

Baroclinic 3D Modeling of Circulation Patterns in the Pamlico-Albemarle Sound System

2026 ADCIRC Users Group Meeting

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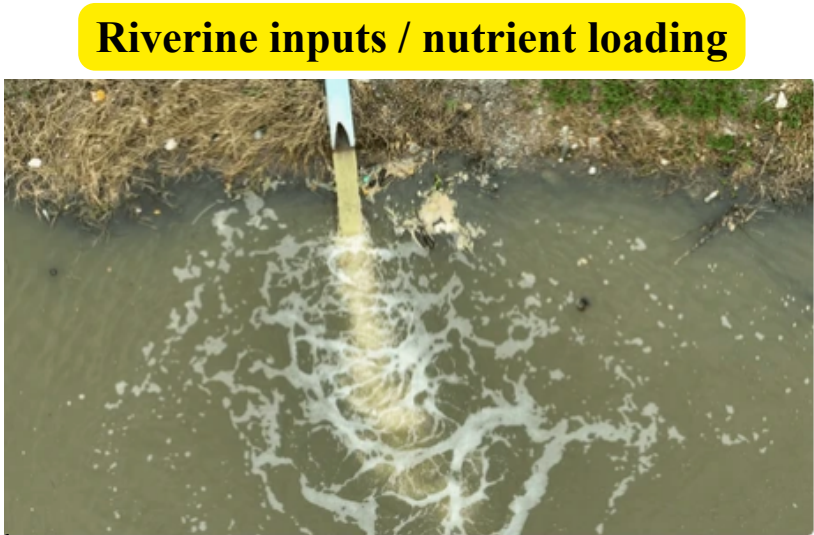
Coastal Engineering

Department of Civil, Construction and Environmental Engineering



Motivation/Problem

Why do circulation and stratification matter for HAB risk studies in PASS?



Potential HAB-favorable conditions



Photo: Astrid Schnetzer



Photo: DEQ

Ecological and health impacts

Health Impacts of Cyanotoxins

Note: Not all cyanotoxins lead to all of these health impacts. These listed impacts are caused by microcystins or cylindrospermopsin, the two cyanotoxins that EPA has issued Health Advisories for.

IN HUMANS

Brain
Source: Ingestion
Symptoms:
• Headache
• Incoherent speech
• Drowsiness
• Loss of coordination

Respiratory System
Source: Inhalation
Symptoms:
• Dry cough
• Pneumonia
• Sore throat
• Shortness of breath
• Loss of coordination

Digestive System
Source: Ingestion, drinking contaminated water, or eating contaminated fish
Symptoms:
• Abdominal pain
• Nausea
• Vomiting
• Diarrhea
• Stomach cramps

Body
Source: Contact, e.g. swimming
Symptoms:
• Irritation in eyes, nose, and throat
• Blistering around the mouth
• Skin rash, including tingling, burning and numbness
• Fever
• Muscle aches (from ingestion)
• Weakness (from ingestion)

Organs
Source: Ingestion
Symptoms:
• Kidney damage
• Abnormal kidney function
• Liver inflammation

Nervous System
Source: Ingestion
Symptoms:
• Tingling
• Burning
• Numbness

IN PETS

Symptoms:
• Vomiting
• Fatigue
• Shortness of breath
• Difficulty breathing
• Coughing
• Convulsions
• Liver failure
• Respiratory paralysis leading to death



Estuarine circulation helps determine where nutrients, blooms, and toxins are transported, retained, or accumulated across PASS.

Research Question and Objectives

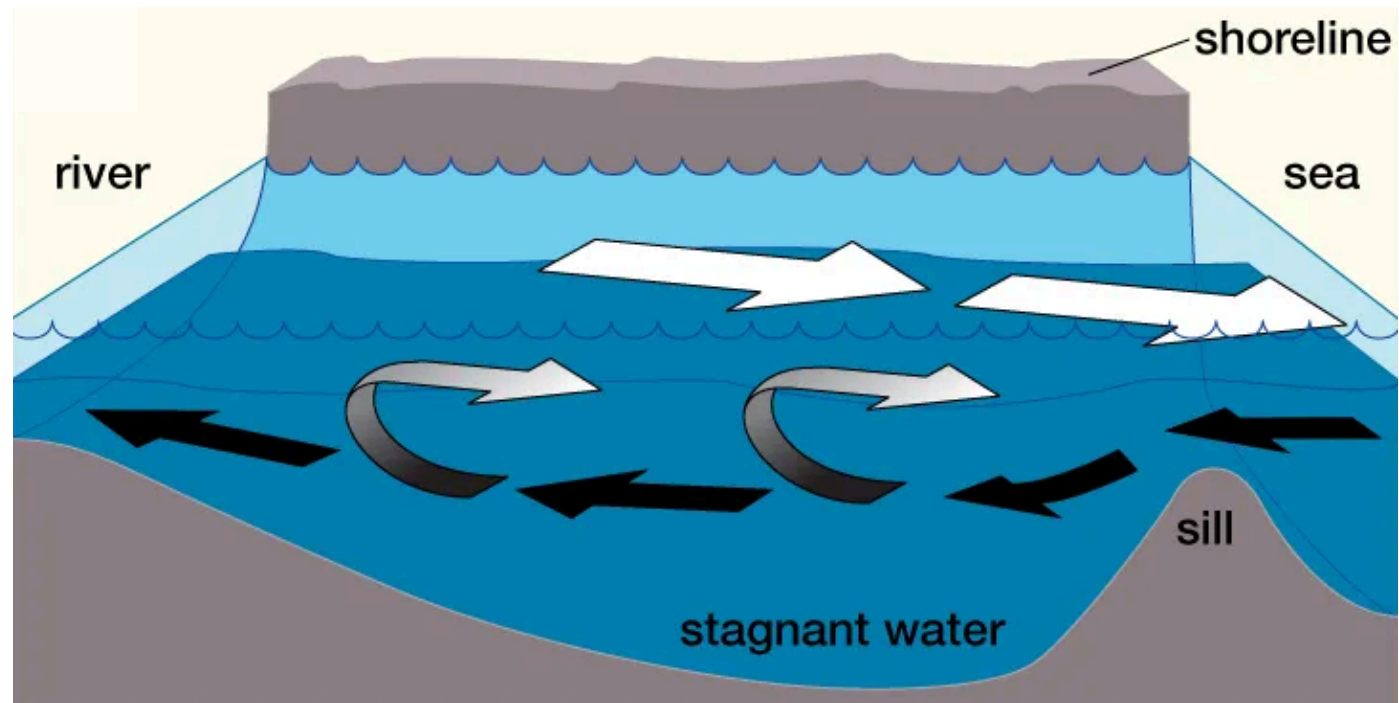
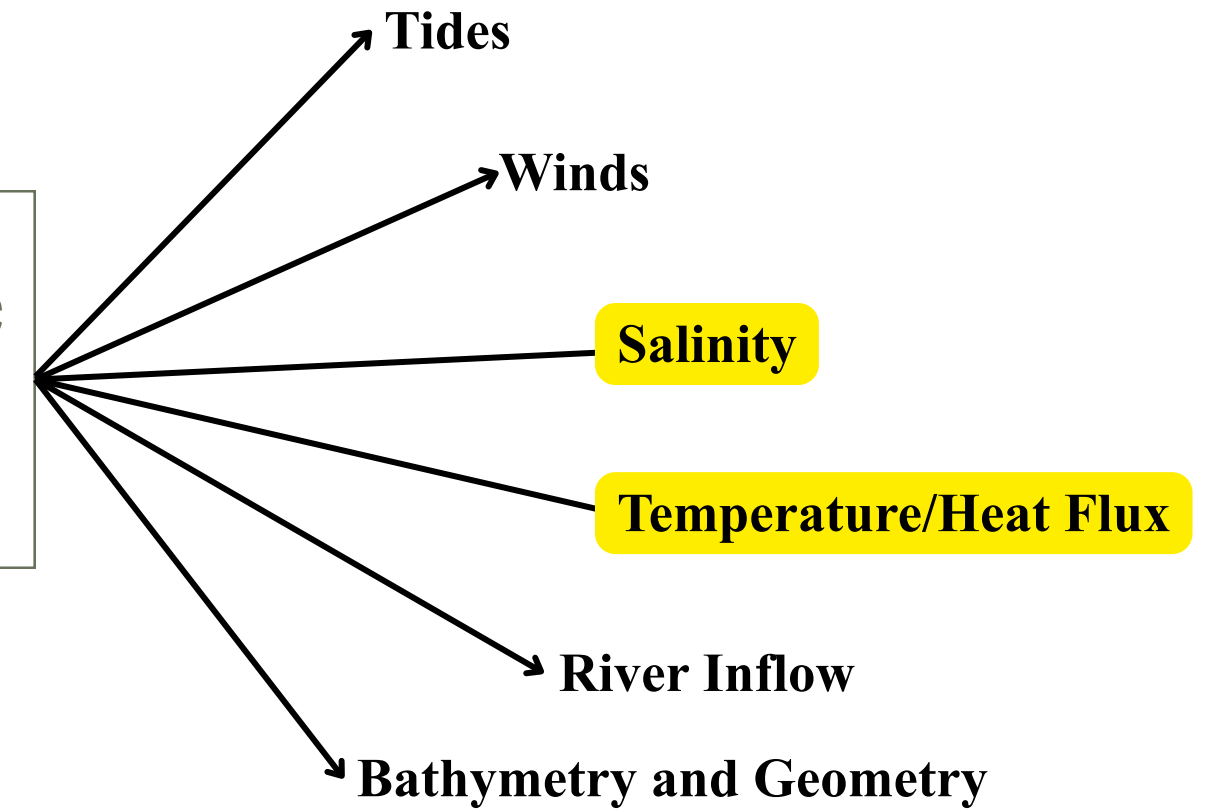


Photo: Encyclopædia Britannica

Drivers of Estuarine Dynamics



Salinity and temperature are emphasized because they shape density structure and influence potential HAB-favorable conditions.

How does 3D baroclinic circulation in PASS control salinity structure, exchange patterns, and weak-flushing regions that may be relevant to hazardous material transport and HAB-favorable conditions?

Objectives:

- Configure an independent 3D baroclinic ADCIRC model for PASS.
- Apply it to summer 2024 simulations with tides, winds, rivers, density, and heat flux.
- Examine salinity structure, exchange patterns, and weak-flushing regions.

ADCIRC 3D Model Setup and Forcing

Initial Salinity & Temperature

- Derived from **SalWise** climatology.
- Provides a climatological baseline density structure.

