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Solar Variability and Climate Cycles

Introduction

The Intergovernmental Panel on Climate Change (IPCC) claims "most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations [italics in the original]" (IPCC, 2007-I, p. 10). The IPCC's authors even tell us they have decided there is a better-than-90-percent probability that their shared opinion is true. But as we demonstrated in Chapter 1, the general circulation models upon which the IPCC rests its case are notoriously unreliable. In Chapter 2 we documented feedback factors and forcings that the IPCC clearly overlooked. In Chapters 3 and 4 we showed that observations do not confirm the temperatures and weather trends the IPCC said should exist if its theory were true.

In this chapter we set out evidence in favor of an alternative theory of climate change that holds that variations in the sun's output and magnetic field, mediated by cosmic ray fluxes and changes in global cloud cover, play a larger role in regulating the earth's temperature, precipitation, droughts, floods, monsoons, and other climate features than any past or expected human activities, including projected increases in GHG emissions. Unlike the IPCC, we do not invent a measure of our confidence in this theory, nor do we confuse it with a forecast of future weather patterns. Rather, we make the case for this alternative theory to demonstrate how much we *don't* know about earth's climate, and therefore how wrong it is to assume that human activity is responsible for any variability in the climate that we cannot explain by pointing to already known forcings or feedbacks.

According to the IPCC, "changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0.12 [+0.06 to +0.30] W m^{-2}," which is an order of magnitude smaller than their estimated net anthropogenic forcing of +1.66 W m^{-2} from CO_2 over the same time period (pp. 3,4). However, the studies summarized in this chapter suggest the IPCC has got it backwards, that it is the sun's influence that is responsible for most climate change during the past century and beyond.

In the spirit of genuine scientific inquiry, in contrast to the IPCC's agenda-driven focus on making its case against GHG, we examine some research that is truly on the frontiers of climate research today. We begin with a discussion of cosmic rays, followed by research on irradiance, and then survey the evidence linking solar variability to climate phenomena both ancient and recent.

References

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5.1. Cosmic Rays

The study of extraterrestrial climatic forcing factors is primarily a study of phenomena related to the sun. Historically, this field of inquiry began with the work of Milankovitch (1920, 1941), who linked the cyclical glaciations of the past million years to the receipt of solar radiation at the surface of the earth as modulated by variations in earth's orbit and rotational characteristics. Subsequent investigations implicated a number of other solar phenomena that operate on both shorter and longer timescales; in this summary we review the findings of the subset of those studies that involve galactic cosmic rays.

We begin with the review paper of Svensmark (2007), Director of the Center for Sun-Climate Research of the Danish National Space Center, who starts by describing how he and his colleagues experimentally determined that electrons released to the atmosphere by galactic cosmic rays act as catalysts that significantly accelerate the formation of ultra-small clusters of sulfuric acid and water molecules that constitute the building blocks of cloud condensation nuclei. He then discusses how, during periods of greater solar magnetic activity, greater shielding of the earth occurs, resulting in less cosmic rays penetrating to the lower atmosphere, resulting in fewer cloud condensation nuclei being produced, resulting in fewer and less reflective low-level clouds occurring, which leads to more solar radiation being absorbed by the surface of the earth, resulting in increasing near-surface air temperatures and global warming.

Svensmark provides support for key elements of this scenario with graphs illustrating the close correspondence between global low-cloud amount and cosmic-ray counts over the period 1984-2004, as well as by the history of changes in the flux of galactic cosmic rays since 1700, which correlates well with earth's temperature history over the same time period, starting from the latter portion of the Maunder Minimum (1645-1715), when Svensmark says "sunspots were extremely scarce and the solar magnetic field was exceptionally weak," and continuing on through the twentieth century, over which last hundred-year interval, as noted by Svensmark, "the sun's coronal magnetic field doubled in strength."

Svensmark cites the work of Bond *et al*. (2001), who in studying ice-rafted debris in the North Atlantic Ocean determined, in Svensmark's words, that "over the past 12,000 years, there were many icy intervals like the Little Ice Age" that "alternated with warm phases, of which the most recent were the Medieval Warm Period (roughly AD 900-1300) and the Modern Warm Period (since 1900)." And as Bond's 10-member team clearly indicates, "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."

In another expansion of timescale—this one highlighting the work of Shaviv (2002, 2003) and Shaviv and Veizer (2003)—Svensmark presents plots of reconstructed sea surface temperature anomalies and relative cosmic ray flux over the last 550 million years, during which time the solar system experienced four passages through the spiral arms of the Milky Way galaxy, with the climatic data showing "rhythmic cooling of the earth whenever the sun crossed the galactic midplane, where cosmic rays are locally most intense." In addition, he notes that the "Snowball Earth" period of some 2.3 *billion* years ago "coincided with the highest star-formation rate in the Milky Way since the earth was formed, in a mini-starburst 2400-2000 million years ago," when, of course, the cosmic ray flux would have been especially intense. In light of these many diverse observations, Svensmark concludes that "stellar winds and magnetism are crucial factors in the origin and viability of life on wet earth-like planets," as are "ever-changing galactic environments and star-formation rates."

Several studies conducted over the past 10 years have uncovered evidence for several of the linkages described by Svensmark in his overview of what we could call the cosmic ray-climate connection. We start with the work of Lockwood *et al*. (1999), who examined measurements of the near-earth interplanetary magnetic field to determine the total magnetic flux leaving the sun since 1868. In doing so, they were able to show that the total magnetic flux from the sun rose by a factor of 1.41 over the period 1964-1996, while surrogate measurements of the interplanetary magnetic field previous to this time indicate that this parameter had risen by a factor of 2.3 since 1901, which observations led the three researchers to state that the variation in the total solar magnetic flux they found "stresses the importance of understanding the connections between the sun's output and its magnetic field and between terrestrial global cloud cover, cosmic ray fluxes and the heliospheric field." The results of this study lead one to wonder just how much of the 0.8°C global temperature rise of the last century might have been a result of the more than two-fold increase in the total magnetic solar flux over that period.

Next, Parker (1999) noted that the number of sunspots had also doubled over the prior 100 years, and that one consequence of the latter phenomenon would have been "a much more vigorous sun" that was slightly brighter. Parker pointed out that spacecraft measurements suggest that the brightness (B) of the sun varies by an amount $\Delta B/B = 0.15\%$, in step with the 11-year magnetic cycle. He then pointed out that during times of much reduced activity of this sort (such as the Maunder Minimum of 1645-1715) and much increased activity (such as the twelfth century Mediaeval Maximum), brightness variations on the order of $\Delta B/B = 0.5\%$ typically occur, after which he noted the mean temperature (T) of the northern portion of the earth varied by 1 to 2°C in association with these variations in solar activity, stating finally that "we cannot help noting that change in T/T = change in B/B."

Knowing that sea surface temperatures are influenced by the brightness of the sun, and that they had risen since 1900, Parker wrote that "one wonders to what extent the solar brightening [of the past century] has contributed to the increase in atmospheric temperature and CO_2" over that period. It was Parker's "inescapable conclusion" that "we will have to know a lot more about the sun and the terrestrial atmosphere before we can understand the nature of the contemporary changes in climate."

Digging deeper into the subject, Feynman and Ruzmaikin (1999) investigated twentieth century changes in the intensity of cosmic rays incident upon the earth's magnetopause and their transmission through the magnetosphere to the upper troposphere. This work revealed "the intensity of cosmic rays incident on the magnetopause has decreased markedly during this century" and "the pattern of cosmic ray precipitation through the magnetosphere to the upper troposphere has also changed."

With respect to the first and more basic of these changes, they noted that "at 300 MeV the difference between the proton flux incident on the magnetosphere at the beginning of the century and that incident now is estimated to be a factor of 5 decrease between solar minima at the beginning of the century and recent solar minima," and that "at 1 GeV the change is a factor of 2.5." With respect to the second phenomenon, they noted that the part of the troposphere open to cosmic rays of all energies increased by a little over 25 percent and shifted equatorward by about 6.5° of latitude. And with the great decrease in the intensity of cosmic rays incident on earth's magnetosphere over the twentieth century, one would have expected to see a progressive decrease in the presence of low-level clouds and, therefore, an increase in global air temperature, as has indeed been observed.

A number of other pertinent papers also appeared at this time. Black *et al*. (1999) conducted a high-resolution study of sediments in the southern Caribbean that were deposited over the past 825 years, finding substantial variability of both a decadal and centennial nature, which suggested that such climate regime shifts are a natural aspect of Atlantic variability; and relating these features to other records of climate variability, they concluded that "these shifts may play a role in triggering changes in the frequency and persistence of drought over North America." Another of their findings was a strong correspondence between the changes in North Atlantic climate and similar changes in ^{14}C production; and they concluded that this finding "suggests that small changes in solar output may influence Atlantic variability on centennial time scales."

Van Geel *et al*. (1999) reviewed what was known at the time 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. This exercise indicated "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. They also reviewed the evidence for various mechanisms by which the postulated solar-climate connection might be implemented, finally concluding 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."

Noting that recent research findings in both palaeoecology and solar science "indicate a greater role for solar forcing in Holocene climate change than has previously been recognized," Chambers *et al*. (1999) reviewed the subject and found much evidence for solar-driven variations in earth-atmosphere processes over a range of timescales stretching from the 11-year solar cycle to century-scale events. They acknowledged, however, that absolute solar flux variations associated with these phenomena are rather small; but they identified a number of "multiplier effects" that can operate on solar rhythms in such a way that, as they describe it, "minor variations in solar activity can be reflected in more significant variations within the earth's atmosphere." They also noted that such nonlinear amplifier responses to solar variability are inadequately represented in the global climate models used by the IPCC to predict future greenhouse gas-induced global warming, even though that organization employs other amplifier effects to model well-known glacial/interglacial cycles of temperature change of the past, as well as the hypothesized CO_2-induced warming of the future.

Noting that "solar magnetic activity exhibits chaotically modulated cycles ... which are responsible for slight variations in solar luminosity and modulation of the solar wind," Tobias and Weiss (2000) attacked the solar forcing of climate problem by means of a model in which the solar dynamo and earth's climate are represented by low-order systems, each of which in isolation supports chaotic oscillations but which when run together sometimes resonate. By this means they determined that "solutions oscillate about either of two fixed points, representing warm and cold states, flipping sporadically between them." They also discovered that a weak nonlinear input from the solar dynamo "has a significant effect when the 'typical frequencies' of each system are in resonance." "It is clear," they say, "that the resonance provides a powerful mechanism for amplifying climate forcing by solar activity."

Contemporaneously, Solanki *et al*. (2000) developed a model of the long-term evolution of the sun's large-scale magnetic field and compared its predictions against two proxy measures of this parameter. The model proved successful in reproducing the observed century-long doubling of the strength of the part of the sun's magnetic field that reaches out from the sun's surface into interplanetary space. It also indicated there is a direct connection between the length of the 11-year sunspot cycle and secular variations in solar activity that occur on timescales of centuries, such as the Maunder Minimum of the latter part of the seventeenth century, when sunspots were few in number and earth was in the midst of the Little Ice Age.

In discussing their findings, the solar scientists say their modeled reconstruction of the solar magnetic field "provides the major parameter needed to reconstruct the secular variation of the cosmic ray flux impinging on the terrestrial atmosphere," because, as they continue, a stronger solar magnetic field "more efficiently shields the earth from cosmic rays," and "cosmic rays affect the total cloud cover of the earth and thus drive the terrestrial climate."

One year later, using cosmic ray data recorded by ground-based neutron monitors, global precipitation data from the Climate Predictions Center Merged Analysis of Precipitation project, and estimates of monthly global moisture from the National Centers for Environmental Prediction reanalysis project, Kniveton and Todd (2001) set out to evaluate whether there is empirical evidence to support the hypothesis that solar variability (represented by changes in cosmic ray flux) is linked to climate change (manifested by changes in precipitation and precipitation efficiency) over the period 1979-1999. In doing so, they determined there is "evidence of a statistically strong relationship between cosmic ray flux, precipitation and precipitation efficiency over ocean surfaces at mid to high latitudes," since variations in both precipitation and precipitation efficiency for mid to high latitudes showed a close relationship in both phase and magnitude with variations in cosmic ray flux, varying 7-9 percent during the solar cycle of the 1980s, while other potential forcing factors were ruled out due to poorer statistical relationships.

Also in 2001, Bond *et al*. (2001) published the results of their study of ice-rafted debris found in three North Atlantic deep-sea sediment cores and cosmogenic nuclides sequestered in the Greenland ice cap (^{10}Be) and Northern Hemispheric tree rings (^{14}C). Based on arduous analyses of deep-sea sediment cores that yielded the variable-with-depth amounts of three proven proxies for the prior presence of overlying drift-ice, the scientists were able to discern and, with the help of an accelerator mass spectrometer, date a number of recurring alternate periods of relative cold and warmth that wended their way through the entire 12,000-year expanse of the Holocene. The mean duration of the several complete climatic cycles thus delineated was 1,340 years, the cold and warm nodes of the latter of which oscillations, in the words of Bond *et al*., were "broadly correlative with the so called 'Little Ice Age' and 'Medieval Warm Period'."

The signal accomplishment of the scientists' study was the linking of these millennial-scale climate oscillations—and their embedded centennial-scale oscillations—with similar-scale oscillations in cosmogenic nuclide production, which are known to be driven by contemporaneous oscillations in solar activity. In fact, Bond *et al*. were able to report 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." In light of this observation they thus concluded that "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.

At this point in their paper, the international team of scientists cited additional evidence in support of the implications of their work. With respect to the global extent of the climatic impact of the solar radiation variations they detected, they reference studies conducted in Scandinavia, Greenland, the Netherlands, the Faroe Islands, Oman, the Sargasso Sea, coastal West Africa, the Cariaco Basin, equatorial East Africa, and the Yucatan Peninsula, demonstrating thereby that "the footprint of the solar impact on climate we have documented extend[s] from polar to tropical latitudes." They note "the solar-climate links implied by our record are so dominant over the last 12,000 years ... it seems almost certain that the well-documented connection between the Maunder solar minimum and the coldest decades of the Little Ice Age could not have been a coincidence," further noting that their findings supported previous suggestions that both the Little Ice Age and Medieval Warm Period "may have been partly or entirely linked to changes in solar irradiance."

Another point reiterated by Bond *et al*. is 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." At two of their coring sites, they identified a series of such cyclical variations that extended throughout all of the previous interglacial and were "strikingly similar to those of the Holocene." Here they could also have cited the work of Oppo *et al*. (1998), who observed similar climatic oscillations in a sediment core that covered the span of time from 340,000 to 500,000 years before present, and that of Raymo *et al*. (1998), who pushed back the time of the cycles' earliest known occurrence to well over one million years ago.

How do the small changes in solar radiation inferred from the cosmogenic nuclide variations bring about such significant and pervasive shifts in earth's global climate? Bond *et al*. described a scenario whereby solar-induced changes high in the stratosphere are propagated downward through the atmosphere to the earth's surface, where they envisioned them provoking changes in North Atlantic deep water formation that alter the thermohaline circulation of the global ocean. In light of the plausibility of this particular scenario, they suggested that "the solar signals thus may have been transmitted through the deep ocean as well as through the atmosphere, further contributing to their amplification and global imprint."

Concluding their landmark paper, the researchers wrote that the results of their study "demonstrate that the earth's climate system is highly sensitive to extremely weak perturbations in the sun's energy output," noting their work "supports the presumption that solar variability will continue to influence climate in the future."

The following year, Carslaw *et al*. (2002) began an essay on "Cosmic Rays, Clouds, and Climate" by noting that the intensity of cosmic rays varies by about 15 percent over a solar cycle, due to changes in the strength of the solar wind, which carries a weak magnetic field into the heliosphere that partially shields the earth from low-energy galactic charged particles. When this shielding is at a minimum, allowing more cosmic rays to impinge upon the planet, more low clouds have been observed to cover the earth, producing a tendency for lower temperatures to occur. When the shielding is maximal, on the other hand, fewer cosmic rays impinge upon the planet and fewer low clouds form, which produces a tendency for the earth to warm.

The three researchers further noted that the total variation in low cloud amount over a solar cycle is about 1.7 percent, which corresponds to a change in the planet's radiation budget of about one watt per square meter (1 Wm^{-2}). This change, they say, "is highly significant when compared ... with the estimated radiative forcing of 1.4 Wm^{-2} from anthropogenic CO_2 emissions." However, because of the short length of a solar cycle (11 years), the large thermal inertia of the world's oceans dampens the much greater global temperature change that would have occurred as a result of this radiative forcing if it had been spread out over a much longer period of time, so that the actual observed warming is something a little less than 0.1°C.

Much of Carslaw *et al.*'s review focuses on mechanisms by which cosmic rays might induce the synchronous low cloud cover changes that have been observed to accompany their intensity changes. They begin by briefly describing the three principal mechanisms that have been suggested to function as links between solar variability and changes in earth's weather: (1) changes in total solar irradiance that provide variable heat input to the lower atmosphere, (2) changes in solar ultraviolet radiation and its interaction with ozone in the stratosphere that couple dynamically to the lower atmosphere, and (3) changes in cloud processes having significance for condensation nucleus abundances, thunderstorm electrification and thermodynamics, and ice formation in cyclones.

