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Lessons & Limits of Climate History:

Was the 20th Century Climate Unusual?

By Willie Soon and Sallie Baliunas

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Executive Summary

This report examines the repeated claim that the climate of the 20th century was unusual compared with those of the last 1,000 years. The claim takes several forms – e.g., that the 20th century has been warmer than any other century, that the 1990s were the warmest decade of the millennium, or that 1998 was the warmest year of the millennium.

These claims imply that the temperature of the past 1,000 years is known well enough to allow an accurate comparison of the 20th century with the previous centuries, decades and individual years. This is not the case. A set of direct temperature measurements is only available since 1861 and there are reasons to question whether these data are sufficiently accurate to compute global average temperatures.

For earlier periods it is possible to use proxy information, e.g., tree growth, the isotopic composition of corals and ice cores, to estimate *local* climate information, sometimes including local temperature.

However, the proxy data are far too incomplete – both in geographic coverage and in temperature information – to allow a realistic estimation of a global surface temperature. The most widely quoted effort to reconstruct the temperature of the Northern Hemisphere for the last 1,000 years depends heavily on a single set of tree growth data from the Western U.S., and the assumption that the differences in temperature between the Western U.S. and the rest of the Northern Hemisphere for the last millennium were the same as they were in the 20th century. This is an unrealistic assumption, because it is well documented that such local climate trends are not uniform over areas as large as a hemisphere.

While proxy data cannot be used to reconstruct the global average climate of the last 1,000 years, they do provide a basis for comparing the climate of the 20th century to the climate of the preceding 900 years within individual locations. A survey of the scientific literature found that it was possible to identify a 50-year period in which temperatures were warmer than any 50-year period in the 20th century in most of the locations of the climate proxies. These results offer strong evidence that the climate of the 20th century was not unusual, but fell within the range experienced during the past 1,000 years.

The proxy data also offer strong support for the existence of:

- the Medieval Warm Period, a period of warmer temperatures, which lasted from about 800 to 1300 C.E.
- the Little Ice Age, a period of colder temperatures, which lasted from about 1400 to as late as 1900 C.E in some regions.

The recovery from the Little Ice Age accounts for some of the warming experienced during the early 20th century, especially early in the century.

The existence of periods like the Medieval Warm Period and the Little Ice Age suggests that local climate varies on century-long time scales, a result that cannot be easily inferred from the much shorter thermometry records.

The available scientific evidence does not support the claim that the climate of the 20th century was unusual when compared to the climate of the previous 900 years.

Introduction

The Intergovernmental Panel on Climate Change (IPCC), the United Nations (UN) body charged with assessing the state of knowledge about climate change, in its Third Assessment Report (TAR) published in 2001 claimed that most of the warming of the last 50 years was likely attributable to human emissions of greenhouse gases.[1] This statement has been cited many times as evidence of the need for drastic actions to reduce human emissions of greenhouse gases. The Marshall Institute, in its recent report, *Climate Science and Policy: Making the Connection*, examined this claim in detail and raised many questions about the certainty with which it was presented.[2]

Claims have also been appearing in both scientific literature and popular media that the 20th century was warmer than any other century in the millennium, that the 1990s were the warmest decade, and that 1998 was the warmest year in that period. A December 1999 World Meteorological Organization (WMO) press release, which was widely reported in the media, is titled: "1999 Closes the Warmest Decade and Warmest Century of the Last Millennium According to WMO Annual Statement on the Global Climate."[3] The body of the press release identifies 1998 as the warmest year.

The IPCC TAR issued similar claims (p. 28):

- The rate and duration of warming in the Northern Hemisphere during the 20th century was greater than any of the previous nine centuries, and
- The 1990s were the warmest decade and that 1998 was the warmest year since 1861.[4]

There is considerable confusion over the difference between weather and climate. Some of what the IPCC and WMO discuss is climate, but much of it is weather.

Temperatures and rates of warming for the 20th century were based on the instrumental temperature record, which only extends back to 1861. Temperatures and warming rates for earlier periods were inferred from climate proxies.

There is considerable confusion over the difference between weather and climate. Some of what the IPCC and WMO discuss is climate, but much of it is weather. *Weather* is what we all experience on a day-by-day or season-by-season basis. *Climate* is the long term average of weather, defined as 30 – 50 years or longer. Climatologists measure weather, and once sufficient data about weather are available, they can calculate average climate. Also of interest are deviations from average climate. These are known as *anomalies*. A warmer, colder, wetter, or drier year, several years, or other periods compared to the climatic average are anomalies.

Understanding past climate and the validity of the WMO or IPCC claims is an important part of the scientific foundation on which wise and effective climate policy should be based. For example, knowledge of inevitable and sustained climate anomalies allows preparation for them.

If the IPCC conclusion were correct, then the climate of the 20th century, particularly the 1951 – 2000 period, would have been both unusual and unnatural. That would mean the latter half of the 20th century would have been dramatically warmer, wetter, or drier than earlier periods, when the small magnitude of human emissions of greenhouse gases would not have significantly affected global climate. While a finding that the climate of the 20th century was similar to past climates does not disprove the IPCC contention about the role of human emissions, it raises still more questions on the confidence or robustness of that conclusion.

This report examines the scientific information available to support or refute claims that the climate of the 20th century was unusual. We consider:

1. How the temperature of the Earth is determined,
2. Temperature patterns over the last 1,000 years,
3. The WMO claim that the 20th century was the warmest of the millennium,
4. The IPCC claim that rate and duration of warming in the Northern Hemisphere during the 20th century were unprecedented during the millennium,
5. The claims that the 1990s were the warmest decade and 1998 the warmest year of either the millennium or within the length of individual temperature record, and
6. What is known and unknown about natural variability of climate.

