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Does sunspot number calibration by the “magnetic needle” make sense?

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ABSTRACT

It has been suggested recently that early sunspot numbers should be re-calibrated and significantly corrected using the observed daily range of the geomagnetic declination (so-called rY values). The suggested “correction” method makes an a priori detrending of the rY series and then extends the linear regression between rY and sunspot numbers established for the last 25 years to earlier times. The suggested “correction” of sunspot numbers by roughly 30% goes far beyond the traditional estimates of observational uncertainties of sunspots. Concentrating here on Zürich sunspot numbers (R_z), we demonstrate that the rY values do not actually imply that the observed R_z values in the 19th century are systematically underestimated. Rather, we find that the R_z numbers are fairly uniform after mid-19th century. The suggested “correction” is largely induced by the detrending of the rY series, which enhances the rY-based sunspot activity in the 19th century relative to later times. We also show that while the annually averaged declinations have a rough relation between sunspots and other related solar parameters, this relation is strongly seasonally dependent and, therefore, not sufficiently accurate or uniform to allow annually averaged rY values to be used as a very reliable proxy of solar activity in early times.

1. Introduction

The evolution of solar activity during the last 100 years is very well known, based on both direct sunspot observations as well as on some independent proxies. Sunspot numbers depict a fairly steady increase of cycle amplitudes from the start of the 20th century until SC 19 in the mid-20th century, with a more variable but still larger than average level thereafter. This evolution is supported by studies based on proxies of solar activity like geomagnetic activity and cosmogenic isotopes. For example, based on the geomagnetic *aa* index it was derived (Lockwood et al., 1999) that the strength of the heliospheric magnetic field was more than doubled during the last century, in agreement with a solar magnetic field model and the observed sunspot numbers (Solanki et al., 2000, 2002). The increasing centennial trend found in solar and geomagnetic activity is further supported by studies using cosmogenic isotopes (Usoskin et al., 2003; Solanki et al., 2004).

Despite this consistency, some doubt was raised on the centennial increase in geomagnetic activity. Introducing a new index of geomagnetic activity, the so-called IHV (inter-hour variability) index, Svalgaard et al. (2004) claimed that there is no long-term increase during the 20th century. However, it was shown soon thereafter that when the effect of the changing data sampling method in the early century is taken into account, the IHV indices of all studied stations show a clearly increasing centennial trend (Mursula and Martini, 2006). The centennial increase was recently further verified using

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a novel *Ah* index which is a closer proxy than IHV to the traditional K-based indices like *Kp*/*Ap*, and *aa* (Mursula and Martini, 2007a, b; Martini and Mursula, 2008).

The relative, Wolf or Zürich sunspot number (called R_z here) was introduced by Rudolf Wolf of Zürich Observatory in mid-19th century. Using the principle of one "primary" observer (for the hierarchy of observers, see Waldmeier, 1961) Wolf aimed in having a homogeneous time series. The bulk of the R_z series in 1849–1981 is based on observations performed at the Zürich Observatory using almost the same technique. Accordingly, R_z values since 1849 are considered quite homogeneous and reliable.

Geomagnetic activity provides fairly reliable proxy data for roughly the same time interval. Although serious concern exists about its long-term homogeneity (Jarvis, 2005; Lockwood et al., 2008; Martini and Mursula, 2008), the *aa* index, sometimes extended by the Helsinki data to start in 1844, verifies that the activity level in the mid-19th century was higher than at the turn of the centuries but lower than in late-20th century. Studies using cosmogenic isotopes in terrestrial archives and meteorites support these results (Usoskin et al., 2003, 2006). However, in 1749–1849, prior to the regular observations at the Zürich Observatory the sunspot observation had several gaps and the R_z indices were often interpolated using various proxy data, in particular the daily range of the geomagnetic declination. Accordingly, the R_z series cannot be considered very reliable for the time before 1849 (Usoskin and Mursula, 2003; Hathaway and Wilson, 2004).

Moreover, the evolution of solar activity during the 19th century is supported by another, completely independent reconstruction of sunspot groups by Hoyt and Schatten (1998), forming a nearly 400-year record of group sunspot numbers R_g. The virtues of R_g are that it includes many more sunspot observations than R_z, it does not include any proxy data (unlike R_z) and it includes all basic information on observations (that are hidden in the R_z series), thus allowing estimates of uncertainties and possible errors. It has been shown that the R_g series is more reliable and homogeneous than the R_z series before 1849, but the two series mostly agree with each other since mid-19th century (Hoyt and Schatten, 1998; Letfus, 1999). The two series disagree slightly on the height of SC 8, 9 and 11, the R_z series giving somewhat higher maximum amplitudes to these cycles. Also, the main solar cycle characteristics as obtained from R_g series are similar to R_z series (Hathaway et al., 2002).

Recently Svalgaard (2007) has re-activated the method of using the daily range of the geomagnetic declination (so-called rY parameter) as a proxy of sunspot numbers. Extending a linear regression between annually averaged rY values and sunspots established for the last 25 years to earlier times, he concluded that the declination requires sunspot numbers from the 1840s until the early 20th century to be sizably re-calibrated and corrected (increased). Taking into account the recent debate on solar influence on climate, Svalgaard's claim is obviously very significant and topical also for climate questions. The suggested "correction" of sunspot numbers by roughly 30% goes far beyond the observational uncertainties of sunspots, especially in the late 19th century when the Sun was already routinely observed by photographic images that were also taken into account in R_g numbers.

