Long-term changes in coastal oxygen: impacts from global and local anthropogenic stressors

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With contributions from many!

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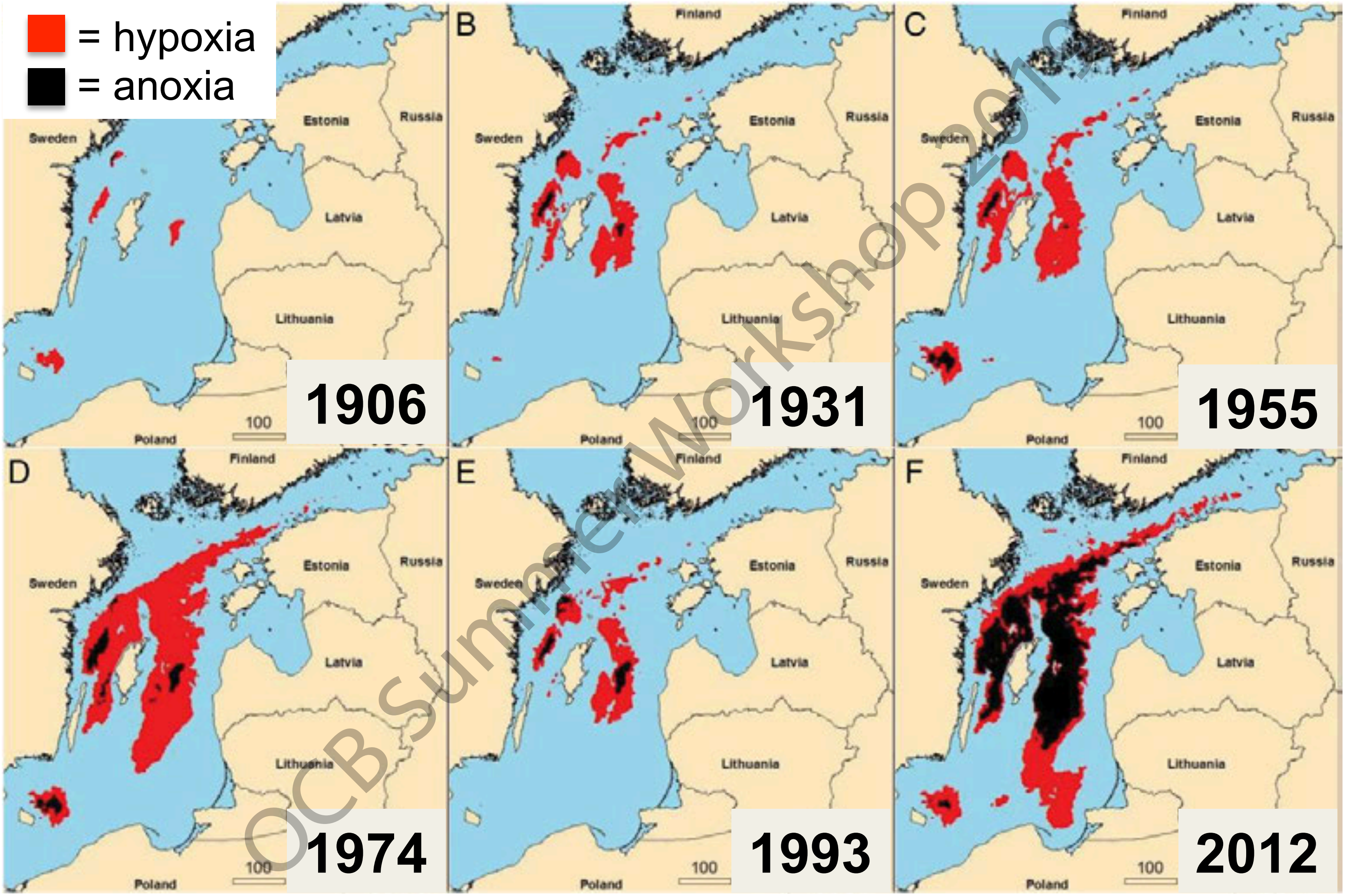
VIMS | William & Mary

Virginia Institute of Marine Science

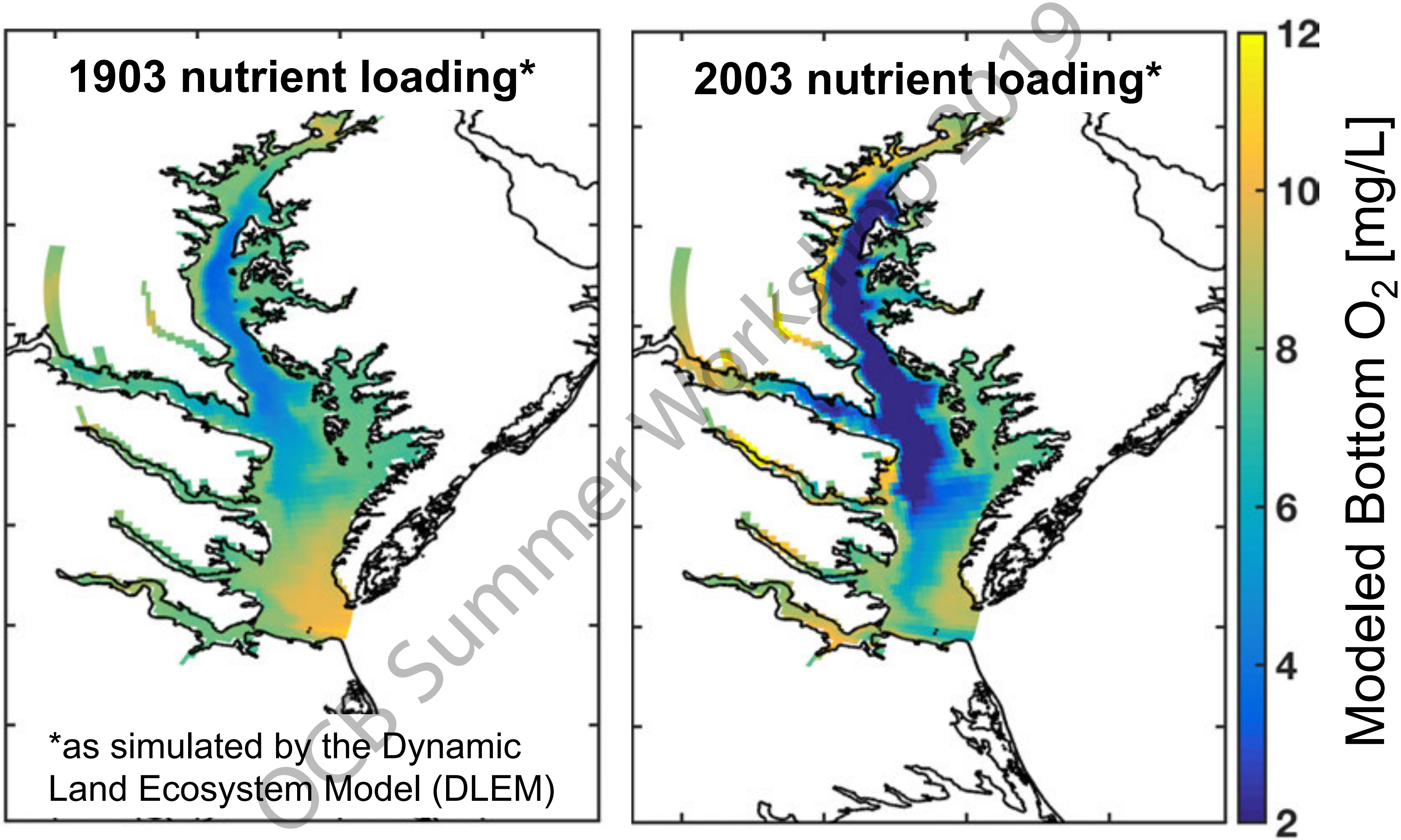
Increasing Baltic Sea hypoxia/anoxia



Spatial distribution of annual mean bottom hypoxia and anoxia over time in the Baltic Sea.

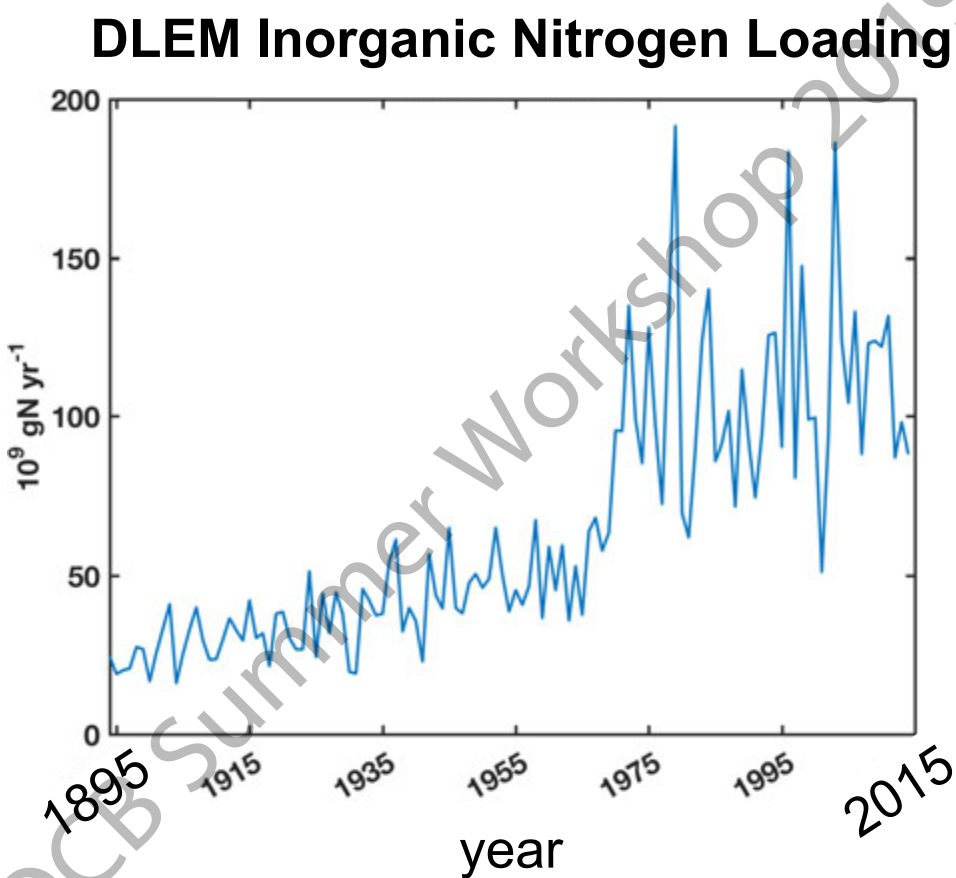
Jacob Carstensen et al. PNAS 2014

Decreasing Chesapeake Bay Bottom Oxygen (July)



