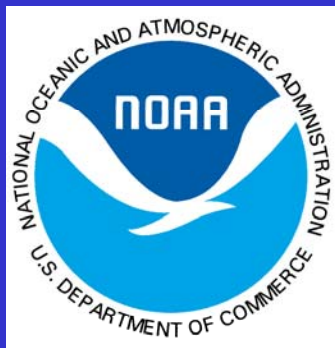


Climate Change Insights from the Paleoclimate Record of Past Centuries

Michael E. Mann
Penn State University

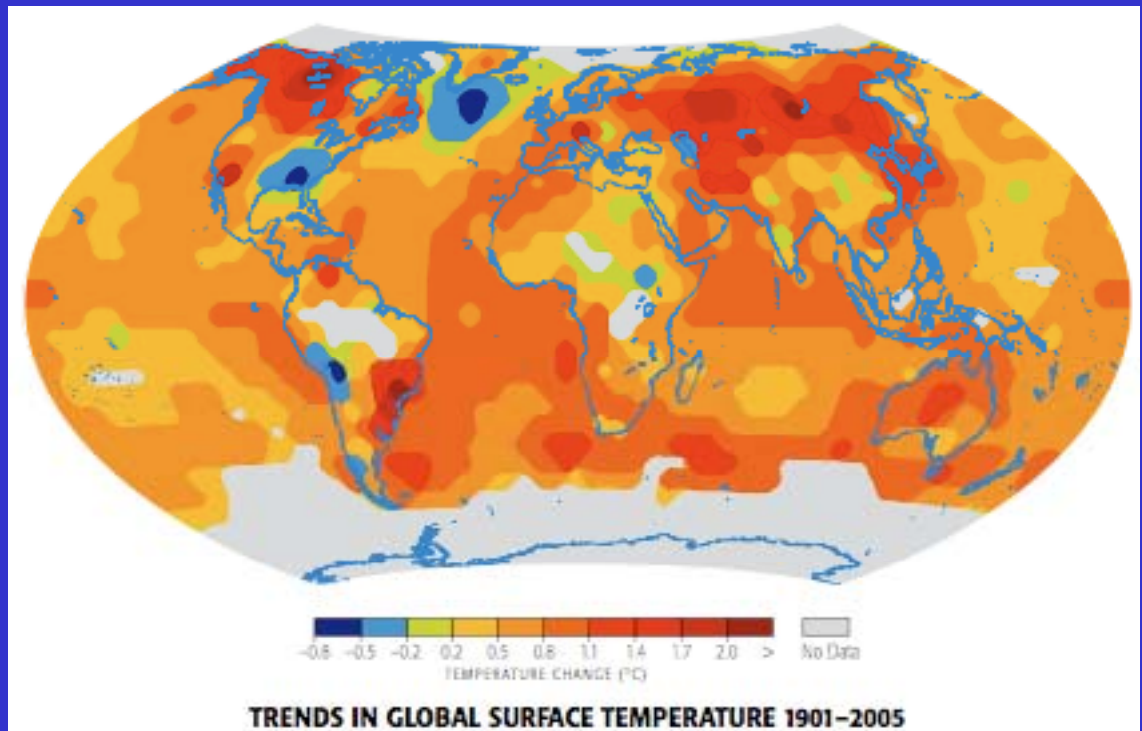
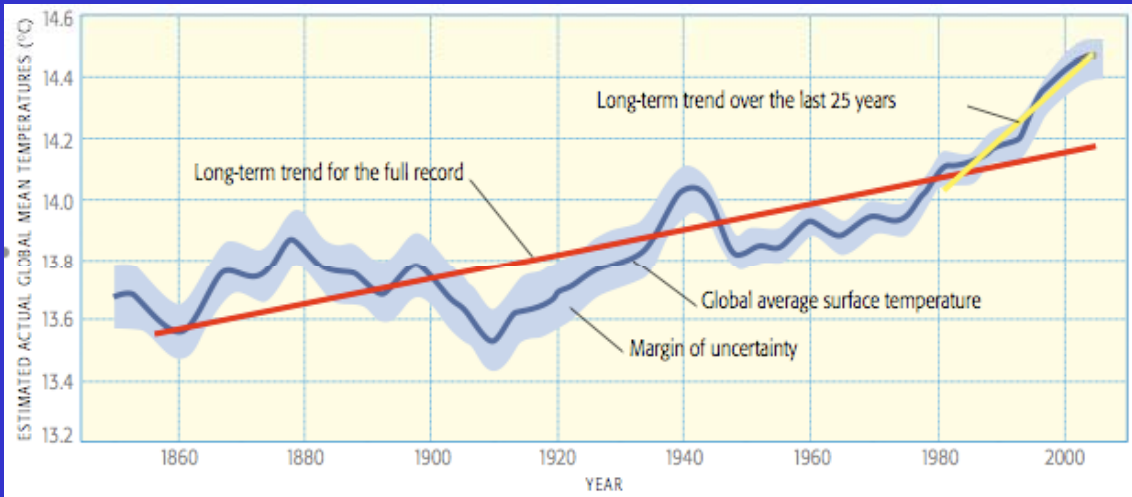
with contributions from:

Caspar Ammann, Raymond Bradley, Elizabeth
Crespin, Jeff Donnelly, Greg Falugevi, Fangxing Fan,
Hugues Goosse, Malcolm Hughes, Klaus Keller,
Scott Rutherford, Drew Shindell, Axel Timmermann,
Jonathan Woodruff, Zhihua Zhang

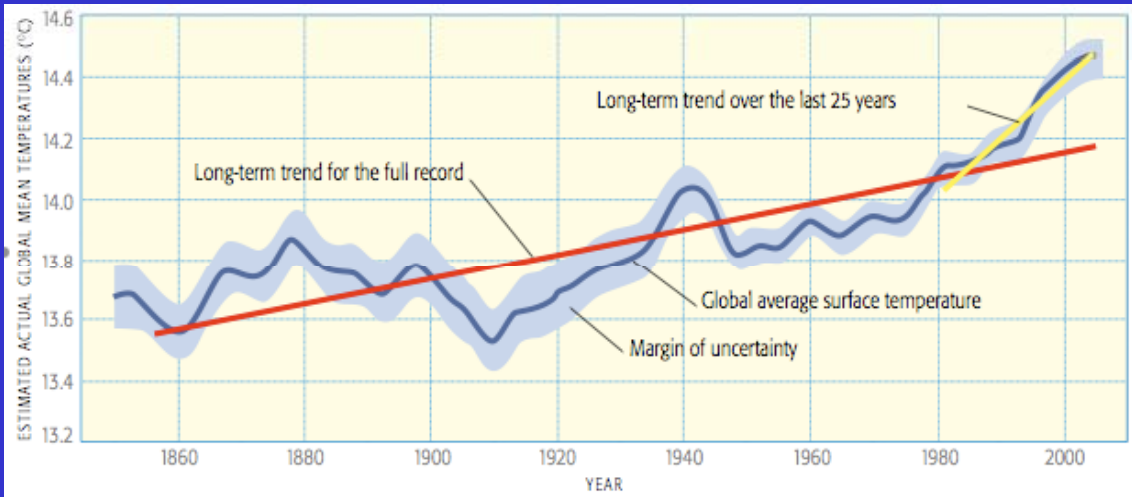


Yale Geology & Geophysics Alumni
Conference
New Haven, CT
November 7, 2009

Global Surface Temperature Changes

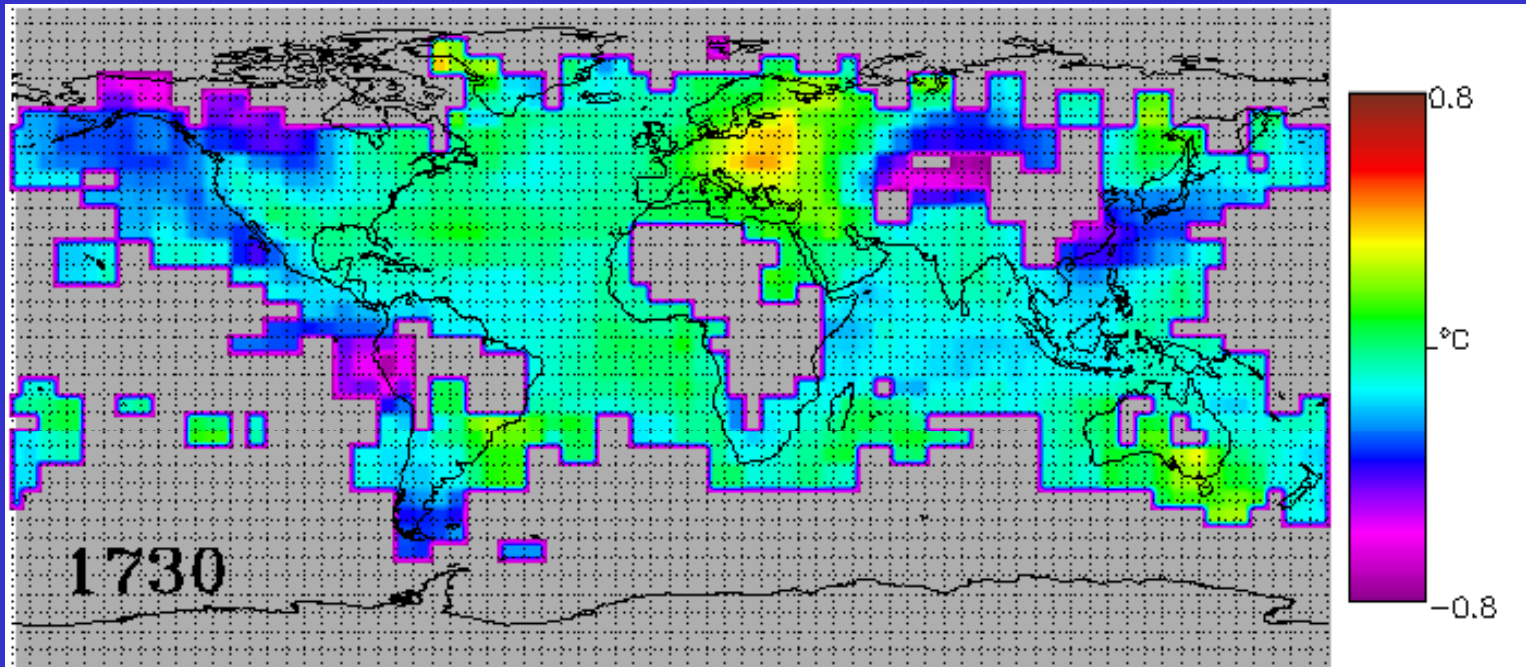


Global Surface Temperature Changes



Climate "Proxy" Data...

Reconstructions of Past Climate



Nature (1998)

articles

Global-scale temperature patterns and climate forcing over the past six centuries

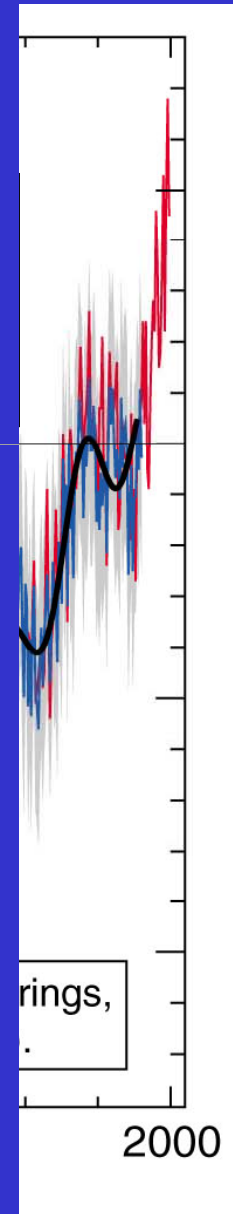
Michael E. Mann*, Raymond S. Bradley* & Malcolm K. Hughes†

* Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003-5820, USA

† Laboratory of Tree Ring Research, University of Arizona, Tucson, Arizona 85721, USA

Climate “Proxy” Data...