River Fluxes

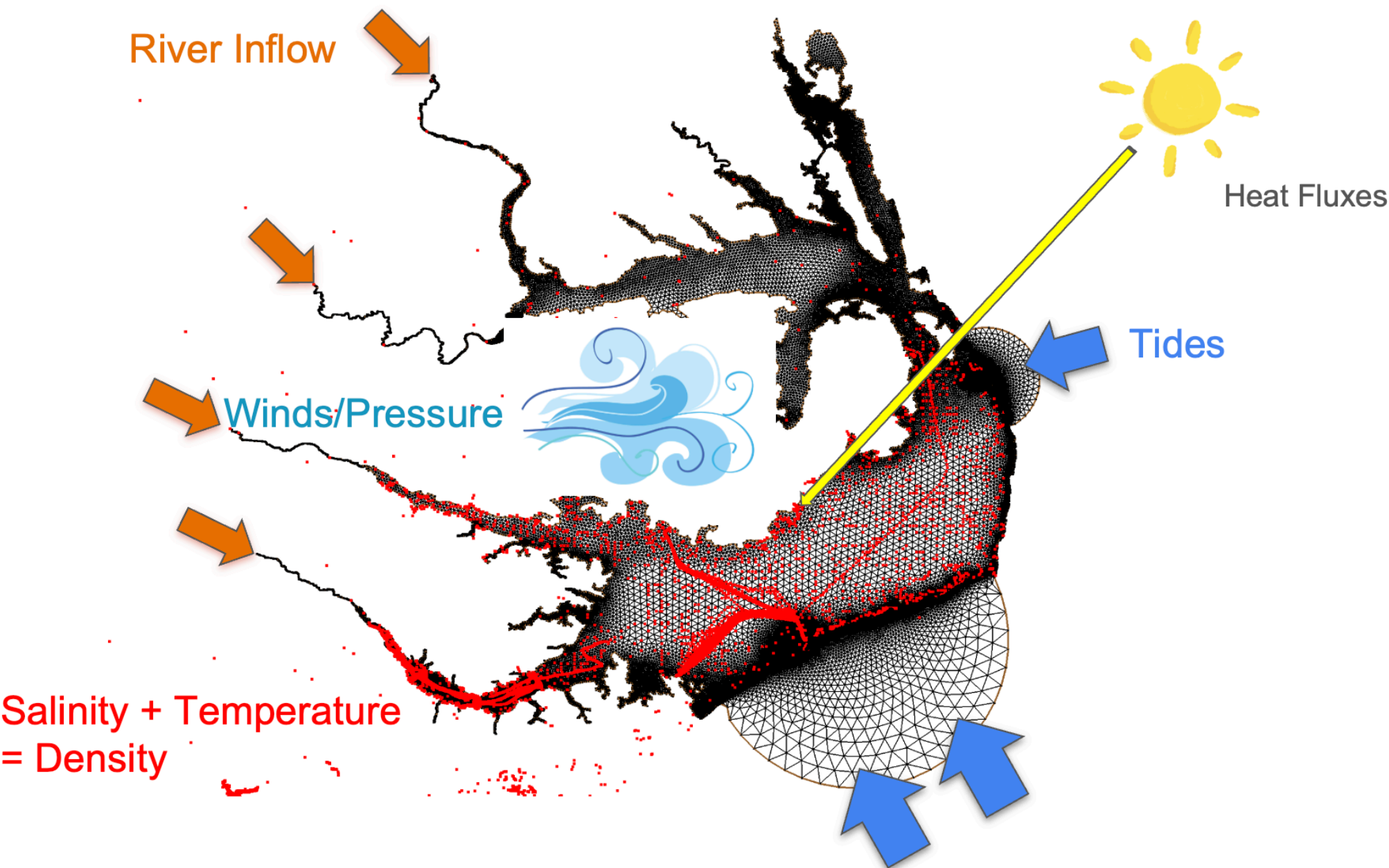
- Time-varying **USGS** discharge.
- Roanoke, Chowan, Tar–Pamlico, and Neuse Rivers.

Tides and Winds

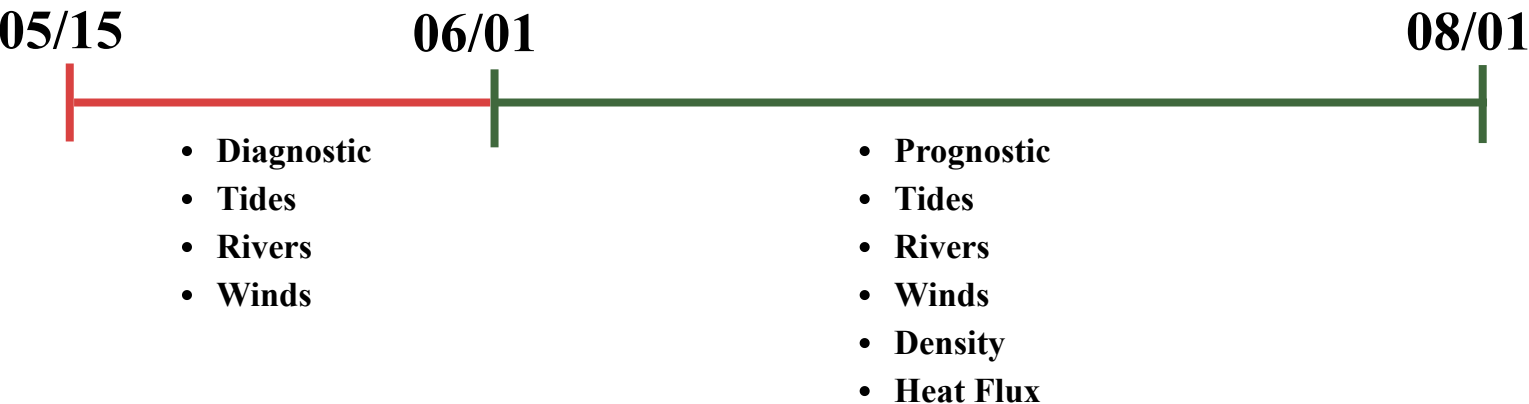
- Eight tidal constituents at open boundary.
- NAM winds and surface pressure

Heat Fluxes

- ERA5 sensible, latent, shortwave, and longwave heat fluxes



Timeline of simulation (2024)



Salinity and Temperature Initialization (SalWise)

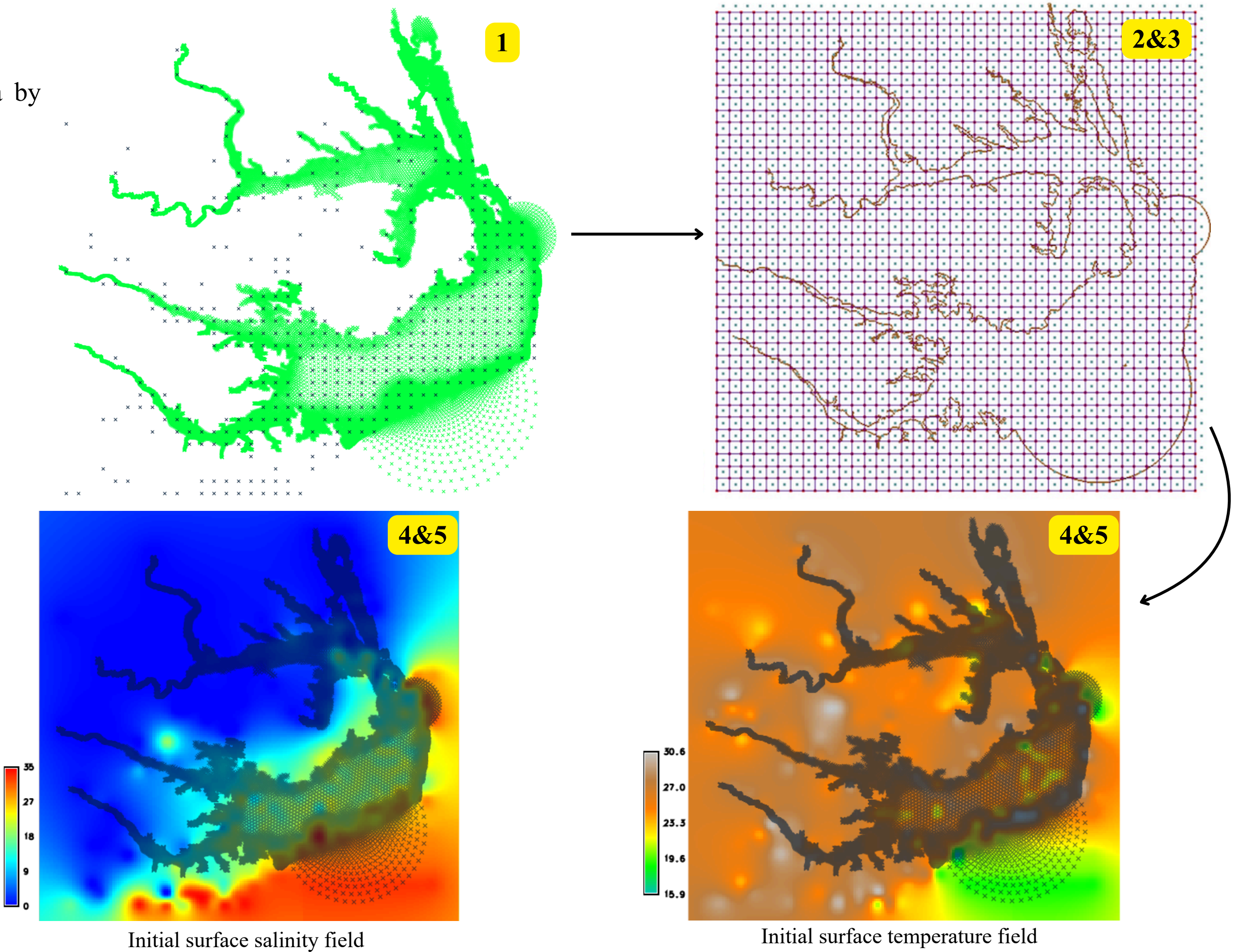
SalWise

- Developed at the University of North Carolina by Dr. Niels Lindquist and Dr. Stephen Fegley
- Over 1,980,000 records
- From 1945 - 2014

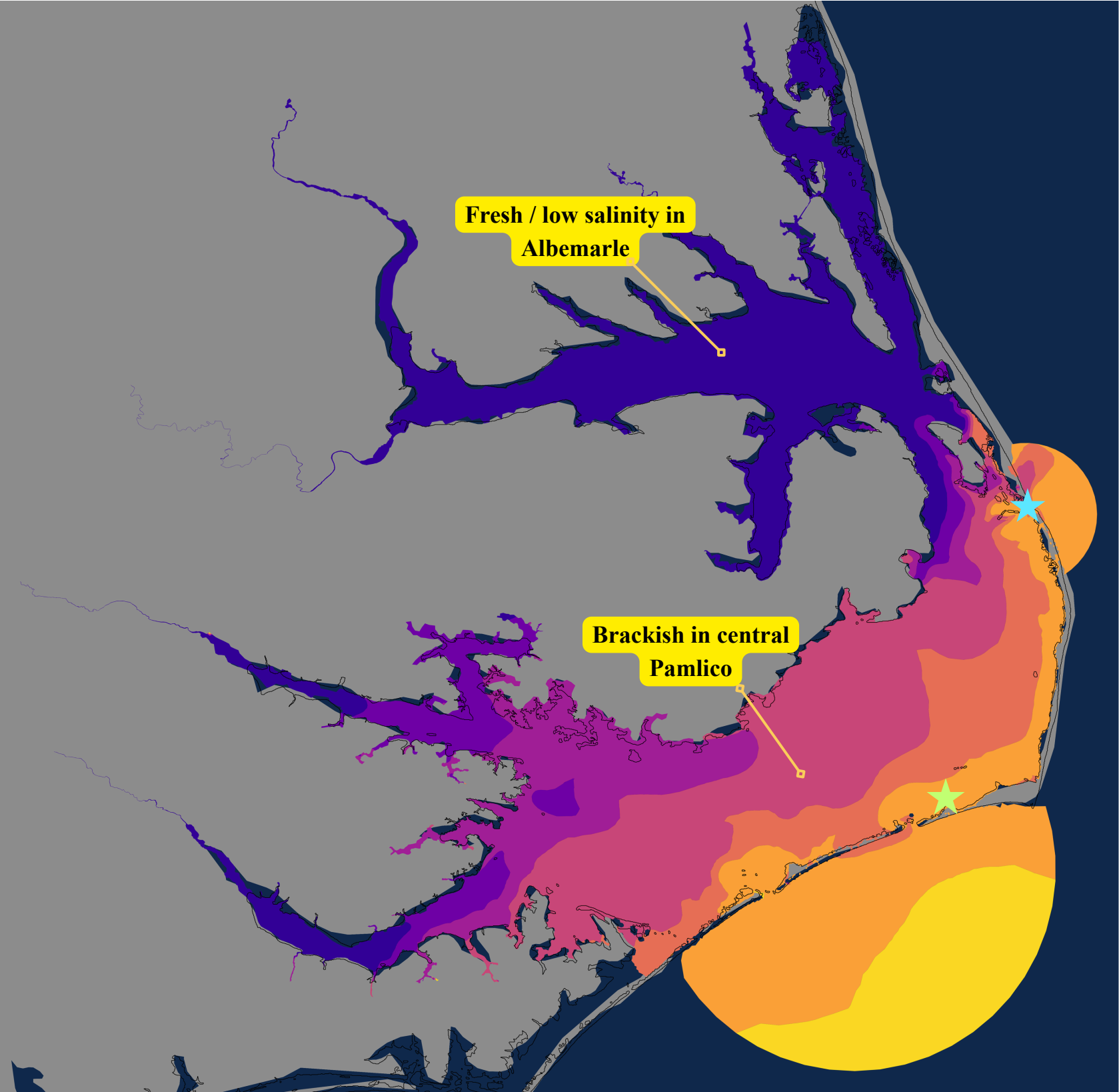
SalWise-to-ADCIRC Workflow

1. Select June SalWise records
2. Bin and average observations across PASS
3. Build continuous surfaces in GRASS GIS
4. Interpolate salinity and temperature to ADCIRC mesh nodes

