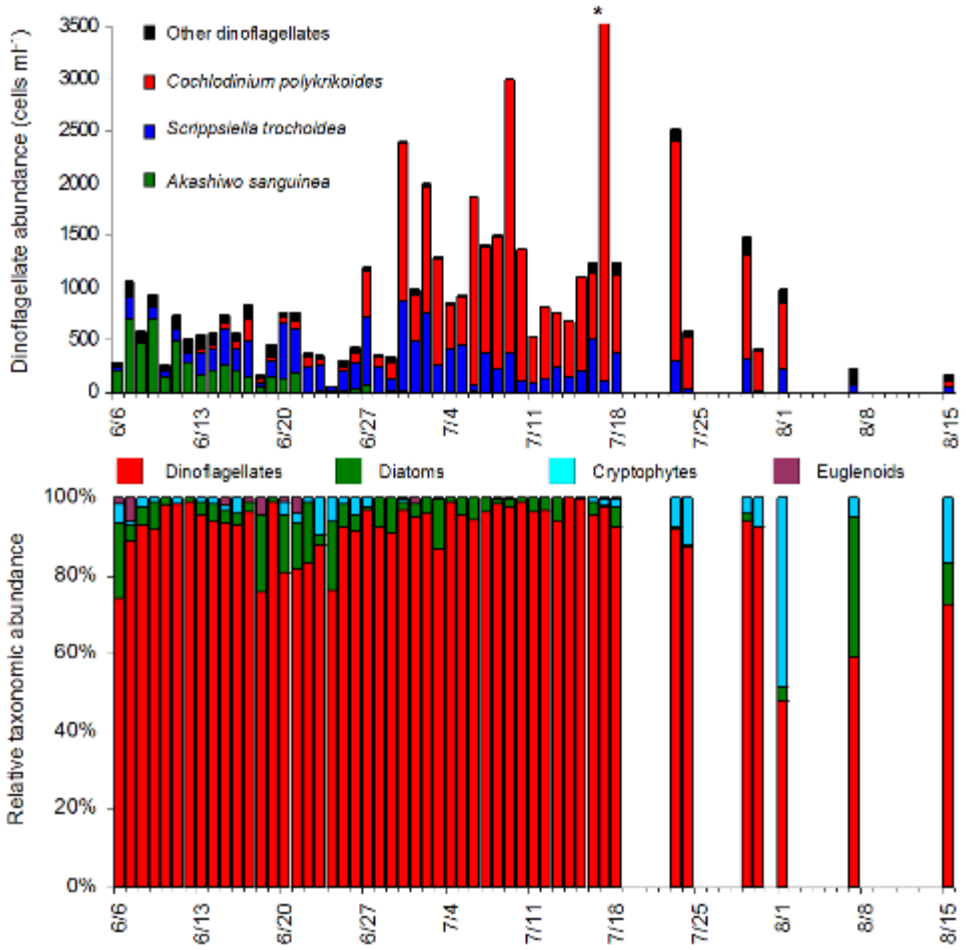
ALEXANDRIUM MONILATUM: COURTESY OF TODD EGERTON, ADJUNCT PROFESSOR, DEPARTMENT OF BIOLOGICAL SCIENCES, OLD DOMINION UNIVERSITY
SANDBRIDGE PHOTO: L. TODD SPENCER | THE VIRGINIAN-PILOT

LAST WEEK'S GLOWING WATER
has provided lots of data fo
ODU researchers interested i
the bioluminescent organisms

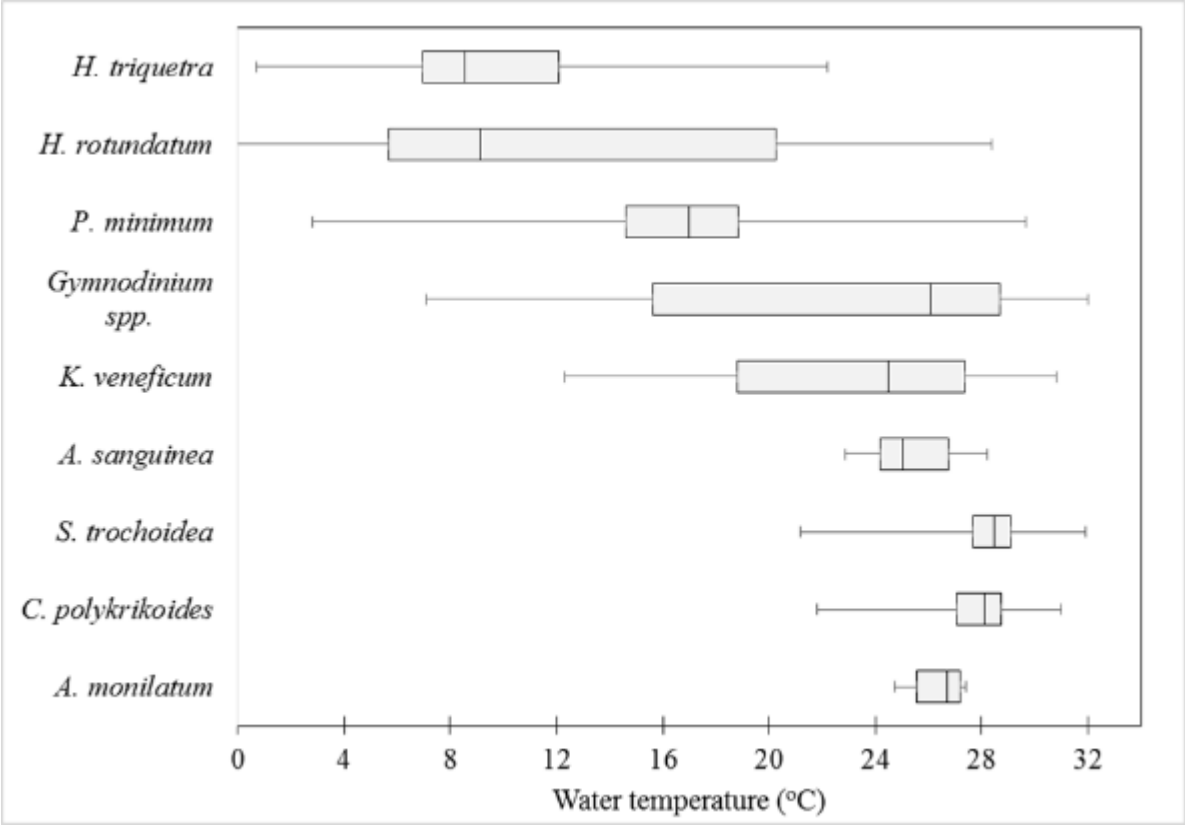
"Now I feel it's in the hands of God, whom I worship, and I'll be prepared for anything that

the culp
Alexandrium
monilatum

- There are many bloom-forming dinoflagellates in the lower James River
- But dinoflagellates are usually the dominant algal taxa



Seasonality of blooms



Mulholland et al. 2017

In general, water temperature plays a role in which species dominates the community

Conceptual model of a bloom

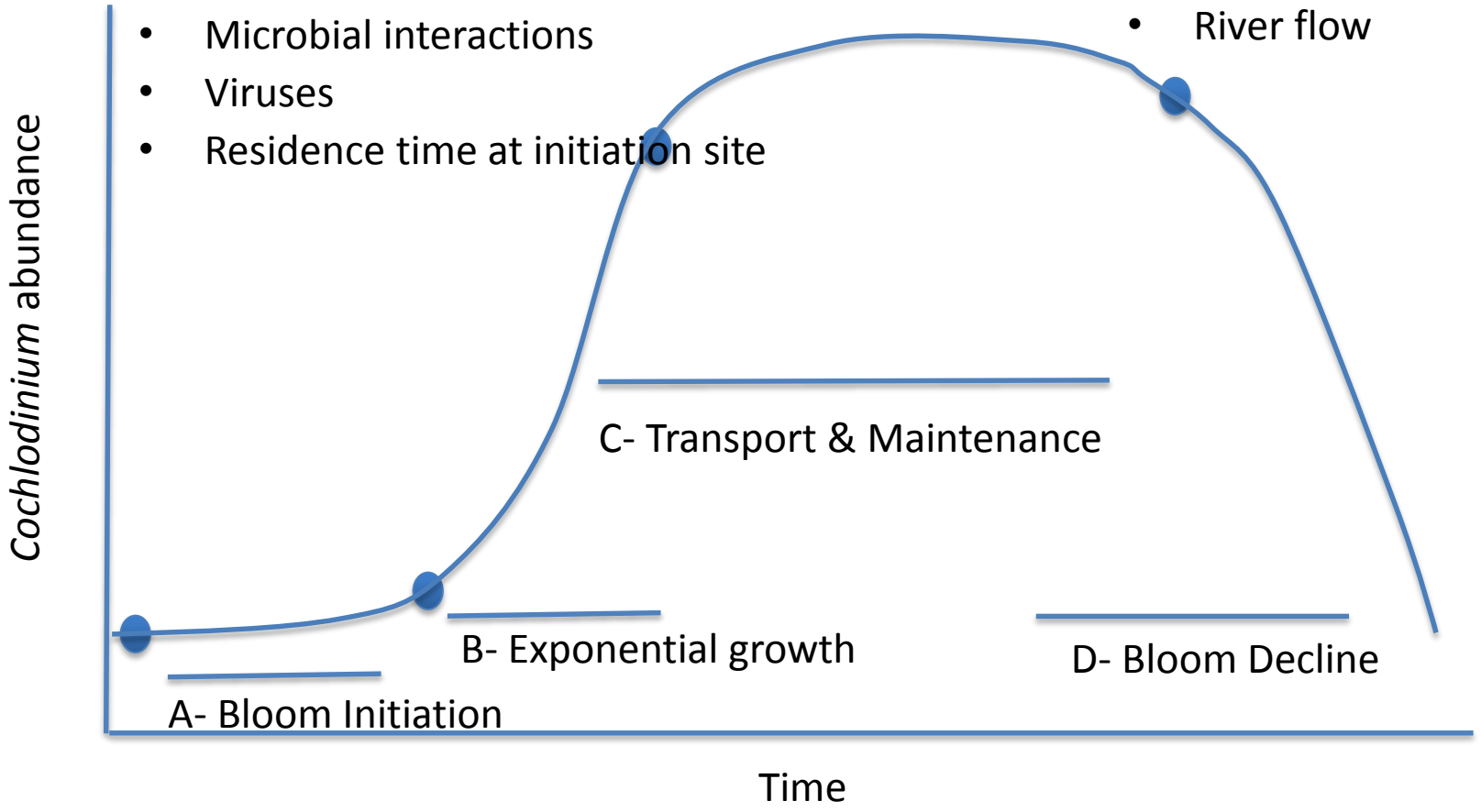
Batch culture analogy

Balance of population growth vs. loss

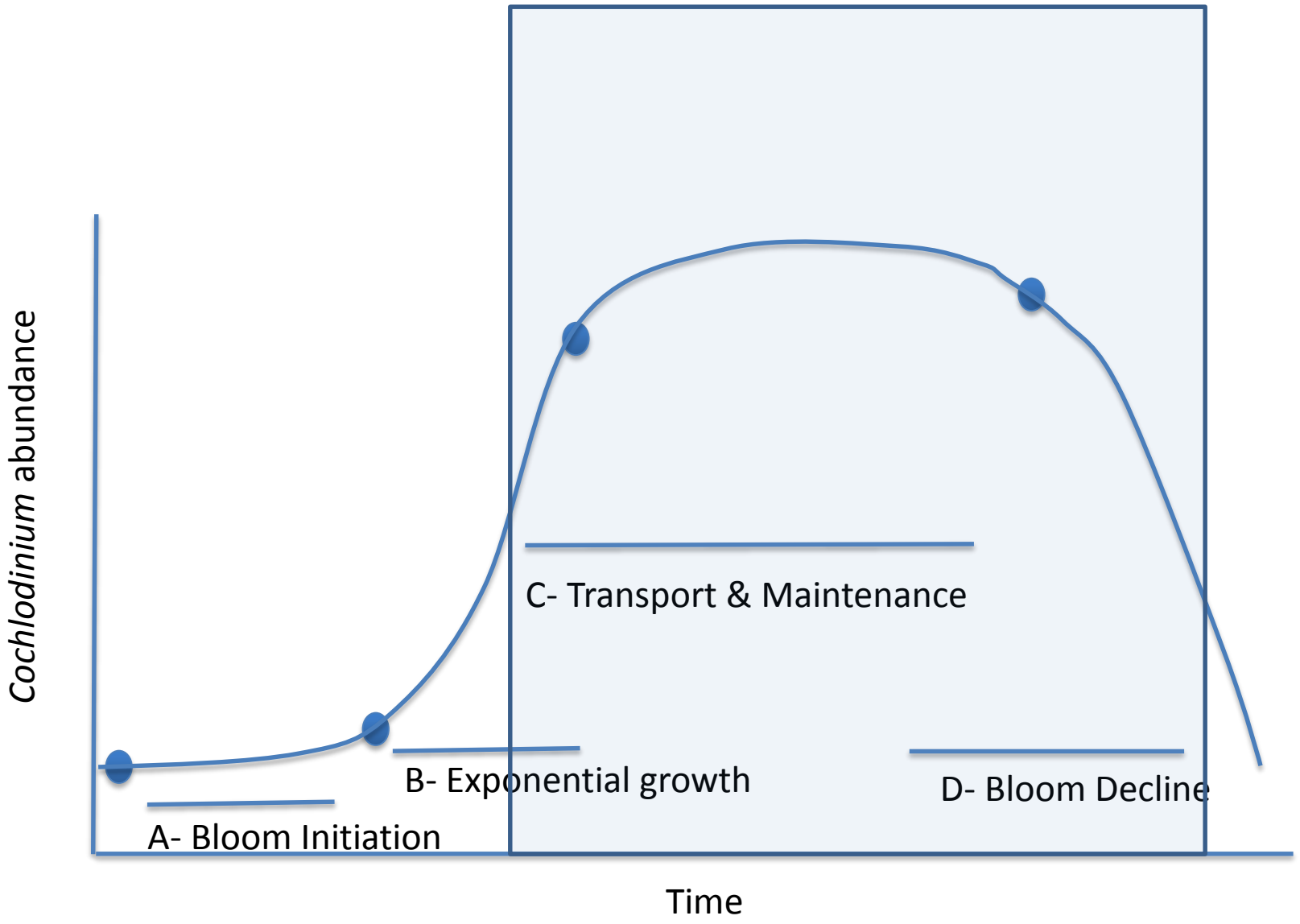
- Nutrients
- Light
- Mixing
- Grazing
- Microbial interactions
- Viruses
- Residence time at initiation site

Population transport

- Tidal advection
- Estuarine circulation
- Wind driven
- River flow

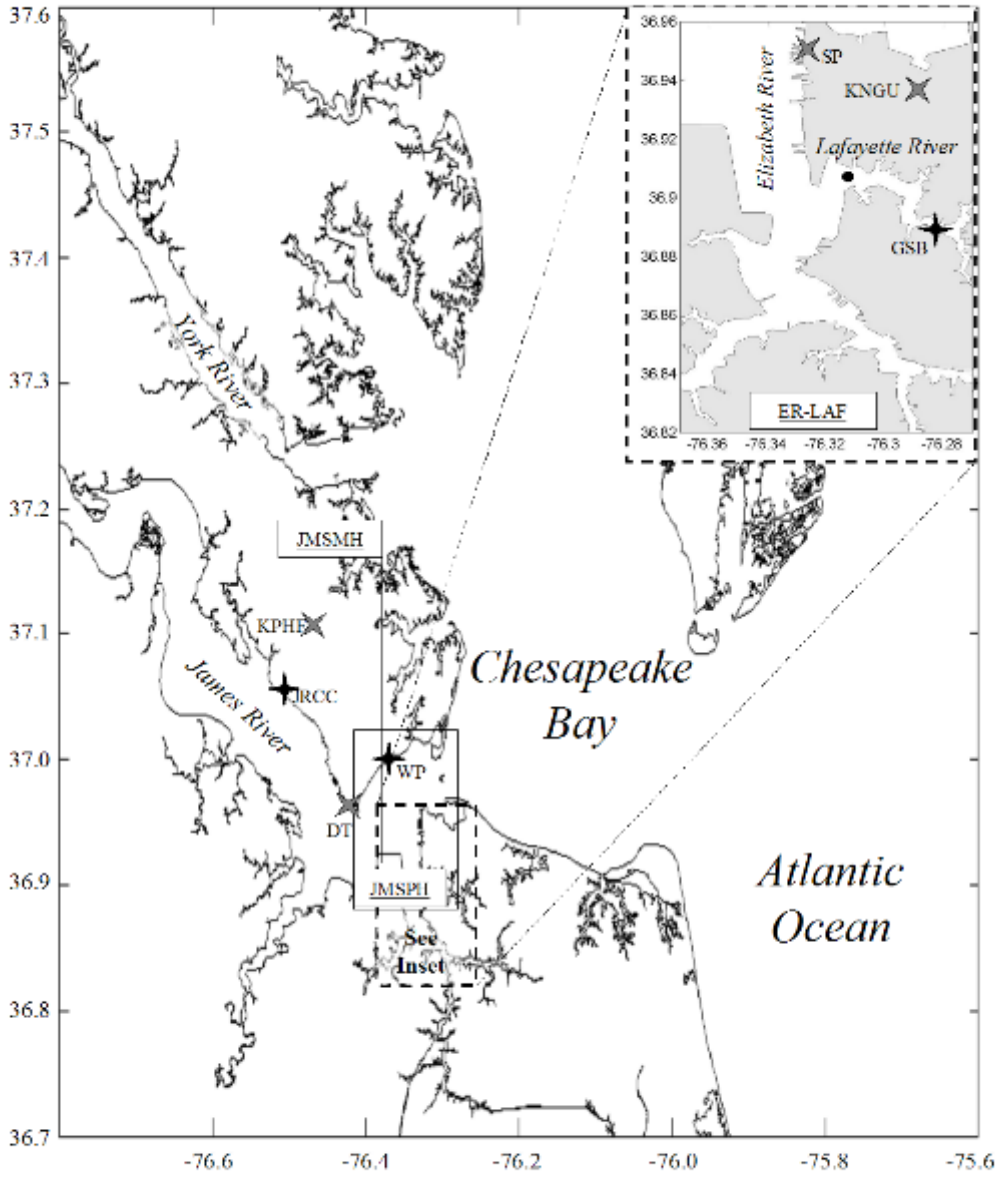


When most studies of blooms are done
Why? Because that's when they are most visible.



