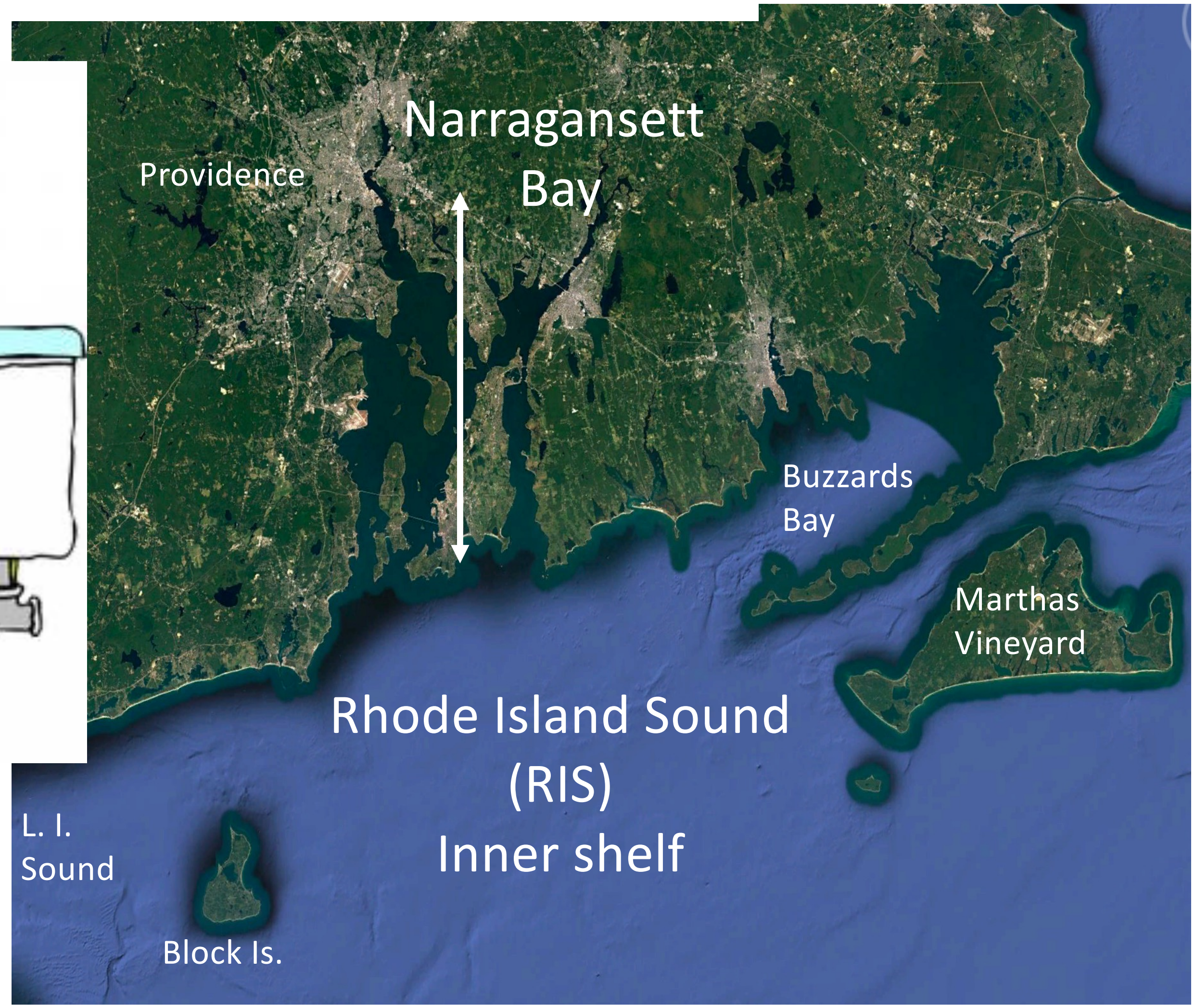
One if by land, two if by sea:

Reassessing the role of watershed vs offshore nitrogen sources for Narragansett Bay productivity

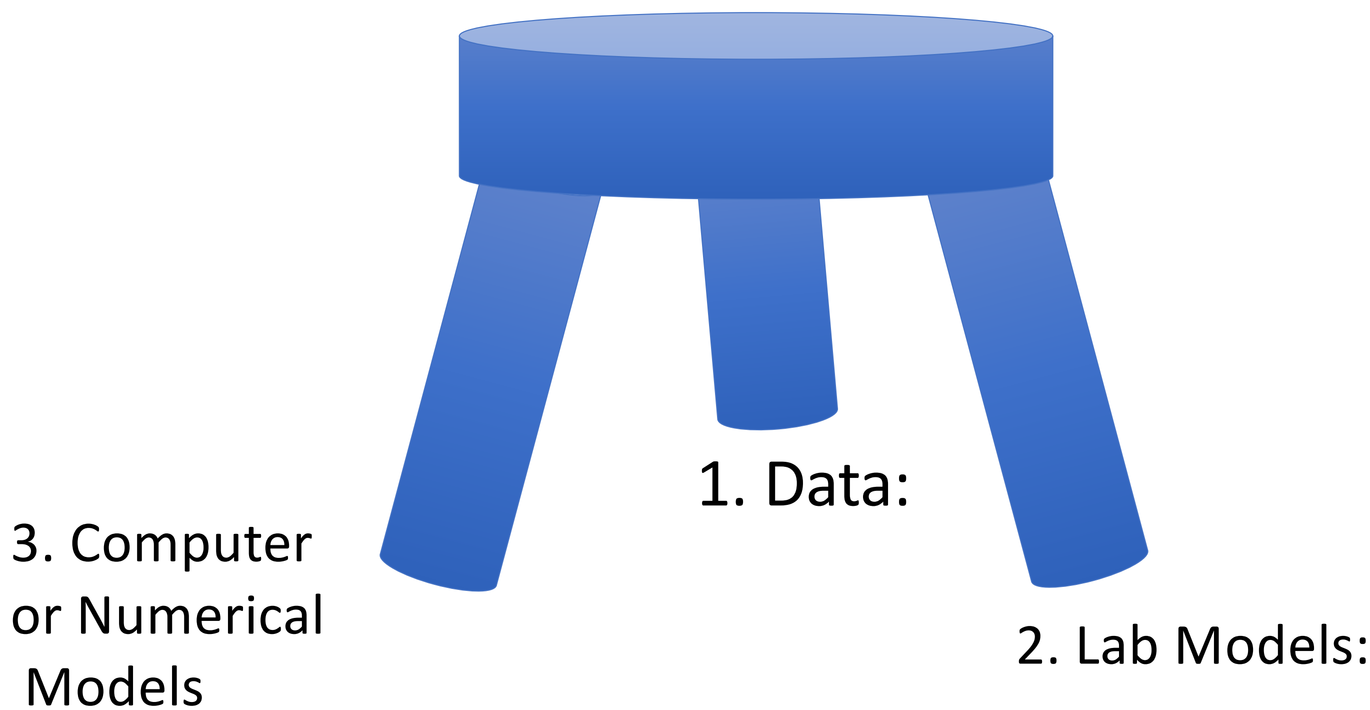
Chris Kincaid
Professor of Oceanography,
URI-Graduate School of Oceanography

January 22, 2024

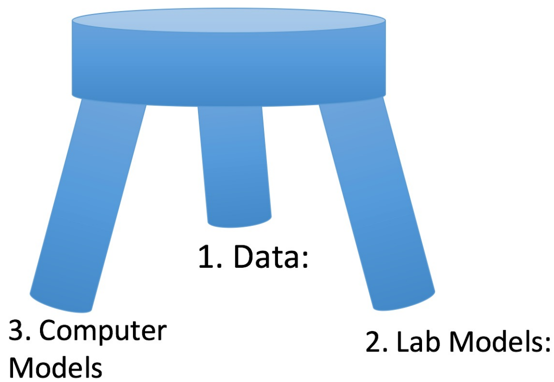
Coastal Plumbing of Rhode Island Coastal Waters

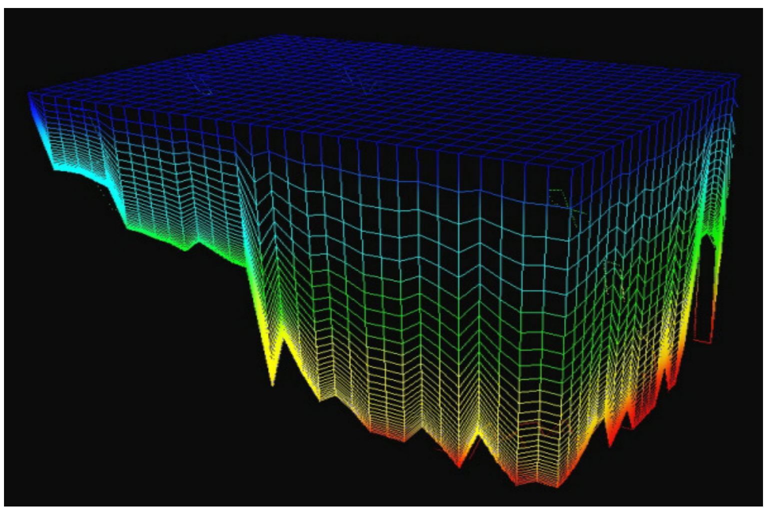


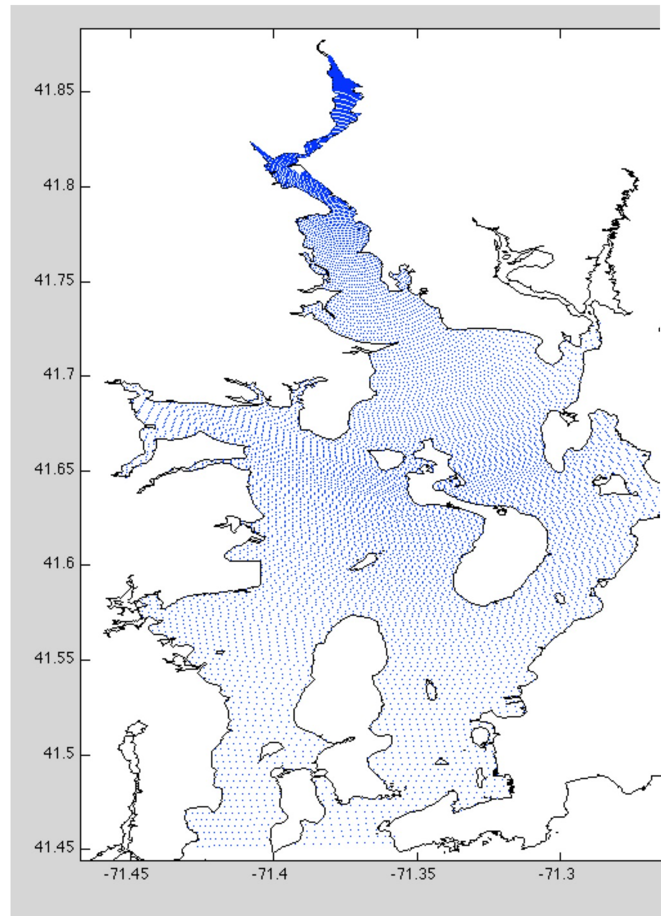
Building better management tool models: The 3-legged stool of Coastal Ocean Physics



Long History of Narragansett Bay Computer Models: ROMS







Points:

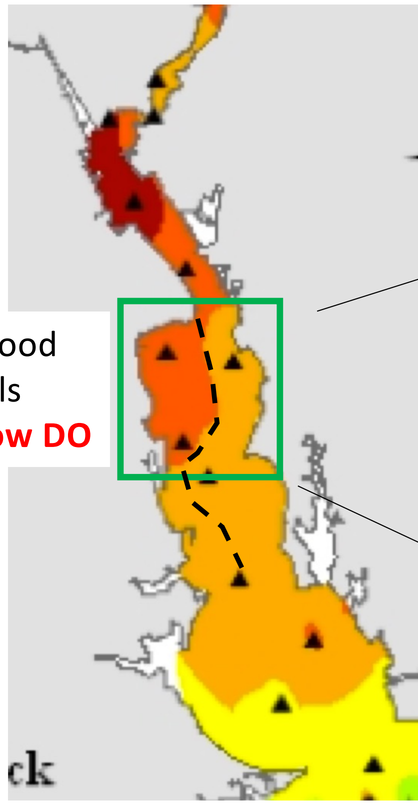
1) A "Discretized Bay"

2) Bay divided into
   1 million "nodes"
   or grid boxes

3) Math equations for
   flow
   temp/salt
   chem. & bio
   solved on the grid.

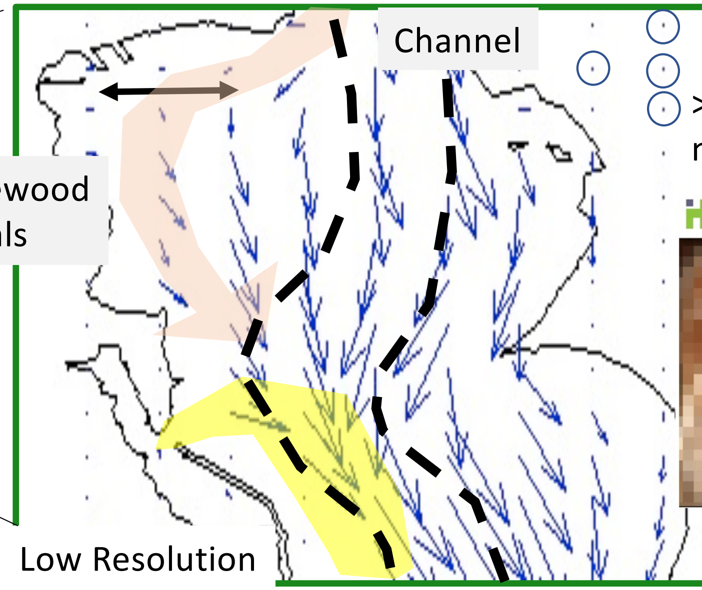
Step through history of data-model validations/advances.

Edgewood Shoals Low DO & *well-flushed?*



Edgewood
Shoals
Red=low DO

ROMS 1: ~ 2005



Channel

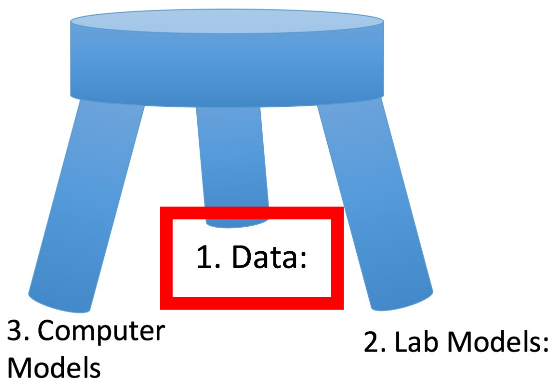
Edgewood
Shoals

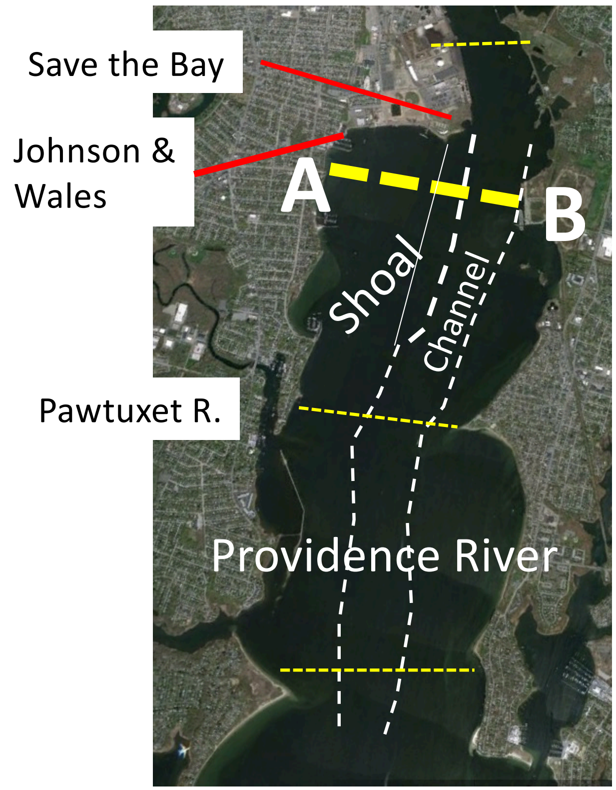
Low Resolution

>200 m
node spacing

“All models are wrong, some are useful”:

Is ROMS #1 useful? Only know by other stool legs.





Strapped to small boat.

Drive repeat lines for tide cycle

16 hours on a small boat......

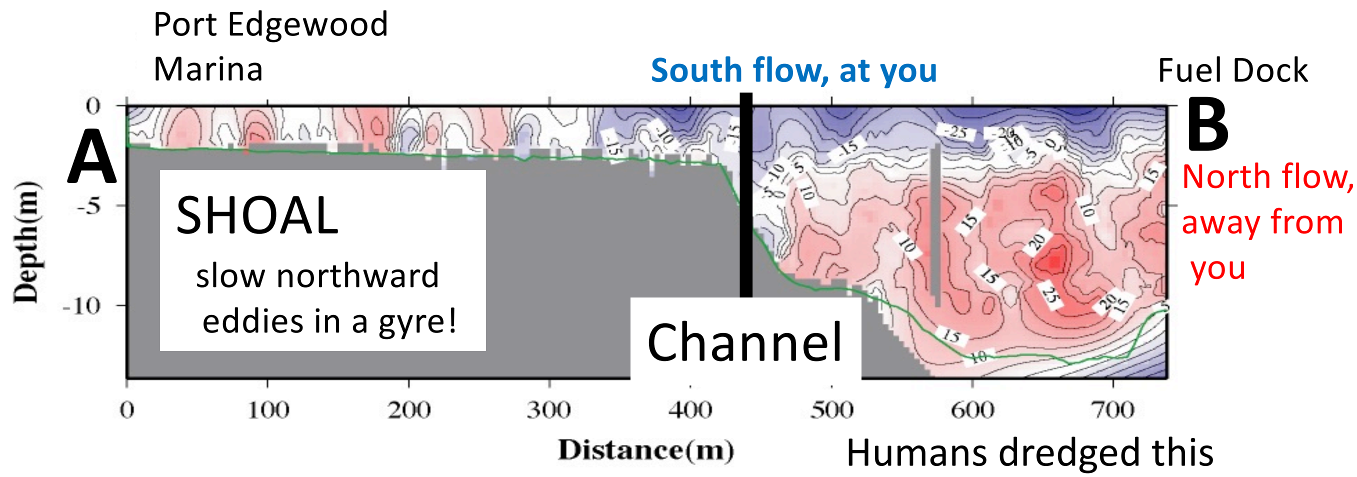
Check out flow thru slice A to B

All models are wrong, some are useful.

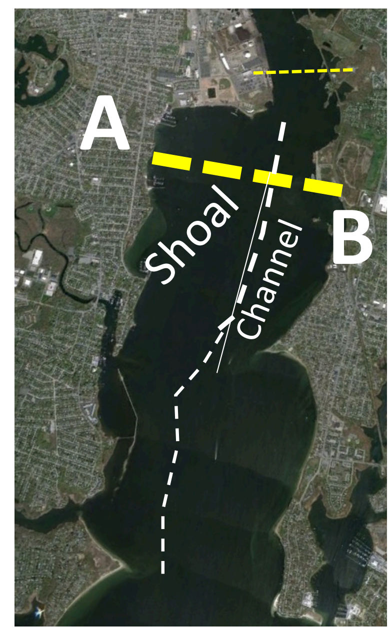
Does ROMS #1 simulate real flows?

Is ROMS #1 useful?

Early 2000's

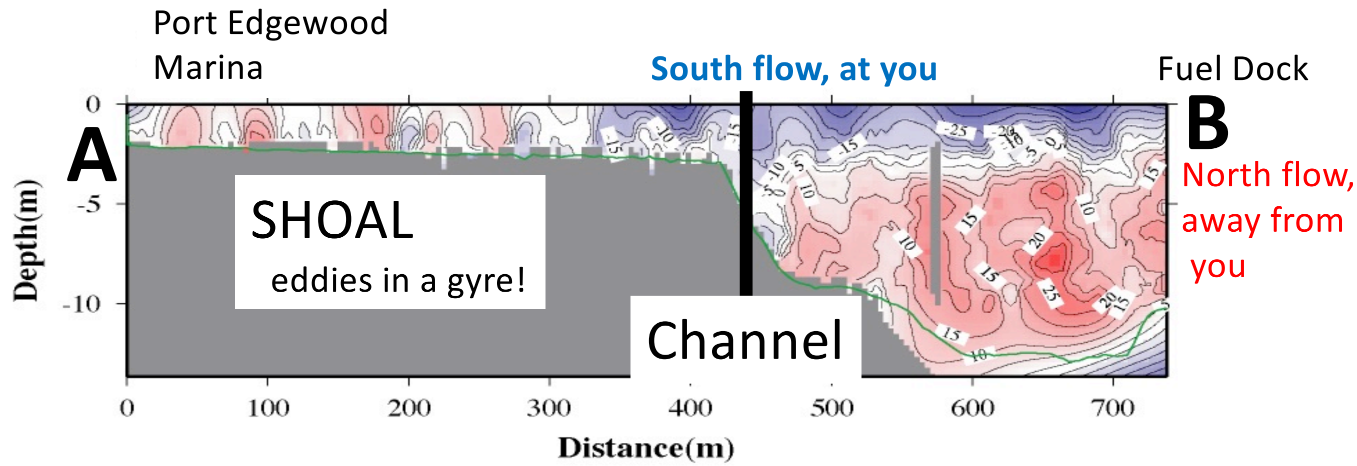


Providence River



Does ROMS #1 simulate real flows?

Is ROMS #1 useful?

