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Tidal Signal Processing by Harmonic Analysis for the Algerian Vertical Reference Determination

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Abstract

The ocean tide is defined as periodic variations of sea levels due to the attraction of the moon and the sun effects. For the Algerian vertical datum determination, the National Institute of Cartography and Remote Sensing (INCT) completed the installation of tow automatic acquisition tide gauge (LOG_aLevel) at Algiers and Jijel harbors (Algeria). The harmonic analysis of tide gauge data from this station provided by the INCT within the INCT/CTS agreement and for a period of over a year, allowed us to determine the tide harmonic constants and the mean sea level at Algiers harbor. The mean sea level calculated in this work, after one year processing of tidal time series for each station, is 40.6 cm at the Algiers harbor and 39.8 cm at Jijel station, that is a difference of 6.6 cm and 5.8 cm, respectively in Algiers and Jijel, compared to the current reference. Spectral analysis has allowed us to locate the significant amplitudes of the tide temporal variation and thus to detect the tide type at each station.

Keywords: Tide gauge, sea level, harmonic analysis, vertical reference, spectral analysis.

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Introduction

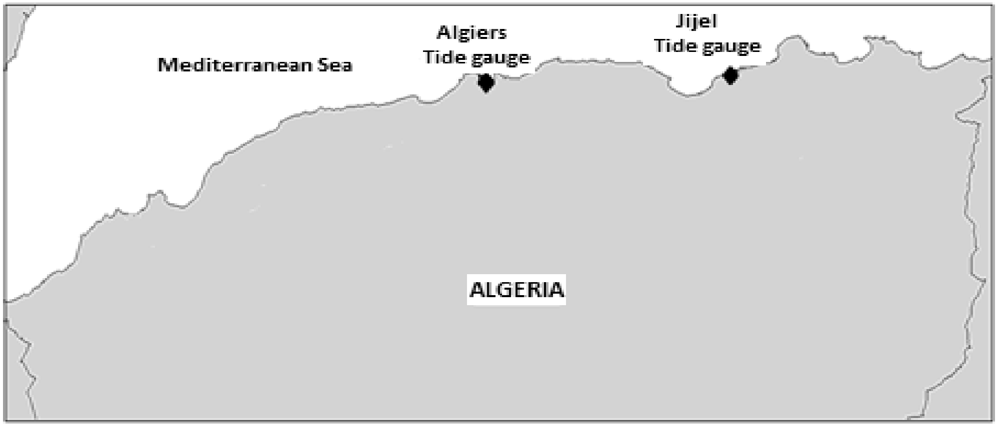
The origin of the Algerian general network leveling (NGA), which dates back to the French colonial period (1889), is still based on the Goulette médimarémètre (near Tunis) with little information exists on its definition and precision (INCT, 20071), this origin is at 34 cm above the Chart datum (Lower Astronomical Tide).

Actually, tide gauges are the only source of direct observations available on decades or hundreds of years, which provide the most information to describe and understand past variations in sea level (Pouvreau, 2008).

At the Algiers harbor, an experimental electronic tide gauge was installed in May 2003 by the National Institute of Cartography and Remote sensing (INCT), near the analogical tide gauge (installed in 1985); The processing of the same period data (29/03/2004 to 27/02/2006) from these two tide gauges allowed position datum to 39.8 cm above chart datum (Haddad et al., 2006) that is a difference of 5.8 cm compared to the current reference.

In this context, the INCT in its capacity as national agency in charge of geographic information with the Space Techniques Centre (CTS) collaboration has completed the installation of digital tide gauges for General Acoustics (LOG-aLevel) along the Algerian coast (figure 1) for the definition of a new national vertical datum; These tidal stations are as follows: in Algiers harbor (November 2011) and Jijel harbor (May 2012).

Figure 1. *Algerian tidal stations situation*



In this study, we will process all the tide gauge time series provided by each station using the tidal harmonic analysis to determinate the tidal harmonic constants and the mean sea level at Algiers and Jijel harbors, which is represented the first determination of the national vertical datum.

The paper is organized as follows: The harmonic analysis method, the inverse barometer and spectral analysis are explained in the "Methodology", the data set from the tide gauge is presented in "tidal data used." The results are presented in the last section "results and analysis."...

Material and Methods

The ocean tide is defined as periodic variations of ocean levels due to the moon and sun attraction effects. It is the apparent relative movement of these celestial bodies that generates periodic gravitational forces causing a periodic and undulatory movement of ocean water masses (Cartwright, 2003).

