Results of Nutrient Tracking & Biological Modeling Using the Regional Ocean Modeling System (ROMS) for Upper Narragansett Bay

Our lab has long history of ROMS developments & applications

Constantly making improvements:

General: ROMS is a community code (organic)

Specific to Narragansett Bay:

Data & Lab models for comparisons

Multiple applications

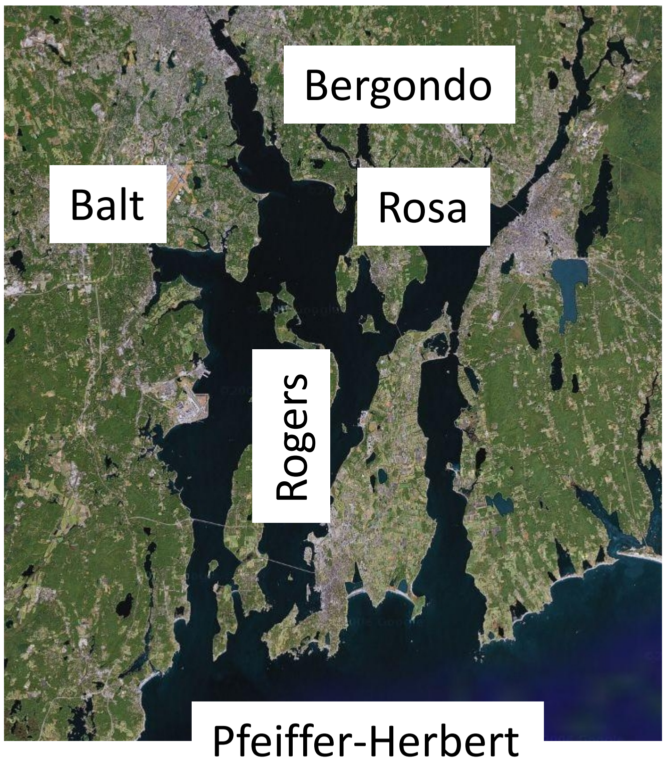
Why improvements necessary?

All numerical models give approximate solutions….

Models have shelf life (2004 ROMS not publishable today..)

ROMS + Flow Data: RI Coastal Waters

Projects from Head to Mouth



Wertmann

Numerous URI Student Projects:

- Bergondo, 2004
- Rogers, 2008
- Pfeiffer-Herbert, 2012
- Balt, 2014
- Rosa & Wertman (present)

Numerous ROMS-Projects:

NBC: Chemical transport / Ecosystem modeling

Today

RISG: Flushing from urban systems

RISG: Larval transport
(Rutherford, Levitt, Mercer, Ullman, Kincaid)

Dept. Homeland Security: Hurricane readiness
(Ginis, Kincaid, Ullman, Rothstein, Hara & UNC)

RI STAC : Unified ROMS for all RI waters
(Fox-Kemper, Ullman, Rothstein **Wertman)**

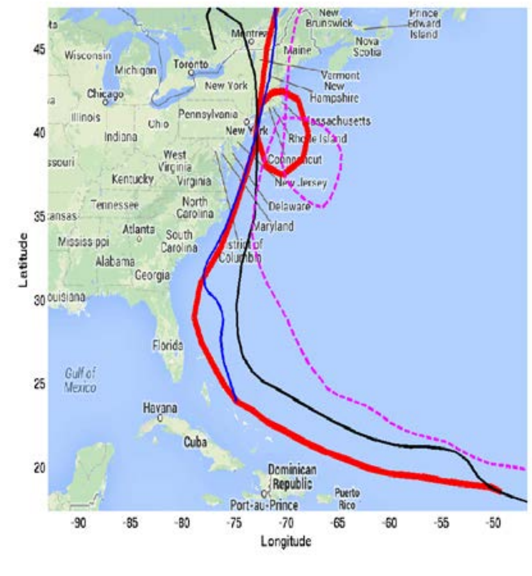
Modeling the combined coastal and inland hazards from high-impact hypothetical hurricanes

PI: Isaac Ginis, Co-Pis: C. Kincaid, T. Hara, L. Rothstein, and D. Ullman (U. of Rhode Island)
Research Collaborator: Wenrui Huang, Florida A&M University

Goals:

- End-to-end model simulations representing extreme hurricanes: open ocean, to shelf, to estuaries and into coastal watersheds.
- Results show impact on infrastructure and challenges in managing multiple threats.

Hypothetical "Hurricane Rhody": high-impact, physically realistic scenario based on historical hurricanes that affected New England



Key activities:

- Simulation historic storms
- Develop hypothetical *Hurricane Rhody*
- Couple hurricanes to ocean circulation, wave and hydrological models:
- Improve understanding through multi-model approach
  ROMS, ADCIRC, WaveWatch III, HEC-HMS and HEC-RAS

Transition Approach and End Users:

- Northeast regional training workshops with with DHS, NOAA/NWS and DHS stakeholders
- RI CRMC and RIEMA, Leverage URI CRC activities to connect with coastal managers to the FEMA resilience planning process

UNC-Chapel Hill Leading Center: New colleagues are experts in ADCIRC

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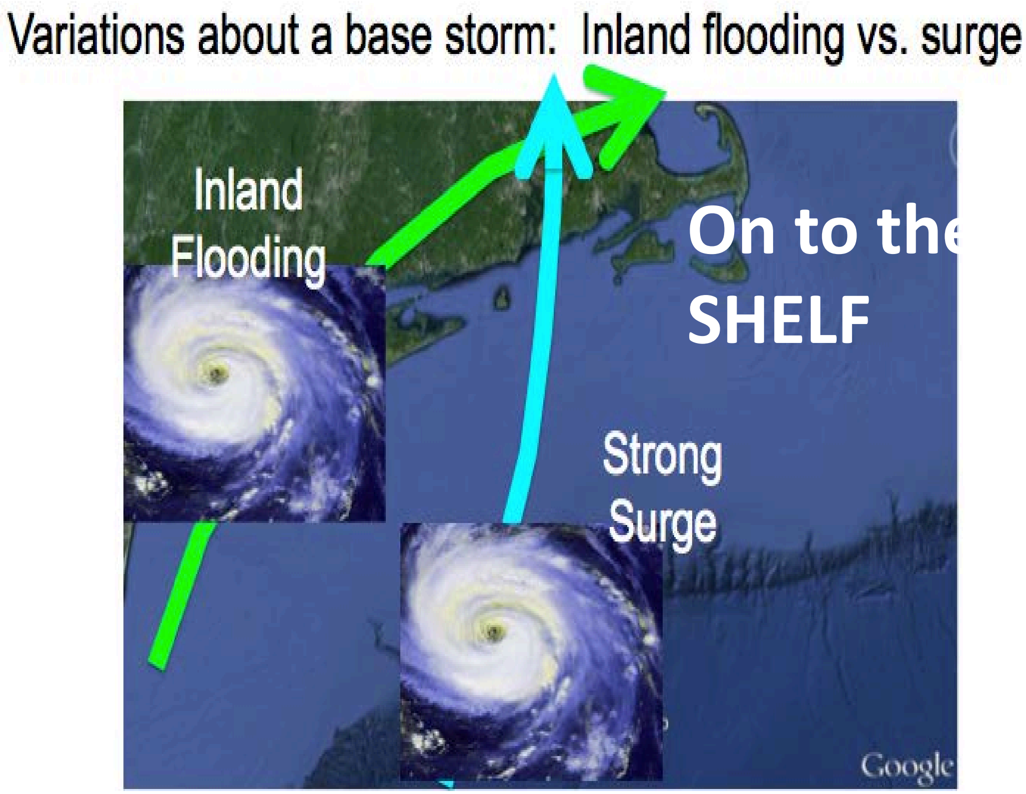
From ocean-scale **to shelf scale**



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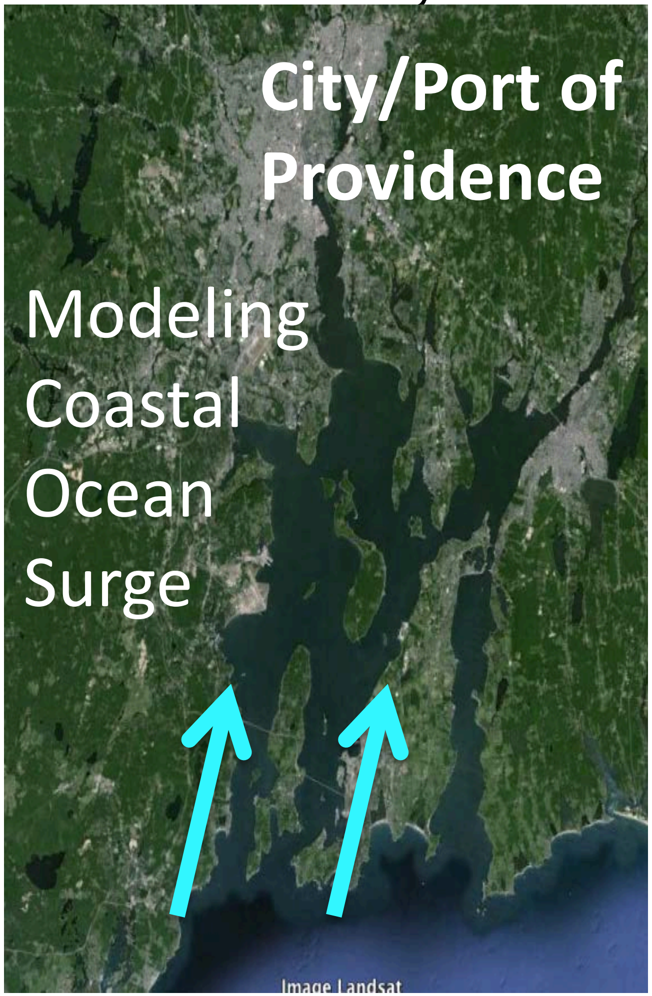
From ocean-scale to shelf scale

to estuarine scale

Narragansett Bay Estuary



Modeling the combined coastal and inland hazards from high-impact hypothetical hurricanes

PI: Isaac Ginis, Co-Pis: C. Kincaid, T. Hara, L. Rothstein, and D. Ullman (U. of Rhode Island)

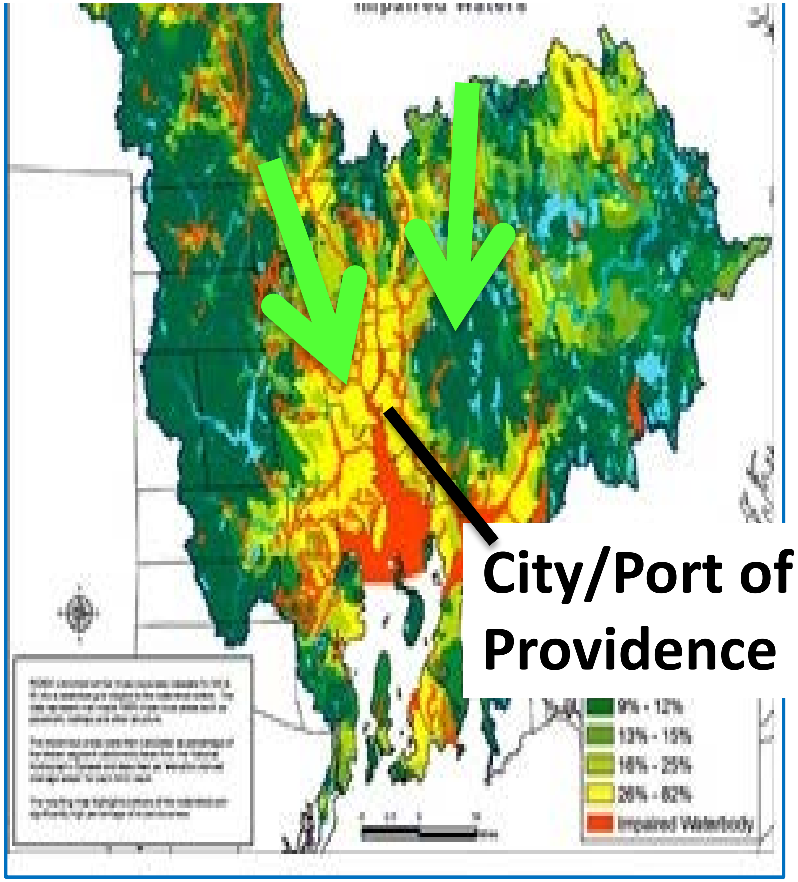
Research Collaborator: Wenrui Huan

Modeling Watershed Flooding: Narragansett Bay

From ocean-scale to shelf scale

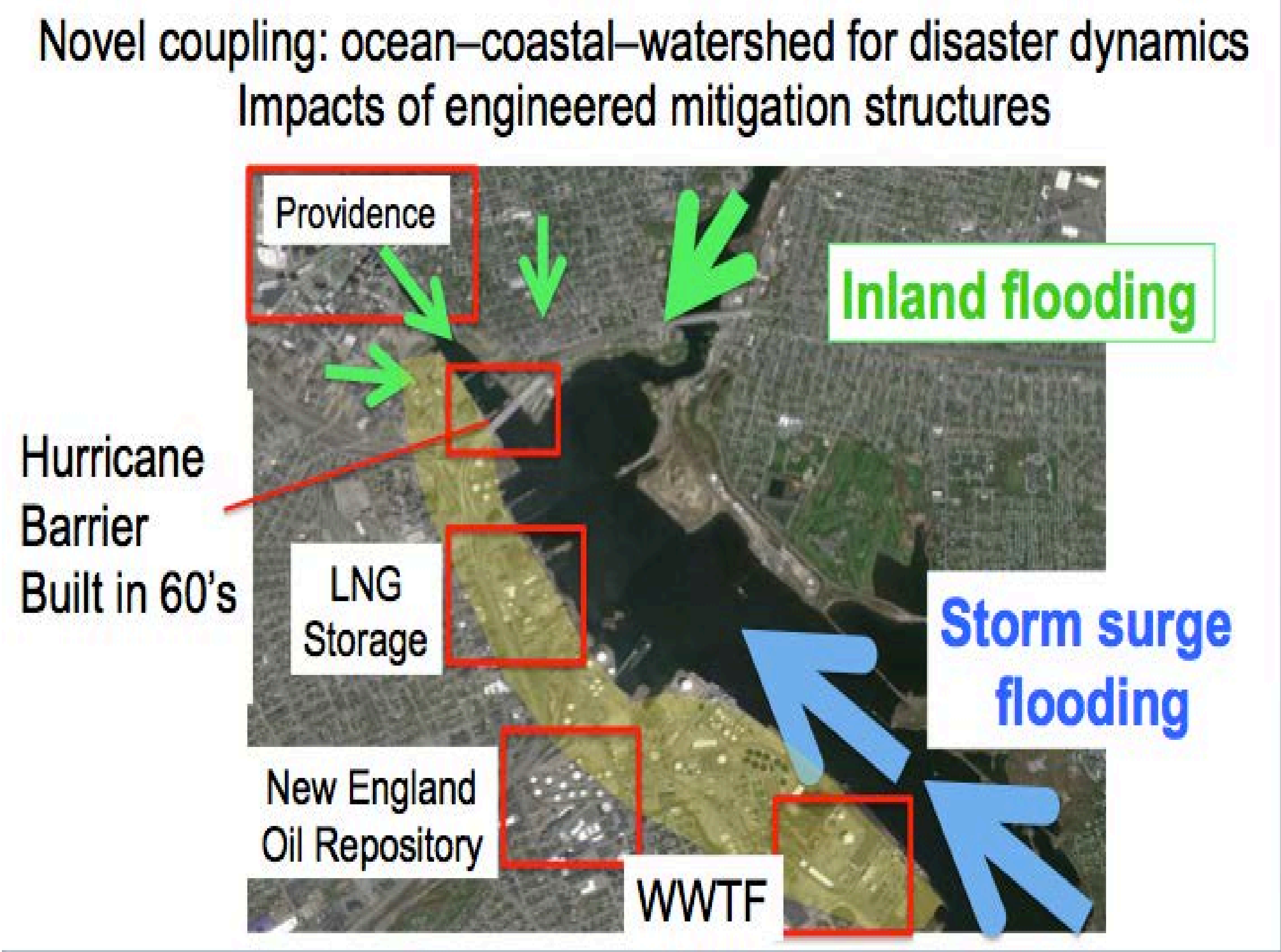
to estuarine scale

to watershed scales



From ocean-scale down to the scale of Port of Providence:

1) Impacts on sensitive resources 2) Positive/negative impacts of engineered structures



Kincaid: ROMS Models for Narragansett Bay

1st: General circulation / transport

- CCW flow through Bay (up the East / Out the West)
- Defining retention zones / circulation gyres

Today

2nd: Hydrodynamics & Chemical transport patterns.

- Forensic Oceanography: Track distinct river & WWTF chemical sources
- Northern sources alternate West vs East Passage flush
- Southern sources wrap to north.......
  - Taunton River into CCW flow (to N. Prudence, Prov. River, Greenwich Bay)
  - Pawtuxet River onto Edgewood and into Seekonk
  - East Prov WWTF northward vs. Fields Pt. southward

3rd: ROMS NPZD

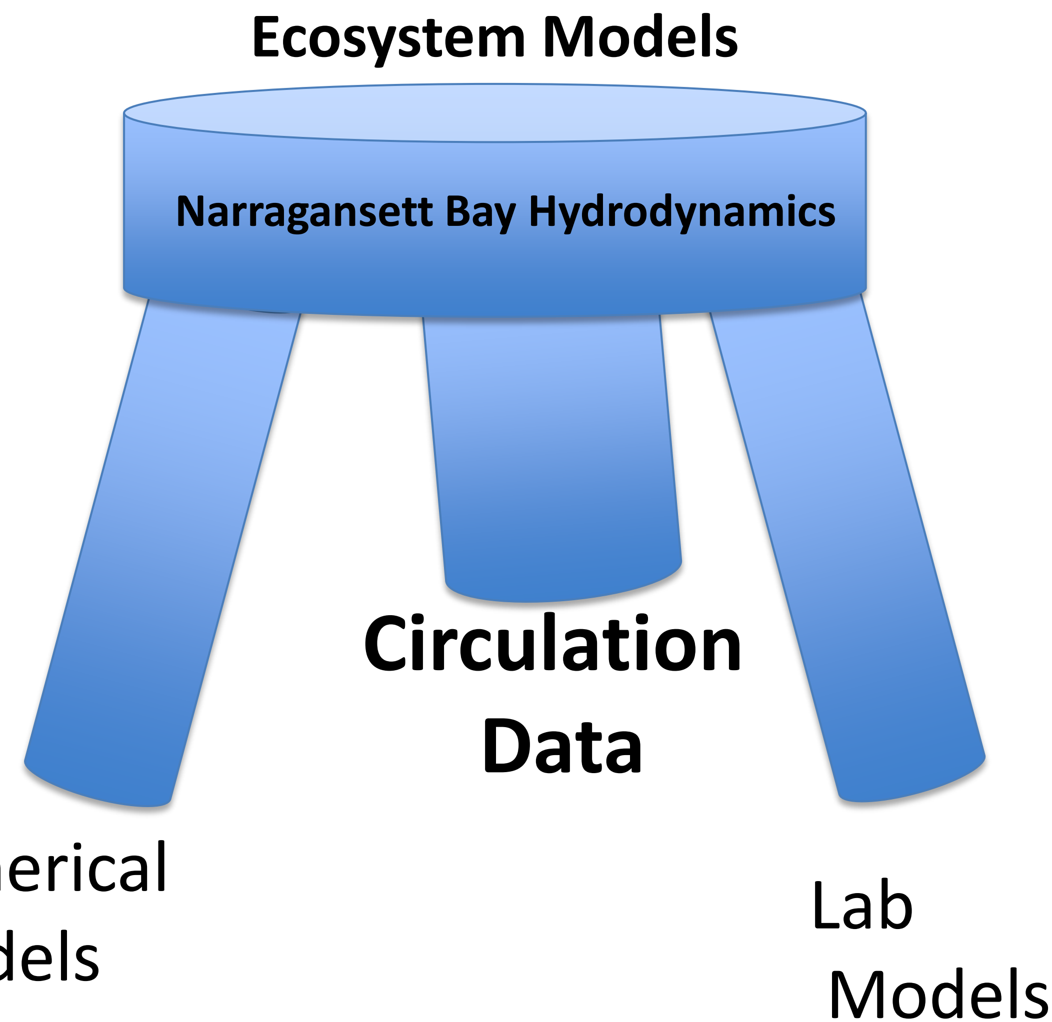
- Hydrodynamics & Ecology/Biology at ~50m horizontal scales.
- physics and eco-parameters at 10 second time steps

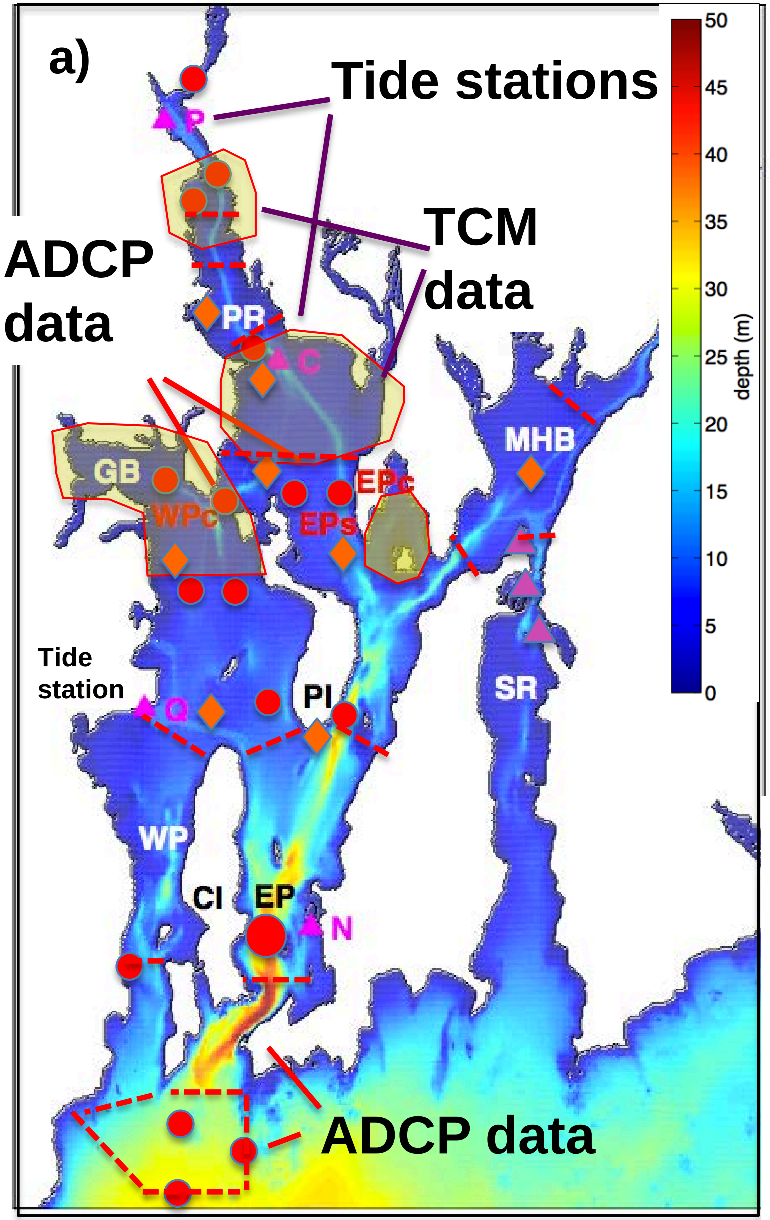
Quick word about….Why model improvements necessary?

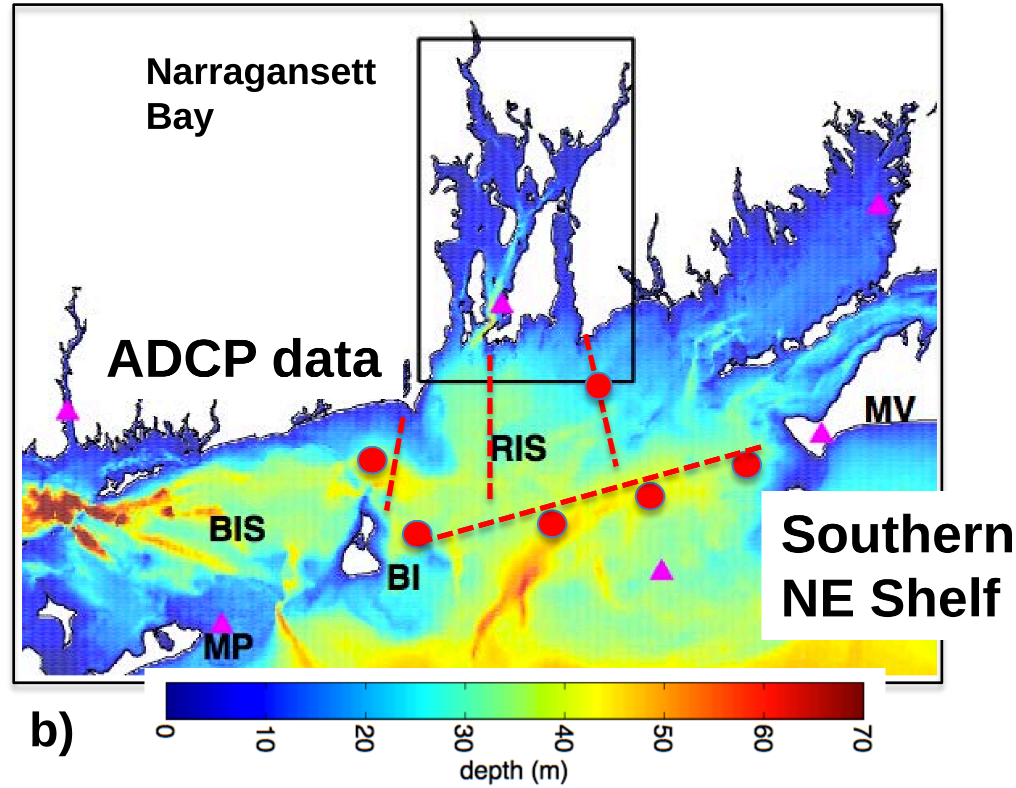
All numerical models give approximate solutions….

Best hydrodynamic foundation not just numerical….DATA….

The 3 Legged Stool





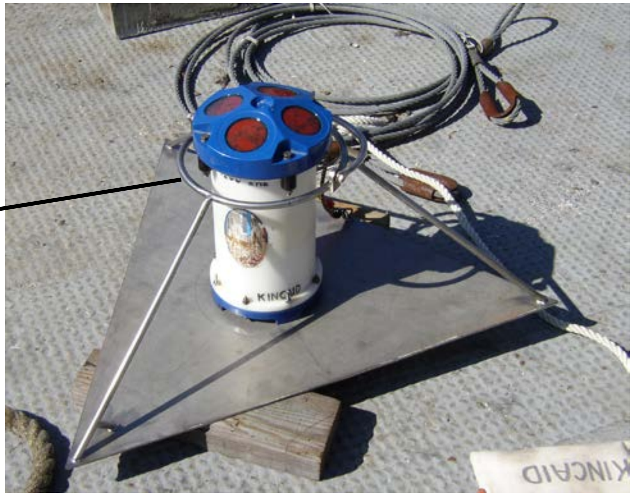


20 years of hydrodynamic data
RI Coastal Waters:

Red circles: Moored ADCP (3-12 mo)
Orange circles: Moored ADCP
Red dash line: ADCP underway transects
Shaded: Spatial-temporal TCM (2-3 mo).
Magenta Triangles: Tide gauge exp.
Orange diamonds: Fixed buoy network

Acoustic Doppler Current Meters
ADCPs

Map water circulation patterns in space & time

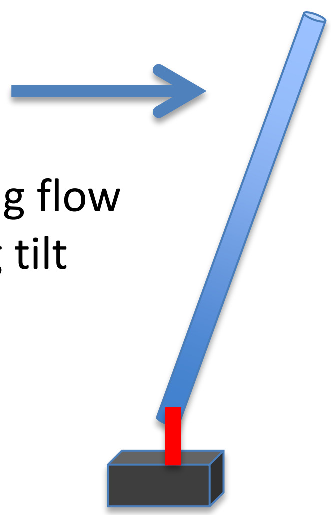


CIRCULATION DATA

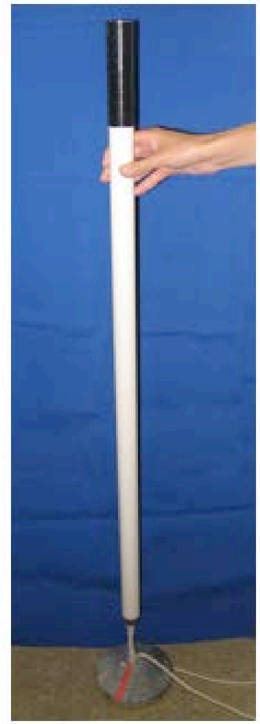
Tilt Current Meters (Low Cost $300 vs. $30000)

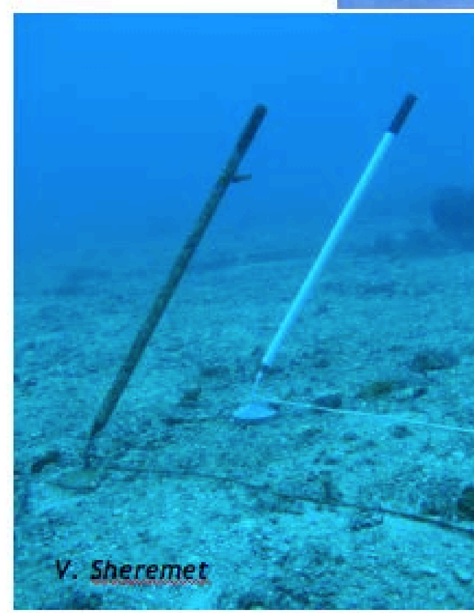
Good spatial & temporal. Details of how Gyres Work.

Weak flow
= small tilt



Strong flow
= big tilt





Resources in RI WATERS for Data-Model Comparisons: Data Point Estimates:

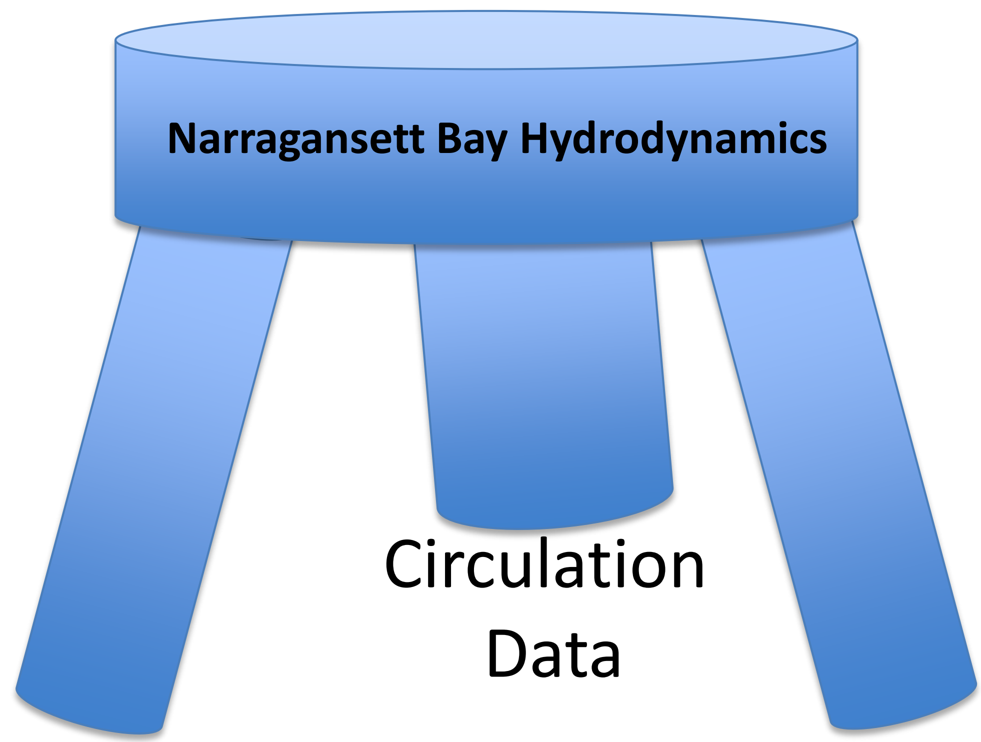
Underway, Shipmounted ADCP Surveys:
70 million circulation data points

Moored, bottom mounted, upward looking ADCPs :
50 million data points

Tilt current meters : **30 million data points**

Our hydrodynamic foundation is solid

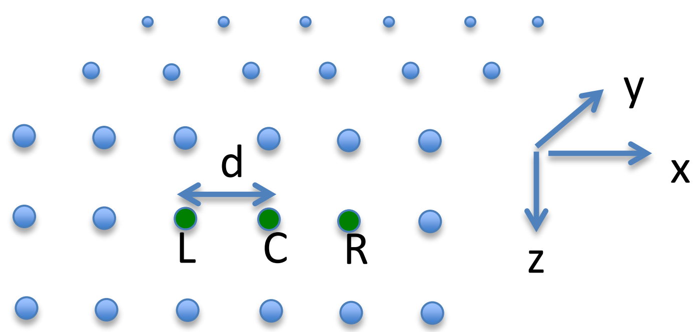
The 3 Legged Stool



All numerical models swap partial derivatives in conservation equations

$$\partial^2 S/\partial x^2$$

For simple arithmetic on a grid



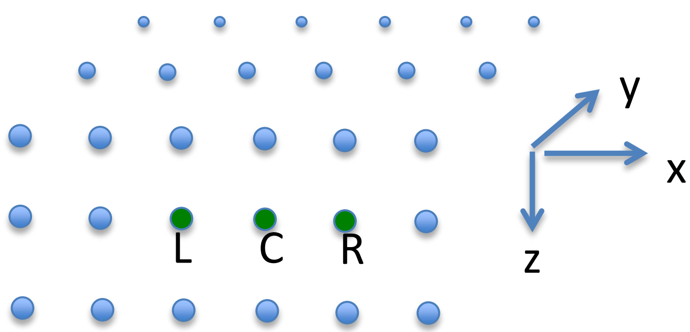
$$\partial^2 S/\partial x^2 \sim (S_L + S_R - 2 * S_C)/d^2$$

Salinity at node L plus salinity at node R minus ………

All numerical models swap partial derivatives in conservation equations

$$\partial^2 S/\partial x^2$$

For simple arithmetic on a grid



$$\partial^2 S/\partial x^2 \sim (S_L + S_R - 2 * S_C)/d^2$$ *+ lots of other terms*

In the conservation equations…tricky

In the numerical models …much simpler…..but neglects stuff

Grids important: Want them closely packed, but open boundaries far removed……

1) Providence River ROMS

Seekonk to N. Prudence
200 m grids (mapview)
Not gyre resolving

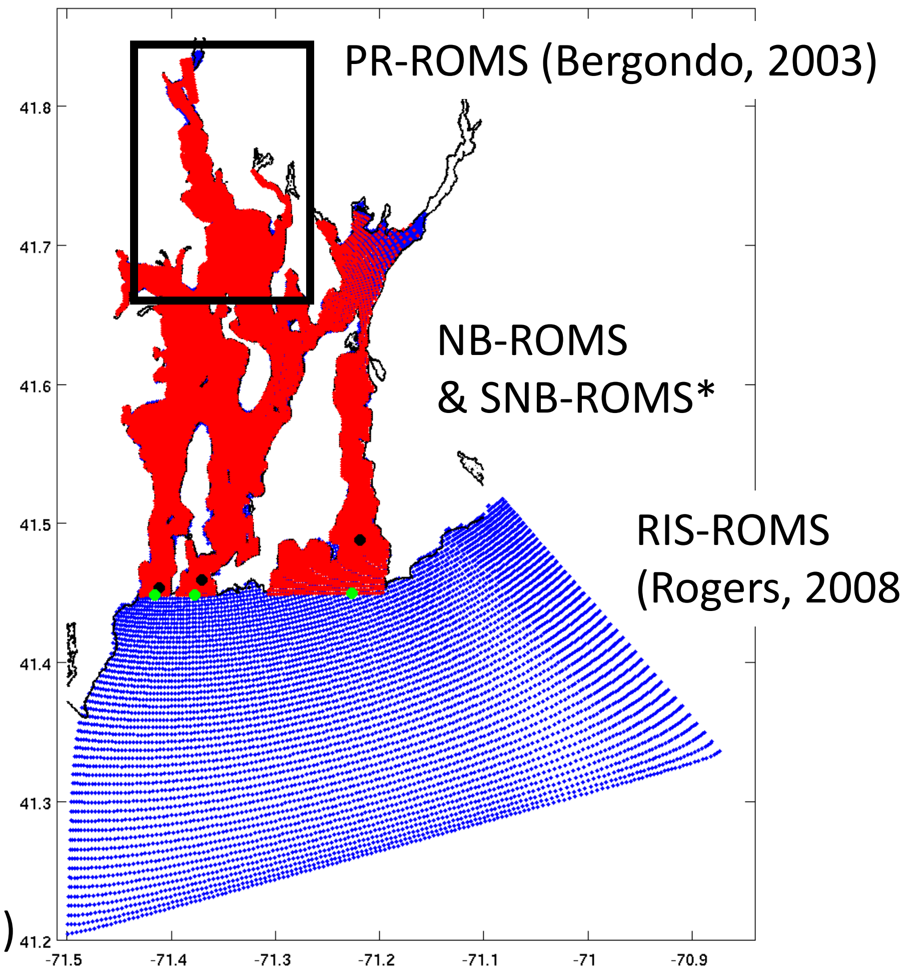
2) Bay-RIS ROMS

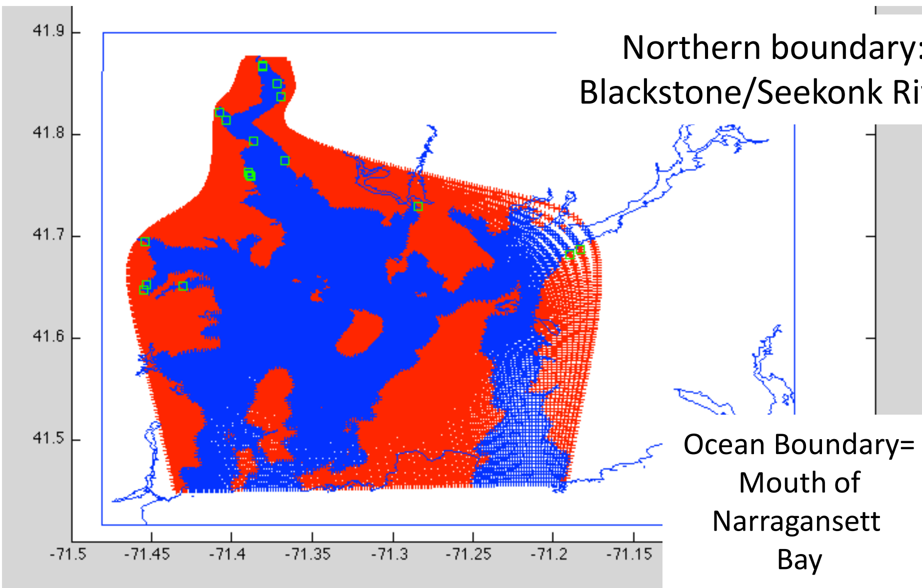
Seekonk to Block Island/Vineyard
>200 m grid spacing (in mapview)

3) Full Bay ROMS

Seekonk to Bay Mouth
Driven at mouth by Bay-RIS ROMS
<50 m grid spacing in north

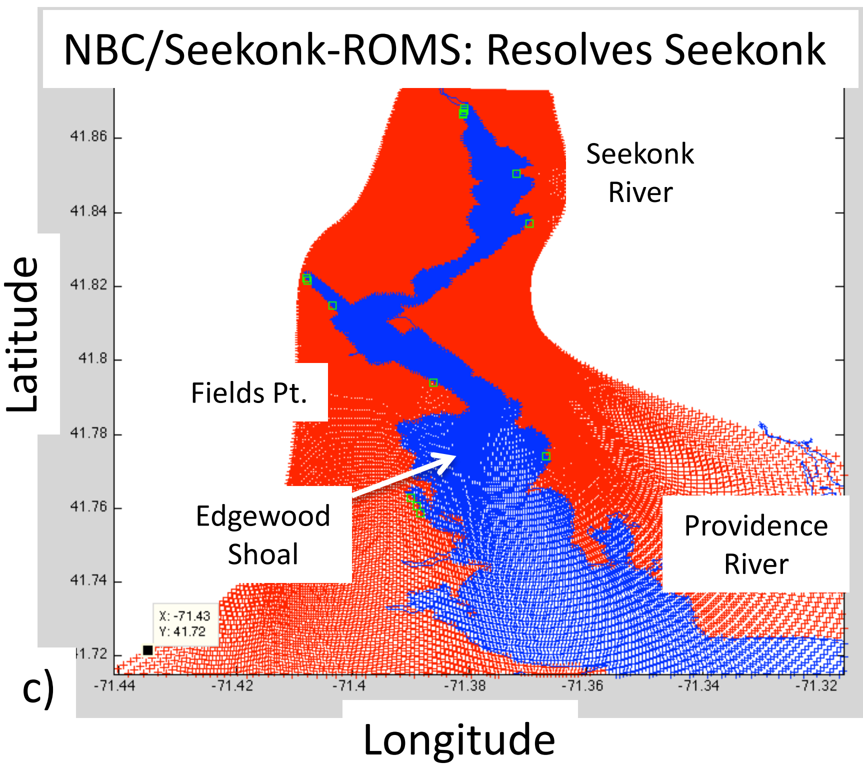
a) CHRP (Seekonk approx.)
b) NBC Seekonk -ROMS (SNB-ROMS)
  resolves Seekonk
  Distinct river/WWTF dyes
  NPZD on

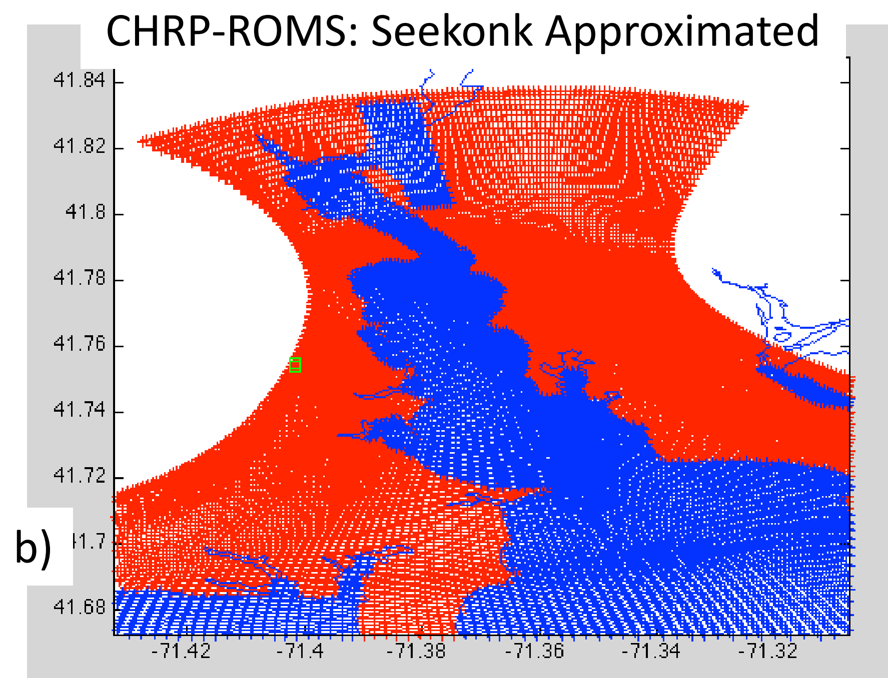




CHRP-ROMS & NBC/Seekonk-ROMS:

