**Anonymous Referee #3 - Comment on essd-2022-438**

We would like to express our gratitude to Referee #3 for meaningful comments and suggestion. We have carefully reviewed your comments and have made necessary updates to our manuscript. We provide point-to-point response to the referee comments shown in blue whereas the revision made to the main text in shown *blue Italics*.

Kind regards

General comments

This study develops an altimetry mapping approach (AltiMaP) that aims to mitigate the mismatches between virtual station (VS) locations and actual river locations, which are caused by DEM errors, the use of discrete river grids, and the allocation of VSs to the center of the WSE observation search area. The topic is interesting to the hydrological community. However, there are many issues unsolved with the manuscript in its present form and I recommend rejection (see details below).

We would like to extend our gratitude to the referee #3 for the time and effort to review our manuscript. We addressed all the comments of the referee #3 and the point-to-point answers were provided below.

1) I think one of the major limitations of the study is that the allocation was performed based on Hydroweb whose VSs are located away from the actual river. What is the added value of the method for self-defined VSs or other data sets when the VSs are delineated right at the center of the river?

We extend our sincere gratitude to referee #3 for providing essential and valuable comments. We would like to reiterate that the primary objective of AltiMaP is to establish meaningful correspondences between VSs and MERIT Hydro, ultimately enabling a reliable comparison between model outputs and satellite altimetry data.While it is important to mention that the “correction of VS location” is indeed a step within the AltiMaP process, it is crucial to recognize that the true essence of AltiMaP lies in ensuring accurate VS-hydrography correspondences. AltiMaP not only facilitates the calibration of parameters but also plays a key role in effectively correcting states through data assimilation techniques.

We firmly believe that our method, AltiMaP, holds significant value even when VSs are self-defined, as demonstrated by the special case where VSs are located at the river mouth under the flag 10 (flag 13, as indicated in supplementary Table S1). In AltiMaP, we also delineate VSs at the centerline of the river, which corresponds to flag 10 in our convention (flag 11, see supplementary Table S1). Therefore, the cases highlighted by referee #3 are just special instances within our flagging approach in AltiMaP. We are confident that AltiMaP possesses broader applicability beyond these specific cases. It can be effectively utilized in various scenarios, making it a versatile and valuable tool for VS-hydrography correspondences and model-satellite altimetry comparisons.

*"Table S1: Secondary Flags used in the AltiMaP"*

| *Main Flags* | *Secondry Flag* | *Description* |
|---|---|---|
| *10* | *11* | *VS was found on the river centerline* |
| | *12* | *VS was found on the river channel but not in the centerline and assigned to the nearest centerline* |
| | *13* | *VS was found in the unit-catchment mouth* |
| *20* | *21* | *VS was found in the ground and assinged to the nearest single channel centerline* |
| | *22* | *VS was found in the ground near large river channel in in mult-channel river and assinged to the larger river centerline* |
| *30* | *31* | *VS was found in the ground near small river channel in mult-channel river and assinged to the large river centerline* |
| | *32* | *VS was found in bifuricating channel and assinged to the large river centerline* |
| *40* | *40* | *VS was found in the ocean and assinged to nearest river channel* |

Even though our objective in this study is to develop a robust methodology to map the VSs of the existing satellite altimetry products such as HydroWeb, DAHITTI, Hydrosat, Copernicus Global Land Service, the methods can be extended to self-defined VSs. We believe most of the WSE (satellite based or in-situ) observations with geographical information (lon/lat) can be mapped into the high-resolution river network map using the AltiMaP. For example, Schneider et al., (2017) projected the self-defined CryoSat-2 data into the model space. We were able to assign those data into MERIT Hydro using AltiMaP (Figure S1).

