Combination of Envisat, CryoSat-2 and SARAL/AltiKa measurements for estimating water level variations of lakes

Franziska Göttl, Christian Schwatke and Denise Dettmering
Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), München, Germany
franziska.goettl@tum.de

Motivation

The estimation of lake water level variations with satellite altimetry is a challenging task because the majority of altimeter waveforms of smaller lakes are contaminated by land. The main goal of this study is the determination of improved long-term water level time series of lakes due to combination of Envisat, CryoSat-2 and SARAL/AltiKa altimeter measurements in an optimal way. While Envisat ant SARAL/AltiKa carry classical pulse-limited radar altimeters on board, CryoSat-2 carries a Delay-Doppler/SAR altimeter on board that allows to exploit the full Doppler bandwidth. Depending on the observation technique and surface conditions the altimeter waveforms vary from specular over land to multi peaks at the land/water transition and brown-like in the center of the lake. In a first step, we have developed a new processing strategy for CryoSat-2 SAR data over lakes based on waveform classification, retracking and outlier rejection. The results are validated with water level time series derived from classical altimeter missions and in-situ gauging data.

Processing strategy for CryoSat-2 SAR data over lakes

1. Waveform classification:

Three classes of CryoSat-2 SAR multi-looked waveforms: water, land/water transition and land can be identified by using the three parameters of the Offset Center of Gravity (OCOG) retracker: amplitude (A) and width (W) of the waveform as well as the gate position of the waveform center of gravity (COG), see Figure 1.

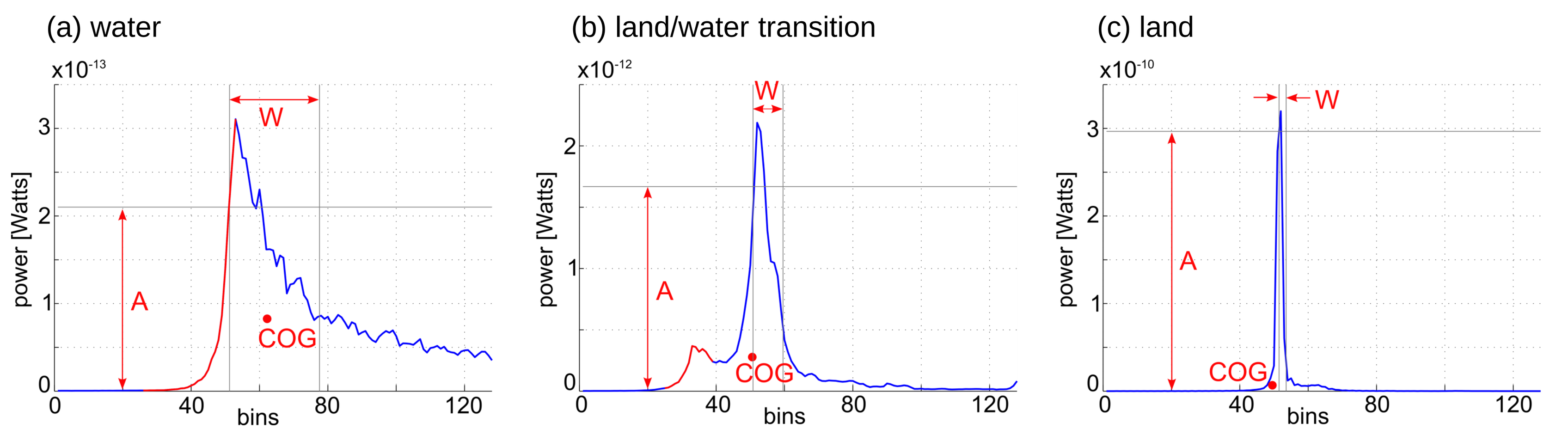


Fig. 1: OCOG parameters for the waveforms of the three classes (a) water, (b) land/water transition and (c) land. The sub-waveforms which are identified within the retracker procedure are marked in red.

The cluster centers of the three classes are determined by applying the k-means algorithm to the three OCOG parameters of the CryoSat-2 SAR waveforms in the training area of the lake Tonle Sap (see Fig. 2). While the cluster for water is well identified, the cluster for the land/water transition contains data points which should be referred to the cluster land. This problem can be solved by adopting the condition that waveforms at the land/water transition should contain one single peak before the main peak. In future we want to consider this feature within the clustering.

