Recent Advances on Unstructured-grid SCHISM Model and its Implication to Triblet Connection

by

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Outline:

I. What and Why the unstructured grid modeling?

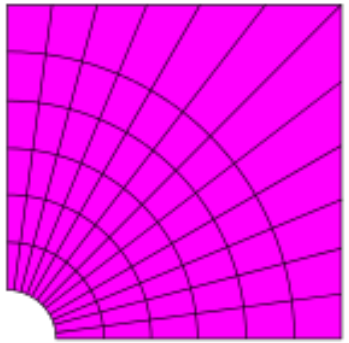
II. Examples of cross-scale applications by SCHISM

A. Impacts of bridge structure on estuarine circulation in the lower James River

B. Hydrodynamic and water quality modeling in the Chester River

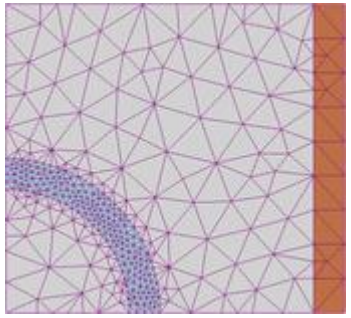
III. Summary

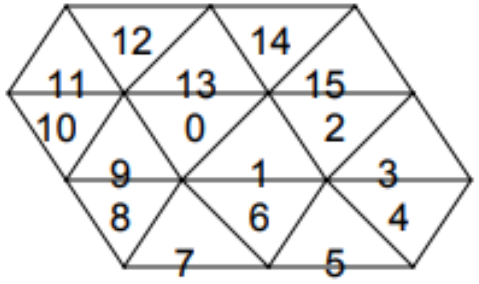
I. What and Why the unstructured grid modeling?



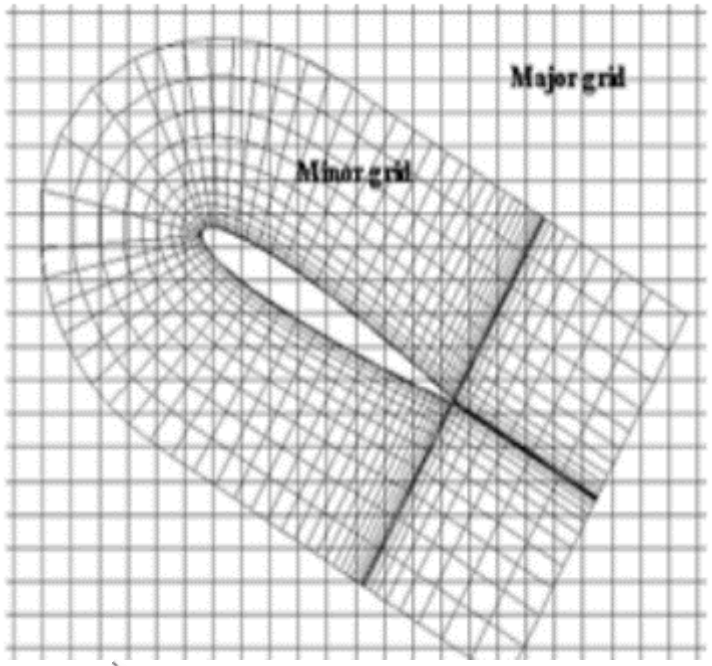
$i-1$	$j+1$	$i+1, j+1$	$i+1 j+1$
$i-1 j$	ij	$i+1 j$	
$i-1 j-1$	$ij-1$	$i+ij-1$	

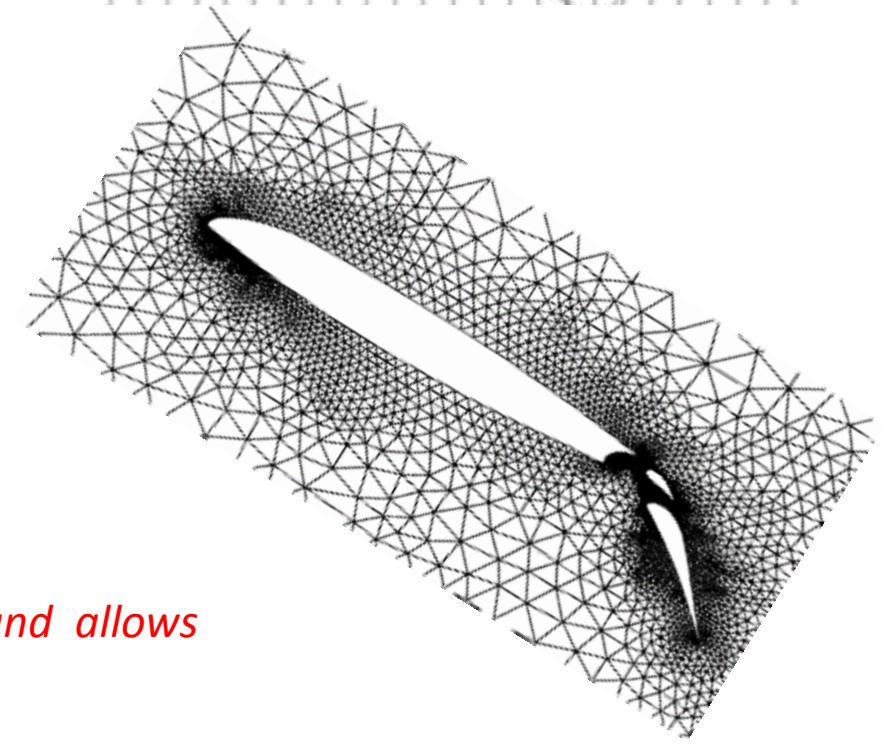
$U(i,j) \Leftarrow$ data stored in a "2-D" array





$U(i) \Leftarrow$ data stored in a "1-D" array

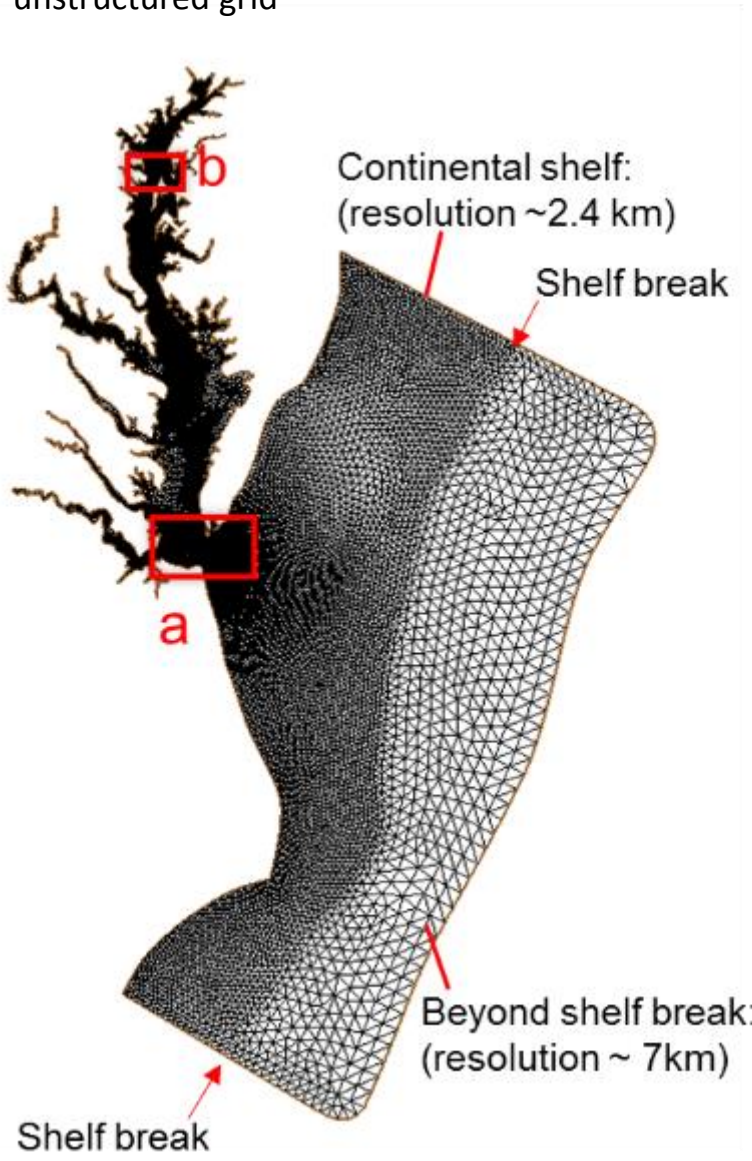




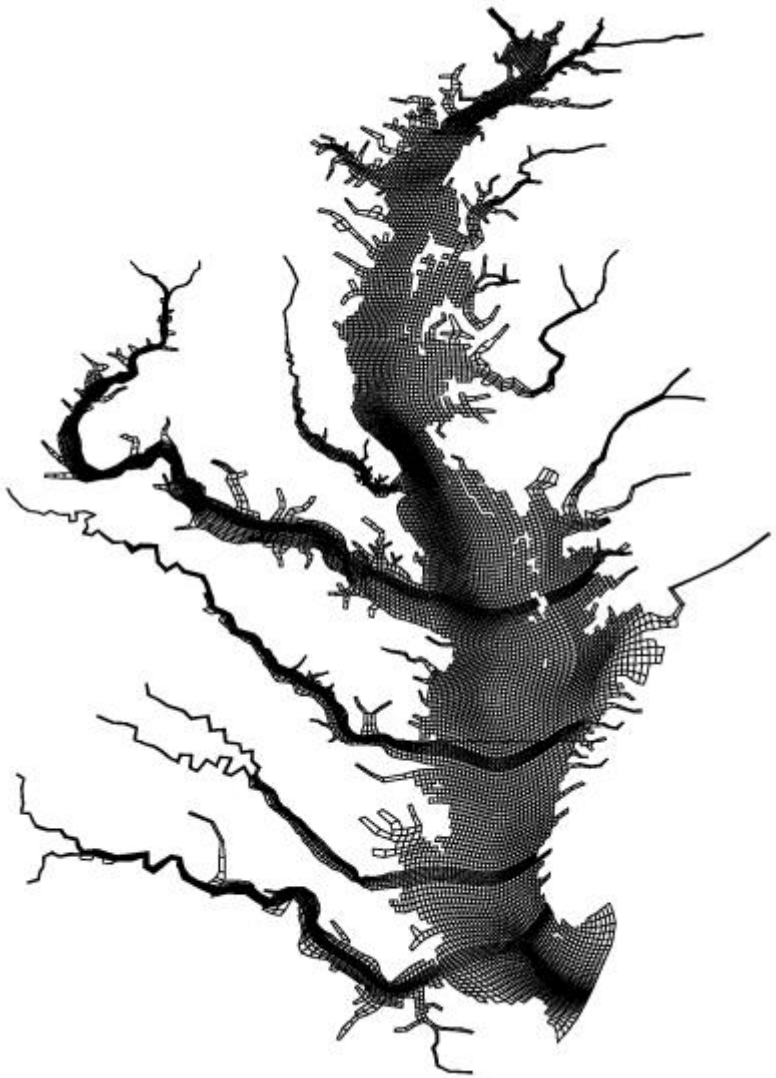
Unstructured grid has the Flexibility to fit the boundary better and allows locally refinable resolution !!!!!

Horizontal unstructured-grid resolves tributaries

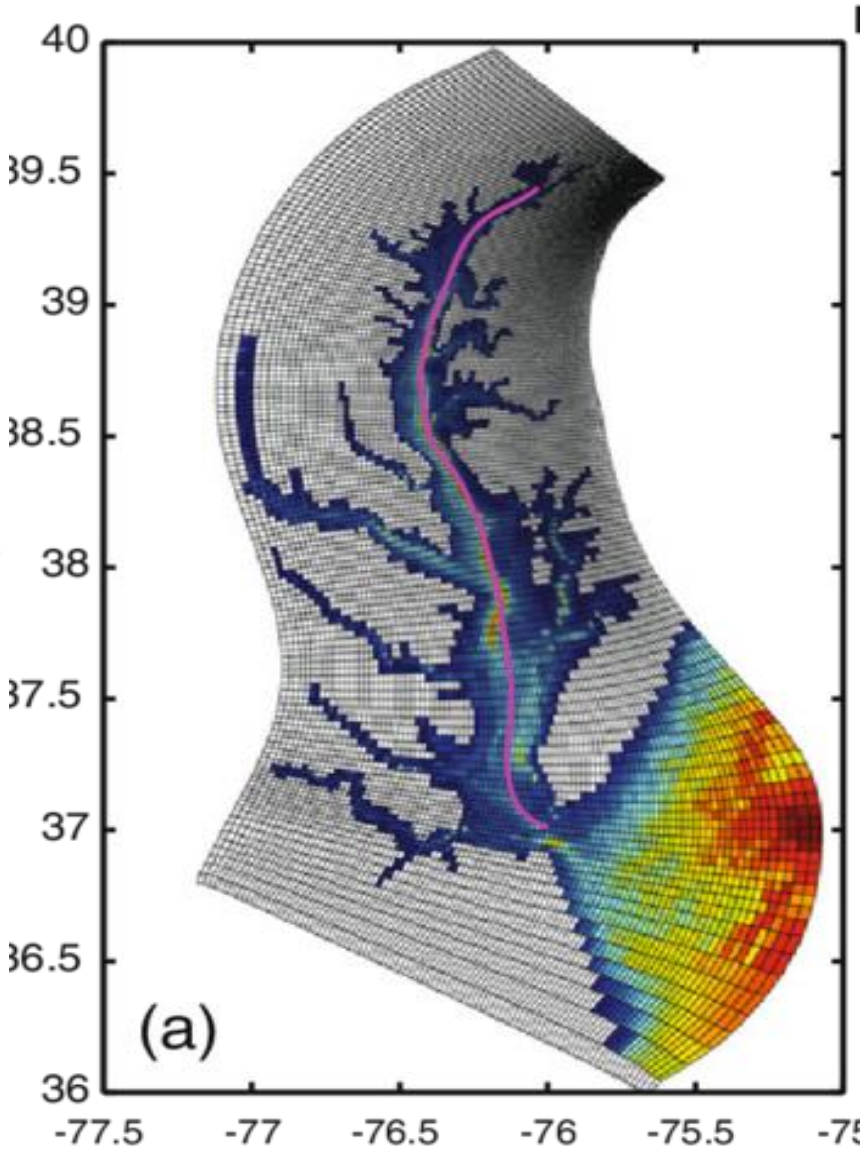
SCHIMSM – mixed triangular and quadrilateral unstructured grid



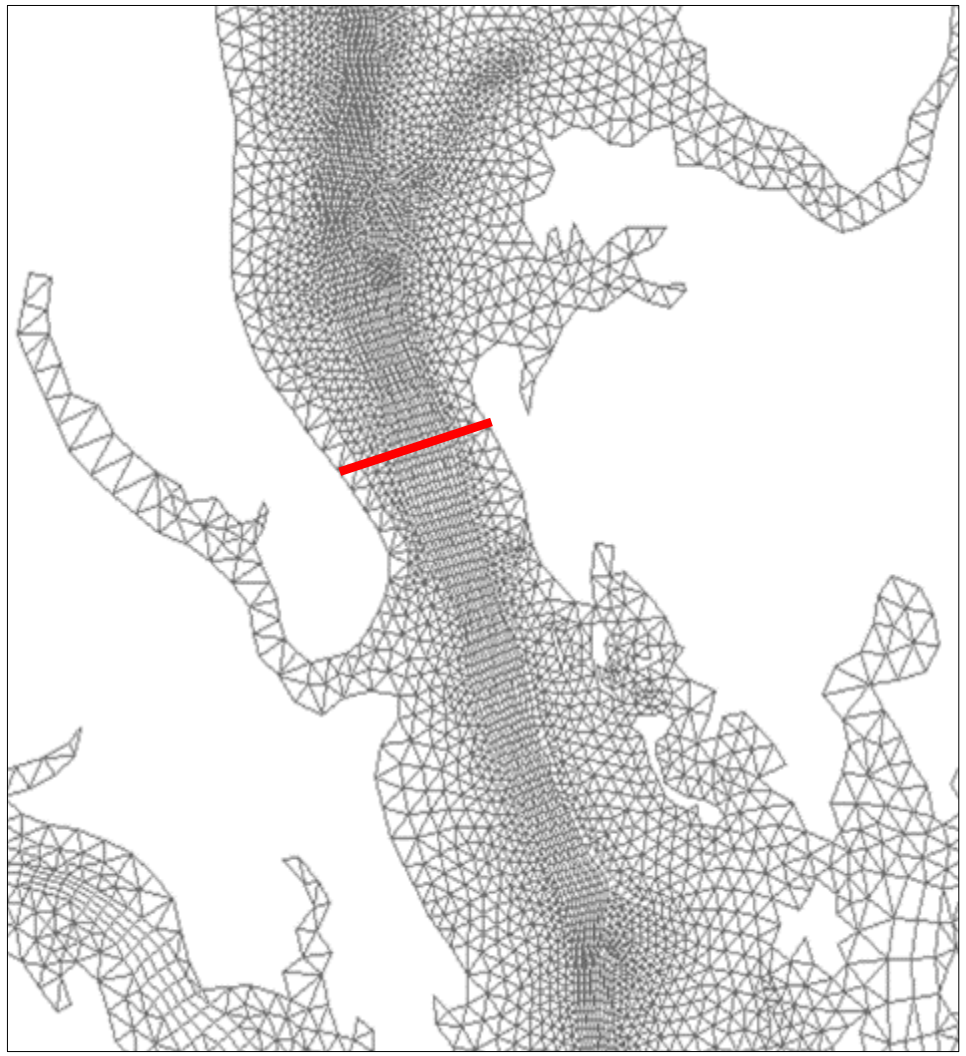
CH3D - Structured curvilinear coordinate



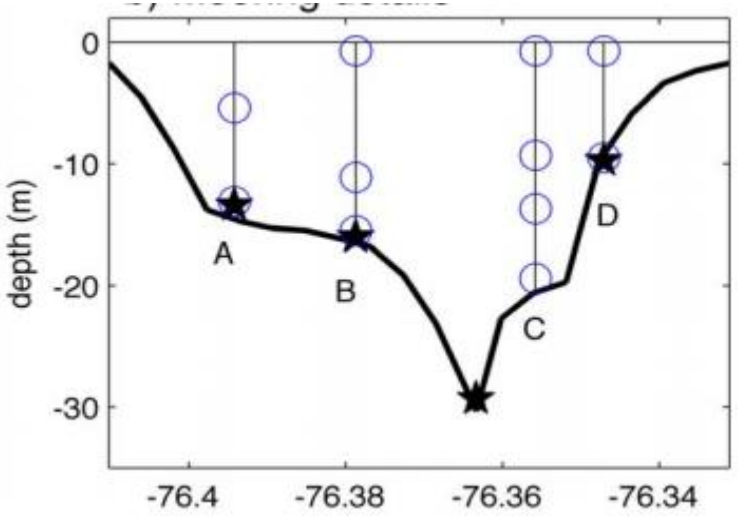
CHES_ROMS - Structured orthogonal grid



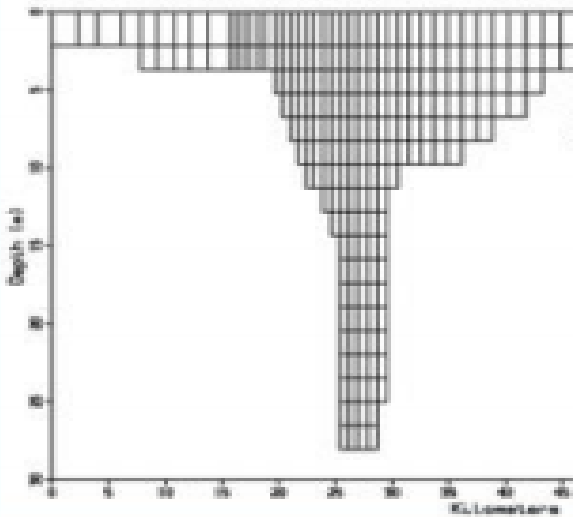
New vertical coordinate resolves cross-sectional geometry