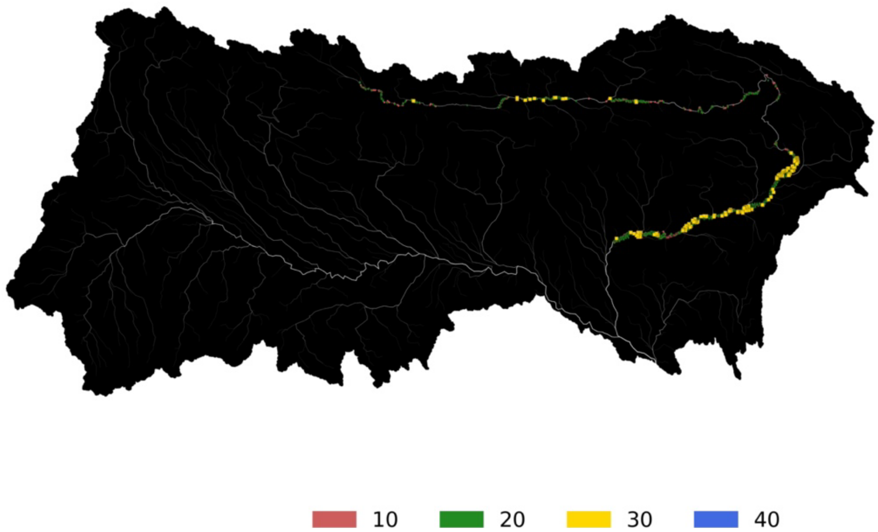


***Figure S1: AltiMaP allocation flags for the CryoSat-2 data provided by Schneider et al., (2017). Here each Cryostat-2 observations has been considered as a VS to allocate into MERIT Hydro because of the drifting orbit of CryoSat-2.***

Moreover, as deriving a global scale satellite altimetry dataset is challenging, for large-scale model such as CaMa-Flood comparison it may be inevitable to use existing datasets such as HydroWeb. According to our knowledge, none of the other models compared WSE against satellite altimetry on a global scale.

Considering the comment by the referee#3, we have revised the text following the referee #3 comment:

*"We introduce our automated altimetry mapping procedure (AltiMaP), which enable better evaluation of WSEs simulated by large-scale hydrodynamic models using available satellite altimetry data."*

On the other hand, despite of the VS self-defined or obtained from the organization, VS needed to be mapped to correct river grid or river reach in grid-based models. VS being point observation it needed to be compared against correct location. To understand the errors of the model simulations, it is important to know the relative position of VS within the unit-catchment. If the VS is delineated at unit-catchment mouth (similar to Flag 12 in Table S1), the observations can be directly compared with simulations.

In addition, we cannot expect the self-defined VS to be at the center of the river networks of the model which delineated using the spaceborne digital elevation model (DEM) which often presents with mismatches with the actual elevations due to vegetation bias, speckle noise, stripe noise, and absolute biases (Yamazaki et al., 2019). These errors in the DEMs can produce mismatches between delineated river with ground truth. Moreover, the rivers can change the location with time (e.g., meandering). In such instances, the VS needed to be allocated to the correct river grid of the model river network.

2) If the authors focus on satellite radar altimetry, the swath interferometric altimetry mission CryoSat-2 with dense spatial coverage should be added as an important data source for validating the method. Further, how applicable is your method to laser altimetry (ICESat-1/2)? I would provide a preliminary result for these data with a short discussion.

We would like to express our gratitude to referee #3 for his important comment. Of course, CryoSat-2 will provide unique data. CryoSat-2 is equipped with the Synthetic Aperture Interferometric Radar Altimeter (SIRAL), which operates in the Ku-band using synthetic aperture radar (SAR) mode. In addition, CryoSat-2 has the capability to perform SAR interferometric (SARIn) measurements using a dual antenna configuration. This SARIn mode allows for the accurate determination of the position of the reflecting point within the radar footprint. This feature is particularly valuable for identifying non-nadir measurements, which can occur when observing terrestrial waters. We think this identifying non-nadir measurements is beyond the scope of our study. We believe the data providers can use such method for quality control. We firmly believe that we should include CryoSat-2 based quality control in the future.

In addition, CryoSat-2 with its' drifting ground track a continuous river masks are needed (Jiang et al., 2017). Moreover, we believe ICESat 1/2 is also provide important accurate estimates of WSE but with low resolution (~91 days). Both ICESat-2 and CryoSat-2 can be assigned to the river centerline depend on the orientation of the satellite track: 1) across-track and 2) along track (Scherer et al., 2022, 2023). Finding the nearest river centerline to the satellite footprint needs to the similar mapping procedure. We believe CryoSat-2 and ICESat-2 would be important addition to our dataset and useful in calibration and validation of global hydrodynamic models such as CaMa-Flood.

