Coastal deoxygenation in the northwest Atlantic due to a large-scale ocean circulation shift over the last century

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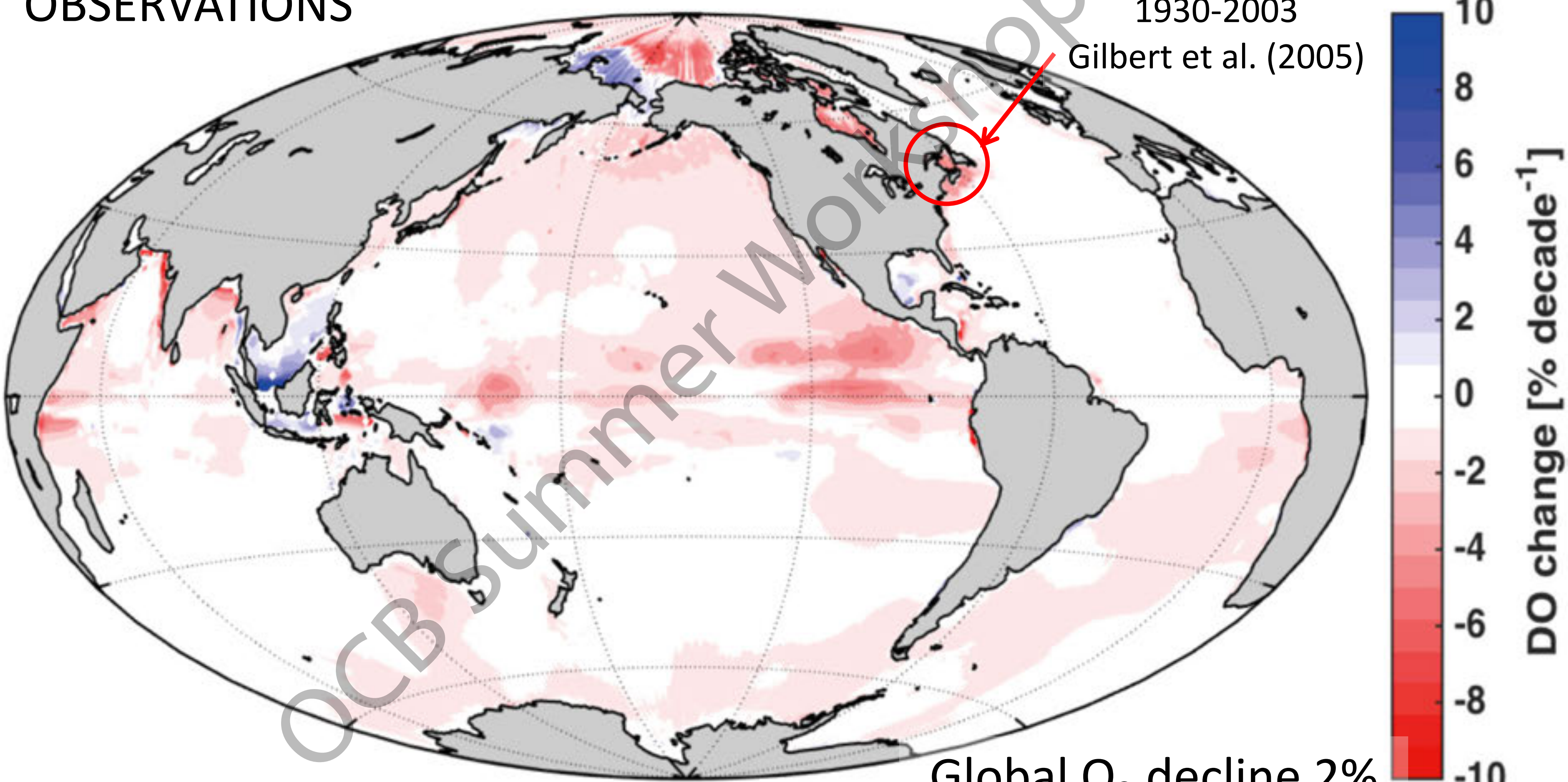
Katja Fennel (Dal), Denis Gilbert (DFO), John Dunne (NOAA)

OBSERVATIONS

O_2 decline 50%
1930-2003
Gilbert et al. (2005)

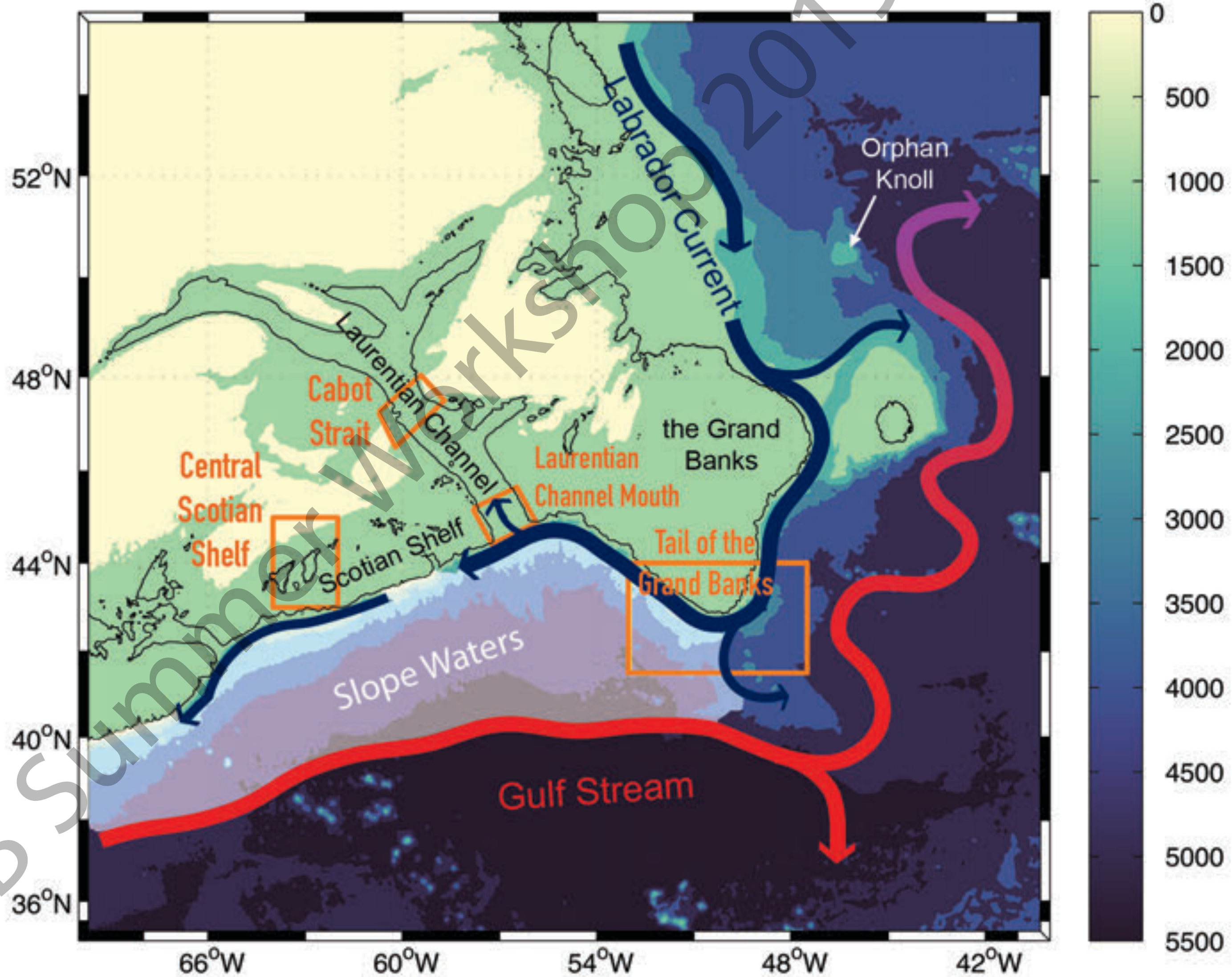


Global O_2 decline 2%
1960-2010

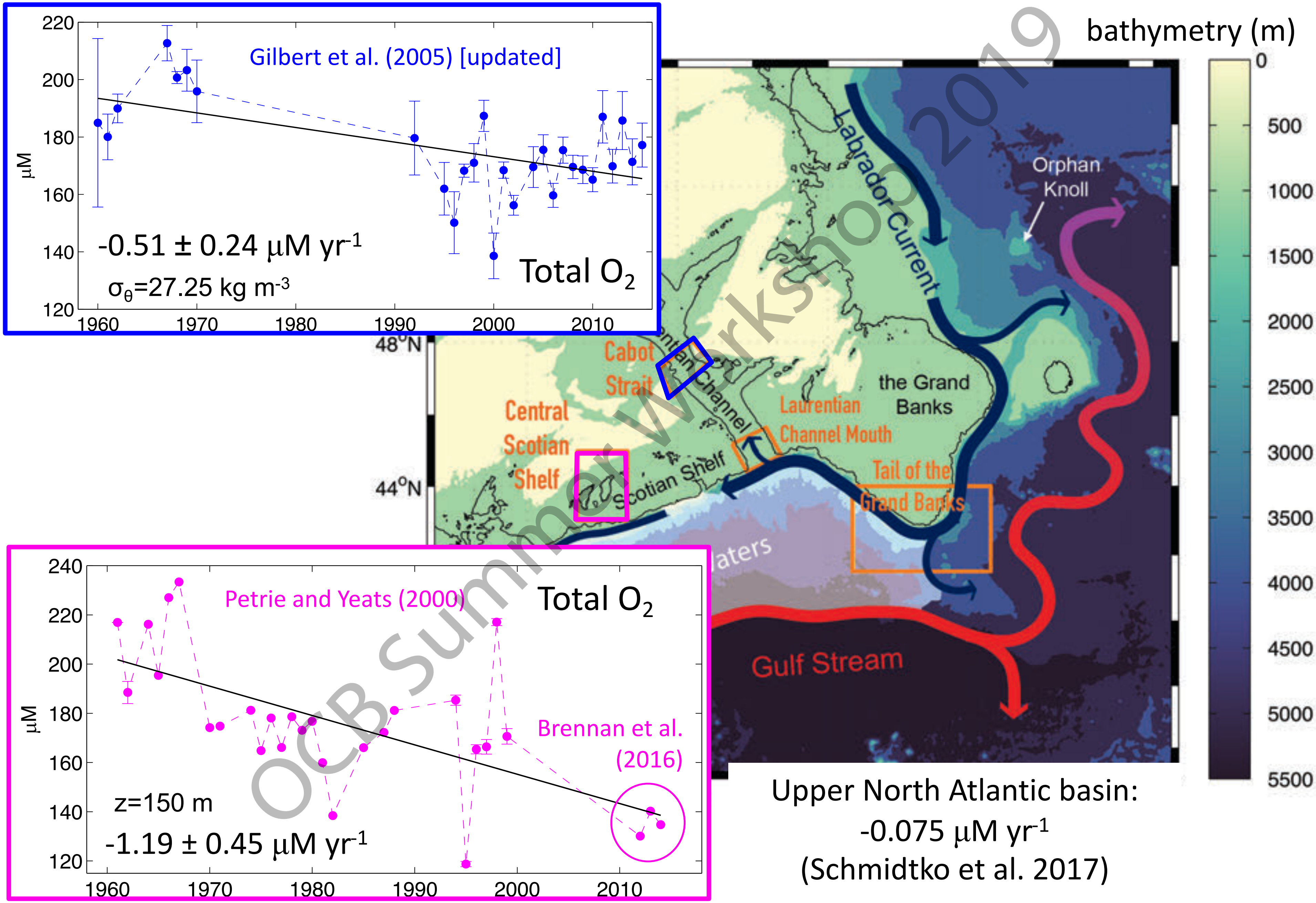
Schmidtko et al. (2017)

