Simulated CO_2-Induced Changes in Tropical Climate and Variability

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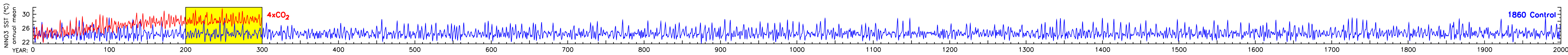
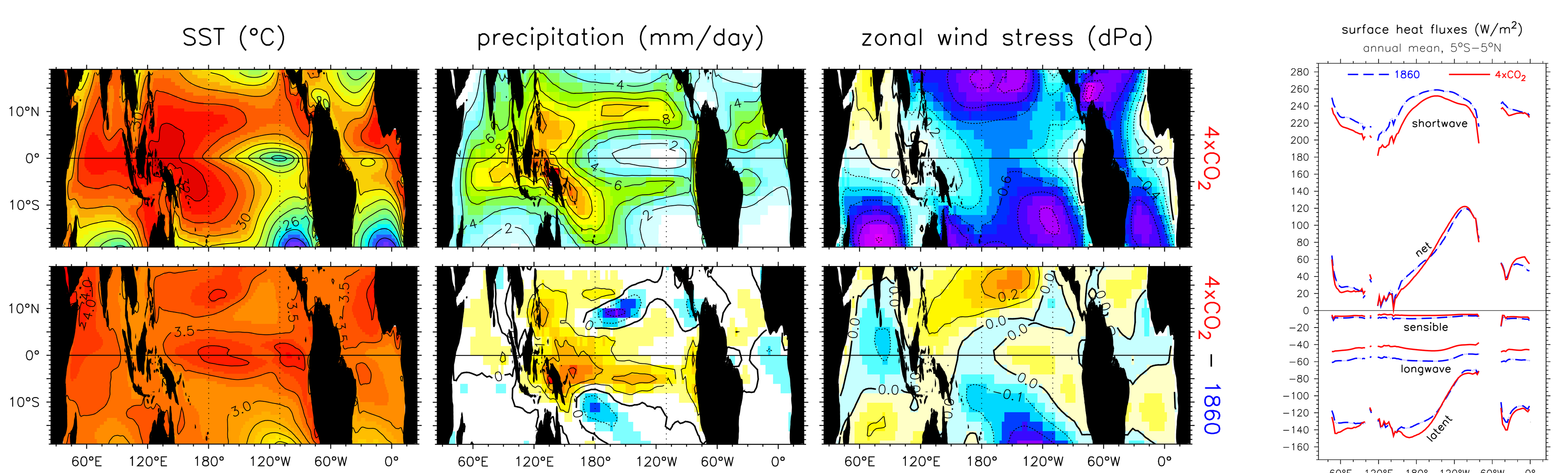