Considering the comments from the referee #3 we added some discussion to the manuscript as follows:

*"4.4 Limitations and Future Perspectives*
*Even though AltiMaP is suitable in mapping the VSs into the given river network with D8 connection, the method is not capable of identifying non-nadir observations (such as floodplain lakes near the river channel). One of the major problem in the conventional altimeters in low-resolution mode (LRM) such as ENVISAT was correcting the observations from the non-nadir view was treated as nadir observations (Calmant et al., 2008; Frappart et al., 2006; da Silva et al., 2012). The dual antenna configuration of the CryoSat-2 allows precise position of reflecting point in the radar footprint and solve the signal location along-track and across-track directions (Cretaux, 2022). Moreover, ICESat-1/2 data can also be a great source of importance over terrestrial waters, but the longer revisit time limit the applications in hydrology. Satellites such as CroySat-2 and ICESat-2 provide an addition challenge in using them in river monitoring. CryoSat-2 with its' drifting orbit ~7.5km makes it challenging to define VSs as in repeat orbits (Schneider et al., 2017). With the complex ground track configuration of ICESat-2 makes it complex to use in river monitoring because the assigning method would differ depend on the satellite track*

*orientation with respect to the river centerline (Scherer et al., 2023). However, with slight modification to the AltiMaP, We would be able to map such data into the MERIT Hydro."*

Moreover, we mapped CryoSat-2 water surface elevation from Schneider et al., (2017) over the Brahmaputra river (Figure S1). We treated each observation as a VS here because of the drafting ground track of the CryoSat-2. Then we projected the CryoSat-2 observations into the most appropriate nearest river pixels using AltiMaP which may slightly different from the method used by Schneider et al., (2017). Figure S2 shows the allocation flag map of CryoSat-2 data into the MERIT Hydro. We found 52.9%, 38.0%, and 9.1% of Flag 10, 20, and 30 but no Flag 40 was found because the data does not consist of the observations near the Ocean.

3) Line 140: You are selecting the largest river for further processing. But it is possible that the observation (also termed POCA, point of closest approach) is from the river closest to the satellite (within the beam limited footprint) when there are multiple river channels near the VS location. Therefore, it would be interesting to perform a similar analysis with the abovementioned assumption (i.e., choosing the closest river as opposed to the largest river to derive WSE) to see the difference.

Thank you very much for the nice suggestion. The assumption that the observation is from the largest river when there are multiple river channels near the VS location due to the fact that the satellite altimetry can be derived only from rivers with substantial river width (e.g., 0.8 km) (Birkett and Beckley, 2010). Hence, we believe that the assumption is valid for the retrackers used in HydroWeb or other similar datasets even though some other methods can be useful for deriving WSE in narrow rivers (e.g., Sulistioadi et al., 2015).

In addition, we have already provided location of nearest smaller river location as kx2, ky2 in the detail dataset and geographic distance for VS location to two selected river pixels in the MERIT Hydro as dist1 and dist2 in AltiMaP dataset. We included a simple analysis using secondary locations kx2, ky2 (only for Flag 30).

