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# The Sun is the climate pacemaker II. Global ocean temperatures

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ABSTRACT

In part I, equatorial Pacific Ocean temperature index *SST3.4* was found to have segments during 1990–2014 showing a phase-locked annual signal and phase-locked signals of 2- or 3-year periods. Phase locking is to an inferred solar forcing of 1.0 cycle/yr. Here the study extends to the global ocean, from surface to 700 and 2000 m. The same phase-locking phenomena are found. The El Niño/La Niña effect diffuses into the world oceans with a delay of about two months.



## 1. Introduction

In a study of equatorial Pacific Ocean temperature [1] it was found that phase locking of annual temperature signals with subharmonic components occurs at subharmonic periods of two or three years. Ten such segments were identified and numbered sequentially in the period 1870–2008. Either the beginning date, the end date, or both, of those segments had a near one-to-one correspondence with previously reported abrupt climate changes or climate shifts. To explain the various phenomena it was concluded that this climate system is driven by a forcing $F_S$ of solar origin at a frequency of 1.0 cycle/yr that causes both the direct-response principal component and the subharmonic response. These, and the 1 cycle/yr component, were phase locked to the annual solar cycle. In this study "phase-locked" always refers to the solar cycle as reference.

In the companion Letter [2] we studied the equatorial Pacific surface temperature *SST3.4* from 1990 to 2014 and found three segments phase locked at subharmonics of $F_S$. The first two update the result reported in [1]: a 1991–1999 segment showing periodicity of 3 years and a 2002–2008 segment showing periodicity of two years. The third is new: a segment from 2008–2013 (end of data) showing periodicity of three years. Phase locking was decisively demonstrated by producing closed Lissajous loops.

Section 2 describes data sets, methods, and background material. Results are analyzed and discussed in Section 3. Section 4 considers related issues and the conclusions are summarized in Section 5.

## 2. Data and methods

### 2.1. Data

This study considers only data from January 1990 through December 2013.

*HadSST3*: A monthly global ocean surface temperature data set *HadSST3* is produced by the Met Office Hadley Centre, Exeter, UK [3].

Average global temperature sets for different depths are available [4]. The data set for each depth $D$ will be labeled "*TD*". For example, *T2000* denotes average global ocean temperature from the surface to a depth of 2000 m. In addition to an average over depths a geographical average is taken over the major oceanic basins: Pacific Ocean, Atlantic Ocean (which includes the entire Arctic Ocean), and the Indian Ocean. These data are quarterly (4 values/yr). The designation of quarters will be with a suffix. For example, the first quarter, Jan/Feb/Mar of 2000 is written as 2000-1; Apr/May/Jun of 2000 as 2000-2; etc.

### 2.2. Separation of high- and low-frequency effects

Studies of many geophysical phenomena involve data sets containing a component of interest that may show components at

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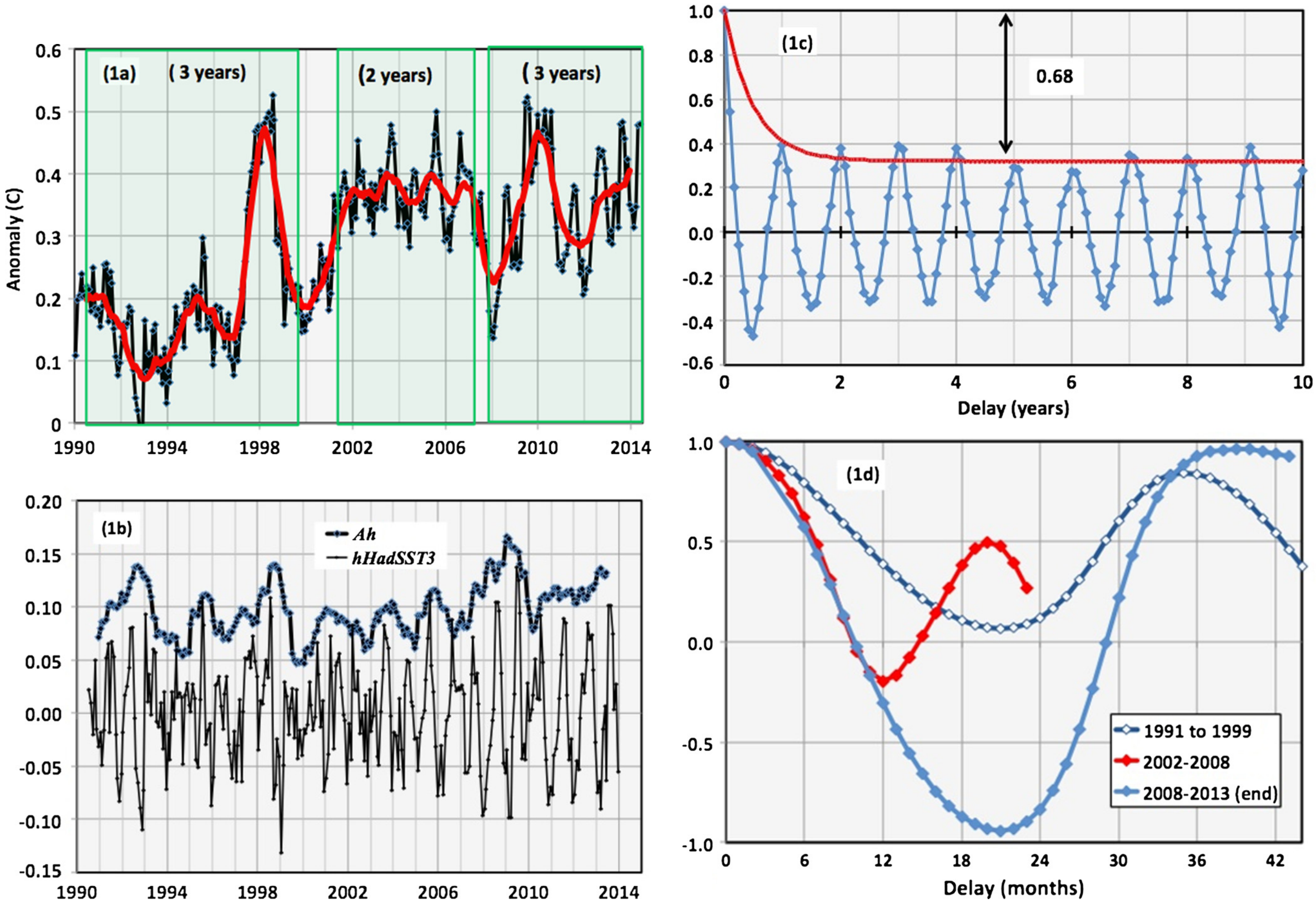