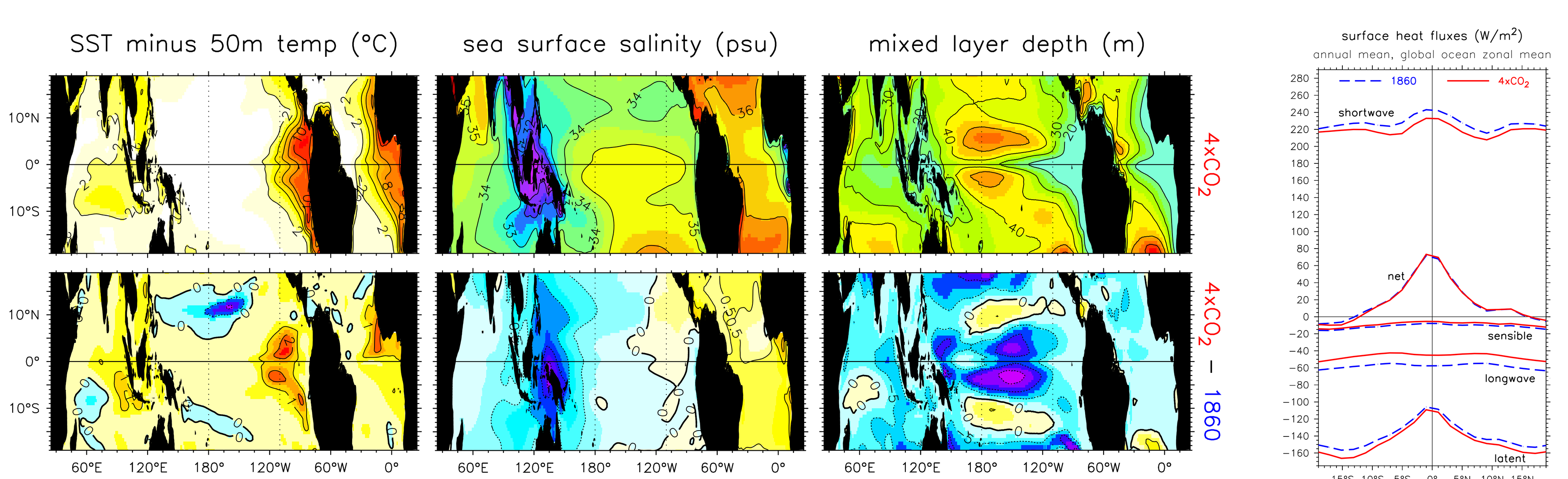
1. Introduction

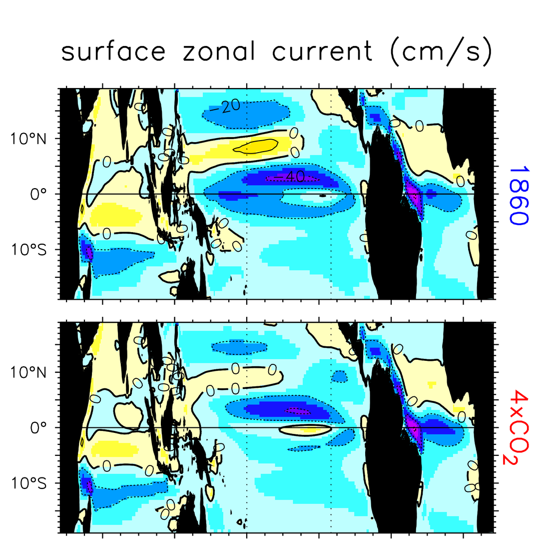
We assess impacts of increased atmospheric CO_2 on tropical climate, using the CM2.0 & CM2.1 global coupled climate models developed at NOAA/GFDL (Delworth et al. and Wittenberg et al., *J. Climate*, 2006). We compare multi-century control runs (with fixed 1860 values of trace gases, aerosols, insolation, land cover, and 286ppmv CO_2) to runs in which CO_2 increases 1%/yr and then stabilizes at $4xCO_2$ (1144ppmv) after year 140. We focus here on years 200–300 of the CM2.1 runs (above); CM2.0 results are similar except for Section 4.

2. Annual-Mean Changes

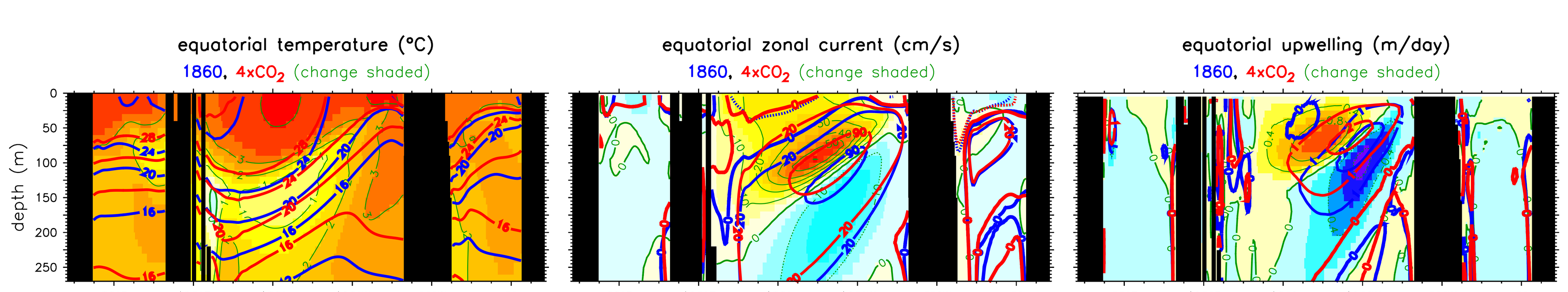
The $4xCO_2$ run shows a fairly uniform 3–4°C warming of SST, with enhanced warming in the equatorial & eastern Pacific. Rainfall increases along and just south of the equator, but decreases in the northern ITCZ. The Pacific trade winds weaken and become more symmetric about the equator. After CO_2 stabilization at 4x, the reduced annual-mean longwave cooling of the surface is balanced by reduced shortwave heating and enhanced evaporation.





