# GMD-2024-58

## Review of "HOTSSea v1: a NEMO-based physical Hindcast of the Salish Sea (1980 – 2018) supporting ecosystem model development" (GMD-2024-58)

### 1. GMD Scope and Aims:

- **Scope and Aim**:
    - The paper falls within the scope of GMD, as it focuses on the development and evaluation of a numerical model (HOTSSea v1) for simulating the physical oceanography of the Salish Sea.
    - The aim of the paper is to present a long-term (1980-2018) hindcast model that can address the lack of observational data and support ecosystem model development in the region.
    - The paper is relevant to the GMD readership, as it addresses challenges and provides insights related to regional ocean modeling, forcing data selection and bias correction, and the application of models to understanding long-term changes and variability in marine systems
- **Relevance:**
    - The Salish Sea is a complex and ecologically important region facing significant pressures from climate change and human activities. The development of a reliable hindcast model is crucial for understanding the region's physical dynamics and their impacts on marine ecosystems and fisheries.
    - The paper's focus on the selection and evaluation of forcing data is highly relevant, as the accuracy of forcing data is a major factor influencing the performance of regional ocean models.
    - The bias correction method, while simple, is effective in improving model performance and highlights the importance of addressing biases in forcing data.
    - The model's ability to reproduce observed temperature variability and trends, as well as extreme events like marine heatwaves, demonstrates its potential for studying climate change impacts and informing ecosystem-based management.
    - The paper contributes to the broader field of ocean modeling by providing insights into the challenges and strategies for developing and evaluating long-term hindcast models in complex coastal systems.
    - While the paper addresses important research questions, its relevance could be further strengthened by explicitly discussing how the model could be used to answer specific scientific questions related to climate change impacts, ecosystem dynamics, and fisheries management in the Salish Sea.
    - The authors could also elaborate on the model's potential limitations and uncertainties, particularly regarding its performance in underrepresented regions (e.g., Puget Sound) and the impact of biases on specific ecological processes.

- **Scientific Significance:**
    - Strengths:
        - Addresses a critical need for a long-term hindcast model in the Salish Sea, a region with limited observational data and facing significant ecological challenges.
        - Provides a valuable baseline for assessing future climate change impacts and developing ecosystem-based management strategies.
        - Offers insights into the spatial and temporal patterns of ocean warming, which are crucial for understanding potential impacts on marine ecosystems and fisheries.
        - Demonstrates the importance of bias correction in regional ocean modeling and the potential effectiveness of even simple correction methods.
    - Weaknesses:
        - The study's scope could be broadened by explicitly addressing specific scientific questions related to climate change, ecosystem dynamics, and fisheries management that the model could help answer.
        - The limitations of the model, particularly in terms of spatial coverage and salinity bias, could impact its applicability for addressing certain research questions.
- **Originality:**
    - Strengths
        - Addresses a clear gap in existing research by providing the first long-term (38-year) hindcast model of the Salish Sea, which is crucial for understanding long-term changes and variability.
        - Employs a systematic experimental approach to assess the sensitivity of the model to different forcing data sets, offering insights into the impact of forcing choices on model performance.
        - Presents new findings on spatial and temporal patterns of ocean warming in the Salish Sea, particularly the potential for faster warming in Jervis Inlet compared to other areas.
        - Demonstrates the feasibility of using a relatively coarse resolution model with bias correction to produce a useful hindcast for ecosystem studies
    - Weaknesses:
        - While the model itself is novel for the Salish Sea, the underlying NEMO model and bias correction methods are established techniques. The paper could further emphasize the unique aspects of the model setup or application that distinguish it from previous work.
        - The authors could discuss the potential implications of their findings for other regional ocean modeling studies, particularly those in complex coastal environments with limited observational data.

## 2. Scientific Quality:

- **Soundness:**
    - Strengths:

        - Model Setup: The authors provide a detailed description of the model configuration, including spatial and temporal resolution, numerical schemes, and parameterizations. This allows for reproducibility and assessment of the model's suitability for the Salish Sea.
        - Forcing Data: The paper thoroughly discusses the selection and evaluation of forcing data, highlighting the challenges of using reanalysis products and the importance of bias correction. This transparency is commendable and aids in understanding the potential limitations of the model.
        - Experimental Design: The authors employ a systematic approach to assess the model's sensitivity to different forcing data sets, providing valuable insights into the sources of error and bias.
        - Bias Correction: The implementation of a temperature bias correction, while simple, demonstrates a clear effort to improve the model's accuracy. The authors acknowledge the limitations of their method and suggest potential future improvements.
    - Weaknesses:
        - NEMO Version: The use of NEMO v3.6 is outdated, as newer versions offer potential improvements in numerical schemes and physical parameterizations. The authors could be asked to discuss the potential benefits of upgrading to a more recent version.
        - Simplified Tidal Forcing: The use of only eight tidal constituents and outdated WebTide data might not fully capture the complex tidal dynamics of the Salish Sea, potentially impacting the accuracy of the model's circulation and mixing.
        - River Discharge Data: The reliance on climatological river discharge data, except for the Fraser River, could introduce uncertainties in the model's representation of freshwater inputs and their effects on salinity.
        - Single Station for Trend Analysis: The use of only one station (Nanoose) for evaluating long-term trends might not be sufficient to capture the spatial variability of changes in the Salish Sea. The authors could be encouraged to explore the use of additional observational data or alternative methods for trend analysis.
- **Completeness**:
    - Strengths:
        - Model Description: The paper provides a thorough description of the model setup, including spatial and temporal resolution, numerical schemes, parameterizations, and forcing data. This allows for reproducibility and assessment of the model's suitability for the Salish Sea.
        - Experimental Design: The authors clearly outline their experimental approach, including the different model versions and the rationale for varying the forcing data. This systematic approach helps to isolate the sources of error and bias in the model.
        - Results Presentation: The paper presents a comprehensive set of results, including statistical metrics, figures, and tables, providing a detailed picture of the model's performance in simulating temperature, salinity, trends, and anomalies.

    - Discussion of Limitations: The authors openly acknowledge the limitations of their study, such as the exclusion of Puget Sound, and the potential for further improvements in bias correction. This transparency is commendable and adds to the completeness of the paper.
  - Weaknesses:
    - Lack of Sensitivity Analysis: While the authors discuss the sensitivity of the model to different forcing data sets, a more quantitative sensitivity analysis could further strengthen their conclusions. This could involve systematically varying model parameters or forcing inputs to assess their impact on the results.
    - Limited Discussion of Physical Mechanisms: The paper could benefit from a more in-depth discussion of the physical mechanisms responsible for the observed trends and biases. This would provide deeper insights into the model's behavior and help to identify areas for further improvement.
    - Comparison with Other Models: A more comprehensive comparison with other existing models for the Salish Sea would help to contextualize the results and highlight the unique contributions of HOTSSea v1. This could involve comparing model outputs, skill scores, or the ability to reproduce specific observed features.
    - Data and Code Availability: While the authors mention that the data and code are available upon request, making them publicly accessible would enhance transparency and reproducibility, facilitating further research and model development by the wider community.

## 3. Presentation Quality:

- Clarity:
  - Strengths:
    - Overall Structure: The paper is well-structured, with clear sections and sub-sections that guide the reader through the model development, evaluation, and discussion.
    - Logical Flow: The narrative follows a logical progression, starting with the introduction and motivation, then describing the model setup and forcing data, followed by a detailed evaluation of the model's performance, and concluding with a discussion of potential future directions.
    - Clear Figures and Tables: Most figures and tables are well-organized and effectively convey the key results of the study. Figure 1 provides a clear overview of the model domain, and the Taylor diagrams (Figures 4, 7) offer a concise summary of model performance.
  - Weaknesses:
    - Terminology: Some acronyms (e.g., CRMSE, WSS) are not explicitly defined upon first use, which could confuse readers unfamiliar with the specific terminology.
    - Equation Presentation: Some equations could be presented more clearly, with better explanations of the variables and symbols used. For example, Equation 1 for the Coriolis parameter could be clarified with additional context and definition of terms.

