

# Pandemics and Solar Activity

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## **1. Introduction**

Influenza is a highly infectious viral disease. Although its primary hosts are poultry and livestock, it can readily be communicated to people, and then spread rapidly through populations. Minor influenza epidemics are almost annual occurrences. However, on occasion more aggressive strains appear, such as the "Spanish Flu" strain in 1918, which caused more than 15 million deaths worldwide. Development of a pandemic depends upon a complex mixture of factors, ranging from the appearance of new viral strains, appropriate circumstances for communication to a viable seed group of humans, and conditions of social contact and population movement that give rise to its rapid spread through the human population. The complexity and unpredictability of these factors suggest it would be unlikely that there would be detectable correlations between the appearance of pandemics and any single natural phenomenon. However, Kilbourne (1976) reported a 10-11 year periodicity in the occurrence of influenza pandemics and proposed that this is due to a periodicity in antigenic shifts.

The strongest influence on the terrestrial environment with such a periodicity is the solar activity cycle, which is driven by 10-12 year cycles in magnetic activity. This coupling is clearly visible in current observations of the terrestrial magnetic field, ionizing radiations in the atmosphere, and even in solar energy output. It is also observable historically back to the Jurassic period or earlier in phenomena such as the thickness of annual tree rings, and in the layer thickness in varved clays.

A role for solar activity in the development of epidemics was explored by Kádár et al. (1981), although the results were inconclusive. These researchers concentrated on climatic factors and their possible relationship with solar activity, and applied them to the propagation of the epidemic. Unfortunately, the complex mix of factors that affect the propagation of the virus makes a solar connection with propagation difficult to identify. A solar connection with pandemics may seem implausible at first sight; however solar modulation of many environmental parameters is now well established, and it is timely to revisit the issue of the connection between the occurrence of pandemics and the rhythm of solar activity.

## 2. Influenza Pandemics and Solar Activity

Garrett (1994) and Potter (1998) listed pandemics up to 1997; they are summarized in Table 1. Reliable and consistent records of sunspot number provide a useful record of solar activity dating back to at least 1700. These data consist of simple counts of the number of sunspots visible on the solar disc. Table 1 shows the pandemics listed by Garrett since the beginning of the sunspot number record in 1700.

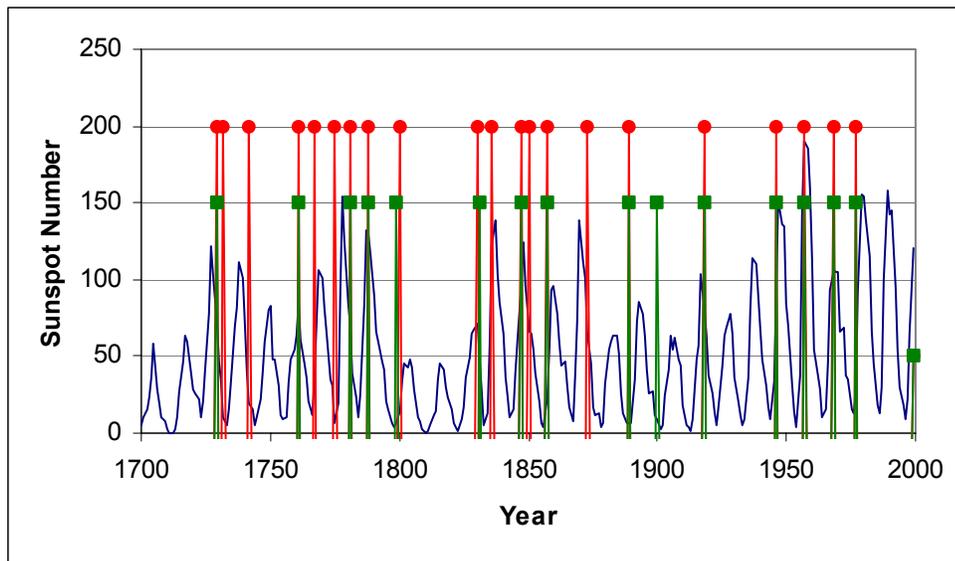
**Table 1: True, Global and Major Pandemics Since 1700**