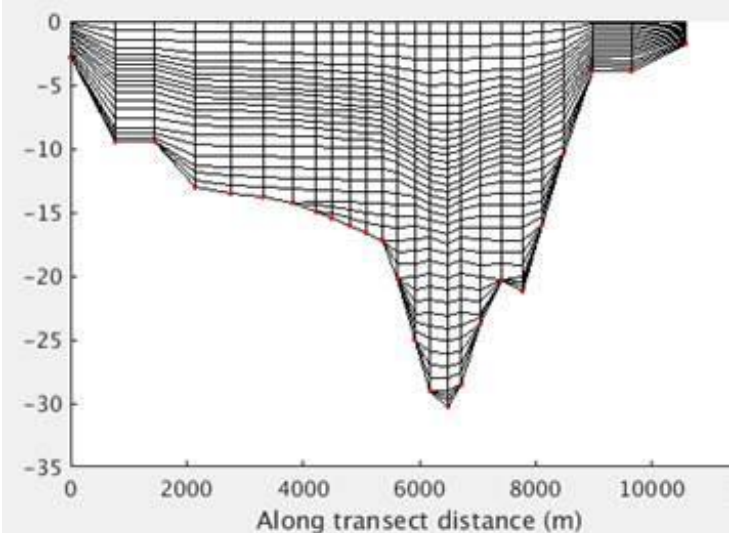
Field measurement



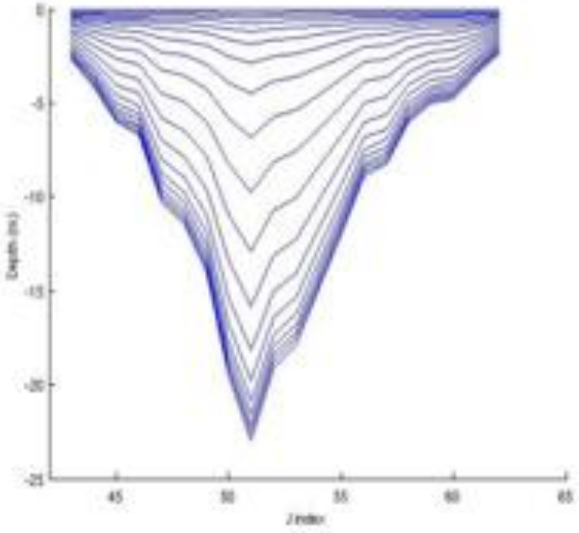
CH3D



SCHISM



CHES-ROMS



Description of a New Localized Sigma Coordinate with shaved cell (LSC^2)

Ocean Modelling 85 (2015) 16–31

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

A new vertical coordinate system for a 3D unstructured-grid model

Yinglong J. Zhang [a,*], Eli Ateljevich [b], Hao-Cheng Yu [d], Chin H. Wu [c], Jason C.S. Yu [d]

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[b] California Department of Water Resource, 1416 Ninth St Rm 215-4, Sacramento, CA 95814, USA
[c] College of Engineering, Department Civil & Environmental Engineering, University of Wisconsin – Madison, 1415 Engineering Dr, Madison, WI 53706, USA
[d] Dept. of Marine Environment and Engineering, National Sun Yat-Sen University, 70 Lien-Hai Road, Kaohsiung 80424, Taiwan

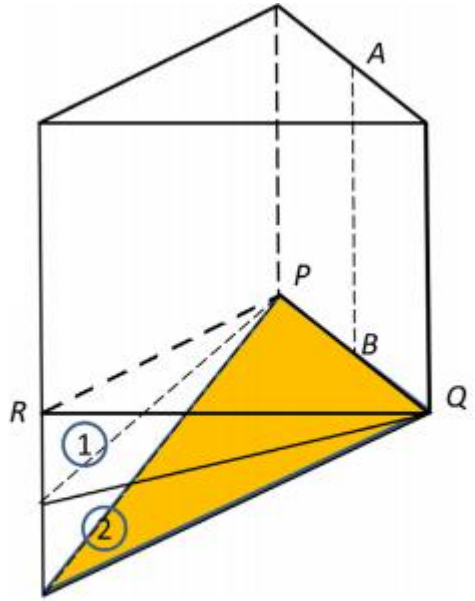
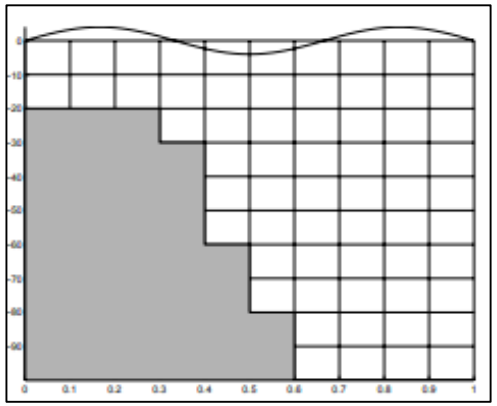
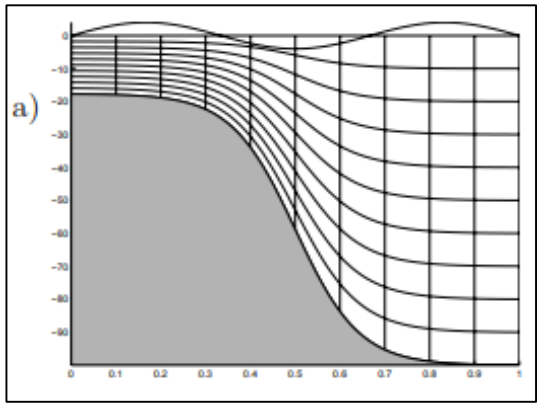


Fig. 2. Conceptual sketch of LSC^2. Two degenerate prisms ("1" and "2") are placed near the bottom to make up the different numbers of levels at 3 nodes (P, Q and R). The heights for the two prisms are degenerate at P and Q. The shaded area is the bottom. Line AB is the bottom-most cell for the momentum equation.

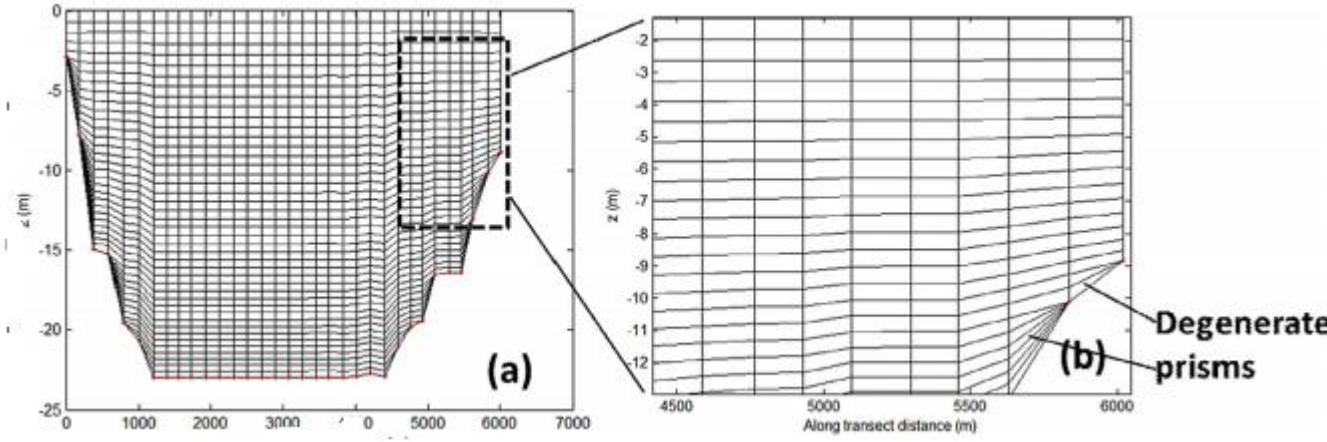
Vertical z-coordinate model



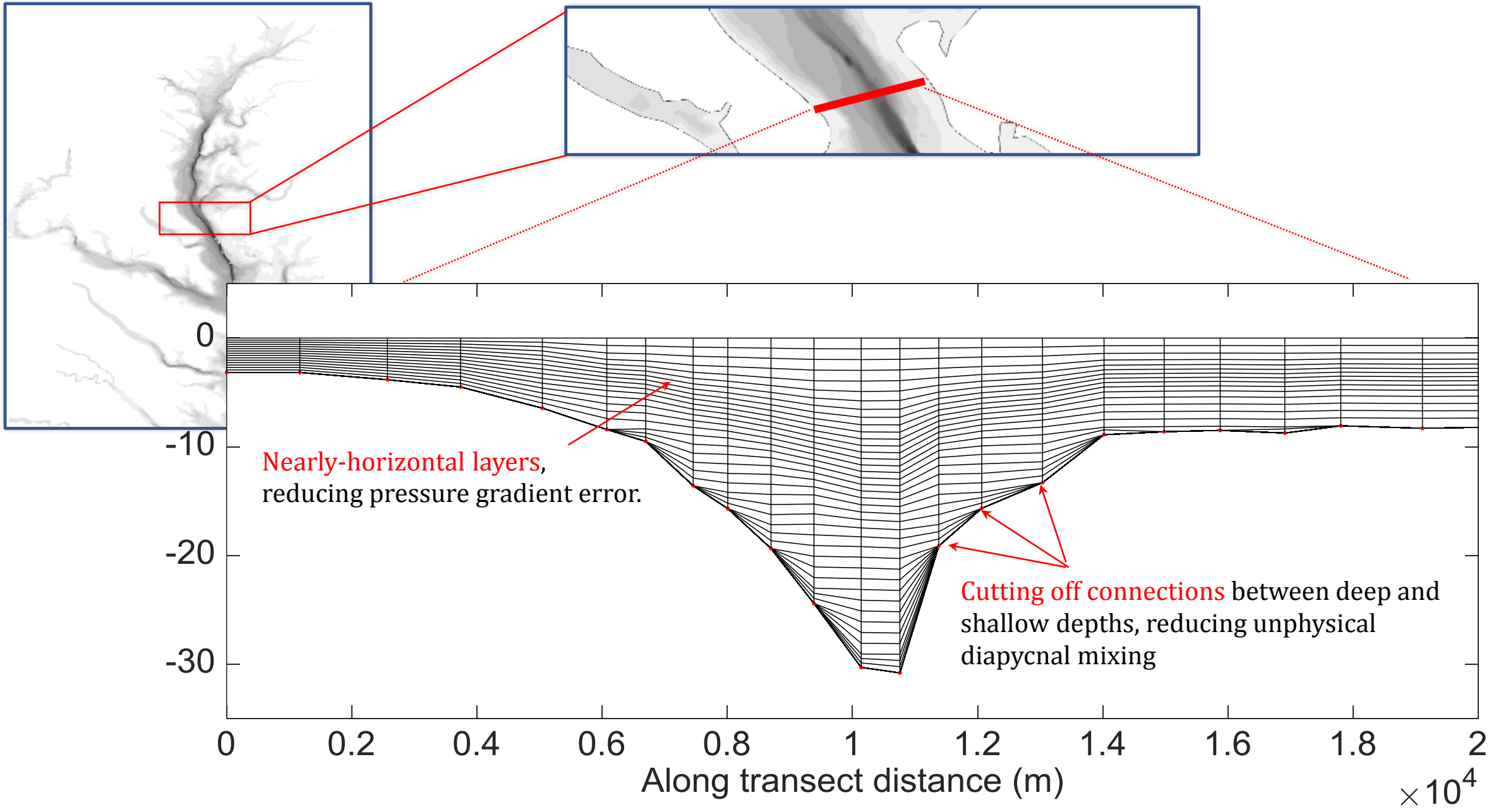
Vertical sigma coordinate



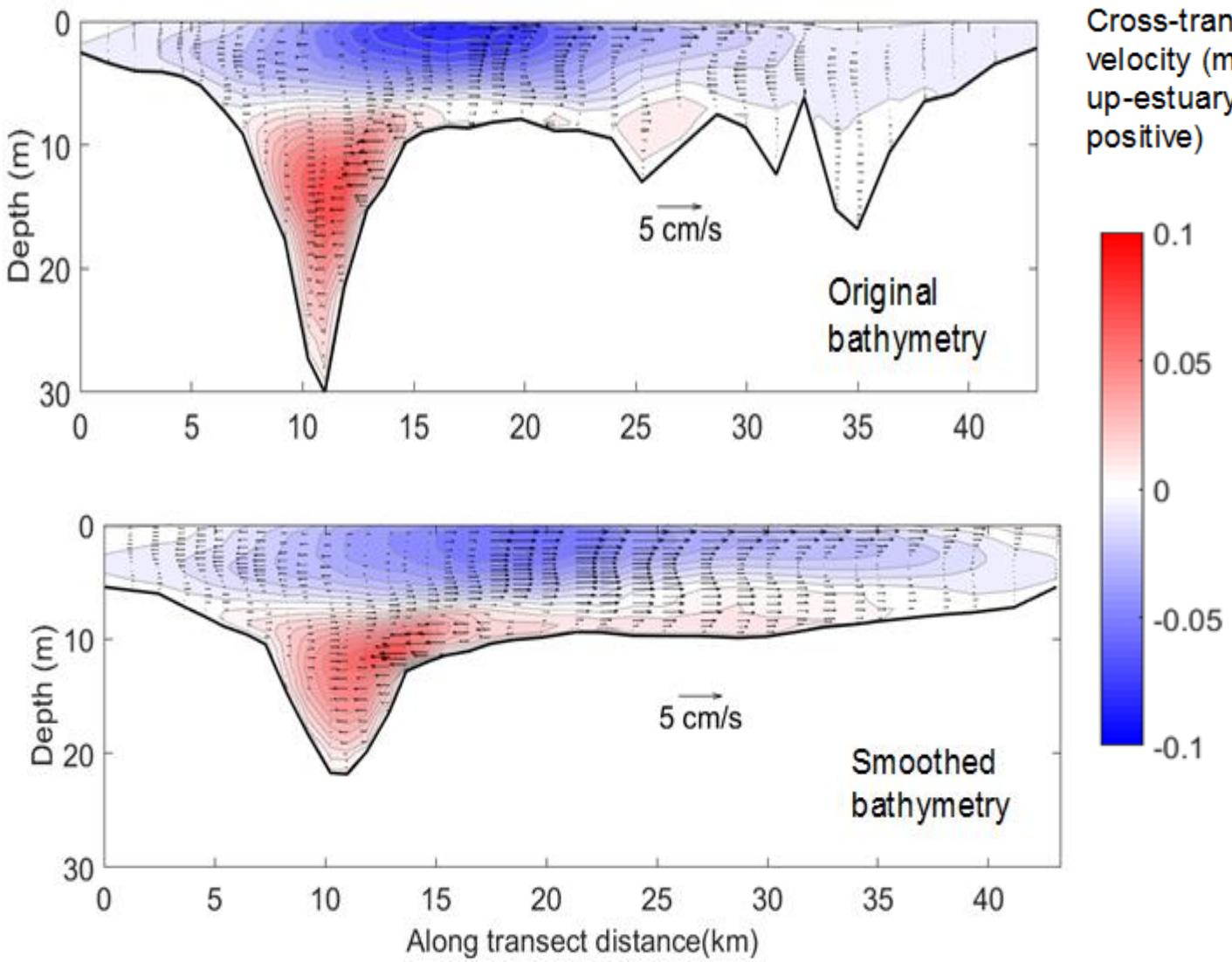
LSC^2



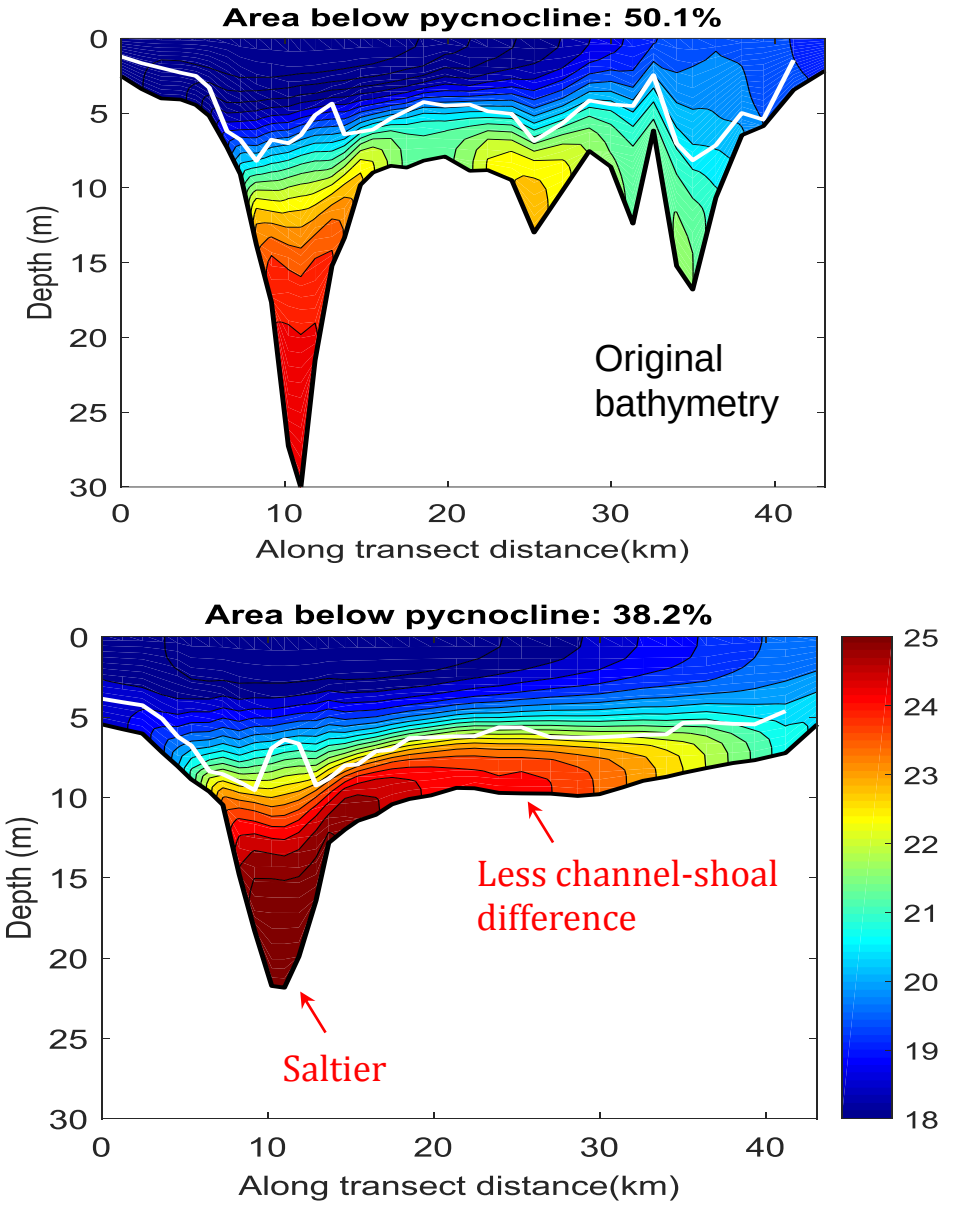
A cross channel transect at mid-Bay using LSC coordinate



