Anonymous Referee #1
Received and published: 25 May 2015

MAJOR COMMENTS

This manuscript is about retrieving inland water level information using radar altimeters from satellites. A new processing schema is proposed based on 1) a careful data pre-processing (including waveform retracking), 2) a Kalman filter approach that incorporates cross-calibrated multi-mission altimeter observations with their uncertainties and 3) a rigorous outlier detection strategy. This processing schema is contributing to populate the new archive called “Database for Hydrological Time Series of Inland Water” (DAHITI) at DGFI-TUM. The performances of the new processing are here assessed in a number of lakes and rivers in North and South America. The authors compare their water level time series with available ground truth and other similar altimeter-derived water level products (e.g., Hydroweb, River & Lake, GRLM). The results show that with the new processing inland water height information is more accurate than that available from the other established inland altimeter services (i.e., Hydroweb, River & Lake, GRLM).

Overall, this manuscript presents a novel method to process altimeter data in inland waters that appears to be very effective for smaller lakes and rivers. It is clear that exploiting all available satellite missions is crucial to construct accurate water level time series, although inter-mission biases must be carefully taken into account.

The new method is clearly documented and data analysis is sufficiently complete. The results from the comparison statistics made at a good number of water targets are well discussed. Three case-studies (Lake Superior, Lake Athabasca and Rio Madeira) are also commented in detail.

What follows are some remarks:

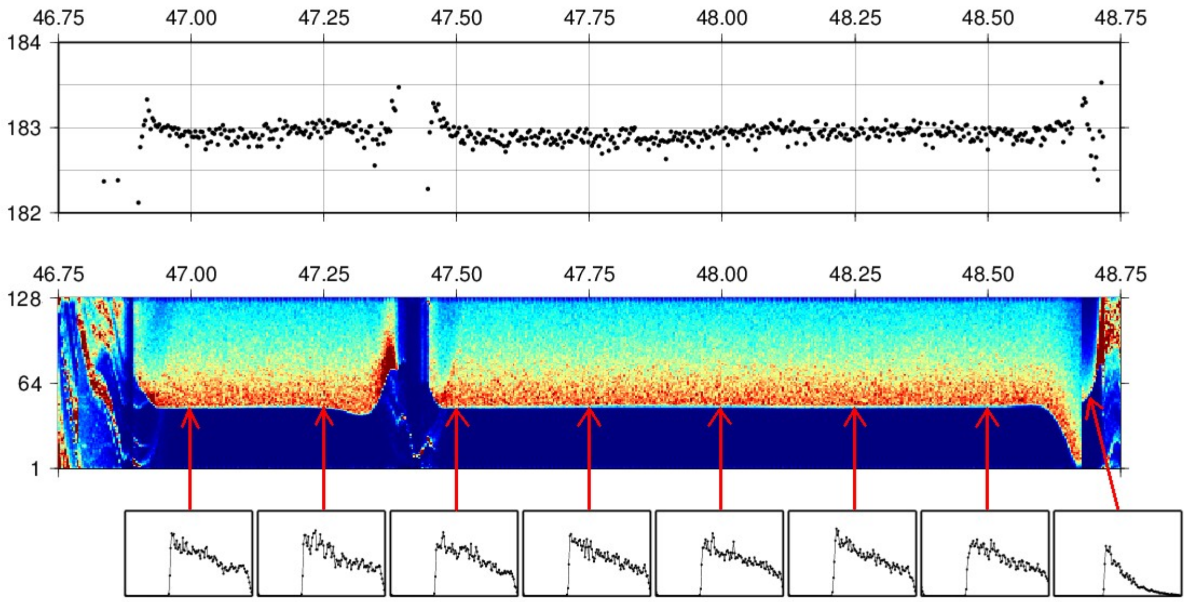
- The authors try to explain the observed disagreements in the various comparisons, however, the discussion about the possible causes is not sufficiently supported by rigorous explanations. A strong recommendation for the authors is to better interpret the results in the three case-studies with reference to all possible reasons that might explain disagreements with ground truth and with the other remote sensing products.

