Assessing 2035 Climate Change Risk to the Chesapeake TMDL using a next-generation unstructured-grid model

--Phase 7 Main Bay Model (MBM)
Mesh revision and recalibration

VIMS team: Joseph Zhang, Jian Shen, Zhengui Wang, Harry Wang, Marjy Friedrichs, Pierre St-Laurent, Qubin Qin

CBPO: Nicole Cai, Richard Tian, Lewis Linker

UMCES team: Jeremy Testa

Advisor: Carl Cerco

April 04-05, 2023

VIMS | William & Mary
Virginia Institute of Marine Science

SCHISM

Enable the model to run in decoupled mode

- Completed coding to enable the model to run in decoupled mode
  - Increase computational performance (dynamic fields are saved hourly)
  - Maintain mass balance
  - Tested code and started to work on water quality model test
- Each time we revise the mesh, we need to redo both steps and recalibrate

~~One step:~~
~~Run all modules together~~

- ~~Hydrodynamic model~~
- ~~Sediment transport model~~
- ~~Wave model~~
- ~~Water quality~~

Two step

- Hydrodynamic model
- Sediment transport model
- Wave model

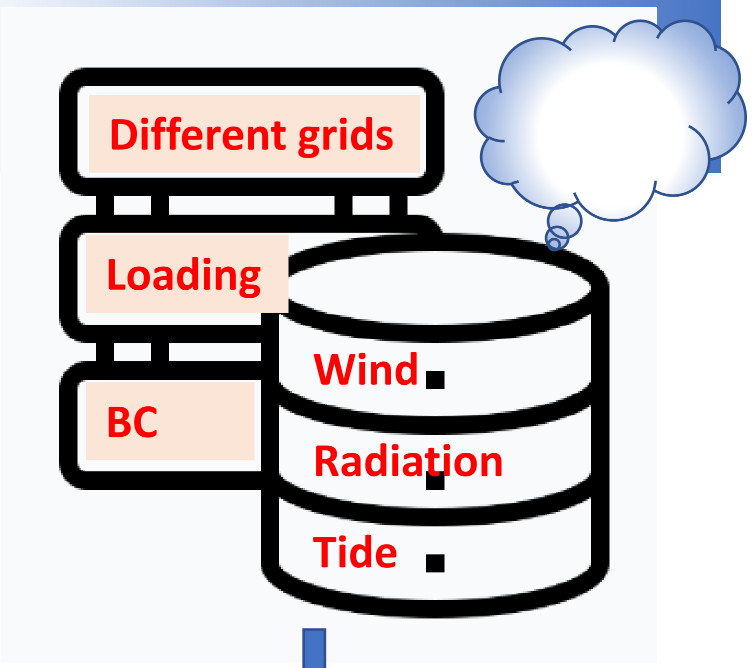
Save dynamic field to the database

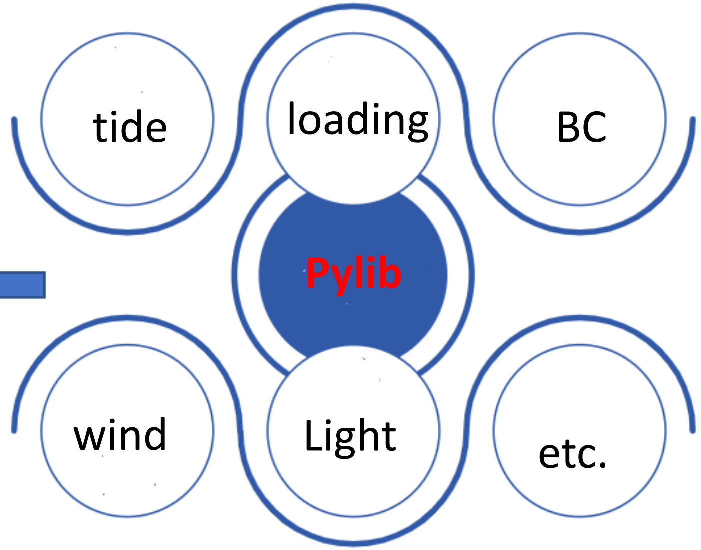
- Run ICM using saved dynamic fields

Python based workflow

- Pylib workflow from mesh generation all the way to analysis/visualization
- Greatly simplified the calibration and production process for MBM

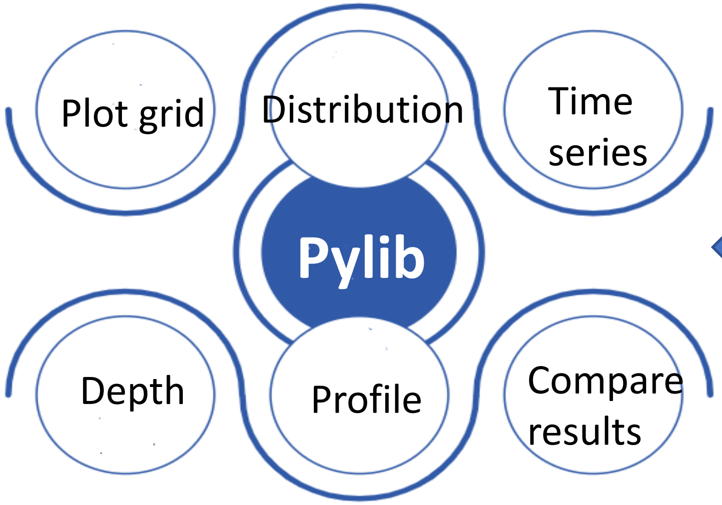
Grid Generation → **Model Setup** → **Analysis**





Input files

```
p.flag['elev2D.th.nc']        = 0 #hydro
p.flag['TEM_3D.th.nc']        = 0 #hydro
p.flag['TEM_nu.nc']           = 0 #hydro
p.flag['SAL_3D.th.nc']        = 0 #hydro
p.flag['SAL_nu.nc']           = 0 #hydro
p.flag['sflux']               = 0 #hydro
p.flag['albedo.gr3']          = 0 #hydro
p.flag['drag.gr3']            = 0 #hydro
p.flag['rough.gr3']           = 0 #hydro,SED
p.flag['watertype.gr3']       = 0 #hydro
p.flag['diffmin.gr3']         = 0 #hydro
p.flag['diffmax.gr3']         = 0 #hydro
p.flag['shapiro.gr3']         = 0 #hydro
p.flag['TEM_nudge.gr3']       = 0 #hydro
p.flag['SAL_nudge.gr3']       = 0 #hydro
```

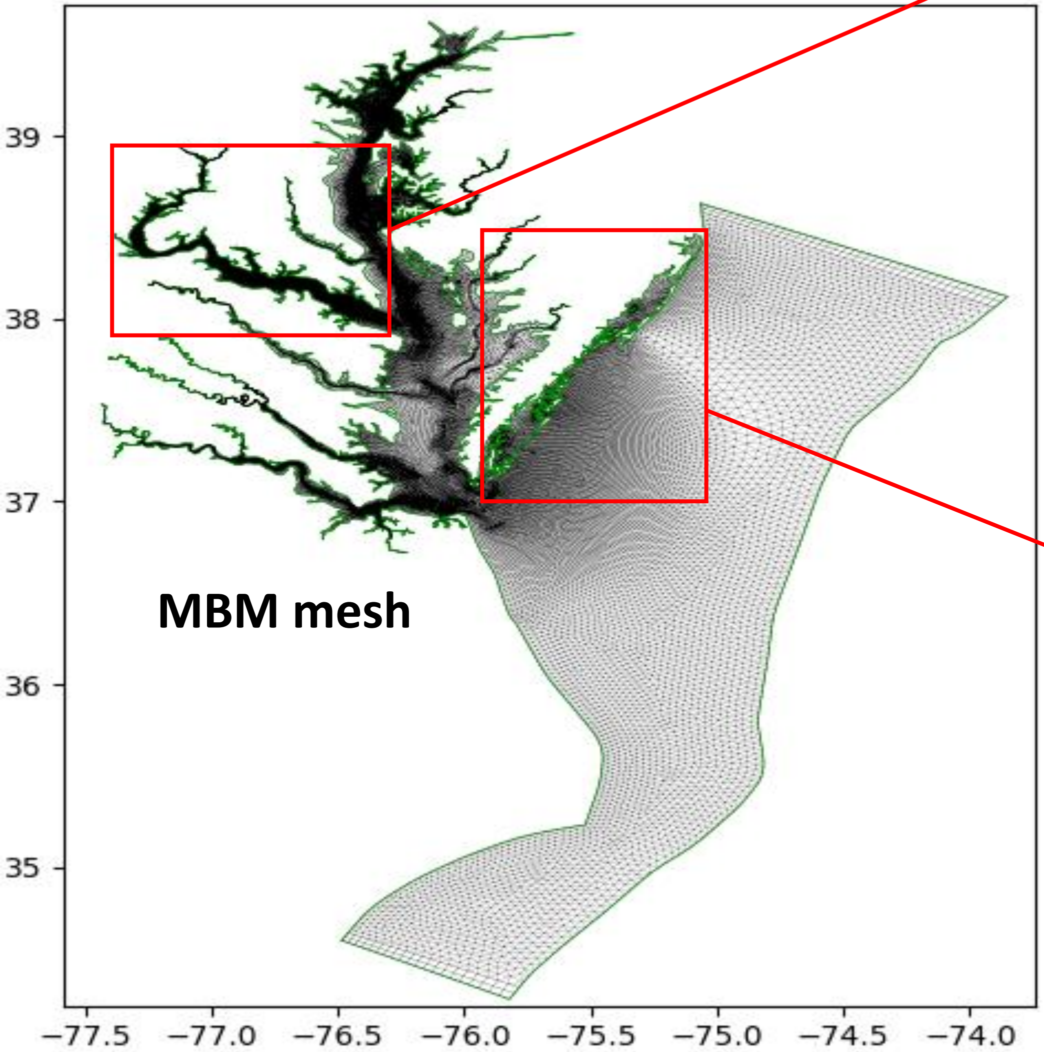


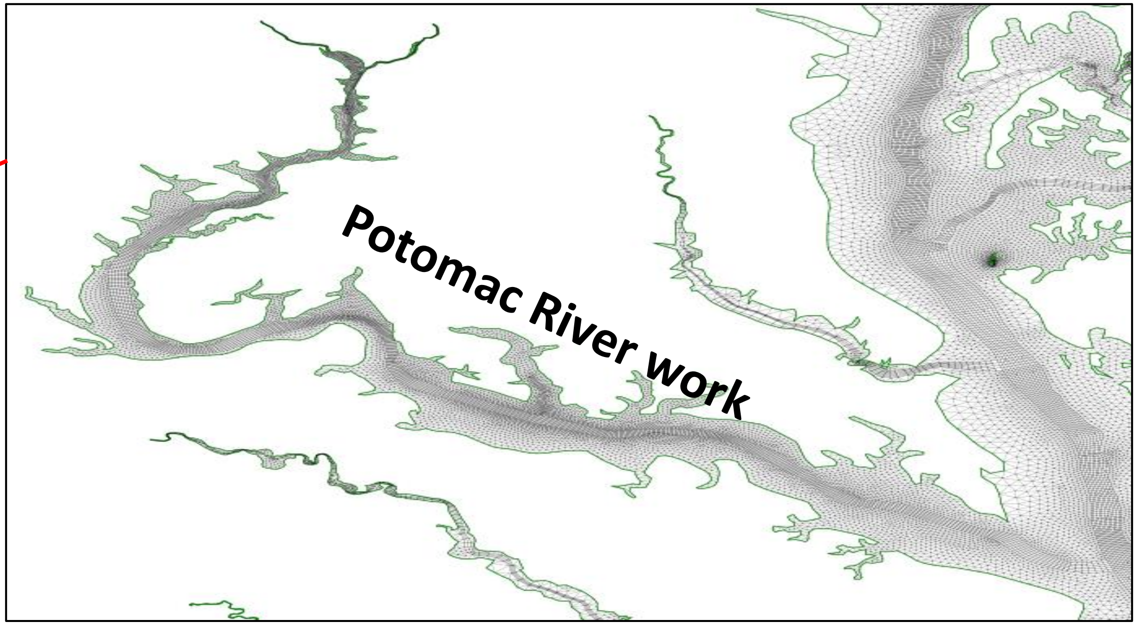
Outline

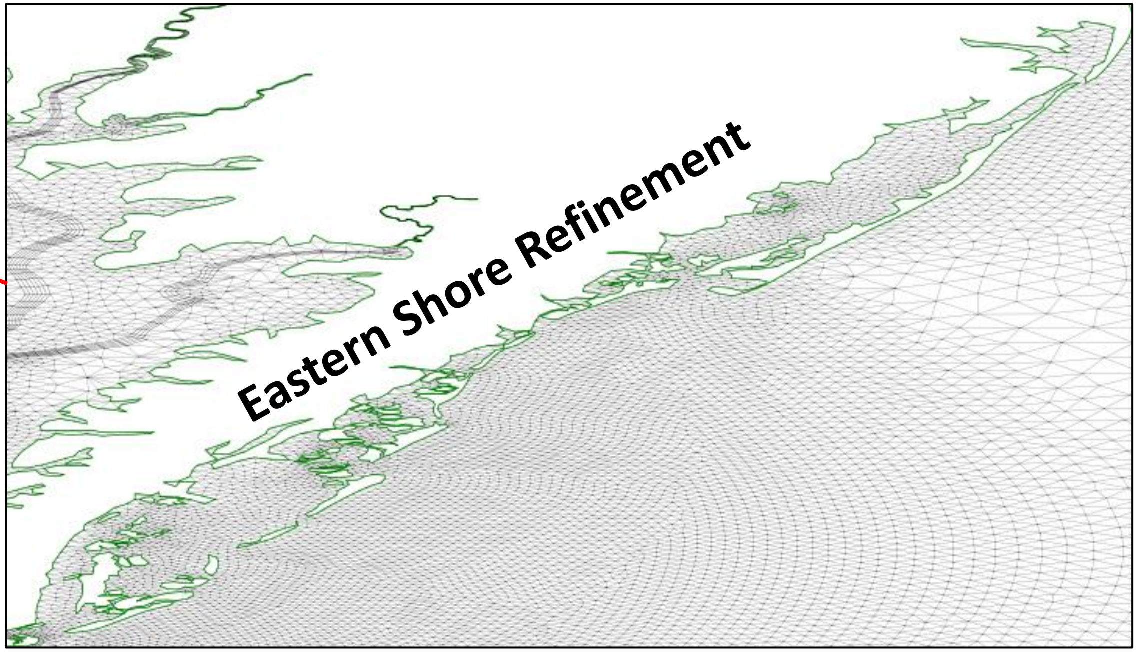
- Improvement of MBM mesh: eastern shore, Potomac,...
- Hydrodynamic recalibration results: 2004-9
- Wave and sediment model results
- Summary and future work

Mesh improvement

- We further refined the MBM mesh in Potomac River and eastern shore based on VIMS shoreline
- Also corrected errors made in a few islands and added some minor access channels (e.g. Baltimore)