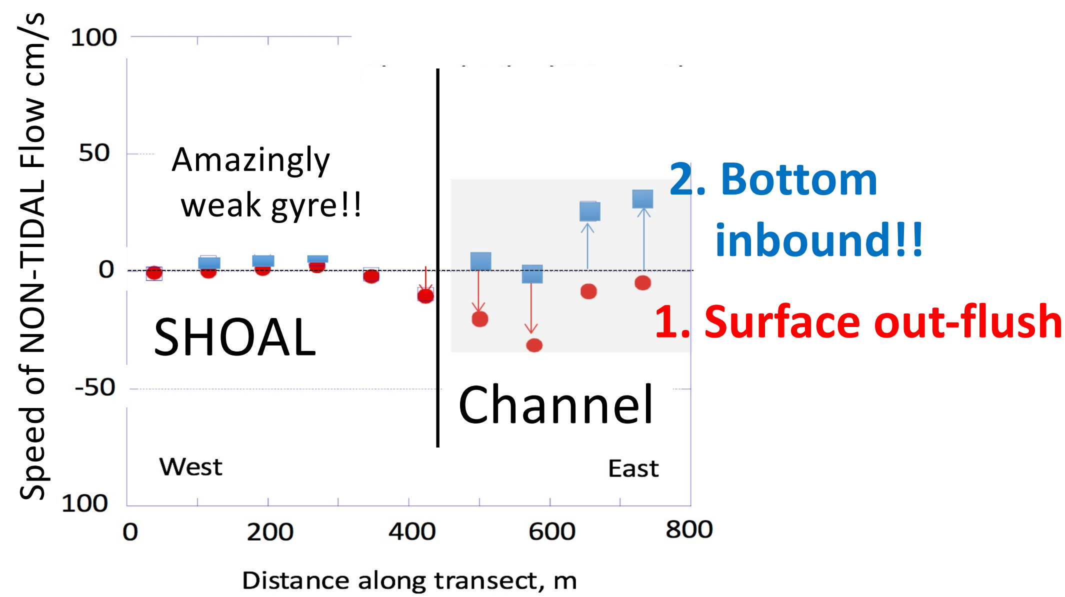


Take home points: Underway ADCP

1. Outflow jet, channel edge
2. Deep channel ALWAYS IN!
3. Shoal: Sluggish gyre, lotsa eddies

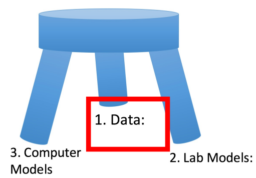
Channel 10-20x faster flow

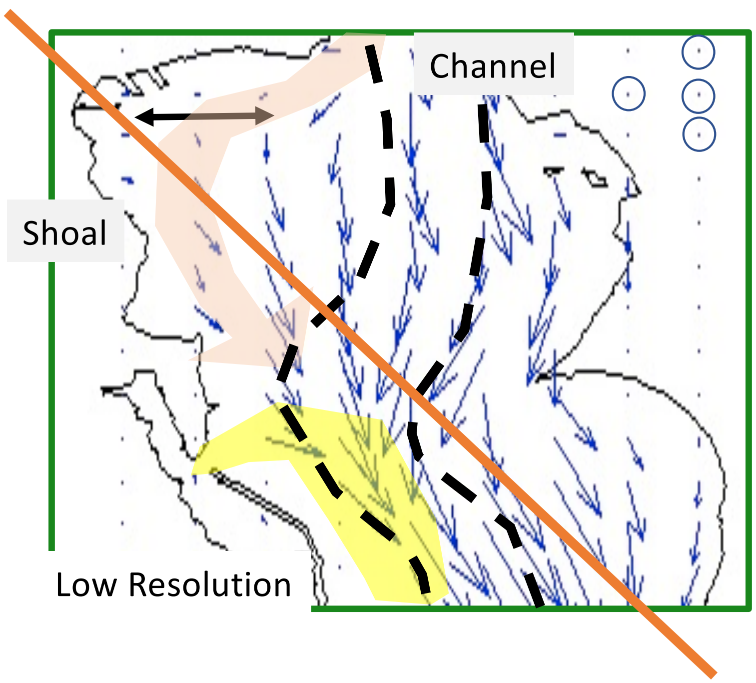
Implications for flushing



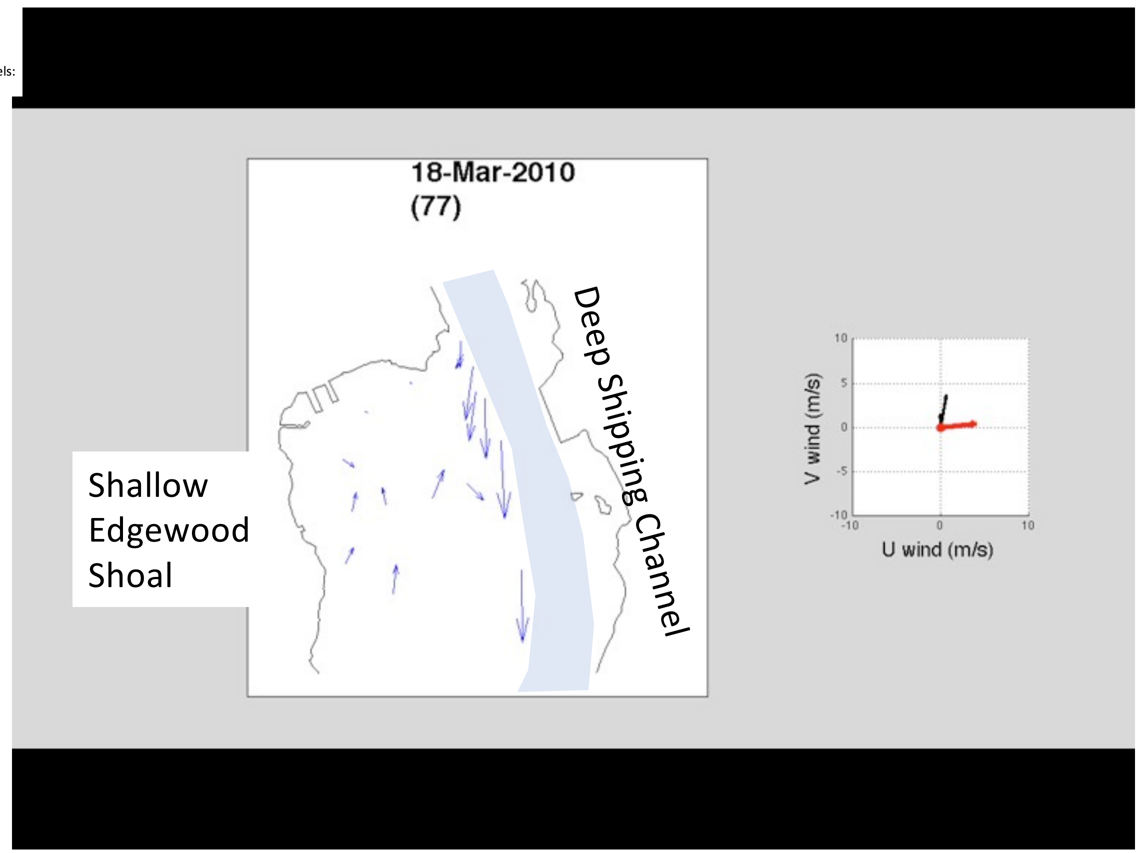
Does ROMS #1 simulate real flows?

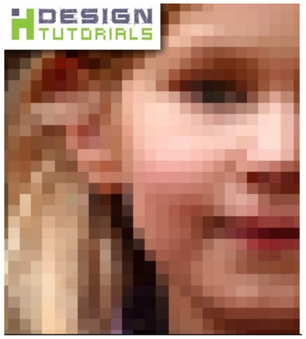
Is ROMS #1 useful?





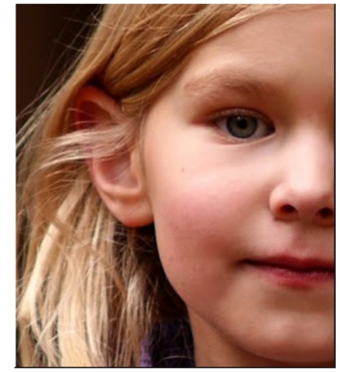
Moored Current Meters: De-tided data



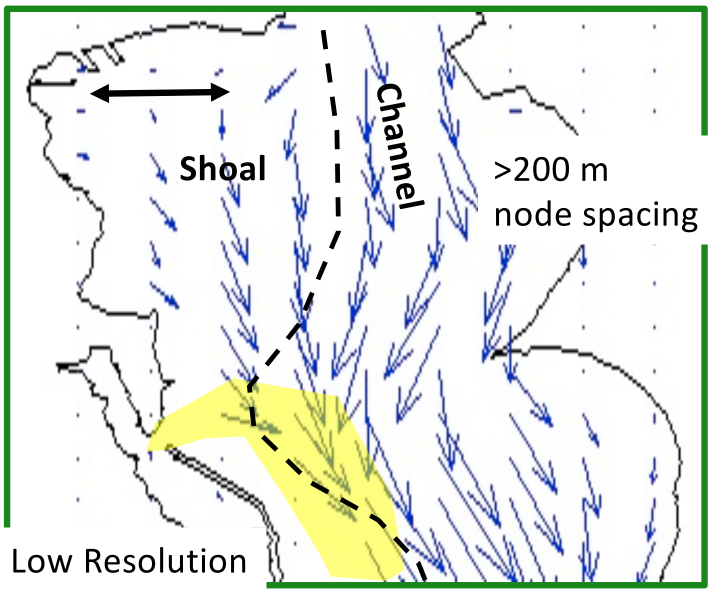


Camera with more pixels, clearer image.

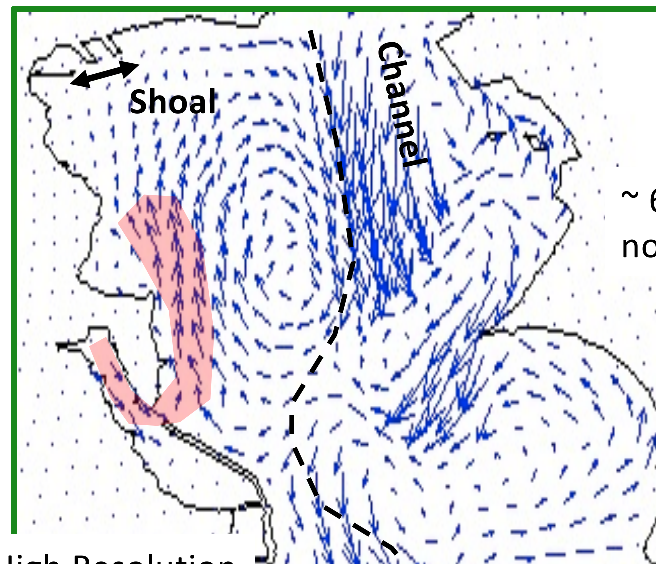
Bay ROMS #2 *more pixels*, better solutions

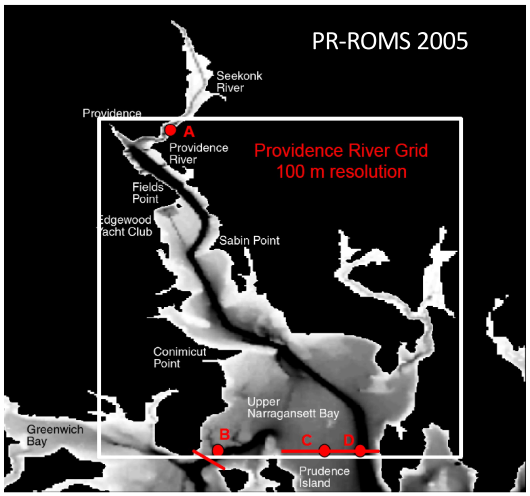


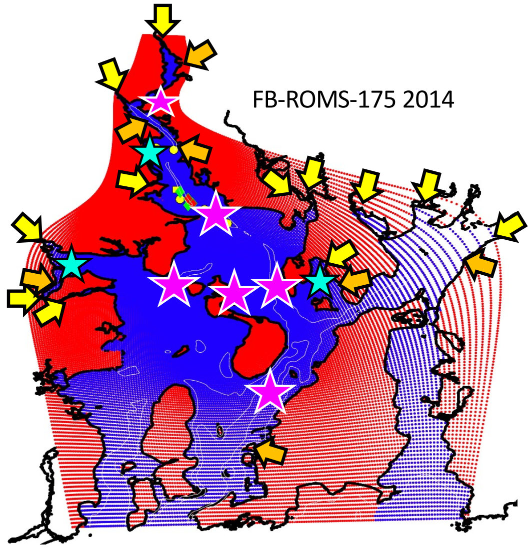
ROMS 1: ~ 2005



ROMS 2: 2010-2019







Bay ROMS 1 (~2000)

Simulates water levels nicely

Misses all key sub-tidal processes:
- flushing
- chemical/pollution transport
- ecosystem processes

Bay ROMS 2 (~2012)

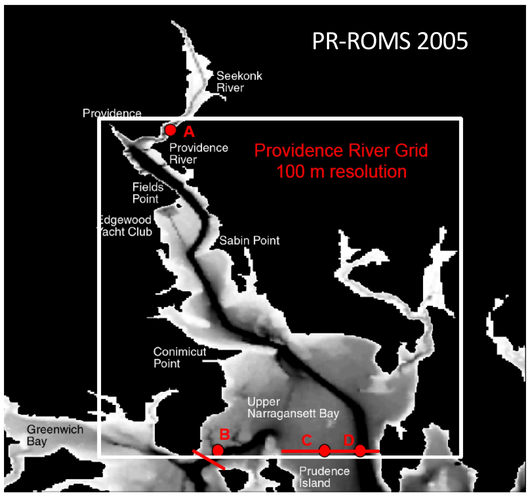
Validation

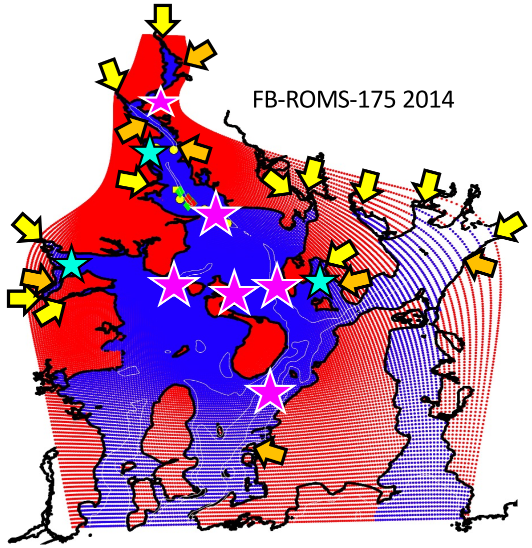
Improved physics,
Simulates key gyres:

★ Providence River
Greenwich Bay
Bristol Harbor

★ ~Mixed success for subtidal flows at ADCPs

Applications





One if by land: watershed nutrients

15 Rivers:	7 WWTFs
Blackstone	Fields Pt.
Woon./Mosh.	Bucklin Pt.
10 Mile	
Pawtuxet	East Prov.
Barrington	New Bedford
GB x 2	Bristol
Hunt	Newport
Silver Brook	GB
Taunton	
Kickemuit/Cole	

Bay ROMS 1 (~2000)

Simulates water levels nicely

Misses all key sub-tidal processes:
- flushing
- chemical/pollution transport
- ecosystem processes

Bay ROMS 2 (~2012)

Validation

Improved physics,
Simulates key gyres:

Providence River
Greenwich Bay
Bristol Harbor

~Mixed success for subtidal flows at ADCPs

Applications

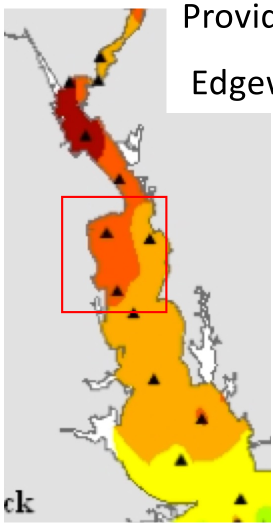
1) Forensic oceanography
   dispersion paths.
   15 rivers/7 WWTFs

2) Ecosystem models:
   nitrogen > phytoplankton
   > zooplankton

Narragansett Bay ROMS 2:
Simulated Dyes & Drifters: Quantify flow paths & flushing efficiencies

Example using the Providence River:

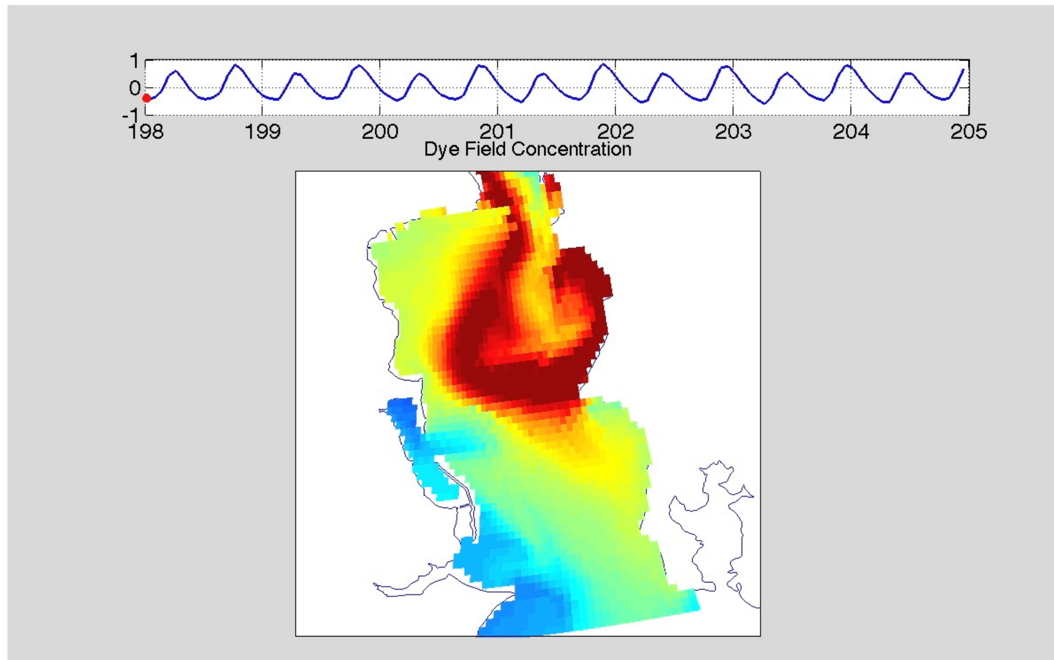
Edgewood Shoals



7 WWTFs
Fields Pt.
Bucklin Pt.

East Prov.
New Bedford
Bristol
Newport
GB

Fields Pt. Dyed Discharge (RED)

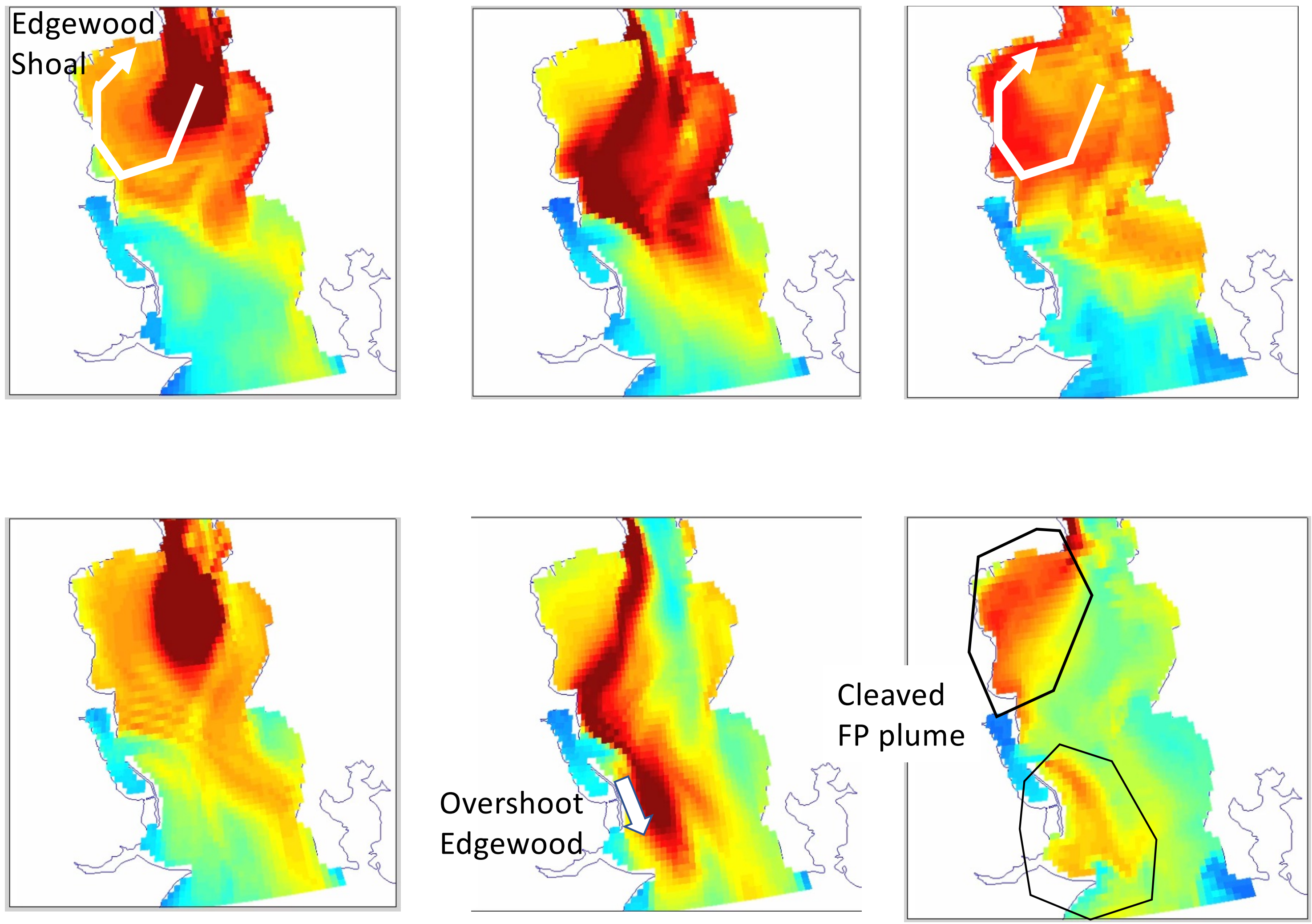


The Wrap Up

Forensic use of dyes/floats.

Fields Pt plume two common transport modes.

The Bifurcate



Use ROMS 2: Simulate bay-wide bloom, June, 2010

WATERSHED NITROGEN -Phytoplankton-Zooplankton Eco-Model

Total Nitrogen MOVIE

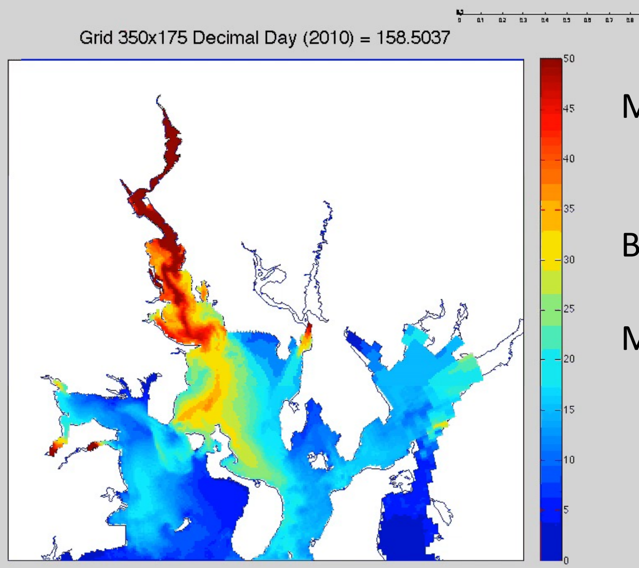
Phytoplankton MOVIE

RED= BLOOM

From north

Alternate West & East Passages.

