Chapter 10

Solar Changes and the Climate

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Chapter Outline

1. INTRODUCTION

The IPCC AR4 discussed at length the varied research on the direct solar irradiance variance and the uncertainties related to indirect solar influences through variance through the solar cycles of ultraviolet and solar wind/geomagnetic activity. They admit that ultraviolet radiation by warming through ozone chemistry and geomagnetic activity through the reduction of cosmic rays and through that low clouds could have an effect on climate but in the end chose to ignore the indirect effect. They stated:

"Since TAR, new studies have confirmed and advanced the plausibility of indirect effects involving the modification of the stratosphere by solar UV irradiance variations (and possibly by solar-induced variations in the overlying mesosphere and lower thermosphere), with subsequent dynamical and radiative coupling to the troposphere. Whether solar wind fluctuations (Boberg and Lundstedt, 2002) or solar-induced heliospheric

Evidence-Based Climate Science. DOI: 10.1016/B978-0-12-385956-3.10010-5

modulation of galactic cosmic rays (Marsh and Svensmark, 2000b) also contribute indirect forcings remains ambiguous." (2.7.1.3)

For the total solar forcing, in the end the AR4 chose to ignore the considerable recent peer review in favor of Wang et al. (2005) who used an untested flux transport model with variable meridional flow hypothesis and reduced the net long-term variance of direct solar irradiance since the mini-ice age around 1,750 by up to a factor of 7. This may ultimately prove to be AR4's version of the AR3's "hockey stick" debacle.

2. EARTH–SUN CONNECTION

The sun is the ultimate source of all the energy on Earth; its rays heat the planet and drive the churning motions of its atmosphere. The brightness (irradiance) of the sun has been measured during recent 11 year solar cycles to vary just 0.1%. A conundrum for meteorologists was explaining whether and how such a small variation could drive major changes in weather patterns on Earth.

Though the sun's brightness or irradiance changes only slightly with the solar cycles, the indirect effects of enhanced solar activity including warming of the atmosphere in low and mid-latitudes by ozone reactions due to increased ultraviolet radiation, in higher latitudes by geomagnetic activity and generally by increased solar radiative forcing due to less clouds caused by cosmic ray reduction may greatly magnify the total solar effect on temperatures.

The following is an assessment of the ways the sun may influence weather and climate on short and long time scales.

2.1. The Sun Plays a Role in Our Climate in Direct and Indirect Ways

The sun changes in its activity on time scales that vary from 27 days to 11, 22, 80, 180 years and more. A more active sun is brighter due to the dominance of faculae over cooler sunspots with the result that the irradiance emitted by the sun and received by the earth is higher during active solar periods than during quiet solar periods. The amount of change of the solar irradiance based on satellite measurements since 1978 during the course of the 11-year-cycle just 0.1% (Willson and Hudson 1988) has caused many to conclude that the solar effect is negligible especially in recent years. Over the ultra-long cycles (since the Maunder Minimum), irradiance changes are estimated to be as high as 0.4% (Hoyt and Schatten, 1997; Lean et al., 1995; Lean, 2000; Lockwood and Stamper, 1999; Fligge and Solanki, 2000). This current cycle has seen a decline of 0.15%.

However, this does not take into account the sun's eruptional activity (flares, solar wind bursts from coronal mass ejections and solar wind bursts from coronal holes) which may have a much greater effect. This takes on more importance since Lockwood et al. (1999) showed how the total magnetic flux leaving the sun has increased by a factor of 2.3 since 1901. This eruptional activity may enhance warming through ultraviolet-induced ozone chemical reactions in the high atmosphere or ionization in higher latitudes during solar-induced geomagnetic storms. In addition, the work of Svensmark (2007), Palle Bago and Butler (2000), and Tinsley and Yu (2002) have documented the possible effects of the solar cycle on cosmic rays and through them the amount of low cloudiness. It may be that through these other indirect factors, solar variance is a much more important driver for climate change than currently assumed. Because, it is more easily measured and generally we find eruptional activity tracking well with the solar irradiance, we may utilize solar irradiance measurements as a surrogate or proxy for the total solar effect.

2.2. Correlations with Total Solar Irradiance

Studies vary on the importance of direct solar irradiance especially in recent decades. Lockwood and Stamper (GRL 1999) estimated that changes in solar luminosity can account for 52% of the change in temperatures from 1910 to 1960 but just 31% of the change from 1970 to 1999.

N. Scafetta and B. J. West of Duke University, in "*Phenomenological Solar Signature in 400 years of Reconstructed Northern Hemisphere Temperature Record*" (GRL 2006 and b0) showed how total solar irradiance accounted for up to 50% of the warming since 1900 and 25−35% since 1980. The authors noted the recent departures may result "from spurious non-climatic contamination of the surface observations such as heat-island and land-use effects [Pielke et al., 2002; Kalnay and Cai, 2003]". There analysis was done using the global databases which may also suffer from station dropout and improper adjustment for missing data which increased in the 1990s. In 2007, in their follow-up paper in the GRL, they noted the sun could account for as much as 69% of the changes since 1900.

This USHCN database though regional in nature would have been a better station database to use for analysis of change as it is more stable, has less missing data, and a better scheme for adjusting for missing data, as well as some adjustments for changes to siting and urbanization.

An independent analysis was conducted using the USHCN data and TSI data obtained from Hoyt and Schatten. The annual TSI composite record was constructed by Hoyt and Schatten (1993) (and updated in 2005) utilizing all five historical proxies of solar irradiance including sunspot cycle amplitude, sunspot cycle length, solar equatorial rotation rate, fraction of penumbral spots, and decay rate of the 11-year sunspot cycle.

The following includes a plot of this latest 11-year running mean solar irradiance vs. a similar 11-year running mean of NCDC annual mean US temperatures. It confirms this moderately strong correlation (r-squared of 0.59).

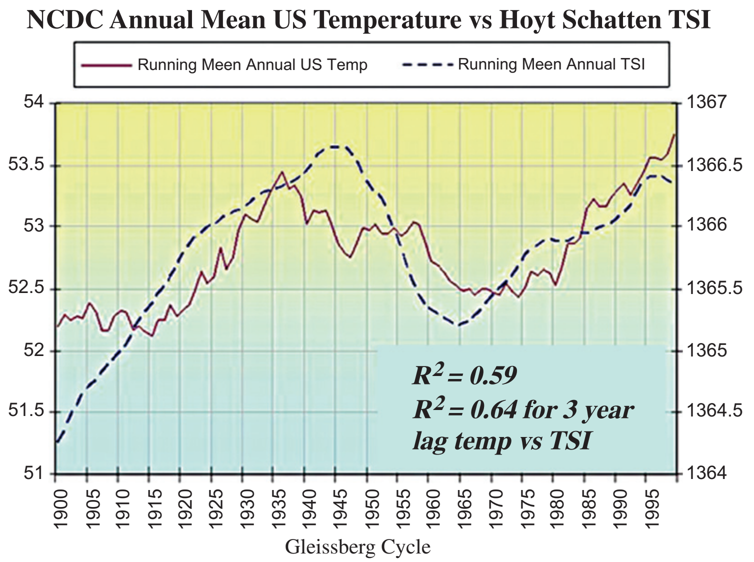

FIGURE 1 USHCN annual mean temperature (11-year running mean) correlated with Hoyt-Schatten-Willson total solar irradiance (also 11-year running mean).

The correlation increases to an *r*-squared value of 0.654 if you introduce a lag of 3 years for the mean USHCN data to the mean TSI. This is close to the 5-year lag suggested by Wigley and used by Scafetta and West. The highest correlation occurred with a 3-year lag (Fig. 1).

