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Latitude Dependence of the Variations of Sunspot Group Numbers (SGN) and Coronal Mass Ejections (CMEs) in Cycle 23

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Abstract The 12-month running means of the conventional sunspot number *Rz*, the sunspot group numbers (SGN) and the frequency of occurrence of Coronal Mass Ejections (CMEs) were examined for cycle 23 (1996 – 2006). For the whole disc, the SGN and *Rz* plots were almost identical. Hence, SGN could be used as a proxy for *Rz*, for which latitude data are not available. SGN values were used for 5° latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25°, 25° – 30° and > 30°, separately in each hemisphere north and south. Roughly, from latitudes 25° – 30° N to 20° – 25° N, the peaks seem to have occurred *later* for lower latitudes, from latitudes 20° – 25° N to 15° – 20° N, the peaks are stagnant or occur slightly *earlier*, and then from latitudes 15° – 20° N to 0° – 5° N, the peaks seem to have occurred again *later* for lower latitudes. Thus, some latitudinal migration is suggested, clearly in the northern hemisphere, not very clearly in the southern hemisphere, first to the equator in 1998, stagnant or slightly poleward in 1999, and then to the equator again from 2000 onwards, the latter reminiscent of the Maunder butterfly diagrams. Similar plots for CME occurrence frequency also showed multiple peaks (two or three) in almost all latitude belts, but the peaks were almost simultaneous at all latitudes, indicating no latitudinal migration. For similar latitude belts, SGN and CME plots were dissimilar in almost all latitude belts except 10° – 20° S. The CME plots had in general more peaks than the SGN plots, and the peaks of SGN often did not match with those of CME. In the CME data, it was noticed that whereas the values declined from 2002 to 2003, there was no further decline during 2003 – 2006 as one would have expected to occur during the declining phase of sunspots, where 2007 is almost a year of sunspot minimum. An inquiry at GSFC-NASA revealed that the person who creates the preliminary list was changed in 2004 and the new person picks out more weak CMEs. Thus a subjectivity (overestimates after 2002) seems to be involved and hence, values obtained before and during 2002 are not directly comparable to values recorded after 2002, except for CMEs with widths exceeding 60°.

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1. Introduction

The 11-year sunspot cycle does not always have a single sharp peak. Often, two or three peaks are observed. Gnevyshev (1967, 1977) concluded that the 11-year cycle has two waves of activity. Thus, in cycle 19 (1954 – 1964), the coronal 5303 Å green line intensity had actually two maxima, the first one in 1957 and the second in 1959 – 1960. During the first maximum of 1957, the intensity increased and subsequently decreased simultaneously at all latitudes. The second maximum of 1959 – 1960 occurred only at low latitudes i.e. latitudes $< 15°$ and this maximum was bigger than the first one. This pattern was reported as seen in both hemispheres (Antalova and Gnevyshev, 1965). The plots for latitudes $15° – 20°$ showed both of the maxima, indicating that the second maximum visible for latitudes $0° – 10°$ is a separate phenomenon and not the result of a shift of the first maximum from high latitudes in the first part of the sunspot cycle to low latitudes near the end of the cycle. Antalova and Gnevyshev (1983) recognized the existence of more peaks (often a third peak) during a cycle. In Kane (2002a, 2003), the evolution of various solar indices around sunspot maximum (two peaks in 12-month running means) was shown to occur almost simultaneously (within a month or two). David Hathaway of NASA has been publishing many NASA Science News Reports, where the nature of sunspot variations near sunspot maximum years (including double peak structures) is often illustrated, including for cycle 23. For cycle 23, there are several publications which discuss a double-peak structure (*e.g.*, De Toma and White, 2004; Zharkova and Zharkov, 2006). However, another important solar phenomenon, namely the CMEs (coronal mass ejections, Tousey, 1973; Munro *et al.*, 1979; Webb and Howard, 1994; Cliver and Hudson, 2002), examined by Kane (2006) for cycle 23, showed a variation near sunspot maximum somewhat different from that of sunspots and other activity indices. Since both sunspots and CMEs could have variations different at different solar latitudes, an attempt is made in the present communication to see whether sunspot activity and CMEs have a better correlation if intensities in similar but narrow latitude belts are compared.

