Variation of ENSO Teleconnections

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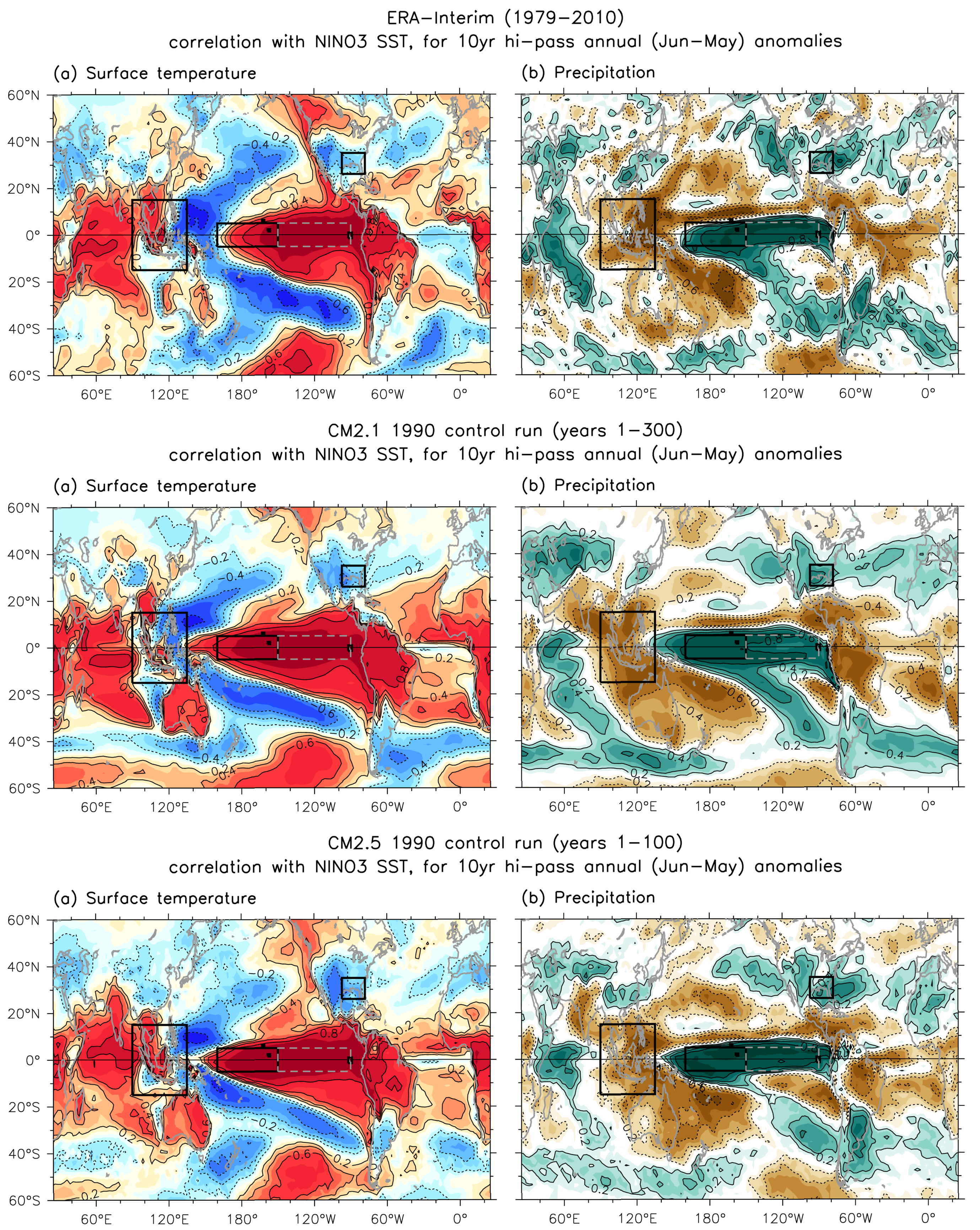
1. Introduction

ENSO affects weather, ecosystems, and economies worldwide. Instrumental records, paleo proxies, and coupled GCM simulations all exhibit strong intrinsic modulation of ENSO behavior, which factors into future climate risks and confounds detection of forced changes (see refs). Here we examine variations in ENSO teleconnections, arising from both intrinsic modulation and radiative forcing changes.