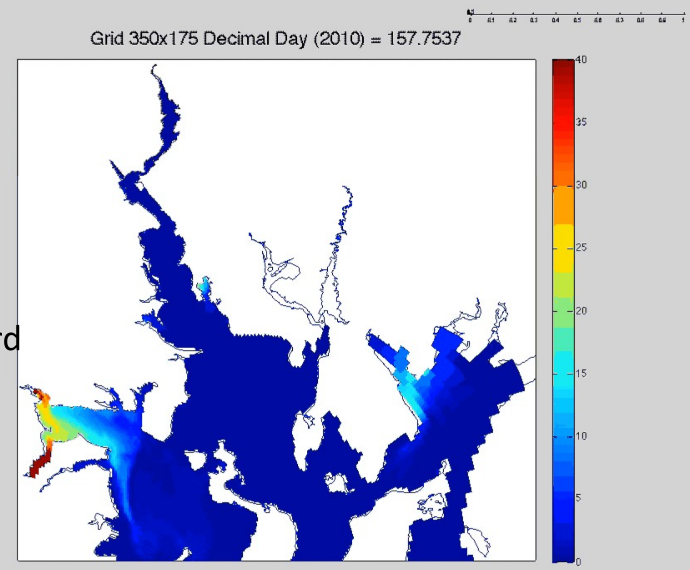
RED= Lotsa N



Mid-Bay is key region

Blooms start

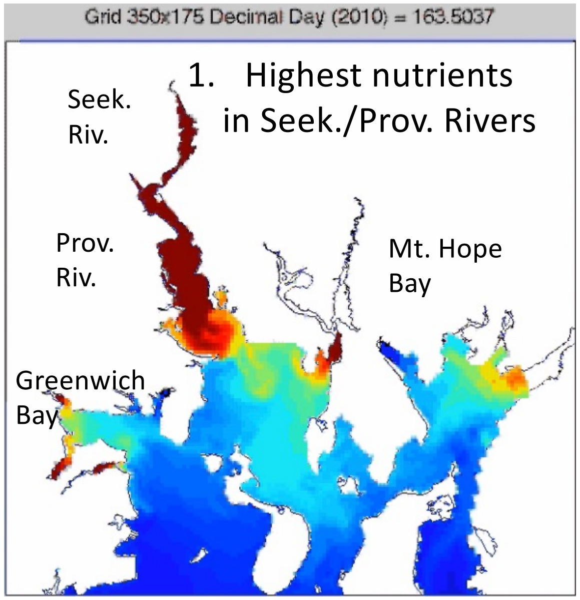
Move northward

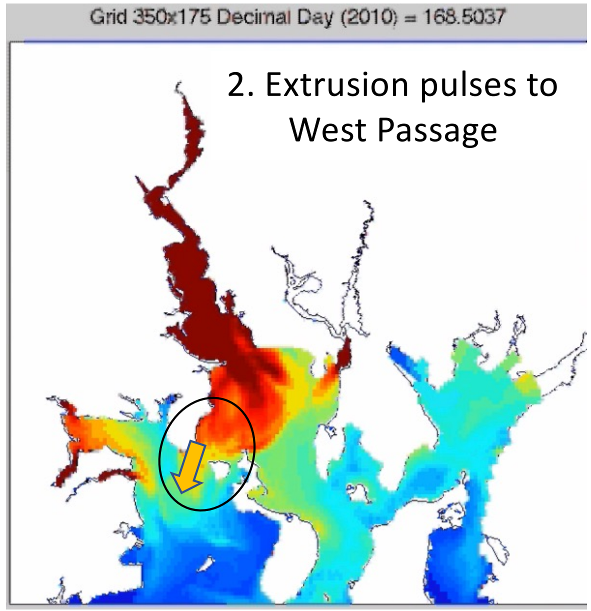


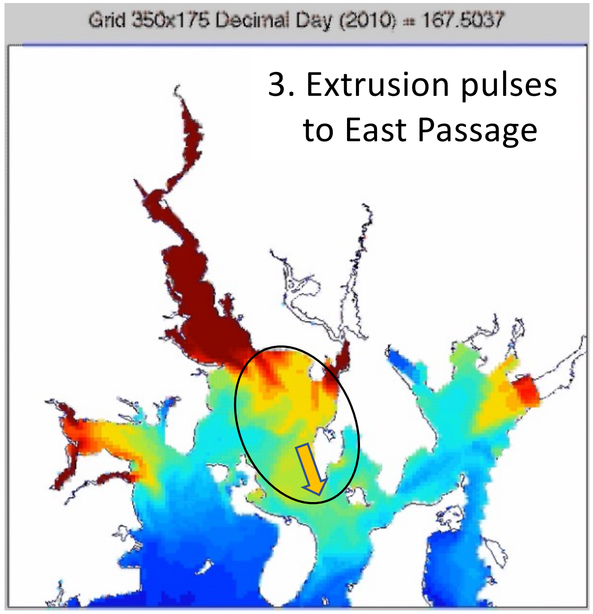
Key Points:

Blooms start mid-Bay, embayments/coves

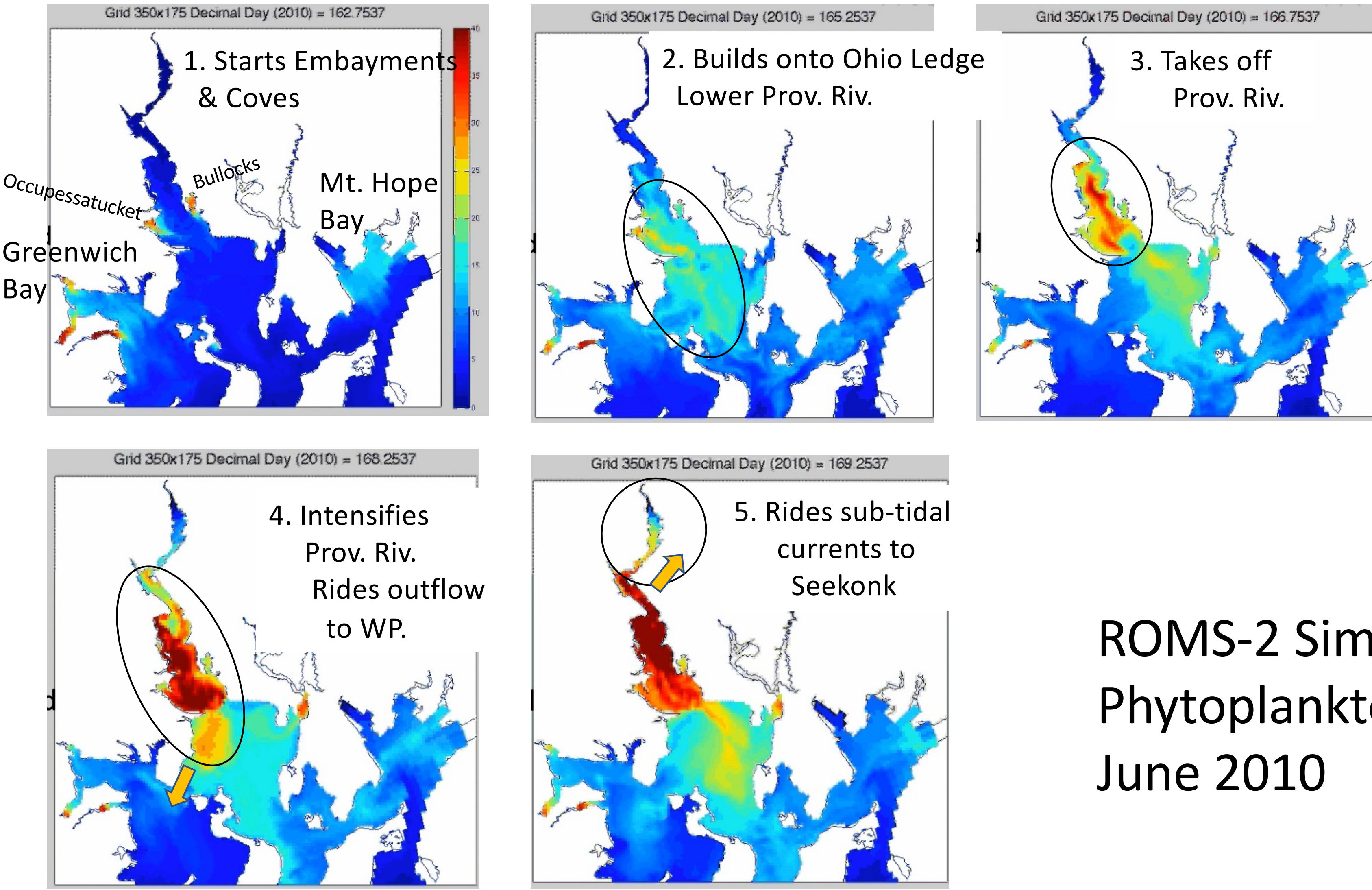
Migrate northward in sub-tidal flows





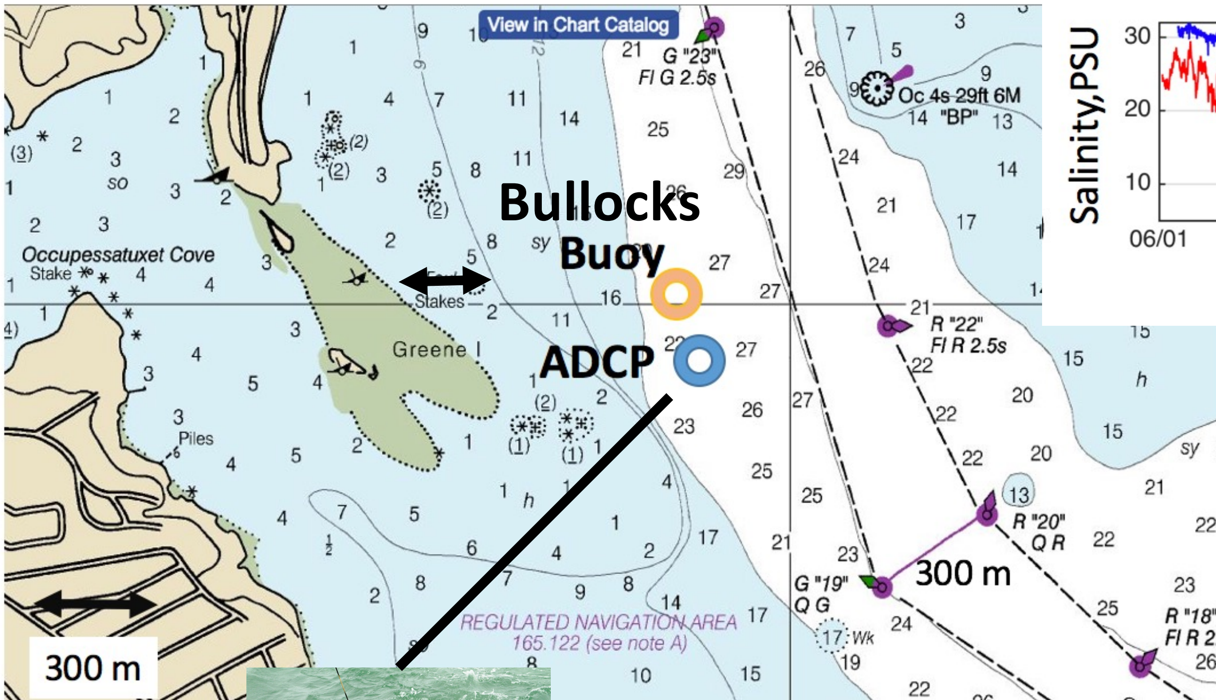


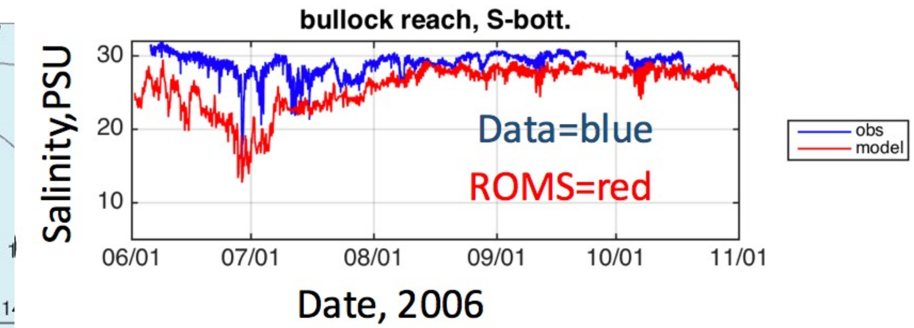
ROMS-2 Simulated
Common Watershed Nutrient Pathways
June 2010

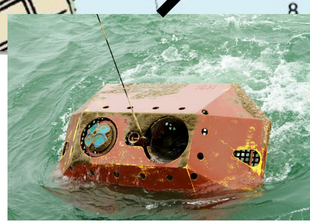


ROMS-2 Simulated Phytoplankton Bloom June 2010

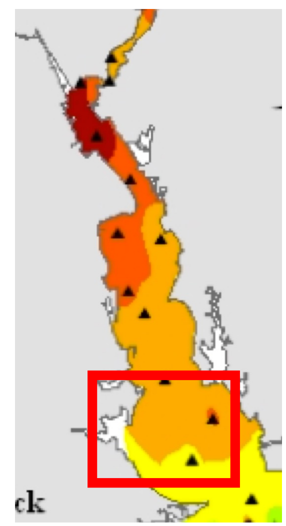
Not all good with ROMS 2: 1) Miss temp/salt properties at Bullocks/Seekonk R.; 2) Miss observed sub-tidal (intrusion) flows in natural & dredged channels







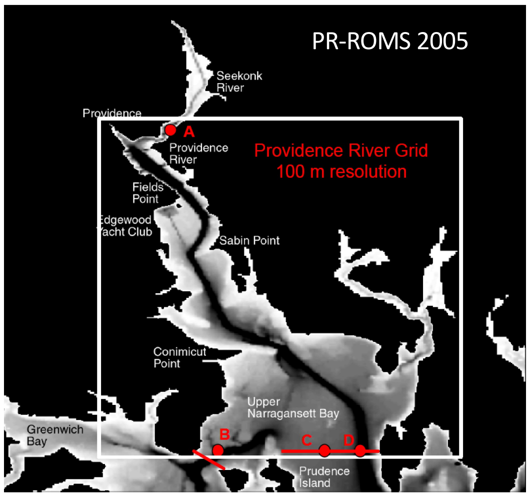
ADCP Data:
Late Summer 2016



Lower Prov. River.

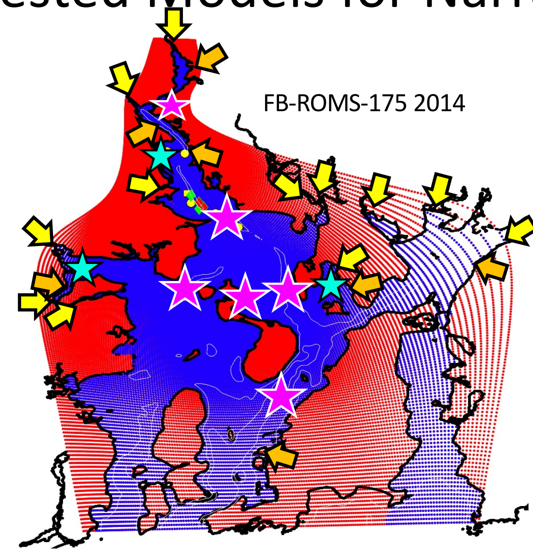
Bullocks Buoy

3 generations of Data-tested Models for Narragansett Bay for Nutrient Dynamics

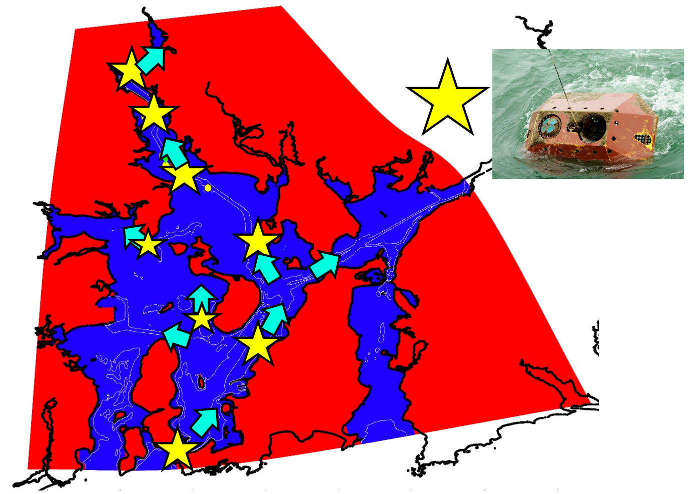


a)

ROMS-1



ROMS-2



c)

ROMS-3 (2020s)

2000s

Model got water levels.

Missed everything else

2010s

Models fixed to simulate processes in Providence or Seekonk Rivers.

Additional data moorings reveal additional data-model issues

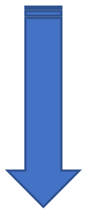
Significantly improved:

a) shelf water intrusions up East Passage

b) retention gyres in Providence River, Greenwich Bay & Bristol Harbor

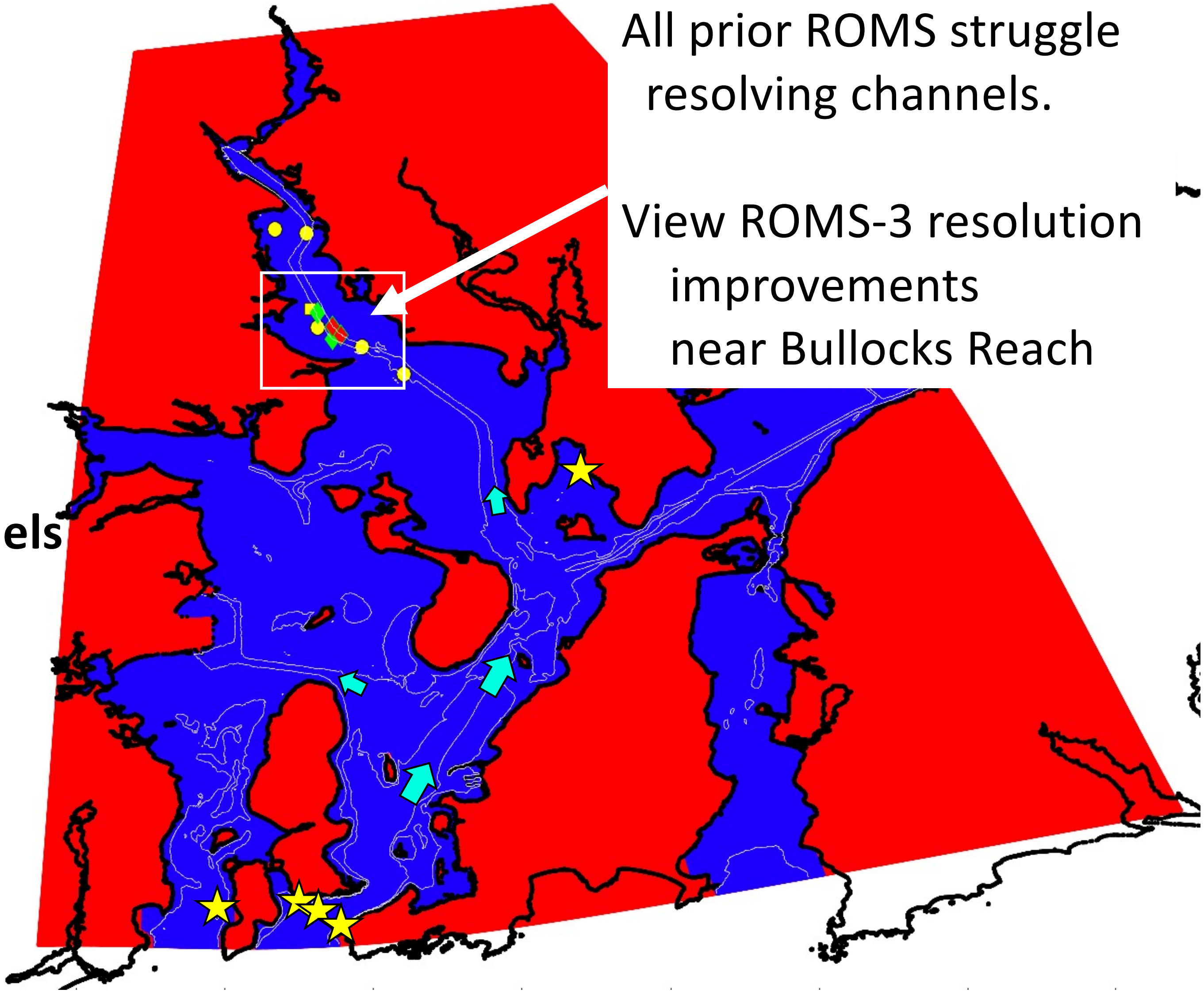
c) Seekonk River intrusions/extrusions

Super High Resolution
ROMS-3 (2020s)



Influence of
natural & dredged channels
on Bay nutrient dynamics

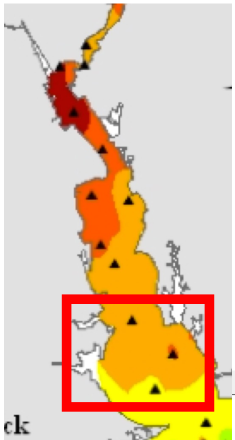
Two if by sea

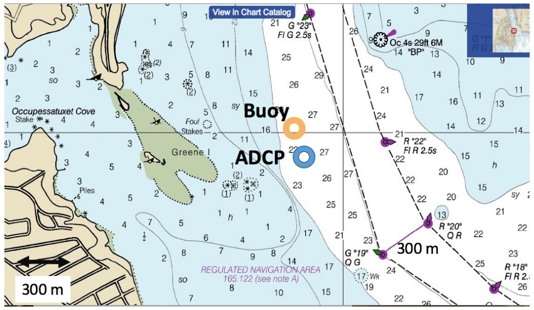


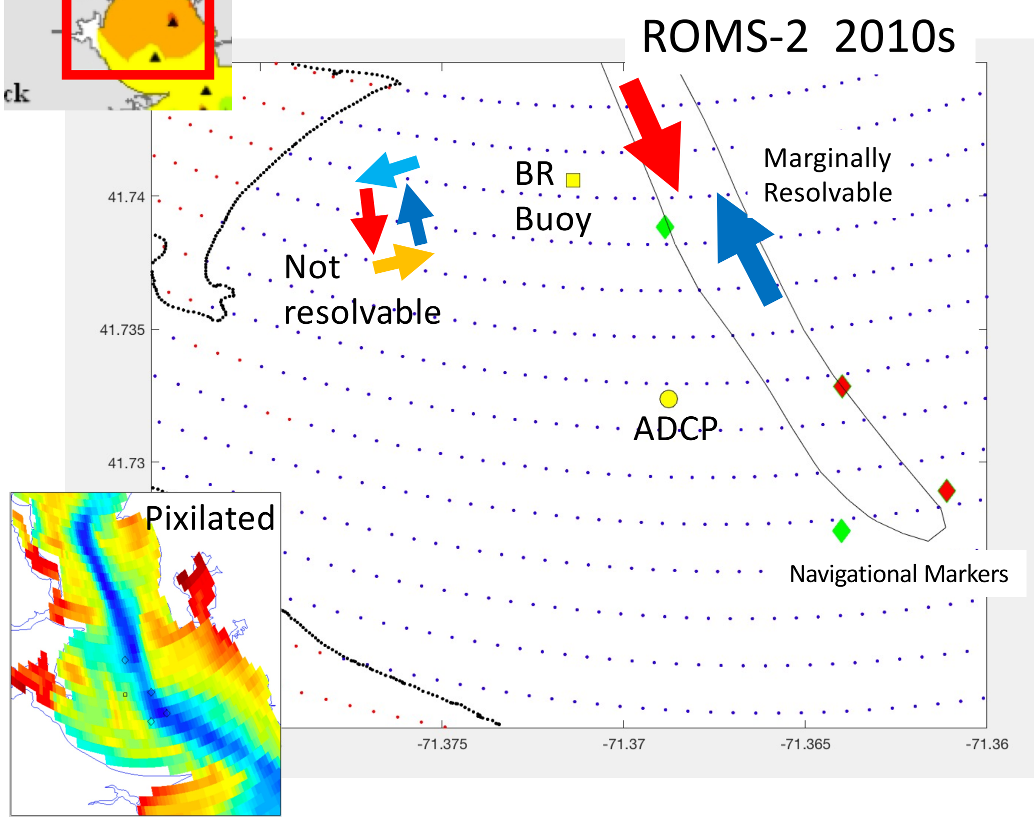
All prior ROMS struggle resolving channels.

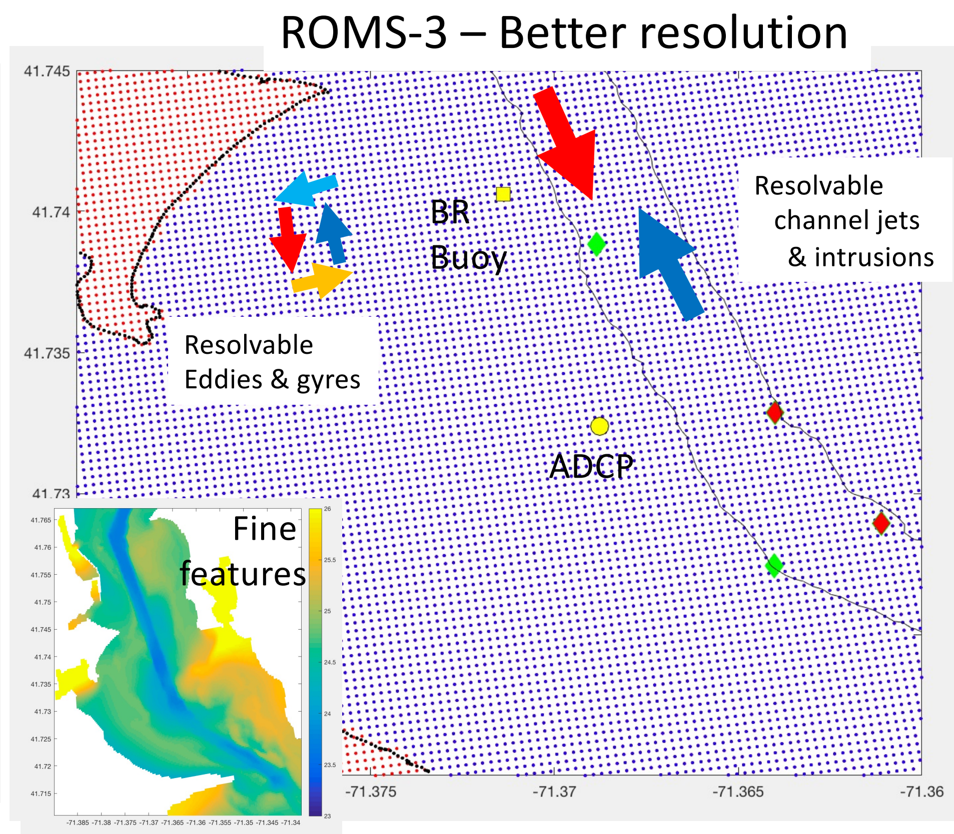
View ROMS-3 resolution improvements near Bullocks Reach

Improved grid resolution in ROMS-3,
reproduces observed flows: a) within channels
b) along-shoals
c) across-shoals









Narragansett Bay ROMS-3 significantly improved for nuances of Bay physics: channels, shoals, embayments....

