Removing ENSO-related Variations from the Climate Record

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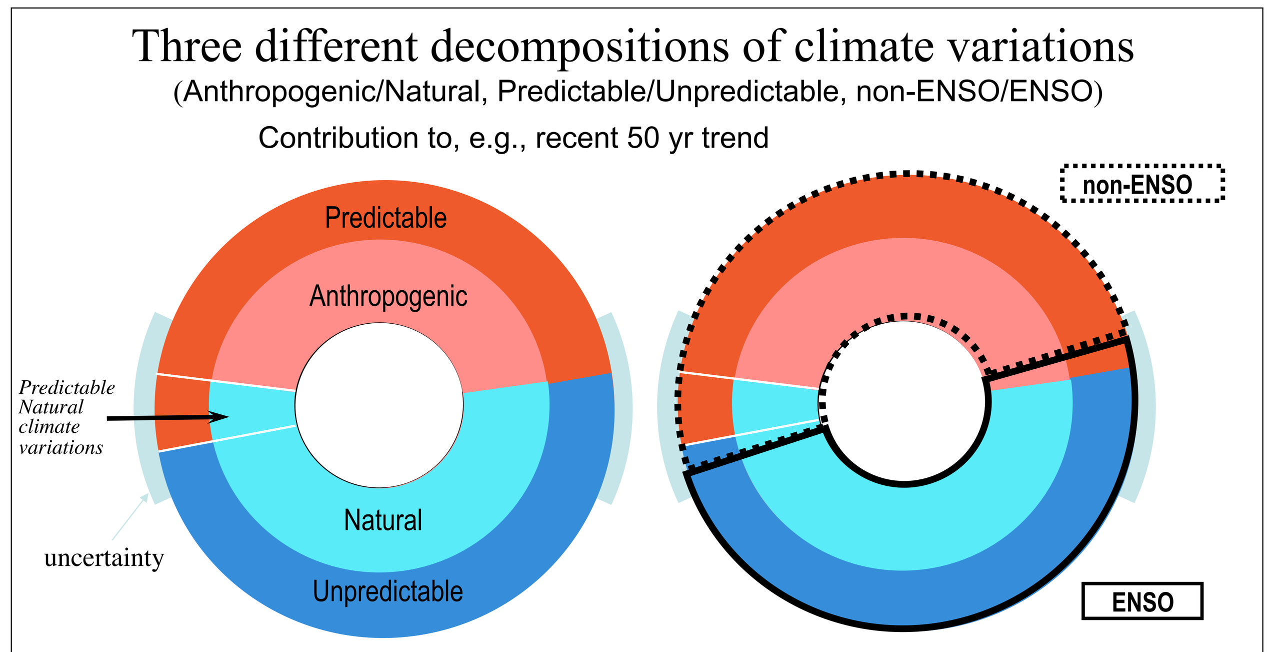
Introduction



Three kinds of Natural variability contributing to, e.g., 50-yr trend:

1. External radiative forcing (volanic, solar) – *potentially predictable*
2. Slow components of climate system – *potentially predictable*
3. Fast climate processes, such as ENSO – largely noise

The El Niño Southern Oscillation (ENSO) phenomenon has a rather long low-frequency tail, which contributes to "ENSO-like multi-decadal variability" and trends. This is mostly climate noise.

1. How should one identify ENSO-related variations?

2. How should one remove such ENSO-related variations from the climate record?

3. What do the trends and multi-decadal variations look like after doing this?

1. How should one identify ENSO-related variations?

Tropical SST state vector : $\mathbf{x}(t) = \mathbf{x}_e(t) + \mathbf{x}_n(t)$

ENSO part ($\mathbf{x}_e$) **Non-ENSO part** ($\mathbf{x}_n$)

Rest of climate state vector : $\mathbf{y}(t) = \mathbf{y}_e(t) + \mathbf{y}_n(t) = \mathbf{A}\,\mathbf{x}_e(t) + \mathbf{y}_n(t)$

Note ! **$\mathbf{x}_e$ is not necessarily orthogonal to $\mathbf{x}_n$, nor is $\mathbf{y}_e$ to $\mathbf{y}_n$**

Non-orthogonality implies that one cannot estimate **A** by regressing **y(t)** on $\mathbf{x}_e(t)$.

