Comments on "Technical Note: Multi-centennial scale analysis and synthesis of an ensemble mean response of ENSO to solar and volcanic forcings" by J. Sánchez-Sesma

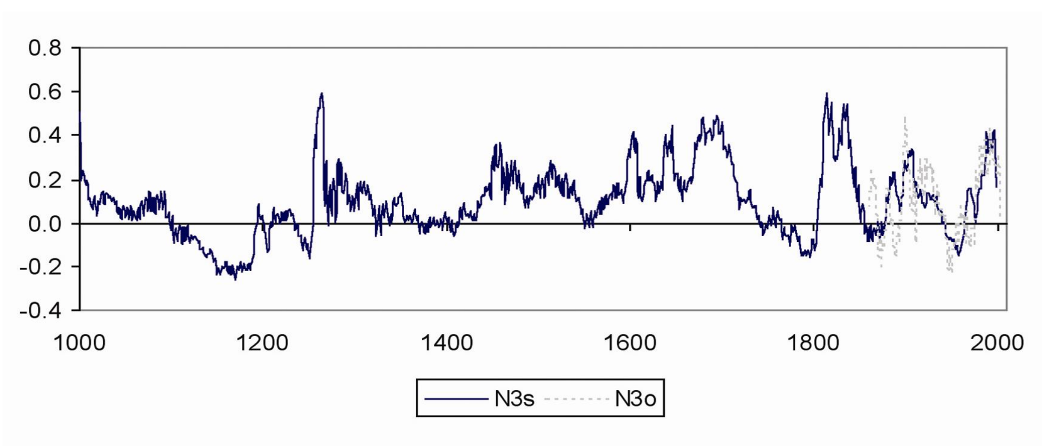
BY JORGE SANCHEZ-SESMA

Firstly, it must be mentioned that we thank our reviewers, their interesting and useful comments about this paper.

The following are our comments.

<u>1. Paper´s goal</u>. The goal of this paper is: **to propose an experimental statistical multidecadal scale forecast of the natural variability of ENSO, and discuss its results for the next decades.** This experimental forecast is based, not directly on the ZC model, but indirectly on the ensemble´s average (EA) of simulations of ENSO obtained, with the ZC model which was forced with solar and volcanic activity (N3SV). Then, **our experimental forecast is not limited by the restrictions of the ZC model because it is based on the extrapolation of the ZC model´s output and it is not based on the ZC model itself**.

<u>2. Goodness of the EA of N3SV</u>. As our long-term forecast is based on the ensamble average (EA) of ZC output, it is necessary to reanalyze of this EA its capacity to represent low frequency variability of the observed records of ENSO, through a comparison with the observed N3 index (N3o). To do that, we compared the smoothed EA of ENSO simulations of the ZC model with natural forcings, N3SV, with the corresponding observations. It is important to emphasize that the EA of N3 simulations (N3SV or N3s) not only reproduce the trends and decadal scale oscillations recorded in the observational record (see Fig. C1a), but also the absolute and RMS differences tend to decrease with time (see Fig C1b).



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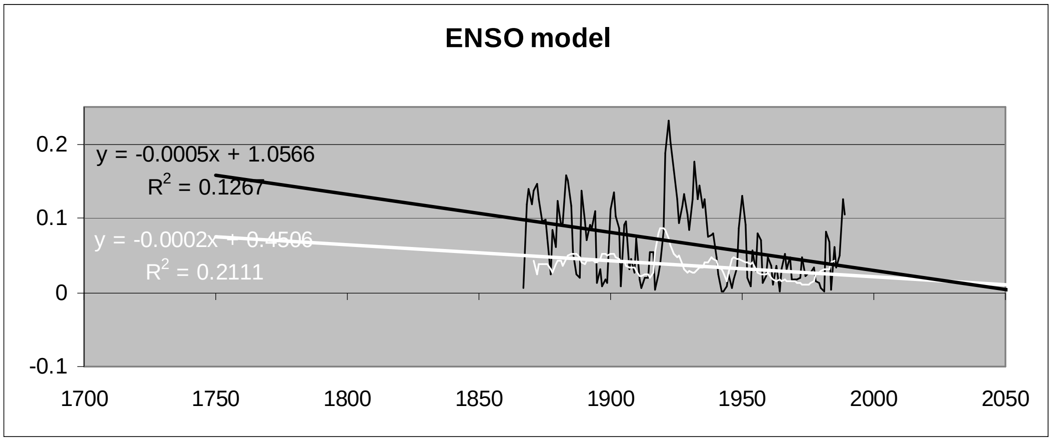


b)

Figure C1: Comparison of smoothed ENSO's model response, N3 [°C], to solar and volcanic forcing. a) observed (N3o) and simulated (N3s) information, obtained from database of IRI and M05, respectively, with a 21yr-MA. b) The absolute diference between simulated and observed values (N3s-N3o) (black line) and its RMS values (white line). Linear trends are also depicted.

