On the Interpretation of Climate Change in the Tropical Pacific[1]

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Abstract

Analysis of sea surface temperature (SST) observations of the last 150 years reveals strong changes in the tropical Pacific climate system during the most recent decades. These changes can be best described as a slow variation of the mean state of the tropical Pacific. The superimposed interannual variability associated with the El Niño/Southern Oscillation (ENSO) phenomenon does not exhibit any significant changes. However, the change in the mean state is "El Niño-like", with many aspects observed during present-day El Niño events. Thus, the change in the mean state biasses the SSTs in the tropical Pacific towards the warm side, which explains the stronger and more frequent El Niños observed during the recent decades.

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The El Niño/Southern Oscillation (ENSO) phenomenon (Philander 1990) is the strongest natural interannual climate fluctuation. ENSO can be understood as an irregular oscillation between a warm state (El Niño) and a cold state (La Niña). Although ENSO originates in the tropical Pacific, it influences the global climate system (Glantz et al. 1991). ENSO is therefore not only of scientific but also of large public interest. The strong El Niños of 1982/1983 and 1997/1998, along with the more frequent occurrences of El Niños during the past few decades (Fig. 1), has led to a discussion of whether human-induced (anthropogenic) greenhouse warming already has or will affect ENSO (Trenberth and Hoar 1996, Goddard and Graham 1997, Rajagopolan et al. 1997, Latif et al. 1997, Timmermann et al. 1999). From a scientific point of view it is important to distinguish between changes in the mean state and changes in the nature of the interannual variability. The observed changes in the tropical Pacific can be understood in two different ways, if interactions between the mean state and the variability are excluded. First, there is a change in the mean state and the superimposed interannual variability remains unchanged. Second, the mean state is stable and the statistics of the interannual variability change. The intention behind this paper is to shed light on this problem.

In order to investigate this question, sea surface temperature (SST) observations were analysed. The dataset used is the Kaplan dataset (Kaplan et al. 1997) which provides monthly mean SSTs for the period 1856-1998 on a 5^o x 5^o grid. This dataset has been used, for instance, by Cane et al. 1997 to study the sea surface temperature trends in the tropical Pacific and by Kumar et al. 1999 to investigate the interdecadal variability in the ENSO/Indian Monsoon relationship. Although the focus of this paper is the tropical Pacific, the SSTs in all three ocean basins have been retained in the analysis, in order to investigate potential teleconnections from the tropical Pacific. The analysis is restricted to the region 30^oS-60^oN, and annual mean values were calculated in order to smooth the data in time. The investigation is based on the Principal Oscillation Pattern (POP) analysis (Hasselmann 1998, von Storch et al. 1988), which is designed to extract the dominant modes of variability from a multi-variate dataset.

