

Estimating Salt-Water Intrusion in the Chesapeake under SLR

Phase 7 estuarine teams

VIMS: **Joseph Zhang**, Jian Shen, Harry Wang, Zhengui Wang, Wenfan Wu

CBPO: Lewis Linker, Richard Tian, Gopal Bhatt

Other contributors: Eli Ateljevich (CA-DWR), Nicole Cai (Yale Univ)

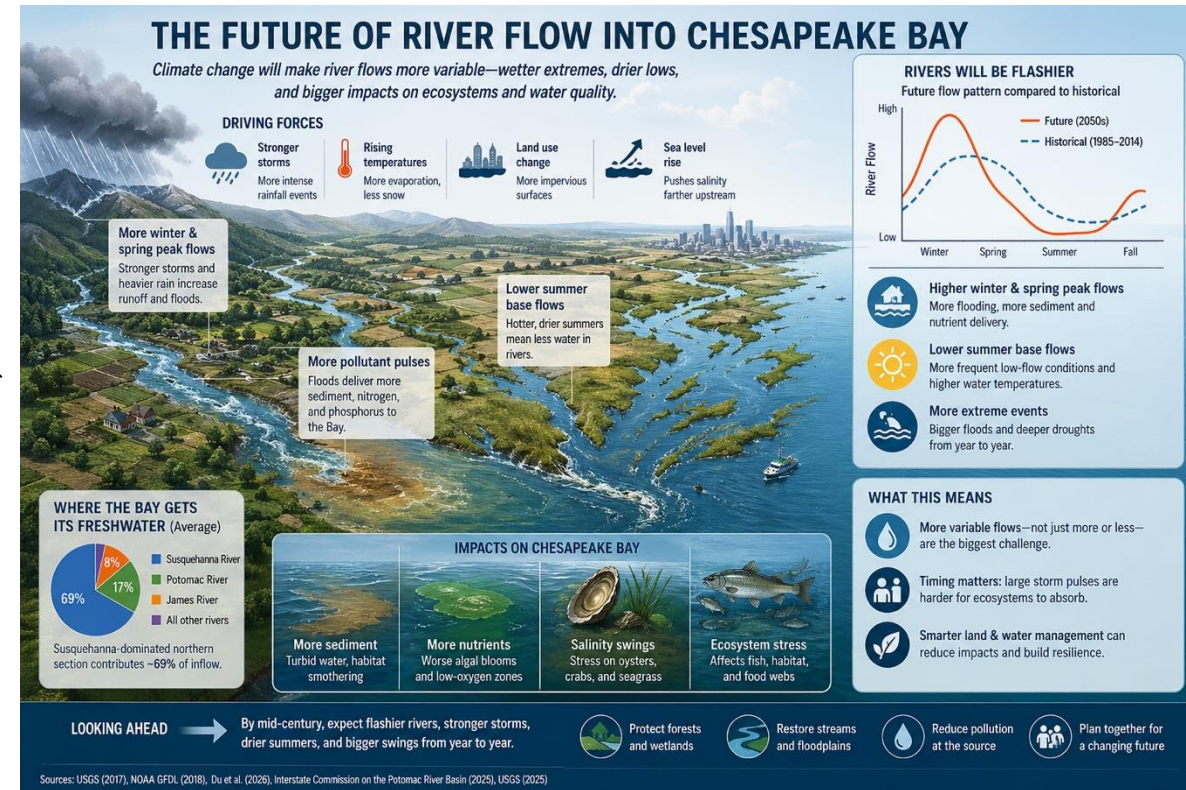
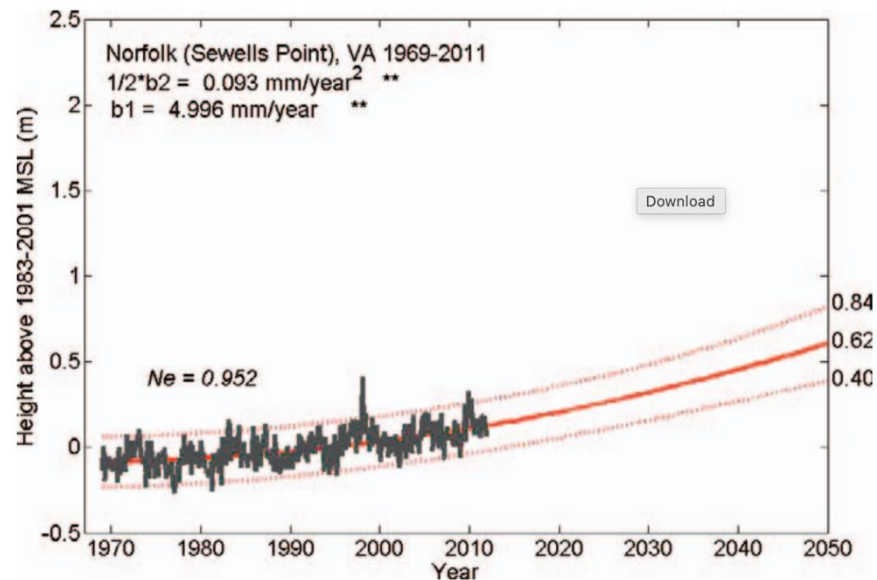
STAC workshop State of the Science of Salinity Risks in the Chesapeake Bay and Its Tributaries: Connecting Monitoring, Modeling and Management

May 2026



Review

- Conventional wisdom: salt intrusion increases with SLR
 - Especially for high SLR
 - Some uncertainty in small to medium SLR
 - Linear or nonlinear response? Shallows?
- Other factors that influence salt intrusion
 - Future hydrology: likely more hydrologic extremes (Rice et al., USGS 2017)
 - Land use: agriculture runoff, desalination discharge likely ↑
 - Groundwater intrusion: ↑ under SLR; hot spots in groundwater → wetland impact
- This talk will focus on SLR impact on salinity, particularly in shallows



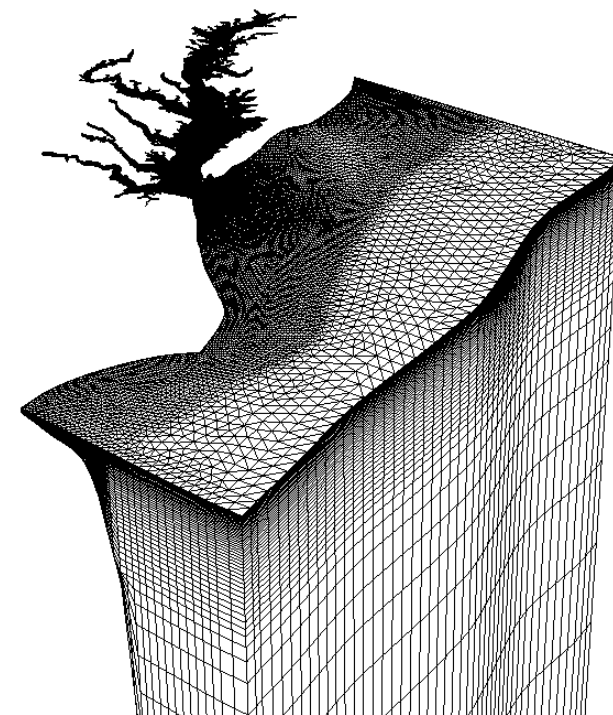
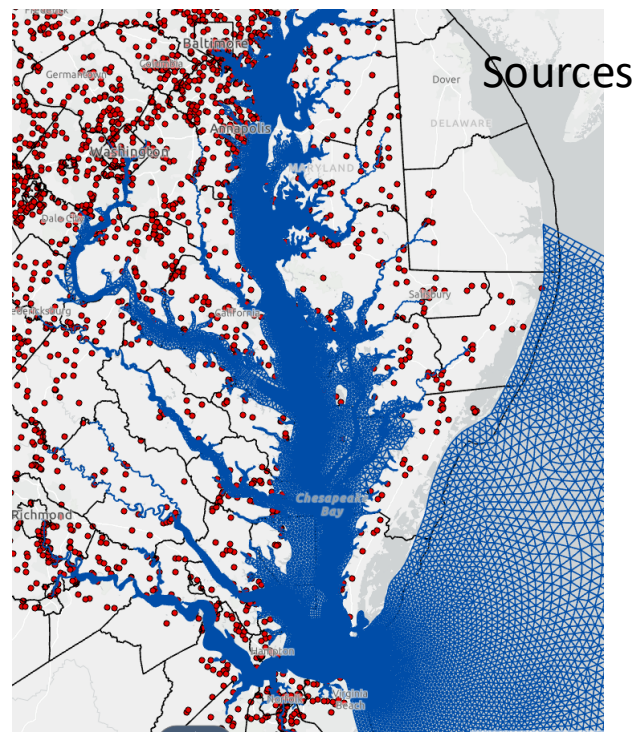
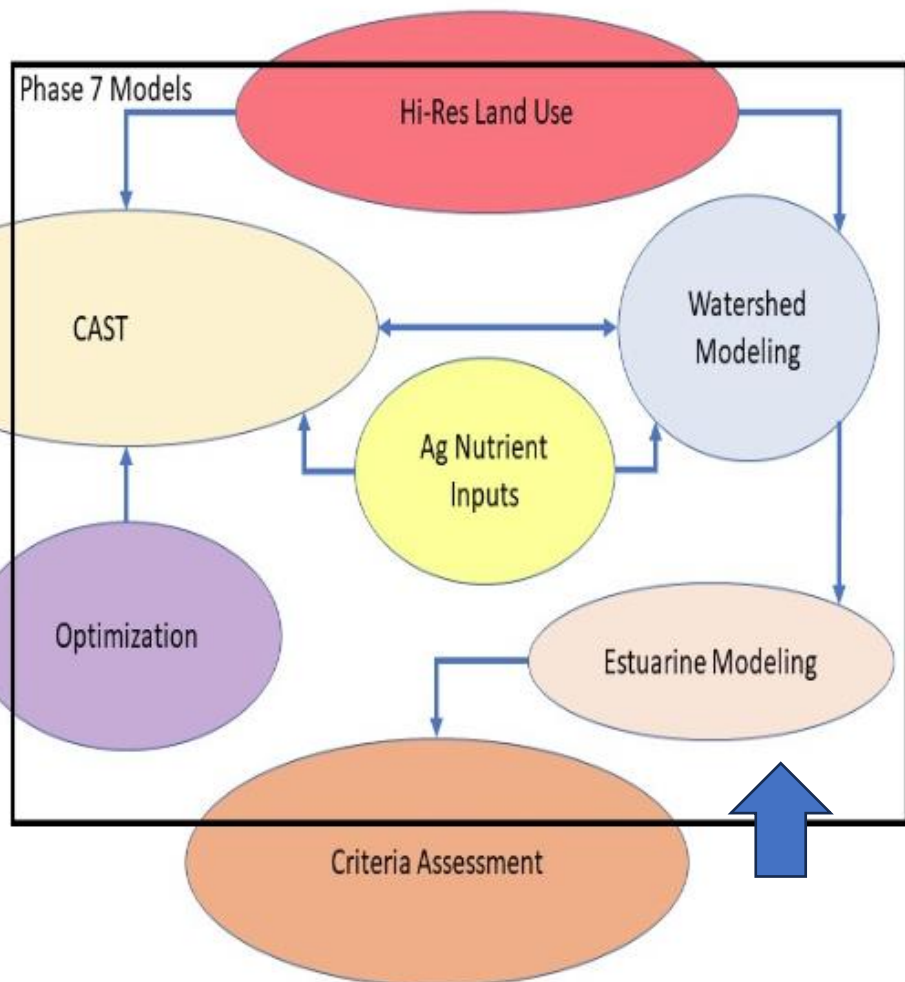
Phase 7 MBM processes do not yet incorporate:

- Difference sources/species of salinity
- Salinity impact on pH and other geochemical processes
- But flexible for extension

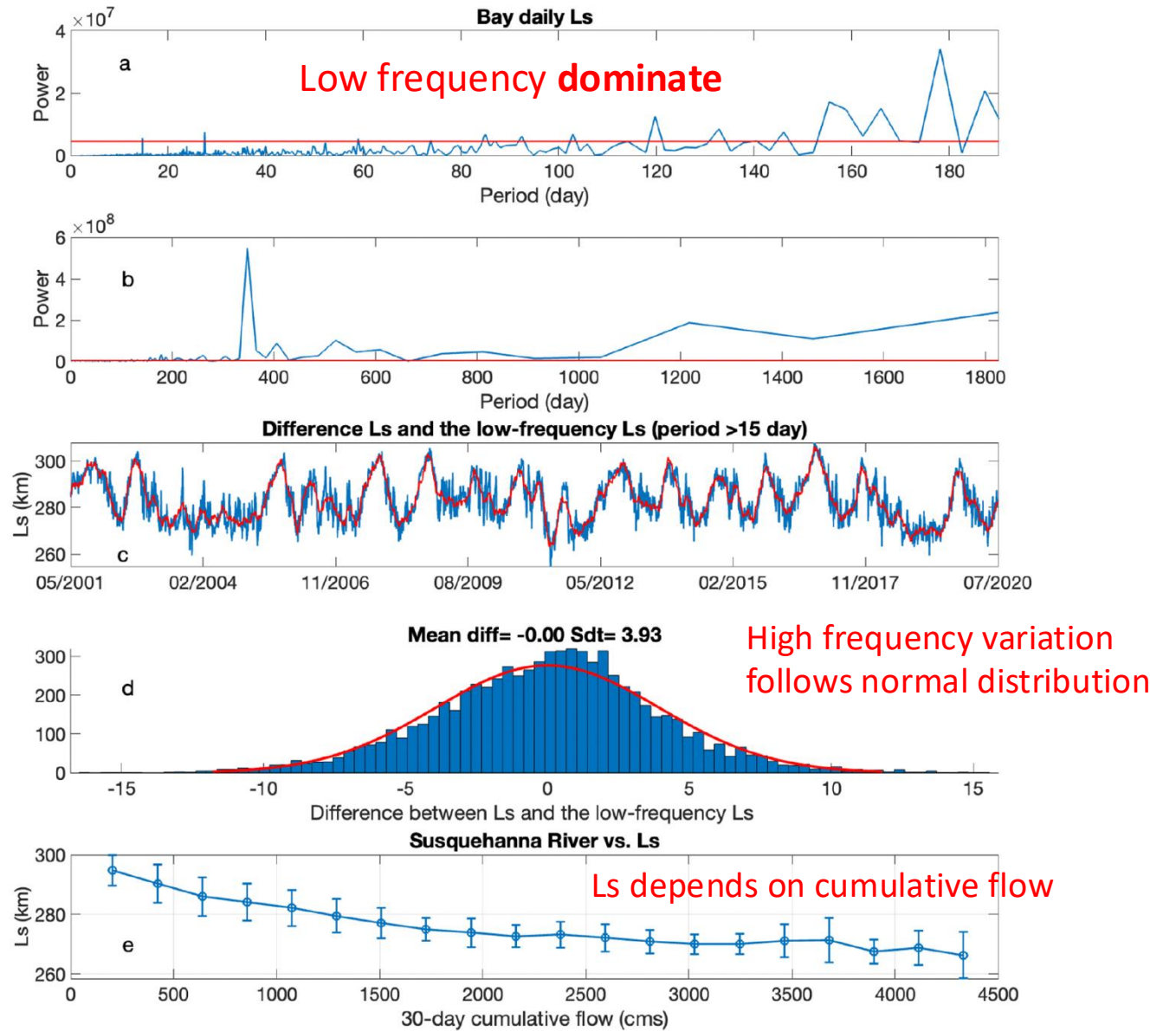
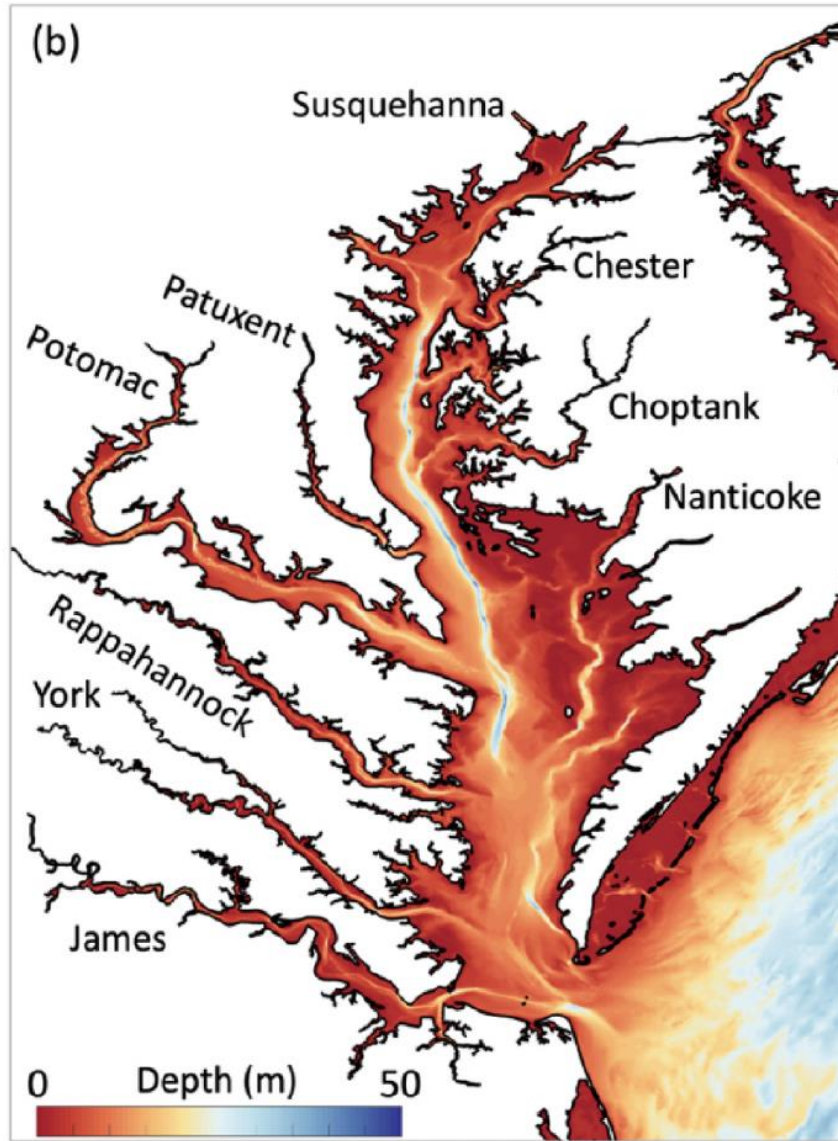
Boon, 2015