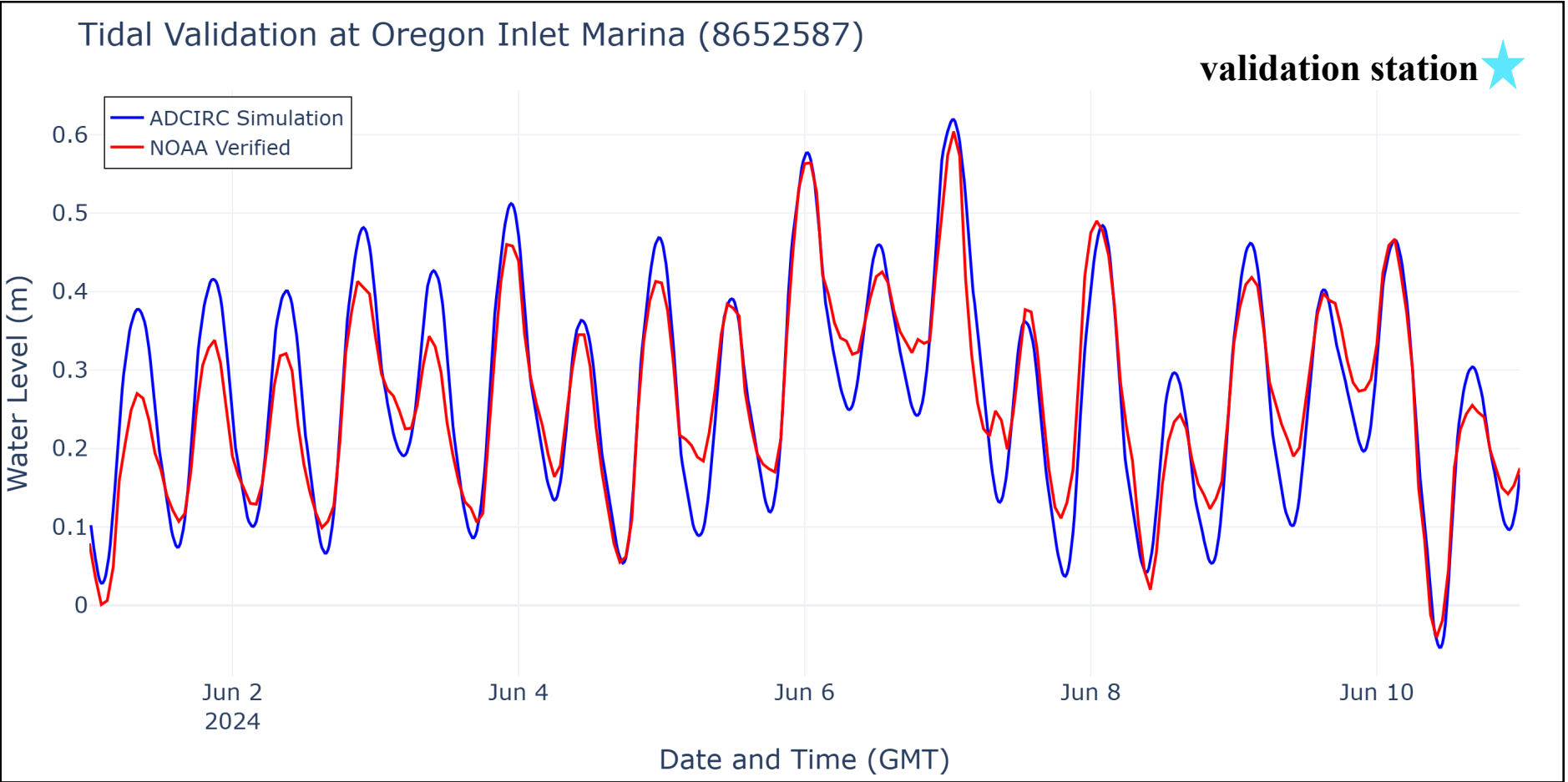
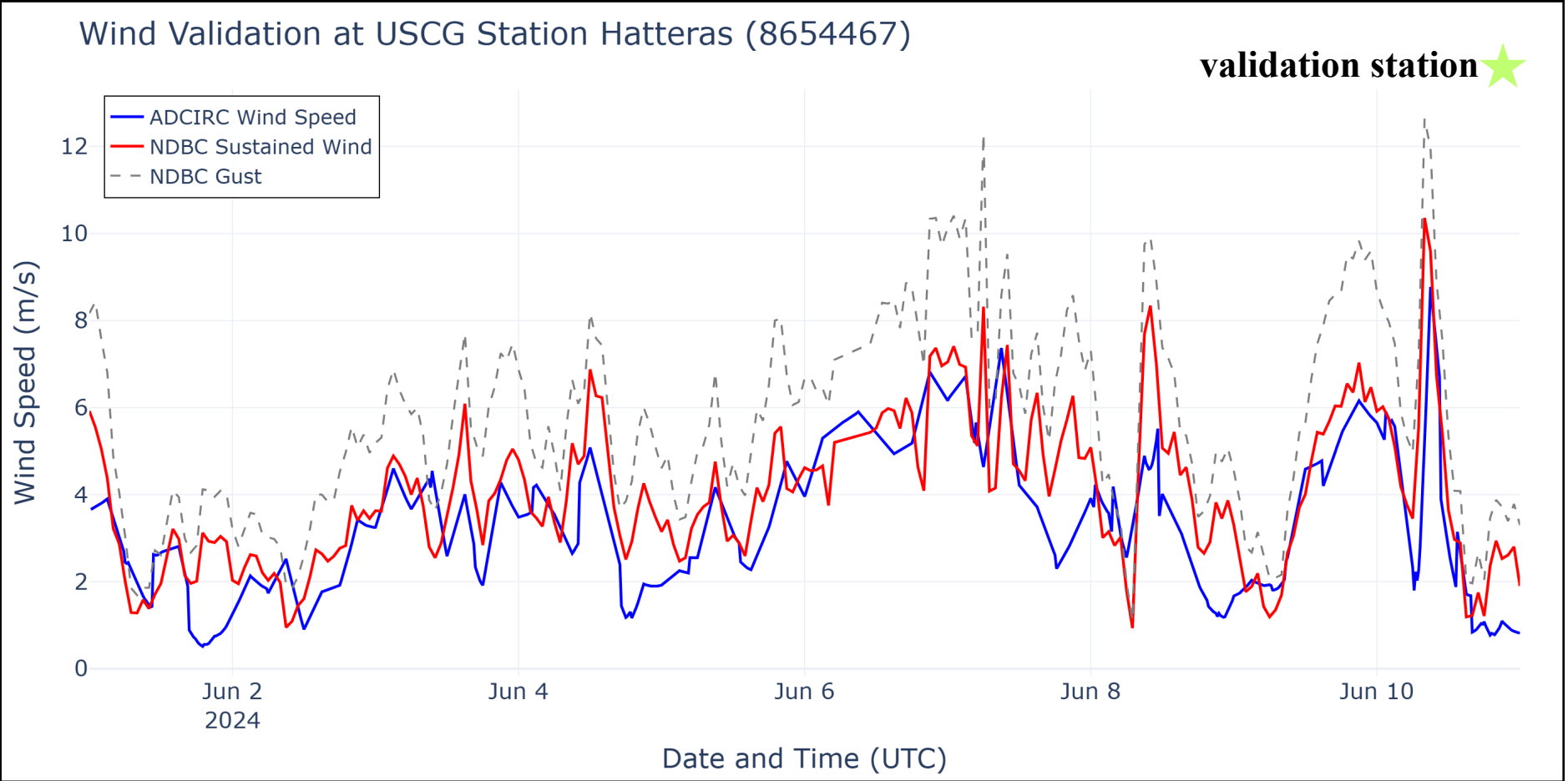
June climatology used to initialize summer 2024 salinity and temperature fields



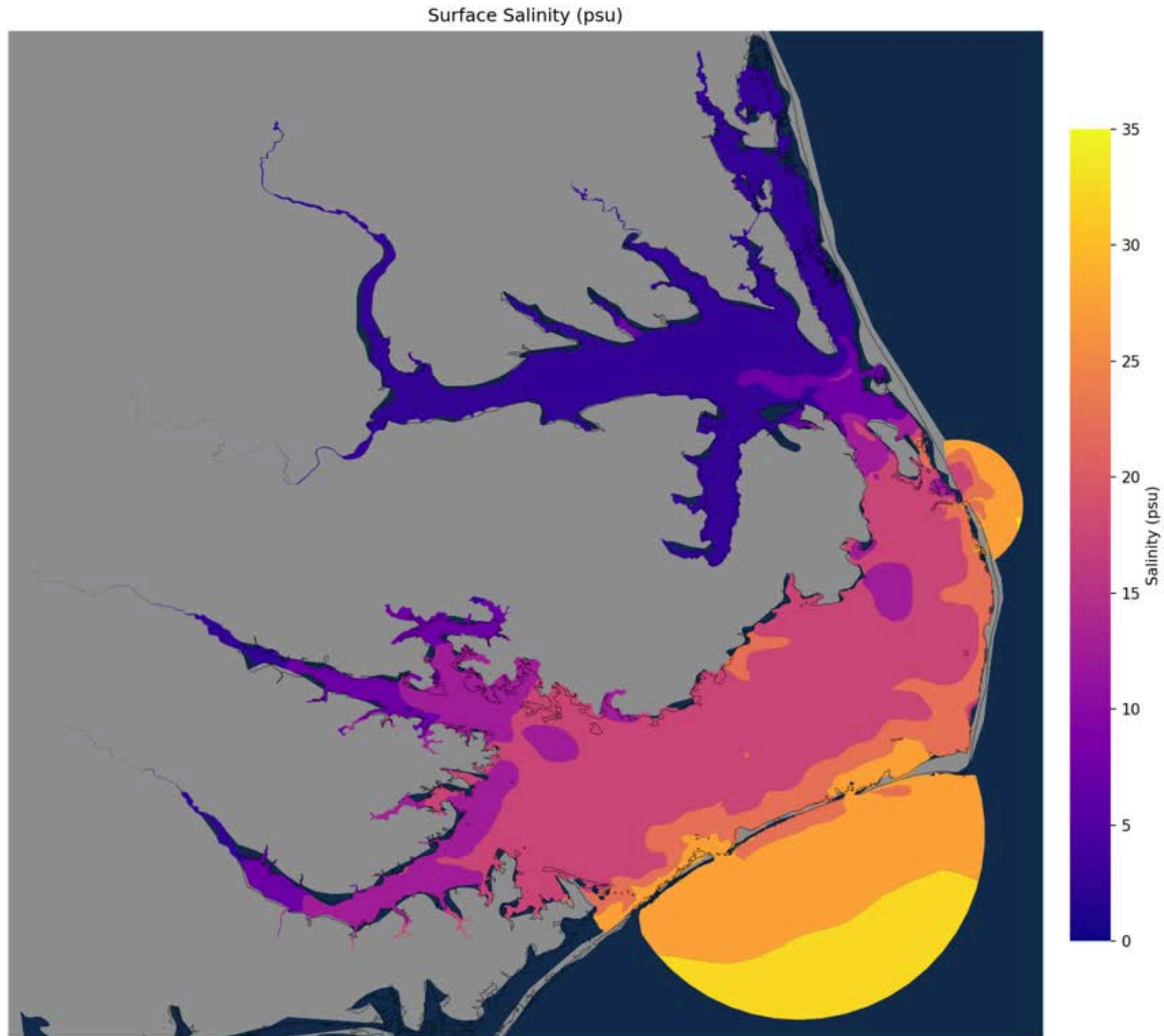
Results: Surface Salinity Structure and Physical Validation