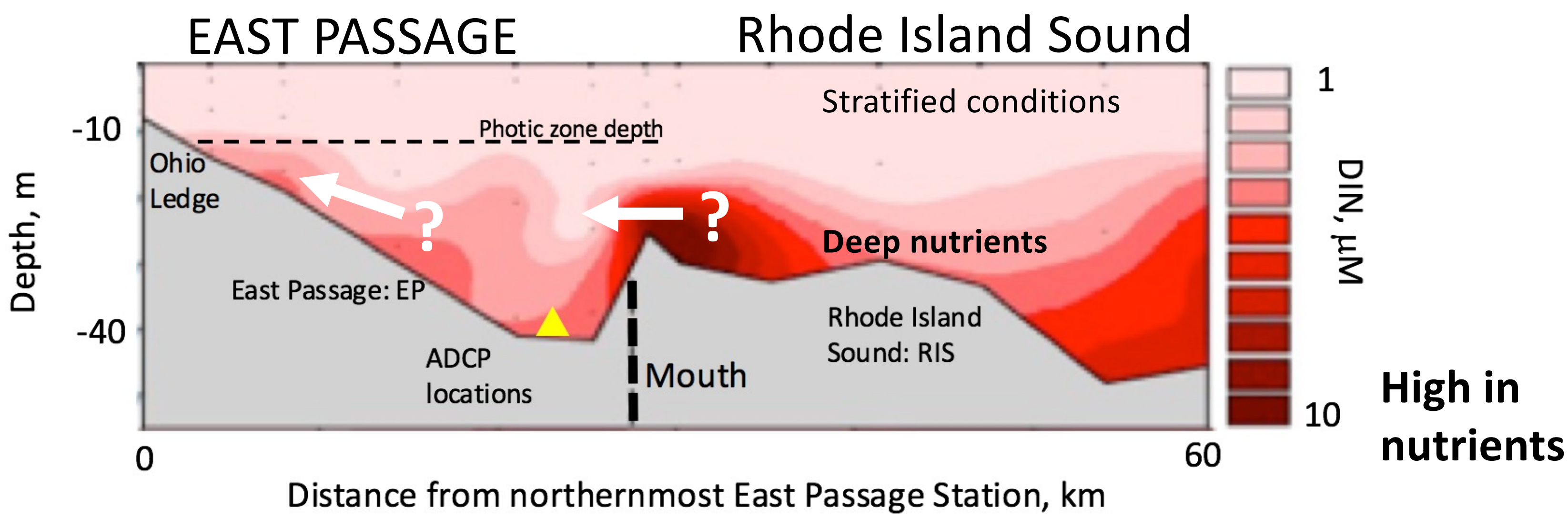
but what about the title?

One if by land, two if by sea:

Reassessing the role of watershed vs offshore nitrogen sources
for Narragansett Bay productivity

?

Scott Nixon, Summer 1992: "You need to get out of the mantle and help me understand impact of Rhode Island Sound (RIS) bottom water nutrients on Bay"



Nixon et al., 1998-2001 Nitrogen Data Cruises

Magnitude & impact of RIS nutrient fluxes to Bay?

Summary of what we know from
moored acoustic current meter data
(aka ADCP).

Nixon led

1) 1998-2001, 2005-08 data

  a) East Passage subtidal **inflow**

  b) West Passage subtidal **outflow**

  c) Intrusion source:

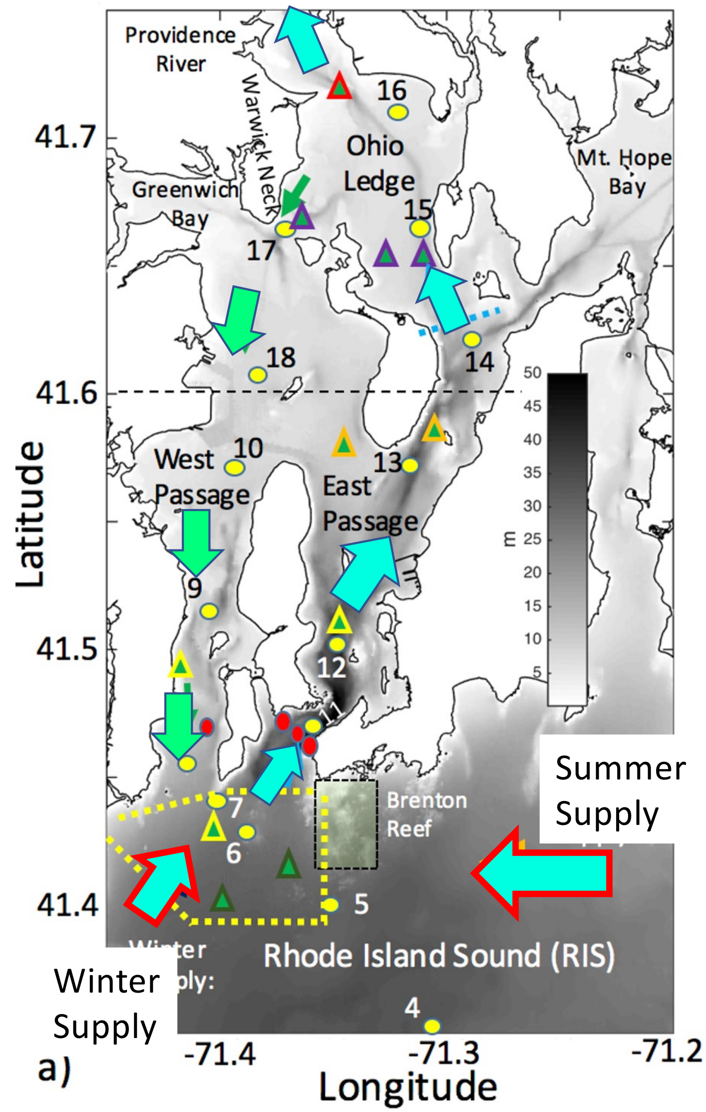
    summer: from east

    winter: from southwest

2) 2018/19 data at mouth

  a) EP intrusion massive

  b) single ADCPs (99-01) miss it!



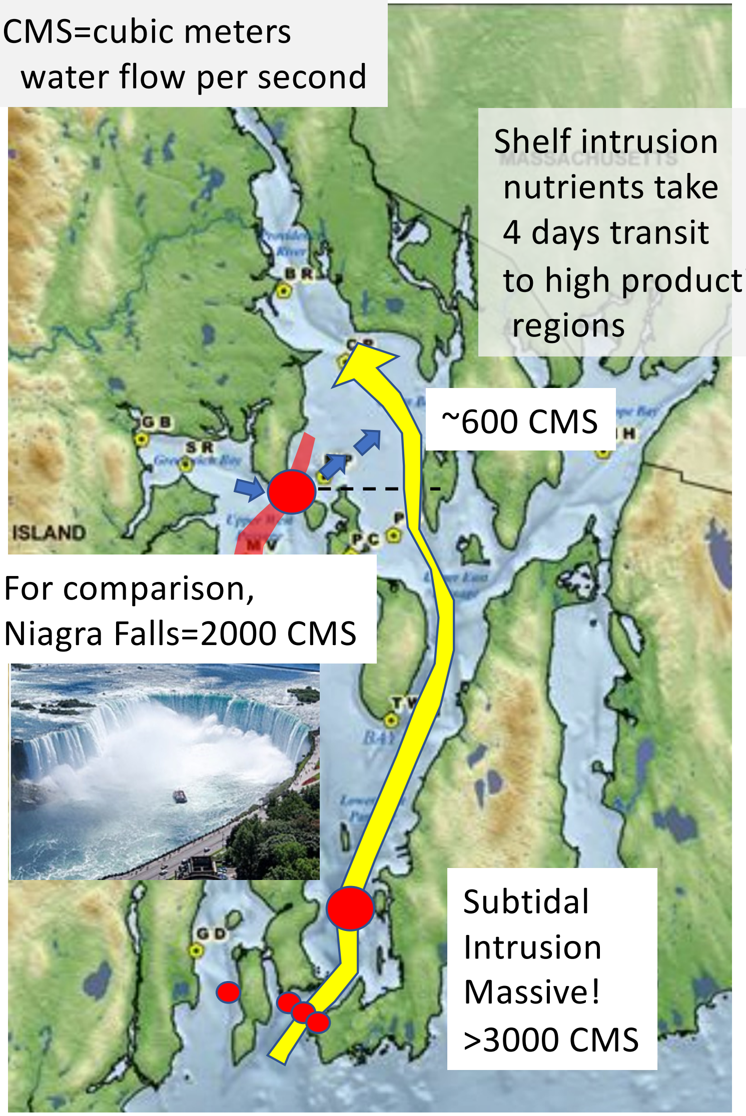
Kincaid, URI-GSO, 2023

RISG Work at Bay Mouth.

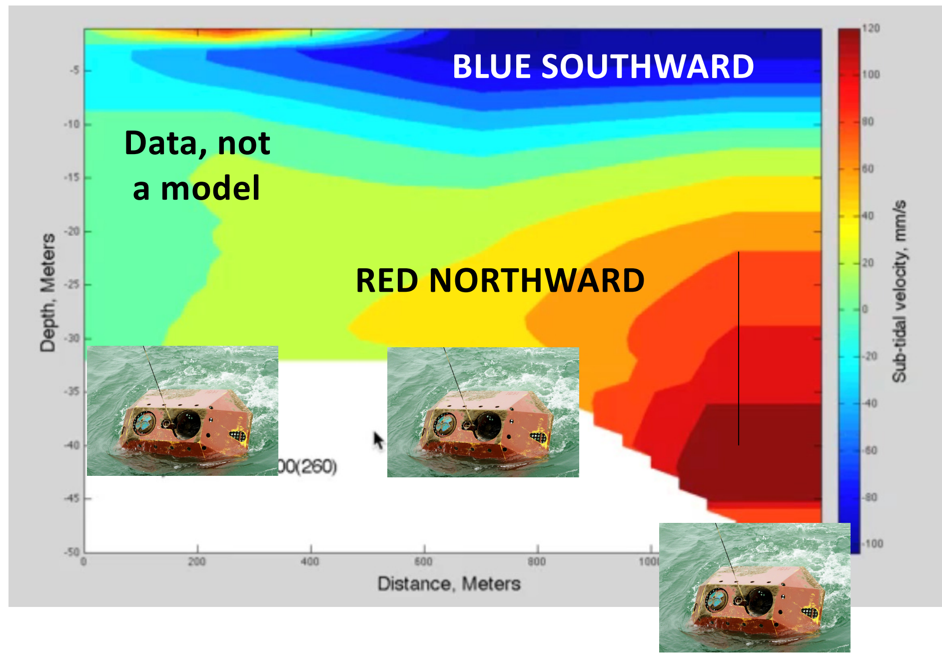
Offshore intrusions are bigger than we thought.
Nutrient levels vary 5-11 micromolar.

Subtidal intrusion enter at Castle Hill

CMS=cubic meters water flow per second



For comparison, Niagra Falls=2000 CMS



4 moored acoustic current meters, 8 months, 2018/2019

Kincaid, URI-GSO, 2023

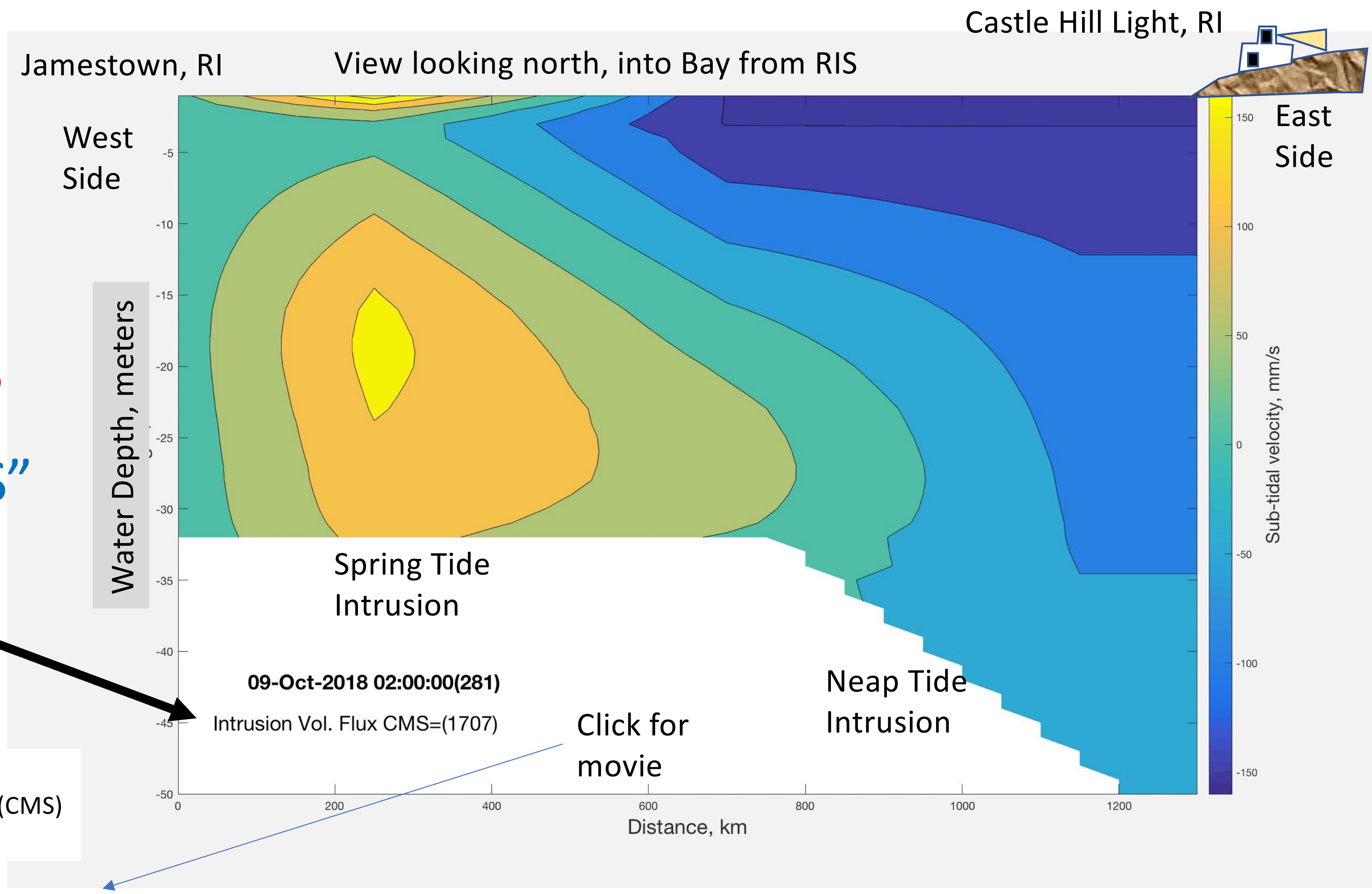
Lower East Passage intrusions, from current meter data. Summer-fall, 2018.

INTRUSIONS

"EXTRUSIONS"

Volume of water flow per second entering Bay in East Passage intrusion.

Volume flow reference: 2000 cubic meters per sec. (CMS) average over Niagra Falls.



In-water DATA at Bay Mouth

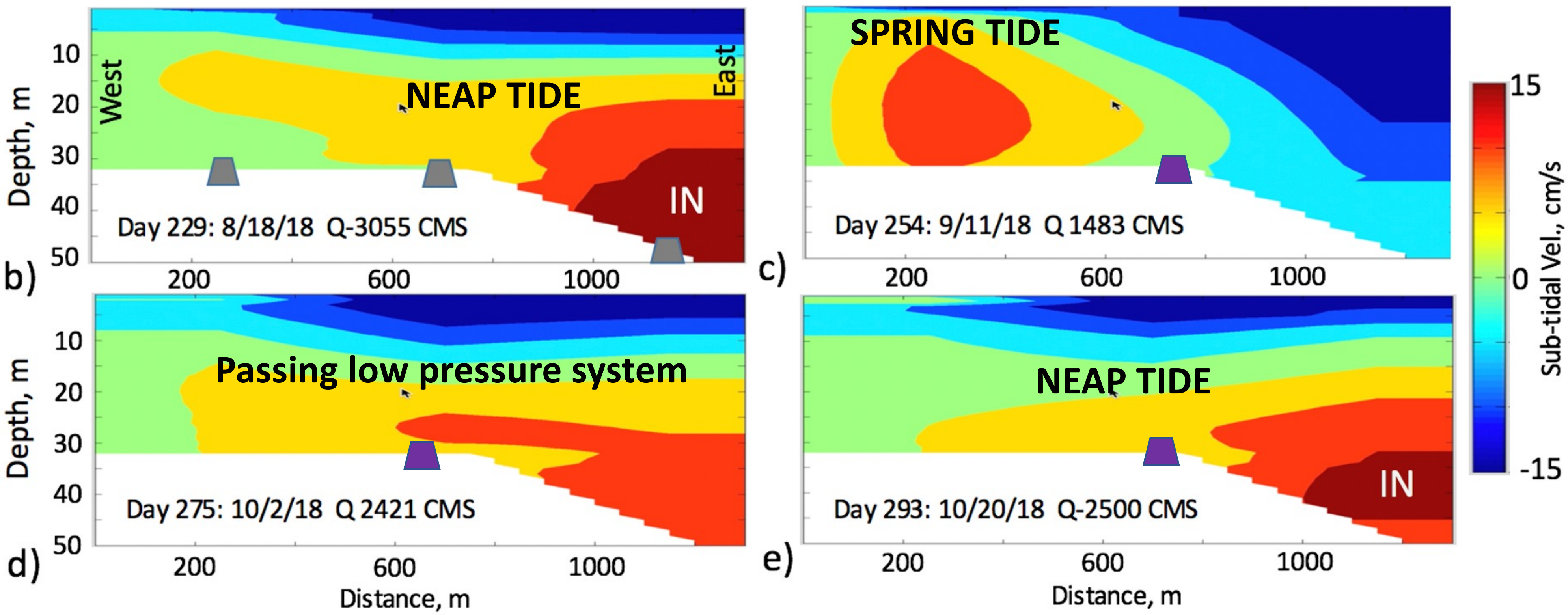
1) 3 ADCPs capture shiftiness/episodicity of East Passage intrusion.

(Past method, single ADCP, misses key details)

2) 4000 CMS! Neap tide + Low Pressure Driveby

NEAP TIDE: Very small tides

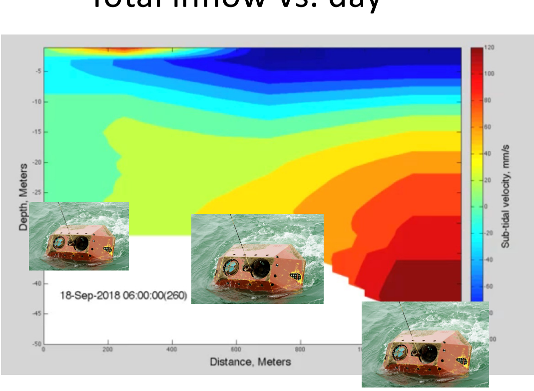
SPRING TIDE: Very big tides

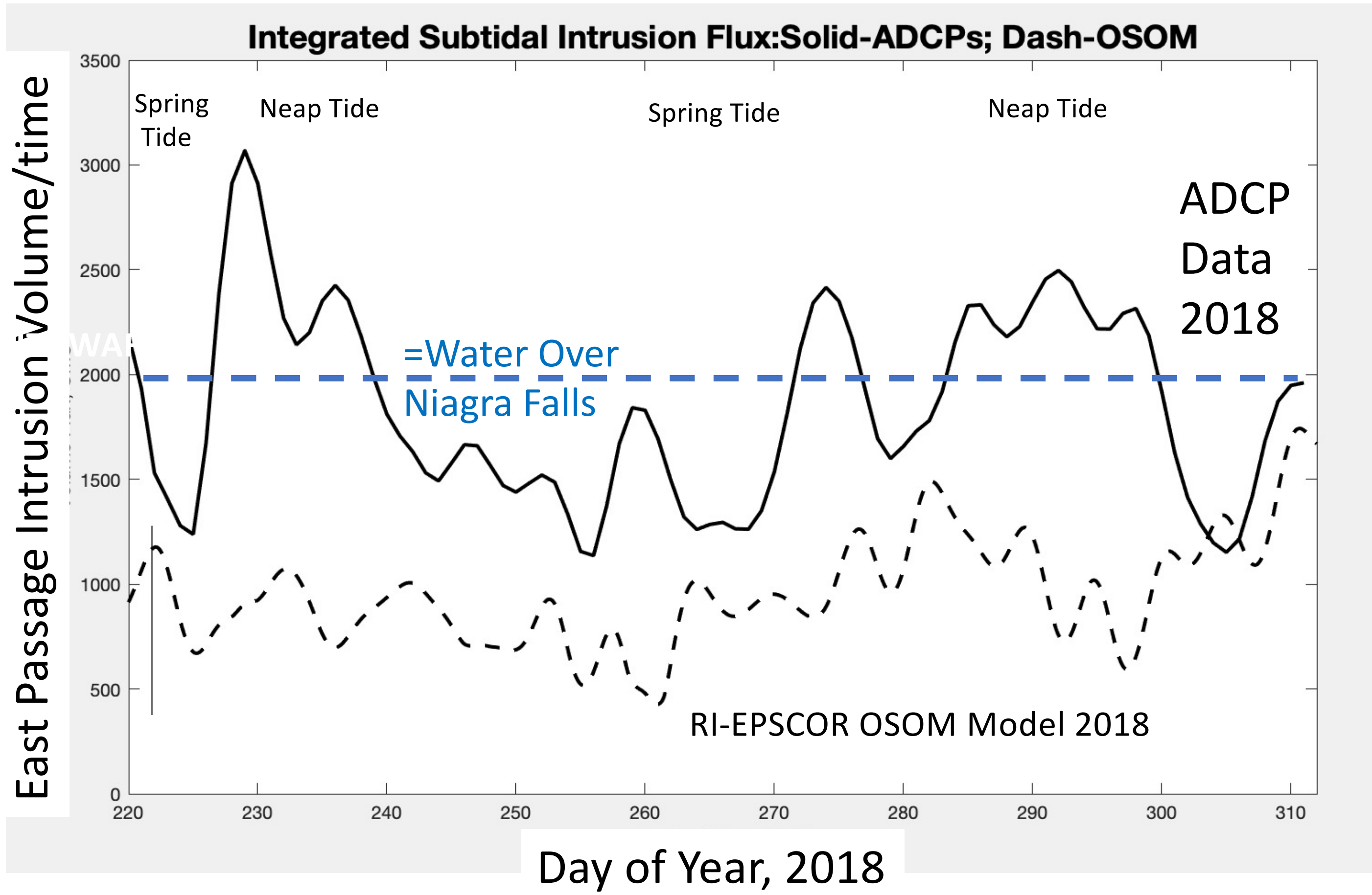


Subtidal intrusion volume flux through mouth vs. time (East Passage, WP~10% of this)

Can't do just a couple ship surveys! Miss time variability.

