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TIDE GAUGE DATA PROCESSING - VIANA DO CASTELO STATION

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Abstract: The classic issue of tide gauge data quality has become more important in the last decade as new technologies have emerged and tide gauge networks have been modernized. This work made it possible not only to evaluate the performance of the tide gauges in the tide gauge network, but also to present quality control techniques for tide data recorded in quasi-real time, which implies the need to implement automatic error detection and signaling software. Quality control consists of detecting anomalous values, incorrect date and time assignments and calculating residuals. To assess the measurement performance of tide gauge equipment, the Van de Casteele test was revisited. The validation of *in situ* sea level observations was based on quality control procedures suggested by international standards.
Keywords: quality control, tide, tide gauges, accuracy, time series.

INTRODUCTION

The Hydrographic Institute (IH) manages the largest national network of tide gauge observations, operating and maintaining 23 tide gauge stations in cooperation with public or private entities.

Knowledge of the tide is of special interest in coastal areas, particularly for hydrography and geodesy, navigation safety (in channels, estuaries and ports), coastal engineering projects (such as the construction of bridges, docks and breakwaters), studies of biological and geological processes, climate change studies and even for recreational activities and fishing (Pugh, 1987).

Issues related to the quality of tide measurements have become more important with the modernization of equipment and recent concerns about the rise in mean sea level.

Thus, in recent decades, much attention has been paid to tidal performance, especially in the context of the GLOSS program (IOC, 1997; Merrifield *et al.*, 2010).

However, systems capable of storing and transmitting large amounts of data allow tide gauges to accurately monitor interesting phenomena such as storm waves or tsunamis. As a result of the growing interest in higher quality and more frequent sea level data, tide gauge monitoring networks have undergone significant technical developments. Traditional mechanical float gauges have been progressively replaced by electronic tide gauges equipped with acoustic, pressure and (more recently) radar sensors. During this process, comparison tests have been carried out and their results published (Woodworth and Smith, 2003). The classic methods applied to analyze data from such equipment (Martin *et al.*, 2005) include techniques such as:

(i) time series analysis of the differences calculated between the tide gauge measurement and the standard or reference measurement;

(ii) calculating the root mean square error (rmsse) of the time series of differences;

(iii) visualization of data from one tide gauge against another (scatter plot) e;

(iv) calculating the slope of the linear regression trend between the two sea level series; this slope expresses the different sensitivities of the gauges to the amplitude of the tides.

This interest in the quality of tide measurements is also evident on the UNESCO/IOC website (www.ioc-sealevelmonitoring.org), where 25% of the tide gauges displayed use radar technology.

However, due to the relatively recent incorporation of these modern sensors into tide gauge networks, there is still a lack of information on their long-term behavior and their suitability for estimating sea level trends. The majority of the comparison tests mentioned above have used hourly data to determine whether tide gauges meet the 1 cm accuracy requirements referenced by GLOSS (IOC, 1997), but have not assessed the reliability of high-frequency data (meaning a sampling interval of a few minutes) or the long-term stability of the sensors.

In this paper, we address these questions using data from two radar tide gauge systems with simultaneous sea level measurements. We present a series of techniques for comparing two measurement systems to assess whether the tide gauges installed in the port of Viana do Castelo are comparable.

QUALITY OF MEASUREMENTS

Since 2015, tide heights have been recorded simultaneously on two radar tide gauges installed at the same tide gauge station located in the port of Viana do Castelo; the location and minute-by-minute tide records between September 1 and 2, 2021 are shown in Figure 1.

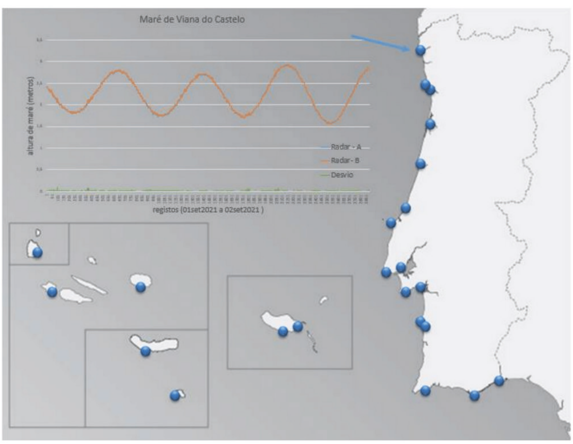


Fig. 1. National tide gauge network (source: Hydrographic Institute).

Every day, in almost real time, the tide gauge records undergo quality control (QC). The quality control *software*, developed and implemented at IH, aims to identify incorrect records and malfunctioning tide gauge equipment at an early stage, creating a time series of tide gauge data with quality signals.

