Bol. Cient. CIOH 2018; 37:17-34

Determination of the maximun flood heights using numerical modeling in Bahía Solano-Chocó

Determinación de las cotas máximas de inundación, mediante modelación numérica, en Bahía Solano Chocó

DOI: 10.26640/22159045.447 **Reception date:** 2018-06-08 **/ Acceptance date:** 2018-07-31

Laura M. Vásquez L.[*]**, José D. Iriarte S.**[**] **& Ronald E. Sánchez E.**[***]

Vásquez, L., Iriarte, J. & Sánchez. R. (2018). *Determination of the maximun flood heights using numerical modeling in Bahía Solano-Chocó.* Bol. Cient.CIOH (37):17-34. ISSN 0120-0542 and ISSN online 2215-9045. DOI: 10.26640/22159045.447

ABSTRACT

The middle and extreme regime of sea level in Bahia Solano, on the coast of the department of Chocó, was determined, showing an average maximum flooding level of 3.9997 m. The results are one of the main inputs for construction of the Highest Tide Line (HTL) for the above region. For the elaboration of the regimes the following assumptions were made: (i) the sea level at a given time is represented by the sum of the tide (astronomical component) and the residual tide (meteorological component), (ii) The astronomical component is considered a deterministic variable, while the tidal residue is considered as a random variable, following an approximately normal distribution, (iv) both components were treated as statistically independent variables. Considering the above, analysis for each components were carried out in the study area using analysis tools, harmonic analysis numerical modeling and indirect methods based on Montecarlo techniques and applied according to the deterministic and stochastic behavior presented by each variable.

KEYS WORDS: Bahía Solano, Colombian Pacific, maximum flooding level, spectral analysis.

RESUMEN

En el presente trabajo se determinó el régimen medio y extremal de nivel del mar en Bahía Solano, sobre el litoral del departamento de Chocó, mostrando una cota máxima de inundación promedio de 3.9997 m. Los resultados obtenidos son uno de los insumos principales para la construcción de la Línea de Más Alta Marea (LMAM) para la región anteriormente mencionada. Para la elaboración de los regímenes se partió de las siguientes hipótesis: (i) el nivel del mar en un instante dado está representado por la suma de la marea (componente astronómica) y el residuo de marea (componente meteorológica), (ii) el componente astronómico es considerado una variable determinista, mientras que al residuo mareal se le considera como variable aleatoria, siguiendo una distribución aproximadamente normal, (iv) ambos componentes son tratados como variables estadísticamente independientes. Así, teniendo en cuenta lo anterior, en el análisis llevado a cabo para cada componente por separado en el área de estudio, se emplearon herramientas de análisis, de tipo armónico, modelado numérico y métodos indirectos basados en técnicas de Montecarlo, aplicadas de acuerdo con el comportamiento determinista y estocástico que presentó cada variable.

PALABRAS CLAVES: *Bahía Solano, Pacífico colombiano, máximo nivel de inundación, análisis espectral.*

---

[*] Oceanographic and Hydrographic Research Center of the Pacific (CCCP), Tumaco. E-mail: lvasquez@dimar.mil.co

[**] Oceanographic and Hydrographic Research Center of the Pacific (CCCP), Tumaco. E-mail: jiriarte@dimar.mil.co

[***] Oceanographic and Hydrographic Research Center of the Pacific (CCCP), Tumaco. E-mail: rsanchez@dimar.mil.co

INTRODUCTION

The sea level behavior, at any moment, is defined by two factors mainly, the astronomical tide and the meteorological tide, this latter due to the atmospheric pressure and wind variations; likewise, the configuration of the coastline and the bathymetry of the zone where this long-period wave is propagated, also play an important role. However, there are other lower-periodicity phenomena, in different temporal scales or with little regional effect, which may modify the sea level in a considerable way; as in the case of tsunamis, some long-term variations associated with global climate change, sea- level anomalies as a consequence of El Niño phenomenon, or discharges of large rivers (Otero, 2004).

The astronomical forcing generate tides with a periodicity in its rise and fall. Considering the frequency, the tides may be classified as a diurnal, semi-diurnal, or mixed tide. A high-tide and a low-tide per day are observed during a diurnal tide, a semi-diurnal tide produces two high-tides and two low-tides with almost the same magnitude every day, whereas a mixed tide is characterized by a notable diurnal inequality in the elevation of the high-tides and the low tides between successive tide cycles (SHOA, 1992).

When working with tide data, it is important to know that the mean hightide in a determined place is defined as the mean water elevation in hightide during a tide period; similarly, the mean low tide is known as the mean water elevation in low tide during a tide period. It is necessary to clarify that the tide period consists of a 19-year oscillation period on a specific place, corresponding to the complete lunar nodal cycle required to go through a complete cycle of the main tide driving forces (Ideam, 2014).

For maritime safety it is imperative to know the behavior of the sea level in a specific place, since it is a determining factor for the design and construction of maritime works and the integrated management of coastal areas, among other reasons. There is awareness about this need, mainly in those zones where the rank of the sea level variation is significant and its dismissal may have consequences in the "levels of design of works" or construction of coastal infrastructure (Kjerfve, 1981). According to the above, the study and analysis of the sea level behavior within a bay acquires significant relevance, since it serves as a tool to decrease the vulnerability to which the population centers that inhabit on the coastal zones are exposed.

The main purpose of this work is the obtainment of the higher high tide level in the sector of Bahía Solano (Choco), as a supply for the elaboration of the HHTLHHTL, this procedure is made from the previous knowledge on the tidal dynamics in this area. The final result will serve for Dimar, to map its jurisdiction in the coastal zone of the study area, properly exercising the control of public properties that are under its jurisdiction. At the same time, the design of the HHTL provides the researchers with a reference for the elaboration of risk maps to mitigate the effects on the flood for extreme sea level over-elevations situations and becomes a tool for the design marine and coastal engineering projects.

STUDY AREA

The study area is located in the northwest of Colombia, on the Colombian Pacific basin, covering part of the coast of the Chocó department, on the internal bay of the corregimiento of Ciudad Mutis (Bahía Solano), extending the coast line approximately 4.4 km.

The study area is an open bay, characterized by a mountainous front that is abruptly elevated from the sea. Serrated sites combined with rectilinear coastal sections are observed in some sectors, associated with rocky edges, stone arches, caverns and isolated rocky sets, forming small islands (Banco de Occidente, 2002).

The cove beaches or bays from the zone of interest are bordering internal areas and forming arches; due to the effect on the tides, these may have between 150 and 200 m wide, highlighting those from Bahía Solano, among others (Banco de Occidente, 2002. This area presents an average tidal rank of 2.6 meters; in spring tide periods , the mean tidal range oscillates between 3.3 and 3.5 meters and between 2.0 and 2.2 meters during neap tides. Based on the above, five (5) monitoring points were established in this work (Figure 1), in order to characterize the study area.