Focusing on the third of these mechanisms, the researchers note that cosmic rays provide the sole source of ions away from terrestrial sources of radioisotopes. Hence, they further refine their focus to concentrate on ways by which cosmic-ray-produced ions may affect cloud droplet number concentrations and ice particles. Here, they concentrate on two specific topics: what they call the ion-aerosol clear-air mechanism and the ion-aerosol near-cloud mechanism. Their review suggests that what we know about these subjects is very much less than what we *could* know about them. Many scientists, as they describe it, believe "it is inconceivable that the lower atmosphere can be globally bombarded by ionizing radiation without producing an effect on the climate system."

Carslaw *et al*. point out that cosmic ray intensity declined by about 15 percent during the last century "owing to an increase in the solar open magnetic flux by more than a factor of 2." They further report that "this 100-year change in intensity is about the same magnitude as the observed change over the last solar cycle." In addition, *we* note that the cosmic ray intensity was already much lower at the start of the twentieth century than it was just after the start of the nineteenth century, when the Esper *et al*. (2002) record indicates the planet began its nearly two-century-long recovery from the chilly depths of the Little Ice Age.

These observations strongly suggest that solar-mediated variations in the intensity of cosmic rays bombarding the earth are indeed responsible for the temperature variations of the past three centuries. They provide a much better fit to the temperature data than do atmospheric CO_2 data; and as Carslaw *et al*. remark, "if the cosmic ray-cloud effect is real, then these long-term changes of cosmic ray intensity could substantially influence climate." It is this possibility, they say, that makes it "all the more important to understand the cause of the cloudiness variations," which is basically the message of their essay; i.e., that we must work hard to deepen our understanding of the cosmic ray-cloud connection, as it may well hold the key to resolving what they call this "fiercely debated geophysical phenomenon."

One year later, and noting that Svensmark and Friis-Christensen (1997), Marsh and Svensmark (2000), and Palle Bago and Butler (2000) had derived positive relationships between global cosmic ray intensity and low-cloud amount from infrared cloud data contained in the International Satellite Cloud Climatology Project (ISCCP) database for the years 1983-1993, Marsden and Lingenfelter (2003) used the ISCCP database for the expanded period 1983-1999 to see if a similar relationship could be detected via cloud amount measurements made in the visible spectrum. This work revealed that there was indeed, in their words, "a positive correlation at low altitudes, which is consistent with the positive correlation between global low clouds and cosmic ray rate seen in the infrared."

That same year, Shaviv and Veizer (2003) suggested that from two-thirds to three-fourths of the variance in earth's temperature (T) over the past 500 million years may be attributable to cosmic ray flux (CRF) variations due to solar system passages through the spiral arms of the Milky Way galaxy. This they did after presenting several half-billion-year histories of T, CRF, and atmospheric CO_2 concentrations derived from various types of proxy data, and after finding that none of the CO_2 curves showed any clear correlation with the T curves, suggesting to them that "CO_2 is not likely to be the principal climate driver." On the other hand, they discovered that the T trends displayed a dominant cyclic component on the order of 135 ± 9 million years, and that "this regular pattern implies that we may be looking at a reflection of celestial phenomena in the climate history of earth."

That such is likely the case is borne out by their identification of a similar CRF cycle of 143 ± 10 million years, together with the fact that the large cold intervals in the T records "appear to coincide with times of high CRF," which correspondence is what would be expected from the likely chain of events: high CRF ==> more low-level clouds ==> greater planetary albedo ==> colder climate, as described by Svensmark and Friis-Christensen (1997), Marsh and Svensmark (2000), Palle Bago and Butler (2000), and Marsden and Lingenfelter (2003).

What do these findings suggest about the role of atmospheric CO_2 variations with respect to global temperature change? Shaviv and Veizer began their analysis of this question by stating that the conservative approach is to assume that the entire residual variance not explained by measurement error is due to CO_2 variations. And when this was done, they found that a doubling of the air's CO_2 concentration could account for only about a 0.5°C increase in T.

This result differs considerably, in their words, "from the predictions of the general circulation models, which typically imply a CO_2 doubling effect of ~1.5-5.5°C," but they say it is "consistent with alternative lower estimates of 0.6-1.6°C (Lindzen, 1997)." We note also, in this regard, that Shaviv and Veizer's result is even more consistent with the results of the eight empirically based "natural experiments" of Idso (1998), which yield an average warming of about 0.4°C for a 300 to 600 ppm doubling of the atmosphere's CO_2 concentration.

In another important test of a critical portion of the cosmic ray-climate connection theory, Usoskin *et al*. (2004b) compared the spatial distributions of low cloud amount (LCA) and cosmic ray-induced ionization (CRII) over the globe for the period 1984-2000. They used observed LCA data obtained from the ISCCP-D2 database limited to infrared radiances, while they employed CRII values calculated by Usoskin *et al*. (2004a) at 3 km altitude, which corresponds roughly to the limiting altitude below which low clouds form. This work revealed that "the LCA time series can be decomposed into a long-term slow trend and inter-annual variations, the latter depicting a clear 11-year cycle in phase with CRII." In addition, they found there was "a one-to-one relation between the relative variations of LCA and CRII over the latitude range 20-55°S and 10-70°N," and that "the amplitude of relative variations in LCA was found to increase polewards, in accordance with the amplitude of CRII variations." These findings of the five-member team of Finnish, Danish, and Russian scientists provide substantial evidence for a solar-cosmic ray linkage (the 11-year cycle of CRII) and a cosmic ray-cloud linkage (the in-phase cycles of CRII and CLA), making the full solar activity/cosmic ray/low cloud/climate change hypothesis appear to be rather robust.

In a review of the temporal variability of various solar phenomena conducted the following year, Lean (2005) made the following important but disturbing point about climate models and the sun-climate connection: "a major enigma is that general circulation climate models predict an immutable climate in response to decadal solar variability, whereas surface temperatures, cloud cover, drought, rainfall, tropical cyclones, and forest fires show a definite correlation with solar activity (Haigh, 2001, Rind, 2002)."

Lean begins her review by noting that the beginning of the Little Ice Age "coincided with anomalously low solar activity (the so-called Sporer and Maunder minima)," and that "the latter part coincided with both low solar activity (the Dalton minimum) and volcanic eruptions." Then, after discussing the complexities of this potential relationship, she muses about another alternative: "Or might the Little Ice Age be simply the most recent cool episode of millennial climate-oscillation cycles?" Lean cites evidence that reveals the sensitivity of drought and rainfall to solar variability, stating that climate models are unable to reproduce the plethora (her word) of sun-climate connections. She notes that simulations with climate models yield decadal and centennial variability even in the absence of external forcing, stating that "arguably, this very sensitivity of the climate system to unforced oscillation and stochastic noise predisposes it to nonlinear responses to small forcings such as by the sun."

Lean reports that "various high-resolution paleoclimate records in ice cores, tree rings, lake and ocean sediment cores, and corals suggest that changes in the energy output of the sun itself may have contributed to sun-earth system variability," citing the work of Verschuren *et al*. (2000), Hodell *et al*. (2001), and Bond *et al*. (2001). She notes that "many geographically diverse records of past climate are coherent over time, with periods near 2400, 208 and 90 years that are also present in the ^{14}C and ^{10}Be archives," which isotopes (produced at the end of a complex chain of interactions that are initiated by galactic cosmic rays) contain information about various aspects of solar activity (Bard *et al*., 1997).

Veretenenko *et al*. (2005) examined the potential influence of galactic cosmic rays (GCR) on the long-term variation of North Atlantic sea-level pressure over the period 1874-1995. Their comparisons of long-term variations in cold-season (October-March) sea-level pressure with different solar/geophysical indices revealed that increasing sea-level pressure coincided with a secular rise in solar/geomagnetic activity that was accompanied by a decrease in GCR intensity, whereas long-term decreases in sea-level pressure were observed during periods of decreasing solar activity and rising GCR flux. Spectral analysis further supported a link between sea-level pressure, solar/geomagnetic activity and GCR flux, as similar spectral characteristics (periodicities) were present among all datasets at time scales from approximately 10 to 100 years.

These results support a link between long-term variations in cyclonic activity and trends in solar activity/GCR flux in the extratropical latitudes of the North Atlantic. Concerning how this relationship works, Veretenenko *et al*. hypothesize that GCR-induced changes in cloudiness alter long-term variations in solar and terrestrial radiation receipt in this region, which in turn alters tropospheric temperature gradients and produces conditions more favorable for cyclone formation and development. Although we are still far from possessing a complete understanding of many solar/GCR-induced climatic influences, this study highlights the ever-growing need for such relationships to be explored. As it and others have shown, small changes in solar output can indeed induce significant changes in earth's climate.

Also working in the North Atlantic region, Macklin *et al*. (2005) developed what they call "the first probability-based, long-term record of flooding in Europe, which spans the entire Holocene and uses a large and unique database of ^{14}C-dated British flood deposits," after which they compared their reconstructed flood history "with high-resolution proxy-climate records from the North Atlantic region, northwest Europe and the British Isles to critically test the link between climate change and flooding." By these means they determined that "the majority of the largest and most widespread recorded floods in Great Britain have occurred during cool, moist periods," and that "comparison of the British Holocene palaeoflood series ... with climate reconstructions from tree-ring patterns of subfossil bog oaks in northwest Europe also suggests that a similar relationship between climate and flooding in Great Britain existed during the Holocene, with floods being more frequent and larger during relatively cold, wet periods." In addition, they say that "an association between flooding episodes in Great Britain and periods of high or increasing cosmogenic ^{14}C production suggests that centennial-scale solar activity may be a key control of non-random changes in the magnitude and recurrence frequencies of floods."

Another intriguing study from this time period, Usoskin *et al*. (2005), noted that "the variation of the cosmic ray flux entering earth's atmosphere is due to a combination of solar modulation and geomagnetic shielding, the latter adding a long-term trend to the varying solar signal," while further noting that "the existence of a geomagnetic signal in the climate data would support a direct effect of cosmic rays on climate." They evaluated this proposition by reproducing 1,000-year reconstructions of two notable solar-heliospheric indices derived from cosmogenic isotope data, i.e., the sunspot number and the cosmic ray flux (Usoskin *et al*., 2003; Solanki *et al*., 2004), and by creating a new 1,000-year air temperature history of the Northern Hemisphere by computing annual means of six different thousand-year surface air temperature series: those of Jones *et al*. (1998), Mann *et al*. (1999), Briffa (2000), Crowley (2000), Esper *et al*. (2002), and Mann and Jones (2003).

In comparing these three series (solar activity, cosmic ray, and air temperature), Usoskin *et al*. found that they "indicate higher temperatures during times of more intense solar activity (higher sunspot number, lower cosmic ray flux)." In addition, they report that three different statistical tests "consistently indicate that the long-term trends in the temperature correlate better with cosmic rays than with sunspots," which suggests that something in addition to solar activity must have been influencing the cosmic ray flux, in order to make the cosmic ray flux the better correlate of temperature.

Noting that earth's geomagnetic field strength would be a natural candidate for this "something," Usoskin *et al*. compared their solar activity, cosmic ray, and temperature reconstructions with two long-term reconstructions of geomagnetic dipole moment that they obtained from the work of Hongre *et al*. (1998) and Yang *et al*. (2000). This effort revealed that between AD 1000 and 1700, when there was a substantial downward trend in air temperature associated with a less substantial downward trend in solar activity, there was also a general downward trend in geomagnetic field strength. As a result, Usoskin *et al*. suggested that the substantial upward trend of cosmic ray flux that was needed to sustain the substantial rate of observed cooling (which was more than expected in light of the slow decline in solar activity) was likely due to the positive effect on the cosmic ray flux that was produced by the decreasing geomagnetic field strength.

After 1700, the geomagnetic field strength continued to decline, but air temperature did a dramatic turnabout and began to rise. The reason for this "parting of company" between the two parameters, according to Usoskin *et al*., was that "the strong upward trend of solar activity during that time overcompensate[d] [for] the geomagnetic effect," leading to a significant warming. In addition, a minor portion of the warming of the last century or so (15-20 percent) may have been caused by the concomitant increase in the atmosphere's CO_2 content, which would have complemented the warming produced by the upward trending solar activity and further decoupled the upward trending temperature from the declining geomagnetic field strength.

In their totality, these several observations tend to strengthen the hypothesis that cosmic ray variability was the major driver of changes in earth's surface air temperature over the past millennium, and that this forcing was primarily driven by variations in solar activity, modulated by the more slowly changing geomagnetic field strength of the planet, which sometimes strengthened the solar forcing and sometimes worked against it. Once again, however, the results leave room for only a small impact of anthropogenic CO_2 emissions on twentieth century global warming.

Publishing in the same year, Versteegh (2005) reviewed what we know about past climatic responses to solar forcing and their geographical coherence based upon proxy records of temperature and the cosmogenic radionuclides ^{10}Be and ^{14}C, which provide a measure of magnetized plasma emissions from the sun that impact earth's exposure to galactic cosmic rays, thereby altering cloud formation and climate. As a result of this exercise, it was concluded that "proxy records provide ample evidence for climate change during the relatively stable and warm Holocene," and that "all frequency components attributed to solar variability re-occur in proxy records of environmental change," emphasizing in this regard "the ~90 years Gleisberg and ~200 years Suess cycles in the ^{10}Be and ^{14}C records," as well as "the ~1500 years Bond cycle which occurs in several proxy records [and] could originate from the interference between centennial-band solar cycles." As a result, Versteegh concludes that "long-term climate change during the preindustrial [era] seems to have been dominated by solar forcing," and that the long-term response to solar forcing "greatly exceeds unforced variability."

Delving further into the subject, Harrison and Stephenson (2005) introduce their contribution by noting that because the net global effect of clouds is cooling (Hartman, 1993), any widespread increase in the amount of overcast days could reduce air temperature globally, while local overcast conditions could do so locally. They compared the ratio of diffuse to total solar radiation (the diffuse fraction, DF)—which had been measured daily at 0900 UT at Whiteknights, Reading (UK) from 1997-2004—with the traditional subjective determination of cloud amount made simultaneously by a human observer, as well as with daily average temperature. They then compared the diffuse fraction measured at Jersey between 1968 and 1994 with corresponding daily mean neutron count rates measured at Climax, Colorado (USA), which provide a globally representative indicator of the galactic cosmic ray flux. The result, as they describe it, was that "across the UK, on days of high cosmic ray flux (which occur 87% of the time on average) compared with low cosmic ray flux, (i) the chance of an overcast day increases by 19% ± 4%, and (ii) the diffuse fraction increases by 2% ± 0.3%." In addition, they found that "during sudden transient reductions in cosmic rays (e.g. Forbush events), simultaneous decreases occur in the diffuse fraction."

As for the implications of their findings, the two researchers note that the latter of these observations indicates that diffuse radiation changes are "unambiguously due to cosmic rays." They also report that "at Reading, the measured sensitivity of daily average temperatures to DF for overcast days is -0.2 K per 0.01 change in DR." Consequently, they suggest that the well-known inverse relationship between galactic cosmic rays and solar activity will lead to cooling at solar minima, and that "this might amplify the effect of the small solar cycle variation in total solar irradiance, believed to be underestimated by climate models (Stott *et al*., 2003) which neglect a cosmic ray effect." In addition, although the effect they detect is small, they say it is "statistically robust," and that the cosmic ray effect on clouds likely "will emerge on long time scales with less variability than the considerable variability of daily cloudiness."

Next, Shaviv (2005) identified six periods of earth's history (the entire Phanerozoic, the

Cretaceous, the Eocene, the Last Glacial Maximum, the twentieth century, and the 11-year solar cycle as manifest over the last three centuries) for which he was able to derive reasonably sound estimates of different time-scale changes in radiative forcing, temperature, and cosmic ray flux. From these sets of data he derived probability distribution functions of whole-earth temperature sensitivity to radiative forcing for each time period and combined them to obtain a mean planetary temperature sensitivity to radiative forcing of 0.28°C per Wm^{-2}. Then, noting that the IPCC (2001) had suggested that the increase in anthropogenic radiative forcing over the twentieth century was about 0.5 Wm^{-2}, Shaviv calculated that the anthropogenic-induced warming of the globe over this period was approximately 0.14°C (0.5 Wm^{-2} x 0.28°C per Wm^{-2}). This result harmonizes perfectly with the temperature increase (0.10°C) that was calculated by Idso (1998) to be due solely to the twentieth century increase in the air's CO_2 concentration (75 ppm), which would have been essentially indistinguishable from Shaviv's result if the warming contributions of the twentieth century concentration increases of all greenhouse gases had been included in the calculation.

Based on information that indicated a solar activity-induced increase in radiative forcing of 1.3 Wm^{-2} over the twentieth century (by way of cosmic ray flux reduction), plus the work of others (Hoyt and Schatten, 1993; Lean *et al*., 1995; Solanki and Fligge, 1998) that indicated a globally averaged solar luminosity increase of approximately 0.4 Wm^{-2} over the same period, Shaviv calculated an overall and ultimately solar activity-induced warming of 0.47°C (1.7 Wm^{-2} x 0.28°C per Wm^{-2}) over the twentieth century. Added to the 0.14°C of anthropogenic-induced warming, the calculated total warming of the twentieth century thus came to 0.61°C, which was noted by Shaviv to be very close to the 0.57°C temperature increase that was said by the IPCC to have been observed over the past century. Consequently, both Shaviv's and Idso's analyses, which mesh well with real-world data of both the recent and distant past, suggest that only 15-20 percent (0.10°C/0.57°C) of the observed warming of the twentieth century can be attributed to the rise in the air's CO_2 content.

