A Thirty-Year Retrospective Analysis of Chesapeake Bay Warming

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VIMS | William & Mary
Virginia Institute of Marine Science

NOAA

Acknowledgements

- BioCOM Lab
- Committee Members, Grace Chiu

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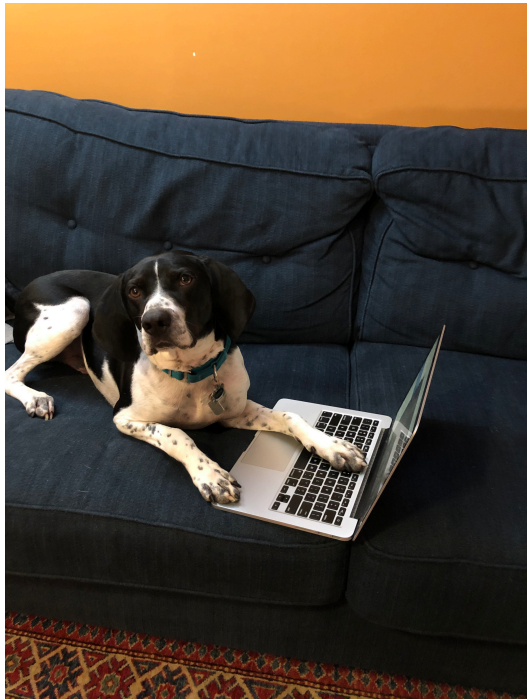
- K-9 intern

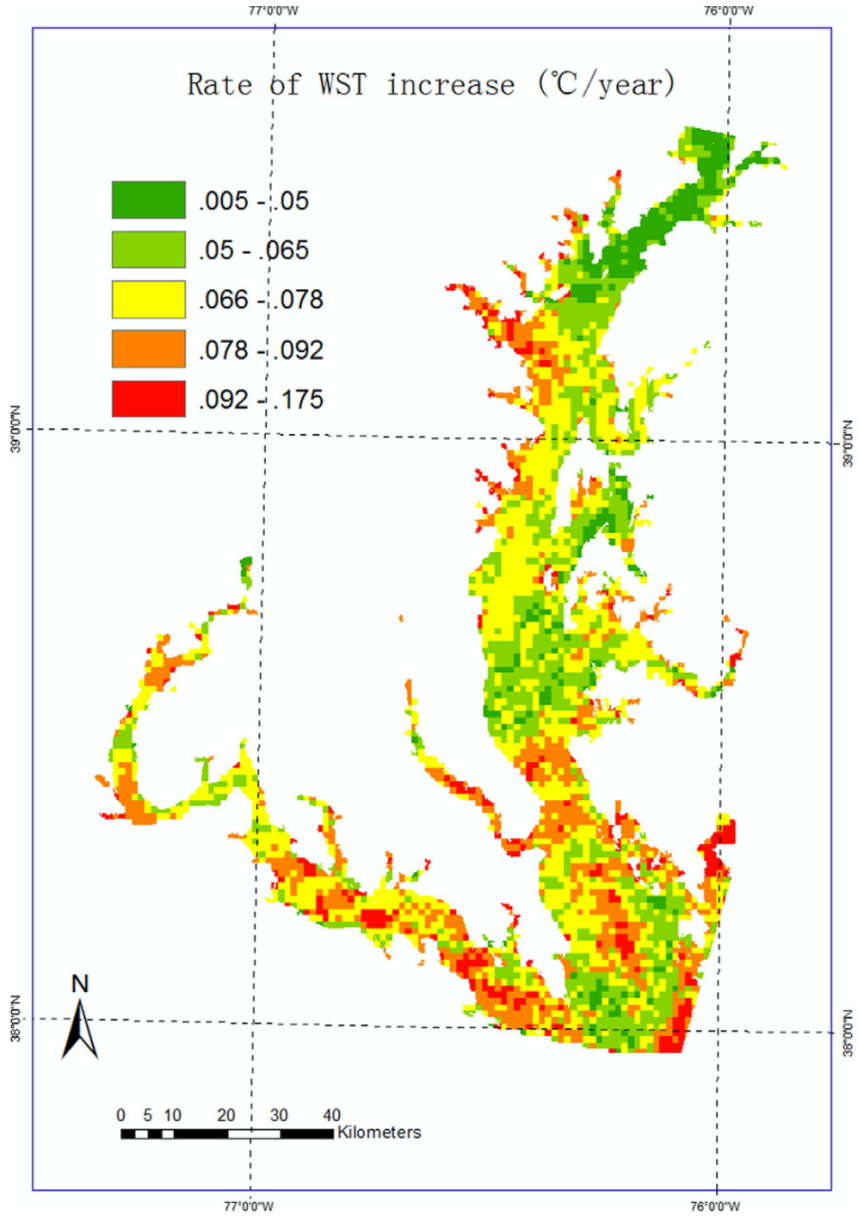


Background

Preston (2004) – average water temperature increase of "~0.8-1.1°C" from 1949-2002

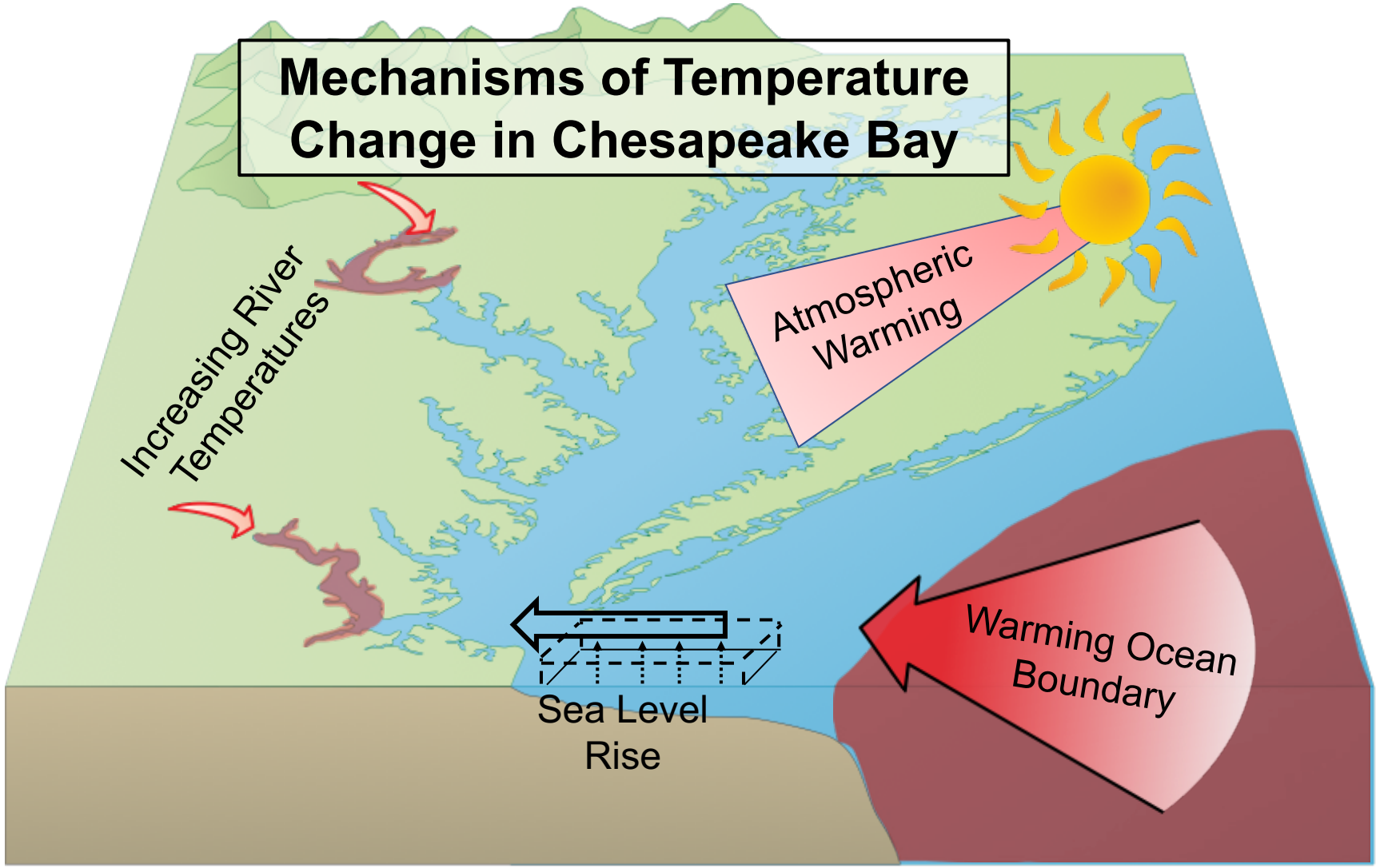
Ding and Elmore (2015) found increase in surface water temperature of ~0.4-2°C from 1984-2010

→ Irby et al. (2018) demonstrated that temperature is likely to be the greatest hypoxia stressor in the future



Ding and Elmore, 2015

How did the Chesapeake Bay warm so rapidly?



Research Objective

What are the relative magnitudes of mechanisms driving observed Chesapeake Bay warming?

ChesROMS-ECB Overview

Atmospheric Forcings

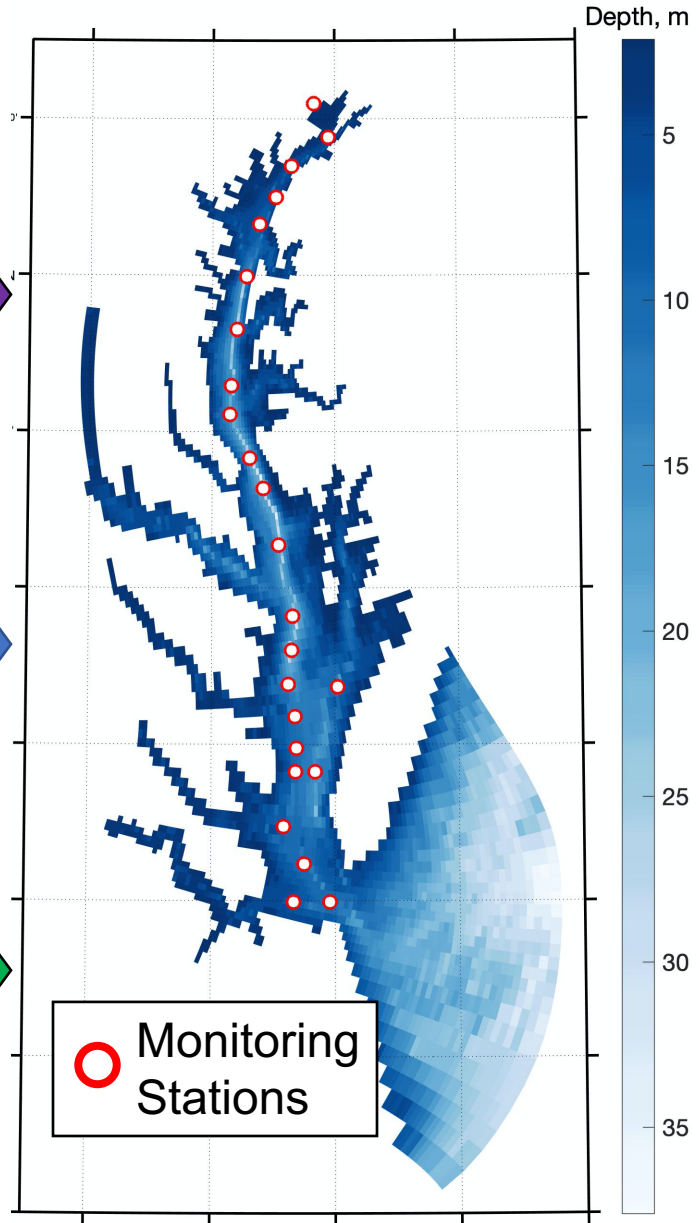
→ Hindcast weather data

Coastal Fluxes

→ Climatological data

Riverine Inputs

→ Phase 6 Watershed Model



Model Information

3-D model, 20 depth layers
Daily outputs
Run from 1985 - 2019

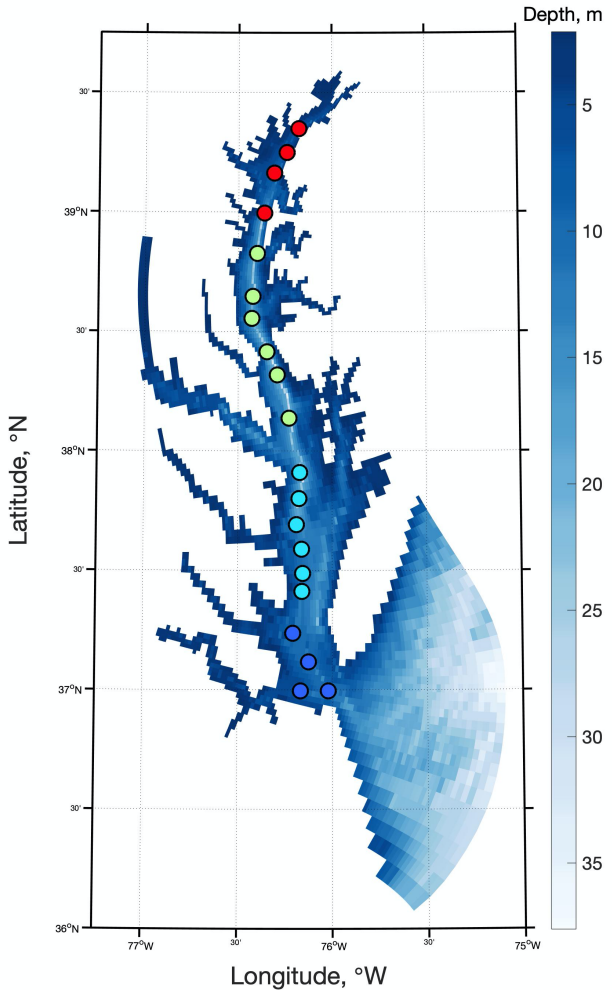
Model Outputs

Bay Temperatures

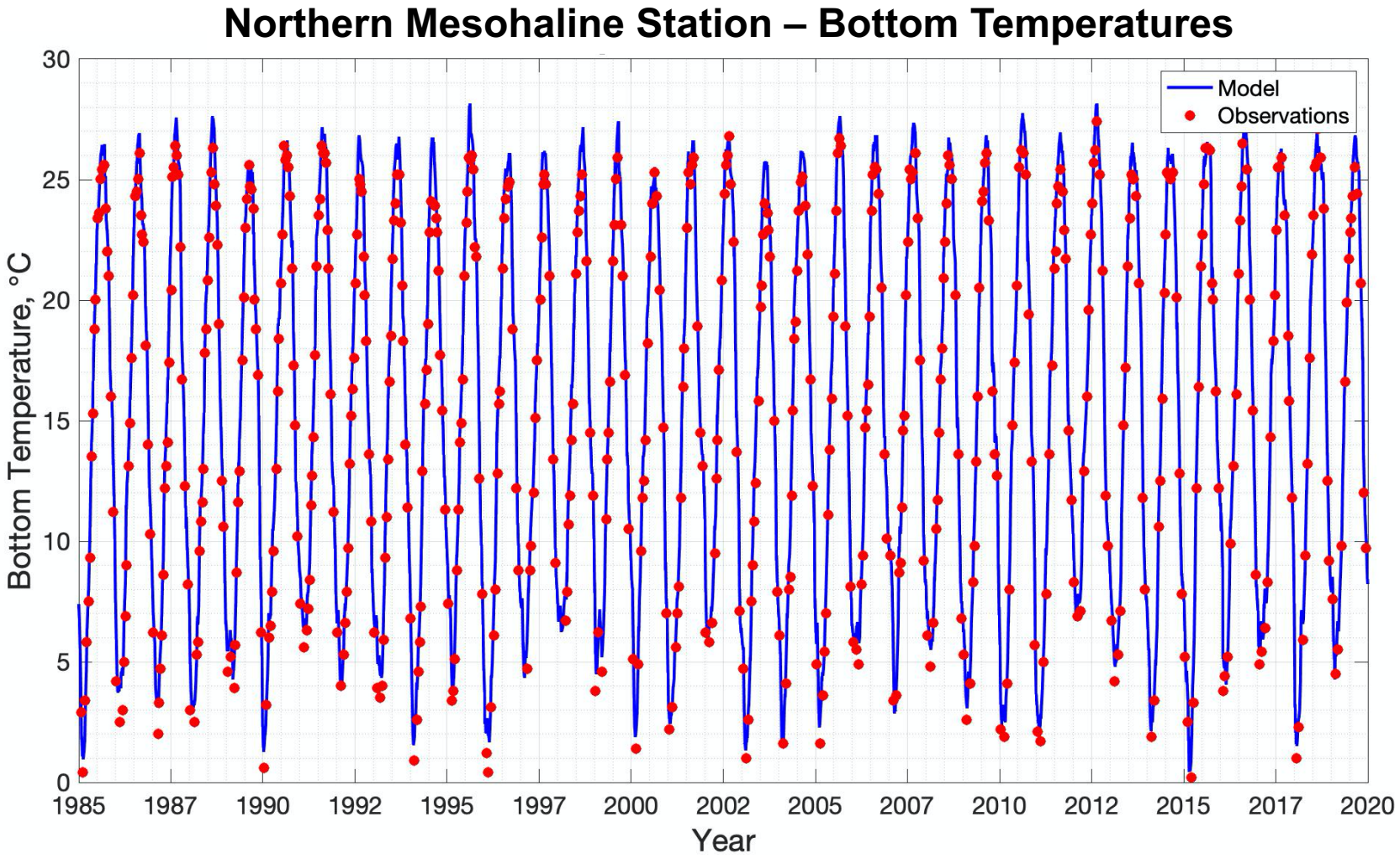
Hydrodynamics and Biogeochemistry

Do model temperatures match observations?

