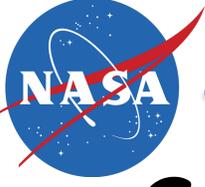


Decomposing LOD with Singular Spectral Analysis

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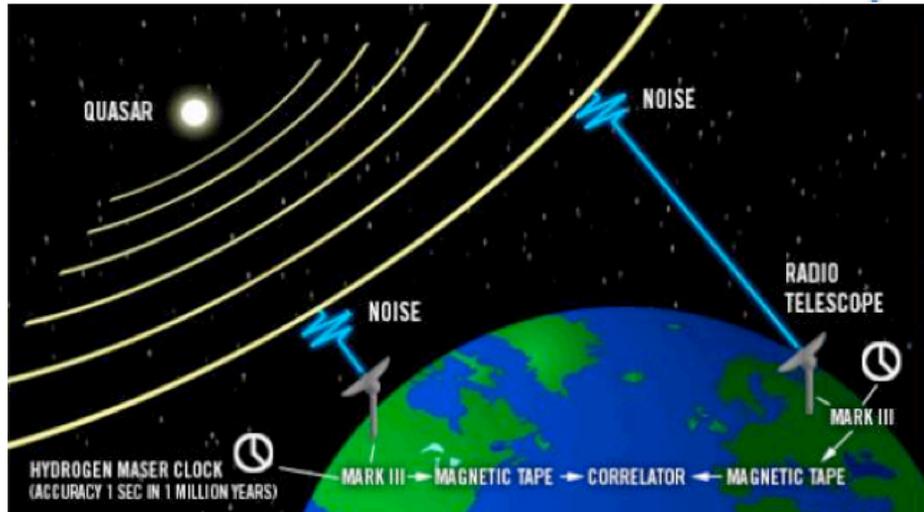
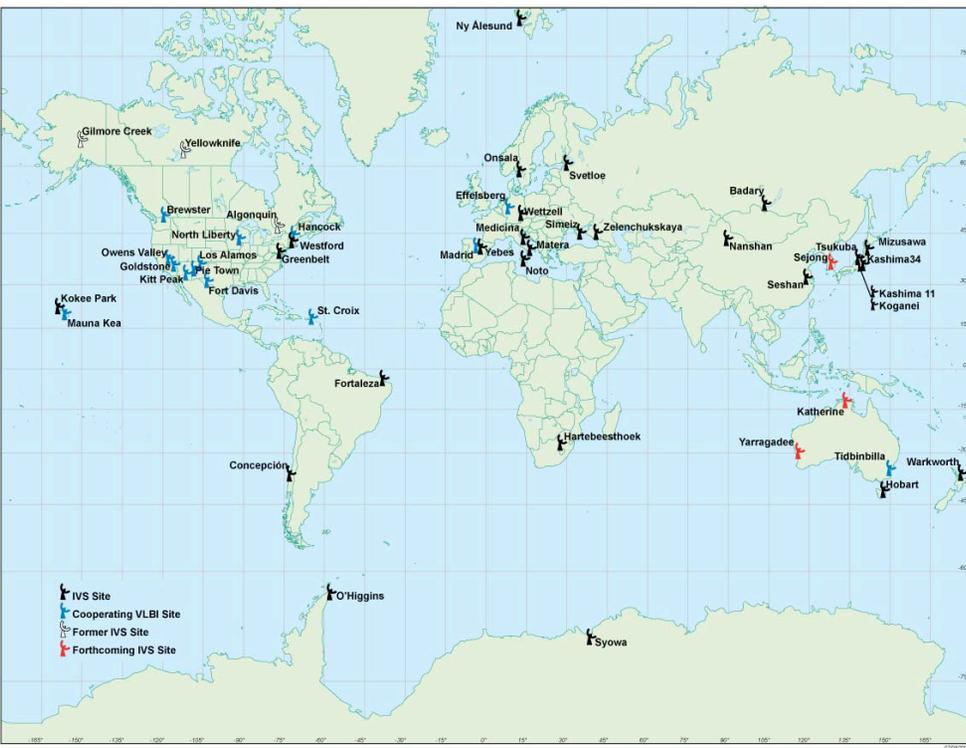


Contents

- *Context of the study*
 - *The Very Long Baseline Interferometry (VLBI);*
 - *Data used: VLBI-derived Length Of Day (LOD) time series;*
 - *Method used: the Singular Spectral Analysis (SSA).*
- *SSA parameters applied to this case:*
 - *Choice of an adequate covariance lag.*
- *Searching for ENSO (El Niño Southern Oscillation):*
 - *Decomposition of LOD with SSA;*
 - *Comparison with the Multivariate ENSO Index (MEI).*
- *Conclusions:*
 - *Can VLBI detect the ENSO signal?*

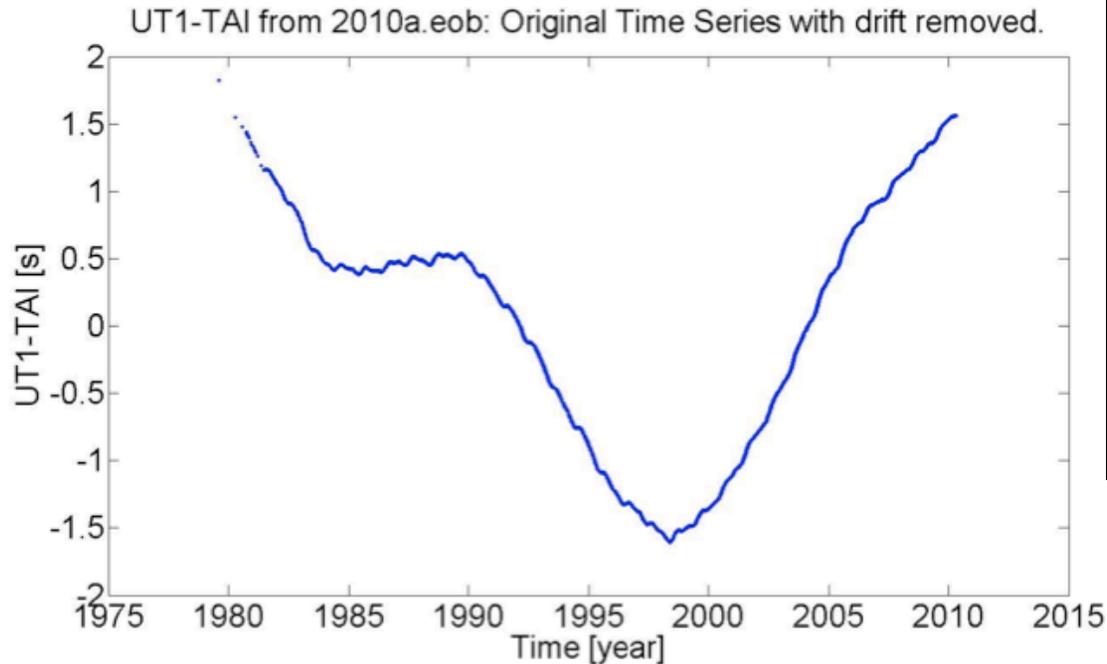
Very Long Baseline Interferometry VLBI

- VLBI measurements from distant sources (such as quasars) observed with a global network of antennas.



