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# Tidal waves propagation in the Ebrié lagoon (south west coast of Côte d'Ivoire)

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***Abstract:*** *From the digitizing of historical marigrams, hourly measurements of water levels have been achieved. To analyze these data, an filter low-passed and an harmonic analyze was used. The tide oscillations are dominant in the lagoon. The tidal wave (M2) runs from the Digue-Ouest to Quai-Nord with decreasing amplitude and a speed of 1.7 m/s within 1h1836s. The amplitude ratio of the M2 wave between the two stations (Digue Ouest / Quai Nord) is equal to 1.49.*

***Keywords:*** *Marigram, tidal wave, Vridi channel, Digue-Ouest, Quai-Nord, Ebrié lagoon*

## I. Introduction

This work was inspired by the one realized by [1] in the San Pedro Harbour. For the opening of the Vridi channel in 1950, the tidal wave spread within the Ebrié lagoon, which has resulted, the change of the hydrodynamic operation of this lagoon ([2], [3], [4], [5] and [6]). The objective of this work is to determine the characteristics of the tidal wave during its propagation in the lagoon of Ebrié.

## II. Materiel And Methods

Covering 566 km$^2$, the Ebrié lagoon is located between latitudes 5°14'-5°22' N and longitudes 4°54'-3°42' W. In the Abidjan region, this lagoon system Ebrié consists of a central basin (harbour basin) Port of Abidjan) link to the sea by the Vridi channel, a western channel and an eastern channel. In addition to tide that penetrates into the lagoon by the Vridi canal, we have the inputs of the Comoé River in lagoon. n annual flood between September and October. This river is characterized by an annual flood in lagoon.

**Data origin**

Printed recording of tidal levels (marigram) of the period from January 1st to August 20th 1985 were available to us by the shom (www.shom.fr) . These tide levels come from two tide gauges whose the locations are illustrated in Fig.1.


**Figure 1:** Locations of tide-gauges Digue-Ouest and Quai-Nord in the Ebrié lagoon.

- the tide gauge Digue-Ouest is located on the west barrier of Vridi about 40 meters from the red lighthouse, which contains the fundamental reference point of the general leveling of Côte d'Ivoire. It served as a reference for tide predictions in Abidjan with an average level of 0.69 m. But this tide gauge was often destroyed by the swell;
- the tide gauge Quai-Nord is located about 8 km from the tide gauge Digue-Ouest. It is at the meeting place of the lagoon and rivers. This equipment is stable and well sheltered. It records the tide in lagoon.
- These two tide gauges are calibrated in local time (Greenwich Mean Time) and in height with zero hydrographic point 1.14 m below the mean sea level.

**Data processing**

The digitization of these print sea levels was performed with the aid of NUNIEAU software for scanning and digitazing old charts data (marigrams) was developed by Cerema, Territorial Division for the Mediterranean Regions. It allows semi-automatic recovery of pixel color (Fig.2). The executable is available for free without liability for any damage that may occur during use. For the latest updates and different styles of data processed, please check the website www.cerema.fr.