In this paper we examine the method used by Svalgaard (2007) and demonstrate that the rY values do not indicate that the observed R_z values are underestimated. (In this paper we concentrate on Wolf numbers, leaving the analysis of R_g values for a separate study.) Rather, the results obtained by Svalgaard (2007) are largely induced by the arbitrary and erroneous detrending of the rY series, which enhances the sunspot activity based on the rY series in the 19th century relative to more recent times. We also show that the relation between annually averaged rY values and sunspots is greatly seasonally dependent, so also inherently inhomogeneous. Therefore, claims of need for a significant revision of sunspot activity in the 19th century are not founded.

2. Overall R_z–rY correlation

Svalgaard (2007) (to be called here S2007) used daily ranges of declination from several stations to construct a combined rY series in 1841–2006. The daily variation of declination is caused by the north–south directed sections of the so-called Sq current system which consists of a western equatorward part and an eastern return current in either hemisphere. S2007 normalized all other stations to the mid-latitude Niemegk (NGK) station but did not mention in detail, e.g., which stations were included and how the early years were joined with the more recent and complete data. Fig. 1 depicts the annual averages of these combined rY values for 1841–2005. The rY values vary clearly with solar cycle with minimum values of about 30–35 in solar minima and maxima of about 45–60 in solar maxima.

In addition to the solar cycle variation, some tendency for a longer-term trend is seen in Fig. 1 (see also Figure 3 in S2007). S2007 noted that there is an overall trend of about 0.0245 nT/year in the (three-year) rY values around solar minima, amounting to a 9.8% increase of rY during the depicted time interval. This trend was suggested to be due to a possible increase in ionospheric conductivity due to a 10% decrease in the intensity of the internal geomagnetic field. We have included this trend in Fig. 1.

Note, however, that the long-term evolution in rY, either at solar minima or more generally, is far from uniform and that the sunspots depict a quite similar long-term behavior as rY values. This is also true for sunspot levels and rY values during sunspot minima. Fig. 2 shows the similar relative variation during the first few minima in these two parameters. In particular, there is no uniformly increasing trend seen around these minima. Even after the time depicted in Fig. 2, the trends at sunspot minima are roughly similar, with an overall increase seen in both parameters during the 20th century. Note also that the increasing activity at sunspot minima

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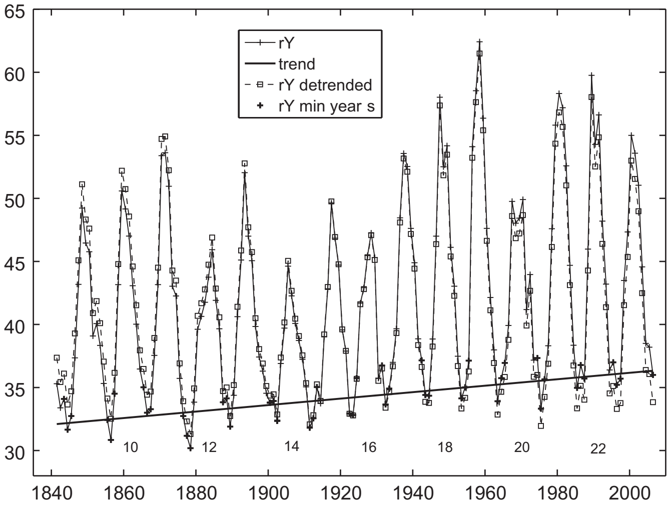

Fig. 1. The original (solid line with pluses) and detrended (dashed line with squares) yearly rY values of Svalgaard (2007). Trend formed by three minimum years per minimum (marked by bold pluses) is also given (solid bold line). Even solar cycles are denoted by number.

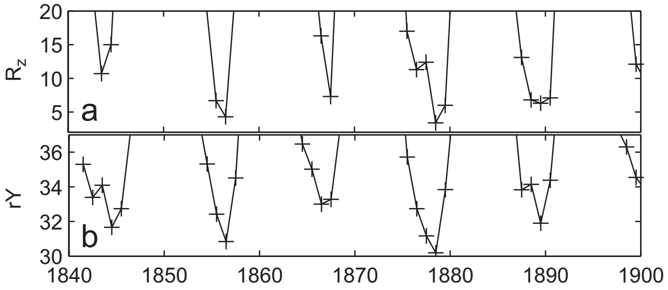

Fig. 2. (a) Yearly sunspot numbers (R_z) and (b) the (original) rY values in minimum years in 1841–1900.

follows the increase of cycle amplitudes and is mainly due to the cycle overlap effect (see, e.g., Hathaway et al., 2002).

Accordingly, the long-term rY trend at solar minima is not uniform and may well be mainly due to the varying sunspot activity. Note also that the suggested effect of the changing geomagnetic intensity upon the ionospheric ionization is not quantitatively verified. Moreover, such an effect may be theoretically motivated at high latitudes in the auroral zone where particle ionization is important but it is quite improbable at low and mid-latitudes where UV controls the dayside ionization and the Sq current intensity. Therefore, it is unmotivated and premature to a priori detrend the rY series by removing the trend formed by the rY values at solar minima.

The effect of removing the trend is to raise the level of rY values in the mid-19th century and decrease them in the late 20th century (see Fig. 1). This is problematic since the main argument in S2007 is that sunspot activity in the mid-19th century is too low. Accordingly, this argument is based on circular evidence.

