Doctoral Program in Business Administration and Quantitative Methods

TIME SERIES

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GLOBAL WARMING OR GLOBAL WARNING? THE PROBLEMS OF TESTING FOR A TREND IN ENVIROMENTAL TIME SERIES.

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The only way to have real success in science ... is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what's good about it and what's bad about it equally. In science you learn a kind of standard integrity and honesty. — *Richard Feynman*

Abstract:

Nowadays there is a contentious debate about the causes of the observed increase in the global temperature as well as the predictions about its future evolution. Some researches have found evidence of a determinist increasing trend using well-known temperature databases. In this work some of the techniques used to study the global warming debate are revised using sea level time series. The implicit idea is that one of the direct consequences of the global warming is the rise of the global sea level, thus if the temperatures are systematically increasing so should the sea level.

The main conclusions are that researches possess certain discretion when modelling this type of time series and that, unless this discretion is cautiously used, conclusions may be questionable. Also, distinguishing for long term trends when the analysed data are reasonably described by ARIMA $(p,1,q)$ models can be very difficult. This type of models exhibit temporary stochastic trends that can not be reasonable expected to continue in the future. Thus, predicting that the present rise in the sea level will persist may not be appropriate.

1. INTRODUCTION

The fact that temperatures have been in the rise during the last two hundred years is indisputable, however the specific causes of this increase generate a debate known as the "global warming controversy". Consequently, there is no consensus about the prediction of future temperatures, nor of the consequences of the current warming. A further source of controversy is around the question of whether the current warming trend is unprecedented or within normal climatic variations over the last 1,000 years. That is to say, are we responsible for this climatic change or is it just part of a natural phenomenon that has already occurred before.

Despite this controversy, the change in the global climate can reasonably be held responsible for short-term fluctuations in the environment (hurricanes, heat waves, droughts, among others), which can strongly affect a country's resource potential (its soil, the vegetation, etc.) and through them the development possibilities of the region. One of these environmental changes is the rise in the global-mean sea level, which is at least partially caused by the increase in the global-mean surface temperature.[1]

In this paper two different time series of average-sea level will be analysed in order to point out how much discretion we could have to study the hypothesis of global warming and also what types of problems we may face when testing for a long run trend in environmental series data. The main hypothesis of the present work is related to the existence of a deterministic increasing trend in the global sea level. In addition, the possibility of a stochastic increasing trend will be studied. In both cases the existence of a trend implies that global warming is actually occurring, but what may differ is the likelihood of this trend to continue in the future.

The time series for this project were obtained from the Global Sea Level Observing System (GLOSS), an international programme conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC). This programme aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The main component of GLOSS is the 'Global Core Network' (GCN)

[1] Many factors influence the relative (to the land) sea level. These factors include: land uplift and subsidence owing to tectonic movements, rebound effects from the last ice age, vertical land movements from local sedimentation and astronomical tides. A formal study of global warming should remove all these effects to isolate the effects in sea level of the climatic change.

of 290 sea level stations around the world for long term climate change and oceanographic sea level monitoring.

Among all these available stations two series will be analysed thoroughly: Smogen station (Sweden) and San Francisco Stations (USA). The selection of these two stations is not arbitrary. In a first stage series of at least 400 observations with no missing data were identified. This process resulted in approximately 50 time series that fulfilled these criteria. After that, the two selected series were considered appropriate enough for the purposes of studying the global warming hypothesis with varied approaches.

It is interesting to highlight the fact that among these 50 time series there were different temporal behaviours: some clearly growing in time, some relatively constant, and a few slightly decreasing. It could have been interesting to formally study the existence of clusters in these dataset, and it could be especially interesting to determine the size of an increasing trend cluster and compare it with the size of the rest of the possible clusters.

2. MODELIZATION OF OUTLIERS IN ENVIRONMETAL TIME SERIES

In this section, we will analyze the behaviour of the monthly time series of average sea level corresponding to the station in Smogen. This station is especially interesting because it seems to have a decreasing trend, as we can see in figure 1. Obviously, this time series could be considered as potential evidence against the global warming hypothesis, clearly a decreasing sea level is against the rationale previously discussed.

