Physical Drivers and Biogeochemical Effects of the Projected Disappearance of the Shelfbreak Jet in the Northwest North Atlantic

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Introduction

The coastal circulation in the northwest North Atlantic Ocean, at the eastern Canadian seaboard, is dominated by the equatorward flow of subpolar water. The shelfbreak jet at the edge of the continental shelf forms a narrow water mass boundary between the cooler, fresher shelf water and warmer, saltier water in the continental slope region (Rutherford & Fennel, 2018).

The northwest North Atlantic shelf is experiencing warming that exceeds the global rate (Brickman et al., 2018; Alexander et al., 2020) and projections show a warming rate that is three times the global average over the next century (Saba et al., 2016).

Will increasing atmospheric CO_2 affect the strength of the shelfbreak jet and, if yes, how will this affect coastal biogeochemical processes in the northwest North Atlantic?

Methods

GFDL CM2.6: high-resolution coupled atmosphere–ocean–ice global model (Delworth et al., 2012). Two runs:

- *Control case*: atmospheric CO_2 is fixed at a preindustrial level (286 ppm).
- *Warming case (2xCO_2):* atmospheric CO_2 is increased at an annual rate of 1% until doubled, and then it is held constant for 10 years. The rapid increase in CO_2 resembles the RCP6 scenario (Claret et al., 2018).

Averages from both cases were calculated from output between 191 and 200 years after initialization (corresponding to the calendar years: 2078 to 2100).

Regional biogeochemical model (ACM): ROMS and BIO_FENNEL forced by monthly anomalies from the CM2.6 warming scenario. Run from 1999 – 2100 (first year as spin-up). Recent-period and future conditions are the average from 2000 to 2010 and 2085 to 2095, respectively.

Results

The shelfbreak jet is steered by the steep topography and driven by pronounced horizontal density gradients in the control run (Figure 1, left panels) where the subsurface horizontal density gradient between denser, cooler sub-polar water and warmer, buoyant subtropical water provides a baroclinic contribution to the southwestward along-shelf flow.

In the 2xCO_2 case, the subsurface density along the continental shelf is strongly reduced, especially downstream of the Tail of the Grand Banks (TGB), essentially leading to a disappearance of the shelfbreak jet downstream of the TGB (Figure 1, middle and right panels).