        - Figure Captions: Some figure captions could be more informative and self-contained, providing sufficient context to understand the figure without having to refer back to the main text.
        - Redundancy: The text could be more concise in some sections, as there is some repetition of information and excessive detail in certain parts of the methods and results.
- **Conciseness:**
    - Strengths:
        - Key Points Highlighted: The paper generally focuses on the essential aspects of the model development, evaluation, and discussion, highlighting the key findings and implications for Salish Sea research.
        - Relevant Literature Review: The introduction provides a concise overview of the relevant literature, focusing on the importance of the Salish Sea and the need for improved oceanographic models.
        - Effective Use of Tables and Figures: The authors make good use of tables (e.g., Table 1 summarizing forcing data) and figures (e.g., Taylor diagrams) to present information in a concise and visually appealing manner.
    - Weaknesses:
        - Repetitive Information: There is some repetition of information across different sections, particularly in the results and discussion sections. For example, the poor performance of the model in the Puget Sound subdomain is mentioned multiple times. w
        - Excessive Detail: Some sections, especially the methods section, contain excessive detail that could be condensed or moved to supplementary material. For instance, the detailed description of the statistical tests could be streamlined or summarized.
        - Lengthy Sentences: Some sentences are overly long and complex, making it difficult for the reader to follow the authors' train of thought. Breaking these sentences into shorter, more focused ones would improve readability.
    - Recommendations:
        - Eliminate Redundancy: Carefully review the text and eliminate any unnecessary repetition of information. Consider consolidating similar findings or moving less critical details to supplementary material.
        - Streamline Methods: Condense the description of standard methods (e.g., statistical tests) and focus on the specific choices and adaptations made for this study.
- Illustrations:
    - Strengths:
        - Informative Figures: The figures generally provide valuable information and support the main text effectively. For example, Figure 1 clearly depicts the model domain and bathymetry, while Figures 4 and 7 summarize the model's performance in a concise and visually appealing manner.
        - Adequate Number of Figures: The number of figures seems appropriate for the length and complexity of the paper. They are distributed

throughout the text to illustrate key concepts and results, aiding in the reader's understanding.
    - Appropriate Figure Types: The authors use a variety of figure types (maps, time series plots, Taylor diagrams, target plots) that are well-suited for presenting different types of data and results.
    - Color Schemes and Clarity: The figures are clear and easy to interpret, with appropriate use of color schemes that effectively highlight the key features of the data.
  - Weaknesses:
    - Caption Detail: While most figure captions adequately describe the content of the figures, some could be more informative and self-contained. For instance, the captions for Figure 4 , more details on the interpretation of diagrams, However Figure 7 does explain the target plot and taylor plot.

## 4. Open Science Considerations:

- Model and Data Availability:
  - Strengths:
    - The authors state that the model code and output data are available upon request, demonstrating a willingness to share their research materials.
    - They have made their custom analysis package available online, which promotes transparency and facilitates reproducibility for certain aspects of the analysis.
- Weaknesses:
  - Code Availability: The model code itself is not publicly available, which is a significant limitation for a paper published in GMD. This hinders reproducibility and prevents other researchers from fully scrutinizing and building upon the authors' work.
  - Data Accessibility: While the data are available upon request, this process can be cumbersome and may limit access for some researchers. Making the data publicly available in a repository with a persistent identifier (e.g., DOI) would be more in line with open science principles.
- Note with regards to Editor's Messages on the above:
  - The editor's messages highlight the importance of adhering to GMD's data and code policy. They emphasize that making the code available is a requirement for publication and that simply stating "available upon request" is not sufficient. The editor also questions the appropriateness of using GitHub repositories for code storage and suggests that referencing them in the paper might be problematic.
- Recommendations (Considering Editor's Messages):
- Make the Model Code Publicly Available: The authors should make their model code publicly available in a suitable repository (e.g., Zenodo, institutional repository) with a persistent identifier. This is essential for reproducibility and transparency.
- Clarify Data Availability: While the authors state that the data are available upon request, they should clarify the process for obtaining the data and consider making it publicly

available in a repository with a DOI. This would facilitate access for other researchers and promote open science practices.

- Additional Considerations:
- Licensing: The authors should ensure that the model code and data are released under an open-source license that allows for reuse and modification by others. This would further enhance the impact and reach of their research.
- Documentation: The authors could provide additional documentation (e.g., README files, user manuals) to explain the model's setup, input requirements, and output formats. This would make it easier for others to use and adapt the model for their own research purposes.