Planned updates in revised version:

- The discussion of the observed disagreements will be extended for the three selected results in Figure 7,8,9.
- Lake Superior:
    - Ice coverage, wind & wave, geoid errors
- Lake Athabasca:
    - Ice coverage, land contamination, impact of mountains near the lake shore, retracker biases, hooking effect
- Amazon River:
    - land contamination, river slope, hooking effect, large footprints can lead to measuring river branches, retracker biases

- The effect of wind and wave fields in the case of Lake Superior should be investigated in order to prove the assumption that the level of the lake is constant. I am also not convinced that all waveforms in this big lake when the satellite is far from land conform to Brown model. I would expect to see Brown, specular and mixed. The authors should provide some figures about this classification from which follows the choice of the appropriate retracker.

We agree that larger lakes do not have a constant surface but hydrodynamic effects from wind and waves have to be taken into account. The sentence “The derived water levels are assumed to be constant over lakes since in general, the water is in balance with gravity and hydrodynamics of lakes is small compared to open ocean conditions” is part of the manuscript since we compute only one height per time step which is assumed to represent the whole water surface. However, in our computations, we take different water levels into account by defining a grid over the surface and estimate heights for each grid point. Thus, different hydrodynamic conditions are considered in the processing.
For larger lakes, we are using the ocean products of the different altimeter mission instead of retracking the data by ourselfs since the data qualitiy is sufficient. . Therefore, retracking is applied only for smaller targets in case the ocean product does not have a good quality.
The image shows that most waveforms are brown-like. The figure shows an altimeter track of Envisat (Pass 0510, Cycle 040) crossing the Lake Superior. The water heights (top) and the corresponding waveforms (bottom) are plotted. Most waveforms over the lake have brown-like shapes. Near land water transitions the trailing edge changes to an exponential shape which can be seen in the last waveform near 48.625°E



Planned updates in revised version:

- We will further explain and discuss the statement/assumption of the “constant” lake surface

The possible presence of ice in the case of Lake Athabasca could be verified looking at backscatter observations.
We will do this. The backscatter coefficient will be implemented as additional outlier criteria for measurements affected by ice coverage in the processing strategy of DAHITI.

Planned updates in revised version:

- We will explain the usage of the backscatter coefficient as additional outlier criteria to reject measurements affected by ice coverage

- The ground tracks are generally not located near water gauge. This means that the two systems observe different water dynamics. This is especially true in rivers where there is some regulation of the flow. There is a need to better characterize the observational context that in the paper is not done. Auxiliary data sources (e.g., optical imagery, meteo data, etc.) could help in this exercise.

We agree that distances between gauging station and altimeter track can influence the river level agreement at different locations. This is already discussed in the manuscript in chapter “4.2 Validation data sets”. These discrepancies will of course map in the validation results. The interpretation of additional optical images might help in interpreting the influence of these effects but are beyond the scope of the paper.

- The bibliography is well cited. Some new manuscripts of interest are suggested, e.g., Surajit Ghosh, Praveen Thakur, Vaibhav Garg, Subrata Nandy, Shivprasad Aggarwal, Sudip Kumar Saha, Rashmi Sharma & S. Bhattacharyya (2015): SARAL/AltiKa Waveform Analysis to Monitor Inland Water Levels: A Case Study of Maithon Reservoir, Jharkhand, India, Marine Geodesy, DOI: 10.1080/01490419.2015.1039680; Jean-François, Crétaux, et al. "Global surveys of reservoirs and lakes from satellites and regional application to the Syrdarya river basin." Environmental Research Letters 10.1(2015): 015002.
Crétaux, et al. (2015) is more related to volume estimation and will not be added as additional reference.

Planned updates in revised version:

- Sharma & S. Bhattacharyya (2015) will be added to our paper

- The title does not clearly reflect the content of the paper. It seems that the only improvement is due to Kalman filter, while it was clear from the text that there are other two important processing steps (waveform retracking and outlier detection). Maybe the author can make an attempt to modify a bit the title to reflect the content of the paper as a whole.
After some investigation we can say that the current implementation of the Kalman Filter without any dynamic model is not the major source for the improvements but the applied outlier detection. Therefore, we decided to change the title of the paper.