- Stations grouped into 4 regions:
  - Oligohaline, **OH**
  - Upper mesohaline, **MH-N**
  - Lower mesohaline, **MH-S**
  - Polyhaline, **PH**
- Monthly skill and trends calculated from available data,1985-2019

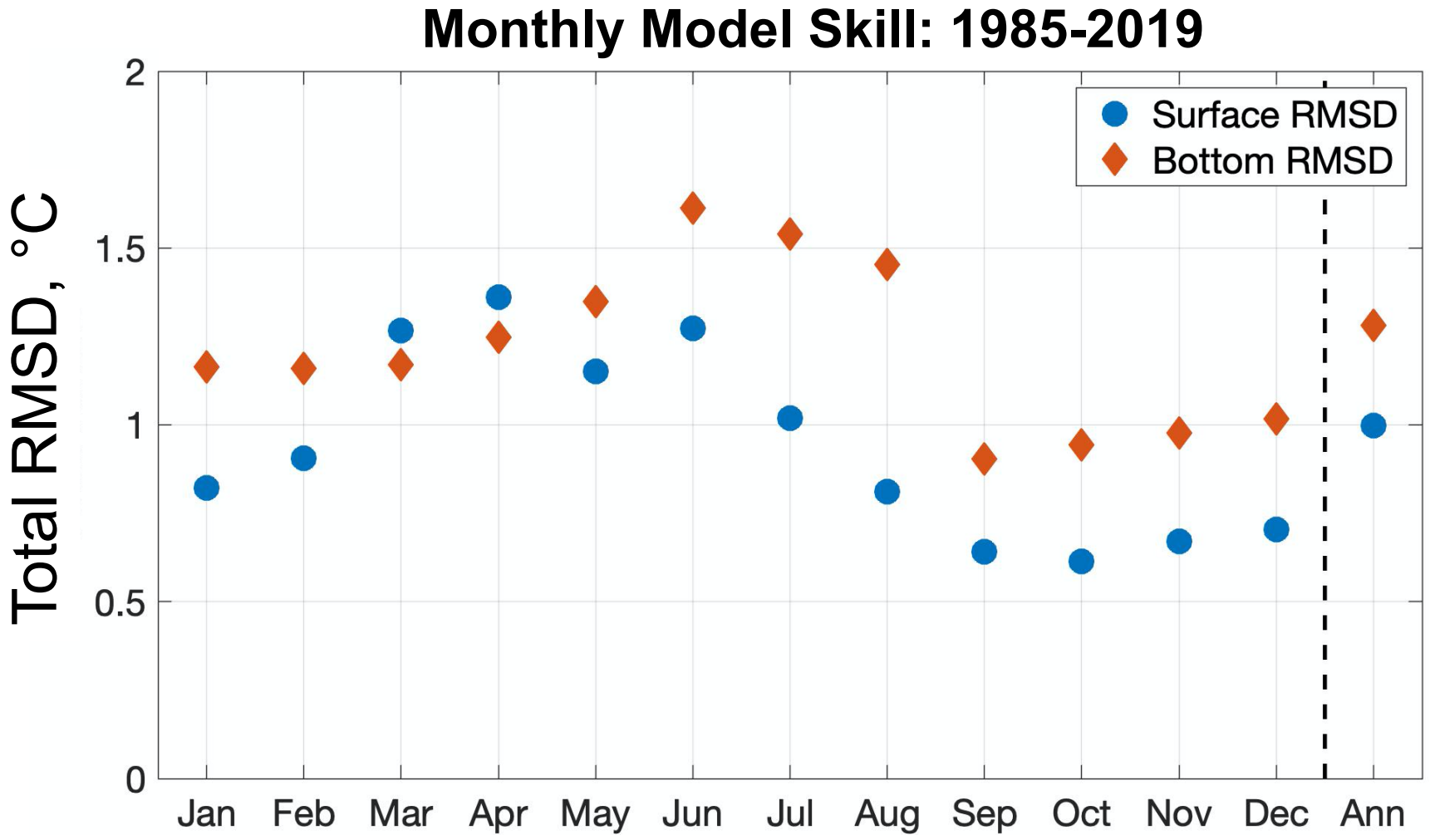


How well does the model match observed temperatures?



- Model may overpredict temperatures, but difficult to quantitatively assess

How well does the model match observed temperatures?

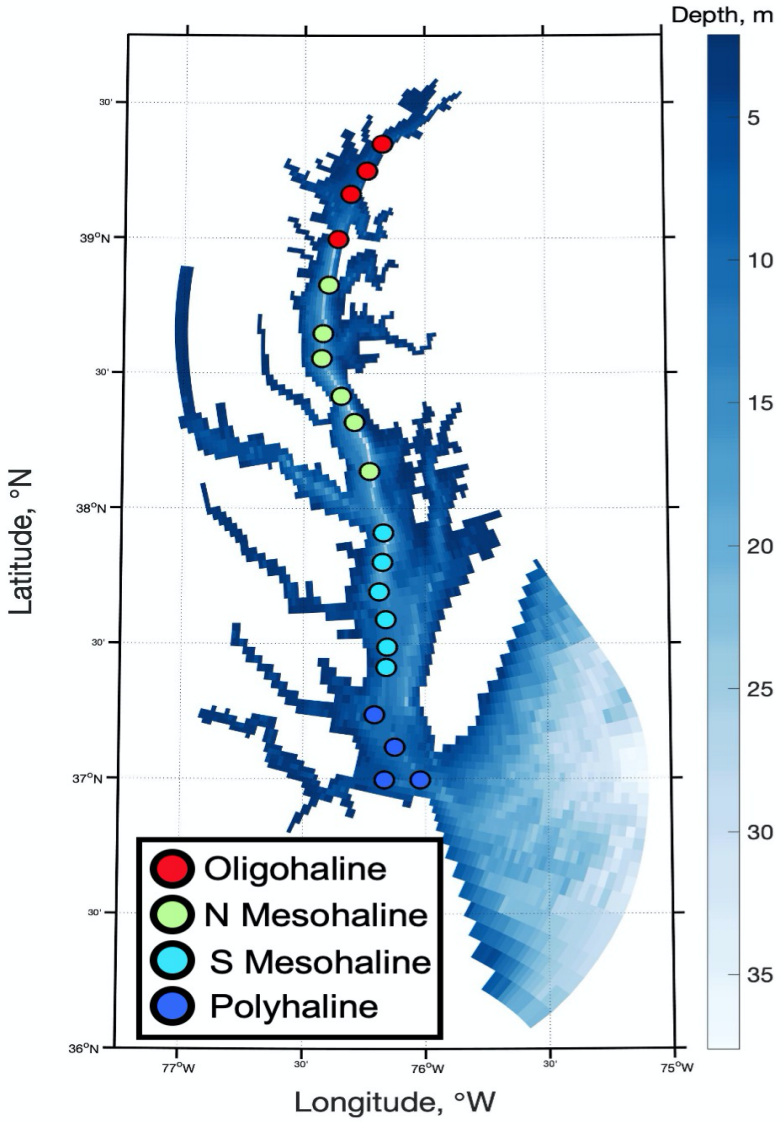


- Overall the model does well, performs better at the surface than the bottom

Do trends in model temperatures match observed trends?

- Can calculate trends using observations and model results from 1985-2019
  1. Observations – grouped by region
  2. Model @ t_{obs}, x_{stn} – model outputs from same time & location as observations

→ Used first-order autoregression (AR1) model of observations and model outputs



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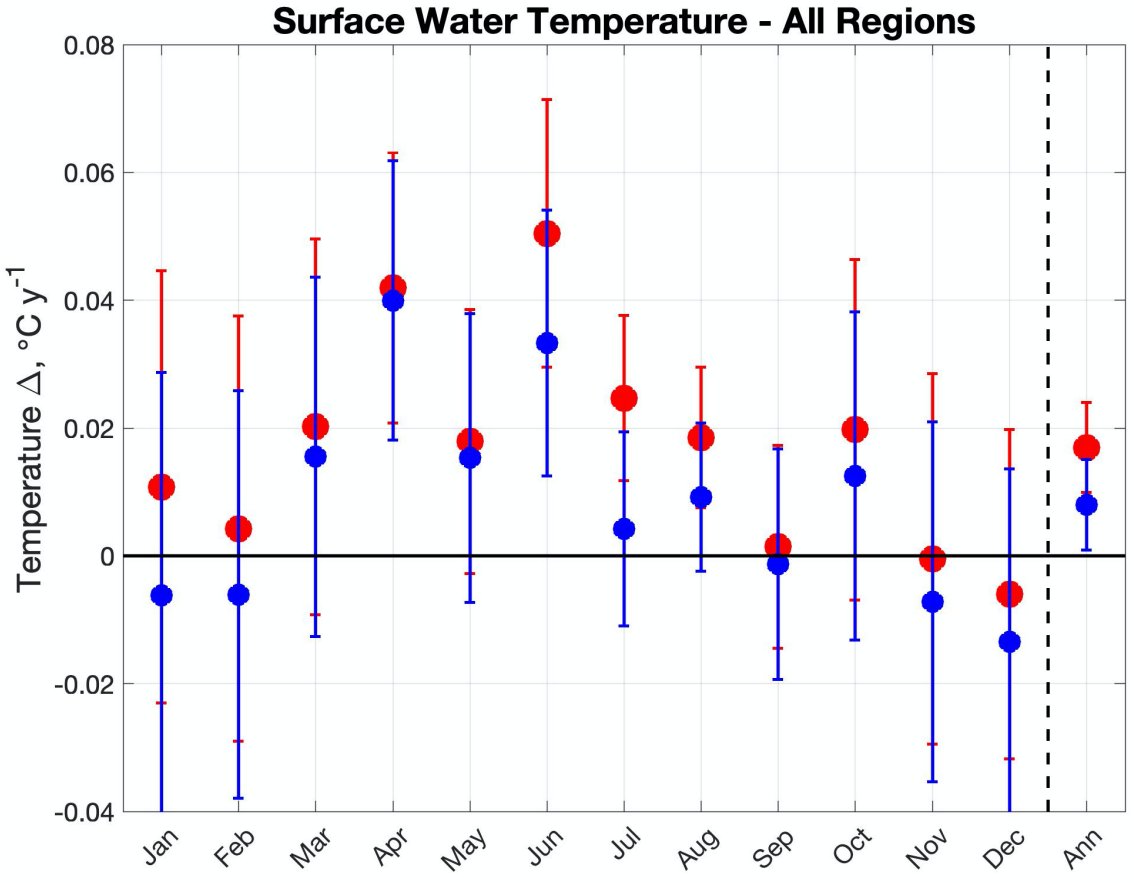

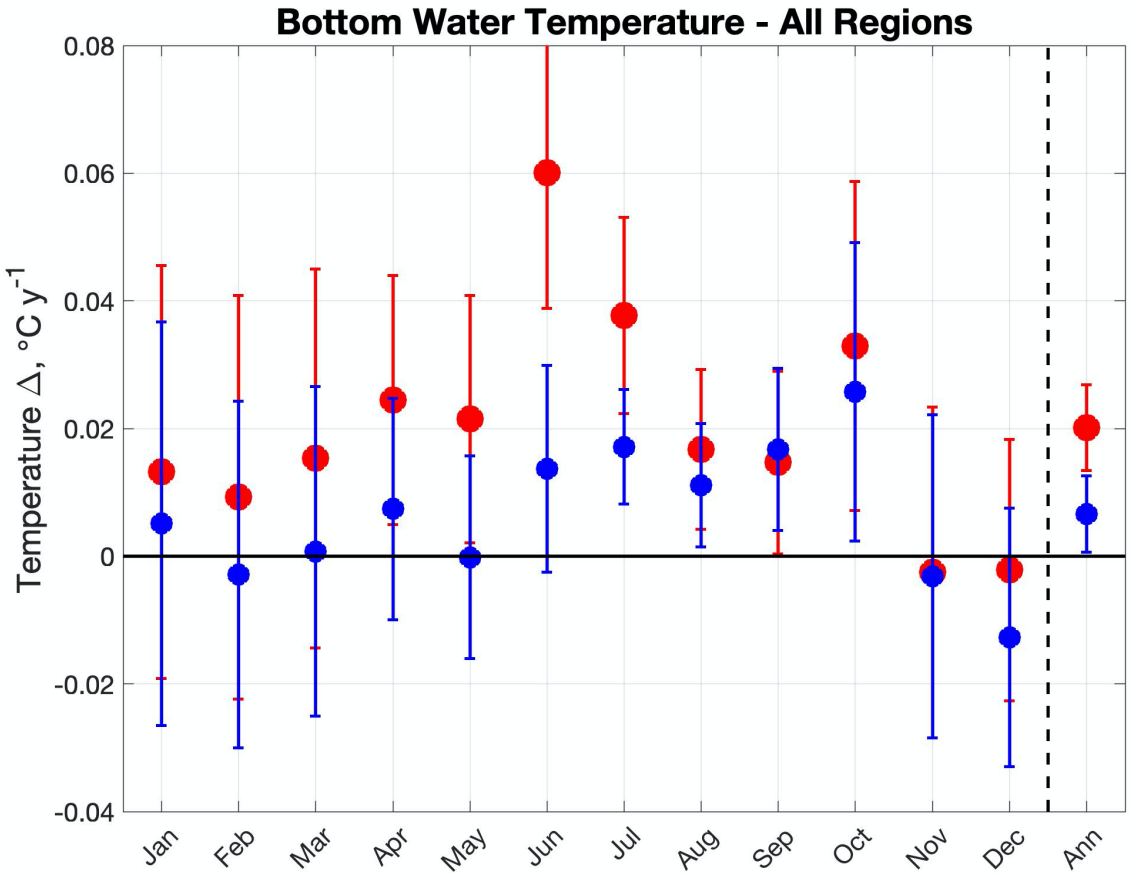

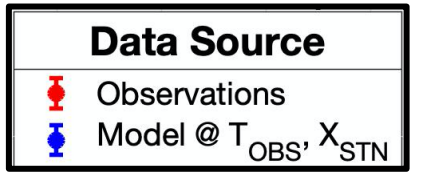

- Modeled and observed trends mostly overlap, exceptions in summer and fall
- Similar warming trends at surface and bottom
- Over 30-year period (1985-89 to 2015-19), average annual increase of ~0.6°C in Bay temperatures

