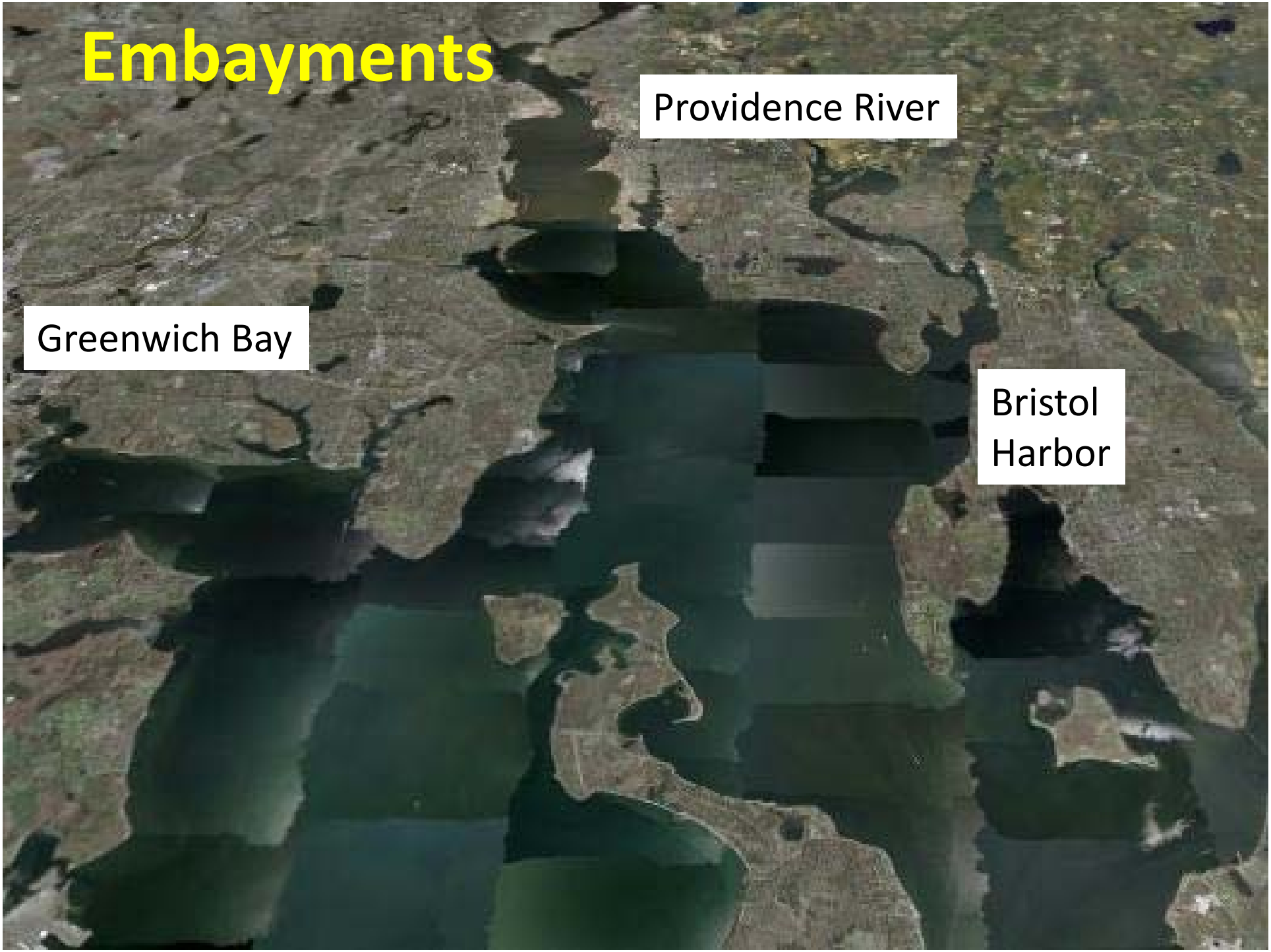
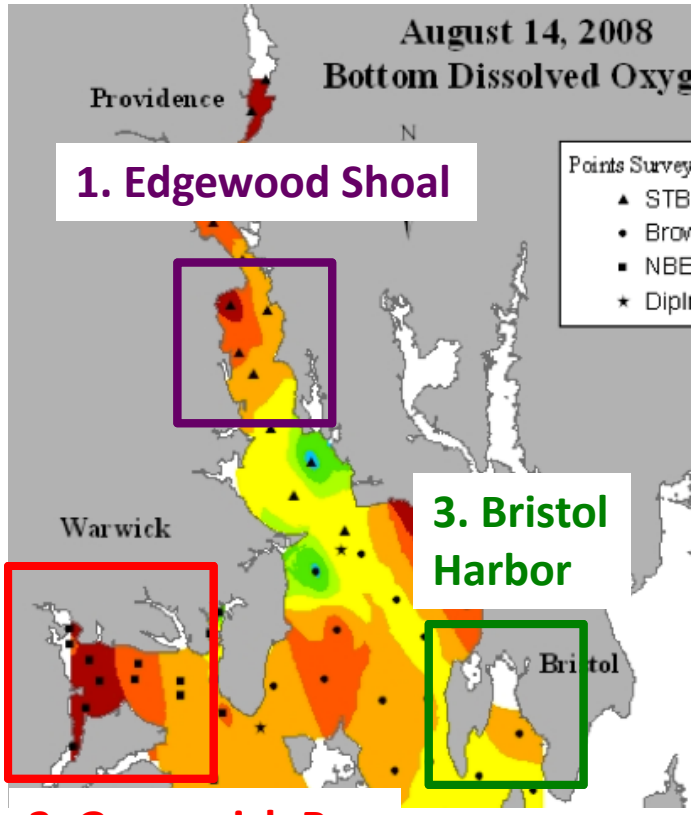
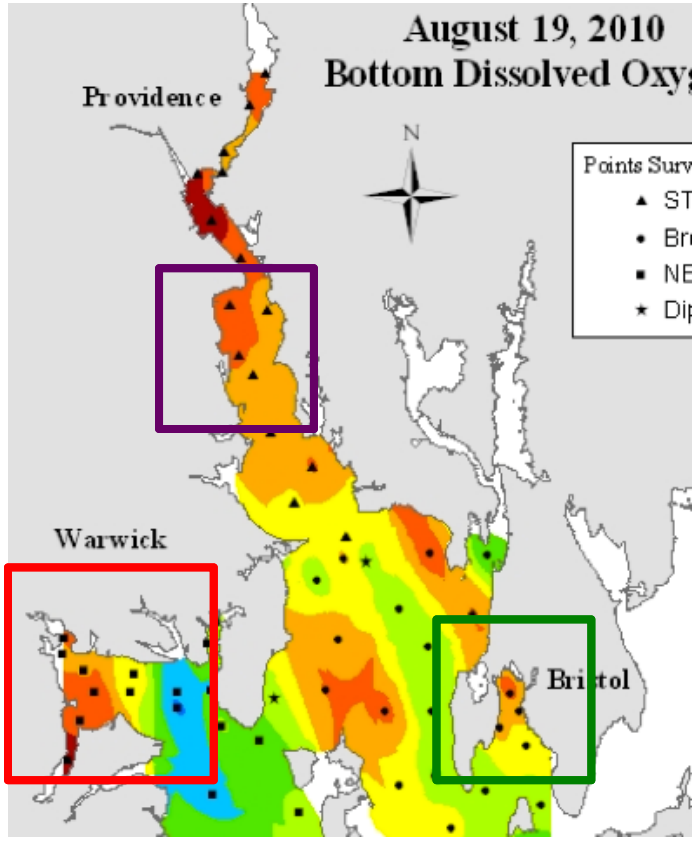

Embayments
Providence River
Greenwich Bay
Bristol Harbor

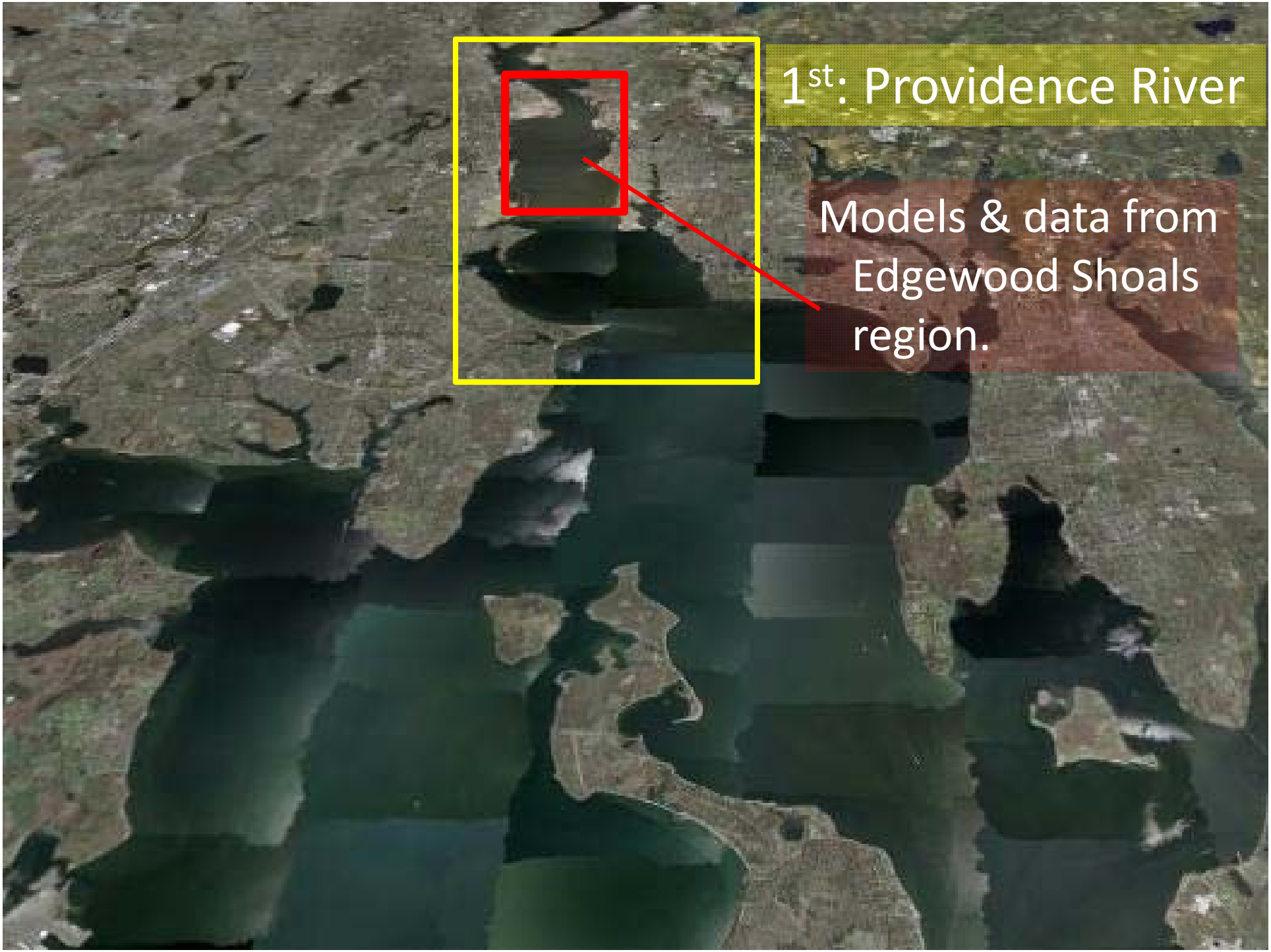
Insomniac Cruises: Low Oxygen = RED



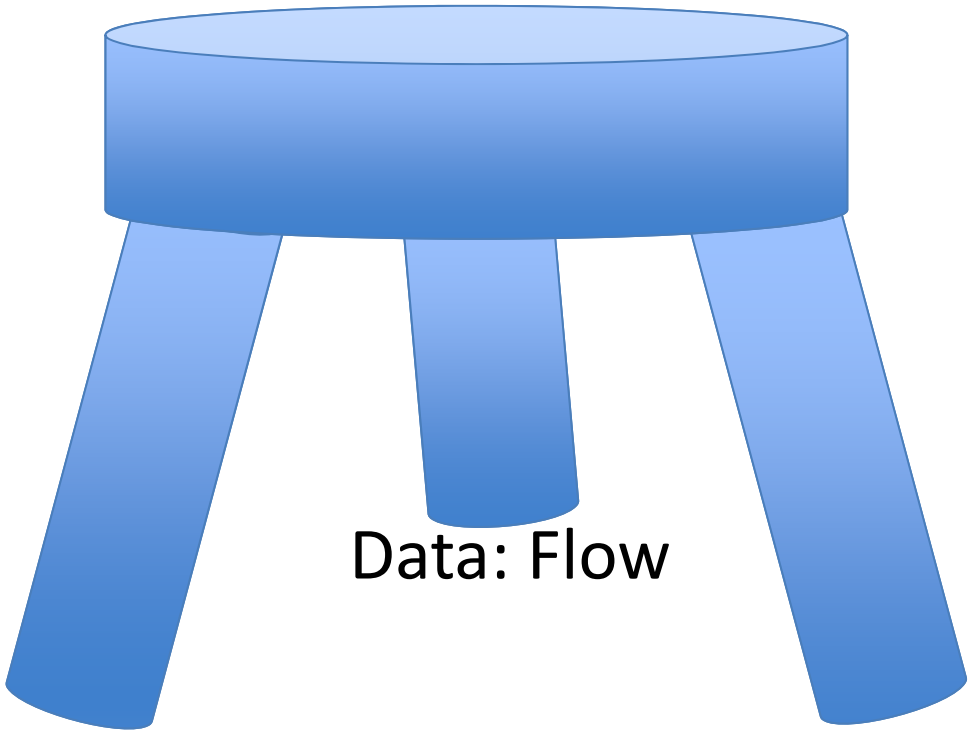


Embayments with Chronic Low Oxygen:

1. Edgewood Shoal, **2. Greenwich Bay**, **3. Bristol Harbor**

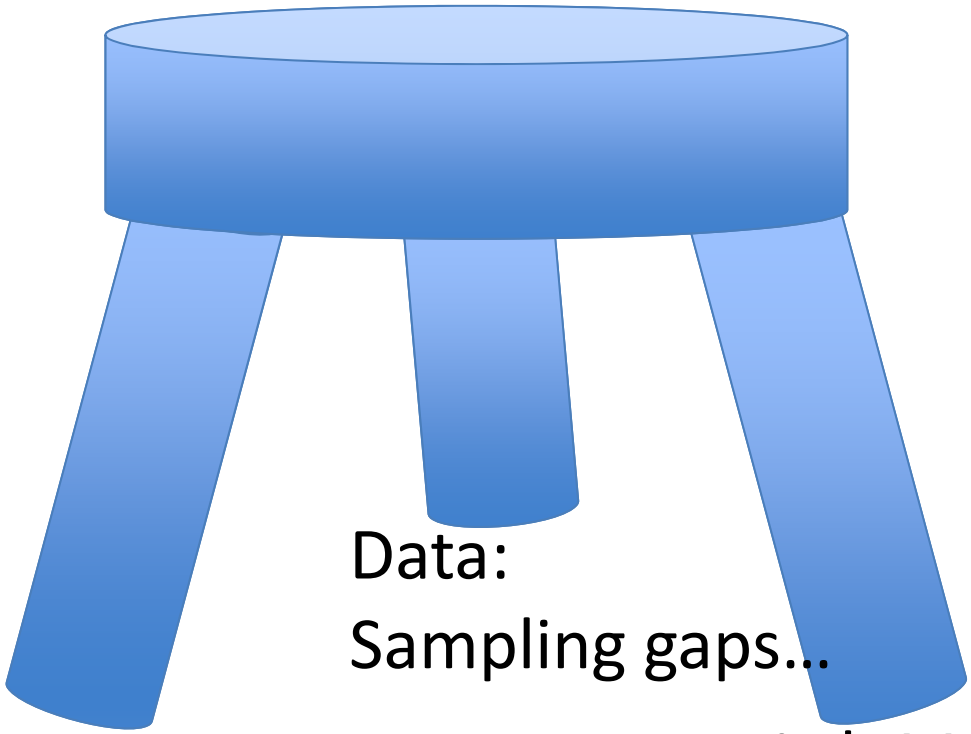

1st: Providence River
Models & data from Edgewood Shoals region.

Hydrodynamics: The 3 Legged Stool



Hydrodynamics: The 3 Legged Stool

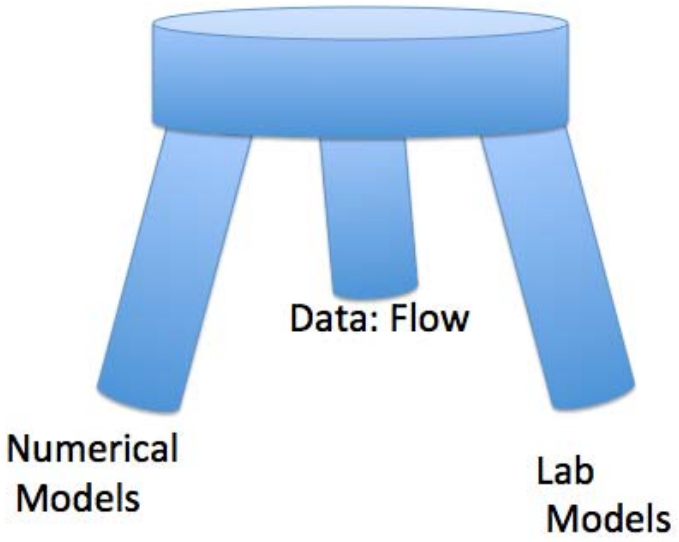
WHY?



Data:
Sampling gaps...

Numerical
Models
- approximations, grid size issues
- turbulence parameterized

Lab Models.
+continuous fluid,
- not all processes



Data:

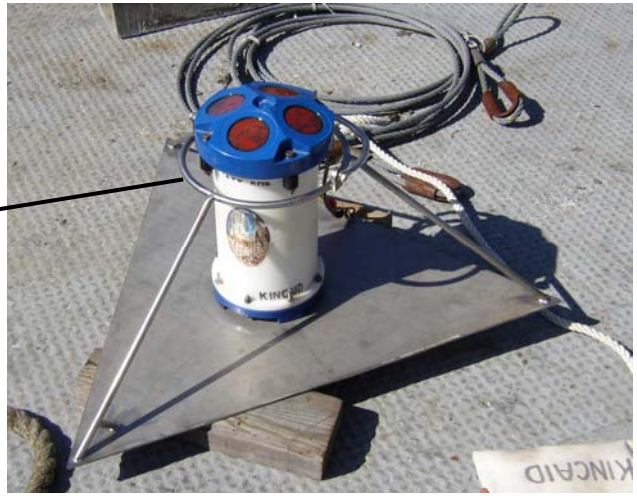
1. Mind-numbing spatial ADCP surveys
   great spatial data, poor temporal
   16 hour (tide cycle) surveys
   key transect lines
   spring/neap; seasonal, etc
   define repeat flow structures

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

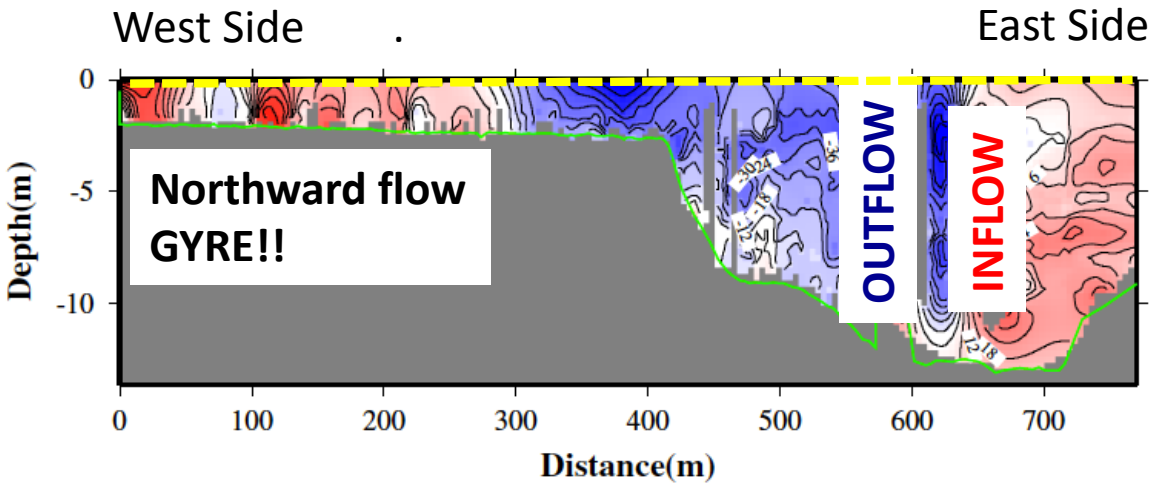
Acoustic Doppler Current Meters
ADCPs

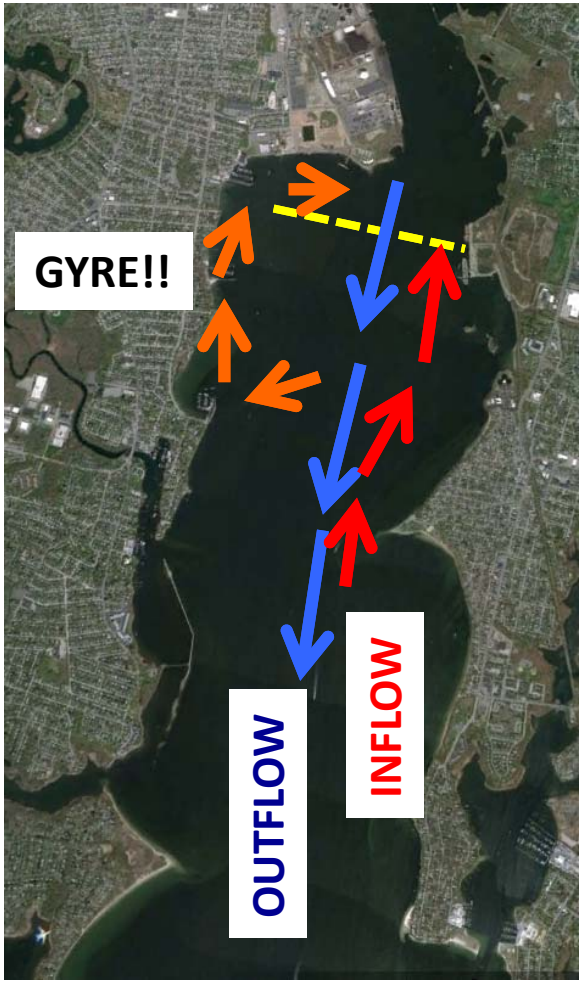
Map water circulation patterns in space & time