Planned updates in revised version:

- The title will be updated, probably to “DAHITI – an innovative approach for estimating water level time series over inland water using multi-mission satellite altimetry”

- Figures 7, 8, 9 are difficult to interpret without zooming out. Author are aware and in fact one year is shown separately. The variability in Lake Superior is around 50-60 cm over the selected time period. It is higher in Lake Athabasca, with some evident inter-annuality (2 meters around 1996-1998). The variability in the river is very high (15m) and no inter-annuality is observed. Is this behaviour realistic, even though the ground truth confirms?
We think that this behavior is realistic. In the case of the Amazon river, an inter-annuality can also be detected (e.g. Between 2009 and 2010). However, it is quite small compared to the large variations of almost 15m and can hardly be seen in the figure.

Planned updates in revised version:

- The figures 7,8,9 will be improved to show the results more clearly

- The manuscript is written with understandable English and very few typos, however, the fluency of the text should be improved with the help from a native English.

Planned updates in revised version:

- We will try to further improve the use of English language.

In summary, I invite the authors to follow the above recommendations and expand the discussion of results, especially in the three case-studies, also where possible with the support of auxiliary information (bibliography, other data sources, etc.).

This study is certainly of interest to the inland water altimetry community with reference to the new processing method, but also to hydrology scientists that could exploit the water level time series in their research studies.

Therefore, the manuscript calls for some revision before to become publishable. I like having a look at the revised manuscript and authors' answers.

MINOR COMMENTS

We will not comment on each point here. All minor corrections will be addressed.

Pg. 2, row 2, "
...
for observing inland water levels of lakes and rivers" – I suggest to rephrase as water levels can be retrieved from reservoirs, wetlands and in general any inland water body, although the radar altimetry technique has been especially applied to rivers and lakes
Update from "However, since some years, this technology is also used for observing inland water levels of lakes and rivers." to "However, for some years, this technology is also used for observing inland water levels of lakes, rivers, and other inland water bodies."

Pg. 2, row 16, "height", I suggest to be homogeneous in the text in using "water height" or "water level"
All "water level heights" will be changed to "water levels"

Pg. 2, row 19, "important task", Who states that ? please refer to bibliography
The following bibliography will be added:

- E. Stakhiv, B. Stewart, Needs for Climate Information in Support of Decision-Making in the Water Sector, Procedia Environmental Sciences, Volume 1, 2010, Pages 102-119, ISSN 1878-0296, http://dx.doi.org/10.1016/j.proenv.2010.09.008.

Pg. 2, row 23-24, "the number of in-situ stations monitoring river discharge is globally declining", Is the number stable or decreasing for lakes too? If you provide the infor for rivers you need also to say something for lakes, otherwise if lakes are well monitored with ground truth there is no need to use altimetry.

Information about the status for in-situ data of lakes will be added

pg. 3, row 4, "water level heights" – it doesn't make sense to say at same time level and height. Again, please be uniform in the text using "water height" or "water level"
and hereinafter correct all occurrences
All "water level heights" will be changed to "water levels"

pg. 3, row 9, "then", change to "than"

pg.3, row 10, "its measurement geometry providing measurements", please rephrase, it is not a problem of geometry but rather than configuration and trade-off between revisiting and coverage

pg. 3, row 12, "not all water bodies can be captured" – I suggest to explain that the touching is by chance, however, big water bodies have more probabilities to be passed.

pg. 3, row 20, "still is", change to "is still"

pg. 3, row 22, “twofold”, change to “two-fold”. A third effect might be due to specular returns with non-brownian response of the target. This may happen frequently in small rivers.
We agree that there are specular waveforms over smaller rivers but the reason for these waveforms is land contamination.

pg. 4, row 2, “The affected waveforms are more peaky” – This statement could confuse the reader. The land can interfere in early or late gates depending on the position of track with respect to the water target (see Abileah, R., et al. "Coherent ranging with Envisat radar altimeter: A new perspective in analyzing altimeter data using Doppler processing." Remote Sensing of Environment 139 (2013): 271-276.).
Phrasing will be updated from “The affected waveforms are more peaky and reliable heights cannot be derived using ocean waveform retrackers” to “The affected waveforms do not have brown-like shapes and cannot be retracked by using ocean waveform retrackers.”

pg. 5, rows 9-10, “Time series of lakes and reservoirs” – add “water level” before “time”

pg. 5, rows 20-26, please rephrase the aim of this paper (that is a new approach to retrieve water heights) that has to be clear to the reader. Comparisons with approaches used in other hydrospace services have to be discussed later. Follow-up work has to be mentioned in the conclusions
In our opinion, the comparison with the other approach should remain in the introduction because it reflects the current state of the art.