The description of the tidal phenomenon has clearly evolved as and that accurate sea level observations became available to scholars. After a first static approach by Newton, the dynamic theory, proposed by Laplace is the basis of all subsequent developments (Cartwright, 2003).

Tidal Harmonic Analysis

According to Cartwright (2003), the tide generation mechanisms are known and described for many decades through successive contributions of many scientists: Newton [1643-1727]; Laplace [1749-1827]; Darwin [1809-1882] and Doodson [1890-1968] are at the origin of the harmonic method development.

Based on the precursor works, Thomson introduced the mathematical operation called harmonic analysis (Thomson, 1869), perfected later by Darwin and Doodson. From the sea level observations, it becomes possible to extract the harmonic constants for the site considered, to predict the astronomical tide.

Darwin presented the first development of tidal generating potential in sinusoidal functions of time; it is quasi-harmonic because it contains pseudo-constants that change very slowly over the time (Darwin, 1883).

The expression of the ocean tide linearized equations leads to search the sea level height difference created by the tide generating force, whose derives the potential, as a sum of elementary sinusoidal functions (Lefevre, 2000):

$$\Delta h_{MO}(\varphi, \lambda, t) = Z_0 + \sum_i H_i(\varphi, \lambda) \cos(\omega_i t - \psi_i(\varphi, \lambda)) \qquad (1)$$

Where:

Z_0 is the mean sea level reported at the chart datum around which oscillates the sea level.

H_i is the amplitude of the wave i.

ψ_i is the phase expressed at the crossing moment of the disruptive body (Moon or Sun) to Greenwich.

ω_i is the frequency of the wave i.

In 1921 Doodson presented a much more complete development of generating potential, based on the lunar theory of Brown where he expressed the coordinates of the Moon relative to the ecliptic. Its developments, unlike those of Darwin, are purely harmonic; they lead to about 400 potential components (Dodson, 1921).

Doodson used the five (05) fundamentals angles and the mean lunar time to position the Moon and Sun movements in the terrestrial frame (Dodson, 1921).

Equation (1) becomes (Lefevre, 2000):

$$\Delta h_{MO}(\varphi, \lambda, t) = Z_0 + \sum_i F_i (A_i \cos(\xi_i) + B_i \sin(\xi_i)) \qquad (2)$$

Where:

$\xi_i = \omega_i t + X_i + U_i$, $A_i = H_i \cos(\psi_i)$ et $B_i = H_i \sin(\psi_i)$

A_i et B_i are the harmonic constants of the considered Harbour.

F_i : The nodal correction coefficient of the wave amplitude.

U_i : The nodal correction coefficient of the wave phase.

X_i : The astronomical argument for t = 0.

ω_i : The frequency of the wave i, it is given by the Doodson development, (extracted from Doodson table).

The analysis of hourly observations allows the exploration of the harmonic components to the daytime twelfths. Nevertheless, some river tides require higher sampling rates because energy is perceptible beyond the thirtieth diurnal (Pouvreau, 2010).

Inverse Barometer Effect

The response of the sea level to air pressure variations is known as the inverse barometer effect; it comes from the pressure force change of the air mass above the sea surface.

The correction of the effect of the inverse barometer is given by the following formula (Aviso, 2008):

$$Inv_{Bar} = \frac{\bar{p}_a - p_a}{\rho\, g} = -9.948\,(P_a - 1013.25) \qquad (3)$$

Where:

P_a : Air Pressure

$\bar{p}_a \approx 1013.25\, mb$: mean air pressure.

$\rho \approx 1.025 g/cm^3$: mean sea water density.

$g \approx 981 cm/s^2$: Gravity acceleration.