CIRCULATION DATA

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



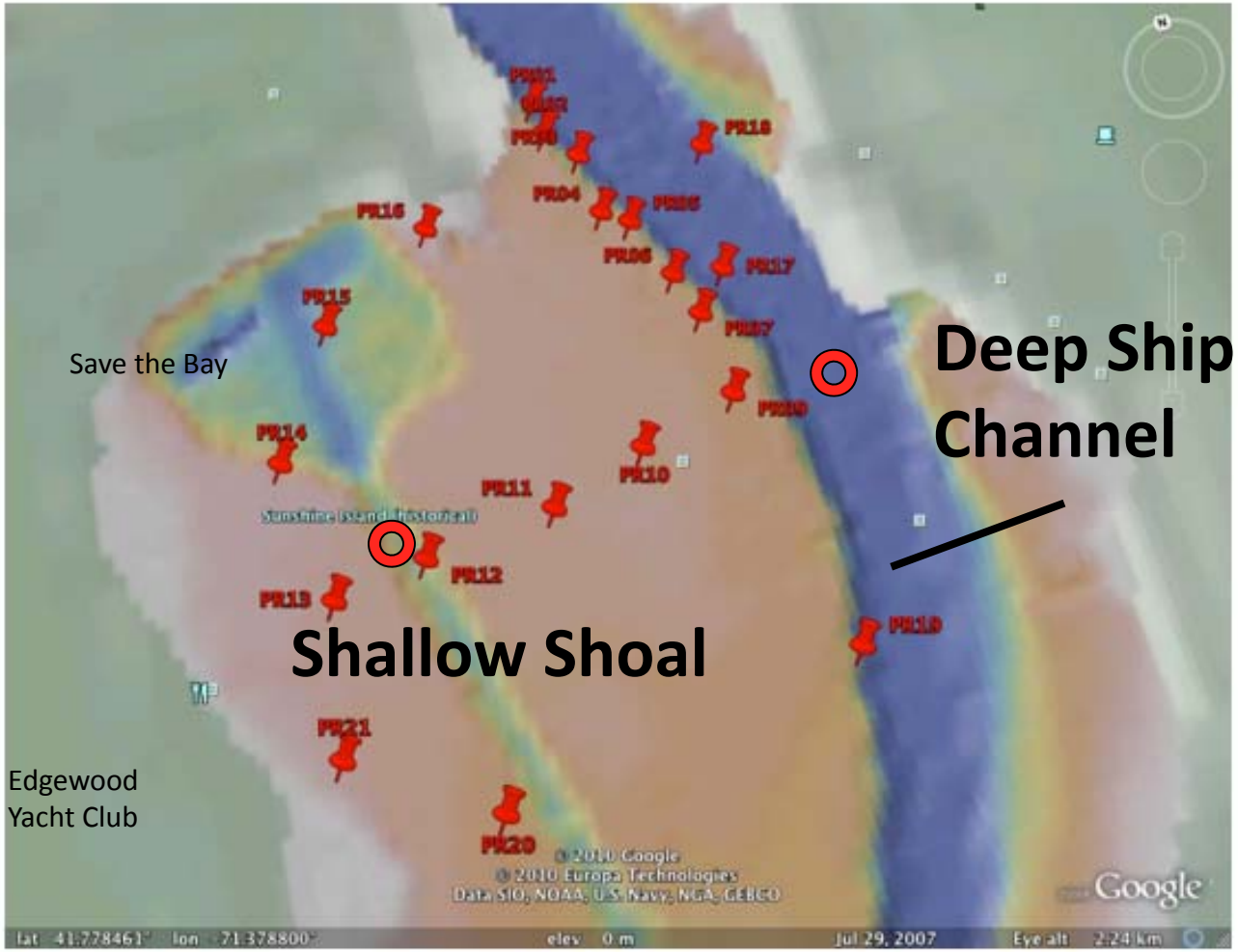


UNDERWAY ADCP:
Basic pattern seen Spring/Neap & summer, winter, fall, spring

Providence River Data: Current Meters (ADCP & Tilt)

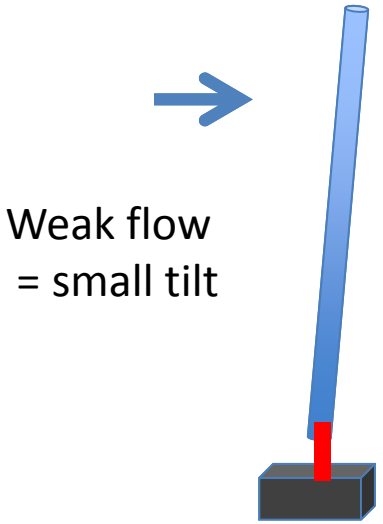
Upper Providence River Bathymetric Map:

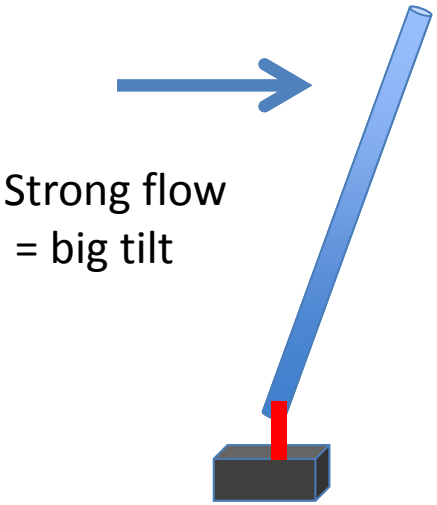
TCM Deployments: 2009 (3 months); 2010 (6 months..**flood**); 2009, 2014

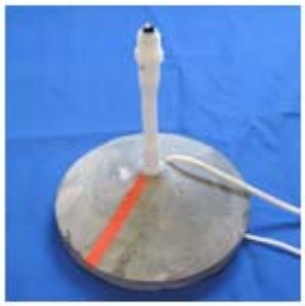


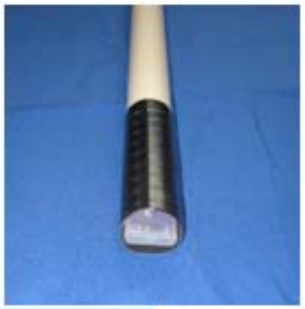
Tilt Current Meters (Low Cost $300 vs. $30000)

Good spatial & temporal. Details of how Gyres Work.



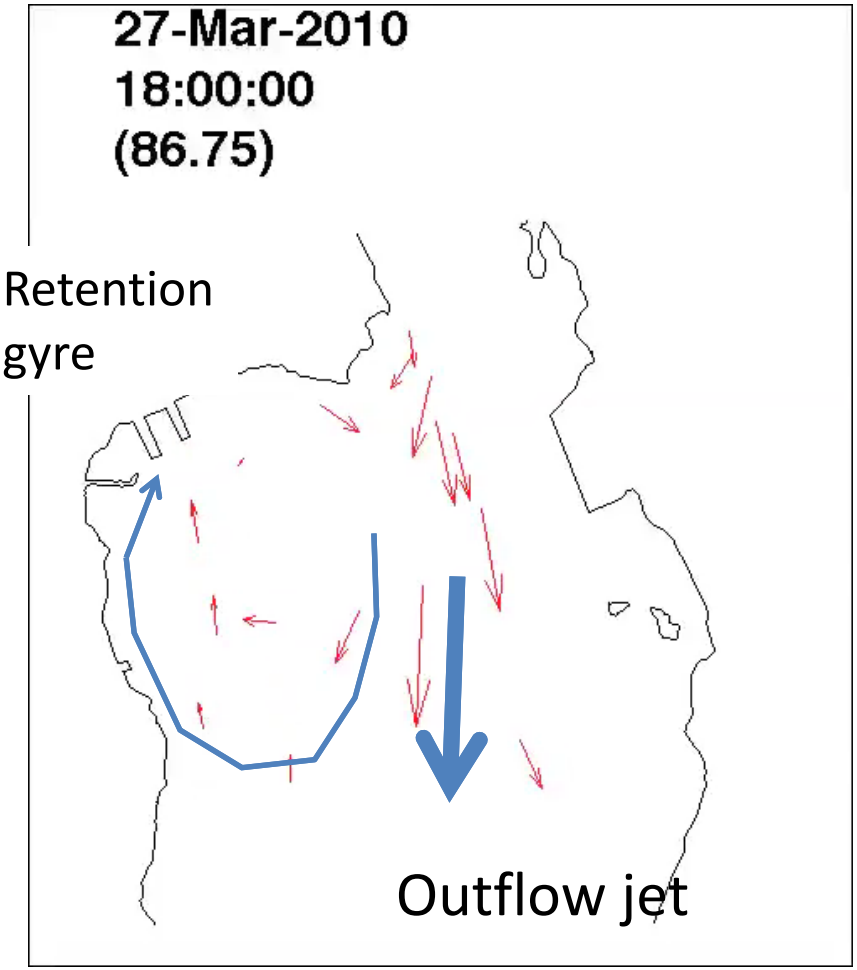






Tilt Current Meter Experiment: Summer, 2009; Spring/Summer 2010

NOT Fast Flush, but Bi-Modal Flush



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**

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

Edgewood Shoals: 8 million cubic meters

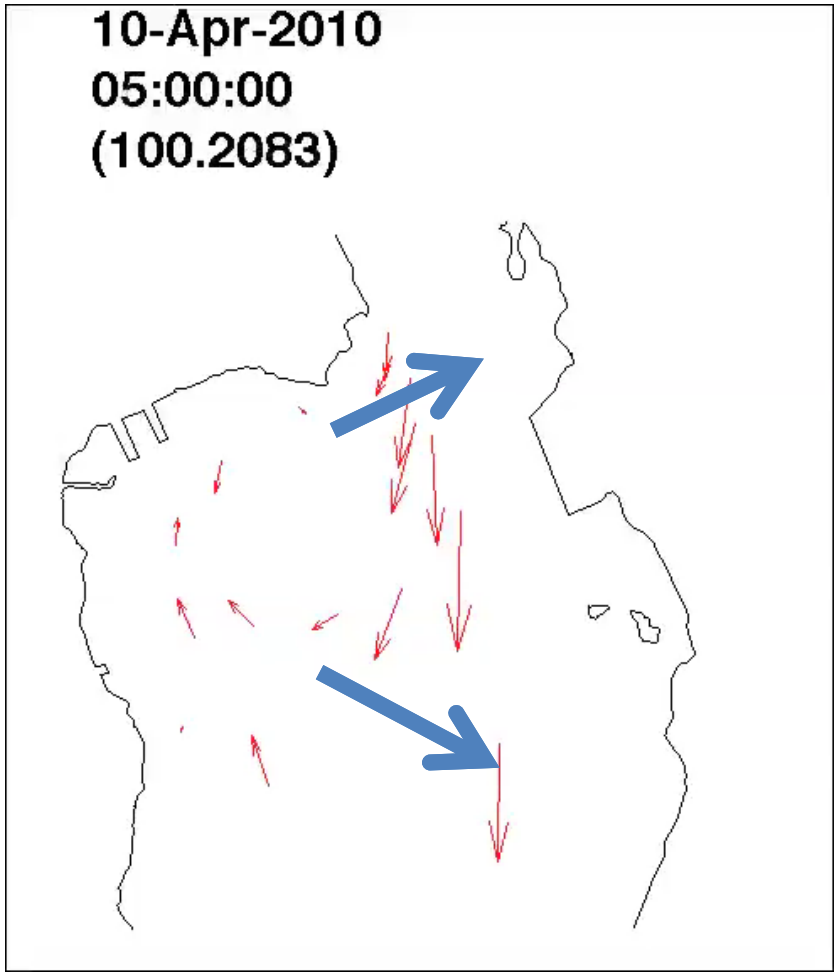
10% of Providence River volume.

Model estimate:

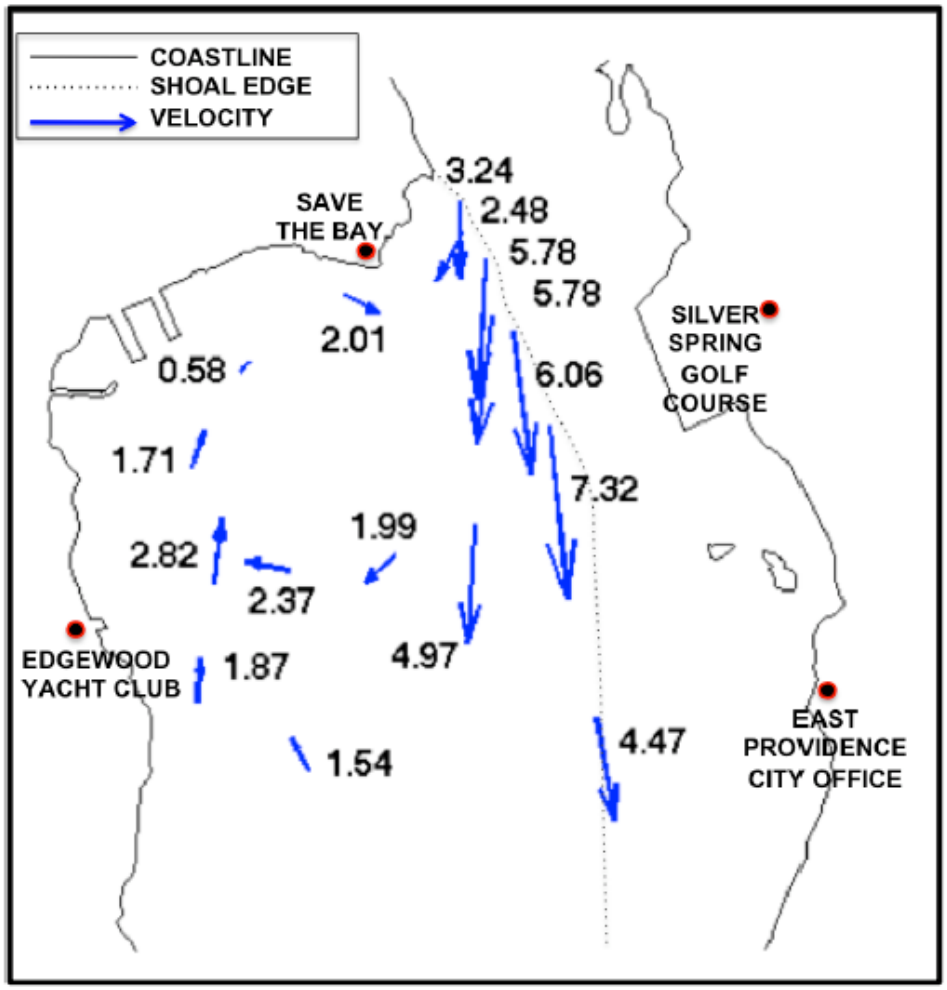
4-5 day retention time.

release in wind event over 1 day.

equivalent to ~13 CMS low oxygen river



Data: Chronic Gyre on Shoal



Data: Gyre persistent

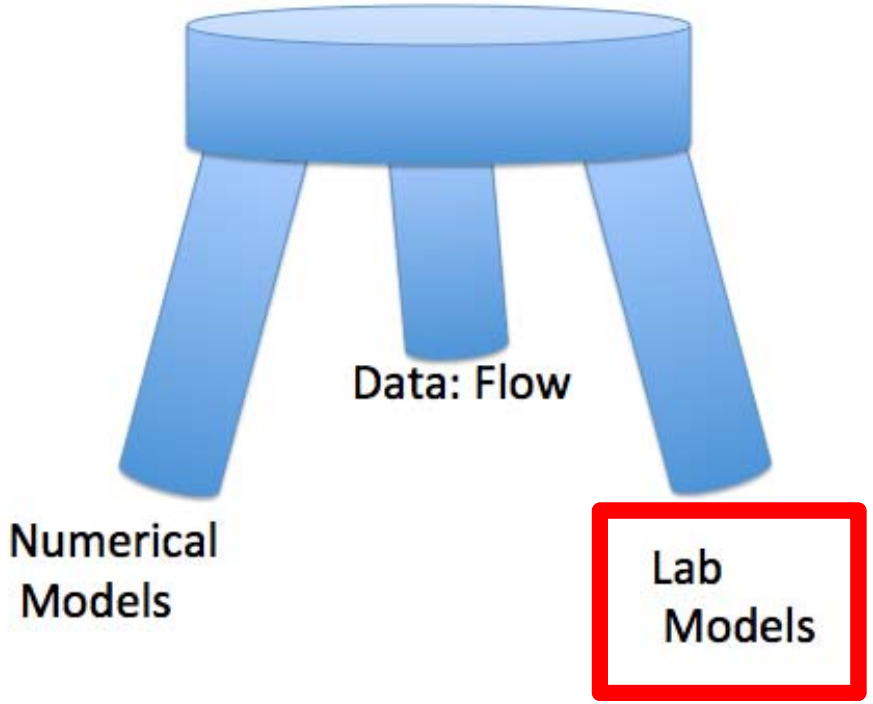
~5 million data points !!!!

3 mo. moored ADCPs

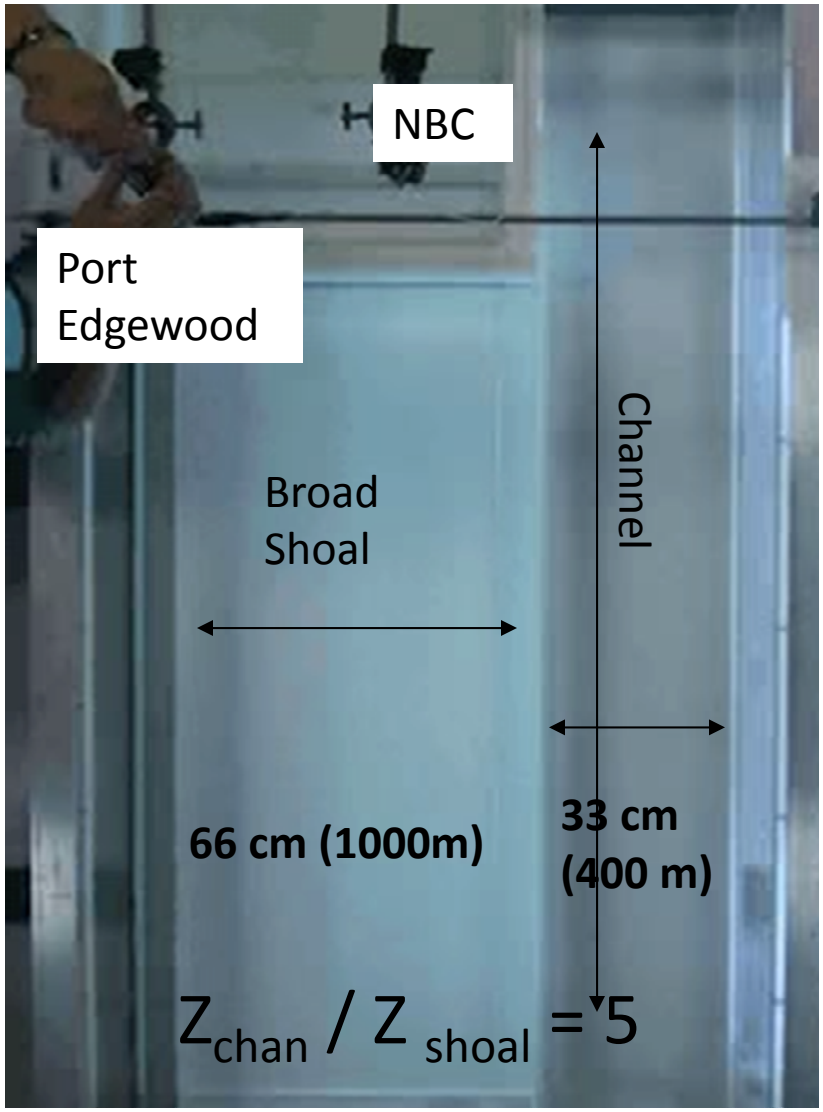
12 full tide cycle ADCP surveys

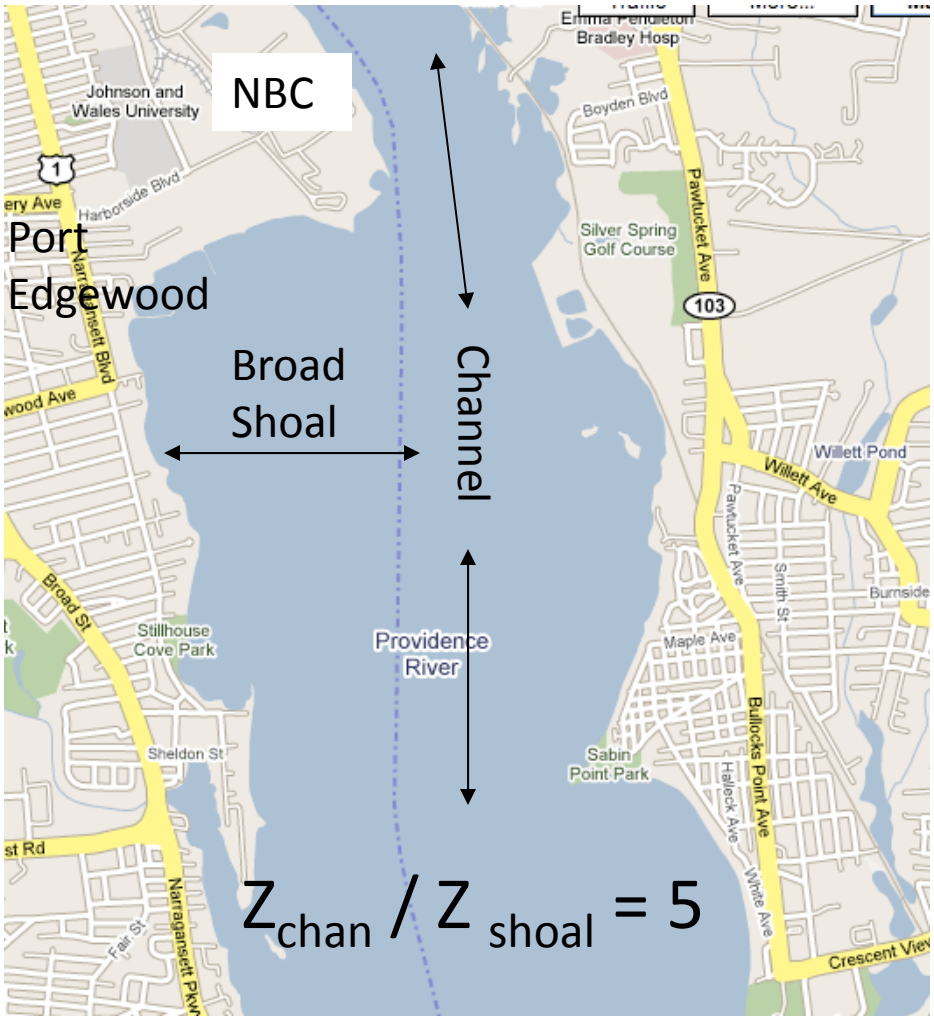
3 x 3 mo., 18 TCMs/ exp.