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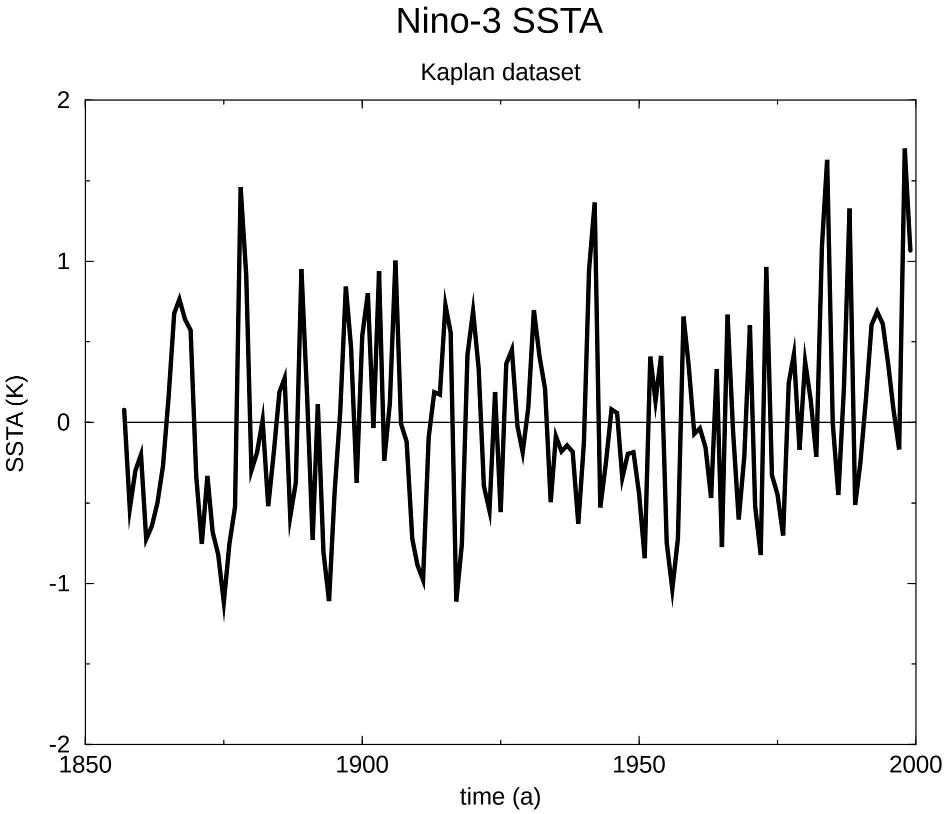

Figure 1: Observed eastern equatorial SST anomaly (K) averaged over the Niño-3 region (5^{o}N-5^{o}S, 150^{o}W-90^{o}W). Note the two strong El Niños 1982/1983 and 1997/1998 and the more frequent occurrences of El Niños during the last few decades.

The POP analysis yields two modes that account for a relatively large amount of variance in the SSTs. These two POP modes together describe the variability in the Niño-3 region very well. The correlation between the reconstructed Niño-3 time series using the two leading POP modes with the original time series (Fig. 1) amounts to 0.96. The leading POP mode accounting for about 27% of the total variance is the ENSO mode. This mode accounts between 60 and 80% of the variability in the eastern and central equatorial Pacific. It is oscillatory, has a rotation period of about 5 years and a damping time of about 1 year. Please note that the relatively small damping time results partly from the large domain considered. The two POP coefficient time series (Fig. 2a) are clearly dominated by interannual variations and show all known major ENSO extremes, including the 1982/1983 and 1997/1998 record El Niños. The real part pattern of the this leading POP mode (Fig. 2b) shows the familiar spatial structure of ENSO extremes. There is a strong anomalous warming in the eastern and central equatorial Pacific and anomalous cooling in the western equatorial Pacific, in the North and South Pacific. Some weak teleconnections to the tropical Indian and Atlantic Oceans are also found, consistent with earlier studies (Klein et al. 1999, Enfield and Mayer 1997). The imaginary part pattern (Fig. 2c) is generally much weaker, supporting the theoretical picture that ENSO is basically a standing oscillation if SST is considered. Propagating anomalies are theoretically expected and observed in the upper ocean heat content of the equatorial Pacific (Neelin et al. 1994).

