27th Annual Climate Diagnostics and Prediction Workshop
21-25 October 2002, George Mason University, Fairfax, VA

Dynamic Characterization of ENSO Using a Multi-Index Approach

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INTRODUCTION

Presently, and historically, El Nino has been characterized by one index, namely its strength. The measure of strength is most commonly taken as the average sea surface temperature (SST) anomaly over a fixed region. The NINO3.4 region (5S-5N; 170W-120W) has been shown in many studies to be one of the most relevant regions to average over due to its proximity to the convectively active western Pacific and its relatively high interannual variance in SST. The strength of an El Nino (or La Nina) event is but one attribute of an event, and it has long been recognized that different "flavors" of El Nino exist that are not fully described by the event's magnitude.

When describing the physics of ENSO one typically invokes the Bjerknes model of the coupled ocean-atmosphere behavior of the tropical Pacific. In this conceptual model, low-level winds flow towards the warmest water over which convection occurs. The upper-level outflow from the convective region and subsequent sinking over the cooler waters leads to tropical circulation cells such as the Walker cell. In the ocean, the low-level winds maintain an east-west tilt in the thermocline that reinforces the east-west temperature gradient that is to some degree responsible for those winds in the first place. Thus there is a coupling between winds, SST and ocean structure. A change to any of those elements can give rise to positive feedbacks in all elements leading to the growth of El Nino or La Nina events. For example, during the growth of an El Nino event, warm SST anomalies in the eastern Pacific reduce the zonal temperature gradient, and the trade winds get weaker allowing convection and warm surface water held in the west to move eastward. This deepens the thermocline in the east making the surface temperatures there warmer and thus the zonal temperature gradient weaker, further weakening the trade winds, and so on.

The global impacts on surface climate from ENSO events, commonly referred to as teleconnections, are communicated to the remote tropics and to the extratropics by the changes in tropical convective heating forced by the ENSO event. The strength and position of these convective anomalies are therefore the link between the ENSO event and the associated global climate impacts. It seems plausible that the “flavors” of El Nino impart important event-to-event differences to the convective anomalies that could yield more specific information regarding how a particular event is likely to impact the climate.

“WALKER INDICES” OF ENSO

A set of ENSO indices is presented that captures three aspects of an ENSO event, which are all potentially relevant to the event's impact on the climate. These aspects are strength, position, and spatial scale. While these indices are highly correlated with SST anomaly indices such as NINO3.4 and with each other, they constitute a more complete and dynamically satisfying description of an ENSO event. Moreover, because they encapsulate more details about the anomalous state of the tropical Pacific region they may lead to a better estimation of the degree to which the climate is likely to be impacted due to the ENSO event.

In determining these indices, certain qualities were sought. First, the indices should not be constrained by any assumptions of linearity, particularly between cold and warm extremes, such as occurs with EOF-based indices like the Multivariate ENSO Index (MEI). Second, the indices should be constructed from relatively well-monitored data with a long history. Although the convective anomalies may be the primary atmospheric ENSO signature, such data is only available since 1979. Finally, the indices should be consistent with the ENSO-associated variability of the tropical Pacific atmosphere described previously. Indices for the strength, position and spatial scale are based on SST, which can be used to describe the three aspects of strength, position and spatial scale while possessing the desired qualities just listed.

1) **Position –** This index tracks the longitude of the warmest SST anomalies.

Following the conceptual model of Bjerknes, where the convection is positioned over the warmest SST, the position of the maximum convective anomalies should be highly correlated with the position of warmest SST anomalies. (For the period 1979-present, this correlation exceeds 0.9). Secondary considerations for this index are that the value lies between 120E and 90W and that total SST at that location exceeds 27 C. The position of the maximum total SST was also considered, since the atmosphere does see total SST, and the impact of SST on convection is not entirely linear.

2) **Strength –** This index measures average SST anomaly over the “Walker Box”, within 5 degrees of equator.

The “Walker Box” is first determined, starting from the Position Index (described above) and then finding the first relative minimum SST anomaly to the east and west of that position, but still within the longitude range 120E-90W. The “Walker Box” is then that region between the relative minimum and maximum positions. Whether the Walker box is that region to the east or to the west of the maximum depends on the sign of the shift in the maximum. This ensures that the region considered is that most likely involved in modifications to the Walker circulation. During an El Nino event, when the maximum SST anomaly is shifted eastward, the Walker Box will lie to the west of the maximum point, and during a La Nina event when the maximum SST anomaly has a relative westward shift, the Walker Box will lie to the east of the maximum point. Examples of the Walker boxes determined for OND 1982 (at peak of an El Nino event) and for OND 1988 (at peak of a La Nina event) are shown in Figures 1 and 2, respectively. The strength of the SST anomalies can influence the strength of the convective anomalies by providing thermodynamic energy to the atmospheric heating.

3) **Structure –** This index measures the anomalous SST gradient over the Walker Box.

