Ocean Basin to Watershed Modeling of the North Pacific Provides a New Basis for Modeling Climate Change Impacts on Salmon

… introducing the SCHISM-based model: CPOEM

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4: Virginia Institute of Marine Science (VIMS)

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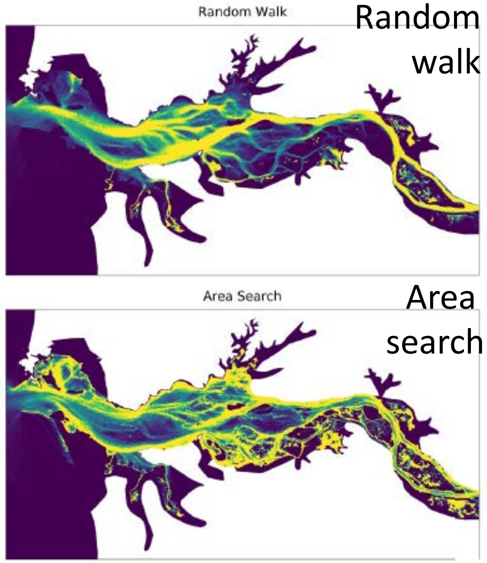
Computational resources: XSEDE, TACC, VIMS

Circulation models support salmon



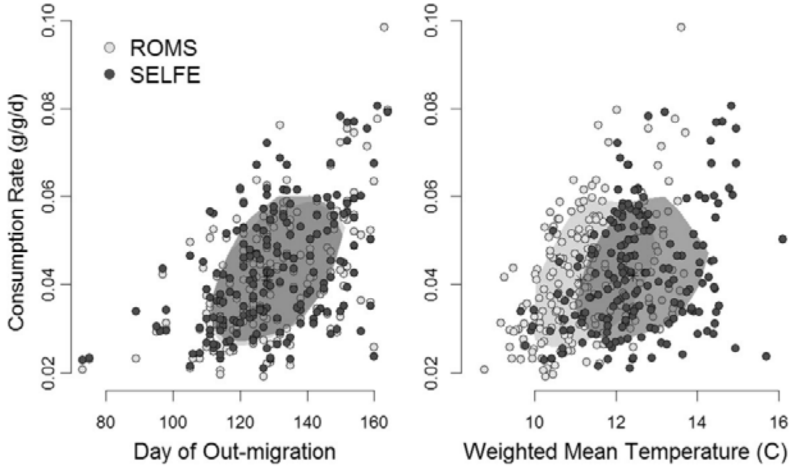
Heatmaps of migration routes in individual based modeling of juvenile Chinook salmon (SELFE)

K.J. Morrice et al, 2020. Ecological Modeling.

	FL (mm	M (g)	SAR
1. May marine density (yearling km^{-1})	**0.759**	**0.773**	**0.770**
2. June marine density (yearling km^{-1})	**0.797**	**0.833**	**0.886**
3. Marine growth rate (% d^{-1}, mm)	**0.778**	**0.805**	**0.727**
4. Size at marine entry	−0.100	−0.142	−0.252
5. Juvenile migration rate (bl sec^{-1})	−0.315	−0.253	−0.070
6. Columbia River flow$_{4_7}$ (m^3 s^{-1})	0.311	0.310	0.514
7. ME$_{BT}$	0.510	0.547	0.639
8. ME$_{PT}$	−0.157	−0.129	0.090
9. PDO$_{7_9}$	**−0.853**	**−0.874**	**−0.918**
10. NPGO$_{4_6}$	**0.906**	**0.893**	**0.715**
11. Plume area$_{4_7}$ (km^2)	**0.894**	**0.901**	**0.935**
12. CCI$_6$	**−0.868**	**−0.860**	**−0.799**
13. SAR	**0.883**	**0.902**	1.000

Intercomparison of biological and physical indices and SAR for Chinook salmon. Physical indices include modeled plume area, highlighted above (SELFE).

J. Miller et al, 2014. PLOS ONE



Juvenile Chinook salmon estimated consumption rate as a function of modeled (ROMS/SELFE) out-migration and mean temperature exposure.