Sum the RED Inflow
Take daily average
Total inflow vs. day

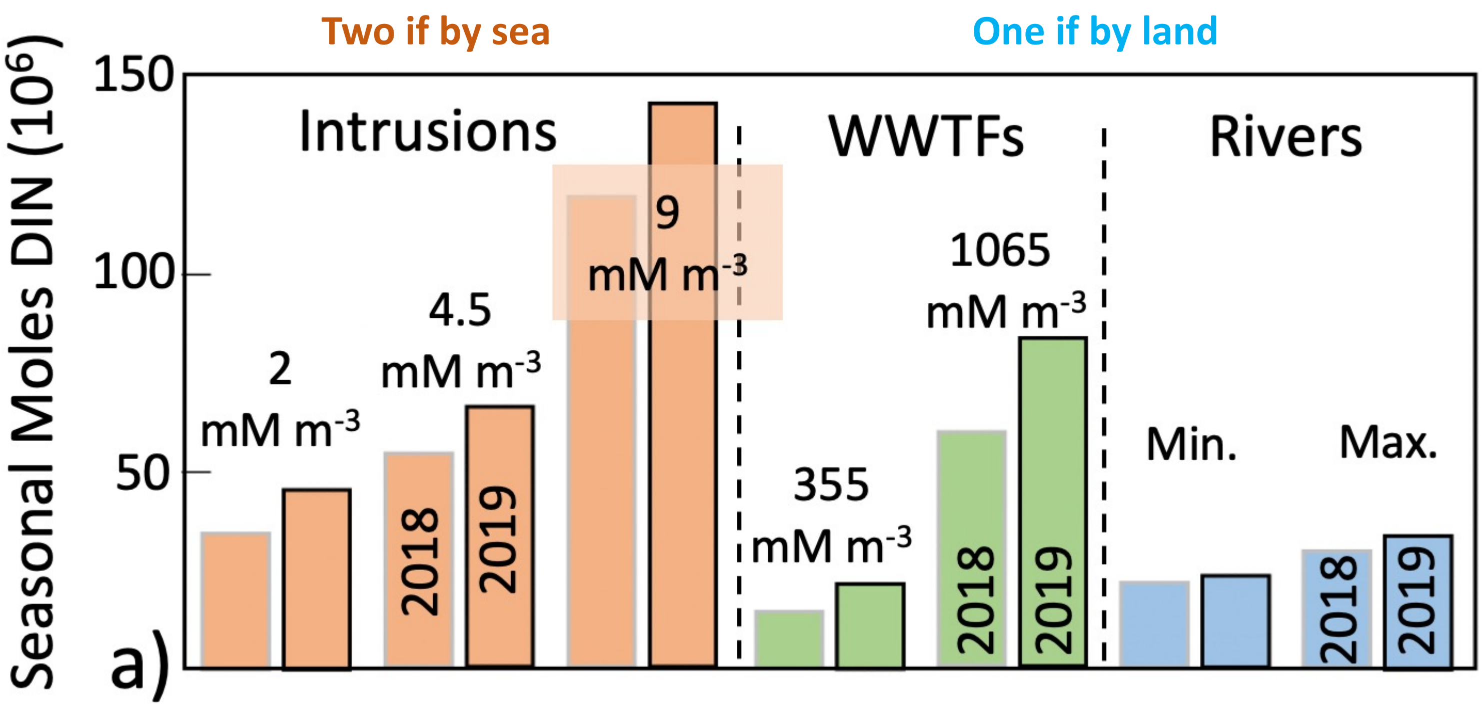




moored acoustic current meters, 8 months, 2018/2019

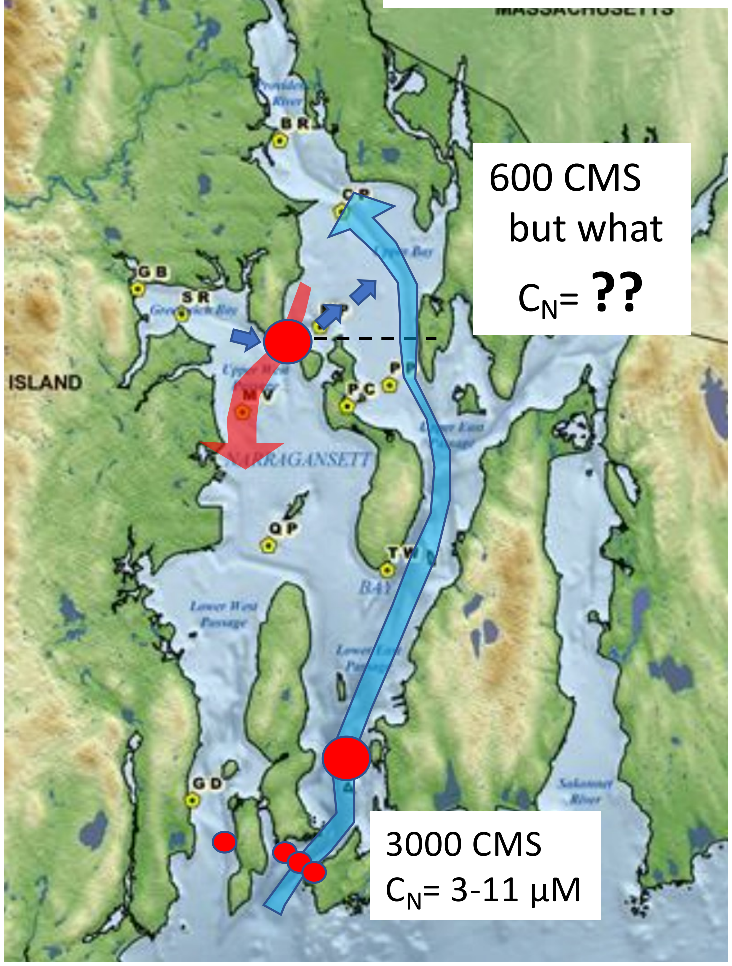
Total summer moles nitrogen: watershed (rivers/WWTFs) vs. intrusions.

a) (Observed **volume flux** of intrusions/discharges) **times** (observed **nutrient levels**)
b) Integrate each nutrient flux record over deployment duration.

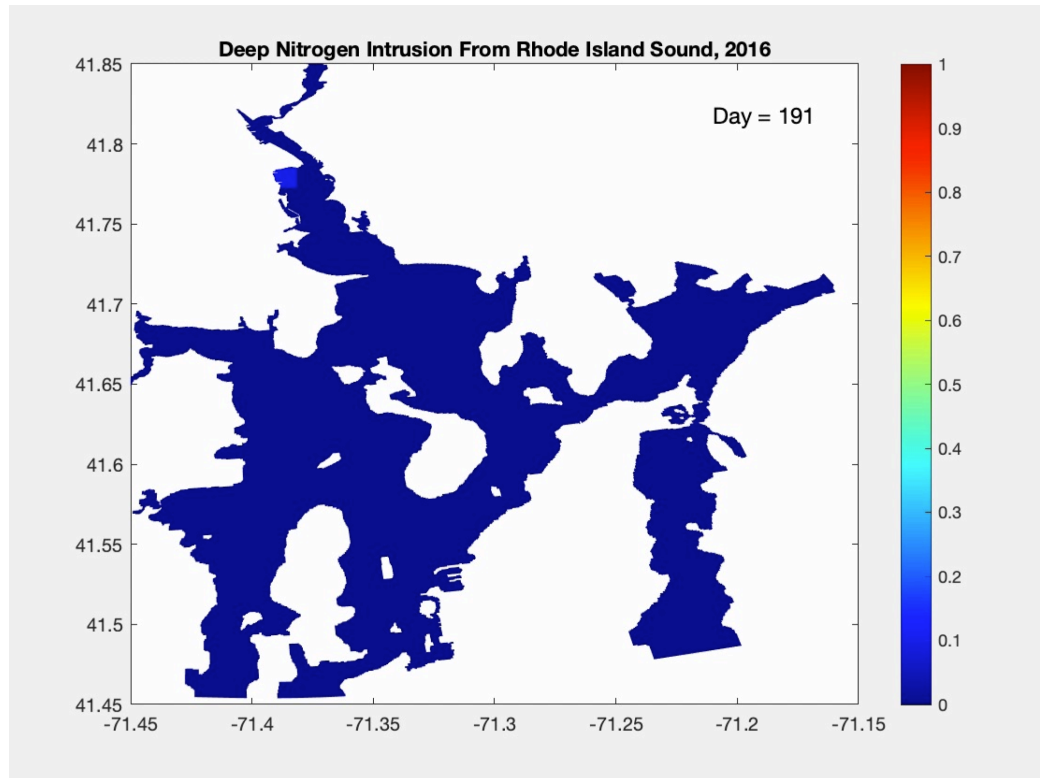


Intrusion fluxes from DATA are larger than previously thought.....

But does this mouth flux influence productive mid/upper Bay?



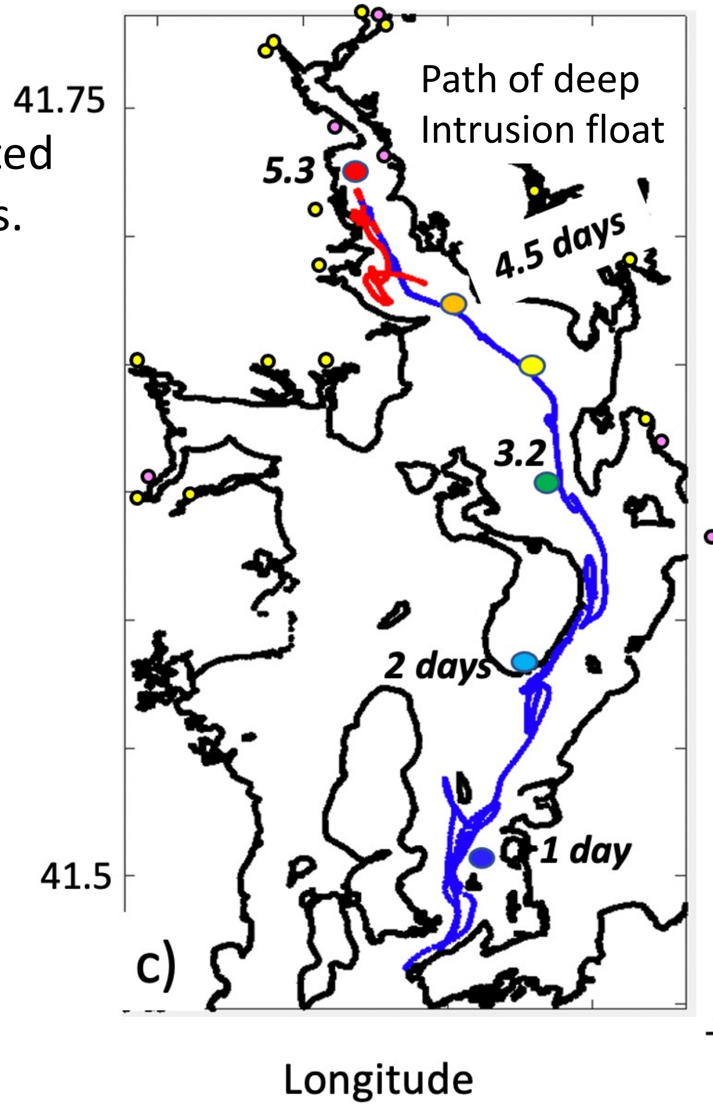
USE ROMS-3: INTRUSION DYE TRANSPORT

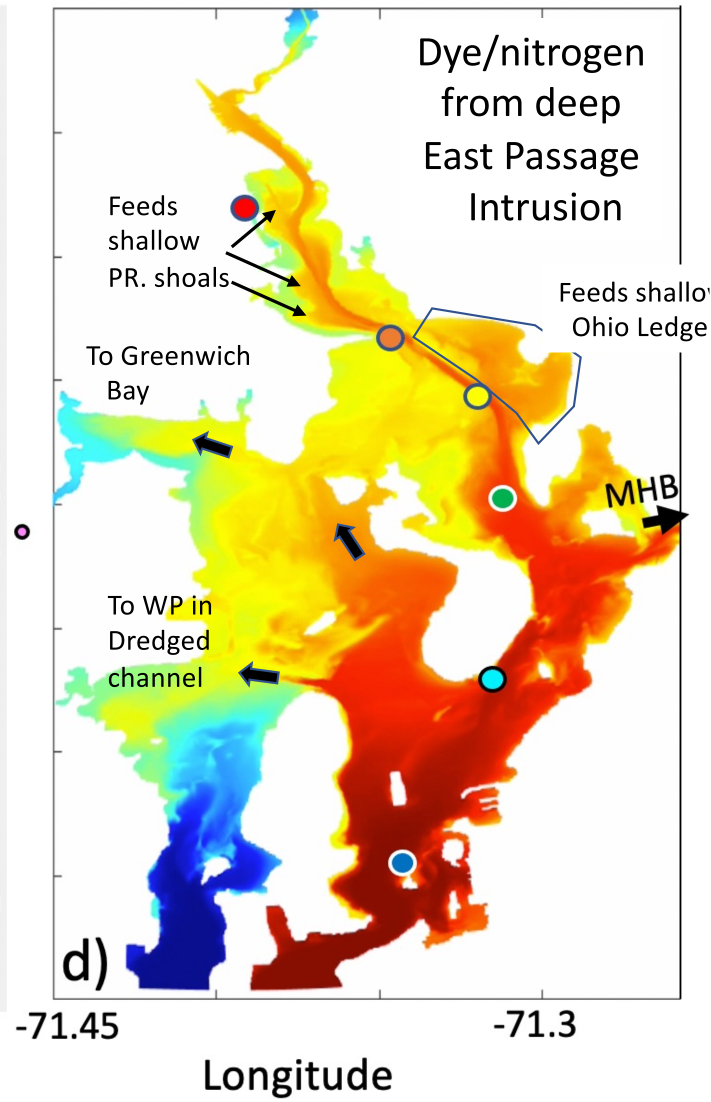


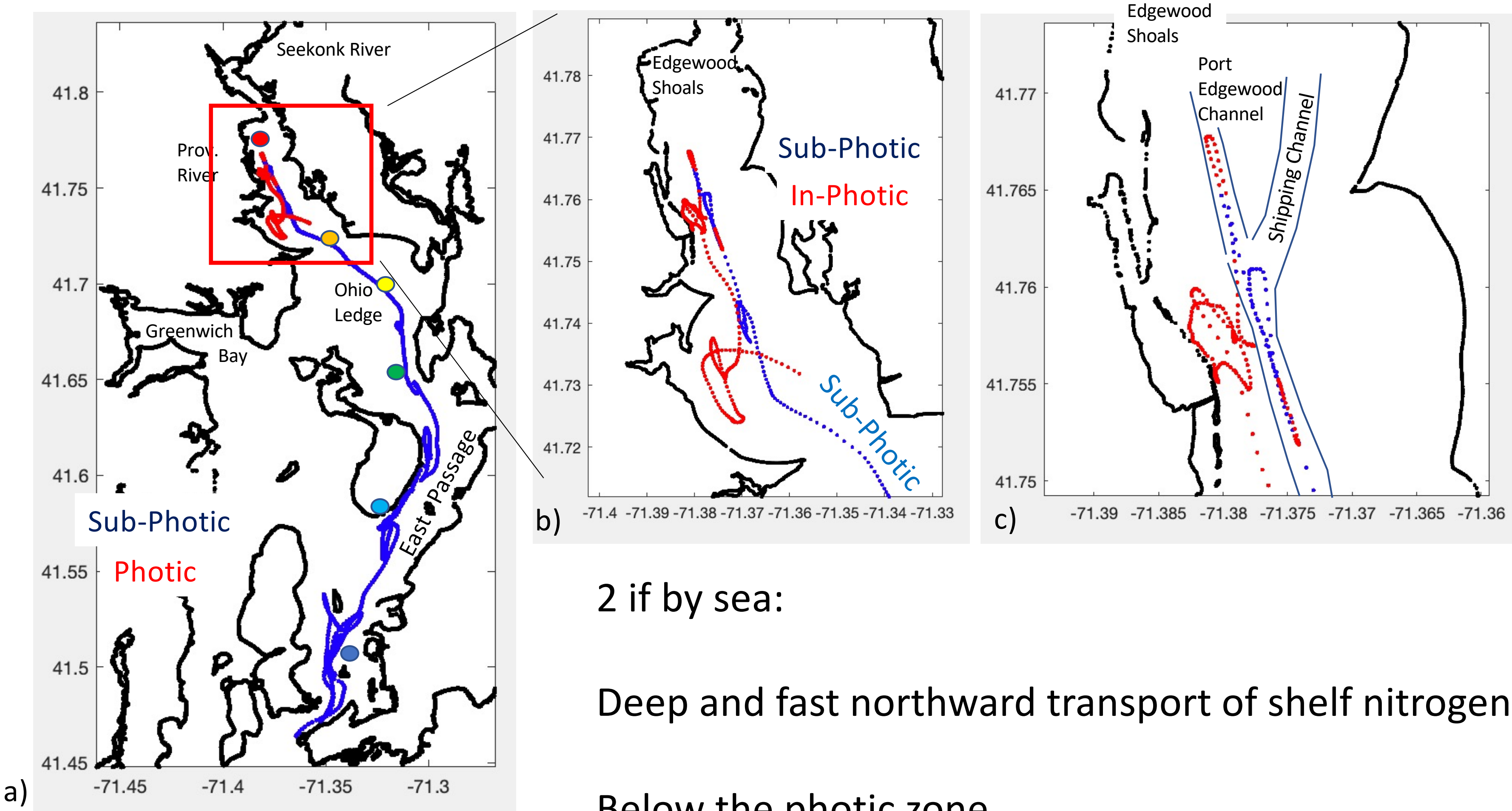
What enters mouth, transported fast & deep to sensitive areas.

Intrusion patterns & time scales:

Simulated in ROMS-3 using passive floats & bottom dyes







2 if by sea:

Deep and fast northward transport of shelf nitrogen.

Below the photic zone

Put watershed & intrusion nitrogen into high resolution ROMS-3 ecosystem model

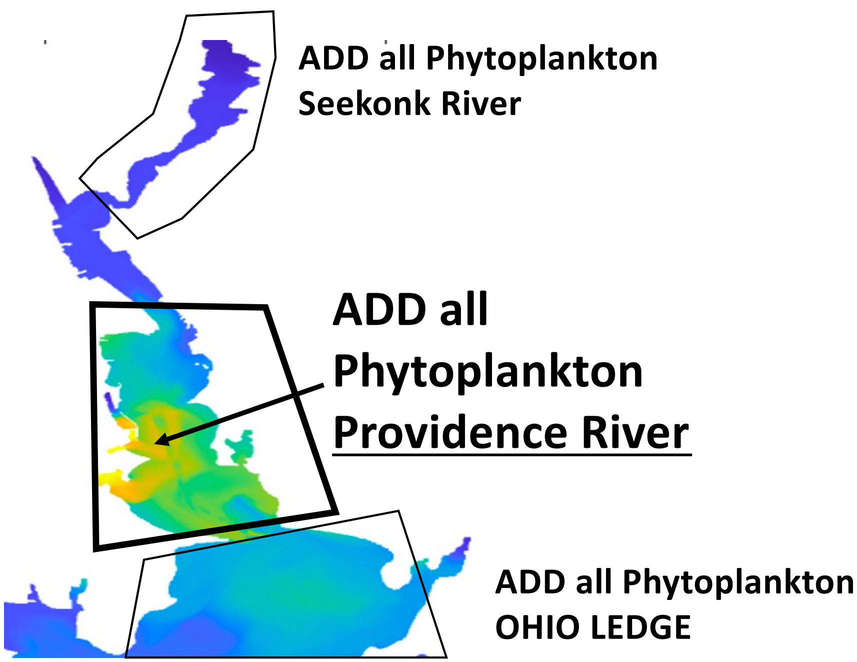
Reference Case: Providence River

WWTFs: 5 mg/L ; No Intrusion nitrogen

One if by land

Two if by sea

Day 170

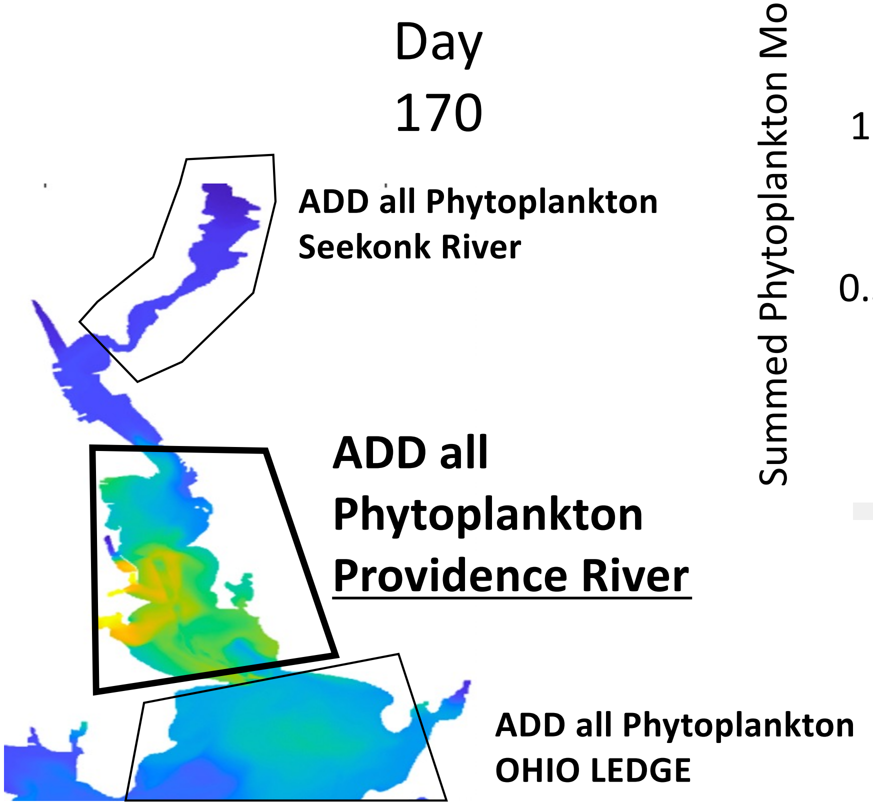


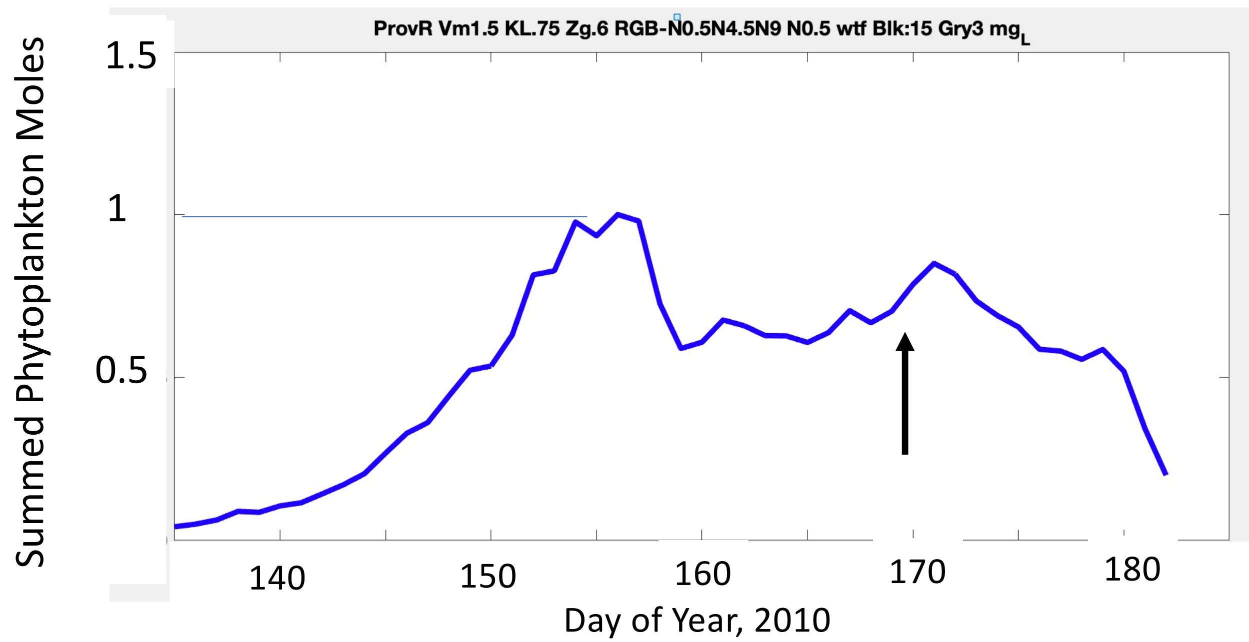
Show volume integrated PHYTOPLANKTON biomass in key regions of mid/upper Bay.

