Waveform retracking for improving altimetry results over African lakes

B. Uebbing[1], E. Forootan[1], J. Kusche[1]

1) Institute of Geodesy and Geoinformation, University of Bonn

igg

universitätbonn

Abstract

Estimating accurate water heights from complex radar return waveforms, as observed by satellite altimeters over inland water bodies, requires the application of post processing algorithms known as retrackers. Here, we introduce a new retracking algorithm, ITG-Retracker (ITGR), which is applied to Topex/Poseidon (T/P), Jason-1 and -2 waveforms over African lakes. The ITGR algorithm first analyzes the pattern of returned waveforms to identify retrackable waveforms. To provide range corrections, it then applies a maximum-likelihood estimator to a flexible waveform model, which is constructed based on the number of identified peaks and their positions in the waveform. ITGR also adopts an adjustable peak model to deal with both symmetric and asymmetric shaped peaks (Halimi et al., 2013). Our approach differs from Halimi et al. (2013) in that we combine the advantages of sub-waveforms, pre-analysis and the ability to handle different additional peaks. We validated our retracked lake level heights (LLHs) over Lake Volta, Lake Victoria and Lake Naivasha by comparing them to tide-gauge measurements and LLHs derived from various retracking algorithms, as well as to water heights from the Global Reservoir and Lake Monitoring database.

Study Areas

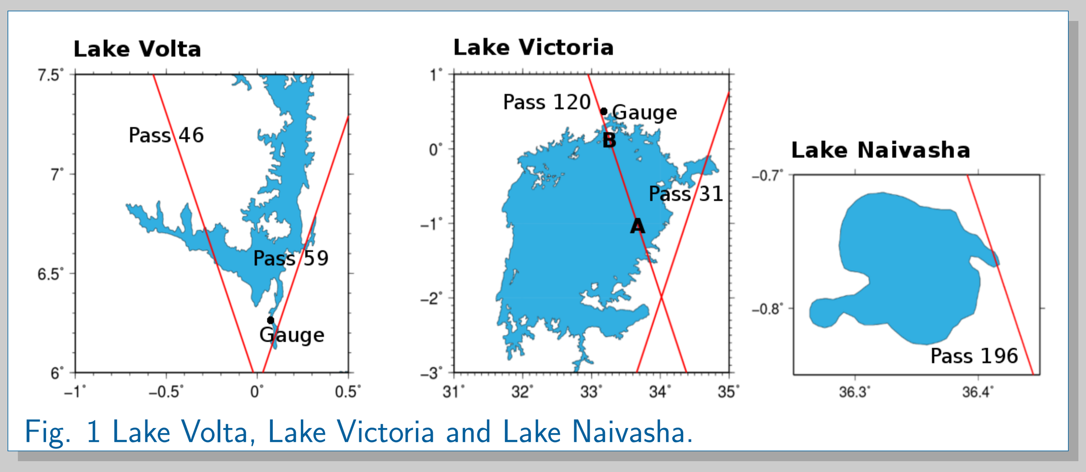

Fig. 1 Lake Volta, Lake Victoria and Lake Naivasha.

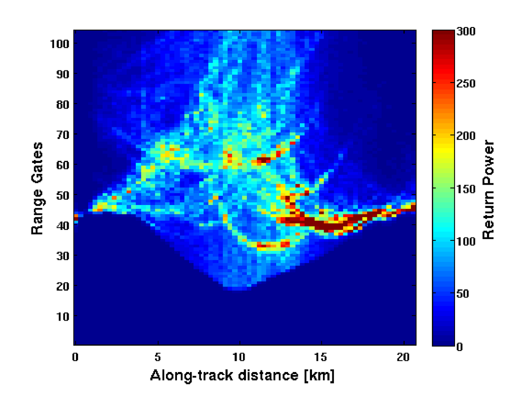

Fig. 2 Jason-2's 20 Hz waveforms of Cycle 47, Pass 46 over Lake Volta. The parabolic shape results from the inability of the on-board tracker to place the nominal tracking gate on the leading edge.

- Lake Volta, Ghana: Pass 46, track coverage of about 16 km.
- Lake Victoria, Uganda/ Kenya/ Tanzania: Pass 120, track coverage of about 200 km.
- Lake Naivasha, Kenya: Pass 196, track coverage of about 5 km.