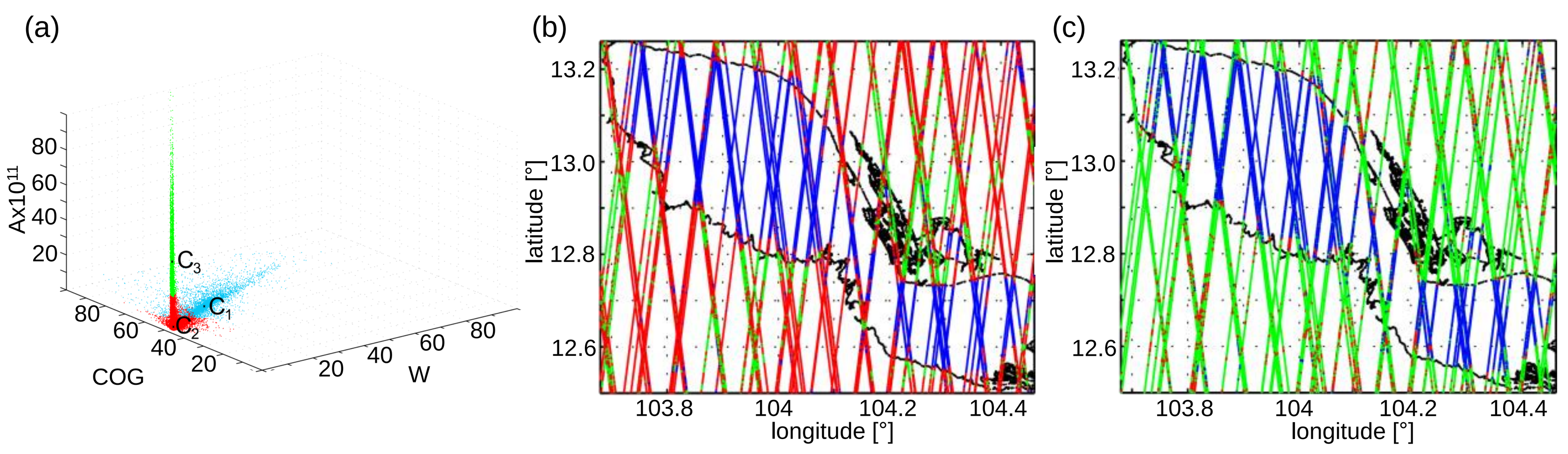


Fig. 2: Classification results for the training area Tonle Sap. a) Data points of each cluster: water (blue), land/water transition (red) and land (green). The cluster centers are marked in black. (b) CryoSat-2 tracks classified as water (blue), land/water transition (red) and land (green) by the k-means algorithm. (c) Revised classification results.

We have tested if the cluster centers of the training area can be used to classify the waveforms of other lakes such as Vänern, Vättern, Okeechobee, Towuti, and Lough Neagh. We found that this classification strategy can be used for all other lakes, too.

2. Waveform retracking algorithms:

Over water, the leading sub-waveform which has to be retracked is located around the maximum peak of the waveform (see Fig. 1). Therefore in our implementation of the Improved Threshold Retracker (ITR; Hwang et al., 2006) the sub-waveform around the maximum peak is chosen. We call it the Maximum Peak Threshold Retracker (MPTR).

Waveforms near the land/water transition are contaminated by land signals and therefore they exhibit a smaller peak before the main peak (see Fig. 1). Here the leading sub-waveform is located around the peak before the maximum peak. Therefore these waveforms are retracked with the Narrow Primary Peak Threshold Retracker (NPPTR; Jain et al., 2015).

