Response to comments posted 1 September 2024 by Referee #2 to "DALROMS-NWA12 v1.0, a coupled circulation-ice-biogeochemistry modelling system for the northwest Atlantic Ocean: Development and validation" (10 September 2024)

We thank the referee for taking the time to review our manuscript and for providing supportive comments. Please find below our response to your comments.

- *Lines 55-56: Is deep convection an additional or dominant component of CO_2 removal in the Labrador Sea, as Tian et al. (2004) discussed? Clarifying this point would strengthen the manuscript.*

Many thanks for your suggestion. In response to your comments and those from another referee, we added a new subsection for assessing the model performance in simulating deep convection through its turbulent vertical mixing scheme. Since we cannot upload our revised manuscript during the discussion period, for your information, I included below the new section 3.5 and a new Fig. 16 discussed therein, as well as a revised Fig. 1 that shows the locations of the depth profiles shown in Fig. 16. We have not yet looked at profiles of simulated biogeochemical fields in the convective region, but in response to your comment we modified the last sentence of section 3.5 to state that this is part of our future research plans.

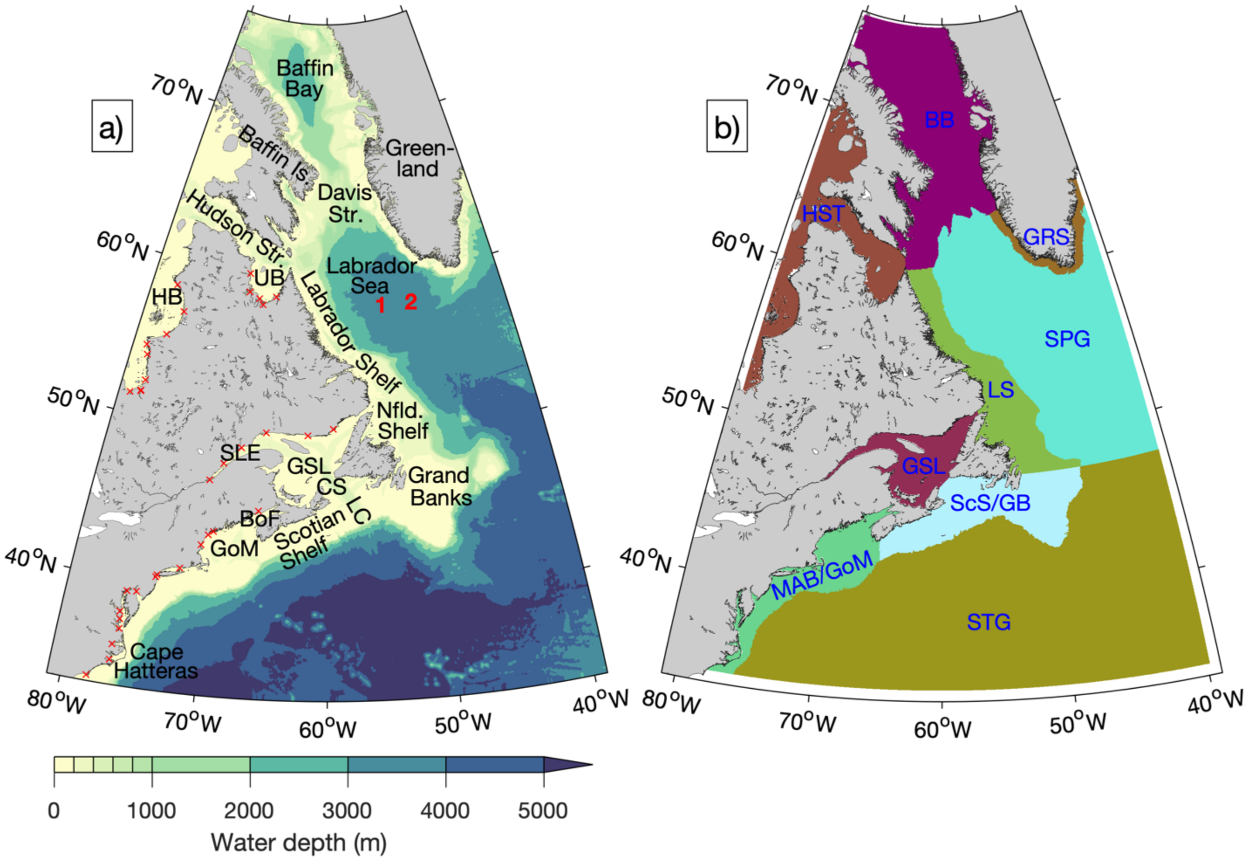

Figure 1. (a) Model domain and bathymetry. Locations of river mouths are indicated by red X marks. Locations for which depth profiles of simulated temperature are shown in Fig. 16 are indicated by numbers in red. Abbreviations are used for: Island (Is.), Strait (Str.), Hudson Bay (HB), Ungava Bay (UB), Newfoundland (Nfd.), St. Lawrence Estuary (SLE), Gulf of St. Lawrence (GSL), Cabot Strait (CS), Laurentian Channel (LC), Bay of Fundy (BoF), and Gulf of Maine (GoM). **(b)** Regions in which metrics of model performance are calculated. The regions are: GRS (Greenland Shelf), HST (Hudson Strait), BB (Baffin Bay), LS (Labrador Shelf), SPG (Subpolar Gyre), GSL (Gulf of St. Lawrence), ScS/GB (Scotian Shelf/Grand Banks), MAB/GoM (Mid-Atlantic Bight/Gulf of Maine), and STG (Subtropical Gyre). Areas within 10 grid points of lateral boundaries are excluded from the error metric calculations.

3.5 Simulation of deep convection in the Labrador Sea

One of the important hydrodynamic features of the NWA is the occurrence of deep winter convection (DWC) in the Labrador Sea and a few other areas. DWC ventilates the deep ocean, contributes to the removal of anthropogenic carbon from near-surface waters, and is thought to influence the larger-scale Atlantic Meridional Overturning Circulation (e.g., Rhein et al., 2011). In this section, we assess the model performance in reproducing the effects of DWC at two locations (indicated by numbers in Fig. 1): location 1 (54.31°W, 58.29°N) which is near the centre of the “convective region” identified by Luo et al. (2014), and location 2 (50.72°W, 58.29°N) which is on the AR7W transect