Seekonk River
Providence River
Ohio Ledge
Mt Hope Bay
Greenwich Bay

Put watershed & intrusion nitrogen into high resolution ROMS-3 ecosystem model

Reference Case: Providence River
WWTFs: 5 mg/L ; No Intrusion nitrogen

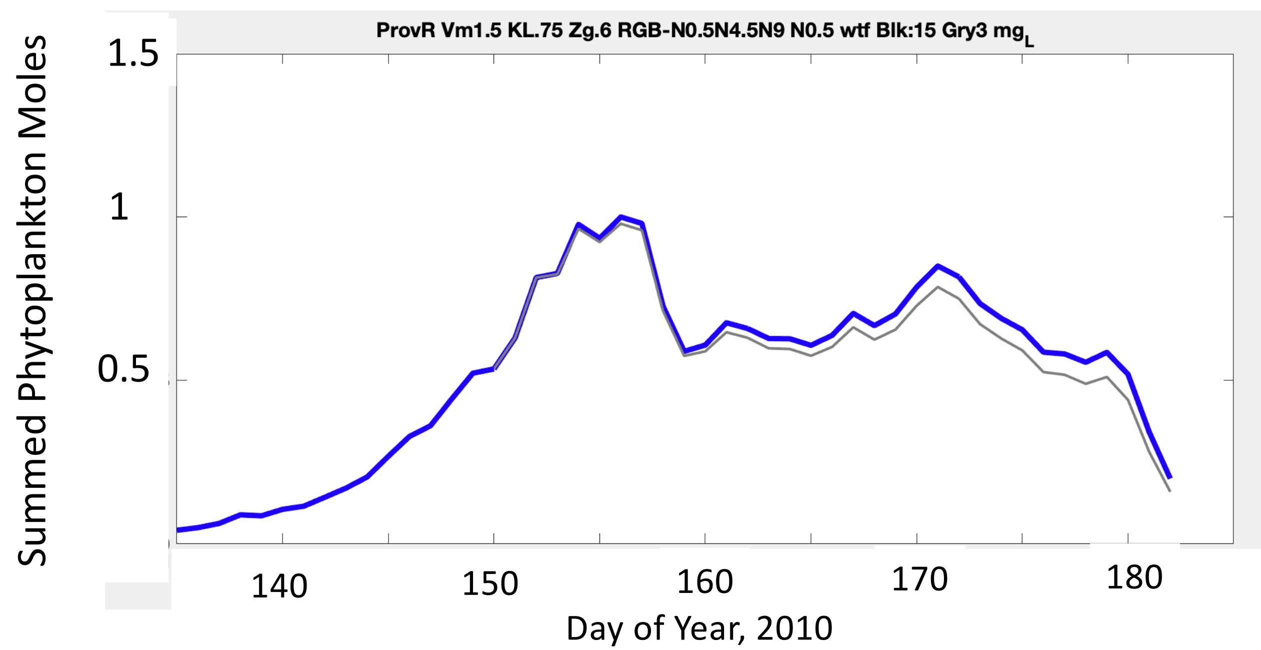




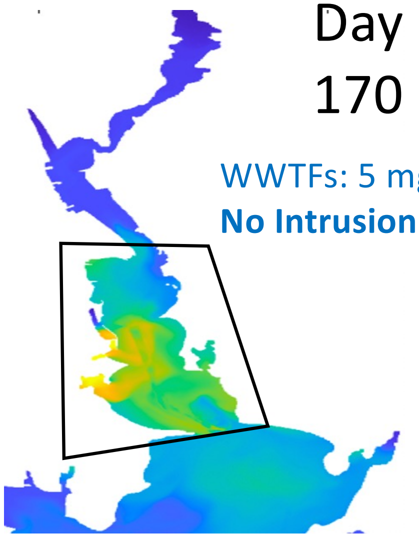
Reference Case: Providence River

WWTFs: 5 mg/L ; No Intrusion nitrogen

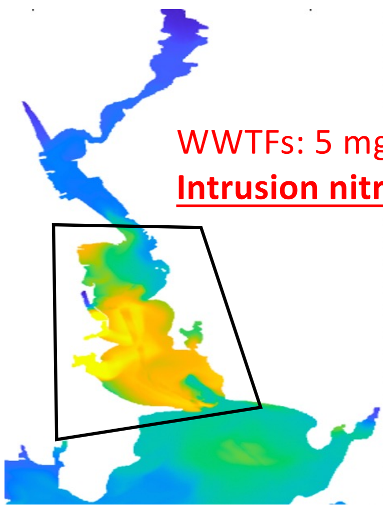
WWTFs: 3 mg/L; No Intrusion nitrogen



Day
170



WWTFs: 5 mg/L ;
No Intrusion nitrogen



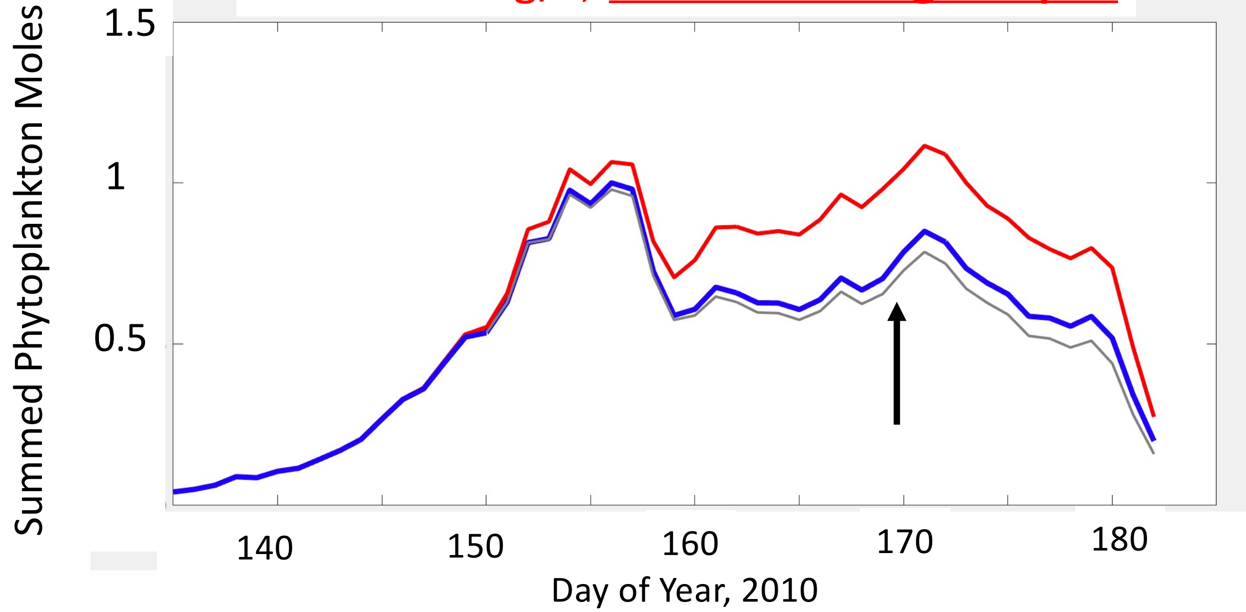
WWTFs: 5 mg/L;
<u>Intrusion nitrogen 9 µM</u>

Reference Case: Providence River

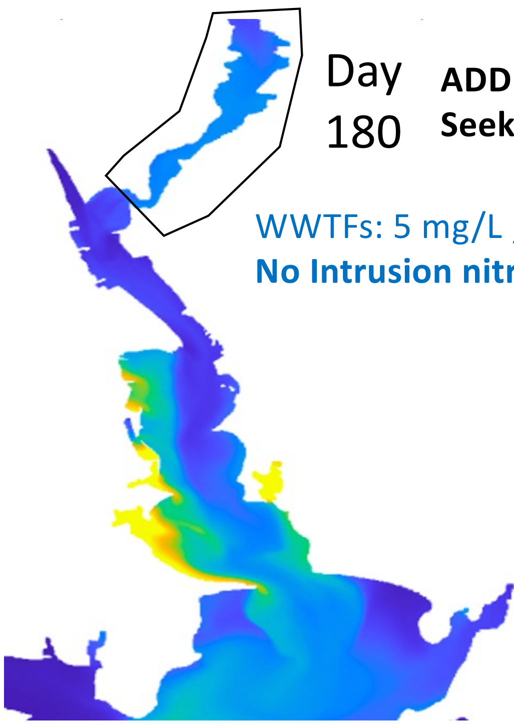
WWTFs: 5 mg/L ; No Intrusion nitrogen

WWTFs: 3 mg/L; No Intrusion nitrogen

WWTFs: 5 mg/L; **<u>Intrusion nitrogen 9 µM</u>**



WWTFs: 3 mg/L; No Intrusion nitrogen



Day 180

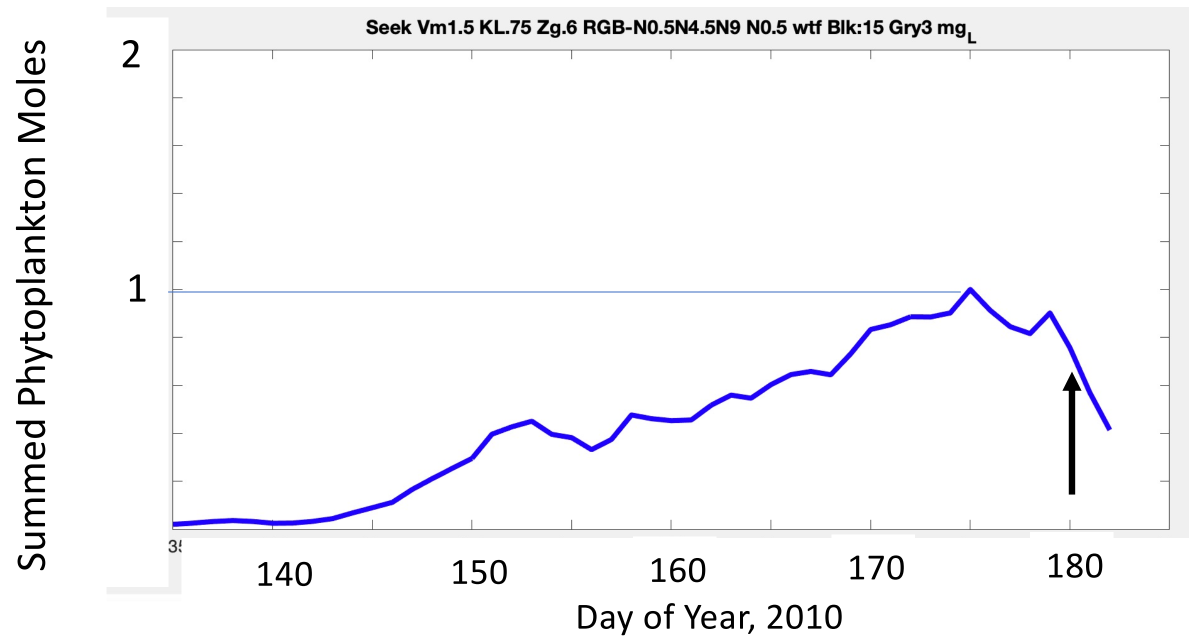
ADD all Phytoplankton Seekonk River

WWTFs: 5 mg/L ;

No Intrusion nitrogen

Reference Case: SEEKONK River

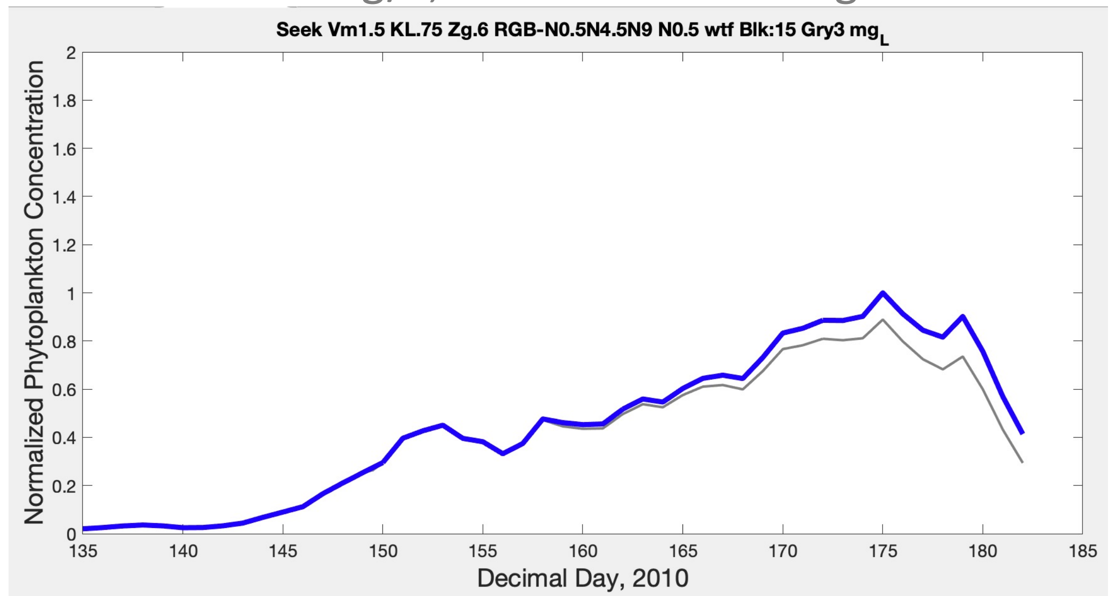
WWTFs: 5 mg/L ; No Intrusion nitrogen

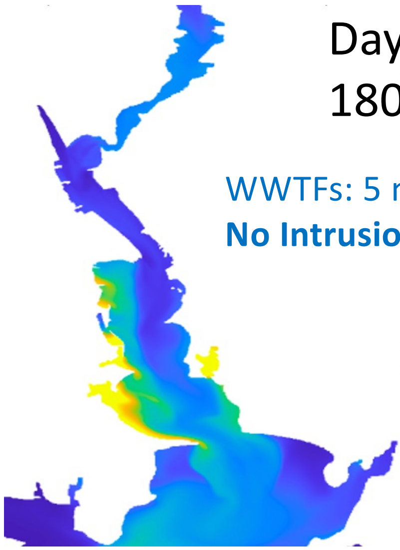


Reference Case: SEEKONK River

WWTFs: 5 mg/L ; No Intrusion nitrogen

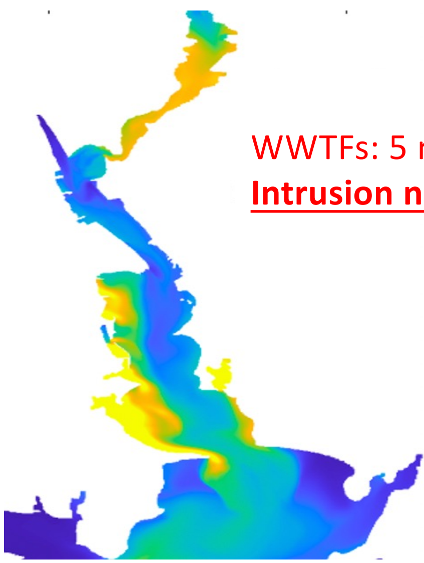
WWTFs: 3 mg/L; No Intrusion nitrogen





Day
180

WWTFs: 5 mg/L ;
No Intrusion nitrogen



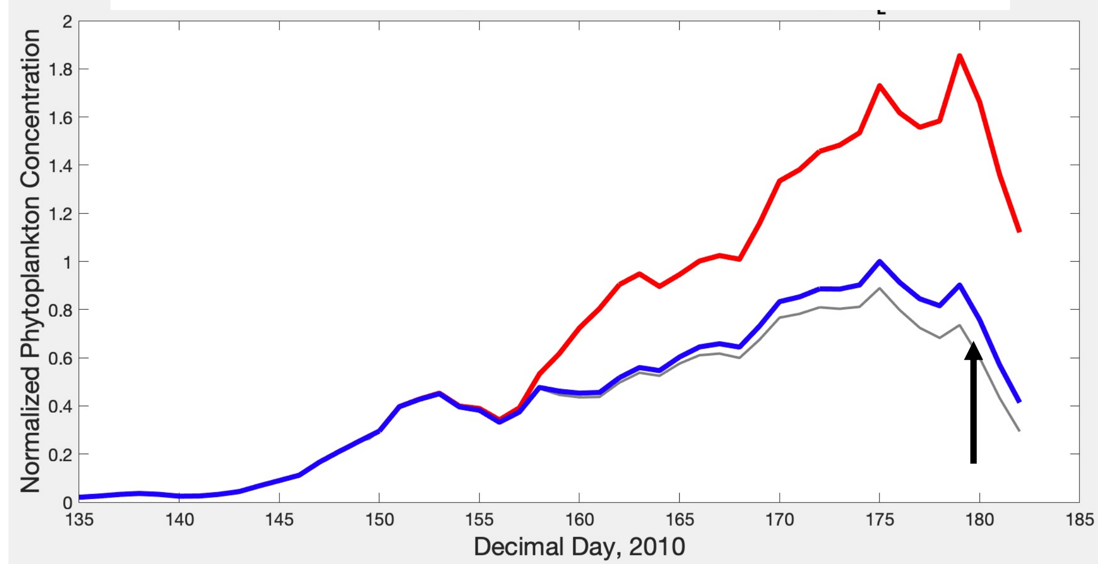
WWTFs: 5 mg/L;
Intrusion nitrogen 9 μM

Reference Case: SEEKONK River

WWTFs: 5 mg/L ; No Intrusion nitrogen

WWTFs: 3 mg/L; No Intrusion nitrogen

WWTFs: 5 mg/L; **Intrusion nitrogen 9 μM**



Conclusions:

Multiple generations of improving Narragansett Bay ROMS Models

Validated & improved vs. 20 years of current meter data & fixed buoy network

Narragansett Bay ROMS-3:

Validation steps

- Matches gyres in Providence River, Greenwich Bay & Bristol Harbor
- Resolves shoal/channel exchange issues in hypoxic areas
- Fixes Seekonk River intrusion/extrusion issues
- Reproduces observed East/West Passage intrusion patterns

Testing watershed vs intrusion nutrients

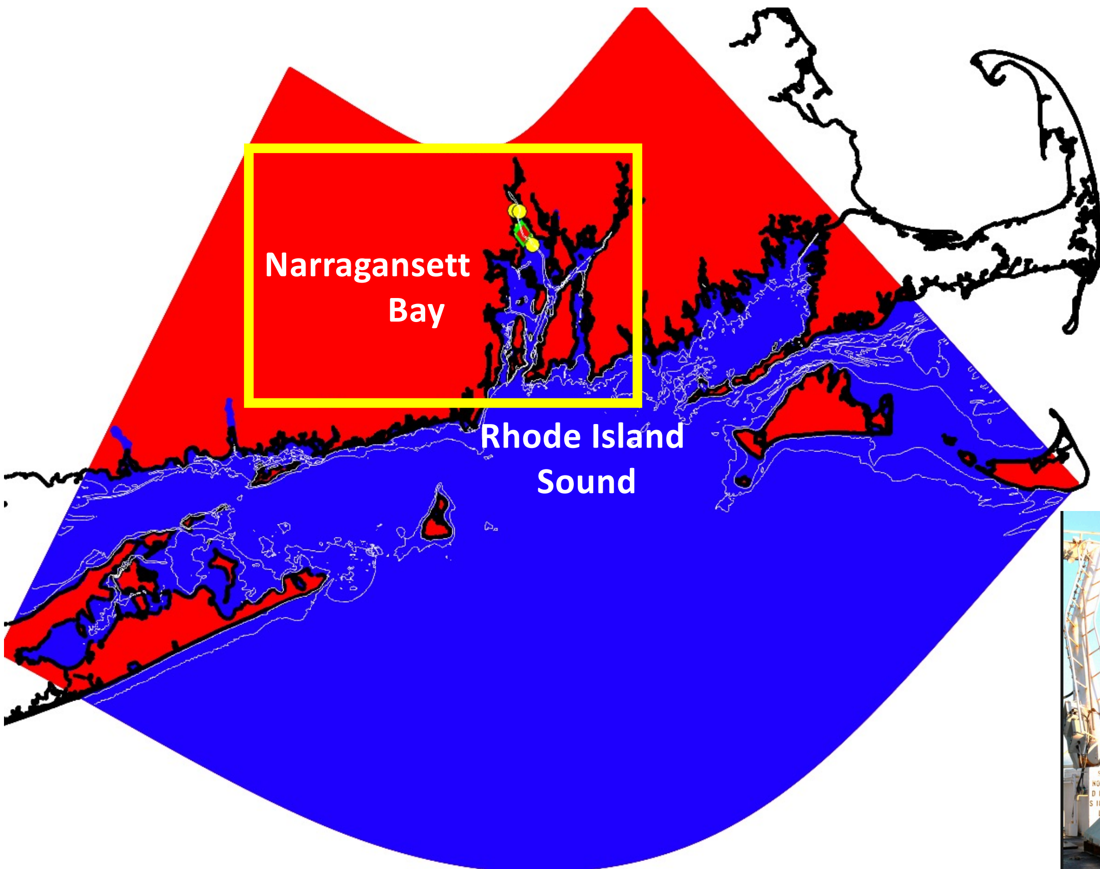
- Intrusion nitrogen essential factor in Bay nutrient budget
- Intrusions supply offshore N fast & deep to chonically hypoxic areas.
  - 4.5 days mouth to Conimicut Pt.; moving at >20' depths
  - surfaces (bio-available) in lower Prov. River shoals
- Intrusions larger impact on Bay blooms than WTFs 5 mg/L to 3 mg/L
  - oddly, intrusions biggest impact in Seekonk River.

Extra Slides in Case Questions / Discussion

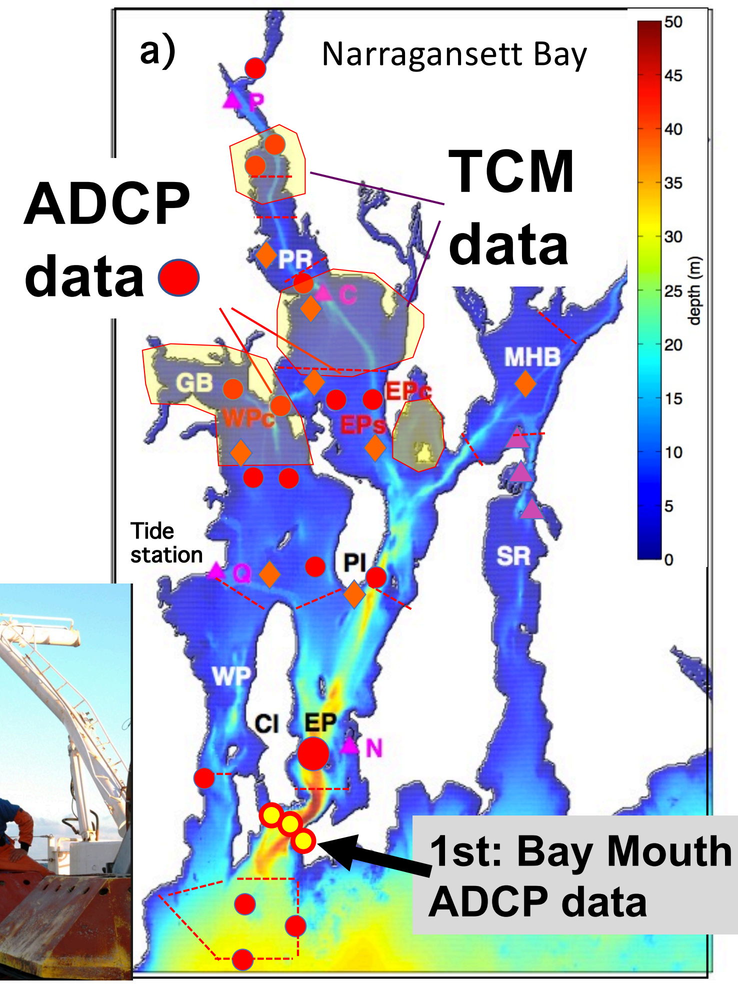
Huge remaining issue with Narragansett Bay models for nitrogen dynamics

- Narragansett Bay ROMS-3:
  - Much improved for foundational physics: channels, shoals, embayments
  - Driven at mouth by RI-EPSCOR ROMS model called OSOM
  - Data show OSOM does very poorly, not currently usable.

