2.2 The Control of the Warm-pool SST over the Magnitude of El Niño Warming

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1. INTRODUCTION

This study concerns the effect of an increase in the warm-pool SST on the magnitude of El Niño warming. It is motivated by the observations that the warm-pool SST has been anomalously high in the last two decades and that the two strongest El Niños of the last century were also observed during this period. Both observational and numerical experiments are presented to argue for a positive impact of an increase in the warm-pool SST on the magnitude of El Niño warming. It is also suggested that to the extent that the warming trend in the tropical maximum SST can be attributed to anthropogenic forcing, global warming may have already contributed significantly to the strengthening of the ENSO cycle.

2. METHODOLOGY

Noting the close link between the tropical maximum SST and the equatorial surface heating, we begin with an analysis of the observed heat balance of the tropical Pacific. The ocean temperature data employed for the analysis are from the NCEP assimilation system (Ji et al. 1995). Specifically, we attempt to determine (1) the role of El Niño in the heat balance of the tropical Pacific, (2) the relationship between the magnitude of El Niño warming and the equatorial upper ocean heat content, and (3) the role of zonal SST contrast in pushing heat absorbed at the surface down to the subsurface ocean. Based on the resulting empirical findings, a hypothesis concerning how the amplitude of ENSO may respond to an increase in the tropical maximum SST is formulated. Finally experiments with a coupled numerical model are performed to test the validity of the hypothesis.

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3. RESULTS

The analysis of the observed heat balance reveals that the poleward heat removal from the equatorial Pacific is achieved episodically—active periods with large poleward heat transport are preceded and then followed by quiescent periods during which the transport is small. The active periods correspond well with the observed El Niños (Fig. 1). This confirms that El Niño is a major mechanism by which the tropical Pacific transports heat poleward. Moreover, the analysis also suggests that El Niño regulates the heat content of the western Pacific: the higher the heat content in the western Pacific, the stronger the subsequent El Niño warming to bring down the heat content in the western Pacific (Fig. 2). The analysis also shows a positive relationship between the zonal SST contrast, the surface heat flux into the equatorial ocean, and the equatorial upper ocean heat content.

These results lead to the following scenario concerning how the amplitude of ENSO may respond to an increase in the tropical maximum SST. An increase in the tropical maximum SST initially increases the zonal SST contrast by the mechanism of Sun and Liu (1996) and Clement et al. (1996). A stronger zonal SST contrast then strengthens the surface winds. Because of the stronger winds and the resulting steeper tilt of the equatorial thermocline, the coupled system is potentially unstable and is poised to release its energy through a stronger El Niño warming. A stronger El Niño then pushes the accumulated heat poleward and prevents heat buildup in the western Pacific and thereby stabilizes the coupled system.

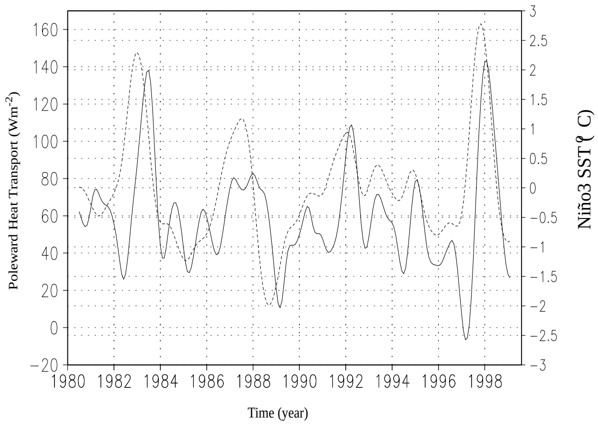

Figure 1: Poleward ocean heat transport out of the equatorial region (5^{o}S-5^{o}N) with the seasonal variations removed. The seasonal variations were removed by first removing the climatology of 1980-1998. The climatological annual mean value was then added to restore the sign of the transport. A Hanning window with a width of 13 months was used to smooth the data. The dashed line indicates Niño3 SST anomaly.

