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DAHITI: Improving altimetry-derived water level time series of inland waters by a combination with optical remote sensing images from Landsat and Sentinel-2

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1. Introduction

For many years, satellite altimetry is providing valuable information on water level variations of inland water bodies.

In this contribution, we demonstrate the potential to improve the DAHITI water level time series by combining multi-mission satellite altimetry with land-water masks derived from Landsat and Sentinel-2. Hereby, surface area time series derived from optical images are used to increase the length and temporal resolution of the water level time series by using the derived hypsometry (height-area relationship). Moreover, a combination of both time series allows for computing water storage changes.

For validation, the resulting water level time series are compared with in-situ data as well as with the original altimetry time series in order to demonstrate the advantage of using time-variable land-water masks.

2. Data

In this study, water levels and surface areas provided by DAHITI are used. DAHITI has been operated by the Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM) since 2013. All data sets are freely available via ***http://dahiti.dgfi.tum.de*** for registered users. In general, DAHITI is targeted at all users who require water levels and surface areas of inland waters for various hydrological applications.

Water Level Time Series From Satellite Altimetry

Currently, the database contains more than **1600** water level time series of inland waters derived from satellite altimetry. The DAHITI approach of estimating water level time series is based on intensive data screening, an extended outlier rejection, and a Kalman Filtering step. More details can be found in *Schwatke et al, 2015*. All available altimeter missions (e.g. Topex/Poseidon, Jason-1/-2/-3, Envisat, Saral, Sentinel-3A etc.) over the inland water body are combined in the DAHITI approach. This allows us to estimate consistent water level time series for lakes and rivers for more than 25 years.

Surface Area Time Series From Optical Imagery

Today, more than **50** surface area time series of lakes and reservoirs are available on DAHITI. The approach of estimating surface area time series is based on the extraction of land-water masks by combining five water indexes and using an automated threshold computation. All remaining data gaps caused by voids, clouds, cloud shadows, or snow are then filled by using a long-term water probability mask. More details can be found in *Schwatke et al, 2019*.

3. Study Areas

In this study, four selected inland waters (Ray Roberts, Benbrook, Toledo Bend, Sam Rayburn) located in the United States are investigated in detail.