Methods: Assessing Warming Mechanisms

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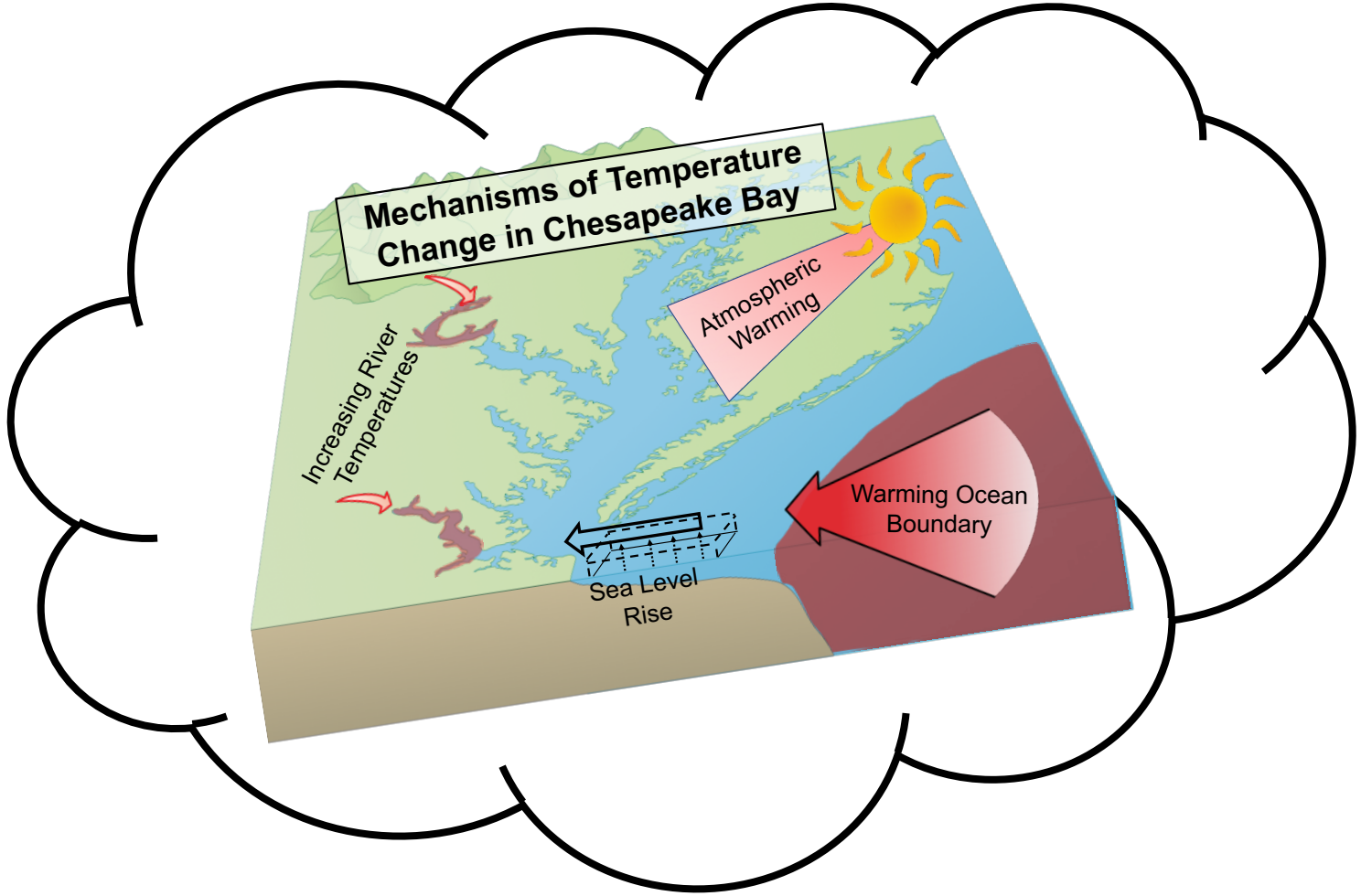
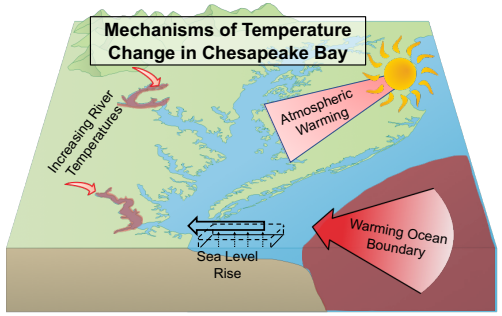


Methods: Assessing Warming Mechanisms

- Scenarios were compared to a realistic 1985-1989 reference run, T_{REF}
- Delta approach (*2015-2019 minus 1985-1989 conditions*) applied
  → All other conditions held constant



Experiment	Ocean T[a]	Air T[b]	Longwave Radiation[b]	River T[c]	SLR[d]
T_{ocn}	T_{REF} + 2.19° C	T_{REF}	T_{REF}	T_{REF}	T_{REF}
T_{atm}	T_{REF}	T_{REF} + 0.75°C	T_{REF} + 6.84 W m^{-2}	T_{REF}	T_{REF}
T_{riv}	T_{REF}	T_{REF}	T_{REF}	T_{REF} + 0.84°C	T_{REF}
T_{slr}	T_{REF}	T_{REF}	T_{REF}	T_{REF}	T_{REF} + 0.15m
T_{all}	T_{REF} +2.19°C	T_{REF} + 0.75°C	T_{REF} + 6.84 W m^{-2}	T_{REF} + 0.84°C	T_{REF} + 0.15m

[a]Derived from in situ coastal data; **varies seasonally*
[b]Derived from ERA5 trend (1985-2019); **varies spatially and monthly*
[c]Derived from Rice and Jastram (2014)
[d]Derived from Duck, NC and Lewes, DE tide gauge

Methods: Temperature Setup

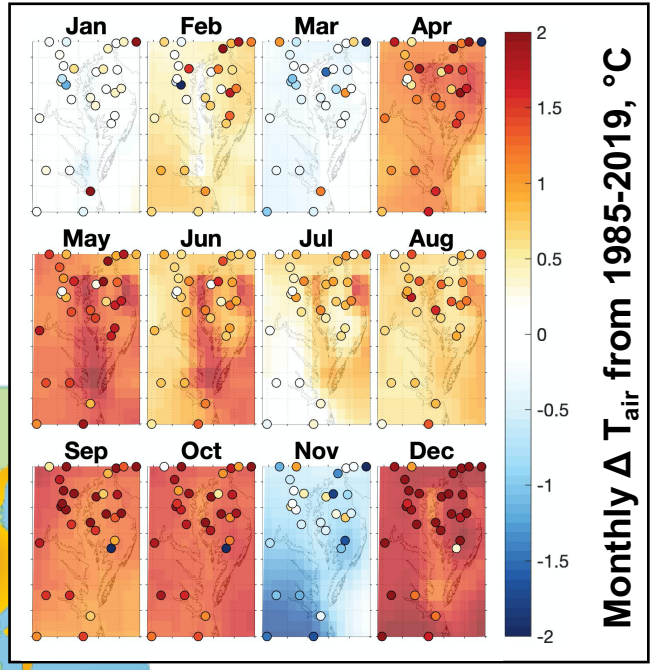
Climatic Change (2015) 128:127–138
DOI 10.1007/s10584-014-1295-9

Rising air and stream-water temperatures in Chesapeake Bay region, USA

Karen C. Rice · John D. Jastram

Received: 7 November 2013 / Accepted: 12 November 2014 / Published online: 26 November 2014

Abstract Monthly mean air temperature (AT) at 85 sites and instantaneous stream-water temperature (WT) at 129 sites for 1960–2010 are examined for the mid-Atlantic region, USA. Temperature anomalies for two periods, 1961–1985 and 1985–2010, relative to the climate normal period of 1971–2000, indicate that the latter period was statistically significantly warmer than the former for both mean AT and WT. Statistically significant temporal trends across the region of 0.023 °C per year for AT and 0.028 °C per year for WT are detected using simple linear regression. Sensitivity analyses show that the irregularly sampled WT data are appropriate for trend analyses, resulting in conservative estimates of trend magnitude. Relations between 190 landscape factors and significant trends in AT-WT relations are examined using principal components analysis. Measures of major dams and deciduous forest are correlated with WT increasing slower than AT, whereas agriculture in the absence of major dams is correlated with WT increasing faster than AT. Increasing WT trends are detected despite increasing trends in streamflow in the northern part of the study area. Continued warming of contributing streams to Chesapeake Bay likely will result in shifts in distributions of aquatic biota and contribute to worsened eutrophic conditions in the bay and its estuaries.



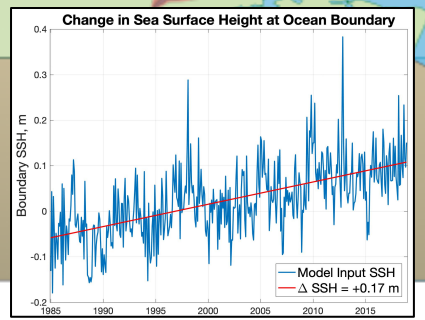
Mechanisms of Temperature Change in Chesapeake Bay

