Historical Changes in Climate


Lamb, 1969
'Hunters in the snow' by Pieter Bruegel, 1565
Retreat of the Rhone Glacier shown by comparing the drawing from 1750 (top) and a photo from 1950 (bottom), demonstrating the changes since the Little Ice Age.
‘Medieval Warm Period’
900-1300AD
Quantifying recent temperature change is critical to separating natural and anthropogenic effects on climate.

The instrumental record of climate:
- Back to 1854 (squares)
- Back to 1902 (shaded area)

*so most of Pacific and southern Ocean only go back to ~1950*
Global annual-mean surface air temperature change derived from the meteorological station network [an update of figure 5 in Henson, Ruedy, Gisscoe, and Sato (1999)]. Uncertainty bars (95% confidence limits) shown for both the annual and 5-year means, account only for incomplete spatial sampling of data.

This figure and tabular data can be found at http://www.giss.nasa.gov/data/update/gistemp/graphs/.
Five-year running mean temperature change for three latitude bands that cover 30%, 40%, and 30% of the global area. Uncertainty bars (95% confidence limits) are based on spatial sampling analysis.

This figure and tabular data can be found at http://www.giss.nasa.gov/data/updated/gistemp/figs/. 
0-300m significant decadal variability
regional differences

Levitus et al., 2000
0-3000m
less climate noise

significant decadal variability

regional differences

Levitus et al., 2000
How to extend the historical record in space and time?

- Ice cores (high latitudes and high altitude tropics, terrestrial)
- Tree rings (mid- to high-latitude terrestrial)
- Corals (tropical ocean temperature)
Tibetan Plateau Cores

Dasuopu (7200 m asl)
avg. = -20.32 \%\text{\textperthousand}

Guliya (6200 m asl)
avg. = -14.23 \%\text{\textperthousand}

Dunde (5325 m asl)
avg. = -10.81 \%\text{\textperthousand}

South American Andes Cores

Huascaran (6048 m asl)
avg. = -18.46 \%\text{\textperthousand}

Quelccaya (5670 m asl)
avg. = -18.06 \%\text{\textperthousand}

Sajama (6542 m asl)
avg. = -16.73 \%\text{\textperthousand}

Thompson et al., 2003
By ‘cross-dating’ tree rings back in time, you can extend tree ring width chronologies back several thousand years.
But what determines ring width?

- temperature
- precipitation
- growth stages of tree
Long-term trends are usually removed from tree ring chronologies; likely related to biological factors.

Tree ring reconstructions are formed from dozens of individual records.
New statistical techniques purport to salvage low-frequency signals from tree rings.

Current drought not unprecedented; huge droughts during overall dry period in MWP, wetter in LIA.

Cook et al., 2004
Drowned stumps in western US lakes grew during Medieval Climate Anomaly – largest change during last millennium in precipitation, not temperature?
Tree Rings

• Can record precip-evap (P-E), T (often hard to deconvolve)
• Annually resolved
• Continuous records only for past 1-2 kyr
• Difficult to properly reconstruct > decadal scale variability
Coral records of tropical climate
Living corals provide records for the last 200 years

Fossil corals enable us to extend the record (ex. 1320-1390 A.D.)

Coral oxygen isotopic records
- sensitive to SST & precip.
- monthly-resolved
- go back to 1600 A.D. (living)
  & to 1000 A.D. (fossil)
During El Niño events, positive SST and precipitation anomalies both contribute to negative coral $\delta^{18}O$ anomalies in the central tropical Pacific.

Interpretation of coral $\delta^{18}O$ on lower frequencies relies on assumption that warm SST drives higher precipitation in the central tropical Pacific, and vice versa.
Palmyra coral calibration

Cobb et al., 2003
- cooler, drier during MWP (linked to prolonged drought in U.S. West?)
- many large El Niño events during LIA
- highly variable El Niño-Southern Oscillation – change decade to decade
- significant trend towards warmer, wetter conditions since 1976
Multi-proxy temperature reconstructions

Mann et al., 1999
-calibrated multi-proxy data network against 20\textsuperscript{th} century global temp. patterns extracted by Principal Component Analysis (PCA)

-used data to reconstruct principal modes of temperature variability back to 1000 A.D.
Departures in temperature (°C) from the 1961 to 1990 average

Medieval Warm Period

Little Ice Age

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

Year

Mann et al., 1999
Tree Ring network for N.H. reconstruction

Esper et al., 2002
Convergence between reconstructions

Northern Hemisphere

Southern Hemisphere
What can cause global temperature change?

