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Hydrology and Earth System Sciences
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Discussions



# *Interactive comment on* "Kalman filter approach for estimating water level time series over inland water using multi-mission satellite altimetry" *by* C. Schwatke et al.

**Anonymous Referee #1**

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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



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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.

- 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.

- The possible presence of ice in the case of Lake Athabasca could be verified looking



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at backscatter observations.

- 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.

- 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.

- 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.

- Figures 7, 8, 9 are difficult to interpret without zooming out. Author are aware and in fact one year is showed 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 (15 m) an no interannuality is observed. Is this behaviour realistic, even though the ground truth confirms?

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



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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

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

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

Pg. 2, row 19, "important task", Who states that ? please refer to bibliography

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.

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

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

pg.3, row 10, "its measurement geometry providing measurements", please rephrase,



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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.

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.).

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 late. Follow-up work has to be mentioned in the conclusions

pg. 6, row 8, “Section”, pleas 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 pos-



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sible altimeter tracks from di erent 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).

pg. 6, row 19, "body", change to "bodies"

pg. 6, row 23-27 and pg. 7, rows 1.3, Info about revisiting time an 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 ?

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).

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 ?

pg. 8, 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 ?



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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 hydrspace 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.

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

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 4813, 2015.