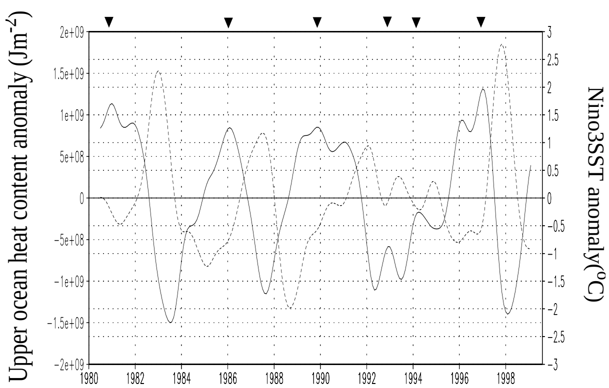

Figure 2: Time series of the upper ocean heat content of the western half of the equatorial Pacific (120^{o}E-205^{o}E). The time series in dashed line is the SST anomaly of the Niño3 region. A Hanning window with a width of 13 months was used to smooth the SST and the heat content. The long-term mean value of the heat content was removed. Shown is the ocean heat content in the upper 260 m. Further increasing the depth in calculating the upper ocean heat content does not change the magnitude of variability significantly, suggesting variability is mostly confined in the upper 260 m. Note that all El Niños are preceded by a peak in the heat content of the western Pacific. The triangles mark the timing of these peaks.

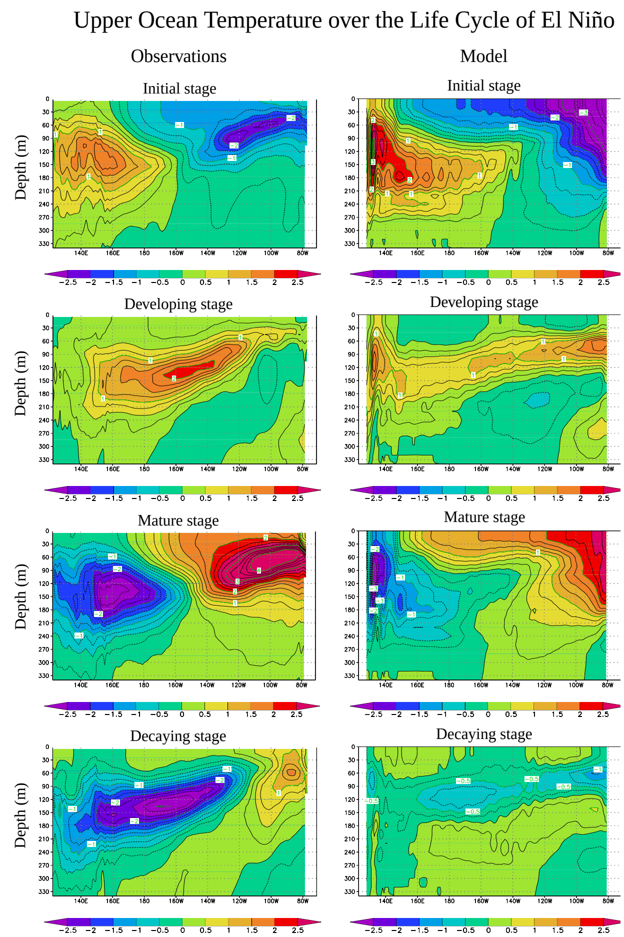

Figure 3: Evolution of the subsurface temperature at various stages of El Niño from experiment II and observations. Shown are anomalies. The initial state corresponds to the time when the Niño3 SST anomaly is at a minimum, the developing stage corresponds to the time when the Niño3 SST anomaly rises 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 experiment II includes 4 cycles of the model oscillation. The ocean temperature data from the NCEP assimilation system (Ji. et al 1995) is used to construct the composite for the observations and it includes all 6 El Niños in the last 20 years. Adapted from Sun (2001).