Fig. 3 presents the scatterplot and correlation between annual sunspot numbers and the (not detrended) annual averages of the combined rY values in 1841–2005 with the best fit line $R_z = 5.698 * \mathrm{rY} - 180.803$ (cc = 0.966). We have used this correlation to depict the observed annual sunspot numbers and the rY-based sunspot numbers in Fig. 4a. One can see that the trends between the two parameters are very similar. We have also correlated the detrended rY values with sunspots and used the respective best fit line to depict them in Fig. 4b. While in Fig. 4a R_z makes the higher maximum in SC 9 and 11 and rY is higher in SC 12 and 13, in Fig. 4b rY has nearly reached R_z in SC 9 and 11, and exceeds it even more during SC 10, 12 and 13. Similar systematic changes are seen in sunspot minima, and opposite changes during the more recent cycles. These notes underline the problematic effect of a priori removing the trend from rY values which arbitrarily raises the rY-based sunspot activity in mid-19th century.

Figs. 5a and b depict the differences between R_z and rY-based sunspot numbers before and after detrending, respectively. Large positive differences (e.g., beyond 20) occur mostly in the beginning of the interval in Fig. 5a and at the end of interval in Fig. 5b, again reflecting the effect of detrending to lower the values in mid-19th century and raise them in the late 20th century. Note also that while before detrending the differences oscillate rather randomly around zero, after detrending they tend to be below zero in late-19th century and above zero in late-20th century. Also, after detrending, the differences show evidence for a step-like behavior (to be discussed later).

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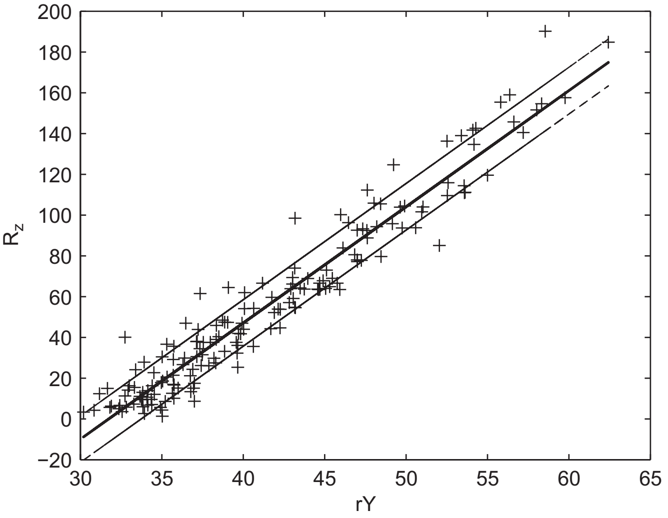

Fig. 3. The scatterplot of yearly R_z values vs. the (original) rY values in 1841–2006. Best fit (solid line) and 95% confidence limit lines (dashed lines) are included.

3. Extending recent R_z–rY correlation to earlier times

S2007 argues (although does not show quantitatively) that the correlation between annual sunspots and rY values depends on the time interval studied, claiming this for an inconstant calibration of sunspots. Therefore, S2007 uses the sunspots of the more recent times 1981–2005 to find the most reliable correlation between sunspots and rY. (This is the period of the international sunspot index constructed at SIDC, Brussels, as a statistical average of several observers rather than using a primary observer method of R_z.) We have depicted the two parameters and their correlation in Fig. 6. As noted above, contrary to S2007, we do not detrend the rY values prior to correlating them with sunspots. Despite this, our correlation is equally good as in S2007 ($cc = 0.9836$) and the best fit line $R_z = 5.7864 * rY - 187.3417$ is only slightly different from the one found there. Note also that the best fit lines for the whole time interval and for the recent years are fairly similar, the differences being within the estimated error.

S2007 then extended the correlation found for these recent years to obtain an rY-based estimate of sunspot activity series since 1841. S2007 found that while rY and R_z agree well since 1940s R_z generally falls below the rY reconstruction before that. This was true for all other cycles in the late 19th century and at the turn of centuries (SC 10–14), except for SC 9. The differences between rY-based and observed Wolf sunspot numbers were found to be occasionally very large, up to about 40%. We have included the early part of Figure 7 of S2007 in Fig. 7. Note in particular how similar the cycle amplitudes and their relative differences are in Fig. 4b and in Fig. 7, suggesting that the differences between rY-based and R_z sunspot cycle amplitudes in the 19th century are indeed mainly due to detrending.

We have depicted in Fig. 8 the rY-based sunspots during the most critical time interval using the correlation depicted in Fig. 6. We also include the estimated 95% confidence level error calculated for the correlation of Fig. 6. It is seen in Fig. 8 that out of the three cycles (10, 12 and 13) where S2007 found the largest differences between rY and R_z, two (SC 10 and 12) are within the error based on correlation for recent years. For SC 13, rY gives a maximum which is significantly (in terms of 95% error) above R_z. On the other hand, in SC 9 the R_z maximum is significantly higher than that based on rY. Thus, one cannot conclude that rY would imply a significantly and systematically higher level of sunspot activity in the 19th century. This suggests that the claim in S2007 of large, systematic differences between rY and R_z is seriously affected by the arbitrary detrending procedure. Instead, our results support the overall homogeneity of R_z values during the studied time interval.

In order to "correct" for the differences found between rY-based and observed sunspot numbers, S2007 correlated rY and sunspots for each cycle separately (using zero intercepts). Thereby S2007 introduced cycle dependent "correction factors" which were applied to the observed sunspot numbers so as to optimally fit them to rY. Accordingly, the "corrected" sunspots attained the levels of the detrended rY during each cycle separately. So, e.g., the weak cycles 10 and 12 were naturally raised considerably, making S2007 to conclude that sunspot level in the mid-19th century must be raised to roughly the same level as the recent cycles.

