A Comparative Evaluation of Various Models For Displacement's Prediction

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Abstract. One of the main study areas of Geodesy is constituted by the monitoring and the analysis of the displacements and deformation of artificial structures (buildings, dams, bridges etc.) and of natural phenomena – geodynamic processes (tectonic movements etc.). Various deformation models have been developed in order to describe the kinematic behavior of a structure or a natural process, which are thought to follow a different procedure of processing.

The goal of this article is the presentation, test and comparison of the appropriate and suitable models of deformation accordingly, with the basic aim of using them as a tool of possible displacements prediction in either one, two or three dimensions.

The main two broader categories of the nowadays used models are the descriptive, the models of cause – effect (response) and their respective subcategories (the congruence models, the kinematic models, the static models and the dynamic models). Additionally other methods of modeling are presented and tested in parallel for the same goal. These methods are widely used by the scientific community in other applications but are rarely used for the prediction of displacements.

The above methods are tested by using real data in order to investigate whether some of them can be used for displacement's prediction. Also the required conditions and presuppositions are referred in order to achieve satisfied results.

Keywords. Geodesy, Displacements Prediction, Prediction Stages, Deformation Models.

1 Introduction

Data provision is now one of the most important and growing areas in most sciences (such as economics, medicine, etc.), attracting the attention of many researchers for its more extensive study, see for example Steyerberg E.W. et al. (2010), Dhar V. (2011). This fact, in conjunction with a special interest presented in the way the science of geodesy finds ways of modeling the kinematic behavior of a phenomenon or structure in order to monitor it and maybe even predict its rating, was the idea behind this essay (Eichhorn A. (2007), R.van der Meij (2008), Dermanis A. (2011), Moschas F. et al. (2011)).

The process of forecasting a phenomenon or a process, no matter which scientific field it belongs to, presents several difficulties and as such, it is crucial to follow some basic principles-stages. In geodesy, the main purpose behind the development of various models is not predicting the future, but rather monitoring the phenomenon. Therefore, the aim of this article is to present both conventional deformation models according to W. Welsch and O. Heunecke (2001), as well as their comparison to predictive methods used in other scientific fields which are mainly based on the theory of time series; a set of data in a particular chronological order. In the latter case, the things tested are the traits of the time series such as the trend, seasonality, circularity, autocorrelation and randomness.

2 General Prediction's Stages

The first and foremost of the stages, and perhaps one of the hardest that will then be a decisive factor in the assessment of the provision, is the very definition of the problem. At this stage, the kind of desired prediction, the reason why it will be held and the purpose the resulting predictions will be used for, need to be made clear. Also, it is useful to define the timescale as well as the accuracy with which the desired provision is sought to be realized.

In addition, it is useful to explore some external factors, such as the cost of the method to be employed, which will depend on the requirements of the process and perhaps the special equipment that might be required, as well as the effortlessness or complexity of the method (Agiakoglou X. et al. (2004)).

The second stage is that of information gathering. If the problem the researcher is interested in has been defined and wishes to make a future prediction of it, the next step is the collection of historical data that will form the basis of the prediction. These data will be analyzed by various methods so that predicting the phenomenon at a particular future time period may become possible. Most of the time it concerns numerical data in the form of time series, and a mathematical statistical analysis for finding a particular pattern the data might follow can be made. However, the word "information" does not only refer to the numerical data but also on any knowledge the researcher has on them. Therefore, a very important factor is to consider the experience and expertise of the scientist that will make the prediction.

The third stage is exploratory analysis. At this stage various statistical indicators are calculated in the numerical data, which will be used. These are the central tendency, standard deviation, the minimum, the maximum and the linear trend. From the above analysis, records in the data which should be removed can be found. Finding such data will assist in choosing the appropriate model, which will give satisfactory results in the specific application.

The fourth and final stage is the choosing and fitting of models as well as the prediction's evaluation. The selection of the type of model which will perform the most accurate prediction is made after the mathematical analysis which took precedence in the third stage. Finally, after all the parameters of the model of prediction are defined, the model is used to produce the predictions. But the procedure does not stop here since the evaluation of the produced predictions must be made using the proper indicators-measures, which are particularly important. After this stage there is a possibility that reevaluation needs to be made by repeating some of the stages.