In recent years, satellite missions designed to measure changes in solar irradiance though promising have produced there own set of problems. As Judith Lean noted the problems is that no one sensor collected data over the entire time period from 1979 "forcing a splicing of from different instruments, each with their own accuracy and reliability issues, only some of which we are able to account for". Fröhlich and Lean in their 1998 GRL paper gave their assessment which suggested no increase in solar irradiance in the 1980s and 1990s.

Richard Willson, principal investigator of NASA's ACRIM experiments though in the GRL in 2003 was able to find specific errors in the data set used by Lean and Froelich used to bridge the gap between the ACRIM satellites and when the more accurate data set was used a trend of 0.05% per decade was seen which could account for warming since 1979 (Fig. 2).

Two other recent studies that have drawn clear connections between solar changes and the Earth's climate are Soon (2005) and Kärner (2002). Soon (2005 GRL) showed how the arctic temperatures (the arctic of course has no urbanization contamination) correlated with solar irradiance far better than with the greenhouse gases over the last century (see Fig. 3). For the 10-year running mean of total solar irradiance (TSI) vs. Arctic-wide air temperature

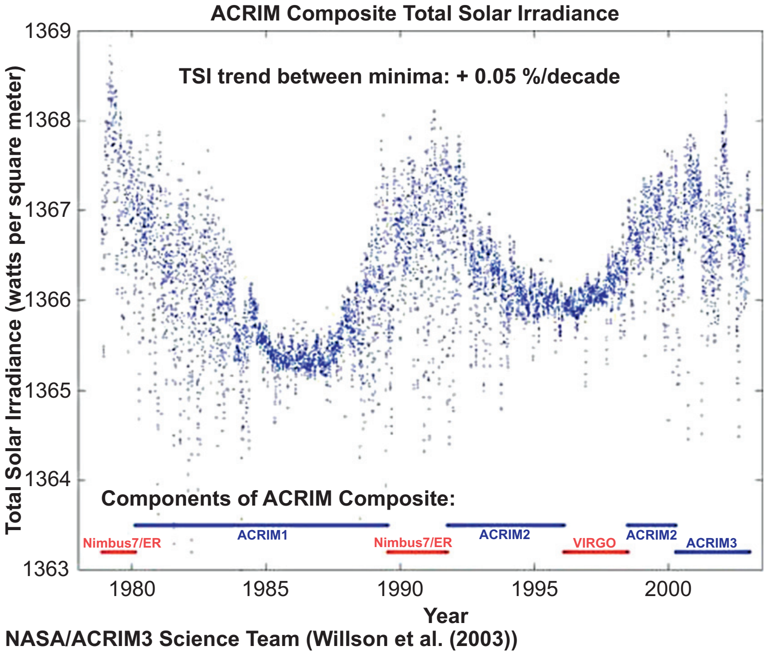

FIGURE 2 Richard Willson (ACRIMSAT) composite TSI showing trend of +0.05%/decade from successive solar minima.

anomalies (Polyokov), he found a strong correlation of (r-squared of 0.79) compared to a correlation vs. greenhouse gases of just 0.22.

2.3. Warming Due to Ultraviolet Effects Through Ozone Chemistry

Though solar irradiance varies slightly over the 11-year cycle, radiation at longer UV wavelengths is known to increase by several (6–8% or more) percent with still larger changes (factor of two or more) at extremely short UV and X-ray wavelengths (Baldwin and Dunkerton, JAS 2004).

Energetic flares increase the UV radiation by 16%. Ozone in the stratosphere absorbs this excess energy and this heat has been shown to propagate downward and affect the general circulation in the troposphere. Shindell et al. (1999) used a climate model that included ozone chemistry to reproduce this warming during high flux (high UV) years. Labitzke and Van Loon (1988) and later Labitzke in numerous papers have shown that high flux (which correlates very well with UV) produces a warming in low and middle latitudes in winter in the stratosphere with subsequent dynamical and radiative coupling to the troposphere. The winter of 2001/02, when cycle 23 had a very strong high flux

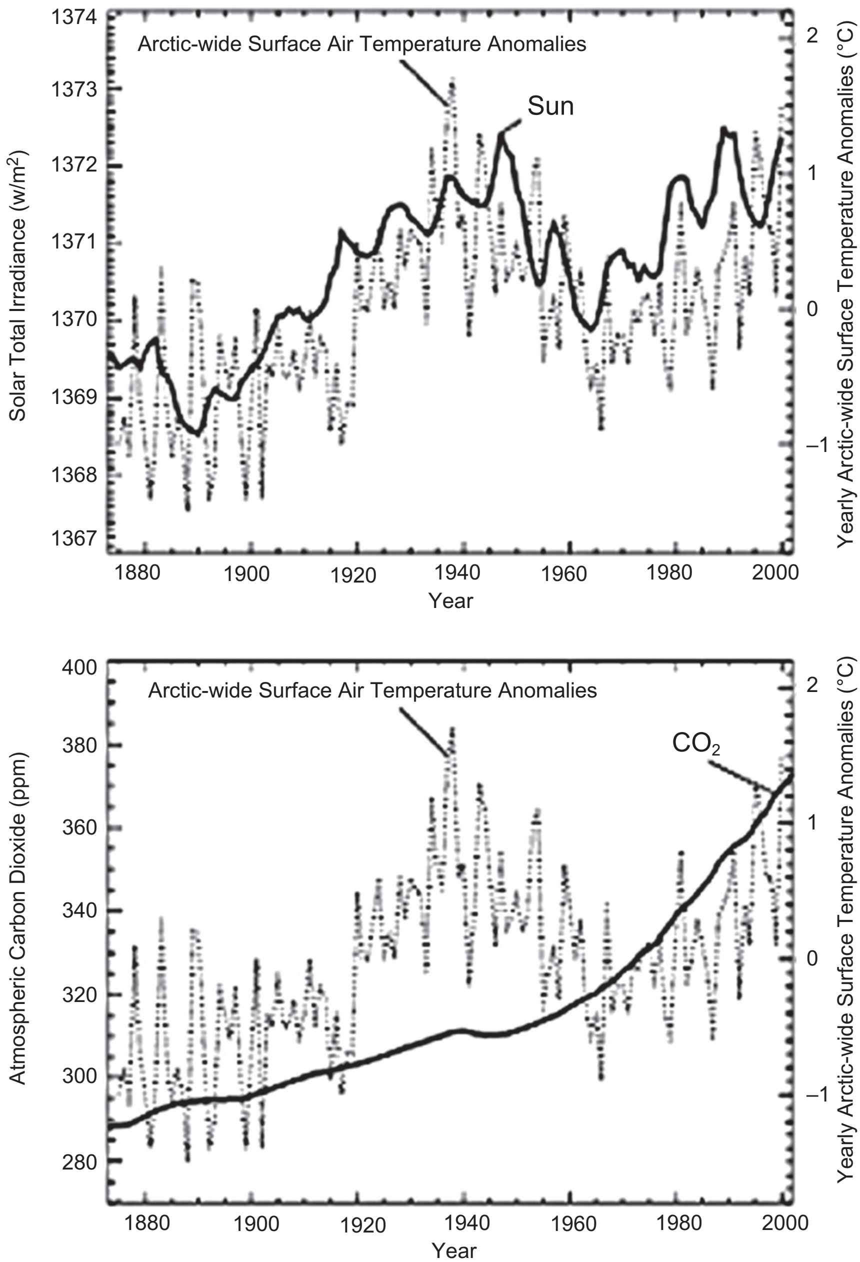

FIGURE 3 Arctic Basin wide air temperatures (Polyokov) correlated with Hoyt–Schatten total solar irradiance (TSI) and with annual average CO_2 (Soon 2005).