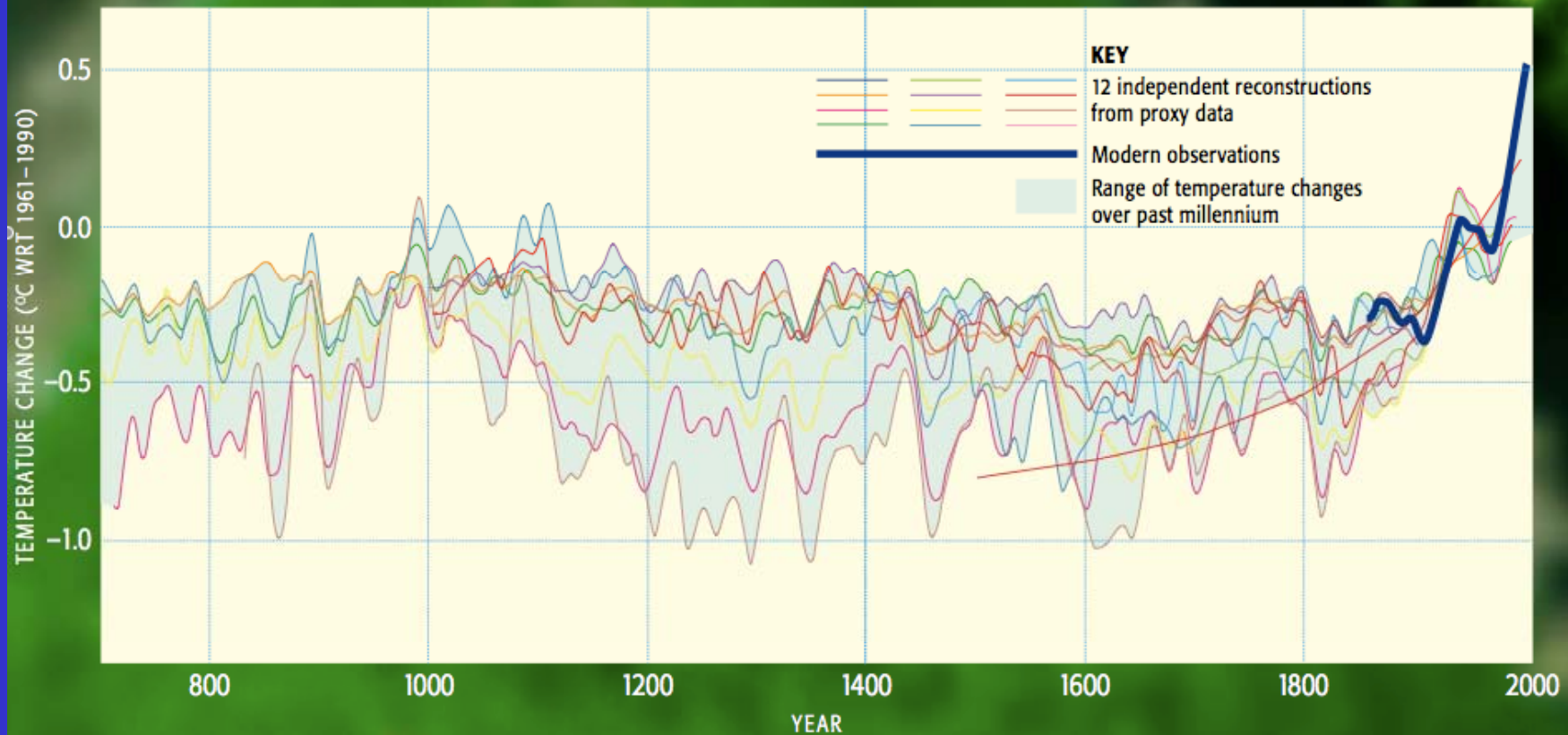
Surface Temperature Reconstructions



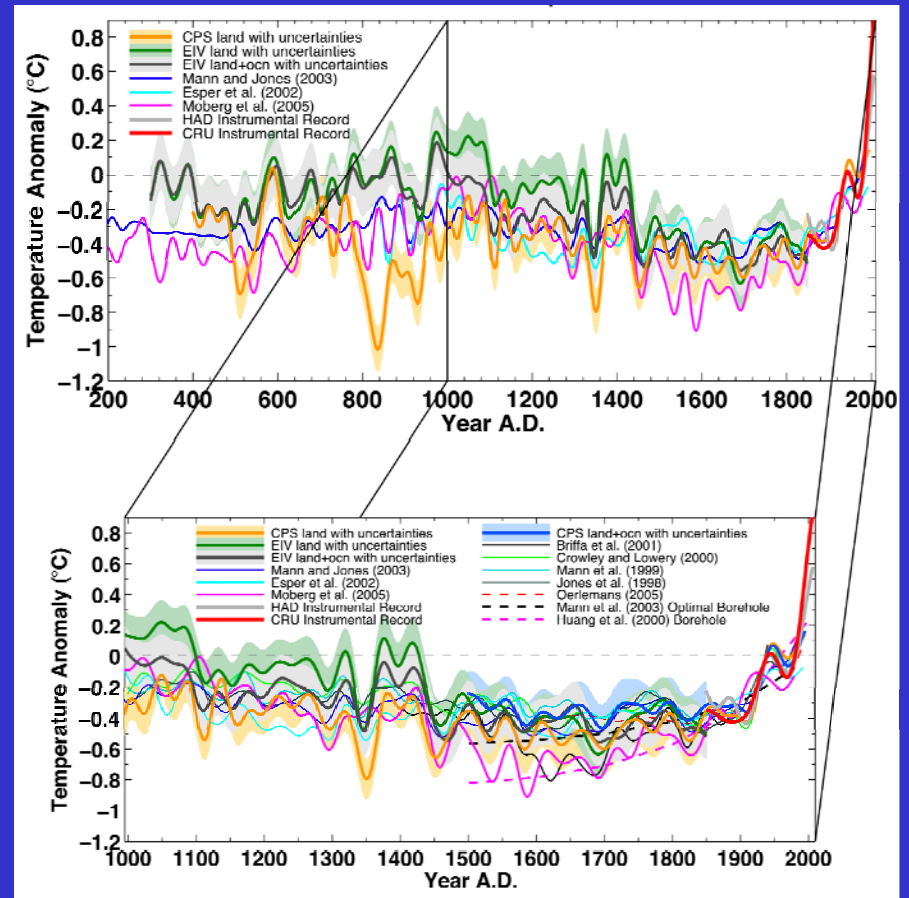
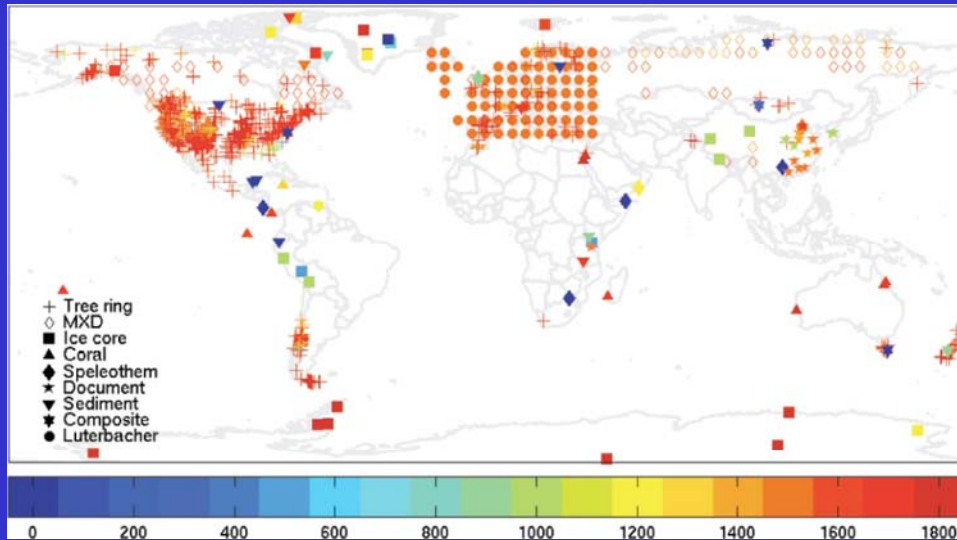
Surface Temperature Reconstructions

NORTHERN HEMISPHERE TEMPERATURE CHANGES OVER THE PAST MILLENNIUM

A number of independent estimates have been made of temperature changes for the northern hemisphere over the past millennium. While there is some variation within the different estimates, which make use of different data and techniques, they all point to the same conclusion: the most recent warming is without precedent for at least the past millennium.



Surface Temperature Reconstructions

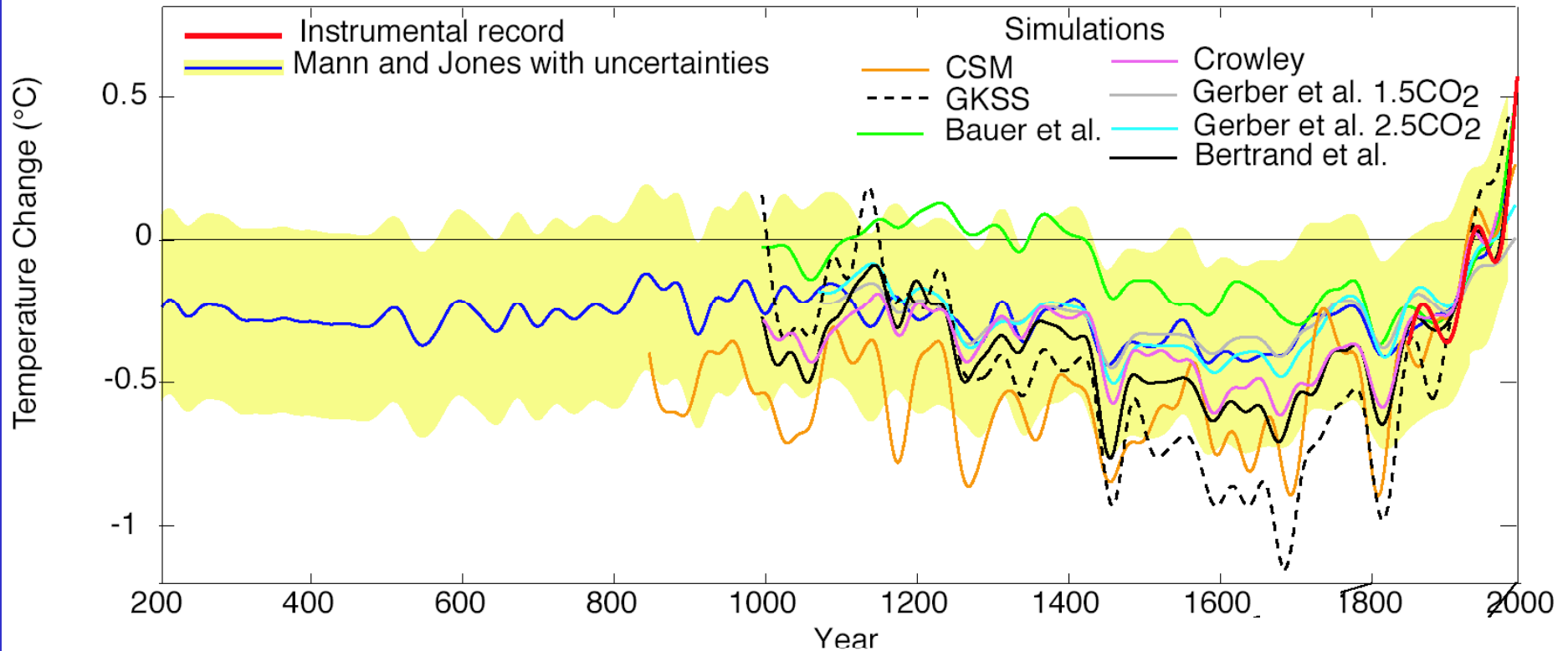


Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia

Michael E. Mann^{*†}, Zhihua Zhang^{*}, Malcolm K. Hughes[‡], Raymond S. Bradley[§], Sonya K. Miller^{*}, Scott Rutherford[¶], and Fenbiao Ni[‡]

^{*}Department of Meteorology and Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802; [†]Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721; [‡]Department of Geosciences, University of Massachusetts, Amherst, MA 01003-9298; and [§]Department of Environmental Science, Roger Williams University, Bristol, RI 02809

Surface Temperature Reconstructions



Reviews of Geophysics (2004)