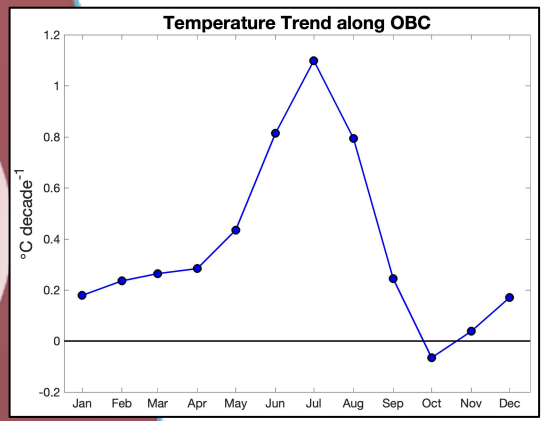
Increasing River Temperatures

Atmospheric Warming

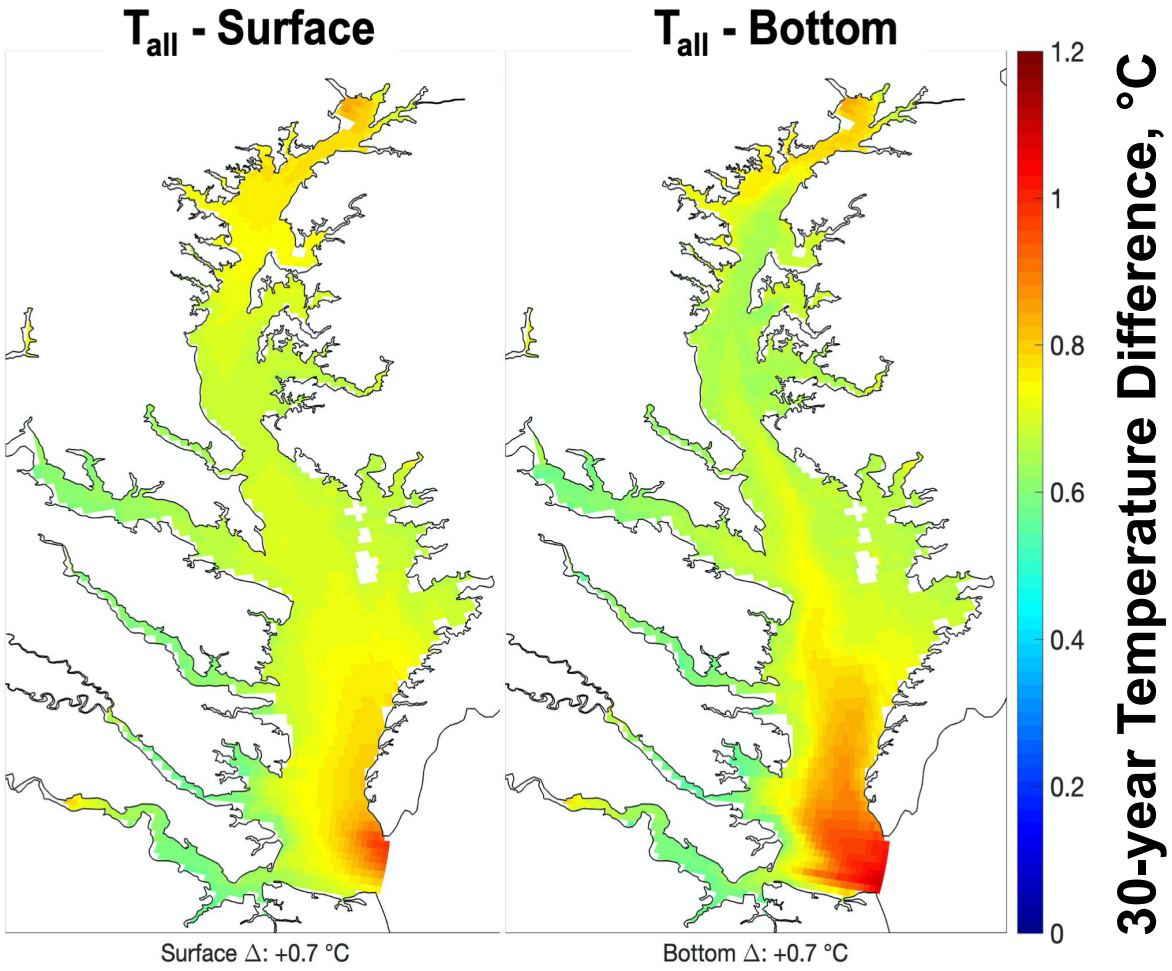
Sea Level Rise

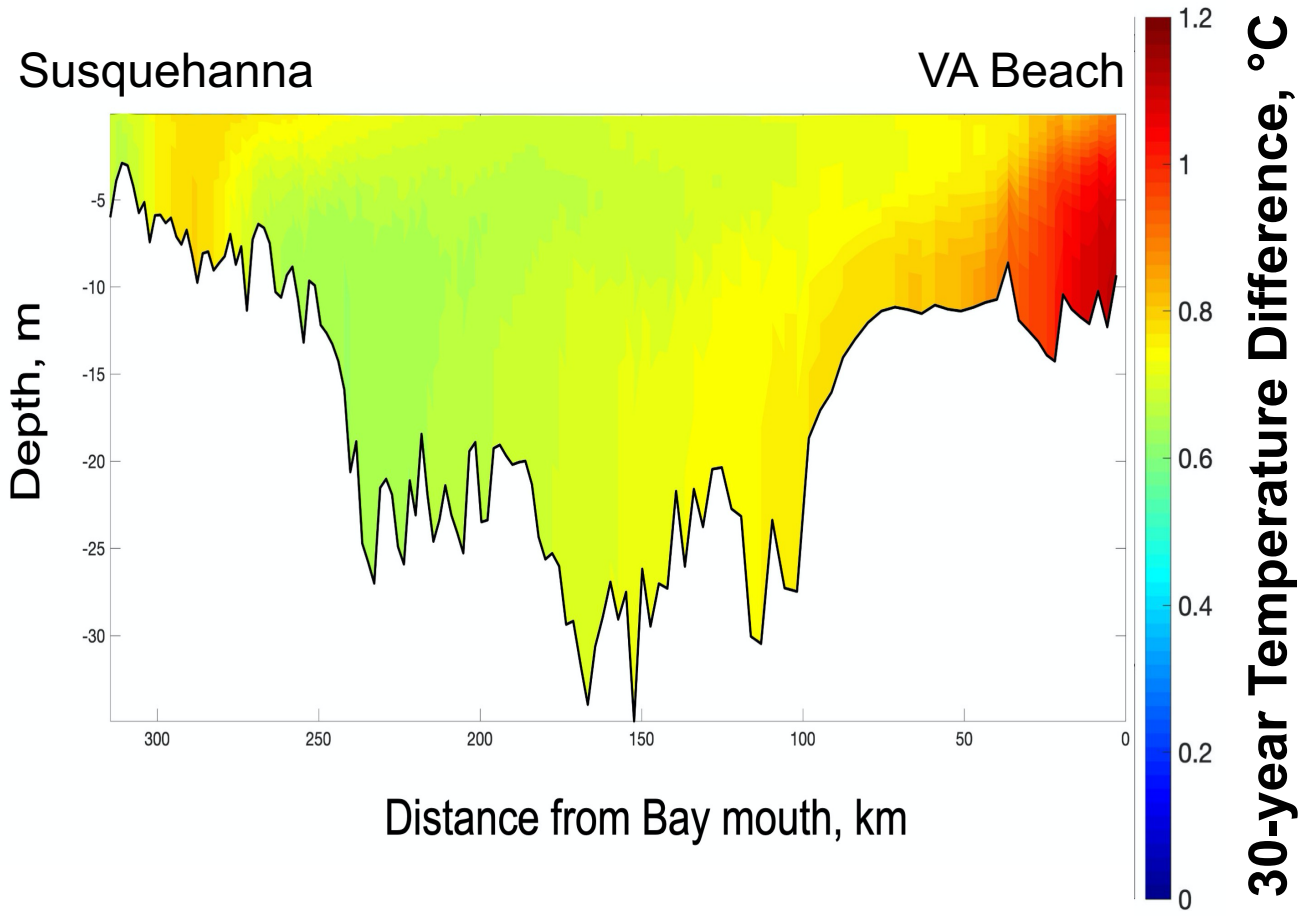
Warming Ocean Boundary





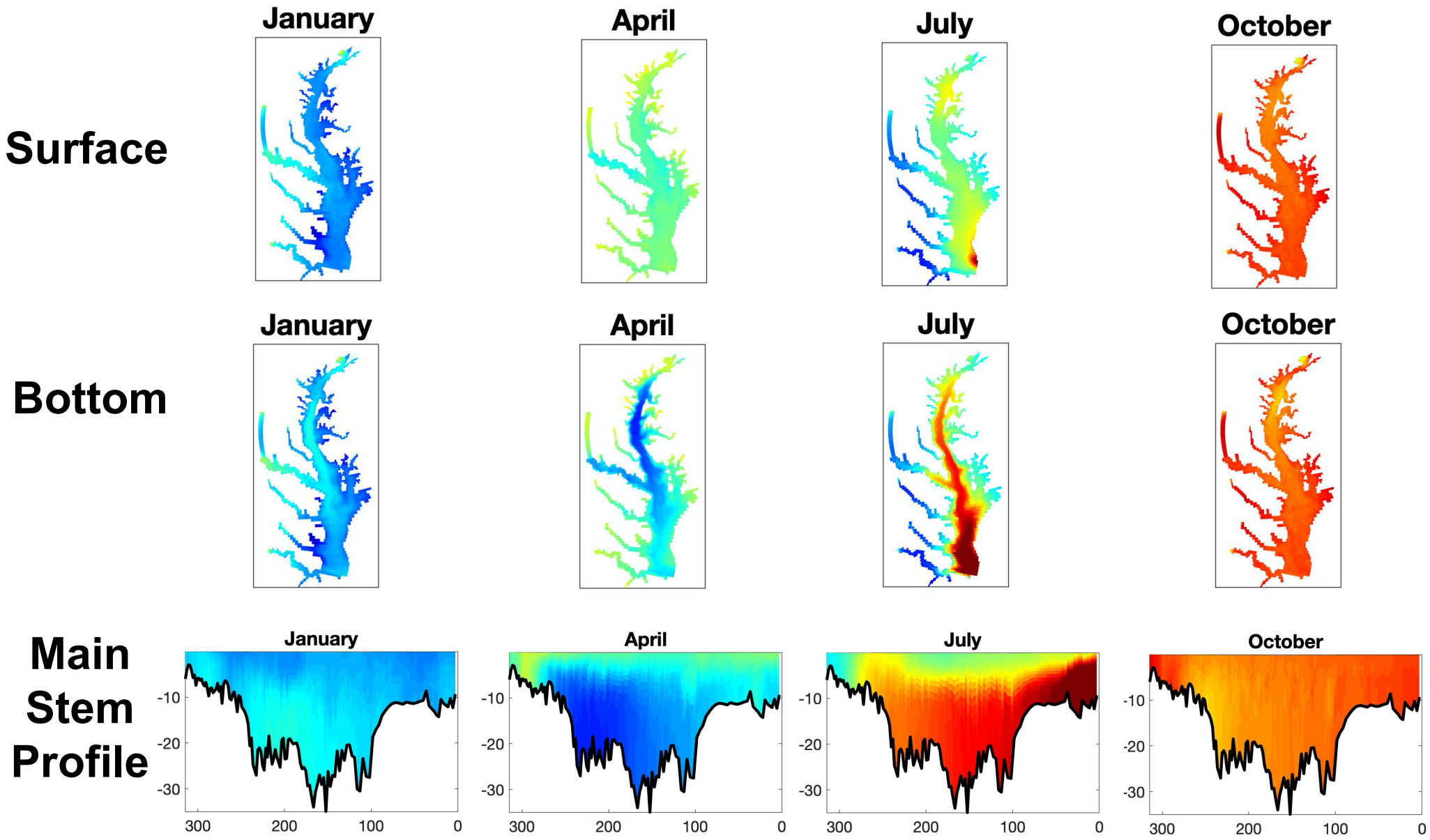
Results

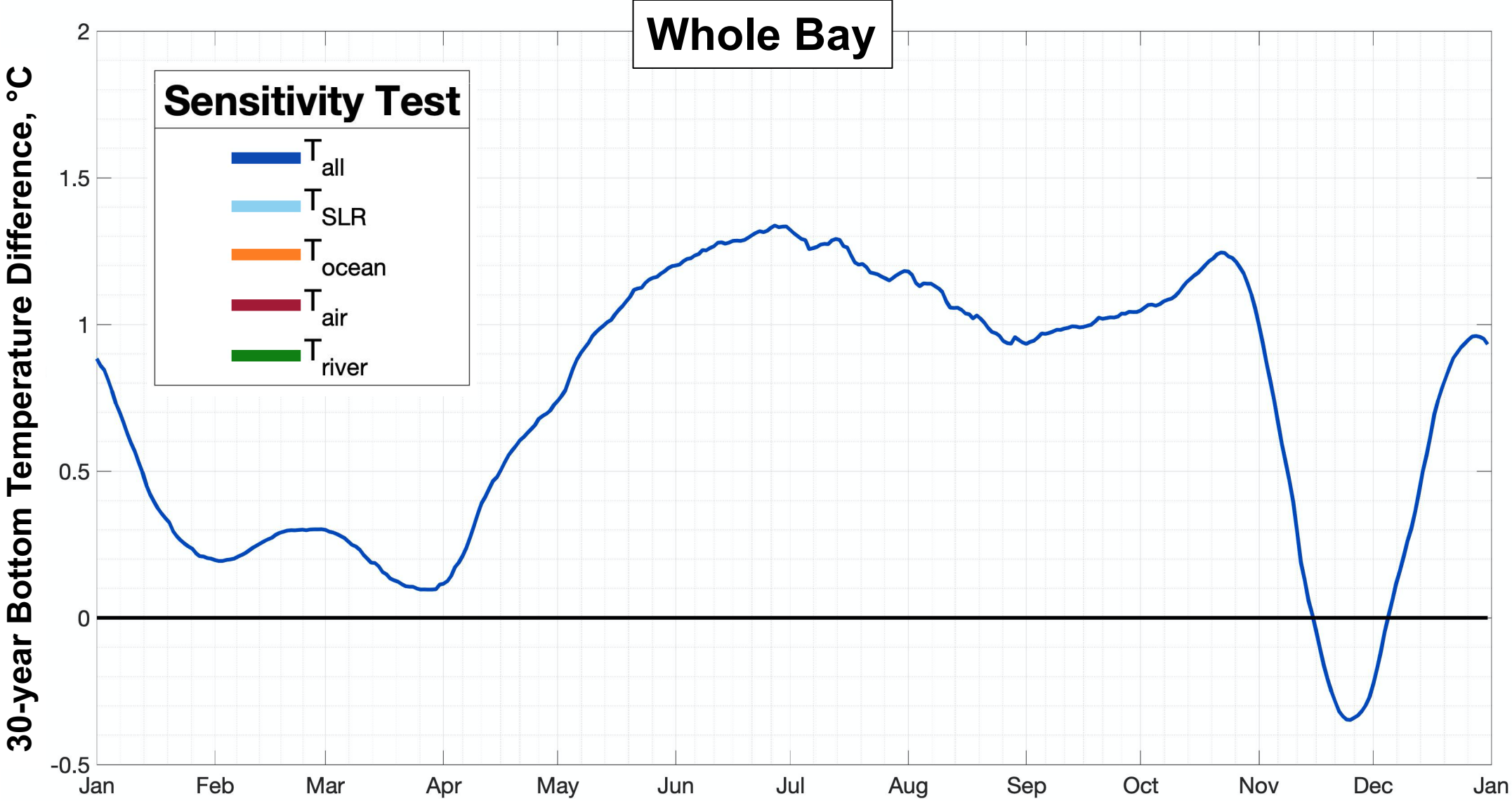




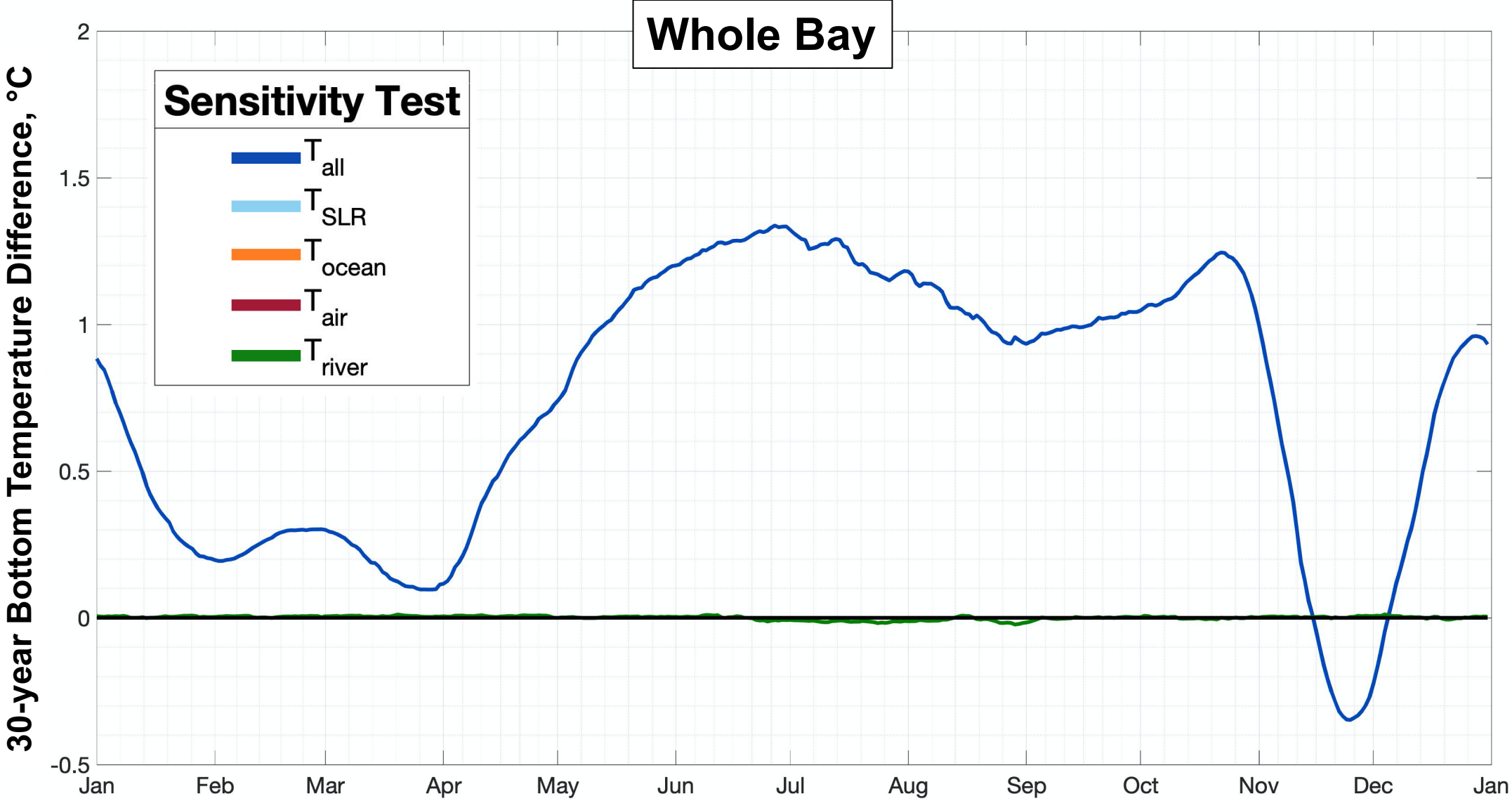
- Approximately similar changes at surface and bottom, some regional differences
- Average change of ~0.7°C

T_{all} Monthly Temperature Changes

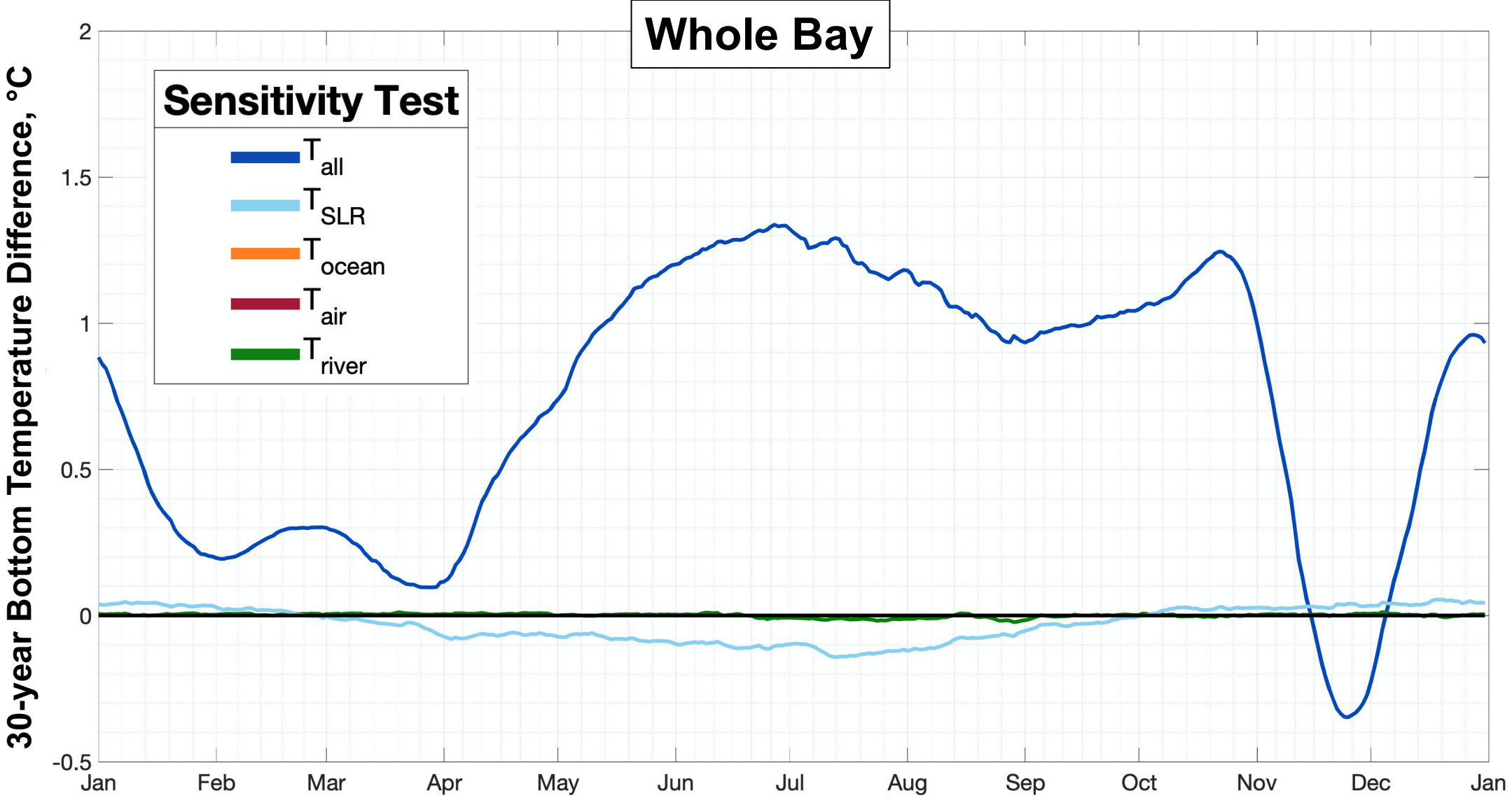




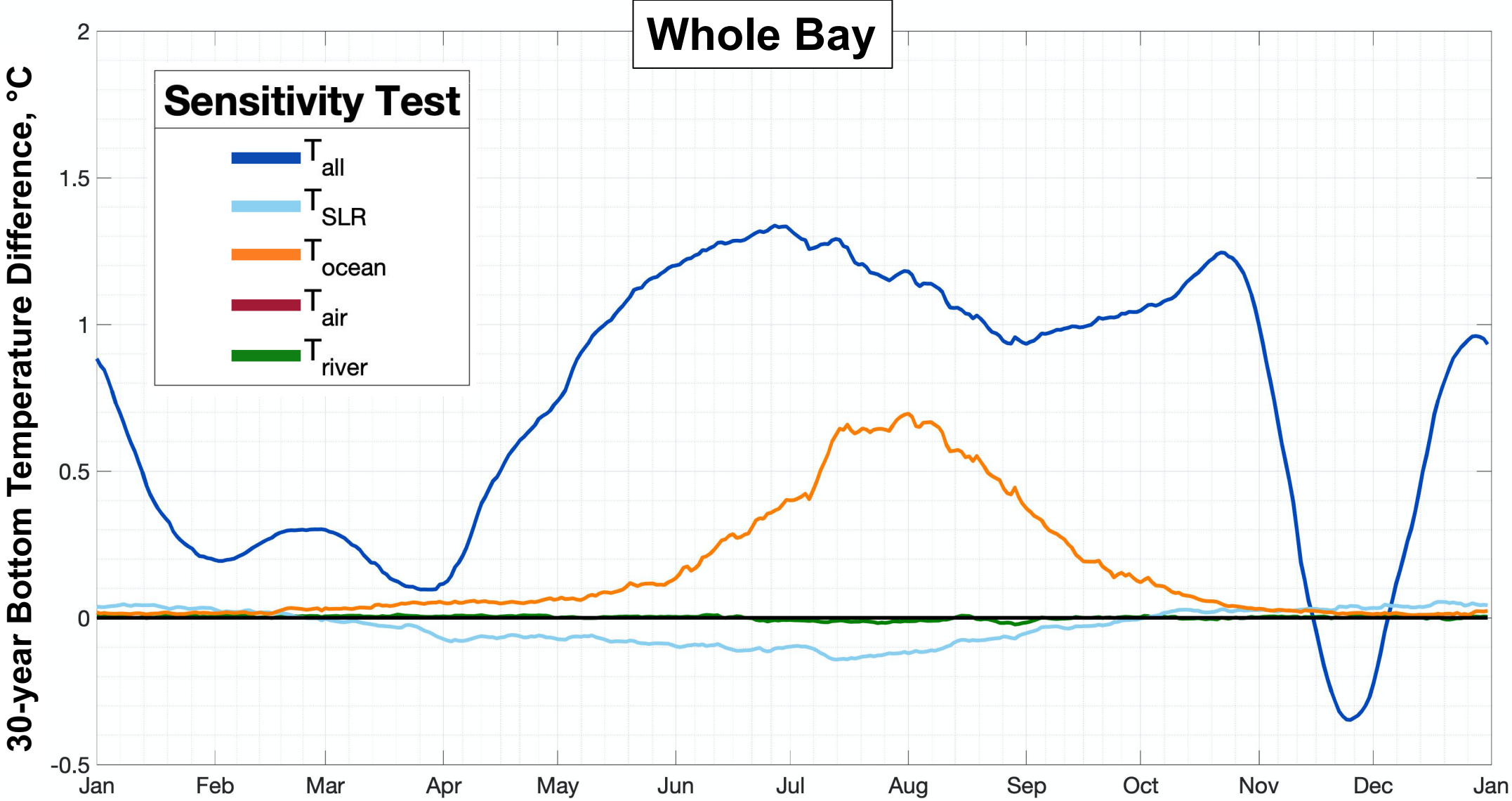
- Temperatures can vary widely from month to month
- Average change ± standard deviation for the Bay is 0.73 ± 0.46°C



