Reviewer #2

"When the fjords take a breath: Influence of wind forcing and Ekman dynamics on deep ventilation in the North Patagonian Fjords"

General remarks:

The article analyses a long term time series at the Guafo mouth in 170 m depth of temperature, salinity and dissolved oxygen together with ERA-5 wind data.

By defining their own, yearly changing, baselines of oxygen concentrations, the authors can define venticalation pulses and ventilation periods. They find that both occur regularly and analyse if the coastal Ekman transport can be attributed to the events. A seasonal analysis finds that the Ekman transport is on average onshore (with a negative τy, Fig. 5). The Ekman pumping changes over the year, being negative (downward pumping) over the austral winter (Fig. 7) and slightly positive during the austral summer. Interesting here is that the mooring is located close to the location within the fjord, where the Ekman pumping switches its sign (Fig. 6, color from red to blue). This suggests a high fluctuation, comapared to more on- and offshore locations.

The authors find that Ekman transport process are a main driver for the oxygenization events, which is an important result and worth of publication.

The authors are further investigating the processes for the ventilation pulses by using a principal component analysis (PCA) and wavelet coherences.

While the paper is well written, using a beautiful long term dataset, to which I congratulate the authors, I have several remarks.

Major comments

The for me most major issue is a more generic description of the location and the drivers of oxygen. I miss a Figure with typical vertical profiles for the different seasons, understanding the vertical structure of T, S and oxygen.

We added a new figure to the manuscript (Fig. 3) to describe the seasonal hydrographic conditions of the water column during. The data were obtained from an oceanographic cruise conducted to preserve and maintain the instruments. The new figure, with its description and methods, was incorporated into the new version of the manuscript.