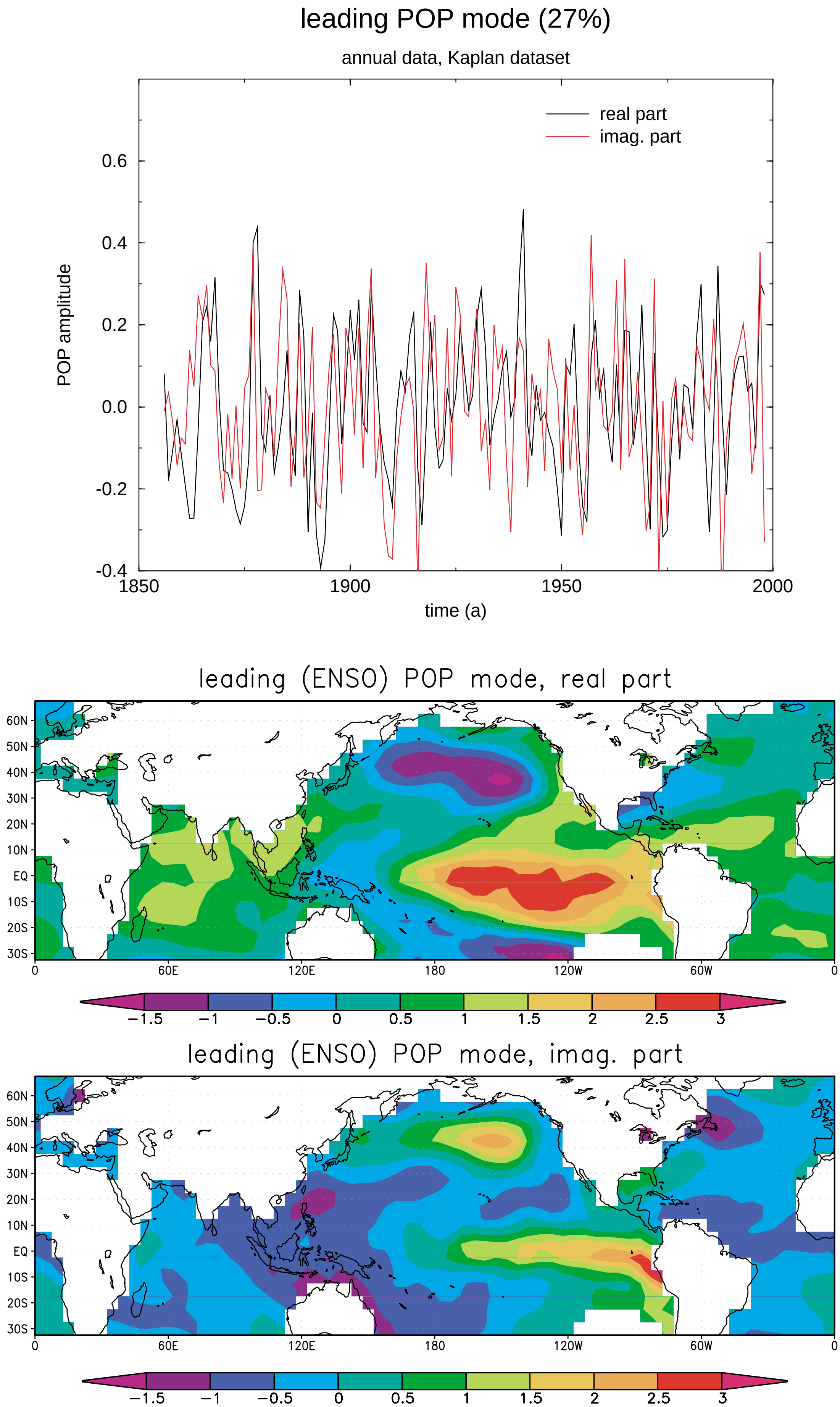

Figure 2: The leading POP mode. a) Time series, b) real part pattern, c) imaginary part pattern. This mode is the ENSO mode which is an interannual oscillatory mode. There is no major change during the last few decades. The time series are in units of (K), while the patterns are dimensionless.

The most important feature of the leading (ENSO) POP mode concerning the problem under consideration is that there does not exist any systematic change of the interannual variability in time. Although the time series exhibit some pronounced interdecadal variations, with active and less active decades, no strong change in the character of the oscillation during the last few decades is discernible (Fig. 2a). It is thus concluded that the statistics of the ENSO variability, as described by the leading POP mode, have not changed during the most recent decades and that there is no apparent impact of greenhouse warming on the nature of the ENSO-related interannual variability.

