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Research Article

Modeling of Earthquakes Recorded in Cuba Using the ROR Methodology

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Abstract

The objective of our work is to model, with the help of the ROR methodology, the earthquakes recorded in Cuba on the Richter scale in order to predict upcoming events, establish if there is any trend in the latitude and longitude where they occur, and see which are the main ones. To carry out this work, we had a database of earthquakes of all magnitudes on the Richter scale taken from 1965 to 2023, a total of 100,736 cases. These data are in the hands of the Cuban Seismology Center, CENAIS., there are no missing data in the sample. Latitude, longitude and magnitude were modeled. For the latitude, earthquakes were reported approximately close to 16 N, then the records rose to 18 N, until 2019, month 3, from now on the latitude rises to approximately 19 N, so the trend over time is to increase. The average values for this variable are 19.9 N. For longitude it occurs similar to latitude, there is a tendency to increase, values range from – 67 W to -74 W approximately on the same dates as latitude. The average values are -75.8 W. The latitude model explains 99.9% of the variance with an error of 0.651443 degrees, the trend is increasing. For longitude, perfect models are obtained, the trend for longitude is to increase as well. The error is 1.67 degrees. For both latitude, longitude and magnitude, good forecasts are presented with errors close to zero. The long-term magnitude model depends on 73 and 74 steps back and the trend is negative which means that smaller magnitudes should occur over time. Observing the small errors and the high explained variance of the models of the variables studied, we can assert that it is advisable to establish a short-medium and long-term forecasting system for the earthquakes recorded using the ROR methodology.

Keywords: Modeling, Earthquakes, Cuba, Forecast, ROR Methodology.

1. Introduction

Since 2012, forecasts of high intensity of earthquakes have been made using mathematical modeling with good results, in these works a large number of variables are predicted such as the year, month, day, the time and magnitude of these phenomena, the modeling is carried out in the long term and it is reiterated that only the Civil Defense bodies are in charge of issuing alerts about the appearance of these phenomena [1]. In other works, earthquakes from 1990 to 2010 and the total number of deaths are modeled; they say that in 2014 there would be an increase in earthquakes globally and that their trend was to increase [2]. Also in 2018, a set of earthquakes are modeled at the Global Level included in the period from 2014-08-27 23.22.23 UTC to 2018-08-27 04.47.36 UTC, predicting the latitude and the longitude of a total of the last 50 earthquakes, obtaining that the compensation between the real value and the forecast was 0.716 for a model, it was also observed that these phenomena had a tendency to increase in longitude, it also depended, among other factors, on 2 steps back for a studied model [3-6]. In these works it is concluded that earthquakes at a Global Level are a regressive event throughout the planet and what happens in one place has an impact on another, not randomly or due to chance, but rather it is a well-determined phenomenon, more recently, made a forecast until the year 2050 of the number of earthquakes of magnitude 5 or more on the Richter scale whose tendency was to increase, showing how the 22-year cycle of the solar cycle impacts, highlighting how the ROR methodology can be used for the prediction of cyclones and also earthquakes, as well as for viral and parasitic entities, the 11-year cycle of the sun and its impact are also presented, in these works it was It is possible to predict for Haiti in the year 2031 a possible earthquake on July 14 at 9:20 minutes latitude 36.60, longitude 133, at a depth of 71.14 m with a magnitude of 6.7 on the Richter scale [4, 5]. The objective of our work is to apply the ROR methodology to earthquakes greater than 6 on the Ricther scale that are monitored in Cuba and predict the next events.

2. Materials and Methods

To carry out this work, we had a database of earthquakes on the Ricther scale taken from 1965 to 2023, a total of 100,736 cases. These data are in the hands of the Cuban Seismology Center, CENAIS, and were extracted of the daily basis.

3. Results and Discussion

It can be seen in Table 1 that the recorded earthquakes are at Latitude 16 N to 26 N with an average of 19.94, the longitude ranges from -86 W to -67 W, the magnitude ranges from 0 to 7.2 on the Richter scale.