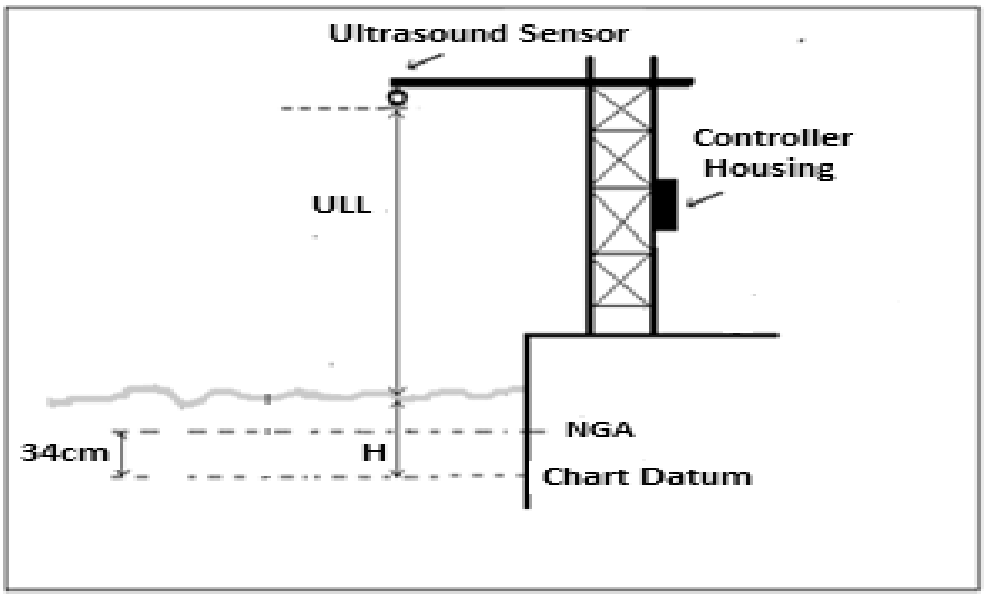
Tide Spectrum

The tide spectrum is an objective representation of the studied signal, the mathematical operation to determine a tide spectrum is called spectral analysis it permit to identify the harmonic components of a particular place, which constitute a clean impression this location (Pugh, 2004). The spectral analysis is to locate, in a frequency range, the significant magnitudes of the tidal temporal variations (Gouriou, 2012). In this work, the spectral analysis was performed using t_tide.

Data Used

The Log-alevel tide gauge is a robust and accurate system for measuring sea surface height (H) above the chart datum and sea wave height the height based on ultrasound technology (Figure 2).

Figure 2. *Principal of Log-aLevel Tide gauge*



The digital tide gauge is a complete acoustic level measurement system with other optional sensors like wind, air pressure, water pressure, temperature and so on (Log aLevel, 2007).

Tide gauge data used in this work are the raw data recorded at each station and are provided by the INCT in the context of the Convention CTS / INCT signed in 2011. These data represent the sea level above the Chart datum and the atmospheric pressure at the surface of the sea every minute.

These data are collected during the period from December 13, 2011 to December 13, 2012 (12 months) for the Algiers station and from May 22, 2012 to May 22, 2013 (12 months) for the Jijel station. All these data was subsequently structured with a sampling rate of one hour.

The determination of the mean sea level at Algiers and Jijel harbor by the harmonic analysis is done using the T-tide package Version March 2011, it is available on the website of the "Department of Earth and ocean science," University of British Columbia: (http://www.eos.ubc.ca/~rich/#T_Tide).

T_tide is widely used by researchers worldwide since to date, at least 313 articles are from research conducted with t_tide (Gouriou, 2012).

The nodal corrections applied in t_tide are designed such that they cannot be used accurately for more than one year observations (Pawlowicz, 2002). The authors therefore recommend to effectuate the harmonic analysis on files containing maximum one year of measurements, thus fragment the original file data to a lots of one year observations (Gouriou, 2012).

Results and Discussion

The harmonic analysis, using T_tide, of the tide gauge data corrected for the inverse barometer effect allows to have the mean sea level (vertical reference) and the harmonic components for each station.

Vertical Reference

Before the tide harmonic analysis, we must correct the raw data of the inverse barometer effect using eq (3) and basing on the air pressure data provided by the tide gauge.

Figure 3. *Sea Level at Algiers Harbor (in Blue Line) and the Calculated Inverse Barometer Effect (in Red Line)*

