An Empirical Model of Decadal ENSO variability

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Introduction

We have developed an empirical stochastic model for simulating and predicting evolution of the ENSO index *x* (**Fig. 1**d; blue line) computed as the leading normalized principal component (PC) of the tropical Pacific sea-surface temperature (SST) anomalies. The latter anomalies were obtained by subtracting the dominant low-frequency modes **y** of the global SST variability defined here in terms of the three leading discriminating patterns (Schneider and Held 2001) and their companion time series—canonical variates (CVs); see **Figs. 1** a–c. The CVs describe climate modes characterized by maximal ratio of interdecadal to subdecadal SST variance, and were treated as *external predictors* in the empirical ENSO model (Kravtsov 2012).

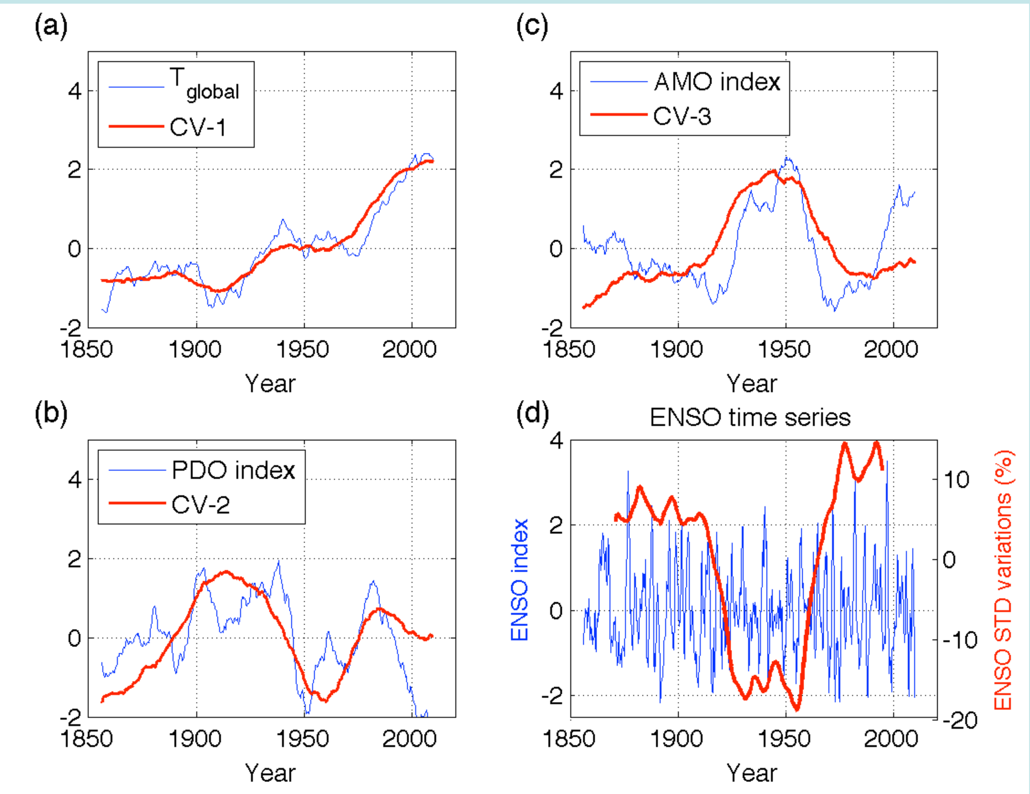

Figure 1: Canonical variates (CVs) and SST indices (1856–2010). (a) CV-1 and area-averaged SST; (b) CV-2 and Pacific Decadal Oscillation (PDO) index; (c) CV-3 and Atlantic Multidecadal Oscillation (AMO) index; (d) ENSO index (blue line, left y-labels) and fractional variations (%) of its 20-year running standard deviation (STD) (red line, right y-labels), smoothed with 20-year boxcar running-mean filter. The SST indices in a–c were smoothed using 10-year boxcar running-mean filter.

Causality of decadal ENSO variations

Is the apparent connection btw multidecadal ENSO STD variations (**Fig. 1d**, red line) and CVs (Figs. 1a–c, red lines) random (Flügel et al. 2004) and/or the result of ENSO's midlatitude teleconnections (Vimont 2005)? This question is addressed in **Fig. 2**.

