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National Report of Germany

Compiled by

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Within the federal system of Germany, responsibilities for waters bodies are divided between national and federal authorities. Two federal agencies are dedicated to hydrological and environmental matters concerning the coastal waters. Both institutions are higher federal authorities.
The *Bundesamt für Seeschifffahrt und Hydrographie* – Federal Maritime and Hydrographic Agency of Germany (BSH) is the maritime partner to shipping and a supporter of environmental conservation efforts and maritime uses. The BSH offers a wide range of maritime services such as: prediction of tides, water level forecast and storm surge warning service, monitoring of the sea, nautical information systems, and maritime spatial planning in the German Exclusive Economic Zone. The *Bundesanstalt für Gewässerkunde* – German Federal Institute of Hydrology- (BfG) is responsible for the German waterways in federal ownership. In this position it has a central mediating and integrating function. The BfG advises federal ministries, such as the Federal Ministry of Transport and Digital Infrastructure (BMVI), and the Federal Waterways and Shipping Administration (WSV) in matters regarding the utilisation and management of the German federal waterways. In this context, the WSV operates a network of gauging stations both in coastal and inland waters. Additionally, the federal states and some harbour authorities operate their own tide gauges.

The coastal tide-gauge network

The tide-gauge network is briefly described below. A list of selected stations can be found in the appendix. There are about 160 tide gauges along the coasts of Germany. About 100 of them are located on tidal rivers such as the Elbe, the Weser, and the Ems. Figure 1 gives an overview of all coastal tide gauges and GNSS (Global Navigation Satellite System) - stations.

The stations Sassnitz, Warnemünde, and Kiel Holtenau, that are located on the Baltic Sea and the tide gauges Hörnum, Helgoland-Binnenhafen, and Borkum-Fischerbalje on the North-Sea are regional extensions to the GLOSS core network. Cuxhaven-Steubenhöft is the German contribution to the GLOSS core network. Additionally, a number of tide gauges in the North-Sea contribute to the **I**ntergovernmental **C**oordination **G**roup for the **T**sunami **E**arly **W**arning and **M**itigation **S**ystem in the **N**orth-**E**astern **A**tlantic, the Mediterranean and Connected Seas (ICG/NEAMTWS). The BSH is the national Tsunami Warning Focal Point (TWFP) for the NEAMTWS in Germany.

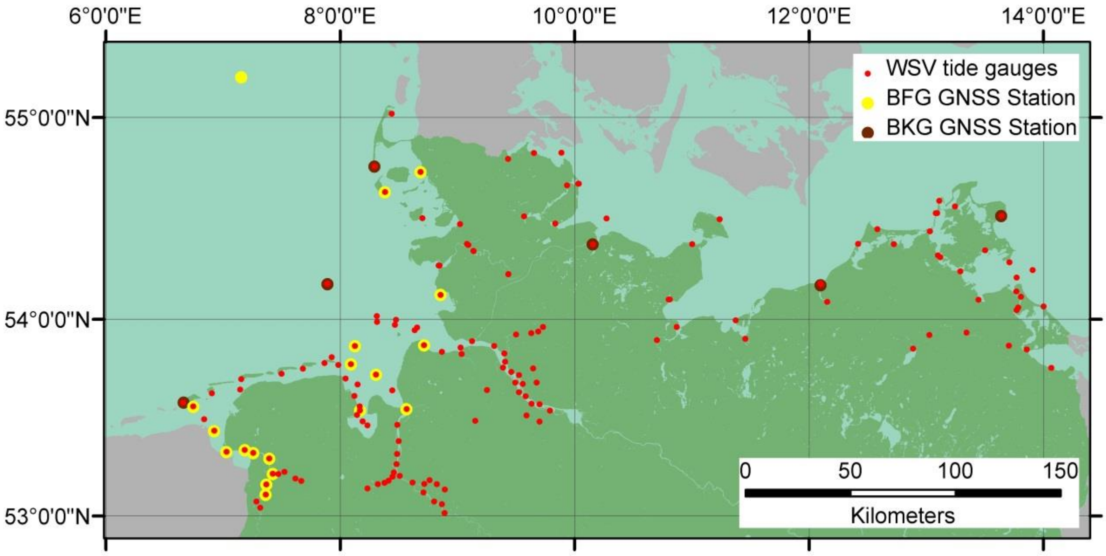

Figure 1: German coastline with tide gauges and GNSS-stations on federal waterways

The raw sea-level data are available at 1-minute intervals and can be retrieved from: http://www.pegelonline.wsv.de/. Seven tide gauges, which serve the national Tsunami Warning Focal Point (TWFP) for the ICG/NEAMTWS are available at the 'IOC Sea level data facility' http://www.ioc-sealevelmonitoring.org/. The raw data are also used by the BSH for the prediction of tides, water levels, storm surges, and currents.