Unsatisfying because:

- Conditions during a bloom are different than those during bloom initiation
  - Organic matter accumulates during blooms (Boneillo & Mulholland 2009)
- Blooms are patchy and move around
- **Need to find sites of bloom initiation – reverse physical oceanography**
- Tapped into HRSD/VECOS dataflow
  - Weekly cruises April-Sept with continuous underway sampling using a YSI 6600 sonde (Chl *a*, salinity, temperature, DO, pH)



HRSD DATAFLOW

- *JMSMH*
- *JMSPH*
- *ER-LAF*

VECOS YSI stations

- *Wythe Pt.*
- *JRCC*

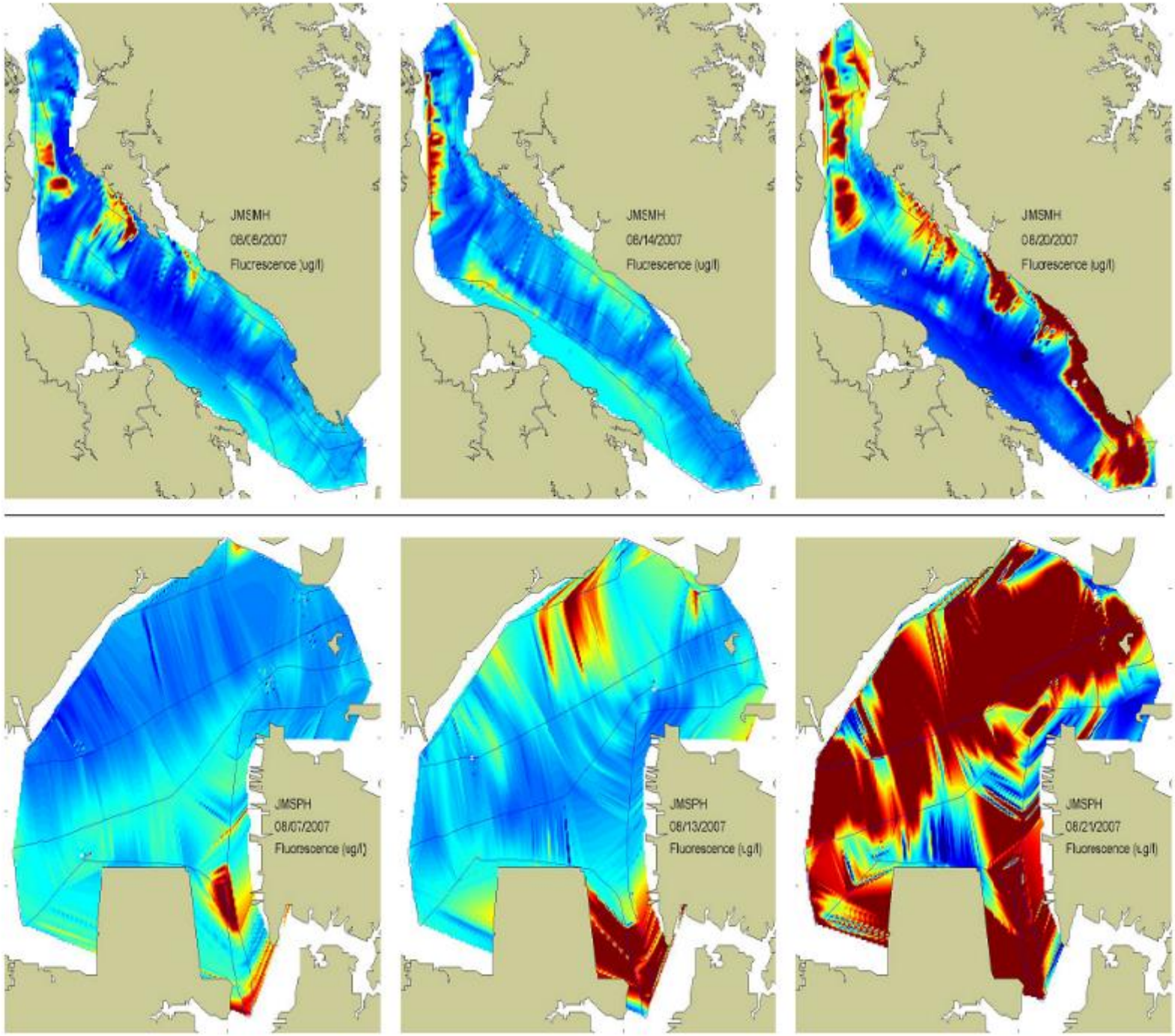
NOAA PORTS

- *Sewell's Pt.*
- *Dominion Terminal*

NAS Norfolk (KNGU)

Lafayette R. timeseries GSB

VIMS HEM3-D dye release simulation


JMSMH
08/06/2007
Fluorescence (ug/l)
JMSMH
08/14/2007
Fluorescence (ug/l)
JMSMH
08/20/2007
Fluorescence (ug/l)
JMSPH
08/07/2007
Fluorescence (ug/l)
JMSPH
08/13/2007
Fluorescence (ug/l)
JMSPH
08/21/2007
Fluorescence (ug/l)
30
25
20
15
10
5
Chlorophyll a (µg l-1)

Found transport mechanism

- Found blooms are transported from areas where they initiate throughout the lower estuary via estuarine circulation (Morse et al. 2011) (HRSD)

Surface_2007 ER initiation.avi

- Dye release simulations using VIMS-HEM3-D model for 2007 data

Lafayette River

- Sub-estuary of Ches Bay
- Watershed entirely in the city of Norfolk
- Freshwater inputs are groundwater and rain

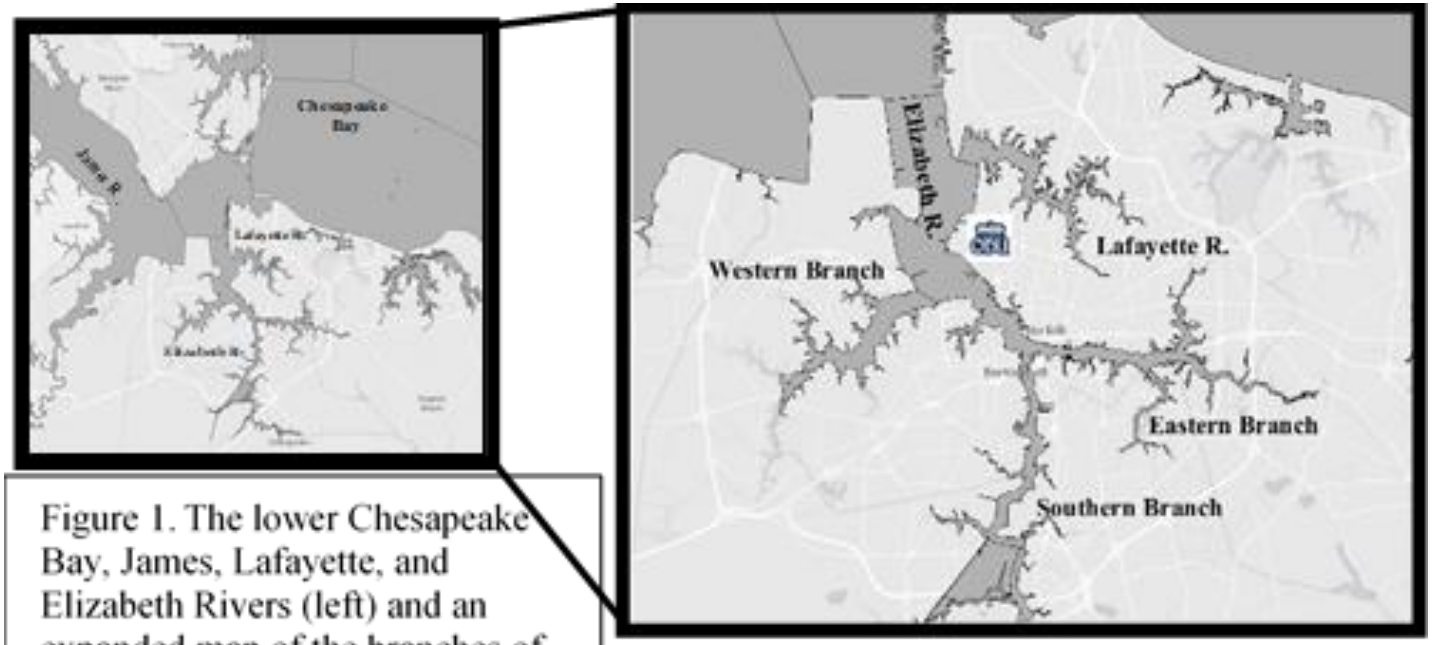
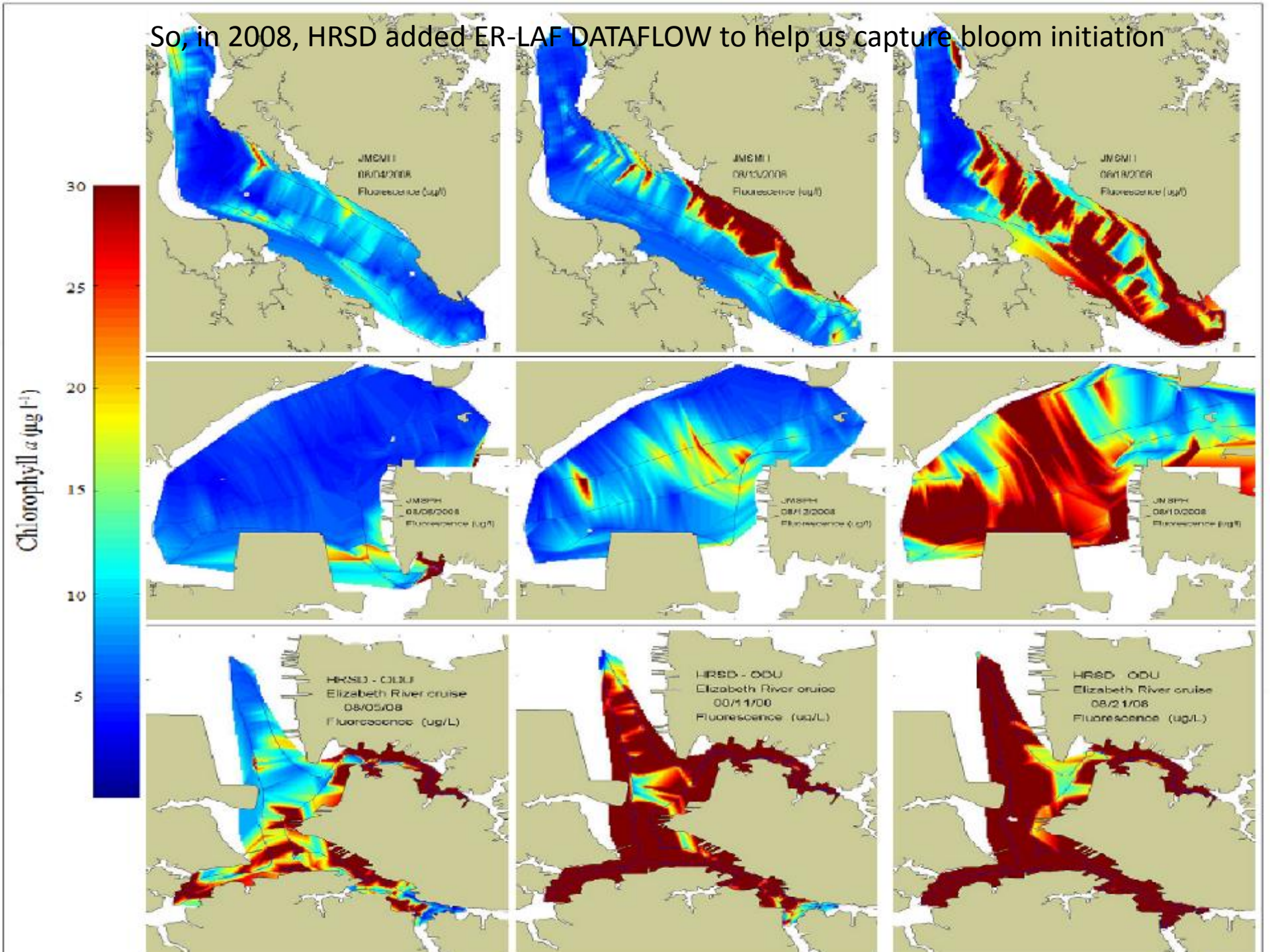
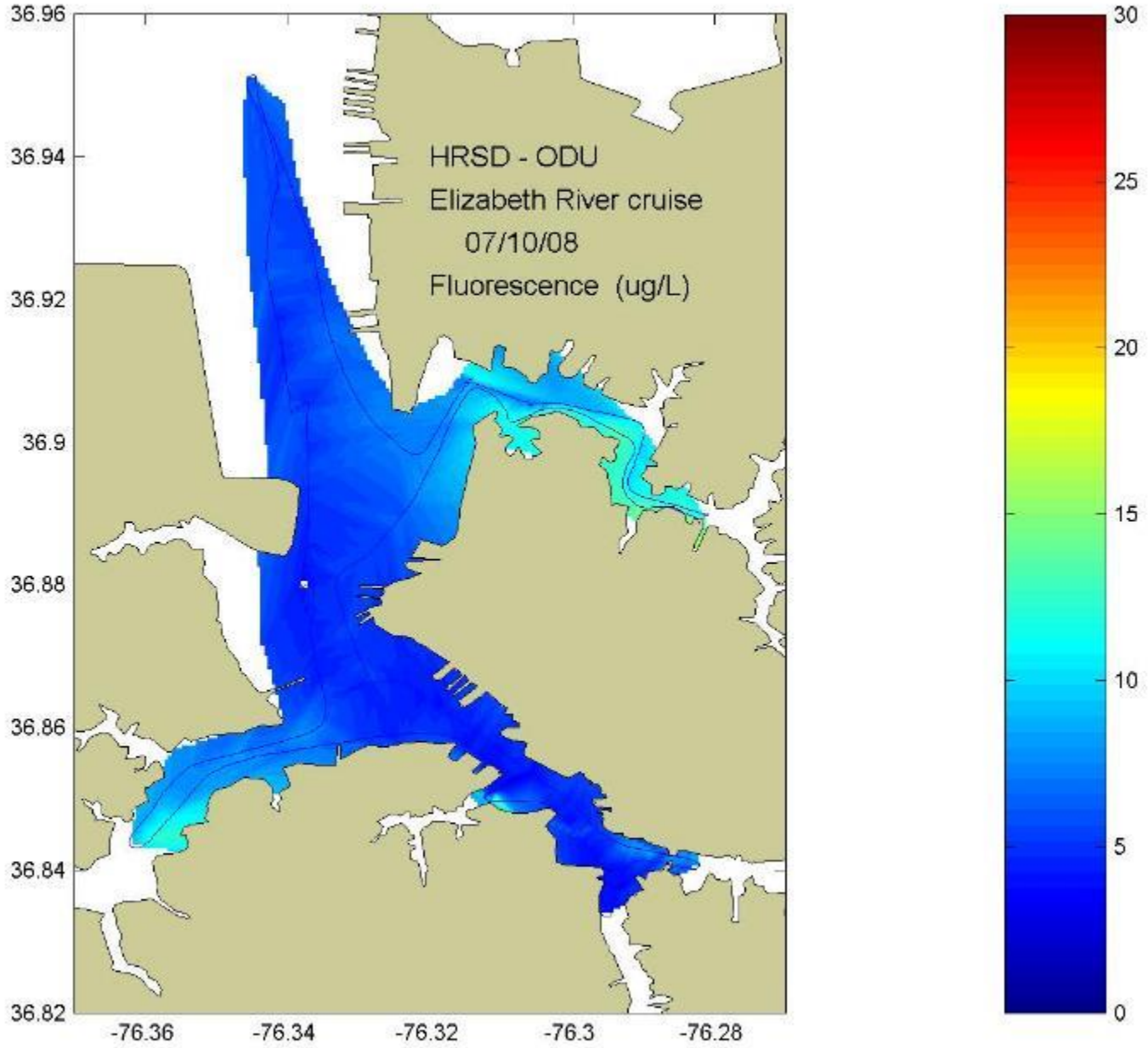


Figure 1. The lower Chesapeake Bay, James, Lafayette, and Elizabeth Rivers (left) and an expanded map of the branches of the Elizabeth River (right).

