The Role of El Niño in Regulating the Long-term Mean Strength of the Walker and Hadley Circulation.

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A coupled model for the Pacific region has been used to study the response of the zonal SST contrast and the strength of Walker circulation to changes in the meridional differential heating over the Pacific ocean. Different from the previous studies that use an intermediate ocean model, the present model employs a primitive equation model for the Pacific ocean—the NCAR Pacific basin model— and therefore has an explicit heat budget for the subsurface ocean. By calculating subsurface ocean temperature explicitly from the first principles, the model also allows feedbacks of El Niños upon the thermal structure of the equatorial upper ocean and thereby upon the stability of the equatorial ocean. Different from full-blown GCM studies that use either a low resolution ocean GCM or questionable treatment of clouds and water vapor that lead to an unrealistic El Niño in the coupled model, the present coupled model has a fine resolution for the equatorial region and employs an empirical atmosphere in which the clouds and water vapor feedbacks have observed values. Consequently, the model simulates ENSO well. The amplitude, the dominant frequency, as well as the evolution of the subsurface temperature in the present model agree well with observations (Fig. 1; Also see Sun 2002)

We found that in the presence of El Niños, the long term mean zonal SST contrast and therefore the long-term mean strength of the Walker circulation is insensitive to either an increase in the surface heating in the equatorial region or an enhanced cooling in the subtropical region. In response to either an increase in the equatorial surface heating or an increase in the subtropical cooling, the zonal SST contrast initially strengthens, but then stronger El Niño develops that warms the eastern equatorial Pacific and cools the equatorial western Pacific, largely reversing the initial response of the zonal SST contrast in the cold-phase. The long-term mean change in the zonal SST contrast is a small residual of the corresponding changes on the inter-annual times-scales (Fig. 2 and Fig. 3)