The model captures the broad fresh-to-brackish-to-marine salinity gradient while reproducing major wind and tidal variability.



Results: Surface Salinity Evolution

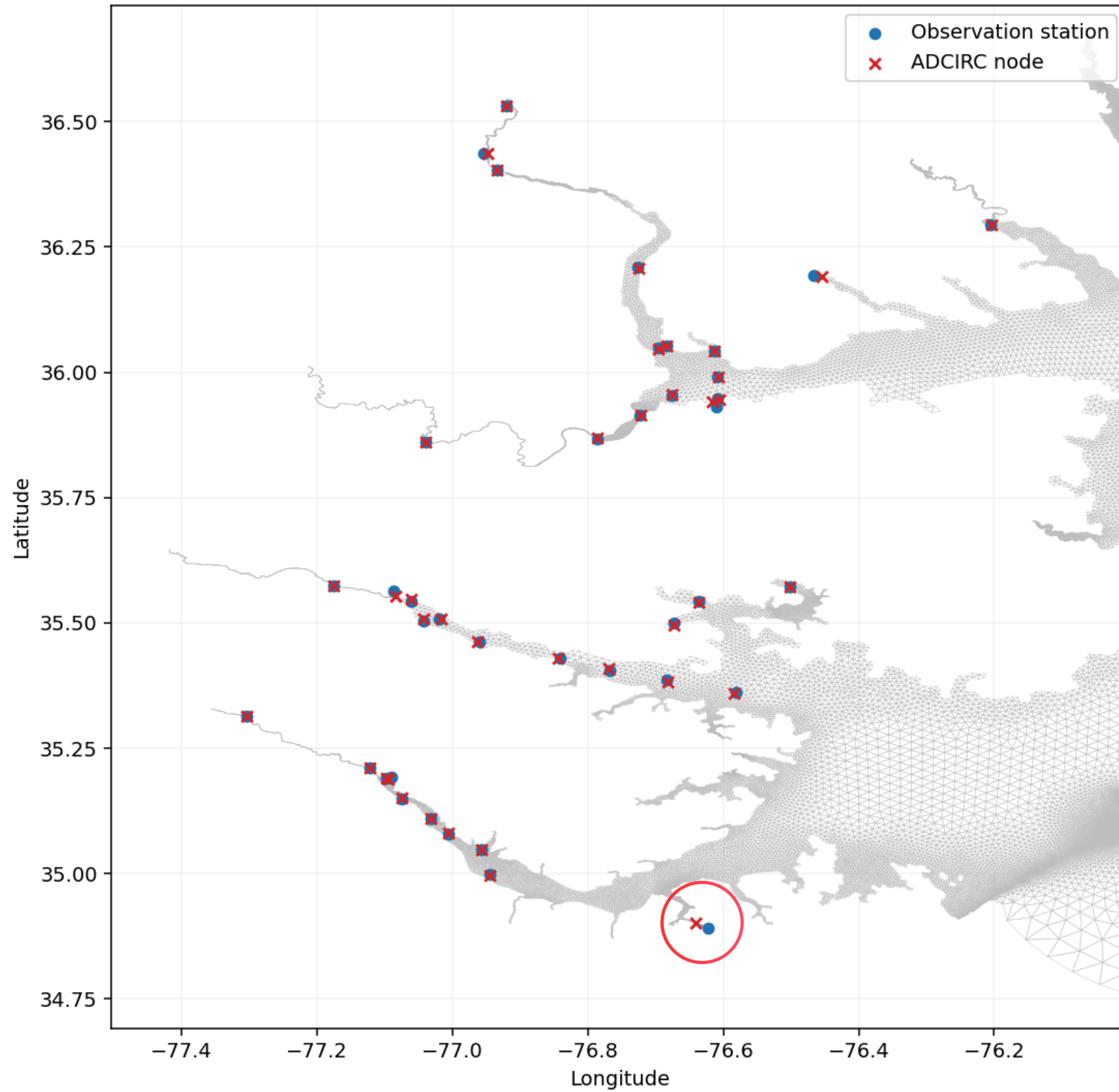


Broad salinity regimes evolve across PASS..

Results: Observational Comparison

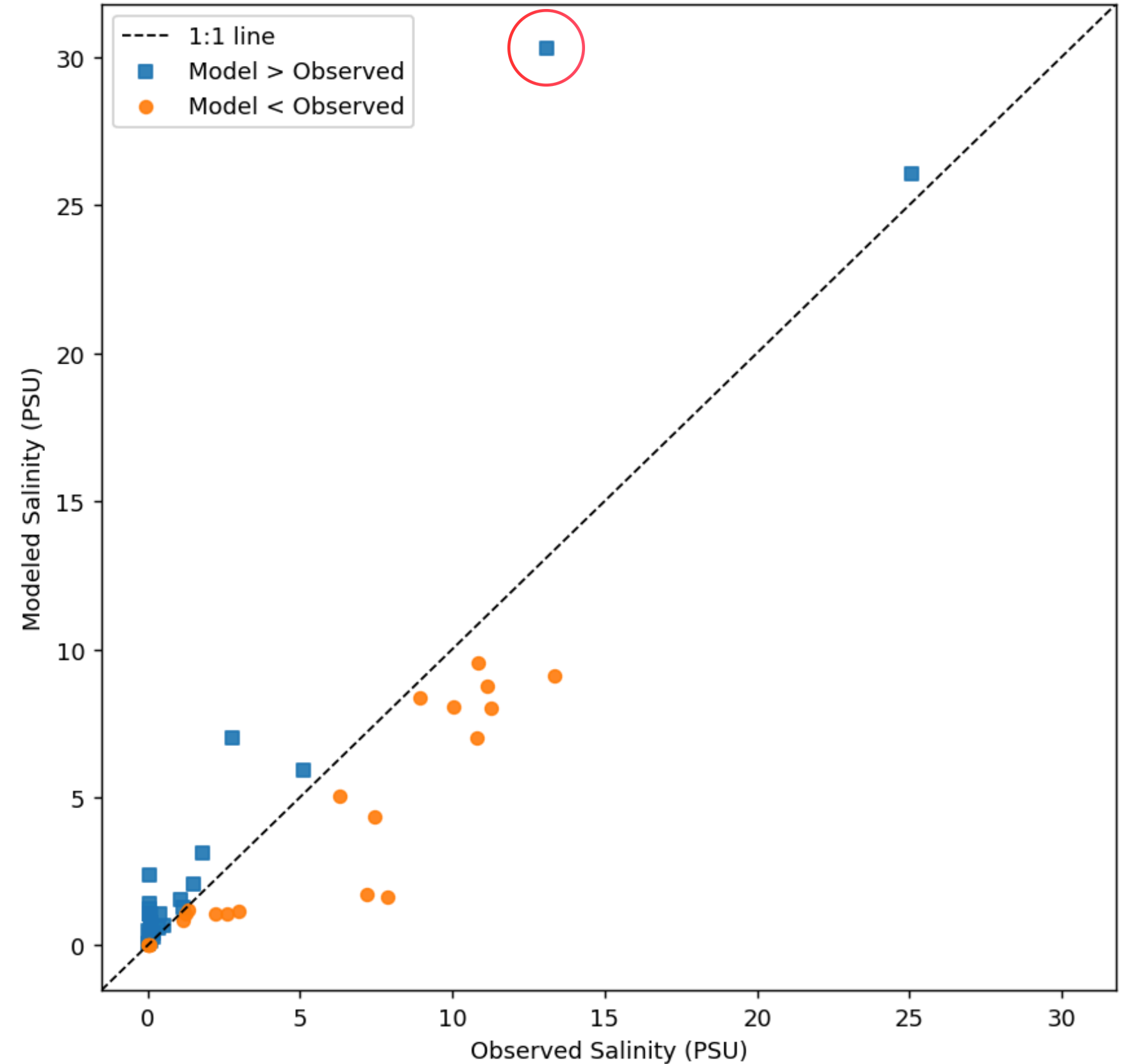
WQP stations matched to nearby ADCIRC nodes

Stations ≤ 2.0 km (Salinity only); N=39



Surface salinity: model vs observed

Salinity one-to-one (surface, ≤ 2.0 km, N=54)



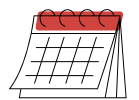
Point-by-point comparison is informative, but interpretation is limited by sparse and uneven observations.