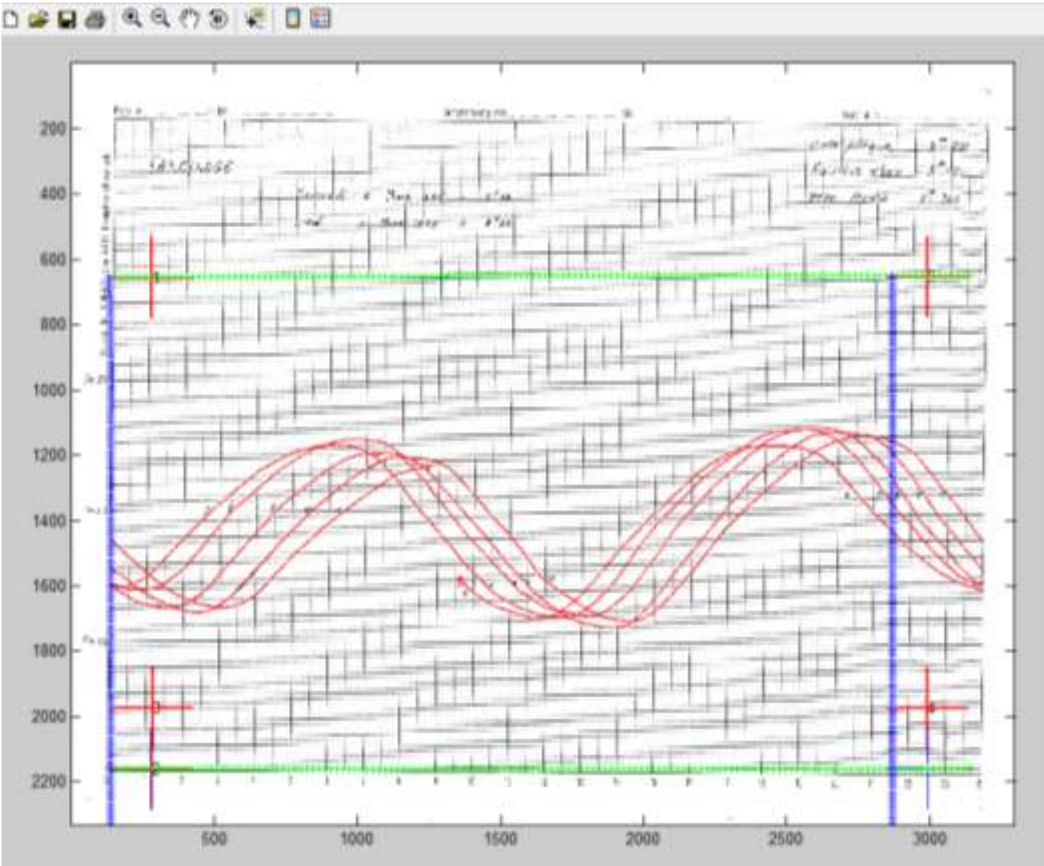


**Figure 2:** Definition of five setting points on an old marigram

***Filtering water level series***

A time serie in general is a superposition of the fluctuations of high frequencies (HF) and low frequencies (BF). A low-pass filter is applied to the water levels of tide gauges Digue-Ouest and Quai-Nord, in order to eliminate from the measurements, the low frequency oscillations. The operator "filters low-pass "is used to separate the oscillations HF from the BF of series of water levels. The principle of this filter is described by [7] in [1].

***Harmonic analyze of tide***

The series of water level were treated by harmonic analysis. This analysis makes it possible to extract from the information of level the deterministic oscillations of astronomical origin whose sum constitutes the signal of tide [1]. The Matlab program (t_tide) of [8] and [9], was used to carry out the harmonic analysis. This program allows obtaining a prediction of the tide and the residual oscillations (observation mimus prediction). This free program is available on: http://www2.ocgy.ubc.ca/~rich/#T_Tide.

## III. Results And Discussion

### Water level variation

Fig.3 shows daily variations of water levels to both stations. A correlation coefficient of 0.8 suggests that the measurements of water levels between the two tide gauges are correlated. According to recommendations of [10], a correlation coefficient of more than 0.7, allows to say that the measurements of water levels are good quality. Indeed, these two stations are close (less than 8 km), they are necessarily subjected to the same meteorological conditions (atmospheric pressure, rive inputs).