These results provide an estimation of the diminishing differences associated to the ZC modeling with natural forcings. Supposing valid these trends, extrapolation of differences result for the next 4 decades an average absolute and RMS values of around 0.042 and 0.045 °C, respectively.

3. ENSO´s simulation and anthropogenic forcings. It can be proposed the following hypothesis, that the anthropogenic forcings are generating an increasing difference between N3o and the EA of N3SV. However, as their evaluated differences tend to diminish in time, and supposing that the accuracy of solar and volcanic reconstructions for the last 150 years are relatively homogeneous, we can reject this hypothesis because, in contrast, the differences are decreasing in time.

As our paper title´s indicates, our experimental forecast has not considered anthropogenic forces. Our experimental forecast takes into account only the ENSO´s response of solar and volcanic forcings, the N3SV signal. However, our results seem to approximately represent the recent observed ENSO´s multidecadal trends without a consideration of the anthropogenic forcings.

Then our results leave out anthropogenic forces because they did not generate significant influences that separate, in an increasing way, the simulated EA of N3SV from the observed, N3O.

4. Sensibility. To show the sensibility of the parameters, the author has developed a program in FORTRAN, to adjust accumulated N3SV´s model with an automatic procedure that minimize RMS errors, varying all employed parameters. With this program we will estimate the goodness and sensitivity of the resulting adjusted models.

5. Curve mass method. The majority of statistical techniques fail to detect low frequency oscillations in relatively short climate records. We have chosen the curve mass method because it is a very simple mathematical tool that enhances low frequency oscillations and diminishes the high frequency oscillations. It can be precisely evaluated in what conditions this enhancement works. The author has programmed, in FORTRAN, an automatic procedure to detect in which combination of amplitudes, phase and frequency the CM method the cumulative curve (curve mass) is closer to the enhanced oscillation. (Later is given another commenta about CM)

6. ZC model output interpretation. The EA of N3SV obtained by M05, can be considered as a paleoclimate proxy reconstruction. It appears to provide key information about the low frequency ENSO variability. It is like a proxy reconstruction because it takes into account, as forcings, another proxy reconstructions of solar and volcanic activity. As all other proxy reconstructions, it must be calibrated with observations, as we have done. Also, it was compared with another proxys from corals (M05). Like other proxy records the EA of N3VS can be extrapolated to estimate future and past (see comment below) ENSO climates.

7. Climate oscillations, 910 yr period. In our paper we evaluated and applied a sine function of the low frequency component with an approximated period of 910 years that minimize RMS errors.

The 910-yr-sine-fuction employed is well supported with independent results coming from: a) the significant contribution in wavelet analysis of the N3SV (M05), b) the proxy reconstructed record of solar activity with anomalies of TSI values (Steinhilber, 2009), and the proxy record of Nile Droughts (Quinn, 1992). However, this does not mean that we accept periodicity in our results. For that reason, in our paper the evaluated forecasted values were obtained with and without considering the extrapolation of the 910-yr-sine-fuction to enhance the independence of the 910-yr-sine-function. Results showed this independence.

This means that our decomposition is based in the 910-yr-sine-fuction mainly to detect better higher frecuency residue in which the non-linear component appears.

When the phenomenon under study is complex, the “period-matching” game should be allowed as a first step in a process to propose and model possible mechanisms. However, when the forcings are well defined as in our case, and its response N3SV is linear, periodicities in solar and volcanic activity can be associated to the N3SV.

N3SV is due to solar and volcanic activity shows a ~910-yr climate oscillation component. As a first step an explanation of this periodicity is that it appears in solar activity. This statement can be tested if we analyze the reconstructed record of solar activity. In Figure C2 the smoothed total solar irradiance (TSI) over the last millennia Steinhilber 2009), is compared with a very simple periodic model of 900 yr period. The model explained more than 60% of the variance of the smoothed TSI signal during last 2000 yrs.

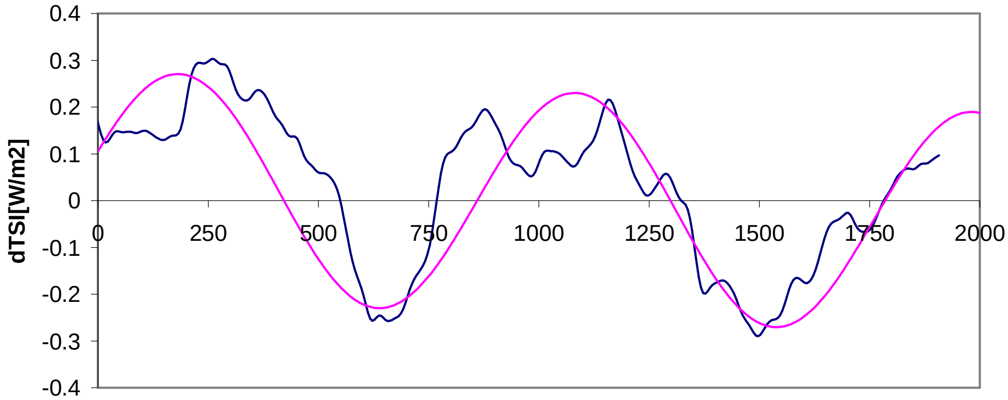


Figure C2. Comparison of anomalies of total solar irradiance (TSI) recosntructed by Steinhilber (2009), and a simple model with a 4 parameters (a linear trend and a 900 yr sine function) that explain more than 60% of the variance.