Hydrodynamic Indicators of Potential HAB-Favorable Zones

SIMULATION CONTEXT



Model: ADCIRC 3D
baroclinic hindcast over PASS



Period: June 1–August 1, 2024
(density spin-up)

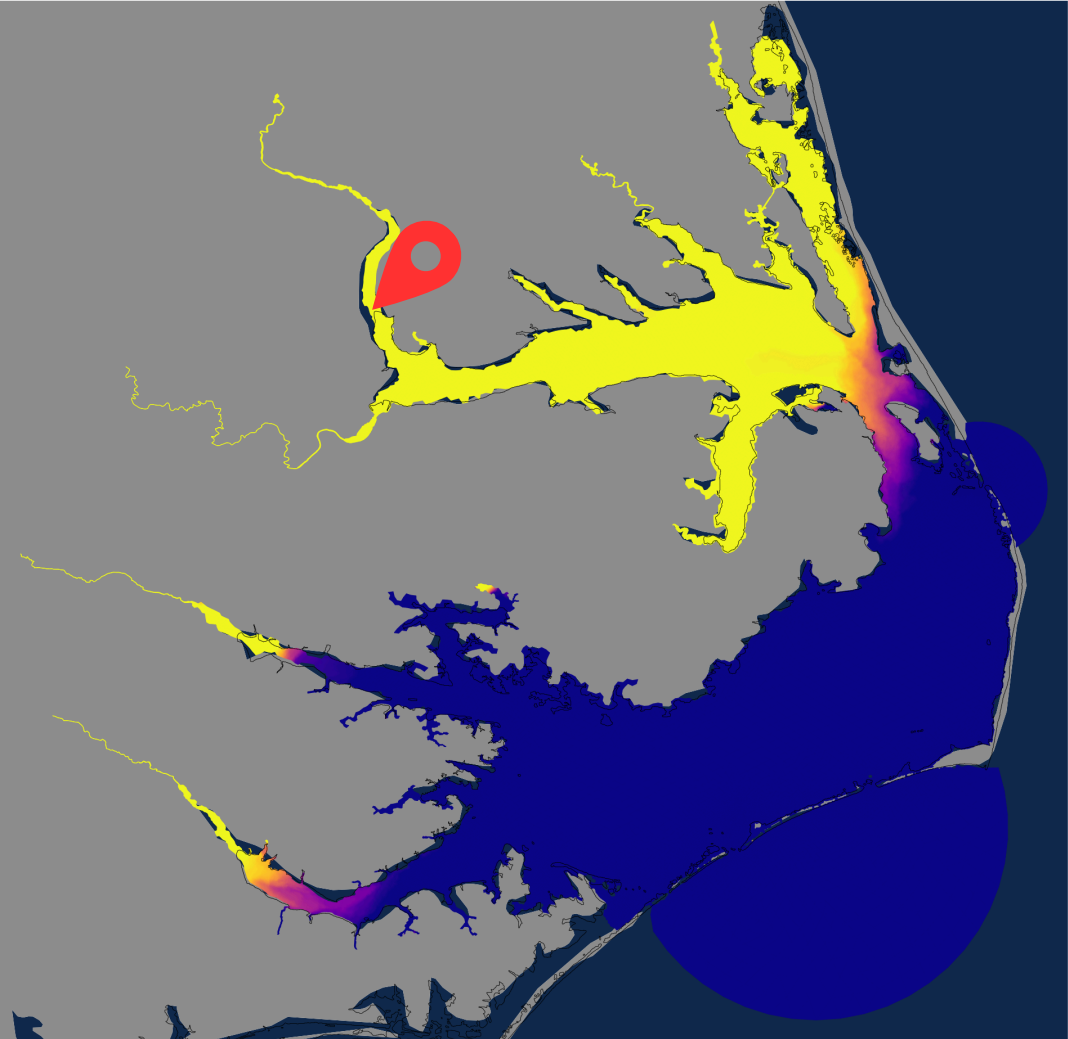


Forcing: tides, winds/pressure,
rivers, heat flux



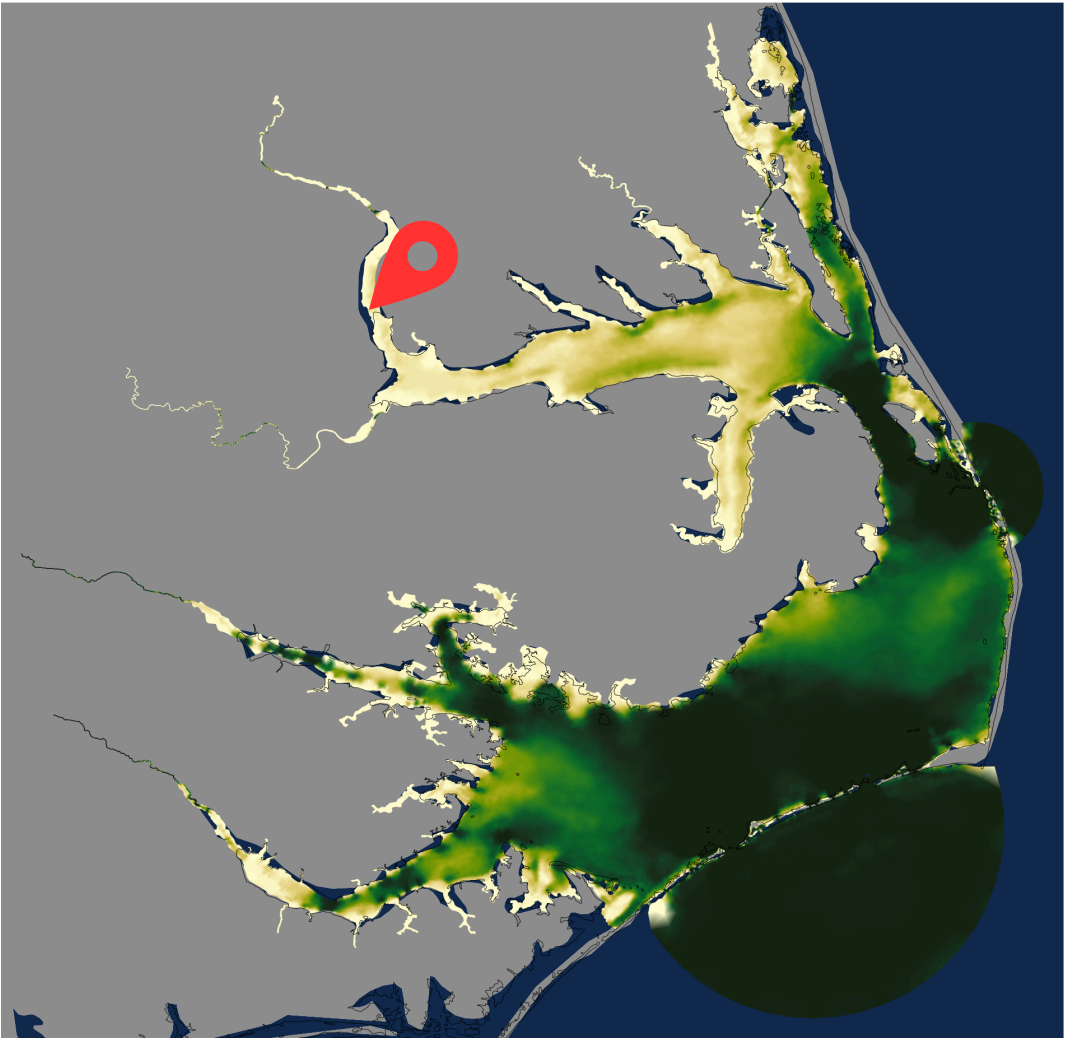
Diagnostics: surface salinity and
velocity persistence

Fraction of Valid Days in Fresh + Oligohaline Water (0–5 psu)



Persistent low-salinity habitat

Fraction of Valid Days with Daily-Mean Surface Speed < 0.05 m/s



Weak flushing / possible retention

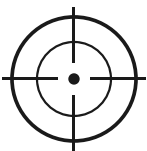
Interpretation



- Persistent 0–5 psu conditions identify low-salinity habitat relevant to cyanobacterial presence.



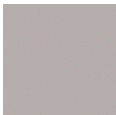
- Low daily mean surface speed suggests weak flushing and possible retention.



- Overlap in the Chowan/upper-estuarine region may favor bloom persistence or accumulation.



Focus: Chowan /
upper-estuarine
region



Land



Ocean

THURSDAY, AUGUST 22, 2024

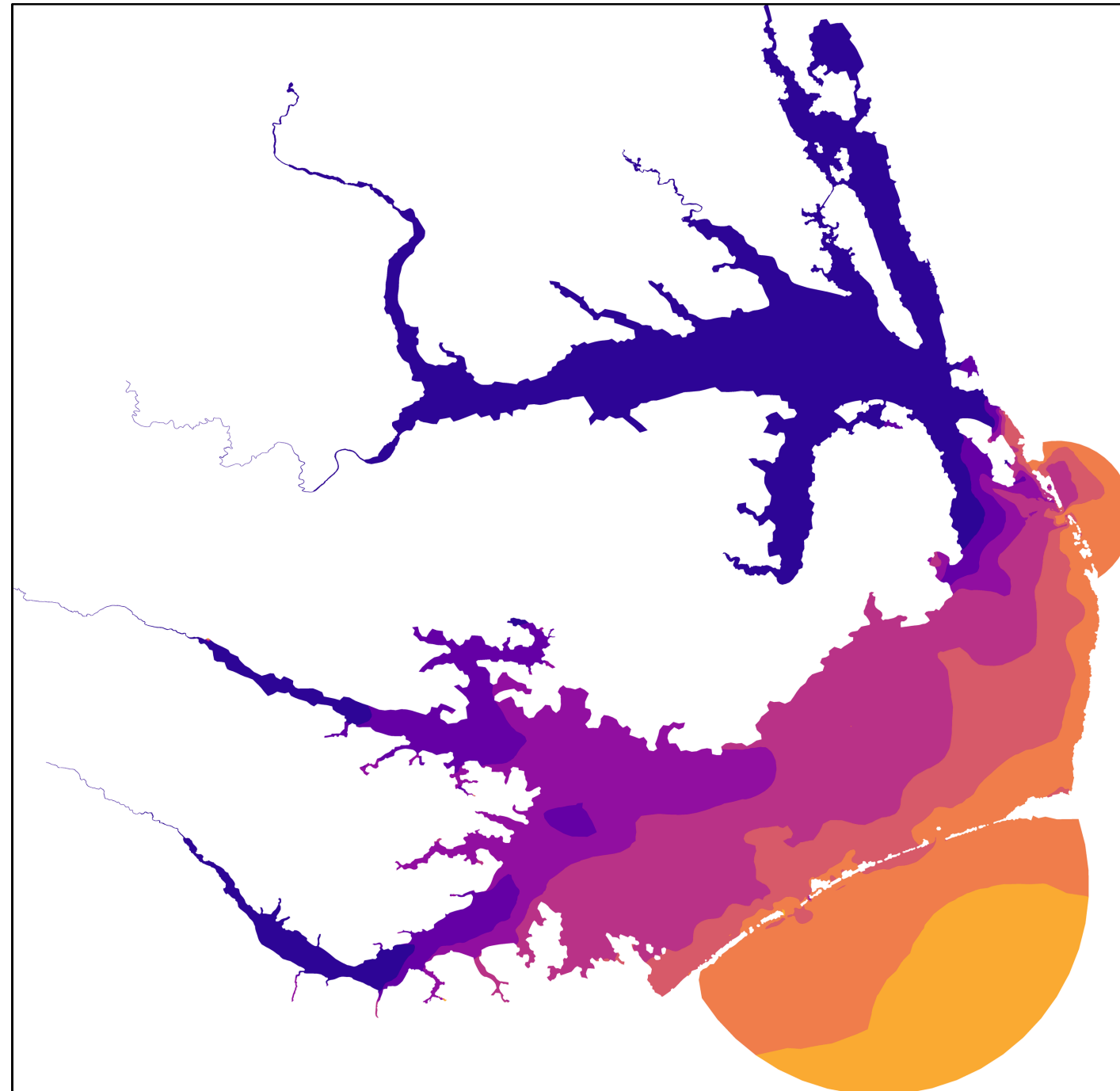
NCDEQ Division of Water Resources advises the public to avoid agal bloom in Chowan River

The North Carolina Department of Environmental Quality Division of Water Resources (DWR) advises the public to avoid contact with green or blue water in parts of the Chowan River in Chowan and Bertie counties due to an algal bloom that has lingered in the area since Aug. 16. The bloom has been observed from near the community of Rockyhock to below the U.S. 17 bridge over the Chowan River near Edenton.