B. Burke et al, 2016. Environ Biol Fish.

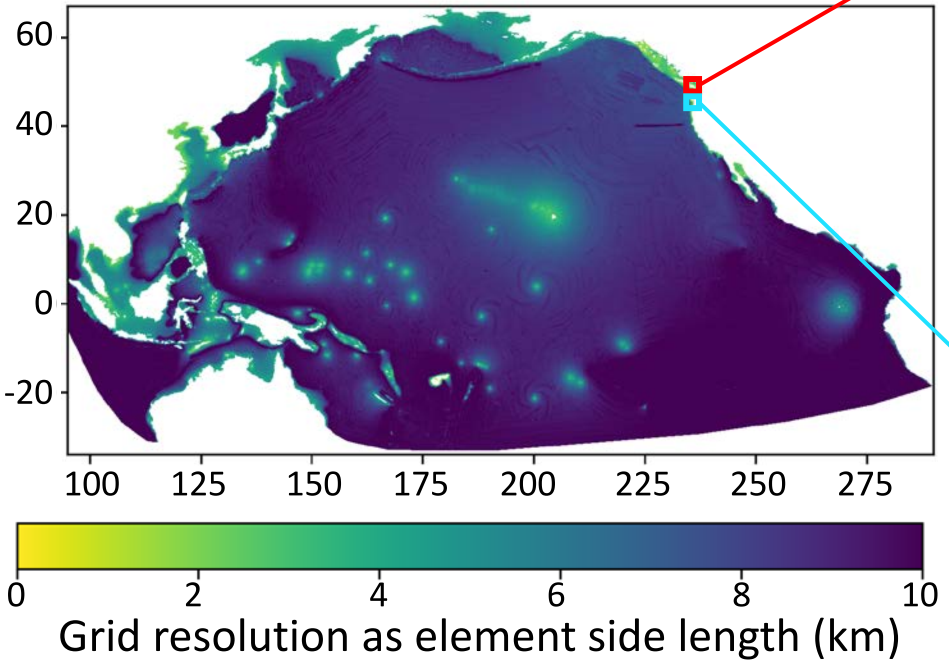
Challenge and opportunity

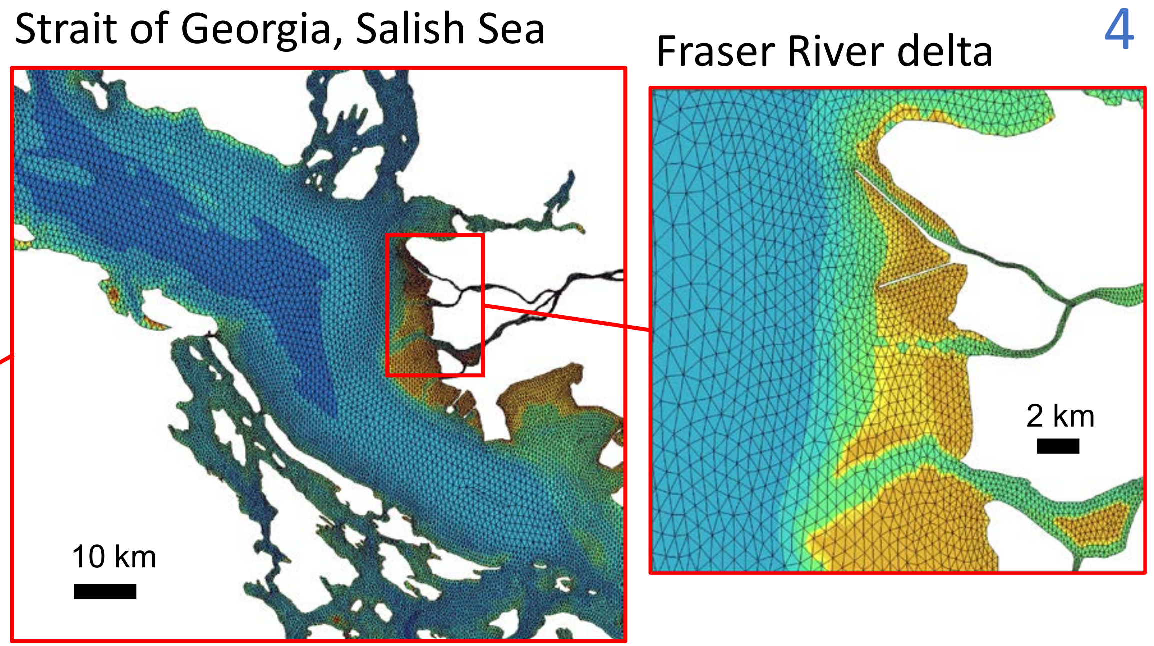
- Challenge:
  - Circulation models for regional to ocean-basin scale use structured grid models (e.g. ROMS, NEMO, MOM6) while models for plume and estuary scale use unstructured grid models (e.g. SCHISM, SELFE, FVCOM)
  - Structured ocean models have limited flexibility in horizontal resolution
  - Unstructured ocean models have limitations in resolving ocean eddies and in model efficiency
  - Missing are circulation models that are continuous across watershed-to-basin scale

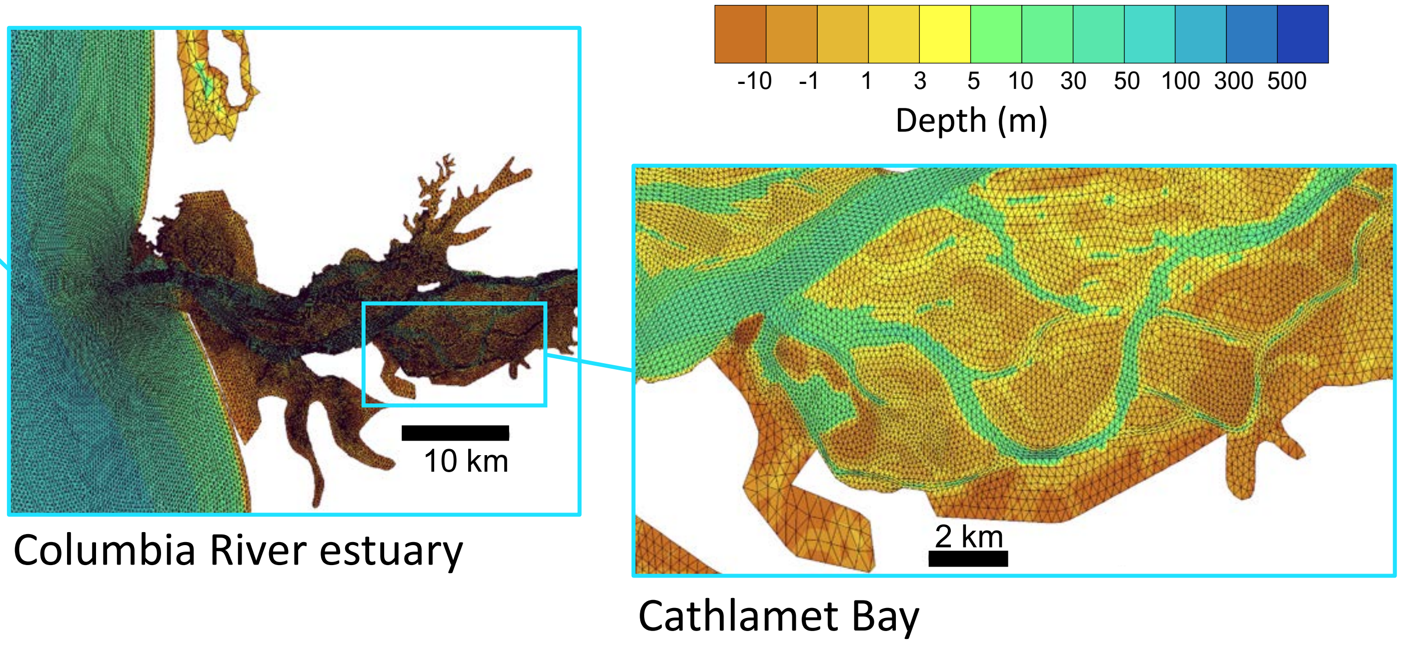
- Opportunity: Recent developments in unstructured-grid 3D modeling allow basin-scale simulations of multi-scale processes
  - New methods (higher order transport solvers) in SCHISM are capable of representing ocean eddies, and model scaling efficiency has been improved allowing very large ocean basin models to run effectively
  - The **CRITFC Pacific Ocean to Estuary Model (CPOEM)** uses SCHISM to demonstrate this capability for the largest ocean basin

Unstructured mesh

CPOEM uses unstructured meshes to represent water levels (tidal and non-tidal), 3-D ocean circulation, salinity and temperature structure at multiple scales, from open ocean to coastlines to estuaries and tidal wetlands at appropriate scales



