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5.3. Temperature

5.3.1. Global

The IPCC's claim that anthropogenic greenhouse gas emissions have been responsible for the warming detected in the twentieth century is based on what Loehle (2004) calls "the standard assumption in climate research, including the IPCC reports," that "over a century time interval there is not likely to be any recognizable trend to global temperatures (Risbey *et al*., 2000), and thus the null model for climate signal detection is a flat temperature trend with some autocorrelated noise," so that "any warming trends in excess of that expected from normal climatic variability are then assumed to be due to anthropogenic effects." If, however, there are significant underlying climate trends or cycles—or both—either known or unknown, that assumption is clearly invalid.

Loehle used a pair of 3,000-year proxy climate records with minimal dating errors to characterize the pattern of climate change over the past three millennia simply as a function of time, with no attempt to make the models functions of solar activity or any other physical variable. The first of the two temperature series is the sea surface temperature (SST) record of the Sargasso Sea, derived by Keigwin (1996) from a study of the oxygen isotope ratios of foraminifera and other organisms contained in a sediment core retrieved from a deep-ocean drilling site on the Bermuda Rise. This record provides SST data for about every 67th year from 1125 BC to 1975 AD. The second temperature series is the ground surface temperature record derived by Holmgren *et al*. (1999, 2001) from studies of color variations of stalagmites found in a cave in South Africa, which variations are caused by changes in the concentrations of humic materials entering the region's ground water that have been reliably correlated with regional near-surface air temperature.

Why does Loehle use these two specific records? He says "most other long-term records have large dating errors, are based on tree rings, which are not reliable for this purpose (Broecker, 2001), or are too short for estimating long-term cyclic components of climate." Also, in a repudiation of the approach employed by Mann *et al*. (1998, 1999) and Mann and Jones (2003), he reports that "synthetic series consisting of hemispheric or global mean temperatures are not suitable for such an analysis because of the inconsistent timescales in the various data sets," noting further, as a result of his own testing, that "when dating errors are present in a series, and several series are combined, the result is a smearing of the signal." But can only two temperature series reveal the pattern of global temperature change? According to Loehle, "a comparison of the Sargasso and South Africa series shows some remarkable similarities of pattern, especially considering the distance separating the two locations," and he says that this fact "suggests that the climate signal reflects some global pattern rather than being a regional signal only." He also notes that a comparison of the mean record with the South Africa and Sargasso series from which it was derived "shows excellent agreement," and that "the patterns match closely," concluding that "this would not be the case if the two series were independent or random."

Loehle fit seven different time-series models to the two temperature series and to the average of the two series, using no data from the twentieth century. In all seven cases, he reports that good to excellent fits were obtained. As an example, the three-cycle model he fit to the averaged temperature series had a simple correlation of 0.58 and an 83 percent correspondence of peaks when evaluated by a moving window count.

Comparing the forward projections of the seven models through the twentieth century leads directly to the most important conclusions of Loehle's paper. He notes, first of all, that six of the models "show a warming trend over the 20th century similar in timing and magnitude to the Northern Hemisphere instrumental series," and that "one of the models passes right through the 20th century data." These results suggest, in his words, "that 20th century warming trends are plausibly a continuation of past climate patterns" and, therefore, that "anywhere from a major portion to all of the warming of the 20th century could plausibly result from natural causes."

As dramatic and important as these observations are, they are not the entire story of Loehle's insightful paper. His analyses also reveal a long-term linear cooling trend of 0.25°C per thousand years since the peak of the interglacial warm period that occurred some 7,000 years ago, which result is essentially identical to the mean value of this trend that was derived from seven prior assessments of its magnitude and five prior climate reconstructions. In addition, Loehle's analyses reveal the existence of the Medieval Warm Period of 800-1200 AD, which is shown to have been significantly warmer than the portion of the Current Warm Period we have so far experienced, as well as the existence of the Little Ice Age of 1500-1850 AD, which is shown to have been the coldest period of the entire 3,000-year record.

As corroborating evidence for the global nature of these major warm and cold intervals, Loehle cites 16 peer-reviewed scientific journal articles that document the existence of the Medieval Warm Period in all parts of the world, as well as 18 other articles that document the worldwide occurrence of the Little Ice Age. And in one of the more intriguing aspects of his study—of which Loehle makes no mention, however—both the Sargasso Sea and South African temperature records reveal the existence of a major temperature spike that began sometime in the early 1400s. This abrupt warming pushed temperatures considerably above the peak warmth of the twentieth century before falling back to pre-spike levels in the mid 1500s, providing support for the similar finding of higher-than-current temperatures in that time interval by McIntyre and McKitrick (2003) in their reanalysis of the data employed by Mann *et al.* to create their controversial "hockey stick" temperature history, which gives no indication of the occurrence of this high-temperature regime.

In another accomplishment of note, the models developed by Loehle reveal the existence of three climate cycles previously identified by others. In his culminating seventh model, for example, there is a 2,388-year cycle that he describes as comparing "quite favorably to a cycle variously estimated as 2200, 2300, and 2500 years (Denton and Karlén, 1973; Karlén and Kuylenstierna, 1996; Magny, 1993; Mayewski *et al.*, 1997)." There is also a 490-year cycle that likely "corresponds to a 500-year cycle found previously (e.g. Li *et al.*, 1997; Magny, 1993; Mayewski *et al.*, 1997)" and a 228-year cycle that "approximates the 210-year cycle found by Damon and Jirikowic (1992)."

The compatibility of these findings with those of several studies that have identified similar solar forcing signals caused Loehle to conclude that "solar forcing (and/or other natural cycles) is plausibly responsible for some portion of 20th century warming" or, as he indicates in his abstract, maybe even all of it.

In spite of potential smearing and dating errors, other globally represented datasets have provided additional evidence of a solar influence on temperature. The 16 authors of Mayewski *et al.* (2004) examined some 50 globally distributed paleoclimate records in search of evidence for what they call rapid climate change (RCC) over the Holocene. This terminology is not to be confused with the rapid climate changes typical of glacial periods, but is used in the place of what the authors call the "more geographically or temporally restrictive terminology such as 'Little Ice Age' and 'Medieval Warm Period'." RCC events, as they also call them, are multi-century periods of time characterized by extremes of thermal and/or hydrological properties, rather than the much shorter periods of time during which the changes that led to these situations took place.

Mayewski *et al*. identify six RCCs during the Holocene: 9,000-8,000, 6,000-5,000, 4,200-3,800, 3,500-2,500, 1,200-1,000, and 600-150 cal yr BP, the last two of which intervals are, in fact, the "globally distributed" Medieval Warm Period and Little Ice Age, respectively. In speaking further of these two periods, they say that "the short-lived 1200-1000 cal yr BP RCC event coincided with the drought-related collapse of Maya civilization and was accompanied by a loss of several million lives (Hodell *et al*., 2001; Gill, 2000), while the collapse of Greenland's Norse colonies at ~600 cal yr BP (Buckland *et al*., 1995) coincides with a period of polar cooling."

With respect to the causes of these and other Holocene RCCs, the international team of scientists says that "of all the potential climate forcing mechanisms, solar variability superimposed on long-term changes in insolation (Bond *et al*., 2001; Denton and Karlén, 1973; Mayewski *et al*., 1997; O'Brien *et al*., 1995) seems to be the most likely important forcing mechanism." In addition, they note that "negligible forcing roles are played by CH_4 and CO_2," and that "changes in the concentrations of CO_2 and CH_4 appear to have been more the result than the cause of the RCCs."

In another study with global implications, eight researchers hailing from China, Finland, Russia, and Switzerland published a paper wherein they describe evidence that makes the case for a causative link, or set of links, between solar forcing and climate change. Working with tree-ring width data obtained from two types of juniper found in Central Asia—*Juniperus turkestanica* (related to variations in summer temperature in the Tien Shan Mountains) and *Sabina przewalskii* (related to variations in precipitation on the Qinghai-Tibetan Plateau)—Raspopov *et al*. (2008) employed band-pass filtering in the 180- to 230-year period range, wavelet transformation (Morlet basis) for the range of periods between 100 and 300 years, as well as spectral analysis, in order to compare the variability in the two tree-ring records with independent $\Delta^{14}C$ variations representative of the approximate 210-year de Vries solar cycle over the past millennium. These analyses indicated that the approximate 200-year cyclical variations present in the palaeoclimatic reconstructions were well correlated ($R^2 = 0.58$-0.94) with similar variations in the $\Delta^{14}C$ data, which obviously suggests the existence of a solar-climate connection. In addition, they say "the de Vries cycle has been found to occur not only during the last millennia but also in earlier epochs, up to hundreds of millions [of] years ago."

After reviewing additional sets of published palaeoclimatic data from various parts of the world, the eight researchers satisfied themselves that the same periodicity is evident in Europe, North and South America, Asia, Tasmania, Antarctica, and the Arctic, as well as "sediments in the seas and oceans," citing 20 independent research papers in support of this statement. This fact led them to conclude there is "a pronounced influence of solar activity on global climatic processes" related to "temperature, precipitation and atmospheric and oceanic circulation."

Complicating the matter, however, Raspopov *et al*. report there can sometimes be "an appreciable delay in the climate response to the solar signal," which can be as long as 150 years, and they note that regional climate responses to the de Vries cycle "can markedly differ in phase," even at distances of only hundreds of kilometers, due to "the nonlinear character of the atmosphere-ocean system response to solar forcing." Nevertheless, the many results they culled from the scientific literature, as well as their own findings, all testify to the validity of their primary conclusion, that throughout the past millennium, and stretching back in time as much as 250 million years, the de Vries cycle has been "one of the most intense solar activity periodicities that affected climatic processes."

