Assessing ENSO Risks for the Coming Decades

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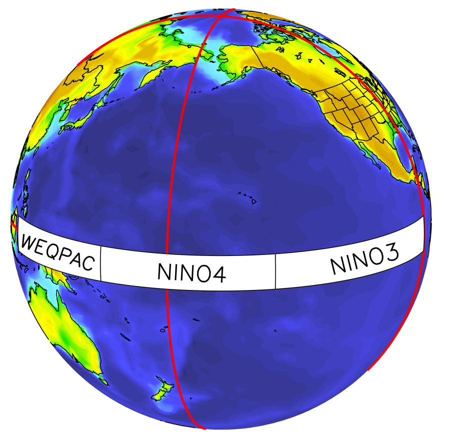
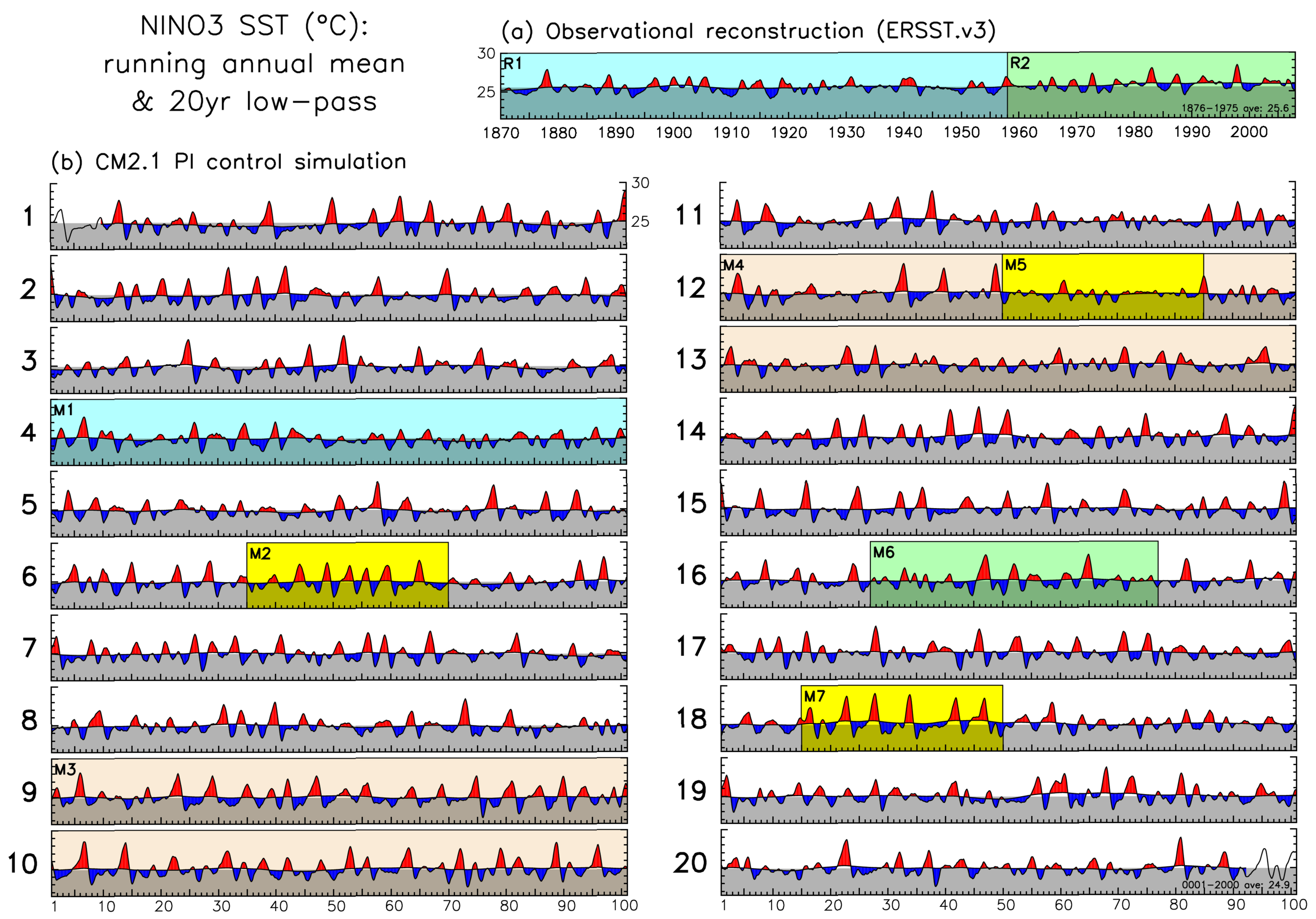
1. Introduction

