COMPARATIVE STUDY OF TIDAL DYNAMICS ON THE COASTS OF MADAGASCAR

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ABSTRACT

Nowadays, most people on the coasts of MADAGASCAR carry out their activities traditionally without having respected their security. Because of this situation there are many accidents. These incidents prompted us to carry out studies to reduce the risk of accidents caused by the movement of the tide. To address this issue, we modeled the spatial distribution of sea level rise using the fuzzy logic set method. This method consists of first collecting temporal tidal data, then performing the analytical and statistical resolution of the average value using Matlab. We then proceed to the spectral analysis of the tidal time series ζ(t), where t designates time. This series represents the tidal height at successive times and predicts its future variations

Keyword : *fuzzy logic, spectral analysis, tide*

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1. INTRODUCTION

The island of Madagascar, located in the Indian Ocean, presents a unique geographic and oceanographic diversity. Tides, a complex and cyclical phenomenon, play a fundamental role in coastal dynamics, influencing marine ecosystems, the economy and human activities along the coast of Madagascar. This study focuses on the exploration and comparison of tidal dynamics on these different coasts, thus revealing the subtleties and singularities of these variations.

To achieve these objectives, a rigorous methodology will be employed, including the collection of tidal data from various sources, the use of fuzzy logic modeling techniques and statistical analysis.

2. METHODOLOGY

2.1 Study area

The study area is the coastal zone (coastal) of Madagascar, but we took the 4 ports in the Mozambique Channel and 4 ports in the Indian Ocean, with the geographical coordinates of 8 major port cities of Madagascar: Nosy Be (Hellville), Mahajanga, Maroantaly, Toliara, Vohemaro, Fenerive Est, Toamasina and Fort Dauphin

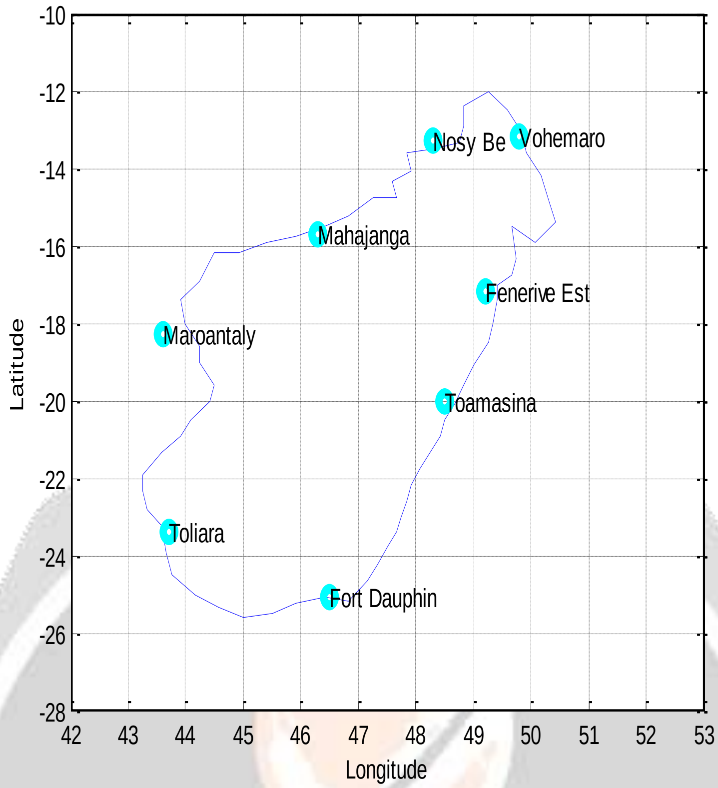

Fig - 1: Study area

Tab - 1: Geographic coordinates

PORTS	LATITUDES	LONGITUDES
Nosy be	- 13,314	48,261
Mahajanga	- 15,717	46,317
Maroantaly	- 18,250	43,261
Toliara	- 23,350	43,700
Vohemaro	- 13,221	49,800
Fenerive Est	- 17,221	49,243
Toamasina	- 20,000	48,500
Fort Dauphin	- 25,157	46,600

2.2 Method

2.2.1 Statistical analysis

a) **Definition**

Science and techniques of mathematical interpretation of complex and numerous data, enabling predictions to be made.