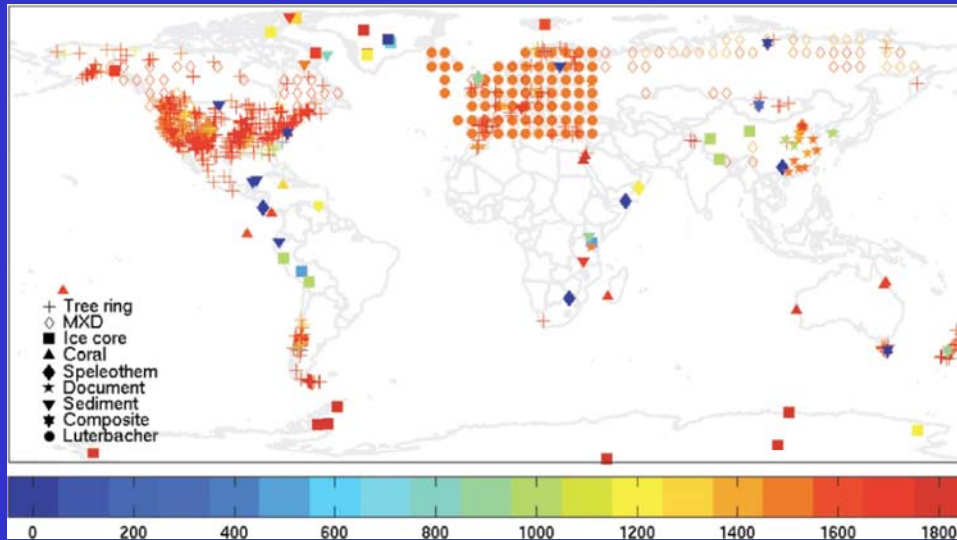
CLIMATE OVER PAST MILLENNIA

P. D. Jones
*Climatic Research Unit
School of Environmental Sciences
University of East Anglia
Norwich, UK*

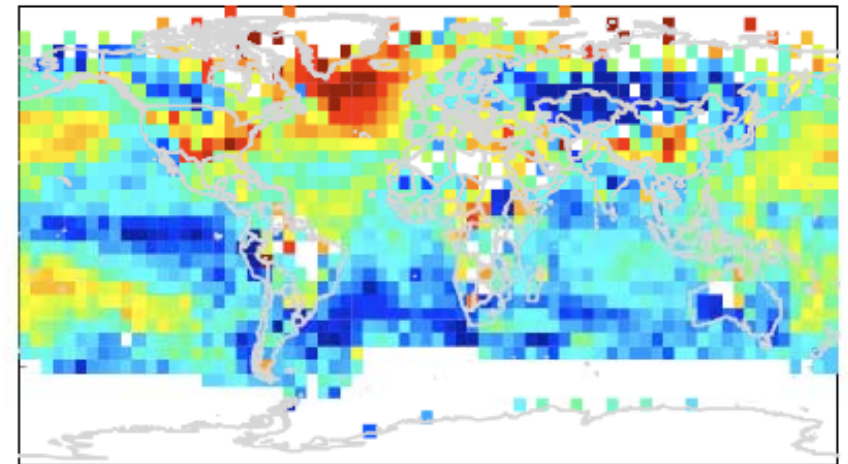
M. E. Mann
*Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia, USA*

Received 20 October 2003; revised 4 February 2004; accepted 17 February 2004; published 6 May 2004.

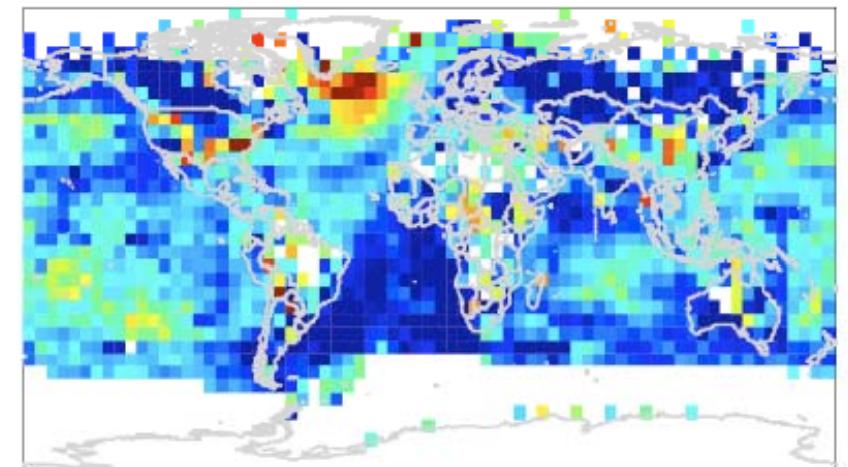
Surface Temperature Reconstructions



Surface Temperature Anomalies – MCA (AD 950–1250)



Surface Temperature Anomalies – LIA (AD 1400–1700)



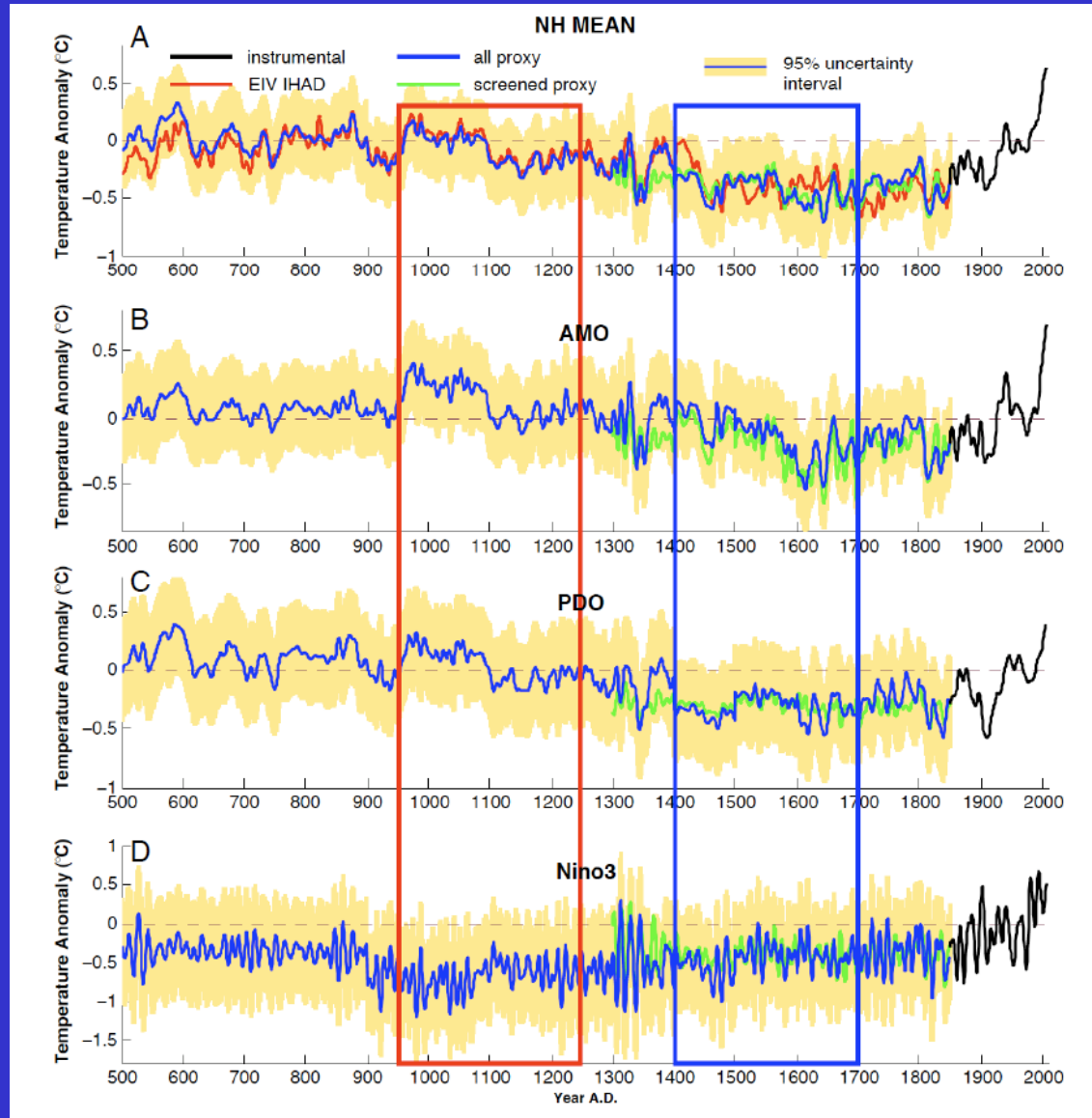
Science (to appear 11/27/09)

REPORT

Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly

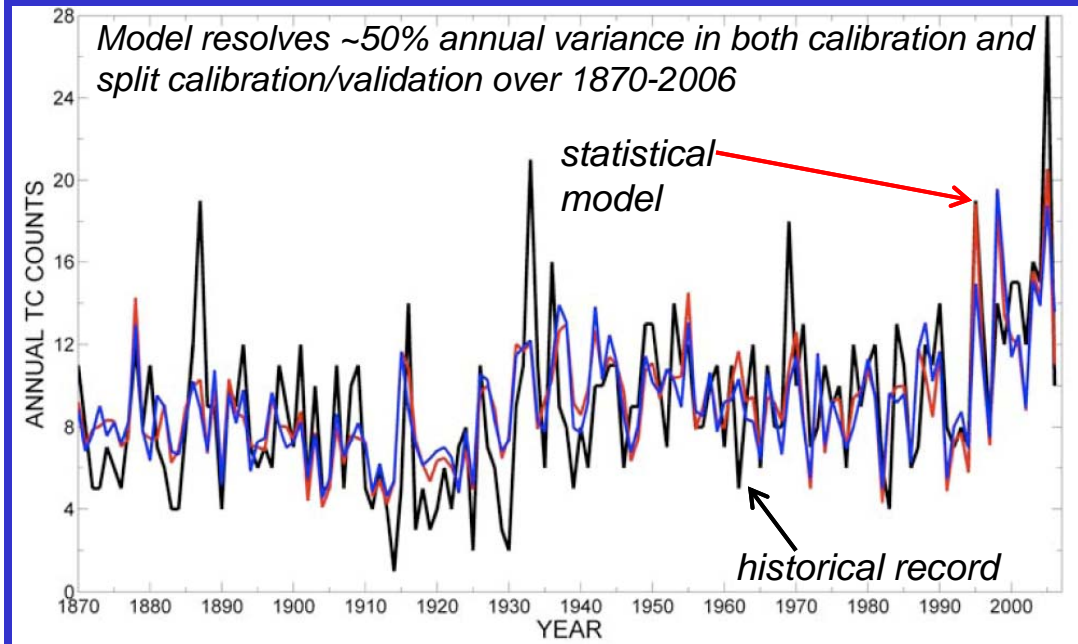
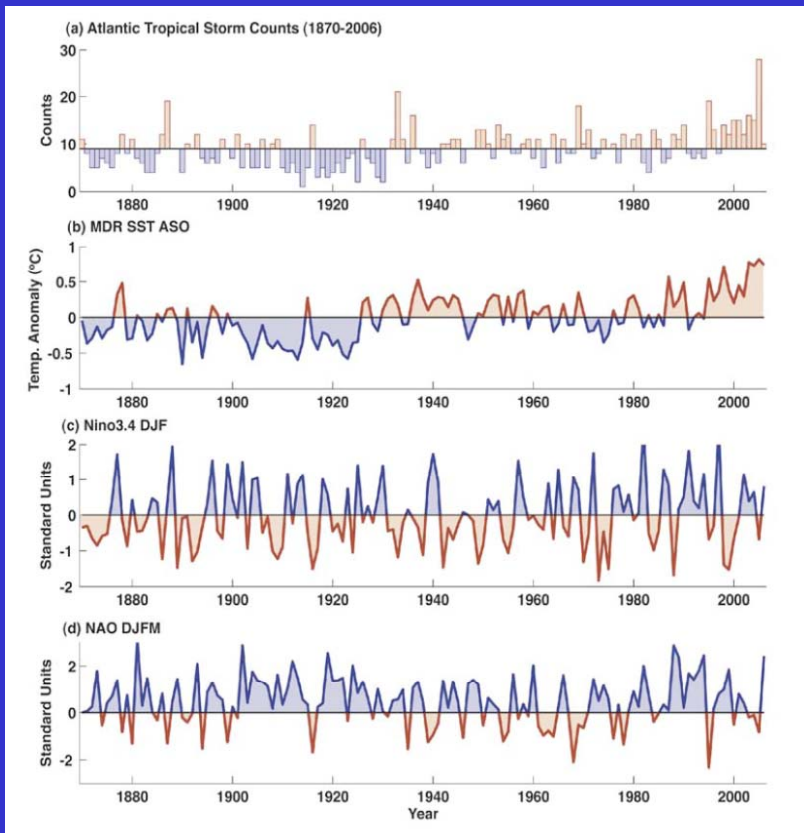
Michael E. Mann,^{1*} Zhihua Zhang,¹ Scott Rutherford,² Raymond S. Bradley,³ Malcolm K. Hughes,⁴ Drew Shindell,⁵ Caspar Ammann,⁶ Greg Faluvegi,⁵ Fenbiao Ni⁴