The NW Atlantic shelf circulation is influenced by large-scale currents

Near the crossroads of **oxygen-rich** subpolar waters (cold and fresh) of the Labrador Current and **oxygen-poor** subtropical waters (warm and salty) of the Gulf Stream

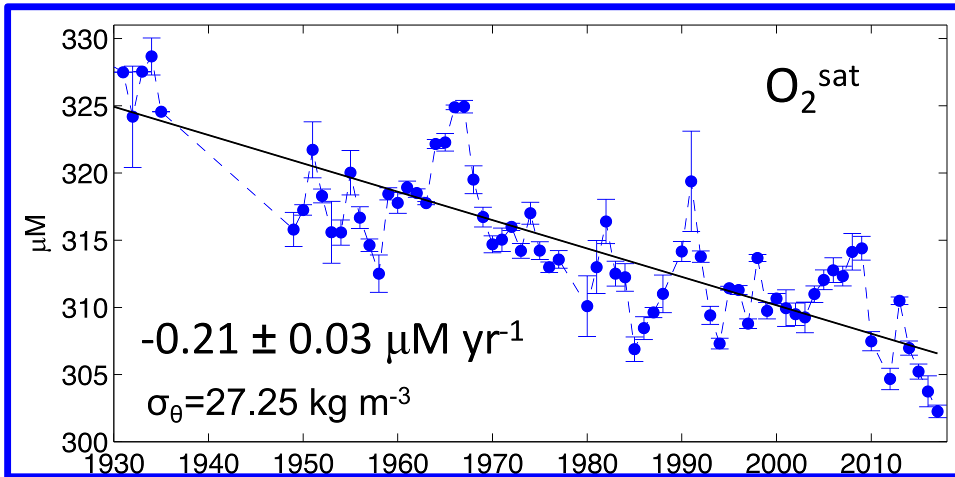


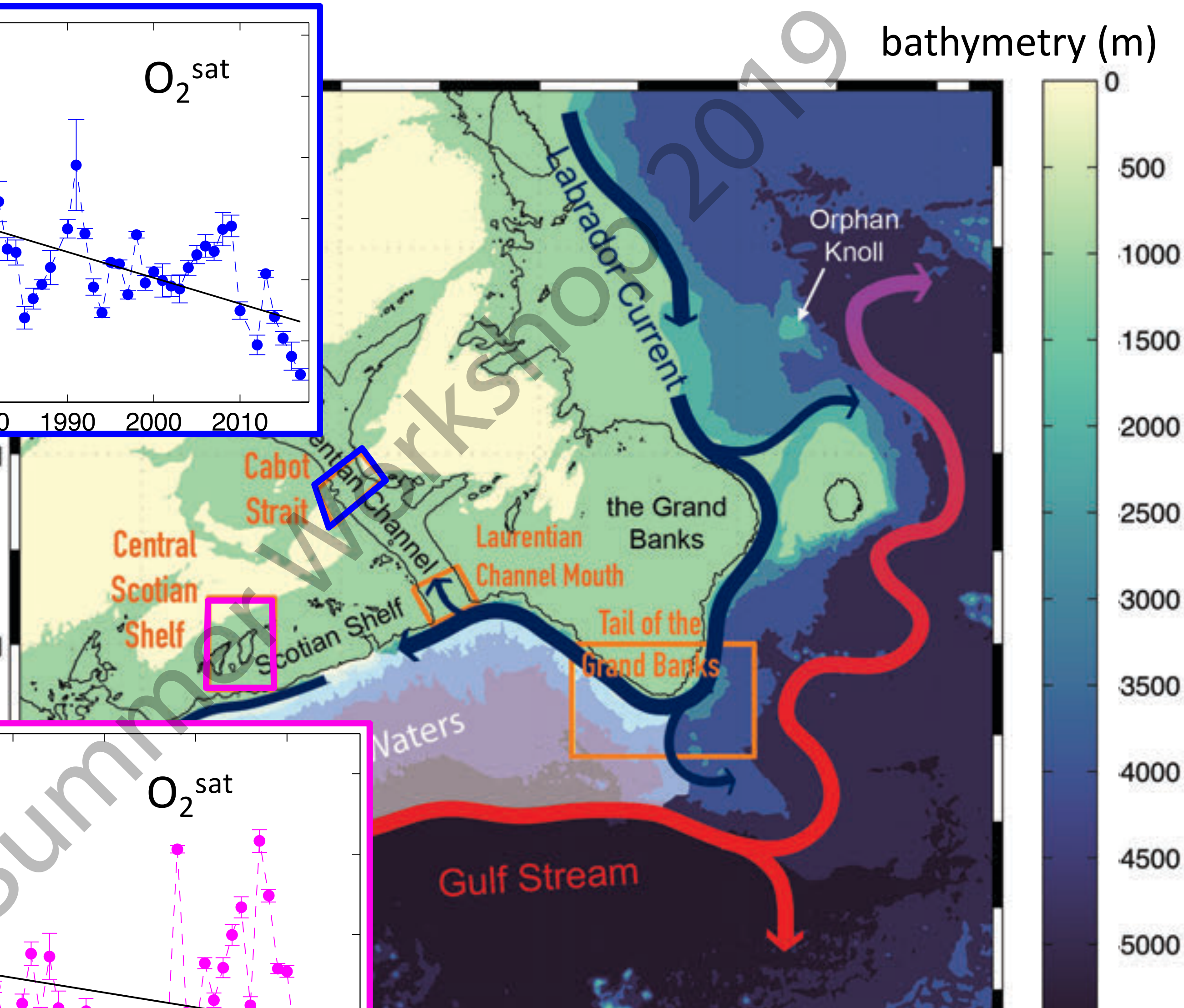
Long deoxygenation observational time series



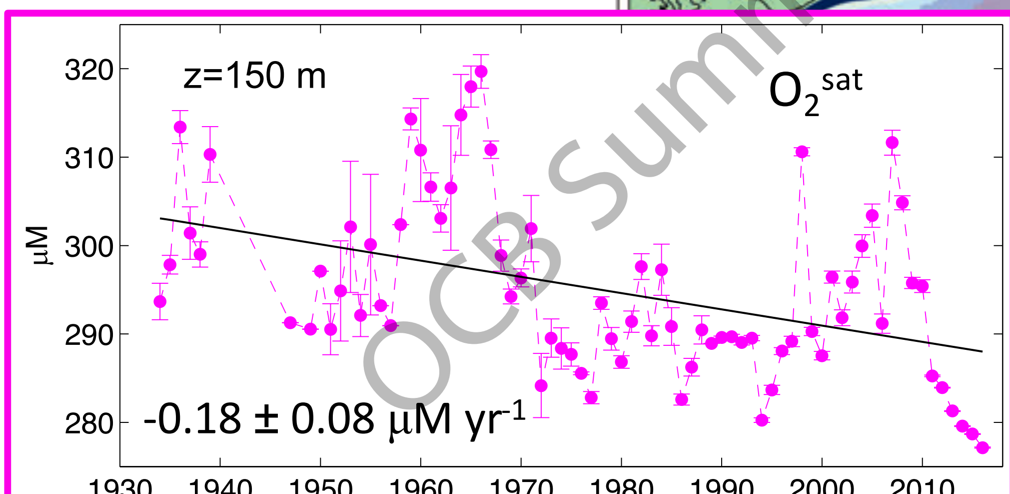
Upper North Atlantic basin:
-0.075 μM yr^{-1}
(Schmidtko et al. 2017)

Half of the oxygen decline explained by warming waters





How much is this oxygen decline due to **local processes** versus **large-scale climate forcing?**