The El Niño / Southern Oscillation (ENSO) affects weather, ecosystems, and economies worldwide, yet its past and future remain uncertain (Vecchi & Wittenberg 2010; Collins et al. 2010; Watanabe et al. 2012). Will the coming decades bring strong ENSO events, or none at all?

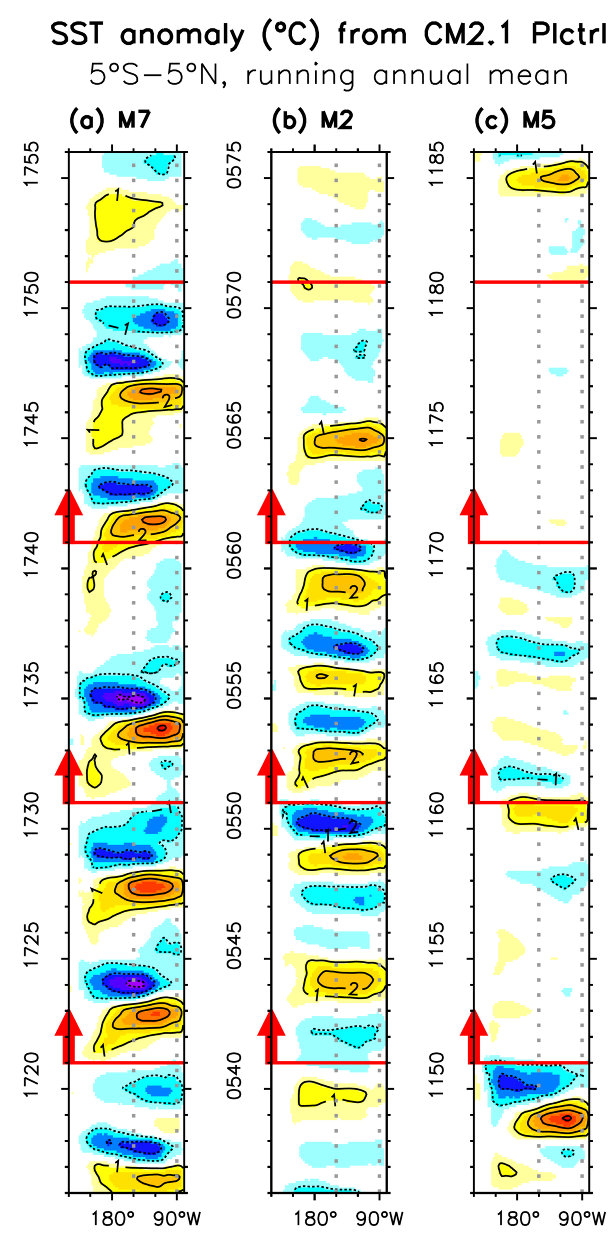


2. Unforced Modulation of ENSO

Historical & paleo records and model simulations all display prolonged epochs of strong or weak ENSO, which complicate model evaluation & intercomparison, hamper detection of anthropogenic impacts, and challenge theoretical understanding (Wittenberg 2015). Model projections suggest that ENSO's behavior over the next few decades could depend as much on intrinsic modulation as anthropogenic forcing (Christensen et al. 2014).

