10B.2 TROPICAL TROPOSPHERIC TEMPERATURE VARIATIONS CAUSED BY ENSO AND THEIR INFLUENCE ON THE REMOTE TROPICAL CLIMATE

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1. Introduction

The connection between interannual variations in tropics-wide tropospheric temperature (hereafter TT) and ENSO is well established (e.g Yulaeva and Wallace 1994). The reason its uniform distribution is well understood; the tropical free atmosphere cannot maintain horizontal pressure gradients, and temperature anomalies become uniformly distributed over the global tropics on time scales of a month or two (e.g. Wallace 1992). What is the effect of this warming on the variability of other tropical climate variables outside the Pacific (hereafter the remote tropics)? The problem can be usefully simplified by assuming ENSO controls interannual TT variations everywhere in the tropics, and considering only the vertical (1-D) response.

2. Model setup

We use a single column model to study the remote tropical vertical column's adjustment to imposed TT perturbations above the boundary layer. The single-column model is based on the radiative-convective model of Rennó, Emanuel, and Stone (1994), and uses the convective scheme by Emanuel (1991) and the radiation scheme of Chou et al. (1991). Clouds are not modeled; and a fixed-depth ocean slab mixed layer is prescribed for the surface.

The perturbation experiments are done for three mean state climates: precipitation (P) > evaporation (E), P<E, and no convection; representing three distinct regions of the tropical atmosphere. The ENSO-related perturbation vertical temperature profile applied to the model was obtained through empirical orthogonal function (EOF) analysis of reanalyses anomalous monthly mean 200mb-750mb temperatures averaged over all longitudes and 16.25°S to 16.25°N.

3. Model results I: sinudoidal forcing

After a model spinup period of 500 days, the perturbation temperature profile is applied to the model in time with a sine wave with period 2 years. The model P>E and P<E responses in P, E and SST are also approximately sinusoidal with the same period, but differ in phase (figure 1). The amplitude of the SST is O(1K) for the 40m mixed layer depth (MLD); the P response is an appreciable fraction of the mean P. Varying the MLD significantly changes the phase and amplitude of the P, E and SST response (figure 1). In the no convection mean state, SST responds much more weakly (O(0.1K)) to the TT perturbation for the 40m MLD.

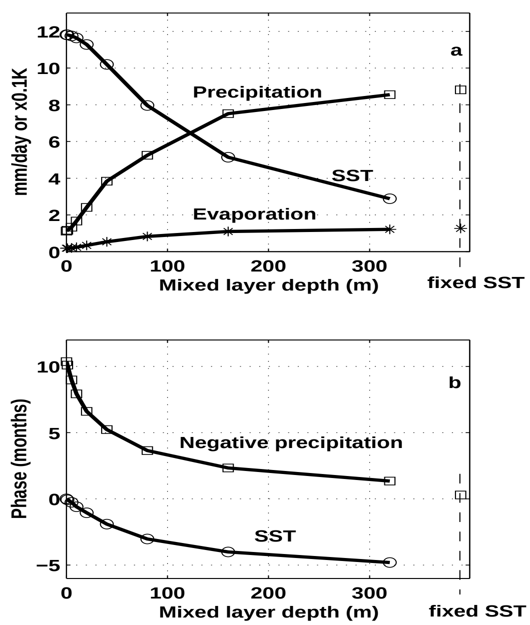

Figure 1: P>E model response with varying MLD. a) P, SST, and E peak-to-peak amplitude; b) Phase of negative P and SST relative to TT forcing; positive phase implies response leads TT. The P<E model response is similar.

4. Interpretation

We argue that the inverse relationship between the model SST and precipitation amplitude is causally linked. If the imposed TT is perturbed, then strict quasi-equilibrium maintains that subcloud-layer equivalent potential temperature (θeb) will follow TT perturbations over timescales comparable to the convective timescale. However, θeb is also tightly linked to the SST through surface latent heat flux, implying that there is another timescale associated with SST adjustment. This timescale turns out to be linear with MLD, with a slope of roughly 4.5mo per 100m. So, for the range of MLD that can be practically considered – from

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shallow O(1m) MLD that may be thought of as a proxy for land, to O(100m) for those parts of the ocean with deep mixed layers and/or downgradient ocean heat transport – the model either can be considered to be in approximate equilibrium to the ENSO TT forcing (shallow MLD) or continually in adjustment (deep MLD).