Table 1: Descriptive Statistics

	N	Mínimum	Máximum	Mean	Estándard Deviation
Latitude	100736	16,000	25,957	19,94766	,722472
Longitude	100736	-86,000	-67,000	-75,80412	1,722319
Magnitude	100736	,0	7,2	1,841	,8908
Year	100963	1965	2023	2010,60	9,838
month	100736	1	12	6,19	3,508
Day	100736	1	31	15,84	8,768
N válido (por lista)	100736				

First, the latitude was modeled, obtaining a model that explains 99.9% of the variance with an error of 0.651443, Table 2.

Table 2: Resume of the Model[c, d]

Modelo	R	R squared[b]	R squared adjusted	Standard error of estimation	Durbin-Watson
1	,999[a]	,999	,999	,651443	2,151

a. Predictors: Lag1LatN, DI, NoC, DS, Lag68LatN, Lag11LatN, Lag6LatN
b. For regression through the origin (the model without intercept), R square measures the proportion of the variability in the dependent variable about the origin explained by the regression. This CANNOT be compared to the R squared for models that include intercept.
c. Dependent variable: Latitude
d. Linear regression through the origin

The analysis of variance was significant with a Fisher's F of 13488069.940 significant at 100%. Table 3.

Table 3: Anova[a, b]

Modelo	Sum of Squares	gl	Cuadrátic Mean	F	Sig.
Regressión	40068339,216	7	5724048,459	13488069,940	,000c
Residual	42718,376	100661	,424		
Total	40111057,592d	100668			

a. Dependent variable: Latitude
b. Linear regression through the origin
c. Predictors: Lag1LatN, DI, NoC, DS, Lag68LatN, Lag11LatN, Lag6LatN
d. This total sum of squares is not corrected for the constant because the constant is zero for the regression through the origin.

The model in question is the following, Table 4. It depends on DS and DI, sawtooth and inverted sawtooth, NoC is the trend that is positive and significant at 100%, Lag6LatN. lag11LatN and lag68LatN are the latitude returned in 6, 11 and 68 cases back, lag1LatN, is the latitude returned in 1 case. All of these variables are 100% significant.

Table 4: Coeficients[a, b]

Model	Coeficients non estandardizeds		Standardized Coeficients	t	Sig.
	B	Stándard Error	Beta		
DS	7,671	,088	,272	87,657	,000
DI	7,676	,088	,272	87,712	,000
NoC	1,310E-6	,000	,004	18,138	,000
Lag6LatN	,141	,003	,141	45,881	,000
Lag68LatN	,094	,003	,094	31,508	,000
Lag11LatN	,131	,003	,131	42,867	,000
Lag1LatN	,246	,003	,246	80,271	,000

a. Dependent variable: Latitude
b. Linear regression through the origin

The residuals have a mean of 0 and a standard deviation of 1. Table 5.

Table 5: Stadísticals of Residuals[a, b]

	Mínimum	Máximum	Mean	Stándard Desviation	N
Predicted value	18,43425	21,92025	19,94813	,310828	100668
Residue	-4,290995	6,226979	,000000	,651424	100668
Standard predicted value	-4,870	6,345	,000	1,000	100668
Standard Residue	-6,587	9,559	,000	1,000	100668

a. Dependent variable: Latitude
b. Linear regression through the origin

In figure 1 you can see the behavior of the latitude, first, from 1965 to approximately 1999, month 6, day 21, earthquakes were reported approximately close to 16 N, then the records rise to 18 N, until 2019, month 3, from now on the latitude rises to approximately 19 N, so the trend over time is to increase in latitude. The average values for this variable are 19.9 N.

