The Physical Evidence of Earth's Unstoppable 1,500-Year Climate Cycle

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Adapted from their forthcoming book,
Unstoppable Global Warming—Every 1,500 Years

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Executive Summary

The Earth currently is experiencing a warming trend, but there is scientific evidence that human activities have little to do with it. Instead, the warming seems to be part of a 1,500-year cycle (plus or minus 500 years) of moderate temperature swings.

It has long been accepted that the Earth has experienced climate cycles, most notably the 90,000-year Ice Age cycles. But in the past 20 years or so, modern science has discovered evidence that within those broad Ice Age cycles, the Earth also experiences 1,500-year warming-cooling cycles. The Earth has been in the Modern Warming portion of the current cycle since about 1850, following a Little Ice Age from about 1300 to 1850. It appears likely that warming will continue for some time into the future, perhaps 200 years or more, regardless of human activity.

Evidence of the global nature of the 1,500-year climate cycles includes very long-term proxies for temperature change — ice cores, seabed and lake sediments, and fossils of pollen grains and tiny sea creatures. There are also shorter-term proxies — cave stalagmites, tree rings from trees both living and buried, boreholes and a wide variety of other temperature proxies.

Scientists got the first unequivocal evidence of a continuing moderate natural climate cycle in the 1980s, when Willi Dansgaard of Denmark and Hans Oeschger of Switzerland first saw two mile-long ice cores from Greenland representing 250,000 years of Earth's frozen, layered climate history. From their initial examination, Dansgaard and Oeschger estimated the smaller temperature cycles at 2,550 years. Subsequent research shortened the estimated length of the cycles to 1,500 years (plus or minus 500 years). Other substantiating findings followed:

- An ice core from the Antarctic's Vostok Glacier — at the other end of the world from Greenland — showed the same 1,500-year cycle through its 400,000-year length.
- The ice-core findings correlated with known glacier advances and retreats in northern Europe.
- Independent data in a seabed sediment core from the Atlantic Ocean west of Ireland, reported in 1997, showed nine of the 1,500-year cycles in the last 12,000 years.

Other seabed sediment cores of varying ages near Iceland, in the Norwegian and Baltic seas, off Alaska, in the eastern Mediterranean, in the Arabian Sea, near the Philippines and off the northern tip of the Antarctic Peninsula all also showed evidence of the 1,500-year cycles. So did lake sediment cores from Switzerland, Alaska, various parts of Africa and Argentina, as did cave stalagmites in Europe, Asia and Africa, and fossilized pollen, boreholes, tree rings and mountain tree lines.

None of these pieces of evidence would be convincing in and of themselves. However, to dismiss the evidence of the 1,500-year climate cycle, it is necessary to dismiss not only the known human histories from the past 2,000 years but also an enormous range and variety of physical evidence found by a huge body of serious researchers.

Introduction

Is the Earth currently experiencing a warming trend? Yes.

Are human activities, including the burning of fossil fuel and forest conversion, the primary — or even significant — drivers of this current temperature trend? The scientifically appropriate answer — cautious and conforming to the known facts — is: probably not.

Indeed, the current warming cycle is not unusual: Evidence from around the world shows that the Earth has experienced numerous climate cycles throughout its history. These cycles include glacial periods (more commonly known as Ice Ages) and interglacial periods, as well as smaller, though significant, fluctuations. During the past 20 years, scientists have been accumulating strong physical evidence that the Earth consistently goes through a climate cycle marked by alternating warmer and cooler periods over 1,500 years (plus or minus 500 years). The evidence indicates that:

"The Earth's climate cycles through 90,000-year Ice Ages interspersed with shorter warm periods."

- The Earth experienced a Little Ice Age from 1300 to 1850.
- A Modern Warming period began about 1850 and continues to the present.

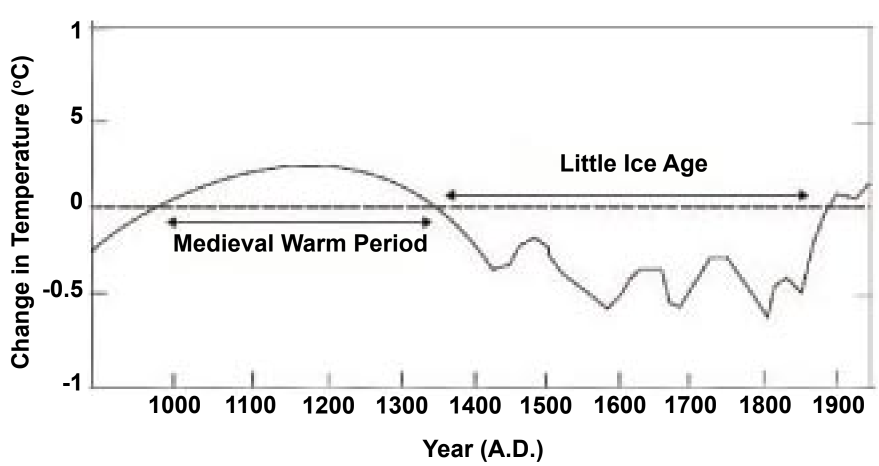
Figure I tracks the Medieval Warming and Little Ice Age that preceded today's Modern Warming.

We have long had physical evidence that the Earth has experienced numerous climate cycles throughout its history. The best-known of these is the Ice Age cycle, with 90,000-year Ice Ages interspersed with far shorter interglacial periods. What is new is the evidence of more moderate, persistent climate cycles within these broader cycles.

"Within the longer cycle, the climate warms and cools in 1,500 year-cycles (plus or minus 500 years)."

FIGURE I

Climate Cycle



Source: Thomas J. Crowley (1996, http://www.gcrio.org/). Compiled by R. S. Bradley and J. A. Eddy (*EarthQuest*, vol. 5, no. 1, 1991) based on J. T. Houghton et al. (1990).

The message that the 1,500-year climate cycle is real, broad — and sudden — is being dug up from the Earth itself by modern science. The key evidence comes from very long-term proxies for temperature change, especially ice cores, seabed and lake sediments, and fossils of pollen grains and tiny sea creatures that document even small changes in Earth's temperature over many thousands of years.

In addition, we have a number of shorter-term proxies (cave stalagmites, tree rings from trees both living and buried, boreholes and a wide variety of other temperature proxies) that testify to the global nature of the 1,500-year climate cycles.

A striking example of the effect of this 1,500-year climate cycle can be seen in the temperature-sensitive history of wine-growing in England.

"Evidence from every continent and ocean confirms the 1,500-year cycle."