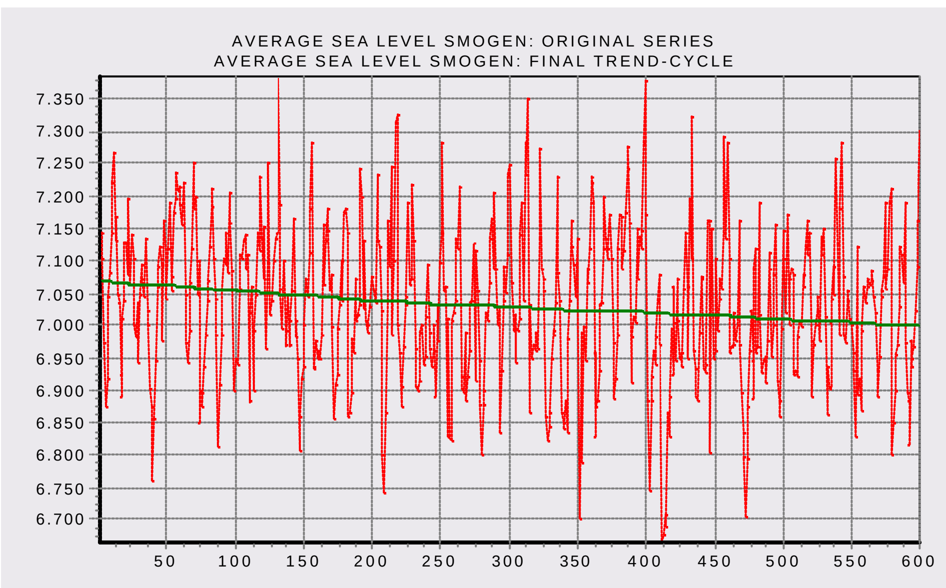

Figure 1

The series consists of 600 observations. Analyzing these data with the TRAMO software we found that the automatically proposed model is an AR(1) in the regular part and an IMA(1) in the seasonal, with mean, Easter correction and using the logarithms of the series.

It seems that the seasonality could be evolving (non stationary), therefore the program takes one difference in the seasonal. Also, the software identifies two outliers: a transitory change and an additive outlier. The AIC and BIC of this model are -3485.8428 and -8.7631 respectively. In the table below the value and the significance of the parameter estimates are presented.

Parameter	Value	Std. Error	t- value
f_1 (AR)	-.41513	0.37882E-01	-10.96
q_1 (MA)	-.93164	0.14985E-01	-62.17
m (Mean)	-.13642E-03	(0.00008)	- 1.61
Easter Effect	0.42645E-02	(0.00212)	2.01
Outlier1: obs 411	-.50083E-01	(0.01115)	- 4.49 (TC)
Outlier2: obs 447	-.42761E-01	(0.01113)	- 3.84 (AO)

Table 1

Regarding the fit of this model to the data, there are several problems that we can point out. First, normality of residuals cannot be assumed since the value of the Jarque-Bera statistics associated to the null hypothesis that errors are normally distributed is 28.30 (well above 5.99). In addition, the Durbin-Watson statistic is equal to 2.03 which indicates the absence of first-order serial correlation in the residuals. Also, even though the residuals seems to be temporally independent (Q statistic is of 28.68), we have dynamic dependence of squared residuals, since the value of the Ljung-Box statistics is above the critical value (92.93). [2]

All these statistics suggest that the model needs to be improved to enhance the fit with the data. Considering that the Ljung-Box of squared residuals is significant and much

[2] The critical value of the Ljung-Box in this case is of 33.9 which corresponds to a c^2 of 22 degrees of freedom.

higher than the Ljung-Box of residuals we are inclined to propose one of two things to improve the fit: use a model of conditional variance or alternatively lower the critical value of outliers. This last alternative is mainly based on the idea that a non linear model can be successfully described as a linear model with outliers. However, this possibility is only reasonably valid if the number of outliers does not exceed the 5% of the realization.

So, as a next step we propose the same model but allowing for more outliers. In this case, we lower the critical value from 4 to 2.8 and we fit the same model. We will exclude the Easter effect since we believe it random that it happened to be significant. The program detects 29 outliers in total, which represents approximately 5% of the observations, and thus it can be considered as a reasonable number of extreme observations. The AIC and BIC of this model are smaller than before, -3703.55 and -8.9204 respectively, which indicates that we have a better model in terms of goodness of fit. In the table below the value and the significance of the estimates are presented.

Parameter	Value	Std. Error	t- value
f_1 (AR)	-.30945	0.40747E-01	-7.59
q_1 (MA)	-.81226	0.29784E-01	-27.27
m (Mean)	-.86092E-04	(0.00012)	-0.69

Table 2

Regarding the fit of this model, even though now normality of residuals cannot be rejected (the Jarque-Bera statistics is of 0.5) and residuals can still be considered temporally independent (Ljung-Box of 20.81), there is still high dynamic dependence in the squared residuals (Ljung-Box of 43.83).

It is important to highlight that by improving the goodness of fit of the model including more outliers, the existing trend, which initially was clearly decreasing, has become less accentuated and the series trend is now practically constant (Figure 2). This means that if the best model to predict the sea-level in Smogen is this one, then the most likely thing to expect is that the sea-level remains more or less constant in the next years.