b) **Statistical average**

The average is a statistical measure characterizing the elements of a set of quantities. There are several ways to calculate the average of a set of values, but it can therefore only be used for a quantitative variable.

$$\overline{X} = \frac{1}{N}\sum_{k=1}^{N} X_k$$

c) **Variance**

Variance is a statistical measure to characterize the dispersion of a distribution or a sample.

$$Var(\mathrm{X}) = \frac{1}{n}\sum_{t=1}^{n}(X_t - \overline{X}_t)^2$$

d) **Standard deviation**

The standard deviation of a statistical series tells us about the dispersion around the mean of the values of this series. It is used to determine the dispersion of data in a sample relative to the mean

2.2.2 Fuzzy logic

a) **Definition of a fuzzy set**

Let X be a countable set or not. A fuzzy subset A of X is characterized by its membership function f_A such that:

f_A: X⟶ [0.1]

x⟶f_A (x)

Or f_A (x) represents the degree of membership with which x belongs to the fuzzy set A. Let f(X) be the set of all fuzzy sets of X.

1-Step of the fuzzy interference system method:

A fuzzy interference system consists of three stages:

Fuzzification: consists of transforming real inputs into a fuzzy part defined on a representation space linked to the input. This representation space is normally a fuzzy subset. During the fuzzification stage, each input variable is associated with fuzzy subsets.

Inference: is a mechanism for condensing the information of a system through a set of rules defined for the representation of any problem. Each rule delivers a filtered conclusion, which is then aggregated with the other rules to provide a conclusion (aggregation).

Defuzzification: allows you to characterize the linguistic variables used in the system. It is therefore a question of converting a fuzzy value into a net value.

b) **Fuzzy representation of input and output variables**

To set up the fuzzification process, you must first know how many input variables will be defined in the SIF. An input variable is an integer parameter which takes its values in a well-defined universe.

Any output variable must be fuzzified because the outputs are linked to the input variables. To do this, you also need to know the number of output variables and correctly define the discourse universe.

c) **Definition of fuzzy rules**

The number of rules in a SIF depends on the number of variables (inputs and outputs). Fuzzy rules are generally of the "IF ... THEN" type and are used to represent relationships between input and output variables. More precisely, a fuzzy rule R is defined in the following form: If x is A then y is B

The first part of the rule “x is A” is the antecedent and the second part of the rule “y is B” is the consequent.

Fuzzy rules can be simple with simple antecedent and consequent or composed, with the combination of several premises of the following conjunctive form:

A: If x_1 is A_1 and x_2 is A_2 and...and x_n is A_n Then y is B

d) Modeling by fuzzy logic

In this paragraph, we apply the fuzzy inference method to associate marine climate variables with terrestrial climate variables. Therefore, we reused the model equations obtained by multiple regression and we followed the following steps:

* For the input variables, we multiply them by their model coefficient. These are the calculated values being mentioned on each figure of the membership function.

* For the output variables, we add the data multiplied by this model coefficient to that of the observed data.