The Romans grew wine grapes in England when they occupied it from the first through the fourth centuries. Aerial photography, remote sensing and large-scale excavation have recently revealed seven Roman-era vineyards in south central England. One site contains nearly four miles of bedding trenches that could have supported some 4,000 grapevines.[1]

A thousand years later, during the Medieval Warming of 950-1300, the Britons themselves grew wine grapes in England. The *Domesday Book*, compiled in the 11th century, recorded 46 places in southern England growing wine grapes. (Richard Tkachuck of the Geosciences Research Institute notes that German vineyards were found as high as 780 meters in elevation during the Medieval Warming, but are found today up to only 560 meters — indicating a temperature difference of 1° to 1.4° C.[2]) During the Little Ice Age (1300-1850), England was too cold to grow wine grapes. Instead, London often held ice festivals on the frozen Thames River, which hasn't frozen in the last 150 years.

Now that the Little Ice Age has given way to the Modern Warming, a few hardy Britons have again begun serious efforts to grow good wine grapes in England — but thus far with spotty success. The Web site www.english-wine.com admits that British wine-making is still a very chancy proposition. Only two years in 10 will the wine be very good, and during four of the other years it will be terrible, "largely due to weather...."

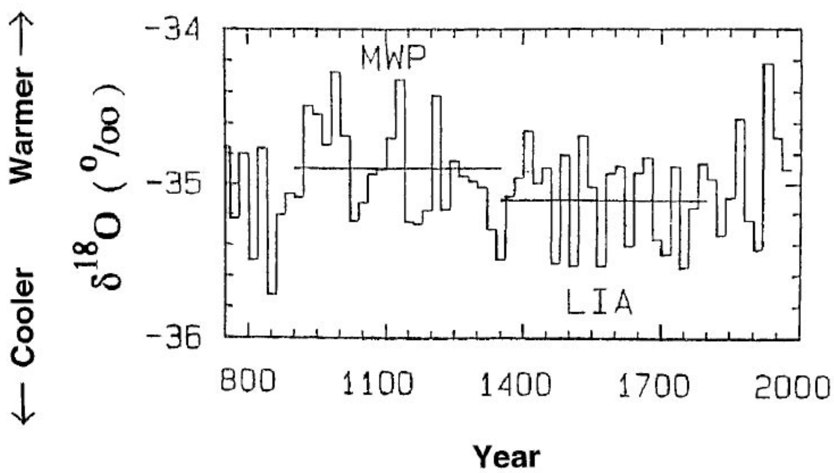
British vintners should be hopeful, however. The Modern Warming is still young, and likely to eventually give them several centuries of good wine production. The Earth is apparently having its third natural, moderate — and unstoppable — warming in 2,000 years.

Taken by itself, the cycle of wine-grape growing in England might be seen as an aberration. However, this is just one bit of the emerging body of physical evidence of a natural climate cycle — a cycle too moderate and too long to have been reported in the Viking sagas and earlier oral histories from people without thermometers.

"The changing concentration of oxygen-18 in Greenland ice cores corresponds to the 1,500-year cycle."

FIGURE II

Change in Oxygen-18 Ratio in Greenland Ice Cores, A.D. 820-1985



Note: The vertical axis shows the mean bidecadal change in oxygen-18 in the Greenland ice cores. The horizontal lines through the graph of the data give the average annual change in $^{18}0$ for the Medieval Warming Period (MWP) and Little Ice Age (LIA).

Source: Sallie Baliunas and Willie Soon, "Climate History and the Sun," George C. Marshall Institute, June 5, 2001; from Minze Stuiver, Pieter M. Grootes and Thomas F. Braziunas et al., "The GISP2δ^{18}O Climate Record of the Past 16,500 Years and the Role of the Sun, Ocean and Volcanoes," *Quaternary Research*, vol. 44, 1995, pages 341-344, Figure 4.

None of these pieces of evidence would be convincing in and of themselves. However, in order to dismiss the huge impact of the 1500-year climate cycle, we would have to dismiss not only the human histories from those periods, but also the enormous range and variety of physical evidence presented here.

Importantly, if the current warming trend is, as the evidence suggests, part of an entirely natural climate cycle, actions proposed to prevent further warming would be futile and could, by imposing substantial costs upon the global economy, lessen the ability of people to adapt to the impacts — both positive and negative — of climate change.

The Ice Cores

In the 1980s scientists got the first unequivocal evidence of a continuing, moderate natural climate cycle. The 1,500-year climate cycle emerged almost full-blown from Greenland in 1983.

Denmark's Willi Dansgaard and Switzerland's Hans Oeschger were among the first people in the world to see two mile-long ice cores that brought up 250,000 years of the Earth's frozen, layered climate history. Over the previous dozen years, the two researchers had pioneered ways to pry information from the ice cores. They had learned, among other things, that the ratio of oxygen-18 isotopes to oxygen-16 isotopes in ice could reveal the air temperature at the time when the snowflakes that made the ice fell to earth. The correspondence of the change in the isotope ratios to the recent Medieval Warming Period (MWP) and Little Ice Age (LIA) is shown in Figure II.[3]

Dansgaard and Oeschger expected to see the big 90,000-year Ice Ages in the cores, and they did. But they were startled to find, superimposed on the big Ice Age swings, a smaller, moderate and more persistent temperature cycle. They estimated the average cycle length at 2,550 years. They dismissed volcanoes as a causal factor because there's no such cycle in volcanic activity. The timing of the cycles seemed to match closely with the known history of recent glacier advances and retreats in northern Europe.

"Ice cores from Antarctica show the same climate cycle."

The report that Dansgaard and Oeschger wrote in 1984, "North Atlantic Climatic Oscillations Revealed by Deep Greenland Ice Cores," was, in retrospect, almost eerie in its accuracy, its completeness and its logical linking of the climate cycles to the sun.[4] The only major correction imposed by subsequent research is that the cycles were more frequent than they thought. The average length of the cycles has now been shortened by almost half — from their original estimate of 2,550 years to 1,500 years (plus or minus 500 years).

Dansgaard and Oeschger were correct when they told us that the climate shifts were moderate, rising and falling over a range of about 4° C in northern Greenland, with very little temperature change at the equator — and only half a degree when averaged over the northern hemisphere.

The cycles were confirmed by 1) their appearance in two different ice cores drilled more than 1,000 miles apart; 2) their correlation with known glacier advances and retreats in northern Europe; and 3) independent data in a seabed sediment core from the Atlantic Ocean west of Ireland.[5]

They noted that the cycle shifts were abrupt, sometimes gaining half of their eventual temperature change in a decade or so. That suggested an external forcing, perhaps amplified and transmitted globally by the ocean currents and winds. (In the mid-19th century, the Upper Fremont Glacier in Wyoming went from Little Ice Age to Modern Warming in about 10 years.[6] That implies a climate driver from outside our planet, almost certainly involving the sun.)