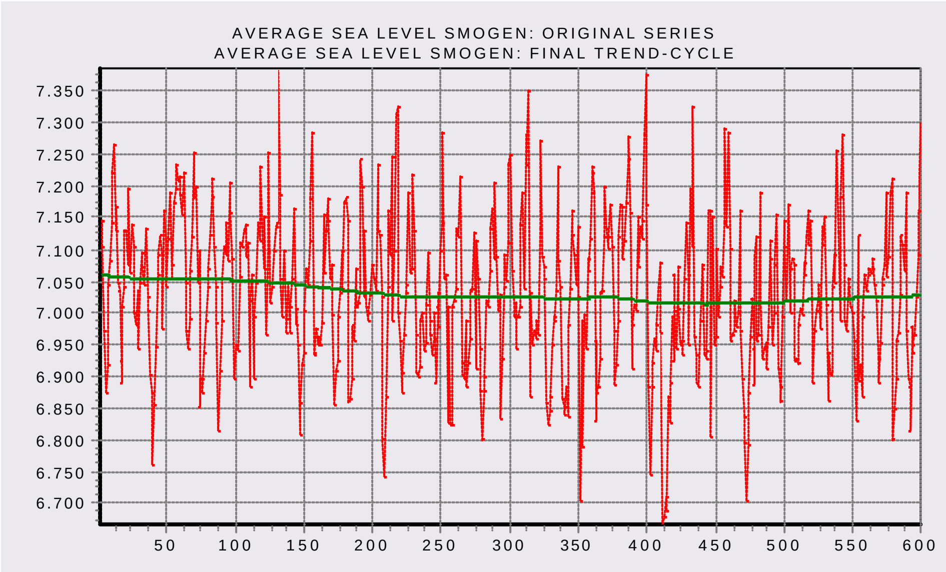

Figure 2

In order to improve the previous model even more and based on the behavior of both the original series and the residuals of the previous model we propose an alternative model, an IMA(2) in the regular part and an IMA(1) in the seasonal, also taking logarithms of the series. That means we are going to take a difference on the regular to account for the decreasing pattern and then we propose and MA(2) for the regular part of the differentiate series.

The critical value for detecting outliers is set equal to 2.8. The software identifies a total of 29 outliers, which is the highest number of outliers we could reasonably assume in the data. The AIC and BIC of this model are -3649.923 and -8.8416 respectively. These values are slightly greater than the previous values, these explains why this model was not selected by TRAMO even tough is better fitting the data than the other two. In the table below the values and the significance of the estimates are presented.

Parameter	Value	Std. Error	t- value
q_1 (MA) R	-.44497	0.40402E-01	-11.01
q_2 (MA) R	-.27247	0.39297E-01	-6.93
q_1 (MA) S	-.88059	0.25168E-01	-34.99

Table 3

The fit of this model is reasonably good. Residuals can be assumed to be normally distributed since the Jarque-Bera statistics is of 2.2, quite lower than the critical value. Also, we the dynamic dependence of residuals and squared residuals that was present in the automatically selected model seems to have disappeared, since the values of the Ljung-Box statistics is of 12.9 for the residuals and of 30.07 for the squared residuals, i.e. lower than the critical value of 36.4.

Again, if this is the best model to describe the temporal evolution of the average sea level in Smogen, mainly because of the goodness of fit, then the decreasing trend is no longer there. What is more, the trend now is very volatile and the outlier corrected series indicates that the level shift occurring in observation 265 has permanently decreased the sea level. In other words, if the outlier had not occurred then the sea-level would certainly be higher than now. This last evidence could be interpreted as partially supporting the global warming hypothesis. This level shift could have been produced by one of the several factors that influence the relative (to the land) sea level: a land uplift due to tectonic movements, vertical land movements from local sedimentation and astronomical tides, for instance.

