

****FULL TITLE****

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The Whole Heliosphere Interval in the context of the current solar minimum

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Abstract. The current solar minimum may not be “peculiar” when considered on scales of a century or more. However, the opportunity for discovery yielded by its extended nature in combination with the abundance of modern observations cannot be overstated. In this paper, we describe the Whole Heliosphere Interval (WHI), an in-depth study of the Sun-Earth system for a solar rotation in March/April 2008. We discuss how WHI fits within the broader context of the current deep, long, and complex solar minimum.

1 Whole Heliosphere Interval

The Whole Heliosphere Interval (WHI) is an internationally coordinated observing and modeling effort to characterize the Sun and heliosphere near solar minimum. Observations were gathered of the Sun during Carrington Rotation 2068 (March 20 - April 16, 2008), of the solar wind emanating from that rotation, and of the impact of that wind and of solar irradiance at the Earth. Synoptic observations provided broad Sun-to-Earth coverage as well as context and baseline measurements. Targeted observing programs were also coordinated during WHI, obtaining high-resolution observations of the quiet Sun, active regions, low-latitude coronal holes, coronal streamers and the origin of slow solar wind, and observations of the source of high-speed solar wind intersecting the Ulysses satellite (which was in quadrature during WHI, and still obtaining limited data). 27 solar, 19 heliospheric, and 21 geospace instruments and approximately 200 individuals are registered as participating in the WHI campaign. Please see <http://ihy2007.org/WHI> for further details.

We chose to embark upon the WHI campaign for several reasons. Recent observations, including data from Hinode and STEREO at the Sun and solar wind, from Themis at the magnetosphere, and from Voyager and IBEX at the heliopause, meant that we had an unprecedented opportunity for spanning the heliosphere in three dimensions. Moreover, advances in end-to-end modeling (Lionello et al. 2009) and three-dimensional reconstruction techniques (Bisi et al. 2009) meant that building a framework for these data was more feasible than

ever before. Our primary motivation, however, was to study the system when it was relatively simple, i.e., near solar minimum.

In August-September 1996, the Whole Sun Month (WSM) campaign characterized the last solar minimum. Observations of a solar rotation were analyzed, with models connecting structures from Sun to Earth. A series of workshops coordinated analysis across disciplines, and publications of these analyses make WSM a well-studied solar minimum interval (Alexander 1999; Biesecker *et al.* 1999; Breen *et al.* 1999a,b; Bromage *et al.* 2000; Dobrzycka *et al.* 1999; Fludra *et al.* 1999; Frazin & Janzen 2002; Galvin & Kohl 1999; Gibson *et al.* 1999a,b; Gibson 2001; Guhathakurta *et al.* 1999, 2006; Gopalswamy *et al.* 1999; Linker *et al.* 1999; Lionello *et al.* 2009; Moran *et al.* 2000; Panasyuk 1999; Posner *et al.* 1999; Riley *et al.* 1999, 2001; Strachan *et al.* 1999, 2000; Zhao *et al.* 1999; Zidowitz 1999). As we reached record low sunspot levels in 2008, it seemed the time had come to define the current solar minimum in a manner directly comparable to WSM.

The science goals for WHI were twofold: 1) to connect the origins and effects of solar structure and activity through the solar wind to the Earth and other planetary systems; 2) to characterize the three-dimensional solar minimum heliosphere. Our hope was that WHI would be a good example of a relatively simple, solar minimum configuration. However, we also hoped for sufficient structure/activity to make the connections interesting. We were in luck, because the WHI rotation satisfied both desires.

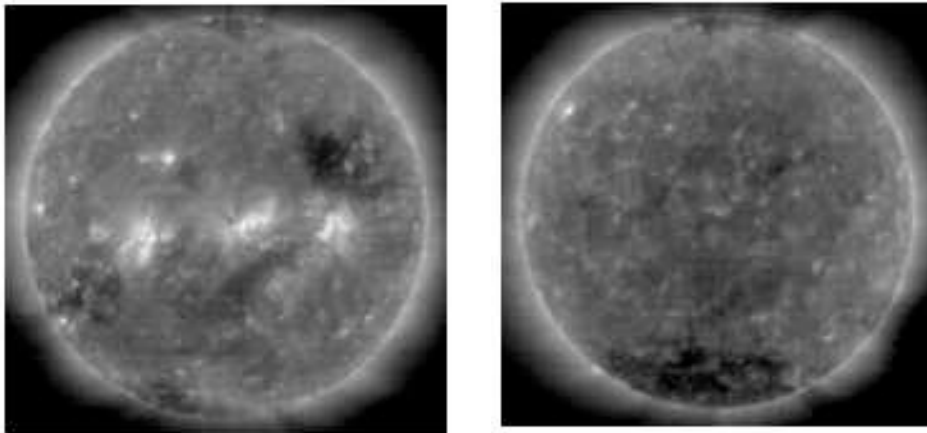


Figure 1. SOHO EIT 195A observations of the corona during the WHI “active” side (March 29, 2008; left) and the “quiet” side (April 11, 2008; right)