The conventional indicator of solar activity is the sunspot numbers Rz available since 1700 (Waldmeier, 1961; McKinnon, 1987) but the quality of the data is considered as "poor" during 1700 – 1748, "questionable" during 1749 – 1817, "good" during 1818 – 1847, and "reliable" from 1848 onwards (McKinnon, 1987). Hoyt and Schatten (1998a, 1998b) examined all the earlier Rz data, made corrections and derived a new and more homogeneous time series of Group sunspot numbers, designated as R_{G}. The implication of the changed series for topics related to climate have been examined by Hoyt and Schatten (1997) and implications for other topics have been examined by Kane (2002b), who found that for data for 1850 onwards, the results obtained by using Rz and R_{G} were *identical*. Also, the R_{G} data are available only up to 1996 (a private communication from K. Schatten revealed that funds were not available for further processing). Thus, for cycle 23 (1996 onwards), only Rz data are available. However, these data are for the whole solar disc and no details are available to us about the values at different solar latitudes. Looking for other parameters, it was found that data for sunspot *areas* were available separately for the northern and southern hemispheres at some observatories (*e.g.*, Rome). But better still, *a listing was available of individual sunspot groups,* with their solar latitudes mentioned. David Hathaway of NASA gives the following information:

"The Royal Greenwich Observatory (RGO) compiled sunspot observations from a small network of observatories to produce a dataset of daily observations starting in May of 1874. The observatory concluded this dataset in 1976 after the US Air Force (USAF) started compiling data from its own Solar Optical Observing Network (SOON). This work was continued with the help of the US National Oceanic and Atmospheric Administration (NOAA) with much of the same information being compiled through to the present. Unfortunately, the more recent data is given in a different format from the original and there are definite changes in the reported parameters from the different sources. In an effort to append the RGO data with the more recent data, I have reformated the USAF and NOAA data to conform to the older RGO data format".

Thus, a magnificent effort has been made by David Hathaway to scrutinize and use all the earlier and recent data and normalize them to produce a reliable continuous data series from 1874 up to date. From that list, we *counted the number of sunspot groups* (irrespective of the areas) which occurred in different latitude belts. We designate these numbers as Sunspot Group Numbers *SGN*. These are *different from the* R_{G} of Hoyt and Schatten (1998a, 1998b) as also from *Rz*, though their percentage variations are similar, as is shown later.

2. Data Analysis

David Hathaway of NASA has presented data series in the website http://solarscience.msfc.nasa.gov/greenwch.shtml. From these, we counted the *number* of sunspot groups and obtained SGN (sunspot group numbers), which occurred during successive three-monthly periods JFM, AMJ, JAS and OND. Information about CMEs was obtained from the GSFC-NASA website http://cdaw.gsfc.nasa.gov/CME_list/index.html, which has the LASCO CME Catalogue. The CME data are given for solar latitudes from the North Pole (0) to the South Pole (180°) on the eastern side and then back from the South Pole (180°) to the North Pole (360°) on the western side of the solar disc. Thus, for each latitude, there are two values available, one for the eastern side and another for the western side. For our analysis, these two are added as (0° – 5° added to 360° – 355°), (5° – 10° added to 355° – 350°) ... (175° – 180° added to 180° – 185°). Information of the conventional sunspot number *Rz* was obtained from the NOAA website ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS.

When monthly values were plotted, the month-to-month values varied rather erratically, with several peaks in a few years. Hence, smoothing of data was done by calculating 12-month running means for all the data. For 1996 – 2006 (cycle 23), Figure 1(a) shows the plots of 12-month running means at intervals of three months, four values per year centered at February, May, August, November, henceforth to be termed as (1), (2), (3), (4), for the conventional sunspot numbers *Rz* (solid line, scale marked on the left) and the sunspot group numbers SGN (full triangles, scale marked on the right). For proper comparison (matching maxima), the SGN values have been divided by a factor of 7.5. As can be seen, the two plots are very similar, with double peaks, one at 2000(2) for both *Rz* (marked by a full dot) and SGN (marked by a circle) and another at 2001(4) for *Rz* and 2002(1) (slightly ahead) for SGN. Thus, *SGN is a good proxy for Rz* and hence, results obtained from a study of the latitude dependence of SGN should be valid for *Rz* also (for which we have only whole disc values, not values at different solar latitudes).

Figure 1(b) shows similar plots for *Rz* (solid line, scale marked on the left) and the CME occurrence frequency (crosses, scale marked on the right). There are some differences. Notably, for *Rz*, the first peak, full dot at 2000(2), is higher than the second peak, full dot at 2001(4), but for a CME, the second peak, encircled cross at 2002(2) is higher than the first peak, encircled cross at 2000(2), indicating that CMEs lasted slightly longer. Also, CME values during the declining phase of sunspot activity (2003 – 2006, crosses) are abnormally high, much above the 1996 level (discussed later). Hence, a study of the latitude dependence was carried out.