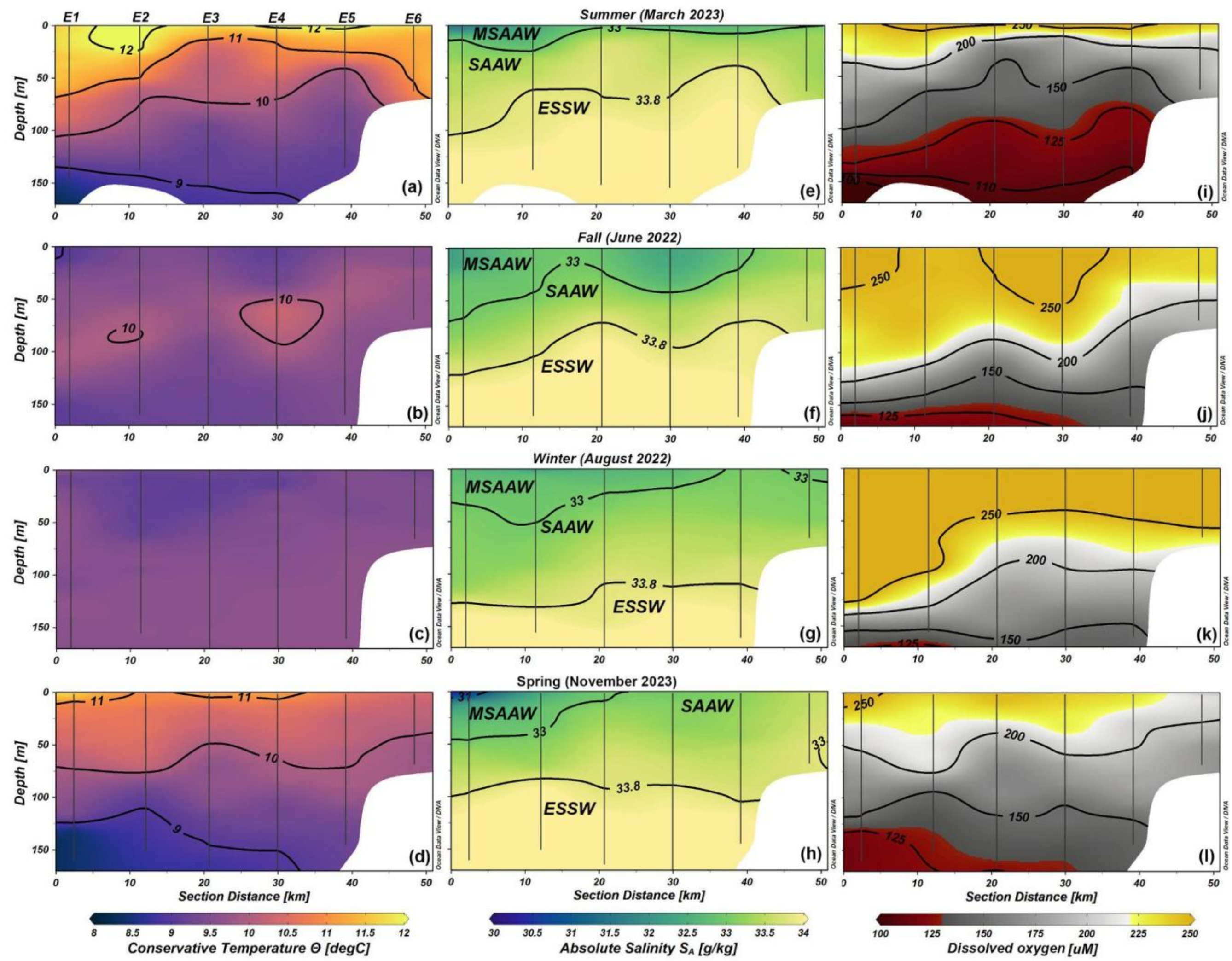


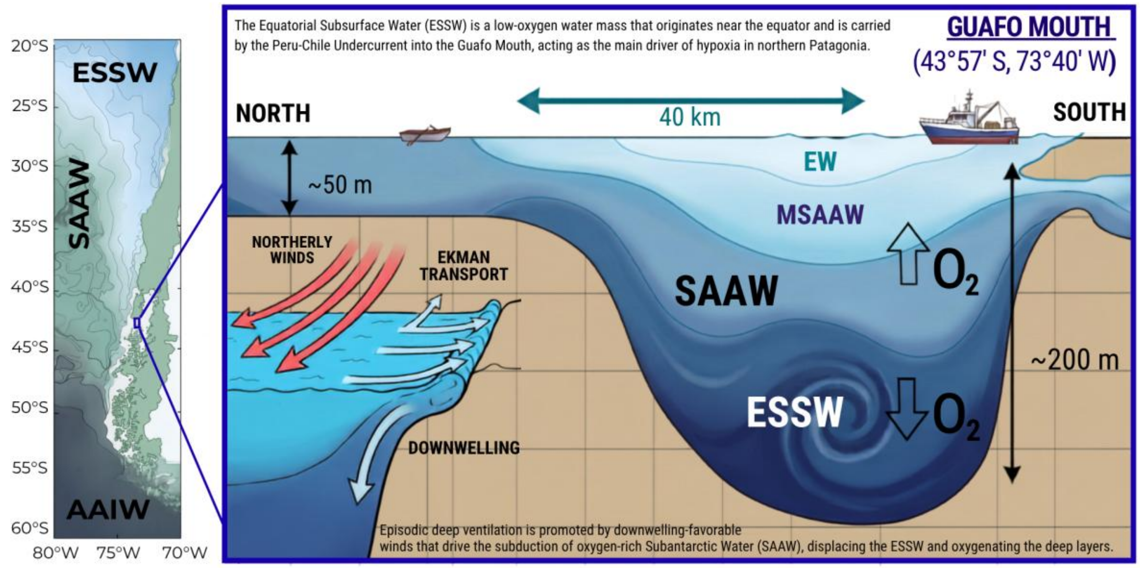
Figure 3. Seasonally hydrographic conditions of the water column in the Guafo Mouth during 2022 and 2023. (a-d) Conservative Temperature, (e-h) Absolute Salinity, and (i-l) Dissolved Oxygen (see Fig. 1c for the station's location).

As a person not familiar with the system I do not understand the sources and sinks for oxygen, why is there hypoxia in 170 m? Is this water transported from oxygen minimum zones into the fjord, or is it local consumption, or is this water from within the fjord, that is transported into the ocean? Here a description in the introduction and/or discussion in the conclusions would be very helpful.