Cross section residual velocity



Cross section salinity distribution



*Fei et al. (2018):"A 3D unstructured-grid model for Chesapeake Bay", *Ocean modeling Vol. 127,p16-39.*

II. Examples of cross-scale applications by SCHISM

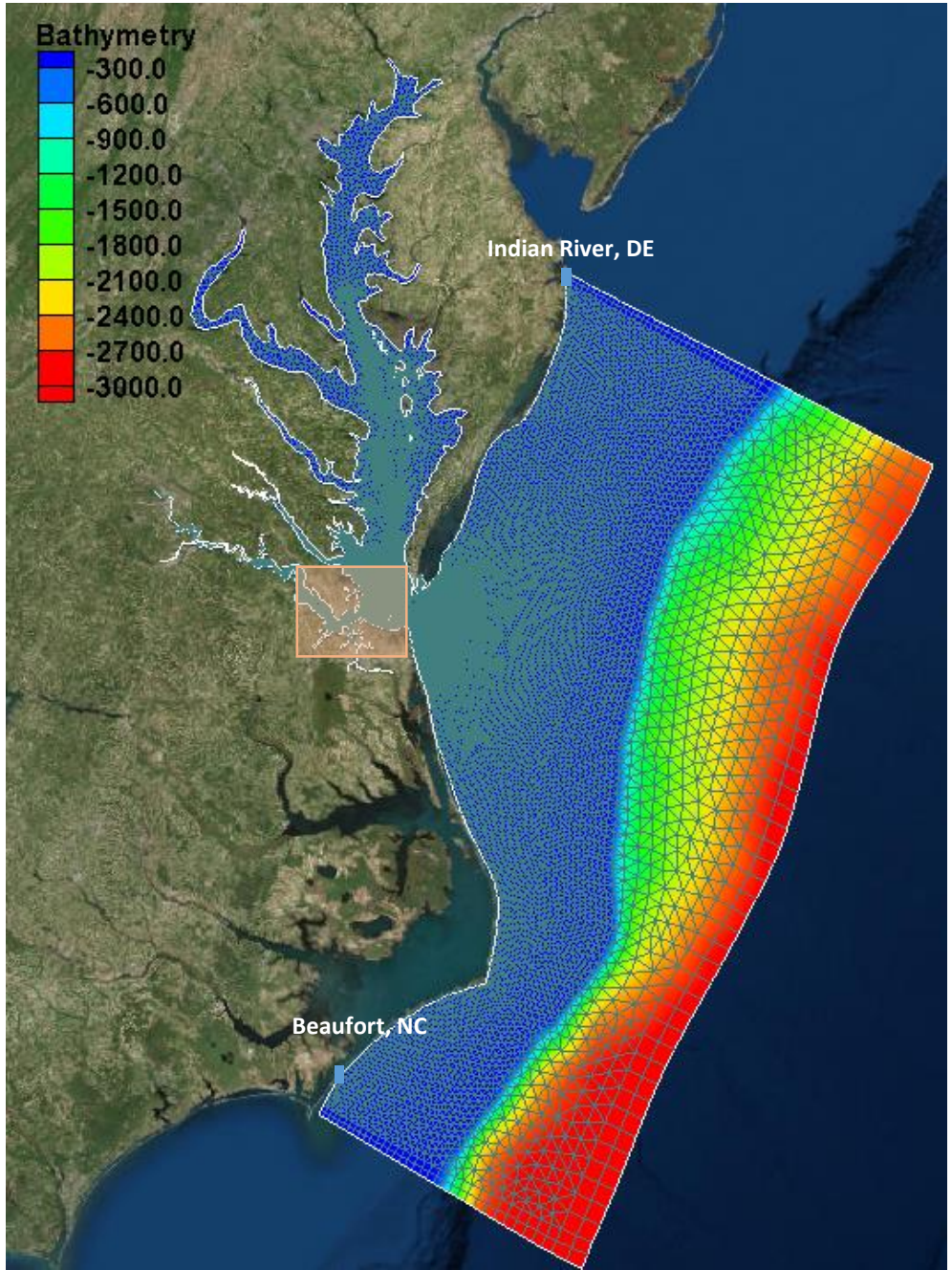
SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) is a new generation 3D baroclinic, unstructured grid, coastal ocean model with the following unique properties:

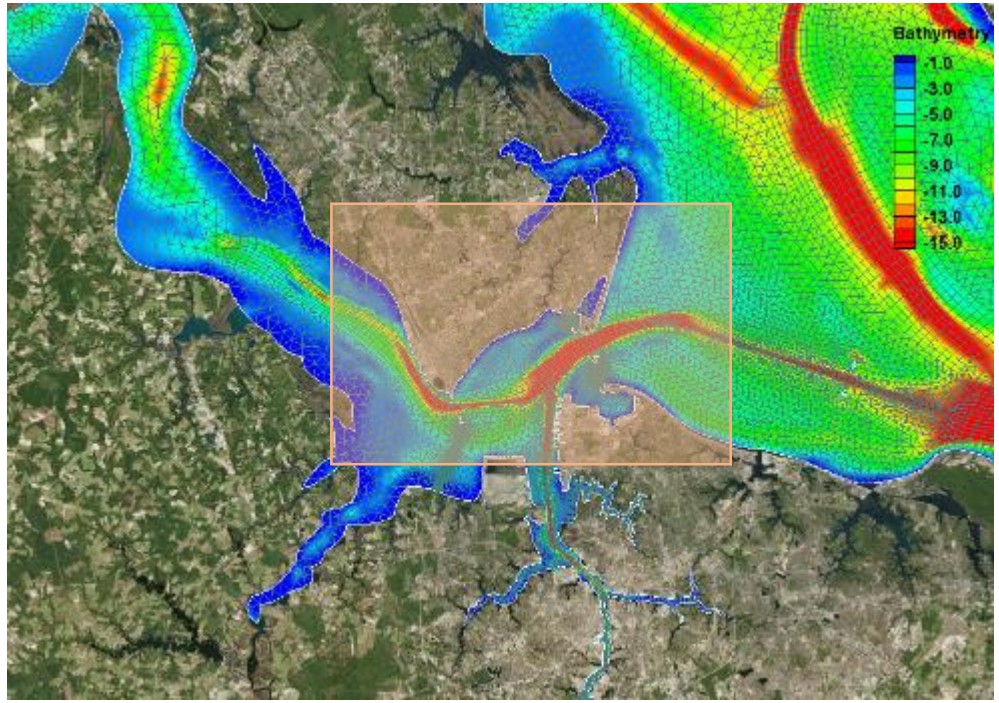
- It uses finite element formulation that allows locally refinement of the grid as it needs;
- Allows mixed triangular and quadrilateral horizontal grids and flexible vertical grid for discretization;
- Includes higher-order schemes for advection in momentum and transport;
- Fully parallelized with domain decomposition (MPI) with good scalability;
- Well-benchmarked inundation scheme for wetting and drying;
- Operationally tested and proven (NOAA, DWR, CWB…)
- Driven by user community needs with Open source http://ccrm.vims.edu/schism/.

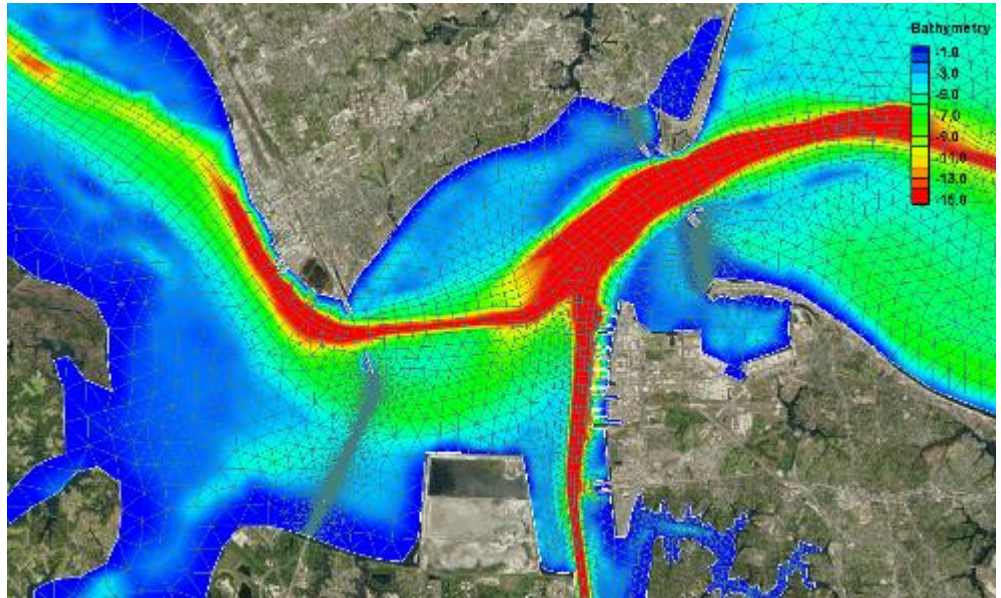
SCHISM

Our mission is to develop a verifiable and comprehensive modeling system for use in the estuarine and coastal ocean application.

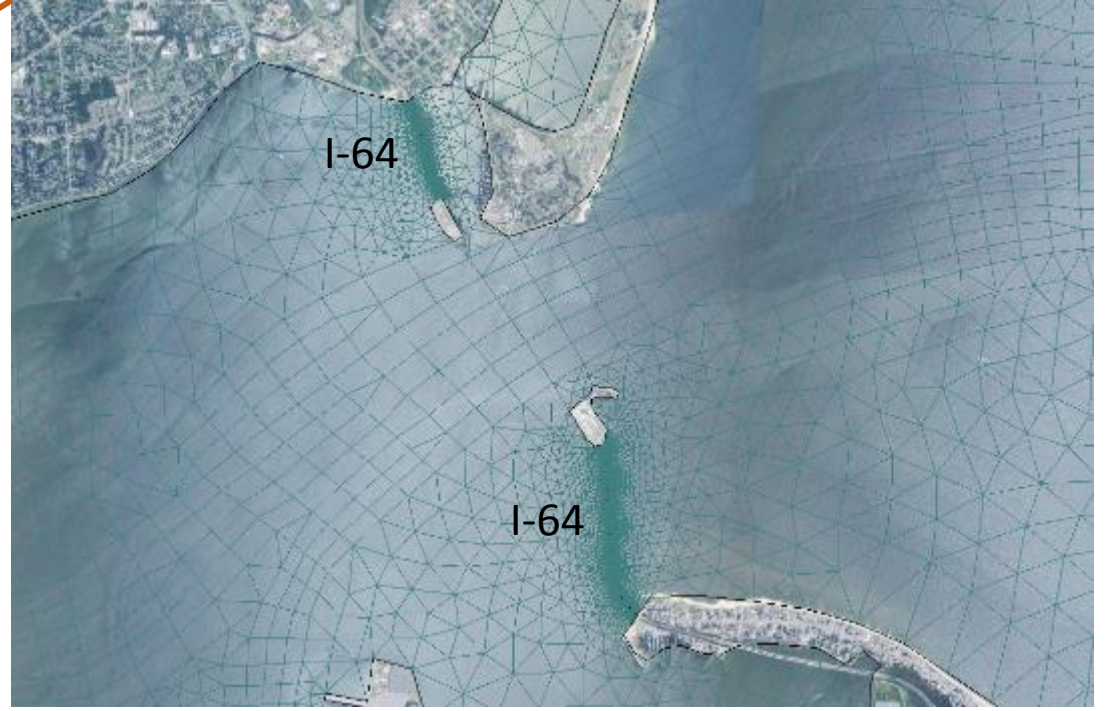
A. Impacts of bridge structure on estuarine circulation in the lower James River