2.1 Prediction evaluation measures

For an evaluation of a prediction to be made possible, the produced results need to be compared with their real values, which are already known for the phenomenon being evaluated. In order to do that some of the following mathematical indicators are used (Smith W.C. et al. (1978), Charnes A. et al. (1985), Mayer J.R. et al. (1994), Schroeder M. et al. (2009), Erdogan S. (2010), Yilmaz M. et al. (2014)).

Table 1. Indicators-criteria for evaluating of the predictions

Error	$e_t = D_t - Y_t$
Mean Error	$(ME) = \frac{1}{N} \cdot \sum_{t=1}^{N} e_t$
Mean Absolute Error	$(MAE) = \frac{1}{N} \cdot \sum_{t=1}^{N} \lvert e_t \rvert$
Mean Squared Error	$(MSE) = \frac{1}{N} \cdot \sum_{t=1}^{N} e_t^2$
Root Mean Squared Error	$(RMSE) = \sqrt{\frac{\sum_{t=1}^{N} e_t^2}{N}}$
Average Percentage Error	$(MPE) = \frac{1}{N} \cdot \sum_{t=1}^{N} \frac{e_t}{D_t} \cdot 100(\%)$
Mean Absolute Percentage Error	$(MAPE) = \frac{1}{N} \cdot \sum_{t=1}^{N} \left\lvert \frac{e_t}{D_t} \right\rvert \cdot 100(\%)$

Where D_t is the real value and Y_t is the evaluation value in a time period T and N is the amount of data and predictions available as well as actual values.

3 Traditional Deformation Models in Geodesy

In order to describe the kinematic behavior of an artificial structure or a physical phenomenon, deformation models are being developed, which theorize that the deformation of an object is the result of an entire process. The development of deformation models is made primarily for the detection of any kinematic behavior of an object which could endanger its static adequacy.

At the same time they are used to confirm their functionality but also for research purposes and even data gathering for designing similar structures. Lastly, there is the possibility for these models to be used in order to make a prediction/forecast of the phenomenon in a future moment.

The most simple deformation model used is the linear model with the admission that an area is deformed homogeneously. According to W. Welsch and O. Heunecke (2001), the deformation models, depending on whether or not they include the sense of time and the reason/forces causing the changes, are split in the two following categories, with their corresponding subcategories: **Descriptive Models** and **Cause-Response Models.**

3.1 Descriptive Models

The descriptive deformation models make up the most conventional models of depicting a deformation and they are the ones primarily used in the science of Geodesy. In these models, the object or phenomenon is represented by a number of points and the forces causing the deformations are not modeled. They are distinguished as:

- ***Congruence Models***

They evaluate the identity models or the correlation of an object between two or more time periods (Welsch W. et al. (2001)). A comparison of the geometry of the object in some moments in time is made using some of its characteristics (Neumann et al. (2006)). Some statistic tests follow to check if there is indeed a deformation. Initially, geodetic methods are used to calculate the position of the points represented in a period of time and are then compared to the corresponding positions in the next.

- ***Kinematic Models***

These models describe the kinematic behavior of the object without taking into account the process that took place to cause this behavior, as done in congruence models. They use polynomials and harmonic functions and calculate the kinematic parameters (travel speeds and accelerations). A distinction of these models can be made according to Teleioni E. (2003) and (2004) in a Scandinavian kinematic model, kinematic models of simple polynomials and kinematic geometric models of surface's speed (Arnoud de Bruijne et al. (2001), Mualla Y. et al. (2005), Acar M. et al. (2008)).

The most widespread are the kinematic models using polynomials (Ehigiator-Irigue R. (2013)). In this case the relation of the evenly changing movement is applied, which connects the position x_i of a point i in the time period t_v with the initial time t_0 (meaning the moment the first series of measures begun). The unknown parameters which must be calculated for the creation of the model are the rhythm of changing of the position of the peak (movement speed) V_i and the changing of speed (acceleration) γ_i.

It concerns a method of regression for researching the association between a reliable variable and one or more independent variables.

3.2 Cause-Response Models

These models differ from the above ones in that they do not focus only on the geometric changing of the object or studied area, but also embody the reasons causing these changes. They perceive whichever movement as to the result (exit) of a dynamic process. The two basic categories are the dynamic models and the static ones. But beyond this differentiation they can also be distinguished in parametric and non-parametric (Welsch W. et al. 2001))

- ***Dynamic deformation models***

The majority of dynamic models is made up by **non-parametric models**, without excluding dynamic models which can be **parametric**. In parametric models, the relation of entrance and exit is known and can be modeled, while it cannot in non-parametric. Hence, the deformation is a function both of weight and time, theorizing that the object is constantly moving.