Measuring the Earth's Temperature

The political debate over the potential for human activities to affect global climate often focuses on *global average surface temperature* as a measure of climate change because it conveys the global nature of the potential problem and because global averaging may make it easier to detect any common, widespread change in climate.

Determining global average surface temperature is not easy. Surface temperatures vary widely between the tropics and polar regions, and between lowlands and mountains. Additionally, the range of temperatures experienced over the course of a day, season, year or decades is significantly different depending on location. A lowland tropical region experiences far less difference in temperature over the course of a year than does a highland temperate region. Determining year-to-year temperature change in one location does not indicate how temperature changes in a region with different geography. Averaging annual temperature over a region, or ultimately over the whole globe, can provide more meaningful information about climate change. However, as will be detailed in this paper, in most cases, the data needed to derive such averages for historical times are limited or non-existent. The following sections describe the methods available for estimating surface temperatures.

Direct Temperature Measurement

The most straightforward way of measuring global average surface temperature is by calculating the weighted average of thermometer readings from the thousands of weather stations distributed around the world. Weighting is necessary because these weather stations are not equally or optimally distributed. Far more of them exist in developed countries than in developing countries. Thus, in determining global average surface temperature, data from a weather station in the U.S. might be used to represent the temperature of a few hundred square miles, while data from a weather station in Africa might be used to represent the temperature of thousands of square miles.[5] The more closely the weather stations are spaced, the more accurate the average will be. The situation is further complicated by the scarcity of data from the oceans, which cover 70% of the surface of the globe.[6]

Inevitably, these factors and others lead to questions of accuracy especially when measurements are made over a long period of time. Two such questions arise on the land temperature record:

1. What is the impact of the urban heat island effect, the higher temperature in cities due to the heat trapped in concrete, asphalt, etc.? The IPCC claims that the urban heat island effect could account for up to 0.12°C of the 20th century temperature rise, one-fifth of the total observed.[7]
2. What is the effect of the adjustments made to the temperature data during the averaging process? These adjustments are made to compensate for changes in weather station procedures and location, missing data, etc., over the long period of time for which temperature data have been collected. Balling and Idso analyzed

> the effect of these changes on U.S. temperature history and found that these adjustments led to "a significantly more positive, and likely spurious" trend in the data.[8] While the U.S. represents only as small portion of the Earth's surface, its temperature data are generally considered among the best quality in the world.

The sea surface temperature (SST) record also is complicated by a change in procedure. Prior to the 1940s, SST was determined by measuring the temperature of a dunked bucket of sea water with a thermometer. After the 1940s, SST was taken by measuring the temperature of the sea water at the intake to the engine cooling system. Large adjustments had to be made to the older data to make it compatible with the new data. These adjustment affected average SST by 0.1 – 0.45°C;[9] The upper end of this range is three quarters of the observed change in global average surface temperature for the 20th century. Problems with defining a global-scale mean climatology for SST still exist. Hurrell and Trenberth showed significant differences in four SST databases, even for periods as late as 1961-1990.[10]

While analysis of weather station data indicates that a global warming trend occurred during the 20th century, they cannot tell us whether this warming was unusual or unnatural.

Keeping these concerns about the accuracy of the temperature record in mind, we now address the temperature record itself. The most up-to-date summaries of global average surface temperature since 1861, the first date for which researchers are willing to calculate a global average surface temperature from direct surface measurements, have been published by Jones, *et al.*[11] These show that global average temperature fluctuated between 1861 and 1910, warmed between 1910 and 1940, cooled between 1940 and 1975, then warmed through 2000. Using these data, the IPCC concluded that global average temperature increased 0.6 $\pm$ 0.2°C (1.1 $\pm$ 0.4°F) during the 20th century.[12] The uncertainty band on this average is an indication of the statistical uncertainty in the weather station measurements and does not reflect systematic errors such as the urban heat island effect or errors in ocean temperature measurements.

Proxy Measurements of Temperature

While analysis of weather station data indicates that a global warming trend occurred during the 20th century, they cannot tell us whether this warming was unusual or unnatural. A longer record is needed to answer this question. Changes in temperature cause many changes in the biological and physical world. Some of these changes are regular enough to be used as quantitative *proxy* measurements for temperature change. For example, in some trees each year's growth creates a measurable ring. Since tree growth tends to hasten in warm weather compared to cold weather, the width and density of tree rings may be proxies for average temperature. Tree growth measurements can be made by taking cores out of living trees, or by examining the cross-section of cut, dead or fossilized trees.

Besides tree growth, proxy climate data, including temperature, have also been obtained from a wide variety of sources. This report focuses on the most commonly used of these additional proxy measures: layers in corals, ocean sediments, and ice cores; the temperature profile in boreholes, i.e., holes drilled deep into the Earth; and the rate and pattern of glacier movements. Techniques for developing proxy temperature information from all of these sources except boreholes are described by R. S. Bradley in his book, *Paleoclimatology: Reconstructing Climates of the Quaternary*.[13] Huang, *et al.* look at ways of deriving century-long trends of surface temperature change from borehole temperatures.[14]

Two major questions must be answered in using climate proxy measurements to determine temperature histories:

1. Does the proxy change being measured mainly owe to one climate variable, e.g., temperature? In the case of tree growth, other factors that affect tree growth must either be known to have a very small effect or their effect must be separable from that of temperature.
2. What is the quantitative relationship between the proxy change and the change in temperature, i.e., how much faster does a tree grow when local seasonal temperature increases? A period during which both good records of *local* weather conditions and good measures of the tree growth are available is needed to establish this correlation.

A discussion of the types of quantitative proxy temperature data available and the cautions to be applied in their use follows.