Surface Temperature Reconstructions



Regional Time Series

Applications: Atlantic Tropical Cyclones



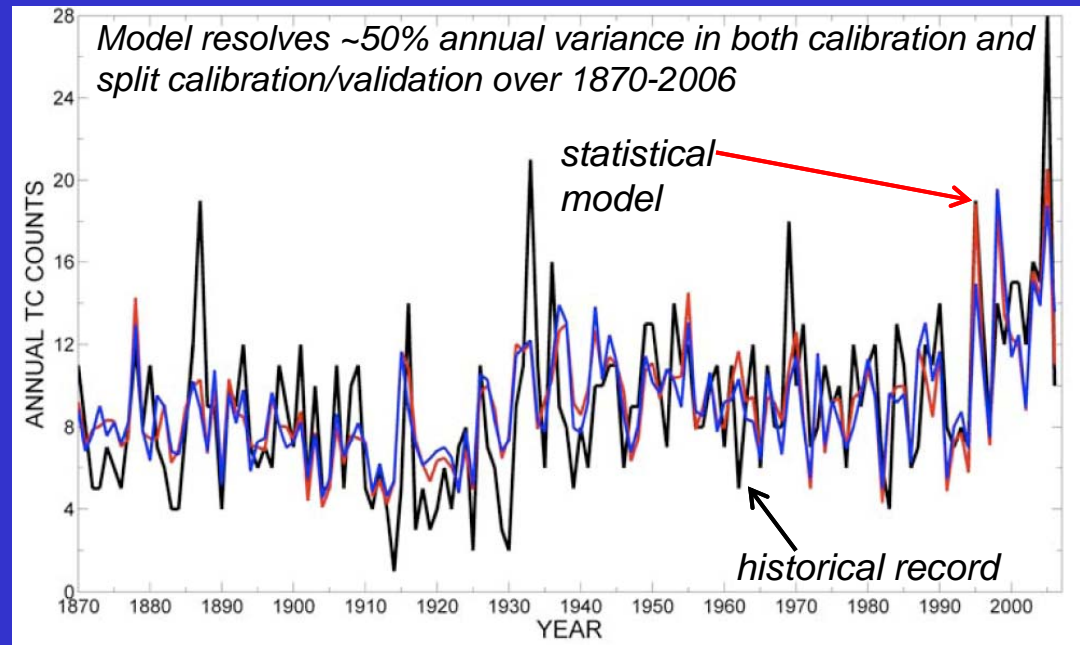
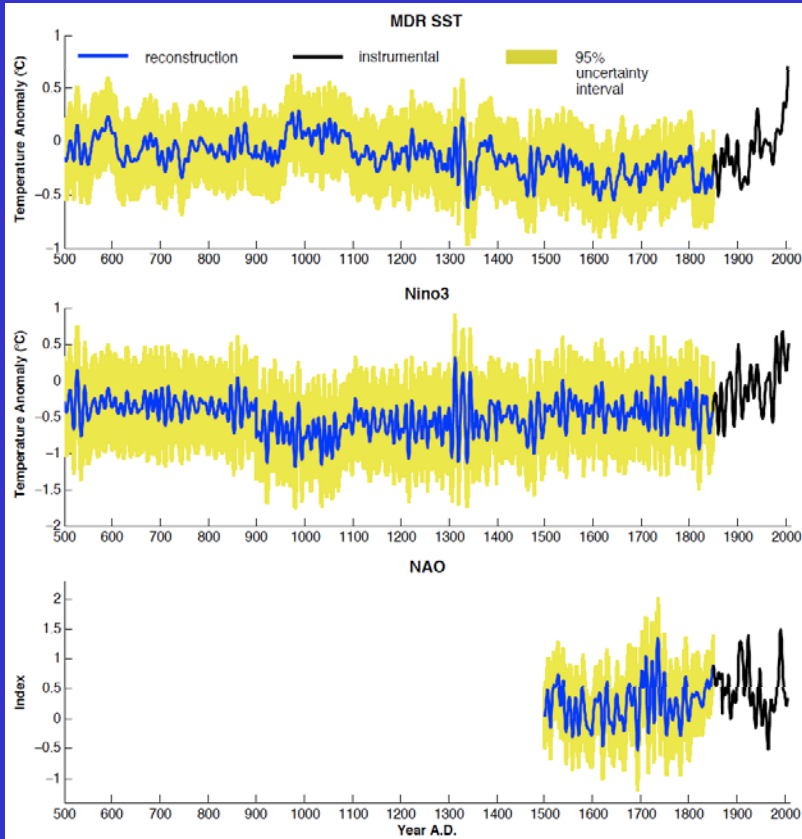
GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L22707, doi:10.1029/2007GL031781, 2007

Evidence for a modest undercount bias in early historical Atlantic tropical cyclone counts

Michael E. Mann,¹ Thomas A. Sabbatelli,¹ and Urs Neu²

Received 22 August 2007; revised 10 October 2007; accepted 18 October 2007; published 24 November 2007.

Applications: Atlantic Tropical Cyclones



nature

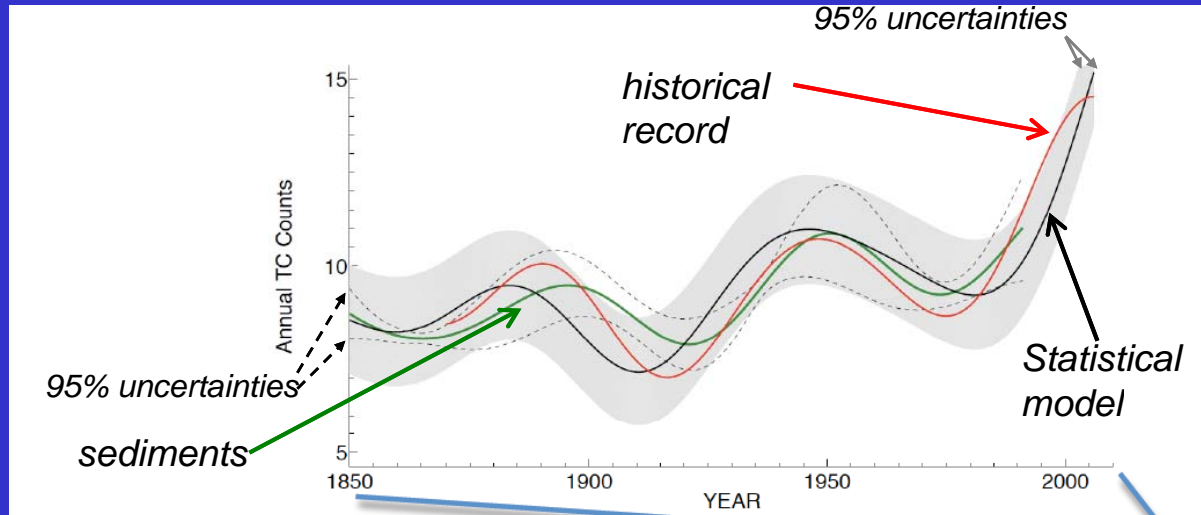
Vol 460 | 13 August 2009 | doi:10.1038/nature08219

LETTERS

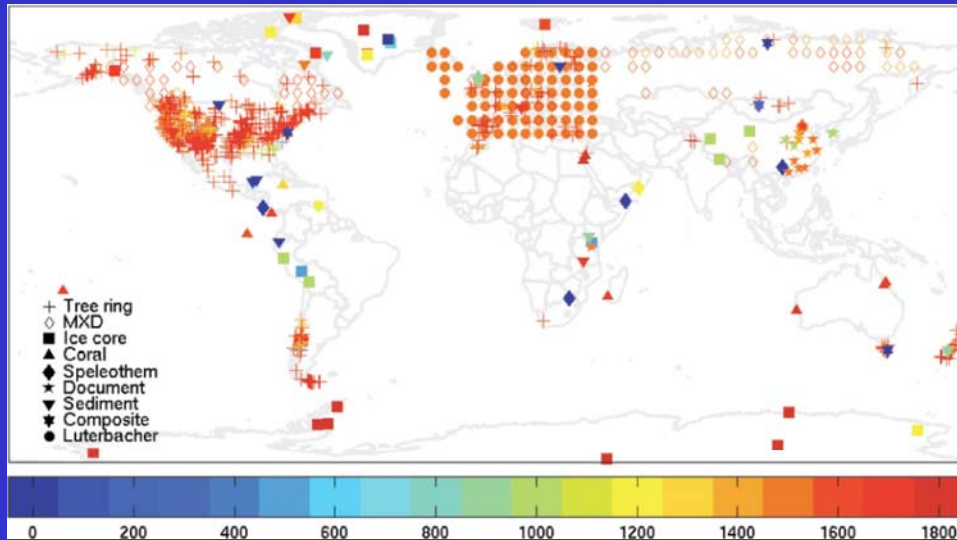
Atlantic hurricanes and climate over the past 1,500 years

Michael E. Mann¹, Jonathan D. Woodruff², Jeffrey P. Donnelly³ & Zhihua Zhang¹

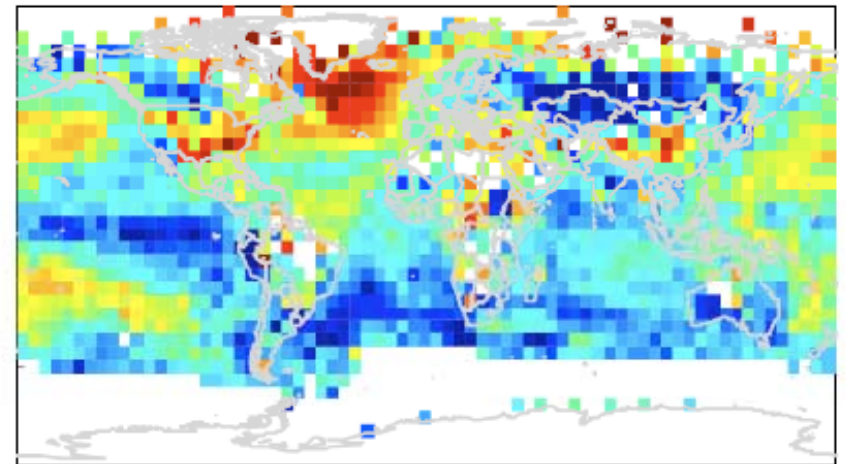
Applications: Atlantic Tropical Cyclones



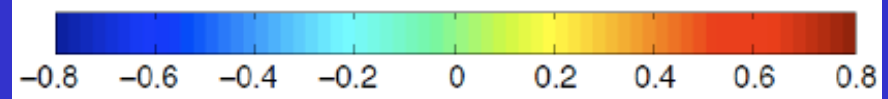
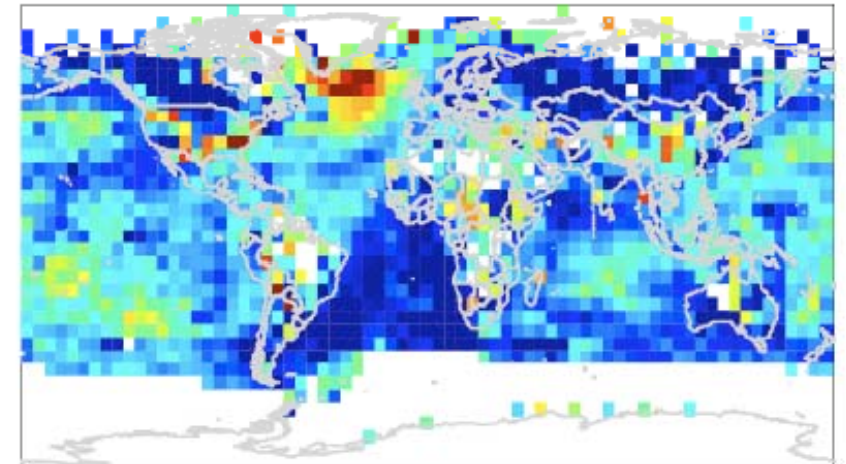
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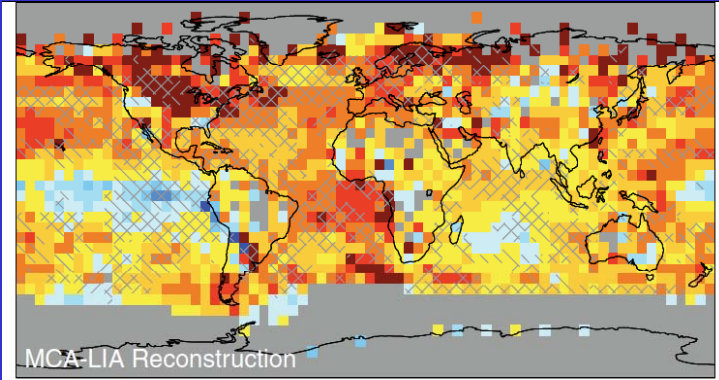
Science (to appear 11/27/09)