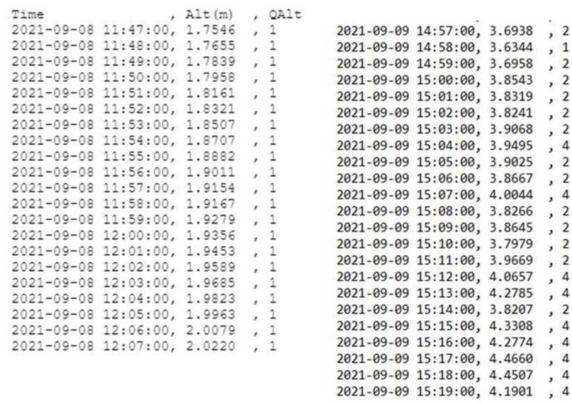
Figure 2 shows the flowchart of the implemented *software*.

Table I shows the legend for the signage on the records (EuroGOOS, 2010):

Indicators	Name
0	No quality control
1	Good value
2	Probably good value
3	Probably bad value
4	Bad value

Table I : Quality control indicators.

Figure 3 shows the time series with the quality signaling applied.



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Time                , Alt(m)  , QAlt
2021-09-08 11:47:00, 1.7546  , 1
2021-09-08 11:48:00, 1.7655  , 1
2021-09-08 11:49:00, 1.7839  , 1
2021-09-08 11:50:00, 1.7958  , 1
2021-09-08 11:51:00, 1.8161  , 1
2021-09-08 11:52:00, 1.8321  , 1
2021-09-08 11:53:00, 1.8507  , 1
2021-09-08 11:54:00, 1.8707  , 1
2021-09-08 11:55:00, 1.8882  , 1
2021-09-08 11:56:00, 1.9011  , 1
2021-09-08 11:57:00, 1.9154  , 1
2021-09-08 11:58:00, 1.9167  , 1
2021-09-08 11:59:00, 1.9279  , 1
2021-09-08 12:00:00, 1.9356  , 1
2021-09-08 12:01:00, 1.9453  , 1
2021-09-08 12:02:00, 1.9589  , 1
2021-09-08 12:03:00, 1.9685  , 1
2021-09-08 12:04:00, 1.9823  , 1
2021-09-08 12:05:00, 1.9963  , 1
2021-09-08 12:06:00, 2.0079  , 1
2021-09-08 12:07:00, 2.0220  , 1

2021-09-09 14:57:00, 3.6938  , 2
2021-09-09 14:58:00, 3.6344  , 1
2021-09-09 14:59:00, 3.6958  , 2
2021-09-09 15:00:00, 3.8543  , 2
2021-09-09 15:01:00, 3.8319  , 2
2021-09-09 15:02:00, 3.8241  , 2
2021-09-09 15:03:00, 3.9068  , 2
2021-09-09 15:04:00, 3.9495  , 4
2021-09-09 15:05:00, 3.9025  , 2
2021-09-09 15:06:00, 3.8667  , 2
2021-09-09 15:07:00, 4.0044  , 4
2021-09-09 15:08:00, 3.8266  , 2
2021-09-09 15:09:00, 3.8645  , 2
2021-09-09 15:10:00, 3.7979  , 2
2021-09-09 15:11:00, 3.9669  , 2
2021-09-09 15:12:00, 4.0657  , 4
2021-09-09 15:13:00, 4.2785  , 4
2021-09-09 15:14:00, 3.8207  , 2
2021-09-09 15:15:00, 4.3308  , 4
2021-09-09 15:16:00, 4.2774  , 4
2021-09-09 15:17:00, 4.4660  , 4
2021-09-09 15:18:00, 4.4507  , 4
2021-09-09 15:19:00, 4.1901  , 4
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Fig. 3. Time series of the Radar-B tide gauge equipment (from the Viana do Castelo station) with quality signaling.

The *software* includes a visualization tool to validate and display the QC of the series of tide gauge records (Figure 4).

The differences (or deviations) between the two pieces of equipment were calculated and plotted on a histogram (Figure 5) to assess their distribution. There is graphical evidence that the distribution of deviations is negatively asymmetrical, confirmed by the asymmetry coefficient of -1.58.

