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Comments on the article “Uncertainty and bias in electronic tide-gauge records: Evidence from collocated sensors” by Stella Pytharouli, Spyros Chaikalis, Stathis C. Stiros in Measurement (Volume 125, September 2018)

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1 **Comments on the article “Uncertainty and bias in electronic tide-gauge records: evidence from**
2 **collocated sensors” by Stella Pytharouli, Spyros Chaikalis, Stathis C. Stiros in Measurement**
3 **(Volume 125, September 2018)**

4
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19 **Declarations of interest:** none.

20
21

22 **Abstract**

23

24 This note comments on the article published in *Measurement* by Stella Pytharouli, Spyros
25 Chaikalis and Stathis C. Stiros (Volume 125, September 2018) entitled “Uncertainty and bias
26 in electronic tide-gauge records: evidence from collocated sensors”. That paper comprises a
27 set of comparisons between sea level data obtained by two or three collocated sensors at
28 10 sites around the world, using statistical methods akin to the buddy-checking methods
29 that are often used by tide gauge operators. Their paper contains a number of incorrect
30 statements. In addition, its comparison of tide gauge data at the 10 sites, which comprises
31 most of the paper, is flawed in several respects.

32

33 **Keywords:** Sea level database; Tide gauge records; Tide gauge benchmarks; Openly
34 accessible data; GLOSS programme

35

36 We refer to a recent article “Uncertainty and bias in electronic tide-gauge records: evidence
37 from collocated sensors” published in *Measurement* by Stella Pytharouli, Spyros Chaikalis
38 and Stathis C. Stiros. This comment aims at correcting some incorrect statements in that
39 paper. In addition, we hope to clarify some important aspects to do with the source of the
40 data used in their study, so as to enable any reader to better understand the findings
41 presented.

42

43 The authors looked at sea level data obtained by two or three collocated sensors at 10 sites
44 around the world, and made comparisons between the different sensors using statistical

45 methods akin to the buddy-checking methods that are often used by tide gauge operators
46 (IOC 2016).

47

48 *(1) They mention that their comparisons were limited by the number of sites with*
49 *collocated sensors. They state (page 496) that “Currently, the percentage of sites*
50 *with collocated sensors is of the order of a few percent of the total sites covered with*
51 *tide-gauges.”*

52

53 Most tide gauge sites from which data are provided to the Intergovernmental
54 Oceanographic Commission (IOC) Global Sea Level Observing System (GLOSS), the
55 Permanent Service for Mean Sea Level (PSMSL), and the University of Hawai’i Sea Level
56 Center (UHSLC) have multiple sensors. For example, most stations in the UK National
57 Network (with which, given the address, one would have assumed the lead author to be
58 familiar) contain dual bubbler systems. Data from both primary and secondary channels can
59 be downloaded readily from the British Oceanographic Data Centre (BODC,
60 <https://www.bodc.ac.uk>).

61

62 Other examples include the modern US (NOAA) network and the international network
63 maintained by the UHSLC. The former has been based on acoustic sensors supplemented by
64 pressure sensors, although that network is now transitioning to radar sensors (Park et al.
65 2014). The latter is primarily based on radar sensors (often two radars at each site)
66 supplemented by pressure sensors when possible. Detailed descriptions of sea level
67 recording in many other countries can be obtained from the national reports to regular

68 meetings of the GLOSS programme (<http://www.gloss-sealevel.org/>) and those reports
69 show that most countries employ two or more sensors at each site.

70

71 All of the data from duplicate or multiple sensors will be available for inspection by the
72 owners of the sites and the local technical specialists. However, it is not necessarily the case
73 that data from all sensors are passed to the IOC Sea Level Station Monitoring Facility
74 (SLSMF) at the Flanders Marine Institute (<http://www.ioc-sealevelmonitoring.org/>), which is
75 where Pytharouli et al. obtained their data. For example, in the case of the UK, data from
76 only the so-called primary bubbler channel are provided to the SLSMF.