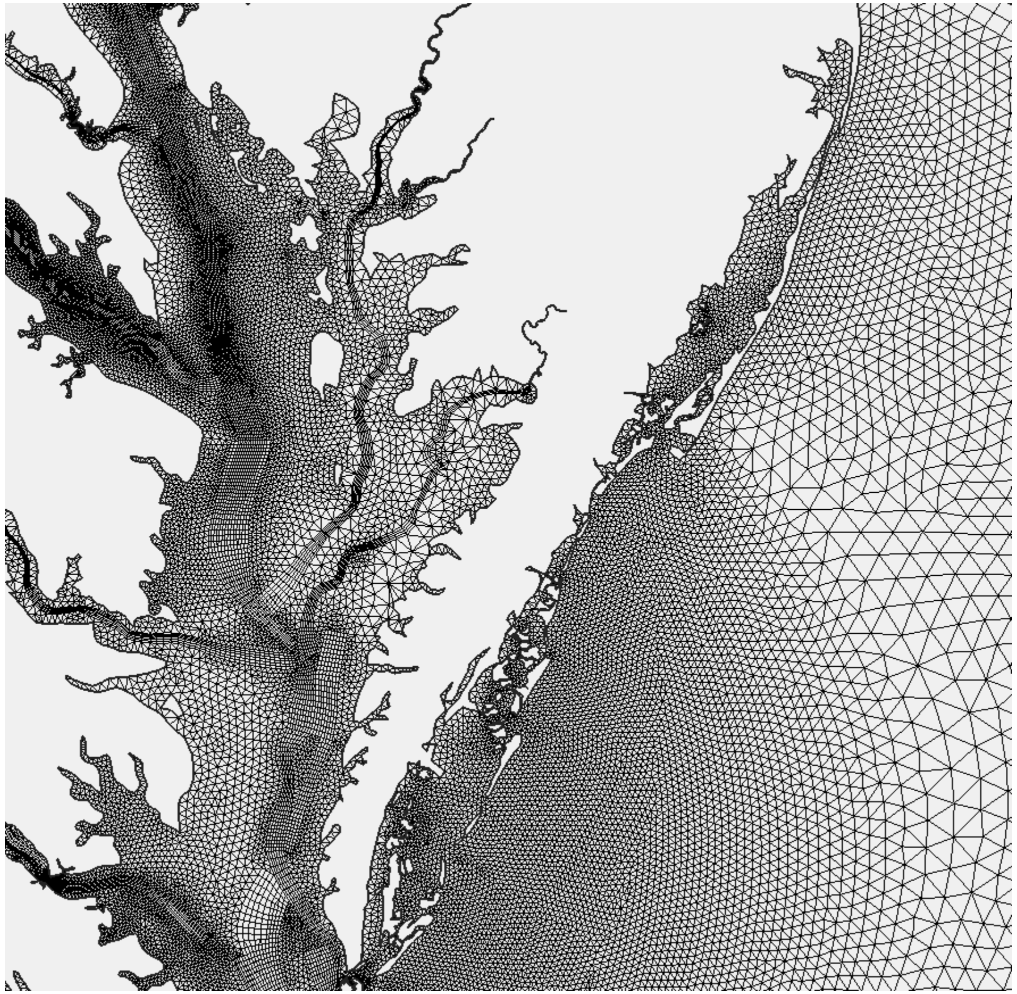


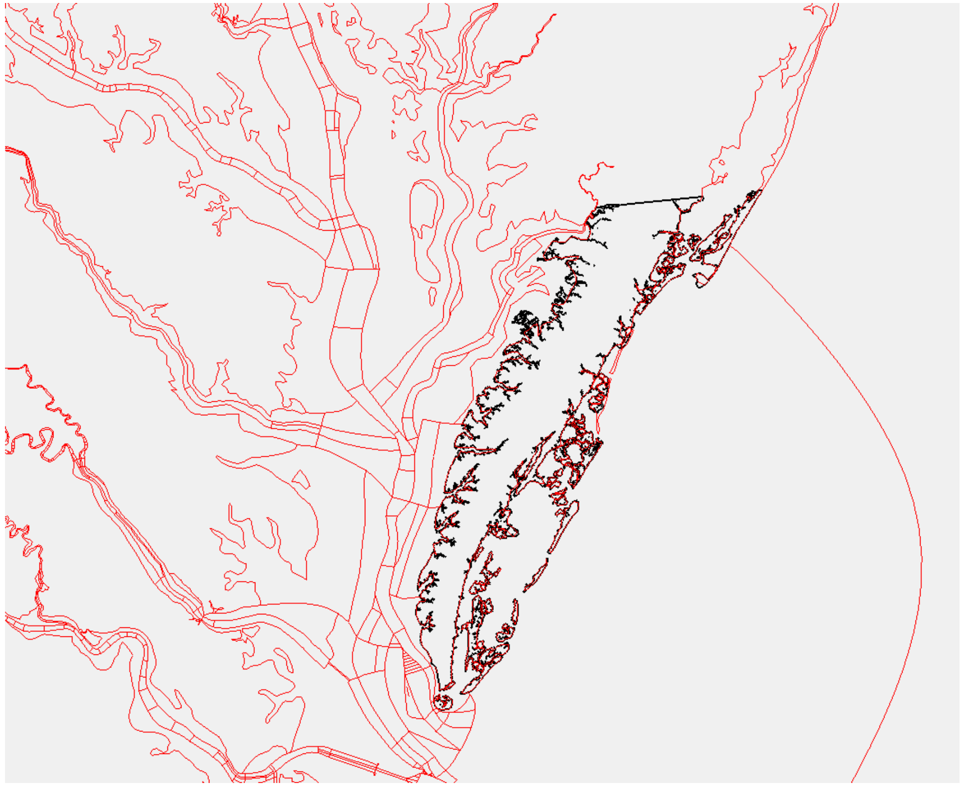
VIMS high-resolution shoreline

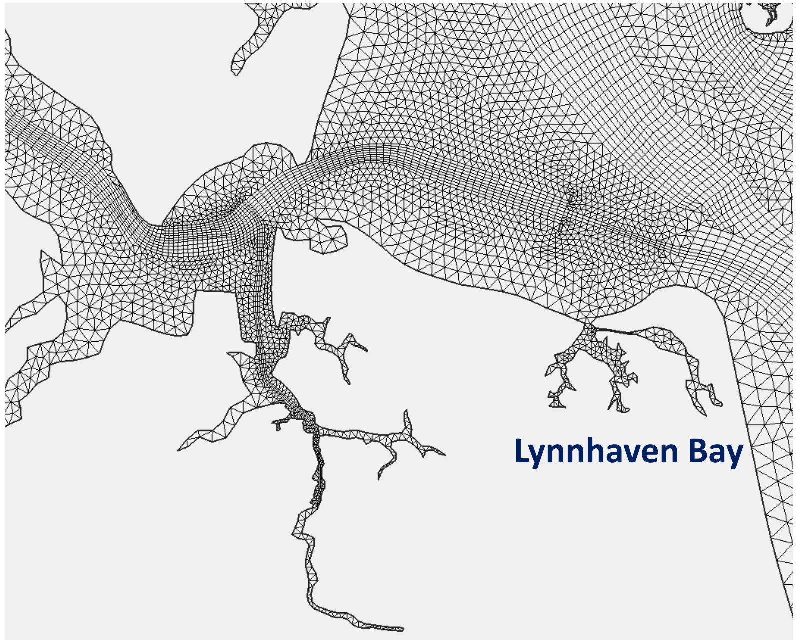
- c/o Karinna Nunez; preliminary version
- Highly detailed shoreline; sub-sampled for mesh generation to keep the mesh size modest
- Corresponds to the historic shoreline condition based on various surveys and/or aerial imagery
    - May need to be adjusted for climate change simulations
    - VIMS will complete MD part of the shoreline in May
    - VIMS will redo the entire shoreline inventory starting in Oct, with better definitions for ‘shoreline’
- Question: which ‘shoreline’ should we used? Coordination with Karinna’s team would be good

Mesh improvement: eastern shore & Lynnhaven

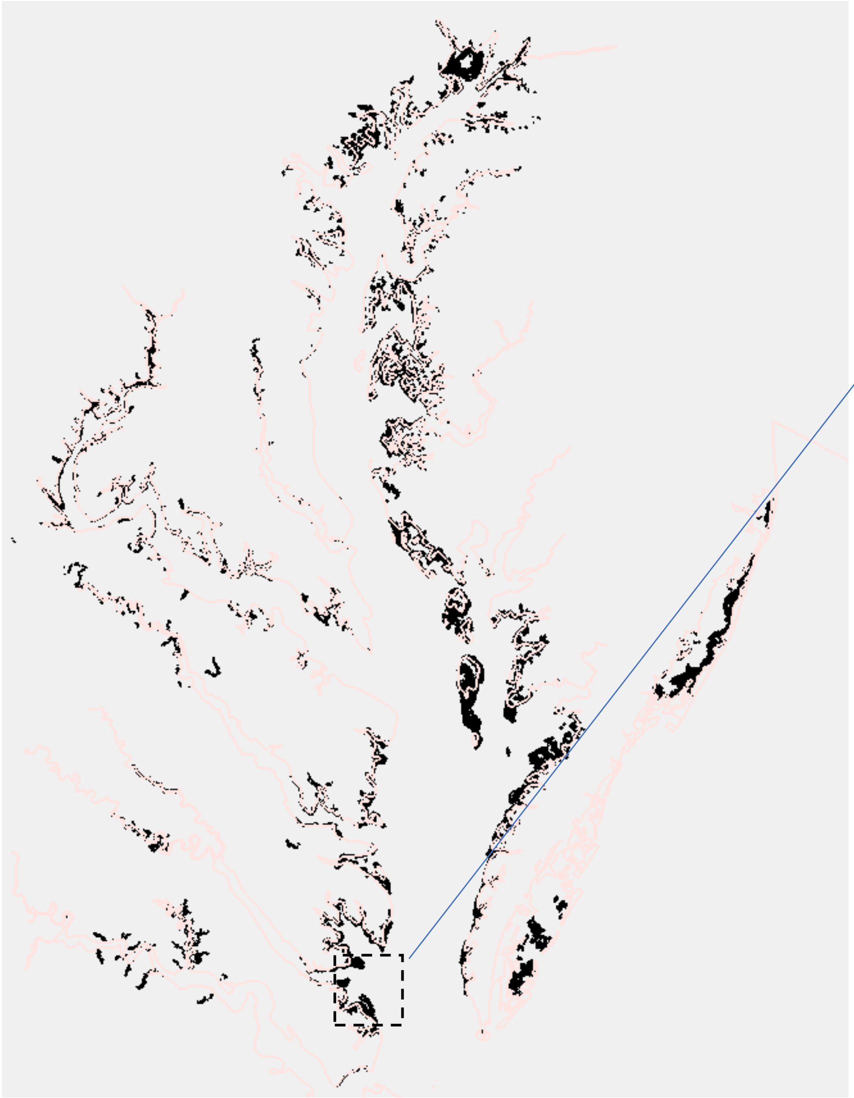
- Used a preliminary version of new shoreline from Karinna for the Bay including eastern shore
- Simplified the shoreline to keep the mesh size modest



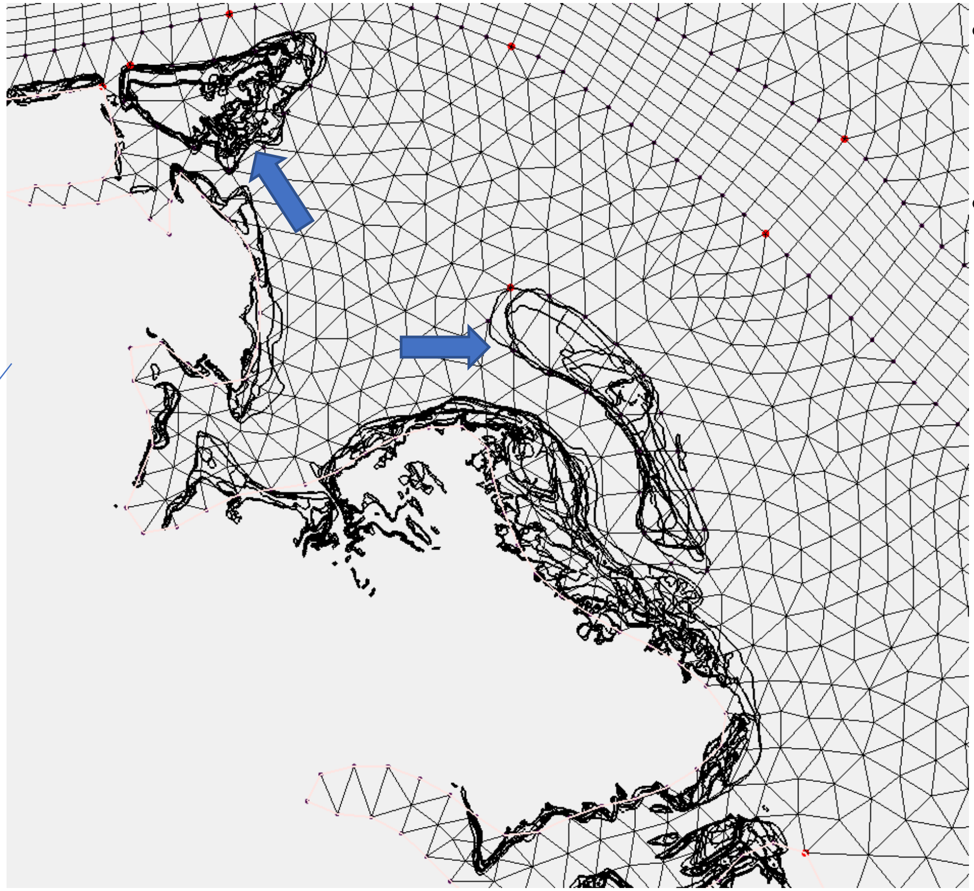




Mesh improvement: SAV



Cumulative SAV bed (max)