CBP Phase 7 Main Bay Model (MBM)

- Complexity of tributaries and sub-tributaries network in Chesapeake Bay
- Varying hydrodynamics, sediment sources, & vegetation communities
- Freshwater usage (agriculture, drinking water)
- MBM was developed at the recommendation of a community workshop in 2018
 - Unprecedented details in shallows
 - Extended ocean domain to facilitate climate change simulation
- MBM is the first CBP estuarine model based on unstructured-grid model (SCHISM)
- Watershed loadings from WSM: **assumed freshwater sources**

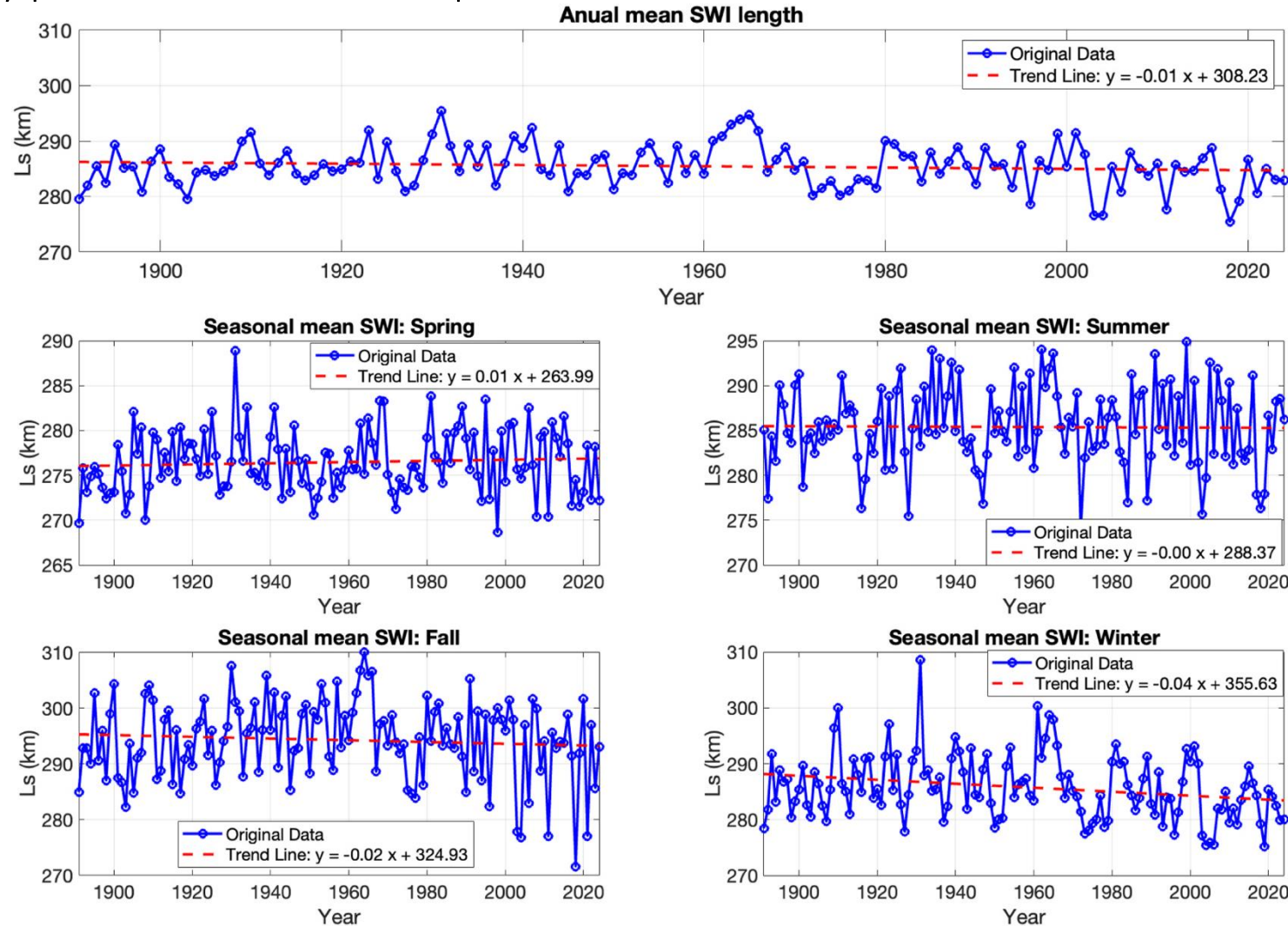


SCHISM Simulations (20-year) of Saltwater Intrusion Length (Ls)



Saltwater intrusion prediction via ML

- Reconstructed saltwater intrusion in the Bay using ML, trained on SCHISM results
- Trend varies with season
- Coming C.C. may produce a different response?

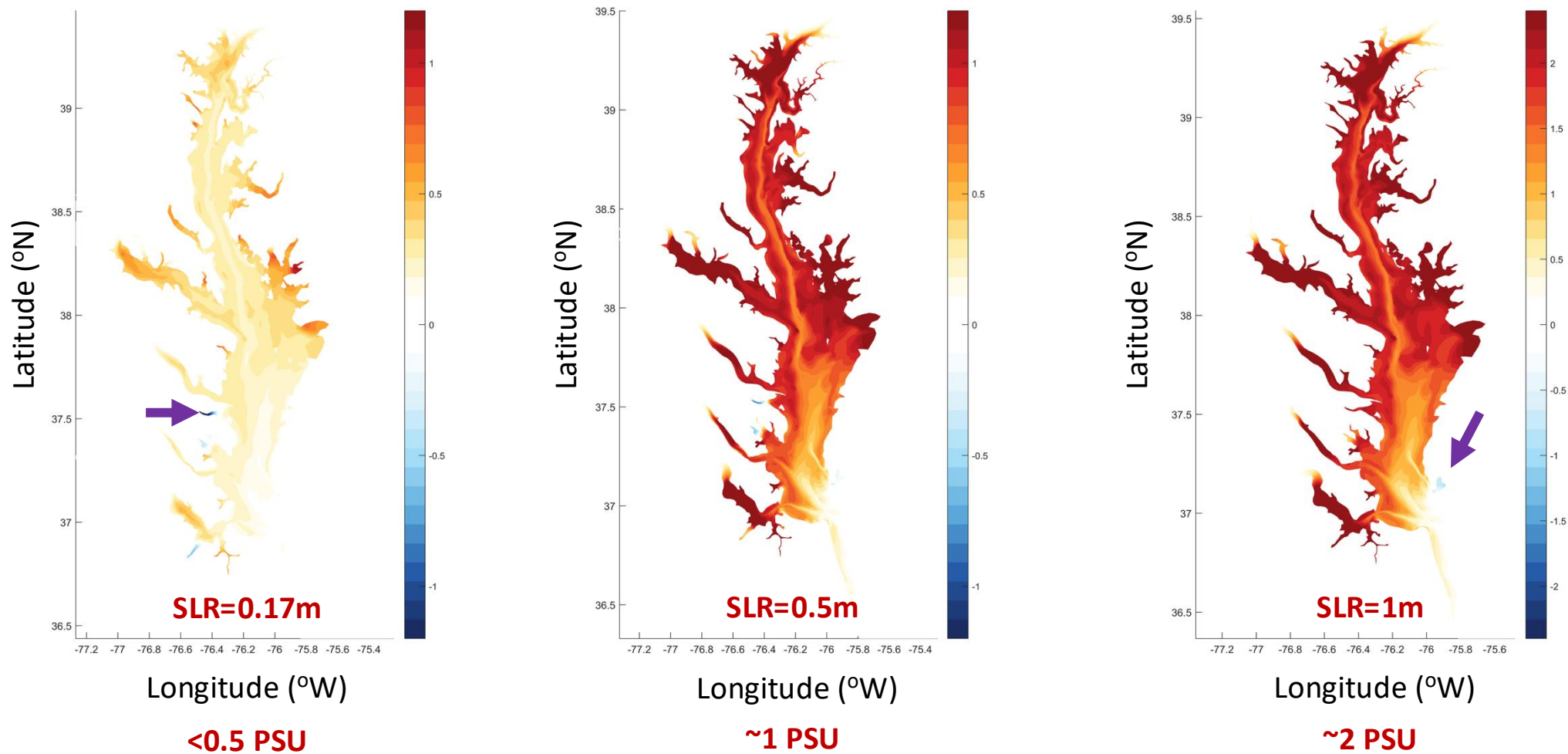


(Shen et al., 2026)

Bottom salinity

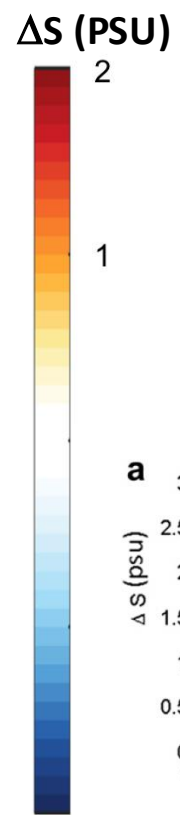
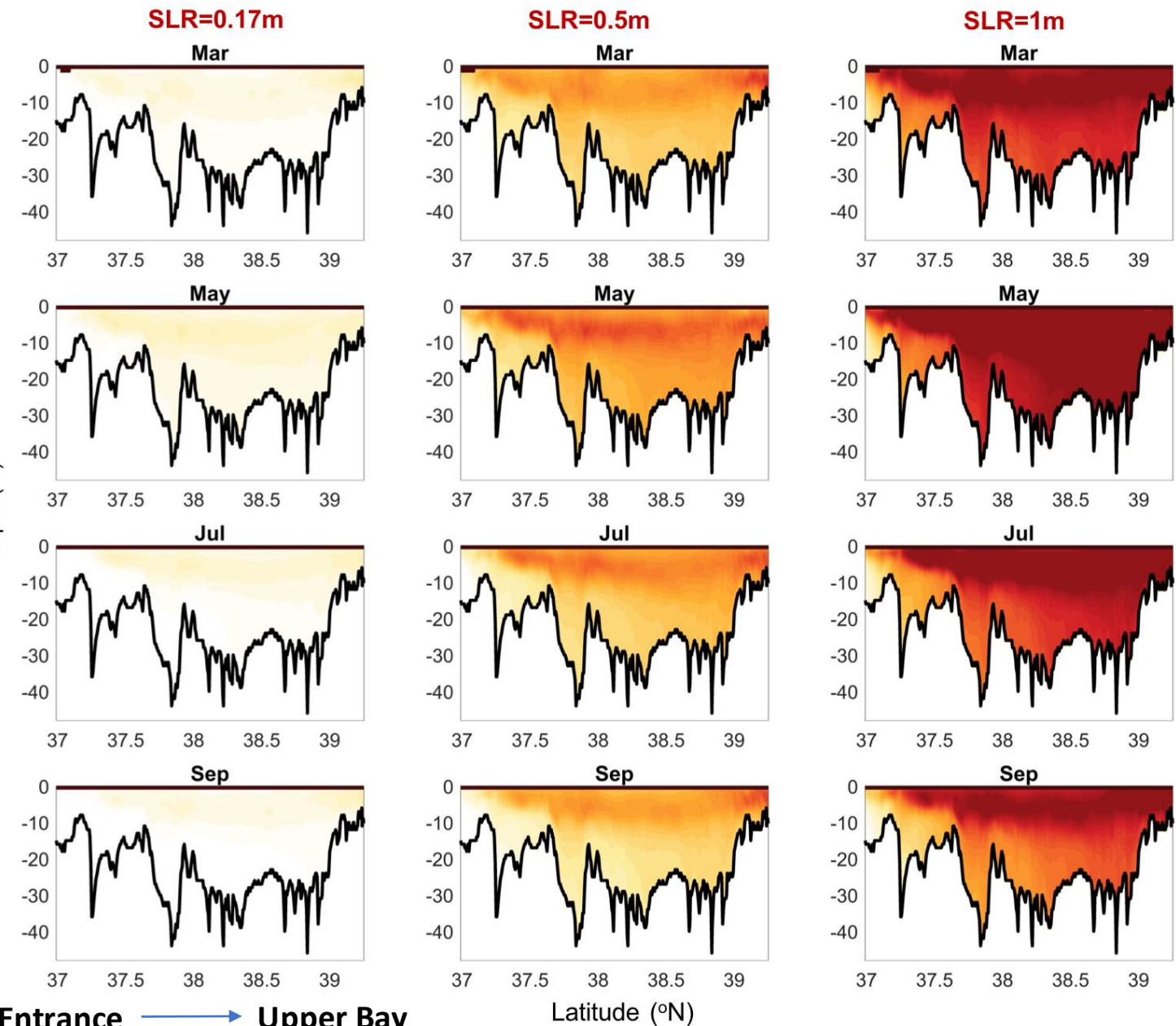
Larger increase happens on the bottom of shallow water tributaries.

