Monitoring of water level, waves and ice with radar gauges

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Abstract

Today’s river and coastal monitoring systems have to manage with the cut down of budgets. Therefore there is a need for cheap but reliable instrumentation requiring less maintenance. In the future radar level gauges will provide a good substitute for gauges used in the moment. Besides that radar level also enable a contact-less acquisition of water level and wave data.

This information can be used on the one hand side to fill a gap in the hydrometry within the coastal zone and on the other hand side to control ship speed on inland rivers.

This paper presents first results of laboratory and field investigations on the applicability of commercially available radar level gauges helping in further improvement of the sensors.

Introduction

The monitoring at German rivers, estuaries and coasts focuses on the collection of water level data in the moment. Today’s standard gauging station is generally based on float gauges installed in a gauge shaft connected to the river respectively to the sea requiring large efforts in installation and maintenance. Parameters like waves and icing are not continuously measured yet.

In order to reduce the investment in the gauging system and the cost of maintenance federal authorities think about using new contact less sensors (BARJENBRUCH et al., 2000). A positive aspect of this measuring principle is its capability to measure water levels, waves and ice thickness with a single sensor at the same time. A first analysis of commercially available radar sensors revealed that the accuracy with respect to the German measurement instructions for water levels is sufficient at inland rivers but not in the coastal zone. With respect to wave monitoring the applicability of these sensors is also restricted (MAI and ZIMMERMANN, 2000).

Therefore a joint research project “Basic investigations of applicability of commercial radar level gauges in monitoring water levels, waves and icing” of the German Federal Institute of Hydrology, Koblenz and the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, University of Hannover, funded by the German Federal Ministry of Education, Science, Research, and Technology BMBF under grant 03 KIS 033 and 03 KIS 03, was initiated to overcome these problems. Besides of the monitoring of water levels and waves, the applicability of the commercial sensors in ice monitoring will be tested.

Surveying techniques of water levels, waves and ice

Within this project traditional surveying techniques of water levels, waves and ice were compared with the radar approach. For the monitoring of water levels several traditional measurement principles exist:

- Staff gauges
- Chain or tape gauges
- Float gauges installed in a gauge shaft
- Hook or point gauges

Wave monitoring techniques are traditional based on measurements of:

- Vertical acceleration of floating buoys (wave rider)
- Resistance or capacity of partially submerged metal electrodes
- Pressure of the water column above the sensor

The icing and ice thickness are traditionally visually observed and measured by drillings.

Radar level gauges employ different measuring principles. On the one hand side the time domain reflectometry and on the other hand side the optical phase ranging (TAYLOR and JACKSON, 1986). Both principles are based on the reflection of a radar signal at the boundary of materials with different electromagnetic properties, i.e. boundaries between air - water, air - ice or water - ice and are illustrated in Figure 1.

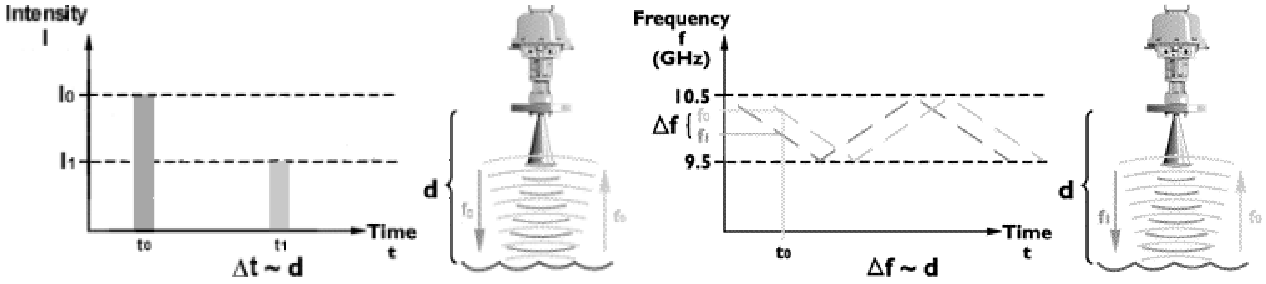

Figure 1 Measuring principles of radar level gauges (left: time domain reflectometry radar; right: optical phase ranging radar)

Within optical phase ranging the frequency of the radio signal is emitted continuously by the sensor. The frequency of the emitted radio signal is modulated. The difference between the frequency of the emitted signal and the frequency of the reflected signal is a measure for the distance between sensor and boundary. In contrast to that the radar signal is pulsed in time domain reflectometry, while the frequency of the pulse is kept constant. The travelling time of the radio pulse from the sensor to the boundary and back is a measure for the distance.

The main problem of radar level gauging is the separation of the radio signal backscattered from the different boundaries and from the background noise caused by reflection within a medium. Figure 2 gives an example of the relative backscattered intensity (solid line) of a radar pulse as a function of time, respectively as a function of distance in an ice-free medium.