# 5. Overall Assessment and Recommendation:

- Summary of Strengths:
    - Addresses a Critical Gap: The paper successfully addresses a significant gap in long-term observational data for the Salish Sea, providing a much-needed resource for understanding decadal-scale changes in physical oceanography.
    - Model Skill: The HOTSSea v1.02 model demonstrates good skill in reproducing observed temperature variability and trends, especially after the implementation of the temperature bias correction at the Juan de Fuca Strait boundary.
    - Bias Correction Effectiveness: The simple bias correction method employed by the authors is shown to be effective in reducing the warm bias in the ORAS5 forcing data, leading to improved model performance.
    - Experimental Design: The systematic approach used to assess the sensitivity of the model to different forcing datasets is a strength, as it provides valuable insights into the sources of error and bias.
    - Relevance to Ecosystem Modeling: The paper clearly articulates the relevance of the model for ecosystem modeling, highlighting its potential to drive biogeochemical and ecosystem models aimed at understanding ecological productivity in the Salish Sea.
    - Potential for Future Applications: The authors outline several promising future applications of the model, including biogeochemical modeling, data assimilation, and Lagrangian particle simulations, demonstrating the model's broader utility beyond the scope of this study
- Summary of Weaknesses:
    - Limited Spatial Coverage:
        - The model's evaluation is primarily focused on the Strait of Georgia, with limited assessment in other regions, particularly the Puget Sound. This raises concerns about the generalizability of the results to the entire Salish Sea.
    - Persistent Biases:
        - The model exhibits persistent biases in salinity, especially in the Discovery Islands and Juan de Fuca Strait. The fresh bias in these regions could significantly impact the accuracy of ecosystem models that rely on this data.

        - While the temperature bias correction is effective, there are still depth-dependent biases in temperature, particularly in deeper waters, indicating potential limitations in the model's representation of vertical processes.
    - Limited Validation Data:
        - The reliance on a single station (Nanoose) for trend analysis and evaluation of interannual variability limits the robustness of the conclusions. The authors should consider using additional data sources (e.g., satellite data, other stations) to validate the model's performance across a wider range of conditions.
    - Simplified Tidal Forcing:
        - The use of only eight tidal constituents and outdated WebTide data might not fully capture the complex tidal dynamics of the Salish Sea, potentially impacting the accuracy of the model's circulation and mixing.
    - Outdated NEMO Version:
        - The use of NEMO v3.6, an older version of the model, might limit the model's capabilities and potential for improvement. Newer versions could offer enhanced numerical schemes and physical parameterizations.
    - Uncertainty Quantification:
        - The paper lacks a rigorous quantification of uncertainties associated with the model's predictions. This makes it difficult to assess the reliability of the results and their implications for future research and applications.

5. Overall Assessment and Recommendation

- Recommendation:
    - I recommend this paper for publication in GMD after minor revisions. The paper presents a valuable contribution to the field of regional ocean modeling by developing a much-needed hindcast model for the Salish Sea. The model demonstrates good skill in reproducing observed temperature variability and trends, and the authors' systematic approach to evaluating forcing data and bias correction is commendable. However, the limitations related to spatial coverage, salinity bias, and depth-dependent errors warrant further attention and should be more thoroughly addressed before final publication.
- Justification:
    - The authors have successfully developed a 38-year hindcast model of the Salish Sea, which is a significant achievement given the limited observational data available for this region. The model's ability to reproduce observed temperature patterns, particularly after bias correction, suggests that it can be a valuable tool for understanding long-term changes and variability in the Salish Sea. The authors' transparency in discussing the limitations of the model, such as its relatively coarse resolution and the lack of data assimilation, is commendable.
    - However, the model's performance in simulating salinity remains a concern, especially in the Discovery Islands and Juan de Fuca Strait. The depth-dependent biases in temperature also raise questions about the model's ability to accurately represent vertical processes. Additionally, the reliance on a single station for trend analysis and the limited spatial coverage of the evaluation warrant further investigation.

- To address these limitations, the authors should consider:
    - Expanding the spatial coverage of the evaluation to include Puget Sound and other underrepresented regions.
    - Investigating the sources of the salinity bias and exploring alternative bias correction methods or model refinements to address this issue.
    - Analyzing the model's performance at finer temporal resolutions relevant to ecological processes.
    - Quantifying uncertainties associated with the model's predictions and conducting sensitivity analyses to assess the robustness of the results.
    - Exploring the potential benefits of data assimilation to further improve model accuracy.
    - The authors could also consider moderating their conclusions regarding the model's applicability for ecosystem modeling, given the lack of data assimilation and the remaining biases. While the model shows promise for studying long-term changes, its limitations should be acknowledged and addressed before it can be confidently used for ecological applications.

Overall, this paper is a valuable contribution to the field of regional ocean modeling, but it requires minor revisions to strengthen its conclusions and address its limitations.