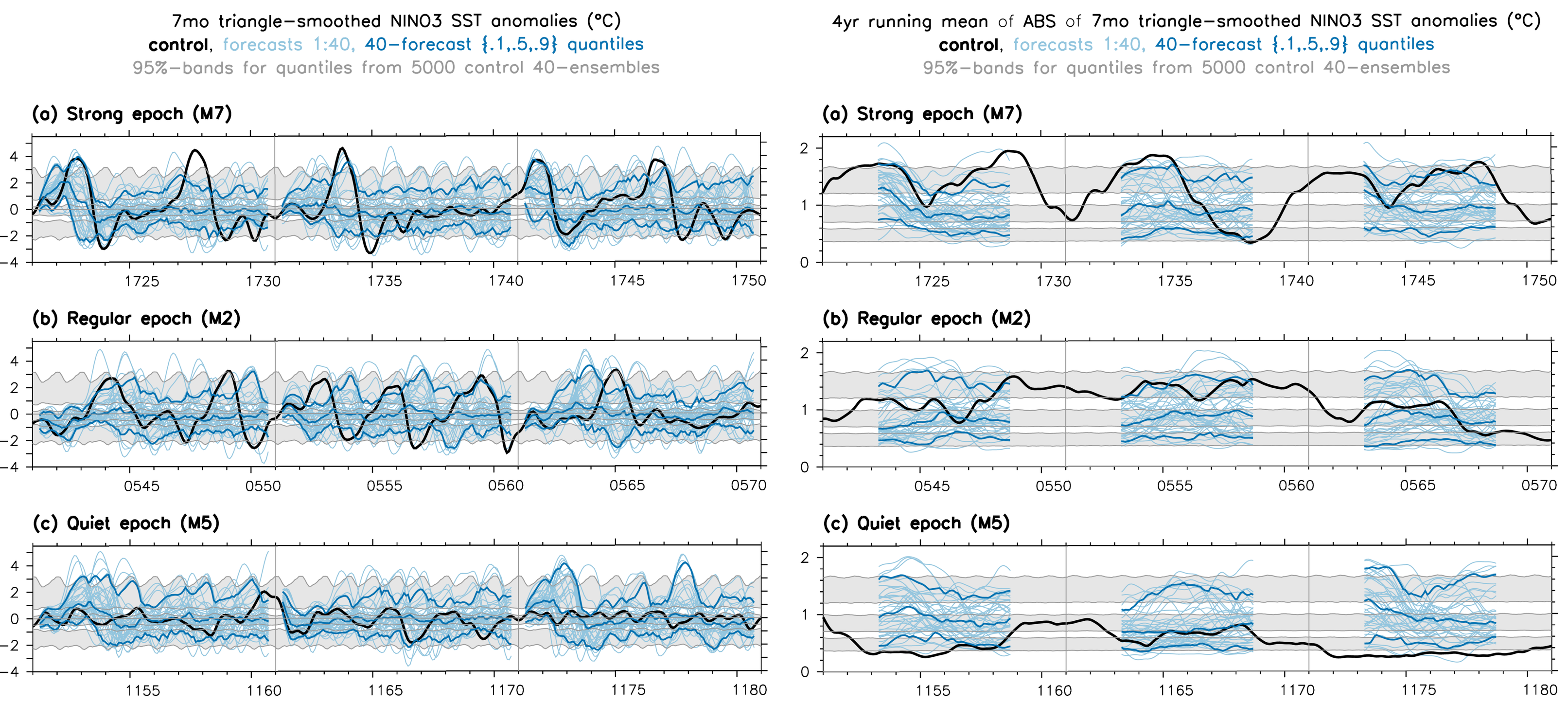


A 4000yr control simulation from the GFDL CM2.1 global coupled GCM (Delworth et al. 2006; Wittenberg et al. 2006), with external forcings held at 1860 values, spontaneously produces extreme ENSO epochs that can last decades, or even centuries (Wittenberg 2009; 20 centuries shown above). Epoch M7 resembles observed ENSO behavior during 1982-98, with strong, warm-skewed ENSO events five or more years apart. M2 resembles 1961-81, with moderate amplitude events that are more regular in time. M5 resembles 1999-2014, with weak, biennial variability near the dateline. The zonal structure & propagation of equatorial SST anomalies (SSTAs, at right) also vary from decade to decade in the control run (Kug et al. 2010; Wittenberg et al. 2014). Relative to M2, M7 shows a westward shift of its cold SSTAs, an eastward shift and more eastward propagation of its warm SSTAs, and more synchronization of its SSTA peaks to the end of the calendar year.