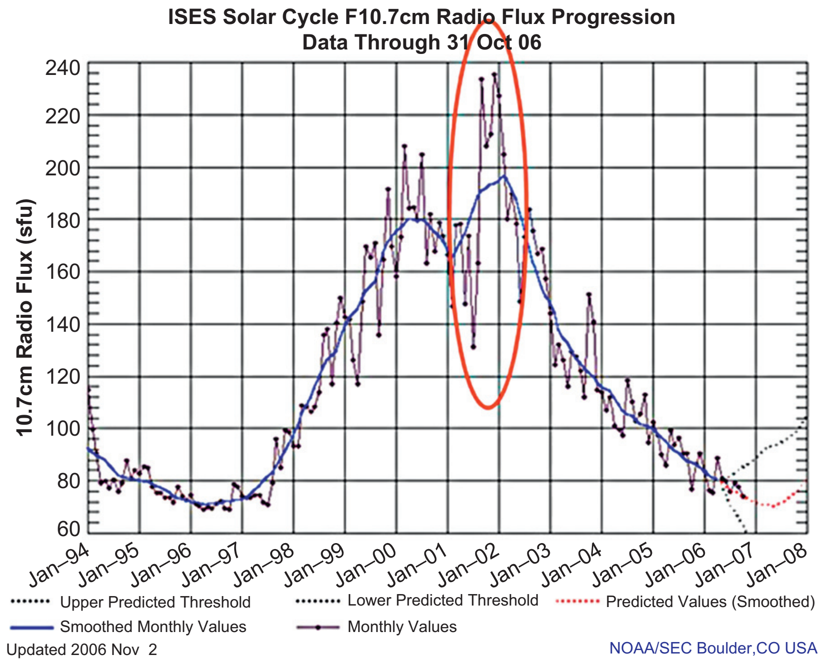

FIGURE 4 NOAA SEC solar flux (10.7 cm) during Cycle 23. Note the second solar max with extremely high flux from September 2001 to April 2002.

second maxima (Fig. 4) provided a perfect verification of Shindell and Labitzke and Van Loon's work.

The warming that took place with the high flux from September 2001 to April 2002 caused the northern winter polar vortex to shrink (Fig. 5) and the southern summer vortex to break into two centers for the first time ever observed (Fig. 7). This disrupted the flow patterns and may have contributed to the brief summer breakup (Fig. 8) of the Larsen ice sheet.

NASA reported on the use of the Shindell Ozone Chemistry Climate Model to explain the Maunder Minimum (Little Ice Age).

Their model showed (Fig. 9) when the sun was quiet in 1680, it was much colder than when it became active again 100 years later. "During this period, very few sunspots appeared on the surface of the Sun, and the overall brightness of the Sun decreased slightly. Already in the midst of a colder-than-average period called the Little Ice Age, Europe and North America went into a deep freeze: alpine glaciers extended over valley farmland; sea ice crept south from the Arctic; and the famous canals in the Netherlands froze regularly — an event that is rare today."

Writing in Environmental Research Letters (2010), Mike Lockwood et al. (2010) verified that solar activity does seem to have a direct correlation with Earth's climate by influencing North Atlantic blocking (NAO) as Shindell has

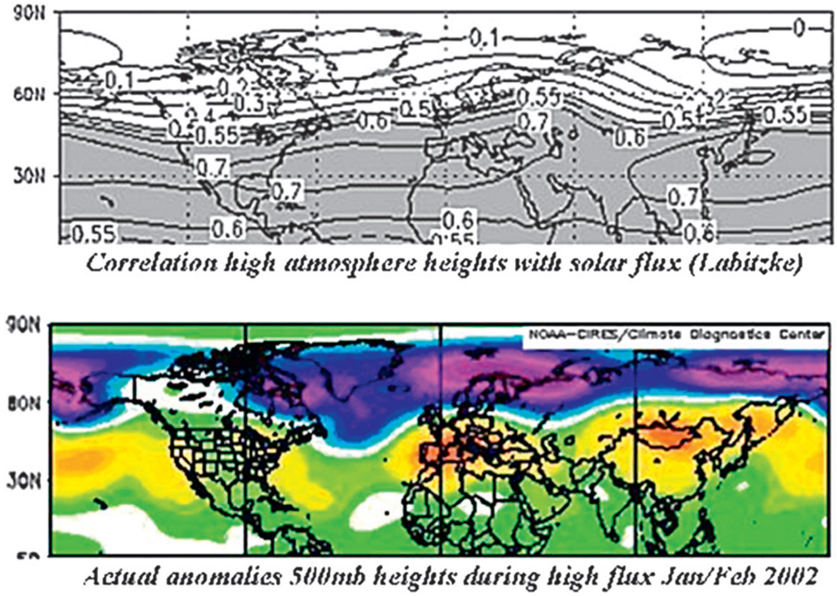

FIGURE 5 Labitzke correlated stratospheric heights with solar flux and actual height anomalies in the mid-troposphere during the high flux mode of the second solar max in early 2002.

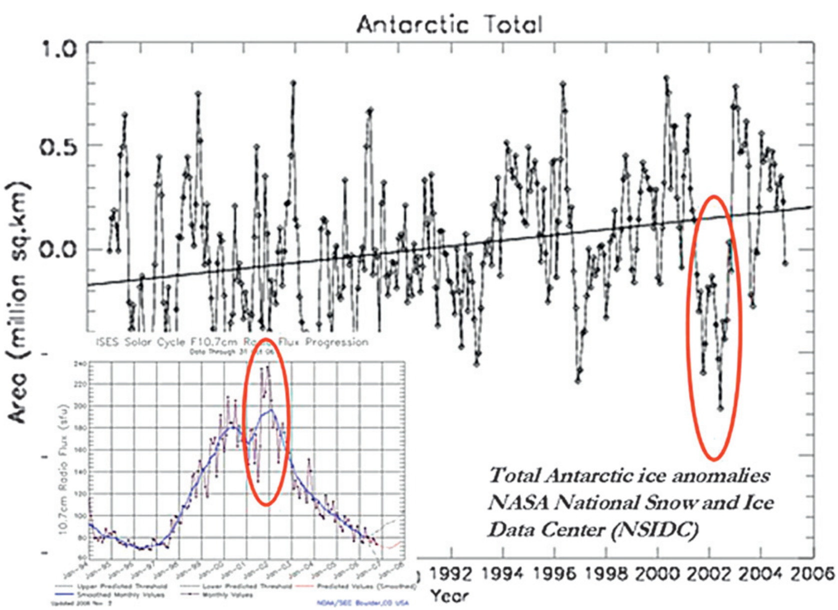

FIGURE 6 NASA NSIDC satellite derived total Antarctic ice extent anomalies from 1979 to 2005. Note the dropoff with the Larsen ice sheet break up in the summer of 2002 corresponding to major atmospheric changes during the high flux second solar maximum.