Tree Rings

As Bradley points out, tree growth, and hence the width and density of tree rings, depends on many factors, including the tree species and age, the availability of stored food in the tree and nutrients in the soil, the full range of climatic variables (sunshine, precipitation, temperature, wind speed, humidity); and their distribution throughout the year.[15]

Of these factors, precipitation is probably the most important, since low water availability will lead to low tree growth, even at high temperature. Research has shown that the density of the wood in individual tree rings is a better indicator of average temperature in the growing season than the width of the tree ring, and most recent proxy temperature studies use this approach.[16] Also, most tree ring studies use multiple samples from each tree and a number of trees to minimize the effect of variations within and between trees.

Once tree ring width and/or density data have been collected, they have to be calibrated against climate variables, typically temperature and precipitation. Temperature and precipitation effects can be separated only if more than one measure of tree growth is available. In the typical situation, both tree ring width and density might be available for 500 years, but data for temperature and precipitation might be available for only 100 years. For that 100 years, standard regression analysis techniques can be used to separate the effects of annual (or growing season) average temperature and precipitation on tree growth. The resulting information can be used to estimate annual (or growing season) average temperature and precipitation for the remaining 400 years.

While the approach described above seems simple and mechanical, it is neither. Several problems arise. First, for the same weather conditions, young trees grow faster than older trees. The effects of this early growth must be removed statistically. The statistical approaches used smooth the year-to-year variability due to weather from the growth record when the tree was young,[17] and even the true year-to-year variability of weather may be lost through the procedure. Next, average values from the multiple samples per tree and multiple trees in the study must be calculated. This can further decrease the size of year-to-year variability in the final results. Also, the steady rise of atmospheric carbon dioxide (CO_2) concentration is a complicating factor in interpreting tree ring data. Plants grow better at higher CO_2 concentration, and there is growing evidence that this has already begun to affect trees growing natural conditions.[18] Since CO_2 concentration has been rising for the same period as weather data are available to calibrate tree ring data, a non-linear error of unknown size has been introduced. Finally, since few trees yield good data for many centuries, it is usually necessary to combine data from several trees to get a multi-century record. The statistical techniques used to combine data filter out the century-scale climate variability. The effect of all of these problems is to make tree growth studies highly suspect as a continuous recorder of temperature histories over many centuries or as long as a millennium

Corals

Coral reefs do not exhibit the finely defined layers trees do, but their growth varies with sea water temperature; the higher the sea water temperature, the more dense the coral. As is the case with tree rings, many other factors also affect the density of coral reefs. However, several attempts have been made to develop a proxy record from the growth layers in coral reefs.[19]

A proxy temperature approach makes use of the fact that corals extract calcium carbonate ($CaCO_3$) from sea water to form their reefs. In the atmosphere, oxygen exists in three stable isotopes[20]: 99.76% is ^{16}O, 0.04% is ^{17}O, and 0.2% is as ^{18}O, and these are the typical proportions that are also present in $CaCO_3$ in sea water. The calcium carbonate that corals extract is slightly enriched in ^{18}O compared with sea water, with the degree of enrichment decreasing as temperature increases. However, the relationship between the amount of ^{18}O in corals and temperature is not simple because the amount of ^{18}O in sea water is not constant. Rainwater is depleted in ^{18}O, so heavy rainfall will lower the concentration of ^{18}O at the surface of the ocean. Conversely, a long dry period, with high evaporation rates, can raise ^{18}O concentration at the ocean's surface. Despite these difficulties, several reconstructed temperature records have been developed based on ^{18}O in coral reefs.[21]

Ocean Sediments

Ocean sediments contain the skeletons of a variety of invertebrates. Variations in the ^{18}O content in their shells can be used to establish a proxy temperature record using many of the same techniques as are used for corals. There are, however, several additional complications. Corals grow at the ocean surface, but the invertebrates deposited in ocean sediments live at different depths in the oceans. Water temperature changes rapidly with depth in the first few hundred feet below the ocean surface, so the knowledge of the depth at which the invertebrate species lived is of critical importance. Also, not all families of invertebrates concentrate ^{18}O with the same efficiency, a fact that must be taken into account when calibrating ocean sediment proxy data.[22]

Ice Cores

The ice sheets that cover Antarctica, Greenland, the islands north of Canada and Russia, and the tops of some mountainous areas, represent the accumulation of as much as several hundred thousand years of snow fall. In very cold, dry areas, such as the interior of Greenland and Antarctica, the record is particularly good because there is little year-to-year evaporation or melt, and snow compresses into annual layers of ice. The thickness of these layers is an indication of the amount of precipitation that fell at that location during the year the layer was deposited, and the isotopic make-up of the water in the ice can provide a proxy for temperature.

As discussed above, oxygen exists in three stable forms, ^{16}O, ^{17}O, and ^{18}O. Hydrogen exists in two stable forms, ^{1}H and ^{2}H. ^{1}H is designated H, while ^{2}H is known as deuterium, and designated by the symbol D. Almost all water is $H_2{}^{16}O$, but two heavier forms, HDO and $H_2{}^{18}O$, are present in sufficient quantities to provide a basis for a proxy temperature record. Both the heavier HDO and $H_2{}^{18}O$ molecules will condense more quickly than $H_2{}^{16}O$. The concentration of D and ^{18}O in the ice sample is a measure of the temperature at which the snow that formed that ice fell. As more precipitation falls, the water vapor in the atmosphere becomes depleted in D and ^{18}O, so the last snow to fall will have a different D and ^{18}O concentration than the first snow that fell. In areas of heavy snowfall this can cause significant differences in proxy temperature estimates.[23]

Boreholes

Temperature changes at the surface of the earth diffuse through the earth and affect long-term temperature patterns below the surface. If the temperature below the surface, and the heat transfer properties of the soil and rock between the surface and the point of temperature measurement, are known it is possible to calculate average surface temperature. The calculation is not an easy one, and is very sensitive to assumptions made about the rate of heat transfer.