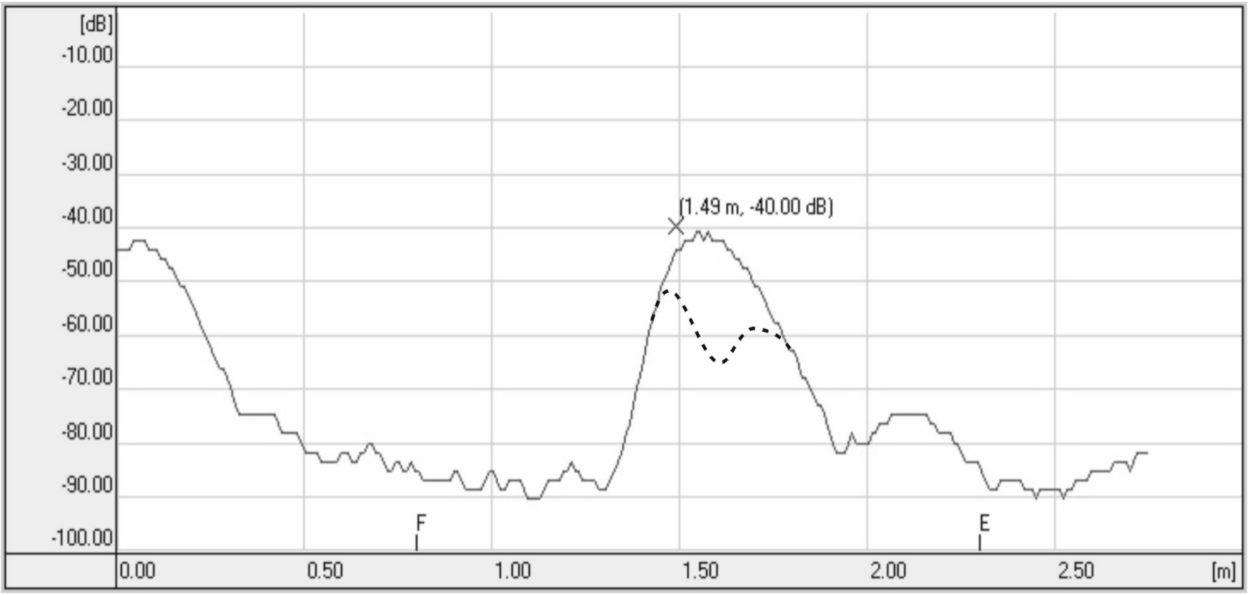

Figure 2 Radar backscatter signal of an ice-free sea surface (solid line) and of an ice-covered sea surface (dotted line)

It is obvious that directly at the sensor the backscattered radio intensity is relatively high and then reaches a constant level. At the water boundary the backscattered radio intensity strongly increases. However there are some uncertainties of the exact location of the boundary due to the width of the peak of the backscattered radio intensity. This uncertainty especially complicates the detection of thin ice layers on the water column, because the peaks in the back scattered signal caused at the interfaces between air - ice and ice - water are not separated well. Figure 2 also gives an example of the relative backscattered intensity (dotted line) having an ice-covered surface.

In order to improve the applicability of radar sensors, laboratory and field measurements are carried out. In these experiments different hardware (e.g. radar level gauges, geometries of antennas, etc) and software (e.g. post processing of radar backscatter, etc.) will be investigated.

Laboratory measurements

The first test phase of laboratory experiments focuses on the investigations of the applicability of commercial radar level gauges in monitoring water levels and waves.

This was carried out in the wave flume WKS, of the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering at the University of Hannover and the large wave tank GWK of the FZK, Coastal Research Centre, Hannover. Figure 3 shows the instrumental set-up of the laboratory measurements at the WKS and GWK. In the experiments five different radar level gauges supplied by the companies Vega, Endress & Hauser, Krohne and Siemens are used. Moreover traditional GHM wave height meters of Delft Hydraulics are used in the WKS and resistance wave height meters developed by TAUTENHAIN (1988) are used in the GWK in order to be compared with the radar level gauge data.