REPORT

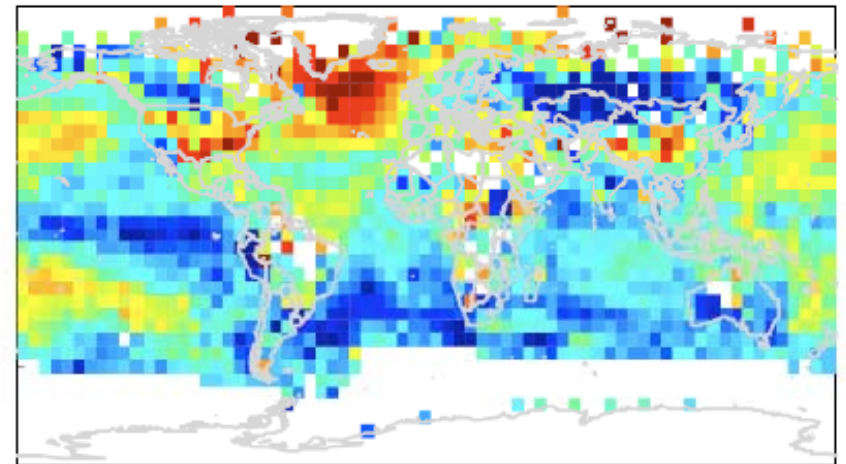
Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly

Michael E. Mann,^{1*} Zhihua Zhang,¹ Scott Rutherford,² Raymond S. Bradley,³ Malcolm K. Hughes,⁴ Drew Shindell,⁵ Caspar Ammann,⁶ Greg Faluvegi,⁵ Fenbiao Ni⁴

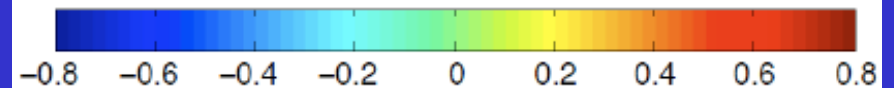
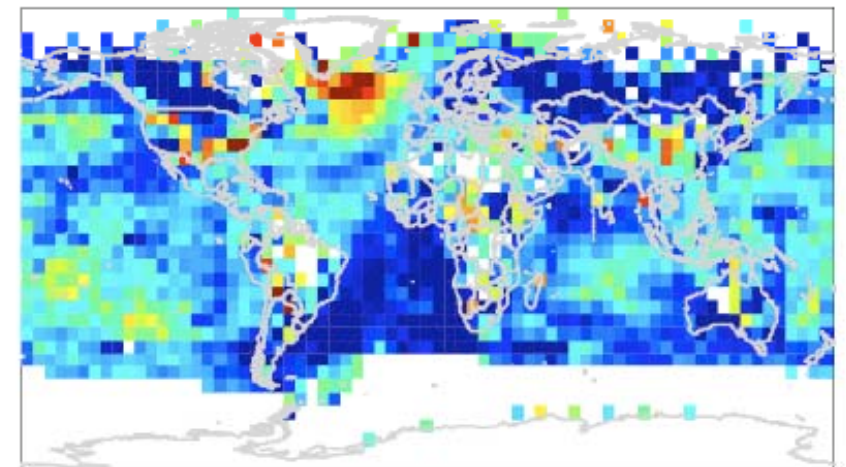
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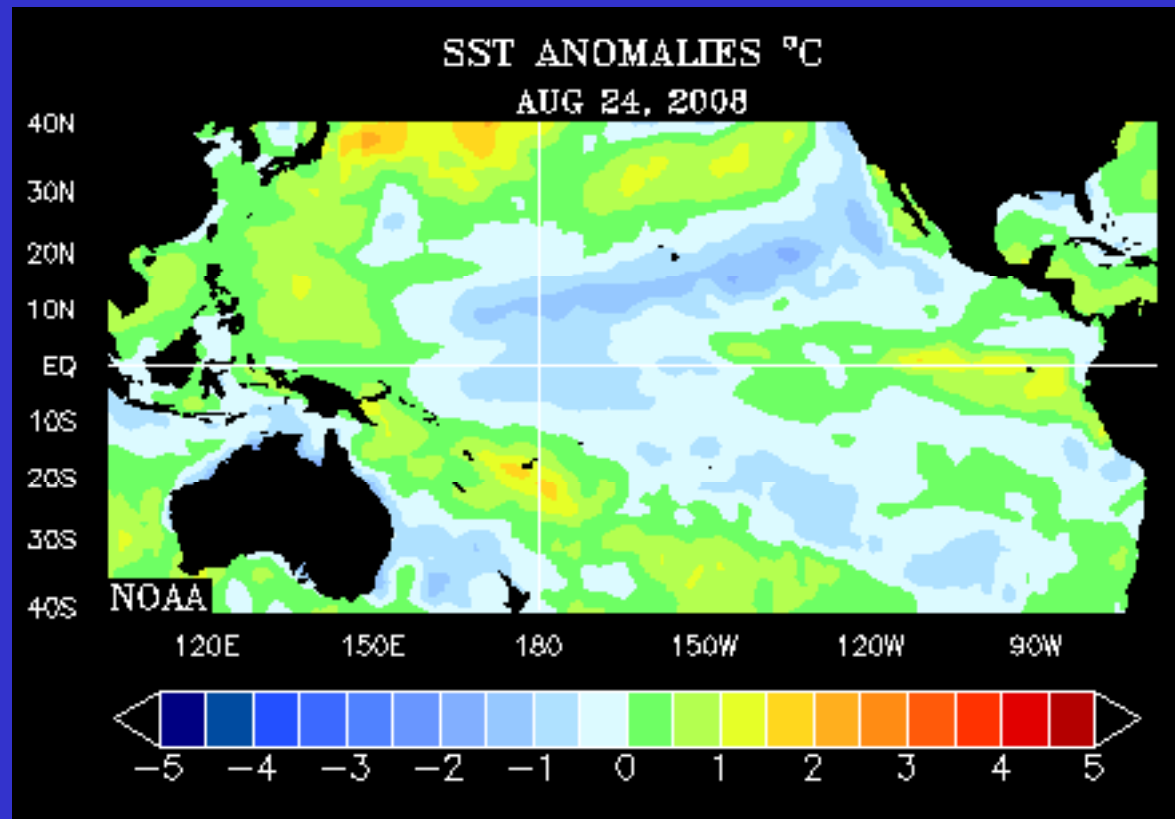
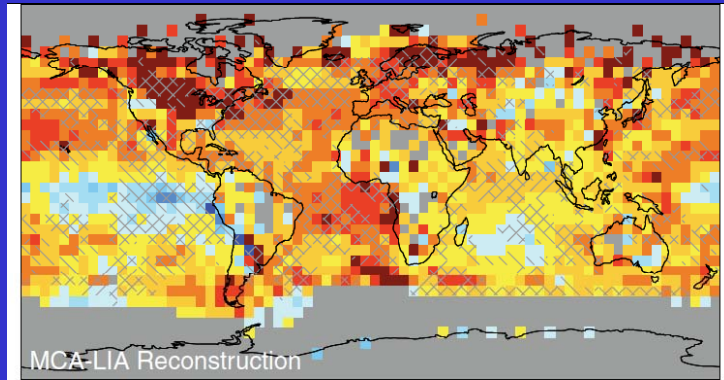
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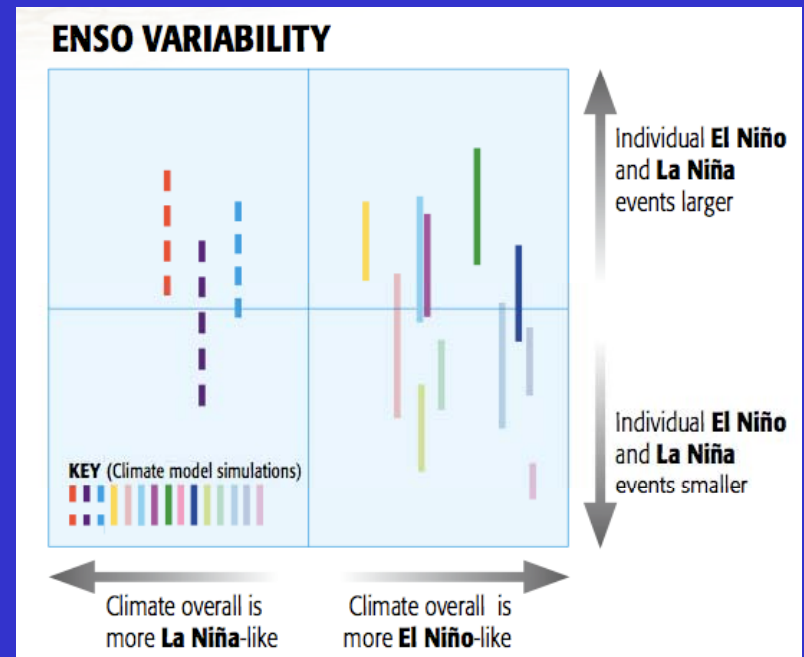
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Surface Temperature Reconstructions

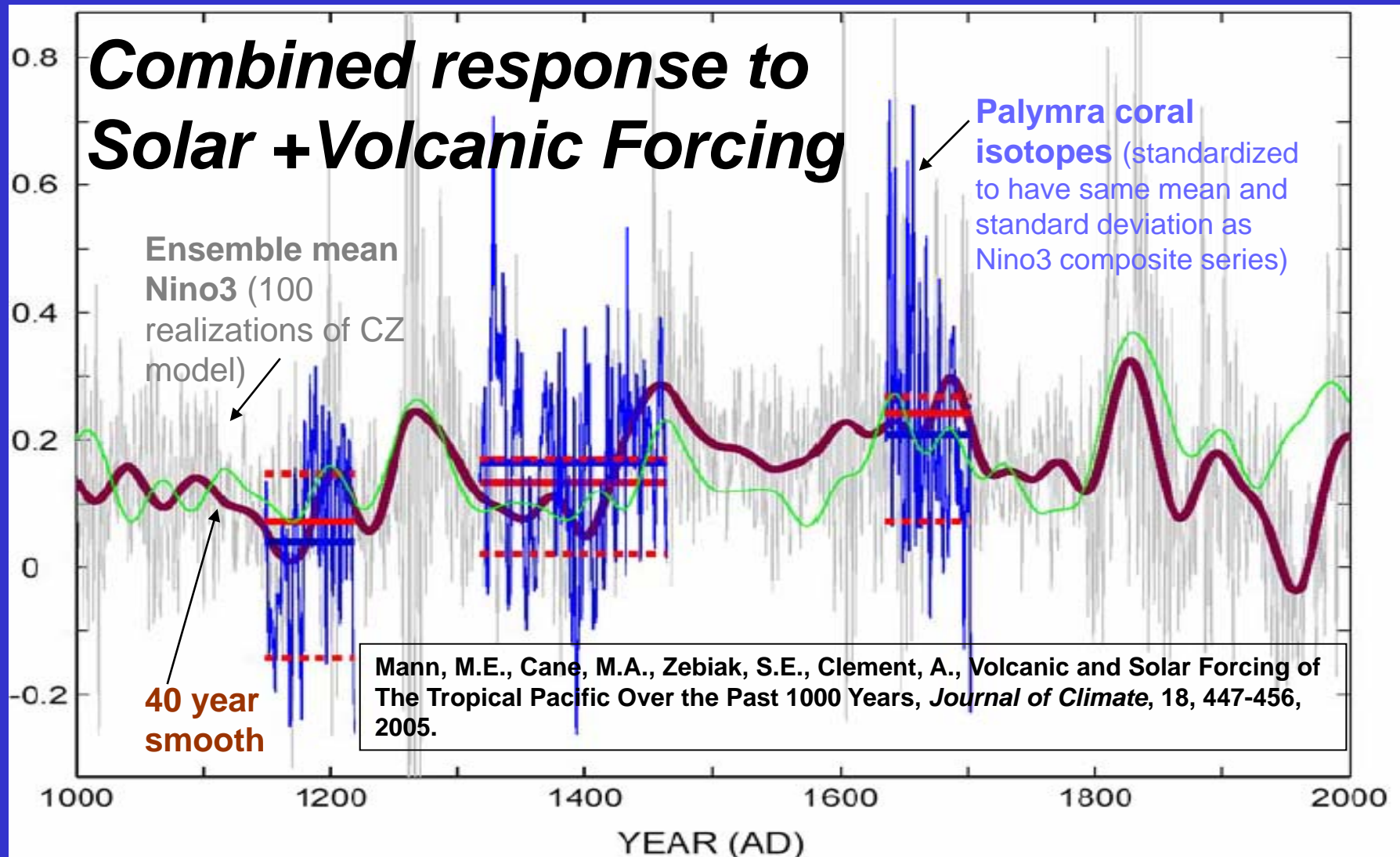


Sources of Uncertainty

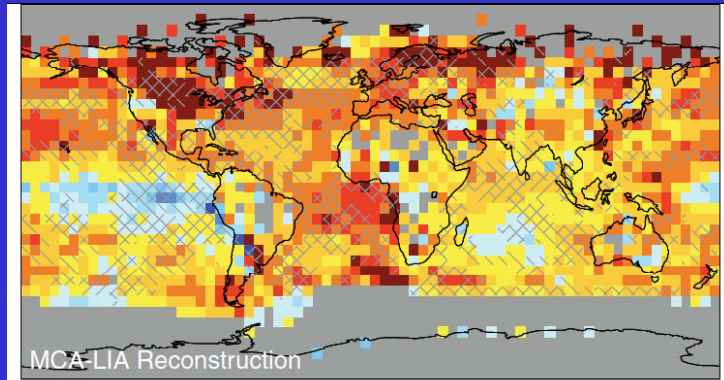


El Nino

How did Natural Forcings Influence ENSO and the Tropical Pacific During the Past Millennium?