Modernization of the German Tide Gauge Network

Monitoring water level has been of vital importance to the German Society since the medieval times. Due to climate and topography over 9000 bodies of water with an overall water course length of around 130000 km can be defined in Germany. In the course of history, sea level rise (due to land subsidence) in combination with occasional heavy inundations (storm surges) lead to land loss and strong changes of the coast line at the North Sea coast. From the period between the years 1200 and 1300, exist 31 historical records of storm surges so heavy they were worth mentioning. January 1362 a storm surge (Grote Mandränke) can be accounted for up to 100000 victims, let alone loss of property and life stock. The reoccurring inundations lead to bad harvests, impoverishment, depopulation and thus less man power to reconstruct dwellings, infrastructure, harbours or damaged dikes. Diking grew more important and effective diking was dependant on sea level observations. Increased trading activities fostered by the emerging Hanseatic League expanded the need for sea level observations as the harbours at the North Sea coast and river estuaries are tidally influenced.

Highly frequented shipping lanes were and still are in the North Sea and the German Bight. Thus a dense network of tide gauges (approx. 160) was built along the coasts, in the tidally influenced estuaries and along rivers and water bodies.

All near-real time transmitting tide gauges consisted of a float system in a stilling well. The mechanical signal of the float was transformed by an angle decoder into electrical signals for the data transmission. In the recent years, the demand for data of high-frequency, high accuracy and high availability has risen constantly. In late 2007 a decree introduced a "Manual on Modern Gauges" and a subsequent implementation plan. The amount provided by the overall budget was ~8.6 million Euros. The "Manual on Modern Gauges" holds a number of criteria and instructions (e.g. need of a gauge, equipment, data transfer, data archiving, inventory, datum points). To fulfil the demands on frequency, accuracy and availability from the technical side, it was decided to equip the gauges with

- two physically independent measuring units per gauge
- two independent data lines between the data storage at the gauge and the central servers
- high-performance batteries for a secured energy supply
- automated system diagnosis for immediate error reports, triggering further action
- enhanced rate of data transfer
- automatic switch from the primary system to the secondary system in case of failure of sensors or data lines

Before modernization, gauges were checked for certain location criteria:

- beginning or end of a waterway
- estuary
- locations where the tidal wave character changes
- at borders
- change of natural environment (transition from uplands to lowlands)
- need for more nautical information
- contracts or international commitment
- unimpeded flow at location
- need for wave damping
- location easily accessible
- need for fortification (ice, shipping)

Between 2009 and 2015 724 tide gauges, including data lines were modernized in accordance with the manual and implementation plan. Because of the diverse locations and their needs, sensors or other equipment were not prescribed and could be chosen by the responsible Federal Waterways and Shipping Department as appropriate. Most of the gauges were additionally equipped with radar sensors or pressure sensors.

As the main tide gauges at the German Coasts belong to the WSV, who are thus responsible for operating and maintaining the tide gauges, it is obviously that the data processing is their hands. On the other side the dissemination of sea level data in the broader context, as of GLOSS, were in the responsibilities of BSH and BfG. Different data streams to various institutes had thus been established. This model proved to be problematic and non-transparent. In 2015, BSH and BfG agreed on following handling of the data transmission to GLOSS: Hydrological data processing will be done by the local offices of the WSV and the BfG. The dissemination will be done by the BSH. This procedure was be implemented in 2017.

Data Archeology in German Coastal Waters: Activities 2015 -2017

Long-term time series are important for calculating characteristics changes due to climate change. Historical tide gauge data offer the opportunity to include new data sets for trend analysis and hind casts (Hein et al. 2011). Therefore the German Federal Institute of Hydrology investigated in data rescue of historical tide gauge records within two projects. The first project addressed the digitalization of water levels from analogue lists and lists found on microfiches. The second, still ongoing project is the challenge of economic digitalization of a large number (more than 100000) of historic paper sheets, and the related quality assurance.