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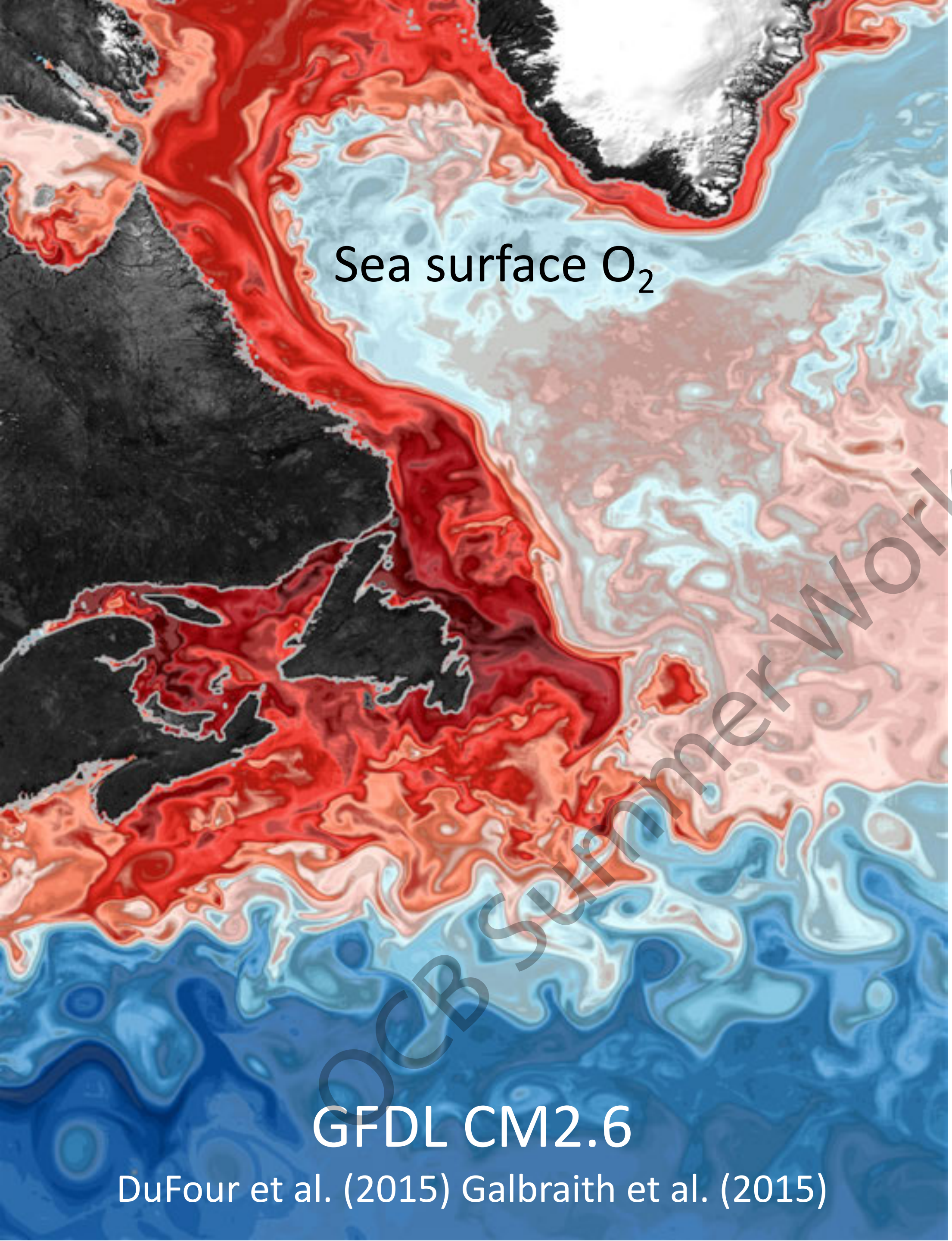
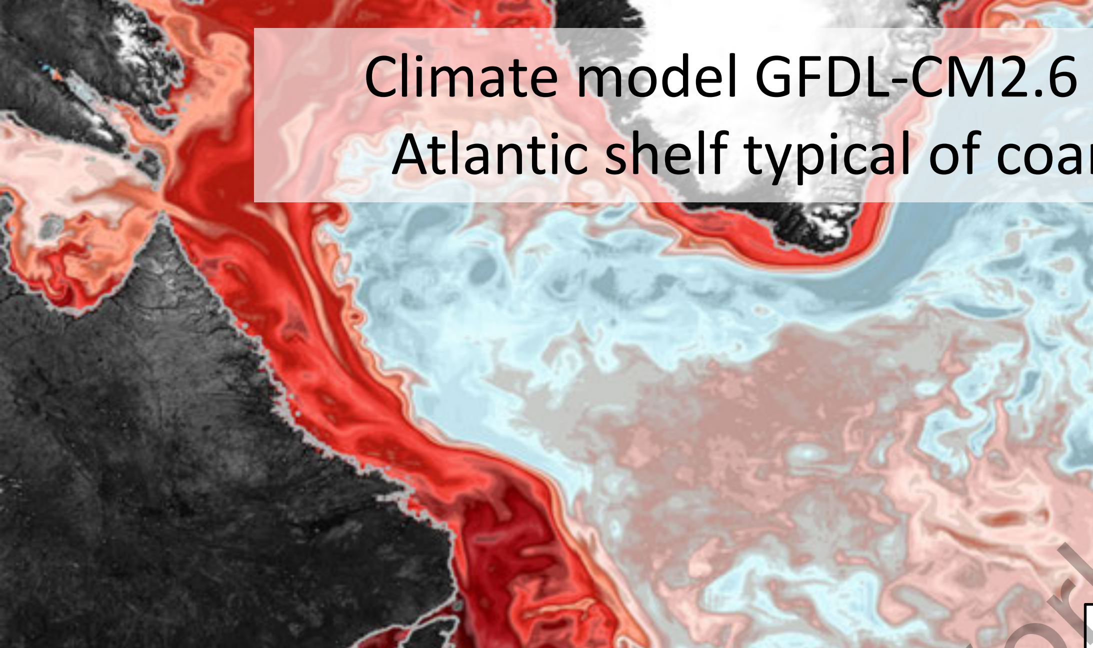


Climate model

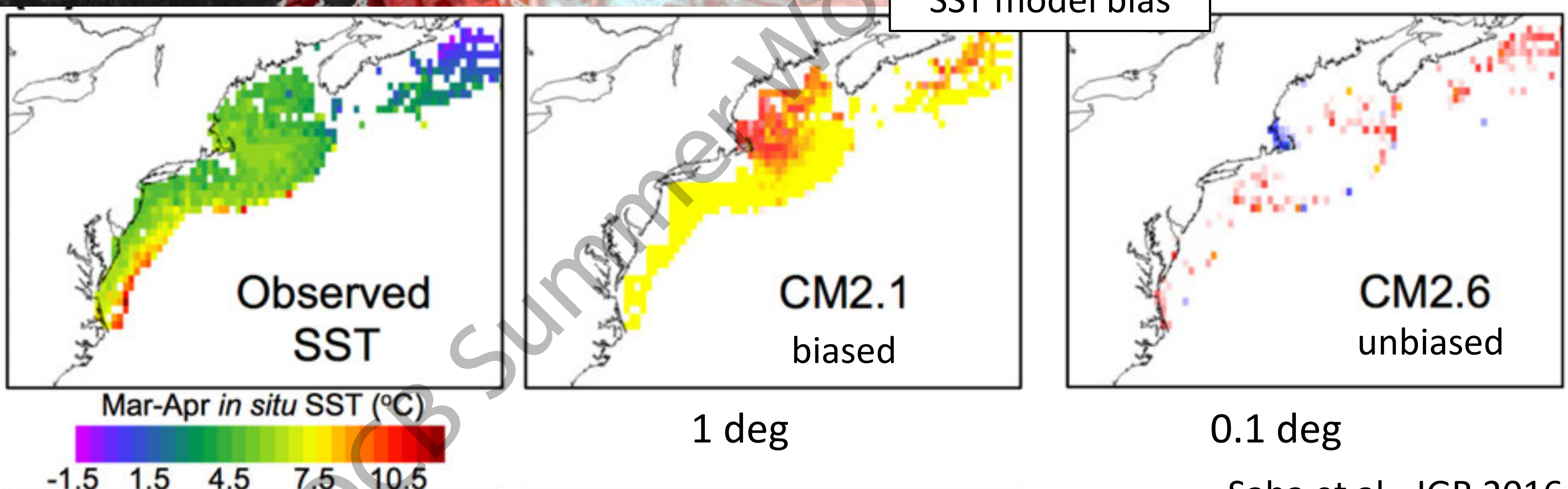
Fully coupled ocean-ice-atmosphere-land **global** model
0.5 deg atmosphere
0.1 deg ocean (8.4 km at 41°N)
Strongly eddying
(no eddy parameterization)
50 vertical ocean levels
miniBLING biogeochemistry
(PO_4, DIC and O_2)

CONTROL:
pre-industrial (200 years)
Idealized CO_2-driven WARMING:
1% CO_2 increase until doubling
(70 years + 10 years)

Climate model GFDL-CM2.6 reduces warm bias in the NW Atlantic shelf typical of coarse-resolution climate models



Temperature and salinity bias in the NW Atlantic shelf **reduces with increased ocean resolution** since Gulf Stream coastal separation location is more realistic and bathymetry is better resolved.



