Comparison of two data acquisition protocols for tide gauge sensors at Imbituba port – Santa Catarina State

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Abstract – The Santa Catarina Tide Gauge Network (SCTGN) is a continuous sea level monitoring system to support fishery, aquaculture, and navigation in general. Deployed in the state of Santa Catarina, Brazil, the initiative started in 2012 with one tide gauge at the Santa Catarina Island South Bay to support aquaculture research projects and hydrodynamic numerical modelling. By 2020, the SCTGN was operational, consisting of 11 tide gauge stations along the 450km of the Santa Catarina coastal line. The next step is standardizing these tide stations to international data collection protocols. Knowledge of the effects different programming protocols have on data collection are important since they may affect the results. Data from a radar gauge (RG) and a vented (or relative) pressure gauge (VPG) were obtained over six months. The difference between RG and VPG measurements showed a 5.07cm^2 variance. Percentage of reading errors was 0.03% and 0.77% for RG and VPG, respectively. This study aims to evaluate the feasibility of the SCTGN data collection protocol in the RG to comply with the Intergovernmental Oceanographic Commission (IOC) recommendations for sea level monitoring. We find that an RG gauge using the SCTGN protocol is adequate to monitor sea levels and has an easier installation and maintenance, and more stable vertical datum control.

Index terms: Monitoring; Navigation; Data quality; Database.

Comparação de dois protocolos de aquisição de dados para sensores de marégrafos no porto de Imbituba – Santa Catarina

Resumo – Um sistema de monitoramento contínuo do nível do mar foi implantado para apoiar a aquicultura, pesca e a navegação em geral. A iniciativa, denominada de SCTGN (do inglês *Santa Catarina Tide Gauge Network*), foi iniciada no ano de 2012 com uma estação maregráfica na Baía Sul da Ilha de Santa Catarina para apoiar projetos de pesquisa na área de aquicultura e modelagem numérica hidrodinâmica. No ano de 2020, a SCTGN se estabeleceu com 11 estações maregráficas. A próxima etapa é padronizar as estações para atender aos protocolos internacionais de coleta de dados. O conhecimento sobre os efeitos de distintos protocolos de programação nas estações maregráficas são muito importantes, pois podem afetar os resultados das medições do nível do mar. Dados do sensor de radar (RG) e do sensor de pressão ventilado (ou relativo) (VPG) foram coletados durante um período de seis meses no mesmo local. A variância da diferença entre os dois sensores foi de 5,07cm^2. O percentual de erro de leituras foi de 0,03% e 0,77% para o RG e o VPG, respectivamente. O objetivo do estudo foi avaliar a viabilidade do uso do protocolo de coleta de dados do SCTGN associado com o sensor RG para atender as recomendações do *Intergovernmental Oceanographic Commission* (IOC) para monitoramento do nível do mar. O uso do protocolo adotado para a SCTGN no marégrafo RG é adequado para monitoramento do nível do mar e tem vantagens em relação ao VPG no que se refere a facilidade de instalação, manutenção e garantia de estabilidade do *datum* vertical.

Termos para indexação: Monitoramento; Navegação; Qualidade de dados; Base de dados.

Introduction

The continuous monitoring of sea levels is extremely important for several applications, especially in populated regions such as the coast of the state of Santa Catarina, Brazil, spanning more than 450km, and accommodating half of its population. Tide monitoring has many applications such as aquaculture, research on climate change, navigation, infrastructure works, mathematical modelling, tourism, and outflow of production via ports. Automation, associated with extending real-time coastal monitoring, implies a significant increase in the volume of received and stored data. Consequently, the protocols used for sampling and storage of datasets require special attention to increase their reliability.

In 2012, the state of Santa Catarina started a sea level continuous monitoring system named SCTGN by installing a tide gauge in the Santa Catarina Island South Bay. By 2020, the SCTGN comprised 11 tide gauge

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stations along the state coastline. The next step is standardizing these stations to international data collection protocols. The aim is to achieve a tide data sampling quality complying with the Intergovernmental Oceanographic Commission recommendations for sea level monitoring (IOC, 2016). The selected monitoring location for the experiment is particularly important because it is the National Datum Reference for altitudes of the Brazilian high-precision altimetry network, defined between 1949 and 1957 as the mean sea level at the Port of Imbituba (SC). Moreover, the tide station aims to determine and monitor the temporal evolution of altimetric data for the Brazilian Geodetic System (IBGE, 2013)

This study compares results of two different tide gauges measuring the sea level at the same location using a Santa Catarina State Agricultural Research and Rural Extension Agency (Epagri) protocol, and an IOC protocol.