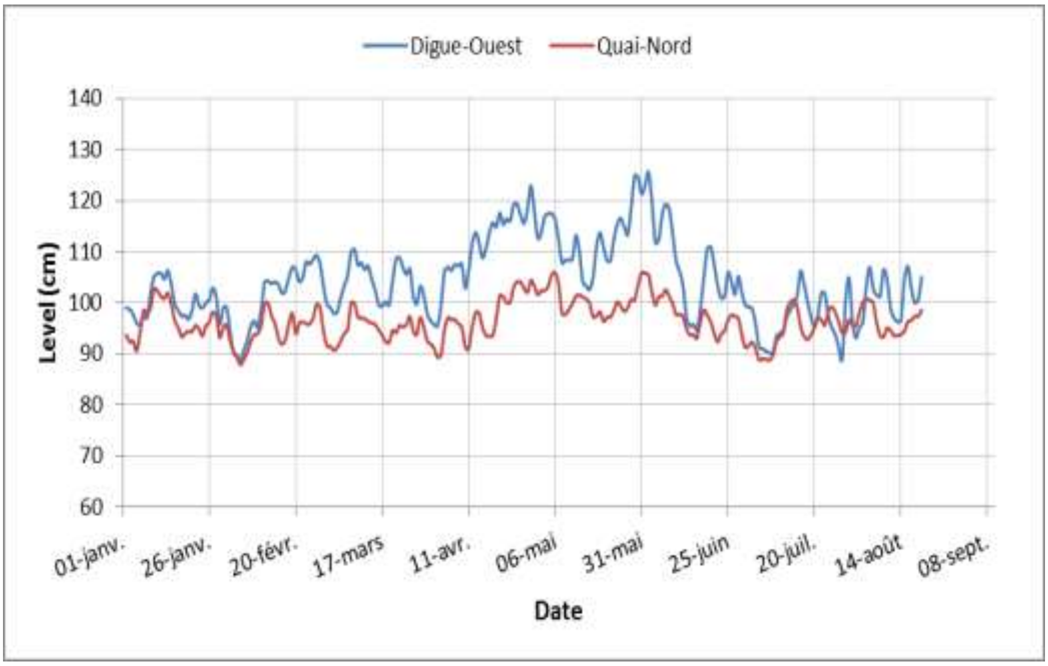


**Figure 3 :** Daily mean sea level variations with a correlation coefficient of 0.8.

The analysis of water levels also showed a horizontal gradient between the tide gauges. Indeed, the water level reached an average level of 104 cm at Digue-Ouest against 96 cm at Quai-Nord, an difference of the order of 8 cm between the two stations. This difference causes a horizontal pressure gradient, and thus contributes to a transportation from the sea to the lagoon. When the water movement by the wind is a local effect, the transport of water bodies by the horizontal gradient of the level is a non-local effect acting across the lagoon [11].

### High and low frequencies Oscillations

The figures 4 and 5 show the original time series, the low-pass series and the high-pass series. The latter is obtained by subtracting the low-pass series from the original series. It is noted that there is no notable difference between the high frequencies oscillations and the tide observed (Fig.4 and Fig.5) at the two stations. We can say that the influence of tide is dominant in the port. But the presence of low frequencies oscillations show there is other phenomena forcing like atmospheric pressure, in particular at the Digue-Ouest station. For example, a rise of the atmospheric pressure causes a fall of the water level. This is the barometer reverses effect. According to [1], the low frequency oscillations of the sea level are also the vertical demonstration of hydrodynamic processes acting in the horizontal level. It is the principle of the continuity of the movement. In the case of Quai-North station, in addition of the atmospheric pressure, we have the river water input that can cause the low frequencies oscillations in the lagoon.

