
Quantifying the Correlation Between the MEI and LOD Variations by Decomposing LOD with Singular Spectrum Analysis

Karine Le Bail, John M. Gipson, and Daniel S. MacMillan

Abstract

Variations in the temporal length-of-day (LOD) contain information on phenomena related to the continuous evolution of Earth processes: tidal energy dissipation and core-mantle coupling (decadal, secular), meteorological and solar-lunar tide effects (annual, semi-annual). In this work, we studied an LOD time series obtained from VLBI measurements and extracted its principal components using the Singular Spectrum Analysis (SSA). After removing the long-term trend which explains 73.8% of the signal, three remaining components explain a further 22.0% of the signal: an annual and a semi-annual signals as well as a second trend. We compared the Multivariate ENSO index (MEI) with the variations in the amplitudes of the annual and semi-annual components and with the second trend. The correlations are significant: 0.58 for the annual component, -0.48 for the semi-annual component and 0.46 for the second trend.

Keywords

Length-Of-Day (LOD) • VLBI • Singular Spectrum Analysis • ENSO • Multivariate ENSO Index (MEI)

1 Introduction

Very Long Baseline Interferometry (VLBI) is a radio-astronomy technique that makes observations of extragalactic astronomical objects (such as quasars) with a global network of antennas. One can estimate Earth Orientation Parameters (EOP) from these observations and specifically length-of-day (LOD) studied in this paper. Variations in the LOD include contributions from atmospheric and zonal tides, atmospheric perturbation, and atmosphere and ocean mass redistribution. These include the phenomenon of El Niño-South Oscillation (ENSO), which couples an oceanic component, El Niño and an atmospheric component, the Southern Oscillation.

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We are interested in investigating the correlation of events such as El Niño with the LOD time series, and especially in answering the question: Can VLBI detect the ENSO signal? For this, we use Singular Spectrum Analysis (SSA) to extract components of the LOD time series and compare them with the Multivariate ENSO Index (MEI) from NOAA (2011) computed from six variables observed over the tropical Pacific: sea-level pressure, components of the surface wind, sea surface and surface air temperatures, cloudiness fraction of the sky.

In Sect. 2 of this paper, we present the analysis strategy to process VLBI data and to obtain the LOD time series we study, and then, we give a summary of what can be expected in these time series. Section 3 gives details on how we apply the SSA to this case. In Sect. 4, we decompose the LOD time series and compare the extracted components with the MEI. The last section concludes this study.

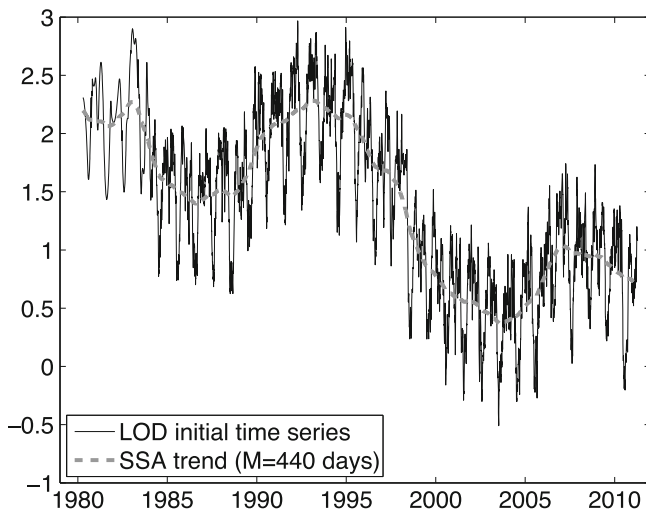


Fig. 1 Daily Excess Length Of Day time series in black derived from the Goddard 2011a VLBI solution in ms. The grey dashed-line curve gives the principal trend extracted by the SSA using a covariance lag of 440 days which explains 73.8% of the initial series

2 Data: Length of Day Time Series

The daily LOD time series we use in this study is derived from the NASA Goddard 2011a VLBI solution. It uses all 24-h VLBI sessions from 1979 to the beginning of 2011. Stations were assumed to move linearly and source positions were estimated as global parameters except for 39 special handling sources that were estimated for each session when they were observed. We estimate in this solution EOP for each 24-h session. High Frequency EOP variations using the 2003 IERS standards are removed during the analysis of the VLBI data. In order to obtain a series with daily values for LOD, we used a two step process. First long period tidal terms are removed from the VLBI estimates. Second, a Kalman filter program was used to provide estimate of these quantities at daily intervals. Figure 1 shows the LOD time series obtained.