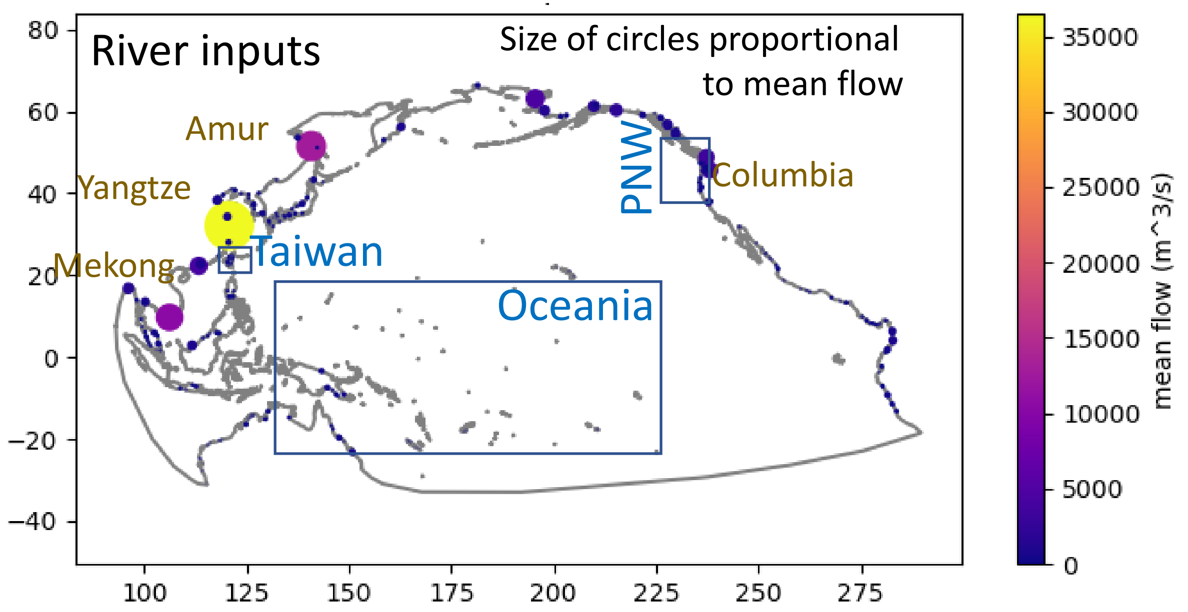




Model setup

Capacity to run 200 years of Pacific simulations in a reasonable large NSF HPC (Frontera) allocation

- SCHISM v5.9+
- Transport solver: 3rd order WENO
- Grid resolution: 20m to 8km
- Friction: depth dependent, with limited local customization
- Grid size: 2.8 million nodes, 1-34 vertical levels
- Timestep: 100 seconds
- Clock time: 1 day in 12 minutes
- Run on: 70 nodes on TACC Frontera HPC (56 tasks per node)
- Domain: Pacific Ocean to 33S latitude
- Focus regions to-date: Oceania, Taiwan, US-Canada Pacific Northwest

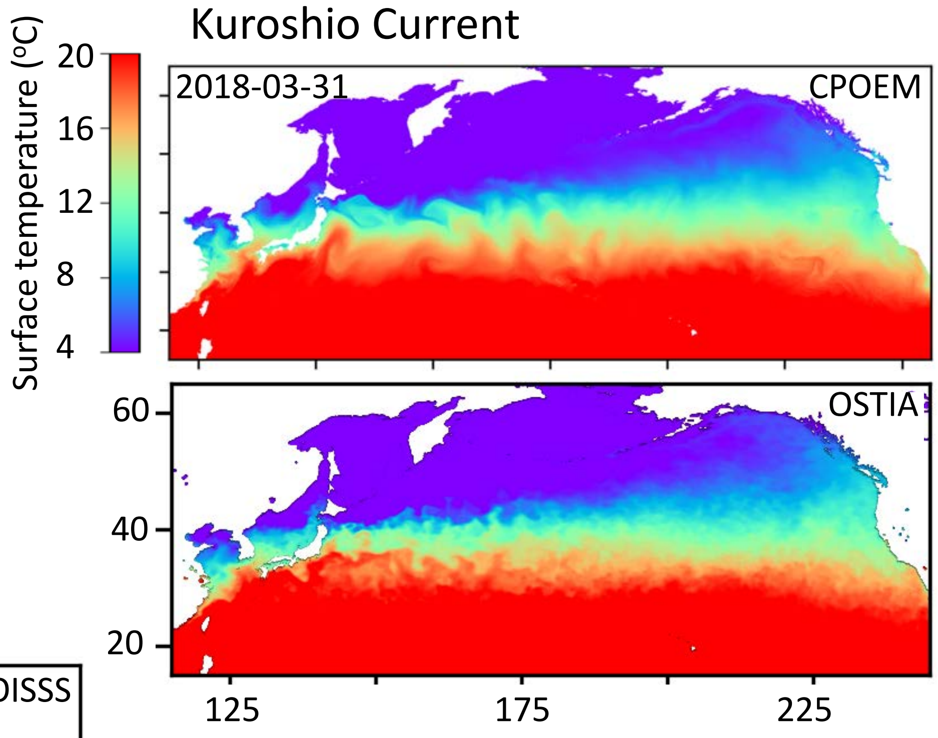


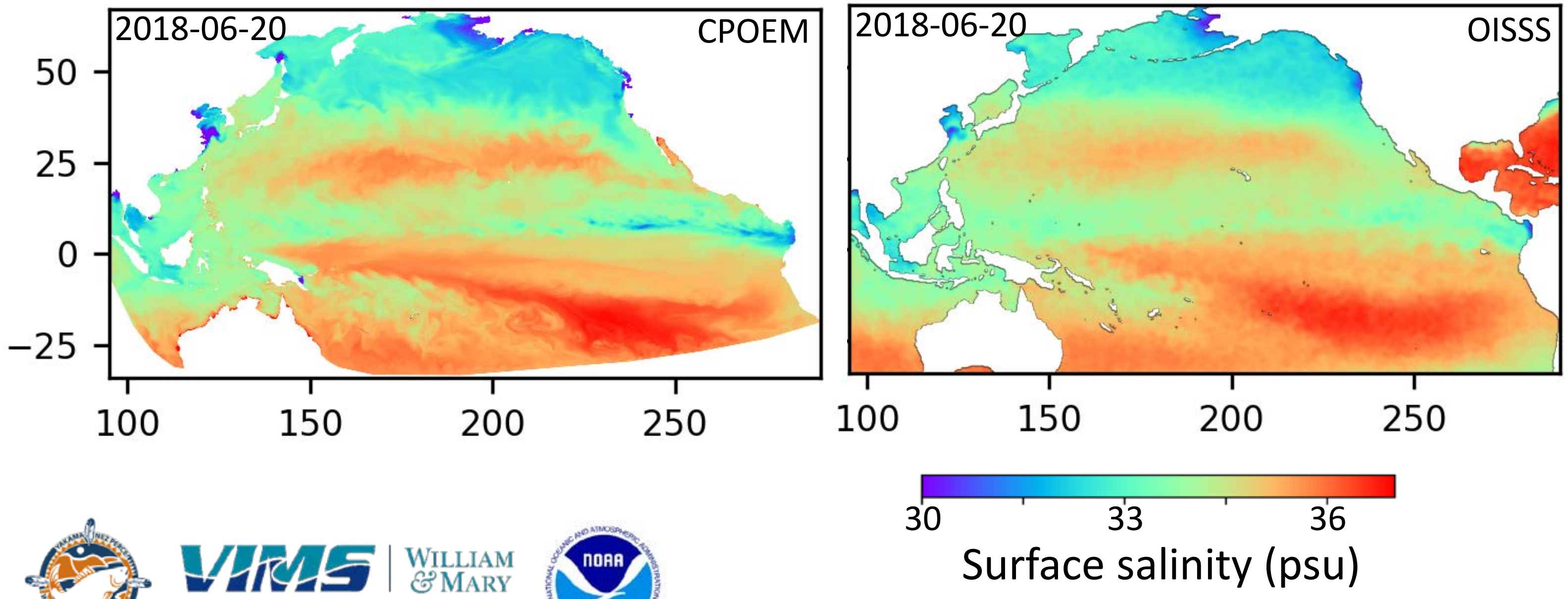
Inputs:
Ocean boundary and nudging: HYCOM
Tides: harmonic models, TPXO9, FES2014a
Bathymetry: multiple sources
Atmosphere: ERA5 (or GFS), HRRR
River inputs: hourly observations or monthly means or climatologies where needed