As for the more recent historical significance of the de Vries cycle, Raspopov *et al*. write that "the temporal synchrony between the Maunder, Sporer, and Wolf minima and the expansion of Alpine glaciers (Haeberlie and Holzhauser, 2003) further points to a climate response to the deep solar minima." In this regard, we again add that Earth's recent recovery from those deep solar minima could well have played a major role in the planet's emergence from the Little Ice Age, and, therefore, could well have accounted for much of twentieth century global warming, as suggested fully 20 years ago by Idso (1988).

Clearly, there is much to recommend the overriding concept that is suggested by the data of these several papers, i.e., that the sun rules the earth when it comes to orchestrating major changes in the planet's climate. It is becoming ever more clear that the millennial-scale oscillation of climate that has reverberated throughout the Holocene is indeed the result of similar-scale oscillations in some aspect of solar activity. Consequently, Mayewski *et al*. suggest that "significantly more research into the potential role of solar variability is warranted, involving new assessments of potential transmission mechanisms to induce climate change and potential enhancement of natural feedbacks that may amplify the relatively weak forcing related to fluctuations in solar output."

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempglobal.php.

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5.3.2. Northern Hemisphere

Evidence of the influence of the sun on Northern Hemisphere temperatures can be found in the seminar research of Bond *et al*. (2001), who examined ice-rafted debris found in three North Atlantic deep-sea sediment cores and cosmogenic nuclides (^{10}Be and ^{14}C) sequestered in the Greenland ice cap (^{10}Be) and Northern Hemispheric tree rings (^{14}C). This study is described in depth in Section 5.1.

Bond *et al*. found 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 solar minimum," and "a solar influence on climate of the magnitude and consistency implied by our evidence could not have been confined to the North Atlantic," suggesting that the cyclical climatic effects of the variable solar inferno are experienced throughout the world. Bond *et al*. also observed that the oscillations in drift-ice they studied "persist across the glacial termination and well into the last glaciation, suggesting that the cycle is a pervasive feature of the climate system."

Björck *et al*. (2001) assembled a wide range of lacustrine, tree-ring, ice-core, and marine records that reveal a Northern Hemispheric, and possibly global, cooling event of less than 200 years' duration with a 50-year cooling-peak centered at approximately 10,300 years BP. According to the authors, the onset of the cooling event broadly coincided with rising ^{10}Be fluxes, which are indicative of either decreased solar or geomagnetic forcing; and since the authors note that "no large magnetic field variation that could have caused this event has been found," they postulate that "the ^{10}Be maximum was caused by distinctly reduced solar forcing." They also note that the onset of the Younger Dryas is coeval with a rise in ^{10}Be flux, as is the Preboreal climatic oscillation.

Pang and Yau (2002) assembled and analyzed a vast amount of data pertaining to phenomena that have been reliably linked to variations in solar activity, including frequencies of sunspot and aurora sightings, the abundance of carbon-14 in the rings of long-lived trees, and the amount of beryllium-10 in the annual ice layers of polar ice cores. In the case of sunspot sightings, the authors used a catalogue of 235 Chinese, Korean, and Japanese records compiled by Yau (1988), a catalogue of 270 Chinese records compiled by Zhuang and Wang (1988), and a time chart of 139 records developed by Clark and Stephenson (1979), as well as a number of later catalogues that made the overall record more complete.

Over the past 1,800 years, the authors identified "some nine cycles of solar brightness change," which include the well-known Oort, Wolf, Sporer, Maunder, and Dalton Minima. With respect to the Maunder Minimum—which occurred between 1645 and 1715 and is widely acknowledged to have been responsible for some of the coldest weather of the Little Ice Age—they report that the temperatures of that period "were about one-half of a degree Celsius lower than the mean for the 1970s, consistent with the decrease in the decadal average solar irradiance." Then, from 1795 to 1825 came the Dalton Minimum, along with another dip in Northern Hemispheric temperatures. Since that time, however, the authors say "the sun has gradually brightened" and "we are now in the Modern Maximum," which is likely responsible for the warmth of the Current Warm Period.

The authors say that although the long-term variations in solar brightness they identified "account for less than 1% of the total irradiance, there is clear evidence that they affect the Earth's climate." Pang and Yau's dual plot of total solar irradiance and Northern Hemispheric temperature from 1620 to the present (their Fig. 1c) indicates that the former parameter (when appropriately scaled, but without reference to any specific climate-change mechanism) can account for essentially all of the net change experienced by the latter parameter up to about 1980. After that time, however, the IPCC surface air temperature record rises dramatically, although radiosonde and satellite temperature histories largely match what would be predicted from the solar irradiance record. These facts could be interpreted as new evidence of the corruptness of the IPCC temperature history.

In a separate study, Rohling *et al*. (2003) “narrow down” temporal constraints on the millennial-scale variability of climate evident in ice-core $\delta^{18}O$ records by “determining statistically significant anomalies in the major ion series of the GISP2 ice core,” after which they conduct “a process-oriented synthesis of proxy records from the Northern Hemisphere.” With respect to the temporal relationships among various millennial-scale oscillations in Northern Hemispheric proxy climate records, the authors conclude that a “compelling case” can be made for their being virtually in-phase, based on (1) “the high degree of similarity in event sequences and structures over a very wide spatial domain,” and (2) “the fact that our process-oriented synthesis highlights a consistent common theme of relative dominance shifts between winter-type and summer-type conditions, ranging all the way across the Northern Hemisphere from polar into monsoonal latitudes.” These findings, they additionally note, “corroborate the in-phase relationship between climate variabilities in the high northern latitudes and the tropics suggested in Blunier *et al*. (1998) and Brook *et al*. (1999).”

Rohling *et al.* further report that although individual cycles of the persistent climatic oscillation “appear to have different intensities and durations, a mean periodicity appears around ~1500 years (Mayewski *et al*., 1997; Van Kreveld *et al*., 2000; Alley *et al*., 2001).” They further report that “this cycle seems independent from the global glaciation state (Mayewski *et al*., 1997; Bond *et al*., 1999),” and that “^{10}Be and delta ^{14}C records may imply a link with solar variability (Mayewski *et al*., 1997; Bond *et al*., 2001).”

Lastly, we come to the study of Usoskin *et al*. (2003), who note that “sunspots lie at the heart of solar active regions and trace the emergence of large-scale magnetic flux, which is responsible for the various phenomena of solar activity” that may influence earth’s climate. They say “the sunspot number (SN) series represents the longest running direct record of solar activity, with reliable observations starting in 1610, soon after the invention of the telescope.” To compare SN data with the millennial-scale temperature reconstruction of Mann *et al*. (1999), the directly measured SN record must be extended back in time at least another 600 years, which Usoskin *et al*. did using records of ^{10}Be cosmonuclide concentration derived from polar ice cores dating back to AD 850. In accomplishing this task, they employed detailed physical models that they say were “developed for each individual link in the chain connecting the SN with the cosmogenic isotopes,” and they combined these models in such a way that “the output of one model [became] the input for the next step.”

The reconstructed SN history of the past millennium looks very much like the infamous “hockey stick” temperature history of Mann *et al*. (1999). It slowly declines over the entire time period—with numerous modest oscillations associated with well-known solar maxima and minima—until the end of the Little Ice Age, whereupon it rises dramatically. Usoskin *et al*. report, for example, that “while the average value of the reconstructed SN between 850 and 1900 is about 30, it reaches values of 60 since 1900 and 76 since 1944.” In addition, they report that “the largest 100-year average of the reconstructed SN prior to 1900 is 44, which occurs in 1140-1240, i.e., during the medieval maximum,” but they note that “even this is significantly less than the level reached in the last century.” Hence, they readily and correctly conclude, on the basis of their work, that “the high level of solar activity since the 1940s is unique since the year 850.”

The studies reported in this section show that the temperature record of the Northern Hemisphere supports the theory that solar cycles strongly influence temperatures. Additional information on this topic, including reviews of newer publications as they become availables, can be found at http://www.co2science.org/subject/s/solartempnhemis.php.

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5.3.3. North America

We begin our review of the influence of the sun on North American temperatures with the study of Wiles *et al*. (2004), who derived a composite Glacier Expansion Index (GEI) for Alaska based on "dendrochronologically derived calendar dates from forests overrun by advancing ice and age estimates of moraines using tree-rings and lichens," after which they compared this history of glacial activity with "the ^{14}C record preserved in tree rings corrected for marine and terrestrial reservoir effects as a proxy for solar variability" and with the history of the Pacific Decadal Oscillation (PDO) derived by Cook (2002).

Results of the study showed Alaska ice expansions "approximately every 200 years, compatible with a solar mode of variability," specifically, the de Vries 208-year solar cycle; and by merging this cycle with the cyclical behavior of the PDO, Wiles *et al*. obtained a dual-parameter forcing function that was even better correlated with the Alaskan composite GEI, with major glacial advances clearly associated with the Sporer, Maunder, and Dalton solar minima.

In introducing the rational for their study, Wiles *et al*. say that "increased understanding of solar variability and its climatic impacts is critical for separating anthropogenic from natural forcing and for predicting anticipated temperature change for future centuries." In this regard, it is most interesting that they make no mention of possible CO_2-induced global warming in discussing their results, presumably because there is no need to do so. Alaskan glacial activity, which, in their words, "has been shown to be primarily a record of summer temperature change (Barclay *et al*., 1999)," appears to be sufficiently well described within the context of solar and PDO variability alone. Four years later, Wiles *et al*. (2008)

reconfirmed this Alaska solar-climate link in a separate study.

Nearby in the Columbia Icefield area of the Canadian Rockies, Luckman and Wilson (2005) used new tree-ring data to present a significant update to a millennial temperature reconstruction published for this region in 1997. The new update employed different standardization techniques, such as the regional curve standardization method, in an effort to capture a greater degree of low frequency variability (centennial to millennial scale) than reported in the initial study. In addition, the new dataset added more than one hundred years to the chronology and now covers the period AD 950-1994.

The updated proxy indicator of temperature showed considerable decadal- and centennial-scale variability, where generally warmer conditions prevailed during the eleventh and twelfth centuries, between about AD 1350-1450 and from about 1875 through the end of the record, while persistent cold conditions prevailed between 1200-1350, 1450-1550, and 1650-1850, with the 1690s being exceptionally cold (more than 0.4°C colder than the other intervals).