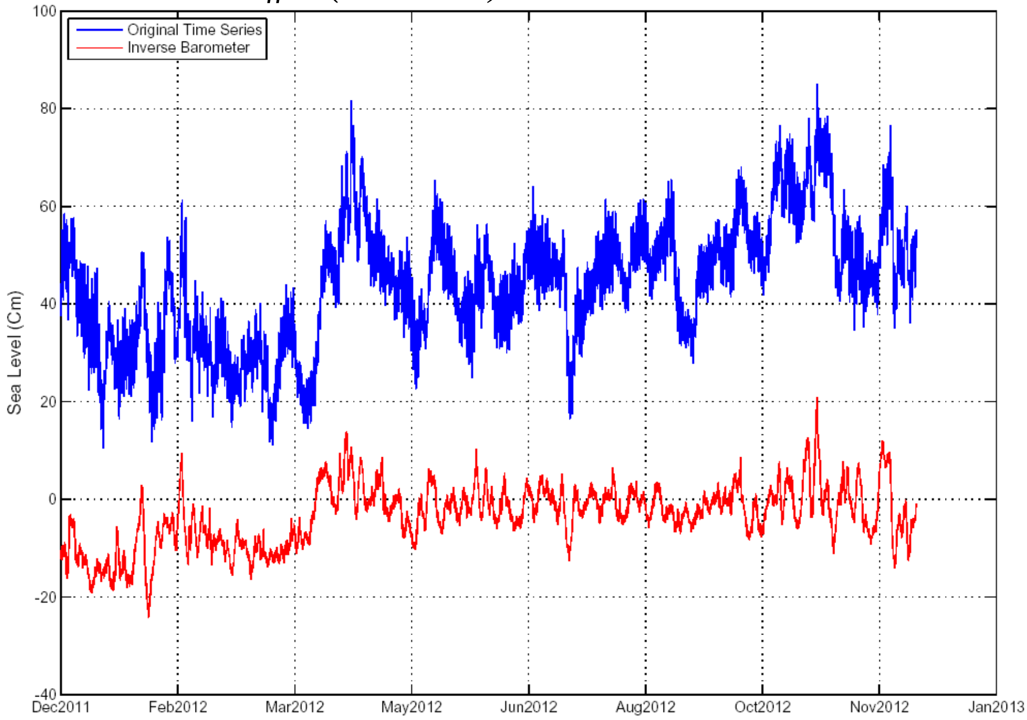
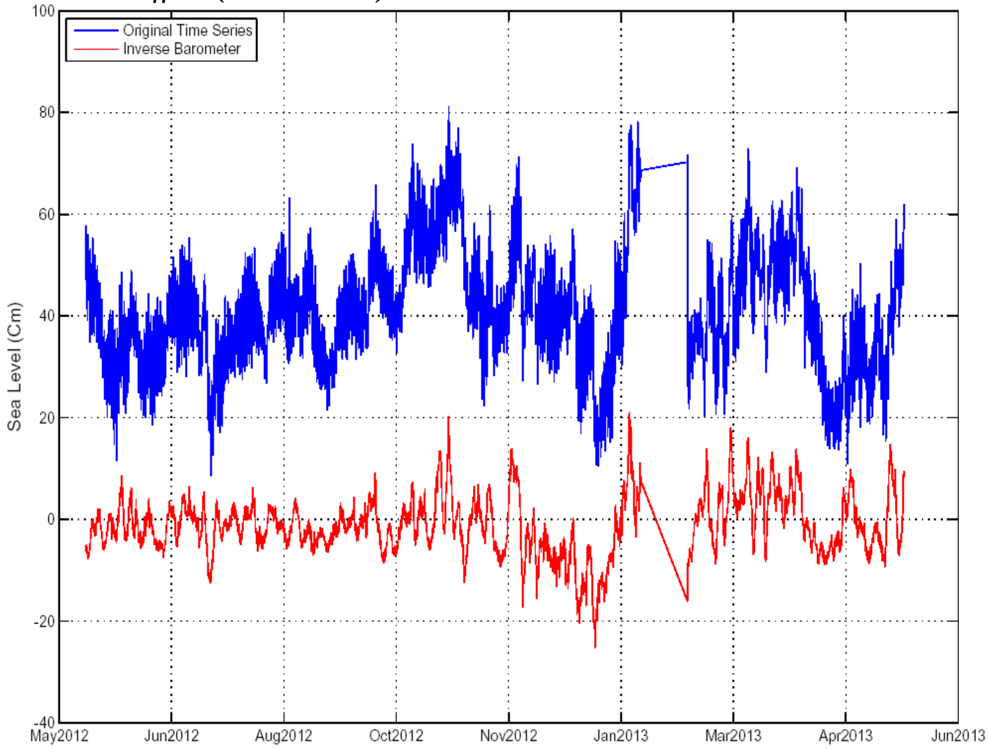


Figure 4. *Sea Level at Jijel Harbor (in Blue Line) and the Calculated Inverse Barometer Effect (in Red Line)*



Figures 3 and 4 show that the shape of sea level variation of each station follows perfectly the inverse barometer effect variation; this is proof to the good quality of the used tidal measurements.

