Dear authors,

Please find below my review or your manuscript entitled "The changing composition of the Gulf of St. Lawrence inflow waters observed from transient tracer measurements". This manuscript describes the composition of the waters of the Gulf of St Lawrence (GSL) using new measured transient tracers. While the science is sound, and the writing relatively good, I wonder what the novelty of this science contributions is. Some results are completely expected and not new, while other puzzling results (gradient of the mean age along the Laurentian Channel) have not been fully exploited in my view. Overall, I am afraid that this study would bring more confusion than clarity in the literature of the GSL. I recommend, if not a rejection, an in-depth re-structuration of this study. I provide below some overall comments and then comments for each section.

General response:

We thank the reviewer for their constructive assessment and feedback. We fully acknowledge the need for clearer structure and stronger emphasis on the study's novelty. In response, we will undertake a substantial revision of the manuscript, including:

- **Reorganizing the discussion section to highlight the new insights provided by transient tracer measurements and their implications for ongoing changes in the Gulf of St. Lawrence ventilation.**
- **Integrating a full deep-water analysis to complement the isopycnal-based results and better illustrate vertical mixing processes of the deep water along the Laurentian Channel.**
- **Restructuring the manuscript to improve clarity and focus, ensuring that results and interpretations are not to question established understanding of the general estuarine circulation.**

We hope that these revisions will address the reviewer's concerns about novelty and clarity, and demonstrate the scientific value of the new transient tracer observations in advancing understanding of GSL deep water ventilation.

Below, we address the reviewer's specific comments in detail.

OVERALL COMMENTS

One of the key results of this study seems to call into question decades of research in the GSL and our basic understanding of the estuarine circulation, that is that the water is getting rejuvenated as it travels from the ocean to the head of the estuary. E.g. in the Discussion: "The temperature, salinity and mean age analysis of the deep water on the

σΘ = 27.26 kg/m3 isopycnal along the Laurentian channel show young, cooler, and fresher water in the Lower Estuary and western Gulf, with older, warmer and more saline water entering through Cabot Strait and within the eastern Laurentian Channel (Figures 3 and 4a). These are the opposite pattern of water mass age that might be expected if water is transported along the Laurentian Channel..."

I think that one problem with this study may be that the analysis is done over a single isopycnal. Is it possible that this isopycnal shoals as the water is advected toward the head of the estuary, giving the impression that the water is getting younger (being enriched by vertical mixing)? What about the same analysis over the bottom waters?

My second concern is that decadal cycles are completely ignored. The study is limited to 2018-2022. How those years related to ~100 years of observations in the GSL? Do we know anything about decadal changes in the circulation?

Finally, I am unsure what is the novelty in this study. I finished the reading thinking "so what?" If the authors decide to revise this study, I recommend making clear in which aspect this study contributes to new knowledge about the GSL.

Response:

We thank the reviewer for their constructive comments, and we appreciate that the novelty of the work was not sufficiently clear in the initial version. From our perspective, the main novelties of this study extending GSL research are:

1. **The observed ongoing shift towards increased NACW contributions to the deep water, as of 2022, which had been observed to have fully happen prior to our analysis.**
2. **The use of transient tracers in water mass analysis, to include insights on circulation and mixing processes.**

We do not intend to question decades of established understanding of the GSL estuarine circulation. The statement quoted by the reviewer does not suggest that the water becomes rejuvenated within the Laurentian Channel. It rather highlights that the relative contribution of NACW, before entering the channel, has increased over time. Consequently, the western part of the system shows higher proportions of LCW, resulting in younger, cooler, and fresher deep water. The misunderstanding may stem from the concept of 'age' as we have used it in this study. We use ventilation age as a water mass tracer, rather than as a measure of residence time in the estuary.