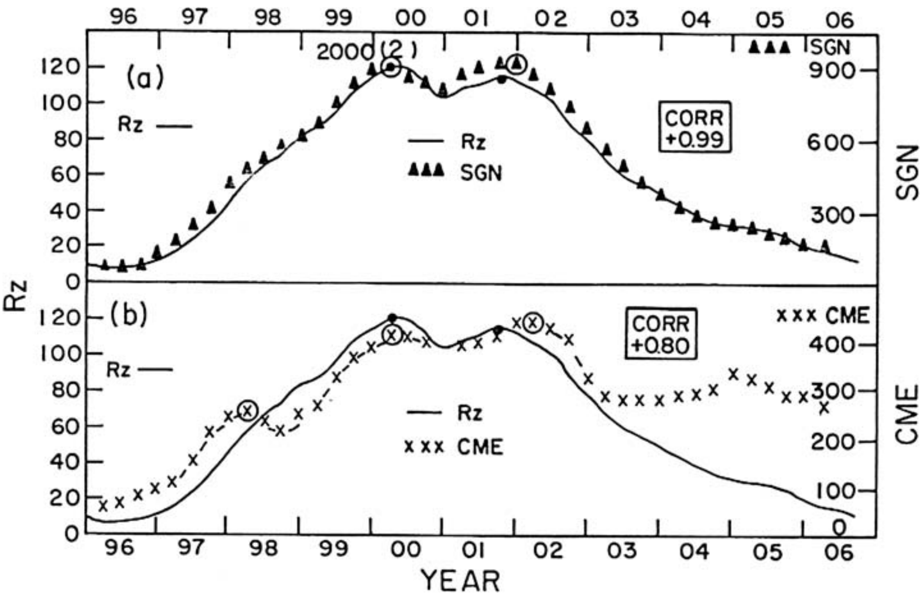

Figure 1 Plots of 12-month running means (three monthly, four values per year) of (a) conventional sunspot number *Rz* (full lines) and the sunspot group number SGN (triangles); (maxima are shown as big dots or encircled symbols), (b) conventional sunspot number *Rz* (full lines) and coronal mass ejections frequency of occurrence (CME; crosses), for cycle 23 (1996 – 2006).

Figure 2 shows the plots of SGN values (12-month running means) for 5° solar latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25° and 25° – 30°. Since the numbers beyond 30° were small, these are lumped together in the latitude interval > 30°. Plots for the northern hemisphere are shown by solid lines, the maxima are indicated by full dots, and the possible relationship of the full dots in successive northern latitudes is indicated by connecting solid lines. Plots for the southern hemisphere (in similar latitude belts) are shown by cross-dashed line, the maxima are indicated by encircled crosses, and the possible relationship in successive southern latitudes is indicated by connecting dashed lines. The following may be noted:

(1) For the northern hemisphere (solid lines), some panels show two peaks (full dots), even the panel of the equatorial belt 0° – 5°, though in some cases, the peaks are very near each other and could be just one peak. Peak selection has been rather a subjective matter.
(2) For the southern hemisphere (cross-dashed lines), some panels show two peaks (encircled crosses), some show only one and some show three. Also, these southern peaks (encircled crosses) do not match exactly with the northern peaks (full dots). Even in the average plots for whole hemispheres (bottom panel in Figure 2), the N and S plots do not match completely, indicating possible hemispheric asymmetry.
(3) The lines joining the peaks in successive latitude belts are not vertical and the peaks seem to show some phase shifts. Table 1 gives the timings and values of the first and second peaks of the SGN. There is a slight indication of latitudinal migration, but this may be a subjective judgement.

Figure 3 shows the plots of CME values (12-month running means) for 5° solar latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25° and 25° – 30°. Since the numbers beyond 30° were small, these are lumped together in two broad latitude intervals 30° – 60°

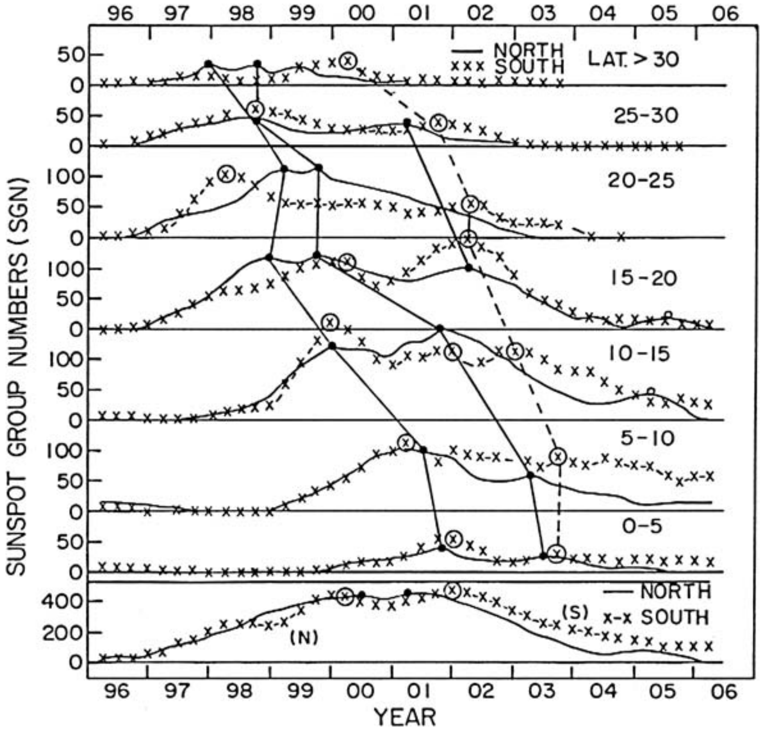

Figure 2 Plots of 12-month running means of sunspot group number SGN for different latitude-belts for northern hemisphere (full lines, maxima shown by full dots) and southern hemisphere (crosses, maxima shown by encircled crosses), for cycle 23 (1996 – 2006). Maxima in successive latitude belts are connected by full lines for northern latitudes and dashed lines for southern latitudes. Bottom plot is for hemispheric averages, for North (full lines) and South (crosses).

