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Large-Scale Temperature Patterns in Past Centuries: Implications for North American Climate Change

Michael E. Mann
Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia 22902 USA; mann@virginia.edu

ABSTRACT

Recent climate reconstructions are analyzed specifically for insights into those patterns of climate variability in past centuries with greatest impact on the North American region. Regional variability, largely associated with the El Nino/Southern Oscillation (ENSO) phenomenon, the North Atlantic Oscillation (NAO), and multidecadal patterns of natural variability, are found to mask the emergence of an anthropogenic temperature signal in North America. Substantial recent temperature anomalies may however indicate a possible recent emergence of this signal in the region. Multidecadal North Atlantic variability is likely to positively reinforce any anthropogenic warming over substantial parts of North America in coming decades. The recent magnitudes of El Nino events appear to be unprecedented over the past several centuries. These recent changes, if anthropogenic in nature, may outweigh the projection of larger-scale climate change patterns onto the region in a climate change scenario. The implications of such changes for North America, however, are not yet clear. These observations suggest caution in assessing regional climate change scenarios in North America without a detailed consideration of possible anthropogenic changes in climate patterns influencing the region.

Key Words: North Atlantic Oscillation, El Nino, climate change, North America.

INTRODUCTION

It is likely that anthropogenic climate forcing will most strongly impact particular regions through its influences on existing natural patterns of climate variability such as El Nino and the North Atlantic Oscillation (*e.g.,* Corti *et al.* 1999). An examination of past patterns of climate variation can thus usefully frame our assessment of possible future regional climate change scenarios. With the latest available evidence, it is now possible to estimate spatial patterns of large-scale climate change during the past several centuries (Briffa 2000; Mann *et al.* 1998, 1999, 2000a,b; Jones *et al.* 1998). I focus here on recent climate reconstructions of Mann and colleagues, that have used "multiproxy" networks of high-resolution natural archives such as tree rings, ice cores, an corals, combined with long historical and instrumental records, to

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reconstruct several centuries to a millennium back in time, large-scale surface temperature patterns (Mann *et al.* 1999, 2000a,b), indices of the El Nino/Southern Oscillation ("ENSO") phenomenon (Mann *et al.* 2000a,b), the North Atlantic Oscillation (Mann 2001; Cullen *et al.* 2001), and patterns of natural (Delworth and Mann 2000) and externally-forced (Waple *et al.* 2001) climate variability. These reconstructions are used to draw inferences into the long-term patterns of climate variability influencing North America and implications for future climate change in the region.

DATA AND METHODS

The Mann *et al.* approach to paleoclimate reconstruction has been discussed elsewhere in more detail (see Mann *et al.* 1998, 1999, 2000a,b). The method involves a multivariate calibration of the leading eigenvectors of the 20th century surface temperature record (*see* Figure 1*; the eigenvectors are calculated from the shaded region during the period 1902-1993*) against a global network of diverse proxy indicators (see Figure 2). This approach exploits the large-scale structure and complementary seasonal and climatic information in a diverse network of climate proxy indicators in reconstructing past global surface temperature patterns. Significant skill in these reconstructions has been indicated in independent cross-validation exercises (see Mann *et al.* 1998, 1999, 2000a,b) and appropriate self-consistent uncertainties have been estimated back in time. The annual-mean reconstructions of Mann *et al.* (1998) have been extended recently to include distinct warm and cold-season reconstructions (Mann *et al.* 2000b). The underlying principle behind this approach is that networks of proxy climate indicators combined with the few available long instrumental or historical climate records can be used to capture the variations in the main patterns of temperature variation in the modern instrumental record. These patterns can then be combined to yield estimates of the surface temperature field back in time. From the reconstructed surface temperature patterns, global, hemispheric, or regional mean averages of interest are readily evaluated.

The methodology employed in these proxy-based climate reconstructions assumes that each proxy record exhibits a linear relationship with one or more of the principal components (PCs) of the instrumental surface temperature record. The methodology does not assume that the proxy record is itself necessarily an indicator of temperature. Only carefully screened records with annual resolution and dating were used. For the period after A.D. 1820, when all 112 records were available, it was possible to skillfully reconstruct 11 PCs, or temperature patterns, calibrating (and cross-validating) between 30 to 40% of the total instrumental surface temperature variance, and 70 to 80% of the instrumental variance in Northern Hemisphere (NH) mean temperature. As the dataset becomes sparser for earlier times, the number of patterns that can be skillfully reconstructed decreases. Back to AD 1000 roughly 40% of the variance in NH is resolved in calibration and verification. The detailed reconstructions are available online in the electronic journal *Earth Interactions* (Mann *et al.* 2000b).