Also, we could confirm this oscillation period with several proxy information of ENSO. Nilometers have been used for gauging the level of water in the Nile River for more than five millennia which is closely associated with ENSO (Eltahir and Wang, 1999). Quinn (1992) has pointed out that, since 1906 a correspondence between good (poor) Nile floods July-October and low (high) pressure conditions June-September over the Middle East were measured. The low pressure over this area are a part of the very large low pressure system that extends over India and the Arabian Sea and brings strong persistent southwestern winds and heavy rainfall over the highlands of Ethiopia during the summer monsoon under cold ENSO condition.

This correspondence between Nile droughts (ND) and warm ENSO events has been the basis of a proxy reconstruction of ENSO events during the period 622-1522 AD based on ND events. The ND reconstructed record by Quinn (1992) provides for each drought its degree of deficiency. Smoothed values of this record (101-yr-MA) shows aproximated millennial scale oscillation with a maximum and minimum, in the middle of the 8th century and at the end of the 12th century, respectively, see Figure C3. This figure also depicts a sine function model, with 910 yr period that explains more than 82% of the variance.

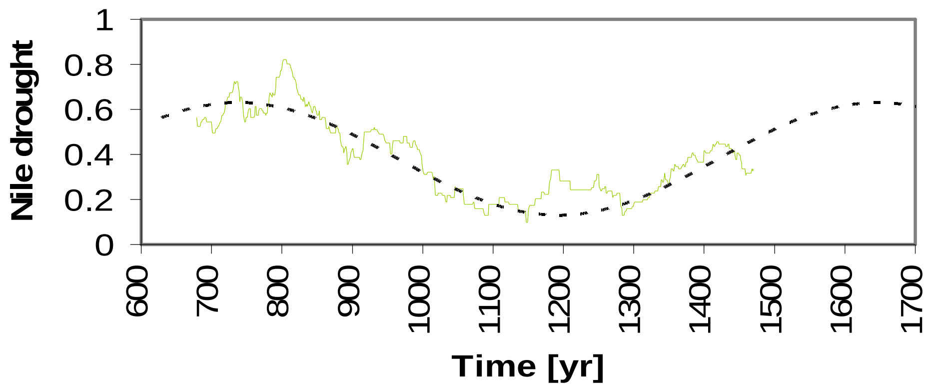


Figure C3. Nile droughts (ND) record and its modeling. ND data was reconstructed by Quinn (1992) and is smoothed with a 101-yr-MA process. It indicates the degree of reduction in maximum Nile flood from long-term averages. A sine function with 910 yr period that explain 82.8% of the ND variance is displayed (dashed line). The minima at the end of the 12th century is concident with the N3SV reconstructed record See Figure C1.

It must be noted that the adjusted model has almost the same phase and period that models adjusted to N3SV simulated record and to the solar TSI record.

Another influences of ENSO amplitude led to stronger NNE trade winds off eastern Brazil, favouring SW transport of sediments from the Paraiba do Sul River that has been recorded in a core from off Cabo Frio during last millenia (Gyllencreutz et al., 2010). Wavelet- and spectral analysis of the related records show a significant ~1000-yr periodicity, which has been attributed to solar forcing (Gyllencreutz et al., 2010).
Additionally, it must be mentioned that as one of the best paleo-hydrologist in the world, Dr. Victor Baker, employed the cumulative analysis (please read Mass Curve method) of Nile river activity that shows an oscillation ~900 years (See Figure 6.3, Baker, 1991). This analysis has put forward that the Nile River shows millennium scale oscillations with similarities with the Vistula river basin of Poland, and also that the past main alluvial discontinuities happened in the United States associated with flooding episodes during the last 2000 years are separated each other no more than 1000 years.

8. Long-term Oscillatory Volcanic Response of ENSO. In our paper, it was not clearly expressed that it is completely accepted that each one of the simulations corresponds to a different initial condition (assigned randomly) with identical forcing. However, we have analyzed EAs of two responses of ENSO, one forced jointly by sun and volcanoes, N3SV (the main part of our paper), and other forced only by volcanoes, N3V (in the supplementary part). Here we explain details of the N3V analysis and synthesis.

The N3V analysis was added to our paper, because it strongly suggests not only a possible long-term forecast of N3V, and a non-linear behavior of one component, but also the possible contribution of millennium scale oscillation and a periodic oscillation. The N3V decomposition and forecast is shown in Figure C4.