The revised Columbia Icefield temperature reconstruction provides further evidence for natural climate fluctuations on centennial-to-millennial timescales and demonstrates, once again, that temperatures during the Current Warm Period are no different from those observed during the Medieval Warm Period (eleventh—twelfth centuries) or the Little Medieval Warm Period (1350-1450). And since we know that atmospheric CO_2 concentrations had nothing to do with the warm temperatures of those earlier periods, we cannot rule out the possibility that they also have nothing to do with the warm temperatures of the modern era.

But if not CO_2, then what? According to Luckman and Wilson, the Columbia Icefield reconstruction "appears to indicate a reasonable response of local trees to large-scale forcing of climates, with reconstructed cool conditions comparing well with periods of known low solar activity," which is a nice way of suggesting that the *sun* is the main driver of these low frequency temperature trends.

Heading south to the warmer regions of North America, Barron and Bukry (2007) extracted sediment cores from three sites on the eastern slope of the Gulf of California. By examining these high-resolution records of diatoms and silicoflagellate assemblages, they were able to reconstruct sea surface temperatures there over the past 2,000 years. In all three of the sediment cores, the relative abundance of *Azpeitia nodulifera* (a tropical diatom whose presence suggests the occurrence of higher sea surface temperatures), was found to be greater during the Medieval Warm Period than at any other time over the 2,000-year period studied, while during the Current Warm Period its relative abundance was actually lower than the 2,000-year mean, also in all three of the sediment cores. In addition, the first of the cores exhibited elevated *A. nodulifera* abundances from the start of the record to about AD 350, during the latter part of the Roman Warm Period, as well as between AD 1520 and 1560, during what we have denominated the Little Medieval Warm Period. By analyzing radiocarbon production data, Barron and Bukry determined that "intervals of increased radiocarbon production (sunspot minima) correlate with intervals of enhanced biosilica productivity," leading the two authors to conclude that "solar forcing played a major role in determining surface water conditions in the Gulf of California during the past 2000 yr." As for how this was accomplished, Barron and Bukry say that "reduced solar irradiance (sunspot minima) causes cooling of winter atmospheric temperatures above the southwest US," and that "this strengthens the atmospheric low and leads to intensification of northwest winds blowing down the Gulf, resulting in increased overturn of surface waters, increased productivity, and cooler SST."

Richey *et al.* (2007) constructed "a continuous decadal-scale resolution record of climate variability over the past 1400 years in the northern Gulf of Mexico" from a box core recovered in the Pigmy Basin, northern Gulf of Mexico [27°11.61'N, 91°24.54'W]," based on "paired analyses of Mg/Ca and $\delta^{18}O$ in the white variety of the planktic foraminifer *Globigerinoides ruber* and relative abundance variations of *G. sacculifer* in the foraminifer assemblages."

Results revealed that "two multi-decadal intervals of sustained high Mg/Ca indicate that Gulf of Mexico sea surface temperatures (SSTs) were as warm or warmer than near-modern conditions between 1000 and 1400 yr B.P.," while "foraminiferal Mg/Ca during the coolest interval of the Little Ice Age (ca. 250 yr B.P.) indicate that SST was 2-2.5°C below modern SST." In addition, they found that "four minima in the Mg/Ca record between 900 and 250 yr. B.P. correspond with the Maunder, Sporer, Wolf, and Oort sunspot minima," providing additional evidence that the historic warmth of earth's past was likely solar-induced.

Also in the Gulf of Mexico, Poore *et al*. (2003) developed a 14,000-year record of Holocene climate based primarily on the relative abundance of the planktic foraminifer *Globigerinoides sacculifer* found in two sediment cores. In reference to North Atlantic millennial-scale cool events 1-7 identified by Bond *et al*. (2001) as belonging to a pervasive climatic oscillation with a period of approximately 1,500 years, Poore *et al*. say of their own study that distinct excursions to lower abundances of *G. sacculifer* "match within 200 years the ages of Bond events 1-6," noting that "major cooling events detected in the subpolar North Atlantic can be recognized in the GOM record." They additionally note that "the GOM record includes more cycles than can be explained by a quasiperiodic 1500-year cycle," but that such centennial-scale cycles with periods ranging from 200 to 500 years are also observed in the study of Bond *et al*., noting further that their results "are in agreement with a number of studies indicating the presence of substantial century-scale variability in Holocene climate records from different areas," specifically citing the reports of Campbell *et al*. (1998), Peterson *et al*. (1991), and Hodell *et al*. (2001). Last, they discuss evidence that leads them to conclude that "some of the high-frequency variation (century scale) in *G. sacculifer* abundance in our GOM records is forced by solar variability."

In still another example of a solar-temperature connection, Lund and Curry (2004) analyzed a planktonic foraminiferal $\delta^{18}O$ time series obtained from three well-dated sediment cores retrieved from the seabed near the Florida Keys (24.4°N, 83.3°W) that covered the past 5,200 years. As they describe it, isotopic data from the three cores "indicate the surface Florida Current was denser (colder, saltier or both) during the Little Ice Age than either the Medieval Warm Period or today," and that "when considered with other published results (Keigwin, 1996; deMenocal *et al*., 2000), it is possible that the entire subtropical gyre of the North Atlantic cooled during the Little Ice Age ... perhaps consistent with the simulated effects of reduced solar irradiance (Rind and Overpeck, 1993; Shindell *et al*., 2001)." In addition, they report that "the coherence and phasing of atmospheric ^{14}C production and Florida Current $\delta^{18}O$ during the Late Holocene implies that solar variability may influence Florida Current surface density at frequencies between 1/300 and 1/100 years," demonstrating once again a situation where both centennial- and millennial-scale climatic variability is explained by similar-scale variability in solar activity.

We conclude with the study of Li *et al*. (2006), who "recovered a 14,000-year mineral-magnetic record from White Lake (~41°N, 75°W), a hardwater lake containing organic-rich sediments in northwestern New Jersey, USA." According to these researchers, a comparison of the White Lake data with climate records from the North Atlantic sediments "shows that low lake levels at ~1.3, 3.0, 4.4, and 6.1 ka [1000 years before present] in White Lake occurred almost concurrently with the cold events at ~1.5, 3.0, 4.5, and 6.0 ka in the North Atlantic Ocean (Bond *et al*., 2001)," and that "these cold events are associated with the 1500-year warm/cold cycles in the North Atlantic during the Holocene" that have "been interpreted to result from solar forcing (Bond *et al*., 2001)."

It is clear that broad-scale periods of warmth in North America have occurred over and over again throughout the Holocene—and beyond (Oppo *et al*., 1998; Raymo *et al*., 1998)—forced by variable solar activity. This suggests that the Current Warm Period was also instigated by this recurring phenomenon, not the CO_2 output of the Industrial Revolution.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempnamer.php.

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5.3.4. South America

Nordemann *et al*. (2005) examined tree rings from species sensitive to fluctuations in temperature and precipitation throughout the southern region of Brazil and Chile, along with sunspot data, via harmonic spectral and wavelet analysis in an effort to obtain a greater understanding of the effects of solar activity, climate, and geophysical phenomena on the continent of South America, where the time interval covered by the tree-ring samples from Brazil was 200 years and that from Chile was 2,500 years. Results of the spectral analysis revealed periodicities in the tree rings that corresponded well with the DeVries-Suess (~200 yr), Gleissberg (~80 yr), Hale (~22 yr), and Schwabe (~11 yr) solar activity cycles, while wavelet cross-spectrum analysis of sunspot number and tree-ring growth revealed a clear relation between the tree-ring and solar series.

Next, utilizing a lichenometric method for dating glacial moraines, the Bolivian and French research team of Rabatel *et al*. (2005) developed what they call "the first detailed chronology of glacier fluctuations in a tropical area during the Little Ice Age," focusing on fluctuations of the Charquini glaciers of the Cordillera Real in Bolivia, where they studied a set of 10 moraines that extend below the present glacier termini. Based on the chronology, the researchers determined that the maximum glacier extension in Bolivia "occurred in the second half of the 17th century, as observed in many mountain areas of the Andes and the Northern Hemisphere." In addition, they found that "this expansion has been of a comparable magnitude to that observed in the Northern Hemisphere, with the equilibrium line altitude depressed by 100-200 m during the glacier maximum." They say "the synchronization of glacier expansion with the Maunder and Dalton minima supports the idea that solar activity could have cooled enough the tropical atmosphere to provoke this evolution."

As for the magnitude and source of the cooling in the Bolivian Andes during the Little Ice Age, three years later Rabatal *et al*. (2008) estimated it to have been 1.1 to 1.2°C below that of the present, while once again noting that at that time there was a "striking coincidence between the glacier expansion in this region of the tropics and the decrease in solar irradiance: the so-called 'Maunder minimum' (AD 1645-1715) during which irradiance might have decreased by around 0.24% (Lean and Rind, 1998) and could have resulted in an atmospheric cooling of 1°C worldwide (Rind *et al*., 2004)."

Further south, Glasser *et al*. (2004) analyzed a large body of evidence related to glacier fluctuations in the two major ice fields of Patagonia: the Hielo Patagonico Norte (47°00'S, 73°39'W) and the Hielo Patagonico Sur (between 48°50'S and 51°30'S). With respect to the glacial advancements that occurred during the cold interval that preceded the Roman Warm Period, they say they are "part of a body of evidence for global climatic change around this time (e.g., Grosjean *et al*., 1998; Wasson and Claussen, 2002), which coincides with an abrupt decrease in solar activity," adding that this observation "led van Geel *et al*. (2000) to suggest that variations in solar irradiance are more important as a driving force in variations in climate than previously believed."