Averaged (1991-1995) **Bottom** Salinity Difference (PSU)

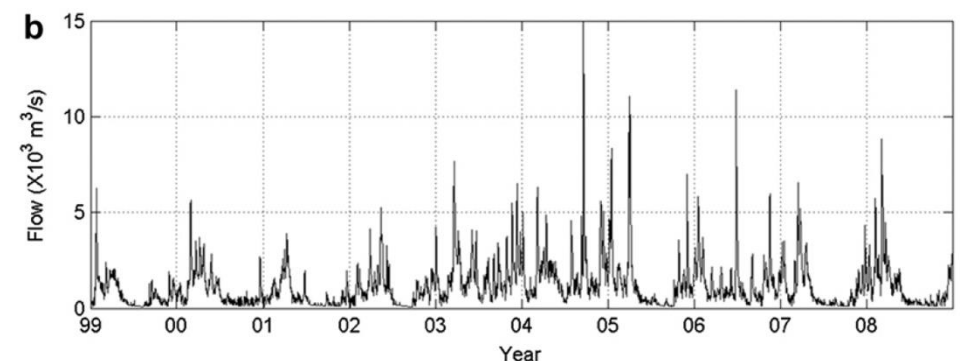
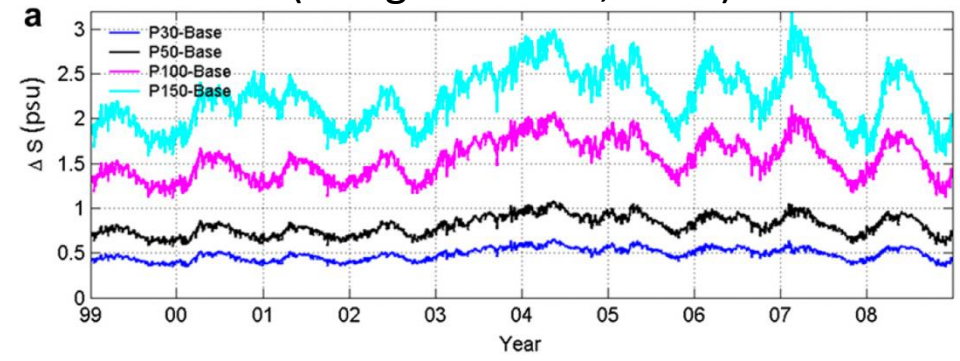


Salinity under SLR

- With increase of SLR, there is more salt intrusion into mainstem
- Model predicts most increase of salinity near the pycnocline



Averaged along Bay main channel
(Hong and Shen, 2012)



Entrance → Upper Bay

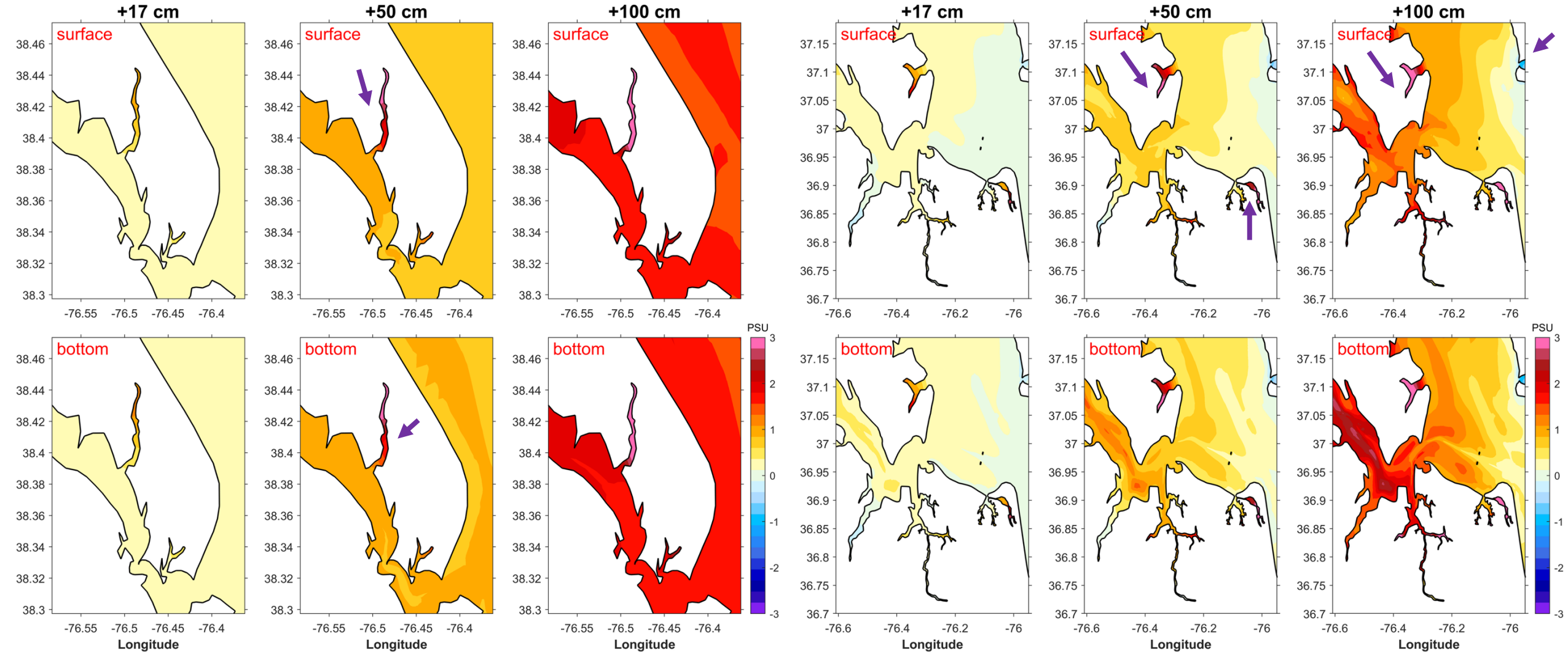
Latitude (°N)

Salinity in tributaries

- Note the nonlinear responses in tribs and sub-tribs

Lower Patuxent River

James/Elizabeth River

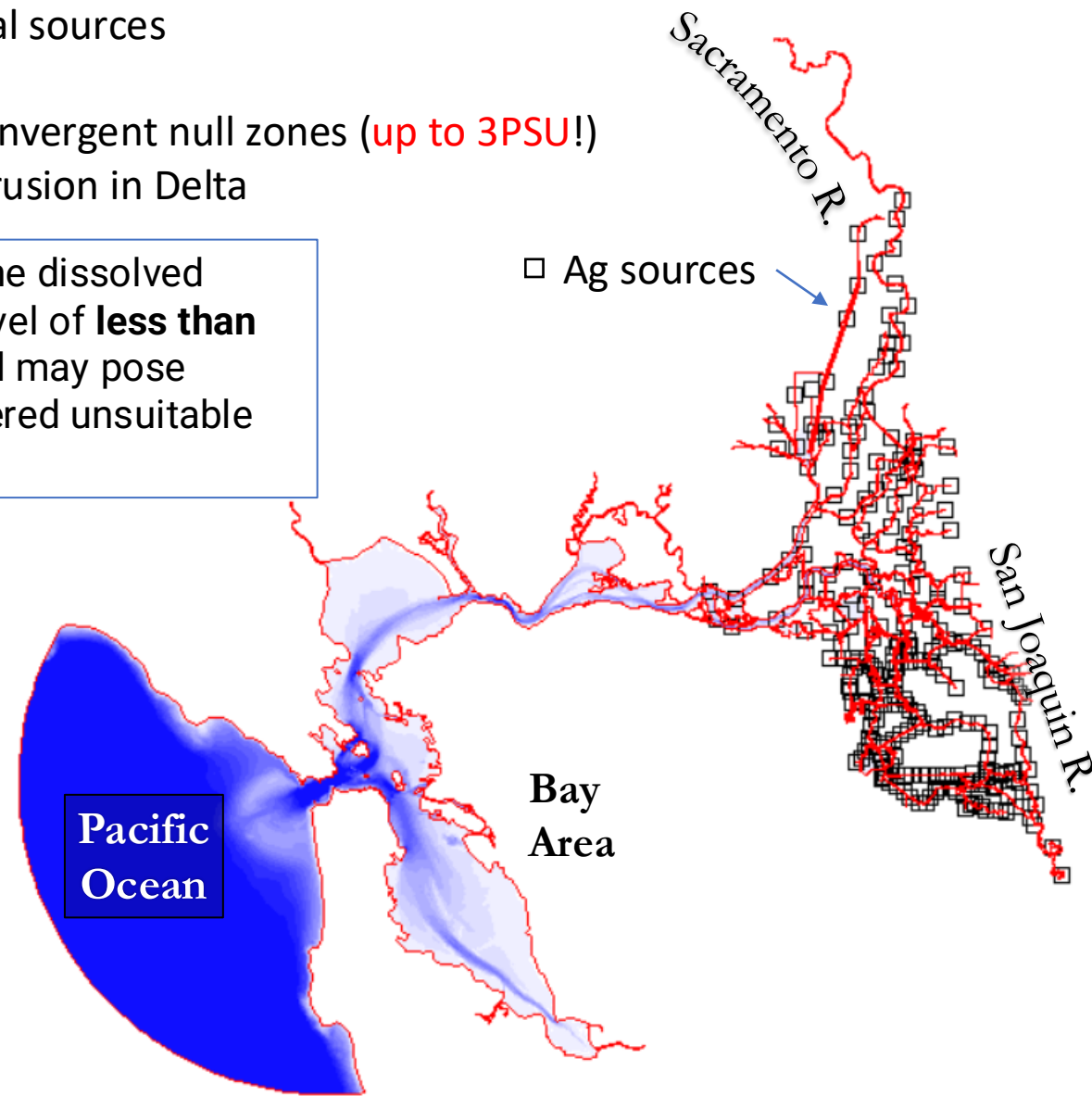
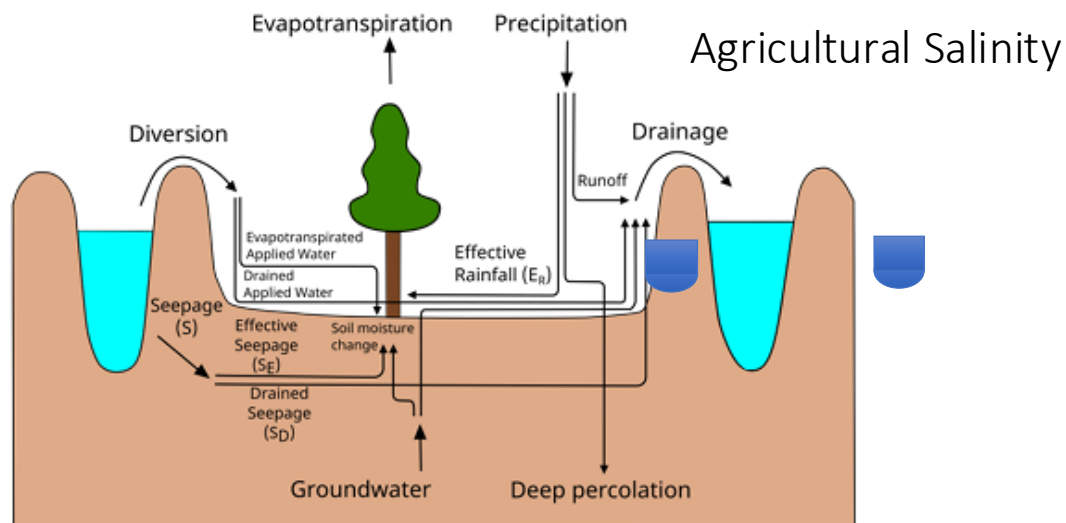


Caveat #1: agricultural & groundwater sources

- San Francisco Bay-Delta: in Central and North Delta, the main salinity sources come from a mixture of ocean and ag runoff
- South Delta: dynamic balances between San Joaquin flow and local sources
- Net Sink determines tidally averaged circulation
- Local sources of salinity (“in-Delta”) are large and be trapped in convergent null zones (up to 3PSU!)
- Island subsidence and levee failure are main causes for salinity intrusion in Delta

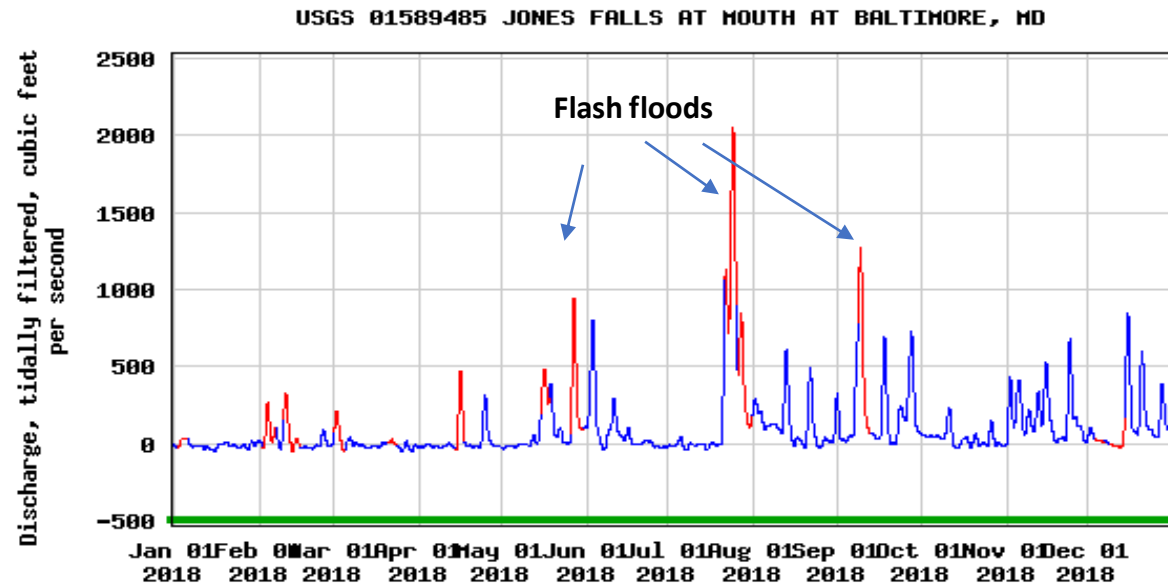
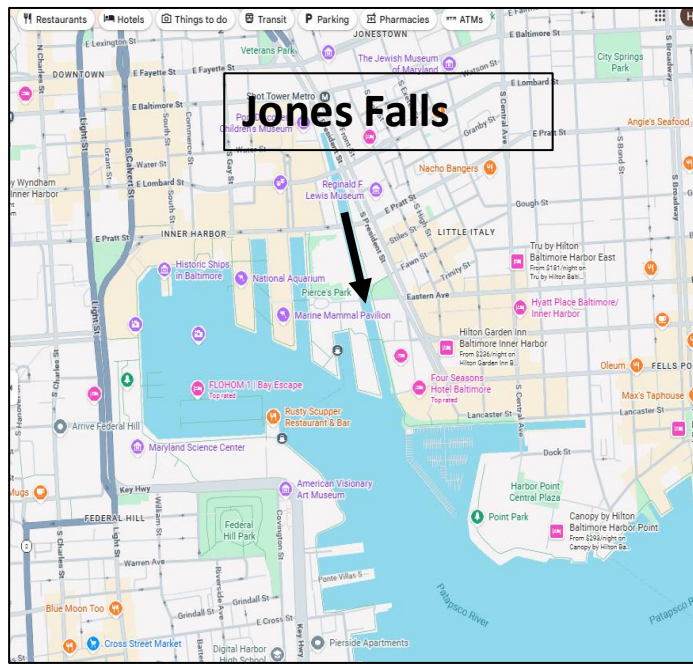
While water with **zero salinity** is ideal, practical standards allow for some dissolved minerals. The **World Health Organization (WHO)** recommends a TDS level of **less than 500 mg/L (ppm)** for drinking water, as higher levels can affect taste and may pose health concerns. Water with TDS above 1,000 mg/L is generally considered unsuitable for consumption...