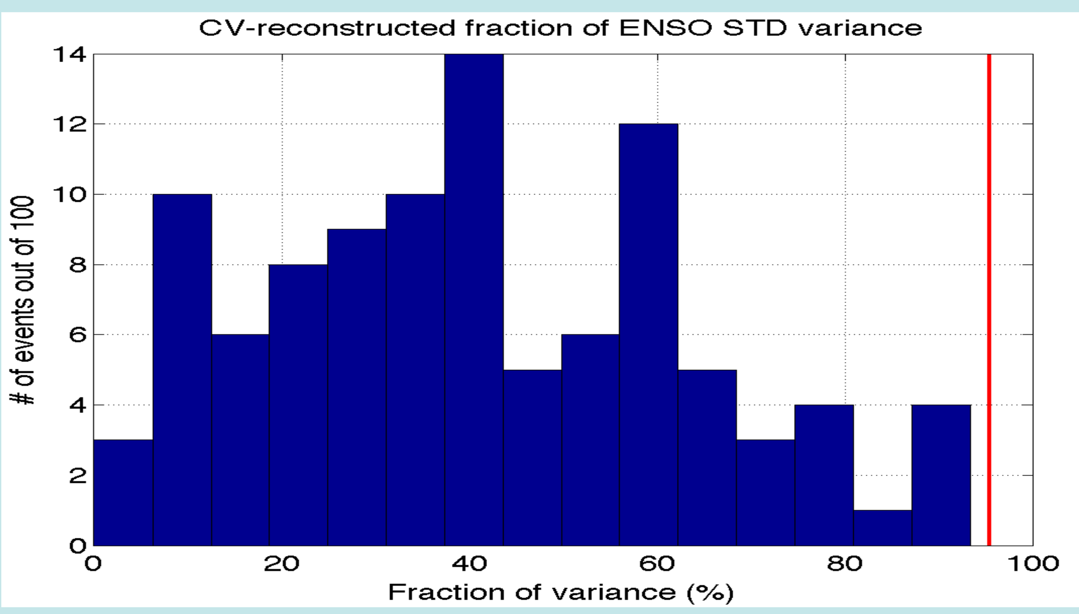

Figure 2: Association between CVs and long-term modulation in ENSO STD in 100 surrogate SST realizations produced by a multivariate linear stochastic model. For each realization, the surrogate ENSO STD time series analogous to the one shown in Fig. 1d (red line) was regressed onto 3 leading CVs of the surrogate SSTs, as in Fig. 1a–c (red lines). Shown is the histogram of fraction of ENSO STD variance (%) explained by the CV reconstruction. Vertical red line shows the observed fraction. **Conclusion: CV predictors y are external to ENSO *x*!**

Model formulation

$$x_{n+1} - x_n = \sum_{p=0}^{P} a_p(\mathbf{y}, t_n)\, x_n^p + r_n, \qquad (1)$$

$$r_{n+1} - r_n = \sum_{l=0}^{L} b_l(\mathbf{y}, t_n)\, x_{n-l} + b_{L+1}(\mathbf{y}, t_n)\, r_n + c(\mathbf{y}, t_n) + r_n^{(1)}. \qquad (2)$$

Equations (1–2) with P=3 and L=4 are two-level parametric model for the evolution (with time index n) of the seasonal-mean ENSO index x; the model coefficients linearly depend on external predictors **y** and on time via harmonic annual preditors (see **Fig. 3**). The second level models the main-level forcing r. The model coefficients are found from data using regularized regression techniques (Kravtsov et al. 2005).