The anomalous gradient of SST is defined (SSTa_east – SSTa_west)/dX. The anomalous zonal temperature gradient has the potential to influence the strength of anomalous convection. To the extent that anomalous low-level winds are in part driven by anomalous SST gradients, the relative convergence into the anomalous convection, and thus resulting ascending motion and associated atmospheric heating, will be affected.

These three indices are the multi-index set proposed to quantify and characterize ENSO events, and variability in the tropical Pacific in general. The indices are *dynamic* because the region over which they are determined is not fixed in size or location, such as the NINO3.4 region.

ASSOCIATED CLIMATE IMPACTS

Ultimately, the value of measuring ENSO events lies in the correspondence of that measure to the overall perturbation to the global climate system. Thus, we investigate the ability of our multi-index description of ENSO to represent better the magnitude of global rainfall variability compared to that associated with the NINO3.4 SST anomaly index.

Cross-validated linear regression models were set up for each of the indices and for the NINO3.4 SST anomaly index relative to the observed global gridded precipitation anomalies in a given season. None of the Walker Indices, on its own, explained more precipitation variability globally than did the NINO3.4 index. For some regions in particular seasons the variability was better described using one of the Walker indices than NINO3.4. Examples include the rainfall over Southeastern China in JFM using the position of maximum total SST, rainfall over the Sahel in JAS using the strength index (SST anomalies averaged over "Walker Box"), and rainfall over Southeastern Brazil for OND using the structure index (gradient of SST anomalies taken over "Walker Box"). As a single index, however, the NINO3.4 outperformed the other indices.

Still, the possibility exists that the Walker Indices are capturing different and important aspects of the ENSO events, and thus a combination of those indices could lead to a more comprehensive description of the potential climate impacts. Thus a multiple linear regression model was constructed using all the Walker Indices together and compared to the linear regression model based on NINO3.4. Since the rainfall prediction model was intended to demonstrate the value of the indices rather than to give a optimized prediction for rainfall, all indices are used at each grid point in the order following the strength of globally averaged correlation. A more careful construction that treated regional dependences differently would likely lead to a better statistical rainfall prediction, but a more complex description of the global impact of the set of ENSO indices.

After cross-validating the multiple regression model, little improvement over the single NINO3.4 index was found. Some regions even showed degradation in skill. Of the regions that showed higher cross-validated correlations relative to those based on the NINO3.4 index, most did not exhibit statistically significant correlations using the multiple regression model.

CONCLUSIONS

A set of indices of tropical Pacific variability was constructed to encapsulate the "flavors" of ENSO that are, at least anecdotally, invoked to explain event-to-event differences in climate impacts. This set of indices was based on observed SST data, and quantified not only the strength of the variability but also the position and structure of the main anomalies influencing variability in the overlying atmosphere. This set of position, strength and structure indices are collectively referred to as "Walker Indices". They are intended to characterize the forced variability of the Walker cell, which is the commonly used to describe the coupled variability that results in the tropical Pacific during ENSO events.

It was found that the NINO3.4 index, which is the primary index currently used to monitor and document ENSO events, captured the global impact on rainfall variability as well or better than any of the Walker Indices. A few regions in particular seasons, however, were found to be sensitive to the ENSO flavor described by one or more of the Walker Indices. Thus although it was not possible to improve upon NINO3.4 as an index of ENSO, which was the goal of this particular study, it is believed (but yet to be shown) that the Walker Indices could provide the basis for a statistical model of rainfall that would outperform a simple linear regression model based only on a single ENSO index such as NINO3.4.