However, Dansgaard and Oeschger noted, "Since the solar radiation is the only important input of energy to the climatic system, it is most obvious to seek an explanation in solar processes. Unfortunately we know much less about the solar radiation output than about the emission of solar particulate matter in the past."

The two scientists did know, however, that both carbon-14 and beryllium-10 isotopes vary inversely with the strength of the solar activator. The isotopes of both elements in their Greenland ice cores showed historic temperature lows during what solar scientists term the Maunder sunspot minimum (1645–1715) — the absolute coldest point of the Little Ice Age and a period when sunspots virtually disappeared.

"Climate cycles coincide with sunspots and variations in solar energy output."

Today, we can measure variations in the sun's irradiance from satellites out beyond the obscuring atmosphere of our own planet. The solar constant isn't — constant, that is. We also know that when the sun is less active, its solar wind weakens and provides less shielding for the Earth from the cosmic rays that bounce around space. With a weaker sun, more of the cosmic rays hit the Earth, creating more charged particles in the atmosphere, which then become low, wet clouds reflecting more heat back into space. A less active sun thus means a cooler Earth.[7]

The importance of the 1,500-year cycles found in the Greenland ice cores increased dramatically four years later when they were also found at the other end of the world — in an ice core from the Antarctic's Vostok Glacier. The Vostok ice core went back 400,000 years, and showed the 1,500-year cycle through its whole length.[8]

The scientific world had known about the sunspot connection to Earth's climate for some 400 years. British astronomer William Herschel claimed in 1801 that he could forecast wheat prices by sunspot numbers, because wheat crops were often poor when sunspots (and thus solar activity) were low. Not only did the Maunder minimum (1645-1715) coincide with the coldest period of the Little Ice Age, the Sporer minimum (1450–1543) aligned with the second-coldest phase of that period.

In 1991, Eigel Friis-Christensen and Knud Lassen noted that the correlation between solar activity and Earth temperatures is even stronger if we use the length of the solar cycle to represent the sun's variations instead of the number of sunspots.[9] (The solar cycles average about 11 years in length, but actually vary between eight and 14 years.) Their paper in *Science* concluded that the solar connection explained 75 to 85 percent of recent climate variation.

Seabed Sediments

Let's look now at another source that seems to confirm the 1,500-year climate cycle: seabed sediments.

Gerard Bond of Columbia University's Lamont-Doherty Earth Observatory analyzed sediments on the floor of the southern North Atlantic. Roughly every 1,500 years, there was a surge in the amount of rocky debris picked up by the glaciers as they ground their way across eastern Canada and Greenland. This ice-rafted debris was then floated much farther south before the icebergs melted and it dropped to the sea floor. Both the increase in the volume of the debris and its floating much farther south indicated severe cold periods.

Bond found nine of these cycles in the last 12,000 years, and they matched those in the cores from the Greenland Ice Sheet and the Vostok Antarctic glacier — again strengthening our confidence that the cycles are real and significant.

Bond's 1997 research report in *Science* [10] begins:

"Evidence from North Atlantic deep-sea cores reveals that abrupt shifts punctuated what is conventionally thought to have been a relatively stable Holocene [interglacial] climate. During each of these episodes, cool, ice-bearing waters from north of Iceland were advected as far south as the latitude of Britain. At about the same times, the atmospheric circulation above Greenland changed abruptly. . . . Together, they make up a series of climatic shifts with a cyclicity close to 1,470 years (plus or minus 500 years). The Holocene events, therefore, appear to be the most recent manifestation of a pervasive millennial-scale climatic cycle *operating independently of the glacial-interglacial climate state."* (emphasis added)

"Glacial rocks deposited in Atlantic seabed sediments show a 1,500-year cycle."

Bond thus points up the fact that the moderate 1,500-year cycle is powerful enough to periodically warm the Earth's climate even when thousands of trillions of tons of ice are determined to keep it Ice-Age cold, and to periodically chill the planet even during warm interglacial periods.

The evidence for this moderate but persistent climate cycle has continued to mount around the world in recent decades.

Peter deMenocal's team found African coastal seabed sediments documented a history of major changes in sea surface temperatures.[11]

Changes in plankton numbers and species gave the deMenocal team ocean temperature readings from the past, and the amounts of dust blown from Africa were an indicator of drought. These proxies tell us that when the sea surface temperatures fell off West Africa, much of the continent went drier for centuries. Then, the climate snapped back, quickly bringing such heavy rains that large lakes formed in the Sahara Desert. The most recent cooling in the region was a two-stage Little Ice Age between 1300 and 1850, essentially simultaneously with similar coolings in the Greenland ice cores, in the seabed sediments of the North Atlantic found by Bond, and in the reconstructed sea surface temperatures of the Sargasso Sea found by Lloyd Keigwin. [12]

Bond concluded that every 1,500 years, harsh cold periods drop North Atlantic ocean temperatures by 2 to 3.5° C. However, deMenocal says *ocean temperatures off Africa simultaneously dropped even more sharply*, with changes of 3 to 4° C.

Bond's subsequent study demonstrated the linkage between the Earth's warming-cooling cycle and the sun, using carbon-14 and beryllium-10 as proxies for solar warming and cooling.[13]

He wrote, "It is highly unlikely that Holocene climate forcing alone could have produced such large and abrupt production-rate changes at essentially the same time in both [the C-14 and Be-10]. Our correlations are evidence, therefore, that over the last 12,000 years virtually every centennial time scale increase in drift ice documented in our North Atlantic records was tied to a distinct interval of . . . reduced solar output.

"A solar influence on climate of the magnitude and consistency implied by our evidence could not have been confined to the North Atlantic...."

"The 1,500-year cycle has persisted more than one million years."