Similar extent, grid resolutions

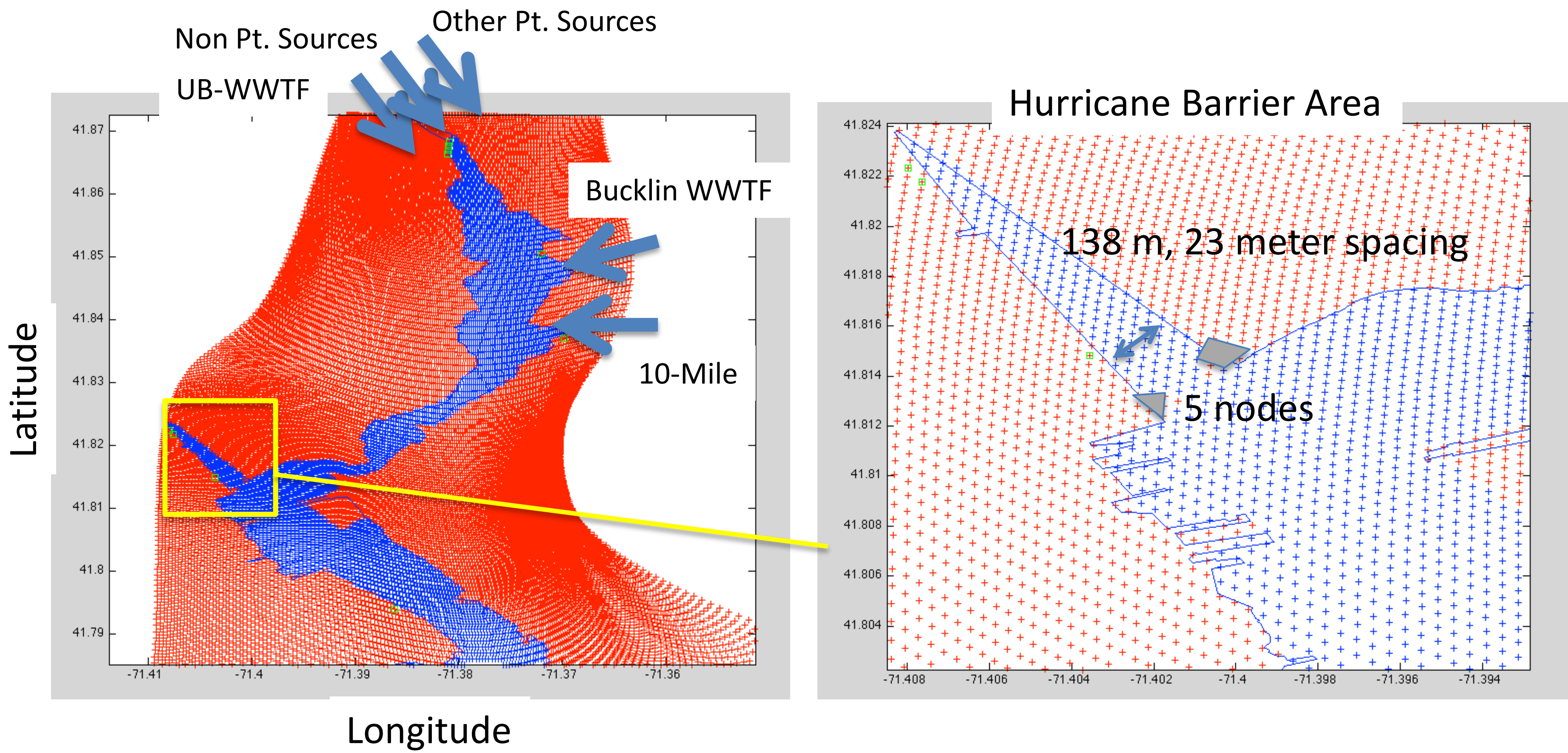




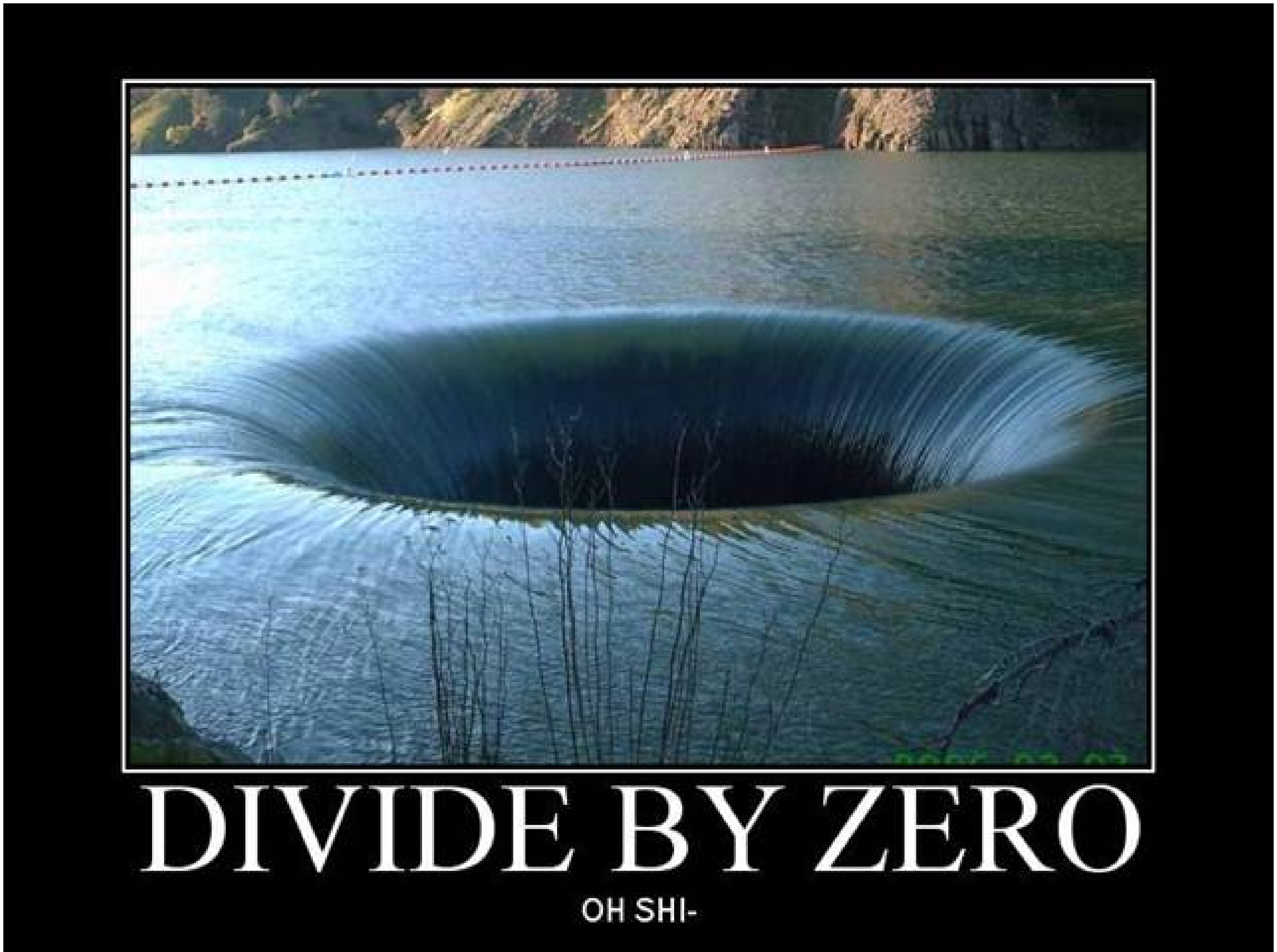
NBC/Seekonk-ROMS: Resolves Seekonk

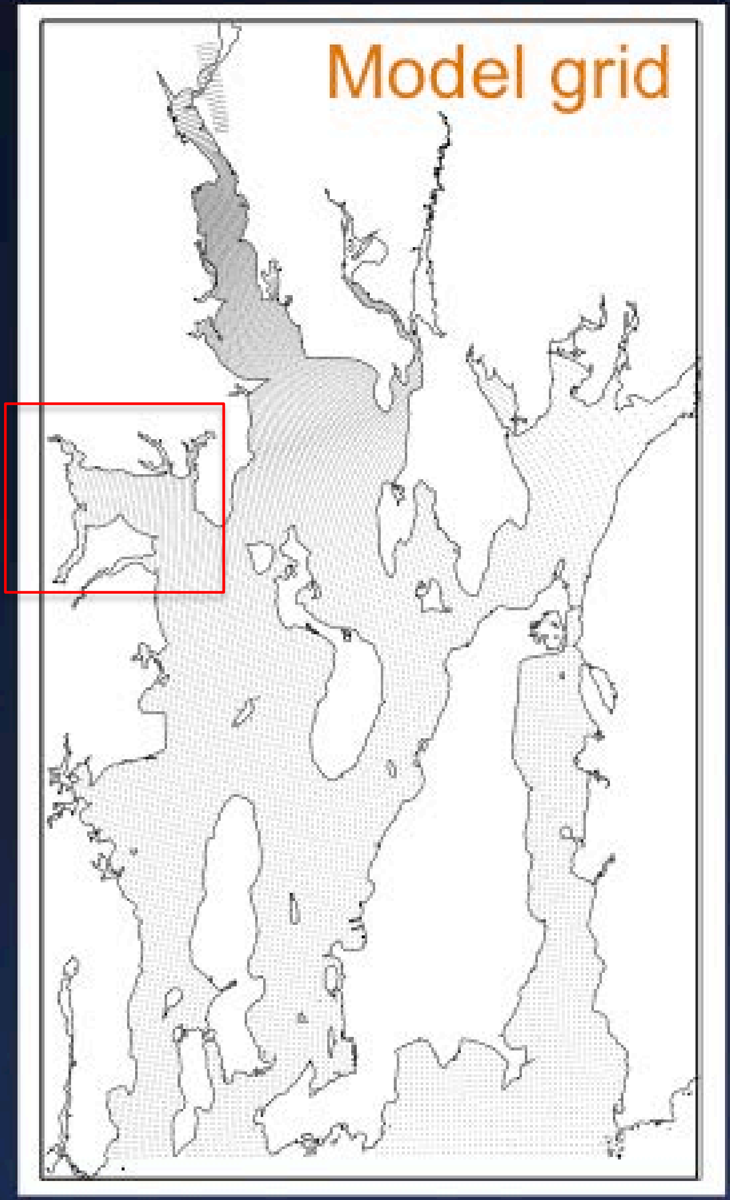
Umass Blackstone TMDL Model Output: 2010-2011

Separate Nitrogen Fluxes:



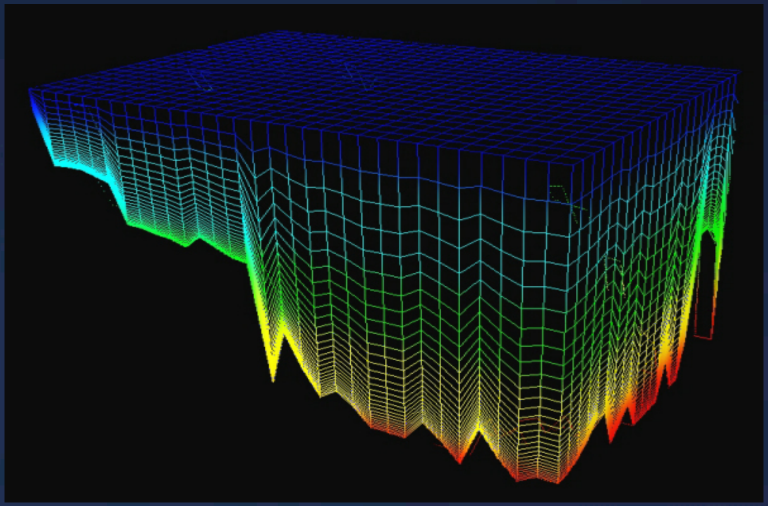
3-D ROMS Computer Models: Brief look under hood





Numerical modeling

Regional Ocean Modeling System (ROMS*) is a three-dimensional hydrodynamic model



* Shchepetkin, A. F., and J. C. McWilliams, 2005: The Regional Ocean Modeling System: A split-explicit, free-surface, topography following coordinates ocean model, Ocean Modelling, 9, 347-404

Workings of the model

Model input

- Forces
  - Tides
  - Wind
  - Rain
  - Heating
  - Runoff
  - Shape

Calculations

Conservation Equations:
Mass
Momentum
Energy, Salt

Model output

- Response
  - Currents
  - Tracer dispersion (dyes & floats)
  - Temperature
  - Salinity
  - Mixing

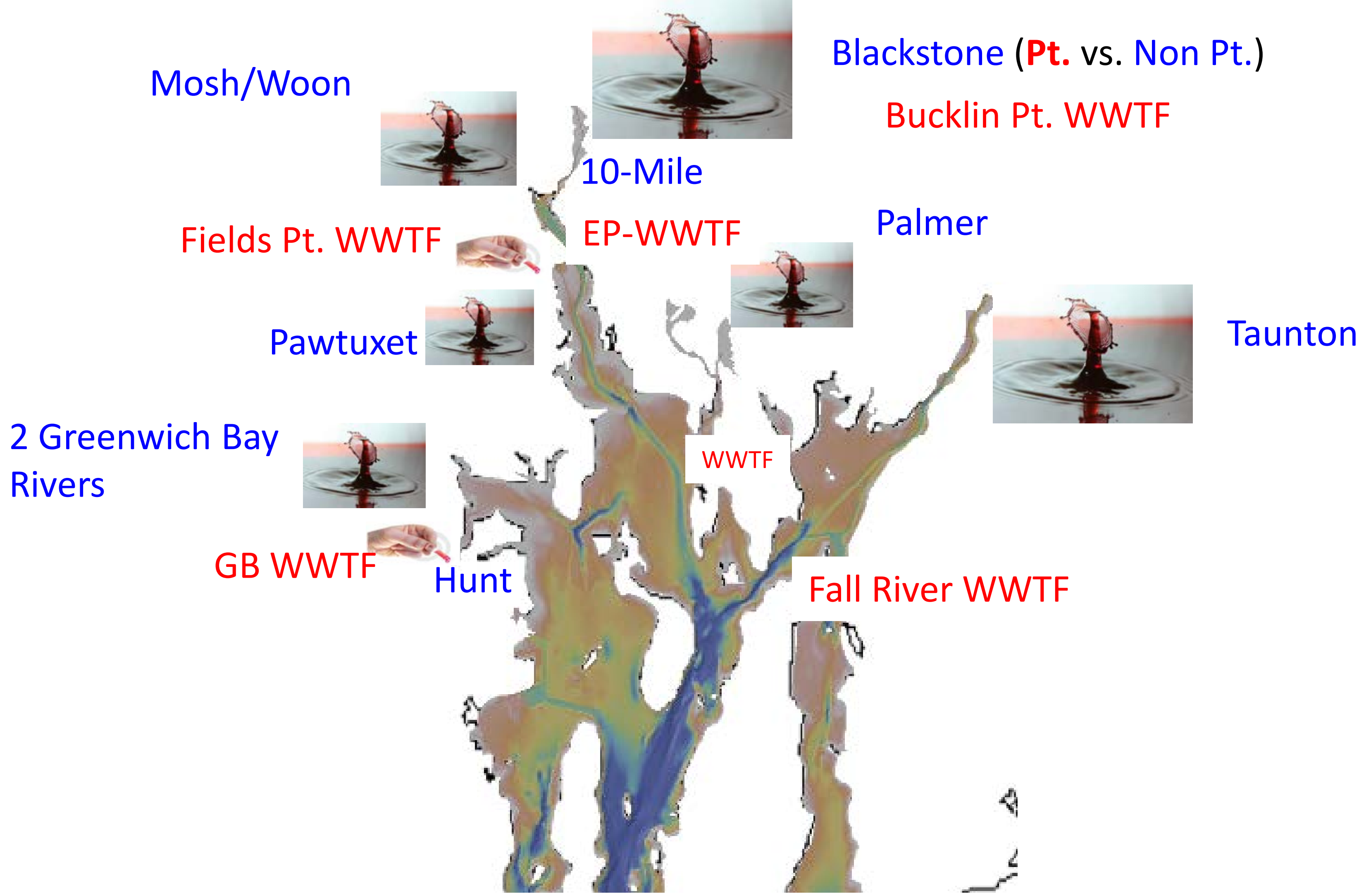
Outline

1. Data sets show basic circulation patterns *(heard it before, little bit later)*

2. ROMS models calibrated versus data *(Dave Ullman summarized)*

3. ROMS models used to simulate flow & chemical transport,
   test management stratgies

1. ROMS NPZD Results

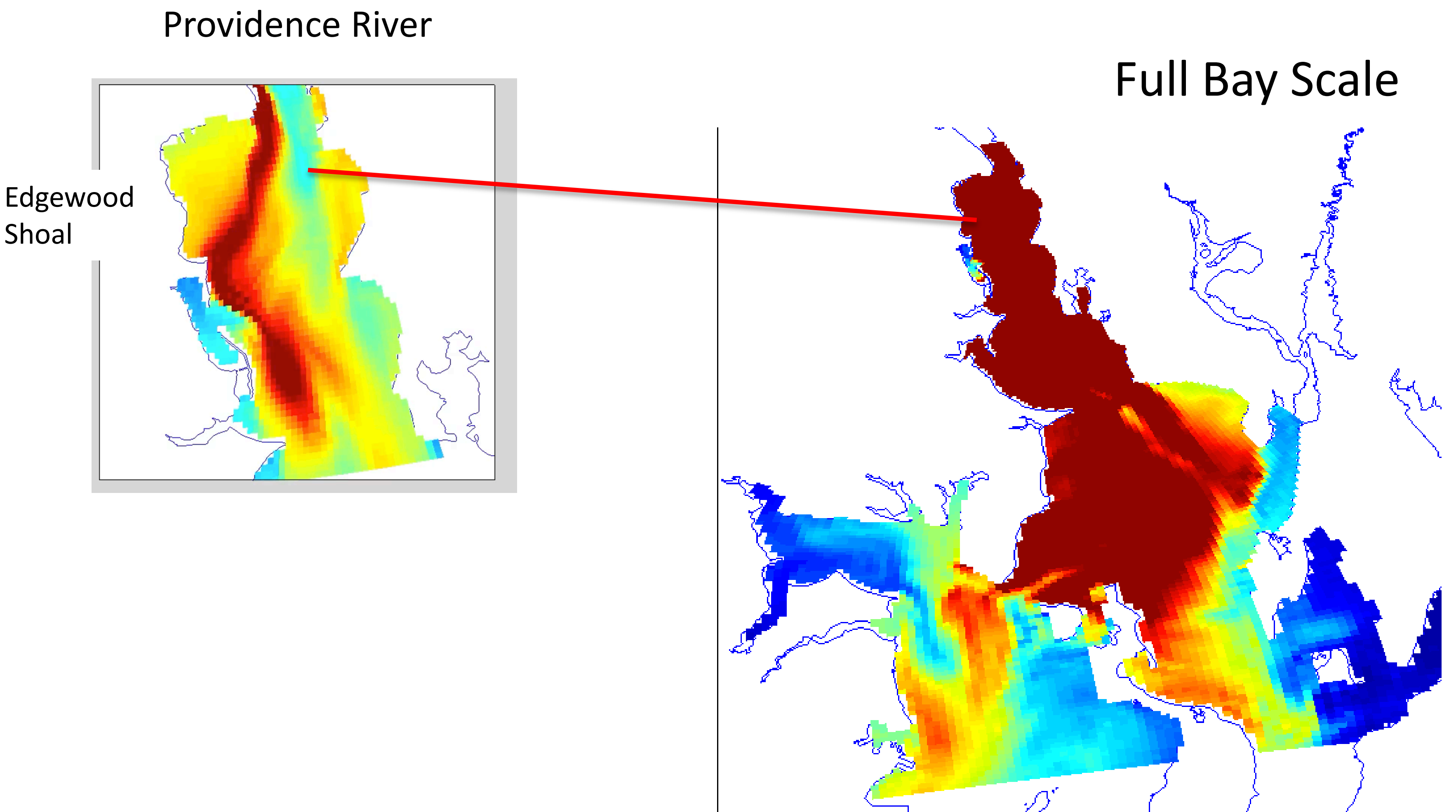


16 Distinct Dyes for Rivers (9) & Waste Water Treatment Facilities(7):

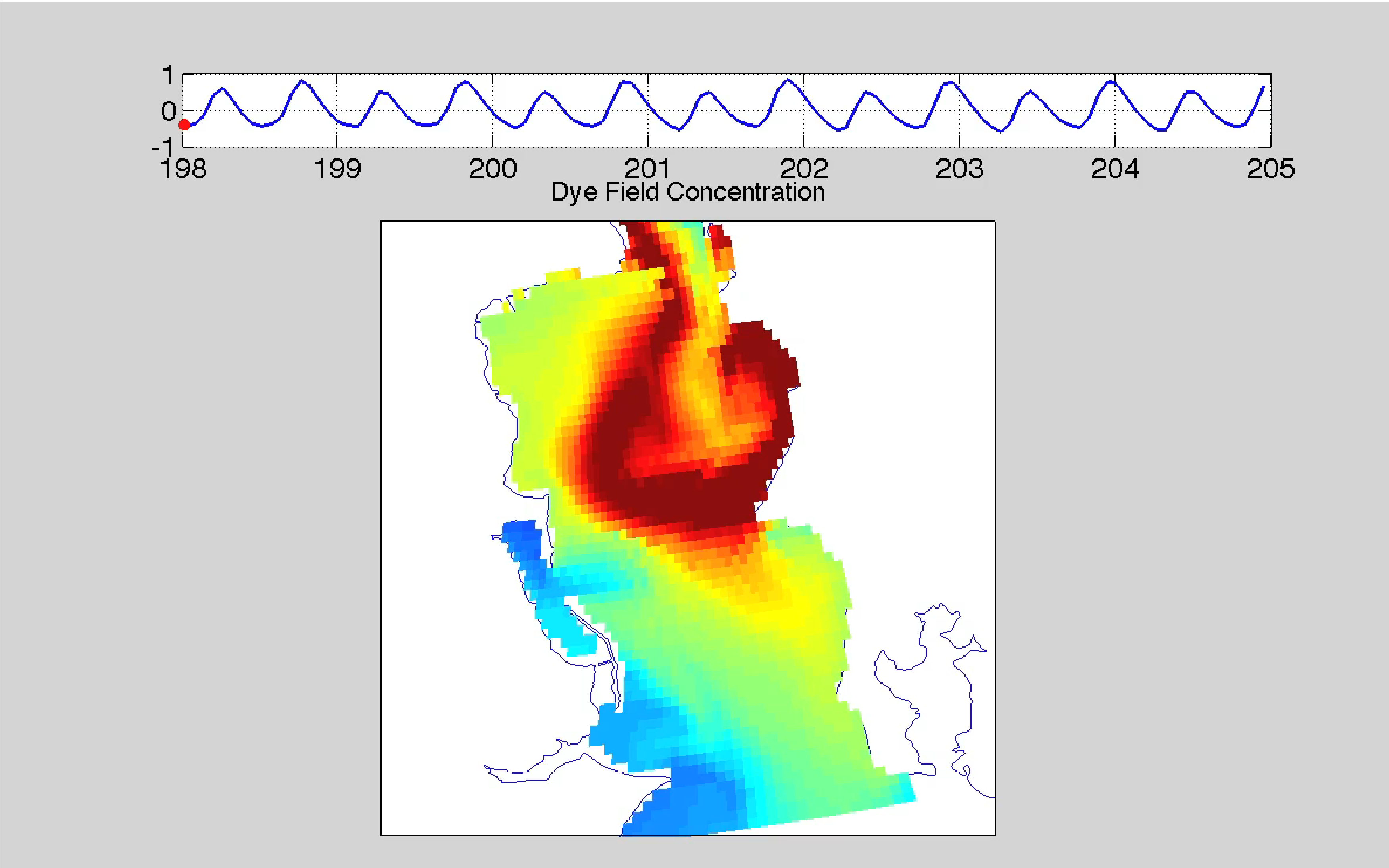
1) How do dyes from each source move through system?
2) Which dyes accumulate in hot spot areas vs. are flushed efficiently?
3) Independent control: Can reduce any one, holding others fixed

ROMS Simulate 4-D flow fields & chemical transport

Distinct dyes reveal transport on scale of sub-systems & bay-wide scales



2010 ROMS Simulation: Tracking Fields Pt. WWTF Dyed Plume, **Near-Surface**



Play video

Passive chemical transport in ROMS:

Weakness: Not a ecosystem model.

Strengths: Define sources/pathways; compare with DYE studies

Dye released from NBC Fields Pt WWTF, 1989
Dye plume appears on Edgewood Shoals.

How did it get there?

ROMS summer 2010 Simulation.
Dye plume from Fields Pt.

How did it get here?

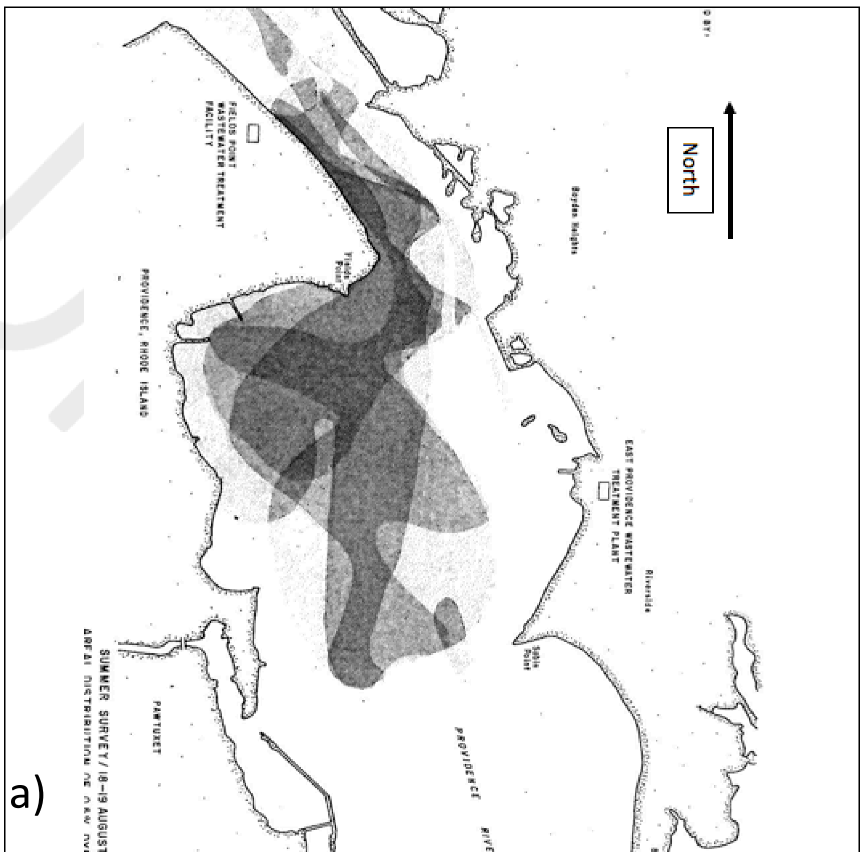
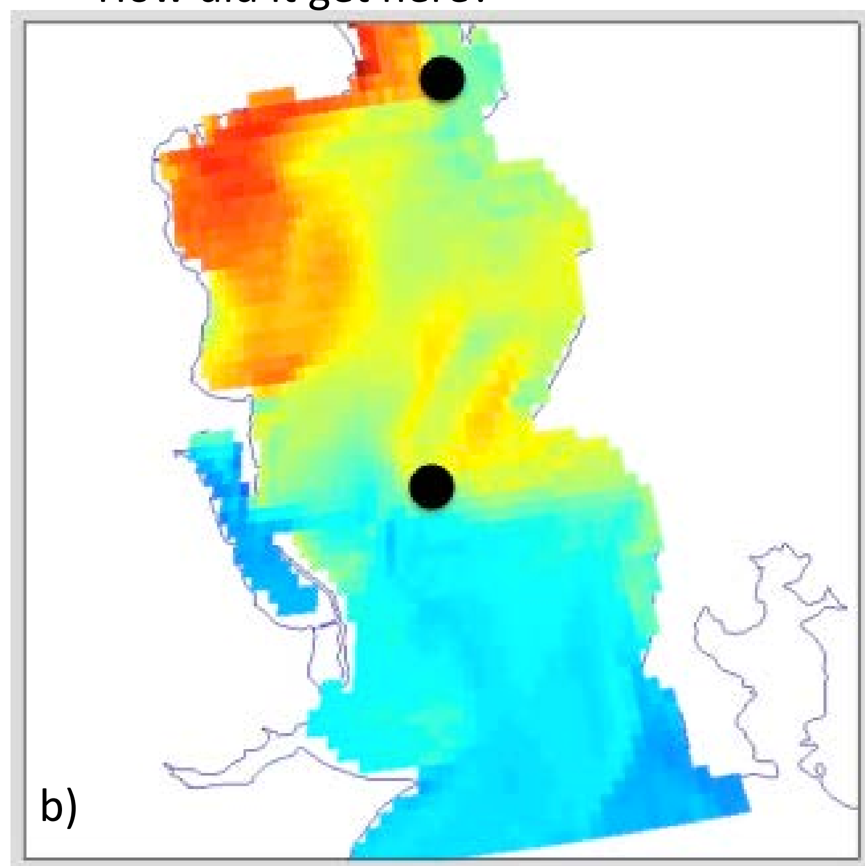
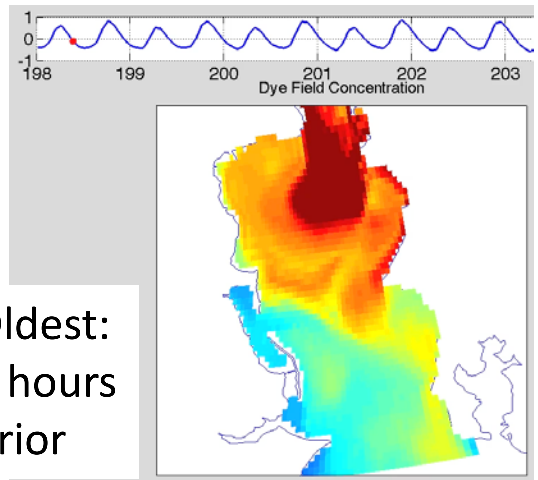


Figure 2: Results of Summer 1989 Dye Test at Fields Point WWTP

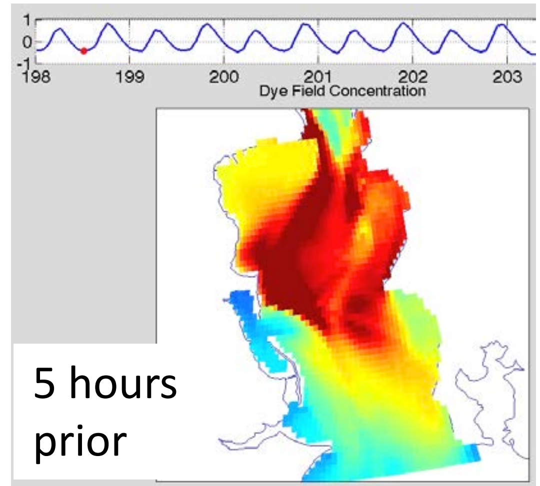


Summer 2010 ROMS simulation: Time evolution Fields Pt. chemical plume.

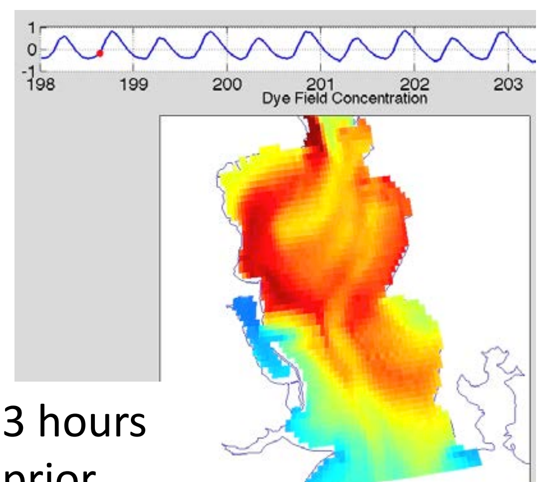
1. Outflow jet along channel-shoal interface.
2. Plume raps clockwise in Edgewood Shoals gyre
3. Time frame of sampling frequency of 1989 dye study



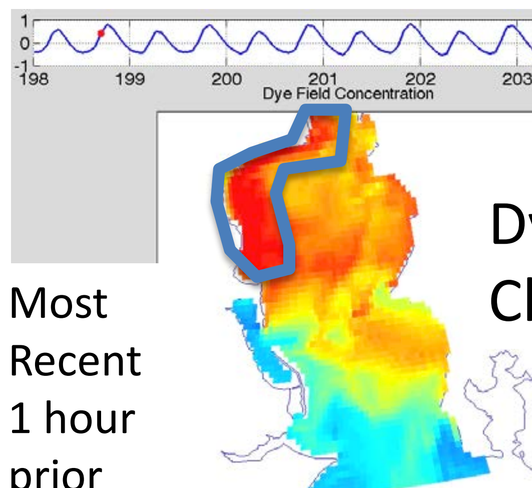
Oldest: 7 hours prior



5 hours prior



3 hours prior

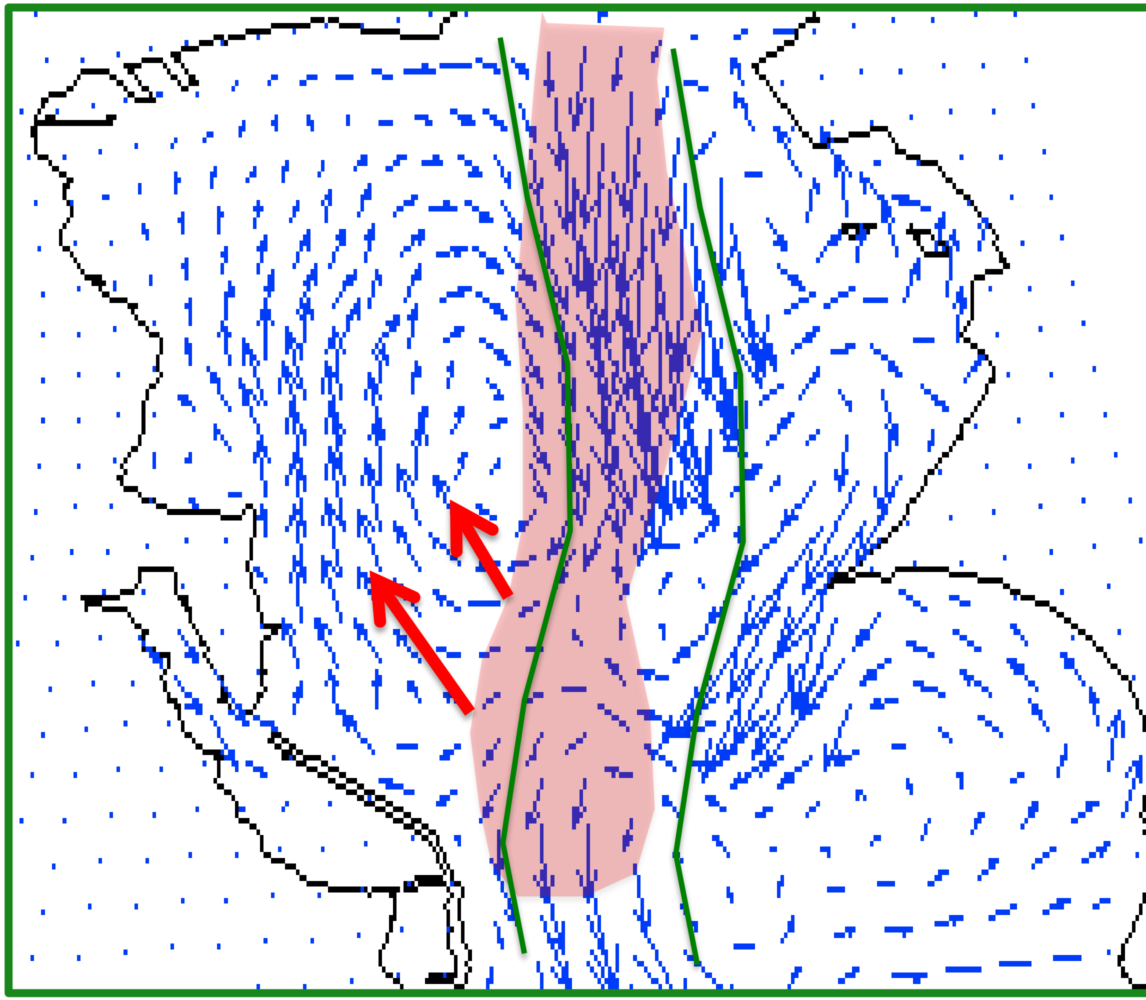


Most Recent 1 hour prior

Dye wraps in Clockwise gyre

Data + High resolution (30m) ROMS: Velocity vectors in mapview

show stable clockwise gyre on Edgewood Shoals (more later)



Take larger scale, down-bay view of chemical transport

Blackstone non-point source dye: Variable pathways

Fields Pt dye: Smaller plume

Taunton River: Wraps into CCW Bay-flow,
felt in Ohio Ledge, Greenwich Bay, Prov. River

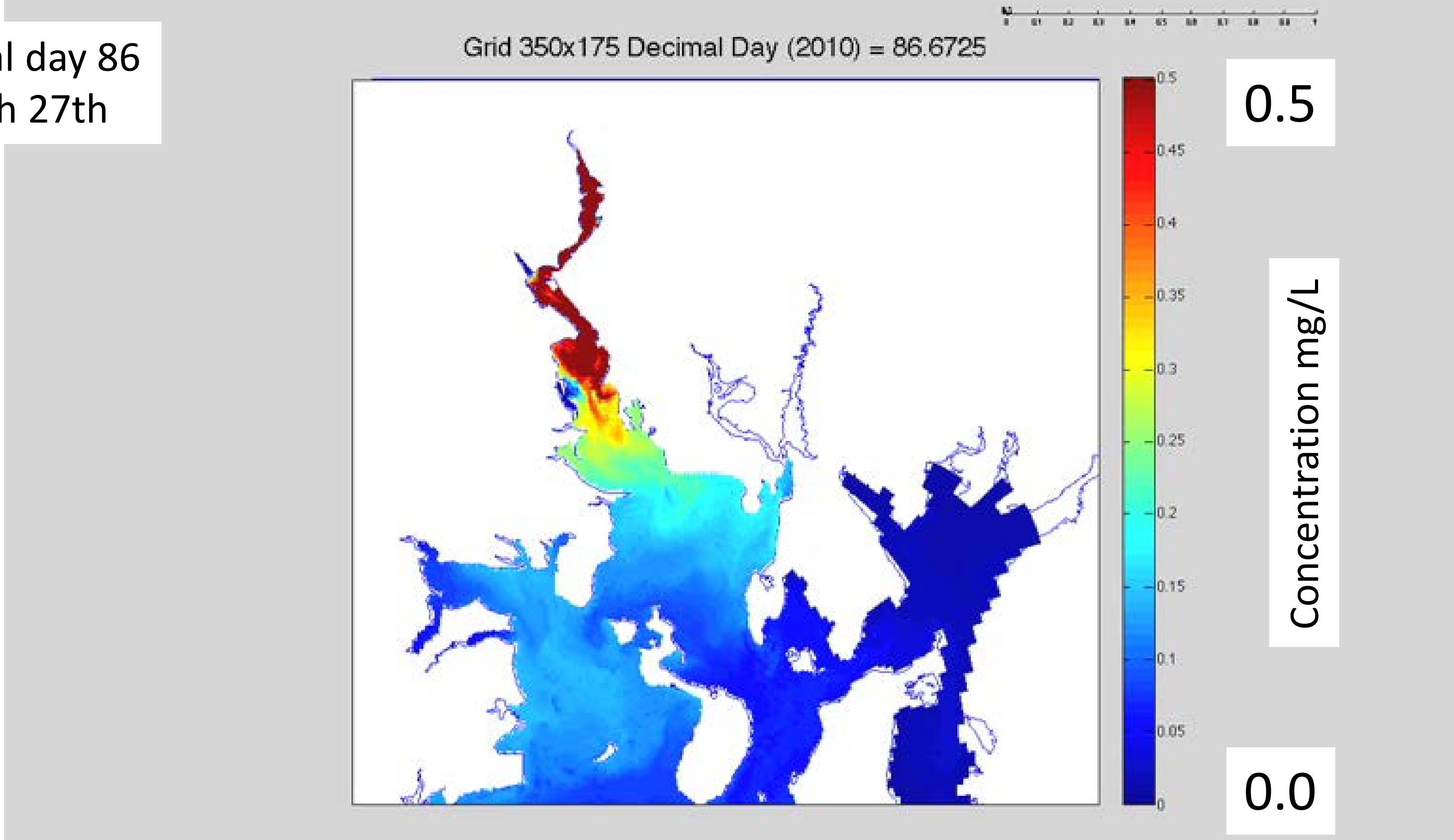
Southern sources go north

**Dye fields are scaled to actual values based on source concentration, but are passive, not active*

Blackstone River Dye (*TD Nitrogen**): Non-Point Sources

Alternate West Passage vs. East Passage Flush (NE-ward wind)

Decimal day 86
= March 27th



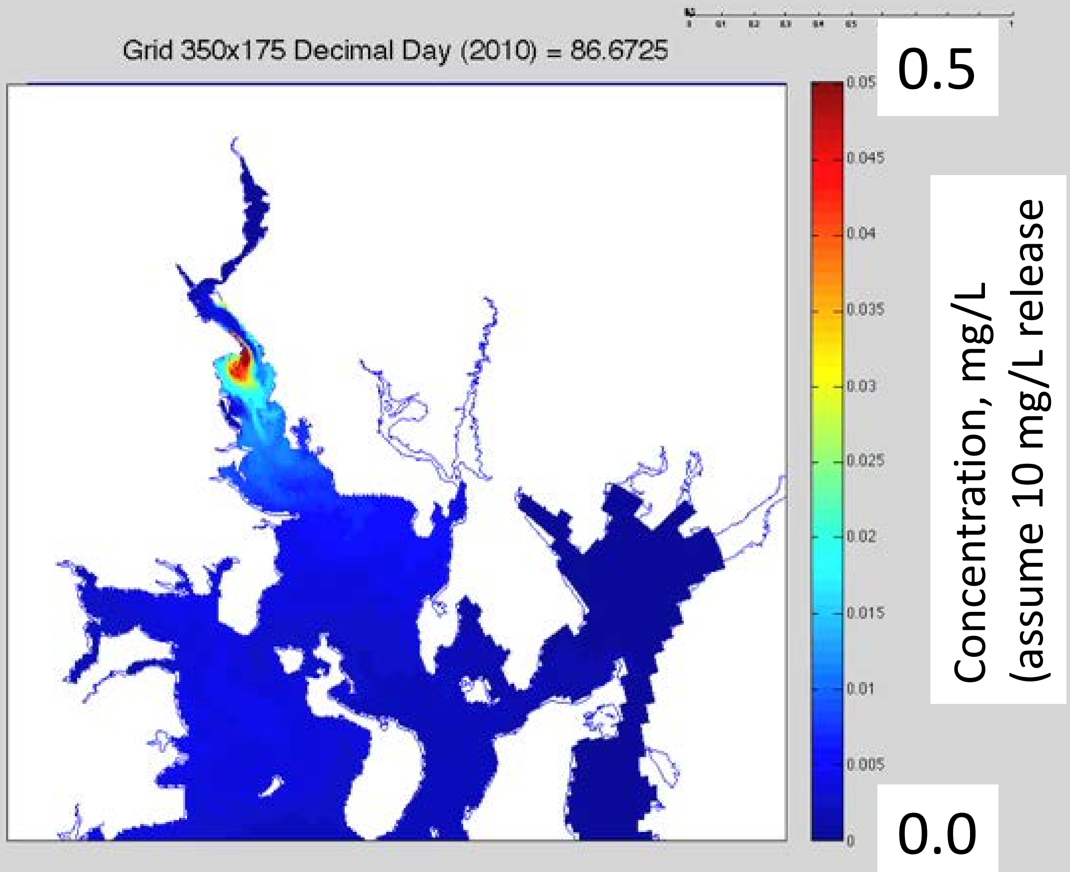
**Dye fields are scaled to actual values based on source concentration, but are passive, not active*

Play Video

Fields Pt. Dye (Scaled to *TD Nitrogen*)

Similar flush, smaller overall chemical plume

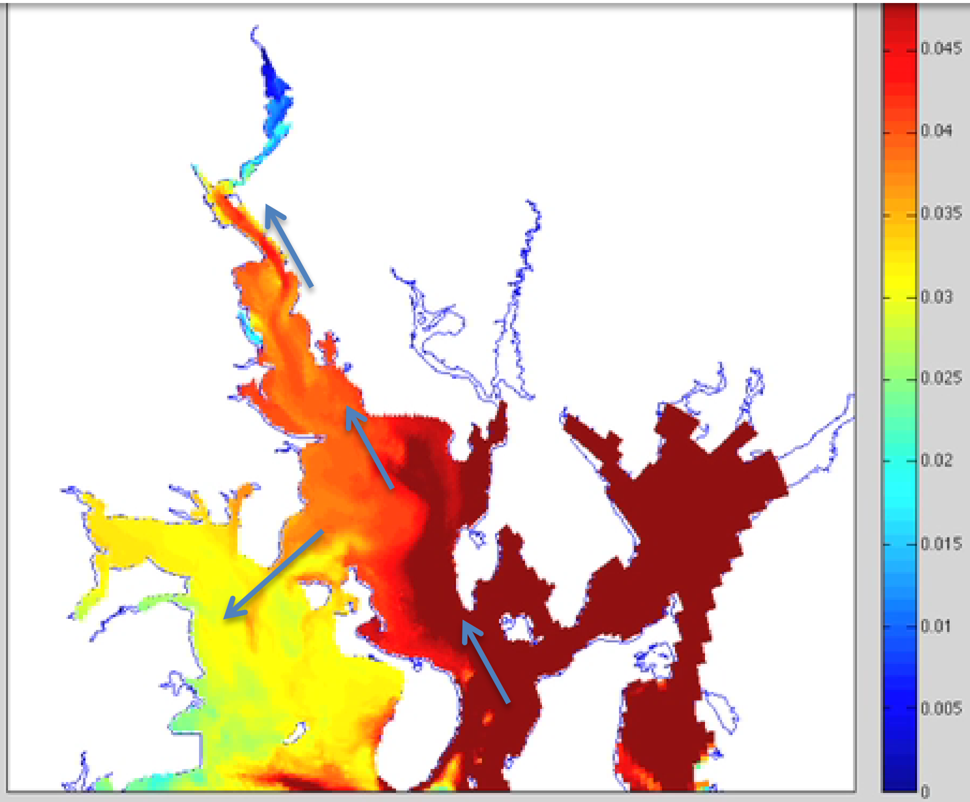
Decimal day 86
= March 27th



Play Video

Pulses of Southwestward Winds, Draw Taunton River Dye/*Nitrogen* from South to North

Mid-level Contours



Play Video

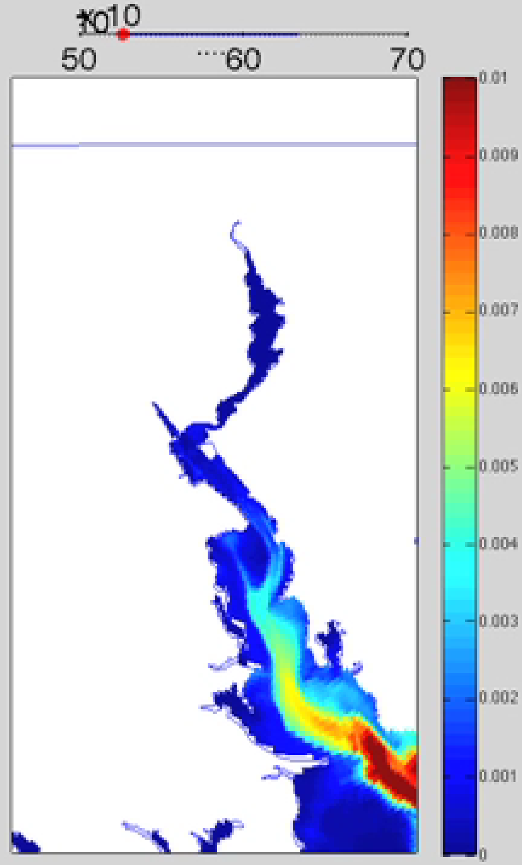
Taunton River Dye: Close up of deep northward path.

Edgewood channel plume

Choke value at India Point

Southward winds after day 60

Stronger northward intrusion

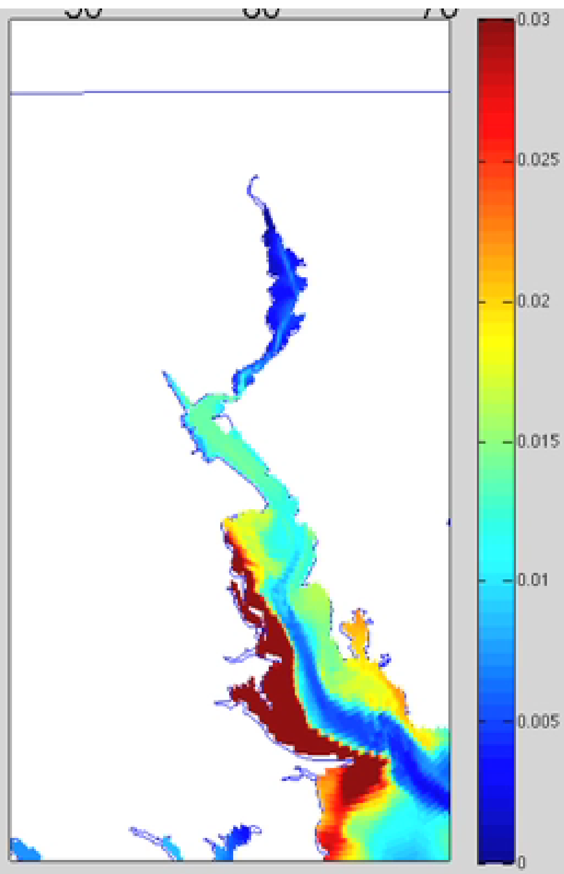


Play Video

Pawtuxet River Dye: Close up of mid-level, northward path.

Onto Edgewood

Choke value at India Point



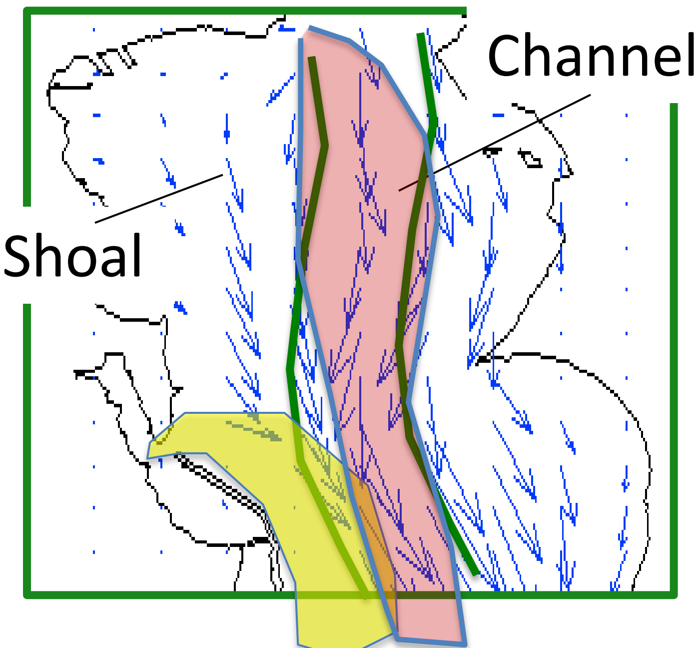
Play Video

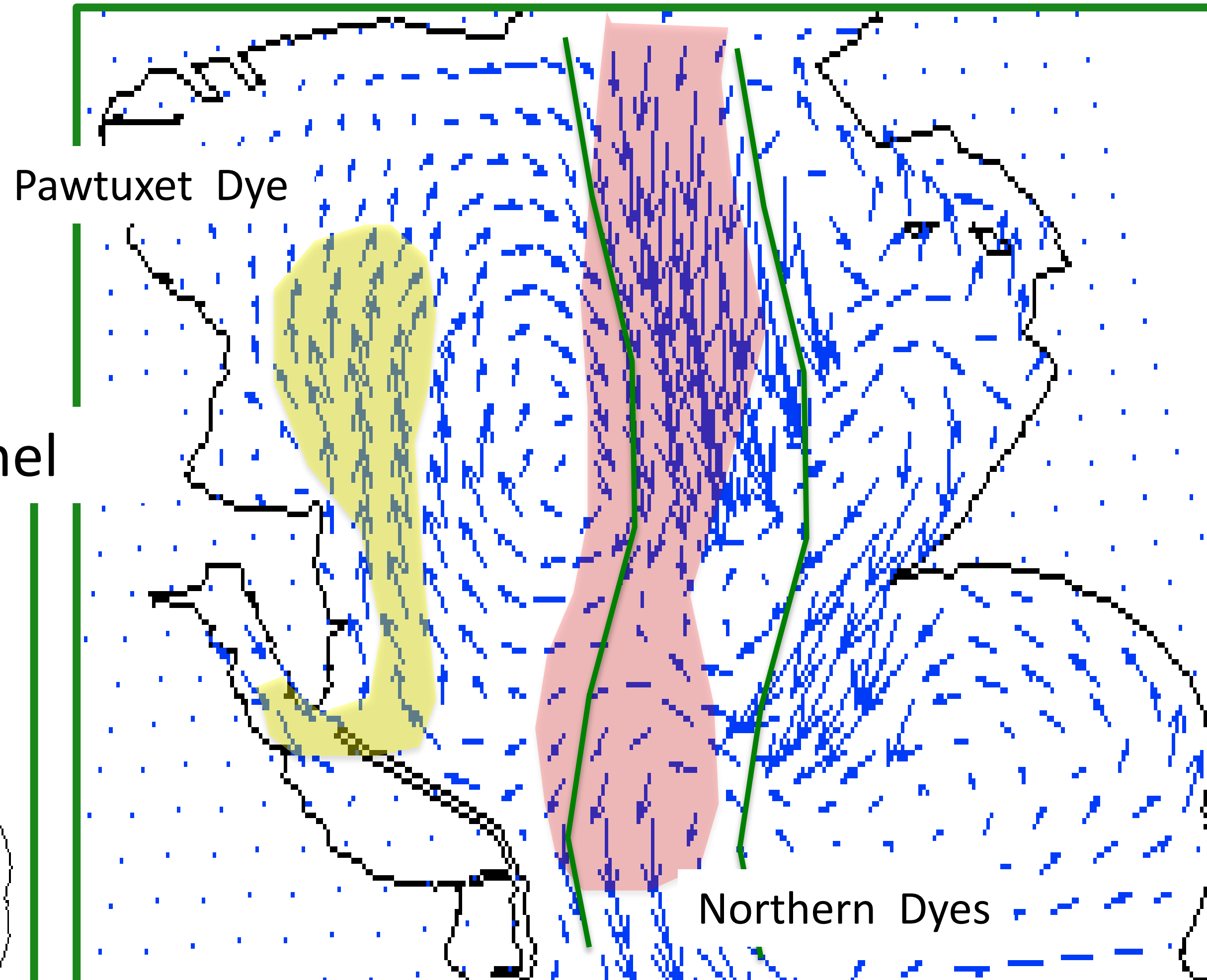
1. Stable gyre.