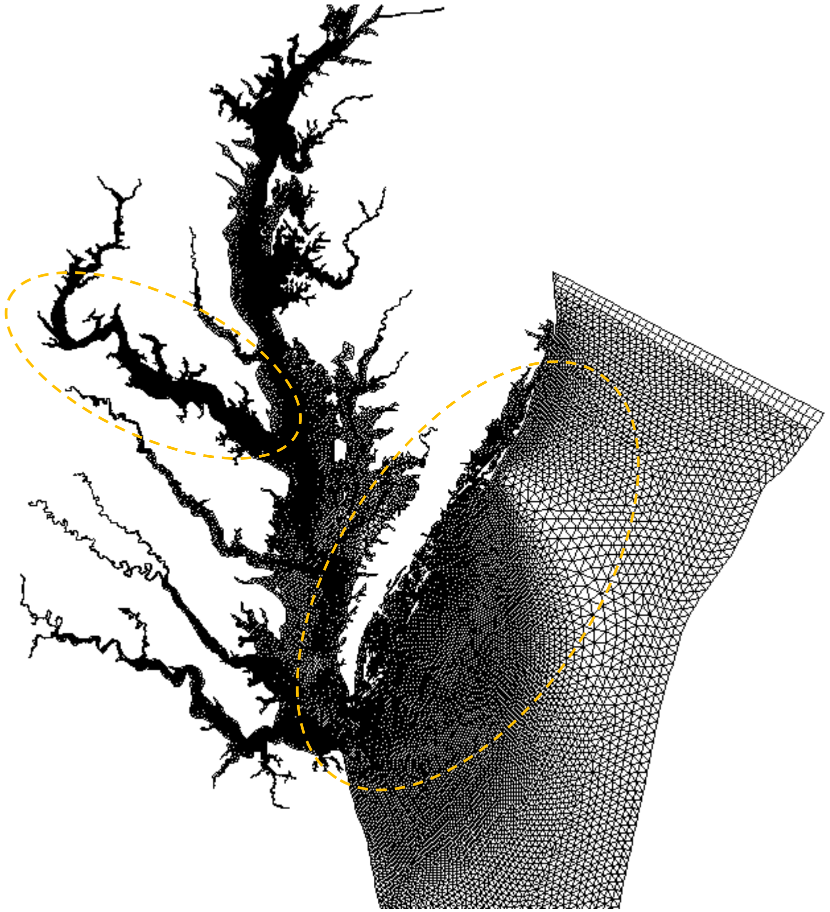


Polygons for some large SAV beds

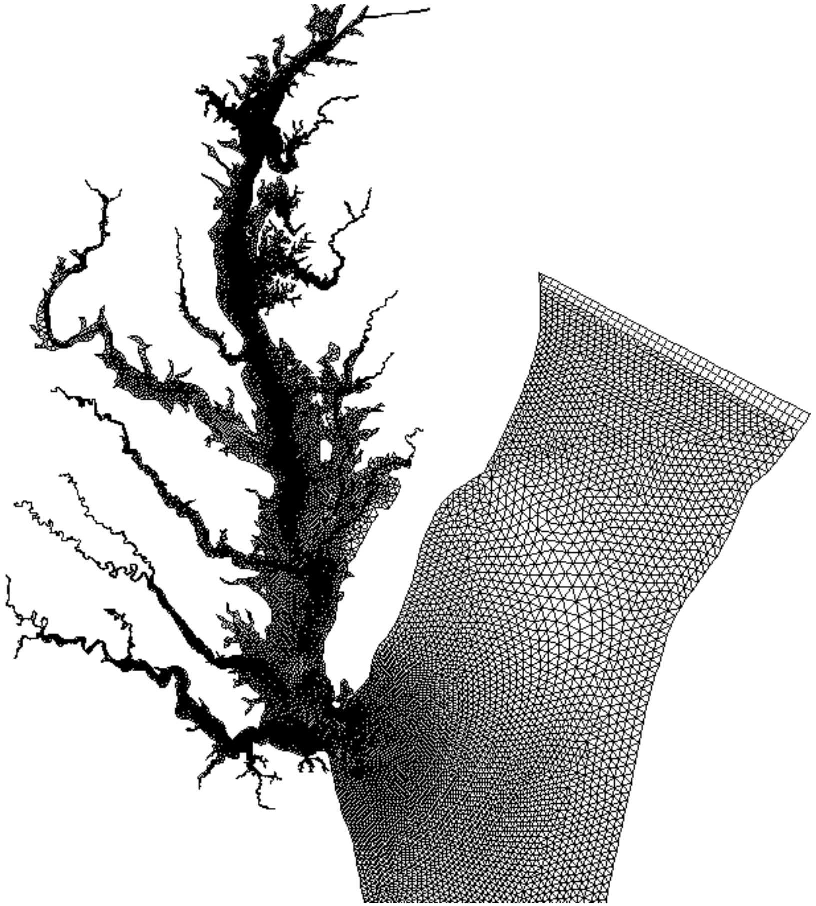
- SAV module inside SCHISM is based on 'density' defined at mesh nodes
- Hope to account for SAV effects for flow and WQ at least qualitatively – with flexibility to use higher resolution in targeted beds (mesh size)
    - SAV physics: vegetation induced 3D form drag, 3D turbulence
    - SAV biochemistry: full dynamic interaction with nutrients, primary producers and sediment diagenesis with growth/decay – these may be omitted for efficiency

Mesh improvement: old vs new mesh

New mesh



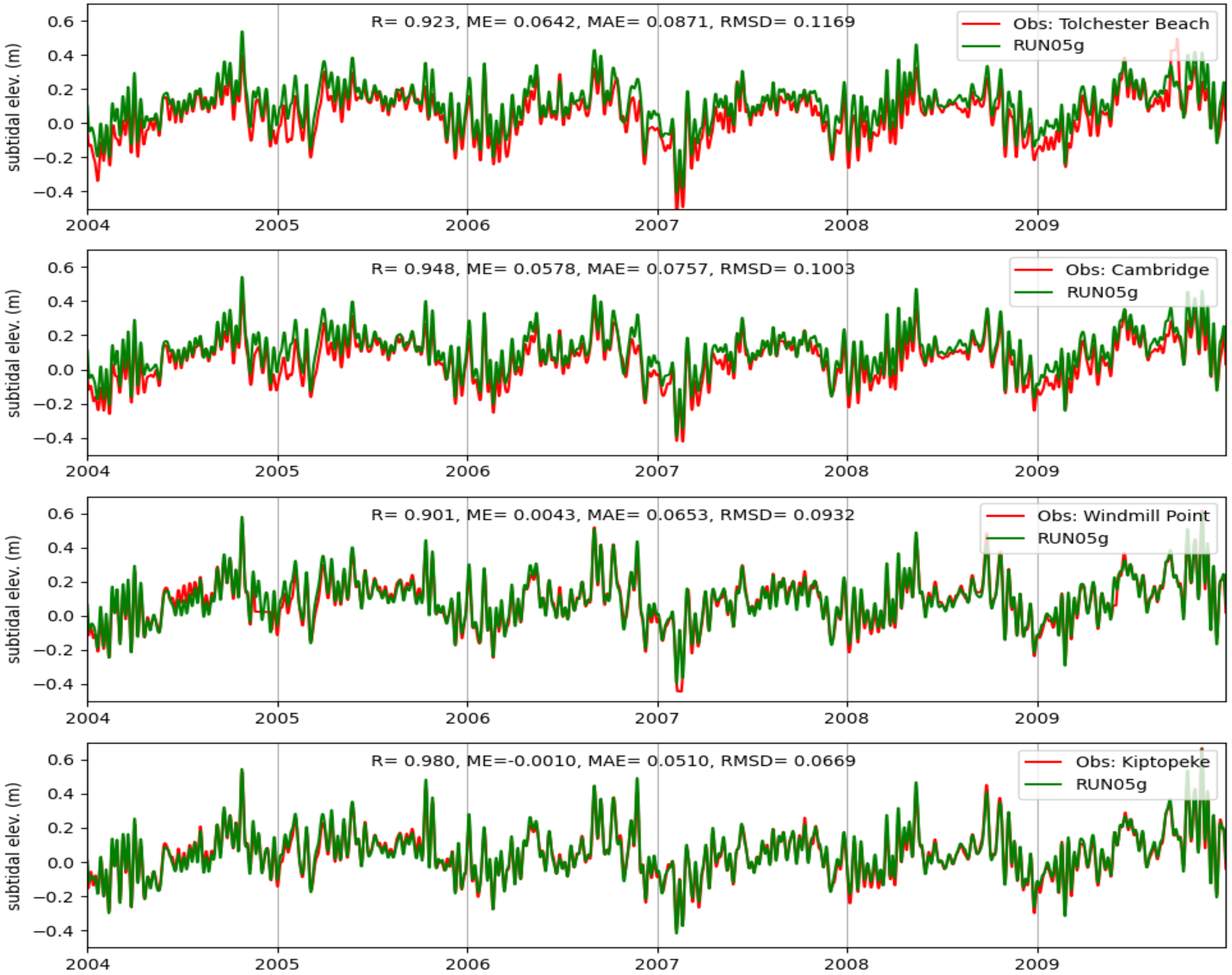
Old mesh



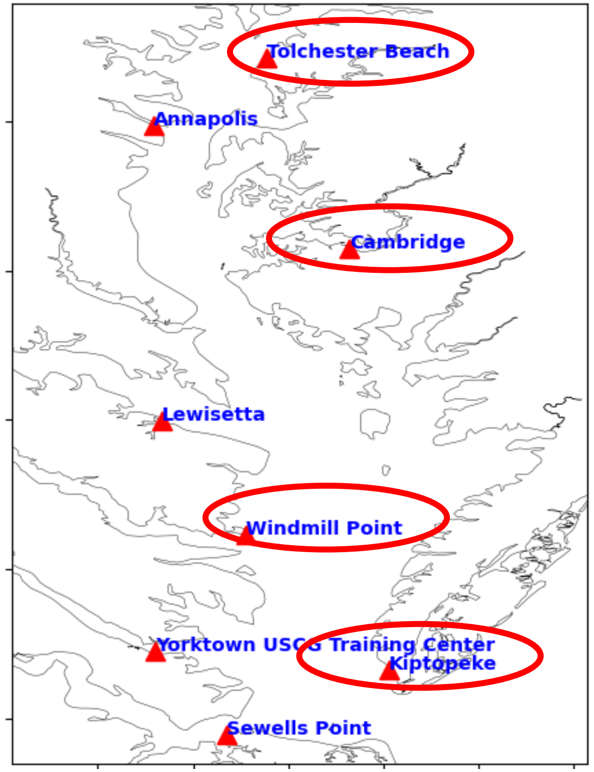
- Mesh size increased from 46K to 69K nodes
- Which means more HPC resources are required
- Going forward, we will need to keep the mesh size at or below this level for efficiency

Model recalibration : sub-tidal elevation

- Modeled elevation is carefully analyzed throughout the Bay for both tidal and non-tidal components
- Subtidal elevation is quite satisfactory (averaged RMSD= 8.85 cm)
- Tidal harmonics are also good



Obs
Model



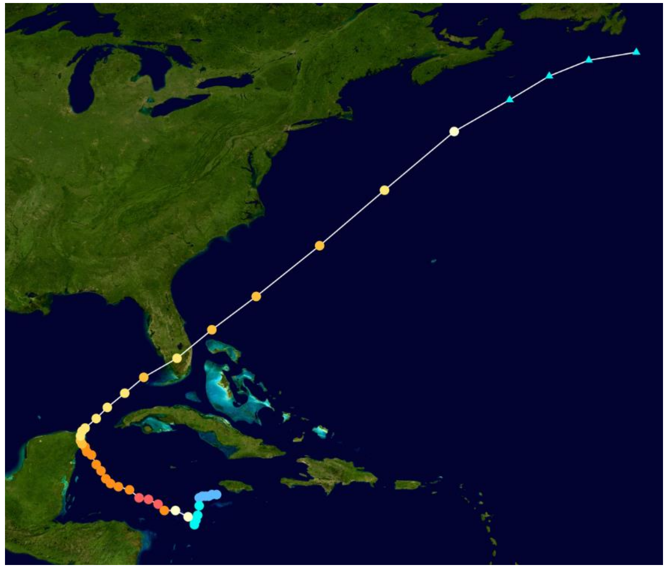
Statistics for sub-tidal elevation (m)

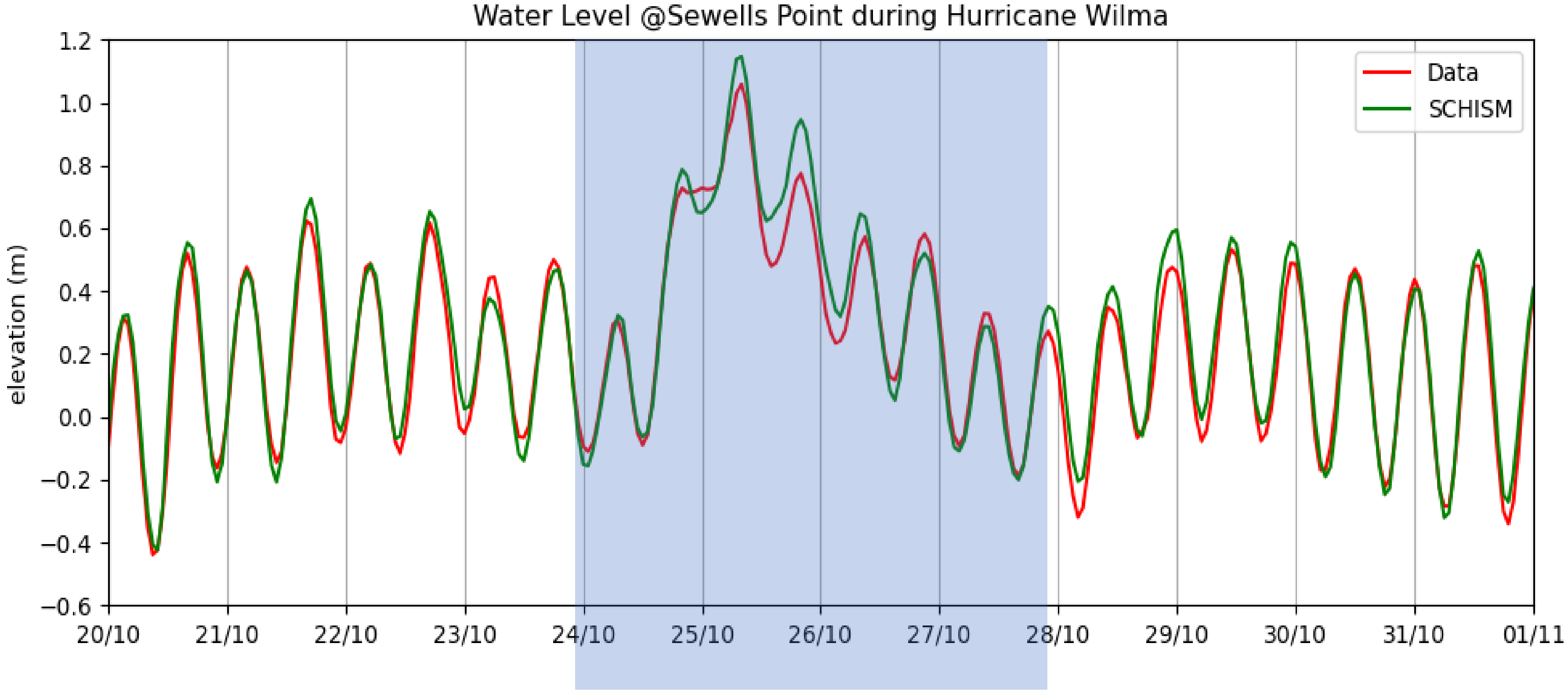
station	R	RMSD	ME	MAE
Tolchester Beach	0.923	0.117	0.064	0.087
Annapolis	0.917	0.105	0.043	0.079
Cambridge	0.948	0.100	0.058	0.076
Lewisetta	0.959	0.066	0.022	0.049
Windmill Point	0.901	0.093	0.004	0.065
Yorktown TC	0.949	0.099	-0.002	0.067
Kiptopeke	0.980	0.067	-0.001	0.051
Sewells Point	0.984	0.060	0.018	0.046

Surges during Hurricane Wilma, 2005 (Category 5)