Figure 1-1 Schematic of the water budget for a Delta Island



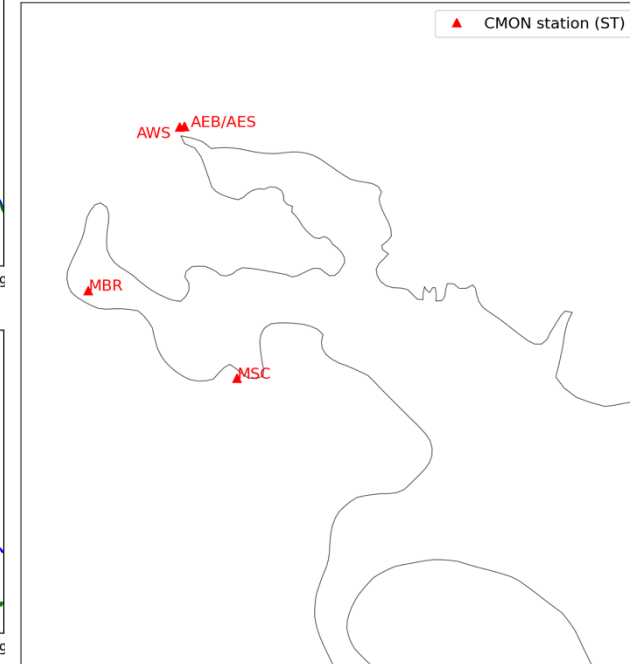
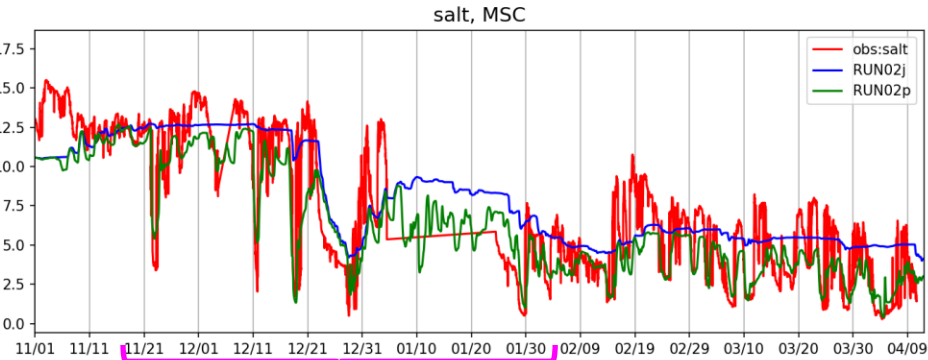
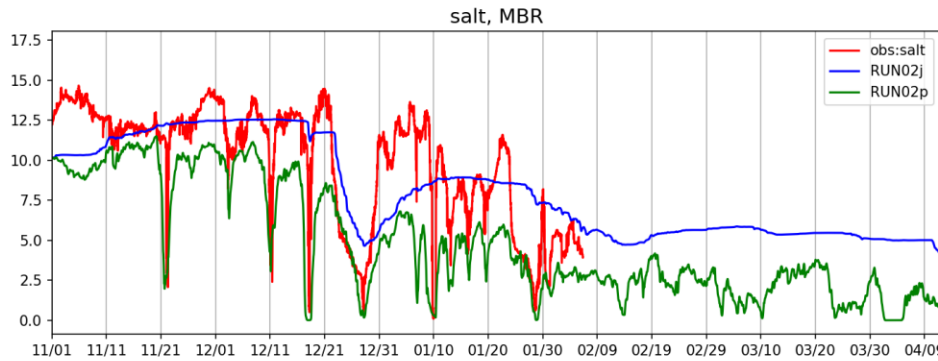
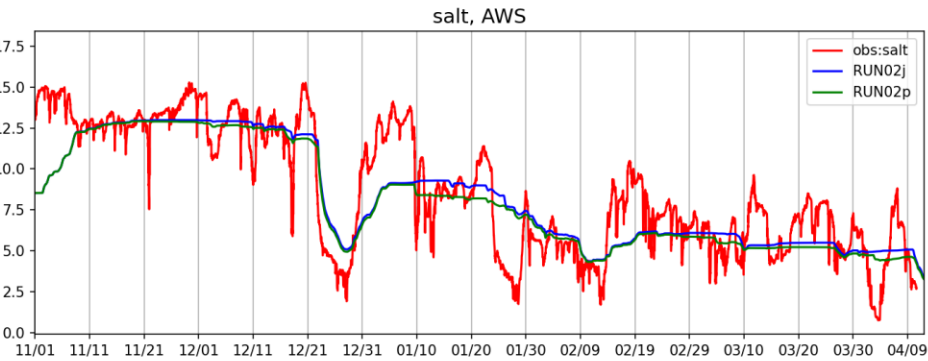
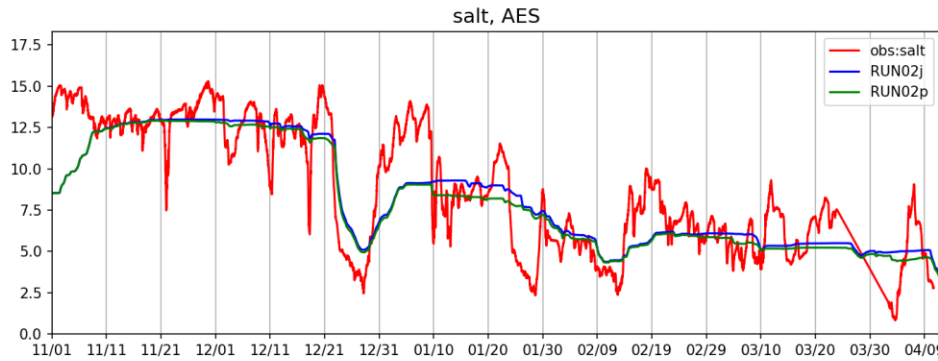
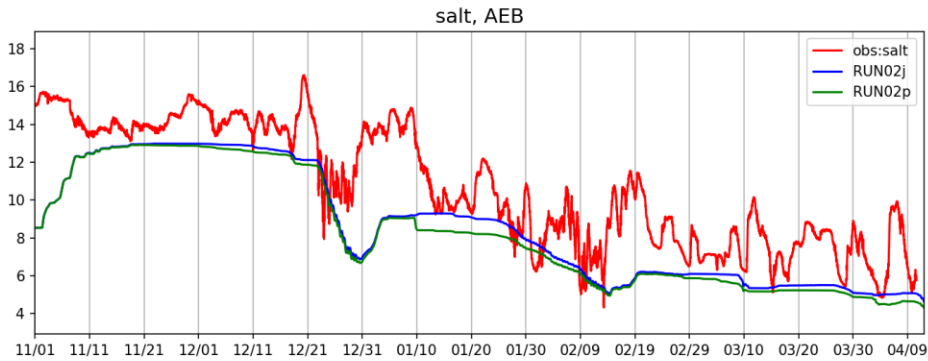
Caveat #2: flash flood

- In many urbanized areas, the runoff is very 'flashy'
- This has significant impact on local salinity variability
- Conversely, storm events can also bring ocean salinity into tidal creeks occasionally
- Has WQ implication
- WSM may need to add these; or we could use SCHISM to look into compound flooding...



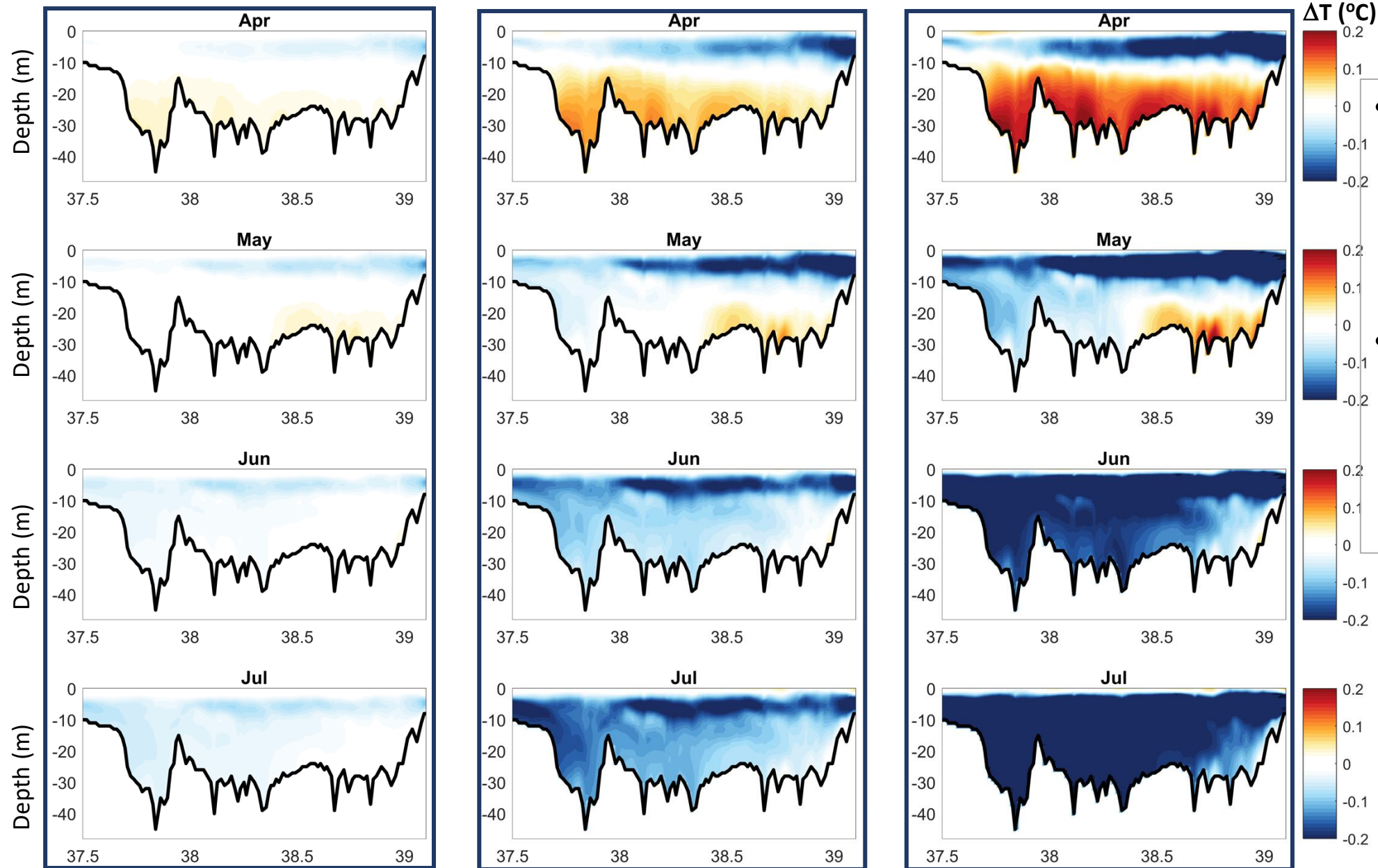
Patapsco River

See the **Green** line with local inflow from USGS gauge (the **Blue** line is for No local inflow)



High-frequency fluctuations of salinity were clearly simulated when local inflows from USGS gauged flow were included

Effects of Sea Level Rise -- Temperature



SLR=0.17m Latitude ($^{\circ}$ N)

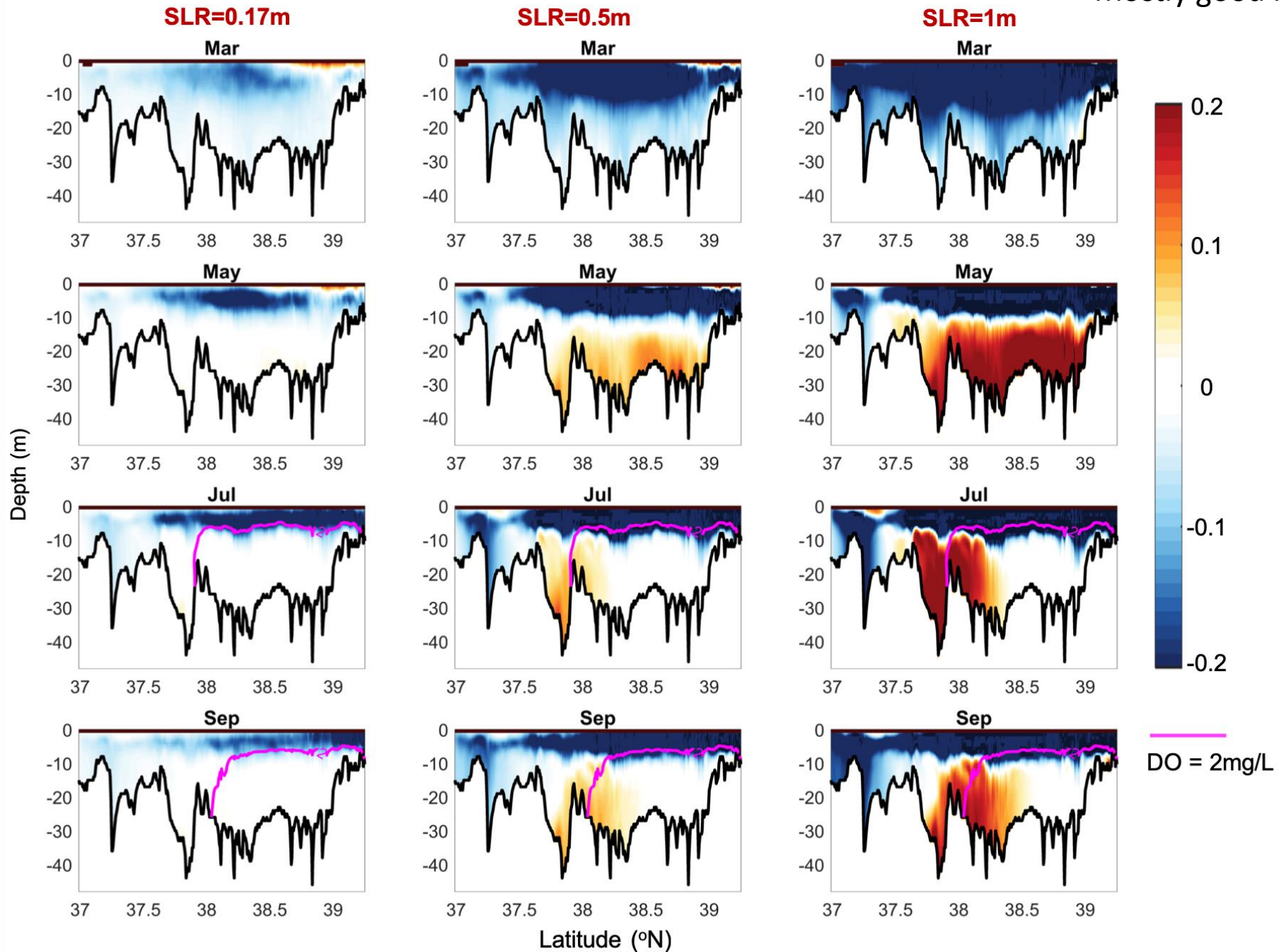
SLR=0.5m Latitude ($^{\circ}$ N)

SLR=1m Latitude ($^{\circ}$ N)

- Model predicts decrease of temperature below the pycnocline in June and July.
- Model predicts mostly decrease of temperature, especially over the pycnocline.