The salient long-term features of the NH reconstruction (Figure 3) are a steady decline of about 0.02°C/century from A.D. 1000 to the mid-19th century, and a sudden, rapid warming during the 20th century. This warming has been attributed

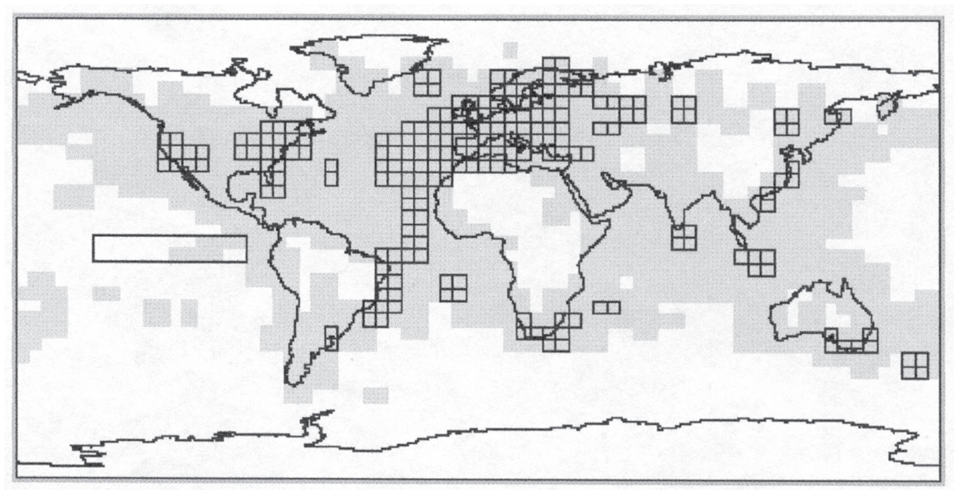

Figure 1. Instrumental temperature data: shaded area used for calibration, 1902-1980; squares used for verification 1854-1901.

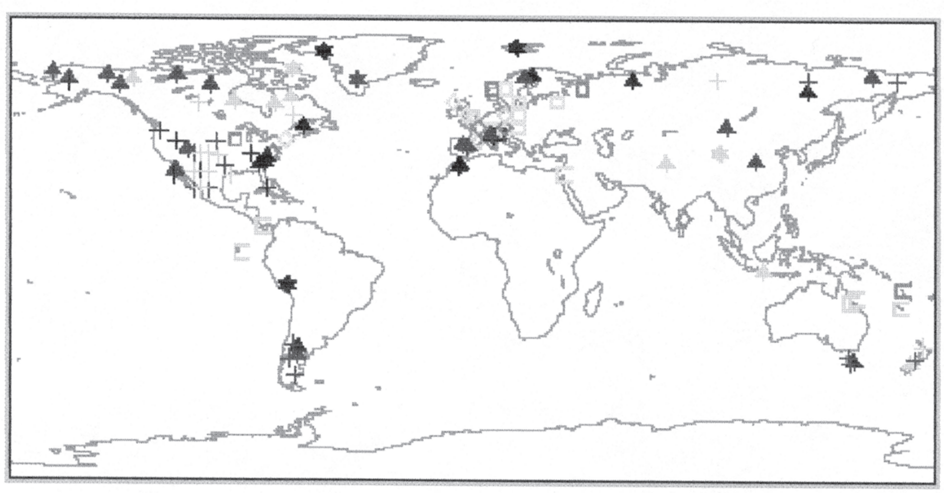

Figure 2. Natural archives used in reconstruction to AD 1400. Tree symbol tree-ring; plus — PCs of dense tree-ring networks, star — ice core/ice melt, 'C' — coral, square early instrumental/historical — temperature — diamond — instrumental precipitation.

to anthropogenic forcing, while much of the residual decadal-scale variability has been attributed to natural forcing factors such as volcanism and solar irradiance variations (Mann *et al.* 1998; Crowley and Kim 1999; Crowley 2000; Mann 2000).