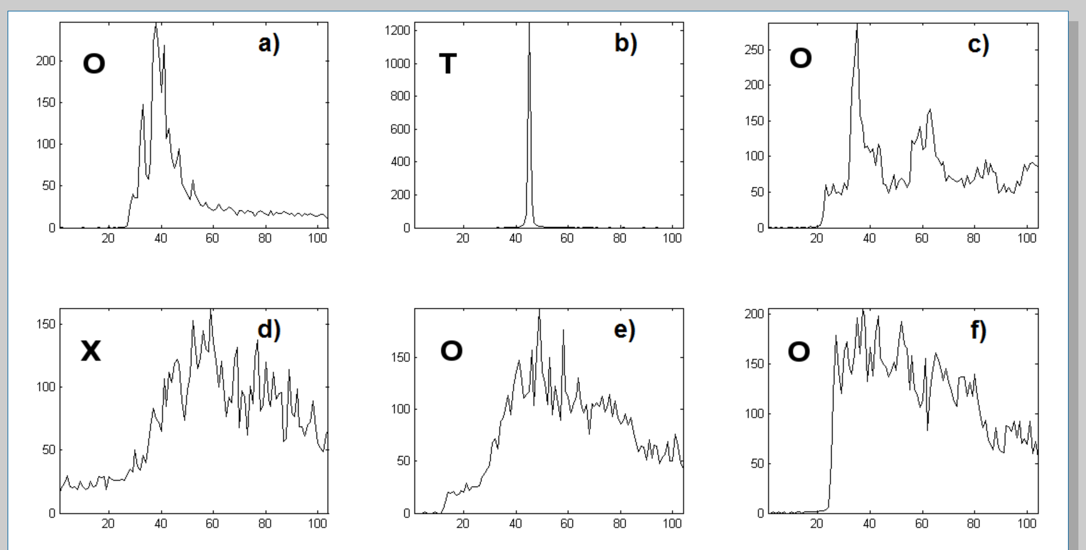

Fig. 3 Example waveforms over Lake Volta: a) peak close to the leading edge, b) high specular peak, c) multiple peaks, d) no leading edge and high thermal noise, e) small leading edge, dominated by large peak on the trailing edge, f) noisy, fast decaying waveform. The waveform examples are labeled, whether they are accepted by the ITGR algorithm (**O**), marked for threshold retracking (**T**) or discarded (**X**).

Retracking Results over Lake Volta

Results from retracking data from Pass 46 of Topex/Poseidon (Cycles 1-342, 1992-2001), Jason-1 (Cycles 1-256, 2002-2008) and Jason-2 (Cycles 1-91, 2008-2010) over Lake Volta (see Fig. 1, left).