We added a detailed description of the oxygen conditions in the study area (Lines 58-74) reported in the manuscripts by Linford et al. (2023 and 2024).

Maybe even with a small comic-style sketch of the system.

We added figure infographic to show the process described in the manuscript.



Similarly the authors do "only" discuss oxygenization events, and very shortly other processes. If there are oxygenization events, are there vice-versa also hypoxic events? Sec. 4.5, "Limitations and perspectives" or elsewhere could be extended, also in comparison with other systems. As far as I understood, the fjord is less of a basin/sill like structure like many other hypoxic/anoxic systems where intrusions of oxygen play a larger role (see 2 examples out of many of literature below for examples of intrusions from the Baltic Sea and the Clew Bay in Ireland) but this differences makes it maybe interesting to discuss this system in comparison with others, that expererience for the same, or different reason, hypoxia. I understand that this request can be extensive, but a short comparison would be helpful.

We edited section 4.4 “Implications for deoxygenation in northern Patagonia”.

In terms of methodology it would be beneficial to really see the comparison of the measured oxygen with the winkler titration. Measuring oxygen is always tricky, especially long term deployments with biofouling etc.

We agree with the comment. In lines 182-185 of the original manuscript, information about Winkler calibration was included.

“Additionally, in 2016, Winkler samples were collected seasonally along the water column. This experiment was repeated in October 2022 (Linford et al., 2023). Comparison between the iodometric titration (the Winkler method) samples and the DO time series of the GM showed good agreement with a correlation coefficient of 0.97, and a centred root mean squared difference (RMSD) of 11.2 µmol L^{-1}”.

Please also review the equations carefully, there are for example often subscripts missing. Please do also mark vector quantities and their components more clearly. Why do the authors use for a transport the notation "U", which is typically a velocity? That might confuse readers. What about M_x, M_y or M_coast as examples?

We edited the equations.

An analysis that I dont really understand is the PCA. What is the use to do it here? For me a "PC1: 48.3 %, PC2: 22.7 %" does not tell me a lot. Please elaborate what that means otherwise this section can be removed.

We appreciate the reviewer's comment and acknowledge that the percentages for PC1 (48.3%) and PC2 (22.7%) may not provide substantial insight in the main text. However, we consider PCA useful as exploratory context to summarize correlations among variables. To avoid distracting from the central narrative, we have moved the PCA results to the Appendix, where they remain available for readers interested in additional detail.

As a last criticism, the AOU is not well defined.

We have now explicitly defined the abbreviation and added its mathematical formula, supported by Sarmiento and Gruber (2006) and Keeling et al. (2010) at its first methodological mention in Section 2.3.1. Additionally, we direct the reviewer to Section 2.3.4, where we describe how AOU is applied as a quantitative criterion to identify ventilation pulses, and to the discussion in Section 4.1, which details how the use of this criterion separates physical water renewal from temperature-driven solubility changes.

Details: Camila

Fig. 1: The scale is ranging between +2000m to -5000m. This is ok for the overview, but for Panel c a new scale is better. What is distance between the isobaths in Panel c? Depths are stated differently (sometimes 170m, sometimes 175 m).