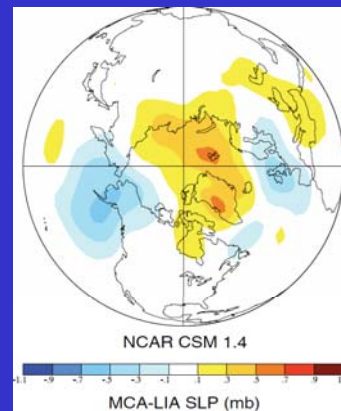
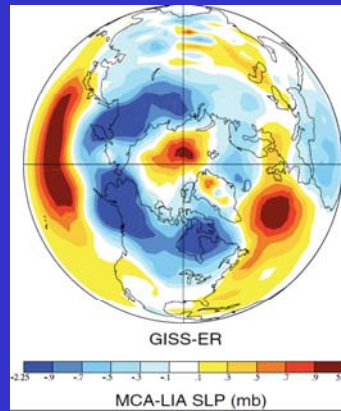
Model-Data Comparisons



Science (to appear 11/27/09) REPORT

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Michael E. Mann,^{1*} Zhihua Zhang,¹ Scott Rutherford,² Raymond S. Bradley,³ Malcolm K. Hughes,⁴ Drew Shindell,⁵ Caspar Ammann,⁶ Greg Faluvegi,⁵ Fenbiao Ni⁴

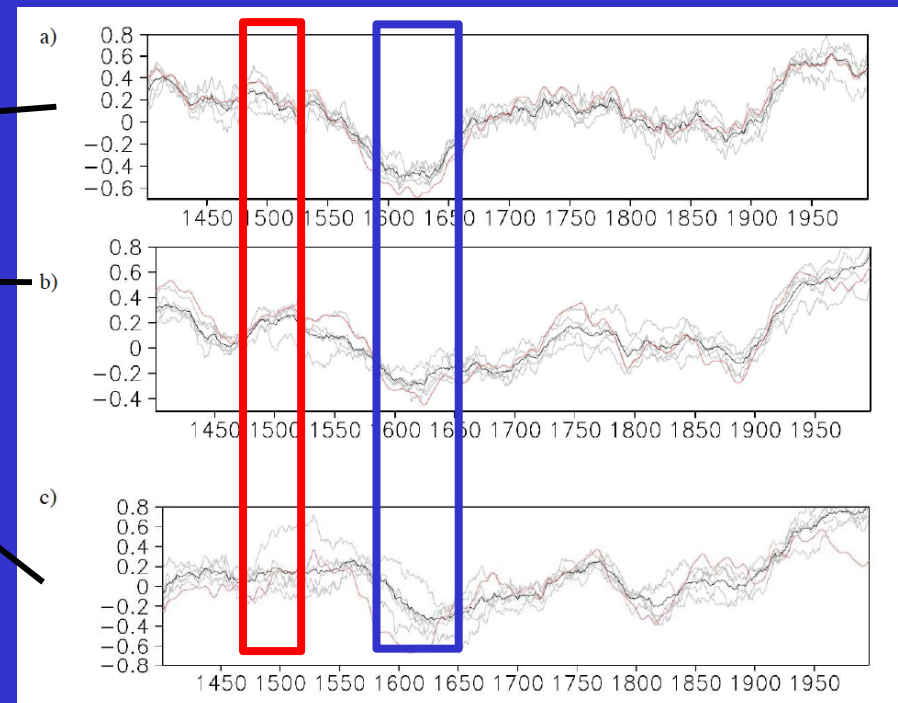
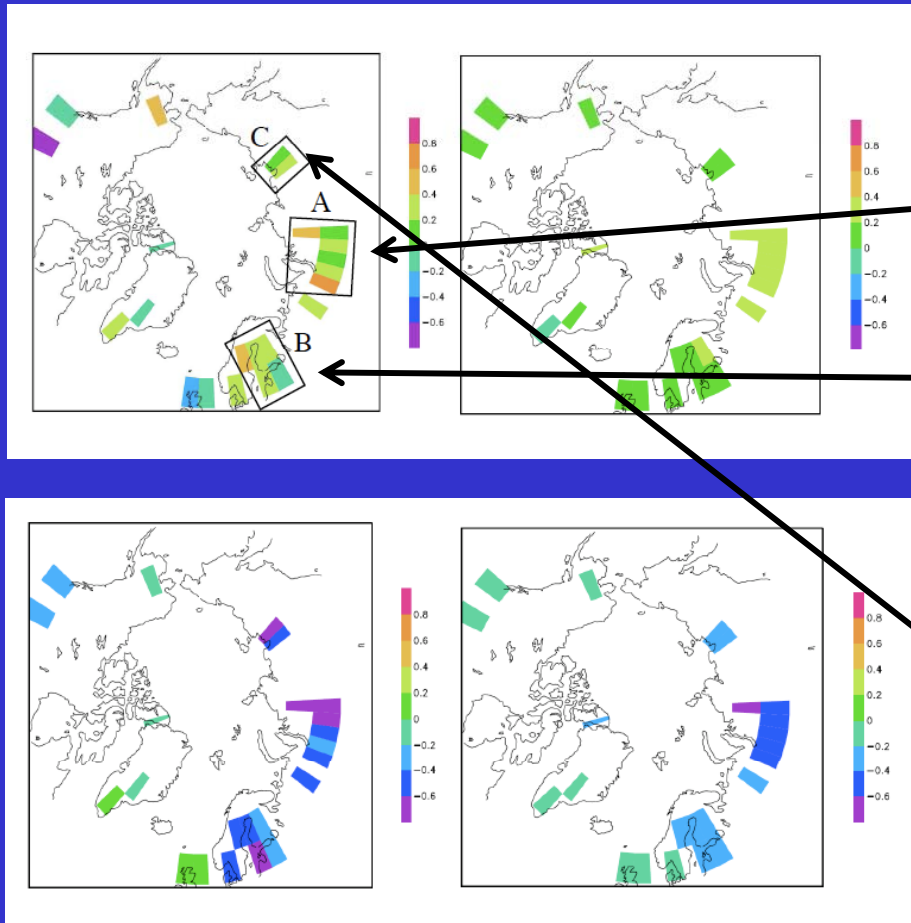


← Positive Phase of Northern Annual Mode

Paleoclimate Data Assimilation

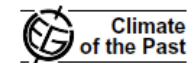
PROXIES

MODEL



Past Natural Arctic warming

Clim. Past, 5, 389–401, 2009
www.clim-past.net/5/389/2009/
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The 15th century Arctic warming in coupled model simulations with data assimilation

E. Crespin¹, H. Goosse¹, T. Fichefet¹, and M. E. Mann²

¹Université catholique de Louvain, Institut d'Astronomie et de Géophysique Georges Lemaître, Chemin du Cyclotron, 2, 1348 Louvain-la-Neuve, Belgium

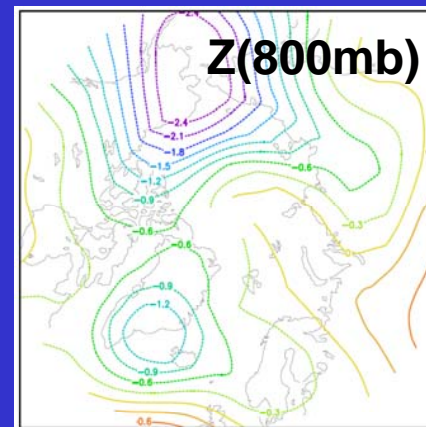
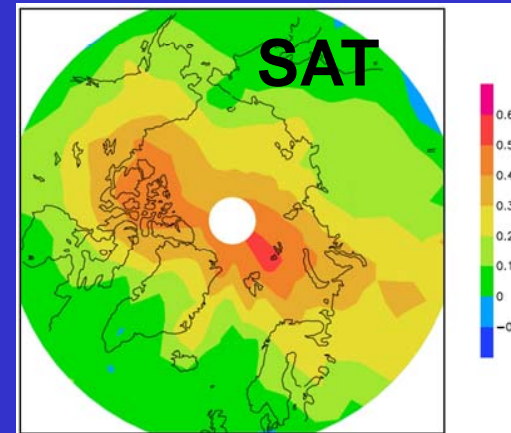
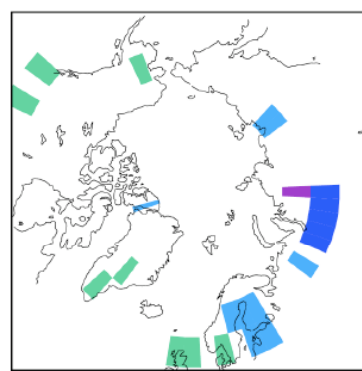
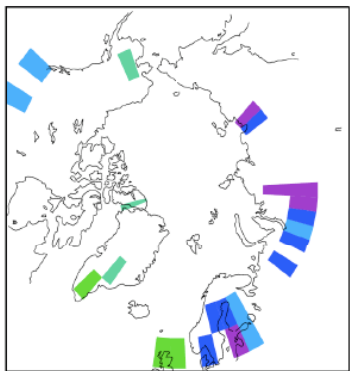
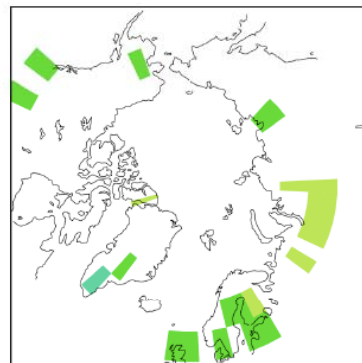
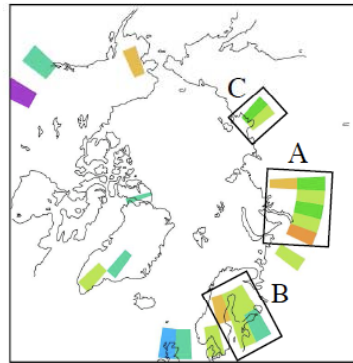
²Department of Meteorology, Department of Geosciences, and Earth and Environmental Systems Institute, Pennsylvania State University, University Park, USA

Received: 4 November 2008 – Published in Clim. Past Discuss.: 7 January 2009
 Revised: 30 April 2009 – Accepted: 7 July 2009 – Published: 22 July 2009

Paleoclimate Data Assimilation

PROXIES

MODEL



Past Natural Arctic warming

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²Department of Meteorology, Department of Geosciences, and Earth and Environmental Systems Institute, Pennsylvania State University, University Park, USA

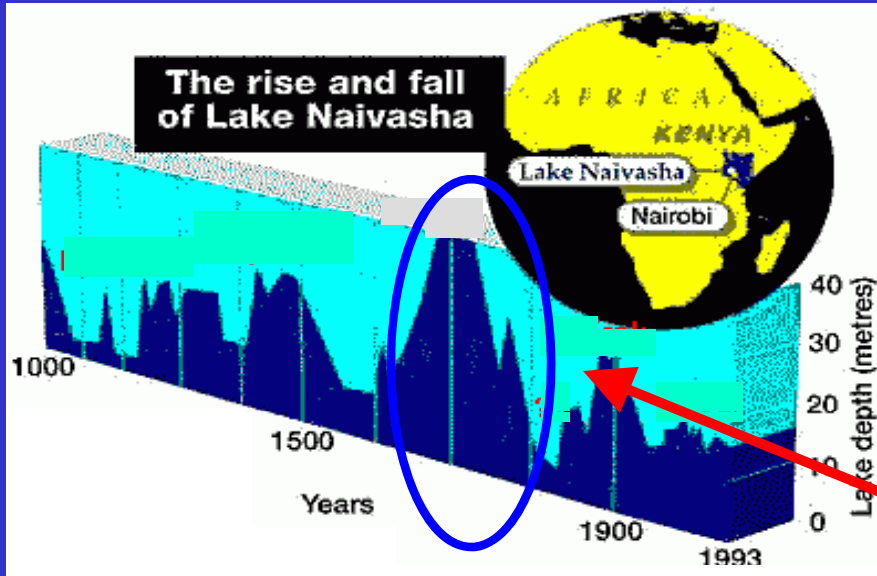
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CONCLUSIONS