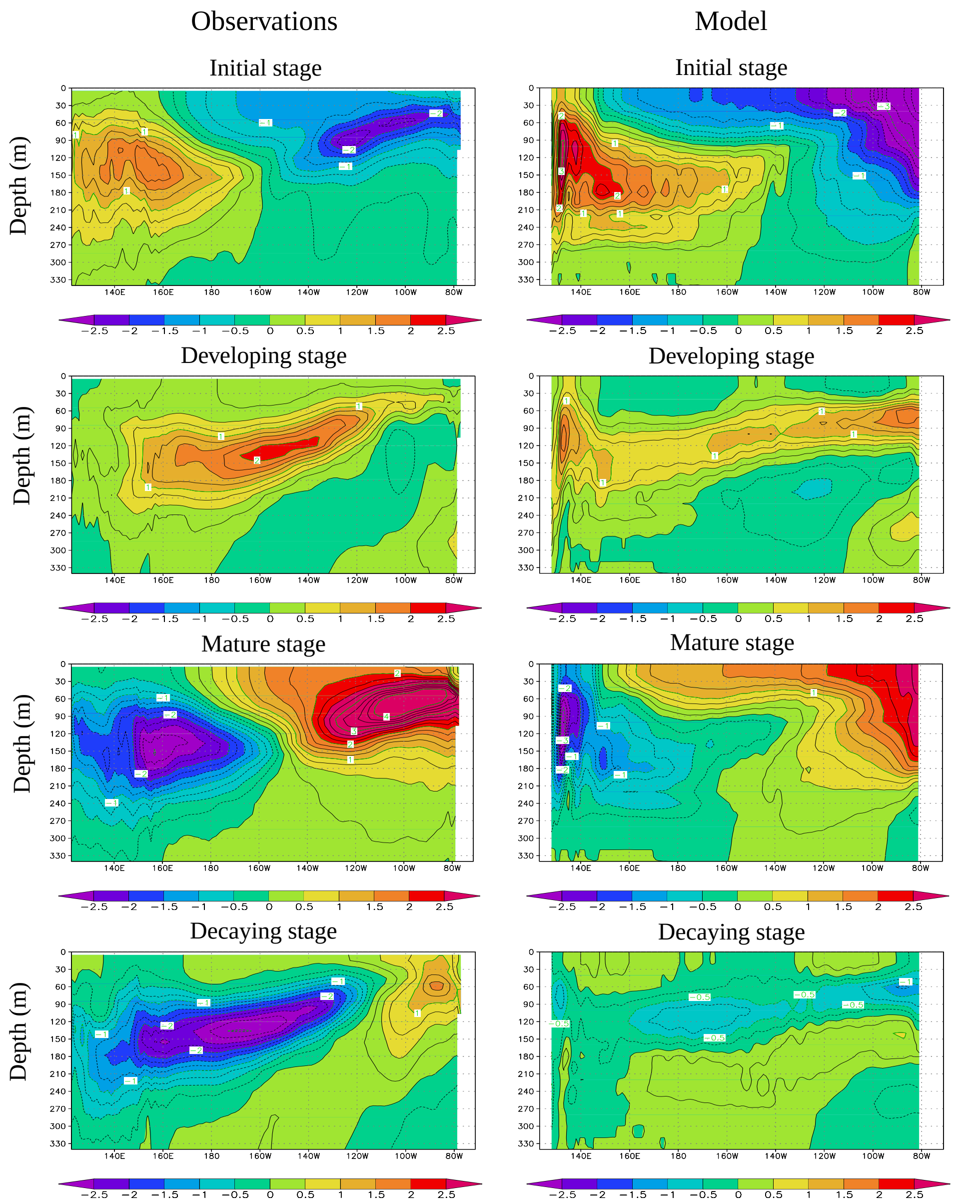

Figure 1: Evolution of the subsurface temperature at various stages of El Niño from the model and observations. The initial state corresponds to the time when the Niño3 SST anomaly is at a minimum, the developing stage corresponds to the time when the Niño3 SST anomaly rises to zero, the mature stage corresponds to the time when the Niño3 SST reaches a maximum, and the decaying stage corresponds to the time when the Niño3 SST anomaly falls back to zero again. Shown are composites. The composite for the model includes 4 cycles of the model oscillation. The ocean temperature data from the NCEP assimilation system is used to construct the composite for the observations and it includes all 6 El Niños in the last 20 years.

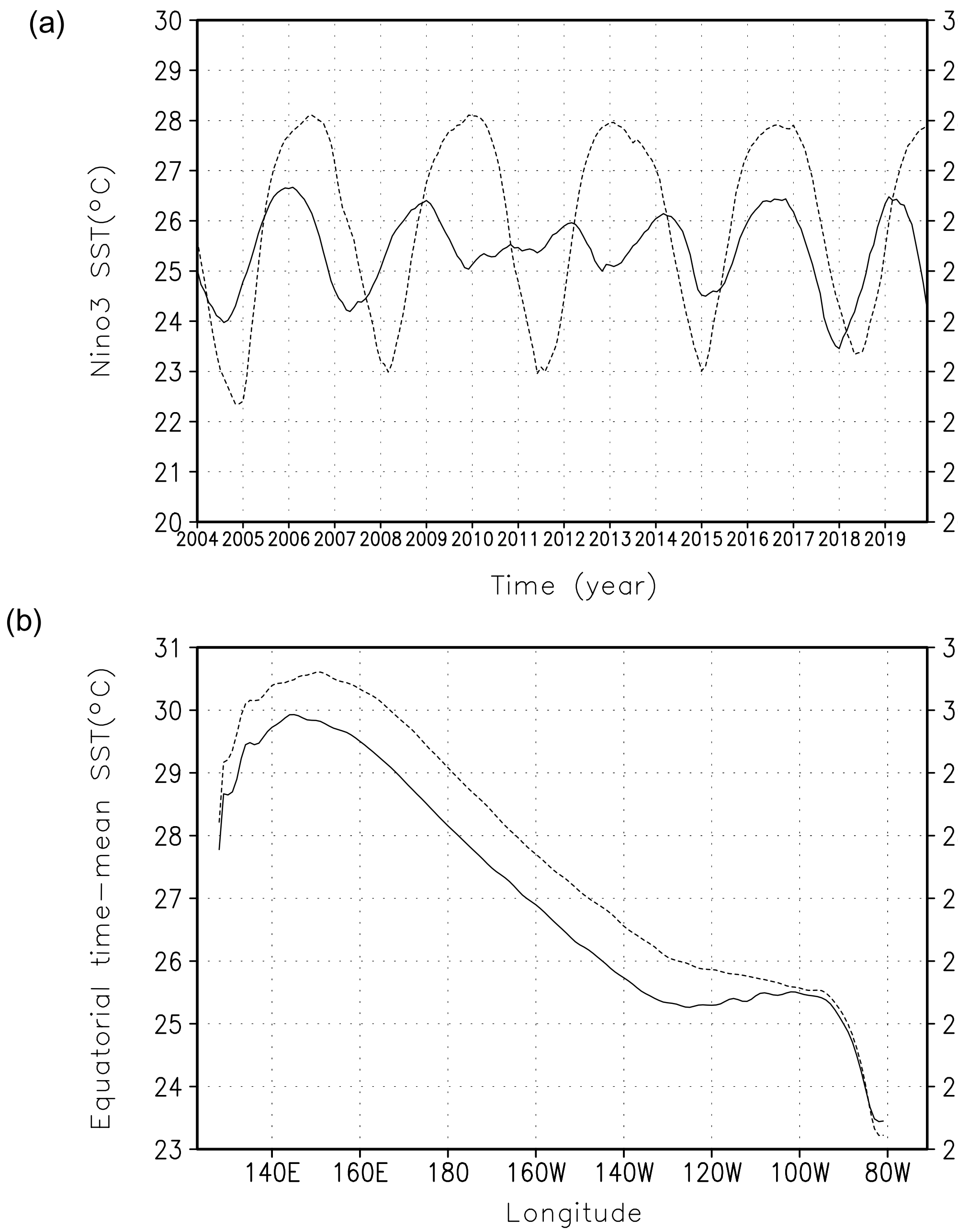

Figure 2: (a) Time series of Niño3 SST from experiment I (solid line) and experiment II (dashed line). (b) Time-mean equatorial SST (5^oS-5^oN) from experiment I (solid line) and experiment II (dashed line). Experiment II was forced with a higher radiative convective equilibrium temperature (SST_p) (i.e., a stronger heating) over the equatorial region.