Usoskin *et al*. (2006) note that many solar scientists believe changes in solar activity have been responsible for significant changes in climate, but that to demonstrate that such is truly the case, a record of past variations in solar activity is required. They write that "long-term solar activity in the past is usually estimated from cosmogenic isotopes, ^{10}Be or ^{14}C, deposited in terrestrial archives such as ice cores and tree rings," because "the production rate of cosmogenic isotopes in the atmosphere is related to the cosmic ray flux impinging on earth," which "is modulated by the heliospheric magnetic field and is thus a proxy of solar activity." A nagging concern, however, is that the isotope records may suffer from what the five scientists call "uncertainties due to the sensitivity of the data to several *terrestrial* [our italics] processes." Consequently, they devised a plan to attempt to resolve this issue.

Noting that the activity of a cosmogenic isotope in a meteorite represents "the time integrated cosmic ray flux over a period determined by the mean life of the radioisotope," Usoskin *et al*. reasoned that (1) "by measuring abundance of cosmogenic isotopes in meteorites which fell through the ages, one can evaluate the variability of the cosmic ray flux, since the production of cosmogenic isotopes ceases after the fall of the meteorite," and that (2) if they could develop such a meteoritic-based cosmogenic isotope record they could use it "to constrain [other] solar activity reconstructions using cosmogenic ^{44}Ti activity in meteorites *which is not affected by terrestrial processes* [our italics]."

The researchers' choice of ^{44}Ti for this purpose was driven by the fact that it has a half-life of about 59 years and is thus "relatively insensitive to variations of the cosmic ray flux on decadal or shorter time scales, but is very sensitive to the level of the cosmic ray flux and its variations on a centennial scale." Hence, they compared the results of different long-term ^{10}Be- and ^{14}C-based solar activity reconstruction models with measurements of ^{44}Ti in 19 stony meteorites (chondrites) that fell between 1766 and 2001, as reported by Taricco *et al*. (2006); in doing so, they ultimately determined that "most recent reconstructions of solar activity, in particular those based on ^{10}Be data in polar ice (Usoskin *et al*., 2003, 2004c; McCracken *et al*., 2004) and on ^{14}C in tree rings (Solanki *et al*., 2004), are consistent with the ^{44}Ti data." Consequently, the results of this study give ever more credence to the findings of the many studies that have reported strong correlations between various climatic changes and ^{10}Be- and ^{14}C-based reconstructions of solar activity.

Dergachev *et al*. (2006) reviewed "direct and indirect data on variations in cosmic rays, solar activity, geomagnetic dipole moment, and climate from the present to 10-12 thousand years ago, [as] registered in different natural archives (tree rings, ice layers, etc.)." They found that "galactic cosmic ray levels in the earth's atmosphere are inversely related to the strength of the helio- and geomagnetic fields," and they conclude that "cosmic ray flux variations are apparently the most effective natural factor of climate changes on a large time scale." More specifically, they note that "changes in cloud processes under the action of cosmic rays, which are of importance for abundance of condensation nuclei and for ice formation in cyclones, can act as a connecting link between solar variability and changes in weather and climate," and they cite numerous scientific studies that indicate that "cosmic rays are a substantial factor affecting weather and climate on time scales of hundreds to thousands of years."

Voiculescu *et al.* (2006) observed "there is evidence that solar activity variations can affect the cloud cover at Earth. However, it is still unclear which solar driver plays the most important role in the cloud formation. Here, we use partial correlations to distinguish between the effects of two solar drivers (cosmic rays and the UV irradiance) and the mutual relations between clouds at different altitudes." They found "a strong solar signal in the cloud cover" and that "low clouds are mostly affected by UV irradiance over oceans and dry continental areas and by cosmic rays over some mid-high latitude oceanic areas and moist lands with high aerosol concentration. High clouds respond more strongly to cosmic ray variations, especially over oceans and moist continental areas. These results provide observational constraints on related climate models."

Gallet and Genevey (2007) documented what they call a "good temporal coincidence" between "periods of geomagnetic field intensity increases and cooling events," as measured in western Europe, where cooling events were "marked by glacier advances on land and increases in ice-rafted debris in [North Atlantic] deep-sea sediments." Their analyses revealed "a succession of three cooling periods in western Europe during the first millennium AD," the ages of which were "remarkably coincident with those of the main discontinuities in the history of Maya civilization," confirming the earlier similar work of Gallet *et al*. (2005), who had found a "good temporal coincidence in western Europe between cooling events recovered from successive advances of Swiss glaciers over the past 3000 years and periods of rapid increases in geomagnetic field intensity," the latter of which were "nearly coeval with abrupt changes, or hairpin turns, in magnetic field direction."

Gallet and Genevey concluded that "the most plausible mechanism linking geomagnetic field and climate remains a geomagnetic impact on cloud cover," whereby "variations in morphology of the earth's magnetic field could have modulated the cosmic ray flux interacting with the atmosphere, modifying the nucleation rate of clouds and thus the albedo and earth surface temperatures (Gallet *et al*., 2005; Courtillot *et al*., 2007)." These observations clearly suggest a global impact on climate, which is further suggested by the close relationship that has been found to exist between "cooling periods in the North Atlantic and aridity episodes in the Middle East," as well as by the similar relationship demonstrated by Gallet and Genevey to have prevailed between periods of aridity over the Yucatan Peninsula and well-documented times of crisis in Mayan civilization.

In another study that took a look at the *really* big picture, painted by rhythmically interbedded limestone and shale or limestone and chert known as *rhythmites*, Elrick and Hinnov (2007) "(1) review the persistent and widespread occurrence of Palaeozoic rhythmites across North America, (2) demonstrate their primary depositional origin at millennial time scales, (3) summarize the range of paleo-environmental conditions that prevailed during rhythmite accumulation, and (4) briefly discuss the implications primary Palaeozoic rhythmites have on understanding the origin of pervasive late Neogene-Quaternary millennial-scale climate variability." They concluded that "millennial-scale climate changes occurred over a very wide spectrum of paleoceanographic, paleogeographic, paleoclimatic, tectonic, and biologic conditions and over time periods from the Cambrian to the Quaternary," and that given this suite of observations, "it is difficult to invoke models of internally driven thermohaline oceanic oscillations or continental ice sheet instabilities to explain their origin." Consequently, they suggest that "millennial-scale paleoclimate variability is a more permanent feature of the earth's ocean-atmosphere system, which points to an external driver such as solar forcing."

Kirkby (2008) reports that "diverse reconstructions of past climate change have revealed clear associations with cosmic ray variations recorded in cosmogenic isotope archives, providing persuasive evidence for solar or cosmic ray forcing of the climate." He discusses two different classes of microphysical mechanisms that have been proposed to connect cosmic rays with clouds, which interact significantly with fluxes of both solar and thermal radiation and, therefore, climate: "firstly, an influence of cosmic rays on the production of cloud condensation nuclei and, secondly, an influence of cosmic rays on the global electrical circuit in the atmosphere and, in turn, on ice nucleation and other cloud microphysical processes." Kirkby observes that "considerable progress on understanding ion-aerosol-cloud processes has been made in recent years, and the results are suggestive of a physically plausible link between cosmic rays, clouds and climate" and "with new experiments planned or underway, such as the CLOUD facility at CERN, there are good prospects that we will have some firm answers to this question within the next few years."

In one final review paper, Lu (2009) showed that in the period of 1980–2007, two full 11-year cosmic ray cycles clearly correlated with ozone depletion, especially the polar ozone loss (hole) over Antarctica. The temporal correlation is also supported by a strong spatial correlation because the ozone hole is located in the lower polar stratosphere at ~18 km, exactly where the ionization rate of cosmic rays producing electrons is the strongest. The results provide strong evidence that the cosmic ray-driven electron-induced reaction of halogenated molecules plays the dominant role in causing the ozone hole. Changes in ozone then have a global impact on climate.

In conclusion, and as Kirkby (2008) rightly notes, "the question of whether, and to what extent, the climate is influenced by solar and cosmic ray variability remains central to our understanding of the anthropogenic contribution to present climate change." Clearly, carbon dioxide is not the all-important dominating factor in earth's climatic history. Within the context of the Holocene, the only time CO_2 moved in concert with air temperature was over the period of earth's recovery from the global chill of the Little Ice Age (the past century or so), and it does so then only quite imperfectly. The flux of galactic cosmic rays, on the other hand, appears to have influenced ups and downs in both temperature and precipitation over the entire 10-12 thousand years of the Holocene, making it the prime candidate for "prime determinant" of earth's climatic state.

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

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5.2. Irradiance

We begin this section of our review of the potential effects of solar activity on earth's climate with the study of Karlén (1998), who examined proxy climate data related to changes in summer temperatures in Scandinavia over the past 10,000 years. This temperature record—derived from analyses of changes in the size of glaciers, changes in the altitude of the alpine tree-limit, and variations in the width of annual tree rings—was compared with contemporaneous solar irradiance data derived from ^{14}C anomalies measured in tree rings. The former record revealed both long- and short-term temperature fluctuations; it was noted by Karlén that during warm periods the temperature was "about 2°C warmer than at present." In addition, the temperature fluctuations were found to be "closely related" to the ^{14}C-derived changes in solar irradiation, leading him to conclude that "the similarity between solar irradiation changes and climate indicate a solar influence on the Scandinavian and Greenland climates." This association led him to further conclude that "the frequency and magnitude of changes in climate during the Holocene [i.e., the current interglacial] do not support the opinion that the climatic change of the last 100 years is unique." He bluntly stated that "there is no evidence of a human influence so far."

Also writing just before the turn of the century, Lockwood *et al*. (1999) analyzed measurements of the near-earth interplanetary magnetic field to determine the total magnetic flux leaving the sun since 1868. Based on their analysis, they were able to show that the total magnetic flux leaving the sun rose by a factor of 1.41 over the period 1964-1996, while surrogate measurements of the interplanetary magnetic field previous to this time indicated that this parameter had increased by a factor of 2.3 since 1901. These findings and others linking changes in solar magnetic activity with terrestrial climate change led the authors to state that "the variation [in the total solar magnetic flux] found here stresses the importance of understanding the connections between the sun's output and its magnetic field and between terrestrial global cloud cover, cosmic ray fluxes and the heliospheric field."

Parker (1999) noted that the number of sunspots also doubled over the same time period, and that one consequence of this phenomenon is a much more vigorous sun that is slightly brighter. Parker also drew attention to the fact that NASA spacecraft measurements had revealed that the brightness (B) of the sun varies by an amount "change in B/B = 0.15%, in step with the 11-year magnetic cycle." He then pointed out that during times of much reduced activity of this sort (such as the Maunder Minimum of 1645-1715) and much increased activity (such as the twelfth century Mediaeval Maximum), brightness variations on the order of change in B/B = 0.5% typically occur, after which he indicated that the mean temperature (T) of the northern portion of the earth varied by 1 to 2°C in association with these variations in solar activity, stating finally that "we cannot help noting that change in T/T = change in B/B."

Also in 1999, Chambers *et al*. noted that recent research findings in both palaeoecology and solar science "indicate a greater role for solar forcing in Holocene climate change than has previously been recognized," which subject they then proceeded to review. In doing so, they found much evidence within the Holocene for solar-driven variations in earth-atmosphere processes over a range of timescales stretching from the 11-year solar cycle to century-scale events. They acknowledge that the absolute solar flux variations associated with these phenomena are rather small; but they identify a number of "multiplier effects" that can operate on solar rhythms in such a way that "minor variations in solar activity can be reflected in more significant variations within the earth's atmosphere."

The three researchers also noted, in this regard, that nonlinear responses to solar variability are inadequately represented (in fact, they are essentially ignored) in the global climate models used by the IPCC to predict future CO_2-induced global warming, while at the same time other amplifier effects are used to model the hypothesized CO_2-induced global warming of the future, where CO_2 is only an initial perturber of the climate system which, according to the IPCC, sets other more powerful forces in motion that produce the bulk of the warming.

At the start of the new millennium, Bard *et al*. (2000) listed some of the many different types of information that have been used to reconstruct past solar variability, including "the envelope of the SSN [sunspot number] 11-year cycle (Reid, 1991), the length and decay rate of the solar cycle (Hoyt and Schatten, 1993), the structure and decay rate of individual sunspots (Hoyt and Schatten, 1993), the mean level of SSN (Hoyt and Schatten, 1993; Zhang *et al*., 1994; Reid, 1997), the solar rotation and the solar diameter (Nesme-Ribes *et al*., 1993), and the geomagnetic aa index (Cliver *et al*., 1998)." They also noted that "Lean *et al*. (1995) proposed that the irradiance record could be divided into 2 superimposed components: an 11-year cycle based on the parameterization of sunspot darkening and facular brightening (Lean *et al*., 1992), and a slowly varying background derived separately from studies of sun-like stars (Baliunas and Jastrow, 1990)," and that Solanki and Fligge (1998) had developed an even more convoluted technique. Bard *et al*., however, used an entirely different approach.

Rather than directly characterize some aspect of solar variability, they assessed certain consequences of that variability. Specifically, they noted that magnetic fields of the solar wind deflect portions of the primary flux of charged cosmic particles in the vicinity of the earth, leading to reductions in the creation of cosmogenic nuclides in earth's atmosphere. Consequently, they reasoned that histories of the atmospheric concentrations of ^{14}C and ^{10}Be can be used as proxies for solar activity, as noted many years earlier by Lal and Peters (1967).

In employing this approach to the problem, the four researchers first created a 1,200-year history of cosmonuclide production in earth's atmosphere from ^{10}Be measurements of South Pole ice (Raisbeck *et al*., 1990) and the atmospheric $^{14}C/^{12}C$ record as measured in tree rings (Bard *et al*., 1997). This record was then converted to total solar irradiance (TSI) values by "applying a linear scaling using the TSI values published previously for the Maunder Minimum," when cosmonuclide production was 30-50 percent above the modern value.

This approach resulted in an extended TSI record that suggests, in their words, that "solar output was significantly reduced between AD 1450 and 1850, but slightly higher or similar to the present value during a period centered around AD 1200." "It could thus be argued," they say, "that irradiance variations may have contributed to the so-called 'little ice age' and 'medieval warm period'.'

In discussing this idea, Bard *et al*. downplay their own suggestion, because, as they report, "some researchers have concluded that the 'little ice age' and/or 'medieval warm period' [were] regional, rather than global events." Noting the TSI variations they developed from their cosmonuclide data "would tend to force global effects," they felt they could not associate this global impetus for climate change with what other people were calling regional climatic anomalies. With respect to these thoughts, we refer the reader to Section 3.2 of this report, where it is demonstrated that the Little Ice Age and Medieval Warm Period were truly global in extent.

Rozelot (2001) conducted a series of analyses designed to determine whether phenomena related to variations in the radius of the sun may have influenced earth's climate over the past four centuries. The results of these analyses revealed, in the words of the researcher, that **"**at least over the last four centuries, warm periods on the earth correlate well with smaller apparent diameter of the Sun and colder ones with a bigger sun." Although the results of this study were correlative and did not identify a physical mechanism capable of inducing significant climate change on earth, Rozelot reports that the changes in the sun's radius are "of such magnitude that significant effects on the earth's climate are possible."

Rigozo *et al*. (2001) created a history of sunspot numbers for the last 1,000 years "using a sum of sine waves derived from spectral analysis of the time series of sunspot number R_Z for the period 1700-1999," and from this record they derived the strengths of a number of parameters related to various aspects of solar variability. In describing their results, the researchers say that "the 1000-year reconstructed sunspot number reproduces well the great maximums and minimums in solar activity, identified in cosmonuclides variation records, and, specifically, the epochs of the Oort, Wolf, Sporer, Maunder, and Dalton Minimums, as well [as] the Medieval and Modern Maximums," the latter of which they describe as "starting near 1900." The mean sunspot number for the Wolf, Sporer, and Maunder Minimums was 1.36. For the Oort and Dalton Minimums it was 25.05; for the Medieval Maximum it was 53.00; and for the Modern Maximum it was 57.54. Compared to the average of the Wolf, Sporer, and Maunder Minimums, therefore, the mean sunspot number of the Oort and Dalton Minimums was 18.42 times greater; that of the Medieval Maximum was 38.97 times greater; and that of the Modern Maximum was 42.31 times greater. Similar strength ratios for the solar radio flux were 1.41, 1.89, and 1.97, respectively. For the solar wind velocity the corresponding ratios were 1.05, 1.10, and 1.11; while for the southward component of the interplanetary magnetic field they were 1.70, 2.54, and 2.67. In comparing these numbers, both the Medieval and Modern Maximums in sunspot number and solar variability parameters stand out above all other periods of the past thousand years, with the Modern Maximum slightly besting the Medieval Maximum.

Noting that a number of different spacecraft have monitored total solar irradiance (TSI) for the past 23 years, with at least two of them operating simultaneously at all times, and that TSI measurements made from balloons and rockets supplement the satellite data, Frohlich and Lean (2002) compared the composite TSI record with an empirical model of TSI variations based on known magnetic sources of irradiance variability, such as sunspot darkening and brightening, after which they described how "the TSI record may be extrapolated back to the seventeenth century Maunder Minimum of anomalously lower solar activity, which coincided with the coldest period of the Little Ice Age." This exercise, as they have described it, "enables an assessment of the extent of post-industrial climate change that may be attributable to a varying sun, and how much the sun might influence future climate change."