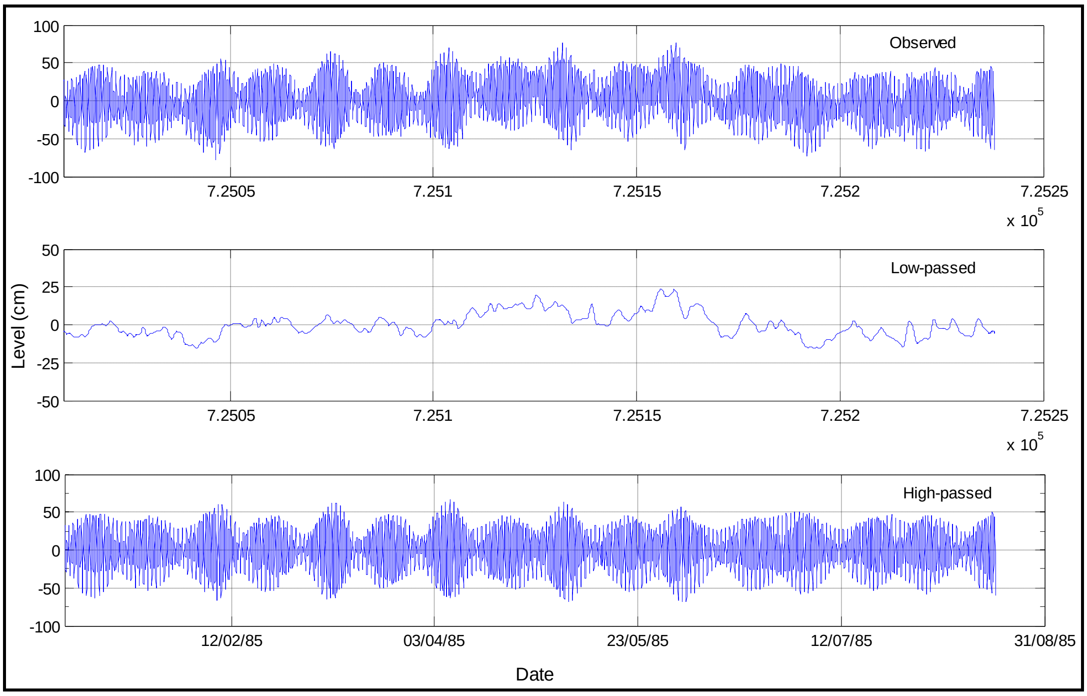


**Figure 4:** Water level (observed), low frequency (low-passed) and high frequency (high-passed) at the station Digue-Ouest.

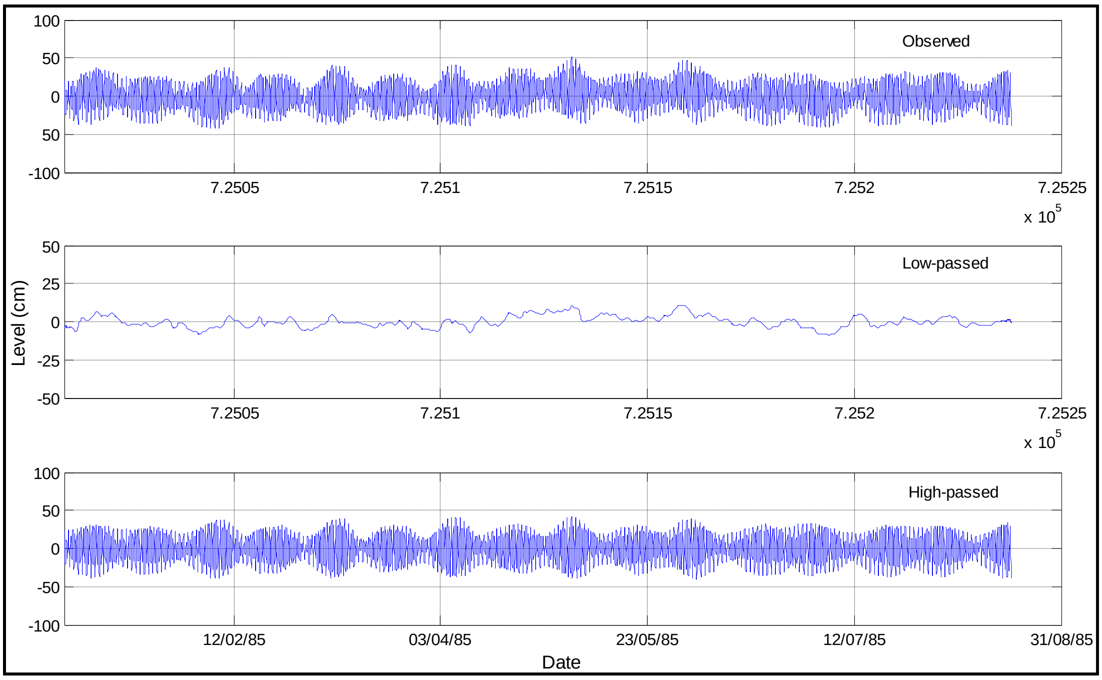


**Figure 5:** Water level (observed), low frequency (low-passed) and high frequency (high-passed) at the station Quai-Nord.