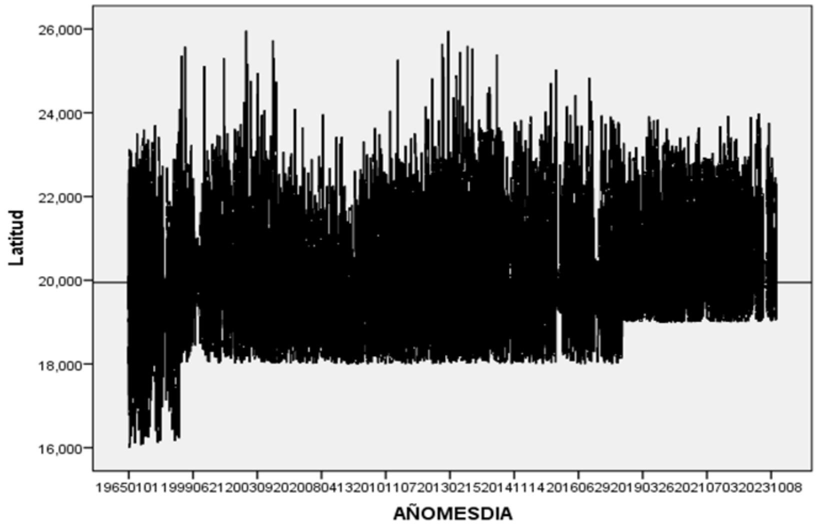

Figure 1: Behavior of Latitude from 1965, Month 1, Day 1 to 2023, Month 10, Day 8 for the Station that Records Earthquakes in Cuba.

In the case of longitude, a similar thing occurs, there is a tendency to increase, values range from – 67 to -74 W approximately on the same dates as latitude. The average values are -75.8 W. Figure 2.

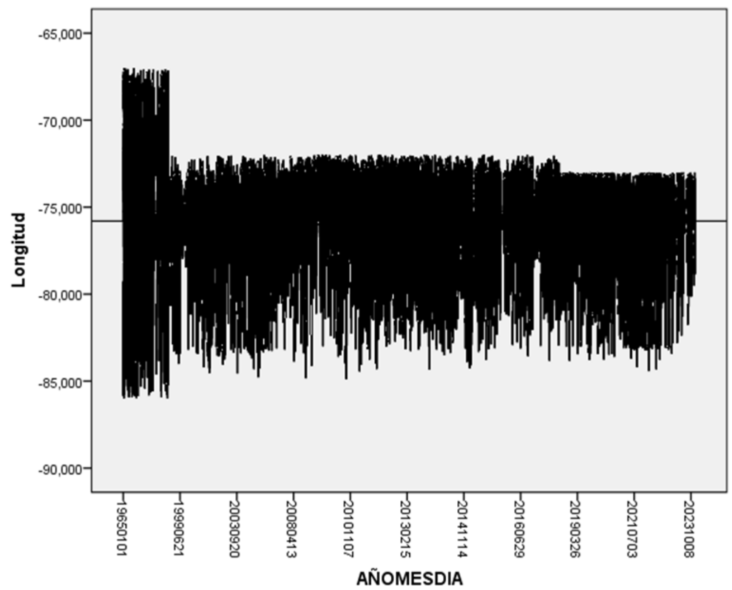

Figure 2: Longitude Behavior from 1965, Month 1, Day 1 to 2023, Month 10, Day 8 for the Station that Records Earthquakes in Cuba.

The longitude was modeled obtaining perfect models, the tables below of the parameters are shown, the trend for the length is increasing. Table 6. The error is 1.67 Degrees.

Table 6: Resume of the Model[c, d]

Modelo	R	R Squared[b]	R squared Adjusted	Error Stándard of Estimate	Durbin-Watson
1	1,000[a]	1,000	1,000	1,675727	1,509

a. Predictors: Lag1LatN, DI, NoC, DS, Lag68LatN, Lag11LatN, Lag6LatN
b. For regression through the origin (the model without intercept), R square measures the proportion of the variability in the dependent variable about the origin explained by the regression. This CANNOT be compared to the R squared for models that include intercept.
c. Dependent variable: Length
d. Linear regression through the origin

In Table 7, Fisher's F is extremely high and significant at 100%.

Table 7: Anovaa, [b]

Model	Sums of Squared	gl	Cuadrátic Mean	F	Sig.
Regressión	578525602,859	7	82646514,694	29431869,161	,000c
Residue	282662,333	100661	2,808		
Total	578808265,193d	100668			

a. Dependent variable: Length
b. Linear regression through the origin
c. Predictors: Lag1LatN, DI, NoC, DS, Lag68LatN, Lag11LatN, Lag6LatN
d. This total sum of squares is not corrected for the constant because the constant is zero for the regression through the origin.