2. Complex transport: % north dyes flush, % south dyes wrap north

3. Flushing? Which N sources to limit? Age of water vs. oxygen?

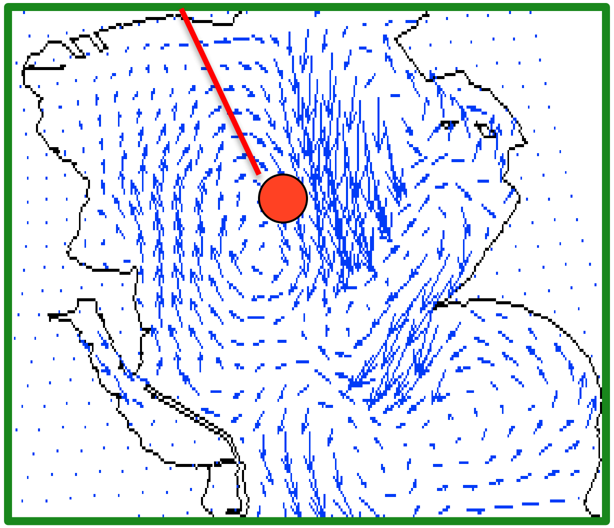
Early version:
Matched tidal flows/heights
Sub-tidal (shown) is bad
No gyre, southward flush

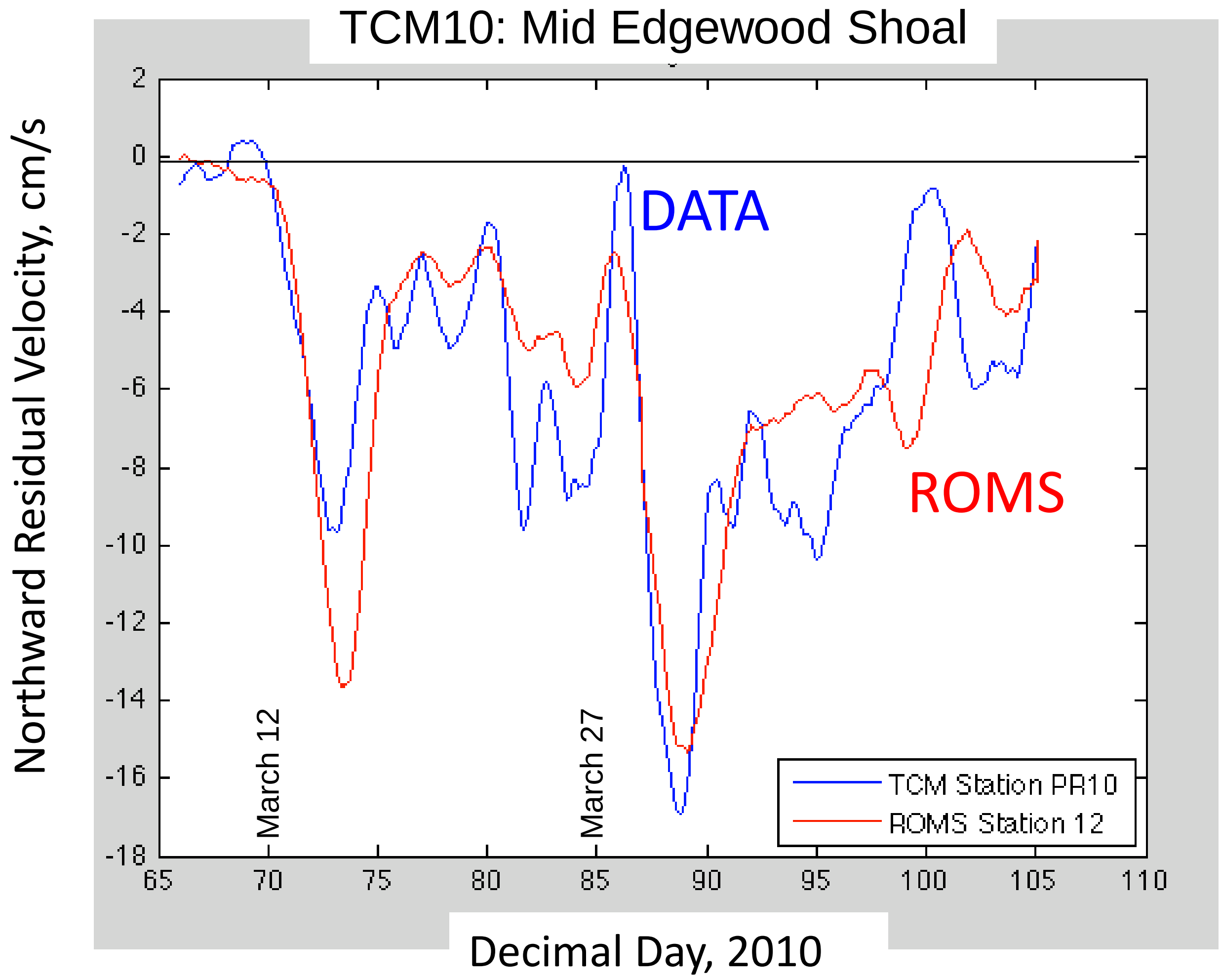




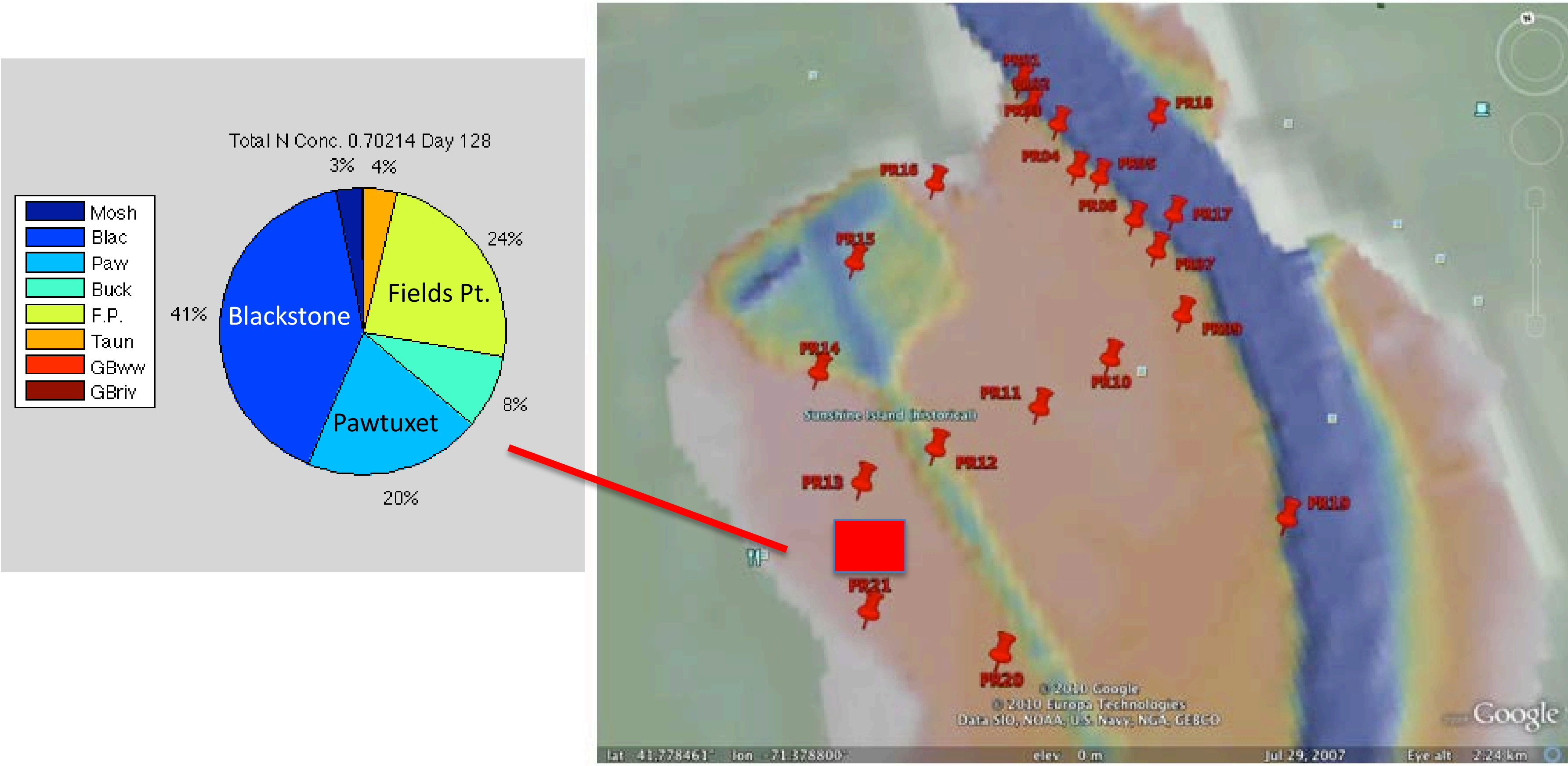
Data-Model Comparisons Show which models accepatable
Tidal and sub-tidal Flow Data vs Model Willmott Skills High: 0.8 – 0.9
Captures challenging flood event

Data/ROMS comparison location





Which Sources Contribute to Nutrient Levels on Edgewood Shoal?

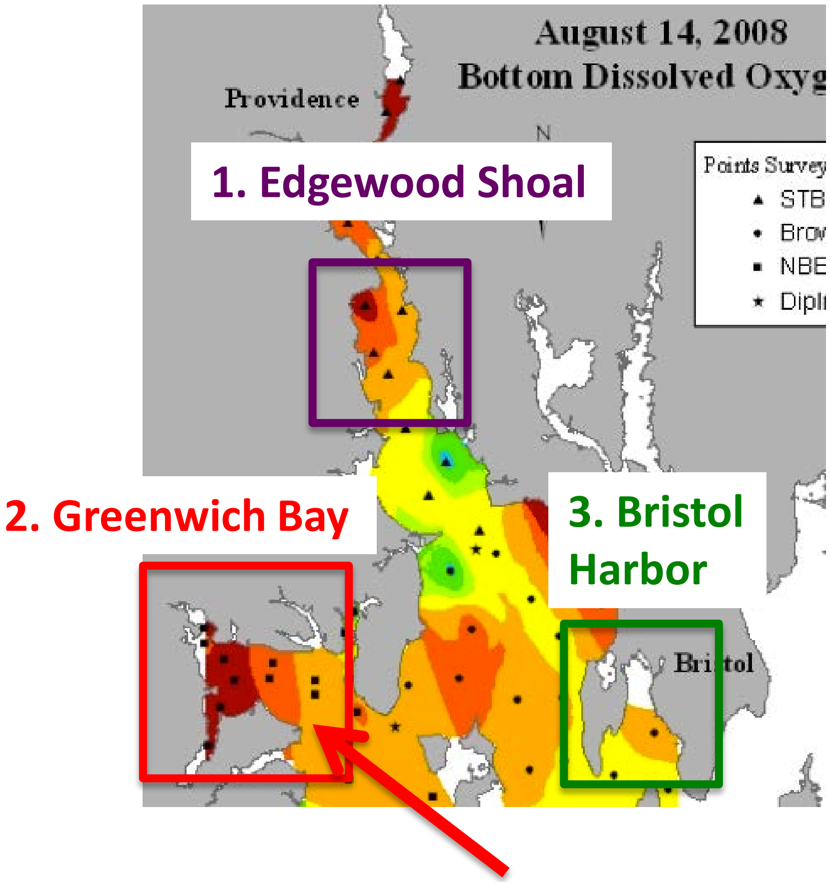


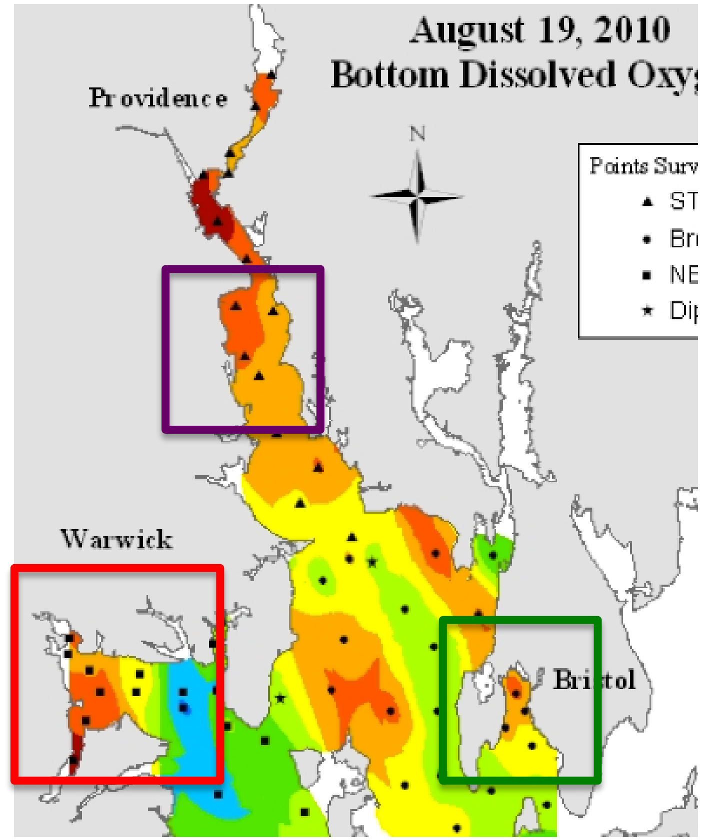
Total Nitrogen at this spot:

41% Blackstone > ~20-25% Fields Pt & Pawtuxet R.

Insomniac Cruises: Low Oxygen = RED

Chronic Low Oxygen Embayments: Edgewood Shoal, Greenwich Bay, Bristol Harbor



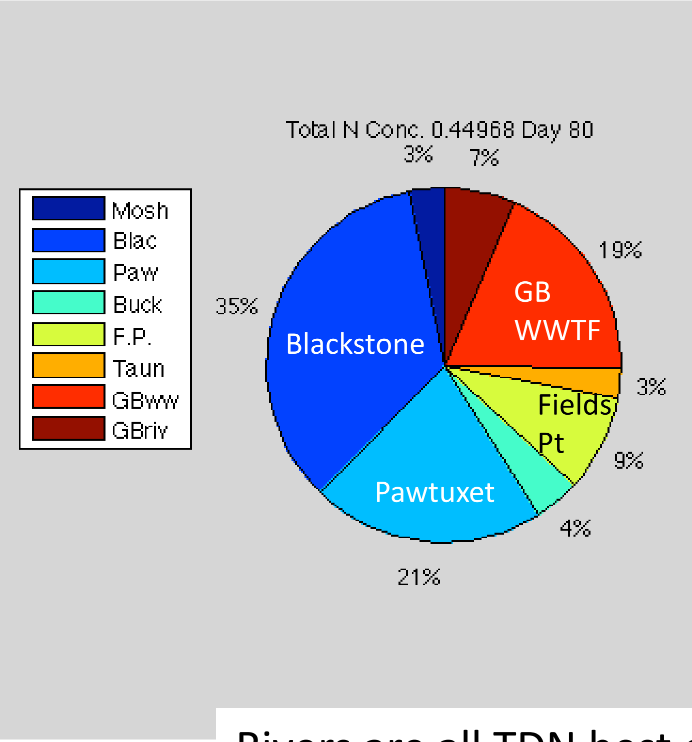


Which Nutrient Sources Supply to Greenwich Bay?

ROMS Simulation Spring 2010 Greenwich Bay Nutrient Supply

1. Pre-2010 Flood: Blackstone, Pawtuxet, Internal

Pre-Flood



Blackstone > Pawtuxet ~ GB internal

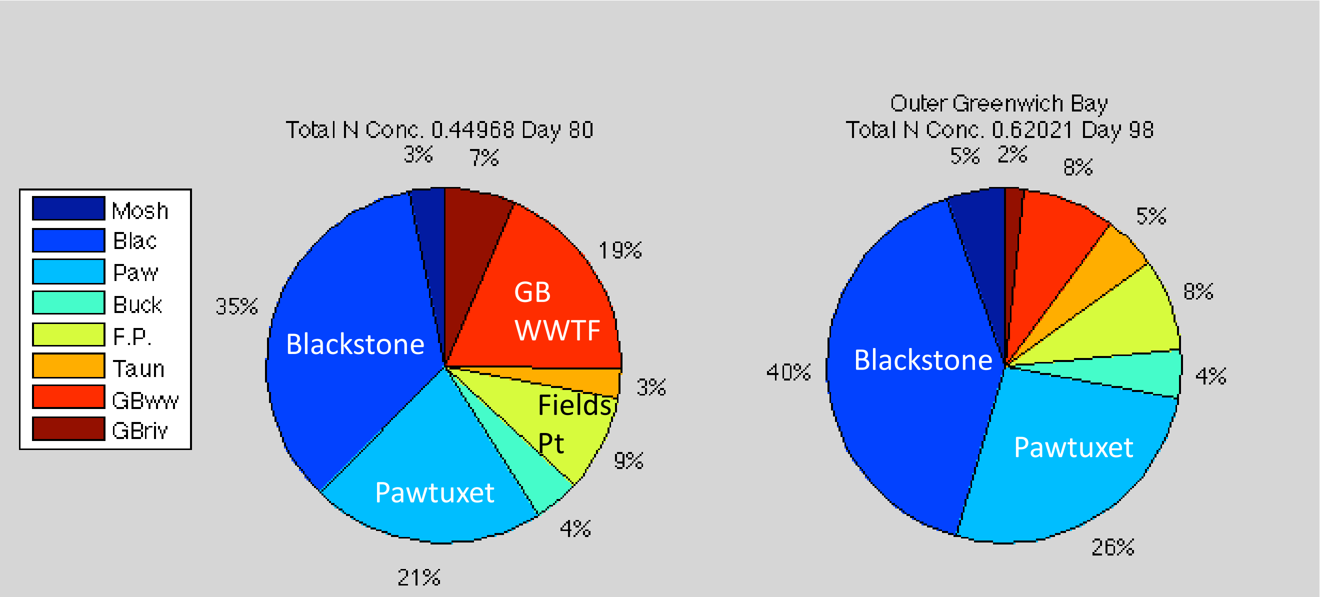
Rivers are all TDN best estimates.   All WWTFs assume 10 mg/l release levels

Spring 2010 Greenwich Bay Nutrient Supply

1. Pre-2010 Flood: Blackstone, Pawtuxet, Internal
2. Post-Flood: Northern rivers more important

Pre-Flood

10 Days Post Flood



Flood infused northern

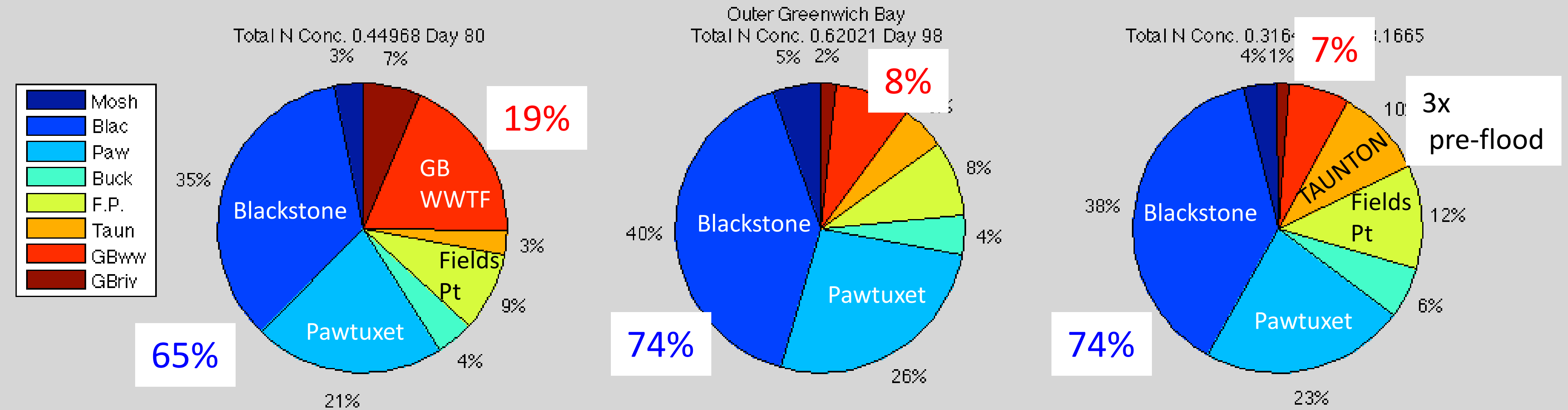
Blackstone
~=Pawtuxet
>> GB internal

Rivers are all TDN best estimates. All WWTFs assume 10 mg/l release levels

Spring 2010 Greenwich Bay Nutrient Supply

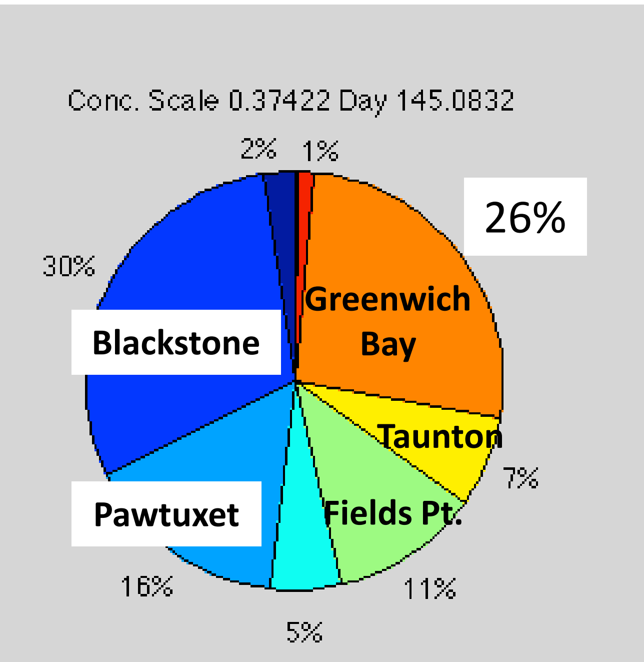
1. Pre-2010 Flood: Blackstone, Pawtuxet, Internal
2. Post-Flood: Northern rivers more important

Pre-Flood | 10 Days Post Flood | 30 Days Post Flood



Flood has infused northern nitrogen into GB

Late Spring 2010 Nutrient Supply to GB Dominated by Internal Sources & Northern Rivers



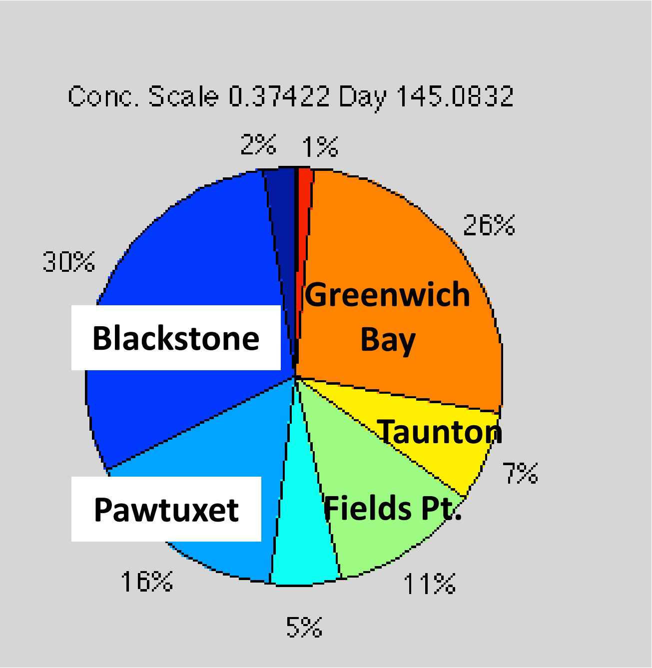
Day 145:
May 25, 2010

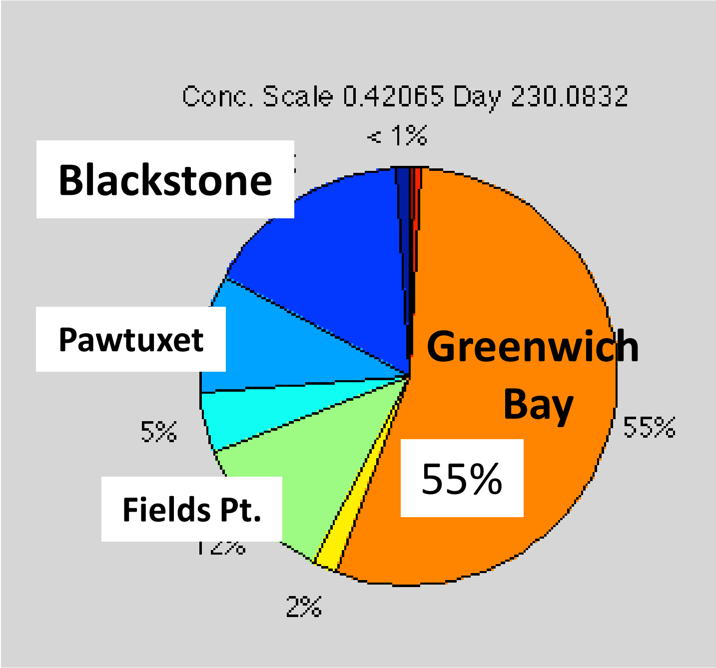
FP + Bucklin = Pawtuxet = 50% of Blackstone

Rivers are all TDN best estimates. All WWTFs assume 10 mg/l release levels

Late Summer 2010 Nutrient Supply to GB Dominated by Internal Sources

55% late summer vs. 7% post flood





Day 145:
May 25, 2010

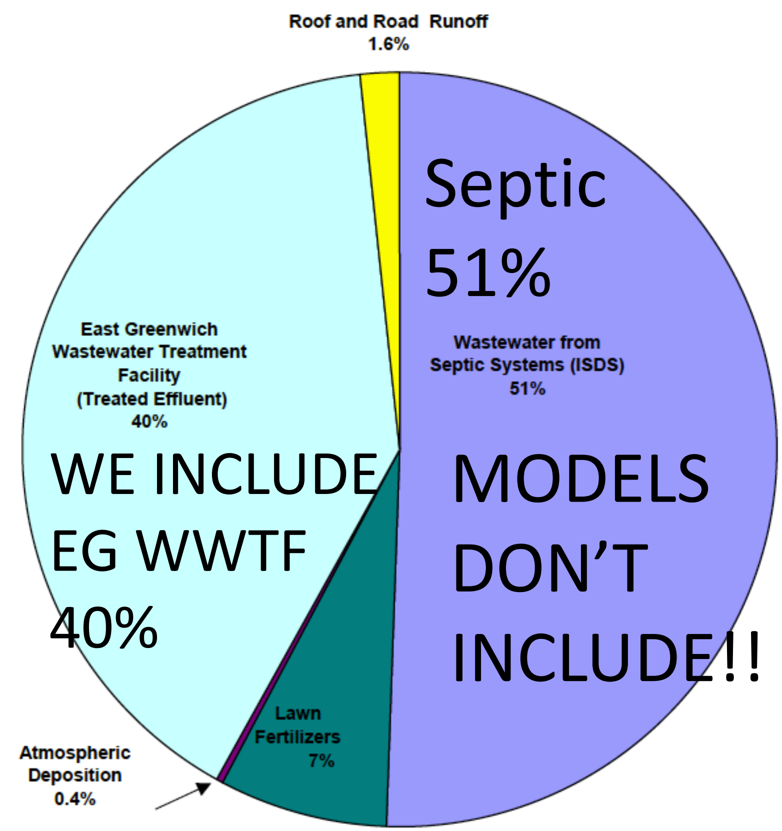
Day 230:
August 18, 2010

Rivers are all TDN best estimates. All WWTFs assume 10 mg/l release levels

From Greenwich Bay TMDL study. We don't include ISDS – Septic, so ours is a maximum estimate for influence from northern river sources.

The pie chart (Fig 6, next page) shows that watershed loads appear to be dominated by ISDSs on the whole (51%). It should be kept in mind that even adequately working septic systems release significant amounts of nitrogen into the groundwater, which slowly transports it to nearby streams and even directly into the shoreline area of Green-wich Bay. Loads from storm water could carry nitrogen (and bacteria) from failing systems. The wastewater treatment facility is the second largest source (40%). Law fertilizer, road run-off, and direct atmospheric deposition account for less than 10% of the total suggesting those sources are not dominant factors.

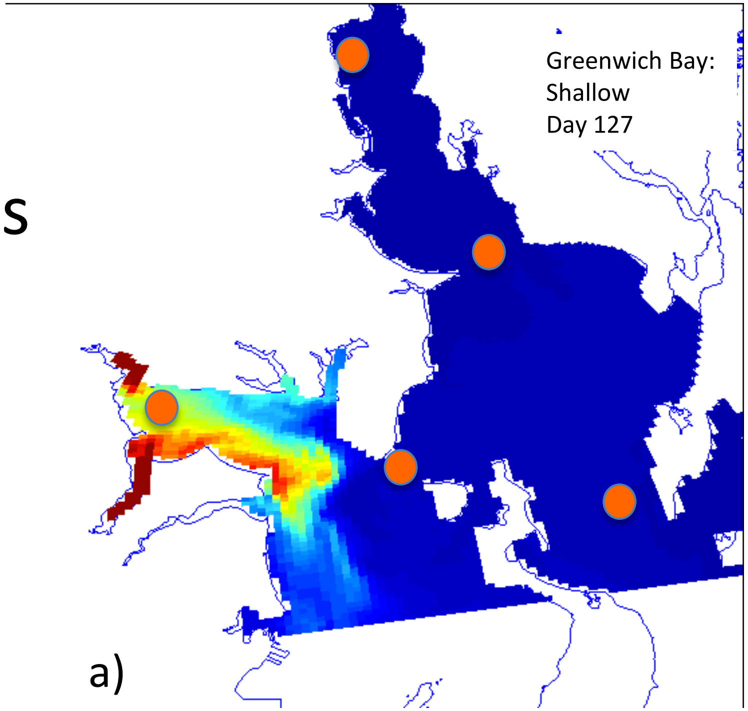
Figure 6 Watershed Nitrogen Sources to Greenwich Bay



Use ROMS to test range in management strategies

Simulate relative response of Fields Pt. WWTF (*only FP*) Nutrient Reduction Strategies

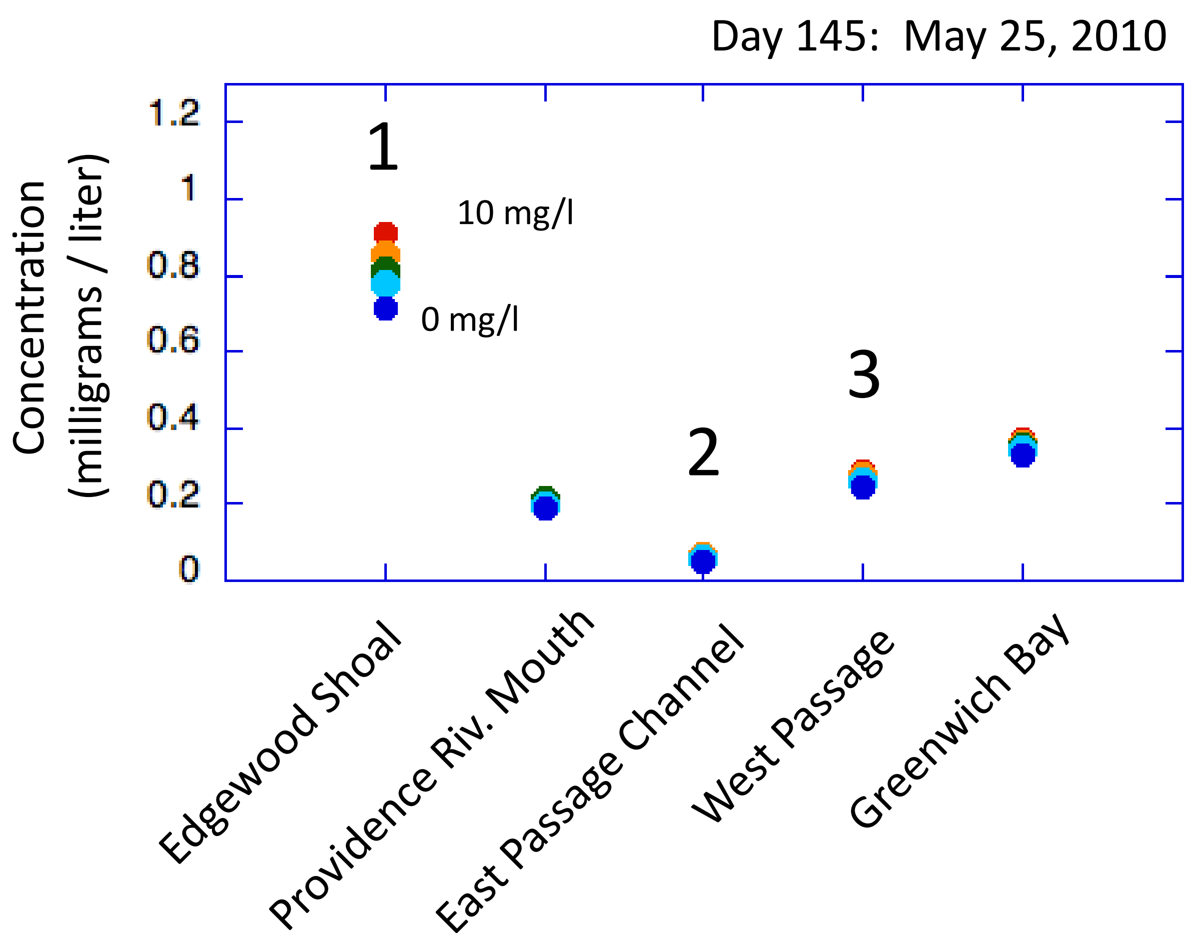
Show modeled nutrient concentrations at 5 locations

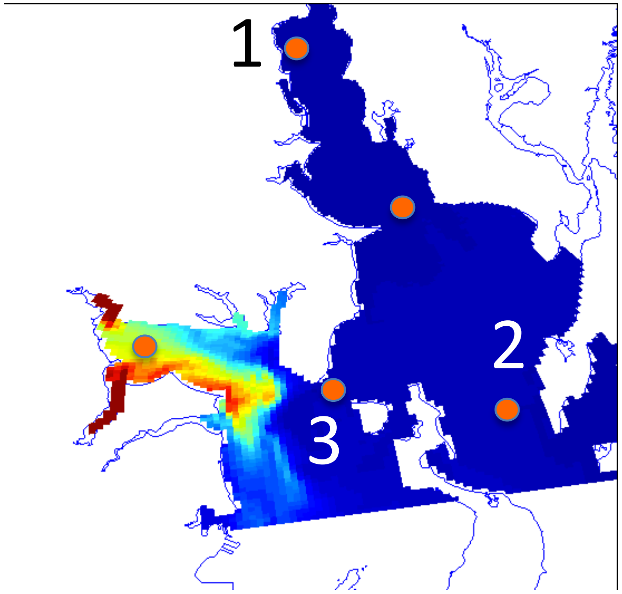


a)

Tracer or Nutrient Concentration Versus Location Down-estuary: Range in Fields Pt. Release Scenarios (10, 7, 5, 3, 0 mg/l)

Note: This treats Nitrogen as PASSIVE (not Active) Tracer Field





Outline

1. Data sets show basic circulation patterns *(heard it before, little bit later)*

2. ROMS models calibrated versus data *(Dave Ullman summarized)*

3. ROMS models used to simulate flow & chemical transport,
   test management stratgies

1. ROMS NPZD Results

Nitrogen is not a conservative dye…..
So NPZD Ecosystem Model turned on in ROMS

N= Total nitrogen; P=phytoplankton, Z=zooplankton

$$\frac{dP}{dt} = \frac{V_m\,N\,P}{k_s + N} - mP - I_i\,Z \qquad (1)$$

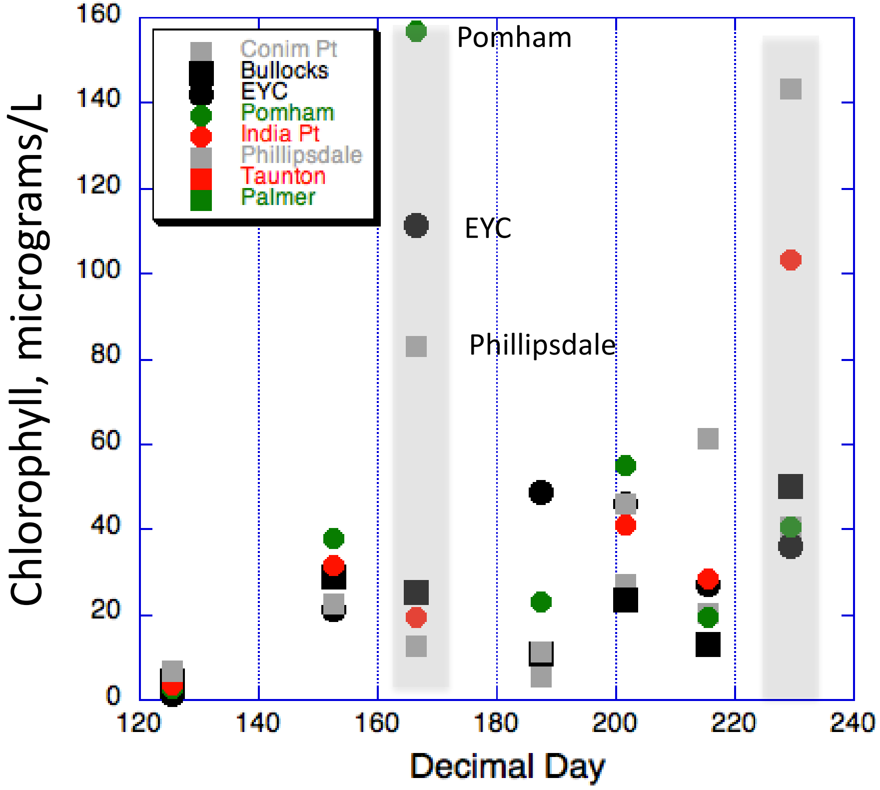
$$\frac{dZ}{dt} = (1-\gamma)I_i\,Z - gZ \qquad (2)$$

$$\frac{dN}{dt} = -\frac{V_m\,N\,P}{k_s + N} + mP + gZ + \gamma I_i\,Z \qquad (3)$$

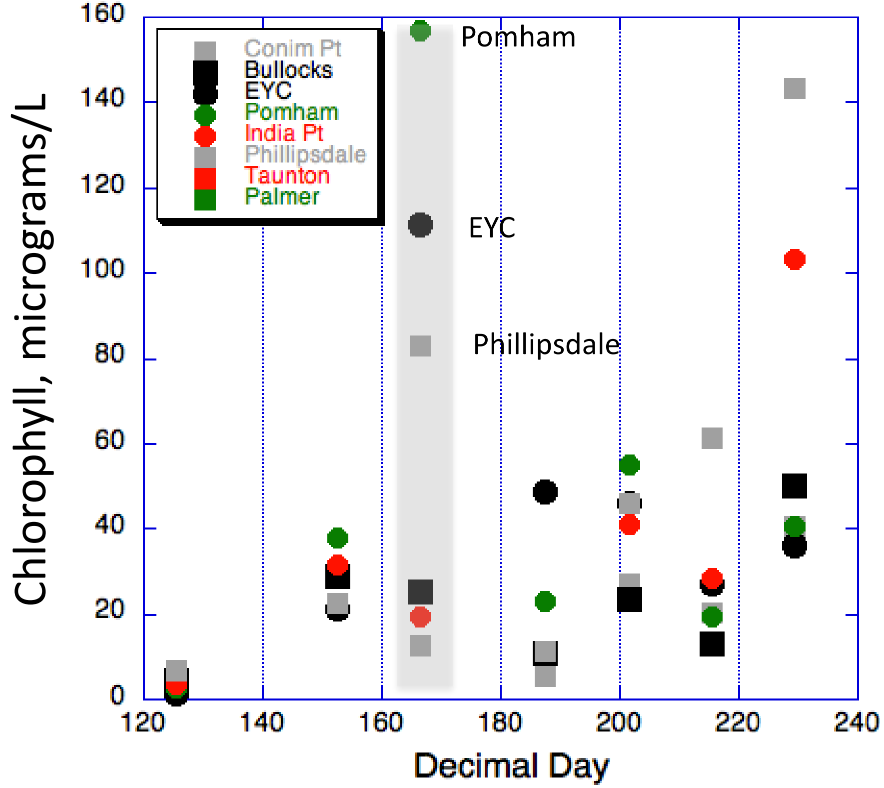
$$I_i = R_m(1 - e^{-\Lambda P}) \qquad (4)$$

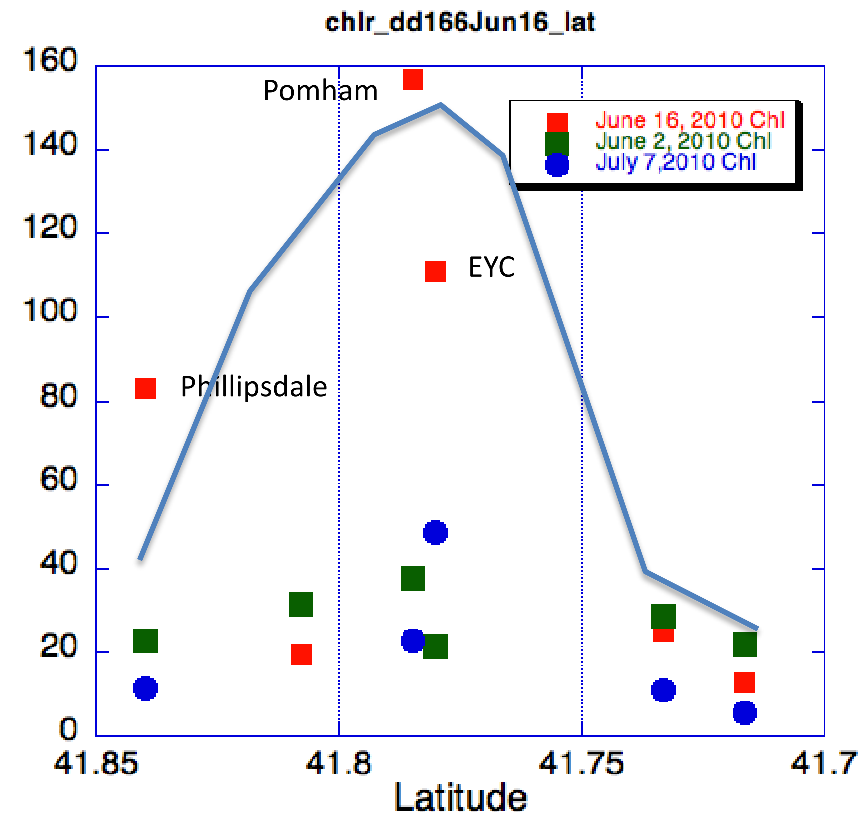
Also Detritus Equation

TWO KEY BLOOMS IN 2010 REVEALED BY NBC DATA



TWO KEY BLOOMS IN 2010 REVEALED BY NBC DATA





June 2010 Bloom vs Latitude

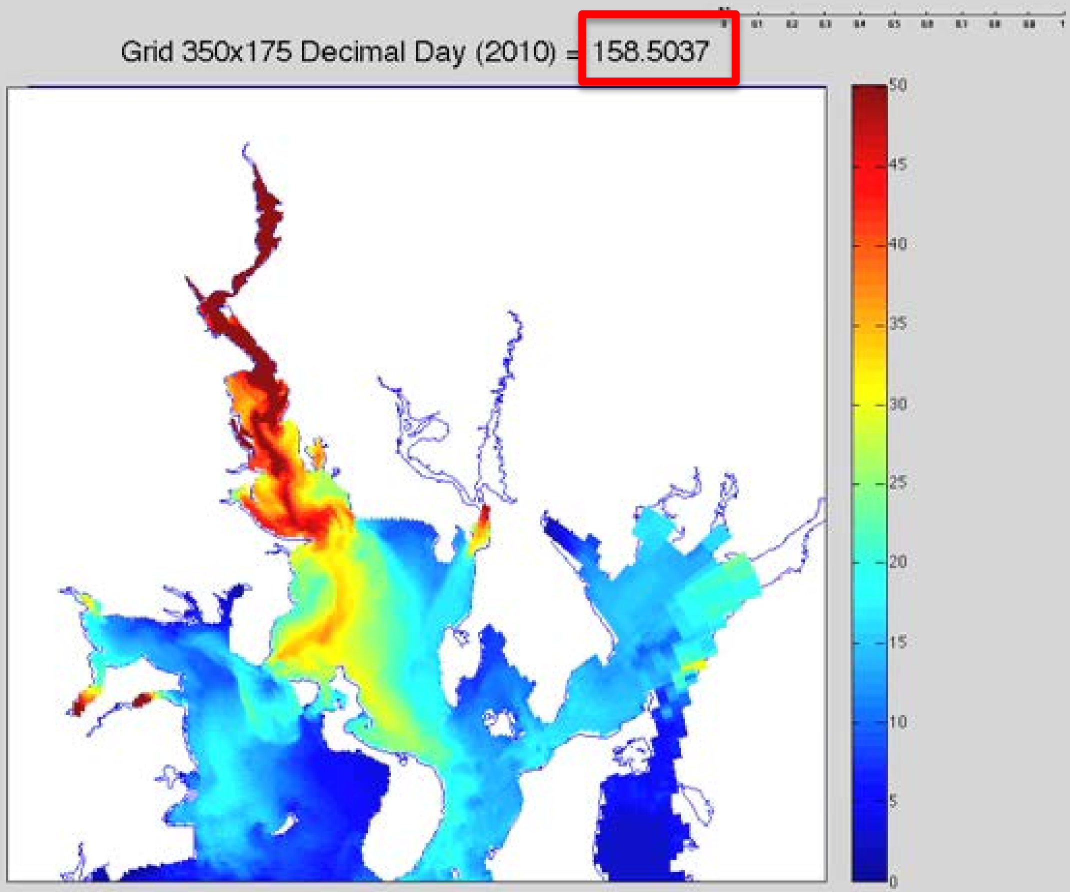
present June 16

not present June 2 & July 7

Start with focus on bay-wide bloom, June, 2010

Total Nitrogen: Surface Reference case: Vm2.5, KL0.75, ZG1.0 .

