RESPONSE TO REVIEWER #3'S COMMENTS

General Comments:

This paper provides a useful review of methods and data available for providing river runoff forcing into operational ocean forecast models (OOFS). The text is clear and accessible to a wide audience. While not an exhaustive list, the summary tables also provide useful reference of different operational configurations. However, my primary concern is that the review is missing a discussion and conclusion. It would greatly benefit from comparison of the different approaches presented, discussion on challenges for operational implementation, and summarising priorities for future work e.g., considering recent R&D that could be brought through to future OOFS.

Further comments relating to specific aspects of the text are listed below.

Response: We thank the Reviewer for this positive and constructive feedback on our manuscript. In response to these general comments, we made the following additions to the manuscript:

- *We added in Section 4 (formerly Section 3.3) a synthesis from the survey of the different methods and data sources used in current OOFS as a means for comparison of the different approaches presented.*
- *We added a discussion and conclusion in Section 5 (Summary and recommendations). In this section, we highlight some of the major limitations and challenges in representing rivers in current OOFS. We also provide recommendations for future research and developments.*

However, our objective in this paper is to make an inventory of existing current approaches and available datasets, rather than providing a detailed gap analysis with recommendations on ways forward, which will be the topic of a follow-up contribution.

Specific Comments:

Abstract: Clarify that here you focus on physical river forcing rather than supply of nutrients or other materials.

Response: In the abstract, we modified the following sentence: "This paper provides an overview of recent ~~advancements in river modelling~~ approaches to representing coastal river discharges and processes in ocean models, with a particular focus on estuaries." We also modified the following sentence: "A review of river data availability is also presented, illustrating various sources of freshwater discharge and salinity […]".

Line 17: I would not refer to the tables as a "compendium" as this suggests a complete summary. I would instead simply say that you present responses from a survey of existing OOFS providers.

Response: The sentence was reformulated as follows: "In addition, responses from a survey of existing operational ocean forecasting systems (OOFS) providers are synthetized, with a focus on how river forcing is treated, from global to coastal scales."

Line 26-27: This suggests upwelling is the only way that productivity is impacted, whereas all the above may impact productivity. Suggest rephrasing.

Response: The sentence was modified as follows: "Freshwater inputs to the ocean also modulate coastal upwelling events. Altogether, ~~thus~~ these factors impact~~ing~~ productivity of the coastal marine environment (Sotillo et al., 2021a)."

Also, please clarify that input of nutrients and other parameters that would impact productivity are neglected within this review, but are clearly important for consideration in future work.

Response: We added the following sentence in the introduction, before introducing the different sections: "The objective of this paper is to provide an inventory of existing methods and available datasets adopted in current operational ocean forecasting systems (OOFS) for representing river forcing. As the focus is on freshwater discharges, the river supply of nutrients and other materials are neglected in this review, but are partly addressed in a separate contribution by Cossarini et al. (2024)."

In the conclusions, we added recommendations on having "standardized inputs of freshwater (and associated river inputs of nutrients and sediment loading)".

Cossarini, G., Moore, A., Ciavatta, S., & Fennel, K. (2024). Numerical Models for Monitoring and Forecasting Ocean Biogeochemistry: a short description of present status. State Planet Discuss., 2024, 1–13. https://doi.org/10.5194/sp-2024-8

Line 33: The use of climatology may not always be limited to coarse resolution models (as suggested here)?

Response: We agree, although this was not exactly the intended meaning. For clarity, the sentence was modified as follows: "At coarse scales that cannot resolve the estuarine dynamics, but even at finer scales in some cases, river outlets are ~~typically~~ often represented in a simplistic way, with climatological runoff and zero or constant salinity values, implicitly neglecting estuarine mixing or exchange"

Line 87-88: Even where resolution may be higher than estuary width, explicitly resolving the estuary may still be challenging and therefore unlikely in many coastal models, e.g., due to large inward tidal extent and/or complex coastlines or coastal infrastructure.

Response: True. We added the following sentence: "[…] the large inward tidal extent and/or complex bathymetries and coastlines, often featuring coastal infrastructures, pose significant challenges for explicitly resolving estuaries, making it impractical in many coastal models."

Section 2.3: This is an active area of research, so worth clarifying where references refer to use in operational systems vs. ongoing R&D configurations? Further discussion on scope for future development here could be useful in an added summary/discussion section (e.g., is computational cost the main barrier for this approach?).

Response: We agree; most examples correspond to R&D configurations. The following sentence was added in Section 2.2: "however, this approach has yet to become standard practice in OOFS".

We also added a summary/recommendation section where recommendations include the need for "standardized inputs of freshwater (and associated river inputs of nutrients and sediment loading), homogenized river forcing approaches, and a more integrated watershed-ocean strategy".

Line 114: Worth acknowledging here that for some countries even larger rivers may lack routine monitoring (for both historical and NRT data).

Response: We made the following addition (underlined): "Moreover, given the global decline of the hydrometric networks, building climatologies is not always possible, especially for small or less- studied rivers, and even for large rivers in regions where routine monitoring is absent."

Section 3.1.2: While the list of possible datasets is useful, a discussion on the various options and pros/cons for different approaches could be useful? For example, could you present similar methods together (e.g., in situ vs remote sensing), and discuss which are static vs. updated?

Response: Our objective in this paper is not to assess the quality or value of a given product or dataset, but rather to provide an inventory of existing methods and available datasets adopted in current OOFS for representing river forcing. This is now made clearer in the introduction.

In Section 3.1.2, we regrouped the list of datasets into sub-groups as follows: in situ databases (4), model-derived databases (3), hybrid database (1), and satellite-based database (1).