With respect to the most recent recession of Hielo Patagonico Norte outlet glaciers from their late historic moraine limits at the end of the nineteenth century, Glasser *et al*. say that "a similar pattern can be observed in other parts of southern Chile (e.g., Kuylenstierna *et al*., 1996; Koch and Kilian, 2001)." Likewise, they note that "in areas peripheral to the North Atlantic and in central Asia the available evidence shows that glaciers underwent significant recession at this time (cf. Grove, 1988; Savoskul, 1997)," which again suggests the operation of a globally distributed forcing factor such as cyclically variable solar activity.

Working on a bog, as opposed to a glacier, Chambers *et al*. (2007) presented new proxy climate data they obtained from the Valle de Andorra northeast of Ushuaia, Tierra del Fuego, Argentina, which data, they emphasize, are "directly comparable" with similar proxy climate data obtained in numerous studies conducted in European bogs, "as they were produced using identical laboratory methods." This latter point is very important because Chambers *et al*. say their new South American data show there was "a major climate perturbation at the same time as in northwest Europe," which they describe as "an abrupt climate cooling" that occurred approximately 2,800 years ago, and that "its timing, nature and apparent global synchronicity lend support to the notion of solar forcing of past climate change, amplified by oceanic circulation."

The five European researchers further state their finding that "rapid, high-magnitude climate changes might be produced within the Holocene by an inferred *decline* in solar activity (van Geel *et al*., 1998, 2000, 2003; Bond *et al*., 2001; Blaauw *et al*., 2004; Renssen *et al*., 2006) has implications for rapid, high-magnitude climate changes of the opposite direction—climatic warmings, possibly related to *increases* in solar activity." In this regard, they further note that "for the past 100 years any solar influence would for the most part have been in the opposite direction (i.e., to help generate a global climate warming) to that inferred for c. 2800-2710 cal. BP." And they conclude that this observation "has implications for interpreting the relative contribution of climate drivers of recent 'global warming'," implying that a solar-induced, rather than a CO_2-induced, climate driver may have been the primary cause of twentieth century global warming.

Polissar *et al*. (2006) worked with data derived from sediment records of two Venezuelan watersheds along with ancillary data obtained from other studies that had been conducted in the same general region. They developed continuous decadal-scale histories of glacier activity and moisture balance in a part of the tropical Andes (the Cordillera de Merida) over the past millennium and a half, from which they were able to deduce contemporary histories of regional temperature and precipitation. The international (Canada, Spain, United States, Venezuela) team of scientists write that "comparison of the Little Ice Age history of glacier activity with reconstructions of solar and volcanic forcing suggest that solar variability is the primary underlying cause of the glacier fluctuations," because (1) "the peaks and troughs in the susceptibility records match fluctuations of solar irradiance reconstructed from ^{10}Be and δ^{14}C measurements," (2) "spectral analysis shows significant peaks at 227 and 125 years in both the irradiance and magnetic susceptibility records, closely matching the de Vreis and Gleissberg oscillations identified from solar irradiance reconstructions," and (3) "solar and volcanic forcing are uncorrelated between AD 1520 and 1650, and the magnetic susceptibility record follows the solar-irradiance reconstruction during this interval." In addition, they write that "four glacial advances occurred between AD 1250 and 1810, coincident with solar-activity minima," and that "temperature declines of -3.2 ± 1.4°C and precipitation increases of ~20% are required to produce the observed glacial responses."

In discussing their findings, Polissar *et al*. say their results “suggest considerable sensitivity of tropical climate to small changes in radiative forcing from solar irradiance variability.” This research from South American strongly suggests that the IPCC is failing to take into account the effect of solar cycles on temperatures.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempsamer.php.

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5.3.5. Asia

We begin our study of Asia with a 2003 paper published in the Russian journal *Geomagnetizm i Aeronomiya*, where two scientists from the Institute of Solar-Terrestrial Physics of the Siberian Division of the Russian Academy of Sciences, Bashkirtsev and Mashnich (2003), say "a number of publications report that the anthropogenic impact on the Earth's climate is an obvious and proven fact," when in their opinion "none of the investigations dealing with the anthropogenic impact on climate convincingly argues for such an impact."

In the way of contrary evidence, they begin by citing the work of Friis-Christensen and Lassen (1991), who first noted the close relationship (r = -0.95) between the length of the sunspot cycle and the surface air temperature of the Northern Hemisphere over the period 1861-1989, where "warming and cooling corresponded to short (~10 yr) and prolonged (~11.5 yr) solar cycles, respectively." They then cite the work of Zherebtsov and Kovalenko (2000), who they say established a high correlation (r = 0.97) between "the average power of the solar activity cycle and the surface air temperature in the Baikal region averaged over the solar cycle." These two findings, they contend, "leave little room for the anthropogenic impact on the Earth's climate." In addition, they note that "solar variations naturally explain global cooling observed in 1950-1970, which cannot be understood from the standpoint of the greenhouse effect, since CO_2 was intensely released into the atmosphere in this period," citing in support of this statement the work of Dergachev and Raspopov (2000).

Bashkirtsev and Mashnich conducted their own wavelet-spectra and correlation analyses of Irkutsk and world air temperatures and Wolf number data for the period 1882-2000, finding periodicities of 22 (Hale cycle) and 52 (Fritz cycle) years and reporting that "the temperature response of the air lags behind the sunspot cycles by approximately 3 years in Irkutsk and by 2 years over the entire globe."

Noting that one could thus expect the upper envelope of sunspot cycles to reproduce the global temperature trend, they created such a plot and found that such is indeed the case. As they describe their results, "the lowest temperatures in the early 1900s correspond to the lowest solar activity (weak cycle 14), the further temperature rise follows the increase in solar activity; the decrease in solar activity in cycle 20 is accompanied by the temperature fall [from 1950-1970], and the subsequent growth of solar activity in cycles 21 and 22 entails the temperature rise [of the last quarter century]."

Bashkirtsev and Mashnich say "it has become clear that the current sunspot cycle (cycle 23) is weaker than the preceding cycles (21 and 22)," and that "solar activity during the subsequent cycles (24 and 25) will be, as expected, even lower," noting that "according to Chistyakov (1996, 2000), the minimum of the secular cycle of solar activity will fall on cycle 25 (2021-2026), which will result in the minimum global temperature of the surface air (according to our prediction)." Only time will tell if such predictions will prove correct.

Turning our attention back toward the past, but staying in the Asian subarctic, Vaganov *et al*. (2000) utilized tree-ring width as a proxy for temperature to examine temperature variations in this region over the past 600 years. According to a graph of the authors' data, temperatures in the Asian subarctic exhibited a small positive trend from the start of the record until about 1750. Thereafter, a severe cooling trend ensued, followed by a 130-year warming trend from about 1820 through 1950, after which temperatures fell once again. In considering the entire record, the authors state that the amplitude of twentieth century warming "does not go beyond the limits of reconstructed natural temperature fluctuations in the Holocene subarctic zone."

In attempting to determine the cause or causes of the temperature fluctuations, the authors report finding a significant correlation with solar radiation and volcanic activity over the entire 600-year period (R = 0.32 for solar radiation, R = -0.41 for volcanic activity), which correlation *improved* over the shorter interval of the industrial period—1800 to 1990—(R = 0.68 for solar radiation, R = -0.59 for volcanic activity).

It is interesting to note that in this region of the world, where climate models predict large increases in temperature as a result of the historical rise in the air's CO_2 concentration, real-world data show a *cooling* trend since around 1940, when the greenhouse effect of CO_2 should have been most prevalent. And, where warming does exist in the record (between about 1820 and 1940), much of it correlates with changes in solar irradiance and volcanic activity—two factors free of anthropogenic influence.

In two additional paleoclimate studies from the continental interior of Russia's Siberia, Kalugin *et al*. (2005) and Kalugin *et al*. (2007) analyzed sediment cores from Lake Teletskoye in the Altai Mountains

(51°42.90'N, 87°39.50'E) to produce multi-proxy climate records spanning the past 800 years. Analyses of the multi-proxy records revealed several distinct climatic periods over the past eight centuries. With respect to temperature, the regional climate was relatively warm with high terrestrial productivity from AD 1210 to 1380. Thereafter, temperatures cooled, reaching peak deterioration between 1660 and 1700, which time period, in the words of Kalugin *et al*. (2005), "corresponds to the age range of the well-known Maunder Minimum (1645-1715)" of solar sunspot activity.

Moving to Japan, an uninterrupted 1,100-year history of March mean temperature at Kyoto was developed by Aono and Kazui (2008), who used phenological data on the times of full-flowering of cherry trees (*Prunus jamasakura*) acquired from old diaries and chronicles written at Kyoto. Upon calibration with instrumental temperature measurements obtained over the period 1881-2005, the results were compared with the sunspot number history developed by Solanki *et al*. (2004).

The results of the study suggest "the existence of four cold periods, 1330-1350, 1520-1550, 1670-1700, and 1825-1830, during which periods the estimated March mean temperature was 4-5°C, about 3-4°C lower than the present normal temperature," and that "these cold periods coincided with the less extreme periods [of solar activity], known as the Wolf, Spoerer, Maunder, and Dalton minima, in the long-term solar variation cycle, which has a periodicity of 150-250 years." In addition, they report that "a time lag of about 15 years was detected in the climatic temperature response to short-term solar variation."

Also in Japan, Kitagawa and Matsumoto (1995) analyzed δ^{13}C variations of Japanese cedars growing on Yakushima Island (30°20'N, 130°30'E), in an effort to reconstruct a high-resolution proxy temperature record over the past two thousand years. In addition, they applied spectral analysis to the δ^{13}C time series in an effort to learn if any significant periodicities were present in the record.