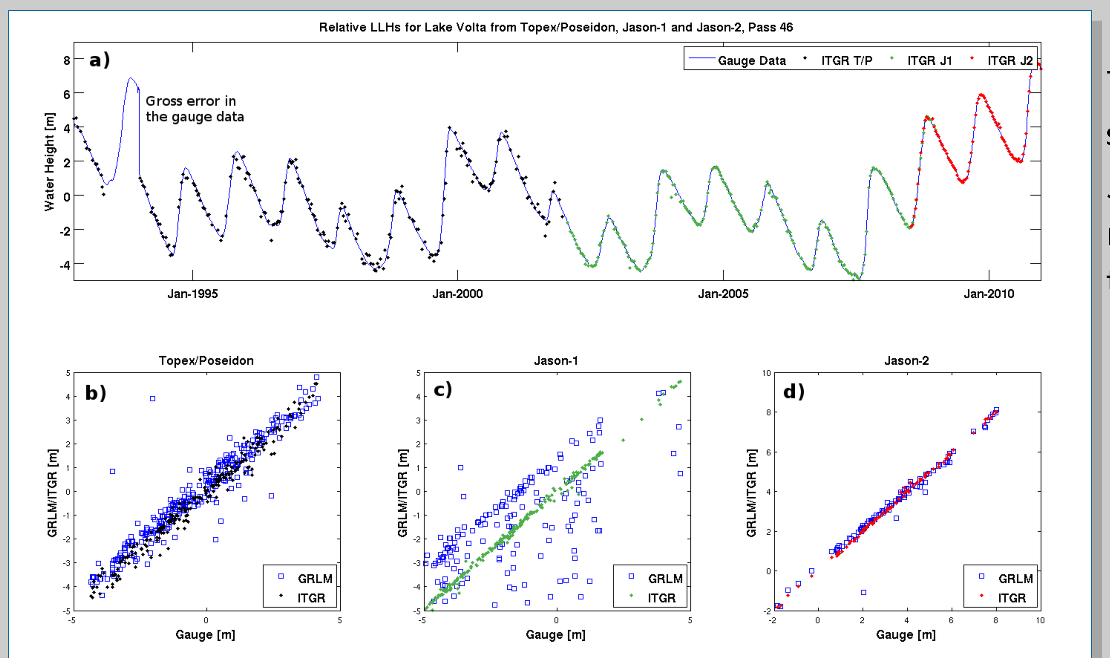

Fig. 5 (a) relative LLHs from retracking T/P (black), Jason-1 (green) and Jason-2 (red) altimetry data over Lake Volta. The bottom graphs show the gauge water heights plotted against water heights derived from GRLM, as well as ITGR LLHs for T/P (b), Jason-1 (c) and Jason-2 (d).

Table 1: Comparison of different retrackers. Number of cycles without sensor data $N_O^a = 39$ for T/P, $N_O^a = 5$ for Jason-1 and $N_O^a = 0$ for Jason-2. N_O^b is the number of cycles, where no meaningful retracking results were possible and N_O^c is the number of LLHs which deviate more than $0.5\,\mathrm{m}$ ($1\,\mathrm{m}$ for T/P) from the gauge data.

	Topex/ Poseidon			**Jason-1**			**Jason-2**		
Retracker	σ_d [m]	N_O^b	N_O^c	σ_d [m]	N_O^b	N_O^c	σ_d [m]	N_O^b	N_O^c
Brown Model	0.40	86	65	0.26	33	77	0.21	2	24
β-5 Model	0.45	30	93	0.26	22	74	0.22	0	23
50%-threshold	0.47	22	90	0.19	22	71	0.15	0	24
30%-threshold	0.43	23	67	0.18	25	36	0.17	1	6
20%-threshold	0.39	24	53	0.18	25	23	0.14	1	3
ITR	0.41	22	62	0.11	22	16	0.08	0	3
SWO3	0.39	23	48	0.12	25	14	0.10	1	1
ITG-Retracker	0.33	24	42	0.10	28	6	0.08	2	0
GRLM	0.38	(42)	31	0.44	(82)	66	0.18	(2)	3

Retracking Results over Lake Victoria

Results for area A is located over the open water with little to no land influence (Fig. 1), while area B is located at the northern end of the lake in a small bay with significant land influence on the waveforms.

Table 2: Comparison of different retrackers. Number of cycles without sensor data $N_O^a = 33$ for T/P and $N_O^a = 9$ for Jason-1. N_O^b is the number of cycles, where no meaningful retracking results were possible and N_O^c is the number of LLHs which deviate more than $0.5\,\mathrm{m}$ ($1\,\mathrm{m}$ for T/P) from the gauge data.

	Area A						**Area B**					
	Topex/ Poseidon			**Jason-1**			**Topex/ Poseidon**			**Jason-1**		
Retracker	σ_d [m]	N_O^b	N_O^c	σ_d [m]	N_O^b	N_O^c	σ_d [m]	N_O^b	N_O^c	σ_d [m]	N_O^b	N_O^c
Brown Model	0.1	6	0	0.05	1	0	0.40	137	5	0.20	54	50
β-5 Model	0.09	5	0	0.06	1	0	0.38	28	166	0.17	41	44
50%-threshold	0.05	1	0	0.03	1	0	0.48	25	189	0.13	37	65
30%-threshold	0.05	2	0	0.03	1	0	0.46	27	132	0.12	45	47
20%-threshold	0.06	5	0	0.03	1	0	0.49	24	124	0.13	51	21
ITR	0.05	1	0	0.03	1	0	0.40	83	4	0.11	37	28
SWO3	0.06	2	0	0.03	1	0	0.36	58	3	0.10	51	13
ITG-Retracker	0.05	2	0	0.03	1	0	0.40	44	4	0.08	60	8
GRLM	0.05	(7)	0	0.02	(8)	0	-	-	-	-	-	-