and 60° – 90°. Plots for the northern hemisphere are shown by solid lines, the maxima are indicated by full dots, and the possible relationship of the full dots in successive latitudes is indicated by connecting full lines. Plots for the southern hemisphere (in similar latitude belts) are shown by cross-dashed lines, the maxima are indicated by encircled crosses, and the possible relationship in successive latitudes is indicated by connecting dashed lines. The following may be noted:

(a) For the northern hemisphere (solid lines), the top panel shows only one peak (full dot) and the second panel shows two peaks. All other panels show three or more peaks, even the panel for the equatorial belt 0° – 5°, but these peaks are not very clear. Even when broader latitude ranges were considered (10° instead of 5°), the peaks in the other panels were not sharp.
(b) For the southern hemisphere (crossed-dashed line), the top two panels have two peaks each, but other panels have several peaks (encircled crosses). The southern peaks (encircled crosses) almost match with the northern peaks (full dots) except for some discrepancies in the 5° – 10° and 10° – 15° latitude belts. In plots for whole hemispheres (bottom panel in Figure 3), the N and S plots have a slight mismatch during 2001 – 2002.
(c) The lines joining the maxima are almost vertical, implying no latitudinal migration, in contrast to what was seen for the SGN in Figure 2.

Table 1 Timings and peak values of SGN in different latitude belts.

Latitude	SGN first maximum		SGN second maximum	
	Time	Value	Time	Value
60 to 90		Nil		Nil
30 to 60	1998(1)	38	1998(4)	41
25 to 30	1998(4)	51	2001(2)	42
20 to 25	1999(2)	115	1999(4)	117
15 to 20	1999(1)	120	1999(4)	124
10 to 15	2000(1)	128	2001(4)	152
5 to 10	2001(3)	109	2003(2)	62
0 to 5	2001(4)	39	2003(3)	27
0 to −5	2002(1)	56	2003(4)	32
−5 to −10	2001(2)	113	2003(4)	91
−10 to −15	2000(1)	164	2002(1)	117
−15 to −20	2000(2)	117	2002(2)	151
−20 to −25	1998(2)	104	2002(2)	60
−25 to −30	1998(4)	63	2001(4)	40
−30 to −60	Only one peak		2000(1)	42
−60 to −90		Nil		Nil

(d) In the broad latitude belts 60°–90° N, 30°–60° N, 0°–30° N, 0°–30° S, 30°–60° S, 60°–90° S, the maximum frequencies are 47, 66, 130, 135, 86, 46 (total 510). Thus, a large number (52%) is concentrated in the 0°–30° N + S belts, and the frequencies are lesser and lesser for higher latitudes, but still substantial, in contrast to the negligible SGN number beyond 30°, N or S.

(e) A notable feature is that after the decline from 2002 to early 2003, the CME occurrence frequency did not decline further. The levels in 2004, 2005, 2006 are very high in both the northern and southern hemispheres, in contrast to the low values of 1996, the last solar minimum. This abnormal feature is discussed later in this paper.

Figure 4(a) shows the plots of SGN (solid lines) and CME frequency (crosses) in the same frame, for northern latitudes, while Figure 4(b) shows similar plots for the southern latitudes (12-month running means, centered three months apart). In the top panels for latitude belt 60°–90°, only CME data (crosses) are available. For 30°–60° latitudes for a CME, the SGN values used for comparison are for latitudes > 30°. In other frames, the latitude ranges are the same for CME and SGN, in steps of successive 5° latitude belts. As can be seen, in almost all latitude belts, the CME and SGN plots are dissimilar and the CME plots have generally a larger number of peaks as compared to SGN peaks. The SGN maxima (full dots) rarely match with CME maxima (encircled crosses). Thus, the evolution of CME during cycle 23 is not parallel to the evolution of sunspots in finer details, in any latitude belt. Table 2(a) 1996–2006 gives the correlation between the SGN and CME plots for the full cycle 23. As can be seen, the correlations vary in a wide range ∼0 to 0.67, but ten out of the 14 correlations are below 0.50, indicating a generally poor relationship. However, in (b) 1996–2002, where the doubtful values of 2003–2006 are omitted, the correlation between CME and SGN is very good for the belt 10°–20° S. Here again, if only data for years near sunspot maximum (c) 1999–2002 are considered, the correlations worsen (some are even

