Response to Reviewer #1

Manuscript ID: ESSD-2025-694 *Earth System Science Data*
Title: A global gridded dataset of significant wave height via fusion of multi-mission altimetry and numerical hindcast
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Review of "A global gridded dataset of significant wave height via fusion of multi-mission altimetry and numerical hindcast"
a paper by Jiang and Su

Synopsis
The authors evaluate the "data fusion" method for blending SWH fields from wave model(s) and altimetry. The method and dataset (or a subset of the dataset, at least) has been previously published. I interpret the methods as a kind of enhanced optimal interpolation. The authors find high accuracy with their product. They offer two forms of their product. One prioritizes temporal stability, which is useful for climate studies. The other prioritizes general accuracy (lower RMSE). The authors encourage others to download and use their dataset.

Recommendation: I think this should be published, after some modest revision.

We sincerely thank the reviewer for the positive assessment of our manuscript and for the constructive and detailed comments. We are pleased that the reviewer considers the dataset suitable for publication after modest revision. The manuscript has been revised according to the comments of the reviewer. The authors hope that the revised version of the manuscript is acceptable to the reviewer. Detailed responses are provided below.

General remark

What is the original reference for the data fusion method? I'm not familiar with the history of the method, but lines 430-432 indicate that there was a previous publication, Wang and Jiang 2024, in which a subset of this same data-fusion dataset was used. I would expect this to come up in Section 2.2, but I didn't find it there.

We thank the reviewer for pointing this out. We agree that the original manuscript did not clearly distinguish between the methodological background of the fusion approach and the previous use of a subset of the fused dataset in Wang and Jiang (2024).

The fusion method used in this study is not intended to be presented as a completely new method. It is based on the general framework of objective analysis / optimal interpolation, for which one classical reference is Bretherton et al. (1976). In the present study, this framework is modified for gridded SWH reconstruction by incorporating several wave-specific factors into the distance/weighting definition, including temporal separation, spatial separation, modelled-SWH difference, correlation-based screening, and a base-distance term to avoid unrealistic along-track striping caused by overly large weights near altimeter tracks.

We have revised Section 2.2 to explicitly cite Bretherton et al. (1976) and to clarify that the present method is a modified space-time objective-analysis approach adapted for SWH fusion. We have also clarified the role of Wang and Jiang (2024): that study used only a five-year subset of the fused SWH product for AI wave-model training and fine-tuning, but it did not provide a dedicated description, validation, or public release of the full long-term gridded dataset. The present manuscript is therefore the dataset paper, providing the full methodology, systematic validation, two product configurations, and data-access information.

Here are the revised texts:

"*Prior to data fusion, a simple one-dimensional look-up table correction is applied to remove the systematic bias between SWHs from the WW3-ST6 hindcast data and the along-track altimeter observations. The fusion method used here is based on the general framework of objective analysis / optimal interpolation, originally developed for meteorological and oceanographic data analysis (e.g., Bretherton et al., 1976). In this framework, sparse observations are used to correct a background field through distance- or covariance-dependent weights. The present study modifies this framework for SWH reconstruction to maximize the retention of the original altimeter SWH observations within the fused product with the corresponding formula expressed as follow:*"

"*It is noted that Wang and Jiang (2024) focused on AI model development and used the fused SWH fields only as training data. It did not provide the full long-term dataset, the two product configurations, the systematic validation, or the public data documentation presented here.*"

Added Reference:

Bretherton, F. P., Davis, R. E., and Fandry, C. B.: A technique for objective analysis and design of oceanographic experiments applied to MODE-73, Deep-Sea Research, 23, 559–582, 1976.

Comments

Line 14: is there a distinction between "fusion" and "post-fusion"?

We agree that the terminology was potentially confusing. By “post-fusion” we intended to emphasize that the correction is performed offline after the numerical hindcast has been produced, rather than through online data assimilation inside the wave model. To avoid ambiguity, we have replaced “post-fusion” with “offline fusion” throughout the manuscript.

Line 86-92: It is not clear from this text if all three limitations are addressed.

We thank the reviewer for this helpful comment. We agree that the original text did not explicitly state how the proposed dataset addresses the three limitations discussed in the preceding paragraph. We have revised the Introduction to clarify that the first two limitations are directly addressed by using jointly calibrated CCI Sea State altimeter observations and by applying an offline fusion framework that can use both past and future observations. The third limitation is avoided, rather than directly solved, because our product reconstructs SWH only and therefore does not require modification of the full directional wave spectrum. The revised text reads:

“*The proposed offline fusion framework addresses these limitations in different ways. First, it uses the jointly calibrated CCI Sea State altimeter record as the observational reference, thereby avoiding calibration against the model background. Second, because the fusion is performed offline after the hindcast has been generated, both past and future altimeter observations can be used to constrain the SWH field at a given analysis time. Third, this retrospective constraint also reduces the dependence of the reconstruction on the forward spectral propagation in the wave model. Therefore, no adjustment of spectral shape is required, and the associated uncertainty is therefore avoided.*”

101: I'm not familiar with the CCI dataset. What is "1-Hz" here? Does this refer to one cycle per day? Is this a normal definition for "Hz"? (usually 1/sec?)