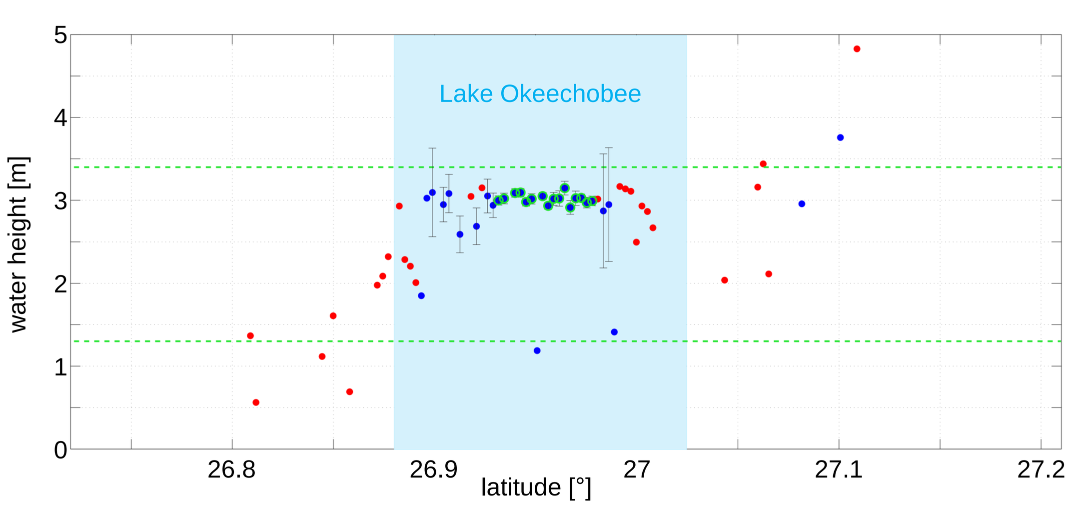
To avoid offsets between the two different retrackers MPTR and NPPTR the same threshold level of 50% is used for both retrackers (see Fig. 3).

3. Outlier rejection:

Inaccurate water levels must be rejected before the determination of the median of the water heights of each track. Therefore the following outlier criteria are applied:

- latitude and longitude thresholds,
- water height thresholds,
- moving 5-point standard deviation [i-2 … i+2] smaller than 10 cm.

Fig. 3: Water heights determined with the MPTR (blue) and NPPTR (red) retrackers for a track crossing the lake Okeechobee. The water height thresholds are mark by green dashed lines and the moving standard deviations of the water heights are displayed by the gray errorbars. Valid results after the outlier rejection are marked in green.