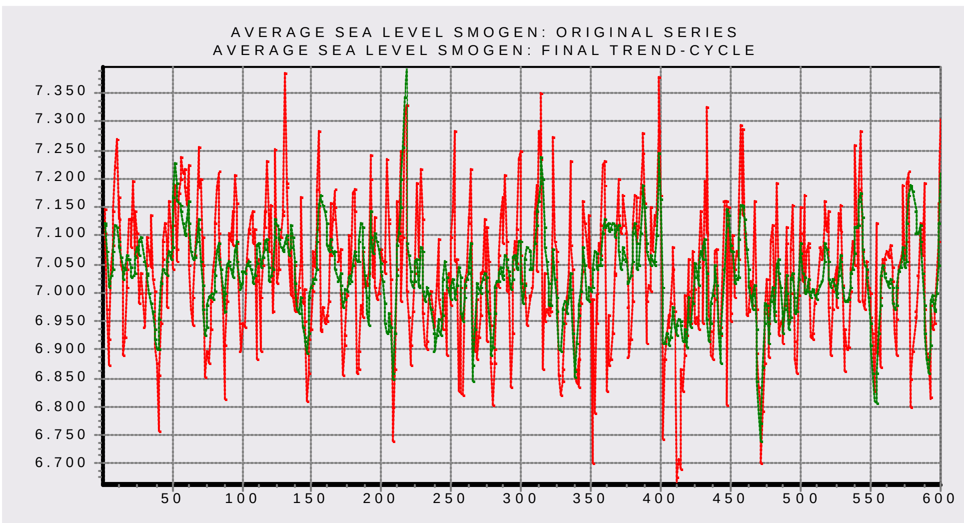

Figure 3

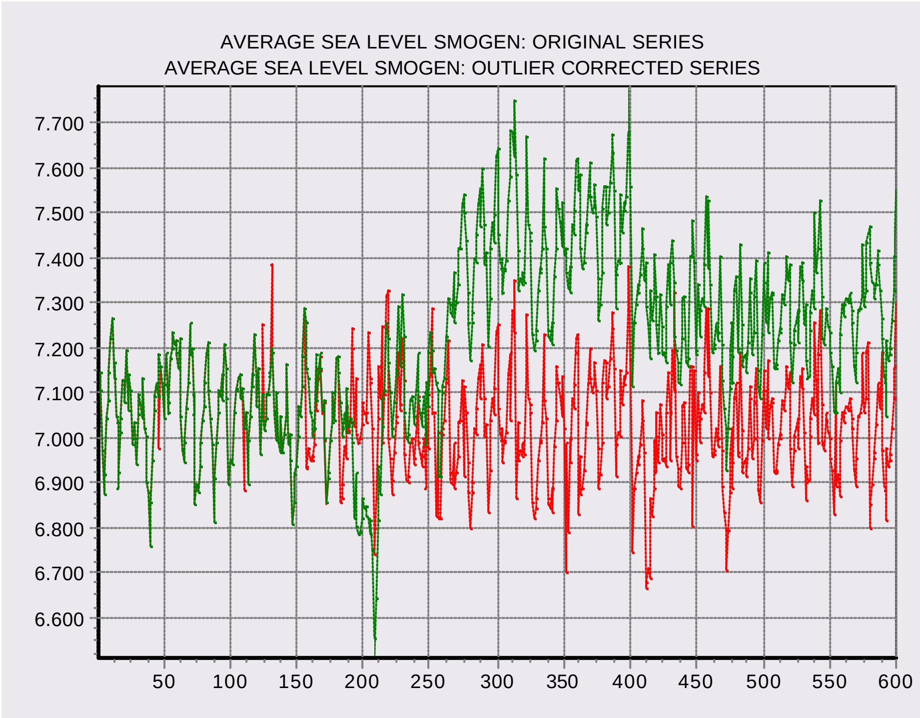

Figure 4

From this section we can conclude that the inclusion of outliers in the modelization of environmental time series can enhance the fit of this type of series through linear models, nevertheless this procedure can at the same time dramatically affect the conclusions that will be drawn regarding the global warming hypothesis. Thus, the use of outliers should be done with caution and formally justifying their inclusion with additional information.

3. TESTS FOR TREND IN ENVIRONMETAL TIME SERIES

Many studies analyzing the hypothesis of global warming have examined different datasets by testing for the presence of a liner deterministic trend. The standard approach is to assume that the environmental time series follows the following model:

$$y_t = a + b.t + e_t \qquad (1)$$

Where y_t stands for the data at moment t and e_t is the error term. A test of hypothesis to assess whether b is zero or not is equivalent to analyzing the presence of global warming or not. If $b \neq 0$, then it can be said that a deterministic long term trend exist, and if this trend is increasing (i.e. $b > 0$), then we can say that there is evidence that global warming is in fact occurring.

However, according to Woodward and Gray (1993), those datasets in which an increasing trend has been determined through this approach, can be reasonably modelled with certain autoregressive-moving average models (ARMA) which exhibit random trends that can be incorrectly predicted to continue in the future.

In order to examine this possibility with the data about sea-level, we will take the monthly time series corresponding to San Francisco, and obtain an annual time series by averaging the sea level of each year. By doing this we have 151 observations, starting from 1854. This is the frequency and the approximate length of the realizations Woodward and Gray use in their work. In the plot below we can see the annual time series obtained. As we can see an increasing trend seems to be present. Also we can observe in figure 6 the increasing trend that TRAMO identifies in this data.

