1. INTRODUCTION

A number of cycles in solar activity have been recognized, including the Schwabe (11 years), Hale (22 years), Gleissberg (88 years), de Vries (210 years), and Bond (1,470 years) cycles. There is nothing to suggest that cyclic behavior in solar activity has ceased for any reason. Therefore, predicting when the next minimum should occur should be as simple as counting forward from the last one. The last major minimum, the Dalton Minimum from 1798 to 1822, was two solar cycles long — Solar Cycles 5 and 6. Recent Gleissberg minima appear to be the decade 1690–1700, Solar Cycle 13 from 1889 to 1901, and Solar Cycle 20 from 1964 to 1976.

A de Vries cycle event, herein termed the Eddy Minimum, has started exactly 210 years after the start of the Dalton Minimum.

Friis-Christensen and Lassen theory, using methodology pioneered by Butler and Johnson at Armagh, can be used to predict the temperature response to the Eddy Minimum for individual climate stations with a high degree of confidence. The latitude of the US-Canadian border is expected to lose a month from its growing season with the potential for un-seasonal frosts to further reduce agricultural productivity.
2. THE CURRENT MINIMUM

As recently as 2008, there was a wide range in estimated amplitudes for Solar Cycle 24, from Dikpati at 190 and Hathaway at 170 respectively to Clilverd (2005) at 42 and Badalyan et al. (2001) at 50. This enormous divergence in projections of solar activity generated very little interest from the climate science community, despite the large impact it would have on climate (Archibald, 2006, 2007). The basis of Clilverd’s prediction was a model for sunspot number using low-frequency solar oscillations, with periods of 22, 53, 88, 106, 213, and 420 years modulating the 11-year Schwabe cycle. The model predicts a period of quiet solar activity lasting until approximately 2030 followed by a recovery during the middle of the century to more typical solar activity cycles with peak sunspot numbers around 120.

The graphs in Figs. 1–15 show data related to solar activity. Additional data may be found in Archibald (2010).

The Eddy Minimum (Fig. 1) has started 210 years after the start of the Dalton Minimum, consistent with it being a de Vries Cycle event.

The graph in Fig. 2 shows that Solar Cycles 3 and 4, leading up to the Dalton Minimum, are very similar in amplitude and morphology to Solar Cycles 22 and 23, leading up to the current minimum. The two data sets are aligned on the month of transition between Solar Cycles 4 and 5 and between Solar Cycles 23 and 24.

In the absence of a significant change in Total Solar Irradiance over the solar cycle, modulation of the Earth’s climate by the changing flux in galactic cosmic

![FIGURE 1](image) Solar cycle amplitude 1701–2045.
rays was proposed by Svensmark and Friis-Christensen (1997). The Dye 3 Be\textsuperscript{10} record (Fig.3) shows a correlation between spikes in Be\textsuperscript{10} and cold periods for the last 600 years. It also shows a steep decline in Be\textsuperscript{10} in the Modern Warm Period, suggesting a solar origin for this warming. Usokin et al. (2005) found
that the level of solar activity during the past 70 years is exceptional, and the previous period of equally high activity occurred more than 8,000 years ago.

The strength of the Interplanetary Magnetic Field (Fig. 4) has fallen to levels below that of previous solar cycle transitions. What is also interesting in

**FIGURE 4** Interplanetary Magnetic Field 1966—2010.

**FIGURE 5** F10.7 flux 1948—2020.
this data is the flatness of this solar magnetic indicator during the 1970s cooling period.

The F10.7 index (Fig. 5) is a measure of the solar radio flux near the peak of the observed solar radio emission. Emission from the Sun at radio wavelengths...
FIGURE 8  The correlation between solar cycle length and mean annual temperature at Armagh, Northern Ireland.

FIGURE 9  Archangel, Russia — solar cycle length relative to average annual temperature.
FIGURE 10 Providence, Rhode Island — solar cycle length relative to average annual temperature.

FIGURE 11 Hanover, New Hampshire — solar cycle length relative to average annual temperature.
is due primarily to diffuse, non-radiative heating of coronal plasma trapped in the magnetic fields overlying active regions. It is the best indicator of overall solar activity levels and is not subject to observer bias in the way that the counting of sunspots is. The graph above shows the F10.7 flux from 1948 with

**FIGURE 12** West Chester, Pennsylvania — solar cycle length relative to average annual temperature.

**FIGURE 13** Portland, Maine — solar cycle length relative to average annual temperature.
a projection to 2020. Note the lower activity of the 1970s cooling period. Activity over the next 10 years is projected to be much lower again.