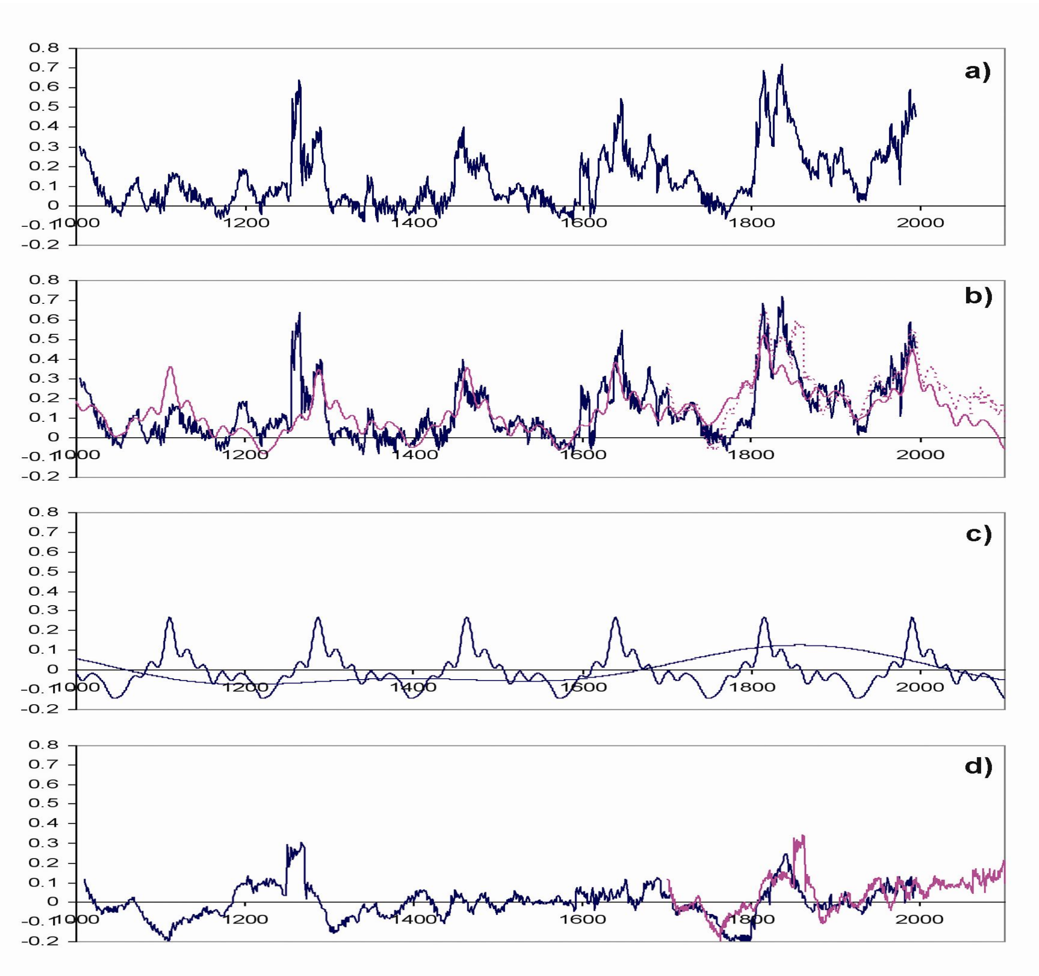
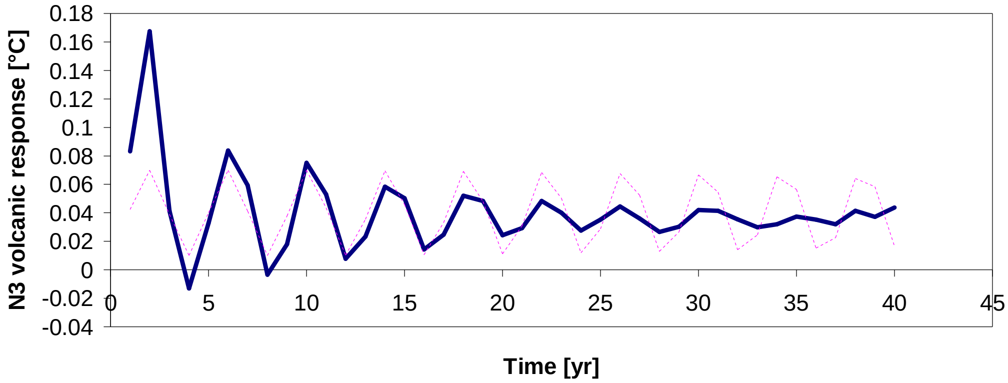


Figure C4. Comparison of volcanic N3 (N3V) annual average records. (a) Simulated, 1000-1999 AD, with ZC model (M05) (nEnsemble); (b) modeled obtained from the two Fourier series components model, VS1 and VS2, with and without the non-linear residue model, VN3S1+VN3S2+R (dark red dotted) and VN3S1+VN3S2 (dark red), respectively; (c) the two Fourier series components model, VN3S1 and VN3S2; and (c) the residual component, R, and its non-linear model (dark red).