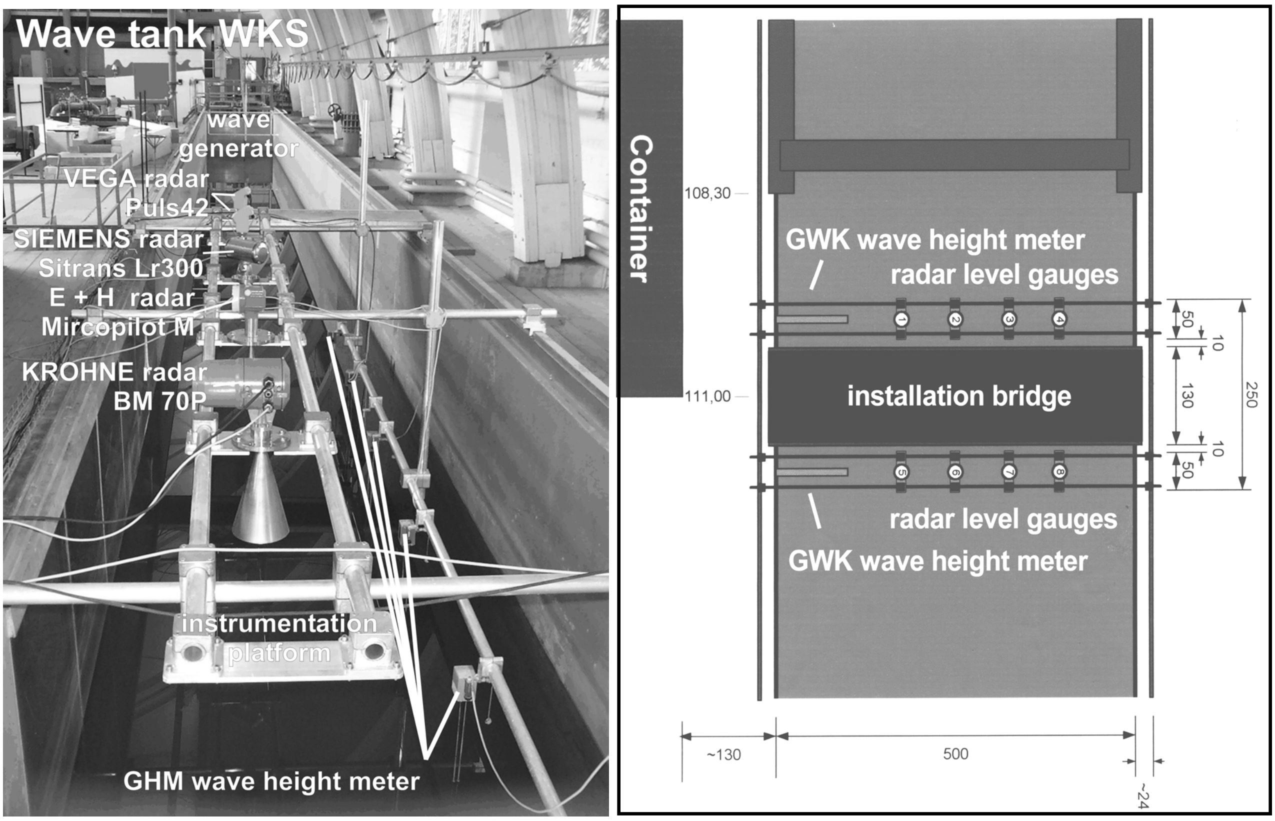

Figure 3 Experimental set-up in the wave flumes WKS (left) and GWK (right)

An example of a time series of the water level elevation, measured with a traditional wave height meter and radar level gauges in the WKS is given in Figure 4