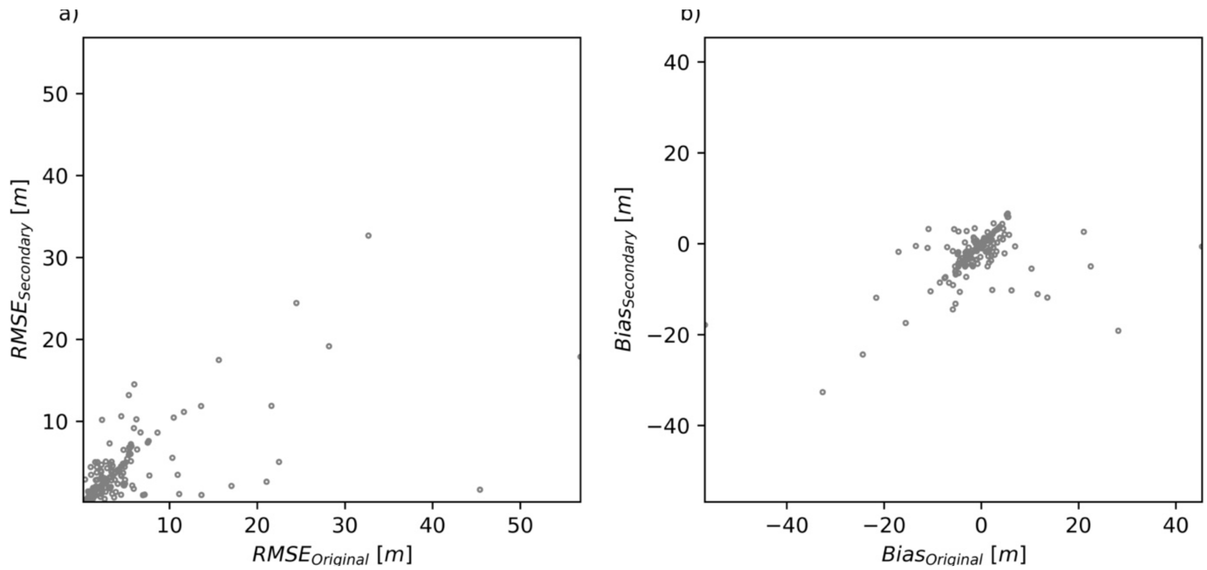


***Figure S2: Comparison of root mean squared error (RMSE: a) and bias (b)for Original and Secondary allocations.***

4) Line 148: Many previous studies have confirmed the reliability of the median value compared with the mean, which is quite sensitive to outliers. I would suggest the authors use the median value as the final WSE and update all the relevant results.

We agree with the referee that mean value can be affected by outliers. But as we are using pre-processed data such as HydroWeb where the outliers have been already removed, the mean values may not be corrupted. We check both mean and median and found that both the values are almost similar and works well for our purpose.

5) Do you use lat and lon at nadir for the allocation of the altimetry measurements? If so, I guess you may need to use the corrected ones instead (lat_cor and lon_cor), which are better representations of the radar echoes.

Thank you for the question. We used the lat and lon information provided by the HydroWeb dataset. The lat/lon values represent the center location of the area allocated for the VS. We think the lat/lon locations provided in HydroWeb is different from locations of radar echoes.

6) While range correction derived from waveform retracking is not within the scope of the manuscript, it is still one of the major sources of error for WSE. The introduction section should at least mention this. It would make more sense to briefly introduce the processing chain of Hydroweb (e.g., what retracker and/or slope correction method it is using), followed by a citation, such that authors without expertise in altimetry could better capture the contribution of the methodology.

Thanking the referee #3, we include additional details to the Table 1.

Minor comments

1) Line 40: ‘following troposphere’-> following dry troposphere?

Thanking referee #3, we revised it.

2) Line 163: what is the timestamp of the MERIT DEM? Because your altimetry data cover a wide range of time periods (1992–2022), how could you confirm the MERIT DEM is representative of the actual topography that is validated against the altimetry missions?

Thank you very much for the question. MERIT DEM is derived from SRTM which was from 2000s and AW3D DEM which operated from 2006-2011 (Yamazaki et al., 2017). The DEM may not be the representative for each satellite mission. This highlights the importance of AltiMaP framework which can provide a mapping table for VSs into the MERIT Hydro river network which then feasibly used for simulation derived from MERIT Hydro.

3) Line 184: ‘then adding 100 to the flag of any VS that is biased’, please explain or reword. Why not add a fifth flag for biased VSs?

We would like to keep the initial allocation flag preserved. Therefore, we added 100 to the existing flag to denote that as biased VS.

4) Table 2: how to obtain the river widths, manually?

The river widths data was provided in MERIT Hydro dataset (Yamazaki et al., 2019). River widths were calculated using an algorithm developed by Yamazaki et al., (2014) using optical imagery.