2. Canonical Teleconnection Patterns

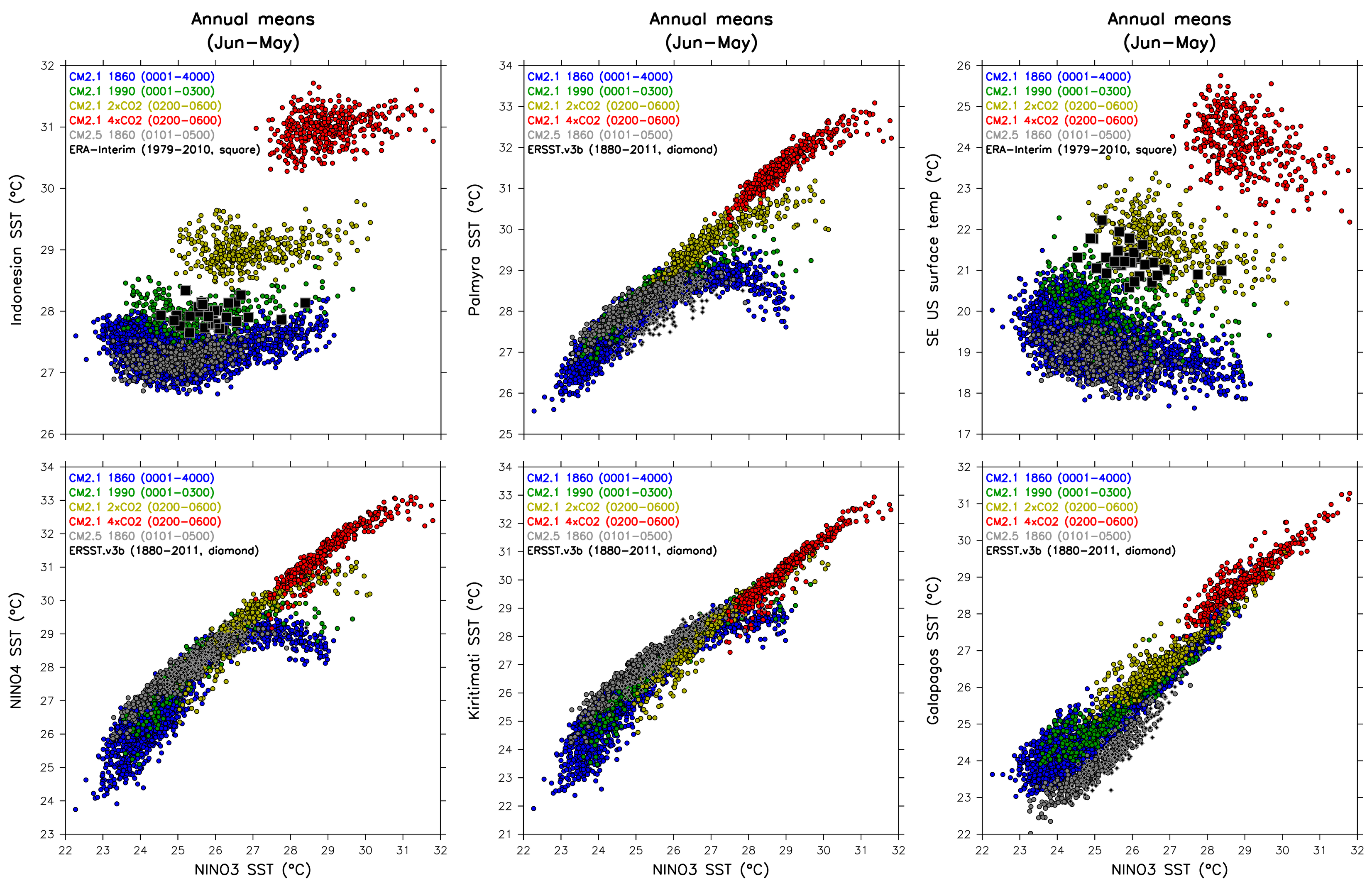
Two coupled GCMs, GFDL-CM2.1 (2° atm, 1° ocean) and GFDL-CM2.5 (0.5° atm, 0.25° ocean), produce reasonable simulations of global climate, ENSO, and ENSO teleconnections:



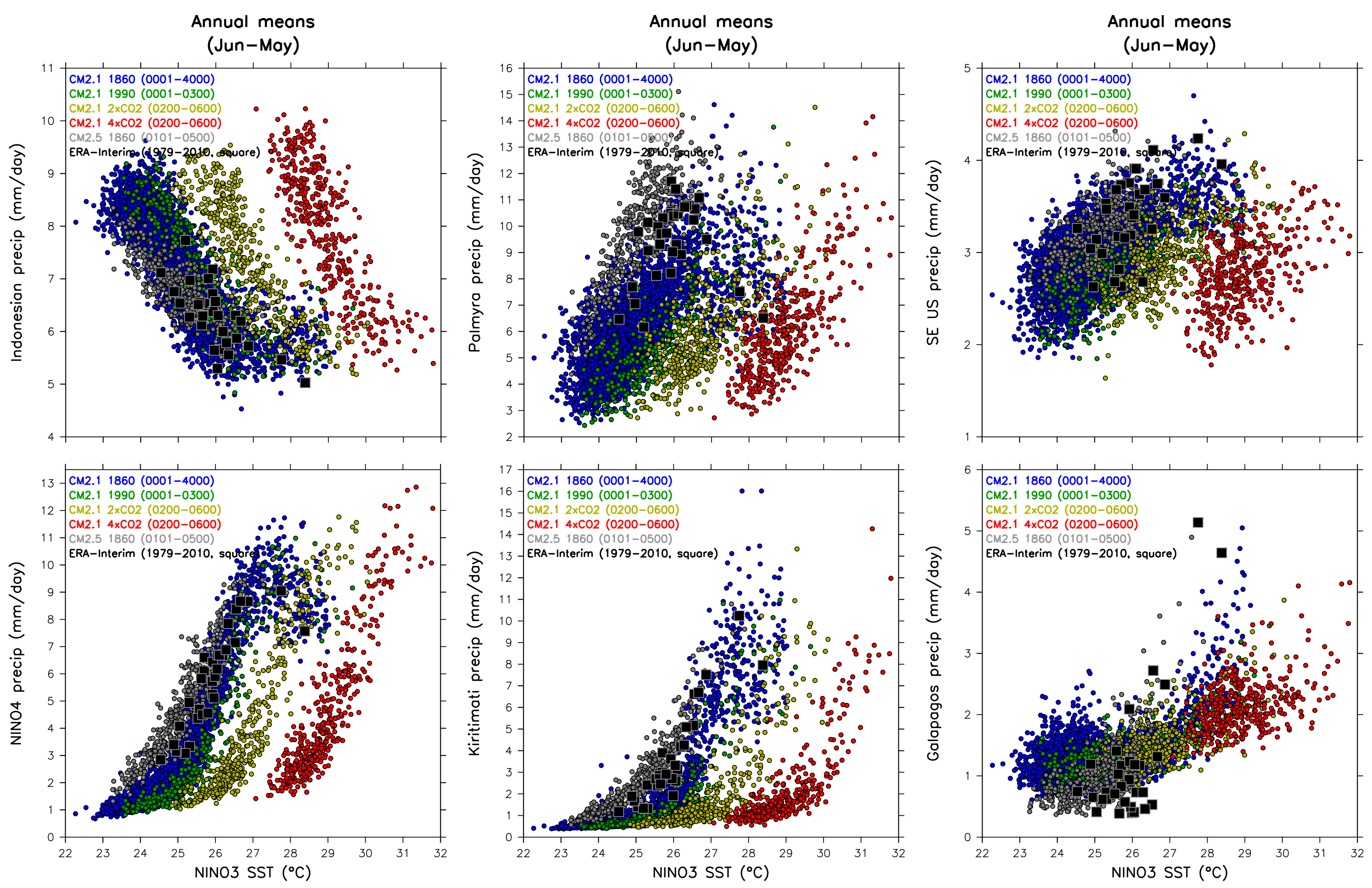
3. Noise, Nonlinearity, and Climate Change

Focusing on the black-boxed regions in the above figure, we examine scatterplots of annual-mean temperatures vs. NINO3 SSTA (gray box). The CM2.1 1990 control run (green dots) generally mimics the observed (**black dots**) climate & teleconnections. SSTAs in the equatorial Pacific vary in tandem with NINO3, while Indonesian & SE U.S. temperatures have weaker links to NINO3. A 4000yr run of CM2.1 with 1860 forcings (blue dots) exposes the nonlinear structure of the teleconnections: (1) Galapagos responds only to strong El Niños; (2) the equatorial Pacific temperature sensitivity to NINO3 is strong for La Niñas or moderate El Niños, but weaker for strong El Niños; and (3) Indonesia cools when NINO3 SST is neutral, and warms during *either* El Niño *or* La Niña. Similar effects are seen in a 500yr 1860-forced run of CM2.5 (gray dots).

