SOLAR CYCLE 24: EXPECTATIONS AND IMPLICATIONS

David C. Archibald
Summa Development Limited, Perth, WA, Australia
E-mail: david.archibald@westnet.com.au
Website: www.davidarchibald.info

ABSTRACT
Archibald (2006) predicted that climate during the forthcoming Solar Cycles 24 and 25 would be significantly cold. As at late 2008, the progression of the current 23/24 solar minimum indicates that a severe cool period is now inevitable, similar to that of the Dalton Minimum. A decline in average annual temperature of 2.2°C is here predicted for the mid-latitude regions over Solar Cycle 24. The result will be an equator-ward shift in continental climatic conditions in the mid-latitudes of the order of 300 km, with consequent severe effects on world agricultural productivity.

1. INTRODUCTION
Published correlations of past solar activity with the historic climate record were reviewed by Brunetti (2003), and detailed work on the 20th century temperature record in relation to solar cycle length was undertaken by Friis-Christensen and Lassen (1991). This original paper was subsequently amended, and their observation of a correlation between solar cycle length and temperature remains valid. These studies include correlations of the record of the ice ages with the Be10 record, which demonstrate that the Earth’s climate moves in sympathy, if not in lockstep, with solar activity. A number of solar physicists have made predictions regarding future solar activity based on statistical and physical models, ranging from Dikpati at the high end to Clilverd at the low end (summarised in Archibald 2007).

The calibration provided by the work on the historic record was used by Archibald (2006) to make a prediction of the global climate response to Solar Cycles 24 and 25. Archibald’s conclusion was that the low amplitudes projected for these two solar cycles would result in a global atmospheric temperature decline of the order of 2°C. This temperature response would be similar to that of the Dalton Minimum from 1796 to 1820, a well documented prior period of low global temperatures associated with the low amplitudes of Solar Cycles 5 and 6.

2. PROGRESSION OF SOLAR CYCLE 23
As at the time of writing of this paper in October 2008, Solar Cycle 23 is now 12 years and five months long, and has still not terminated. This is shown in context in Figure
1, which compares the progression of solar minima in the late 19th and early 20th century with those of the late 20th century. With respect to the ramp up of the solar cycle following the minimum, the average solar cycle length in the late 20th century was 28 months greater than the average length of the late 19th century cycles. The current progression of the Solar Cycle 23 to 24 minimum is shown on the diagram as the dashed line. The weaker and longer solar cycles of the late 19th and early 20th century were associated with weather that was much colder than that of the late 20th century (Loehle 2007).

Although common usage has solar cycles starting at the month of minimum between cycles, they are actually discrete pulses of magnetic activity that start with the magnetic reversal near the peak of the previous cycle. Almost all solar cycles tend to be about eighteen and a half years long, measured from the peak of the previous cycle. Figure 2 compares the average of three cycles, 21 to 23, from the late 20th century with three, 14 to 16, from the late 19th century and early 20th century. Also shown on the same basis is Solar Cycle 5, the first half of the Dalton Minimum. Out of the 24 named solar cycles to date, Solar Cycle 24 is now the latest-developing after Solar Cycle 5. Solar Cycle 24 is now three years later than the average start month of Solar Cycles 14 to 16. Given that these cycles had an average peak amplitude of 80, and the observed correlation between late cycles and low cycle amplitude, Solar Cycle 24 is likely to have a peak amplitude substantially less than 80.

Figure 3 compares cumulative spotless days in the current minimum relative to the average of other groups of solar cycles. Based on the evolution of spotless days during the current period of low solar activity, the month of minimum could be July, 2009, or later. This would make Solar Cycle 23 just over thirteen years long, the longest recorded apart from the cycle which preceded the Dalton Minimum (Solar Cycle 4, length 13.6 years). Figure 4 compares Solar Cycles 4 and 23 aligned on the month of minimum. Solar Cycles 5 and 6 of the Dalton Minimum are also shown. It is apparent that Solar Cycles 22 and 23 are very similar to Solar Cycles 3 and 4 which preceded the Dalton Minimum.

Figure 1. Late 19th and Early 20th Century Solar Minima compared to Late 20th Century Solar Minima
Figure 2. Late 20th Century Solar Cycles compared to Late 19th and early 20th Century Solar Cycles

Figure 3. Evolution of Spotless Days in the Solar Cycle 23 to 24 Transition

Data Source and Methodology: Jan Janssens, Belgian Solar Section
3. CYCLE-LENGTH / TEMPERATURE CORRELATION: US AND EUROPE

The methodology of Friis-Christensen and Lassen (1991), that demonstrated a relationship between solar cycle length (in one cycle) and temperature over the following solar cycle, was first applied to an individual station temperature record by Butler and Johnson (1996). The station was Armagh in Northern Ireland, for which a correlation of 0.5° C temperature decline for every extra year of solar cycle length was apparent (see Figure 5 of that paper). Archibald (2006) demonstrated a similar relationship in the De Bilt, Netherlands climate record. Here, Figure 5 shows another similar correlation for the Central England Temperature record, this time of 0.6° C cooling per year of extra cycle length. Steeper cooling correlations are found also, for instance, in long climate records from the north-eastern United States. Figures 6 and 7 show the records for Portland Maine, and Hanover New Hampshire, respectively. These exhibit cooling of 0.7° C per extra year of cycle length.