In the LOD time series, we expect to see signals at different scales. Signals with periods longer than 10 years, with secular variation or decadal fluctuation, are known to be due to tidal energy dissipation and core-mantle coupling. Meteorological and solar-lunar tide effects lead to signals that have periods less than 1 year, seasonal or short-period variations such as annual and semi-annual.

Other scientists have studied the relation between the LOD time series and the ENSO phenomenon using a variety of tools: by simple decomposition (cf. Chao 1984; 1989), detrended fluctuation analysis (Alvarez-Ramirez et al. 2010), wavelets (Sello 2011) or even SSA and its derived methods (Gross et al. 1996; Dickey et al. 2011). Some of these papers show that the ENSO is transmitted to the solid Earth with a

delay, so the impact on LOD is not immediate. Chao (1989) detected a 2 months delay, Gross et al. (1996) a 4 months delay for the semi-annual component.

3 Studying the LOD with the Singular Spectrum Analysis

The paper by Ghil et al. (2002) is an excellent paper gathering all the information on statistical methods used in climatology. The Singular Spectrum Analysis (SSA) is also described in detail in this paper.

The SSA consists in dividing the data $x(i)_{i=1..N}$ in series of length M , called covariance lag, and to build an auto-covariance matrix C of size (M,M) defined as: $C = D^t D$

$$\text{with } D = \begin{pmatrix} x(1) & x(2) & \cdots & x(M) \\ x(2) & x(3) & \cdots & x(M+1) \\ \vdots & \vdots & \ddots & \vdots \\ x(N-M+1) & x(N-M+2) & \cdots & x(N) \end{pmatrix}$$

The eigenvalues of C are studied to extract the different components (see Fig. 2). An isolated eigenvalue corresponds to a “trend” in the signal. A pair of eigenvalues indicates a periodic signal, which is analogous to the cosine and sine components in Fourier analysis. The reconstruction of the extracted components is done via the eigenvectors determined in the previous step for each eigenvalue. This method is easy to apply and fast, and yields the time-varying amplitudes of the periodic signals.

According to Ghil et al. (2002), the parameter M should be chosen appropriately. We did some tests with several different covariance lags ranging from $M = 30$ days to $M = 440$ days to select the optimal M for this study. When looking at the case $M = 30$ days, we found that the SSA extracts all the periodicities larger than 30 days into one component. This is a “trend” which explains the major part of the signal (96.5%). The 29 remaining eigenvalues which are all similar in size, explain less than 3.5% of the signal. Hence the SSA with $M = 30$ days was not a useful tool to decompose LOD.

Since we expect to see signals with periods less than or equal to 1 year, we select $M = 440$ days (see Fig. 2). $M = 365$ days would have been another possible option but we may have missed the quasi-annual term which is close to 365 days. When choosing $M = 440$ days, the signal is decomposed into one major trend which captures variations longer than 440 days (73.8%), two periodic signals (13.3% and 7.1%) and a second trend (1.6%). The remaining 434 terms account for the residual 4.2% of the signal, with the largest contribution being 0.3%. The major trend (Fig. 1) captures the long-term variation of LOD. We are more interested in the short-term variation which is captured by the quasi-periodic signals and the residual trend. This is discussed in more detail in the next section.