During the first half of WHI, a string of three active regions and two opposite-polarity, low-latitude coronal holes crossed the disk (see Figure 1, left). Most of the coronal mass ejections or other transients during WHI originated from this “active side” of the rotation (Sterling 2010; Webb *et al.* 2010). In particular, a series of events occurred on April 5-9 (Landi *et al.* 2009), and energetic, fast CMEs associated with coronal arcades, dimmings, EUV waves and shocks occurred March 25 (Gopalswamy *et al.* 2009) and just after WHI on

April 26 (Webb et al. 2010). Studies are ongoing on how the magnetic evolution of the three active regions relate to sub-surface flows and to global magnetic field and heliospheric current sheet evolution. High-speed solar wind streams originating from the low-latitude coronal holes of the active side also periodically impacted the Earth’s space environment and upper atmosphere (Leamon & McIntosh 2009; Gibson et al. 2009; Dal Lago et al. 2010; Maris & Maris 2010). Towards the end of WHI, however, the Sun showed another, quieter side (see Figure 1, right). WHI targetted quiet sun observations took place during this period (McIntosh & DePontieu 2009), as did a NASA sounding rocket flight which provided the most accurate reference for the current solar minimum irradiance spectrum in XUV/EUV (Chamberlin et al. 2009; Woods et al. 2009).

2 WHI in the context of the current solar minimum

The depth, or quietness of the current solar minimum has been much discussed (see e.g. Gibson et al. (2009), and references therein). This was apparent by the time of WHI, where levels comparable to or lower than last solar minimum had already been reached at the Sun (sunspot number, polar magnetic field strength, solar irradiance), in the solar wind (interplanetary magnetic field, density), and at the Earth (geomagnetic indices, auroral electron power).

Was WHI representative of the current solar minimum? It depends upon what you look at, and how you define solar minimum. If minimum is defined as a point in time – for example – the point at which new cycle sunspots outnumber old cycle sunspots (August, 2008; *D. Hathaway, SOHO 23 presentation, 2009*), or the minimum of a 13-month smoothed sunspot number (November-December, 2008; *ftp.ngdc.noaa.gov*), or the minimum of a 13-month smoothed total solar irradiance (December, 2008; *G. Kopp, private communication, 2009*), then the WHI period occurred before the minimum point. However, such a minimum point is not well-specified, as it changes significantly if one varies the length of time used in averaging and/or wavelength of irradiance being considered (*T. Woods, private communication, 2009*). This arises because of another key attribute of the current solar minimum: it is longer than any we have observed in the space age, and the slope of many observables vs. time is flat. Because of the length of this solar minimum, it is better characterized as a period of low solar activity, rather than a point in time (de Toma et al. 2010).

Moreover, minimum at the Sun does not necessarily imply that things are quiet at the Earth. High-speed solar wind streams are typical of the declining phase of the solar cycle; what was not typical this minimum (compared to prior space-age minima) was high-speed streams dominating the Sun-Earth interaction for months after sunspots had reached record low levels. The continued presence of periodic high-speed streams impacting the Earth during 2008 was due to low-latitude coronal hole open magnetic flux, in turn most likely due to the weak polar magnetic fields. Variable solar wind speed (fast and slow) at low latitudes characterized WHI and indeed most of 2008 (Tokumaru et al. 2009; Bisi et al. 2009; Manoharan 2010; Riley et al. 2010), illustrating the third attribute of the current solar minimum: its complexity relative to other space-age solar cycles.

The interplanetary magnetic field (IMF) continued to decrease through 2008 and 2009. A lag between sunspots and IMF reaching minimum levels has been observed in prior cycles. It arises because sunspot number relates to magnetic flux emergence, while IMF relates to the evolution of “open” magnetic flux at the Sun. The extended length of this solar minimum allowed an extended period of open flux evolution essentially uninfluenced by flux emergence. By 2009, this evolution had led to the decay of the large low-latitude coronal holes and disappearance of high-speed solar wind streams at the Earth, and an ever-deepening minimum in the solar wind and at the Earth (de Toma et al. 2009, 2010).

3 Conclusions

So again we ask, was WHI representative of the current solar minimum? Yes and no – and the duality of that answer is a direct consequence of the “peculiarity” of the current minimum. WHI had solar irradiance levels and sunspot numbers typical for the very flat minimum seen at the Sun, and occurred near the transition from old-cycle to new-cycle dominated flux emergence. The low-latitude coronal holes seen during WHI were typical for 2008, but differed from the simpler solar coronal configuration of 2009 after continued evolution of the open magnetic flux.

Indeed, the length of this cycle minimum allows us to probe Sun-Earth physical processes as never before. In 2008, geospace was periodically impacted by high-speed streams, even though solar irradiance, activity, and IMF were lower than last solar minimum. This time period – of which WHI is typical – allows us to isolate the effects of fast solar wind streams on the Earth in an otherwise quiet heliosphere. In 2009 solar magnetic flux evolved – perhaps to smaller spatial scales (*S. McIntosh, private communication, 2009*) – yielding a Sun-Earth system that can be studied at its quietest. Because of the depth, length, and complexity of the current solar minimum, one solar rotation is not enough to characterize it!

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