Results indicated significant decadal to centennial-scale variability throughout the record, with temperatures fluctuating by about 5°C across the series. Most notable among the fluctuations were multi-century warm and cold epochs. Between AD 700-1200, for example, there was about a 1°C rise in average temperature (pre-1850 average), which the authors state "appears to be related to the 'Medieval Warm Period'." In contrast, temperatures were about 2°C below the long-term pre-1850 average during the multi-century Little Ice Age that occurred between AD 1580 and 1700. Kitagawa and Matsumoto also report finding significant temperature periodicities of 187, 89, 70, 55, and 44 years. Noting that the 187-year cycle closely corresponds to the well-known Suess cycle of solar activity and that the 89-year cycle compares well with the Gleissberg solar cycle, they conclude that their findings provide further support for a sun-climate relationship.

Ten years later, Cini Castagnoli *et al*. (2005) re-examined the Kitagawa and Matsumoto dataset for evidence of recurring cycles using Singular Spectrum Analysis and Wavelet Transform, after which it was compared with a 300-year record of sunspots. Results of the newer analyses showed a common 11-year oscillation in phase with the Schwabe cycle of solar activity, plus a second multi-decadal oscillation (of about 87 years for the tree-ring series) in phase with the amplitude modulation of the sunspot number series over the plast 300 years, which led this second group of authors to conclude that the overall phase agreement between the climate reconstruction and variation in the sunspot number series "favors the hypothesis that the [multi-decadal] oscillation" revealed in the record "is connected to the solar activity."

Turning to China, there have been several studies documenting a solar influence on temperature from several proxy temperature indicators. Beginning with stalagmite-derived proxies, Paulsen *et al*. (2003) utilized high-resolution records of δ^{13}C and δ^{18}O from a stalagmite in Buddha Cave, central China [33°40'N, 109°05'E], to infer changes in climate there over the past 1,270 years. Among the climatic episodes evident in the authors' data were "those corresponding to the Medieval Warm Period, Little Ice Age and 20th-century warming, lending support to the global extent of these events." The authors' data also revealed a number of other cycles superimposed on these major millennial-scale temperature cycles, which they attributed to cyclical solar and lunar phenomena.

In a separate study, Tan *et al*. (2004) established an annual layer thickness chronology for a stalagmite from Beijing Shihua Cave and reconstructed a 2,650-year (BC 665-AD 1985) warm season (MJJA: May, June, July, August) temperature record for Beijing by calibrating the thickness chronology with the observed MJJA temperature record (Tan *et al*., 2003). Results of the analysis showed that the warm season temperature record was "consistent with oscillations in total solar irradiance inferred from cosmogenic

^{10}Be and ^{14}C," and that it also "is remarkably consistent with Northern Atlantic drift ice cycles that were identified to be controlled by the sun through the entire Holocene [Bond *et al*., 2001]." Going backwards in time, both records clearly depict the start of the Current Warm Period, the prior Little Ice Age, the Medieval Warm Period, the Dark Ages Cold Period, the Roman Warm Period, and the cold climate at the start of both records.

The authors conclude that "the synchronism between the two independent sun-linked climate records therefore suggests that the sun may directly couple hemispherical climate changes on centennial to millennial scales." It stands to reason that the cyclical nature of the millennial-scale oscillation of climate evident in both climate records suggests there is no need to invoke rising atmospheric CO_2 concentrations as a cause of the Current Warm Period.

Working with a stalagmite found in another China cave, Wanxiang Cave (33°19'N, 105°00'E), Zhang *et al*. (2008) developed a δ^{18}O record with an average resolution of 2.5 years covering the period AD 190 to 2003. According to the 17 authors of this study, the δ^{18}O record "exhibits a series of centennial to multi-centennial fluctuations broadly similar to those documented in Northern Hemisphere temperature reconstructions, including the Current Warm Period, Little Ice Age, Medieval Warm Period and Dark Age Cold Period."

In addition, Zhang *et al*. state that it "correlates with solar variability, Northern Hemisphere and Chinese temperature, Alpine glacial retreat, and Chinese cultural changes." And since none of the last four phenomena can influence the first one, solar variability appears to have driven the variations in the other factors mentioned. In a commentary that accompanied Zhang *et al*.'s article, Kerr (2008) quotes other researchers calling the Zhang *et al*. record "amazing," "fabulous," and "phenomenal," and it "provides the strongest evidence yet for a link among sun, climate, and culture."

Still in China, we turn next to the study of Hong *et al*. (2000), who developed a 6,000-year high-resolution δ^{18}O record from plant cellulose deposited in a peat bog in the Jilin Province of China (42° 20' N, 126° 22' E), from which they inferred the temperature history of that location over the past six millennia. They then compared this record with a previously derived δ^{14}C tree-ring record that is representative of the intensity of solar activity over this period.

Results indicated the study area was relatively cold between 4000 and 2600 BC. Then it warmed fairly continuously until it reached the maximum warmth of the record about 1600 BC, after which it fluctuated about this warm mean for approximately 2,000 years. Starting about AD 350, however, the climate began to cool, with the most dramatic cold associated with three temperature minima centered at about AD 1550, 1650, and 1750, corresponding to the most severe cold of the Little Ice Age.

Of particular note is the authors' finding of "an obvious warm period represented by the high δ^{18}O from around AD 1100 to 1200 which may correspond to the Medieval Warm Epoch of Europe." They also report that "at that time, the northern boundary of the cultivation of citrus tree (*Citrus reticulata Blanco*) and *Boehmeria nivea* (a perennial herb), both subtropical and thermophilous plants, moved gradually into the northern part of China, and it has been estimated that the annual mean temperature was 0.9-1.0°C higher than at present."

Hong *et al*. also note "there is a remarkable, nearly one to one, correspondence between the changes of atmospheric δ^{14}C and the variation in δ^{18}O of the peat cellulose," which led them to conclude that the temperature history of the past 6,000 years at the site of their study has been "forced mainly by solar variability."

In another study, 18 radiocarbon-dated aeolian and paleosol profiles within a 1,500-km-long belt along the arid to semi-arid transition zone of north-central China were analyzed by Porter and Weijian (2006) to determine variations in the extent and strength of the East Asian summer monsoon throughout the Holocene.

The dated paleosols and peat layers, in the words of Porter and Weijian, "represent intervals when the zone was dominated by a mild, moist summer monsoon climate that favored pedogenesis and peat accumulation," while "brief intervals of enhanced aeolian activity that resulted in the deposition of loess and aeolian sand were times when strengthened winter monsoon conditions produced a colder, drier climate." They also report that the climatic variations they discovered "correlate closely with variations in North Atlantic drift-ice tracers that represent episodic advection of drift ice and cold polar surface water southward and eastward into warmer subpolar water."

The researchers state that "the correspondence of these records over the full span of Holocene time implies a close relationship between North Atlantic climate and the monsoon climate of central China."

They also state that the most recent of the episodic cold periods, which they identify as the Little Ice Age, began about AD 1370, while the preceding cold period ended somewhere in the vicinity of AD 810. Consequently, their work implies the existence of a medieval warm period that began some time after AD 810 and ended some time before AD 1370. In addition, their relating of this millennial-scale climate cycle to the similar-scale drift-ice cycle of Bond *et al.* (2001) implies they accept solar forcing as the most likely cause of the alternating multi-century mild/moist and cold/dry periods of North-Central China. As a result, Porter and Weijian's work helps to establish the global extent of the Medieval Warm Period, as well as its likely solar origin.

Much more evidence of a solar-climate link has been obtained from the Tibetan Plateau in China. Wang *et al*. (2002), for example, studied changes in δ^{18}O and NO_3^- in an ice core retrieved from the Guliya Ice Cap (35°17'N, 81°29'E) there, comparing the results they obtained with ancillary data from Greenland and Antarctica. Two cold events—a weak one around 9.6-9.2 thousand years ago (ka) and a strong one universally referred to as the "8.2 ka cold event"—were identified in the Guliya ice core record. The authors report that these events occurred "nearly simultaneously with two ice-rafted episodes in the North Atlantic Ocean." They additionally report that both events occurred during periods of weakened solar activity.

Remarking that evidence for the 8.2 ka cold event "occurs in glacial and lacustrine deposits from different areas," the authors say this evidence "suggests that the influence of this cold event may have been global." They also say that "comprehensive analyses indicate that the weakening of solar insolation might have been the external cause of the '8.2 ka cold event'," and that "the cause of the cold event around 9.6-9.2 ka was also possibly related to the weaker solar activity." The authors thus conclude that all of these things considered together imply that "millennial-scale climatic cyclicity might exist in the Tibetan Plateau as well as in the North Atlantic."

In a contemporaneous paper enlarging this thesis, Xu *et al*. (2002) studied plant cellulose δ^{18}O variations in cores retrieved from peat deposits west of Hongyuan County at the northeastern edge of the Qinghai-Tibetan Plateau (32° 46'N, 102° 30'E). Based on their analysis, the authors report finding the existence of three consistently cold events that were centered at approximately 500, 700, and 900 AD, during what is sometimes referred to as the Dark Ages Cold Period. Then, from 1100-1300 AD, they report "the δ^{18}O of Hongyuan peat cellulose increased, consistent with that of Jinchuan peat cellulose and corresponding to the 'Medieval Warm Period'." Finally, they note that "the periods 1370-1400 AD, 1550-1610 AD, [and] 1780-1880 AD recorded three cold events, corresponding to the 'Little Ice Age'."

Regarding the origins of these climatic fluctuations, power spectrum analyses of their data revealed periodicities of 79, 88, and 123-127 years, "suggesting," in the words of the authors, "that the main driving force of Hongyuan climate change is from solar activities." In a subsequent paper by the same authors, Xu *et al.* (2006) compared the Hongyuan temperature variations with solar activity inferred from atmospheric ^{14}C and ^{10}Be concentrations measured in a South Pole ice core, after which they performed cross-spectral analyses to determine the relationship between temperature and solar variability, comparing their results with similar results obtained other researchers around the world. What did they learn this time?

Xu *et al*. (2006) report that "during the past 6000 years, temperature variations in China exhibit high synchrony among different regions, and importantly, are in-phase with those discovered in other regions in the northern hemisphere." They also say that their "comparisons between temperature variations and solar activities indicate that both temperature trends on centennial/millennial timescales and climatic events are related to solar variability."