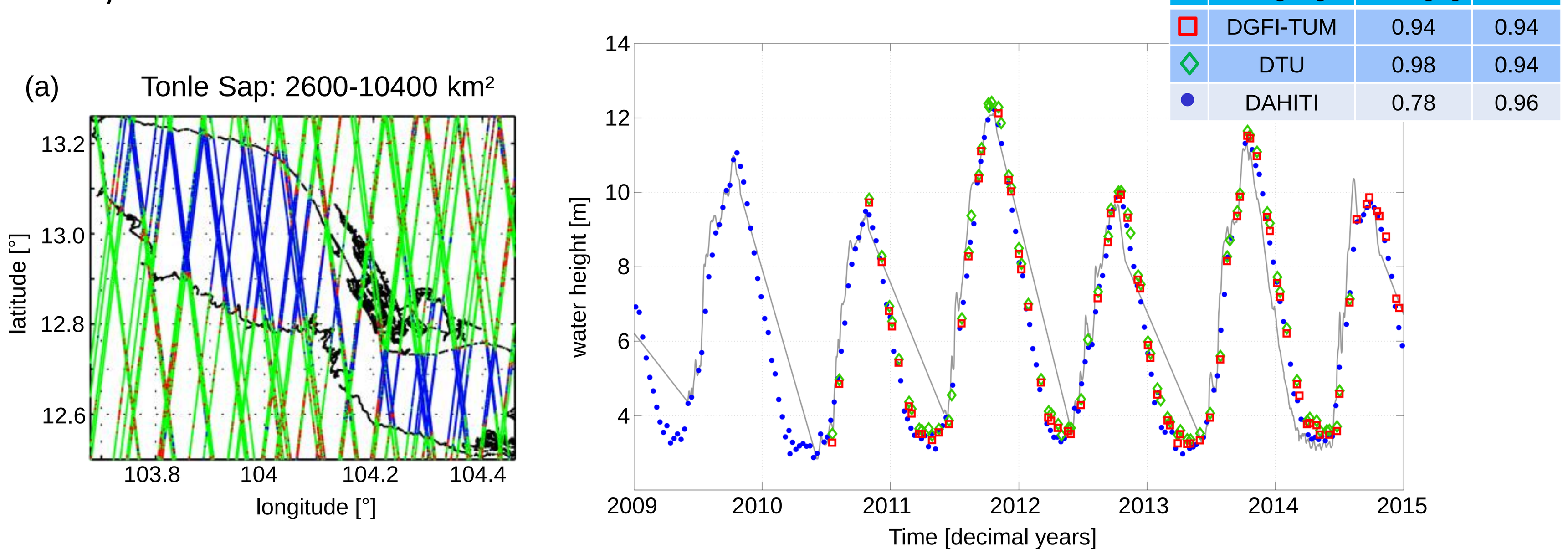


Data sources for the validation

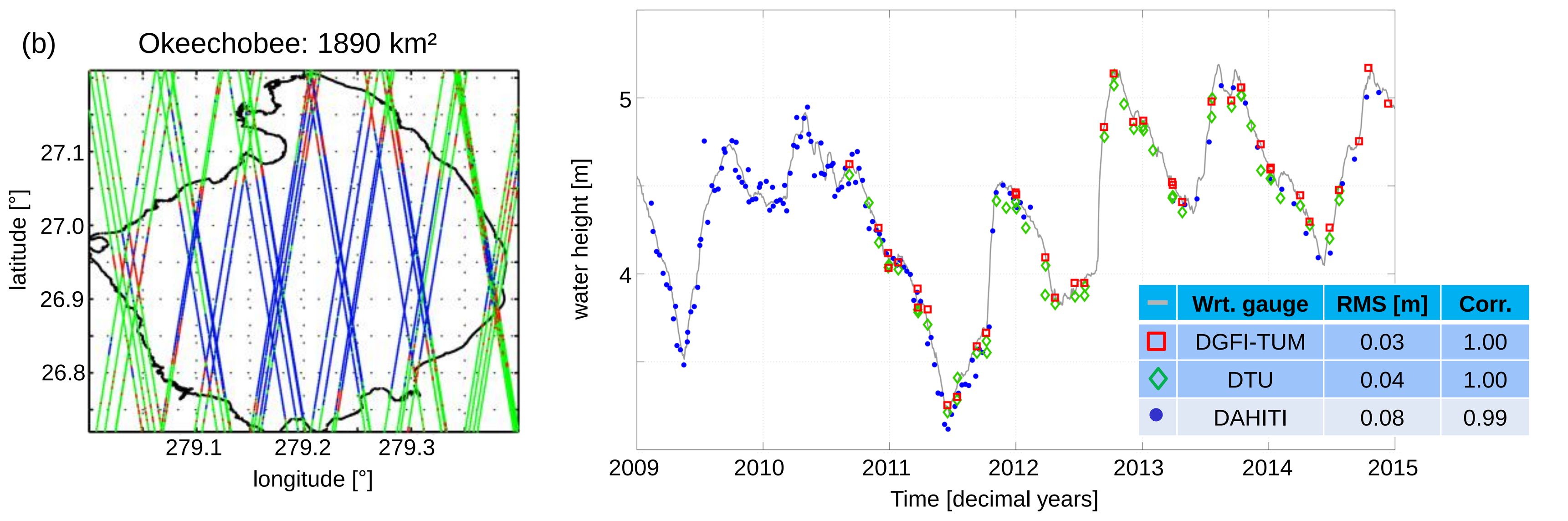
- Modeled water level time series derived from CryoSat-2 SAR observations by the Technical University of Denmark (DTU) are provided via the open web service AltWater (Altimetry for inland Water, http://www.altwater.dtu.space/index.html).
- Multi-mission water level time series derived from classical altimeter missions such as Envisat, Jason-2 and SARAL/AltiKa are provided by the open web service DAHITI (Database for Hydrological Time Series over Inland Waters, http://dahiti.dgfi.tum.de/en/), which is run by the Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM).
- In-situ gauging data are provided by the Mekong River Commission (http://ffw.mrcmekong.org/), the National Water Information System (http://waterdata.usgs.gov/nwis/sw) and the Rivers Agency, Department of Agriculture and Rural Development (https://www.dardni.gov.uk/rivers-agency).