Dissolved Oxygen Difference (g/m^3)

Mostly good news for hypoxia



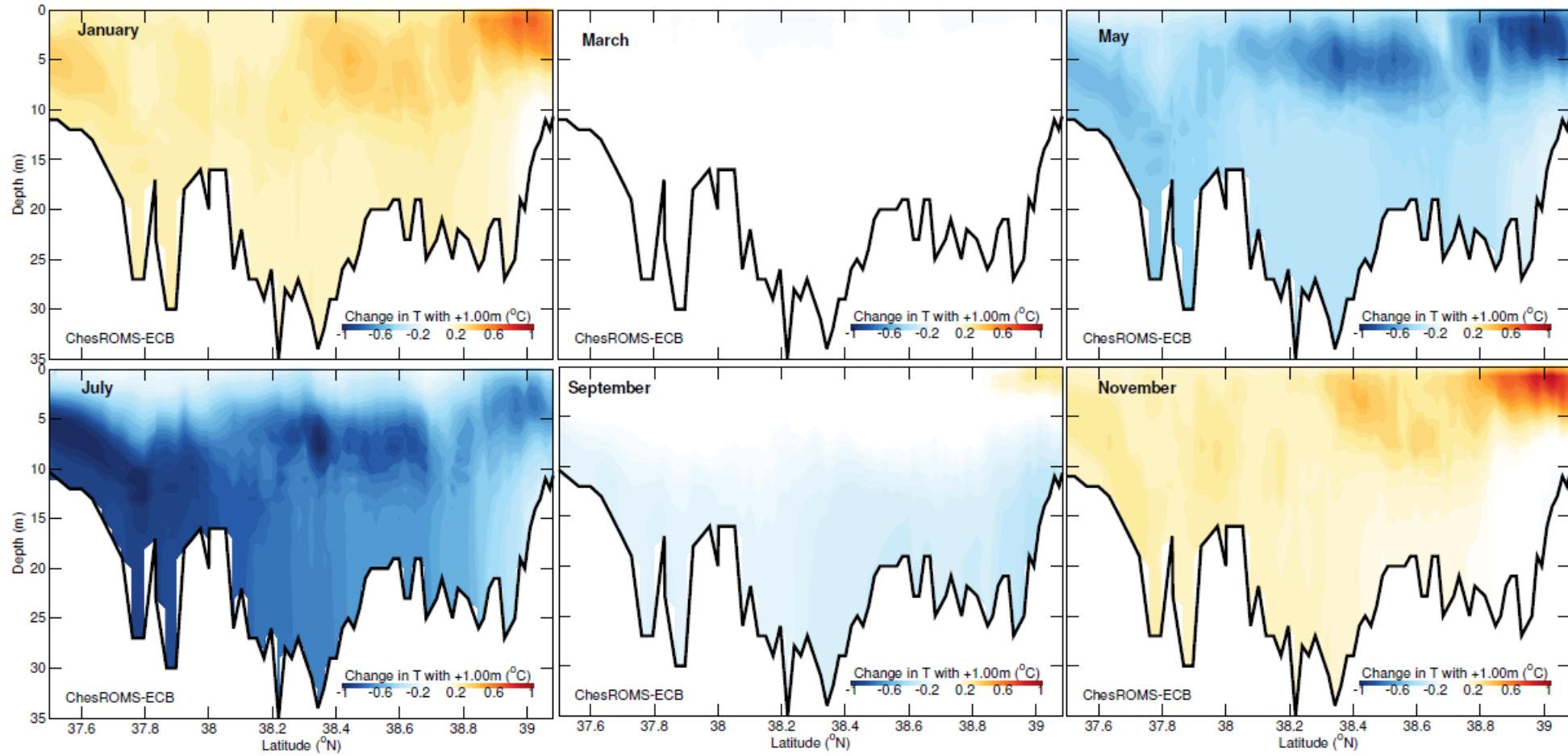
Summary

- We are developing Phase 7 MBM to address system-wide challenges in Chesapeake Bay hydrodynamic and water quality processes
 - Unprecedented details are being revealed in productive shallows as well as their connection to remote forcings in coastal ocean, under climate change
- **Flexibility and high resolution of MBM allows us to**
 - **Explore cross-scale responses to various forcings (SLR, C.C., land use ...)**
 - **Incorporate new geochemical processes related to salinity, vegetation ...**
- We used MBM to study the impacts of **sea level rise** on salinity intrusion and lower Bay hypoxia under the scenarios of +0.17m, +0.5m and +1m
 - Sea level rise generally causes larger salt intrusion into mainstem
 - Responses in tribs and shallows are nonlinear
 - Challenges identified for watershed model in ag salinity sources and urbanized areas (flash flood)
 - Temperature response is beneficial for hypoxia
- Besides SLR, other forcings (ag runoff, hydrological regime shift etc) are also important for salinity intrusion in climate change predictions
 - Scenario simulations and review start next year

Supplementary slides

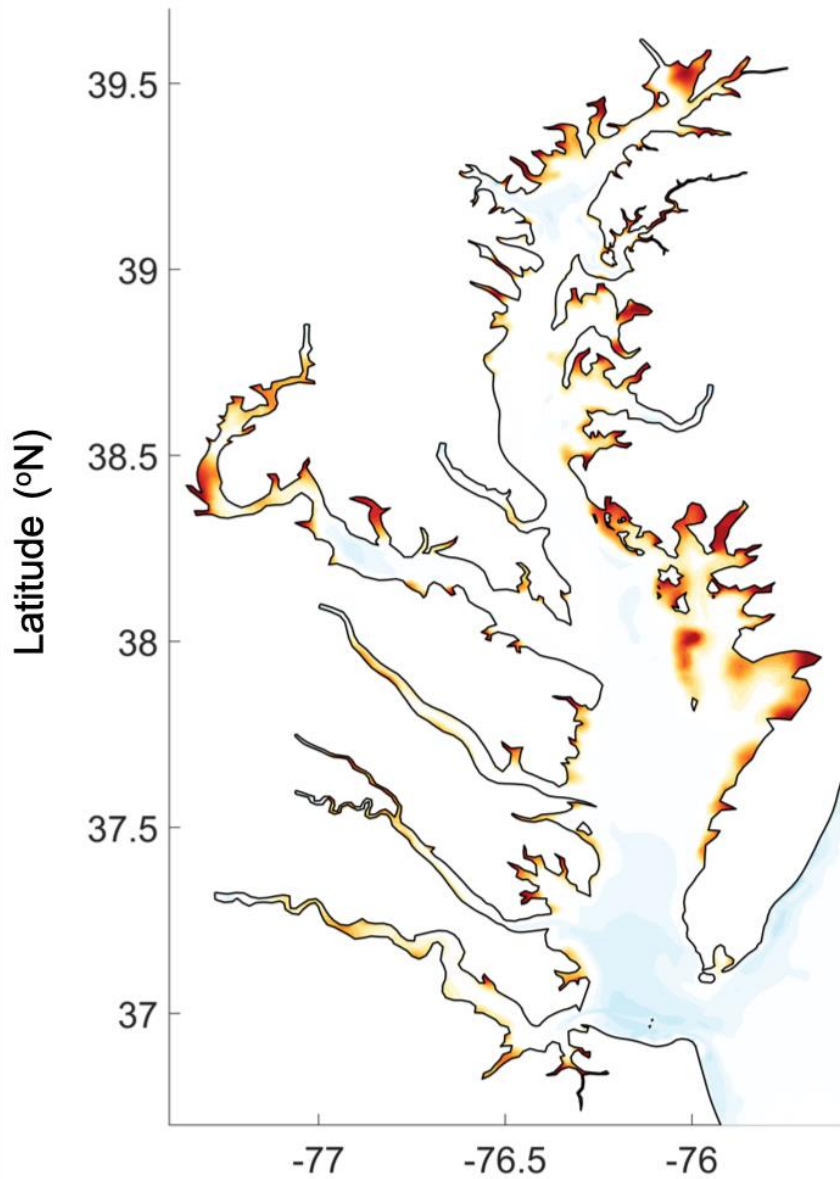
ROMS-ECB (c/o Pierre St-Laurent)

Change in T due to $\Delta SL = +1.00\text{m}$, ChesROMS-ECB

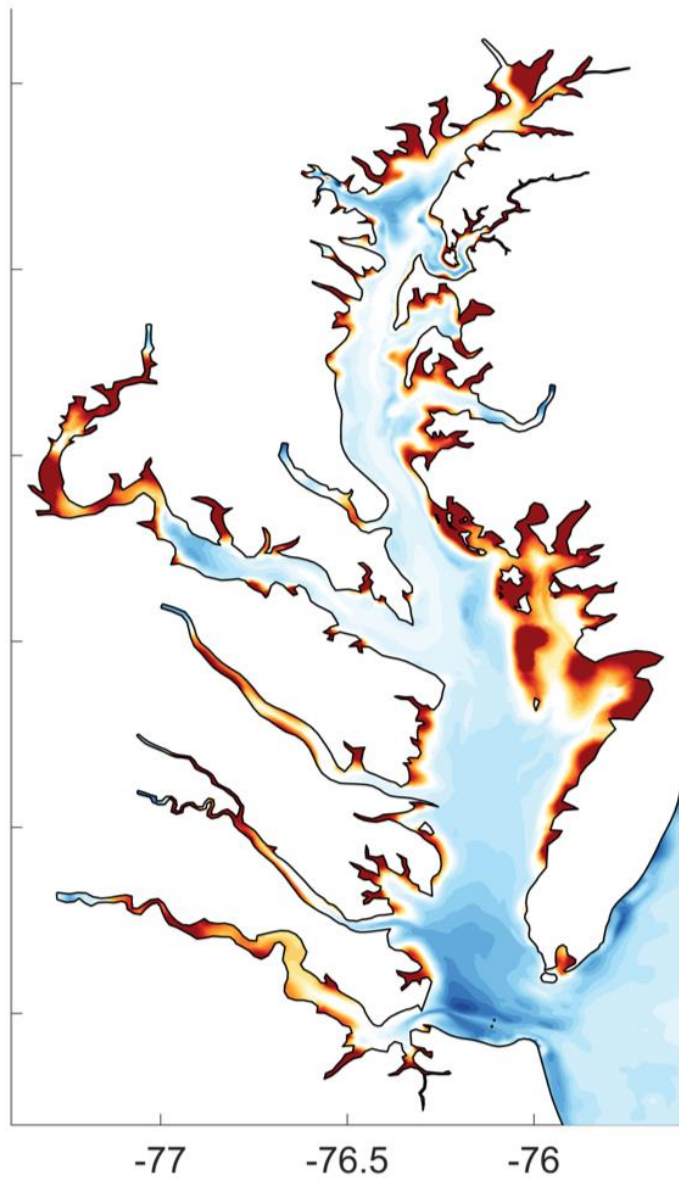


Bottom Temperature Difference in July (°C)

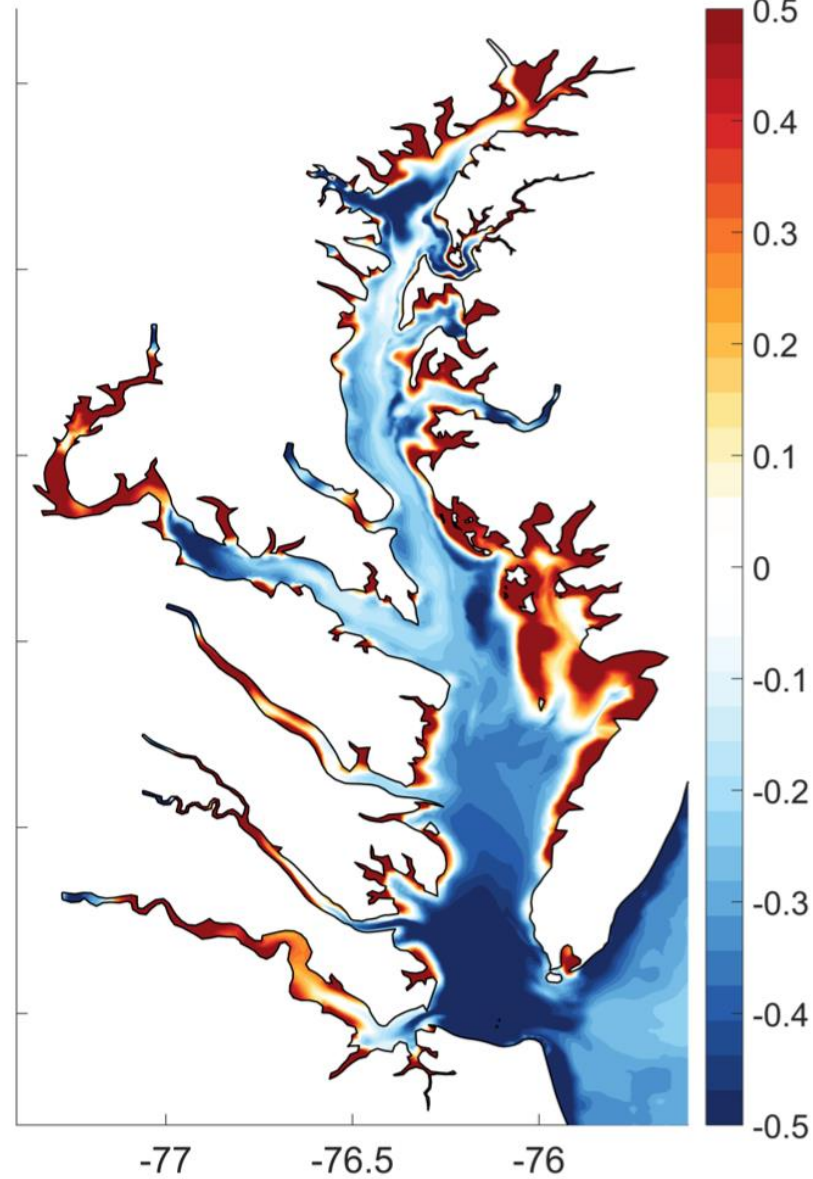
SLR=0.17m



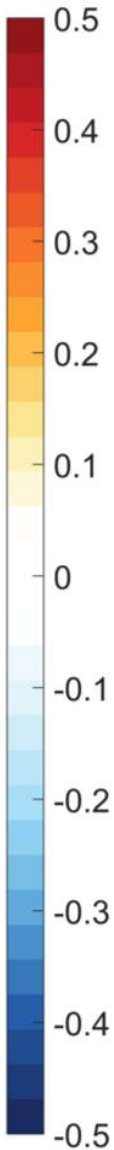
SLR=0.5m



SLR=1m



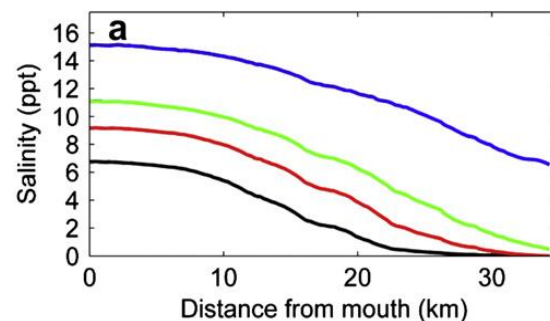
ΔT (°C)