In addition the dynamic models can differentiate depending on their input number (e.g. causes of deformation) and their output number (e.g. deformation) in SISO (single input-single output), MISO (multiple input-single output) and MIMO (multiple input-single output).

The fundamental equation of a **parametric dynamic model** is the following:

$$\begin{vmatrix} \mathbf{K} & \mathbf{D} & \mathbf{M} \end{vmatrix} \begin{vmatrix} x(t) \\ \frac{dx}{dt} \\ \frac{d^2x}{dt^2} \end{vmatrix} = y(t) \quad (1)$$

Where the tables $\mathbf{K}$, $\mathbf{D}$ and $\mathbf{M}$ in the case of application to a building represent the parameters of rigidity, damping and mass (Welsch W. et al. (2001)).

The more common case of a non-parametric model is that of a SISO model which is represented by an ordinary differential equation (Welsch W. (1996), Welsch W. et al. (2000)):

$$a_q \cdot \frac{d^q x}{dt^q} + a_{q-1} \cdot \frac{d^{q-1} x}{dt^{q-1}} + \ldots + a_1 \cdot \frac{dx}{dt} + a_0 \cdot x = b_p \cdot \frac{d^p y}{dt^p} + b_{p-1} \cdot \frac{d^{p-1} y}{dt^{p-1}} + \ldots + b_1 \cdot \frac{dy}{dt} + b_0 \cdot y \quad (2)$$

Another known non-parametric dynamic model is the ARMA (autoregressive moving average):

$$x_k = a_1 \cdot x_{k-1} + a_2 \cdot x_{k-2} + \ldots + a_q \cdot x_{k-q} + b_0 \cdot y_k + b_1 \cdot y_{k-1} + \ldots + b_p \cdot y_{k-p} \quad (3)$$

➢ ***Static deformation models***

The characteristic of these models is that they describe the relation between stress and strain. The stress is caused by charges or forces acting on the object, and as such cause its geometric change. The static models can be regarded as a subcategory of the Dynamic deformation models and are expressed with the following equation (Welsch W. et al. (2001)):

$$\mathbf{K} \cdot x(t) = y(t) \quad (4)$$

The characteristics of deformation models, as produced by the bibliographical research done, are presented briefly on the following table. Specifically, with ✗ is declared the lack of the corresponding characteristic and with ✔ its existence.

Table 2. Brief presentation of deformation models

MODEL		Time modeling	Force/charges modeling	Object balance
Cause-response	Static	✗	✔	✔
	Dynamic	✔	✔	✗
Descriptive	Kinematic	✔	✗	✗
	Congruence	✔	✔	✔

4 General models of prediction with time series analysis

Many models whose main goal is the prediction of a phenomenon's value in a future time moment are based in the analysis and theory of time series. Especially in the last few years, with the surging development of computers and respective software, the production of such models and their usage in most scientific fields have made them one of the most basic tools of researchers/scientists. For this reason follows a brief presentation of the methods which can be used for the development of such models. Depending on each occasion the suitability of each method should be tested, using the criteria analyzed before (Smith W.C. et al. (1978), Charnes A. et al. (1985), Mayer J.R. et al. (1994), Schroeder M. et al. (2009), Erdogan S. (2010), Yilmaz M. et al. (2014)).

It should be mentioned that these methods are ones for quantitative forecasting. There are also the qualitative or judgmental forecasting methods in which the experience and judgment of the researcher is taken into consideration, hence the name, and the technological forecasting methods. These two other techniques will not be analyzed in this essay. They are used mainly in cases where the phenomenon's data is insufficient. On the contrary, quantitative methods are "impartial" and demand a series of data of the tested phenomenon for their mathematic modeling. According to Vaidanis M. (2005), a quantitative prediction can be based on:

- time series models, in which obviously the information is in a time series of data and in
- casual models, in which the variable to be predicted depends on one or more parameters.

These two categories of models can be combined. Therefore, according to Agiakoglou X. and Oikonomou G. (2004), predicting the values of a variable through the analysis of time series can occur depending on three categories of predictions: smoothing methods, time series decomposition and the ARIMA analysis.

