Diagnosing ENSO Variability in the CCSM3.5

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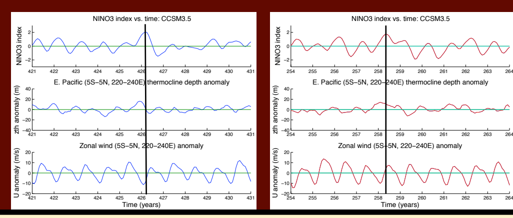
Abstract

Modeling the El Nino - Southern Oscillation (ENSO) has traditionally been extremely difficult, often resulting in significant errors in ENSO period and amplitude. When combined with the uncertainties involved with paleoclimatic reconstruction, the problem of understanding ENSO during past climates becomes extraordinarily complex. We use NCAR's Community Climate System Model (CCSM) version 3.5, which has been able to more faithfully reproduce present-day ENSO behavior than most models to date, to perform a bulk analysis of El Nino in the model. There is a large amount of wave activity present in the CCSM3.5, which will require additional investigation to classify. Also, we note that it appears that pre-existing conditions in the eastern Pacific may act to amplify El Nino events; a closer look at phase relations between model parameters should prove to be extremely interesting.

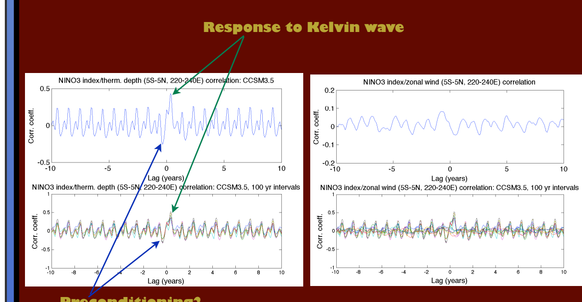
Lag/Lead Relationships

In order for an El Nino event to occur, anomalies in thermocline depth/ prevailing winds must be communicated across the Pacific. This is typically done via Kelvin waves, with crossing times of approximately 4 months. When one looks at the time series of NINO3 index (average SST between 5S-5N, 90-150 E; used to define an El Nino) in relation to the time series of zonal wind or thermocline depth, definite lags are seen.



Relations between variations in NINO3 index (top) and conditions in the eastern Pacific: thermocline depth (middle) and zonal wind (bottom).

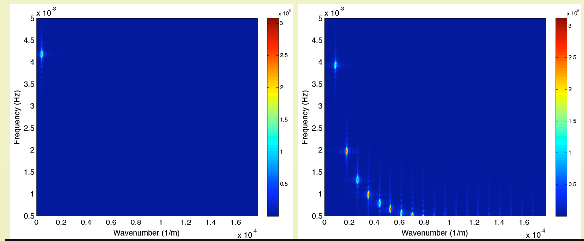
However, a lag-correlation analysis (below) shows that NINO3 correlates with wind and thermocline depth at both positive and negative lead times! This indicates that pre-existing anomalies (shallow thermocline depth, westward zonal wind) in the eastern Pacific may act to amplify a propagating Kelvin wave, and trigger a larger El Nino/La Nina event than might have otherwise occurred.



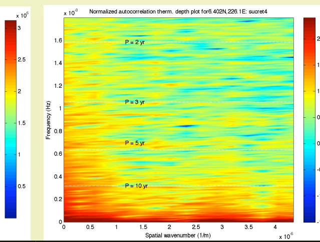
Lag-correlations between NINO3 index, zonal wind, and thermocline depth in the eastern Pacific. Upper panel: correlations for the entire model run. Lower panels: intervals of 100 years, spanning the entire run. Negative lags indicate NINO3 leading; positive, NINO3 lagging.

Autocorrelation

The autocorrelation matrix for the thermocline depth field was computed, and is shown in Figure 2. This matrix is created by cross-correlating the time series of a variable at every grid point with the time series at every other grid point, at every possible lag time. After undergoing Fourier transforms in space and time, the autocorrelation matrix thus represents signals transmitted throughout the Pacific as a function of temporal and spatial frequency. Patterns resembling Rossby wave dispersion relations may be seen., although they are most likely obscured by the presence of multiple wave modes.



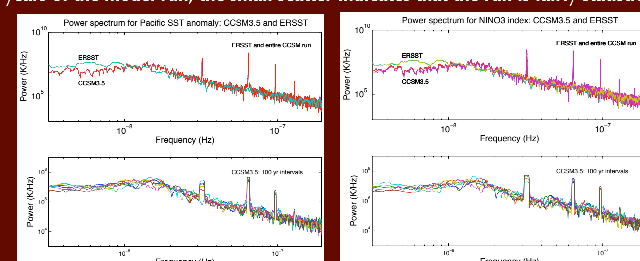
Sample autocorrelation plots, showing a wave at a single frequency/wavenumber (left) and the dispersion relation for a Rossby wave (right).



Autocorrelation matrix for thermocline depth, generated at 4 N.

Model Validation

Tthe CCSM3.5 represents an improvement in the treatment of ENSO, in particular in replicating El Nino amplitude at periods from 2-4 years. NOAA's Extended Reconstructed SST (ERSST) project is used to illustrate this point, as seen in CCSM3.5 and ERSST power spectra below. The two show good agreement, with some underprediction of long-period variability by CCSM. Lower panels display CCSM power spectra for each 100 years of the model run; the small scatter indicates that the run is fairly statistically robust.



Power spectra for: mean Pacific SST (5S - 5N, 140-270 E), at left; and NINO3 SST (5S - 5N, 210-270E), at right. Both the ERSST dataset (green) and the CCSM3.5 (blue) are shown in top panels. Lower panels show CCSM3.5 power spectra for each 100 years of the run.

Conclusions & Future Work

This work represents a preliminary look at ENSO in the CCSM3.5. We have been able to improve the representation of ENSO at periods between 2-4 years, and find good agreement with real-world data from the ERSST project.

On examining the strongest El Nino and La Nina events in the model, we find that these are often preceded by anomalies in either thermocline depth or zonal wind. This indicates that pre-existing conditions in the east have the ability to significantly enhance propagating anomalies which might not otherwise lead to strong El Nino/La Nina conditions.

Future work on simulation output will focus on identifying the wave modes operating in CCSM3.5, and investigating the phase relationships between wave reflection events and the onset/end of El Nino. We would like to answer the question: does wave reflection play a role in the transition from El Nino to La Nina?

The techniques described here remain equally valid when applied to satellite measurements, or datasets constructed from paleoclimate proxies. We hope to extend this analysis to both types of data in the future, both for model validation purposes and to better understand the sources of ENSO variability in the real climate system.