The Minimum Between Cycle 23 and 24: Is Sunspot Number the Whole Story?

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Abstract. During recent years we have observed a long and deep solar minimum with sunspot number in 2008 and 2009 reaching the lowest level in about a century. In spite of the lack of sunspot activity at the Sun, observations have shown that a relatively complex corona and heliosphere persisted for most of the minimum phase. The solar corona did not reach the simple “dipolar” shape often seen during solar minima, while low-latitude coronal holes, and their associated corotating high-speed solar wind streams, persisted to 2008, modulating the solar wind. We compare the current and previous minima to show how, even during very quiet times, different magnetic configurations are possible at the Sun and discuss how these different morphologies can affect the corona, heliosphere, and even the geospace.

1 A Long Solar Minimum

Solar minimum is a period of low magnetic activity at the Sun occurring during the declining phase of the old cycle and the overlapping rising phase of the new cycle. The present minimum has been a longer than average one because of the slow decline in activity of cycle 23 and slow increase of cycle 24. Magnetic activity, which has been low since 2006, reached its lowest level in 2008 and 2009; in 2008 there were 266 days without spots and in 2009 there were already 250 days without spots by the end of November 2009. Hence, for the past two years, the Sun had no sunspot activity for about 70% of the time. This is the lowest activity level observed since 1913 and makes the present minimum very long and deep.

While this minimum is not unprecedented, and long and deep solar minima have happened before, e.g., the long minima in 1875–1879 and 1910–1914, this is the first time that such a long and deep minimum in solar activity has been observed with a broad range of observations that cover the entire Sun-to-Earth system. The present minimum, thus, offers a unique opportunity to learn how the Sun affects the Earth during its quietest times. Also very instructive is the comparison of the current minimum with the past two minima, for which we have a large set of observations available. Finally, it is interesting to follow the changes at the Sun and in the heliosphere during this extended minimum.
Figure 1. Sunspot number from 1982 to the end of 2009, daily values are in grey and 81-day averages in black. The present minimum is longer and deeper than the two previous ones. The new cycle 24 has dominated over cycle 23 since October of 2008, but the overall activity level has remained low throughout 2009.

2 The Evolution of Magnetic Flux during the Present Minimum

This long minimum has been characterized by a slow decline of cycle 23 activity that began in the northern hemisphere. This was accompanied by a slow start of cycle 24. The first spot of cycle 24 was in January 2008 and was followed by sporadic new cycle activity separated by long periods without spots. Only recently has cycle 24 started to produce more complex and longer-lived active regions. Thus, even though the two cycles have overlapped for about a year and a half (the latest spot from cycle 23 was in July 2009), the overall level of flux emergence in 2008–2009 has remained low (see Figure 1). Nonetheless, the existing magnetic flux continued to evolve, causing changes in the large-scale magnetic field of the Sun. In particular, the predominantly unipolar magnetic regions at mid- to low-latitudes, corresponding to the large coronal holes prominent in 2007 and 2008, diffused and decayed, ultimately leading to the disappearance of the coronal holes themselves in 2009. This change in coronal hole distribution caused a shift in the sources of the solar wind at the Earth and, consequently, a change in the properties of the solar wind.

Another interesting aspect of the present minimum has been the very low value of the polar magnetic flux at the Sun (e.g., Sheeley 2008; de Toma & Arge 2009). The net polar magnetic flux measured at the photosphere was about 40% less than observed during the previous two minima, and has remained at this low value since about 2005, as illustrated in Figure 2. This is an important difference since the magnetic flux within the polar coronal holes is a major source of the magnetic flux that opens to the heliosphere during the solar minimum phase. Low polar fluxes at the photosphere mean that the large-scale magnetic field of the Sun has a lower polar dipole component and this was one of the reasons for the more complex appearance of the solar corona during the present minimum (e.g., Luhmann et al. 2009). Even at times of extremely low magnetic activity, coronal streamers were not confined to low heliolatitudes, but rather the corona had multiple streamers extending to relatively high latitudes (e.g., de Toma et al. 2009).
Is Sunspot Number the Whole Story?

Figure 2. Polar magnetic flux from 1982 to the present for the northern and southern hemispheres as measured at NSO/Kitt Peak. The magnetic flux near the poles is lower this minimum than during the two previous minima.

