Interactive comment on „Water levels of the Mekong River Basin based on CryoSat-2 SAR data classification"

by Eva Boergens et al.

Anonymous Referee #1

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Summary

This paper presents a new method for classifying satellite SAR-altimetry returns over inland water targets. The conventional approach is to select inland water returns from the dataset using static or dynamic water-land masks. This paper presents an alternative methodology, in which properties of the signal itself are used to determine whether the signal is returned by inland water or not. Such a method is useful for the inland water altimetry community, because time-consuming water-land masking steps may be saved and because it may provide new ways of filtering outliers from the altimetric record. The study would benefit from a more systematic comparison of the new approach developed here and the conventional approach using land-water masks.

Review Comments

1. p. 2, line 10ff: The authors state that the/some land-water-masks are "constant over time" and therefore neglect seasonal variations of the water extent. Dynamic water masks can be derived fairly easy from, for example, Sentinel-1 SAR imagery or, cloud cover permitting, from Landsat or Sentinel-2 optical imagery (e.g. NDVI or NDWI).

Furthermore (p. 2, line 21), the authors state that their method can "overcome the problems and limitations of land-water-masks".

Thank you for this comment. You are right that dynamic water masks are more or less easy to derive nowadays but with two limitations: The first is the mentioned cloud cover for optical sensors. In regions with strong weather seasonality like the Mekong with the monsoon, during the high water time nearly no images are available due to the rain clouds. The second limitation regards the SAR images, which have with Sentinel-1 a high enough spatial resolution, but are only available since 2014.

We added in the text:

Extracting dynamic land-water-masks from optical or SAR remote sensing images is difficult in the study area since cloud-free optical data is only available during the dry season with low water level. Moreover, SAR images with sufficient spatial resolution are only available from 2014 on with the launch of Sentinel-1.

And changed the sentence to:

To be independent from the accuracy and availability of land-water-masks,….

It seems, however, that especially highly variable seasonal water extents hinder the application of the developed classification in the downstream parts of the Mekong (p. 10, line 4 ff: "the width of the river feature larger seasonal changes than in the other regions. This can influence the waveform and RIP significantly") In this case, the introduction shouldn't mention this as an advantage of the developed method.

The main problem of the downstream region is not the changing features but the water areas besides the river. Any classification algorithm will probably meet a problem discerning between water that belongs to the river and water that belongs to a pond or paddy field. We think that our approach would still work if only the features change between seasons as we then could define more water classes (for dry and wet season). But as it is wetlands resemble dry season river returns this is not possible. We deleted the reference to the changing features in the text and changed it to:

There, the rivers are surrounded by seasonal wetland whose observations are also water returns, which the classification algorithm cannot discern.

2. Validation of Water Levels: Besides using the differences between observations 369 days apart, which only provides an indirect way of validating the observed heights, a direct validation against in situ water levels still should be possible. At least for CryoSat-2 observations in proximity of in situ stations, where simple assumptions about river slope can hold true.

Unfortunately, comparing absolute water levels with the gauge is not possible, as they do not have an absolute height value but record only relative level variations. Therefore, only relative changes derived by Cryosat-2 could be validated against the gauge. The second problem arising is that the gauge time series ends with 2012, whereas we do not have CryoSat-2 before April 2011 and then only for part of the region (see figure 2). Even with a margin of 30km around the gauges we get to little CryoSat data for validation against the gauge. To compute a mean and RMSE from 5 overlapping points would not be statistically valid (and this would be the best case we found).

We added at the beginning of the validation section:

Besides this, the temporal overlap between the CryoSat-2 data and the gauge data is only about 1.5 years or even less (April 2011 until December 2012)

3. It would be interesting to compare results to the conventional approach of using a river mask, and simply filter points with that. This has been done by the authors, but only mentioned in the manuscript briefly for the validation. So how many water observations do you get from the river mask vs. the classification, how many outliers, how good is the fit for an actual validation against in

situ data as suggested above? The question is whether there is a clear benefit of the classification approach over the conventional river masking.

We think that the benefit of the classification over the mask approach is apparent from Table 4. However, it is true, that we do not mention in the paper the number of water levels gained by both methods. For this we have to separate the two regions. In the upstream region the classification leads to even more valid heights than the mask approach (see table below). And then more of the heights of the mask approach are dismissed in the outlier detection. For the middle stream region the mask approach leads to more water levels but again more are dismissed in the outlier detection. See table below for the exact numbers.

	Classification	Mask
Upstream region		
Before outlier detection	1740	1646
After outlier detection	1703	1534
Middle region		
Before outlier detection	529	1417
After outlier detection	516	1364

A validation against gauges is not possible as explained above.

We added in the text:

In the middle region along the main river the land-water-mask and the classification approach yield comparable results in the validation. However, in absolute numbers of observations the land-water-mask approach produce more water levels but with a higher amount of outliers.