So, in 2008, HRSD added ER-LAF DATAFLOW to help us capture bloom initiation




HRSD - ODU
Elizabeth River cruise
07/10/08
Fluorescence (ug/L)
36.96
36.94
36.92
36.9
36.88
36.86
36.84
36.82
-76.36
-76.34
-76.32
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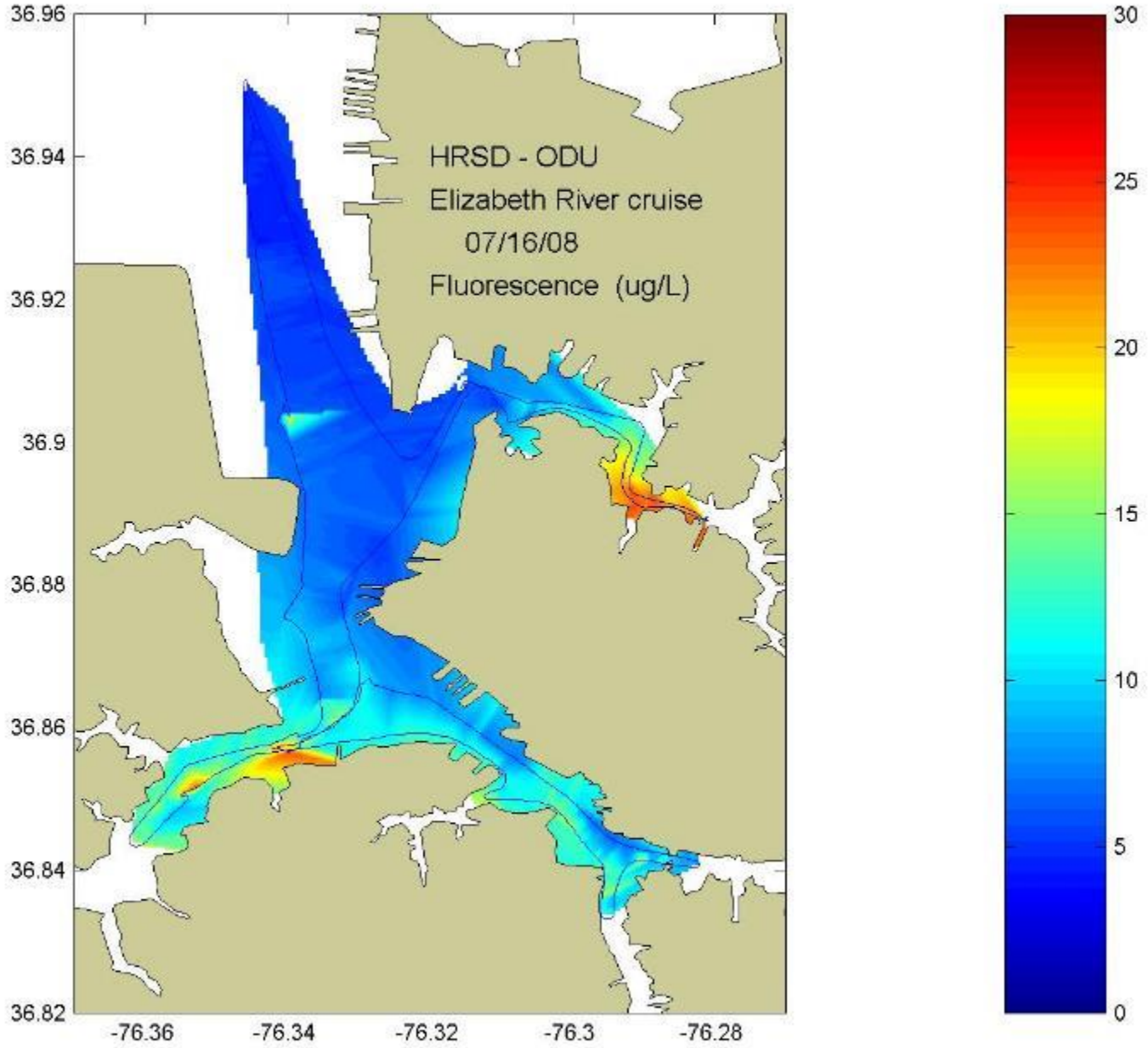
HRSD - ODU
Elizabeth River cruise
07/16/08
Fluorescence (ug/L)
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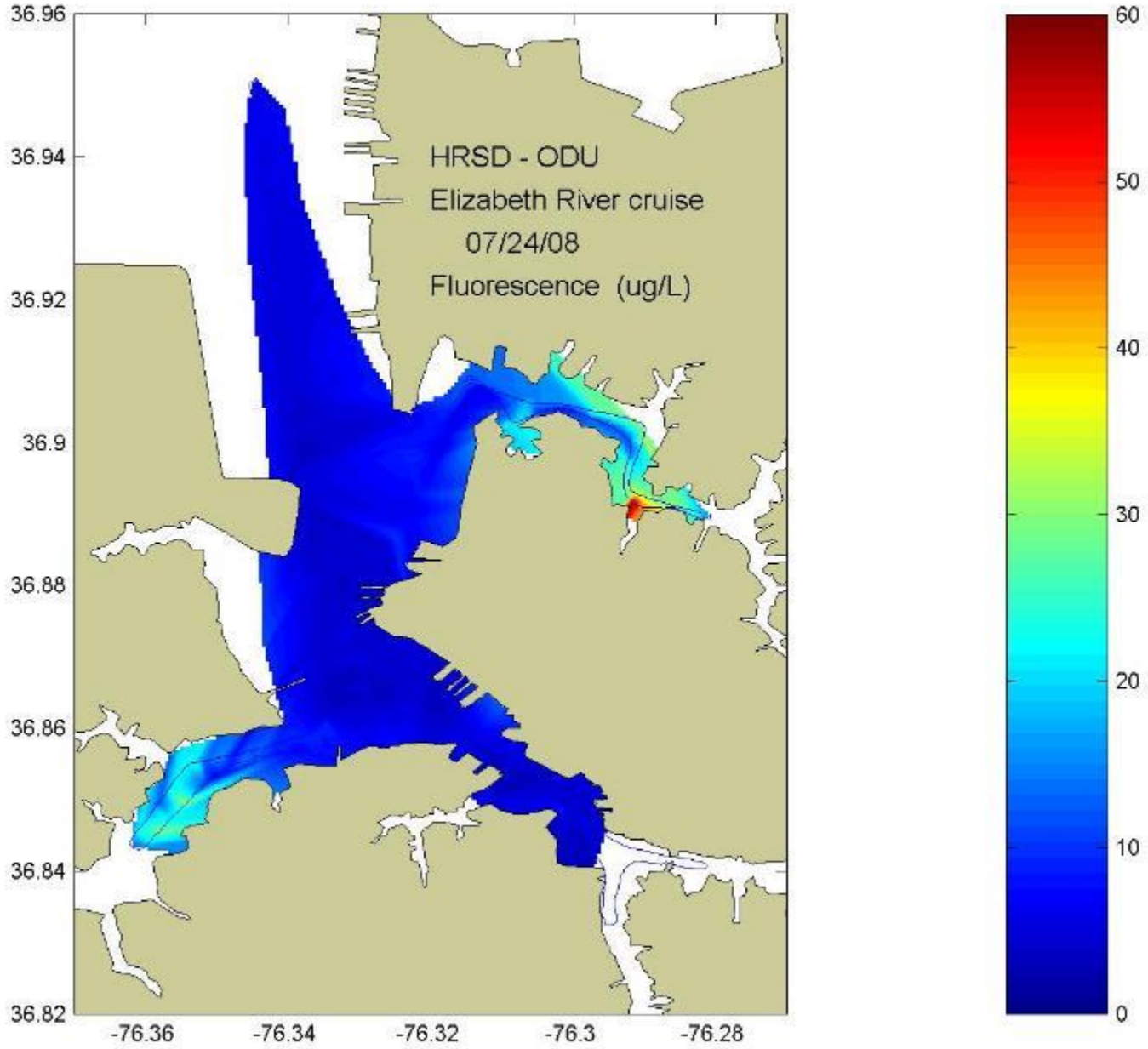
HRSD - ODU
Elizabeth River cruise
07/24/08
Fluorescence (ug/L)
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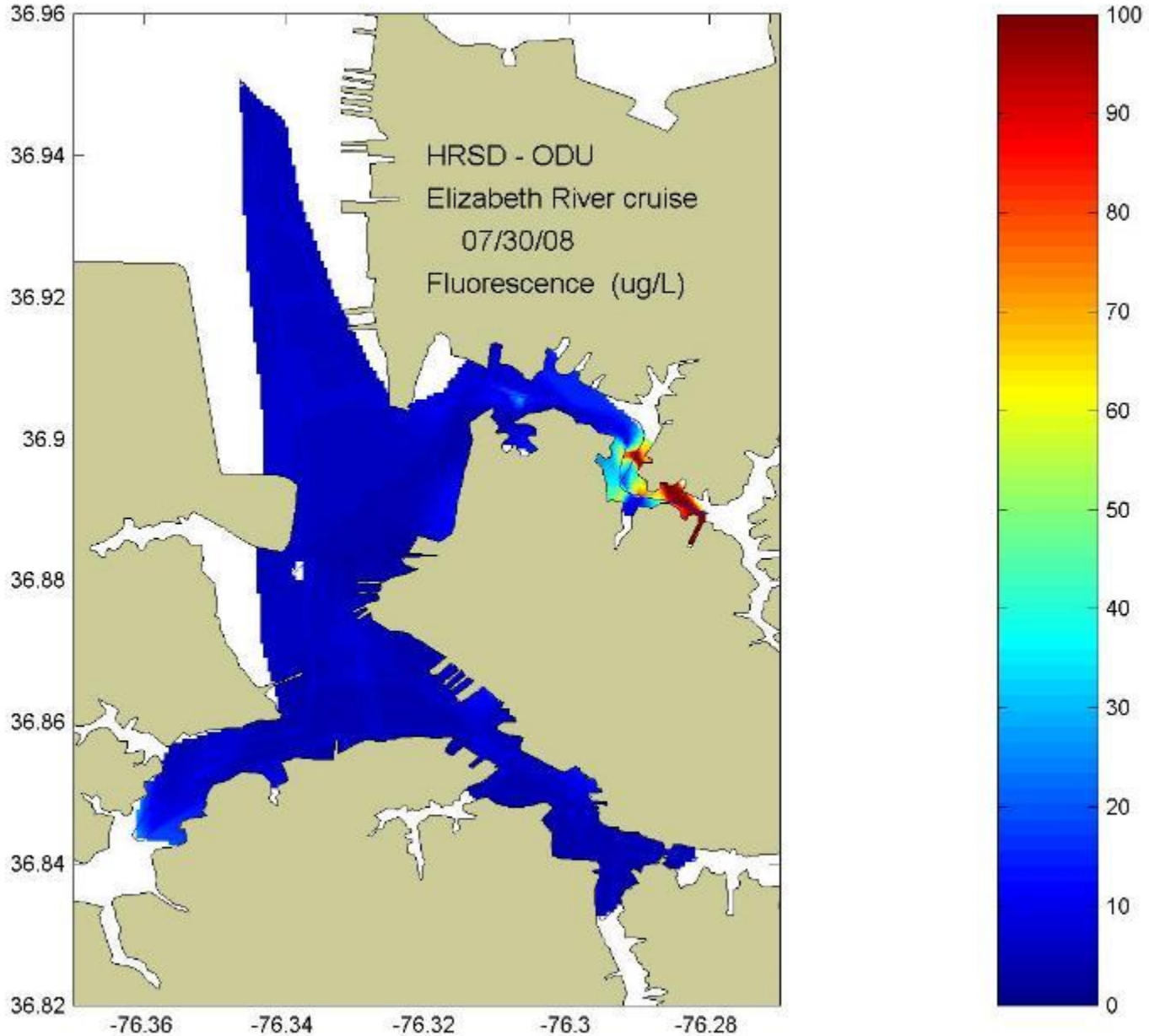
HRSD - ODU
Elizabeth River cruise
07/30/08
Fluorescence (ug/L)
36.96
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36.84
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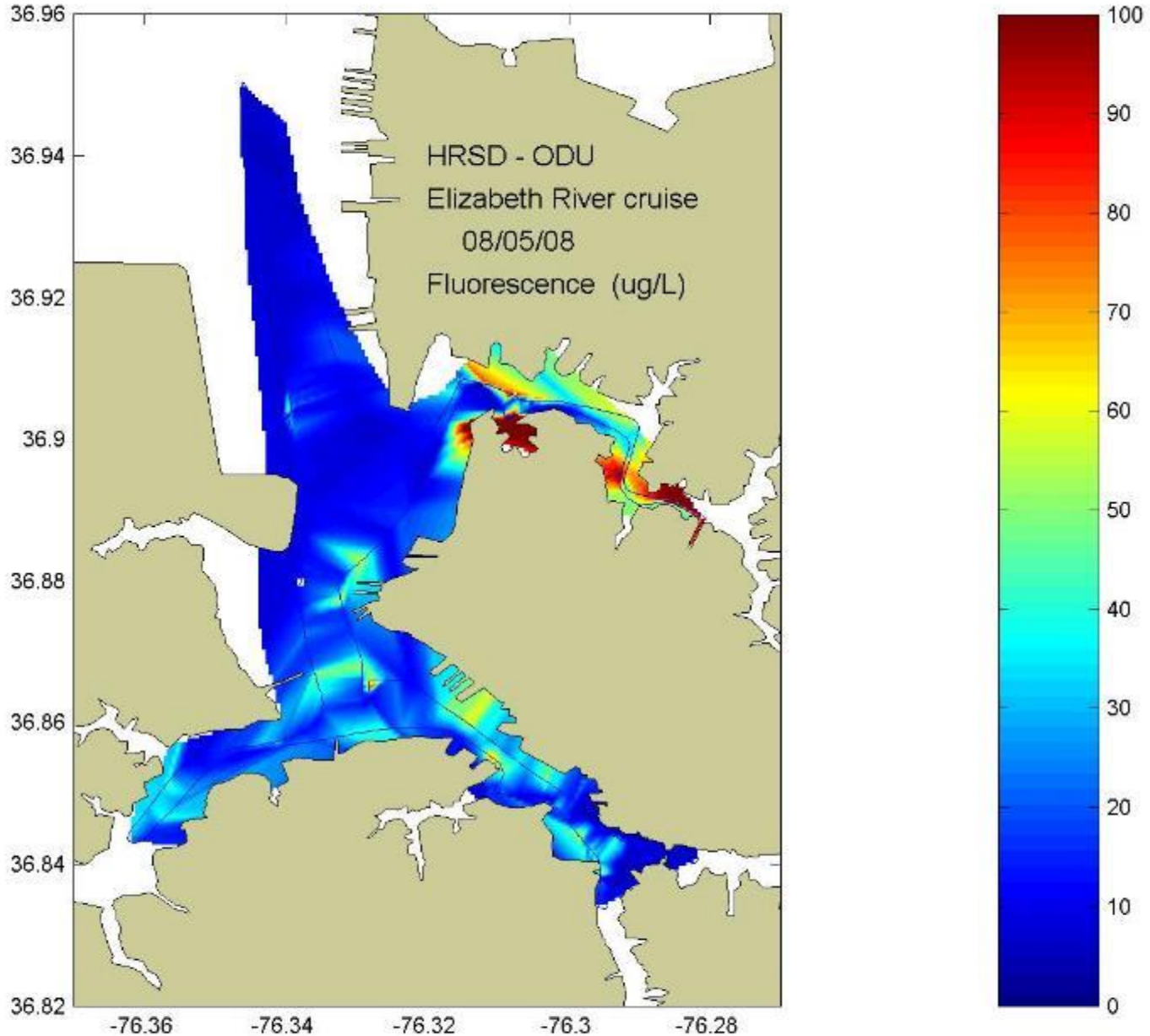
HRSD - ODU
Elizabeth River cruise
08/05/08
Fluorescence (ug/L)
36.96
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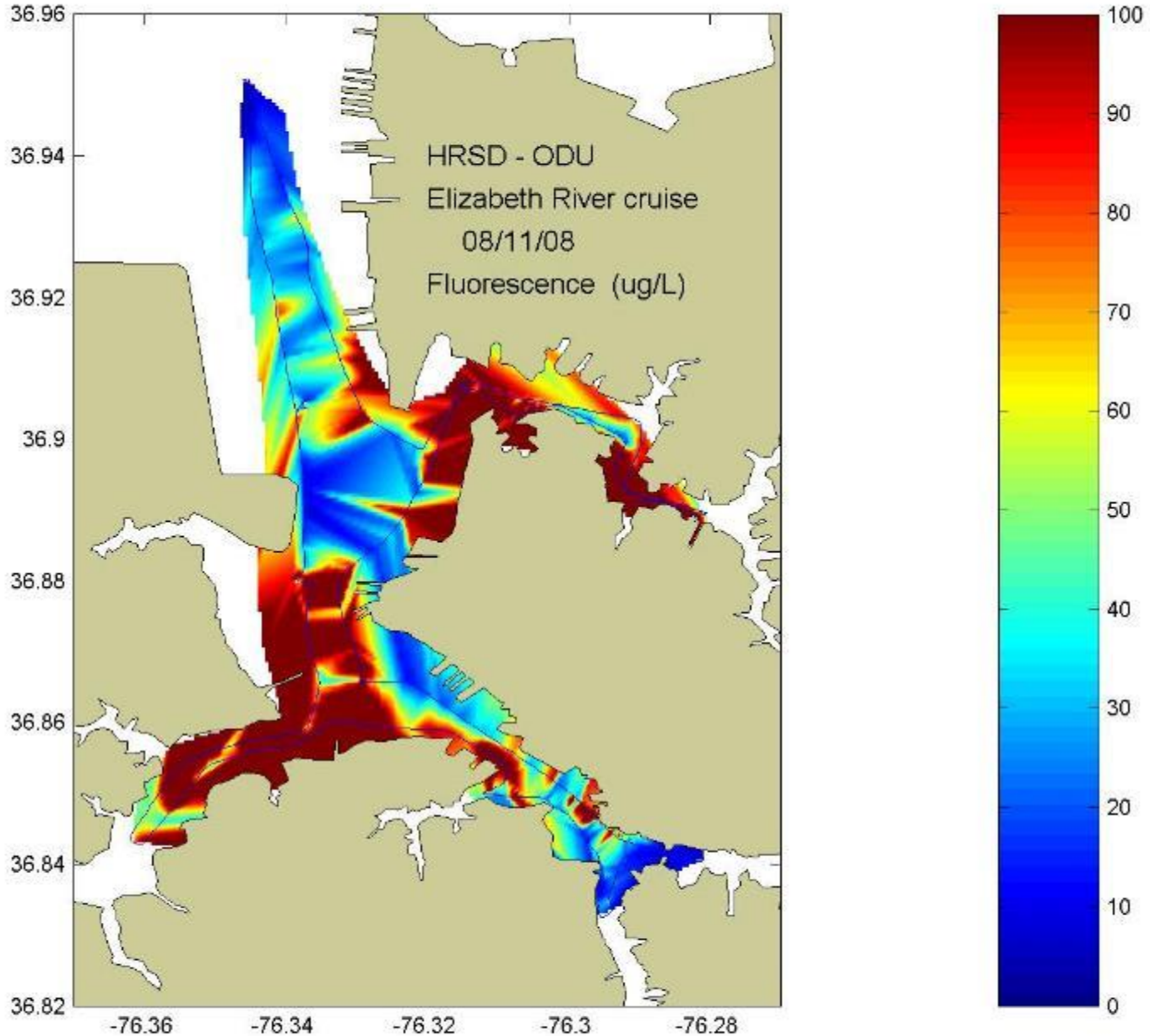