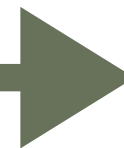
NCDEQ advisory for a Microcystis bloom in the Chowan
River, August 2024

Transition to Temperature: Future Work

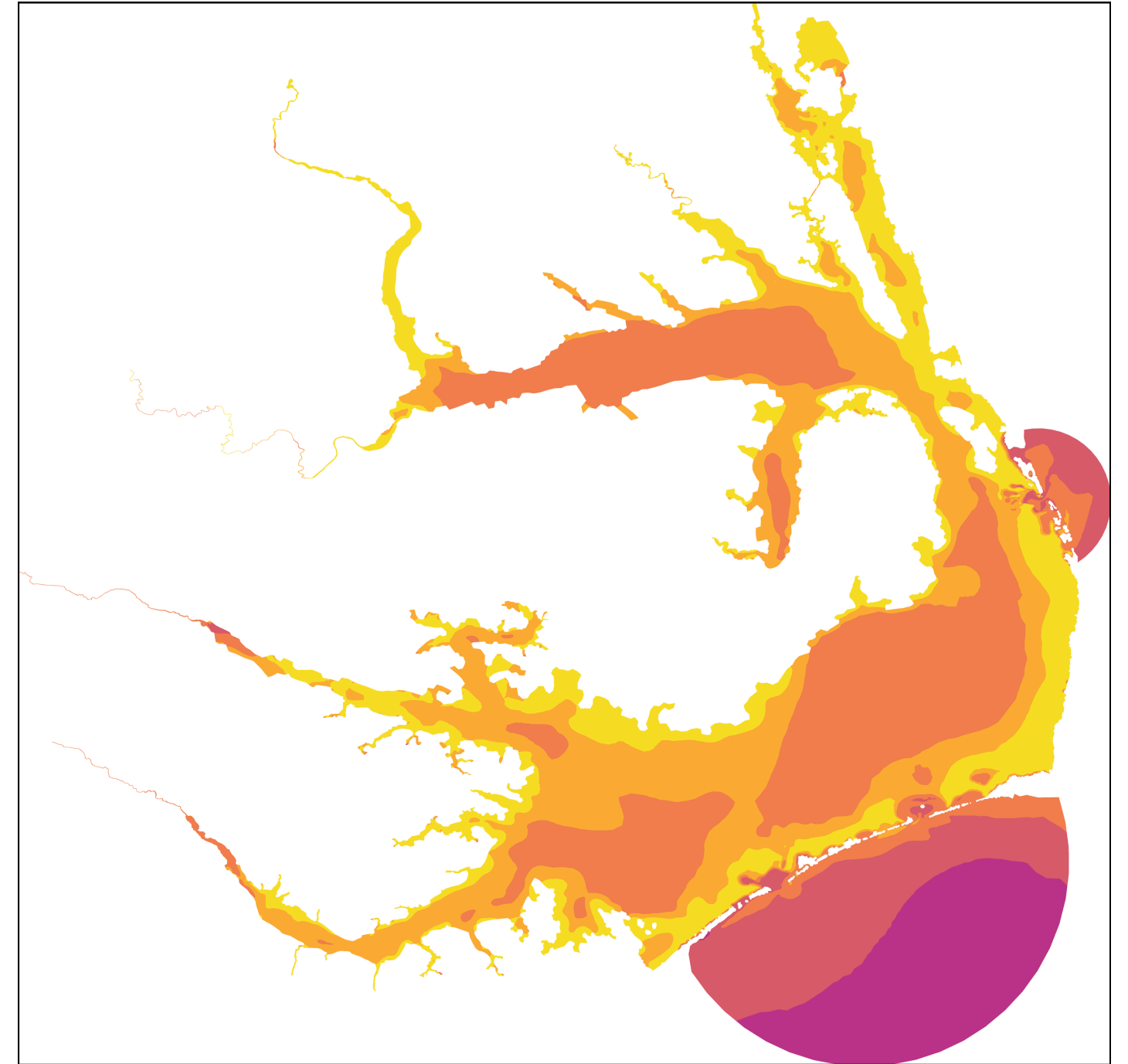
Salinity-focused results so far



Shift in focus



Next: surface temperature response



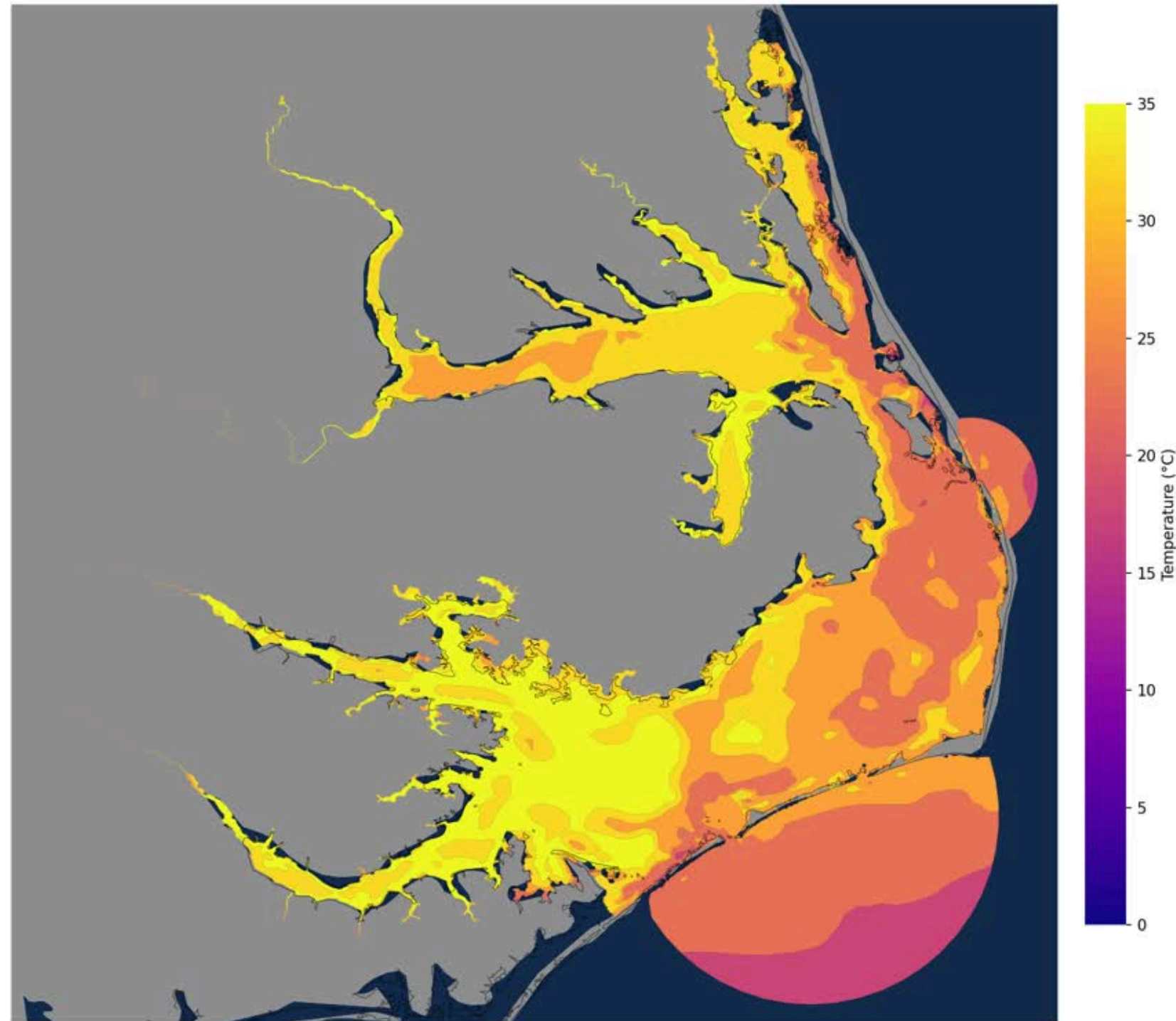
- Salinity structure and weak-flushing regions have been examined
- Temperature affects density, stratification, and HAB-relevant conditions
- Temperature evaluation remains ongoing / future work.

We now shift from salinity-focused results to ongoing temperature-focused model evaluation.

Surface Temperature Response Under Two Mixing Configurations

Depth-dependent NTVMIN

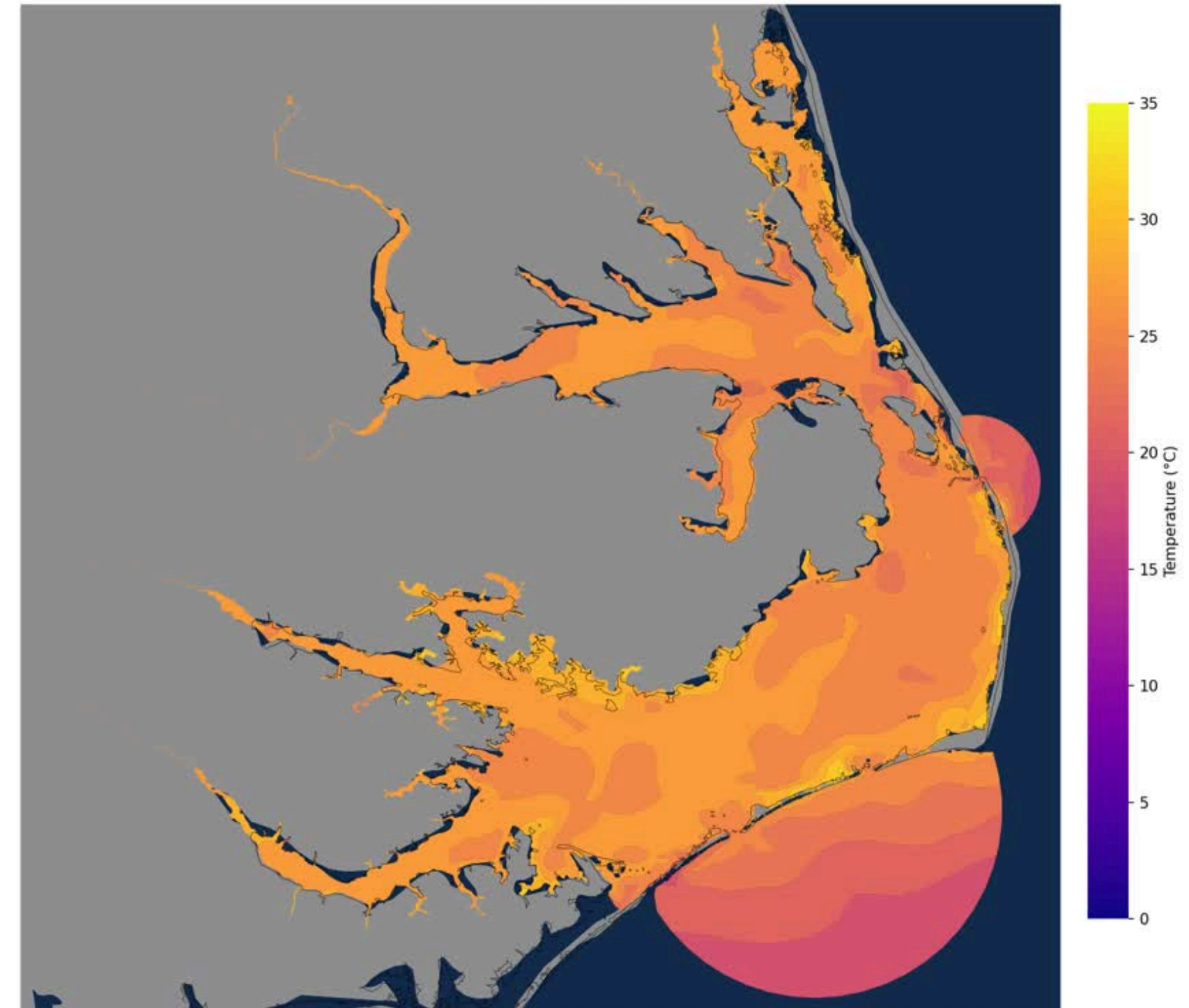
Surface Temperature (°C)



- Reduced artificial mixing
- Stronger stratification
- Stronger surface temperature response.

