A comparison study of tidal prediction techniques for applications in the German Bight

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Motivation

Tidal analyses and predictions for the German Bight are difficult because of shallow waters and long rivers. The classic harmonic method often fails to deliver adequate results, e.g., when modelling the steep rises after low water (Fig. 1).
In this study, we compare observations with tidal predictions using five different techniques.

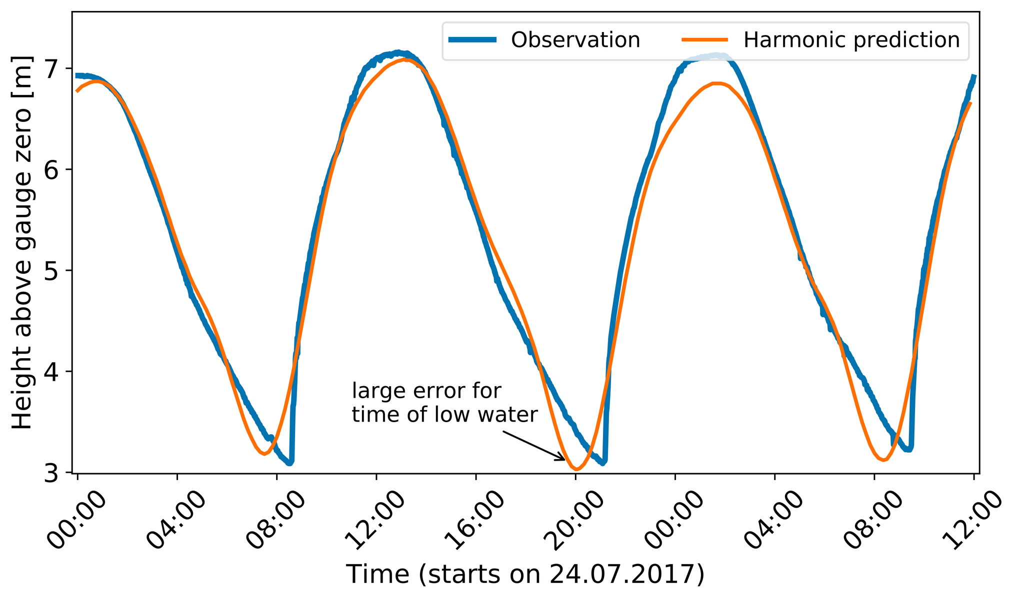
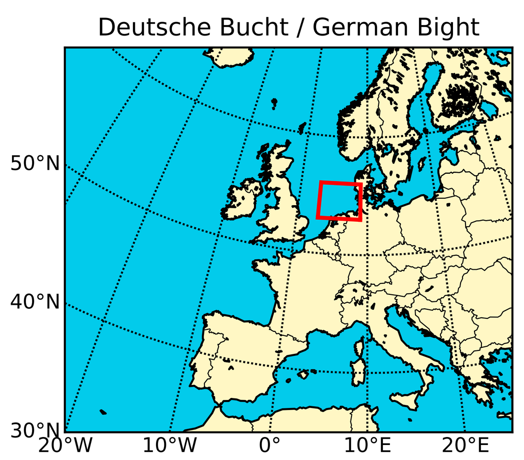
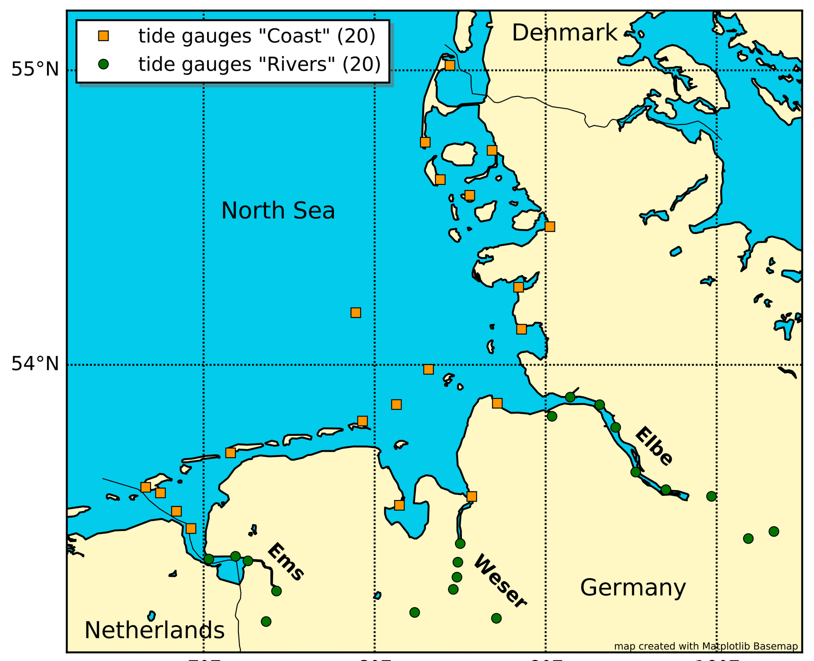