Corrected

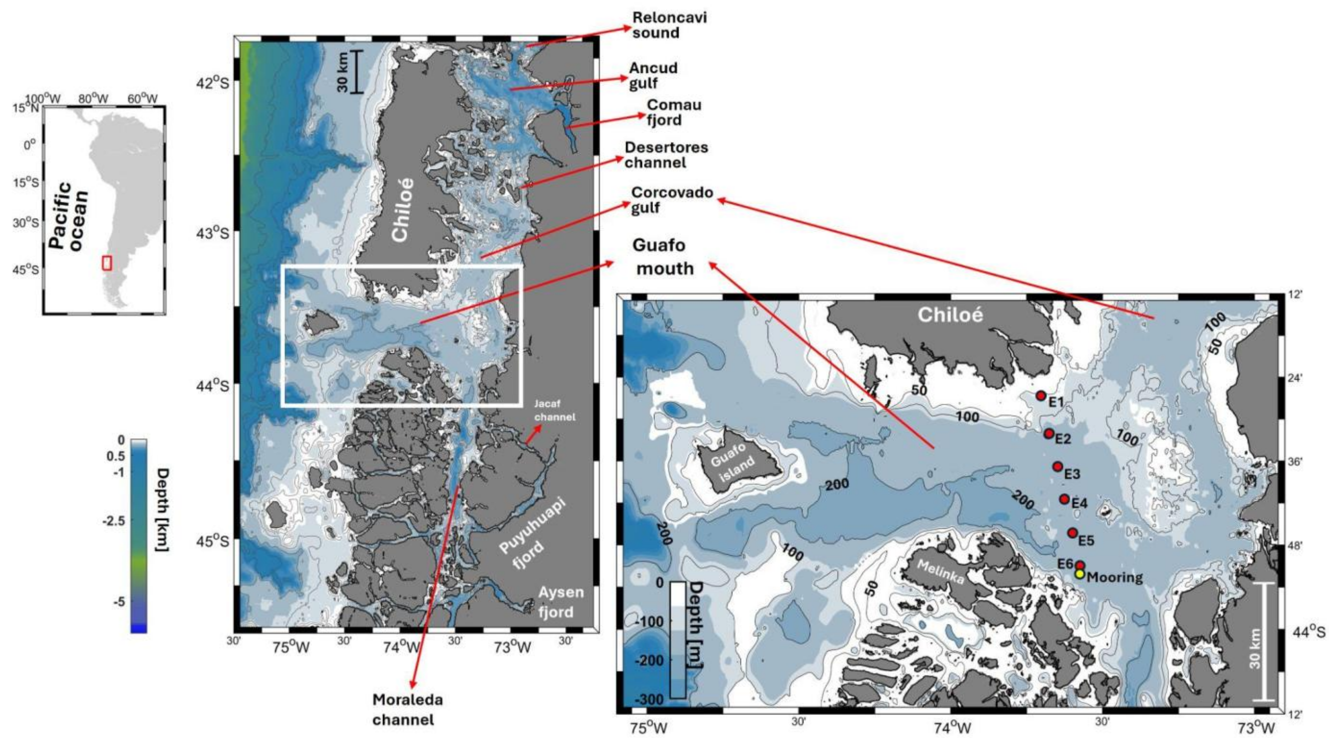


Figure 1. Location and bathymetric features of the study area in the northern Patagonian fjords. (a) Continental map of South America indicating the location of the study region (red box). (b) Regional map (white rectangle delineates the Guafo Mouth area). (c) Bathymetric map of the Guafo Mouth and adjacent zones. Red circles denote the locations of the oceanographic stations (E1–E6) used to generate the seasonal vertical profiles. Yellow point (43° 51' 44.10"S, 73° 33' 24.10"W) also marks the specific position of the mooring. Color scales in (b) and (c) represent depth in kilometres and meters, respectively. Depth data were downloaded from ©GEBCO Compilation Group (2025).

Fig. 2d: Why is there a temperature peak during the austral winter?

In the Guafo Mouth at 170 m depth, the seasonal temperature cycle is decoupled from surface atmospheric heat fluxes. Instead, the observed winter thermal maximum is primarily driven by wind-forced vertical mixing and Ekman dynamics. During the austral winter, prevailing meridional winds induce strong vertical mixing and Ekman downwelling. This dynamic actively transports and deepens warmer upper-layer water masses, specifically the Subantarctic and Modified Subantarctic Water (SAAW/MSAAW), down to the 170 m layer.

This mechanism is supported by the seasonal wind stress and Ekman pumping climatologies (e.g., original Figures 5 and 7), which demonstrate peak downwelling-favorable conditions during these months. Furthermore, the newly incorporated Figure 3, which details seasonal vertical profiles across the Guafo Mouth, clearly illustrates this wintertime vertical homogenization and the effective deepening of warmer waters towards the bottom. Consequently, the deep layer reaches its highest temperatures in winter, which contrasts with the colder conditions driven by the upward advection of Equatorial Subsurface Water (ESSW) during summer

Fig 4, caption: τy, subscripts

We have corrected the notation in the Figure and the rest of the manuscript.