Material and methods

The tide gauges are located at Imbituba Port, 28°13’53”S 48°39’01”W (Datum Sirgas 2000), under the mooring platform (Figure 1A). The location for measuring tides is optimal because the harbor breakwater protects the gauges. The two types of sensors used to measure the sea level were: i) radar gauge (RG); and ii) vented pressure gauge (VPG). The RG (Figure 1B) sits at a location above the maximum expected sea level plus the blanking distance of the equipment and measures the distance from the installation point until the sea surface via the time spent by the electromagnetic pulse to move from the sensor to the sea surface and back. The pulse transmission frequency is 24.1 GHz (OTT, 2015). The VPG (Figure 1C), on the other hand, must be submerged below the lowest expected sea level and locked to a known position allowing its reallocation after maintenance or other purposes. The sensor measures the difference between water column and atmospheric pressures, converting it into a signal between 4 to 20mA proportional to the water level (NIVETEC, 2017). Although VPG contains a tube protecting it, it fails to work as a stilling well.

Both tide gauge stations contain a level sensor, a datalogger to define reading procedures for the sensors and averaging protocols, a General Packet Radio Services (GPRS) modem to send data via internet to a database server, and a power supply consisting of a solar panel, charge controller, and battery.

The RG tide station protocol reads the water level every five minutes and, due to its intrinsic characteristics, performs an average of 320 measurements in, approximately, 20 seconds (16Hz sampling). Our samples were obtained during the first 20 seconds of the five-minute interval.

The VPG tide station was configured to follow the IOC protocol of continuous sampling, averaging 60 measurements per minute (1Hz sampling). The equipment sampled from 30 seconds before a full minute to 30 seconds after that minute, averaging the measured values.

Sea level data for both tide gauges were obtained for 200 days from October 2018 until May 2019, resulting in 57.410 and 287.050 samples for RG and VPG, respectively. Data received by the server passed through a data quality control system based on three tests: 1 - physical limits (range) test to check if the data were within an acceptable interval; 2 - abrupt variation test to check for variations over a possible interval; 3 - persistence test to check if the equipment was returning a fixed value (GRAYBEAL et al., 2004). Finally, once the dataset was received and checked by the server, tide values were referenced to the same specific vertical point on land (or benchmark) to establish a relation between the two tide gauges. Only five-minute samples were used from both tide gauges to guarantee the same sample size. The harmonic analysis was made using the PAC Mare software from Franco (2009).

Results and discussion

Before showing the comparison between RG and VPG measurements, we must highlight that the VPG requires no correction for the effects of atmospheric pressure variations. The vent of the sensor applies the atmospheric pressure directly to the opposite side of the sensor, correcting the measurements representing the true water column. Besides, RG has intrinsic advantages over VPG in its easy installation, maintenance, vertical data stability due to its lack of contact with the water and, avoids biofouling.

Figure 1. Tide gauges location at Imbituba port (A); RG and its support (B); VPG, its support and protection tube (C). Photos: Google Earth and Matias Guilherme Boll

Figura 1. Localização dos marégrafos (A); RG e seu suporte (B); Tubo de suporte, proteção e VPG (C). Fotos: Google Earth and Matias Guilherme Boll

Table 1. Statistical values comparing the measurements of RG and VPG tide gauges for 200 days at Imbituba port, Santa Catarina, Brasil

Tabela 1. Valores estatísticos comparando os resultados das medições entre os dois marégrafos RG e VPG durante 200 dias no porto de Imbituba, Santa Catarina, Brazil

Test	RG tide station	VPG tide satiation
Average sea level	49.27 cm	49.25 cm
Standard deviation	23.81 cm	24.35 cm
Maximum	123.6 cm	126.3 cm
Minimum	-37.6 cm	-38.2 cm
Coefficient of Determination (r^2)	0.982	

We prepared two timeseries for comparisons and estimations. We discarded all VPG values that failed to pair with RG values, maintaining only time-coincident values. Moreover, if one of the tide gauges series lacked a value, we also discarded the equivalent value for the other gauge. During the 200-day experiment, our server identified 117 and 246 missing values due to errors on GPRS transmission for RG and VPG, respectively. The server data quality protocol identified problems in 16 (0.03%) and 440 (0.77%) RG and VPG values, respectively. The resulting dataset consists of 57.410 values for each timeseries.