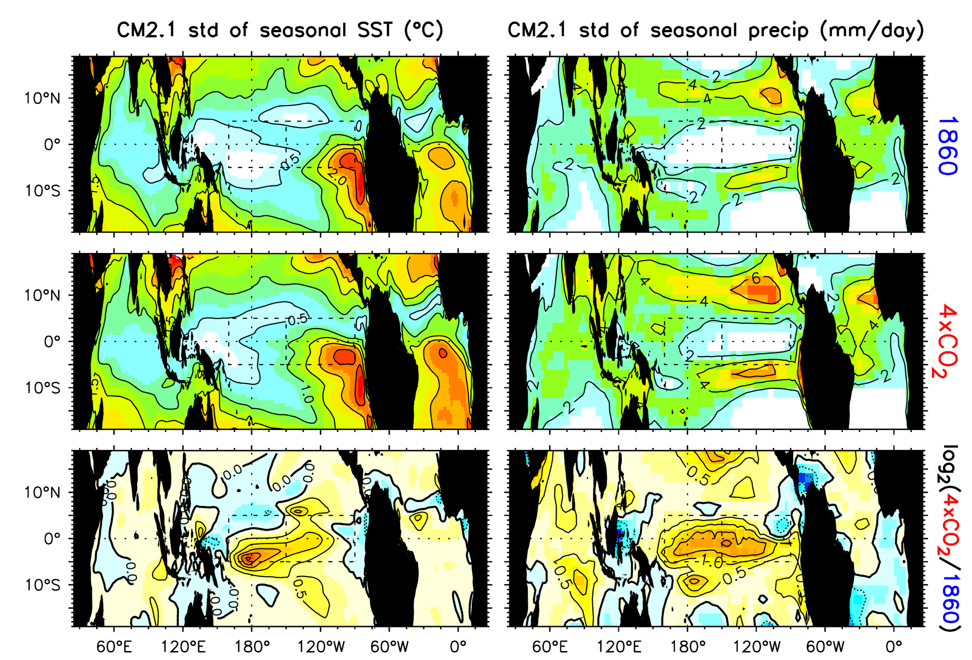


Over most of the tropical oceans, the thermal stratification increases over the top 50m, the mixed layer shoals, and the surface currents weaken. The thermocline flattens, shoals, and intensifies, and the equatorial undercurrent and upwelling become shallower. The Indo-Pacific warm pool grows fresher near the surface, while the tropical Atlantic becomes saltier. In the eastern equatorial Pacific, increased downward surface heat fluxes indicate enhanced ocean-dynamical cooling; the opposite holds near the dateline and in the southeast tropical Pacific.

