Assessing ENSO Risks for the Coming Decades

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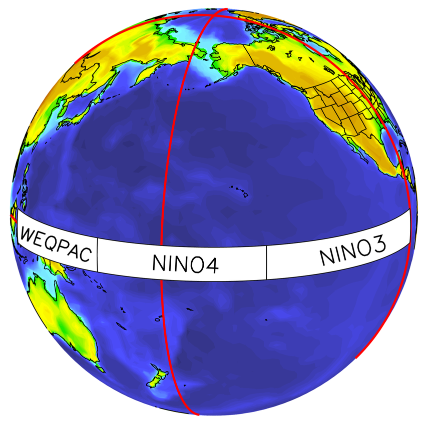
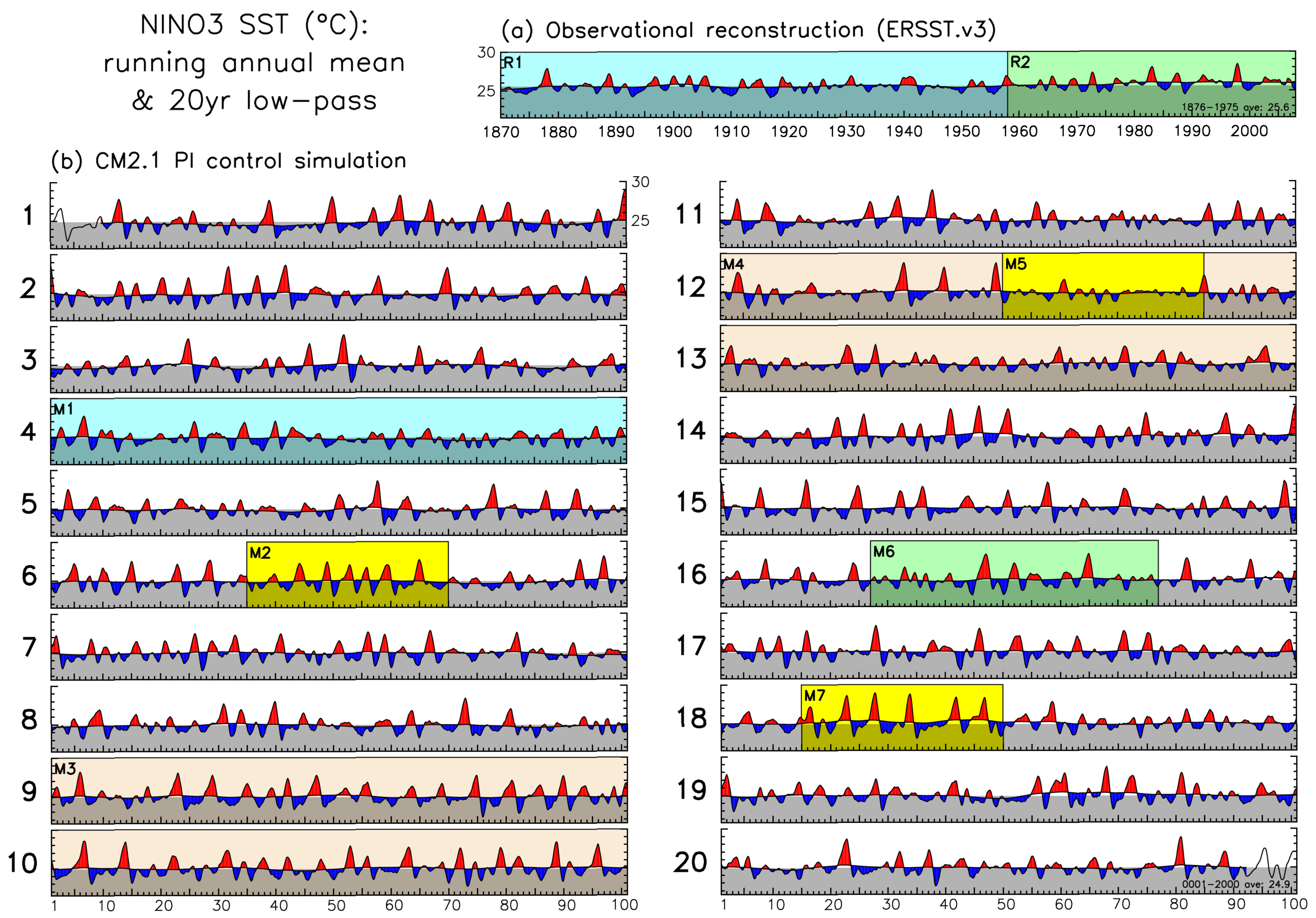
1. Introduction