The periodic component of ENSO´s response to volcanoes suggests a periodic component of the volcanic forcing. However to test this suggestion we need to demonstrate that the N3V is a linear response of the volcanic forcing.

Firstly, we have estimated that the EA of the simulated volcanic ENSO, N3V, response, shows a memory. However, it can be estimated with the simulation of ENSO with only volcanic forcing, N3V. When this N3V EA output is decomposed as a linear contribution for each previous year affected by volcanic eruption, through a solution of an over estimated system of linear equations, a signal is obtained for a unit perturbation of -1[W/m2]. This process was done with both annual and also smoothed outputs. Figures C2a and C2b show the corresponding linear responses to volcanic forcing due to a decrease of 1 W/m2 of the radiation blockage by volcanic ashes. While Figure C2a shows the non-smoothed oscillatory response for each unit eruption, Figure C2b shows a multidecadal mean response for each eruption.



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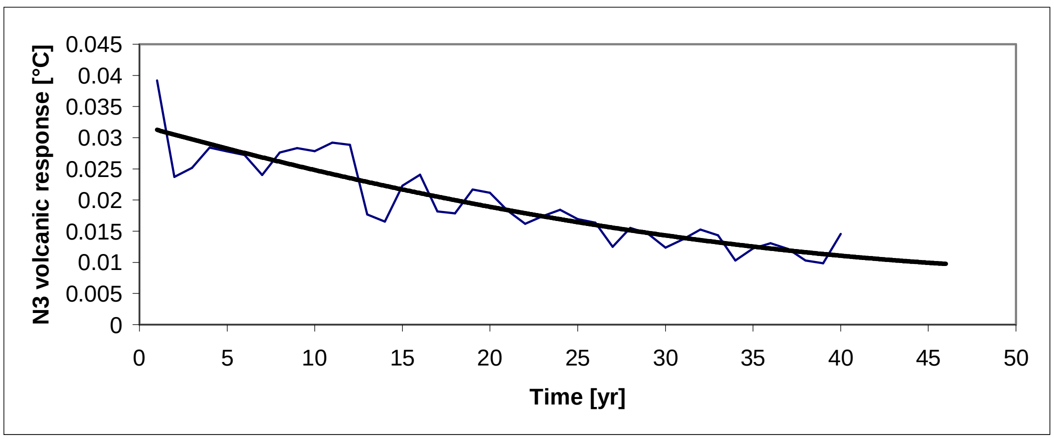


b)

Figure C5. Linear N3 response to a unit volcanic eruption -1[W/m2]. A) Response based on annual values. A sine function with 4 yr period is added. B) Response based on smoothed values.

The resulting linear response of smoothed values suggests us that ZC model act as an interpolator of volcanic eruption events. Then, the smoothed values of the N3V signals let us to evaluate approximately periodic signals of volcanic activity.

Also, this linear response of the unit volcanic eruptions supports an extrapolation of the founded periodicity of N3V to a similar periodicity of the volcanic forcings of ENSO (Sánchez-Sesma, 2011a). As we have decomposed the oscillations of the EA-N3V signal using a Fourier Series function with 176 yr period, this function and its period can be considered representative of one component of the volcanic eruptions forcing employed by M05.

<u>9. Physical support of a forecast of N3V and its volcanic forcing.</u> As these variables are linearly related, with the forecast of N3V we can estimate its volcanic forcing (or the forecast of volcanic activity).

The mechanism that explain volcanic activity periodicity is outside of the scope of this paper. However it is possible to present an association with a physical solar oscillation that match in frequency and in phase.

Figure C6 shows a smoothed physical function evaluated with the DE-406 solar planetary simulation archives of the JPL/NASA, through the Horizons (2010) system.

