The Unusual Solar Cycle 23: The Vanishing Solar Wind its Cause and Impact

P. Janardhan[1] and S. Ananthakrishnan[2]

[1] Physical Research Laboratory, Astronomy & Astrophysics Division, Navrangpura, Ahmedabad - 380 009, India. email: jerry@prl.res.in

[2] Electronic Science Department, Pune University, Pune, India. email: subra.anan@gmail.com

Abstract

Solar cycle 23 was very unusual, in many ways, with polar magnetic fields showing a steady decline throughout the cycle and with the sunspot minimum being the deepest that we have experienced in a century. Recent studies even suggest that sunspots may entirely vanish by cycle 25. Apart from this cycle 23 had several instances when the solar wind apparently "disappeared" for periods exceeding 24 hours. We examine these solar wind disappearance events which correspond to density decreases, at 1 AU, by over two orders of magnitude for extended periods of time and show that these events though not associated with explosive solar phenomena, produce observable space weather effects at 1 AU. Understanding these events is therefore important in establishing and understanding solar terrestrial relationships in absence of explosive solar events. With the exception of CIR's solar wind disappearance events, provide the only evidence for solar terrestrial connection caused by a non-explosive solar events.

1 Introduction

The current sunspot minimum that we have seen at the end of cycle 23 have been one of the deepest minima that we have experienced in recent times with roughly 71%—-73% of the days in 2008 and 2009 respectively being entirely spotless. As stated earlier cycle 23 has also shown several other peculiarities, like a second maximum during the declining phase that is unusual of odd numbered cycles, a slower rise to maximum than other odd numbered cycles and a slower than average polar field reversal. In addition to all of the above, there have been several instances in solar cycle 23 when solar wind densities at1 AU have dropped to abnormally low values (< 0.1 cm^{-3}) that have persisted for extended periods (> 24 hours) of time and were accompanied by lower than normal solar wind flows (average ~ 450 km s^{-1}) at 1 AU. Such phenomena are now referred to as "solar wind disappearance events". One consequence is a dramatic expansion of the Earth's magnetosphere and bow shock and in the case of one event (11 May 1999), the expanding bow shock, normally located at 10 Earth radii, reached an upstream distance of ~60 Earth radii, the lunar orbit. Since the 11 May 1999 event, first studied using interplanetary scintillation (IPS) observations at 327 MHz [1], two more events that occurred in March and May 2002 have been studied using space-based observations. With the exception of co-rotating interacting regions (CIR), disappearance events provide the first link between the Sun and space weather effects at 1 AU, arising from non-explosive solar events.

Though disappearance events have been well studied [1, 2,3,4,5], none of these have been able to explain the cause or locate their solar source. It has also been speculated [5,1] that such events were related to the solar polar field reversals. Recently, the solar origins of these unusual events have been traced to coronal hole active region complexes (AR-CH) located at central meridian [6, 7].

2 Characteristic Features of Disappearance Events

Disappearance events are long lasting (>24 hours), highly non-radial, low density, solar wind flows at 1 AU having stable and unipolar magnetic fields [6, 7]. Figure 1 shows ACE measurements (hourly averages) of solar wind densities (left) and the deviation from the radial flow direction of the solar wind (right) for three events that occurred in May 1999 (top), March 2002 (middle) and May 2002 (bottom) respectively. The finely dotted line at θ_v=0 in the right hand panels represents the radial flow direction while the vertically oriented dashed parallel lines demarcate the event day. The Carrington Rotation in which the events occurred is

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indicated at the top of the left hand panels. Figure 2 shows the variation of the azimuthal component of the