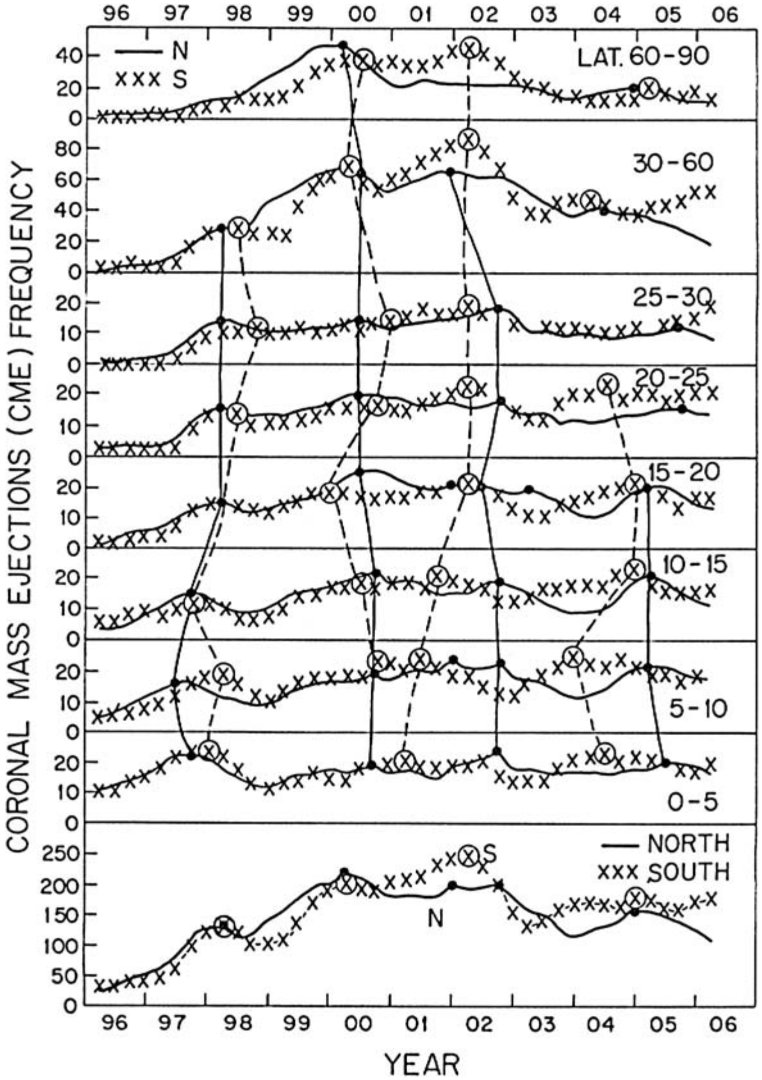

Figure 3 Similar to Figure 2, for CMEs.

negative), indicating large dissimilarities between the variations of CME and SGN during sunspot maximum years.

As mentioned earlier, in all the plots in Figures 2 and 3, the CME values did not decline during 2003 – 2006, as expected when sunspot activity decreased. Instead, the level remained almost constant and at a level much higher than the sunspot minimum levels of 1996. Suspecting data errors, we contacted Dr. Nat Gopalswamy of GSFC, NASA whose response was as follows:

"Yes, we have noticed this. Our current thinking is that this is a combination of subjectiveness of human detection and the actual variation. The person who creates preliminary list changed in 2004 and he picks out more weak CMEs. But the activity increases after 2004

