Is it warmer now than for the last 1,000 years?

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3. The Science
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4. Does It Matter?
On average, temperatures have been rising world-wide for the last century:
1988: World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) establish the **Intergovernmental Panel on Climate Change** (IPCC).

IPCC publishes Assessments Reports every 5–6 years.

- Fourth Assessment Report is in preparation.
The Past 1,000 Years

1990: IPCC publishes an estimate of how temperature has changed over the past 1,000 years.
2001: IPCC revises the history, based on work by Michael Mann and co-workers.

Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
The Hockey Stick

- The “hockey stick” shape of the new graph suggests:
  - steady cooling in Northern Hemisphere from AD 1000 to around 1900;
  - abrupt warming since then.
- Becomes the icon of “global warming”

New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1,000 years. It is also likely that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year.

- Note. The grey shading indicates “statistical uncertainty”:
  - Wide band, particularly before AD 1600.
  - Often ignored—sigh...
What Happened to the Medieval Warm Period?

- Major difference between 1990 and 2001 figures: the Medieval Warm Period disappeared.
- Reasons explored energetically by Stephen McIntyre and Ross McKitrick, despite difficulties in obtaining Mann’s data and methods.
- M&M claim to find statistical flaws in Mann et al.’s methods, which can introduce spurious “hockey stick” trends.
- Blog wars: climateaudit.org versus realclimate.org.

- Representatives Joe Barton (R, Texas), Chair of the House Committee on Energy and Commerce, and Ed Whitfield (R, Kentucky), Chair of its Subcommittee on Oversight and Investigations, ask Mann and others to provide extensive background on their work.

- Representative Sherwood Boehlert (R, New York), Chair of the House Committee on Science, has “strenuous objections” to the request, finding it “misguided and illegitimate.”
2006: Two reports on the controversy are commissioned.

- Barton and Whitfield ask Ed Wegman (George Mason) to assemble a small group of statisticians to look into M&M’s claims.

  Wegman adds:
  - Yasmin Said (Johns Hopkins);
  - David Scott (Rice).

- Boehlert asks the National Academies to form a panel to review the science of climate reconstruction. Jerry North (Texas A&M) is asked to chair.

Statisticians:
- Doug Nychka (National Center for Atmospheric Research–formerly NCSU);
- Peter Bloomfield (NCSU).
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What Are Proxy Data?

- Hemispheric and global temperature records go back only to around AD 1850.
- Prior to that, temperatures must be inferred from proxy data:
  - tree ring widths and densities;
  - ocean sediments;
  - isotopic concentrations in ice cores;
  - glacier lengths and borehole temperatures (not strictly proxies);
  - other proxies.
- Some studies use more than one source: multiproxy reconstructions.
Rings from several trees can be linked into a single chronology:
An Ocean Sediment Core

A Southern Ocean (Antarctic) core sample:

*core sample taken from 15.5 to 16.6 meters beneath the ocean floor*

*notice the distinctly different layers at different depths in the core sample*

(2 halves shown side by side)
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Collecting ice cores in Greenland, 2005:
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A Glacier retreats

The Qori Kalis Glacier, Quelccaya Ice Cap, Peru, in 1978 and 2002:
All proxy methods must be used with care:

- Tree rings respond to moisture as well as temperature; they work well only at high latitudes or altitudes;
- Ocean sediments reflect sea surface temperature, not air temperature, and are influenced by circulation.
- Ice cores are available only where there’s ice (!)
- And so on...
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A Collection of Reconstructions

NAS panel identifies some key reconstructions:

- Borehole temperatures (Huang et al. 2000)
- Glacier lengths (Oerlemans et al. 2005)
- Multiproxy (Mann and Jones 2003)
- Multiproxy (Moberg et al. 2005)
- Multiproxy (Hegerl et al. 2006)
- Tree rings (Esper et al. 2002)
- Instrumental record (HadCRUT2v)
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Mann *et al.* developed their own procedure to reconstruct temperatures from proxy data.

- Uses both inverse regression and least squares methods:
  - difficult to capture all uncertainties;
  - possibly under-estimates error bars.

- Uses Principal Components Analysis to combine many proxies into a few:
  - unconventional standardization can introduce spurious trends.
Principal Components

A workhorse of multivariate data analysis:

- Basically the *singular value decomposition* of a $n \times p$ data matrix $X$.
- Equivalently, the *eigen value decomposition* of either $X^T X$ or $XX^T$.
- Classically, *rows* of $X$ are a random sample from a multivariate population with covariance matrix $\Sigma$:
  - $(1/n)X^T X$ estimates $\Sigma$, so the right singular vectors of $X$ estimate the eigen vectors of $\Sigma$. 
With time series data, the rows are correlated:

- \((1/n)X^T X\) still estimates \(\Sigma\);
- The \textit{left} singular vectors of \(X\) are the principal component time series.
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The politicization of academic scholarly work leads to confusing public debates. . . . In the present example there was too much reliance on peer review, which seemed not to be sufficiently independent.

Sharing of research materials, data, and results is haphazard and often grudgingly done. . . . When code and data are not shared and methodology is not fully disclosed, peers do not have the ability to replicate the work and thus independent verification is impossible.
The public policy implications of this debate are financially staggering and yet apparently no independent statistical expertise was sought or used.

While the paleoclimate reconstruction has gathered much publicity because it reinforces a policy agenda, it does not provide insight and understanding of the physical mechanisms of climate change except to the extent that tree ring, ice cores and such give physical evidence such as the prevalence of green-house gases. What is needed is deeper understanding of the physical mechanisms of climate change.
Mann’s assessments that the decade of the 1990s was the hottest decade of the millennium and that 1998 was the hottest year of the millennium cannot be supported by his analysis.

The *Wall Street Journal* jumped the gun with an editorial entitled “Hockey Stick Hokum.”
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Mann *et al*.’s statistical methods were problematic.

More recent work with different statistical methods yield similar results.

Reconstructions from AD 1600 to the present are based on various proxies, which gives them credibility.

Prior to AD 1600, reconstructions depend heavily on tree-rings, and are less credible.
With a high level of confidence:

- Global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries.
- This statement is justified by the consistency of the evidence from a wide variety of geographically diverse proxies.

With less confidence:

- Presently available proxy evidence indicates that temperatures at many, but not all, individual locations were higher during the past 25 years than during any period of comparable length since A.D. 900.
Plausible:
- The Northern Hemisphere was warmer during the last few decades of the 20th century than during any comparable period over the preceding millennium.

Even less confidence:
- The original conclusions by Mann et al. (1999) that “the 1990s are likely the warmest decade, and 1998 the warmest year, in at least a millennium.”
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Large-scale surface temperature reconstructions for the last 2,000 years are *not* the primary evidence for the widely accepted views that:

- global warming is occurring;
- human activities are contributing, at least in part, to this warming;
- the Earth will continue to warm over the next century.
The primary evidence for these views includes:

- measurements showing large increases in carbon dioxide and other greenhouse gases beginning in the middle of the 19th century;
- instrumental measurements of upward temperature trends and concomitant changes in a host of proxy indicators over the last century;
- simple radiative transfer calculations of the forcing associated with increasing greenhouse gas concentrations together with reasonable assumptions about the sign and magnitude of climate feedbacks;
- numerical experiments performed with state-of-the-art climate models.
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