Fig. 1: Tide gauge Papenburg in the Ems river: systematic and significant differences between harmonic prediction and observation.

Tide Gauges

The maps show the locations of the German Bight and the investigated 40 tide gauges. The gauges are grouped into two classes: Coast and Rivers.





References

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Codiga, D.L. (2011). Techn. Rep. 2011-01. Grad. School of Oceanography, Univ. of Rhode Island.
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Methods

We investigate five different techniques that can be used to predict times and heights of high and low water **(HW/LW = vertices)** and/or the full tidal **curve**.

	Method	HW / LW	Curve
1	Harm. representation of inequalities – vertices	x	
2	Harm. representation of inequalities – curve	x	x
3	Harmonic method: BSH	x	x
4	Harmonic method: UTide	x	x
5	Mean observed tide stretched to HRoI-vertices		x

1) Harmonic representation of inequalities (HRoI) – vertices

The HRoI is based on the assumption that the variations in the individual heights and lunitidal intervals of high and low waters around their respective mean values can be described by sums of harmonic functions. The HRoI uses 39 long-period constituents. This method is used at BSH since 1954 for official tidal predictions of high and low water.
(Horn, 1960; Boesch, 2019)

2) Harmonic representation of inequalities (HRoI) – curve

The full tidal curve can be analysed with this generalization of the HRoI. The curve is resampled and investigated at equal fractions of the mean lunar day.
(Müller-Navarra, 2013)

3) Harmonic method: BSH

An implementation developed at BSH of the classic harmonic method using 69 constituents. Nodal corrections are omitted as 19 years of observations are used. The analysis includes two iterations with a 3-sigma-clipping in between.

4) Harmonic method: UTide

With the widely used Matlab-Package UTide the harmonic analysis is solved with the ordinary least squares method, assuming a white noise floor. The constituents are selected with the automated decision tree method. The confidence interval is determined with the linearized method. The time series is reconstructed using the built-in superposed harmonic fits.
(Codiga, 2011)

5) Mean observed tide stretched to HRoI-vertices

Mean tide curves derived from observations are fitted to HW/LW calculated with the HRoI. This method combines the observed hydrological information of a curve's shape with astronomically-driven predictions of times and heights of the vertices.

Observational Data for Tidal Analyses

Years of observational data being used for tidal analyses with the above introduced methods 1)–5):

1) Officially validated heights and times of high and low water: 1997–2015
2) - 4) Raw observations with basic data validation/correction: 1997–2015 (Δ t = 10 min)
5) Mean tide curve: Raw observations with basic data validation/correction: 2015 (Δ t = 1 min)

Results

Tidal predictions with methods 1)–5) are compared against observations for the year 2017 (Δ t = 10 min). For seven days in July, observations and the different predictions together with the corresponding residuals are shown in Fig. 2.