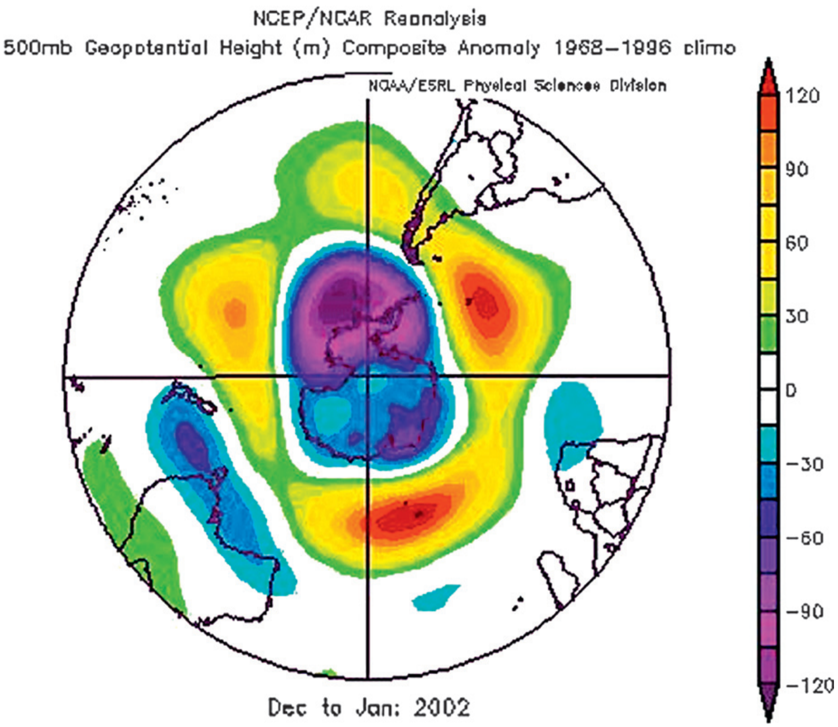

FIGURE 7 December 2001 to January 2002 500 mb height anomalies for Southern Hemisphere. Note the ring of warming with the high flux induced UV ozone chemistry as a ring surrounding a shrunken polar vortex as seen in the Northern Hemisphere in Fig. 2. Note how the vortex actually became a dipole with weakness in center. The changing winds and currents very likely contributed to the ice break of the Larsen ice sheet.

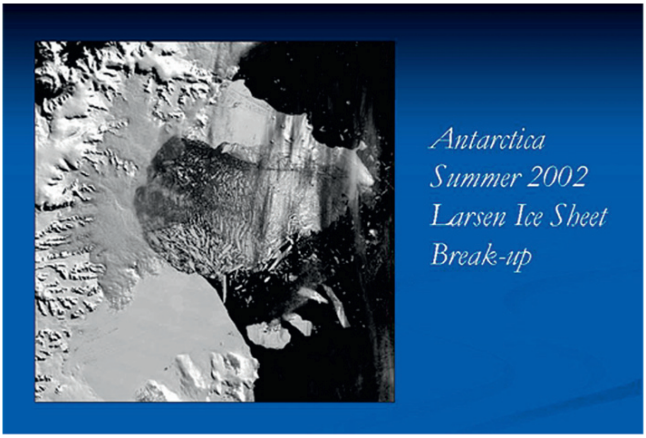

FIGURE 8 Larsen ice sheet break up late summer 2000 following strong solar flux break-up of southern polar vortex.

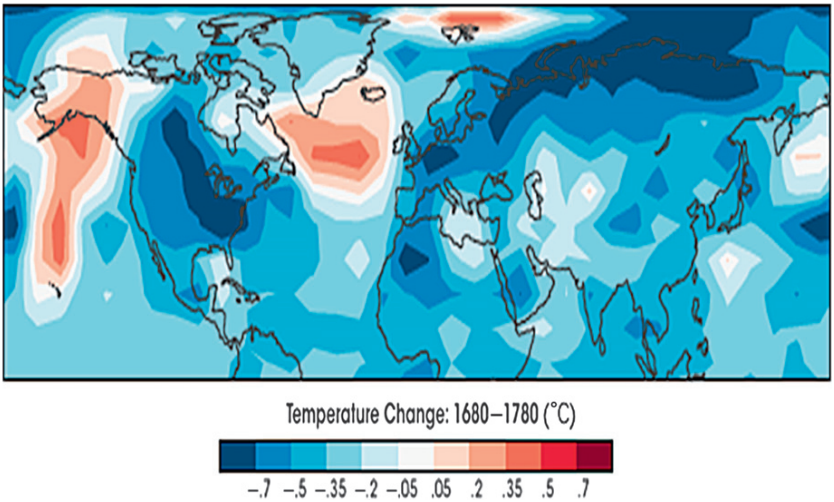

FIGURE 9 Shindell ozone chemistry model forecast of the difference between the quiet solar period of the Maunder Minimum and the active late 18th century. *Shindell NASA Observatory and Shindell 2001 http://earthobservatory.nasa.gov/IOTD/view.php?id=7122*

shown. The reason that the scope of the study is limited to that area, or at most Europe, is that it is one of the few regions that there is a reliable, continuous temperature record going back to the Little Ice Age.

They noted further "solar activity during the current sunspot minimum has fallen to levels unknown since the start of the 20th century. The Maunder Minimum (about 1650–1700) was a prolonged episode of low solar activity which coincided with more severe winters in the United Kingdom and continental Europe. Motivated by recent relatively cold winters in the UK, we investigate the possible connection with solar activity. We identify regionally anomalous cold winters by detrending the Central England temperature (CET) record using reconstructions of the northern hemisphere mean temperature.

We show that cold winter excursions from the hemispheric trend occur more commonly in the UK during low solar activity, consistent with the solar influence on the occurrence of persistent blocking events in the eastern Atlantic. We stress that this is a regional and seasonal effect relating to European winters and not a global effect. Average solar activity has declined rapidly since 1985 and cosmogenic isotopes suggest an 8% chance of a return to Maunder Minimum conditions within the next 50 years (Lockwood, 2010 *Proc. R. Soc.* A 466 303–29): the results presented here indicate that, despite hemispheric warming, the UK and Europe could experience more cold winters than during recent decades."

We note the NAO has ties to the Arctic Oscillation (AO) and together they have far greater influence on hemisphere than implied. This past winter with a record negative arctic oscillation and persistent negative NAO was the coldest in the UK and the southeastern United States since 1977/78, coldest in Scotland since 1962/63, coldest ever recorded in parts of Siberia. Coldest weather since 1971/72 was reported in parts of North China.

2.4. Tropical Effects

Elsner et al. (2010) found the probability of three or more hurricanes hitting the United States goes up drastically during low points of the 11-year sunspot cycle. Years with few sunspots and above-normal ocean temperatures spawn a less stable atmosphere and, consequently, more hurricanes, according to the researchers. Years with more sunspots and above-normal ocean temperatures yield a more stable atmosphere and thus fewer hurricanes. Elsner has found that between the high and low of the sunspot cycle, radiation can vary more than 10% in parts of the ultraviolet range. When there are more sunspots and therefore ultraviolet radiation, the warmer ozone layer heats the atmosphere below.

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The sun's yearly average radiance during its 11-year cycle only changes about one-tenth of 1%, according to NASA's Earth Observatory. But the warming in the ozone layer can be much more profound, because ozone absorbs ultraviolet radiation. Elsner has found that between the high and low of the sunspot cycle, radiation can vary more than 10% in parts of the ultraviolet range. When there are more sunspots and therefore ultraviolet radiation, the warmer ozone layer heats the atmosphere below. Their latest paper shows evidence that increased UV light from solar activity can influence a hurricane's power even on a daily basis (Fig. 10).

Meehl et al. (2009) found that chemicals (ozone) in the stratosphere and sea surface temperatures in the Pacific Ocean respond during solar maximum in a way that amplifies the sun's influence on some aspects of air movement. This can intensify winds and rainfall, change sea surface temperatures, and cloud cover over certain tropical and subtropical regions, and ultimately influence global weather. An international team of scientists led by the National Center for Atmospheric Research (NCAR) used more than a century of weather observations and three powerful computer models to tackle this question.

