Using the hooking effect in satellite altimetry data for water level time series estimation over smaller rivers in the Mekong basin

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Since many years the numbers of available in-situ gauging stations are declining. Satellite altimetry can be used as a gap-filler even over smaller inland waters like rivers. However, since altimetry measurements are not designed for inland water bodies a special data handling is necessary in order to estimate reliable water level heights over inland waters. We developed a new routine using the RANSAC algorithm for estimating water level heights over smaller inland waters with satellite altimetry by using the off-nadir measurements of the hooking effect. These off-nadir measurements, together with the motion of the satellite, lead to overlong slant ranges and heights declining in a parabolic shape. The vertex of this parabola represents the correct height of the water surface. Therefore, by estimating the parabola we are able to determine the water level height without the need of any measurement point over the water body itself. With the utilization of the hooking effect we are able to retrieve water level height time series from the smaller parts of Mekong River and its tributaries from ERS-2, Envisat, and SARAL/AltiKa high frequency data. It is possible to determine reliable time series even if the river has only a width of 500 m or less.

1. Data

Altimetry:

Altimetry satellite missions:

- ERS-2, Envisat, and SARAL/AltiKa
- Time period: 1995 - 2015

In situ Data:

- 9 gauges along Mekong and tributaries, maintained by the *Mekong River Commission*
- Time period: 1995-2012

Figure 1: Study area of the lower Mekong River, indicating the gauging stations used in the validation, the virtual stations, and the Envisat altimetry tracks.

2. Hooking Effect

- The hooking effect is an off-nadir distortion of altimetry measurements that occurs at the water-land transition.
- The water surface reflects more strongly than the surrounding land surface. The altimeter measures the distance to the water surface even when not vertically positioned over the water (Figure 2).
- The measured off-nadir distances form a parabolic shape in the along-track altimetric height profiles.
- The height H_i at the distance d_i is

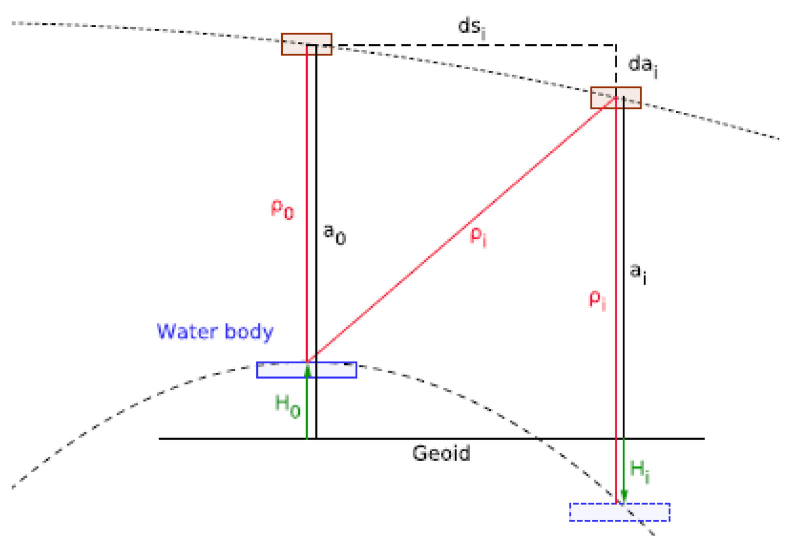

Figure 2: Schematic of the hooking effect

$$H_i = H_0 - ds_i^2 \left(\frac{1}{2\rho_0}\right)\left(1 + \left(\frac{\partial a}{\partial s}\right)^2\right)$$

3. Methodology

a) Retracking

- All altimeter measurements are retracked using the Multi Subwaveform Retracker (MSR) (Boergens et al. 2015)
- The most prominent subwaveform is supposed to be caused by the water reflexion (see Figure 3 and 4)