Dating Back a Million Years. Near Iceland, Maureen Raymo of Boston College found the Earth was undergoing Dansgaard-Oeschger's 1,500-year climate cycles more than a million years ago. Raymo and her research team retrieved a very long sediment core from the deep sea bottom south of Iceland. As the Raymo team wrote in *Nature*:

"Here we use sediment records of past iceberg discharge and deep-water chemistry to show that such millennial-scale oscillations in climate occurred over one million years ago.... Our results suggest that such climate instability may be a pervasive and long-term characteristic of Earth's climate...."[14]

A Global Sampling of Sea Bed Cores. South of Iceland, Giancarlo Bianchi and Nicholas McCave studied a 1,500-year climate cycle that "may be related to an internal oscillation of the climate system." The grain sizes of sediments carried by the Iceland-Scotland part of the "Atlantic ocean conveyor" reveal the strength of the current. Colder periods with less ice melt generate slower bottom currents that carried smaller sediment grains; warmer periods with stronger currents carried larger sediment grains. They found that flows changed with the Medieval Warming and the Little Ice Age, "*and extend over the entire Holocene epoch with a quasi-periodicity of ~1500 years*."[15] (emphasis added)

In the Norwegian Sea, Sweden's Carin Andersson led a team which constructed a 3,000-year temperature history from the stable isotopes in the plankton and the number and types of protozoan skeletons from seabed sediment cores.[16] The climate history shows a long cold period before the Roman Warming, then the Dark Ages, the Medieval Warming and the Little Ice Age.

A Baltic Sea sediment core shows a cold-weather period beginning about 1200, characterized by "a major decrease in the [algae cyst] assemblage and an increase in cold water [algae species]."[17] The study also found the present Baltic is still too cold to support the subtropical marine species it had during the Medieval Warming.

Off Alaska, Old Dominion University's Dennis Darby analyzed sediments from the continental shelf.[18] The number and species of dinocysts (tiny "cocoons" left behind by one-celled organisms) gives evidence of sea surface temperatures and sea-ice cover. The most surprising result of this study was the large variation in Arctic temperatures shown by the proxies — 6° C over the last 8,000 years, a greater range than on the Greenland Ice Sheet.

In the eastern Mediterranean, sediments accumulate rapidly and yield highly accurate seabed cores. Bettina Schilman from the Geological Survey of Israel used such proxies as oxygen-18 and carbon-13 isotopes in phytoplankton, titanium/aluminum ratios, iron/aluminum ratios, magnetic susceptibility, and color index to analyze past climates.[19] She says abrupt climatic events occurred 270 years ago and 800 years ago that "probably correlate" with the Little Ice Age and the Medieval Warming. She also notes corroborating evidence of the Medieval Warming in high Saharan lake levels,[20, 21] and high levels in the Dead Sea,[22, 23, 24, 25] and the Sea of Galilee,[26, 27] as well as a precipitation maximum at the Nile headwaters.[28, 29]

"Abrupt climate changes can occur within a decade."

In the Arabian Sea, west of Karachi, Pakistan, two seabed sediment cores date back nearly 5,000 years, and show "the 1,470-year cycle previously reported from the glacial-age Greenland ice record." W. H. Berger and Ulrich von Rad suggested the cycles were tide-driven. However, they also note that *"internal oscillations of the climate system cannot produce them."*[30] (emphasis added)

Near the Philippines, the productivity of the phytoplankton is closely related to the strength of the winter monsoon. The production of phytoplankton was larger during glacial periods than during interglacial periods, but the researchers found that "the 1,500-year cycle...seems to be a pervasive feature of the monsoon climatic system."[31]

Off the northern tip of the Antarctic Peninsula, Boo-Keun Khim of Seoul University found the Little Ice Age and Medieval Warming, along with earlier warming/cooling cycles.[32] Khim also notes that evidence of the Little Ice Age has been found in several other studies of Antarctic marine sediments, including Leventer and Dunbar, who reported on their study of algae microfossils at Antarctica's McMurdo Sound in 1988.[33]

Lake Sediments

Findings from analysis of lake sediments reinforces those from seabed sediments. Some examples:

In Switzerland, the remains of tiny aquatic creatures in the sediments of Lake Neufchatel showed Swiss temperatures fell by 1.5° C during the shift from the Medieval Warming to the Little Ice Age.[34] The authors note that mean annual temperatures during the warming were "on average higher than at present."

In southwest Alaska, the University of Illinois' F. S. Hu analyzed the silica produced by living organisms, organic carbon and organic nitrogen in lake sediments. He found the climate shifts have been similar in the subpolar regions of both the North Atlantic and North Pacific — "possibly because of sun-ocean-climate linkages."[35]

In West Africa, sediments from Cameroon's Lake Ossa show that the climate oscillates with the 1,500-year cycle in the northern and southern movements of the Intertropical Convergence Zone.[36] Francis Nguetsop of the French National Museum of Natural History says his lake sediment core showed southward shifts of the zone were marked by low precipitation in the northern subtropics (Nigeria and Ghana) and high precipitation in the sub-equatorial zone (Zaire and Tanzania).[37]

"Sediments from dry lakebeds show 1,500-year cycles of droughts and floods."

In East Africa, Belgium's Dirk Verschuren built an 1,100-year rainfall-drought history for Kenya's Lake Naivasha, based on 1) sediments, 2) fossil diatoms and 3) midge species and numbers.[38] "In tropical Africa," Verschuren says, "the data indicate that, over the past millennium, equatorial east Africa has alternated between contrasting climate conditions, with significantly drier climate than today during the 'Medieval Warm Period' (1000–1270) and a relatively wet climate during the 'Little Ice Age' (1270–1850) that was interrupted by three prolonged dry episodes."

In Africa's Central Highlands, sediment cores from Lake Victoria show a 1,400- to 1,500-year spacing of precipitation-evaporation fluctuations over the past 10,000 years. [39]

In a lake high on Mount Kenya, Weizmann Institute researchers retrieved a six-foot core of sediment that accumulated between 2250 B.C. and A.D. 750. The team analyzed the ratio of oxygen isotopes in the algae skeletons (called biogenic opal). The largest anomaly was a rapid warming — 4° C — during the 800 years between 350 B.C. and A.D. 450, reflecting a warmer climate in equatorial East Africa.[40] Was this the Roman Warming? The researchers noted warming during the same period in the Swedish part of Lapland and in the northeastern St. Elias Mountains of Alaska and the Canadian Yukon.

In Central America, near the abandoned Mayan cities, lake sediment cores testify to a prolonged drought during the cold Dark Ages that may have caused the collapse of the entire Mayan culture.[41] A team from the University of Florida, led by David Hodell, recently confirmed evidence of a Yucatan drought from 800 to 1000, based on the gypsum levels in a core from the muddy bottom of ancient Lake Chichancanab.[42]

Seabed cores from the Cariaco Basin just off the Venezuelan coast (in the same climatic region) echo the Mayan drought. Gerald Haug of the University of Southern California and Konrad Hughen of the Woods Hole Oceanographic Institute analyzed titanium concentrations; more titanium was associated with more rainfall.[43]

Mayan cities thrived in the Yucatan lowlands for 1,000 years — mostly during the Roman Warming era. In the cold Dark Ages, however, the Mayans suffered at least 100 years of low rainfall, punctuated by periods of three to nine years in a row with little or no rainfall.