Pandemics Listed by Garrett			Pandemics Listed by Potter		
Years	Magnitude	Phase*	Years	Magnitude	Phase*
1729-30	High	+0.20	1729-33	High	+0.20
1732-33	High	+0.50	-	-	-
1742-43	Moderate	+0.36	-	-	-
1761-62	High	+0.00	1761-62	Low	+0.00
1767	Moderate	-0.22	-	-	-
1775-76	Moderate	-0.33	-	-	-
1781-82	High	+0.33	1781-82	High	+0.33
1788-89	Low	+0.07	1788-90	Low	+0.07
1800-02	Moderate	-0.33	1799-1802	Moderate?	+0.42
1830-33	High	+0.00	1830-33	High	+0.10
1837-37	High	-0.10	-	-	-
1847-48	High	-0.08	1847-48	Moderate	-0.07
1850-51	Moderate	+0.15	-	-	-
1857-58	Mild	-0.27	1857-58	Low	-0.27
1873-75	Mild	+0.27	-	-	-
1889-90	High	-0.33	1889-90	High	-0.33
-	-	-	1900	Low?	-0.50
1918-19	High	+0.10	1918-20	High	+0.10
1946	?	+0.20	1946-48	Low	+0.20
1957	High	+0.00	1957-58	High	+0.00
1968-70	High	+0.00	1968-70	High	+0.00
1977	?	-0.20	1977-78	High	-0.20

\* This quantity, phase offset from activity maximum, is described later in the text.

Where a magnitude estimate is present, question marks indicate that the estimate is doubtful. Where there is no magnitude estimate, it indicates that none is yet available.

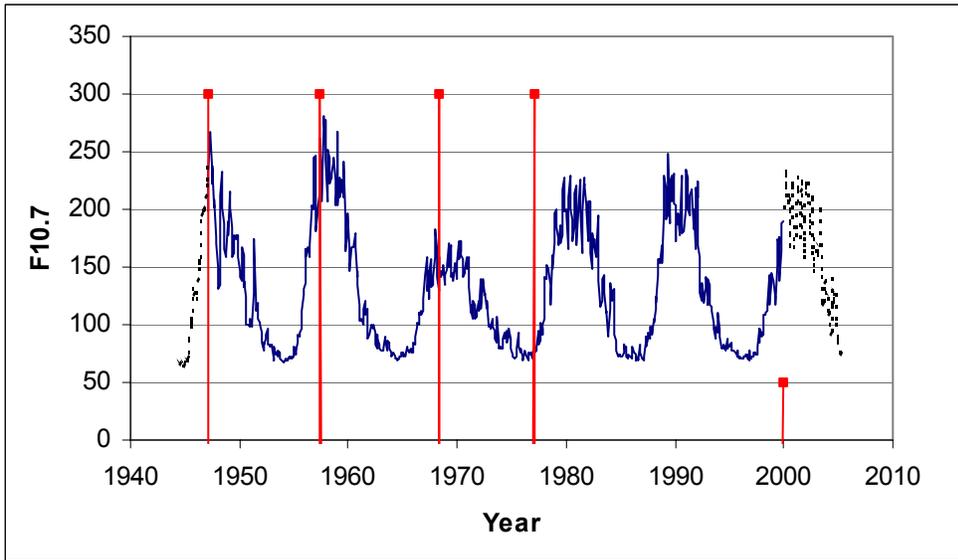
Figure 1 shows a plot of annual means of sunspot number from 1700 to the present. The years in which pandemics are reported in the two lists are shown as spikes. Those listed by Garrett (1994) are shown as spikes reaching the 200 level on the vertical scale, and capped with diamonds, and those listed by Potter (1998) as spikes reaching the 150 level, and capped with squares. The small spike of height 50 in the year 1999 shows the epidemic in progress at that time.



**Figure 1: A plot of start years of pandemics (shown as spikes) and sunspot number. Pandemics listed by Garrett (1994) are shown as spikes to 200, topped with diamonds, and those listed by Potter (1998) as spikes to 150, topped with squares. The square at the 50 level, in 1999, represents the flu epidemic of 1999-.**

After 1946 a more consistent index of solar activity became available: the 10.7cm Solar Flux. This index is an effective measure of the total amount of magnetic flux in the solar atmosphere, which is the foundation of all aspects of solar activity. This index has the advantages of being completely objective and not requiring empirical correction procedures, and is more directly related to the total amount of magnetic activity. The properties and origins of the 10.7cm Solar Flux are discussed by Tapping (1987), Tapping and DeTracey (1990) and Tapping and Harvey (1994).