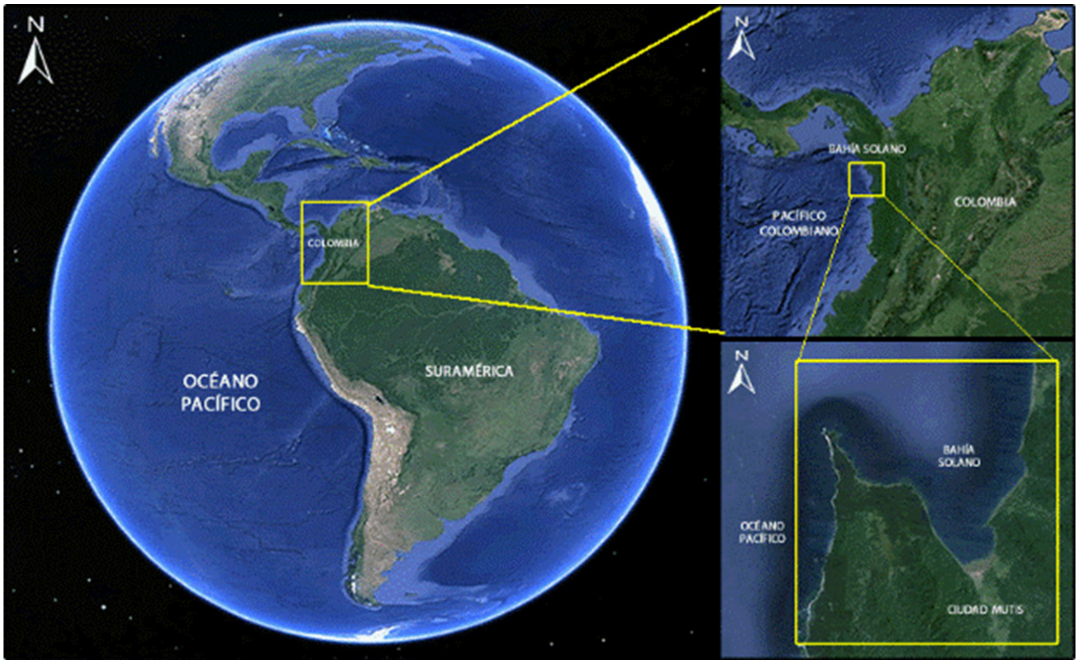


Figure 1. Study area. (Images taken from Google Earth).

MATERIALS AND METHODS

It was necessary to carry out a separate analysis of the astronomical and meteorological tide, estimating the methodologies established for that purpose (Otero, 2005), therefore, the astronomical and meteorological tide were determined using numeric models, harmonic component analysis and indirect simulation methods based on Montecarlo techniques (statistical simulation).

The methodology detailed below was used to obtain the mean and extreme regimes, from which the maximum flood heights are obtained.

Determination of astronomical tide

The astronomical tide is considered as the rise and fall movement generated by the attraction force exercised by the Moon and the Sun on the Earth with periods of approximately 12 or 24 hours, due to the Moon revolves around the common center of masses of the Earth-Moon system during a 28-day period (Grupo de Dinámica de Flujos Ambientales, 2012-2013).

For the study case, there was little instrumental information to comply with the objective of this work, therefore, it was resorted to the numerical modeling as an alternative to generate astronomical tide time series and propagate them to the coast, using the hydrodynamic H2D model [7], which uses the global Grenoble sea level database, as a source of information that uses 13 harmonics that are characteristic from the tide wave (M2, S2, K2, L2, N2, T2, MU2, NU2, 2N2, K1, O1, P1 y Q1), through points in an equidistant 0,5º x 0,5º resolution grid, to generate tide contours in the areas of interest (Andersen, Woodworth & Flather, 1995).

The bathymetric information was provided by the Oceanographic and Hydrographic Research Center of the Pacific (CCCP); and the configuration and calibration of the model were made according to the methodology established by (Otero, 2005).

In order to obtain an astronomical tide that better represents the lunar phases, considering that the simulated tide series have a short time period, an harmonic analysis was made to forecast the tide during the desired time.

This analysis consists on obtaining the amplitudes and phases of the component waves from an hourly record of sea level data, whereas the period may be determined from astronomical information, since they coincide with periodic movements between the Earth, the Moon, and the Sun (Grupo de Dinámica de Flujos Ambientales, 2012-2013). For the harmonic analysis, the method elaborated by Dronkers (1964) was used, based on least squares, where the astronomical tide approximates to the sum of these constituent waves.

$$S_{MA}(t) = a_0 + \sum_{i=1}^{n} a_i \cos(\varpi_i t + \varphi_i) \quad \textbf{(1)}$$

Where:

a_o is the amplitude of the mean reference level

a_i is the amplitude of the wave *i*

ω_i is the frequency of the component wave *i*

φ_i is the gap of the component wave *i*

t is the instant in which the tide is calculated

n is the number of considered components

The extraction of the harmonics was made using the tool developed by Pawlowicz (T_Tide), which adjusts the tide components by the least squares methods, considering its pre-established frequencies (Rosenfeld *et al.,* 2009). The constituents are selected based on its relative expected importance, with respect to the time measurement series and the possibility of separation of the frequency (Pawlowicz *et al.,* 2002; Leffler & Jay, 2009; Kang *et al.*, 2009).

Determination of the meteorological tide

The meteorological tide is the sea level response to the tangential tensions induced by the wind and the normal efforts generated by the atmospheric pressure fields, which may generate an over-elevation of the mean level (Grupo de Dinámica de Flujos Ambientales, 2012-2013).

This tide may be represented through the meteorological residue that is obtained after the performance of an harmonic analysis to a sea level series. Such residue is random and its mean regime follows an approximately normal distribution (GIOC, 2002).

Since there were no enough instrumental sea level records in Bahía Solano, the meteorological residues of measured sea level series of the stations closer to the area of interest were analyzed, under the hypothesis that meteorological factors such as wind and pressure fields exercise its influence in a quite wide spatial scale in the ocean. From this analysis developed in the document "Methodology to establish the mean higher high water in sheltered waters when there are no instrumental records", the parameters of location and scale (Table 1), employed to generate the meteorological tide using Montecarlo statistical techniques were established (Otero, 2005).

Table 1. Parameters of location and scale.

Regime	Parameter	Value
Mean	Location λm	-0.45256623
	Escale δm	-0.07870149
Extreme	Location λe	0.43567796
	Scale δe	-0.02389298
Probability associated with the point of intersection	F_p	0.99984541
Meteorological tide level associated with the probability	S_{mm}	0.645

Spearman Coefficient

The intensity of the relation that exists between two variables, when these do not have a normal distribution, may be evaluated through the Spearman correlation coefficient (rs). This coefficient may obtain values between *1* and *-1,* passing through zero 0, as shown in Table 2.

Table 2. Spearman correlation coefficient.

Coefficient	Correlation
Between -1 and -0.9	Strong inverse
Between -0.9 and -0.5	Moderate inverse
Between -0.5 and 0	Weak inverse
Between 0 and 0.5	Weak positive
Between 0.5 and 0.9	Moderate positive
Between 0.9 and 1	Fuerte positiva

Where values close to *1* indicate a strong positive correlation, values close to *-1* indicate a negative strong correlation and values close to 0 indicate a non-linear association (Lehman *et al.,* 2013).