Ocean **S**tate **O**cean **M**odel: OSOM-ROMS



Models Vs. DATA

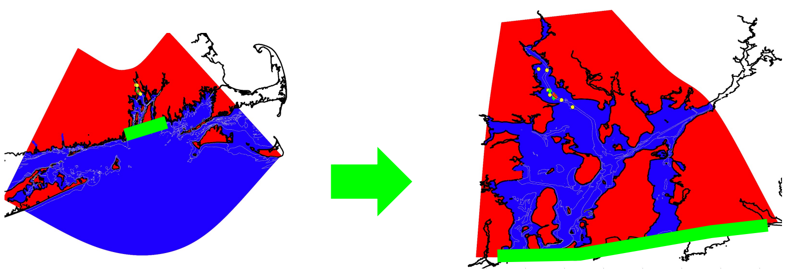


RI-EPSCOR OSOM Model is yet not ready to be an accurate tool for future climate impacts on RI waters.

Compares poorly at this early stage to heat exchange data at mouth.

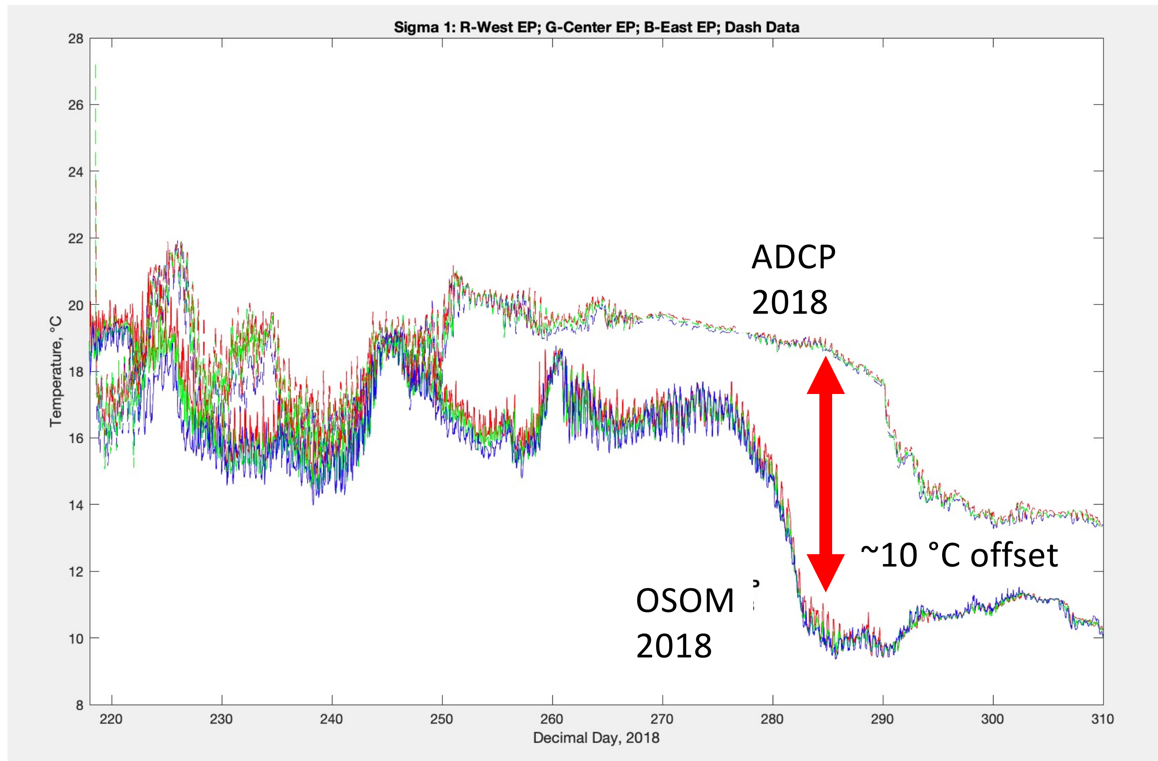
More data (more trustworthy modeling tools) requires better facilities, like the new coastal access facility.

Bottom temperatures in OSOM Model vs. moorings across the mouth of the East Passage of Narragansett Bay



Nesting..

we've got a problem Houston

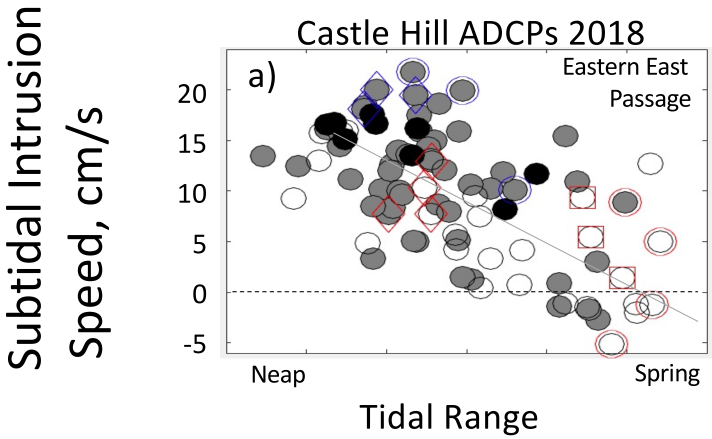


Presently OSOM-Model cannot provide accurate forcing information for higher resolution, nested models of Narragansett Bay and its impacted embayments/rivers.

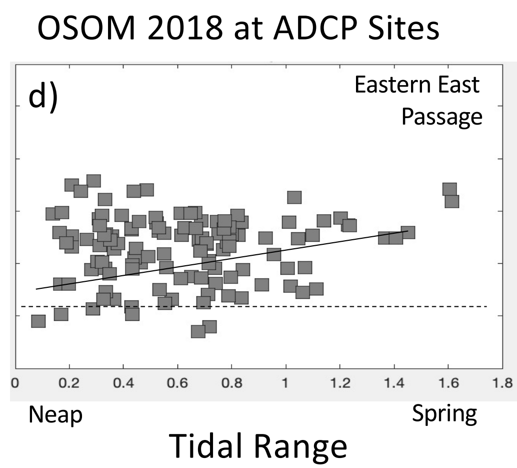
OSOM misses the functional relationships between mouth exchange and physical drivers.

New coastal access facility needed to provide the next generation data sets for accurate modeling tools.

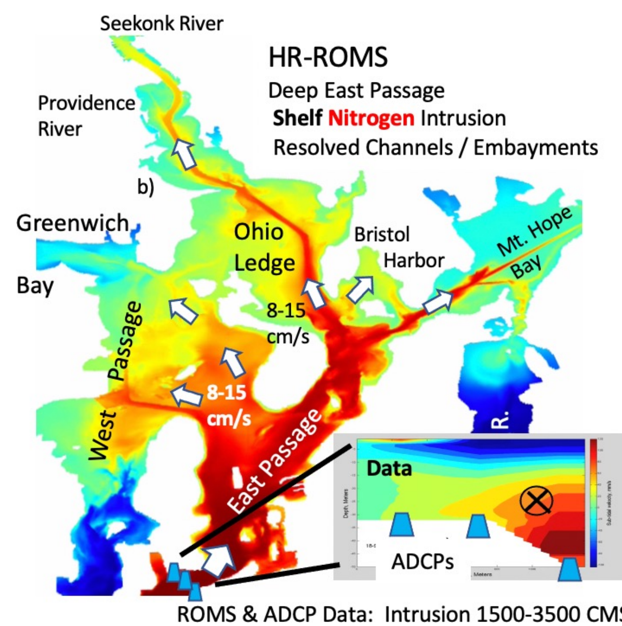
Deep Intrusion rates vs. location vs Spring/Neap



DATA



OSOM Model

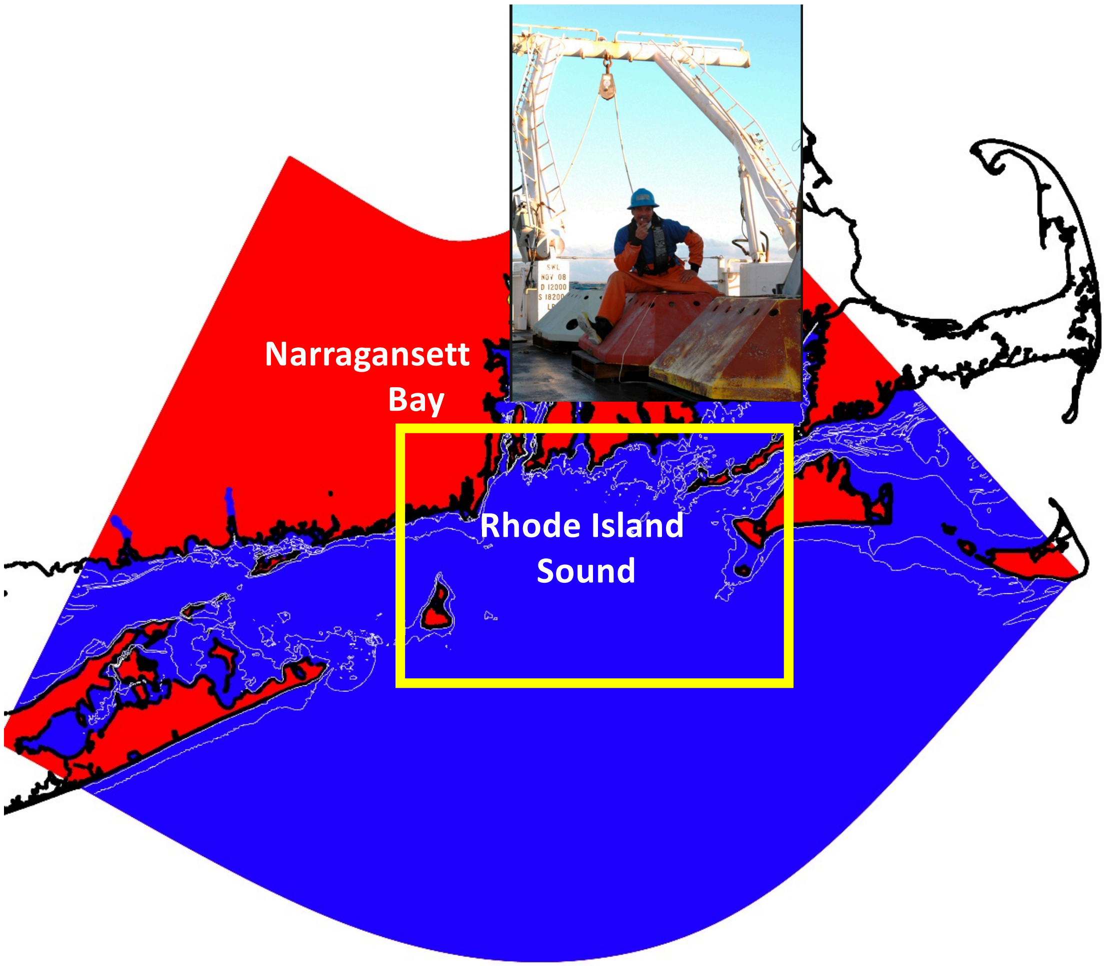


Essential Next Step Need for Narragansett Bay Nitrogen Dynamics

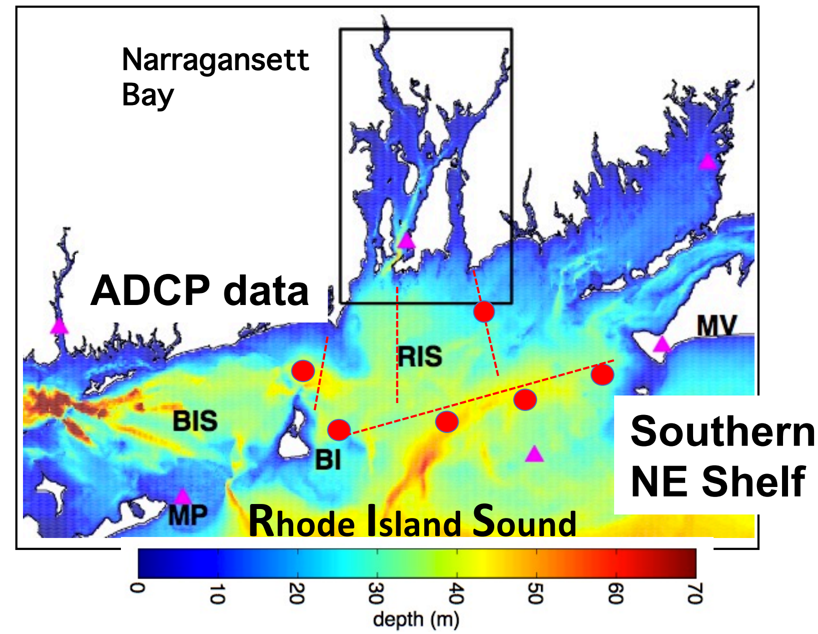
OSOM does very poorly at MOUTH of Narragansett Bay (shown above)

OSOM also very inaccurate in predicting water supply pathways for intrusion waters.

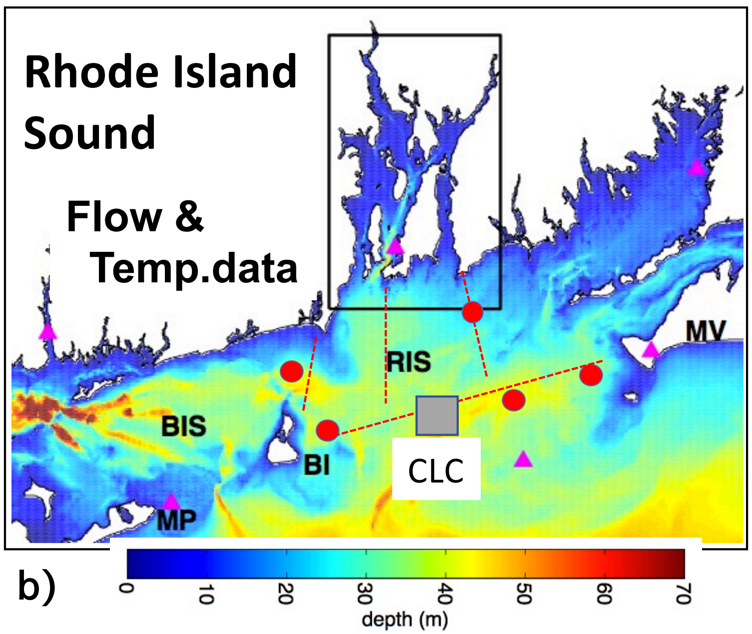
Ocean State Ocean Model: OSOM-ROMS

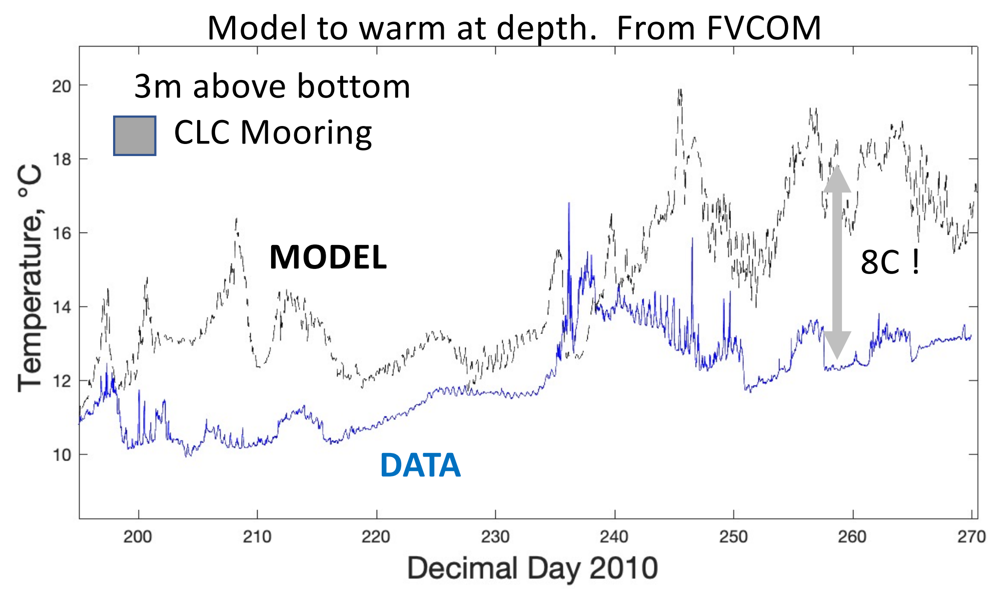


Models Vs. DATA
Rhode Island Sound

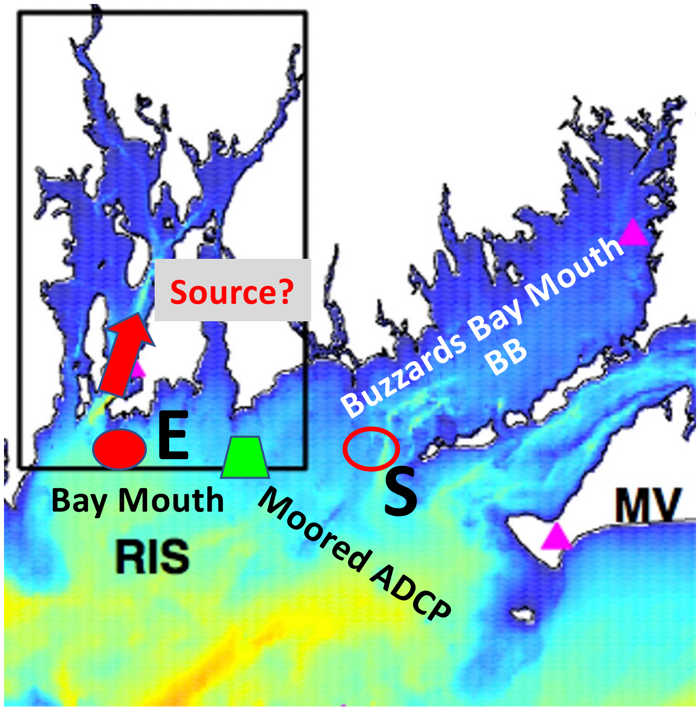


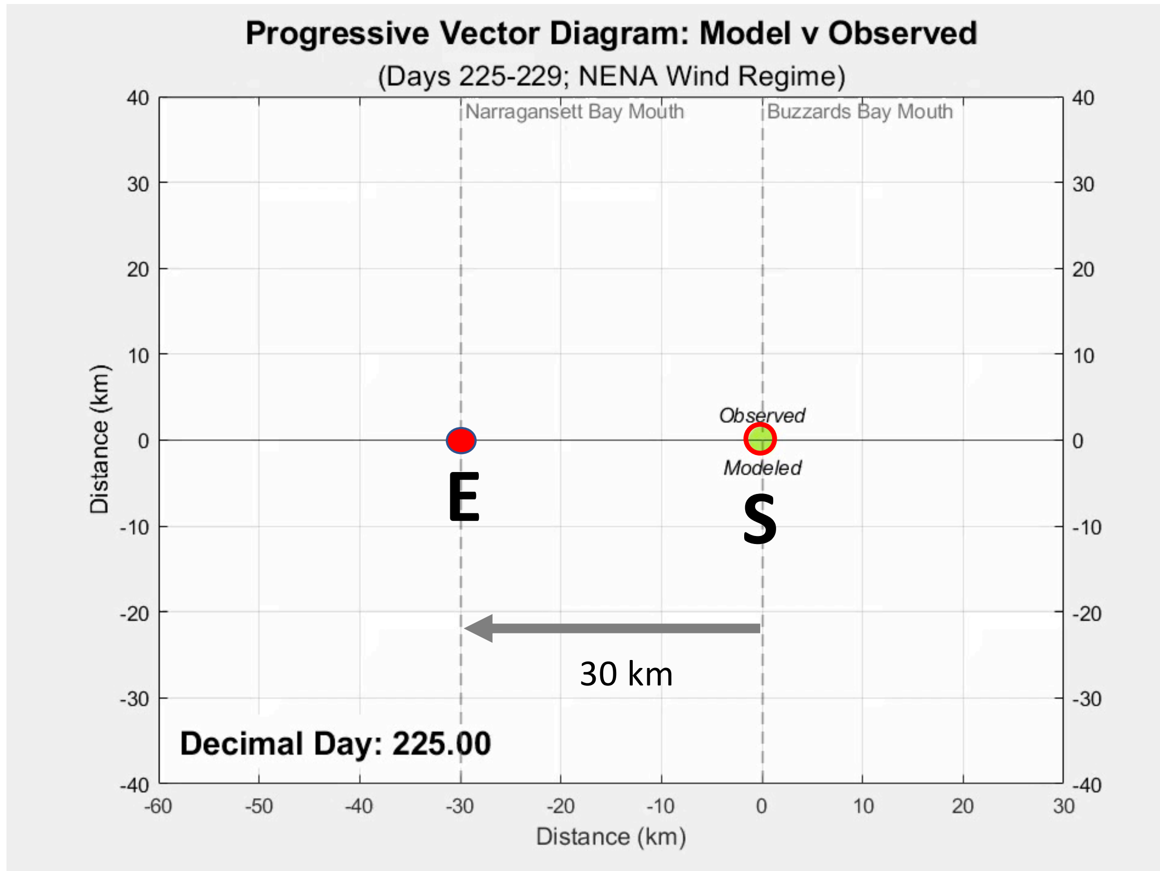
Data-model temperatures & long-term transport way off in Rhode Island Sound





Data-model long-term transport way off in Rhode Island Sound



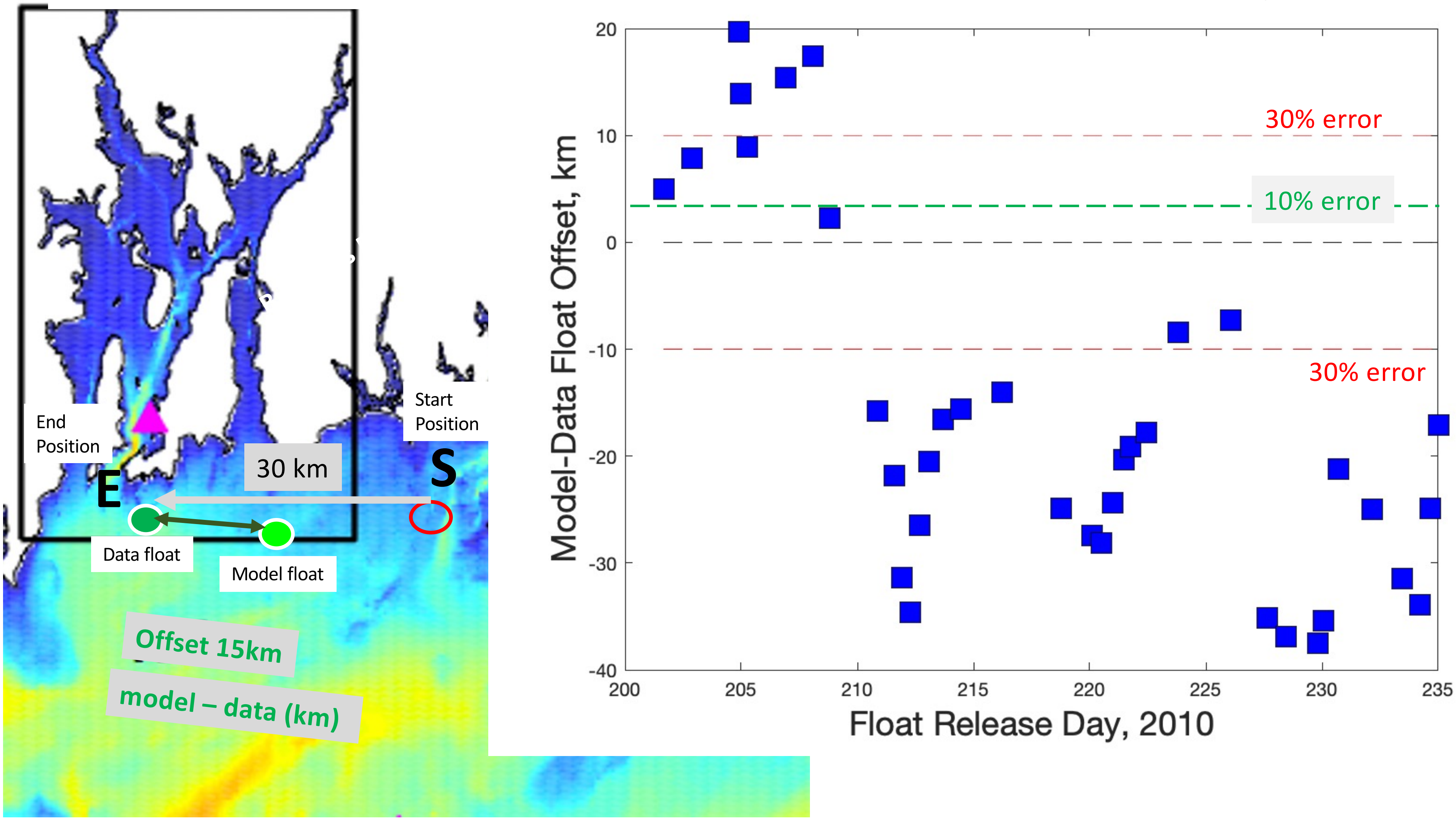


Student J. Lawrence Thesis Goal:
Role of BB flux to Bay Mouth?