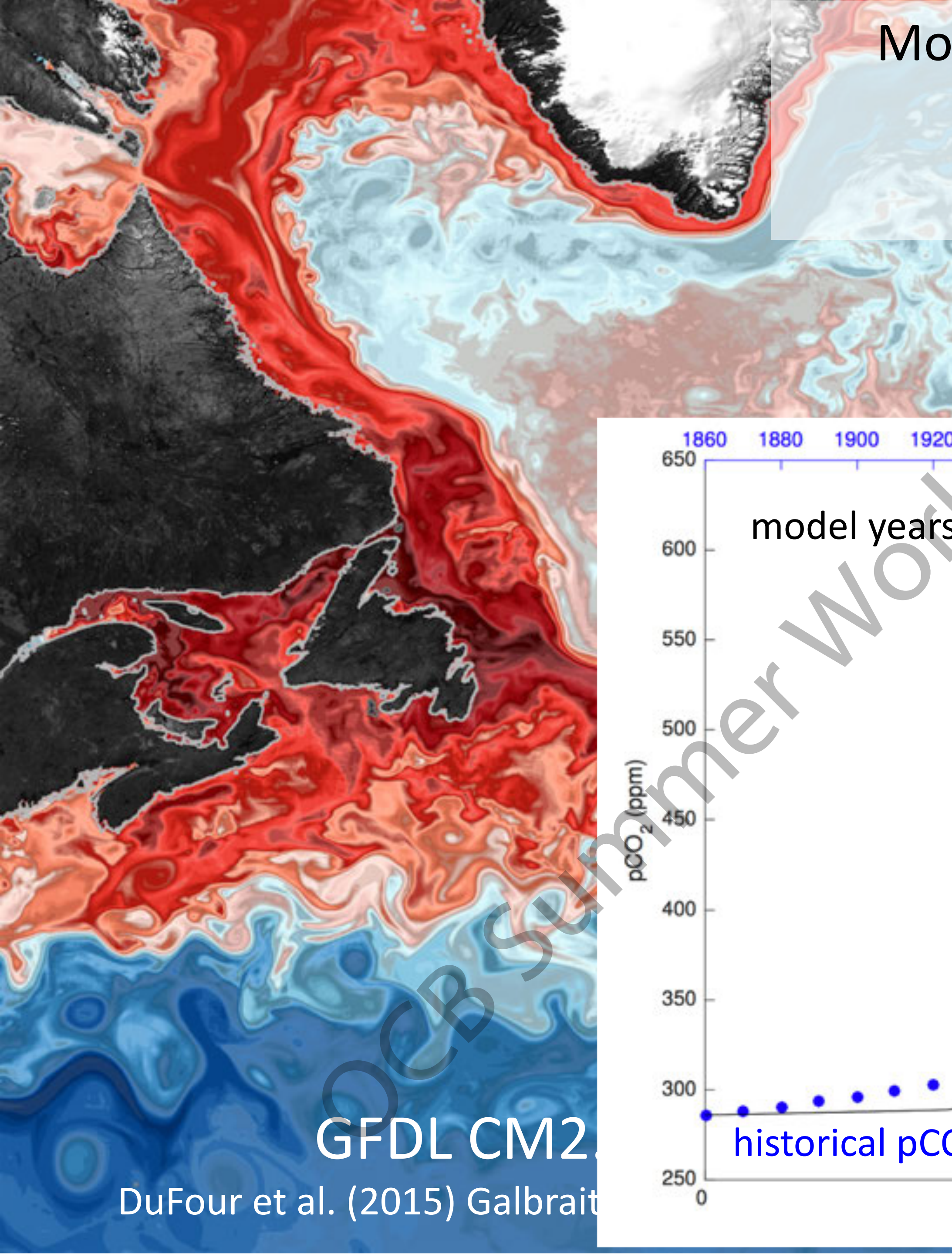
Saba et al., JGR 2016

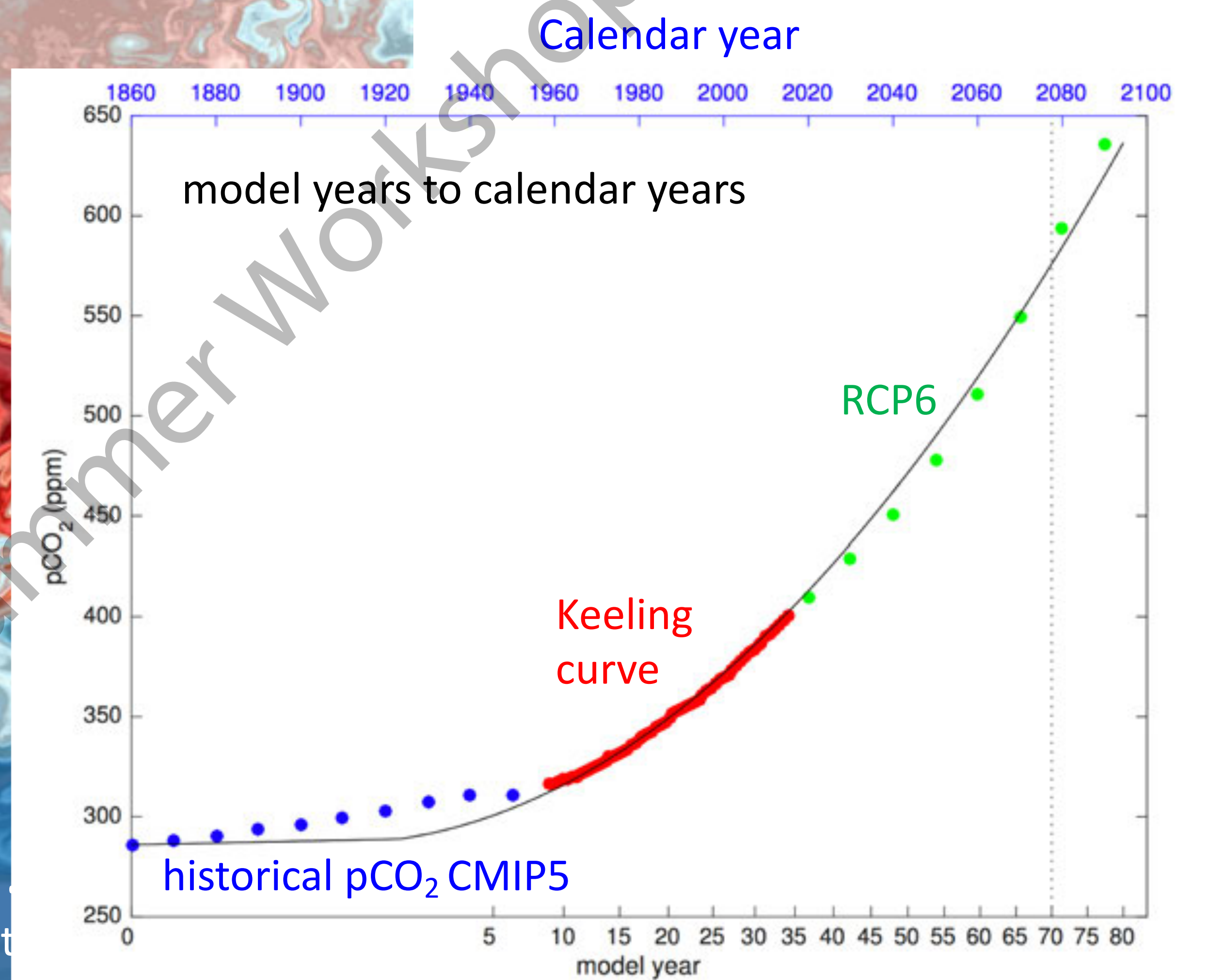
GFDL CM2.6

DuFour et al. (2015) Galbraith et al. (2015)

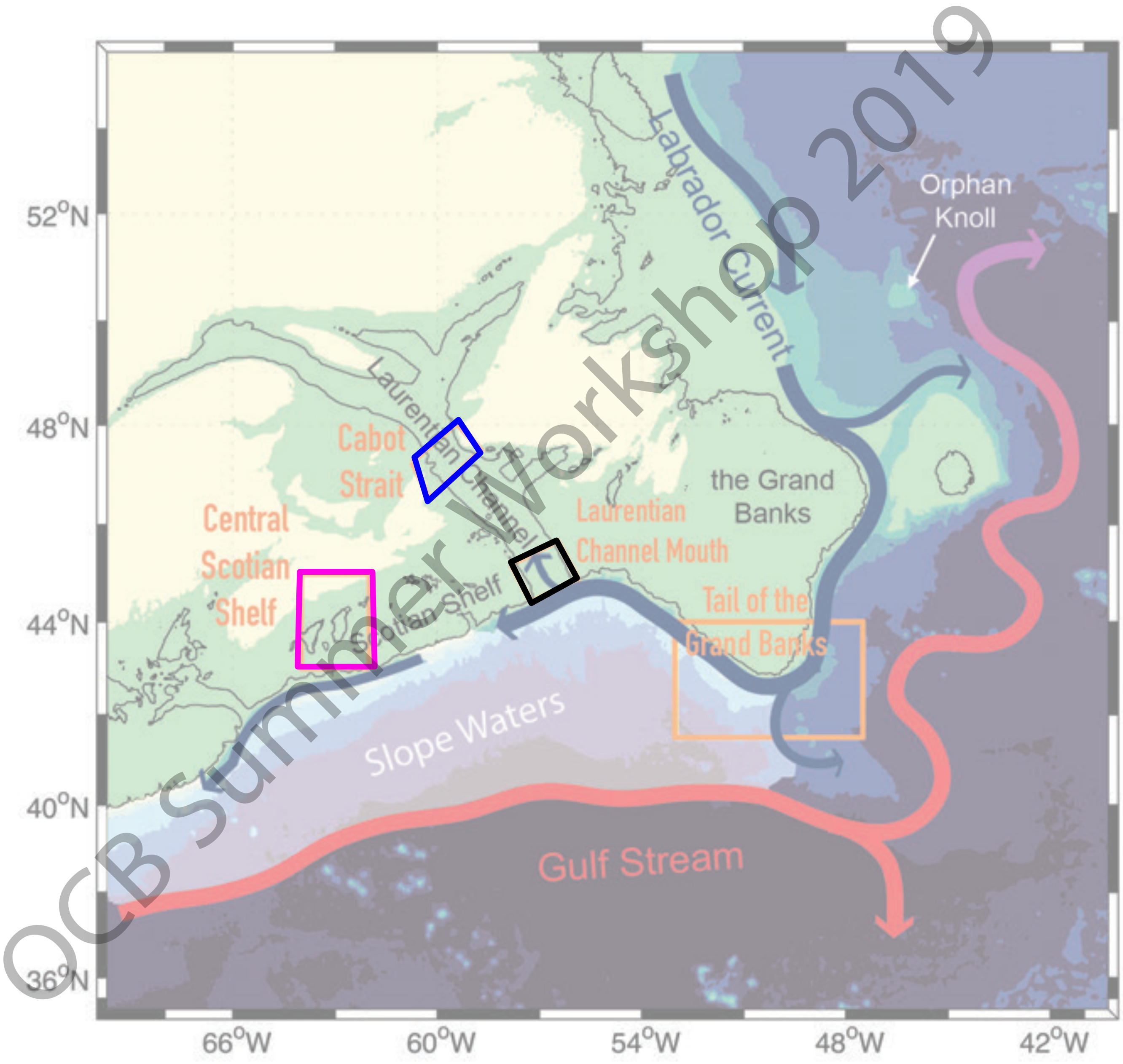
Model output to data comparison

Model output is sampled and analyzed in the same way as observations

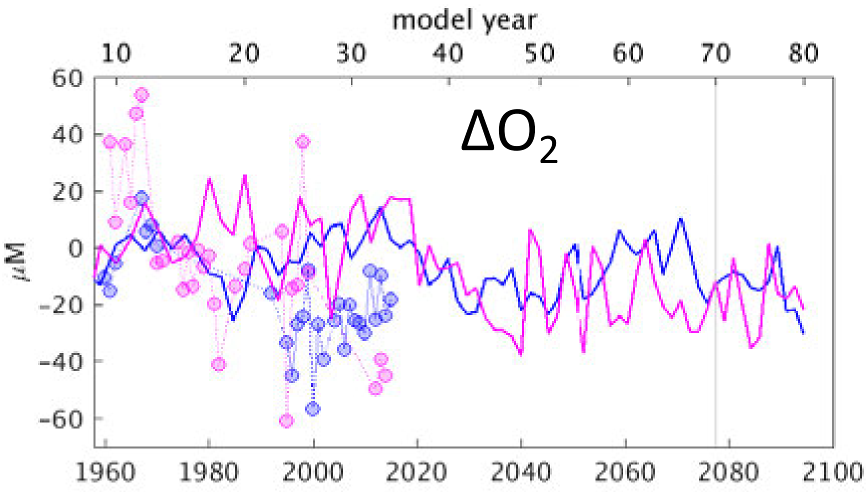


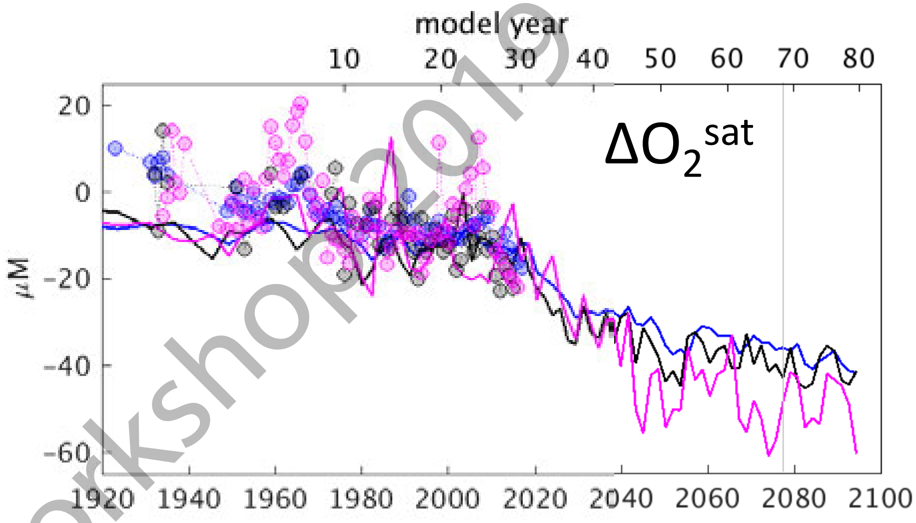


Geographic sites where model output is extracted for model-data comparison



Warming simulation reproduces O_2^{sat} and hydrographic changes





Dots: observations
Solid lines: climate model

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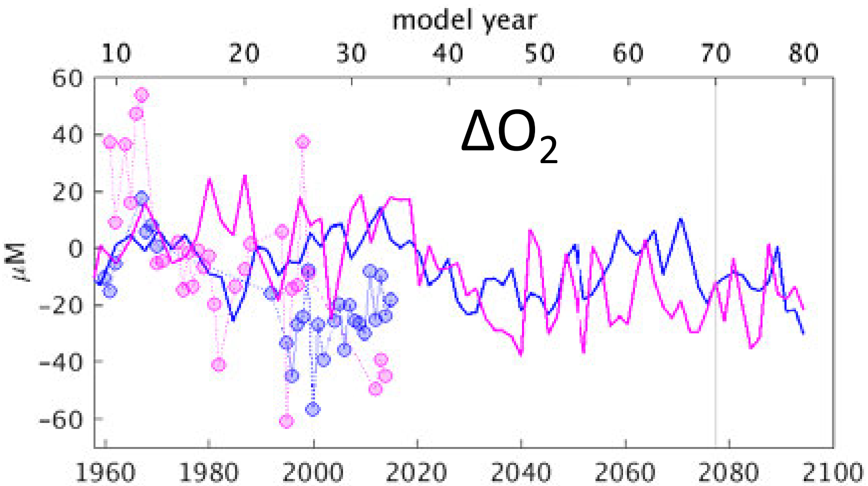