In Figure 1 some tendency for pandemics to favour periods of high solar activity (Sunspot Number >50) is evident. This is also apparent in Figure 2, which shows the 1946, 1957 and 1968 events occurring at solar activity maximum. There are conspicuous exceptions, such as the pandemic of 1977, which occurred close to activity minimum.



**Figure 2: The 1946, 1957, 1968 and 1977 pandemics (shown as spikes) on a plot of the 10.7cm Solar Flux index. The flux values prior to 1947 (shown dotted) are estimated from sunspot data, and those beyond 2000 (also dotted) are estimated from a previous activity cycle. The small spike in 1999 represents the influenza epidemic in progress at that time.**

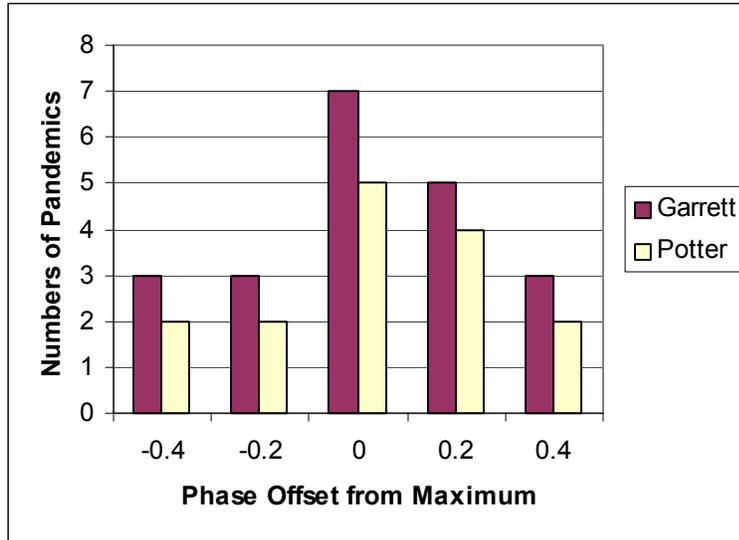
To show the relationship between the pandemics and the maximum of solar (sunspot) activity, the duration of each cycle was determined and the position of any pandemic that occurred in that activity cycle expressed in terms of phase offset in the cycle, defined by:

$$\text{Phase Offset} = \frac{\text{Year of Pandemic} - \text{Year of Maximum}}{\text{Year of Cycle End} - \text{Year of Cycle Start}}$$

In this case a Phase Offset of zero coincides with the year of solar maximum, and one of  $\pm 0.5$  corresponds with the preceding (-) or succeeding (+) activity minima. The counts of pandemics as a function of cycle phase are shown in Table 2.

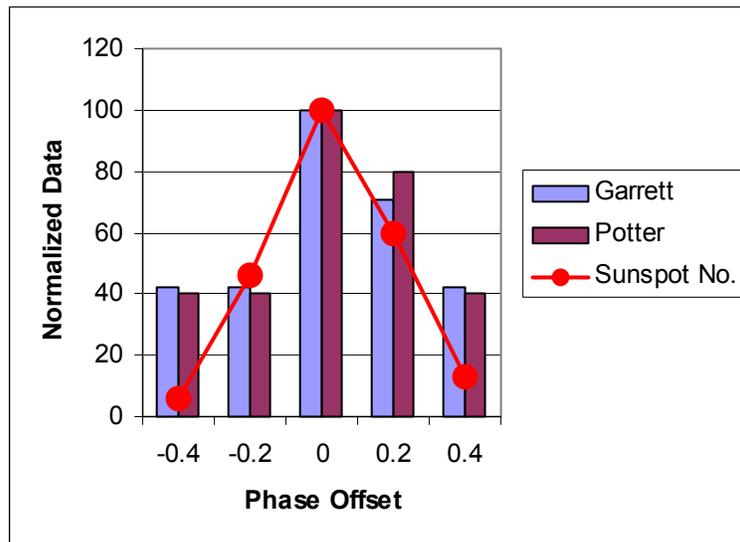
**Table 2**

Class Bounds		Class	Data Set	
Lower	Upper	Centre	Garrett	Potter
-0.5	-0.3	-0.4	3	2
-0.3	-0.1	-0.2	3	2
-0.1	0.1	0	7	5
0.1	0.3	0.2	5	4
0.3	0.5	0.4	3	2
		<b>Totals</b>	<b>21</b>	<b>15</b>



