Dear Dr. Stigebrandt,

We appreciate your thoughtful and constructive review of our manuscript. Your comments helped us improve the clarity and depth of this study.

**Comment 1**: The rate of change of DO along the flow path depends on (i) the rate of oxygen consumption OUR by mineralization of OM, (ii) the rate of oxygen supply by inflow through Cabot Strait, which is determined by the advective flow speed u and the concentration of DO of the inflowing water (boundary concentration), and (iii) the rate of supply of oxygen by turbulent vertical diffusion from the oxygen rich Cold Intermediate Layer overlying the deepwater. Turbulent vertical diffusion is known to take place essentially at the bottom boundary, where most of the vertical mixing occurs due to breaking internal waves, often driven by internal tides generated at sloping bottoms and steps in the bottom. Vertical mixing at bottom boundaries creates horizontal buoyancy gradients that drive transversal circulation, not described by a 1D model, that distributes the effects of mixing to the whole water body. Changes of DO due to changes in the rate of change of turbulent vertical mixing are hard to show. If the turbulent mixing is driven by the internal tide, it may change if the vertical stratification changes. This could be discussed in the manuscript.

This is an important point, and we recognize the significance of internal tide-driven mixing in the bottom boundary layer and its potential influence on vertical and horizontal oxygen fluxes into the deep layer. Previous studies (Cyr et al., 2011, 2015) have shown that while interior mixing accounts for the majority (70%) of CIL erosion near Rimouski (proximal to the head of the Laurentian Channel in the Lower Estuary), significant boundary-layer turbulence also occurs where the CIL intersects with the sloping seafloor. It was also noted that the relative contribution of these processes is likely to shift even further towards interior mixing dominance in the open Gulf. Whereas our 1D model neglects vertical diffusivity, this simplification is supported by tracer-based observations from Stevens et al. (2024) in which the authors report basin-wide effective vertical diffusivities on the order of $10^{-5}$ $m^2 s^{-1}$ ($6.5 \times 10^{-6}$ $m^2 s^{-1}$ in the interior, $1.5 \times 10^{-5}$ $m^2 s^{-1}$ in boundary regions). Although localized enhancements in vertical mixing were observed near the basin slopes, these effects were spatially limited. These findings are consistent with earlier microstructure measurements (Cyr et al., 2011) and support our use of a steady-state 1D advection-diffusion framework focused on along-channel dynamics. That said, such localized mixing may contribute to spatial heterogeneity in oxygen concentrations and secondary circulation, particularly near topographic features, and we now acknowledge this as a potential limitation of our approach. A brief discussion of these points and their significance now appears in Section 3.2 of the revised manuscript.

**Comment 2:** The 1D model is tuned using historical data, and data from the large-scale tracer experiment TReX in the Bay of St Lawrence. It is required that the model can describe the distribution of DO along its path. If it can, one may have confidence in model results when changing the boundary concentration of DO at Cabot Strait.

We agree that confidence in the model's projections depends on its ability to reproduce present-day DO distributions. The 1D advection-diffusion model utilized in this study is constrained using physical parameters derived from the TReX tracer experiment (Stevens et al., 2024), specifically the along-channel advection velocity and horizontal diffusivity. For each run (or year), the model is fit to observed, along-channel DO concentrations using a least-squares fit repeated over 1000 iterations, providing a robust fit to the data. The resulting model output captures the observed along-channel DO gradient in both magnitude (amount of DO consumed within the channel) and slope (OUR). This supports the validity of investigating the impact of possible mitigation scenarios upon varying boundary conditions.

**Comment 3:** Horizontal diffusion, but not vertical diffusion, is included in the model. The argument for discarding vertical diffusion is that is has a time scale of 30 years while the horizontal time scale is 5 years. However, the vertical time scale is estimated using the vertical diffusivity $K_z = 1x10^{-5}$ $m^2s^{-1}$. The horizontal mean $K_z$ is maybe larger because one may expect high values at the boundaries (hot mixing spots). With $K_z = 1x10^{-4}$ $m^2s^{-1}$, the vertical time scale would be only 3 years. This should be discussed in the manuscript because vertical diffusion possibly may provide a significant contribution to the DO budget of the deepwater.

