Response to Reviewer 1: Sebastián Loyola

We thank the reviewer for the careful and constructive evaluation of our manuscript, as well as for the positive assessment of its scientific potential and relevance. We appreciate the detailed comments provided, which will help us to improve the clarity, structure, and scientific positioning of the study. Below we address each point raised.

The manuscript addresses a relevant and timely topic: the year-round characterization of coastal upwelling along the Uruguayan coast. It convincingly proposes the use of sea surface salinity as an alternative proxy to sea surface temperature outside the summer season. The ocean model appears to be well configured, the methodological basis is solid, and the analysis is extensive. Overall, the study has clear potential and could make a valuable contribution to the understanding of coastal upwelling processes in the region.

However, the manuscript presents several issues related to structure, focus, and scientific positioning that currently weaken its overall impact. In many passages, the text reads more like a technical report or a project deliverable than a scientific article oriented toward hypothesis-driven research, critical comparison, and discussion of results in the context of existing literature.

The Introduction section, in particular, is not clearly closed. It is difficult to identify where the introduction ends and where the methodology begins (around lines 75–90, when the description of CROCO and the model setup starts). The introduction would benefit from a more explicit motivation for the modeling approach adopted, a clearer justification for the use of this specific tool, and a more precise formulation of the study objectives and its novel contributions. I would expect to find a paragraph explaining why this type of model is needed, what gap in current knowledge it addresses, and what questions this study is able to resolve, followed by a clear statement of objectives. In addition, heat fluxes are discussed and analyzed in the Results section; however, the "Methodology" does not describe how these heat fluxes were calculated. The manuscript should clearly specify which heat flux formulation or parameterizations were used in CROCO.

More generally, the manuscript would benefit from a clearer and more conventional scientific structure, with well-defined sections (e.g., Introduction, Methodology, Results, Discussion, and Summary and Conclusions). At present, the boundaries between sections are not always clear, making it difficult to distinguish between background information, methodological descriptions, results, and interpretation. This also affects the readability of the manuscript and the clarity of its main messages.

We will reorganize the manuscript to improve the clarity of section boundaries and enhance the overall readability. We will reorganize the manuscript into clearly separated sections which improves the clarity of the manuscript's structure and main messages.

The corrected version of the manuscript is going to be organized as follows:

> Section 2 describes the methods, including the model configuration, the simulation domain, the datasets used, and the statistical approach applied to identify upwelling events.

> Section 3 presents the simulated fields and evaluates the model's ability to reproduce the mean state and interannual variability through comparisons with reanalyses, in situ observations, and published studies.

Section 4 focuses on the analysis of upwelling processes, including the identification of upwelling dates, the composite distribution of SST and SSS anomalies, and the examination of selected spring and autumn events and their vertical structure.

Finally, Section 5 summarizes the main findings and provides concluding remarks.

The reviewer notes that heat fluxes are analyzed in the Results section, but their formulation is not described in the Methodology, and requests clarification on the heat flux parameterization used in CROCO. The heat flux discussed in the Results section corresponds to the net air–sea heat flux output from the CROCO simulation. It is not externally imposed in the analysis, but rather a model variable consistently computed during the integration as with other prognostic variables (e.g., temperature and salinity). It reflects the surface energy exchange resulting from the prescribed atmospheric forcing and the model's surface flux formulation. This will be clarified in the revised Methodology section.

The comparison with previous studies is rather limited. While there is some discussion of the water column structure, there is little quantitative comparison with existing literature or independent datasets, particularly regarding the validation of vertical velocities and the vertical structure of temperature and salinity. As a result, it is not always clear whether the simulated values are realistic. The limited use of references to benchmark the results also makes it difficult to clearly identify the novelty of the study beyond its descriptive analysis.

The model validation presented in our study, includes comparisons with (to our knowledge) all available observational datasets in the region, including in situ temperature and salinity time series from Isla de Flores and vertical profiles from the BARDO database, as well as comparisons with GLORYS reanalysis fields. These comparisons demonstrate that the model realistically reproduces the vertical structure and variability of temperature and salinity in the coastal region. We note that observational data in this region remain spatially and temporally limited, particularly regarding the vertical structure and spatial extent of upwelling events. This limitation has been highlighted in previous studies and represents one of the main motivations for using high-resolution numerical simulations. To clarify this point, we will revise the manuscript to more explicitly highlight the validation results and the novelty of the study.

The novelty of this work lies in the identification and characterization of upwelling events throughout the year for the Uruguayan region, and in demonstrating the relevance of sea surface salinity as an alternative proxy for detecting these events outside the summer season. This approach provides new insights into the seasonal variability and structure of upwelling in the region, which cannot be fully resolved using currently available observational datasets alone.

The methodology section requires more technical detail, especially for shallow bathymetric regions. For instance, the minimum and maximum depths considered in the simulations should be explicitly stated. In addition, the description of the forcing needs to be more detailed, particularly regarding freshwater inputs and tidal forcing.