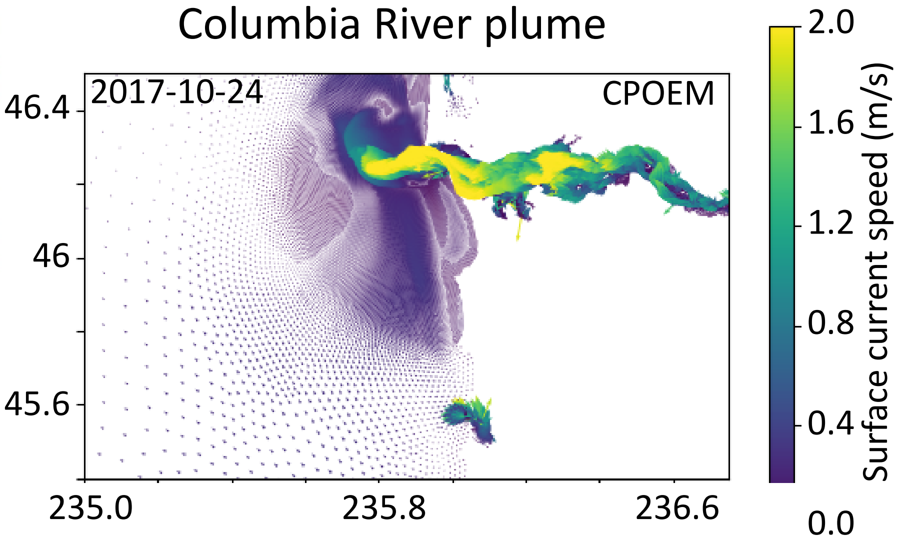
http://schism.wiki https://www.tacc.utexas.edu/

Surface currents

- The model solution describes sea surface salinity and temperature variability qualitatively well at a variety of scales
- Results are for a simulation started 2017-10-02