Finally, in Section 3.1.2, we had already provided some elements of discussion, repeated here (additions are underlined):

- *"Of particular importance is the fact that some of these databases use model-simulated runoff ratios (e.g. from Community Land Model (CLM) or river routing model) over gauged and ungauged drainage areas to estimate the contribution from the areas not monitored by the hydrometric network and adjust the station flow to represent river mouth outflow (e.g. Dai et al. (2009). This allows more precise derivation of the total discharge into the global oceans, through the sum of both gauged and ungauged discharges."*
- *"Unless explicitly stated (e.g. for EMODnet Physics), it is not evident that any of these databases are updated on a regular schedule; some remain static, others are updated irregularly (at an unknown frequency). Such databases are useful in the context of a reanalysis, but less so in an operational context where near-real-time data feeds are required. Furthermore, a detailed comparative assessment of these various data sources is still lacking."*

Line 137-138: I think these two sources should be referred to separately as provide regional rather than global datasets.

Response: Agreed. We separated these two sources and added two new sources, as follows:

"Regional databases also exist, such as:

- *(NEW) Long-term (1993-2011) satellite-derived estimates of continental freshwater discharge into the Bay of Bengal (Papa et al., 2012).*
- *A database of pan-Arctic river discharge (R-Arcticnet: https://www.r-arcticnet.sr.unh.edu/v4.0/index.html).*
- *A database for Greenland liquid water discharge from 1958 through 2019 (Mankoff et al., 2020).*
- *(NEW) A river discharge climatology and corresponding historical time series for all rivers flowing into the Adriatic Sea with an average climatological daily discharge exceeding 1 m3s−1 (Aragão et al., 2024).*

Line 170-172: How many of the other products are actually freely available? (For both historical and NRT?)

Response: We have not documented the type of licence that comes with the data, or whether these are freely available, for each of the listed operational products. No actions taken.

Section 3.2: I expected this section to have more discussion around the forcing of T/S at river outflow, rather than purely model validation? While it's worth stressing that tuning models based on incorrect data is an issue, it's also worth reiterating that having T/S data within river outflows (e.g., from hydrological runoff models?) could help avoid this issue. The same would apply for outflow of nutrients and other parameters of course.

Response: We agree. We added the following in Section 3.2:

"A recent study in the German Bight (Thao et al., 2024) demonstrated the critical role of high-resolution salinity inputs at estuarine mouths in improving the predictive capabilities of coupled wave-ocean models. Using the GCOAST model system, which seamlessly integrates estuarine and coastal dynamics with regional ocean models, researchers validated salinity and temperature fields against in-situ observations. The results highlighted that estuarine inflows significantly enhance the accuracy of coastal ocean models."

[…]

"Moreover, integrating salinity, temperature, and other parameters such as nutrients or sediments directly into river outflows could improve model performance (Verri et al., 2018; Thao et al., 2024). While these factors play a secondary role in influencing oceanographic processes, their inclusion could advance research on coastal hypoxia, carbon cycling, and regional weather and climate, ultimately supporting seamless predictions of land–ocean–atmosphere feedbacks in next-generation Earth system models (Feng et al. 2021)."

Also, in Section 4 we added a comment from the survey responses regarding T/S, as follows: "Salinity and temperature of the input freshwater can either be set to zero and to the local SST, respectively, or derived from a combination of real-time gauge data and monthly averages when available."

Section 3.3: This currently feels like an odd way to complete the review. There is a need to provide a summary and discussion section. For example, summarising the current "state of the art" developments, limitations of existing OOFS, and priorities for future work? To help this flow, I feel the table provided should be included as an appendix (and ideally in landscape format, to assist reading columns with more content).

Response: We significantly expanded Section 4 (formerly Section 3.3) by providing a summary of the current OOFS methods and data sources from the survey, both in the text and with a new figure. Also, we added a Section 5 (Summary and recommendations) that briefly addresses the limitations of existing OOFS and priorities for future work (see response to Reviewer 1). The tables were also moved to a new Appendix A in landscape format (in the original version, landscape format was not allowed at the submission stage).

Within each of the tables, for each of the systems it would be useful to understand whether there are references to the data source and/or publications? If this isn't available from the survey, then noting simply the responding institution or provider for each OOFS would be useful to provide a contact for

further information. Please also clarify whether responses to the survey have been summarised/rephrased or provided as given (I presume the latter, but need to clarify).

Response: We tried to find official references for each system, but the information is often hidden in multiple papers and not always easy to find. Instead, we added one column for the institution/provider. Links to the systems webpages, or relevant data source, are included as footnotes for each system.

The responses to the survey are reported as given by the participants; nearly no changes were made to each contributed entry, except for a few added references and acronym definitions. This is now explained in the introduction to Appendix A, as follows:

"This Appendix presents results of a survey conducted among members of the OceanPredict community in May 2023. The responses are reported in the following tables as given by the participants; nearly no changes were made to each contributed entry, except for a few added references and acronym definitions."

Section 3.3.3: How did you differentiate between coastal vs regional domains?

Response: Coastal or regional domains were differentiated by respondents who filled in the tables.

Technical Corrections:

Line 40: OOFS acronym introduced without being defined.

Response: Corrected. The OOFS acronym is now introduced.

Line 111: Suggest rephrasing "freshwater and salinity" to "volume fluxes and salinity" inputs?

Response: Corrected as suggested.

Figure 2: Please clarify whether river networks shown come from GloFAS?

Response: "River networks come from GloFAS" was added to the figure caption.

Hyperlinks: Throughout the text there appear to be hyperlinks to relevant data sources. However, these links don't work. Please ensure they do in the revised version, or make sure to reference in an alternative format.

Response: Thank you for this comment. Apparently, the links were lost during conversion to PDF. Full web addresses are now added in the text as footnotes.

Acronyms: There are multiple within the survey responses. Please define where possible.

Response: All acronyms were defined where possible.