The best fit slopes, i.e. the "correction factors" for each cycle, were found to vary from 0.905 (SC 19) to 1.403 (SC 13) for R_z and from 0.961 (SC 22) to as large as 1.580 (SC 12) for R_g. (Note that the suggested error of 58% for SC 12 is against three independent estimates by Wolf, by the Royal Greenwich Observatory and by Spoerer who agree within 9% on the number of sunspot groups for this cycle.) Moreover, the coefficients were found to group in three sets with different levels, the first set for SC 10–13 with an average level of about 1.3, the second at about 1.15 for SC

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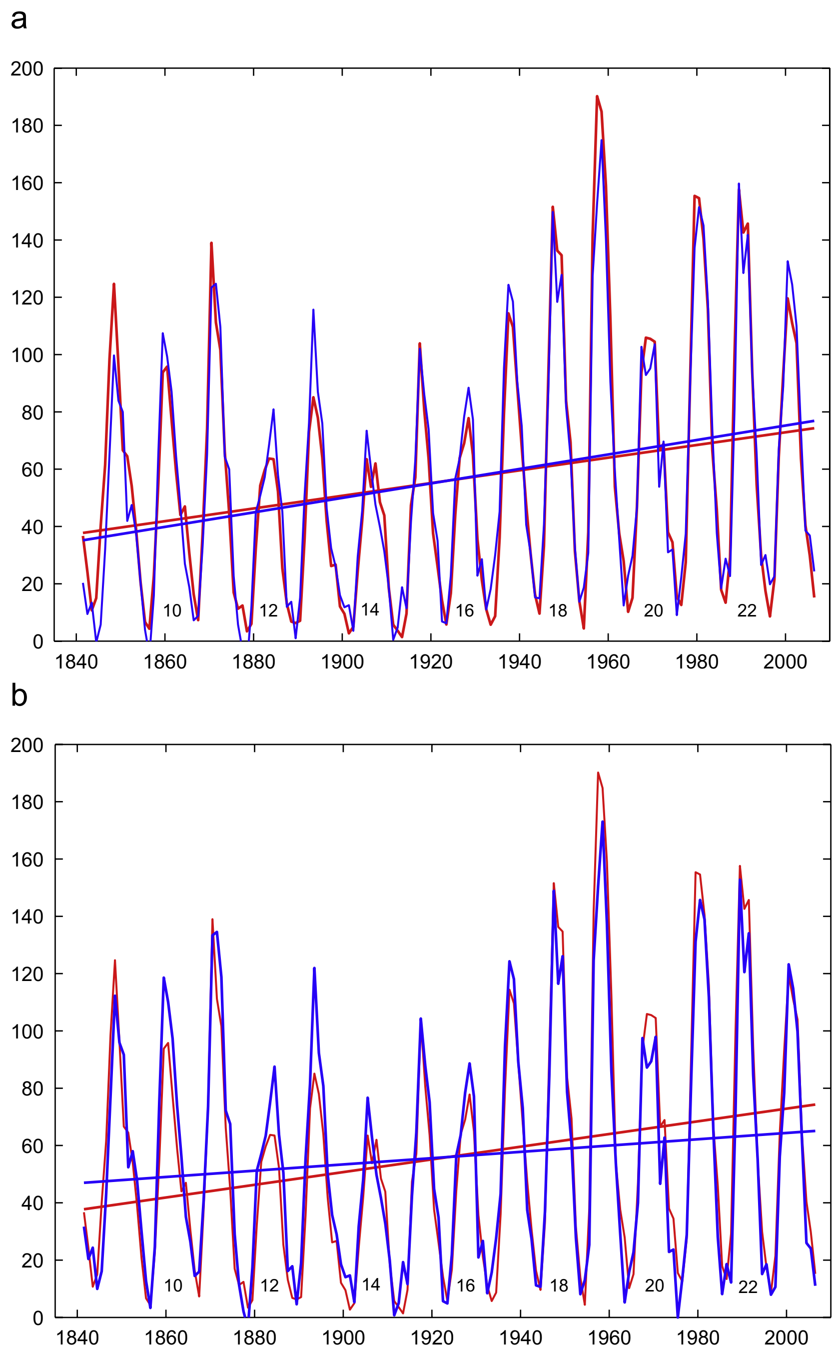

Fig. 4. The yearly R_z (solid line) and rY-based sunspot values (dashed line) in 1841–2006 (a) using original rY values; (b) using detrended rY values. The corresponding overall best fit trends are also included. Even solar cycles are denoted by number.

14–17 and the third of about 1 for the recent cycles. These steps in the "correction factors" were connected in S2007 to the changes in 1893 (from Wolf to Wolfer) and in 1945 (from Brunner to Waldmeier) of the primary observer of R_z.