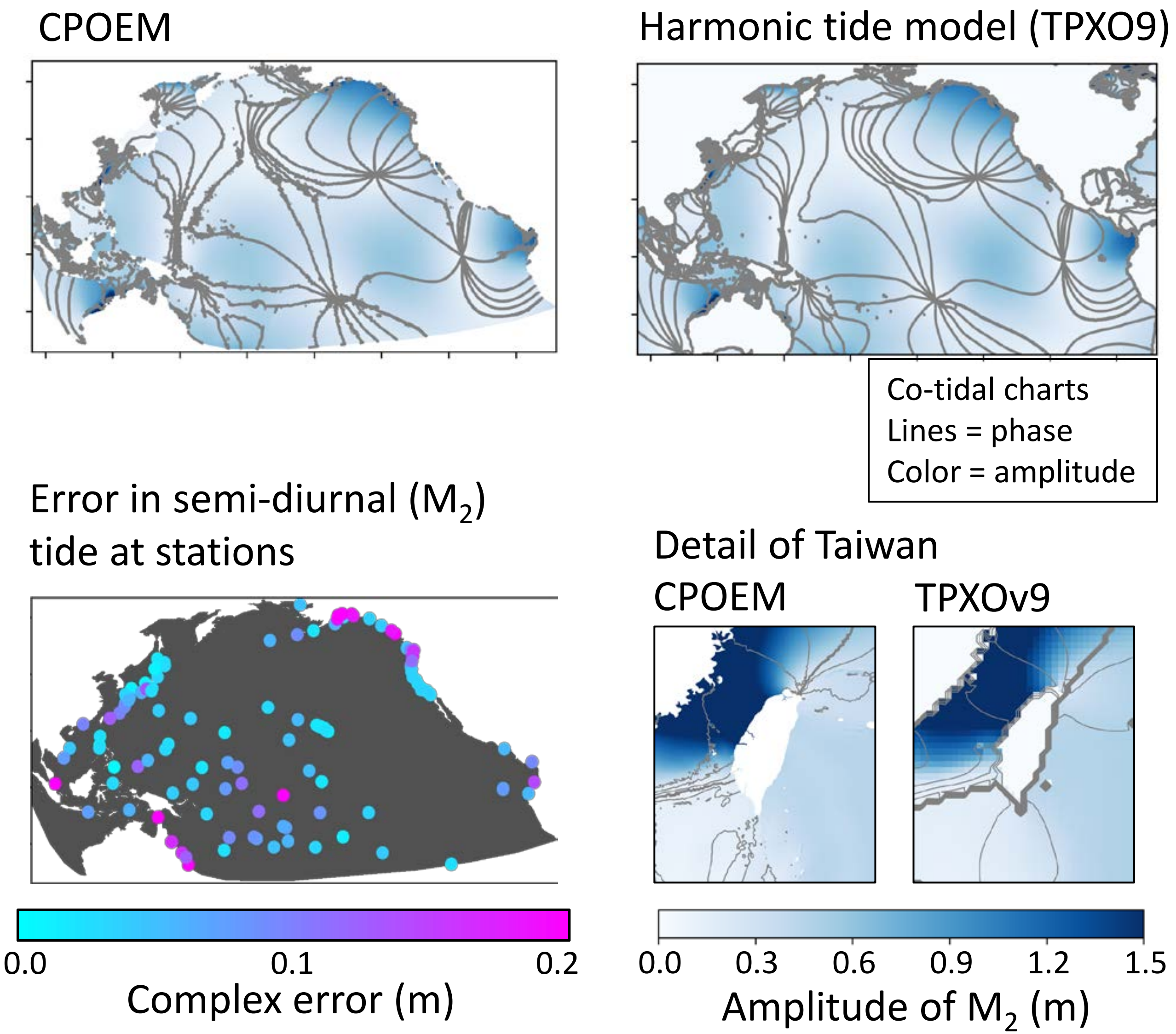






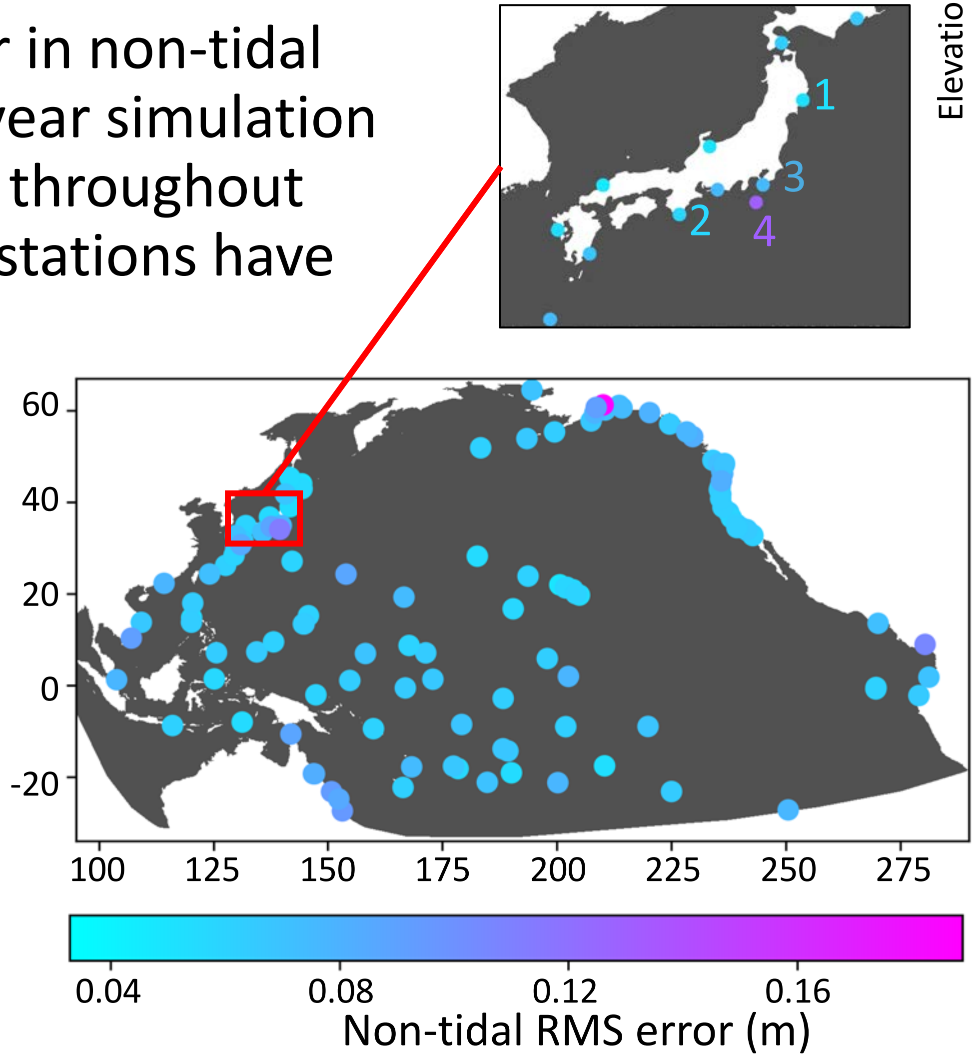
Tides

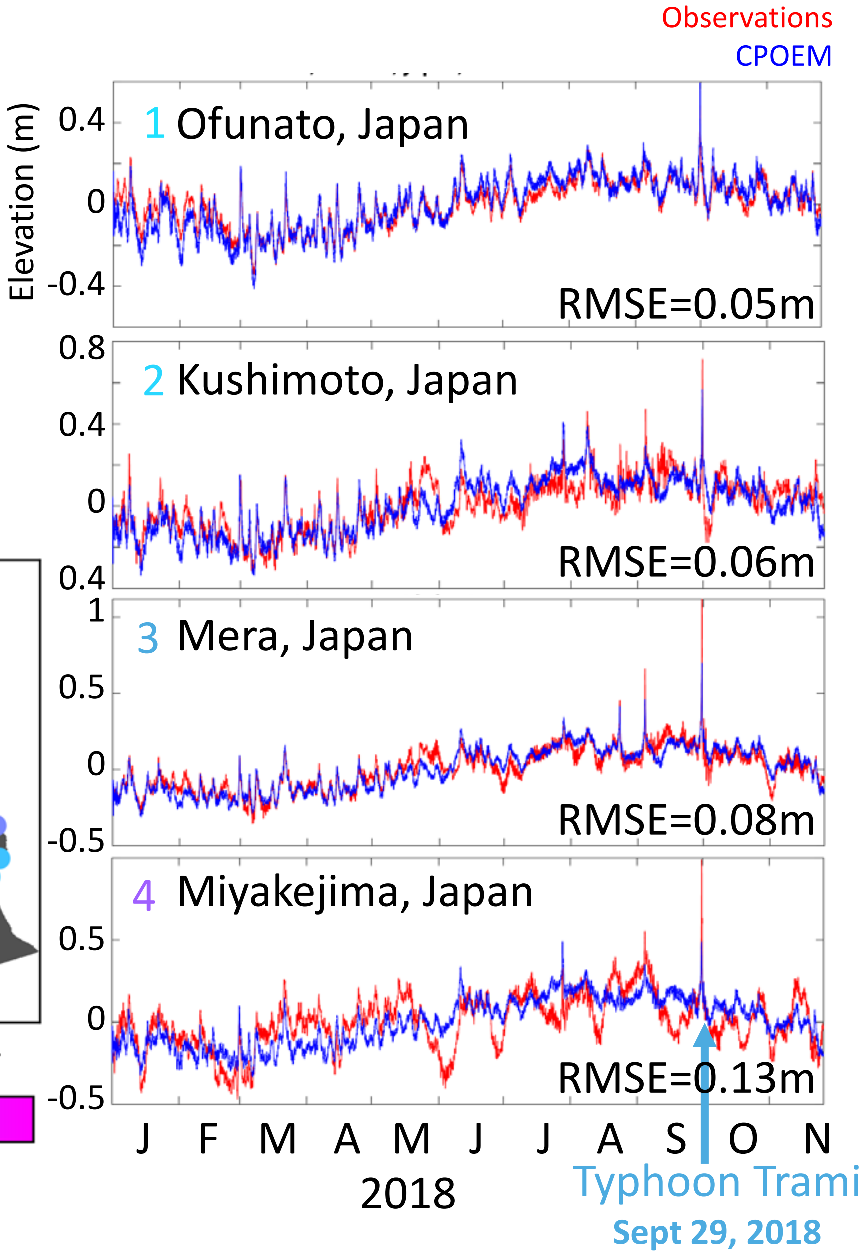
- Good performance representing harmonic tides
- Tides are critical to drive circulation processes and to define habitat in wetlands
- Model skill at stations is partly dependent on accurate high-resolution bathymetry and on grid resolution



Non-tidal elevations

- Median RMS error in non-tidal elevation for full-year simulation is 6 cm at stations throughout the basin. 90% of stations have RMSE < 9 cm
- Seasonal patterns and storm surges are well captured (e.g. Typhoon Trami, in Japan)