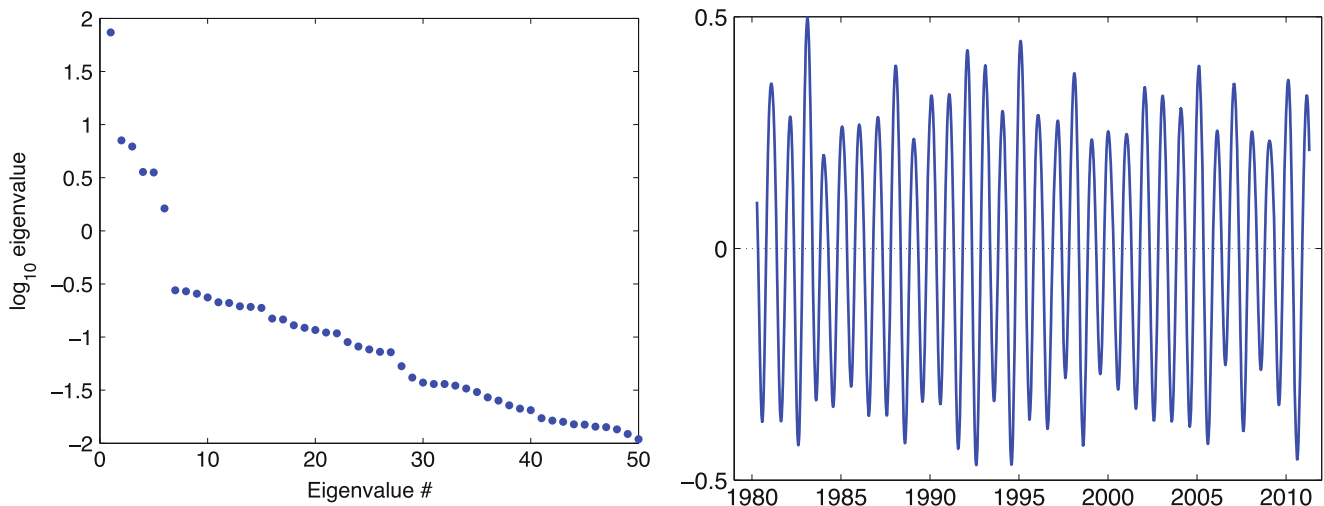


Fig. 2 Eigenvalues obtained by the SSA using a covariance lag equal to 440 days. The first eigenvalue explains 73.8% of the initial series, the eigenvalues 2 and 3 13.3%, the eigenvalues 4 and 5 7.1% and the eigenvalue 6 1.6%

4 Decomposition of the LOD Time Series

Two Major Periodic Signals of the Series: Annual and Semi-annual Terms

When computing the power spectral density of the two periodic signals extracted by the SSA (cf. Fig. 3), the first one is identified as an annual component (period of 365.61 days) and the second one is a semi-annual component (period of 182.81 days). They both have time-varying amplitudes. We compare the MEI time series with the time-varying amplitude of these periodic signals and not with the time series themselves. We extract the amplitudes of the time series using the complex demodulation method (Bloomfield 1976) and plot them in Fig. 4. An equivalent comparison has been made in Gross et al. (1996).

The solid-line curves are the time-varying amplitudes and the grey dashed-line curve is the MEI time series. We scaled the MEI time series for each case to have the same mean standard deviation as the solid-line curve. In the case of the semi-annual component, we reversed the sign of MEI to make the correlation clear. Visually there is a significant correlation between the components and MEI. Computing the correlation coefficients at zero time lag, we obtain 0.58 for the annual term and -0.48 for the semi-annual term. This provides evidence that ENSO is influencing LOD in both the annual and semi-annual components. An exception is an event in 1998, where the two components extracted by the SSA underestimate the event. Those results are similar to those from Gross et al. (1996). The LOD time series studied