We agree that this term needed clarification for readers who are not familiar with satellite altimetry terminology. In satellite altimetry, “1-Hz” refers to a low-rate along-track product with approximately one SWH observation per second, not to one cycle per day. Many altimeter missions also provide higher-rate measurements, such as 20-Hz data, but the 1-Hz product is commonly used in operational and climate applications because averaging/resampling to this lower rate reduces random noise and improves the signal-to-noise ratio.

The text has been revised to:

"*The most important altimeter dataset used in this study is the Level-3 1-Hz significant wave height (SWH) product from the CCI (Climate Change Initiative) Sea State dataset (Dodet et al., 2020), with each record associated with its own time, latitude, and longitude. Here, "1-Hz" denotes along-track observations provided at approximately one measurement per second (corresponding to a spatial resolution of about 7 km).*"

101 again: I guess this is a daily product on a fixed, regular, lat-lon grid?

We thank the reviewer for identifying this ambiguity. The CCI Sea State product used here is not a daily product on a fixed regular latitude–longitude grid. It is an along-track altimeter product containing exact observation time, latitude, longitude, and SWH records. The revised text has been shown in the previous response.

183: Has the "parameter set" been introduced?

We agree that the term "parameter set" was introduced too abruptly. We have revised the sentence to explicitly state that the parameter set refers to the combination of the tuning parameters C, S_1, T_1, Q, S_{thr}, T_{thr}, r_{thr}. To better explain this, we have revised the corresponding part to:

"The fused results were then validated against the independent Jason-2 observations, and the combination of tuning parameters (C, S_1, T_1, Q, S_{thr}, T_{thr}, r_{thr}) that yielded small overall errors was selected."

191-210: This block of text deserves a heading of some kind.

We thank the reviewer for this suggestion. We agree that the purpose of this paragraph should be made clearer. Since this block is still part of the methodological description of the fusion approach, we prefer not to introduce an additional formal subsection heading. Instead, we have added an introductory sentence before this paragraph to clarify that the following points explain the main modifications of our approach relative to conventional objective-analysis / optimal-interpolation methods:

"*The main modifications of the present fusion approach relative to conventional objective-analysis / optimal-interpolation methods are summarized below. While conventional methods often define weights primarily according to spatial separation, our approach introduces several additional terms to better reflect the characteristics of wave fields*"

Fig. 2 caption: to assist readers who are skimming, add 3-4 more words to the caption to explain what CMEMS is.

We agree and have revised the caption to briefly define CMEMS (Copernicus Marine Environment Monitoring Service). The same revision has been conduct in Section 2 where CMEMS dataset is first introduced.

350: for clarity, "data fusion" ==> "data fusion is applied to both datasets"

We have revised the sentence accordingly:

"***Fig. 5.*** *Comparison between WW3-ST6 (forced by ERA5 winds) and WW3-ST4 (forced by CFSR winds) before and after data fusion is applied to both hindcasts using the same altimeter observations in January 2011.*"

448: This section "Data description and availability" looks weird to me. There are two sections about data availability. Is it a normal practice for this journal to have a very small section prior to the Summary, about data availability? Why not put this content in the section after the Summary, "Code and data availability"?

We thank the reviewer for this comment. We understand the concern that the manuscript appeared to contain two data-availability sections. However, the two sections serve different purposes. The section "Data description and availability" is intended to describe the dataset produced in this study, namely the global gridded fused SWH dataset, including its two versions, file structure, variables, and metadata. This type of dataset-specific description is commonly included in dataset papers before the Summary, so that users can understand the actual product before the concluding section.

In contrast, the required "Code and data availability" section after the Acknowledgement provides access information for all data and model resources used in the study, including the CCI Sea State product, WW3-ST4/ST6 hindcasts, CMEMS gridded SWH product, NDBC buoy observations, the fused dataset, and the AI wave model of Wang and Jiang (2024), to ensure the reproducibility of this study.

468-473: The basis for these findings should be given.

