Removing ENSO-related Variations from the Climate Record

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1. How should one identify ENSO-related variations?

Tropical SST state vector: \( x(t) = x_E(t) + x_L(t) \)

Enso part
Non-Enso part

Rest of climate state vector: \( y(t) = y_E(t) + y_L(t) \)

\[ x(t) = \sum \alpha_i E_i(t) = \sum \alpha_i E_i(t) \quad \text{where } \alpha_i \text{ are the EOFs} \]

\[ y(t) = \sum \beta_i E_i(t) = \sum \beta_i E_i(t) \quad \text{where } \beta_i \text{ are the PC of ENSO-unrelated variations} \]

Note! \( x \) is not necessarily orthogonal to \( y \), nor is \( y \) to \( y \).

Non-orthogonality implies that one cannot estimate any of the ENSO-related components from \( x(t) \).

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

Some difficulties with traditional approaches:
1. Defining \( x \) as the band-pass filtered \( x \) in the 2-6 yr band assumes that all of the SST variability in this band, and none outside it, is ENSO-related.
2. Defining \( x \) in terms of an SST index in grid space (such as a Niño3.4 index) implies that there can never be a non-Enso part \( x \) in that index by definition, for instance, one can never have a “global warming” signal in Niño3.4.
3. Defining \( x \) in terms of an SST index in EOF space (such as the 1st PC) has the same problem. In addition, it assumes that \( x \) is orthogonal to \( y \).

Define ENSO from the dynamical operator \( L \) governing Tropical SST evolution (Penland and Sardeshmukh 1995; Penland and Matrosova 2008):

\[ x(t) = \exp(Lt) x(0) + \text{noise}(t) \]

estimating \( L \) from the lag covariances \( C(t) = \text{cov}(x(t) + x(t)') \) of monthly SST in the HadISST dataset (1949-2004) at lag 0 and lag 3 months as

\[ L = \frac{1}{\tau_E} \ln \left( \text{Cov}(x(t) + x(t)) \right) \]

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?

Second, project these ENSO modes onto the observed tropical SST record to form \( \zeta_E(t) \). Then, extend ENSO to extratropical SSTs \( \zeta_E(t) \) using an “Atmospheric Bridge” \( A \). Finally, remove both from original monthly SST record.

\[ \text{Tropical SST: } (x(t) - y(t)) = \exp(L(t) + r) x(0) \quad \text{over short-interval } t \quad \text{(second season)} \]

\[ \text{Extratropical SST: } (x(t) - y(t)) = \exp(A(t) + r) x(0) \]

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 ~80% of the original trend.

What do multidecadal variations look like after removing ENSO?

4. Conclusions

1. Identifying and removing ENSO-related variations by using simple regressions on any single ENSO index can be problematic.

2. \textit{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 which the ENSO component has been removed) reflect a combination of anthropogenic, naturally forced, and coherent internal multidecadal 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.