**Figure 3: Distribution of the numbers of pandemics in both lists shown as a function of phase offset from solar activity maximum. Activity maximum occurs at a phase offset of 0, and activity minima at phase offsets of  $\pm 0.5$**

For comparison purposes, an average activity cycle was determined by scaling each cycle individually so that its maximum value is 100, expressing the positions of each scaled sunspot number value in terms of phase offset in the cycle, and then averaging all the cycles since 1700. The counts of pandemics were normalized to maxima of 100, and plotted in Figure 4. In the plot, depending upon the length of the cycle, 0.1 of phase offset corresponds to between 0.91 and 1.1 calendar years.



**Figure 3: Distribution of the Pandemics in both lists as a function of phase offset from solar activity maximum. Data are normalized for a maximum of 100. The solar activity minimum lies at a phase offset of  $\pm 0.5$ . The activity maximum is at a phase offset of 0. The data in Garrett (1994) are shown in blue; those in Potter (1998) in brown. Sunspot Number is shown in red.**

There is a clear tendency for pandemics to occur close to solar activity maximum. However, what is the probability that such a configuration of data could occur on a random basis?

### **3. Tests of Significance**

To estimate the probability that the association discussed here could simply be a random event, a simulation run of one million trials was carried out. In each trial a number of events equal to the number in the list in question (21 and 15 respectively for Garret and Potter), were assigned random phase offsets in the range -0.5 to +0.5 and then binned in five bins. If bins 3 (phase offset in range -0.1 to 0.1) and bin 4 (phase offset 0.1 to 0.3) together contain at least 12 observations (Garrett) out of 21 or 9 observations out of 15 (per Fax), with no other bin containing more than 3 (Garrett) or 2 (Potter), then the trial was deemed a success. Otherwise the trial was designated a failure. From this simulation of a million such trials, the probability of obtaining a result on a random basis that would lead to the conclusion discussed in this paper is estimated at being less than 2%.

### **4. Solar-Environmental Connections**

In establishing a connection between solar activity and the occurrence of pandemics we must consider three factors:

- a) the variable aspects of the Sun's behaviour, and how they are related to the sunspot number and 10.7cm Solar Flux indices of solar activity;
- b) the Earth's climatic and environmental responses to the various manifestations of solar activity;
- c) how these responses can impact the origin and/or the propagation of the viral strain.

These three topics cover a diverse range of topics, so the references include sources of general background information. A useful review of solar astrophysics is given by Zirin (1988). A very comprehensive review of the workings of the Sun, solar-terrestrial interaction and the sun-climate connection is given by Lang (1994). More detailed discussion of the current, past and future Sun, and terrestrial climate are given in Sonett Giampapa and Matthews (1991) and Pap *et al.* (1994).