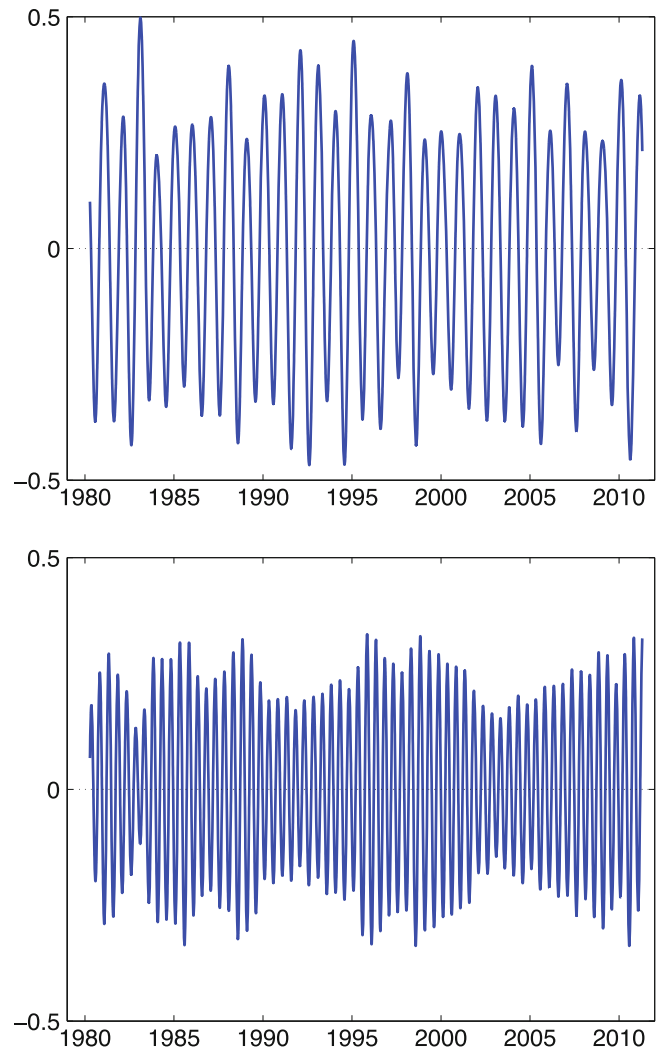


Fig. 3 The two periodic terms detected by the SSA: annual (*top plot*) and semi-annual (*bottom plot*) components with time-varying amplitudes. The unit is ms

in Gross et al. (1996) covers an earlier period, from 1962 to 1993, and is a combination of independent Earth rotation measurements taken using the techniques of optical astrometry, VLBI, and lunar laser ranging. The authors detect a very strong correlation between the Southern Oscillation Index and the LOD annual and semi-annual variations. However, they do not study the second trend they obtain with the SSA, which we investigate in the next section.

Second Trend

To compare with the second trend, we scaled the MEI time series in the same way as above. A high correlation between those two time series is visible in Fig. 5, especially after 1985. The correlation coefficient computed at zero time lag is 0.46. A spectral analysis of the time series show the presence of a significant signal at 2.39 years.

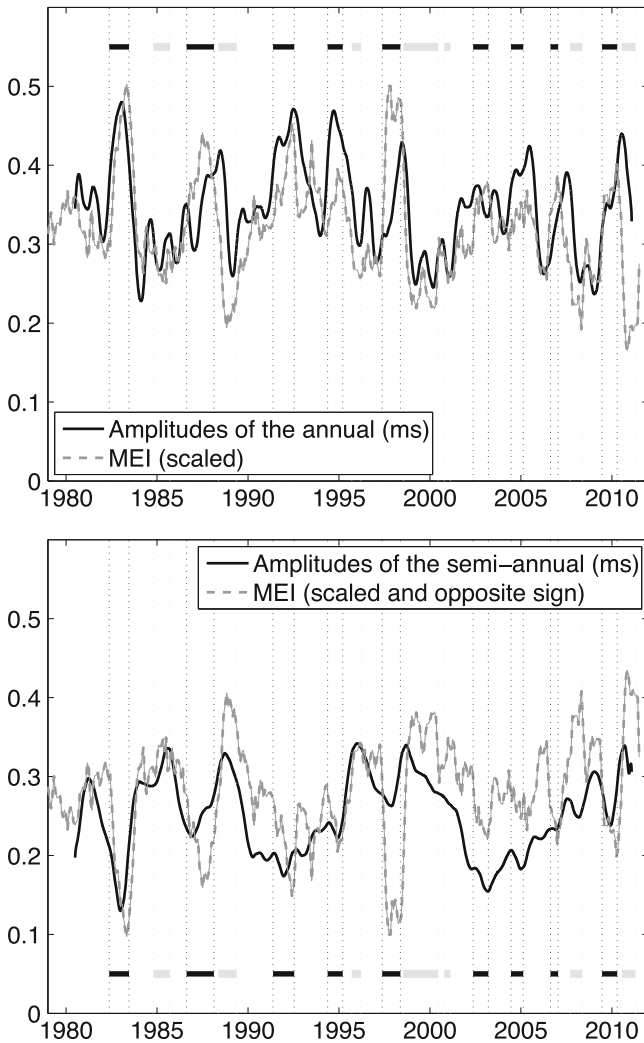


Fig. 4 Time-varying amplitudes of the two periodic terms detected by the SSA in *solid-line* compared with the MEI time series in *grey dashed line*. The unit for the amplitudes is in ms. The MEI series has no unit but it is scaled and plotted with opposite sign for the semi-annual component. The annual is on the *top* of the figure, the semi-annual on the *bottom*. The phenomena of El Niño and La Niña are indicated specifically in *black* and *grey* respectively

Residual Time Series

To check for the remaining signal in the residual time series, we looked at the time series obtained after removing the first four components extracted by the SSA. When compared with the MEI, no obvious correlation is visible, but the level of noise is significant (see Fig. 6). A spectral analysis of the time series show the presence of significant intraseasonal signals (121.87, 91.40 and 62.97 days among others).