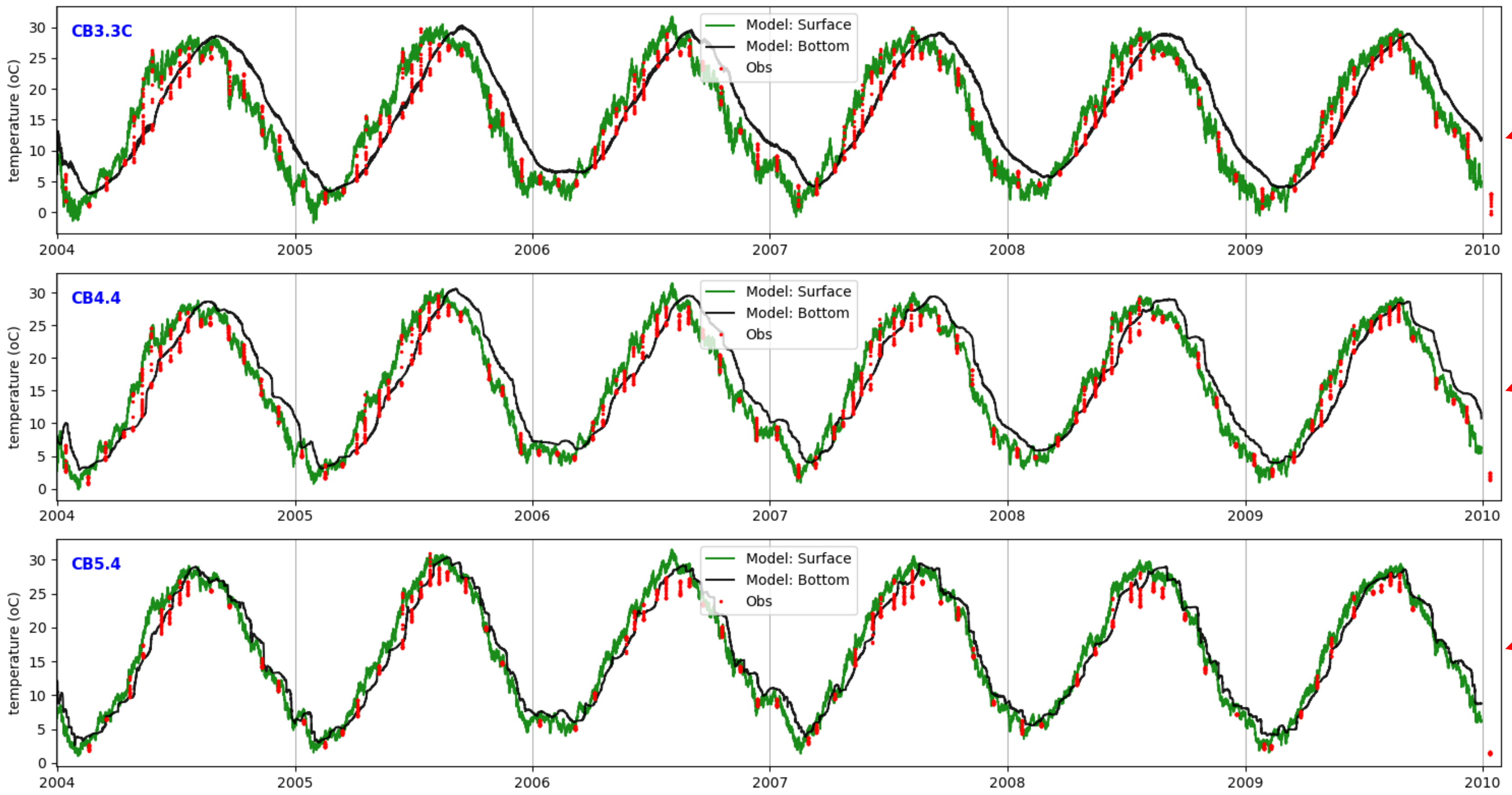
- Model uses high resolution in both space and time
- Model successfully captured the storm surge when Wilma passed bay Chesapeake Bay on 10/25, 2005

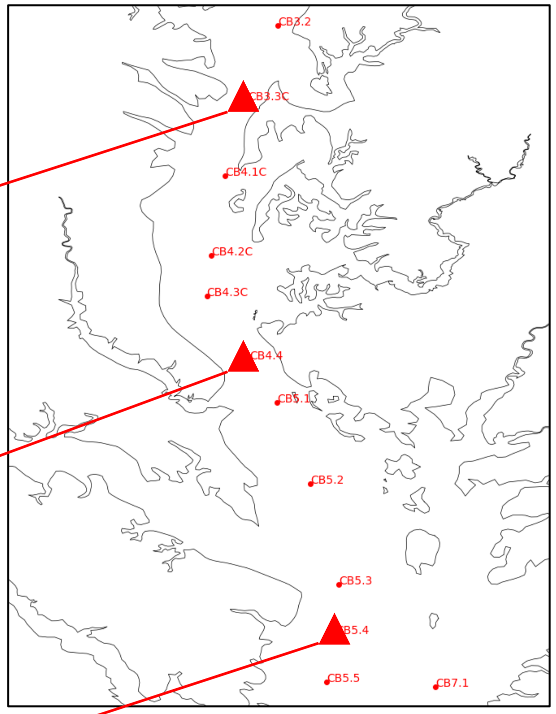
Hurricane Track: October 15-27





Temperature





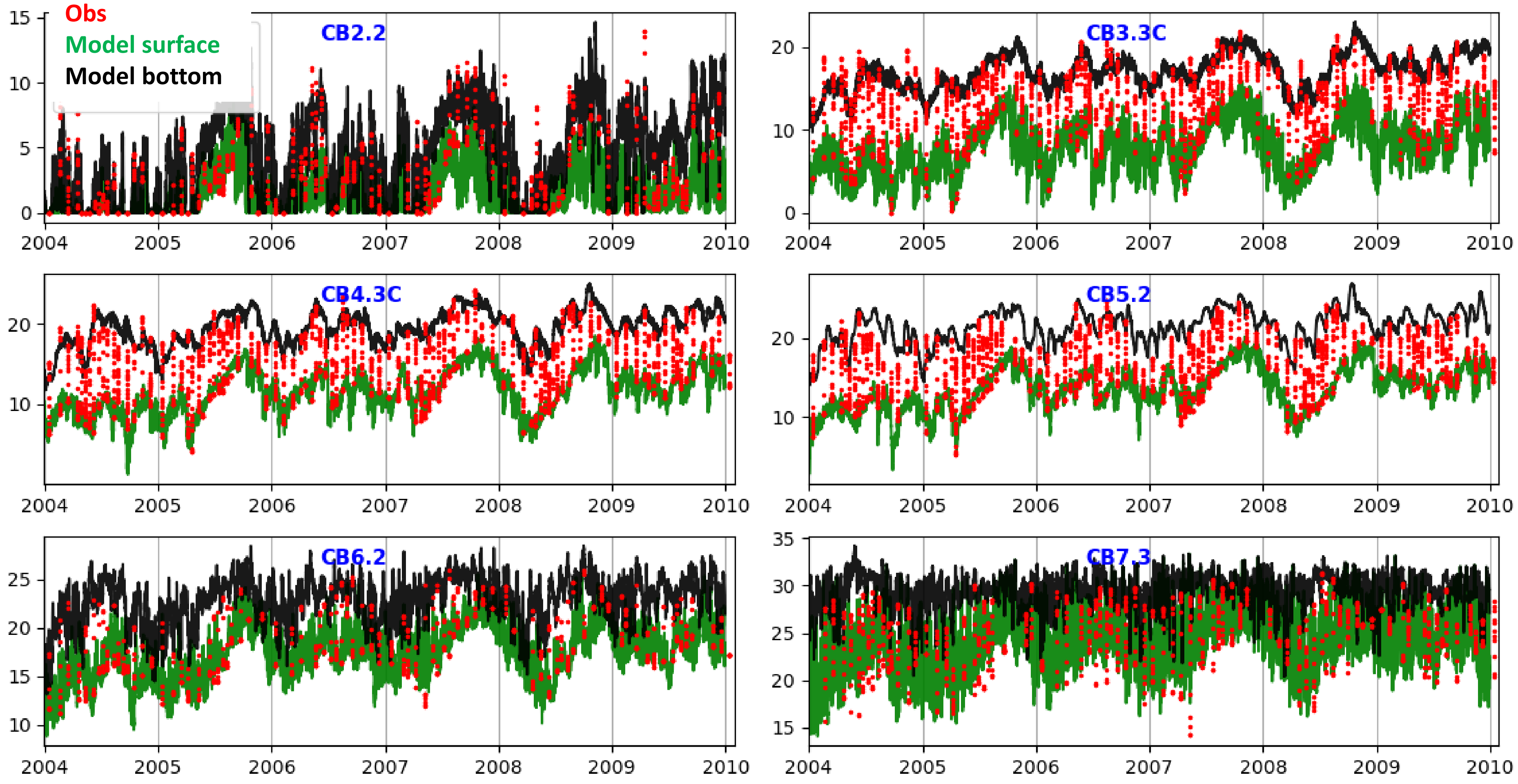
Obs
Model surface
Model bottom

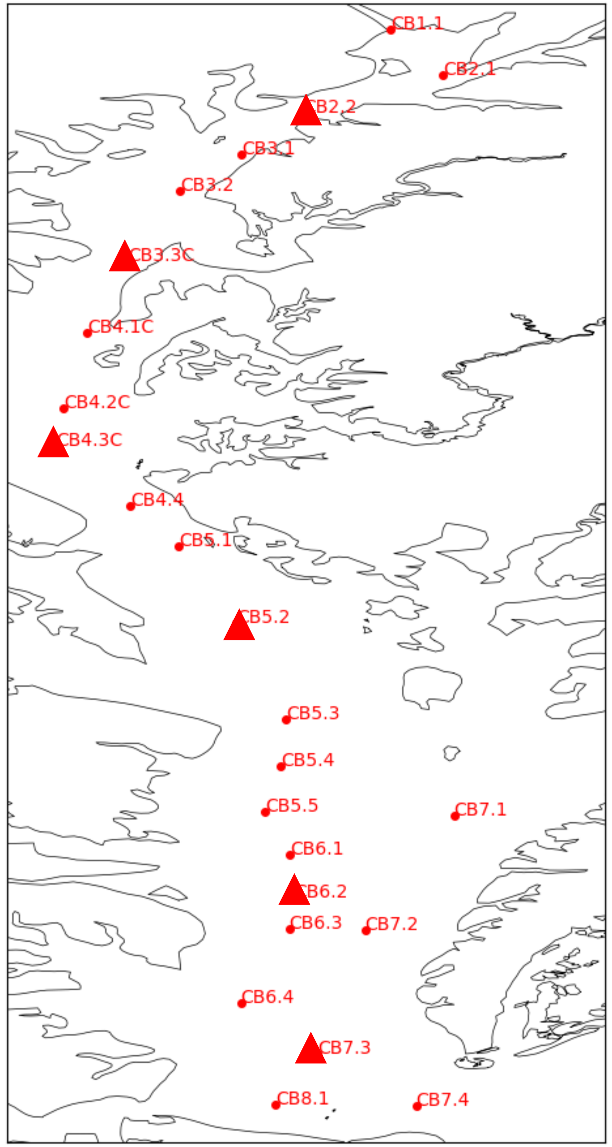
- **Temperate is well simulated throughout the Bay: averaged RMSD= 0.64 °C @surface, 1.78 °C @bottom**

Temperature		CB1.1	CB2.1	CB2.2	CB3.1	CB3.2	CB3.3C	CB4.1C	CB4.2C	CB4.3C	CB4.4	CB5.1	CB5.2	CB5.3	CB5.4	CB5.5	CB6.1	CB6.2	CB6.3	CB6.4	CB7.1	CB7.2	CB7.3	CB7.4	CB8.1
Surface	R	0.993	0.995	0.998	0.998	0.999	0.998	0.998	0.998	0.998	0.999	0.998	0.999	0.999	0.998	0.998	0.999	0.999	0.999	0.998	0.997	0.998	0.998	0.996	0.998
	RMSD	1.071	0.942	0.600	0.616	0.615	0.556	0.602	0.652	0.760	0.453	0.476	0.598	0.691	0.682	0.710	0.486	0.412	0.391	0.648	0.638	0.511	0.547	1.059	0.724
	ME	0.008	-0.278	0.219	0.337	0.386	0.099	0.242	0.437	0.539	0.132	0.092	0.408	0.503	0.451	0.462	0.093	0.098	0.082	0.347	0.034	0.063	0.215	0.651	0.359
	MAE	0.716	0.594	0.382	0.381	0.426	0.337	0.375	0.456	0.575	0.276	0.286	0.448	0.518	0.483	0.520	0.326	0.256	0.240	0.426	0.402	0.297	0.340	0.675	0.447
Bottom	R	0.994	0.995	0.995	0.992	0.977	0.984	0.979	0.983	0.986	0.985	0.987	0.990	0.994	0.993	0.995	0.996	0.997	0.998	0.994	0.996	0.994	0.981	0.966	0.984
	RMSD	1.033	0.950	1.248	1.706	2.426	2.247	2.327	2.182	2.046	2.074	1.997	1.865	1.690	1.724	1.649	1.634	1.454	1.355	1.698	1.375	1.594	2.148	2.441	1.869
	ME	0.184	-0.260	0.853	1.365	1.670	1.711	1.602	1.562	1.504	1.487	1.488	1.399	1.355	1.350	1.327	1.371	1.219	1.144	1.329	1.075	1.249	1.483	1.598	1.268
	MAE	0.655	0.603	0.962	1.400	1.856	1.751	1.778	1.689	1.597	1.649	1.613	1.530	1.379	1.419	1.389	1.385	1.227	1.144	1.329	1.092	1.250	1.484	1.601	1.287

Salinity: Main Bay Stations

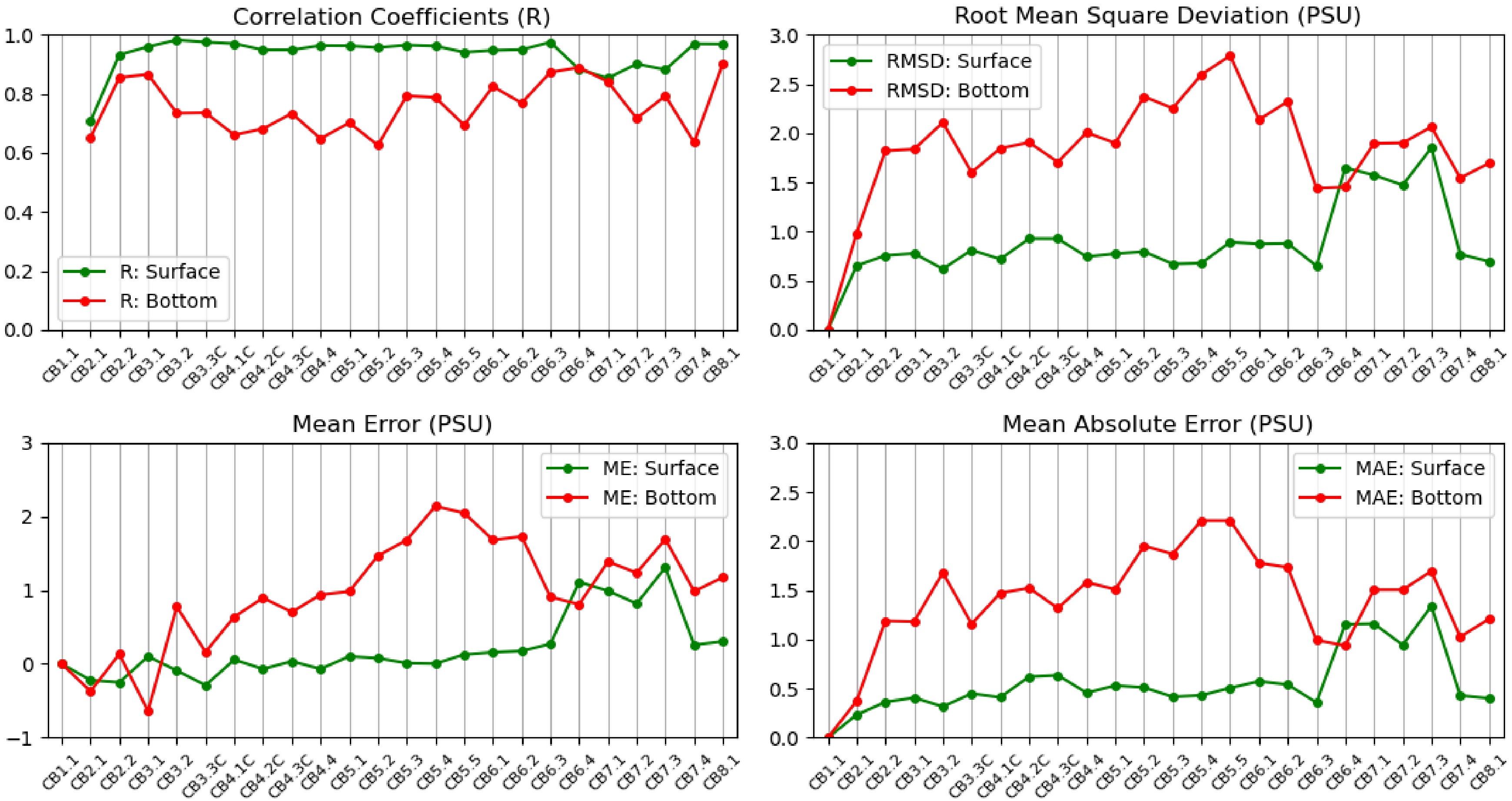
- SCHISM surface and bottom salinity and stratification are assessed with observations along the Main Bay channel
- In general, the salinity variation and stratification are captured well by the model





