North–south asymmetry of some solar indices

R.P. Kane*

Instituto Nacional de Pesquisas Espaciais, C. P. 515 São José dos Campos, 12201-970 SP, Brazil

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Abstract

The smoothed values of the N–S asymmetry of the particular solar parameter LA (longitudinal asymmetry of vectorial sunspot area) were shown by Vernova et al. (Solar Phys. 205 (2002) 371–382) to have an average pattern about the zero epoch, wherein the oscillation starts by a northern dominance (N–S positive) of LA value in the ascending phase of the solar cycle which lasts for about 2–3 years, followed by a southern dominance (N–S negative) 1.2–1.7 years later. The southern dominance (N–S negative) lasts for about 1.6 years and ends slightly before the end of the magnetic reversal (zero epoch). In the present communication, these patterns were studied for two other solar indices, namely, solar flare index (SFI) and solar group area (SGA), for solar cycles 21 and 22. It was noticed that (a) the patterns for SFI and SGA were very similar to each other (correlation +0.92), (b) the large northern dominance (N–S positive) 2–3 years before the zero epoch in the average pattern was seen in SFI using the same zero epochs (1981.8 for cycle 21 and 1991.8 for cycle 22) as Vernova et al. (2002), (c) the large southern dominance (N–S negative) ~1 year before the zero epoch in the average pattern was seen in SFI in cycle 21, but in cycle 22, the N–S trough was at or after the zero epoch (not one year earlier), (d) after the zero epoch, the average pattern was supposed to be rather quiet. However, in cycle 21, SFI had large N–S troughs (southern dominance) after the zero epoch, while in cycle 22, SFI had a broad N–S trough near the zero epoch, (e) in cycles 21 and 22, SFI had fluctuations with peak spacings of 15–20 months before the zero epoch.

Keywords: Solar indices; North–south asymmetry

1. Introduction

Solar activity changes are often asymmetric between the northern (N) and southern (S) solar hemispheres. This has been illustrated for different solar features: major flares (Roy, 1977; Verma, 1987, 1993; X-ray flares (Garcia, 1990; Li et al., 1998); flare index (Knoska, 1985; Ataç and Özgüç, 1996, 1998, 2001); sunspot number and sunspot areas (Swinson et al. 1986; Carbonell et al., 1993; Oliver and Ballester, 1994, 1996; Watari, 1996); sudden disappearances of solar prominences (Vizoso and Ballester, 1990; Joshi, 1995); sunspot groups and solar flare numbers (Yadav et al., 1980; Verma, 1993; Joshi, 1995); and 20 solar-activity phenomena (Li and Gu, 2000). Roy (1977) showed that the N–S asymmetry of solar flares does not follow the 11- or 22-year cycle of the occurrence of major flares. Swinson et al. (1986) observed that during the period of northern sunspot dominance, 78% of solar flares were observed in the N hemisphere. For cycle 22, Ataç and Özgüç, 1998 reported (for annual values) that the N–S asymmetry of the solar flare index (SFI) began in 1986 in the N hemisphere and drifted to the S hemisphere, then swept from the S hemisphere again to the N hemisphere during 1987, and later during 1988–1993, the flare

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*Fax: +55 12 3945 6952.
E-mail address: kane@laser.inpe.br (R.P. Kane).
activity showed drift behaviour in an alternating way between the two hemispheres every two years.

Recently, Vernova et al. (2002) studied the solar cycle evolution during 8 solar cycles (15–22) using a ‘vectorial sunspot area’ called the longitudinal asymmetry (LA) parameter. The LA parameter is calculated by the polar diagram technique (Vernov et al., 1979), which takes into account the area and the Carrington longitude of each sunspot group. LA is a measure of longitudinally asymmetric sunspot activity during one Bartels rotation. Vernova et al. (2002) found a systematic dipolar-type oscillation in the dominating hemisphere during high solar activity times. The LA parameter has slight differences with respect to the conventional indices like sunspot area and the sunspot number. For example, Cycle 19 (peak in 1957–58) is not the highest cycle according to LA. Using the superposed epoch method with the date of magnetic reversal in the solar S hemisphere as the zero epoch time, these authors produced an average pattern in which the oscillation starts by an excess of the northern LA value in the ascending phase of the solar cycle which lasts for about 2–3 years. Soon after the maximum northern dominance, the S hemisphere starts dominating, reaching its minimum 1.2–1.7 years later. The southern dominance lasts for about 1.6 years and ends slightly before the end of the magnetic reversal (zero epoch).

In the present communication, the N – S asymmetry is studied for two solar indices, namely the sunspot group area (SGA) and the SFI calculated by Atac and Özgüz from Bogazici University Kandilli Observatory, Istanbul, Turkey, for solar cycles 21 (1976–1985), 22 (1986–1995) and part of cycle 23 (1996–2001), and compared with the average pattern described by Vernova et al. (2002).