We checked the timeseries for significant differences between the measurements from the two gauges. We obtained the difference in values from both gauges by directly subtracting the measured values. Figure 2 shows the difference between the two gauges. We compared our results to Mehra's et al. (2009) who reported a variance of 5.7cm^2, after correcting their sensors for atmospheric pressure. The variance obtained from the difference between the two gauges was 5.07cm^2.

The peaks in Figure 2 reached absolute values of up to 40cm, probably due to high-frequency water level variation and some isolated sensor errors that the quality data protocol failed to tag. The largest peaks occurred on December 8th, 2018, marked as two red dots in Figure 2. The wind speed showed a daily average of 14km h^{-1}, and a maximum daily peak of 33km h^{-1}. Both sensors showed high value fluctuation throughout the day, reaching a five-minute maximum of 73cm and 45cm for RG and VPG, respectively. The variance of the difference obtained for that day was ten times greater than the average value for the complete timeseries, resulting in 58.94cm^2. In both cases the data acquisition protocols, IOC and ours, were unable to register a steady timeseries. On the other hand, most of peaks are isolated values in the time series, associated with low-speed winds unable to cause high frequency waves that could disrupt the measurements. Some examples (green dots), such as January 31st, 2019, and March 3rd, 2019 showed average wind speeds of 6km h^{-1} and 9.6km h^{-1}, and maximum daily speed of 24km h^{-1} and 18.5km h^{-1}, respectively.

Both timeseries showed a positive tendency, probably due to the short period of monitoring. We independently adjusted a linear equation for each timeseries. Both series produced the same 0.0004 angular coefficient, indicating that this tendency was probably due to environmental conditions, and not sensor problems. Table 1 shows the results of our basic statistical tests.

We graphically compared both timeseries to check for significant variations. Figure 3 shows this comparison. The data showed a 0.99 correlation coefficient, with the sensors concomitantly registering high frequencies (Figure 3B).

Finally, we obtained the amplitude via a harmonic analysis of the tidal constituents, that is, half the range of a tidal constituent, and the phase, that is, the phase lag of the observed tidal constituent relative to the theoretical equilibrium tide, for RG and VPG. Table 2 shows all the main tidal constituents with amplitudes greater than 1cm. The values were estimated using the 200-day data.

Resembling Mehra's et al. (2009) findings, the main diurnal, semidiurnal, and fortnightly tide amplitude difference between RG and VPG is less than 1mm. Moreover, Table 2 shows reduced phase differences, none above 1º.

Although all the tests used the 5-minute timeseries, the tide gauge at Imbituba port can now perform measurements at 1-minute intervals, with redundancies, complying with all IOC recommendations for a sea level monitoring facility (http://www.ioc-sealevelmonitoring.org/station.php?code=imbi).

This study compared two tide gauge data collection protocols to evaluate the similarity of the results and the viability of using the SCTGN protocol to

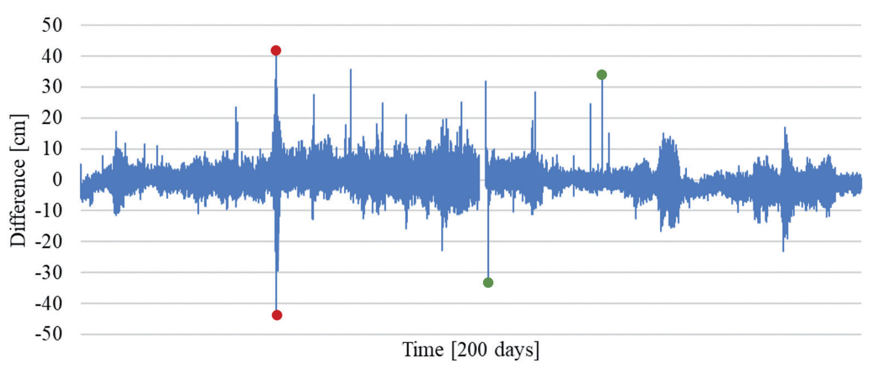

Figure 2. Graph of the difference in the values recorded by the RG and VPG tide gauges at Imbituba port from October 2018 until May 2019. The high red peaks occurred during high-speed winds, and high green peaks, during low-speed winds