3. RESULTS AND DISCUSSION

3.1 Results 1

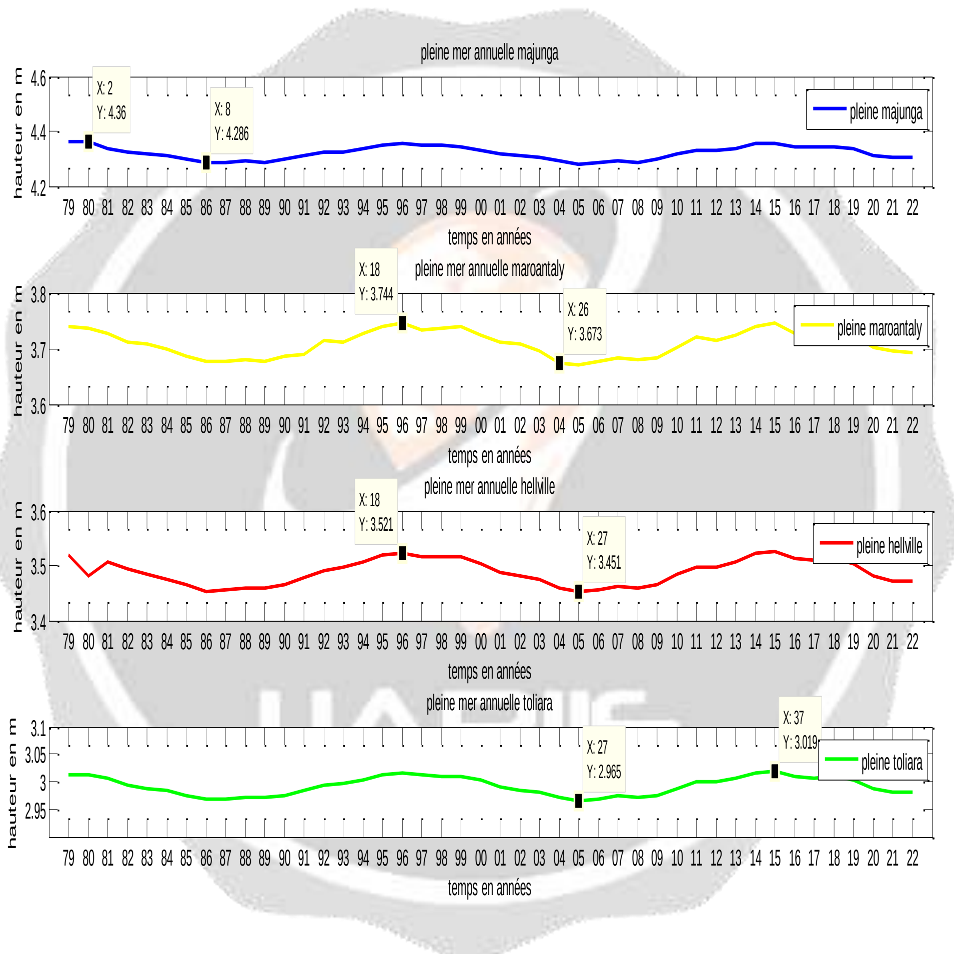

Chart - 1: Annual average high seas on the Mozambique Channel

Tab - 2: Tide height on the Mozambique Channel

Port	Years	Height of high tide	Years	Height of low tide
Majunga	1979 1996 2015 2019	4.362 4.353 4.357 4.344	1986 1989 2005 2008	4.286 4.289 4.283 4.288
Hellville	1979 1996 1999 2015	3.518 3.521 3.514 3.526	1986 1989 2005 2008	3.454 3.458 3.451 3.458
Maroantaly	1979 1996 1999 2015	3.739 3.744 3.74 3.745	1986 1989 2005 2008	3.676 3.677 3.671 3.680
Toliara	1979 1996 1999 2015	3.013 3.017 3.011 3.019	1986 1989 2005 2008	2.968 2.97 2.965 2.971

