Decreasing Ratio Between Sunspot and Sunspot Group Counts

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ABSTRACT

Using raw sunspot counts from the SIDC reference station Locarno and from over 400,000 individual observations from the German SONNE observer net we show that the number of single spots per sunspot group has steadily decreased since the mid-1990s to about half of the average for 1947-1995. The sunspot number derived from the Mount Wilson Observatory Magnetic Plage Strength Index exhibits a simlar variation. A weak solar cycle variation is superposed on this general decline. We interpret our finding as a decline in the number of small spots, consistent with the shift to lower values of the distributions of magnetic field strength and visibility proposed by Livingston & Penn.

Subject headings: Sun: Sunspots, Decreasing with time

1. Introduction

Penn & Livingston (Penn & Livingston 2006, 2011) report that sunspots are gradually becoming warmer and less magnetic since the 1990s, leading to reduced contrast and thus decreased visibility. As a consequence, they infer that fewer small spots should form or become visible as the distribution of field strength shifts to fall increasingly below the threshold of 1450 G required for a visible sunspot. If so, that should be evident in the ratio between the number of spots and the number of sunspot groups ('active regions'), which should decrease over the same time interval.

We investigate this prediction using data from the German SONNE network of sunspot observers (SONNE 2012) and from the long-running Swiss station Locarno (Locarno 2012), the latter serving as reference or 'pilot' station for the International Relative Sunspot Number (Clette et al. 2007), supplemented by observations at Zürich by Waldmeier (Waldmeier 1968) and Zelenka and Keller (Keller & Friedli 1995). From each data source, the number, G, of groups and the number, S, of 'spots' reported by the observers are extracted and tabulated. 'Spots' is in quotation marks because Waldmeier (Waldmeier 1948), and to this day Locarno as well, weighted larger spots stronger than small spots, so the weighted 'spot' count will be 30-50% larger than the raw count where each spot is counted only once as in Wolf's and Wolfer's original scheme (Wolfer 1907)[1]. The SONNE observers

[1] "Notiert ein Beobachter mit seinem Instrumente an irgend einem Tage g Fleckengruppen mit insgesamt f Einzelflecken, ohne Rücksicht auf deren Grösse, so ist die

do not employ weighting: each spot is counted only once. It is important that for both groups of observers, the counting methods (albeit different) have been unchanged over the period of interest. Finally, we compare with a non-sunspot series to see if it is consistent with the results from the sunspot record.

2. Data Analysis

If the Relative Number, R, and the Group count are known, the spot count can be calculated as $S = R/k - 10G$, where k is the so-called k-factor introduced by Rudolf Wolf to bring observers onto the same scale as Wolf himself, who by definition had $k = 1$. For the later Swiss observers k is set by *adoption* to 0.60. The SONNE series is constructed to match the Swiss k-factor, which, however, is also applied to the group numbers so that a composite group count can be computed over many observers, effectively reducing the formula for the Spot count, S, to simply $S = R - 10G$, thus independent of the k-value. The published data for Waldmeier and SONNE gives R and G, so S has to be calculated as detailed above. For Locarno, Zelenka, and Keller, both S and G are available directly. Given G and S, either determined directly or calculated from R and G, the average number of spots per group, S/G, can now be computed for each year.

Figure 1 shows that the average number of spots per group has been decreasing steadily for both SONNE and Locarno and is therefore not due to drifts of calibration or decreasing visual acuity of the primary Locarno observer (Sergio Cortesi since 1957). Because the Locarno observers weight the spot count according to structure and size of spots, they see on average 36% more spots that the SONNE observers. This is clearly seen in panel (c). The weighted Locarno spot count was 40% higher than the unweighted Locarno spot count during 2003-2012. Also, in Figure 1 we plot the variation of the ratio between spots and groups for the more than 431,000 SONNE individual daily observations without any correction for k-factors (green line with plus marks). The 'raw' data show the same general variation and decline as the corrected observations.