The Model Setup (Section 2) will be revised to explicitly state that a minimum depth of 5 m was imposed to ensure numerical stability in shallow coastal regions. The description of freshwater and tidal forcing will also be expanded in the modified version to clearly specify the datasets used and their implementation in the simulations. Additional configuration details are also provided in previously published and validated studies (de Mello et al., 2022, 2023).

Figures and captions will be updated to ensure consistency, clarity, and coherence throughout, and labels, abbreviations, and panel lettering will be standardized to align with the captions and the terminology used in the main text.

Specific comments:

In the revised manuscript, we will incorporate general references supporting the underlying physical mechanisms described and some studies for other estuaries showing varying thermal profiles along the year (Knauss 1997; Geyer 2010 and Mahardja et al., 2022). To the best of our knowledge, there are no previous studies that explicitly document this specific mechanism for the Uruguayan coastal region. If he is aware of relevant references addressing this process, either locally or in comparable freshwater-influenced coastal systems, we would be grateful for the suggestion and would gladly incorporate them to further strengthen the manuscript. We also clarify that this paragraph was intended to present the   physical reasoning underlying our working hypothesis rather than to summarize previously established regional results. Accordingly, we will reformulate the text to emphasize its conditional and hypothesis-driven nature (e.g., using expressions such as "are likely to" and "may result"), so as not to present these statements as established facts. The seasonal modulation is subsequently examined using the model simulations.

He suggests that sentences in the Introduction referred explicitly to the application of the Maximum Covariance Analysis to be removed and the paragraph reformulated to focus on the objectives and scientific motivation of the study. Following this suggestion, the methodological description of the MCA is going to be presented exclusively in Section 2, where the analysis will be introduced in detail.

We have revised the figure accordingly. Specifically, we added a broader regional context to clearly situate the study area within South America. The model domain is now explicitly indicated, and internal administrative boundaries have been removed to avoid visual distraction. Isobaths have been incorporated in the bathymetry panel to improve readability. In addition, the labels TR, CL, and RdP have been explicitly included in the figure, and their meaning has been clarified in the caption. The improved version of Figure 1 is provided below.
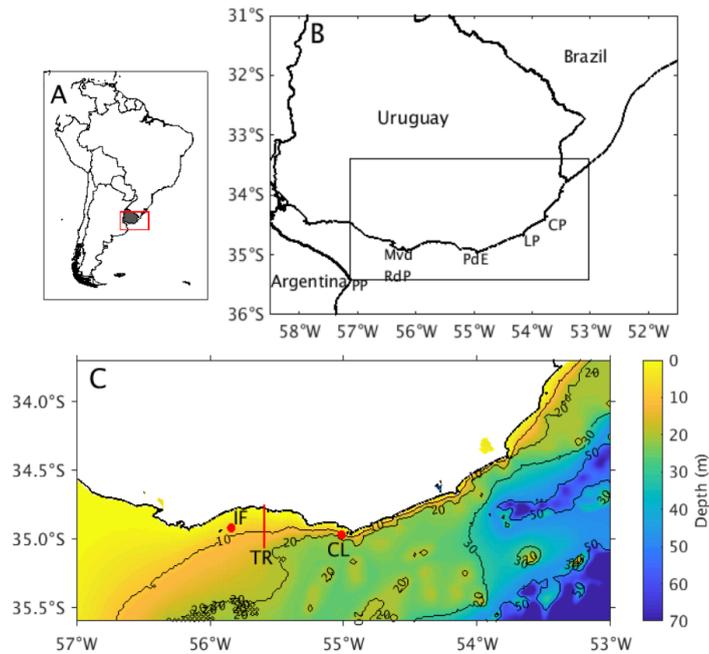
Figure 1. (A) Geographical context of the study area, showing Uruguay within South America; the red rectangle indicates the region displayed in panel B. (B) Model setup area along the Uruguayan shelf. The inner rectangle indicates the subdomain used for the analysis and identification of upwelling events. Mvd: Montevideo; PdE: Punta del Este; LP: La Paloma; CP: Cabo Polonio; PP: Punta Piedras; RdP: Río de la Plata. (C) ETOPO1 bathymetry (color scale in meters). Black contours indicate selected isobaths. IF marks Isla de Flores (location used for model–observation comparison of SST and SSS); CL indicates the coastal location used to extract vertically averaged seasonal profiles; TR denotes the transect used to analyze the vertical structure of simulated upwelling.

Around lines 115–120, it appears that only two river inputs are included. Please clarify whether these are the only freshwater sources considered in the simulation. Furthermore, the tidal forcing should be specified more clearly, including which tidal model or tidal constituents were used.

The freshwater input corresponds to the Río de la Plata discharge, computed as the combined flow of the Paraná and Uruguay rivers. The total discharge was imposed at the head of the Río de la Plata estuary and divided into two source points to ensure numerical stability and to adequately represent the estuarine inflow without generating instabilities in the model. These are therefore not two independent river systems, but a numerical implementation of the single Río de la Plata discharge.