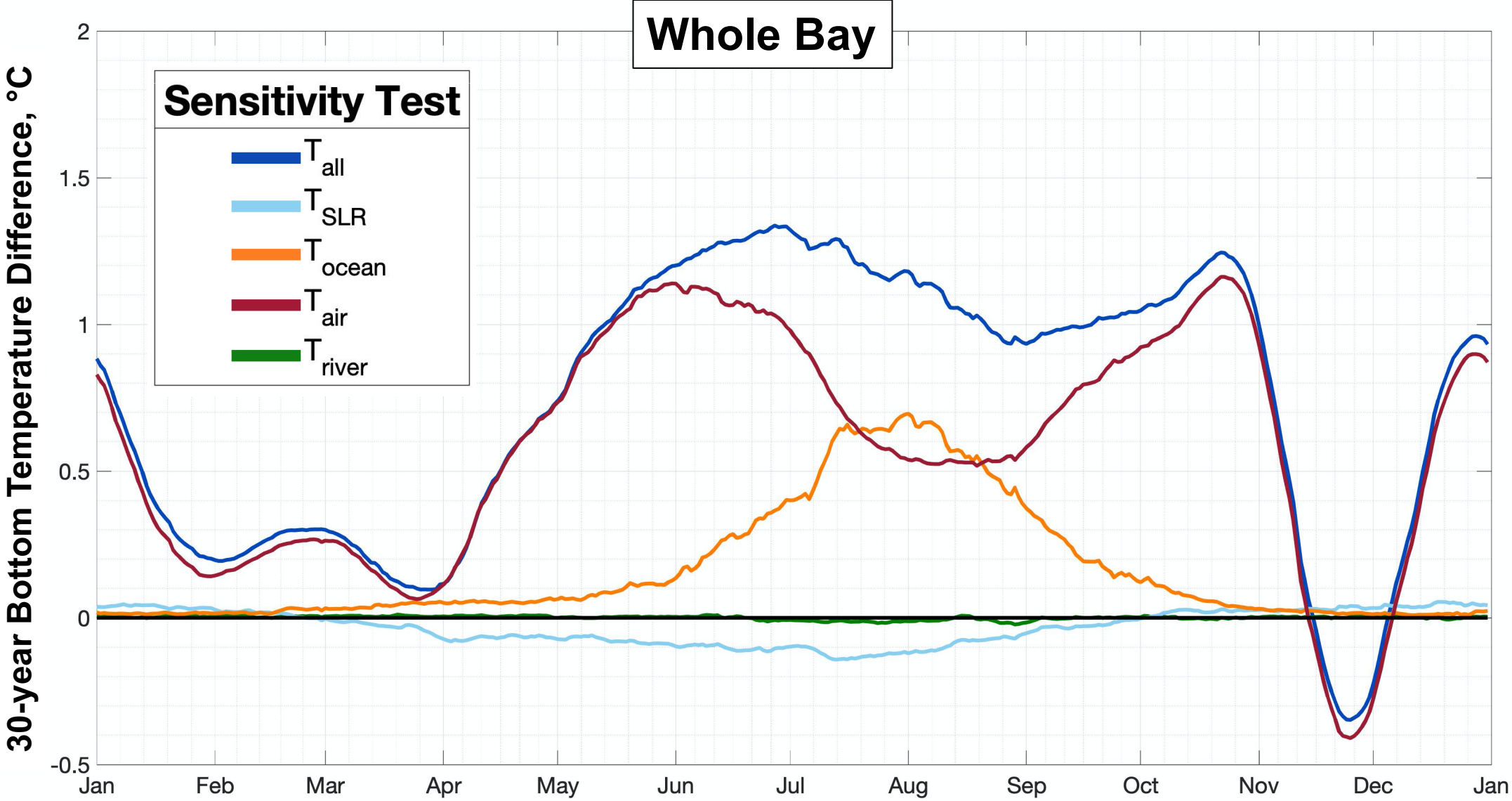
- Change due to increasing river temperatures is insignificant in the mainstem Bay, more important in the tributaries



- Sea level rise slightly cools mainstem bottom waters during spring and summer and produces a slight warming effect in winter months

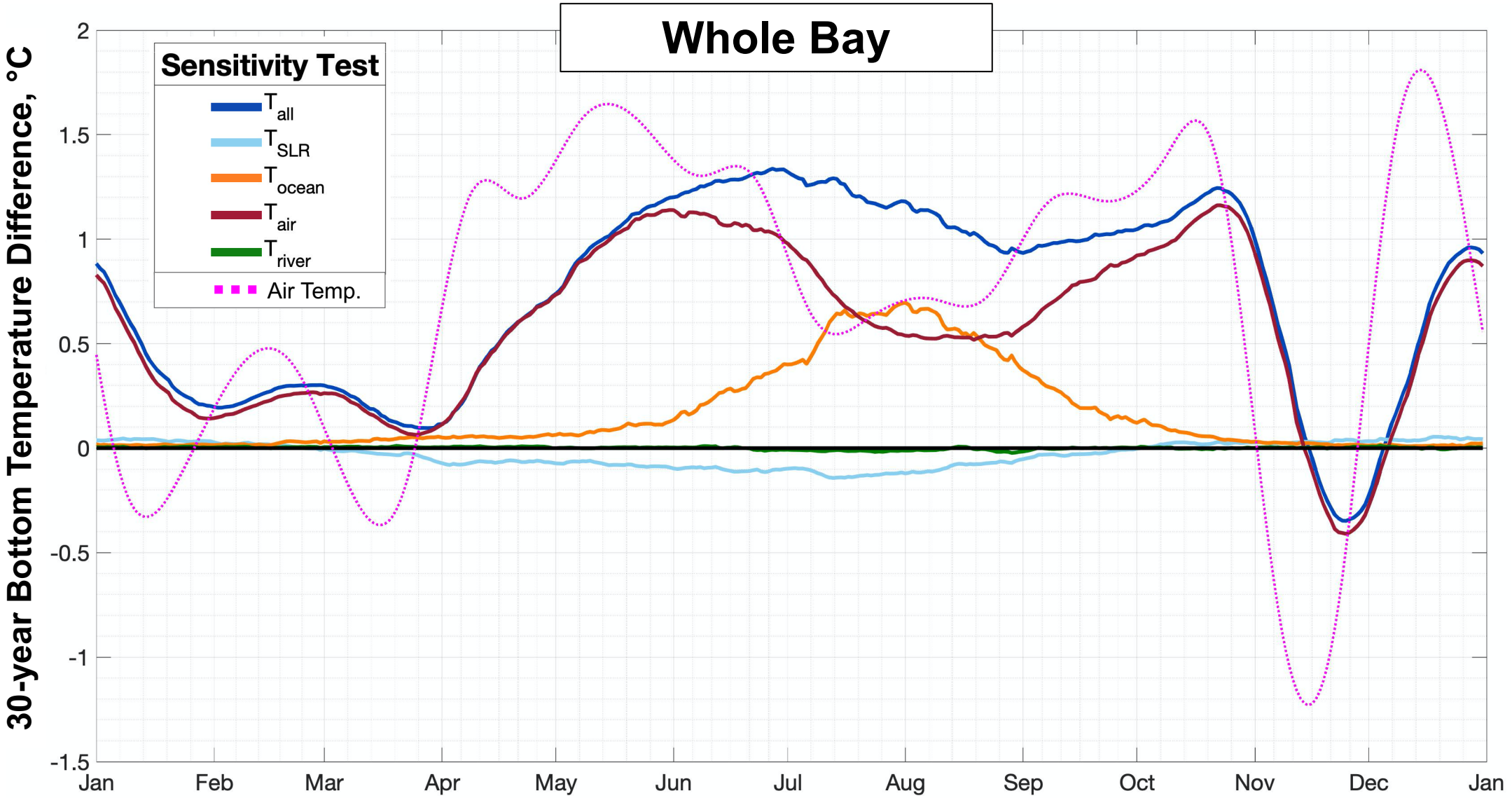


- Increasing ocean temperatures play a significant role in total temperature change during summer
- Minimal effect of ocean temperatures in other months



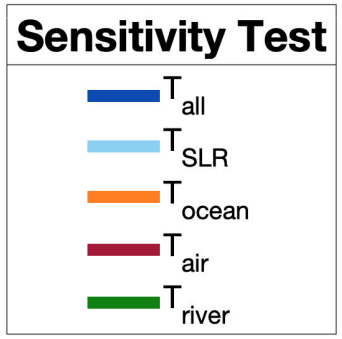
- Increasing air temperatures and downwelling longwave radiation play biggest role in total temperature change
- T_{air} is only diminished by the large contribution of ocean warming to summer temperatures

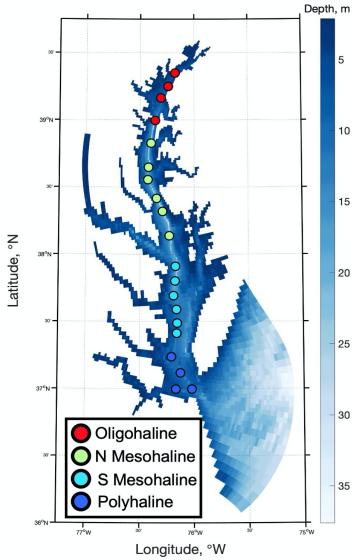
Does the Bay response match air temperature changes?

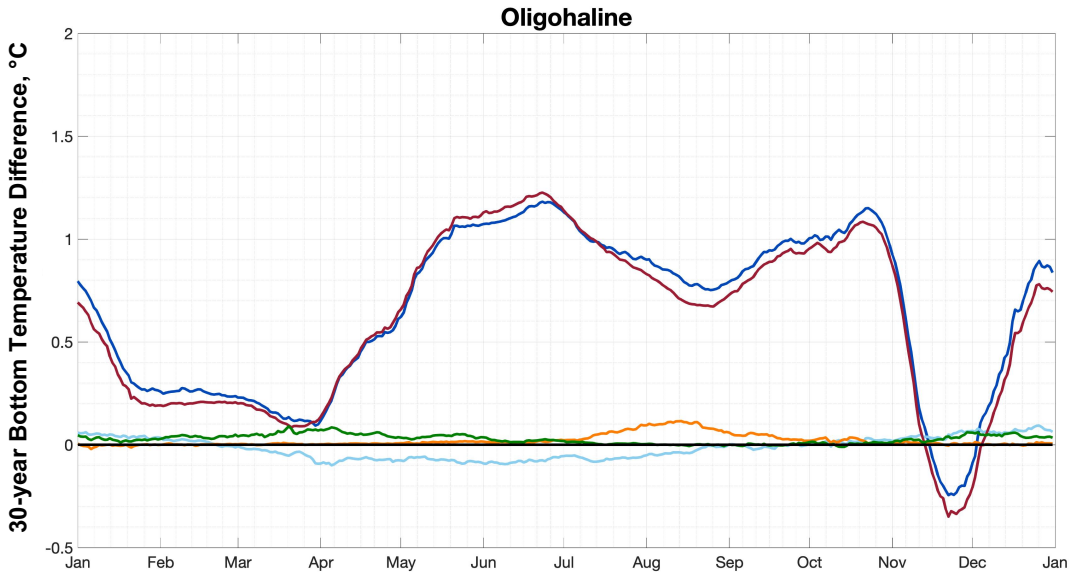


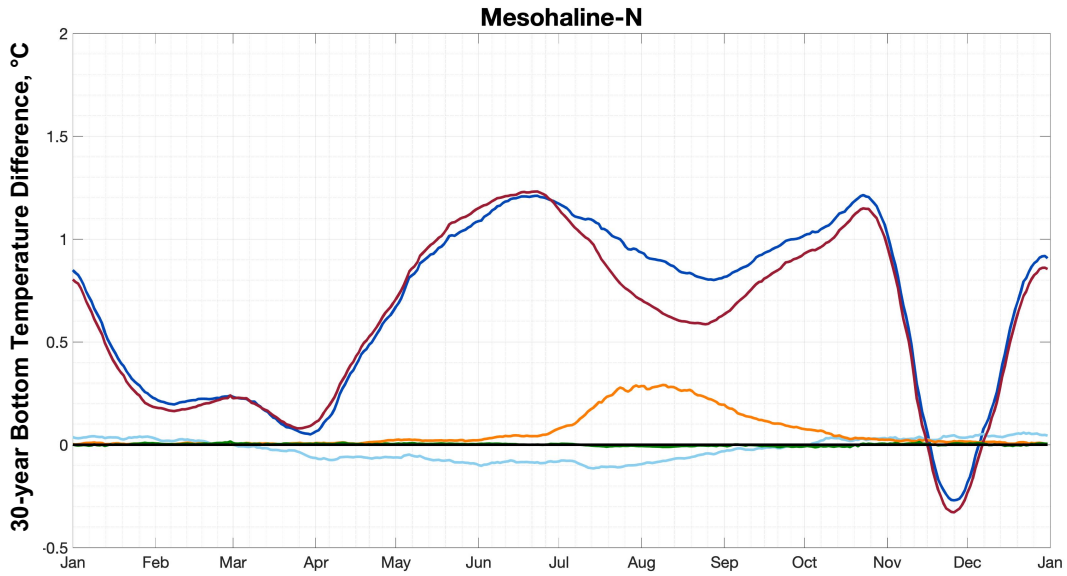
- Generally, Δ T_{all} follows Δ atmospheric temperatures
- Total change in bottom water temperatures lags air temperatures by ~1 month

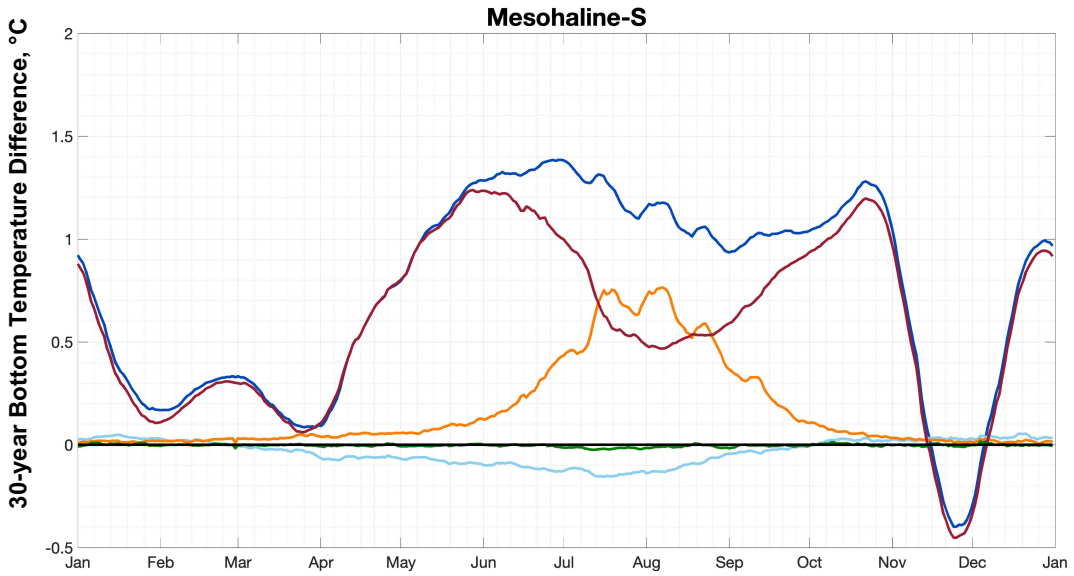
How do warming mechanisms affect regional bottom temperatures?