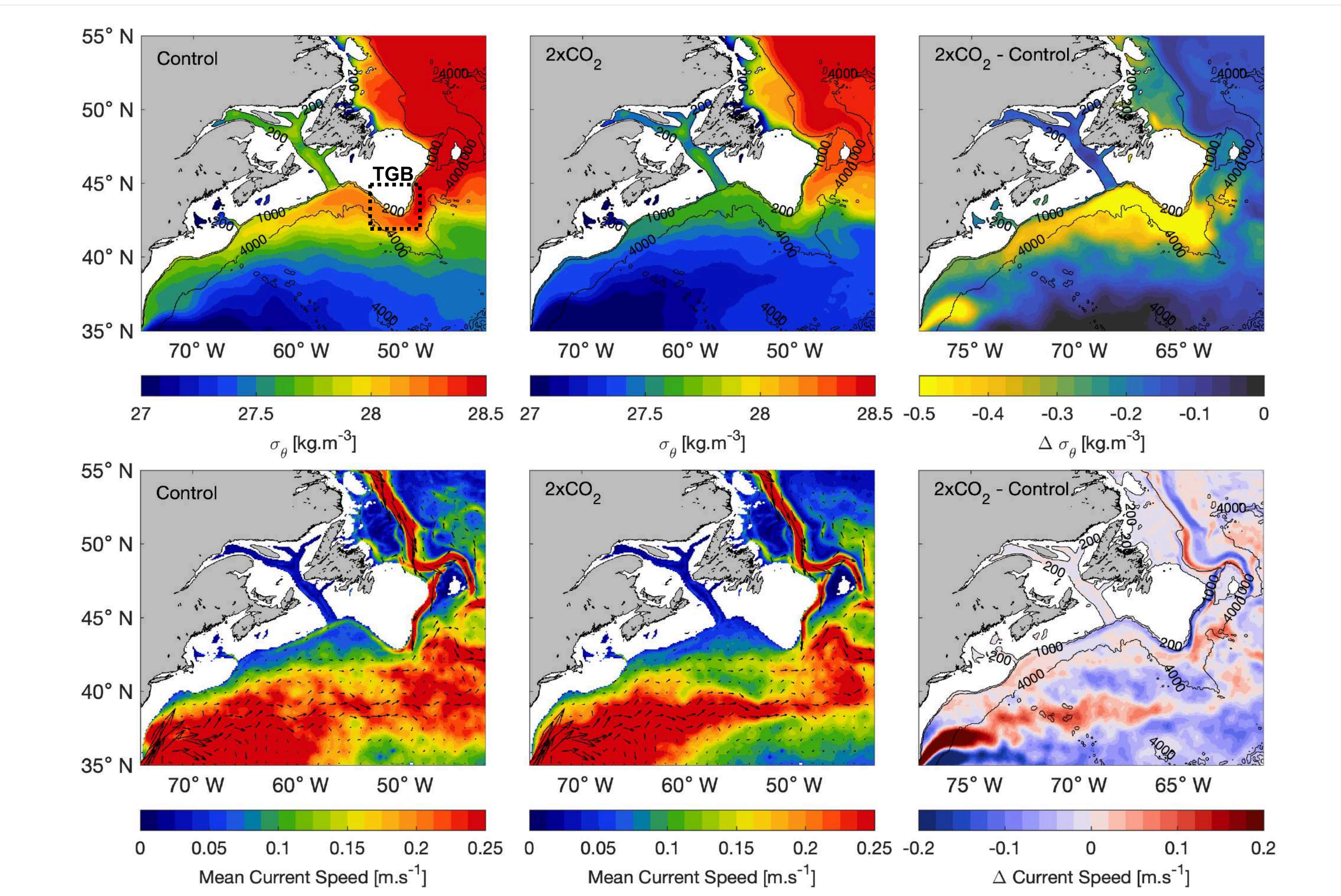

Figure 1. Subsurface (150 m - 200 m) potential density (top) and mean current speed and directions (bottom) from CM2.6 in the control case (left), 2xCO_2 case (middle), and difference 2xCO_2 minus Control (right). Dashed square in upper left panel shows the location of the Tail of the Grand Banks (TGB).

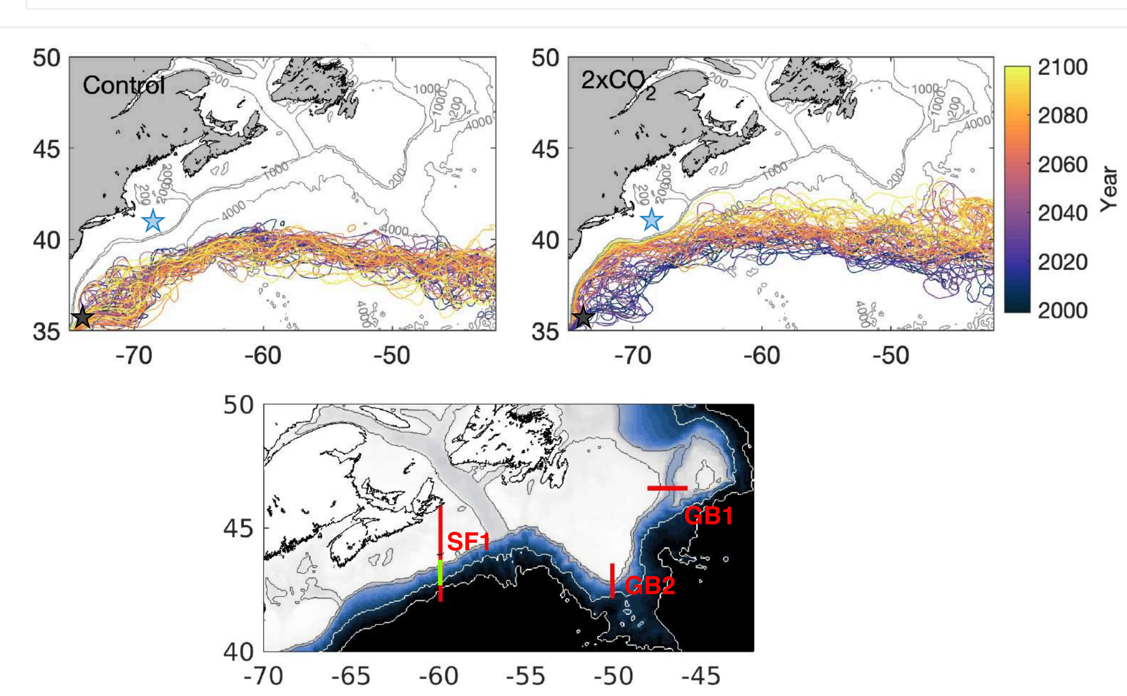

Figure 2. Annual mean of Gulf Stream path from CM2.6 in the control case (upper left) and 2xCO_2 case (upper right). Path defined by the Gulf Stream North Wall index (15°C isotherm at 200 m depth). Section locations for vertical transects (red lines at the bottom panel) and net volume transport (red lines for **GB1** and **GB2**, green line for **SF1**). The stars in upper panels show the approximate location of Georges Bank (blue) and Cape Hatteras (black).