HRSD - ODU
Elizabeth River cruise
08/11/08
Fluorescence (ug/L)
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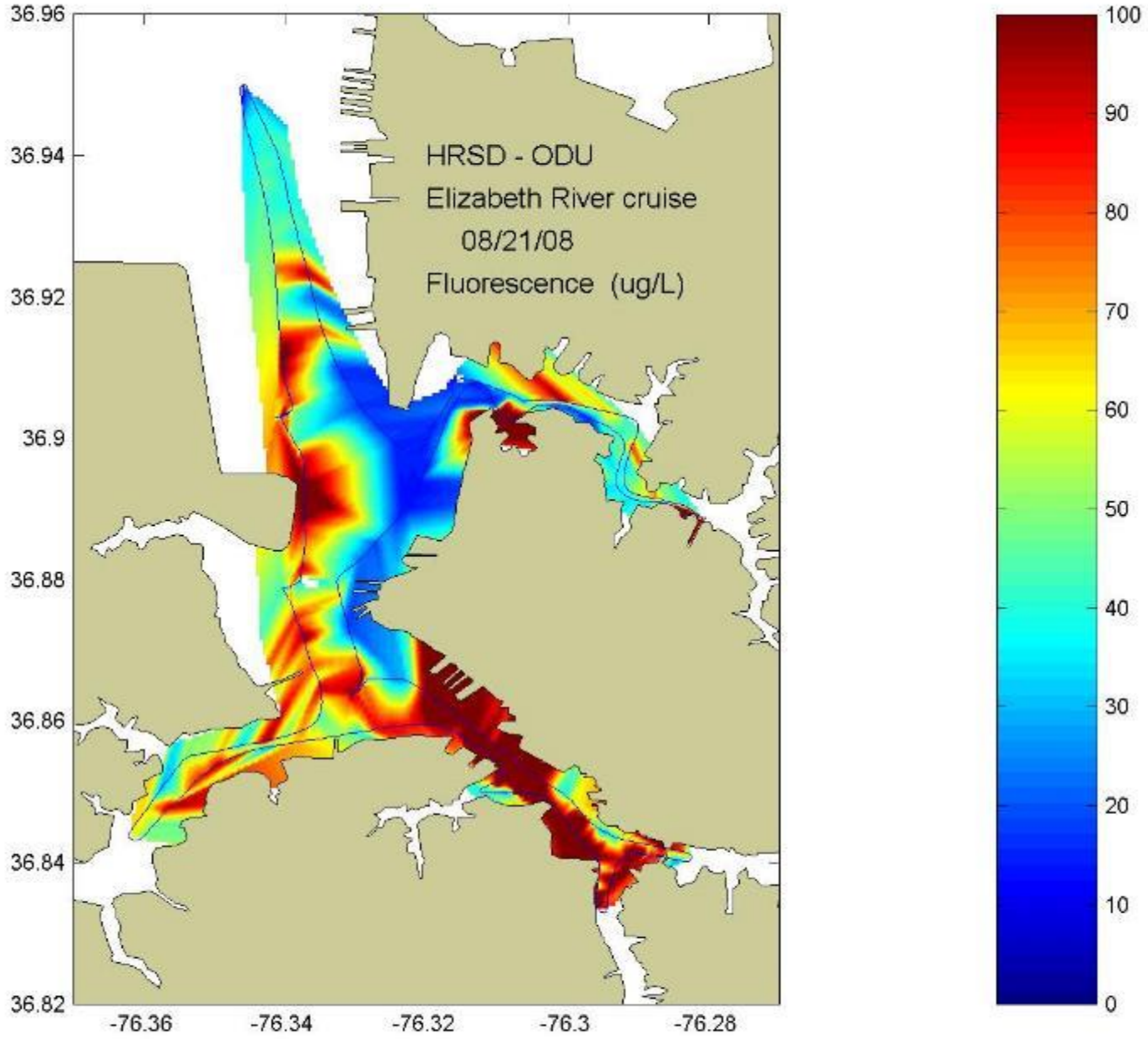
HRSD - ODU
Elizabeth River cruise
08/21/08
Fluorescence (ug/L)
36.96
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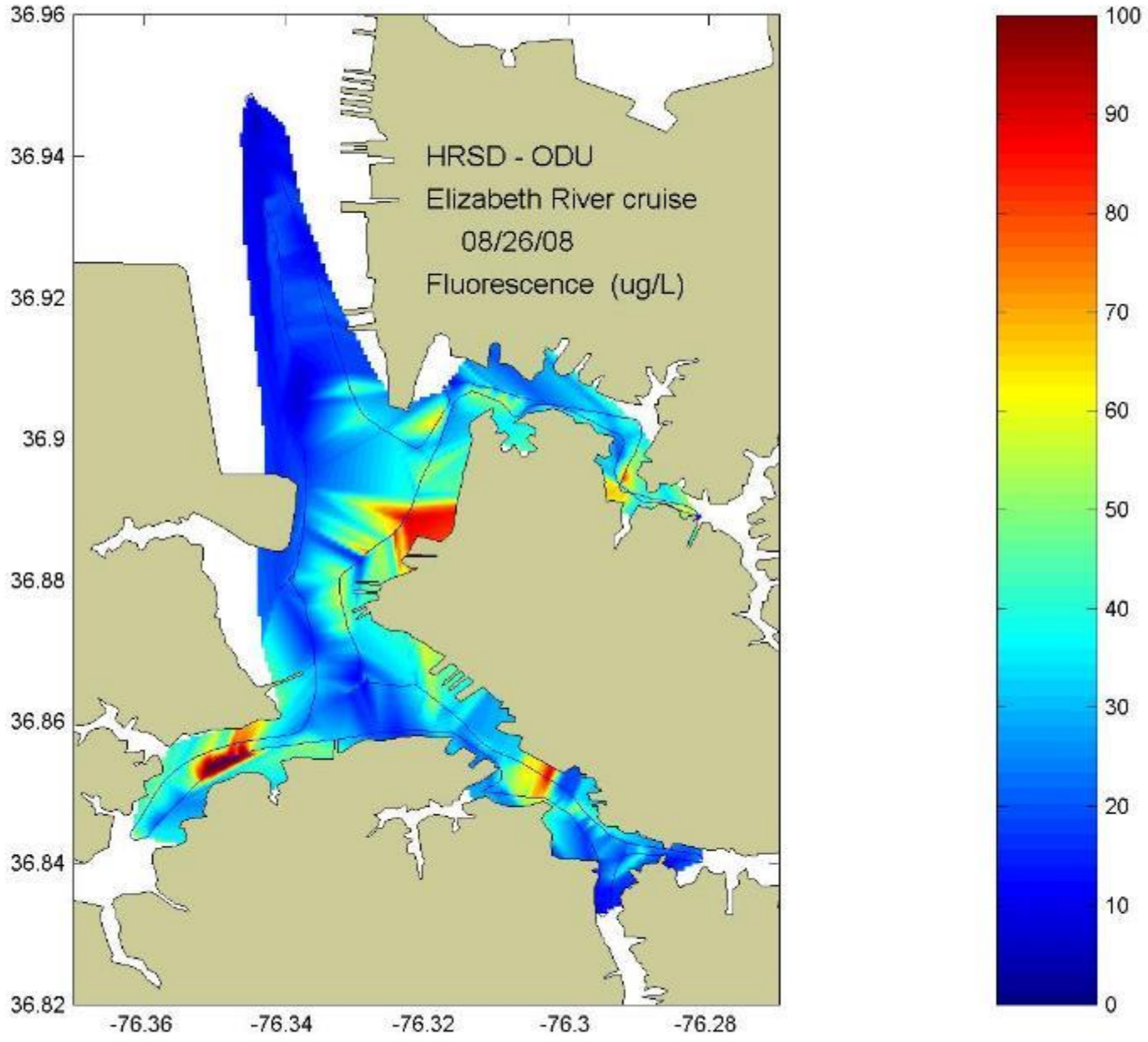
HRSD - ODU
Elizabeth River cruise
08/26/08
Fluorescence (ug/L)
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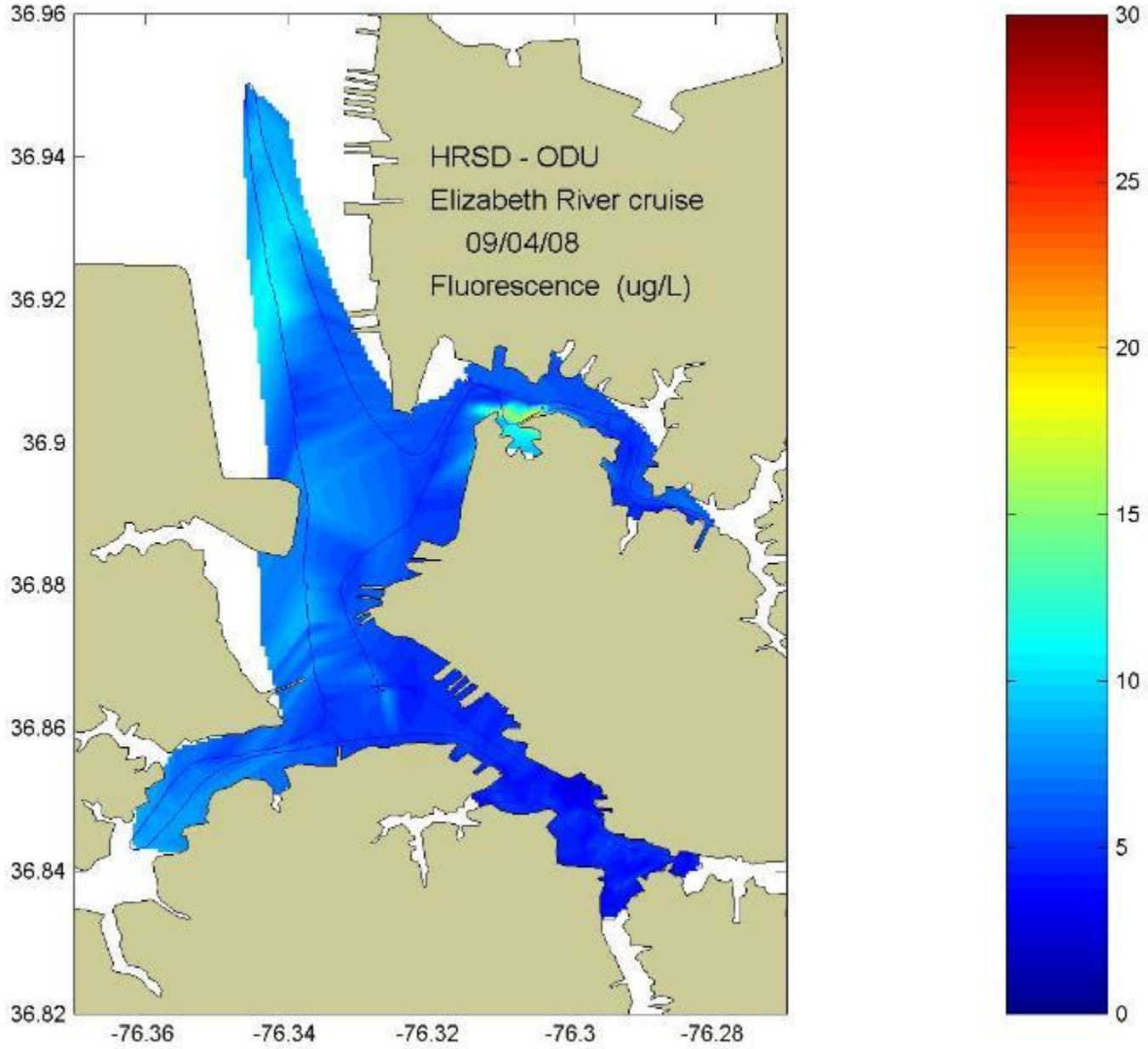
HRSD - ODU
Elizabeth River cruise
09/04/08
Fluorescence (ug/L)
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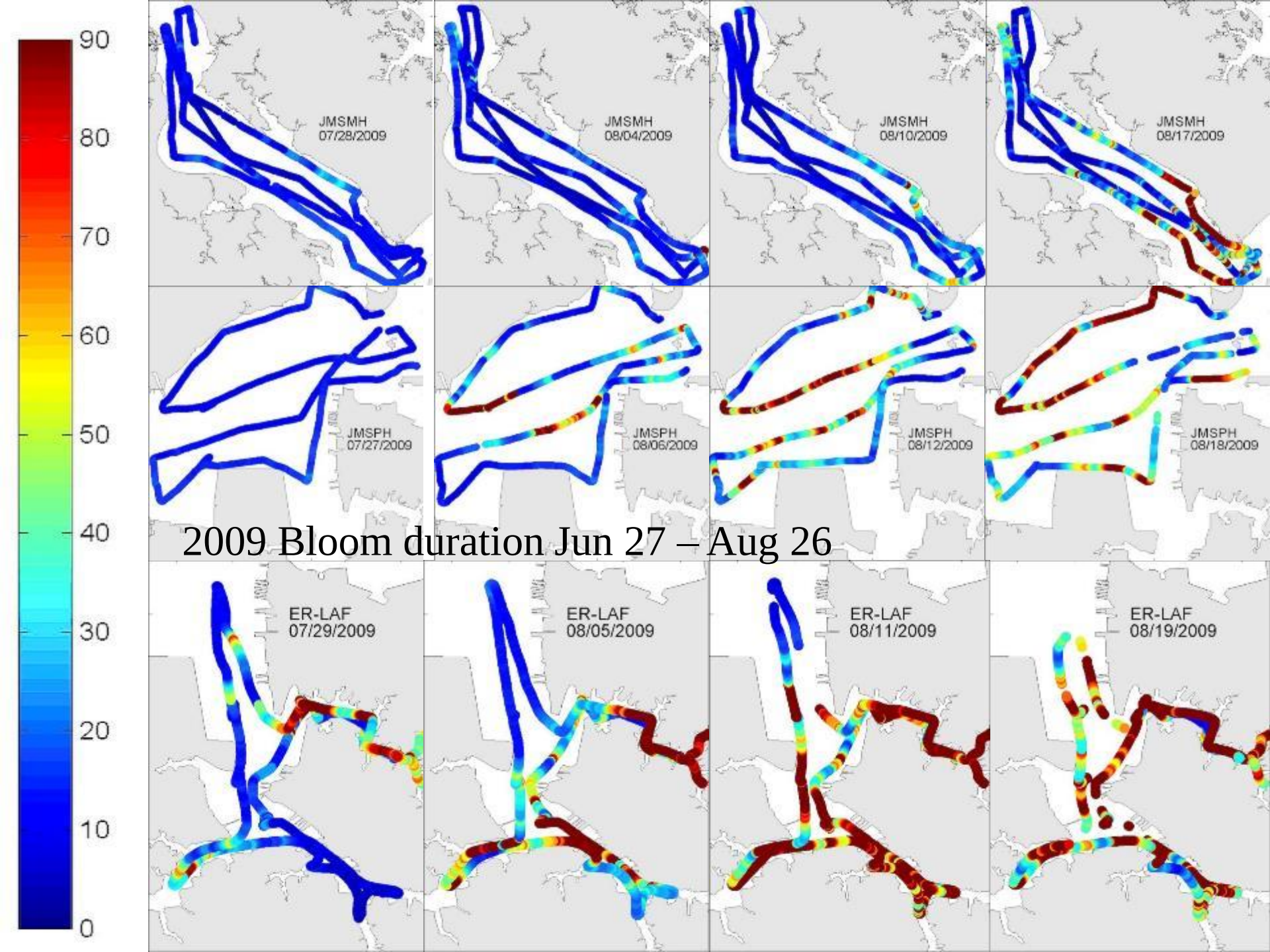
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JMSMH
07/28/2009
JMSMH
08/04/2009
JMSMH
08/10/2009
JMSMH
08/17/2009
JMSPH
07/27/2009
JMSPH
08/06/2009
JMSPH
08/12/2009
JMSPH
08/18/2009
2009 Bloom duration Jun 27 – Aug 26
ER-LAF
07/29/2009
ER-LAF
08/05/2009
ER-LAF
08/11/2009
ER-LAF
08/19/2009