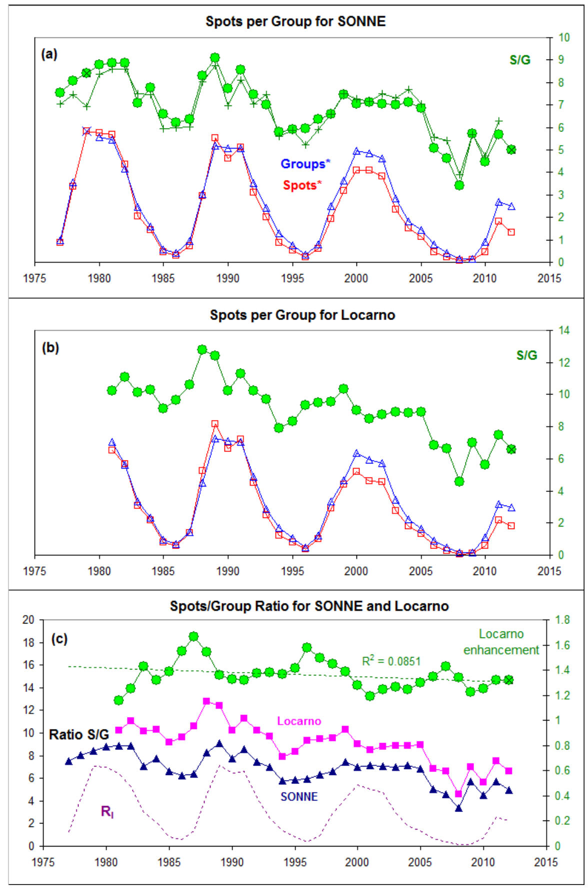

Fig. 1.— (a) The number of spots per group as a function of time (green circles) for SONNE. The green curve with pluses shows the ratio derived from the raw counts, not corrected with k-factors. Points marked with a cross are either interpolated (for 1979) or preliminary (2012). The lower part of the panel shows the variation of number of groups (blue triangles) and the number spots (red squares) both scaled to match each other before 1992. Note the decreasing spot count, relative to the group count. (b) Same, but for Locarno. (c) The decrease of the ratio Spots/Groups for Locarno (pink squares) and for SONNE (blue triangles) using the left-hand scale. The enhancement of the Locarno ratio (see text) is shown by the green circles (right-hand scale). The trend indicated is not significant.

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In Figure 2 we compare the ratio for Locarno with that of Waldmeier, and note that the number of spots per group has stayed almost constant near 10 over the five solar cycles from 1945 until the 1990s, after which it has declined by almost half, consistent with the expected variation resulting from the 'Livingston-Penn Effect'.

In Figure 3 we compare the International Sunspot Number to the Mount Wilson Observatory Magnetic Plage Strength Index: For each magnetogram taken at the 150-Foot Solar Tower, a Magnetic Plage Strength Index (MPSI) value is calculated by summing the absolute values of the magnetic field strengths for all pixels where the absolute value of the magnetic field strength is between 10 and 100 gauss. This number is then divided by the total of number of pixels (regardless of magnetic field strength) in the magnetogram. The magnetic calibration after the instrument upgrade in 1982 is believed to be good, or at least constant (MPSI 2012).

There is a clear solar cycle effect on the sunspot number as a function of MPSI: the ratio is high in the approach to solar minimum and in the very early part of the ascending phase of the cycle (large boxes) before settling down at solar maximum (for solar minimum years, the ratio is between two very small numbers and is thus very noisy and at times undefined), but it is also clear that the ratio has been declining the past two cycles, consistent with the similar findings by Svalgaard & Hudson (Svalgaard & Hudson 2010) using the F10.7 microwave flux as a proxy for the magnetic flux, and by Lefèvre & Clette (Lefèvre & Clette 2011) analyzing the time variation of the distribution of group classes. It seems likely that the inferred secular decrease of sunspot formation is mixed with a solar cycle variation. Observations at or after the current maximum should settle the matter of the reality of a secular change.

We discuss this in Section 3.

3. Discussion

The analyses described above confirm earlier studies...

4. Conclusion

We have confirmed...

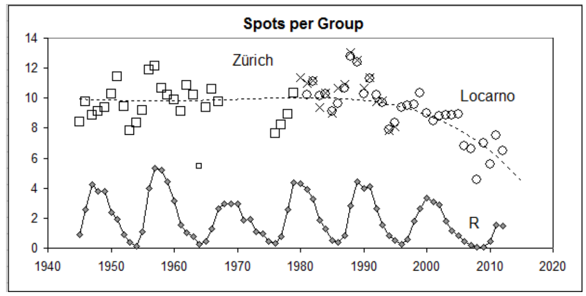

Fig. 2.— The number of spots per group since 1945 determined from the Zürich observers Waldmeier (squares), Zelenka and Keller (crosses), and primarily by Cortesi at Locarno (circles). The value for 1954 is the ratio between two very small numbers and is clearly an outlier. The ratio has been near 10 until the mid-1990 after which it has declined by almost a factor of two. It is important to note that both the Zürich count and the Locarno count have been weighted the same way. The dashed curve is an arbitrary fit simply to delineate the change and has no further significance. For reference, the sunspot number is shown at the bottom.

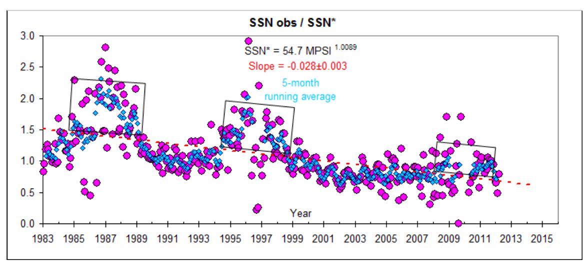

Fig. 3.— The observed International Sunspot Number (SSN) divided by a synthetic sunspot number derived from the Magnetic Plage Strength Index: $SSN^* = 54.7 MPSI^{\ 1.0089}$ (pink circles for monthly values). A 5-month, centered running average is shown by blue diamonds. The ratio is high in the approach to solar minimum and in the very early part of the ascending phase of the cycle (large boxes) before settling down at solar maximum. For solar minimum years, the ratio is between two very small numbers and is thus very noisy and at times undefined. There is also a second-order annual variation of unknown origin, phased with solar distance.

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