This technique cannot provide information about annual temperature changes or for times near the present. It is limited to periods of about a thousand years, since at longer times the effect of changes in surface temperature becomes too weak to interpret. However, researchers have used this technique to estimate century-long temperature trends at numerous points around the globe.[24]

Glacier Movements

Mountain glaciers grow and advance during colder (and moister) periods. They shrink and retreat during warmer periods. Because of the large mass of ice in glaciers, it takes a significant period of time for a glacier to respond to a change in climate. This lag in response times means glacier movements cannot be used to determine annual changes in temperature. However, glaciers are good indicators of longer term trends, because their movements reflect average climate conditions over decades or longer. The rate of movement of glaciers can be determined from historical records, or from dating the moraines (rock deposits) they leave at their furthest point of advance.[25] Because glacier movements provide an integration of climate over an extended period of time, they provide qualitative information about the century-long climate trends we will be discussing in the reminder of this report. However, they cannot provide quantitative measures of century-scale climate variability.

Considerable scientific ingenuity has gone into efforts to obtain proxy climate data from biological and physical sources. However, the task is a challenging one and the results obtained are subject to many complications and potential uncertainties.

Summary: Proxies

Considerable scientific ingenuity has gone into efforts to obtain proxy climate data from biological and physical sources. However, the task is a challenging one and the results obtained are subject to many complications and potential uncertainties. Proxy results are best used to indicate climate tendencies or trends. A high proportion of proxy results indicating the same climatic trend is a strong indicator that that trend occurred, even if the magnitude of the change cannot be quantified.

Temperature Patterns of the Last 1,000 Years

Historical records provide a great deal of information about the climate of Europe and the North Atlantic for the last 1,000 years. A thousand years ago, it was relatively warm in this part of the world; wine grapes grew in Southern England and the Vikings could sail to Iceland and Greenland in open boats. This warm period, referred to as the Medieval Warm Period or Medieval Optimum, lasted from about 800 to 1300. From 1300 to 1900 it was colder, a period referred to as the Little Ice Age. Historical records of this latter period are documented in detail by Fagan.[26] Since 1900 the world has been getting warmer.

Weather and climate were not uniform during any of these periods; there were colder periods during the Medieval Warm Period and warmer periods during the Little Ice Age. And while direct measurements of temperature indicates that the world has warmed since 1900, it has not done so continuously — from 1940 to 1975 was a period of cooling. Also, while we have given specific dates for the beginnings and ends of these periods, the transition between them was diffuse. Finally, there were regions that showed different trends from the global average. For example, during the 1770s, one of the coldest periods of the Little Ice Age in Europe, it was relatively warm in the Antarctic, and Captain Cook was able to sail further south than ships have usually been able to reach in this century.[27] More recently the Eastern U.S. has cooled, even though the global average temperatures have risen.[28]

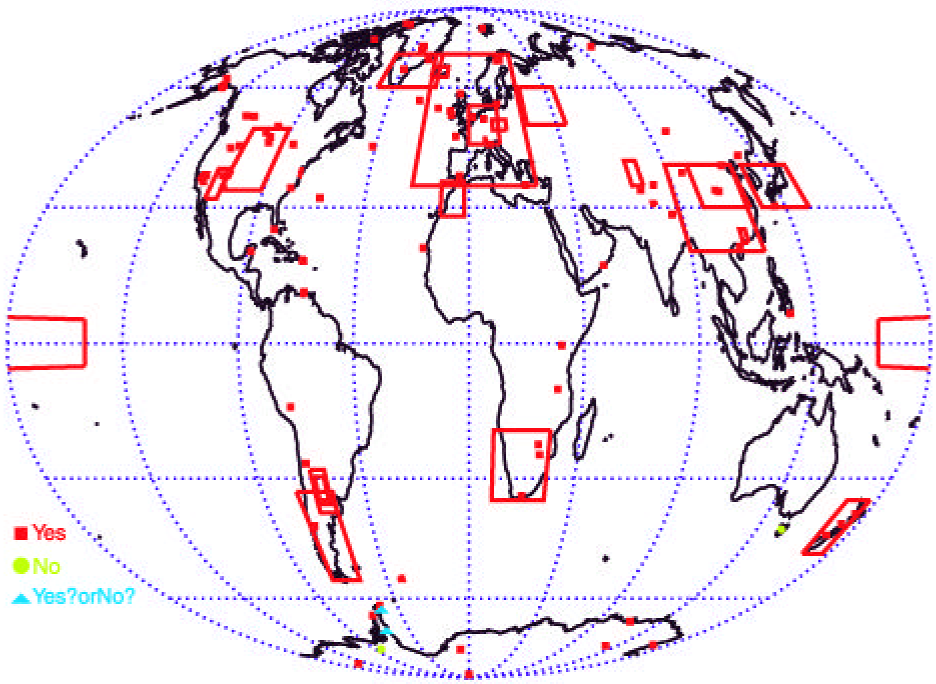
Climate records are more limited from other portions of the world, but it appears that the same overall pattern of warm and cool periods that dominated the North Atlantic were also present in China,[29] Japan,[30, 31] and New Zealand.[32]

The complexity and variability of climate records has led some to question whether the Medieval Warm Period and Little Ice Age were limited to the North Atlantic rather than being global phenomena. (See, for example, Hughes and Diaz[33] and Bradley and Jones.[34]) To answer this question we surveyed the proxy climate measurements reported in the scientific literature to answer three questions:

1. Was there a 50-year or longer period of sustained colder, wetter, or drier than average climate during the 1300 – 1900 period known as the Little Ice Age?
2. Was there a 50-year or longer period of sustained warmer, drier, or wetter than average climate during the 800 – 1300 period known as the Medieval Warm Period?
3. Is there a 50-year period in the proxy record that is warmer than the 20th century?