The next energetic POP mode accounting for about 14% of the total variance has a rotation period of about 110 years and a damping time of about 5 years. The very small damping time together with the weak amplitude of the imaginary part time series (Fig. 3a) indicate that this POP mode does not reflect an oscillatory but rather a growing mode which is represented by its real part. Most outstanding is the increase of the real part time series towards the end of the last century from 1950 onwards (Fig. 3a). Whether this behaviour is due to anthropogenic greenhouse warming or an expression of natural interdecadal variability is not the subject of this paper. It is only concluded here that a strong and almost monotonous change in the SST has occurred during the last 50 years. This slowly evolving change can be regarded as a change in the mean state relative to ENSO and its short period. Please note that in contrast to earlier studies (e. g. Knutson et al. 1999) no a priori information about the nature of the slow mode has been assumed. The POP analysis is able to distinguish between different modes, which have similar spatial structures (as shown below) but very different time evolutions. EOF analysis failed to distinguish between the two modes.

The real part pattern of the second energetic POP mode (Fig. 3b) shows many features that have been discussed in the context of anthropogenic climate change (e. g. IPCC 1996, Meehl and Washington 1996, Hegerl et al. 1997, Cane et al. 1997, Knutson et al. 1999), with a strong El Niño-like change in the tropical Pacific. This change is referred to as “El Niño-like” to distinguish it from the El Niño itself. While the latter is the warm phase of the leading interannual oscillatory mode, as decribed above, the “El Niño-like” SST change associated with the second energetic POP mode evolves much more slowly in time and does not seem to be oscillatory in nature (Fig. 3a). It is this slowly growing “El Niño-like” pattern which biassed the SSTs in the eastern tropical Pacific towards the warm side during the most recent decades, so that El Niños appear to have become stronger and more frequent. This bias amounts to typically 0.3^{o}C in the Niño-3 SST anomaly index during the last 25 years. It is this warm bias that made the two El Niños 1982/1983 and 1997/1998 to record El Niños. This can be shown by reconstructing the past El Niños by using only the leading POP mode (not shown). Such a reconstruction yields record El Niños in 1877/1888 and 1941/1942. If the second POP mode is added to the reconstruction, the El Niños 1982/1983 and 1997/1998 become the record El Niños.

The SST anomaly pattern associated with the real part of the second mode (Fig. 3b), however, shows some interesting differences to the classical El Niño pattern (Fig. 2b). The most important difference is the lack of strong warming in the equatorial east Pacific, a region where warming during present-day El Niños is strongest. Instead, strongest warming is found off the equator in the eastern Pacific and at the equator in the west (Fig. 3b), features which have not been fully explaind yet and may be related to specific equatorial ocean dynamics, as hypothesised by e. g. Cane et al. 1997. Teleconnections to the North and South Pacific and to the Indian Ocean are present in the SST anomaly pattern of the real part of the second energetic POP mode, features observed also during present-day El Niños (Fig. 2b). Other features to be noted are the strong warming of the subtropical South Indian Ocean, the warming of the subtropical South Atlantic, and the cooling of the North Atlantic.