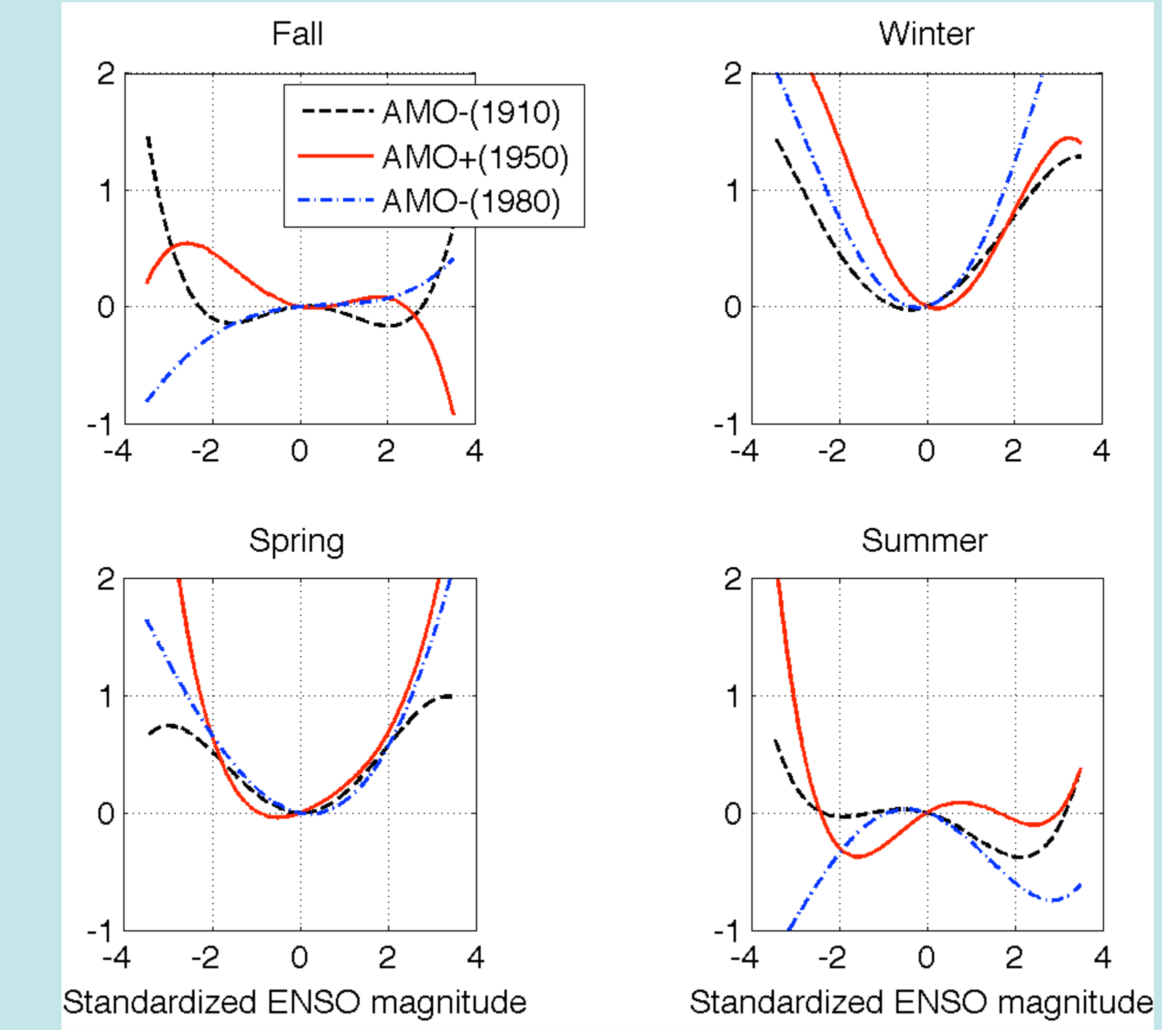

Figure 3: The potential function based on the main level (1) of the 1-D empirical model (1–2) of ENSO index x with three decadal predictors **y** given by CVs 1–3 (see Fig. 1a–c), for each season and three different phases of external multidecadal variability.

Model performance

Our empirical model captures many aspects of the observed Niño-3 evolution (**Fig. 4**), including interdecadal modulation of Niño-3 variance largely anti-correlated with the AMO index [cf. Dong et al. (2006)]; see also **Fig. 1d**, red line.