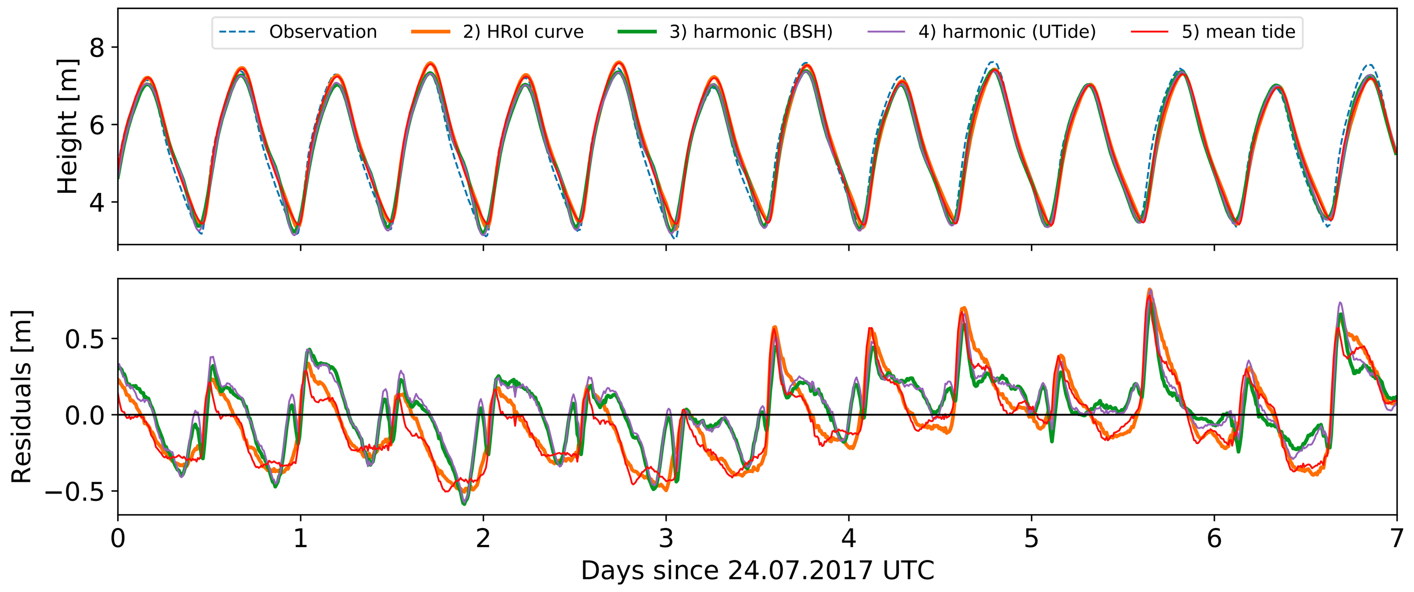

Fig. 2: Tide gauge Hamburg, St. Pauli in the Elbe river: The two harmonic predictions lead to very similar residuals. The residuals of the HRoI and the adjusted mean tide show less variation during times of falling tide.

Standard deviation of residuals

Table 1 summarizes for each group of tide gauges (Coast, Rivers) the averaged standard deviations of the different residuals. The cells are colour-coded (green-yellow-red) from low to high values.

Table 1		1) HRoI – vertices	2) HRoI – curve	3) Harmonic method: BSH	4) Harmonic method : Utide	5) Mean observed tide
HW/LW: Times [min]	Coast	11.285	12.053	14.216	14.449	--
	Rivers	12.172	14.213	20.115	20.168	--
HW/LW: Heights [m]	Coast	0.319	0.319	0.315	0.314	--
	Rivers	0.351	0.355	0.366	0.354	--
Curve: Heights [m]	Coast	--	0.396	0.391	0.391	0.401
	Rivers	--	0.392	0.390	0.391	0.405

Similarity of curves

The standard deviation of the curves' residuals considers only the differences at each time step, but does not take into account the shape of the curves. However, observations can differ from predictions due to the weather, while still following a similar trend. The similarity of the two curves is measured using the Dynamic Time Warping (DTW) algorithm: a lower value indicates a higher similarity (Tab. 2).

Table 2	2) HRoI – curve	3) Harmonic method: BSH	4) Harmonic method : Utide	5) Mean observed tide
Coast	34013	32853	30718	34009
Rivers	35882	36861	38052	34935

Conclusions

The presented results suggest that best predictions for HW/LW are achieved in total with the HRoI (vertices). Only for HW/LW-heights in the group "Coast" is the harmonic method a good alternative. For full tide curve predictions, the harmonic method leads to the lowest standard deviations of the residuals and the lowest DTW-values for the group "Coast". For the group "Rivers", the shape of the curve is better reconstructed using the mean observed tide stretched to HRoI-vertices.

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