Changes in density patterns due to a retreat of the Labrador Current (Figure 1) coincide with a northerly shift of the Gulf Stream which becomes attached to the shelf break between Cape Hatteras and Georges Bank (Figure 2).

Reduced net volume transport is found in all the three sections **GB1**, **GB2**, and **SF1** (see Figure 2 for transect location) in the 2xCO_2 case compared to the control, especially at depths below 100 m where interannual variability is higher (Figure 3).

The effect of increasing atmospheric CO_2 causes a shift in the subsurface along-shelf current. Net transport below 100 m depth and across **GB2** and **SF1** switches from southwestward to poleward direction several times (Figure 3).

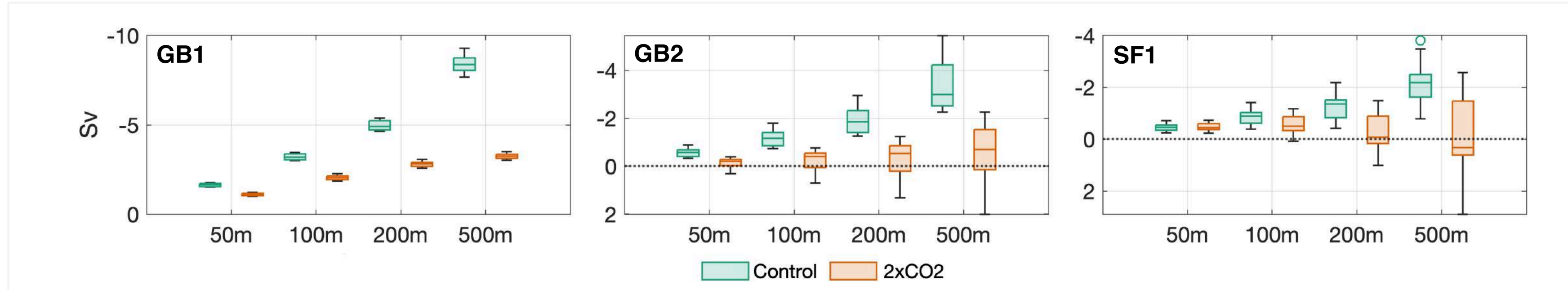

Figure 3. Annual mean net volume transport [Sv] from 2078 to 2100 in the CM2.6, calculated in vertical bins from surface to 50, 100, 200, 500 m depth across sections **GB1**, **GB2**, and **SF1**. Dashed line stands for the division between southwestward (negative) and poleward (positive) net volume transport. Net transport: balance between equatorward and poleward transport.

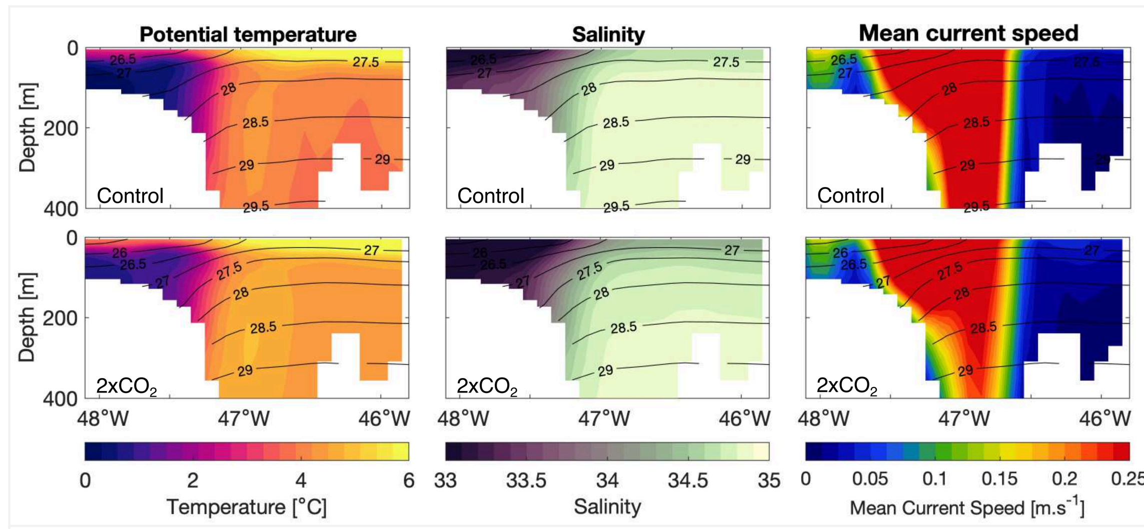

Figure 4. Mean vertical transects of potential temperature (left), salinity (middle), and current speed (right) for section **GB1** at Flemish pass from CM2.6 in both control and 2xCO_2 cases.