The answer, the new study found, has to do with the Sun's impact on two seemingly unrelated regions: water in the tropical Pacific Ocean and air in the stratosphere, the layer of the atmosphere that runs from around 6 miles (10 km) above Earth's surface to about 31 miles (50 km).

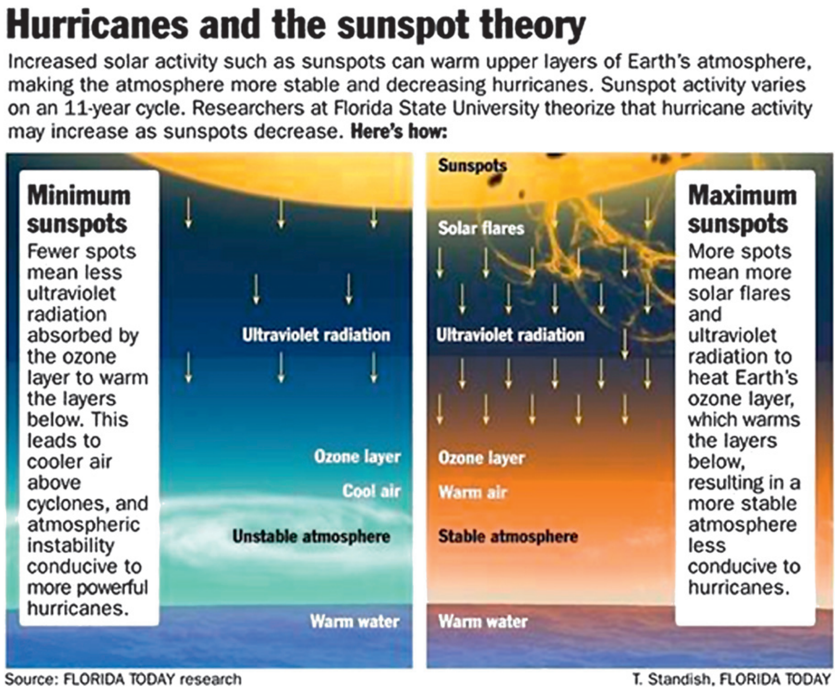

FIGURE 10 Research by Robert Hodges and Jim Elsner of Florida State University found the probability of three or more hurricanes hitting the United States goes up drastically during low points of the 11-year sunspot cycle, such as we're in now. Years with few sunspots and above-normal ocean temperatures spawn a less stable atmosphere and, consequently, more hurricanes, according to the researchers. Years with more sunspots and above-normal ocean temperatures yield a more stable atmosphere and thus fewer hurricanes.

The study found that chemicals in the stratosphere and sea surface temperatures in the Pacific Ocean respond during solar maximum in a way that amplifies the sun's influence on some aspects of air movement. This can intensify winds and rainfall, change sea surface temperatures, and cloud cover over certain tropical and subtropical regions, and ultimately influence global weather.

"The sun, the stratosphere, and the oceans are connected in ways that can influence events such as winter rainfall in North America," said lead author of the study, Gerald Meehl of NCAR. "Understanding the role of the solar cycle can provide added insight as scientists work toward predicting regional weather patterns for the next couple of decades."

The new study finds that weather patterns across the globe are partly affected by connections between the 11-year solar cycle of activity, Earth's stratosphere, and the tropical Pacific Ocean. The study could help scientists get an edge on eventually predicting the intensity of certain climate phenomena, such as the Indian monsoon and tropical Pacific rainfall, years in advance.

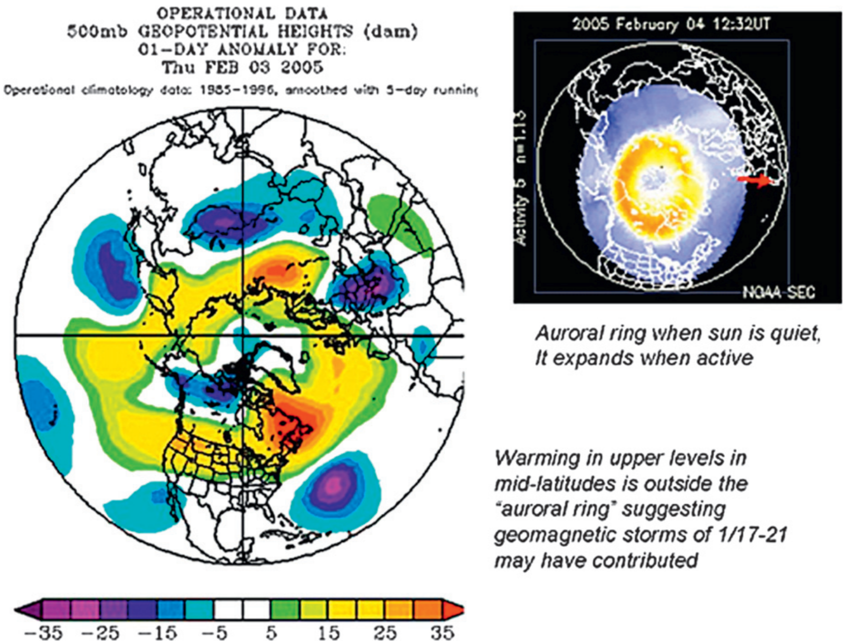

FIGURE 11 Anomaly at 500 mb 2 weeks after a major geomagnetic storm in 2005. Warmth seen in approximate location and shape of auroral ring.

2.5. Geomagnetic Storms and High Latitude Warming

When major eruptive activity (i.e., coronal mass ejections, major flares) takes place and the charged particles encounter the earth, ionization in the high atmosphere leads to the familiar and beautiful aurora phenomenon. This ionization leads to warming of the high atmosphere which like ultraviolet warming of the stratosphere works its way down into the middle troposphere with time.

Here is an example of an upper level chart two weeks after a major geomagnetic storm. Note the ring of warmth (higher than normal mid-tropospheric heights) surrounding the magnetic pole (Fig. 11).

2.6. Solar Winds, Cosmic Rays and Clouds

A key aspect of the sun's effect on climate is the indirect effect on the flux of Galactic Cosmic Rays (GCR) into the atmosphere. GCR is an ionizing radiation that supports low cloud formation. As the sun's output increases the solar wind shields the atmosphere from GCR flux. Consequently the increased solar irradiance is accompanied by reduced low cloud cover, amplifying the climatic effect. Likewise when solar output declines, increased GCR flux enters the

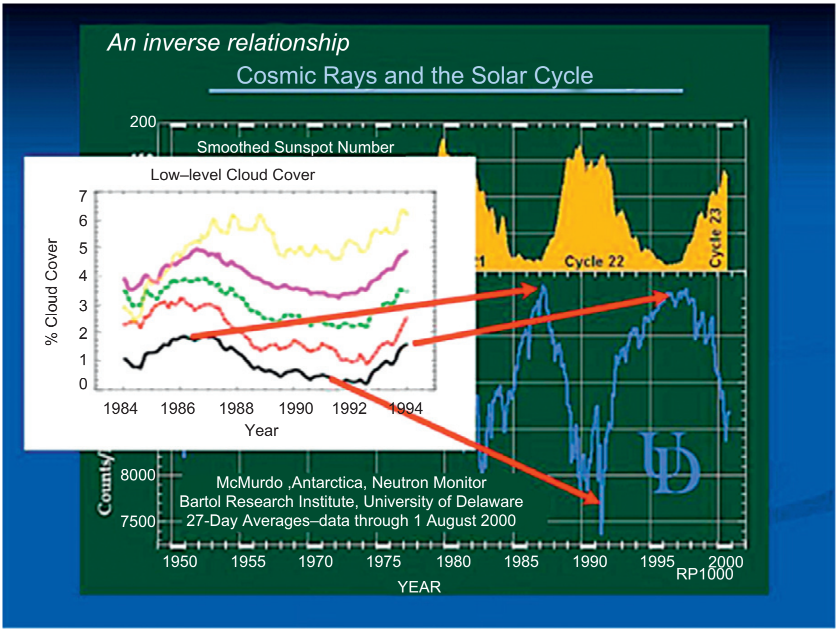

FIGURE 12 Cosmic ray neutrons are inversely proportional to solar activity and directly proportional to low cloudiness (from Palle Bago and Butler, 2001).

atmosphere, increasing low cloudiness and adding to the cooling effect associated with the diminished solar energy.