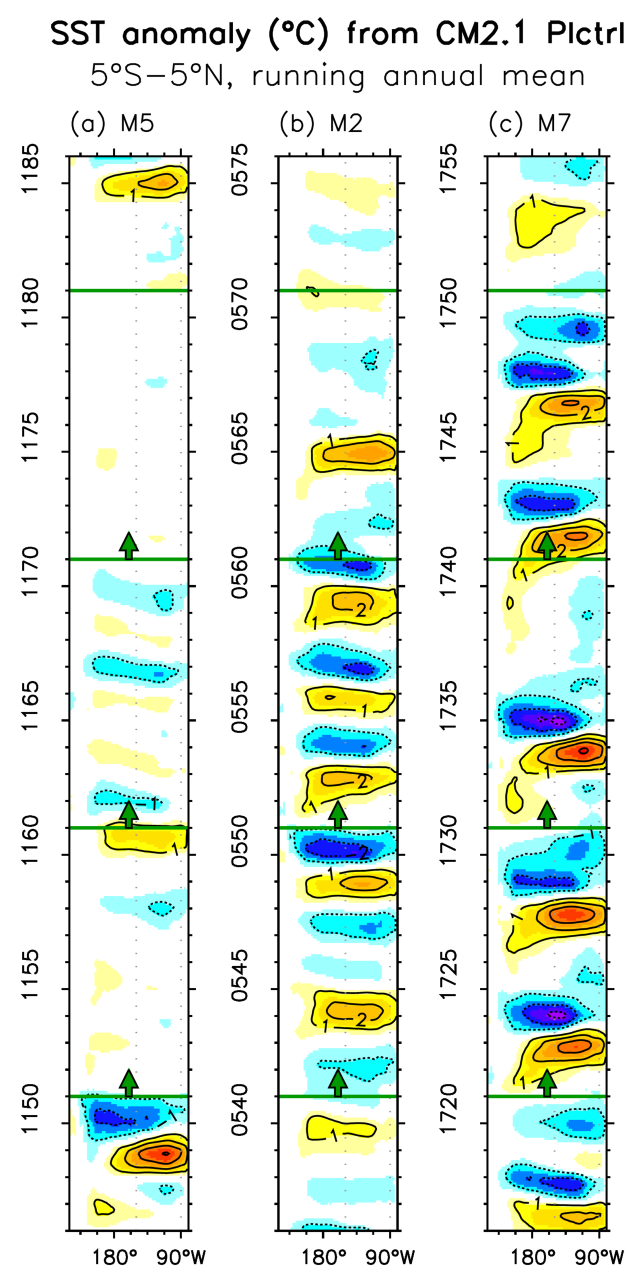
The El Niño / Southern Oscillation (ENSO) affects weather, ecosystems, and economies worldwide. Yet its future remains uncertain (Guilyardi et al. 2009; Vecchi & Wittenberg 2010; Collins et al. 2010). Will the decades ahead bring strong ENSO events, or none at all?

2. Intrinsic Modulation of ENSO

Have the past 140yr of observations captured ENSO's full repertoire? CMIP3 model projections suggest that ENSO's behavior over the next few decades could depend as much on intrinsic modulation as anthropogenic forcing. Historical & paleo records and model simulations all display prolonged epochs of strong or weak ENSO, which challenge theories, hamper detection of anthropogenic impacts, and complicate model evaluation & intercomparison.