We acknowledge the reviewer's point regarding the limitation of focusing on a single isopycnal. This focus was due to the sampling strategy, which provided the highest density of data at σ_Θ = 27.26 kg/m^3. However, we recognize that this

approach constrains our ability to assess vertical mixing along the deep-water inflow from Cabot Strait to the Lower St. Lawrence Estuary. In the revised version, we plan to expand the analysis to include the full deep-water section, which will allow us to better illustrate both vertical mixing and the limited shoaling of the isopycnal towards the estuary head (see Figure). However, there are limited datapoints throughout the deep water.

Regarding decadal variability, we fully agree that it represents an important aspect of GSL dynamics. Unfortunately, as this study presents the first transient tracer measurements in the region, the available dataset is temporally limited to the year of 2022. While we cannot address decadal cycles directly, we hope that this work highlights the value of including transient tracers in future long-term monitoring efforts, which could eventually enable such analyses.

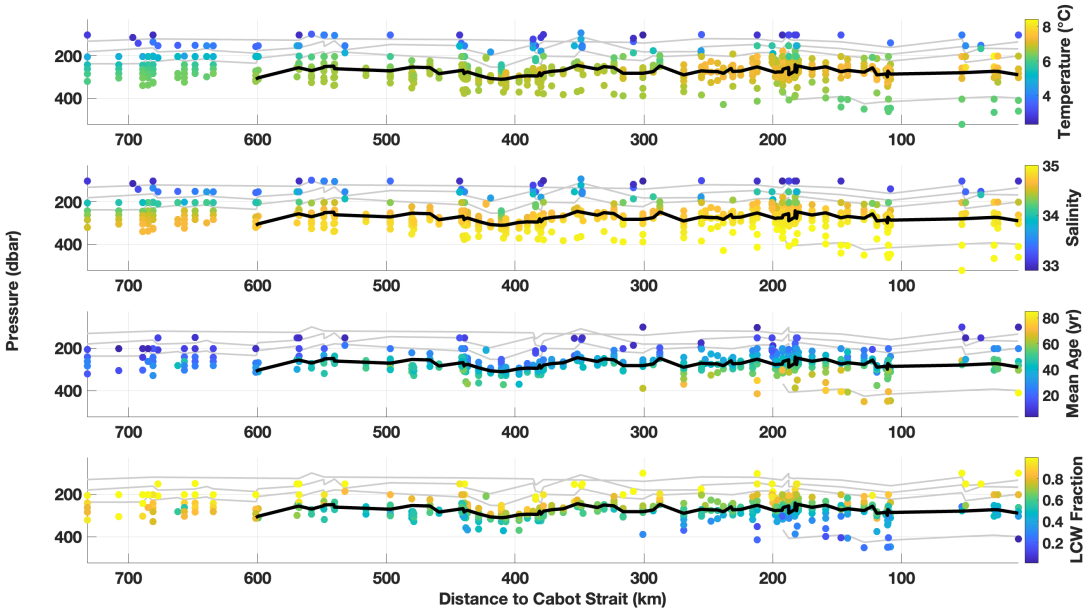

Figure: **Display of various variables along the Laurentian Channel deep waters as a function of depth (shown as distance from Cabot Strait, where greater distance corresponds to locations farther toward the Lower St. Lawrence Estuary). From top to bottom: Temperature, Salinity, Mean Age and LCW fraction. The black line indicates the σ_Θ=27.26kg/m^3 isopycnal for all measurements at this isopycnal included in the analysis. The grey lines represent the 26.5, 26.75, 27.0, and 27.5 isopycnals. (As a reference, the Lower St. Lawrence Estuary starts at a distance of about 600km from Cabot Strait)**

Suggested changes in manuscript:

In the revised manuscript we intent to:

- **Clarify the novel contributions of this study.**

- **Expand the analysis to a full deep-water section, showing that the σ_Θ = 27.26 kg/m^3 isopycnal does not significantly shoal, but include vertical mixing processes along the Laurentian Channel. We intent to add this or a similar figure to the manuscript.**
- **Emphasize that transient tracer measurements are of high value, when analyzing water masses, including mixing processes.**
- **Clarify at the beginning of the manuscript that the reported mean ages refer to ventilation ages, used as a water mass tracer, and do not represent residence time within the estuary.**

1. INTRODUCTION

The Introduction is well written. I don't have many comments except better explaining the SF6 and CFC-12, their relevance, and why it is useful to measure them (how it works).