Results

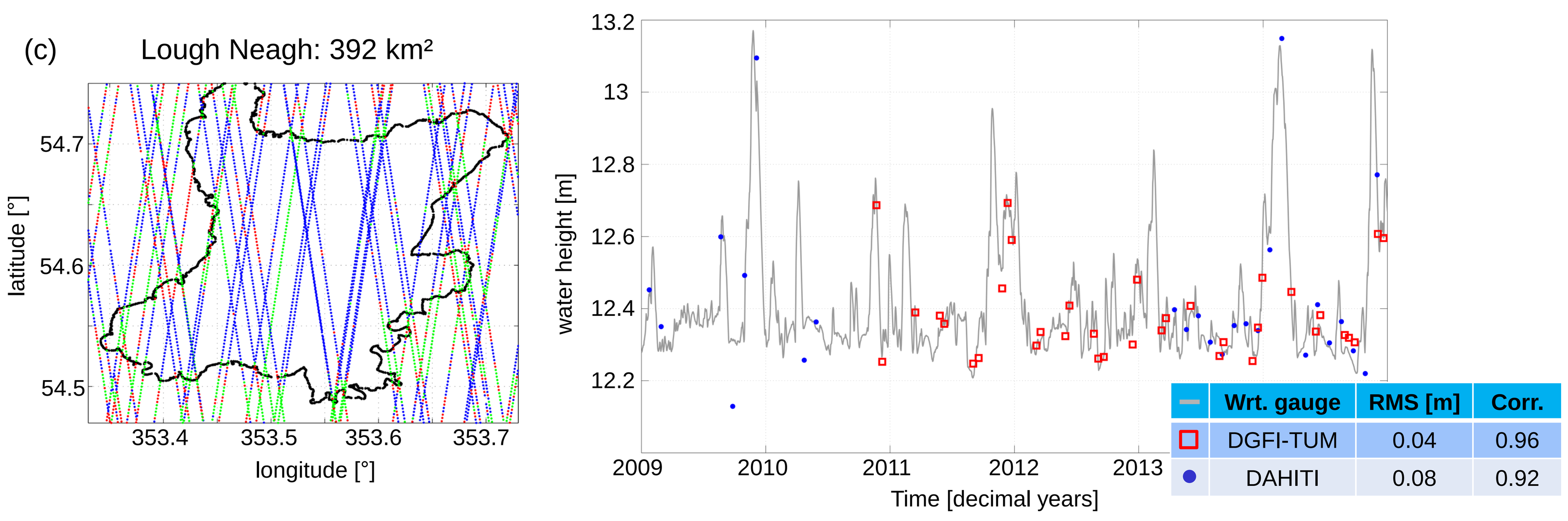
Comparison of lake water level time series derived from CryoSat-2 SAR data (DGFI-TUM) with external data sets.



Wrt. gauge	RMS [m]	Corr.
DGFI-TUM	0.94	0.94
DTU	0.98	0.94
DAHITI	0.78	0.96



Wrt. gauge	RMS [m]	Corr.
DGFI-TUM	0.03	1.00
DTU	0.04	1.00
DAHITI	0.08	0.99



Wrt. gauge	RMS [m]	Corr.
DGFI-TUM	0.04	0.96
DAHITI	0.08	0.92

Conclusions / Outlook

- The CryoSat-2 SAR mode waveform classification based on the three OCOG parameters is successfully applied over smaller and larger lakes.
- DGFI-TUM water level time series based on CryoSat-2 SAR data show similar quality as the modeled CryoSat-2 water level time series of DTU.
- Water heights especially of smaller lakes can be derived from CryoSat-2 SAR multi-looked waveforms with higher precision than from classical altimeter waveforms.
- In the next step, the CryoSat-2 SAR data processing shall be integrated in DAHITI in order to determine improved long-term water level time series.
- In future, this classification algorithm and class-dependent processing strategy shall be adopted to the new CryoSat-2 Baseline C and Sentinel-3 products.

References:

Göttl F., Schwatke C., Dettmering D. & Müller F.: ***Cryosat-2 SAR mode retracking strategy for lakes: Waveform classification, sub-waveform retracking, outlier rejection***. Remote Sens., in preparation.

Hwang C., Gua J., Deng X., Hsu H.Y. & Liu Y. (2006): ***Coastal gravity anomalies from retracked Geosat/GM altimetry: improvement, limitation and the role of airborne gravity data***. J. Geodesy, 80, 204-216.

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