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El Niño phases embedded in Asian and North American drought reconstructions

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ABSTRACT

The amplitude of El Niño-Southern Oscillation (ENSO) varies substantially at each phase of its evolution, affecting the timing and patterns of atmospheric teleconnections around the globe. Instrumental records are too short to capture the full behavior of ENSO variability. Here we use the well-validated Monsoon Asia Drought Atlas (MADA) and North America Drought Atlas (NADA) for the past 700 years, and show that tree-ring records from different regions represent tropical sea surface temperature (SST) conditions at various phases of ENSO. Three modes of tree-ring based summer drought variability are found to be correlated with ENSO: summer droughts over the Maritime Continent and Southwest North America (NA), and a dipole mode between Central and South Asia. A lagged correlation analysis is performed to determine the time when precipitation and temperature anomaly imprints on summer droughts as recorded in tree-rings. Drought anomalies in the Maritime Continent and Southwest NA represent ENSO at the developing and peak phases respectively, while those over Central/South Asia are associated with tropical-wide SST anomalies (including the Indian Ocean) at the decay phase of ENSO. Thus proxy records from different regions can provide valuable information on long-term behavior of ENSO at different phases.

1. Introduction

The El Niño-Southern Oscillation (ENSO) phenomenon dominates tropical ocean–atmosphere variability on interannual timescales, with profound impacts on global weather and climate (McPhaden et al., 2006; Deser et al., 2010). One fundamental property of El Niño, the ENSO warm phase, is that its evolution tends to be phase-locked to the annual cycle, with peak warming around the end of the calendar year (Rasmusson and Carpenter, 1982; Trenberth, 1997). Because of evolving patterns of tropical sea surface temperature (SST) anomalies and atmospheric teleconnections, ENSO effects display strong seasonality in various parts of the globe. Droughts tend to occur in India (Indonesia) in summer (fall) of the El Niño developing year (Shukla and Paolino, 1983; Ropelewski and Halpert, 1987; Haylock and McBride, 2001). Precipitation and temperature anomalies tend to peak over North America during winter at the peak phase of ENSO (Trenberth et al., 1998; Alexander et al., 2002; Johnson and Feldstein, 2010). Warm temperature over India and reduced precipitation over the northwest Pacific east of the Philippines linger through the El Niño decay summer (Xie et al., 2009; Du et al., 2011).

Each El Niño event evolves differently from others, with the amplitude varying substantially throughout the life cycle at the developing, peak, and decay phases (Fig. 1). The large variations in El Niño amplitude, plus the interactions with other climate phenomena such as the Indian Ocean Dipole (IOD), have caused marked changes in ENSO teleconnection patterns around the globe (Krishna Kumar et al., 1999; Annamalai et al., 2005; Xie et al., 2010; Chowdary et al., 2012; Li et al., 2013). Since the 1970s, for example, the ENSO effects weaken on India summer rainfall (Krishna Kumar et al., 1999) but strengthen on Indian Ocean SST and summer rainfall over the northwest Pacific and East Asia (Xie et al., 2010; Chowdary et al., 2012). Therefore, it is important to determine El Niño amplitude variations at each phase of its evolution, a crucial step toward understanding changes in the teleconnection patterns.

Instrumental records indicate that ENSO exhibits strong variability on the classical 2–7-year band in the past 150 years, and that

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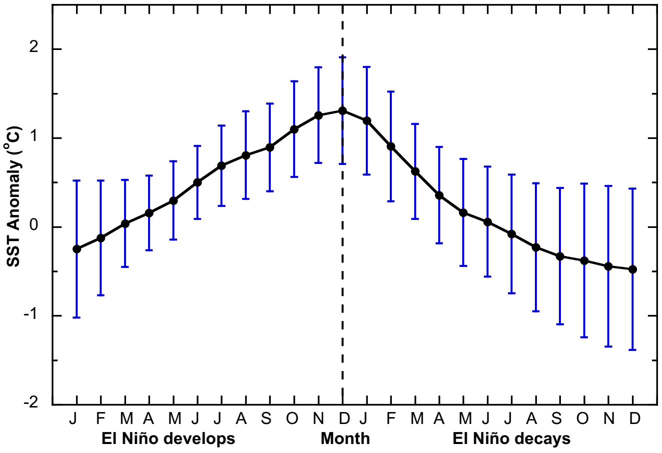

Fig. 1. Composite mean and standard deviation of monthly Niño3.4 indices, based on SST anomalies for 20 observed El Niño events during 1950–2011. El Niño events are defined according to the criteria that maximum warming in the Niño3.4 region during the months of November–January (NDJ) exceeds 0.5 °C. Anomalies are relative to the 1971–2000 base period.