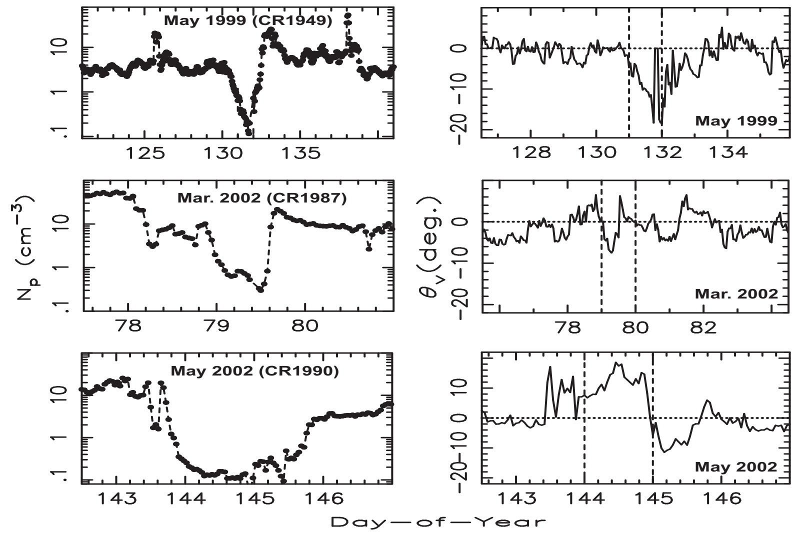

Figure 1: Hourly averages of solar wind density (filled circles joined by a dashed line) as a function of day-of-year for the events of May 1999 (top left), March 2002 (middle left) and May 2002 (bottom left). The right hand panels show the corresponding deviations from the radial flow direction of the solar wind.

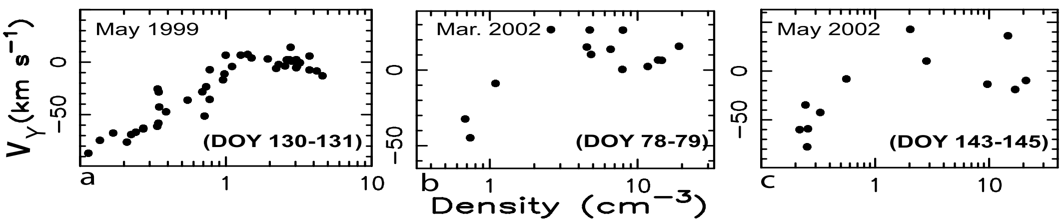

Figure 2: The azimuthal component of the solar wind velocity (V_y), as a function of density for the events of May 1999 (left), March 2002 (middle) and May 2002 (right) respectively.

solar wind velocity (V_y), as a function of density for the events of May 1999 (left), March 2002 (middle) and May 2002 (right) respectively. The densities and velocities are hourly averages measured by the SWEPAM instrument on board the ACE spacecraft, with the negative values of V_y implying a westward flow deviation in the azimuthal plane. It is clear from Fig. 2 that as the density decreases, the azimuthal or westward flow deviation of the solar wind increases. Given the fact that the magnetic field is constant, the Alfvén radius, normally a function of both the density and the magnetic field, would be a strong function of the density during the disappearance events.

3 Source Regions of Disappearance Event

It has been shown [9] that solar wind outflows from active regions contribute 30–50% during solar maximum. The three disappearance events under discussion were traced back to the sun, using constant velocities along Archimedean spirals, and it was shown that they all originated at large active region complexes, at central meridian, associated with open fields that connected out to the interplanetary medium (IPM) [7]. Figure 3 show maps of the solar photosphere corresponding to the traceback dates of the three events, *viz.* 05 May 1999 (DOY 125 – left); 15 March 2002 (DOY 74 – middle); and 21 May 2002 (DOY 141 –right). The locations of the large active regions, to the vicinity of which the solar wind flows were traced back, are shown and marked with a arrow each panel.