77

78 *(2) Section 2.1 states that the data used in this paper were obtained from the IOC*
79 *SLSMF.*

80

81 The IOC SLSMF was established to provide near-real time displays of data from those tide
82 gauges around the world which are part of GLOSS or the several regional IOC tsunami
83 networks (IOC 2012). The facility was provided primarily for the operational benefit of tide
84 gauge owners who do not have their own display systems so that faults could be identified
85 and fixed as soon as possible.

86

87 All data are displayed as received, archived and are accessible to interested users. However,
88 the web site makes clear that the data has not undergone any quality control, and there is a
89 clear disclaimer to that effect. The data providers for each station are mentioned in order to
90 facilitate contact in case of a user's concerns or requests (e.g., if data are required for
91 commercial purposes).

92

93 The data from the SLSMF have occasionally been used in scientific research. However, such
94 research has usually been made by people who are aware of the difficulties of dealing with
95 such data and who have been able to make additional quality control. Pytharouli et al. state
96 correctly that the *“policy of IOC is to check data in time due and automatically discard or*
97 *repair sections of time series, so that final records are free of errors and of significant*
98 *inconsistencies”*. For operational or research applications, users are directed by the SLSMF
99 to dedicated IOC/GLOSS data centres which differ in the type of data quality control applied
100 and the delay in making data available (IOC 2012).

101

102 *(3) Section 2.1 rightly mentions the need for access to metadata as well as to tide gauge*
103 *data itself.*

104

105 All tide gauge stations experience problems in their supply of data from time to time. Some
106 stations are remote and will have had power outages, communication problems etc. as well
107 as technical faults in the gauge hardware itself. Occasionally, it will have been necessary to
108 replace the sensors. Over a period of a decade or more (this paper seems to consider data
109 from 2007 onwards) it is inevitable that there will have been gaps in the recording or data
110 which appears anomalous in some way.

111

112 When inspecting time series of real-time tide gauge data from the SLSMF (or a local display),
113 the only people who are in a position to understand anything that looks anomalous are the
114 owners and operators of the equipment who will have access to installation reports and

115 maintenance logs. Such detailed information is not available to a random user of the SLSMF
116 web site.

117

118 For example, Figure 4 of the paper shows flat values near low tide for pressure sensor PRS1
119 at Aden. The installation report of the Aden station shows that PRS1 was installed as a 'half-
120 tide sensor' (IOC 2006) for which the observed bottoming-out at low tide was in fact
121 intentional. (PRS2 was installed much deeper than PRS1 and may also occasionally bottom-
122 out during very low tidal levels.) This is something that cannot be appreciated without some
123 knowledge of the hardware and the station layout. A thoughtless downloading of data from
124 all channels, and subjecting them to a statistical comparison, is pointless. The radar data
125 from this station have proved to be very reliable (e.g. Woodworth et al. 2009). (We can
126 further point out that the location of Aden shown in Figure 2 is incorrect.)

127

128 Section 3.2.2 refers to zero values for some or all sensors at certain sites. These can
129 sometimes arise from local hardware malfunction but are as likely to occur from
130 transmission errors between the station, the satellite (e.g. Meteosat), the Global
131 Telecommunications System (GTS) and the SLSMF. Meteosat and other meteorological
132 satellites are not 100% reliable for data transmission, with occasional bit-error corruptions
133 and short data gaps which meteorological data users can usually tolerate. Nevertheless,
134 these satellites are made available freely to tide gauge owners in GLOSS, which explains why
135 they have been adopted as one of the main data transmission methods for the global
136 network. In practice, zero values can be spotted instantly and rejected from any record, with
137 small gaps interpolated. We do not see why the authors felt the need to discuss such a
138 trivial issue.

139

140 Another example we can mention is to do with the Alexandria pressure sensors in Figure 6.
141 Alexandria was installed as part of modernisation of the African sea level network
142 (Woodworth et al. 2007) for which there were many problems with pressure sensors,
143 explaining the time series shown in this figure. Sensors were replaced from time to time,
144 hence the jumps in datum. Bad data are never removed from the SLSMF archive in case they
145 are needed again in the future, and neither are they flagged as bad, so there is always a
146 danger that they can be spotted and remarked on by authors such as the present ones who
147 are not in a position to know all the historical details. At this station the radar sensor
148 provided good data for many years (2009-2016) with monthly mean sea level values
149 included in the PSMSL data set.