3. Are Extreme ENSO Epochs Predictable?

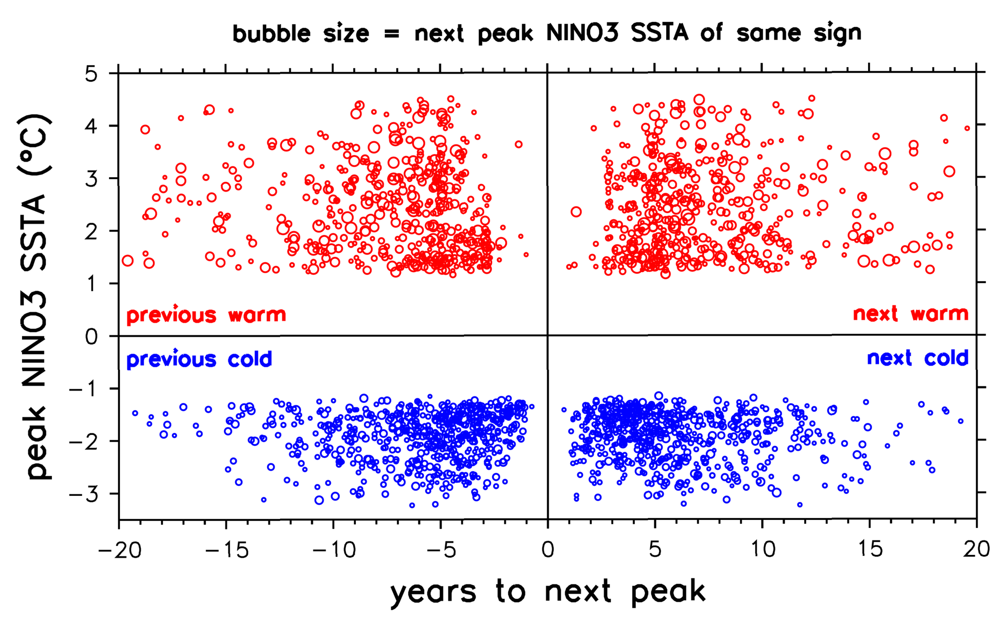
To assess the predictability of CM2.1's extreme ENSO epochs, we "reforecast" these epochs using the model itself (Wittenberg et al. 2014). Near-perfect initial conditions are generated by slightly perturbing the ocean temperature ($\Delta T \sim 0.0001$K) at a single gridpoint, for each of the nine Januaries indicated by the red arrows in the last figure of Section 2.