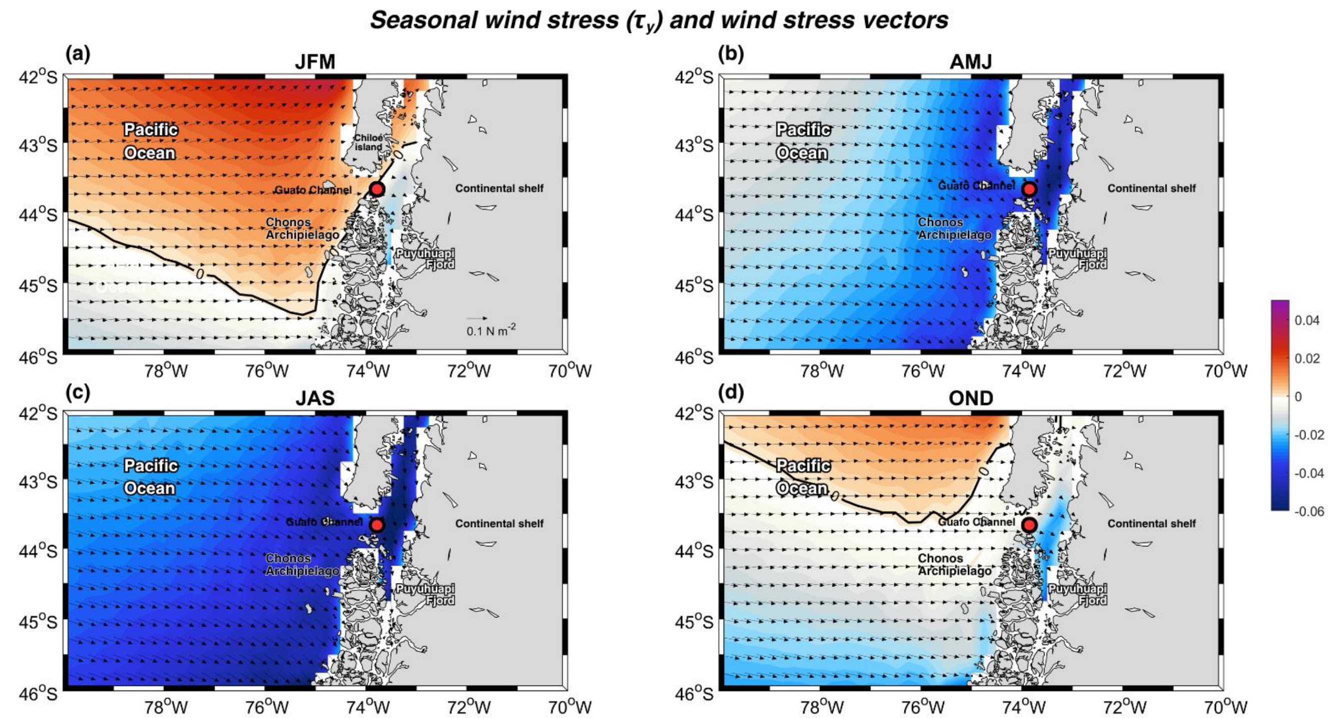


Figure 6. Long-term seasonal mean of meridional wind stress (τ_y; colour shading, N m^{-2}) and wind stress vectors (τ_x, τ_y; arrows) for (a) JFM, (b) AMJ, (c) JAS, and (d) OND over the Guafo Mouth region (42–46° S, 70–78° W). Positive τ_y values indicate southerlywind stress, whereas negative values indicate northerlywind stress, following the ERA5 convention. Arrows indicate the direction and relative magnitude of wind stress (τ_x, τ_y). The red point marks the mooring location. ERA5 reanalysis data ©ECMWF/Copernicus.

65: "(GM) (Linford et al., 2023)": Two brackets, maybe (GM, Linford et al., 2023)
Corrected. We have modified the citation formatting to (GM; Linford et al., 2023) to avoid consecutive brackets.

182: "along the water column": This is unclear, are vertical CTD profiles with water samples meant?
We added a new figure to the manuscript (Fig. 3) to describe the seasonal hydrographic conditions of the water column during. The data were obtained from an oceanographic cruise conducted to preserve and maintain the instruments. The new figure, with its description and methods, was incorporated into the new version of the manuscript.