Almost all previous studies have assumed orthogonality, even though there is no physical reason to do so.

Some difficulties with traditional approaches:

1. Defining $\mathbf{x}_e$ as the band-pass filtered **x** in the 2 to 6-yr band assumes that **all** of the SST variability in this band, and none outside it, is ENSO-related.
2. Defining $\mathbf{x}_e$ in terms of an SST index in grid space (such as a Nino3.4 index) implies that there can never be a non-ENSO part $\mathbf{x}_n$ in that index *by definition*, for instance, one can never have a "global warming" signal in Nino3.4
3. Defining $\mathbf{x}_e$ in terms of an SST index in EOF space (such as the 1st PC) has the same problem. In addition, it assumes that $\mathbf{x}_n$ is orthogonal to $\mathbf{x}_e$.

Define ENSO from the dynamical operator L governing Tropical SST evolution (Penland and Sardeshmukh 1995; Penland and Matrosova 2006):

$$\mathbf{x}(t+\tau) = \exp(\mathbf{L}\tau)\,\mathbf{x}(t) + \mathbf{noise}(t)$$

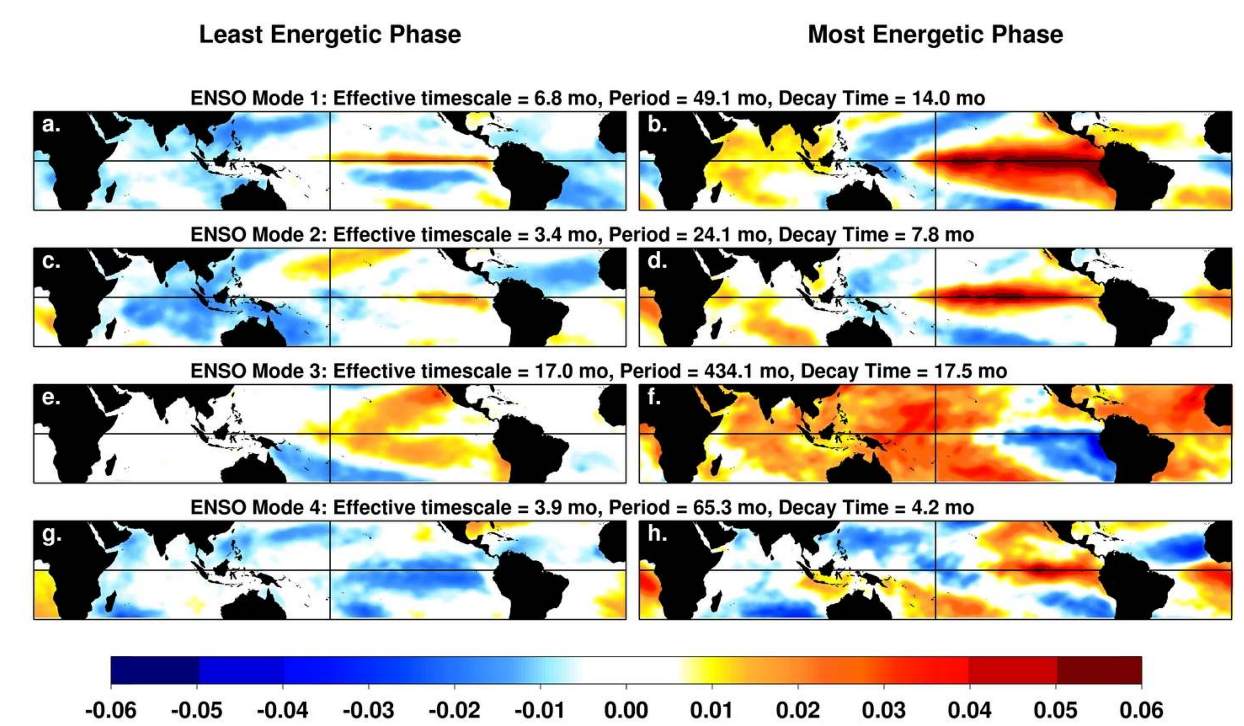
estimating **L** from the lag covariances $\mathbf{C}(t) = \langle \mathbf{x}(t)\mathbf{x}^T(t) \rangle$ of monthly SST in the HadISST dataset (1949-2004) at lag 0 and lag τ_0 = 3 months as

