Tide gauge records at Dakar, Senegal (Africa): towards a 100-years consistent sea-level time series?

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Context of the study

An important issue concerned with the understanding of sea level variations due to climate change is that long-term sea level records do not present a uniform geographical distribution. With a small number of exceptions, these records are located on the Northern hemisphere, mainly in Europe, North America, and Northern Asia. Only 7 stations in Africa with a reliable datum continuity have over 40 years record lengths, according to the PSMSL databank. In this context, the investigation that we have initiated at Dakar, Senegal, to find and rescue past sea-level records may prove worthwhile.

Sea level records in Africa

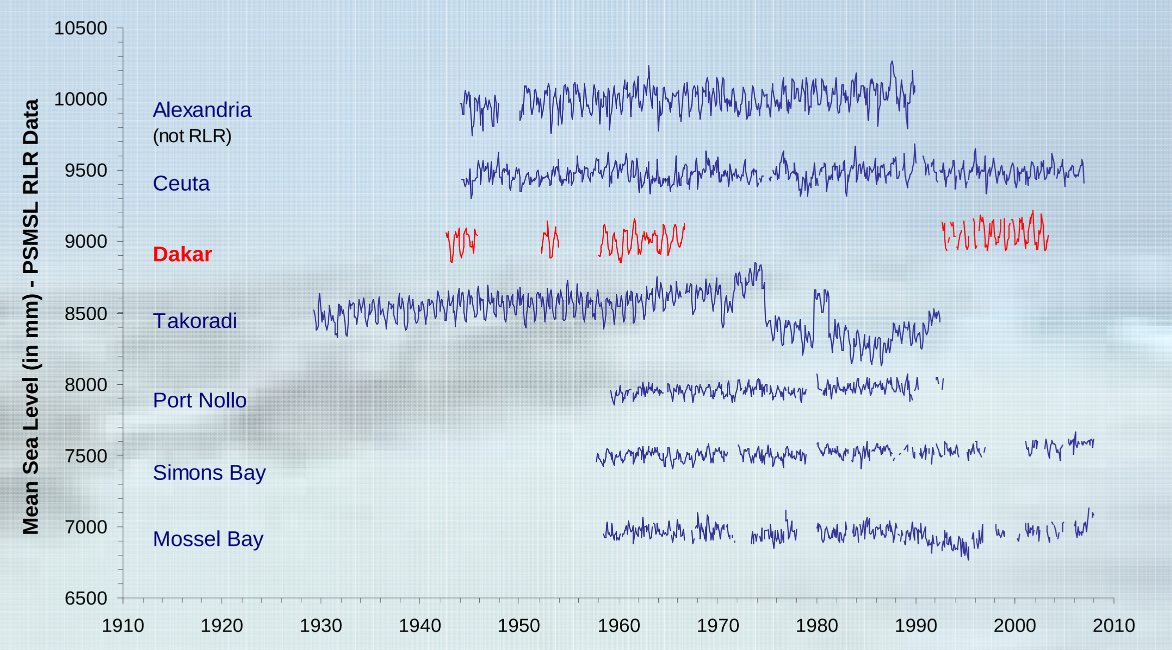

Figure 1. Monthly mean sea level time series for the 7 stations in Africa that have data at PSMSL over a time period of more than 40 years. Each time series contains an arbitrary offset.

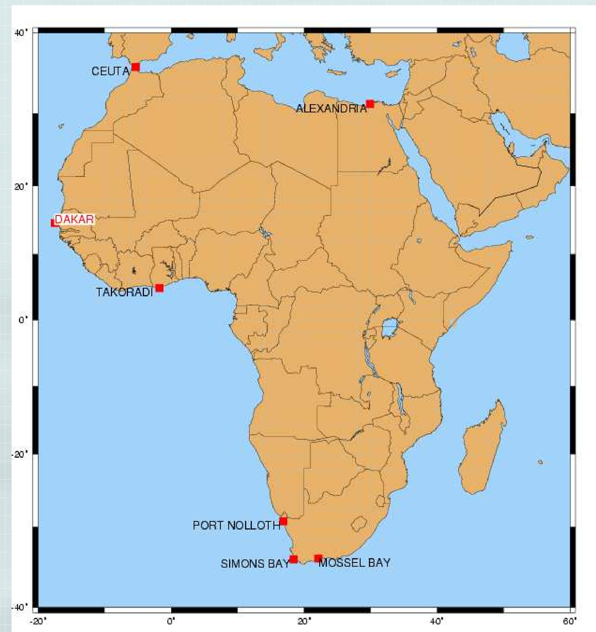

Figure 2. Location of the 7 African stations for which there is data over more than 40 years at PSMSL.