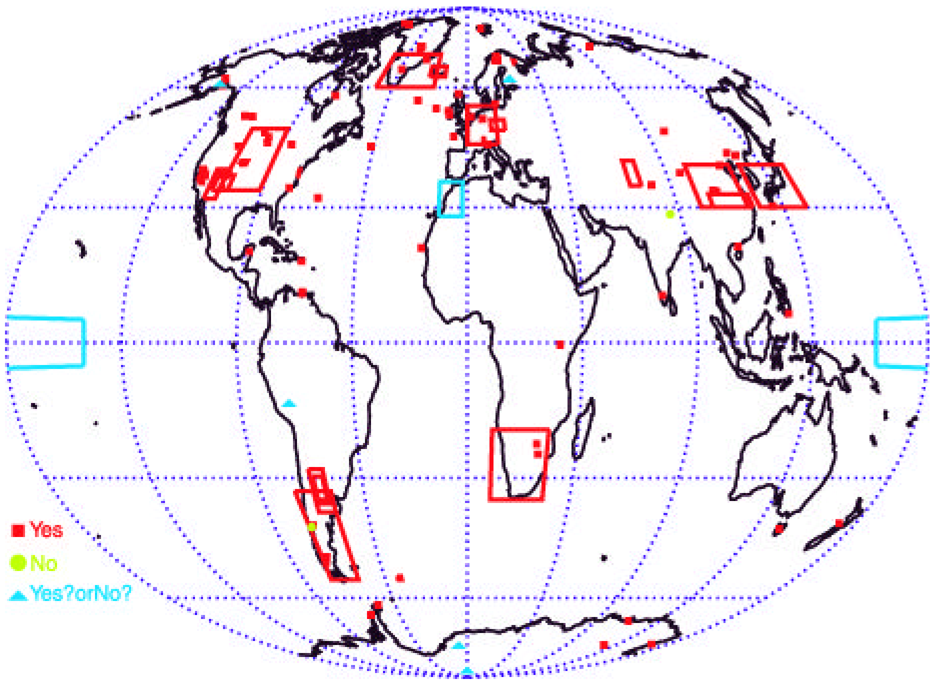
We limited our consideration to proxy records which either contained information about one or more of these three questions or had a continuous record of at least 400 – 500 years. Full details of this analysis are available in our papers.[35]

Figure 1
Geographical distribution of local answers to the following question: Is there an objectively discernible climatic anomaly during the Little Ice Age interval (1300-1900) in this proxy record?



We found 124 studies that addressed the question of whether there was a Little Ice Age; all but two of which contained evidence confirming the existence of the Little Ice Age. Thirty of the studies were in the Southern Hemisphere, of which 26 showed the unequivocal presence of the Little Ice Age, and two records that did not. These results are summarized in Figure 1.

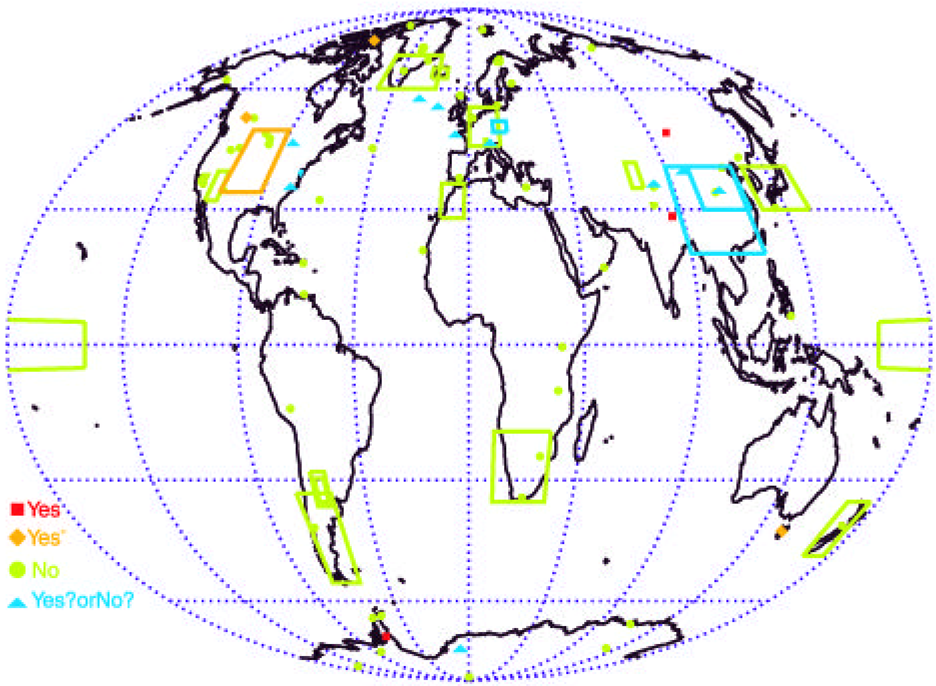
Figure 2
Geographical distribution of local answers to the following question: Is there an objectively discernible climatic anomaly during the Medieval Warm Period (800-1300) in this proxy record?



One hundred twelve studies contained information about the Medieval Warm Period. Of these, 103 showed evidence for the Medieval Warm Period, 2 did not, and 7 had equivocal answers. Looking just at the Southern Hemisphere, we found 22 studies, 21 of which showed evidence of a Medieval Warm Period and one which did not. These results are summarized in Figure 2.

Figure 3
Geographical distribution of local answers to the following question: Is there an objectively discernible climatic anomaly within the 20th century that may validly be considered the most extreme (the warmest, if such information is available) period in the record?

An answer of 'Yes*', indicated by yellow filled-diamonds or unfilled boxes, marks an early to middle 20th century warming rather than the post-1970s warming.



One hundred two studies contained information about whether the 20th century was the warmest or most anomalous on record. Three of these studies answered yes, 16 had equivocal answers, and of the remaining 83, 79 show periods of at least 50 years which were warmer than any 50 year period in the 20th century. The final 4 show the warmest or most anomalous conditions during the first half of the 20th century, when human contribution to atmospheric concentrations of greenhouse gases was still negligible. These results are summarized in Figure 3.