In Table 8, the model parameters, except trend (NoC), all variables are significant and depend on longitude in the same steps back as latitude.

Table 8: Coeficientes[a, b]

Model	No estandardized Coeficients		Standardized Coeficients	t	Sig.
	B	Error estándar	Beta		
DS	-61,117	,225	-,570	-271,491	,000
DI	-61,115	,225	-,570	-271,479	,000
NoC	4,217E-8	,000	,000	,227	,820
Lag6LatN	-,175	,008	-,046	-22,160	,000
Lag68LatN	-,126	,008	-,033	-16,305	,000
Lag11LatN	-,153	,008	-,040	-19,369	,000
Lag1LatN	-,283	,008	-,075	-36,022	,000

a. Dependent variable: Length
b. Linear regression through the origin

Finally, a graph of the forecasts for the year 2023, Figure 3. We see an agreement between the actual predicted values and also the errors are around zero.

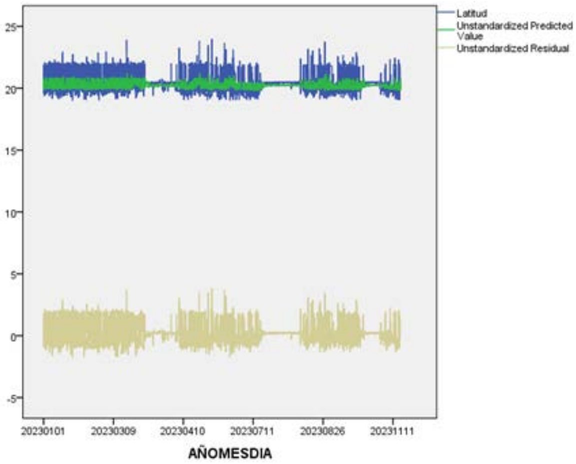

Figure 3: Actual value, forecast and errors for the latitude model.

In the case of longitude, good forecasts are also presented with errors close to zero. Because we work with a large amount of data, it was decided to display the graphs of the forecast values for the year 2023 only.

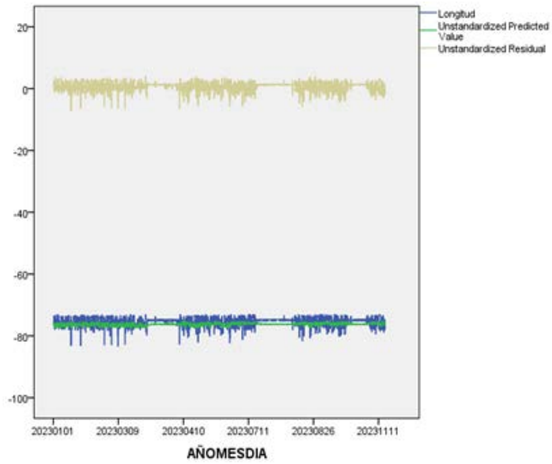

Figure 4: Actual value, forecast and errors for the length model.

A model was also made for the magnitude, which explains 92.6% of the variance with an error of 0.7690, this is a long-term model. Table 9

Table 9: Resume of the Model[c, d]

Model	R	R Squaredb	R Squared Adjusted	Stándard Error of Estimate	Durbin-Watson
1	,926a	,858	,858	,7690	,904

a. Predictors: Lag74Magnitude, DS, NoC, DI, Lag73Magnitude
b. For regression through the origin (the model without intercept), R square measures the proportion of the variability in the dependent variable about the origin explained by the regression. This CANNOT be compared to the R squared for models that include intercept.
c. Dependent variable: Magnitude
d. Linear regression through the origin

Fisher's f is highly significant at 100% as well. Table 10.

Table 10: Anova[a, b]

Model	Sum of Squared	gl	Cuadrátic Mean	F	Sig.
Regressión	360262,588	5	72052,518	121848,178	,000[c]
Residue	59521,532	100657	,591		
Total	419784,120[d]	100662			

a. Dependent variable: Magnitude
b. Linear regression through the origin
c. Predictors: Lag74Magnitude, DS, NoC, DI, Lag73Magnitude
d. This total sum of squares is not corrected for the constant because the constant is zero for the regression through the origin.