Harmonic analysis, by T_tide, of the tide gauge data corrected for the inverse barometer effect allows us to determinate the mean sea level and a matrix containing the list of harmonic components defined for the three stations: the wave name, frequency, amplitude and its uncertainty.

Figures 5, 6 represent the tidal time series corrected for the inverse barometer effect and the astronomical tide reconstructed from the identified harmonic components (SNR≥2).

The SNR (Signal-to-noise ratio) ; his is an indicator of transmission quality of information, it is expressed by the ratio between the wave amplitude and the error thereon. $SNR = (amp / amp\_err)^2$ (Pawlowicz and all, 2002).

Figure 5. *Sea Level at Algiers Harbor Relative to Chart Datum: Corrected Data from the Inverse Barometer Effect (in Blue Line), Tidal Prediction from Analysis (in Green Line) and the Difference (in Red Line)*

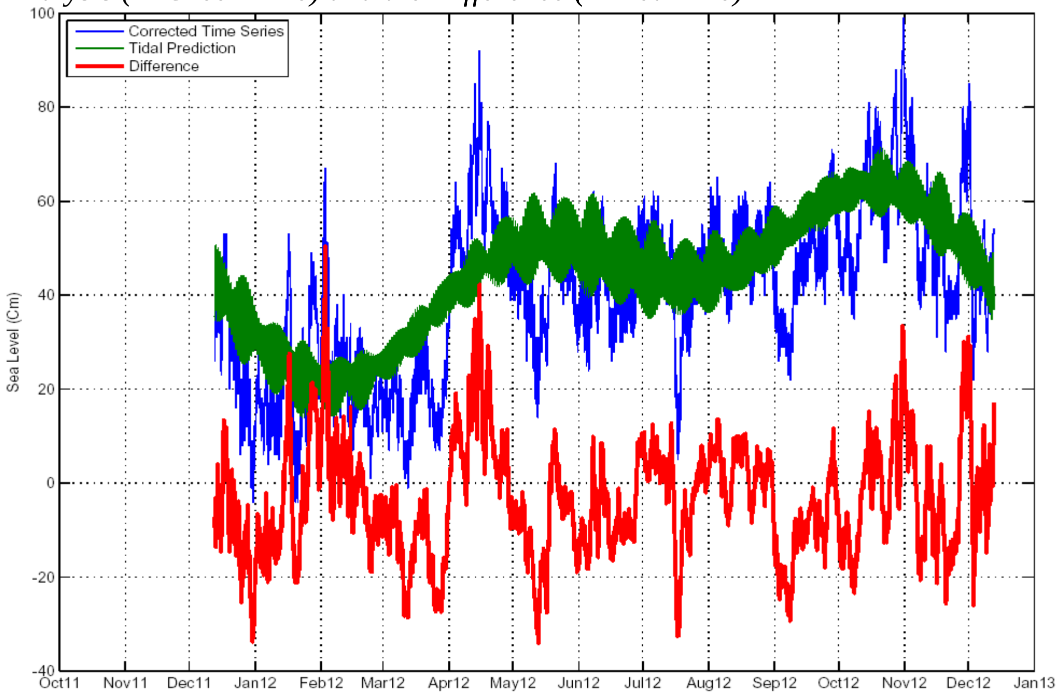
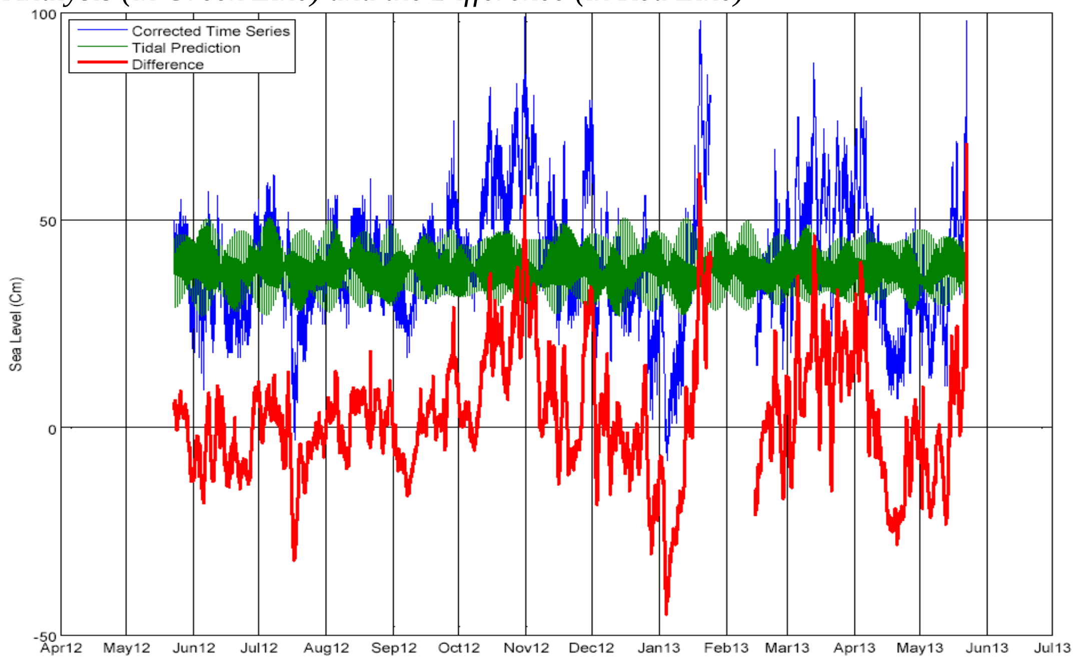