The researchers' final conclusion was that "quasi-100-year fluctuations of solar activity may be the primary driving force of temperature during the past 6000 years in China." And since their data indicate that peak Medieval Warm Period temperatures were higher than those of the recent past, it is not unreasonable to assume that the planet's recent warmth may have been solar-induced as well.

Still in the northeast edge of the Tibetan Plateau, two years later Tan *et al*. (2008) developed a precipitation history of the Longxi area of the plateau's northeast margin since AD 960 based on an analysis of Chinese historical records, after which they compared the result with the same-period Northern Hemisphere temperature record and contemporaneous atmospheric ^{14}C and ^{10}Be histories.

In their words, Tan *et al*. discovered that "high precipitation of Longxi corresponds to high temperature of the Northern Hemisphere, and low precipitation of Longxi corresponds to low temperature of the Northern Hemisphere." Consequently, their precipitation record may be used to infer a Medieval Warm Period that stretched from approximately AD 960 to 1230, with temperature peaks in the vicinity of AD 1000 and 1215 that clearly exceeded the twentieth century peak temperature of the Current Warm Period. They also found "good coherences among the precipitation variations of Longxi and variations of atmospheric ^{14}C concentration, the averaged ^{10}Be record and the reconstructed solar modulation record," which findings harmonize, in their words, with "numerous studies [that] show that solar activity is the main force that drives regional climate changes in the Holocene," in support of which statement they attach 22 other scientific references.

The researchers ultimately concluded that the "synchronous variations between Longxi precipitation and Northern Hemisphere temperature may be ascribed to solar activity," which apparently produced a Medieval Warm Period that was both longer and stronger than what has been experienced to date during the Current Warm Period in the northeast margin of the Tibetan Plateau.

Lastly, Xu *et al*. (2008) studied decadal-scale temperature variations of the past six centuries derived from four high-resolution temperature indicators—the δ^{18}O and δ^{13}C of bulk carbonate, total carbonate content, and the detrended δ^{15}N of organic matter—which they extracted from Lake Qinghai (36°32'-37°15'N, 99°36'-100°47'E) on the northeast Qinghai-Tibet plateau, comparing the resultant variations with proxy temperature indices derived from nearby tree rings and reconstructed solar activity. Results of the analysis showed that "there are four obvious cold intervals during the past 600 years at Lake Qinghai, namely 1430-1470, 1650-1715, 1770-1820 and 1920-1940," and that "these obvious cold intervals are also synchronous with the minimums of the sunspot numbers during the past 600 years," namely, "the Sporer, the Maunder, and the Dalton minimums," which facts strongly suggest, in their words, "that solar activities may dominate temperature variations on decadal scales at the northeastern Qinghai-Tibet plateau."

If the development of the significant cold of the worldwide Little Ice Age was driven by a concomitant change in some type of solar activity, which seems fairly well proven by a wealth of real-world data, it logically follows that the global warming of the twentieth century was driven primarily by the reversal of that change in solar activity, and not by the historical rise in the air's CO_2 content. However, as also noted by Xu *et al*., how small perturbations of solar activity have led "to the observed global warming, what is the mechanism behind it, etc., are still open questions."

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempasia.php.

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5.3.6. Europe

We begin our review of the sun's influence on Europe's temperatures with the study of Holzhauser *et al*. (2005), who presented high-resolution records of variations in glacier size in the Swiss Alps together with lake-level fluctuations in the Jura mountains, the northern French Pre-Alps, and the Swiss Plateau in developing a 3,500-year climate history of west-central Europe, beginning with an in-depth analysis of the Great Aletsch glacier, which is the largest of all glaciers located in the European Alps.

Near the beginning of the time period studied, the three researchers report that "during the late Bronze Age Optimum from 1350 to 1250 BC, the Great Aletsch glacier was approximately 1000 m shorter than it is today," noting that "the period from 1450 to 1250 BC has been recognized as a warm-dry phase in other Alpine and Northern Hemisphere proxies (Tinner *et al*., 2003)." Then, after an intervening unnamed cold-wet phase, when the glacier grew in both mass and length, they say that "during the Iron/Roman Age Optimum between c. 200 BC and AD 50," which is perhaps better known as the Roman Warm Period, the glacier again retreated and "reached today's extent or was even somewhat shorter than today." Next came the Dark Ages Cold Period, which they say was followed by "the Medieval Warm Period, from around AD 800 to the onset of the Little Ice Age around AD 1300," which latter cold-wet phase was "characterized by three successive [glacier length] peaks: a first maximum after 1369 (in the late 1370s), a second between 1670 and 1680, and a third at 1859/60," following which the glacier began its latest and still-ongoing recession in 1865. In addition, they state that written documents from the fifteenth century AD indicate that at some time during that hundred-year interval "the glacier was of a size similar to that of the 1930s," which latter period in many parts of the world was as warm as, or even warmer than, it is today. Data pertaining to the Gorner glacier (the second largest of the Swiss Alps) and the Lower Grindelwald glacier of the Bernese Alps tell much the same story, as Holzhauser *et al*. report that these glaciers and the Great Aletsch glacier "experienced nearly synchronous advances" throughout the study period.

With respect to what was responsible for the millennial-scale climatic oscillation that produced the alternating periods of cold-wet and warm-dry conditions that fostered the similarly paced cycle of glacier growth and retreat, the Swiss and French scientists report that "glacier maximums coincided with radiocarbon peaks, i.e., periods of weaker solar activity," which in their estimation "suggests a possible solar origin of the climate oscillations punctuating the last 3500 years in west-central Europe, in agreement with previous studies (Denton and Karlén, 1973; Magny, 1993; van Geel *et al*., 1996; Bond *et al*., 2001)." And to underscore that point, they conclude their paper by stating that "a comparison between the fluctuations of the Great Aletsch glacier and the variations in the atmospheric residual ^{14}C records supports the hypothesis that variations in solar activity were a major forcing factor of climate oscillations in west-central Europe during the late Holocene."

In another study of paleoclimate in western Europe, Mauquoy *et al*. (2002a) extracted peat monoliths from ombrotrophic mires at Lille Vildmose, Denmark (56°50'N, 10°15'E) and Walton Moss, UK (54°59'N, 02°46'W), which sites, being separated by about 800 km, "offer the possibility of detecting supraregional changes in climate." From these monoliths, vegetative macrofossils were extracted at contiguous 1-cm intervals and examined using light microscopy. Where increases in the abundances of *Sphagnum tenellum* and *Sphagnum cuspidatum* were found, a closely spaced series of ^{14}C AMS-dated samples immediately preceding and following each increase was used to "wiggle-match" date them (van Geel and Mook, 1989), thereby enabling comparison of the climate-induced shifts with the history of ^{14}C production during the Holocene.

Results indicated the existence of a climatic deterioration that marked the beginning of a period of inferred cool, wet conditions that correspond fairly closely in time with the Wolf, Sporer, and Maunder Minima of solar activity, as manifest in contemporary δ^{14}C data. The authors report "these time intervals correspond to periods of peak cooling in 1000-year Northern Hemisphere climate records," adding to the "increasing body of evidence" that "variations in solar activity may well have been an important factor driving Holocene climate change."

Two years later, Mauquoy *et al*. (2004) reviewed the principles of ^{14}C wiggle-match dating, its limitations, and the insights it has provided about the timing and possible causes of climate change during the Holocene. Based upon their review, the authors stated that "analyses of microfossils and macrofossils from raised peat bogs by Kilian *et al*. (1995), van Geel *et al*. (1996), Speranza *et al*. (2000), Speranza (2000) and Mauquoy *et al*. (2002a, 2002b) have shown that climatic deteriorations [to cooler and wetter conditions] occurred during periods of transition from low to high delta ^{14}C (the relative deviation of the measured ^{14}C activity from the standard after correction for isotope fractionation and radioactive decay; Stuiver and Polach, 1977)." This close correspondence, in the words of the authors, again suggests that "changes in solar activity may well have driven these changes during the Bronze Age/Iron Age transition around c. 850 cal. BC (discussed in detail by van Geel *et al*., 1996, 1998, 1999, 2000) and the 'Little Ice Age' series of palaeoclimatic changes."

Working with a marine sediment core retrieved from the southern Norwegian continental margin, Berstad *et al*. (2003) reconstructed sea surface temperatures (SSTs) from δ^{18}O data derived from the remains of the planktonic foraminifera species *Neogloboquadrina pachyderma* (summer temperatures) and *Globigerina bulloides* (spring temperatures). Among other things, the authors' work depicted a clear connection between the cold temperatures of the Little Ice Age and the reduced solar activity of the concomitant Maunder and Sporer solar minima, as well as between the warm

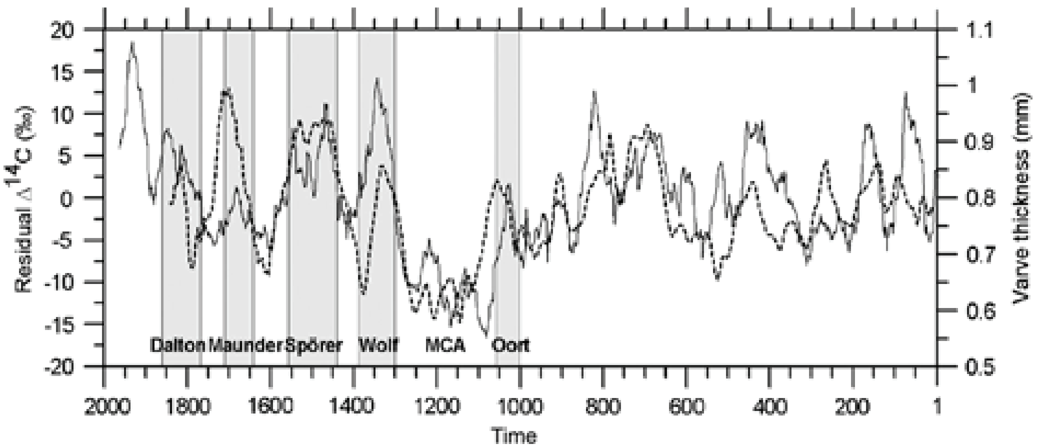

Figure 5.3.6. Residual $\Delta^{14}C$ data (dashed line) and varve thickness (smooth line) vs. time, specifically highlighting the Oort, Wolf, Sporer, Maunder and Dalton solar activity minima, as well as the "Medieval Climate Anomaly (also referred to as Medieval Warm Period)," during the contemporaneous "solar activity maxima in the Middle Ages." Adapted from Haltia-Hovi *et al.* (2007).

temperatures of the most recent 70 years and the enhanced solar activity of the concomitant Modern solar maximum, which they clearly implied in their paper is a causative connection, as is also implied by the recent sunspot number reconstruction of Usoskin *et al*. (2003).