However, as seen in Fig. 5, while the differences between the R_z and rY-based sunspots are oscillating around zero rather randomly in Fig. 5a, the detrending of rY values tends to form similar stepping as noted in S2007 in the "correction factors". It is very indicative that the steps depicted in Fig. 5b are located at the same times and have roughly the same size as in the "correction factors". So, our conclusion is that the differences between the R_z and rY-based sunspots are mostly produced by detrending the rY values. As noted in S2007 with some embarrassment, the same steps with even larger relative differences were found for the group sunspot numbers which are

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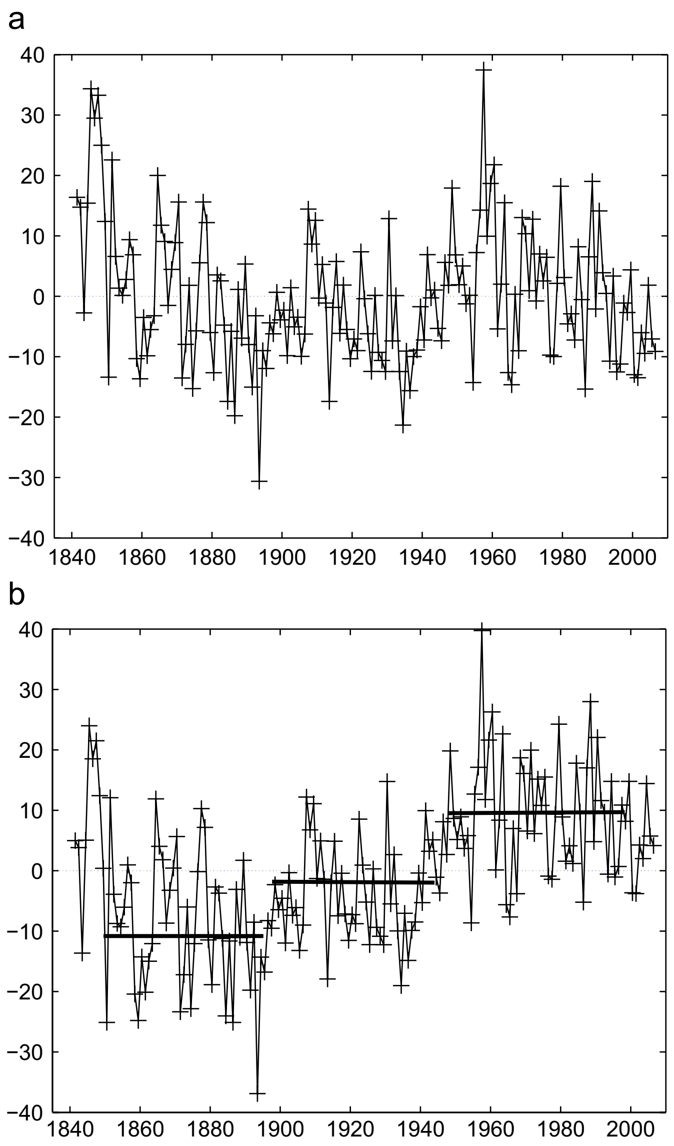

Fig. 5. Difference between the yearly R_z and rY-based sunspot values in 1841–2006 (a) using original rY values; (b) using detrended rY values.

independent of the changes in primary observers. This note can now be better understood.

4. Seasonal R_z–rY correlation

We have also studied the correlation between R_z and rY in more detail. In order to find how the rY values really vary, we have plotted in Fig. 9 the scatterplot of monthly R_z values and monthly rY values calculated for the NGK station in 1890–2005. (Note that the rY values combined from several stations in S2007 were normalized to NGK.) We have taken three months of each year (March, June and December) and plotted the data points corresponding to these three months using different symbols.

Fig. 9 depicts large systematic differences between the three months. The rY values in December range typically from 15 to 40 for R_z varying from 0 to 200. Similarly, March rY values range from 30 to 70 and June values from 45 to 90 for the same R_z values. Accordingly, the range of rY values is greatly dependent on season, contrary to the view expressed in S2007. This seasonal variation of the rY range reflects the annual change of the location of the Sq current system, as observed at one fixed station in the northern hemisphere. The reduced rY values in December are due to fact that when the Sq system moves equatorwards, the station sees the Sq system to shrink. The opposite effect takes place in the local Summer: the Sq currents are closer, stronger and wider in local time, leading to a larger rY.

Moreover, the correlation between monthly R_z and rY values depends on the season. The best fit lines are $R_z = 5.811 * \mathrm{rY} - 93.527$ $(\mathrm{cc} = 0.623)$ for December, $R_z = 4.344 * \mathrm{rY} - 152.329$ $(\mathrm{cc} = 0.890)$ for March and $R_z = 4.335 * \mathrm{rY} - 213.014$ $(\mathrm{cc} = 0.925)$ for June. Accordingly,