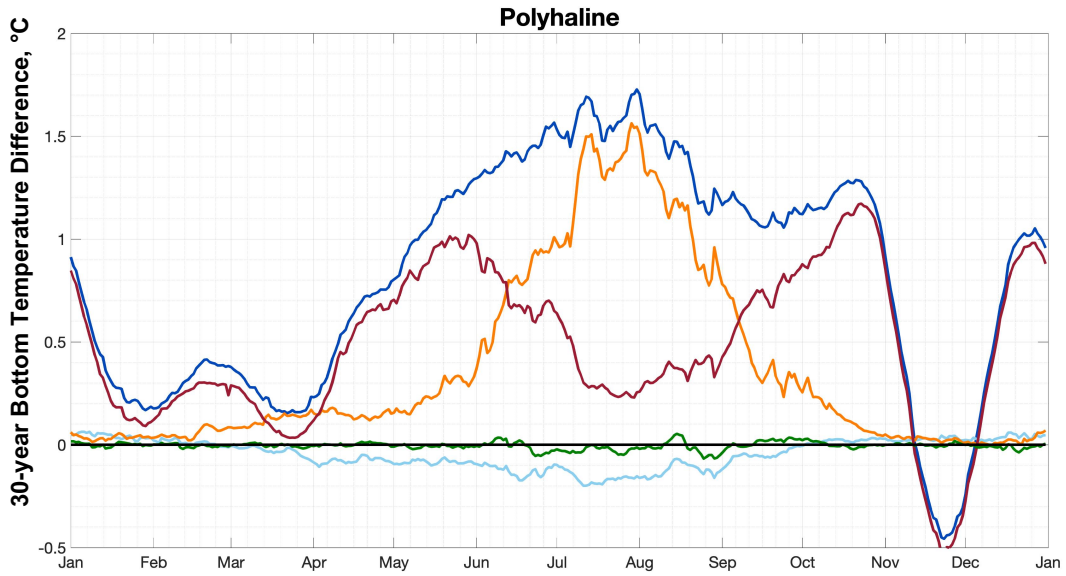










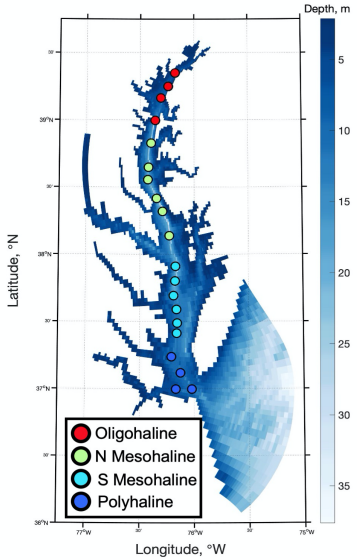


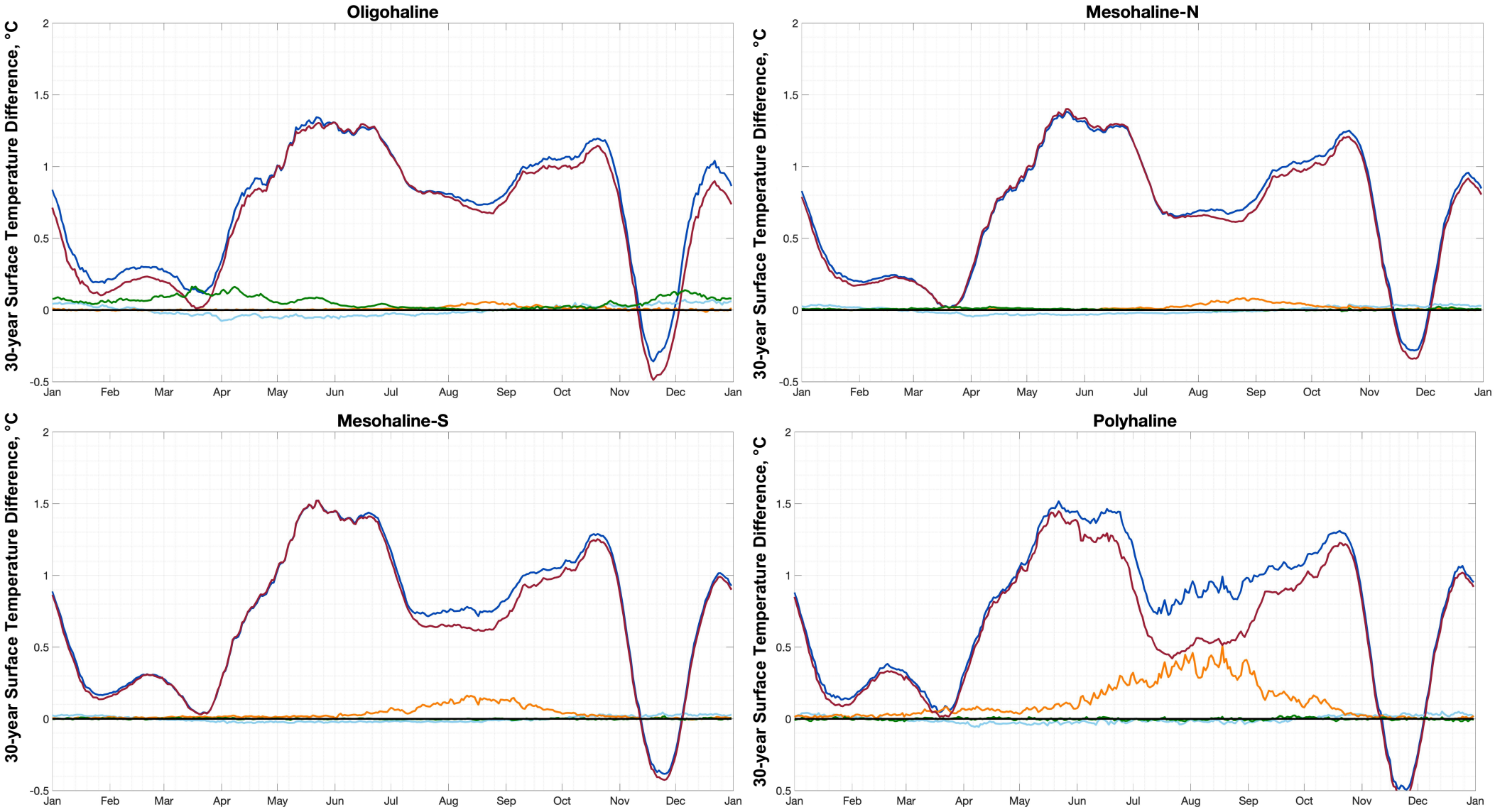
- The effects of ocean warming and SLR are greater closer to the Bay mouth
- Warming air temperatures are still the dominant mechanism driving warming patterns

How do warming mechanisms affect regional surface temperatures?

Sensitivity Test

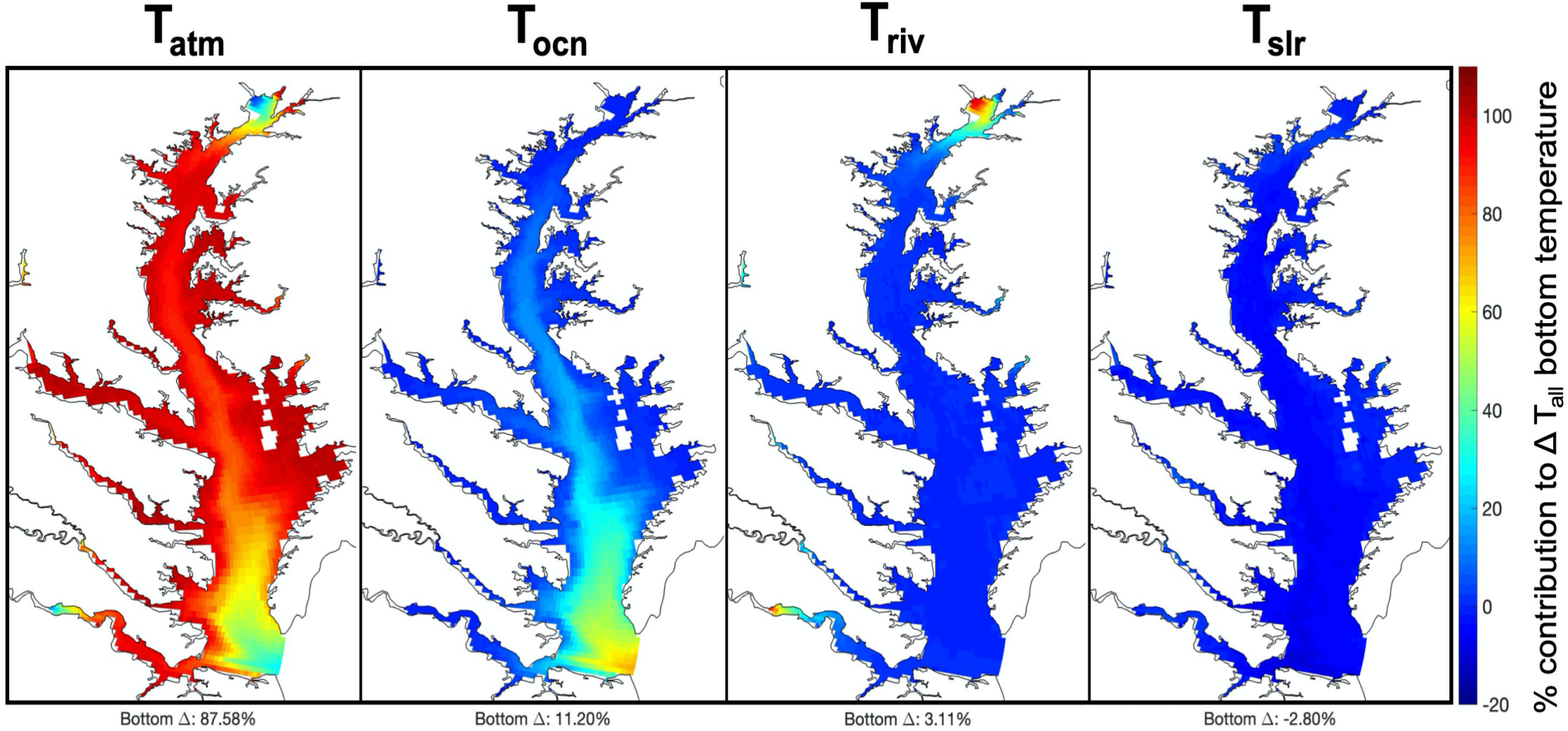
- T_{all}
- T_{SLR}
- T_{ocean}
- T_{air}
- T_{river}





- The effects of ocean warming is largest closer to the Bay mouth
- Warming air temperatures dominate warming patterns

Where does each warming mechanism have the largest impact?



- Air temperature is dominant almost everywhere
- Ocean warming is important in the southern Bay
- Rivers play a role in tributaries, and SLR is slightly negative everywhere

Conclusions

- Since 1985, the Chesapeake Bay has warmed by ~0.7°C
- Increasing atmospheric temperatures have driven most of the Bay warming (~0.6°C)
- Ocean warming primarily increases southern Bay bottom temperatures (~0.5°C) during the summer
- Sea level rise has slightly cooled summer Bay temperatures (~0.1°C)
- Increasing river temperatures have not affected Bay warming

- Why is air temperature so important?
  - Bay surface area >> Bay mouth volume exchange

Context and Implications

Observed

IPCC Avg. Ocean Warming
0.11 ± 0.02°C decade^{-1}

<

Preston (2004)
0.16-0.21°C decade^{-1}

<

Our Work
0.24°C decade^{-1}

Context and Implications

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Projected

2050 – N. Atlantic SST
Zhang and Li (2019)

- Reduced Emissions: 0.23°C decade^{-1}
- High Emissions: 0.34°C decade^{-1}

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0.24°C decade^{-1}

Projected

2050 – N. Atlantic SST
Zhang and Li (2019)

- Reduced Emissions: 0.23°C decade^{-1}
- High Emissions: 0.34°C decade^{-1}

- Impacts on hypoxia, phenology, survival thresholds
- How might ocean circulation offshore change Bay warming?

Extra Slides

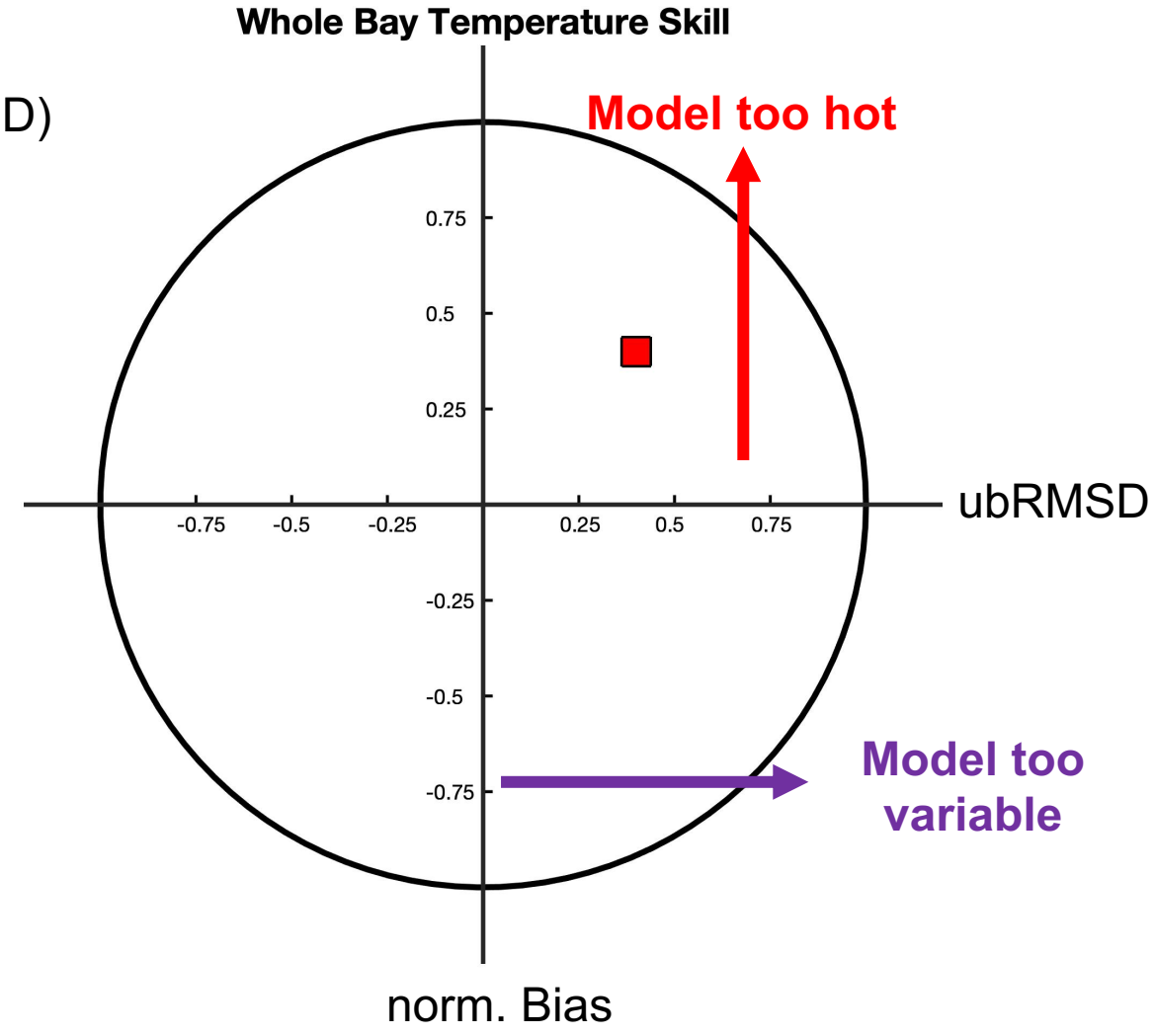
How well does ChesROMS match observed temperatures?