Nearby in Finland, Haltia-Hovi *et al*. (2007) extracted sediment cores from beneath the 0.7-m-thick ice platform on Lake Lehmilampi (63°37'N, 29°06'E) in North Karelia, eastern Finland, after which they identified and counted the approximately 2,000 annual varves contained in the cores and measured their individual thicknesses and mineral and organic matter contents. These climate-related data were then compared with residual $\Delta^{14}C$ data derived from tree rings, which serve as a proxy for solar activity.

According to Haltia-Hovi *et al*., their "comparison of varve parameters (varve thickness, mineral and organic matter accumulation) and the activity of the sun, as reflected in residual $\Delta^{14}C$ [data] appears to coincide remarkably well in Lake Lehmilampi during the last 2000 years, suggesting solar forcing of the climate," as depicted in Figure 5.3.6 for the case of varve thickness. What is more, the low deposition rate of mineral matter in Lake Lehmilampi in AD 1060-1280 "possibly implies mild winters with a short ice cover period during that time with minor snow accumulation interrupted by thawing periods." Likewise, they say that the low accumulation of organic matter during this period "suggests a long open water season and a high decomposition rate of organic matter." Consequently, since the AD 1060-1280 period shows the lowest levels of both mineral and organic matter content, and since "the thinnest varves of the last 2000 years were deposited during [the] solar activity maxima in the Middle Ages," it is difficult not to conclude that that period was likely the warmest of the past two millennia in the part of the world studied by the three scientists.

Hanna *et al*. (2004) analyzed several climatic variables over the past century in Iceland in an effort to determine if there is "possible evidence of recent climatic changes" in that cold island nation. Results indicated that for the period 1923-2002, no trend was found in either annual or monthly sunshine data. Similar results were reported for annual and monthly pressure data, which exhibited semi-decadal oscillations throughout the 1820-2002 period but no significant upward or downward trend. Precipitation, on the other hand, appears to have increased slightly, although the authors question the veracity of the trend, citing a number of biases that have potentially corrupted the database.

With respect to temperature, however, the authors indicate that of the handful of locations they examined for this variable, all stations experienced a net warming since the mid-1800s. The warming, however, was not linear over the entire time period. Rather, temperatures rose from their coldest levels in the mid-1800s to their warmest levels in the 1930s, whereupon they remained fairly constant for approximately three decades. Then came a period of rapid cooling, which ultimately gave way to the warming of the 1980s and 1990s. However, it is important to note that the warming of the past two decades has not resulted in temperatures rising above those observed in the 1930s. In this point the authors are particularly clear, stating emphatically that "the 1990s was definitely *not* the warmest decade of the 20th century in Iceland, in contrast to the Northern Hemisphere land average." In fact, a linear trend fit to the post-1930 data would indicate an overall temperature decrease since that time.

As for what may be responsible for the various trends evident in the data, Hanna *et al*. note the likely influence of the sun on temperature and pressure values in consequence of their finding a significant correlation between 11-year running temperature means and sunspot numbers, plus the presence of a 12-year peak in their spectral analysis of the pressure data, which they say is "suggestive of solar activity."

In another study, Mangini *et al*. (2005) develop a highly resolved 2,000-year $\delta^{18}O$ proxy record of temperature obtained from a stalagmite recovered from Spannagel Cave in the Central Alps of Austria. Results indicated that the lowest temperatures of the past two millennia occurred during the Little Ice Age (AD 1400-1850), while the highest temperatures were found in the Medieval Warm Period (MWP: AD 800-1300). Furthermore, Mangini *et al.* say that the highest temperatures of the MWP were "slightly higher than those of the top section of the stalagmite (1950 AD) and higher than the present-day temperature." At three different points during the MWP, their data indicate temperature spikes in excess of 1°C above present (1995-1998) temperatures.

Mangini *et al*. additionally report that their temperature reconstruction compares well with reconstructions developed from Greenland ice cores (Muller and Gordon, 2000), Bermuda Rise ocean-bottom sediments (Keigwin, 1996), and glacier tongue advances and retreats in the Alps (Holzhauser, 1997; Wanner *et al*., 2000), as well as with the Northern Hemispheric temperature reconstruction of Moberg *et al*. (2005). Considered together, they say these several datasets "indicate that the MWP was a climatically distinct period in the Northern Hemisphere," emphasizing that "this conclusion is in strong contradiction to the temperature reconstruction by the IPCC, which only sees the last 100 years as a period of increased temperature during the last 2000 years."

In a second severe blow to the theory of CO_2-induced global warming, Mangini *et al*. found "a high correlation between $\delta^{18}O$ and $\delta^{14}C$, that reflects the amount of radiocarbon in the upper atmosphere," and they note that this correlation "suggests that solar variability was a major driver of climate in Central Europe during the past 2 millennia." In this regard, they report that "the maxima of $\delta^{18}O$ coincide with solar minima (Dalton, Maunder, Sporer, Wolf, as well as with minima at around AD 700, 500 and 300)," and that "the coldest period between 1688 and 1698 coincided with the Maunder Minimum." Also, in a linear-model analysis of the percent of variance of their full temperature reconstruction that is individually explained by solar and CO_2 forcing, they found that the impact of the sun was fully 279 times greater than that of the air's CO_2 concentration, noting that "the flat evolution of CO_2 during the first 19 centuries yields almost vanishing correlation coefficients with the temperature reconstructions."

Two years later, Mangini *et al*. (2007) updated the 2005 study with additional data after which they compared it with the Hematite-Stained-Grain (HSG) history of ice-rafted debris in North Atlantic Ocean sediments developed by Bond *et al*. (2001), finding an undeniably good correspondence between the peaks and valleys of their $\delta^{18}O$ curve and the HSG curve. The significance of such correspondence is evidenced by the fact that Bond *et al*. reported 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 solar minimum."

Other researchers have found similar periodicities in their climate proxies. Turner *et al*. (2008), for example, found an ~1500 year cycle in a climate history reconstructed from sediment cores extracted from two crater lake basins in central Turkey, which they indicate "may be linked with large-scale climate forcing" such as that found in the North Atlantic by Bond *et al*. (1997, 2001). McDermott *et al*. (2001) found evidence of millennial-scale climate cycles in a $\delta^{18}O$ record from a stalagmite in southwestern Ireland, as did Sbaffi *et al*. (2004) from two deep-sea sediment cores recovered from the Tyrrhenian Sea, which latter proxy corresponded well with the North Atlantic solar-driven cycles of Bond *et al*. (1997).

Nearby in the Mediterranean Sea, Cini Castagnoli *et al*. (2002) searched for possible solar-induced variations in the $\delta^{13}C$ record of the foraminifera *Globigerinoides rubber* obtained from a sea core located in the Gallipoli terrace of the Gulf of Taranto (39°45'53"N, 17°53'33"E, depth of 178 m) over the past 1,400 years. Starting at the beginning of the 1,400-year record, the $\delta^{13}C$ values increased from about 0.4 per mil around 600 A.D. to a value of 0.8 per mil by 900 A.D. Thereafter, the $\delta^{13}C$ record remained relatively constant until about 1800, when it rose another 0.2 per mil to its present-day value of around 1.0 per mil.

Using statistical procedures, the authors were able to identify three important cyclical components in their record, with periods of approximately 11.3, 100, and 200 years. Comparison of both the raw $\delta^{13}C$ and component data with the historical aurorae and sunspot time series, respectively, revealed that the records are "associable in phase" and "disclose a statistically significant imprint of the solar activity in a climate record." Three years later, Cini Castagnoli *et al*. (2005) extended the $\delta^{13}C$ temperature proxy from the Gulf of Taranto an additional 600 years, reporting an overall phase agreement between the climate reconstruction and variations in the sunspot number series that "favors the hypothesis that the [multi-decadal] oscillation revealed in $\delta^{13}C$ is connected to the solar activity."

Finally, we report on the study of Desprat *et al*. (2003), who studied the climatic variability of the last three millennia in northwest Iberia via a high-resolution pollen analysis of a sediment core retrieved from the central axis of the Ria de Vigo in the south of Galicia (42°14.07'N, 8°47.37'W). According to the authors, over the past 3,000 years there was "an alternation of three relatively cold periods with three relatively warm episodes." In order of their occurrence, these periods are described by the authors as the "first cold phase of the Subatlantic period (975-250 BC)," which was "followed by the Roman Warm Period (250 BC-450 AD)," which was followed by "a successive cold period (450-950 AD), the Dark Ages," which "was terminated by the onset of the Medieval Warm Period (950-1400 AD)," which was followed by "the Little Ice Age (1400-1850 AD), including the Maunder Minimum (at around 1700 AD)," which "was succeeded by the recent warming (1850 AD to the present)." Based upon this "millennial-scale climatic cyclicity over the last 3000 years," which parallels "global climatic changes recorded in North Atlantic marine records (Bond *et al*., 1997; Bianchi and McCave, 1999; Chapman and Shackelton, 2000)," Desprat *et al*. conclude that "solar radiative budget and oceanic circulation seem to be the main mechanisms forcing this cyclicity in NW Iberia."