and is within the area ("Central Labrador Sea") for which Yashayaev (2024, hereafter Y24) composited the available observations to form time series of ocean properties from the surface to the 2000-m depth. (Location 1 is near the western edge of the Central Labrador Sea as defined by Y24.) The output of Prog will be used here so that the model's response to the conditions that trigger DWC can be assessed. Because the time series of Y24 indicated that conditions in 2014 were markedly different from those of subsequent years, the model results of 2014 will be included here even though they were excluded from the preceding discussions of model performance.

Time series of temperature profiles at the two locations are shown in Fig. 16. The time series at location 1 is generally more similar to the observation-based, area-composite time series of Y24 (his Fig. 3) than at location 2. This is consistent with the fact that location 1 is at the centre of the area where DWC occurred in the modelling study of Luo et al. (2014), which they found to agree with areas of convection observed by, e.g., Lavender et al. (2000). The time series of simulated temperature profiles at location 1 includes several features that appear in Y24, such as: 1) the turbulent vertical mixing/convection being much stronger in 2015 than in 2014, with the 3.4°C contour of simulated temperatures extending down to the ~1600-m depth in 2015 but just to the ~1000-m depth in 2014; 2) temperatures below 3°C occurring from the surface to the ~200-m depth from late 2015 to early 2016; and 3) temperatures above 6°C extending to a maximum of ~100 m below the surface during the summer. Given that: 1) our model does not directly simulate or parameterize deep convection and 2) we are comparing the temporal evolution of simulated temperatures at one location against a composite of observations over an area with a diameter of *O*(100 km) in Y24, we find these similarities encouraging.

It should be noted that the horizontal grid size of our model is *O*(1 km), which is much coarser than the typical horizontal scale of *O*(100 m) for the convective plumes (e.g., The Lab Sea Group, 1998). Furthermore, our circulation model does not use an explicit winter advection scheme and instead uses large vertical mixing coefficients produced by the modified "2.5-level" scheme of Mellor and Yamada (1982) to mimic the intense convective mixing associated with DWC. A fine-resolution model with a horizontal grid size of *O*(100 m) nested within DALROMS-NWA12 v1.0 will be used in our future research to develop better parameterizations of DWC over the NWA and to examine how the model simulates deep ocean ventilation and near-surface carbon removal due to DWC.

Additional references

Lavender, K. L., Davis, R. E., and Brechner, O. W.: Mid-depth recirculation observed in the interior Labrador and Irminger seas by direct velocity measurements, Nature, 407, 66–69, https://doi.org/10.1038/35024048, 2000.