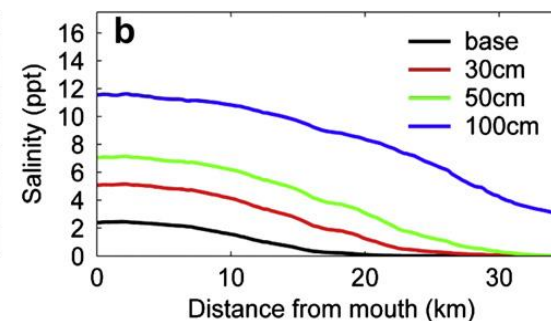
Salinity intrusion in James River

- Our prediction is mostly consistent with Rice et al. (2012)
- Some hints of nonlinear response in their paper, but results are only shown along thalweg

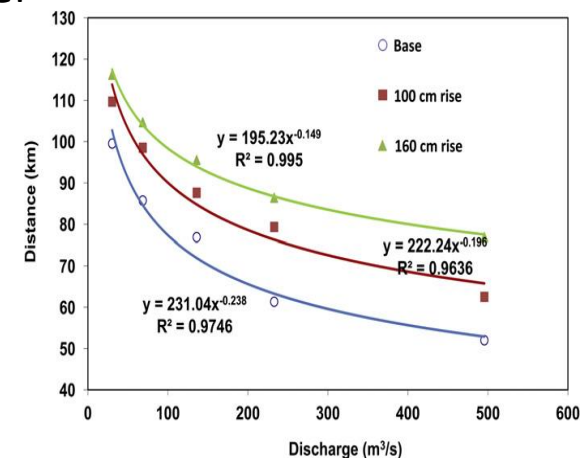
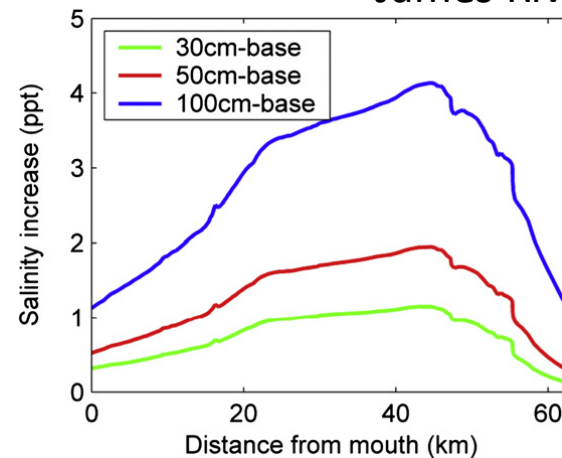
Chickahominy River.
(dry year 2002)



Chickahominy River
Typical Year

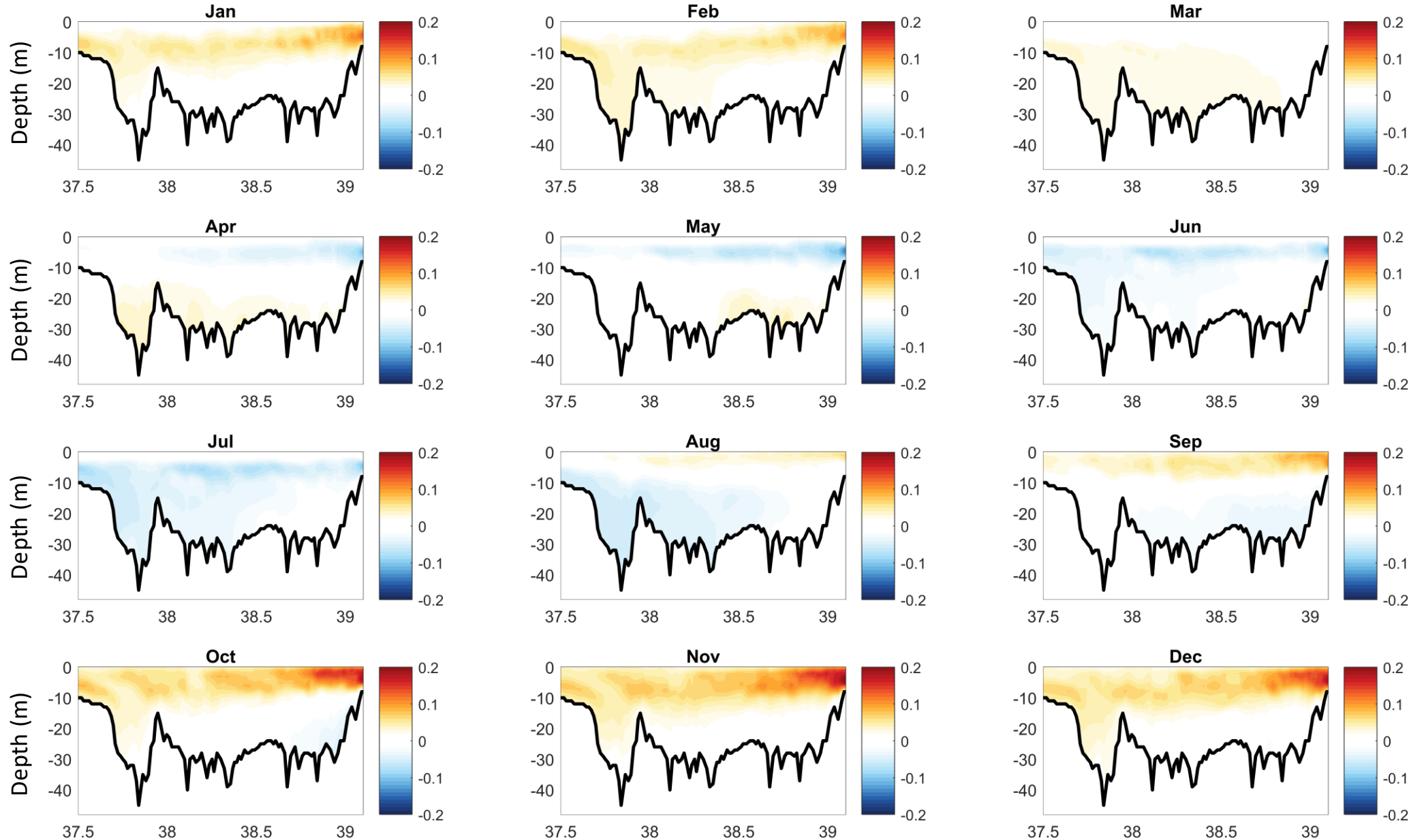


James River



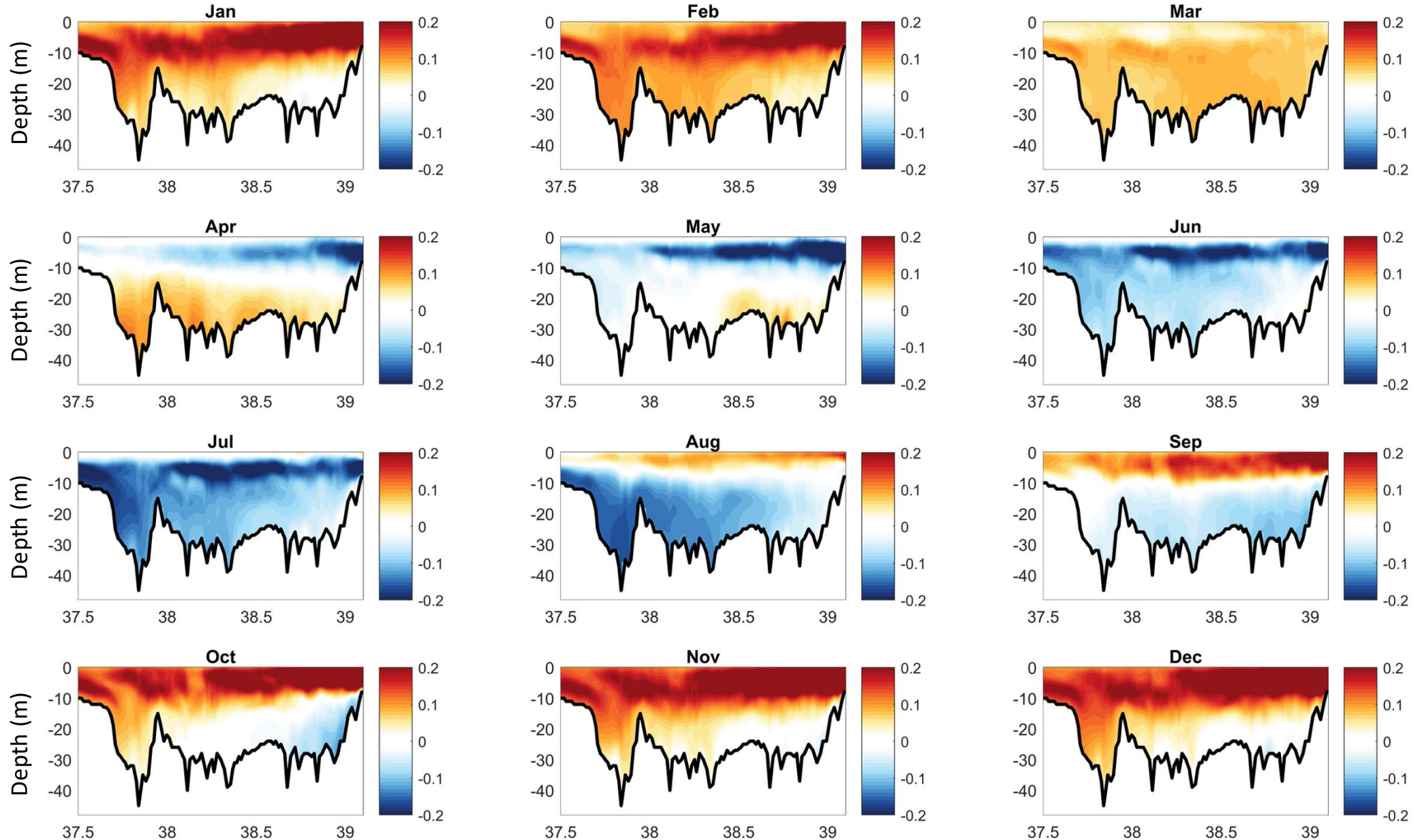
Seasonal Pattern of Temperature Difference -- 0.17m

(°C)



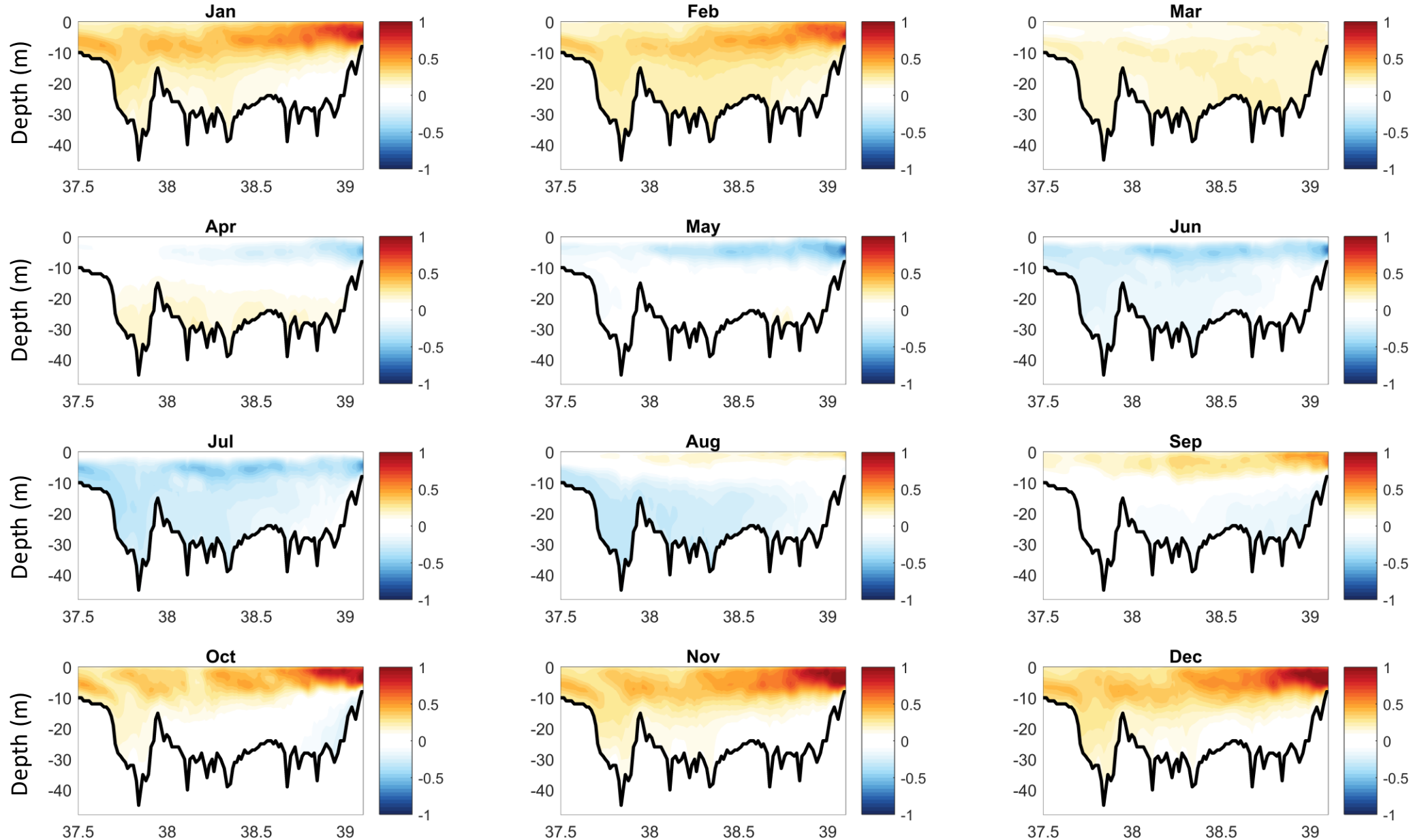
Seasonal Pattern of Temperature Difference -- 0.5m