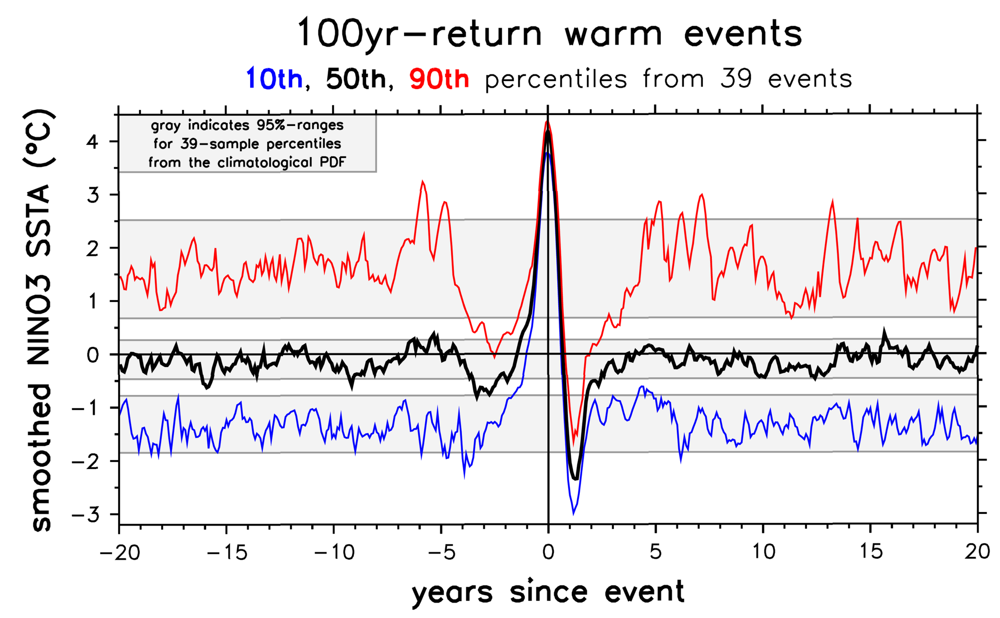
Initially the 40 ensemble members (thin blue lines, above left) are tightly packed around the control trajectory (**black line**). Over the next few years they rapidly disperse, eventually giving rise to completely different ENSO behavior from that seen in the corresponding decades of the control run. Five years post-perturbation, the percentiles (dark blue) of the 40 reforecasts generally fluctuate within their climatological ranges (gray bands) – indicating little memory or predictability of the NINO3 SSTA trajectory beyond interannual time scales. Right panel shows a measure of ENSO amplitude: the running 4yr mean of |NINO3 SSTA|. For this statistic too, within five years the reforecast percentiles generally fall within their climatological ranges – indicating that even the decadal *amplitude* of ENSO is unpredictable in this simulation.

4. Strong ENSO Events Can Boost Predictability

The strength of a CM2.1 ENSO event is linked to the strength of the previous and subsequent events. Strong events are more isolated from their neighbors – especially their strong neighbors – prolonging memory and predictability, as the large signals ring through the climate system (Karamperidou et al. 2014).



Next we composite the strongest El Niños in the 4000yr simulation – those with NINO3 SSTAs that occur only once per century. In CM2.1 there is a slight but statistically significant increase in the likelihood of an El Niño occurring 5-7yr, and even 13yr, after an "El Niño of the Century".