As CO2 doubles (yellow dots) and quadruples (red dots) relative to 1860, the climate warms. For CM2.1, the 4xCO2 warming relative to 1860 is easily detectable with a single annual-mean over Indonesia, while at Galapagos it takes several years to detect reliably. At high CO2, the CM2.1 ENSO weakens and the teleconnections become more linear. These changes are not easily detectable in a 30yr record, like those currently available from TAO & satellites.

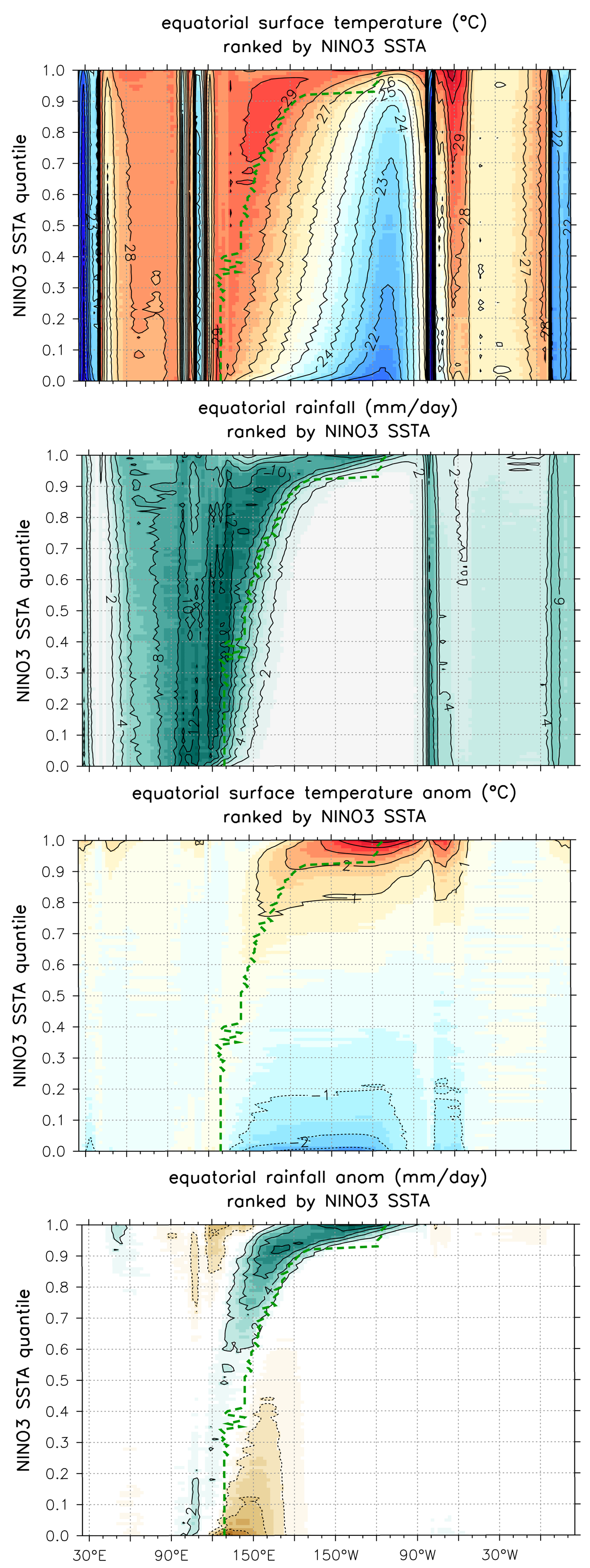


The teleconnections for rainfall (below) are noisier & more nonlinear than for temperature. During El Niño, rainfall increases over the equatorial Pacific & SE U.S., and decreases over Indonesia. But Indonesia cannot dry further for strong El Niños, and NINO4 & Palmyra rainfall peak for moderate El Niños. Kiritimati & Galapagos rainfall, in contrast, respond almost exclusively to the strongest El Niños. Such nonlinearities pose challenges for the linear methods currently used to reconstruct paleoclimate.