Figure 6. *Sea Level at Jijel Harbor Relative to Chart Datum: Corrected Data from the Inverse Barometer Effect (in Blue Line), Tidal Prediction from Analysis (in Green Line) and the Difference (in Red Line)*



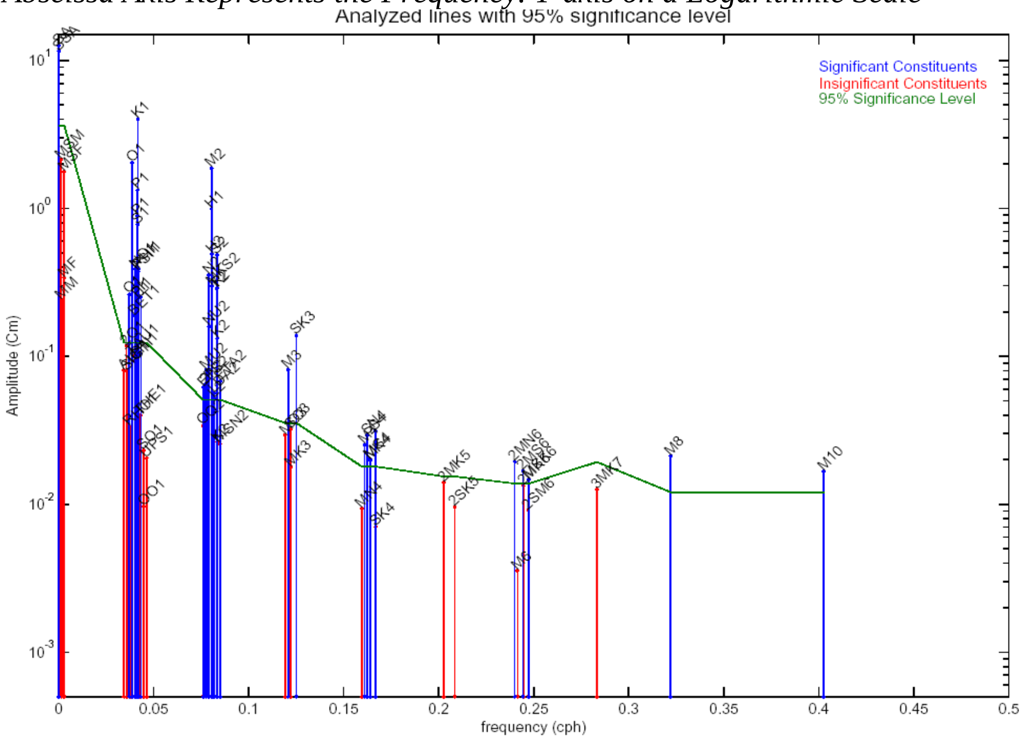
Figures 5 and 6 show that the reconstructed astronomical tide follows the general shape of tidal observations for each station.

The mean sea level calculated at the Algiers harbor is 40.6 cm, a difference of 6.6 cm compared to the current reference and that calculated at the Jijel harbor is 39.8 cm, a difference of 5.8 cm from the actual reference.