**Fig. 1.** Plots associated with *HadSST3*. a. Plot of *HadSST3* (black, with data points) and *aHadSST3* (red). The 24-month and 36-month phase-locked segments are indicated by green shaded rectangles. b. Plot of high-frequency component *hHadSST3* (lower curve) and its amplitude ***A***(*hHadSST3*). c. Autocorrelation of *hHadSST3* indicating a periodicity of 12 months. d. Autocorrelation of segment of *aHAdSST3* from February 2002 to March 2008 (in red) and of segment of *aSST3.4* from 2008 to the end of available data (2013), indicating, respectively, periodicities of 24 and 36 months. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

frequencies of 1.0 cycle/yr and its harmonics. Subharmonics related to non-annual effects such as El Niño/La Niña can also appear. For a full understanding of the data set these components must be separated. In this paper we continue to use the filter, methodology, and notation described previously. The high-frequency component is denoted by prefix "*h*" and the low-frequency component by "*a*". Thus, for example, we will have *hSST3.4*, *aT700*, etc. By definition for any set $G$ these are related by $G = hG + aG$, point by point. See Appendix A in [2]. Finally, in the present analysis only anomalies are treated. Thus we replace a parent series $G_0$ by $G = G_0 - \langle G_0 \rangle$, where $\langle G_0 \rangle$ is the average of the parent series over the period.

### *2.3. Identifying phase-locked time segments*

Geophysical indices $aG$ in which seasonal effects have been removed are often found, as in this work, to contain time segments with components having periods that are exactly a multiple of one year. These segments are identified by computing the autocorrelation function *versus* delay time $\tau$ of a candidate segment. When there are time segments in $aG$ showing a periodicity of a multiple of one year, a complete classification is given by three discrete indices: subharmonic number, parity, and sub-state index [1,2].

In Ref. [2], subharmonic phase locking was demonstrated by showing that $aG$ *vs.* $hG$ formed a closed Lissajous loop pattern where the number of loops was the subharmonic number. Alas, $hG$ is not available for any of the data sets considered in this Letter because the parent data are not available. For data without $hG$ one must rely only on the autocorrelation test.

It is sometimes useful to consider the amplitude of the high-frequency data series $hG$, defined as

$$\boldsymbol{A}(hG) = \left(2\,\mathrm{average}\left(hG^2\right)\right)^{1/2}, \qquad (1)$$

where the average is over one year, symmetric about the point in question, and $hG^2$ is the set of squares of the individual numbers in $hG$.

## 3. Analysis and discussion

### *3.1. Global Ocean surface temperatures*

*HadSST3*. The global *HadSST3* time series has had the annual cycle supposedly removed by a climatology scheme. Fig. 1a shows *HadSST3* (black) and *aHadSST3* (red). The fact that the annual effect has not been removed is seen clearly in *hHadSST3* (Fig. 1b) and particularly by the autocorrelation of *hHadSST3* (Fig. 1c). Also shown in Fig. 1b is the amplitude ***A***(*hHadSST3*). The autocorrelation shows a rapid drop (less than 1 year) from 1.0 to a sustained oscillation of 1.0 cycle/yr of amplitude ~0.32. The rapid drop is modeled by an exponential decay to the sustained amplitude with a characteristic time $t_e$. The best fit was for values of $t_e$ less than 1.0 year. The red curve is a plot for $t_e = 0.5$ years. It is pointed out that although there is an annual component in *hHadSST3*, it