→ Decreased bottom O_2 in deep mainstem

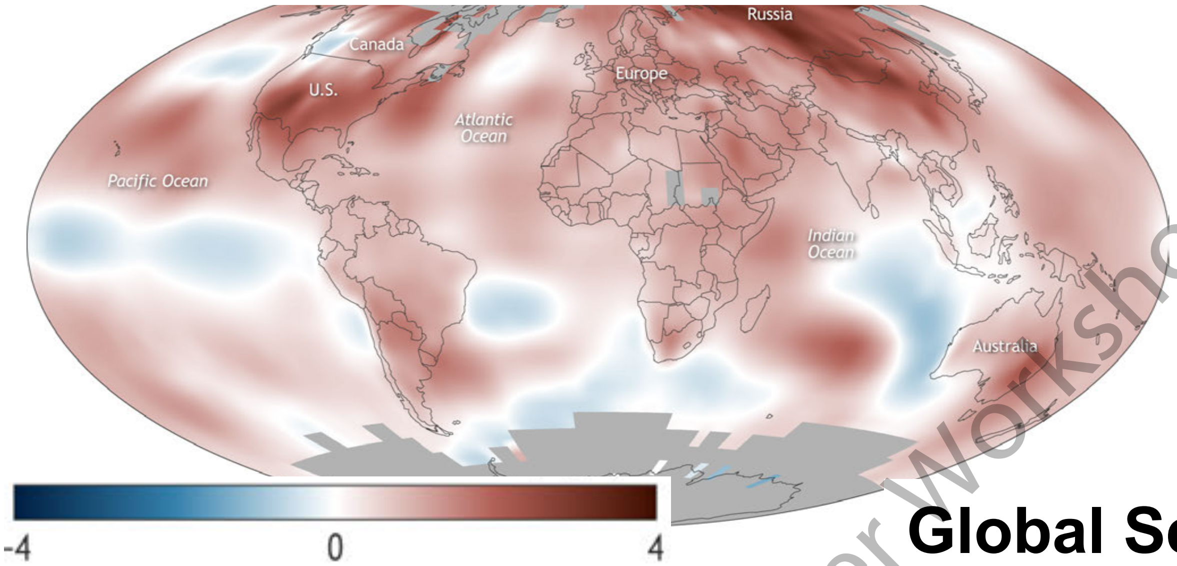
Local Anthropogenic Changes
from the Dynamic Land Ecosystem Model (DLEM)



→ Large 1960s increase in DIN loading
→ Recent decreases in DIN loading

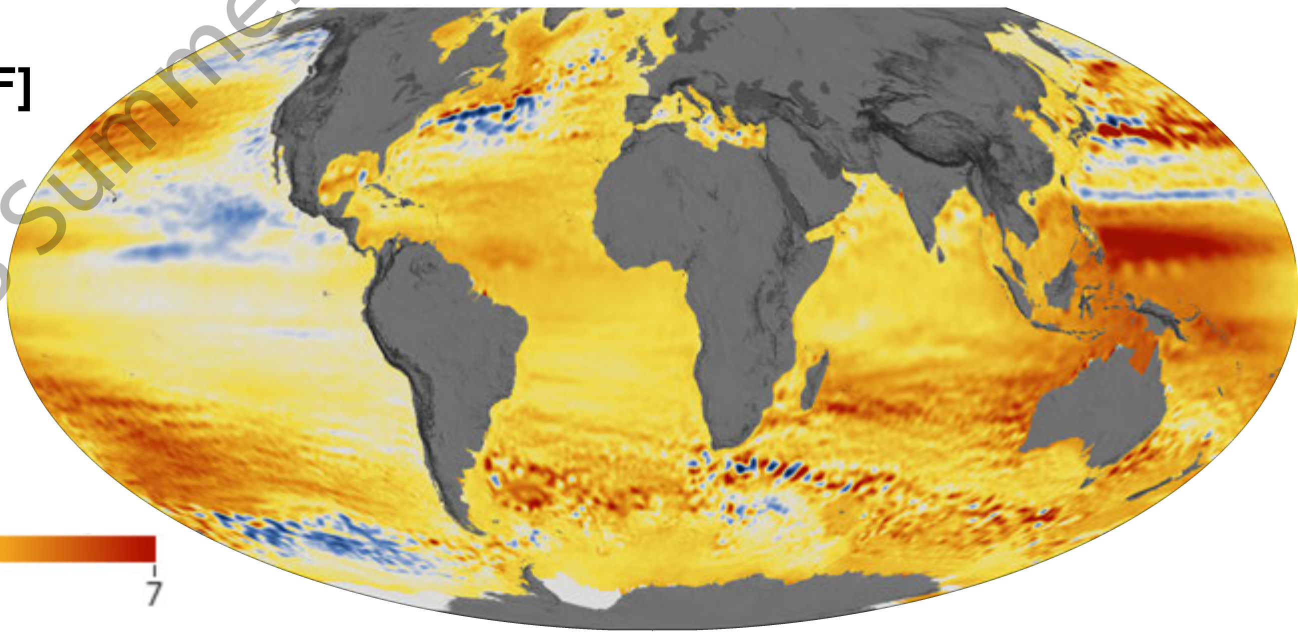
Global Anthropogenic Changes

Global temperature change

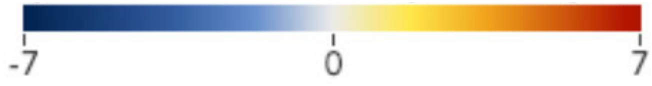


T_{atm} difference between 2017 & 1981-2010 mean [°F]

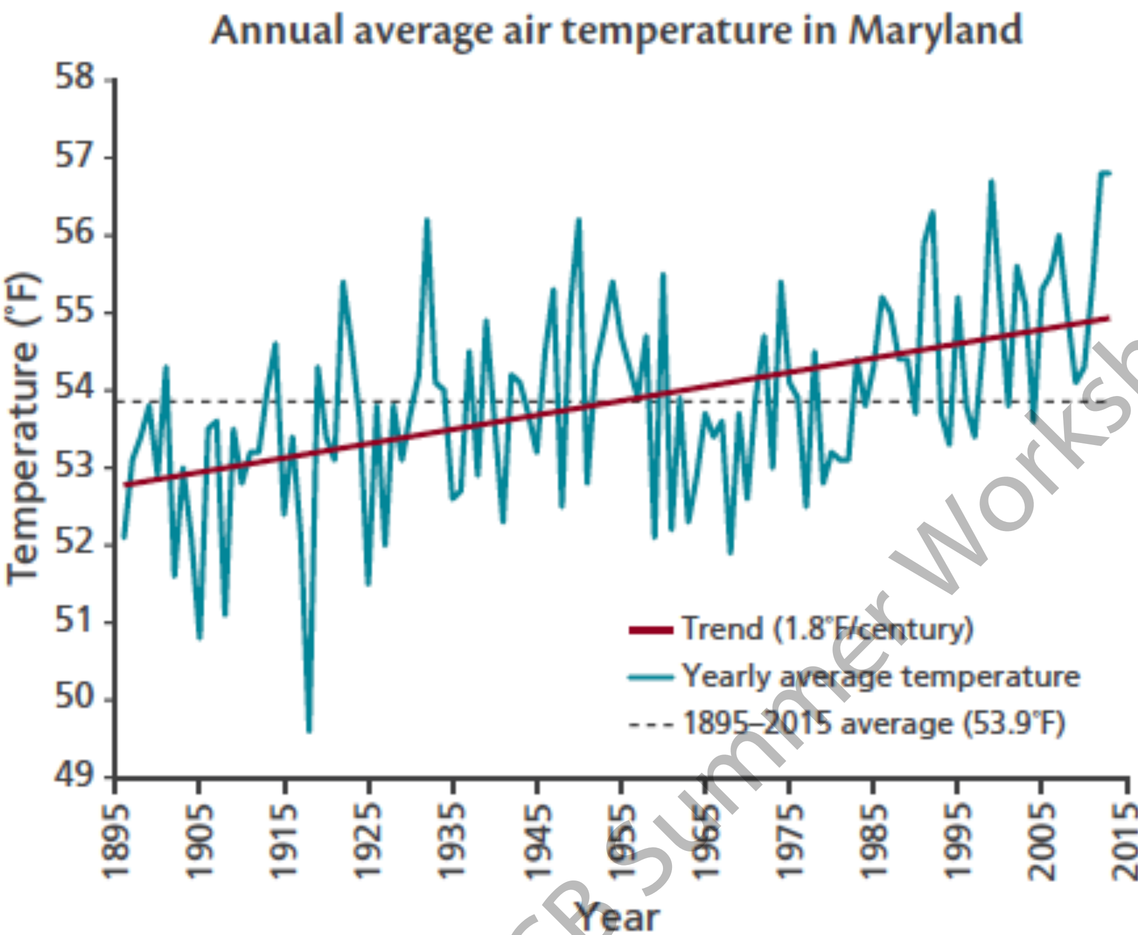
Global Sea Level Rise (SLR)