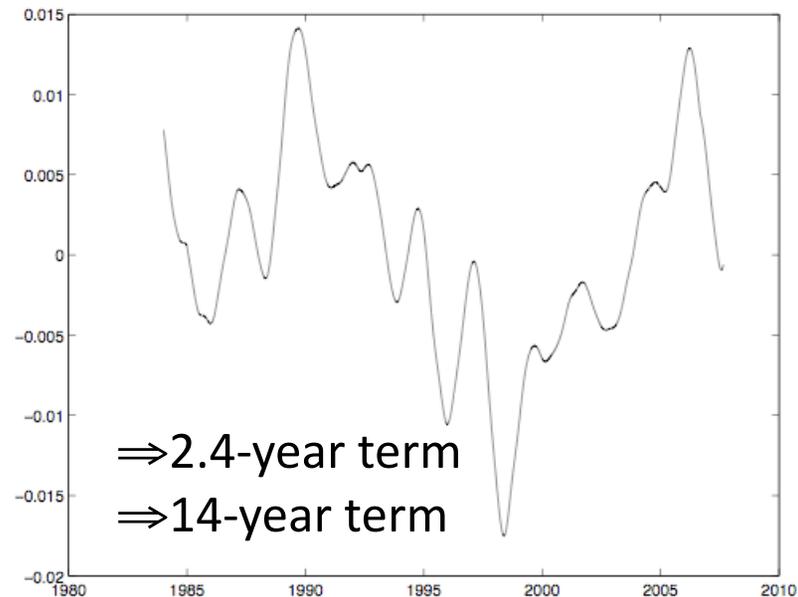
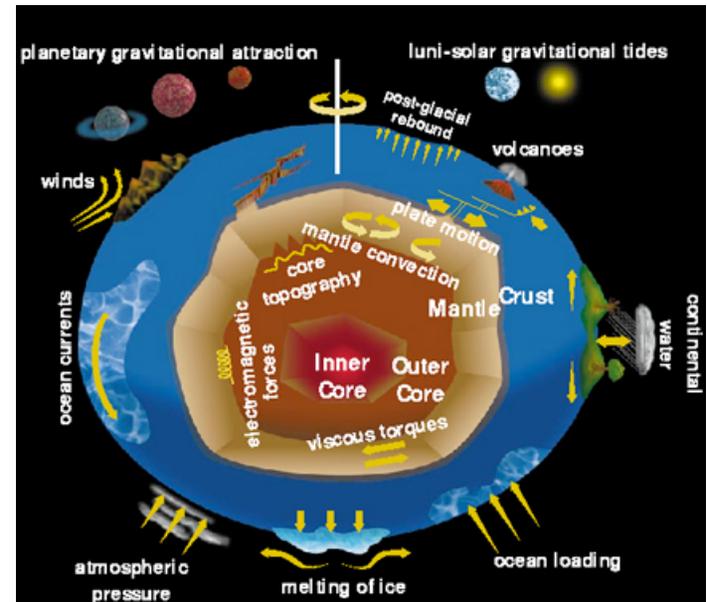
- Processing:
 - Celestial Reference Frame (sources);
 - Terrestrial Reference Frame (stations)
 - Earth Orientation Parameters.

Earth rotation



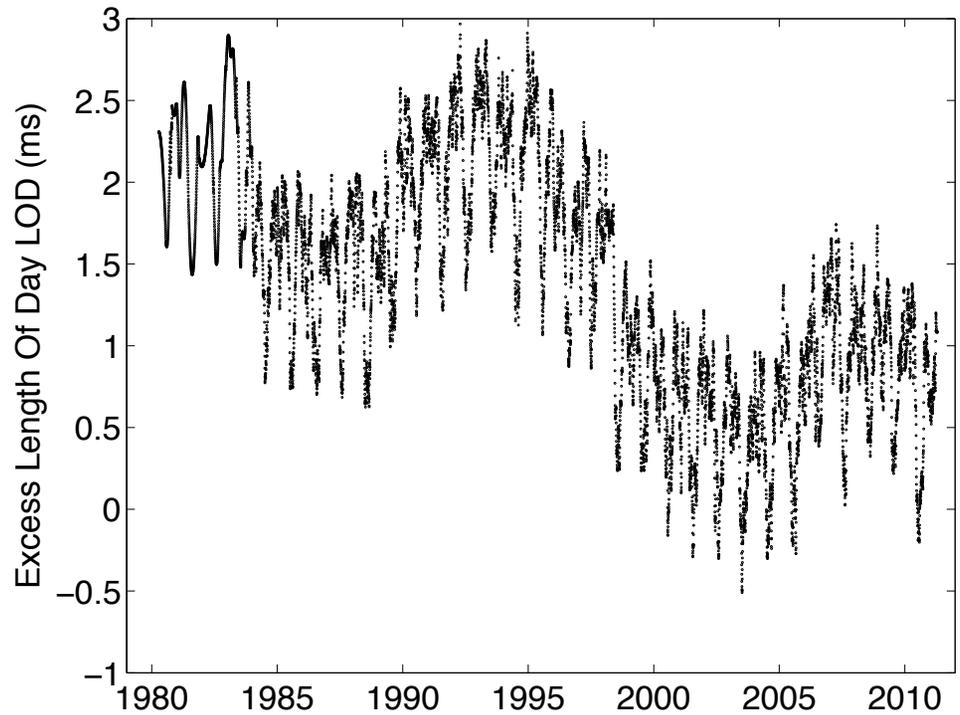
2010 AGU Fall Meeting:
 Periodic terms (2.4 and 14 years) detected when
 UT1-TAI time series studied with the SSA.
 ⇒ Atmospheric perturbation?

Chao 1984: “The question is whether the South
 Oscillation effect on the LOD is strong enough
 to be detected, and if so, how important is it?”



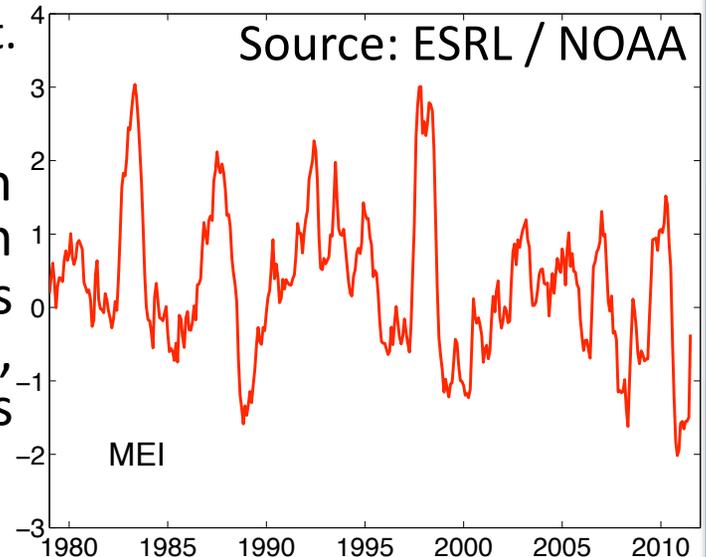
Length Of Day (LOD) time series

- Daily LOD time series derived from the Goddard 2011a VLBI solution:
 - Using all 24-hour VLBI sessions from 1979 through the beginning of 2011;
 - Stations were assumed to move linearly;
 - Source positions were estimated as global parameters apart from 39 special handling sources;
 - Estimation of X-pole, Y-pole, UT1, UT1-rate and nutation for each 24 hour session;
 - High Frequency EOP using the 2003 IERS standards removed during the analysis of the VLBI data;
 - Longer period tidal variations removed from the EOP estimates after the VLBI processing;
 - Kalman filtering of the resulting EOP time series to obtain estimates of UT1, X and Y-wobble, and LOD.



Studies of LOD

- What we expect to see in the LOD:
 - Periods > 10 years: secular variation and decade fluctuation
⇒ Tidal energy dissipation and core-mantle coupling.
 - Periods < 1 year: seasonal and short-period variations (annual and semi-annual)
⇒ Meteorological and solar-lunar tide effect.
- Multivariate ENSO Index (MEI).
 - Note: El Niño Southern Oscillation (ENSO) is transmitted to the solid Earth with a delay. So the impact on LOD is not immediate (Chao 1989: 2 months, Dickey et al. 1993: 1 month, Gross 1996: 4 months for the semi-annual).
- Bibliography:
 - Simple decomposition (Chao 1984, Chao 1989);
 - Detrended Fluctuation Analysis (Alvarez-Ramirez et al. 2010);
 - Wavelets (Sello 2011);
 - SSA/M-SSA (Gross et al. 1996, Dickey et al. 1999, Dickey et al. 2011).