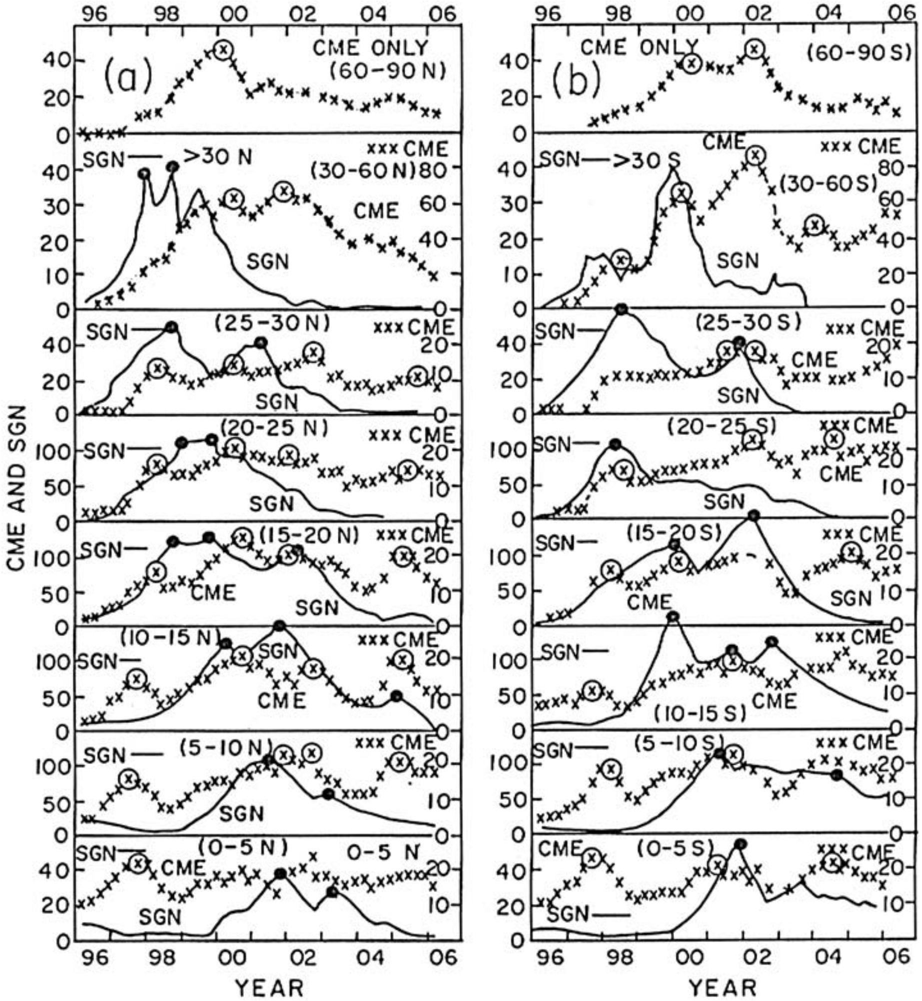

Figure 4 Superposed plots of 12-month running means of sunspot group number SGN (full lines) and CME (crosses).

due the super active regions in late 2004, Jan 2005, Sep 2005. There should be no problem if you use CMEs with width > 30 deg."

(All CMEs have a width (longitudinal spread). Weak ones are very narrow with a width of $< 30°$, while the very strong ones (Halo CMEs) have an almost 360° spread).

Thus both, subjectively setting a lower threshold in detection by a new operator, and effect of physical phenomena which occurred as late as in 2004 – 2005 are involved. Since Dr. Nat Gopalswamy suggested that the ambiguity would not be there if only CMEs with width $> 30°$ are considered, to check this, the CME variation for the limited latitude belt 15° – 20° N for all CMEs and for CMEs with different width limits (implying strengths), namely, $> 0°$, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90° and 100° was examined. The values are given in Table 3(a), which gives the maximum values in the bottom row. The same

Table 2 Correlation between 12-month running means of SGN and CME occurrence frequency in different latitude belts for (a) 1996 – 2006, (b) 1996 – 2002 and (c) 1999 – 2002.

Latitude	(a) 1996 – 2006	(b) 1996 – 2002	(c) 1999 – 2002
> 30	−0.02	−0.10	−0.63
25 to 30	0.29	0.37	−0.64
20 to 25	0.45	0.62	−0.30
15 to 20	0.53	0.73	−0.53
10 to 15	0.64	0.75	0.44
5 to 10	0.48	0.71	0.68
0 to 5	0.08	0.12	0.26
0 to −5	0.27	0.28	0.72
−5 to −10	0.67	0.69	0.79
−10 to −15	0.56	0.84	0.50
−15 to −20	0.48	0.95	0.83
−20 to −25	−0.03	0.54	−0.23
−25 to −30	0.02	0.30	−0.42
> −30	0.17	0.24	−0.27

Northern is +, Southern is −.

values expressed as percentages of the respective maximum values are given in Table 3(b) and shown in Figure 5. The following may be noted:

(1) The CME plots are roughly similar for all widths, with a major maximum mostly in 2001, but in some latitudes, in 2000 and in one case (widths exceeding 100°), in 1999.
(2) There is a second small maximum in 2005 for narrow CMEs and in 2004 for broad CMEs, due to the activity increases after 2004 due the superactive regions in late 2004, Jan 2005 and Sep 2005, as mentioned above by Dr. Nat Gopalswamy.
(3) The almost-zero level of 1996 is attained again in 2006 (shown by crosses) only by CMEs with breadths > 90°, but starting from > 60°. For narrower CMEs, the 2006 level (shown by vertical bars) is well above the 1996 level. This, partially, has to be attributed to the "subjectiveness of human detection" mentioned above by Dr. Nat Gopalswamy. Another reason for the difference is that in 2006, solar activity was not yet in minimum. Thus, for widths below 60°, the human judgement errors (overestimates in 2002 onwards as compared to the earlier values) are larger and larger for smaller and smaller CME widths. If the values beyond 2002 are ignored, the correlations improve as shown in Table 2(b). From the 14 correlations, eight are above +0.50 but six are still low.

However, all the main conclusions in the present work are based on data before 2003 when the new operator changed. So, the results should be considered as reliable.