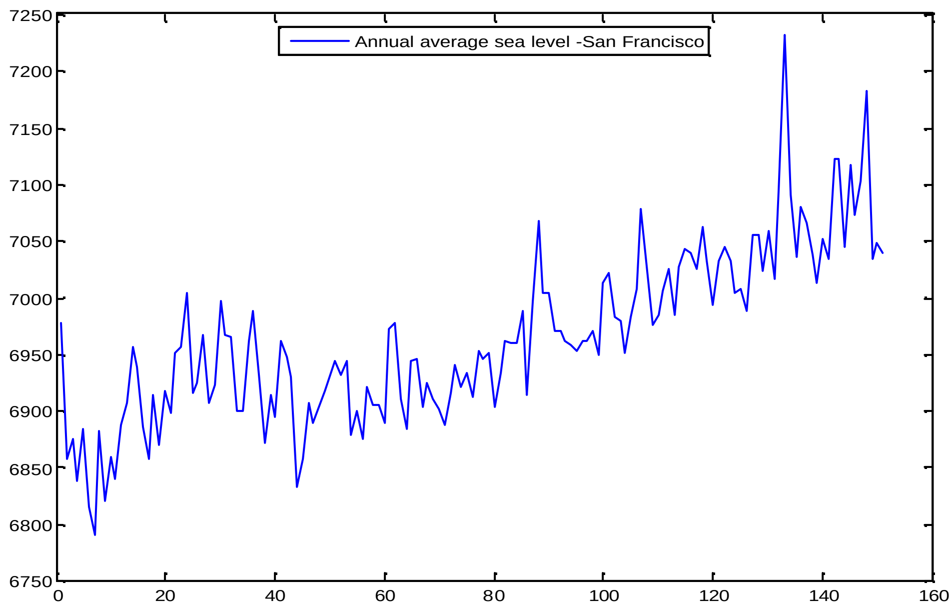

Figure 5

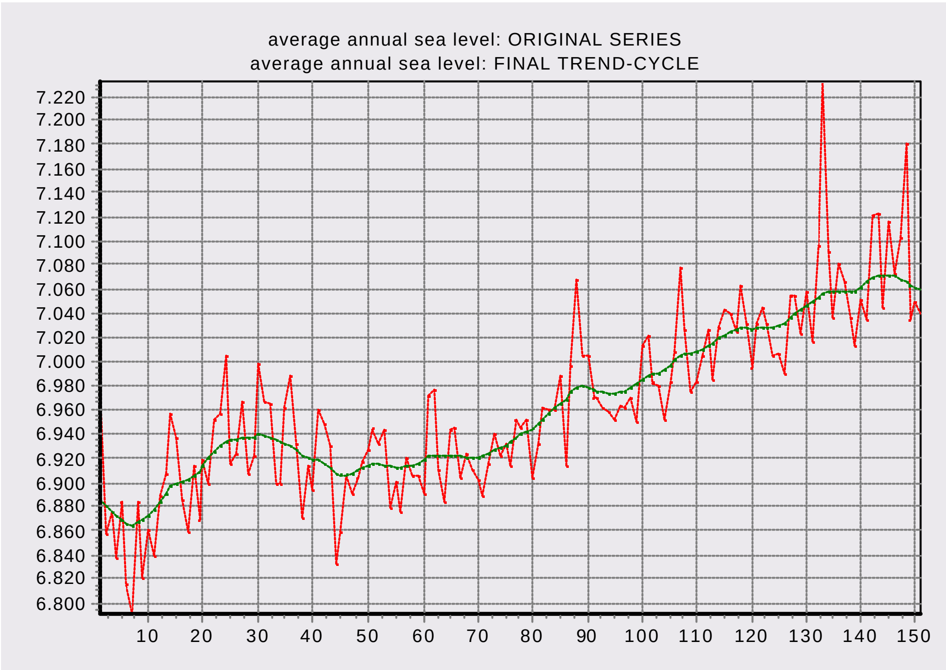

Figure 6

The OLS estimator of b in this case is of 1.3729, indicating an increasing behaviour of the average annual sea level in time. Under the regular assumptions of the OLS regressions (i.e. residuals have zero mean, are independent and normally distributed) the ratio: $\frac{b}{\hat{s}_b}$, where $\hat{s}_b$ stands for the estimated standard error of the OLS estimator, is distributed as a Student's t with 149 degrees of freedom. In this case the value of this ratio is of: 16.94353, which is associated to a nil p-value for the hypothesis of interest. This would lead us to conclude that the sea level will continue to rise in the future, supporting the global warming hypothesis.

However, the validity of this conclusion is reduced if we analyze the residuals behaviour through a plot and observe that there is some noticeable autocorrelation among observed errors.