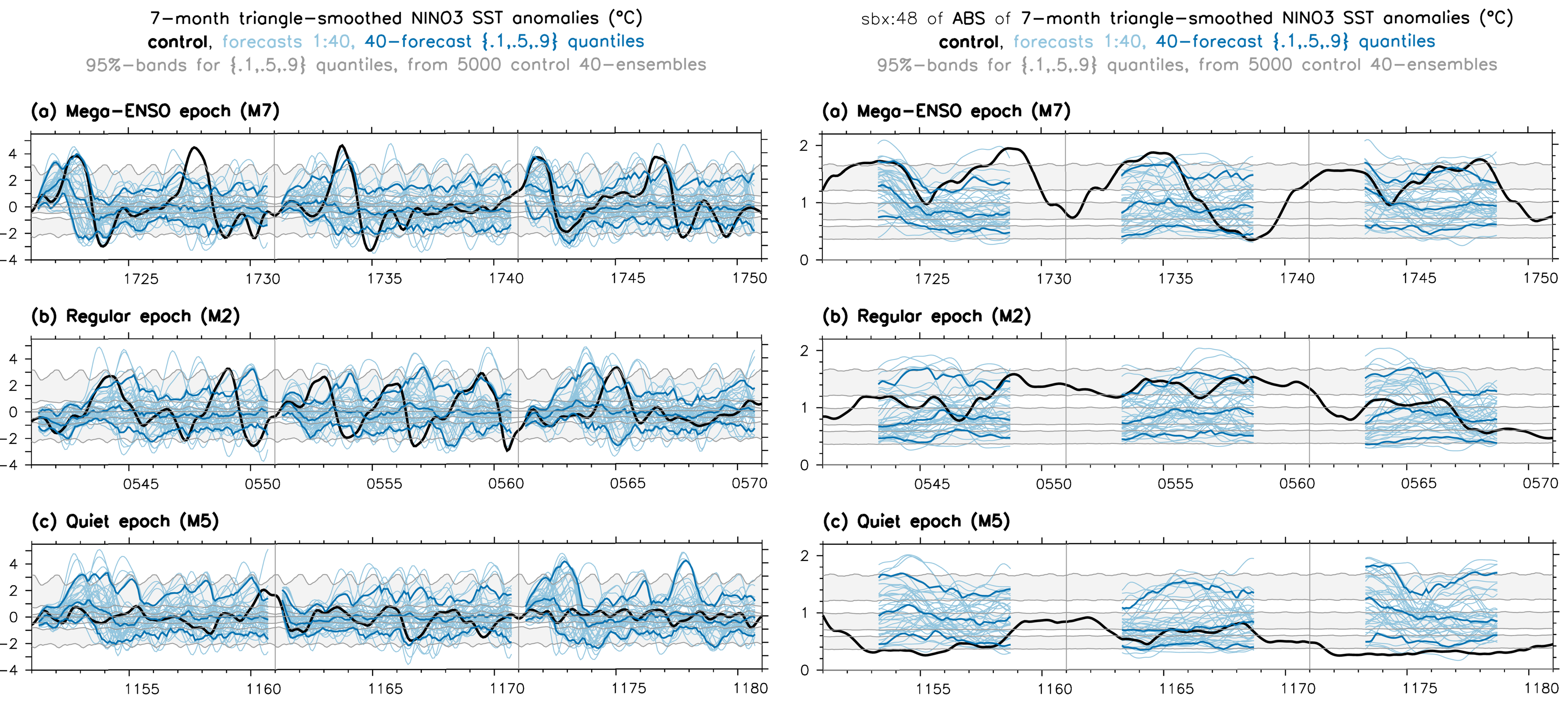


A 4000yr control simulation from the GFDL CM2.1 global coupled GCM (Delworth et al. 2006; Wittenberg et al. 2006), with external forcings held at 1860 values, spontaneously produces extreme ENSO epochs that can last for decades, even centuries (20 centuries shown above; Wittenberg 2009). Epoch M5 resembles the real-world ENSO behavior during the early 1990s & 2000s, with weak, biennial variability near the dateline. M2 looks like the 1960s & 1970s, with moderate amplitude and very regular events. M7 resembles the 1980s & late 1990s, with strong, warm-skewed ENSO events five or more years apart. The zonal structure & propagation of SST anomalies (SSTAs) also varies from decade to decade in the control run (Kug et al. 2010). Relative to M2, M7 shows a westward shift of its cold anomalies, an eastward shift and more eastward propagation of its warm anomalies, and more phase locking of its warm peaks to the end of the calendar year.



