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Earth System Dynamics Discussions
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Interactive comment on "ESD Ideas: Long-period tidal forcing in geophysics – application to ENSO, QBO, and Chandler wobble" *by* Paul R. Pukite

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Thank you for the review.

I agree that a validation step is needed for this particular ENSO model to be accepted. The usual issue with validation against future events is that a sufficient time interval must elapse before sufficient statistics are gathered for the model to be substantiated (or debunked). And some models, such as those for astrophysics, are forecast for millions of years in the future, so the lack of a predictive validation step is acceptable for that scientific discipline. However, as an alternative approach, often one can employ cross-validation techniques such that one portion of the time-series can be used as a training interval and another interval can be used as a test or validation step.

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Discussion paper

A simple signal processing technique that was hinted at in the idea submission can be used to substantiate that deterministic characteristics exist within the ENSO time-series. The technique applies a Fourier spectrum analysis to reveal an underlying double-sideband suppressed carrier modulation in the signal. If the measured signal does have a modulation imparted by a carrier signal, then the frequency spectrum should show a mirror symmetry about the carrier frequency – for every frequency a pair of positive and negative side-lobes will appear. See Fig. 1

As the general assumption is that an annual seasonal barrier is responsible for triggering an El Nino (or La Nina) episode, the annual frequency provides the carrier signal which is used as the mirror symmetry point in the Fourier spectra. By mirror folding the frequency beyond the 0.5/year point, this double-sideband modulation is observed (nothing like this has been reported in the literature, as far as I know). See Fig.2

As mentioned in the paper, a solution of Laplace's tidal equations (LTE) was derived elsewhere (see Pukite et al, Mathematical Geoenergy, Wiley/2018) and that was used to train a time-series over a fixed ENSO interval, from 1880 to 2016 of the NINO34 data set. More recent data post-2016 is then used as a cross-validation step. Long-period tidal forcing calibrated to length-of-day (LOD) data was used as the modulating stimulus and the annual barrier was applied as the "carrier" signal – these are shown in steps A through G below in Fig. 3.

The cross-validation takes place when the model is extended beyond 2016, assuming the cyclic tidal pattern will continue – see the chart Fig.4:

Certainly this is not considered a perfect "blind test", as one can rightly state that fits that did not work were discarded. Yet, in the spirit of open analysis, others can replicate the calculations or experiment via the instructions that are included via the supplemental information uploaded to the Copernicus page.

From my understanding, tidal forcing is being included in recent GCM packages. There is a disconnection between many of the reduced models used to demonstrate some aspect of ENSO behavior, such as Cane-Zebiak, and the full-blown GCMs. The LTE formulation I am working from may provide a useful approach that is simple but bridges to the more comprehensive GCM solution.

Thank you again for reviewing the idea. Eventually some machine learning model based on a neural net connectivity may find a similar pattern match, yet with little insight on how the net was physically constructed (see citation [1] below). So whether or not it is completely understood, I fully expect that a ML algorithm will be able to make the same connections and provide a predictive capability. In contrast, the model described in this idea was developed from first principles and one can see the sequence of steps from forcing to response.

[1] Pukite, Paul. "Nonlinear Differential Equations with external forcing." ICLR 2020 Workshop on Integration of Deep Neural Models and Differential Equations. 2020.

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$$\underbrace{V_m \cos(\omega_m t)}_{\text{Message}} \times \underbrace{V_c \cos(\omega_c t)}_{\text{Carrier}} = \underbrace{\frac{V_m V_c}{2}\left[\cos((\omega_m + \omega_c)\,t) + \cos((\omega_m - \omega_c)\,t)\right]}_{\text{Modulated Signal}}$$