But add 3rd Leg of GFD Stool: Laboratory Models



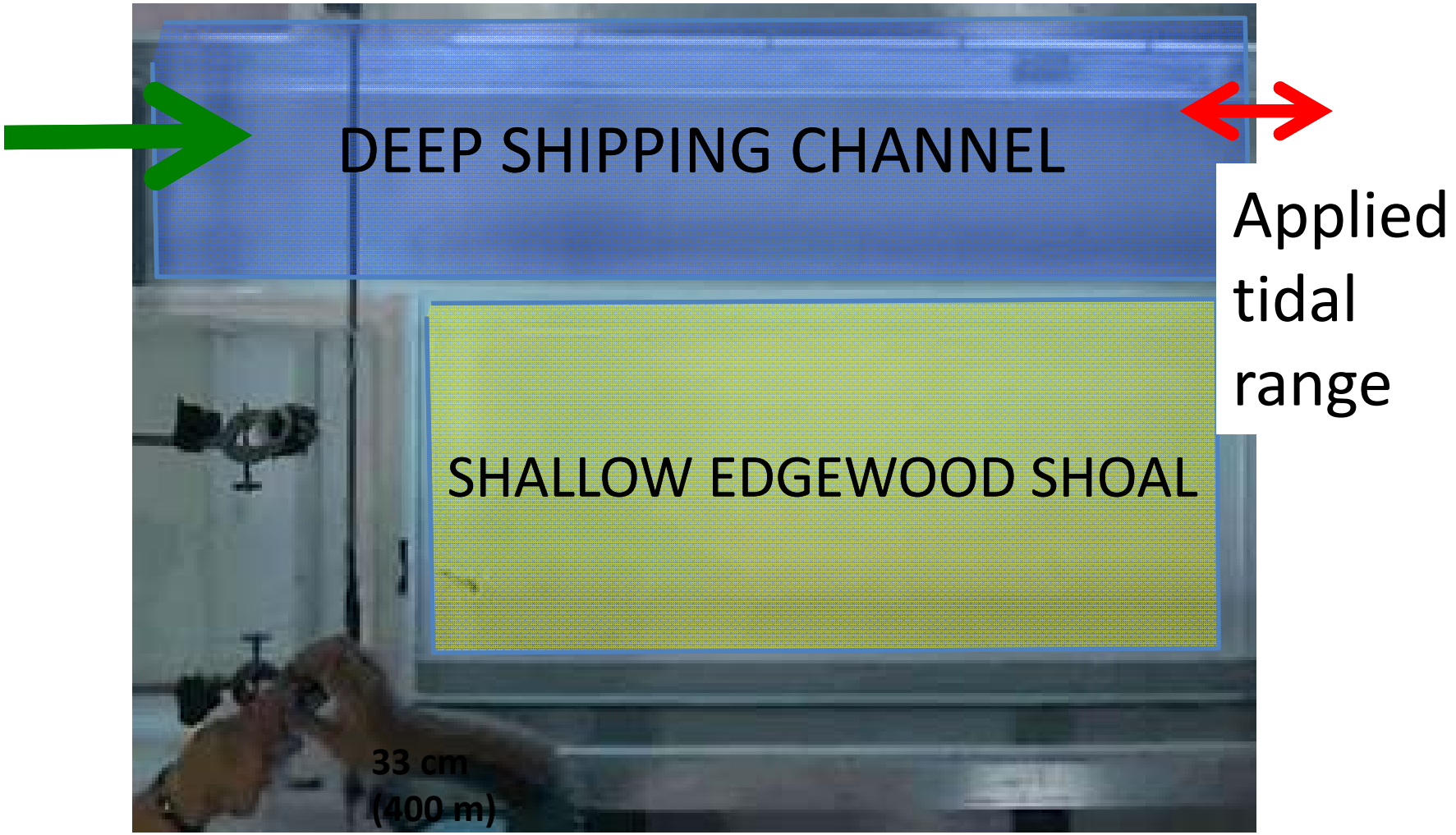
3rd Leg of GFD Stool: Laboratory Models





POWERPOINT SOMETIMES FLIPS THIS ON SIDE

Applied river runoff



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

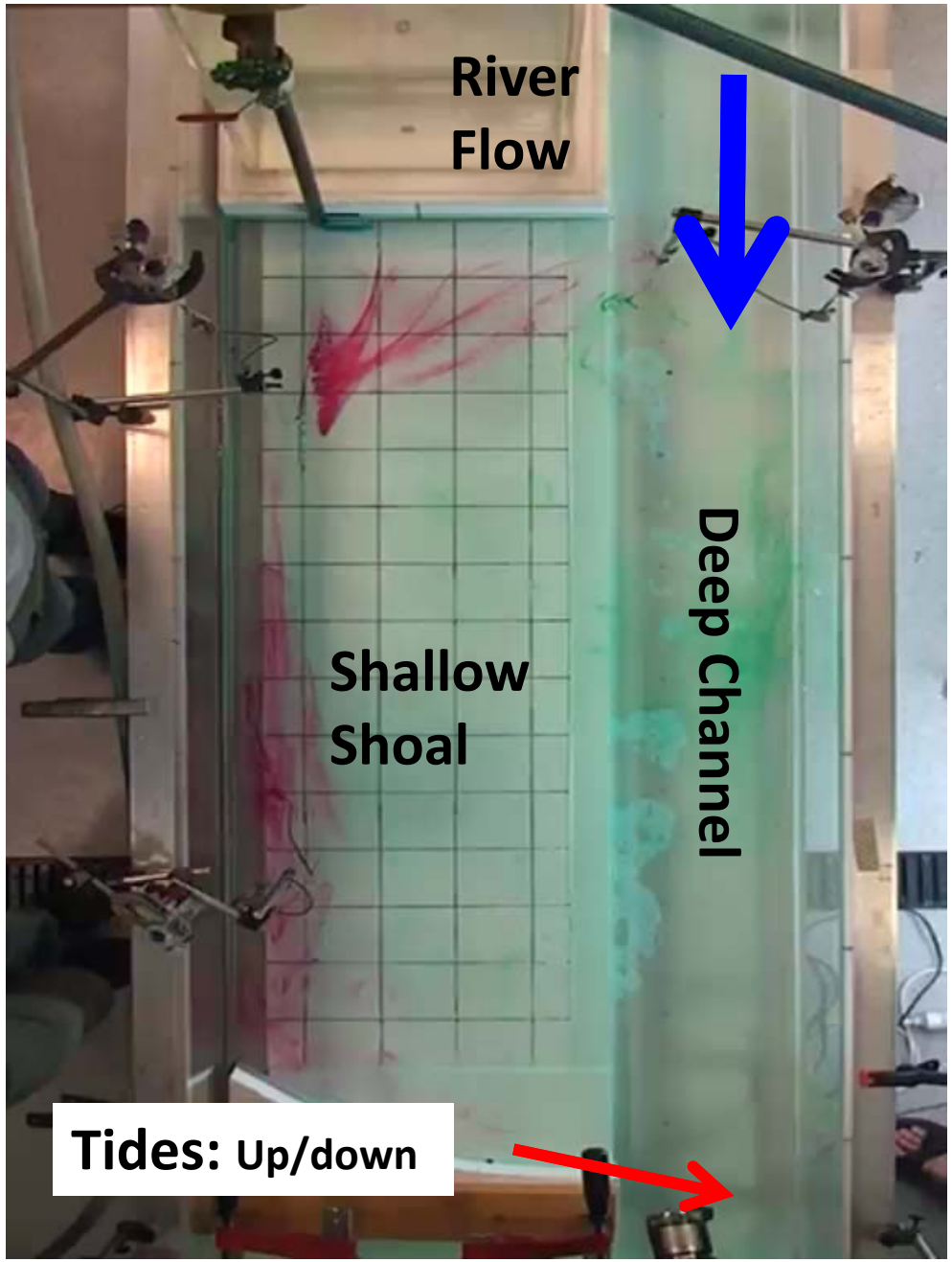
Channel & Shoal

River Runoff

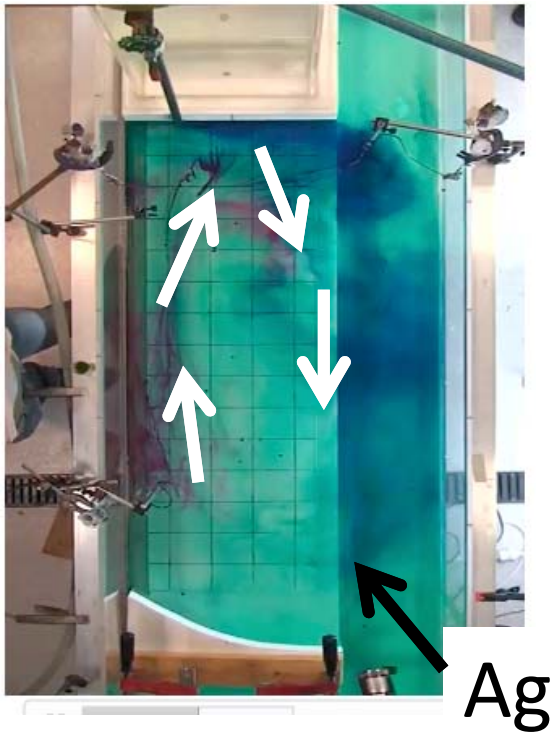
Tides

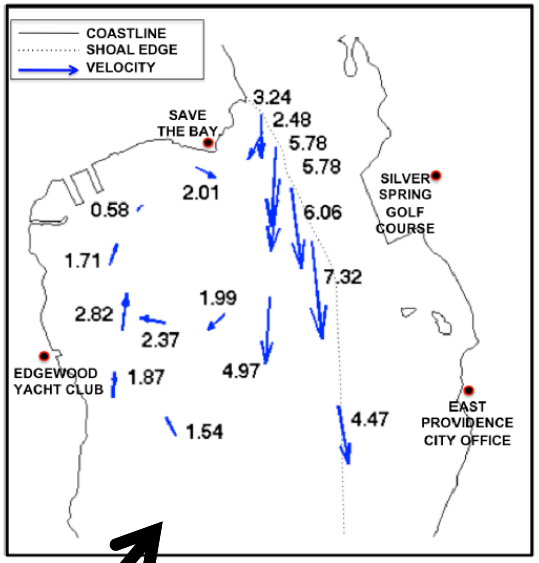
- No wind
- No density differences

+ Real Fluid



LAB & Data: Chronic Gyre on Shoal





Agree…*almost*

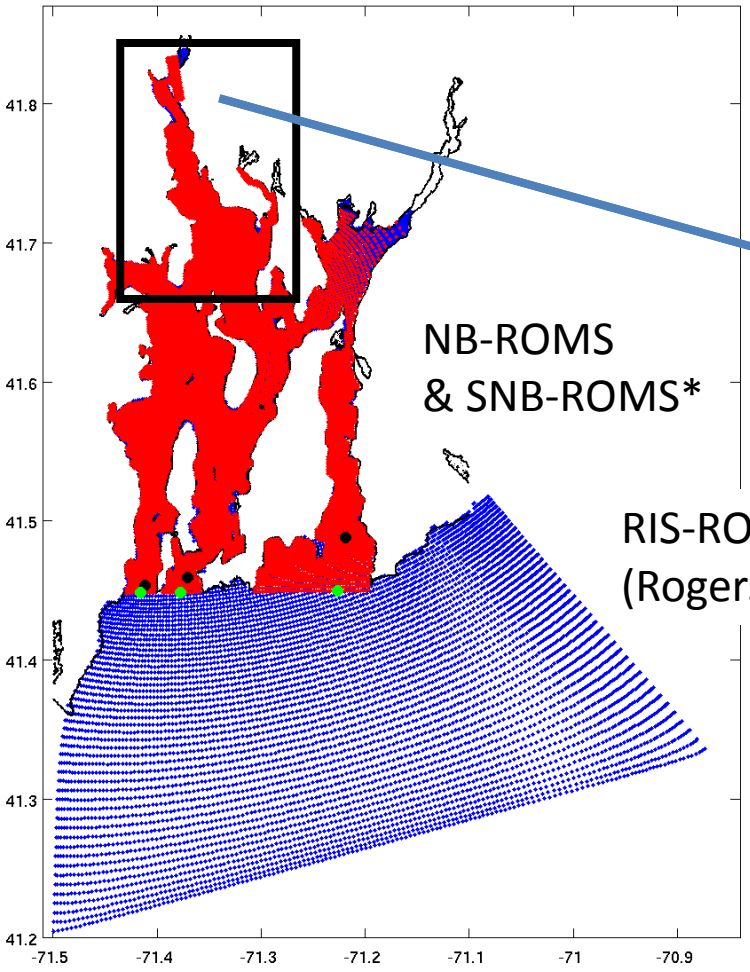
Lab shows extreme isolation of shoal bottom water.

Outflow + Bathy = Stratified flow

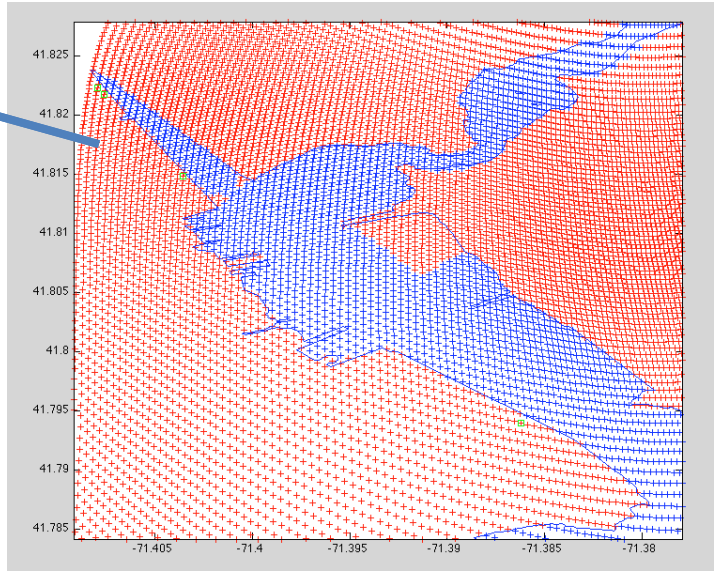
Easy retain for 10-20 tide cycles

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

ROMS: Regional Ocean Modeling System



<30m grid cells Providence/Seekonk Rivers

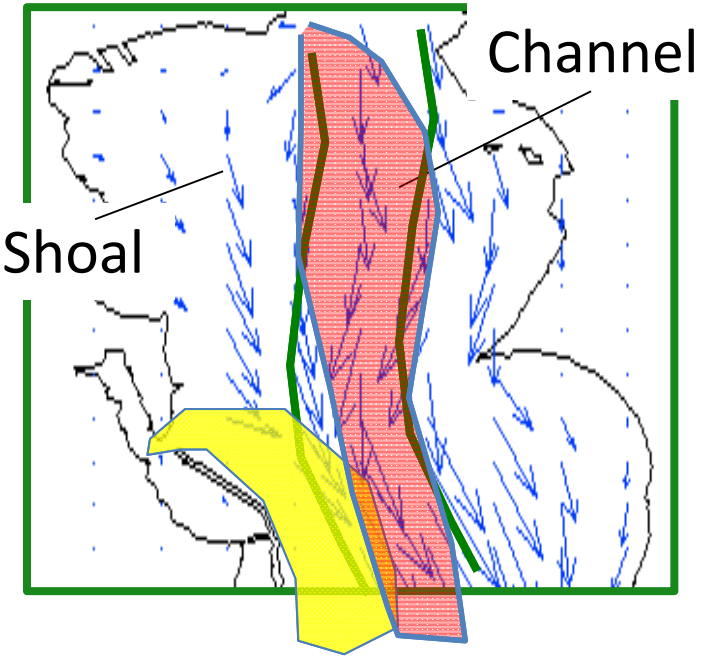


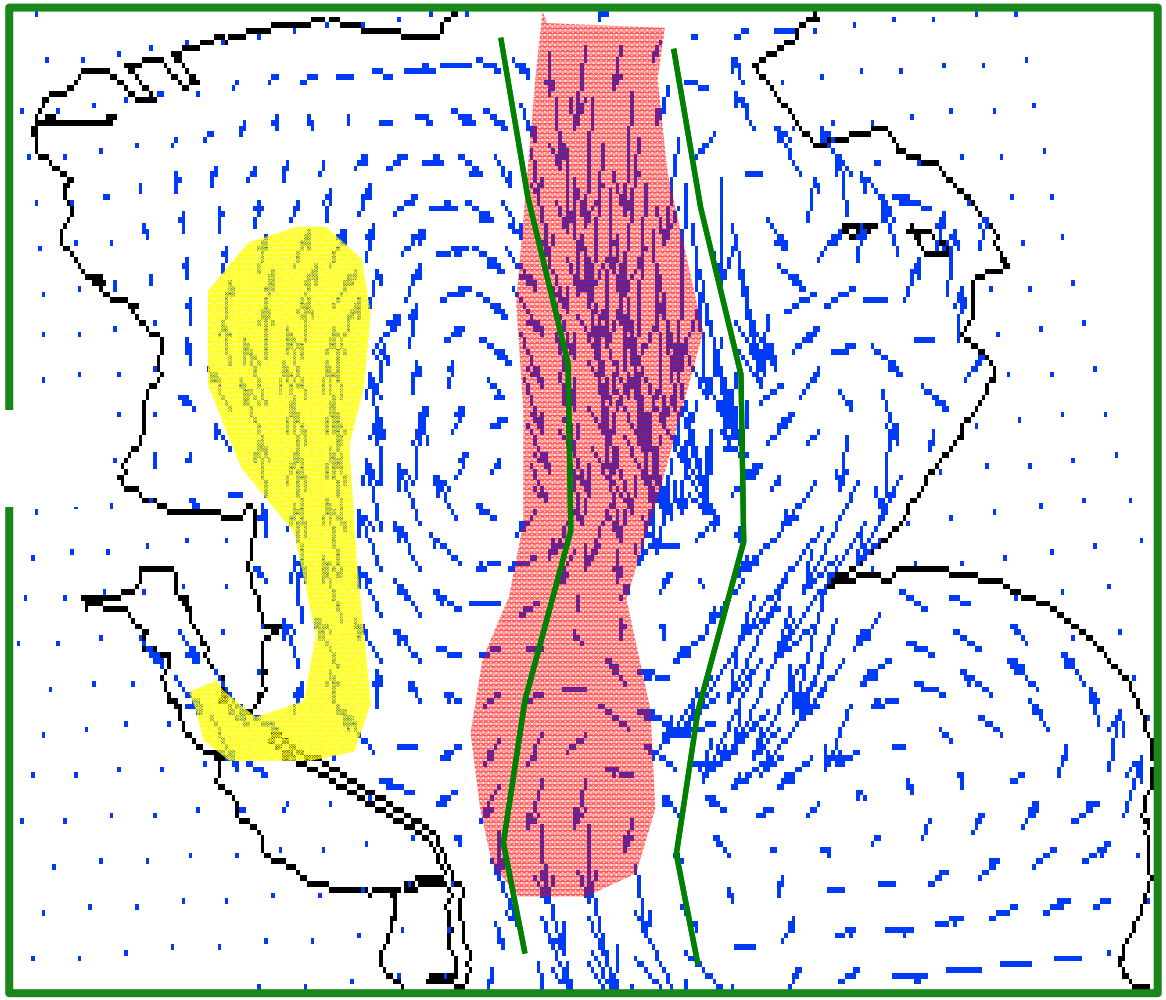
High resolution (30m) ROMS: 1. Stable gyre.

2. Complex transport north sources flush, south source wraps

3. Flushing? Age of water vs. oxygen?

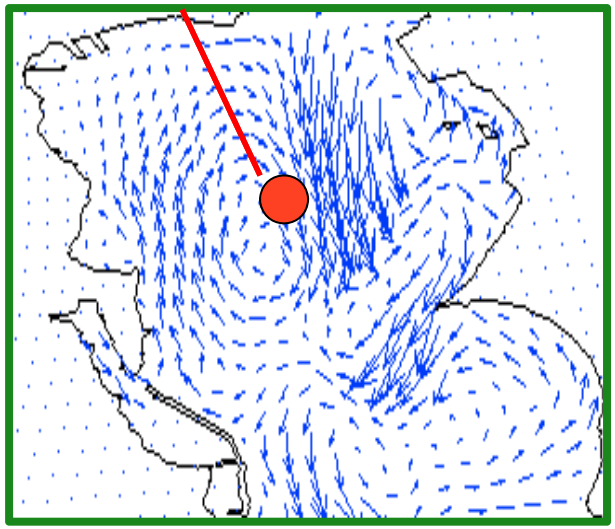
Early version:
Matched tidal flows/heights
Sub-tidal (shown) is bad

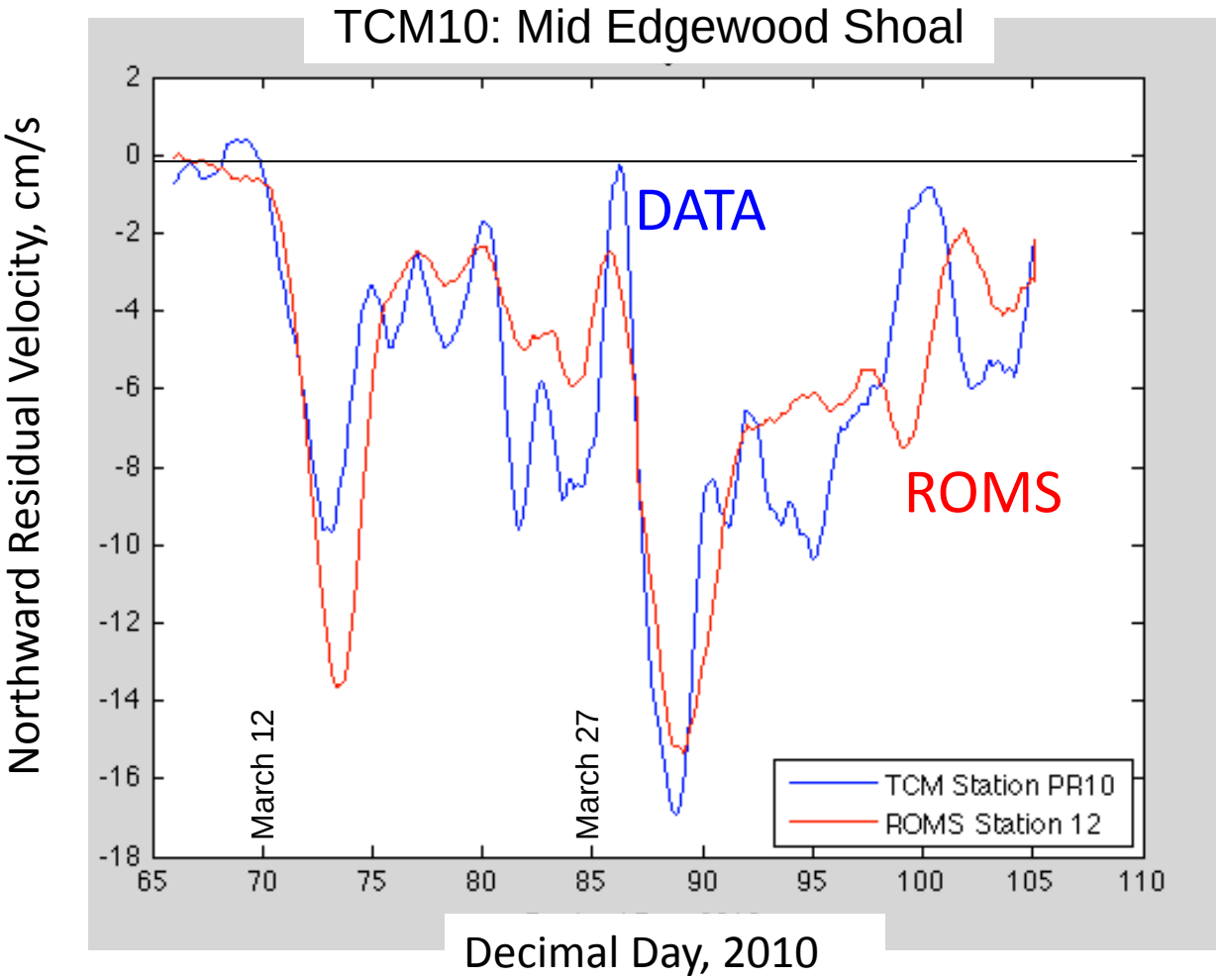




Tidal and sub-tidal Flow Data vs Model Willmott Skills High: 0.8 – 0.9
Even captures challenging flood event