"Climate shifts in the opposite direction in some regions."

In Argentina, a study of saline lake sediments from a high volcanic plateau found that rainfall and climate changed sharply when the world shifted from warm to cool and back again. The study team concluded, "The Little Ice Age stands as a significant climatic event in the Altiplano and South America." [44]

More Global Connections. A remarkable similarity in weather patterns has been documented for southeastern Africa's Lake Malawi and the Cariaco Basin off the coast of Venezuela. Researchers studied sediment layers in Lake Malawi, and reconstructed a climate record by comparing the algae fossils and ratios of niobium to titanium over 25,000 years.[45] More niobium indicated a dryer climate with the Intertropical Convergence Zone shifted to the south, so more volcanic ash was wind-blown from north of the lake. Knowing that both Lake Malawi and the Caribbean are impacted by the ITCZ, they found the reconstructed Malawi climate history "remarkably similar" to that of the Cariaco Basin since the Late Glacial period. They also found that the Lake Malawi record was often anti-phased to the Greenland climate record.

In central Chile, geochemicals, sediments and algae cyst populations from Laguna Aculeo showed a major increase in floods during 400 B.C. to A.D.200 (the pre-Roman cold era), 500 to 700 (the Dark Ages) and from 1300 to 1700 (the Little Ice Age). During cooling periods, westerly winds bring additional rainfall to the lake.[46]

*Near Antarctica***,** on Signy Island, lake sediments clearly show the Roman Warming and the Dark Ages, the Medieval Warming, the Little Ice Age and the 20th century warming — which is cooler to date than the Medieval Warming.[47]

Cave Stalagmites

Cave stalagmites vary with temperature and moisture, in their carbon and oxygen isotopes and in their trace element contents. Moreover, the stalagmites go back farther in time than the tree evidence. Cave stalagmites have been found in Ireland, Germany, Oman, China and South Africa whose layers all show the Little Ice Age, the Medieval Warming, the Dark Ages and the Roman Warming. Most also show the unnamed cold period that preceded the Roman Warming.[48,49,50,51]

On the Arabian Peninsula, a stalagmite study also emphasized the "globalness" of climate. Germany's Ulrich Neff found oxygen-18 isotopes yielded a very precise record of the 1,500-year climate cycle in the region's monsoon rainfall. Neff says the monsoons were considerably stronger during the Climate Optimum (5,000 to 7,000 years ago), which also produced an era of heavy rainfall in the Sahel regions of Africa, in Arabia and in India. The Oman stalagmite's cycles were also in phase with the temperature fluctuations recorded in Greenland ice cores 10,000 years ago, indicating that both were then controlled by glacial boundaries. Since the melt-off of the huge ice sheets, however, the stalagmite proxy says the Indian Ocean monsoon has been governed by variations in solar activity instead.[52]

In China, researchers analyzed a cave stalagmite near Beijing using the manganese/strontium ratio as a "geochemical thermometer."[53] The team found a strong warming from 700 to 1000, corresponding to the Medieval Warm Period, which may have reached China earlier than Europe. From 1500 to 1800, the air temperature was about 1.2° C lower than now.

*In South Africa***,** a cave stalagmite from the Makapansgat Valley shows that the Medieval Warming started before 1000 and lasted until around 1300. [See Figure III.] Temperatures there may have been 3 to 4° C higher than at present. The Little Ice Age in the region extended from around 1300 to 1800, and was about 1° C cooler than today.[54] The lowest temperatures were recorded during the Maunder and Sporer minimums when low sunspot counts indicated low solar activity. The same South African stalagmite revealed cold periods in the cave region between 800 and 200 B.C. — corresponding to the unnamed cooling period before the Roman Warming.[55] (The stalagmite doesn't show unusual warming in the 20th century.)

"The effects of warming and cooling are global."

In New Zealand, the oxygen-18 isotopes in a stalagmite show the coldest recent period was 1600 to 1700, following exceptionally warm temperatures from 1200 to 1400.[56] A. T. Wilson and Chris Hendy of New Zealand's Waikato University state specifically that since their country is "in the Southern Hemisphere and a region meteorologically separated from Europe," finding the Medieval Warming and the Little Ice Age there demonstrates they are "not just a local European phenomenon."

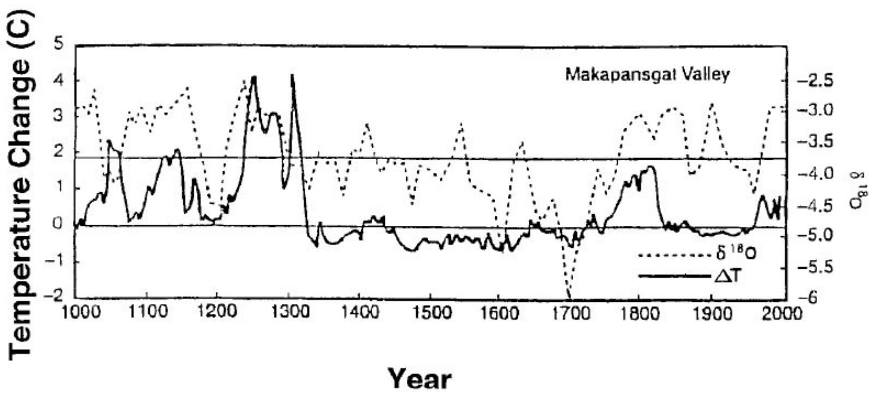
Fossilized Pollen

In northwestern Spain, pollen analysis from 3,000 years of sediments in the Ria de Vigo shows an alternation of three relatively cold periods with three relatively warm episodes. The research team concluded that "a millennial-scale climatic cyclicity over the last 3,000 years is detected for the first time in northwest Iberia, paralleling global climatic changes recorded in North Atlantic marine records."[57]

In East Africa, pollen data from the bottom of Kenya's Lake Naivasha showed a two-century drought during the warming period from 980 to 1200.[58] The lake's water levels fell to their lowest point in 1,000 years, while the vegetation shifted strongly away from woody plant species toward more grasses.

FIGURE III

Temperature Change Inferred from South Africa Stalagmites



Note: The solid line shows temperature change as measured by the left vertical scale and the dotted line shows the change in the oxygen-18 ratio as measured by the right vertical scale.