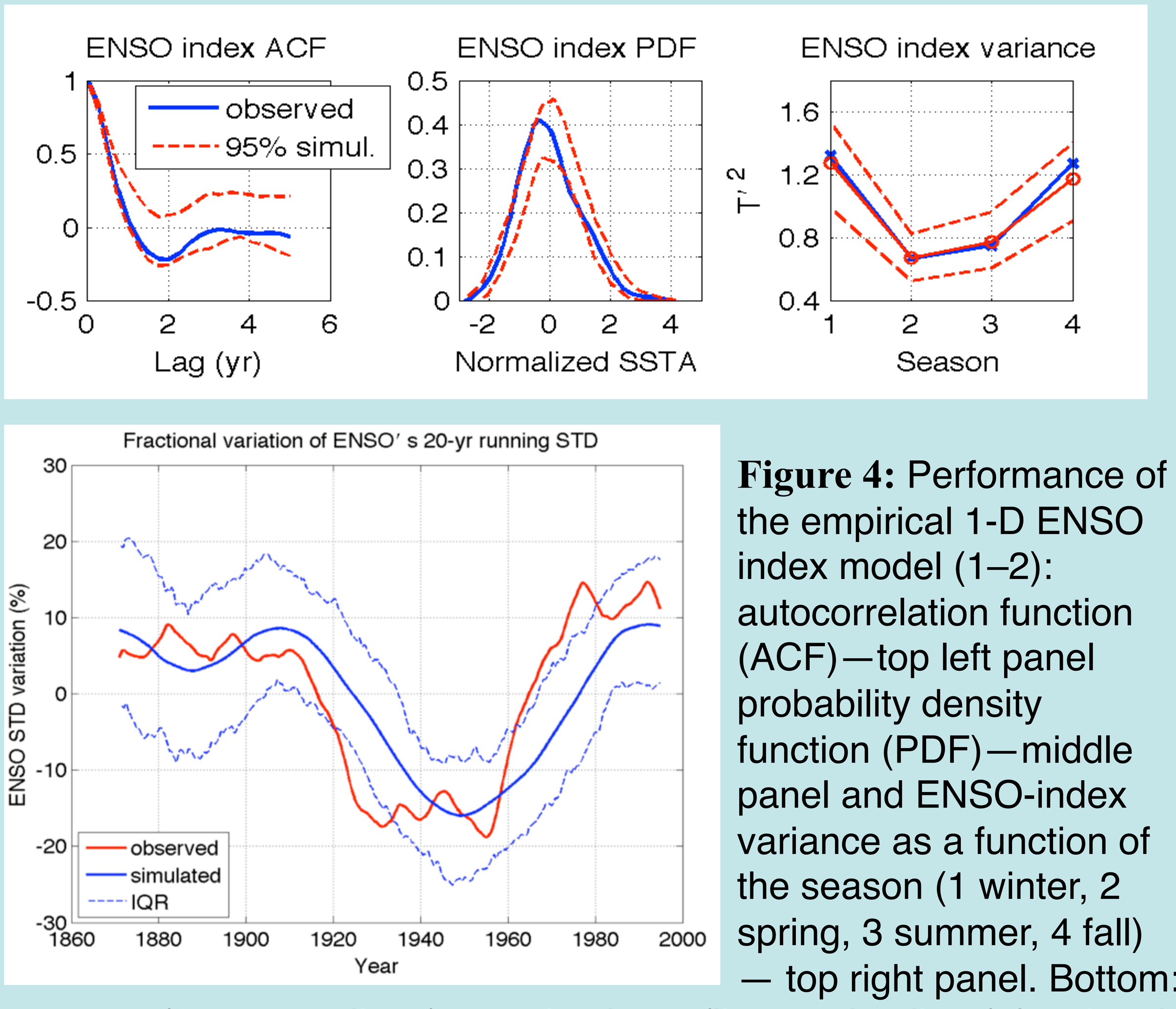

Figure 4: Performance of the empirical 1-D ENSO index model (1–2): autocorrelation function (ACF)—top left panel probability density function (PDF)—middle panel and ENSO-index variance as a function of the season (1 winter, 2 spring, 3 summer, 4 fall) — top right panel. Bottom: observed (heavy red lines) and simulated (lighter blue lines) fractional variations (%) of the ENSO index 20-year running standard deviation (STD), smoothed with 20-year boxcar running-mean filter.

Hindcasts of decadal ENSO variability

Cross-validated jack-knifing hindcasts of of the ENSO STD are presented in **Fig. 5** for different choices of external predictors and their extrapolation methodologies. All in all, these results demonstrate the potential for skillful forecasts of the ENSO variance if the external predictors can themselves be forecasted. The results suggest potential long-term ENSO STD predictability *if the external predictors can themselves be forecasted*.