Planned updates in revised version:

- We will rephrase to aim of the paper in more detail
- Follow-up work will be moved into the conclusion/outlook

pg. 6, row 8, “Section”, please be homogenous writing always “Section” or “Sect.”

pg. 6, row 10, “The paper finishes with a conclusion”, I don’t like this sentence, please rephrase

pg. 6, row 12-13, “For more than two decades, satellite altimetry has been providing data for various applications over ocean and inland waters”, please remove as already stated in the introduction

pg. 6, row 13-16, “The approach presented in this paper combines as many as possible altimeter tracks from different missions over an investigated water body in order to increase the temporal resolution of the final water level time series, to maximize the probability to cover smaller inland waters, and to increase the accuracy” – In this section the reader expects description of data used and then processing applied. The previous sentence is somewhat to be placed in the introduction (what, why).
We think that the information about our multi-mission approach and the resulting increase of the temporal resolution should be highlighted (repeated)also in the data section because it is strongly related to the data which is introduced afterward.

pg. 6, row 19, “body”, change to “bodies”

pg. 6, row 23-27 and pg. 7, rows 1.3, Info about revisiting time a cross track separation was already provided in the introduction. I recommend to avoid repeating things, suggesting removal from introduction, where are not key to understand (one can simply say that revisiting is of order of ten days and more, along track coverage is dense and there gaps between tracks)

pg. 7, row 15-17, can you show some examples of waveforms with reference to the areas of investigation ?

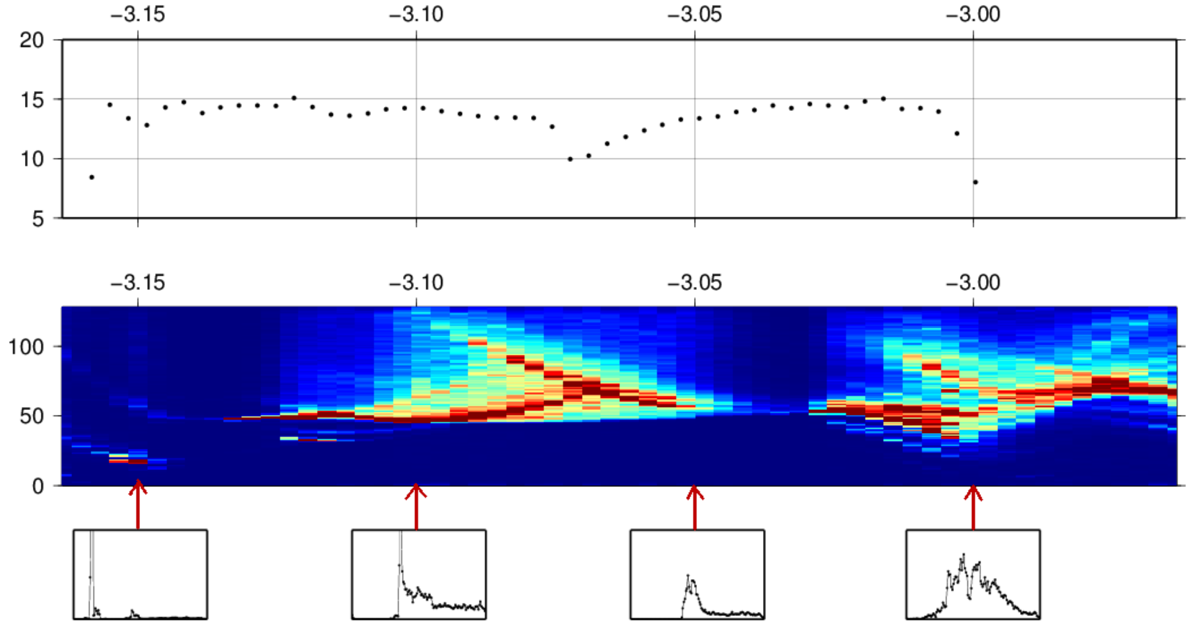


Figure 2. Example of a crossing satellite track from Envisat (Cycle 040, Passnr 0564) over the Amazon river with water heights (top) and waveforms (middle). Additionally four waveforms are shown in detail.