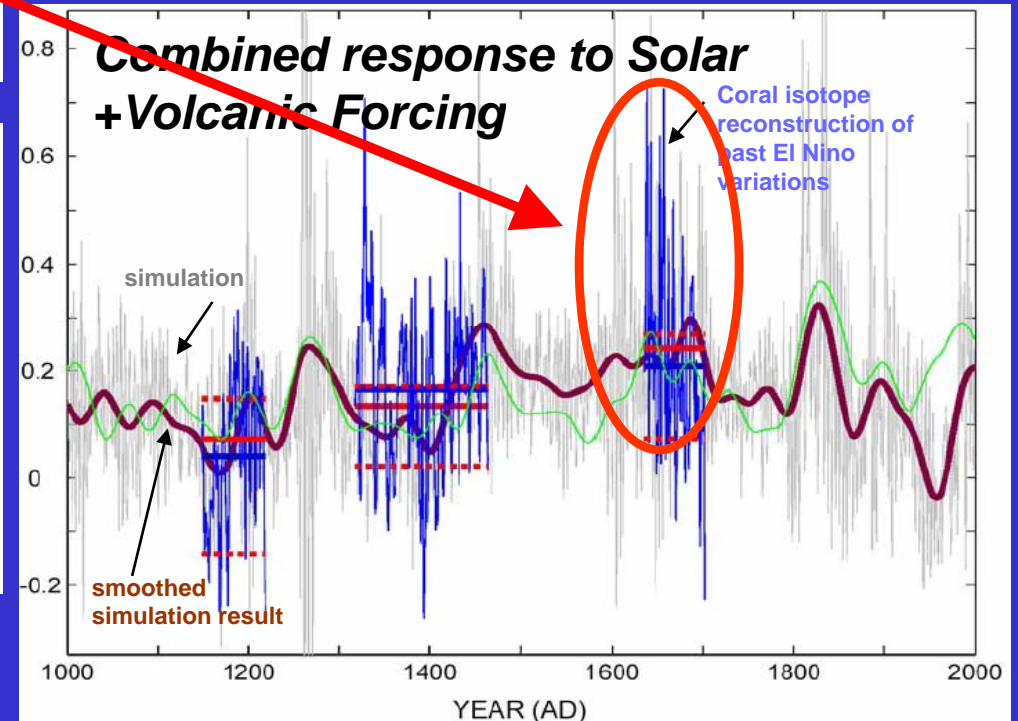
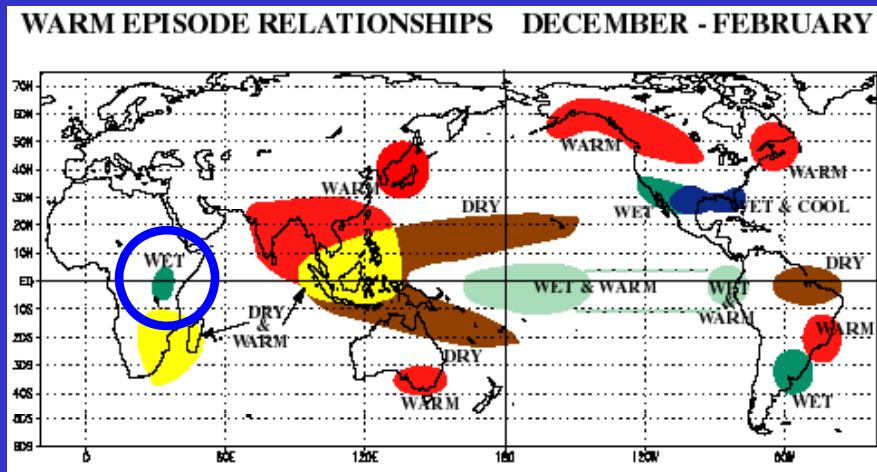
- Recent hemispheric-scale warmth anomalous in at least a millennial context; can only be explained by anthropogenic radiative forcing
- Prior to the 20th century, warmth and cold was highly regionally variable
- Medieval warmth in high-latitude North Atlantic and parts of North America rivaled modern warmth
- Reconstructed La Nina-like pattern during Medieval times, and El Nino-like anomalies during the “Little Ice Age”, suggest a ‘thermostat’ response response to natural radiative forcing
- Response of Northern Annular Mode/NAO to natural volcanic and solar radiative forcing appears to explain enhanced ‘Little Ice Age’ and ‘Medieval Warm Period’ temperature signal in regions such as Europe
- Combination of warm tropical Atlantic and La Nina-like conditions in the tropical Pacific can explain periods of relatively high past Atlantic Hurricane activity



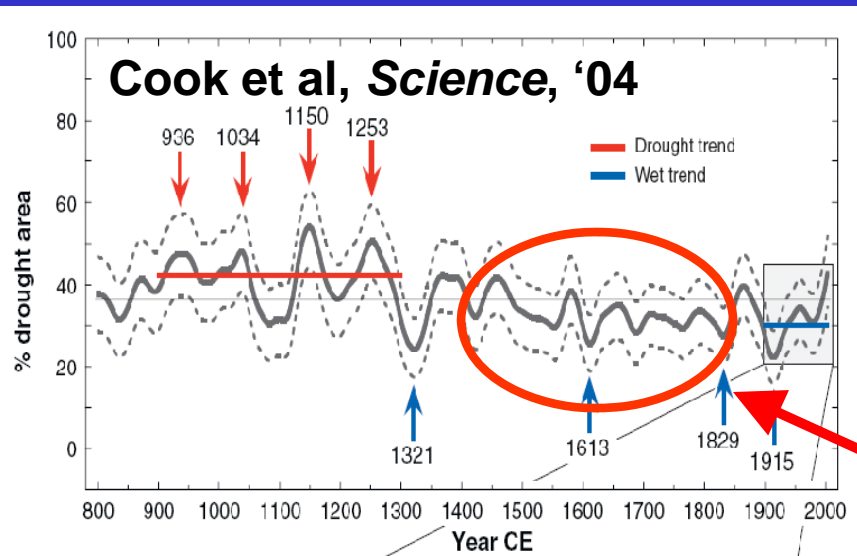
How did Natural Forcings Influence ENSO and the Tropical Pacific During the Past Millennium?



*'Little Ice Age' wet in Kenya:
El Nino-like conditions*

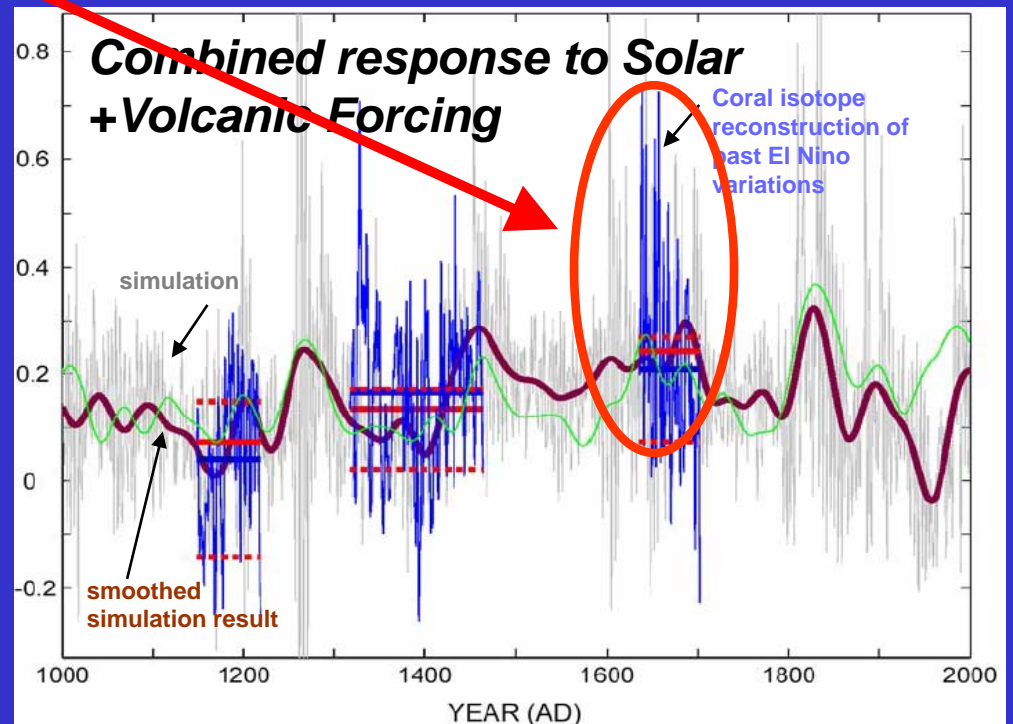
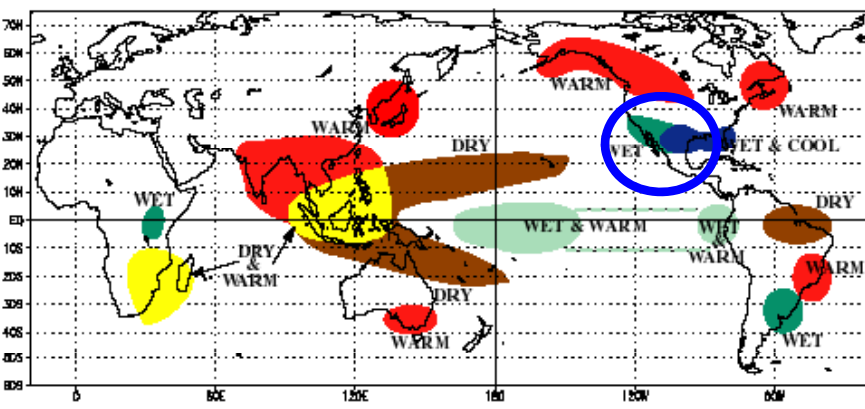


How did Natural Forcings Influence ENSO and the Tropical Pacific During the Past Millennium?