5) Line 202: ‘river channel river’. A typo here?

Thank you for pointing this out. We carefully checked the manuscript for correct such typos.

6) Figure 4: please increase the font size of the figure

Thank you very for the valuable suggestion. We have revised the Figure 4 as shown below.

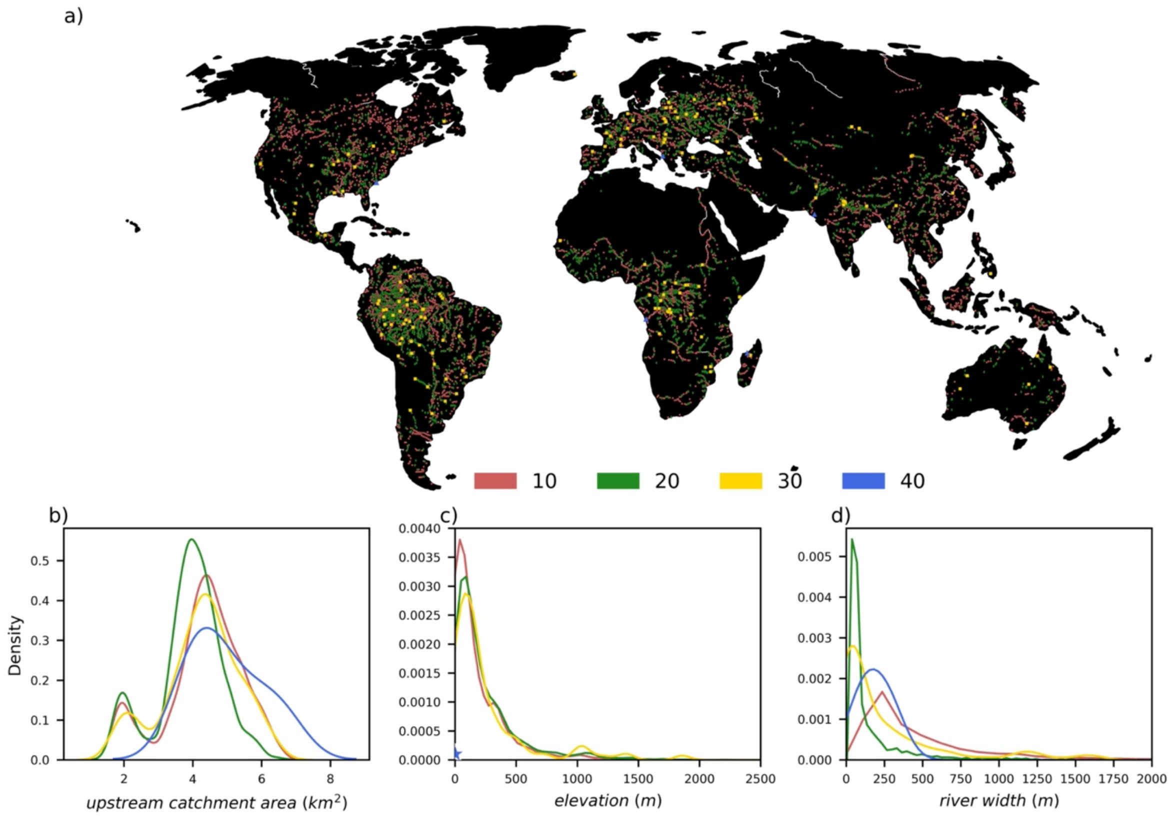


***Figure 4: Global map of allocation flags. Panel at lower left corner shows probability distribution of the upstream catchment area in log scale for different flags. Flags 10, 20, 30, and 40 are indicated by light blue, medium blue, dark blue, and red colors, respectively.***

7) Figure 5: please add a title for the y-axis in b,c, and d

Thanking the referee #3, we revised the Figure 5 as follows.