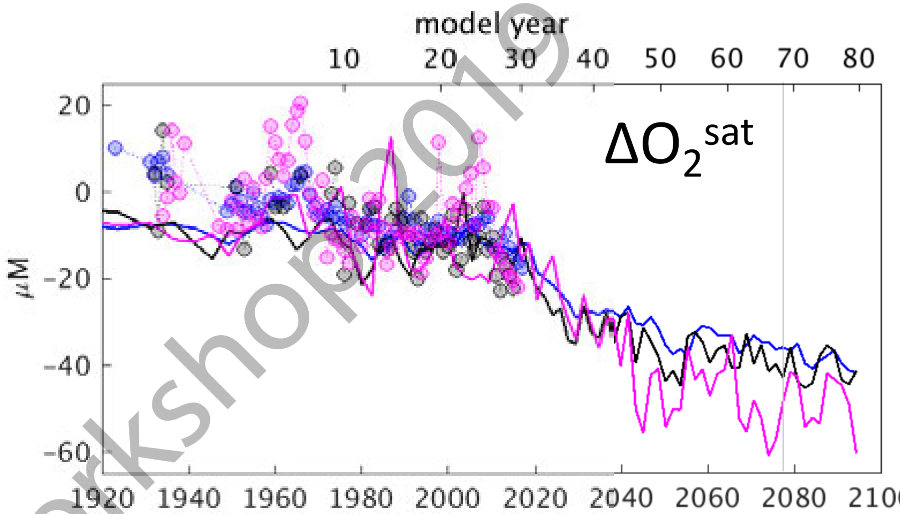

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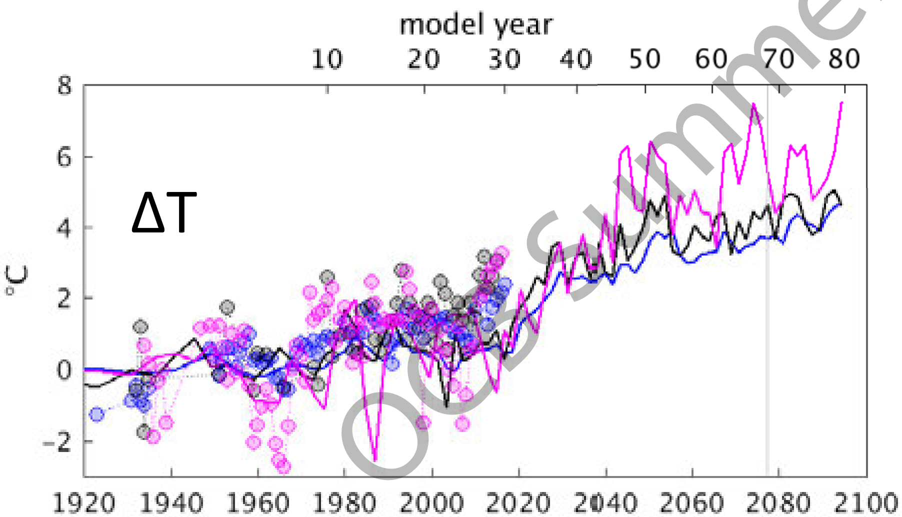
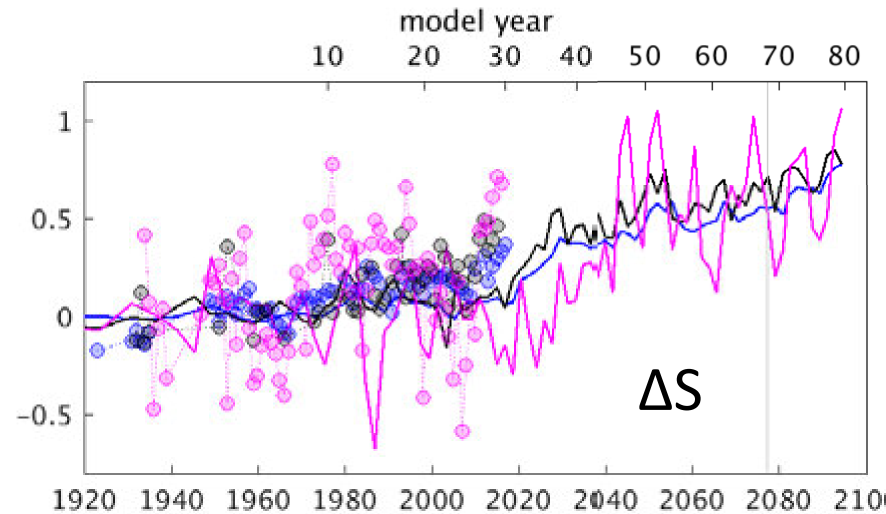
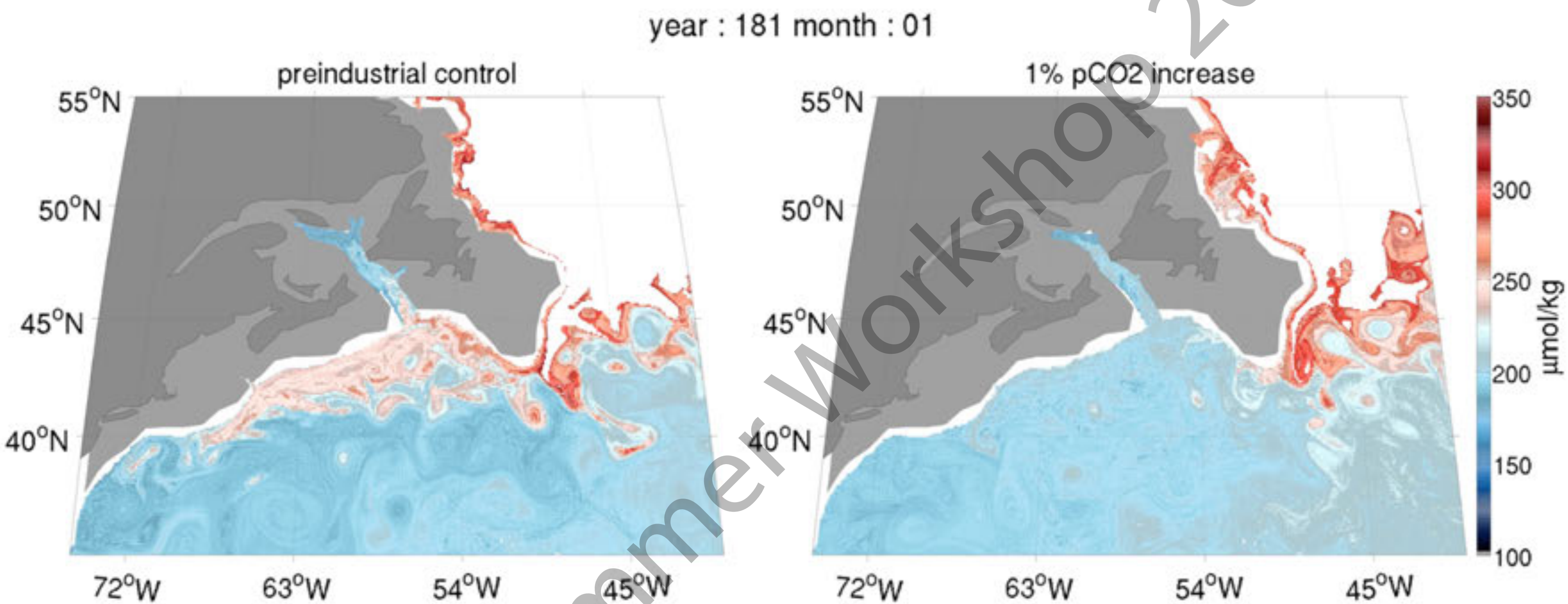


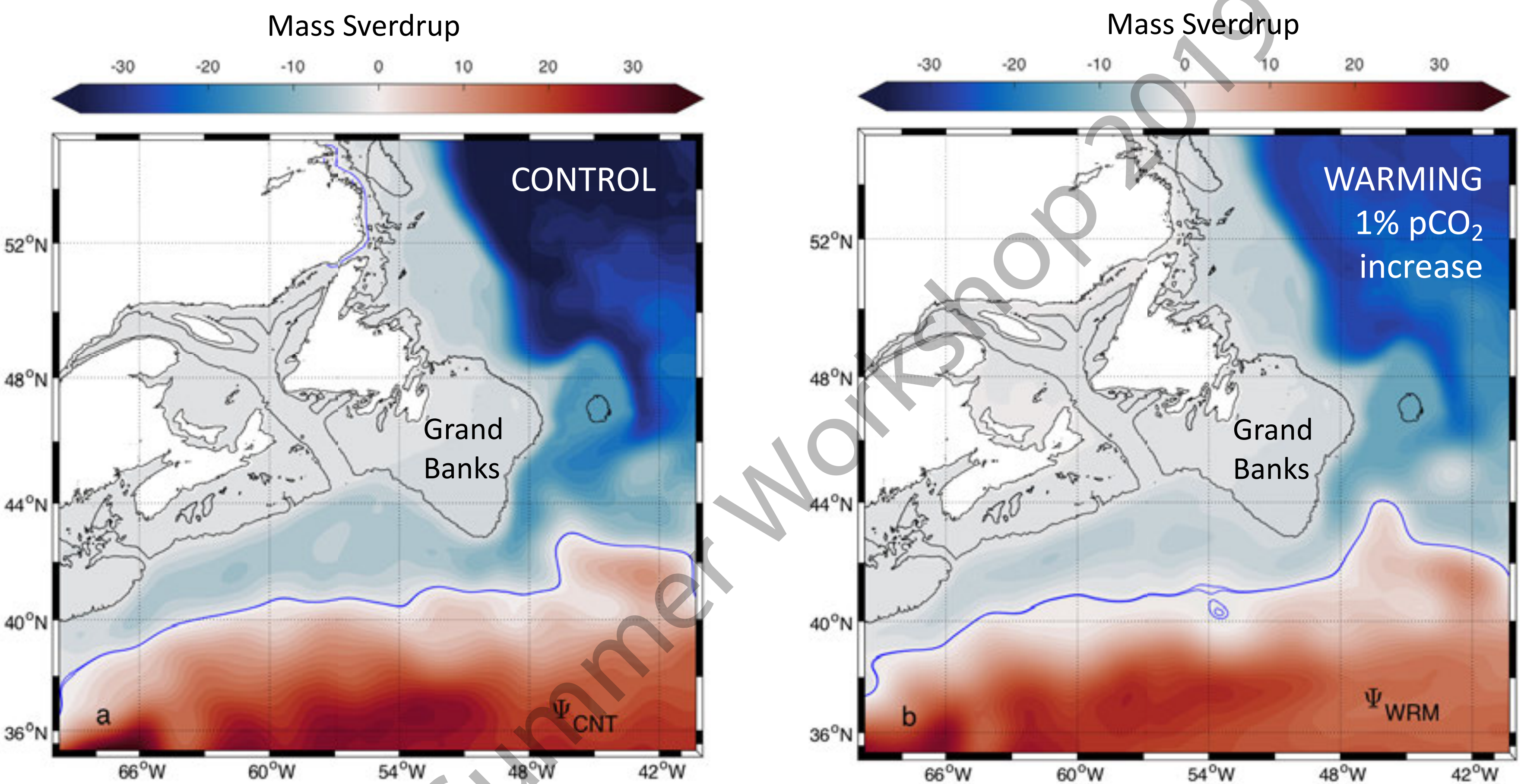


Reduction of oxygen supply to the estuary occurs at the Tail of Grand Banks, which is a chokepoint for the westward transport of oxygen