To evaluate the quality of the astronomical tide signals obtained through numerical modeling, using the H2D hydrodynamic model, the observed tide series for the tide gauge station closest to the study area was chosen as a reference. The station belongs to Dimar and is located at 6°13’ 58.02’’N and 77° 24’44.13’’ W. To perform the correlation, a 720-hour series was selected, with 0.4 % of missing data, comprised between January 1st 2014 and January 31st 2014.

Spectral analysis

The spectral analysis of temporal series is a statistic technique that allows, among other applications, the decomposition of a temporal series in its frequential components in order to discover cyclical components immerse in noise (Kurmyshev, 2003; Pardo & Rodríguez, 2013). This temporal series $(f(t))$, being a finite succession of real numbers, may be written as a linear combination of sines and cosines in the following way (equation 2):

$$f(t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos \omega_n t + b_n \sin \omega_n t) \quad \textbf{(2)}$$

Where $\omega_n = 2\pi n / T$ are the natural frequencies and the amplitudes a_O, a_k, b_k are determined from:

$$a_0 = \frac{1}{T}\int_0^T f(t) \cdot dt$$
$$a_n = \frac{2}{T}\int_0^T f(t) \cdot \cos \omega_n t \, dt \qquad \textbf{(3)}$$
$$b_n = \frac{2}{T}\int_0^T f(t) \cdot \sin \omega_n t \, dt$$

Being $(f(t))$ the periodic function with period *T*.

The Fourier integral (equation 4) is obtained replacing equation 3 in equation 2 and using mathematical processes.

$$f(t) = \frac{1}{\pi}\int_0^{\infty} d\,\omega \int_{-\infty}^{\infty} f(\lambda)\cdot\cos[\omega_n(t-\lambda)]\cdot d\lambda \qquad \textbf{(4)}$$

Replacing in the above equation, the amplitudes (equations 3) in function of frequency, results in:

$$a(\omega) = \int_{-\infty}^{\infty} f(\lambda)\cos(\omega\lambda)d\lambda \quad ; \quad b(\omega) = \int_{-\infty}^{\infty} f(\lambda)\sin(\omega\lambda)d\lambda \qquad \textbf{(5)}$$

And carrying out some arithmetic processes, the Fourier transform (equation 6) may be obtained, which allows to evaluate the presence of patterns or cycles in the behavior of a temporal series, since it decomposes any periodic function in a series of harmonics, and its amplitudes are determined integrating in the interval of the function (Kurmyshev, 2003; Manzano *et al.,* 2007.

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t}\,dt \qquad \textbf{(6)}$$

For the study case, the dominant frequencies were obtained for both the simulated series and the measured series in a common point on Bahía Solano, Choco, in order to evaluate the quality of the simulated series.

Courtier coefficient

From the amplitudes of the main harmonic components of the temporal tide series, the tidal behavior corresponding to the study area is obtained through the Courtier coefficient (equation 7) (Fierro, 2000; Pugh, 2004).

$$F = \frac{H_{k_1}+H_{o_1}}{H_{M_2}+H_{S_2}} \qquad \textbf{(7)}$$

If : $0<F<0.25$ Semi-diurnal regime

If : $0.25<F<1.50$ Semi-diurnal mixed regime

If : $1.50<F<3.00$ Diurnal mixed regime

If : $3.00\leq F$ Diurnal regime

Mean regime

The mean sea level regime describes the behavior of this variable in an mean year (GIOC, 2002). For its determination, it is necessary to define parameters such as: the harmonic astronomical tide components, the hours per year and time (years) to be simulated; and the distribution and scale parameters for the over-elevation by meteorological tides (Otero, 2005; GIOC, 2002).

The obtainment of this regime is wholly based on the methodology established in Dimar (Otero, 2005), reason why it is required to reconstruct an astronomical tide series of from the harmonic components y simulate a meteorological tide series from the parameters of distribution and scale, through Montecarlo statistical techniques. These two series are summed to obtain a sea level series; this process is repeated for 100 series aged 500 years and finally, an mean series is obtained applying statistical techniques, which is in ascending order and is represented in function of the distribution and the number of hours per year that a determined height is overcome, through the following relation (equation 8).

$$N = 8760(1-F) \qquad \textbf{(8)}$$

Extreme regime

The extreme sea level regime is a statistic model that allows describing with which probability the sea level may overcome certain risk value (Puertos Del Estado, Ministerio de Fomento, s.f.). This information has great application in construction of coastal infrastructures to guarantee certain level of safety in constructions exposed to the sea action.

The way how the extreme regime is obtained, was based on the methodology established in the Dimar's research centers (Otero, 2005; GIOC, 2002), for which 100 meteorological tide series aged 500 years were simulated, each one of them was added to the 500-years old astronomical tide series, reconstructed from the harmonic components. The annual maximum value for each of the sea level series was determined and the mean and the standard deviation were obtained for each probability value, with which the confidence band of 90 % (equation 9) were estimated, to construct the extreme regime.

$$\left(\bar{x}-1.645\hat{s}\sqrt{n/a},\bar{x}+1.645\hat{s}\sqrt{n/b}\right) \tag{9}$$

Where $\bar{x}$ is the point estimation of the mean, $\hat{s}$ is the point estimator of the standard deviation, n is the size of the sample and a and b are coefficients that consider a variability in the standard deviation and that depends on n (Castillo & Pruneda, 2001). This information is represented in double scale: cumulative probability and return period, through the following relation:

$$R = 1/(1-F) \tag{10}$$

Where R is the return period (years), which is an intuitive mode of evaluating frequency of occurrence of an event and F is the cumulative probability.

RESULTS

To construct the mean and extreme sea level regimes in Bahía Solano (Choco), five points of interest were chosen according to the geomorphology of the coast. The location in coordinated points is shown below (Figure 2 and Table 3).

Figure 2. Geographic location of the points of interest on Bahía Solano. (Images taken from Google Earth).

Table 3. Ubicación geográfica de los puntos de interés sobre Bahía Solano.

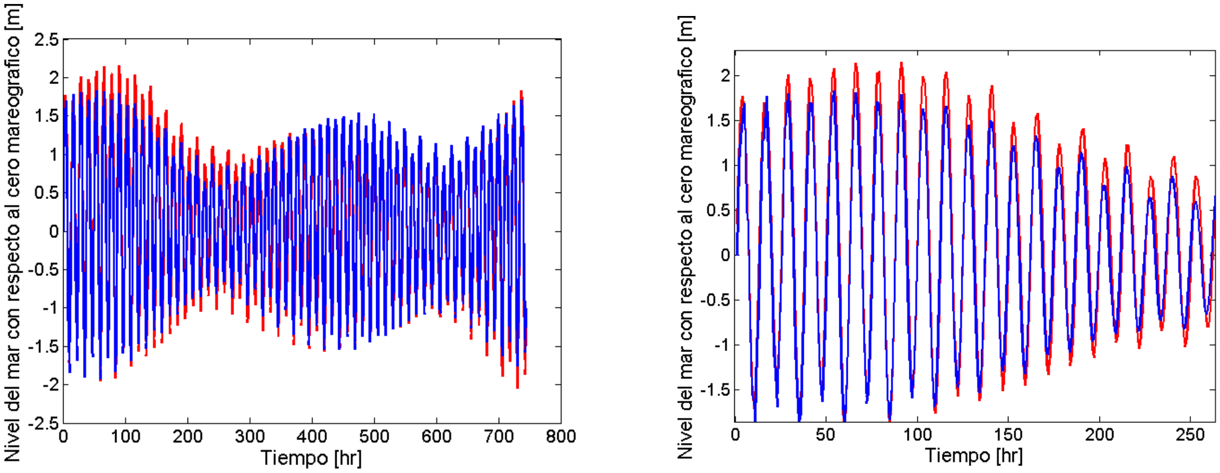
Identificator	Location	
	Longitude W	Latitude N
1	-77.4242	6.2548
2	-77.4161	6.2399
3	-77.4065	6.2344
4	-77.3984	6.244
5	-77.4038	6.2508

A Spearman correlaion analysis was carried out (Lehman *et al.,* 2013), considering that the distribution of the tide series is not normal. The Spearman coefficients (r_s) obtained for each one of the five simulated series is shown in the table below (Table 4).