4.1 Smoothing Methods

➢ ***Simple mean method***

In this case the prediction is made through calculating the average value of the data.

$$F_{t+1} = \frac{\sum X_i}{n} \quad (5)$$

Where F_{t+1} is the prediction for the next interval X_i is the available values of the variable and n is the multitude of the variable's values.

➢ ***Simple moving average method***

What changes in this case is that the average value is calculated taking in mind only the data of the most recent intervals. Hence, every time a new observation is entered, the new average of the sample is calculated, discarding the oldest observation, meaning that there is always the same number of observations, albeit updated.

$$F_{t+1}=\frac{X_t+X_{t+1}+...+X_{t-n+1}}{n}=\frac{1}{n}(\sum_{i=t-n+1}^{t}X_i) \quad (6)$$

And with the addition of a new observation and hence the discarding of the oldest one, equation 6 becomes:

$$F_{t+1}=F_t+\frac{X_t}{n}-\frac{X_{t-n}}{n} \quad (7)$$

- ***Simple exponential smoothing method***

The difference of this method compared to the above two is in that it focuses on the prediction based on the most recent observations, rather than the older ones, as well as demanding a smaller number of data for the calculation of the prediction. The following formula is used (http://people.duke.edu/~rnau/411avg.htm):

$$F_{t+1}=\frac{1}{n}\cdot X_t+(1-\frac{1}{n})F_t=\alpha\cdot X_t+(1-\alpha)\cdot F_t \quad (8)$$

Where α is a measure of gravitation of the most recent real value in relation to the most recent prediction (Vaidanis M. (2005)) and is named smoothing constant, taking values from 0 to 1.

- ***Double moving average method***

In this case, the researcher must have observed whether the time series values present an upward or downward course. In this way of analysis, the linear stress is taken into account and that is why the method is known as linear moving average method. The equation of this method is the following one (http://people.duke.edu/~rnau/411avg.htm):

$$F_{t+h}=\alpha_t+h\cdot b_t \quad (9)$$

Where F_{t+h} is the desired prediction in the time period h. And so, there is a possibility of predicting the next time period or even more future periods. For the above association, the simple mobile arithmetic M_t from the following association and then the double mobile arithmetic M'_t had to be calculated:

$$M_{t+1}=\frac{1}{n}\cdot\sum_{j=1}^{n}X_{t-j+1} \qquad M'_{t+1}=\frac{1}{n}\cdot\sum_{j=1}^{n}M_{t-j+1} \quad (10)$$

$$\alpha_t=2\cdot M_t-M'_t \qquad b_t=\frac{1}{n-1}\cdot(M_t-M'_t) \quad (11)$$

- ***Double exponential smoothing method or Brown method*** (Brown R. G. (1956)).

This method follows the same line of thinking as the previous one and has the same prerequisites, albeit smoothing the values of the original time series. The equation of this method for the calculation of the prediction F_{t+h} in a future h time is the same with the previous one (equation 9):

In this case the original observation needs to be smoothed with the method of simple smoothing.

$$A_t=\alpha\cdot X_t+(1-\alpha)\cdot A_{t-1} \quad (12)$$

Where α is the smoothing constant, A_t are the values after the smoothing for t=2,3,..,n and for t=1 the initial condition $A_1 = X_1$ is set (Agiakoglou et al. (2004)). Following that, second smoothing needs to be done:

$$A'_t=\alpha\cdot A_t+(1-\alpha)\cdot A'_{t-1} \quad (13)$$

$$\alpha_t=2\cdot A_t-A'_t \qquad b_t=\frac{\alpha}{1-\alpha}\cdot(A_t-A'_t) \quad (14)$$

- ***Exponential smoothing adjusted for trend method or Holt method*** (Holt C. (1957))

In this case there are two smoothing parameters, the time series smoothing parameter α and the stress smoothing parameter β so the prediction occurs from the association

$$F_{t+h}=A_t+h\cdot T_t \quad (15)$$

Where h=1,2,3,.. and

$$A_t=\alpha\cdot X_t+(1-\alpha)\cdot(A_{t-1}+T_{t-1}) \quad (16)$$

Where A_t are the values after the smoothing for t=2,3,..,n and for t=1 the initial condition $A_1=X_1$ is set and

$$T_t=\beta\cdot(A_t-A_{t-1})+(1-\beta)\cdot T_{t-1} \quad (17)$$

Where T_t is the values after the stress smoothing for t=2,3,..,n and for t=1 the initial condition $T_1=0$ is set.