Dissolved oxygen on isopycnal 27.25 kg m^{-3}

Model shows a retreat of the Labrador Current east of Grand Banks



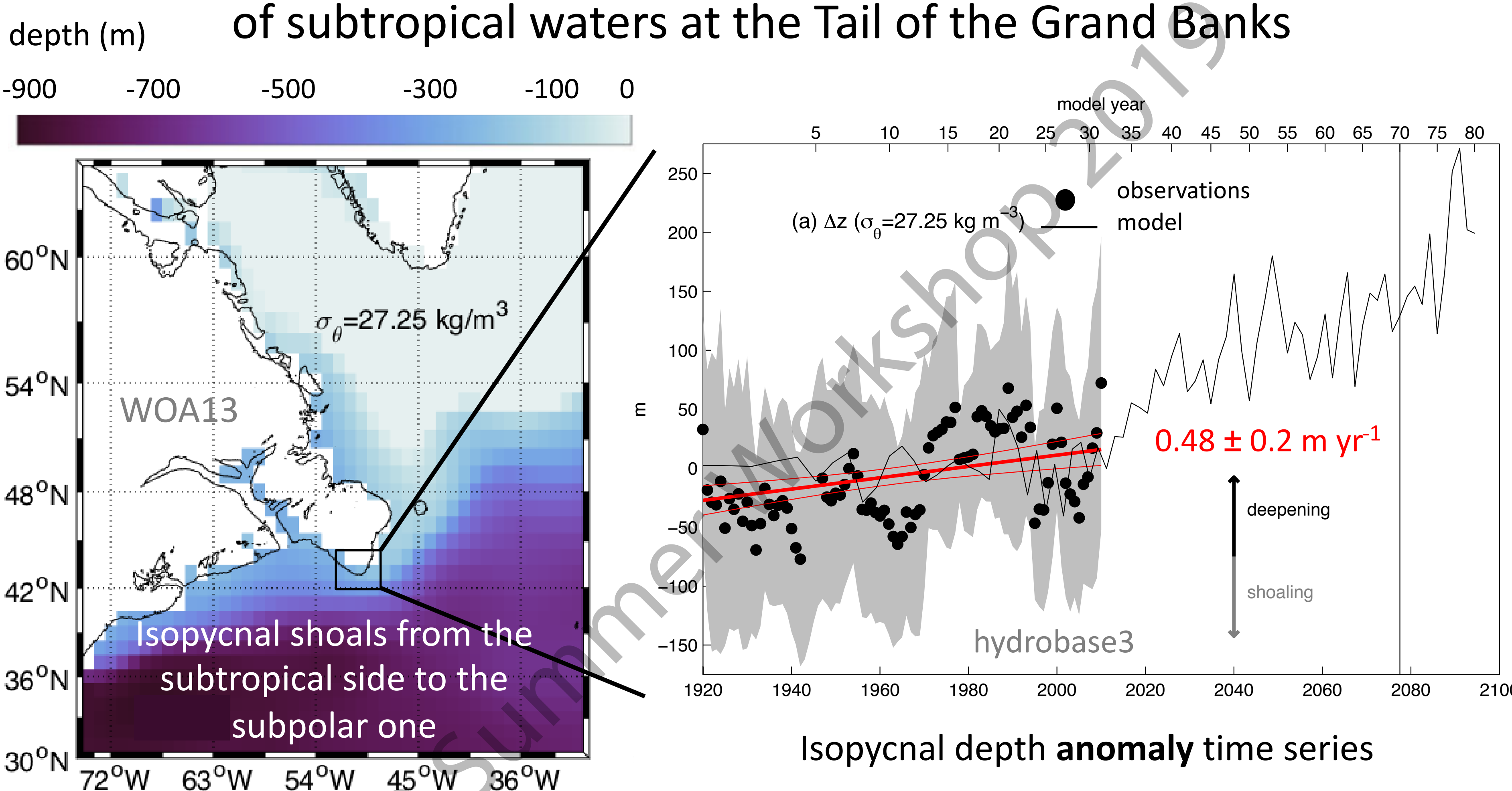
Mass quasi-streamfunction (Ψ, over 1000 m).

Negative is cyclonic subpolar circulation, **positive** is anticyclonic subtropical circulation.

+ Weakening of the Labrador Current north of Grand Banks
+ Greater impingement of the Gulf Stream at Grand Banks

} Reduced transport of ventilated subpolar waters west of Grand Banks

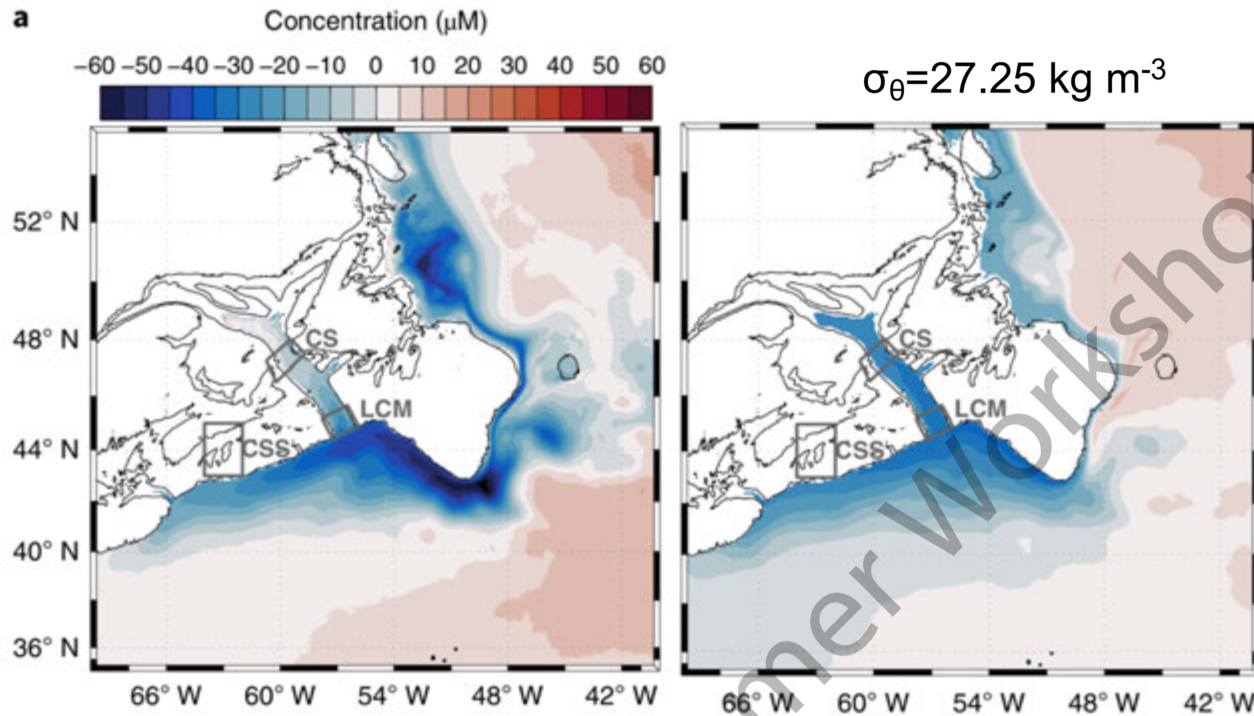
Observational evidence of enhanced presence of subtropical waters at the Tail of the Grand Banks



Isopycnal deepening means an increase in buoyant subtropical waters relative to dense subpolar waters. This is consistent with the modeled retraction of the Labrador Current and Gulf Stream impingement at Grand Banks.

How much of the oxygen decline is explained by a remote circulation shift?

$$\Delta O_2 = \Delta O_2^{sat} + (-\Delta AOU)$$



Mechanisms of deoxygenation

ΔO_2^{sat} decrease reflects **hydrographic** changes due to:

+ Reduction of ventilated subpolar waters west of Grand Banks.

+ Decrease in solubility of source waters.

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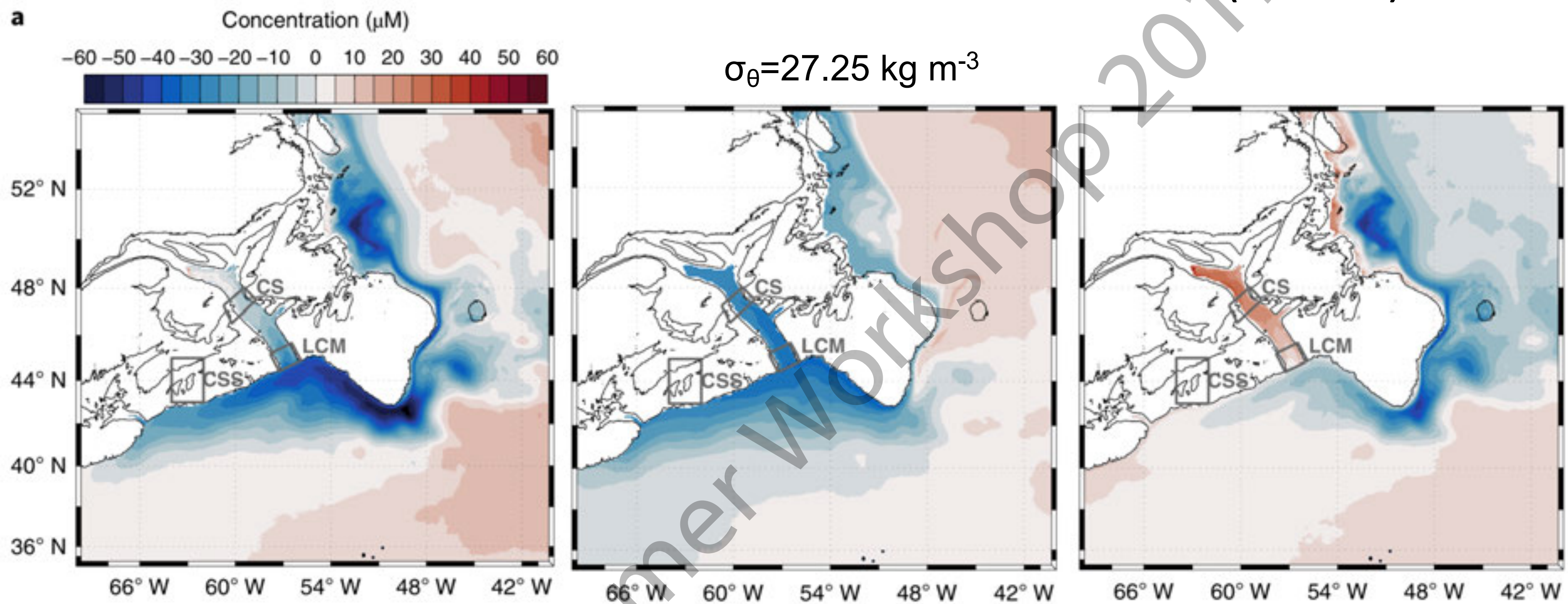

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ΔAOU reflects changes in:

+ Water ventilation. Increased stratification reduces water ventilation east of Grand Banks.