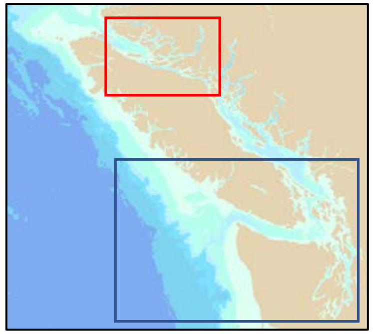




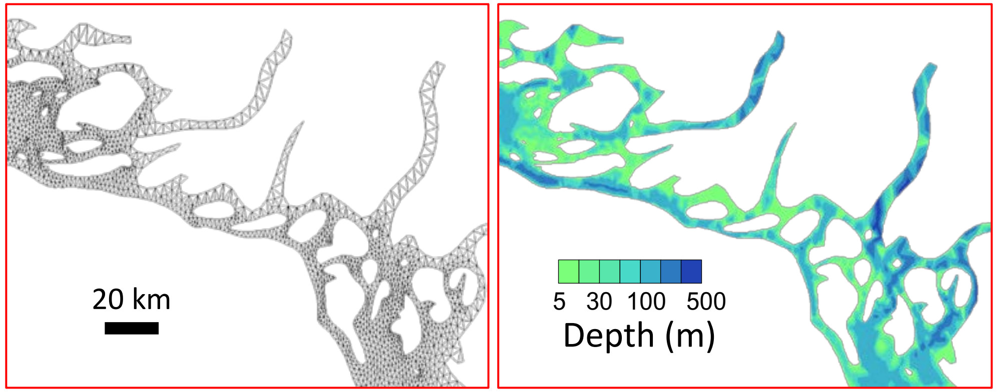
Impact of resolution and bathymetry

- Appropriate resolution in grid and accuracy of bathymetry are essential to model skill
- Simulations with lower and higher resolution lead to drastically different skill