In reporting their results, Frolich and Lean state that "warming since 1650 due to the solar change is close to 0.4°C, with pre-industrial fluctuations of 0.2°C that are seen also to be present in the temperature reconstructions." From this study, therefore, it would appear that solar variability can explain a significant portion of the warming experienced by the earth in recovering from the global chill of the Little Ice Age, with a modicum of positive feedback accounting for the rest. With respect to the future, however, the two solar scientists say that "solar forcing is unlikely to compensate for the expected forcing due to the increase of anthropogenic greenhouse gases which are projected to be about a factor of 3-6 larger." The magnitude of that anthropogenic forcing, however, has been computed by many different approaches to be much smaller than the value employed by Frohlich and Lean in making this comparison (Idso, 1998).

Contemporaneously, Douglass and Clader (2002) used multiple regression analysis to separate surface and atmospheric temperature responses to solar irradiance variations over the past two-and-a-half solar cycles (1979-2001) from temperature responses produced by variations in ENSO and volcanic activity. Based on the satellite-derived lower tropospheric temperature record, they evaluated the sensitivity (k) of temperature (T) to solar irradiance (I), where temperature sensitivity to solar irradiance is defined as $k = \Delta T/\Delta I$, obtaining the result of $k = 0.11 \pm 0.02$°C/(W/m^2). Similar analyses based on the radiosonde temperature record of Parker *et al*. (1997) and the surface air temperature records of Jones *et al*. (2001) and Hansen and Lebedeff (1987, with updates) produced k values of 0.13, 0.09, and 0.11°C/(W/m^2), respectively, with the identical standard error of ± 0.02°C/(W/m^2). In addition, they reported that White *et al*. (1997) derived a decadal timescale solar sensitivity of 0.10 ± 0.02°C/(W/m^2) from a study of upper ocean temperatures over the period 1955-1994 and that Lean and Rind (1998) derived a value of 0.12 ± 0.02°C/(W/m^2) from a paleo-reconstructed temperature record spanning the period 1610-1800. They concluded that "the close agreement of these various independent values with our value of 0.11 ± 0.02 [°C/(W/m^2)] suggests that the sensitivity k is the same for both decadal and centennial time scales and for both ocean and lower tropospheric temperatures." They further suggest that if these values of k hold true for centennial time scales, which appears to be the case, their high-end value implies a surface warming of 0.2°C over the last 100 years in response to the 1.5 W/m^2 increase in solar irradiance inferred by Lean (2000) for this period. This warming represents approximately one-third of the total increase in global surface air temperature estimated by Parker *et al*. (1997), 0.55°C, and Hansen *et al*. (1999), 0.65°C, for the same period. It does not, however, include potential indirect effects of more esoteric solar climate-affecting phenomena, such as those discussed in Section 5.1 of this report, that could also have been operative over this period.

Foukal (2002) analyzed the findings of space-borne radiometry and reported that "variations in total solar irradiance, S, measured over the past 22 years, are found to be closely proportional to the difference in projected areas of dark sunspots, AS, and of bright magnetic plage elements, APN, in active regions and in enhanced network," plus the finding that "this difference varies from cycle to cycle and is not simply related to cycle amplitude itself," which facts suggest there is "little reason to expect that S will track any of the familiar indices of solar activity." On the other hand, he notes that "empirical modeling of spectro-radiometric observations indicates that the variability of solar ultraviolet flux, FUV, at wavelengths shorter than approximately 250 nm, is determined mainly by APN alone."

Building upon this conceptual foundation, and using daily data from the Mt. Wilson Observatory that covered the period 1905-1984, plus partially overlapping data from the Sacramento Peak Observatory that extended through 1999, Foukal derived time series of both total solar and UV irradiances between 1915 and 1999, which he then compared with global temperature data for the same time period. This work revealed, in his words, that "correlation of our time series of UV irradiance with global temperature, T, accounts for only 20% of the global temperature variance during the 20th century," but that "correlation of our total irradiance time series with T accounts *statistically* for 80% of the variance in global temperature over that period."

The UV findings of Foukal were not impressive, but the results of his total solar irradiance analysis were, leading him to state that "the possibility of significant driving of twentieth century climate by total irradiance variation cannot be dismissed." Although the magnitude of the total solar effect was determined to be "a factor 3-5 lower than expected to produce a significant global warming contribution based on present-day climate model sensitivities," what Foukal calls the "high correlation between S and T" strongly suggests that changes in S largely determine changes in T, the confirmation of which suggestion likely merely awaits what he refers to as an "improved understanding of possible climate sensitivity to relatively small total irradiance variation."

In the following year, Willson and Mordvinov (2003) analyzed total solar irradiance (TSI) data obtained from different satellite platforms over the period 1978-2002, attempting to resolve various small but important inconsistencies among them. In doing so, they came to the realization that "construction of TSI composite databases will not be without its controversies for the foreseeable future." Nevertheless, their most interesting result, in the estimation of the two researchers, was their confirmation of a +0.05%/decade trend between the minima separating solar cycles 21-22 and 22-23, which they say "appears to be significant."

Willson and Mordvinov say the finding of the 0.05 percent/decade minimum-to-minimum trend "means that TSI variability can be caused by unknown mechanisms other than the solar magnetic activity cycle," which means that "much longer time scales for TSI variations are therefore a possibility," which they say "has obvious implications for solar forcing of climate." Specifically, it means there could be undiscovered long-term variations in total solar irradiance of a magnitude that could possibly explain centennial-scale climate variability, which Bond *et al*. (2001) have already demonstrated to be related to solar activity, as well as the millennial-scale climatic oscillation that pervades both glacial and interglacial periods for essentially as far back in time as paleoclimatologists can see (Oppo *et al*., 1998; Raymo *et al*., 1998).

Like Willson and Mordvinov, Foukal (2003) acknowledged that "recent evidence from ocean and ice cores suggests that a significant fraction of the variability in northern hemisphere climate since the last Ice Age correlates with solar activity (Bond *et al*., 2001)," while additionally noting that "a recent reconstruction of S [total solar irradiance] from archival images of spots and faculae obtained daily from the Mt. Wilson Observatory in California since 1915 shows remarkable agreement with smoothed global temperature in the 20th century," citing his own work of 2002. However, he was forced to acknowledge that the observed variations in S between 1978 and 2002 were not large enough to explain the observed temperature changes on earth within the context of normal radiative forcing. Hence, he proceeded to review the status of research into various subjects that might possibly be able to explain this dichotomy. Specifically, he presented an overview of then-current knowledge relative to the idea that "the solar impact on climate might be driven by other variable solar outputs of ultraviolet radiation or plasmas and fields via more complex mechanisms than direct forcing of tropospheric temperature." As could have been expected, the article contained no grand revelations; when all was said and done, Foukal returned pretty much to where he had started, concluding that "we cannot rule out multi-decadal variations in S sufficiently large to influence climate, yet overlooked so far through limited sensitivity and time span of our present observational techniques."

The following year, Damon and Laut (2004) reported what they described as errors made by Friis-Christensen and Lassen (1991), Svensmark and Friis-Christensen (1997), Svensmark (1998) and Lassen and Friis-Christensen (2000) in their presentation of solar activity data, correlated with terrestrial temperature data. The Danish scientists' error, in the words of Damon and Laut, was "adding to a heavily smoothed ('filtered') curve, four additional points covering the period of global warming, which were only partially filtered or not filtered at all." This in turn led to an apparent dramatic increase in solar activity over the last quarter of the twentieth century that closely matched the equally dramatic rise in temperature manifest by the Northern Hemispheric temperature reconstruction of Mann *et al*. (1998, 1999) over the same period. With the acquisition of additional solar activity data in subsequent years, however, and with what Damon and Laut called the proper handling of the numbers, the late twentieth century dramatic increase in solar activity totally disappears.

This new result, to quote Damon and Laut, means that "the sensational agreement with the recent global warming, which drew worldwide attention, has totally disappeared." In reality, however, it is only the agreement with the last quarter-century of the discredited Mann *et al*. "hockey stick" temperature history that has disappeared. This new disagreement is most welcome, for the Mann *et al*. temperature reconstruction is likely in error over this stretch of time. (See Section 3.2.)

Using a nonlinear non-stationary time series technique called empirical mode decomposition, Coughlin and Tung (2004) analyzed monthly mean geopotential heights and temperatures—obtained from Kalnay *et al*. (1996)—from 1000 hPa to 10 hPa over the period January 1958 to December 2003. This work revealed the existence of five oscillations and a trend in both datasets. The fourth of these oscillations has an average period of 11 years and indicates enhanced warming during times of maximum solar radiation. As the two researchers describe it, "the solar flux is positively correlated with the fourth modes in temperature and geopotential height almost everywhere [and] the overwhelming picture is that of a positive correlation between the solar flux and this mode throughout the troposphere."

Coughlin and Tung concluded that "the atmosphere warms during the solar maximum almost everywhere over the globe." And the unfailing omnipresent impact of this small forcing (a 0.1 percent change in the total energy output of the sun from cycle minimum to maximum) suggests that any longer-period oscillations of the solar inferno could well be causing the even greater centennial- and millennial-scale oscillations of temperature that are observed in paleotemperature data from various places around the world.

Additional light on the subject has been provided by widespread measurements of the flux of solar radiation received at the surface of the earth that have been made since the late 1950s. Nearly all of these measurements reveal a sizeable decline in the surface receipt of solar radiation that was not reversed until the mid-1980s, as noted by Wild *et al*. (2005). During this time, there was also a noticeable dip in earth's surface air temperature, after which temperatures rose at a rate and to a level of warmth that the IPCC claims were both without precedent over the past one to two millennia, which phenomena they attribute to similarly unprecedented increases in greenhouse gas concentrations, the most notable, of course, being CO_2.

This reversal of the decline in the amount of solar radiation incident upon the earth's surface, in the words of Wild *et al*., "is reconcilable with changes in cloudiness and atmospheric transmission and may substantially affect surface climate." They say, for example, that "whereas the decline in solar energy could have counterbalanced the increase in down-welling longwave energy from the enhanced greenhouse effect before the 1980s, the masking of the greenhouse effect and related impacts may no longer have been effective thereafter, enabling the greenhouse signals to become more evident during the 1990s." Qualitatively, this scenario sounds reasonable; but when the magnitude of the increase in the surface-received flux of solar radiation over the 1990s is considered, the statement is seen to be rather disingenuous.

Over the range of years for which high-quality data were available to them (1992-2002), Wild *et al*. determined that the mean worldwide increase in clear-sky insolation averaged 0.68 Wm^{-2} per year, which increase they found to be "comparable to the increase under all-sky conditions." Consequently, for that specific 10-year period, these real-world data suggest that the total increase in solar radiation received at the surface of the earth should have been something on the order of 6.8 Wm^{-2}, which is not significantly different from what is implied by the satellite and "earthshine" data of Palle *et al*. (2004), although the satellite data of Pinker *et al*. (2005) suggest an increase only about a third as large for this period.

Putting these numbers in perspective, Charlson *et al*. (2005) report that the longwave radiative forcing provided by all greenhouse gas increases since the beginning of the industrial era has amounted to only 2.4 Wm^{-2}, citing the work of Anderson *et al*. (2003), while Palle *et al*. say that "the latest IPCC report argues for a 2.4 Wm^{-2} increase in CO_2 longwave forcing since 1850." Consequently, it can be readily appreciated that the longwave forcing of greenhouse gases over the 1990s would have been but a fraction of a fraction of the observed increase in the contemporary receipt of solar radiation at the surface of the earth. To thus suggest, as Wild *et al*. do, that the increase in insolation experienced at the surface of the earth over the 1990s may have enabled anthropogenic greenhouse gas signals of that period to become more evident, seems incongruous, as their suggestion implies that the bulk of the warming of that period was due to increases in greenhouse gas concentrations, when the solar component of the temperature forcing was clearly much greater. And this incongruity is made all the worse by the fact that methane concentrations rose ever more slowly over this period, apparently actually stabilizing near its end (see Section 2.6. Methane). Consequently, a much more logical conclusion would be that the primary driver of the global warming of the 1990s was the large increase in global surface-level insolation.

A final paper of note from 2005 was that of Soon (2005), who explored the question of which variable was the dominant driver of twentieth century temperature change in the Arctic—rising atmospheric CO_2 concentrations or variations in solar irradiance—by examining what roles the two variables may have played in decadal, multi-decadal, and longer-term variations in surface air temperature (SAT). He performed a number of statistical analyses on (1) a composite Arctic-wide SAT record constructed by Polyakov *et al*. (2003), (2) global CO_2 concentrations taken from estimates given by the NASA GISS climate modeling group, and (3) a total solar irradiance (TSI) record developed by Hoyt and Schatten (1993, updated by Hoyt in 2005) over the period 1875-2000.

The results of these analyses indicated a much stronger statistical relationship between SATs and TSI, as opposed to SATs and CO_2. Solar forcing generally explained well over 75 percent of the variance in decadal-smoothed seasonal and annual Arctic SATs, while CO_2 forcing explained only between 8 and 22 percent of the variance. Wavelet analysis further supported the case for solar forcing of the SAT record, revealing similar time-frequency characteristics for annual and seasonally averaged temperatures at decadal and multi-decadal time scales. By contrast, wavelet analysis gave little to no indication of a CO_2 forcing of Arctic SSTs. Based on these data and analyses, therefore, it would appear that the sun, not atmospheric CO_2, has been the driving force for temperature change in the Arctic.

Lastovicka (2006) summarized recent advancements in the field, saying "new results from various space and ground-based experiments monitoring the radiative and particle emissions of the sun, together with their terrestrial impact, have opened an exciting new era in both solar and atmospheric physics," stating that "these studies clearly show that the variable solar radiative and particle output affects the earth's atmosphere and climate in many fundamental ways." That same year, Bard and Frank (2006) examined "changes on different time scales, from the last million years up to recent decades," and in doing so critically assessed recent claims that "the variability of the sun has had a significant impact on global climate." "Overall," in the judgment of the two researchers, the role of solar activity in causing climate change "remains unproven." However, as they state 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 another study from 2006, which also reviewed the scientific literature, Beer *et al*. (2006) explored what we know about solar variability and its possible effects on earth's climate, focusing on two types of variability in the flux of solar radiation incident on the earth. The first type, in their words, "is due to changes in the orbital parameters of the earth's position relative to the sun induced by the other planets," which arises from gravitational perturbations that "induce changes with characteristic time scales in the eccentricity (~100,000 years), the obliquity (angle between the equator and the orbital plane, ~40,000 years) and the precession of the earth's axis (~20,000 years)," while the second type is due to variability within the sun itself.

With respect to the latter category, the three researchers report that direct observations of total solar irradiance above the earth's atmosphere have been made only over the past quarter-century, while observations of sunspots have been made and recorded for approximately four centuries. In between the time scales of these two types of measurements fall neutron count rates and aurora counts. Therefore, ^{10}Be and other cosmogenic radionuclides (such as ^{14}C) —stored in ice, sediment cores, and tree rings—currently provide our only means of inferring solar irradiance variability on a millennial time scale. These cosmogenic nuclides "clearly reveal that the sun varies significantly on millennial time scales and most likely plays an important role in climate change," especially within this particular time domain. In reference to their ^{10}Be-based derivation of a 9,000-year record of solar modulation, Beer *et al.* note that its "comparison with paleoclimatic data provides strong evidence for a causal relationship between solar variability and climate change."

We have now reached the work of Nicola Scafetta, a research scientist in the Duke University physics department, and Bruce West, chief scientist in the mathematical and information science directorate of the U.S. Army Research Office in Research Triangle Park, North Carolina. To better follow the arc of their work, we'll temporarily abandon our chronological ordering of this literature review.

Scafetta and West (2006a) developed "two distinct TSI reconstructions made by merging in 1980 the annual mean TSI proxy reconstruction of Lean *et* *al*. (1995) for the period 1900-1980 and two alternative TSI satellite composites, ACRIM (Willson and Mordvinov, 2003), and PMOD (Frohlich and Lean, 1998), for the period 1980-2000," and then used a climate sensitivity transfer function to create twentieth century temperature histories. The results suggested that the sun contributed some 46 to 49 percent of the 1900-2000 global warming of the earth. Considering that there may have been uncertainties of 20 to 30 percent in their sensitivity parameters, the two researchers suggested the sun may have been responsible for as much as 60 percent of the twentieth century temperature rise.

Scafetta and West say the role of the sun in twentieth century global warming has been significantly underestimated by the climate modeling community, with various energy balance models producing estimates of solar-induced warming over this period that are "two to ten times lower" than what they found. The two researchers say "the models might be inadequate because of the difficulty of modeling climate in general and a lack of knowledge of climate sensitivity to solar variations in particular." They also note that "theoretical models usually acknowledge as solar forcing only the direct TSI forcing," thereby ignoring "possible additional climate effects linked to solar magnetic field, UV radiation, solar flares and cosmic ray intensity modulations." In this regard, we additionally note that some of these phenomena may to some degree be independent of, and thereby add to, the simple TSI forcing Scafetta and West employed, which suggests that the totality of solar activity effects on climate may be even greater than what they calculated.