- ***Exponential smoothing adjusted for trend and seasonality method***

This last method is used when a specific stress appears in the tested time series along with a specific seasonality (L). The outcome for the prediction for n periods is given from the association:

$$F_{t+n} = (S_t + b_t \cdot n) \cdot I_{t-L+n} \quad (18)$$

Where the exponentially smoothing series S_t, the assessment of seasonality I_t and the stress estimator b_t need to be updated, respectively:

$$S_t = \alpha \cdot \frac{X_t}{I_{t-L}} + (1-\alpha) \cdot (S_{t-1} + b_{t-1}) \quad (19)$$

$$I_t = \beta \cdot \frac{X_t}{S_t} + (1-\beta) \cdot I_{t-L} \quad (20)$$

$$b_t = \nu \cdot (S_t + b_t \cdot n) \cdot I_{t-L+n} \quad (21)$$

4.2 Times series decomposition method

This method is based on finding the key characteristics of a time series (ie trend, cyclicality, seasonality and randomness) and then to isolate them. The process of the prediction with the analysis-division of a timetable aims to find whatever stress there is and adjust it according to the seasonality and circularity indicators, which have been set from the analysis of the time series according to the diagram below:

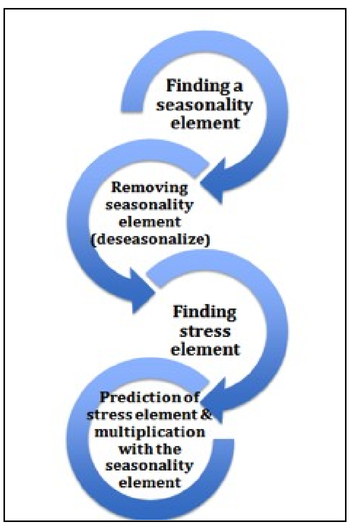

Fig. 1. Process of prediction with time series decomposition method

4.3 ARIMA models

Autoregressive Integrated-Moving Average models (ARIMA) are stochastic mathematical models which are mainly used to describe the evolution of an arbitrary quantity. These models are also called Box-Jenkins Models (Reinsel Gregory C. (1977)). A nonseasonal ARIMA model is classified as an "ARIMA (p,d,q)" model, where p is the number of autoregressive terms, d is the number of nonseasonal differences needed for stationarity, and q is the number of lagged forecast errors in the prediction equation. Generally, a p-order ARIMA model defined as follow:

$$Y_t = c + \varphi_1 \cdot Y_{t-1} + \varphi_2 \cdot Y_{t-2} + \ldots + \varphi_p \cdot Y_{t-p} + e_t \quad (22)$$

5 Application to GPS permanent station

After the theoretical analysis of the various methods possible to be used in the actualization of a prediction in any science, follows the comparison and evaluation of some of them using geodetic data. The first and primary step for a prediction is made up by the clear definition of the problem itself. Hence, in this study, the problem is defined as the possibility of prediction of movement (in the class of a few cm) of a point of natural earth surface and specifically of a permanent GPS station. The stations of a permanent GPS network were selected since there is a large number of data dating many years that can lead to a prediction of satisfactory precision. It should be noted that the prediction and the creation of a model is attainable if the number of data is a large one. In the particular application, depending on the model-type of prediction created, a prediction possibility is defined to exist:

- For the next day alone
- As a long-term prediction dating even 3 years.

Hence the network chosen is part of the scientific program EarthScope (http://www.earthscope.org) and is named Plate Boundary Observatory (PBO). There are also 1100 permanent stations of constant function, the data of which is available for free in the Internet through the webpage of the program.

In this essay, for reasons of abbreviating, only the results of the measuring of one station are presented and, in particular, those of the one with the code ORES (latitude = 34° 44′ 20.76″, longitude = 239° 43′ 17.04″). However, methods' comparison was performed for all the GPS stations but the results obtained are presented only for the one selected as a representative example. Following that, the next two steps are analyzed, the one of preliminary analysis of the data and of course, the application of the models and their evaluation.

5.1 Description of the time series - Data processing

The data to be used make up a time series of the geocentric coordinates X, Y and Z from the ORES station in the Global Reference Frame IGS08, from the year 1999 to the year 2015.