The conjectured mechanism connecting GCR flux to cloud formation received experimental confirmation in the recent laboratory experiments of Svensmark (Proceedings of the Royal Society, Series A, October 2006), in which he demonstrated exactly how cosmic rays could make water droplet clouds.

Palle Bago and Butler showed in 2002 (Int. J. Climate.) how the low clouds in all global regions changed with the 11-year cycle in inverse relation to the solar activity. Changes of 1–2% in low cloudiness could have a significant effect on temperatures through changes in albedo (Fig. 12).

Recently, Henrik Svensmark and Eigil Friis-Christensen published a reply to Lockwood and Fröhlich – The persistent role of the Sun in climate forcing, rebutting Mike Lockwood's Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature. In it, they correlated tropospheric temperature with cosmic rays. Figure 13 features two graphs. The first graph compares tropospheric temperature (blue) to cosmic rays (red). The second graph removes El Nino, volcanoes, and a linear warming trend of 0.14 °C per decade.

Jasper Kirkby of CERN as an introduction to CERN's CLOUD experiment which "aims to study and quantify the cosmic ray-cloud mechanism in

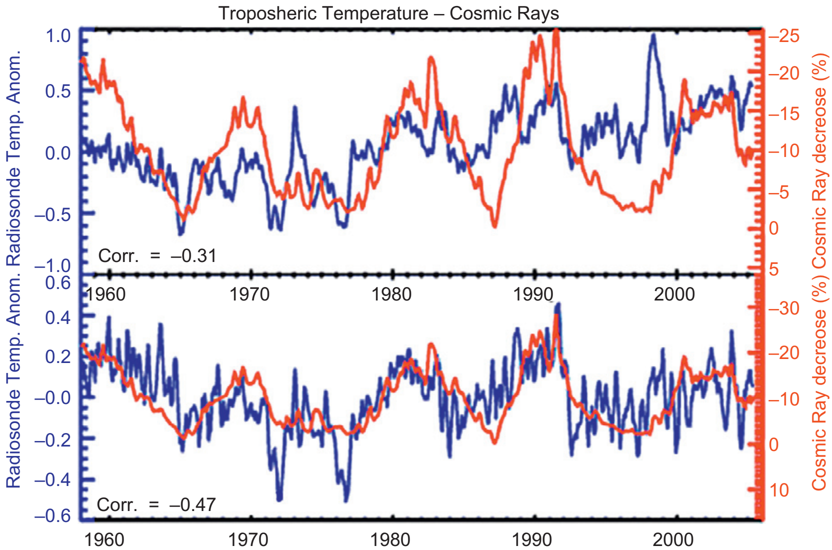

FIGURE 13 Tropospheric cosmic rays vs. radiosonde temperature anomalies raw and bottom filtered and detrended (Henrik Svensmark and Eigil Friis-Christensen).

a controlled laboratory experiment" and answer "the question of whether—and to what extent—the climate is influenced by solar/cosmic ray variability" found compelling evidence that indeed there could be such a connection (Figs. 14, 15).

Cosmic ray influence appears on the extremely long geologic time scales. Shaviv (JGR 2005 estimated from the combination of increased radiative forcing through cosmic ray reduction and the estimated changes in total solar luminosity (irradiance) over the last century that the sun could be responsible for up to 77% of the temperature changes over the 20th century with 23% for the anthropogenic. He also found the correlation extended back in the ice core data 500 million years (Fig. 16).

The degree to which cosmic rays is a climate driver is yet to be determined. It could still be that the cosmic rays are a proxy for one or more of the other solar factors, one more easily measured. There appears little doubt that the sun through many ways is the main driver for the earth's climate over time.

2.6.1. Throwback Solar Cycle 23

In NASA's David Hathaway's own words, Cycle 23 has been a cycle like we have not seen in century or more. The irradiance dropped 50% more than recent cycles, the solar wind was at the lowest levels of the satellite age. There were over 800 sunspotless days, well more than double those of the recent cycles. The cycle lasted 3 years longer than Cycle 22, longest since Cycle 6 that peaked in 1810 (Figs. 17, 18).

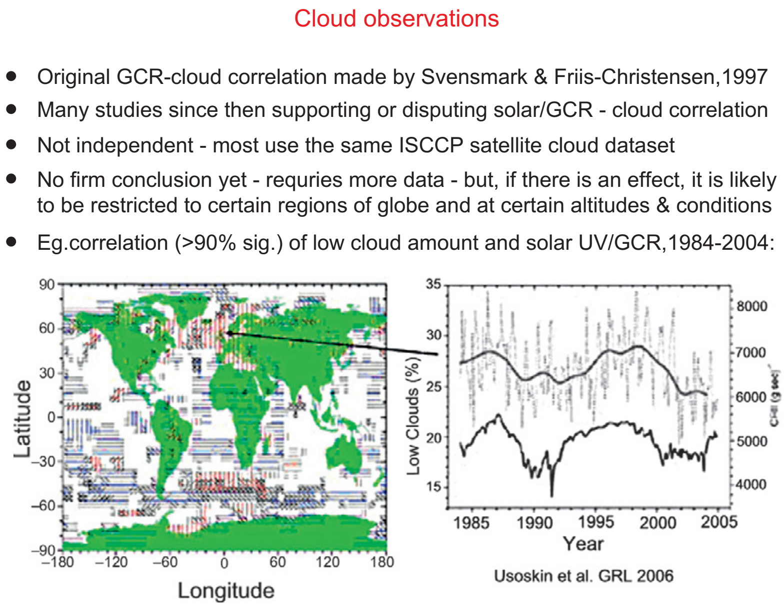

FIGURE 14 Jasper Kirkby of CERN as an introduction to CERN's CLOUD experiment summarized the state of the understanding.

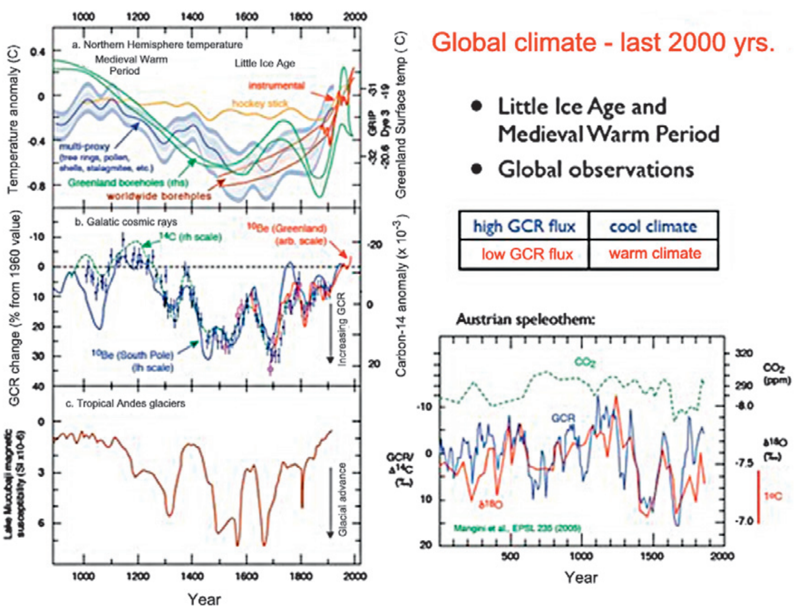

FIGURE 15 Jasper Kirkby of CERN shows excellent correlations of galactic cosmic rays and temperatures for the Northern Hemisphere, Greenland, Tropical Andes, and Austria.