Data/ROMS
comparison location

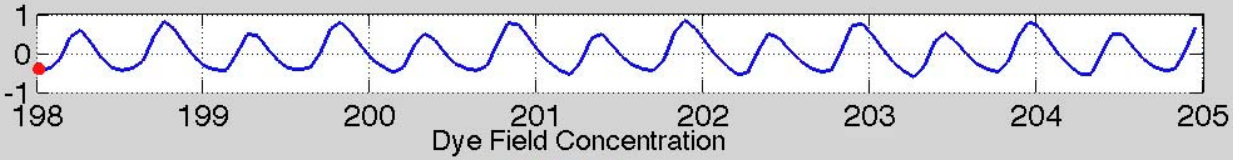


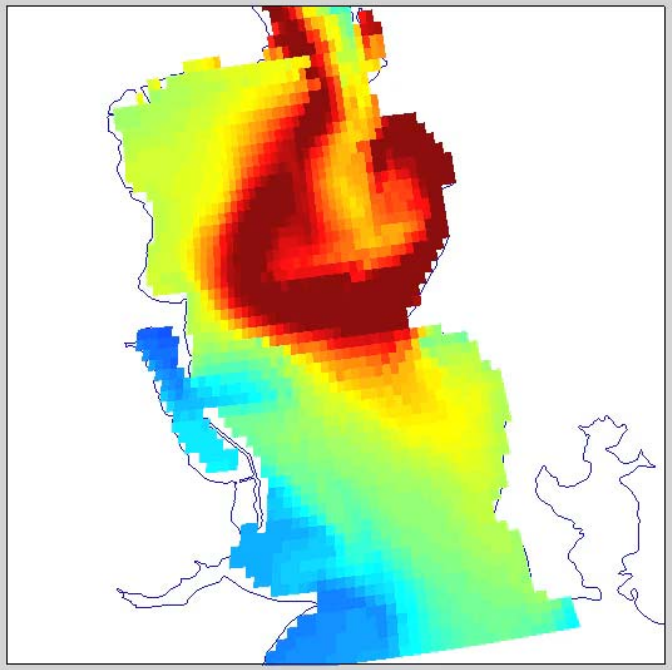


2010 ROMS Simulation: Transport of temperature/salt/**chemical dyes**

Individual dyes for 9 rivers and 7 WWTFs:

Can track accumulation/flushing/transport of all major source

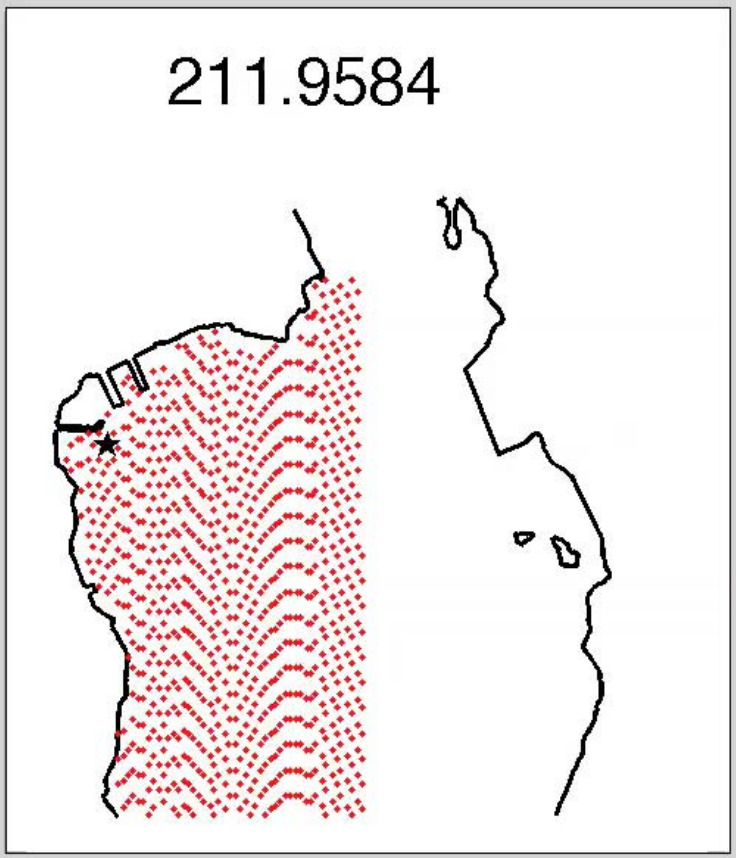


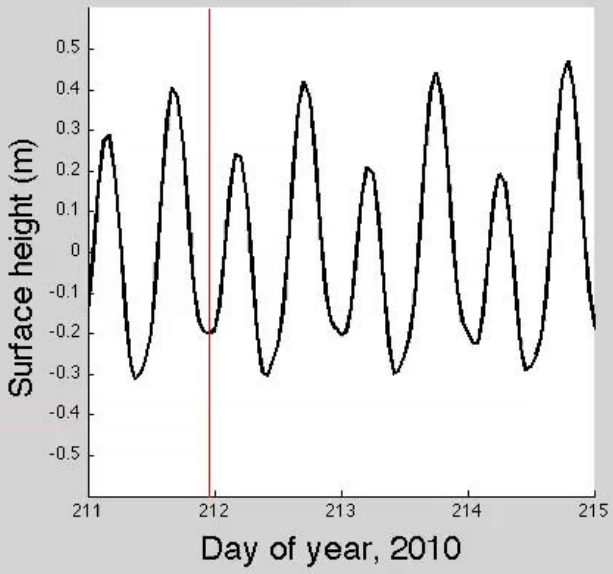


Red= Dye from Fields Pt. WWTF

Modeling Embayment Retention: Floats & Passive dyes

2010 Summer ROMS Simulation, flushing of numerical “floats”





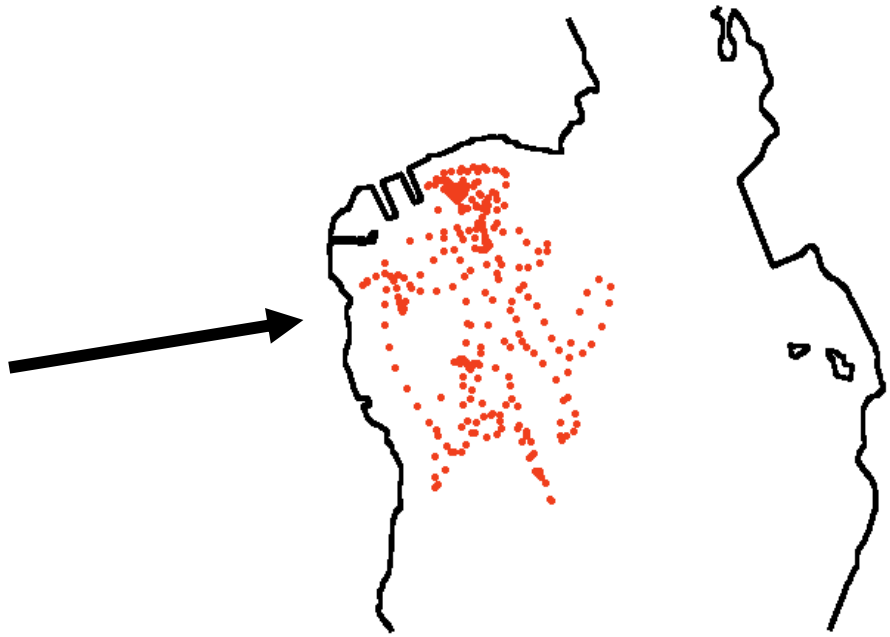
Grant: For physics-side of eco-model, ***age of water*** *is key*

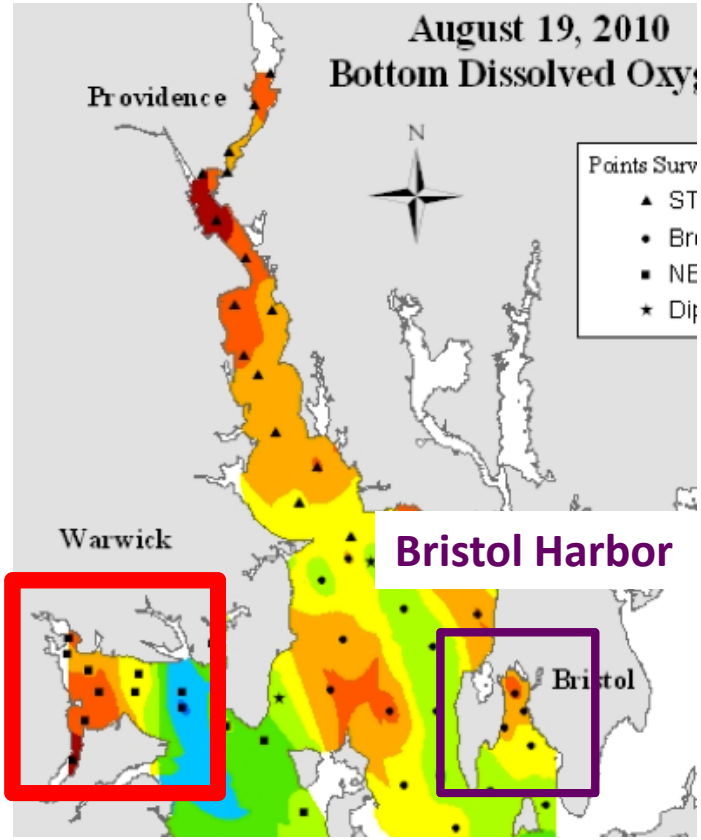
Box models & Coarse ROMS Prov. River Flushing: 1 - 3 days

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

jet 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

Summer 2009 & 2010

Summer 2012

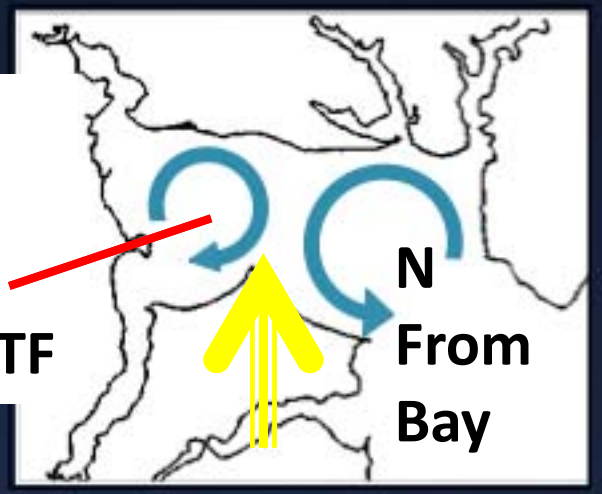
ADCP & TCM Data

Field observations

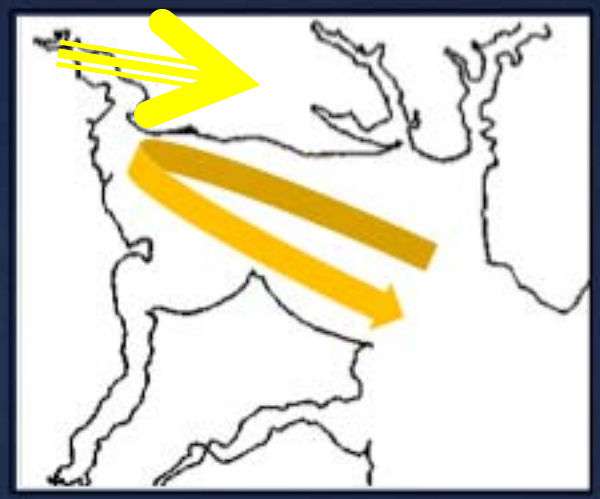
- RED → SeaHorse Tilt Current Meter (TCM)
- YELLOW → Acoustic Doppler Current Profiler (ADCP)

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

- Northward-blowing wind



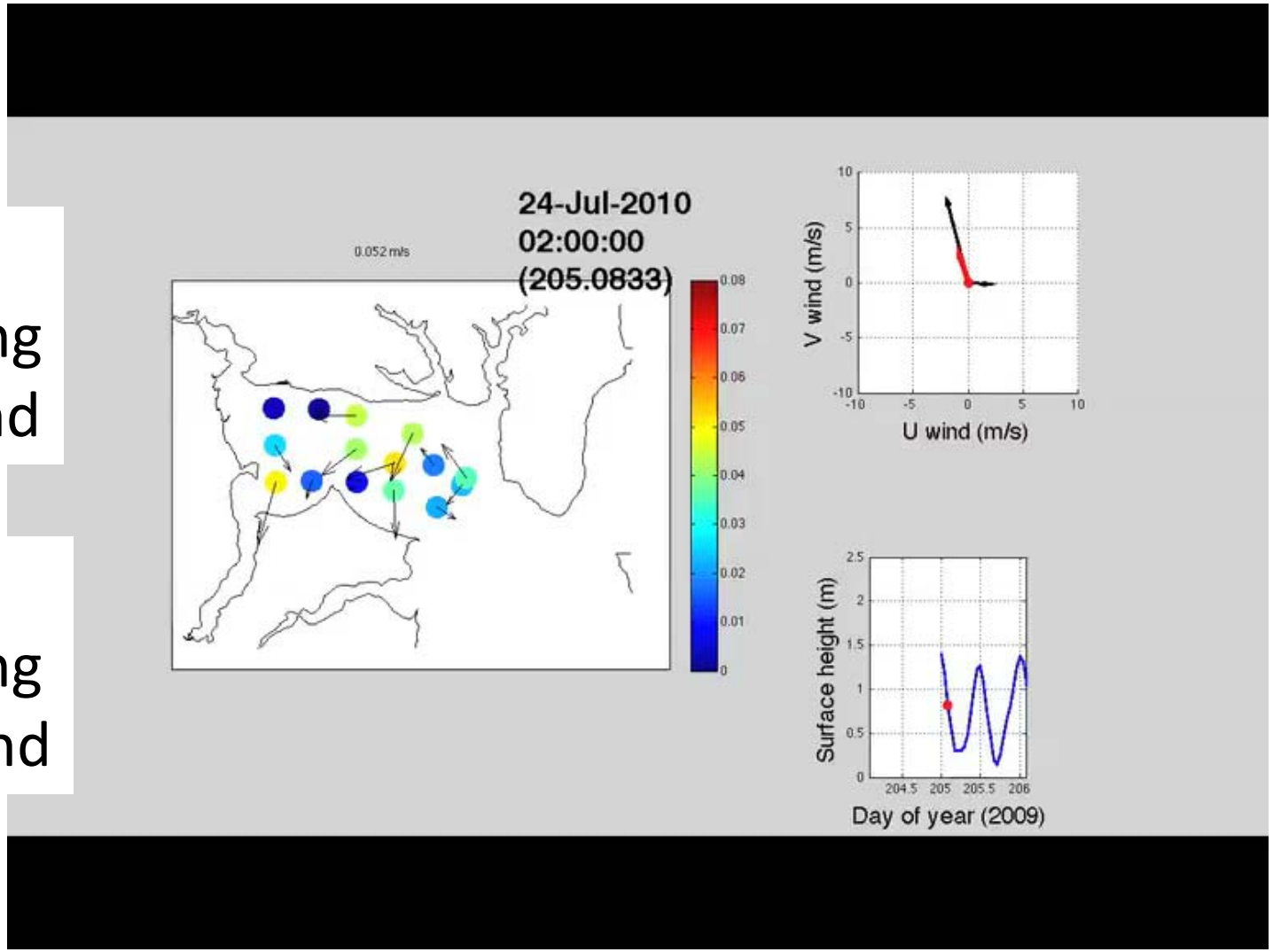
- Eastward-blowing wind



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

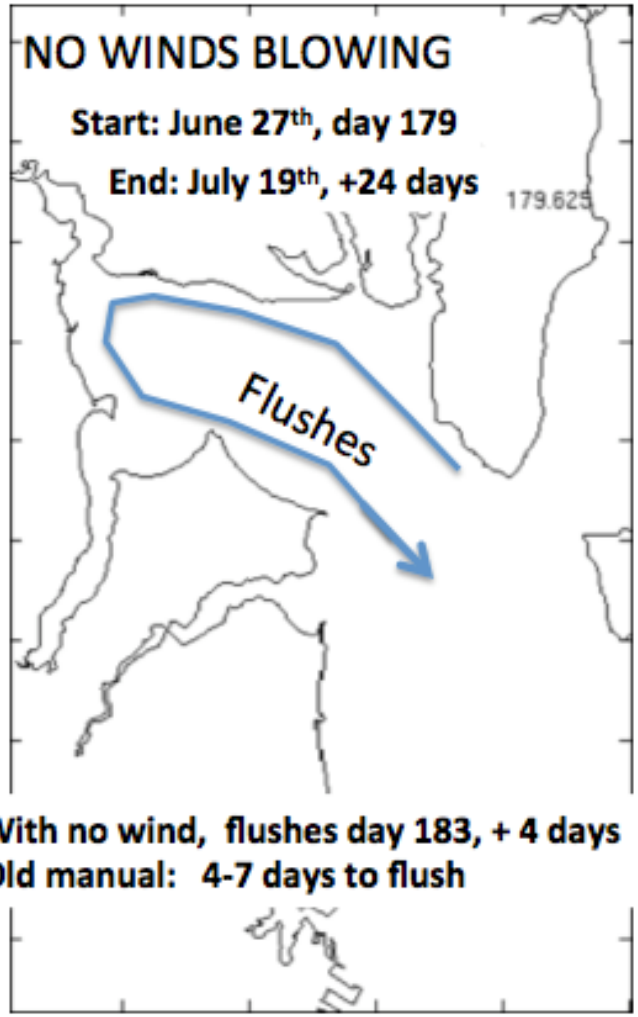
July 26:
Low flushing
E-ward wind

July 28:
Low flushing
N-ward wind

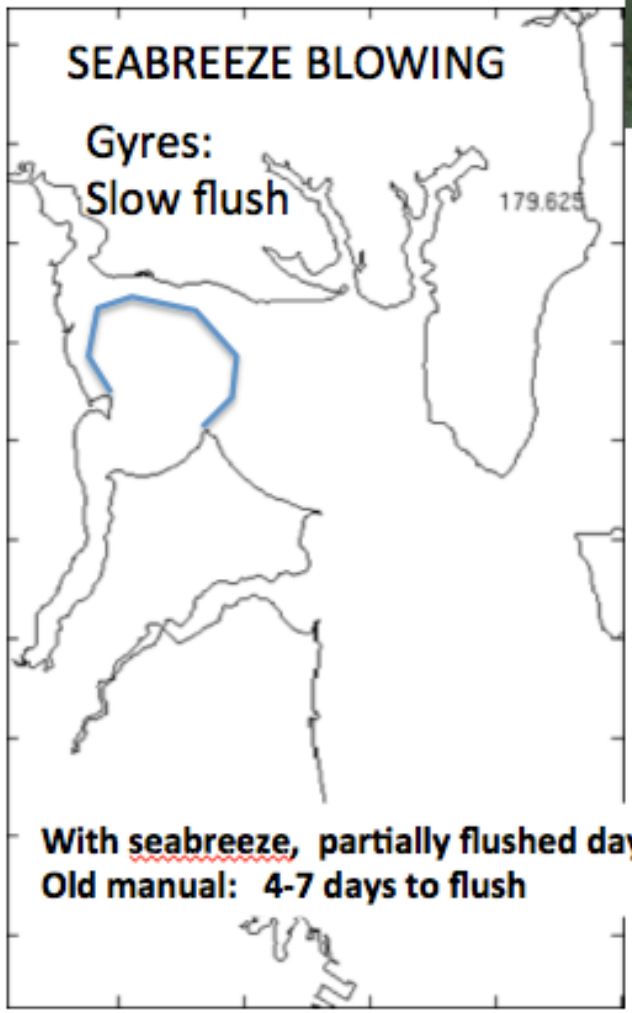


ROMS Model Results

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



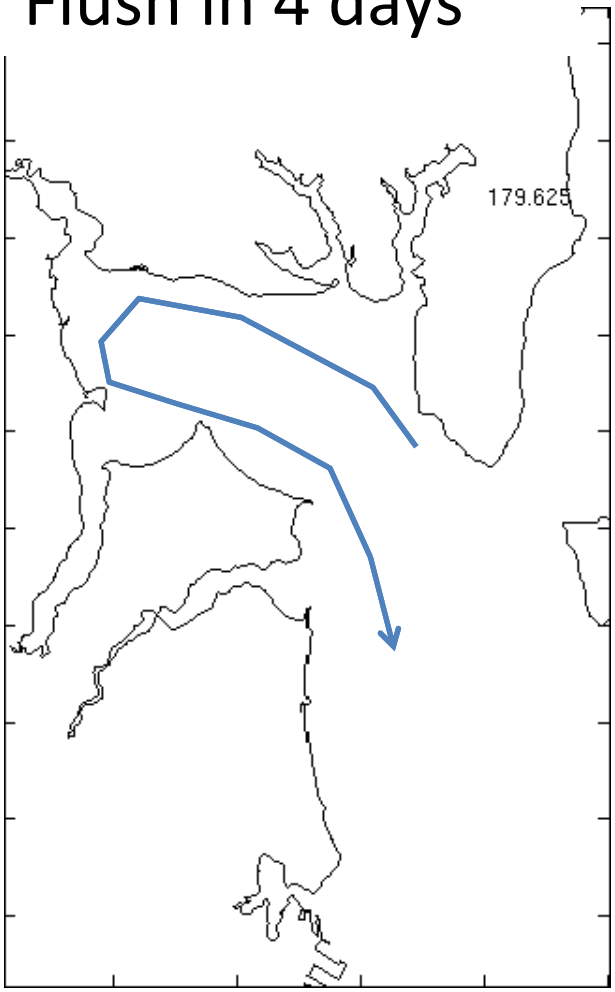
With no wind, flushes day 183, + 4 days
Old manual: 4-7 days to flush



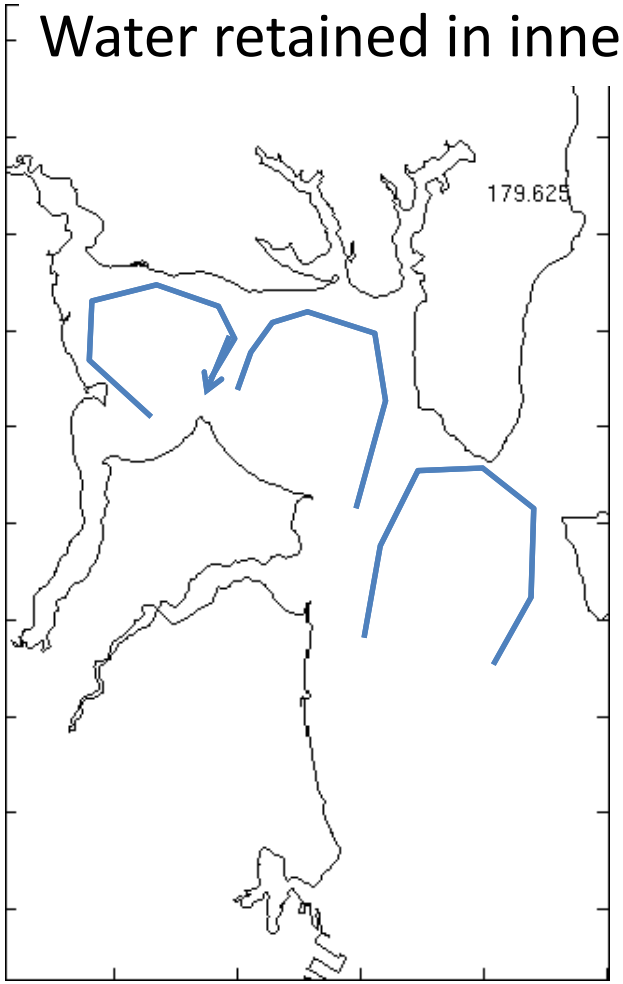
With seabreeze, partially flushed day 195, + 16 days
Old manual: 4-7 days to flush