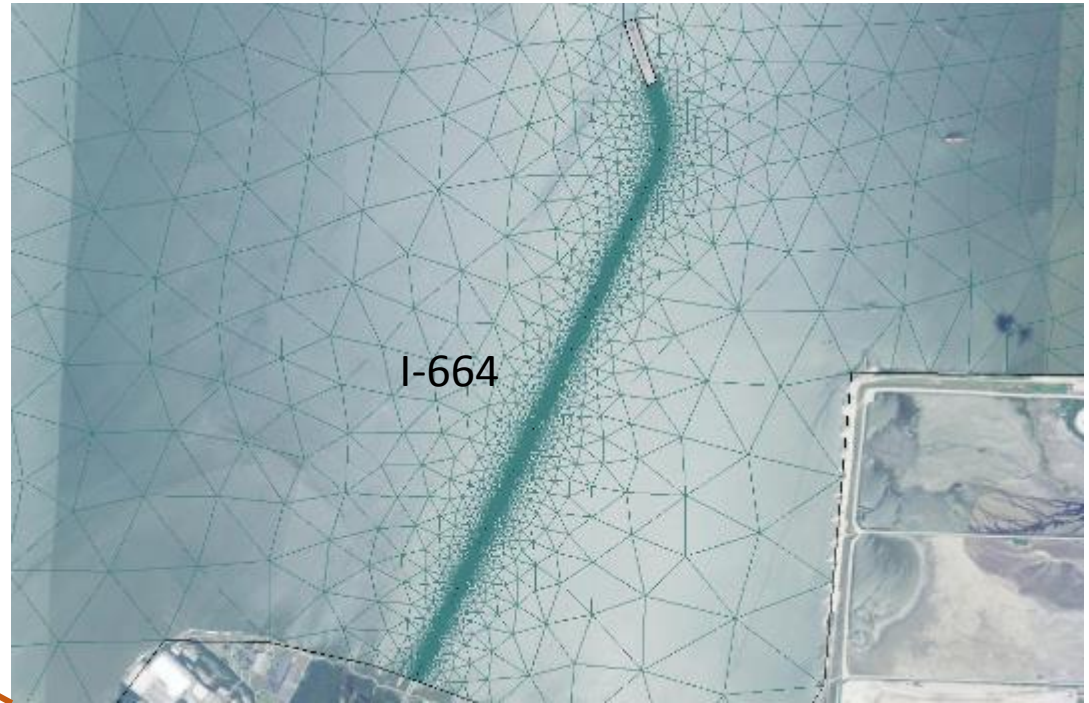


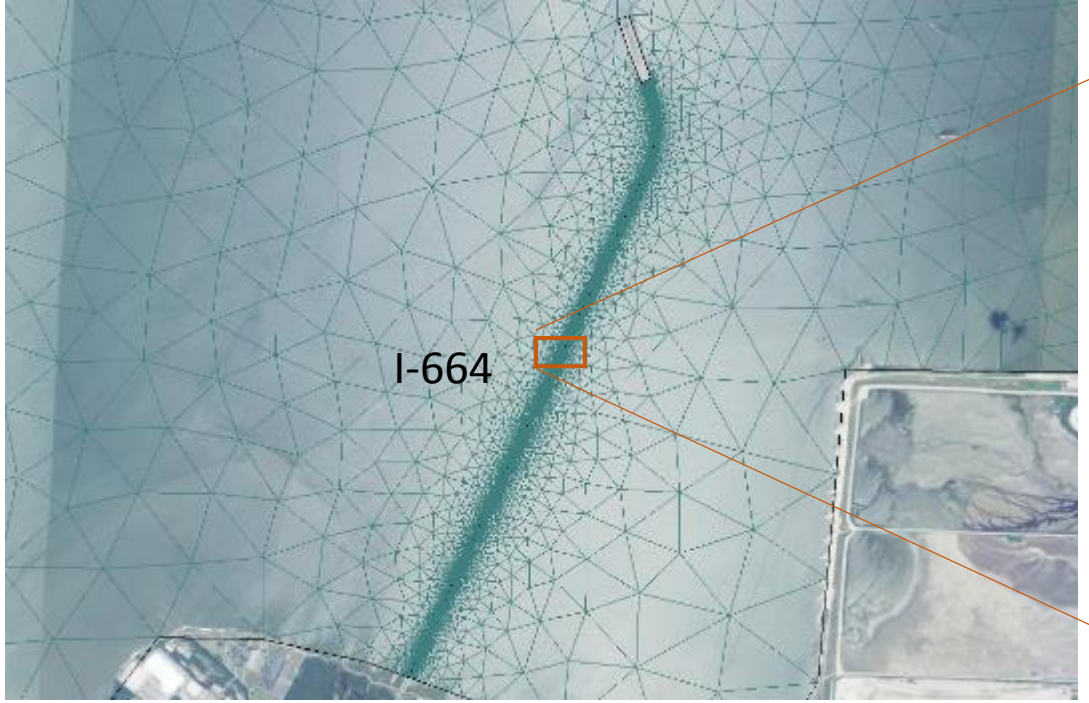


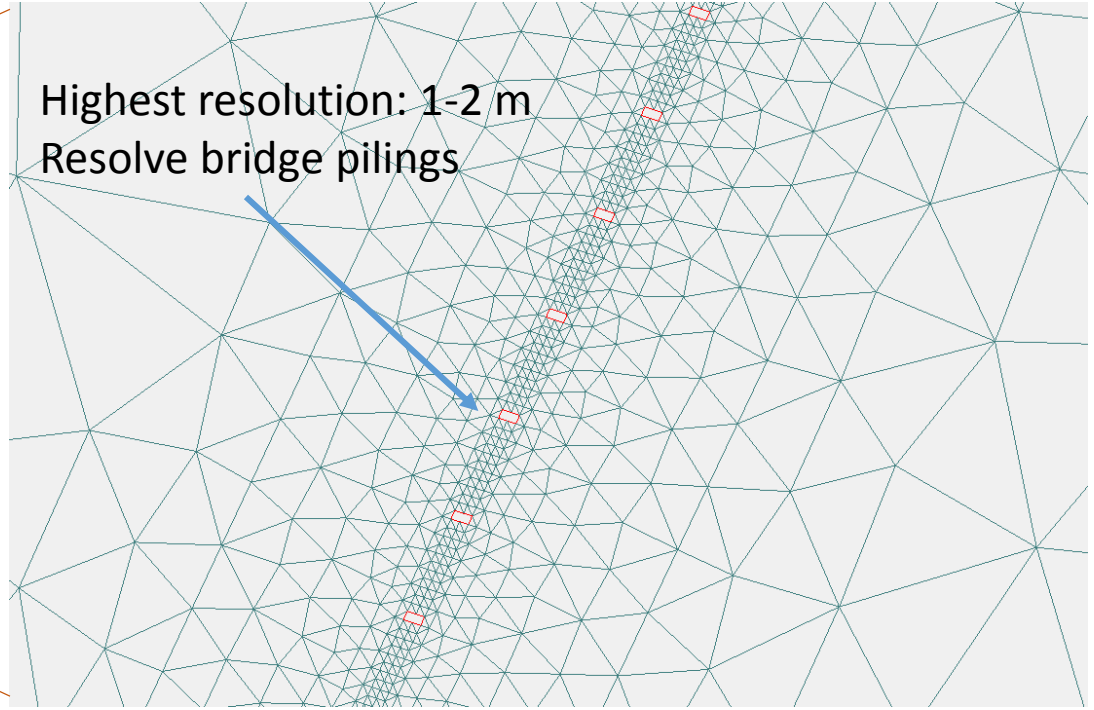


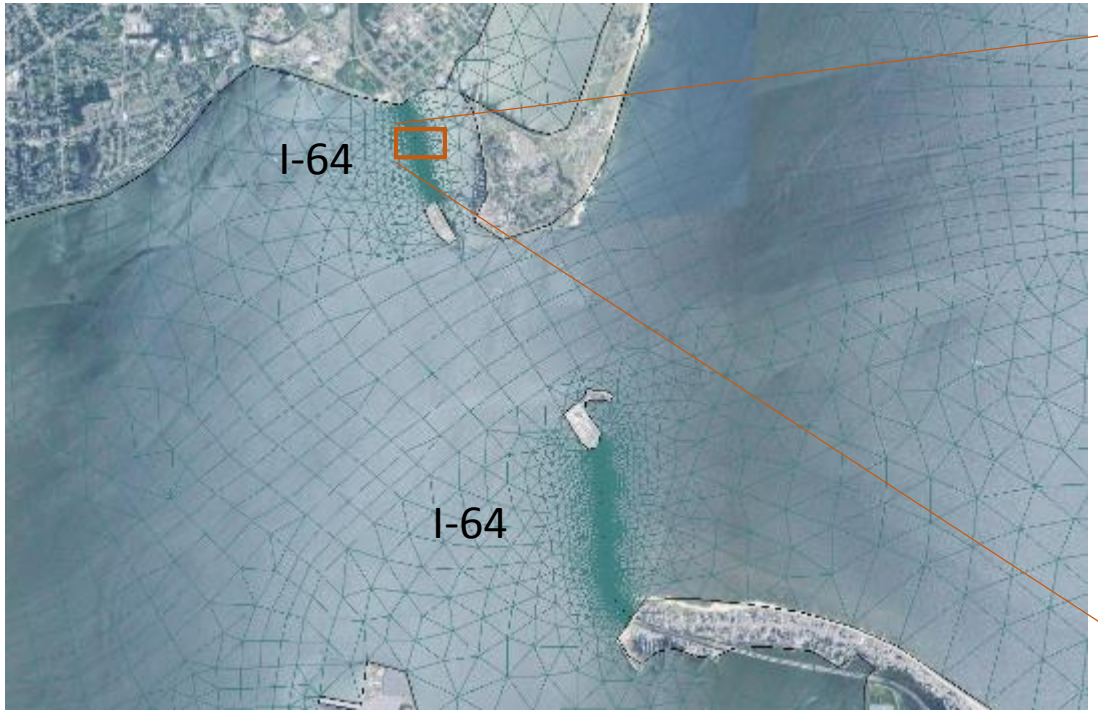
Bridge-resolved grid

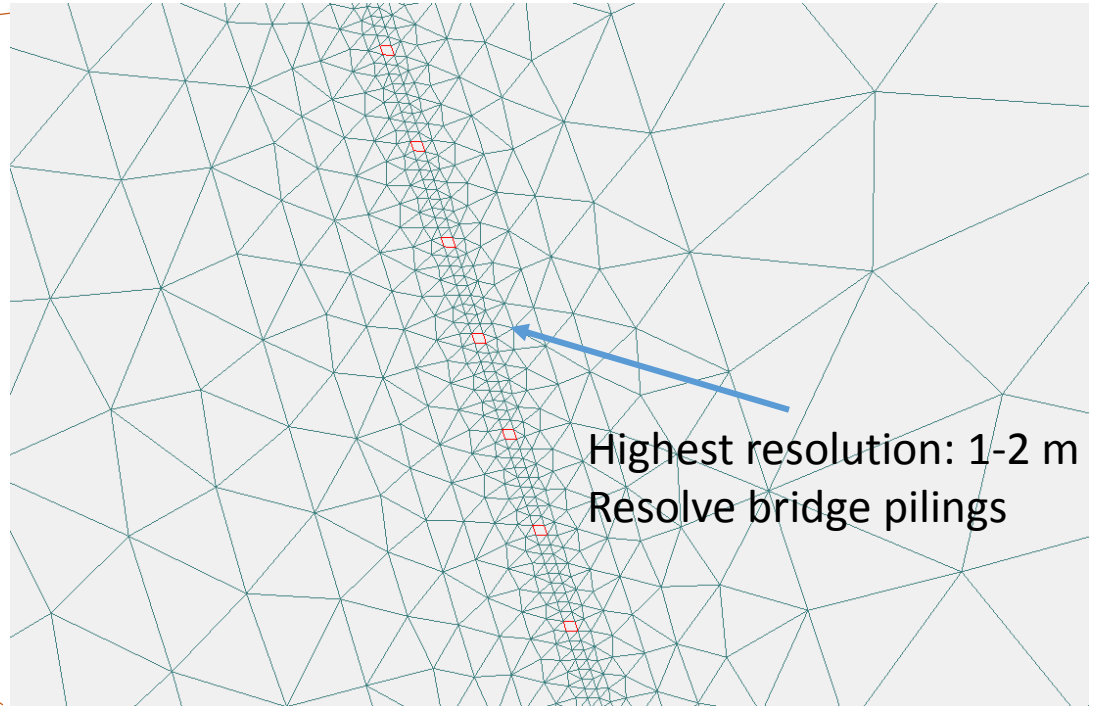





I-664


Highest resolution: 1-2 m
Resolve bridge pilings


I-64
I-64


Highest resolution: 1-2 m
Resolve bridge pilings

Model setup and performance

Ocean Dynamics
https://doi.org/10.1007/s10236-018-1148-6

Impact of small-scale structures on estuarine circulation

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Received: 28 November 2017 / Accepted: 16 March 2018

Abstract
We present a novel and challenging application of a 3D estuary-shelf model to the study of the collective impact of many small-scale structures (bridge pilings of 1 m × 2 m in size) on larger-scale circulation in a tributary (James River) of Chesapeake Bay. We first demonstrate that the model is capable of effectively transitioning grid resolution from ~ 400 m down to ~ 1 m near the pilings without introducing undue numerical artifact. We then show that despite their small sizes and collectively small area as compared to the total channel cross-sectional area, the pilings exert a noticeable impact on the large-scale circulation, and also create a rich structure of vortices and wakes around the pilings. As a result, the water quality and local sedimentation patterns near the bridge piling area are likely to be affected as well. However, when evaluating over the entire waterbody of the project area, the near field effects are weighed with the areal percentage which is small compared to that for the larger unaffected area, and therefore the impact on the lower James River as a whole becomes relatively insignificant. The study highlights the importance of the use of high resolution in assessing the near-field impact of structures.

a. Model domain:

Coupled Chesapeake Bay and the continental shelf model domain with 3000 m along the east open boundary condition

North cross-shore boundary: adjacent to Indian River Bay, DE

South cross-shore boundary: adjacent to Beaufort, NC, including a small portion of the Gulf Stream

b. Grid:

Total 37450 elements, 22552 nodes, 25 s-layers

c. Forcing:

NOAA NARR wind;

Major river discharges in Chesapeake Bay obtained from USGS

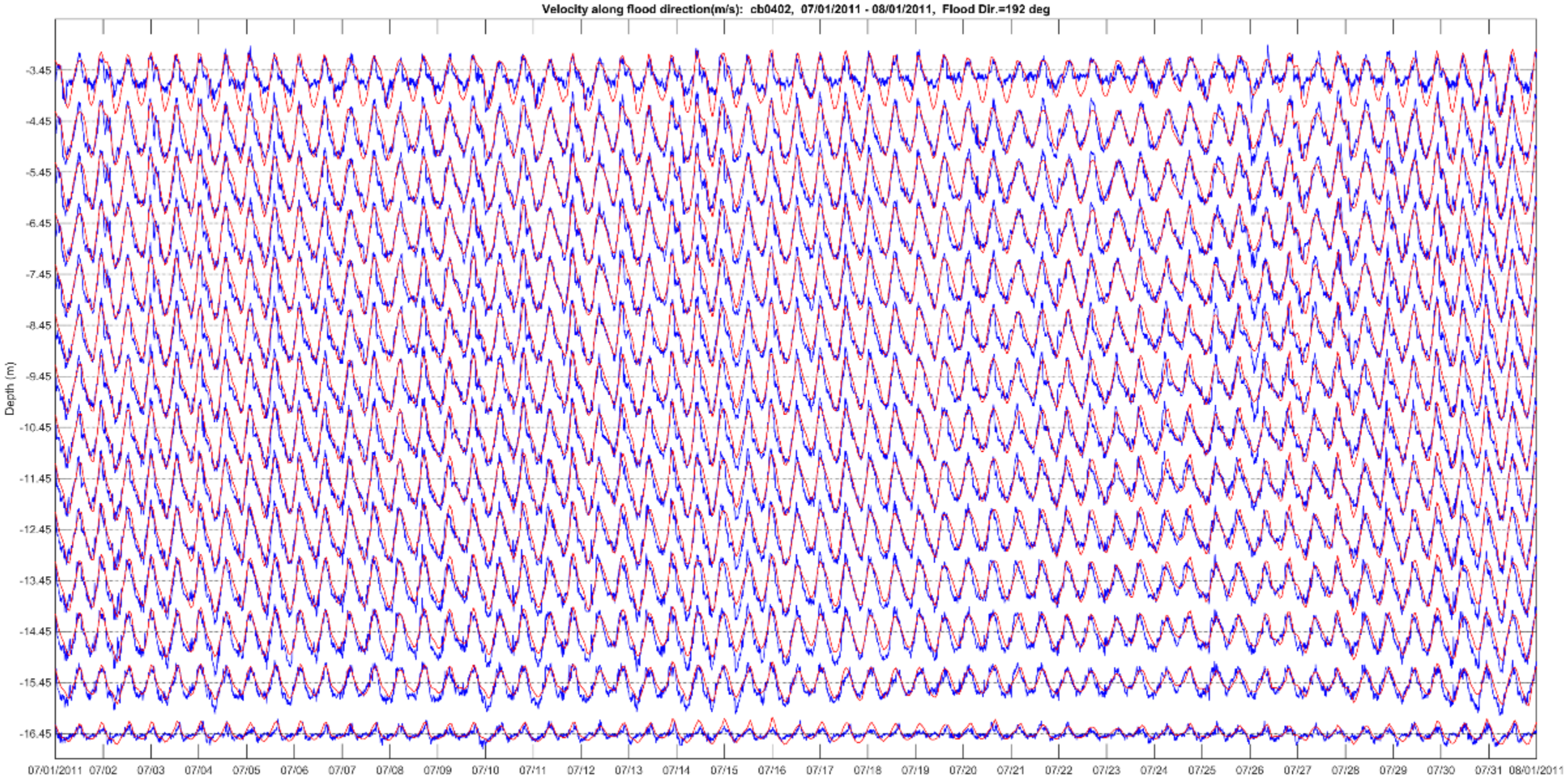
Tidal elevation reconstructed from NOAA observations at Beaufort, NC and Lewes, DE;

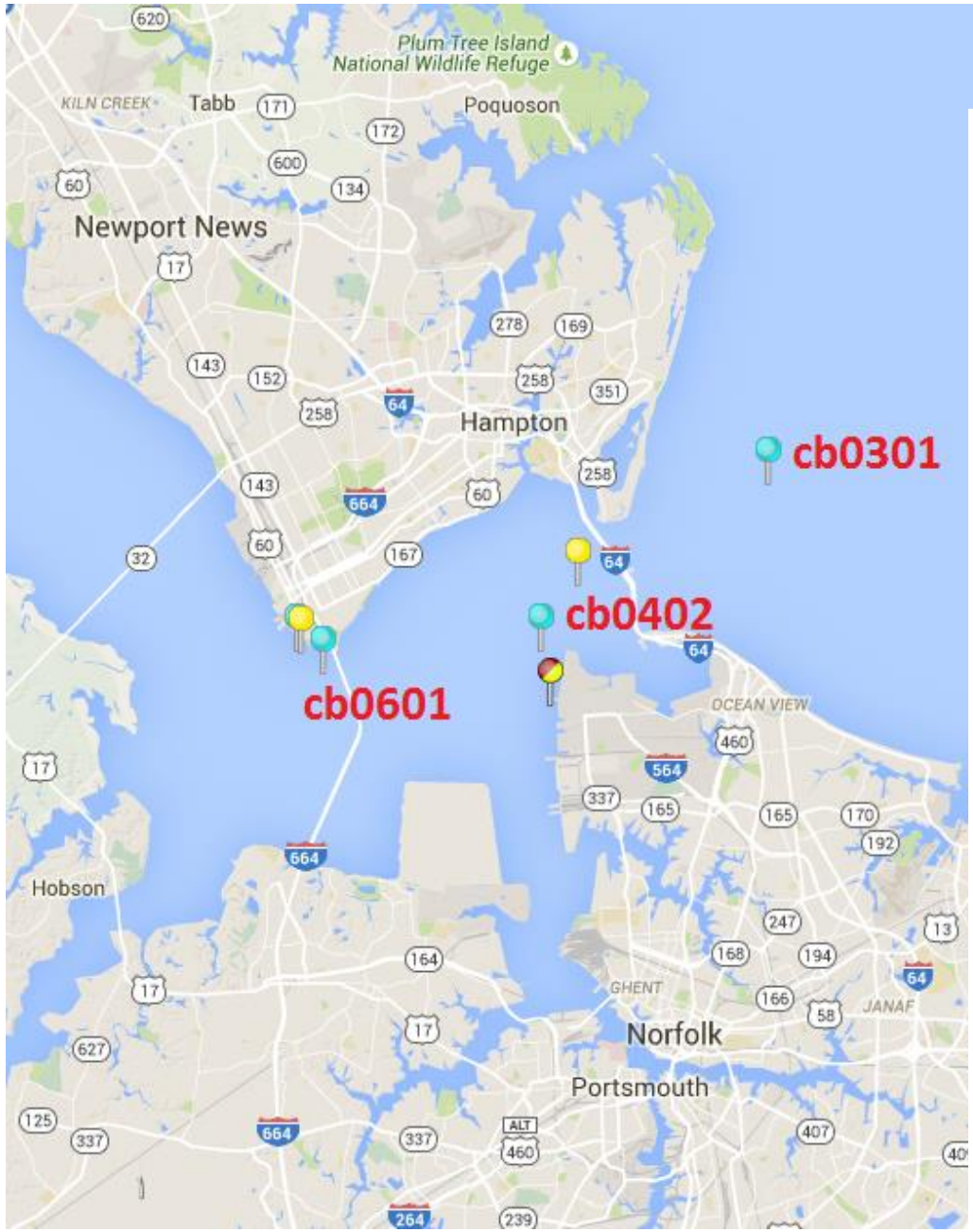
Open boundary condition: 3D velocity and 3D salinity, temperature obtained from HYCOM

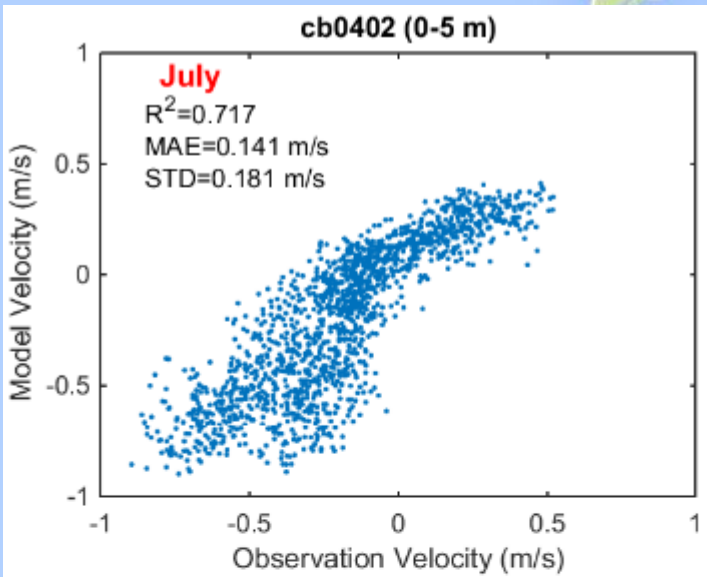
d. Performance:

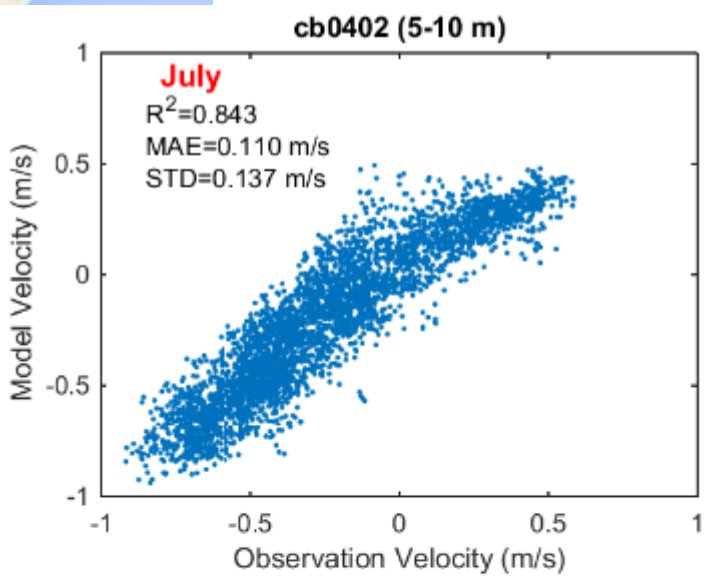
About 20 hours for a 1-year simulation with 64 CPUs on a HPC computer cluster

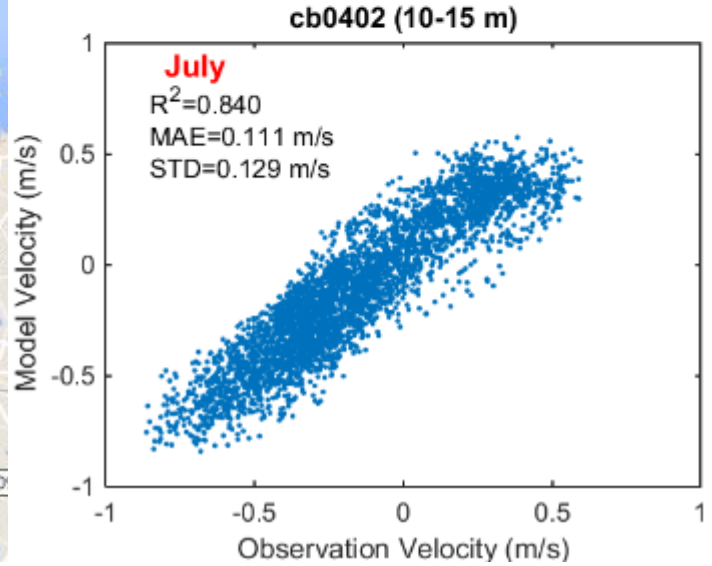
Velocity profile comparison

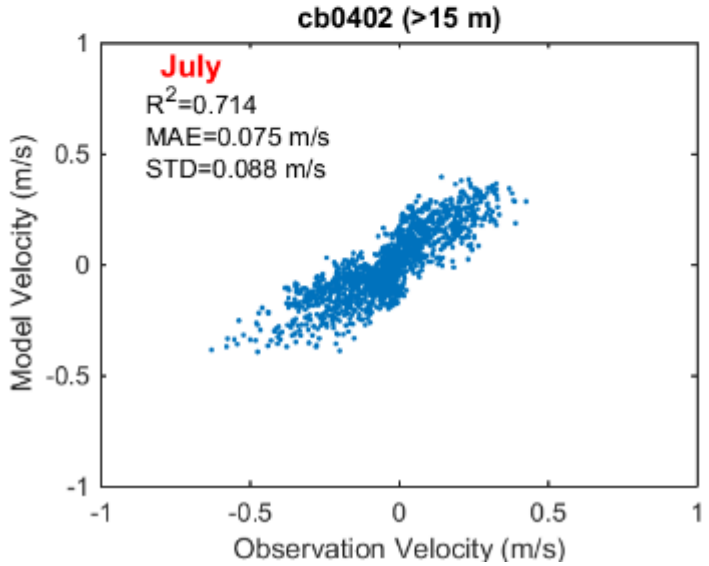



Plum Tree Island
National Wildlife Refuge
KILN CREEK
Tabb
Poquoson
Newport News
Hampton
Kiptopeke
cb0301
cb0402
cb0601
OCEAN VIEW
GHENT
JANAF
Norfolk
Portsmouth
Hobson


cb0402 (0-5 m)
July
R2=0.717
MAE=0.141 m/s
STD=0.181 m/s
Model Velocity (m/s)
Observation Velocity (m/s)