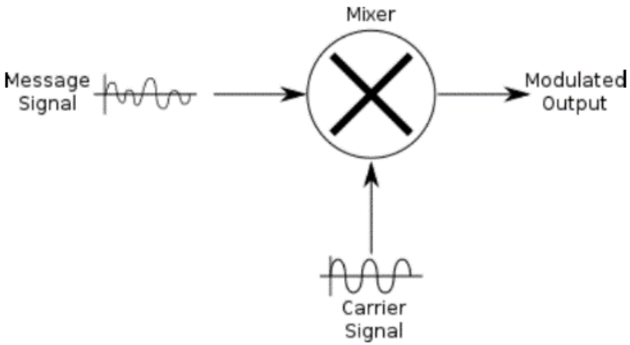

Fig. 1. Mechanism of double-sideband suppressed carrier modulation (DSSCM)

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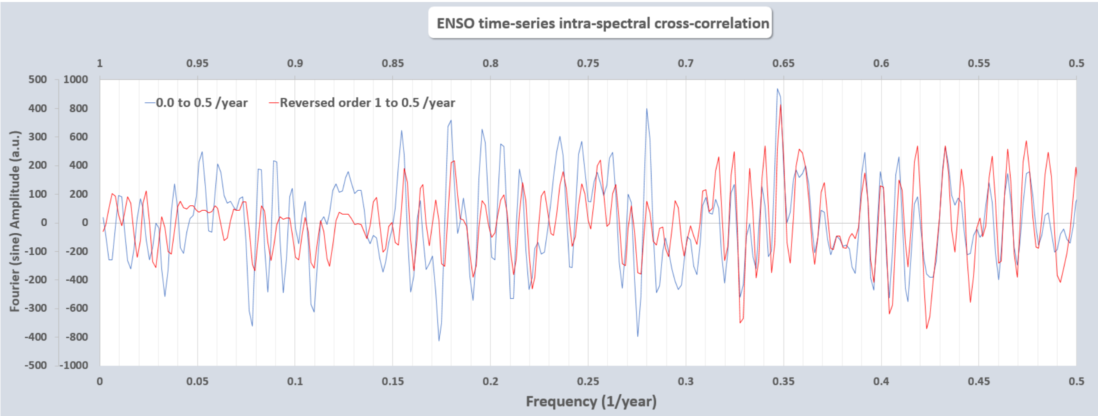

Fig. 2. ENSO spectrum showing DSSCM

Fig. 3. ENSO tidal forcing model

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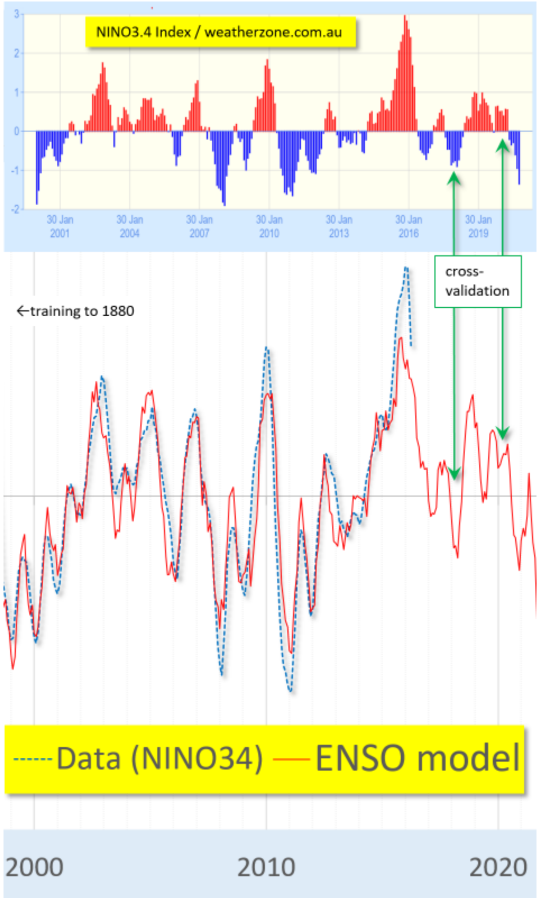

Fig. 4. ENSO cross-validation of out-of-band data

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