**Analyse harmonic tide and predictions of tide**

The main semi-diurnal (M2, S2, N2, and K2) and diurnal (K1, O1, P1, and Q1) harmonic components contain most of the tidal signal (80% to 90%). Taking these waves into account permits to assess with good accuracy the basic characteristics required for the tide of a certain point (Simon, 2007). The table I gives the amplitudes and phases of these constituents at sea (Digue-Ouest) and in the Ebrié lagoon (Quai-Nord).

**Table I :** Amplitudes and phases of diurnal (K1, O1, P1 and Q1) and semi-diurnal (M2, S2, N2, K2) harmonic components from harmonic analysis of water levels with their confidence intervals of 95%.

| **Harmonic constituents** | | | **Digue-Ouest station** | **Quai-Nord station** |
|---|---|---|---|---|
| **Diurnal components** | $K_1$ | Amplitude (cm) | 10.15 ± 0.33 | 6.91 ± 0.16 |
| | | Phase (°) | 352 ± 1.75 | 337 ± 1.21 |
| | $O_1$ | Amplitude (cm) | 2.34 ± 0.29 | 1.64 ± 0.14 |
| | | Phase (°) | 327.69 ± 7.71 | 316 ± 5.23 |
| | $P_1$ | Amplitude (cm) | 3.35 ± 0.29 | 2.28 ± 0.17 |
| | | Phase (°) | 359 ± 5.34 | 344 ± 3.76 |
| | $Q_1$ | Amplitude (cm) | 0.47 ± 0.29 | 0.34 ± 0.14 |
| | | Phase (°) | 103 ± 37.64 | 89 ± 24.11 |
| **Semi-diurnal components** | $M_2$ | Amplitude (cm) | 32.54 ± 0.47 | 21.89 ± 0.53 |
| | | Phase (°) | 127.36 ± 0.99 | 89 ± 1.48 |
| | $S_2$ | Amplitude (cm) | 13 ± 0.51 | 7.75 ± 0.56 |
| | | Phase (°) | 155 ± 2.29 | 115 ± 3.84 |
| | $N_2$ | Amplitude (cm) | 8.33 ± 0.58 | 4.95 ± 0.59 |
| | | Phase (°) | 125 ± 3.90 | 89 ± 6.24 |
| | $K_2$ | Amplitude (cm) | 3.84 ± 0.41 | 2.35 ± 0.43 |
| | | Phase (°) | 154 ± 7.09 | 103 ± 10.29 |

Furthermore, with the amplitudes and phases of tidal waves, it is now possible to predict the tide in sea and lagoon. In blue, we have the observations, in green the predictions and in red the residuals oscillations (Fig.6 and Fig.7).