Figura 2. Gráfico apresenta a diferença nos valores registrados pelo marégrafo RG em relação ao VPG no porto de Imbituba entre outubro de 2018 até maio de 2019. Picos altos marcados em vermelho ocorreram durante ventos de alta velocidade e picos altos marcados em verde ocorreram durante ventos de baixa velocidade

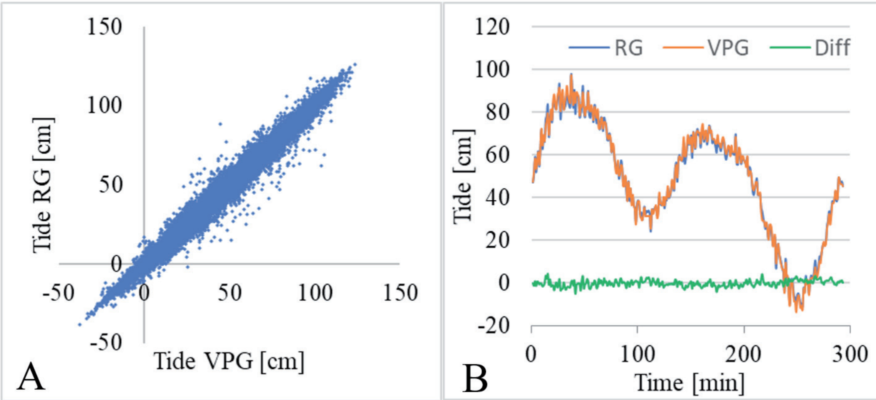

Figure 3. A) Data correlation for RG and VPG measurements at Imbituba port, and B) Sample of the timeseries recorded for 300 minutes showing RG and VPG measurements and the difference between them (Diff)
Figura 3. A) Correlação dos dados dos níveis do mar registrados pelos dois marégrafos RG e VPG no porto de Imbituba e B) Amostra das séries temporais registradas para o período de 300 minutos apresentado as medições de RG, VPG e a diferença entre elas (Diff)

Table 2. Main harmonic constituents extracted from the timeseries for both tested tide gauges at Imbituba port, Santa Catarina, Brasil
Tabela 2. Principais constituintes harmônicas extraídas das séries temporais para ambos os marégrafos testados, Santa Catarina, Brazil

Harmonic constituents[1]	RG		VPG	
	Amplitude [cm]	Phase [°]	Amplitude [cm]	Phase [°]
Q1	2.78	52.46	2.78	53.05
O1	10.73	68.43	10.73	68.48
P1	1.82	126.16	1.82	126.79
K1	6.08	127.87	6.11	127.92
2N2	1.23	132.1	1.23	131.54
MU2	1.41	92.65	1.4	92.81
N2	3.5	146.33	3.5	146.43
M2	14.86	57.57	14.87	57.56
S2	11.12	54.02	11.13	54.04
K2	3.61	43.77	3.62	44
M3	1.31	140.77	1.3	140.19
MN4	1.36	301.56	1.37	300.78
M4	3.26	344.81	3.27	344.63
MS4	1.33	68.05	1.33	67.46

[1]Names of the harmonic constituents available at: https://www.gdacs.org/Public/download.aspx?type=DC&id=172

conform to IOC recommendations. The RG showed fewer reading errors, with 0.03% and 0.77% of errors for the RG and VPG, respectively, mostly related to equipment characteristics rather than sampling protocols. Both gauges showed expected higher variations during high-speed winds, considering the absence of a stilling well.

Conclusion

Based on 200 days of continuous measurements we conclude that the SCTGN protocol is adequate for sea level monitoring and produces almost identical results and tidal constituents as the IOC protocol.

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