We agree that the role of vertical diffusion warrants a more in-depth discussion. This was partially addressed in our response to "Comment 1" above. In the manuscript, we estimate a vertical diffusive timescale of ~30 years based on a representative vertical diffusivity $K_Z = 10^{-5}$ $m^2$ $s^{-1}$, consistent with basin-wide estimates by Stevens et al. (2024) based on results of the TReX tracer experiment. Stevens et al. (2024) also report effective vertical diffusivities of ~$6.5\times10^{-6}$ $m^2$ $s^{-1}$ in the interior and up to $1.5\times10^{-5}$ $m^2$ $s^{-1}$ near the boundaries of the Laurentian Channel, values that are consistent with previous microstructure measurements in the Lower Estuary (Cyr et al., 2011). Whereas localized "hotspots" of mixing may exhibit even higher $K_Z$ values (e.g., $10^{-4}$ $m^2$ $s^{-1}$), these regions are likely spatially constrained. Thus, basin-wide averages seem appropriate to assess the large-scale DO budget in the Laurentian Channel. Whereas we acknowledge that vertical diffusion could affect DO distributions, especially in regions with rough topography, our decision to neglect vertical diffusivity in the 1D framework is justified by the dominance of along-channel transport over large spatial scales. As noted in our response to "Comment 1", a brief discussion of these issues was added to Section 3.2 of the revised manuscript.

**Comment 4:** The model describes quite well the observed year to year changes in DO in the deepwater using only known changes of the DO concentration in the Cabot Strait. The model uses a constant UOR. One would expect that UOR might be greater in the inner part of the St. Lawrence River Estuary due to possibly greater production of OM here due to nutrient supply by the river. It would be interesting if the authors could discuss the sensitivity of model results to the assumption of a constant UOR. It would also be interesting to know if there are large variations in the annual supply of nutrients from the St. Lawrence River, and the expected annual supply of OM to the deepwater.

We agree that the assumption of a spatially uniform OUR may overlook heterogeneity in primary production and organic matter supply across the St. Lawrence Estuary and Gulf. Below, we address the model's sensitivity to this assumption and summarize relevant literature on the variability of nutrient and organic matter supply. To evaluate the impact of a spatially heterogeneous OUR, we modified the 1D advection-diffusion model and doubled the remineralization rate (S) over the final 200 km of the Laurentian Channel (approximately corresponding to the LSLE), while retaining the best-fit S value elsewhere. This scenario was intended to represent enhanced respiration in nearshore regions due to elevated OM supply. The simulation was run to steady state (over a 10-year period or roughly 2 transit times) and used 2022 as a test year due to its extensive spatial data coverage. As shown in the figure below (Fig. R1), introducing a spatially variable S leads to slightly lower predicted DO concentrations in the inner estuary, particularly beyond 600 km. While the reduction in least-squares misfit is modest (–2.3%), the fit appears visibly improved in the LSLE, suggesting a slightly better spatial alignment between model and observations. This suggests that, although spatial heterogeneity in remineralization rates likely exists, the large-scale DO trends are effectively captured by a spatially averaged OUR in the present model configuration that integrates over regional scales. With respect to the variability of nutrient and OM supply, several studies point to distinct seasonal and spatial patterns in source contributions and productivity across the system. For instance, Savenkoff et al. (2001) and Jutras et al. (2020) show that most of the nitrate input to the LSLE during the summer originates from deep water upwelling at the head of the Laurentian Trough. In contrast, Bluteau et al. (2021) report that during the winter, the primary nitrate source is fluvial, owing to reduced upstream production. The origin of the settling organic matter also appears to vary along the estuarine gradient. Benoit et al. (2006) and Wang et al. (2025) show that sediments (and, presumably deep waters) of the Upper Estuary receive more allochthonous organic matter, which tends to be less labile, whereas autochthonous organic matter fluxes dominate in the LSLE and this OM is more readily respired. This is consistent with the inferred (from conversion of multi-mission remote sensing datasets to daily Chl α concentrations between 1998-2019) spatial and seasonal distribution of Chl α (in the Estuary and Gulf), including the presence of a mid-estuary maxima (Laliberté and Larouche, 2023), and would suggest a spatially varying remineralization potential. Nonetheless, our model, which resolves large-scale advection and integrates over relatively long spatial and temporal scales, agrees well with observed deepwater DO concentrations using a single OUR value. This suggests that, whereas OUR heterogeneity exists, its impact on the deepwater DO distribution is reduced by the large spatial and temporal scales of the channel, which tend to smooth out local heterogeneity. Nonetheless, we agree that spatially resolved models would be required to further investigate DO dynamics. A brief discussion of primary productivity heterogeneity and the OUR sensitivity analysis was added to Section 3.3 of the revised manuscript. Figure R1 was added to Supplemental Material S8 and referred to in the revised manuscript.