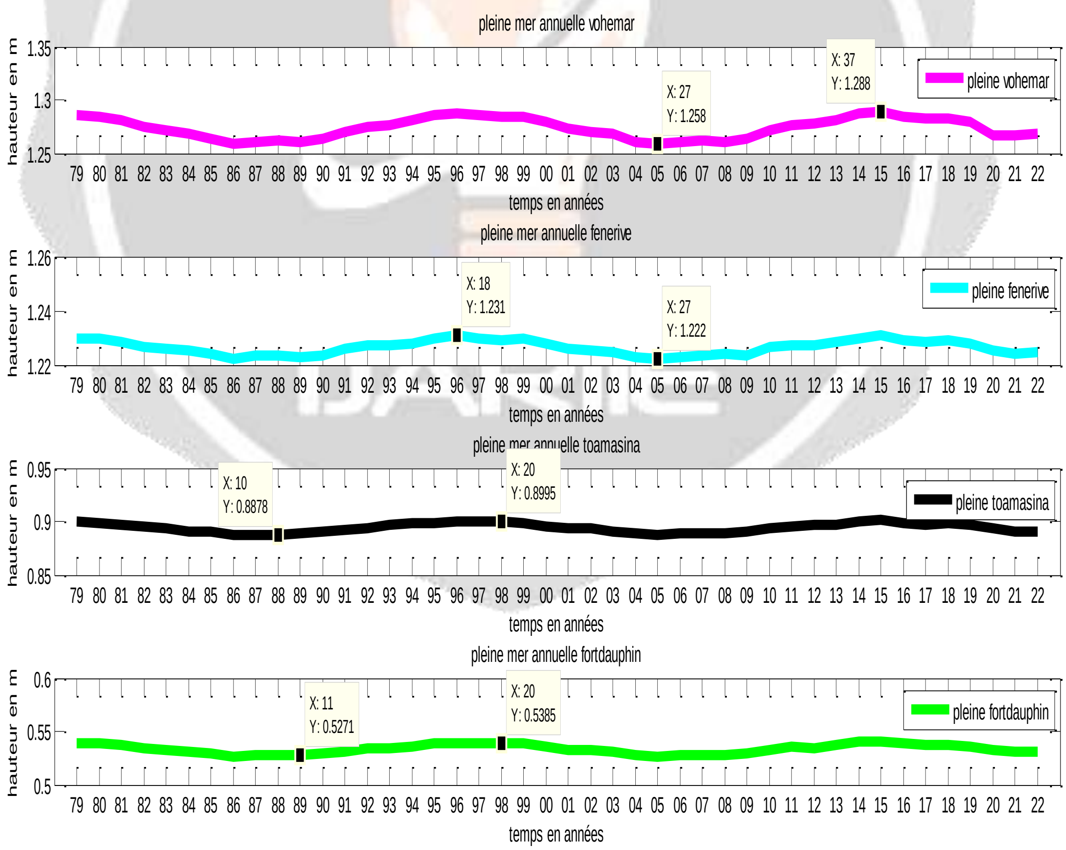

Chart - 2: Annual average high seas over the Indian Ocean

Tab - 3: Tidal height in the Indian Ocean

Port	Years	Height of high tide	Years	Height of low tide
Fenerive Est	1979	1.230	1986	1.229
	1996	1.231	1989	1.223
	2015	1.229	2005	1.221
	2019	1.231	2009	1.228
Vohemaro	1979	1.286	1986	1.259
	1996	1.287	1989	1.261
	2015	1.288	2005	1.258
	2019	1.279	2008	1.260
Toamasina	1979	0.899	1986	0.888
	1997	0.899	1987	0.887
	2014	0.900	2005	0.887
	2019	0.896	2008	0.888
Fort dauphin	1979	0.899	1986	0.526
	1996	0.539	1989	0.527
	2015	0.540	2005	0.526
	2019	0.536	2008	0.527