The Singular Spectral Analysis (SSA)

- Choice of a covariance lag M to obtain the auto-covariance matrix C of size (M, M) and defined as:

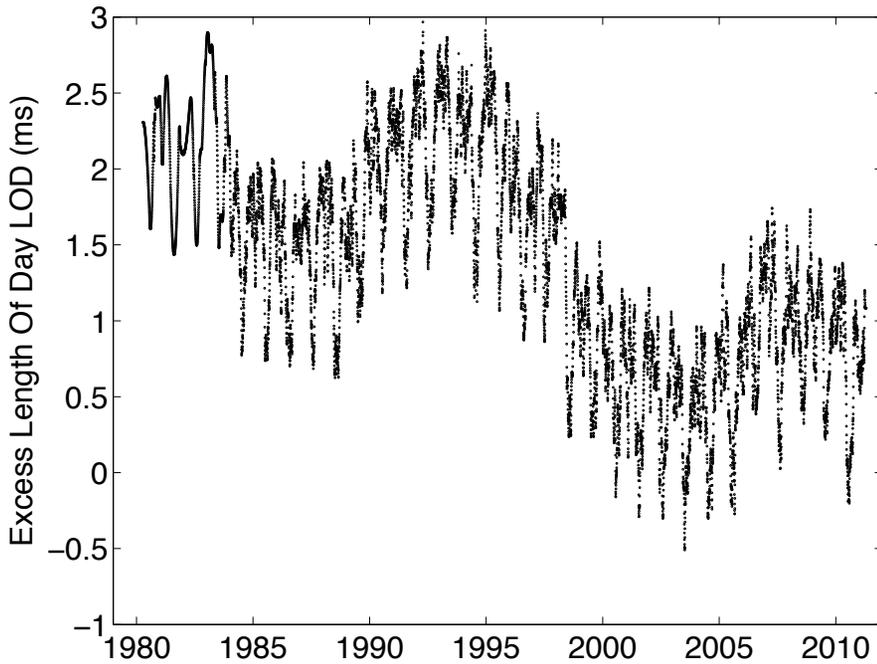
$$C = D^t D$$

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

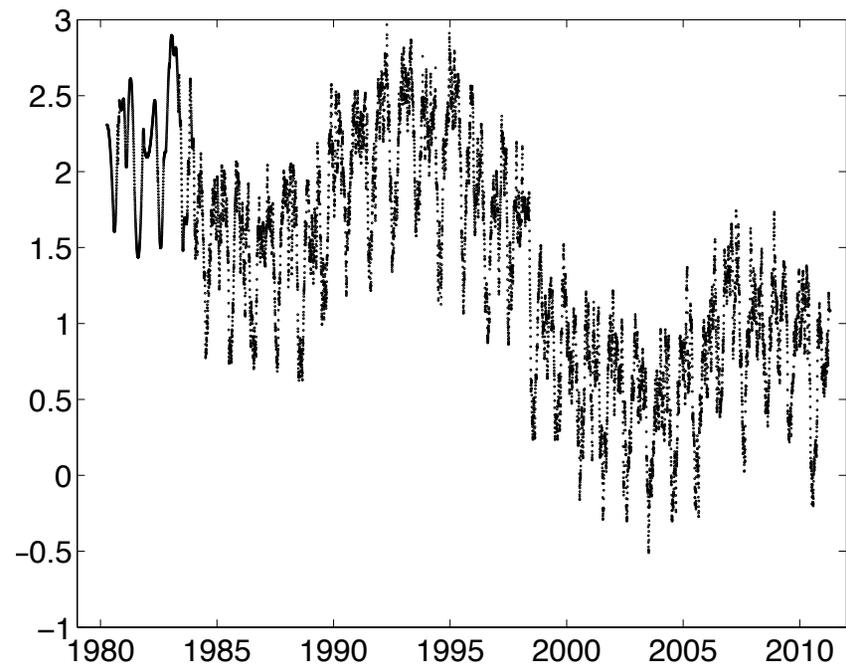
- C eigenvalues study to extract signal:
 - If one isolated eigenvalue => tendency;
 - If two isolated eigenvalues => periodic signal.
- Reconstruction of the extracted components via the eigenvectors determined in the previous step.
- Advantages of this method: easy, fast and giving time-varying amplitudes of the periodic signals extracted by SSA.

Choice of the covariance lag M (1)

$M = 30$ days

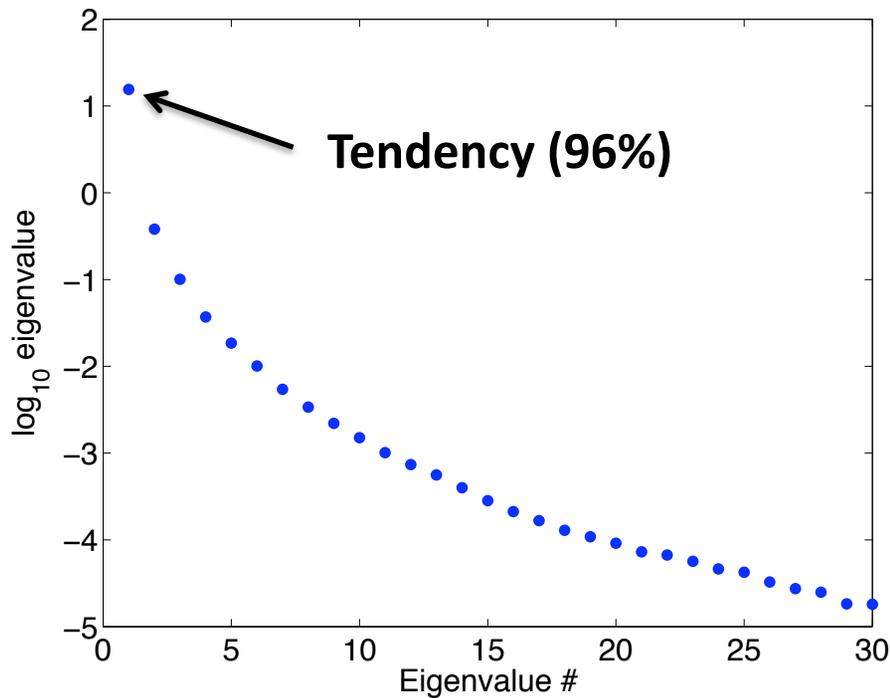


$M = 440$ days

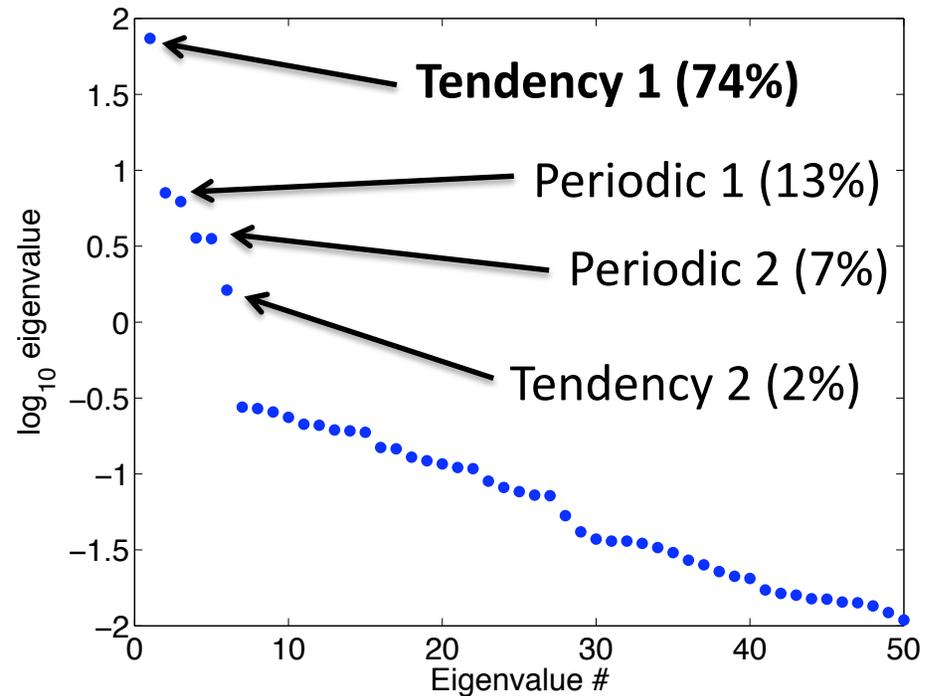


Choice of the covariance lag M (2)