Introduction to target diagrams

- x-axis: unbiased root-mean squared difference (ubRMSD)
- y-axis: bias (model minus observations)

- Can normalize (divide by St.Dev.) values to compare different variables (T, S) on same plot

- All values within the circle perform **better** than the average of observations
- Center of target match observations perfectly



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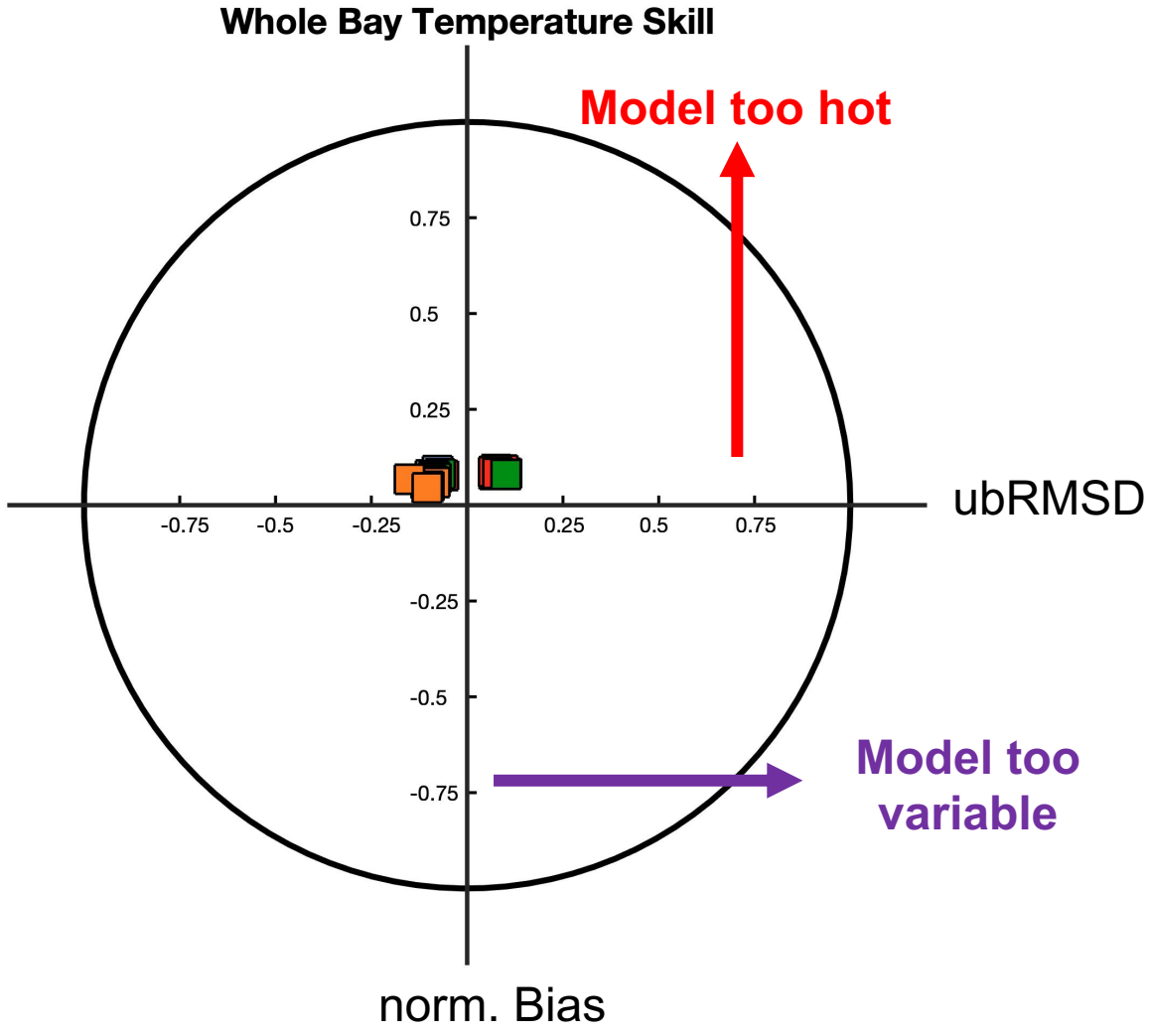
→ **Surface model temperatures match observations well**



OH Bottom Surface

MH-N Bottom Surface

MH-S Bottom Surface

PH Bottom Surface

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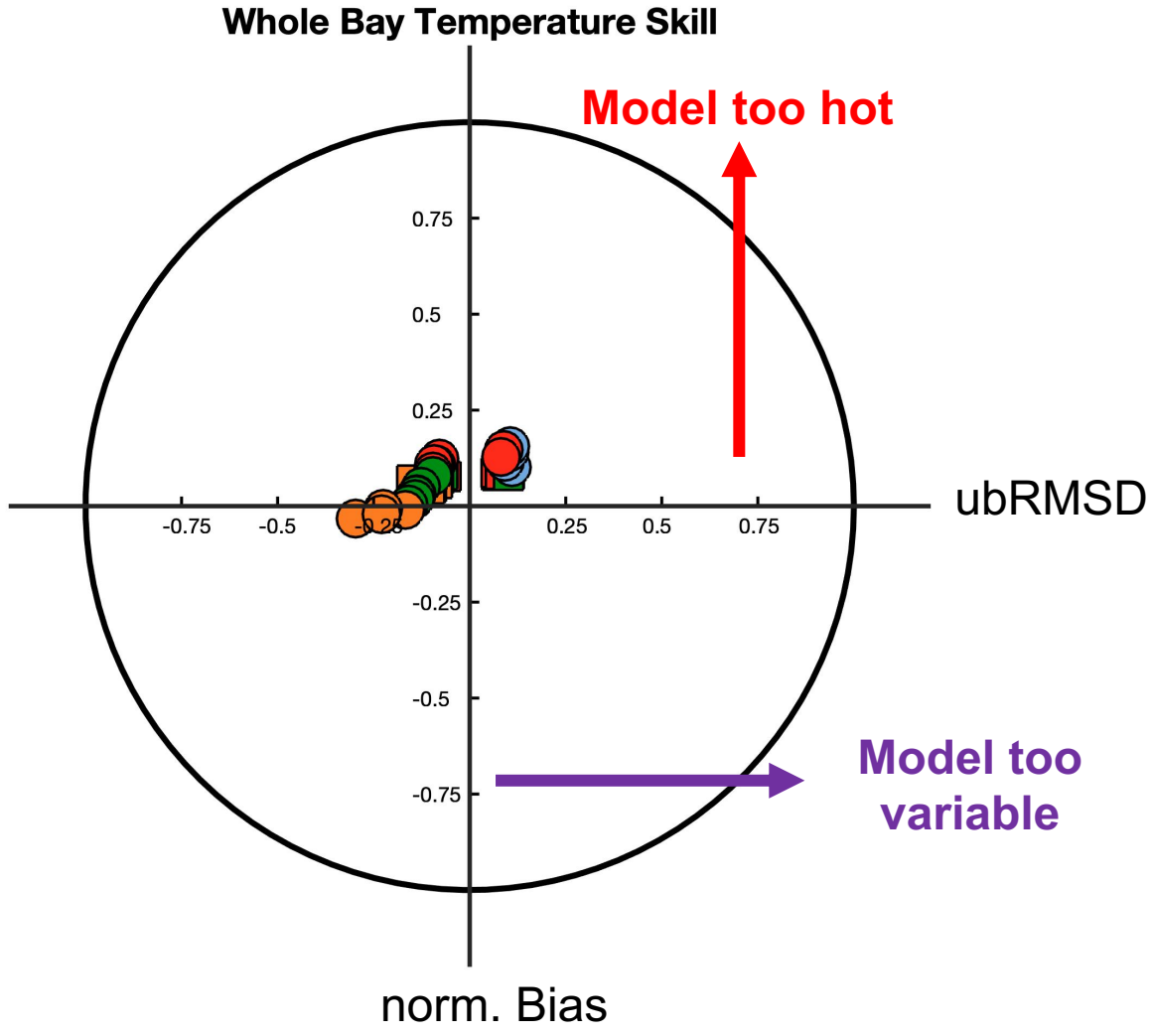
→ **Surface model temperatures match observations well**

→ **Bottom model observations also match observations well, but aren't as close as surface outputs**