STATION	Time span	# valid years	Trend (mm/yr)	Month RMS (mm)	Annual RMS (mm)
Alexandria	1944-1989	46	2.03±0.27	80	-
Ceuta	1945-2006	54	0.39±0.22	57	29
Dakar	**1943-2002**	**16**	**1.48±0.21**	**72**	**17**
Takoradi	1930-1991	61	-	-	-
Port Nolloth	1959-2007	30	1.11±0.28	35	20
Simons Bay	1958-2007	28	1.14±0.34	36	23
Mossel Bay	1959-2006	26	-0.66±0.47	53	32

Table 1. Basic statistics for the above 7 time series available at PSMSL (April 2008).

Notes:
1. Statistics have not been computed for Takoradi because of the suspect behavior of its time series after 1974.
2. Alexandria data is from the so-called 'Metric' data set (i.e. there is no information on the datum, or not yet quality controlled at PSMSL)
3. RMS is the root-mean-square computed from the monthly or annual values with respect to the linear trend values.

Sea level records in Dakar

Several decades of sea level observations recorded at Dakar have been found so far, the earliest dating back to 1889 (Pouvreau, PhD Thesis). This poster provides an overview of the past and present sea level records at Dakar. Most of the historical records are in paper form (tidal charts and tabulations). They are not included in public data banks yet. Most of the digitalisation has been performed (see details in Table 2). The quality control has just started, carried out at SHOM and University of La Rochelle. We present here very preliminary results.

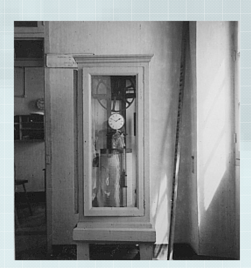

Figure 3. View of the recording drum and clock of the mechanical floating tide gauge at Dakar (SHOM, 1959).

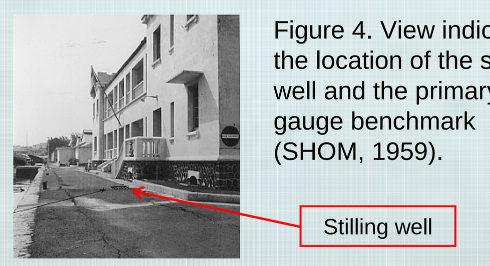

Figure 4. View indicating the location of the stilling well and the primary tide gauge benchmark (SHOM, 1959).