TEMPERATURE CHANGES IN NORTH AMERICA

It is instructive to compare the hemispheric trends shown in Figure 3 with the more regional temperature trends of North America (Plate 1; the North American series is constructed by areally averaging the temperature reconstructions over the North American gridpoints shown in Figure 1; owing to the loss of spatial degrees of freedom in the reconstructions back in time, it is not possible to meaningfully estimate this regional series prior to about 1750). It is clear that the 19th century was anomalously cold in North America (approximately 0.6 C colder than the Northern Hemisphere on the whole). The subsequent warming trend since the 19th century has thus been somewhat larger for North America than for the hemisphere on the whole (approximately 1.2 C vs. 0.6 C). The variability in this region is significantly greater than that for the entire hemisphere on almost all timescales, as we would expect from the spatial sampling characteristics of a smaller region. In particular, however, there is considerably enhanced variability on multidecadal-to-century timescales. This results from patterns of natural variability, which have considerable influence on this region, as discussed further below. Such substantial multidecadal and century-scale variability in past centuries has also been noted in patterns of North American continental drought in past centuries (*e.g.,* Hughes and Graumlich 1996; Woodhouse and Overpeck 1998).

Owing to this natural variability, the latter 20th century, while the warmest period in the North American temperature reconstruction, is not clearly outside the range of natural variability (*e.g,* the mid 20th century warmth is similar to that of the late 18th century in the reconstruction). However, the 1990s are the warmest decade in the reconstructed history of the past 250 years, suggesting the possible emergence of a warming trend from the background of noise in the recent past. The comparison of hemispheric and regional temperature trends emphasizes the importance of regional overprints of natural variability at these spatial scales, as discussed further below.

THE NORTH ATLANTIC OSCILLATION (NAO) AND RELATED PATTERNS OF VARIABILITY

The NAO is one primary pattern of interannual-to-decadal climate variability in the Northern Hemisphere. The influence is largely restricted to the winter season, and regions in or downstream from the North Atlantic, although there is a modest influence on eastern North America (Hurrell 1996). A prolonged positive anomaly in the NAO has been observed in recent decades (Hurrell and Van Loon 1997). This anomaly has been argued to be outside the range of natural variability as estimated from model simulations (Osborn *et al.* 1999). Proxy (Cullen *et al.* 2001) and long instrumental-based (Jones *et al.* 1997; Luterbacher *et al.* 1999) extensions of the

* Plates appear following page 1247.

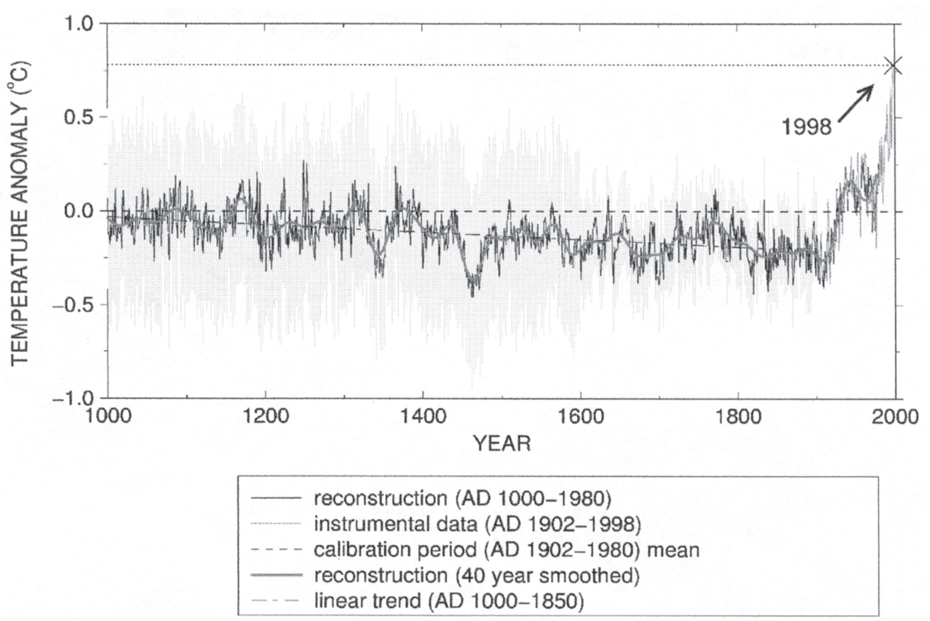

Figure 3. **Northern Hemisphere mean annual temperature.** The shaded band indicates 95% confidence limits. Note that uncertainties increase back in time. 1998 value is shown for comparison [(from Mann *et al.* 1999, (C) American Geophysical Union].