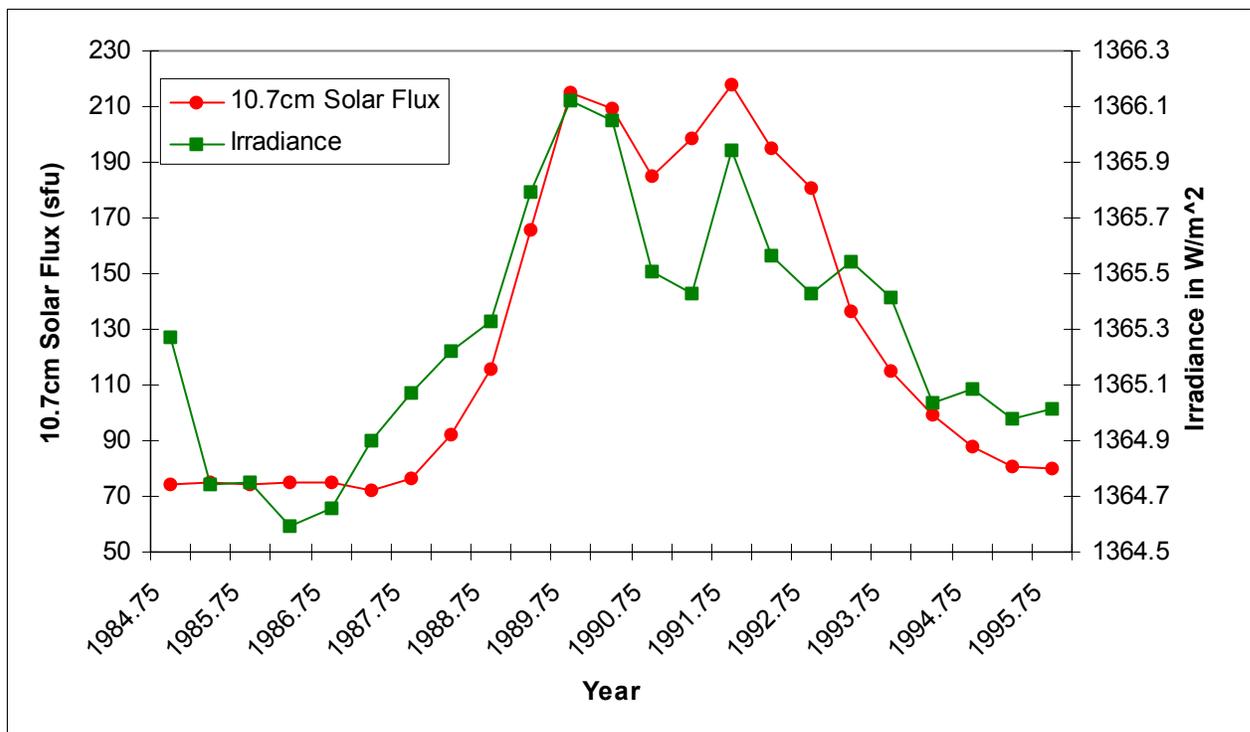
#### **4.1 Solar Activity**

The various manifestations of solar activity are driven by the changing amount and distribution of magnetic flux in the Sun. Solar activity was first discovered through observations of sunspots. Reliable counts of sunspots, integrated into an index called *sunspot number* date back from the present to at least the beginning of the 18<sup>th</sup> Century.

Sunspots are but one of many phenomena due to solar magnetic activity. Convective and shear flows in the plasmas of the solar interior give rise to electrical currents and thence to magnetic fields. These in turn erupt through the visible “surface” (the photosphere) of the Sun in an 11-year pattern. The presence of magnetic fields enable storage and subsequent catastrophic release of energy in flares, coronal mass ejections and other phenomena.

Until recently it was widely accepted that apart from a slow increase in its luminosity over its evolution, the Sun’s energy output showed no variation. This theory was firmly disproved as soon as measurements of the Sun’s energy output could be made from spaceborne platforms (see the review by Frölich *et al.*, 1991). These demonstrated that the Sun’s energy output is modulated by solar activity, so that it rises and falls over the 11-year activity cycle. This is brought about by magnetic fields interfering with energy flow from the Sun’s core (see review by Spruit, 1991, and Fox and Sofia, 1994).

In 1946 a better index of solar magnetic activity was discovered: the 10.7cm Solar Flux. This index is an objective measurement of radio emission from plasma concentrations supported in the solar corona by magnetic fields and are tightly and linearly correlated with the total magnetic flux (Tapping 1987, Tapping and Harvey, 1994). Harvey (1994) described a clear correlation between the total magnetic flux and the solar irradiance (energy flux per square meter measured at the Earth). The correspondence between the 10.7cm Solar Flux and total magnetic flux suggests that there should be a correspondence between the solar irradiance and the 10.7cm Solar Flux. This is indeed the case, as can be seen in Figure 5. Over a solar cycle, the Sun’s energy output varies by about 0.1%.



**Figure 4: The Sun's energy output, expressed in terms of Irradiance, and the 10.7cm Solar Flux index plotted over a solar activity cycle.**

The 10.7cm Flux is also tightly correlated with the Sun's output of soft x-rays, extreme ultraviolet and ultraviolet emission. Sunspot number and 10.7cm Solar Flux are therefore useful indicators of the level of Sun's input to various terrestrial processes.