2. Data

The data were obtained from the websites http://science.nasa.gov.ssl/pad/solar/greenwch.htm and ftp://ftp.koeri.boun.edu.tr/pub/astronomy/flare_index/, with some recent SFI data obtained privately from Atıla Özgüz, Kandilli Observatory, Istanbul, Turkey and Kitt Peak magnetic field data from Karen Harvey.

3. Plots of long-term (year-to-year) variations

The monthly values often showed large month-to-month fluctuations, mostly irregular. Hence, 12-month running means (also called moving averages) were calculated and used. Vernova et al. (2002) used running means over 13 Bartels rotations. These 12-month running means were centered on the sixth month, for example, average of January, February,..., December, was considered as centered at June. Imposing a timing error of 15 days which, however, is negligible in the present context.

Fig. 1(a) shows the plot of the 12-month running means for the N hemisphere SFI for 1976–2001 and part of 2002. Broadly, there are maxima during 1979–1981, 1988–1990, and 1999–2001, the solar cycle maxima of cycles 21, 22, 23. However, there are fluctuations near the maxima, with peaks as indicated by big dots. The peak spacings are about 15–25 months (circled numbers). Fig. 1(c) shows the plot for the S hemisphere, with similar peak spacings. Fig. 1(b) shows the total SFI index (N+S) and Fig. 1(d) the (N – S) asymmetry. The latter depicts large fluctuations, with peak spacings of 15–22 months, in the ascending and descending phases of the solar cycles. The full triangles indicate the positions of the solar magnetic field reversals in the S hemisphere, 1981.8 for cycle 21, 1991.8 for cycle 22 (from Table I of Makarov and Makarova (1996), also given as Table I in Vernova et al., 2002), and 2002.4 for cycle 23 (Harvey and Recely, 2002). A similar analysis was done for SGA. The N – S asymmetry for SGA is shown in Fig. 1(e) and is very similar to Fig. 1(d). The correlation between the (N – S) asymmetry of SFI (d) and SGA (e) was +0.92. Hence, only SFI is considered for further illustration and analysis.

To check whether there were any similar changes in the full disc magnetic field of the Sun, Fig. 1(f) shows the 12-month running means of the Kitt Peak Observatory solar magnetic field observations. There is an indication of some double peaks with spacing of ~22 months. Karen Harvey sent us magnetic field values for active regions (AR) and for the quiet sun (QS) separately. These are plotted in Fig. 1 (g), AR (full lines), QS (crosses). The QS variation is small, with broad maxima at solar maxima. The AR variation is large and shows double peaks with spacings of 24–30 months.

The peaks of 15–20 months in solar indices should have an intrinsic importance in evolution of solar indices. In a recent communication, Kane (2002) examined the evolution of various solar indices around sunspot maximum and sunspot minimum years and noticed that the recent cycles had two peaks at solar maximum, whose relative heights were different for different solar indices. Vernova et al. (2002) noticed the 15–20 month oscillations, suggested that the N and S hemispheres are magnetically connected with each other, and the spacings of 15–20 months may be related to the periodicity recently detected at the tachocline at the bottom of the solar convection layer (Howe et al., 2000), as well as earlier in solar wind speed (Richardson et al., 1994) and other solar and heliospheric variables (Mursula and Zieger, 2000).

Fig. 2 shows a comparison of the average pattern of (N – S) given in Vernova et al. (2002, p. 378) with the N – S patterns of SFI for (a) solar cycle 21 (1976–1986)
and (b) solar cycle 22 (1986–1996). In both (a) and (b), the full line is the Vernova et al. (2002, p. 378) average $N/C_0$ pattern, for 6 years before and after the zero epoch, where the zero epoch is the magnetic field reversal in the solar south polar region. In (a), the crosses joined by dashed lines represent the $N/C_0$ SFI, 6 years before and after the zero epoch 1981.8, and in (b) around the zero epoch 1991.8. The following may be noted:

1. The average pattern (full lines) has a strong northern dominance ($N/C_0$ positive, one strong peak) 2–3 years before the zero epoch. The SFI in (a) also shows the northern dominance, but there are large fluctuations, with 3 peaks before the zero epoch of spacings of 15–20 months and one peak after the zero epoch. The SFI in (b) also shows such fluctuations but with smaller amplitudes.

2. The average pattern has a strong southern dominance ($N/C_0$ negative, one strong trough) ~1 year before the zero epoch. The SFI in (a) also shows a similar trough, but SFI in (b) shows a broad minimum around the zero epoch time.

3. After the zero epoch, the average pattern is comparatively quiet, depicting small fluctuations. The SFI in (a) shows very large troughs, while in (b), there is only one large trough near about the zero epoch.