$M = 30$ days

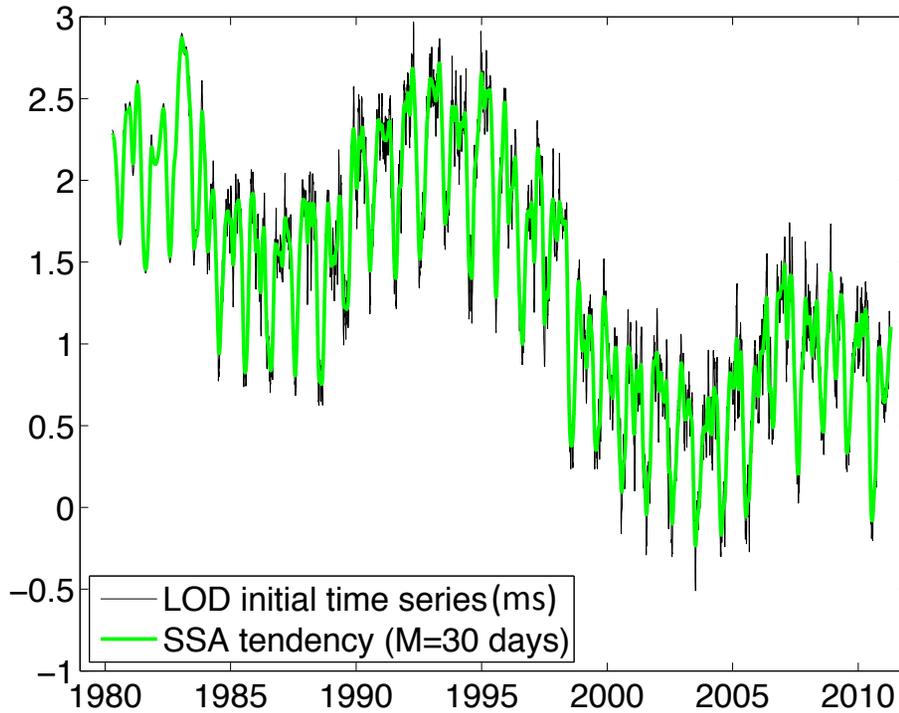


$M = 440$ days

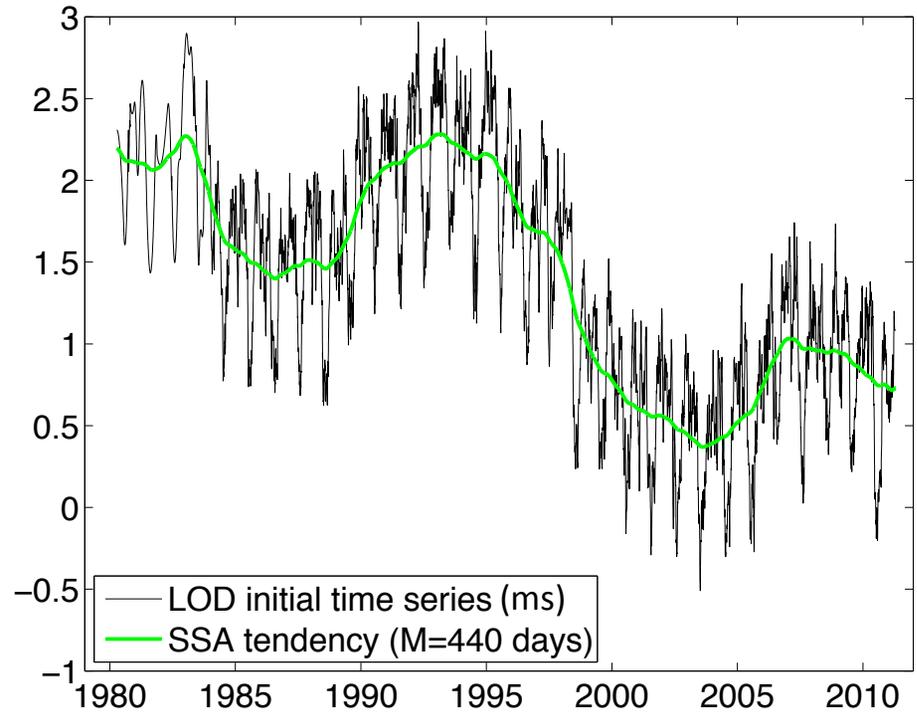


Choice of the covariance lag M (3)

$M = 30$ days



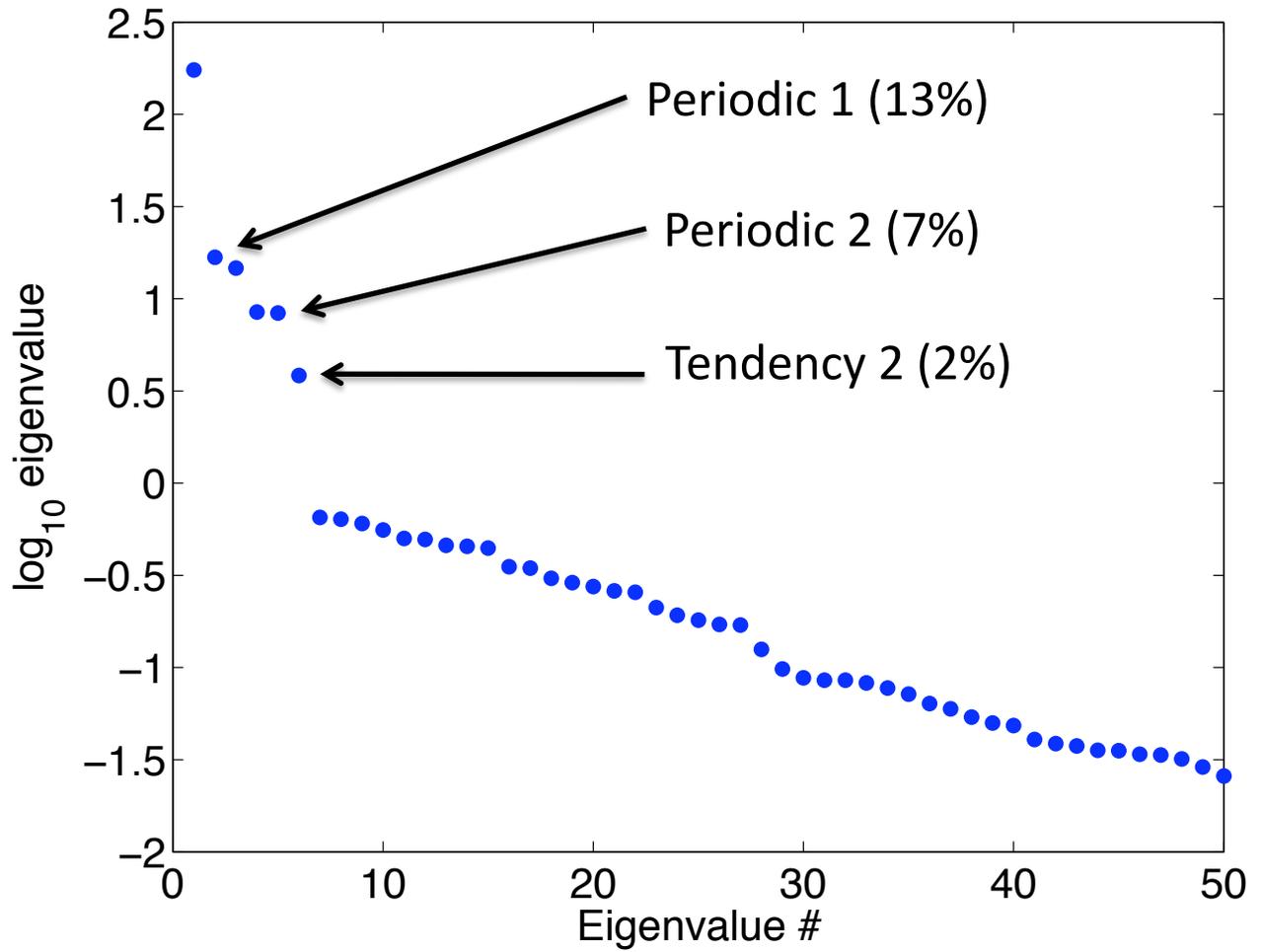
$M = 440$ days



Small value of M : short-term and long-term components not separated.