Data inventory

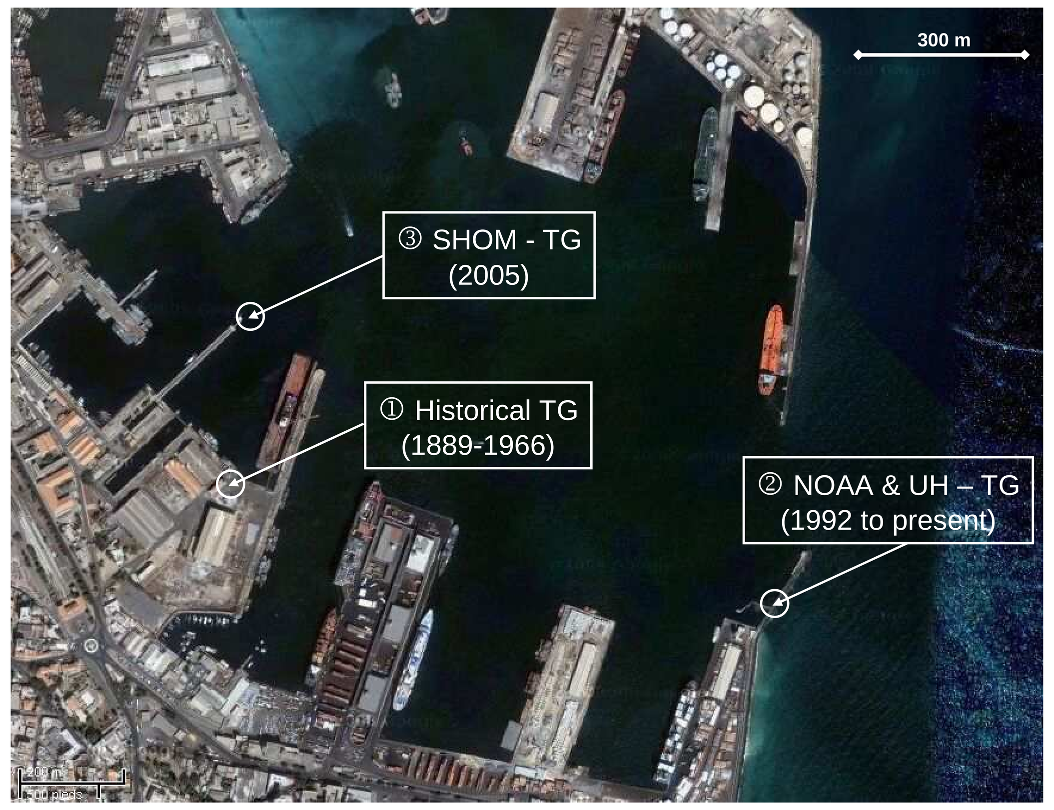

Figure 5. Google Earth image showing the location and authorities that have performed sea level observations at Dakar harbor from 1889 till present.

Data set (Time Span)	Site (Cf. Maps)	Data archive source	Data form (Type of gauge)	Numerical form	MSL available at PSMSL
1889; 1900	①	SHOM (Brest)	Tidal charts (Floating gauge)	No	No
1902-1919	①	SHOM (Brest)	Tidal charts (Floating gauge)	Yes	No
1920; 1930; 1932	①	SHOM (Brest)	Tidal charts (Floating gauge)	No	No
1936; 1937	①	SHD (Rochefort)	Manuscript (Floating gauge)	No	No
1942-1945 1952-1953	①	SHOM (Brest)	Tidal charts (Floating gauge)	Yes	Yes
1958-1966	①	SHOM (Brest)	Tidal charts (Floating gauge)	Yes	Yes
1983-1984; 1986; 1987-1989	④	ORSTOM (Paris)	Numerical data (Pressure gauge)	Yes	Yes (Metric)
1992-1996	②	NOAA (USA)	Numerical data (Acoustic gauge)	Yes	Yes
1997-2003	②	UH (USA)	Numerical data (Acoustic gauge)	Yes	Yes
2003 (5 days); 2005 (3 months)	③	SHOM (Brest)	Numerical data (Pressure gauge)	Yes	No
2007 to present	②	UH (USA)	Numerical data (Radar gauge)	Yes	No

Table 2. Main characteristics of the Dakar sea level data sets currently available. (Locations ④ and ⑤ are 5 to 15 km away from Dakar harbor.

Continuity of the sea level observations datum

Historical documentation shows evidence for continuity of the zero level of sea level observations at Dakar. This zero is called "Zéro Hydrographique" (ZH); it corresponds to the Chart Datum.

- Le Bail (1911) reports the installation of a new primary tide gauge benchmark ("Nr. 0") and the determination of its height above the "Zéro Hydrographique" (ZH). The objective was to prevent the ZH from possible destruction because of the harbor extension.
- In 1932, the primary benchmark "Nr. 0" was rebuilt to prevent it from possible deterioration; its height remains unchanged (Doniol, 1947).
- Bureau Hydrographique (1942) reports that the height of benchmark "Nr. 0" was checked (confirmed to be 2.312 m above ZH). An additional benchmark was installed inside the protected well of the tide gauge (Benchmark "Nr. 0 bis") as a measure of precaution. Its height was determined to be 2.301 m above ZH.
- Doniol (1947) analysed the historical documentation related to ZH. It stressed the importance of the reference: the ZH is used by many local authorities (Harbor, Hydrographic, Mapping, Topographic…). Doniol concluded that the benchmark "Nr 0" (2.312 m) can be considered as unchanged since its installation in 1910, and that subsequently the ZH datum is locally stable and continuous since its origin.
- SHOM (1961) reports the height of the benchmark "Nr 21" is 3.091 m above ZH (see Figure 6).
- Univ. of Hawaii (2007) reports the zero level of its tide gauge at Dakar is 3.090 m (see Figure 6).