Identical Summer Runs Except for Wind

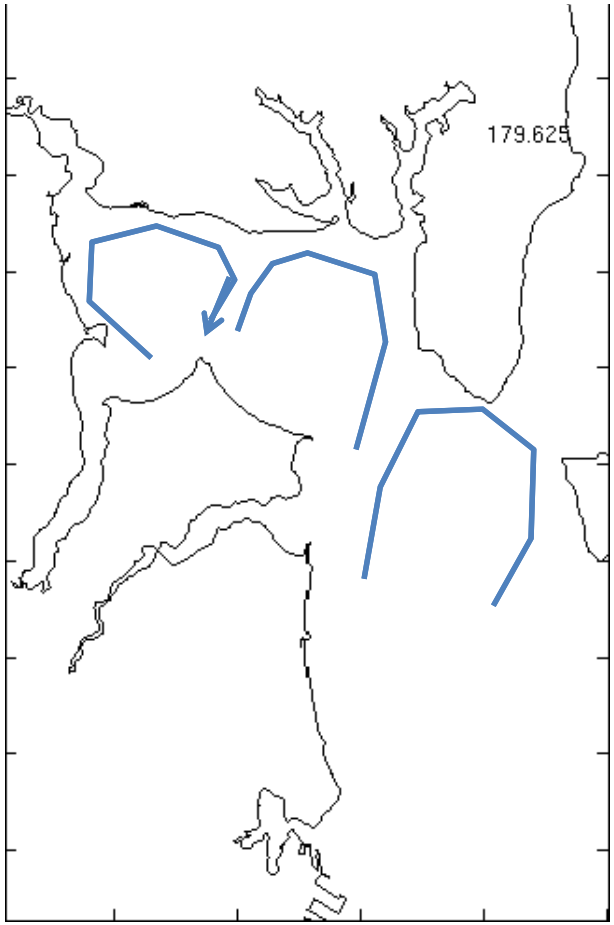
Winds turned off.
Flush in 4 days



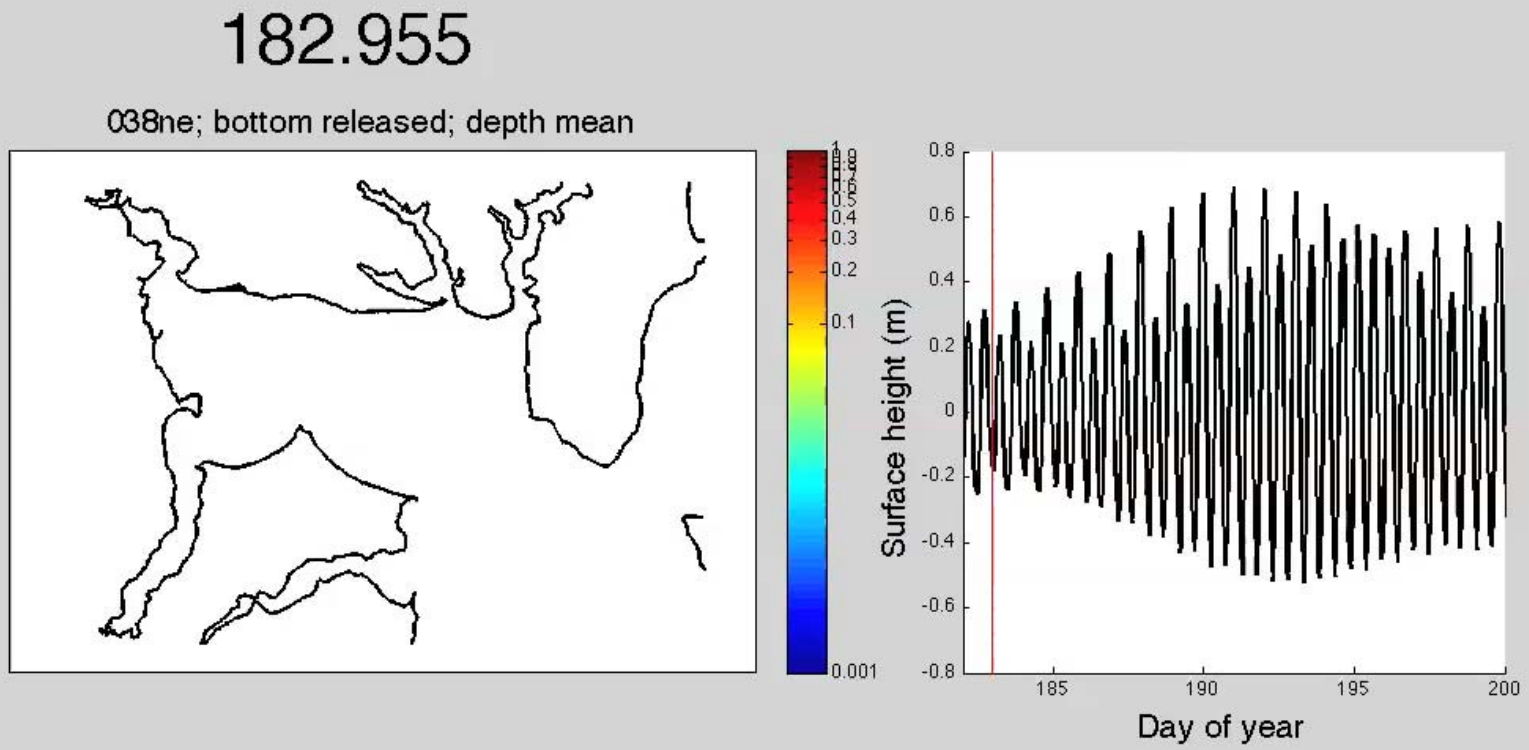
Seabreeze, N-ward winds on
Multiple gyres.
Water retained in inner basin



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



Use Passive DYES and Floats to Quantify Circulation & Flushing



Decimal Day 182 is July 1

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

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

Nitrogen is not a conservative dye…..

So NPZD Ecosystem Model turned on in ROMS

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

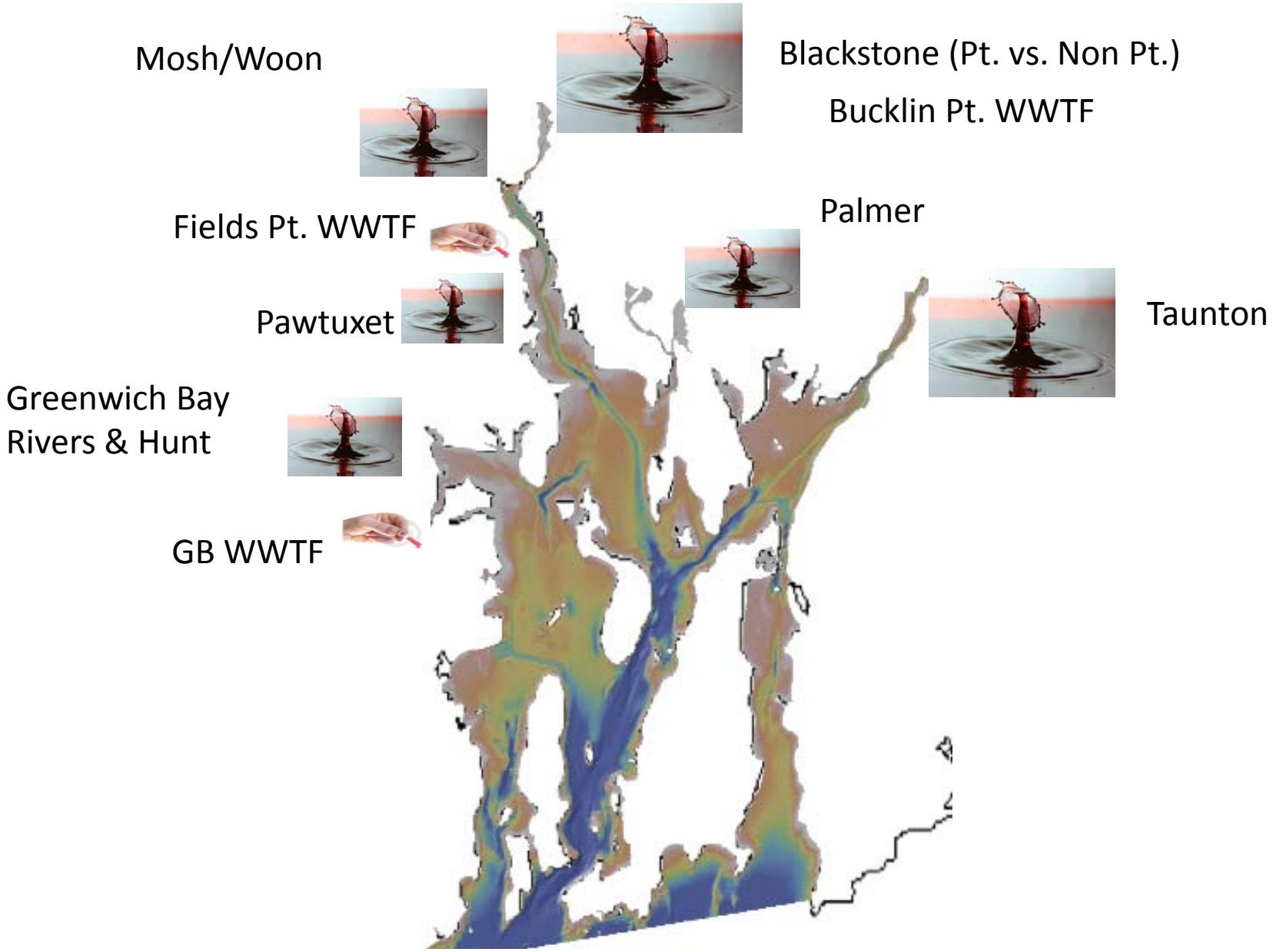
$$\frac{dP}{dt} = \frac{V_m\, N\, P}{k_s + N} - mP - I_i\, Z \qquad (1)$$

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

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

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

Also Detritus Equation

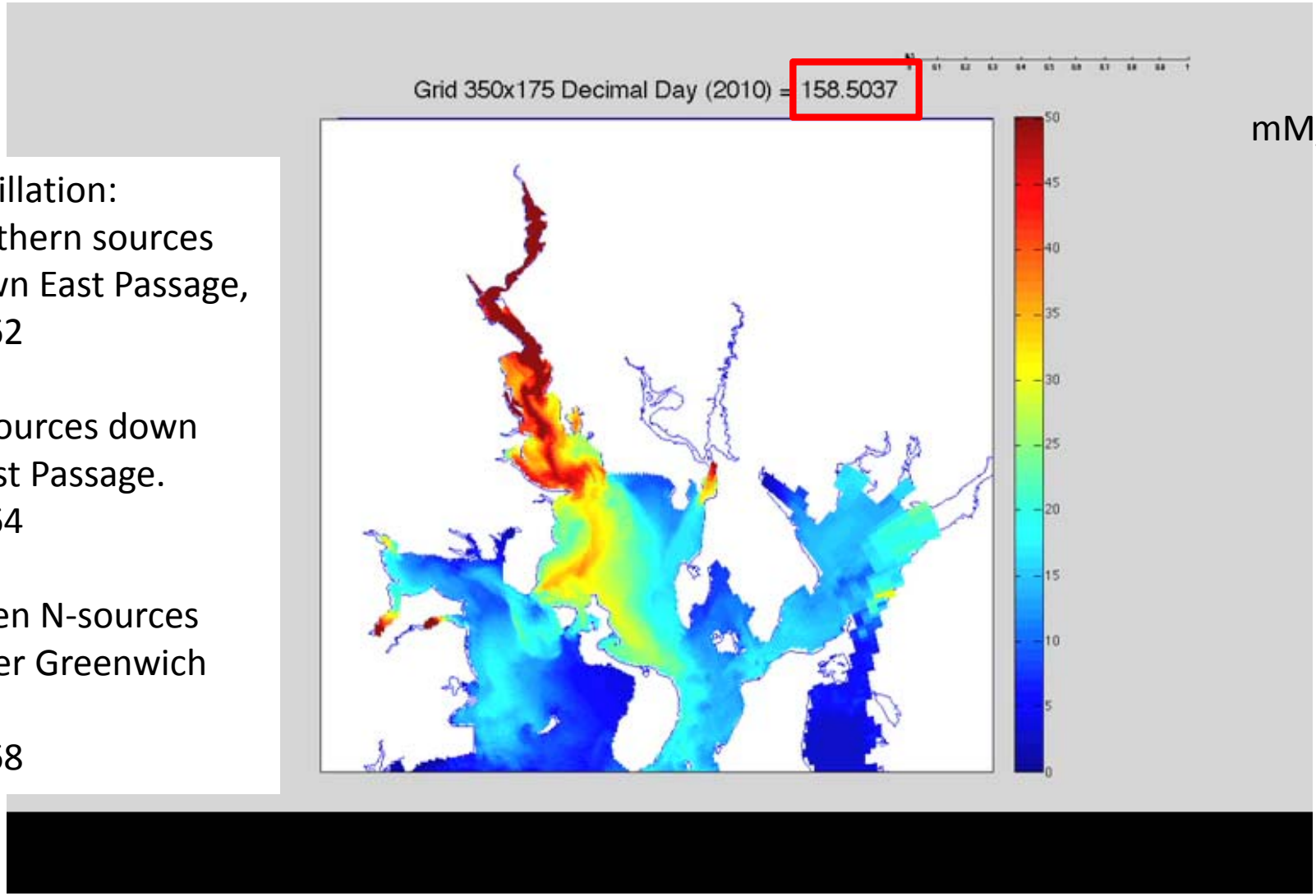


Nitrogen from 9 Rivers & 7 for Waste Water Treatment Facilities:
Independent control, can reduce any river or any WWTF

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

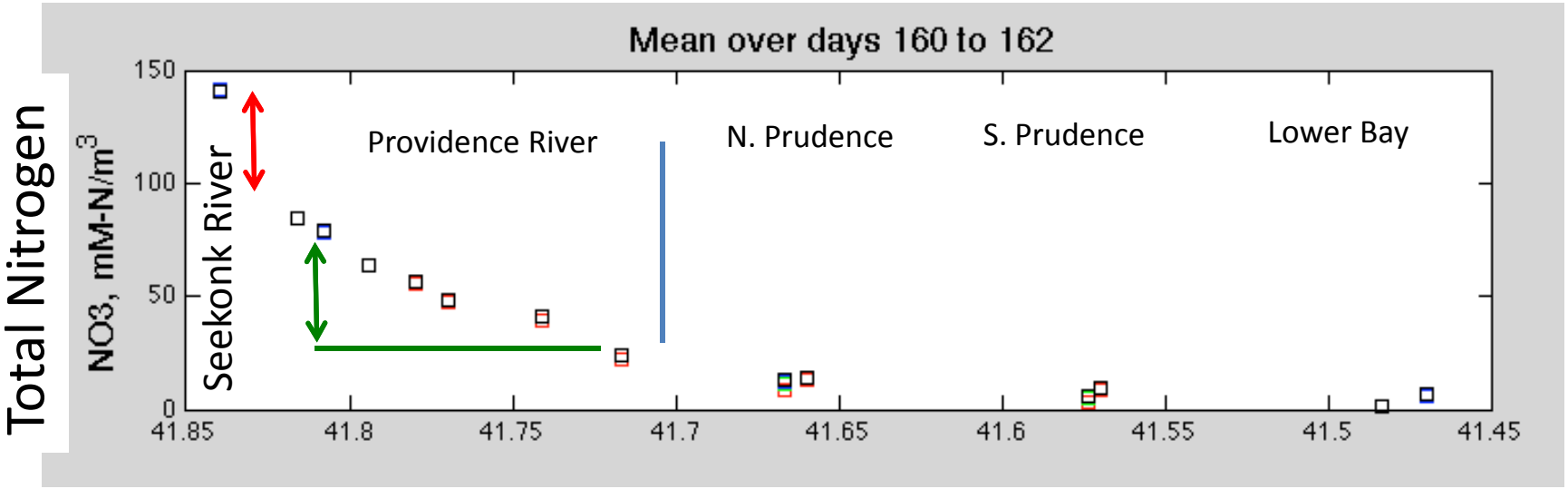
N-sources down West Passage. D164

Often N-sources enter Greenwich Bay D168

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

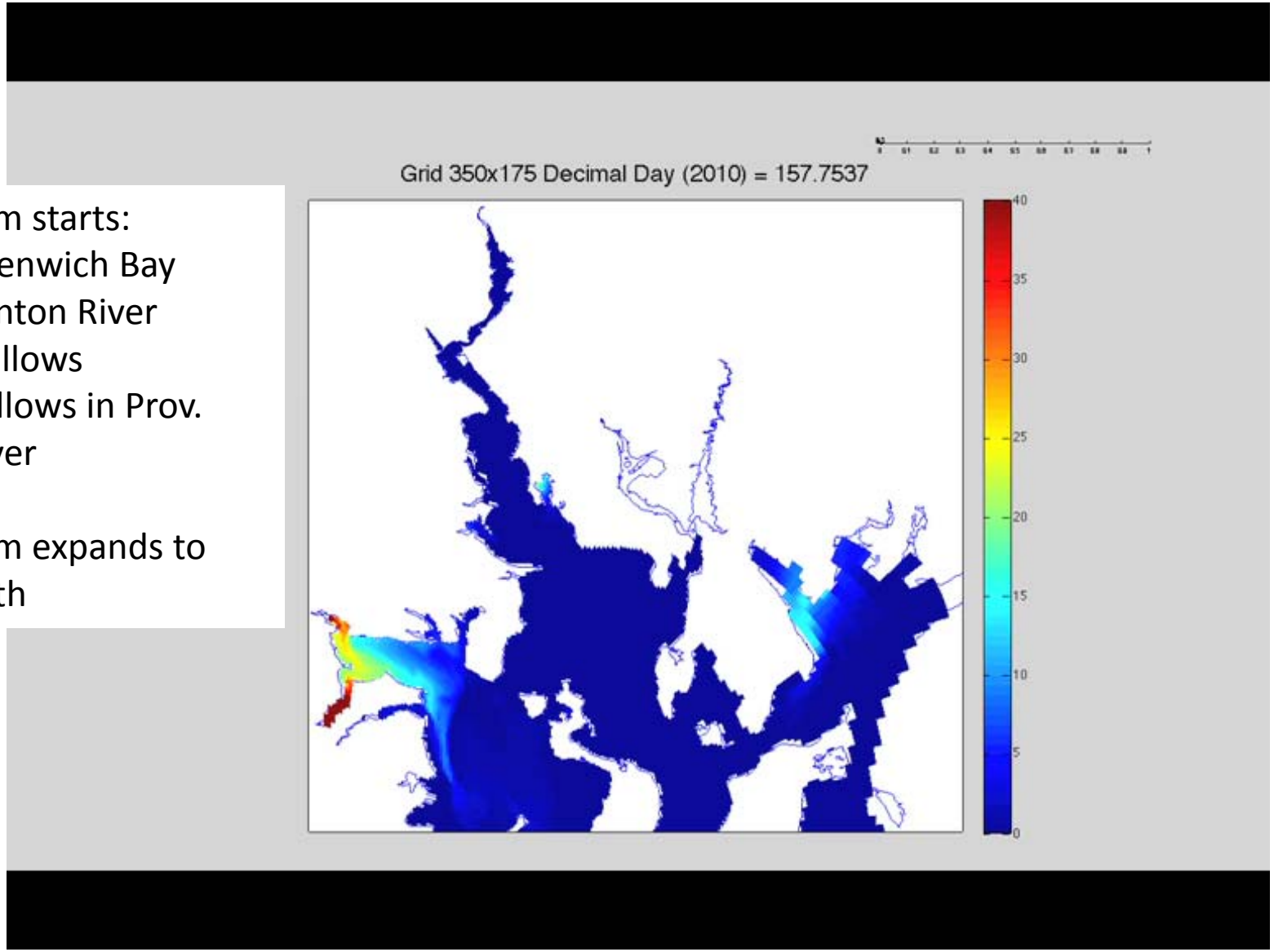


Multiple runs: Uptake rate, Light extinction, Zoo Grazing, Mortality, **WWTF levels**

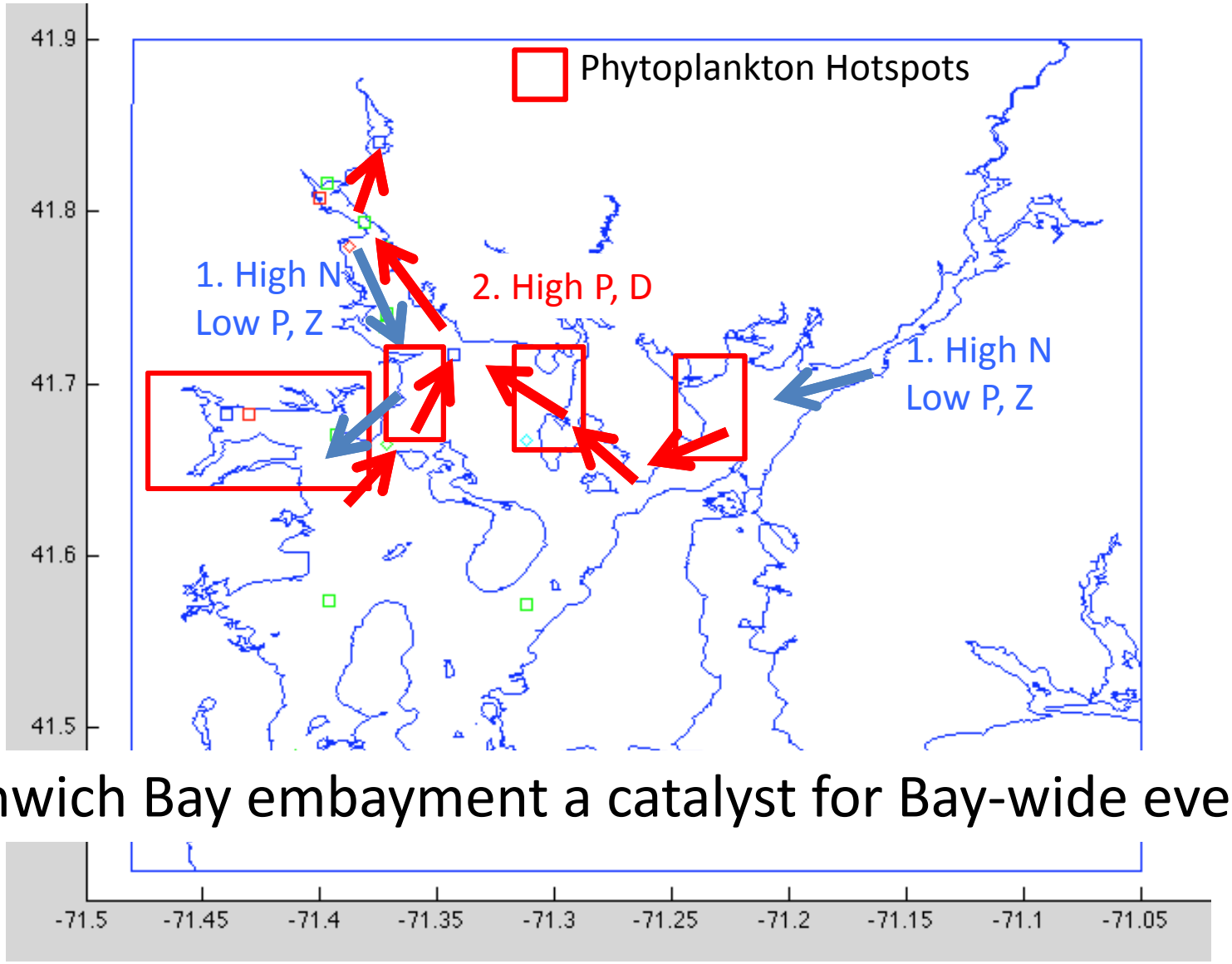
Phytoplankton: Surface Reference case: Vm2.5, KL0.75, ZG1.0.
Shows it starts in Greenwich Bay and Mt Hope Bay