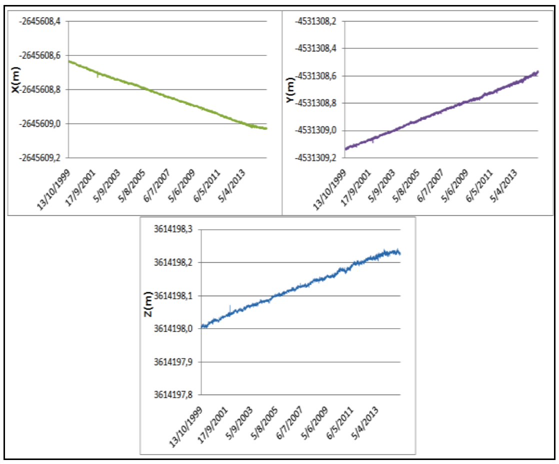

Fig. 2. Graphical representations of geocentric Coordinates X, Y and Z time series (October 1999-February 2015)

The stage of preprocessing the GPS data is the most serious stage. In most case such time series present problems, like signal loss (due to changing of the antenna, for example), false data or even noise. For this reason, techniques of processing the time series are applied to avoid such problems and reduce probable noise (since noise cannot be erased but only reduced).

A basic stage of this essay is the de-noise of the time series before it is used for a future prediction. For this reason a code in the MATLAB® software, version 2015[a] was composed. The program checks double recordings of data, lack of recordings and of course, if a data is inaccurate (noise). This last problem proved to be the most complex one. After tests, it was found that the best and most proper way to find these "anomalies" in the signal is to remove the data in pairs and define a threshold on which the value of the time series can be theorized as an "anomaly". Fig.3 presents the time series of the X geocentric coordinate as an example but mainly focus on the presentation of the noise found which is highlighted in the green circle.

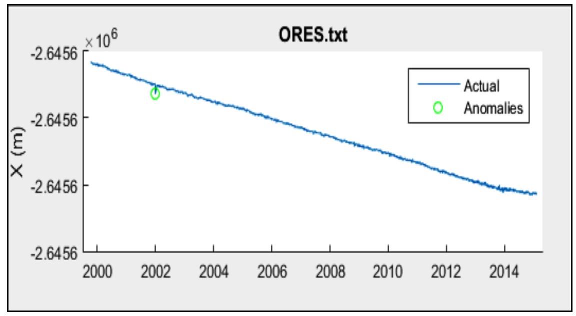

Fig. 3. Graphical representation of Coordinate X time series and error found

Also, a check to confirm that it was indeed a wrong recording and that no extreme phenomenon like an earthquake had happened, using historic data. Lastly follows a usual process for all prediction methods of the segregation of the data into "training" data for the finding of the parameters of each model, but also in data to be used for the evaluation of the model. This segregation was done empirically and following the bibliography, where usually the 80% is used for the model and 20% is used for evaluation, as occurs in this particular essay.

5.2 Application models – Evaluation

The nature of this essay did not allow for the application of all models and methods analyzed in the theoretic part. As far as traditional movement models of Geodesy are concerned, the only one applied was the *kinematic model* since, as mentioned, models time and the researcher does not need to have knowledge of the causes of the phenomenon. Also, various restrictions occurred for the time series analysis and finally the models of methods *Simple mean method, Simple moving average method, Simple exponential smoothing method, Brown method and Holt method* were actualized. The final result of each method was revealed after many trials in order to find the best one (table 1).

For all these methods the comparison was done using the evaluation measures (§ 2.1). The evaluation of these methods showed that it is not possible for all of them to be used for the predictions of movement of a permanent station in future time since, as it had been defined earlier, the problem references the prediction of movement of the class of a few mm.

Therefore, the results of the methods *Simple mean method, Simple moving average method and Simple exponential smoothing method* were rejected since they did a prediction with a ME of the class of 25-30 cm. The results are presented in the figures 4, 5, 6, 7.