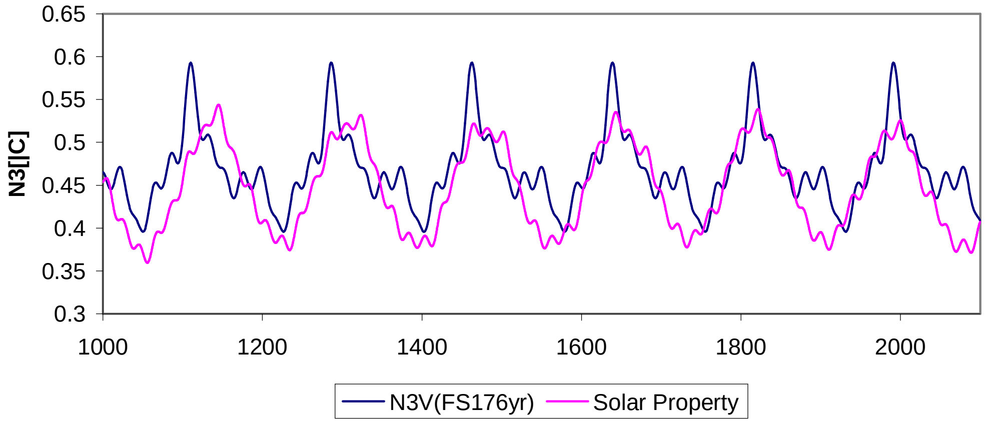
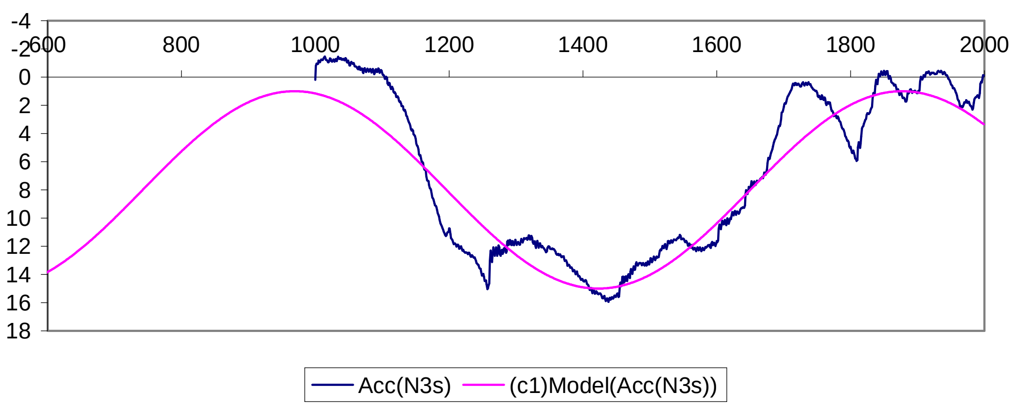


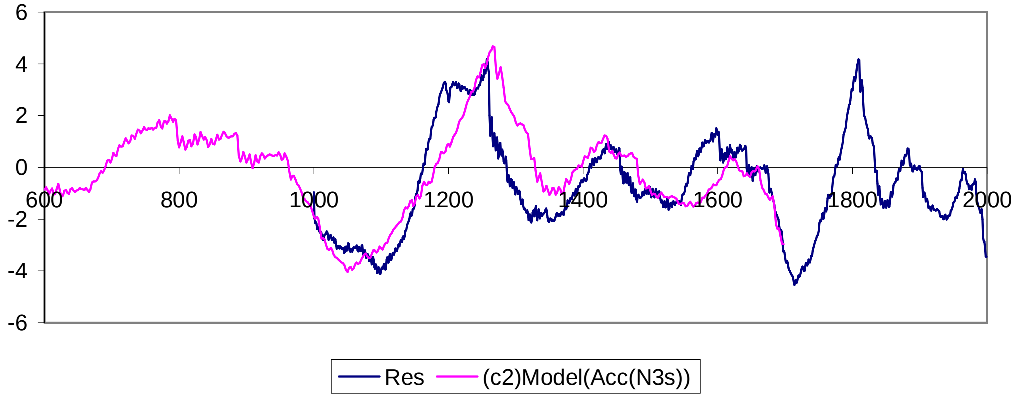
Figure C6. Comparison of Volcanic response of ENSO, N3V, with a solar physical property for the period 1000-2100 AD. (Sánchez-Sesma, 2011a)

10. An independent test of our experimental forecast method. Considering that our experimental forecast method, not only can be applied to forecast of ENSO´s natural, N3SV forward trends, during future decades, but also it can applied to hindcast past trends of ENSO, N3SV backward trends. This hindcast constitutes an important test of the proposed N3SV forecast technique.

This test consists in two steps: 1) the application of the proposed forecast technique back in time, and 2) a comparison with previous information of ENSO.

First, in order to test the proposed method of N3SV forecast, it has applied backwards. It means that the method has been applied to extrapolate to forecast a previous period to 1000 AD, it is a hindcasting going back in time exercise. The application of the same method is displayed in figures C7 and C8.