Source: Sallie Baliunas and Willie Soon, "Climate History and the Sun," George C. Marshall Institute, June 5, 2001; from P.D. Tyson, "The Little Ice Age and Medieval Warming in South Africa," *South African Journal of Science*, vol. 96, March 2000, pages 121-146, Figure 3.

"The composition of stalagmites from South Africa vary with the 1,500-year cycle."

*In Peru***,** declining amounts of fossilized pollen in a 4,000-year core from a lake bed indicate declining vegetation (and rainfall) for several centuries after A.D. 100 —when the Roman Warming gave way to the Dark Ages.[59] After 900, increased pollen indicated greater numbers of plants and warmer temperatures, followed by the Little Ice Age and another pollen decline.

Boreholes

Boreholes are useful for about 1,000 years into the past, as rock transmits past surface temperatures downward. The University of Michigan's Shaopeng Huang led a study of 6,000 boreholes in 1997 from all continents. The results showed global average temperatures during the Medieval Warming were warmer than today's, and during the Little Ice Age they averaged 0.2 to 0.7° C below present.[60]

Tree Rings

Tree rings can be counted to date events, and their summertime width is wider under good growing conditions (warmth, rainfall) than during poor growing seasons (cold, dry). Tree ring studies are limited by the distance back in time for which researchers can find live trees, dead trees, buried wood or even structural wood from an earlier time which can be accurately dated to its growth period.

A 1,400-year tree ring study in 1990 led by Britain's Keith Briffa showed little evidence of the Medieval Warming or Little Ice Age.[61] In 1992, however, Briffa and several of the same coauthors published another report in *Climate Dynamics*, noting that "our previously published reconstruction was limited in its ability to represent long-timescale temperature change because of the method used to standardize the original tree-ring data. Here we employ an alternative standardization technique which enables us to capture temperature change on longer timescales."[62] This second report found a cool period from 500 to 700, with 660 an especially cold year. Then it showed generally warm periods from 720 to 1360 (the Medieval Warming) with "peaks of warmth" in the 10th, 11th, 12th and 15th centuries — up to 1430.

In northern Quebec, tree rings and growth sequences from more than 300 spruce tree skeletons buried in a peatland near the tree line showed colder weather from 760 to 860, a warming from 860 to 1000, and severe cold from 1025 to 1400.[63]

"Tree-growth rings show a 1,500-year pattern in rainfall and temperature."

In Siberia, a continuous 2,200-year temperature record from relict tree rings (rings from trees preserved from an earlier period) shows a warming from 850 to 1150, followed by a sharp cooling from 1200 through 1800, very much in phase with Asia's climate cycling. The authors report that 20th century warming is "not extraordinary" according to their tree rings.[64]

On Yakushima Island off southern Japan, carbon-13 isotopes from a giant Japanese cedar infer a temperature 2° C below present from 1600 to 1700, and a warm period about one degree Celsius above present between 800 and 1200.[65]

In northwestern Pakistan, more than 200,000 tree-ring measurements from 384 trees and more than 20 individual sites show the warmest decades occurred between 800 and 1000, and the coldest periods between 1500 and 1700.[66]

Mountain Tree Line Elevations

A "major [European] retreat from farming" occurred during the cold Dark Ages when large parts of the continent were allowed to reforest themselves. Then, during the Medieval Warming, farming staged a strong recovery, and both farming and tree lines moved upslope again — until the beginning of the Little Ice Age.[67]

In Western Siberia, advances in the tree lines during the warming weather of the first half of the 20th century were "part of a long-term reforestation of tundra environments." Swiss scientists note that "stumps and logs of *Larix sibirica* can be preserved for hundreds of years," and that "above the tree line in the Polar Urals such relict material from large, upright trees were sampled and dated, confirming the existence, around A.D. 1000, of a forest tree line 30 meters above the late 20th century limit." They also note that "this previous forest limit receded around 1350, perhaps caused by a general cooling trend." Thus, the Siberian tree lines testify to the Medieval Warming and the Little Ice Age far from Europe.[68]

The southern tip of South America became abnormally dry for several centuries during the Medieval Warming before 1350. It was so dry, in fact, that trees as old as 100 years grew in the beds of Lakes Argentino, Cardiel and Ghio before the lakes reflooded during the heavier rains of the Little Ice Age.[69]

Glacier Advances and Retreats

Historical records tell of glaciers retreating during the Medieval Warming, and advancing again like huge bulldozers during the Little Ice Age. Glacial moraines can be dated through carbon-14 from lichens and organic material in the debris where they mark their glaciers' farthest advances. The moraines tell us the glaciers' most recent advances occurred during the Little Ice Age — but the piles of rocky rubble often contain datable material from more than one advance.

"Today, many glaciers are advancing, not retreating."

Jean Grove, one of the top authorities on the Little Ice Age, recently did a review of the scientific literature, dating the age's beginning "before the early 14th century" in regions surrounding the North Atlantic."[70] She says "field evidence clearly shows that glaciers on all continents expanded and fluctuated about forward positions during recent centuries."

The UN Intergovernmental Panel on Climate Change, in its 2001 report, published data showing that one-half of the world's glaciers had stopped shrinking, and that many of these had recently been growing.[71]

In the Arctic, the 18 glaciers with the longest observation histories were examined in 1997.[72] More than 80 percent of them had lost mass since the end of the Little Ice Age. Surprisingly, however*, there's no evidence the Arctic glaciers have shrunk faster during the* CO_2*-enriched 20th century*. In fact, the researchers say the glaciers have been losing *less mass per year as time goes by.*[73] The Arctic glaciers thus tell us their region *is not currently warming.* The glaciers retreated during the Medieval Warming for "at least a few centuries before 1200," and then advanced three times during the Little Ice Age: the early 15th century, the middle 17th century and the last half of the 19th century.

On the Arctic island of Novaya Zemlya, the glaciers retreated rapidly before 1920 — but the retreat then slowed.[74] After 1950, more than half of the glaciers stopped retreating, and many tidewater glaciers began to advance.

The island's temperatures in the last four decades have been lower than the previous 40 years — in both the winter and the summer.

In the Alps, Austria's Gernot Patzelt says 55 glaciers have lost 50 percent of their area and 60 percent of their ice since 1850. He says they lost 20 percent of their area from 1855 to 1890, held constant from 1890 to 1925, lost another 26 percent from 1925 to 1965, held constant from 1965 to 1980, and have lost another 5 percent since 1980. The melting surges represent *a lagged record* of the surges in the Modern Warming.[75]

In Italy, the Ghiacciaio del Calderone, in the Italian Apennines, is the southernmost glacier in Europe. Historic records indicate that it has currently lost about half the mass it held in 1794, the earliest record of its surface area.[76] Maurizio D'Orefice of the Italian Geological Service says the Calderone lost ice volume very slowly from 1794 to 1884 and then melted more rapidly until 1990.