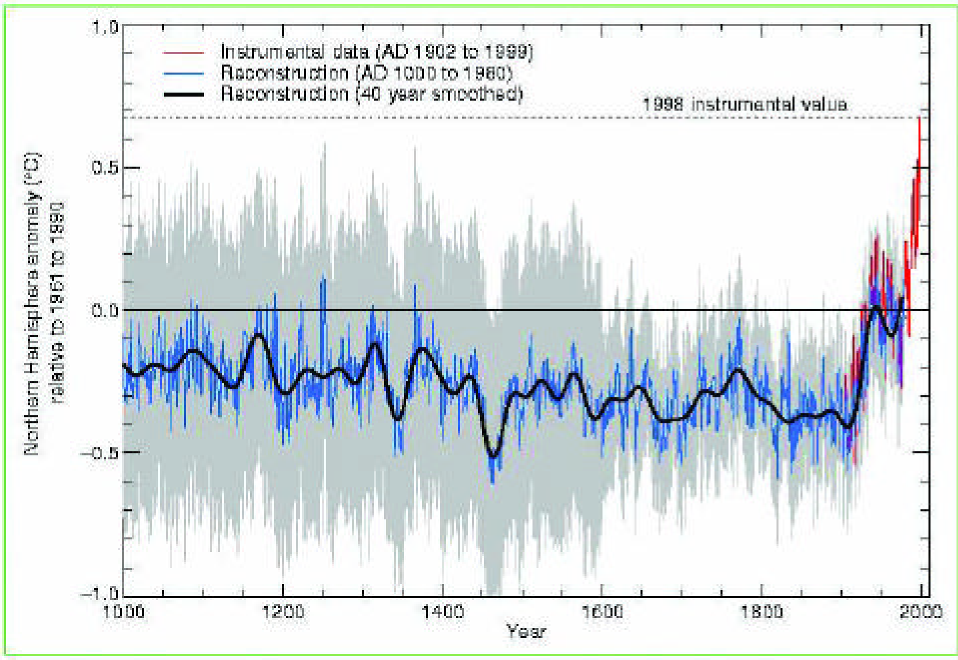
Proxy studies yield information on the immediate locality for which they are made. Data from approximately 100 locations do not fully characterize the globe, but the overwhelming trend in the data strongly suggests that the Medieval Warm Period and the Little Ice Age were widespread phenomena that affected the entire Earth.

Was the 20th Century the Warmest or Most Extreme of the Last Millennium?

Individual proxies represent local climate information, but they have been used to reconstruct past regional climate. One of the more ambitious of these attempts, a reconstruction of the temperature history of the Northern Hemisphere for the past millennium using a variety of proxy measurements, was published in 1999 by Mann *et al.*[36] This reconstruction was highlighted in the IPCC TAR and used as the basis for the IPCC's claim that the rate and duration of warming of the 20th century was greater than any of the previous nine centuries.[37] The WMO claim that the 20th century was the warmest of the millennium is likely to have been the same reconstruction.

> *Data from approximately 100 locations do not fully characterize the globe, but the overwhelming trend in the data strongly suggests that the Medieval Warm Period and the Little Ice Age were widespread phenomena that affected the entire Earth.*

Figure 4
UN IPCC TAR record of Northern Hemisphere temperature change estimated from proxies (1,000-1980) and thermometers (1902-1999) adopted from Mann et al. (1999).



The Mann, *et al.* reconstruction as published in the IPCC TAR is reproduced as Figure 4. It shows a "range" around the reconstructed temperature that is exceeded only late in the 20th century. The "range" is meant to indicate uncertainty or error-band, but it does not account for systematic errors and biases. The actual uncertainty is much larger for the following reasons:

1. The reconstruction for the millennium is an extension of the 600 year temperature reconstruction Mann, *et al.* published in 1998.[38] The extension was based on the addition of just 12 proxy records. We doubt that 12 proxies can adequately represent the complexity of the northern Hemisphere's climate for 400 years, especially since the authors "range" of uncertainty for the reconstruction depends on a single proxy, tree-ring data from Western North America. If this set of data is removed from the reconstruction, Mann, *et al.* admit that the calibration and verification procedures they used would fail.

The importance of this one data set in determining the reconstructed temperature history of the millennium can be seen in a later Mann publication[39] by comparing figures showing the temperature history of Western North America from the tree growth proxies with the temperature reconstruction for the Northern Hemisphere for the last millennium.

2. The temperature reconstruction depends on assuming that the spatial distribution of climate patterns for the whole period was the same as observed in the 20th century direct measurement record. Put another way, if temperatures in Europe were cooler than in the U.S. during the 20th century, Mann, *et al.* assumed that Europe would have been cooler than the U.S. at all times during the last millennium. Given the observed spatial variations of climate, this assumption is too simplistic.

> *We conclude that the available scientific data do not support the claim that the 20th century was the warmest or most unusual of the millennium.*

As demonstrated in Figure 3, the preponderance of proxy measurements show that there were periods of 50 years or longer in a wide variety of locations around the world that had warmer temperatures than the 20th century. The claim that the 20th century was the warmest or most extreme of the millennium depends on a reconstruction of Northern Hemisphere temperature over the past 1,000 years that seems to depend, to an inordinate degree, on a single set of proxy measurements, and is therefore unreliable. We conclude that the available scientific data *do not* support the claim that the 20th century was the warmest or most unusual of the millennium.

Was the Rate and Duration of Northern Hemisphere Warming during the 20th Century Greater than that of the Previous Nine Centuries?