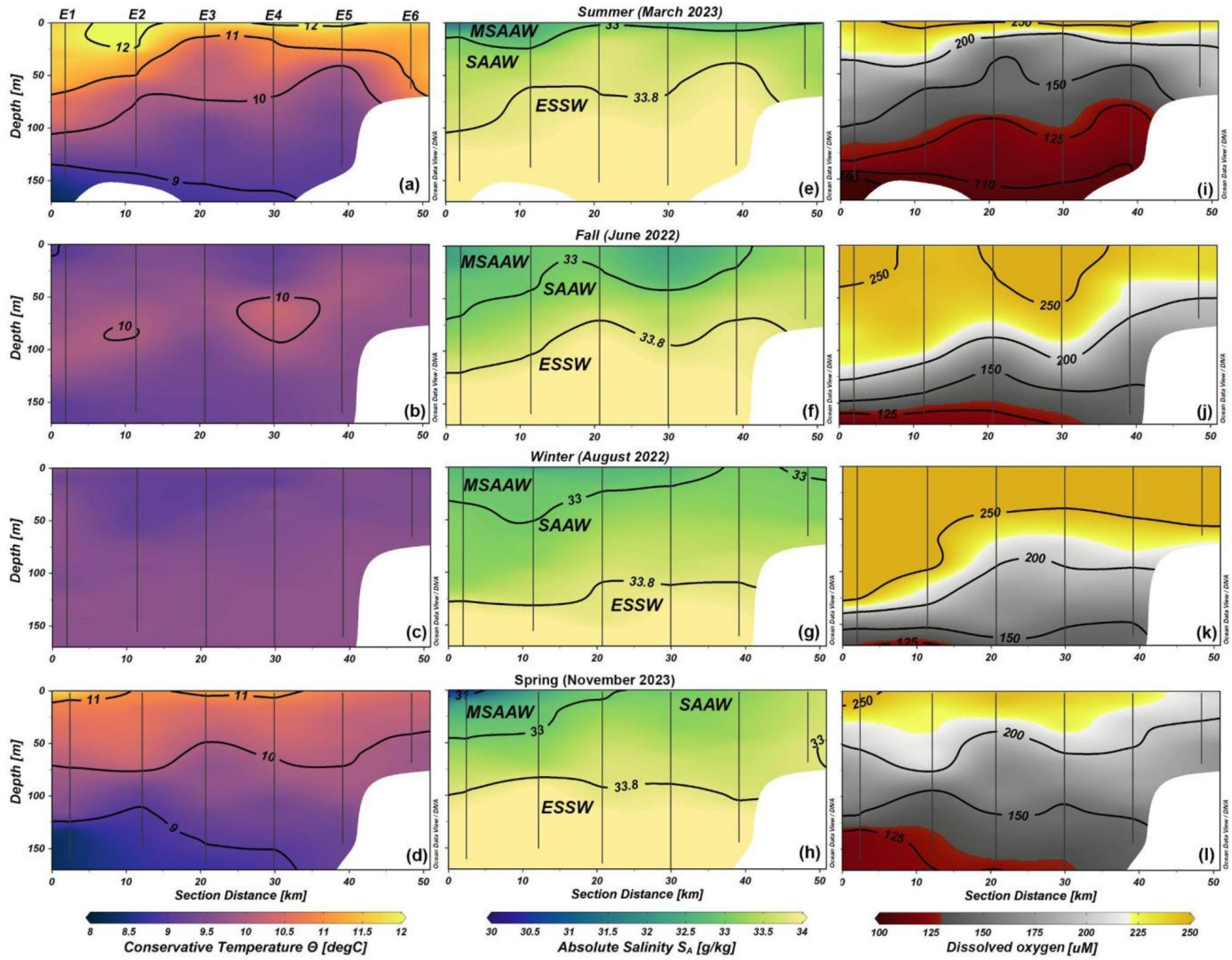


Figure 3. Seasonally hydrographic conditions of the water column in the Guafo Mouth during 2022 and 2023. (a-d) Conservative Temperature, (e-h) Absolute Salinity, and (i-l) Dissolved Oxygen (see Fig. 1c for the station's location).