We thank the reviewer for this comment. These statements were intended as methodological limitations rather than direct validation findings. First, the fusion product inherits the spatial and temporal resolution of the background wave model and the smoothing implied by the

fusion procedure, so it is not designed to retain small-scale or high-frequency signals present in Level-2 along-track observations. Second, the background WW3-ST6 hindcast used in this dataset does not include wave–current interactions, so the fused product should not be used as a primary dataset for studying such interactions. We have rephrased these statements accordingly. We have revised this part to:

"*Although this high-accuracy gridded dataset offers many practical advantages, it also has some limitations compared with along-track altimeter observations. These limitations arise from the design of the fusion framework. Because the fused fields are generated on the spatial grid and temporal resolution of the numerical hindcast and involve space-time interpolation, small-scale signals present in the original along-track observations are smoothed. Therefore, the product is not intended for studies that require the full fine-scale variability of altimeter measurements, such as analyses of regional-scale SWH gradients or other small-scale wave-field features. In addition, because the WW3-ST6 background hindcast used here does not explicitly account for wave–current interactions, the fused product should not be used as a primary dataset for diagnosing such interactions, even though some wave-current-interaction signals are present in the original altimeter data.*"

The summary section is not too long, but is a jumble. Here's my attempted categorization of the content:
458-460 : background
460-462 : methods
462-463 : findings
463-467 : methods
468-473 : findings
474 : method
475-479 : background
479-484 : discussion
485-490 : future work
This structure means that the reader has to sort it out. If a reader just wants a bald statement of the outcome of the research, it should be easier to find.
I don't want to micromanage this, but I suggest to at least have a section or sub-section with a clear list of findings. Here, "finding" = something that is a direct outcome of the analysis and experiments described in the paper. It does not include conclusions that could have been made without the work in the paper.

We agree that the original Summary mixed background, methods, findings, limitations, and future work in a way that made the main outcomes less easy to identify. We have rewritten the Summary section to follow a clearer structure: background/motivation, method, main findings, limitations, and future work:

"Satellite altimeters can provide long-term, high-accuracy observations of SWH across the global ocean. However, their inherently sparse spatial and temporal coverage introduces undersampling errors, which can limit the reliability of wave climate analyses, particularly for extreme wave climate. To address this limitation, this study developed a global gridded SWH dataset by applying an offline fusion framework to combine WAVEWATCH III hindcast fields with along-track, jointly calibrated altimeter observations from the CCI Sea State dataset. To cater to different applications, two versions of the fused dataset are provided: (1) a two-sat version, which incorporates data from only two satellites at any given time and is optimized for wave climate studies, ensuring temporal consistency throughout the record; and (2) a all-sat version, which assimilates observations from as many altimeter missions as possible and is intended for applications such as training artificial intelligence-based wave models, where high spatial and temporal fidelity is critical.

Validation against buoy measurements and independent satellite data demonstrates that the resulting fused gridded product achieves high accuracy, demonstrating that combining the spatial and temporal continuity of numerical hindcasts with the accuracy of altimeter observations provides a more reliable gridded SWH field than either source alone. Experiments using different background hindcasts show that the fused results are not strongly dependent on the specific numerical background field, provided that the background offers a physically reasonable estimate of the large-scale SWH distribution. Although the fused product inevitably retains some dependence on the background model, the discrepancies between products generated from different hindcasts are effectively reduced after fusion.

Although this high-accuracy gridded dataset offers many practical advantages, it also has some limitations compared with along-track altimeter observations. These limitations arise from the design of the fusion framework. Because the fused fields are generated on the spatial grid and temporal resolution of the numerical hindcast and involve space-time interpolation, small-scale signals present in the original along-track observations are smoothed. Therefore, the product is not intended for studies that require the full fine-scale variability of altimeter measurements, such as analyses of regional-scale SWH gradients or other small-scale wave-field features. In addition, because the WW3-ST6 background hindcast used here does not explicitly account for wave–current interactions, the fused product should not be used as a primary dataset for diagnosing such interactions, even though some wave-current-interaction signals are present in the original altimeter data.

Despite these limitations, this fused dataset already offers substantial utility across a wide range of applications. Future improvements can be made by incorporating additional satellite missions and extending the temporal coverage of the dataset. In particular, including more recent altimeter and wave-scatterometer observations, such as those from Haiyang-2 and CFOSAT, may further improve the multi-sat product and support more robust analyses of long-term wave-climate variability and trends."

Minor comments:
Fig. 2 and 3 and possibly other figures. The statistics are given to too many decimal places

Thank you for pointing this out. We have reduced the number of decimal places used for the error metrics in Figures 2 and 3 and Tables 2-4. All reported error metrics are now shown with no more than three decimal places.

Typos: Line 67, Line 68

We appreciate the reviewer for pointing out these minor issues. We have gone through the entire manuscript again to minimize typos and grammatical errors.