SSH difference 2014 – 1992 [cm]



Chesapeake Bay T_{atm} and Sea Level Change



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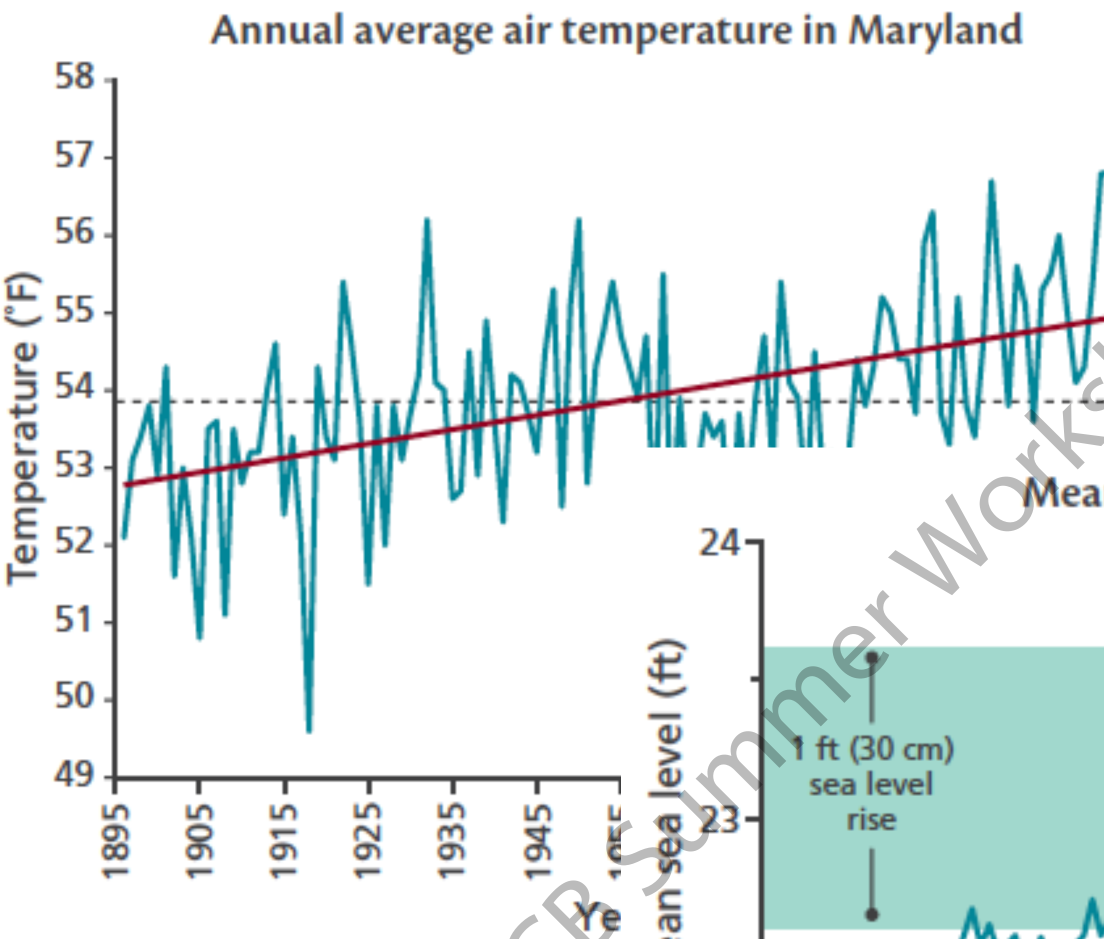

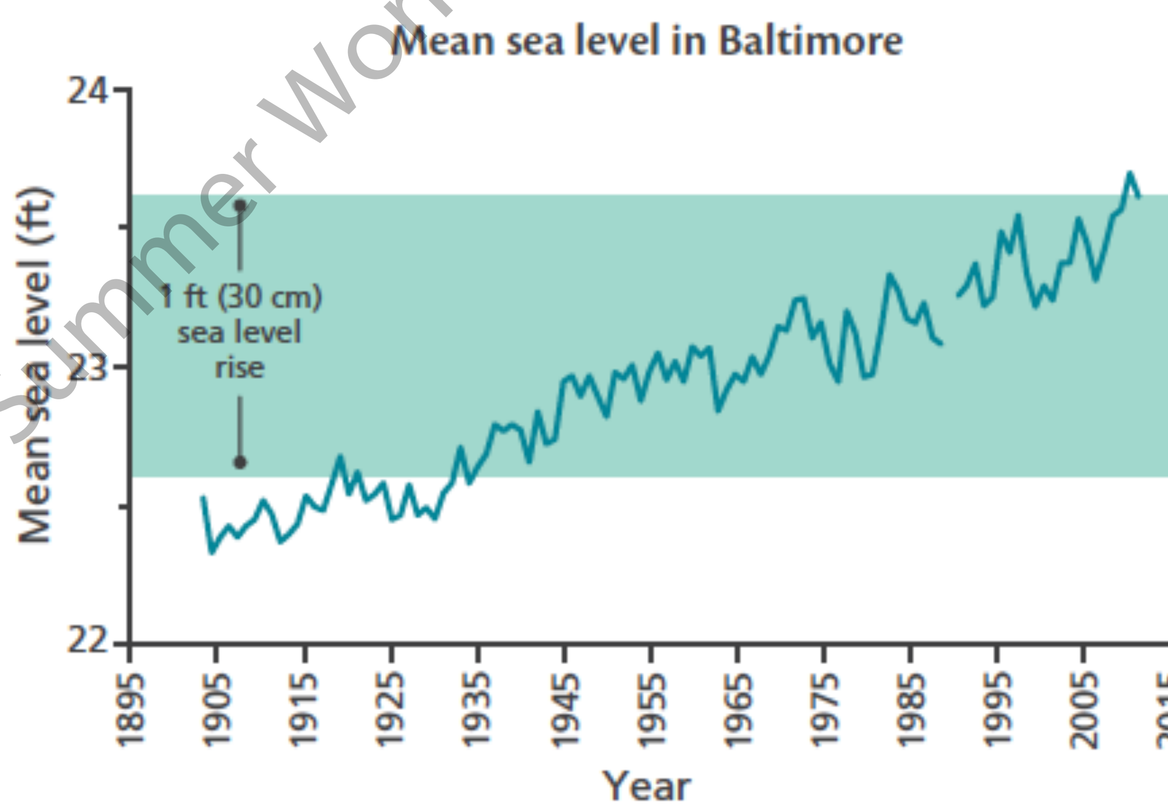

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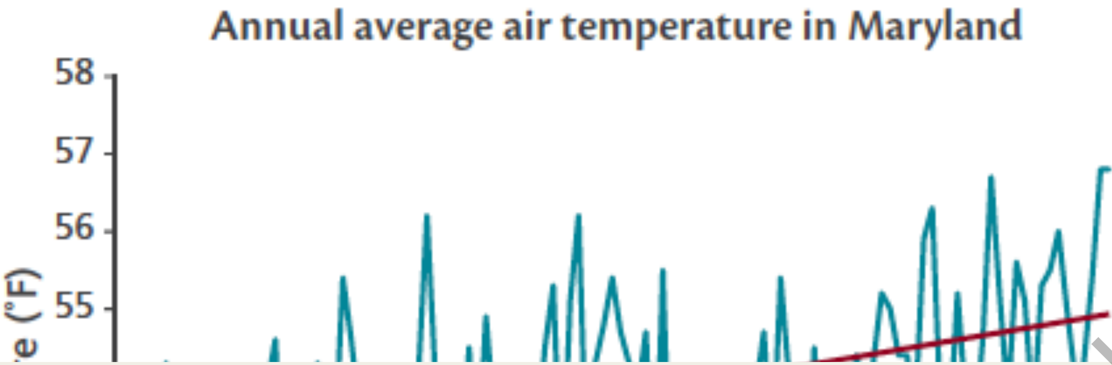
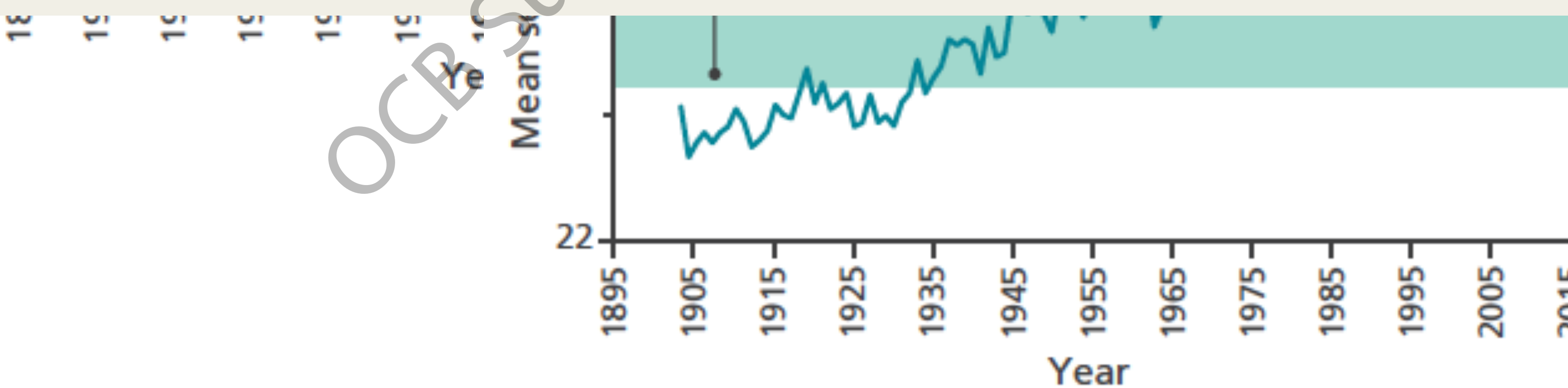


Over the next century, how will these local and global anthropogenic changes impact coastal oxygen, given the complex feedbacks between the multiple physical, chemical and biological processes involved?