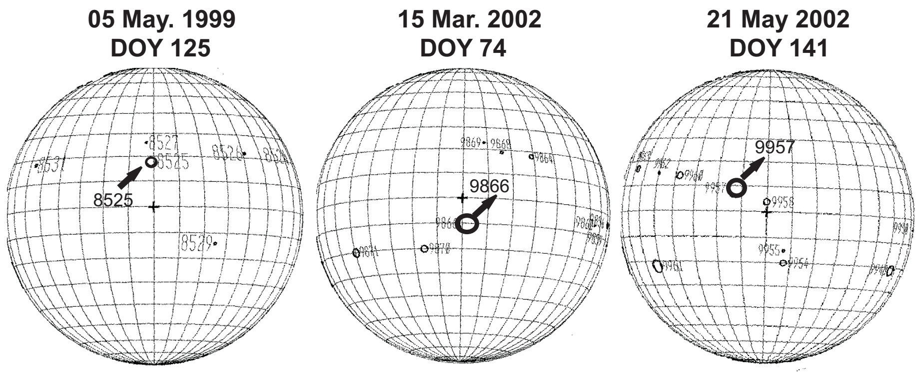

Figure 3: Maps of the solar photosphere showing the locations of the active regions at the source region of the disappearance events of May 1999 (left), March 2002 (middle) and May 2002 (right). The dates indicated correspond to the dates when the flows responsible for the events probably began on the sun.

4 Conclusions

Using both ground based and spacecraft observations the source regions of three disappearance events have been located [6,7,9]. The flows responsible for the events originate from central meridian located AR-CH boundaries which showed open field lines connecting to the IPM. Not considering CIRs, these observations thus provide the first evidence for the so called Sun-Earth "transmission-line" arising from non-explosive solar events. As stated earlier, cycle 23 was very unusual in many senses. Figure 4 shows measurements of

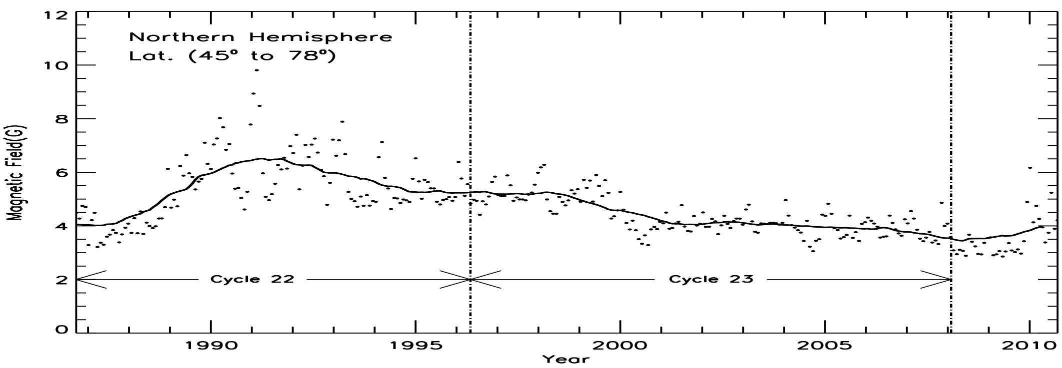

Figure 4: Measurements of magnetic field in the north solar hemisphere as a function of time for the solar cycles 22–23 derived from NSO/Kitt-Peak data.

polar magnetic fields in cycles 22–23. The filled dots represent the actual measurements while the solid line is a smoothed fit. A steady decline in the field can be seen throughout the cycle which continues into cycle 24 [10]. Apart from this, the very extended sunspot minimum at the end of cycle 23 raises the question of whether these phenomena are indicators of things to come in cycle 24 and beyond and if sunspot numbers will recover at all? A recent study using spectroscopic changes measured in temperature sensitive molecular lines [11] have indicated that sunspot umbrae are steadily increasing in temperature, while sunspot magnetic fields are steadily decreasing. In fact these authors have suggested that sunspots may entirely vanish beyond cycle 24. Therefore, any such departures from "*normal*" behaviour, like the specific events discussed, need to be studied and understood as they could be significant in the context of understanding the evolution of solar magnetic fields and space weather in future cycles.

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