Salinity error statistics : Main Bay Stations

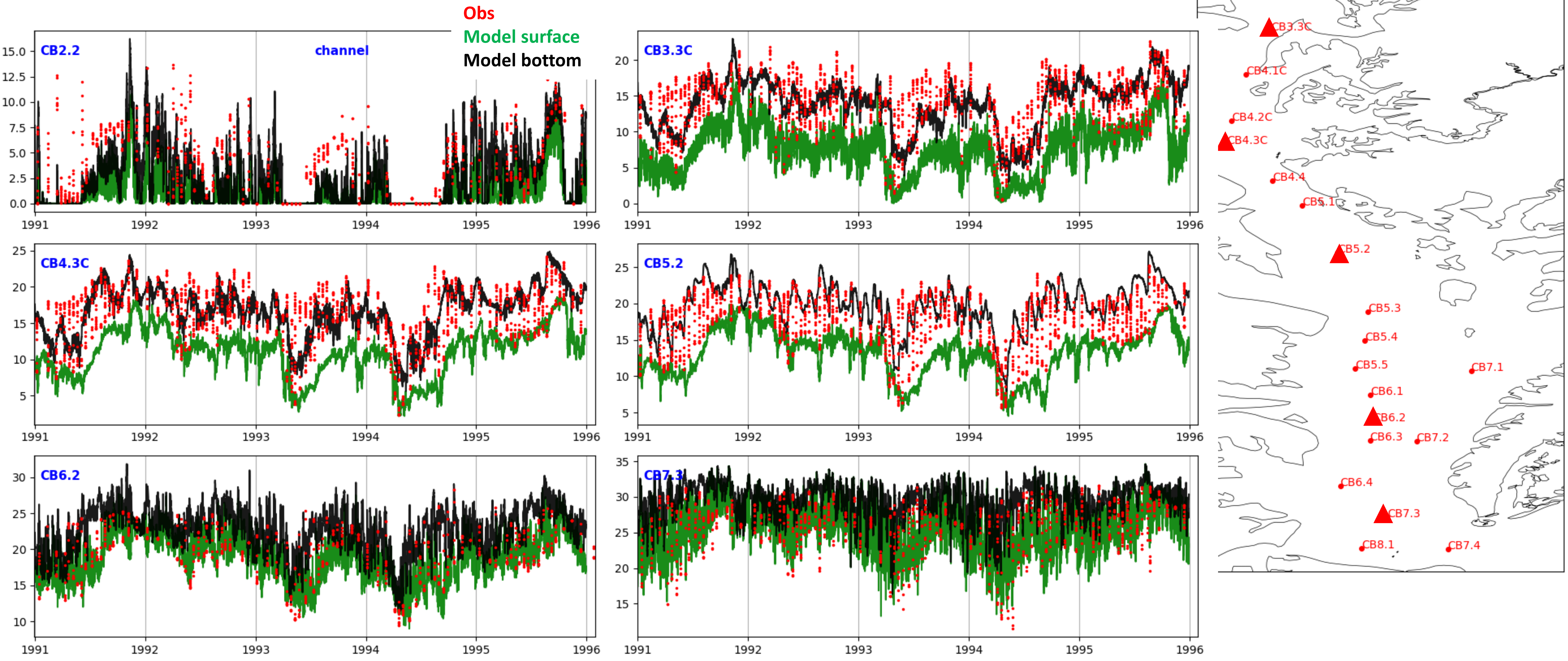
- Surface salinity has an error generally <1 PSU
- Bottom salinity has relatively larger error (1-2 PSU). One reason is found to be the mismatch of the location depths between model and measurements (i.e. DEM uncertainties)



MainBay		CB2.1	CB2.2	CB3.1	CB3.2	CB3.3C	CB4.1C	CB4.2C	CB4.3C	CB4.4	CB5.1	CB5.2	CB5.3	CB5.4	CB5.5	CB6.1	CB6.2	CB6.3	CB6.4	CB7.1	CB7.2	CB7.3	CB7.4	CB8.1
Surface	R	0.708	0.933	0.960	0.983	0.976	0.971	0.949	0.949	0.964	0.963	0.957	0.966	0.963	0.941	0.948	0.950	0.975	0.883	0.854	0.901	0.882	0.970	0.969
	RMSD	0.653	0.756	0.777	0.619	0.811	0.719	0.927	0.927	0.744	0.774	0.795	0.670	0.678	0.892	0.874	0.879	0.650	1.649	1.574	1.473	1.852	0.769	0.695
	ME	-0.219	-0.250	0.101	-0.090	-0.288	0.056	-0.068	0.035	-0.067	0.102	0.078	0.011	0.004	0.128	0.158	0.176	0.271	1.113	0.991	0.819	1.309	0.258	0.306
	MAE	0.232	0.362	0.406	0.316	0.449	0.411	0.621	0.635	0.456	0.530	0.510	0.416	0.431	0.506	0.574	0.540	0.357	1.153	1.159	0.944	1.339	0.429	0.401
Bottom	R	0.652	0.855	0.867	0.735	0.736	0.661	0.682	0.734	0.648	0.702	0.626	0.794	0.788	0.694	0.825	0.769	0.874	0.889	0.841	0.717	0.794	0.635	0.903
	RMSD	0.982	1.821	1.838	2.108	1.601	1.847	1.907	1.706	2.006	1.900	2.373	2.254	2.596	2.789	2.138	2.323	1.440	1.452	1.896	1.902	2.064	1.545	1.694
	ME	-0.370	0.133	-0.639	0.777	0.162	0.639	0.896	0.705	0.939	0.982	1.468	1.681	2.140	2.048	1.682	1.730	0.908	0.809	1.387	1.236	1.692	0.986	1.176
	MAE	0.372	1.188	1.181	1.679	1.158	1.472	1.522	1.318	1.581	1.509	1.952	1.869	2.209	2.208	1.777	1.734	0.992	0.937	1.505	1.505	1.694	1.025	1.206

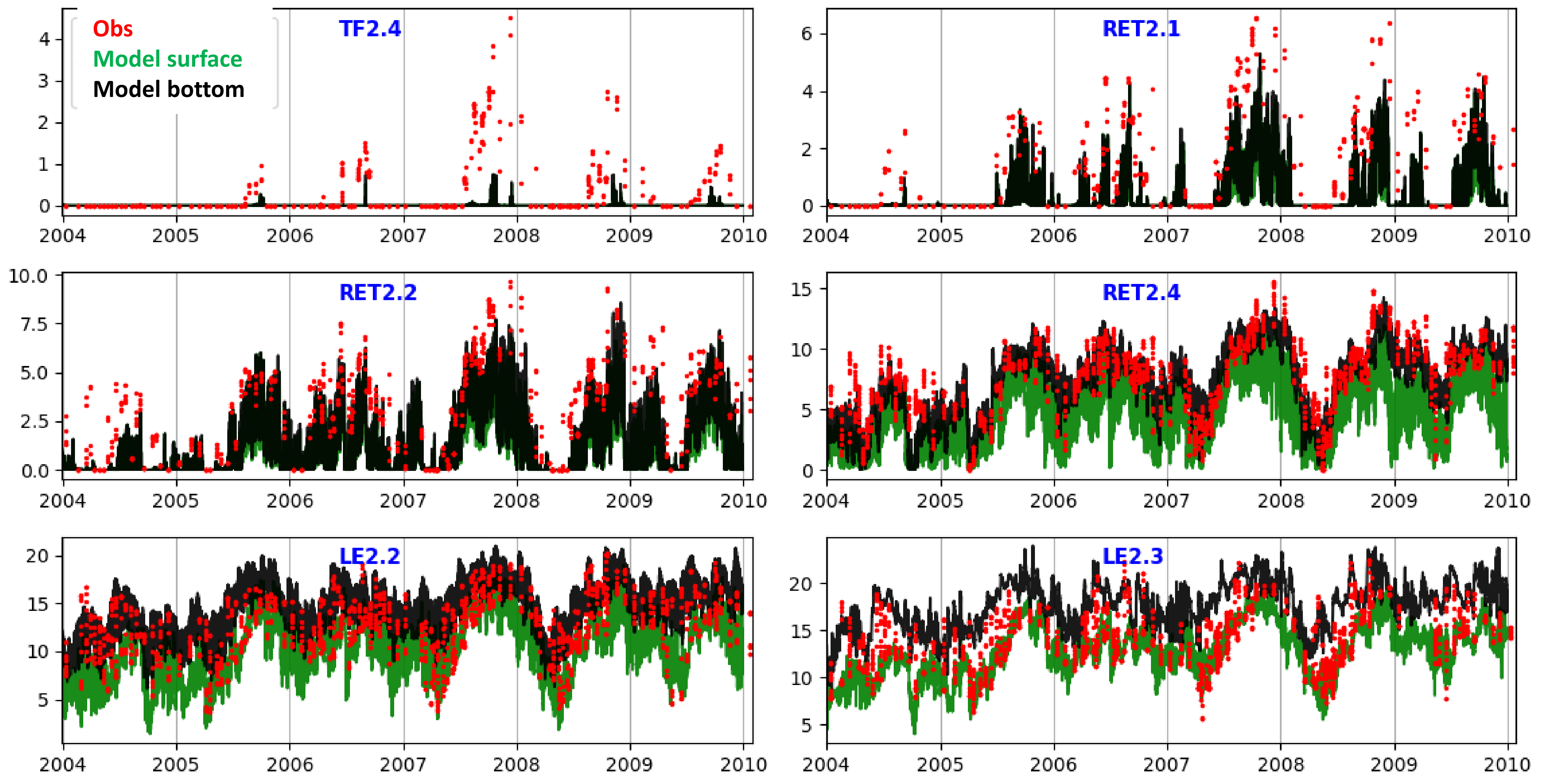
Salinity results for 1991-1995

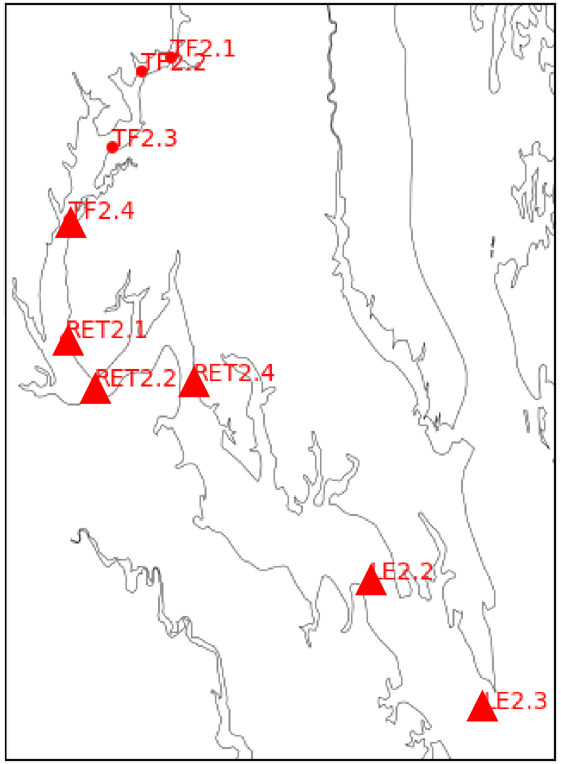
- SCHISM skill is reaffirmed for this period



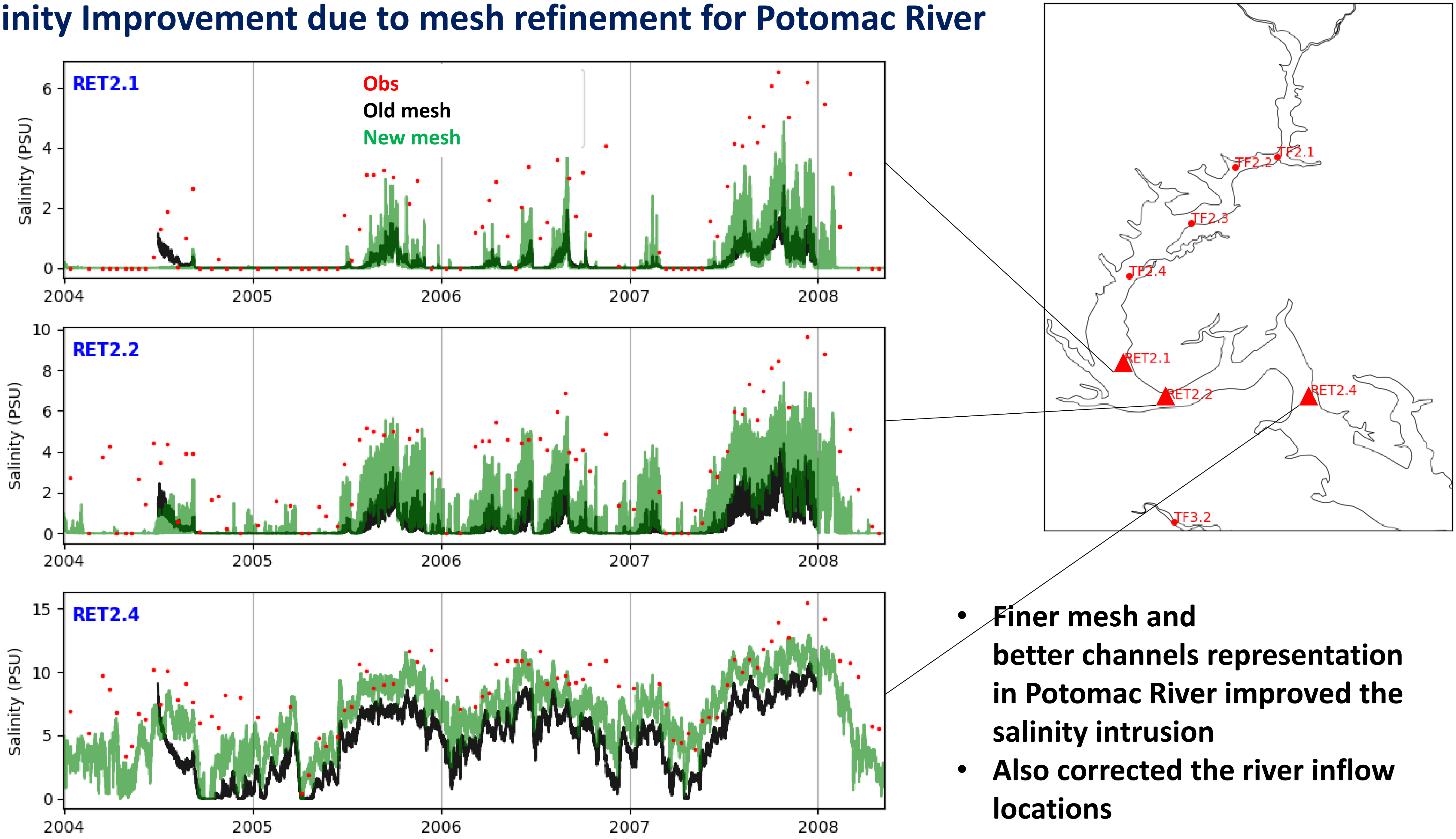
Salinity along Potomac River

- c/o Nicole Cai's work on MTM
- SCHISM surface and bottom salinities are now well simulated along Potomac
- Model evaluations (statistics) are done for all major tributaries of Chesapeake Bay