Table 4. Spearman correlation coefficients for each point of interest.

Point of interest	Correlation coefficient with respect to observed tide
1	0.8077
2	0.8063
3	0.8053
4	0.8055
5	0.8068

The table shows that the correlation coefficients are above 80 %, indicating that the simulated tide has a great similarity with respect to the real tide, despite both series do not correspond to the same period. Figure 3 shows the similarity between the simulated tide (Blue) and the measured tide (Red) in one of the selected points in the area of interest.



Figurae 3. Similarity between the simulated tide series and measurement of 2014, Ciudad Mutis.

Spectral tide analysis in Bahía Solano

Through the spectral analysis previously described (Fast Fourier Transform (FFT)), applied to the tide series recorded by the Dimar's tide gauge (from January 1st 2014 to April 29th 2014), and the reconstructed astronomical tide series, the main frequency ranges were obtained for each of the series (Figure 4) with relation to its main harmonic components (Godin, 1972; Beer, 1997).

From Figure 4, it can be observed that both the simulated and the real series, have dominant frequencies in 0.042f, 0.08f, and 0.083f (Table 5), considering that the sampling frequency of the signal is every hour, periods of 23.93 h, 12.42 h, and 12.04 h were obtained, corresponding to the diurnal K1 (Lunar declination), semi-diurnal M2 (Main lunar), and S2 (Main solar) components, respectively.

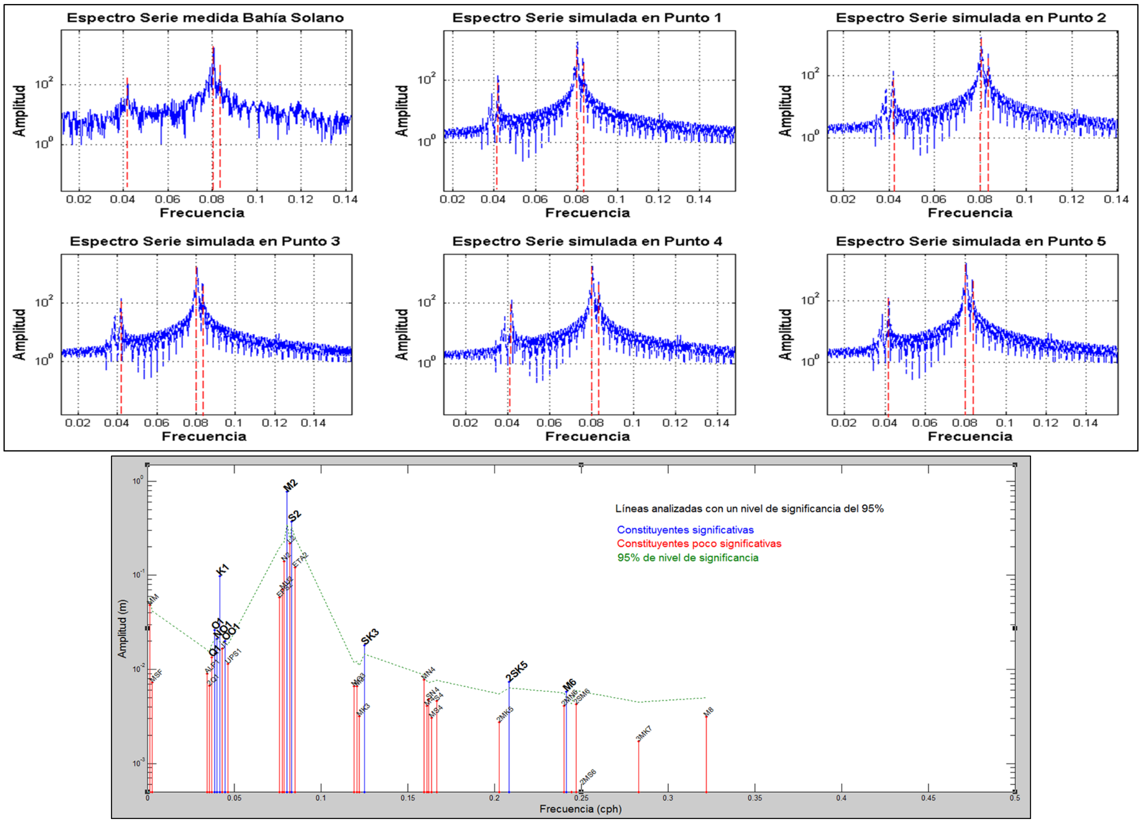


Figure 4. Spectral analysis for the series simulated and observed in Bahía Solano.

Table 5. Main harmonic components for the tide wave.

Harmonic component groups per species		
Long-term components	**Symbol**	**Frequency in solar hours**
Biweekly lunar	M_f	327.9
Monthly lunar	M_m	661.3
Semiannual solar	S_{sa}	4383
Solar anual	S_a	8766
Diurnal components	**Symbol**	**Frequency in solar hours**
Lunisolar declination	K_1	23.93
Main diurnal lunar	O_1	25.82
Main diurnal solar	P_1	24.07
Greater elliptical lunar	Q_1	26.87
Semi-diurnal components	**Symbol**	**Frequency in solar hours**
Main lunar	M_2	12.42
Main solar	S_2	12.00
Greater elliptical lunar	N_2	12.66
Lunisolar declination	K_2	11.97

Likewise, the above corroborates that the simulated series follow a behavior adjusted to the real, serving as a supply in the obtainment of the maximum flood heights in places where there are no enough instrumental records for the study area.

The main harmonics obtained from the harmonic analysis in Bahía Solano are shown in (Table 6):

Table 6. Main harmonic components obtained in the study area.