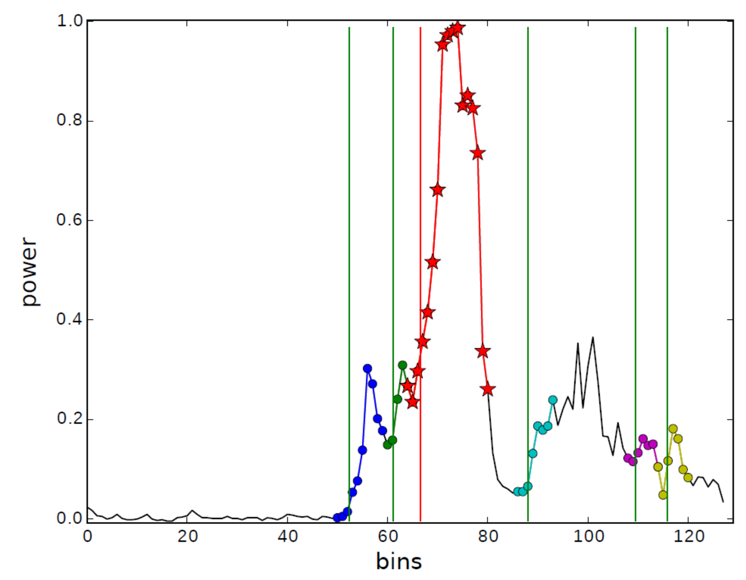

Figure 3: Typical waveform near the water-land transition. The identied sub-waveforms are marked with different colors (most prominent red stars) Vertical lines are the leading edge of each sub-waveform.

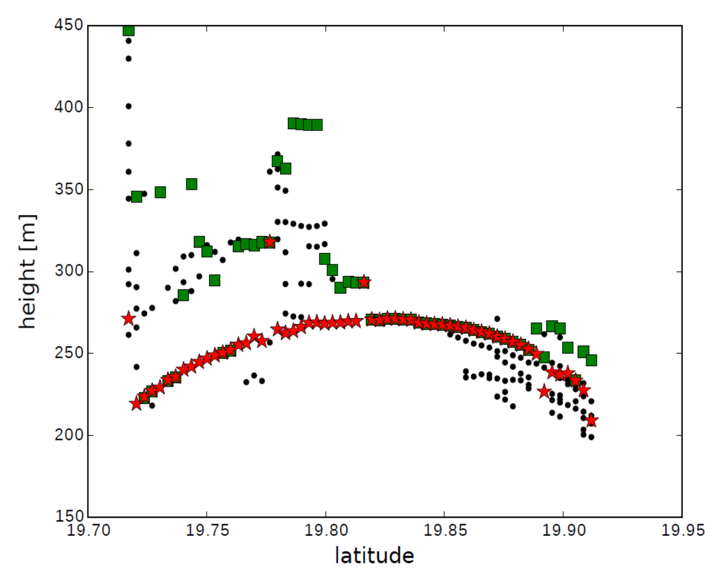

Figure 4: The heights obtained from the best waveforms in the MSR (red stars) and Improved Threshold Retracker (green squares) .

b) Fitting the parabola

The RANdom SAMple Consensus algorithm (RANSAC) is used to identify the height measure-ments affected by the hooking effect (Fischler & Bolles, 1981)

The algorithm consists of three steps:

1. Select the initial values: A sufficient number of points to unambiguously define the model are randomly picked from all data.
2. Calculate the a-priori model: This step uses the chosen points from step 1.
3. Find the consensus set:
   a) The consensus set contains all data points that fit the model within a specified limit.
   b) Recalculate the model using all points in the consensus set, and determine and save the new consensus set.