Significant management interest in Chesapeake Bay oxygen

Managers want to know:

- **How much more difficult will it be to meet our oxygen restoration goals, when we account for climate change?**
- **How much greater would our progress be if climate change wasn't underway?**

Management model results

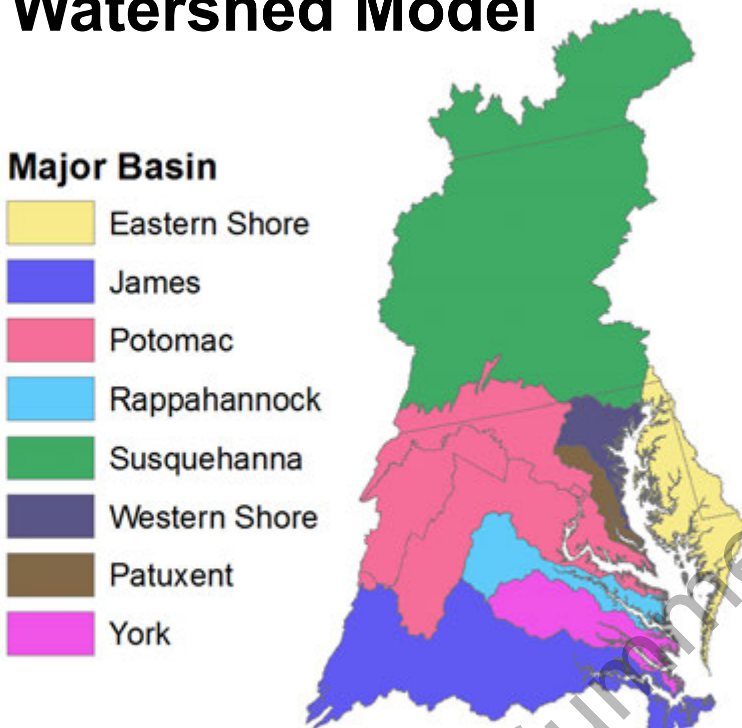
- **CBP used their watershed-hydrodynamic-water quality modeling system**
- **Preliminary results showed:**

→ Impact climate change < impact of nutrient reductions
→ Climate change *increased* bottom oxygen, primarily due to sea level rise

Redo climate change experiments with another modeling system forced with identical watershed model outputs – do the results agree?

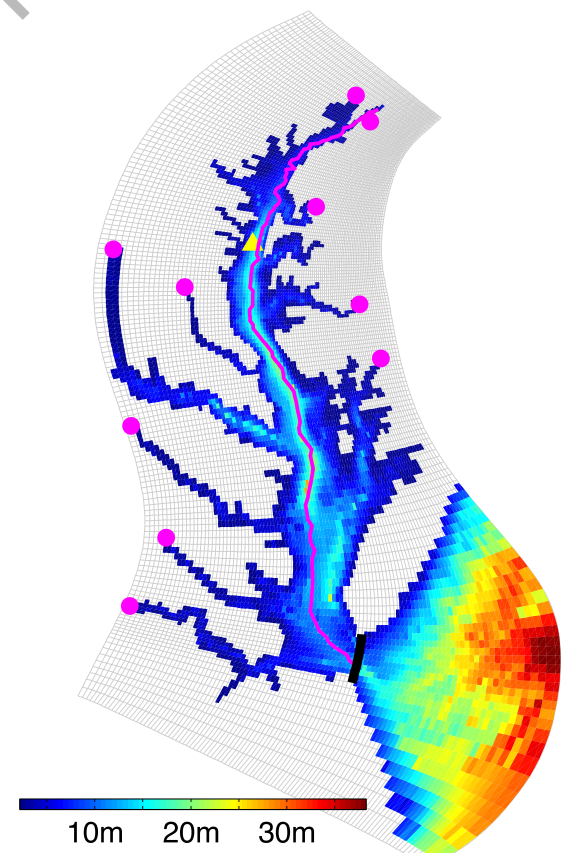
Irby et al. (Biogeosciences, 2018)

Chesapeake Bay Program's
Watershed Model



(Shenk and Linker, 2013)

ChesROMS-ECB



(Feng et al., 2015; Da et al., 2018)

- **Realistic nutrients (Base run)**
- **Reduced nutrients (TMDL)**
- **1990's climate (T, SLR, rivers)**
- **2050's climate (T, SLR, rivers)**

Irby et al. (Biogeosciences, 2018)

In 2050, relative to 1990s, assume:

Water Temperature

1.75°C

Everywhere in water column

Muhling et al., 2017

Sea Level Rise

0.5m

At open boundary

Hong & Shen 2012

River discharge

~10-15%

mostly in Nov-Feb

CBP, 2017

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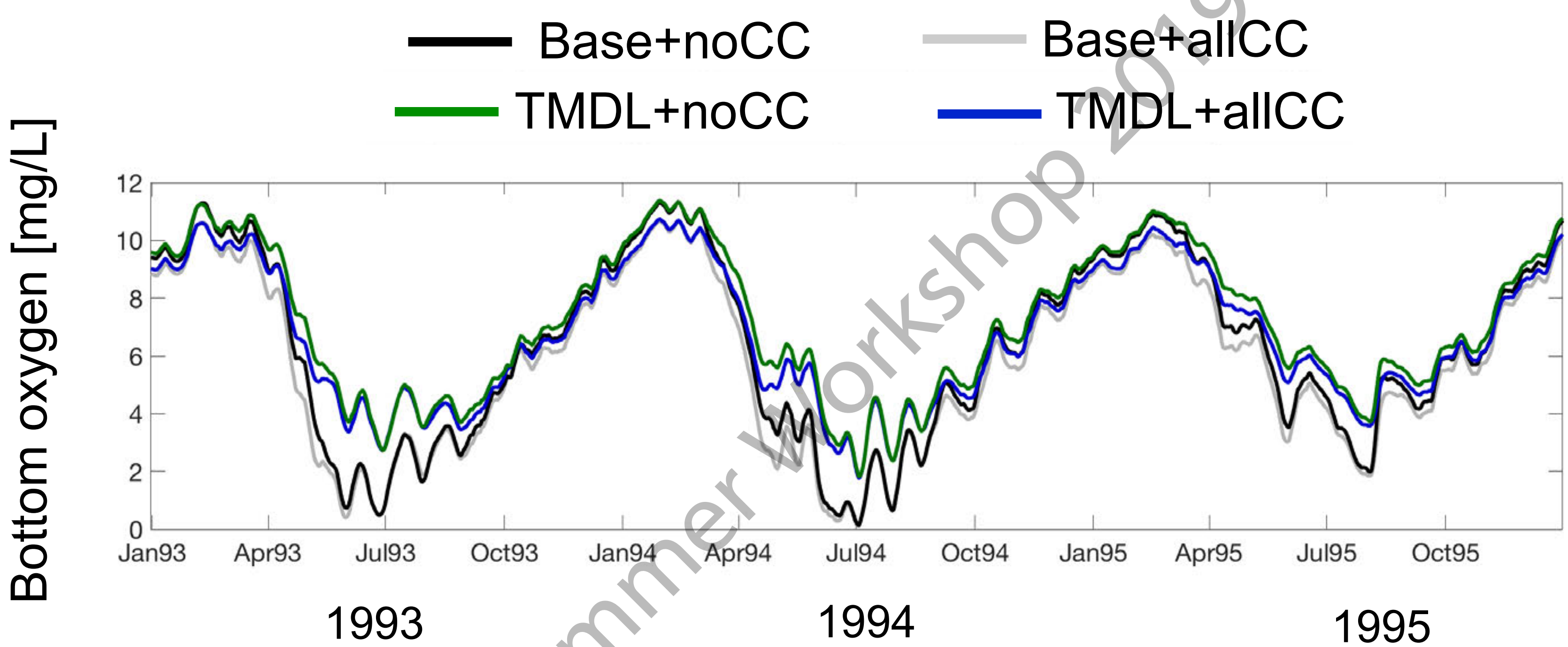
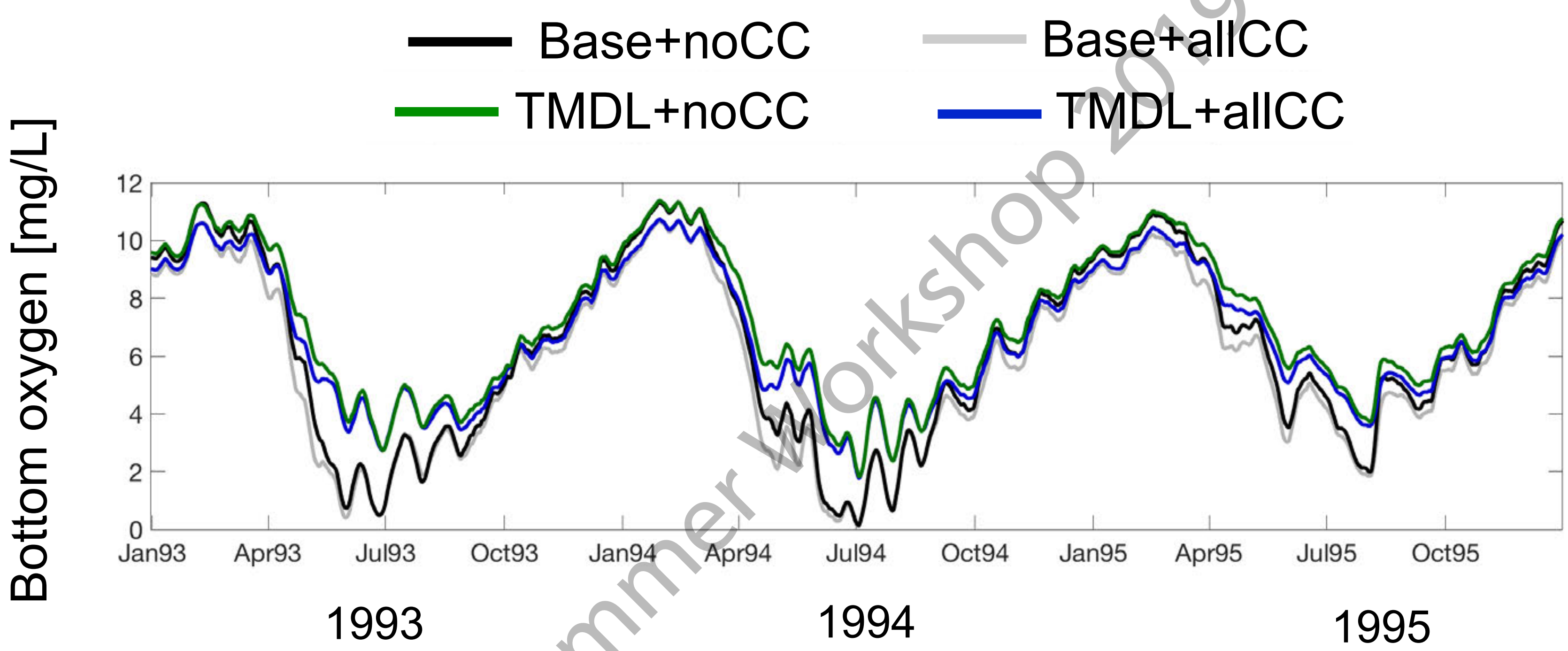