The transition from cold, fresh water on the shelf to warm, salty water over the upper slope at **GB1** (see Figure 2 for transect location) is associated with a strong along-shelf jet at the shelfbreak (Figure 4).

Shoaling of the shelfbreak jet occurs under a doubling CO_2 scenario but the strength of the jet is not markedly reduced.

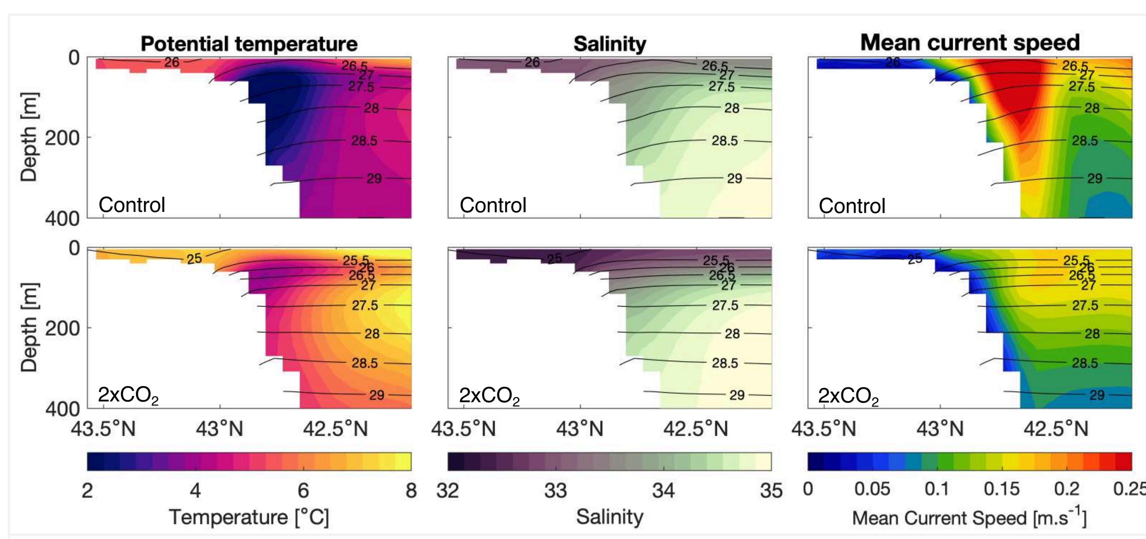

Figure 5. Same as in Figure 4 but for section **GB2** at the TGB.

Subsurface isopycnals flatten in **GB2** compared to **GB1** and the shelfbreak jet is much weaker in the 2xCO_2 case (Figure 5).

Changes in water mass distribution increase the presence of Gulf Stream waters at the TGB in the 2xCO_2 case and force a significant portion of the main branch of the Labrador Current to leave the western boundary.