Contours in mMole/m^3 (divide by 75 to get to mg/l).



mM/m^3

Oscillation: northern sources down East Passage, D162

N-sources down West Passage. D164

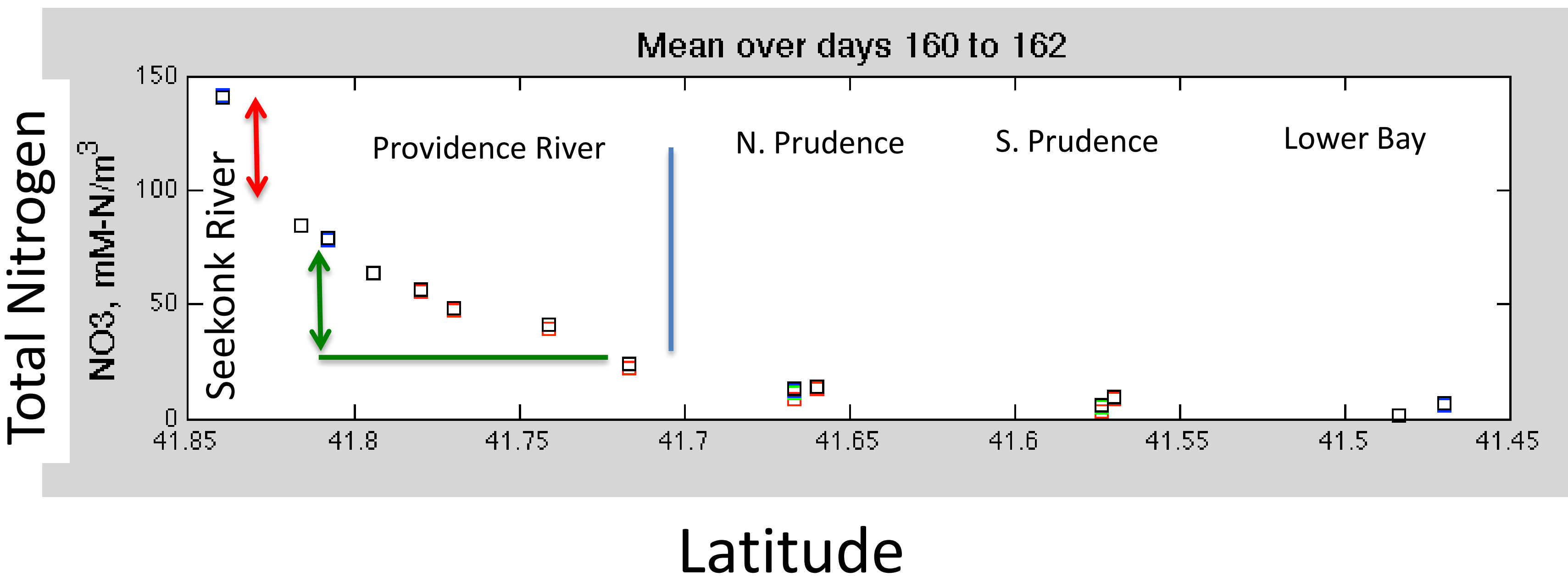
Often N-sources enter Greenwich Bay D168

Play Video

Fundamental observation in Bay: TN reduction from Seekonk to Mouth of Providence River

All runs (pre-bloom) have TN match basic observation:

1. 40% reduction Head of Prov. River to Mouth
2. Seekonk 50% higher than upper Prov. River

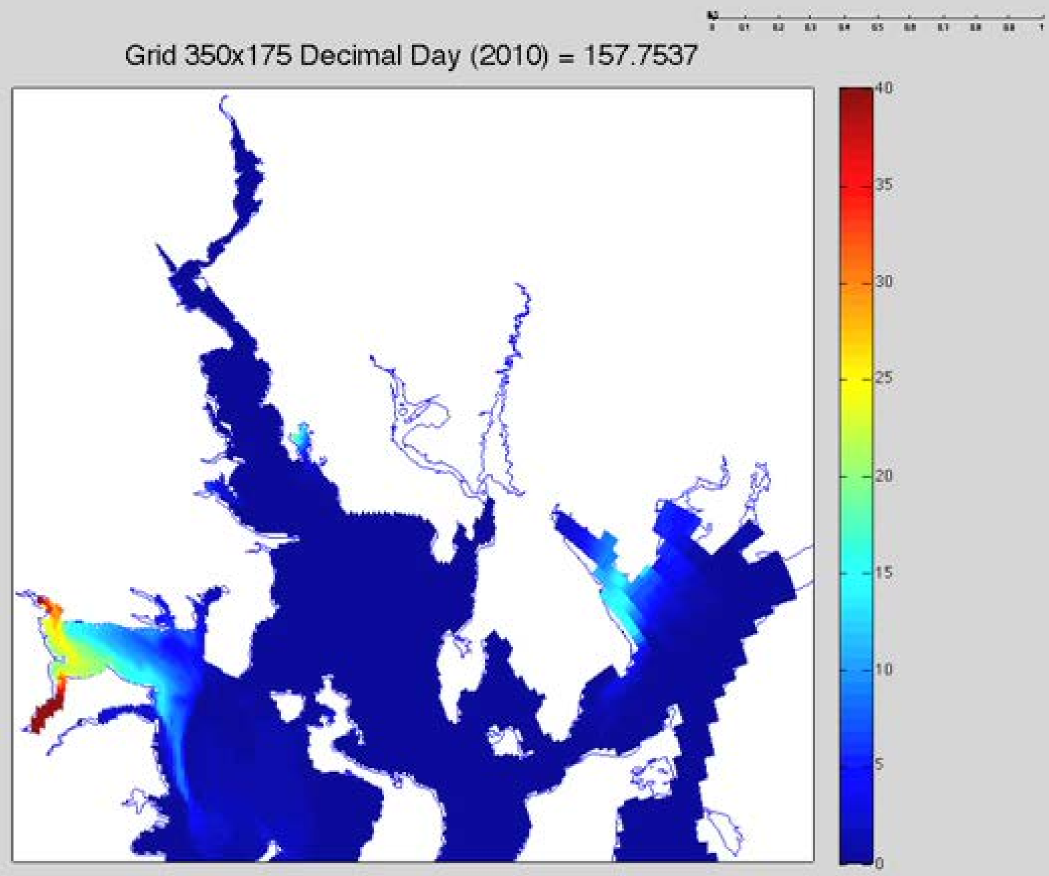


Multiple runs: Uptake rate, Light extinction, Zoo Grazing, Mortality, **WWTF levels**

Phytoplankton: Surface Reference case: Vm2.5, KL0.75, ZG1.0.
Shows it starts in Greenwich Bay and Mt Hope Bay

Bloom starts:
- Greenwich Bay
- Taunton River shallows
- Shallows in Prov. River

Bloom expands to north



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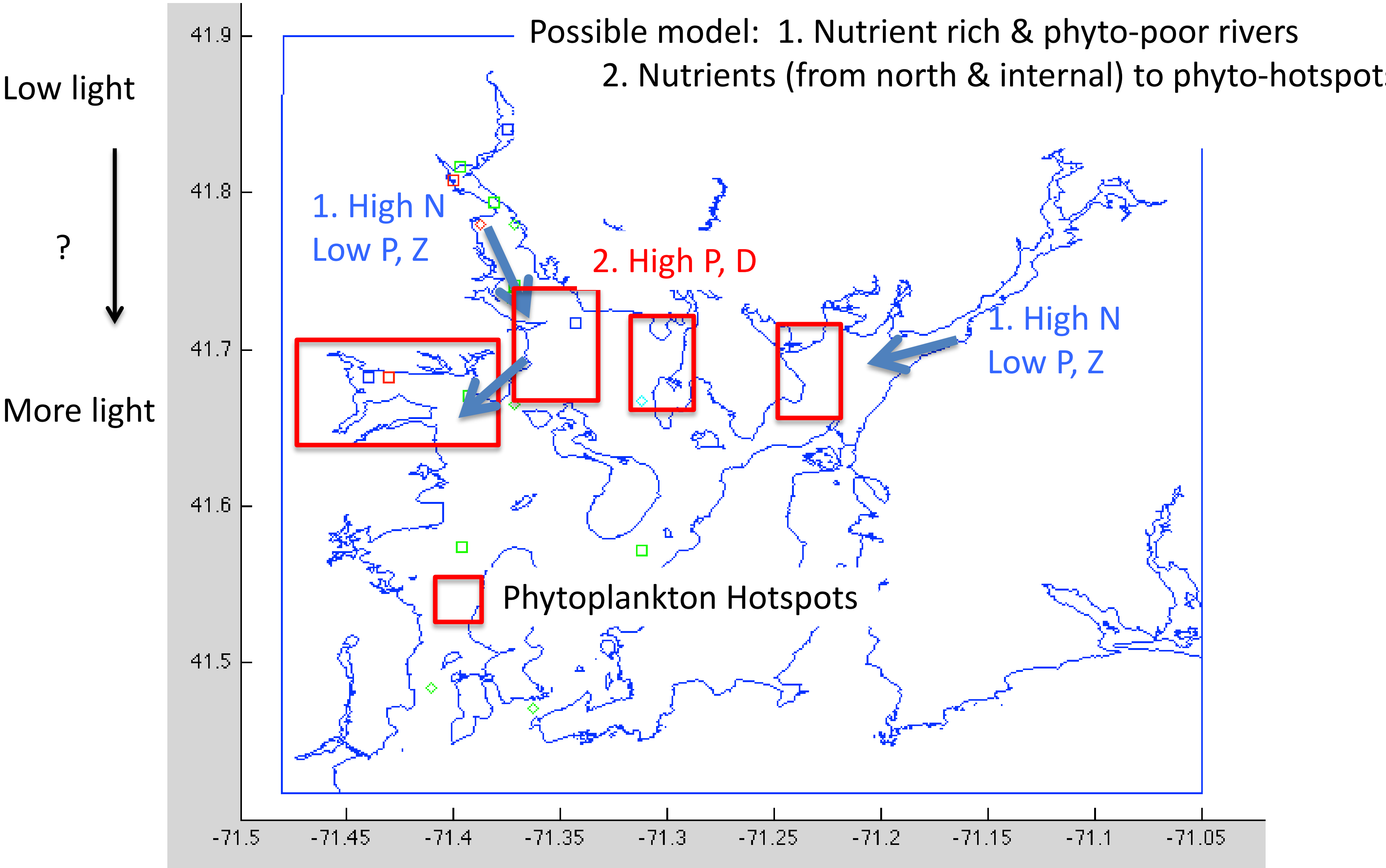
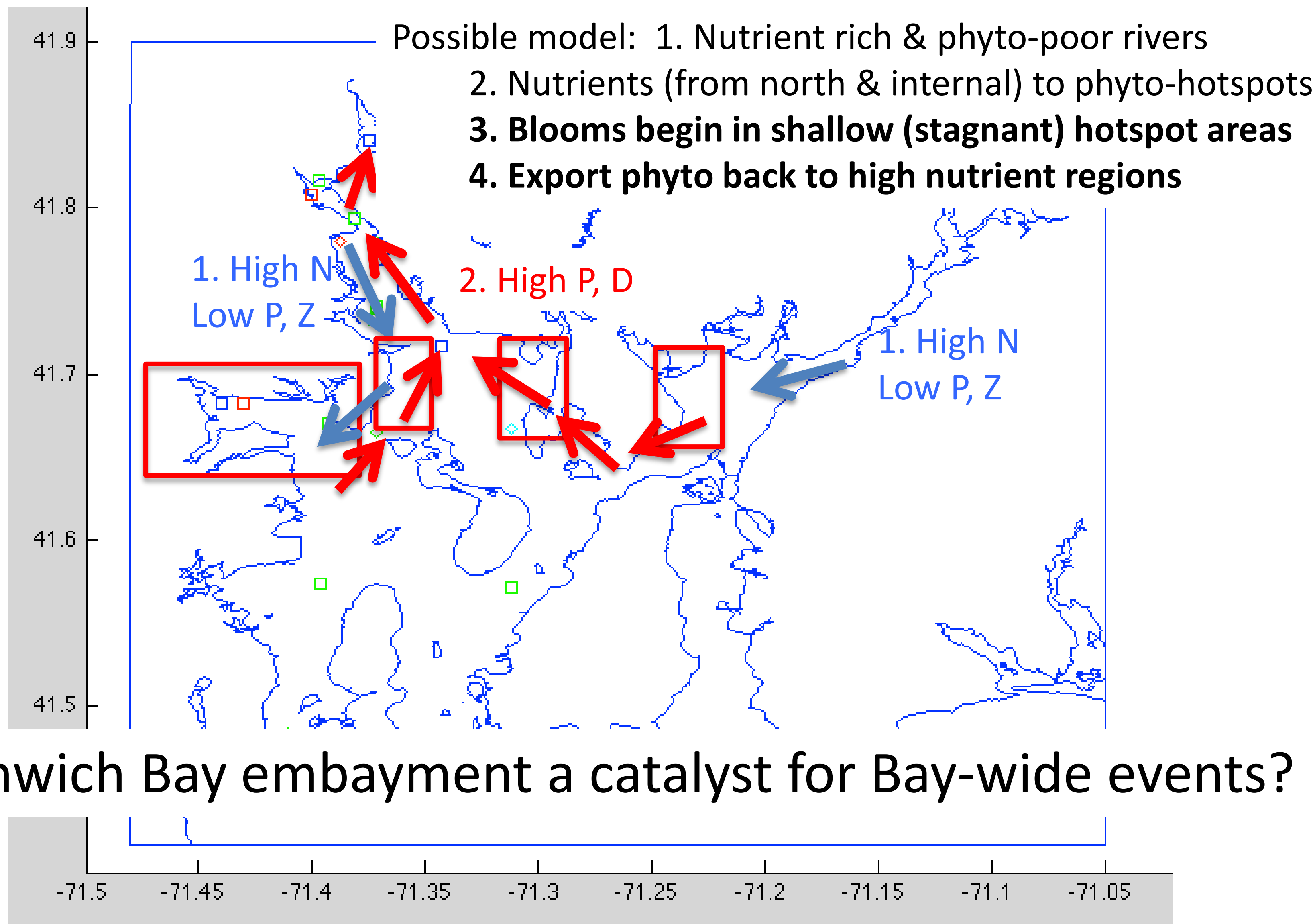
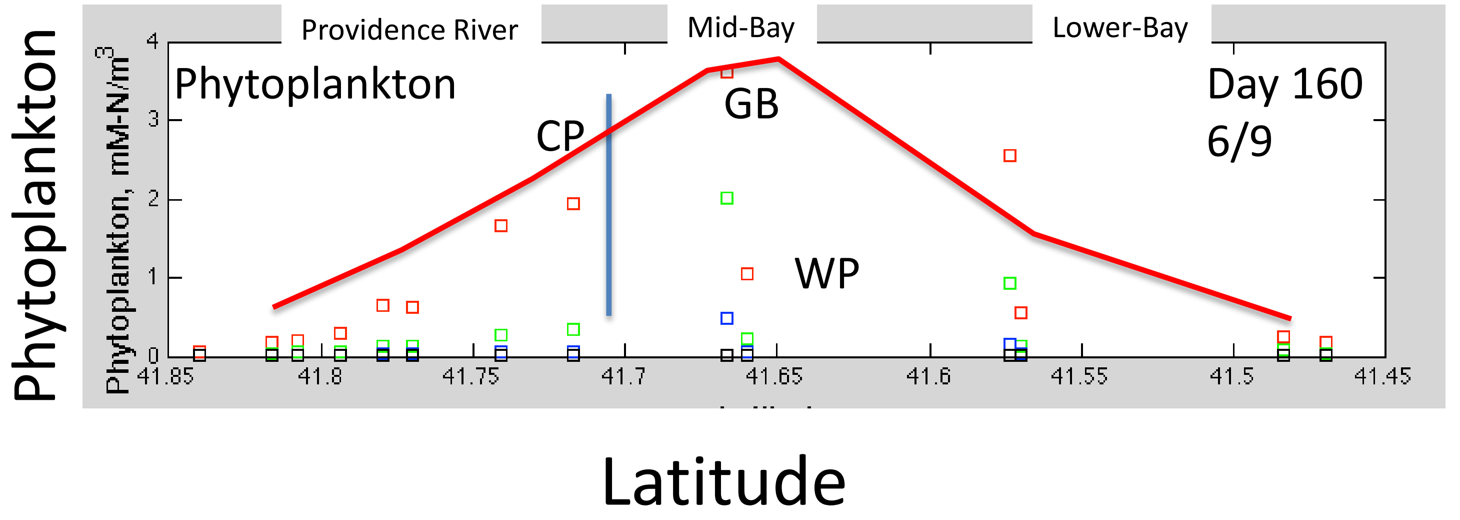
NPZD ROMS & Data (June 2010) show bloom starts Greenwich Bay, appears mid-Bay and later in Providence & Seekonk Rivers





Is Greenwich Bay embayment a catalyst for Bay-wide events?



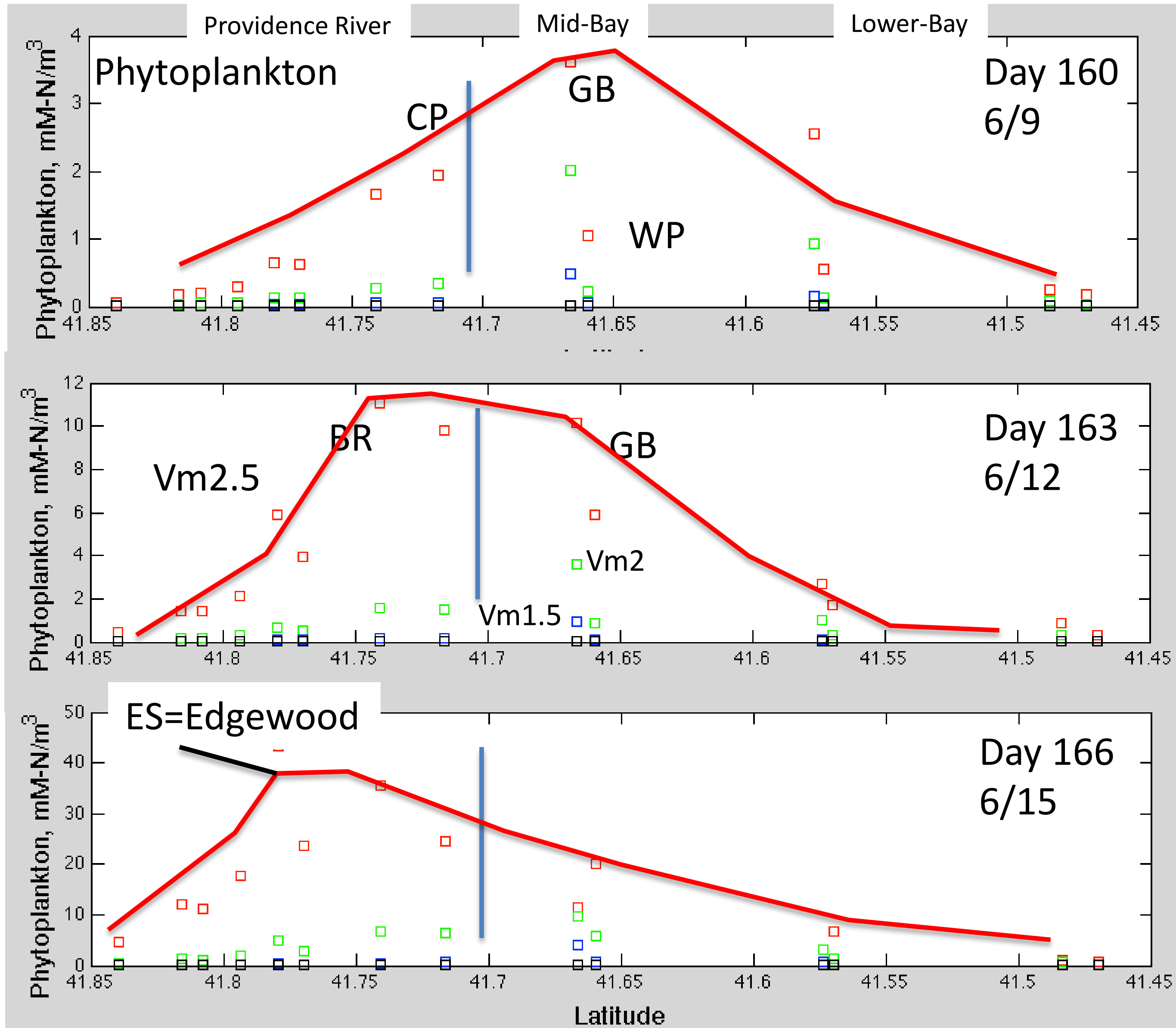
These are complex models, with lots of parameters.

Good to ask, What are repeatable processes / patterns?

Blooms start in Greenwich Bay, spill to mid-Bay.

Bloom progresses like wave, south to north:

Bloom progresses like wave, south to north

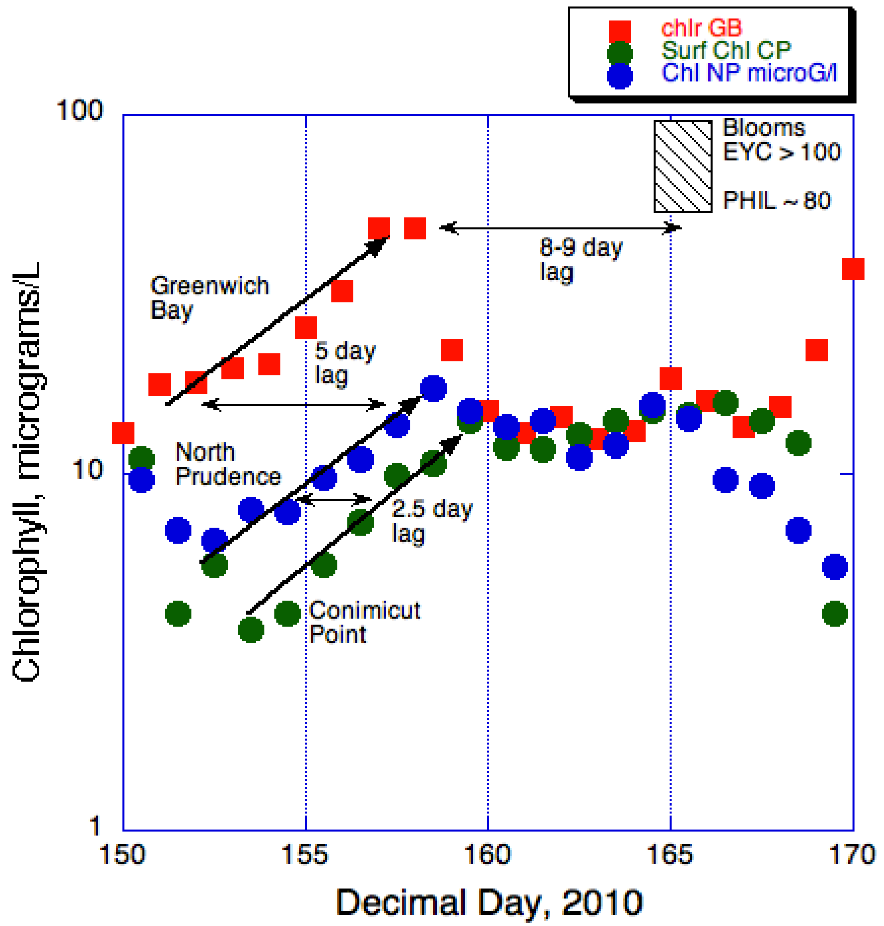


Edgewood higher bloom magnitude

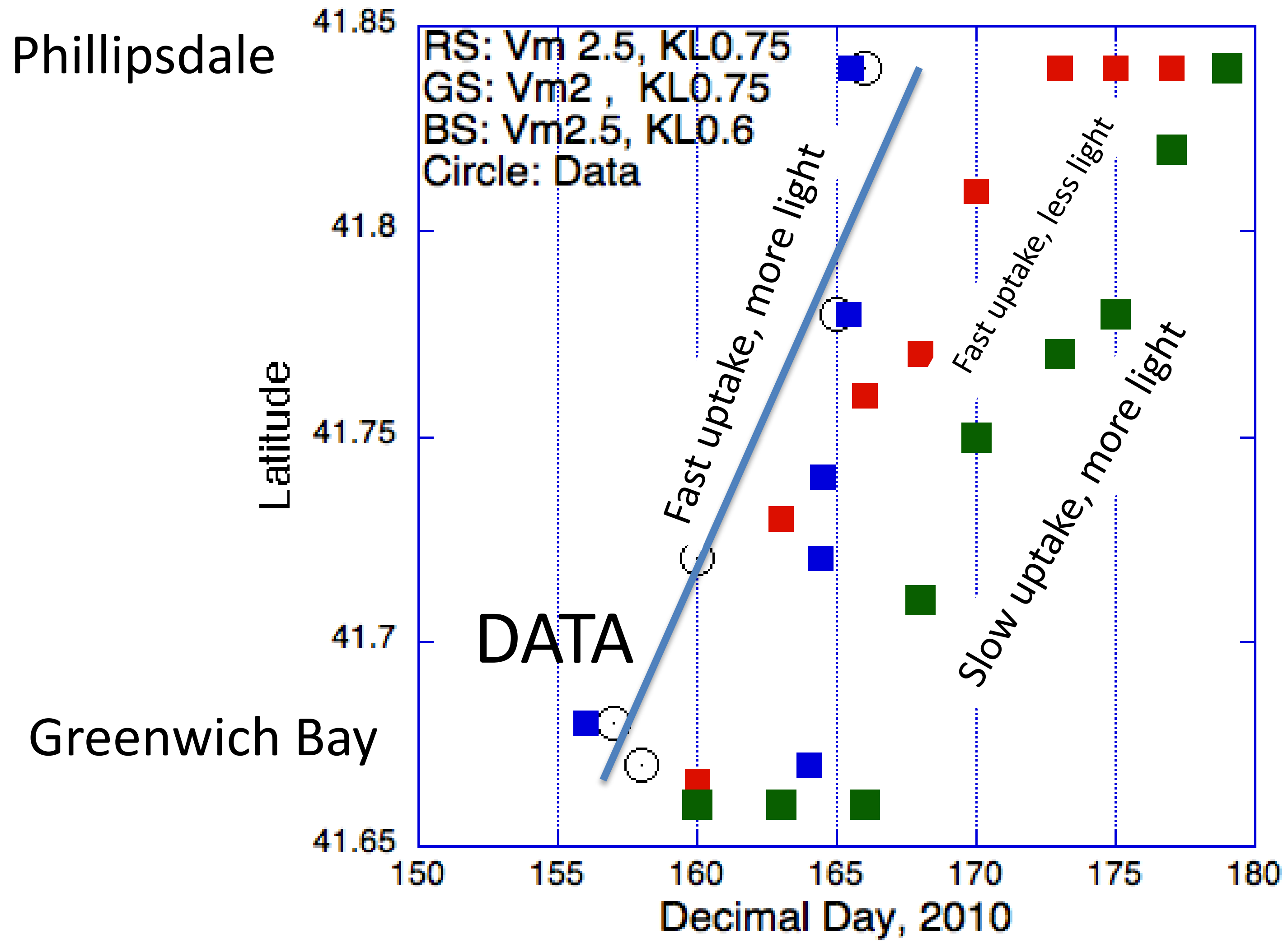
Matches data

Larger uptake rates match size/progression of bloom

Adjust ROMS NPZD parameters to fit age progression for this bloom seen in buoy data

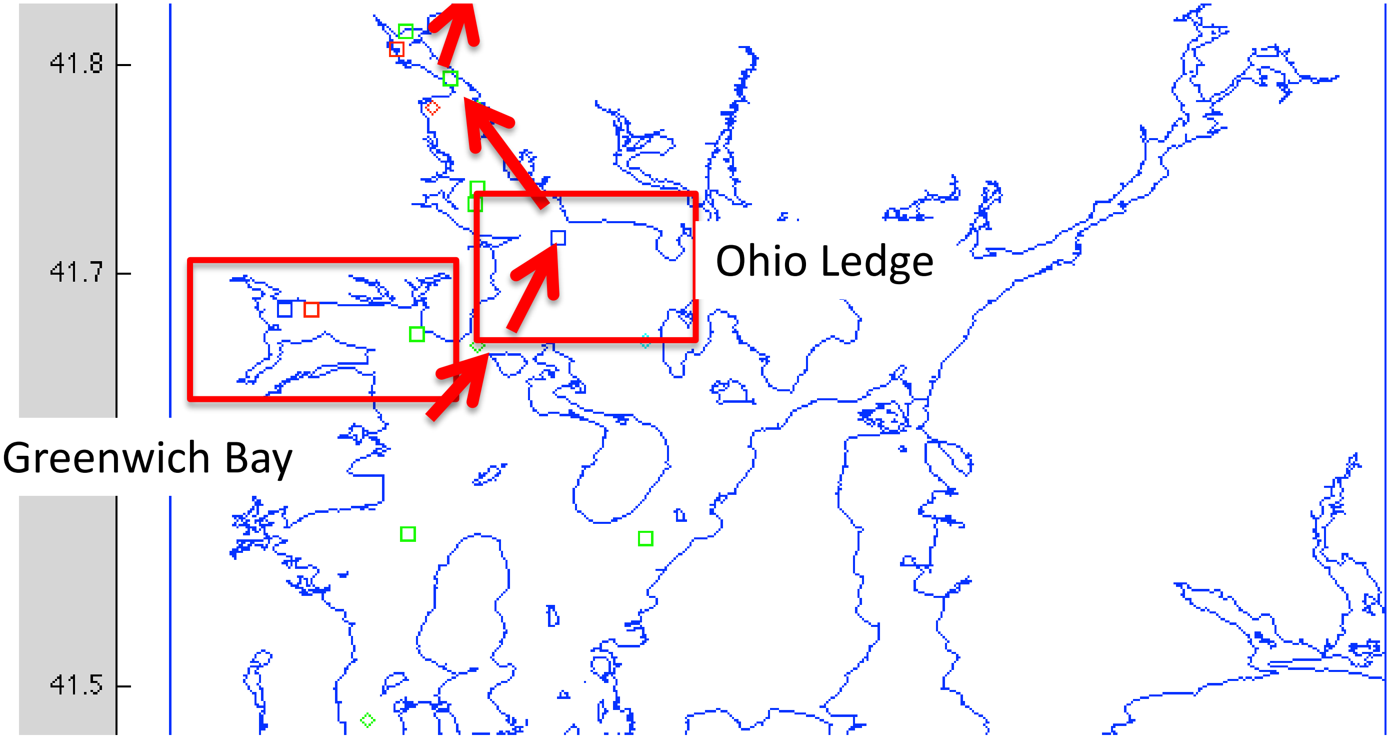


Bloom Occurrence Latitude vs. Time (June 2010). Data vs. Model: Key N uptake rate & Light



2010 Data show Greenwich Bay in near-constant state of elevated chlorophyll

How might GB products make it out onto Ohio Ledge and not flush south?

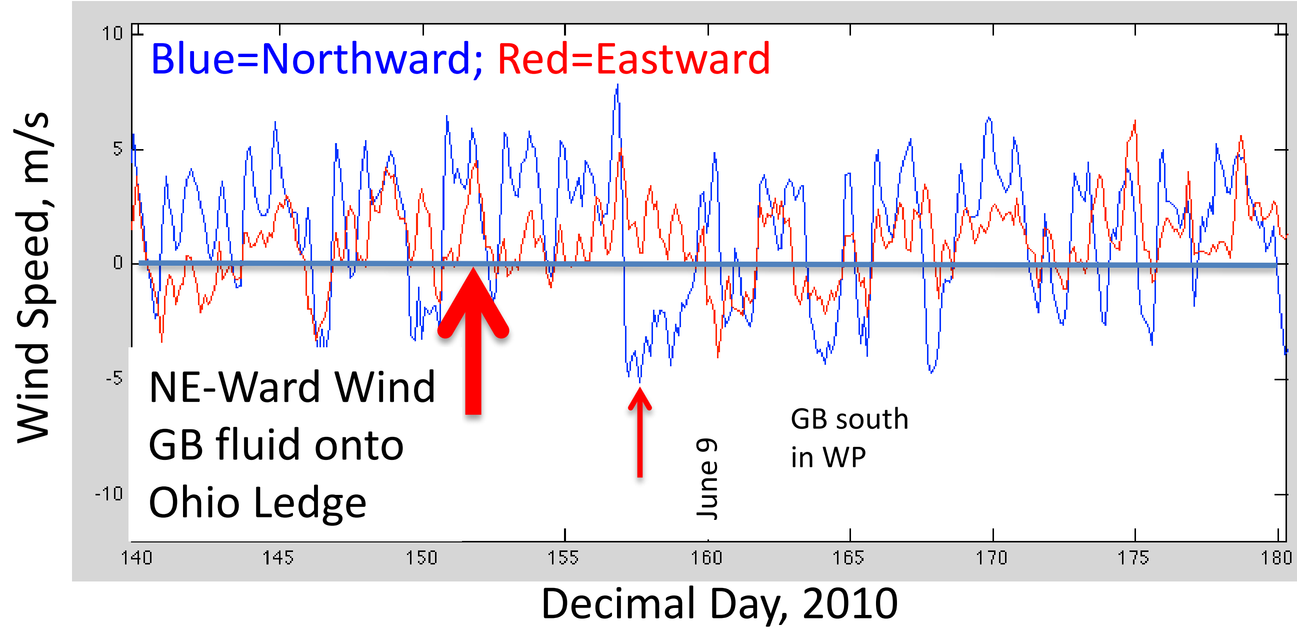


Models show:

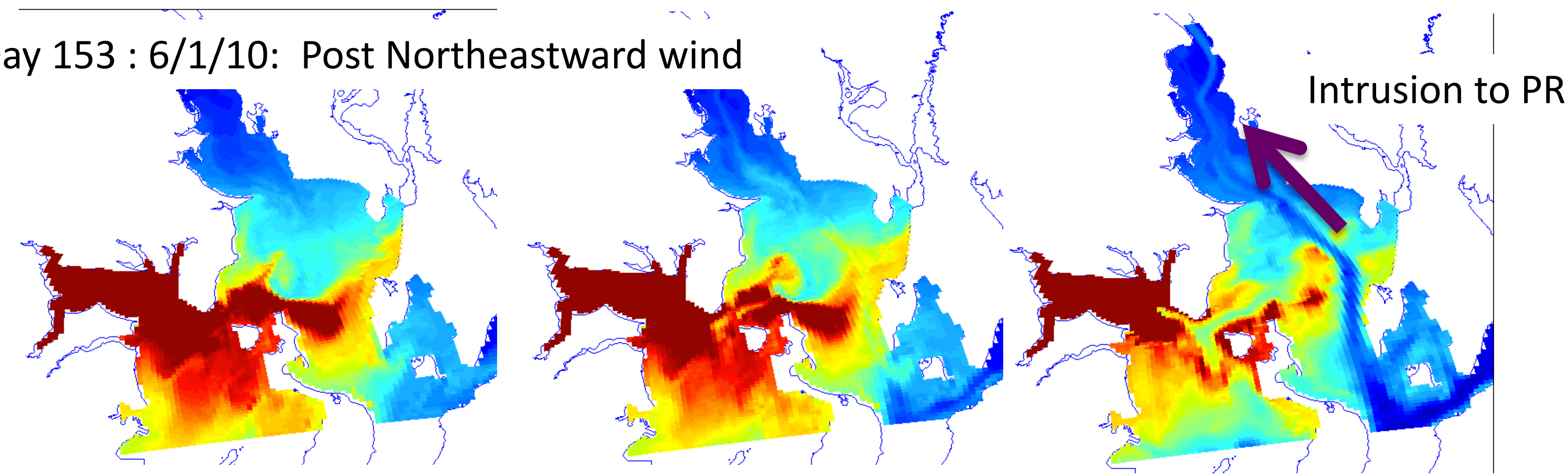
(1) wind driven pulses and

(2) tidal pumping through Warwick Neck constriction

Winds pump GB bloom products to Ohio Ledge

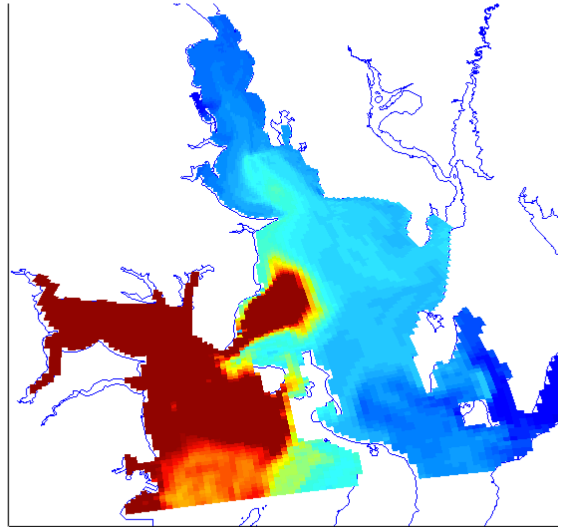


Day 153 : 6/1/10: Post Northeastward wind

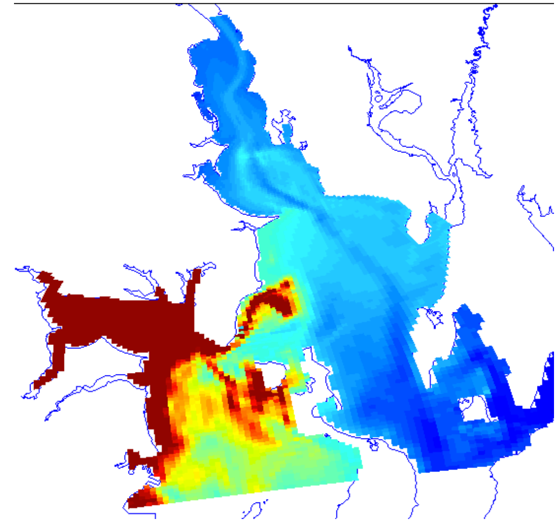


a) Surface b) Mid-water c) Bottom

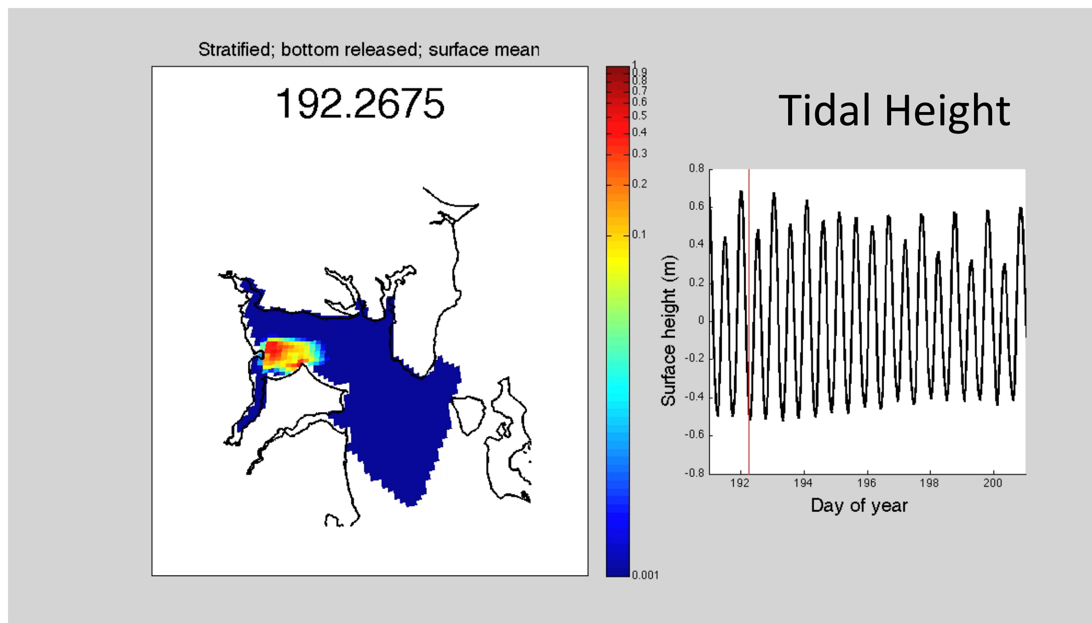
Day 160 : 6/8/10:   Low Wind: Tidal Pumping thru Warwick Neck constriction



a) Surface



b) Mid



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Example of GB Tidal
Pump thru Warwick Neck
Runs has wind zero-ed out

Passive dye patch

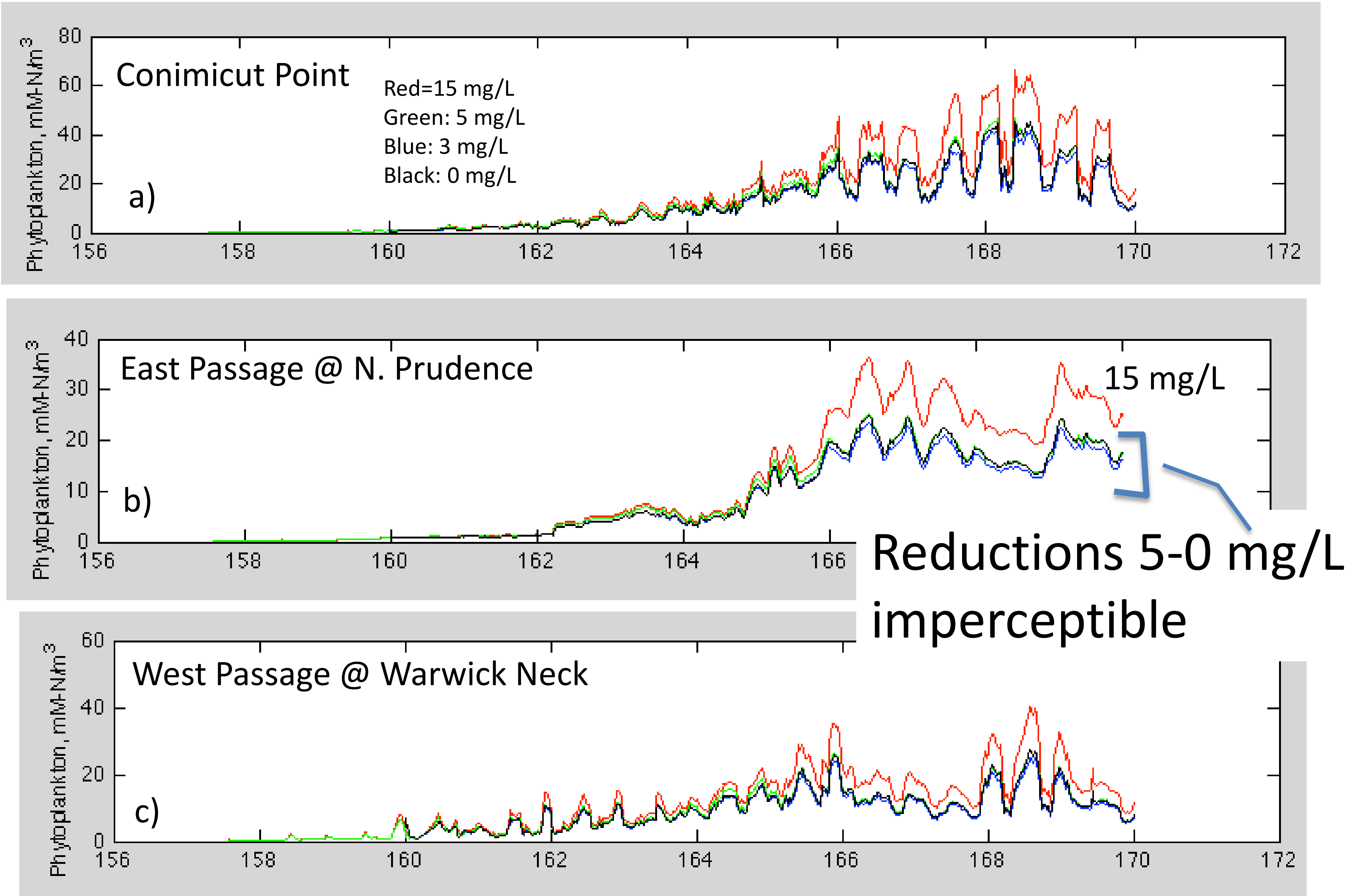
Model Scenario/Process Tests: Two Applications

1) Test impact of different WWTF release levels.

15 mg/l, 8 mg/l, 5 mg/l, 3 mg/l, 0 mg/l

2) Is Greenwich Bay a bad gallbladder, influencing bloom dynamics throughout entire system?

Phytoplankton Levels vs. Time: Compare mid-Bay levels for range of (all) WWTF release levels



Summary

Dye (N as conservative tracer) show transport pathways for sources.

Southern dyes move north efficiently (Taunton, Pawtuxet, EP-WWTF)

Nitrogen to GB? oscillate, northern river sources vs. local sources

GB dye pumped periodically to mid-Bay site

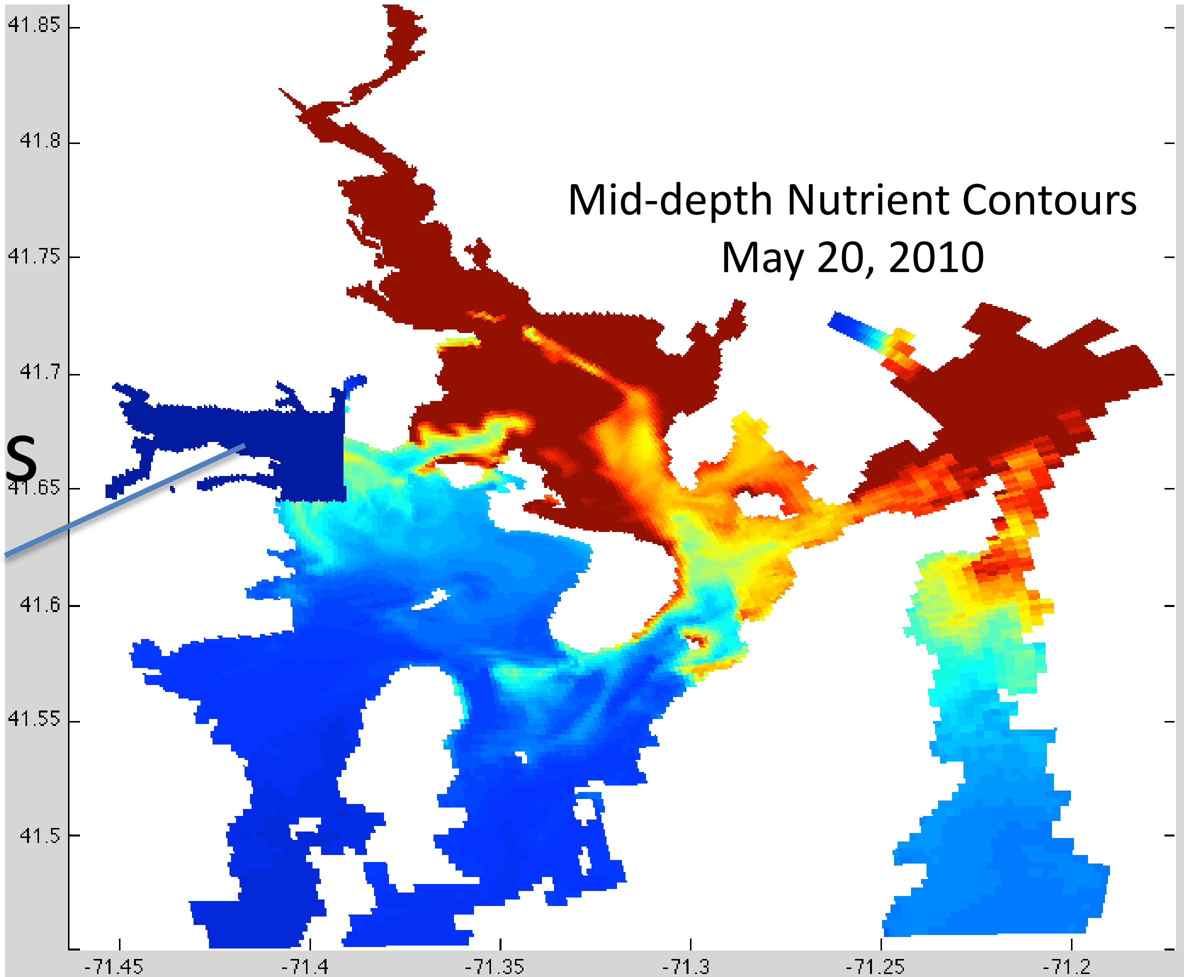
ROMS NPZD / Data trends suggest Greenwich Bay can be a hotspot for blooms

Wind events and tidal pumping produce GB to Ohio Ledge export.

ROMS Eco-process tests: Weighing bloom magnitude vs : 1) nutrient reductions. 2) physical drivers. **3) hotspots**

Greenwich Bay bloom products independent of parameter choices
If cut it out, does it influence NPZD products baywide?