"Most glaciers advanced during the Little Ice Age."

South American glaciers on the eastern side of the Andes — in Peru, Chile and Patagonia — all advanced during the Little Ice Age. [77] (The eastern side is protected from the vagaries of the Pacific Decadal Oscillation.) The Peruvian glaciers were most extensive in the 17th century, those in Patagonia (farther from the equator) during the 19th century.

Tropical Glaciers also show the Little Ice Age and the Modern Warming. The University of Innsbruck's Georg Kaser says the glaciers of South America, Africa and New Guinea all reached their greatest extents during the Little Ice Age.[78] They've been receding "since the second half of the 19th century," just as the end of the Little Ice Age would lead us to expect. The 1930s and 1940s brought a marked loss of the tropical glaciers' ice masses. Around 1970 the melting generally slowed, and some glaciers even advanced. Then the 1990s again brought "marked glacier recession on all tropical mountains under observation."

In New Zealand, the moraines of more than 130 glaciers show three particular periods of glacial advance during the Little Ice Age, with the farthest advances in 1620, 1780 and 1830.[79] The Mueller Glacier on Mount Cook and the Tasman Glacier also reached their greatest extent during the Little Ice Age.[80]

In the South Shetland Islands, glaciers just north of Antarctica advanced during the Little Ice Age, based on the age of lichens[81] and analysis of lake sediments.[82]

On the Antarctic's Scott Coast, the Wilson Piedmont Glacier advanced at approximately the same time as the main phase of the Little Ice Age, based on carbon-14 dating of the organic material in the glacier's raised beaches.[83]

Miscellaneous Climate Proxies

Off Greenland's east coast, on Raffles Ø Island [sic], birds became scarce during the Little Ice Age. In the last 100 years, as the region has warmed, the birds have returned in large numbers. This is confirmed by "an increase in organic matter in the lake sediment and by bird observations." Based on the chemistry of the sediments, however, the bird numbers are still not as large as they were during the Medieval Warming. [84]

On Greenland, the University of Michigan's Henry Fricke tested the tooth enamel of dead Vikings for O-18 to O-16 ratios. Comparing the tooth enamel of skeletons buried in 1100 with those buried in 1400, he documented a 1.5° C drop in temperatures. [85]

In the Swiss Alps, the three most recent and best-documented periods of landslides (colder and wetter weather) were during the Little Ice Age, the Dark Ages and the unnamed cold period before the Roman Warming.[86]

In north central England, archeologists have found the nettle groundbug thrived in the city of York in both Roman and Medieval times. Its typical habitat today is on stinging nettles in the much-warmer south of England.[87]

In Argentina, the remains of prehistoric villages show the native peoples clustered in the lower valleys during the Dark Ages, then moved higher up the slopes as the Medieval Warming brought "a marked increase of environmental suitability, under a relatively homogeneous climate." Habitation moved as high as 4,300 meters in the Central Peruvian Andes around 1000 with warmer and more stable climate. After 1320 the people migrated back downslope in the colder, less stable climate of the Little Ice Age.

"Movements of animals and peoples are linked to the 1,500-year cycle."

In southern Africa, carbon-dated crop remains prove the climate of the region must have been both warmer and wetter during the Medieval Warming (from about 900 to 1300) — or the millet and cowpeas couldn't have been grown where their dated remains have been found. [88]

A recent environmental impact assessment for a gas pipeline reported that the Little Ice Age began about 1300, when colder and drier conditions drove the ancestors of the present day Nguni and Sotho-Tswana speakers from East Africa into South Africa. The climate warmed again between 1425 and 1675.[89]

The Tibetan Plateau, based on oxygen-18 isotopes from peat bogs, had: three severely cold intervals during the Dark Ages, a warm period from 1100 to 1300, and then cold periods again during 1370 to 1400, 1550 to 1610 and 1780 to 1880.[90]

Summing Up the Worldwide Physical Evidence

One of the broadest and most revealing sets of physical evidence — with testimony from outside the North Atlantic region — comes from Yang Bao of the

Chinese Academy of Sciences. He reconstructed China's temperature history for the last 2,000 years from ice cores, lake sediments, peat bogs, tree rings and the historic documents that date back in China farther than in any other country. He found China had its highest temperatures during the second and third centuries, toward the end of the Roman Warming.[91] China's climate was also warm from 800 to 1400, cold from 1400 to 1920, and began to warm again after 1920.

We have less extensive documentation of North American climate change, but as the sidebar shows, the existing evidence corresponds to that gathered elsewhere in the world. [See Climate Cycling in North America.]

This paper has offered a sampling of the Earth's physical evidence of past climate cycles documented by researchers around the world in recent decades, from tree rings and ice cores, from stalagmites and dust plumes, from prehistoric villages and collapsed cultures, from fossilized pollen and algae skeletons, from titanium profiles and niobium ions. The evidence has come from around the world.

"The geographic range and variety of evidence for a 1,500-year climate cycle is too great to dismiss."

Evidence of a 1,500-year climate cycle is clear and convincing. Models that posit a human impact on the climate must better take this evidence into account before any conclusions are drawn regarding humanity's ability to prevent future climate change.

Climate Cycling in North America

North America has no records going as far back as the Medieval Warming, unless we count the oral testimony of the Greenland Vikings. The sagas say they found grapes growing on what is now called Newfoundland. The Vikings, impressed, named it "Vinland," or vineland.

For the more recent Little Ice Age, fur traders' records tell us that lake freezing dates now are 8.7 days later in the Hudson's Bay region than they were in 1850, while ice break-up dates are 9.8 days earlier. That means temperatures are now about 1.8 degrees C warmer.

Ezra Stiles, then president of Yale University, recorded daily Connecticut temperatures from 1779. His records show June 1816 is still the coldest June ever recorded in the state, 2.5 degrees C colder than the mean for Connecticut from 1780 to 1968.

The two most broadly powerful pieces of climate cycle evidence in North America:

First*, the North American Pollen Database* reveals nine continent-wide temperature-driven shifts in vegetation during the past 14,000 years, an average of one every 1,650 years.[92, 93] Thousands of pollen studies show that the vegetation shifts occurred across the whole of North America. The most recent major shift happened about 600 years ago "culminating in the Little Ice Age, with maximum cooling 300 years ago." The previous shift began about 1,600 years ago, and "culminated in the maximum warming of the Medieval Warm Period 1,000 years ago." The pollen analysis was led by Andre Viau of the University of Ottawa who wrote, "We suggest that North Atlantic millennial-scale climate variability is associated with rearrangements of the atmospheric circulation with far-reaching influences on the climate."