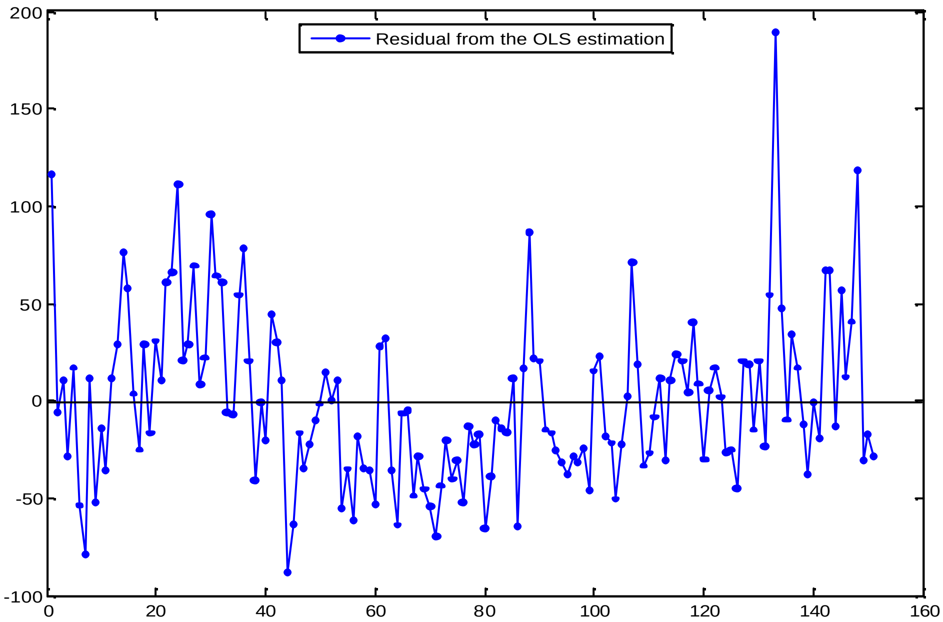

Figure 7

Thus, this residuals behaviour implies that the usual regression model is not appropriate for testing the hypothesis following the previous procedure. Woodward and Gray analyze three different procedures to test the hypothesis, basically by computing b with the OLS criteria but using an estimation of the standard error that does not need the independence of errors to test for the significance of the b estimate. These mechanisms try to overcome the fact that the OLS estimation of the standard error will be underestimated because of the autocorrelation of residuals. Thus the corrected estimators are always greater than the OLS ones, reducing the chances of finding a significant deterministic trend.

In Woodward and Gray study, the worst case was a t ratio almost 37% smaller than the original one (from 13.15 to 4,78). In this case, we will not compute these modified standard errors to retest the hypothesis. Even though we expect that the new standard error estimations would be dramatically reduced, since the original t value is quite large we also expect that the deterministic trend may be found to be significant even after the inclusion of this correction.

Another example of robust tests can be found in Fomby & Vogelsang (2001). These authors claim that the strong correlation present in environmental time series can generate spurious evidence of a significant deterministic positive trend. They analyze a serial-correlation robust trend test which does not require estimates of serial correlation nuisance parameters. Then, they provide a re-examination of environmental data that had been analyzed with the standard hypothesis test approach using this robust technique and they suggest that positive trends in temperatures are still significant.

An alternative mechanism to study this phenomenon is to use a time series approach to model the data and test for the presence of stochastic trends, and then analyze the possibility of this trend to continue in the future. For this purpose we introduce the data in TRAMO and observe that the program automatically selects for this series an IMA (2), with no mean and with two outliers (two additive outliers: 1986 and 2001). In the table below we can observe the values of the estimated parameters.

Parameter	Value	Std. Error	t- value
q_1 (MA) R	-.56394	0.79664E-01	-7.08
q_2 (MA) R	-.18887	0.80218E-01	-2.35

Table 4

The AIC and BIC of this model are of 1507.9296 and 7.2904 respectively. Normality of the residuals can be assumed since the Jarque-Bera statistics is of 1.58. Also, there is no dynamic dependence in the residuals or in squared residuals since the Ljung-Box is of 6.08 and 6.52 in each case.

The question now is the following: under this time series modelization of the average-sea level in San Francisco, is there evidence of a stochastic trend. And if so, can we predict that the future sea level will continue to increase? Put differently, under this time series analysis can we conclude that there is global warming judging by the time evolution of the average annual sea level?

Based on the model chosen for the data: $(1-B)y_t = \theta(B)e_t$, future values of the sea level will tend to a constant. That is, a model with one positive unit root (or one near positive unit root) will have short-term predictions which are relatively stable. If the model has two roots equal to 1 (or near 1), then the forecasts follow a line determined by the last two observed values of the realization. It follows that; models of the type $(1-B)^2 y_t = \theta(B)e_t$ will forecast that an increasing trend in the sea level, if present, will continue in the future. Nevertheless, if the model for this series has only one root equal to or near 1, the best forecast for the sea level is constant and not increasing.

In order to explore more these ideas two procedures will be used: unit root tests and time series simulations. The unit root test will be used to test for stochastic trends and also for the likelihood of this trend to continue in time. In this way, we will assess the validity of the global warming hypothesis through an alternative procedure to the OLS option. Then, we will simulate short and long realizations of an IMA(2) process to show how the temporary trends that are implicit when the process has one unit root, may not continue to exist in the future.

Let us start with the unit root tests. According to what was previously stated an ARIMA $(p,1,q)$ model will produce forecast relatively constant, whereas an ARIMA $(p,2,q)$ model will produce forecast that tend to a line. Thus, if the data of average annual sea level in San Francisco exhibits evidence of two unit roots we can conclude that the increasing trend we visualize in the present realization is very likely to continue in the future. However, if the evidence suggests the presence of only one unit root we can conclude that there is a stochastic trend in this data, but we cannot predict that it will continue to exist in the future.