Response:

We thank the reviewer for this helpful comment. We agree that a clearer explanation of the relevance and application of SF_6 and CFC-12 will improve the introduction.

Suggested changes in manuscript:

We intend to expand the first paragraph and better describe how these transient tracers are used in ocean ventilation studies and why they provide valuable insights into water mass age, supported by relevant literature references.

2. HYDROGRAPHY

Well written.

3. 2 OBSERVATIONS

- I would like more information about the transient tracers. You need to specify that this is not only valid for the GSL, but for the global ocean as well (e.g. first paragraph).

- GLODAP database is mentioned. Can you say more about this database and how representative it is? How the database was interrogated, etc. I am specifically thinking of figure 4b: why only those points are on the map? I am sure much more of Atlantic Canada was sampled.

Response/ Suggested changes in manuscript:

We thank the reviewer for these valuable comments. We agree that additional clarification is needed regarding the global context of transient tracers and our use of the GLODAP database. In the revised manuscript, we will aim to give a broader explanation on the relevance of transient tracers such as SF_6 and CFC-12 for the world oceans.

Regarding the GLODAP database, we acknowledge that much more data are available for the North Atlantic and Labrador Sea than what is shown in Figure 4b. For our analysis, we specifically selected stations near the entrance of the GSL to ensure consistency in the choice of the Δ/Γ-ratio and to obtain the closest possible reference measurements for defining the boundary conditions of the LCW and NACW mean ages. We will add more details to clarify the data selection process and explain why only those stations are displayed and used.

3.4 CABOT STRAIT

- "A fixed location within Cabot Strait (47.2 °N; 59.7 °W) was selected, and the distance from each sampling point to this location was calculated."

-> How this works? The exact same station was sampled all the time? Figure 6 suggests that several dozens of points are from Cabot Strait between 2018 and 2022. These are all from the exact same location?

Response:

We thank the reviewer for pointing out this potential confusion. We did not sample directly at the fixed Cabot Strait location. Instead, our goal was to construct a time series representative of the Cabot Strait inflow, based on measurements collected in 2022. Using the transit time estimates from Stevens et al. (2024) and the known sampling positions along the Laurentian Channel, we inferred the approximate time when each sampled water parcel would have

passed through Cabot Stait. Consequently, data collected farther west in the Laurentian Channel were assigned earlier equivalent years (e.g. 2018) when they passed through Cabot Stait, reflecting the estimated four-year transit time through the Laurentian Channel.

Suggested changes in manuscript:

We will carefully review and revise the corresponding text to clearly explain that the Cabot Strait time series is a reconstructed dataset, derived from 2022 measurements combined with estimated water parcel transit times

- "Using a transit speed of 0.5 cm/s..."

-> It was argued in section 2 that several estimations of the speed have been done. Why this one more than another?

Response:

We thank the reviewer for this comment. We selected the transit speed of 0.5 cm s^{-1} because it was determined from the tracer release experiment described in Stevens et al. (2024). This experiment measured the dispersion from released CF_3SF_5, a tracer measured simultaneously to the transient tracers analyzed in our study. Therefore, this estimate provides the most consistent and directly comparable transit speed for the conditions and tracers used here.

- "To account for changes in DO concentrations, the oxygen utilization rate (OUR) within the Laurentian Channel, estimated to be 21.1 μmol/kg per year (Nesbitt et al., 2025 - in revision), was considered in the calculation."

-> As far as I can tell, OUR is not used further in the text. I am unsure why this sentence is here.

Response:

We thank the reviewer for this observation and this was raised by other reviewers as well. The use of OUR was indeed part of the time series estimation for Cabot Strait, where we applied the value of 21.1 μmol/kg per year to the back-calculated oxygen values at the Cabot Strait inflow. We acknowledge that this was not clearly described in the text, which may have caused confusion.