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

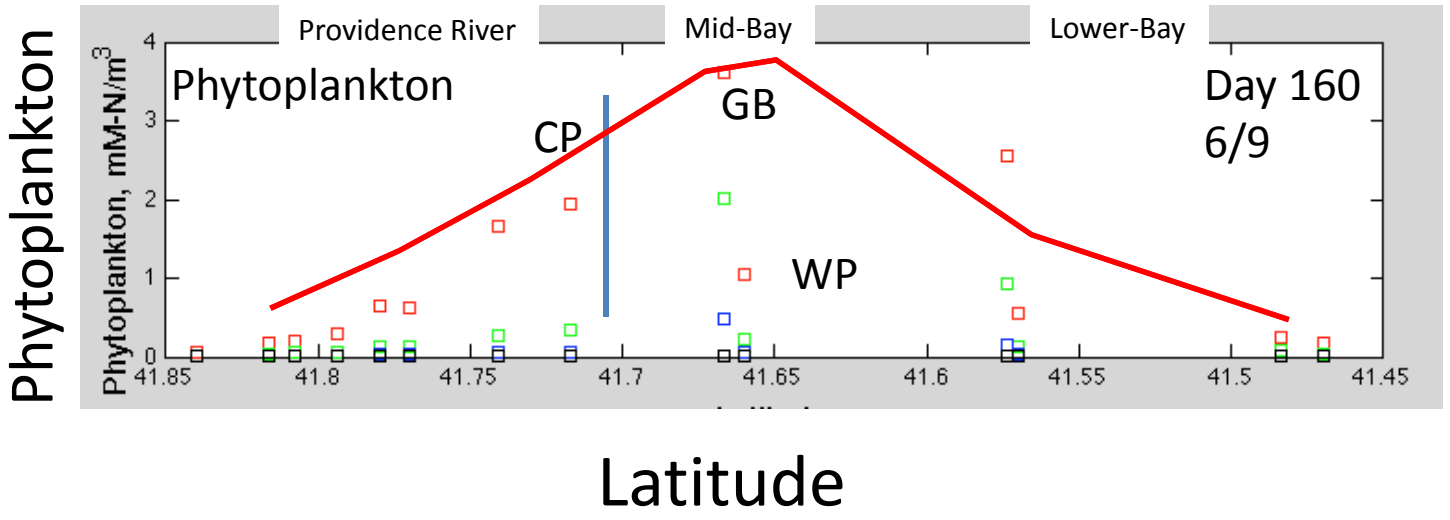
Bloom expands to
north



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 often sits high

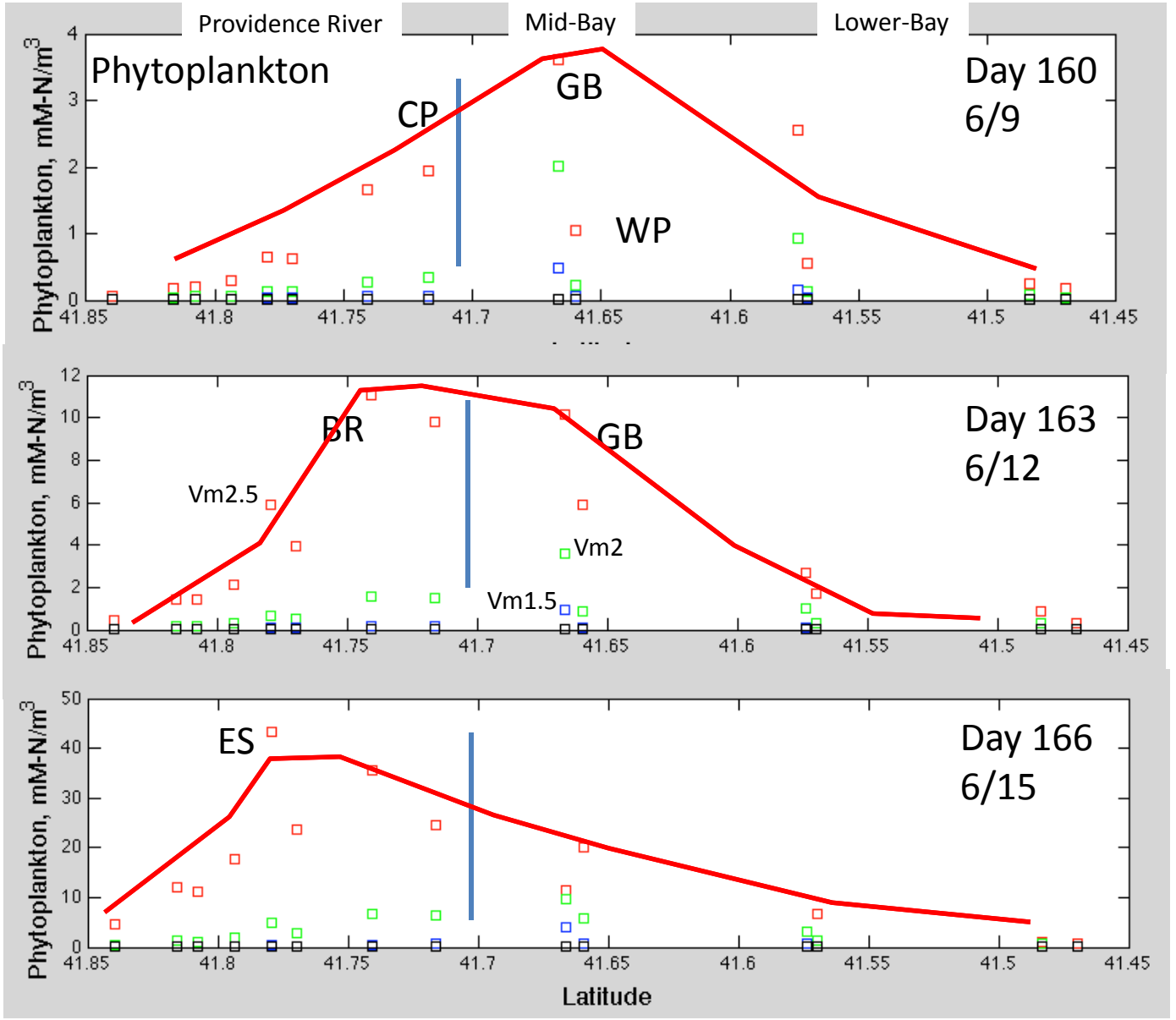
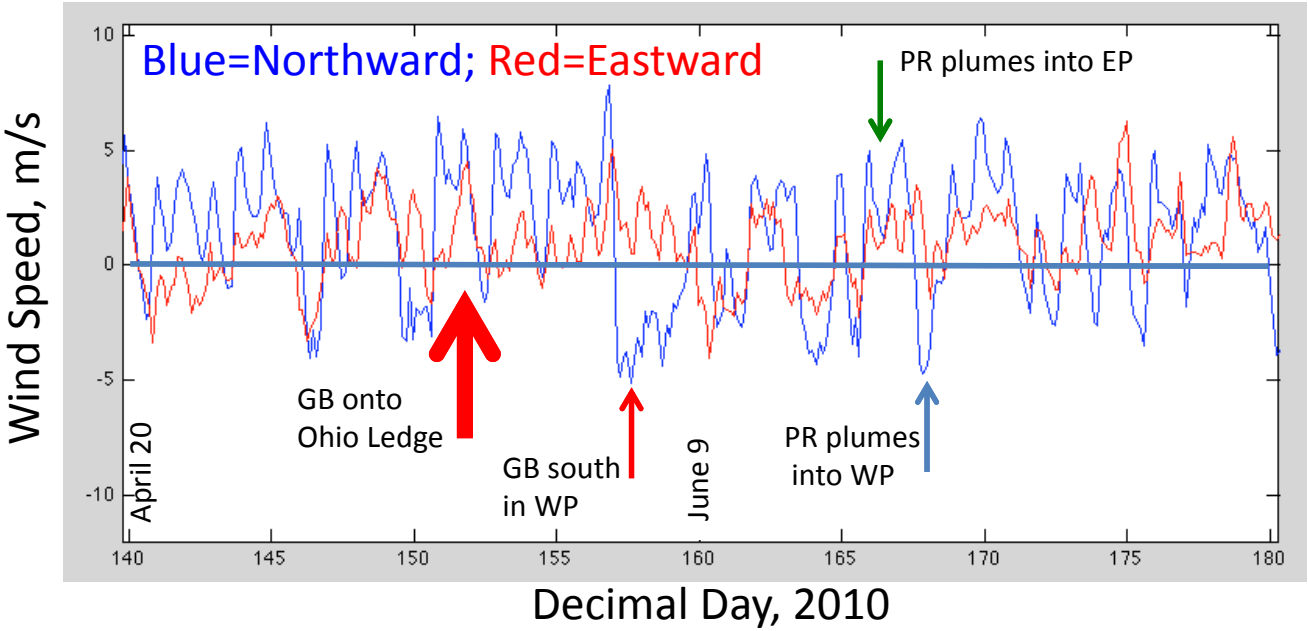


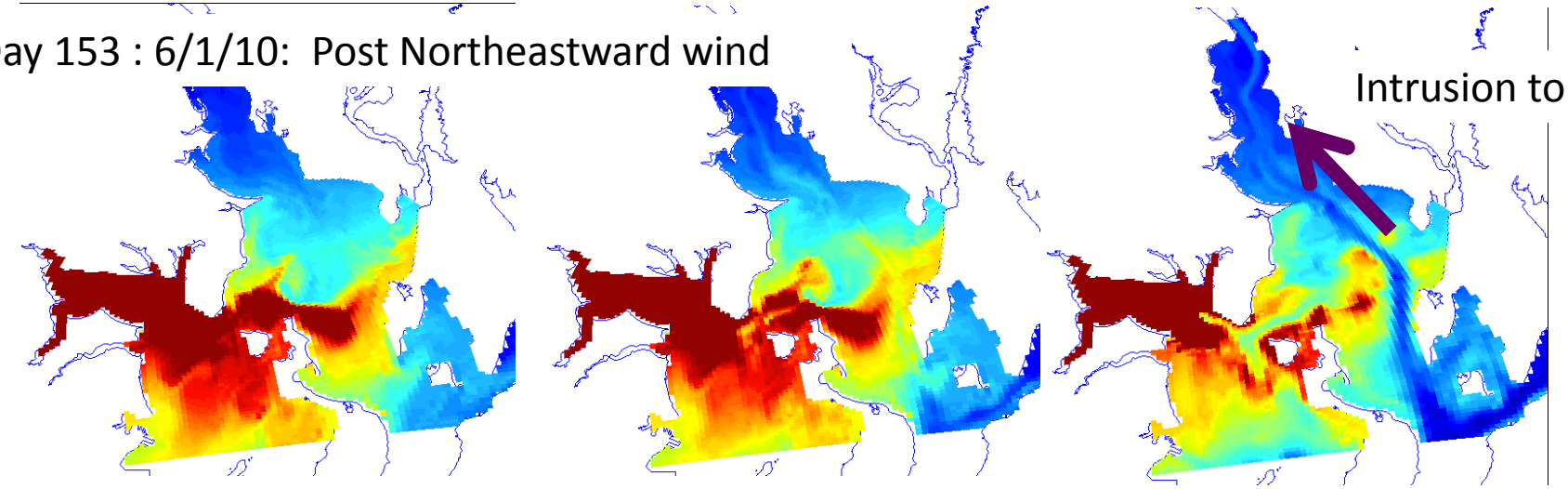
Figure 40. Plots of phytoplankton concentration versus latitude for cases with WWTF levels of 355 mM m^{-3} and highlighting the difference between three N uptake rates (R:Vm2.5, G:Vm2, B:Vm1.5). Start of bloom at mid-latitude. CP=Conimicut Pt., BR=Bullocks Reach, ES=Edgewood Shoal, GB=Greenwich Bay, WP=West Passage at Warwick Neck.

A pesky embayment as a catalyst for baywide eco-processes..

Winds pump GB bloom products to Ohio Ledge



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



a) Surface

b) Mid-water

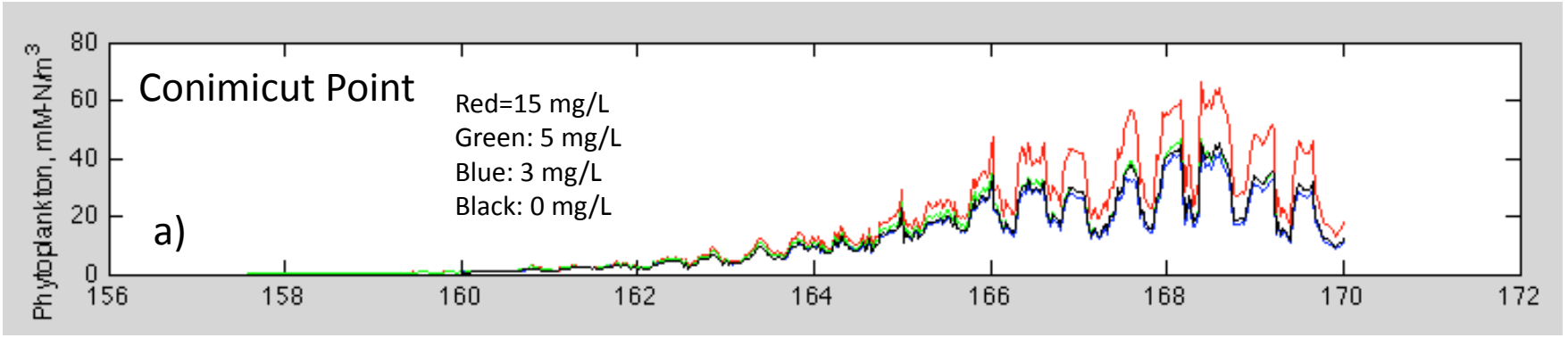
c) Bottom

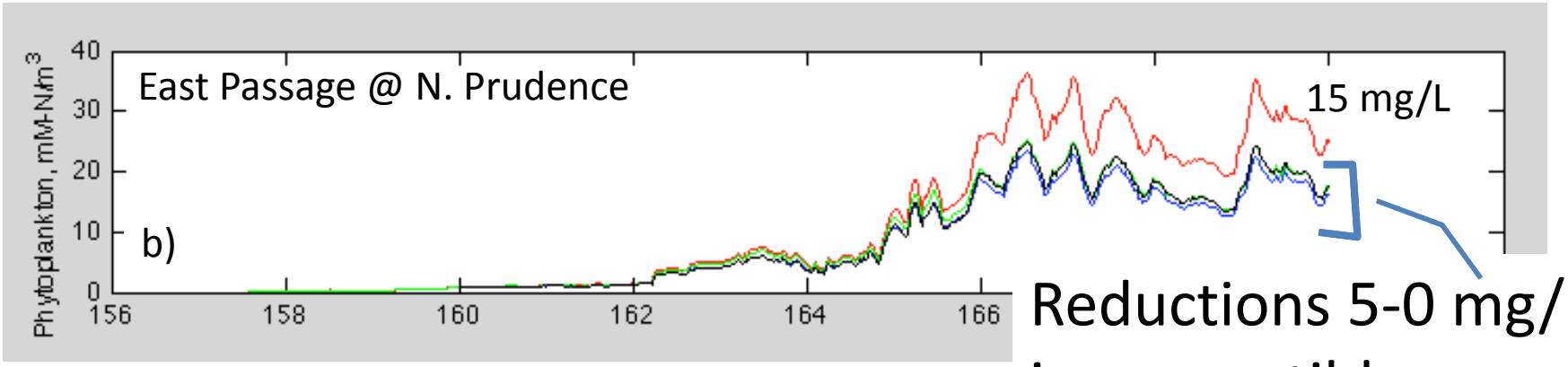
Model Scenario/Process Tests:

1) Test impact of different WWTF release levels.
15 mg/l, 8 mg/l, 5 mg/l, 3 mg/l, 0 mg/l

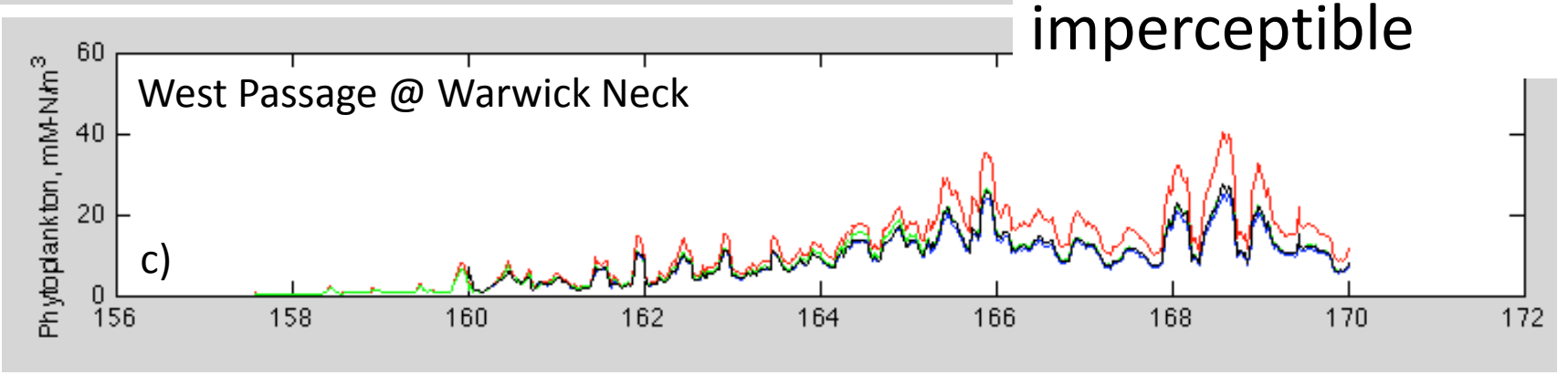
2) Is Greenwich Bay a bad gallbladder, influencing bloom dynamics throughout entire system?

Phytoplankton Levels vs. Time:
Comparing mid-Bay levels for range of WWTF release levels





Reductions 5-0 mg/L imperceptible



Summary

Data + Numerical Models + Lab Models: Stable gyres in chronic hypoxic regions (embayments)

Tracers/dyes show hotspots have periods of >5 day retention bottom water, rapid flush

Dye (N as conservative tracer) show transport pathways for sources.
- southeastern dyes move well north
- 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*

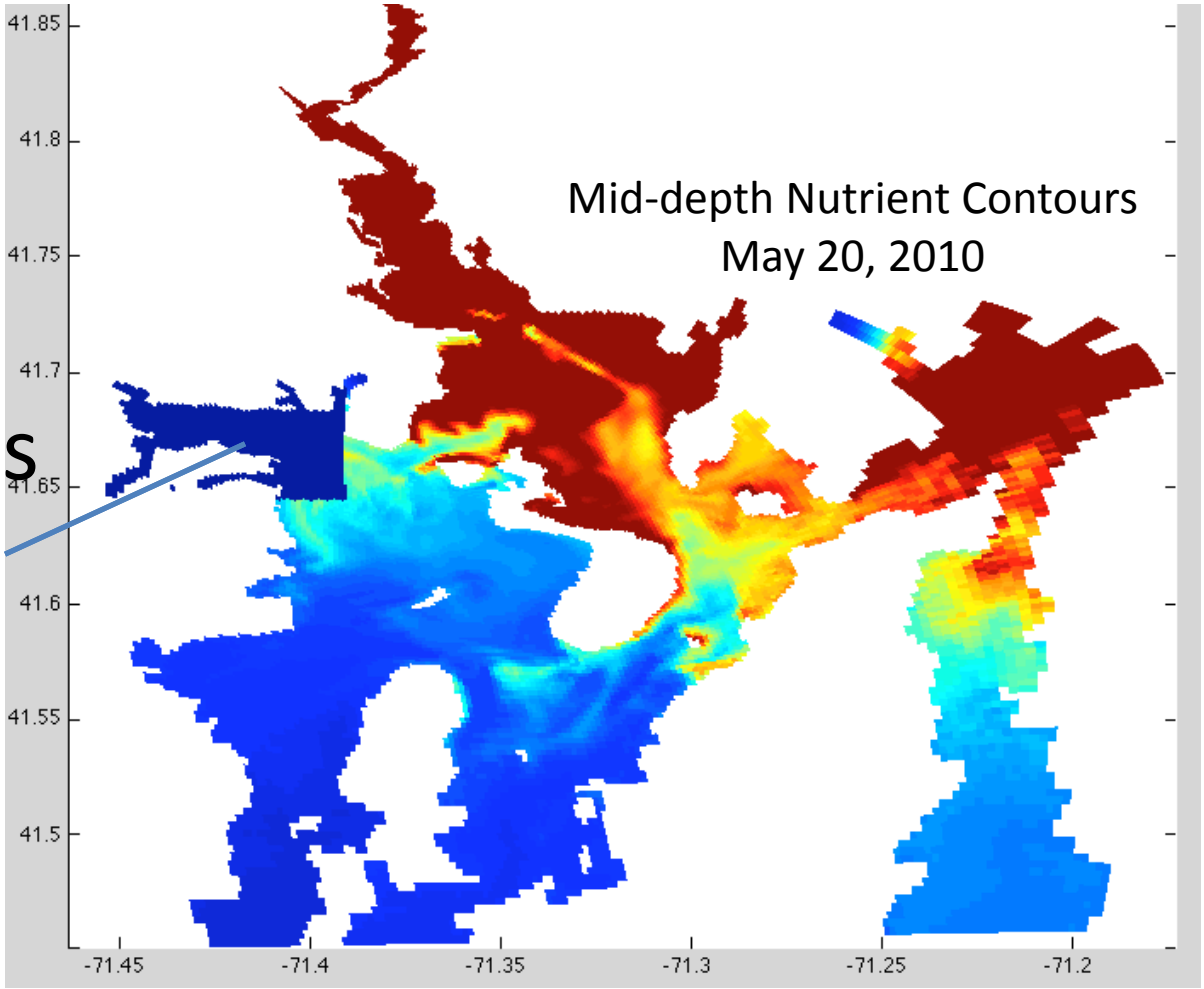
Timing of Ohio Ledge export to Providence River vs. wind events & zooplankton growth can produce either muted or enhanced PR/SR blooms.