Bloom develops over period of week(s)

Residence times in Lafayette estimated as 1-4 months depending on amount of rain

Revised animation with Lafayette initiation site during neap tide (longer residence time)

Surface_2008 Laf initiation.avi

FW HAB Intoductions

- Miller et al. (2010) has documented transport of FW cyanobacteria & toxin into coastal CA waters leading to intoxication of top predators
- Numerous CB examples of FW cyanobacteria blooms that likely flush into brackish waters (e.g., Sassafras, Transquaking, James)
- Some FW *Microcystis* have salinity tolerance (~11 psu)

Animal number	Stranding date	Stranding region	Sample tested	MCY-RR
1280-04 (Captive control)	6/27/2002	N/A	Liver	nd[1]
1485-06 (Captive control)	11/14/2001	N/A	Liver	nd
3216-99	7/28/1999	Monterey Bay	Liver	1.36
3377-00	6/26/2000	Monterey Bay	Liver	2.04
3858-03	3/17/2003	Estero Bay	Liver	nd
3955-03	5/8/2003	Monterey Bay	Liver	3.19
4240-04	6/5/2004	Monterey Bay	Liver	nd
4294-04	8/25/2004	Monterey Bay	Liver	13.13
3110-98	5/14/2006	Monterey Bay	Liver	9.52
4811-06	8/25/2006	Estero Bay	Liver	7.71
4844-06	9/24/2006	Monterey Bay	Liver	3.62
4913-07	1/30/2007	Monterey Bay	Liver	61.58
5020-07	6/9/2007	Monterey Bay	Liver	38.45
5023-07	6/9/2007	Monterey Bay	Liver	104.46
5036-07	6/25/2007	Monterey Bay	Liver	2.69
5082-07	8/16/2007	Monterey Bay	Liver	5.29
5108-07	9/23/2007	Monterey Bay	Liver	14.39
5167-07	11/21/2007	Monterey Bay	Liver & feces	18.7 & 16.4
5174-07	11/30/2007	Monterey Bay	Liver	6.18
5179-07	12/1/2007	Monterey Bay	Liver	3.76
5182-07B	12/2/2007	Monterey Bay	Liver	4.8
5185-07	12/6/2007	Estero Bay	Liver	1.97
5416-08	11/8/2008	Big Sur	Liver	7.58

Possible Bay HA Introductions for Triblets

- *Prorocentrum minimum*-Chester, Carol Creek (Annapolis Harbor), Choptank, Rhode
- *Karlodinium veneficum*-Bird, Middle, Gunpowder
- *Cochlodinium*-James tribs, e.g., Lafayette
- *Alexandium monilatum*-York's Sarah's Creek & Perrin River

Alliance for the CB

ABCNews2

VIMS

Found potential initiation site(s). Now, what causes bloom initiation?

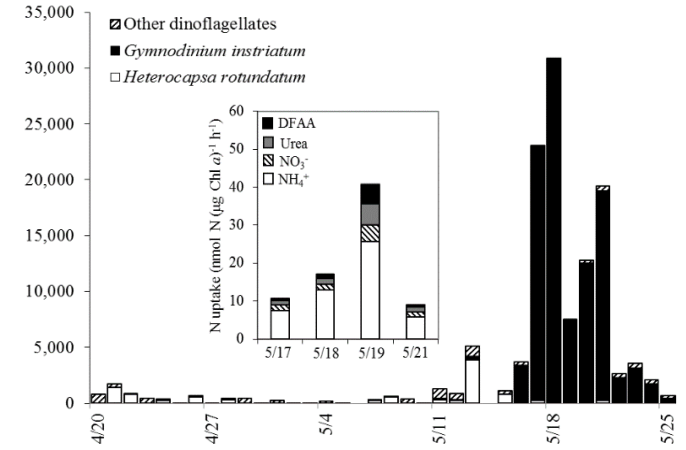
- Temperature?
  - Blooms do not occur in all years
- Nutrient inputs?
  - Nutrient concentrations are generally high
- Physical forcing?
- Absence of grazing?

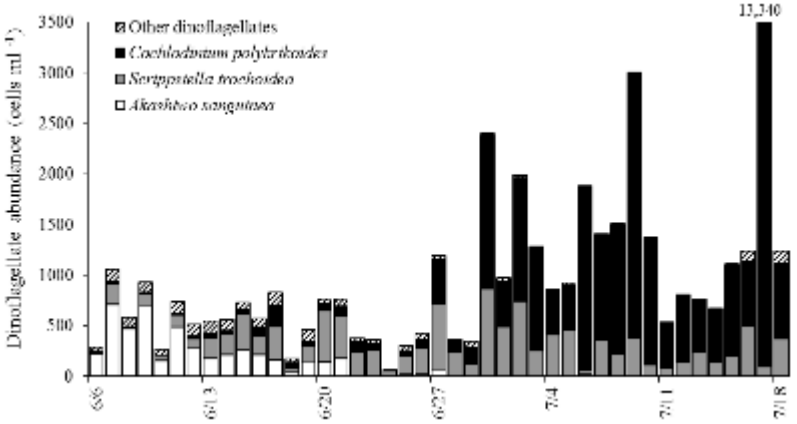
Sampled daily leading up to bloom in 2005 and found possible link between *Cochlodinium* blooms to temperature and meteorological forcing (Morse et al. 2014)

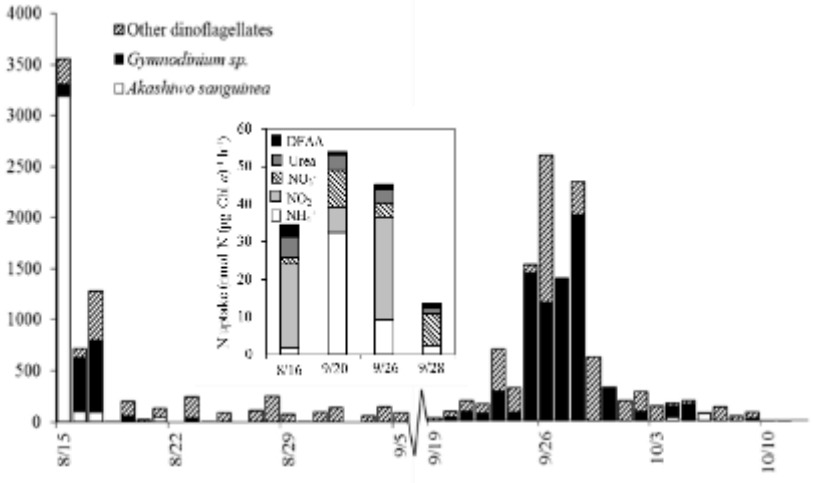
Tidal cycle and residence time also important during incubation phase

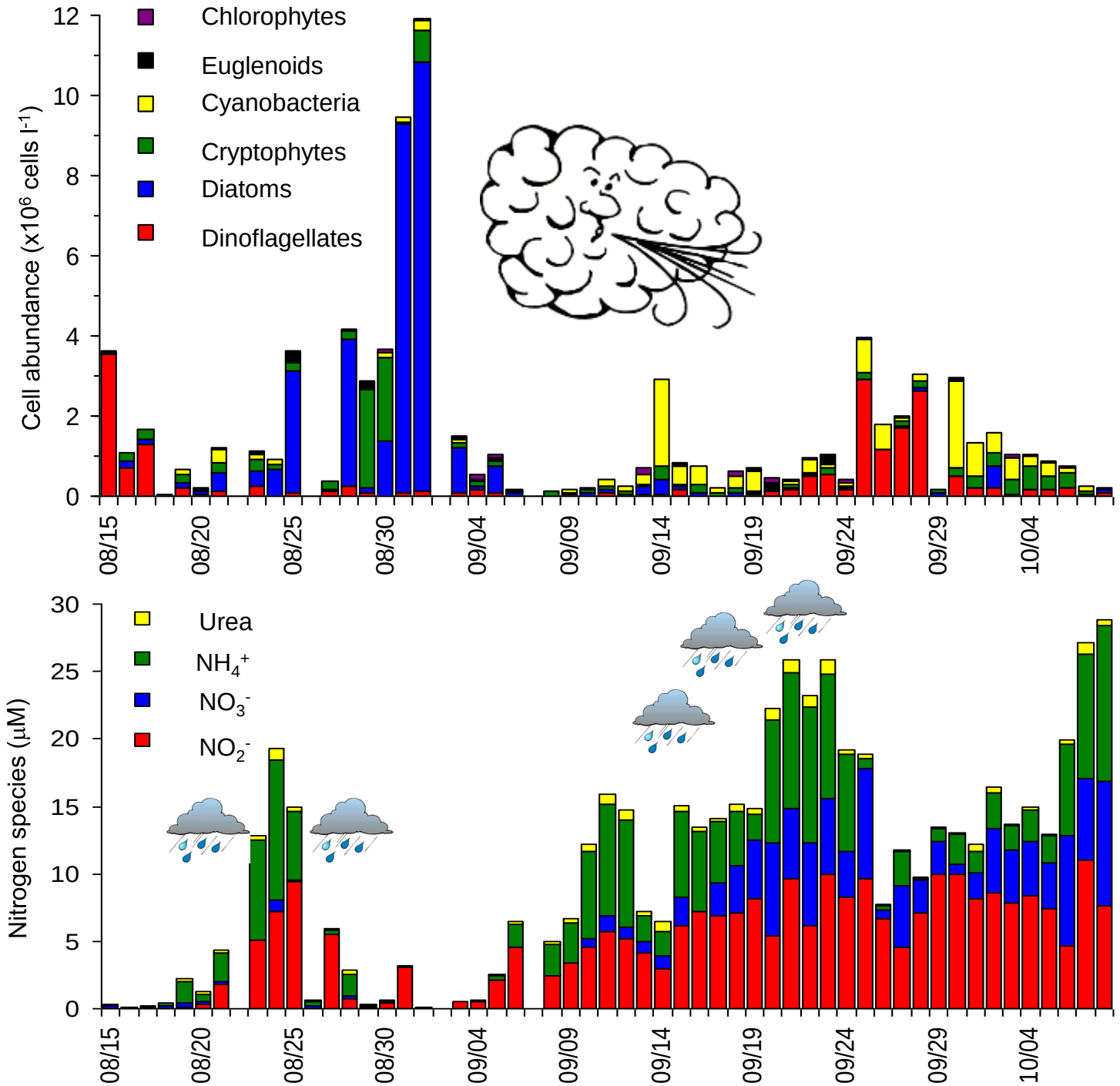
How to observe bloom initiation?

- Sample daily or continuously at a site where we think blooms initiate (physiologically demanding – on people)
- 2005 and 2006 (NSF & VEE) – CCPO & Granby Street Bridge
- 2012 – 2017 (VA DEQ & HRSD)







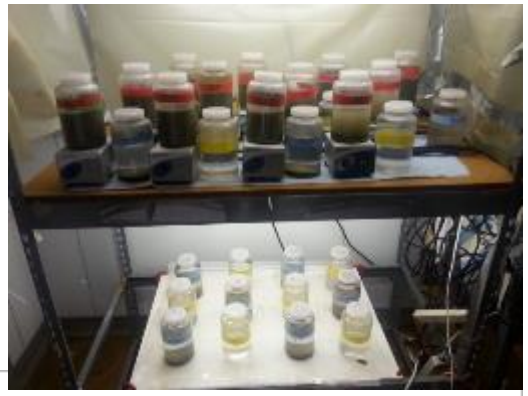

Chlorophytes
Euglenoids
Cyanobacteria
Cryptophytes
Diatoms
Dinoflagellates
Cell abundance (x10^6 cells l^-1)
0
2
4
6
8
10
12
08/15
08/20
08/25
08/30
09/04
09/09
09/14
09/19
09/24
09/29
10/04
Urea
NH4+
NO3-
NO2-
Nitrogen species (µM)
0
5
10
15
20
25
30
08/15
08/20
08/25
08/30
09/04
09/09
09/14
09/19
09/24
09/29
10/04

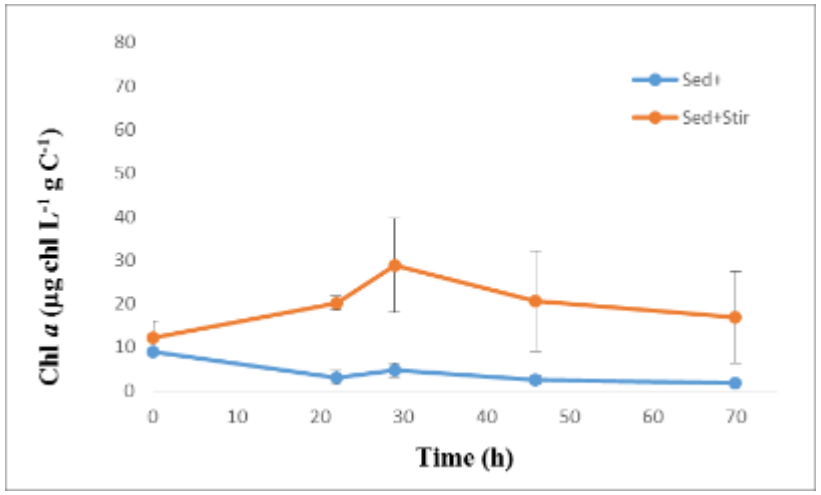
Causal factors – meteorological forcing

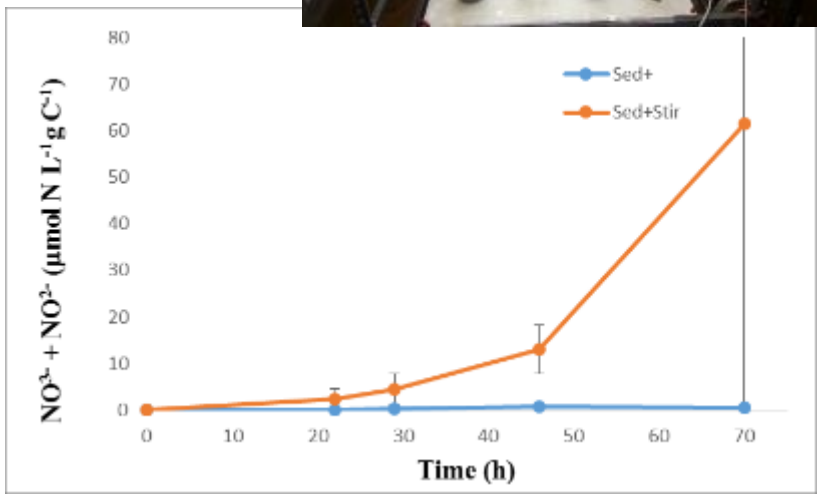
- Linked bloom initiation with meteorological forcing/rainfall (Morse et al. 2013)
- From storm chasing, found that storms both trigger and disrupt blooms (Filippino et al. 2017)
- Is it inputs from the top or bottom that are more important during a meteorological event?