3. Are Extreme ENSO Epochs Predictable?

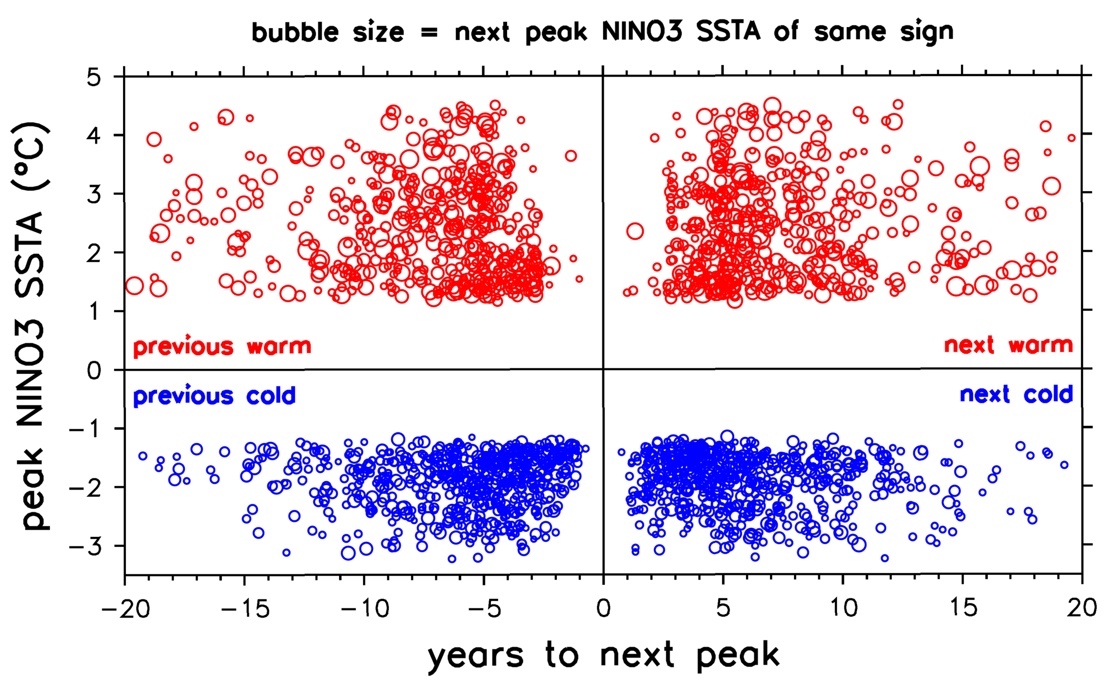
To establish an upper bound for the predictability of CM2.1's intrinsically-generated extreme ENSO epochs, we "reforecast" these epochs using the model itself. Near-perfect initial conditions are generated by slightly perturbing the ocean temperature ($\Delta T \sim 0.0001$°C) at a single gridpoint, for each of the nine Januaries indicated by green arrows at bottom left.