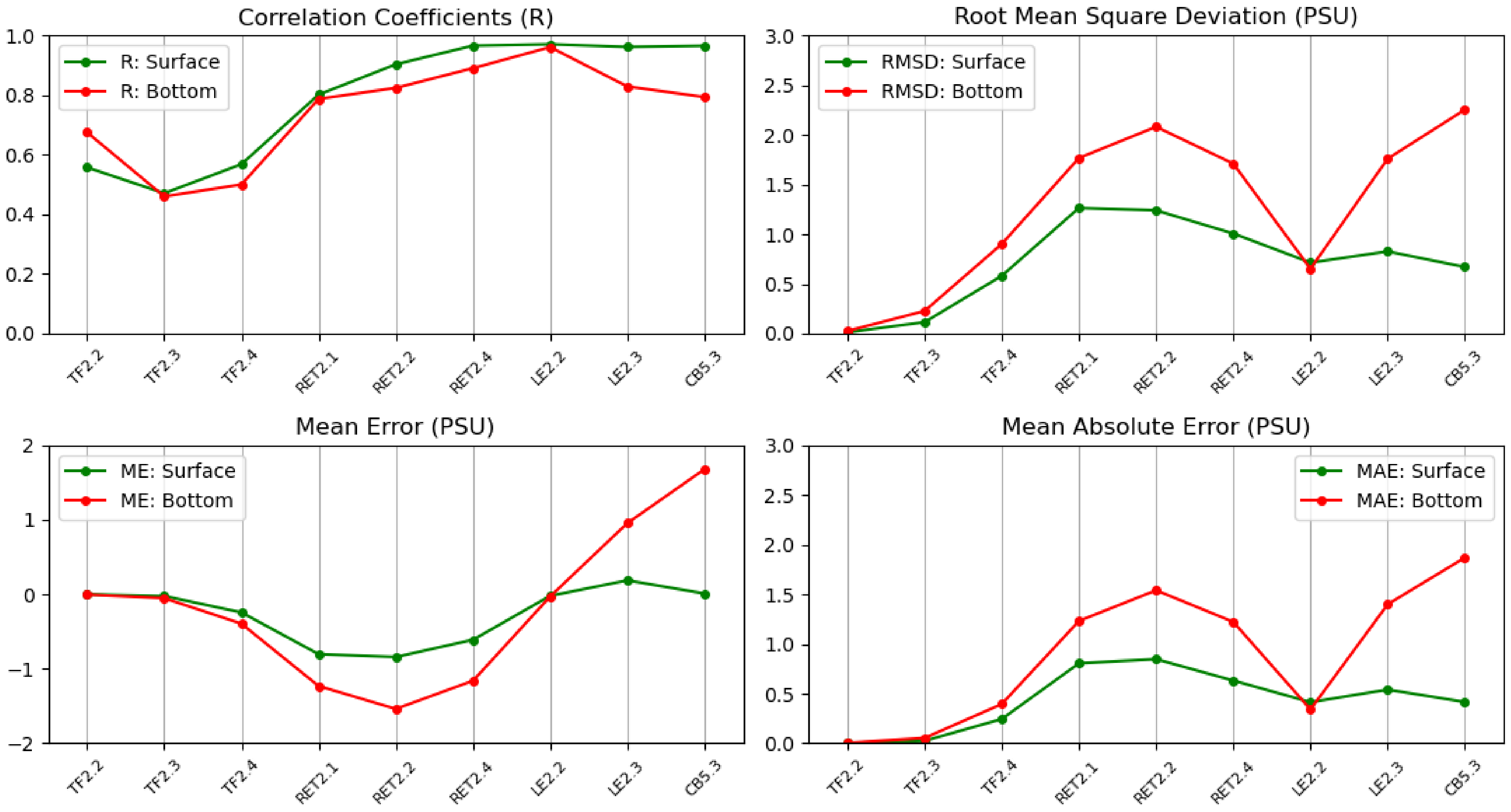
Salinity Improvement due to mesh refinement for Potomac River

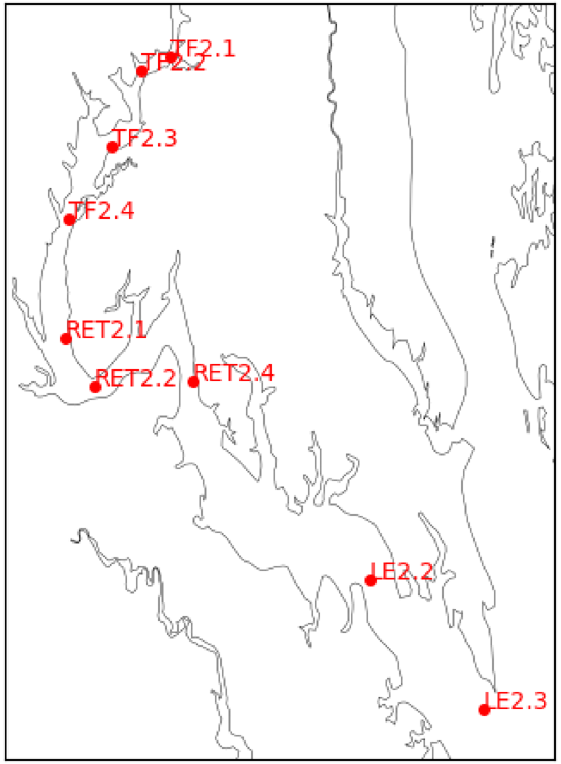


- Finer mesh and better channels representation in Potomac River improved the salinity intrusion
- Also corrected the river inflow locations

Salinity error statistics: Potomac River

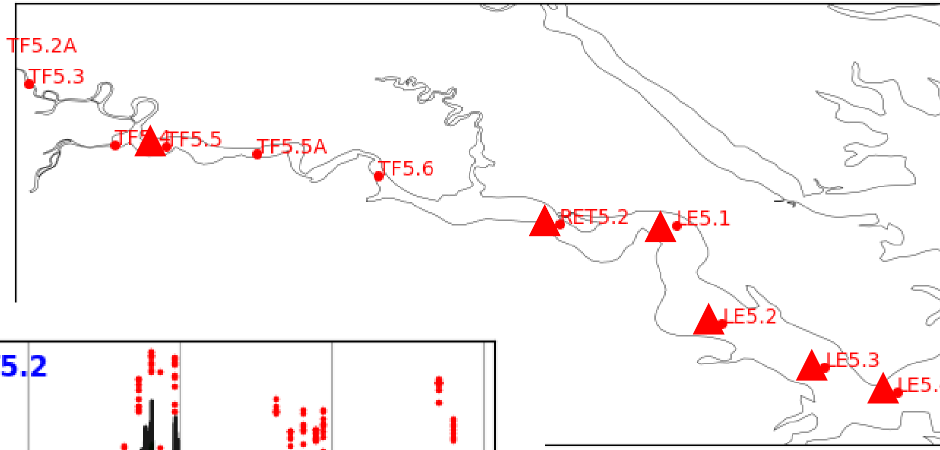
- Surface salinity has an error generally <1 PSU
- Bottom salinity has slightly larger error (1-2 PSU)

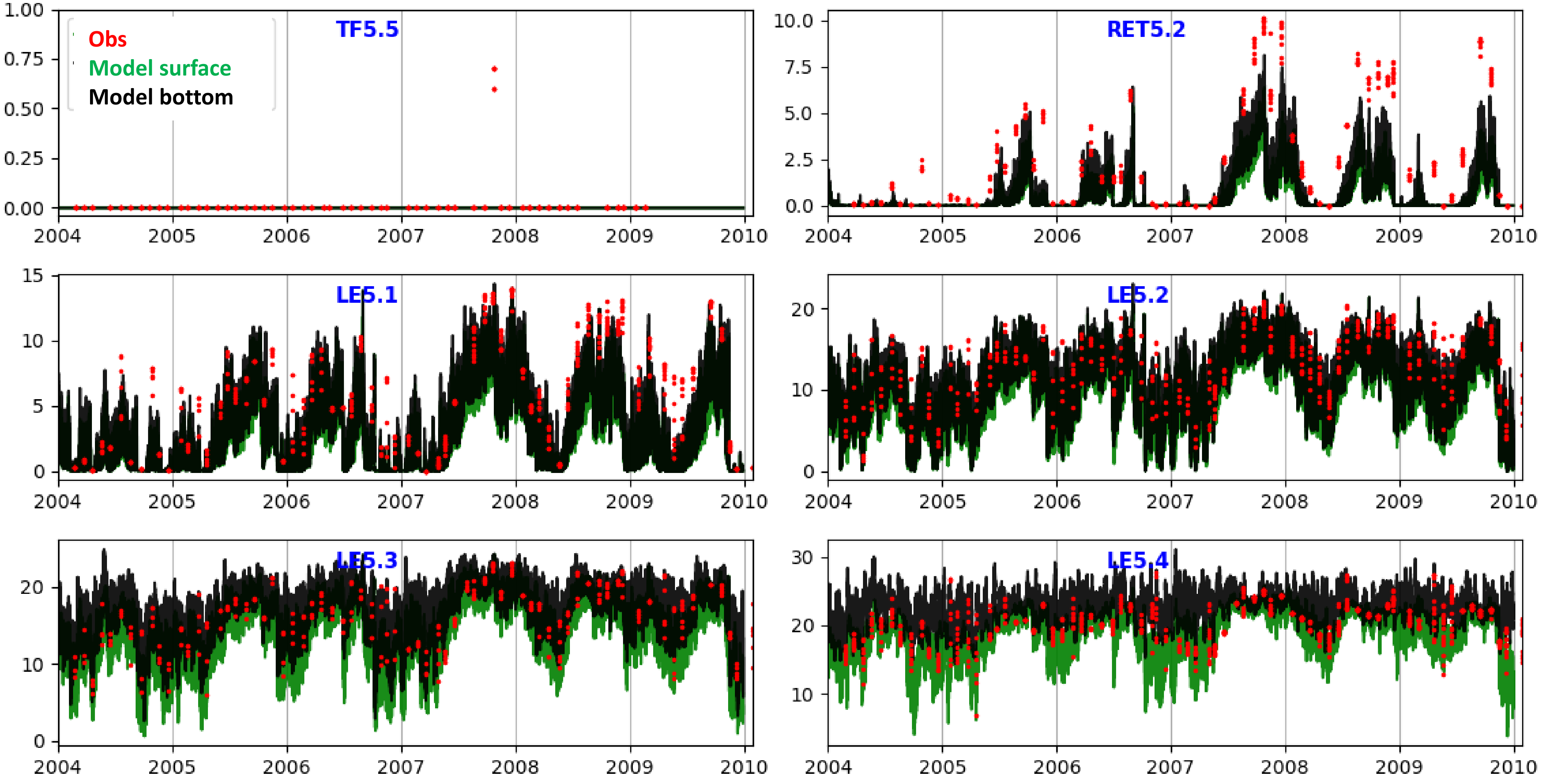




Salinity: James River

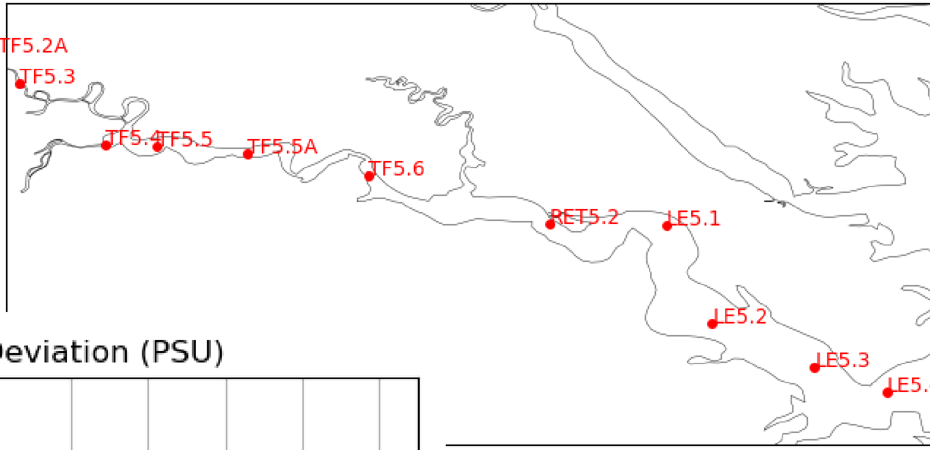
- **SCHISM surface and bottom salinities are well simulated in James River**