193: "Major to 7d): Again unclear, that das Major mean here?

We apologize for this translation error ("major to" instead of "greater than"). We have corrected the phrasing in Section 2.3 and throughout the manuscript to read "greater or equal to 7 days (≥7d)" where appropriate.

257: AOU not defined and abbraviation not explained.

Corrected

284: \rho_a subscript

Corrected

294: U_e, V_e subscript

Corrected

Line 310 and Equation 4: Ue and Ve are not defined, components of M? M is also a vectorial component, this needs to be made more clear.

We have revised Section 2.4.2 and Equation (4) to clearly define the vector nature of the Ekman transport (M) and its components. We now explicitly present the formulas for the zonal and meridional Ekman transport components in terms of the corresponding wind stress components (Tau u and Tau v).

Line 465: (τ_v): Typo, \tau_y
Corrected

466: "The long-term monthly mean ranged from −0.056 N m^{-2} in August to 0.026 N m^{-2} in January, yielding a seasonal amplitude of 0.082 N m^{-2}.": I dont see this, January seems also to have a negative windstress.

There was a transcription error in the text regarding the wind stress values. Re-evaluating our climatology, we confirm that January indeed presents a negative meridional wind stress. The text has been corrected to state that the long-term monthly mean ranges from -0.078 N N m^{-2} in August to -0.006 N m^{-2} in January, yielding a seasonal amplitude of 0.072 N m^{-2} .

865: Here water renewal processes by intrusions could be compared to other well known hypoxic systems as the Baltic Sea.

We have expanded Section 4.4 to explicitly compare the renewal dynamics at the Guafo Mouth with the central Baltic Sea. Specifically, we incorporated a comparison between our observed high-frequency, wind-driven ventilation pulses and the mid-water lateral oxic intrusions in the Baltic Sea (Holtermann et al., 2020). We highlight that in both systems, the advective-intrusive balance—rather than vertical diapycnal mixing—acts as the primary oxygen source maintaining the hypoxic transition zones. Furthermore, drawing a parallel to how highly episodic Baltic intrusions cumulatively deliver more oxygen than the rarer decadal Major Baltic Inflows (MBIs), we emphasize the critical, yet highly discontinuous, role that synoptic atmospheric forcing plays in buffering long-term deoxygenation in the Patagonian fjords.

920: "Ultimately, the GM functions as a dynamic gateway, where episodic renewal intermittently counteracts the long-term influence of low-oxygen subsurface waters entering northern Patagonia." This is an important sentence and should be elaborated more. See comment above.

New paragraph: Ultimately, the GM functions as a dynamic gateway rather than a passive boundary. At this critical control point, an advective-intrusive balance dictates the oxygenation state of the interior northern Patagonian fjords. Episodic, wind-driven subduction of oxygenated Subantarctic waters intermittently counteracts the continuous, long-term poleward intrusion of low-oxygen Equatorial Subsurface Water (ESSW). Consequently, the resilience of the interior fjord ecosystem against progressive deoxygenation is highly dependent on the frequency and intensity of these synoptic atmospheric events at the gateway.

Fig. 5: Title fonts are not consistently bold, (b) is bold, the other labels not.

corrected

Fig. 9: Mark the location of GM in the map with a dot

We added the location of the Guafo mouth in the figure with a white star.