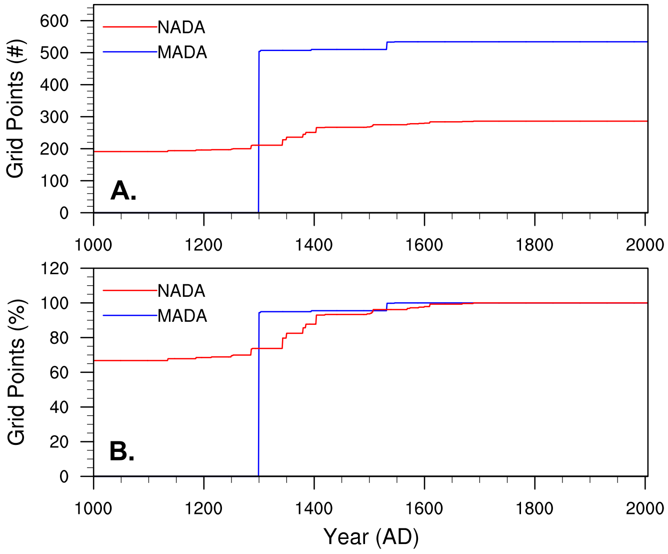

Fig. 3. Number (A) and percentage (B) of reconstructed grip points available back in time in MADA and NADA.

its amplitude and frequency are modulated at decadel to interdecadal timescales (Fang et al., 2008; Deser et al., 2010; Li et al., 2011). In light of such decadal to interdecadal modulation, existing instrumental records are too short to characterize the full behavior of ENSO variability (Guilyardi et al., 2009; Wittenberg, 2009; Yeh et al., 2011; Stevenson et al., 2012). Long integrations of coupled general circulation models (GCMs) have been used to evaluate slow modulations of ENSO (Wittenberg, 2009; Yeh et al., 2011). However, current GCMs have limited ability to reproduce historical ENSO variability, and that they yield a wide range of projections for future ENSO variability (Guilyardi et al., 2009; Yu and Kim, 2010; Ham and Kug, 2012). A better understanding of long-term ENSO variability is necessary for improving climate models and their projection of ENSO behavior linked to global warming.

Proxy records are the primary source to study climate variability beyond the instrumental period. Many proxies, in particular seasonally to annually resolved tree-rings and corals, have been used to reconstruct ENSO variability during the past millennium (e.g., Stahle et al., 1998; Cobb et al., 2003; D'Arrigo et al., 2005; Braganza et al., 2009; Wilson et al., 2010; Emile-Geay et al., 2013; Li et al., 2013). These reconstructions have provided valuable information on long-term ENSO behaviors, such as its frequency change, amplitude modulation, and possible effects of solar and volcanic forcing on ENSO occurrence. Based on various proxy records and statistical methods, however, these reconstructions exhibit large inconsistency in ENSO variability in both low- and high-frequency components (D'Arrigo et al., 2005; McGregor et al., 2010; Wilson et al., 2010).

Part of the ENSO reconstruction uncertainty was introduced by statistical treatment of proxy data (i.e., removal of biological trend in proxies) and/or different method used for each reconstruction (von Storch et al., 2004; Mann et al., 2007; Wilson et al., 2010, Emile-Geay et al., 2013). This type of uncertainty could be minimized by rigorously evaluating and improving the statistical methods (Mann et al., 2007; Smerdon et al., 2010, 2011). Meanwhile, the reconstruction uncertainty was equally likely caused by shifts in ENSO teleconnection patterns, as most of previous studies did not consider seasonal evolution and spatial structure of ENSO and their influence on the spatial/temporal stability of teleconnections (Cole and Cook, 1998; Trenberth and Stepaniak, 2001;

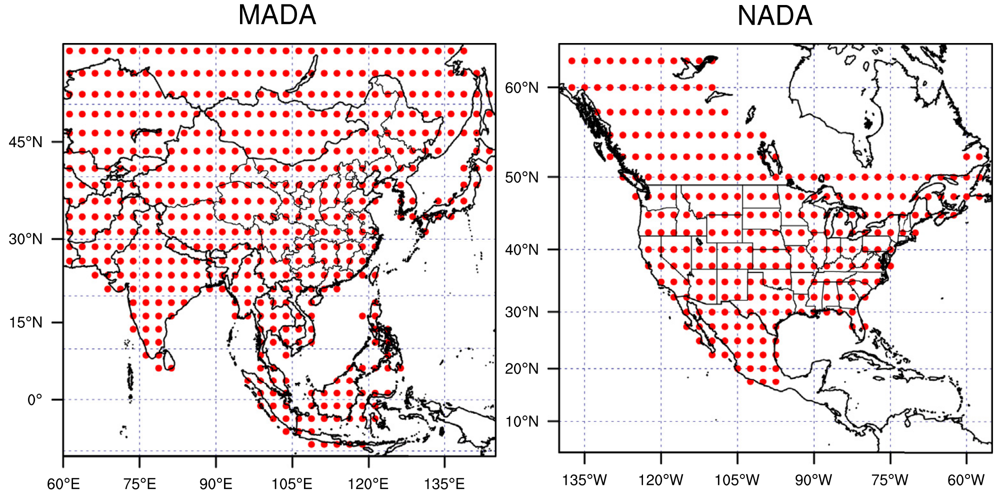

Fig. 2. Map of Asia and North America showing the locations of the reconstructed PDSI grid points in MADA and NADA.