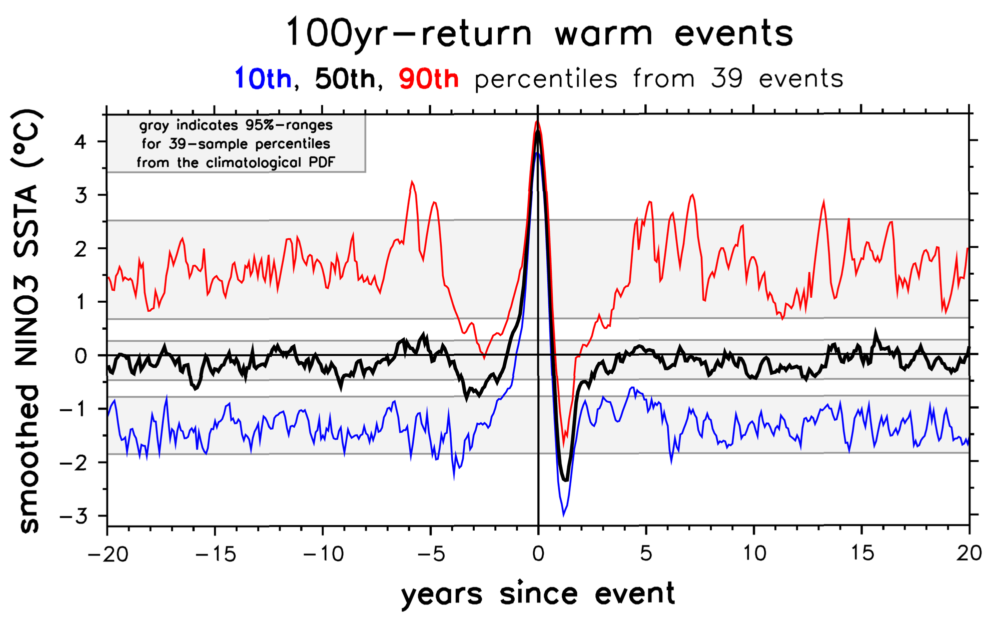


Initially the 40 ensemble members (thin blue lines, above left) are tightly packed around the control trajectory (**black line**), but they disperse rapidly over the next few years. Later, we see that the tiny perturbations lead to ENSO behavior completely different from what occurred in the control epochs. Five years after perturbation, the 10th, 50th, and 90th percentiles (dark blue) of the 40 forecasts generally fluctuate within their climatological ranges estimated from the control run (gray bands) – indicating little memory or predictability of the NINO3 SSTA trajectory beyond interannual time scales. Above right shows a measure of ENSO amplitude, the running 4yr mean of |NINO3 SSTA|. Five years after perturbation, the reforecast percentiles for this statistic also fall within their climatological ranges – so even this integrated measure of amplitude is predictable only for a few years.

4. Strong ENSO Events Can Prolong Predictability

The strength of a CM2.1 ENSO event is linked to the strength & timing of prior and subsequent events of the same sign. Stronger events are more isolated from their neighbors – prolonging memory and predictability as the large perturbations ring through the global climate system. This effect is largest for El Niños, which are more extreme than La Niñas.