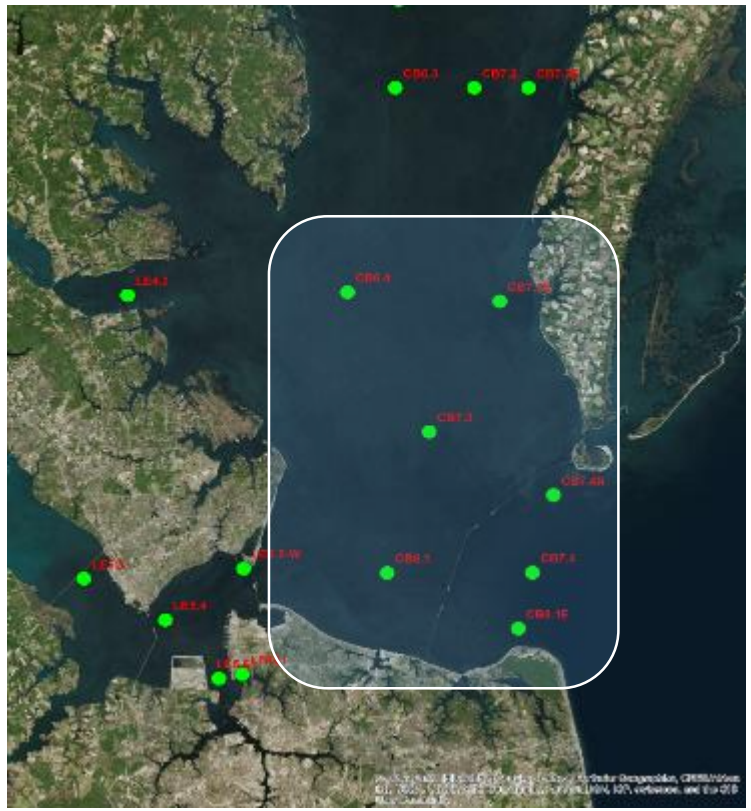

cb0402 (5-10 m)
July
R2=0.843
MAE=0.110 m/s
STD=0.137 m/s
Model Velocity (m/s)
Observation Velocity (m/s)

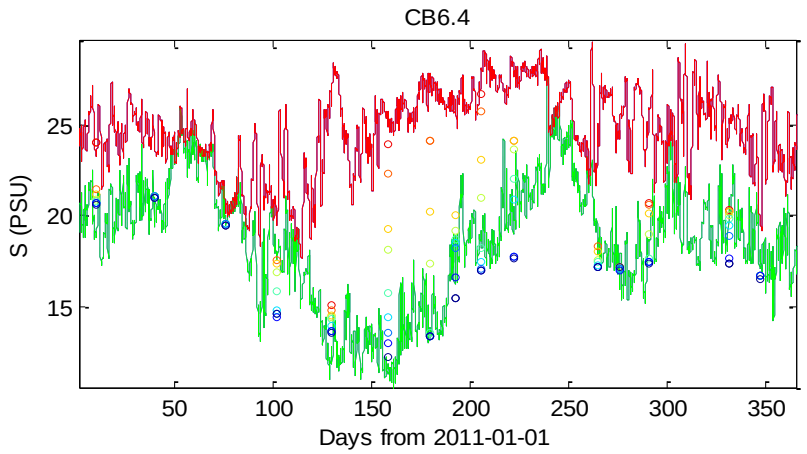

cb0402 (10-15 m)
July
R2=0.840
MAE=0.111 m/s
STD=0.129 m/s
Model Velocity (m/s)
Observation Velocity (m/s)

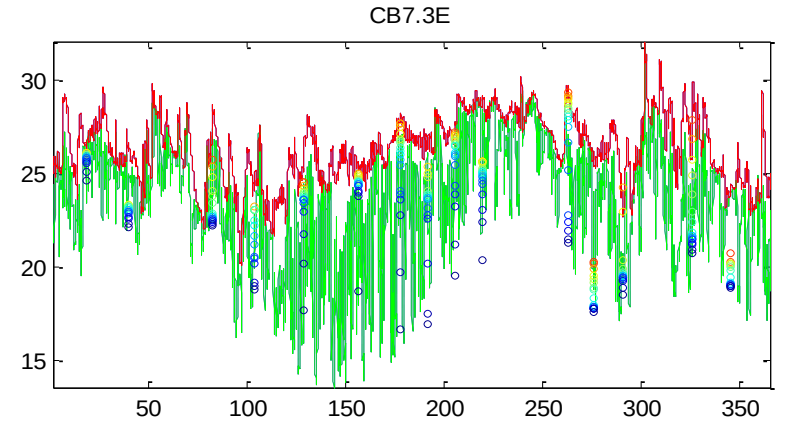

cb0402 (>15 m)
July
R2=0.714
MAE=0.075 m/s
STD=0.088 m/s
Model Velocity (m/s)
Observation Velocity (m/s)

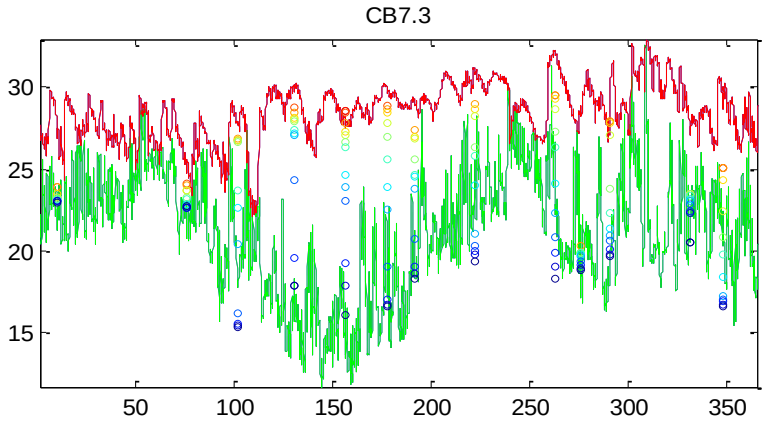
Salinity comparison

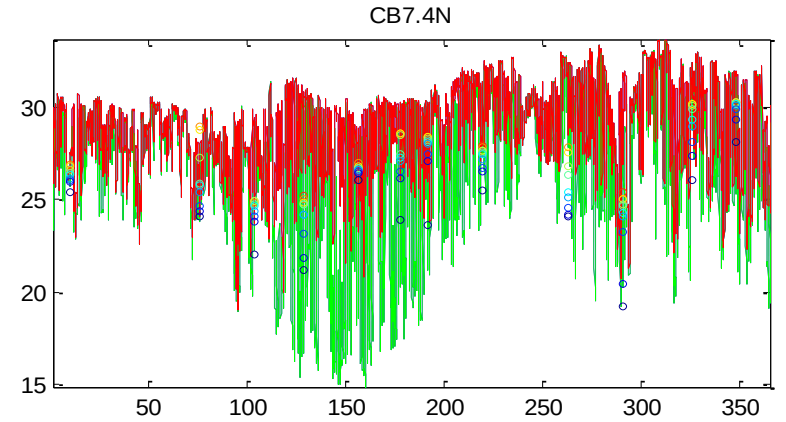
Lower Chesapeake Bay

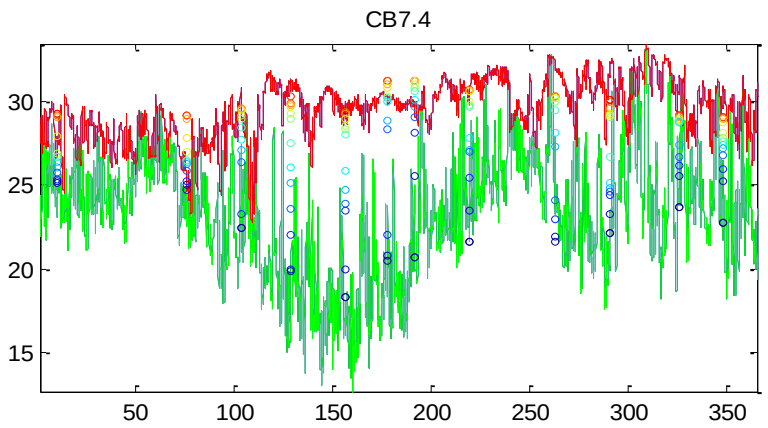


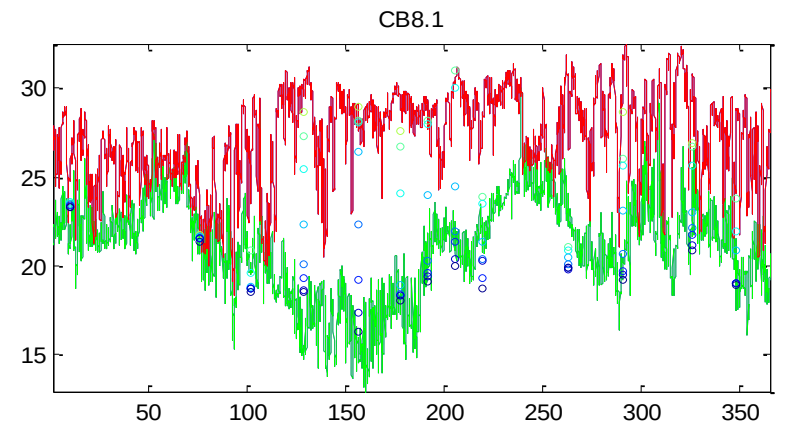






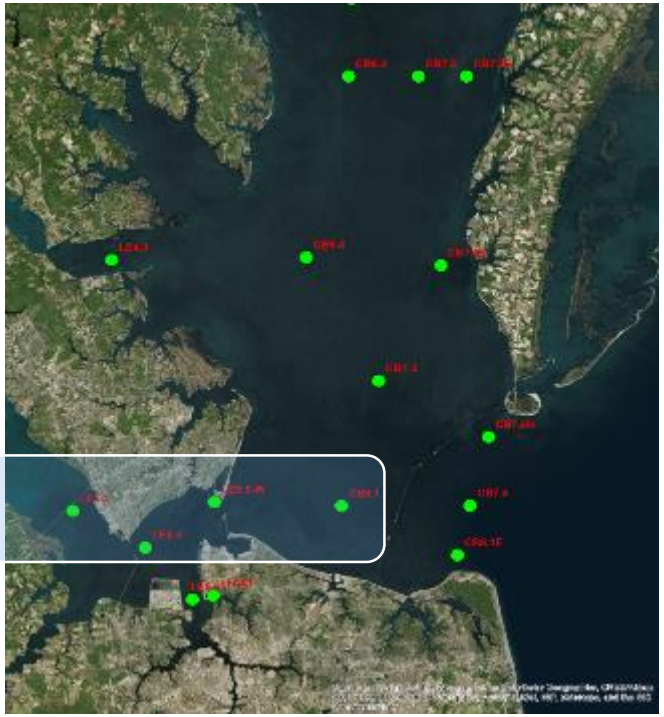


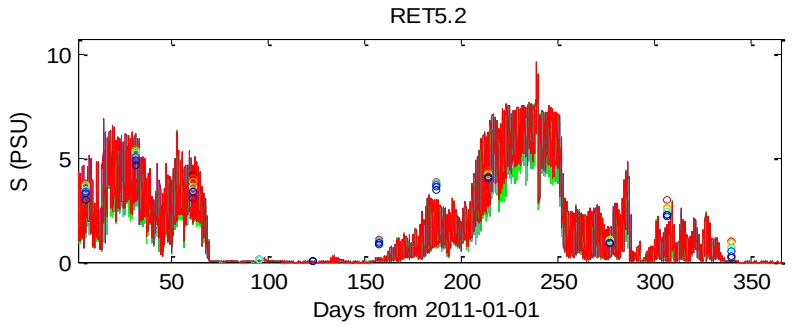


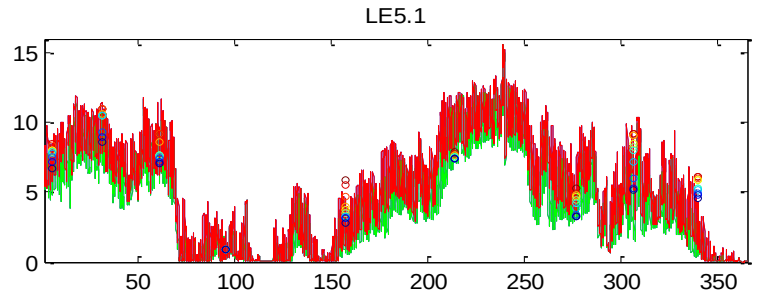


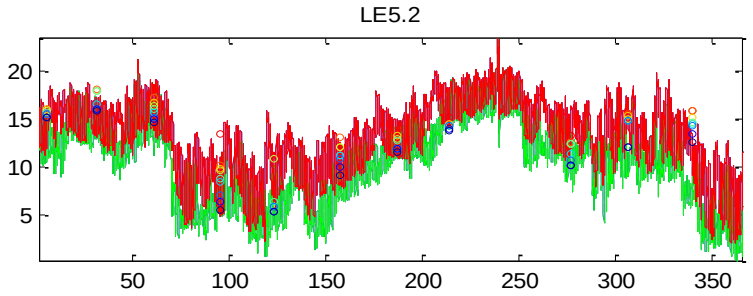
Salinity comparison (con't)