Palmyra captures moderate events but misses big El Niños, *attenuating* the inferred amplitude modulation of NINO3 SSTA. Galapagos sees only big events, *amplifying* the inferred modulation of NINO3 SSTA. NINO4 rainfall, while highly sensitive at moderate NINO3 SSTA, is clipped and even inverted at extreme NINO3 SSTA. Rainfall proxies at these locations thus record different aspects of ENSO — so they need to be interpreted in concert, not individually.

4. The ENSO Continuum and Local Vulnerability

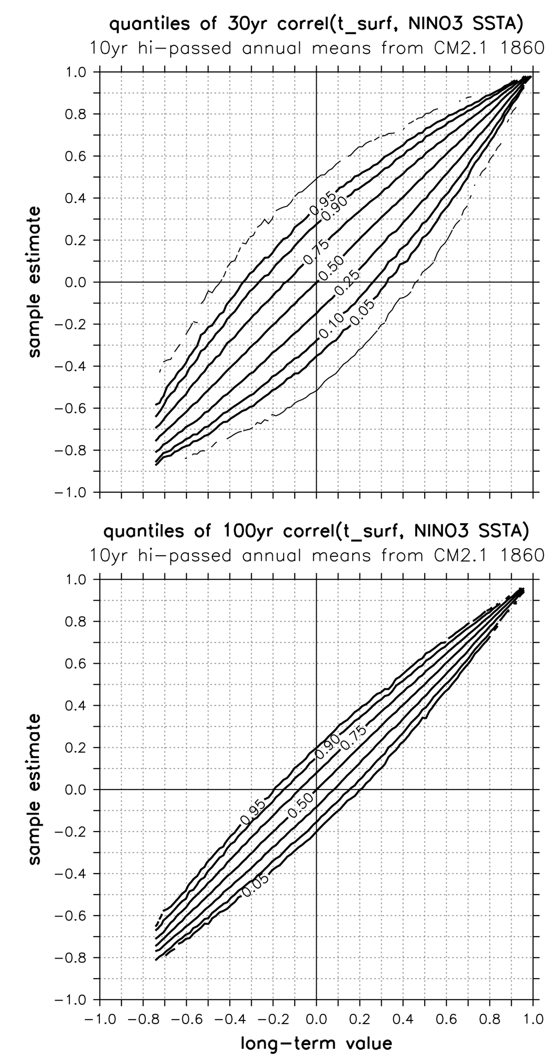


To shed light on these nonlinear relationships, the figure at left shows the 4000 June-May annual-means of equatorial surface temperature & rainfall from the CM2.1 1860 simulation, sorted by NINO3 SSTA and smoothed by 100yr along the quantile axis. The dashed green line (repeated all panels) marks the longitude of peak equatorial Pacific SSTA. In CM2.1, NINO3 is evidently a good proxy for both the strength & peak longitude of equatorial SSTA. The peak rainfall anomaly sits 20-30° west of the peak SSTA, sliding eastward with the peak SSTA as NINO3 warms.

CM2.1 exhibits a continuum of ENSO events, with SSTAs that can peak at any longitude. But the strong El Niños are rather distinct from moderate events and La Niñas. During strong El Niños, heavy rain expands across the entire Indian & Pacific oceans at the equator. Galapagos (at 90W) gets substantial annual rainfall only during the strongest El Niños, while Indonesia dries during strong events of either sign. Such nonlinearities can produce counter-intuitive relationships between teleconnection strength and decadal ENSO amplitude. During strong-ENSO epochs, when a linear regression model poorly fits the teleconnection curves, the regression coefficient can shrink despite a stronger signal-to-noise ratio. This motivates the use of nonlinear methods to characterize teleconnections. However, such methods may be hard to constrain with the short instrumental records currently available.