The model depends on magnitude 73 and 74 steps back and the trend is negative which means that smaller magnitudes should occur over time. Table 11.

Table 11: Coeficientes[a, b]

Model	No Standardized Coeficients		Standardized Coeficients	t	Sig.
	B	Stándard Error	Beta		
DS	,917	,008	,317	114,156	,000
DI	,920	,008	,319	114,602	,000
NoC	-1,249E-6	,000	-,036	-14,890	,000
Lag73Magnitud	,271	,004	,272	71,884	,000
Lag74Magnitud	,263	,004	,263	69,601	,000

a. Dependent variable: Magnitude
b. Linear regression through the origin

In Figure 5, the forecast of the magnitude with its error can be seen the good agreement between real and predicted values, the errors have a mean of zero.

Observing the small errors and the high explained variance of the models of the studied variables, we can assert that it is advisable to establish a short-medium and long-term forecasting system for the earthquakes recorded using the ROR methodology.

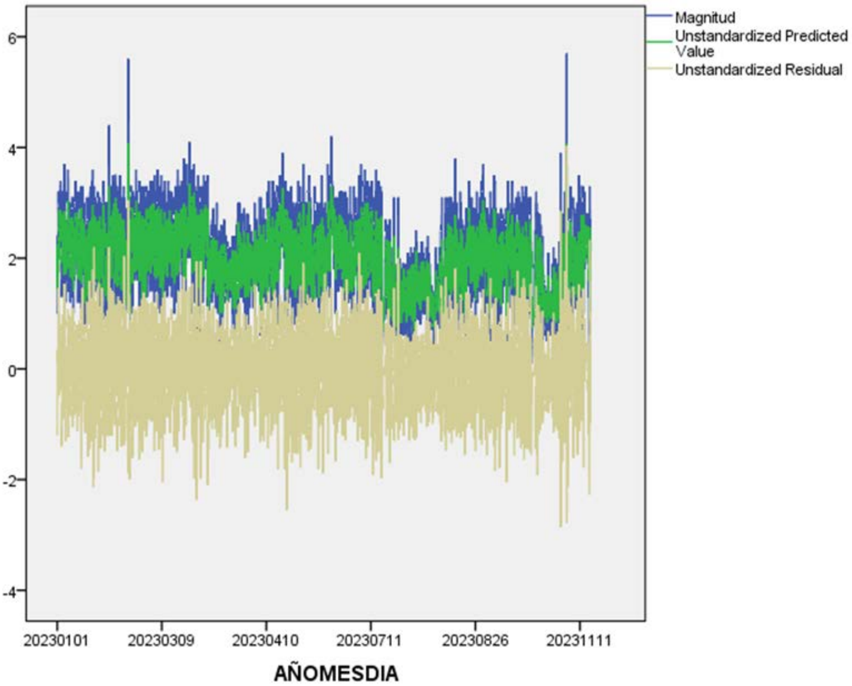

Figure 5: Forecast of the Magnitude of the Earthquakes to be Recorded in Cuba. Year 2023.

4. Conclusions

- For the latitude, earthquakes were reported approximately close to 16 N, then the records rose to 18 N, until 2019, month 3, from now on the latitude rises to approximately 19 N, so the trend along of time is to increase. The average values for this variable are 19.9 N.
- For longitude it happens similar to latitude, there is a tendency to increase, values range from – 67 to -74 W approximately on the same dates as latitude. The average values are -75.8 W.
- The latitude model explains 99.9% of the variance with an error of 0.651443 degrees, the trend is increasing. For longitude, perfect models are obtained, the trend for longitude is to increase as well. The error is 1.67 degrees.
- For both latitude, longitude and magnitude, good forecasts are presented with errors close to zero.
- The magnitude model depends on 73 and 74 steps back and the trend is negative which means that smaller magnitudes should occur over time.
- Observing the small errors and the high explained variance of the models of the variables studied, we can assert that it is advisable to establish a short-medium and long-term forecasting system for the earthquakes recorded using the ROR methodology.

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