Spectral Analysis

The spectral analysis is applied for the Algiers station data to identify the harmonic components, and thus constitute the local tide identity (Fig.7). Spectral analysis was performed using t_tide from hourly heights of the period December 2011 - December 2012.

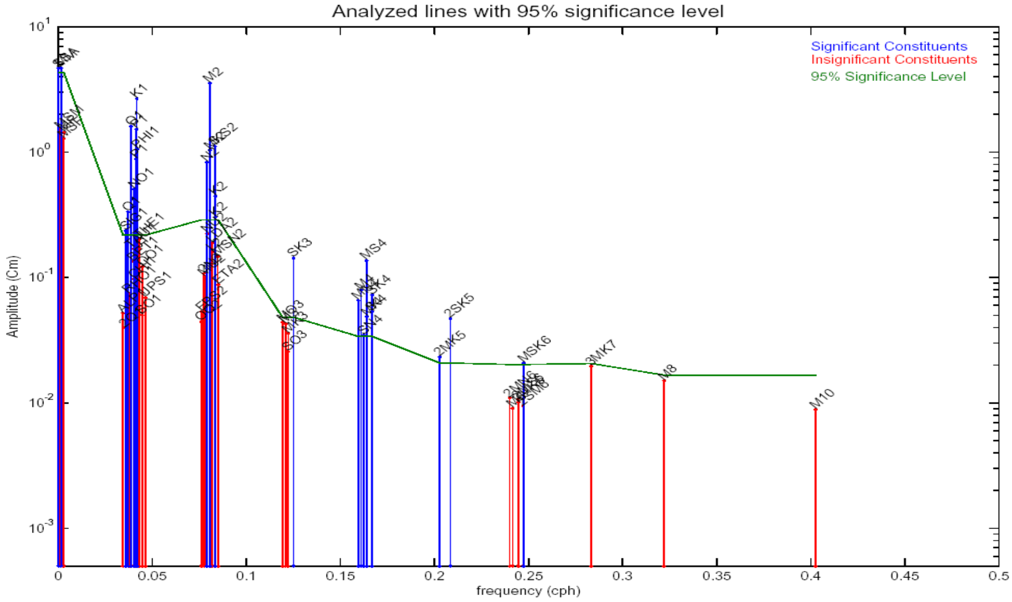
Figure 7. *Tide Harmonic Components Spectrum at the Algiers Harbor. The Abscissa Axis Represents the Frequency. Y-axis on a Logarithmic Scale*



The tide spectrum in Algiers is dominated by diurnal and semi-diurnal species forming the harmonic components group with the highest amplitudes, with their heads, K1 (≈ 4.01 cm) for the diurnal wave and M2 (≈ 1.87cm) for the semi-diurnal waves. Indeed, only diurnal and semi-diurnal species present the major part of the astronomical tide directly resulting of the moon and sun actions.

We also realized a spectral analysis of the Jijel station data to identify the harmonic components, and thus constitute the local tide identity (Fig. 8). Spectral analysis was performed using t_tide from hourly heights of the period Mai 2012 - Mai 2013.

Figure 8. *Tide Harmonic Components Spectrum at the Jijel Harbor. The Abscissa Axis Represents the Frequency. Y-axis on a Logarithmic Scale*



The results of spectral analysis at Jijel station are largely statistically similar to those of Algiers. The spectrum is dominated by the diurnal and semi-diurnal species, K1 (≈ 2.65 cm) and (M2: ≈ 3.55 cm).

Conclusions

The installation of three tidal gauge stations automatic acquisitions along the Algerian coast (Algiers, Jijel and Oran) is of great interest, particularly for sea level monitoring, the altitude reference definition, etc…

The objective of this project is to determine a national vertical datum using the Tide time series from these three stations.

The processing of tide gauge time series provided by each station using the tidal harmonic analysis allowed us to determine a new reference at Algiers and Jijel harbors. Analysis of the results shows a small difference between the current reference and those determined at Algiers (6.6 cm) and Jijel (5.8 cm) harbor.

In perspective, and in the under agreement CTS/INCT, the analysis of a long period of tide gauge data will allow the definition of a new vertical datum that will be used to the national origin reference for the Algerian general leveling network. Note here that the identified harmonic components will be used for the tide prediction.

The installation of new tide gauge stations, especially Tenes (Chlef), Ghazaouet (Tlemcen) and Annaba, will certainly improve the accuracy of the national vertical reference system definition.

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