Suggested changes in manuscript:

We will revise the manuscript to clarify, how the OUR was used in estimating the Cabot Strait time series. In addition, we plan to move most of the oxygen-related data and figures to the supporting information, as oxygen is not a primary focus of this study.

4. RESULTS

- Most of the sub-sections here are very thin... Section 4.4, for example is 2 sentences! Overall, it is not clear to me what is novel here.

Response/Suggested changes in manuscript:

We thank the reviewer for their helpful comment and agree that some sub-sections are too thin. In the revised manuscript, we will combine short sections and expand on them where appropriate to provide a more detailed explanation of the results.

- Figures 3 to 6: recall dates/time presented in this figure and where the data come from (TREX or GLODAP?). From one figure to the other, it looks like different data source are used but this information does not appear in the caption.

Response/Suggested changes in manuscript:

We thank the reviewer for this useful point of view, that the figure captions are missing information. We agree that the data sources and time frames should be stated more clearly and in the revised manuscript, we will add detailed descriptions to each figure legend. Specifying their data origin (TreX or GLODAP) and sampling years. (Except for figure 4b, all data is coming from the TreX missions in 2022.)

- section 4.2: "we observe oldest water (70 – 105 years) to be located south and west of Cabot Strait with considerably younger water located to the northeast (5 – 20 years)."

-> Can you name those places? I am assuming that you refer to the Scotian shelf and the Newfoundland shelf near Flemish Cap.

Response/Suggested changes in manuscript:

We thank the reviewer for highlighting the need for a more detailed geographical description. We will add this in the revised manuscript by specifying that the NACW is primarily represented by waters over the Scotian shelf and southeast of the Scotian shelf, while the LCW corresponds to waters near the Newfoundland Shelf and Flemish cup.

- L.260: "Consistent with the temperature and salinity spatial variability, deep layer mean age shows an abrupt 5 – 10 year shift towards younger waters at approximately 63 °W (i.e., the southeastern tip of Anticosti Island; see Figure 4c)."

-> First, there is no longitude in Figure 4c; Second, I do not understand where to look for this "shift"

Response/Suggested changes in manuscript:

We thank the reviewer for this observation. You are correct that the longitude is not directly visible in Figure 4c. The difference in mean age is represented by color-coding data points, where blue symbols correspond to stations west of 63°W and red symbols to those east of it. We will clarify this in the figure legend and revise the manuscript text to explain more clearly where and how this shift is observed.

- Section 4.3: I think that it is worth recalling the type of analysis here. "water mass analysis" is broad.

Response/Suggested changes in manuscript:

In the revised manuscript we will briefly restate the type of analysis performed in this section.

- L. 287: "Despite inherent uncertainties that limit the interpretation of the estimated fraction values, observational evidence suggests that the fraction of LCW gradually decreases from the west to the east within the Laurentian Channel."

-> Figure 5 suggests that there is 100% LCW in the Lower estuary. Is this realistic? If true, would it mean that we have been wrong in our understanding of the system for several decades?

Response/Suggested changes in manuscript:

The thank the reviewer raising this important point. The apparent 100% LCW fraction near the Lower St. Larence Estuary indeed results from the uncertainties inherent in the water mass fraction calculations, but it should demonstrate that LCW is still present within the Gulf of St. Lawrence. Our findings do not contradict the established understanding of the Laurentian and Estuarine circulation pattern. Instead, they suggest that the transition towards a greater NACW contribution, previously predicted to have fully reached dominance, is still ongoing as of 2022. We will add this information more detailed to the text and figure in the revised manuscript.

5. DISCUSSION

- L. 305: "The temperature, salinity and mean age analysis of the deep water on the σΘ = 27.26 kg/m3 isopycnal along the Laurentian channel show young, cooler, and fresher water in the Lower Estuary and western Gulf, with older, warmer and more saline water entering through Cabot Strait and within the eastern Laurentian Channel (Figures 3 and 4a). These are the opposite pattern of water mass age that might be expected if water is transported along the Laurentian Channel..."