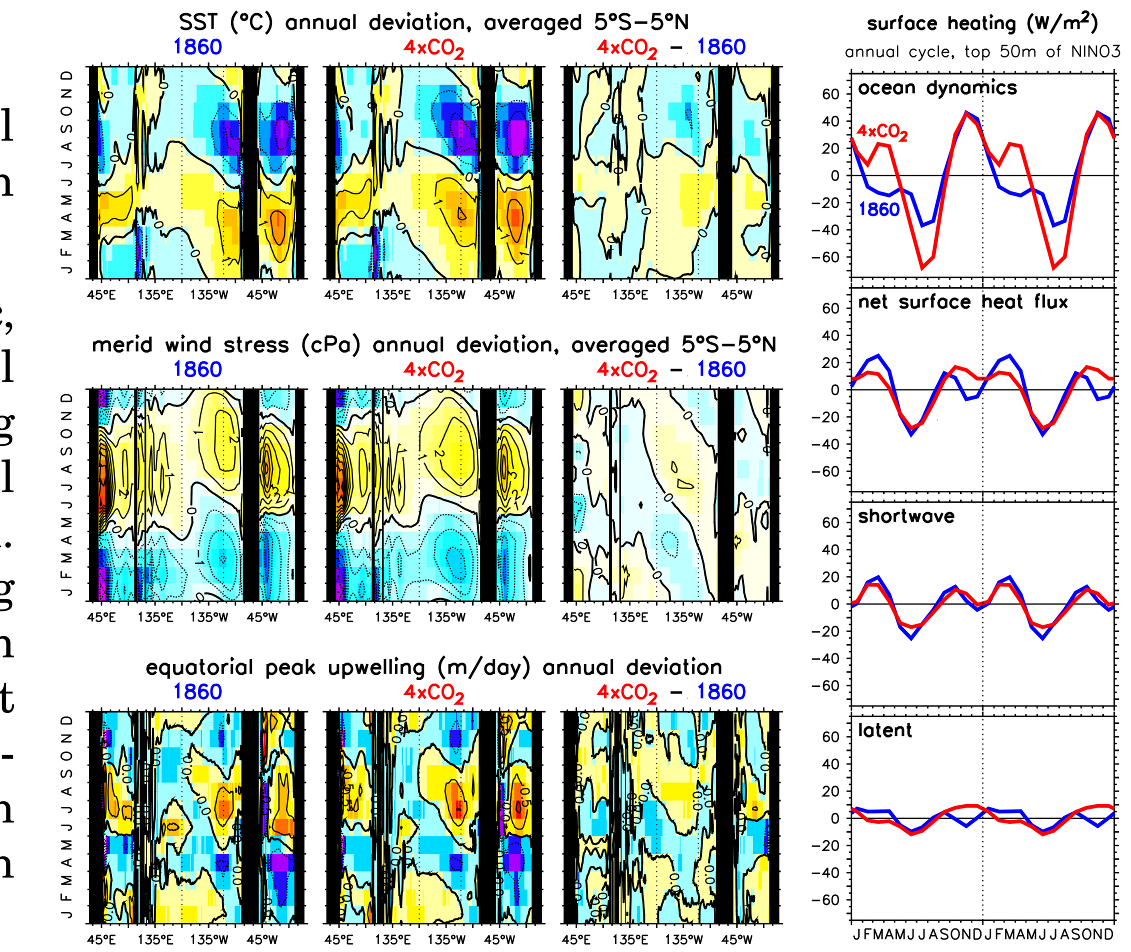


3. Seasonal Cycle Changes

The $4xCO_2$ simulation shows a stronger seasonal cycle of SST over the equatorial central Pacific, Atlantic, and eastern Indian Ocean. The seasonal cycle of rainfall is enhanced in the northern & southern ITCZs, the equatorial Pacific, and the tropical Indian Ocean.