(°C)



Seasonal Pattern of Temperature Difference -- 1m

(°C)



CALIFORNIA DEPARTMENT OF WATER
RESOURCES

Salinity Issues and Management in the San Francisco Bay-Delta and California

NSF Workshop, October 2025



Eli Ateljevich, PE, PhD, Modeling Support Office

The Delta:



Covers 738,000 acres,
55,000 acres of which is water

Includes over
1,100 miles of levees

Provides recreation to
12 million users

Largest estuary on the west coast - supporting
majority of state's commercial salmon fisheries

Conveys water to support California's
\$3.4 trillion economy (world's 5th largest)

Provides drinking water for over
27 million people
(two-thirds of the State's population)

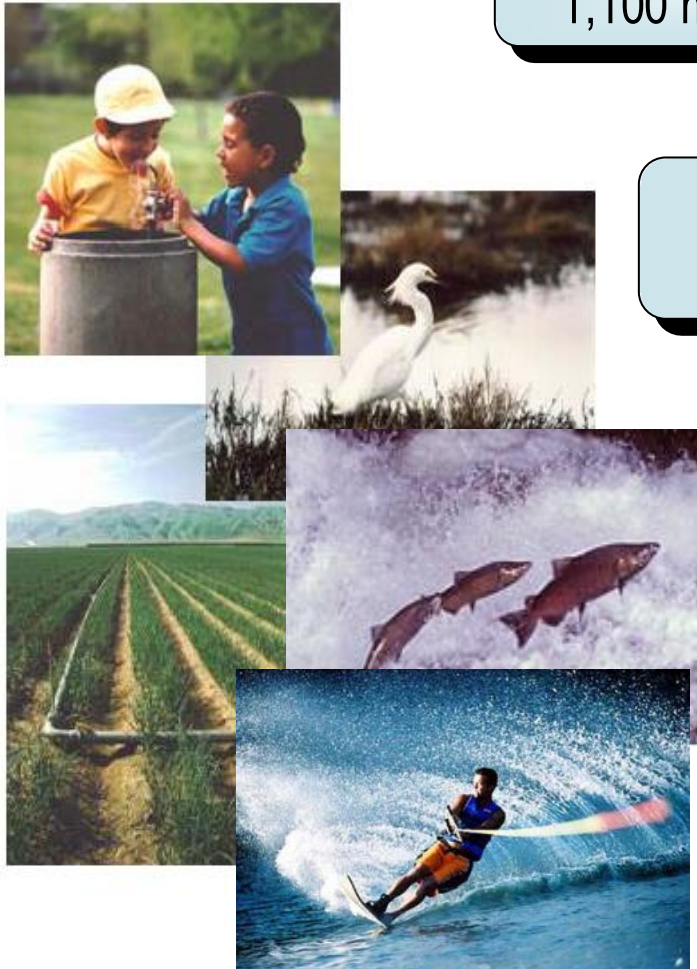
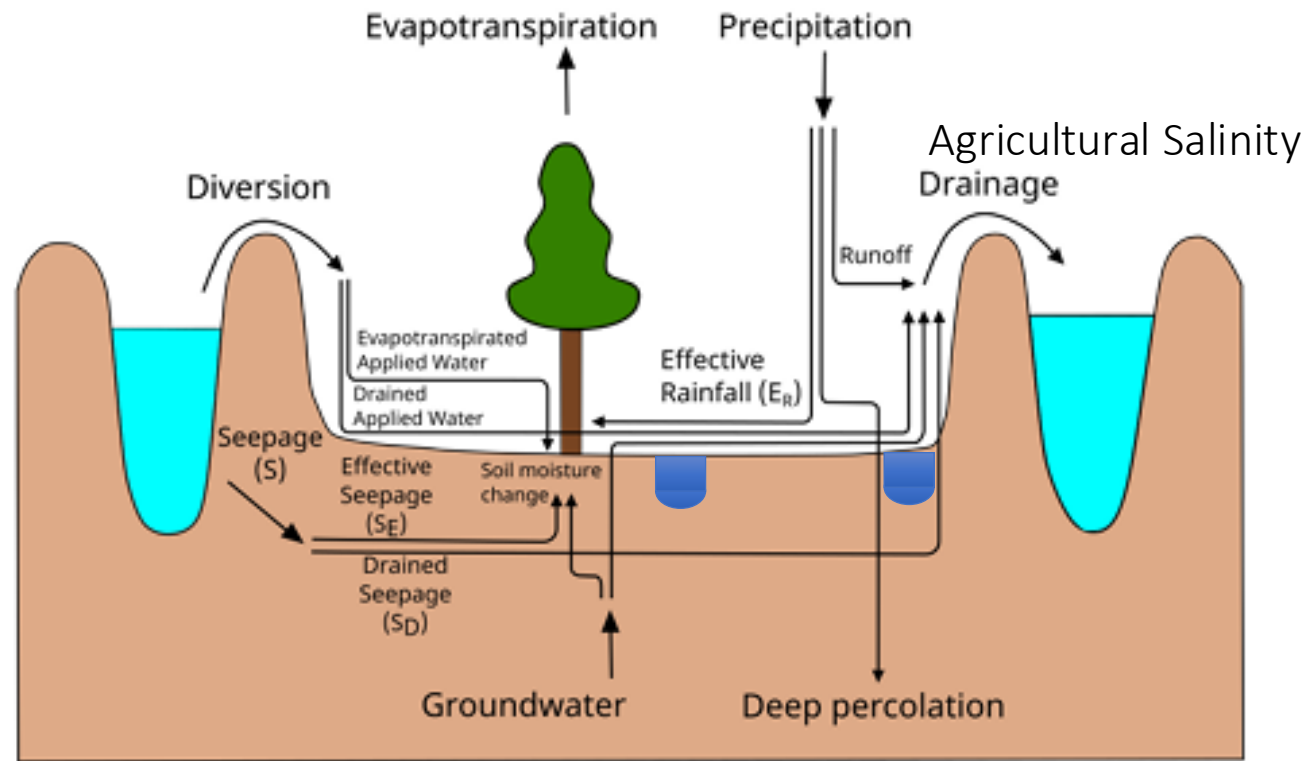
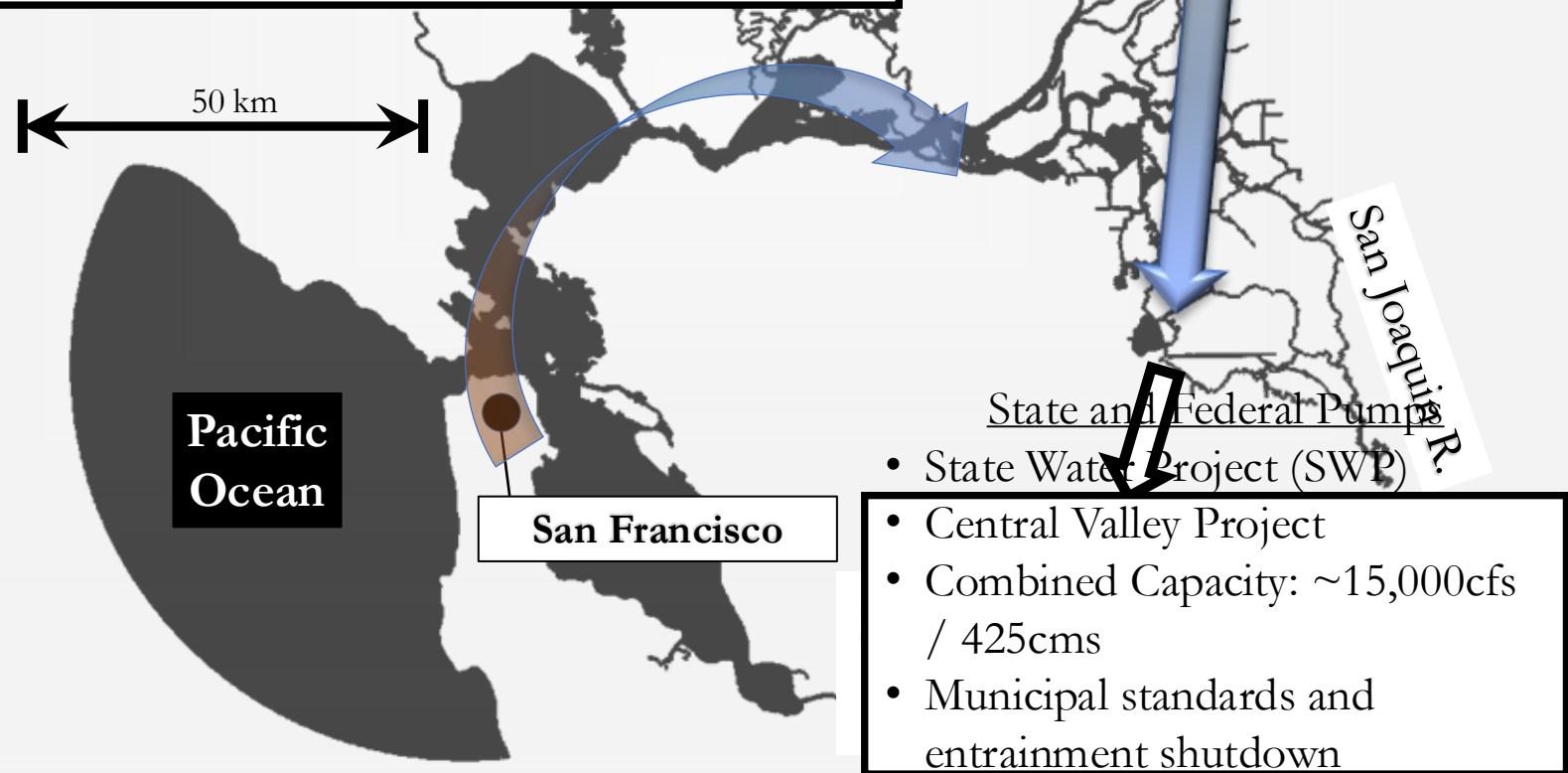


Figure 1-1 Schematic of the water budget for a Delta Island



Delta Freshwater Corridor

- Dispersive mixing in channels/junctions and trapping
- Local sources of salinity in Central Delta with impact dependent on outflow and exports.
- Source and sink an $O(1)$ contributor to outflow and contribute to landward trapping of estuarine highs.



Sacramento

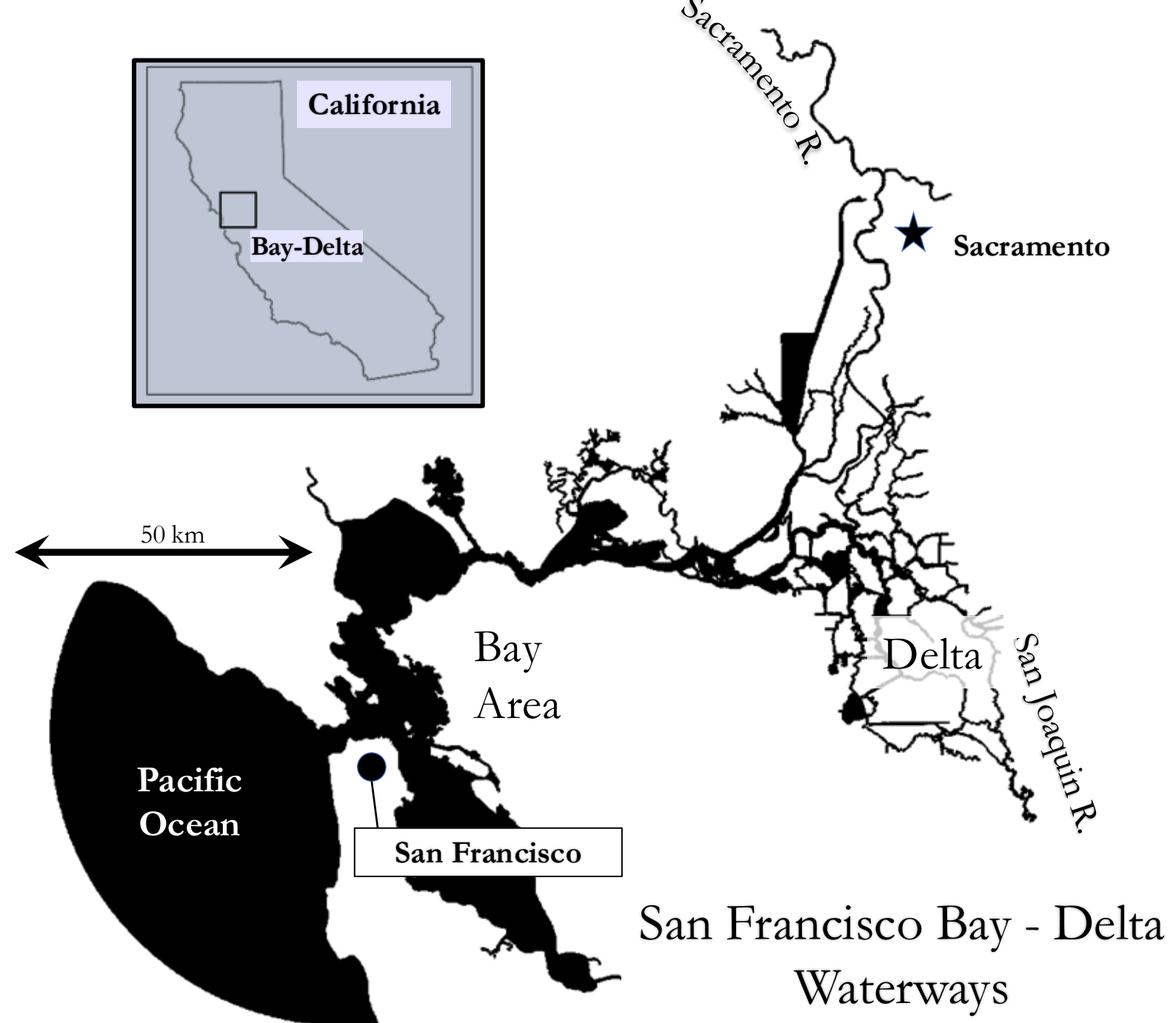
San Joaquin R.