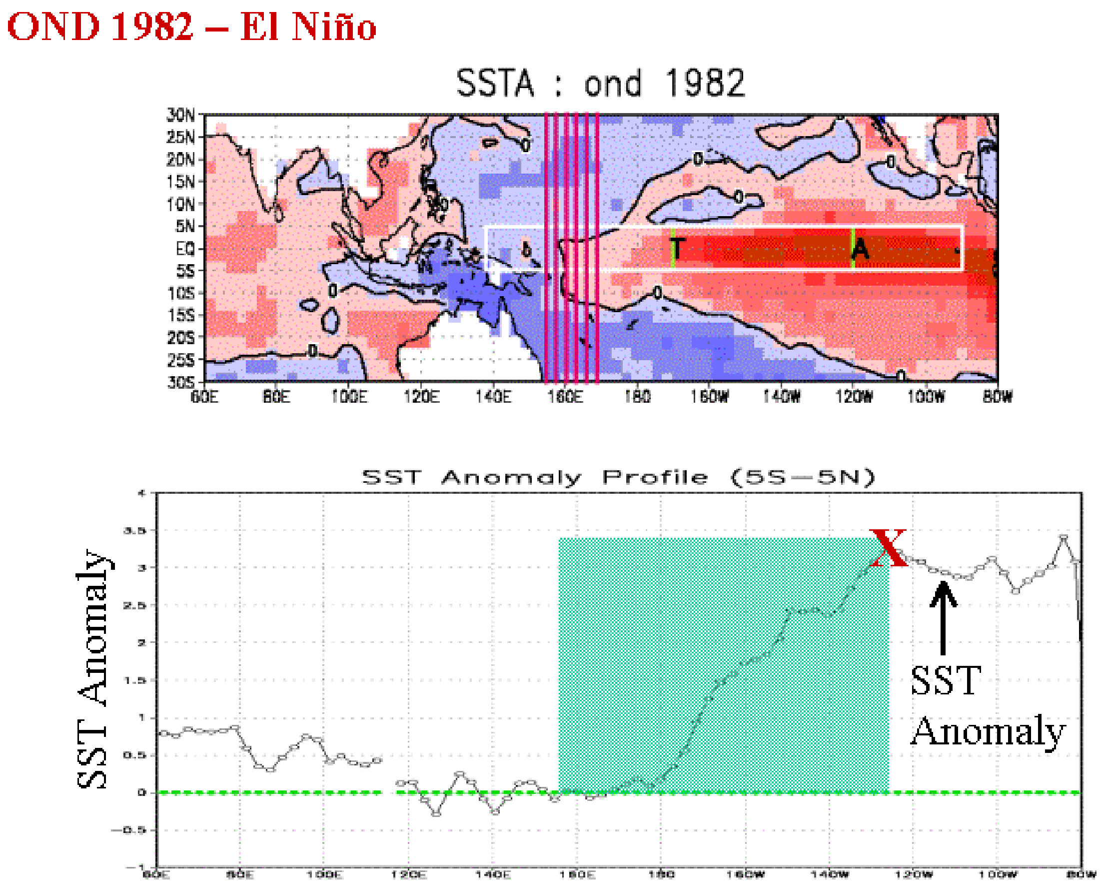

Figure 1.

Example of "Walker Box" for OND 1982 (El Nino conditions). Upper panel shows observed SST anomalies. "T" marks longitudinal position of maximum *total* SST, and "A" marks longitudinal position of maximum *anomalous* SST, averaged within 5 degrees of equator within the Pacific domain from 120E to 90W. Walker Box is delimited by white rectangle which is bounded in east by domain limit (i.e. 90W) and in west by first local minimum in SSTa. For reference NINO3.4 region is outlined in light green (5S-5N; 170W-120W). The magenta lines indicate climatological near-normal region of maximum total SST. Lower panel shows longitudinal profile of SST anomalies, averaged 5S to 5N. The red "X" marks the position of maximum anomalous SST (same as "A" in upper panel). The blue box represents the "Walker Box" (i.e. western portion of white box in upper panel, since "A" (and "T") is shifted eastward from mean position.

OND 1988 – La Niña

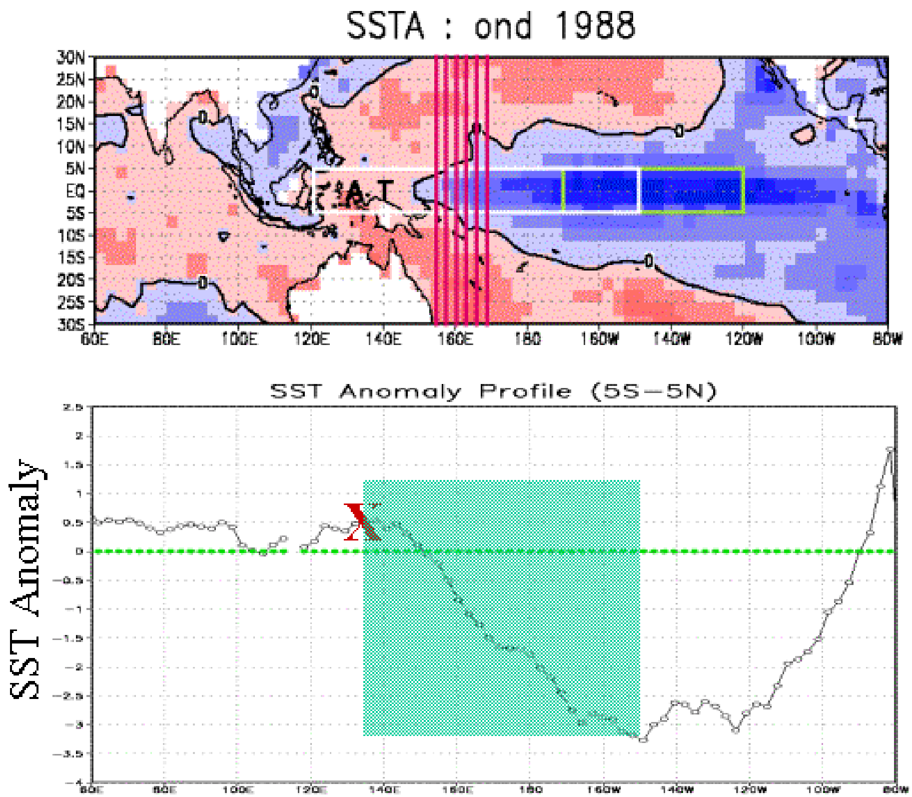

Figure 2.

Similar to Figure 1, but for case of OND 1998 (La Nina conditions). Note that in this case the "Walker Box" is the eastern portion of white box in upper panel, since "A" (and "T") is shifted westward from mean position.