NAO back through the early 19th and 18th centuries, however, show similar, if not quite as large, anomalies in the past, and it remains unclear whether these recent trends are anthropogenic in nature.

Keigwin and Pickart (2000) suggest that NAO anomalies coincided with large-scale climate trends in the past millennium. If so, the NAO may have imprinted a stronger signal of the "Little Ice Age' and "Medieval Warm Period" in parts of Europe and North America (see Mann 2000). Demenocal *et al.* (2000) note, however, that a more basin-wide pattern of warming and cooling in the North Atlantic appears to have accompanied these changes. Such a basin-wide pattern related to, but distinct from, the NAO has indeed been implicated in recent analyses of multidecadal and century-scale variability in paleoclimate reconstructions (Mann *et al.* 1995, 1998) and coupled ocean-atmosphere model simulations (Delworth and Mann 2000).

These latter studies suggest a multidecadal pattern of climate variability associated with coupled ocean-atmosphere processes, with a distinct projection onto North American temperature changes on multidecadal and century timescales. Shown (Plate 2*) is one assessment of the spatial (upper panel) and temporal (lower panel) signature of this multidecadal signal. Note the downturn in recent decades, implying an overprint of cooling in North America in recent decades, which has likely masked the global warming signal. Indeed it is quite likely that a reversal of this downturn is taking place, which implies enhanced warming in North America and the tropical North Atlantic in the coming decades. The combination of such natural warming on top of an emerging anthropogenic warming could have significant consequences for regional temperature patterns in eastern North America. Moreover, the associated enhanced warming in the tropical North Atlantic could lead to increased frequency and intensity of Atlantic tropical storms influencing the East Coast of the United States (see Kerr 2000).

ENSO INFLUENCES

The Niño-3 index of ENSO-related variability (Figure 6) is diagnosed by averaging the cold-season temperature reconstructions (see Mann *et al.* 2000b) over the Niño-3 region of the tropical Pacific (the rectangular region in the eastern equatorial Pacific shown in Figure 1). This index resolves 60 to 70% of the observed Niño-3 variance during the 20th century and, as shown in Plate 3*, correlates highly ($r=0.64$) with the largely independent winter Southern Oscillation Index (SOI) series of Stahle *et al.* (1998). In contrast to the Northern Hemisphere series, there is no clear trend in the Niño-3 index in recent decades. However, the two single largest events appear to have occurred during the past two decades (the '97/'98 and '82/'83 events are nominally the largest two events in the chronology, and both are outside the estimated uncertainty range in the reconstructions). Timmermann *et al.* (1999) argue that such behavior is consistent with recent model simulations of the response of the tropical Pacific to anthropogenic climate change. It is thus quite possible that this unusual recent behavior of ENSO is anthropogenic in nature.

The implications for North America of such possible changes in ENSO are more difficult to assess, as the extratropical teleconnections of ENSO into North America are themselves not necessarily stationary on multidecadal timescales (*e.g.,* Cole and Cook 1998; Mann *et al.* 2000a). Shown in Plate 4 (from Mann *et al.* 2000a) is the characteristic correlation pattern of the cold-season Niño-3 index against annual-mean global surface temperatures, in distinct 50 year intervals back through 1650. The variability in the North American teleconnections, particularly in the Eastern United States, is especially evident, and even the sign of the temperature signature of ENSO appears to be variable on multidecadal timescales in the latter region. Thus, while it is quite possible that anthropogenic forcing may increase the magnitude and frequency of warm ENSO events (*i.e.,* El Niños), the teleconnections into many parts of North America are not robust enough to obviate the likely influence of such changes.

CONCLUSIONS

It is clear that climate changes in North America, let alone particular sub-regions of North America such as the eastern United States, exhibit far greater variability on nearly all timescales than the Northern Hemisphere on the whole. While multidecadal natural variability appears to have masked anthropogenic warming in North America in past decades, it appears that a warming signal in this region is now emerging. In fact, the combination of a positive upturn in the dominant pattern of multidecadal natural variability superimposed on an anthropogenic warming trend could lead to a particularly dramatic warming in North America during the next few decades. Related warming in the tropical North Atlantic, moreover, may support an increase in tropical storm activity influencing the east coast of the United States. It is also likely that strong El Nino episodes may become more prominent, leading to greater interannual extremes of temperature, flood, and drought patterns in North America in coming decades. A proper assessment of environmental risk in North America associated with potential future anthropogenic climate change must take these regional factors into account.

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