These steps are repeated for a number of times sufficient enough to find the correct model. The model with the largest consensus set is chosen.

c) Find final water level height per epoch

- The RANSAC algorithm is used to find three models, two parabolas and one line
- Restricted parameter estimation with hypothesis testing is used to determine which of those models fit together and using them to define one water level per epoch

d) Time series of water level heights

- For outlier detection an annual signal is estimated through whole time series
- All points that are outside the 95% confidence interval of this annual signal are considered outliers if their direct neighbors are not outside this interval

4. Results and Validation

The methodology was used to derive 14 water level time series along the Mekong and its tributaries

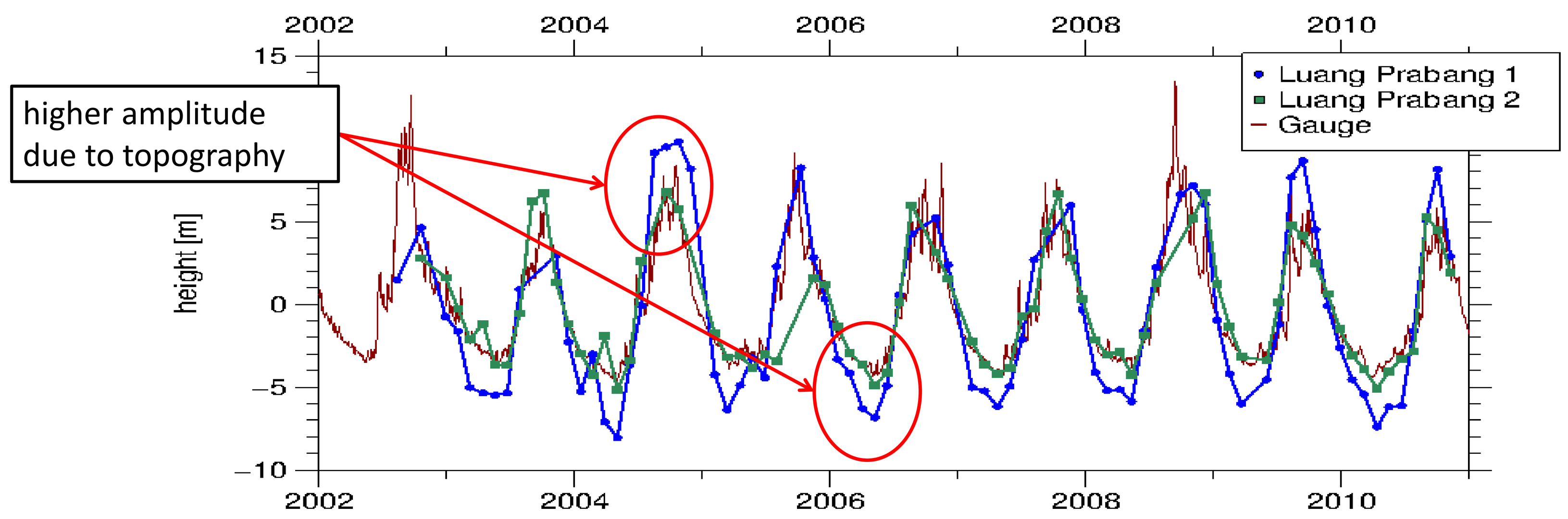

Figure 5: Altimetric time series near Luang Prabang, Envisat only

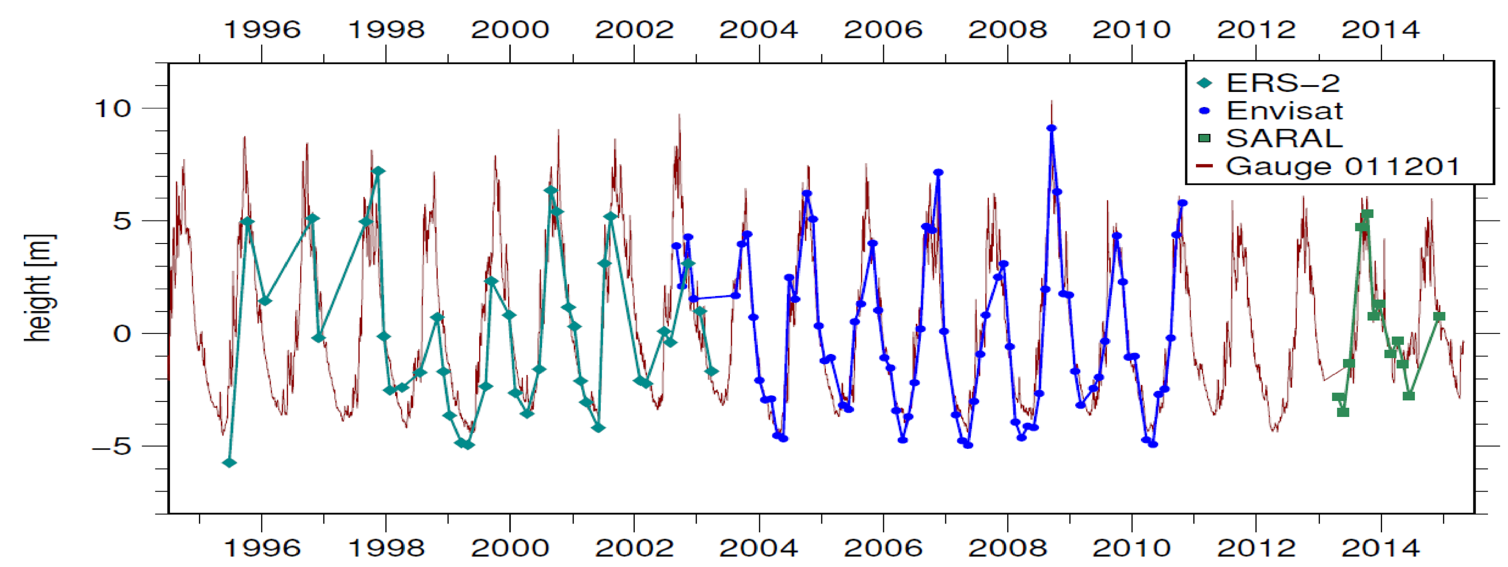

Figure 6: 20 years altimetric time series at Chiang Khan 1

The time series are validated against close by in situ data from gauging stations

Station name	width [m]	RMS	R^2	# points / cycles available
Chiang Saen	200	1.83	0.84	55 / 80
Luang Prabang 1	380	2.26	0.97	77 / 83
Luang Prabang 2	500	0.95	0.91	73 / 83
Chiang Khan 1	420	0.86	0.94	72 / 80
Chiang Khan 2	500	1.08	0.89	62 / 80
Chiang Khan 3	850	1.48	0.90	70 / 80
Vientiane 1	800	1.22	0.86	69 / 82
Mukdahan 1	1250	0.97	0.89	67 / 83
Mukdahan 2	1500	0.50	0.97	77 / 86