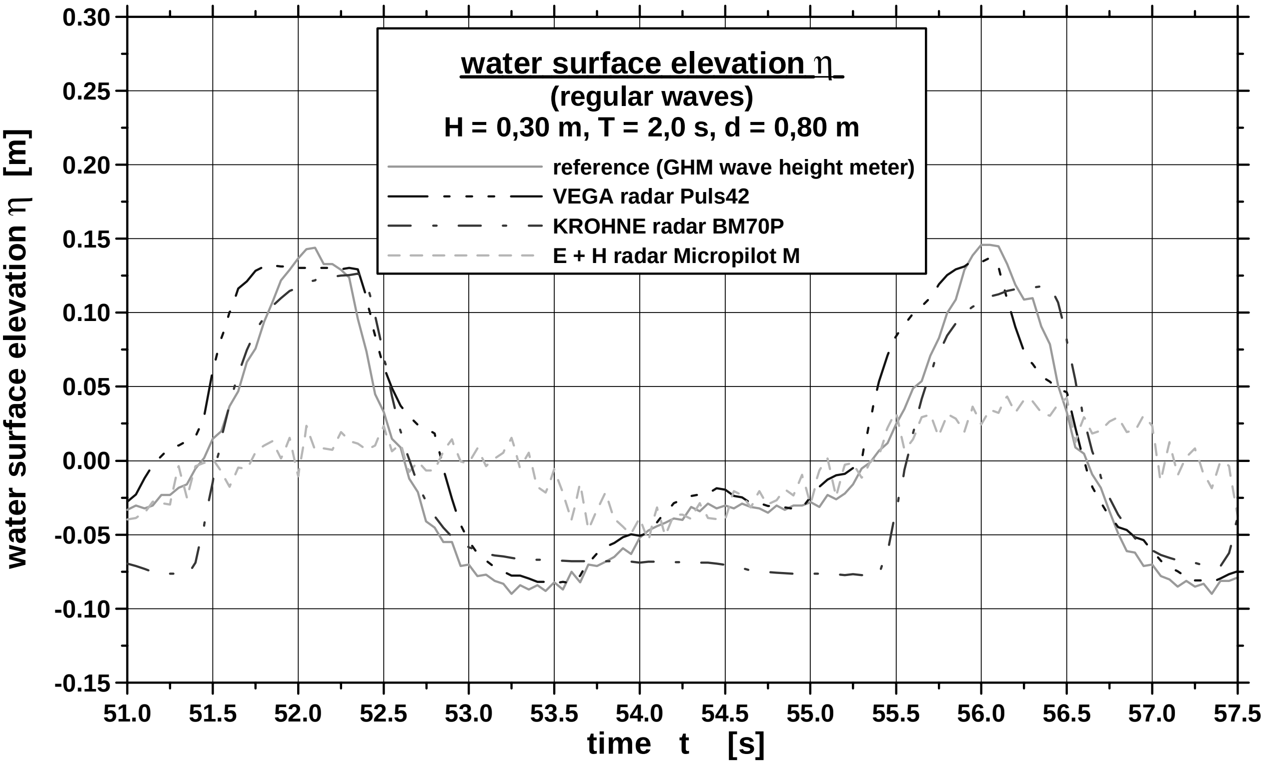

Figure 4 Example of a time-series of water level elevation measured in WKS with GHM wave height meter and radar gauges of Vega Ltd., Endress & Hauser Ltd. and Krohne (regular waves: H = 0,3 m, T = 2 s, d = 0,8 m)

Without any modification at the radar level gauges, the radar sensor VEGA Puls42 agrees best with the traditional GHM wave height meter. However as in previous investigations (MAI, 2001) all radar gauges underestimate the real maximum and minimum surface elevation.

Besides of additional tests with different hard- and software the second test phase of laboratory experiments comprises also tests in an ice tank.

On-site measurements

In addition to the laboratory experiments similar field investigations at the gauge "Borkum" near the island Borkum were carried in order to uncover problems due to environmental impacts like fog, rain, wind, temperature, salinity, birds, etc.

Figure 5 shows the location and instrumentation of the gauge "Borkum" equipped with various wave and water level sensors. In the field experiments the same radar level gauges are used, as in the laboratory experiments. Moreover a resistance wave height meter of the GWK was installed. The gauge "Borkum" also provides a float gauge installed in a gauge shaft to measure water level data.