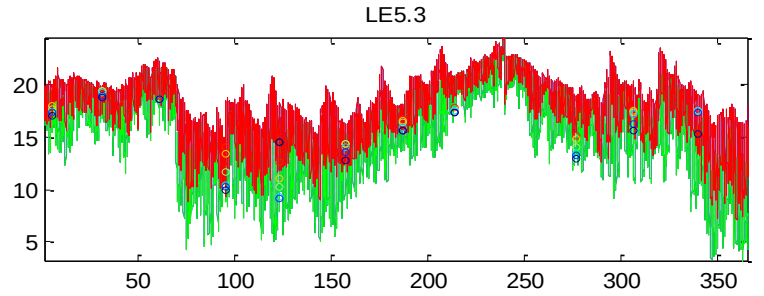
Lower James River

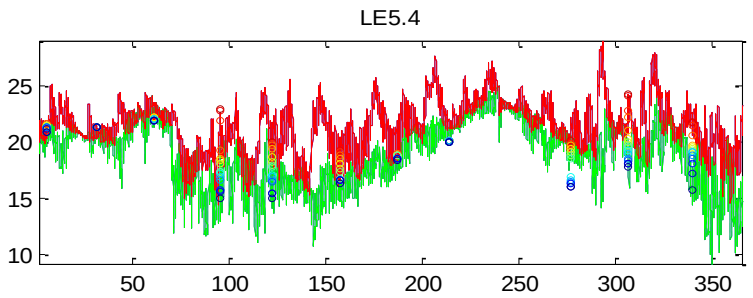


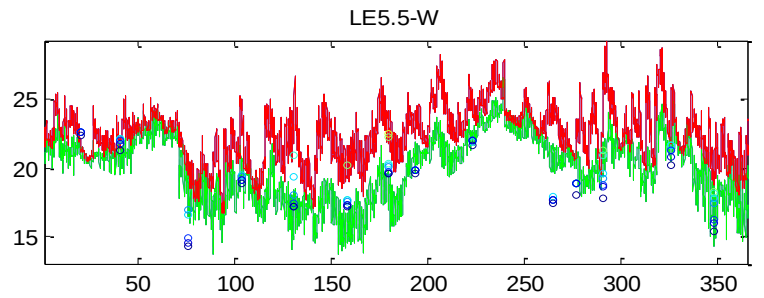


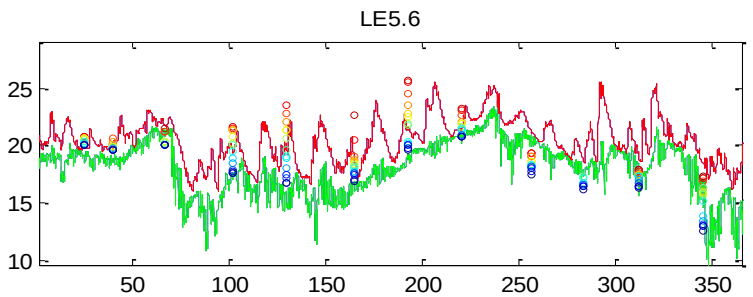


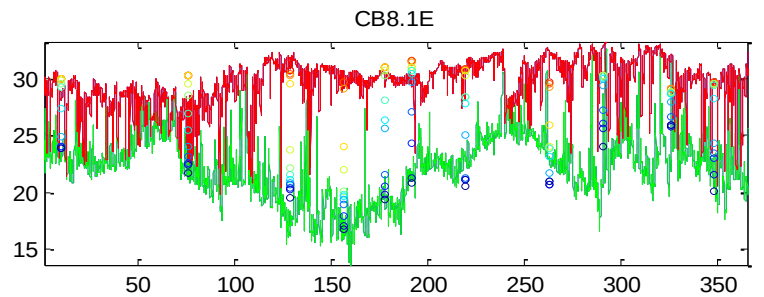






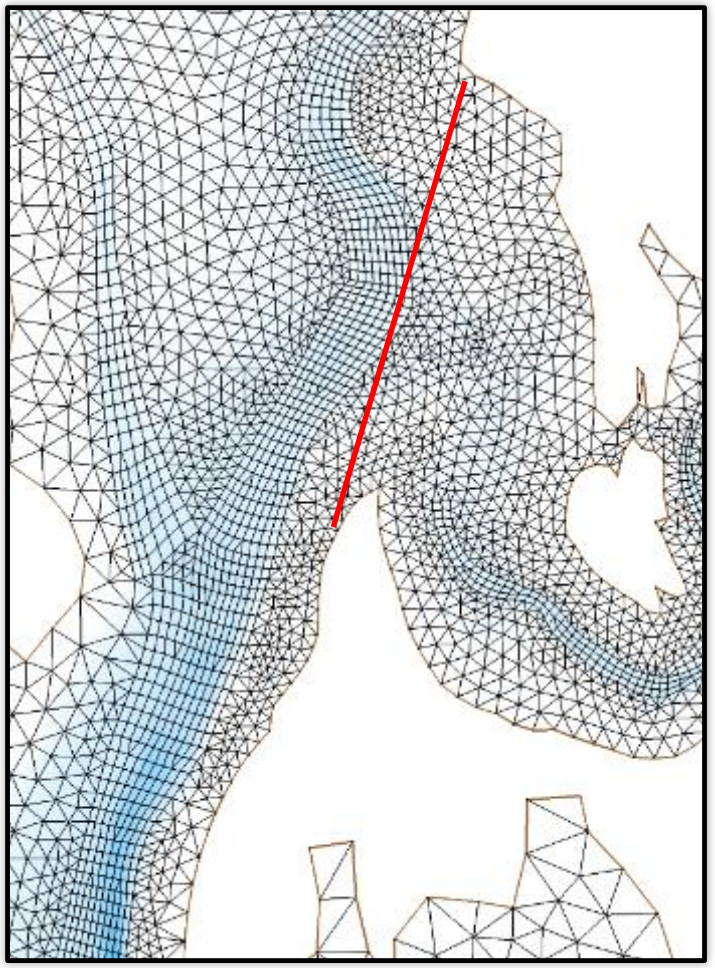




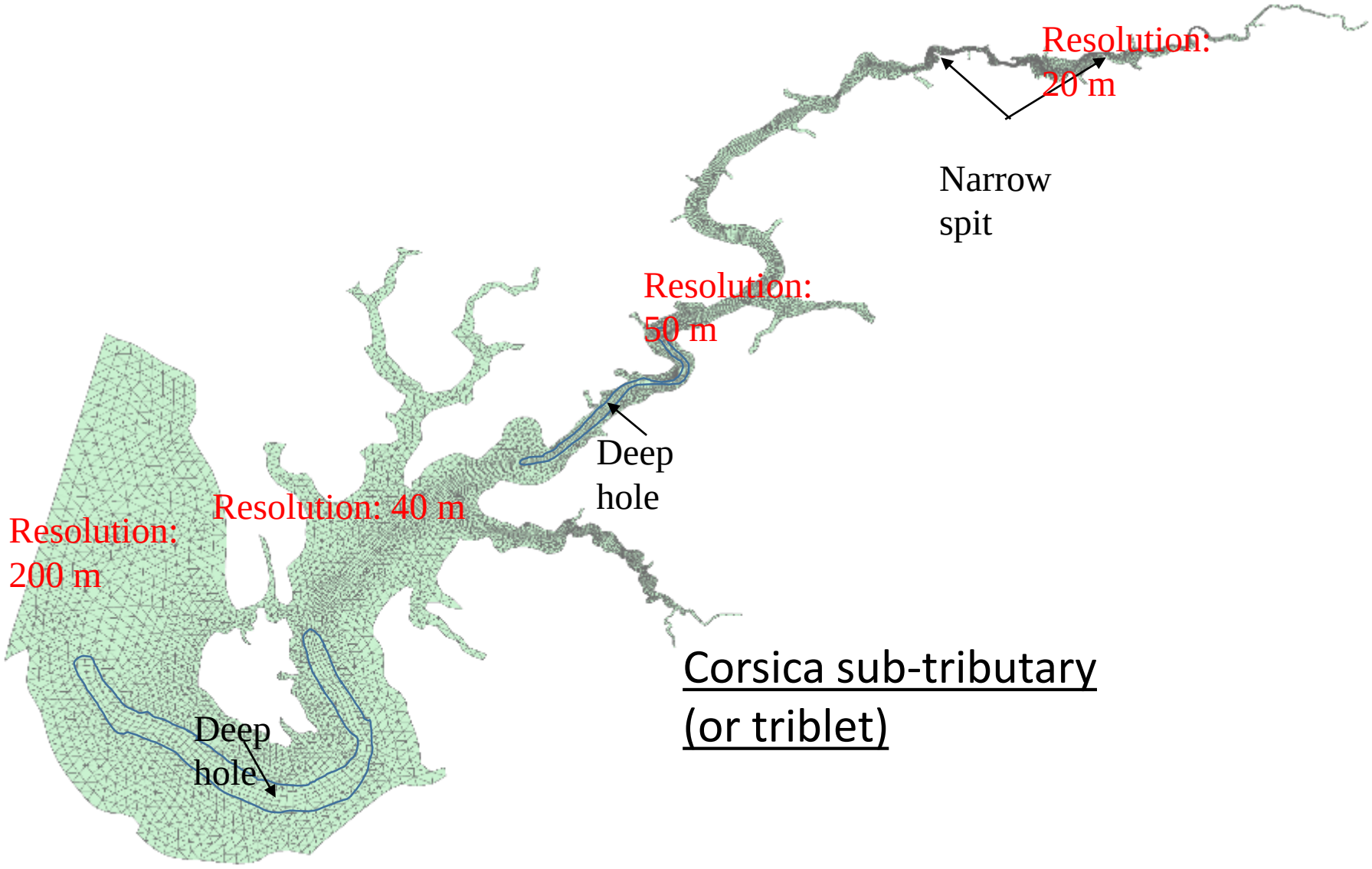


B. Hydrodynamic and water quality modeling in Chester River

Upper Chesapeake Bay

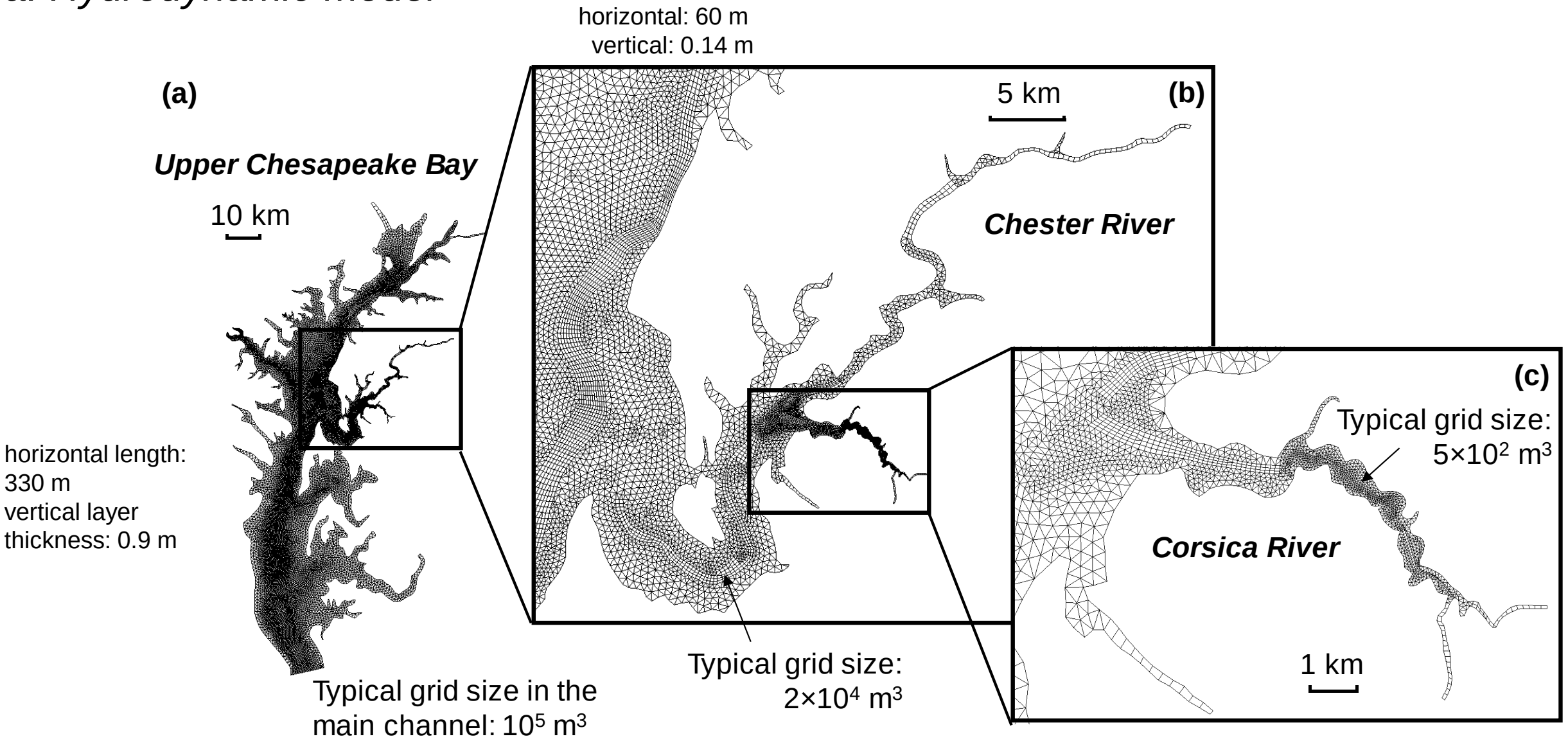


Chester River tributary



Corsica sub-tributary
(or triblet)

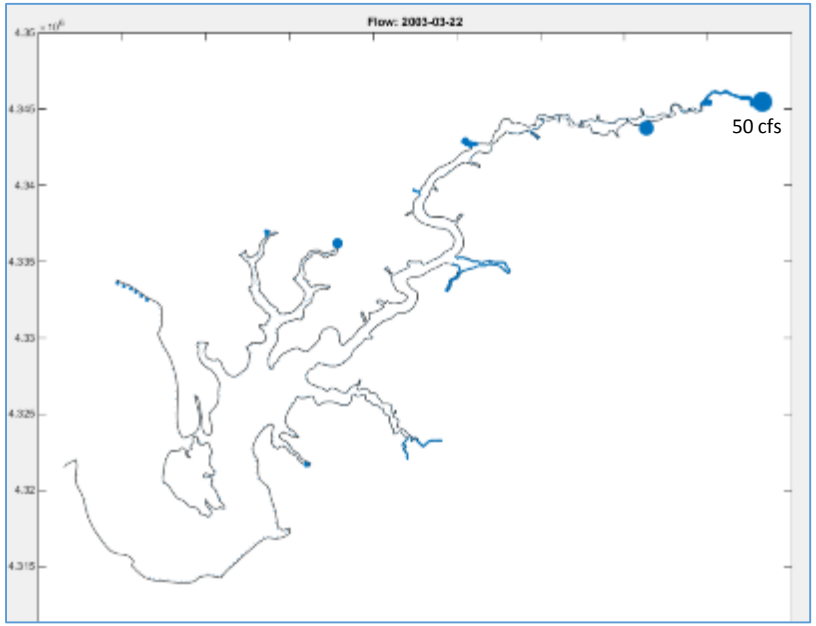
a. Hydrodynamic model



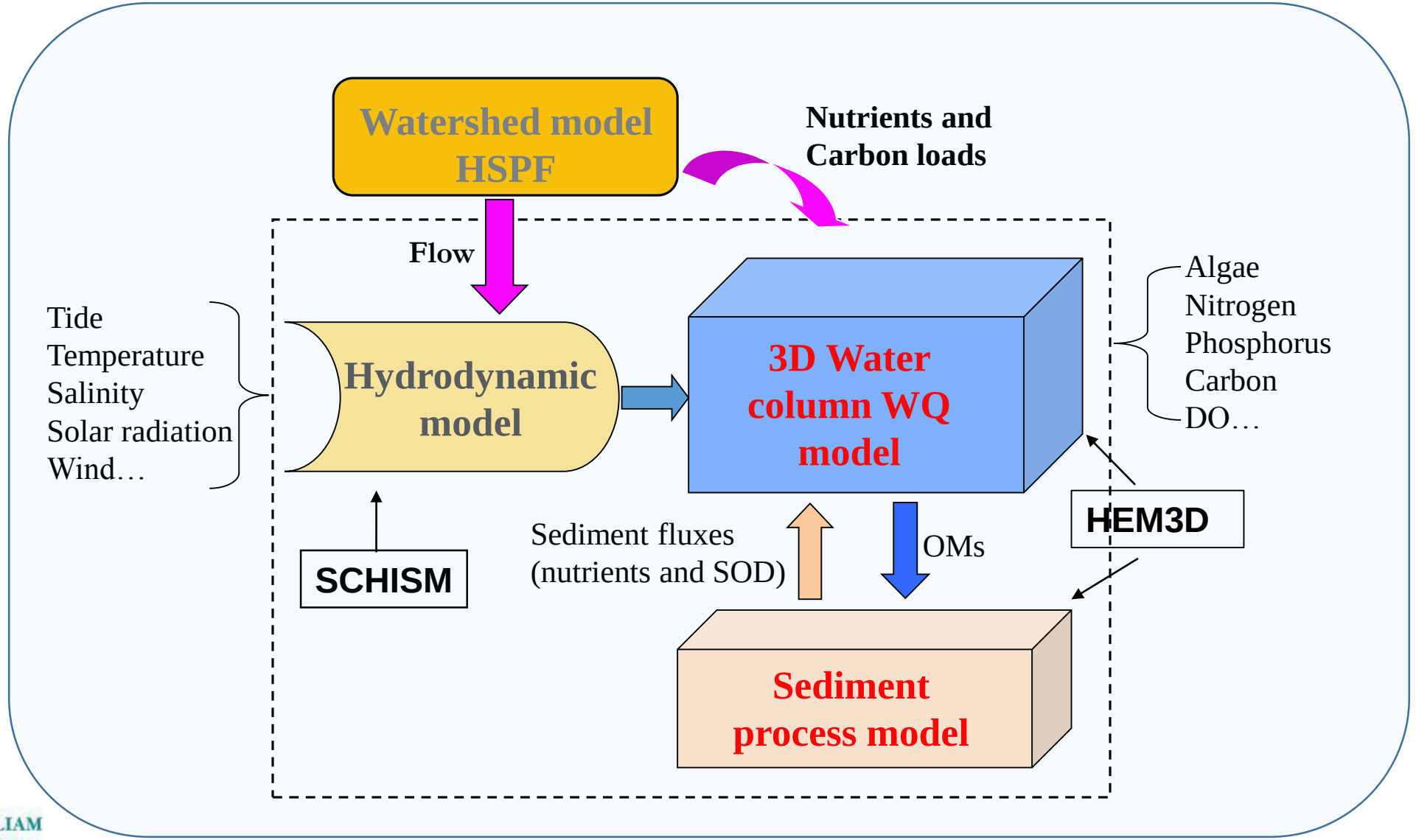
Cross-scale: main stem → tributary → sub-tributary (triblet)

Chester River watershed delineation

Example of watershed daily flow distribution



b. Water quality modeling framework



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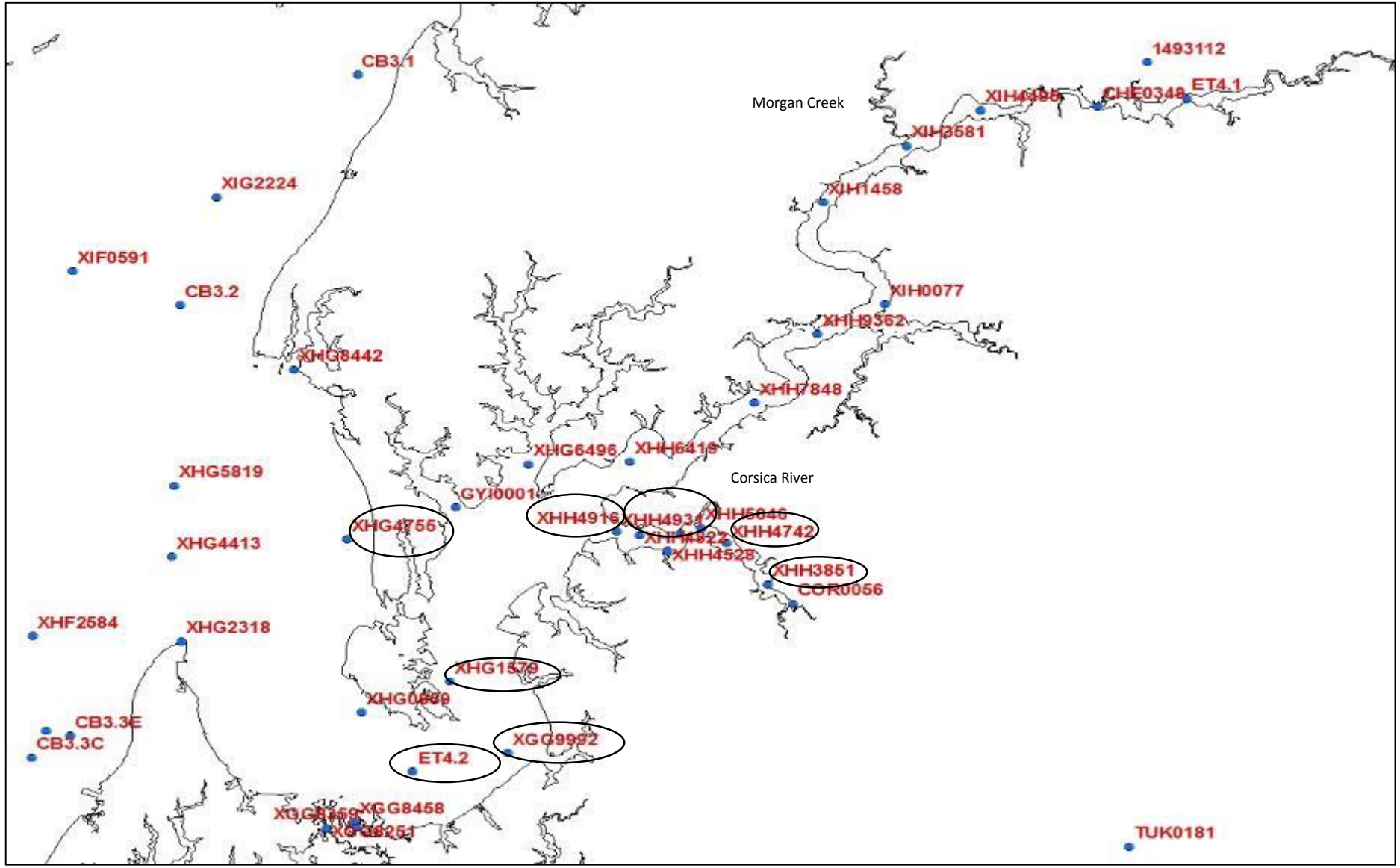
c. Water quality modeling results

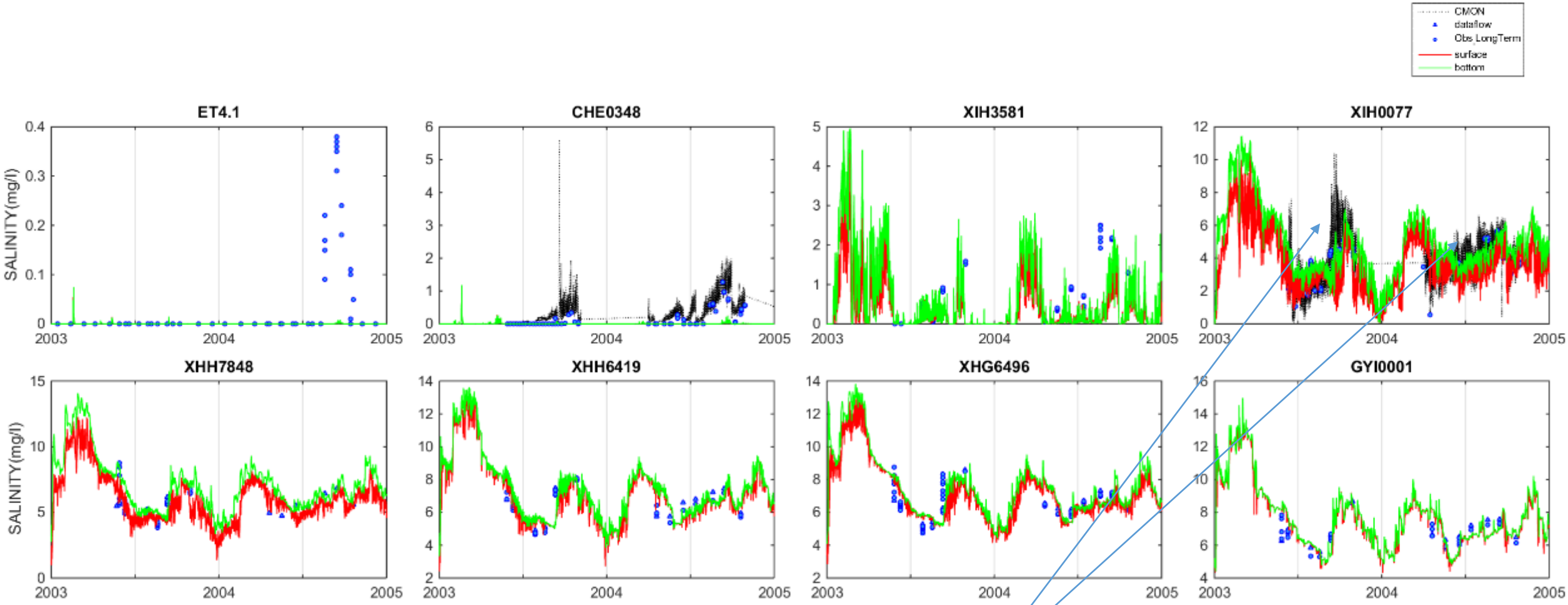
1. The water quality model is executed directly coupling with SCHISM. The time step used for both model is 120 sec.
2. Water quality model has been verified by simulating consecutive years of 2003 and 2004