- Climate change impact on bottom O_2 << impact of nutrient reductions
  → *same result as CBP model*
- Climate change decreased bottom O_2
  → management efforts are going to have to be greater than we originally thought (*opposite result from CBP model!*)

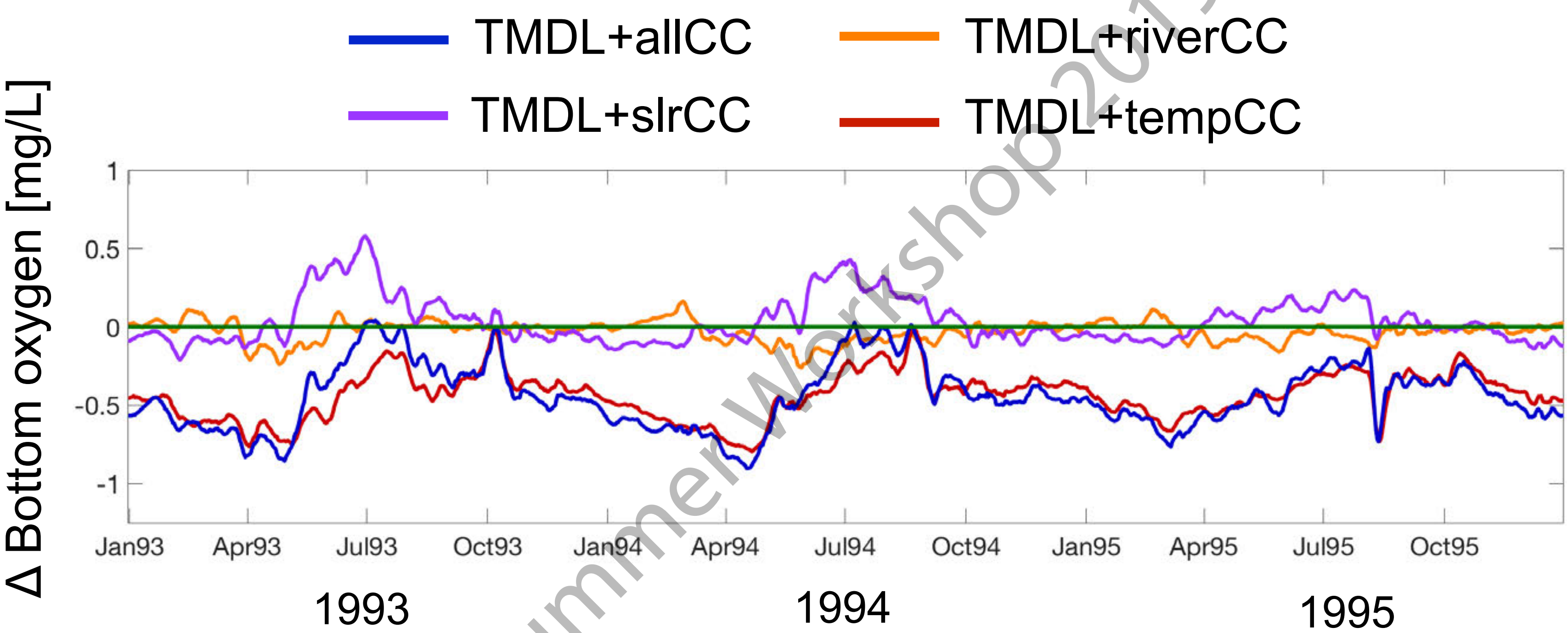
Irby et al. (Biogeosciences, 2018)



Which mechanism causes lower O_2 concentrations?
Temperature? SLR? Rivers?

→ Three more experiments to isolate individual mechanisms

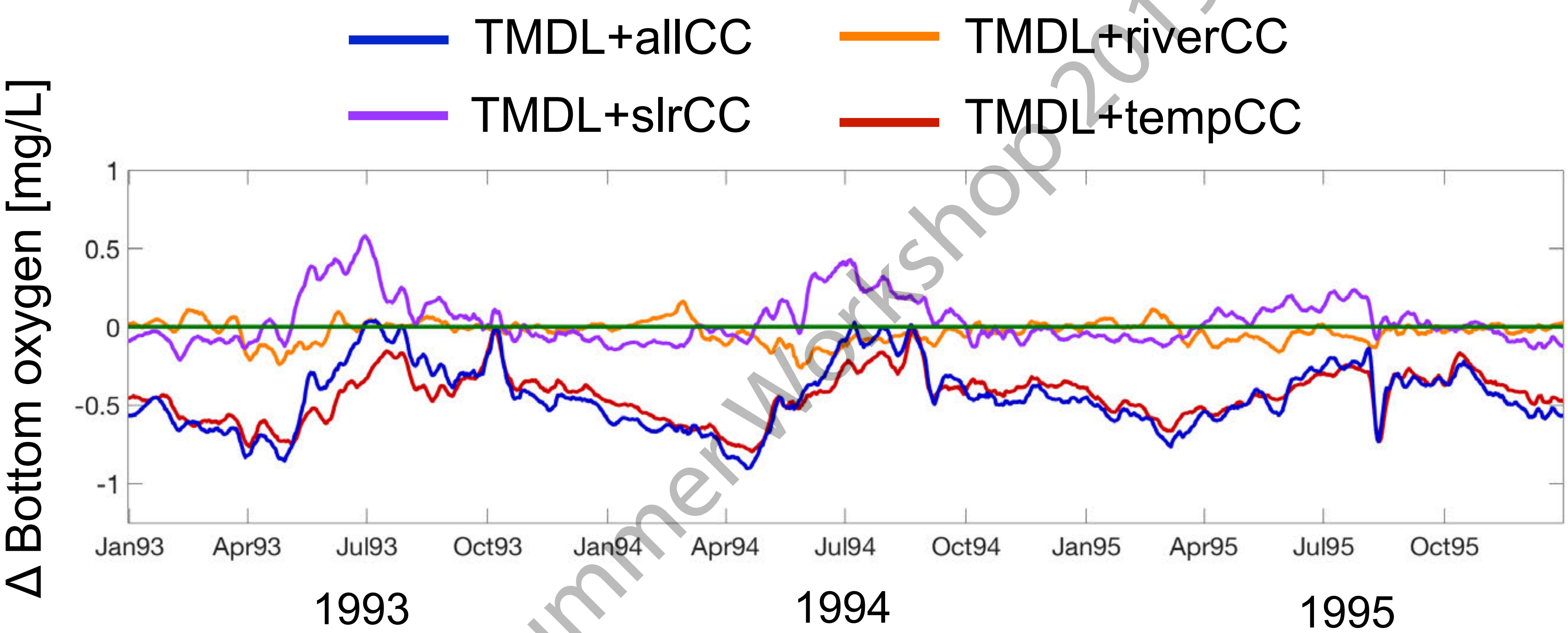
Irby et al. (Biogeosciences, 2018)