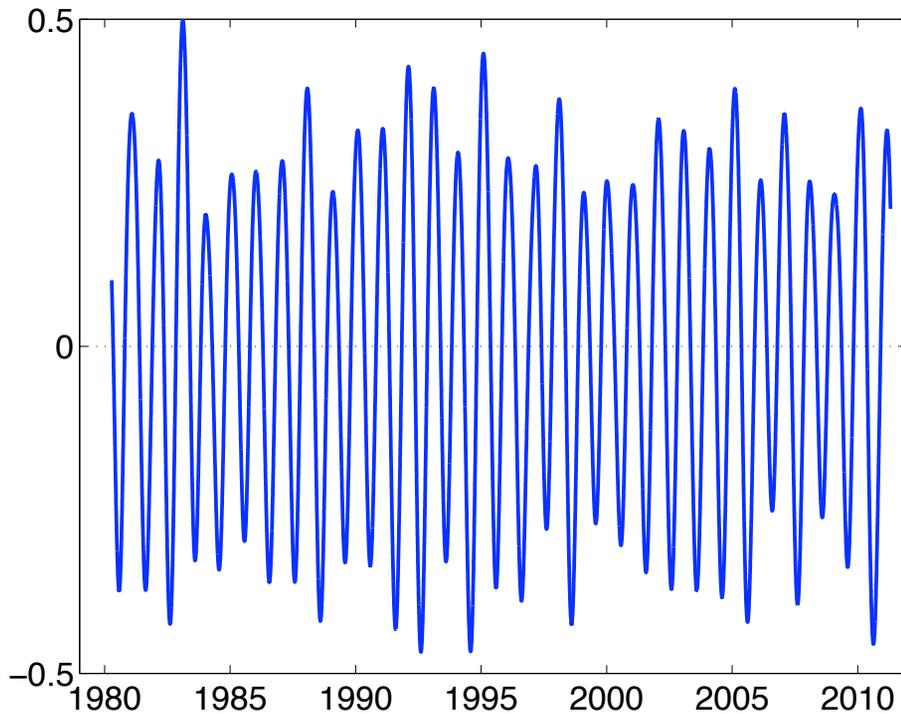
Searching for ENSO (1)

- Focus on the short-term components of the signal.

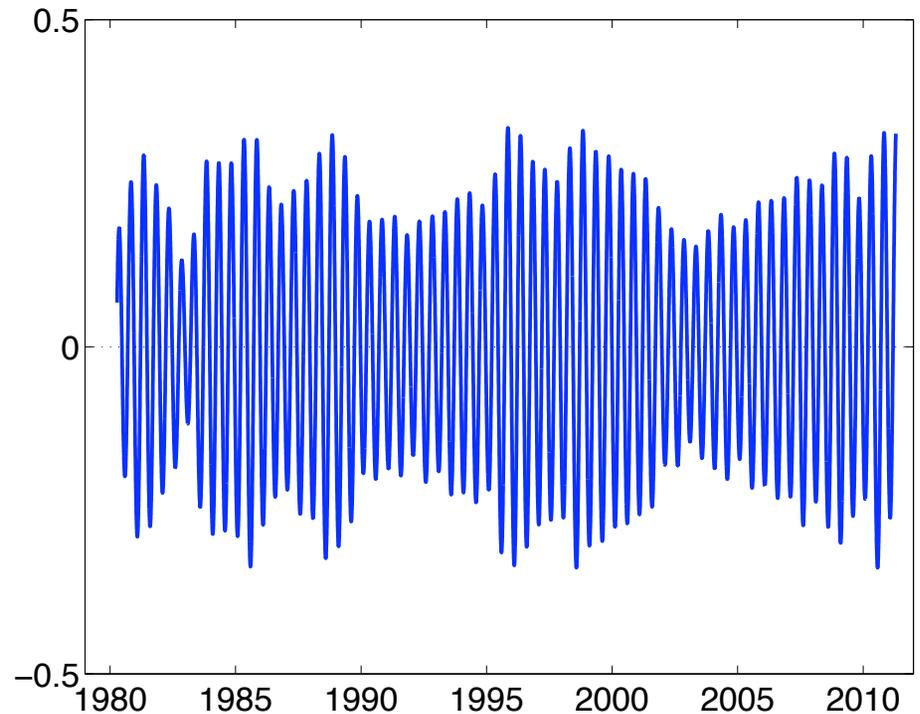


Searching for ENSO (2)

**Periodic 1:
Annual component (ms)**



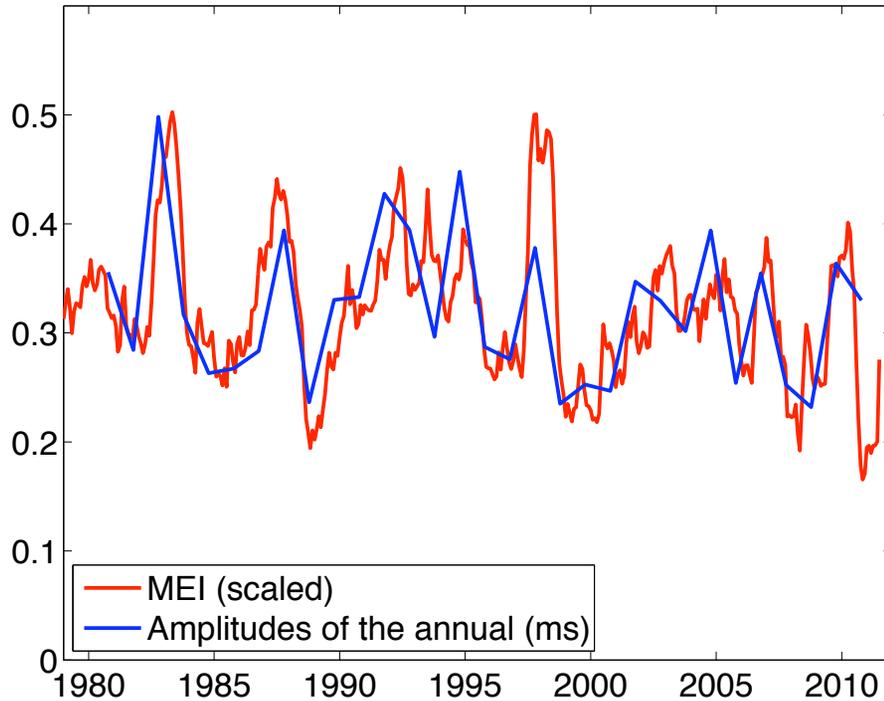
**Periodic 2:
Semi-annual component (ms)**



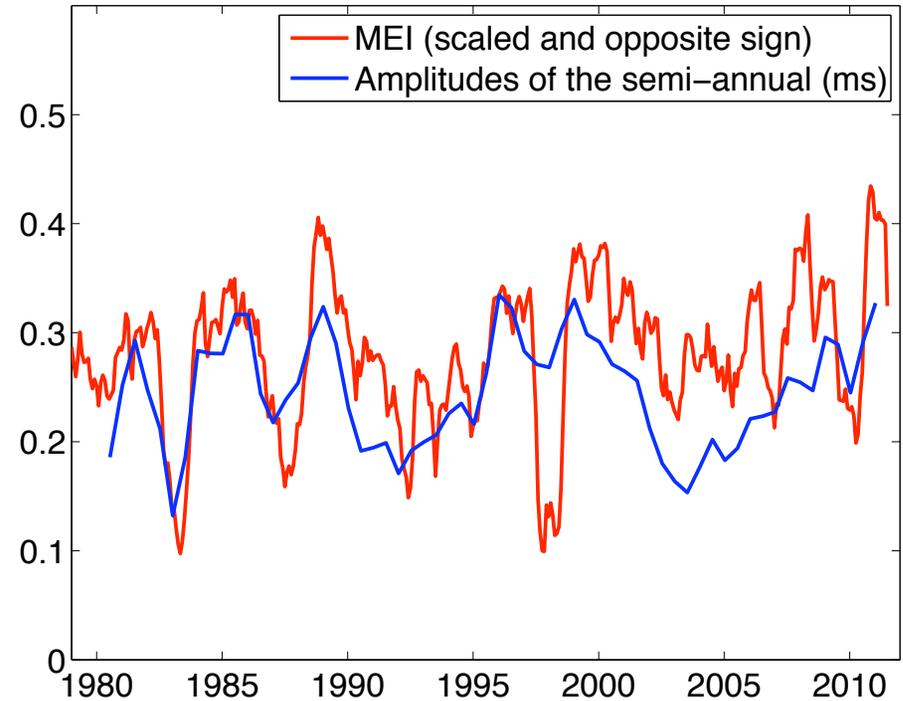
⇒ Periodic components obtained with SSA decomposition:
time-varying amplitudes.