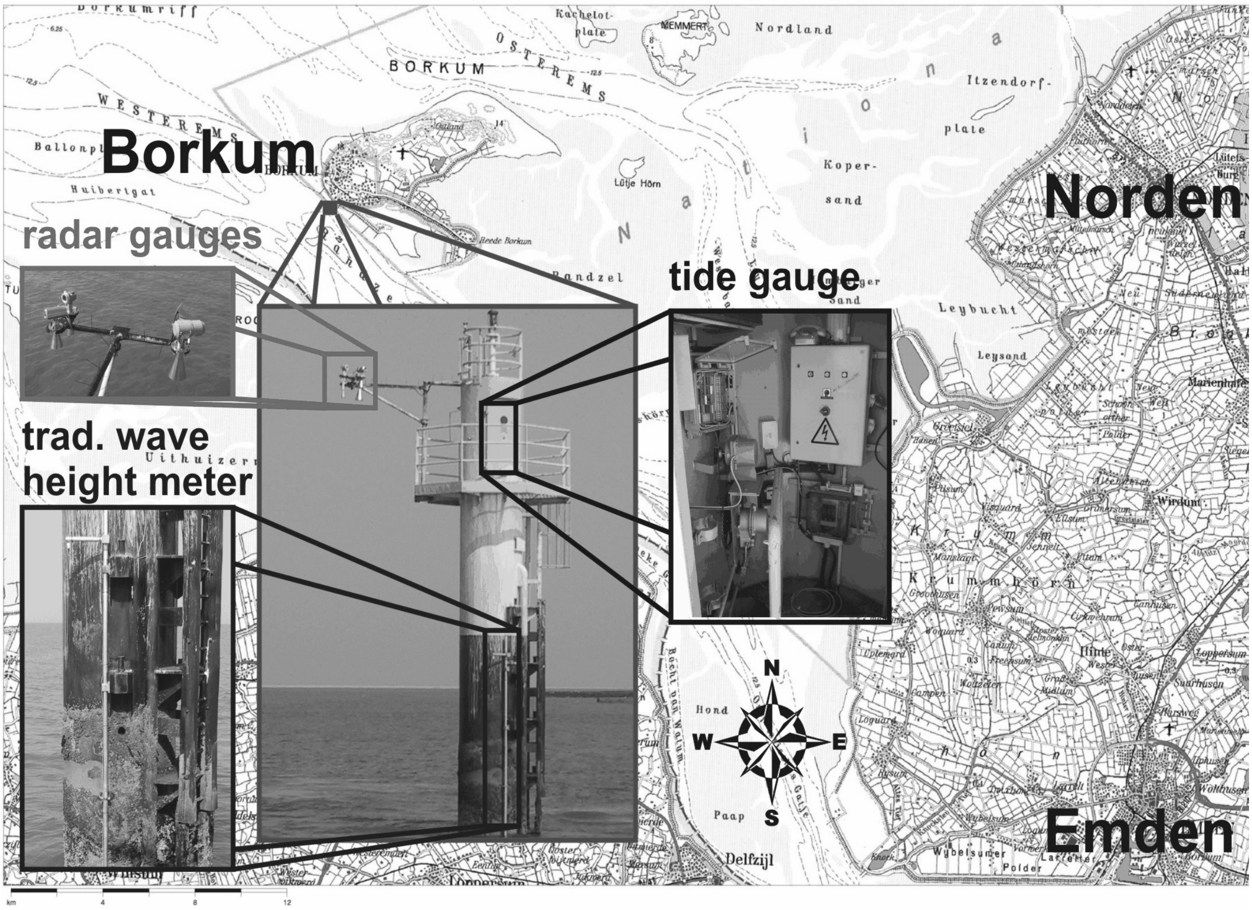

Figure 5 Location of the gauge "Borkum" near the island Borkum and experimental set-up with various wave and water level sensors

Putting the focus on short-term water level elevations (i.e. waves) the unfiltered radar data is compared to the GWK wave height meter data. An example of a time series of the water level elevations due to waves is given in Figure 6. The wave crests and troughs are also underestimated in the field measurements, as in the laboratory tests.

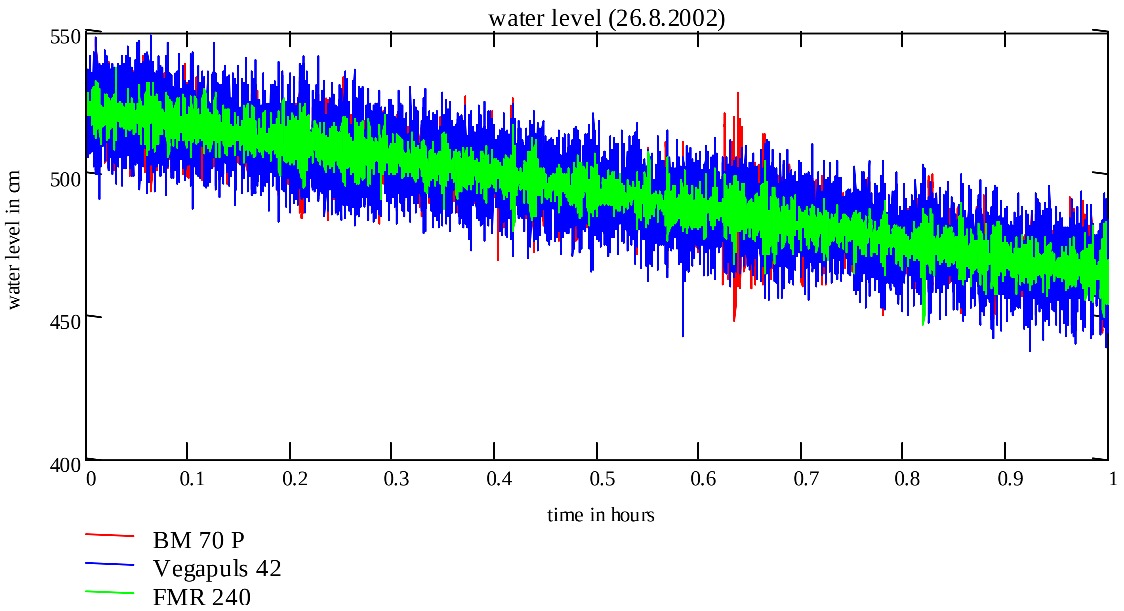

Figure 6 Example of a time-series of water level elevation measured near Borkum with the radar gauges of Vega Ltd., Endress & Hauser Ltd. and Krohne (26. Aug. 2002)

An example of a tide curve measured at the gauge "Borkum" by a traditional water level gauge (float gauges installed in a gauge shaft) and by the radar level gauges is given in Figure 7. In order to remove short-term water elevations due to waves following exponential smoothing function was applied to the radar data:

For time t=0 $ex_0 = x_0$

for time t>0 $ex_t = \alpha * x_t + (1-\alpha) * ex_{t-1}$ with α = 0.01

The agreement of measured tide curves is quite good, the maximum deviation of measurement data are 2 - 3 cm. Figure 8 gives a histograms of the error frequency of measured tide curves with radar level gauges.