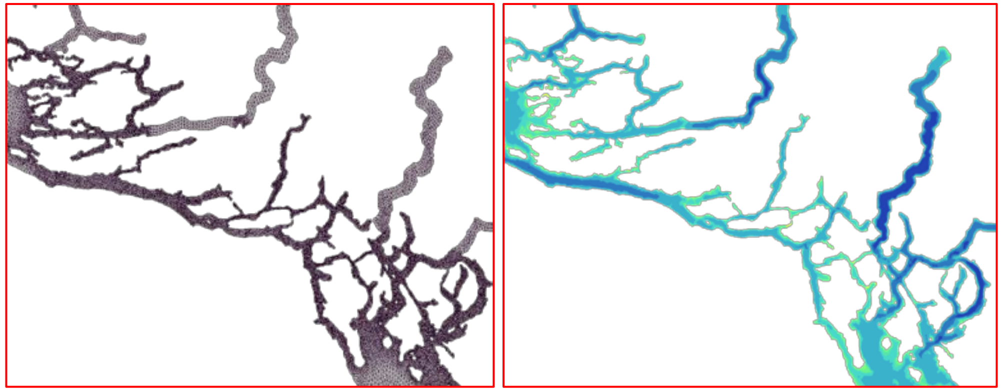
Salish Sea



Johnstone Strait
Lower resolution



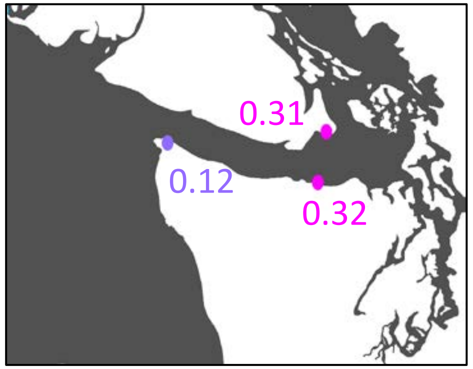
Higher resolution



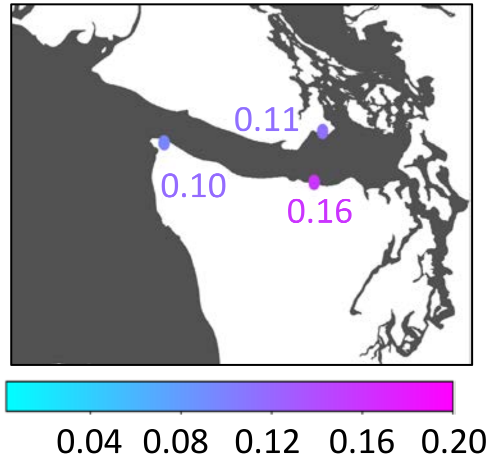
Grid

Bathymetry

Strait of Juan de Fuca
Lower resolution



Higher resolution

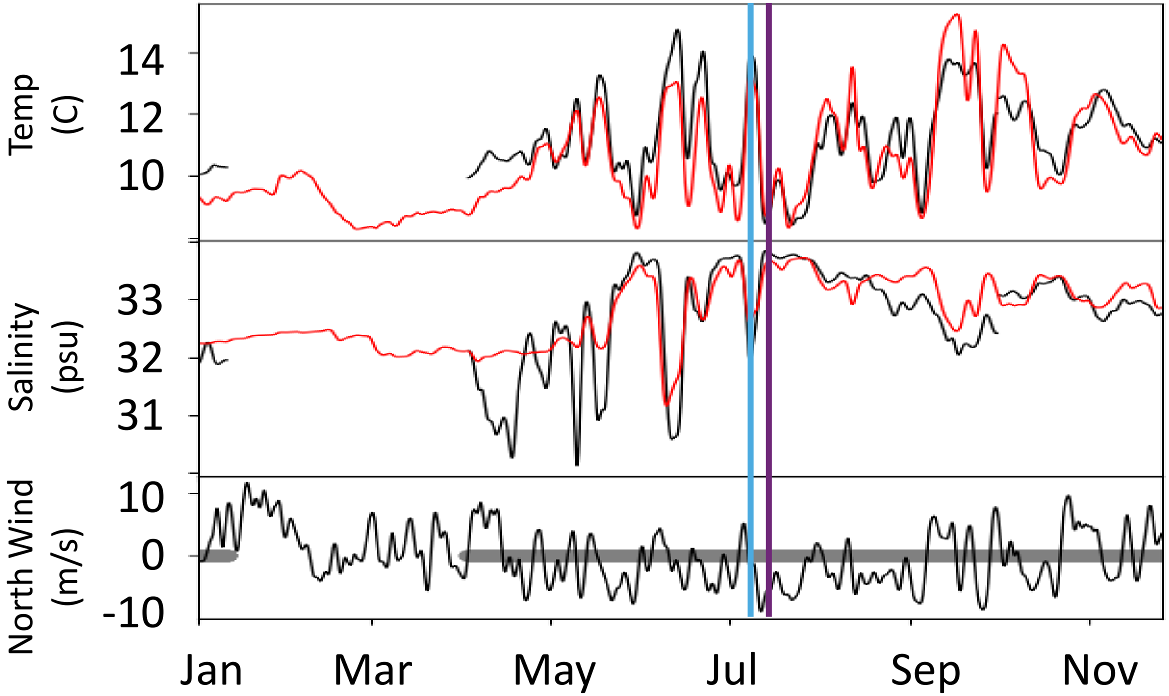


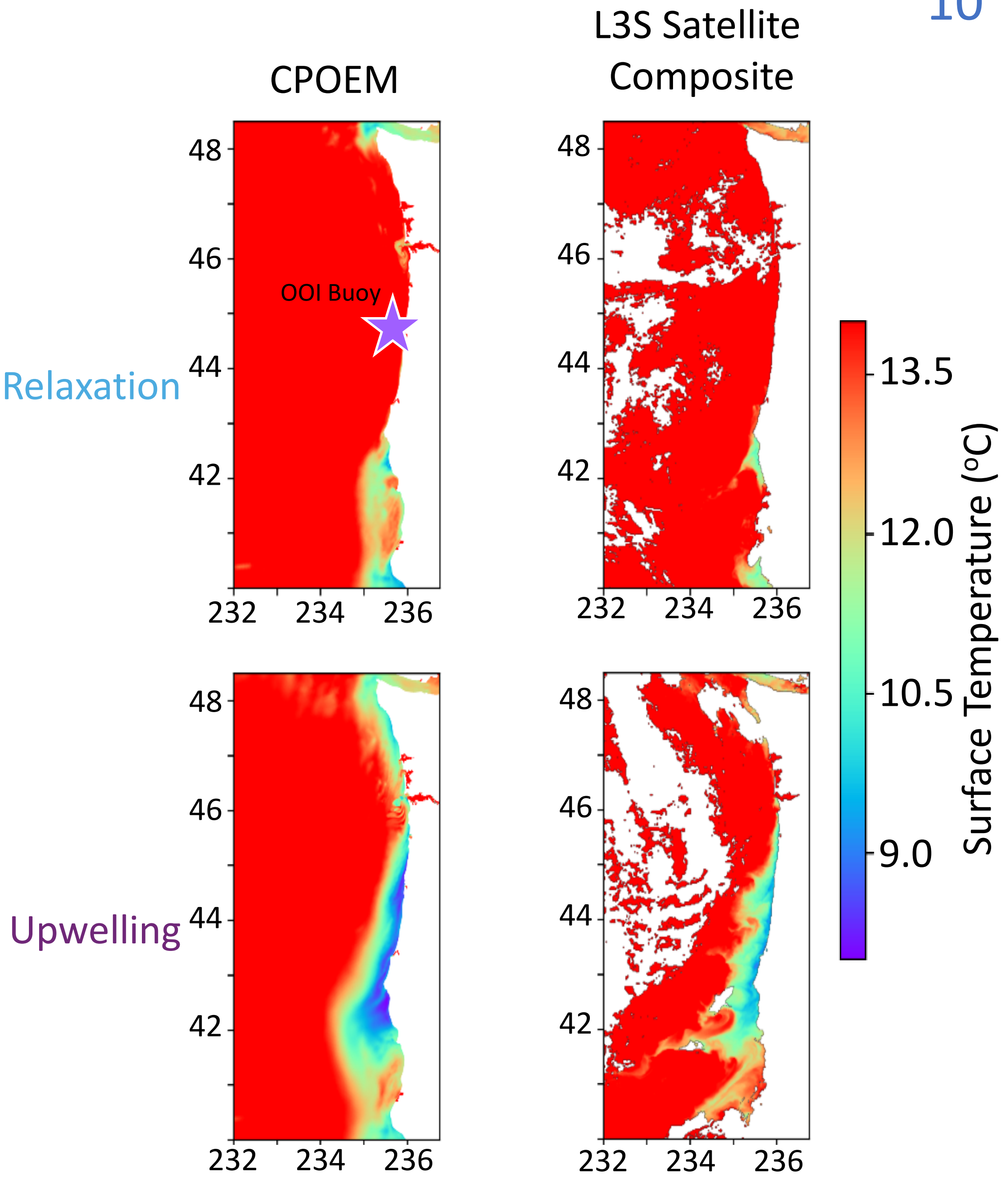
Complex error (m)
Semi-diurnal tide (M_2)

Upwelling

- Model captures upwelling and relaxation events along Oregon-Washington coast

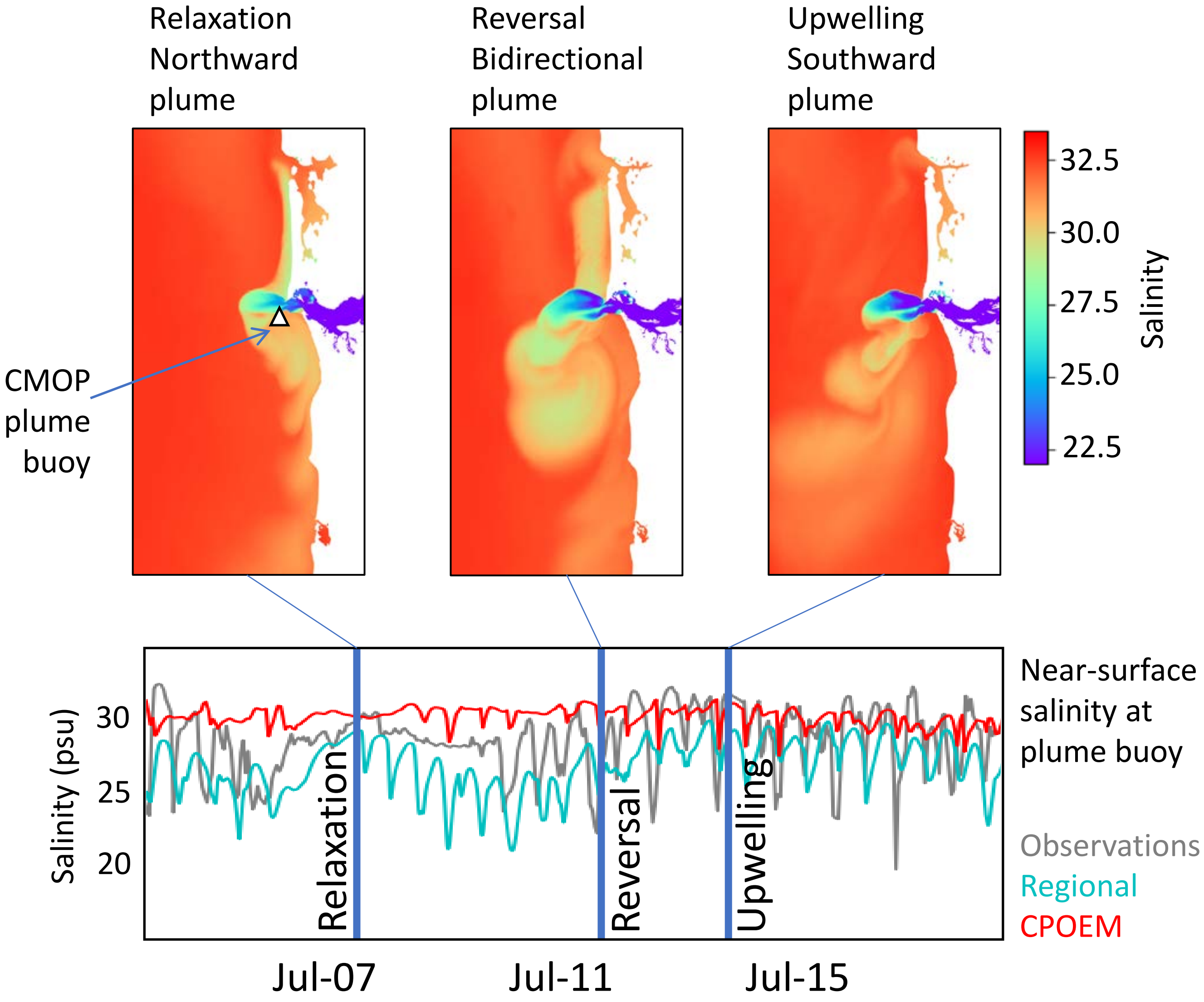
Surface Buoy Observations
(OOI Oregon near-shore station)