Searching for ENSO (3)

Periodic 1: Amplitudes of the annual component compared to MEI



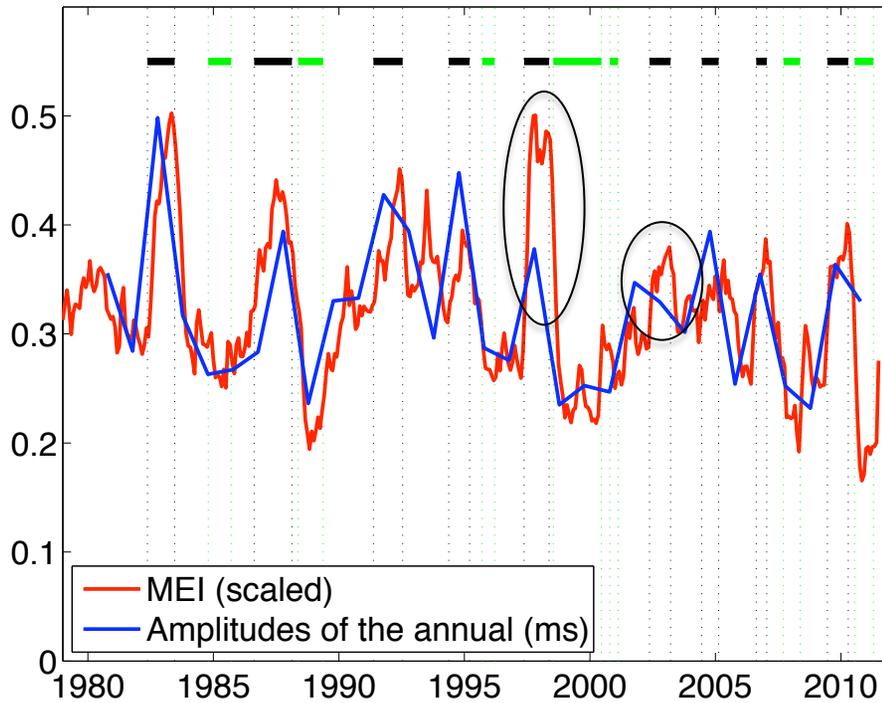
Periodic 2: Amplitudes of the semi-annual component compared to MEI



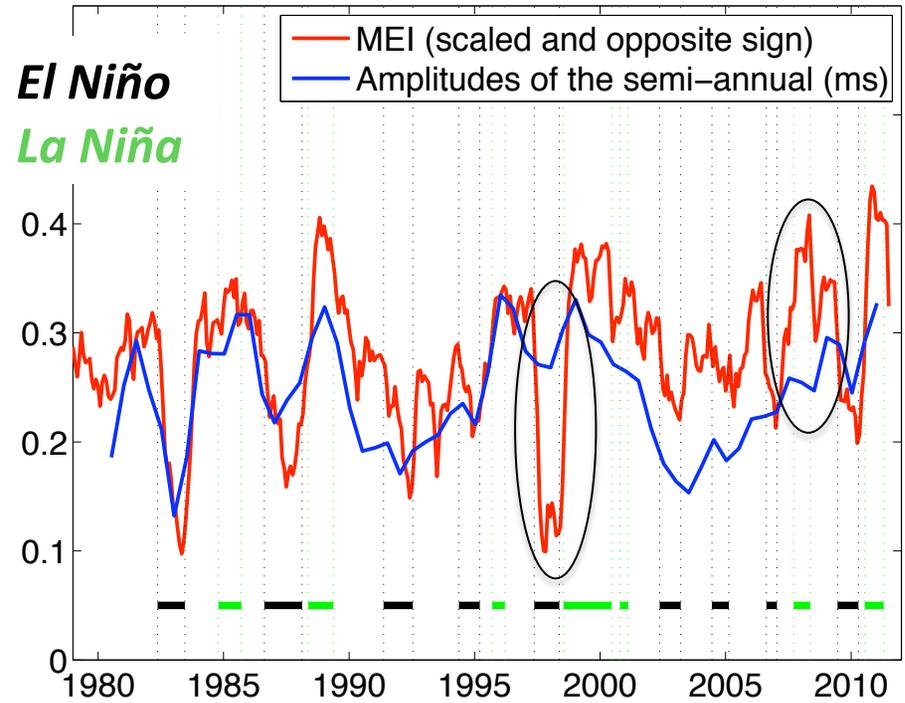
⇒ Evidence of ENSO impacting LOD on annual and semi-annual components.

Searching for ENSO (3)

Periodic 1: Amplitudes of the annual component compared to MEI



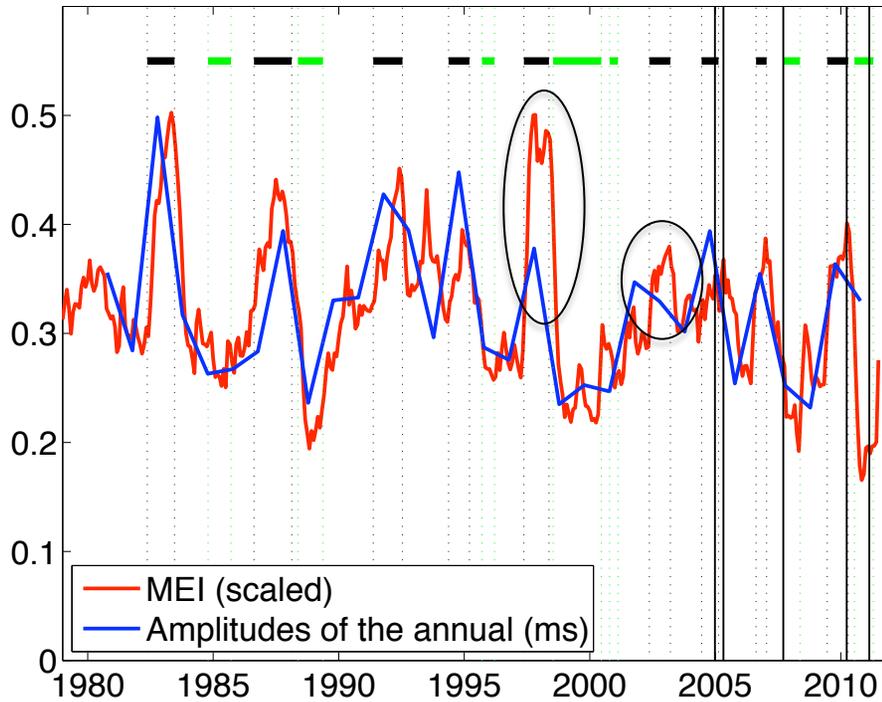
Periodic 2: Amplitudes of the semi-annual component compared to MEI



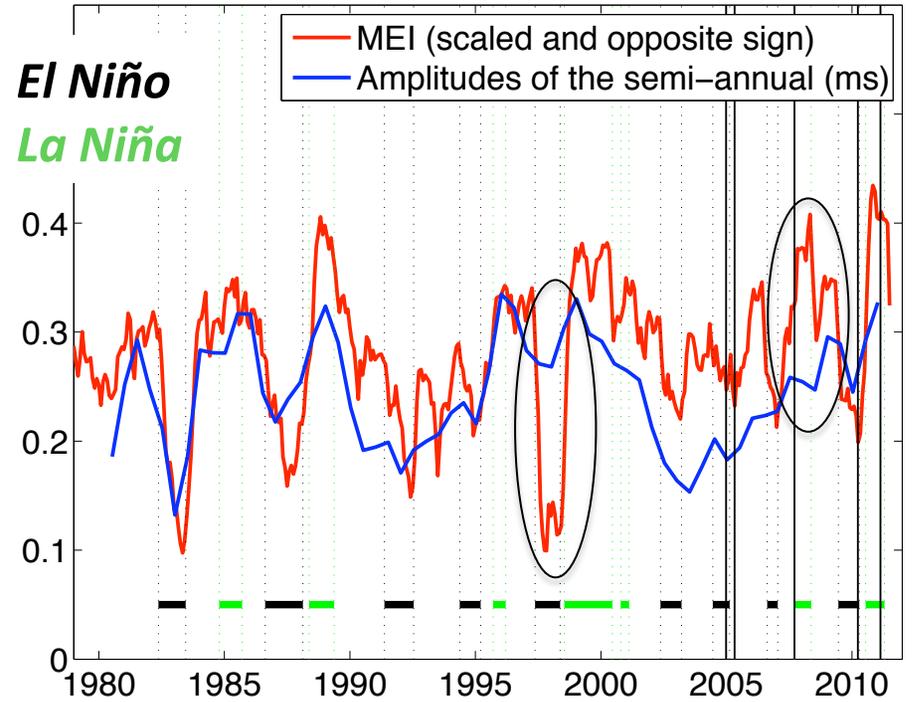
⇒ Evidence of ENSO impacting LOD on annual and semi-annual components.