In a second study published in the same year, Scafetta and West (2006b) begin by noting that nearly all attribution studies begin with pre-determined forcing and feedback mechanisms in the models they employ. "One difficulty with this approach," according to Scafetta and West, "is that the feedback mechanisms and alternative solar effects on climate, since they are only partially known, might be poorly or not modeled at all." Consequently, "to circumvent the lack of knowledge in climate physics," they adopt "an alternative approach that attempts to evaluate the total direct plus indirect effect of solar changes on climate by comparing patterns in the secular temperature and TSI reconstructions," where "a TSI reconstruction is not used as a radiative forcing, but as a proxy [for] the entire solar dynamics." They then proceed on the assumption that "the secular climate sensitivity to solar change can be phenomenologically estimated by comparing ... solar and temperature records during the pre-industrial era, when, reasonably, only a negligible amount of anthropogenic-added climate forcing was present," and when "the sun was the only realistic force affecting climate on a secular scale."

Scafetta and West used the Northern Hemispheric temperature reconstruction of Moberg *et al*. (2005), three alternative TSI proxy reconstructions developed by Lean *et al*. (1995), Lean (2000), and Wang *et al*. (2005), and a scale-by-scale transfer model of climate sensitivity to solar activity changes created by themselves (Scafetta and West, 2005, 2006a) and found what they called a "good correspondence between global temperature and solar induced temperature curves during the pre-industrial period, such as the cooling periods occurring during the Maunder Minimum (1645-1715) and the Dalton Minimum (1795-1825)." In addition, they note that since the time of the seventeenth century solar minimum, "the sun has induced a warming of $\Delta T \sim 0.7$ K," and that "this warming is of the same magnitude [as] the cooling of $\Delta T \sim 0.7$ K from the medieval maximum to the 17th century minimum," which finding, in their words, "suggests the presence of a millenarian solar cycle, with ... medieval and contemporary maxima, driving the climate of the last millennium," as was first suggested fully three decades ago by Eddy (1976) in his seminal study of the Maunder Minimum.

Scafetta and West say their work provides substantive evidence for the likelihood that "solar change effects are greater than what can be explained by several climate models," citing Stevens and North (1996), the Intergovernmental Panel on Climate Change (2001), Hansen *et al*. (2002), and Foukal *et al*. (2004); and they note that a solar change "might trigger several climate feedbacks and alter the greenhouse gas (H_2O, CO_2, CH_4, etc.) concentrations, as 420,000 years of Antarctic ice core data would also suggest (Petit *et al*., 1999)," once again reiterating that "most of the sun-climate coupling mechanisms are probably still unknown," and that "they might strongly amplify the effects of small solar activity increase." That being said, however, the researchers note that in the twentieth century there was "a clear surplus warming" above and beyond what is suggested by their solar-based temperature reconstruction, such that something in addition to the sun may have been responsible for approximately 50 percent of the total global warming since 1900. This anomalous increase in temperature, it could be argued, was due to anthropogenic greenhouse gas emissions. Scafetta and West say the temperature difference since 1975, where the most noticeable part of the discrepancy occurred, may have been due to "spurious non-climatic contamination of the surface observations such as heat-island and land-use effects (Pielke *et al*., 2002; Kalnay and Cai, 2003)," which they say is also suggested by "an anomalous warming behavior of the global average land temperature vs. the marine temperature since 1975 (Brohan *et al*., 2006)."

In their next paper, Scafetta and West (2007) reconstructed a phenomenological solar signature (PSS) of climate for the Northern Hemisphere for the last four centuries that matches relatively well the instrumental temperature record since 1850 and the paleoclimate temperature proxy reconstruction of Moberg (2005). The period from 1950 to 2010 showed excellent agreement between 11- and 22-year PSS cycles when compared to smoothed average global temperature data and the global *cooling* that occurred since 2002. Describing their research in an opinion essay in *Physics Today* (published by the American Institute of Physics), they say "this cooling seems to have been induced by decreased solar activity from the 2001 maximum to the 2007 minimum as depicted in two distinct TSI reconstructions" and "the same patterns are poorly reproduced by present-day GCMs and are dismissively interpreted as internal variability (noise) of climate. The nonequilibrium thermodynamic models we used suggest that the Sun is influencing climate significantly more than the IPCC report claims" (Scafetta and West, 2008).

In 2009, Scafetta and a new coauthor, Richard C. Willson, senior research scientist at Columbia's Center for Climate Systems Research, addressed the issue of whether or not TSI increased from 1980 to 2002. The IPCC assumed there was no increase by adopting the TSI satellite composite produced by the Physikalisch-Meteorologisches Observatorium Davos (PMOD) (see Frohlich, 2006). PMOD assumed that the NIMBUS7 TSI satellite record artificially increased its sensitivity during the ACRIM-gap (1999.5-1991.75), and therefore it reduced the NIMBUS7 record by 0.86 W/m^2 during the ACRIM-gap period, and consequently the TSI results changed little since 1980. However, this PMOD adjustment of NIMBUS7 TSI satellite data was never acknowledged by the experimental teams (Willson and Mordvinov, 2003; supporting material in Scafetta and Willson, 2009).

Scafetta and Willson (2009) proposed to solve the ACRIM-gap calibration controversy by developing a TSI model using a proxy model based on variations of the surface distribution of solar magnetic flux designed by Krivova *et al.* (2007) to bridge the two-year gap between ACRIM1 and ACRIM2. They use this to bridge "mixed" versions of ACRIM and PMOD TSI before and after the ACRIM-gap. Both "mixed" models show, in the authors' words, "a significant TSI increase of 0.033%/decade between the solar activity minima of 1986 and 1996, comparable to the 0.037% found in the TSI satellite ACRIM composite." They conclude that "increasing TSI between 1980 and 2000 could have contributed significantly to global warming during the last three decades. Current climate models have assumed that TSI did not vary significantly during the last 30 years and have, therefore, underestimated the solar contribution and overestimated the anthropogenic contribution to global warming."

Backing up now to 2007, Krivova *et al*. (2007) note there is "strong interest" in the subject of long-term variations of total solar irradiance or TSI "due to its potential influence on global climate," and that "only a reconstruction of solar irradiance for the pre-satellite period with the help of models can aid in gaining further insight into the nature of this influence," which is what they set about to achieve in their paper. They developed a history of TSI "from the end of the Maunder minimum [about AD 1700] to the present based on variations of the surface distribution of the solar magnetic field," which was "calculated from the historical record of the sunspot number using a simple but consistent physical model," i.e., that of Solanki *et al*. (2000, 2002).

Krivova *et al*. report that their model "successfully reproduces three independent datasets: total solar irradiance measurements available since 1978, total photospheric magnetic flux since 1974 and the open magnetic flux since 1868," which was "empirically reconstructed using the geomagnetic *aa*-index." Based on this model, they calculated an increase in TSI since the Maunder minimum somewhere in the range of 0.9-1.5 Wm^{-2}, which encompasses the results of several independent reconstructions that have been derived over the past few years. In the final sentence of their paper, however, they also note that "all the values we obtain are significantly below the ΔTSI values deduced from stellar data and used in older TSI reconstructions," the results of which range from 2 to 16 Wm^{-2}.

Shaviv (2008) has attempted to quantify solar radiative forcing using oceans as a calorimeter. He evaluated three independent measures of net ocean heat flux over five decades, sea level change rate from twentieth century tide gauge records, and sea surface temperature. He found a "very clear correlation between solar activity and sea level" including the 11-year solar periodicity and phase, with a correlation coefficient of r=0.55. He also found "that the total radiative forcing associated with solar cycles variations is about 5 to 7 times larger than those associated with the TSI variations, thus implying the necessary existence of an amplification mechanism, though without pointing to which one." Shaviv claims "the sheer size of the heat flux, and the lack of any phase lag between the flux and the driving force further implies that it cannot be part of an atmospheric feedback and very unlikely to be part of a coupled atmosphere-ocean oscillation mode. It must therefore be the manifestation of real variations in the global radiative forcing." This provides "very strong support for the notion that an amplification mechanism exists. Given that the CRF [Cosmic Ray Flux]/climate links predicts the correct radiation imbalance observed in the cloud cover variations, it is a favorable candidate." These results, Shaviv says, "imply that the climate sensitivity required to explain historic temperature variations is smaller than often concluded."

Pallé *et al.* (2009) re-analyzed the overall reflectance of sunlight from Earth ("earthshine") and re-calibrated the CERES satellite data to obtain consistent results for Earth's solar reflectance. According to the authors, "Earthshine and FD [flux data] analyses show contemporaneous and climatologically significant increases in the Earth's reflectance from the outset of our earthshine measurements beginning in late 1998 roughly until mid-2000.After that and to date, all three show a roughly constant terrestrial albedo, except for the FD data in the most recent years. Using satellite cloud data and Earth reflectance models, we also show that the decadal-scale changes in Earth's reflectance measured by earthshine are reliable and are caused by changes in the properties of clouds rather than any spurious signal, such as changes in the Sun-Earth-Moon geometry."

Ohmura (2009) reviewed surface solar irradiance at 400 sites globally to 2005. They found a brightening phase from the 1920s to 1960s followed by a 20-year dimming phase from 1960 to 1980. Then there is another 15-year brightening phase from 1990 to 2005. Ohmura finds "aerosol direct and indirect effects played about an equal weight in changing global solar radiation. The temperature sensitivity due to radiation change is estimated at 0.05 to 0.06 K/(W m^{-2})."

Long *et al.* (2009) analyzed "all-sky and clear-sky surface downwelling shortwave radiation and bulk cloud properties" from 1995 through 2007. They "show that widespread brightening has occurred over the continental United States ... averaging about 8 W m^{-2}/decade for all-sky shortwave and 5 W m^{-2}/decade for the clear-sky shortwave. This all-sky increase is substantially greater than the (global) 2 W m^{-2}/decade previously reported ..." Their "results show that changes in dry aerosols and/or direct aerosol effects alone cannot explain the observed changes in surface shortwave (SW) radiation, but it is likely that changes in cloudiness play a significant role."

These observations by Shaviv, Pallé, Ohmura, and Long *et al.* point to major variations in earth's radiative budget caused by changes both in aerosols and clouds. Both are affected by natural and anthropogenic causes, including aircraft, power plants, cars, cooking, forest fires, and volcanoes. However, solar activity and cosmic rays also modulate clouds. When GCMs ignore or underestimate causes or modulation by solar cycles, magnetic fields and/or cosmic rays, they overestimate climate sensitivity and anthropogenic impacts.

Although there thus is still significant uncertainty about the true magnitude of the TSI change experienced since the end of the Maunder Minimum, the wide range of possible values suggests that long-term TSI variability cannot be rejected as a plausible cause of the majority of the global warming that has fueled earth's transition from the chilling depths of the Little Ice Age to the much milder weather of the Current Warm Period. Indeed, the results of many of the studies reviewed in this summary argue strongly for this scenario, while others suggest it is the only explanation that fits all the data.

The measured judgment of Bard and Frank (2006) seems to us to be right on the mark. The role of solar activity in causing climate change is so complex that most theories of solar forcing of climate change must be considered to be as yet "unproven." It would also be appropriate for climate scientists to admit the same about the role of rising atmospheric CO_2 concentrations in driving recent global warming. If it is fairly certain that the sun was responsible for creating multi-centennial cold and warm periods, it is clear the sun could easily be responsible for the majority or even the entirety of the global warming of the past century or so.

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

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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 $\delta^{13}C$ 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 $\delta^{13}C$ 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 $\delta^{13}C$ and $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{14}C$ 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 $\delta^{18}O$ 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 $\delta^{14}C$ and the variation in $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ and $\delta^{13}C$ of bulk carbonate, total carbonate content, and the detrended $\delta^{15}N$ 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 $\delta^{14}C$ 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 $\delta^{18}O$ 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

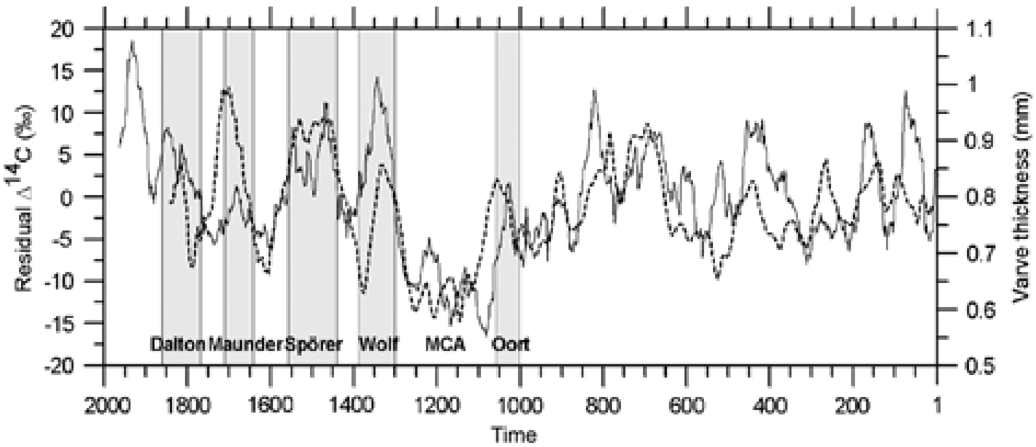

Figure 5.3.6. Residual $\Delta^{14}C$ data (dashed line) and varve thickness (smooth line) vs. time, specifically highlighting the Oort, Wolf, Sporer, Maunder and Dalton solar activity minima, as well as the "Medieval Climate Anomaly (also referred to as Medieval Warm Period)," during the contemporaneous "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 of IRD [ice rafted debris] events ... in the North Atlantic," which have been described by Bond *et al*. (1997) and attributed to "solar variability amplified through oceanic and atmospheric dynamics," as detailed by Bond *et al*. (2001).

Li *et al*. (2006, 2007) also developed a precipitation proxy from a lake-level record, based on lithologic and mineral magnetic data from the Holocene sediments of White Lake, New Jersey, northeastern USA (41°N, 74.8°W), the characteristics of which they compared with a host of other paleoclimatic reconstructions from this region and beyond.

According to the authors of these two papers, the lake-level history revealed low lake levels at ~1.3, 3.0, 4.4, and 6.1 thousand years before present; comparison of the results with drift-ice records from the North Atlantic Ocean according to Li *et al*. (2007) "indicates a striking correspondence," as they "correlate well with cold events 1, 2, 3 and 4 of Bond *et al*. (2001)." They also report that a comparison of their results with those of other land-based studies suggests "a temporally coherent pattern of climate variations at a quasi-1500-year periodicity at least in the Mid-Atlantic region, if not the entire northeastern USA." In addition, and with respect to the other node of the climatic cycle, they note that "the Mid-Atlantic region was dominated by wet conditions, while most parts of the conterminous USA experienced droughts, when the North Atlantic Ocean was warm."

In discussing their findings, the three researchers say the dry-cold correlation they found "resembles the modern observed relationship between moisture conditions in eastern North America and the North Atlantic Oscillation (NAO), but operates at millennial timescales, possibly through modulation of atmospheric dynamics by solar forcing," and in this regard they write that the sun-climate link on millennial timescales has "been demonstrated in several records (e.g., Bond *et al*., 2001; Hu *et al*., 2003; Niggemann *et al*., 2003), supporting solar forcing as a plausible mechanism for modulating the AO [Arctic Oscillation]/NAO at millennial timescales."

Along the same vein of research, Dean *et al*. (2002) analyzed the varve thickness and continuous gray-scale density of sediment cores taken from Elk Lake, MN (47°12'N, 95°15'W) for the past 1,500 years. Results indicated the presence of significant periodicities throughout the record, including multidecadal periodicities of approximately 10, 29, 32, 42, and 96 years, and a strong multicentennial periodicity of about 400 years, leading the authors to wonder whether the observed periodicities are manifestations of solar-induced climate signals, upon which they present strong correlative evidence that they are. The 10-year oscillation was found to be strongest in the time series between the fourteenth and nineteenth centuries, during the Little Ice Age, and may well have been driven by the 11-year sunspot cycle.

Further south in Mexico, Lozano-Garcia *et al*. (2007) conducted a high-resolution multi-proxy analysis of pollen, charcoal particles, and diatoms found in the sediments of Lago Verde (18°36'46" N, 95°20'52"W)—a small closed-basin lake on the outskirts of the Sierra de Los Tuxtlas (a volcanic field on the coast of the Gulf of Mexico)—which covered the past 2,000 years. The five Mexican researchers who conducted the study say their data "provide evidence that the densest tropical forest cover and the deepest lake of the last two millennia were coeval with the Little Ice Age, with two deep lake phases that follow the Sporer and Maunder minima in solar activity." In addition, they suggest that "the high tropical pollen accumulation rates limit the Little Ice Age's winter cooling to a maximum of 2°C," and they conclude that the "tropical vegetation expansion during the Little Ice Age is best explained by a reduction in the extent of the dry season as a consequence of increased meridional flow leading to higher winter precipitation." Concluding their study, Lozano-Garcia *et al*. state "the data from Lago Verde strongly suggest that during the Little Ice Age lake levels and vegetation at Los Tuxtlas were responding to solar forcing and provide further evidence that solar activity is an important element controlling decadal to centennial scale climatic variability in the tropics (Polissar *et al*., 2006) and in general over the North Atlantic region (Bond *et al*., 2001; Dahl-Jensen *et al*., 1998)."

Across the Gulf of Mexico in a study from the sea, as opposed to from a lake, Lund and Curry (2004) analyzed 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) in an effort to examine centennial to millennial timescale changes in the Florida Current-Gulf Stream system over the past 5,200 years. Based upon the analysis, isotopic data from the three cores indicated that "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.” Hence, we once again have a situation where both centennial- and millennial-scale climatic variability is explained by similar-scale variability in solar activity.