$$\mathbf{L} = \frac{1}{\tau_o} \ln\left\{\mathbf{C}(\tau_o)\mathbf{C}(0)^{-1}\right\}$$

2. How should one remove ENSO-related variations from the climate record?

First, define ENSO as the 4 *dynamical* eigenmodes of **L** that contribute most to the observed growth and decay of events.

What do these modes of **L** look like?



(left) Least energetic and (right) most energetic phases of the four dynamical ENSO modes used for defining the ENSO-related tropical SST variations. Each mode's effective time scale is indicated. Each mode evolves from (left) the least energetic phase **a** to (right) the most energetic phase **b**, then to **-a**, and then to **-b** with the indicated period while decaying with the indicated decay time scale. The **a** phase is normalized to unity in the left panel. Note that the **a** and **b** phases of each mode are spatially orthogonal to each other by construction.

Second, project these ENSO modes onto the observed Tropical SST record to form $\mathbf{x}_e$. Then, extend ENSO to extratropical SSTs $\mathbf{y}_e$ using an "Atmospheric Bridge" **A**. Finally, remove both from original monthly SST record.

Tropical SSTs : $\mathbf{x}(t+\tau) = \exp(\mathbf{L}\tau)\mathbf{x}(t) + \varepsilon$ over short intervals τ (~ several seasons)

$$\mathbf{x}(t) = \mathbf{x}_e(t) + \mathbf{x}_n(t)$$

$$\mathbf{x}_e(t) = \sum_{i=1,4} \alpha_i(t)\, u_i = \sum_{i=1,4} [v_i^T \mathbf{x}(t)]\, u_i$$

where u_i are the 4 ENSO-relevant eigenvectors of **L** and v_i are the corresponding adjoint eigenvectors

Extratropical SSTs :

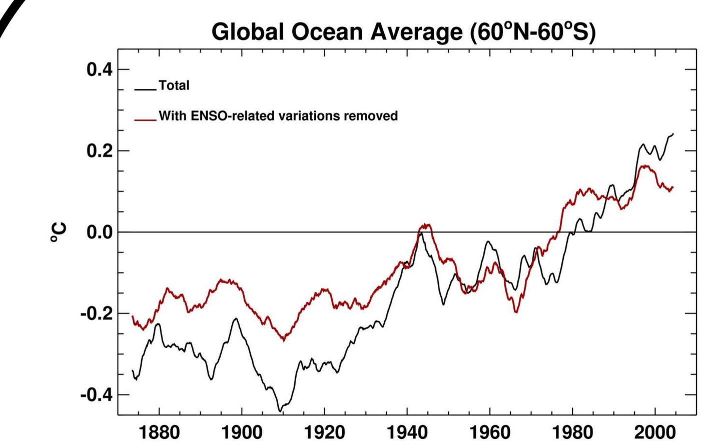
$$\mathbf{y}(t) = \mathbf{y}_e(t) + \mathbf{y}_n(t)$$