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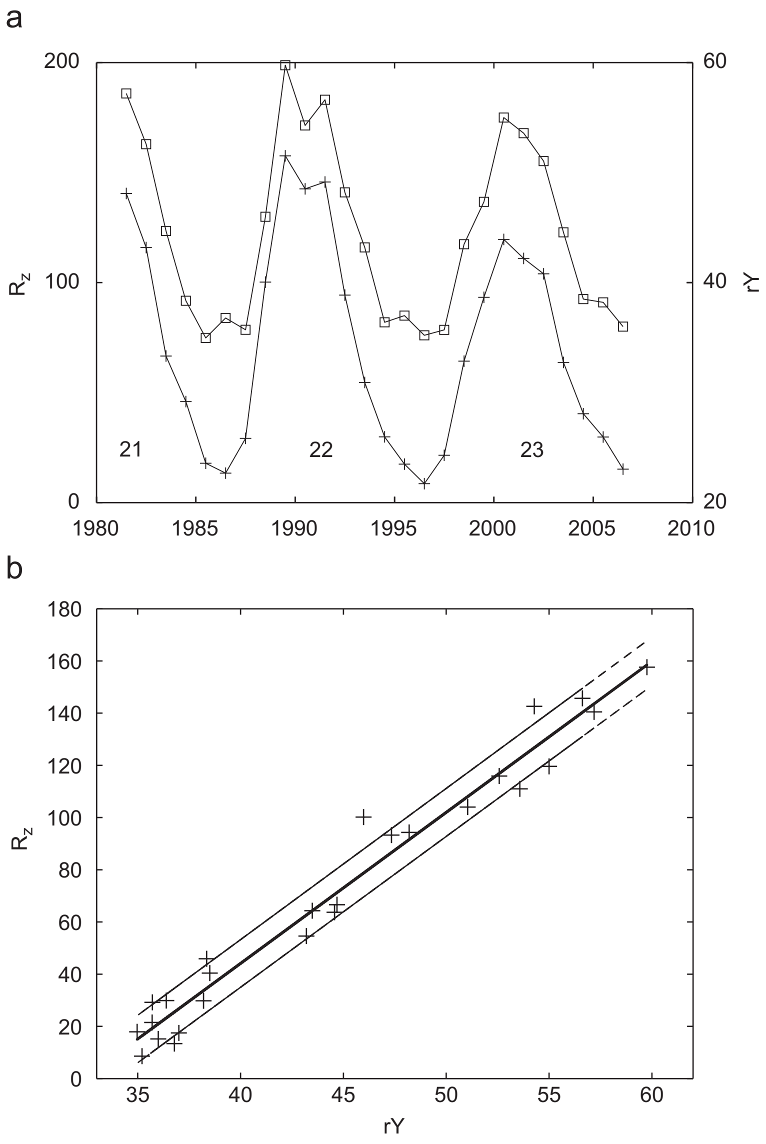

Fig. 6. (a) Time series of yearly R_z values (solid line with pluses; left y-axis) and the (original) rY values (solid line with squares; right y-axis) in 1981–2006 with sunspot cycle numbers marked below; (b) their scatterplot (pluses) with best fit line (solid) and 95% confidence level lines (dashed).

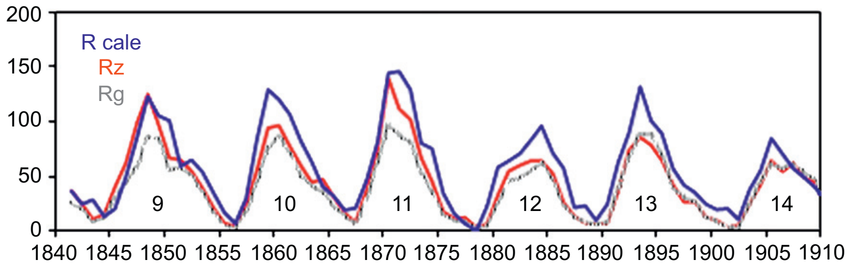

Fig. 7. The early part Figure 7 of Svalgaard (2007): the time series of the detrended rY-based sunspots (Rcalc; solid black line), and the observed R_z (gray line) and R_g (light gray line with black dots) numbers for cycles 9–14.

the sensitivity (inverse of the slope of the regression line) of rY to solar activity is roughly similar in March and June but clearly smaller in December. The smaller sensitivity in Winter is natural because the focus of the Sq current system is quite far from the station and the variations in Sq intensity are only weakly reflected there.

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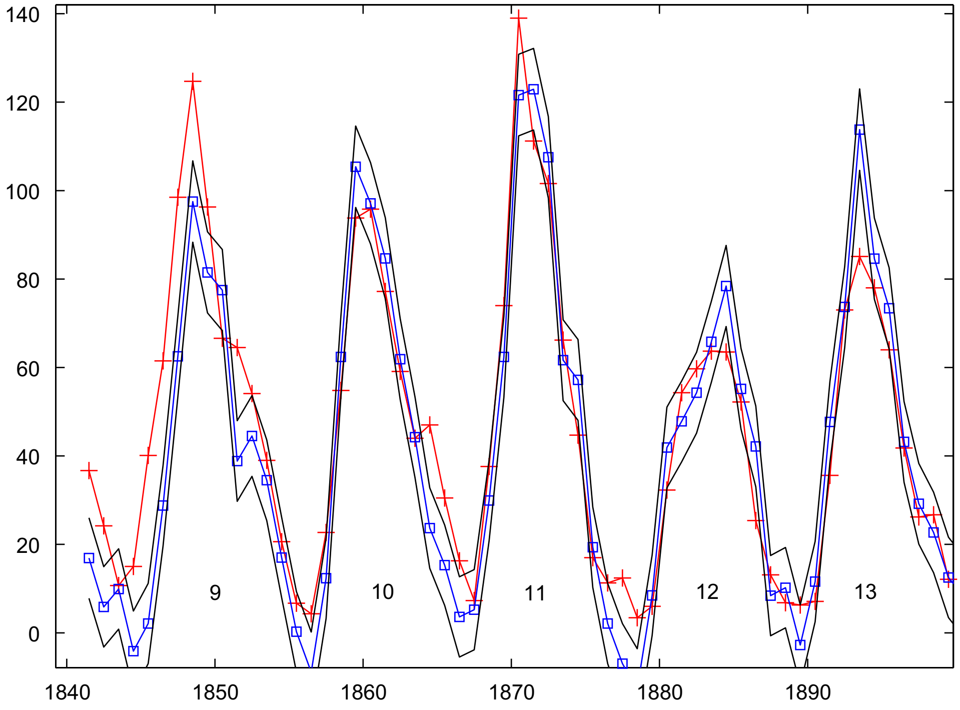

Fig. 8. Time series in the 19th century of yearly R_z values (solid line with pluses) and the rY-based sunspots (dashed line with squares) from R_z–rY correlation in 1981–2006, together with 95% confidence lines (dotted lines). Sunspot cycles are numbered.