Searching for ENSO (3)

Periodic 1: Amplitudes of the annual component compared to MEI



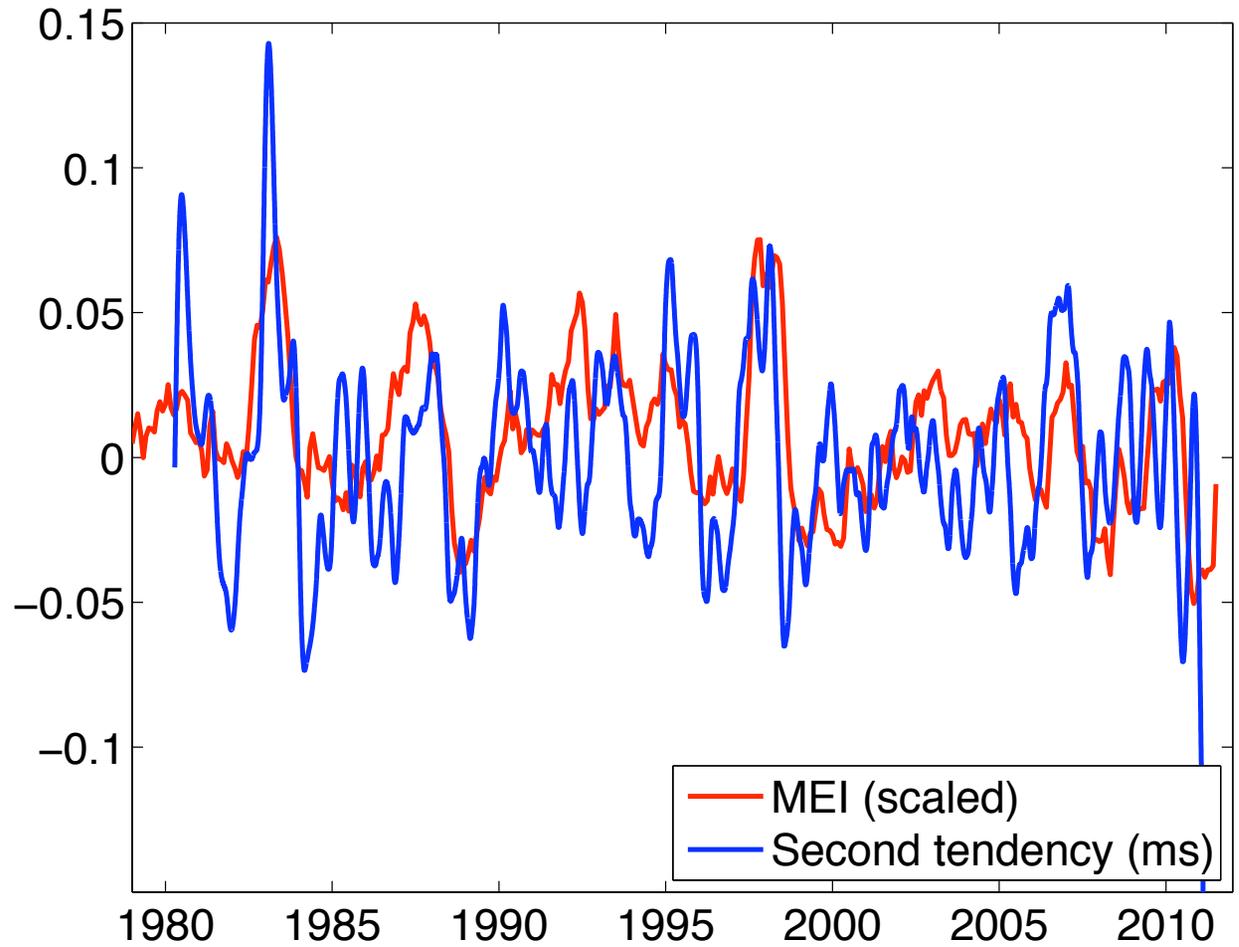
Periodic 2: Amplitudes of the semi-annual component compared to MEI



⇒ Evidence of ENSO impacting LOD on annual and semi-annual components.

Searching for ENSO (4)

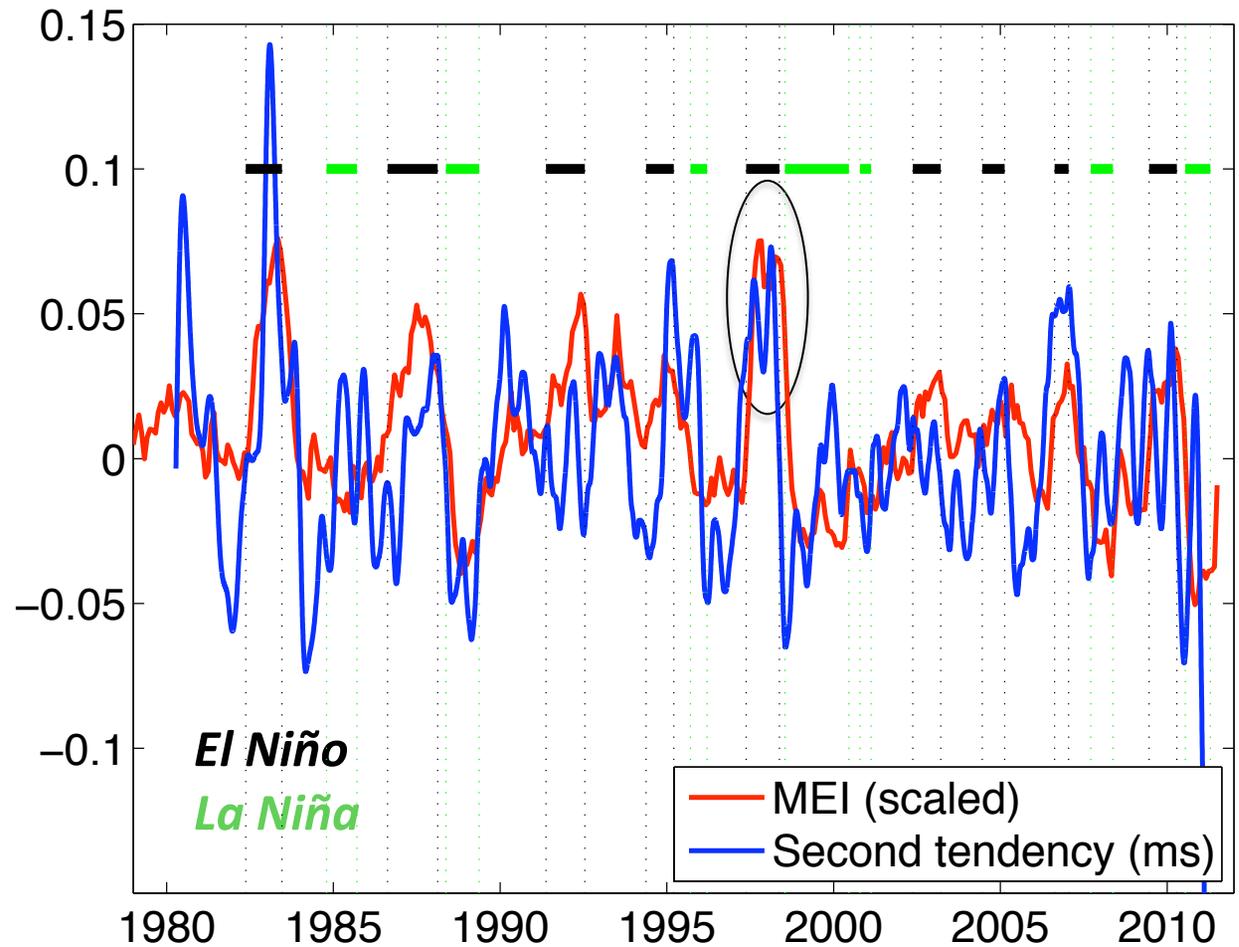
- Second tendency extracted from the LOD time series and comparison with MEI.