Fig. 3(a) (upper half), shows the comparison of the average pattern of $(N - S)$ (thick line) given in Vernova et al. (2002, page 379, Fig. 5, bottom part) with their individual $N - S$ patterns of solar cycle 21 (1976–1986) and solar cycle 22 (1986–1996). As can be seen, there are considerable differences with the average curve. In cycle 21 (left half), after 1981, the average (thick line) shows northern dominance, but the individual plot (thin line) shows violent fluctuations around the zero line. In cycle 22 (right half), the matching is better if the very fast fluctuations are ignored. Fig. 3(b) (lower half) shows a comparison of our SFI (crosses and dashes) with the individual values (thin lines) of Vernova et al. (2002) for cycles 21 (left half) and 22 (right half). The matching is not good. Thus, our SFI and Vernova LA do not seem to represent exactly the same parameter.

To get a quantitative estimate of the similarity (or dissimilarity) of SFI and LA, an average of our SFI for cycles 21 and 22 was obtained by superposed epoch analysis, and inter-correlations were obtained between SFI (cycle 21), SFI (cycle 22), SFI (average), Vernova LA (cycle 21), Vernova LA (cycle 22) and Vernova LA...
The results were as given in Table 1. The following may be noted.

(1) LA of cycles 21 and 22 are not well inter-correlated (+0.27 only). However, LA (Average) is reasonably well correlated with LA (Cycle 21) (+0.63) and LA (cycle 22) (+0.68).

(2) SFI of cycles 21 and 22 are not at all well inter-correlated. SFI (average) is very well correlated with SFI (cycle 21) (+0.86) and moderately correlated with SFI (cycle 22) (+0.48). (In Fig. 3, note that the variations in cycle 21 are larger than those in cycle 22, and therefore, their average is dominated by the variation of cycle 21).

(3) Variations of LA and SFI in cycle 21 are moderately correlated (+0.51), but LA and SFI in cycle 22 are poorly correlated (+0.24). LA (average) and SFI (Average) are only moderately correlated (+0.36), confirming that our SFI and Vernova LA do not seem to represent exactly the same parameter.

4. Conclusion

The smoothed values of the N – S asymmetry of the particular solar parameter LA (longitudinal asymmetry of vectorial sunspot area) were shown by Vernova et al. (2002, p. 378) to have an average pattern about the zero epoch (magnetic field reversal at the solar southern pole) wherein the oscillation starts by an excess of the
northern LA value in the ascending phase of the solar cycle which lasts for about 2–3 years. Soon after the maximum northern dominance, the S hemisphere starts dominating, reaching its minimum 1.2–1.7 years later. The southern dominance lasts for about 1.6 years and ends slightly before the end of the magnetic reversal (zero epoch). In the present communication, these patterns were studied for two other solar indices, namely, SFI and SGA, for solar cycles 21 and 22. The following was noticed.

(1) The patterns for SFI and SGA were very similar (correlation +0.92).
(2) The large northern dominance 2–3 years before the zero epoch in the average pattern was seen in SFI using the same zero epochs (1981.8 for cycle 21 and 1991.8 for cycle 22) as Vernova et al. (2002).
(3) The large southern dominance ~1 year before the zero epoch in the average pattern was seen in SFI in cycle 21, but in cycle 22, the trough was slightly later, around the zero epoch.
(4) After the zero epoch, the average pattern was supposed to be rather quiet. However, in cycle 21, SFI had large troughs (southern dominance) after the zero epoch, while in cycle 22, SFI had a broad trough near the zero epoch.
(5) In cycles 21 and 22, SFI N–S asymmetry had fluctuations with peak spacings of 15–20 months before the zero epoch.

Table 1
Inter-correlations between SFI (cycle 21), SFI (cycle 22), SFI (average), Vernova LA (cycle 21), Vernova LA (cycle 22) and Vernova LA (average)

<table>
<thead>
<tr>
<th></th>
<th>Ver. Cy.21</th>
<th>Ver. Cy.22</th>
<th>Ver. Ave.</th>
<th>SFI Cy.21</th>
<th>SFI Cy.22</th>
<th>SFI Ave.</th>
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</tr>
<tr>
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<td>Ver. Ave.</td>
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<td>0.68</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>SFI Cy.22</td>
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<td>1.00</td>
<td></td>
</tr>
<tr>
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<td>0.17</td>
<td>0.36</td>
<td>0.86</td>
<td>0.48</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 3. Plots of (a) average values (thick line) and individual cycle values (thin line) for cycles 21 (left half) and 22 (right half) (Vernova et al., 2002, their Fig. 5, bottom part), (b) individual cycle values (thin lines, Vernova et al., 2002) and our SFI (crosses and dashes), for cycles 21 (left half) and 22 (right half).
In cycle 23, the large northern dominance 2–3 years before the zero epoch indicated in the average pattern is seen in SFI as two peaks before the zero epoch at 2002.4 (see Fig. 1(d)). The large southern dominance ~1 year before the zero epoch indicated in the average pattern is seen in SFI in cycle 23 as small negative N – S values starting about an year before the zero epoch 2002.4, but the trough of N – S values (not yet certain) will probably coincide with the zero epoch, as in cycle 22.

A correlation analysis showed that our SFI and the Vernova LA do not represent exactly the same parameter.

Acknowledgements

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References