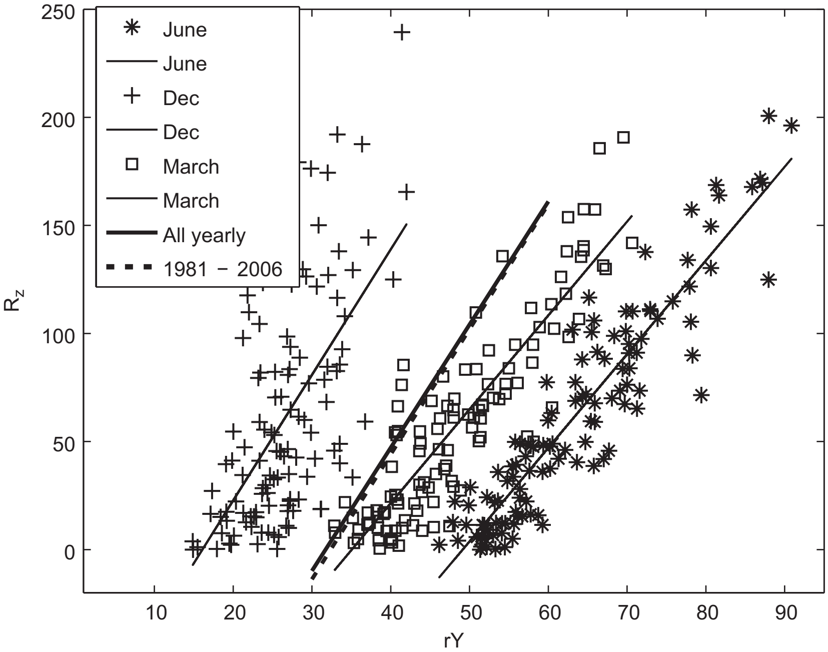

Fig. 9. Scatterplots and best fit lines of monthly R_z and NGK rY values in 1890–2005 separately for December (pluses), March (squares) and June (stars). The best fit lines based on R_z–rY correlation in 1841–2006 (thick solid line) and in 1981–2006 (dashed line) are included for comparison.

We have also depicted in Fig. 9 the two best fit lines obtained above between R_z and rY using annual averages. (They are hardly distinguishable from each other in Fig. 9.) Note that, interestingly, the sensitivity of rY on R_z in December is quite similar to (only slightly weaker than) the sensitivity using annual averages. Actually, one would

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expect that the sensitivity using annual averages would be between Winter Summer sensitivities. However, the December fit is considerably worse than the Summer fit, including data points far outside the best fit line (see Fig. 9), especially for large R_z. These points demonstrate the nearly complete insensitivity of Winter rY (at NGK) on solar activity, and strongly decrease the sensitivity of annual averages below that for Summer (or Spring) only. Therefore, the correlation between R_z and rY using yearly averages is strongly contaminated by the annual motion of the Sq current system, contrary to what was assumed in S2007. Also, this shows that the correlation between annual averages of R_z and rY is not sufficiently consistent or accurate for rY to be used as a very reliable proxy of R_z. We also note that using all monthly values would yield a best fit line whose slope would be very small, implying higher sensitivity than any of the individual months. This clearly demonstrates the arbitrariness of the suggested method.

Note also that the fact that the correlation between R_z and rY varies over the year also indicates that the correlation of annual values is dependent on the distribution of solar activity over the year. This causes enhanced scatter in the R_z–rY relation. This effect is particularly important during years of weak or rapidly changing solar activity when the relative annual variation of sunspot activity can be much larger than during highly active years. Accordingly, while the correlation between annual R_z and rY values is driven by the most highly active years and gives an average relation for weak and high activity years, there is an enhanced level of scatter around this average R_z–rY relation during weak sunspot years. Actually, the success of extending the R_z–rY relation for recent years to the early years (Fig. 4a) is quite amazing and lends support for fair homogeneity of the R_z series.

5. Discussion and conclusions

We have studied here a recent claim (Svalgaard, 2007) that the early measurements of the daily range (rY) of geomagnetic declination implies that sunspot activity is significantly underestimated in the mid- to late 19th century. We have noted that detrending the rY data using solar minimum years is largely responsible for the suggested higher level of sunspot activity in the 19th century based on the rY values. Also, there is no uniform trend in rY values at solar minima. Rather, these values follow the long-term trend and the cycle-by-cycle variation of sunspot minima, suggesting that the decreasing geomagnetic field intensity has a minor effect on the trend, contrary to the suggestion in S2007.

We have also noted that while, without detrending, the residuals between observed and rY-based sunspots oscillate rather randomly round zero, after detrending they seem to develop a step-like behavior with an average below zero in the late 19th century, around zero in early 20th century and above zero in the late 20th century. A similar stepping was found in S2007 in the cycle dependent “correction factors” introduced to raise the observed sunspots to the rY-based level. This stepping was suggested in S2007, for the part of R_z numbers, to be due to the changes in primary observer in the Zürich Observatory. Note, however, that this explanation does not apply to R_g numbers where a similar stepping was also found in the similar “correction factors”.