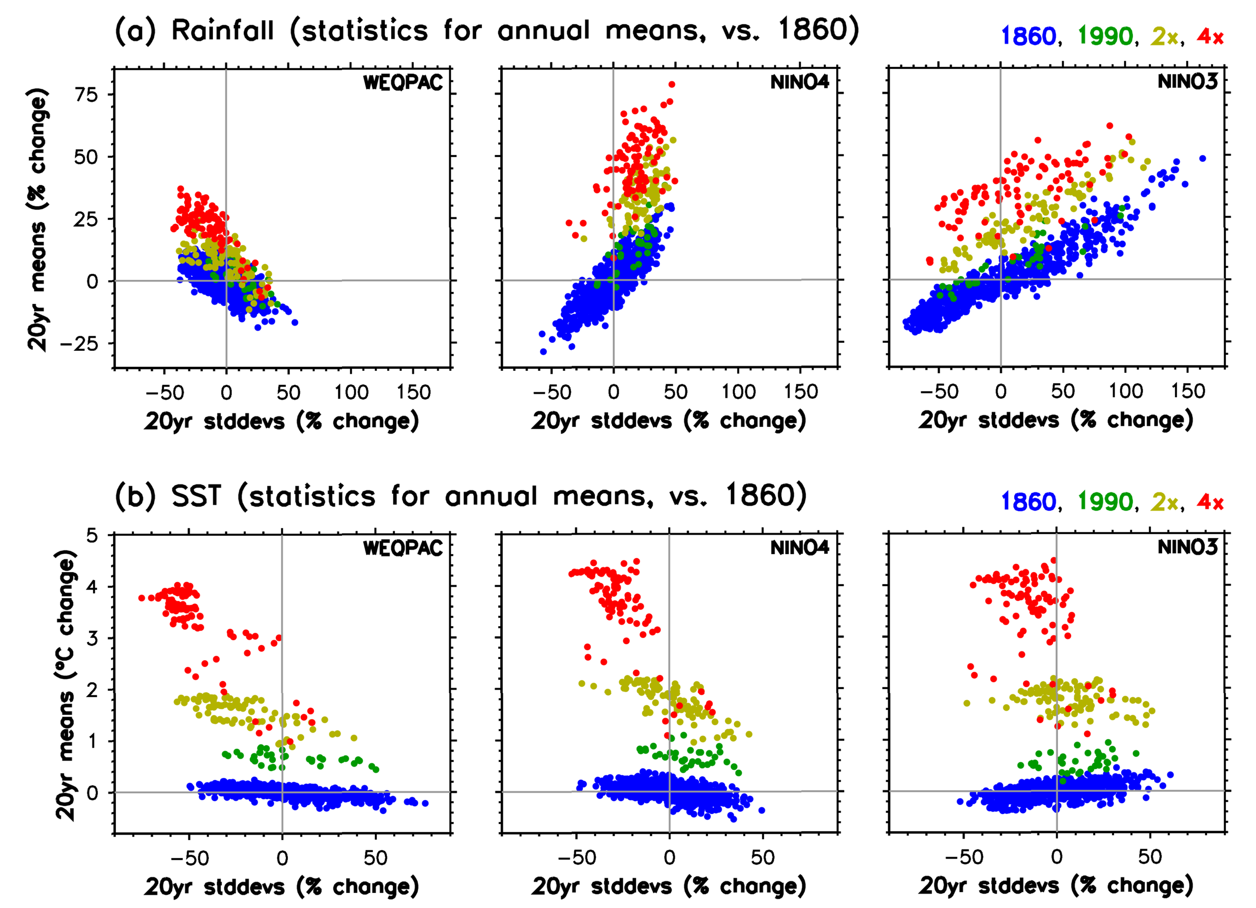




Next we composite the strongest El Niños in the 4000yr simulation – those with NINO3 warming expected to occur only once per century. In CM2.1 there is a slight (but statistically significant) increase in the likelihood of an El Niño occurring 5 to 7yr, and even 13yr, after an "El Niño of the century".

5. Changes in ENSO with Increasing CO_2

The figure below shows the CM2.1-simulated range of interannual and decadal variability for equatorial Pacific SST & rainfall. The 1860 simulation (blue) again shows strong modulation of ENSO (20yr-stddev of annual means, horizontal axis), as well as slow departures of 20yr means from the long-term mean (vertical axis). Active-ENSO epochs are linked to bidecadal cool & dry conditions in the west, and warm & rainy conditions in the east. Both the bidecadal background variations and the ENSO modulation 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 equatorial SST warms by 3-4degC and rainfall increases 25-50%. Interannual SST variations weaken, especially in the west. Interannual rainfall variations also weaken in the west, but strengthen in the central & east Pacific where the mean rainfall sees its strongest fractional increase at 4xCO_2. At high CO_2, there is less amplitude modulation of ENSO, and bidecadal means of rainfall are less variable.

For CM2.1, changes in ENSO SST & rainfall are more detectable in the west Pacific than in the east. But even in the west, several decades of observations might be needed to detect changes in ENSO at 4xCO_2 relative to 1860.

6. Summary

Simulations suggest that ENSO's behavior over the next few decades may depend less on CO_2, and more on an intrinsic modulation that is not decadally predictable – except perhaps after a strong El Niño. Longer term, equatorial Pacific climate and variability could both be significantly influenced by CO_2.

References

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