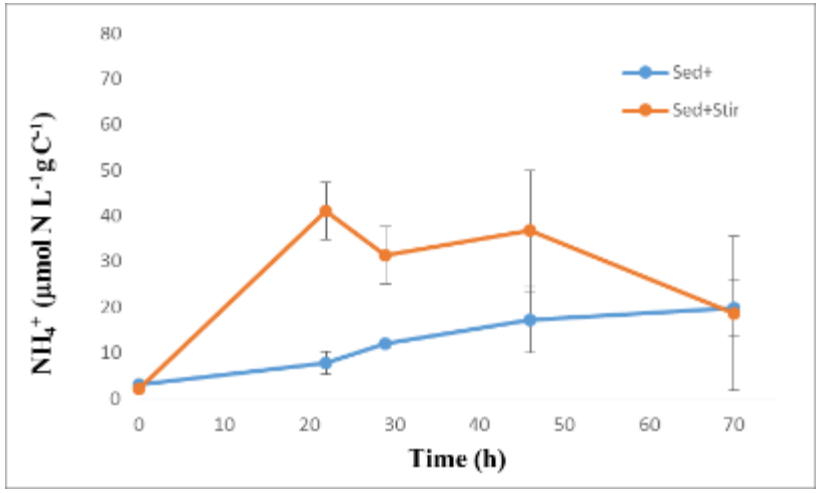
Sediment resuspension studies

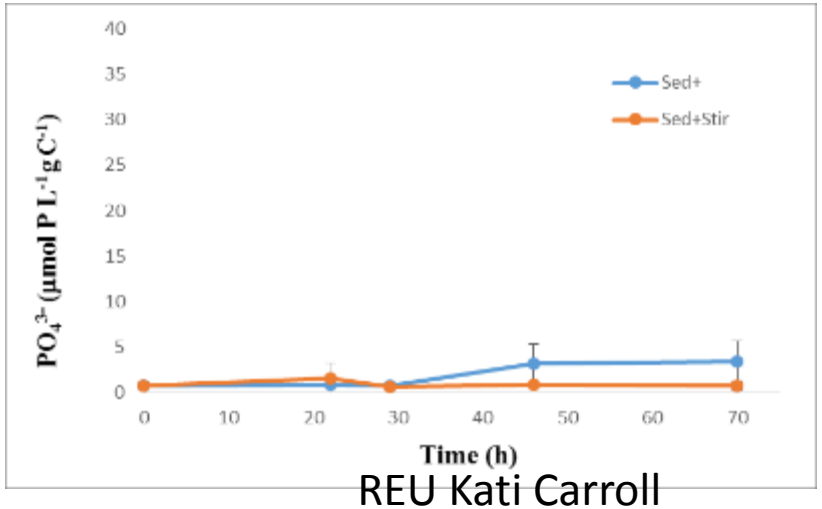
- There is a large repository of nutrients in sediments





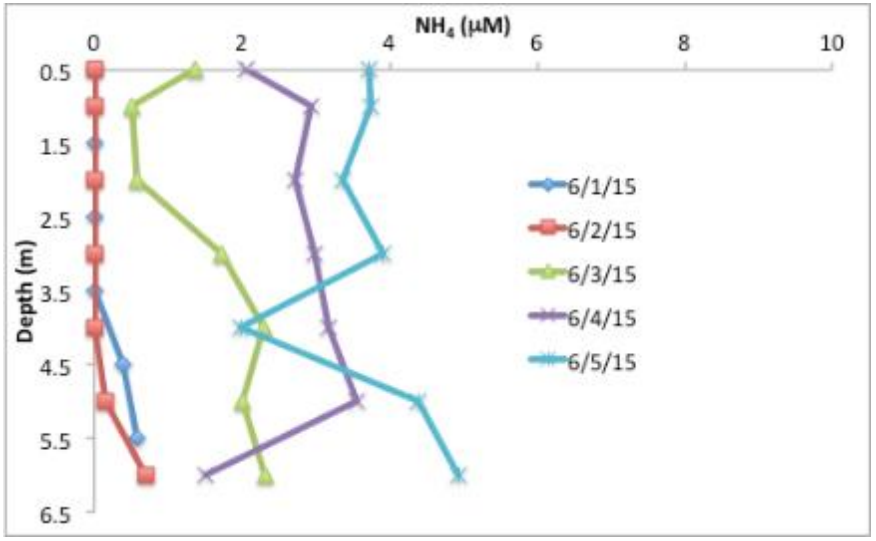


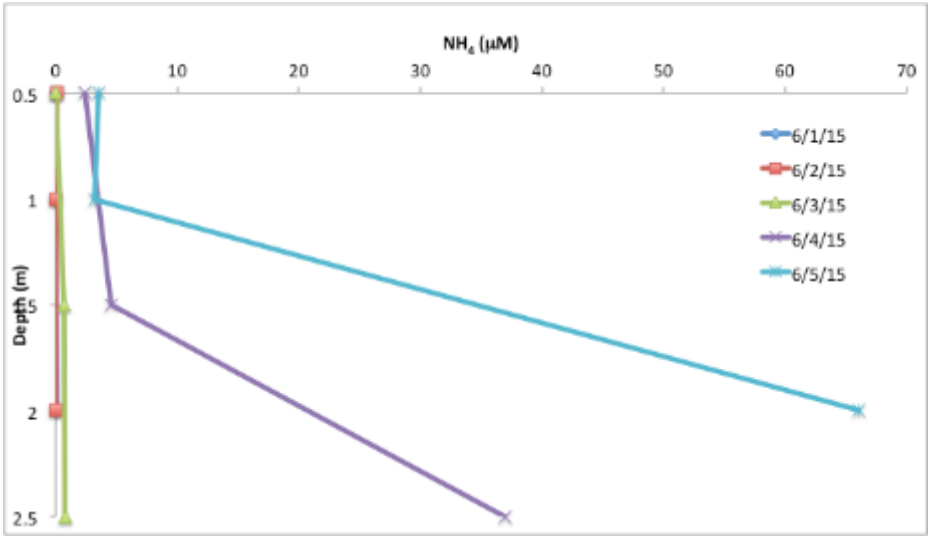




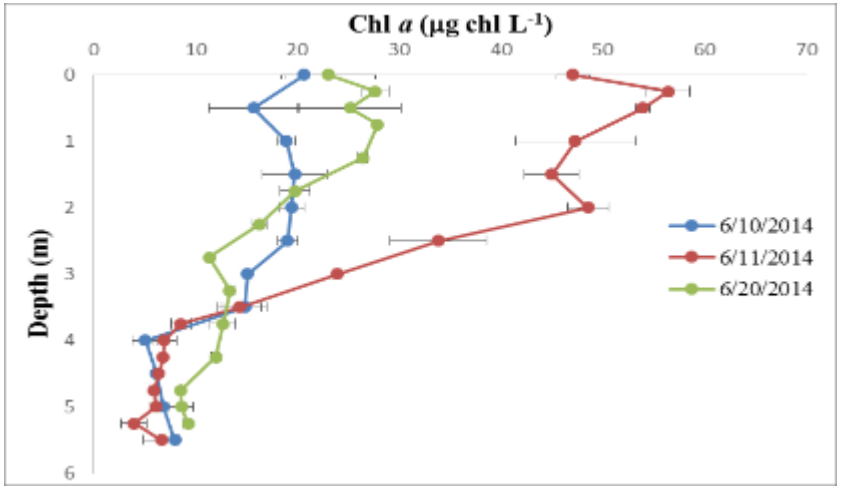
REU Kati Carroll

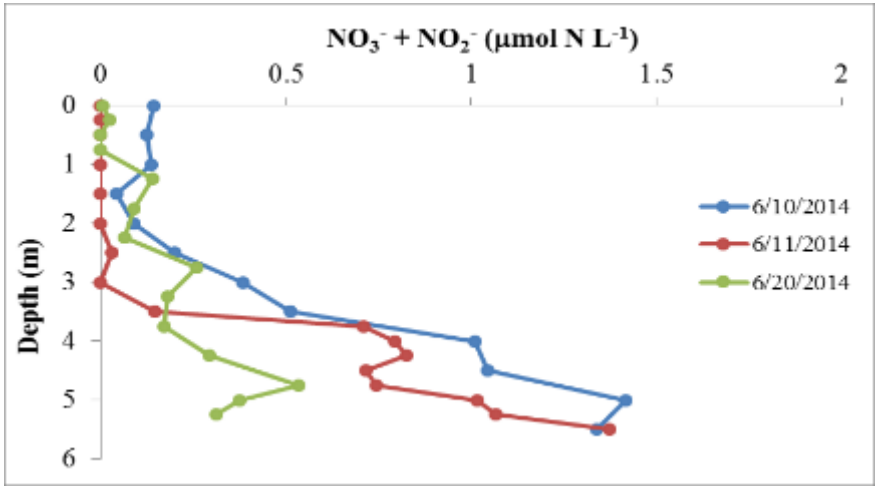
At two monitoring sites in the Lafayette River, higher concentrations of ammonium observed near bottom after wind events at the shallow water station.

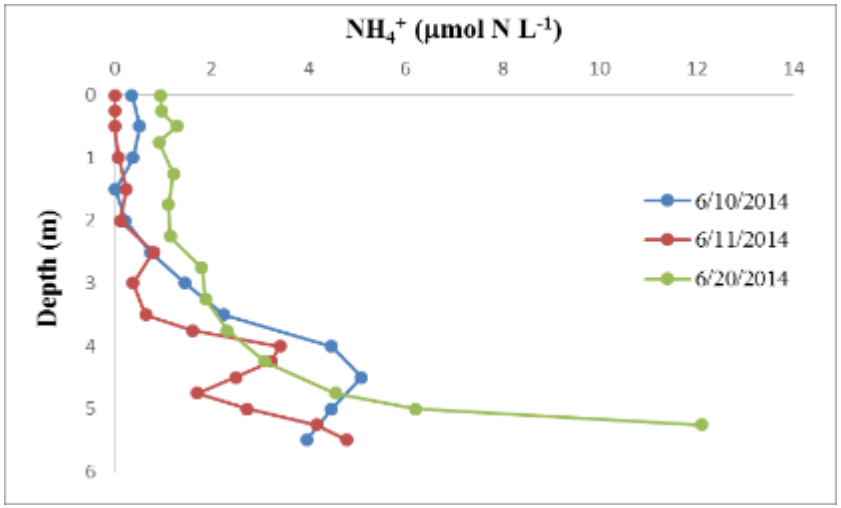


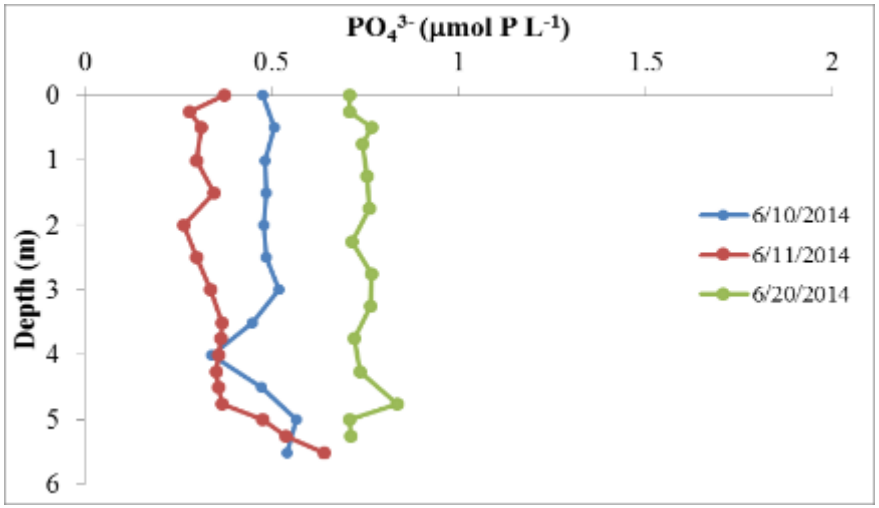


REU Palmer

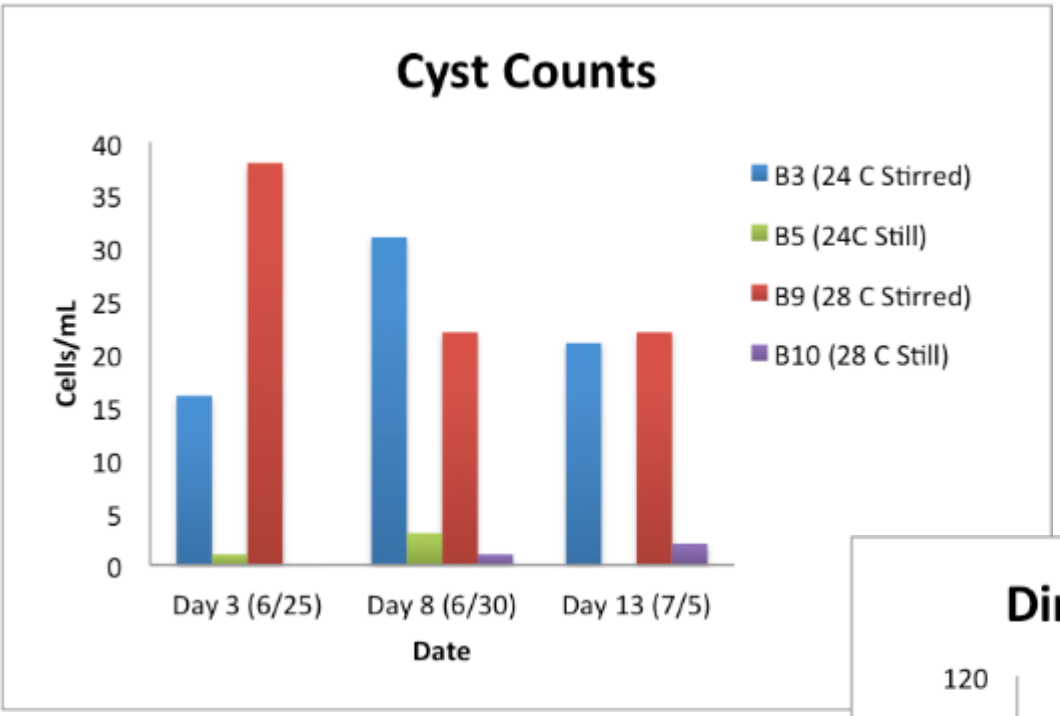

Chl a (µg chl L-1)
0
10
20
30
40
50
60
70
Depth (m)
0
1
2
3
4
5
6
6/10/2014
6/11/2014
6/20/2014


NO3- + NO2- (µmol N L-1)
0
0.5
1
1.5
2
Depth (m)
0
1
2
3
4
5
6
6/10/2014
6/11/2014
6/20/2014

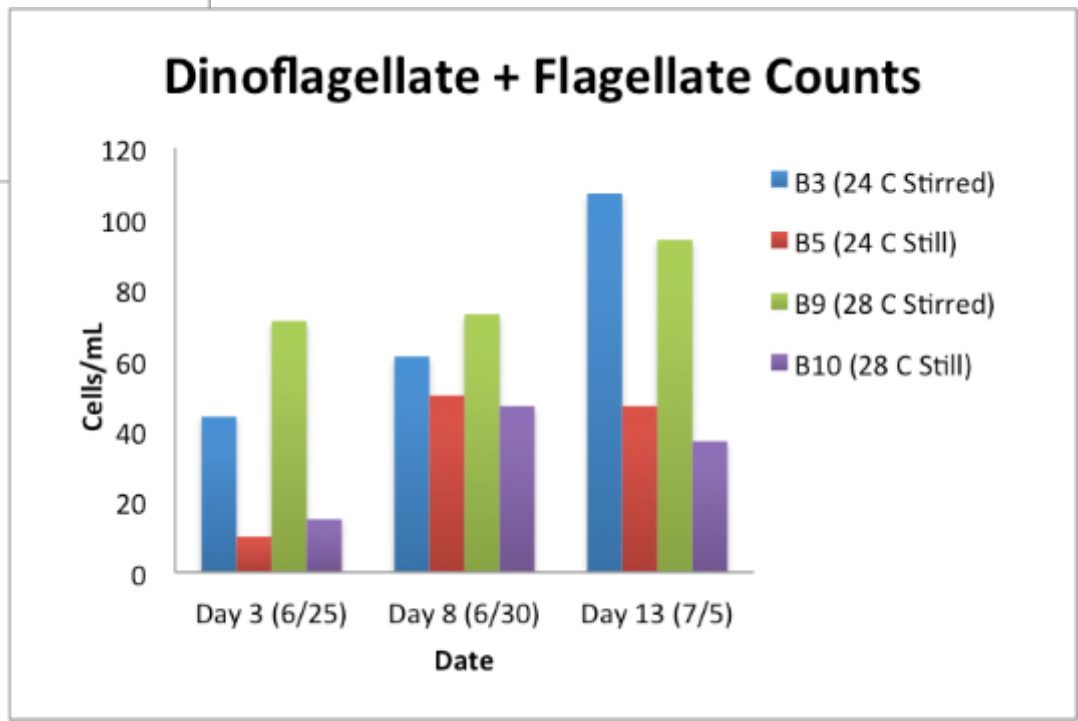

NH4+ (µmol N L-1)
0
2
4
6
8
10
12
14
Depth (m)
0
1
2
3
4
5
6
6/10/2014
6/11/2014
6/20/2014


PO43- (µmol P L-1)
0
0.5
1
1.5
2
Depth (m)
0
1
2
3
4
5
6
6/10/2014
6/11/2014
6/20/2014

Cyst and Dinoflagellate Abundance



- Stirring is necessary to put cysts in the water



- Dinoflagellates grew when cysts were suspended.