Climate warmed both on a global level and in the Northern Hemisphere during the 20th century. However, to make a judgment, as the IPCC has, about whether *the rate and duration* of this warming was unprecedented in the past millennium requires a detailed knowledge of the temperature history over the millennium. That includes knowing the range of variations, especially on century-long periods, and sampled for centuries, over many regions of the world. The IPCC claim depends on the Mann, *et al.* reconstruction of Northern Hemisphere temperatures for the past 1,000 years discussed above. Given its uncertainties, this reconstruction cannot be used to make a sweeping statement about the rate and duration of warming. The claim that Northern Hemisphere warming during the 20th century was unprecedented in the past 1,000 years is not supported by the available scientific data.

Were the 1990s the Warmest Decade and 1998 the Warmest Year of the Millennium?

While proxy data tell us much about past climate, they do not have the accuracy or resolution to support statements about a specific decade or year being the warmest in the millennium.

The direct temperature measurement record, despite the concerns about accuracy discussed earlier in this report, represents the best information available about global temperature trends since 1861. During this limited period, it appears that the 1990s were the warmest decade and 1998 the warmest year. However, care must be taken in interpreting these statements.

Global climate since 1861 has been determined by at least two factors: recovery from the Little Ice Age, which ended about the same time and an increase in atmospheric concentrations of greenhouse gases. The split between these two factors is unknown, but the significant increase in global average temperature between 1910 and 1940, before most of the increase in greenhouse gas concentration, would argue strongly that the recovery from the Little Ice Age has played a major role. And since cyclical changes in climate such as the Medieval Warm Period and the Little Ice Age last for hundreds of years, there seems little reason to limit the effect of recovery from the Little Ice Age to the 30 years of warming between 1910 and 1940.

While we know that climate exhibits natural variability, we do not have a good measure of that variability, especially on multi-decades- to century-long timescales. This is one of the great unresolved issues of climate science.

The cooling that occurred between 1940 and 1975 did not necessarily mark the end of recovery from the Little Ice Age. Climatic change is not uniform, and there may be periods of cooling in a generally warming trend, and periods of warming in a generally cooling trend. The most famous example of cooling during a generally warming trend occurred 10,000 – 11,000 years ago during the Younger Dryas period, when, after the start of a recovery from the last Ice Age, the glaciers again advanced and the world was subjected to a millennium of renewed ice age conditions. The mechanics of these changes are not understood, but the geologic record clearly indicates that they occurred.

The Natural Variability of Climate

Climate varies. It varies on a timescale of many millennia between ice ages and interglacial periods. It also varies on much short timescales, measured in terms of a few centuries, between periods like the Medieval Warm Period and the Little Ice Age. And it varies on still shorter periods, measured in terms of a few decades, as indicated in the temperature history of the early 20th century. All of these variations occurred before any suggestion of a human influence on the climate system. They represent the natural variability of climate.

While we know that climate exhibits natural variability, we do not have a good measure of that variability, especially on multi-decades- to century-long timescales. This is one of the great unresolved issues of climate science. If we knew the natural variability of climate on multidecadal or centennial timescale, it would be easier to answer the question "Was the climate of the 20th century unusual?" It would be a matter of running the correct statistical analysis. We also would have better tools for judging the performance of climate models. Those that correctly modeled natural variability would be better models than that which didn't. And, perhaps most importantly, if we knew the natural variability of climate, we would have a better guide to judging whether the changes projected by climate models were significantly different from what might be expect naturally.

The 140 year-long direct temperature measurement record is too short, and the longer time-frame proxy measures are too limited (in terms of their geophysical, chemical, and biological sensitivities to climatic variables) to provide good measures of natural variability in its full dynamic range. In addition, not all proxy measures are suitable for estimating natural variability. Some of them, e.g., borehole data and glacier movements, do not provide annual estimates of temperature, but only indicate longer-term average changes. Others, e.g., tree growth proxies are able to resolve year-to-year changes but involve the use of statistical techniques that lose much of the longer-term temperature detail in parts of the record.

The climate system is highly non-linear, which may not exhibit simple modes of variability. A characteristic of non-linear systems is that it can switch from one stable mode (e.g., ice age) to another (e.g., interglacial). The natural variability in these two modes could be different, with still another, presumably higher, level of variability during the transition. Climate models have been run to simulate the transition between ice age and interglacial conditions, but there is no way of knowing whether these simulations are a reasonable representation, let alone the projection, of the Earth's climate system.

Summary: Was the Climate of the 20th Century Unusual?

We know that global average surface temperature rose during the 20th century, and that the 1990s were the warmest period in the 140 year-long direct temperature measurement record. However, these facts, alone, do not support a claim that the climate of the 20th century was unusual.

Support for a claim that the climate of the 20th century was unusual could come from either a valid reconstruction of the climate of the past 1,000 years or from a valid estimate of natural climate variability. Neither is available. Lacking this knowledge, the claim that the temperature of the 20th century was unusual cannot be supported.

Proxy information (tree growth, isotope concentrations in coral reefs and ice cores, etc.) can be used to estimate past local temperatures. A survey of the scientific literature shows that 79 of the 102 proxy temperature studies identified a 50-year period during the past millennium that was warmer than any 50 years in the 20th century. While these results do not allow estimation of globally-averaged surface temperature for the past 1,000 years, they are strong evidence that the temperatures experienced during the 20th century were not unusual.