3. Discussion and Conclusions

The 12-month running means of the conventional sunspot number *Rz*, the sunspot group numbers (SGN), and the occurrence frequency of Coronal Mass Ejection (CME) were examined for cycle 23 (1996 – 2006). The following was noted:

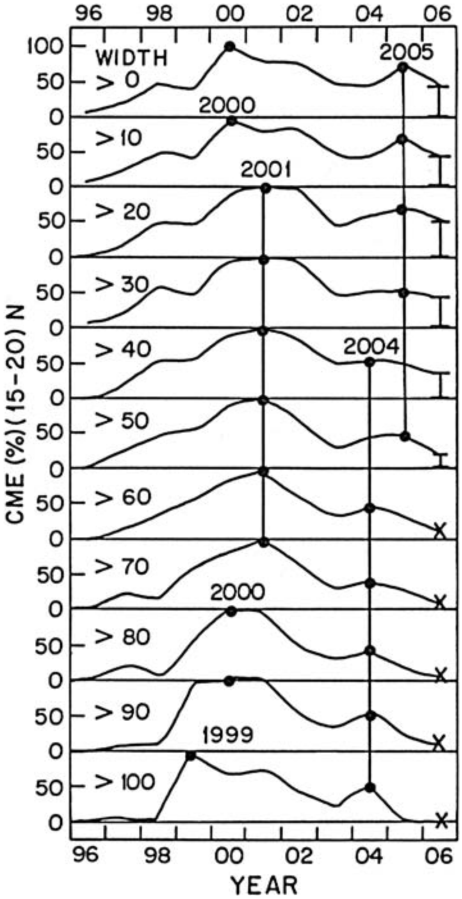

Figure 5 Plots of CME (%) values for the limited latitude belt 15° – 20° N for CMEs of widths > 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, 100°, for cycle 23 (1996 – 2006). Maxima in successive plots are connected with lines. For 2006, the crosses mark the five lower plots having 2006 values almost the same as for 1996 (CMEs with widths exceeding 60°). In the six upper plots (CMEs with widths less than 60°), the vertical bars indicate 2006 levels far above the 1996 levels (due to data discrepancies, see text).

(1) For the whole disc, the SGN and *Rz* plots were almost identical. Hence, the SGN could be used as a good proxy for *Rz*.

(2) Since the *Rz* values at different solar latitudes were not available to us, the SGN values were used instead, for 5° latitude belts 0° – 5°, 5° – 10°, 10° – 15°, 15° – 20°, 20° – 25°, 25° – 30° and > 30°, separately in each hemisphere North and South. The plots of the SGN for some latitude belts showed two peaks during the solar maximum years 2000 – 2002, though in some cases, the peaks were very near each other and could be considered as only one peak. Roughly, for the northern hemisphere from latitudes 25° – 30° N to 20° – 25° N, the peaks seem to have occurred *later* for lower latitudes, from latitudes 20° – 25° N to 15° – 20° N, the peaks are stagnant or occur slightly *earlier*, and then from latitudes 15° – 20° N to 0° – 5° N, the peaks seem to have occurred again *later* for lower latitudes, the latter reminiscent of the Maunder butterfly diagrams. Thus, latitudinal migration is suggested, clearly in the northern hemisphere, not very clearly in the southern hemisphere. Similar plots for CME occurrence frequency also showed multiple peaks (two or three) in almost all latitude belts, but the peaks were almost *simultaneous* at all latitudes, indicating no latitudinal migration.

(3) In plots where SGN and CME values were superposed, the two plots were dissimilar in all latitude belts. The CME plots had in general more number of peaks than the SGN

Table 3 (a) CME occurrence frequency for the limited latitude belt 15° – 20° N for CME widths exceeding 0° (all CMEs), 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90° and 100° and their maximum values (bottom row), and (b) the same values expressed as percentages of the maximum values.

(a)	CME occurrence frequency for CME widths (strengths) as given below										
Year	> 0	> 10	> 20	> 30	> 40	> 50	> 60	> 70	> 80	> 90	> 100
1996	3	3	3	3	0	0	0	0	0	0	0
1997	9	9	8	7	5	5	4	4	3	1	0
1998	26	24	20	19	15	11	8	3	1	1	0
1999	20	20	17	16	15	14	12	10	10	10	10
2000	54	49	36	30	27	24	19	14	13	10	7
2001	42	39	37	33	28	25	22	17	12	10	7
2002	41	40	37	31	24	17	13	11	6	5	4
2003	26	24	17	15	13	8	7	5	4	3	2
2004	25	22	22	17	16	11	9	7	6	5	5
2005	37	33	27	17	13	11	8	4	3	2	0
2006	24	24	20	15	10	5	2	1	1	0	0
Maximum	54	49	37	33	28	25	22	17	13	10	10