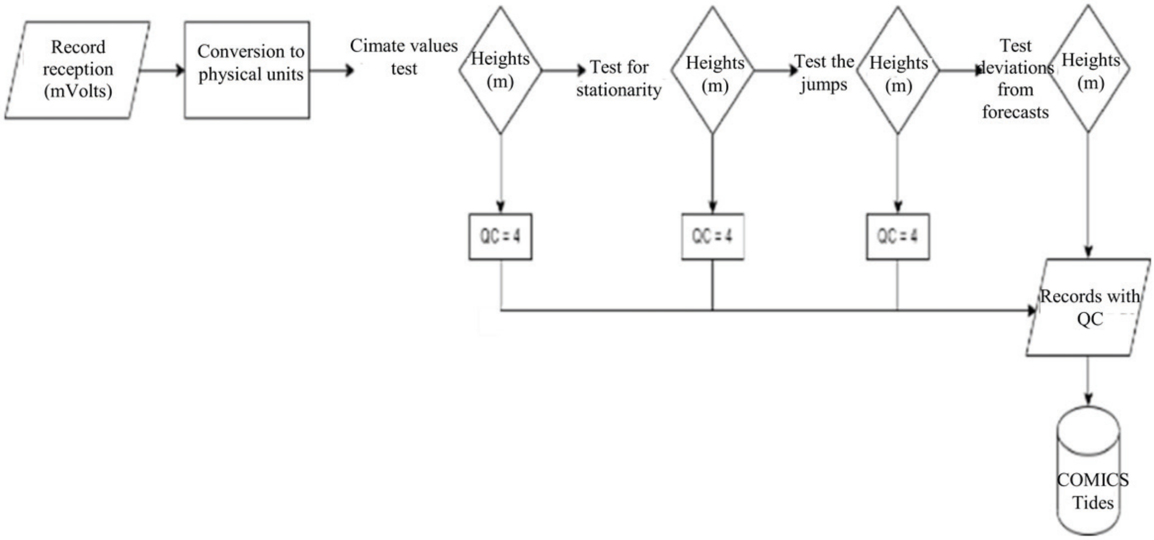

Fig. 2. Flowchart of the software implemented at IH.

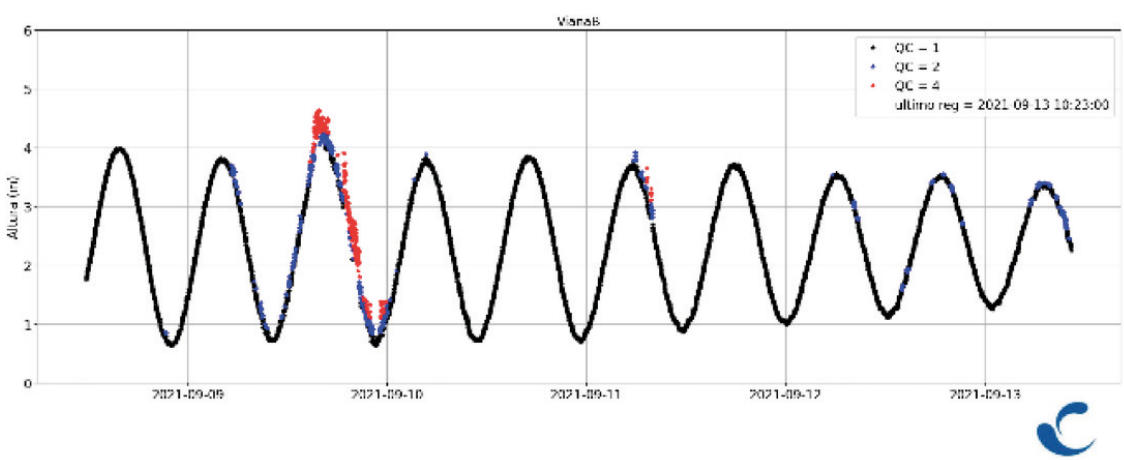

Fig. 4. Detection and signaling of anomalous records from the Radar-B tide gauge equipment (from the Viana do Castelo station).

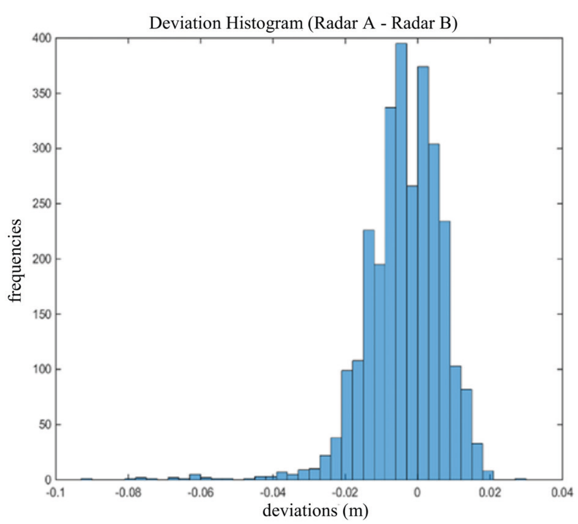

Fig. 5 Histogram of deviations.

The difference in measurements shows an average deviation of 0.81 cm (in absolute value) with a standard deviation of 0.77 cm.

The scatter plot was constructed and the slope of the linear regression was found (Figure 6).