3.2 Résultats 2

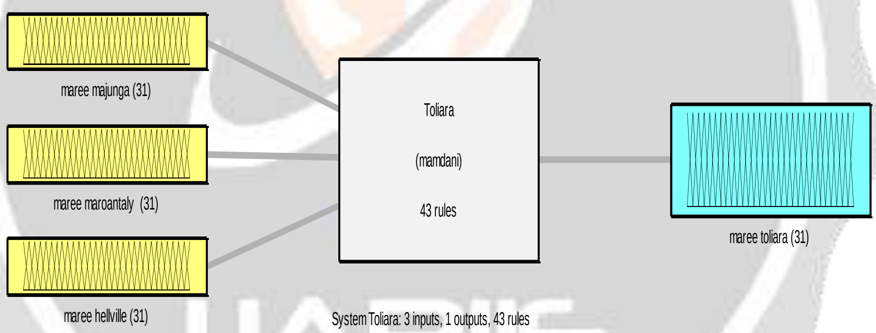

Fig - 2: Mapping of the Mozambique Channel tidal model

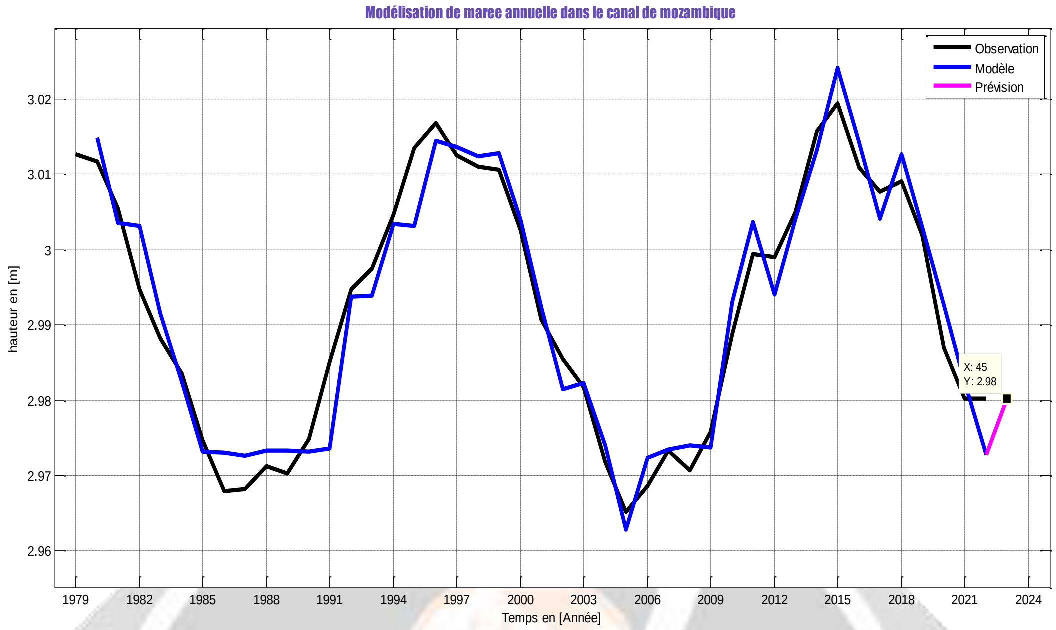

Chart - 3: Modeling annual average tides through the Mozambique Channel

3.3 Discussion

3.3.1 Discussion for result 1:

a) Analysis of the height of the tides on the coasts of Madagascar

This study aims to analyze the height of the tides along the coasts of Madagascar, based on Figures 2 and 3 above, representing the average height of the tide on the eight (8) major ports, namely: port of Nosy Be, Majunga, Maroantaly, Toliara in the Mozambique Channel while Antalaha, Fenerive Est, Toamasina and Fort Dauphin in the Indian Ocean.

Coast of the Mozambique Channel (figure 2)

The Mozambique Channel, an arm of the sea separating Madagascar from the African continent, presents a variation in the height of the tides. In Figure (2), areas at the top indicate higher tides, while areas at the bottom indicate lower tides. This variation could be attributed to the proximity to the African coast and specific marine currents in the Mozambique Channel.

Indian Ocean coast (figure 3)

On the east coast of Madagascar, bordered by the Indian Ocean, the figure also shows a variation in tide height. However, there appear to be more areas where the height is low, indicating lower tides compared to the West Coast. This trend could be due to the influence of the larger Indian Ocean and its ocean currents.

b) Comparative analysis

Comparing the two sides, it seems that the east coast of Madagascar tends to have lower tides than the west coast. However, there are variations along each coast, with some areas experiencing higher or lower tides than others.

This study shows the dynamics of tides on the coasts of Madagascar and highlights the importance of taking into account local variations when studying tides.

Tables 2 and 3 show us the annual trends of each port (08 ports) and the significant heights with the respective years. The exact period values are represented on the x-axis, while the exact height of high and low tides is represented by the y-axis in Figure 5.

3.3.2 Discussion for result 2:

The multiple regression model gave us the equation:

Toliara = 0.1330+0.4420*Majunga+6.7021e-02*Maroantaly+0.2008*Hellville

$$Let \begin{cases} \varphi_1 = 0.442: \ coeffient\ Majunga \\ \varphi_2 = 0.06,7021: \ coeffient\ Maroantaly \\ \varphi_3 = 0.2008: \ coeffient\ Hellville \\ \xi = 0.1330: \ constant \end{cases}$$

* Toliara: tide from the Mozambique Channel to Toliara is the output variable
* Hellville: tide from the Mozambique Channel to Hellville; tide from the Mozambique Channel to Majunga; tide from the Mozambique Channel to Maroantaly are the input variables.

a) Membership function:

The universe of discourse and the number of partitions for each variable are presented in Table 4 below:

Tab - 4: Partitions of variables for modeling the Toliara tide

Variables	Universe of speech	Numbers of partitions
Tide Majunga tide	U_{MJ}=[1.895 1.925]	30 partitions (T1,T,T3,…T31)
Tide Maroantaly	U_{MR}=[0.24 0.25]	30 partitions (P1, P2, P3,… P31)
Tide Hellville	U_{HLL} =[0.69 0.708]	30 partitions (E1, E2, E3,… E31)
Tide Toliara	U_{TL}=[2.83 2.88]	30 partitions (S1, S2, S3,… S31)

b) Mapping of the fuzzy interference system

Figure 4 illustrates the Mapping of the Mozambique Channel tide model including: Majunga tide has 31 fuzzy sets, Maroantaly tide has 31 fuzzy sets, Hellville tide has 31 fuzzy sets, the output variable is Toliara tide has 31 fuzzy sets, the fuzzy rules are 43.

c) Modeling and prediction

Figure 5 above shows us the modeling of data in annual average tides using the fuzzy interference system. This figure represents 3 curves of different colors including, in black color: the observation data, in blue color: the result of the model, and in pink color, the tide forecast for one year (in 2023). We see that the curve of the observed data is collinear and follows the appearance of that of the model. This explains why the method is excellent. It is therefore a model of order 1. Our 2023 forecasts, the tide of the Mozambique Channel will increase by 2.98 m.
Fuzzy interference system. We can conclude that:
- The analysis of the fuzzy membership function allows us to deduce the fuzzy sets of each equation of the different parameters. For the equation:

** Toliara = 0.1330+0.4420*Majunga+6.7021e-02*Maroantaly+0.2008*Hellville

The input variables have:
-31 fuzzy sets of Hellville
-31 fuzzy sets of Majunga
-31 fuzzy sets from Maroantaly

The output variable has:
-31 fuzzy sets of Toliara

- This model mapping contains 43 rules;
-This modeling is of order 1.

- The observed data and model curves are collinear and of the same shape; the models obtained are excellent

4. CONCLUSION

In conclusion, these graphs provide a valuable visualization of the tidal variation in Nosy Be, Mahajanga, Maroantaly, Toliara, Vohemaro, Fenerive Est, Toamasina and Fort Dauphin, allowing a more in-depth understanding of tidal phenomena in these regions.

The determination of the tide height in the regions cited above, as illustrated in each graph, is obtained by numerical resolution using the fuzzy logic model and by harmonic analysis. The fuzzy logic model is a global tidal model that solves fluid dynamics equations on a finite mesh grid, allowing accurate representation of geographic features. Harmonic analysis, on the other hand, is a mathematical method used to decompose a periodic signal, such as tides, into a sum of sinusoidal functions of different frequencies, which allows future tidal cycles to be predicted. These combined methods provide a robust and accurate prediction of tide height.

5. REFERENCES

[1]. ODILE GUERIN, “Everything you need to know about the tides”, Éditions Ouest-France, 2004, (ISBN 2-7373-35051)

[2]. BERNARD SIMON, “The coastal ocean tide, a co-edition of the Oceanographic Institute and SHOM”, France, 2007, 433 pages, (ISBN 978-2-903581-32-9), ISSN 1272-0763, ref 942MOG,

[3]. The SHOM guides (France), “La Marée”, ref OG941, 1997,

[4]. CECILE M; TAHIARIKI L; “Optimization of the calculation of tidal currents in the model

[5]. MOTHY » End-of-studies internship report No. 1048; NATIONAL SCHOOL of METEOROLOGY (ENM) Toulouse, France; (2006)

[5]. TIDAL MANUAL”, WARREN D. FORRESTER, Ph. D. under contract with the Department of Fisheries and Oceans, Ottawa, 1983.

[6]. FABIEN LEFEVRE: “Modeling of ocean tides on a global scale”, thesis of doctorate University Toulouse III Paul Sabatier, September 22

[7]. GILLES ROULET, “La Marée”, Ifremer (France) master’s course 2011-2012

[8]. JACQUES W; NATECH; “Revised technical guide for carrying out studies of delimitation of the plume of thrust effluents and recent tidal modeling”; National Water Research Institute, Environment CANADA; p.33-34; (March 2003)

[9]. AMANDINE NICOLLE: “Modeling of tides and storm surges in the Pertuis Charentais”, doctoral thesis UNIVERSITE ROCHELLE, June 2009.

[10]. http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Pa