The aa Index (Fig. 6) is a geomagnetic activity index which is driven by the solar coronal magnetic field strength. The strength of the solar coronal magnetic field doubled over the 20th century. At the same time, the Earth came

FIGURE 14 The ability to look forward using a model of solar activity.

FIGURE 15 The correlation between the de-trended time series for the Parana River stream flow and sunspot number.
out of the Little Ice Age. There was a dip in the aa Index associated with the 1970s cooling period. The aa Index has now fallen back to levels last seen in the Little Ice Age in the late 19th century.

A weaker Interplanetary Magnetic Field results in more galactic cosmic rays reaching the inner planets of the solar system, seen in Fig. 7 of the neutron count of the Oulu station in Finland. The peak neutron count can be more than a year later than the month of solar minimum. This is due to the time the solar wind takes to reach the heliopause, which is the boundary of the solar atmosphere with interstellar space. Note the much higher average neutron count during the 1970s cooling period associated with Solar Cycle 20. The increased galactic cosmic ray flux expected over Solar Cycle 24 will cause increased cloudiness, which will in turn increase the Earth’s albedo, and the world will then cool in search of a new equilibrium temperature.

Friis-Christensen and Lassen (1991) demonstrated that global temperature over a solar cycle is better correlated with the length of the previous solar cycle than with solar cycle amplitude. In 1996, Butler and Johnson at the Armagh Observatory applied that theory to the temperature record of the observatory and produced the graph shown in Fig. 8. This graph can be considered as the Rosetta Stone of solar–climate studies; in that it has significant predictive power. Simply, Solar Cycle 22 was 9.6 years long, equating to a temperature of about 9.6 °C at Armagh. Solar Cycle 23 was 12.5 years long, equating to a temperature of 8.2 °C at Armagh. The difference is 1.4 °C which is the temperature fall, on average, predicted over Solar Cycle 24. There is not much scatter on this graph and therefore this result is almost certain.

A number of European temperature records show a correlation between solar cycle length and temperature, including the Central England Temperature record and de Bilt in the Netherlands. Generally, the more northerly the location, the better the correlation. The graph in Fig. 9 shows the correlation for Archangel in Russia.

Providence, Rhode Island will be 1.8 °C colder over Solar Cycle 24 relative to its average temperature over Solar Cycle 23 (Fig. 10).

Hanover, New Hampshire will be 2.2 °C colder over Solar Cycle 24 relative to its average temperature over Solar Cycle 23 (Fig. 11).

West Chester, Pennsylvania will be 1.5 °C colder over Solar Cycle 24 relative to its average temperature over Solar Cycle 23 (Fig. 12).

Portland, Maine will be 2.1 °C colder over Solar Cycle 24 relative to its average temperature over Solar Cycle 23 (Fig. 13).

The graph in Fig. 14 is from a model provided by Ed Fix (this volume). The notion that the orbits of the planets, particularly Jupiter, are responsible for generating the sunspot cycle has been with us since the discovery of the sunspot cycle by Samuel Schwabe in 1843. The model is based on changes in the Sun’s orbit about the barycenter of the solar system as the driver of the sunspot cycle. It is a simple oscillatory model driven by the acceleration of the radial component of the barycenter’s position relative to the Sun. The model has
a very good hindcast match. At face value, it is predicting two very short and weak cycles. What is more likely is that there will be phase destruction over Solar Cycle 24, including the possibility that the solar magnetic poles will not reverse at solar maximum, predicted by other methods to be in 2015.

The Parana River, in central South America, runs through Brazil, Paraguay, and Argentina for nearly 4,000 km and is the second largest river in South America after the Amazon. Its outlet is the River Plata a few kilometers north of Buenos Aires. In 2010, three Argentinean researchers, Pablo Mauas, Andrea Buccino, and Eduardo Flamenco, published a paper showing the very strong correlation between sunspot activity and stream flow of the Parana River (Fig. 15). The relationship demonstrated has predictive power, and points to future drought conditions in the Amazon region as a consequence of the weak activity of Solar Cycle 24.

3. SUMMARY

The world has entered a de Vries cycle event in solar activity which will produce a decline in temperature in the range of 1.2—2.2 °C in the mid-latitude regions, with a consequent impact on agricultural productivity.

REFERENCES