→ On average, surface and bottom model results are within ± 1°C of observations



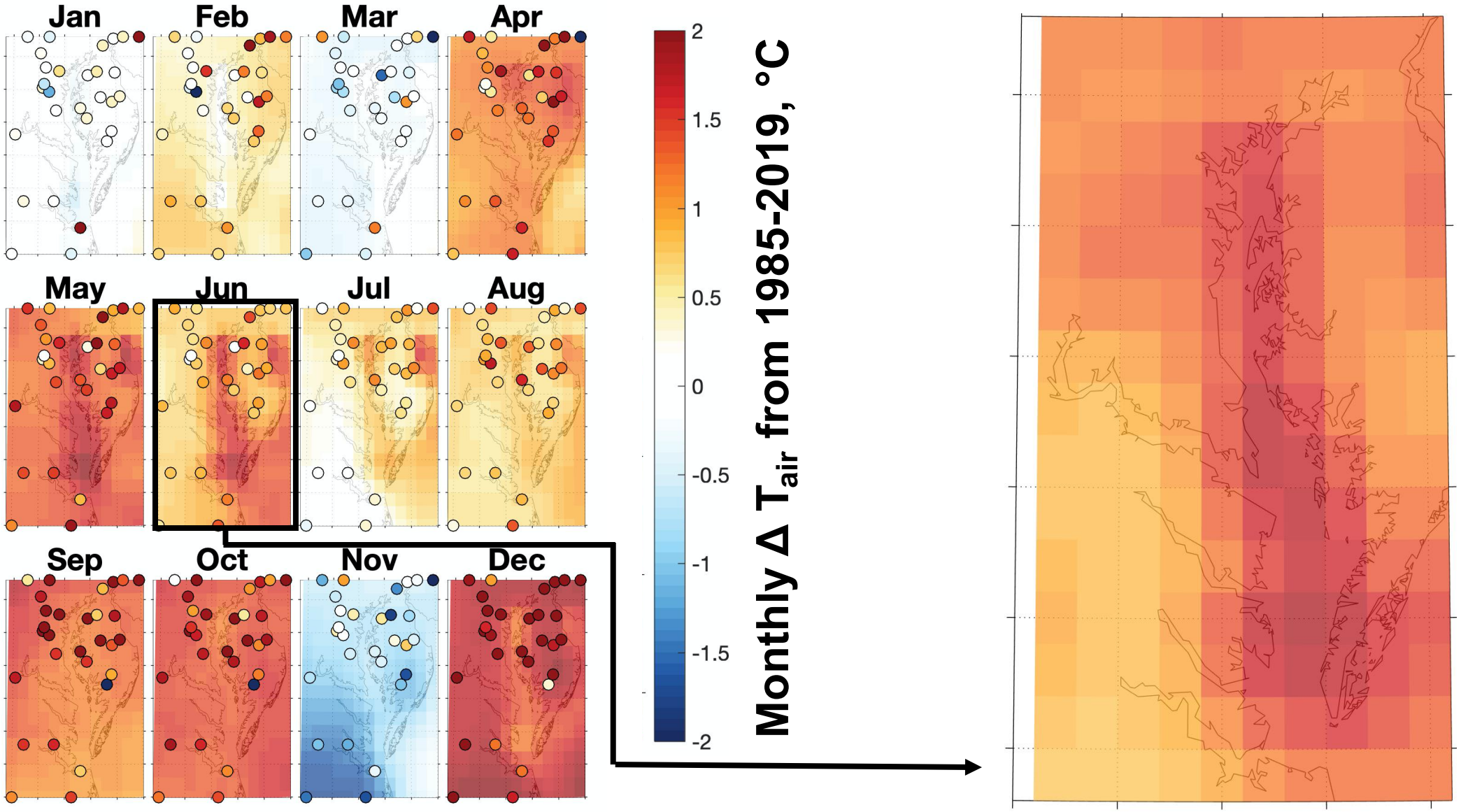
OH Bottom Surface

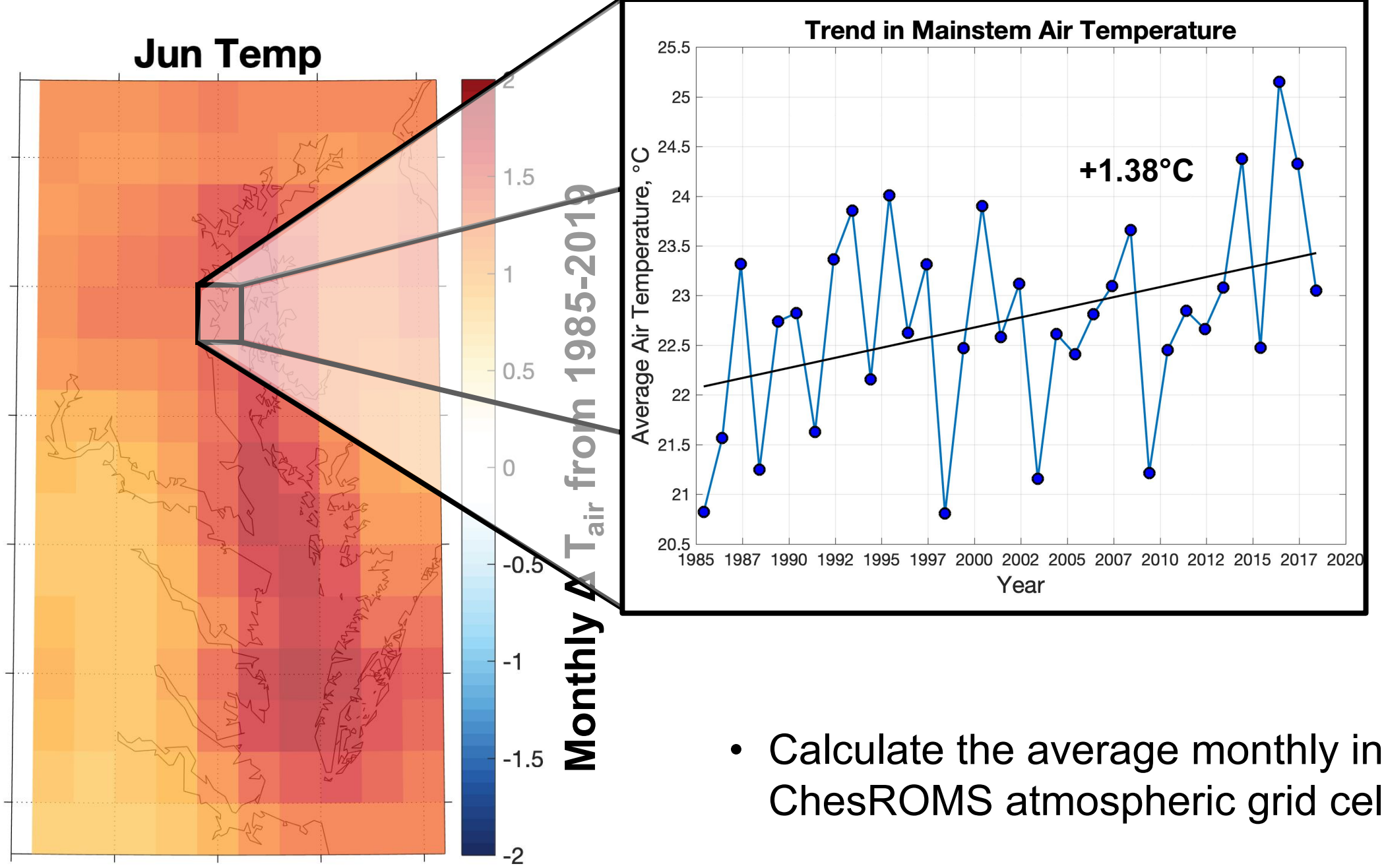
MH-N Bottom Surface

MH-S Bottom Surface

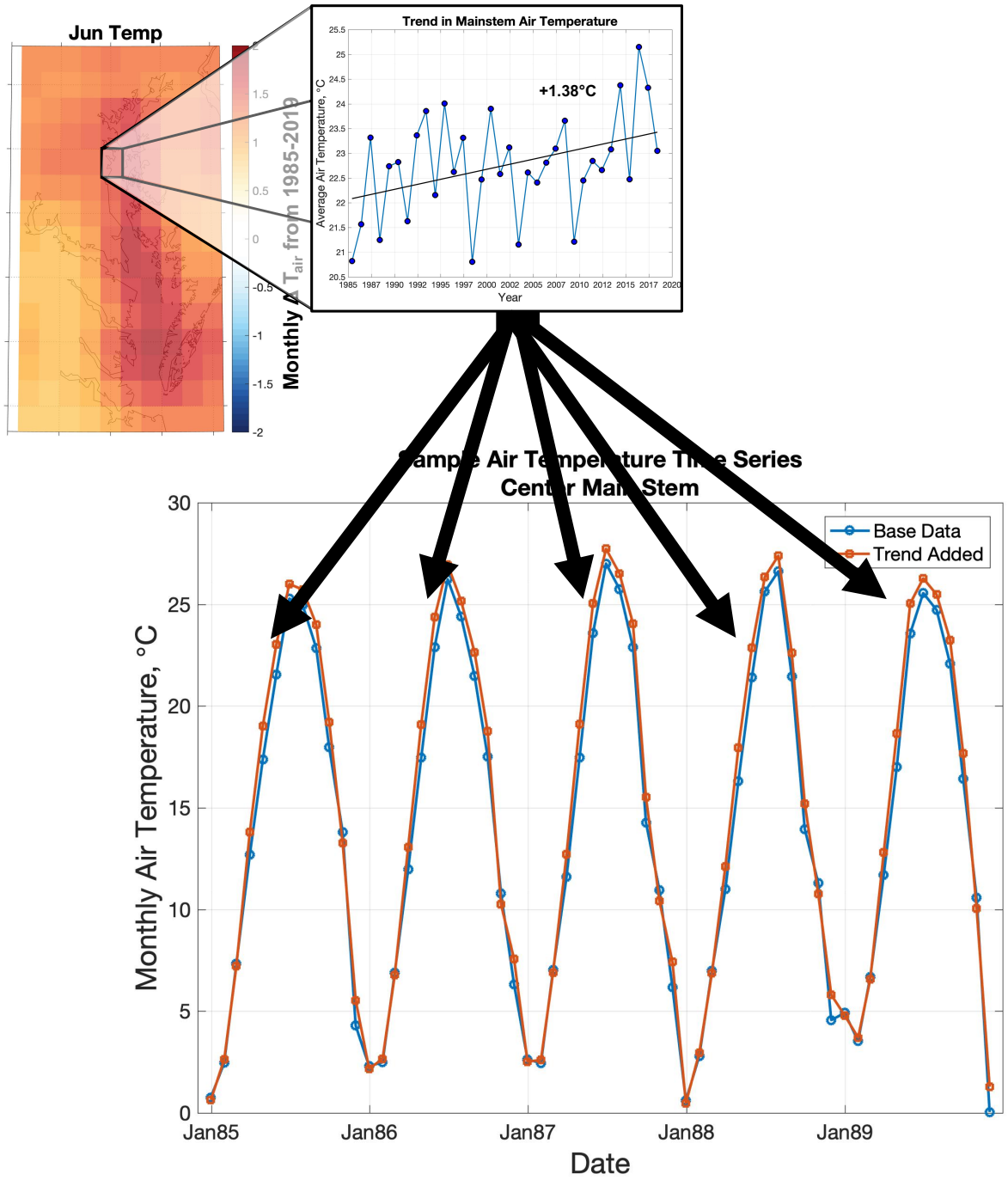
PH Bottom Surface

Methods: Temperature Setup

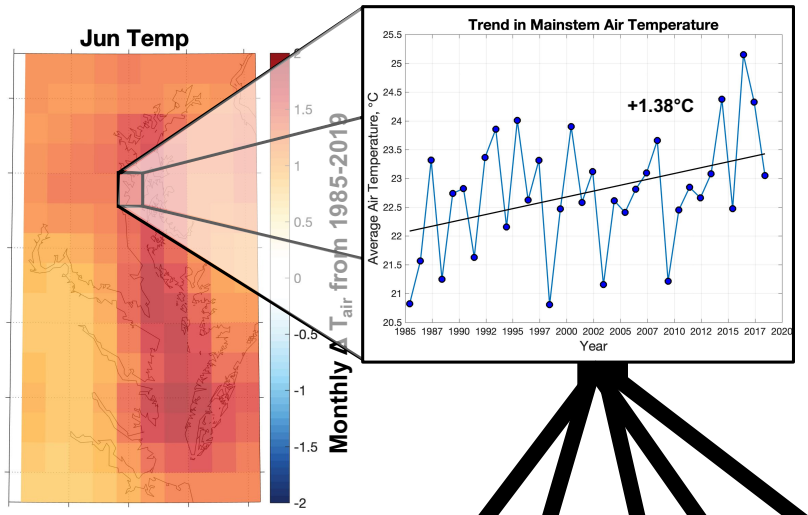


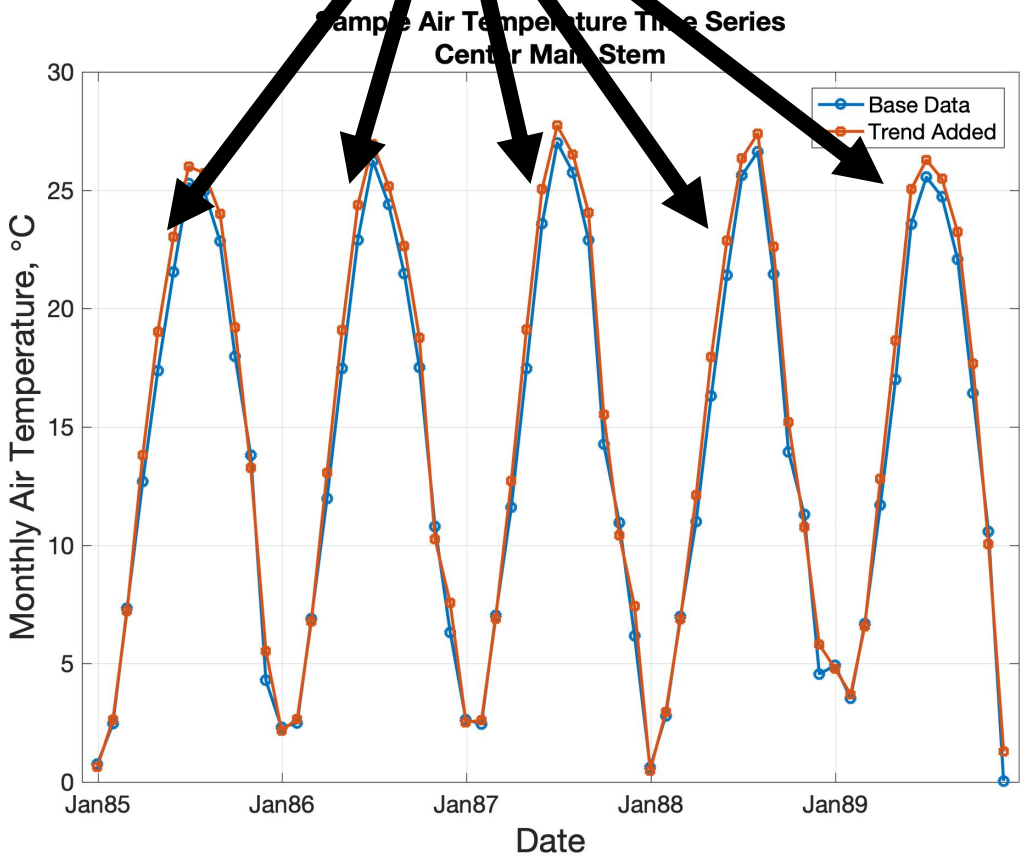


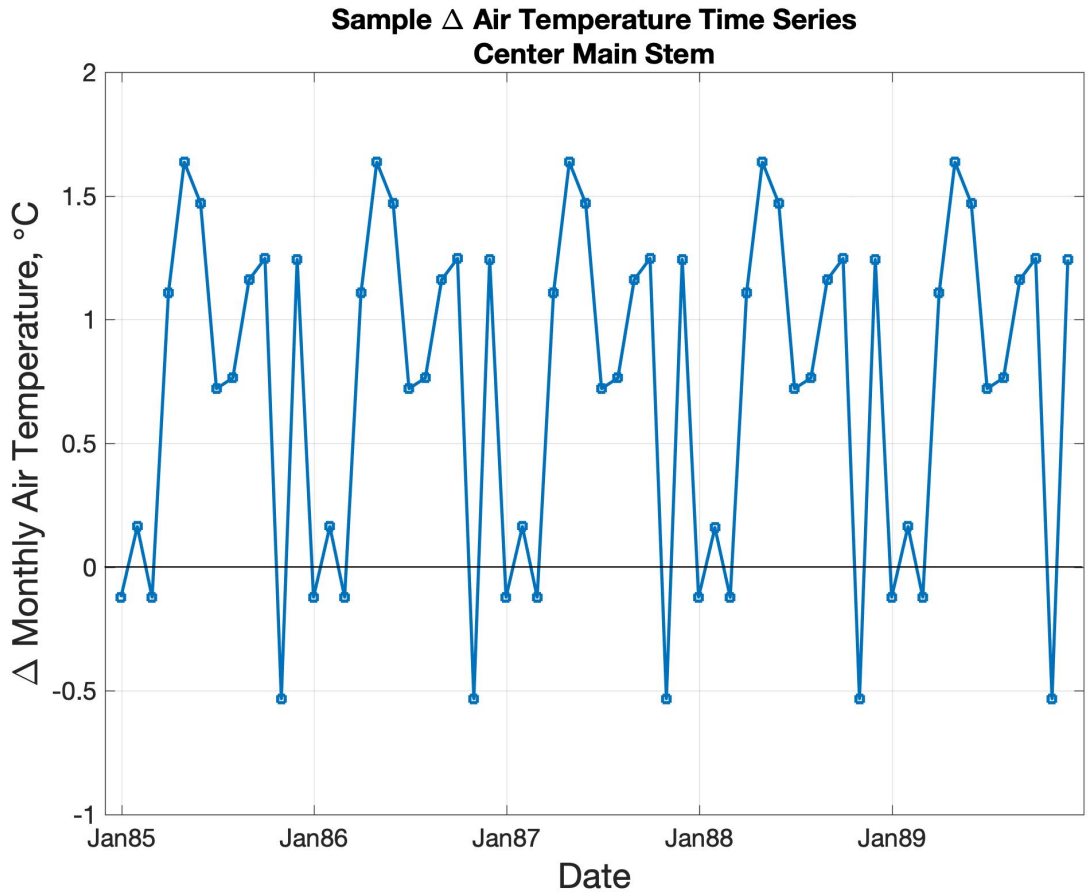
- Calculate the average monthly increase for all ChesROMS atmospheric grid cells



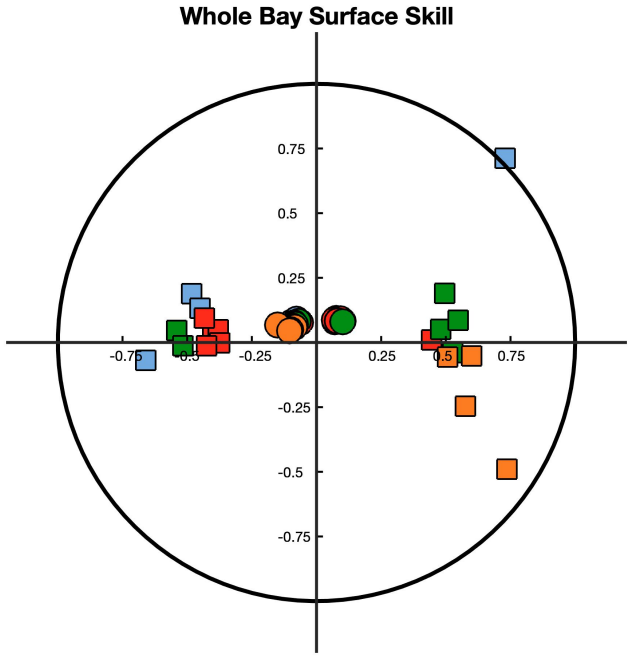
- Apply the calculated delta to model atmosphere (ocean, river) inputs for sensitivity experiment

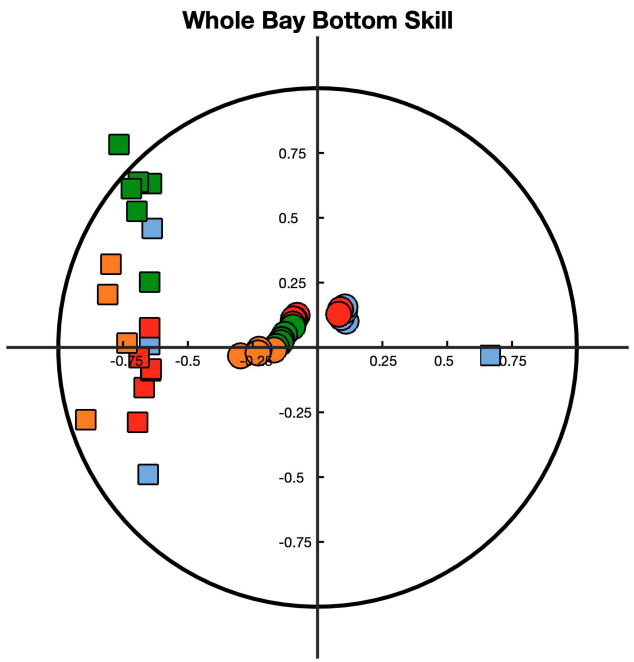


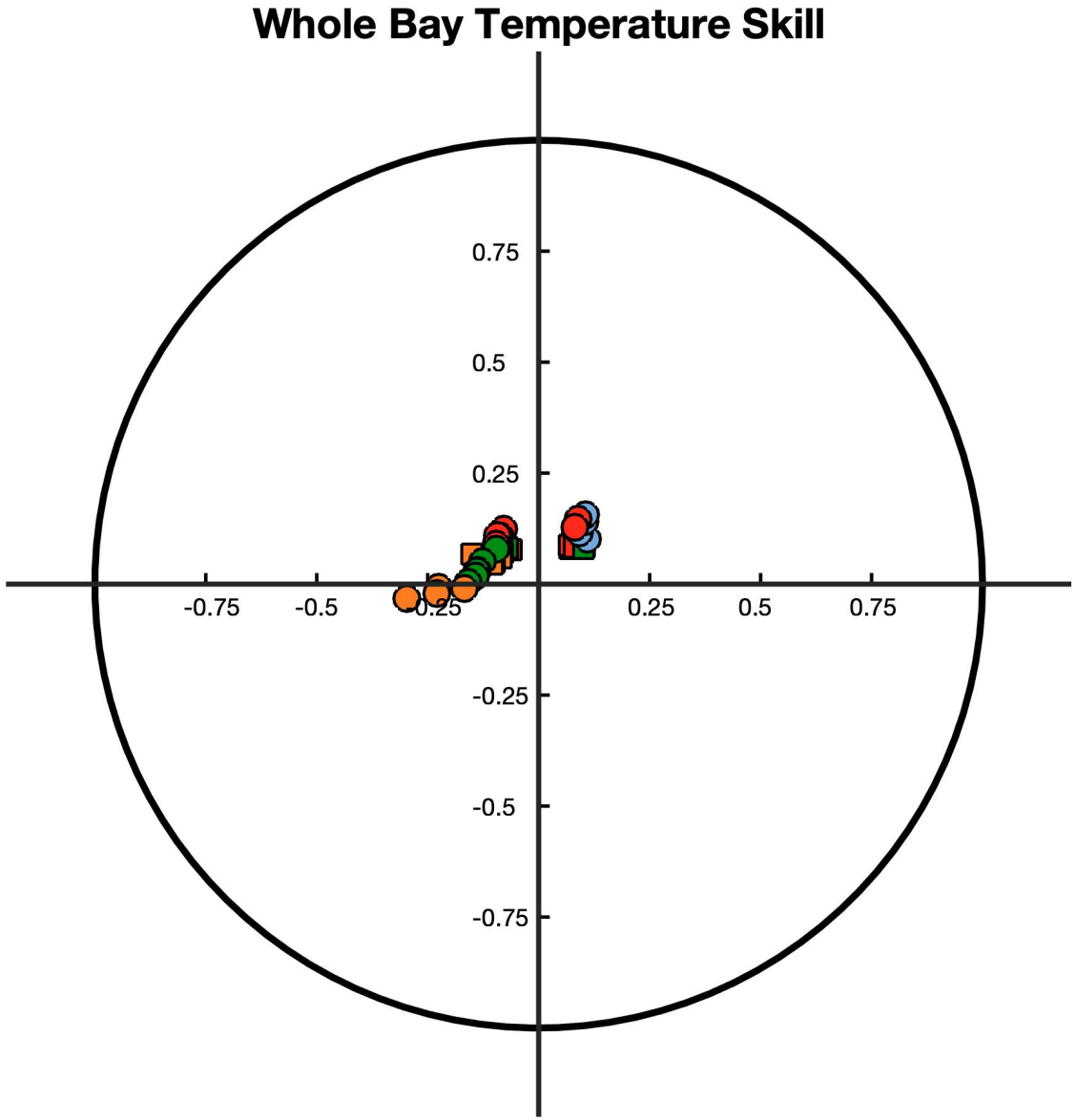




- Apply the calculated delta to model atmosphere (ocean, river) inputs for sensitivity experiment


Whole Bay Surface Skill
0.75
0.5
0.25
-0.25
-0.5
-0.75
0.25
0.75


Whole Bay Bottom Skill
0.75
0.5
0.25
-0.25
-0.5
-0.75
0.25
0.5
0.75


Whole Bay Temperature Skill
0.75
0.5
0.25
-0.25
-0.5
-0.75
-0.75
-0.5
0.25
0.5
0.75

How well does ChesROMS-ECB match observed temperatures?

- Model performs best in southern Bay at both surface and bottom
- Greater difference between model and observations in northern mainstem at surface and bottom