Harmonic name	Frequency [cph]	Amplitude [m]	Phase [°]
MM	0.0015122	0.0485	294.48
MSF	0.0028219	0.0073	143.81
ALP_1	0.0343966	0.0090	128.10
$2Q_1$	0.0357064	0.0067	342.79
Q_1	0.0372185	0.0134	268.06
O_1	0.0387307	0.0262	164.36
NO_1	0.0402686	0.0210	38.30
$*K_1$	0.0417807	0.0975	61.27
J_1	0.0432929	0.0167	125.27
OO_1	0.0448308	0.0201	90.88
UPS_1	0.0463430	0.0114	332.20
EPS_2	0.0761773	0.0584	154.92
MU_2	0.0776895	0.0709	328.07
N_2	0.0789992	0.1400	293.31
$*M_2$	0.0805114	0.7700	16.28
L_2	0.0820236	0.2194	99.87
S_2	0.0833333	0.3707	77.25
ETA_2	0.0850736	0.1219	249.92
MO_3	0.1192421	0.0066	200.80
M_3	0.1207671	0.0067	336.37
MK_3	0.1222921	0.0032	25.06

Harmonic name	Frequency [cph]	Amplitude [m]	Phase [°]
$\mathbf{SK}_3$	0.1251141	0.0179	294.33
$\mathbf{MN}_4$	0.1595106	0.0077	175.10
$\mathbf{M}_4$	0.1610228	0.0041	102.90
$\mathbf{SN}_4$	0.1623326	0.0048	142.13
$\mathbf{MS}_4$	0.1638447	0.0031	157.76
$\mathbf{S}_4$	0.1666667	0.0046	198.94
$\mathbf{2MK}_5$	0.2028035	0.0027	167.64
$\mathbf{2SK}_5$	0.2084474	0.0074	129.98
$\mathbf{2MN}_6$	0.2400221	0.0041	224.12
$\mathbf{M}_6$	0.2415342	0.0058	190.84
$\mathbf{2MS}_6$	0.2443561	0.0003	296.65
$\mathbf{2SM}_6$	0.2471781	0.0043	217.03
$\mathbf{3MK}_7$	0.2833149	0.0017	88.55
$\mathbf{M}_8$	0.3220456	0.0031	34.45

* Representative harmonics of the series.

Courtier coefficient

From the main harmonic components of the evaluated zone, and applying the Courtier coefficient, a coefficient 0.10 was obtained, evidencing a semi-diurnal tidal regime in the study area.

$$\frac{\mathbf{K1}\ (0.0975) + \mathbf{O1}\ (0.021)}{\mathbf{M2}\ (0.7700) + \mathbf{S2}\ (0.3707)} = 0.10 \quad \textbf{Semidiurno}$$

Mean and extreme tidal regime in Bahía Solano

It should be noted that, for the calculation of the mean and extreme regime, it was necessary to reconstruct 500 years of astronomical tide for each of the series simulated from the harmonic components obtained for each one.

In the same way, 100 meteorological tide series aged 500 years were simulated based on the parameters of location and scale using the Montecarlo method. The mean and extreme regime obtained for the five points of interest selected is shown below (Figures 5-9)

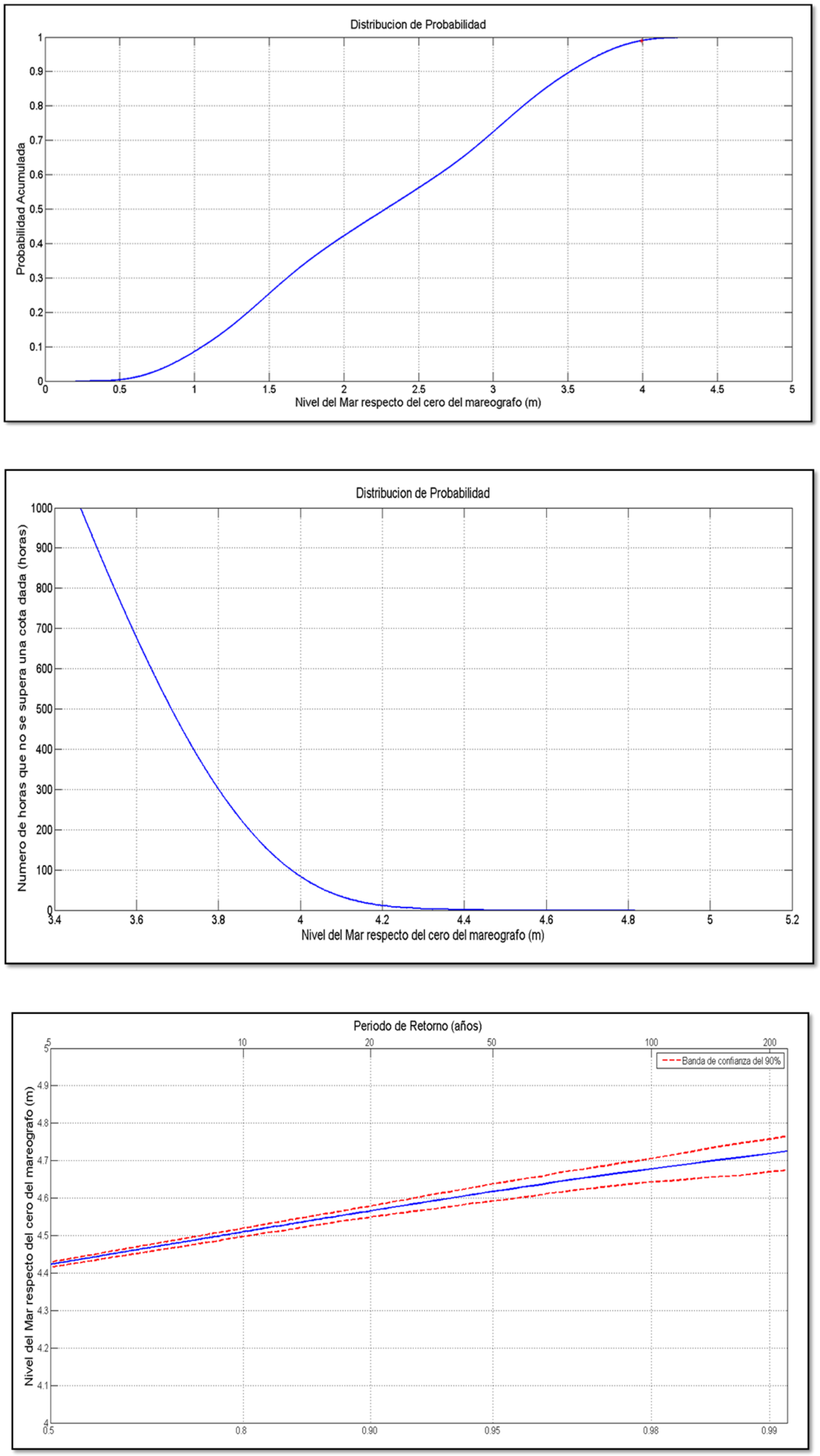


Figure 5. Mean and extreme regime point 1.