Digitalization of Tidal High Water and Tidal Low Water from table data

In the first step the digitally available data of Tidal High Water (THW) and Tidal Low Water (TLW) of assorted tide gauges in the estuaries of the German Bight (Weser, Ems and Elbe) were gathered. Frequently, time series were incomplete or of unknown sources. The water and shipping authorities were contacted and available sea level data in analogue tabular form were requested. The data were partly provided as scans from the analogue sheets.
Further data could be found in the year books for the watershed of northern Germany. The year books provide sea level data from 1901 ongoing in analogue form and provide two daily values of THW and TLW. In order to fill further gaps and extend the time series, data that had been archived on microfiches during a campaign by the BfG in the nineties, was digitized.
In consideration of coastal hydrological events and the concerns of waterway management a set of representative tide gauges located along estuaries was selected for digitalization. Criteria for the selection were the availability of sea level data before the construction of tidal weirs in the upper estuaries and more or less evenly spaced distances between the tide gauges along the estuaries.

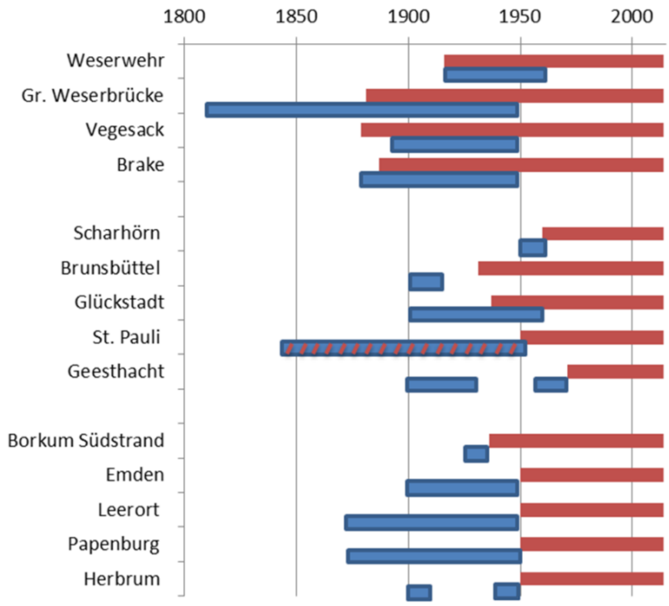

Figure 2:Newly digitalized tide gauge data. Red: Data was available before, blue: New data sets.

The digitalization resulted in a surplus value of digitally existing daily data of over 100 years (Fig. 2). Sometimes new and old data overlap, which means that in this cases only the time of occurrence of the THW and the TLW digitalized newly or that only half-yearly data was digitally available.

The data in the sheet were not all recorded daily and include small gabs, due to technical problems of the gauge, processing changes, weather conditions, etc. Additional it was a challenge to gather together the zero points of the tide gauges; these were not always documented well in the historic list or tide gauge description books.

The documented values from the Great Weser Bridge level lead back to 1815. Between 1815 and 1895, only daily values were recorded which were read at a particular time of the day. The values from 1815 to 1900 were listed in feet and inches and had to be transferred to the metric system for further processing. Between 1883 and 1895, initiated by Ludwig Franzius (German hydraulic engineer), the river bed of the upper Weser estuary was deepened. The new data (Fig. 2) clearly show the transition from an inland waterway to a tidally influenced waterway at this point.

Quality assurance of historical high resolution water level data

Long time series are important for calculating characteristic changes due to climate change, therefore the BfG invests in data rescue of historical tide gauge records. Historical tide gauge data offer the opportunity to include new data sets for trend analysis and hind casts (Hein et al. 2011). However, before these analyses can be performed extensive quality control has to be conducted (Holinde et al. 2015).