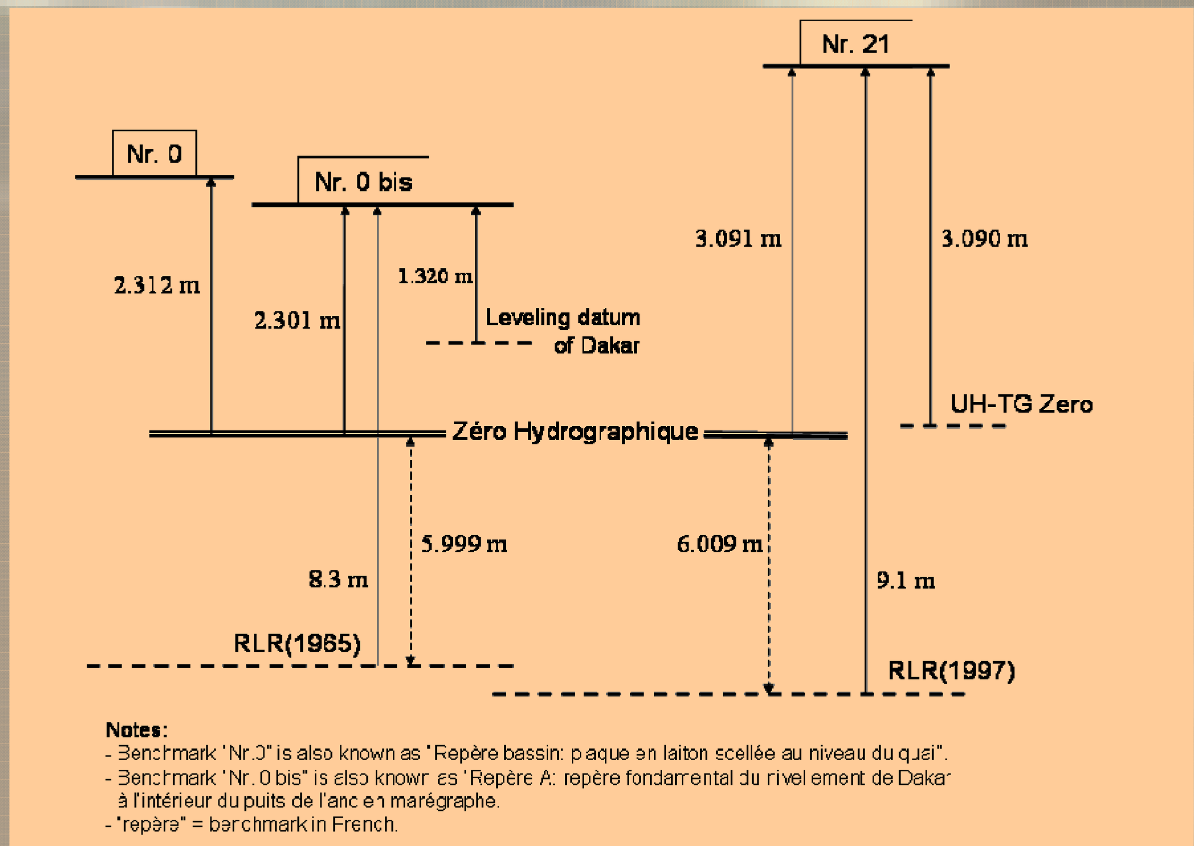

Figure 6. Diagram showing the situation of the relevant tide gauge benchmarks and datums.

Common data in 2003

- There are ~6 days (140 hourly values) of common observations between SHOM and US tide gauges in 2003 (See table 2).
- SHOM data is referred to ZH. The analysis of the differences gives: **2.3 ± 1.3 mm** , which is a difference that is statistically insignificant.