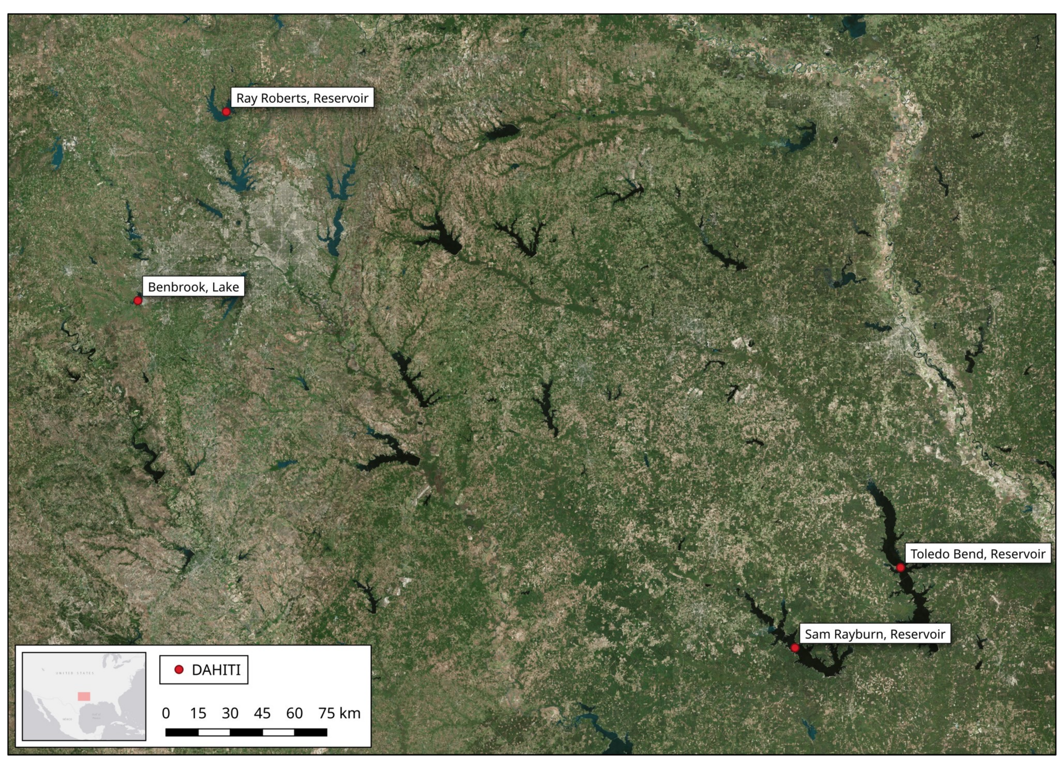


Figure 1: Map of study areas

4. Methodology

In order to densify the water level time series from satellite altimetry, we use the surface area time series and the knowledge of the monotone increasing dependency of both data sets caused by the topography. We demonstrate our approach in detail for the Lake Ray Roberts in the United States.

Characteristics of Lake Ray Roberts:

- Surface Area: **28.15 - 126.17** km²
- Water Level: **180.094 - 196.415** m

The validation of the DAHITI water level time series with in-situ data using **329** points leads to a RMSE of **0.26** m and a correlation coefficient of **0.95**.

In order to estimate a hypsometry, we use surface areas (DAHITI) and water levels (DAHITI, in-situ). The hypsometry is computed by using Support Vector Regression with Radial Base Functions (SVR) shown in Figure 2.

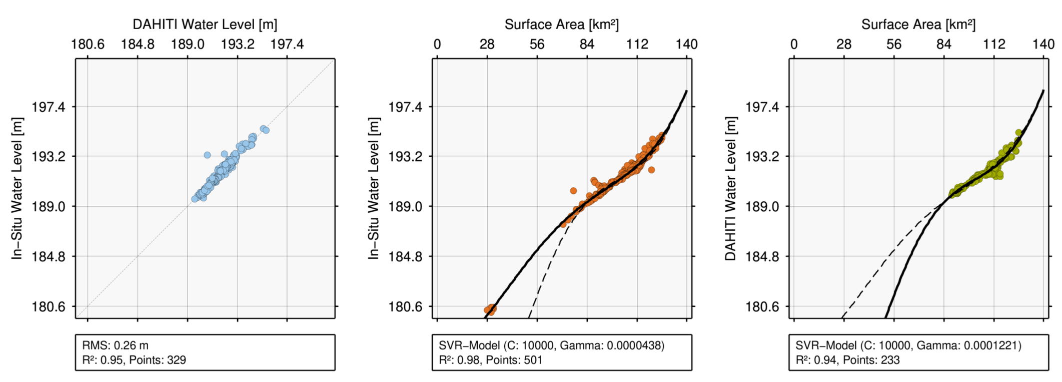


Figure 2: Validation of water level time series from DAHITI using in-situ data (left). Hypsometry using surface areas (DAHITI) and water levels (in-situ) (middle). Hypsometry using surface areas (DAHITI) and water levels (DAHITI) (right). The computed hypsometry is shown in black. The hypsometry of the other water level data set is highlighted as dashed line for comparison.

Comparisons of both hypsometry models show a very good agreement for water levels above 188 m. Because of additional in-situ water levels of about 180 m, the differences of the estimated hypsometry increase significantly for water levels less than 188 m.

One can conclude that the hypsometry is very accurate in the range between minimum and maximum water levels, named confidence range.

The calculated hypsometry using surface areas and water levels from DAHITI is used to derive additional water levels from surface areas.