ROMS Eco-process tests: Weighing bloom magnitude vs :

1) nutrient reductions. 2) physical drivers. **3) hotspots**

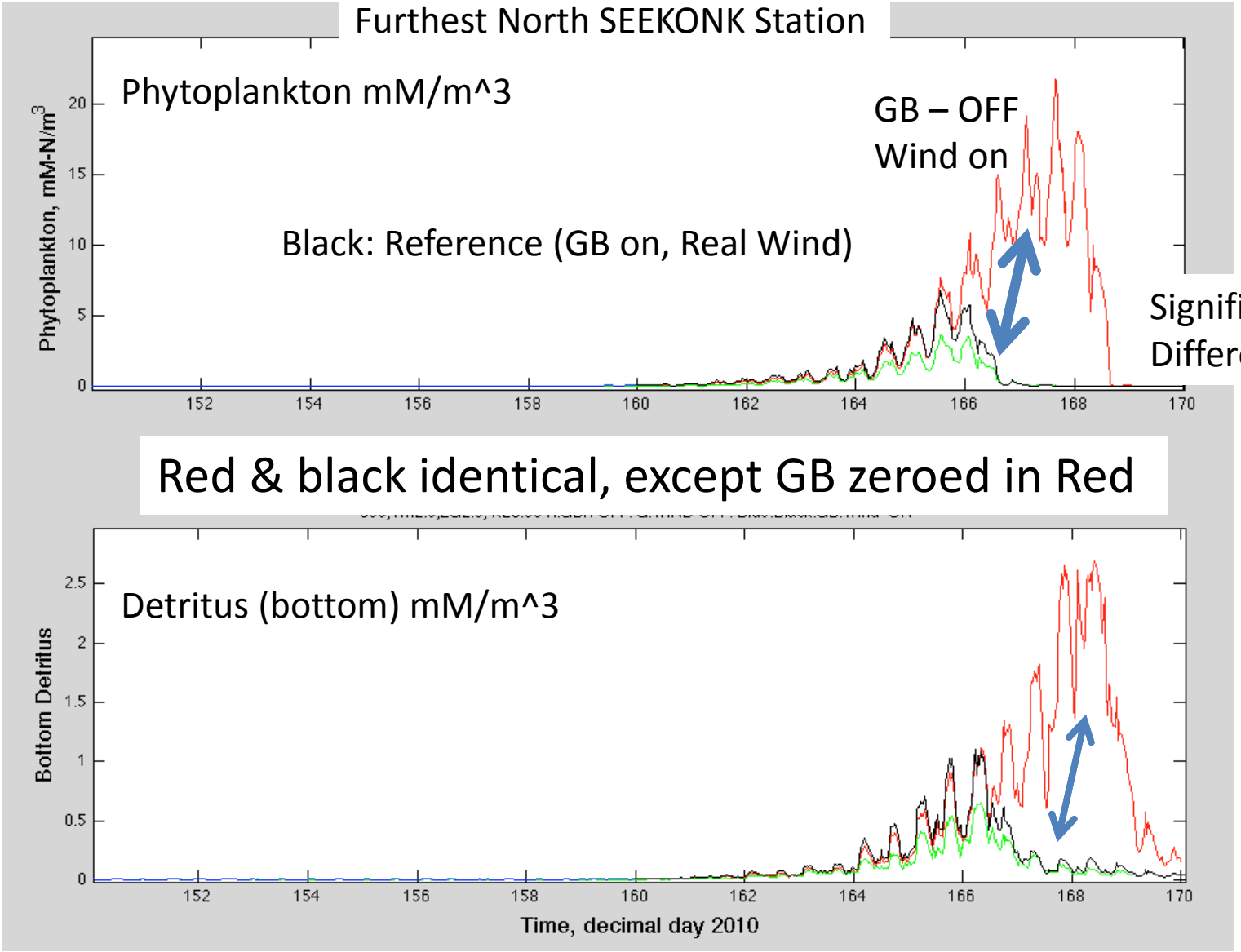
Greenwich Bay bloom products independent of parameter choices
If cut it out, does it influence NPZD products baywide?

GB nutrients set to 0

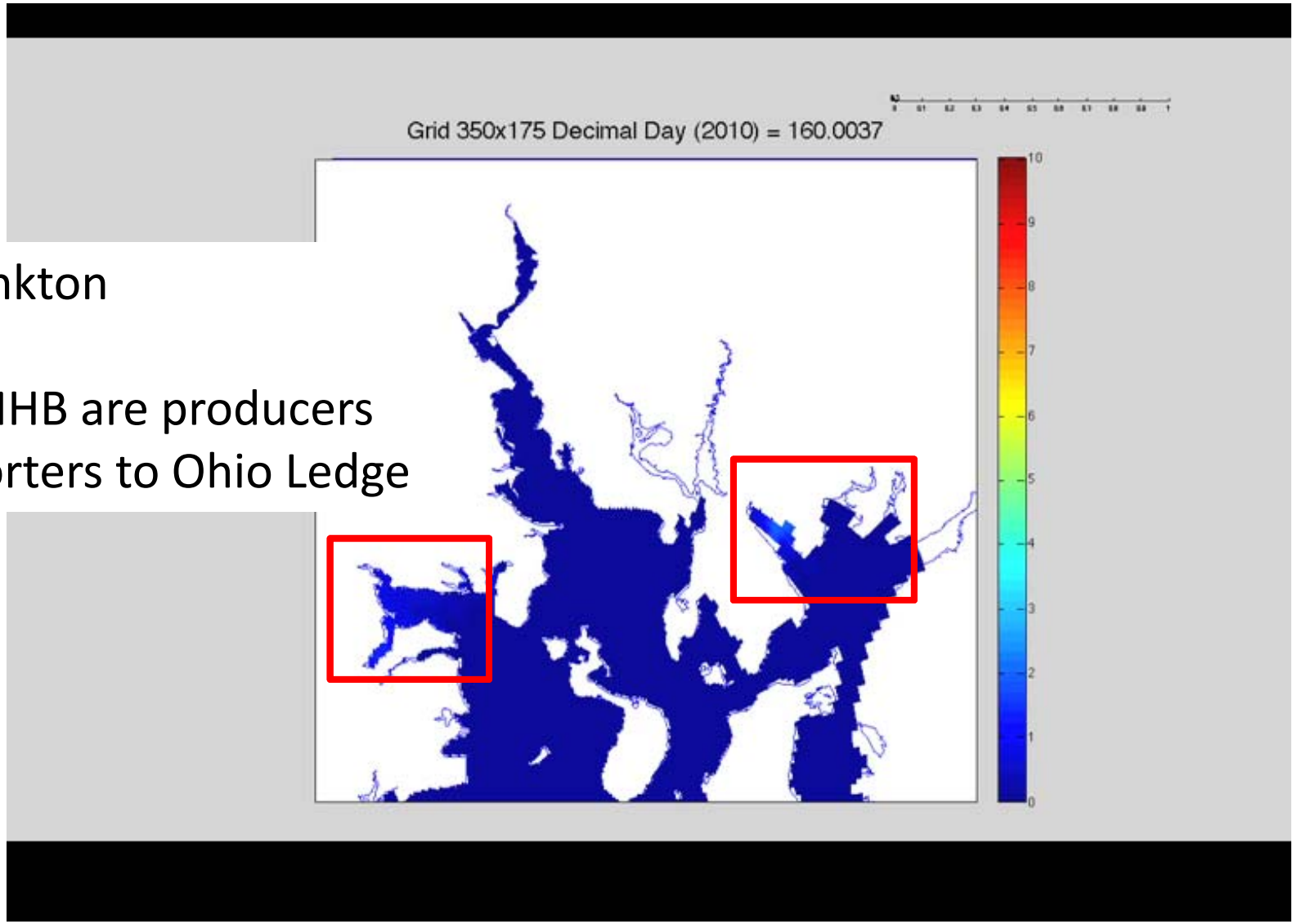


Greenwich Bay off = Big Effect on Prov./ Seekonk Blooms.

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



Surface Zooplankton: **without** Greenwich Bay zeroed



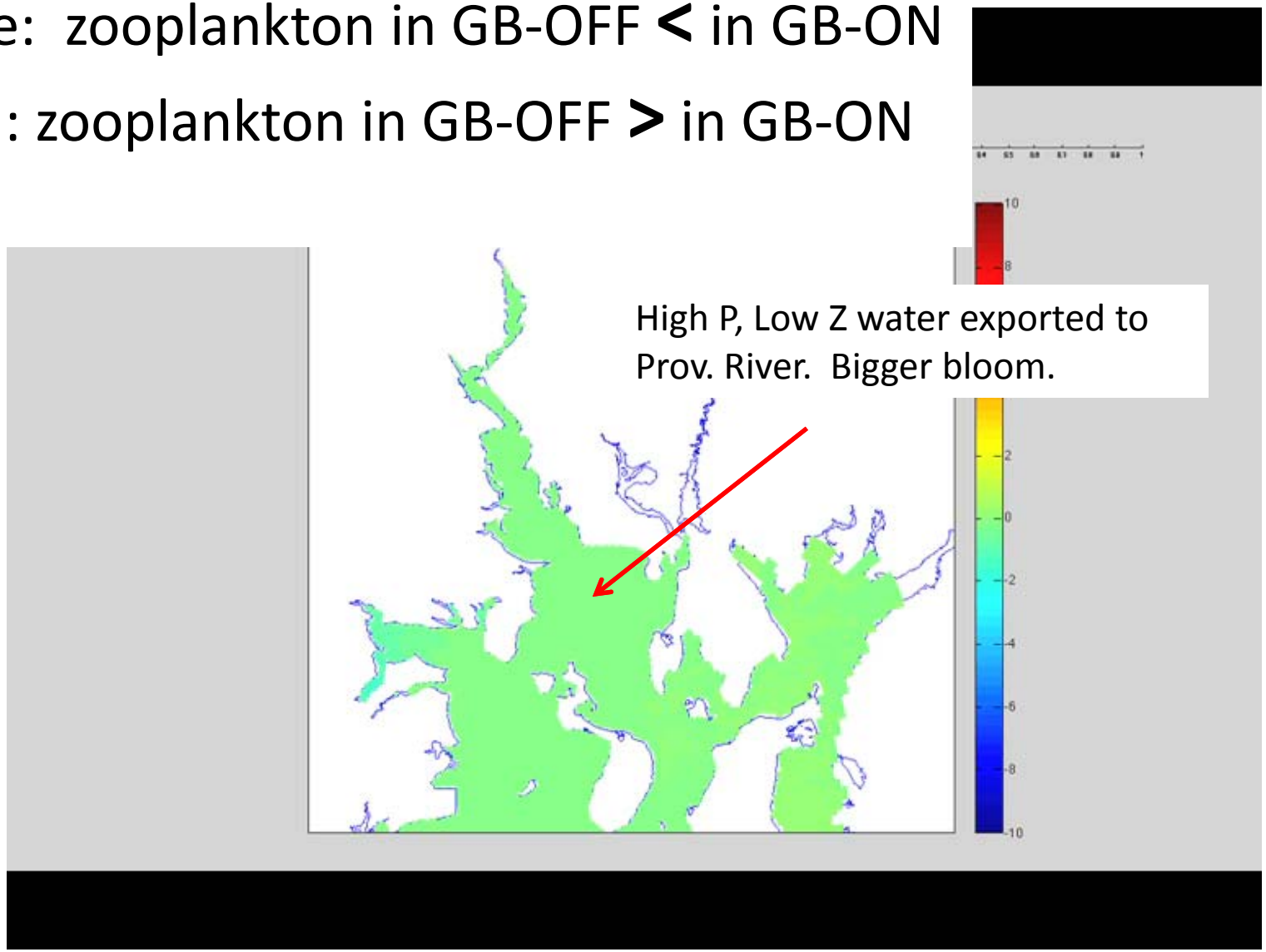
Zooplankton

GB & MHB are producers
& exporters to Ohio Ledge

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

Blue: zooplankton in GB-OFF **<** in GB-ON

Red: zooplankton in GB-OFF **>** in GB-ON



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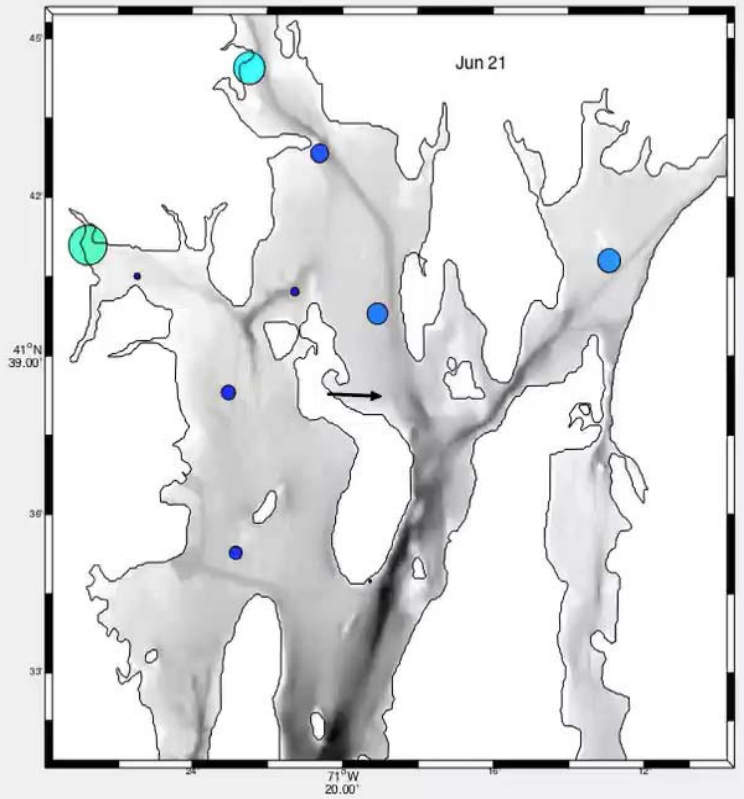
Summer 2012 Chlorophyll Buoy Data

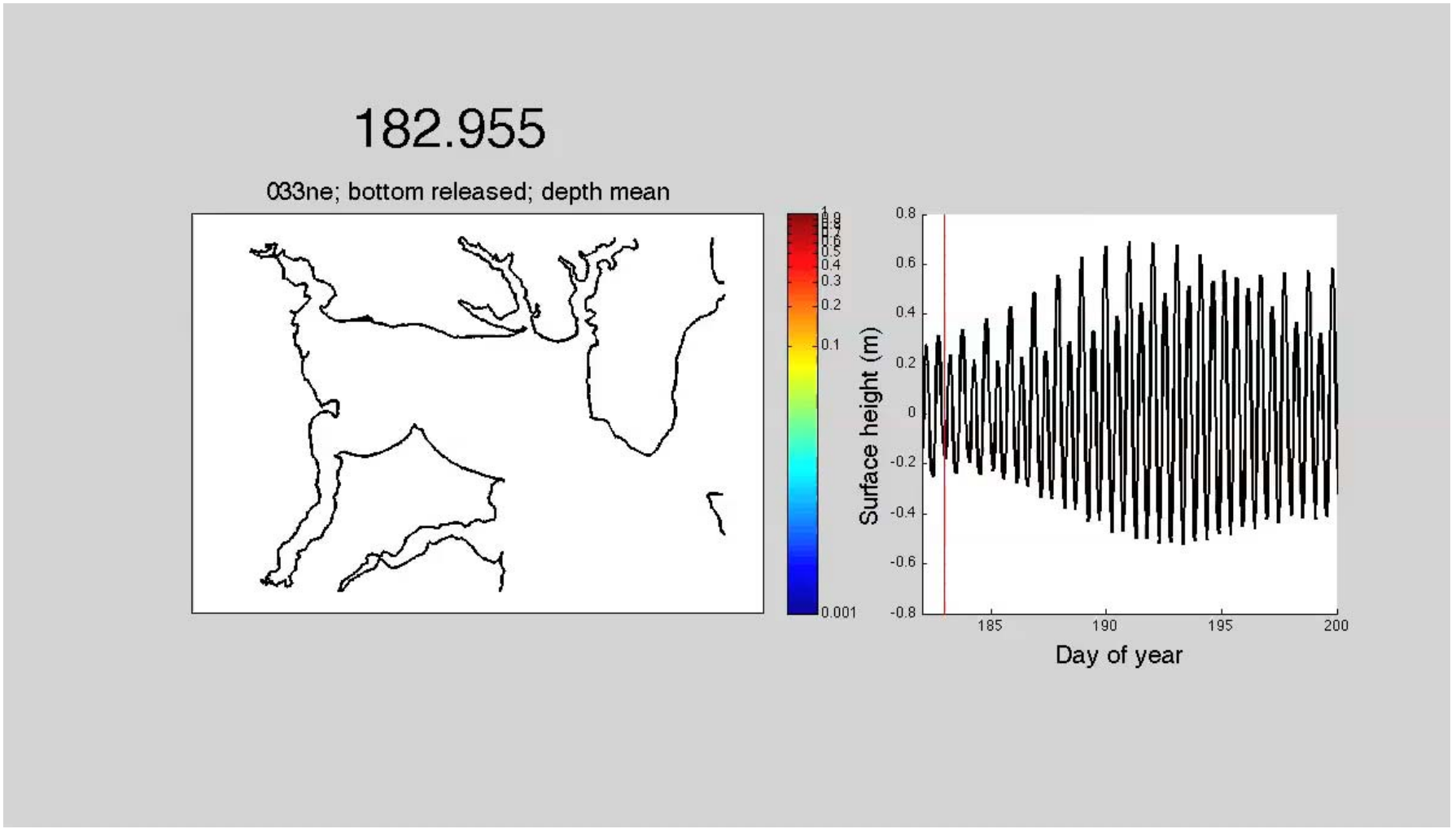


Available flow data: 4 months Summer 2012

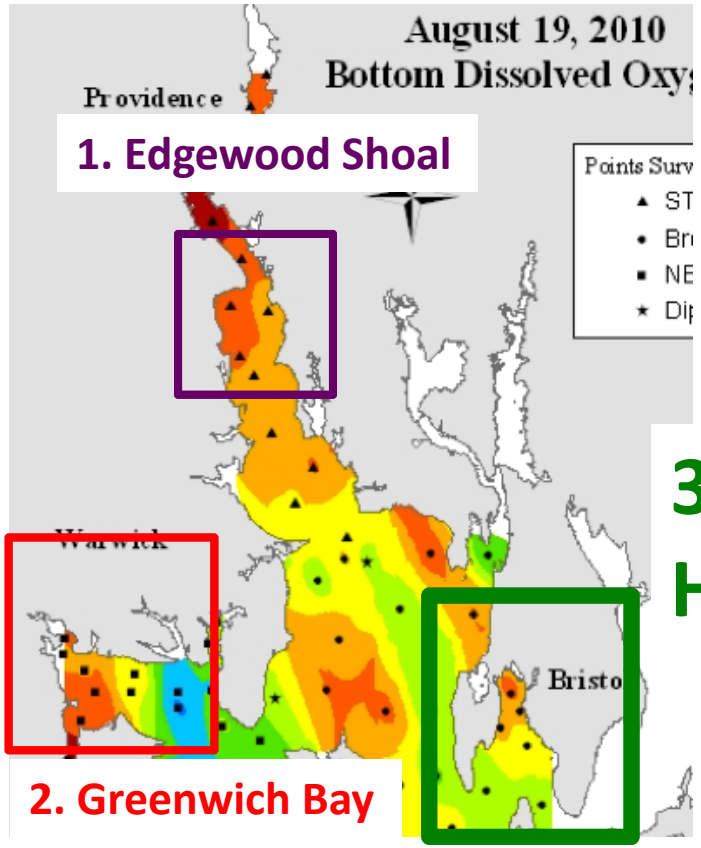
Student K. Rosa: Combining buoy data, flow data & ROMS (w/ NPZD)

Role of embayments in ecosystem processes.

Northward bio-chemical fluxes & bloom dynamics



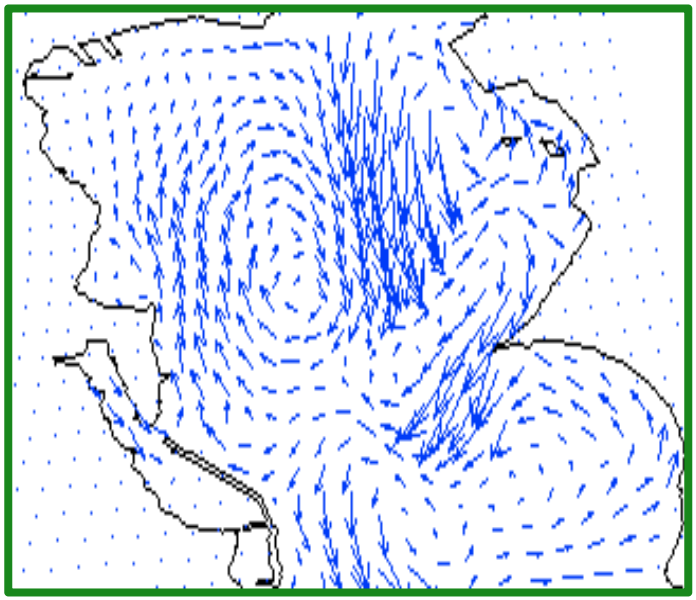
Same 2010 Conditions But:
Imposed North-ward Blowing Wind Event

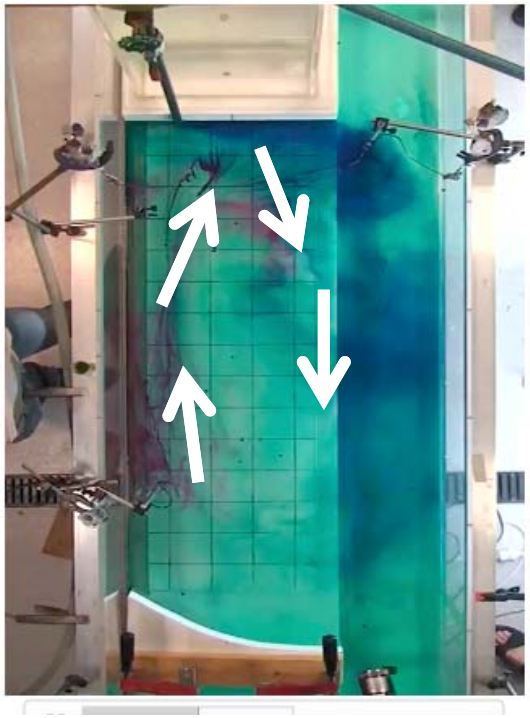


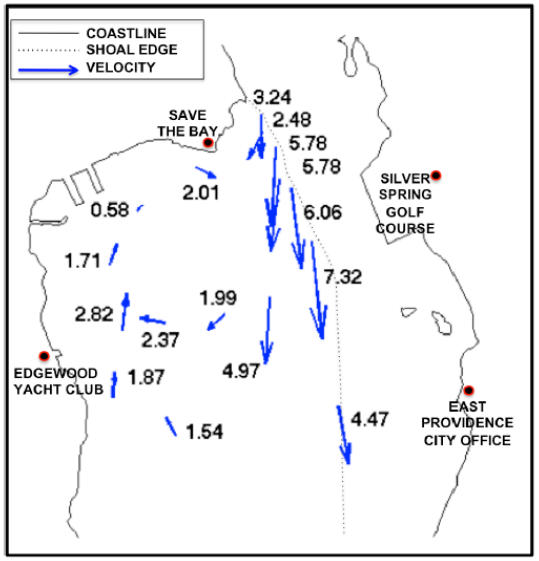
Prime areas of chronic low oxygen have retention gyres:

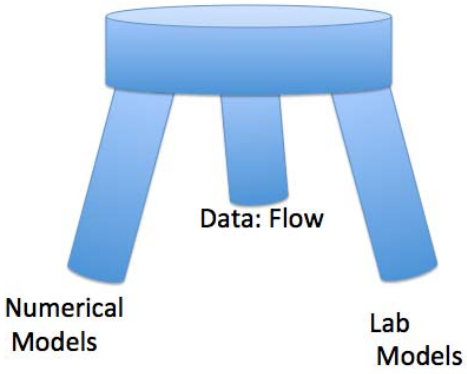
Based on Data & Models

Numerical & LAB & Data: Chronic Gyre on Shoal









But…..