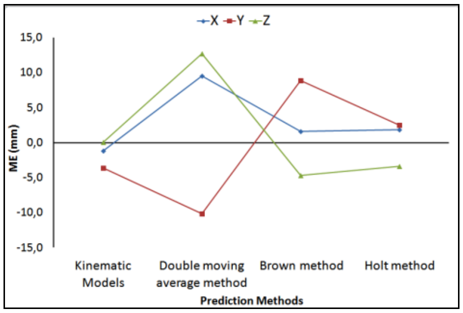

Fig. 4. Comparison of Mean error (ME)

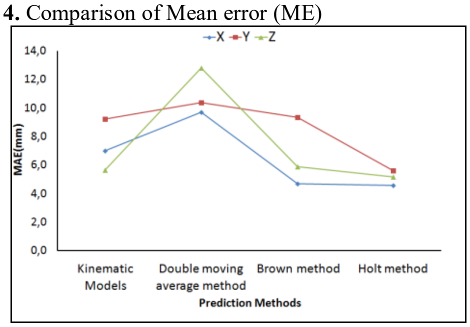

Fig. 5. Comparison of Mean Absolute Error (MAE)

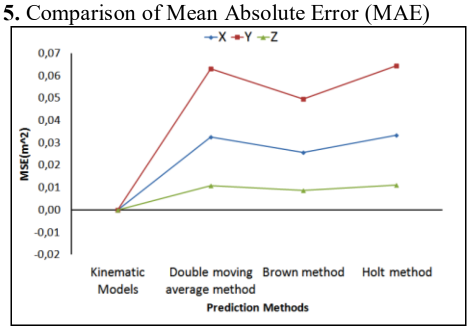

Fig. 6. Comparison of Mean Squared Error (MSE)

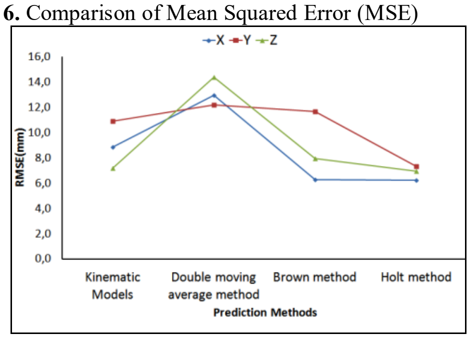

Fig. 7. Comparison of Root Mean Squared Error (RMSE)

6 Concluding Remarks

The main goal of this paper is to record and present the models and methods that are widely used by the scientific community in other applications but are rarely used for the prediction of displacements in order to examine whether any of them can be used for this purpose.

The traditional deformation models in Geodesy and some key features that differentiate them from one another and classify them into two categories with their respective subcategories, are presented. Specifically, the main classification characteristic is whether they model the cause/forces which contribute to deformation and the modeling of time. The latter option, the modeling of time was the driving idea for the investigation of their usability for future forecasting and not just for modeling such phenomena, as they are used today.

The aim of the present study is to further highlight the main forecasting methods based on time series analysis and to determine the possibility of using some of the models to forecast displacement. From the theoretical exposition of these methods it became clear that it is not possible to use all of them, ultimately only those that are also capable of modeling time.

To analyze the above, data from permanent GPS reference stations (Plate Boundary Observatory) were used. Specifically the data to be used make up a time series of the geocentric coordinates X, Y and Z from the ORES station in the Global Reference Frame IGS08, from year 2000 to 2014. Thus, utilizing this data was implementing what traditional model deformation and general models meet the criteria that would allow prediction realization (time modeling and not knowing the causes generating movement). Thus, a kinematic model as well as the methods Simple mean method, Simple moving average method, Simple exponential smoothing method, Double exponential smoothing method and Exponential smoothing adjusted for trend method, were used.

These methods were tested by using indicators-criteria for evaluating of the predictions. From this assessment and by using the pointer ME, it appeared immediately that the methods simple mean method, simple moving average method, simple exponential smoothing method could not be used to forecast as they presented a ME of the class of 25-30 cm. Also, from the fig.4 (ME) and fig.5 (MAE) it is understood that if the prediction is set as a prediction of displacement of around 1cm it would be possible to use all four methods to give satisfactory results. Observing fig.6 (MSE) it seems for all three components of X,Y,Z the kinematic model outperforms all other three, but in terms of the X and Z the other methods provide similar results in the same order. Also in fig.7 (RMSE) we can see that the kinematic model and Holt method produce better predictions as RMSE values are close to zero, but it is assessed that the Holt method is perhaps more likely to predict in the order of one cm.

This work was the first step in a larger research and it is proposed investigate further this methods and other using more data.

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