- **2050 temperature** decreases oxygen

→ **Temperature has greatest impact on hypoxia, mostly (75%) due to solubility**

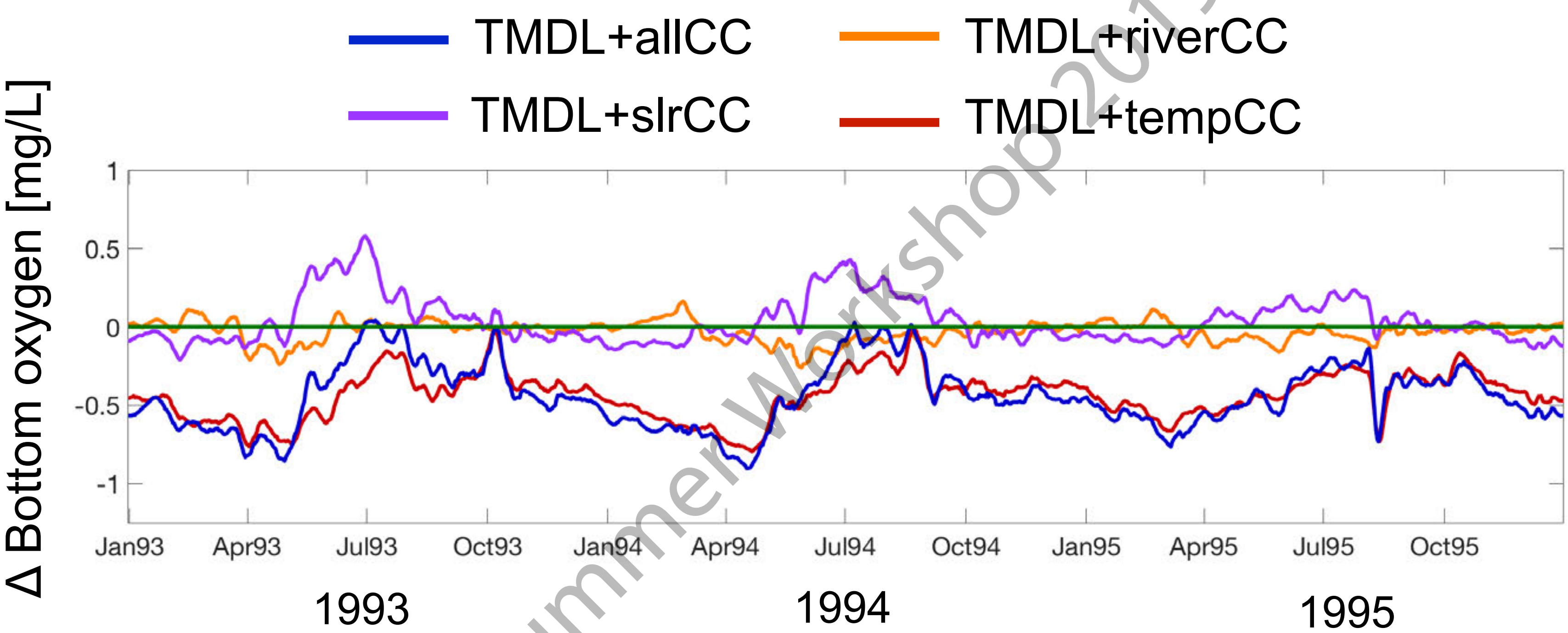
Irby et al. (Biogeosciences, 2018)



- **2050 temperature** decreases oxygen

→ Original CBP results had underestimated coastal ocean warming

Irby et al. (Biogeosciences, 2018)



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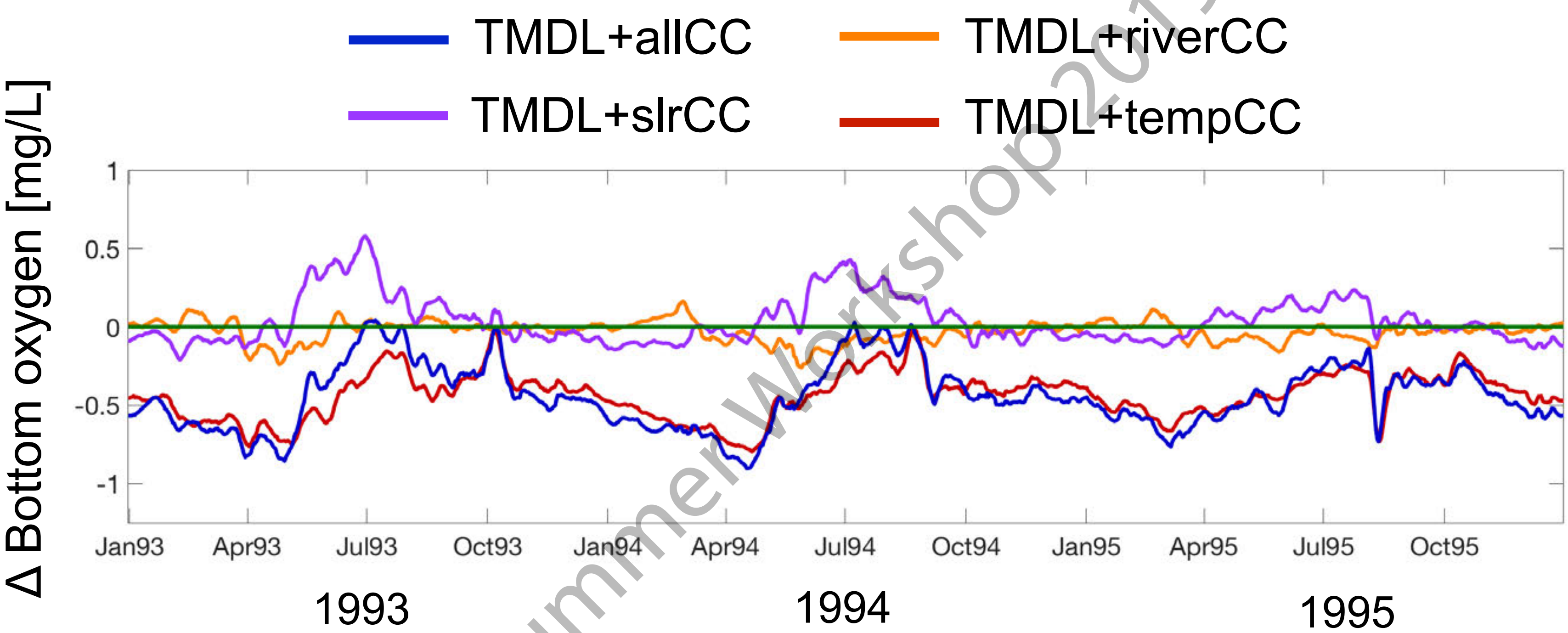
- **2050 rivers/precip** causes small change in oxygen

Irby et al. (Biogeosciences, 2018)



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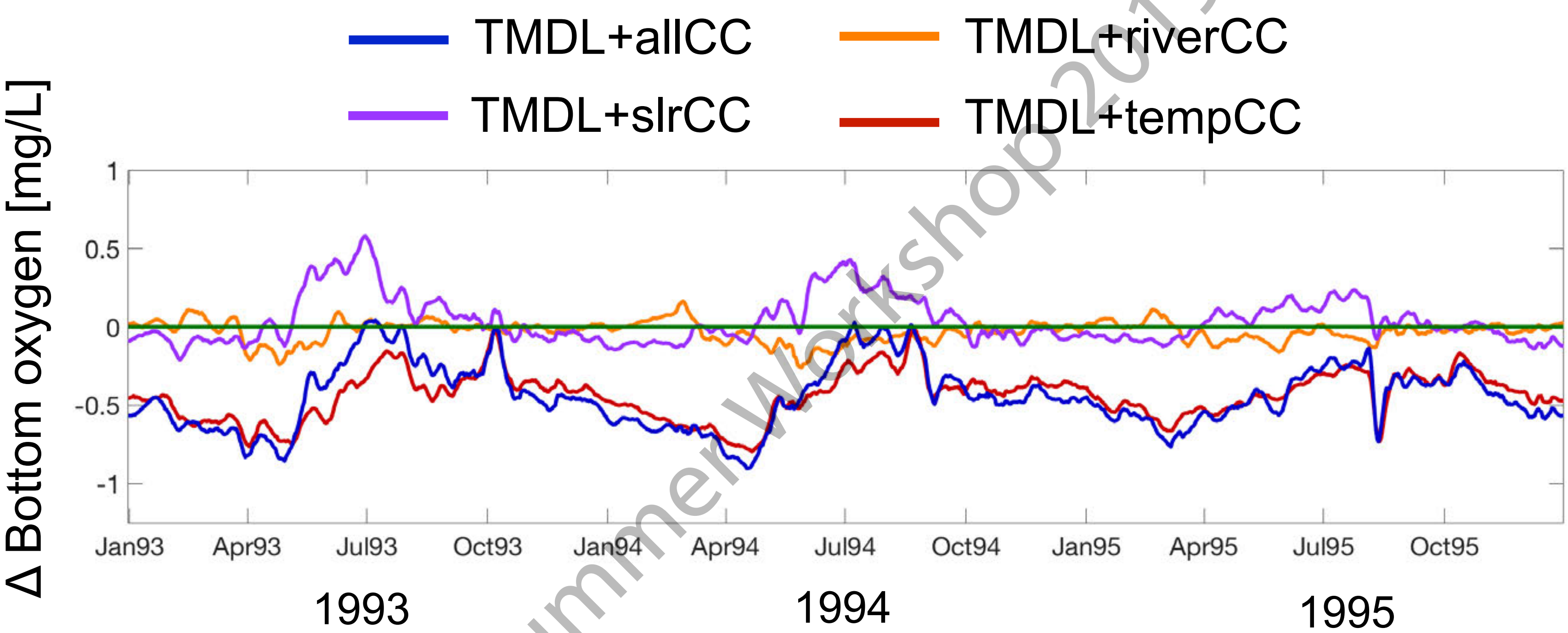