-> This is a strong statement that bring confusion. See my overall comments.

<u>Response/Suggested changes in manuscript:</u>

We thank the reviewer for this important comment and agree that the original phrasing could create confusion. Our intention is not to challenge the established understanding of the Gulf of St. Lawrence and Lower St. Lawrence Estuary circulation pattern. Rather, our results indicate that the transition towards increased NACW contribution is still ongoing as of 2022, and has not yet reached full dominance through the deep waters of the Laurentian Channel.

To avoid misinterpretation and any misunderstanding, we will revise that statement cited by the reviewer in combination with the statement listed in the next comment. In doing so, we will aim to clearly outline that this study does not question any general estuarine circulation pattern and emphasize the novel aspect of this study, particularly the use of transient tracers to analyze ventilation patterns and water mass contributions, sampled for the first time in the Gulf of St. Lawrence. This was pointed out by the reviewer to include more in the discussion.

- L.314: "These observations of water mass ages support the general hypothesis of a recent change in the composition of the Gulf of St. Lawrence's deep inflow towards an increased NACW composition"

-> Does it? two sentences before you say that these observations are opposite to what is commonly known... Again, this adds more confusion than answers.

Response/Suggested changes in manuscript:

We thank the reviewer for pointing out this potential inconsistency and for highlighting where our wording may lead to misunderstanding. Our observations indeed support the general hypothesis that the deep water inflow to the Gulf of St. Lawrence is shifting toward greater NACW contribution. However, our results also indicate that this transition is still ongoing rather than fully complete, which constitutes the key novelty of this study. We will revise the discussion to clarify this distinction and ensure that the interpretation of our findings is consistent throughout the text.

- L. 320 to 338: Nothing new is learn here, I don't think that this belongs in the Discussion.

Response/Suggested changes in manuscript:

We agree with the reviewer that this section does not contribute new insights to the discussion. We will therefore remove the paragraph summarizing previous studies and their NACW contribution estimates to maintain focus on the novel findings of this work. However, we will include them in the introduction to provide context and link our results to previous research.

- L. 350: "The oldest water with the lowest LCW fraction in 2022 is observed all the way near Cabot Strait, indicating that fractions of LCW were present throughout the Laurentian Channel at the time of the surveys."

-> I am not sure I understand what this means.

Response/Suggested changes in manuscript:

The intended meaning is that the lowest LCW fractions were observed near Cabot Strait, while higher LCW contributions appeared farther west within the Laurentian Channel. This pattern suggests that the LCW contribution decreases over time as the water flows from Cabot Strait toward the Lower St. Lawrence Estuary. Even when including a look of the entire deep water column, which adds vertical mixing of fresher and younger water, this shift is still visible and adds to

the general novelty of the study, that LCW contributions are present within the Laurentian deep channel waters in 2022. We will revise this sentence for clarity in the manuscript to ensure the interpretation is unambiguous.

- L. 351- 354: again, the fact that the oxygen is consumed as the water travels in the estuary is nothing new.

Response/Suggested changes in manuscript:

We thank the reviewer for this comment and agree that the observation of oxygen and oxygen consumption along the estuarine pathway is not focus of this manuscript. Our intention in including this variable to the analysis was to place our results within the broader context of the known oxygen decline in the GSL, thereby demonstrating consistency with the established understanding and previous findings. We will rephrase this part of the text to make this purpose clearer, however, moving most parts of the oxygen analysis to the supporting information and referring to that.

6. CONCLUSION

- The first sentence recalls the novelty of this study. More of these statements should appear in the Discussion as well.

Response/Suggested changes in manuscript:

We thank the reviewer pointing to this sentence and we agree that the discussion would benefit from a stronger emphasis on the studies novel aspects. In the revised manuscript, for which we will integrate clearer statements throughout the discussion highlighting the first sampling of transient tracers and the ongoing shift towards higher NACW contributions, as already outlined in the response to earlier comments.