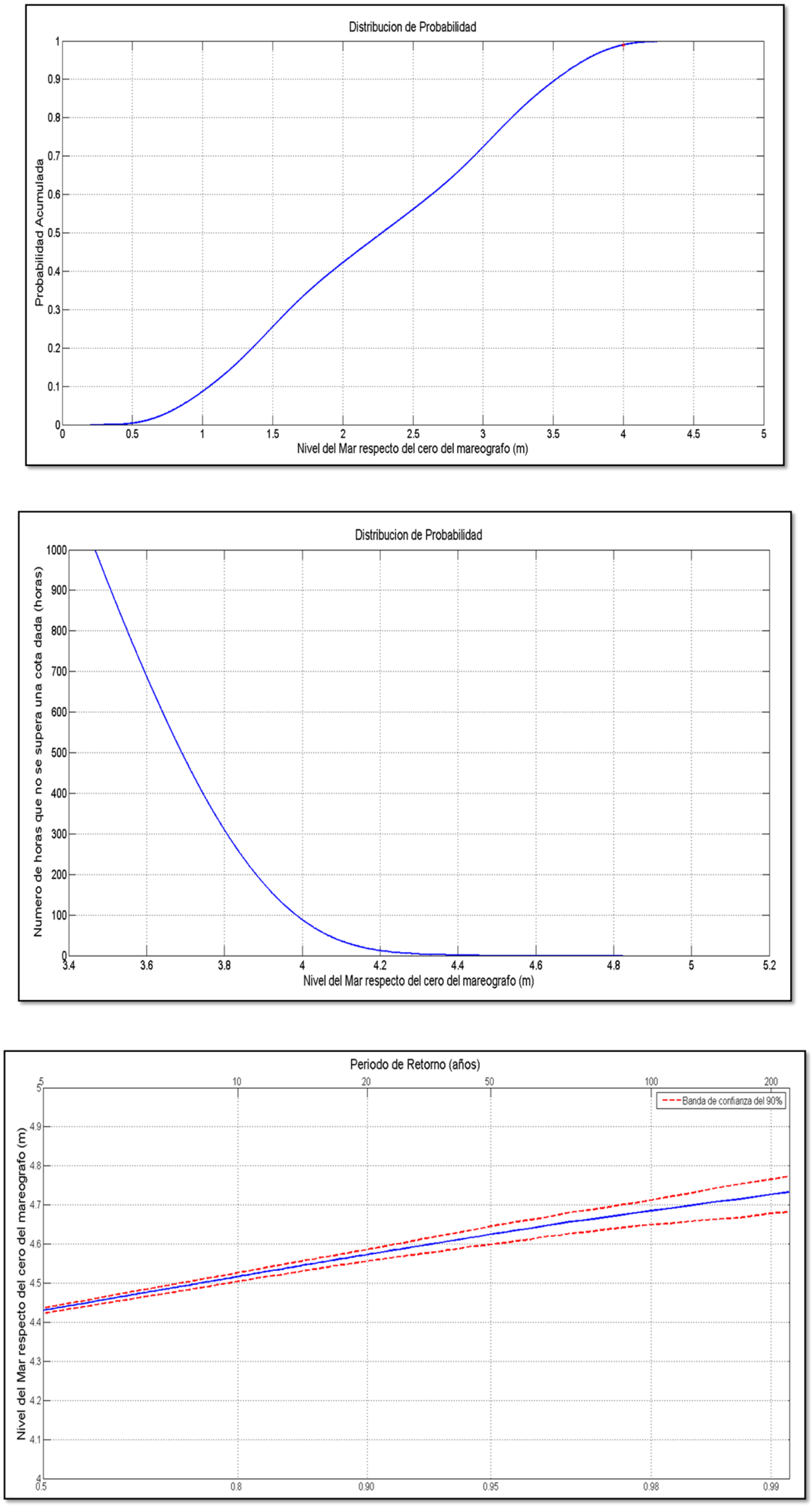


Figure 6. Mean and extreme regime point 2.

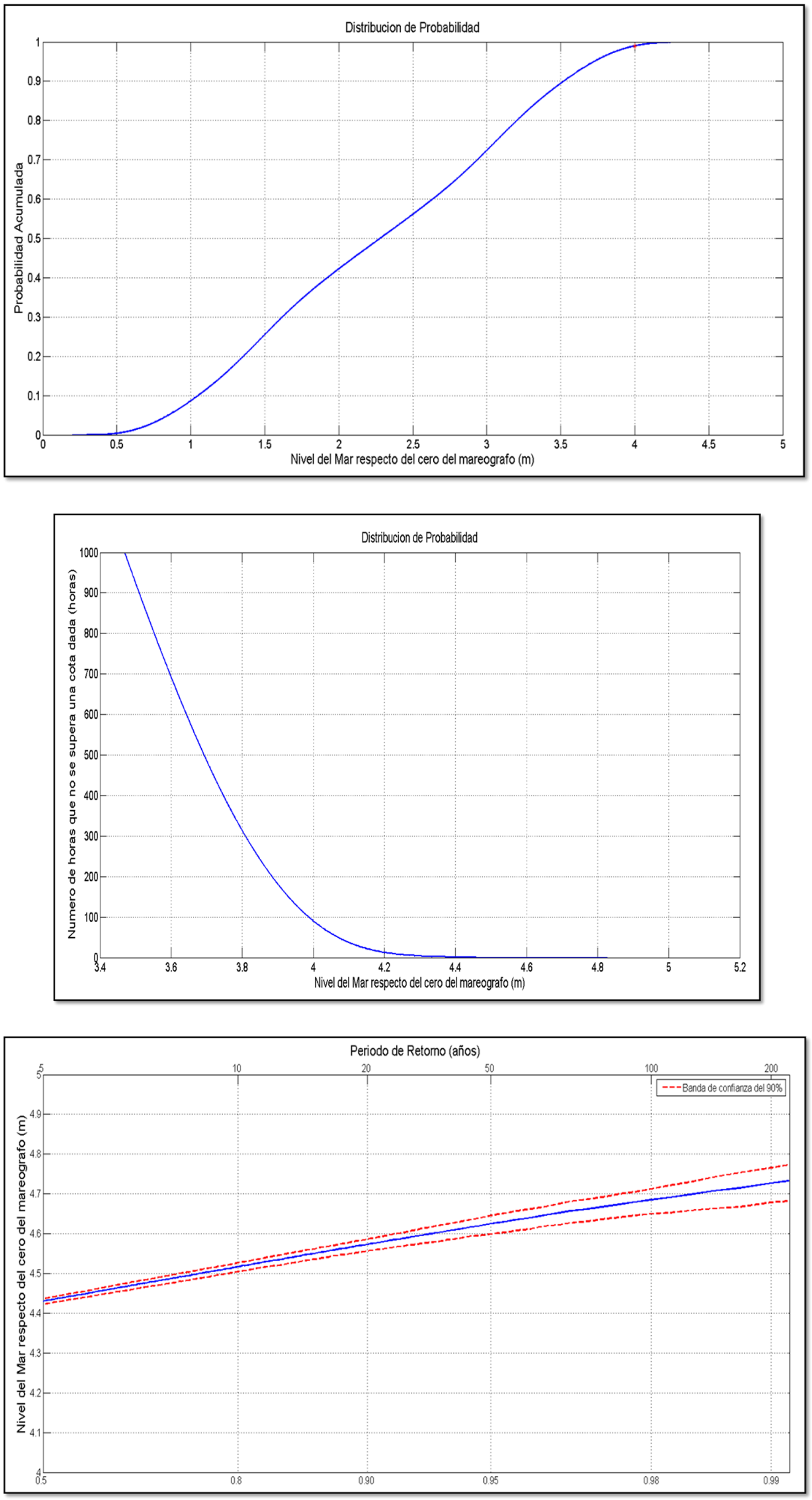


Figure 7. Mean and extreme regime point 3.