5. Response of the remote tropics to ENSO

We forced the model (P>E basic state) with realistic TT variations over 1979-1999, and compared the model SST and T output (figure 2) to observations.

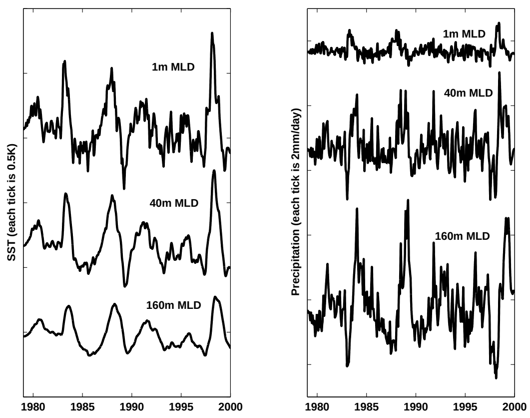

Figure 2: P>E model response (1m, 40m, 160m MLD) to realistic TT forcing. Left is SST; right is P. Tick intervals are 0.5K and 2mm/day

The model SST variation is similar to each other, and to the TT forcing (with a few months phase lag), for the various MLD considered. This generally corresponds to the observed remote tropical surface temperature response to ENSO (Yulaeva and Wallace 1994, Klein et al. 1999). The P response is more varied for different MLD, and not readily associated with the forcing. It suggests that ENSO-related remote tropical precipitation variations may not be trivially related to the standard ENSO indices; and furthermore, the response depends crucially on the nature of the surface response.

Our model offers a simple dynamical explanation (weak temperature gradients; convective quasi-equilibrium) for the gross observed tropics-wide spatial structure of the ENSO-related remote surface temperature response over both land and ocean regions (figure 3). It additionally offers a simple explanation for the lack of response over the southeast tropical Atlantic and southeast tropical Indian oceans. Those regions have high stratus cloud cover (not shown) and are thus have high lower tropospheric stability and no convection. The surface is therefore decoupled from the free troposphere, and cannot respond to TT.

Finally, our model predicts that latent heat flux variations due to change in the air-sea temperature difference is a major process responsible for the remote tropical surface response to ENSO. This is in addition to the wind speed and cloudiness variations that have been shown from observations to be significant (Klein et al. 1999).

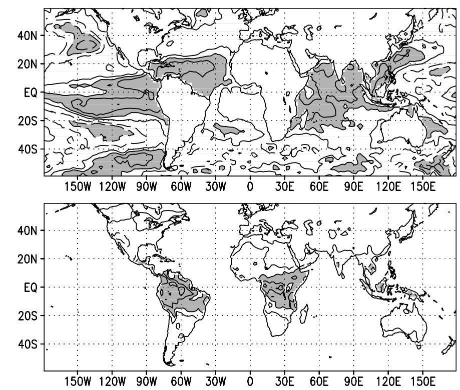

Figure 3: Linear correlation between the 40m MLD SST timeseries in figure 2, and reanalyses surface temperature. Top: over ocean; bottom: over land. Contour interval is 0.15, magnitudes over 0.3 are shaded. Dashed lines are negative correlation; the zero line is not shown.

6. References

Chou, M.-D., D. P. Krantz, and W. Ridgeway, 1991: Infrared heating parameterizations in numerical climate models. *J. Climate*, **4**, 424-437.

Emanuel, K. A., 1991: A scheme for representing cumulus convection in large-scale models. *J. Atmos. Sci.*, **48**, 2313-2335.

Klein, S. A., B. J. Soden, and N.-C. Lau, 1999: Remote sea surface temperature variations during ENSO: evidence for a tropical atmospheric bridge. *J. Climate*, **12**, 917-932.

Rennó, N. O., K. A. Emanuel, and P. H. Stone, 1994: Radiative-convective model with an explicit hydrologic cycle. 1: Formulation and sensitivity to model parameters. *J. Geophys. Res.*, **99**, 14429-14441.

Wallace, J. M., 1992: Effect of deep convection on the regulation of tropical sea-surface temperatures. *Nature*, **357**, 230-231.

Yulaeva, E. and J. M. Wallace, 1994: The signature of ENSO in global temperature and precipitation fields derived from the Microwave Sounding Unit. *J. Climate*, **7**, 1719-1736.