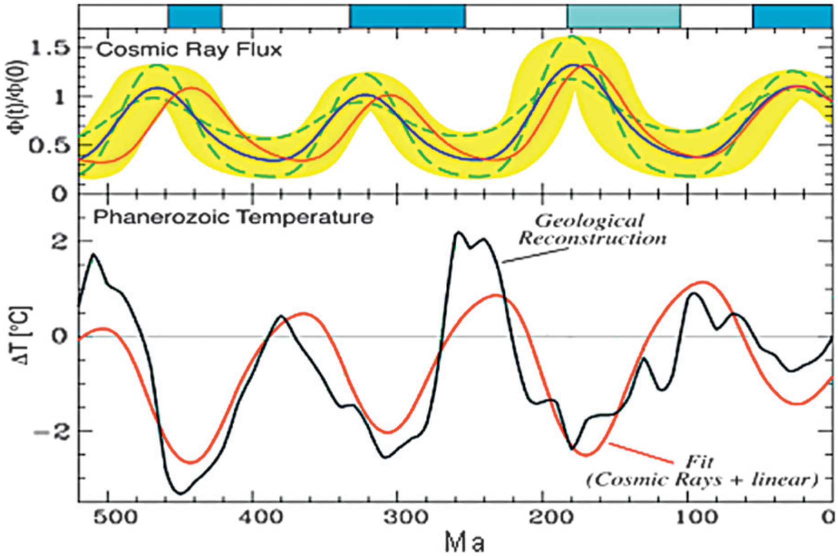

FIGURE 16 Shaviv cosmic ray flux plus irradiance vs. geological reconstruction of temperatures.

Historically, cycle length has correlated well with temperatures (Figs. 19, 20).

Cosmic rays according to NASA recently reached a space age high (Figs. 21, 22).

The Russian Pulkovo Observatory believes a Maunder like minimum is possible (Fig. 23).

2.7. Secular Cycles − Combined Natural Factors

Temperature trends coincides with the ocean and solar TSI cyclical trends as can be seen in this diagram that overlays standardized ocean temperature

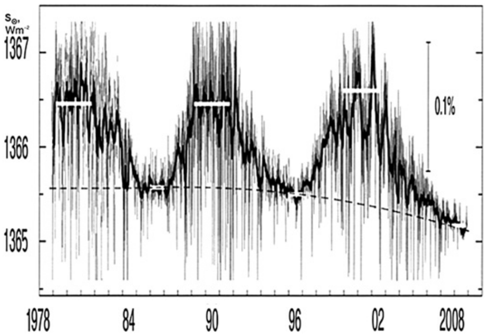

FIGURE 17 The irradiance in Cycle 23 dropped about 50% more than prior minima (with a change of near 0.15% from maxima).

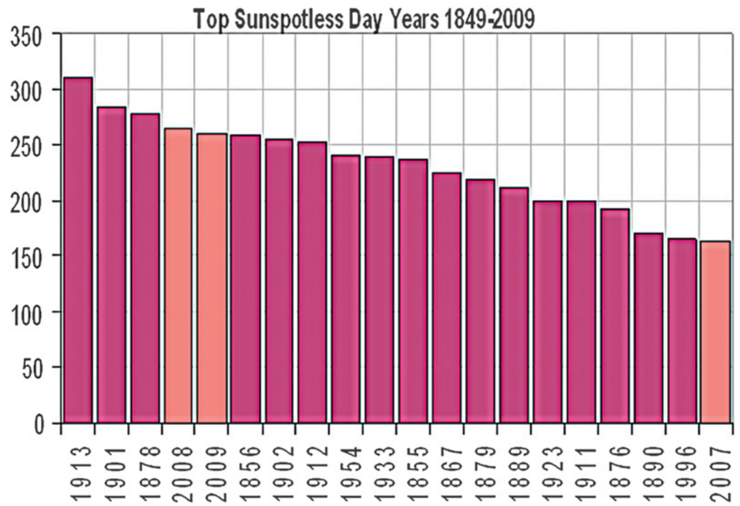

FIGURE 18 The number of sunspotless days per year since 1849. *Source: Daily Wolfnumbers from SIDC, RWC Belgium.*

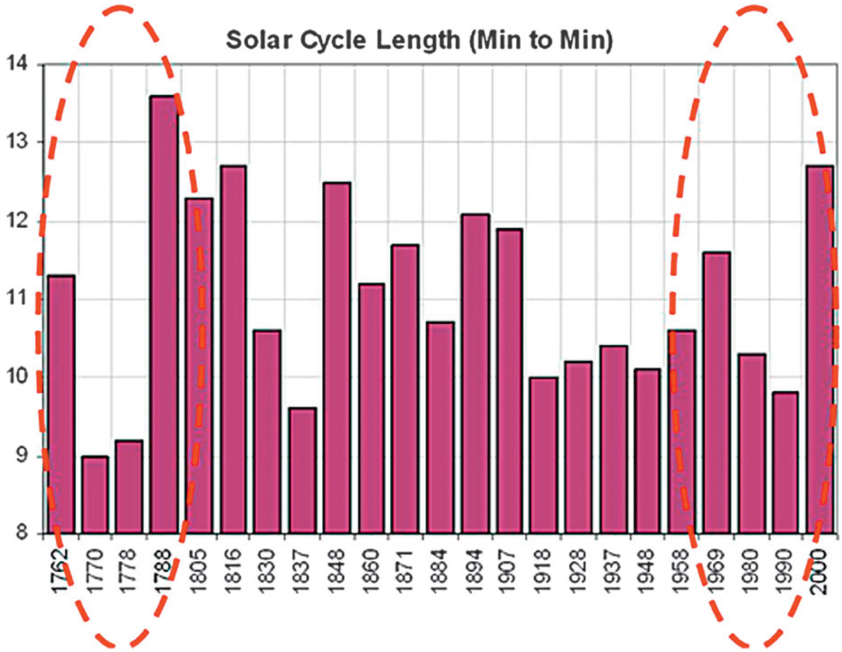

FIGURE 19 Solar cycle lengths (years) from minimum to minimum for cycles 1 through 23. Year of maximum shown as label.