Stations selected in Tidal fresh and middle Chester River stations

Stations selected in Corsica River and lower Chester River

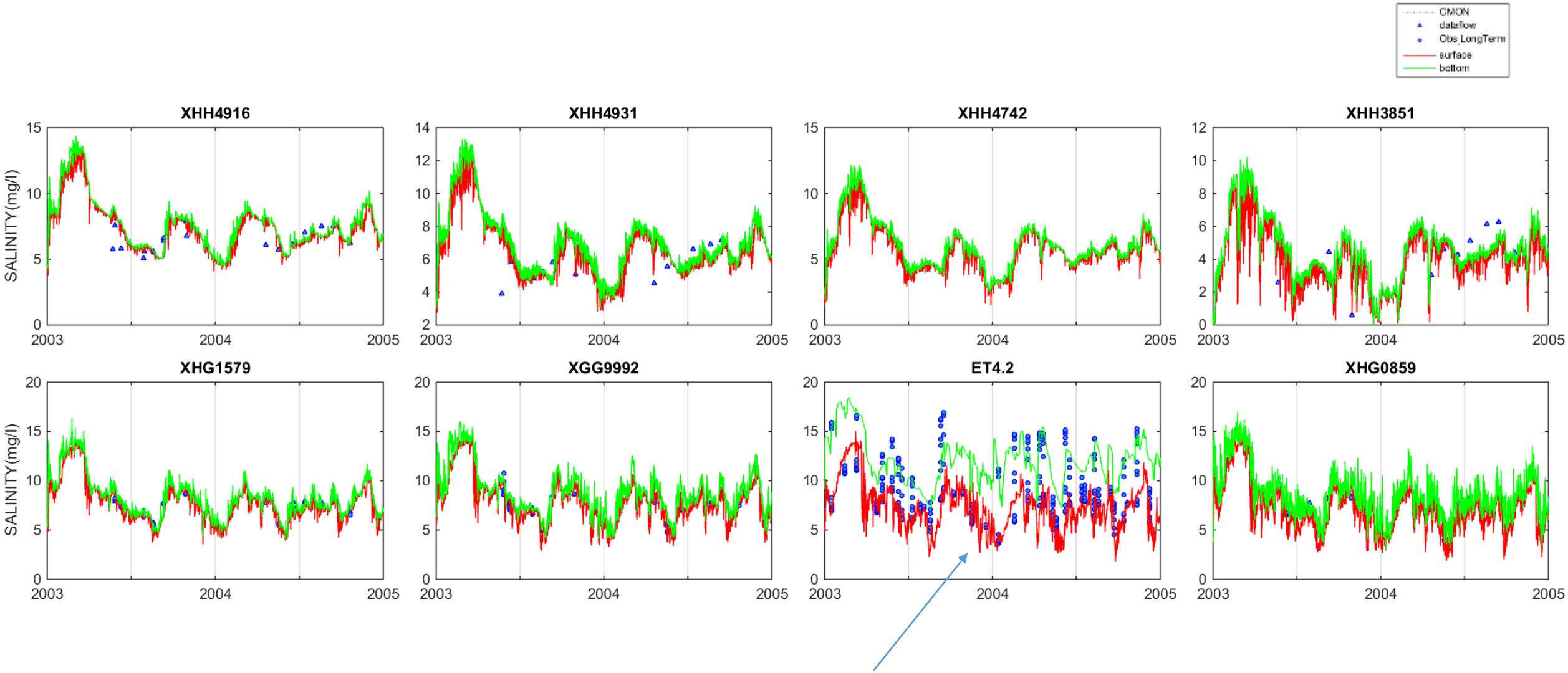


Salinity in the tidal fresh and middle Chester River



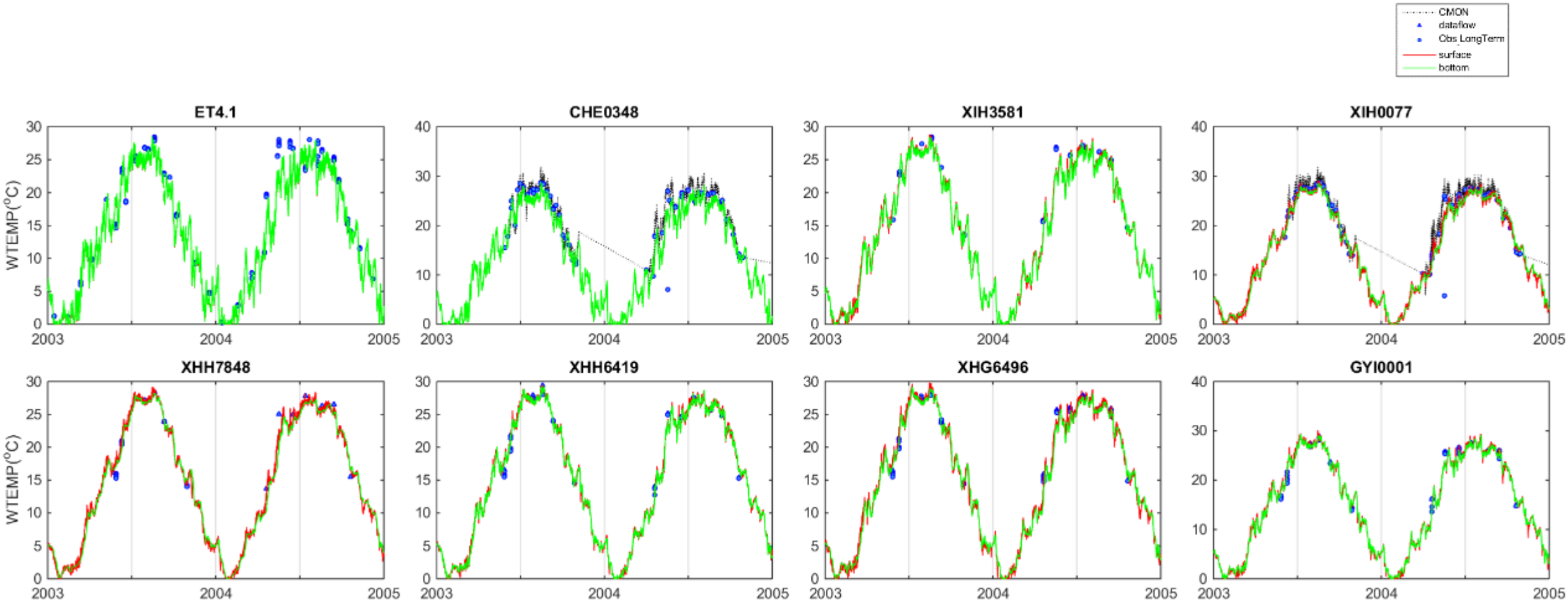
Salt intrusion prediction was better

Salinity in the Corsica River and lower Chester River

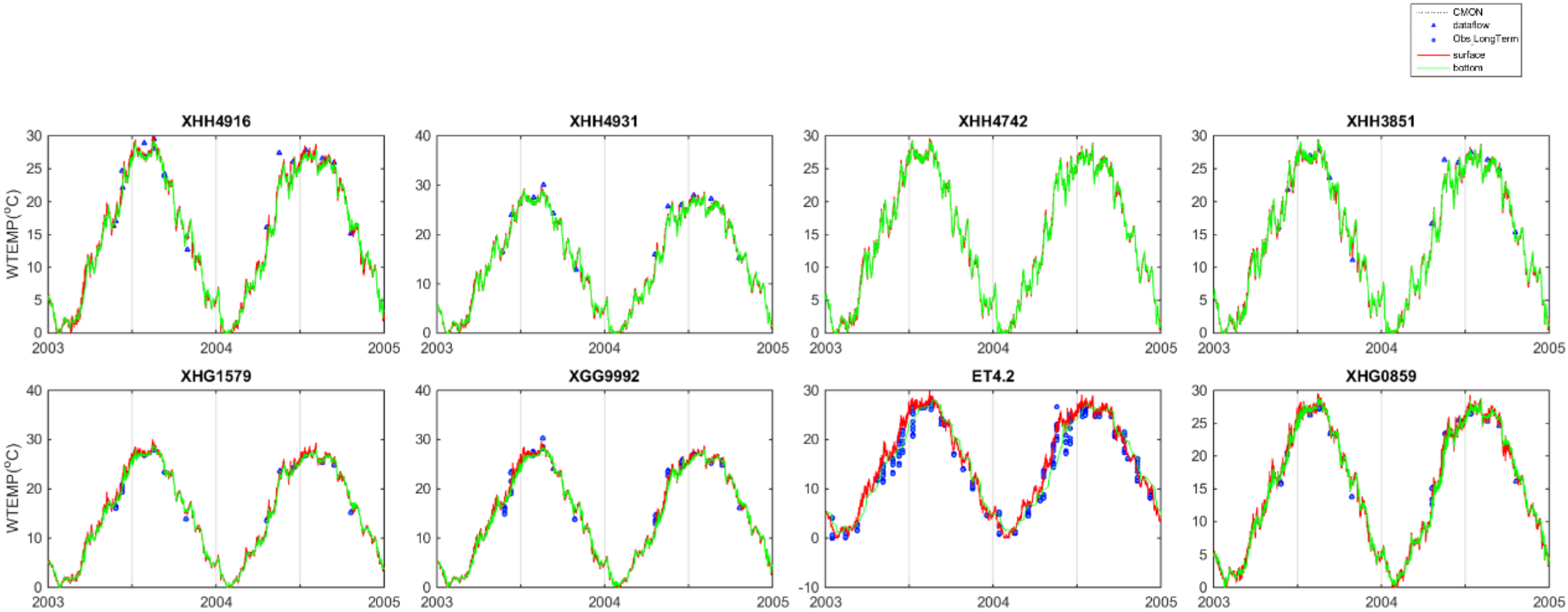


Salt intrusion prediction was better

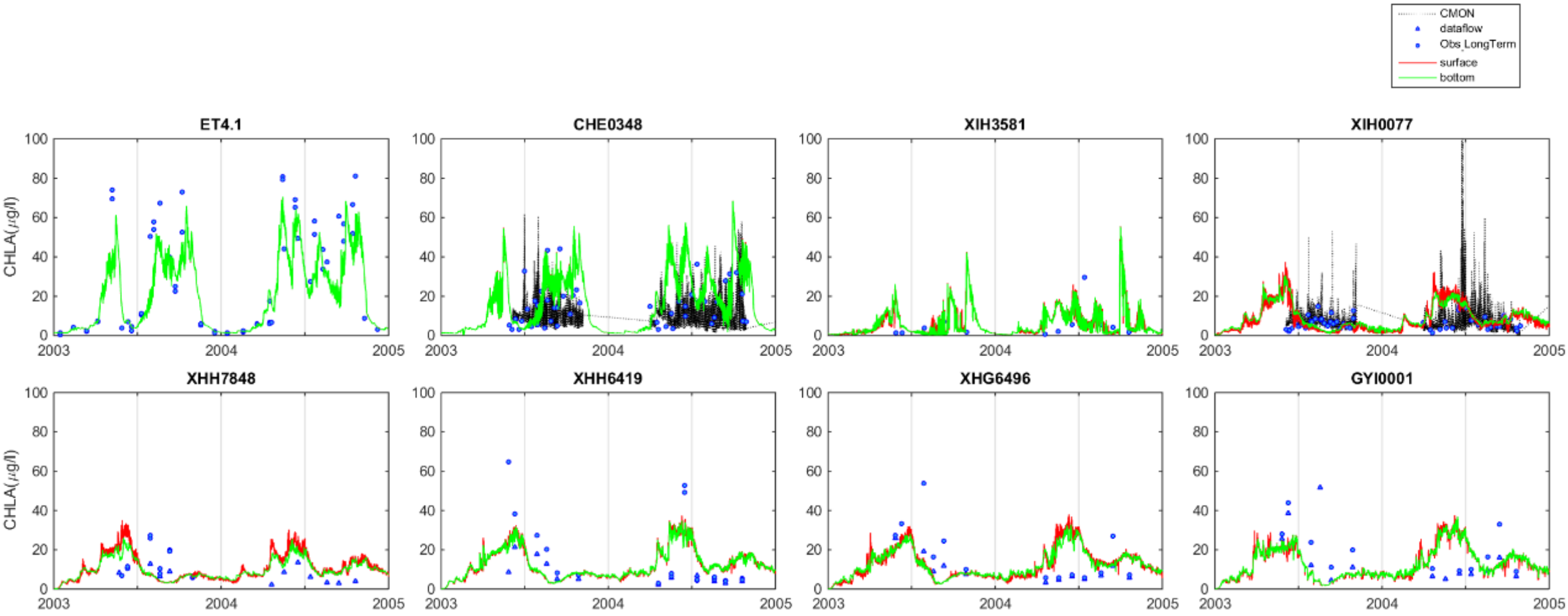
Temperature in the tidal fresh and middle Chester River



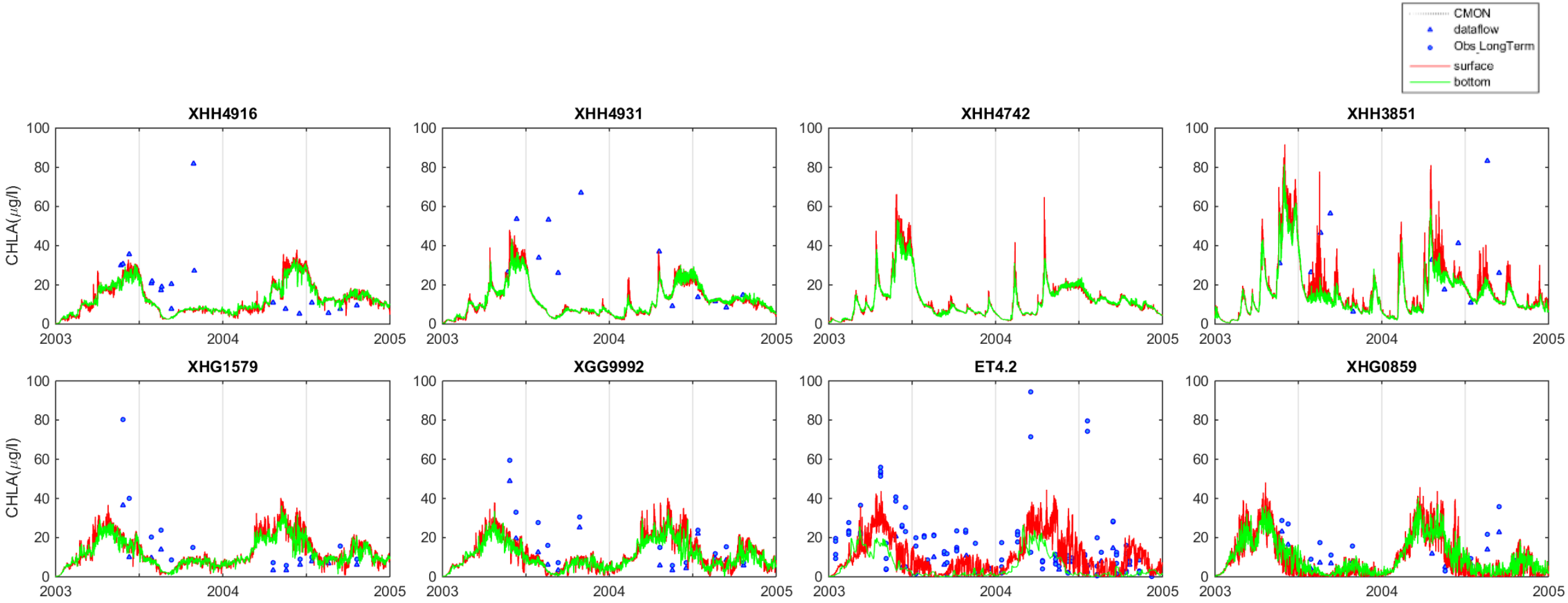
Temperature in the Corsica River and lower Chester River



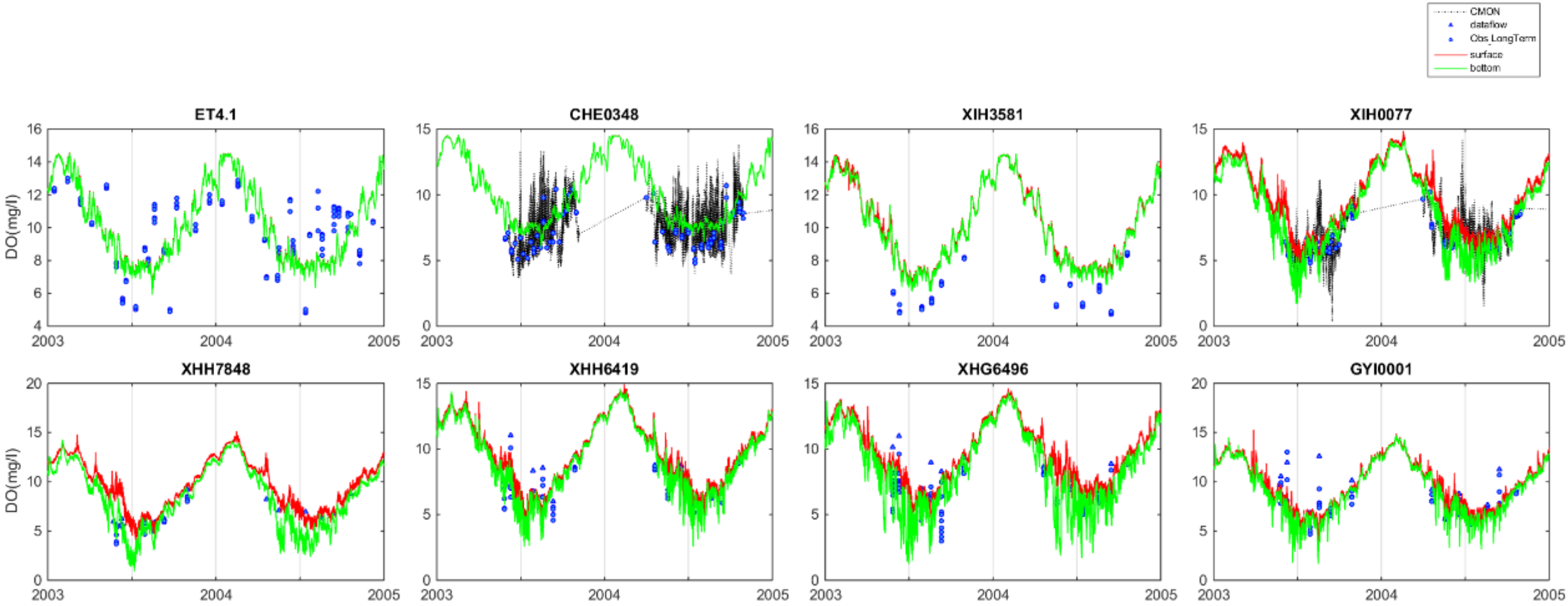
Chlorophyll in the tidal fresh and middle Chester River



