Indian Journal of Radio & Space Physics
Vol. 40, February 2011, pp. 7-10

Solar activity during sunspot minimum

R P Kane

Instituto Nacional de Pesquisas Espaciais—INPE, C P 515, São Jose dos Campos, Brazil

E-mail: Kane@dge.inpe.br

Received 1 January 2010; revised 8 October 2010; re-revised received and accepted 4 January 2011

During the sunspot minimum years 2007-2009 of solar cycle 23, the sunspot number, Rz, declined from January 2007 till the end of 2007 and further till September 2009. But in between, there were sporadic increases during January, June, December 2007; March 2008; and September 2009. These were reflected very well in timing in the 2800 MHz solar radio emission flux F-10, X-ray background, and the occurrence frequency of coronal mass ejections (CME). Thus, all these have a major origin in the same active regions.

Keywords: Solar activity, Sunspot number, Solar radio emission flux, Coronal mass ejection (CME)

PACS Nos: 96.60.*ph;* 96.60.*qd*

1 Introduction

The solar activity parameter of longest history is the sunspots, discovered by Galileo in 1612, who noted that sunspots seemed to be moving on the solar surface. He guessed correctly that this was because the Sun was itself rotating with a rotation period of ~27 days, slightly faster at the equator as compared to higher latitudes. Schwabe[1] discovered that the sunspot numbers had a ~11-year cycle. Considering annual values only, the plot of sunspot numbers shows just one peak about 4-5 years after the sunspot minimum. But if shorter time scales are considered (12-month running means), few years near sunspot maximum show two distinct peaks separated by few months. Such peaks and their gaps were discovered first by Gnevyshev[2,3] in coronal green line index and are called Gnevyshev peaks and gaps. In cycle 23, there were two peaks, one in early 2000 and another in late 2001. Many other solar parameters showed these peaks. For solar electromagnetic radiations (Lyman-α, 2800 MHz radio emission, etc.), the peaks were almost in the same months as for sunspot number, but for some corpuscular radiations, notably coronal mass ejections (CMEs), the peaks were displaced by several months[4].

In the present paper, it is examined, whether during sunspot minimum period, any such structures (small peaks at different time intervals) were shown by sunspot number time series and whether these were reflected in some other solar parameters at the same time intervals. If yes, a common origin would be indicated.

2 Data

Data were obtained from the NOAA websites: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/ for sunspot number; http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarradio.html for 2800 MHz solar radio emission; ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/Satellite_ENVIRONMENT/XRAY_BGND/GOESBGND.06 for solar X-ray background; and from the SOHO-LASCO catalogue http://cdaw.gsfc.nasa.gov/CME_list/index.html for coronal mass ejection (CMEs) occurrence frequency.

3 Plots of monthly values

Figure 1 (a) shows the monthly maximum values (histograms) of sunspot numbers, Rz, during January - June 2010. The dots connected by lines are the monthly average sunspot numbers. As can be seen, the sunspot activity was still considerable (sunspot number more than 30) in the beginning of 2007 but declined slowly, thereafter, with some sporadic increases in between (January, June, December 2007; March 2008; September 2009, February 2010, all marked by open triangles). The average monthly value dropped from 16 in January 2007 to values below 5 by the end of 2007 and remained low except in the three months June, December 2007; March