- Energy coming in from the sun
- Greenhouse gas concentration
- Albedo
Shown are (a) bolometric facular brightening parameterized using He 1083 nm EW data, (b) sunspot darkening calculated from white light solar images, and (c) their net modulation of total irradiance during the Schwabe cycle, compared with measurements made by ACRIM on the SMM and UARS spacecraft, cross-calibrated using overlapping ERBS observations. Deviations of the SMM and UARS data from the reconstructed irradiances in 1980 and 1992, respectively, may reflect instrumental effects in the ACRIM data, since space-based radiometers are most susceptible to sensitivity changes during their first year of operation.
Question is how to scale this sunspot reconstruction to watts/m^2?

Can directly calibrate 11-yr cycle, but what about longer-term variability?
Solar input reconstruction (green) graphed with estimated surface temperatures from the past (blue) and measured northern hemisphere temperatures (red, dashed). Solar irradiance was relatively more important in forcing temperature until about 1800; by comparison only 1/3 of the temperature increase in past 150 years is attributed to solar forcing. Volcanic eruptions resulted in a major dip in temperature from 1800 to 1850.
Solar Irradiance

- There are small changes in irradiance (about .1%) associated with 11-year sunspot cycles.
- Changes in irradiance with longer period variations in sunspots (Maunder minimum) less certain: 0.025% to 0.25%.
- Maunder minimum corresponds to Little Ice Age in time, but global significance of LIA uncertain (was it mostly a circum-North Atlantic event?)
Volcanoes

• Large particles have little climate impact
• Particles injected into troposphere are quickly washed out and have little climate impact.
• Injection of sulfur-bearing gases (e.g., SO$_2$) into stratosphere, photochemical reactions form small sulfuric acid (H$_2$SO$_4$) droplets, which do have a climate impact
Left side: observed and modeled temperature change near the time of Pinatubo eruption. Right side: similar to left except all three levels are referenced to the 12 months before the month of the Pinatubo eruption, stratospheric observations are global, vertical weighting functions are applied to the model stratospheric and tropospheric data, the model surface air temperatures are averaged over only the region with observational data, and the seasonal cycle is removed from the model by differencing with the previous 10 model years rather than by subtracting the control run.

In the Cane-Zebiak ENSO model, large volcanic eruptions Trigger El-Nino conditions in the tropical Pacific.  
[Solar irradiance also has an effect:  high irradiance = cool TP]  

Mann et al., 2005
Purple: Net effect of solar + volcanic on model
Blue: observed fossil coral data
Greenhouse Gases

Increase of greenhouse gas concentrations over the last 200 years from Antarctic ice cores: CO₂ (from Deschger & Siegenthaler 1986), CH₄ (from Pearman et al. 1986), N₂O (from Khalil & Rasmussen 1986). The population growth is included for comparison.

The global mean radiative forcing of the climate system for the year 2000, relative to 1750.
Modeling climate of the last millennium

A

Radiative Forcing for Ice Core Volcanic Indices

-10
0
5
10
15

Mill. h. c. t. RF(-1)
1400. h. c. t. RF
Sato (-1)

Radiative Forcing (W/m^2)

0
5
10
15
20
25

B

Net Radiative Forcing

-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

Bard Be10
Lean.2000
Modeling climate of the last millennium

Crowley et al, 2000
Climate models with moderate climate sensitivity (1.5-2.5°C/ doubled CO₂) best fit data
Climate of the Last 1000 yrs

- causes and expression of Medieval Climate Anomaly and Little Ice Age still unclear
- large precipitation changes inferred (massive western US droughts), causes uncertain
- may be a role for sun, but variations may be too small to cause temperature changes
- Volcanoes cause sharp cooling on much shorter time scales (1-2 years); may impact other aspects of climate
- Warming of the last decade is very likely the result of excess greenhouse gases