5. How Uncertain are the Teleconnections?

Because instrumental records are short, and extremes are rarely sampled, historically-observed teleconnections may not accurately reflect ENSO's full repertoire. The CM2.1 1860 run can be used to compute maps of temperature & rainfall correlations with NINO3 SSTA, using the full 4000yr simulation (r_{true}), or subsampled N-yr chunks (r_N). Binning r_N by r_{true}, we find that for $r_{true} = 0$ there is a 10% chance that $|r_{30}| > 0.35$, and a 10% chance that $|r_{100}| > 0.2$. For $r_{true} = 0.7$, there is a 5% chance that $r_{30} < 0.5$. The confidence intervals for rainfall are nearly identical to those for temperature, and these intervals can be used to assess uncertainties of teleconnections diagnosed from short climate records, and to evaluate risks of proxy selection biases & overfitting in paleo reconstructions.



References

Collins, M., and Coauthors, 2010: The impact of global warming on the tropical Pacific and El Niño. *Nature Geoscience*, **3**, 391-397. doi: 10.1038/ngeo868

Delworth, T. L., and Coauthors, 2006: GFDL's CM2 global coupled climate models, Part I: Formulation and simulation characteristics. *J. Climate*, **19**, 643-674. doi: 10.1175/JCLI3629.1

Delworth, T. L., and Coauthors, 2012: Simulated climate and climate change in the GFDL CM2.5 high-resolution coupled climate model. *J. Climate*, **25**, 2755-2781. doi: 10.1175/JCLI-D-11-00316.1

DiNezio, P. N., B. P. Kirtman, A. C. Clement, S.-K. Lee, G. A. Vecchi, and A. Wittenberg, 2012: Mean climate controls on the simulated response of ENSO to increasing greenhouse gases. *J. Climate*, **25**, 7399-7420. doi: 10.1175/JCLI-D-11-00494.1

Emile-Geay, J., K. Cobb, M. Mann, and A. T. Wittenberg, 2013a: Estimating central equatorial Pacific SST variability over the past millennium. Part 1: Methodology and validation. *J. Climate*, in press. doi: 10.1175/JCLI-D-11-00510.1

Emile-Geay, J., K. Cobb, M. Mann, and A. T. Wittenberg, 2013b: Estimating central equatorial Pacific SST variability over the past millennium. Part 2: Reconstructions and uncertainties. *J. Climate*, in press. doi: 10.1175/JCLI-D-11-00511.1

Guilyardi, E., A. Wittenberg, A. Fedorov, M. Collins, C. Wang, A. Capotondi, G. J. van Oldenborgh, and T. Stockdale, 2009: Understanding El Niño in ocean-atmosphere general circulation models: Progress and challenges. *Bull. Amer. Meteor. Soc.*, **90**, 325-340. doi:10.1175/2008BAMS2387.1

Knutson, T. R., F. Zeng, and A. T. Wittenberg, 2013: Multi-model assessment of regional surface temperature trends: CMIP3 and CMIP5 20th century simulations. *J. Climate*, in review.

Kug, J.-S., J. Choi, S.-I. An, F.-F. Jin, and A. T. Wittenberg, 2010: Warm pool and cold tongue El Niño events as simulated by the GFDL CM2.1 coupled GCM. *J. Climate*, **23**, 1226-1239. doi: 10.1175/2009JCLI43293.1

Vecchi, G. A., and A. T. Wittenberg, 2010: El Niño and our future climate: Where do we stand? *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 260-270. doi: 10.1002/wcc.33

Watanabe, M., and A. T. Wittenberg, 2012: A method for disentangling El Niño-mean state interaction. *Geophys. Res. Lett.*, **39**, L14702. doi: 10.1029/2012GL052013.

Watanabe, M., J.-S. Kug, F.-F. Jin, M. Collins, M. Ohba, and A. T. Wittenberg, 2012: Uncertainty in the ENSO amplitude change from the past to the future. *Geophys. Res. Lett.*, **39**, L20703. doi: 10.1029/2012GL053305

Wittenberg, A. T., 2004: Extended wind stress analyses for ENSO. *J. Climate*, **17**, 2526-2540. doi: 10.1175/1520-0442(2004)017%3C2526:EWSAFE%3E2.0.CO;2

Wittenberg, A. T., A. Rosati, N.-C. Lau, and J. J. Ploshay, 2006: GFDL's CM2 global coupled climate models. Part III: Tropical Pacific climate and ENSO. *J. Climate*, **19**, 698-722. doi: 10.1175/JCLI3631.1

Wittenberg, A. T., 2009: Are historical records sufficient to constrain ENSO simulations? *Geophys. Res. Lett.*, **36**, L12702. doi: 10.1029/2009GL038710

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