In conclusion, paleoclimatic studies from Europe provide more evidence is for the global reality of the solar-induced millennial-scale oscillation of temperatures pervading both glacial and interglacial periods. The Current Warm Period can consequently be viewed as the most recent manifestation of this recurring phenomenon and unrelated to the concurrent historical increase in the air's CO_2 content.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempeurope.php.

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5.3.7. Other

Rounding out our examination of the influence of the sun on earth's temperatures, we begin with the review study of Van Geel *et al*. (1999), who examined what is known about the relationship between variations in the abundances of the cosmogenic isotopes ^{14}C and ^{10}Be and millennial-scale climate oscillations during the Holocene and portions of the last great ice age. As they describe it, "there is mounting evidence suggesting that the variation in solar activity is a cause for millennial-scale climate change," which is known to operate independently of the glacial-interglacial cycles that are forced by variations in the earth's orbit about the sun. Continuing, they add that "accepting the idea of solar forcing of Holocene and Glacial climatic shifts has major implications for our view of present and future climate," for it implies, as they note, that "the climate system is far more sensitive to small variations in solar activity than generally believed" and that "it could mean that the global temperature fluctuations during the last decades are partly, or completely explained by small changes in solar radiation." These observations, of course, call into question the conventional wisdom of attributing the global warming of the past century or so to the ongoing rise in the air's CO_2 content.

In a study published the following year, Tyson *et al*. (2000) obtained a quasi-decadal-resolution record of oxygen and carbon-stable isotope data from a well-dated stalagmite recovered from Cold Air Cave in the Makapansgat Valley, 30 km southwest of Pietersburg, South Africa, which they augmented with temperature data reconstructed from color variations in banded growth-layer laminations of the stalagmite that were derived from a relationship calibrated against actual air temperatures obtained from a surrounding 49-station climatological network over the period 1981-1995, which had a correlation of +0.78 that was significant at the 99 percent confidence level.

According to the authors, both the Little Ice Age (prevailing from about AD 1300 to 1800) and the Medieval Warm Period (prevailing from before AD 1000 to around 1300) were found to be distinctive features of the climate of the last millennium. Relative to the period 1961-1990, in fact, the Little Ice Age, which "was a widespread event in South Africa specifically and southern Africa generally," was characterized by a mean annual temperature depression of about 1°C at its coolest point. The Medieval Warm Period, on the other hand, was as much as 3-4°C warmer at its warmest point. The researchers also note that the coolest point of the Little Ice Age corresponded in time with the Maunder Minimum of sunspot activity and that the Medieval Warm Period corresponded with the Medieval Maximum in solar activity.

In a study demonstrating a solar-climate link on shorter decadal to centennial time scales, Domack *et al*. (2001) examined ocean sediment cores obtained from the Palmer Deep on the inner continental shelf of the western Antarctic Peninsula (64° 51.71' S, 64° 12.47' W) to produce a high-resolution proxy temperature history of that area spanning the past 13,000 years. Results indicated the presence of five prominent palaeoenvironmental intervals over the past 14,000 years: (1) a "Neoglacial" cool period beginning 3,360 years ago and continuing to the present, (2) a mid-Holocene climatic optimum from 9,070 to 3,360 years ago, (3) a cool period beginning 11,460 years ago and ending at 9,070 years ago, (4) a warm period from 13,180 to 11,460 years ago, and (5) cold glacial conditions prior to 13,180 years ago. Spectral analyses of the data revealed that superimposed upon these broad climatic intervals were decadal and centennial-scale temperature cycles. Throughout the current Neoglacial period, they report finding "very significant" (above the 99 percent confidence level) peaks, or oscillations, that occurred at intervals of 400, 190, 122, 85, and 70 years, which they suggest are perhaps driven by solar variability.

Moving upward to the warmer ocean waters off the Cook Islands, South Pacific Ocean, Dima *et al*. (2005) performed Singular Spectrum Analysis on a Rarotonga coral-based sea surface temperature (SST) reconstruction in an effort to determine the dominant periods of multi-decadal variability in the series over the period 1727-1996. Results of the analysis revealed two dominant multi-decadal cycles, with periods of about 25 and 80 years. These modes of variability were determined to be similar to multi-decadal modes found in the global SST field of Kaplan *et al*. (1998) for the period 1856-1996. The ~25-year cycle was found to be associated with the well-known Pacific Decadal Oscillation, whereas the ~80-year cycle was determined to be "almost identical" to a pattern of solar forcing found by Lohmann *et al*. (2004), which, according to Dima *et al*., "points to a possible solar origin" of this mode of SST variability.

We conclude this brief review with the study of Bard and Frank (2006), who reviewed what is known, and unknown, about solar variability and its effects on earth's climate, focusing on the past few decades, the past few centuries, the entire Holocene, and orbital timescales. Of greatest interest to the present discussion are Bard and Frank's conclusions about sub-orbital time scales, i.e., the first three of their four major focal points. Within this context, as they say in the concluding section of their review, "it appears that solar fluctuations were involved in causing widespread but limited climatic changes, such as the Little Ice Age (AD 1500-1800) that followed the Medieval Warm Period (AD 900-1400)." Or as they say in the concluding sentence of their abstract, "the weight of evidence suggests that solar changes have contributed to small climate oscillations occurring on time scales of a few centuries, similar in type to the fluctuations classically described for the last millennium: The so-called Medieval Warm Period (AD 900-1400) followed on by the Little Ice Age (AD 1500-1800)."

In the words of Bard and Frank, "Bond *et al*. (1997, 2001) followed by Hu *et al*. (2003) proposed that variations of solar activity are responsible for quasi-periodic climatic and oceanographic fluctuations that follow cycles of about one to two millennia." As a result, they say that "the succession from the Medieval Warm Period to the Little Ice Age would thus represent the last [such] cycle," leading to the conclusion that "our present climate is in an ascending phase on its way to attaining a new warm optimum," due to some form of solar variability. In addition, they note that "a recent modeling study suggests that an apparent 1500-year cycle could arise from the superimposed influence of the 90 and 210 year solar cycles on the climate system, which is characterized by both nonlinear dynamics and long time scale memory effects (Braun *et al*. 2005)."

These studies demonstrate that the warming of the earth since the termination of the Little Ice Age is not unusual or different from other climate changes of the past millennium, when atmospheric CO_2 concentrations were stable, lower than at present, and obviously not responsible for the observed variations in temperature. This further suggests that the warming of the past century was not due to the contemporaneous historical increase in the air's CO_2 content.

Additional information on this topic, including reviews of newer publications as they become available, can be found at http://www.co2science.org/subject/s/solartempmisc.php.

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5.4. Precipitation

The IPCC claims to have found a link between CO_2 concentrations in the air and precipitation trends. In this section of our report, we show that solar variability offers a superior explanation of past trends in precipitation.

5.4.1. North America

We begin our review of the influence of the sun on North American precipitation with a study that examines the relationship between the sun and low-level clouds, considering the presence of low-level clouds to be correlated with precipitation. According to Kristjansson *et al*. (2002), solar irradiance "varies by about 0.1% over the 11-year solar cycle, which would appear to be too small to have an impact on climate." Nevertheless, they report that "persistent claims have been made of 11-year signals in various meteorological time series, e.g., sea surface temperature (White *et al*., 1997) and cloudiness over North America (Udelhofen and Cess, 2001)." Kristjansson *et al*. purposed to "re-evaluate the statistical relationship between low cloud cover and solar activity adding 6 years of ISCCP [International Satellite Cloud Climatology Project] data that were recently released."

For the period 1983-1999, the authors compared temporal trends of solar irradiance at the top of the atmosphere with low cloud cover derived from different sets of satellite-borne instruments that provided two measures of the latter parameter: full temporal coverage and daytime-only coverage. Results indicated that "solar irradiance correlates well with low cloud cover," with the significance level of the correlation being 98 percent for the case of full temporal coverage and 90 percent for the case of daytime-only coverage. As would be expected if the variations in cloud cover were driven by variations in solar irradiance, they also report that lagged correlations between the two parameters reveal a maximum correlation between solar irradiance and low cloud cover when the former leads the latter by one month for the full temporal coverage case and by four months for the daytime-only situation.

The authors' observation that "low clouds appear to be significantly inversely correlated with solar irradiance" compelled them to suggest a possible physical mechanism that could explain this phenomenon. Very briefly, this mechanism, in their words, "acts through UV [ultraviolet radiation] in the stratosphere affecting tropospheric planetary waves and hence the subtropical highs, modulated by an interaction between sea surface temperature [SST] and lower tropospheric static stability," which "relies on a positive feedback between changes in SST and low cloud cover changes of opposite sign, in the subtropics." Based on experimentally determined values of factors that enter into this scenario, they obtain a value for the amplitude of the variation in low cloud cover over a solar cycle that "is very close to the observed amplitude."

In pursuing other indirect means of ferreting out a solar influence on precipitation, several authors have examined lake level fluctuations, which are generally highly dependent on precipitation levels. Cumming *et al*. (2002), for example, studied a sediment core retrieved from Big Lake (51°40'N, 121°27'W) on the Cariboo Plateau of British Columbia, Canada, carefully dating it and deriving estimates of changes in precipitation-sensitive limnological variables (salinity and lake depth) from transfer functions based on modern distributions of diatom assemblages in 219 lakes from western Canada.

On the basis of observed changes in patterns of the floristic composition of diatoms over the past 5,500 years, the authors report that "alternating millennial-scale periods of high and low moisture availability were inferred, with *abrupt* [our italics] transitions in diatom communities occurring 4960, 3770, 2300 and 1140 cal. yrs. BP." They also indicate that "periods of inferred lower lake depth correspond closely to the timing of worldwide Holocene glacier expansions," and that the mean length of "the relatively stable intervals between the abrupt transitions ... is similar to the mean Holocene pacing