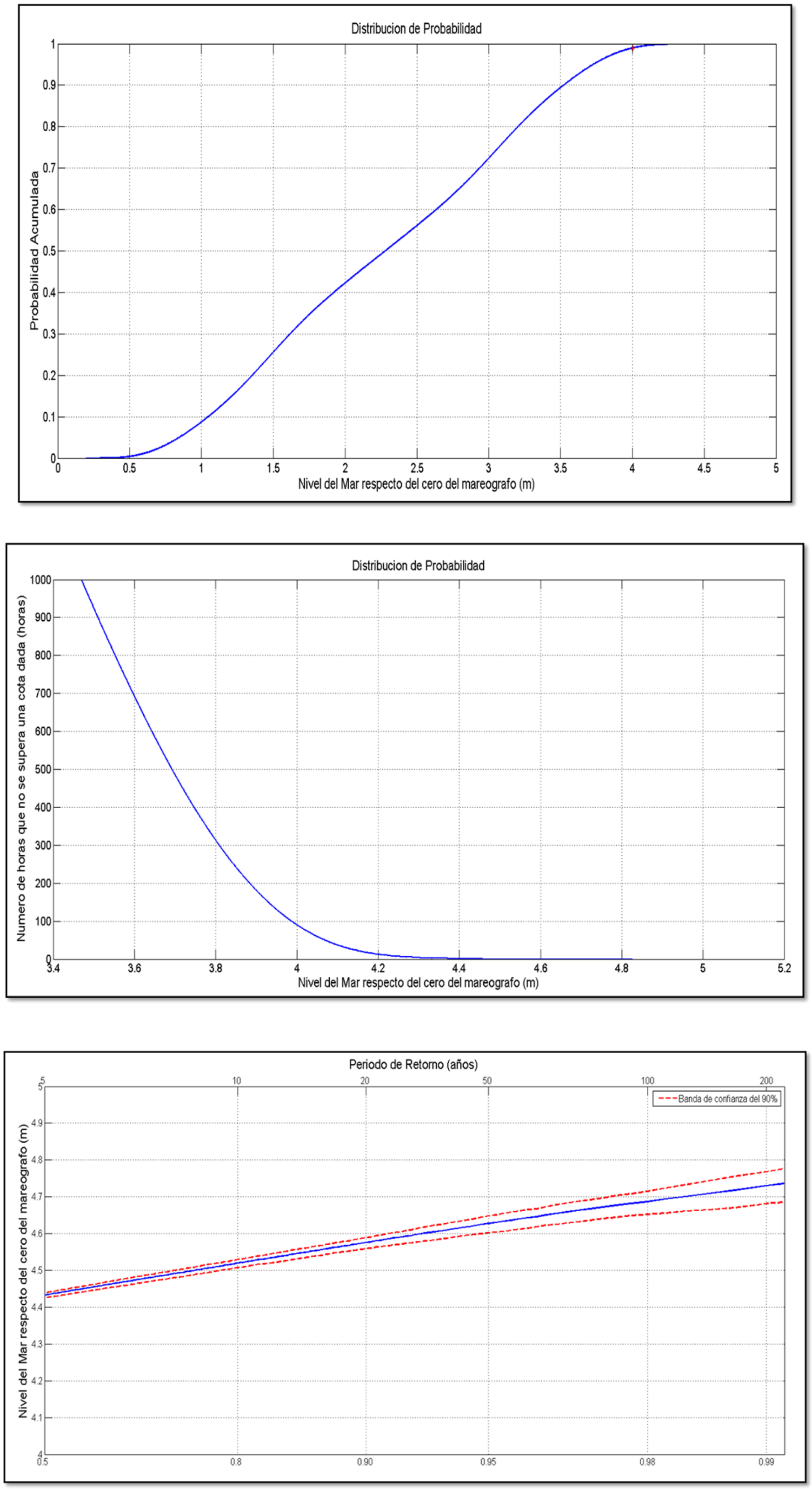


Figure 8. Mean and extreme regime point 4.

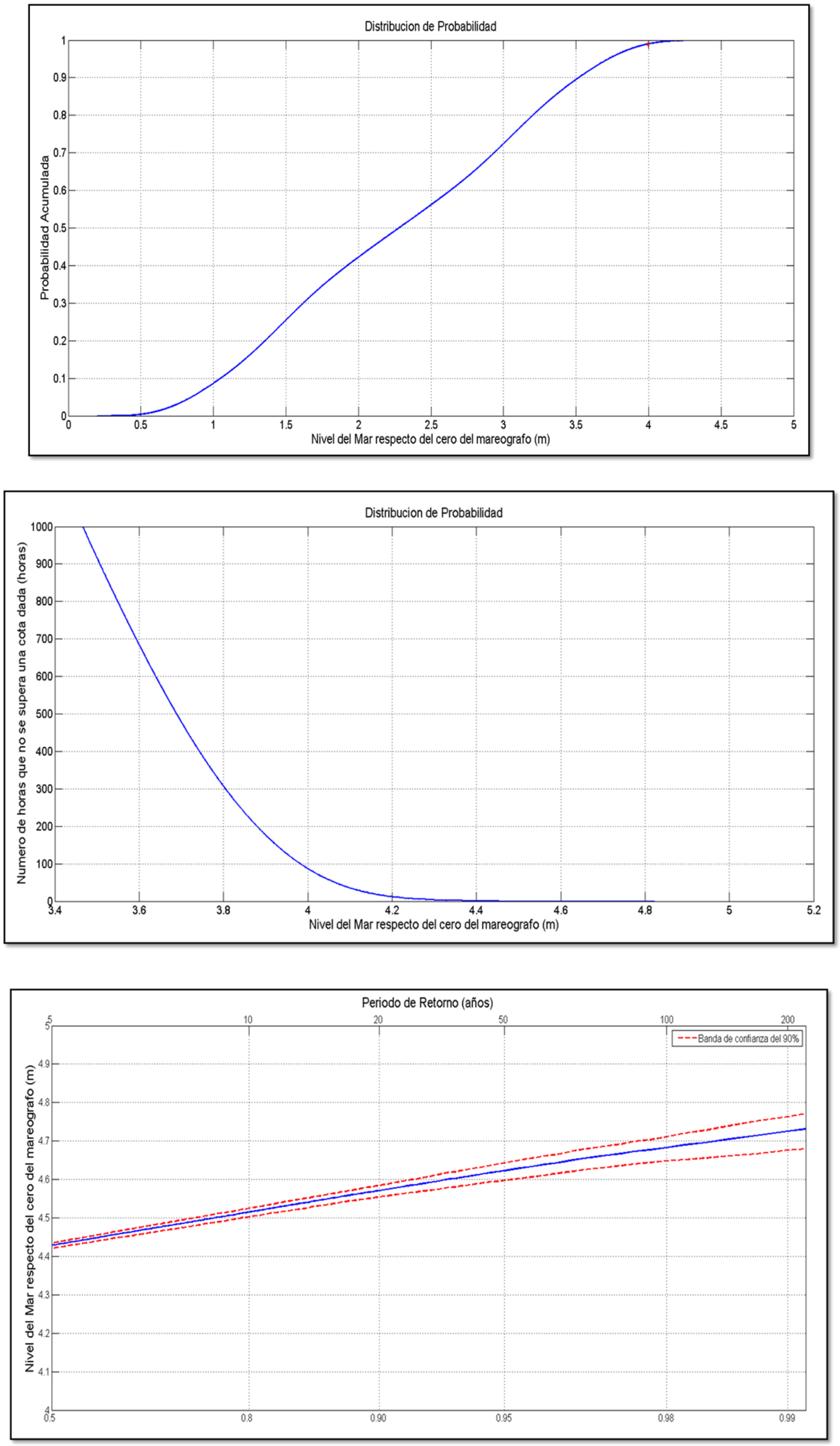


Figure 9. Mean and extreme regime point 5.