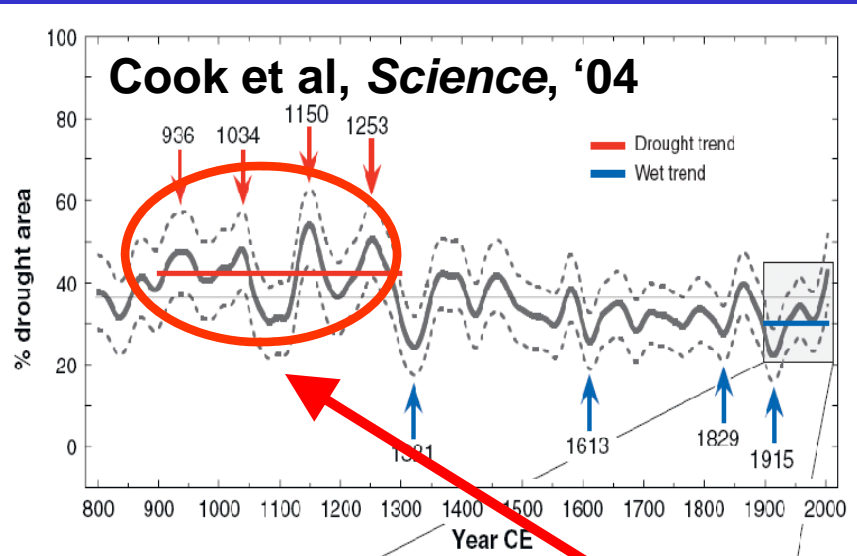


'Little Ice Age' wet in southwestern U.S.: El Nino-like conditions

WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY

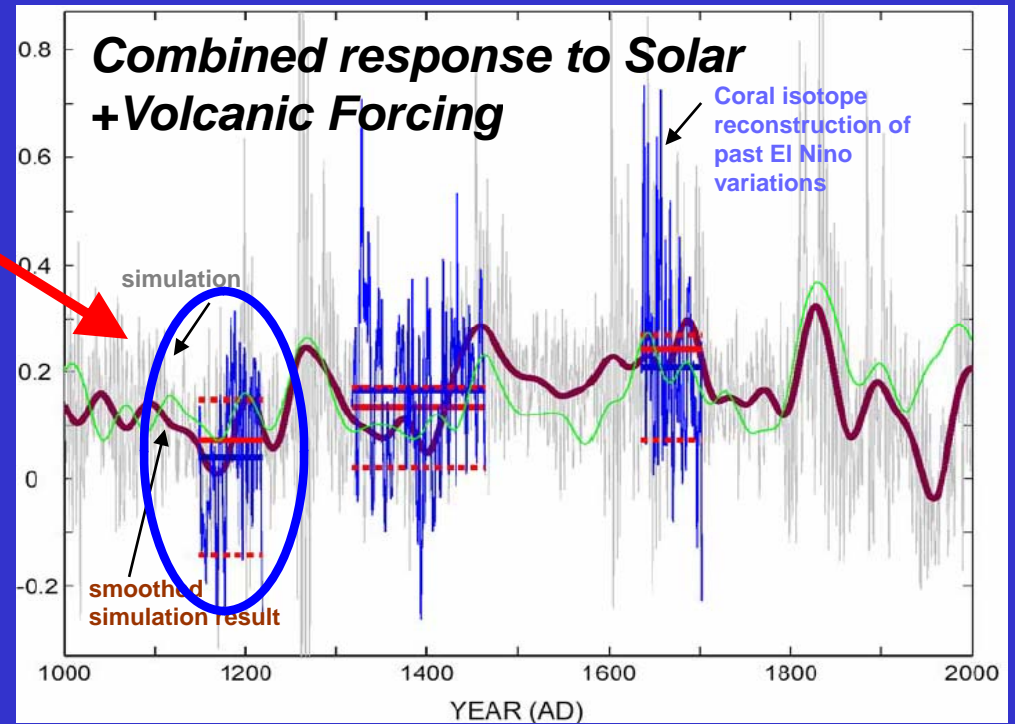
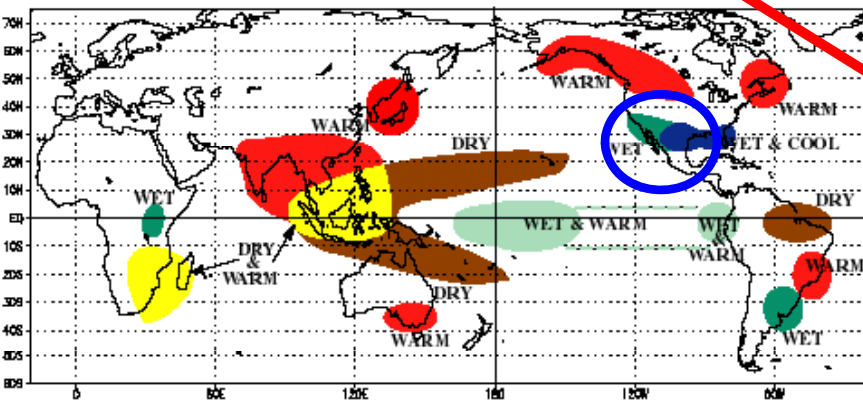


How did Natural Forcings Influence ENSO and the Tropical Pacific During the Past Millennium?

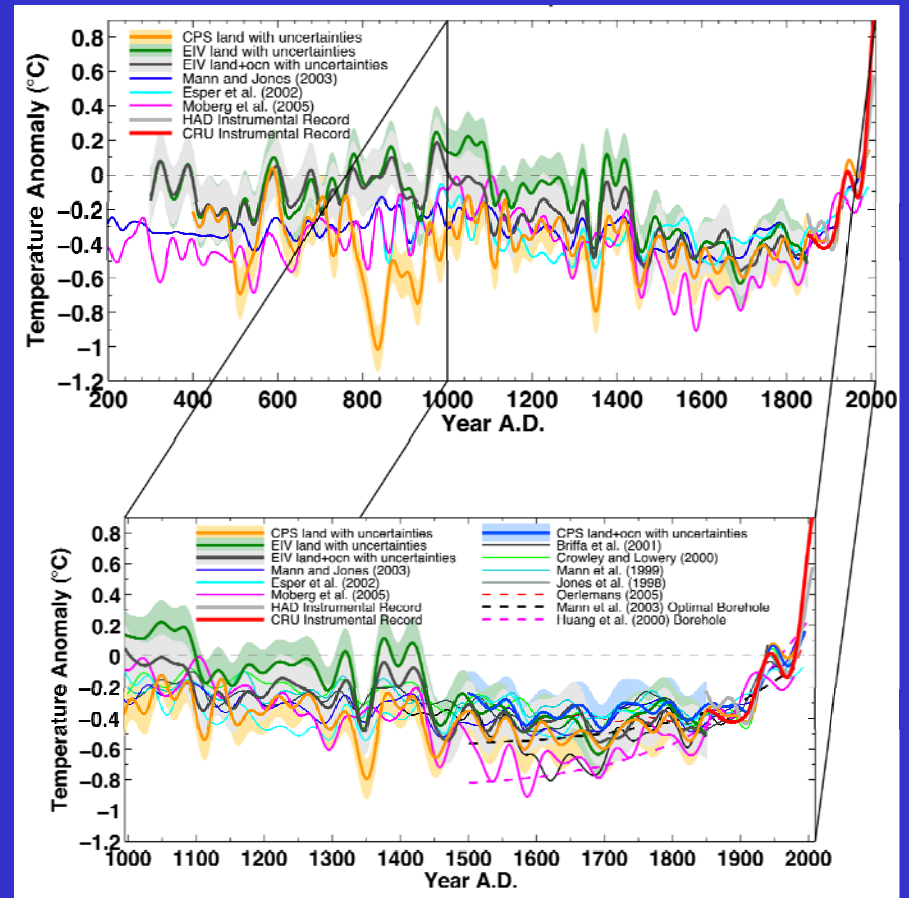
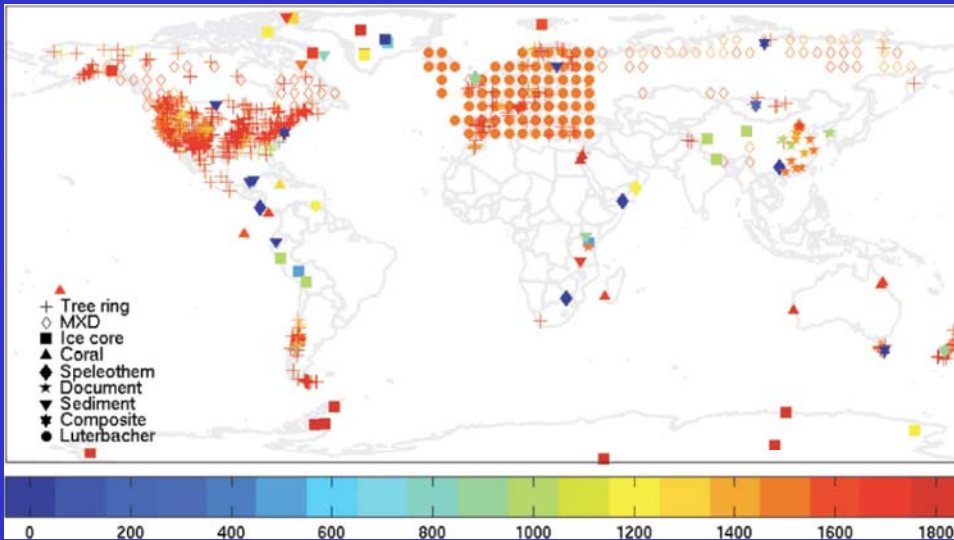


'Medieval Warm Period' dry in southwestern U.S.: La Nina-like conditions

WARM EPISODE RELATIONSHIPS DECEMBER FEBRUARY



Surface Temperature Reconstructions



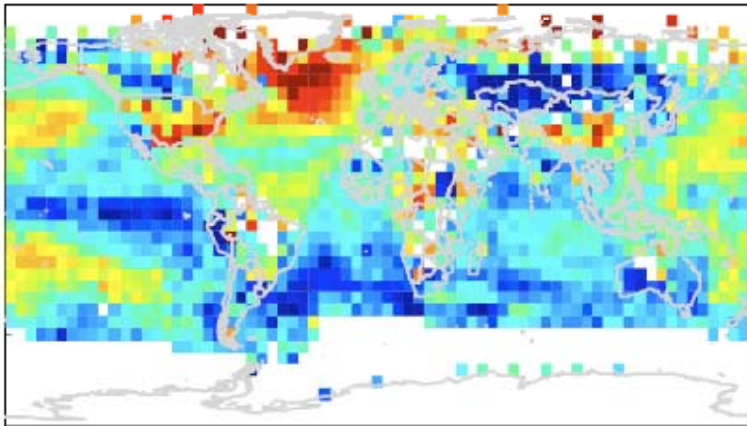
Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia

Michael E. Mann^{*†}, Zhihua Zhang^{*}, Malcolm K. Hughes[‡], Raymond S. Bradley[§], Sonya K. Miller^{*}, Scott Rutherford[¶], and Fenbiao Ni[‡]

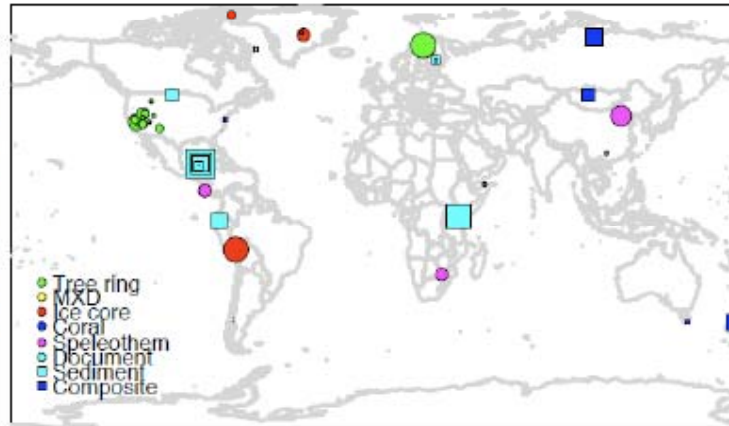
^{*}Department of Meteorology and Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802; [†]Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721; [‡]Department of Geosciences, University of Massachusetts, Amherst, MA 01003-9298; and [§]Department of Environmental Science, Roger Williams University, Bristol, RI 02809

Reconstructed Temperature Patterns

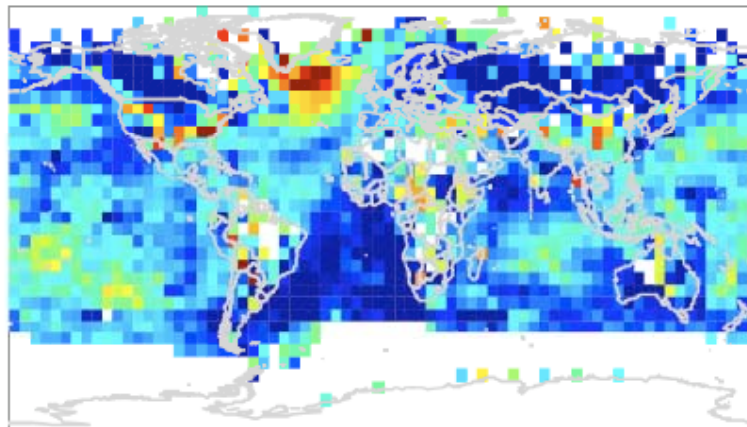
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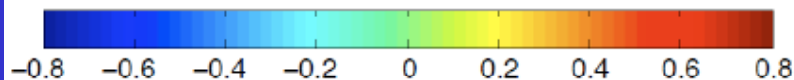
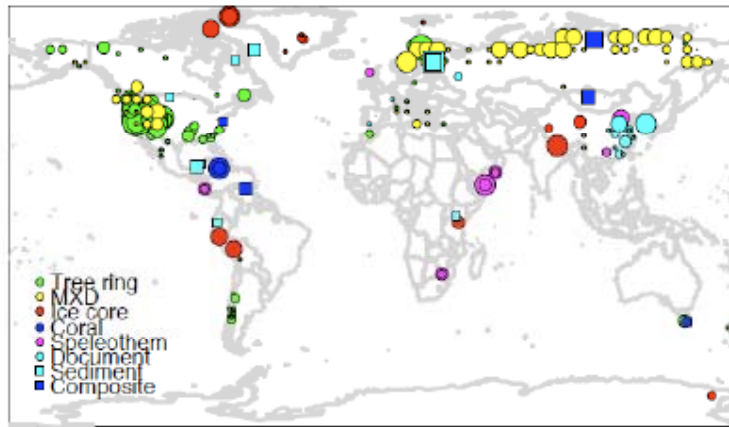
Proxy Weights (low-frequency band) – MCA



Surface Temperature Anomalies – LIA (AD 1400–1700)



Proxy Weights (low-frequency band) – LIA



Spatial Patterns

Mann, M.E., Zhang Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Falugevi, G., Ni, F., Global Signatures and Dynamical Origins of the “Little Ice Age” and “Medieval Climate Anomaly”, *Science* (in press).