150

151 A final example is the “sudden step” in the difference between radar and pressure sensors
152 from Kaunapali, Hawai‘i shown in Figure 7. The discussion of this step is rightly attributed
153 to station maintenance, but it is a naïve and misleading perspective without noting that this
154 offset is not carried forward into the quality-controlled sea level datasets provided by GLOSS
155 data centres. When a radar (or any other) sensor is serviced or replaced, it must be
156 unmounted and then remounted. Station technicians perform an engineering-grade survey
157 to find the offset of the reinstalled sensor relative to the station benchmarks. This offset is
158 then applied to the observed levels prior to distributing the data for oceanographic and
159 geodetic applications. As discussed elsewhere in this response, data from the SLSMF is for
160 real-time monitoring purposes and not appropriate for other applications. Thus, the offset
161 should not be classified as an “error” as the authors present. Rather, the offset reflects
162 water level measurements before they have been converted to sea level. By definition, ‘sea

163 level' is water level relative to land, or more specifically, relative to geodetic benchmarks.
164 Variability in SLSMF data is not guaranteed to represent sea level in this strict sense due to
165 an inability to apply levelling offsets in real time.

166

167 Section 2.1 implies that the authors made *"inquiries to tide-gauge or data basis curators"*,
168 from which they might have learned more about the histories of recording at their 10 sites.
169 That would indeed have been sensible. However, there is no record of them having made
170 enquiries for information from IOC, SLSMF, National Oceanography Centre (NOC, which
171 provided the Alexandria gauge), UHSLC (which provided the Hawai'i and Tern gauges), GFZ
172 Potsdam (which provided the Aden gauge) or from any of the other station contacts given
173 on the SLSMF web site.

174

175 *(4) Different sensors for different purposes.*

176

177 This leads to a further aspect of sea level recording that appears to have been ignored in the
178 paper, which is that different sensors are installed for different purposes. The paper seems
179 to treat all channels as equally worthy of statistical comparison.

180

181 The GLOSS Implementation Plan (IOC 2012) and IOC Manuals (IOC 2006; 2016) make it clear
182 that new stations must have multiple sensors (as mentioned above, most of them already
183 have multiple sensors). For example, radar gauges have been shown to be capable of
184 providing time series with little or no instrumental drift, unlike pressure sensors which do
185 tend to drift. However, both are desirable at a site, given that pressure sensors can be
186 sampled at high frequency, and so be useful for detecting processes such as seiches and

187 tsunamis (and even waves if sampled at 1 Hz or similar). There is little point, therefore, in
188 deriving statistical conclusions as in this paper from sensors that were installed for different
189 purposes.

190

191 We can furthermore point out that channels of data into the SLSMF could be occasionally
192 from experimental setups and therefore provide information that is completely meaningless
193 to anyone else.

194

195 *(5) Their abstract states "Pressure gauges were found significantly more sensitive to*
196 *noise than radar-type sensors, and with higher chances of long-term transient bias".*

197

198 The finding of a 'long-term transient bias' with pressure sensors is something that has been
199 known for years (Woodworth and Smith 2003; Martin Míguez et al. 2012), and which is now
200 discussed at length in manuals and textbooks (IOC 2006; Pugh and Woodworth 2014). In
201 brief, pressure tide gauges are based on the principle of measuring sub-surface pressure,
202 which is converted to height based on knowledge of the water density and local
203 acceleration due to gravity. However, all pressure gauges are sensitive to temperature
204 effects and are prone to instrumental ageing. Some sensors have an in-built temperature
205 sensor to allow temperature compensation. However, large instrumental drifts have been
206 reported in excess of 1 mm/year, even when using the best possible (and most costly)
207 sensors (Martin Míguez et al. 2012). This is clearly a major concern for long-term sea level
208 studies. (There is an additional source of datum error if pressure sensors are taken out of
209 the water for annual maintenance and replaced at a slightly different height, see IOC 2006).
210 Pressure gauge designs exist which attempt to circumvent these problems (e.g., see