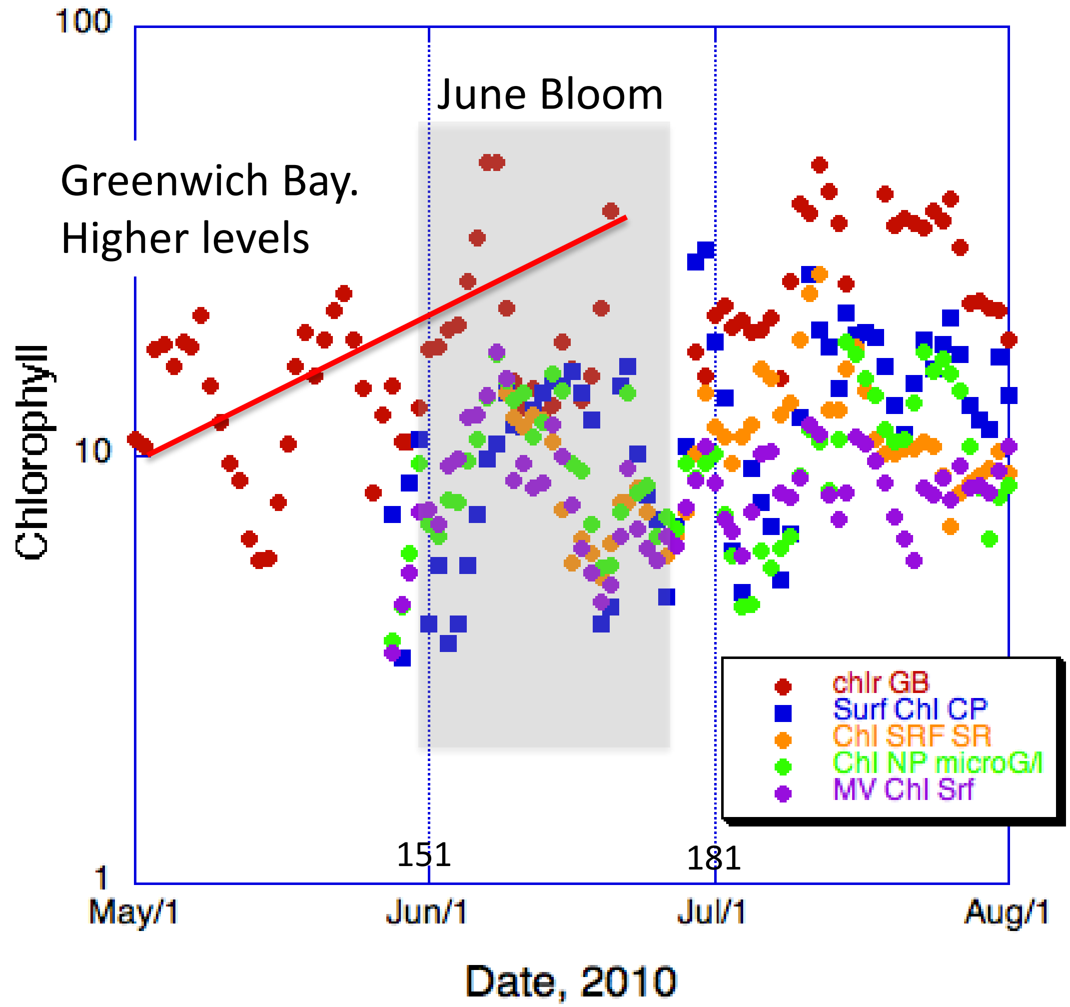
GB nutrients set to 0



June 2010 Bay-wide bloom event:

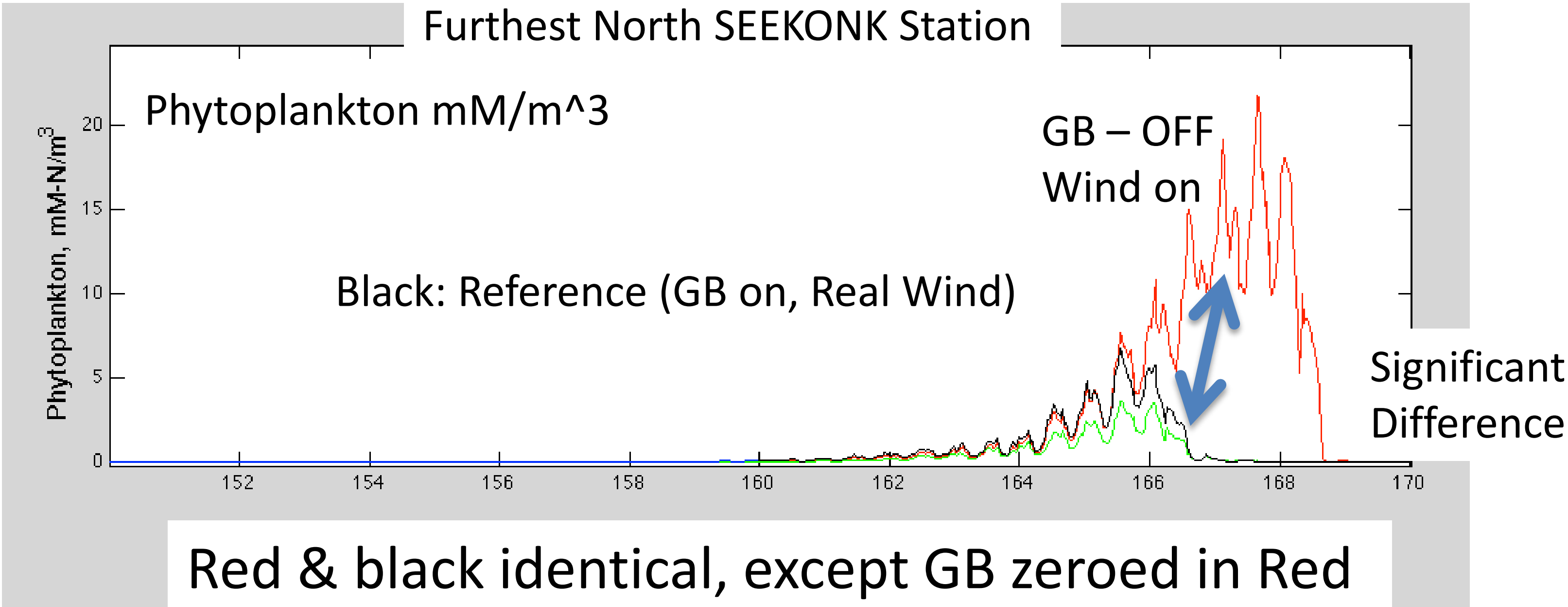
During this period Greenwich Bay consistently high CHL levels

Use ROMS to see, What if Greenwich Bay zero-ed out?



Greenwich Bay off = Big Effect on Prov./ Seekonk Blooms.

Embayments, with chonically poor flush, potentially far-reaching impacts

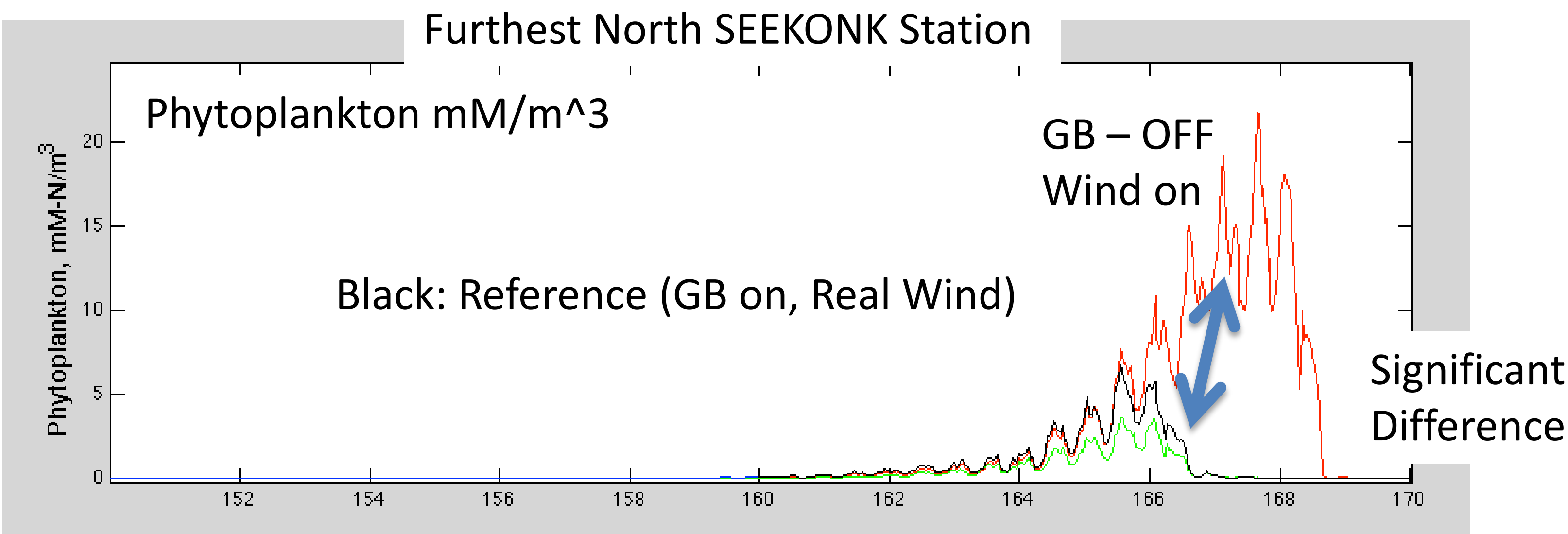


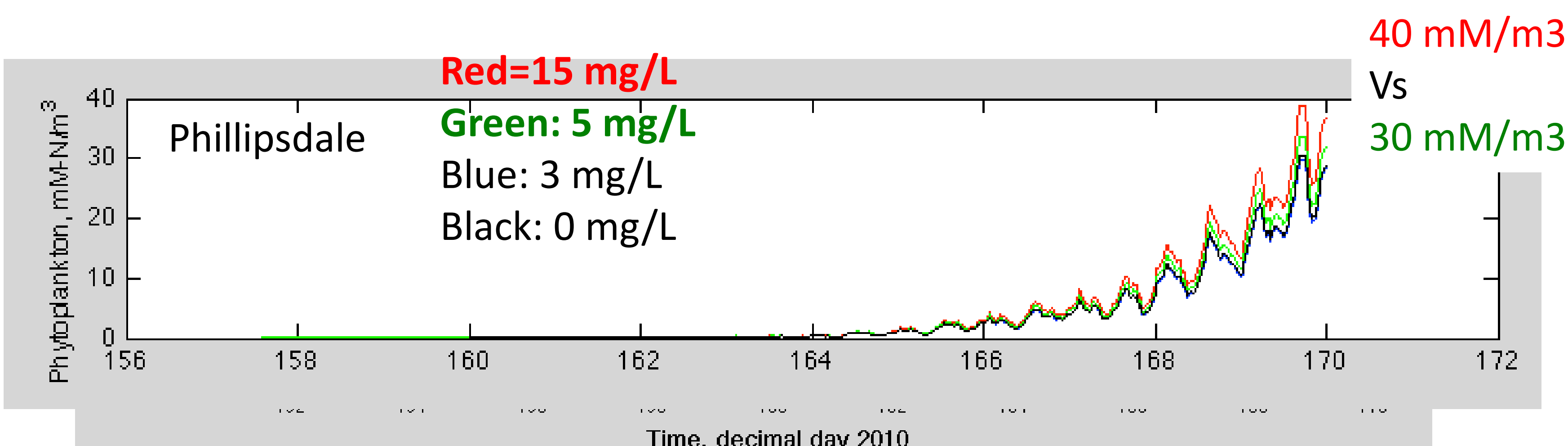
ROMS predicts zero-ing Greenwich Bay produces 3-4 times larger Phytoplankton concentration at Phillipsdale

Altering GB role in bloom = Bloom 3-4 times larger

Changing winds = Alters bloom (weaker or stronger) by factor 2

Changing WWTF inputs 15 mg/L to 5 mg/L , 25% reduction in PD bloom



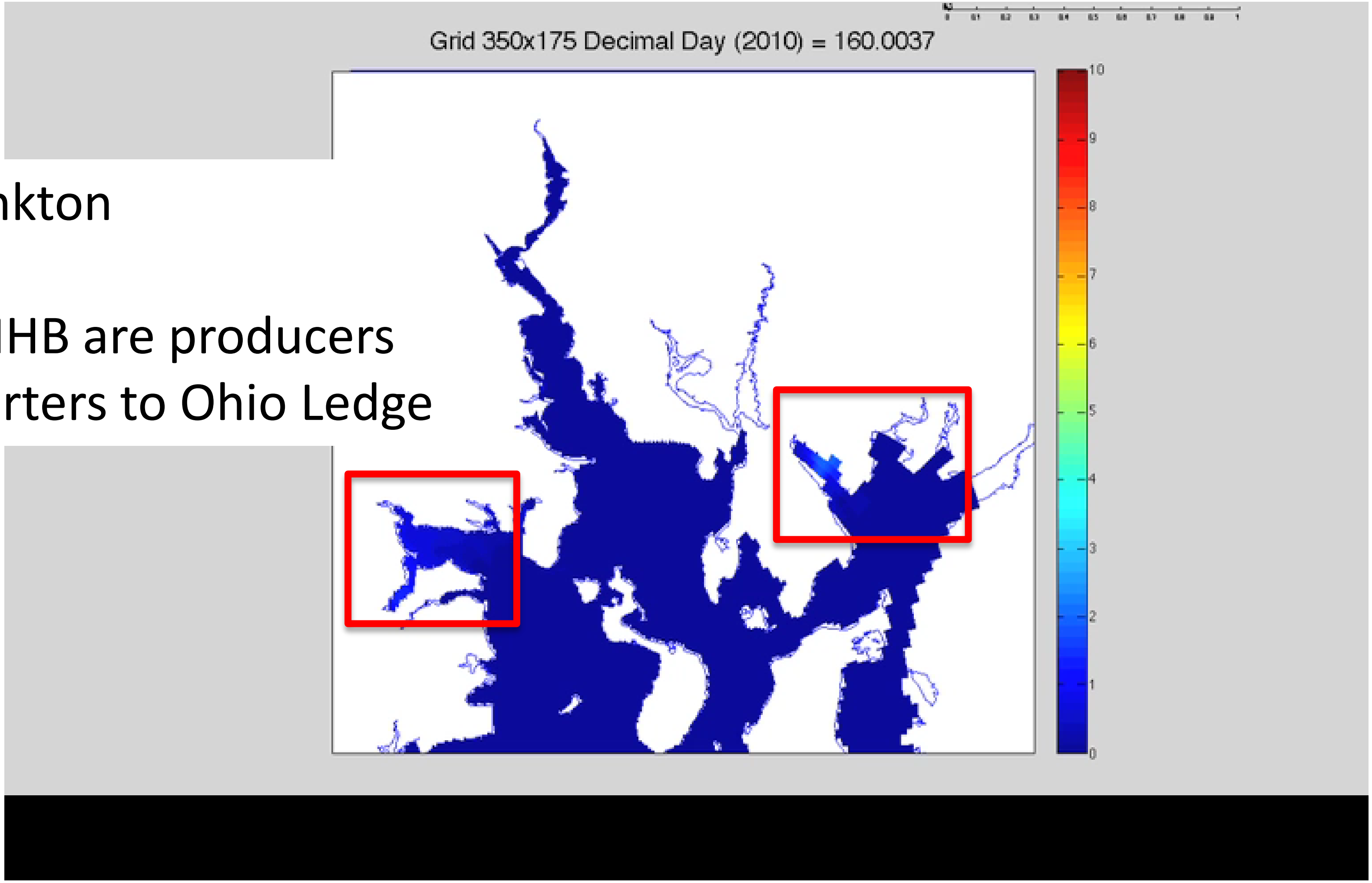


What's going on here? Why different? 1st …

Surface Zooplankton: **without** Greenwich Bay zeroed

Zooplankton

GB & MHB are producers
& exporters to Ohio Ledge



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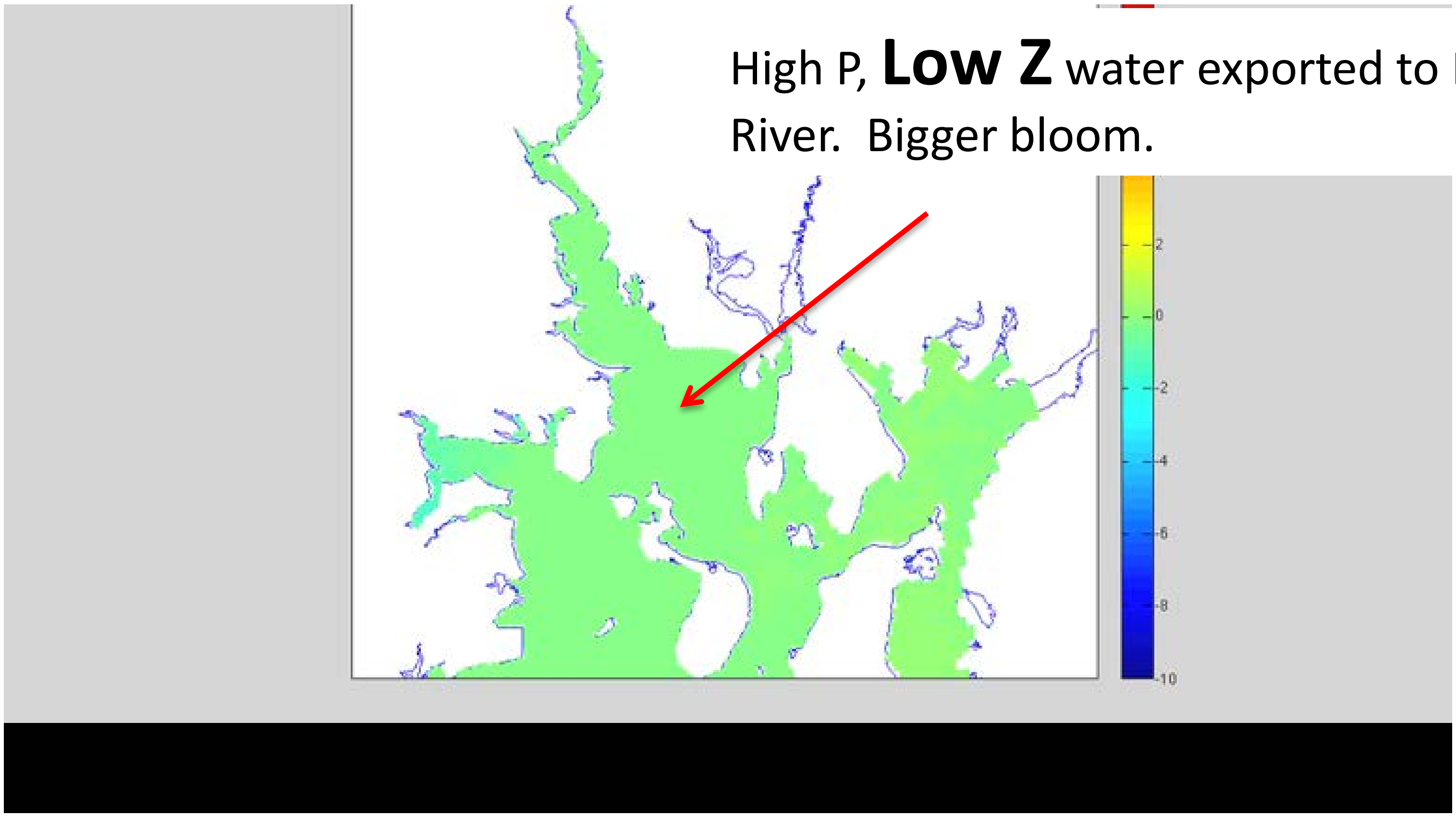
Surface Zooplankton: **(GB-OFF – GB-ON)**

Blue: zooplankton in GB-OFF case **less than** GB-ON

Red: zooplankton in GB-OFF **greater than** GB-ON

High P, **Low Z** water exported to Prov. River. Bigger bloom.



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Summary

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Nitrogen to GB? oscillate, northern river sources vs. local sources

GB dye pumped periodically to mid-Bay site

ROMS NPZD / Data trends suggest Greenwich Bay is a hotspot for blooms

Wind events and tidal pumping produce GB to Ohio Ledge export.

Zooplankton grazing controls length of bloom (Zg=2 best match).

But also can lead to very important divergence in solutions.

Time scale of P and Z growth paths vs time scale of wind-driven events

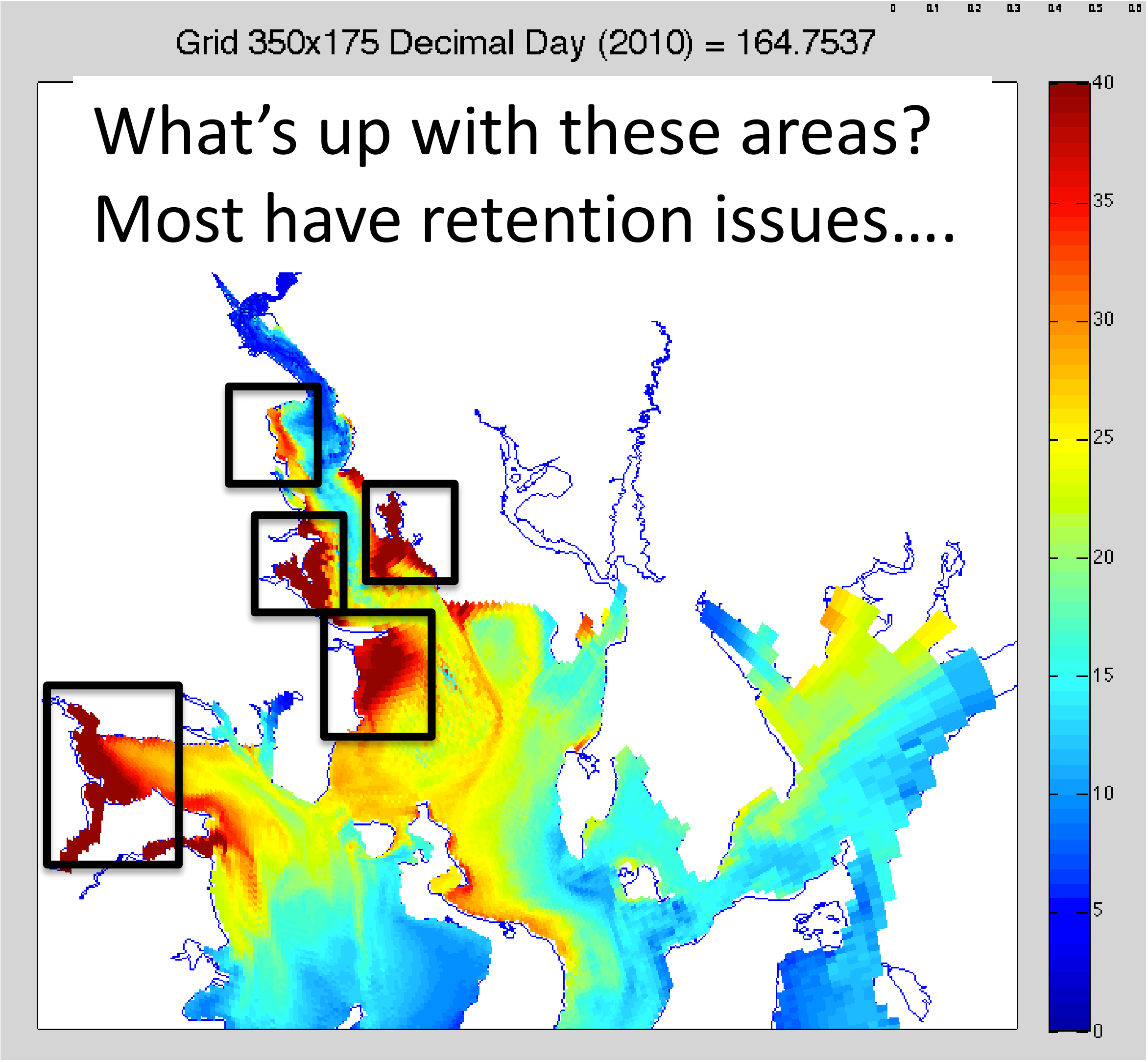
Timing of Ohio Ledge export to Providence River vs. wind events & zooplankton growth can produce either muted or enhanced PR/SR blooms.

Greenwich Bay (other mid-Bay sites) & winds can have big impact on way north

For all runs, do a reference run with bio turned off, making Nitrogen passive

Contour here of near surface nitrogen(NO BIO) minus nitrogen (WITH BIO)

Red areas where N is drawn down



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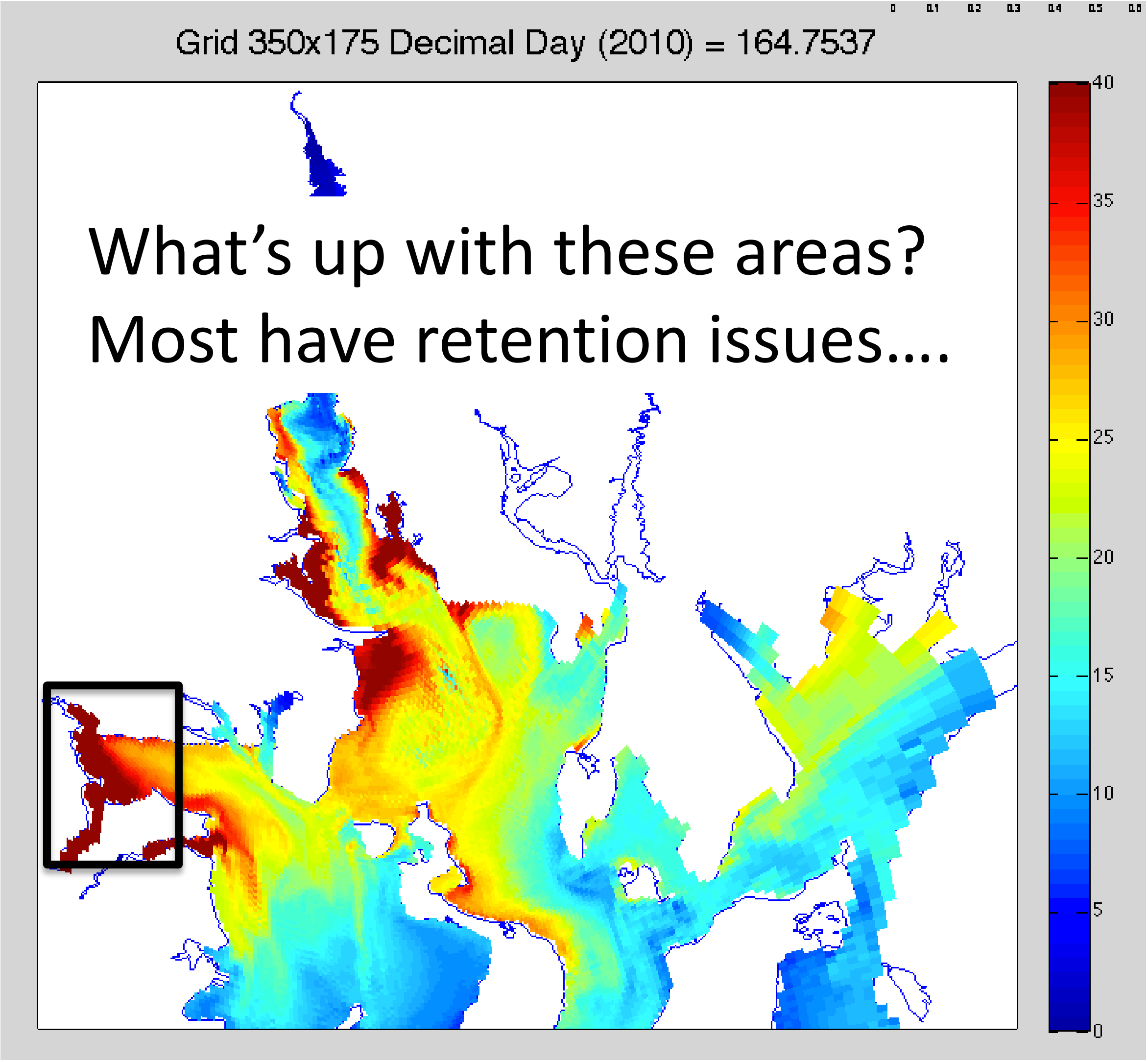


ADCP & TCM Data

Summer 2009 & 2010

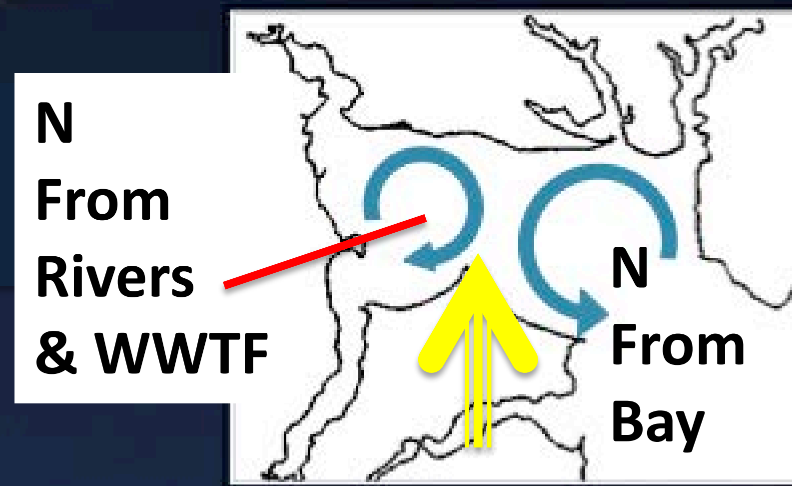
Summer 2012

Field observations

- RED → SeaHorse Tilt Current Meter (TCM)
- YELLOW → Acoustic Doppler Current Profiler (ADCP)

Data (and models) show isolation of Greenwich Bay inner basin

- Northward-blowing wind

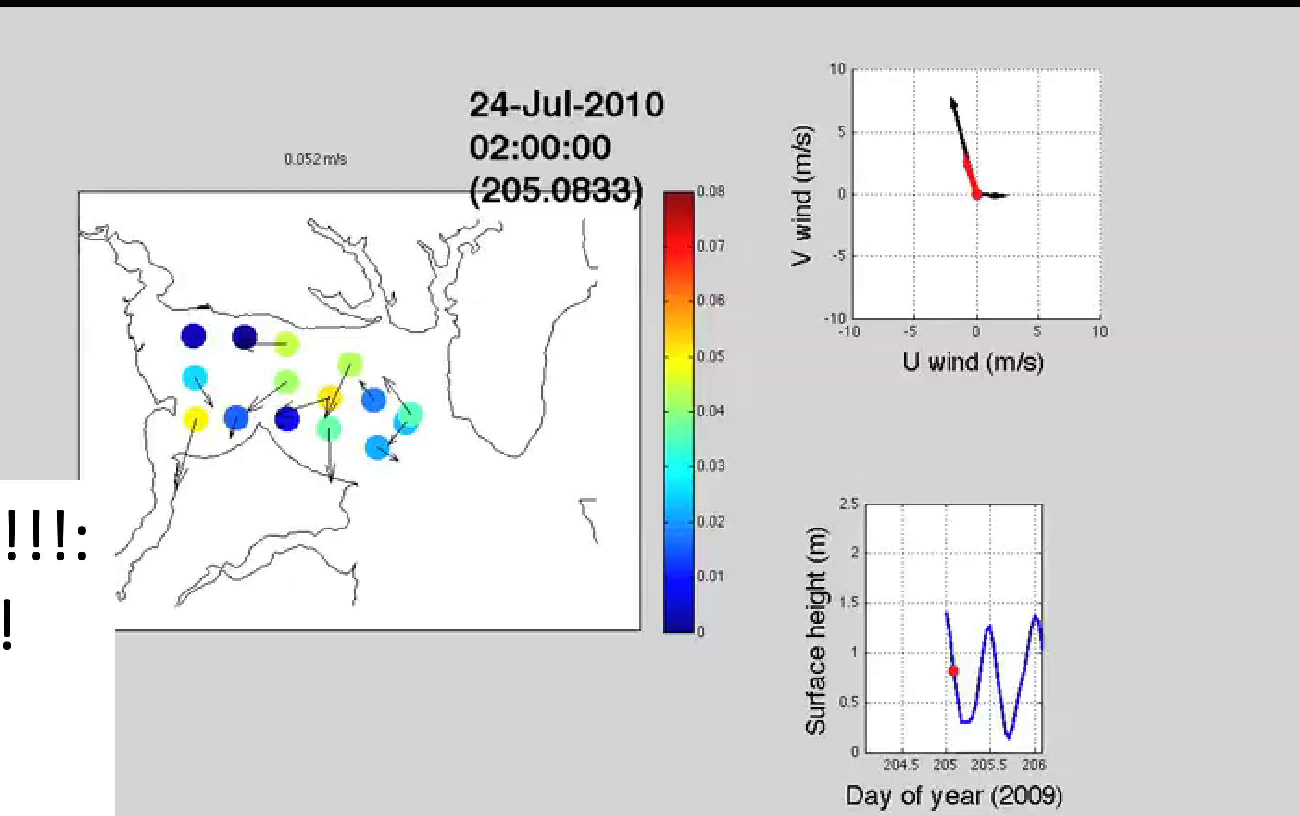


- Eastward-blowing wind

Greenwich Bay Tilt Current Meters: MAP BOTTOM CURRENTS
Chronic inner basin GYRE: Northward winds

July 25-27:
E-ward wind
Good flushing

July 28-Aug 5th!!!:
And >Aug 8th!!!
N-ward wind
Bad flushing



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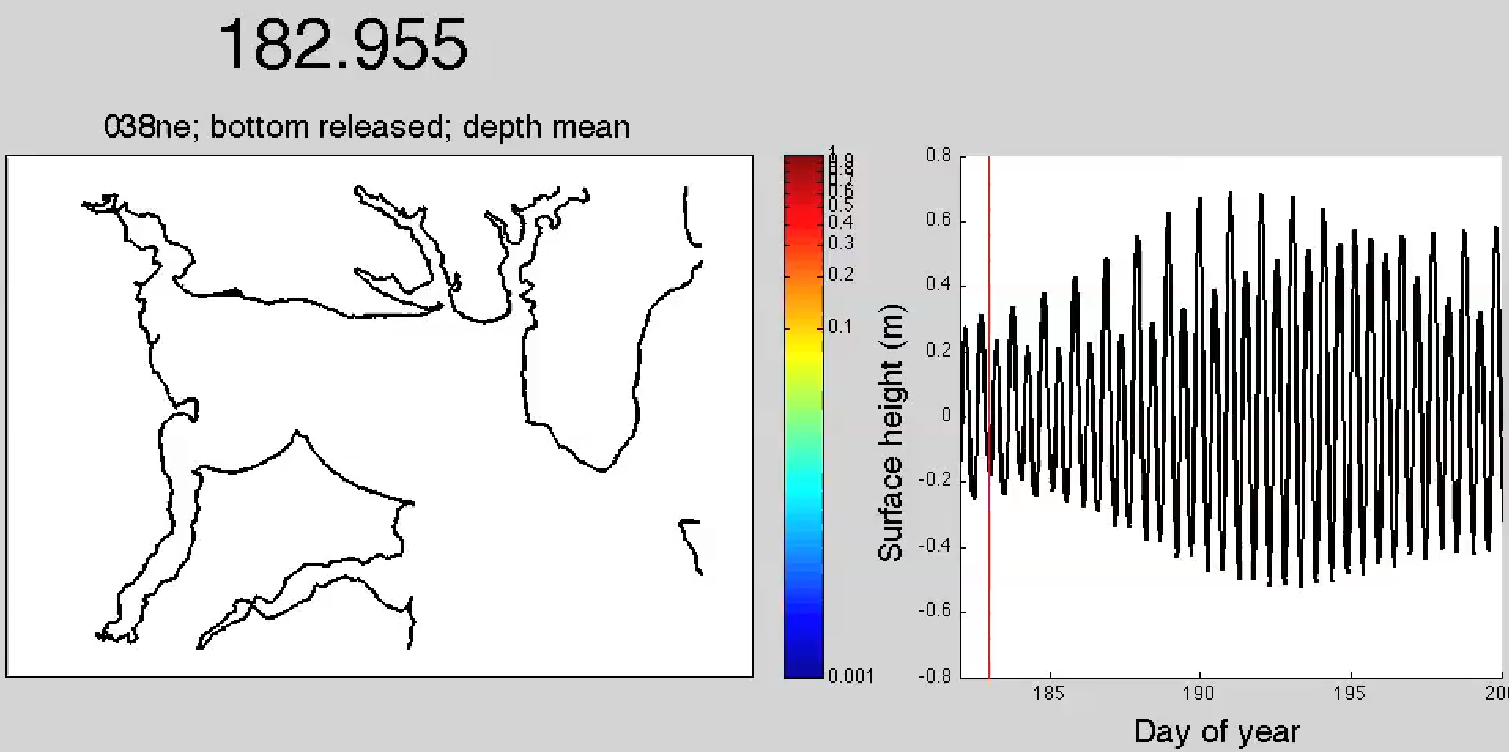
Use Passive DYES and Floats to Quantify Circulation & Flushing



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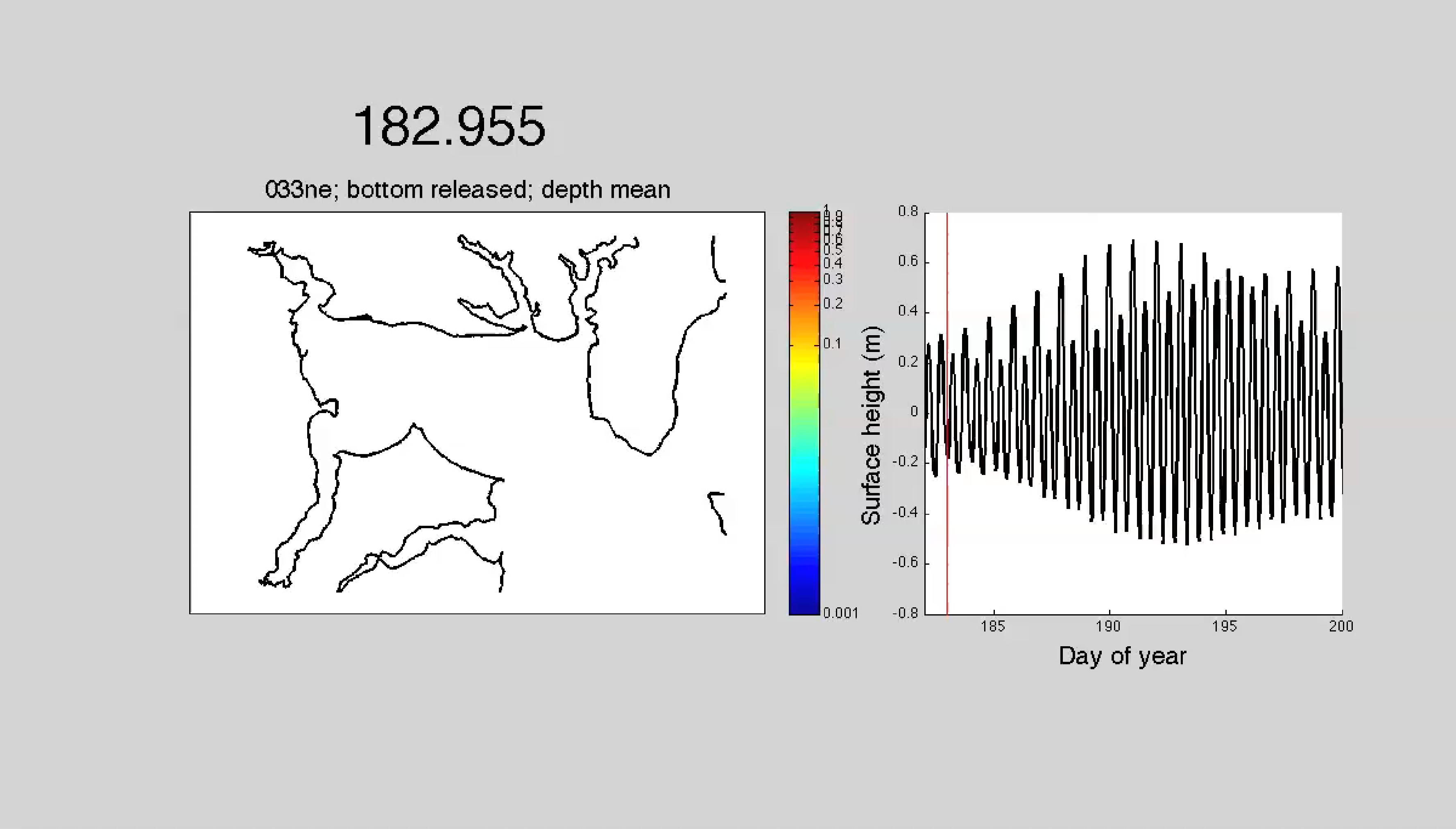
Decimal Day 182 is July 1

FLUSHING FAVORABLE: Southeast-**ward** Wind Event



Play Video

Same 2010 Conditions But:
Imposed North-ward Blowing Wind Event

For all runs, do a reference run with bio turned off, making Nitrogen passive

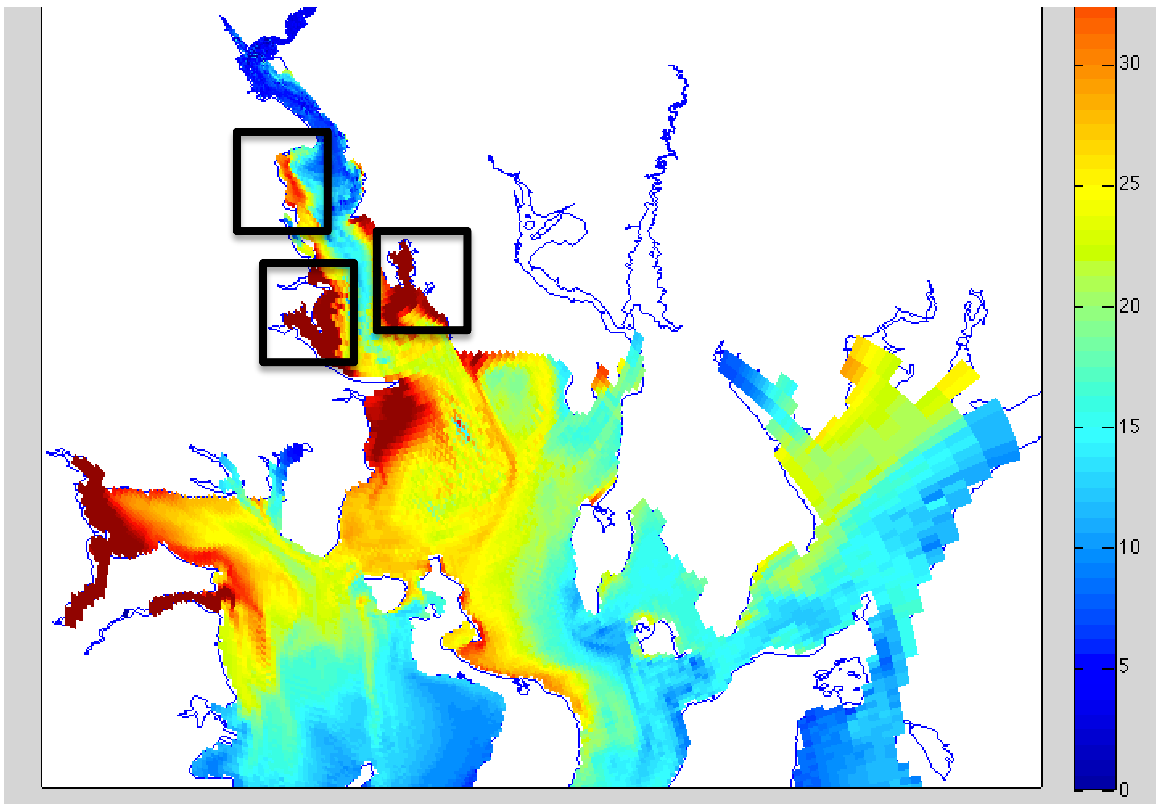
Contour here of near surface nitrogen(NO BIO) minus nitrogen (WITH BIO)

Red areas where N is drawn down

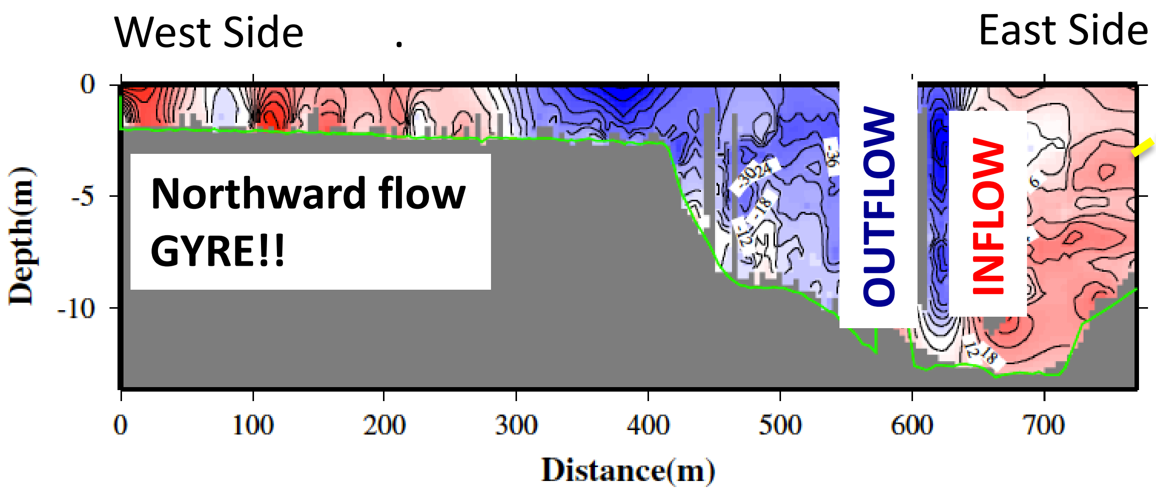
Grid 350x175 Decimal Day (2010) = 164.7537

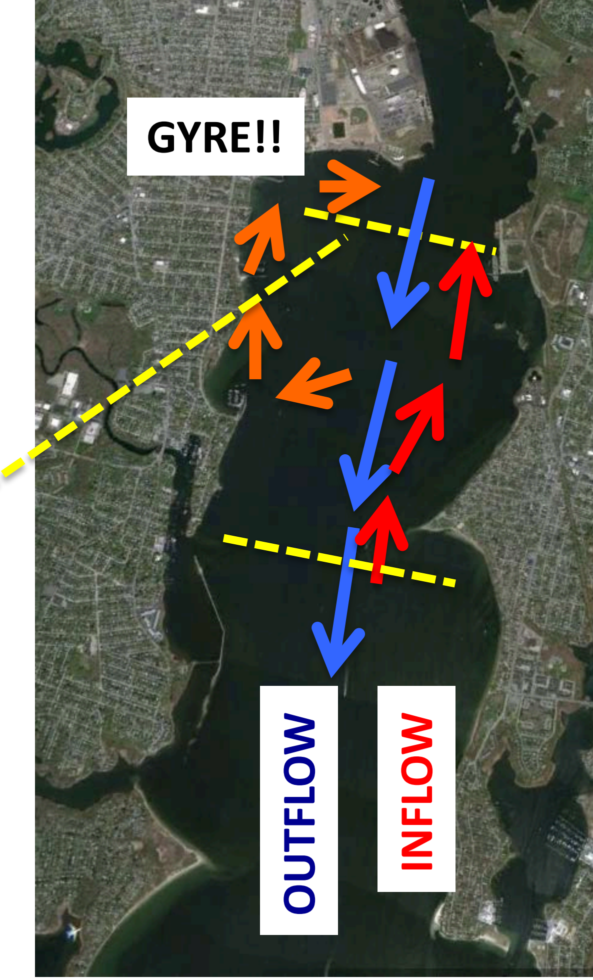
What’s up with these Providence River areas?

Serious retention ….