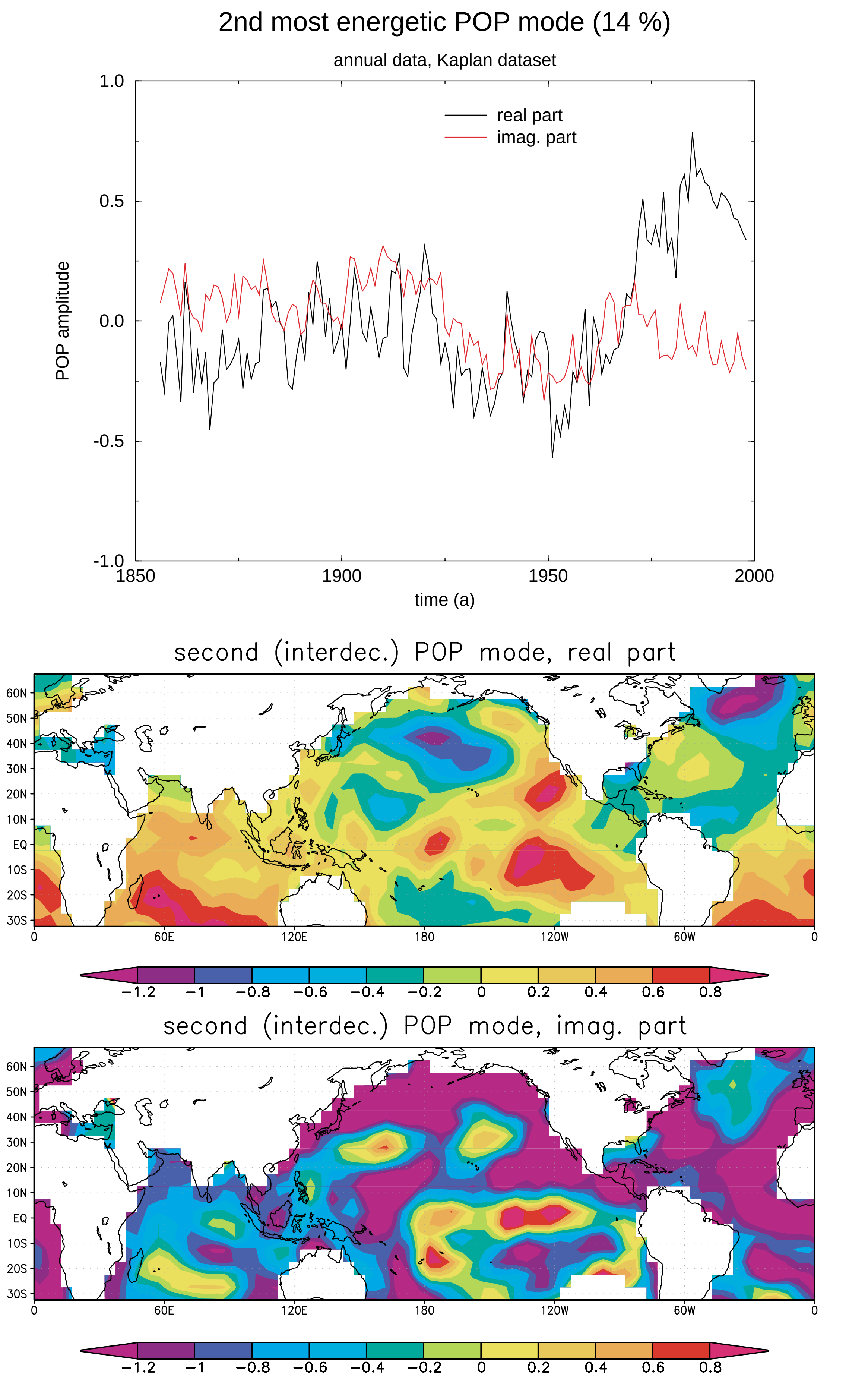

Figure 3: The second energetic POP mode. a) Time series, b) real part pattern, c) imaginary part pattern. This mode is a growing mode that is mainly represented by its real part. Note the strong increase of the real part time series in a) during the recent decades. The time series are in units of (K), while the patterns are dimensionless.

The results of the POP analysis indicate that the recent tropical Pacific climate change can be described best by a superposition of a slowly changing mean state (or ultra low-frequency variability) and an unchanged superimposed interannual variability. It is important from a scientific point of view to distinguish between the slowly growing “El Niño-like” change in the tropical Pacific and the oscillatory ENSO mode, since they may involve completely different physics, which is indicated by the differences in the spatial patterns of the two modes. While the former may perhaps represent a forced mode resulting from enhanced greenhouse warming, the latter is an internal mode of interannual variabilty of the coupled ocean-atmosphere system in the tropical Pacific. The observational results presented here are consistent with a greenhouse warming simulation described by Timmermann et al. 1999, in which the ENSO variability does not change significantly prior to the middle of this century and changes before are mostly due to a change in the mean state. However, the study by Timmermann et al. 1999 shows also that the ENSO statistics may change in response to the changes in the mean state, if the latter become sufficiently strong. Thus, it may well be possible that the nature of the ENSO-related interannual variability will change, if the trend observed in the tropical Pacific continues in the future.

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