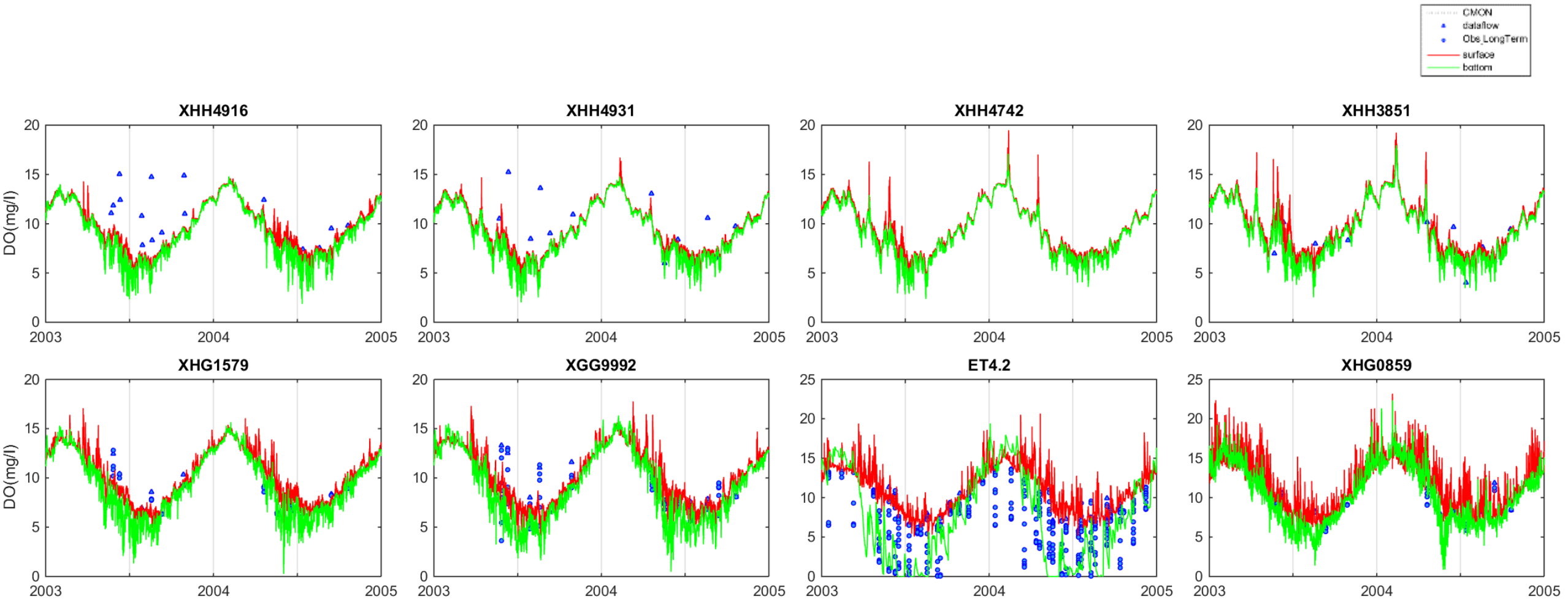
Chlorophyll in the Corsica River and lower Chester River



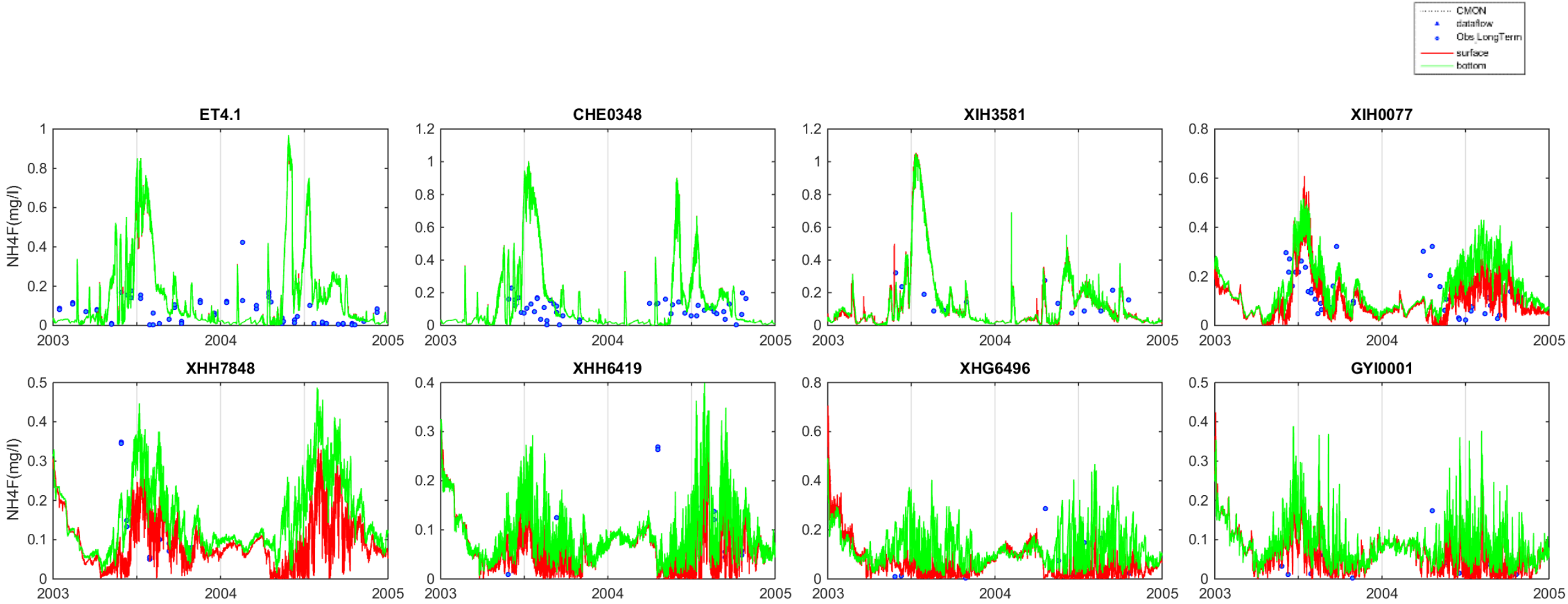
Dissolve oxygen in the tidal fresh and middle Chester River



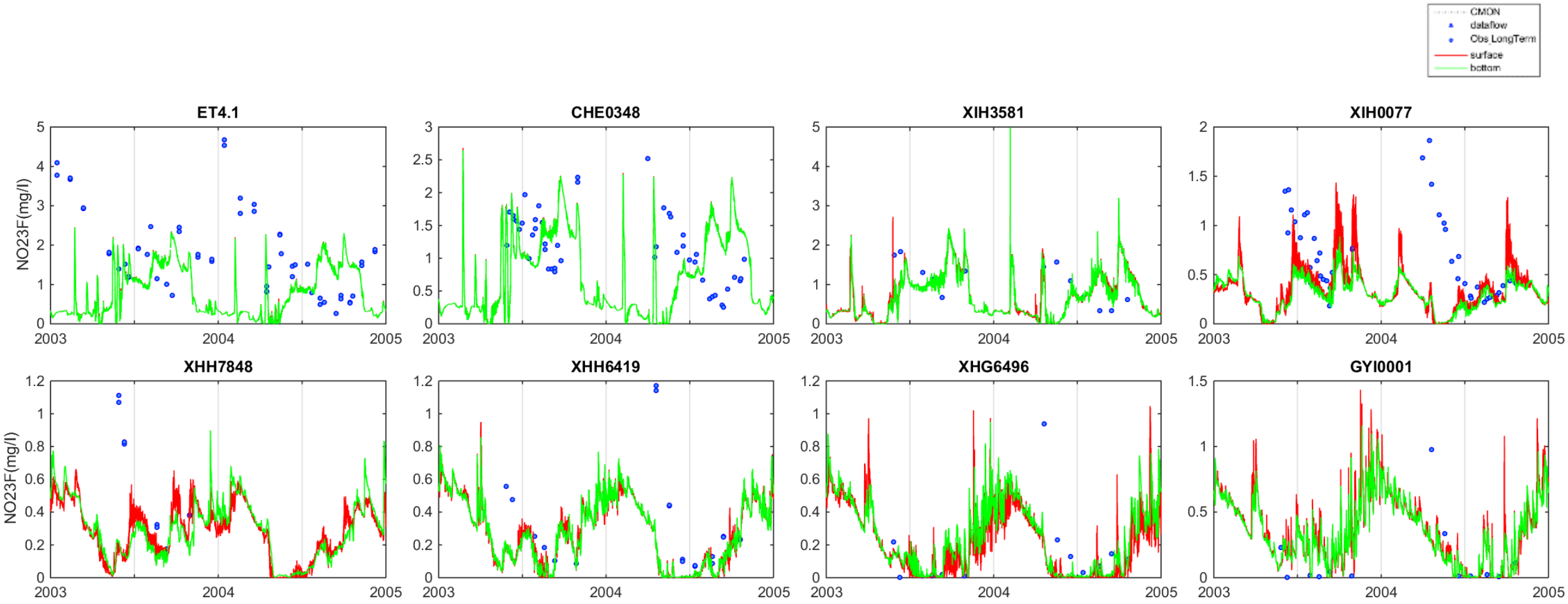
Dissolve oxygen in the Corsica River and lower Chester River



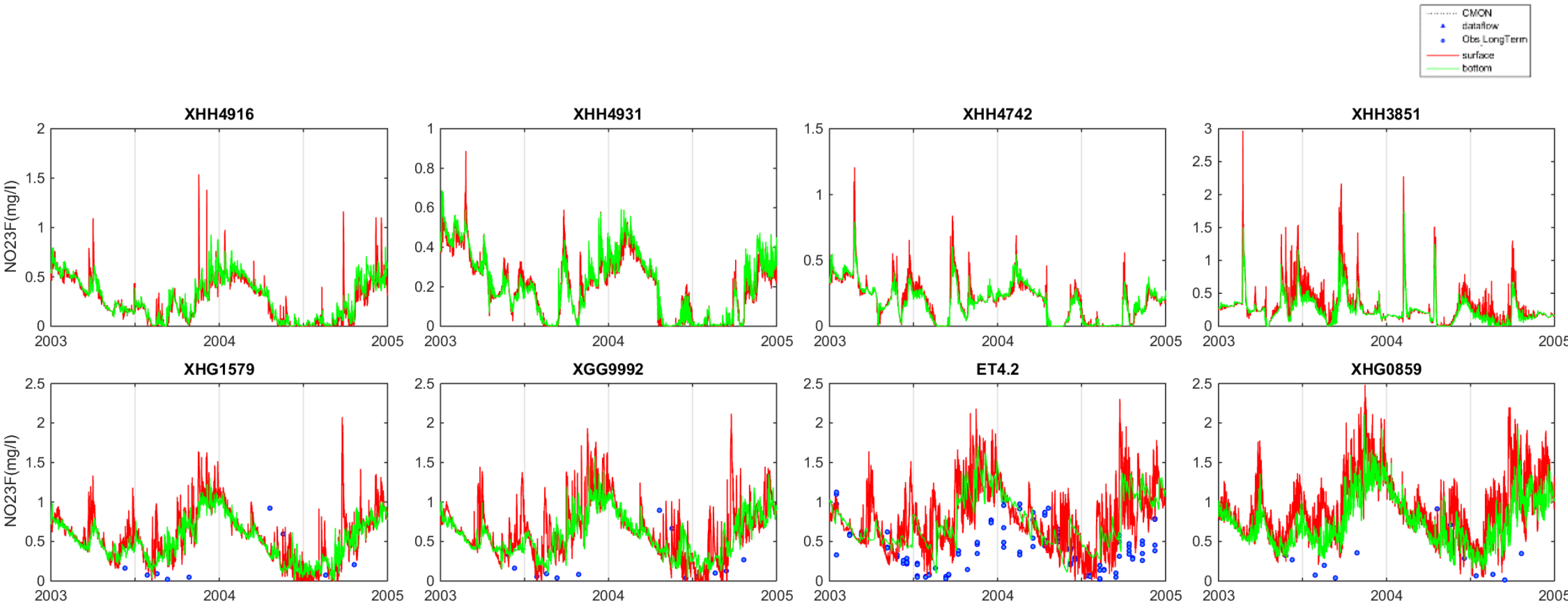
Ammonia in the tidal fresh and middle Chester River



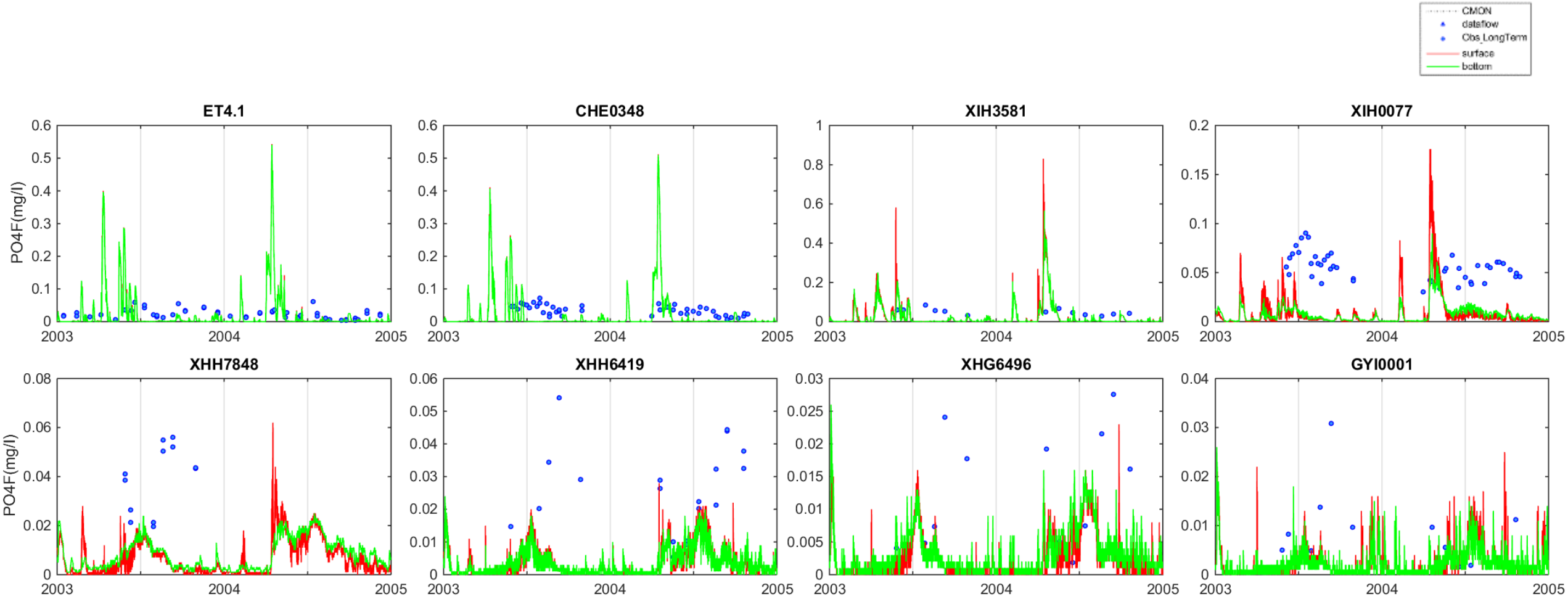
Nitrite/nitrate in the tidal fresh and middle Chester River



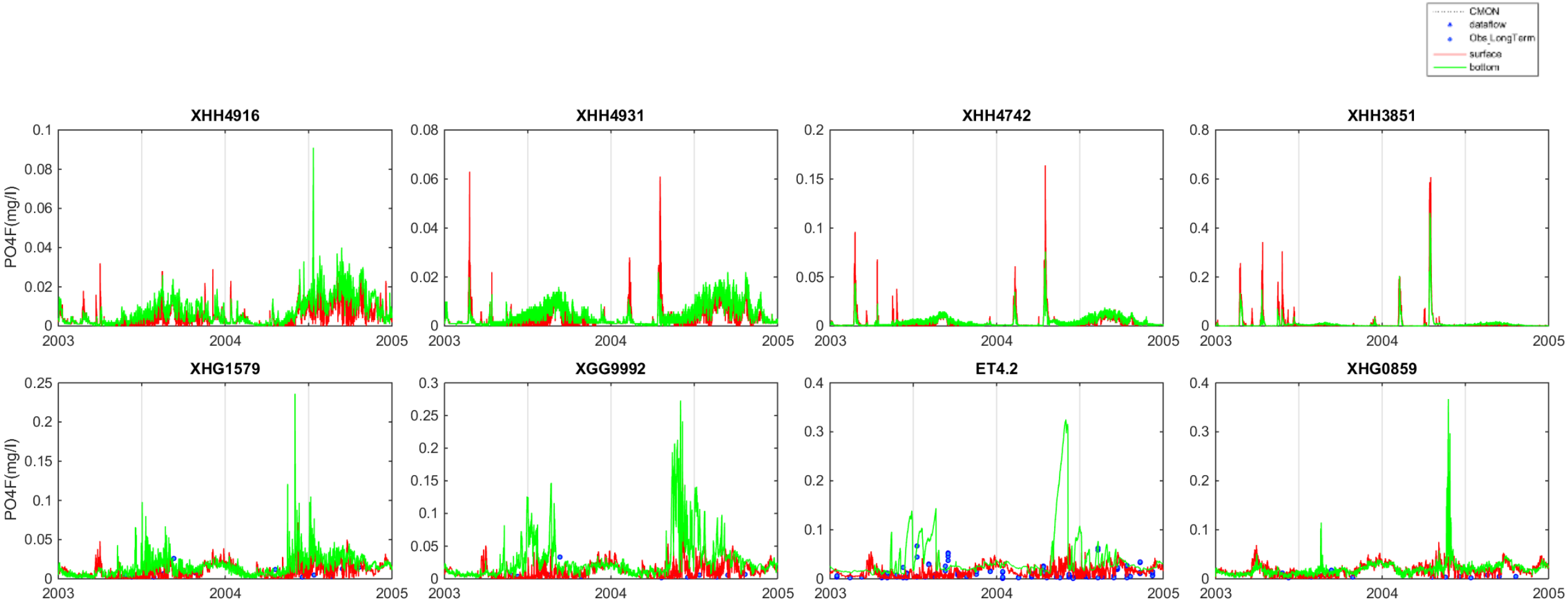
Nitrite/nitrate in the Corsica River and lower Chester River



Phosphate in the tidal fresh and middle Chester River



Phosphate in the Corsica River and lower Chester River



III. Summary

1. Unstructured grid, compared with the structured grid, has the flexibility to fit the complicated boundary (e.g. shore line) and, at the same time, allows locally refinable resolution as it needs.

2. The SCHISM model, a cross-scale estuarine/coastal model using finite element and semi-implicit schemes, has been applied in the Chesapeake Bay and tributaries including impact of fine scale structure in the James and water quality simulation in the Chester River. It is operational and well-benchmarked.

3. A new vertical coordinate developed recently further improves the simulation of vertical stratification and the channel versus shoal lateral dynamics.

4. With parallelization computational framework, triblets are feasible to be connected to the main Bay model to allow interactions between triblet-tributary, and tributary-main bay

Future work

a. Model domain:

Coupled Chesapeake Bay and the continental shelf model domain aligned with the 3500 m bathymetry line at the east boundary
North cross-shore boundary: adjacent to Indian River Bay, DE
South cross-shore boundary: adjacent to Beaufort, NC, including a small portion of the Gulf Stream

b. Grid:

Total 42289 elements, 26631 nodes, 25.0 vertical layers on average (16-67 layers depending on depth)

c. Time step: 120 seconds

d. Forcing:

Atmospheric forcing: NARR+NOAA observation
Freshwater discharges: USGS+Watershed model
Open boundary condition: 3D salinity from climatology, with nudging; 3D temperature from HYCOM, with nudging; elevation, 3D velocity (hybrid: sub-tidal HYCOM + tidal signals from larger domain barotropic model);