Moving up the Atlantic coast to Newfoundland, Hughes *et al*. (2006) derived a multi-proxy palaeoclimate record from Nordan’s Pond Bog, a coastal plateau bog in Newfoundland, based upon “analyses of plant macrofossils, testate amoebae and the degree of peat humification,” which enabled them to create “a single composite reconstruction of bog surface wetness (BSW)” that they compare with “records of cosmogenic isotope flux.”

Results of the analysis indicated that “at least 14 distinctive phases of increased BSW may be inferred from the Nordan’s Pond Bog record,” commencing at 8,270 cal. years BP, and that “comparisons of the BSW reconstruction with records of cosmogenic isotope flux ... suggest a persistent link between reduced solar irradiance and increased BSW during the Holocene.” Furthermore, Hughes *et al*. conclude that the “strong correlation between increased ^{14}C production [which accompanies reduced solar activity] and phases of maximum BSW supports the role of solar forcing as a persistent driver of changes to the atmospheric moisture balance throughout the Holocene,” which finding further suggests that the sun likely orchestrated the Little Ice Age to Current Warm Period transition, which altered precipitation regimes around the globe. Consequently, the authors state that “evidence suggesting a link between solar irradiance and sub-Milankovitch-scale palaeoclimatic change has mounted,” and the “solar hypothesis, as an explanation for Holocene climate change, is now gaining wider acceptance.”

Asmerom *et al*. (2007) developed a high-resolution Holocene climate proxy for the southwest United States from $\delta^{18}O$ variations in a stalagmite obtained in Pink Panther Cave in the Guadalupe Mountains of New Mexico. Spectral analysis performed on the raw $\delta^{18}O$ data revealed significant peaks that the researchers say “closely match previously reported periodicities in the ^{14}C content of the atmosphere, which have been attributed to periodicities in the solar cycle (Stuiver and Braziunas, 1993).” More specifically, they say that cross-spectral analysis of the $\Delta^{14}C$ and $\delta^{18}O$ data confirms that the two records have matching periodicities at 1,533 years (the Bond cycle), 444 years, 170 years, 146 years, and 88 years (the Gleissberg cycle). In addition, they report that periods of increased solar radiation correlate with periods of decreased rainfall in the southwestern United States (via changes in the North American monsoon), and that this behavior is just the opposite of what is observed with the Asian monsoon. These observations lead them to suggest that the proposed solar link to Holocene climate operates “through changes in the Walker circulation and the Pacific Decadal Oscillation and El Niño-Southern Oscillation systems of the tropical Pacific Ocean.”

Since the warming of the twentieth century appears to represent the most recent rising phase of the Bond cycle, which in its previous rising phase produced the Medieval Warm Period (see Bond *et al*., 2001), and since we could still be embedded in that rising temperature phase, which could well continue for some time to come, there is a reasonable probability that the desert southwest of the United States could experience an intensification of aridity in the not-too-distant future, and that wetter conditions could be expected in the monsoon regions of Asia, without atmospheric greenhouse gases playing any role.

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

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5.4.2. South America

We begin our investigation of the influence of the sun on precipitation in South America with the study of Nordemann *et al*. (2005), who analyzed tree rings from species sensitive to fluctuations in precipitation from 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 from 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.

Working with a sediment core retrieved from the main basin of Lake Titicaca (16°S, 69°W) on the Altiplano of Bolivia and Peru, Baker *et al*. (2005) reconstructed the lake-level history of the famous South American water body over the past 13,000 years at decadal to multi-decadal resolution based on $\delta^{13}C$ measurements of sediment bulk organic matter.

Baker *et al*. report that "the pattern and timing of lake-level change in Lake Titicaca is similar to the ice-rafted debris record of Holocene Bond events, demonstrating a possible coupling between precipitation variation on the Altiplano and North Atlantic sea-surface temperatures." Noting that "cold periods of the Holocene Bond events correspond with periods of increased precipitation on the Altiplano," they further conclude that "Holocene precipitation variability on the Altiplano is anti-phased with respect to precipitation in the Northern Hemisphere monsoon region." In further support of these findings, they add that "the relationship between lake-level variation at Lake Titicaca and Holocene Bond events also is supported by the more coarsely resolved (but very well documented) record of water-level fluctuations over the past 4000 years based on the sedimentology of cores from the shallow basin of the lake (Abbott *et al*., 1997)."

Also examining a time interval spanning the length of the Holocene, Haug *et al*. (2001) utilized the titanium and iron concentrations of an ocean sediment core taken from a depth of 893 meters in the Cariaco Basin on the Northern Shelf of Venezuela (10°42.73'N, 65°10.18'W) to infer variations in the hydrologic cycle over northern South America over the past 14,000 years. Results indicated that titanium and iron concentrations were lower during the Younger Dryas cold period between 12.6 and 11.5 thousand years ago, corresponding to a weakened hydrologic cycle with less precipitation and runoff. During the Holocene Optimum (10.5 to 5.4 thousand years ago), however, concentrations of these metals remained at or near their highest values, suggesting wet conditions and an enhanced hydrologic cycle for more than five thousand years. Closer to the present, the largest century-scale variations in precipitation are inferred in the record between approximately 3.8 and 2.8 thousand years ago, as the amounts of these metals in the sediment record varied widely over short time intervals. Higher precipitation was noted during the Medieval Warm Period from 1.05 to 0.7 thousand years ago, followed by drier conditions associated with the Little Ice Age (between 550 and 200 years ago).

With respect to what factor(s) might best explain the regional changes in precipitation inferred from the Cariaco metals' records of the past 14,000 years, the authors state that the regional changes in precipitation "are best explained by shifts in the mean latitude of the Atlantic Intertropical Convergence Zone," which, in turn, "can be explained by the Holocene history of insolation, both directly and through its effect on tropical Pacific sea surface conditions."

The results of these studies in South America demonstrate the important influence of solar variations on precipitation, necessarily implying a smaller possible role or no role at all for greenhouse gases.

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

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5.4.3. Africa

We begin our examination of Africa with a study covering the period 9,600-6,100 years before present, where Neff *et al*. (2001) investigated the relationship between a ^{14}C tree-ring record and a delta^{18}O proxy record of monsoon rainfall intensity as recorded in calcite delta^{18}O data obtained from a stalagmite in northern Oman. The correlation between the two datasets was reported to be "extremely strong," and a spectral analysis of the data revealed statistically significant periodicities centered on 779, 205, 134, and 87 years for the delta^{18}O record and periodicities of 206, 148, 126, 89, 26, and 10.4 years for the ^{14}C record. Because variations in ^{14}C tree-ring records are generally attributed to variations in solar activity and intensity, and because of this particular ^{14}C record's strong correlation with the delta^{18}O record, as well as the closely corresponding results of the spectral analyses, Neff *et al*. conclude there is "solid evidence" that both signals (the ^{14}C and delta^{18}O records) are responding to solar forcing.

In another study from eastern Africa, Stager *et al*. (2003) studied changes in diatom assemblages preserved in a sediment core extracted from Pilkington Bay, Lake Victoria, together with diatom and pollen data acquired from two nearby sites. According to the authors, the three coherent datasets revealed a "roughly 1400- to 1500-year spacing of century-scale P:E [precipitation:evaporation] fluctuations at Lake Victoria," which they say "may be related to a ca. 1470-year periodicity in northern marine and ice core records that has been linked to solar variability (Bond *et al*., 1997; Mayewski *et al*., 1997)."

Further support of Stager *et al*.'s thesis comes from Verschuren *et al*. (2000), who developed a decadal-scale history of rainfall and drought in equatorial east Africa for the past thousand years based on lake-level and salinity fluctuations of a small crater-lake basin in Kenya, as reconstructed from sediment stratigraphy and the species compositions of fossil diatom and midge assemblages. They compared this history with an equally long record of atmospheric $^{14}CO_2$ production, which is a proxy for solar radiation variations.

They found equatorial east Africa was significantly drier than today during the Medieval Warm Period from AD 1000 to 1270, while it was relatively wet during the Little Ice Age from AD 1270 to 1850. However, this latter period was interrupted by three periods of prolonged dryness: 1390-1420, 1560-1625, and 1760-1840. These "episodes of persistent aridity," in the words of the authors, were "more severe than any recorded drought of the twentieth century." In addition, they discovered that "all three severe drought events of the past 700 years were broadly coeval with phases of high solar radiation, and the intervening periods of increased moisture were coeval with phases of low solar radiation."

Verschuren *et al.* note that their results "corroborate findings from north-temperate dryland regions that instrumental climate records are inadequate to appreciate the full range of natural variation in drought intensity at timescales relevant to socio-economic activity." This point is important, for with almost every new storm of significant size, with every new flood, or with every new hint of drought almost anywhere in the world, there are claims that the weather is becoming more extreme than ever before as a consequence of global warming. What we can learn from this study, however, is that there were more intense droughts in the centuries preceding the recent rise in the air's CO_2 content.

Verschuren *et al*. state that variations in solar radiative output "may have contributed to decade-scale rainfall variability in equatorial east Africa." This conclusion is hailed as robust by Oldfield (2000), who states that the thinking of the authors on this point is "not inconsistent with current views." Indeed, he too suggests that their results "provide strong evidence for a link between solar and climate variability."

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

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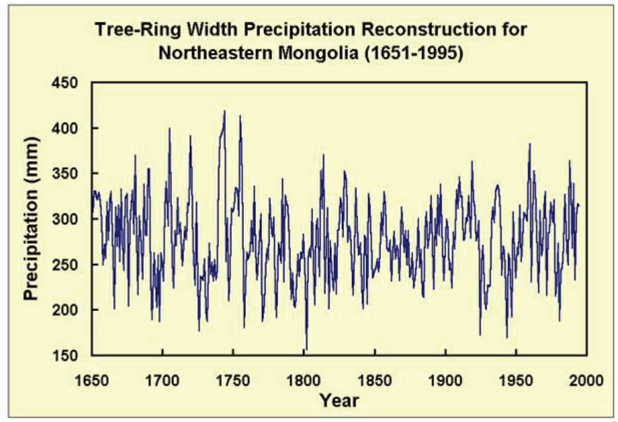
5.4.4. Asia

Our review of the influence of the sun on Asian precipitation trends begins with the study of Pederson *et al*. (2001), who utilized tree-ring chronologies from northeastern Mongolia to reconstruct annual precipitation and streamflow histories for this region over the period 1651-1995.

Analyses of both standard deviations and five-year intervals of extreme wet and dry periods revealed that "variations over the recent period of instrumental data are not unusual relative to the prior record." (See Figures 5.4.4.1 and 5.4.4.2.) The authors state, however, that the reconstructions "appear to show more frequent extended wet periods in more recent decades," but they note that this observation "does not demonstrate unequivocal evidence of an increase in precipitation as suggested by some climate models." More important to the present discussion, however, is the observation that spectral analysis of the data revealed significant periodicities of around 12 and 20-24 years, suggesting "possible evidence for solar influences in these reconstructions for northeastern Mongolia."

Nearby, Tan *et al*. (2008) developed a precipitation history of the Longxi area of the Tibetan 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. Results indicated 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." 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. As a result, the researchers ultimately concluded that the "synchronous variations between Longxi precipitation and Northern Hemisphere temperature may be ascribed to solar activity."



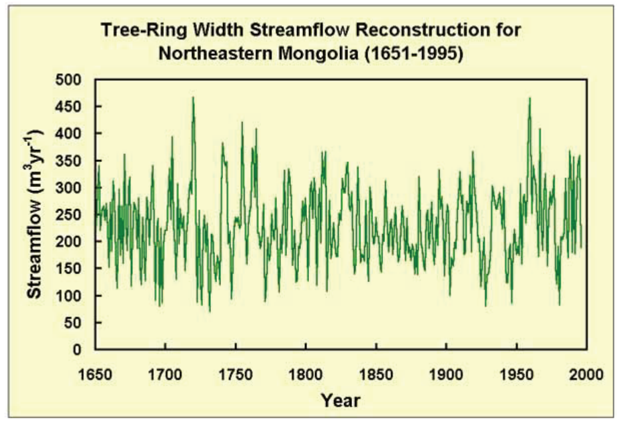


Figure 5.4.4.1. Pederson *et al.* (2001) reconstruction of annual precipitation in mm in northeastern Mongolia over the period 1651-1995.

Figure 5.4.4.2. Pederson *et al.* (2001) reconstruction of annual variation in streamflow (m3yr-1) in northeastern Mongolia over the period 1651-1995.

Paulsen *et al*. (2003) utilized "high-resolution records of $\delta^{13}C$ and $\delta^{18}O$ in stalagmite SF-1 from Buddha Cave [33°40'N, 109°05'E] ... to infer changes in climate in central China for the last 1270 years in terms of warmer, colder, wetter and drier conditions." Results indicated the presence of several major climatic episodes, including the Dark Ages Cold Period, Medieval Warm Period, Little Ice Age, and 20th-century warming, "lending support to the global extent of these events." With respect to hydrologic balance, the last part of the Dark Ages Cold Period was characterized as wet, followed by a dry, a wet, and another dry interval in the Medieval Warm Period, which was followed by a wet and a dry interval in the Little Ice Age, and finally a mostly wet but highly moisture-variable Current Warm Period. Some of this latter enhanced variability is undoubtedly due to the much finer one-year time resolution of the last 150 years of the record as compared to the three- to four-year resolution of the prior 1,120 years. This most recent improved resolution thus led to the major droughts centered on AD 1835, 1878, and 1955 being very well delineated.

The authors' data also revealed a number of other cycles superimposed on the major millennial-scale cycle of temperature and the centennial-scale cycle of moisture. They attributed most of these higher-frequency cycles to cyclical solar and lunar phenomena, concluding that the summer monsoon over eastern China, which brings the region much of its precipitation, may thus "be related to solar irradiance."

In conclusion, as we have consistently seen throughout this section, precipitation in Asia is determined by a conglomerate of cycles, many of which are solar-driven, but nearly all of which are independent of the air's CO_2 concentration.

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

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5.4.5. Europe

In this section, we investigate the natural influence of the sun on precipitation in Europe.

"Raised bogs," in the words of Blaauw *et al.* (2004), "are dependent on precipitation alone for water and nutrients." In addition, the various species of plants that are found in them each have their own requirements with respect to depth of water table. As a result, the vertical distribution of macro- and micro-fossils in raised bogs reveals much about past changes in local moisture conditions, especially, as the authors note, "about changes in effective precipitation (precipitation minus evapotranspiration)."

At the same time, changes in the carbon-14 content of bog deposits reveal something about solar activity, because, as Blaauw *et al.* describe the connection, "a decreased solar activity leads to less solar wind, reduced shielding against cosmic rays, and thus to increased production of cosmogenic isotopes [such as ^{14}C]." Consequently, it is possible to compare the histories of the two records (effective precipitation and $\delta^{14}C$) and see if inferred changes in climate bear any relationship to inferred changes in solar activity, which is exactly what Blaauw *et al.* did.

Two cores of mid-Holocene raised-bog deposits in the Netherlands were ^{14}C "wiggle-match" dated by the authors at high precision, as per the technique described by Kilian *et al.* (1995, 2000) and Blaauw *et al.* (2003), while changes in local moisture conditions were inferred from the changing species composition of consecutive series of macrofossil samples. Results indicated that nine of 11 major mid-Holocene $\delta^{14}C$ increases (for which they provide evidence that the rises were "probably caused by declines in solar activity") were coeval with major wet-shifts (for which they provide evidence that the shifts were "probably caused by climate getting cooler and/or wetter"). In the case of the significant wet-shift at the major $\delta^{14}C$ rise in the vicinity of 850 BC, they additionally note that this prominent climatic cooling has been independently documented in many parts of the world, including "the North Atlantic Ocean (Bond *et al.*, 2001), the Norwegian Sea (Calvo *et al.*, 2002) [see also Andersson *et al.* (2003)], Northern Norway (Vorren, 2001), England (Waller *et al.*, 1999), the Czech Republic (Speranza *et al.*, 2000, 2002), central southern Europe (Magny, 2004), Chile (van Geel *et al.*, 2000), New Mexico (Armour *et al.*, 2002) and across the continent of North America (Viau *et al.*, 2002)." This close correspondence between major shifts in $\delta^{14}C$ and precipitation has additionally led Mauquoy *et al.* (2004) to conclude 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."

Based upon these considerations, Blaauw *et al.* (2003) state that their findings "add to the accumulating evidence that solar variability has played an important role in forcing climatic change during the Holocene." The broad geographic extent of the observations of the 850 BC phenomenon also adds to the accumulating evidence that many of the climate changes that have occurred in the vicinity of the North Atlantic Ocean have been truly global in scope, providing even more evidence for their having been forced by variations in solar activity, which would be expected to have considerably more than a regional climatic impact.

In another bog study, cores of peat taken from two raised bogs in the near-coastal part of Halland, Southwest Sweden (Boarps Mosse and Hyltemossen) by Björck and Clemmensen (2004) were examined for their content of wind-transported clastic material via a systematic count of quartz grains of diameter 0.2-0.35 mm and larger than 0.35 mm to determine temporal variations in Aeolian Sand Influx (ASI), which is correlated with winter storminess in that part of the world.

According to the authors, "the ASI records of the last 2500 years (both sites) indicate two timescales of winter storminess variation in southern Scandinavia." Specifically, they note that "decadal-scale variation (individual peaks) seems to coincide with short-term variation in sea-ice cover in the North Atlantic and is thus related to variations in the position of the North Atlantic winter season storm tracks," while "centennial-scale changes—peak families, like high peaks 1, 2 and 3 during the Little Ice Age, and low peaks 4 and 5 during the Medieval Warm Period—seem to record longer-scale climatic variation in the frequency and severity of cold and stormy winters."