Based on the above, it may be deduced that the maximum flood heights in an mean year for the study area are: 3.9937 m, 4.0003 m, 4.0033 m, 4.0028 m , and 3.9985 m, respectively (Table 7), with a probability that would not exceed 99 %. That is, the maximum sea level height in this bay is in an mean of 3.9997 m with a deviation of 0.0039 m.

Table 7. Maximum flood heights and extremes for the points of interest.

Point of interest	Maximum flood heigh [masl]	Extreme [masl]
1	3.9937	4.5660
2	4.0003	4.5730
3	4.0033	4.5760
4	4.0028	4.5760
5	3.9985	4.5710

CONCLUSIONS

- According to the spectrums obtained, there is evidence that the dominant frequencies for both the measured tide series and the simulated series are the semi-diurnal M2, S2 and diurnal K1; with periods of 12.42 h, 12.04 h y 23.93 h respectively.
- Considering that the Courtier coefficient (form factor) obtained in the study area of 0.10, it is concluded that Bahía Solano is under the influence of a semi-diurnal tidal regime.
- The Spearman correlation index higher than 80 % obeys to a positive moderate correlation, which indicates that both the simulated and real series have a good similarity, validating the modeling process made to the generate the tide series in the points of interest selected where there are no instrumental records.
- The maximum flood heights obtained in this study area have an mean value of 3.9997 m with a deviation of 0.0037,with a probability of non-exceedance of 99 %; indicating that the variation in the maximum sea level height in an mean year, in the points of interest selected does not show a marked change, whose conclusion is that the dispersion of the data is minimal, that is, the variation in the maximum flood heights in this zone will be very little.

REFERENCES

Andersen, O., Woodworth, L. & Flather, A. (1995). *Intercomparison of recent global ocean tide models*. Journal of Geophysical Research Oceans, 100 (C12), 25261-25282. Doi: 10.1029/95JC02642.

Banco de Occidente. (2002). Libros de la Colección Ecológica del Banco de Occidente: Golfos y Bahías de Colombia. Cali, Colombia: Banco de Occidente. Recuperado de http://www.imeditores.com/banocc/golfos/presentacion.htm

Beer, T. (1997). Tides. En Beer, T. *Environmental Oceanography*. (2nd Ed.). (pp. 87-115). Bosa Roca, USA: Taylor & Francis Inc.

Castillo, E. & Pruneda, R. (2001). *Estadística aplicada*. Santander, España: Moralea.

Fierro, J., Bravo, M. & Castillo, M. (2000). *Caracterización del régimen de mareas y corrientes a lo largo del canal de Moraleda*, Ciencia y Tecnología del Mar, 23. 3-14. Valparaiso, Chile: Comité Oceanográfico Nacional.

Godin, G. (1972). *The Analysis of Tides*. Pp. 264. Toronto, Canadá: University of Toronto Press.

Grupo de Dinámica de Flujos Ambientales. (2012-2013). *Ingeniería Marítima, oscilaciones de largo periodo: Marea Astronómica*. Granada, España: Universidad de Granada.

_______. (2012-2013). *Ingeniería Marítima, oscilaciones de largo periodo: Marea Meteorológica.* Granada, España: Universidad de Granada.

Grupo de Ingeniería Oceanográfica y de Costas (GIOC). (2001). *Aqualab, Manual de referencia.* Santander, España: Universidad de Cantabria.

_______. (2002). *Atlas de inundación del litoral peninsular español.* Documento temático. Santander, España: Ministerio de Medio Ambiente y Universidad de Cantabria.

Instituto de Hidrología, Meteorología y Estudios Ambientales - IDEAM. (2014). *Pronóstico de Pleamares y Bajamares Costa Pacífica Colombiana.* Bogotá, Colombia.

Kang, W., Park, S., Moon, S. & Lee, K. (2009). Analyzing sea level rise and tide characteristics change driven by coastal construction at Mokpo Coastal Zone in Korea, Ocean Engineering. 36(6) 415-425. Doi: 10.1016/j.oceaneng.2008.12.009. Estados Unidos: ElSevier.

Kjerfve, B. (1981). Tides of the Caribbean Sea, Journal of Geophysical Research. 86(C5), 4243–4247.Estados Unidos.

Kurmyshev E. (2003). Fundamentos de métodos matemáticos para física e ingeniería. México: Editorial Limusa S.A.

Leffler, K & Jay, D. (2009). Enhancing tidal harmonic analysis: Robust (hybrid L1=L2) solutions, Continental Shelf Research, 29(1), 78-88. Doi: 10.1016/j.csr.2008.04.011. Estados Unidos: Elsevier.

Lehman A., O´Rounke N., Hatcher L. & Stepanski E. (2013). JMP for Basic Univariate and Multivariate Statistics: A Step-by-step Guide (pp.146-147). Carolina del Norte, USA: SAS Institute.

Manzano F., Corchete V.& Lastra X. (2007). Análisis espectral del registro de marea en la estación de Ceuta. España.

Otero, L. (2004). Determinación del nivel medio y extremal del nivel del mar para la bahía de Buenaventura. Boletín Científico: Centro de Investigaciones Oceanográficas e Hidrográficas del Pacífico No. 11, 30-41.Tumaco, Colombia.

_______. (2005). Metodología para establecer la línea de más alta marea en aguas abrigadas (bahías, estuarios, etc.) cuando no se tienen registros instrumentales. (Informe técnico). Tumaco, Colombia: Centro de Investigaciones Oceanográficas e Hidrográficas del Pacífico.

Pardo, E. & Rodríguez, F. (2013). Análisis espectral de series temporales de variables geológicas con muestreo irregular. Boletín Geológico y Minero, 124(2) 323-327. Doi: 10.21701/bolgeomin . Granada, España.

Pawlowicz, R., Beardsley, B. & Lentz, S. (2002). Classical tidal harmonic analysis with errors in matlab using t-tide, Computers & Geosciences, 28(8), 929-937. Doi: 10.1016/S0098-3004(02)00013-4. Estados Unidos: Elsevier.

Pugh, D. (2004). Changing sea level, Weather and Climate. Pp.256. Cambridge, UK: Cambridge University Press.

Servicio Hidrográfico y Oceanográfico de la Armada de Chile, SHOA. (1992). Glosario de Marea y Corrientes. 2da Ed. Valparaíso, Chile: SHOA.