+ Biological processes dominate in the deep channel of GofSL.

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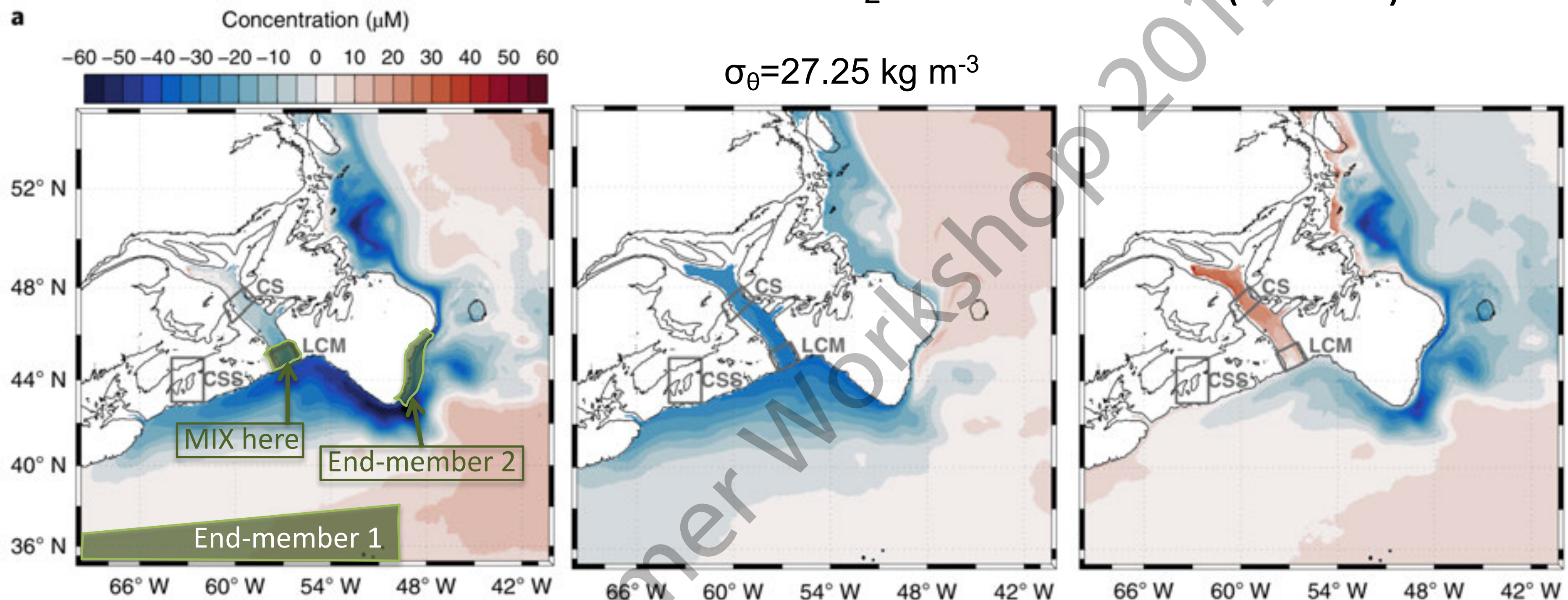

Two end-member mixing model (MIX) at deep estuary entrance

O_2 decline is driven by:

2/3 retreat of the LC

1/3 LC end member reduced ventilation and warming

ΔO_2^{sat} decrease reflects **hydrographic** changes due to:

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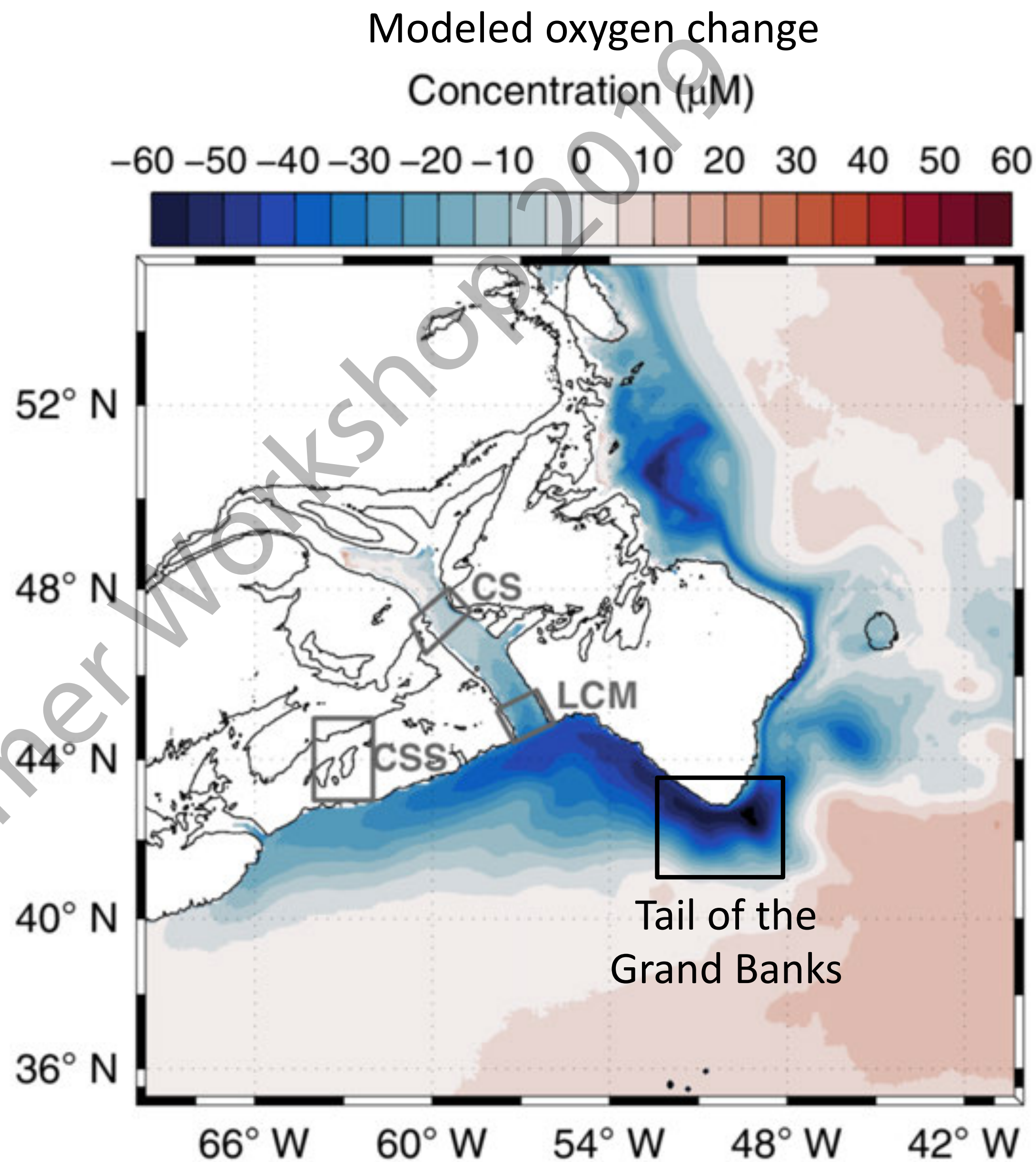
Summary

- The northwest Atlantic shelf dramatic deoxygenation vastly outpaces that of the upper North Atlantic basin.
- Climate model reproduces O_2^{sat} change due to a retreat of the Labrador Current (LC) at the Tail of the Grand Banks (TGB) with CO_2-driven warming.
- The retreat of the LC at TGB is also unveiled in centennial-scale hydrographic time series.

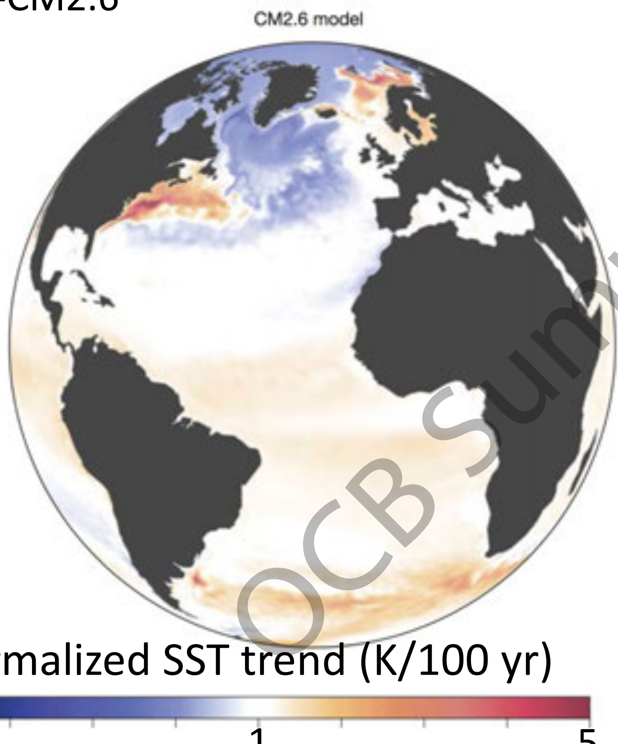


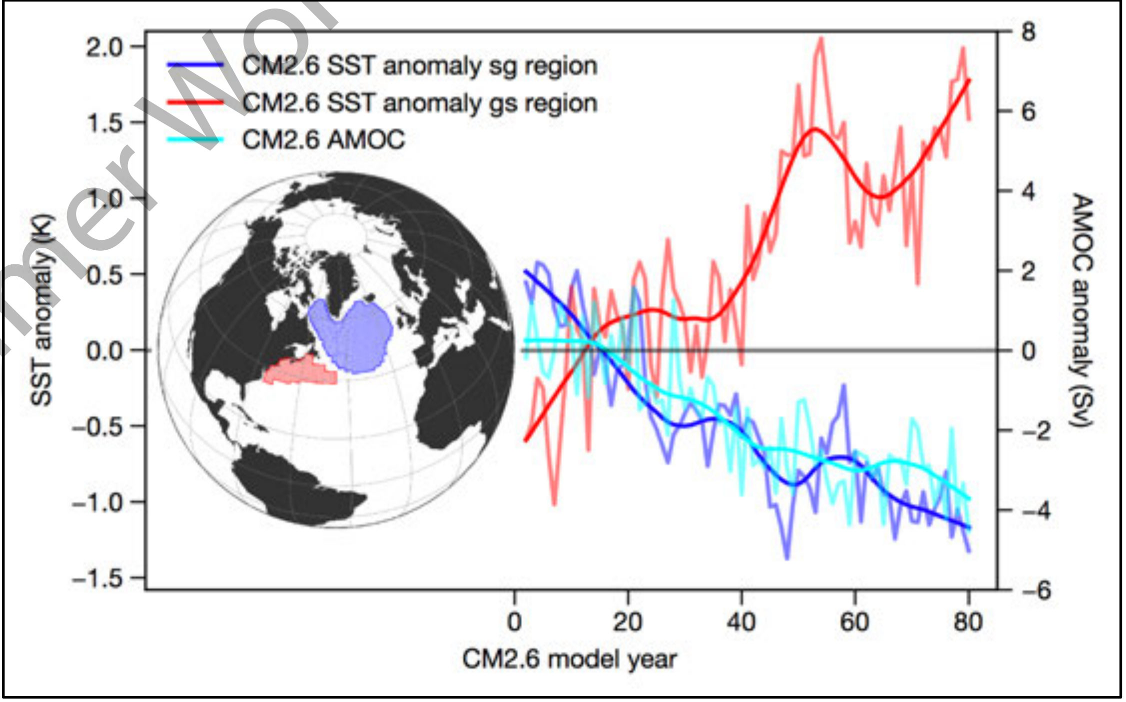
Summary and potential implications

In the climate model used, these shifts are highly correlated with an Atlantic Meridional Overturning Circulation (AMOC) slowdown.