1. Outflow
1. Deep inflow
1. Re-circulation gyre

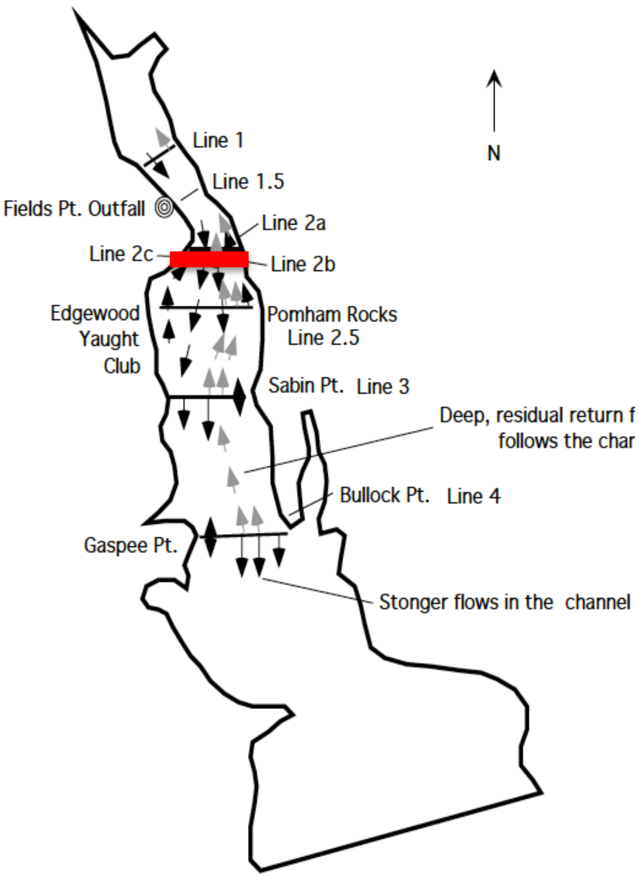


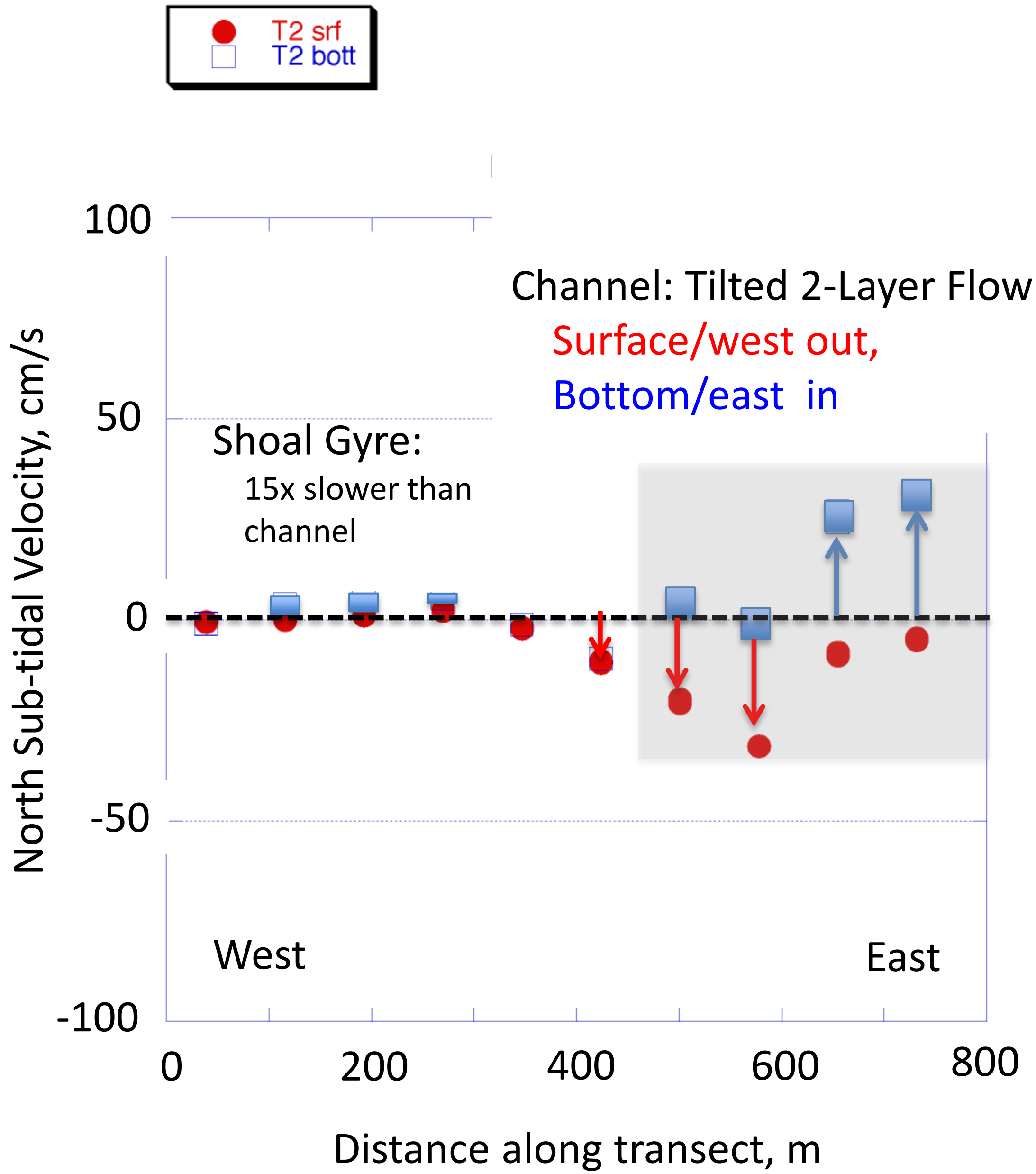


UNDERWAY ADCP:
Basic pattern seen Spring/Neap
& summer, winter, fall, spring

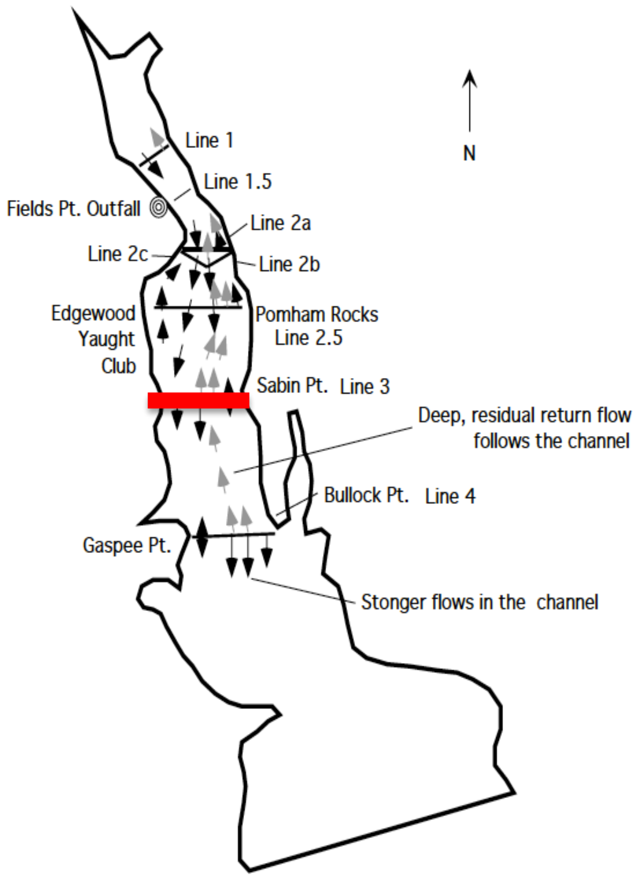
Sub-tidal Flow:

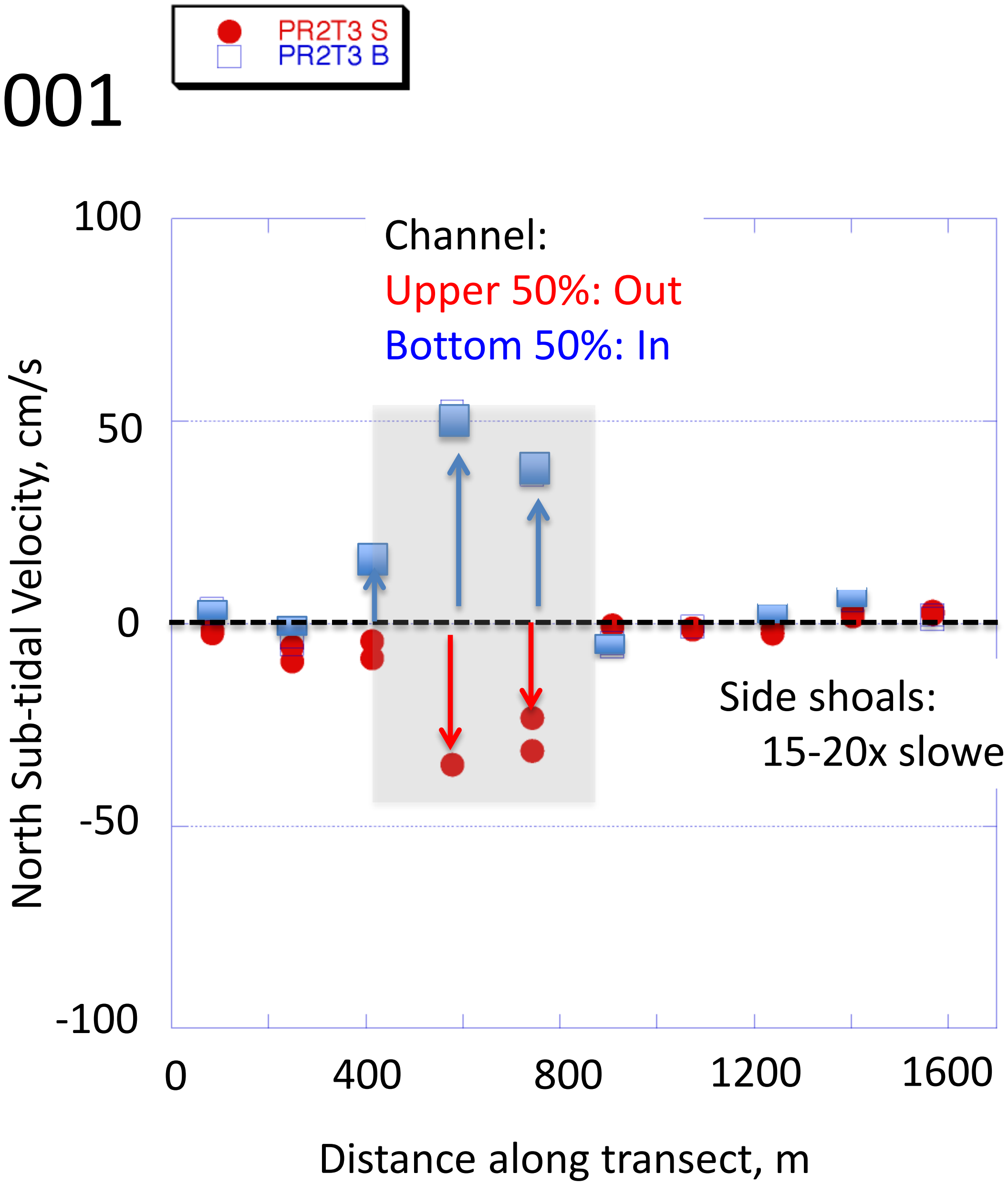
Edgewood Shoals Line, Summer , 2001



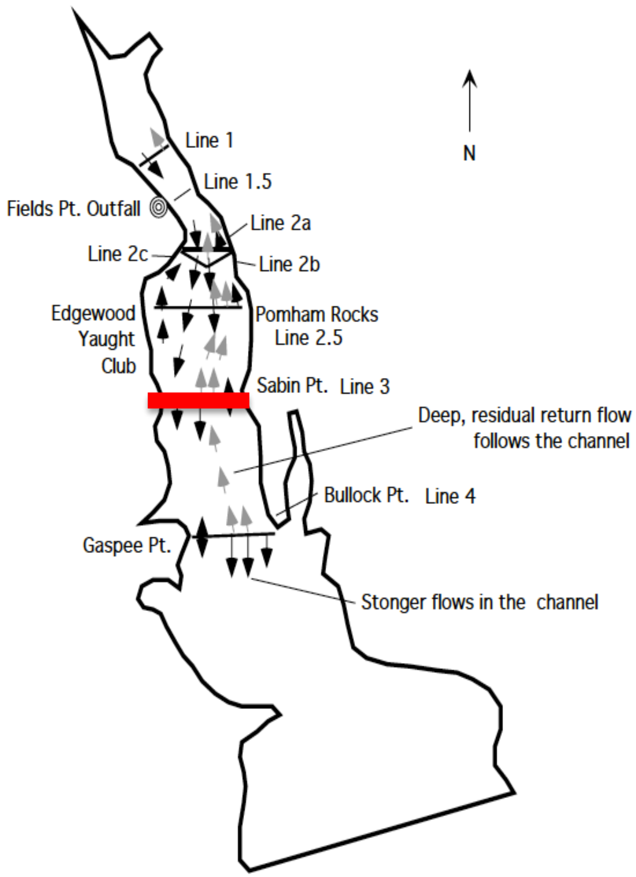


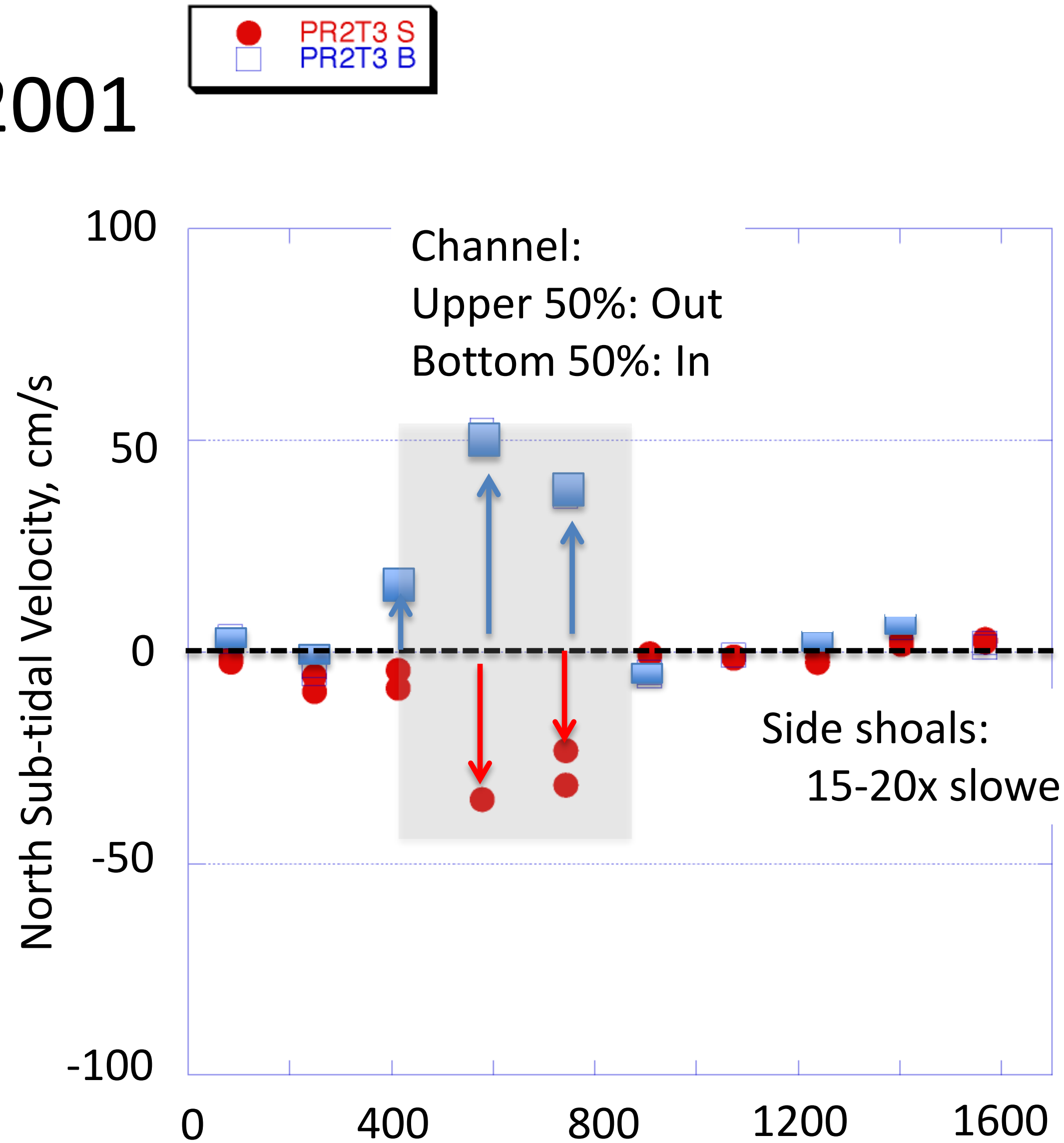
Sub-tidal Flow:
Sabin Pt. Line, Fall 2001





Sub-tidal Flow:
Sabin Pt. Line, Fall 2001



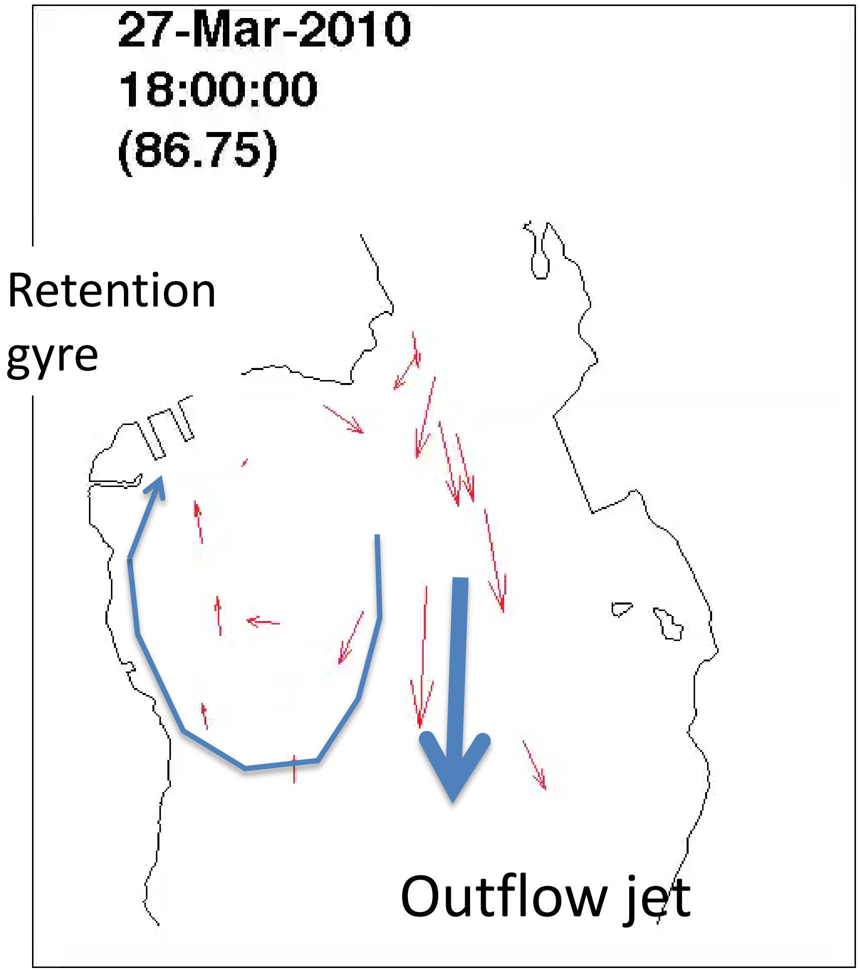


Key Point: Retention=bad water nucleation site

Edgewood, Sabin, Gaspee Shoals are stagnant relative to channel

Tilt Current Meter Experiment: Summer, 2009; Spring/Summer 2010

Gyre: Periods of retention, periods of fast flush



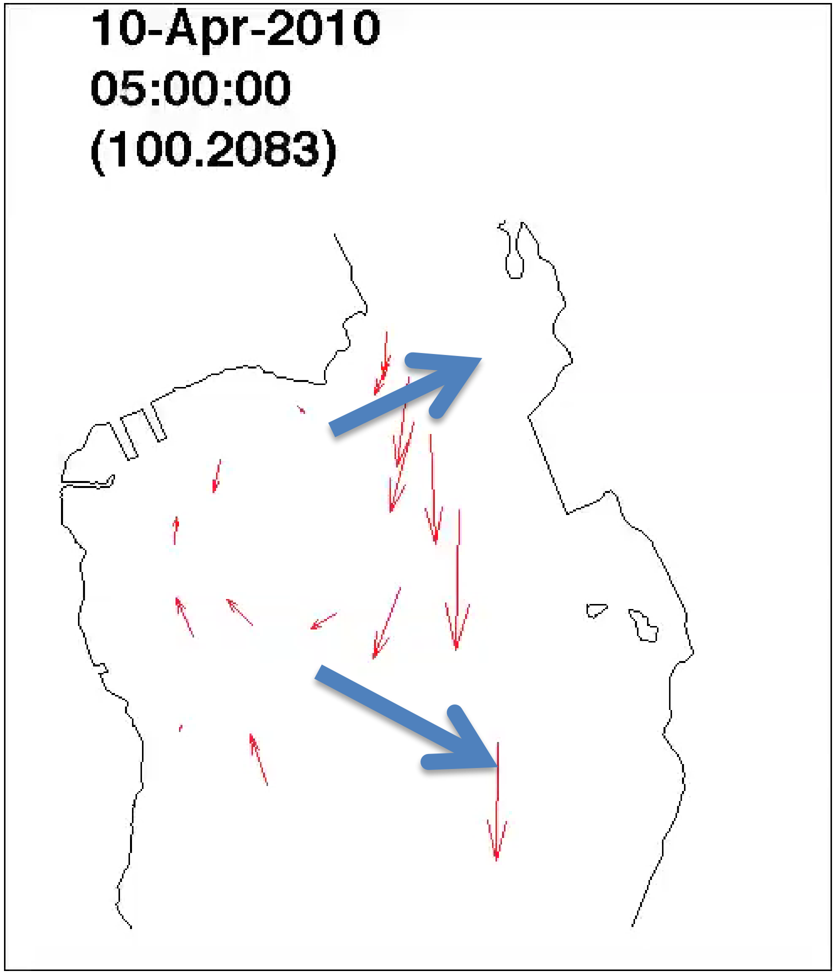
Play Video

Great RI Flood: March 28th (22:00)

Thru April 7, very stable

Gyre is chronic (summer, winter, spring, fall)

Do see a) shape/spin changes, b) **periodic flush**



Play Video

Impact of 5-8 day retention, 1-2 day flush?

<u>Box Model, Edgewood Shoals</u>
<u>Periodic retention> oxygen drawdown > discharge</u>

Edgewood Shoals: 6 million cubic meters

~9% of Providence River volume.

Model estimate:

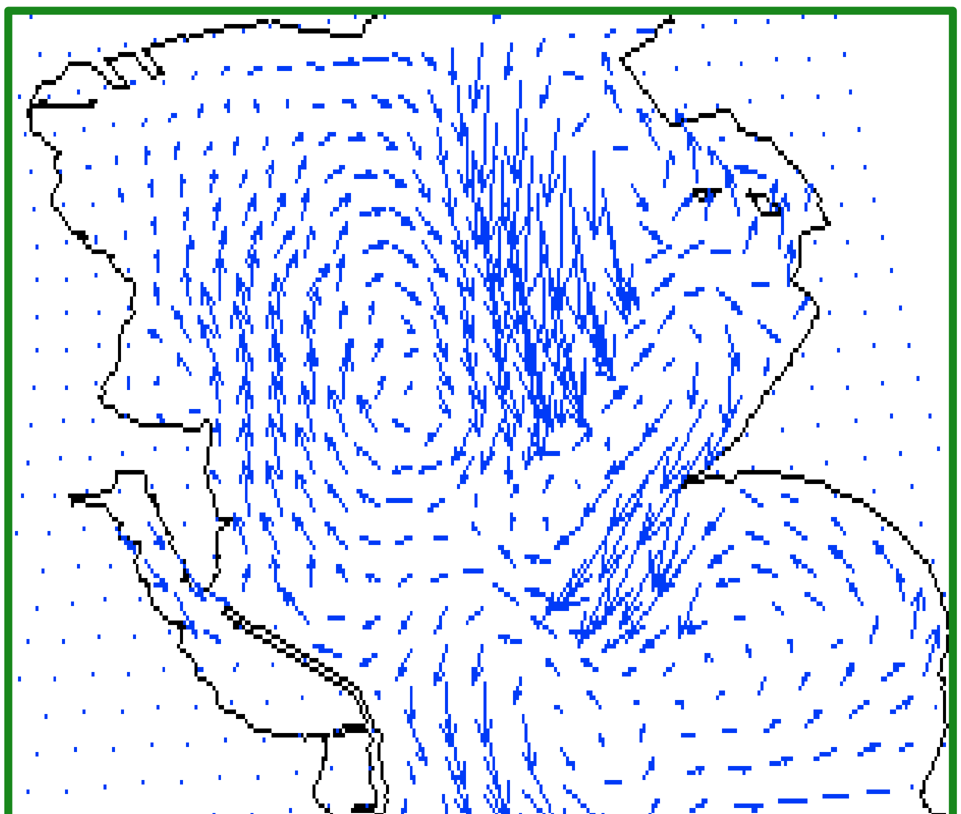
5 day retention time.

release in wind event over 2 days.

equivalent to constant ~10 CMS low oxygen river

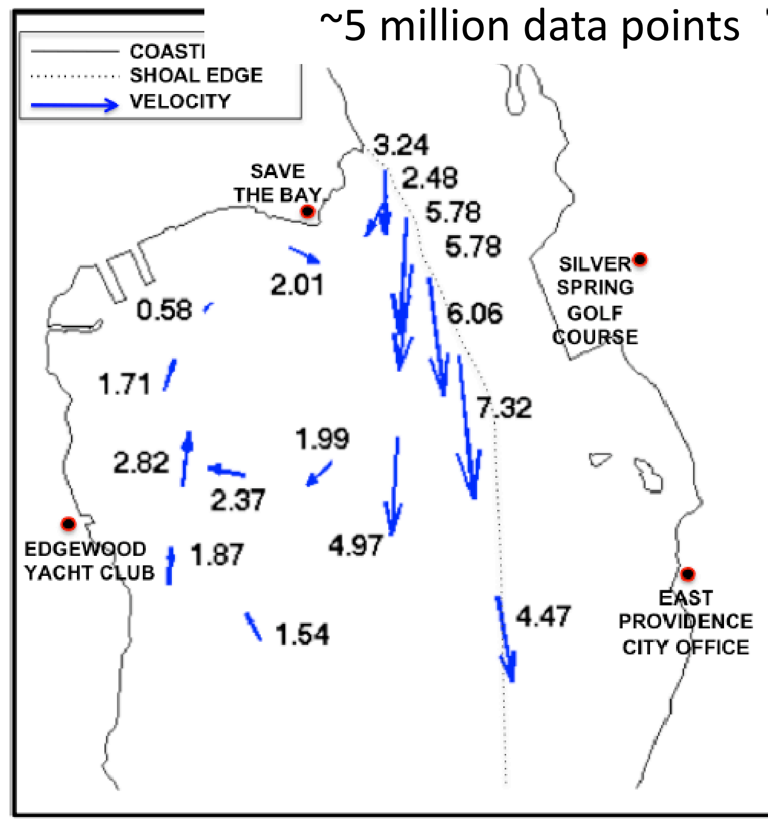
Data + ROMS: Amazingly Stable Gyre on Shoal coincides with region of chronically low oxygen

Edgewood + Sabin + Gaspee Stagnation Zones significant volume of Providence River

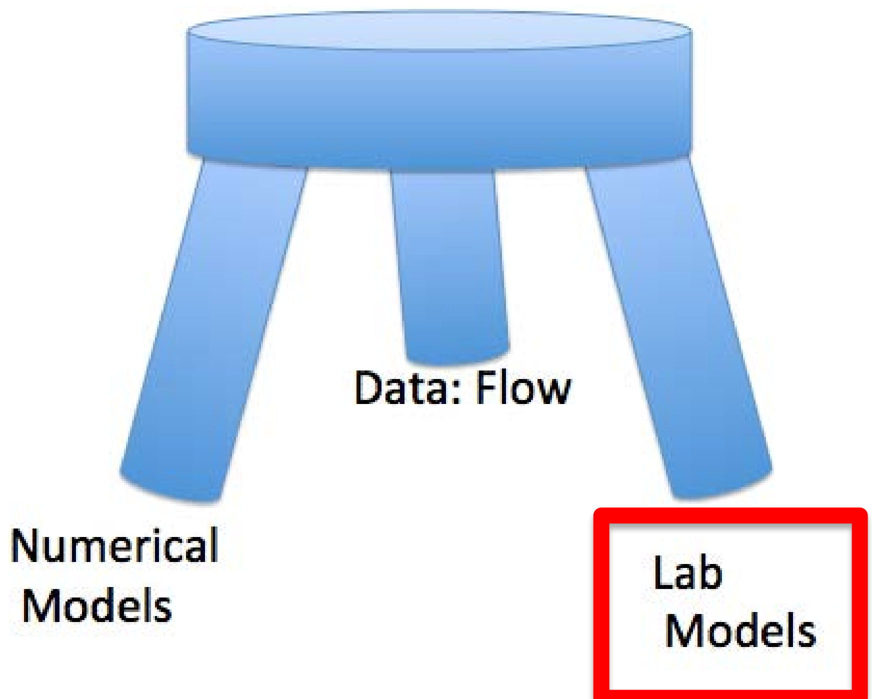


Data:

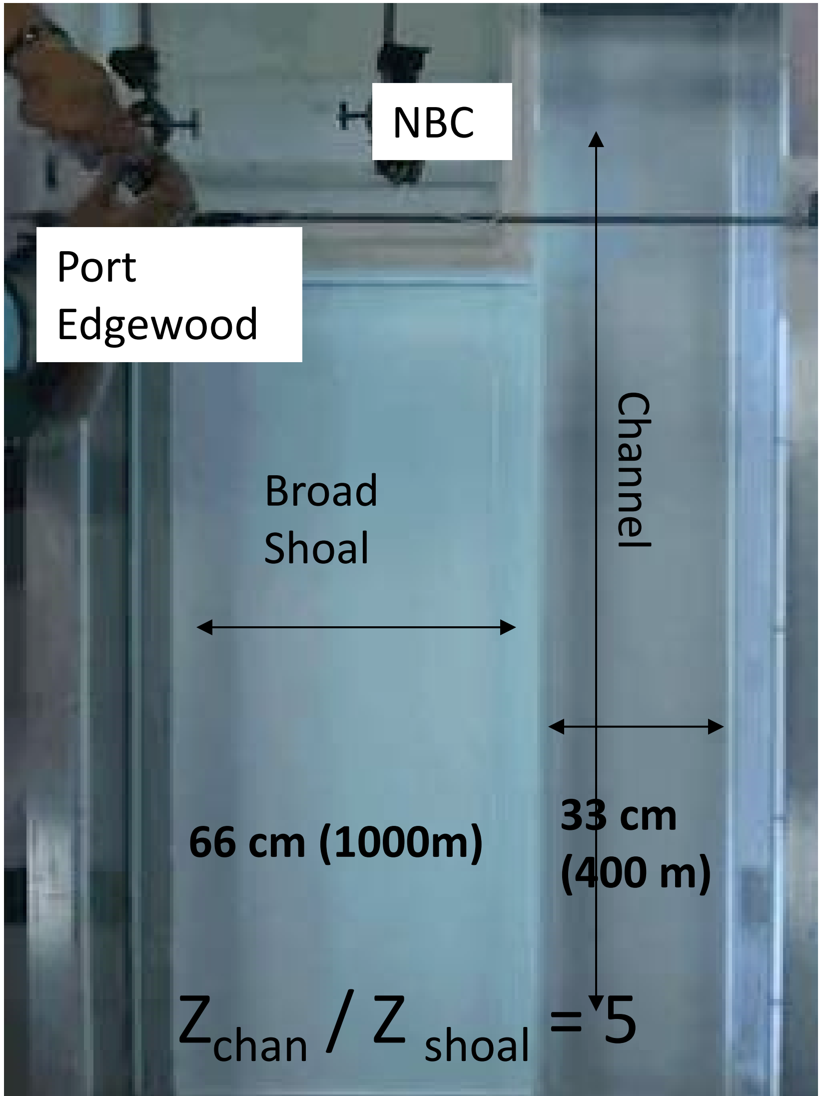
~5 million data points

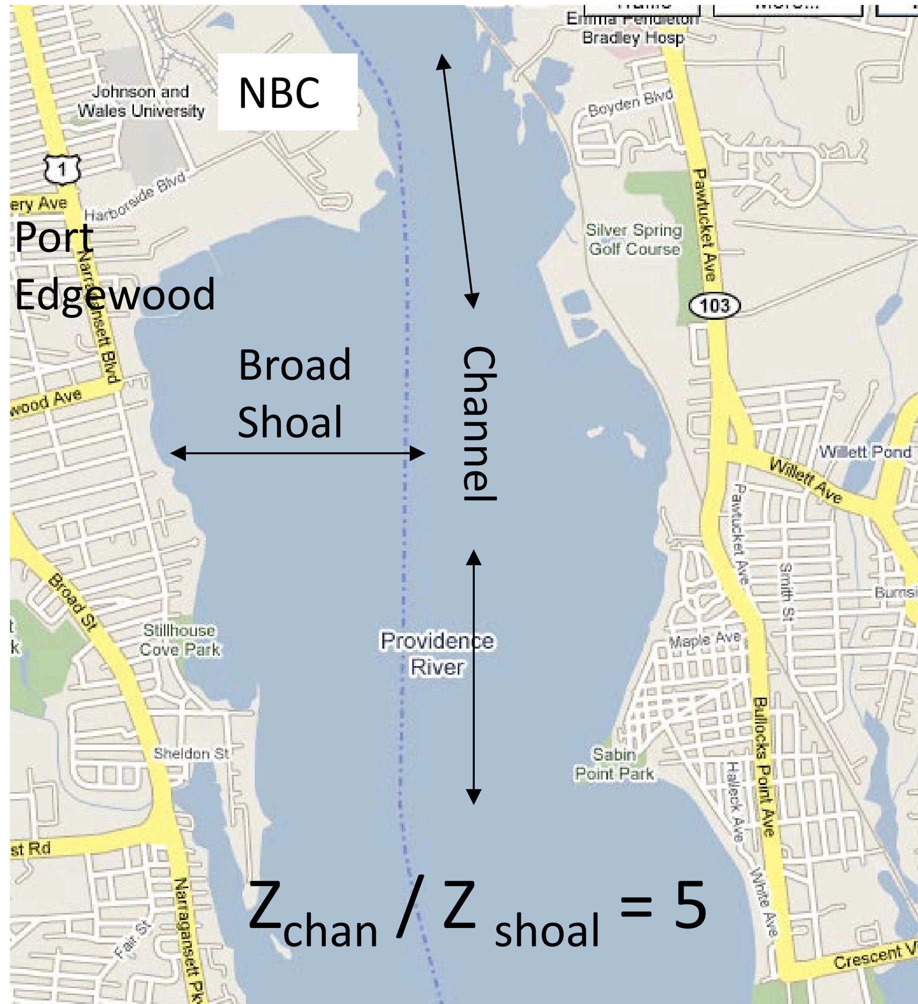


Can we enhance flushing from chronic areas?
Perspective from 3rd Leg of GFD Stool:
Laboratory Models



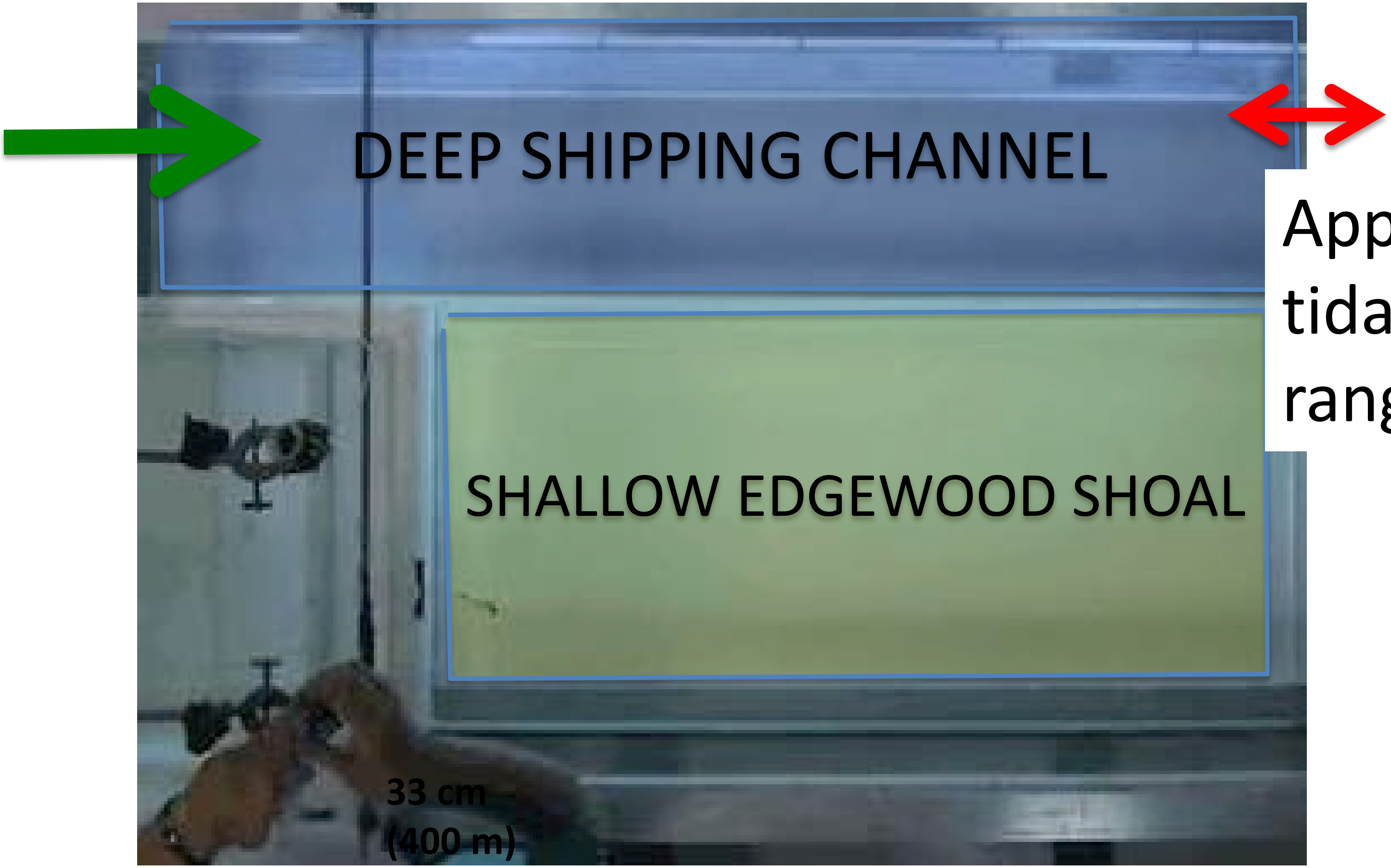
3rd Leg of GFD Stool: Laboratory Models





POWERPOINT SOMETIMES FLIPS THIS ON SIDE

Applied river runoff



Applied tidal range

Scaled Lab Model:
<u>Providence River</u>

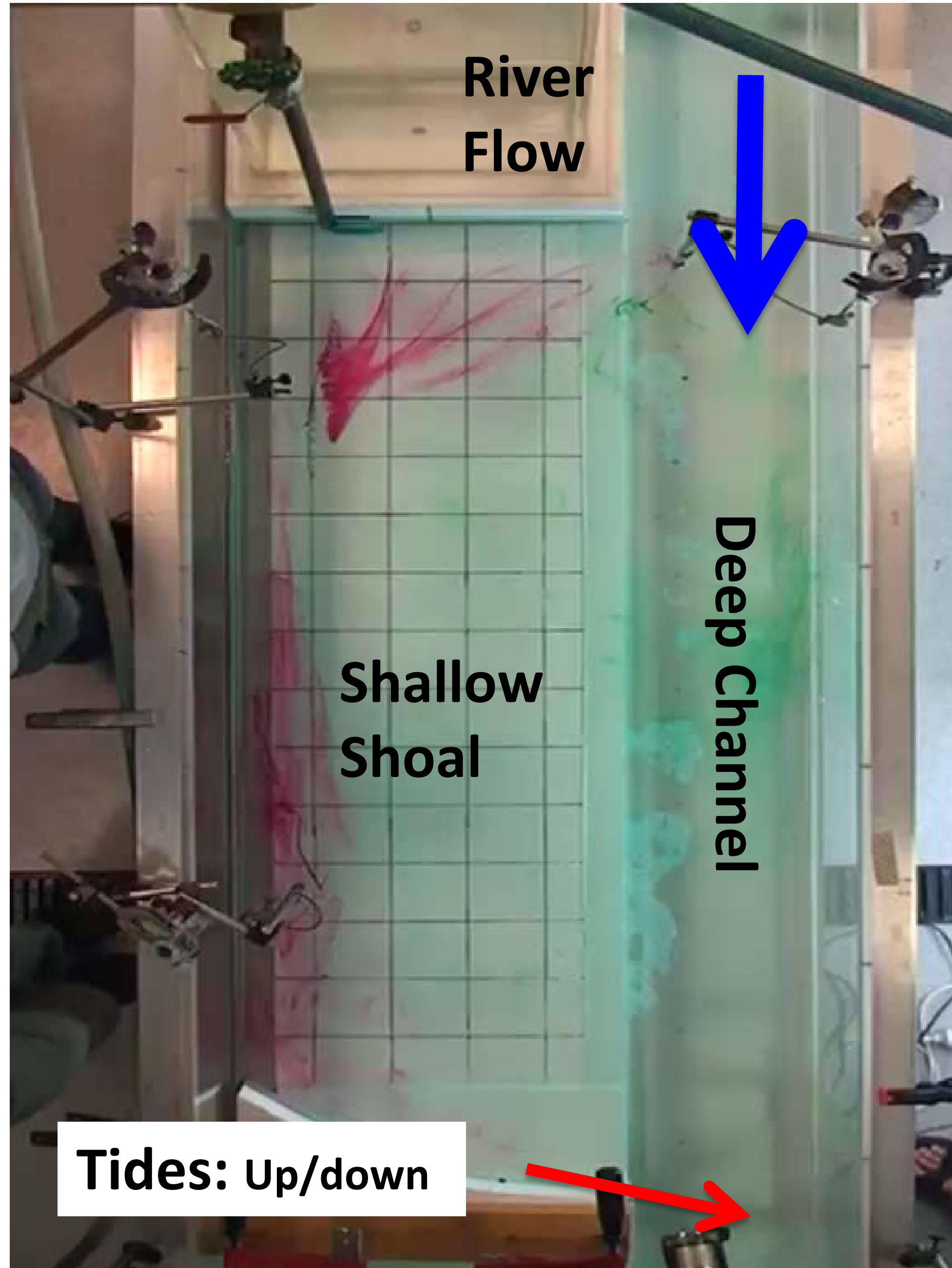
Channel & Shoal

River Runoff

Tides

- No wind
- No density differences

+ Real Fluid



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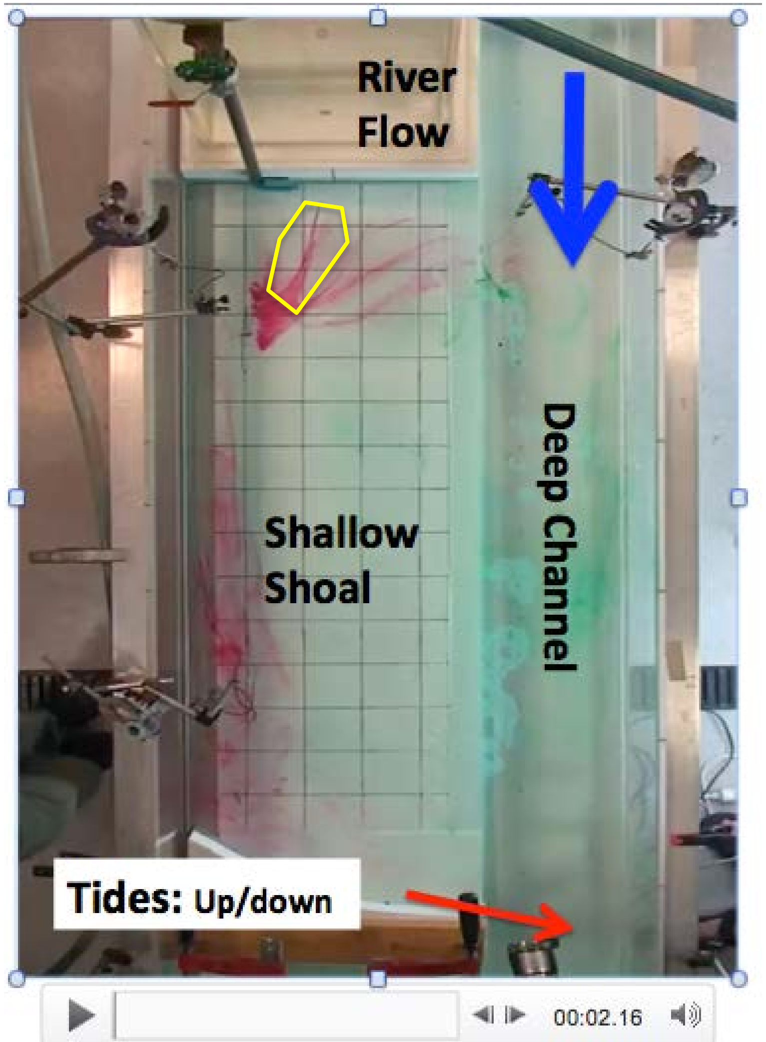
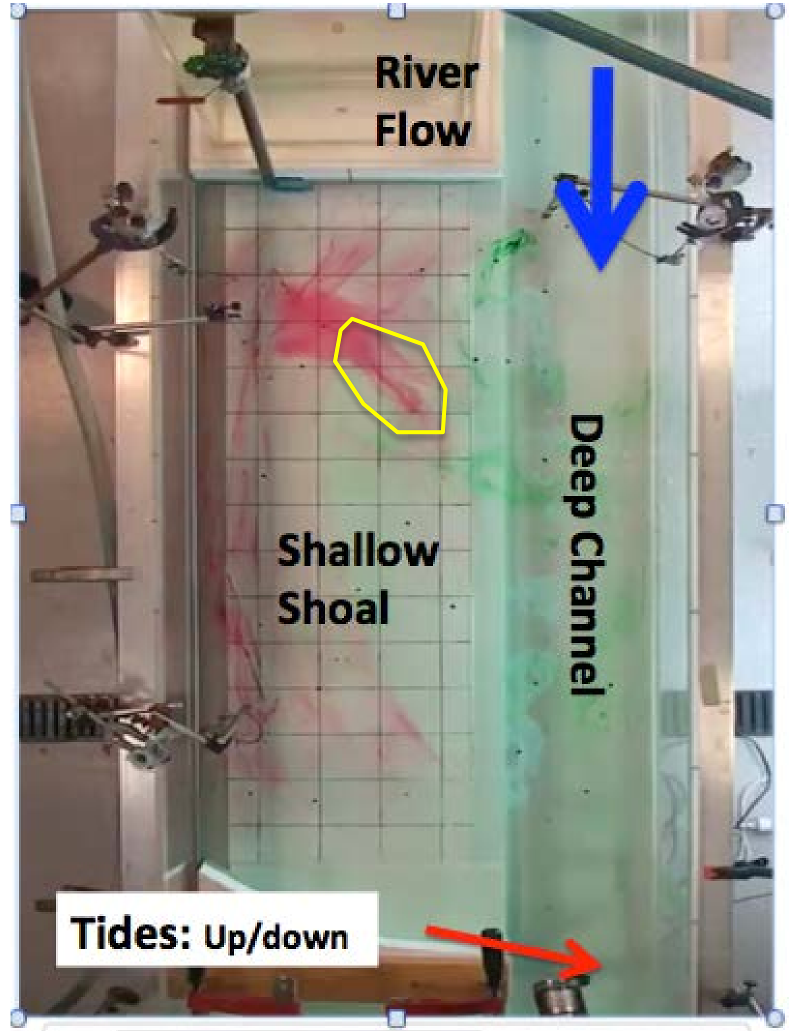
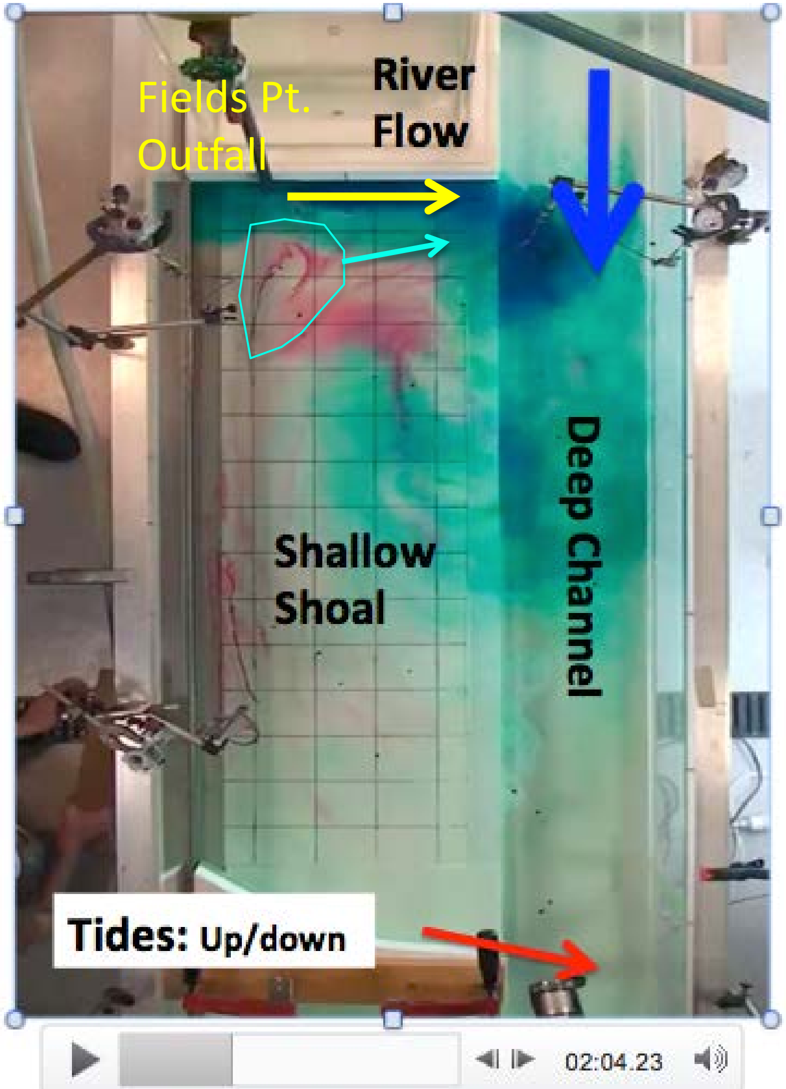
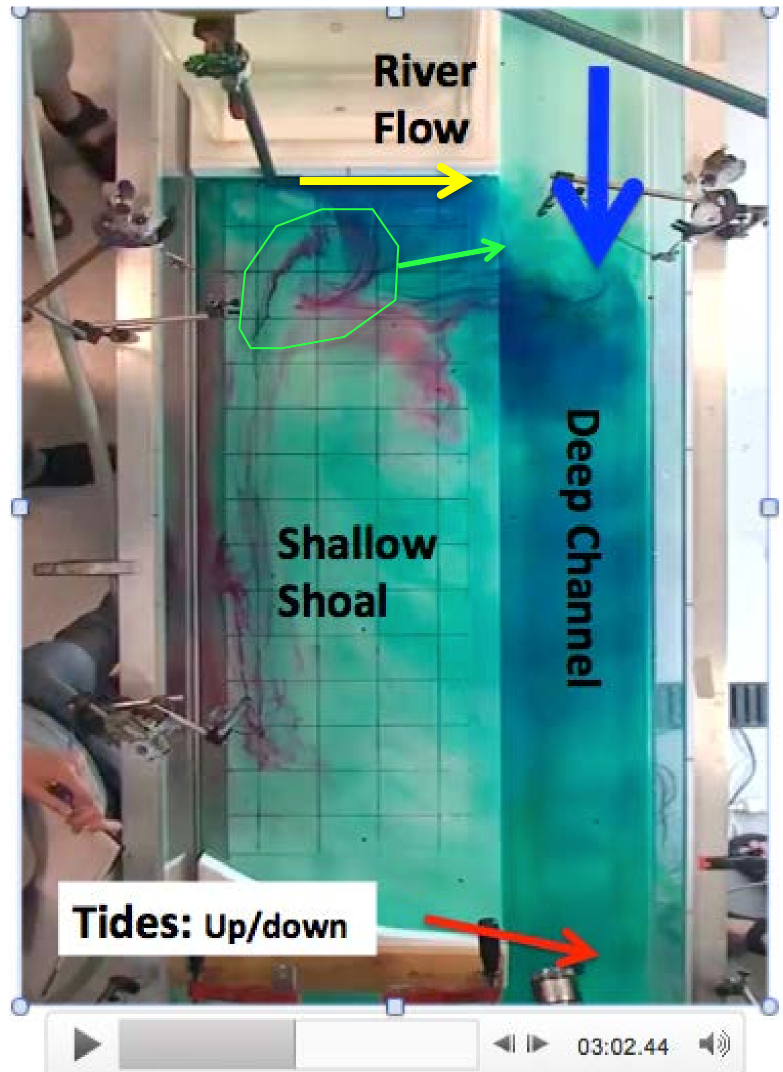