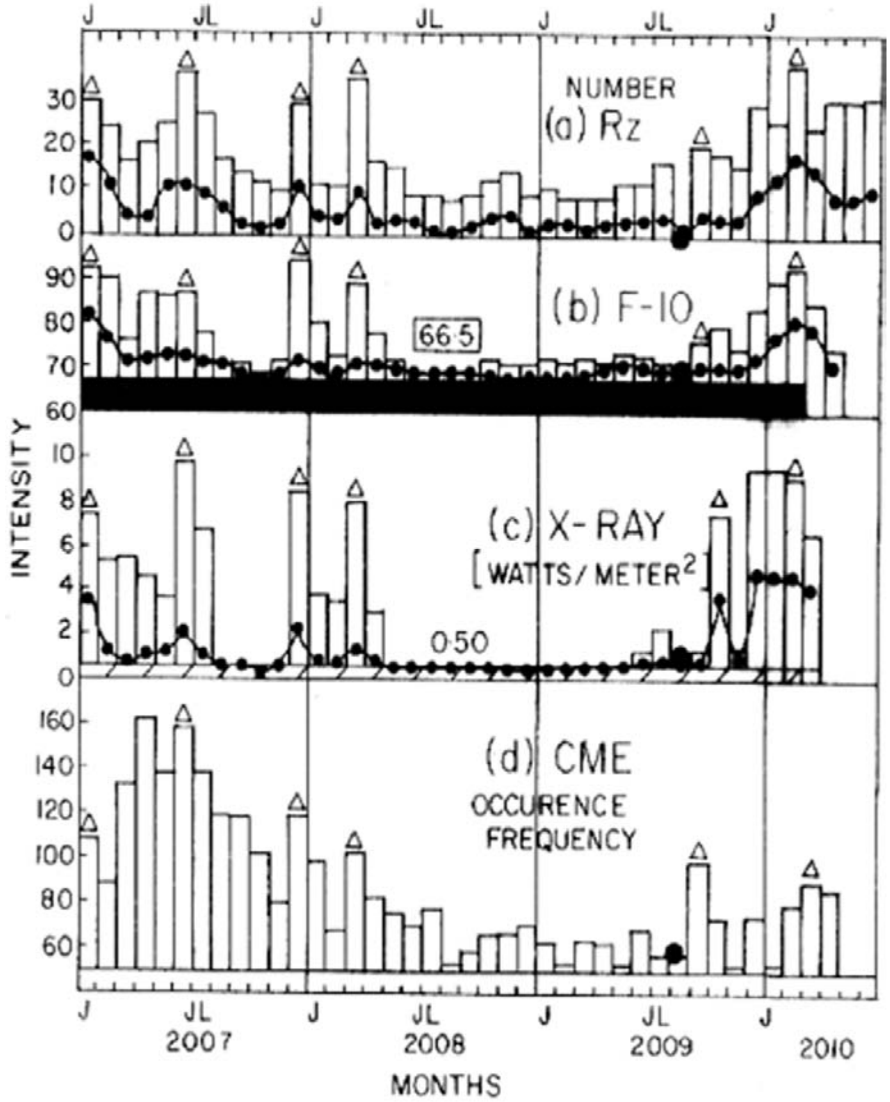

Fig. 1 — Plots of monthly values during January 2007-June 2010 for: (a) sunspot number, Rz, monthly maximum, histograms and monthly averages, dots joined by lines; (b) 2800 MHz solar radio emission F-10 (units 10^{-22} J s^{-1} sq m^{-1} Hz^{-1}); (c) X-ray background ((1-8 A and 8-20 A bands, units W m^{-2}); (d) coronal mass ejection (CME) monthly occurrence frequency. The triangles indicate abnormal increases in sunspot numbers during January, June, December 2007, March 2008, September 2009 and February 2010

2008. In particular, in August 2009, the sunspot number was zero (no sunspots at all).

Figure 1 (b) shows a similar plot for the 2800 MHz (10.7 cm) solar radio emission F-10 (units 10^{-22} J s^{-1} sq m^{-1} Hz^{-1}). The plot is similar to that of sunspot number and even the sporadic increases in January, June, December 2007; March 2008; September 2009; and February 2010. Thus, 2800 MHz emission follows the same characteristics as sunspot numbers. The black portion indicates the level 60-68 units of the F-10 flux, indicating that the F-10 flux never dropped below 68, in contrast to sunspot numbers which went to zero. The correlation between Rz (max) and F-10 (max) was +0.86±0.05, while correlation between Rz (average) and F-10 (average) was +0.91±0.03. The F-10 flux is of coronal origin and in the quiet corona (sunspot activity almost zero) (ref. 5), the F-10 values stand near the value ~69.

Figure 1 (c) shows a similar plot for the X-ray background (units W m^{-2}). In the data table, low values are mentioned as <1.0. These have been set as 0.50. The matching with (a) and (b) is good. The correlation between Rz (max) and X-ray (max) is +0.89±0.04, while correlation between Rz (average) and X-ray (average) is +0.88±0.05.