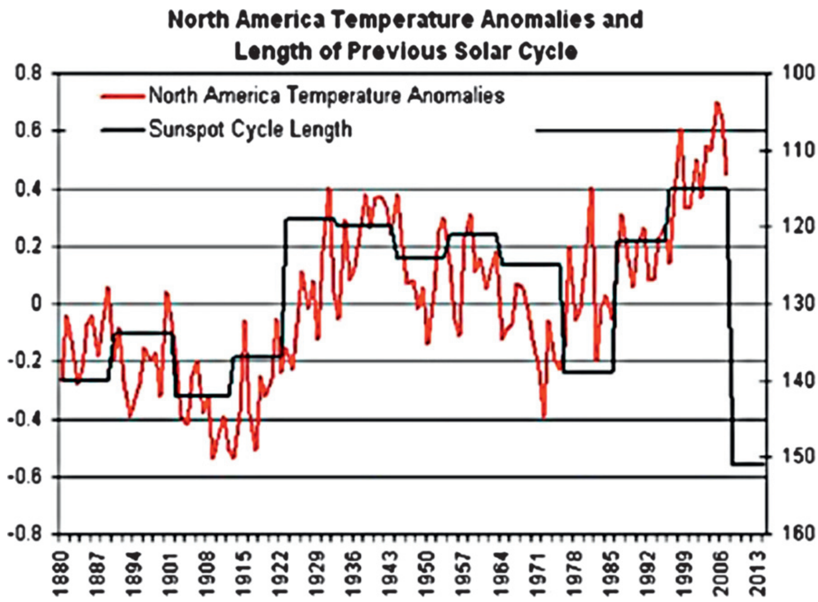

FIGURE 20 Historically, the North American temperatures have correlated well with solar cycle length. Note the rapid increase in length for Cycle 23, implying an upcoming cooling.

configuration indices (PDO + AMO and Hoyt Schatten/Willson TSI and USHCN version 2 temperatures). The 60-year cycle clearly emerges including that observed warming trend. The similarity with the ocean multidecadal cycle phases also suggest the sun play a role in their oscillatory behavior. Scafetta (2010) presents compelling evidence for this 60-year cyclical behavior (Fig. 24).

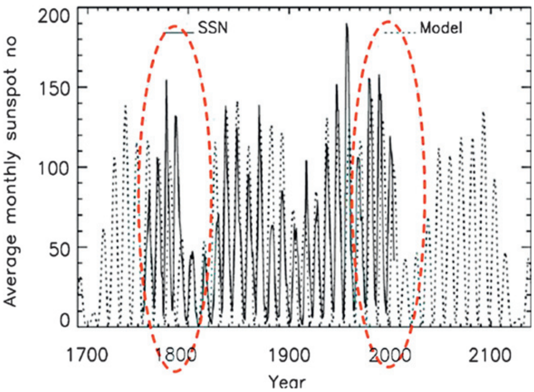

FIGURE 21 Clilverd et al. (2006) did a regression analysis of the various solar cycles and built a model that showed skill in predicting past cycles. The model suggests a Dalton like minimum is coming.

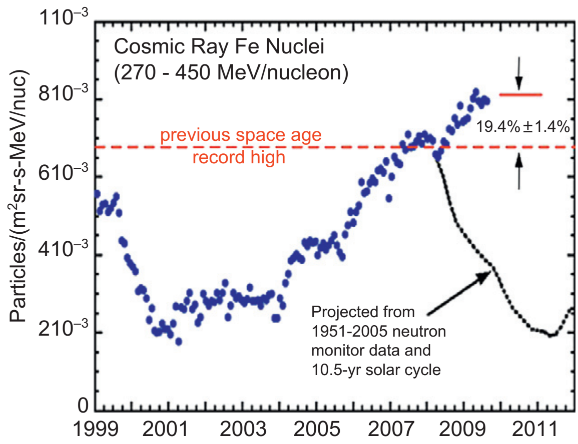

FIGURE 22 NASA depicted cosmic ray monitoring showing that the number of particles was approximately 19.4% higher than any other time since 1951.

Dr. Don Easterbrook has used the various options of a 60-year repeat of the mid-20th century solar/ocean induced cooling, Dalton Minimum, and a Maunder Minimum scenarios to present this empirical forecast range of options (Fig. 25).

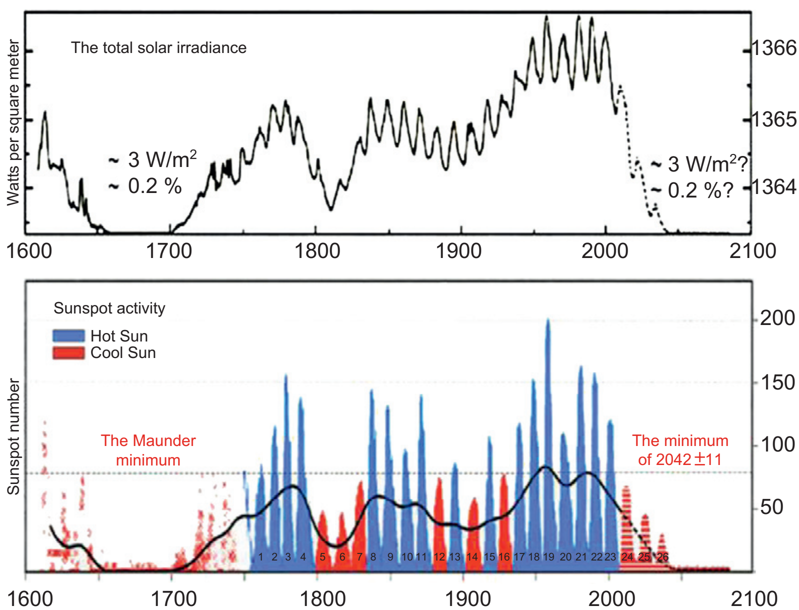

FIGURE 23 Habibullo Abdussamatov, Dr. Sc. Head of the Pulkovo Observatory has projected a decline in upcoming cycles to Maunder Minima levels.

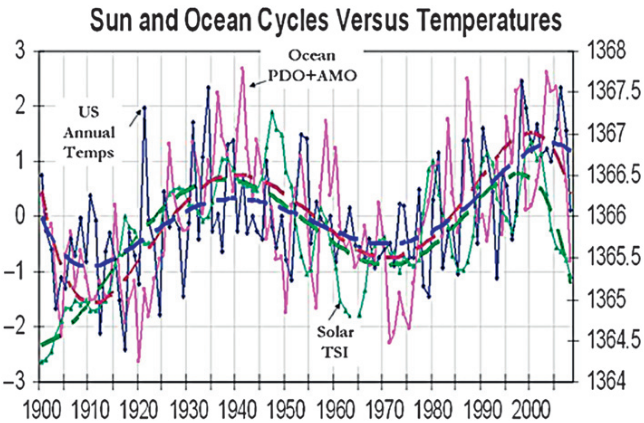

FIGURE 24 Solar TSI (Hoyt/Schatten TSI calibrated to Willson AMCRIMSAT TSI) and PDO + AMO (STD) vs. the USHCN annual plots with polynomial smoothing.

3. SUMMARY

Though the sun's brightness or irradiance changes only slightly with the solar cycles, the indirect effects of enhanced solar activity including warming of the atmosphere in low and mid-latitudes by ozone reactions due to increased ultraviolet radiation, in higher latitudes by geomagnetic activity and generally by increased radiative forcing due to less clouds caused by cosmic ray reduction may greatly magnify the total solar effect on temperatures. The sun appears to be the primary driver right up to the current time.

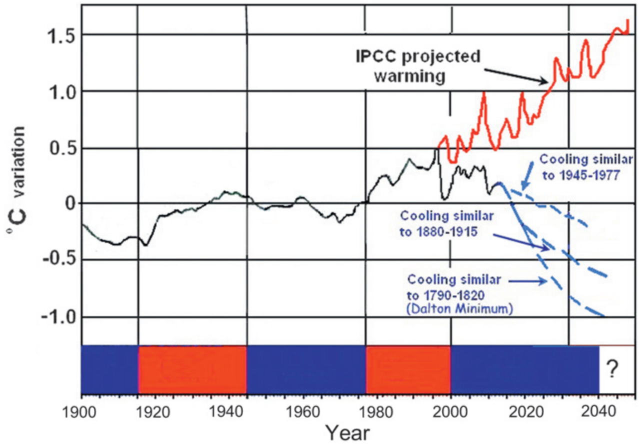

FIGURE 25 Projected future temperatures from the IPCC, to ocean/solar 60-year cycle cooling, to a Dalton minima to a Maunder Minima (D'Aleo and Easterbrook, 2010).

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