NTVMIN = EVMIN

Surface Temperature (°C)

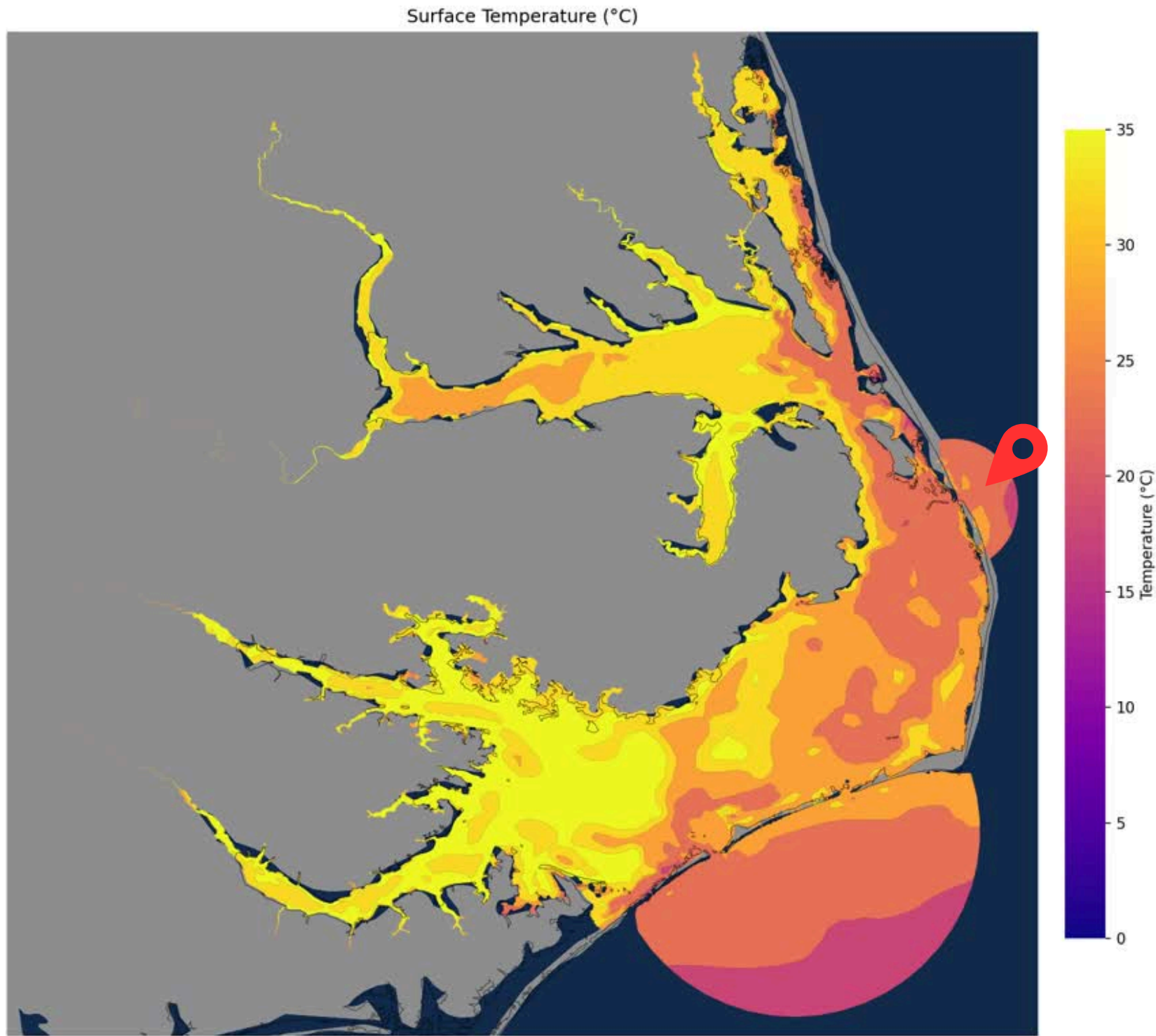


- Strong vertical mixing
- Weak surface heating/cooling response
- Nearly uniform water column.

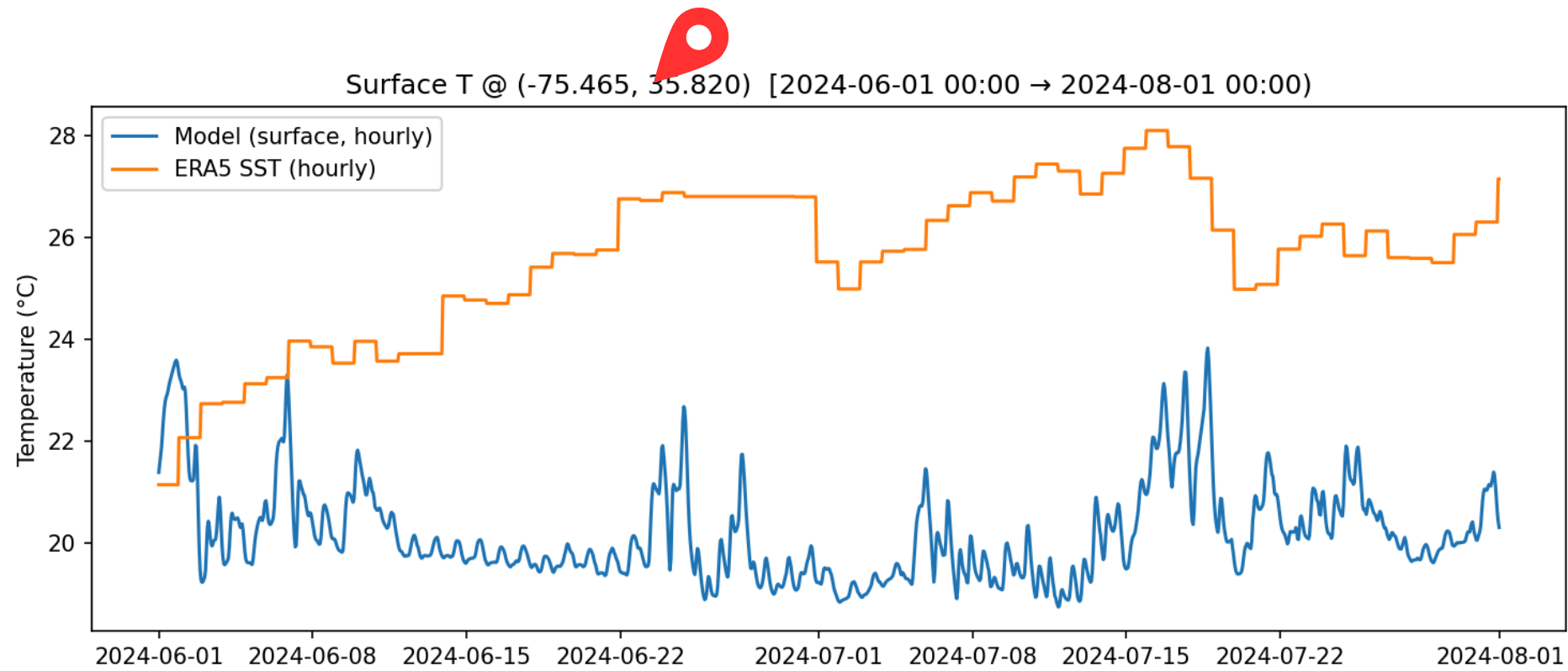
Adjusting vertical diffusivity explains model sensitivity, but it does not fully resolve the surface-temperature problem.

Heat-Flux Problem in the Current Workflow

Current ADCIRC setup uses ERA5 heat fluxes directly



Surface temperature evolution suggests physically questionable spatial heating/cooling behavior.



Model surface temperature vs. ERA5 SST

Key findings

- Model surface temperature exhibits large short-term oscillations
- Daily temperature swings appear stronger than expected
- The expected summer warming trend is much weaker than in ERA5 SST
- These behaviors suggest that the present heat-flux treatment may be contributing to the surface-temperature response.

Motivation: Revisit surface heat-flux implementation using the COARE bulk algorithm.