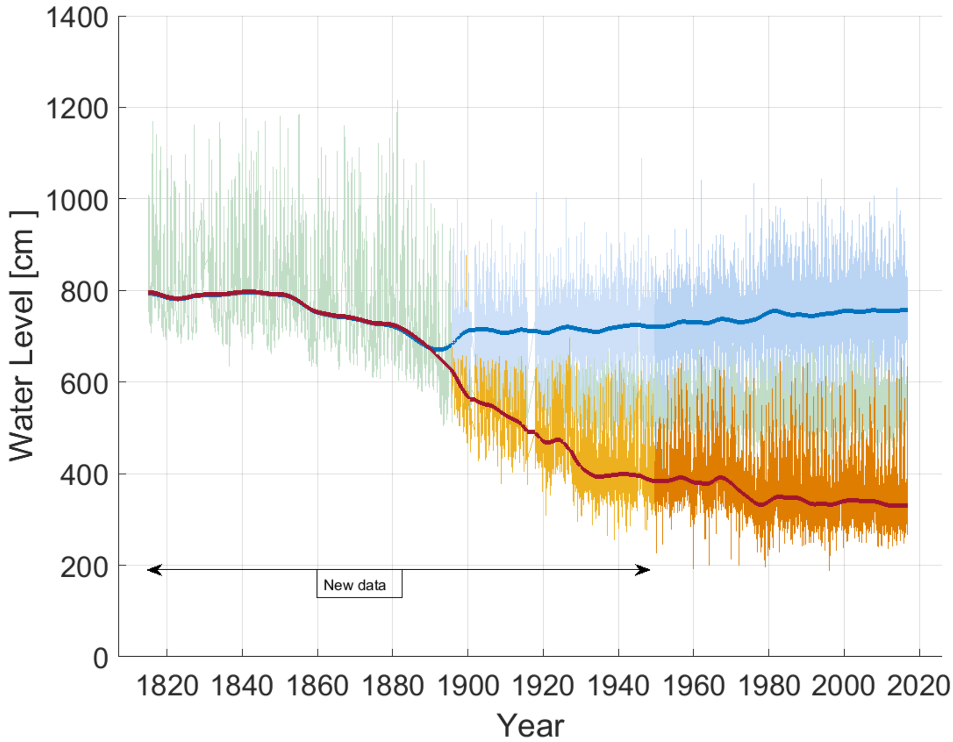

Figure 3: Water level at the tide gauge "Große Weserbrücke". Green: Mean Water Level, Red: Tidal Low Water, Blue: Tidal High Water.

Due to the difficulties of digitalizing historical water level data and the extent of the resulting time series, new automatic quality control procedures have to be developed (Hein et al. 2012). The study focuses on detection of outliers and discontinuities as well as filling gaps in time series. For error detection statistics, machine learning and neural networks are used. Gaps will be filled using interpolation methods as well as neural networks.

Several methods were tested for detection success of outliers, the values determined lie between 62% and 99.4%. In general, an overestimation of outliers was found in all methods. The results for neural networks depend on the implementation (inputs, neurons, layer). Machine learning and neural network are faster than statistical methods but require an extensive learning period.

Concerning the filling of gaps, the gap length is the main factor for the quality of resulting time series. Linear interpolation is only meaningful for very short gaps and during ebb and flood. Neural networks fit well for interpolation of gaps longer than 12.5 hour with supporting points from neighboring tide gauges.

Further investigation will aim at the optimization of different neural network methods and also into the automatization and generalization of the procedures.

Literature

Hein, H., Mai, S., & Barjenbruch, U. (2011). What tide gauges reveal about the future sea level. In Proceedings of the 4th Conference on Acqua Alta.

Hein, H., Barjenbruch, U., Blasi, C., and Mai, S. (2012). Computer-aided quality assurance of high-resolution digitized historic tide-gauge records. Proc. of the Int. Conf. Hydro 2012, Rotterdam.

Holinde et al.: Processing of water level derived from water pressure data at the Time Series Station Spiekeroog, Earth Syst. Sci. Data, 7, 289-297, doi:10.5194/essd-7-289-2015, 2015.

Holinde, L., Hein, H., & Barjenbruch, U. (2017, April). Digitalizing historical high resolution water level data: Challenges and opportunities. In EGU General Assembly Conference Abstracts (Vol. 19, p. 2924).