⇒ Strong correlation.

Searching for ENSO (4)

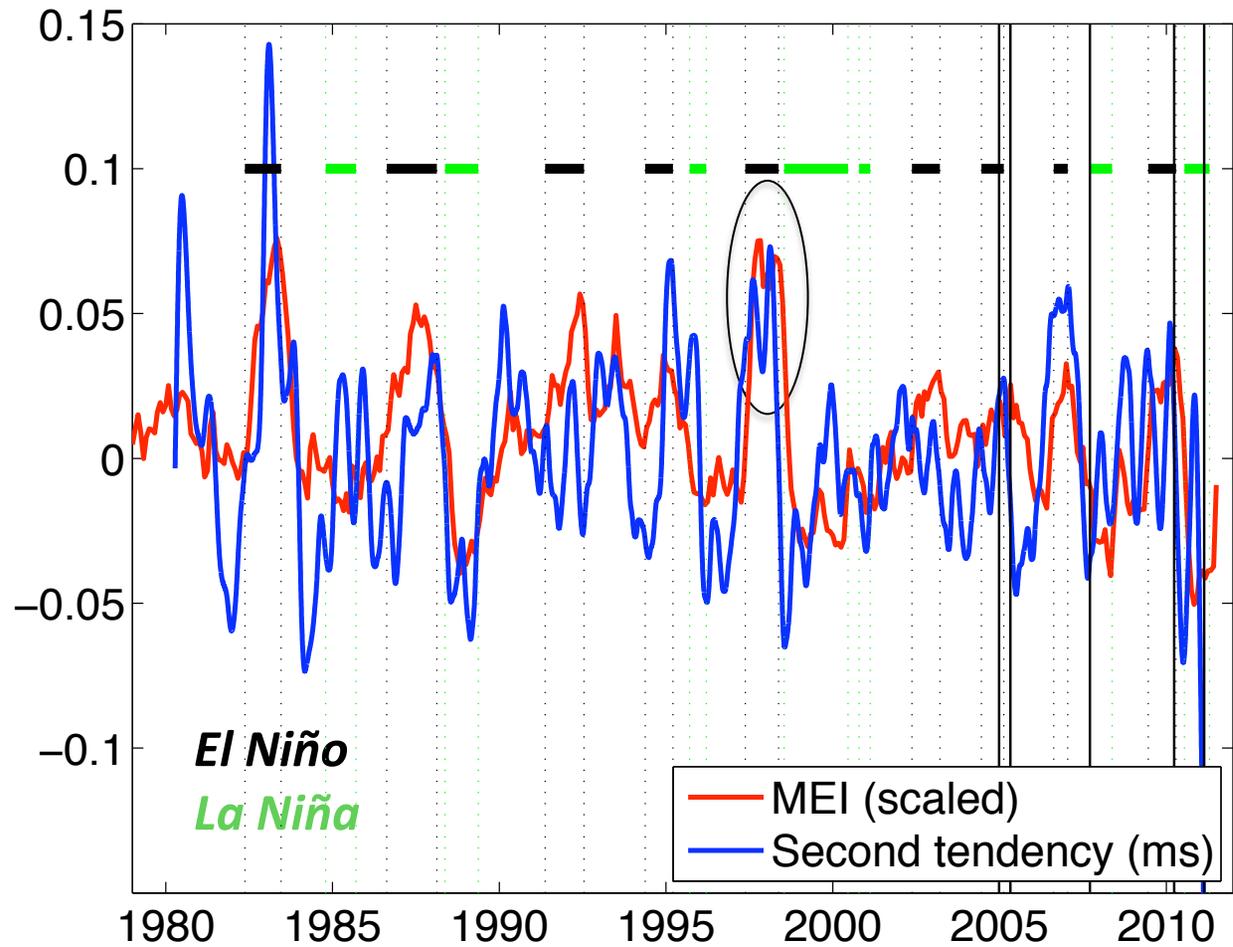
- Second tendency extracted from the LOD time series and comparison with MEI.



⇒ Strong correlation.

Searching for ENSO (4)

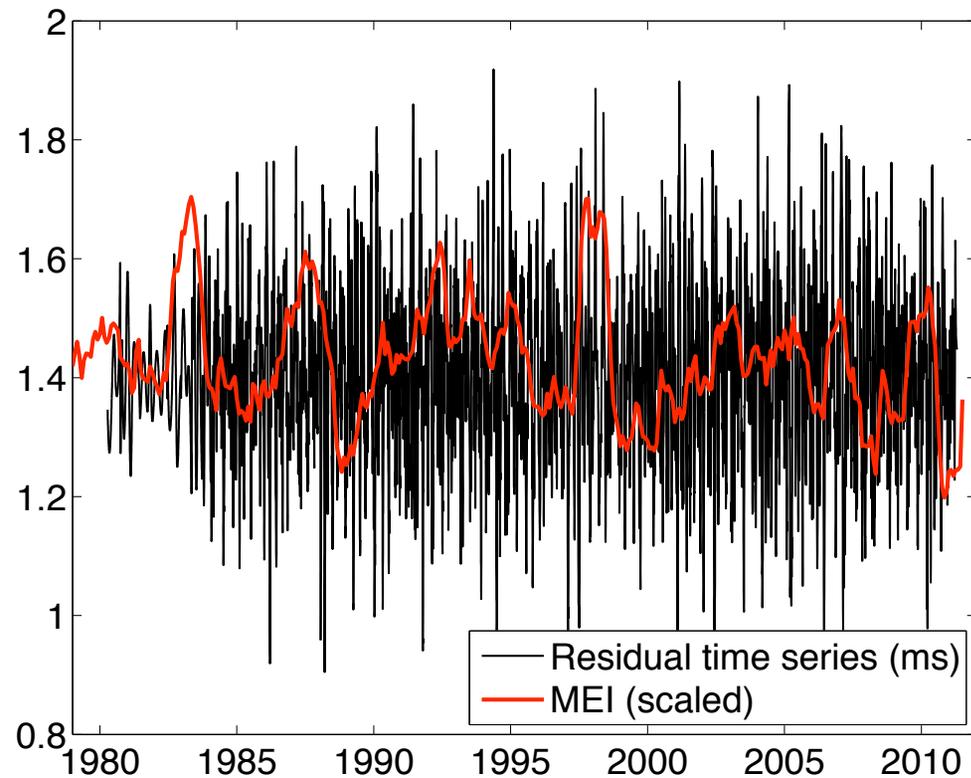
- Second tendency extracted from the LOD time series and comparison with MEI.



⇒ Strong correlation.

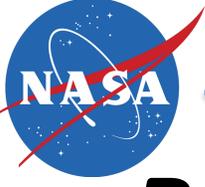
Searching for ENSO (5)

- What is left?
 - SSA on the residual time series indicating a monthly component;
 - Residuals.



Conclusions

- This study takes a look at the LOD time series derived from VLBI data processing over the period 1979 to 2011.
- The SSA is chosen to analyze the LOD time series to take advantage of its characteristics: easy to use and fast, and giving access to periodic signals of time-varying amplitudes.
- The LOD time series is very complex: it is composed of various components (long-term tendency at 74%, annual at 13%, semi-annual at 7%, short-term tendency at 2%, monthly at <1%), related to various phenomena acting on the rotation of the Earth.
- Comparing with the Multivariate ENSO Index, this study shows the LOD is affected by the El Nino Southern Oscillation at different scales (annual, semi-annual and tendency) up to 0.5 ms.
- Future developments:
 - Investigation of the M-SSA.
 - Investigation of the Earthquakes effect of the LOD.



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