(b)	CME occurrence frequency (%) for CME widths (strengths) as given below										
Year	> 0	> 10	> 20	> 30	> 40	> 50	> 60	> 70	> 80	> 90	> 100
1996	6	6	8	9	0	0	0	0	0	0	0
1997	17	18	22	21	18	20	18	24	23	10	0
1998	48	49	54	58	54	44	36	18	8	10	0
1999	37	41	46	48	54	56	55	59	77	100	100
2000	100	100	97	91	96	96	86	82	100	100	70
2001	78	80	100	100	100	100	100	100	92	100	70
2002	76	82	100	94	86	68	59	65	46	50	40
2003	48	49	46	45	46	32	32	29	31	30	20
2004	46	45	59	52	57	44	41	41	46	50	50
2005	69	67	73	52	46	44	36	24	23	20	0
2006	44	49	54	45	36	20	9	6	8	0	0

plots, and the peaks of SGN rarely matched those of CME. The correlation between SGN and CME values at different latitudes varied in a wide range 0 to 0.67, but were mostly below 0.50, indicating poor relationship.

(4) In the CME data, it was noticed that whereas the values declined from 2002 to 2003, there was no further decline during 2003 – 2006 as one would have expected to occur during the declining phase of sunspots, where 2006 is almost a year of sunspot minimum. An inquiry at GSFC-NASA revealed that the person who creates preliminary list changed in 2004 and he picks out more weak CMEs. Thus a subjectiveness was involved and hence, values obtained before and during 2002 were not directly comparable with values recorded after 2002. We found that this effect in 2003 – 2006 was larger for CMEs of widths lesser than 60°. If the data for 2003 onwards are ignored, the correlations between SGN and CME improve considerably. However, this does not affect the conclusions of the present study, as these are based on data during 1996 – 2002.

Sunspots and similar parameters are only a rough guide of the evolution of solar activity. These have no relevance for the interplanetary space, where the solar effects are carried over mainly by solar charged particles as in coronal mass ejections, with their associated magnetic field configurations. Hence, the dissimilarity between the evolutions of CME and SGN in almost all latitude belts would imply that the CME variations, and not the sunspot variations, need to be considered for studying interplanetary effects. How important are the CME latitudinal variations, is a moot question. The Sun is a small blob in the vast interplanetary space. Hence, fine structures like the latitudinal differences of CME probably will not extend beyond a few solar radii from the solar surface. In addition, the CME characteristics are considerably modified in their transit up to the orbit of Earth (1 AU). Fast CMEs are decelerated and slow ones are accelerated, trying to match with the ambient solar wind (Gopalswamy *et al.* 2000, 2001). At Earth, what one encounters is ICMEs (Interplanetary CMEs), which might have velocities and magnetic configurations different from those at the starting point near the Sun (Cane, Richardson, and von Rosenvinge, 1996; Gonzalez-Esparaza *et al.*, 2003; Dal Lago *et al.*, 2004; Kane, 2006). Further away in the deep heliosphere where cosmic ray (CR) modulation occurs, the mechanism for CR modulation consists of time-dependent heliospheric drifts and outward propagating diffusive barriers, which are formed by merging of coronal mass ejections (CMEs), shocks and high-speed flows at 10 – 15 AU from the Sun (Merged Interaction Regions, MIRs; Burlaga *et al.*, 1985). Since only some MIRs are effective in modulating CRs throughout the heliosphere (Burlaga, McDonald, and Ness, 1993), Global MIR (GMIR) were conceived which are regions extending 360° around the Sun mostly in the ecliptic plane and responsible for the step-like changes in CR counting rates. Thus, the finer latitude dependence of CMEs observed at the Sun may not have any direct relevance for interplanetary phenomena. Interestingly, the two peak structure of CMEs is reflected in galactic cosmic ray intensity also observed on Earth (Storini and Pase, 1995), but the cosmic ray gap between the peaks is dissimilar to those of other parameters (Kane, 2007).

Wu, Lepping, and Gopalswamy (2006, and references therein) have shown a very good correlation (~ 0.97) between yearly-average sunspot numbers and yearly occurrence rate of CMEs. Such a correlation is not very meaningful or informative, for the following reason. In yearly values, finer short-term structures (double peaks, *etc.*) are almost wiped out and the correlation is dominated almost completely by the 3 – 4 year values in the rising phase of sunspot activity, which is similar in all solar parameters, including CMEs. For example, in our case, the yearly values (or even the 12-month running means) of all CMEs (full solar disc, all latitudes combined) and SGN (full solar disc, all latitudes combined) have an inter-correlation of $+0.96$ for 1996 – 2002. Only when values in different latitude belts are considered that the correlations vary in a wide range as shown in our Table 2, indicating similarities and dissimilarities of their evolutions in the initial (rising) phase (1996 – 1998) and the subsequent variations in sunspot maximum years (1999 – 2002). Incidentally, for SGN, a plot of yearly values showed that double peaks appeared at some latitudes but there was only one peak in the others. So, connecting peaks in one latitude plot to the peaks in next latitude plot became ambiguous, and a latitude migration could not be ascertained unambiguously.

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