Ban Mixai	150	1.68	0.70	43 / 81
Ban Keng Done	300	1.40	0.55	68 / 85
Voeun Sai 1	470	0.34	0.88	69 / 84
Voeun Sai 2	330	0.89	0.59	61 / 85
Siempang	340	1.49	0.72	69 / 85

- RMS ranges from 0.34 m to 2.26 m, with a mean of 1.22 m.
- RMS is below 1.5 m in 80% of the cases.
- R^2 lies between 0.55 and 0.97 with a mean of 0.83 (improving to 0.91 for the main river only).
- RMS exceeds 2 m in only one time series (Luang Prabang 1), where the river topography is especially prone to seasonal effects (see Figure 5)
- At Luang Prabang 1 the river valley is much smaller than at the gauging station, which leads to amplified amplitudes

5. Conclusion

By using the hooking effect we are able to derive reliable water level time series even for rivers with a width of less then 500m. Still, the topography around the virtual station has a large influence on the resulting time series. This methodology is usable for the data of the ERS, Envisat and SARAL/AltiKa satellite missions which leads to a 20 years time series of water level heights. The accuracy is mostly between 1 m and 1.5 m.

References:

Boergens et al. (2015). Treating the Hooking Effect in satellite altimetry data: A case study along the Mekong River and its tributaries (in revision)
Fischler, M. A., & Bolles, R. C. (1981). Random sample consensus: a paradigm for model tting with applications to image analysis and automated cartography. Communications of the ACM, 24 , 381-395.

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