Broad-scale impacts
Coastal deoxygenation in the NW Atlantic is a sensitive indicator of a large-scale dynamical shifts in the open ocean.

Climate model
GFDL-CM2.6





Caesar et al., Nature 2018

Summary and potential implications

These shifts may ultimately influence the oxygen variability of the open North Atlantic.

Coarse-resolution climate models predict patchy oxygen changes in the upper NA due to weakening and poleward shift of the North Atlantic Current, the extension of the Gulf Stream off-shore Grand Banks.

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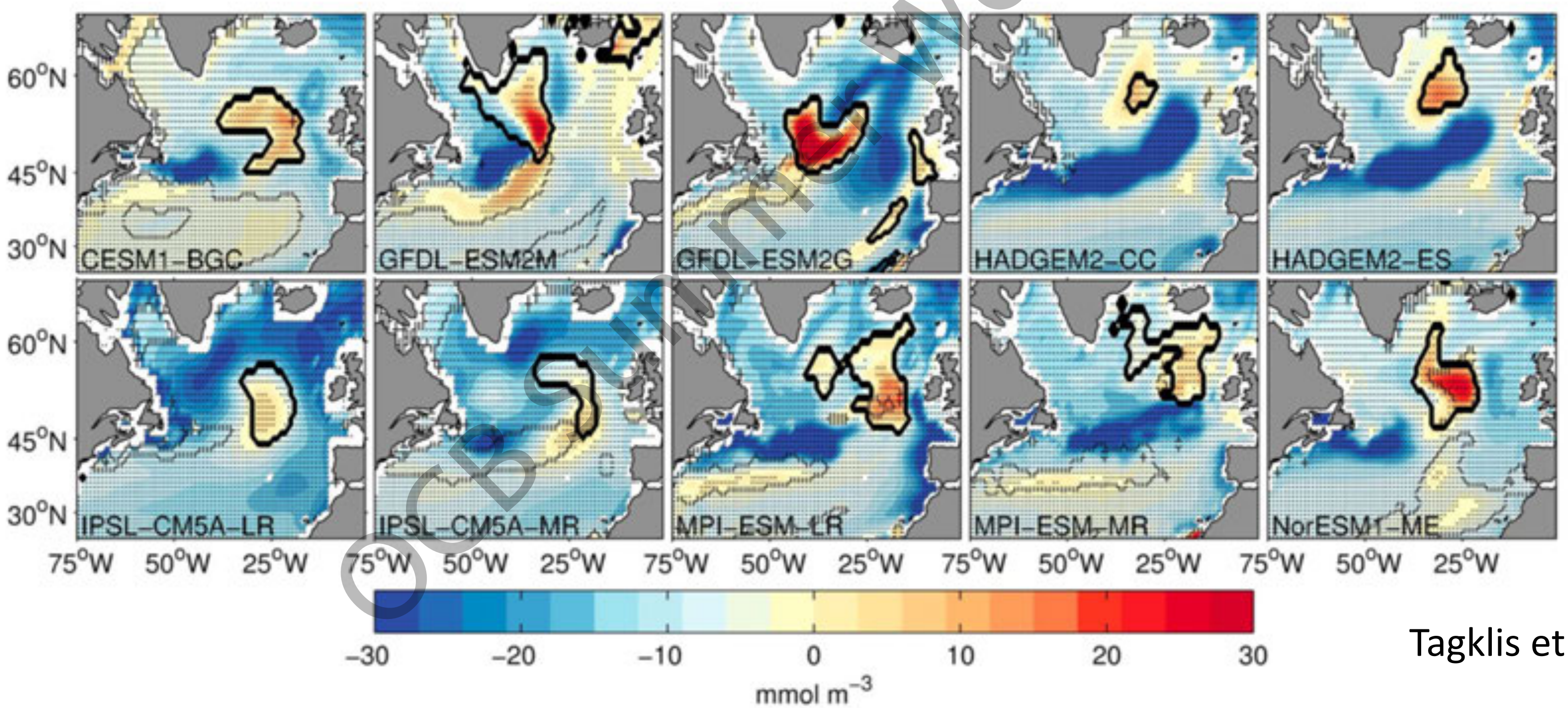


O_2 change upper 700 m

CMIP5 projections ~1 deg ocean

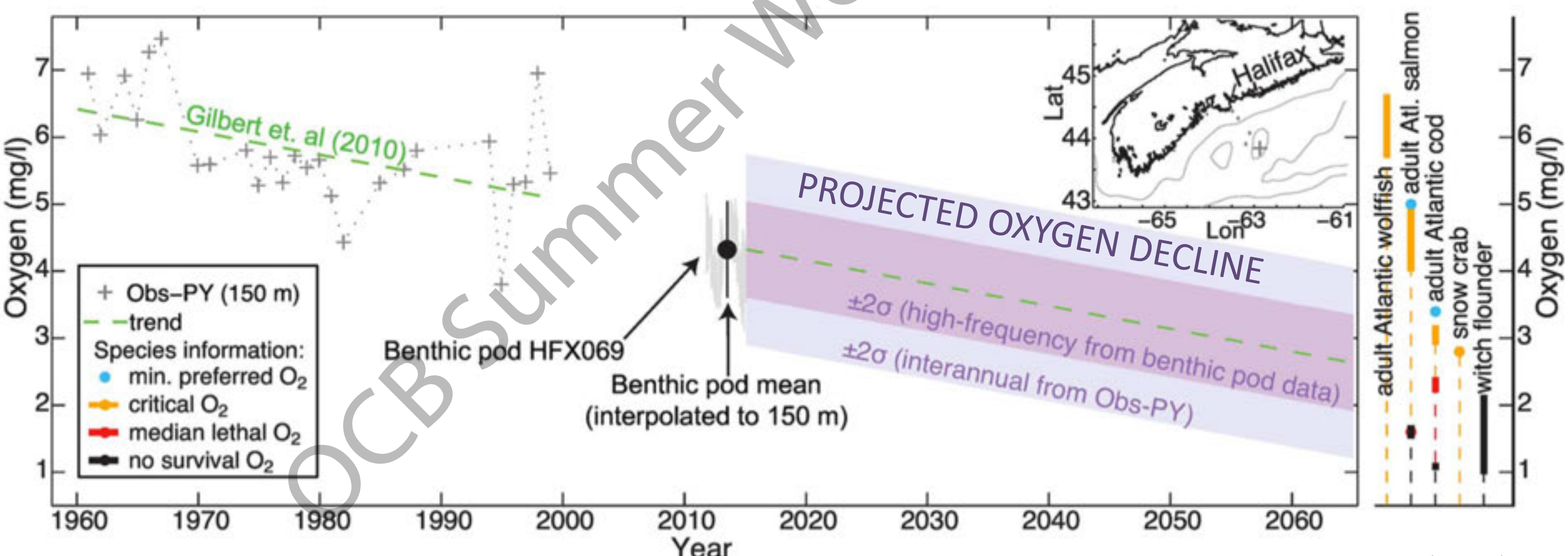
Tagklis et al. (2017)

Summary and potential implications

Local ecosystem impacts

Under continued warming, the presence of subtropical oxygen-poor waters may increase in the NW Atlantic shelf threating the life/presence of benthic fish and invertebrates

Current oxygen levels at the Scotian Shelf start to be critical for the Atlantic wolffish and will be critical for snow crab within next decades



Brennan et al. (2016)

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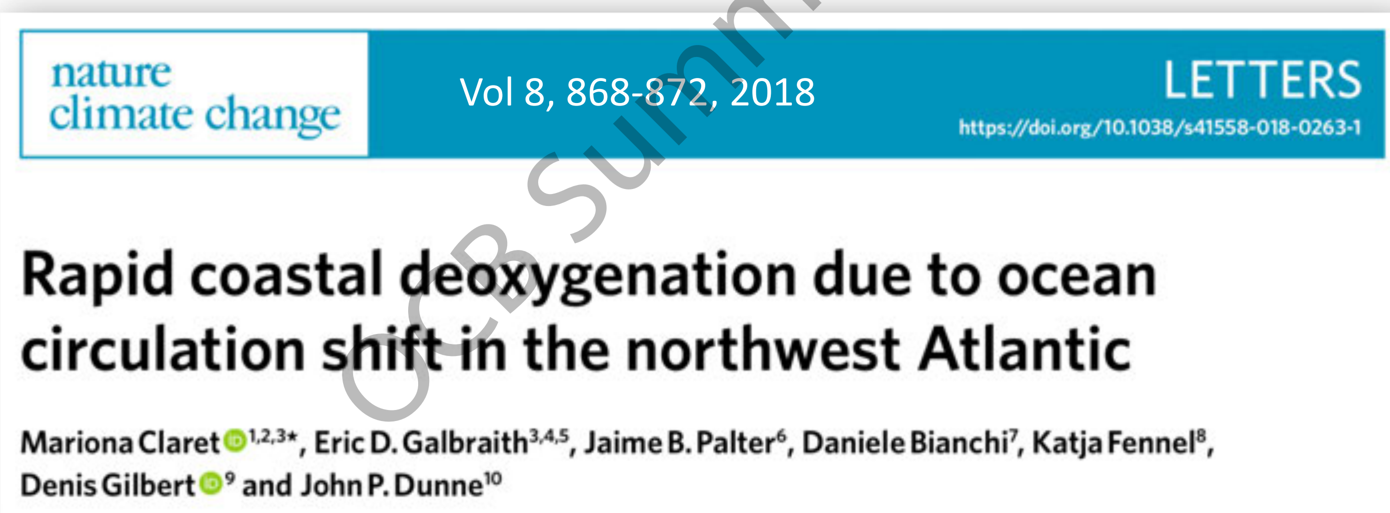
nature climate change
Vol 8, 868-872, 2018
LETTERS
https://doi.org/10.1038/s41558-018-0263-1

Rapid coastal deoxygenation due to ocean circulation shift in the northwest Atlantic

Mariona Claret[1,2,3*], Eric D. Galbraith[3,4,5], Jaime B. Palter[6], Daniele Bianchi[7], Katja Fennel[8], Denis Gilbert[9] and John P. Dunne[10]

THANKS FOR YOUR ATTENTION

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