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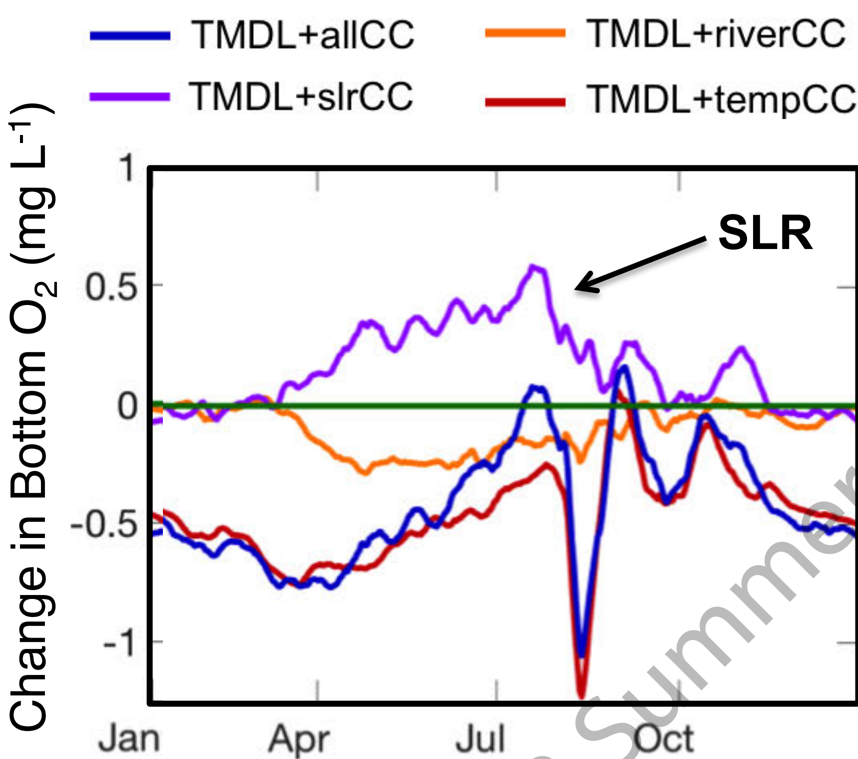
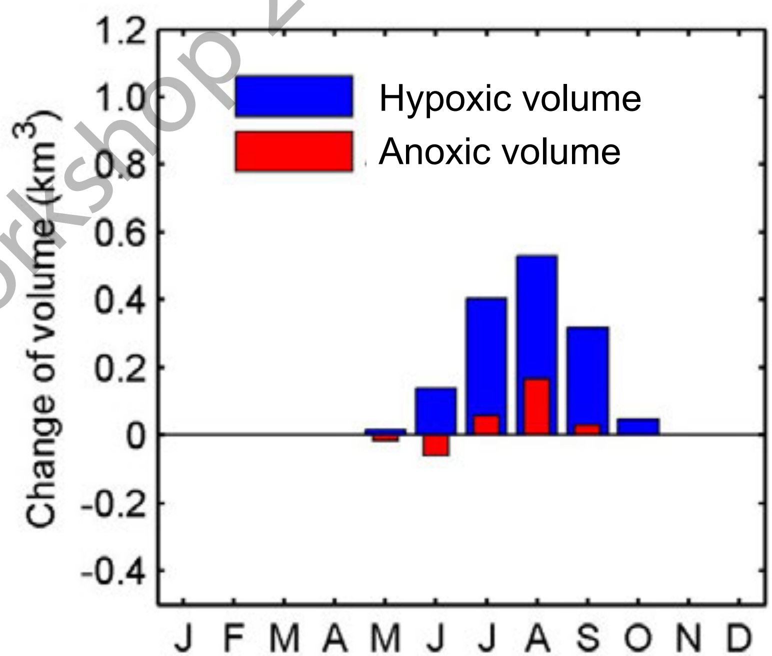
→ Why does SLR increase bottom oxygen?

St-Laurent, in prep.

Impacts of SLR on oxygen: Differences between 2050 and 1995



***Ches*ROMS-ECB**
Irby et al., 2018



UMCES-ROMS-RCA
Ni et al., 2018

SLR increases bottom O_2

SLR decreases O_2

St-Laurent, in prep.

Why do we see opposite results in two ROMS-based models?

- Both models indicate SLR causes increases estuarine circulation
- Why opposite effects on O_2?

Original hypothesis:

- One model shows SLR ***increases*** O_2 because more ***high oxygen*** water is advected in from shelf
- One model shows SLR ***decreases*** O_2 because more ***high salinity*** water is advected in from shelf

St-Laurent, in prep.

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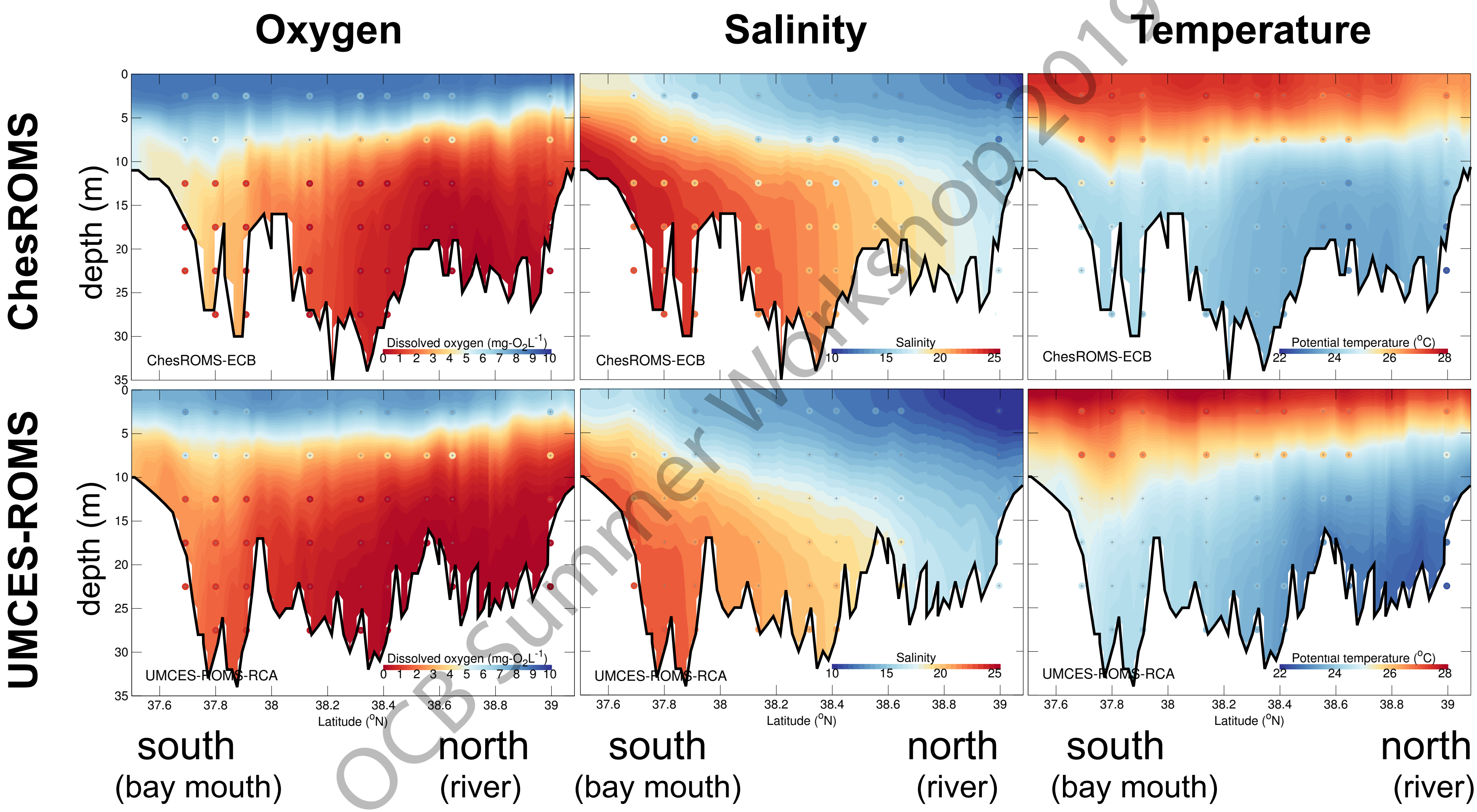
St-Laurent, in prep.