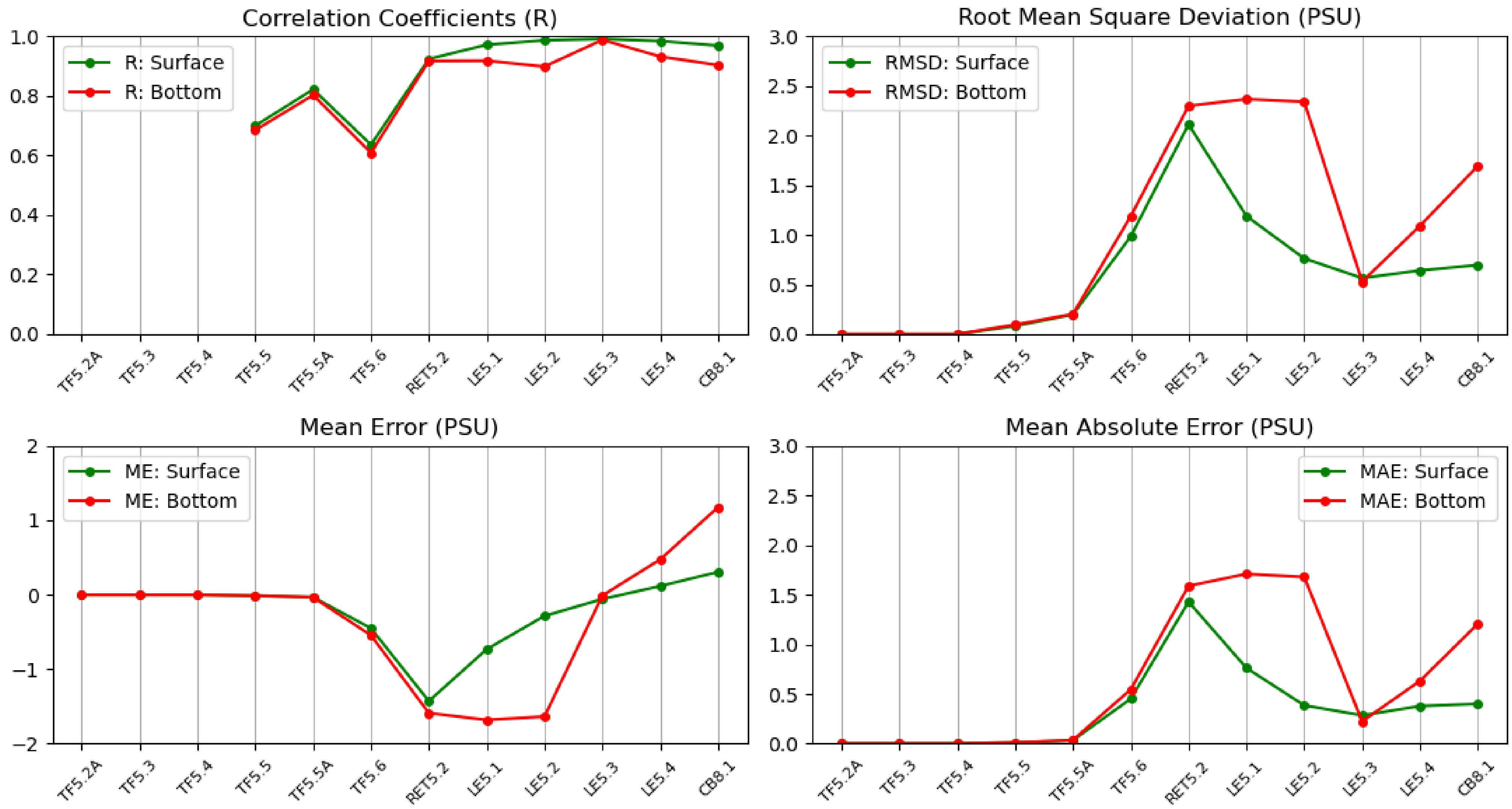




Salinity error statistics: James River

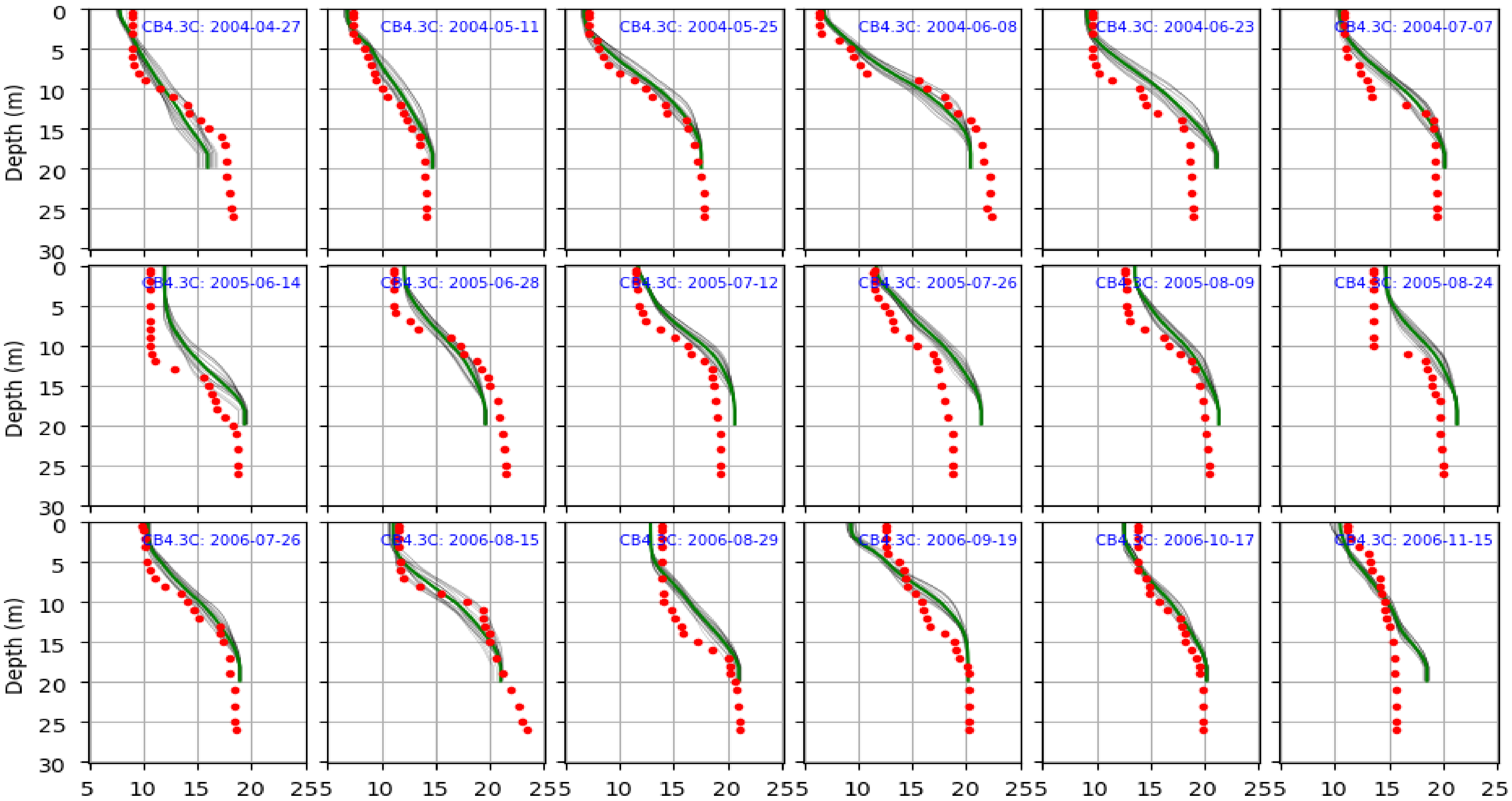
- Surface salinity has an error generally <1 PSU
- Bottom salinity has slightly larger error (1-2 PSU)





Salinity: Profiles @CB4.3C

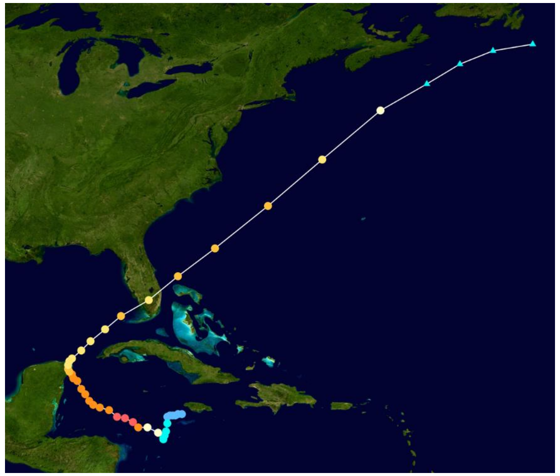
- It is challenging to compare salinity profiles point-wise, as the results are sensitive to the location depths in the model and measurements (e.g., obs below indicates a larger depth)
- The model generally matches the salinity profile, with some discrepancies



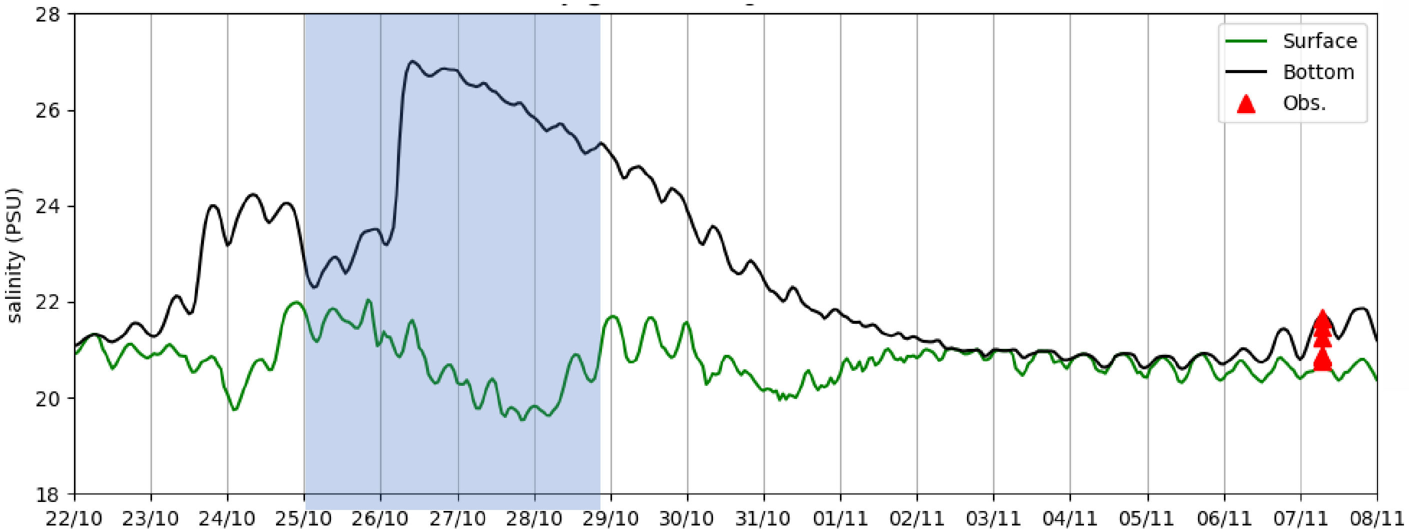
Salinity: Storm Effect During Wilma 2005

- The model reasonably simulated the hydrodynamic when hurricane passes Chesapeake Bay.

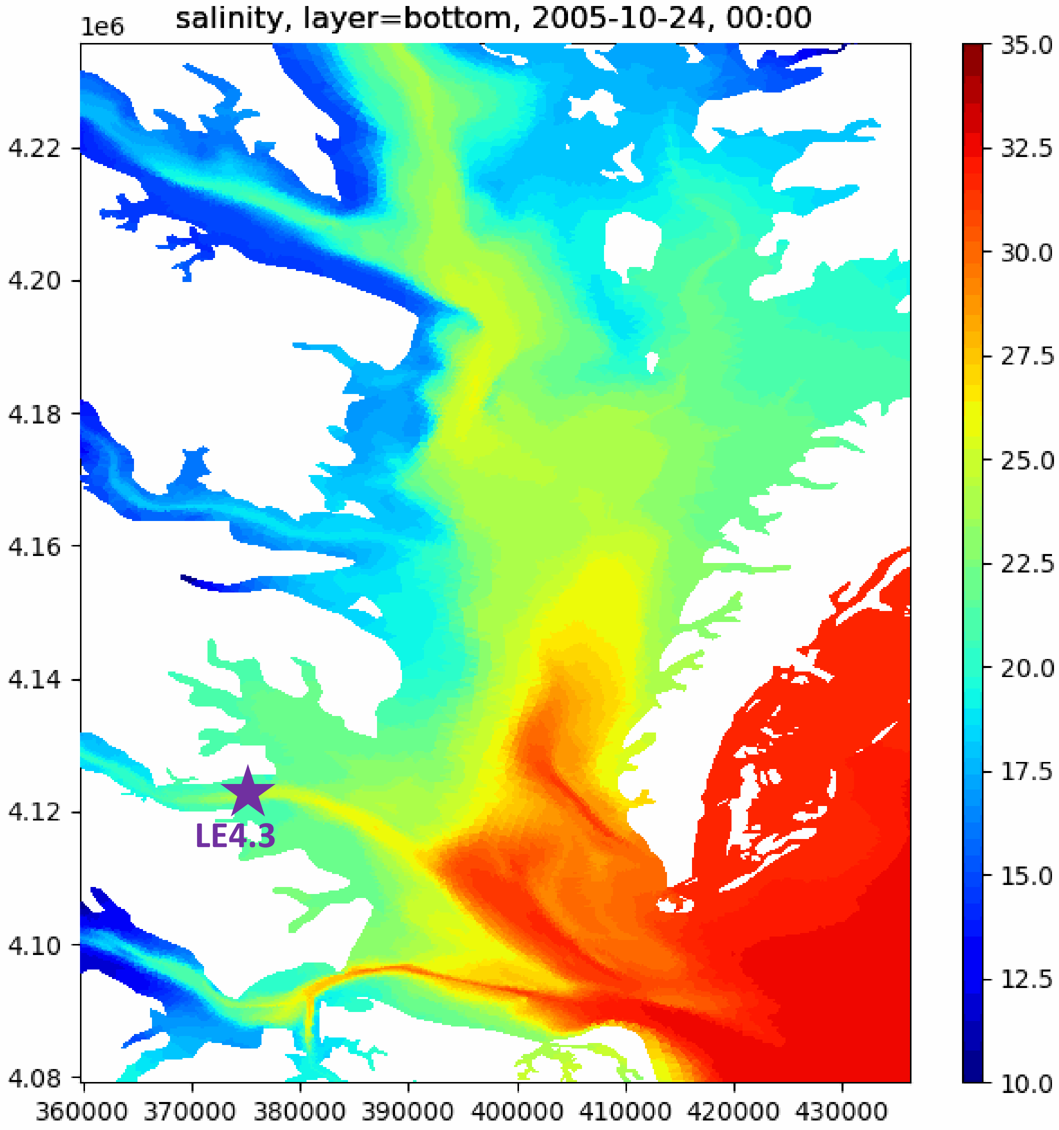
Hurricane Track: October 15-27



Salinity time series @LE4.3 during Wilma, 2005



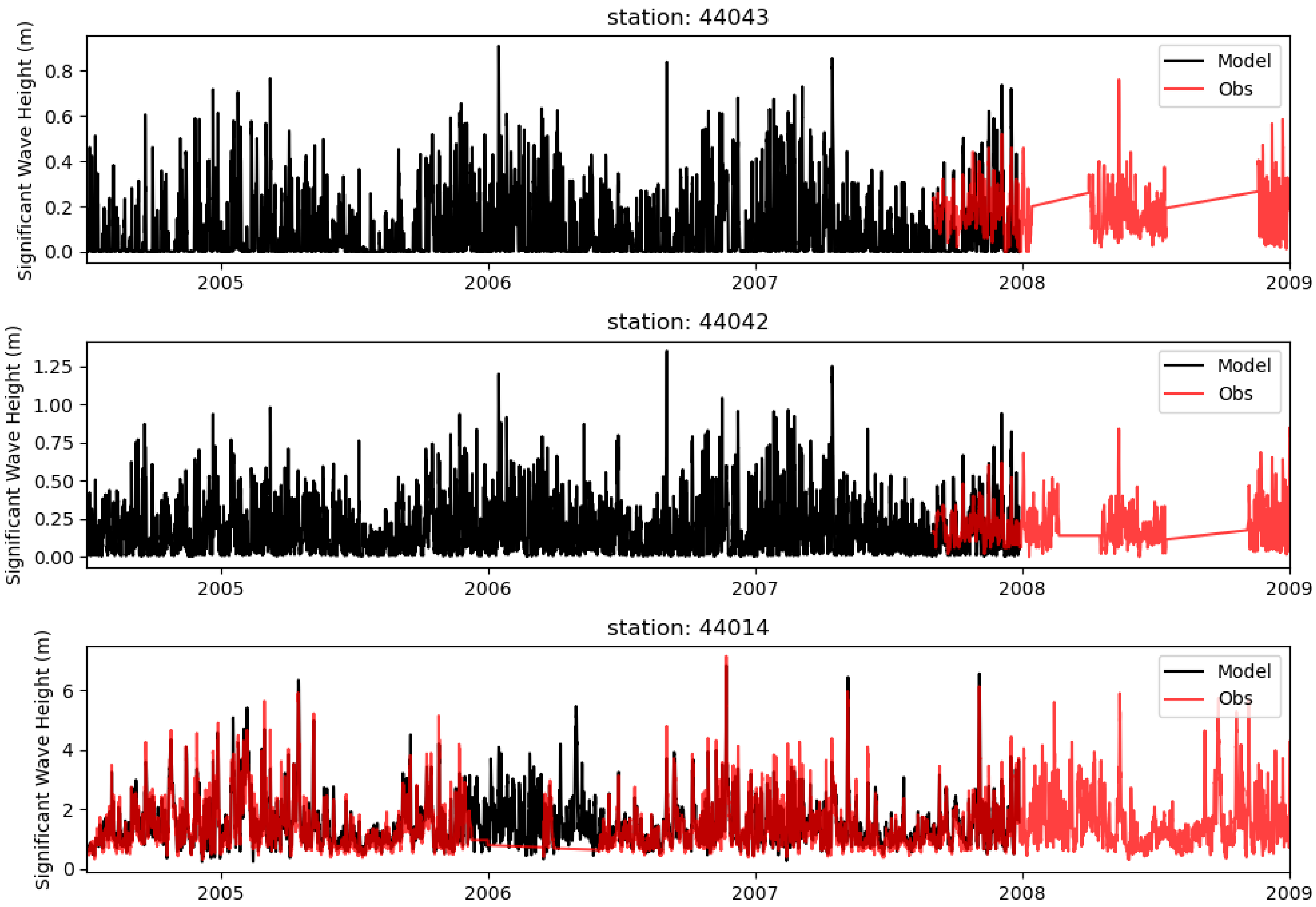
Animation: Bottom Salinity during Wilma (10/25)