Ian Campbell and John McAndrews of Environment Canada found that as the Little Ice Age cooled southern Ontario's climate, the predominant forest trees shifted from warmth-loving beeches to cold-tolerant oaks, and then to cold-adapted evergreens.[94] Since 1850, that shift has been reversing, with oak trees gradually displacing the evergreens, and the beech trees awaiting their turn. The scientists' computer simulation found the tree species still lagging behind the Modern Warming in 1993, though most of the warming predated 1940. Tree populations may thus need centuries to adapt to the major climate shifts. Campbell and McAndrews also concluded that the total plant mass of Ontario forests fell by 30 percent in the Little Ice Age; the forests still have not recovered the full productivity they had during the Medieval Warming.

Second, *the water levels of the Great Lakes* show a strong response to the 1,500-year climate cycle, with the lake levels high during climate coolings and low during warming periods. Todd Thompson of Indiana University and Steve Baedke of James Madison University studied "strandplains"—shore-parallel sand ridges that have a core of water-laid sediment.[95] These "strandplains" commonly occur on shore as a series of ridges and swales that reveal the upper level of the lake waters, while the organic sediments indicate the age of the ridges.

The Great Lakes were at their highest levels in the record — by far — about 4,500 years ago, just after the end of the very warm Climate Optimum. (The last of the huge Laurentide Ice Sheet may have melted during that period.) Water levels fell sharply — by 4.5 meters — during the next 1,000 years, and then rose, less dramatically, between 3,100 and 2,300 years ago during the cold that preceded the Roman Warming. The lakes were low from 2,300 to 1,900 years ago, reflecting the Roman Warming. Then water levels rose again from 100 to 900, in response to the cold Dark Ages. The waters were high again in both 1300 and 1600, reflecting the two-stage Little Ice Age.[96]

Evidence of warmer past temperatures has also been found in Central Alaska — in the expansion of forest ranges, and the absence of permafrost during the prior interglacial era.[97]

In Northern Quebec, centuries-old ice wedges in the soil surface indicate that the region was cold until about A.D. 140, followed by a warmer period that persisted up to 1030, the Medieval Warming. The region was severely cold between 1500 and 1900 — the Little Ice Age. Colder conditions have prevailed again during the last 50 years.[98]

In the southern Sierra Nevada Mountains, foxtail pine and western juniper tree rings indicate a Medieval Warming from 1100 to 1375, and a cold period from 1450 to 1850, corresponding to the Little Ice Age.[99] Tree ring widths in the very long-lived bristlecone pine trees of the Sierra Nevada correlate statistically from 800 to the present century "with the temperatures derived for central England."[100]

Lisa Graumlich of Montana State University combined both tree rings and tree line changes in the Sierra Nevada, where high-growing trees are preserved in place, living and dead, for up to 3,000 years. Graumlich says, "A relatively dense forest grew above the current tree line from the beginning of our records to around 100 B.C., and again from A.D. 400 to 1000, when temperatures were warm. Abundance of trees and elevation of tree line declined very rapidly from 1000 to 1400, the period of severe, multi-decadal droughts. Tree lines declined more slowly from 1500 to 1900 under the cool temperatures of the Little Ice Age, reaching current elevations around 1900."[101]

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The NCPA was established in 1983 as a nonprofit, nonpartisan public policy research institute. Its mission is to seek innovative private sector solutions to public policy problems.

The center is probably best known for developing the concept of Medical Savings Accounts (MSAs), now known as Health Savings Accounts (HSAs). The *Wall Street Journal* and *National Journal* called NCPA President John C. Goodman "the father of Medical Savings Accounts." Sen. Phil Gramm said MSAs are "the only original idea in health policy in more than a decade." Congress approved a pilot MSA program for small businesses and the self-employed in 1996 and voted in 1997 to allow Medicare beneficiaries to have MSAs. A June 2002 IRS ruling frees the private sector to have flexible medical savings accounts and even personal and portable insurance. A series of NCPA publications and briefings for members of Congress and the White House staff helped lead to this important ruling. In 2003, as part of Medicare reform, Congress and the President made HSAs available to all nonseniors, potentially revolutionizing the entire health care industry.

The NCPA also outlined the concept of using tax credits to encourage private health insurance. The NCPA helped formulate a bipartisan proposal in both the Senate and the House, and Dr. Goodman testified before the House Ways and Means Committee on its benefits. Dr. Goodman also helped develop a similar plan for then presidential candidate George W. Bush.

The NCPA shaped the pro-growth approach to tax policy during the 1990s. A package of tax cuts, designed by the NCPA and the U.S. Chamber of Commerce in 1991, became the core of the Contract With America in 1994. Three of the five proposals (capital gains tax cut, Roth IRA and eliminating the Social Security earnings penalty) became law. A fourth proposal — rolling back the tax on Social Security benefits — passed the House of Representatives in summer 2002.

The NCPA's proposal for an across-the-board tax cut became the focal point of the pro-growth approach to tax cuts and the centerpiece of President Bush's tax cut proposal. The repeal by Congress of the death tax and marriage penalty in the 2001 tax cut bill reflects the continued work of the NCPA.

Entitlement reform is another important area. With a grant from the NCPA, economists at Texas A&M University developed a model to evaluate the future of Social Security and Medicare. This work is under the direction of Texas A&M Professor Thomas R. Saving, who was appointed a Social Security and Medicare Trustee. Our online Social Security calculator, found on the NCPA's Social Security reform Internet site (www.TeamNCPA.org) allows visitors to discover their expected taxes and benefits and how much they would have accumulated had their taxes been invested privately.

Team NCPA is an innovative national volunteer network to educate average Americans about the problems with the current Social Security system and the benefits of personal retirement accounts.

In the 1980s, the NCPA was the first public policy institute to publish a report card on public schools, based on results of student achievement exams. We also measured the efficiency of Texas school districts. Subsequently, the NCPA pioneered the concept of education tax credits to promote competition and choice through the tax system. To bring the best ideas on school choice to the forefront, the NCPA and Children First America published an *Education Agenda* for the new Bush administration, policy-makers, congressional staffs and the media. This book provides policy-makers with a road map for comprehensive reform. And a June 2002 Supreme Court ruling upheld a school voucher program in Cleveland, an idea the NCPA has endorsed and promoted for years.

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