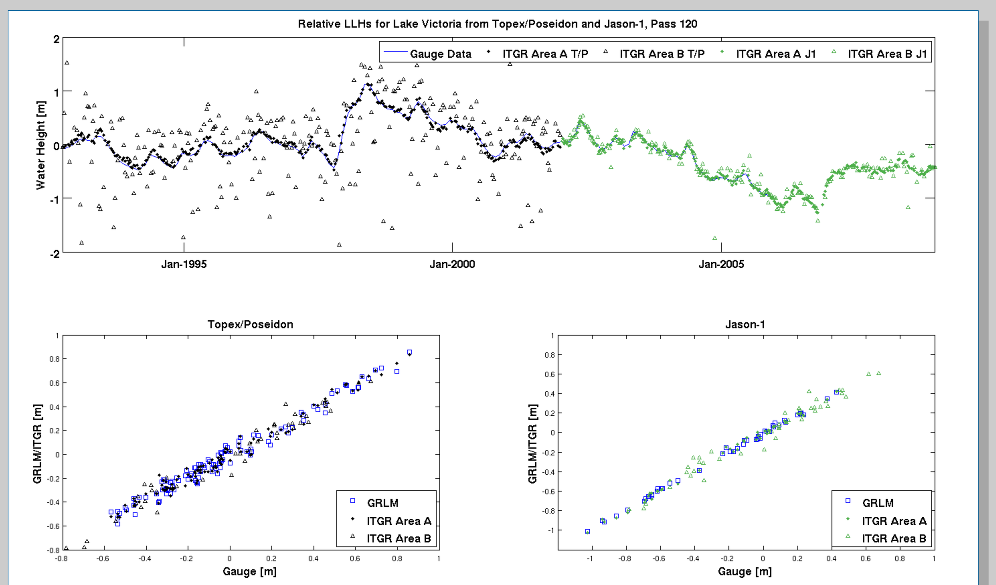

Fig. 6 (a): relative LLHs from retracking T/P (black) and Jason-1 (green) altimetry data over Lake Victoria. The bottom graphs show the gauge water heights plotted against water heights derived from GRLM, as well as ITGR LLHs for T/P (b) and Jason-1 (c).

ITGR-Methodology I

- Step-1: Pattern analysis to distinguish waveforms that include an ocean-like leading edge from specular peak waveforms and to discard highly noisy waveforms.
- Step-2: Detect sub-waveforms (Hwang et al., 2006) and derive initial parameters for the ocean-like waveform $S(t)$ from the 1st sub-waveform.
- Step-3: Reduce $S(t)$ from the total waveform to compute the residual waveform. Then, apply a window with a predefined size, which is centered on the initial leading edge from step-2. Find the peak observations, which exceed 30% of the initially found amplitude and model the most significant peak. Label unmodeled peaks for down-weighting.

$$W(t) = S(t) + \begin{cases} 0 & \text{for no modeled peak} \\ P_s(t) & \text{for a symmetric peak} \\ P_a(t) & \text{for an asymmetric peak} \end{cases} \quad (1)$$

- Step-4: Use the initial estimates and weights from step-3 in a flexible waveform model (Eq. 1) which includes $S(t)$ and possibly one (a)symmetric peak. Estimate the final parameters, such as the range correction, using LS or MLE for Gaussian or Gamma distributed noise, respectively.

ITGR-Methodology II

- Combines advantages of sub-waveforms (Hwang et al., 2006) and waveform peak estimation (Halimi et al., 2013).