State and Federal Pumps

- State Water Project (SWP)
- Central Valley Project
- Combined Capacity: ~15,000cfs / 425cms
- Municipal standards and entrainment shutdown

Pacific Ocean

San Francisco



San Francisco Bay - Delta
Waterways

A tale of two bays: Chesapeake Bay vs San Francisco Bay-Delta

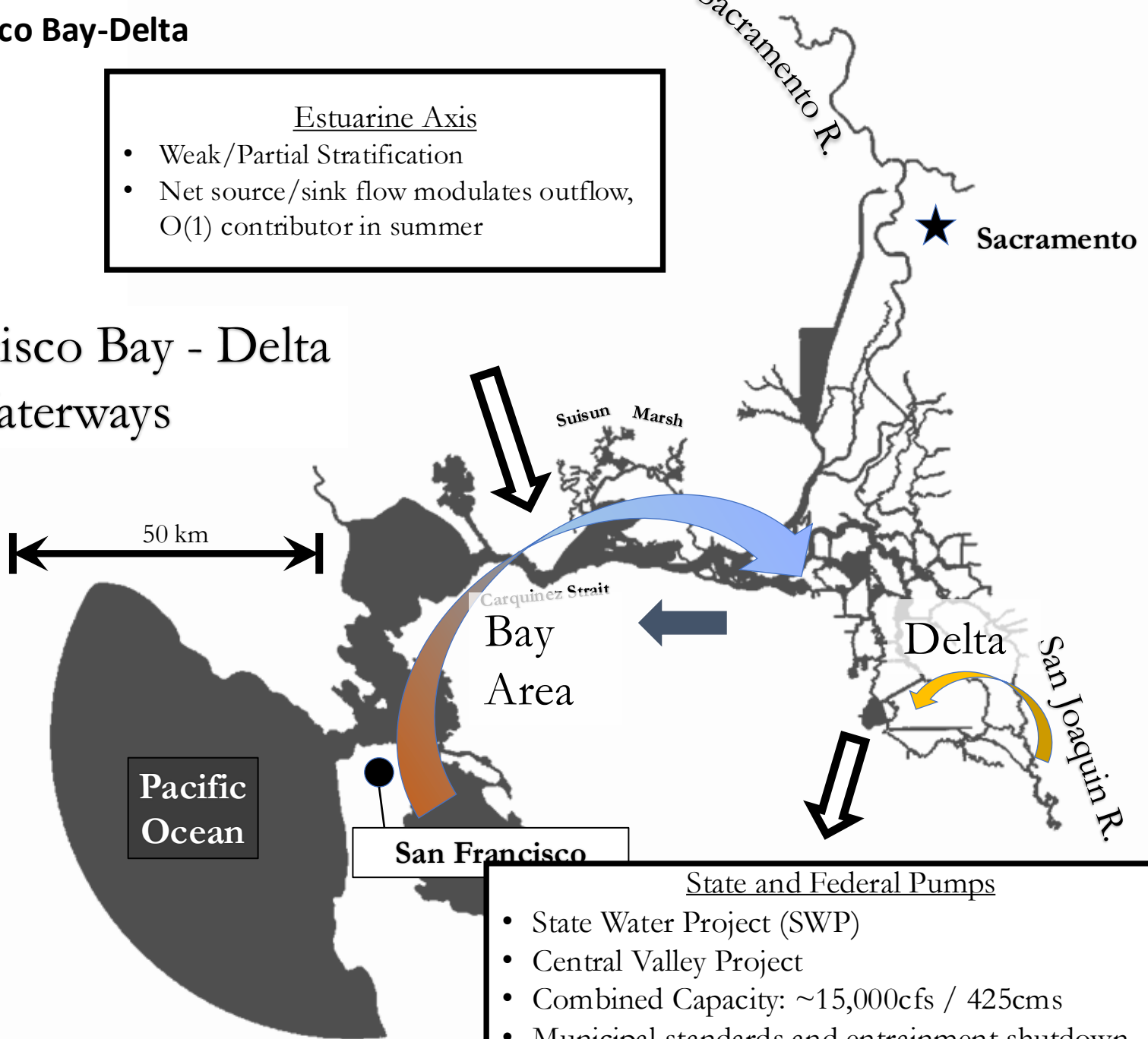
- Like CB, Bay-Delta system has heavy ag presence

Estuarine Axis

- Weak/Partial Stratification
- Net source/sink flow modulates outflow, O(1) contributor in summer

San Francisco Bay - Delta Waterways

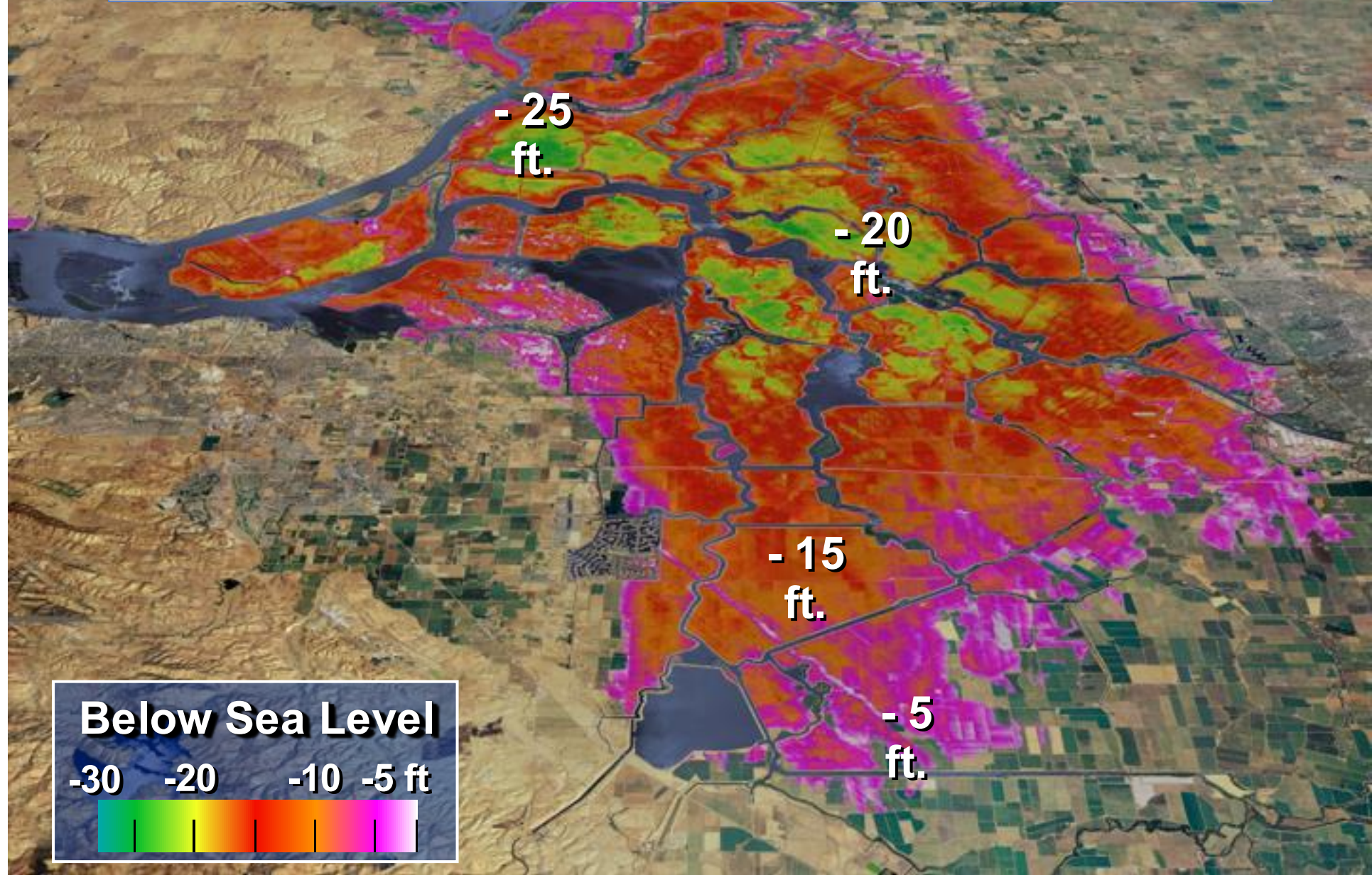
50 km



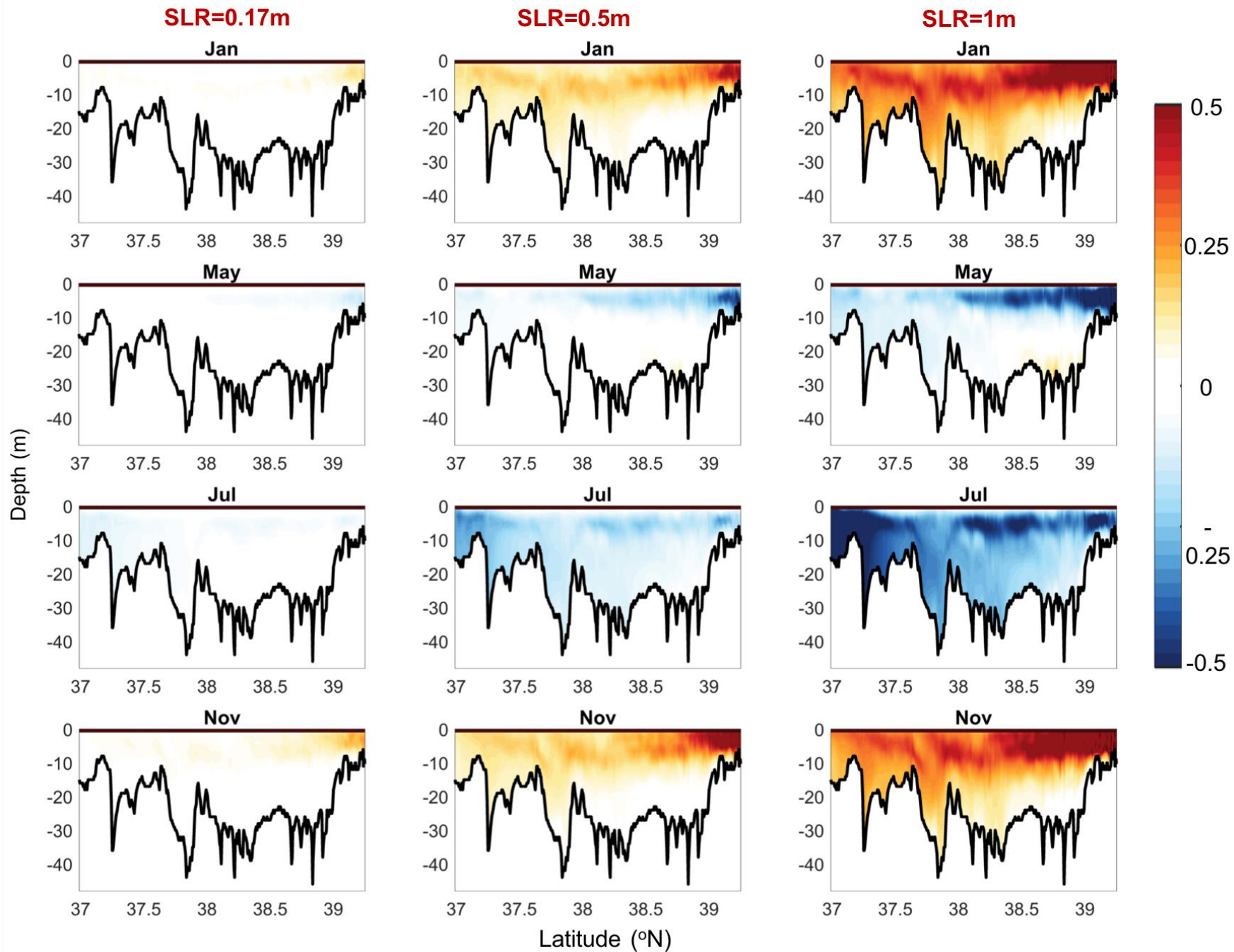
State and Federal Pumps

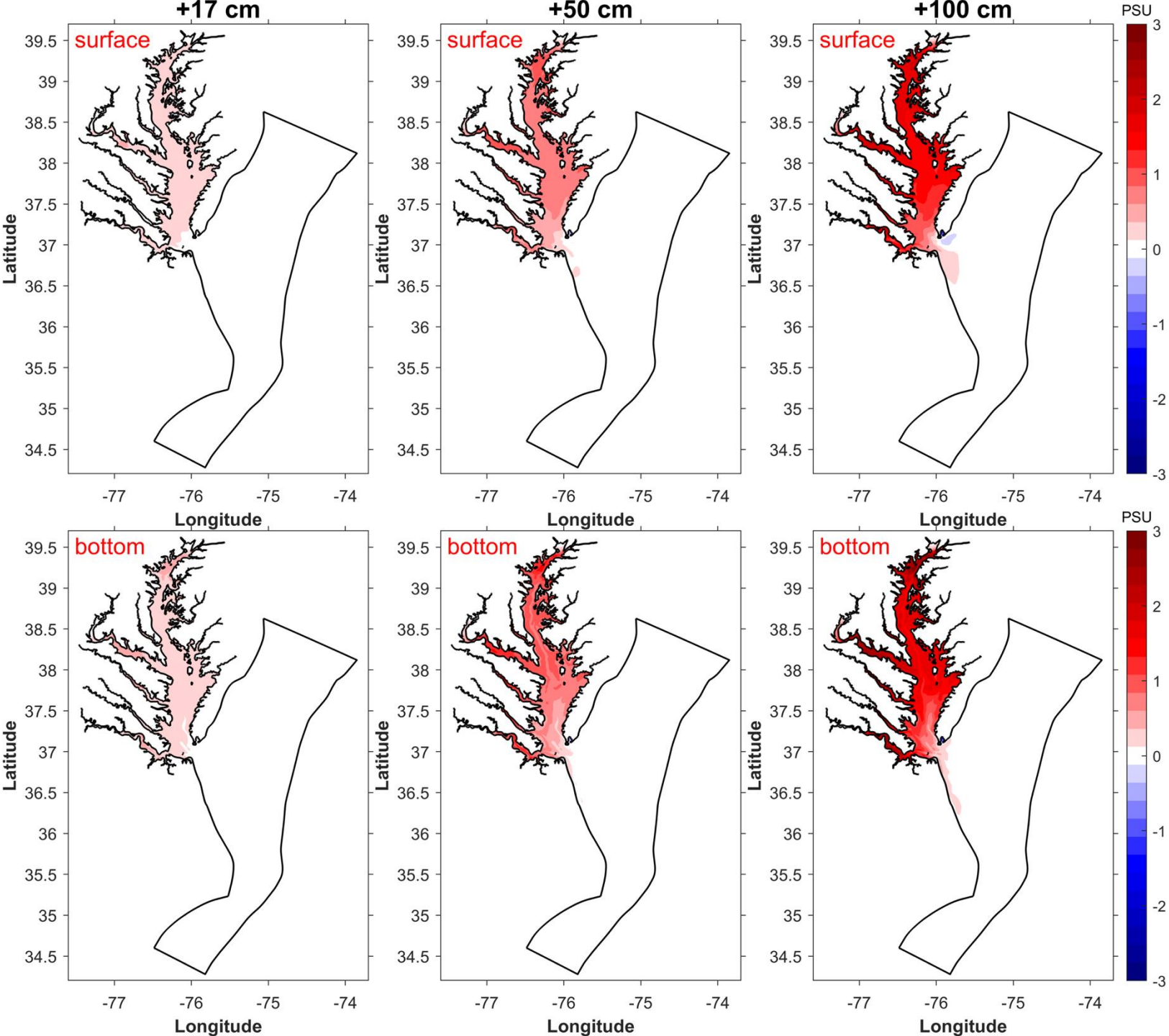
- State Water Project (SWP)
- Central Valley Project
- Combined Capacity: ~15,000cfs / 425cms
- Municipal standards and entrainment shutdown
- Serves >30+ million ag/municipal users

Delta Islands & Subsidence



Temperature ($^{\circ}\text{C}$)





Surface/Bottom salinity difference between the SLR cases and base run

Nonlinear responses of saltwater intrusion to the SLR

Lower Rappahannock River

Lower Chester River