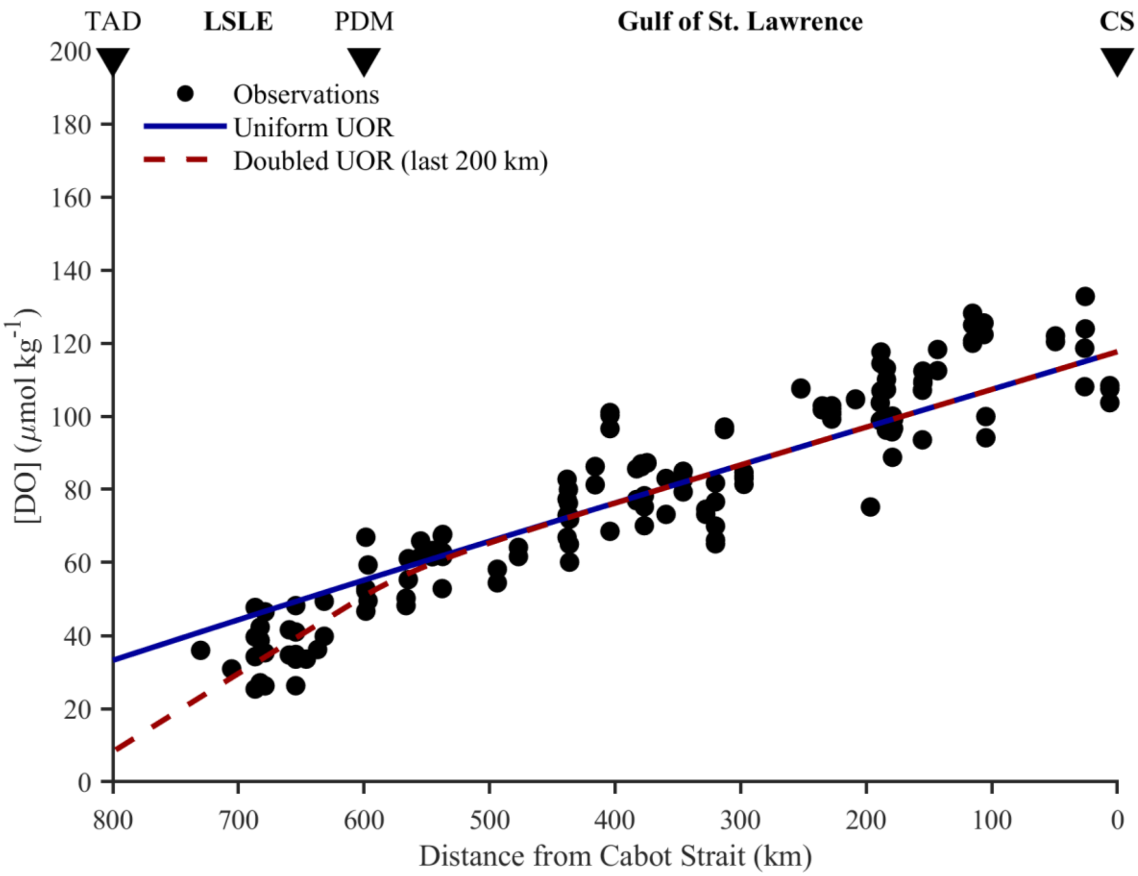


**Figure R1: Sensitivity of the 1D advection-diffusion model to spatial variability in the oxygen utilization rate (OUR). The model is initialized with observed deepwater $O_2$ concentrations at Cabot Strait and run forward with either a spatially uniform OUR (solid blue line; fit to observations from 2022 (black dots)) or a doubled OUR in the inner 200 km of the Laurentian Channel (dashed red line), approximating elevated remineralization in the LSLE where the supply of allochthonous OM is enhanced. Regional labels highlight key longitudinal transitions along the Laurentian Channel: TAD = Tadoussac, LSLE = Lower St. Lawrence Estuary, PDM = Pointe-des-Monts, and CS = Cabot Strait. The spatial pattern of [DO] is well captured in both cases, with the doubled-OUR scenario yielding only a ~2% decrease in misfit.**

**Comment 5:** The physics of the model, i.e. the current speed u and the horizontal diffusivity $K_H$, has been calibrated using results from the transient plume of the tracer experiment TReX. Since the duration of the tracer experiment was shorter than the residence time of the deepwater it was necessary to include horizontal diffusivity to describe the observed spreading of the tracer. For a quasi-steady description of DO it might possibly be more important to include vertical diffusion since vertical diffusion might contribute to the DO budget of the deepwater. The authors should discuss this and estimate the uncertainty of model results due to the explicit ignorance of vertical diffusion.

The vertical diffusion may contribute to the deep layer oxygen budget. Here, we perform a rough estimation of its magnitude using Fick's Law:

$$F = -K_Z \times \frac{\partial C}{\partial z}$$

We define the concentration gradient ($\partial$C) as the Deep Layer [DO] (with respiration removed, i.e. the boundary condition) – the average CIL [DO]. The depth of the diffusive layer ($\partial$z) was set to 100 m (the same depth used for the dimensional analysis). We used data from 2022 (as this was a robust year for data collection) for an example calculation and explored the average estimated flux based on 3 scenarios: 1) The basin-wide effective $K_Z$ of $10^{-5}$ (Stevens et al., 2024), 2) The boundary mixing effective $K_Z$ of $1.5\times10^{-5}$ (Cyr et al., 2011; Stevens et al., 2024), and finally 3) The hypothetical hotspot $K_Z$ of $10^{-4}$. The $\partial C$ for 2022 was estimated to be ~129 µmol $kg^{-1}$ (CIL aver DO = 254 µmol $kg^{-1}$, and DL inflow (respiration removed) = 125 µmol $kg^{-1}$). The fluxes for the 3 scenarios are as follows:

1) Basin-wide average: ~1.1 µmol $kg^{-1}$ $yr^{-1}$ (5.3% of OUR).
2) Boundary-enhanced mixing: ~1.7 µmol $kg^{-1}$ $yr^{-1}$ (7.9% of OUR).
3) Hot spot scenario: ~11.1 µmol $kg^{-1}$ $yr^{-1}$ (53% of OUR).

These estimates show that even under enhanced mixing conditions at the boundaries, the contribution of vertical diffusion remains modest compared to the horizontal advection and remineralization dynamics resolved in the 1D model. This supports our decision to omit vertical diffusion in the core framework, while acknowledging that it may introduce spatial heterogeneity in DO near topographic boundaries / slopes and more significantly in localized hot spots. We added a paragraph to the expanded discussion on $K_Z$ in Section 3.2 of the revised manuscript.

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