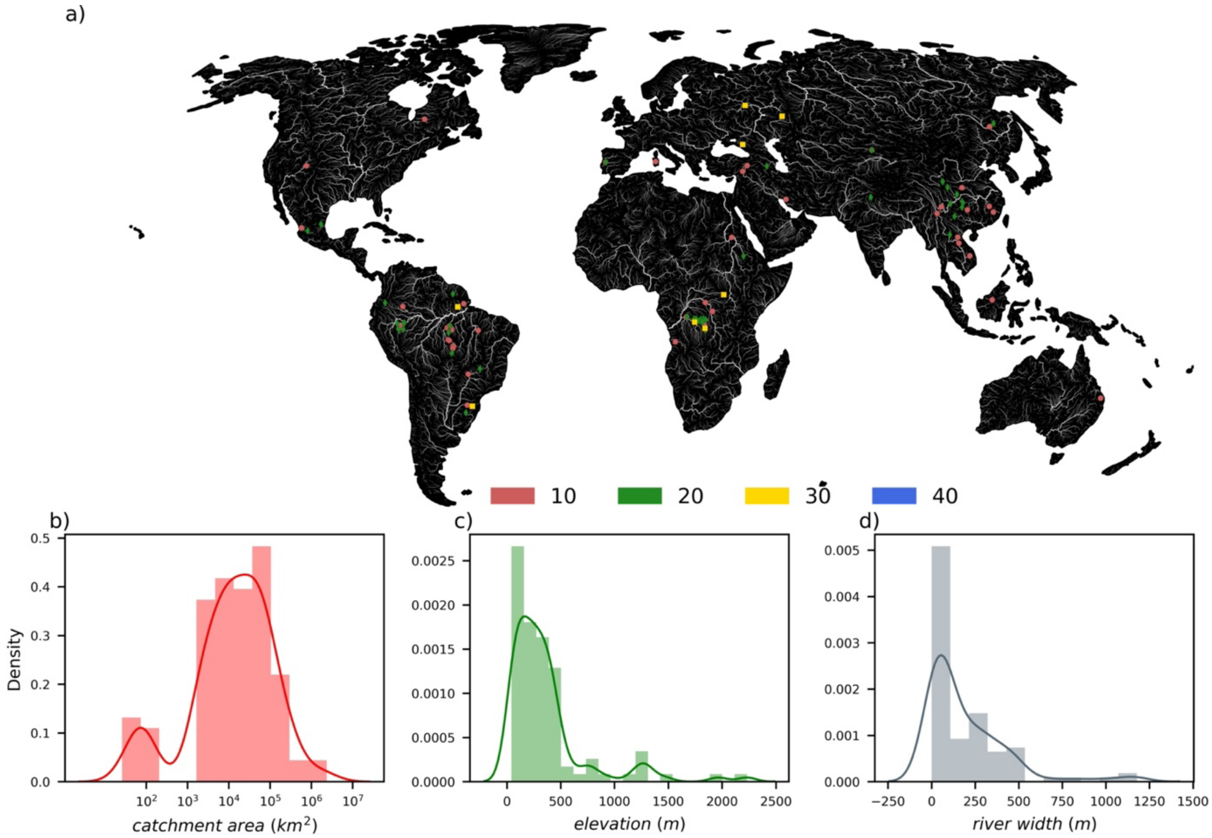


***Figure 5: a) Global distribution, b) histogram of catchment area (km2), c) histogram of elevation (m), and d) histogram of river width (m) of biased VSs. Light blue circles, medium blue diamonds, dark blue squares, and red triangles for flags 10, 20, 30, and 40, respectively in panel a.***

Reference:

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5. Schneider, R., Nygaard Godiksen, P., Villadsen, H., Madsen, H. and Bauer-Gottwein, P.: Application of CryoSat-2 altimetry data for river analysis and modelling, Hydrol. Earth Syst. Sci., 21(2), 751–764, doi:10.5194/hess-21-751-2017, 2017.
6. Sulistioadi, Y. B., Tseng, K. H., Shum, C. K., Hidayat, H., Sumaryono, M., Suhardiman, A., Setiawan, F. and Sunarso, S.: Satellite radar altimetry for monitoring small rivers and lakes in

Indonesia, Hydrol. Earth Syst. Sci., 19(1), 341–359, doi:10.5194/hess-19-341-2015, 2015.

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10.