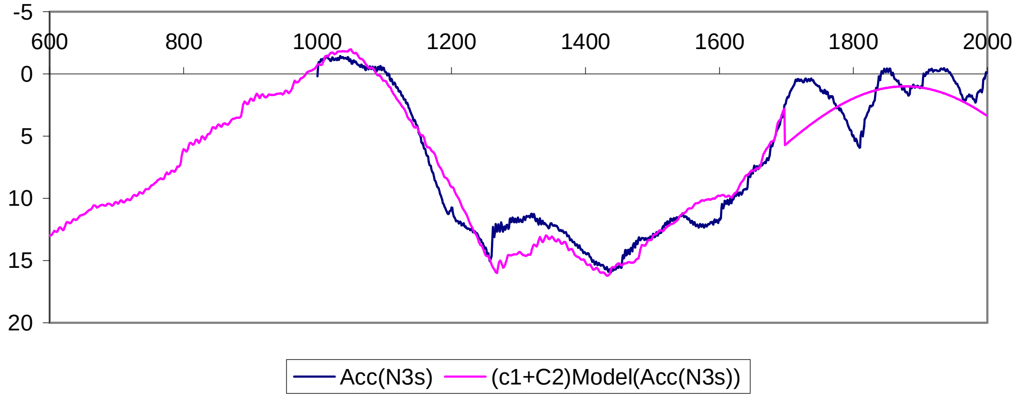
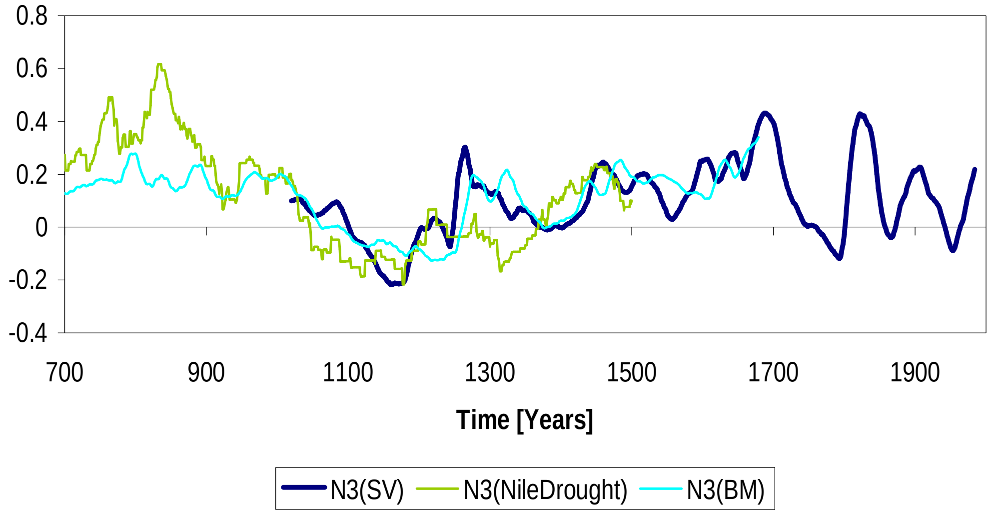


Figure C7. (a) Accumulated N3s ($\eta 3_s$) information and its simple model (c1, see Eq. 3 and 4), obtained from database M05 and a FS model with NF=1, a period of 908 years, respectively. (b) Residue of Accumulated N3s ($\eta 3_s$) information after eliminating the millennium component (c1, 908 yr oscillation). A simple non-linear model (c2, Eq. 3, 5 and 6), with γ =1./0.45 (see Eq. 2-4), t0 =2000, and t1 =1700, is also displayed. (c) Accumulated N3s ($\eta 3_s$) information and its simple complete model [c1 +c2, see (a) and (b)].

Second, in order to compare our results, a proxy reconstruction of ENSO for the period before the year 1000 is needed. These conditions are fulfilled by the Nile´s drought (ND) information reconstructed by Quinn, (1992). This ND is based on historical information of Nile levels which permitted to reconstruct the number and intensities of ND during the period 622 to 1520 AD (see previous comment about). However this record requires a calibration to be compared with the N3SV backward extrapolation.

The calibration was developed adjusting for the period 1000-1500 AD, four aspects of ND record: mean, standard deviation, linear trend, and a lag time. Calibrated results are compared in Figure C8.



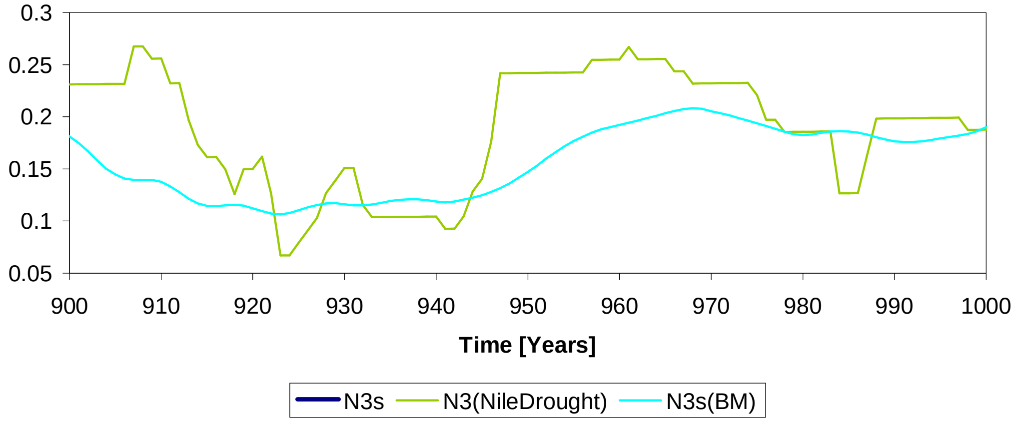


Figure C8. Comparison of three smoothed N3 records. Simulated, 1000-1999 AD, with ZC model (M05) (nEnsemble), recosntructed proxy record from Nile Droughts (Quinn, 1992), and obtained from differentiation of the accumulated signal obtained from the two components model, FS and SS (c1+c2=Linear + Non Linear Models) (Figure C6), 700-1700 AD. (a) Values for the period 700-2000; and (b) a zoom of values over 900-1000 AD.