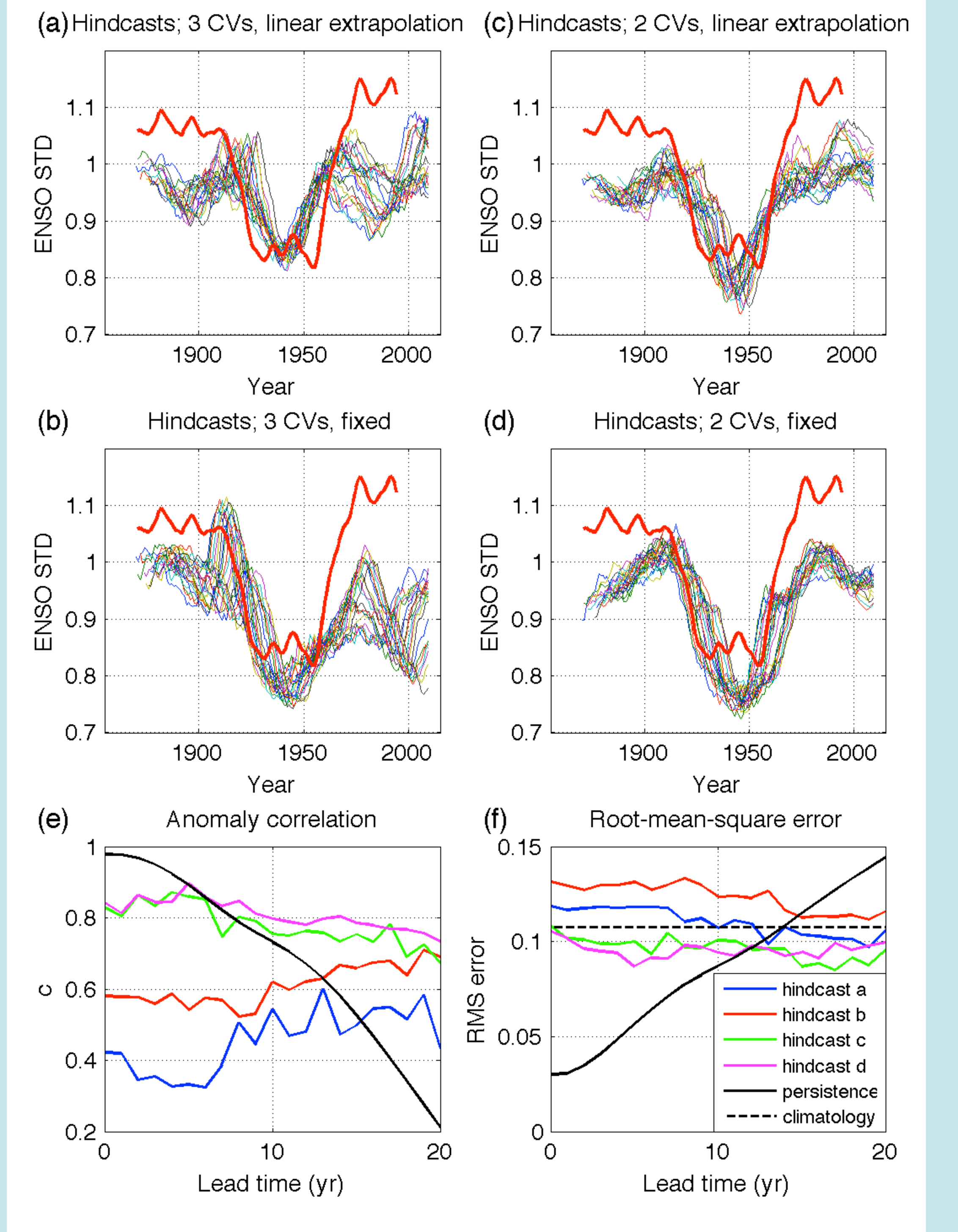

Figure 5: Hindcasts of ENSO standard deviation (STD). Observed STD is shown as a heavy red line, spaghetti plots are for hindcasts at various lead times up to 20 years.

Discussion

The central result of this paper is that the random variations of ENSO statistics have an insufficient magnitude to rationalize its observed multidecadal behavior (the peak-to-trough variations of the ENSO STD **in Fig. 4**). Furthermore, the association between the external predictors and ENSO variance is unlikely to be due to random chance (**Fig. 2**). Hence, the Flügel et al. 2004 and Wittenberg's (2009) null hypothesis for decadal ENSO modulation is formally rejected, within our empirical model framework, and the effect of the external predictors on ENSO statistics is shown to be quantitatively substantial.

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