Appendix

List of selected stations

Coordinate Reference System (CRS): DE_ETRS89_Lat- Lon

		Latitude			Longitude			
Station name	**Station-ID**	**Deg**	**Min**	**Sec**	**Deg**	**Min**	**Sec**	**Agency**
North Sea								
Büsum	9510095	54	07	12	08	51	35	WSA Tönning
Helgoland, Binnenhafen	9510070	54	10	33	07	53	29	WSA Tönning
Husum	9530020	54	28	20	09	01	34	WSA Tönning
List	9570070	55	00	60	08	26	31	WSA Tönning
Hörnum	9570050	54	45	29	08	17	51	WSA Tönning
Wittdün	9570010	54	37	55	08	23	07	WSA Tönning
Brunsbüttel	5970055	53	53	15	09	07	33	WSA Cuxhaven
Cuxhaven-Steubenhöft	5990020	53	52	04	08	43	03	WSA Cuxhaven
LT Großer Vogelsand	9510050	53	59	44	08	28	36	WSA Cuxhaven
Zehnerloch	9510010	53	57	20	08	39	30	WSA Cuxhaven
Bake A (Scharhörnriff)	9510063	53	59	04	08	18	55	WSA Cuxhaven
Bake Z (Großer Vogelsand)	9510066	54	00	49	08	18	53	WSA Cuxhaven
Scharhörn	9510060	53	58	12	08	28	05	WSA Cuxhaven
Mittelgrund	9510132	53	56	31	08	38	10	WSA Cuxhaven
Otterndorf	5990010	53	50	03	08	52	08	WSA Cuxhaven
Osteriff	5970095	53	51	19	09	01	46	WSA Cuxhaven
Brokdorf	5970050	53	51	46	09	19	03	WSA Hamburg
Glückstadt	5970035	53	47	04	09	24	39	WSA Hamburg
Bremerhaven, Alter LT	4990010	53	32	42	08	34	11	WSA Bremerhaven
Alte Weser, Leuchtturm	9460040	53	51	48	08	07	44	WSA Bremerhaven
Dwarsgat, Unterfeuer	9460020	53	43	07	08	18	33	WSA Bremerhaven
Robbensüdsteert	9460010	53	38	21	08	26	48	WSA Bremerhaven
Nordenham, Unterfeuer	4970040	53	27	52	08	29	22	WSA Bremerhaven
Rechtenfleth	4970030	53	22	52	08	30	07	WSA Bremerhaven
Wangerooge, Nord	9420030	53	48	23	07	55	45	WSA Wilhelmshaven
Wangerooge, Ost	9420020	53	46	02	07	59	06	WSA Wilhelmshaven
Mellumplate, Leuchtturm	9420010	53	46	18	08	05	33	WSA Wilhelmshaven
Schillig	9430030	53	41	57	08	02	50	WSA Wilhelmshaven
Hooksielplate	9430020	53	40	09	08	08	55	WSA Wilhelmshaven
Voslapp	9430010	53	36	39	08	07	22	WSA Wilhelmshaven
Wilhelmshaven, Ölpier	9430040	53	33	31	08	10	03	WSA Wilhelmshaven
Wangerooge, West	9420040	53	46	35	07	52	05	WSA Wilhelmshaven
Borkum, Fischerbalje	9340020	53	33	27	06	44	58	WSA Emden
Norderney, Riffgat	9360010	53	41	47	07	09	21	WSA Emden
Spiekeroog	9410010	53	44	57	07	41	00	WSA Emden
Langeoog	9390010	53	43	15	07	40	56	WSA Emden
Memmert	9350010	53	37	29	06	54	30	WSA Emden
Borkum, Südstrand	9340030	53	34	37	06	39	46	WSA Emden
Dukegat	3990020	53	26	01	06	55	39	WSA Emden
Emshörn	9340010	53	29	37	06	50	33	WSA Emden
Knock	3990010	53	19	38	07	01	56	WSA Emden

Coordinate Reference System (CRS): DE_ETRS89_Lat- Lon

		Latitude			Longitude			
Station name	**Station-ID**	**Deg**	**Min**	**Sec**	**Deg**	**Min**	**Sec**	**Agency**
Baltic Sea								
Flensburg	9610010	54	47	42	09	26	04	WSA Lübeck
Langballig	9610015	54	49	24	09	39	20	WSA Lübeck
Schleimünde Seepegel	9610025	54	40	22	10	02	17	WSA Lübeck
Eckernförde	9610045	54	28	29	09	50	15	WSA Lübeck
Kappeln	9610035	54	39	52	09	56	22	WSA Lübeck
LT Kiel	9610050	54	29	59	10	16	29	WSA Lübeck
Kiel-Holtenau	9610066	54	22	20	10	09	30	WSA Lübeck
Heiligenhafen	9610070	54	22	23	11	00	25	WSA Lübeck
Marienleuchte	9610075	54	29	48	11	14	25	WSA Lübeck
Travemünde	9620085	53	57	29	10	52	25	WSA Lübeck
LT Kalkgrund	9610020	54	49	29	09	53	22	WSA Lübeck
Althagen	9650024	54	22	18	12	25	08	WSA Stralsund
Barhöft	9650040	54	26	04	13	01	56	WSA Stralsund
Barth	9650030	54	22	16	12	43	23	WSA Stralsund
Greifswald Eldena	9650072	54	05	33	13	26	46	WSA Stralsund
Kloster	9670050	54	35	05	13	06	41	WSA Stralsund
Koserow	9690093	54	03	37	14	00	02	WSA Stralsund
Lauterbach	9670063	54	20	25	13	30	08	WSA Stralsund
Neuendorf Hafen	9670046	54	31	28	13	05	37	WSA Stralsund
Ruden	9690077	54	12	15	13	46	19	WSA Stralsund
Sassnitz	9670065	54	30	39	13	38	35	WSA Stralsund
Thiessow	9690077	54	16	50	13	42	35	WSA Stralsund
Warnemünde Tonnenhof	9640002	54	10	11	12	06	12	WSA Stralsund
Greifswalder Oie	9690078	54	14	28	13	54	26	WSA Stralsund
Karlshagen	9690085	54	06	28	13	48	27	WSA Stralsund