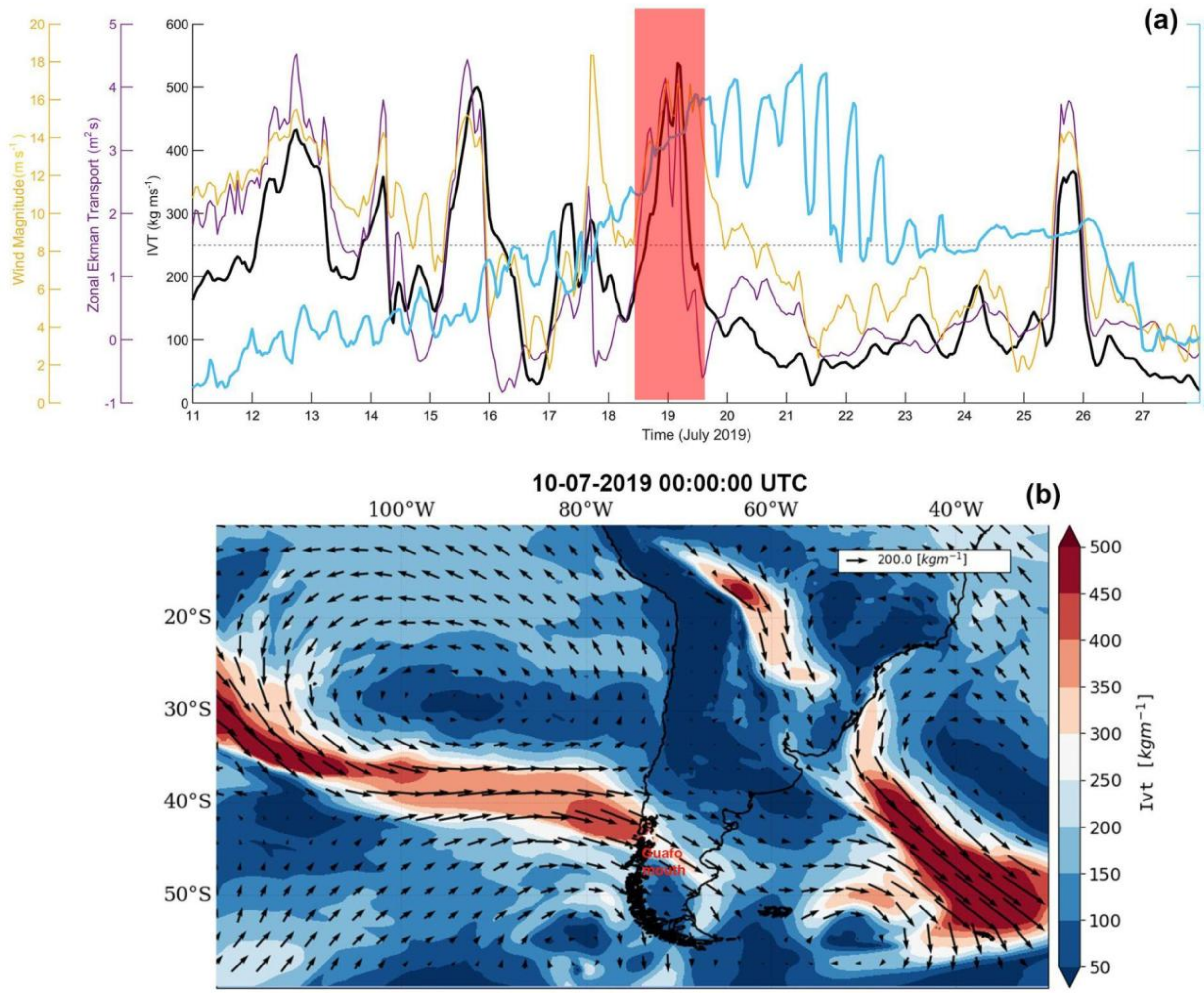


Figure 11. (a) Hourly time series of integrated vapor transport (IVT), with values exceeding 250 kg m^{-1} s^{-1} used to identify the influence of atmospheric rivers (ARs). The panel also displays an hourly time series for dissolved oxygen (DO), zonal Ekman transport (U_e), and wind magnitude. (b) Map depicting the passage of the AR on 19 Jul, 2019. The colour scale indicates IVT values, whereas arrows represent the wind magnitude and direction. The Guafo mouth location was marked with a white star.

Literature:

Holtermann, P., Prien, R., Naumann, M. and Umlauf, L. (2020), Interleaving of oxygenized intrusions into the Baltic Sea redoxcline. Limnol Oceanogr, 65: 482-503. https://doi.org/10.1002/lno.11317

Kelly, Seán, et al. "Characterizing ventilation events in an anoxic coastal basin: Observed dynamics and the role of climatic drivers." Limnology and Oceanography 65.10 (2020): 2420-2442.