Luo, H., Bracco, A., and Zhang, F.: The seasonality of convective events in the Labrador Sea, J. Clim., 27(17), 6456–6471, https://doi.org/10.1175/JCLI-D-14-00009.1, 2014.

Rhein, M., Steinfeldt, R., Kieke, D., Stendardo, I., and Yashayaev, I.: Ventilation variability of Labrador Sea Water and its impact on oxygen and anthropogenic carbon: a review, Phil. Trans. R. Soc. A, 375, 20160321, https://doi.org/10.1098/rsta.2016.0321, 2017.

Yashayaev, I.: Intensification and shutdown of deep convection in the Labrador Sea were caused by changes in atmospheric and freshwater dynamics, Commun. Earth Environ., 5, 1–23, https://doi.org/10.1038/s43247-024-01296-9, 2024.

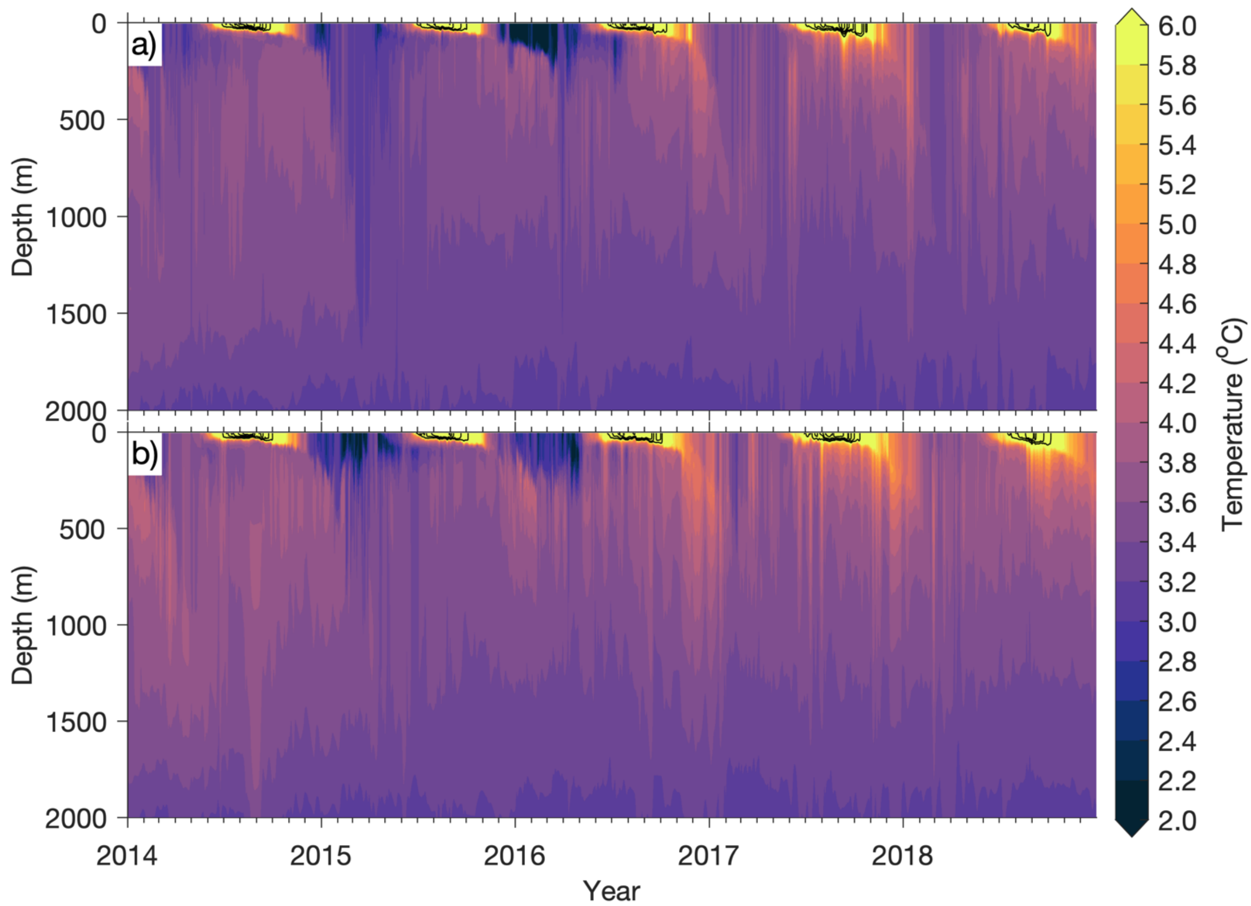

Figure 16. Daily-mean simulated temperatures from Prog, vertically interpolated to 5-m depth intervals between the 0- and 2000-m depths, at location 1 (54.31° W, 58.29° N) **(a)** and location 2 (50.72° W, 58.29° N) **(b)**, indicated as "1" and "2" respectively in Fig. 1. Major tick marks correspond to 1 January of each year and minor tick marks correspond to the first days of February–November. Temperature values between 6°C and 11°C are shown with black contour lines at 1°C intervals.