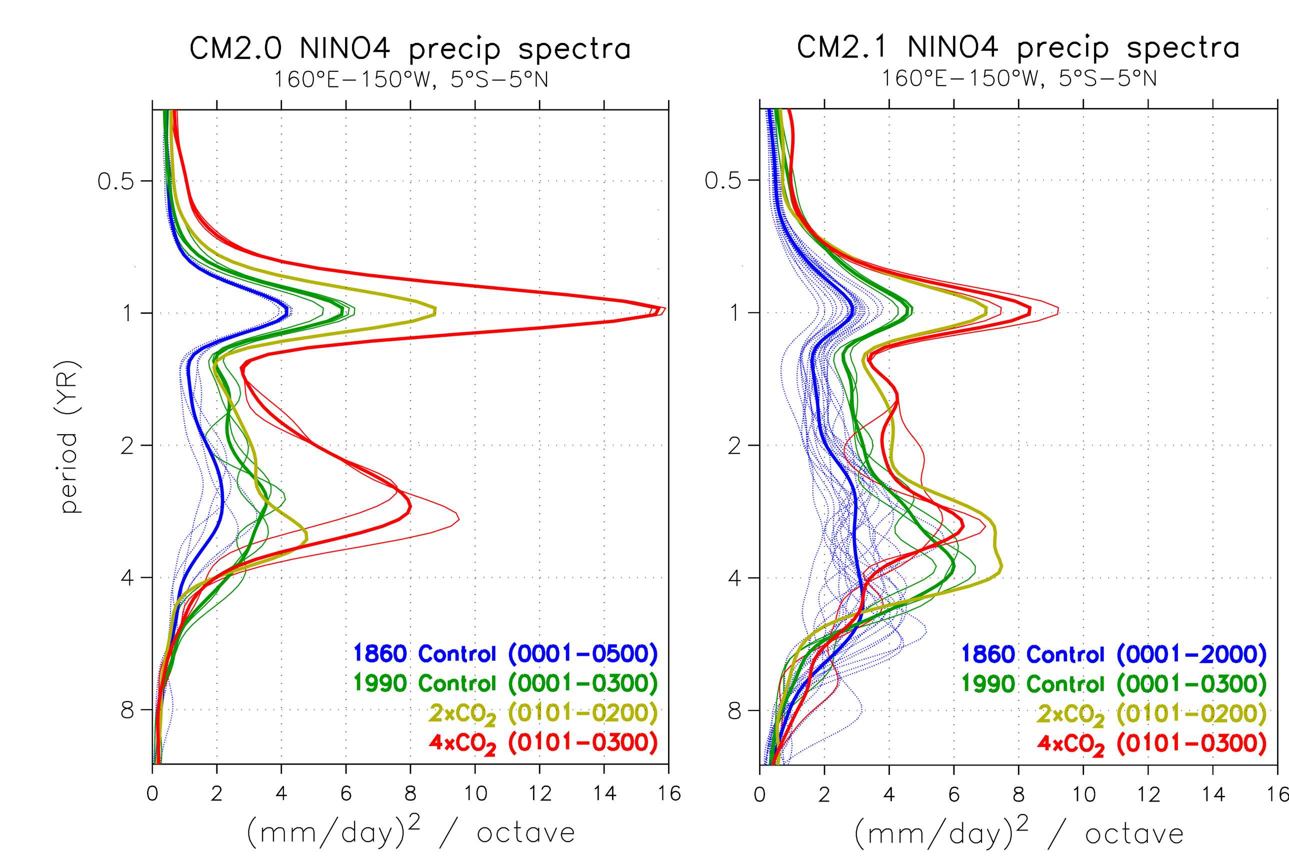


In the eastern equatorial Pacific, stronger southeasterly trades in boreal summer/fall enhance the upwelling peak, and weaker trades in boreal spring amplify the upwelling minimum. These increased seasonal upwelling variations act upon the stronger mean upper-ocean thermal stratification at $4xCO_2$, giving an enhanced seasonal cycle of ocean-dynamical cooling — which is slightly opposed by the changes in net surface heat fluxes.