## 6. Detailed Comments:

- Abstract:
    - Strengths:
        - Concisely summarizes the key points of the paper, including the motivation, methodology, main findings, and potential applications.
        - Clearly states the problem of observational gaps in the Salish Sea and the need for a long-term hindcast model.
        - Highlights the model's skill in reproducing observed temperature trends and anomalies, as well as its potential for supporting ecosystem model development.
    - Weaknesses:
        - Could be more specific about the magnitude and types of biases found in the forcing data and the model.
        - The statement about "new insights" into ocean trends could be more explicit, outlining what specific new information the model provides.
        - Could briefly mention the limitations of the model, such as the exclusion of Puget Sound and the persistent bias in salinity.
- Section 1
    - Strengths:
        - Provides a comprehensive overview of the Salish Sea's ecological and economic importance, emphasizing the need for better understanding of its physical oceanography.
        - Clearly articulates the motivation for developing a long-term hindcast model, citing the lack of observational data and the potential impacts of climate change on the ecosystem.

        - Discusses the limitations of existing models for the Salish Sea, justifying the need for a new model like HOTSSea v1.
        - Outlines the specific objectives of the paper, focusing on evaluating the model's performance and investigating potential biases.
    - Weaknesses:
    - The discussion of climate change impacts on the Salish Sea could be more specific, mentioning specific examples of observed or projected changes in temperature, salinity, or circulation patterns.
    - The potential applications of the model for ecosystem modeling could be more clearly articulated, with specific examples of how the model's output could be used to inform ecological research and management.
- Section 2. Model Overview:
    - NEMO Version: While the use of NEMO 3.6 is understandable given resource constraints, the authors should acknowledge that newer versions (e.g., NEMO 4.x ) offer potential advantages, such as improved numerical schemes, physical parameterizations, wetting and drying and computational efficiency. A brief discussion of these potential benefits and the rationale for using NEMO 3.6 would strengthen the paper.
    - Model Resolution: The choice of 1.5 km horizontal resolution is a compromise between accuracy and computational cost. However, the authors should discuss the implications of this resolution for capturing fine-scale processes, particularly in areas with complex topography like the Discovery Islands. A sensitivity analysis with different resolutions could be considered in future work.
    - Vertical Coordinates: The use of z-level coordinates might not be ideal for the Salish Sea, which is characterized by steep bathymetry and strong stratification. The authors could discuss the potential advantages of using terrain-following (s- or sigma-) coordinates, which might better capture vertical variations in water properties.
    - Section 2.2 Boundary Conditions and Forcings:
        - Open Boundary Conditions: The use of a monthly climatology for the northern boundary and outdated WebTide data for tidal forcing could introduce errors in the model. The authors should acknowledge these limitations and discuss potential alternatives, such as using higher-resolution reanalysis data or a more recent tidal model.
        - River Discharge: The reliance on climatological river discharge data for most rivers (except the Fraser River) could also introduce uncertainties, as it doesn't account for interannual variability. The authors could explore using a hydrological model to provide more realistic and temporally varying freshwater inputs.
- Section 3. Model Evaluation:
    - Limited Spatial Coverage: The evaluation primarily focuses on the Strait of Georgia, with limited assessment in other regions, especially Puget Sound. This raises concerns about the generalizability of the results. The authors should acknowledge this limitation and discuss potential strategies for expanding the evaluation in future work.

    - Choice of Metrics: While the use of CRMSE and WSS is appropriate, the authors could consider additional metrics to provide a more comprehensive evaluation of model performance. For example, they could assess the model's skill in reproducing specific features of the Salish Sea circulation, such as the estuarine exchange flow or the seasonal cycle of stratification.
    - Statistical Significance: The authors should consistently report the statistical significance of their results, particularly for trend analysis and comparisons between different model versions. This would strengthen the robustness of their conclusions.
- Section 4. Results and Discussion:
    - Depth-Dependent Biases: The model exhibits biases in both shallow and deep waters, particularly for temperature. The authors should delve deeper into the potential causes of these biases, such as inaccuracies in the forcing data, limitations in the vertical mixing scheme, or other model parameterizations.
    - Salinity Bias: The persistent fresh bias in salinity, especially in the Discovery Islands and Juan de Fuca Strait, remains a major concern. The authors should investigate the sources of this bias and explore potential model refinements or alternative forcing data to address it.
    - Overestimation of Variability: The model tends to overestimate the variability in salinity. This issue warrants further investigation to understand its potential causes and implications for ecosystem modeling.
- Section 5. Conclusions:
- Overconfidence: The authors express a high degree of confidence in the model's capabilities despite the identified limitations. They should acknowledge these limitations more explicitly and moderate their conclusions accordingly.
- Future Work: The authors should provide a more detailed roadmap for future model development, including plans to address the identified limitations, explore alternative forcing data and bias correction methods, and expand the model's evaluation to include other regions and variables.