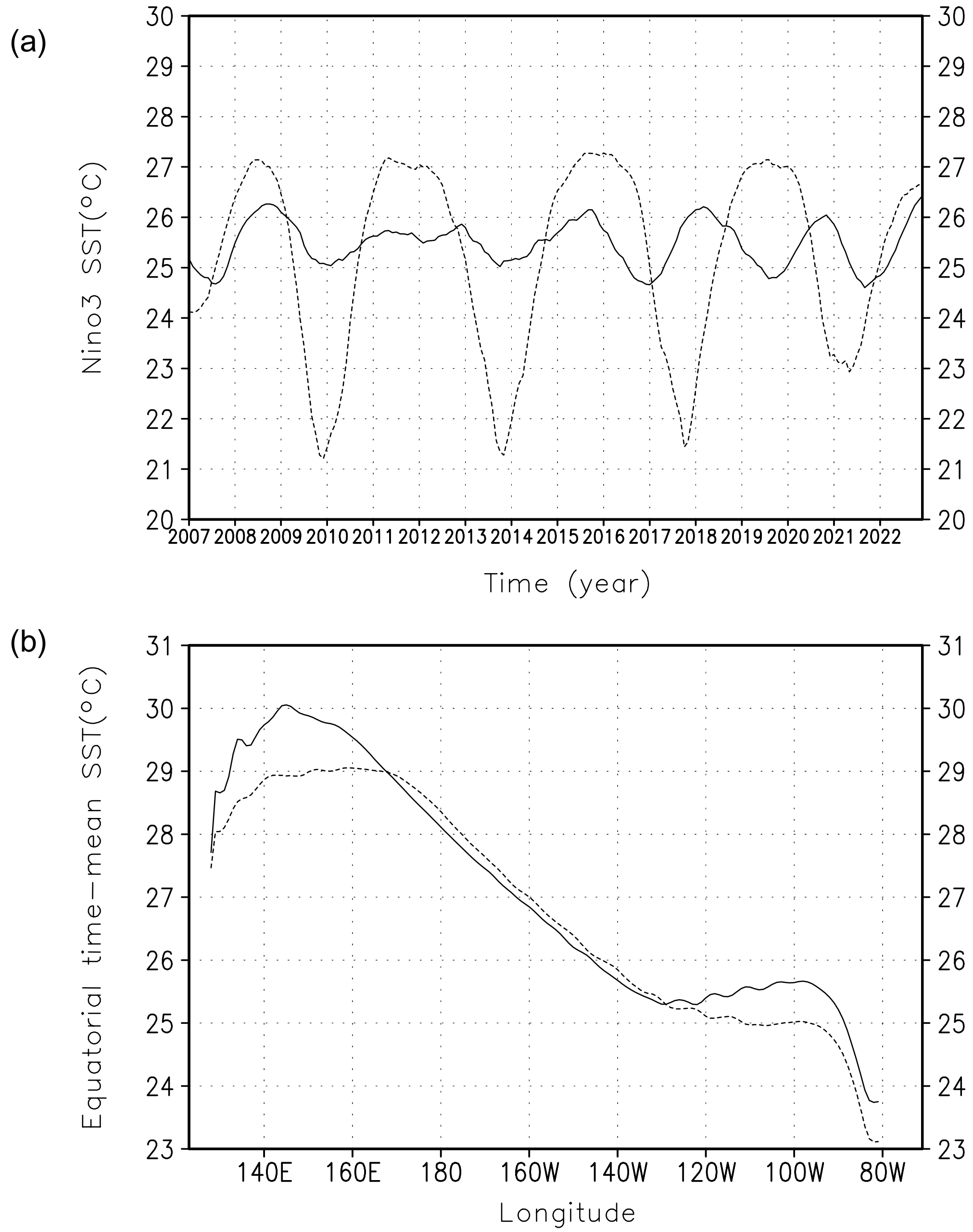

Figure 3: (a) Time series of Niño3 SST from experiment I (solid line) and experiment III (dashed line). (b) Time-mean equatorial SST (5^oS-5^oN) from experiment I (solid line) and experiment III (dashed line). Experiment III was forced with a reduced radiative convective equilibrium temperature (SST_p) (i.e., a stronger cooling) over the subtropical region (Sun et al. 2002)

By regulating the strength of the Walker circulation, it appears that El Niño helps to maintain a sufficiently strong Hadley circulation in the atmosphere to deliver heat efficiently to the higher latitudes. This finding supports the original “heat pump” concept for ENSO (Sun and Trenberth 1998, Sun 2002, Sun 2002). It also implies that the observed strengthening of the Hadley circulation over the last two decades may be related to the exceptional strength of El Niño events during this period.

References:

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