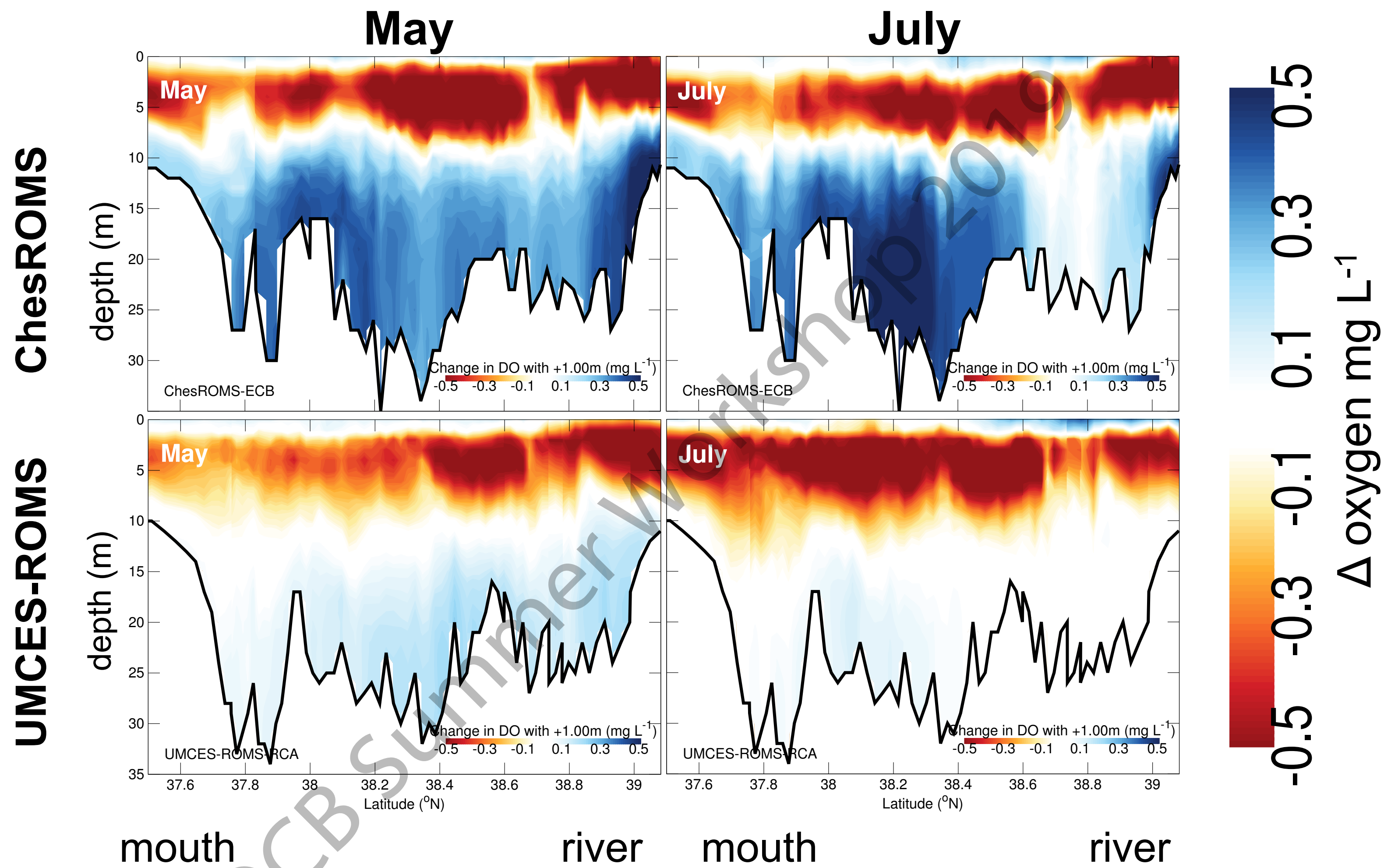
Relative skill of two models
(mean July conditions)



→ Both models reproduce observations similarly well

St-Laurent, in prep.

How does modeled O_2 respond to 1m SLR?



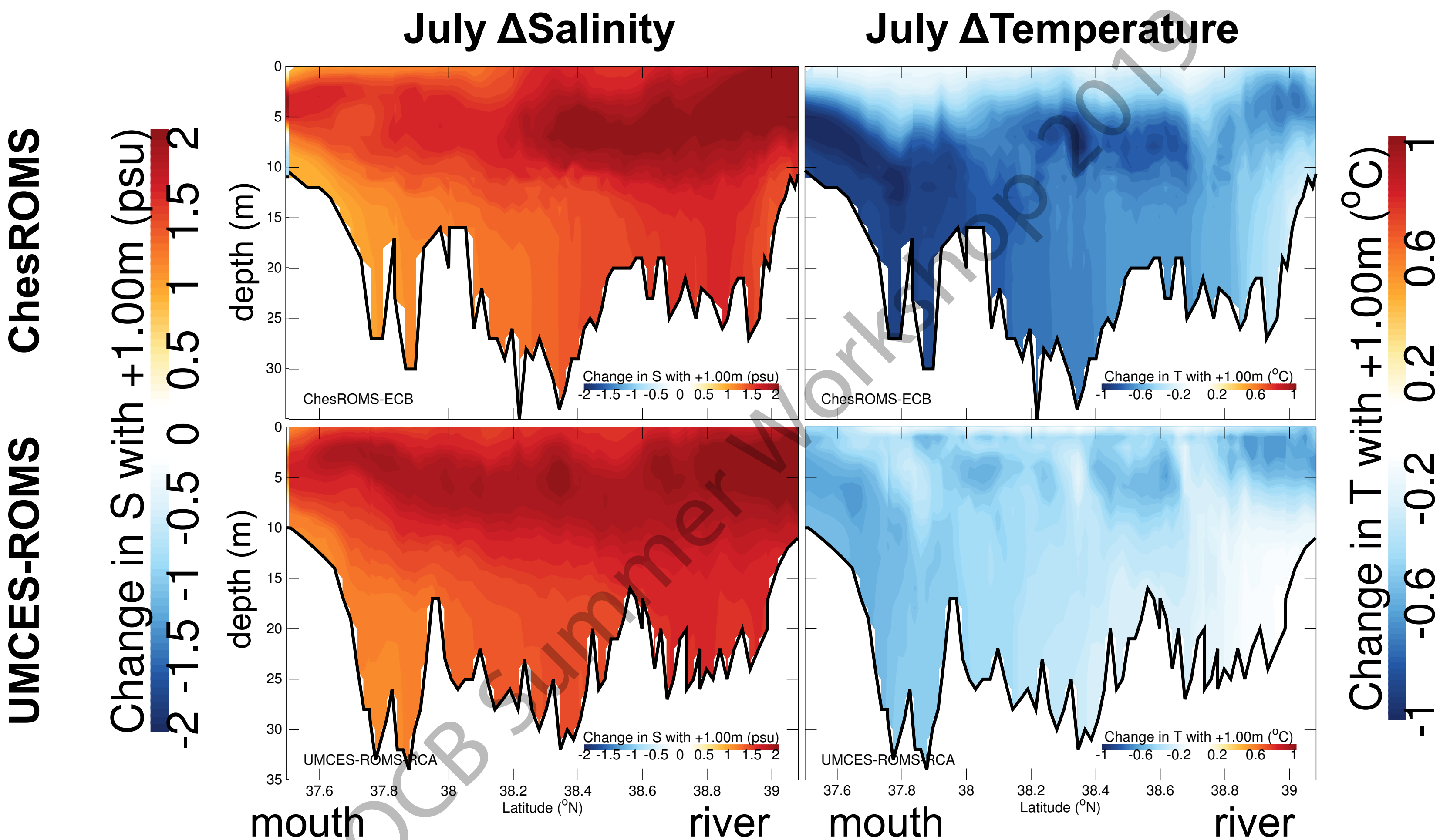
→ Both models show O_2 decreasing in upper waters, increasing at depth

→ ChesROMS shows much greater increase at depth

→ Why? Physics? Biology? Chemistry?

St-Laurent, in prep.

How does modeled T and S respond to 1m SLR?



→ Both models show similar increase in salinity
→ ChesROMS shows greater decrease in July ***temperature***
→ Why?

St-Laurent, in prep.

Why do we see opposite results in two ROMS-based models?

Revised hypotheses:

Different physics (vertical mixing):

ChesROMS - cold water advected in from shelf in summer reduces respiration, O_2 increases

UMCES-ROMS - higher vertical mixing causes surface heat fluxes to warm cold water entering from shelf, before it reaches the deep hypoxic trench region; no O_2 increase

Different biology (respiration):

ChesROMS-ECB has a respiration rate that is more sensitive to temperature change than that used in UMCES-ROMS-RCA.

Colder waters entering from shelf cause a greater decrease in respiration rate (O_2 increase) for ChesROMS-ECB than for UMCES-ROMS-RCA.

St-Laurent, in prep.

Conclusions

- Oxygen response to planned nutrient reductions >> oxygen response to climate change
- But restoring the Bay to previous oxygen concentrations will be slightly harder with climate change, because….

Conclusions (cont.)

- Warming bay waters will *decrease* O_2
  - → **decreased solubility year-round, throughout Bay**
  - → **increased respiration/remineralization rates in spring**
- Changing river inputs will only slightly change O_2
- Increasing sea level – results still unclear:

  Preliminary results suggest this depends on assumptions:

  Physics - vertical mixing rates
  Biology - temperature dependence of O_2 consumption

Conclusions (cont.)

- **Both local and global anthropogenic changes are affecting estuarine O_2 in complex ways**
  → through physical, chemical, and biological processes

- **Important to use multiple models when working with managers and with complex modeling systems**

- **Possible to work with managers and do meaningful, interesting science!**

Extra Slides