Endnotes

1. *Ibid.*, Pg.10.
2. George Marshall Institute (2001). *Climate Science and Policy: Making the Connection*. (George Marshall Institute: Washington, D.C.).
3. WMO Press Release (1999): "1999 Closes the Warmest Decade and Warmest Century of the Last Millennium According to WMO Annual Statement of Global Climate" www.wmo.ch/Press/Press644.html.
4. Houghton, J.T., *et al.* (2001): Climate Change 2001: The Scientific Basis, Cambridge University Press, Pg. 2-3.
5. NAS (2000): Reconciling Observations of Global Temperature Change, Pg. 18.
6. Houghton, J.T., *et al.* (2001), *op. cit*, Pg. 110-112.
7. *Ibid.*, Pg. 106.
8. Balling, Jr., R.C. and C. D. Idso (2002): "Analysis of adjustments to the United States Historical Climatology Network (USHCN) temperature database." *Geophysical Research Letters*, **29**: 1029-1031.
9. Parker, D.E., C.K. Folland, and M Jackson (1995): "Marine surface temperature: Observed variations and data requirements." *Climatic Change*, **31**: 559-600; and Folland, C.K., *et al.* (2001): "Global temperature change and its uncertainties since 1861." *Geophysical Research Letters*, **28**: 2621-2624.
10. Hurrell, J. W. and K. E. Trenberth (1999): "Global sea surface temperature analyses: Multiple problems and their implications for climate analysis, modeling, and reanalysis." *Bulletin of the American Meteorological Society*, **80**: 2661-2678.
11. Jones, P.D., *et al.* (2001): "Adjusting for sampling density in grid box land and ocean surface temperature time series." *Journal of Geophysical Research*, **106**: 3371-3380.
12. Houghton, J.T., *et al.* (2001), *op. cit.*, Pg. 3.
13. Bradley, R.S. (1999): *Paleoclimatology: Reconstructing Climates of the Quaternary*. International Geophysics Series, Vol. 64, Harcourt Academic Press, 610 pp.
14. Huang, S., *et al.* (1996): "Deriving century-long trends in surface temperature change from borehole temperatures." *Geophysical Research Letters*, **23**: 257-260.
15. *Ibid.*, Pg. 398-399.
16. For example, see Briffa, K. R., *et al.* (2001): "Low-frequency temperature variations from a northern tree ring density network." *Journal of Geophysical Research*, **106**: 2929-2941.

17. Cook, E. R., *et al.* (1990): "Tree-ring standardization and growth-trend estimation." In *Methods of Dendrochronology: Applications in Environmental Sciences*, 104-123. Cited in Bradley, R.S. (1999): *op. cit.* Pg. 408.

18. Jarvis, P.G. , ed. (1998): *European Forests and Climate Change: The Likely Impacts of Rising CO_2 and Temperature.* Cambridge University Press.

19. Bradley, R.S. (1999): *op. cit.*, Pg. 249.

20. *Ibid.*, Pg. 129.

21. *Ibid.*, Pg. 250-252.

22. *Ibid.*, Pg. 200.

23. *Ibid.*, Pg. 129.

24. Huang, S., *et. al.* (1996): *op. cit.*

25. *Bradley, R. S.* (1999): *op. cit.*, Pg. 304-312.

26. Fagan, B. (2000): *The Little Ice Age: How Climate Made History 1300-1850.* 246 pp.

27. Lamb, H.H. (1997): *Climate History and the Modern World*, 2nd Ed.

28. Robinson WA, Ruedy R, Hansen J (2002): "General circulation model simulations of recent cooling in the east-central United States." *J Geophys Res* **107** (D24): 4748, doi:10.1029/2001JD001577.

29. Hong, Y.T. and 8 others (2000): "Response of climate to solar forcing recorded in a 6000-year ? 18O time-series of Chinese peat cellulose." *Holocene* **10**: 1-7. Yang B, Braeuning A, Johnson KR, Shi Y (2002): "General characteristics of temperature variation in China during the last two millenia." *Geophys Res Lett* **29**: 10.1029/2001GL014485, 38-1-38-4.

30. Tagami, Y. (1993): "Climate change reconstructed from historical data in Japan." In *Proceedings of International Symposium on Global Change by International Geosphere-Biosphere Programme*, Pg. 720-729.

31. Tagami, Y. (1996): "Some remarks on the climate in the Medieval Warm Period in Japan. In Mikami, T., *et al.* (eds.) *Paleoclimate and Environmental Variability in Austral-Asian Transect Suring the Past 2000 Years*, International Geosphere – Biosphere Programme.

32. Wilson, A.T., *et al.* (1979): "Short-term climate change and New Zealand Temperatures during the last millennium." *Nature* **279**: 315-317. D'Arrigo RD and 6 others (1998): "Tree-ring records from New Zealand: Long-term context for recent warming trend." *Clim Dyn* **14**: 191-199.

33. Hughes, M.K. and H.F. Diaz (1994): "Was there a 'Medieval Warm Period," if so, where and when?" *Climatic Change*, **26**: 109-142.

34. Bradley, R.S. and P. D. Jones (1993): 'Little Ice Age" summer temperature variations: their nature and relevance to recent global warming trends." *Holocene*, **3**: 367-376.

35. Soon, W., and Baliunas, S. (2003): "Proxy climate and environmental changes of the past 1,000 years." *Climate Research*, **23**: 89-110 and Soon, W., Baliunas, S., Idso, C., Idso, S., and Legates, D. R. (2003): "Reconstructing climatic and environmental changes of the past 1,000 years: A reappraisal." *Energy & Environment*, **14** (no. 2) (expected end of March 2003). These papers are available by request from: wsoon@cfa.harvard.edu

36. Mann, M. E., *et al.* (1999): "Northern hemisphere temperatures during the past millennium: Interferences, uncertainties, and limitations." *Geophysical Research Letters* **26**: 759-762.

37. Houghton, J. T., *et al.*(2001): *op. cit.*, Pg. 3.

38. Mann, M. E., *et al.*(1998): "Global-scale temperature patterns and climate forcing over the past six centuries." *Nature* **392**: 779-787.

39. Mann, M.E. (2001): "Little Ice Age." In MacCracken, M.C. and J. S. Perry (eds.), *Encyclopedia of Global Environmental Change: Vol. 1 – The Earth System*, Pg. 504-509.

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