• *Line 104: The resolution of "O(km)" is mentioned. Currently, eddy-resolving circulation models of the North Atlantic typically have resolutions between 1 and 10 km. A more specific definition of the model resolution would be helpful for readers.*

Thank you for your suggestion. Since the horizontal grid size of our model ranges from ~8 km in the south to ~2 km in the north, we changed "a horizontal grid size of O(km) that decreases with latitude" to "a horizontal grid size of O(1 km) that decreases with latitude" accordingly.

• *Line 119: Is the freshwater flux separated into solid and liquid components? If not, could the authors provide a rationale for this choice?*

The freshwater fluxes described in this paragraph, from rivers and from the melting of ice and snow on land, are in liquid form. In response to your comment, we added the following sentences after the description of the freshwater inputs: "Another source of salt/freshwater flux at the sea surface is sea ice, which is a source of salt through brine rejection at the time of freezing and a source of fresh water at the time of melting. Lateral movement of sea ice results in these two surface fluxes occurring at different locations."

• *Lines 153-154: The model diffusion/viscosity is zero. What boundary condition is used for the tangential velocity component, and does this formulation accurately represent the friction in the lateral boundary Ekman layer?*

The adaptive radiation-nudging open boundary condition is used for both the normal and tangential components of depth-varying currents. (For depth-averaged currents, the Shchepetkin scheme which we use is applied to the normal component, and specifying this scheme automatically results in the Chapman scheme being used for the tangential component.) We nudged the simulated currents, temperature, and salinity towards GLORYS reanalysis near lateral open boundaries (Lines 175–178) to ensure the ocean state in this area is as realistic as possible, which might be difficult with just the lateral open boundary conditions. We added these points to the manuscript.

• *Lines 348-350: The salinity model error may be related to boundary conditions in this region of the model domain. Do the GLORYS simulations provide adequate boundary conditions? The higher* *horizontal resolution of your model suggests that the GLORYS model might underestimate horizontal advective transport through the open boundary of the St. Lawrence Estuary.*

The head of the St. Lawrence Estuary is not an open boundary in our model. Instead, there is an artificial channel representing the St. Lawrence River, at the head of which we specify the river discharge. This discharge value is estimated by the St. Lawrence Global Observatory using the regression model of Bourgault and Koutitonsky (1999) whose input is the observed water level of the river, so we expect this dataset to be reliable.

• *Lines 550-556: The impact of tides on temperature and salinity in the Bay of Fundy appears minimal (Fig. 19). Could the authors discuss why the tidal effect is relatively small in this area? I would expect them to be more significant.*

Our model results do demonstrate large effects of tides on the sub-tidal circulation and hydrography in the Bay of Fundy, which were not mentioned in the previous version of our manuscript. Based on your comments, we revised Lines 584–590 as follows (Fig. 19 is now Fig. 20 because we have added a new Fig. 16): "The effect of tides is also evident in the region surrounding two other areas with large tidal ranges, the St. Lawrence Estuary and the Bay of Fundy. In both winter and summer, ΔS_{sfc}^{P-NT} in the St. Lawrence Estuary (Fig. 20a,c) is positive (up to ~6.0 in most of the Estuary but >10 in parts of the Upper Estuary during the summer), suggesting that tidal mixing brings higher-salinity subsurface water towards the surface. In summer (Fig. 20c), the influence of this higher salinity due to tidal mixing spreads into the northwest Gulf of St. Lawrence due to the propagation of the estuarine plume. In the Bay of Fundy, the salinity difference is also positive in both seasons. In winter, ΔS_{sfc}^{P-NT} ranges from ~0.4 in most of the Bay to ~2.4 near the Saint John River's mouth and in summer, it ranges from ~1.2 in the upper Bay to ~3.6 near the Saint John River's mouth. The role of tidal mixing is also evident in the patterns of sea surface temperatures (Fig. 20b,d), with ΔT_{sfc}^{P-NT} positive in winter (up to ~1.5°C in both the St. Lawrence Estuary and the Bay of Fundy) and negative in summer (as low as ~-4.5°C in both areas)."