## **4.2 Terrestrial Climatic and other Environmental Responses**

A proportional response of the terrestrial climate to solar activity (and irradiance) variations has been sought without success for decades. It is reasonable therefore to assume that such a relationship does not exist. However, indications of solar influence on the terrestrial climate are well known. The global climate machine is now believed to be only marginally stable, and switches between a number of quasi-stable states (Anderson, 1991). Small changes in the Sun's behaviour are enough to make the climate machine change state, triggering significant climatic changes.

The consequences of Sun-induced climatic phase switching are clearly visible in a number of natural phenomena. Studies of the thickness of tree rings provide a record of the 11-year cycle of solar activity covering more than a thousand years. Similar variations have been found in varved clays that are 250 million years old. There is some evidence of the cycle in varve deposits laid down more than a billion years ago (Anderson, 1991).

Dramatic demonstrations of the climatic response are provided by the historical evidence of dramatic drops in global temperature that occurred during the periods 1290-1330, 1410-1520 and 1660-1700, when the level of solar activity dropped to almost zero for decades. These periods are now termed the Wolf, Spörer and Maunder Minima. The last of these is often referred to as the "Little Ice Age". These events are discussed by Lean et al. (1994) and Lang (1995). It is now quite well established that there is a connection between solar activity and global temperature over such timescales (Friis-Christensen and Lassen, 1994).

There have been suggestions that one of the main channels through which the solar variabilities enter the climate system though pumping the Quasi-biennial Oscillation and the El Niño/Southern Oscillation (Ropelewski and Halpert, 1987, van Loon and Labitzke, 1988, Sellers, 1990). El Niño events (longitudinal oscillations in the temperature and thickness of the mixed layer in the tropical and subtropical Pacific Ocean that are accompanied by changes in the Trade Wind patterns) are about four times as likely when solar activity is low (Anderson, 1990).

### **4.3 Impact Upon Viral Mutation and Propagation**

The development of a pandemic depends upon three factors: (i) that a new viral strain appear to which there is poor population resistance; (ii) that this viral strain is communicated to a sufficiently large seed population; and (iii) that circumstances have to exist that promote its rapid spread through the host population.

The complex mix of societal and environmental factors makes it unlikely that a solar connection would be identifiable in the propagation of the virus. It is most likely that the solar connection is with the first factor: appearance of new viral strains.

## **5. Discussion and Conclusions**

The results of this study support the suggestion by Kilbourne (1976) that there is a 10-11 year periodicity superimposed upon the occurrence of influenza pandemics. Moreover, we find evidence that there is a tendency for pandemics to peak in occurrence at solar activity maxima. The data set is small, and there is a degree of uncertainty in the dates of the pandemics, but the probability of the criteria for our conclusion arising on a random basis is around 2%, so there is a reasonable chance that the association is real.

When we consider the complex nature of the relationship between solar activity and climatic changes that have environmental and societal impacts strong enough to modulate the propagation of the virus, it seems unlikely that any significant association between solar activity and the occurrence of pandemics would be observable. The correlation we see between solar activity and the occurrence of these pandemics could be best explained in terms of one strong relationship, rather than a chain of smaller ones. Kádár et al., (1981), proposed that the effects of weather on propagation could be the relevant factor. The solar relationship with climate is believed to be significant, but is highly non-linear and difficult to quantify. The suggestion by Kilbourne (1976) that the periodicity is in antigenic shifts may be a better explanation. This provides a strong, single phenomenon to be modulated.

Solar behaviour and the terrestrial responses are now reasonably well identified. We have observed the modulation by solar magnetic activity of not only the Sun's total energy output, but also its output of ultra-violet radiation (some of which penetrates to sea level) and soft X-rays, which do not. However it is not clear how the antigenic shifts might be caused. The influenza virus survives only short periods in the open air. Could the shifts occur in the hosts? Changing levels of ultraviolet flux could affect hosts at the dermal and subdermal levels. Modulation of the environmental level of Carbon 14 could be another possibility. However, at this point no substantive conclusion can be drawn.

The significance of the result is certainly high enough to justify further examination. Even if we can at this point make no well-founded suggestion as to how solar activity affects the appearance of new viral strains, knowing of such a possible connection could be useful in medical planning and epidemic management.

## **6. Acknowledgements**

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