6 cycles ~ 3 days,
Just for bottom water to go 25% around gyre

With eastward injection in location & direction of natural flush path: Separate patches flush shoal in 3 cycles



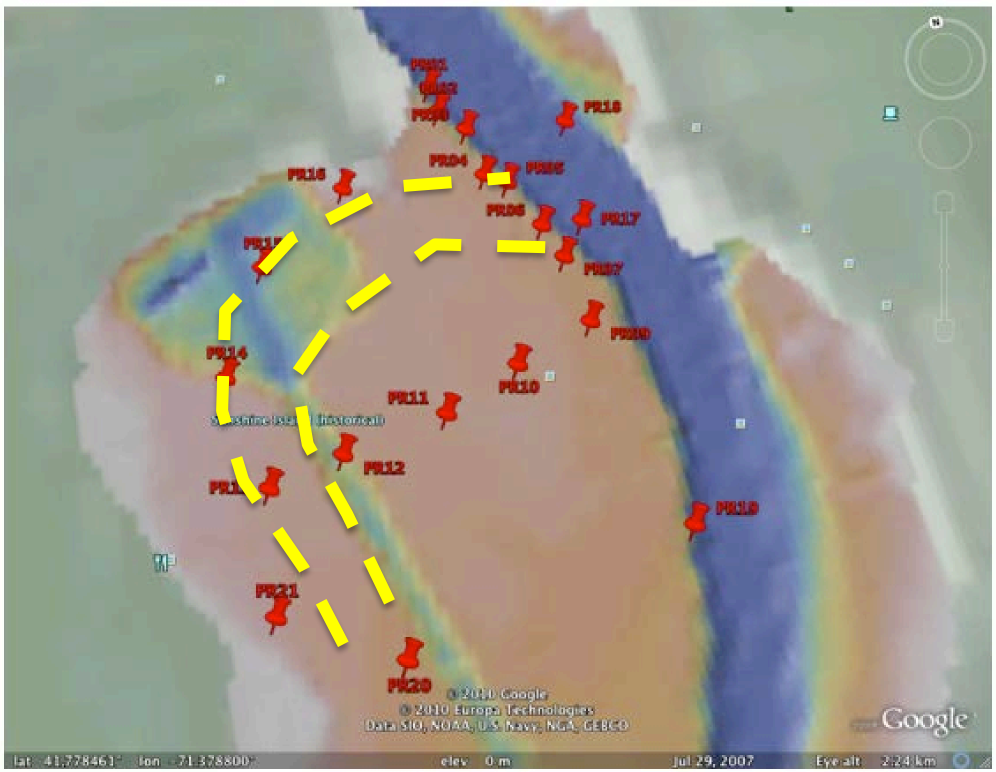


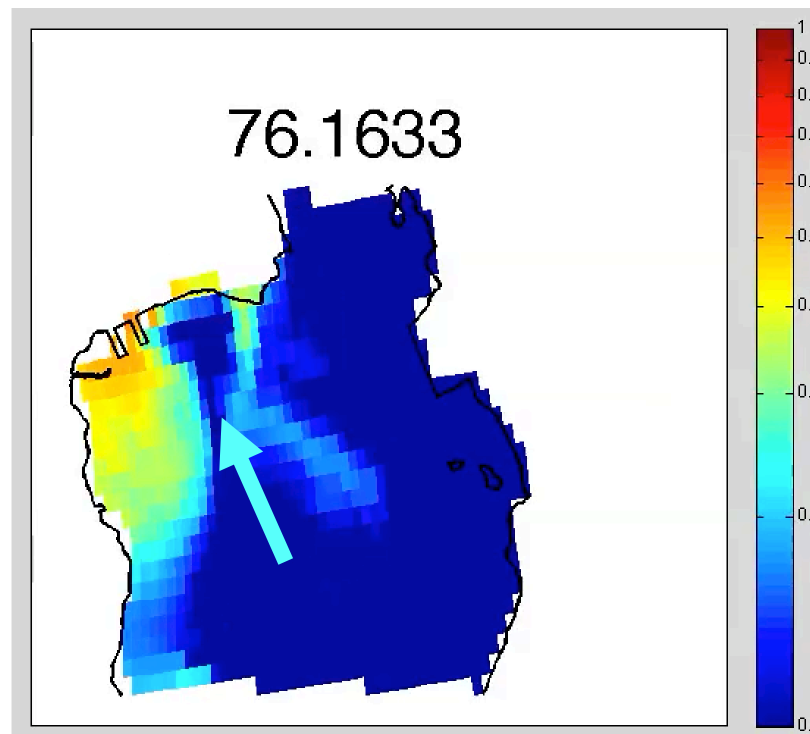
Nutrient Reductions at Waste Water Facilities 100s Millions of $

What about Strategic Engineering Solutions?

Port Edgewood Channel Attempts to Flush Shoal

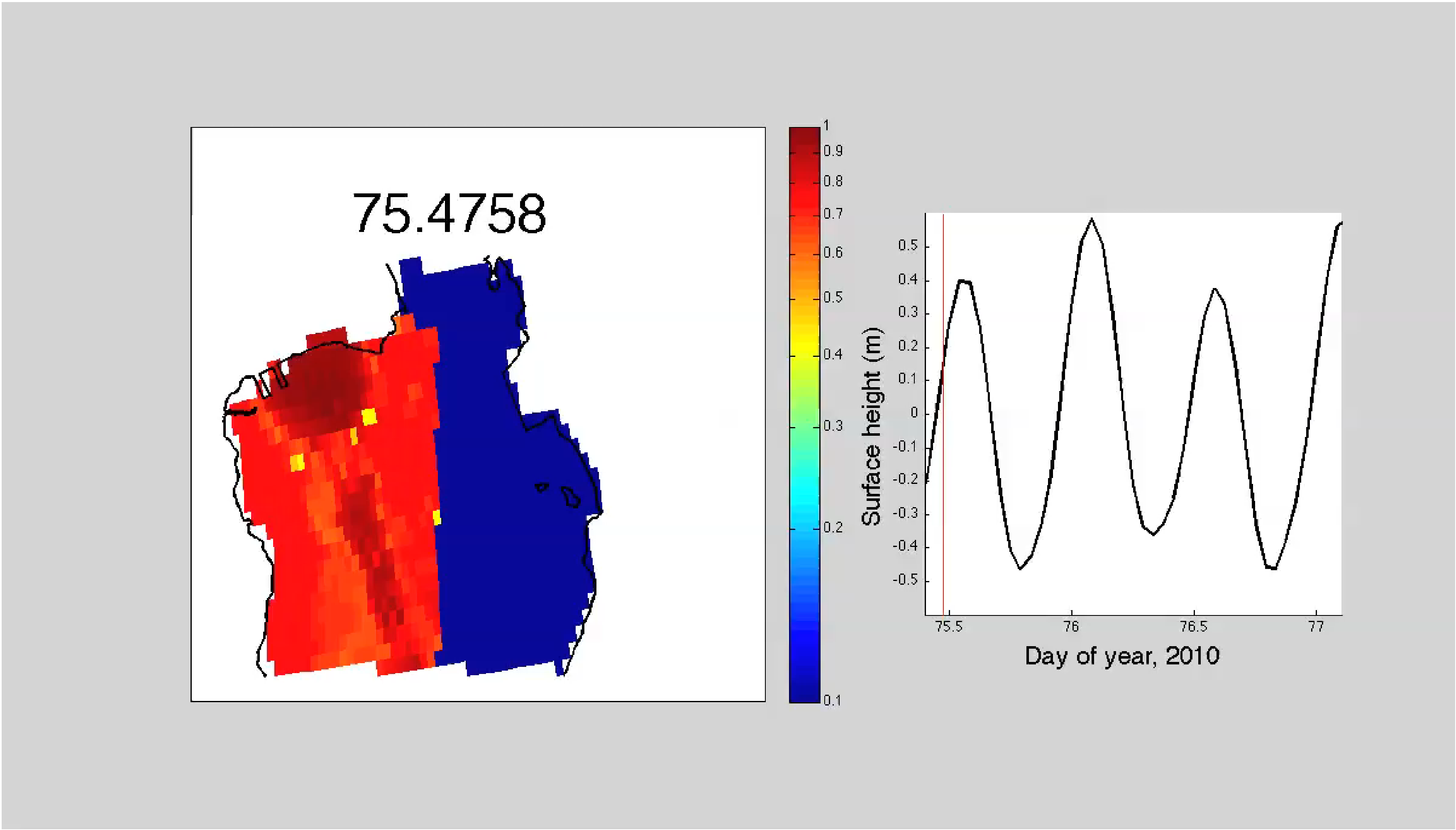
Would dredged connection to channel enhance flushing?



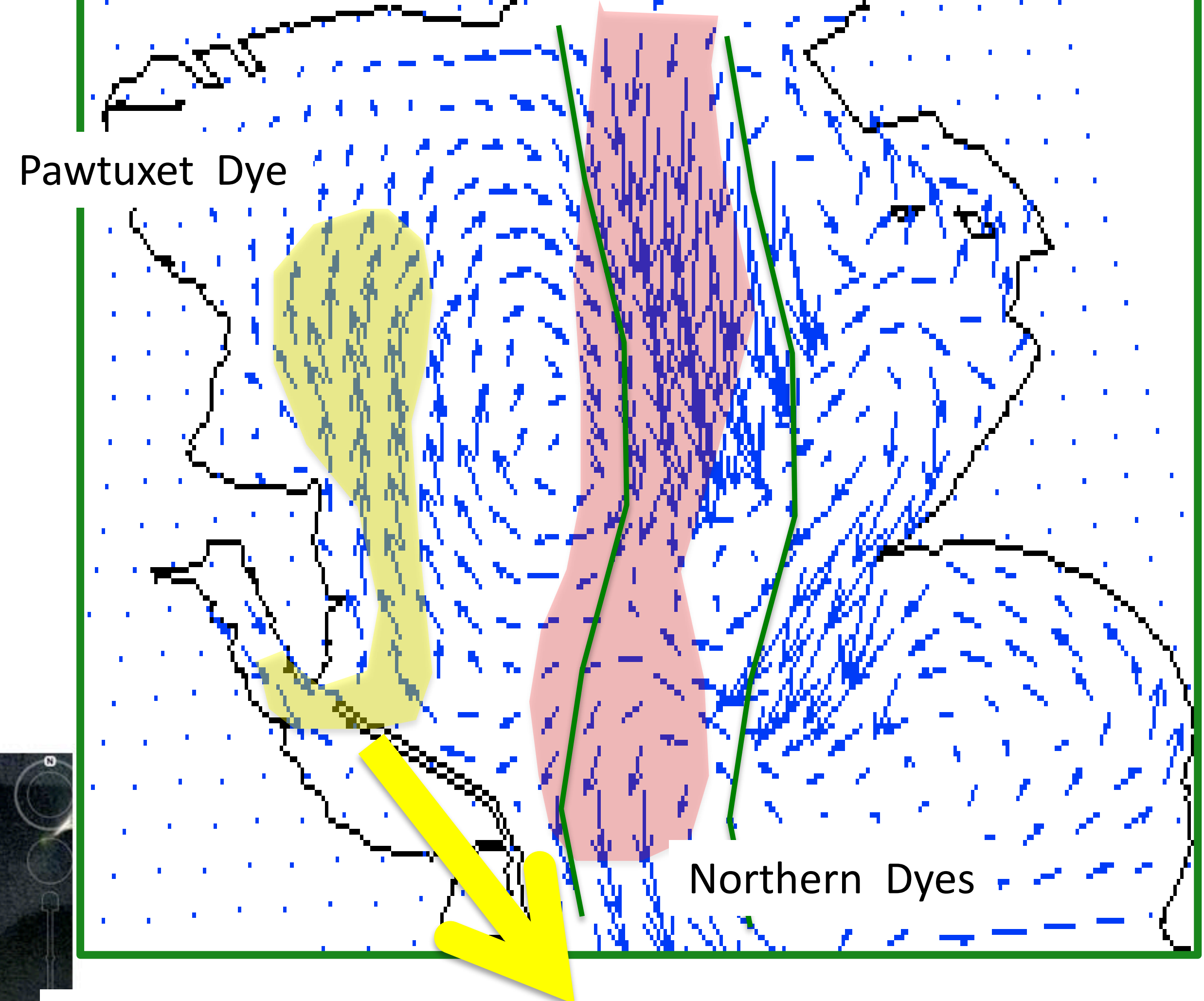


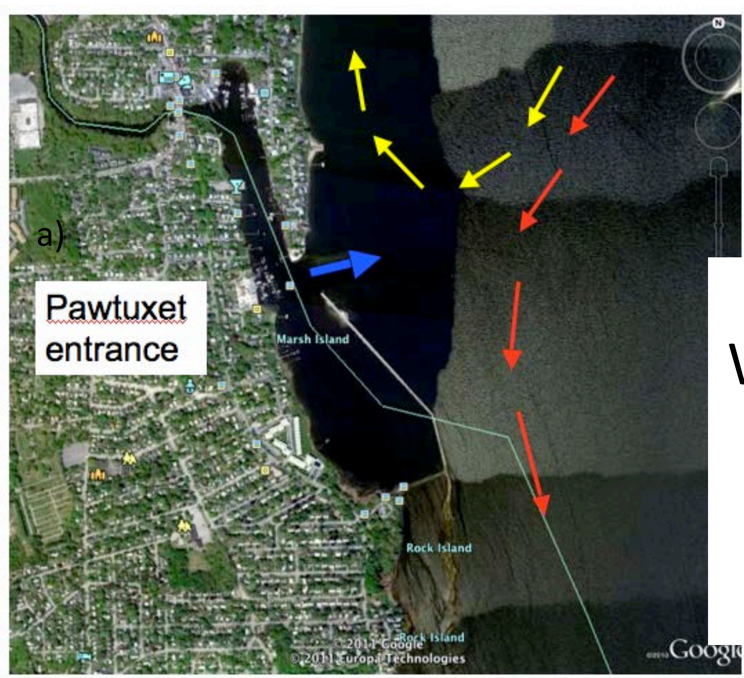
Passive dye on Edgewood for case with no wind, no runoff (weak gyre)

Port Edgewood Channel acts to flush shoal



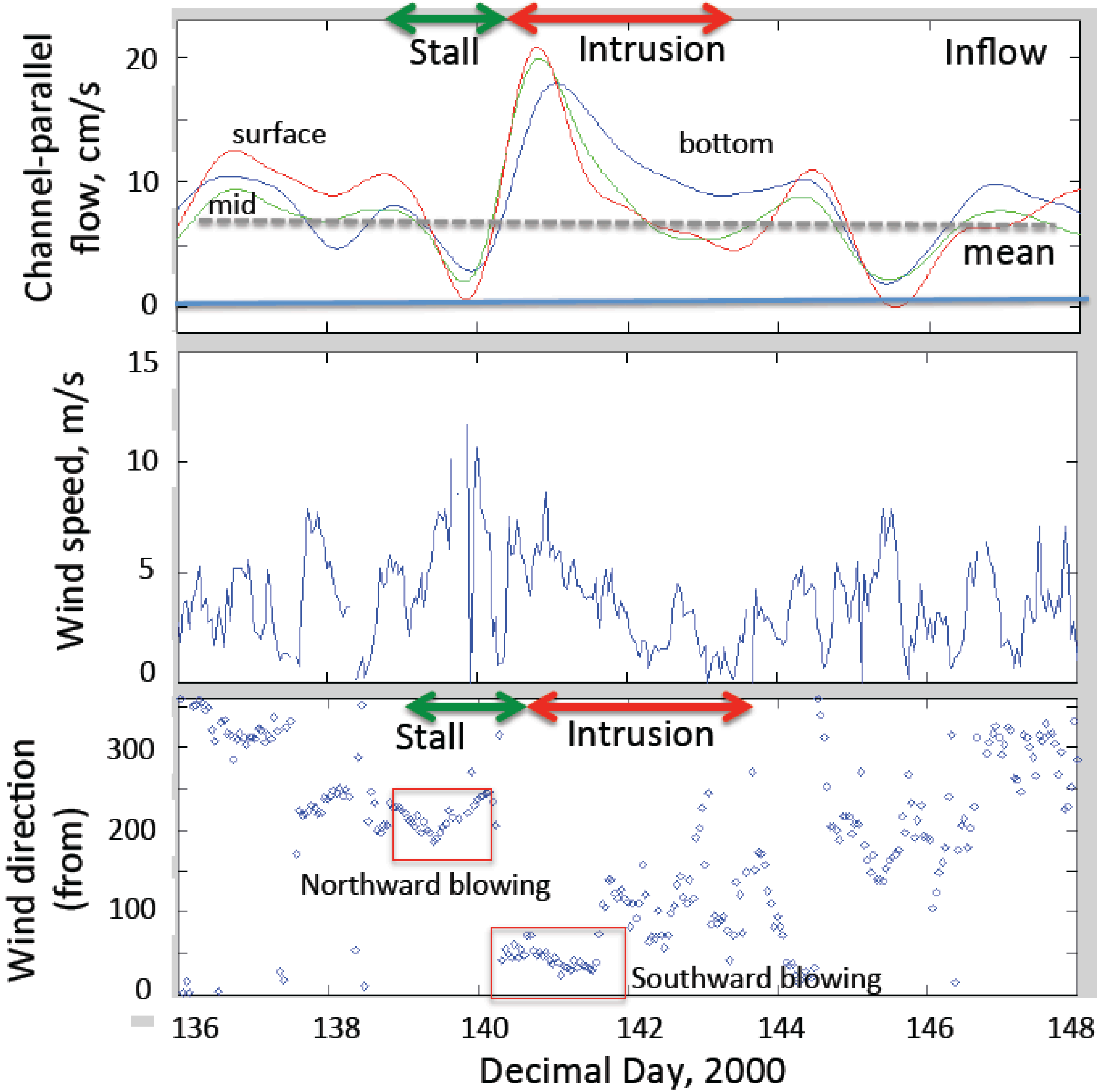
Play Video





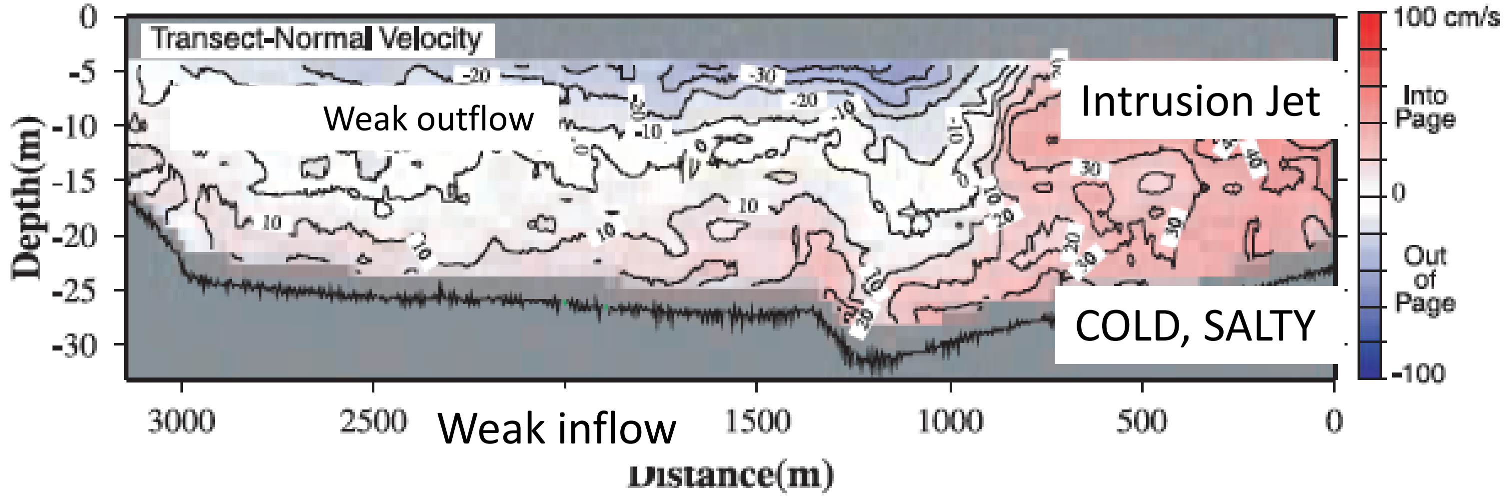
Would fixing Pawtuxet entrance limit nutrient inputs as much/more than WWTF reductions?

Embayments



Stall
Intrusion
Inflow
Channel-parallel flow, cm/s
20
10
0
surface
mid
bottom
mean
Wind speed, m/s
15
10
5
0
Stall
Intrusion
Wind direction (from)
300
200
100
0
Northward blowing
Southward blowing
136
138
140
142
144
146
148
Decimal Day, 2000

A) Summer (07/23/1998)



0.1 m/s x 1000 m x 20 m = 4000 CMS

2.5 days x 3600 s/hr x 24 hr/d = 216000 seconds

864 million cubic meters of water per major intrusion

Bay Volume: 2.7 billion cubic meters

30% of Bay's volume per event…..what's in this water?

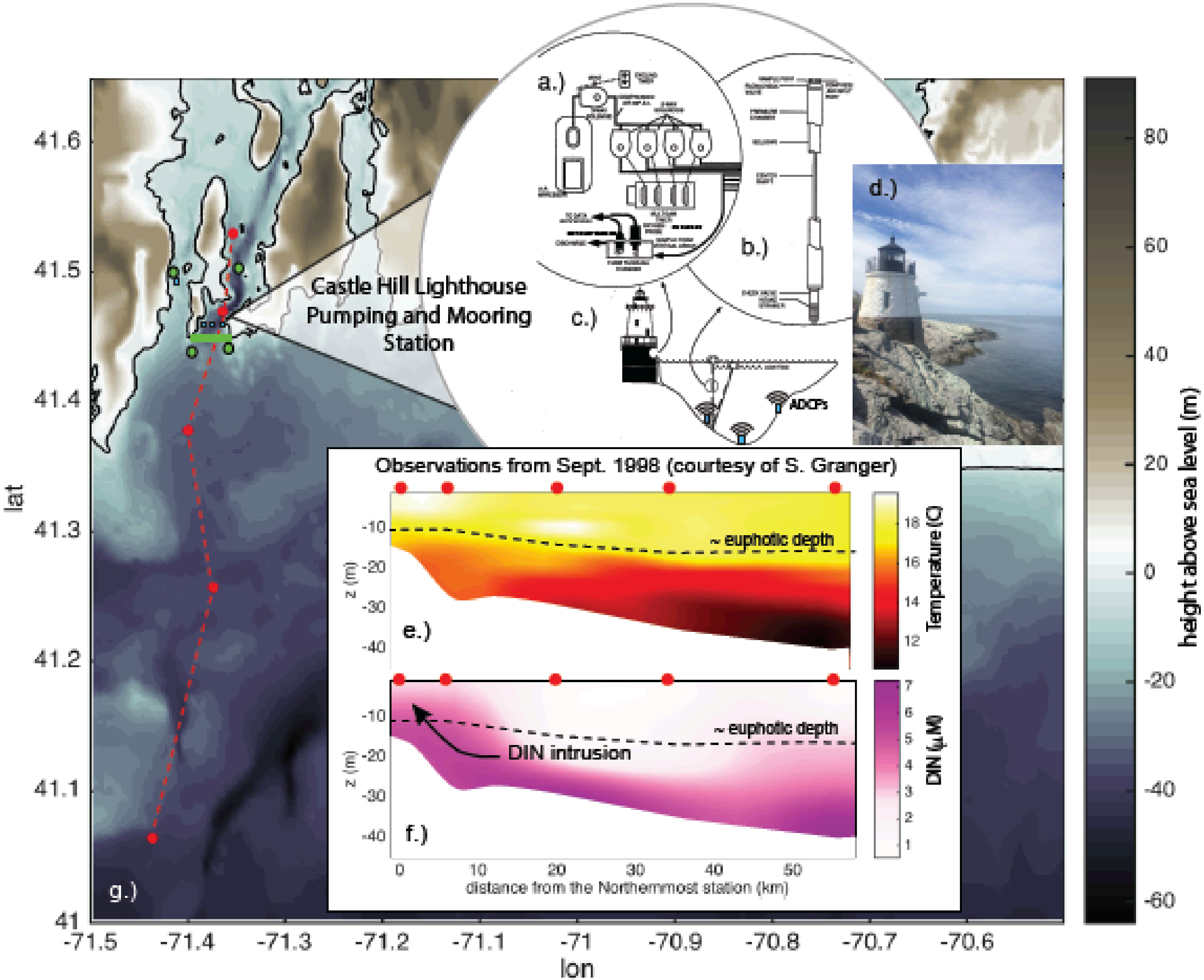
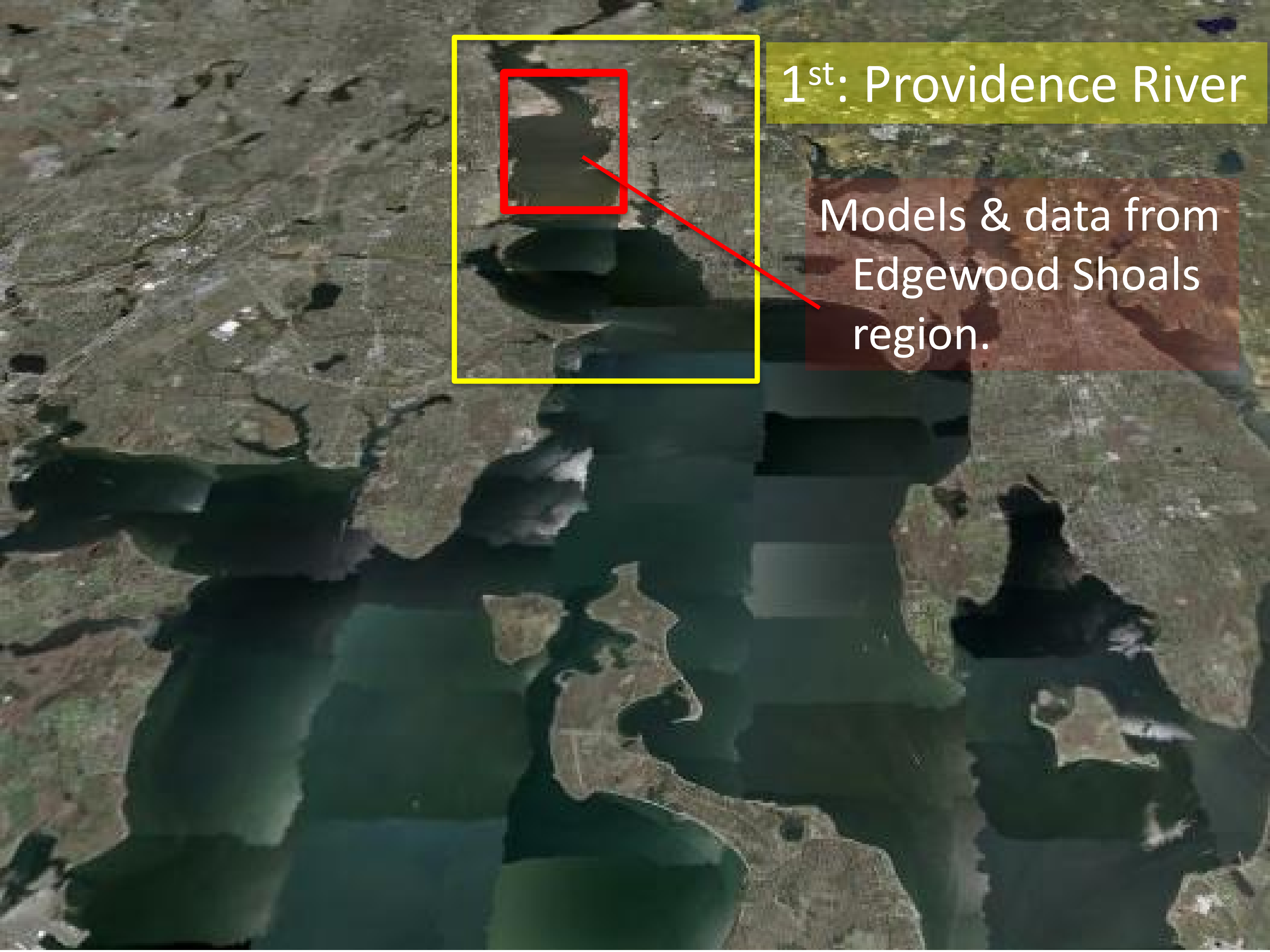

a.)
b.)
c.)
ADCPs
d.)
Castle Hill Lighthouse
Pumping and Mooring
Station
Observations from Sept. 1998 (courtesy of S. Granger)
~ euphotic depth
e.)
Temperature (C)
z (m)
DIN intrusion
f.)
DIN (μM)
distance from the Northernmost station (km)
g.)
lat
lon
height above sea level (m)

Table 1: Nitrogen sources for Narragansett Bay from Krumholz (2012). Only outside sources are shown (i.e. we do not include N from the benthos). See text for details on estimated inputs from the Sound.

Source	**DIN** (10^6 moles)
Atmospheric deposition	24
Rivers	173
Urban runoff	29
Direct sewage discharge	100
Total	**326**
Input from RIS per summer	21

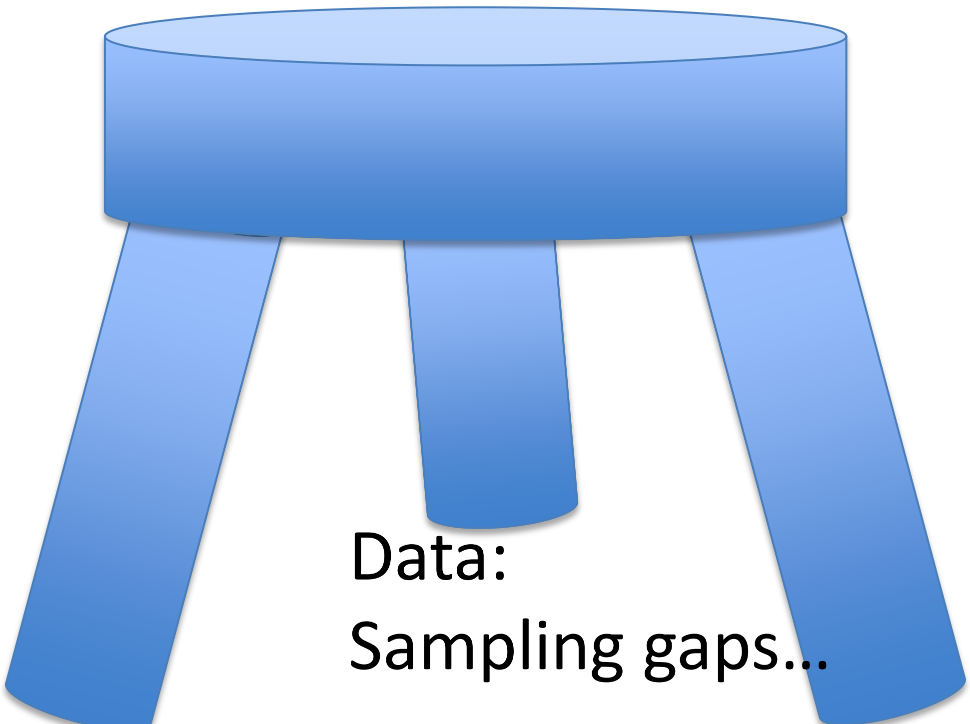
Just for events. Steady flow is also carrying RIS DIN

Concentrated over short period (days), during summer conditions


1st: Providence River
Models & data from Edgewood Shoals region.

Hydrodynamics: The 3 Legged Stool

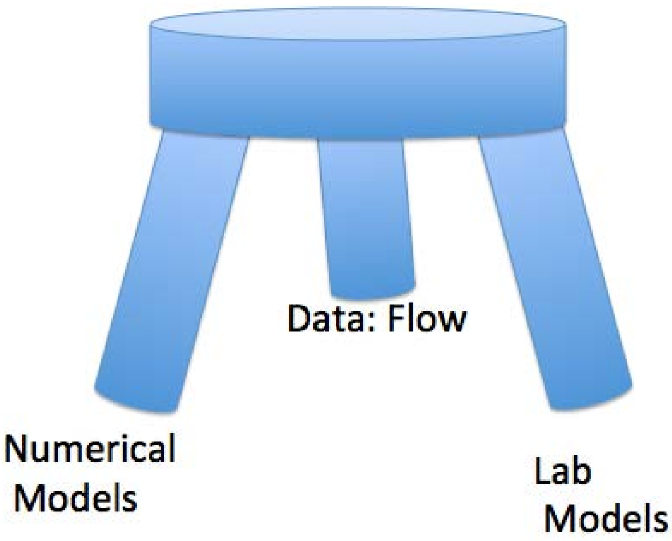
WHY?



Data:
Sampling gaps…

Numerical
Models
- approximations, grid size issues
- turbulence parameterized

Lab Models.
+continuous fluid,
- not all processes



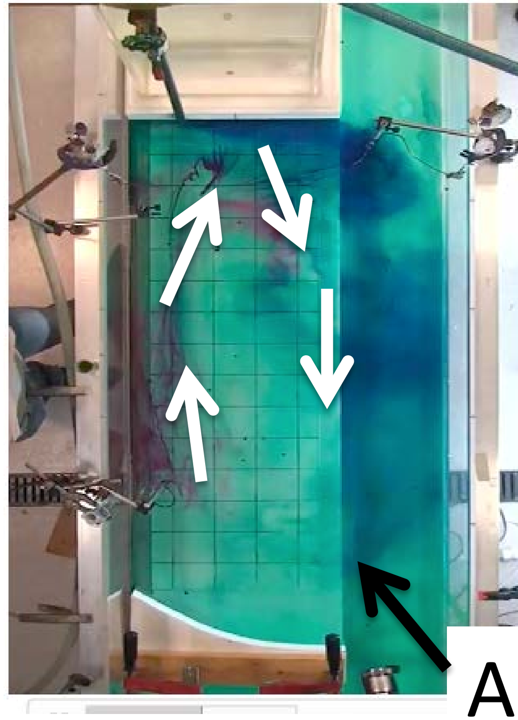
Data:

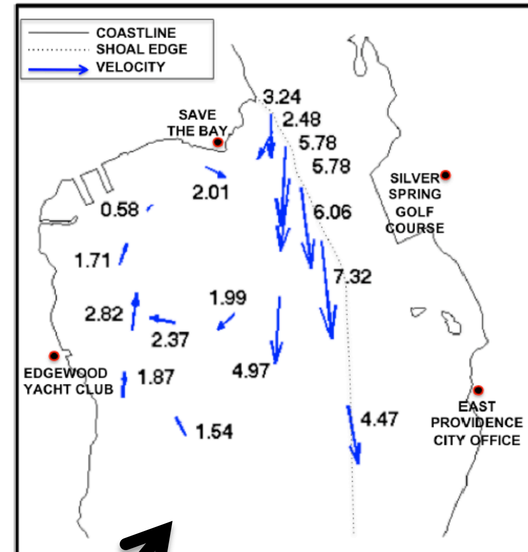
1. Mind-numbing spatial ADCP surveys
   great spatial data, poor temporal
   16 hour (tide cycle) surveys
   key transect lines
   spring/neap; seasonal, etc
   define repeat flow structures

2. Moored ADCPs in key locations.
   lots of $, grey hair
   amazing temporal
      every 5 mins, for 4 -12 months
   poor spatial
      50 cm bins, but only 1-5 sites

3. Tilt current meters in key locations
   good spatial & temporal, low cost

LAB & Data: Chronic Gyre on Shoal





Agree…*almost*

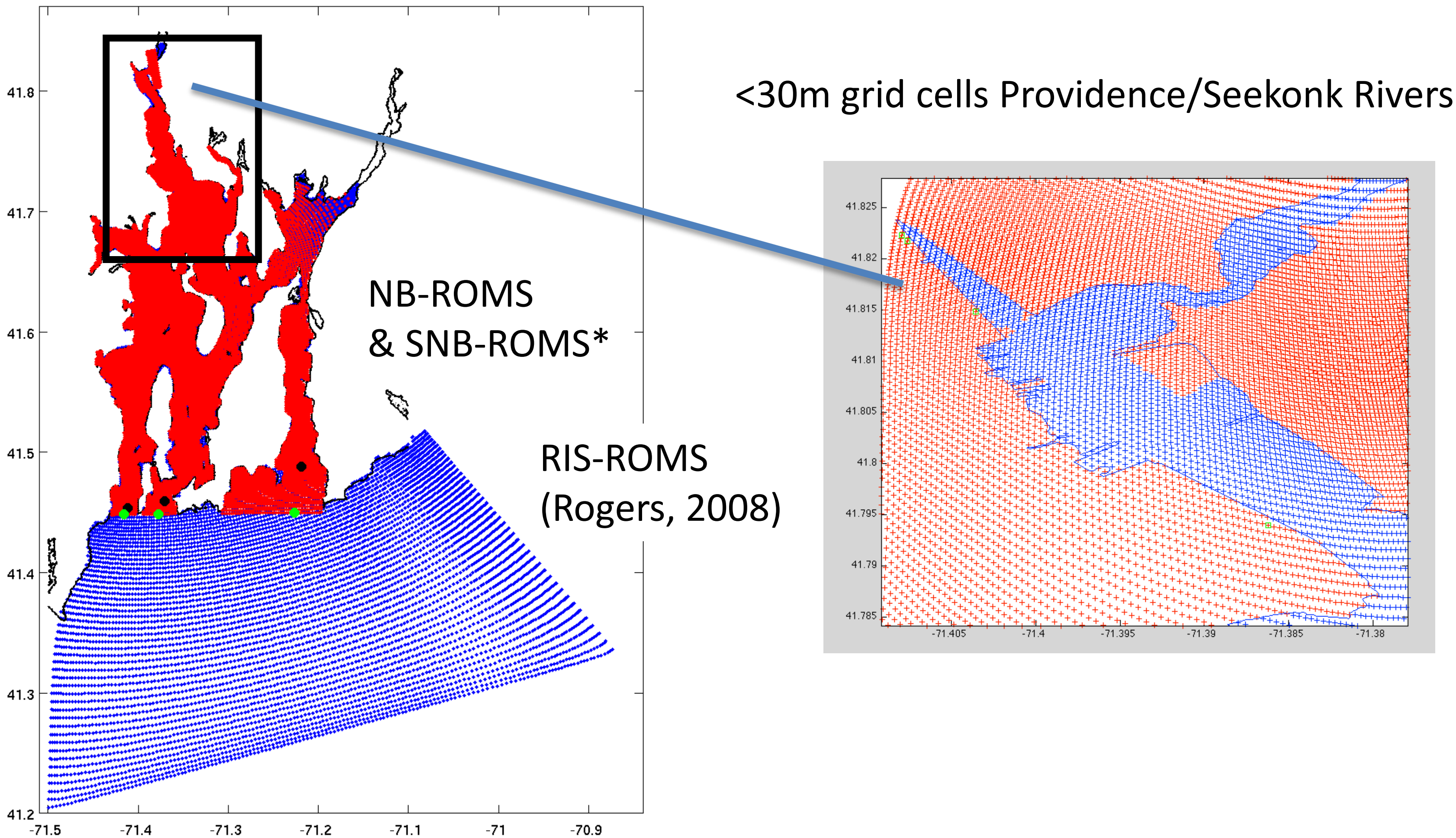
Lab shows extreme isolation of shoal bottom water.

Outflow + Bathy = Stratified flow

Easy retain for 10-20 tide cycles

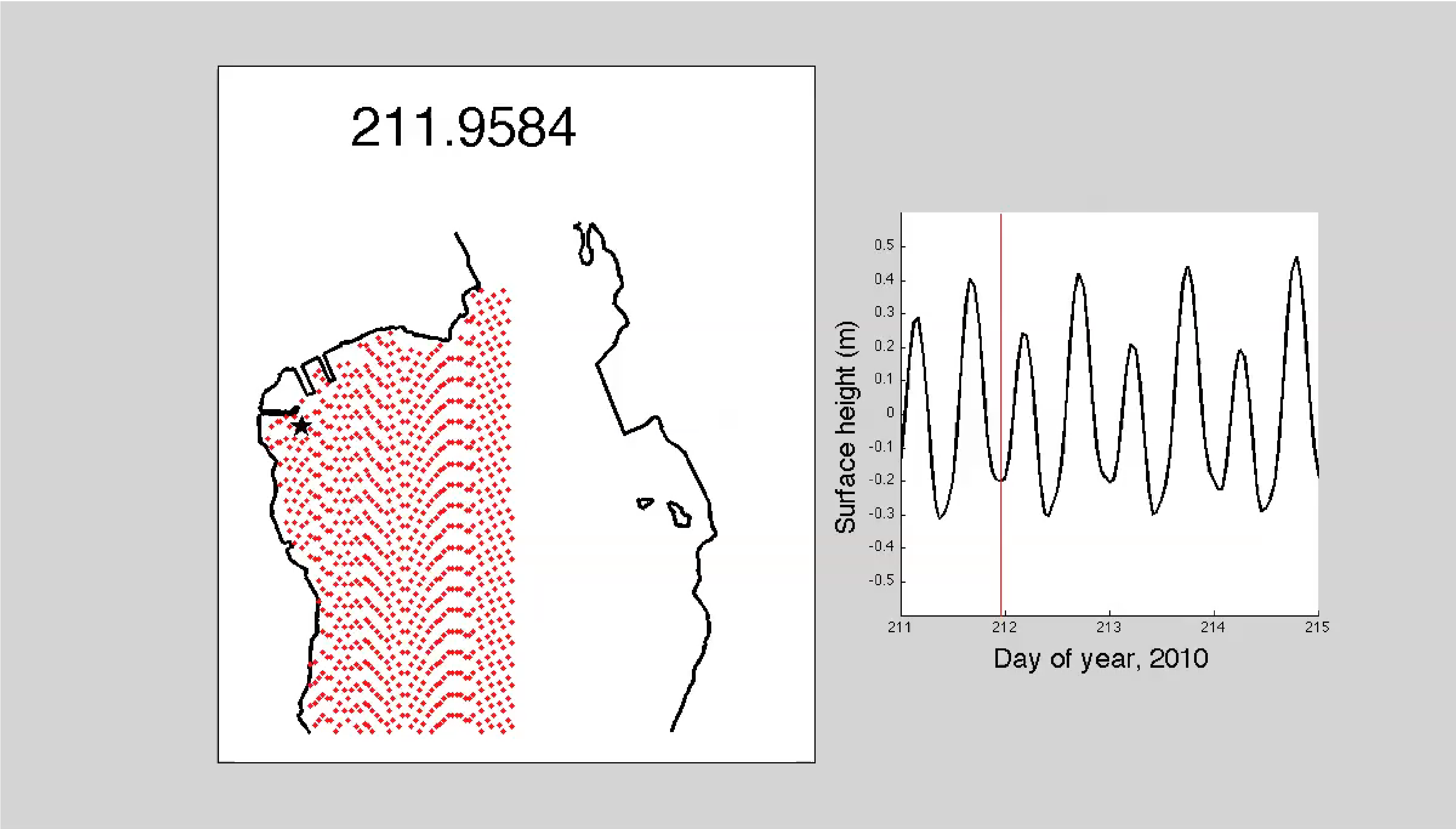
Kincaid, Ullman and URI/GSO Students: Multiple generations of ROMS models.