And

In the upstream region the water levels of the classification approach are superior over those of the land-water-mask approach as well in terms of validation results and absolute numbers of valid observations. For both regions the number of outliers is much larger for the mask than for the classification approach.

4. P7L20ff: It appears that, for the validation of the classification, and also in order to find out which of the kmeans clusters represent water (P10L2ff), a water mask is still required… So maybe the selling point for this methodology is not so much that it can operate without land-water masks but rather that it can improve outlier filtering?

We do not depend on a land water mask for the validation of the resulting heights. It is only used for the comparison with the land-water-mask approach.

For the k-means cluster identification we only need the approximate location of the river which could also be the center line of the river. We searched for the classes with all points in the vicinity of the approximate location of the river and not only inside the mask. Therefore, we could do this with an even less accurate mask for regions where only the global land-water-masks are available.

Additionally, we changed the text to:

This was done by visual inspection of the mean waveform and RIP for each class and the locations of the observations in each class related to the approximate location of the river known from the land-water-mask (see \autoref{sec:data}).

5. P7L24ff: Apparently, the region of interest has to be divided into subregions prior to the application of the method because it is "too diverse in the reflectivity properties of water bodies". How would this play out for a routine application of this method in a new basin, what is the operational procedure to slice the region up into appropriate sub-regions?

We used the ETOPO1 topographical model of the region which is globally available (Probably any topography model could be used for this). For each grid cell of the model we calculated a roughness index based on the standard deviation of the heights in a 10km radius. This roughness coefficient and the absolute height were used to define the subregions. Afterwards the borders of the subregions were extended with a margin for the overlap which also smoothed out the edges. For a new basin the same procedure could be employed but the thresholds for roughness and height might be different. We have not tested this for other basins and it is also highly possible that it is not necessary for every basin to subdivided regions.

We added in the text of section 2:

The regions are determined by the roughness of a topography model and the absolute height. Afterwards a margin around each subregion allows for an overlap.

6. P15L8ff: It is probably difficult to get to any general conclusion regarding the relative performance of the classification and the masking approaches, as, obviously, the performance of the masking approach will depend on the quality of the mask. Lower performance in the upstream region may simply indicate that the mask is less reliable there. One could even think of a reversed sales argument here, and argue that in regions with narrow rivers SAR altimetry offers a tool to map water surfaces that are too small to be reliably resolved by Landsat/Sentinel SAR imagery.

That is very true, thank you for the suggestion. We added in the text:

This shows the opportunity SAR altimetry provides for rivers too small to be reliably identified in optical (e.g. Landsat) or SAR (e.g. Sentinel-1) images. As already shown in \autoref{sec:classification} and \autoref{map_class} the classification of SAR altimetry identifies even rivers which are not visible in the land-water-mask derived from aerial images.

Details

1. p. 2, line 14 ff: Can we really say that a 30m resolution is insufficient? In the reviewer's experience, such precise water masks often can be buffered (i.e. enlarged) to obtain a higher number of water level measurements. This is likely linked to the size of the footprint of the altimeter, which also in SAR mode is much larger than the resolution of the water mask.

30m is indeed very precise for a land-water-mask, but when buffering the mask to obtain more altimeter measurements one also might (and probably will) get measurements which are not water reflections. The mask is also not time variable, which is less a problem for the narrow gorges but for the middle part of the river flood expansions.

We reformulated the sentence to:

Although, a high accuracy land-water-mask is provided by the Mekong River Commission (\url{http://portal.mrcmekong.org/map_service}) which has an accuracy of 30\,m, this accuracy might not be sufficient for small and smaller rivers. Additionally, the mask has no seasonal variations included.

2. The classification of rivers into large, smaller and small is inconvenient and easily misunderstood. It may be better to operate with classes A, B, and C or similar and just define breaks between the classes.

Thank you for this remark; we agree that it can be confusing for the reader with larger, smaller and small though we defined it at the beginning. However, A, B and C are not easier to understand for a reader who is not reading the whole paper. We decided to rename it to large, medium and small sized rivers.

3. P1L14: “smaller upstream regions” should probably be “upstream regions with smaller water bodies”.

We changed the sentence

4. Some in-text citations are messed up (e.g. P1L17, P3L9)

Thank you for this, we fixed the references.

5. P2L9: Please add a few arguments explaining why the dense spatial distribution is an advantage, esp. for rivers.

We added in the text:

This is especially useful for rivers to better monitor the continuous progression of it. Unlike lakes a river can change its water level rapidly over its course which makes a denser spatial distribution of observations desirable.

6. P3L6: "gauges" should probably be "gorges"

Changed

7. P3L17-18: Sentence repeated from above.

We removed above the sentence about the mode mask. However, we left the sentence below as we introduce the different mode more thoughoutly here.

8. Fig 1: Map legend entries have different symbology from shown layers

There seems to be a problem with this figure, which is also mentioned by the other reviewer. We hope to have fixed this now and that the figure is now visible on all platforms.

9. P7L15: delete "a" before "several"

done