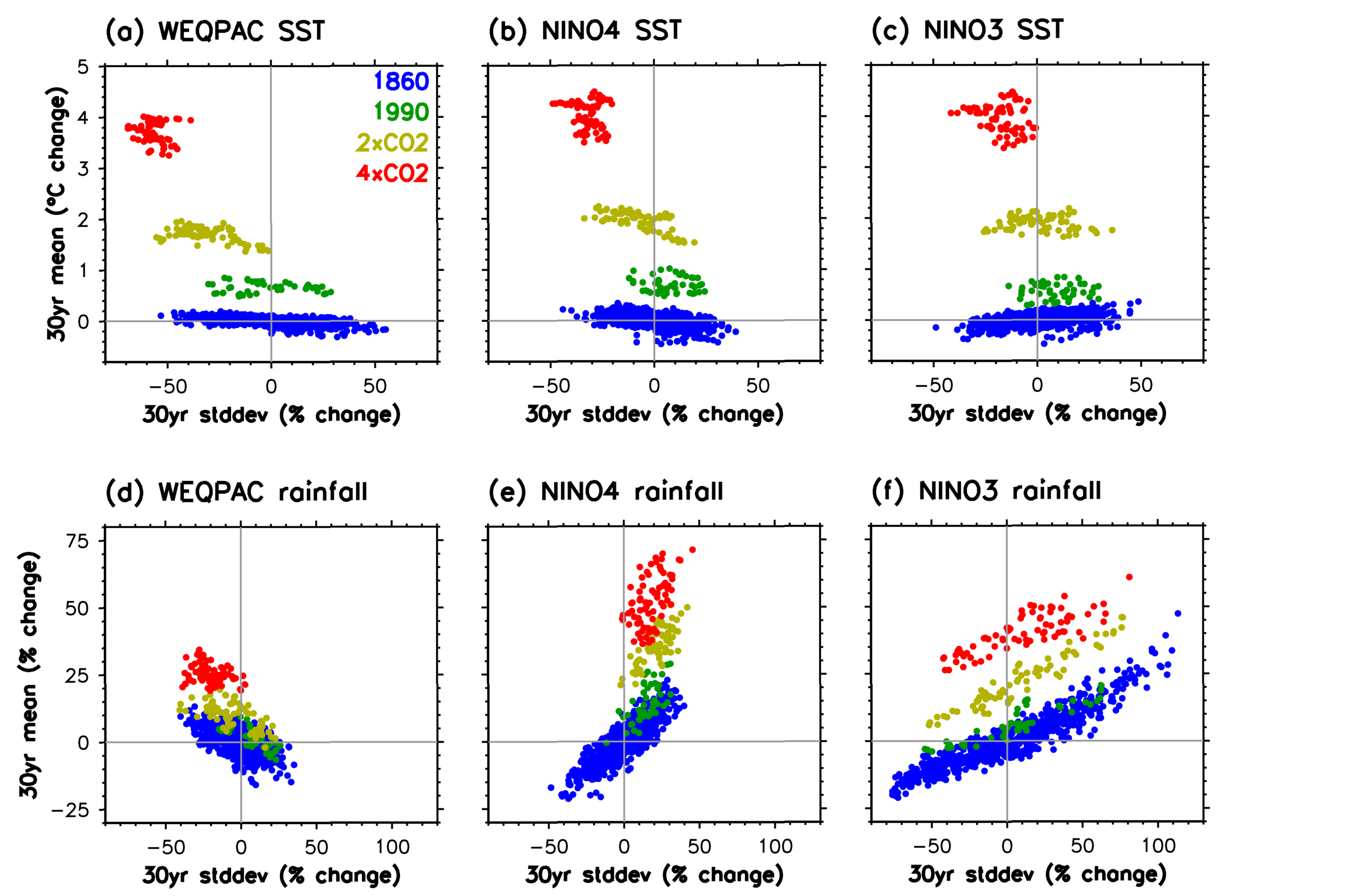


5. Changes in Pacific Climate and ENSO with Increasing CO_2

The ranges of interannual and decadal variability for CM2.1's equatorial Pacific SST & rainfall are shown below (Wittenberg 2015). The 1860 simulation (blue) again shows strong ENSO modulation (30yr-stddev of annual means, abscissa), as well as slow departures of 30yr means from the 4000yr mean (ordinate). Strong-ENSO epochs correspond to multidecadal means that are cool & dry in the west and warm & rainy in the east, with weaker trade winds and a reduced zonal slope of the thermocline (Watanabe & Wittenberg 2012; Ogata et al. 2013), which in turn affects global climate on decadal scales (Kosaka & Xie 2013; Delworth et al. 2015). Both the ENSO modulation and the multidecadal-scale variations are stronger for rainfall than SST; and for rainfall, are stronger in the east than the west.

As atmospheric CO_2 quadruples (red) relative to 1860, the simulated SST warms by 3-4K to unprecedented levels, and rainfall increases by 25-50%. ENSO SSTA & rainfall variance both *weaken* in the west. But the rainfall variance *strengthens* in the central & east Pacific, where the mean climate also becomes much wetter. In the east, the ENSO SSTA variance *peaks* near present-day CO_2. At high CO_2 the ENSO modulation weakens, and there is less multidecadal variability of rainfall.

In CM2.1, CO_2's impacts on ENSO variance (abscissa) are most detectable in the west Pacific. Yet even there, *decades of observations* would be needed to reliably detect changes in ENSO relative to its 1860 behavior. Nonlinearity and opposing changes in future ENSO feedbacks also make the projected changes in ENSO very model-dependent (DiNezio et al. 2012; Choi et al. 2015; Capotondi et al. 2015ab).



6. Summary

Simulations suggest ENSO's behavior over the next few decades may depend less on CO_2 than on ENSO's intrinsic modulation, which may be largely unpredictable. On the longer term, CO_2 could strongly affect both Pacific climate and ENSO.

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Poster:

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