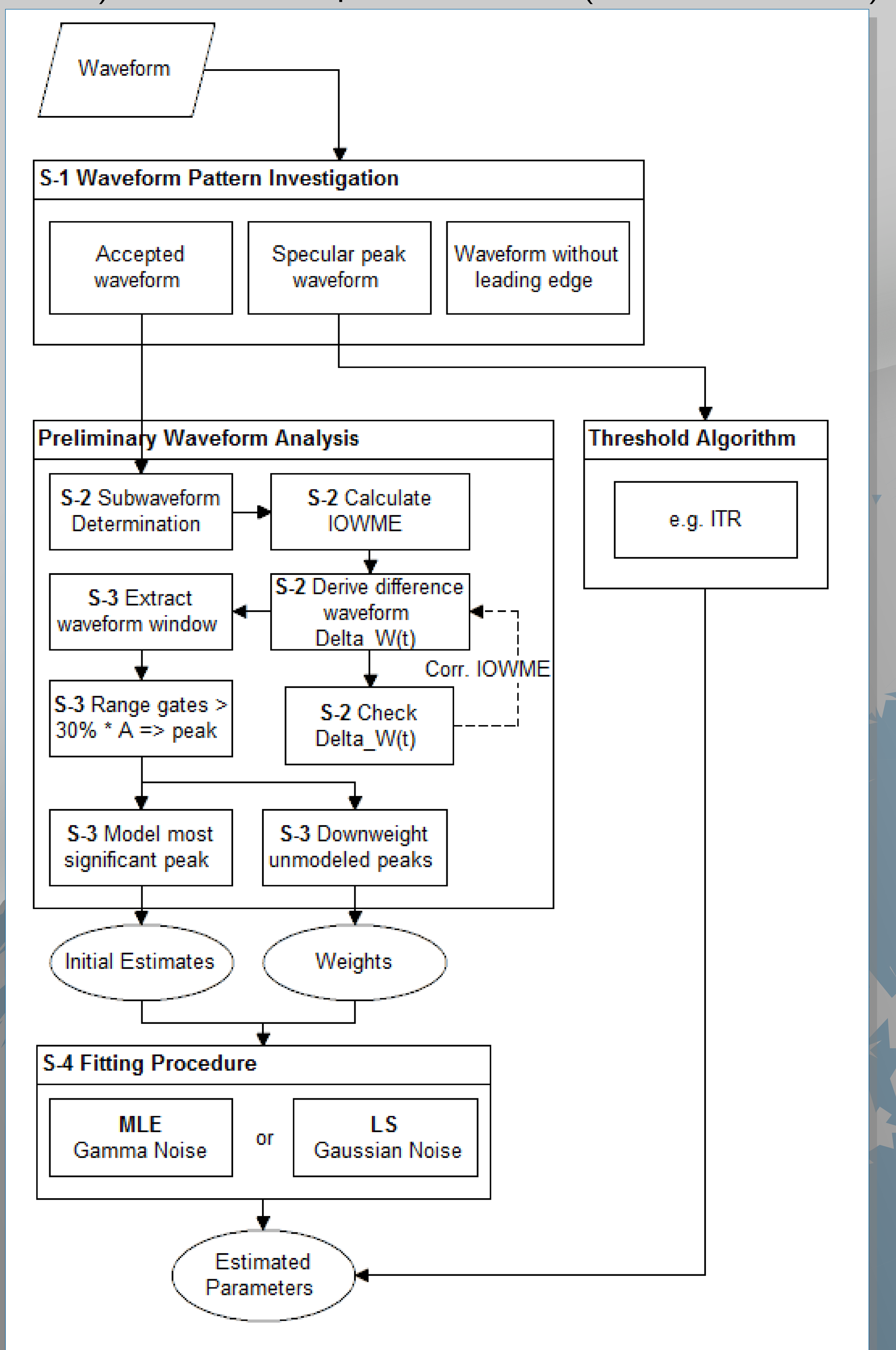

Fig. 4 Different operations of the ITGR algorithm. Abbreviations: Step (S), initial ocean waveform model estimates (IOWME), Least Squares (LS), Maximum Likelihood Estimator (MLE), initial amplitude (A).

Retracking Results over Lake Naivasha

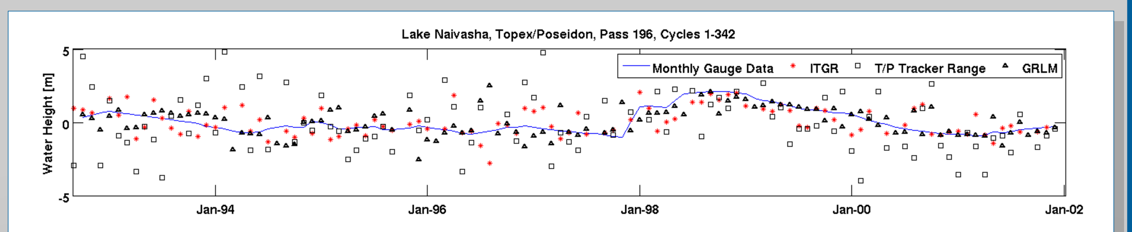

Fig. 7 Relative LLHs from retracking T/P over Lake Naivasha. Water heights from in situ gauge (solid line), unretracked tracker range (squares), the GRLM database (triangles) and ITGR-retracked LLHs (red) are shown.

Summary and Conclusions

- The accuracy of LLHs, which is mainly restricted by the amount of land influence in the altimeter footprint, was found between a few centimeters up to a few decimeter.
- We introduced a new retracking method, which benefits from the advantages of sub-waveform retracking and the ability to handle different kind of peaks on the waveform.
- Comparing the capabilities of different retrackers in deriving meaningful LLHs over African lakes, sub-waveform retrackers, including our ITGR, performed superior and provided LLHs with better standard deviation and less outliers compared to conventional retracking algorithms.

Acknowledgement

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Contact
Bernd Uebbing,
uebbing@geod.uni-bonn.de,
www.igg.uni-bonn.de/apmg

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