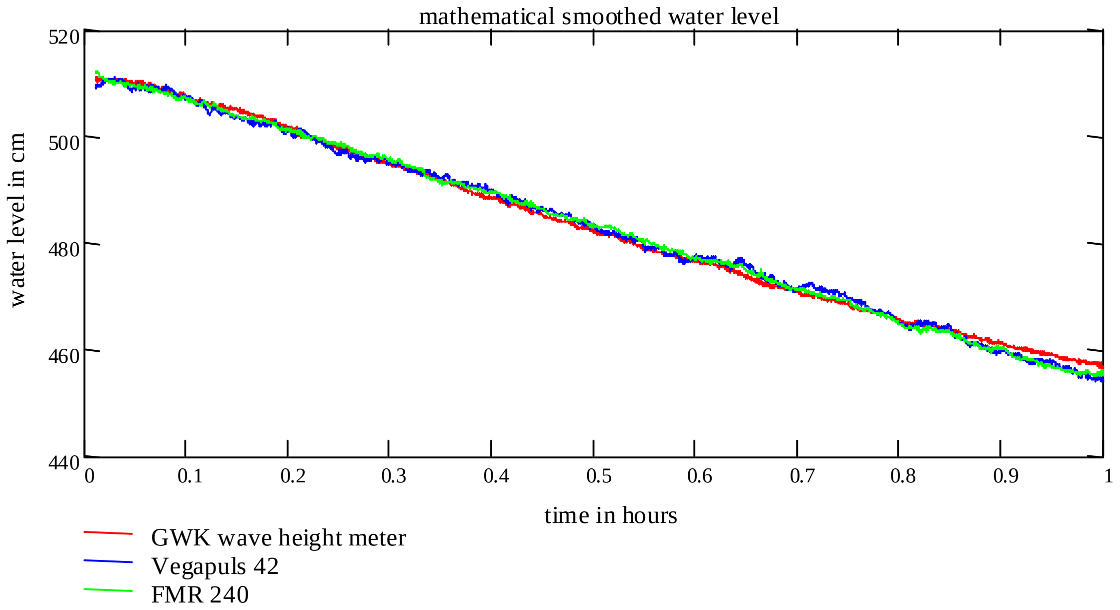

Figure 7 Example of a smoothed time-series of water level elevation measured near Borkum with a GWK wave height meter and the radar gauges of Vega and Endress & Hauser (26. Aug. 2002)

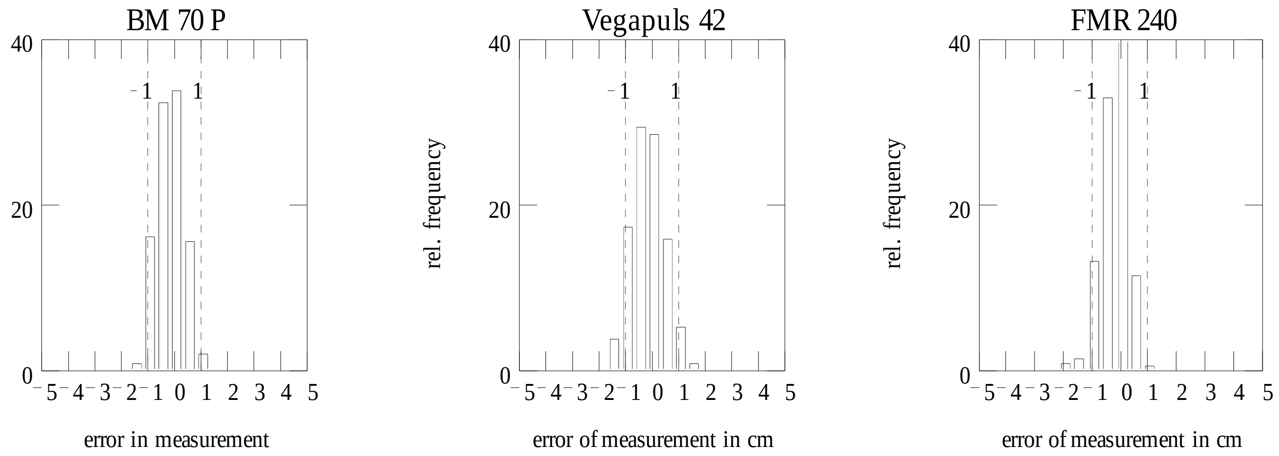

Figure 8 Agreement of measured tide curves with radar level gauges, 99.15%, 95.58% and 97.46% of the measurement error are within the confidential interval of ± 1 cm respectively for the Radar sensors Krohne, Vega and Endress & Hauser

Preliminary Results

Analysing the time series of water level elevations using the zero-down-crossing method, the underestimation of the wave crests and troughs results in a shift of the statistics of wave height. The statistics of wave period remains nearly unchanged by this effect. Figure 9 shows the statistic of wave height and wave period as a result of an experiment with irregular waves in the WKS.