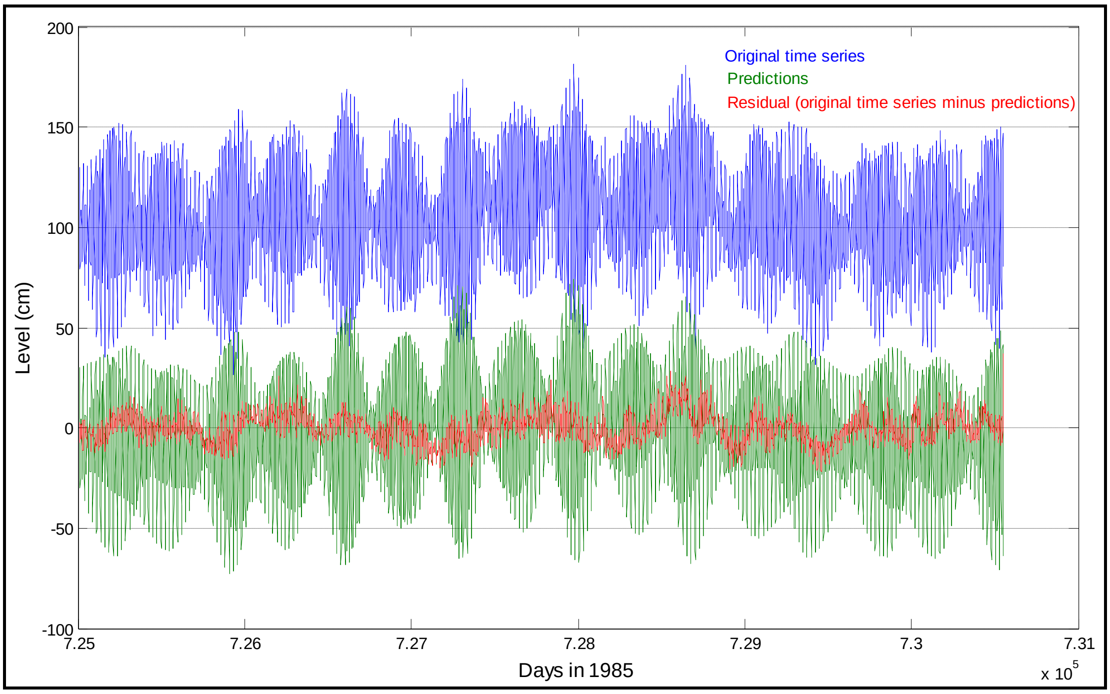


**Figure 6:** Water levels observed (blue), predictions (green) and low frequency oscillations (red) at the station Digue-Ouest for the period January 1 to august 20, 1985.

In examining the amplitudes of the harmonic component M2, we realize that, it is only in sea that the amplitude of the wave M2 is the highest (0.3 m). Over the evolution of the tide wave in the lagoon, the amplitude of M2 decreases until 0.2 m. The difference is of the order of 10 cm. The amplitude ratio of the M2 wave between the two stations (Digue Ouest / Quai Nord) is equal to 1.49.
With these amplitudes, the Van der Stock (R) coefficient was calculated using the following formula [12]:

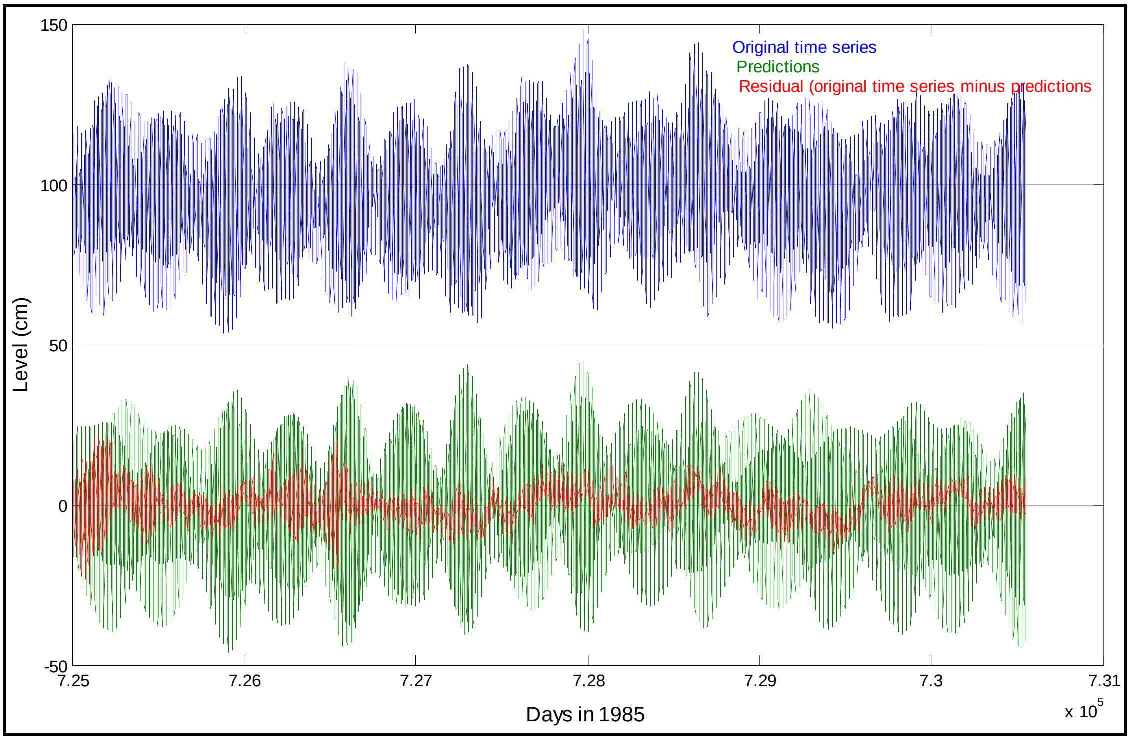


**Figure 7 :** Water levels observed (blue), predictions (green) and low frequency oscillations (red) at the station Quai-Nord for the period January 1 to august 20, 1985.

$$R = \frac{A_{K1} + A_{O1}}{A_{S2} + A_{M2}} \qquad (1)$$

With $A_{xx}$ the amplitude of the wave considered.
The Van der Stock R coefficients calculated for each station are shown in the table II. We have a mixed tide (0.25 <R <1.5). There are two unequal high tides and two unequal low tides per tidal day, and the difference in height between successive high (or low) tides is called the diurnal inequality**.** The same result was observed in the San Pedro Harbor, where, [1] found a number of form F equal to 0.3.

**Table II :** Van Der Stock coefficient (R) for each station

| Stations | Digue-Ouest | Quai-Nord |
|---|---|---|
| Van Der Stock coefficient R | 0.27 | 0.29 |

The residuals (original time series minus prediction) are usually between ± 20 cm. In our case, the monthly residues are less than 10 cm (Table III), suggesting of the right good quality of original time series and thus predictions ([10] and [13]).

**Table III :** Monthly rmse (cm) of residuals (original time series minus prediction)

| **Stations** | **January** | **February.** | **March.** | **April** | **May** | **June** | **July** | **August** |
|---|---|---|---|---|---|---|---|---|
| **Digue-Ouest** | 5.28 | 7.52 | 6.81 | 7.73 | 8.89 | 8.10 | 7.73 | 6.76 |
| **Quai-Nord** | 7.94 | 5.47 | 8.27 | 9.17 | 6.23 | 5.00 | 5.43 | 5.47 |

**Propagation of the tidal wave**

Harmonic analysis of water levels showed that the semi-diurnal harmonic component (M2) is the largest component of the tide at each tidal station (table I).
The travel time of the tidal wave M2 between the two stations, Digue-Ouest and Quai-Nord has been estimated by the follow formula: T (hour) = (phase 1-phase 2)*(period of M2/360), with phase 1= phase of M2 at the station 1 and phase 2, the phase of M2 at the station 2. The tidal wave M2 is a semi-diurnal principal lunar wave of period 12.42 hours. The numerical application give T = (127 – 89) * 12.42/360 = 1.31 hours (1h18mn36s). The wave M2 to go from Digue-Ouest to Quay-North takes 1h18mn36 s.
The distance (d) between the two tide gauges is 8000 m for a time (t) of courses of 1h18mn36 s (4716 s). The horizontal rate of travel of the tidal wave is: V = d/t. The numerical application of this formula give: V = 8000

/4716 = 1.70 m/s. The wave M2 moves into the lagoon with a speed of 1.70 m/s. This low speed of tide will produce only weak tide currents in the harbour but in the Vridi channel, this speed should be often stronger.

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation.

## IV. Conclusion

The tidal wave (M2) from the Digue-Ouest (sea) to Quai-Nord (lagoon) moves at a speed of 1.7 m/s. The difference in phase between Digue-Ouest and Quai-Nord is 1h18mn36s. The amplitude ratio of the M2 wave between the two stations (Digue Ouest / Quai Nord) is equal to 1.49.

The low-pass filter applied to these data showed that the tide oscillations are dominant in the port. The low-frequency oscillations, although limited, reflect the influence of the atmospheric pressure and the river inputs on the variations of water levels.

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