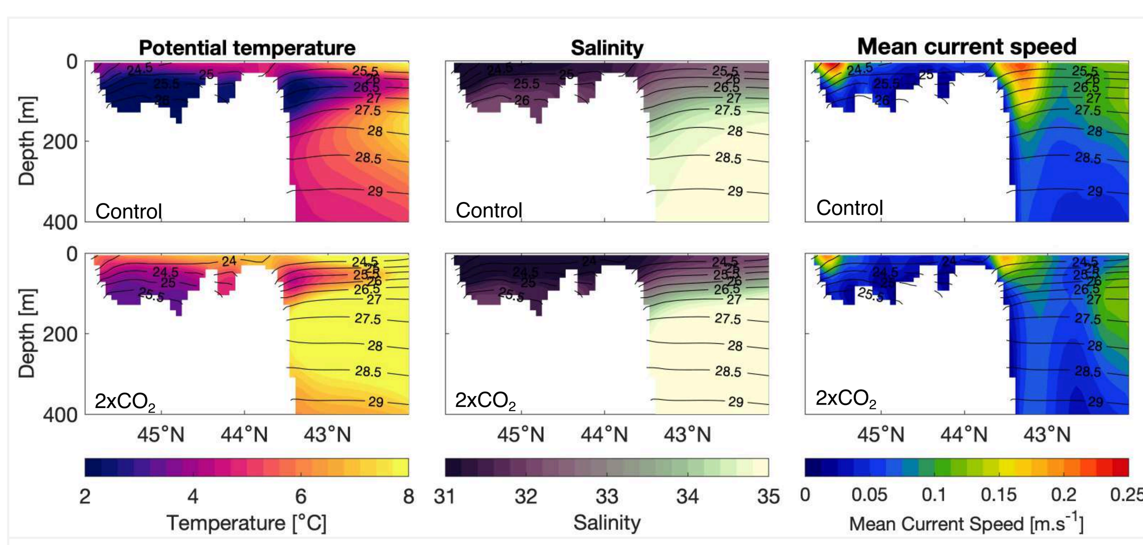

Figure 6. Same as in Figure 4 but for section **SF1** at the Scotian shelf.

At **SF1**, warmer and fresher surface water increases the vertical density gradient over the slope region compared to **GB2** (Figure 6).

At this transect the core of the shelfbreak jet weakens significantly in the 2xCO_2 case.

Biogeochemical effect

The expansion of nutrient-poor, subtropical waters in the slope area and into the Gulf of Maine leads to a decrease in nitrate availability in these regions. In the northeastern half of the Scotian Shelf, nitrate availability increases for reasons yet to be determined.

DIC increases as more atmospheric CO_2 dissolves in the ocean. The rate of increase varies considerable throughout the model domain and is largest near shore and in tidally mixed regions.

Oxygen decreases significantly in the Gulf of St Lawrence and on the Scotian Shelf but increases on the Grand Banks.

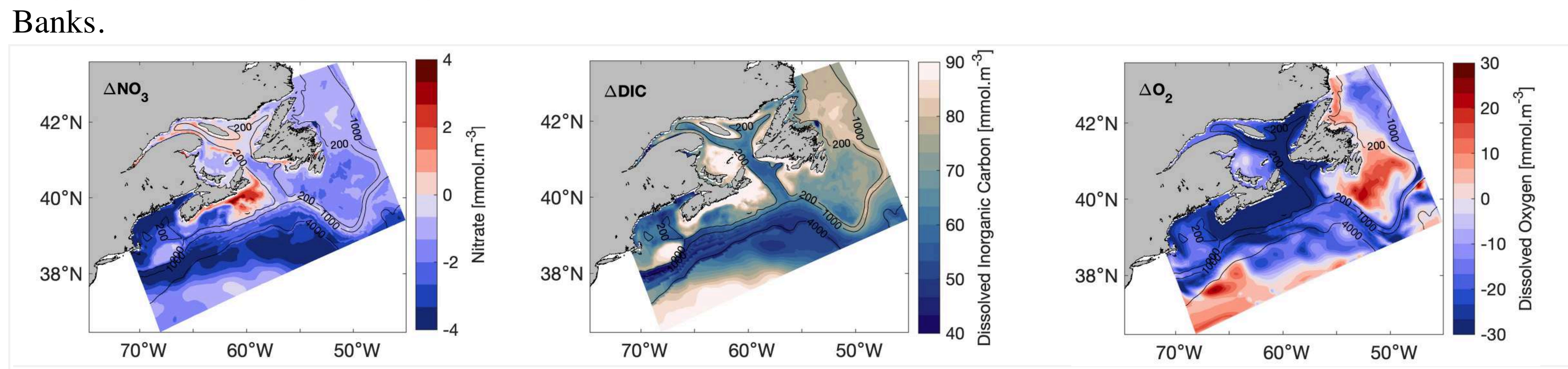

Figure 7. Spatial pattern for changes in nitrate (left), DIC (middle), and dissolved oxygen (right) in the ACM between future and recent period. Horizontal fields are a composite of nitrate at 200 m depth (where the water depth ≥ 200m) and nitrate at the bottom (where the water depth is < 200 m) for each period.

Conclusions and Next Steps

- Our results indicate that the strength of the buoyancy-driven shelfbreak jet is particularly sensitive to climate variability due to its position near the crossroads of the subtropical and subpolar gyres.
- Under a changing climate scenario, along-shelf horizontal density gradients decrease and the core of the shelfbreak jet shoals upstream of the TGB and almost disappears downstream of the TGB.
- This projected shift in circulation would have significant biogeochemical consequences for nutrient supply, acidification, and deoxygenation on the Scotian shelf.
- Future work will include analysis of a long projection from 2000-2100 and more detailed analyses of the biogeochemical consequences.

References

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