Data-model validation: OSOM Model sub-tidal transport not usable for this study

Progressive Vector / Float Trajectories highlight Data-Model subtidal mismatches

Distance between model advected float - data advected float (when data float arrives at Bay Mouth)



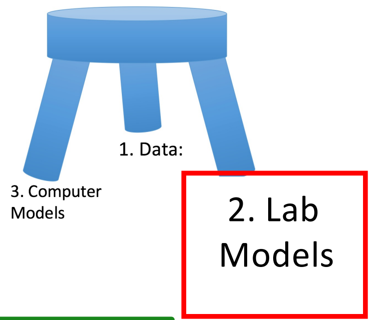
ROMS-3: Significant improvement on eddy/gyre circulation channel vs shoals vs 100 million physics data in Providence River (RI).

Reproduce huge energy difference channel vs Edgewood Shoal.

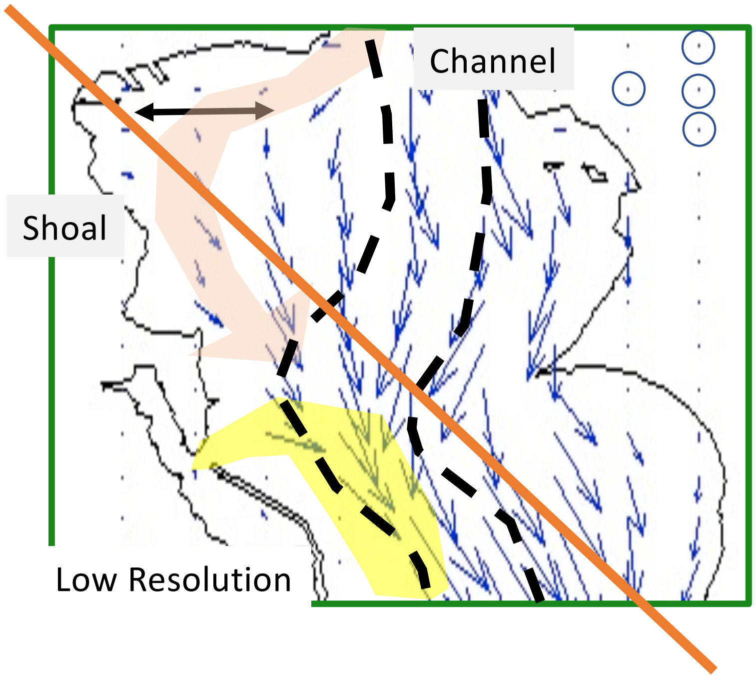
Best model estimate for flushing dynamics (closer to Lab Models)

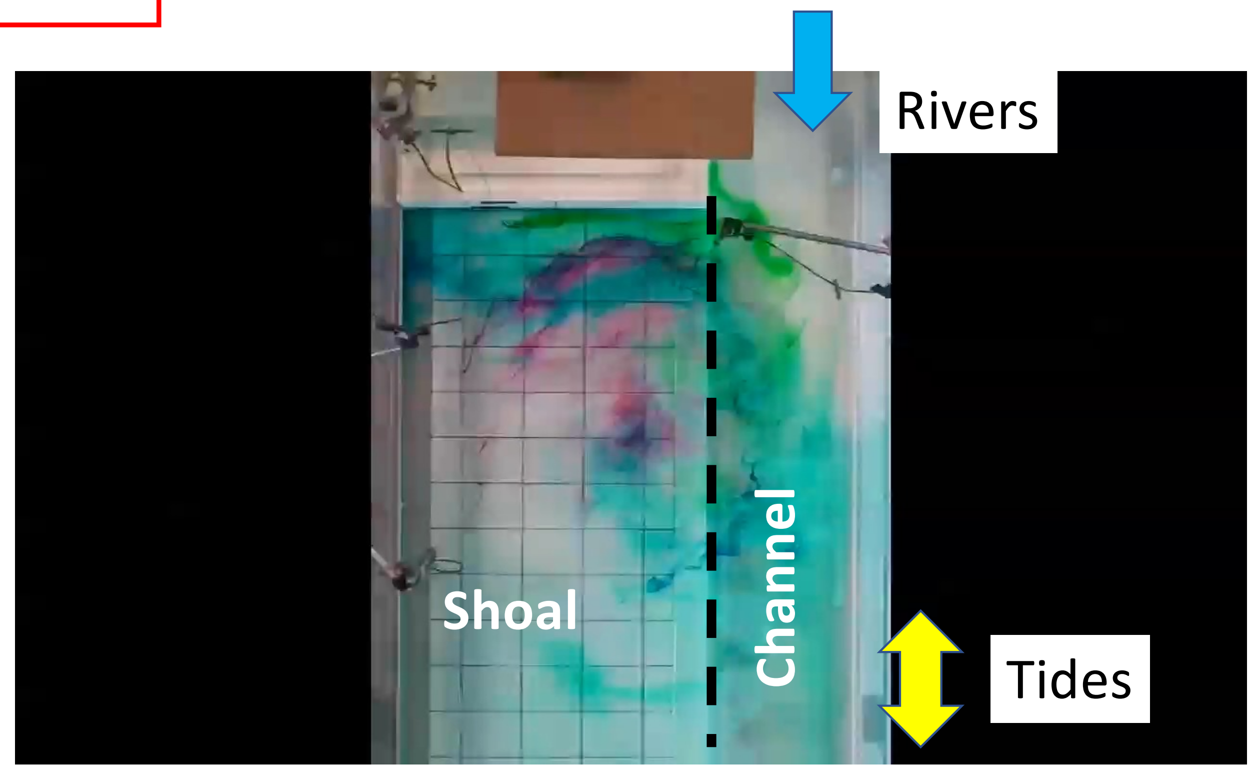
Does ROMS #1 simulate real flows?

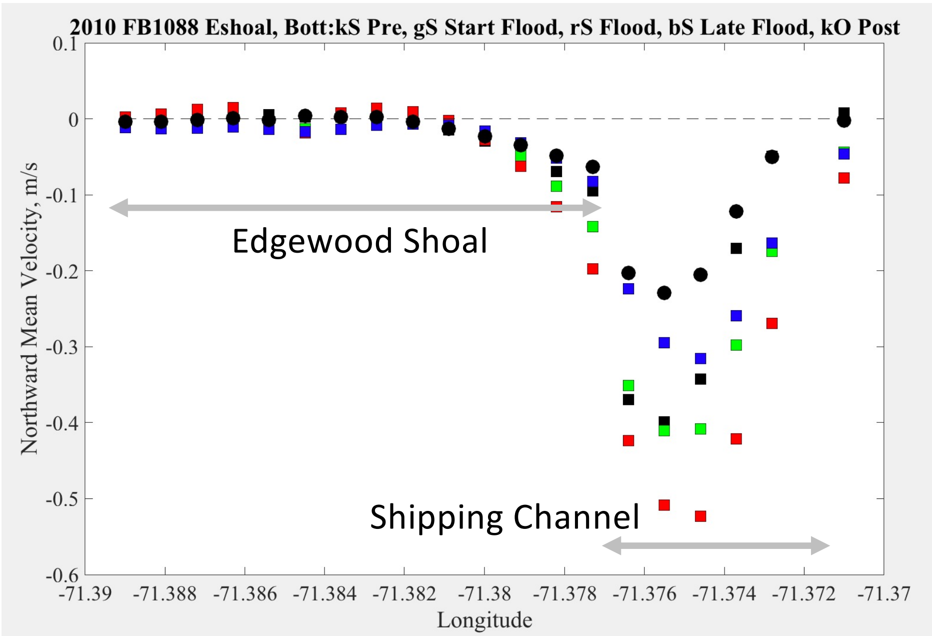
Is ROMS #1 useful?



Lab Model of Providence River Flushing:
Real fluid, "scaled" to estuary.







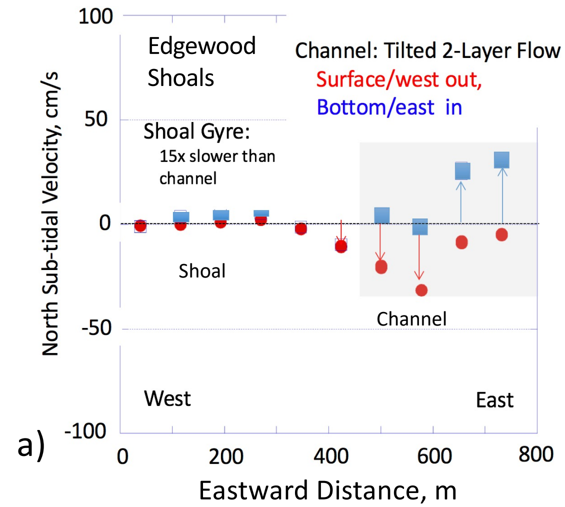
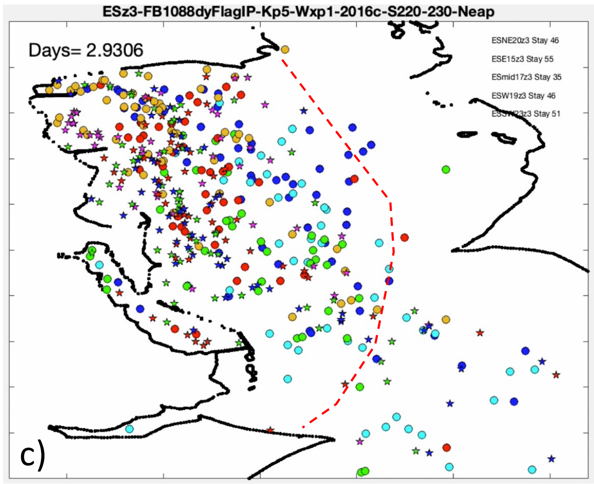
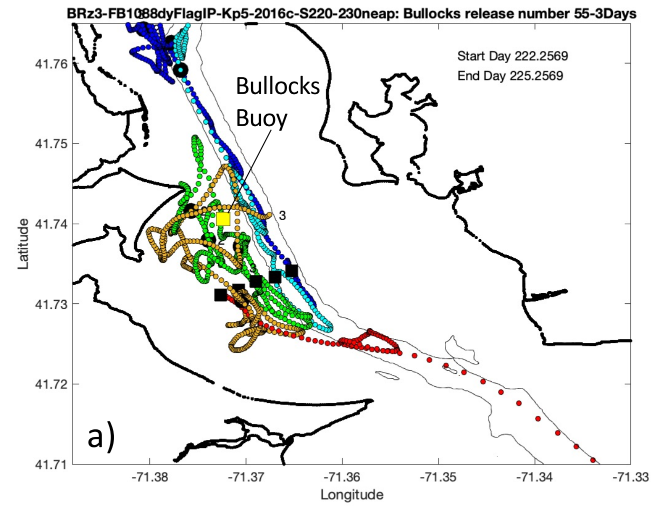


Figure 42. Plot of FB-ROMS-1088 model residual northward flows versus longitudinal position across the shoal for periods before, during and after the great flood of 2010. The high resolution model represents the sharp hydrodynamic transition between channel and shoal for all stages. As in figure 41, colors represent averages taken over: days 67-84 or normal, pre-flood conditions (black squares), days 85-90 during the lead up to the flood (green squares), days 87-91 during peak flood (red squares) and days 91-97 during the recovery or return to normal post-flood (blue squares). Conditions well past the flood event are shown as black circles (days 98-117).





High resolution = better resolved gyres & eddies

Matches observed extremes in channel vs. shoal circulation energy.

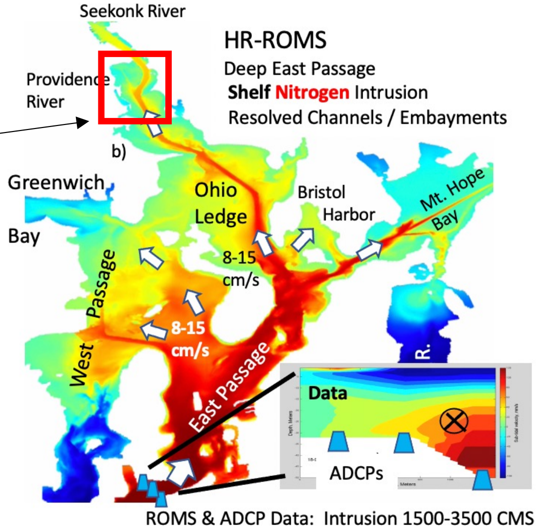
Flushing of passive drifters in High resolution Narragansett Bay ROMS validated against data from 30 current meter moorings

Versus

Coarser-grid OSOM model flushing of drifters for same runs/same release sites.

Edgewood Shoals of the Providence River.

Suffers chronic hypoxia.



Available validation data:

14 hour-long, underway ADCP cruises. Tidal & sub-tidal circulation.
5 transects covered, 6 times per tide cycle, 2 cruises per season, 4 seasons .

37 Seahorse current meters, 3 month deployent, 1 min sample freq.,
4 moored ADCPs: 4 month deployment, 5 min sampling freq.

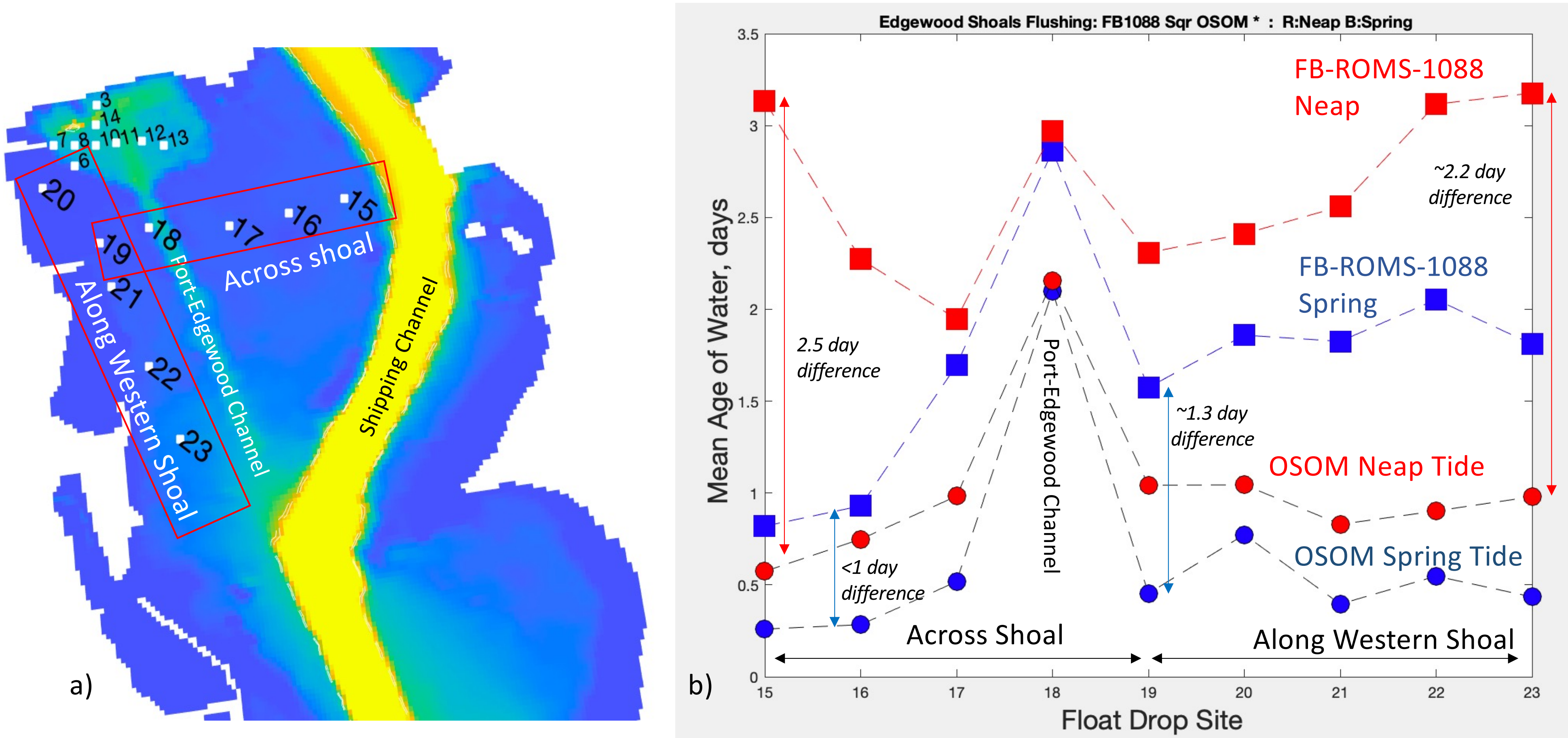
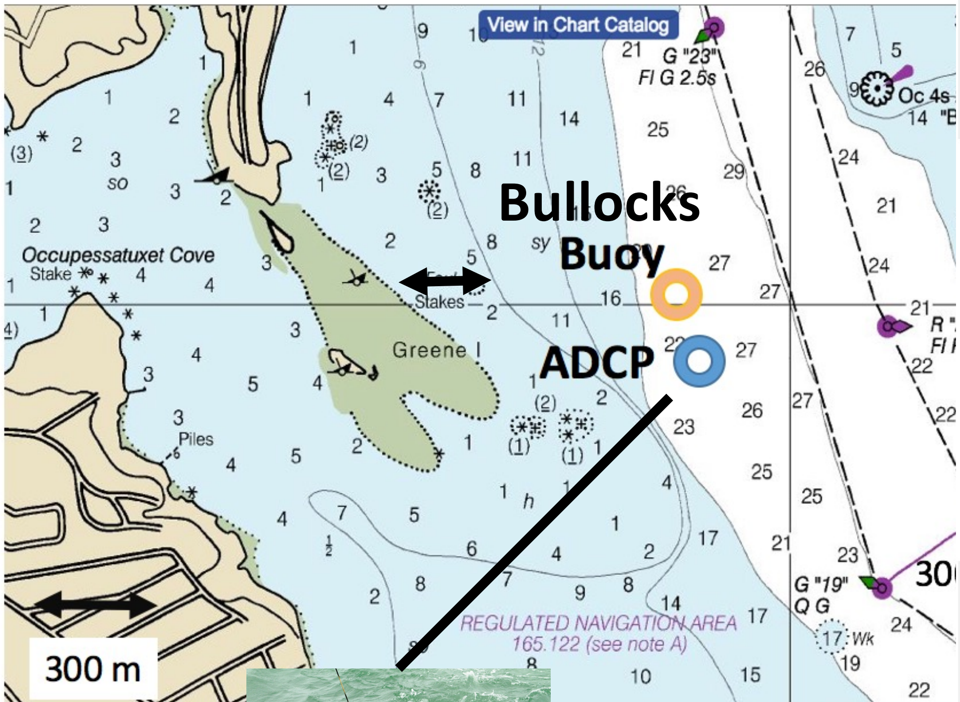
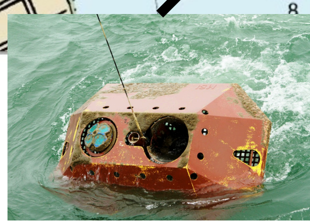


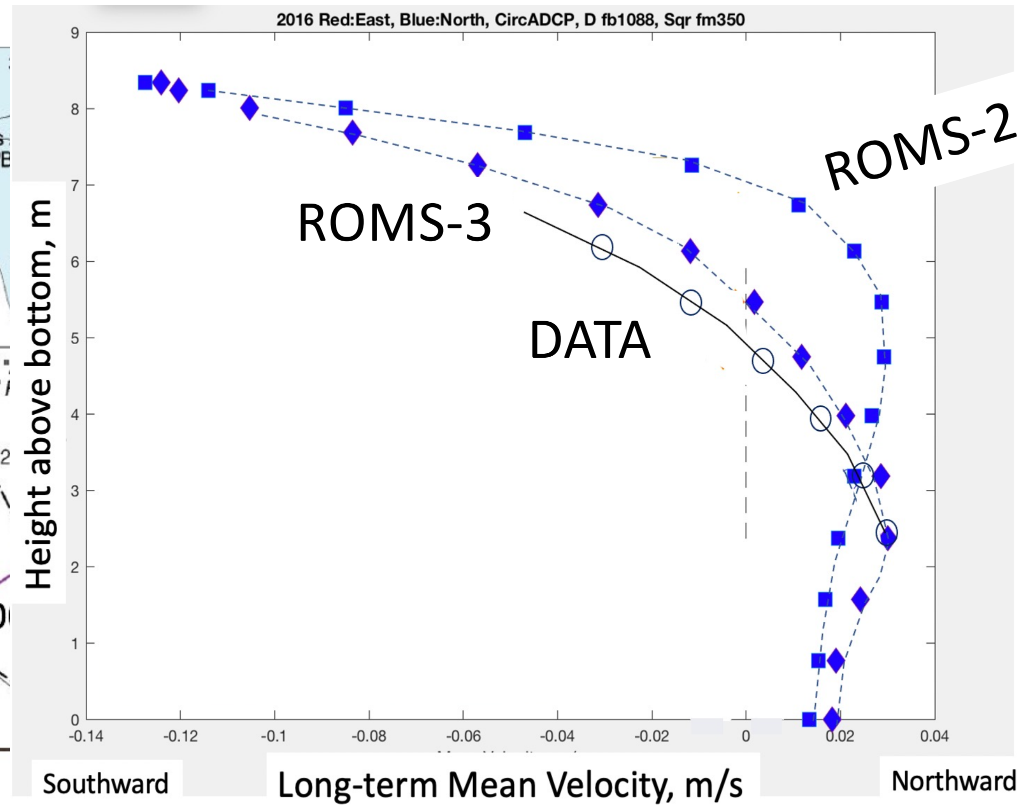
Figure 74. a) Similar map of station release sites. These results are for sites 15-19, from east to west across the shoal and 20-23 running north-south along the western shore of the shoals. b) Here spring versus neap conditions are shown to have a larger impact on mean water ages. Neap tides are consistently larger ages, from ~0.5 days over most of the areas to 2 days with floats released near the shoal-channel edge. Floats released into the Port Edgewood Channel also show larger retention ages. These results show significant retention differences between the higher resolution FB-ROMS-1088 and the lower resolution OSOM models. During neap conditions, OSOM predicts faster flushing by 1-2.5 days compared with the higher resolution model.

ROMS-3 large improvements in circulation physics channels, shoals & embayments.





ADCP Data:
Late Summer 2016



We need to be careful with data sampling bias.

- Single long term moorings can miss lateral variability
- Moorings often placed in super-complex hydrodynamic transition regions.

We need to be careful with data sampling bias.

Single long term moorings can miss lateral variability
Moorings often placed in super-complex hydrodynamic transition regions.