On the variability of ENSO over the past six centuries

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[1] The instrumental record is too brief for evaluation of the El Niño-Southern Oscillation (ENSO) system and its long-term response to climate forcing. To supplement these data, we use a new reconstruction of December–February Niño-3 sea surface temperatures based on subtropical North American tree-ring records to investigate aspects of ENSO variability over the past six centuries (AD 1408–1978). Spectral analyses reveal that the reconstruction best resolves variability within the “classical” ENSO band of 2–8 years. A low amplitude ENSO epoch in the 17th to 18th centuries broadly coincides with “Little Ice Age” conditions over much of the globe. The detailed behavior shows good agreement with shorter tree-ring reconstructions of ENSO over the past few centuries, but differs at times from other longer coral ENSO records and recent model simulations of past ENSO behavior. We discuss possible reasons for these discrepancies. Citation: D’Arrigo, R., E. R. Cook, R. J. Wilson, R. Allan, and M. E. Mann (2005), On the variability of ENSO over the past six centuries, Geophys. Res. Lett., 32, L03711, doi:10.1029/2004GL022055.

1. Introduction

[2] Although paleoclimatic records provide one of the few means available for assessing the long-term variability of the El Niño-Southern Oscillation (ENSO) system, relatively few have been used to directly reconstruct ENSO indices. Two recent efforts in this regard are a tree-ring reconstruction of the Dec–Feb Southern Oscillation Index (SOI) (Stahle et al. [1998], 1706–1977; hereinafter referred to as the ST98 reconstruction), and a multiproxy reconstruction of Oct–Mar Niño-3 sea surface temperatures (SSTs) (Mann et al. [2000], 1650–1980; hereinafter referred to as the MBH00 reconstruction). These reconstructions, which employ different methodologies and nearly independent data sets, provide complementary information on key variables used to measure the ENSO system. The ST98 series is based almost entirely on subtropical North American tree-ring data, and as such best reflects the ENSO teleconnection to that region. The MBH00 series incorporates multiproxy data from various locations around the globe, both within and outside the ENSO domain in the Indo-Pacific. While the ST98 series (due to autoregressive modeling) generally lacks decadal and longer-term information on ENSO, the MBH00 series exhibits more lower-frequency variability. Here we evaluate past ENSO variability using a new tree-ring reconstruction of Niño-3 SST. It is based on a subtropical North American tree-ring width data set that largely overlaps with that used in the ST98 reconstruction, and to a lesser extent the data used in the MBH00 series. However, the new reconstruction is considerably longer than these previous series, spanning six centuries. Below, we analyze this reconstruction and compare our results to these other studies.

2. The Tree-Ring Based Niño-3 SST Reconstruction

[3] The new reconstruction is calibrated on Niño-3 Pacific SSTs [Kaplan et al., 1998] (5°N–5°S, 90°–150°W) and covers 1408–1978 (Figures 1a–1b) (Cook [2000] hereinafter referred to as the Cook reconstruction). The ring-width records used are all from moisture-sensitive sites in the southwestern USA and Mexico. Such records from this “Tex-Mex” region of North America have the strongest ENSO signal yet detected in tree-ring data worldwide (ST98). An important caveat, however, is that this signal is communicated through extratropical ENSO teleconnections (which could change over time), rather than actual underlying tropical Indo-Pacific climate changes associated with ENSO. 175 chronologies were screened as potential predictors (lags $t; t + 1$) of the instrumental Niño-3 data in principal component regression [Cook and Kairiukstis, 1990]. Both the tree-ring and instrumental data were prewhitened using autoregressive modeling, with instrumental persistence added back in to the reconstruction [Cook and Kairiukstis, 1990]. Series significantly correlated ($>0.05$ level) with the instrumental record were used to reconstruct Niño-3 SSTs. Calibration/verification testing (Figures 1c–1d) strongly support the reconstruction’s validity. A nested procedure (in which the number of chronologies declines back in time) was used to develop the longest possible reconstruction, with iterative nests beginning in 1408, 1507, 1608 and 1709. The final reconstruction was developed by averaging early and late calibration reconstructions within each nest, and splicing these series together after their variance and mean had been adjusted to that of the 1709–1978 nest. The fidelity of the signal decreases back in time (Figure 1). The $r^2$ values range from 52% to 43% between the most and least-replicated models, similar to skill levels established in the shorter ST98 and MBH00 reconstructions.

[4] The Cook reconstruction models the boreal winter (Dec–Feb) season of greatest ENSO variability [Allan, 2000]. Positive values are typically associated with warm (El Niño) events and negative values with cold (La Niña) events. Although instrumental persistence has been added back in, low-frequency variability may still be less strongly
expressed than in the instrumental record. Thus, this reconstruction best reflects the “classical” band of ENSO variability of ~2–8 yr [Allan, 2000]. It correlates with the ST98 record at r = 0.77 (1706–1977) and with the MBH00 record at r = 0.55 (1650–1978). Stronger correlation with the former at least partly arises through greater overlap in predictors used.