To test this hypothesis, experiments have been carried out with a coupled model. The atmospheric component is an empirical model in which the equatorial wind stress is proportional to the zonal SST contrast, and the equatorial surface heating is proportional to the difference between the tropical maximum SST and the actual SST. The ocean component is a GCM—the NCAR Pacific basin model (Gent and Cane 1989). Therefore, different from earlier intermediate ocean models for ENSO (Zebiak and Cane 1987, Battisti 1988), the present model explicitly calculates the heat budget of the entire equatorial upper ocean, not just the heat budget of the mixed layer. The numerical model produces ENSO-like oscillations. The period of the oscillation is about 3.5 years. The evolution of the subsurface ocean temperature over the life cycle of the model El Niño resembles that from observations (Fig. 3). In response to an increase in the tropical maximum SST, the model has a stronger ENSO (Fig. 4). The experiment with a higher maximum SST also has higher time-mean SST across the equatorial Pacific.

4. IMPLICATIONS

The present results support the earlier suggestion by Sun (1997) and Sun and Trenberth (1998) concerning the role of the tropical maximum SST and the equatorial surface heating in determining the magnitude of El Niño warming, and more generally the "heat pump" concept of Sun (2000). The "heat pump" picture extends our understanding of ENSO in that it delineates the importance of the thermodynamic conditions that are required to support El Niño. In analogy with Biology, the coupled wave dynamics emphasized in the delayed oscillator hypothesis (Battisti 1988, Suarez and Schopf 1988) may be regarded as a "gene" of the coupled climate system. Whether the gene in a real biological organism expresses or fully expresses itself depends on the environment it is subjected to (for example, whether the environment has sufficient nutrients). Whether the coupled climate system is able to sustain El Niño depends on the value of the tropical maximum SST or more simply how warm the tropical Pacific is (relative to the deep ocean temperature or the extratropical SST)

More specifically, the results suggest that the exceptional strength of the 1982-83 and the 1997-98 El Niño may be linked to the anomalously high warm-pool SST during the last two decades. To the extent that the warming trend in the warm-pool SST can be attributed to global warming, the results further suggest that global warming may have already contributed to the strengthening of the ENSO cycle. It has been noted that the tropical maximum SST has been warming up in a similar fashion as the global mean surface air temperature (Sun 2001). The results also suggest that the underestimate of ENSO variability in the NCAR CSM (Meehl and Arblaster 1998) may be partially related to the colder warm-pool SST in the model (Kiehl 1998).

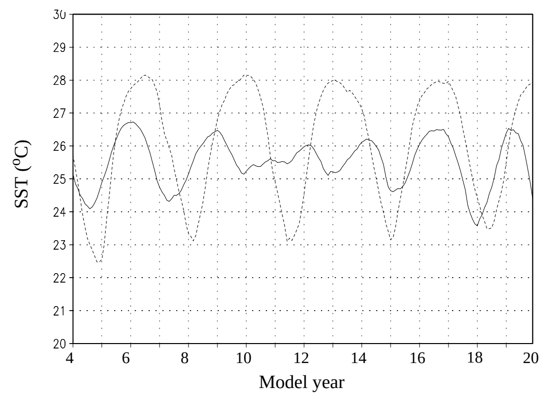

Figure 4: Time series of Niño3 SST from experiment I (solid line) and experiment II (dashed line). Experiment II starts at the same initial conditions as experiment I, and both are run for 20 years. Shown are the last 16 years of the experiments. Experiment II has a higher tropical maximum SST than experiment I.

5. ACKNOWLEDGMENTS

This research was partially supported by NOAA and partially supported by NSF climate dynamics program under Grant ATM—9912434. The author would like to thank helpful comments from Dr. Mike Alexander, Dr. Martin Hoerling, Dr. Prashant Sardeshmukh, Dr. Richard Seager, and Dr. Kevin Trenberth. Technical support from Mr. Andres Roubicek is also gratefully acknowledged.

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