COARE Bulk Algorithm: Why It Matters and Python Testing

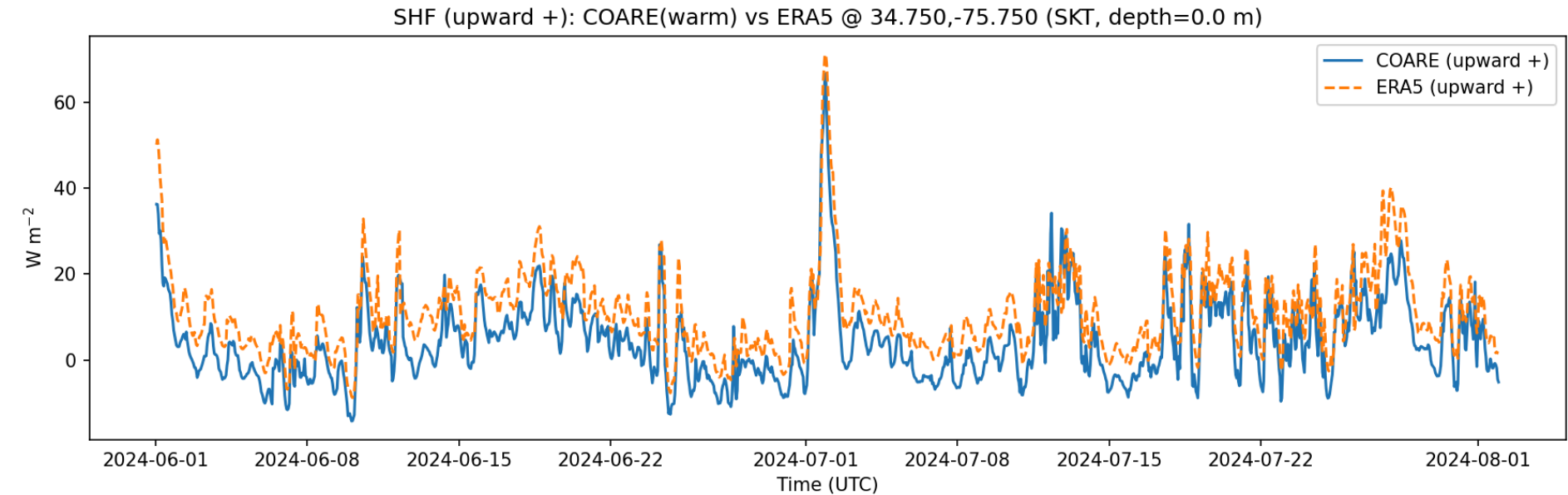
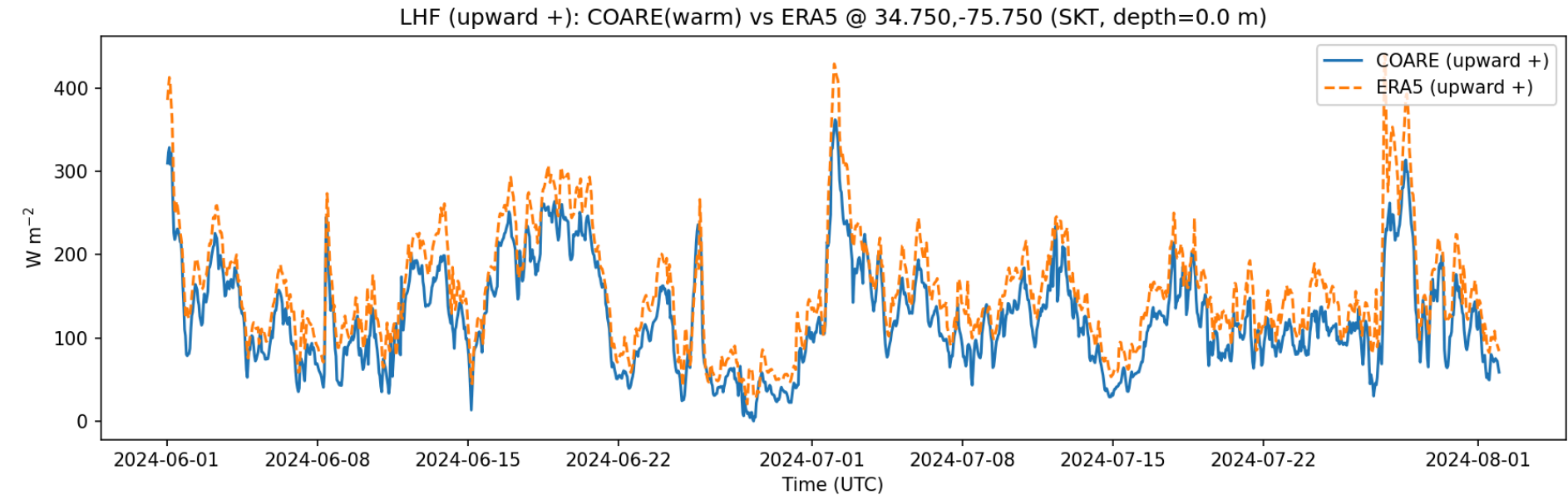
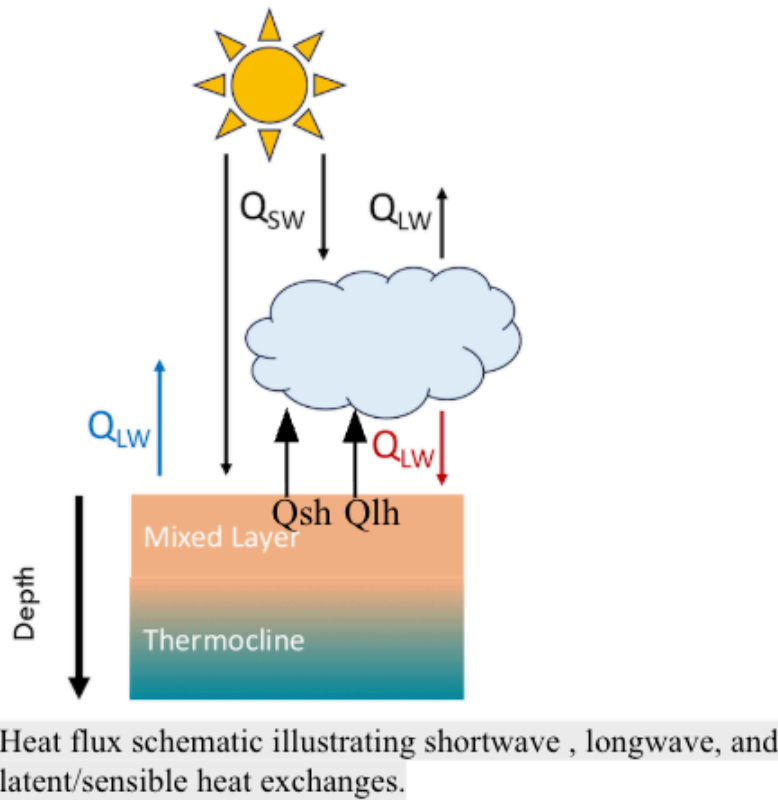
Why COARE?

- ERA5 latent/sensible heat fluxes are computed using ERA5 SST
- ADCIRC develops its own evolving SST on the model grid
- Prescribed fluxes do not adjust when model SST becomes too warm or too cold

COARE bulk approach

- Uses wind, air temperature, humidity, pressure, and SST
- Recomputes turbulent heat fluxes from the local air–sea state
- Creates a feedback loop: if model SST changes, latent/sensible heat fluxes adjust

$$Q = Q_{sw} + Q_{lw} + Q_{sh} + Q_{lh}$$

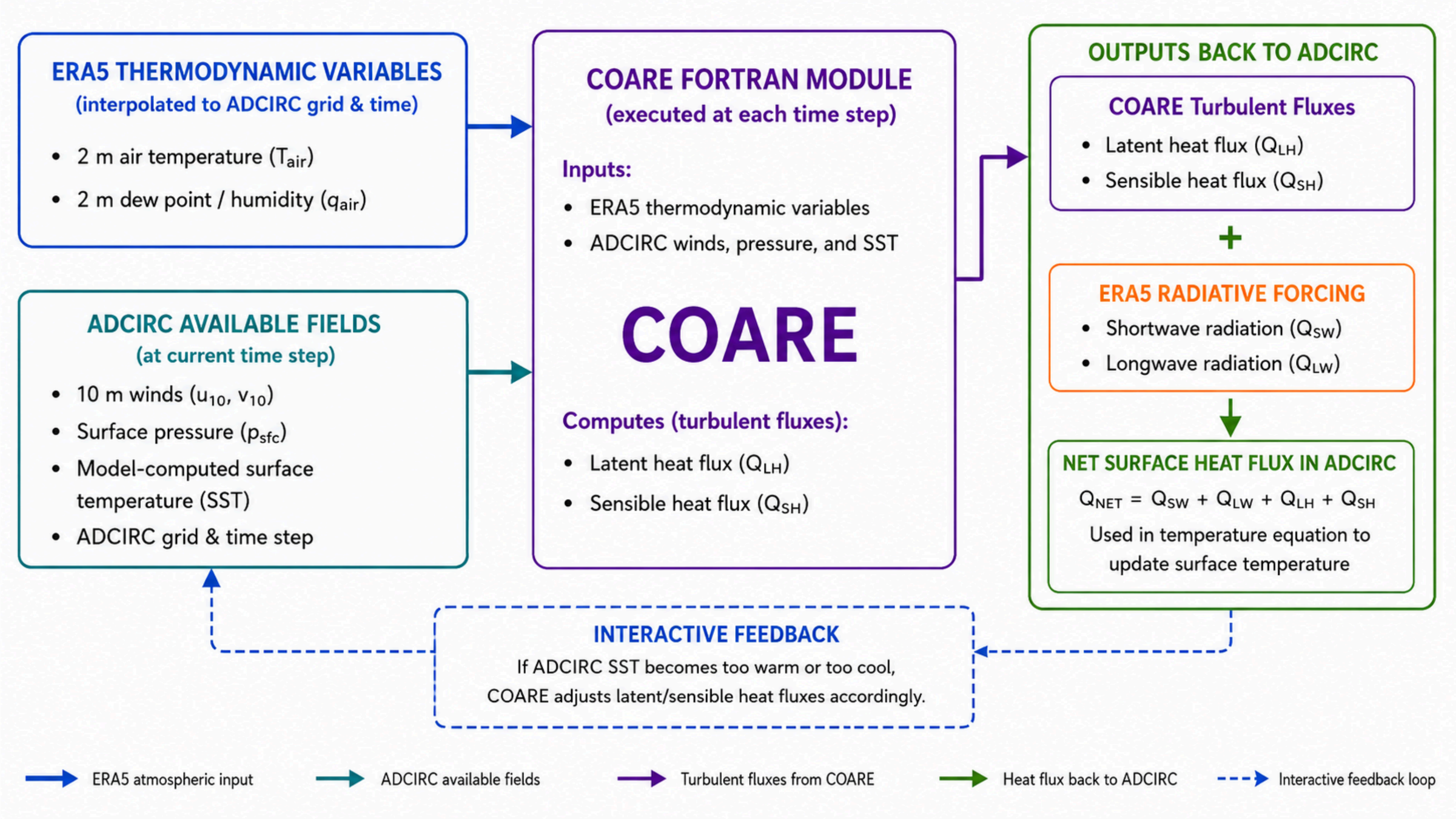


Python test

ERA5 winds + air temperature + dew point/humidity + pressure + ERA5 SST
→ Python COARE
→ latent and sensible heat fluxes
→ compare with ERA5 latent/sensible heat fluxes

Takeaway: Python testing checks COARE behavior before implementing the Fortran version inside ADCIRC.

COARE Bulk Algorithm: ADCIRC Implementation Plan



ADCIRC 3D Code Fixes / Community Contribution

Fix 3D baroclinic hotstart, I/O, and scalar diffusivity handling #509

View status

Code

Open

Thesigmaprogrammer wants to merge 3 commits into `adcirc:main` from `Thesigmaprogrammer:Thesigmaprogrammer/more-fix-for-3d-adcirc-code`

Conversation 2

Commits 3

Checks 1

Files changed 8

+289 -99

Thesigmaprogrammer commented 5 days ago

Description

This PR includes fixes for 3D baroclinic ADCIRC workflows, especially for temperature/salinity simulations, hotstart handling, and 3D NetCDF input/output consistency.

The main updates are to 3D baroclinic startup and boundary condition handling, 3D hotstart logic, 3D NetCDF input/output handling, 3D related input/output controls, bottom friction coefficient protection, and depth dependent minimum scalar diffusivity for 3D temperature/scalar transport.

Two changes intentionally affect 3D model behavior. The first is the 3D bottom-friction TK clamp in `nodalattr.F`, which bounds the bottom friction related coefficient relative to the bottom layer velocity magnitude. The second is the restored depth dependent minimum scalar diffusivity in `vsmy.F`, which restores the intended 3D scalar/temperature workflow behavior. These changes were isolated during testing and are expected parts of the corrected 3D workflow.

Reviewers

No reviews

Still in progress? [Convert to draft](#)

Assignees

No one assigned

Labels

None yet

Projects

None yet

```
9a0afe42 Fix multiple 3D baroclinic model routines
043ddd18 Restore depth-dependent scalar diffusivity for 3D temperature
882a2118 (HEAD -> Thesigmaprogrammer/more-fix-for-3d-adcirc-code, origin/Thesigmaprogrammer/more-fix-for-3d-adcirc-code) Avoid GLOBAL_3DVS dependency in nodalattr legacy build
src/cstart.F      | 9  ++++++--
src/hstart.F      | 72 ++++++-----
src/netcdfio.F90   | 105 ++++++-----
src/nodalattr.F    | 16 ++++++--
src/read_input.F   | 78 ++++++-----
src/timestep.F     | 8  +++++--
src/vsmy.F         | 42 ++++++-----
src/write_output.F | 58 ++++++-----
8 files changed, 289 insertions(+), 99 deletions(-)
```

These fixes strengthen the ADCIRC 3D framework needed for PASS simulations and move locally developed improvements closer to broader ADCIRC community use.

Code contribution

- PR #509 submitted to ADCIRC
- Branch: more-fix-for-3d-adcirc-code
- 3 commits, 8 source files modified
- Legacy build issue fixed in follow-up commit

What was fixed

- 3D hotstart handling
- 3D NetCDF salinity, temperature, and density output
- 3D baroclinic input/output controls
- Bottom-friction and vertical scalar diffusivity protections

Next Steps

Validation (Future work)

- Continue improving validation using DEQ/WQP observations, including salinity gradients and available stratification data.

Model Improvements

- Implement and test the Fortran COARE module inside ADCIRC.
- Replace constant ocean T/S forcing with time-varying NAOR boundary conditions.
- Continue developing the new PASS mesh for improved channels, rivers, inlets, and estuarine connections.

Application

- Use improved circulation fields for particle tracking, residence-time analysis, and HAB transport/risk interpretation.

Thank you!