Lab & Data agree on vertical flow structure

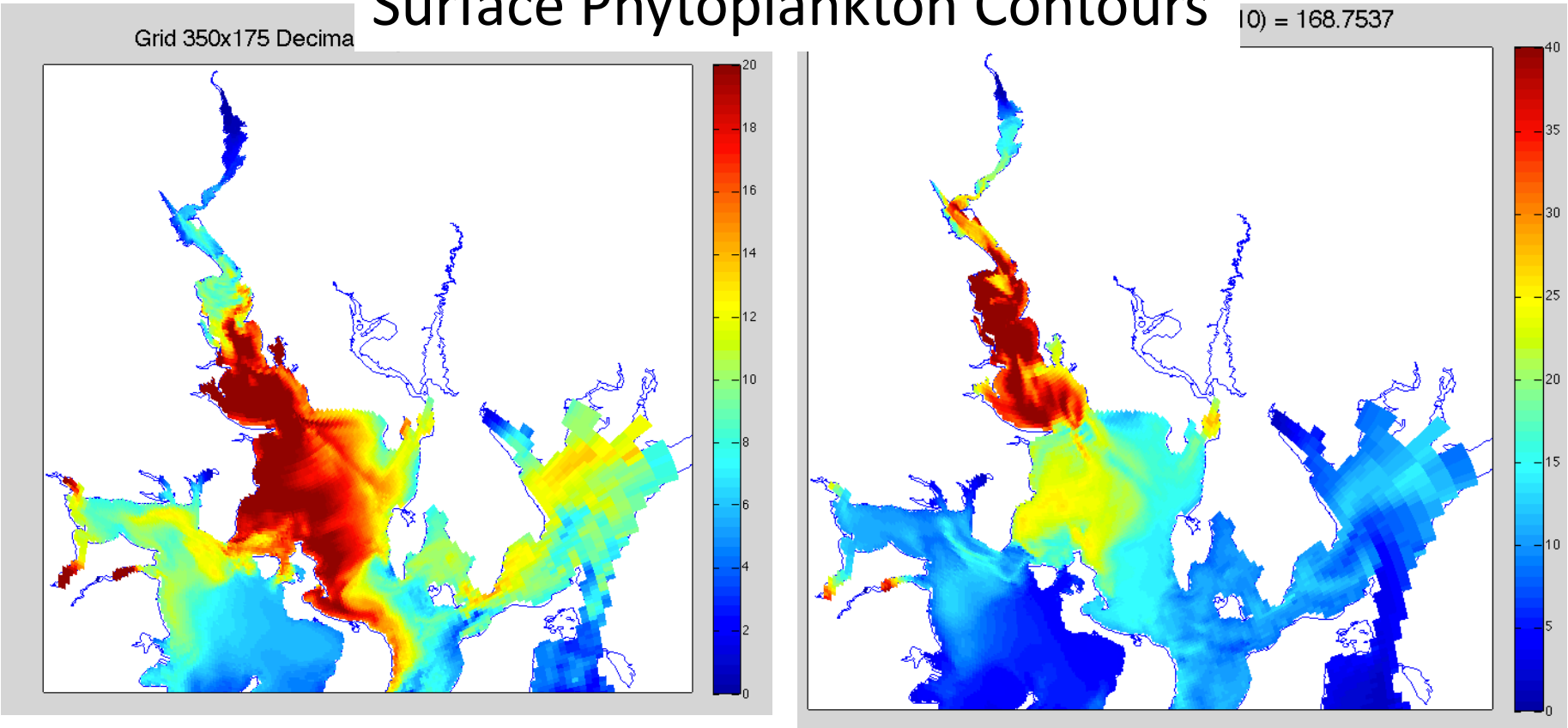
Numerical model misses it

Stage 1: GB start (*spill to mid-Bay*)

Stage 2: Mid-bay bloom (*spill northward*)

Stage 3: Bloom progresses rapidly northward

Surface Phytoplankton Contours



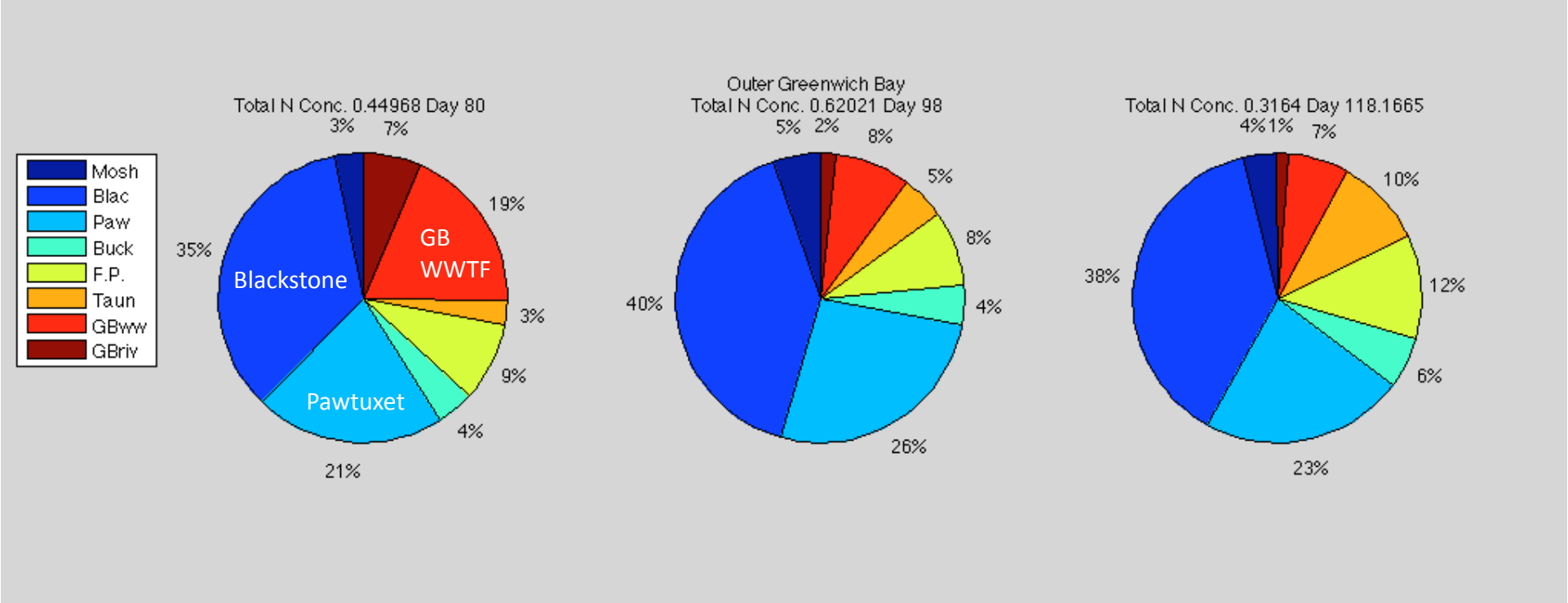
2010 Flood: Greenwich Bay Dye Accumulations

%'s change with runoff, wind & other forcings

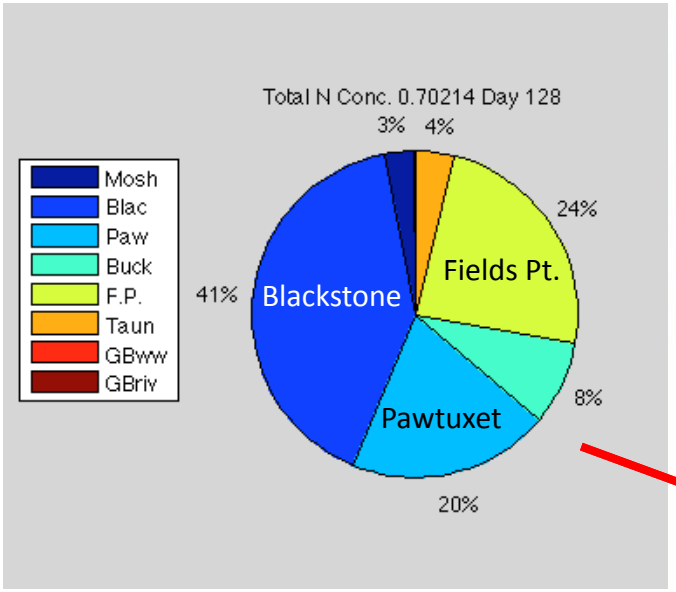
Pre-Flood

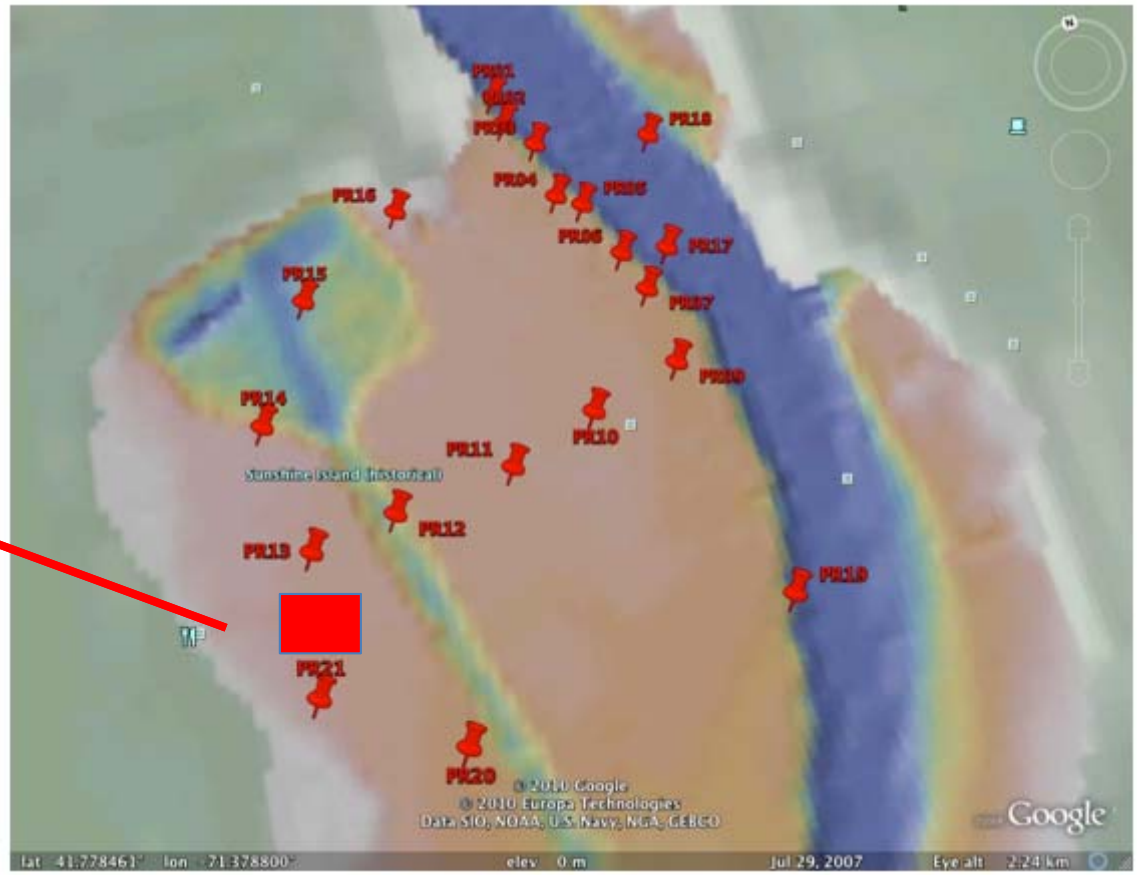
10 Days Post Flood

30 Days Post Flood



Which Sources Contribute to Nutrient Levels on Edgewood Shoal?

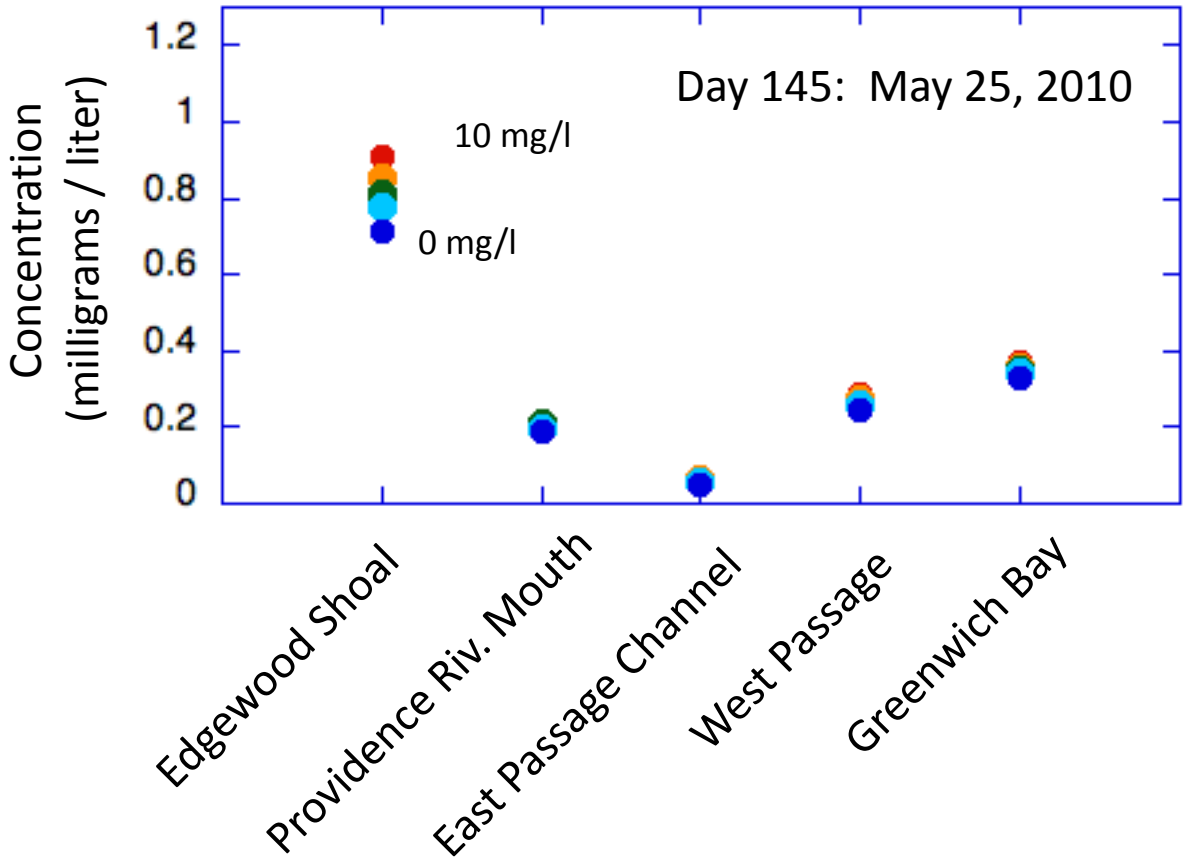


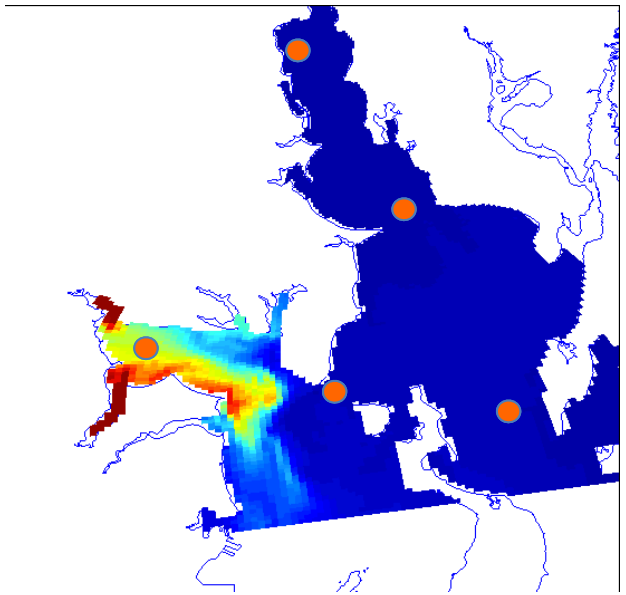


Convert all dyes to total nitrogen:

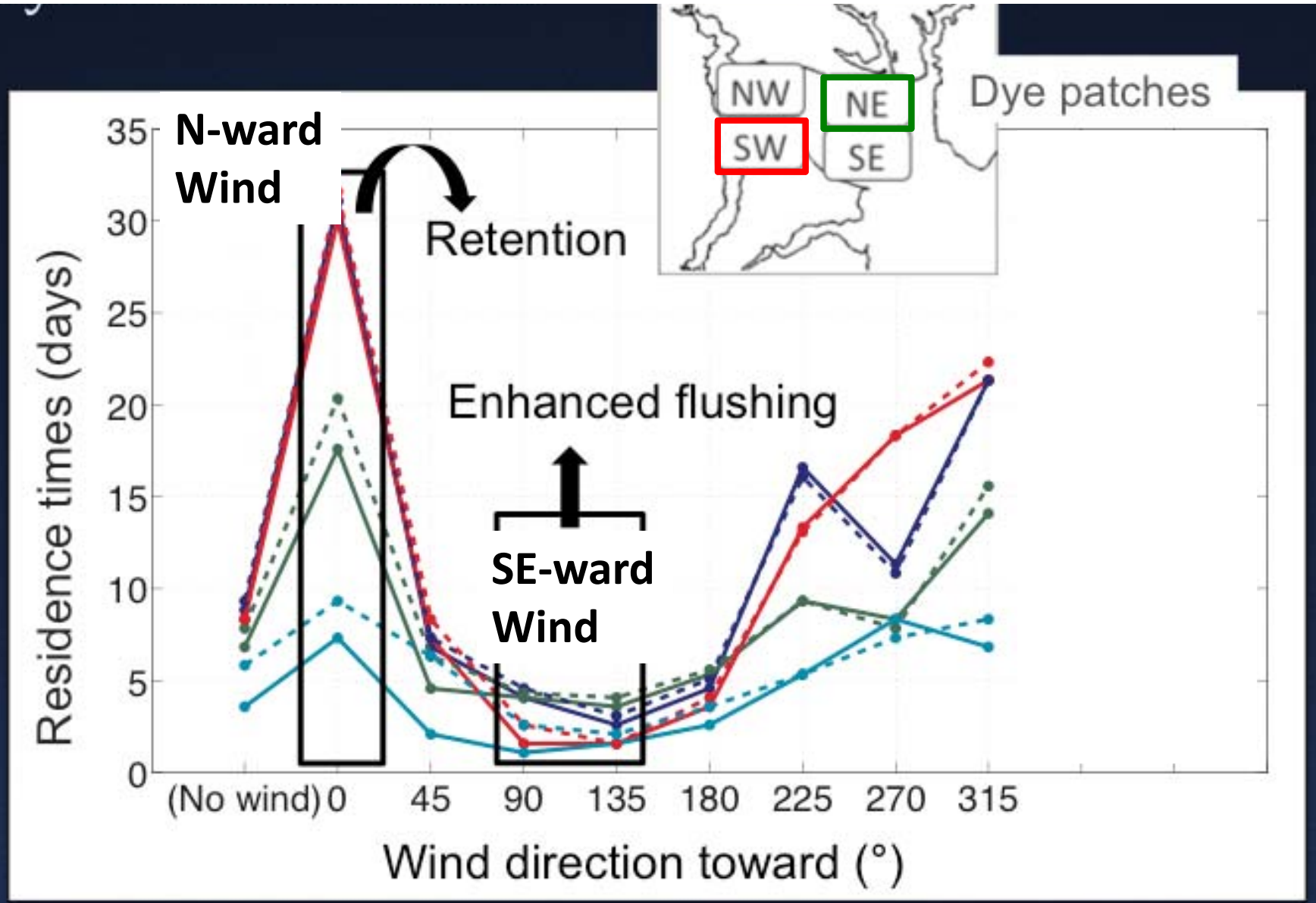
1. Which Nitrogen sources most important in hypoxic areas?
2. Impact of WWTF nitrogen reductions (if conservative)?

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

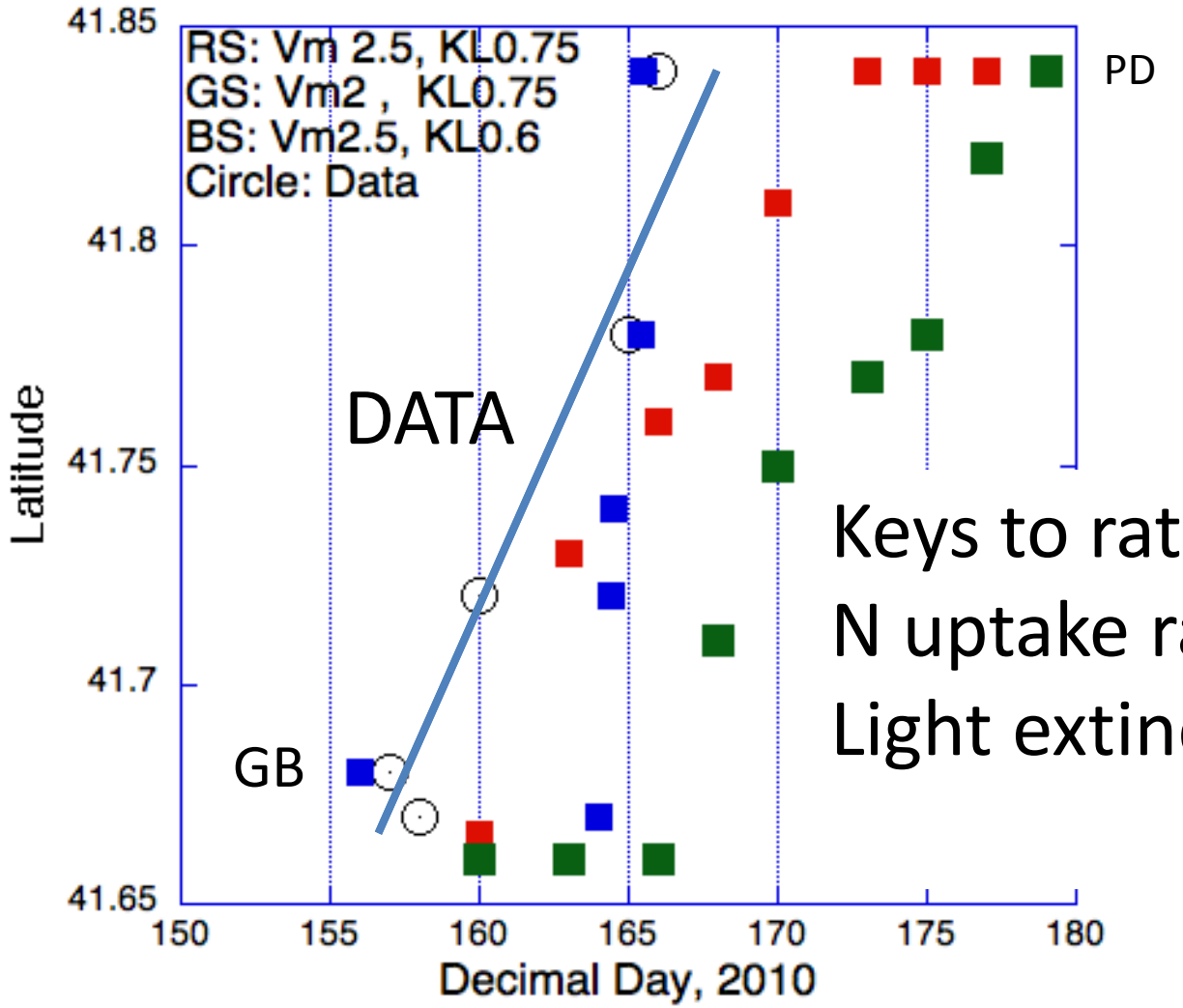




Greenwich Bay: Idealized wind: Dye residence times



Bloom Occurrence Latitude vs. Time (June 2010). Data vs. Model



Keys to rate:

N uptake rate in P

Light extinct.

Pick June 2010 Bay-wide bloom event to start ROMS NPZD