Björck and Clemmensen also found a striking association between the strongest of these winter storminess peaks and periods of reduced solar activity. They specifically note, for example, that the solar minimum between AD 1880 and 1900 "is almost exactly coeval with the period of increased storminess at the end of the nineteenth century, and the Dalton Minimum between AD 1800 and 1820 is almost coeval with the period of peak storminess reported here." In addition, they say that an event of increased storminess they dated to AD 1650 "falls at the beginning of the Maunder solar minimum (AD 1645-1715)," while further back in time they report high ASI values between AD 1450 and 1550 with "a very distinct peak at AD 1475," noting that this period coincides with the Sporer Minimum of AD 1420-1530. In addition, they call our attention to the fact that the latter three peaks in winter storminess all occurred during the Little Ice Age and "are among the most prominent in the complete record."

Shifting gears, several researchers have studied the precipitation histories of regions along the Danube River in western Europe and the effects they have on river discharge, with some of them suggesting that an anthropogenic signal is present in the latter decades of the twentieth century and is responsible for that period's drier conditions. Ducic (2005) examined such claims by analyzing observed and reconstructed river discharge rates near Orsova, Serbia over the period 1731-1990. He notes that the lowest five-year discharge value in the pre-instrumental era (period of occurrence: 1831-1835) was practically equal to the lowest five-year discharge value in the instrumental era (period of occurrence: 1946-1950), and that the driest decade of the entire 260-year period was 1831-1840. Similarly, the highest five-year discharge value for the pre-instrumental era (period of occurrence: 1736-1740) was nearly equal to the five-year maximum discharge value for the instrumental era (period of occurrence: 1876-1880), differing by only 0.7 percent. What is more, the discharge rate for the last decade of the record (1981-1990), which prior researchers had claimed was anthropogenically influenced, was found to be "completely inside the limits of the whole series," in Ducic's words, and only slightly (38 m^3s^{-1} or 0.7 percent) less than the 260-year mean of 5356 m^3s^{-1}. Thus, Ducic concludes that "modern discharge fluctuations do not point to [a] dominant anthropogenic influence." Ducic's correlative analysis suggests that the detected cyclicity in the record could "point to the domination of the influence of solar activity."

Next, we turn to 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 temperature and precipitation 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.

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 one final study, Lamy *et al*. (2006), utilized paleoenvironmental proxy data for ocean properties, eolian sediment input, and continental rainfall based on high-resolution analyses of sediment cores from the southwestern Black Sea and the northernmost Gulf of Aqaba to infer hydroclimatic changes in northern Anatolia and the northern Red Sea region during the last ~7500 years, after which the reconstructed hydroclimatic history was compared with $\Delta^{14}C$ periodicities evident in the tree-ring data of Stuiver *et al*. (1998).

Analysis of the data showed "pronounced and coherent" multi-centennial variations that the authors say "strongly resemble modern temperature and rainfall anomalies related to the Arctic Oscillation/North Atlantic Oscillation (AO/NAO)." In addition, they say that "the multicentennial variability appears to be similar to changes observed in proxy records for solar output changes," although "the exact physical mechanism that transfers small solar irradiance changes either to symmetric responses in the North Atlantic circulation or to atmospheric circulation changes involving an AO/NAO-like pattern, remains unclear."

In conclusion, each of the studies above indicates cyclical solar activity induces similar cyclical precipitation activity in Europe. They indicate, in Lamy *et al*.'s words, that "the impact of (natural) centennial-scale climate variability on future climate projections could be more substantial than previously thought."

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

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5.5. Droughts

The IPCC claims earth's climate is becoming more variable and extreme as a result of CO_2-induced global warming, and it forecasts increasing length and severity of drought as one of the consequences. In the next chapter of this report, we report evidence that modern drought frequency and severity fall well within the range of natural variability. In the present section, however, we examine the issue of attribution, specifically investigating the natural influence of the sun on drought. We begin with a review of the literature on droughts in the United States.

According to Cook *et al*. (2007), recent advances in the reconstruction of past drought over North America "have revealed the occurrence of a number of unprecedented megadroughts over the past millennium that clearly exceed any found in the instrumental records." Indeed, they state that "these past megadroughts dwarf the famous droughts of the twentieth century, such as the Dust Bowl drought of the 1930s, the southern Great Plains drought of the 1950s, and the current one in the West that began in 1999," all of which dramatic droughts pale when compared to "an epoch of significantly elevated aridity that persisted for almost 400 years over the AD 900-1300 period."

Of central importance to North American drought formation, in the words of the four researchers, "is the development of cool 'La Niña-like' SSTs in the eastern tropical Pacific." Paradoxically, as they describe the situation, "warmer conditions over the tropical Pacific region lead to the development of cool La Niña-like SSTs there, which is drought inducing over North America." In further explaining the mechanics of this phenomenon, on which both "model and data agree," Cook *et al*. state that "if there is a heating over the entire tropics then the Pacific will warm more in the west than in the east because the strong upwelling and surface divergence in the east moves some of the heat poleward," with the result that "the east-west temperature gradient will strengthen, so the winds will also strengthen, so the temperature gradient will increase further ... leading to a more La Niña-like state." They add that "La Niña-like conditions were apparently the norm during much of the Medieval period when the West was in a protracted period of elevated aridity and solar irradiance was unusually high."

Shedding some more light on the subject, Yu and Ito (1999) studied a sediment core from a closed-basin lake in the northern Great Plains of North America, producing a 2,100-year record that revealed four dominant periodicities of drought that matched "in surprising detail" similar periodicities of various solar indices. The correspondence was so close, in fact, that they say "this spectral similarity forces us to consider solar variability as the major cause of century-scale drought frequency in the northern Great Plains."

One year later, Dean and Schwalb (2000) derived a similar-length record of drought from sediment cores extracted from Pickerel Lake, South Dakota, which also exhibited recurring incidences of major drought on the northern Great Plains. They too reported that the cyclical behavior appeared to be in synchrony with similar variations in solar irradiance. After making a case for "a direct connection between solar irradiance and weather and climate," they thus concluded that "it seems reasonable that the cycles in aridity and eolian activity over the past several thousand years recorded in the sediments of lakes in the northern Great Plains might also have a solar connection."

Moving to east-central North America, Springer *et al*. (2008) derived a multi-decadal-scale record of Holocene drought based on Sr/Ca ratios and $\delta^{13}C$ data obtained from stalagmite BCC-002 from Buckeye Creek Cave (BCC), West Virginia (USA) that "grew continuously from ~7000 years B.P. to ~800 years B.P." and then again "from ~800 years B.P. until its collection in 2002."

Results of their study indicated the presence of seven significant Mid- to Late-Holocene droughts, six of which "correlate with cooling of the Atlantic and Pacific Oceans as part of the North Atlantic Ocean ice-rafted debris [IRD] cycle, which has been linked to the solar irradiance cycle," as per Bond *et al*. (2001). In addition, they determined that the Sr/Ca and $\delta^{13}C$ time series "display periodicities of ~200 and ~500 years and are coherent in those frequency bands." They also say "the ~200-year periodicity is consistent with the de Vries (Suess) solar irradiance cycle," and they "interpret the ~500-year periodicity to be a harmonic of the IRD oscillations." Noting further that "cross-spectral analysis of the Sr/Ca and IRD time series yields statistically significant coherencies at periodicities of 455 and 715 years," they go on to note that "these latter values are very similar to the second (725-years) and third (480-years) harmonics of the 1450 ± 500-years IRD periodicity." As a result of these observations, the five researchers conclude their report by saying their findings "corroborate works indicating that millennial-scale solar-forcing is responsible for droughts and ecosystem changes in central and eastern North America (Viau *et al*., 2002; Willard *et al*., 2005; Denniston *et al*., 2007)," adding that their high-resolution time series now provide even stronger evidence "in favor of solar-forcing of North American drought by yielding unambiguous spectral analysis results."

In Nevada, Mensing *et al*. (2004) analyzed a set of sediment cores extracted from Pyramid Lake for pollen and algal microfossils deposited there over the past 7,630 years that allowed them to infer the hydrological history of the area over that time period. According to the authors, "sometime after 3430 but before 2750 cal yr B.P., climate became cool and wet," but "the past 2500 yr have been marked by recurring persistent droughts." The longest of these droughts, according to them, "occurred between 2500 and 2000 cal yr B.P.," while others occurred "between 1500 and 1250, 800 and 725, and 600 and 450 cal yr B.P." They also note that "the timing and magnitude of droughts identified in the pollen record compares favorably with previously published $\delta^{18}O$ data from Pyramid Lake" and with "the ages of submerged rooted stumps in the Eastern Sierra Nevada and woodrat midden data from central Nevada." When they compared the pollen record of droughts from Pyramid Lake with the stacked petrologic record of North Atlantic drift ice of Bond *et al.* (2001), like other researchers they too found "nearly every occurrence of a shift from ice maxima (reduced solar output) to ice minima (increased solar output) corresponded with a period of prolonged drought in the Pyramid Lake record." Mensing *et al.* conclude that "changes in solar irradiance may be a possible mechanism influencing century-scale drought in the western Great Basin [of the United States]." Indeed, it would appear that variable solar activity is the major factor in determining the hydrological state of the region and all of North America.

Moving slightly south geographically, Asmerom *et al*. (2007) developed a high-resolution climate proxy for the southwest United States from $\delta^{18}O$ variations in a stalagmite found in Pink Panther Cave in the Guadalupe Mountains of New Mexico. Spectral analysis performed on the raw $\delta^{18}O$ data revealed significant peaks that the researchers say "closely match previously reported periodicities in the ^{14}C content of the atmosphere, which have been attributed to periodicities in the solar cycle (Stuiver and Braziunas, 1993)." More specifically, they say that cross-spectral analysis of the $\Delta^{14}C$ and $\delta^{18}O$ data confirms that the two records have matching periodicities at 1,533 years (the Bond cycle), 444 years, 170 years, 146 years, and 88 years (the Gleissberg cycle). In addition, they report that periods of increased solar radiation correlate with periods of decreased rainfall in the southwestern United States (via changes in the North American monsoon), and that this behavior is just the opposite of what is observed with the Asian monsoon. These observations thus lead them to suggest that the proposed solar link to Holocene climate operates "through changes in the Walker circulation and the Pacific Decadal Oscillation and El Niño-Southern Oscillation systems of the tropical Pacific Ocean."

Making our way to Mexico, Hodell *et al*. (2001) analyzed sediment cores obtained from Lake Chichancanab on the Yucatan Peninsula, reconstructing the climatic history of this region over the past 2,600 years. Long episodes of drought were noted throughout the entire record, and spectral analysis revealed a significant periodicity that matched well with a cosmic ray-produced ^{14}C record preserved in tree rings that is believed to reflect variations in solar activity. Hence, they too concluded that "a significant component of century-scale variability in Yucatan droughts is explained by solar forcing."

Expanding the geographical scope of such studies, Black *et al.* (1999) found evidence of substantial decadal and centennial climate variability in a study of ocean sediments in the southern Caribbean that were deposited over the past 825 years. Their data suggested that climate regime shifts are a natural aspect of Atlantic variability; in relating these features to records of terrestrial climate, they concluded that "these shifts may play a role in triggering changes in the frequency and persistence of drought over North America." In addition, because there was a strong correspondence between these phenomena and similar changes in ^{14}C production rate, they further concluded that "small changes in solar output may influence Atlantic variability on centennial time scales."

Moving to Africa, Verschuren *et al*. (2000) conducted a similar study in a small lake in Kenya, documenting the existence of three periods of prolonged dryness during the Little Ice Age that were, in their words, "more severe than any recorded drought of the twentieth century." In addition, they discovered that all three of these severe drought events "were broadly coeval with phases of high solar radiation"—as inferred from ^{14}C production data—"and the intervening periods of increased moisture were coeval with phases of low solar radiation." They thus concluded that variations in solar activity "may have contributed to decade-scale rainfall variability in equatorial east Africa."

Also in Africa, working with three sediment cores extracted from Lake Edward (0°N, 30°E), Russell and

Johnson (2005) developed a continuous 5,400-year record of Mg concentration and isotopic composition of authigenic inorganic calcite as proxies for the lake's water balance, which is itself a proxy for regional drought conditions in equatorial Africa. They found "the geochemical record from Lake Edward demonstrates a consistent pattern of equatorial drought during both cold and warm phases of the North Atlantic's '1500-year cycle' during the late Holocene," noting that similar "725-year climate cycles" are found in several records from the Indian and western Pacific Oceans and the South China Sea, citing as authority for the latter statement the studies of von Rad *et al*. (1999), Wang *et al*. (1999), Russell *et al*. (2003) and Staubwasser *et al*. (2003). In light of these findings, the two scientists say their results "show that millennial-scale high-latitude climate events are linked to changes in equatorial terrestrial climate ... during the late Holocene," or as they phrase it in another place, that their results "suggest a spatial footprint in the tropics for the '1500-year cycle' that may help to provide clues to discern the cycle's origin," noting there is already reason to believe that it may be solar-induced.

Lastly, Garcin *et al*. (2007) explored hydrologic change using late-Holocene paleoenvironmental data derived from several undisturbed sediment cores retrieved from the deepest central part of Lake Masoko (9°20.0'S, 33°45.3'E), which occupies a maar crater in the Rungwe volcanic highlands of the western branch of Africa's Rift Valley, where it is situated approximately 35 km north of Lake Malawi.

According to the 10 researchers who conducted the work, "magnetic, organic carbon, geochemical proxies and pollen assemblages indicate a dry climate during the 'Little Ice Age' (AD 1550-1850), confirming that the LIA in eastern Africa resulted in marked and synchronous hydrological changes," although "the direction of response varies between different African lakes." In this regard, for example, they report that "to the south (9.5-14.5°S), sediment cores from Lake Malawi have revealed similar climatic conditions (Owen *et al*., 1990; Johnson *et al*., 2001; Brown and Johnson, 2005)" that are "correlated with the dry period of Lakes Chilwa and Chiuta (Owen and Crossley, 1990)," and they say that "lowstands have been also observed during the LIA at Lake Tanganyika ... from AD 1500 until AD 1580, and from ca. AD 1650 until the end of the 17th century, where the lowest lake-levels are inferred (Cohen *et al*., 1997; Alin and Cohen, 2003)." By contrast, however, they report that "further north, evidence from Lakes Naivasha (0.7°S) and Victoria (2.5°S-0.5°N) indicates relatively wet conditions with high lake-levels during the LIA, interrupted by short drought periods (Verschuren *et al*., 2000; Verschuren, 2004; Stager *et al*., 2005)." Lastly, Garcin *et al*. state that "inferred changes of the Masoko hydrology are positively correlated with the solar activity proxies."

In discussing their findings, the African and French scientists note the Little Ice Age in Africa appears to have had a greater thermal amplitude than it did in the Northern Hemisphere, citing in support of this statement the paleoclimate studies of Bonnefille and Mohammed (1994), Karlén *et al*. (1999), Holmgren *et al*. (2001), and Thompson *et al*. (2002). Nevertheless, the more common defining parameter of the Little Ice Age in Africa was the moisture status of the continent, which appears to have manifested opposite directional trends in different latitudinal bands. In addition, the group of scientists emphasizes that the positive correlation of Lake Masoko hydrology with various solar activity proxies "implies a forcing of solar activity on the atmospheric circulation and thus on the regional climate of this part of East Africa."

There seems to be little question but what variations in solar activity have been responsible for much of the drought variability of the Holocene in many parts of the world.

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

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5.6. Floods

The IPCC claims that floods will become more variable and extreme as a result of CO_2-induced global warming. In the next chapter of this report, we show modern flood frequency and severity fall well within the range of natural variability. In the present section, we limit our examination once again to the issue of attribution, specifically investigating the influence of the sun on floods.

We begin by reviewing what is known about the relationship of extreme weather events to climate in Europe during the Holocene. According to Starkel (2002), in general, more extreme fluvial activity, of both the erosional and depositional type, is associated with cooler climates. “Continuous rains and high-intensity downpours,” writes Starkel, were most common during the Little Ice Age. Such “flood phases,” the researcher reports, “were periods of very unstable weather and frequent extremes of various kinds.” More related to the present discussion, Starkel also notes that “most of the phases of high frequency of extreme events during the Holocene coincide with the periods of declined solar activity.”

Noren *et al*. (2002) extracted sediment cores from 13 small lakes distributed across a 20,000-km^2 region in Vermont and eastern New York, after which several techniques were used to identify and date terrigenous in-wash layers that depict the frequency of storm-related floods. Results of the analysis showed that “the frequency of storm-related floods in the northeastern United States has varied in regular cycles during the past 13,000 years (13 kyr), with a characteristic period of about 3 kyr.” There were four major storminess peaks during this period; they occurred approximately 2.6, 5.8, 9.1, and 11.9 kyr ago, with the most recent upswing in storminess beginning “at about 600 yr BP [before present], coincident with the beginning of the Little Ice Age.” With respect to the causative factor(s) behind the cyclic behavior, Noren *et al*. state that the pattern they observed “is consistent with long-term changes in the average sign of the Arctic Oscillation [AO],” further suggesting that “changes in the AO, perhaps modulated by solar forcing, may explain a significant portion of Holocene climate variability in the North Atlantic region.”