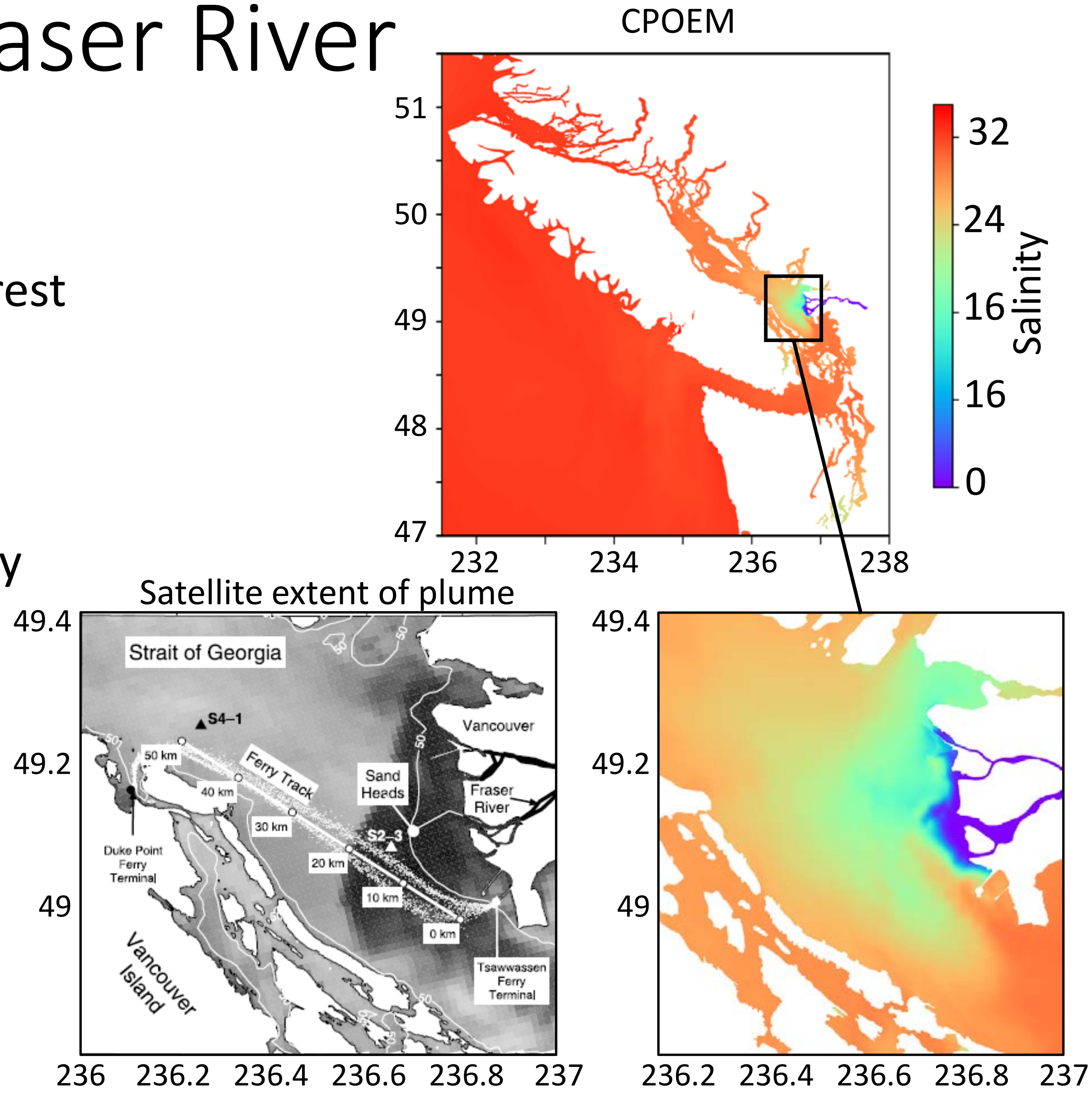
Rivers and estuaries: Columbia River plume

- Famously difficult to model
- SCHISM performs well in a regional model at 60s timestep
- 100s timestep used in CPOEM requires further local recalibration
- Even with too much vertical mixing in estuary, plume dynamics are captured
- CPOEM generates better non-tidal and tidal elevations in Columbia River than regional model (not shown)



Rivers and estuaries: Fraser River

- Fraser River exemplifies the process for adding detail in representation of local features of interest
- Higher resolution in Salish Sea was added to improve water levels
- With improved resolution, Fraser River plume extent is broadly comparable to satellite imagery
- Incorporating additional higher resolution bathymetry (10m and 100m Canadian NONNA DEMs) will further improve accuracy in representing Fraser River delta and plume



Halverson, Pawlowicz (2008)

Potential for climate change modeling

- **CRITFC will leverage cross-scale skill of CPOEM to support much needed climate impact studies on Pacific salmon**
- Cross-scale characterization of circulation links basin-scale events to coastal impacts (and vice versa)
- Multiple coastal and estuarine regions of interest can be progressively integrated into our multi-scale model (as recently done for the Fraser)
- Cross-scale processes can be modeled effectively, including major currents, marine heatwaves, cross-shore transport, coastally trapped waves, river plumes, and estuarine processes

- Efficient model performance makes simulations of 200 years practical within a medium-sized annual allocation on a high-performance computing cluster

Conclusion

- We created and continue to improve CPOEM, a SCHISM-based multi-scale 3D model of the Pacific Ocean, capable of being used for climate change impact modeling
- The model covers the Pacific basin north of 30 S at 8-12km resolution in deep ocean, with extreme refinement up to 50m in target areas, including US and Canadian West Coasts
- The model incorporates fresh water forcing globally, with detailed representation in select watersheds, additional areas of interest can be incorporated relatively easily

Actively seeking collaborators to connect our multi-scale physical model to ecological modeling and climate change impacts modeling

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- Computational resources: XSEDE, TACC, VIMS
- Bathymetry/Topography sources: NOAA, Taiwan Central Weather Bureau, Climate Central for CoastalDEM, DeepReef.org for 3D-GBR and nthaus100

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