Concluding remarks on the datum continuity and consistency

1. The datum "Zéro Hydrographique" (ZH) remains unchanged since its origin. It can be considered as a stable local reference over the 100 years of recording sea level at Dakar, that all authorities carrying out leveling or sea level observations have used.
2. Rounding of 3.091 m value for the height of the benchmark "Nr. 21" to 3.090 m in some documents suggests that the zero level of the US tide gauge (NOAA, then University of Hawaii) is actually the ZH to which the historical sea level records are referred to.
3. Reference RLR(1965) of Dakar MSL values at PSMSL is 8.3 m (see PSMSL document 390001.docu), not 10.3 m as it is stated in 390001.html
4. The difference of 0.010 m between the PSMSL datums RLR(1965) and RLR(1997) may come
   (1) either from a confusion between benchmarks: "Nr. 0" instead of "Nr. 0 bis" (height difference of 0.011 m).
   (2) or a typing error in PSMSL documentation, which indicates a value of 2.302 m under the "fundamental benchmark" and neither corresponds to 2.301 m (height of "Nr 0 bis"), nor to 2.312 m (height of "Nr. 0").

Results

Preliminary analysis and results

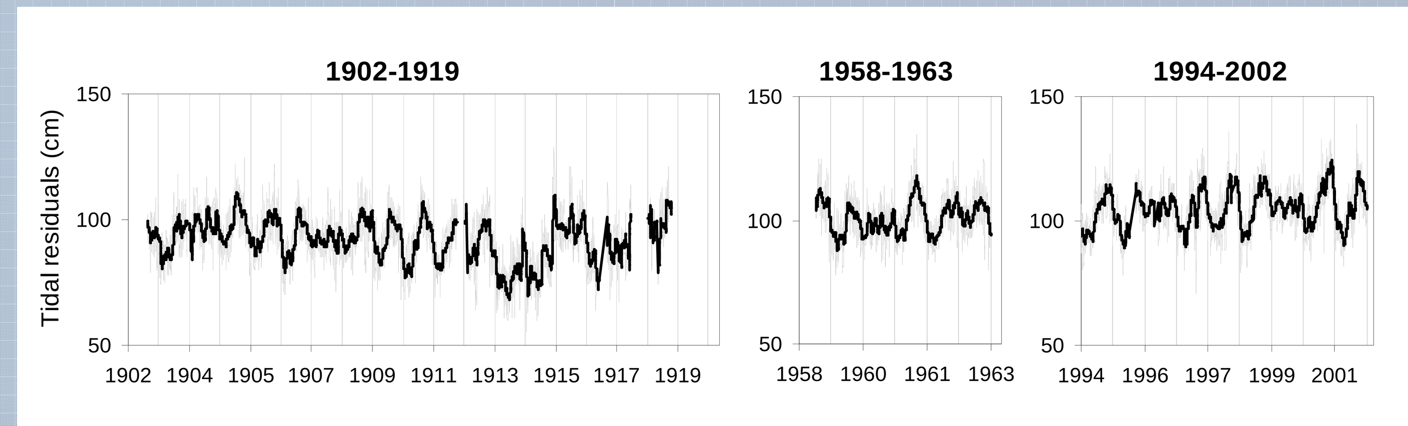

Figure 7. Hourly tidal residuals in Dakar considered for this study. The original time series has been decimated (line grey) and averaged (line black) to ease visualization.

Some preliminary analysis have been performed on the hourly time series now digitalized (1902-1919 and 1958-1963) to study their quality, compare them with the most recent data (1994-2003) and assess the consistency of the whole data set. As a consequence, some dubious periods were identified and discarded. T_TIDE software (Pawlowicz et al., 2002) was used to perform the harmonic analysis over periods of one year and calculate tidal residuals (observation minus tidal prediction).

The residuals are presented in Figure 7. One of the most evident features is the seasonal variation of the signal which can be explained by the changes in the meteorological regime. Two different seasons can be distinguished in the region, a dry and cold season from December to May (trade winds and coastal upwelling processes) and a rainy warm season from June to October. The associated changes in wind, temperature and atmospheric pressure can explain the observed seasonal variability in the tidal residuals.