$$\mathbf{y}_e(t) = \mathbf{A}\,\mathbf{x}_e(t)$$

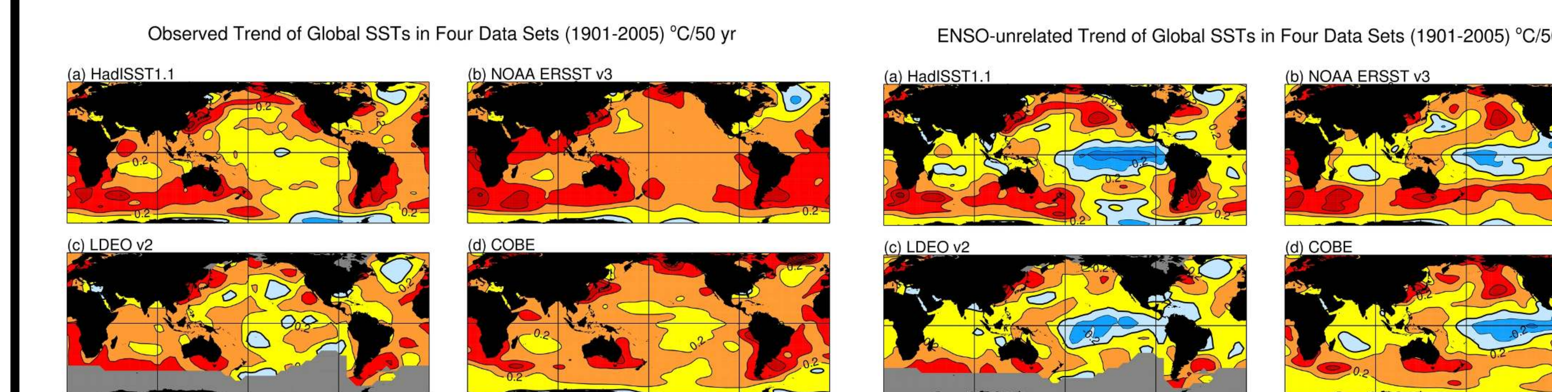
$$\mathbf{A} = \langle \mathbf{y}_b(t)\,\mathbf{x}_b^T(t) \rangle \langle \mathbf{x}_b(t)\,\mathbf{x}_b^T(t) \rangle^{-1} = \text{"Atmospheric Bridge" operator}$$

where $\mathbf{x}_b$ and $\mathbf{y}_b$ are band-pass filtered time series of **x** and **y** in the 2 to 72-month period band.