The strength of the solar-cycle-length – annual-average-temperature correlation enables solar cycle length to be used as a climate predictor tool. If the month of minimum for the Solar Cycle 23 to 24 transition is July 2009, this would make Solar Cycle 23 over thirteen years long. This in turn would mean that it would be 3.2 years longer than Solar Cycle 22, and imply that the annual average temperature of Hanover, New Hampshire will be 2.2° C cooler during Solar Cycle 24 than it had been on average over Solar Cycle 23.

Figure 4. Solar Cycle 23 compared to Solar Cycle 4
Figure 5. The Solar Cycle Length – Annual Average Temperature Correlation in the Central England Temperature Record

Figure 6. The Solar Cycle Length – Annual Average Temperature Correlation in the Climate Record of Portland, Maine
4. PROJECTION OF PEAK NEUTRON COUNT FOR SOLAR MINIMUM

The basis of the hypothesis of Svensmark and Friis-Christensen (1997) is that weak solar activity causes a weak solar wind, which in turn increases the number of galactic cosmic rays penetrating the Earth’s atmosphere. This increases low level cloud formation and the Earth’s albedo. The Earth cools as a consequence.

A neutron count representative of cosmic ray flux is available from the Oulu station in Finland, with this data shown in Figure 8. The solar minima during the period are marked. The 1970s cooling period is associated with elevated counts over the second half of Solar Cycle 20, relative to other solar cycles. Peak neutron count is approximately one year after solar minimum, due to the one year delay in the solar wind reaching the heliopause. The monthly neutron count is now higher than it has been at any time for the last fifty years. If the month of solar minimum proves to be July 2009, peak neutron count may not be until mid-2010. On this basis, and according to Svensmark and Friis-Christensen’s hypothesis, peak cloudiness, and therefore peak rate of cooling, will be reached in mid-2010.
5. LONG TERM CORRELATION OF SOLAR ACTIVITY WITH CLIMATE

The aa Index is a geomagnetic activity index which is driven by the solar coronal magnetic field strength. There are now 140 years of aa Index data, shown in Figure 9. The strength of the solar coronal magnetic field doubled over the 20th century. At the same time, the Earth came out of the Little Ice Age. The 1970s cooling period, during Solar Cycle 20, was associated with a weak aa Index. During the current solar minimum, the aa Index is likely to fall to levels last seen in the late 19th century.

Figure 10 shows an incontrovertible association between solar activity and climate. The spikes in Be\textsuperscript{10} concentration coincide with the cold periods in Earth’s history for the last 600 years. All the major climate minima are evident in the Be\textsuperscript{10} record, including the cold period at the end of the 19th century. What is also evident is that Be\textsuperscript{10} levels started falling away dramatically at the beginning of the Modern Warm Period, consistent with the warming of the 20th century being solar-driven.

6. PAST AND FUTURE WARMING FROM ANTHROPOGENIC CO\textsubscript{2}

Archibald (2007) illustrated the logarithmic warming effect of carbon dioxide. The first 20 ppm of carbon dioxide in the atmosphere has a greater warming effect than the following 400 ppm (Figure 11). The increase in atmospheric carbon dioxide concentration from the pre-industrial level of 280 ppm to the current level of 384 ppm is calculated to have resulted in a 0.1° C rise in atmospheric temperature. If the atmospheric carbon dioxide level increases to 600 ppm, a further 0.3° C increase in temperature is projected due to this factor.

There is a high rate of exchange of carbon dioxide between the oceans, vegetation and the atmosphere. The average residence time of a carbon dioxide molecule in the
atmosphere is seven years, and the atmosphere and a portion of the upper part of the oceans are in effective partial pressure equilibrium with a lag of only a few years (Broecker and Peng, 1982). As the oceans cool over Solar Cycles 24 and 25, the increased solubility of carbon dioxide in the surface waters of the oceans is projected to largely offset the anthropogenic contribution and result in an average rate of increase of atmospheric carbon dioxide of between 0 and 1 ppm per annum.

7. SUMMARY AND PROJECTIONS
Based on our understanding of the interaction of solar and terrestrial processes, the following projections are made for a number of climate-related physical processes:

1. Month of Solar Cycle 23/24 minimum: July, 2009
3. Amplitude of Solar Cycle 24: 45
4. Temperature Decline Solar Cycle 24: 2.2° C
5. Oulu Neutron Count Monthly Peak: 6,900
6. Month of Oulu Neutron Count Peak: July, 2010
7. Atmospheric Carbon Dioxide Level: Relatively flat 2010 - 2030

Bases of Projections
1. This paper
2. Weak ramp up of Solar Cycle 24, this paper
4. This paper
6. This paper
7. This paper

Figure 9. aa Index 1868 to 2008
**Figure 10.** Dye 3 Ice Core, Greenland, Be\(^{10}\) Record

**Figure 11.** Relative Contributions of Pre-Industrial and Anthropogenic CO\(_2\)
REFERENCES
Clilverd, M. 2005, Prediction of solar activity the next 100 years Solar Activity: Exploration, Understanding and Prediction, Workshop in Lund, Sweden