REU Matthew Gschwend

Daily vertical profiles with YSI.

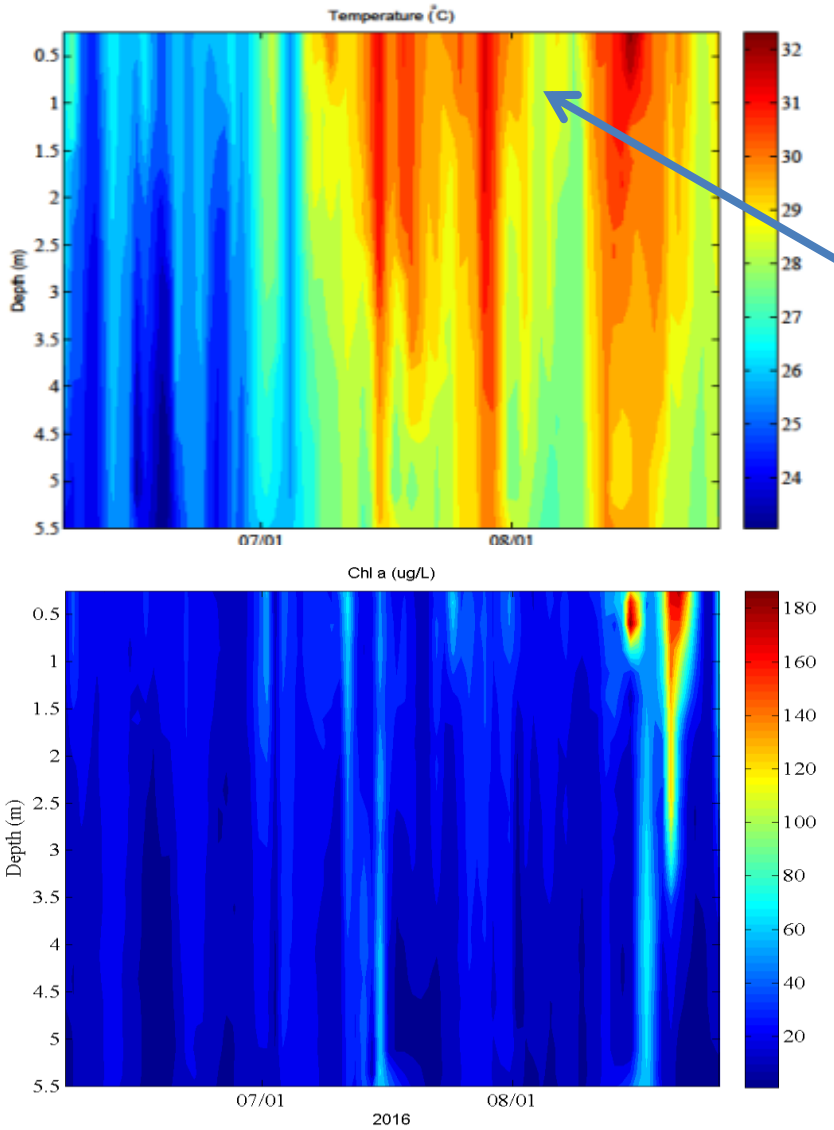


Figure 9. Water temperature (upper panel) and Chl *a* concentrations (lower panel) measured mid-day at our fixed station at NYCC during daily vertical profiling.

Storm with record rainfall (7”) & wind

Nutrient inputs from bottom and top.

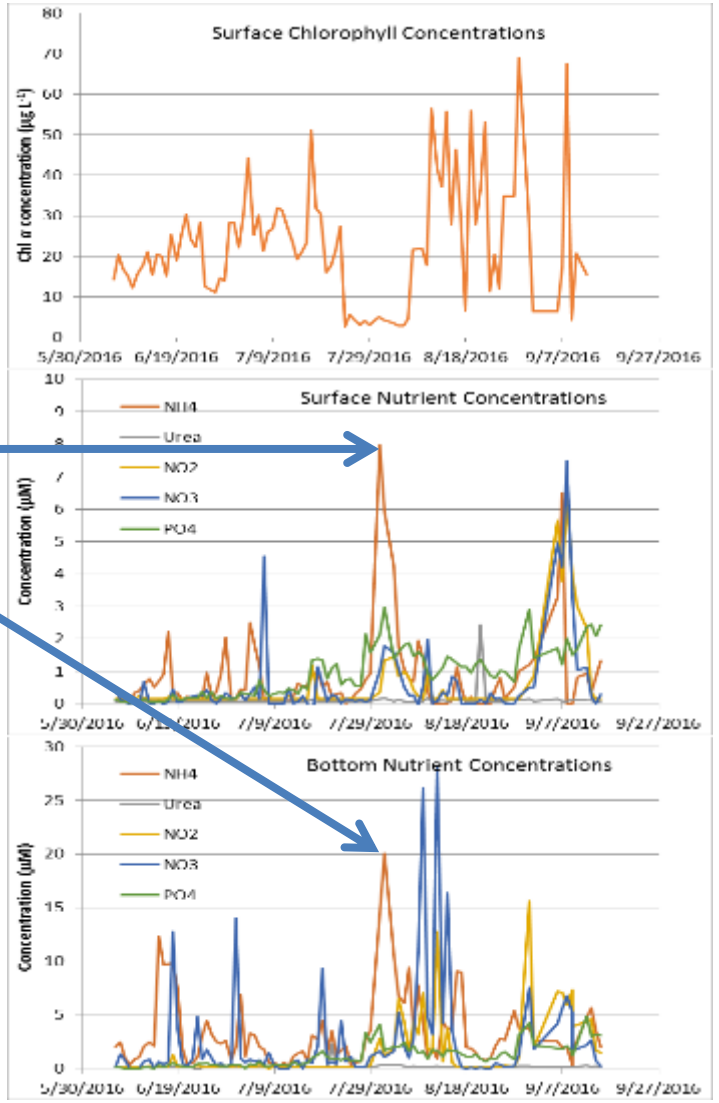


Figure 14. Surface extracted Chl *a* concentrations (top panel), surface nutrient concentrations (middle panel) and bottom nutrient concentrations (bottom panel) measured during daily sampling at NYCC in 2016.

Could turbidity offer insights?

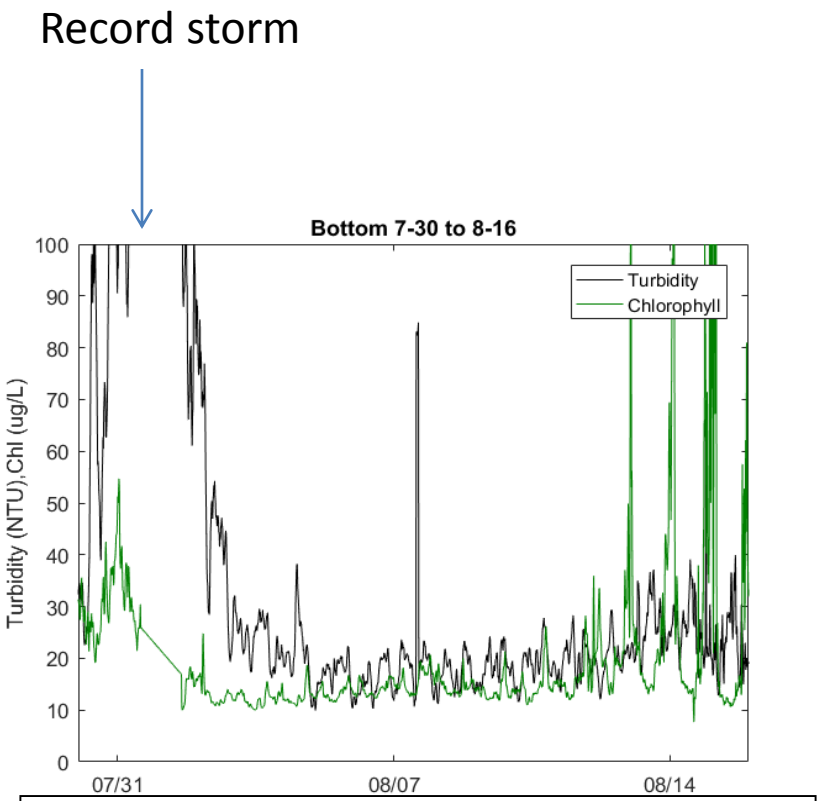
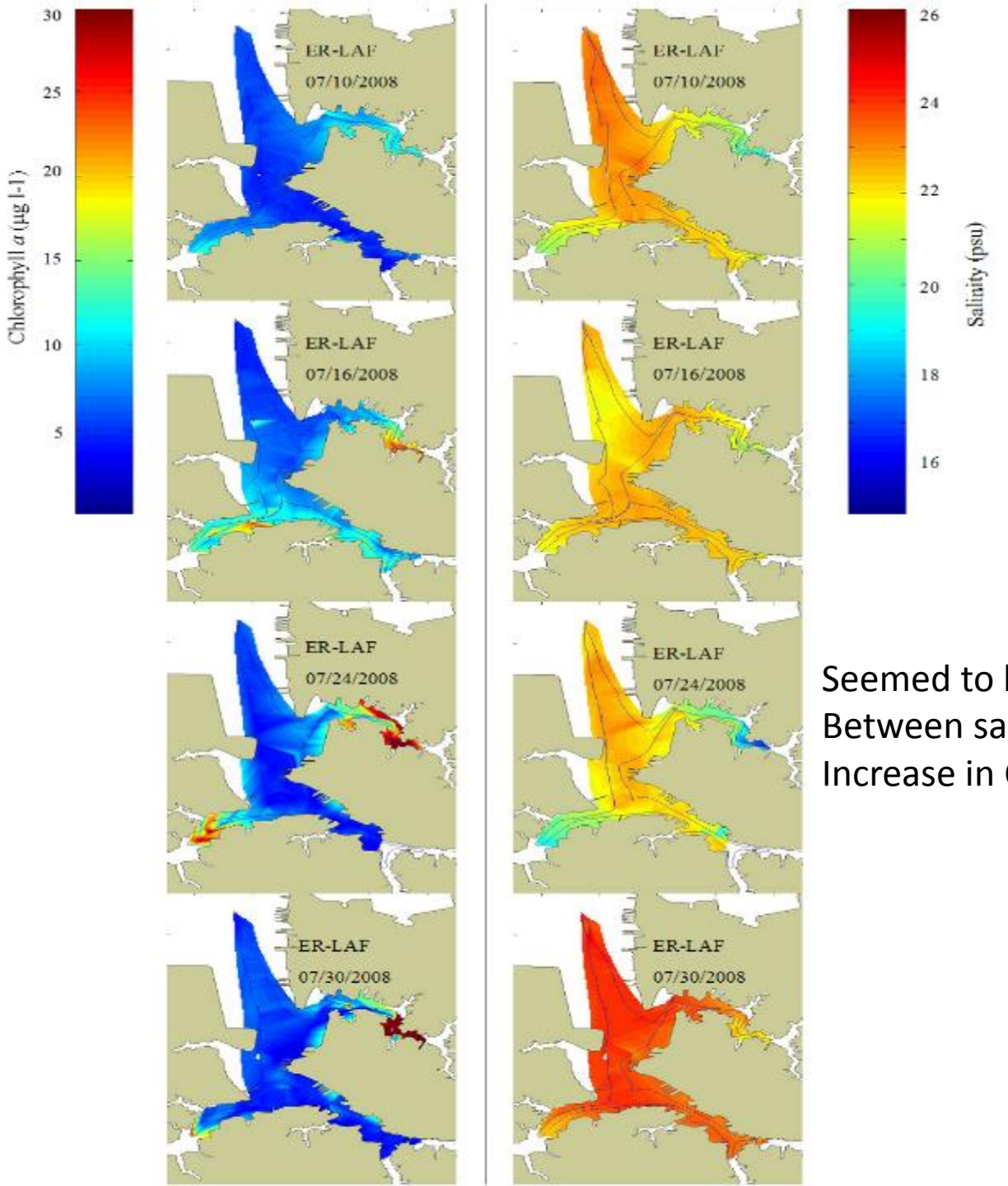


Figure 15. Turbidity and Chl *a* fluorescence in near bottom waters over the period preceding the *C. polykrikoides* July 31 – Aug 16, 2016, at NYCC.

Conclusions

- Nutrient inputs from sediment resuspension may be greater than that from rainwater (data not shown)
  - Implications for setting nutrient loads
- Wind can also resuspend cysts which may be a factor in bloom initiation
- What stimulates cyst germination?



Seemed to be a relationship
Between salinity and
Increase in Chl *a*

How to deal with increased coastal flooding?

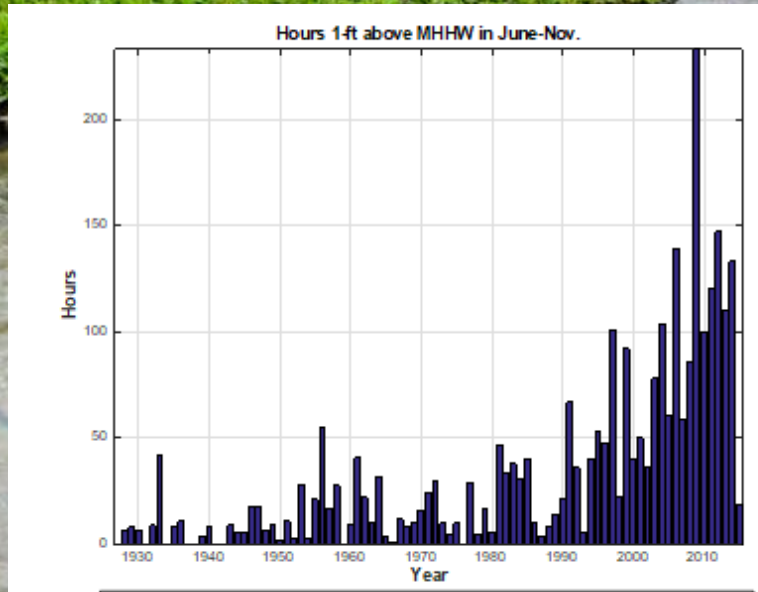
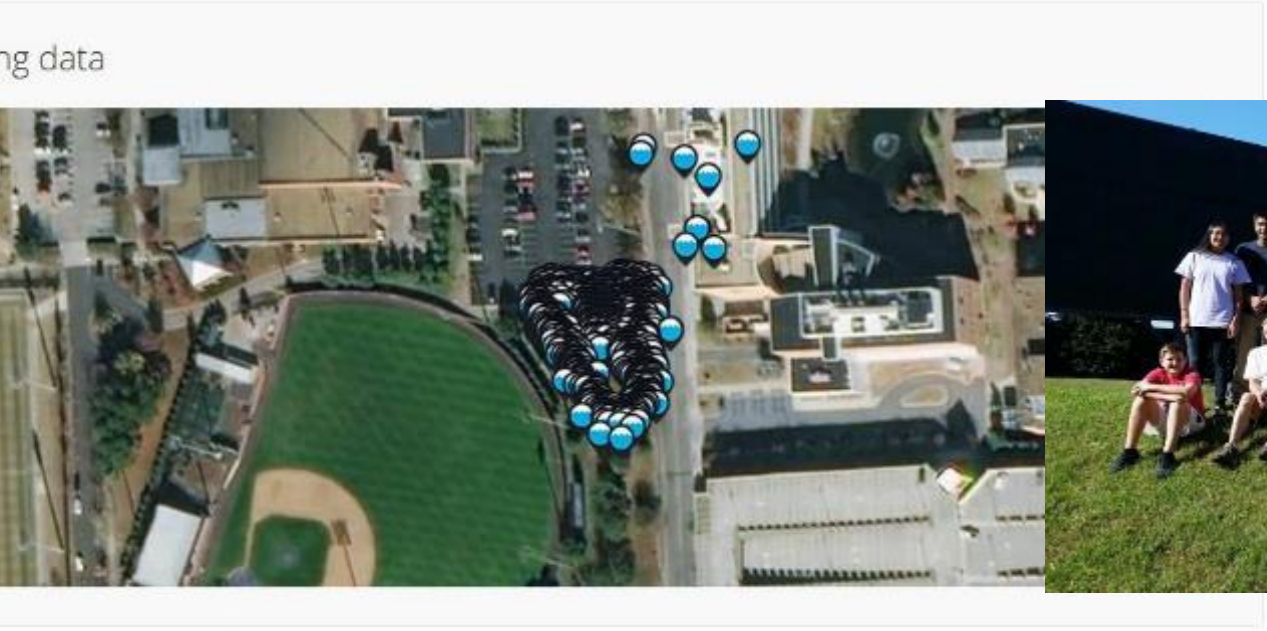


Figure 2. Hours spent 1-ft above mean higher high water (MHHW) during June-Nov. as measured at the Sewell's Point tide gauge in Norfolk, VA.