To start with, decomposing the time series in the trend-cycle elements:

$$y_y = TD_t + TS_t + C_t \qquad (2)$$

We will perform a unit root test of the form:

$$H_0 : TS_t = 0 \quad (y_t \sim I(1)) \quad \text{vs.} \quad H_1 : \quad TS_t \neq 0 \quad (y_t \sim I(0))$$

Below we can see the results of the Augmented Dickey-Fuller test for this hypothesis. As we can see there is enough evidence to accept the presence of a unit root, which implies that a stochastic increasing trend exists in the San Francisco data.

ADF Test Statistic	0.924541	1% Critical Value*	-2.5797
		5% Critical Value	-1.9420
		10% Critical Value	-1.6168
*MacKinnon critical values for rejection of hypothesis of a unit root.			

Table 5- Unit root test for the original series

Now we need to test if the series needs another differentiation to be rendered stationary, i.e. if the series exhibits evidence of a second unit root. For this purpose we will perform the same hypothesis test, but this time with the differentiated time series. Below we can see the results of this test, which suggest that the series does not have a second unit root. This implies that the stochastic increasing trend detected by the previous unit root test can not be predicted to persist.

ADF Test Statistic	-8.366971	1% Critical Value*	-2.5798
		5% Critical Value	-1.9420
		10% Critical Value	-1.6168
*MacKinnon critical values for rejection of hypothesis of a unit root.			

Table 6- Unit root test for the differentiated series

Consequently, we can conclude from the results of these unit root tests that, San Francisco average sea level has a stochastic increasing trend but we cannot forecast that this increasing trend will continue in the future.

Now let us deal with the simulations of time series IMA(2) models to have a closer examination of the behaviour of this type of models. Simulations are a useful technique for analysing time series behaviour and particularly, in this case, to observe how stochastic trends are present in this type of models yet none of these trends seem to continue to exist in the future evolution of a series.

Several simulations of a IMA(2) process were run. In the figures that appear below some of the most interesting behaviours are depicted. In all cases a realization of 500 observations was generated, and then the first 150 observations of this simulation were plot together with the total 500 observations. In figure 8 we observe that the short realization exhibits a stochastic increasing trend, however when we look at the whole realization we note that the series starts having an opposite behaviour.

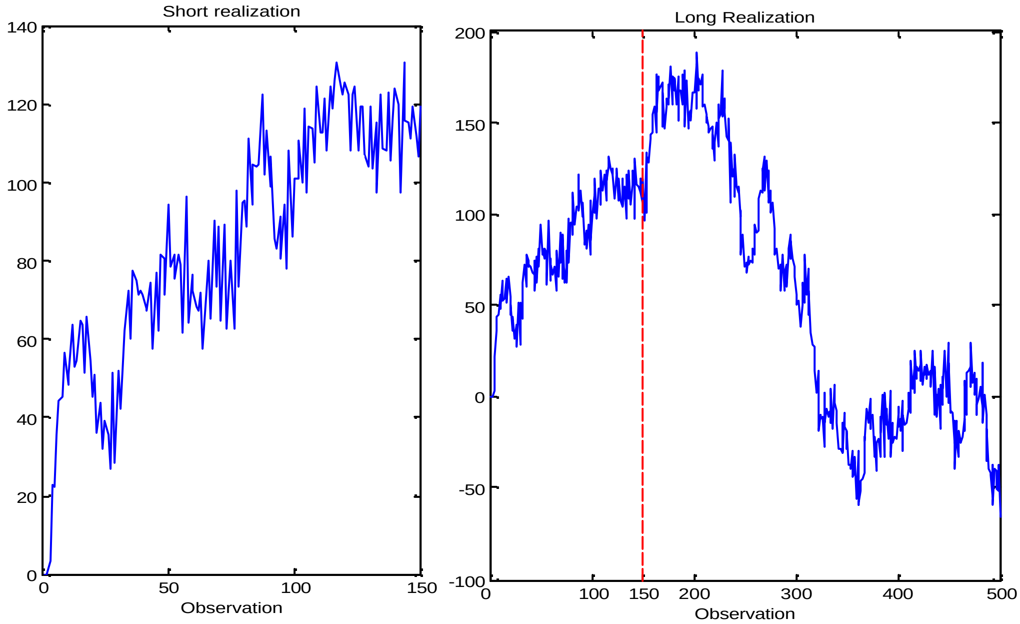

Figure 8

Something very similar occurs in figure 9 where an initial increasing behaviour is followed by a more stable evolution. In figure 10, what seems to be a decreasing trend in the 150 first observations is then reverted to an increasing behaviour in the rest of the realization. In all the cases, the stochastic trend present in the short realization does not persist in the future evolution of the simulated series.