Planned updates in revised version:

- We don't want to add additional images about waveforms in the paper because this is well-known in the community. Instead, we will add a reference which shows different waveforms over inland water

pg. 8, row 6, "conventions", maybe you wanted to say "corrections"

pg. 9, rows 2-3, "The derived water levels are assumed to be constant over lakes since in general, the water is in balance with gravity and hydrodynamics of lakes". This can be a reasonable assumption for small water bodies. The wind set-up can pile-up water somewhere in lakes and the water level cannot be assumed constant. I think the point needs to be explained here and then discussed if supposed relevant in selected water targets (e.g., Lake Superior).
The impact of wind and currents on the lake surface will be discussed.

pg.9, row 24, "water level height", see previous note

pg. 10, row 16, "a floating box of 5 data points" – why defining a window of 5 points ? is there any reason ? why not using consecutive points to measure the noise ?
We improved our "error" estimation for each measurement. Now we, are using sliding boxes along the satellite track of +-3.5 km for large lakes, +-1.5 km small lakes/large rivers and +-0.5 km for small rivers. The definition of the floating box in km instead of number of points makes this results more comparable with other missions which are measuring in 10Hz, 20Hz, or 40Hz. Because the number of measurements can vary within a box but the used track length is constant.
Moreover, instead of calculating standard deviations within each box, we are estimating a median of the water heights. Then the median height is subtracted from the current water height. The absolute

value of the difference is then used as “error” of the measurement. These method lead to reliable errors than the former approach if more than the half of the used point are over water.

Planned updates in revised version:

- The new error estimation method will be explained

pg. 12, row 11, “Figure”, please be homogeneous in the text (Fig. or Figure)

pg. 12, row 5, Which land mask are you using ? how much is the resolution ?
The used land mask is provided within the Generic Mapping Tool (GMT). GMT uses the Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG). For cases that investigated inland bodies are not included in the dataset or have an unuseful shape, no mask is applied for the computation. I don’t know the resolution but the data is provided as shape file which will be rastered for our purpose.

pg. 13, row 15, missing “.”

pg. 14, row 20, remove “.”

pg. 17, row 12, “LEGOS, ESA-DMU or GRLM”, please use the exact acronyms of these hydrospace services and not the institutions who developed them.

Pg. 17, row 25, “The Great Lakes show seasonal variations of about 1m” – please provide reference

Pg. 18, row 24, “extend”, change to “extent”

pg. 19, row 17, “LEGOS, ESA-DMU, see previous note

pg. 20, row 3, “show”, change to “shows”

pg. 20, row 7, “preformed”, change to “performed”

pg. 20, row 10, “LEGOS, ESA-DMU, see previous note

pg. 20, row 24, “LEGOS, ESA-DMU, see previous note and correct all occurrences hereinafter

pg. 20, row 28, “For a detailed few, results”, please rephrase

pg. 21, row 9, “RMS differences show is”, please rephrase

pg. 23, rows 16-18, “Since only one DAHITI time series is computed per lake, these variations demonstrate uncertainties of the in-situ data sets” – I am not convinced about this statement. For big lakes we can have discrepancies due to metocean effects. This is a key point to be investigated.

I agree that the different RMS differences between the single DAHITI time series and different in-situ data can not only be explained by uncertainties of in-situ data. For large lakes effects such as wind can influence the consistency to used in-situ station.

Planned updates in revised version:

- We will explain that the discrepancies of RMS from different in-situ stations are not only due to the in-situ data but also to wind or currents which can lead to a rougher surface over larger lakes.

Pg. 24, row 16, "Certainly this is not only due to the altimeter time series but also caused by the accuracies of the in-situ data" - The authors here are a bit speculating as there is no proof that ground truth is not accurate.

All data which are measured in any way contain measurement errors. Also in-situ data contain measurement errors which are mostly unknown (since gauging stations do not provide any error estimates). Therefore, we can not suppose that in-situ are perfect.

The sentence will be updated from "Certainly this is not only due to the altimeter time series but also caused by the accuracies of the in-situ data." to "Certainly this is not only due to the altimeter time series but also caused by the accuracies of the in-situ data which also contain measurement errors."