5 Conclusions

This study investigated the length-of-day time series derived from VLBI data processing over the period 1979 to 2011. We chose the method of Singular Spectrum Analysis to

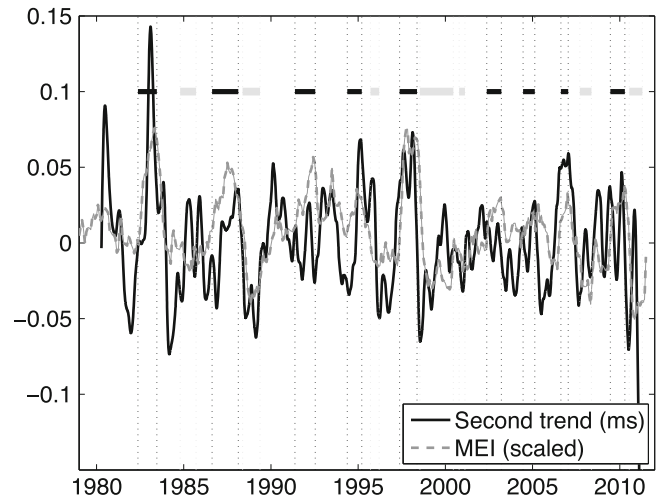


Fig. 5 Second trend detected by the SSA in *solid-line* compared with the MEI time series scaled in *grey dashed line*. The unit for the second trend is ms. The MEI series has been scaled. The phenomena of El Niño and La Niña are indicated specifically in *black* and *grey* respectively

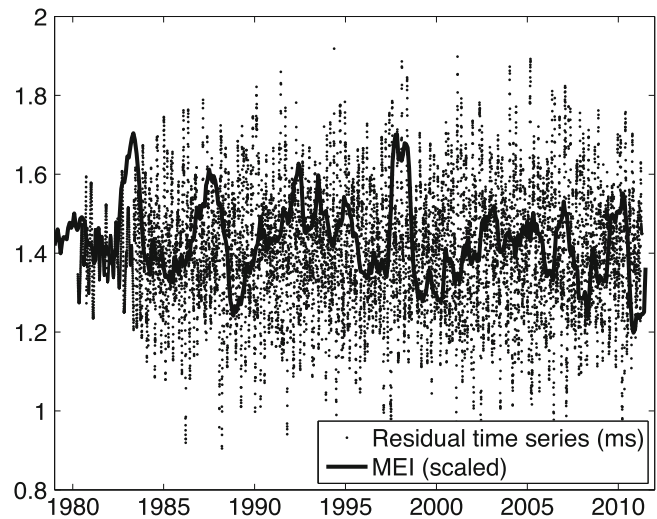


Fig. 6 Residual time series in black points when the four first components extracted by the SSA have been removed compared with the MEI time series scaled in *solid-line*. The unit for residual time series is ms. The MEI series has been scaled

analyze the LOD time series and to determine its periodic signals with time-varying amplitudes and its trends.

The LOD time series is very complex and is composed of several principal components: the long-term trend explains 73.8% of the initial series, the annual 13.3%, the semi-annual 7.1%, and the short-term trend 1.6%. We used complex demodulation to extract the amplitude of the annual and semi-annual components. We found significant correlation between Multivariate ENSO Index (MEI) and: (A) the amplitude of the annual component (58%); (B) the amplitude of the semi-annual component (48%); and (C) the residual short-term trend (46%).

The ENSO phenomena is a large scale quasiperiodic climate pattern which, although concentrated in the Pacific Ocean, has effects that are globally felt. One aspect of this phenomena is a re-distribution of the angular momentum between the solid Earth, the oceans and the atmosphere resulting in a change in the LOD. Another aspect is a change in air-pressure and sea-surface temperature which serve as inputs to the calculation of the Multivariate ENSO Index. Hence it is not surprising that changes in LOD and the MEI are correlated since they have a common origin.

The future development of this study requires the investigation of the remaining signal in more detail, and the determination of a delay between the extracted components of the LOD with the MEI.

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