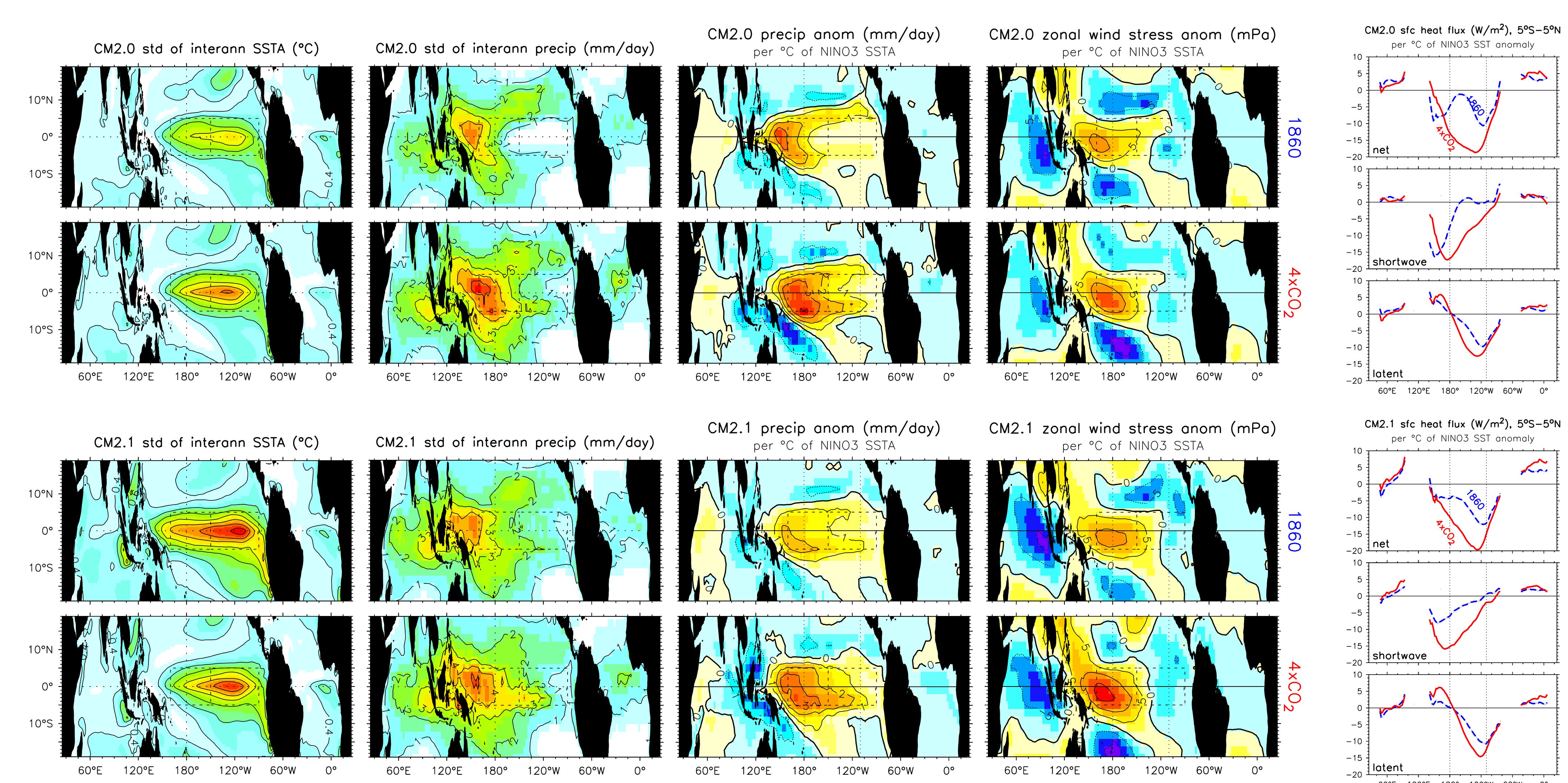


4. Interannual Variability and ENSO

Many of the simulated CO_2-induced changes in ENSO are detectable only with long time series, due to the strong multidecadal modulation of ENSO in CM2.0 & CM2.1. However, in both models there is a clear strengthening & eastward shift of the equatorial Pacific rainfall variations. This occurs even in CM2.1, which has reduced interannual SST variance at $4xCO_2$ (see below). The plots at right show spectra of NINO4 rainfall, from individual centuries (thin lines) and multi-century means (thick lines). As CO_2 levels rise, both models show monotonically increasing precipitation variance at time scales shorter than 2yr. At time scales beyond 2yr, ENSO amplifies & shifts to longer periods at first; but at higher CO_2 it shifts back to shorter periods and (in CM2.1) weakens. The thresholds for these changes differ between the models, with CM2.1 acting like a higher-CO_2 version of CM2.0. At $4xCO_2$, both models show increased sensitivity of equatorial Pacific rainfall & zonal wind stress to ENSO SSTAs.



The surface heat flux damping of SSTAs also increases, due to enhanced cloud shading (in the central Pacific) and evaporation (in the east Pacific) during ENSO warm events. Compared to CM2.1, CM2.0 shows a larger increase in surface heat flux damping, and more of an eastward shift of the equatorial zonal wind stress response to SSTAs. Over the Indian Ocean, Atlantic, and east Pacific, the variance of zonal wind stress weakens at both interannual and subannual time scales (not shown). The $4xCO_2$ case also amplifies the ENSO heat flux forcing of the Atlantic, with enhanced solar heating and greater reductions in evaporation during El Niño.



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