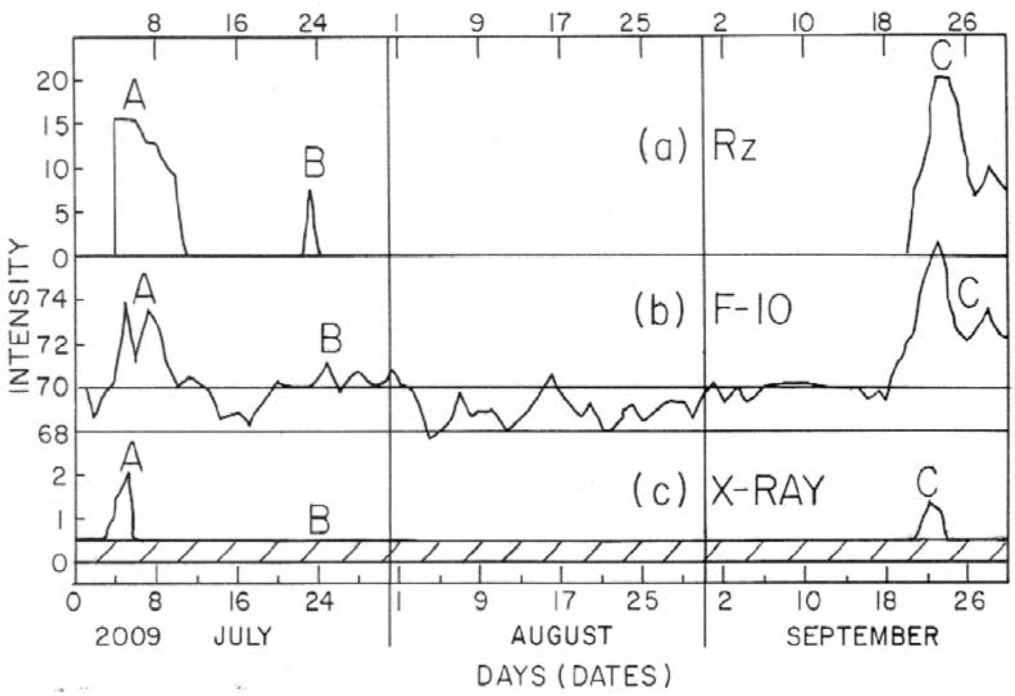

Fig. 2 — Plots of daily values during July, August, September 2009 for: (a) sunspot number, Rz; (b) 2800 MHz solar radio emission F-10; (c) X-ray background. A, B, C indicate intervals when sunspots were more than zero

Figure 1 (d) shows a similar plot for the occurrence frequency (number per month) of the coronal mass ejection (CME), discovered by Tousey[6] and given in the SOHO-LASCO catalogue and discussed in Gopalswamy *et al.* (ref. 7 and references therein). The lowest frequency has been 47 in August 2009. The correlation between Rz (max) and CME occurrence frequency is +0.73±0.09. The CME data are up to April 2010. The first four peaks (Δ) in 2007-2008 match well in all (a), (b), (c), (d); but the fifth peak in 2009 matches in (a), (b) (d) but out by one month in (c) X-rays. The sixth peak in 2010 matches in (a), (b), (c) but out by one month in (c). Thus, differences of one month can occur.

4 Plots of daily values

To check whether the matching is valid even for daily values, data has been chosen for July-September 2009, where the August values for Rz have been zero. Figure 2 (a) shows the plots of the daily values of Rz. There is a group of non-zero values of Rz (marked as A) during 4-10 July, a single value on 23 July (marked as B), no sunspots during August and a group during 21-30 September (marked as C).

Figure 2 (b) shows a plot for 2800 MHz radio emission F-10. There is good matching for group A and C and a rough matching for B. Also, when Rz has been zero, the F-10 did not show a zero or steady level but fluctuated in a narrow range of 68-70 units. This variation in the range 68-70 may not be significant because of the sensitivity of the instrument (instrumental error), but its accentuated presence in August indicates some systematic difference. Incidentally, 2800 MHz originates in a range of altitudes in the lower and upper corona and hence, dissimilarity may be partially due to different origin regions.