Tidal forcing was incorporated using harmonic constituents derived from the TPXO7 global tidal model (Egbert and Erofeeva, 2002). Tidal elevation and depth-integrated velocities associated with the main tidal constituents were included directly in the CROCO tidal forcing file, following the standard CROCO tidal forcing framework. These constituents were applied dynamically at the open boundaries using Flather-type conditions for barotropic velocities, allowing realistic tidal propagation into the model domain. This implementation follows the configuration described and validated in de Mello et al. (2023). The manuscript will be revised accordingly to clearly specify those details.

In Figure 2 (around line 160), the panel labels (a, b, c, etc.) should be placed outside the title, particularly for panels e and f, where the letters appear to be part of the title. It is recommended to place the panel labels as text positioned, for example, in the upper-left corner of each panel.

In Figure 5 (around line 210), please revise the order of the panel labels so that the left panels are labeled a, b, c, d, and the right panels e, f, g, h, to improve clarity and consistency.

Finally, in the caption of Figure 7 (around line 240), the word "upwelling" is repeated twice and should be corrected.

Figures and captions will be updated in the final version of the manuscript as suggested.

For Figure 3 (around line 175), I suggest adding a vertical profile from the nearest GLORYS grid point to provide a clearer reference and vertical validation of the model results.

We extracted seasonal temperature and salinity profiles from the nearest GLORYS location to the coastal site and provided them here for comparison (Figure X, not present in the manuscript). The seasonal cycle and overall vertical structure are consistent between both datasets, with warmer and more stratified conditions in DJF and more homogeneous profiles in JJA (compared with Figure 3). GLORYS shows salinity-driven stratification in all seasons, which is also captured by the regional model, although with differences in magnitude and vertical gradients. These differences are expected given the higher horizontal resolution of our regional model (1/36°) compared to GLORYS (1/12°), which allows a better representation of sharp coastal gradients. Overall, the comparison supports the physical consistency of the simulated vertical structure.
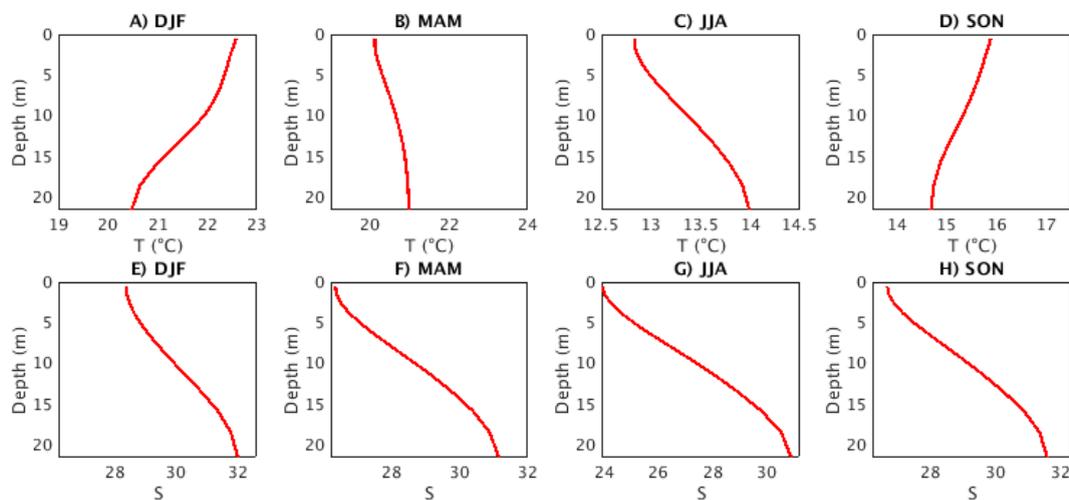

Figure X. GLORYS seasonal average vertical profiles of temperature (A-D) and salinity (E-H) at the closest GLORYS point to the coastal location. Different scales were used for temperature profiles.

In addition, the use of a high-resolution regional model aims to provide a representation of coastal processes that is closer to real ocean conditions than that of the GLORYS reanalysis (as shown in Figure X2, not added in the manuscript).
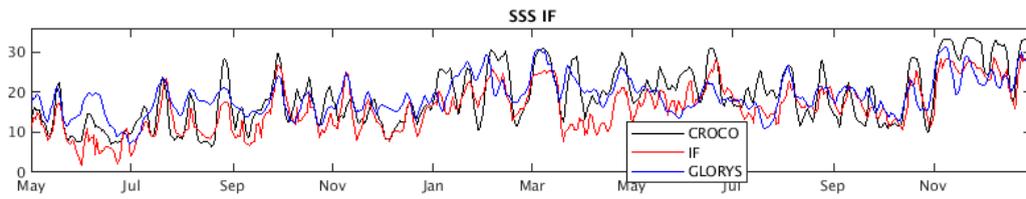
Figure X2. Evolution of daily SST (E) and SSS (F) for the period May 2019 – December 2020 simulated by CROCO (black line), measured in situ (red line) at Isla de Flores Location and represented by the GLORYS reanalysis (blue line). Correlation between GLORYS and Isla de Flores was 0.79 and between CROCO and IF 0.83.