Figure 3. Interplanetary magnetic field magnitude averaged over 27 days from 1982 to the end of 2009 from the OMNI database. These observations show a slow and continual decline throughout the minimum phase of cycle 23.

The interplanetary magnetic field (IMF) also reached very low values during this minimum, but changed in a different manner from the the polar fields or sunspot activity. While the polar magnetic flux at the photosphere remained relatively constant during the minimum years, the IMF continued to decrease up to the present time. Measurements above the Sun’s poles obtained by the Ulysses spacecraft in 2007–2008 were already lower by 30–35% relative to similar measurements made last cycle minimum (Smith & Balogh 2008). This is consistent with observations near the ecliptic plane, as shown in Figure 3. The current value of the IMF is below 4.0 nT compared to values of 5–5.5 nT during the two previous minima. These are the lowest values measured during the approximately 50 years of in-situ solar wind measurements.

2.1 Consequences for the Heliosphere

The heliosphere changed significantly during this extended minimum in response to the changes in the large-scale magnetic field of the Sun mentioned above. From 2006 to 2008, the heliosphere was still relatively complex (e.g., McComas et al. 2006; Luhmann et al. 2009). For example, in 2008 the coronal field at 5 \( R_\odot \) was lower than in 1996 but the heliospheric current sheet was more warped.
and low-latitude coronal holes were still significant sources of the solar wind observed at the Earth, as shown by the Potential Field Source Surface (PFSS) extrapolations in Figures 4 and 5. While the average solar wind velocity was about the same in 1996 and 2008, i.e., 423 km/s and 450 km/s respectively, the distribution of solar wind speeds was quite different (de Toma et al. 2009). In 2008, the solar wind observed at the Earth was still organized in recurrent high speed streams producing moderate and periodic geomagnetic disturbances at the Earth (Emery et al. 2009; Gibson et al. 2009).

Between the end of 2008 and beginning of 2009, the low-latitude coronal holes closed down. This corresponded to the disappearance of the recurrent high-speed solar wind streams that had dominated in 2008 and led to lower solar wind velocities. The mean solar wind speed dropped below 380 km/s in 2009.
By March of 2009, most of the solar wind reaching the Earth was originating from the edges of the polar coronal holes, and the heliospheric current sheet had flattened considerably, as illustrated in the bottom panels of Figures 4 and 5. This morphology was similar to the one observed in 1996. This indicates that, while the polar fields did not change much throughout the minimum phase and stayed at low values in 2009, the change in the low-latitude distribution of magnetic flux was sufficient to induce such morphological change. Thus, the balance of the low- and high-latitude sources of magnetic flux is more important than the absolute level of magnetic activity in determining the heliospheric structure.
3 Conclusions

There are noticeable differences between this minimum and the shorter minima in 1996 and 1986. Not only has this been a longer and deeper minimum with extremely low sunspot activity, but the magnetic flux distribution was also different. The presence, during this minimum, of weaker polar magnetic fields and the persistence of large, low-latitude coronal holes (which are usually seen during the declining phase) throughout a significant fraction of the minimum phase reflected a magnetic distribution where the sources of the magnetic flux open to the heliosphere were not limited to polar regions. The shape of the corona and heliosphere are largely determined by how the magnetic flux is organized at the Sun. Consequently, in spite of the fact that magnetic activity in 2007–2008 was as low or lower than in 1996 and 1986, the corona and heliosphere retained a certain complexity and the solar wind was still structured in regular, high-speed streams that continued to produce moderate and recurrent geomagnetic disturbances. Only in early 2009 did the structure of the heliosphere start to resemble the one observed in 1996.

Observations from the current minimum illustrate that even during very quiet times, there can be different magnetic morphologies at the Sun with important consequences for the heliosphere and geospace. They also show the limits of traditional indices of solar activity like sunspot number. While sunspot number is a good indicator of the overall level of magnetic activity, it cannot tell us the 3D magnetic structure of the Sun. Moreover, the decrease in sunspot number near and during minimum can differ from the evolution of the IMF. Thus, the sunspot number, while a useful index of solar activity, is not sufficient to infer the properties of the corona and solar wind.

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References

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