In the hindcasted period, 700-1000 AD, the backward model extrapolatation, N3s(BM) shows a long-term maxima of around the 8 and 9th century. In the same period the proxy record of N3 based on ND, N3(ND), shows the two greatest maxima values of the 800 years period (700-1500 AD). The last century of the hindcasted period, 900-1000 AD, the backward model extrapolatation, N3s(BM) shows a qualitatively match with the proxy record of N3 based on ND, N3(ND). Their values shown for the next periods the following: a) 980-1000 AD. No significant change; b) 970-980 AD. Small decrease. c) 940-970 AD. Significant increase; d) 920-940 AD. Small change; and e) 980-1000 AD. Significant decrease.

<u>11. Statistical significance.</u> The statistical significance of the climate shift forecasted can be estimated with different models. Different statistical models will be adjusted directly to the simulated N3SV record or indirectly to its hindcasted values. One is to a repetitive "hindcasted" forecast will provide statistical element for an estimation of probability levels for a given range of forecasted values and trends. With this end, several works will be taken into account (Enfield and Cid, 2006; Eltahir and Wang, 1999).

12. Additional application of the non-linear decomposition and forecast.We have applied similar non-linear techniques to forecast solar activity for the next decades.

Based on the same proposed methodology, with linear and non-linear decomposition, a decrease on solar activity is forecasted for the next centuries (Sánchez-Sesma, 2011a). This forecast confirms previous efforts of several authors (Landscheidt, 1987; Fairbridge and Shirley, 1987; Duhau and de Jager, 2010) that have forecasted a possible solar grand-minima for the next decades. For example, recent findings about periodicities in the solar tachocline and their physical interpretation permit us to estimate that solar variability is presently entering into a long Grand Minimum, this being an episode of very low solar activity, not shorter than a century (Duhau and Jager, 2010).

13. An alternative forecast approach. As the climate scenarios associated with global warming does not shows a clear influence on ENSO (IPCC 2007; Latif and Keenlyside 2009), we require to discus and apply alternative techniques to forecast ENSO´s climate variability.

In addition of AO-GCMs with global or regional coverage, analysis end extrapolation of simulated and proxy based reconstructions of ENSO must be developed. When the AO-GCMs modelling does not define well changes in response to global warming. Latif and Keenlyside (2009) have pointed out that, "At this stage of understanding we have simply to state that we do not know how global warming will affect the Tropical Pacific climate system." In their study they said that "global climate model and observation of the coupled system will not undergo a major bifurcation in the next few decades, because they simulate strong changes only under rather high greenhouse gas concentrations, that is, by the end of this century or thereafter. Moreover, the mean state and ENSO responses differ strongly from model to model, and a consensus does not exist."

Also, Latif and Keenlyside (2009) have pointed out the folowing: "Virtually all global climate models suffer from serious problems in simulating Tropical Pacific climate. The annual mean state, the annual cycle, and the interannual variability as expressed by ENSO are often badly simulated. Even the "best models" exhibit large systematic errors, such as strong warm biases in the eastern tropical oceans or cold biases along the equator. The realistic simulation of Tropical Pacific thus still poses a challenge. Model improvement is therefore a prerequisite for reliable global change projections in the Tropics. Simulation of Tropical Pacific climate is particularly difficult, because of the complex and strong ocean–atmosphere feedbacks that exist there and that amplify errors in the representation of physical processes. These errors are due to incomplete understanding of the physical process and their simplified treatment in models, necessary because of computational constraints."

Taking into account all these limitations, we would like to emphasize the importance of the estimation of ENSO´s multidecadal trends with alternative techniques. There are alternatives that need to be explored to develop other independent methods. A physical based alternative has been explored that provide similar trends to La Niña for the next decades.

14. Final comments

In this paper we have presented and tested an experimental multidecadal forecast technique for ENSO. We have detected and applied successfully a non-linear (self-similarity) component, in decomposing different climate related processes: a) ENSO response to solar+volcanic forcing, b) ENSO response to volcanic forcing, and c) solar activity (Sánchez-Sesma, 2011).

We hope that this paper promotes discussion, modeling and applications of non-linear approaches, with self-similarity included, to analyze and forecast ENSO and other climate related variations. With this promotion, our ENSO models will be able to define the key tipping point behavior during next future taking into account non-linear aspects of all processes involved.

This is a long-term process that urgently needs to be improved and focused in the next years. We need to initiate an open discussion of this multidecadal forecast of ENSO. Mexico as other countries in the world (Argentina, Australia, Venezuela, etc.) has been severely affected by the present La Niña conditions during last year. It appears that a trend toward La Niña conditions has been underway during last years and will continue for the next decades. It is time to analyze all possible ENSO scenarios, with traditional and alternative methods, providing key information to prevent the possible tremendous impacts all over the world.

NOTE: All suggested detailed corrections and changes are being considered for the last version of our paper.

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