Linear regression allowed us to define the equation: .

$$\widehat{RadarA} = 1{,}0029 \text{ x RadarB - } 0{,}0102$$

A correlation coefficient of 0.9993 is evidence of a strong relationship between the measurements of the two pieces of equipment, i.e. the two tide gauges are accurate, but not precise.

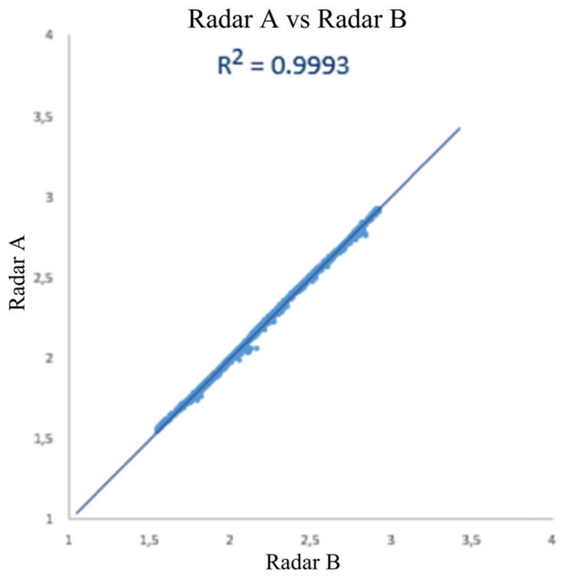

Fig. 6. Slope of the linear regression line *Y=a+bX* between radar tide gauge measurements.

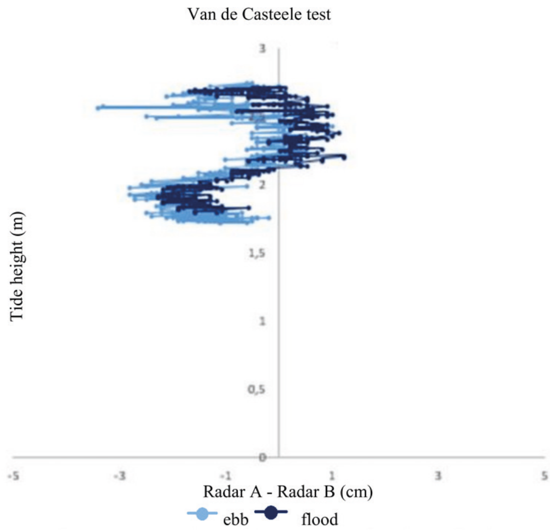

Fig. 7. Application of the Van de Casteele Test.

The Van De Casteele test was designed in 1962 to assess the mechanical performance of tide gauges with floats. GLOSS, in 1985, recommended its application to all types of equipment, in order to compare the readings between a hand-held probe and the readings of tide gauges, in different tidal cycles. The results are used to produce a graph with the sea level on the *yy* axis and the differences on the *xx* axis (Lennon, 1968). The hand probe is used as a reference instrument assuming that its measurements are more accurate than those of the equipment to be compared (IOC, 1985; Le Roy, 2006). The results also depend on the skill of the hand probe operator, so human error cannot be completely ruled out.

In this work, the Van de Casteele test was applied in order to compare the measurements of the two tide gauges; Radar A is considered to be the main tide gauge station; the results were used to produce a graph with the tide level measurement on the ordinate axis and the differences (ΔH) on the abscissa axis: Radar B.

Figure 7 shows the results of applying the Van de Casteele test to radar tide gauges.

This test confirms the results obtained through the regression study and the asymmetry coefficient.

FINAL CONSIDERATIONS

The aim of this work was to present an evaluation of tide height measurements between two pieces of equipment installed at the same tide gauge station (Viana do Castelo)

The implementation of automatic error detection and signaling *software* has proved to be an asset in monitoring tide gauge records in near-real time , which allows for faster and more effective action, usually in storm situations.

Quality control, developed at the IH, consists of detecting anomalous records, incorrect date and time assignments and calculating residuals (difference between forecasts and observations).

The Van de Casteele test was revisited to diagnose whether tide height records are capable of meeting GLOSS requirements and proved to be a useful tool in assessing the accuracy of tide gauges.

Classical methods were applied to the data and found an average deviation of ~ 0.81 cm in absolute value between observations recorded minute by minute.

Despite the satisfactory results for the majority of tide monitoring applications (e.g. port works), the deviation in some measurements is greater than desirable, 1 cm, which could affect mean sea level trend studies.

The analysis of the precision and accuracy of the observations is never finished, so it necessary to continue comparing measurements and evaluating the variations in deviations after removing the harmonic constituents and comparing the harmonic constants obtained in each tide gauge record after one year of data.

As future work, we intend to develop a technique for the appropriate analytical and statistical treatment, the aim of which is to obtain solutions for calculating the inspection period that minimizes the number of failures of the tide gauge station.

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