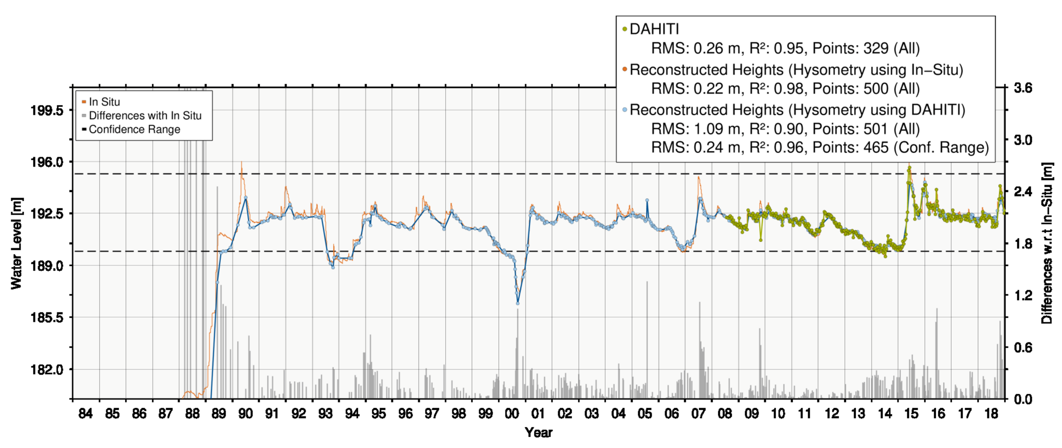


Figure 3: Water levels from DAHITI (green) and reconstructed water levels using hypsometry (blue) are shown. For validation, the in-situ data is highlighted in orange. The error bars (gray) show the differences of water levels derived from surface areas and in-situ data.

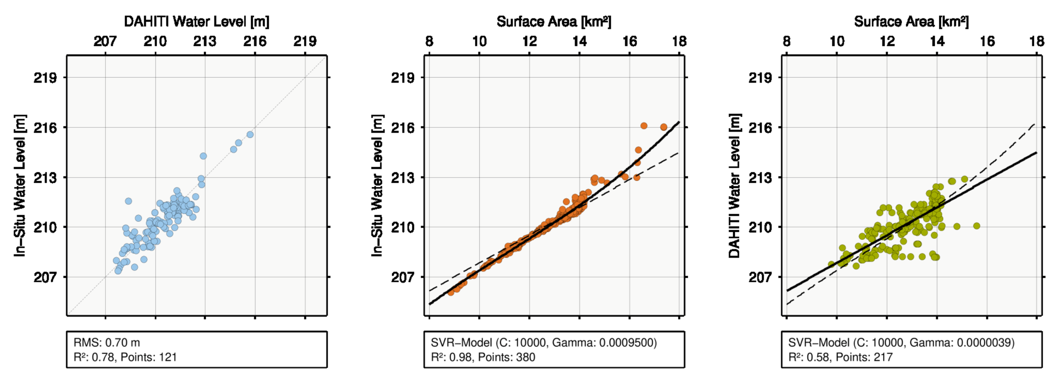
Figure 3 shows the water level time series from DAHITI (green) and the reconstructed water levels using hypsometry (blue). Validation with in-situ data within the confidence range (dashed lines) shows a RMSE of **0.26** m for DAHITI water levels and a RMSE of **0.24** m for reconstructed heights using surface areas.

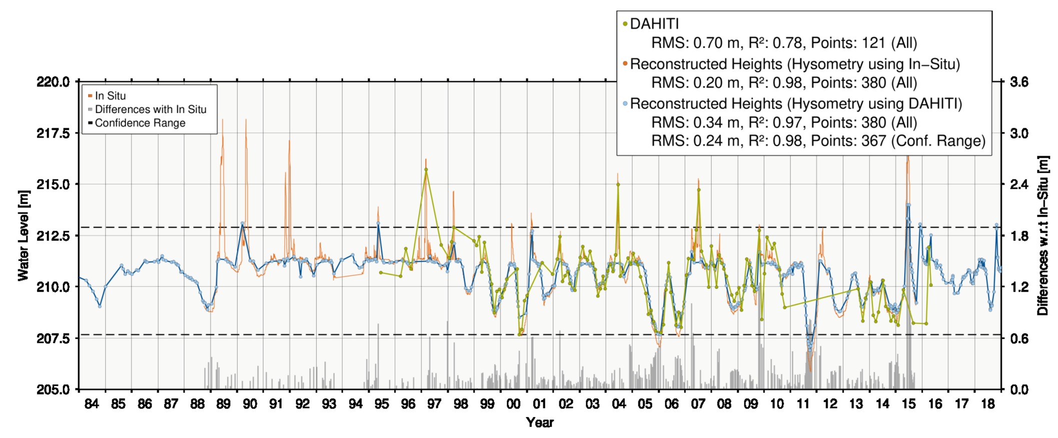
This results shows that surface area data has a high potential to extend water level time series from satellite altimetry significantly as the quality is similar as heights from satellite altimetry.