Changes in M2 amplitude and phase were also considered. M2 amplitude varied between 44.7 cm and 46.4 cm with statically not significant greater values in the 1958-1963 period (95% confidence level). M2 phase varied from 252º to 267º. The differences in phase will be further analyzed in detail to quality control the digitized hourly data as they can reflect problems in timing or stilling well obstruction.

A time series reconstruction over 100 years

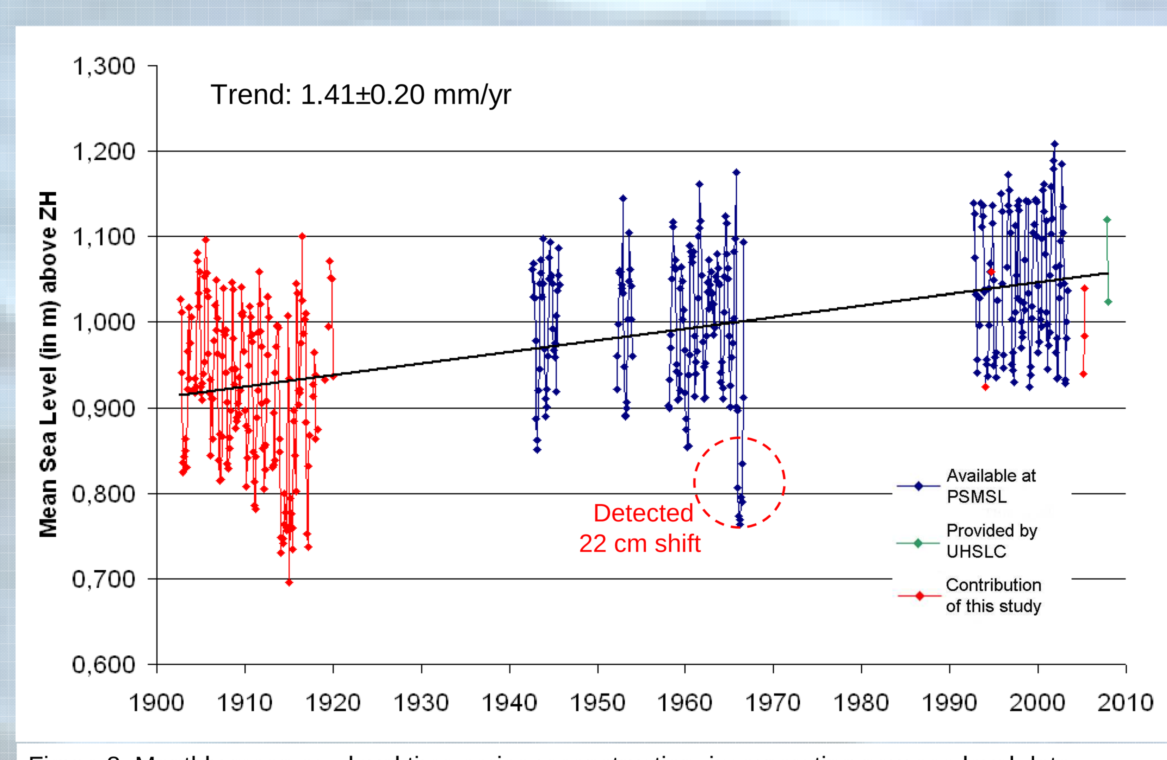

Figure 8. Monthly mean sea level time series reconstruction, incorporating new sea level data recovered from tidal charts and tabulations at SHOM.

CONCLUSIONS - PERSPECTIVES

Following the finding and digitalization of ancient Dakar sea level records, a first attempt to construct a consistent hourly sea level time series spanning more than 100 years has been undertaken. Evidence of the continuity of the zero level of sea level observations can be found after thorough inspection of the historical documentation. In spite of further in-depth analysis being required, first results show that most of the sea level set is comparable in terms of data quality. Some interesting features such as the seasonal oscillation of the sea level are evidenced and suggest a broad field of research ahead.

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