Also working in the United States, Schimmelmann *et al*. (2003) identified conspicuous gray clay-rich flood deposits in the predominantly olive varved sediments of the Santa Barbara Basin off the coast of California, which they accurately dated by varve-counting. Analysis of the record revealed six prominent flood events that occurred at approximately AD 212, 440, 603, 1029, 1418, and 1605, “suggesting,” in their words, “a quasi-periodicity of ~200 years,” with “skipped” flooding just after AD 800, 1200, and 1800. They further note that “the floods of ~AD 1029 and 1605 seem to have been associated with brief cold spells,” that “the flood of ~AD 440 dates to the onset of the most unstable marine climatic interval of the Holocene (Kennett and Kennett, 2000),” and that “the flood of ~AD 1418 occurred at a time when the global atmospheric circulation pattern underwent fundamental reorganization at the beginning of the ‘Little Ice Age’ (Kreutz *et al*., 1997; Meeker and Mayewski, 2002).” Lastly, they report that “the quasi-periodicity of ~200 years for southern California floods matches the ~200-year periodicities found in a variety of high-resolution palaeoclimate archives and, more importantly, a *c*.208-year cycle of solar activity and inferred changes in atmospheric circulation.”

As a result of these findings, Schimmelmann *et al*. “hypothesize that solar-modulated climatic background conditions are opening a ~40-year window of opportunity for flooding every ~200 years,” and that “during each window, the danger of flooding is exacerbated by additional climatic and environmental cofactors." They also note that "extrapolation of the ~200-year spacing of floods into the future raises the uncomfortable possibility for historically unprecedented flooding in southern California during the first half of this century." When such flooding occurs, there will be no need to suppose it came as a consequence of what the IPCC calls the unprecedented warming of the past century.

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

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5.7. Monsoons

The IPCC's computer models fail to predict variability in monsoon weather. One reason is because they underestimate the sun's role.

For the period 9,600-6,100 years before present, Neff *et al*. (2001) investigated the relationship between a ^{14}C tree-ring record and a $\delta^{18}O$ proxy record of monsoon rainfall intensity as recorded in calcite $\delta^{18}O$ data obtained from a stalagmite in northern Oman. According to the authors, the correlation between the two datasets was reported to be "extremely strong," and a spectral analysis of the data revealed statistically significant periodicities centered on 779, 205, 134, and 87 years for the $\delta^{18}O$ record and periodicities of 206, 148, 126, 89, 26, and 10.4 years for the ^{14}C record.

Because variations in ^{14}C tree-ring records are generally attributed to variations in solar activity and intensity, and because of this particular ^{14}C record's strong correlation with the $\delta^{18}O$ record, as well as the closely corresponding results of the spectral analyses, the authors conclude there is "solid evidence" that both signals (the ^{14}C and $\delta^{18}O$ records) are responding to solar forcing.

Similar findings were reported by Lim *et al*. (2005), who examined the eolian quartz content (EQC) of a high-resolution sedimentary core taken from Cheju Island, Korea, creating a 6,500-year proxy record of major Asian dust events produced by northwesterly winter monsoonal winds that carry dust from the inner part of China all the way to Korea and the East China Sea. The Asian dust time series was found to contain both millennial- and centennial-scale periodicities; cross-spectral analysis between the EQC and a solar activity record showed significant coherent cycles at 700, 280, 210, and 137 years with nearly the same phase changes, leading the researchers to conclude that centennial-scale periodicities in the EQC could be ascribed primarily to fluctuations in solar activity.

In another study, Ji *et al*. (2005) used reflectance spectroscopy on a sediment core taken from Qinghai Lake in the northeastern part of the Qinghai-Tibet Plateau to construct a continuous high-resolution proxy record of the Asian monsoon over the past 18,000 years. As a result of this effort, monsoonal moisture since the late glacial period was shown to be subject to "continual and cyclic variations," including the well-known centennial-scale cold and dry spells of the Dark Ages Cold Period (DACP) and Little Ice Age, which lasted from 2,100 to 1,800 yr BP and 780 to 400 yr BP, respectively. Sandwiched between them was the warmer and wetter Medieval Warm Period, while preceding the DACP was the Roman Warm Period. Also, time series analysis of the sediment record revealed statistically significant periodicities (above the 95 percent level) of 123, 163, 200, and 293 years. The third of these periodicities corresponds well with the de Vries or Suess solar cycle, which suggests cyclical changes in solar activity are important triggers for some of the cyclical changes in monsoon moisture at Qinghai Lake.

Citing studies that suggest the Indian summer monsoon may be sensitive to changes in solar forcing of as little as 0.25 percent (Overpeck *et al*., 1996; Neff *et al*., 2001; Fleitmann *et al*., 2003), Gupta *et al*. (2005) set out to test this hypothesis by comparing trends in the Indian summer monsoon with trends in solar activity across the Holocene. In this endeavor, temporal trends in the Indian summer monsoon were inferred from relative abundances of fossil shells of the planktic foraminifer *Globigerina bulloides* in sediments of the Oman margin, while temporal trends in solar variability were inferred from relative abundances of ^{14}C, ^{10}Be and haematite-stained grains.

Spectral analyses of the various datasets revealed statistically significant periodicities in the *G. bulloides* time series centered at 1550, 152, 137, 114, 101, 89, 83, and 79 years, all but the first of which periodicities closely matched periodicities of sunspot numbers centered at 150, 132, 117, 104, 87, 82, and 75 years. This close correspondence, in the words of Gupta *et al*., provides strong evidence for a "century-scale relation between solar and summer monsoon variability." In addition, they report that intervals of monsoon minima correspond to intervals of low sunspot numbers, increased production rates of the cosmogenic nuclides ^{14}C and ^{10}Be, and increased advection of drift ice in the North Atlantic, such that over the past 11,100 years "almost every multi-decadal to centennial scale decrease in summer monsoon strength is tied to a distinct interval of reduced solar output," and nearly every increase "coincides with elevated solar output," including a stronger monsoon (high solar activity) during the Medieval Warm Period and a weaker monsoon (low solar activity) during the Little Ice Age.

As for the presence of the 1,550-year cycle in the Indian monsoon data, Gupta *et al*. consider it to be "remarkable," since this cycle has been identified in numerous climate records of both the Holocene and the last glacial epoch (including Dansgaard/Oeschger cycles in the North Atlantic), strengthening the case for a sun-monsoon-North Atlantic link. Given the remarkable findings of this study, it is no wonder the researchers who conducted it say they are "convinced" there is a direct solar influence on the Indian summer monsoon in which small changes in solar output bring about pronounced changes in tropical climate.

In still another study, Khare and Nigam (2006) examined variations in angular-asymmetrical forms of benthic foraminifera and planktonic foraminiferal populations in a shallow-water sediment core obtained just off Kawar (14°49'43"N, 73°59'37"E) on the central west coast of India, which receives heavy river discharge during the southwest monsoon season (June to September) from the Kali and Gangavali rivers.

Down-core plots of the data showed three major troughs separated by intervening peaks; "since angular-asymmetrical forms and planktonic foraminiferal population are directly proportional to salinity fluctuations," according to Khare and Nigam, "the troughs ... suggest low salinity (increased river discharge and thus more rainfall)," and that "these wet phases are alternated by dry conditions." They further report that the dry episodes of higher salinity occurred from AD 1320-1355, 1445-1535, and 1625-1660, and that the wet phases were centered at approximately AD 1410, 1590, and 1750, close to the ending of the sunspot minima of the Wolf Minima (AD 1280-1340), the Sporer Minima (AD 1420-1540), and the Maunder Minima (AD 1650-1710), respectively.

Although Khare and Nigam say that "providing a causal mechanism is beyond the scope of the present study," they note that "the occurrence of periods of enhanced monsoonal precipitation slightly after the termination of the Wolf, Sporer and Maunder minima periods (less sun activity) and concomitant temperature changes could be a matter of further intense research." The correspondences seem to be more than merely coincidental, especially when the inferences of the two researchers are said by them to be "in agreement with the findings of earlier workers, who reported high lake levels from Mono Lake and Chad Lake in the vicinity of solar minima," as well as the Nile river in Africa, which "witnessed high level at around AD 1750 and AD 1575."

Nearby in the Arabian Sea, Tiwari *et al*. (2005) conducted a high-resolution (~50 years) oxygen isotope analysis of three species of planktonic foraminifera (*Globigerinoides ruber*, *Gs. sacculifer* and *Globarotalia menardii*) contained in a sediment core extracted from the eastern continental margin (12.6°N, 74.3°E) that covered the past 13,000 years. Data for the final 1,200 years of this period were compared with the reconstructed total solar irradiance (TSI) record developed by Bard *et al*. (2000), which is based on fluctuations of ^{14}C and ^{10}Be production rates obtained from tree rings and polar ice sheets.

Results of the analysis showed that the Asian SouthWest Monsoon (SWM) "follows a dominant quasi periodicity of ~200 years, which is similar to that of the 200-year Suess solar cycle (Usokin *et al*., 2003).” This finding indicates, in their words, “that SWM intensity on a centennial scale is governed by variation in TSI,” which “reinforces the earlier findings of Agnihotri *et al*. (2002) from elsewhere in the Arabian Sea.” However, in considering the SWM/TSI relationship, the five researchers note that “variations in TSI (~0.2%) seem to be too small to perturb the SWM, unless assisted by some internal amplification mechanism with positive feedback.” In this regard, they discuss two possible mechanisms. The first, in their words, “involves heating of the earth’s stratosphere by increased absorption of solar ultraviolet (UV) radiation by ozone during periods of enhanced solar activity (Schneider, 2005).” According to this scenario, more UV reception leads to more ozone production in the stratosphere, which leads to more heat being transferred to the troposphere, which leads to enhanced evaporation from the oceans, which finally enhances monsoon winds and precipitation. The second mechanism, as they describe it, is that “during periods of higher solar activity, the flux of galactic cosmic rays to the earth is reduced, providing less cloud condensation nuclei, resulting in less cloudiness (Schneider, 2005; Friis-Christensen and Svensmark, 1997),” which then allows for “extra heating of the troposphere” that “increases the evaporation from the oceans.”

In another study, Dykoski *et al*. (2005) obtained high-resolution records of stable oxygen and carbon isotope ratios from a stalagmite recovered from Dongge Cave in southern China and utilized them to develop a proxy history of Asian monsoon variability over the last 16,000 years. In doing so, they discovered numerous centennial- and multi-decadal-scale oscillations in the record that were up to half the amplitude of interstadial events of the last glacial age, indicating that “significant climate variability characterizes the Holocene.” As to what causes this variability, spectral analysis of $\delta^{14}C$ data revealed significant peaks at solar periodicities of 208, 86, and 11 years, which they say is “clear evidence that some of the variability in the monsoon can be explained by solar variability.”

Building upon this work, as well as that of Yuan *et al*. (2004), Wang *et al*. (2005) developed a shorter (9,000-year) but higher-resolution (4.5-year) absolute-dated $\delta^{18}O$ monsoon record for the same location, which they compared with atmospheric ^{14}C data and climate records from lands surrounding the North Atlantic Ocean. This work indicated their monsoon record broadly followed summer insolation but was punctuated by eight significantly weaker monsoon periods lasting from one to five centuries, most of which coincided with North Atlantic ice-rafting events. In addition, they found that “cross-correlation of the decadal- to centennial-scale monsoon record with the atmospheric ^{14}C record shows that some, but not all, of the monsoon variability at these frequencies results from changes in solar output,” similar to “the relation observed in the record from a southern Oman stalagmite (Fleitmann *et al*., 2003).”

In a news item by Kerr (2005) accompanying the report of Wang *et al*., one of the report’s authors (Hai Cheng of the University of Minnesota) was quoted as saying their study suggests that “the intensity of the summer [East Asian] monsoon is affected by solar activity.” Dominik Fleitman, who worked with the Oman stalagmite, also said that “the correlation is very strong,” stating that it is probably the best monsoon record he had seen, calling it “even better than ours.” Lastly, Gerald North of Texas A & M University, who Kerr described as a “longtime doubter,” admitted that he found the monsoon’s solar connection “very hard to refute,” although he stated that “the big mystery is that the solar signal should be too small to trigger anything.”

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

In the words of the authors, the dated paleosols and peat layers “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.” 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. 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,” which correlation implies solar forcing (see Bond *et al*., 2001) 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.

We end with a study of the North American monsoon by Asmerom *et al*. (2007), who developed a high-resolution climate proxy for the southwest United States in the form of $\delta^{18}O$ variations in a stalagmite found in Pink Panther Cave in the Guadalupe Mountains of New Mexico.

Spectral analysis performed on the raw $\delta^{18}O$ data revealed significant peaks that the researchers say "closely match previously reported periodicities in the ^{14}C content of the atmosphere, which have been attributed to periodicities in the solar cycle (Stuiver and Braziunas, 1993)." More specifically, they say that cross-spectral analysis of the $\Delta^{14}C$ and $\delta^{18}O$ data confirms that the two records have matching periodicities at 1,533 years (the Bond cycle), 444 years, 170 years, 146 years, and 88 years (the Gleissberg cycle). In addition, they report that periods of increased solar radiation correlate with periods of decreased rainfall in the southwestern United States (via changes in the North American monsoon), and that this behavior is just the opposite of what is observed with the Asian monsoon. These observations thus lead them to suggest that the proposed solar link to Holocene climate operates "through changes in the Walker circulation and the Pacific Decadal Oscillation and El Niño-Southern Oscillation systems of the tropical Pacific Ocean."

In conclusion, research conducted in countries around the world has found a significant effect of solar variability on monsoons. This necessarily implies a small role, or no role, for anthropogenic causes.

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

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5.8. Streamflow

In this section we highlight some of the scientific literature that demonstrates the influence of solar viability on streamflow, a climate variable related to precipitation, droughts, and floods. If a significant influence exists, it follows that greenhouse gases or global warming (regardless of its cause) played a smaller or even non-existent role in streamflow trends during the twentieth century.

Starting in northeastern Mongolia, Pederson *et al*. (2001) used tree-ring chronologies to reconstruct annual precipitation and streamflow histories in this region over the period 1651-1995. Analyses of both standard deviations and five-year intervals of extreme wet and dry periods revealed that "variations over the recent period of instrumental data are not unusual relative to the prior record." The authors state, however, that the reconstructions "appear to show more frequent extended wet periods in more recent decades," but they note this observation "does not demonstrate unequivocal evidence of an increase in precipitation as suggested by some climate models." More relevant to the present discussion is the researchers' observation that spectral analysis of the data revealed significant periodicities around 12 and 20-24 years, suggesting "possible evidence for solar influences in these reconstructions for northeastern Mongolia."

In Western Europe, several researchers have studied precipitation histories of regions along the Danube River and the effects they have on river discharge, with some of them suggesting that an anthropogenic signal is present in the latter decades of the twentieth century and is responsible for that period's drier conditions. In an effort to validate such claims, Ducic (2005) analyzed observed and reconstructed river discharge rates near Orsova, Serbia over the period 1731-1990.

Results of the study indicated that the lowest five-year discharge value in the pre-instrumental era (period of occurrence: 1831-1835) was practically equal to the lowest five-year discharge value in the instrumental era (period of occurrence: 1946-1950), and that the driest decade of the entire 260-year period was 1831-1840. Similarly, the highest five-year discharge value for the pre-instrumental era (period of occurrence: 1736-1740) was nearly equal to the five-year maximum discharge value for the instrumental era (period of occurrence: 1876-1880), differing by only 0.7 percent. What is more, the discharge rate for the last decade of the record (1981-1990), which prior researchers had claimed was anthropogenically influenced, was found to be "completely inside the limits of the whole series," in Ducic's words, and only slightly (38 m^3s^{-1} or 0.7 percent) less than the 260-year mean of 5356 m^3s^{-1}. In conclusion, Ducic states that "modern discharge fluctuations do not point to [a] dominant anthropogenic influence." Ducic's correlative analysis suggests that the detected cyclicity in the record may "point to the domination of the influence of solar activity."

Solar-related streamflow oscillations have also been reported for the Nile. Kondrashov *et al*. (2005), for example, applied advanced spectral methods to fill in data gaps and locate interannual and interdecadal periodicities in historical records of annual low- and high-water levels on the Nile over the 1,300-year period AD 622 to 1922. In doing so, they found several statistically significant periodicities, including cycles of 256, 64, 19, 12, 7, 4.2, and 2.2 years. With respect to the causes of these cycles, Kondrashov *et* *al*. say the 4.2- and 2.2-year oscillations are likely the product of El Niño-Southern Oscillation variations. They find the 7-year cycle may be related to North Atlantic influences, according to them, while the longer-period oscillations may be due to solar-related forcings.

Mauas *et al*. (2008) write that river streamflows "are excellent climatic indicators," especially in the case of rivers "with continental scale basins" that "smooth out local variations" and can thus "be particularly useful to study global forcing mechanisms." Focusing on South America's Parana River—the world's fifth largest in terms of drainage area and its fourth largest with respect to streamflow—Mauas *et al*. analyzed streamflow data collected continuously on a daily basis since 1904. With respect to periodicities, they report that the detrended time series of the streamflow data were correlated with the detrended times series of both sunspot number and total solar irradiance, yielding Pearson's correlation coefficients between streamflow and the two solar parameters of 0.78 and 0.69, respectively, at "a significance level higher than 99.99% in both cases." This is strong evidence indeed that solar variability, and nont man-made greenhouse gas emissions, were responsible for variation in streamflow during the modern industrial era.

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

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