Figure 2 (c) (for X-rays) shows good matching for groups A and C. For B, the data as mentioned has been <1.0, so matching could not be judged due to the instrumentation sensitivity limit of GOES sensors.

5 Conclusions

During the sunspot minimum years 2007-2010 of cycle 23, the monthly maximum sunspot number, Rz, as well as its monthly averages declined from January 2007 till the end of 2007 and continued to be low further till September 2009. But in between, there were sporadic increases during January, June, December 2007; March 2008; September 2009, and February 2010. These have been reflected very well in time (within one month) in the 2800 MHz solar radio emission flux F-10, X-ray background, and the occurrence frequency of coronal mass ejections

(CME). In daily values during July-September 2009, abnormal intervals of Rz increases were accompanied by similar increases in F-10 and X-ray background. Thus, during sunspot minimum, any sporadic increases in sunspot numbers occur simultaneously in other solar indices also within a day or two This would indicate similar origins, probably due similar magnetic configurations affecting all parameters simultaneously. The zero value of Rz in August 2009 was accompanied by lowest levels (but not zero) in F-10, X-rays and CME occurrence frequency.

Ramesh & Raman[8] have reported similar results for the earlier cycle where sunspot minimum was in 1996. However, no detailed analysis was presented for the minimum year 1996 as such. Ramesh & Rohini[9] and Ramesh[10] have noted some difference in behavior of sunspot number (Rz) and sunspot area and feel that the CME frequency is better related with sunspot area than with sunspot numbers. However, the difference is very small, because as mentioned in Kane[4], the sunspot number and sunspot area are very highly inter-correlated (>+0.95). Therefore, sunspot number (Rz), sunspot group number (SGN) and the sunspot area could be used as good proxies for each other, at least in cycle 23. Incidentally, this good correlation is obtained due to similar variations near sunspot maximum. But, in low sunspot activity also, these could be used as proxies for each other. In August 2009, when sunspot number (Rz) was zero, the sunspot area was also zero.

Acknowledgements

The author gratefully acknowledges the partial support for this work by FNDCT, Brazil, under contract FINEP-537/CT.

References

1 Schwabe S H, Die Sonne**,** *Astron Nachr (Germany)*, 21 (495) (1844) pp 234**–**235**.**

2 Gnevyshev M N, On the 11-years cycle of solar activity, *Sol Phys (Netherlands)***,** 1 *(*1967) pp 107–120**.**

3 Gnevyshev M N, Essential features of the 11-year solar cycle, *Sol Phys (Netherlands)*, 51 (1977) pp 175-183.

4 Kane R P, Similarities and dissimilarities between the variations of CME and other solar parameters at different heliographic latitudes and time scales, *Sol Phys (Netherlands)*, 248 (1) (2008) pp 177-190.

5 Ramesh K B, 5303Å coronal irradiance and its relation to the photospheric magnetic activity, *Sol Phys (Netherlands)*, 183 (1998) pp 295-303.

6 Tousey R, The Solar Corona, *in Cospar Space Research Vol. 13*, M J Rycroft & S K Runcom, eds (Akademie-Verlag, Berlin), 1973, pp 713- 730.

7 Gopalswamy N, Mäkelä P, Xie H, Akiyama S & Yashiro S, CME interactions with coronal holes and their interplanetary consequences, *J Geophys Res (USA),* 114 (2009) A00A22, doi: 10.1029/2008JA013686.

8 Ramesh K B & Raman K S, X-ray spectral irradiance variability, *Sol Phys (Netherlands),* 234 (2006) pp 393-408.

9 Ramesh K B & Rohini V S, 1-8 Angstrom background X-ray emission and the associated indicators of photospheric magnetic activity, *Astrophy J Lett (USA)*, 686 (2008) L41-L44.

10 Ramesh K B, Coronal mass ejections and sunspot-solar cycle perspective, *Astrophys J Lett (USA)*, 712 (2010) pp L77-L80.