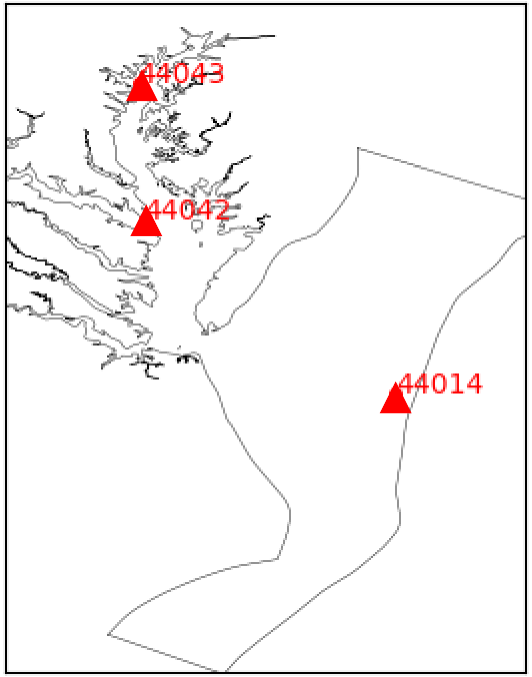


Wave results

❖ Wave attenuation from ocean to the Bay is well reproduced
❖ Better wind forcing is key (e.g. NARR blended with wind obs)

Significant Wave Height

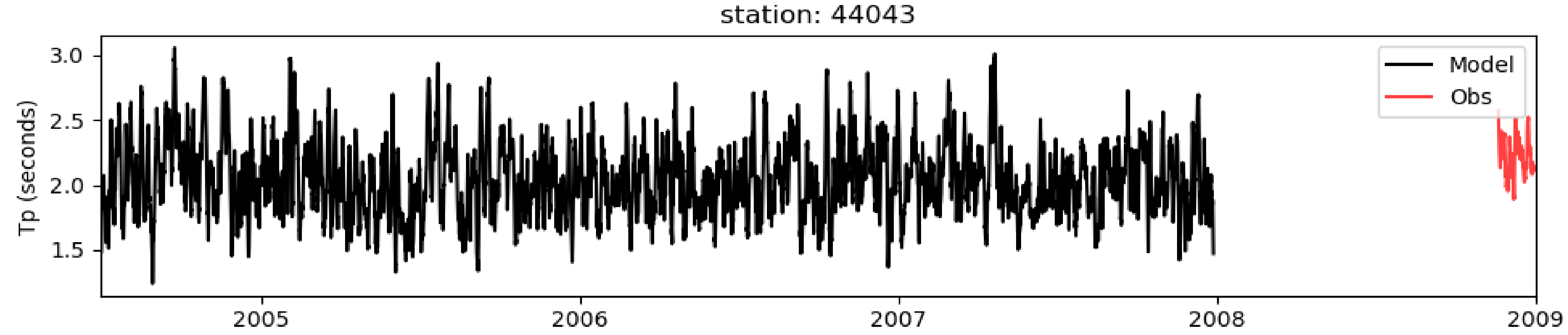


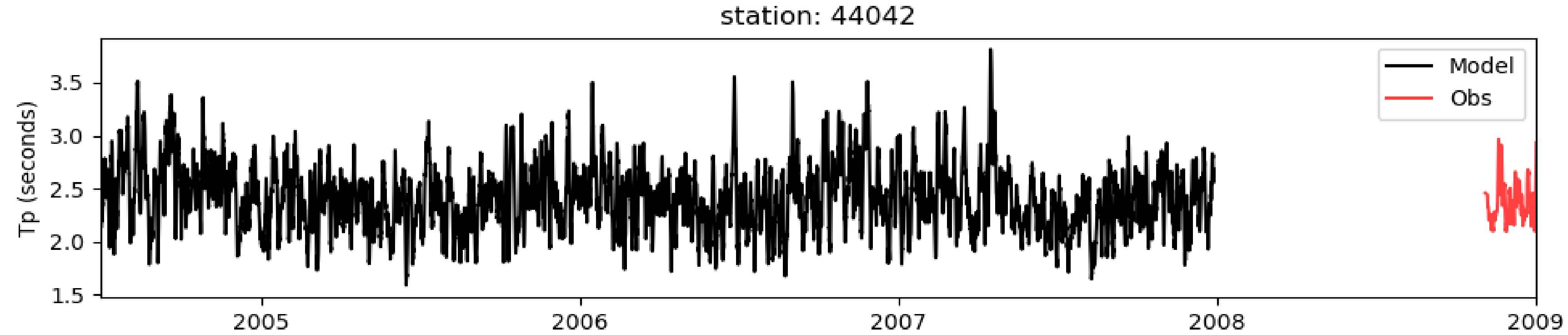


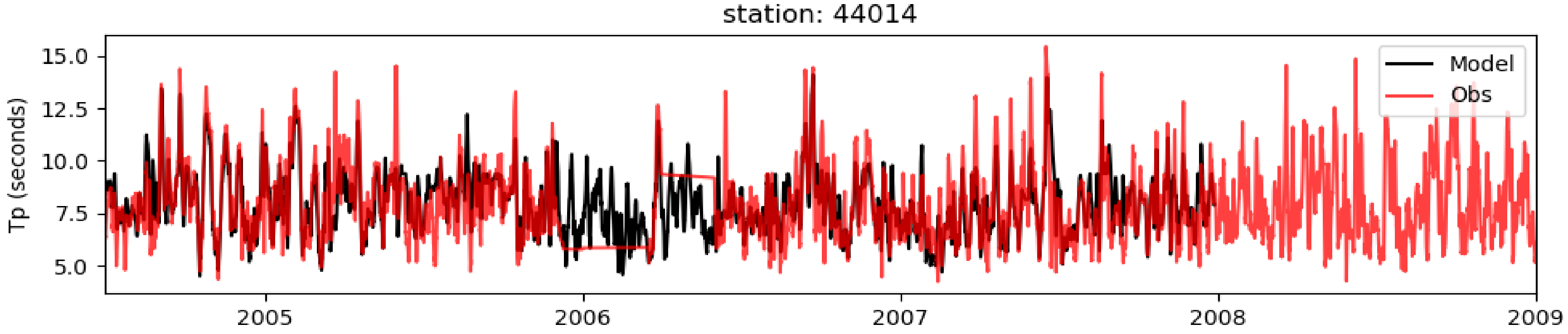
Wave results

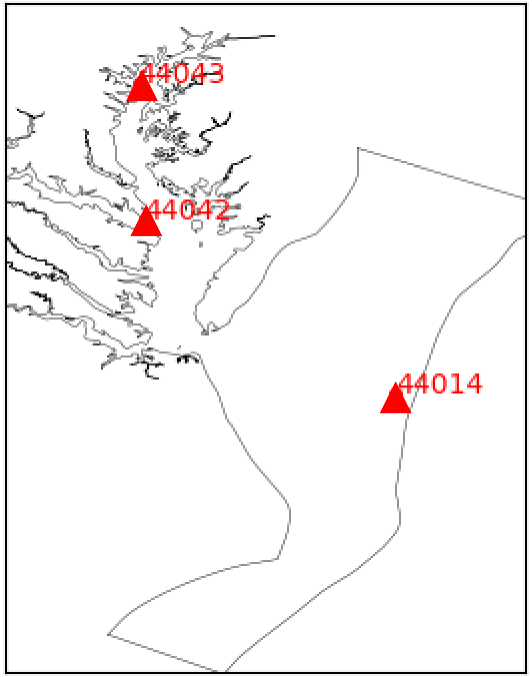
❖ Wave period from ocean to the Bay is reasonably reproduced

Dominant Wave Period





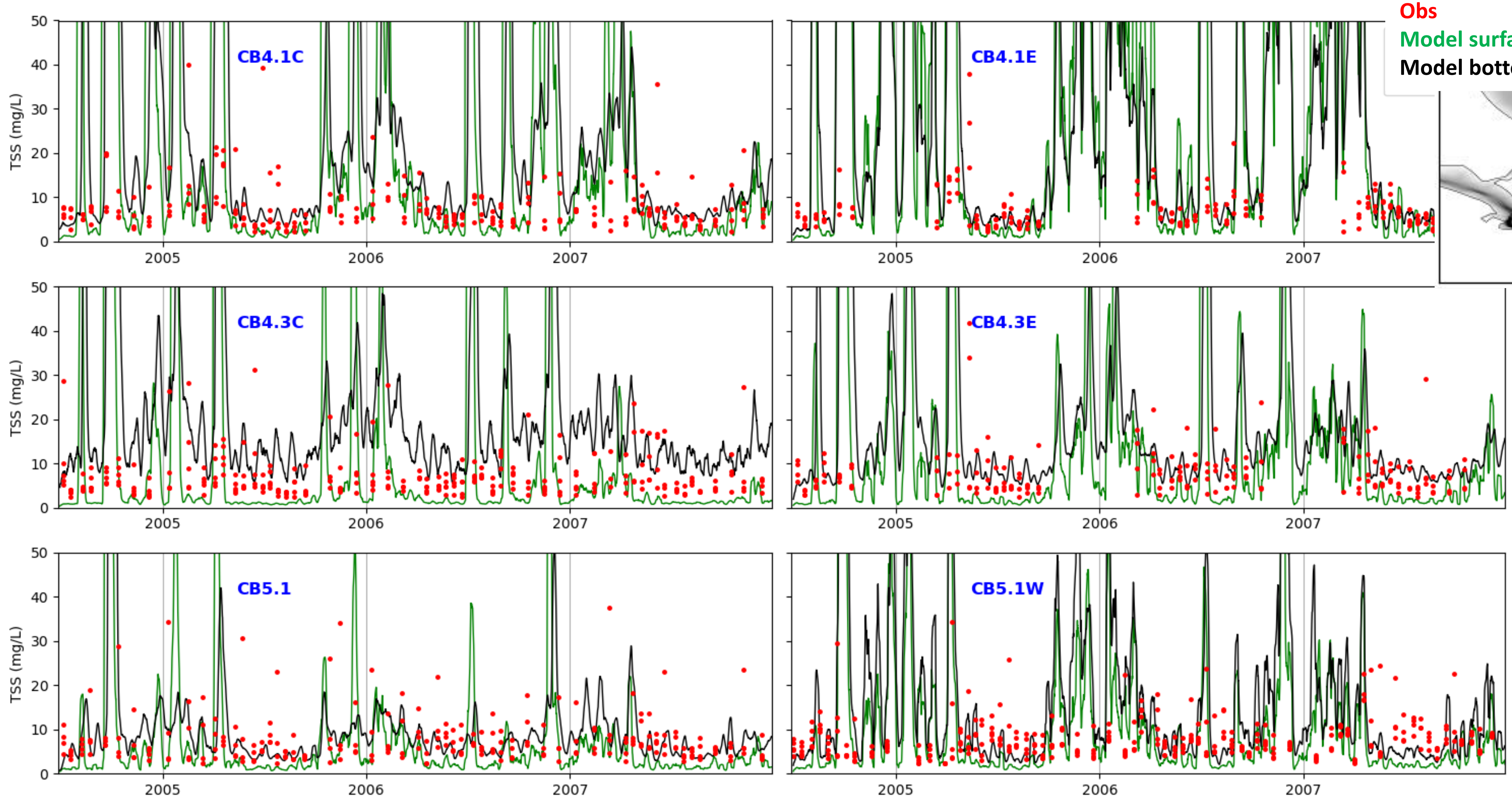


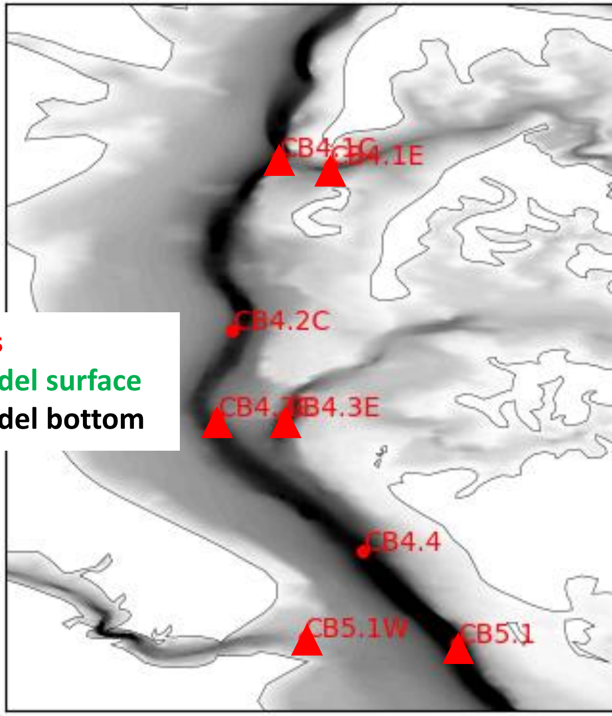


Sediment

- The sediment transport model can dynamically simulate the large high-frequency swings of sediment concentrations, which qualitatively matches the observations

Channel (deep) Stations | **Shoal (shallow) Stations**





Summary

- We have revised the MBM mesh for eastern shore, Potomac River, some SAV beds and some access channels
- Recalibrated SCHISM for hydrodynamics, sediment and wave dynamics throughout the Bay
  - Python based workflow made the recalibration process easy
- Error statistics for elevation, temperature, salinity, wave heights and sediment concentrations are generally satisfactory for both Bay channel stations and most of tributary stations
  - Model results can be potentially used to examine episodic events (large river flows, hurricanes, etc.)

Future work

- Finalize mesh and recalibrate
  - Andy and Karinna's final boundary (we already used a preliminary version from Karinna)
  - Rappahannock Shoal Channel
- The mesh size currently stands at 69K nodes (104K cells), which is probably at the limit of what we can handle with the HPC resources available to us

Performance tuning

- 5 SYPD at the moment using 504 cores (Frontera) for the ICM step
- 10 SYPD is the target
- The competing requirements for accuracy (processes) and efficiency are stretching the model to the limit!
- Proposed solution: divide the 10-yr simulation into two runs
  - Each run covers 6 years, with 1 year overlap
  - Each run is 'hot started' from a well warmed-up simulation
  - Preliminary results showed promise for this approach