3. What do trends look like after removing ENSO?

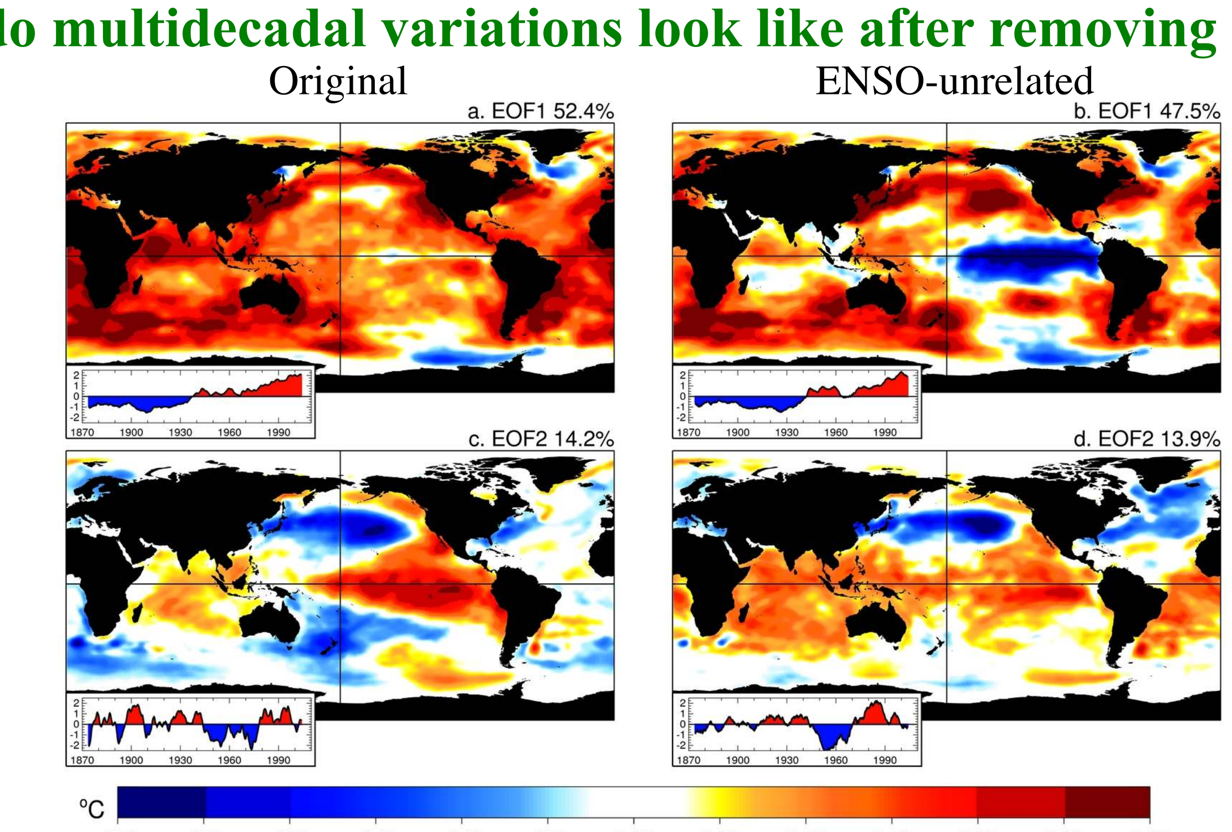


Time series of the global ocean average surface temperature anomaly (black curve) and its ENSO-unrelated component (red curve). A 10-yr running mean has been applied to both series. Anomalies are relative to a 1949–2004 climatology. **The ENSO-unrelated trend is ~60% of the original trend.**



(left 4 panels) Global maps of observed linear trends and (right 4 panels) after ENSO has been removed over 1901–2005 from four different SST datasets: (a) HadISST v1.1, (b) NOAA ERSST version 3, (c) LDEO SST version 2, and (d) COBE SST. Contour interval is 0.2°C change per 50 years. The zero contour is thickened.

What do multidecadal variations look like after removing ENSO?



(left) The two leading Empirical Orthogonal Functions (EOFs) and associated principal components PCs (inset) of 5-yr running mean SST anomalies from the 1871–2006 HadISST dataset and (right) the same quantities computed using the ENSO-unrelated SST anomalies. The fraction of variance explained in (a),(c) the original dataset and (b),(d) the ENSO-unrelated dataset is indicated over each panel. Note that the PCs are normalized to have unit amplitude, while the EOFs show the observed magnitude (°C) for a unit deviation of the PC. The contour interval is 0.05°C.

4. Conclusions

1. Identifying and removing ENSO-related variations by using simple regressions on any single ENSO index can be problematic.
2. ***ENSO is not a number***. It is an evolving dynamical process.
3. We identify ENSO-related SST variations with the projection on the 4 most important dynamical SST eigenmodes involved in the growth and decay of ENSO events over several seasons.
4. Removing ENSO-related variations has a large effect on SST trends, up to 40% of the total trend in globally-averaged ocean temperatures. There is a strong cooling trend in the eastern equatorial Pacific Ocean.
5. The residual SST data (that is, data from whom the ENSO component has been removed) reflect a combination of anthropogenic, naturally forced, and coherent internal multi-decadal variability.
6. The 1st EOF of the residual SST data has a general "global warming" structure, but also a pronounced cooling in the eastern equatorial Pacific.
7. The 2nd EOF is strongly suggestive of a multi-decadal zonally symmetric Tropical-Extratropical SST seesaw (TESS). Is this forced or natural variability?

References: Compo, G.P., and P.D. Sardeshmukh, 2010: Removing ENSO-related variations from the climate record. J. Climate, 23, 1957-1978. DOI: 10.1175/2009JCLI2735.1.
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