ROMS: Regional Ocean Modeling System



Modeling Embayment Retention: Floats & Passive dyes

2010 Summer ROMS Simulation, flushing of numerical “floats”



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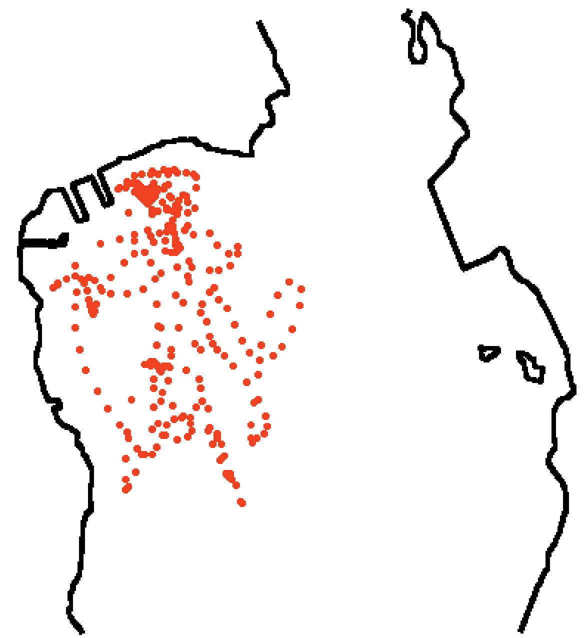
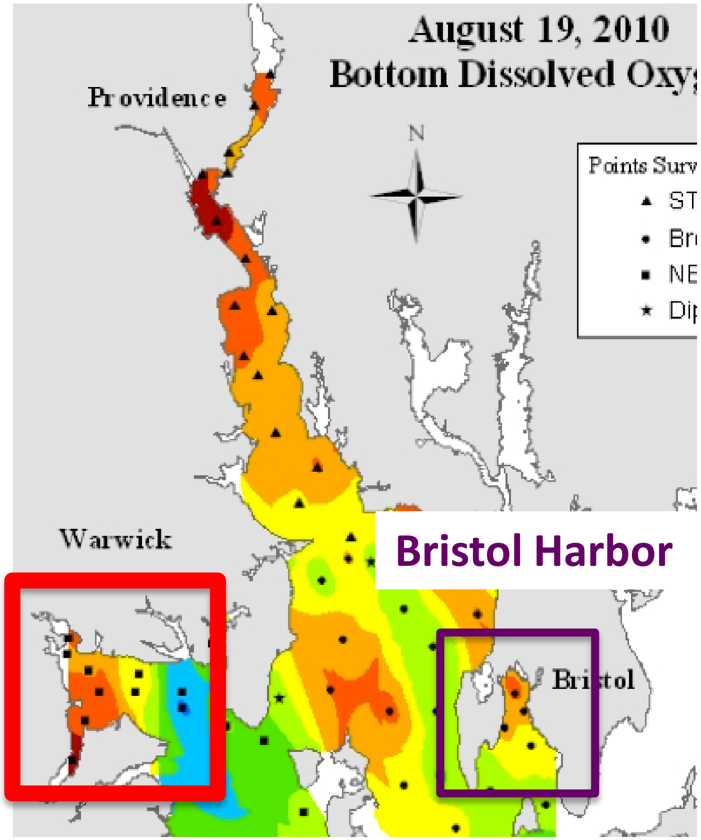
*Grant: For physics-side of eco-model, **age of water** is key*

Box models & Coarse ROMS Prov. River Flushing: 1 - 3 days

Lab & High Res. ROMS Flushing BI-MODAL: 1-3 days jet (5-15 days) gyres

High % tracers on shoal after 5 days





Greenwich
Bay:

Two other embayments

Poor water quality
Chronically low oxygen

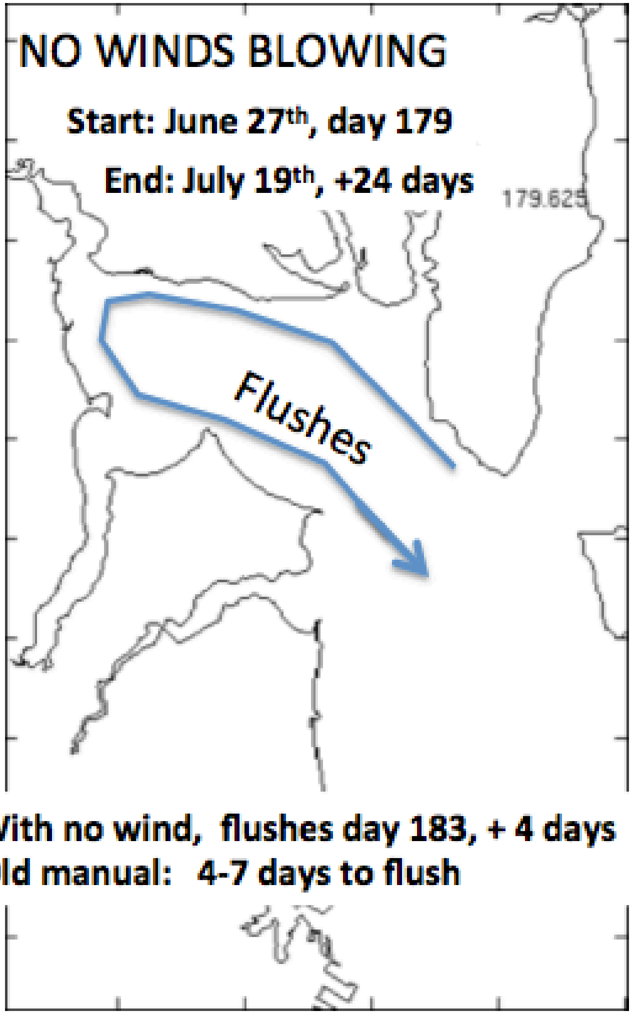
Both have very stable gyres shown in Data/Models

Focus Greenwich Bay:
a catalyst for bay-wide eco-system events?

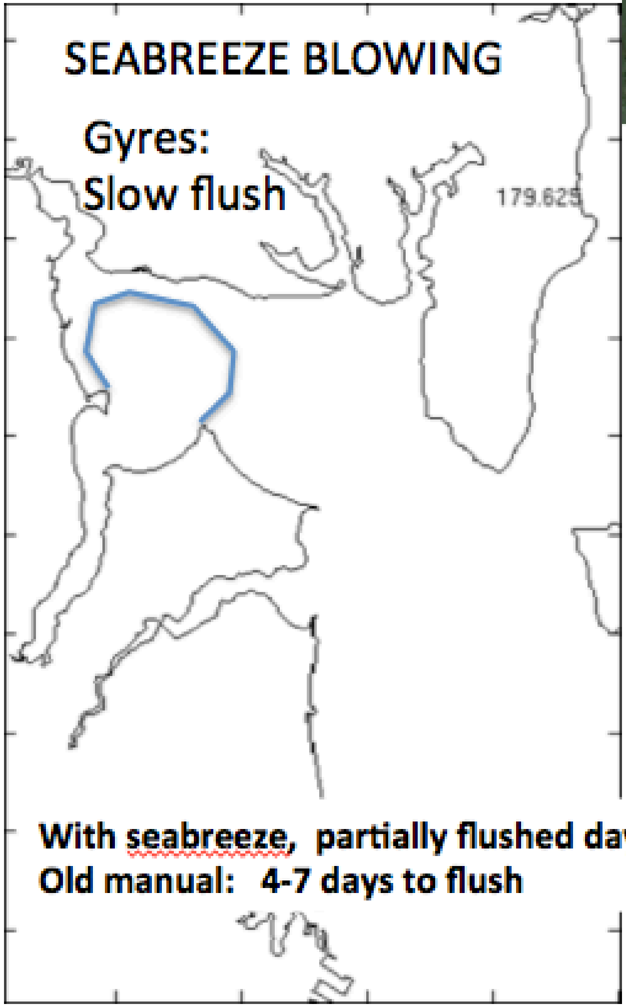
Outline: 1. Data. 2. Flushing models. 3. NPZD models

ROMS Model Results

Passive "numerical tracers move with circulation
2006 Summer Conditions
Case 1: Winds turned off. Case 2: Sea Breeze on.



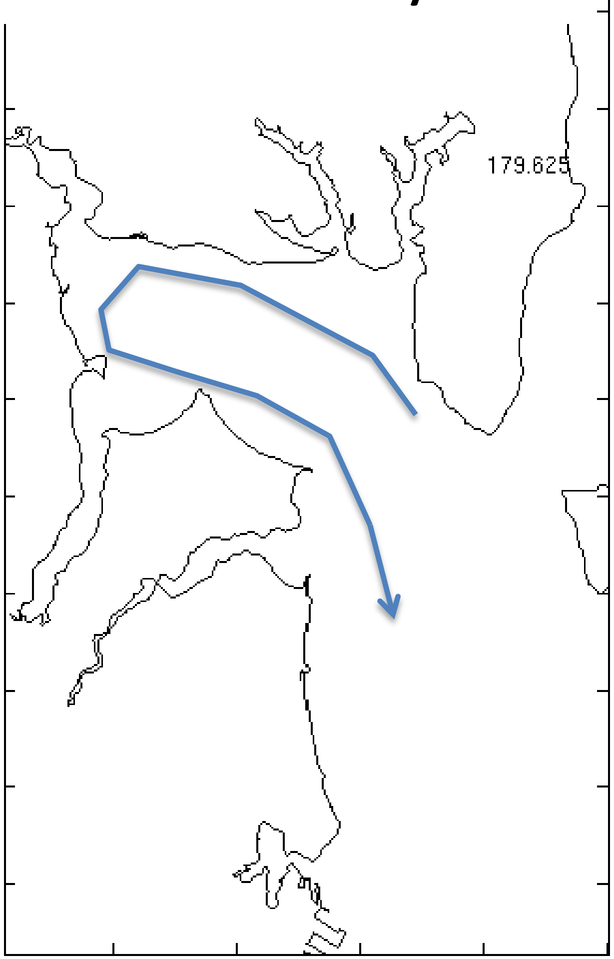
With no wind, flushes day 183, + 4 days
Old manual: 4-7 days to flush



With seabreeze, partially flushed day 195, + 16 days
Old manual: 4-7 days to flush

Identical Summer Runs Except for Wind

Winds turned off.
Flush in 4 days



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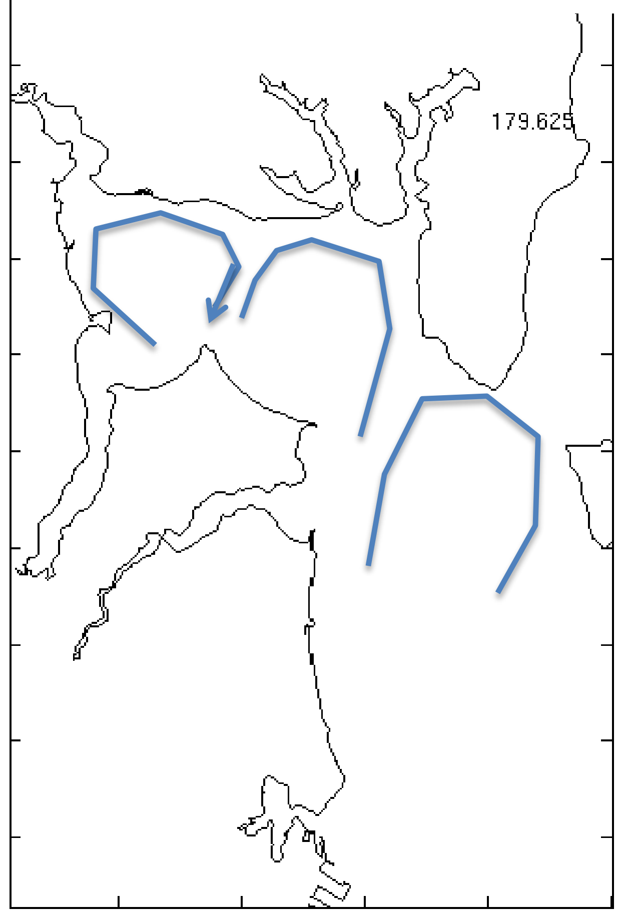
Seabreeze, N-ward winds on
Multiple gyres.
Water retained in inner basin



Play Video

Greenwich Bay Summary:

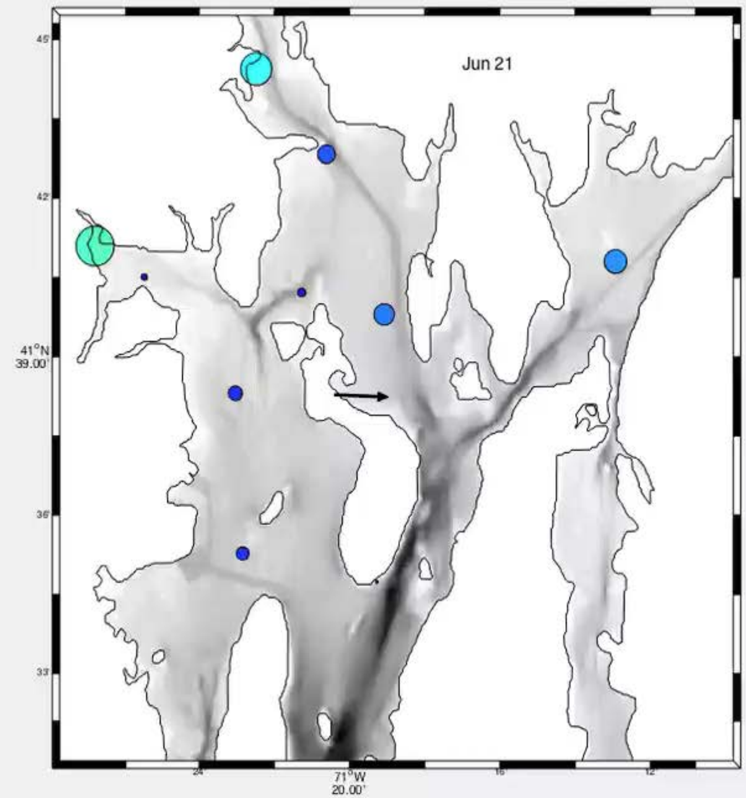
A) N-ward winds: >15 day residence time

2006: Severe GB hypoxia, frequent N-ward winds

B) E-ward winds: <4 day residence time

2007: Mild GB hypoxia,
frequent NE-ward to E-ward winds

Summer 2012 Chlorophyll Buoy Data



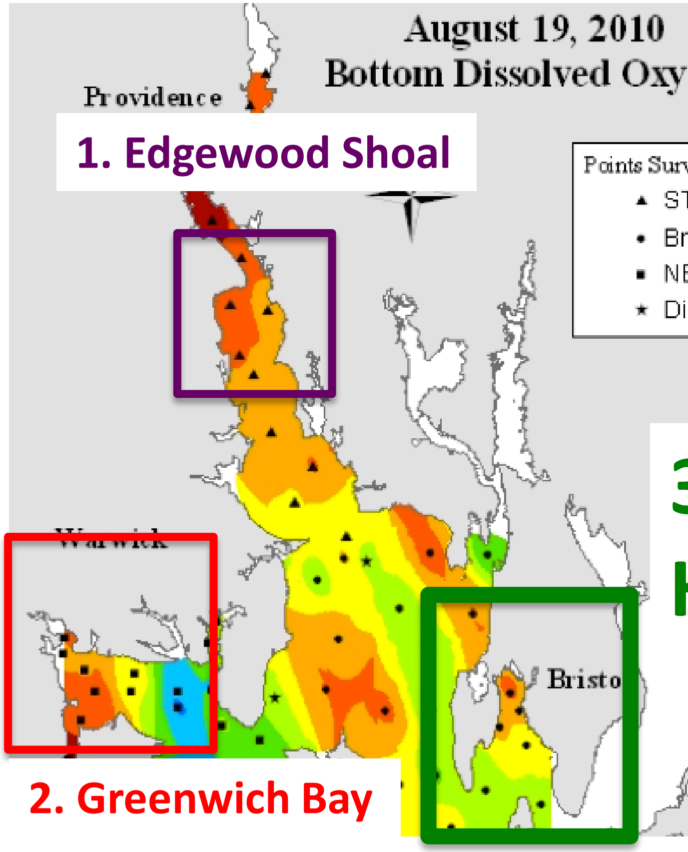
Available flow data: 4 months Summer 2012

Play Video

Student K. Rosa: Combining buoy data, flow data & ROMS (w/ NPZD)

Role of embayments in ecosystem processes.

Northward bio-chemical fluxes & bloom dynamics



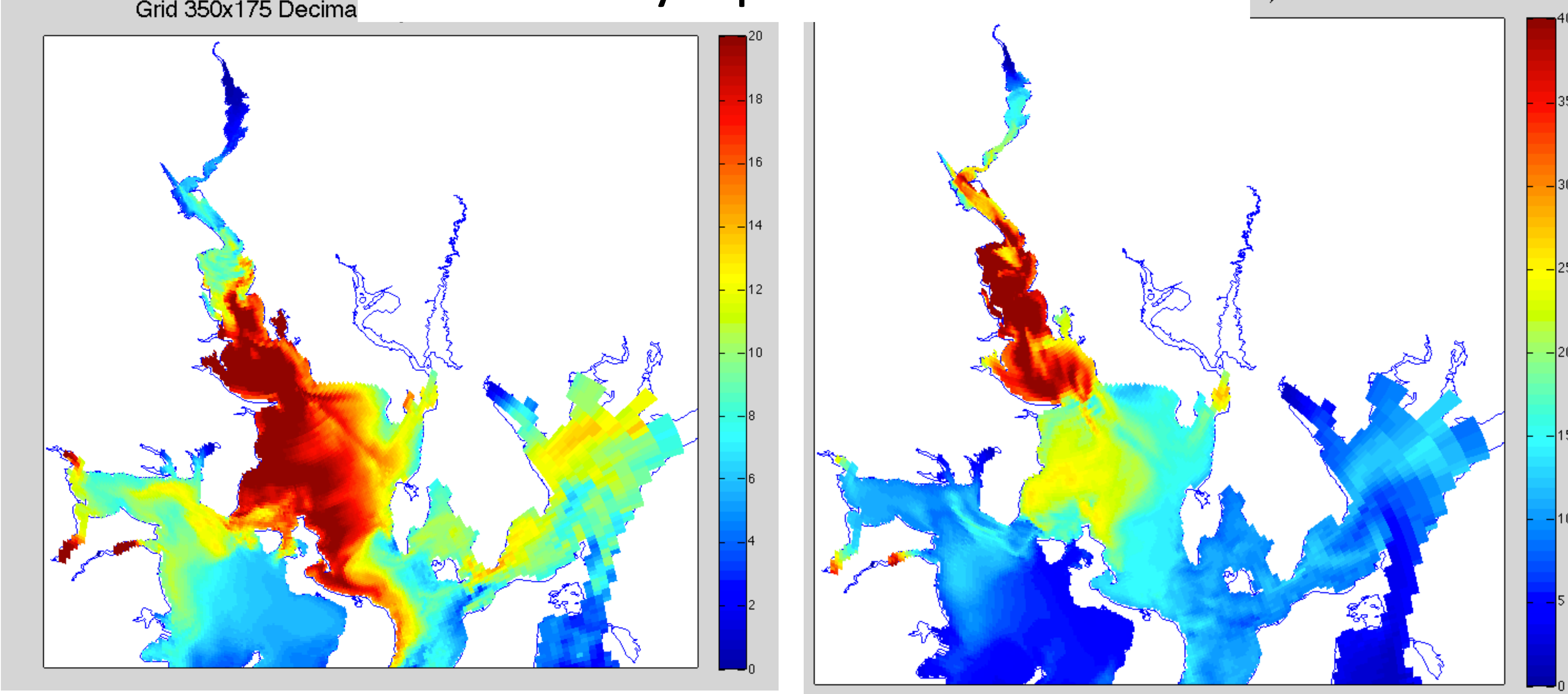
3. Bristol Harbor

Prime areas of chronic low oxygen have retention gyres:

Based on Data & Models

Stage 1: GB start (*spill to mid-Bay*)
Stage 2: Mid-bay bloom (*spill northward*)
Stage 3: Bloom progresses rapidly northward

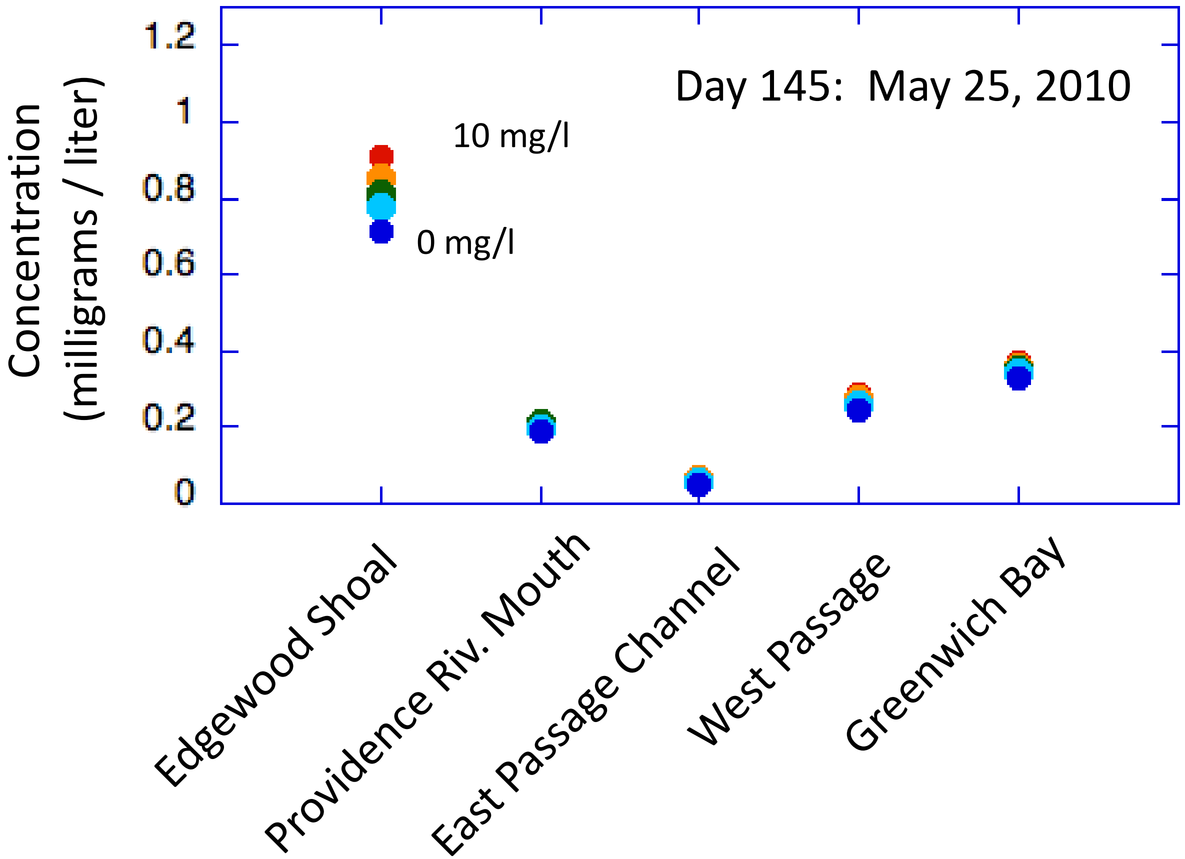
Surface Phytoplankton Contours

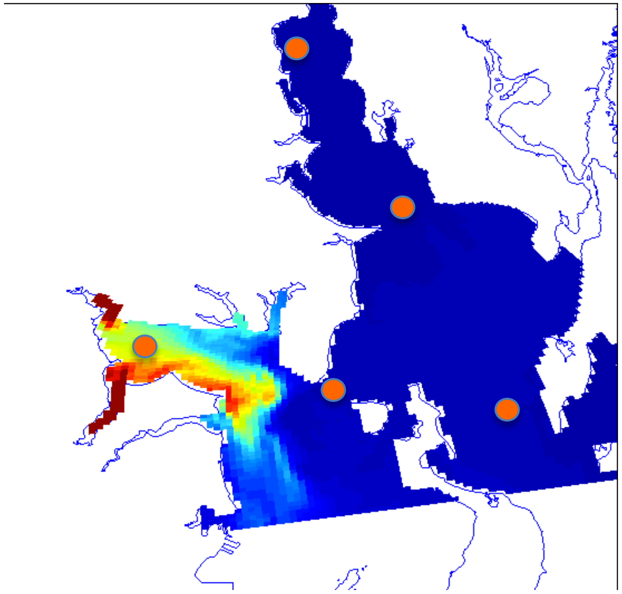


Convert all dyes to total nitrogen:

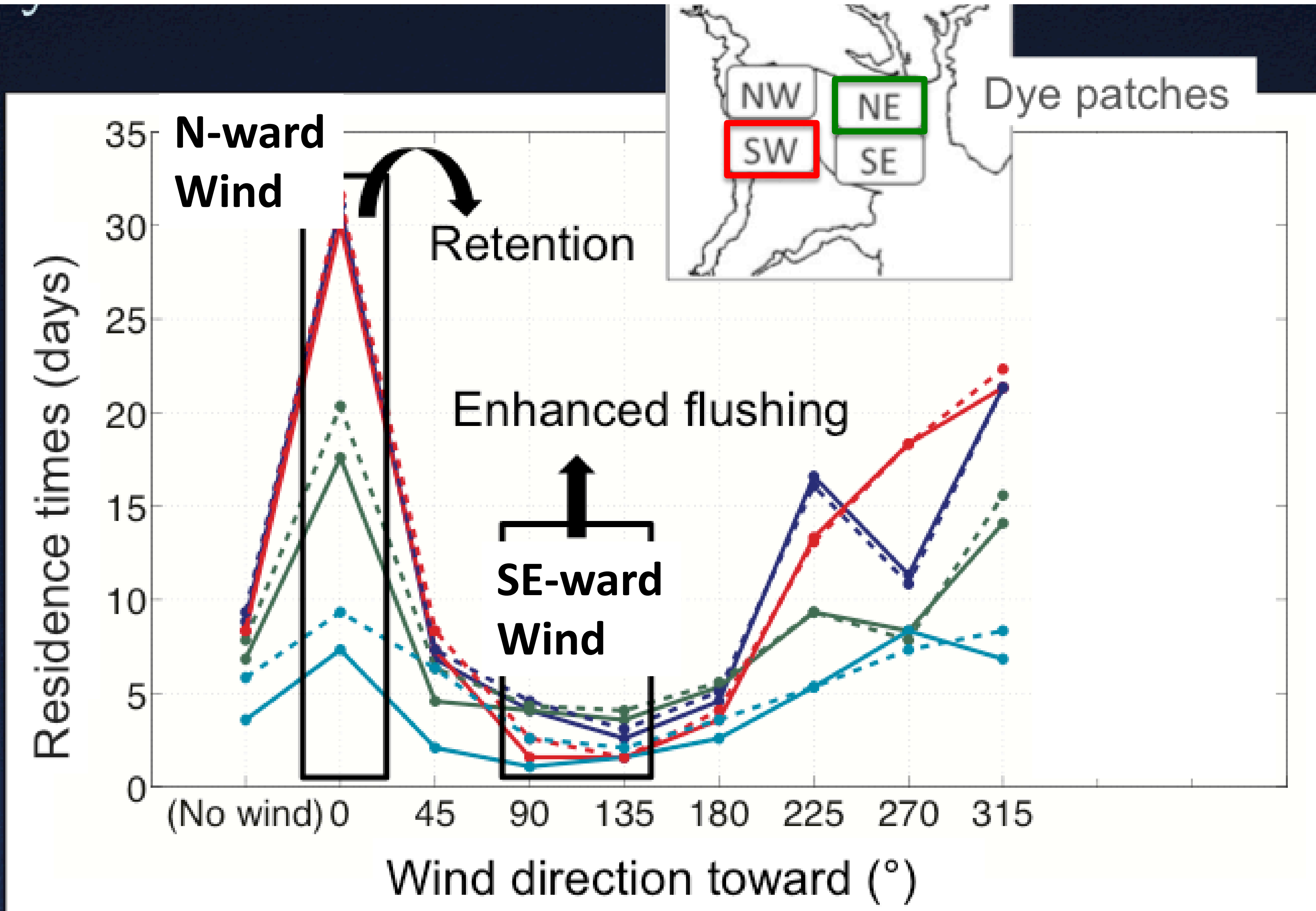
1. Which Nitrogen sources most important in hypoxic areas?
2. Impact of WWTF nitrogen reductions (if conservative)?

Fields Pt WWTF Release Scenarios (10, 7, 5, 3, 0 mg/l)





Greenwich Bay: Idealized wind: Dye residence times



Kincaid: ROMS Models for Narragansett Bay

1st: General circulation / transport

- CCW flow through Bay (up the East / Out the West)
- Defining retention zones / circulation gyres

Today

2nd: Hydrodynamics & Chemical transport patterns.

- Forensic Oceanography: Track distinct river & WWTF chemical sources
- Northern sources alternate West vs East Passage flush
- Southern sources wrap to north.......
  - Taunton River into CCW flow (to N. Prudence, Prov. River, Greenwich Bay)
  - Pawtuxet River onto Edgewood and into Seekonk
  - East Prov WWTF northward vs. Fields Pt. southward

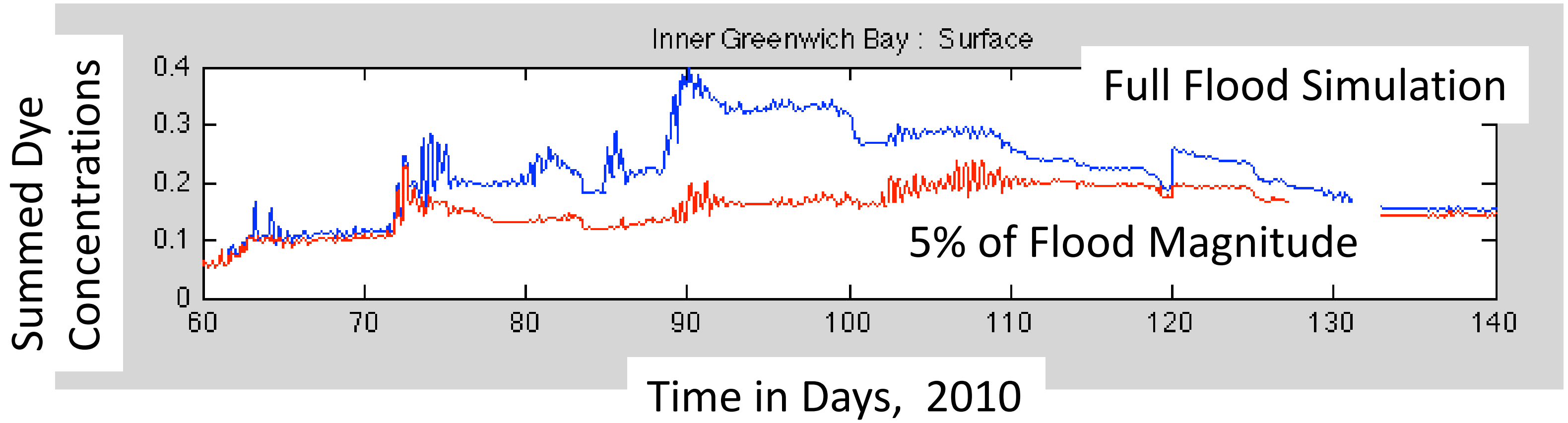
3rd: ROMS NPZD

- Hydrodynamics & Ecology/Biology at ~50m horizontal scales.
- physics and eco-parameters at 10 second time steps

Nice Feature of ROMS……what if?

Impact of flood versus no-flood?

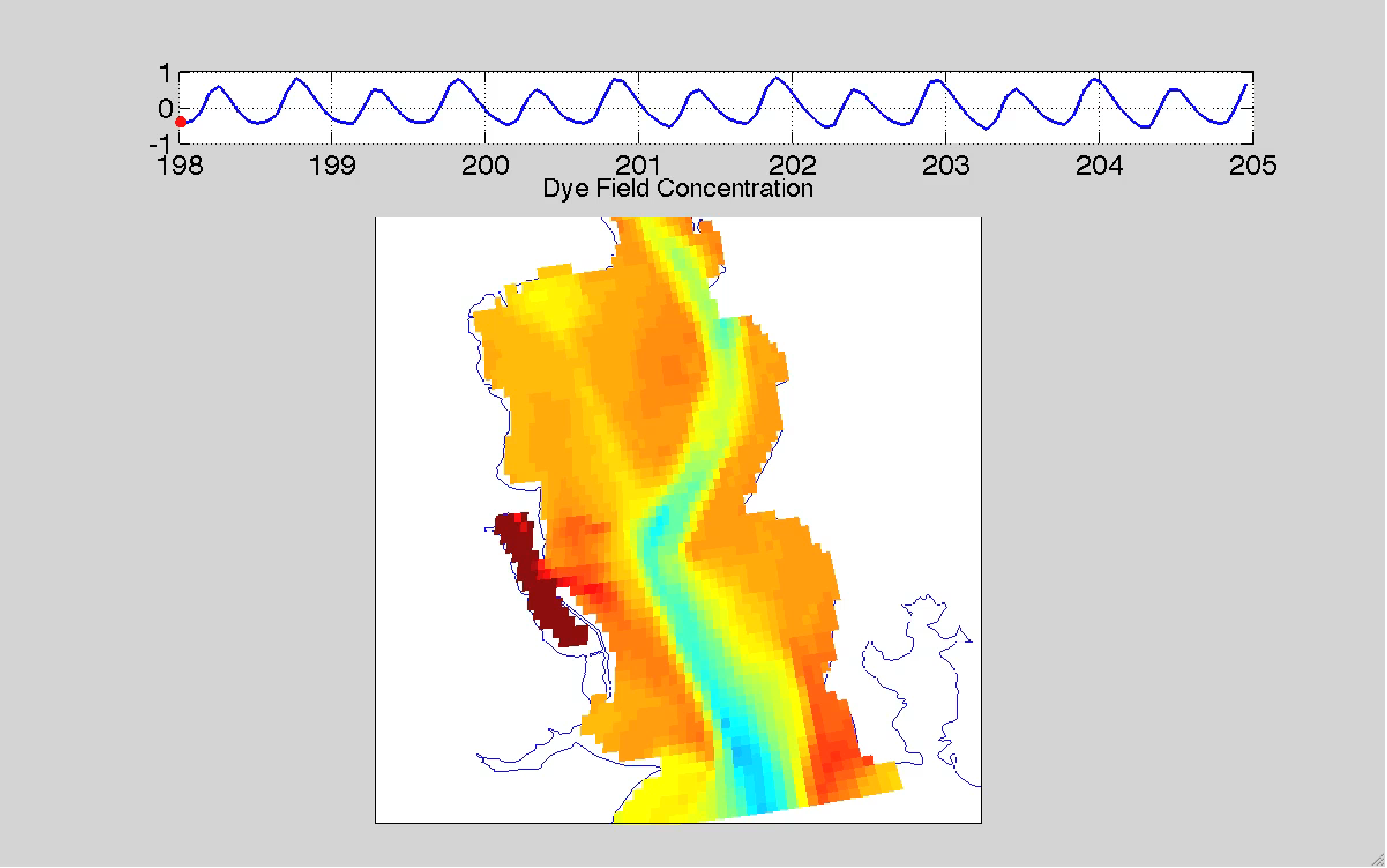
The 2010 Great RI Flood seeded Greenwich Bay more/longer than any other sub-region



Return to Background
Day 130
42 Days Post-Flood

2010 ROMS Simulation: Tracking Pawtuxet River Dyed Plume, **Mid-Depth**

Pawtuxet Likes to go North mid-depth to deep water currents



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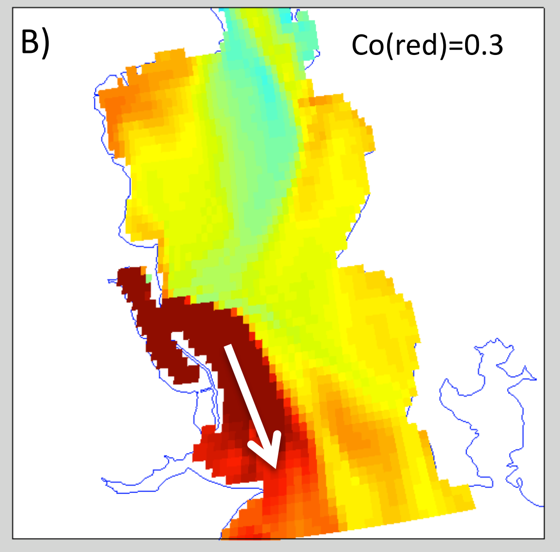
Dye (Nutrient) Sources from South Can Be Important

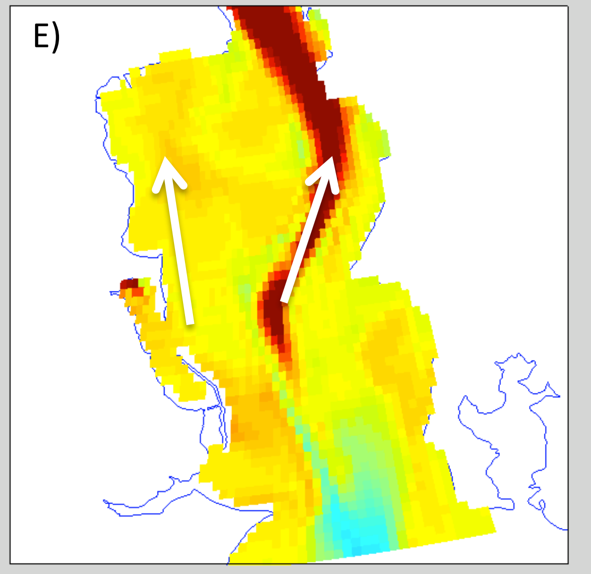
Pathways Complex

Surface: Bends South



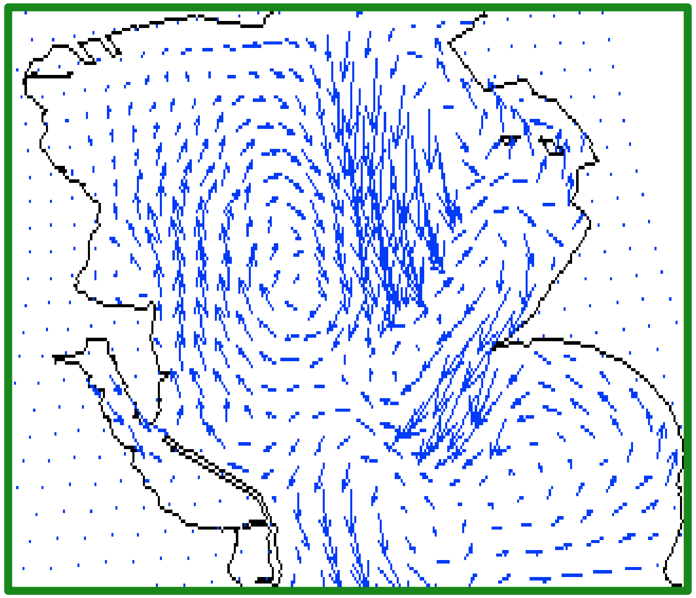
Mid & Bottom:

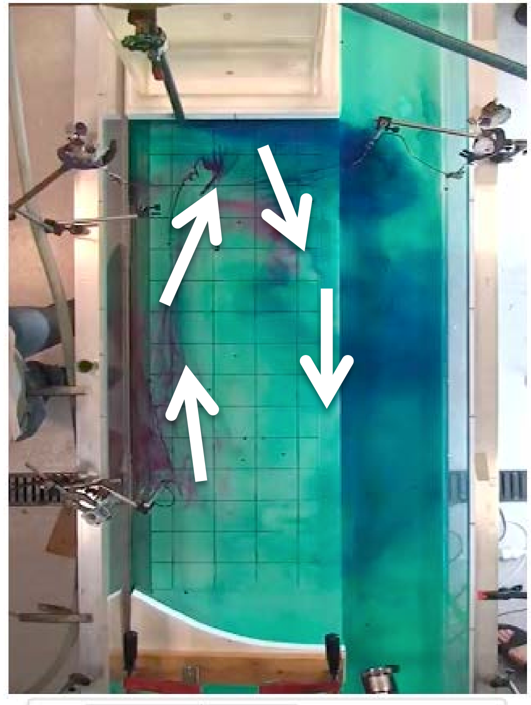
Feed Gyre & Channel

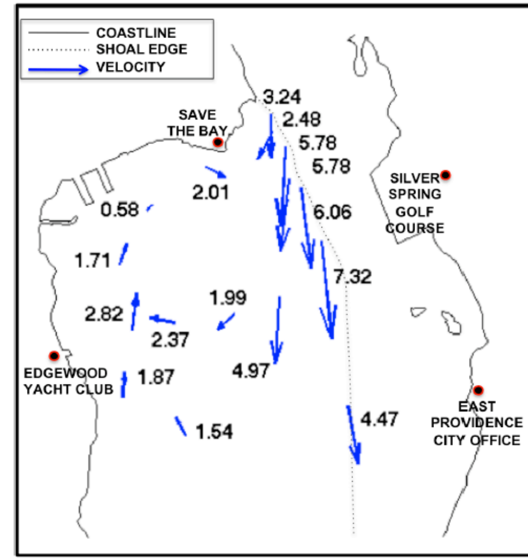


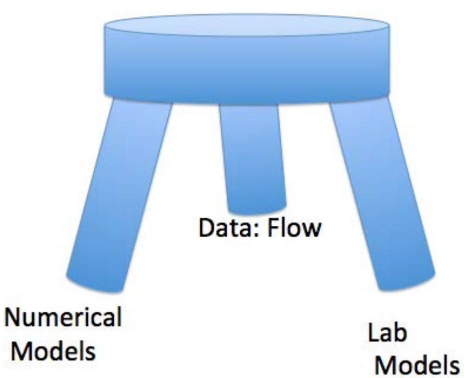
Pawtuxet River Dye

Numerical & LAB & Data: Chronic Gyre on Shoal









But.....

Lab & Data agree on vertical flow structure

Numerical model misses it

CHARACTERIZING THE INFLUENCE OF THE GREAT 2010 FLOOD ON CIRCULATION, FLUSHING AND CHEMICAL TRANSPORT IN NARRAGANSETT BAY

AN OUTSIDE-THE-BOX VIEW OF CIRCULATION IN THE NARRAGANSETT BAY SYSTEM: INSPIRATION FROM SCOTT

Chris Kincaid, Dave Ullman & Rob Pockalny (Graduate School of Oceanography, URI)

Many Years of Excellent Students:

Deanna Bergondo
William Deleo
Christelle Balt
Anna Pfeiffer-Herbert
Justin Rogers
Kurt Rosenberger

Great Funding Support

ROMS Developments for Narragansett Bay

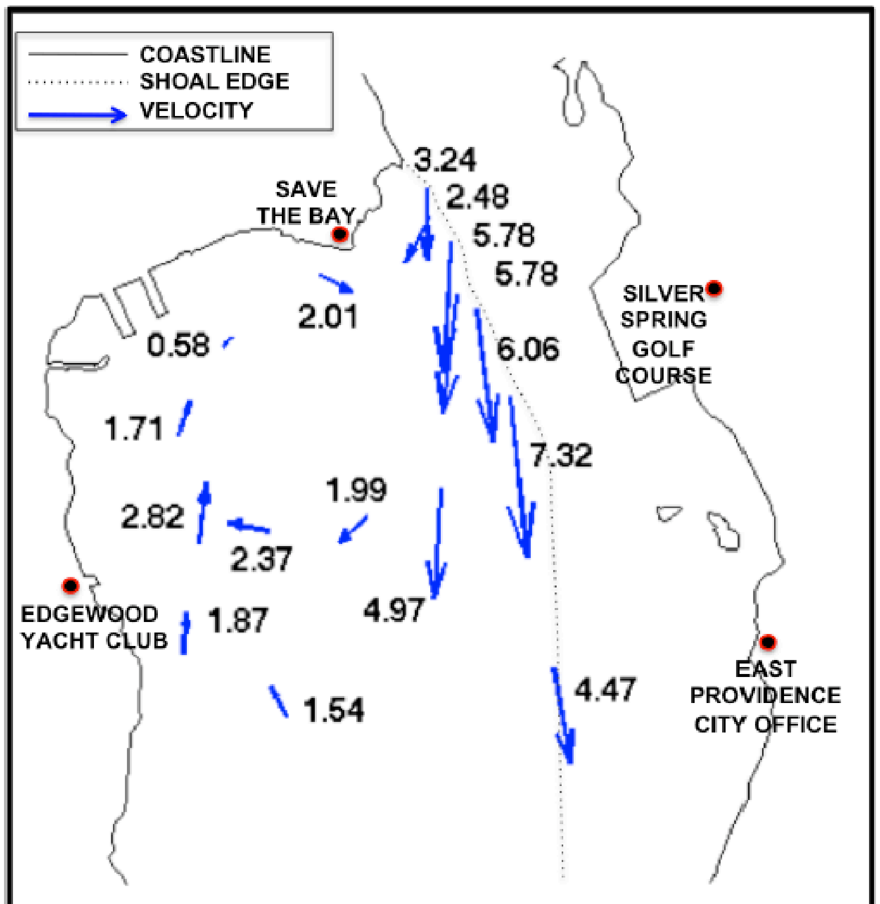
Numerical models provide approximate solutions

(keys to succes: mixing parameterizations, grid size, etc)

The 3-legged hydrodynamics stool

Data + Lab + ROMS: Amazingly Stable Gyre on Shoal coincides with region of chronically low oxygen

Edgewood + Sabin + Gaspee Stagnation Zones significant volume of Providence River



Can we break them?

Data: Gyre persistent

~5 million data points !!!!
- 3 mo. moored ADCPs
- 12 full tide cycle ADCP surveys
- 3 x 3 mo., 18 TCMs/ exp.

ROMS vs. TCM: Sub-tidal: 2010 data.

Table 3. Statistical data-model comparison for sub-tidal or residual flow fields for NBC - supported TCM stations.

ROMS Station	**TCM Station**	Willmott Skill (eqn. 1)
18	**3**	0.78
16	**5**	0.88
14	**7**	0.82
12	**10**	0.89
8	**14**	0.82
3	**19**	0.8

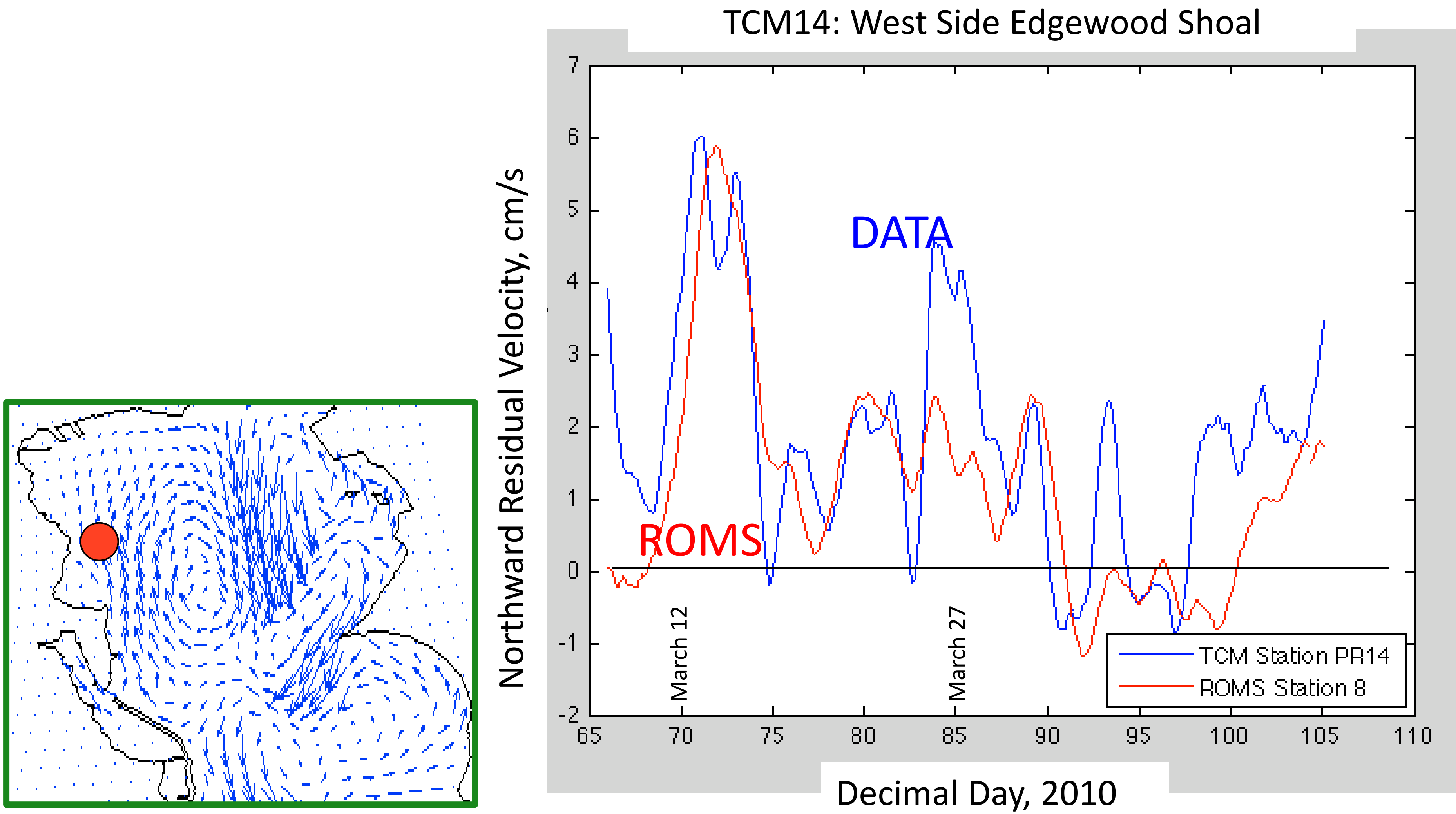


Figure 40. Plot showing the remarkable match between ROMS simulations and the TCM record at station 14 (see Figure 13) located along the western side of the shoals. ROMS captures the magnitude and timing of most of the oscillations recorded in the TCM data.