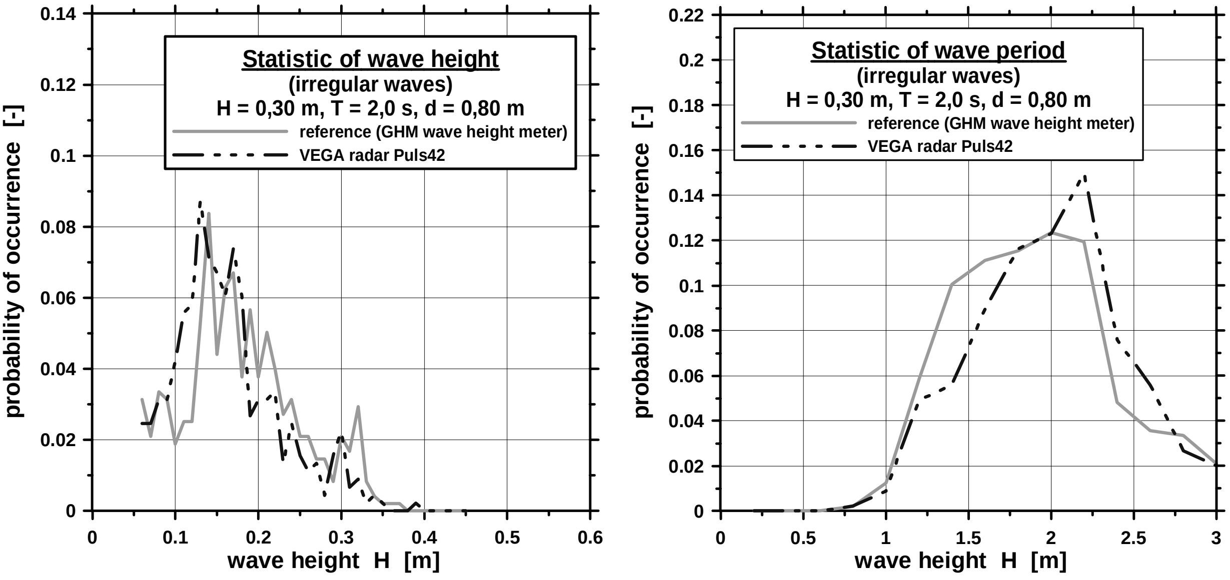

Figure 9 Statistics of wave height (left) and wave period (right) measured with radar gauges and GHM wave height meter in WKS

Similar results were also achieved by analysing the laboratory experiments in frequency domain. Figure 10 shows the wave spectrum measured with radar gauges and GHM wave height meter. While the peak period is represented well by the radar sensors the significant wave height H_{m0} is underestimated.