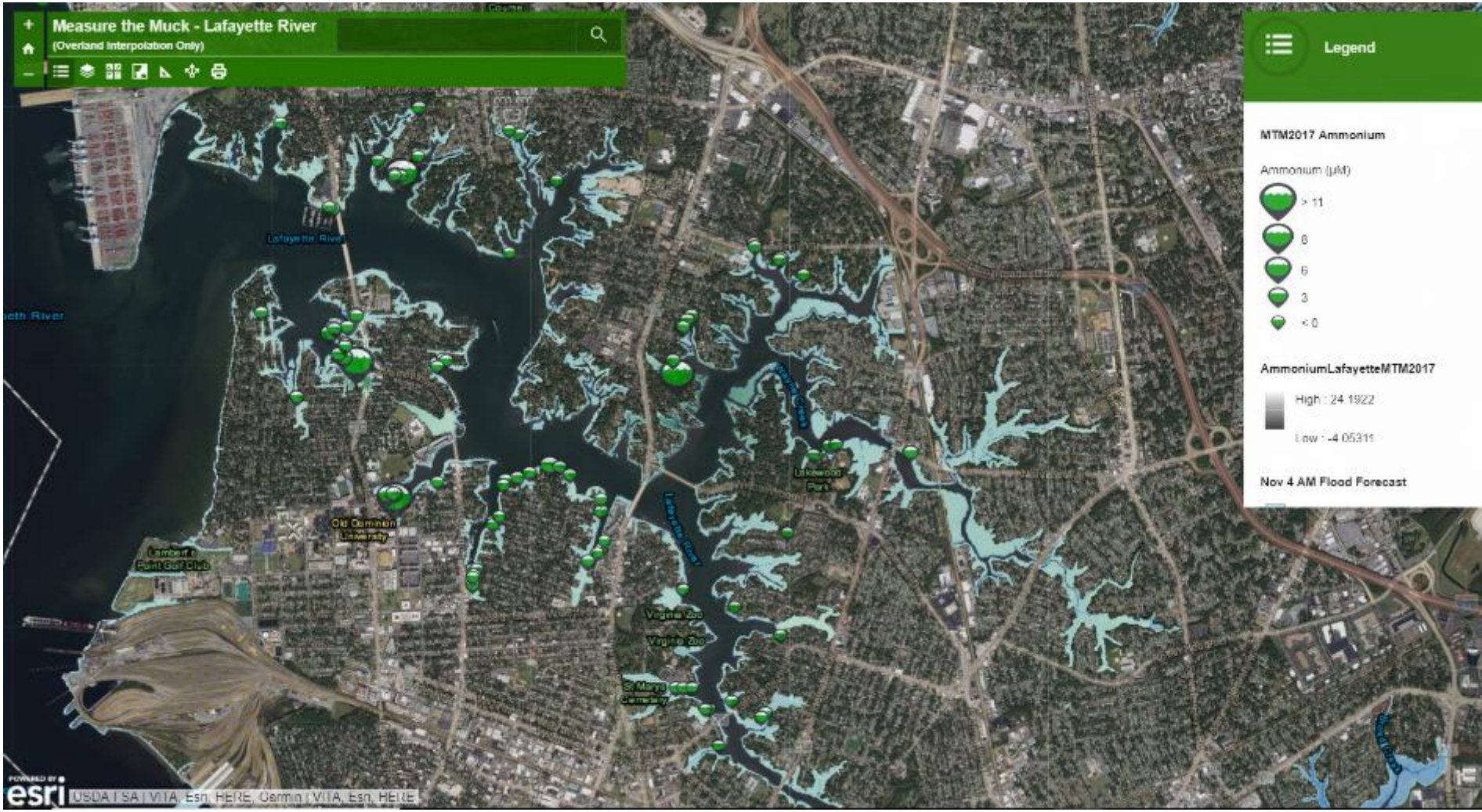
Tidal flooding under blue skies

Measure the Muck

- In association with Capture the King Tide we collected over 200 water samples to try and determine hot spots for nutrient loading from coastal flooding.
- Simultaneously mapped water level
- When: November 5, 2017

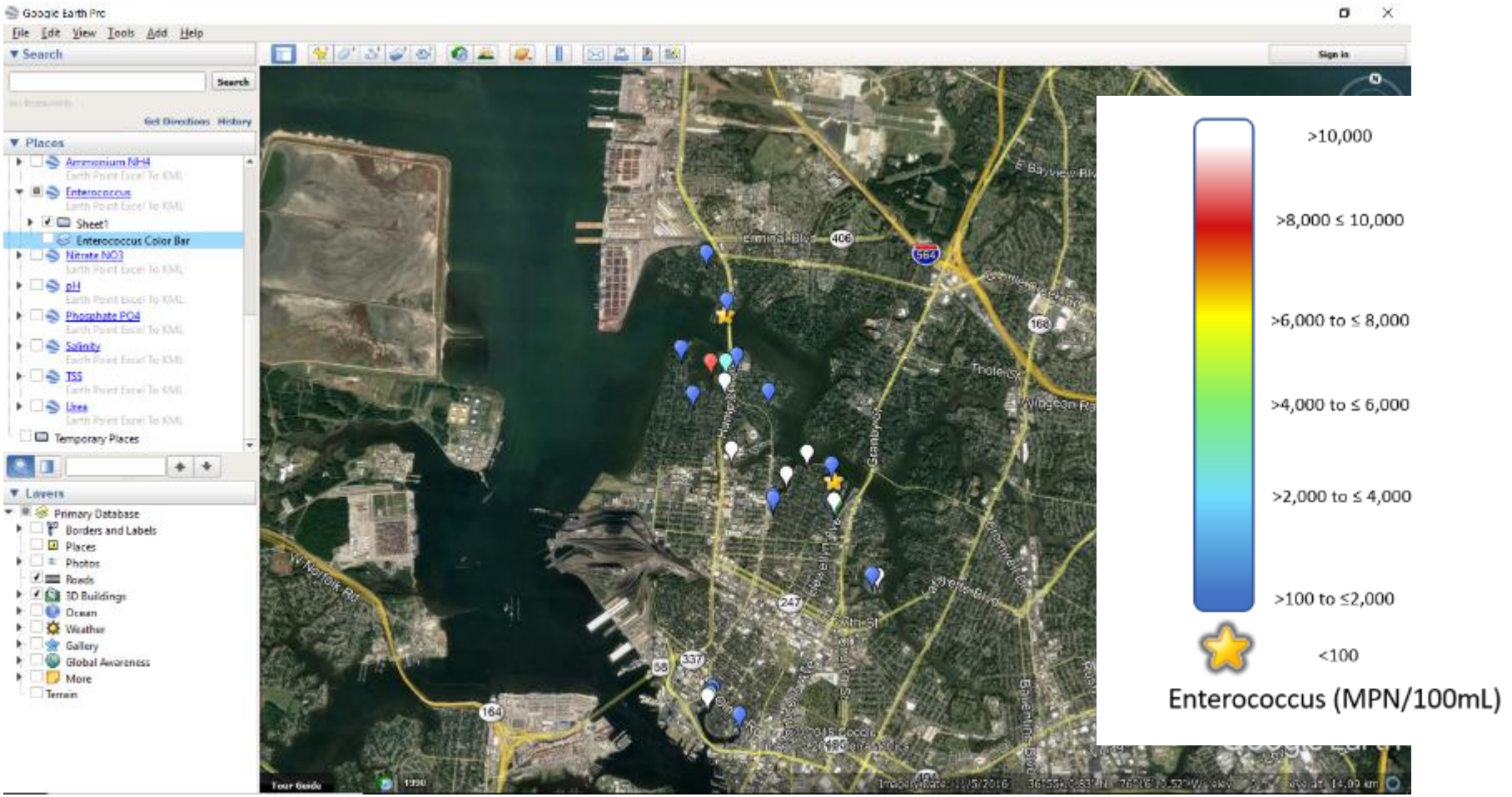


There you activate the layers in the menu located in the upper left. The only layer that is currently available with this type of map is for (1) sample-specific Ammonium concentration and (2) Ammonium flooding interpolation. In this image you can observe the samples taken in the Lafayette River.

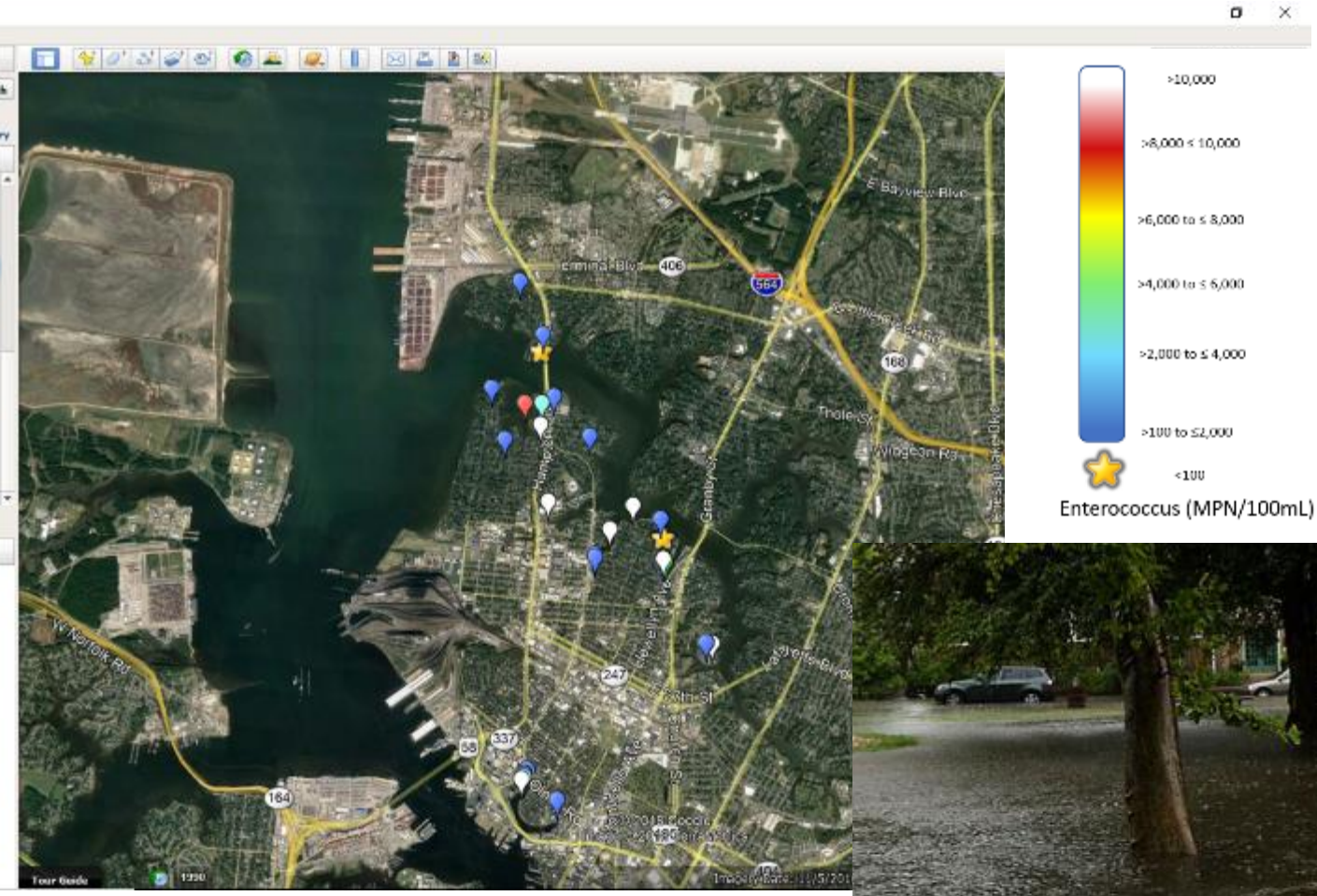


The interpolation for the Ammonium concentration is marked in ‘light green’. This interpolation was built with a ‘King tide flood modeling data’ considering inundation only.
To observe the actual values calculated for the interpolation you have to zoom-in at the region of interest. Can evaluate using other Google map tools (e.g., land use)

Enterococcus



Will also collect 40 samples to measure *Enterococcus*!

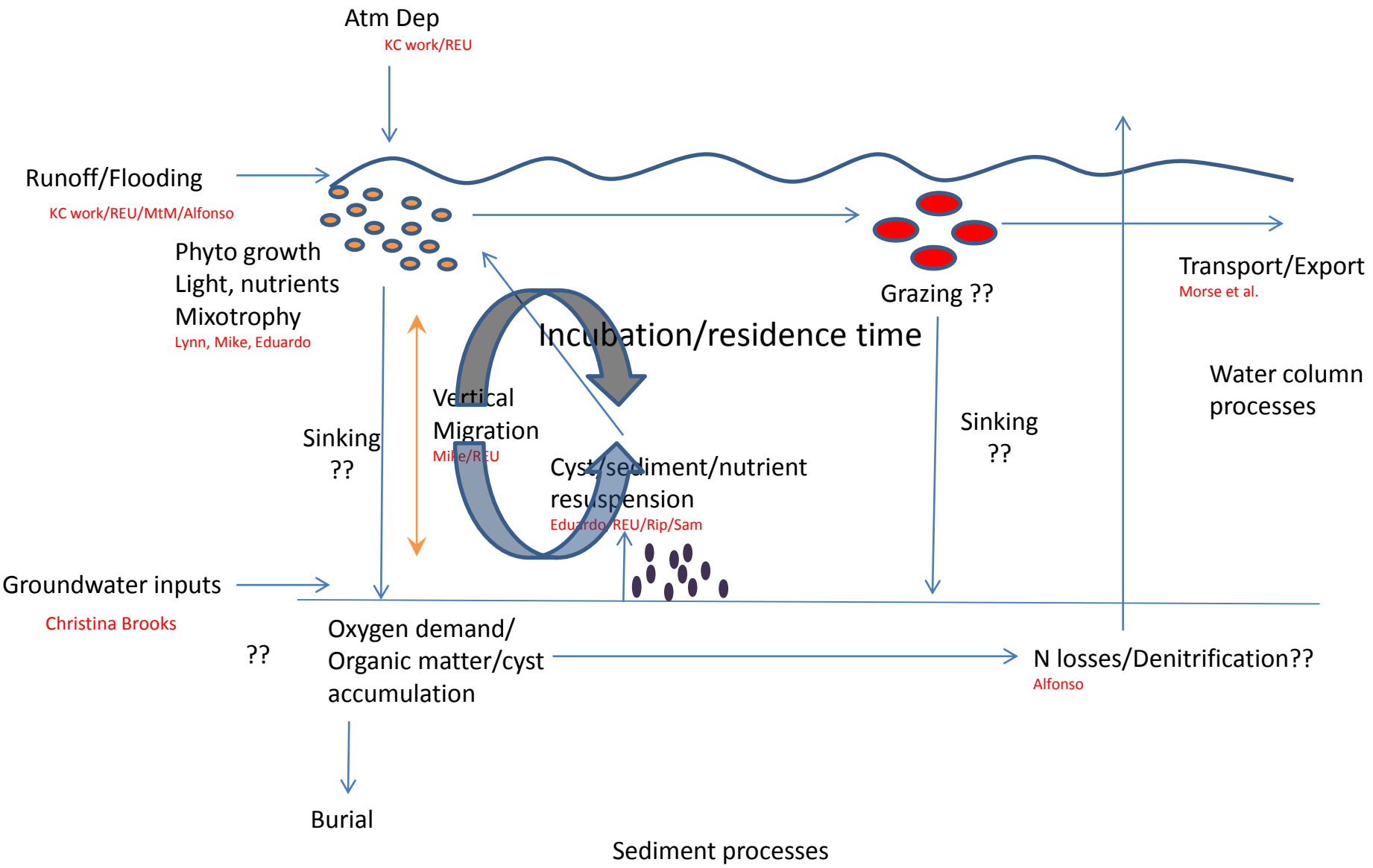


June 6, 2009 Ghent
Virginian Pilot photo

What we've learned

- We have identified hotspots & hot times for bloom initiation and are focusing on those
- Understand transport and maintenance – estuarine circulation and metabolic flexibility
- Legacy of nutrients past in the sediments of shallow water systems may delay restoration
- Impacts of coastal flooding/storms – not included in nutrient loading estimates – but potentially great

Developing model



Questions?

Photo by Jeff Robertson & Rach