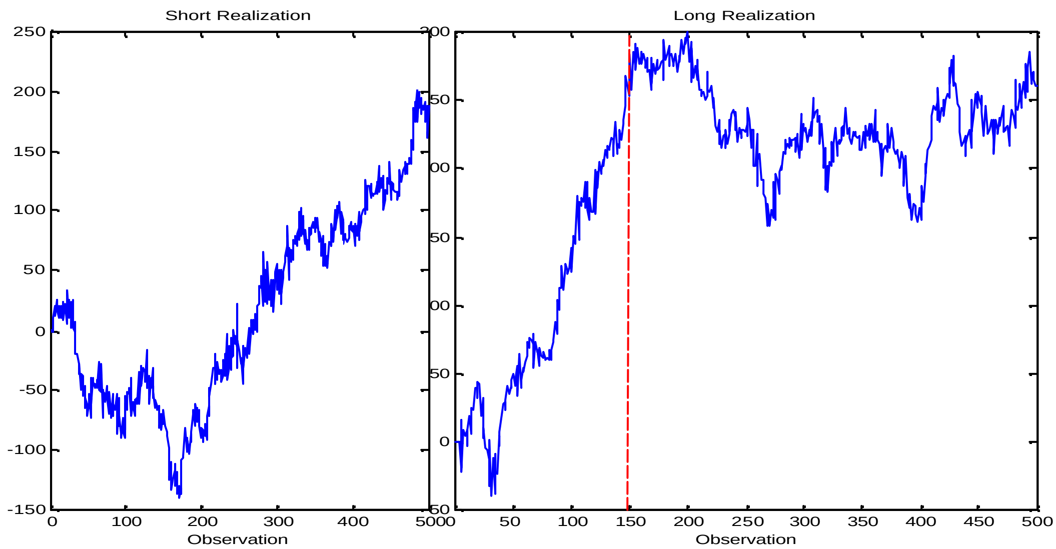

Figure 9

It can be concluded from the observation of these simulations that the model that best describes the San Francisco data, that is an IMA(2), is likely to exhibit lengthy trends but none of these trends seem to be persistent. We observed that in realizations of an IMA(2) model with 150 observations either increasing or decreasing trends appeared, however in each case the trends did not continue in the whole realization.

Consequently, as far as the IMA(2) is a plausible description of the realization observed in San Francisco, it is reasonable to consider inappropriate to predict that the increasing trend observed will continue in the future. Put differently, concluding that there is global warming via deterministic trend tests in small realization (150 or 200) can lead to incorrect predictions if the sea level data behaves according to an ARIMA model of the type analyzed here.

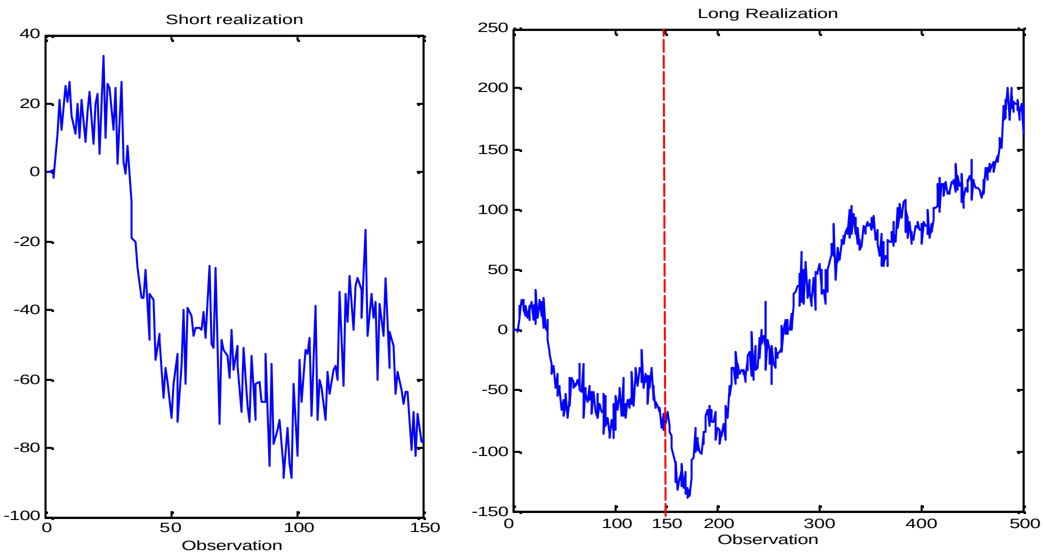

Figure 10

4. DISCUSSION AND CONCLUSIONS

I had two main objectives in the elaboration of this paper. The first aim was to assess how much discretion we may have to model environmental time series in order to study the possibility of global warming. As we have seen through the example studied in this work, researches may have some discretion unless the inclusion of outliers is formally justified with historical or scientific evidence that supports both the time and the type of outlier included. This type of intervention analysis could provide more validity to the conclusions and results obtained.

A second objective was to identify problems we may face when testing for a long run trend in environmental series data. The more general problem is that these types of data are clearly serially correlated over time, thus the traditional OLS testing procedures cannot be directly applied. As well, when the environmental time series can be reasonably described through ARIMA $(p,1,q)$ the distinction between data with long term trends and data with stochastic temporal trends can be difficult. This does not mean that global warming does not exist; it just calls for caution at the moment of making prediction that this increasing current tendency will persist in time.

5. REFERENCES

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