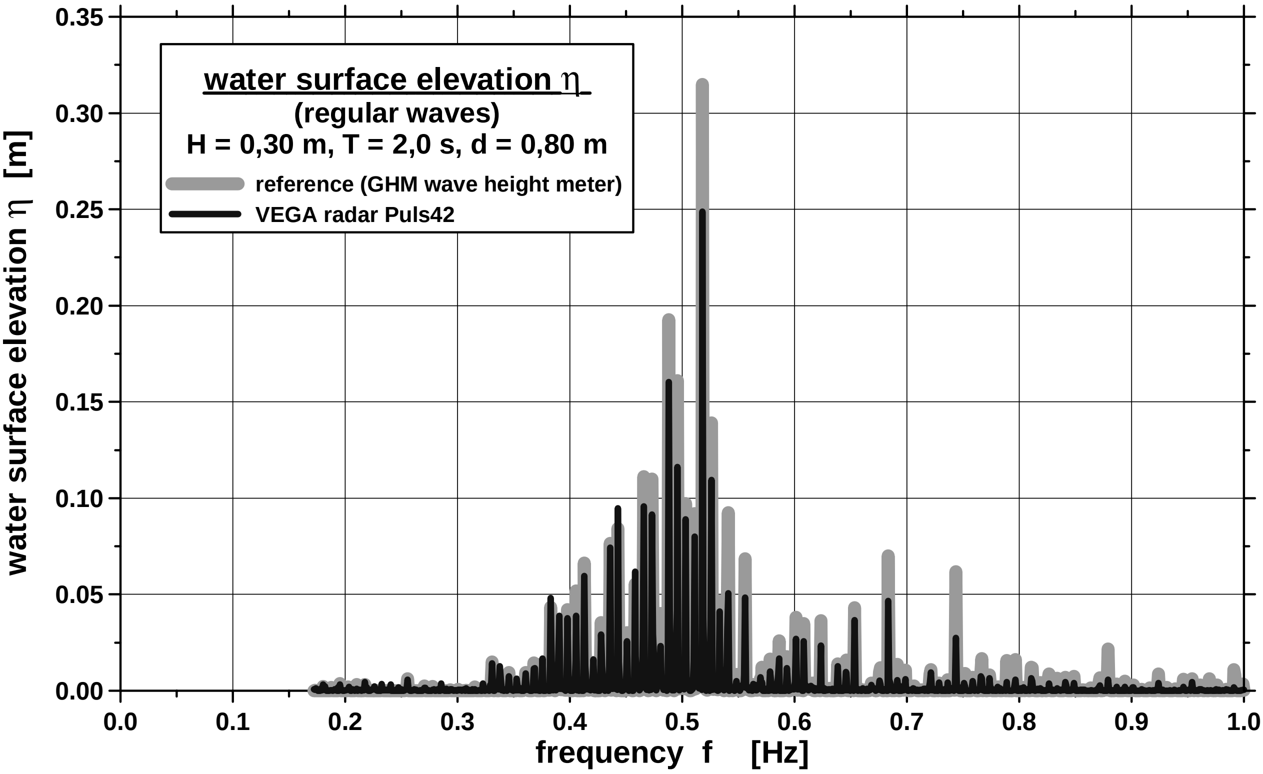

Figure 10 Wave spectrum measured with radar gauges and GHM wave height meter in WKS

At this moment, both the analysis in time and frequency domain reveal that without any modifications the sensor VEGA Puls42 shows the best agreement.

The deviation in significant wave height derived by radar sensors and by the GHM wave height meter increases with decreasing wave periods and increasing wave heights. Figure 11 illustrates these effects.

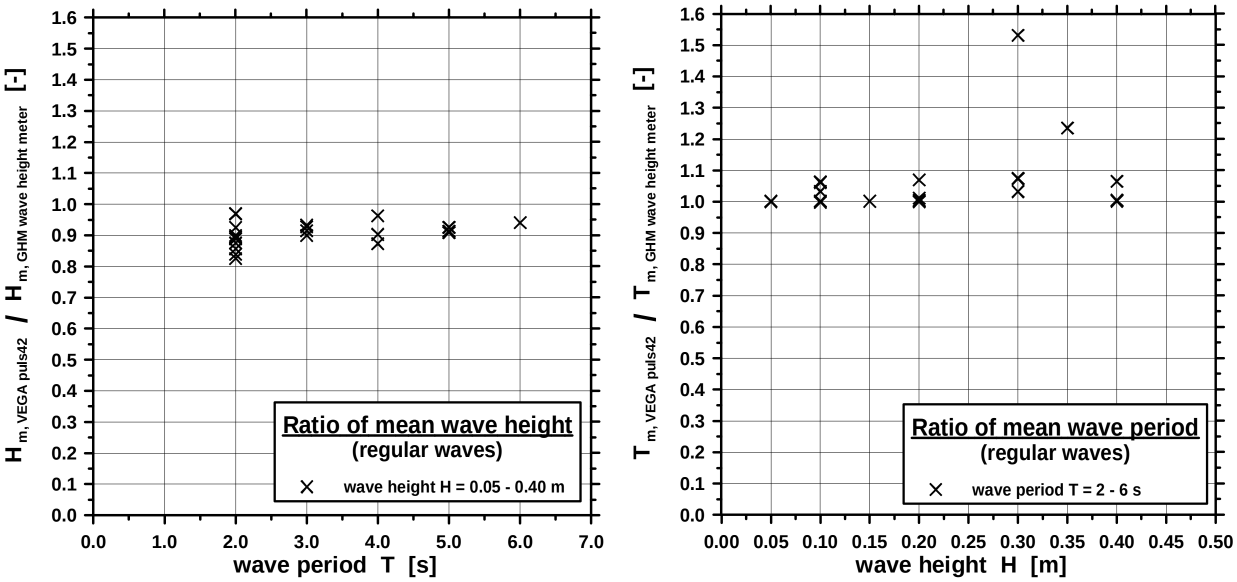

Figure 11 Ratio of the significant wave height measured with radar gauges and GHM wave height meter in WKS (left: influence of wave height; right: influence of wave period)

Conclusions

The investigation so far revealed, that commercially available radar level gauges are suitable for measurements of tidal water levels, however the accordance with the German gauging regulations are still under investigation.

An application of radar sensors in wave monitoring still requires major improvements in hard- and software. Different improvements like different geometries of antennas and post processing analysis are still under investigation in the moment.

However a set of two radar sensors and one traditional wave height meter can be already used to measure directional wave spectra near coastal structures (VAN DER VLUGT et al., 1999). Therefore detailed investigations will be carried out in the two-dimensional wave basin in Marienwerder (WBM) of the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering at the University of Hannover.

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