211 discussion of 'B gauges' in IOC 2006). However, they can be expensive and have not been
212 adopted by most groups. As for different noise levels, one should note that measurements
213 with the same nominal sampling period (e.g. one or several minutes) are not necessarily
214 equivalent, those by pressure sensors sometimes being spot (instantaneous) measurements
215 while radar values will be averages over manufacturer-defined periods.

216

217 Why then are pressure sensors still so widely used in coastal tide gauge stations? The reason
218 is that they are particularly well suited for installation and operation in environmentally
219 hostile areas at sites with minimal infrastructure and harsh weather conditions, where the
220 exposed structures may be subject to extreme winds and waves. Hence, they are more likely
221 to resist and record a tsunami wave or a storm surge (identification of which does not
222 require rigorous datum stability). Consequently, pressure gauges are important components
223 of multi-application sea level networks such as the GLOSS core network of sea level stations,
224 in which they complement the primary tide gauge (typically a radar sensor nowadays). We
225 suggest that the authors read IOC (2016) for more information.

226

227 *(6) The abstract further says that on average, over the 1-4 year timespan of data*
228 *considered, "only 9% of the sensors analysed were found to satisfy the 1-cm accuracy*
229 *criterion" imposed by the GLOSS programme (IOC 2012).*

230

231 This finding is consistent with our comments above on the way that the authors selected
232 their data for analysis, especially since their study considered multi-year periods of
233 operation. It is interesting that, of the ten stations with co-located sensors analysed in their
234 paper, only Punta Cana, Dominican Republic had two co-located sensors which were both

235 radar gauges. The radar technique has progressively replaced the previous tide gauge
236 technologies over the past decade (e.g., Martin Míguez et al 2008; Park et al. 2014), even
237 though additional research is required concerning their longer-term suitability at some
238 locations (IOC 2016). It is thus comforting to read that a 1.8 cm rms (root mean square)
239 difference between sensors was found at Punta Cana, and no substantial bias reported over
240 a 518-days long recording time span.

241

242 *(7) Section 4.9 states that “Errors usually found in raw tidal data are removed and not*
243 *displayed in data bases. Such modification tends to shadow important metrological*
244 *information. On the contrary, raw and corrected data sets should be fully shown, as*
245 *is the case in disciplines, for example in data bases used in Climatology”*

246

247 This is a misleading statement. When raw data are passed for further quality control to the
248 other centres connected with the GLOSS programme (IOC 2012), they are processed to
249 modern data management standards, with all data flagged and capable of recovery and not
250 simply deleted. As the lead author is based in the UK, we suggest that she discusses with
251 BODC how they process and archive sea level data.

252

253 *(8) Section 2.2.1 states that to provide records with a common datum one needs 19*
254 *years of data.*

255

256 This is a tangential point but is worth clarifying. The text is alluding to the traditional
257 requirement for 18.6 years of data for the definition of hydrographic datums such as Lowest
258 Astronomical Tide (a requirement that in practice is almost never met). However, in the

259 context of a common datum discussed here, there is no data requirement at all. Provision of
260 a common datum is a simple technical issue.

261

262 In conclusion, we believe that this paper is misleading in several respects and that the
263 statistical analyses undertaken have little value. In our opinion, if the authors intend to
264 continue investigating tide gauge data, we encourage them to engage properly with IOC,
265 SLSMF, NOC or UHSLC and to understand properly the data that they are dealing with. Blind
266 data mining studies such as this are of little value. At least we can agree with the paper
267 ending on a positive note, recognising that it is becoming increasingly common to have
268 multiple sensors at tide gauge sites and that there is much to be learned about systematic
269 errors from their inter-comparison.

270

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272

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274 and other colleagues.

275

276

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