Especially, surface areas which are available since 1984 can help to provide remotely-sensed water levels in the 1980s and 1990s, when satellite altimetry was not yet available or the quality over inland waters was not as good as nowadays.

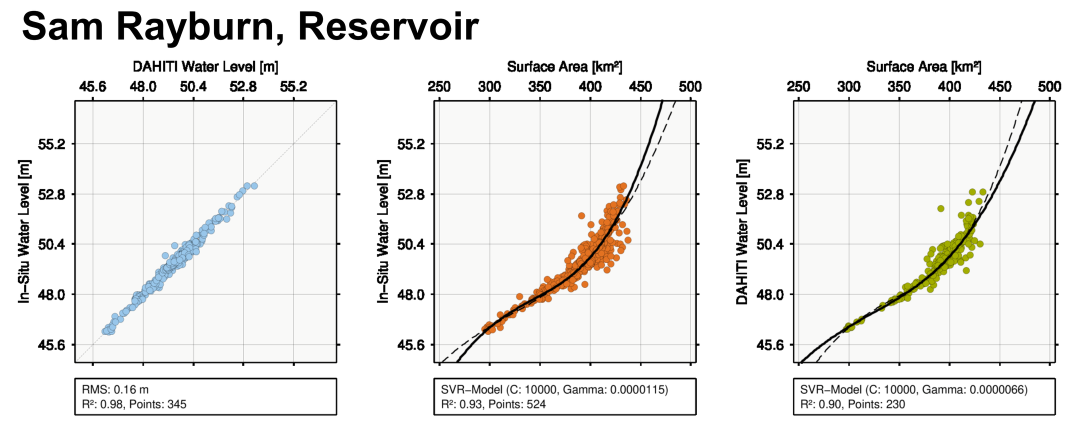
5. Results

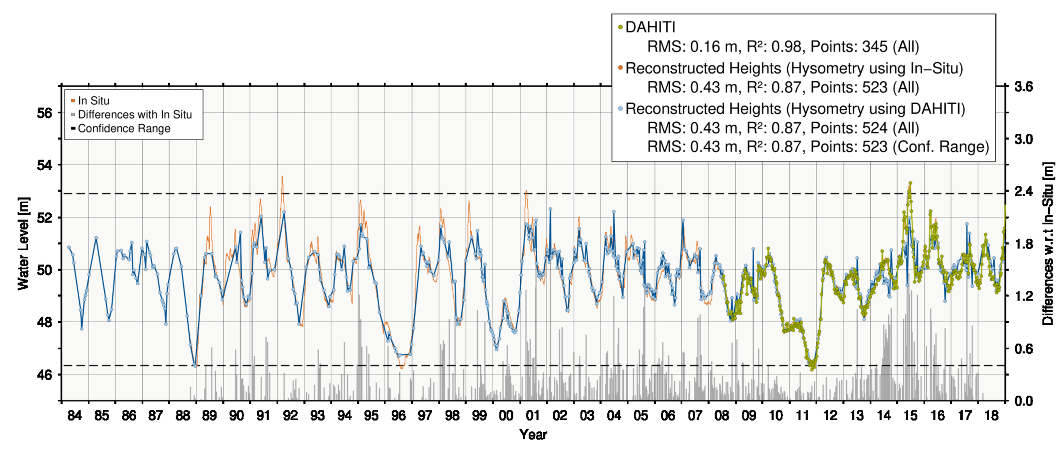
Benbrook, Lake



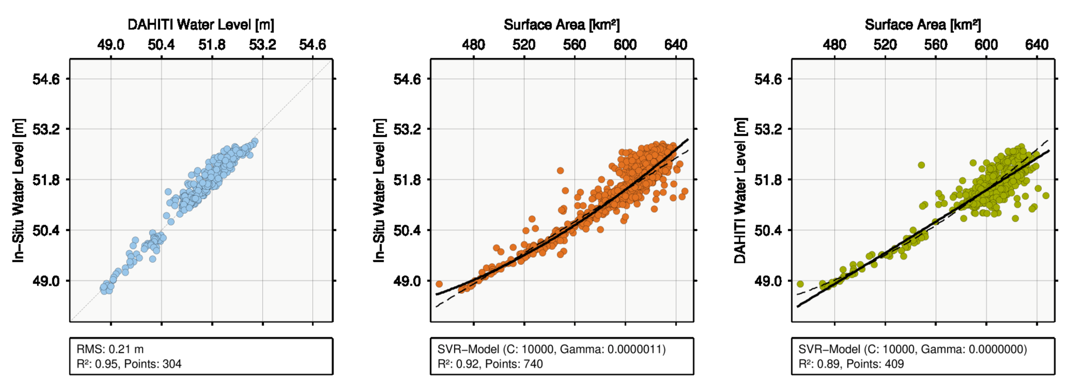


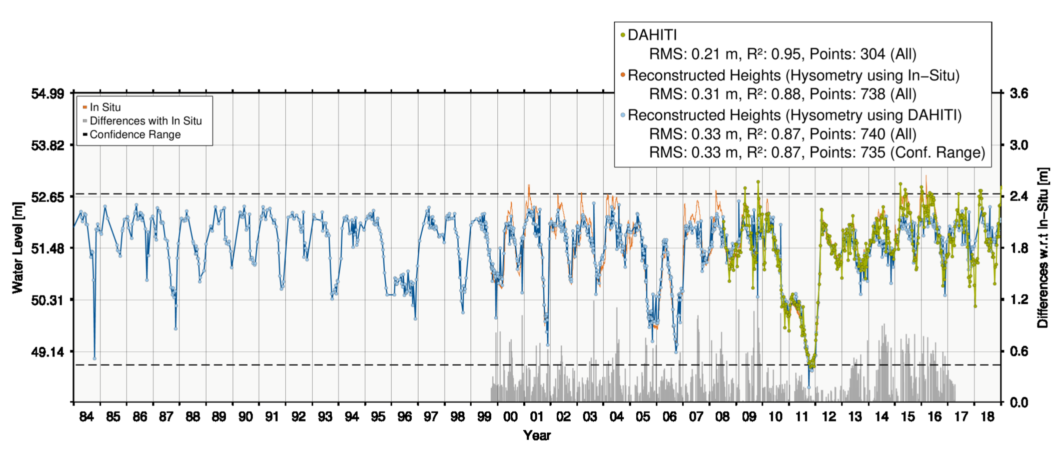
Sam Rayburn, Reservoir





Toledo Bend, Reservoir





5. Conclusion

- Support Vector Regression is used to compute accurate hypsometry models using surface areas from optical images and water levels from satellite altimetry.
- Surface area time series have the capability to extend water level time series from satellite altimetry, especially in the 1980s and 1990s.
- The quality of water levels derived from surface areas is similar or better as water levels from satellite altimetry.

References

- *Schwatke C., Dettmering D., Bosch W., Seitz F.:* **DAHITI - An Innovative Approach for Estimating Water Level Time Series over Inland Waters using Multi-Mission Satellite Altimetry**. Hydrol. Earth Syst. Sci., 19, 4345 4364, doi:10.5194/hess-19-4345-2015, 2015
- *Schwatke C., Scherer D., Dettmering D.:* **Automated Extraction of Consistent Time-Variable Water Surfaces of Lakes and Reservoirs based on Landsat and Sentinel-2**. Remote Sensing, 11(9), 1010, doi:10.3390/rs11091010, 2019