3. Results and Discussion

[5] The spectral properties of the Cook reconstruction were compared to those of the instrumental record using the multi-taper method [Mann and Lees, 1996] for 1859–1978. The reconstruction reproduces the main spectral features of the instrumental record, displaying peaks within the 3.5–4 yr period band that exceed the 95% confidence limit (Figures 2a and 2b). A weaker decadal peak is consistent with identification of lower-frequency modes in the instrumental record [Allan, 2000]. Recent global analyses of joint SST and mean sea-level pressure (MSLP) signals on interannual to multidecadal timescales [Meinke et al., 2005] indicate that there does not appear to be a distinct decadal (9–13 yr) ENSO band in Tex-Mex rainfall data, and thus this frequency band might not be expected in the Cook series in any case. Interestingly, a coral-based reconstruction from the tropical Indo-Pacific does reflect such lower-frequency variability (R. D’Arrigo et al., Tropical-North Pacific climate linkages over the past four centuries, submitted to Journal of Climate, 2004, hereinafter referred to as D’Arrigo et al., submitted manuscript, 2004). The reconstruction spectrum for the Cook preinstrumental period (1408–1858; Figure 2c) generally indicates periodicities consistent with those in the instrumental period, with strong peaks in all three series at ~3.5–4 and 5.5–6 years (Figures 2a–2c).

[6] Morlet wavelet analysis [Torrence and Compo, 1998] was performed to assess significant spectral changes over time in the Cook record (Figure 3a). Results are broadly consistent with peaks identified above, but show considerable amplitude modulation within the “classical” ENSO bandwidth. One noteworthy feature is an episode of low variability during the generally globally-cold “Little Ice Age” interval [Grove, 1988; Mann et al., 1999] of the later 1600s-early 1700s (Figure 3), coincident with the latter part of the Maunder Minimum (MM) period of low solar irradiance [Eddy, 1976] discussed further below. Low amplitude at this time is also evident using singular spectrum analysis [Vautard, 1995].

[7] To further investigate possible evidence for a relation between ENSO variability and climate forcing, we plotted variance over time (sliding 31-year window) for the three ENSO-related reconstructions and instrumental Nin˜o-3 record (Figure 3b). We also show variance plots from two coral records that correlate significantly with ENSO [Cobb et al., 2003; D’Arrigo et al., submitted manuscript, 2004]. Figure 3c shows the variance of Nin˜o-3 model estimates based on volcanic and solar forcing [Mann et al., 2005], and

Figure 1. (a) Actual and estimated indices. (b) Niño-3 SST reconstruction, plus full period calibration r² (AD 1408–1978). Horizontal line = mean; heavy line is 25-yr cubic smoothing spline. (c) Calibration (x², 1859–1918) and verification (Pearson’s correlation r, Reduction of Error (RE) and Sign Test (ST), 1919–1978). * = ST not significant at 95% CL (p = 0.08). Grey = number of predictors entered into each nested model. (d) As in (c) but for 1919–1978 and 1859–1918. The RE measures common variance between actual and estimated series; positive values indicating regression skill. ST measures how well estimates track yr-yr changes in instrumental data [Cook and Kairiukstis, 1990].
4. Conclusions

[8] We have examined past ENSO variability using a new reconstruction of Niño-3 SST. The reconstruction is well verified and captures the dominant spectral properties in the instrumental record for the classical ENSO bandwidth. We thus consider this record to be a valid expression of ENSO variability with the caveats noted above. The longest such record of its kind, the Cook reconstruction extends information on Niño-3 SSTs back to the early 1400s. Comparison with other ENSO series shows remarkably good agreement in variance changes in recent centuries (Figure 3). This result appears to indicate stationarity in this aspect of ENSO variability.
behavior between the equatorial Pacific and its teleconnection to subtropical North America, though other evidence does suggest some degree of breakdown in this teleconnection during certain periods, such as the mid 19th century [Mann et al., 2000; Urban et al., 2000; D’Arrigo et al., submitted manuscript, 2004]. We have also evaluated the Cook and other reconstructions for a proposed ENSO-radiative forcing connection. In general, ENSO variability appears to be somewhat modulated by external forcing — higher variance in the ENSO-related tree-ring and coral series coincides during some intervals with decreased radiative forcing, in broad agreement with previous coral [Cobb et al., 2003] and modeling [Mann et al., 2005] studies. One possible exception, however, is the low reconstructed variance during the later 17th to early 18th centuries, a period of low solar irradiance in the MM, considered to represent a “crucible” for understanding of climate change [Rind et al., 2004]. Additional proxy investigations from the tropical Pacific and ENSO teleconnection regions, along with modeling studies, should further refine how ENSO amplitude has varied on a range of time scales.

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References


Meinke, H., et al. (2005), Rainfall variability at decadal and longer time scales: Signal or noise?, J. Clim., 18, 89—96.


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