When extending the correlation between the annual averages of international sunspot numbers and rY values (without prior detrending) in 1981–2006 to the mid- and late 19th century, we find a good correlation between observed R_z values and the rY-based sunspot numbers, with most cycles agreeing with each other within 95% confidence limits (one cycle was higher in R_z and one in rY). Regression parameters between rY and sunspots in recent years are almost identical to those for the whole time interval (1841–2006). These results give strong evidence for the homogeneity of the R_z series over the time interval studied. Anyway, the observed R_z numbers in mid-19th century are not systematically lower than the rY-based estimates yield.

We have also studied here the long-term dependence of rY values on solar activity using monthly averages. We have shown that sensitivity of rY on sunspots varies greatly seasonally, following the seasonal motion of the Sq current system. At mid-latitudes, the Winter time sensitivity is much weaker due to the enhanced distance to the Sq focus. So, contrary to the assumption in S2007, the annual range of the rY values is dominated by a seasonal variation, which causes enhanced scatter in sunspot–rY relation especially for weak solar activity times. Accordingly, the relation between annually averaged R_z and rY values is rather inaccurate, inhomogeneous and even slightly nonlinear, excluding a very precise extrapolation over long time intervals. Thus, attempts to “correct” one by another using a linear relation are invalid.

Concluding, while the daily declination range can be used to obtain a rough relation between sunspots and other related solar parameters (like F10.7, UV flux, etc.), their mutual relation is strongly seasonally dependent and not sufficiently accurate, uniform or linear for annually averaged rY values to be used as a very reliable proxy of, e.g., sunspots in early times. So, an accurate sunspot number calibration by the “magnetic needle” does not make sense. Moreover, the R_z values of the late 19th century are in accordance with the sunspot level predicted by their recent relation with rY, indicating R_z to be fairly uniform over this interval. On the other hand, a priori detrending of rY values using solar minimum years is questionable and artificially enhances the rY-based sunspot level in the 19th century.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online vesion at doi:10.1016/j.jastp.2008.04.017.

References

Hathaway, D.H., Wilson, R.M., 2004. What the sunspot record tells us about space climate. Solar Physics 224, 5–19.

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Hathaway, D.H., Wilson, R.M., Reichmann, E.J., 2002. Group sunspot numbers: sunspot cycle characteristics. Solar Physics 211, 357–370.

Hoyt, D.V., Schatten, K., 1998. Group sunspot numbers: a new solar activity reconstruction. Solar Physics 179, 189–219.

Jarvis, M.J., 2005. Observed tidal variation in the lower thermosphere through the 20th century and the possible implication of ozone depletion. Journal of Geophysical Research 110 (A4), A04303.

Letfus, V., 1999. Daily relative sunspot numbers 1749–1848: reconstruction of missing observations. Solar Physics 184, 201–211.

Lockwood, M., Stamper, R., Wild, M.N., 1999. A doubling of the sun's coronal magnetic field during the past 100 years. Nature 399, 437–439.

Lockwood, M., Whiter, D., Hancock, B., Henwood, R., Ulich, T., Linthe., H.J., Clarke, E., Clilverd, M.A., 2008. The long-term drift in geomagnetic activity: calibration of the aa index using data from a variety of magnetometer stations. Annales Geophysicae, in print.

Martini, D., Mursula, K., 2008. Centennial geomagnetic activity studied by a new, reliable long-term index. Journal of Atmospheric and Solar-Terrestrial Physics 78, 1074–1087.

Mursula, K., Martini, D., 2006. Centennial increase in geomagnetic activity: latitudinal differences and global estimates. Journal of Geophysical Research 111, A08209.

Mursula, K., Martini, D., 2007a. A new verifiable measure of centennial geomagnetic activity: modifying the K index method for hourly data. Geophysical Research Letters 34, L22107.

Mursula, K., Martini, D., 2007b. New indices of geomagnetic activity at test: comparing the correlation of the analogue ak index with the digital Ah and IHV indices at the Sodankylä Station. Advances in Space Research 40, 1105–1111.

Solanki, S.K., Schüssler, M., Fligge, M., 2000. Evolution of the Sun's large-scale magnetic field since the Maunder minimum. Nature 408, 445–447.

Solanki, S.K., Schüssler, M., Fligge, M., 2002. Secular variation of the Sun's magnetic flux. Astronomy and Astrophysics 383, 706–712.

Solanki, S.K., Usoskin, I.G., Kromer, B., Schüssler, M., Beer, J., 2004. Unusual activity of the Sun during recent decades compared to the previous 11,000 years. Nature 431, 1084–1087.

Svalgaard, L., 2007. Calibrating the sunspot number using the "magnetic needle". CAWSES News 4 (1), 6–8 and detailed addendum.

Svalgaard, L., Cliver, E.W., Le Sager, P., 2004. IHV: a new long-term geomagnetic index. Advances in Space Research 34, 436–439.

Usoskin, I.G., Mursula, K., 2003. Long-term solar cycle evolution: review of recent developments. Solar Physics 218, 319–343.

Usoskin, I.G., Solanki, S., Schüssler, M., Mursula, K., Alanko, K., 2003. Millennium-scale sunspot number reconstruction: evidence for an unusually active Sun since the 1940s. Physical Review Letters 91 (21), 211101–211104.

Usoskin, I.G., Solanki, S.K., Taricco, C., Bhandari, N., Kovaltsov, G.A., 2006. Long-term solar activity reconstructions: direct test by cosmogenic 44Ti in meteorites. Astronomy and Astrophysics 457, L25–L28.

Waldmeier, M., 1961. The Sunspot Activity in the Years 1610–1960. Schulthess Company AG, Zürich, Switzerland.

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