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Reexamination of the coronal index of solar activity

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[1] The coronal index (CI) of solar activity is the irradiance of the Sun as a star in the coronal green line (Fe XIV, 530.3 nm or 5303 Å). It is derived from ground-based observations of the green corona made by the network of coronal stations (currently Kislovodsk, Lomnický Štít, Norikura, and Sacramento Peak). The CI was introduced by Rybanský (1975) to facilitate comparison of ground-based green line measurements with satellite-based extreme ultraviolet and soft X-ray observations. The CI since 1965 is based on the Lomnický Štít photometric scale; the CI was extended to earlier years by Rybanský et al. (1994) based on cross-calibrations of Lomnický Štít data with measurements made at Pic du Midi and Arosa. The resultant 1939–1992 CI had the interesting property that its value at the peak of the 11-year cycle increased more or less monotonically from cycle 18 through cycle 22 even though the peak sunspot number of cycle 20 exhibited a significant local minimum between that of cycles 19 and 21. Rušin and Rybanský (2002) recently showed that the green line intensity and photospheric magnetic field strength were highly correlated from 1976 to 1999. Since the photospheric magnetic field strength is highly correlated with sunspot number, the lack of close correspondence between the sunspot number and the CI from 1939 to 2002 is puzzling. Here we show that the CI and sunspot number are highly correlated only after 1965, calling the previously-computed coronal index for earlier years (1939–1965) into question. We can use the correlation between the CI and sunspot number (also the 2800 MHz radio flux and the cosmic ray intensity) to recompute daily values of the CI for years before 1966. In fact, this method can be used to obtain CI values as far back as we have reliable sunspot observations (~1850). The net result of this exercise is a CI that closely tracks the sunspot number at all times. We can use the sunspot-CI relationship (for 1966–2002) to identify which coronal stations can be used as a basis for the homogeneous coronal data set (HDS) before 1966. Thus we adopt the photometric scale of the following observatories for the indicated times: Norikura (1951–1954; the Norikura photometric scale was also used from 1939 to 1954); Pic du Midi (1955–1959); Kislovodsk (1960–1965). Finally, we revised the post-1965 HDS and made several small corrections and now include data from Kislovodsk, Norikura, and Sacramento Peak to fill gaps at Lomnický Štít.

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1. Introduction

1.1. Background

[2] Young and Harkness independently made the first observation of the coronal emission line at 5303 Å during the total solar eclipse of 7 August 1869. The "green line," as it came to be called, was originally attributed to the hypothetical element "coronium." The puzzle of the 5303 Å line and coronium was solved by *Grotrian* [1939] and *Edlén* [1942] who concluded that the emission line originated in highly ionized Fe (Fe XIV).

[3] A new era in coronal line observations began in 1939 when Waldmeier initiated green line measurements at Arosa (Switzerland) with a *Lyot* [1932] coronagraph [*Waldmeier*, 1957]. The coronagraph patrol started by Waldmeier was taken up over the years at other coronal stations resulting in an inhomogeneous set of records that extends to the present time. These records provide an indicator of solar activity in the corona, in much the same way that the sunspot record characterizes photospheric activity. At present, four coronal stations (Lomnický Štít (Slovakia), Norikura (Japan), Kislo-

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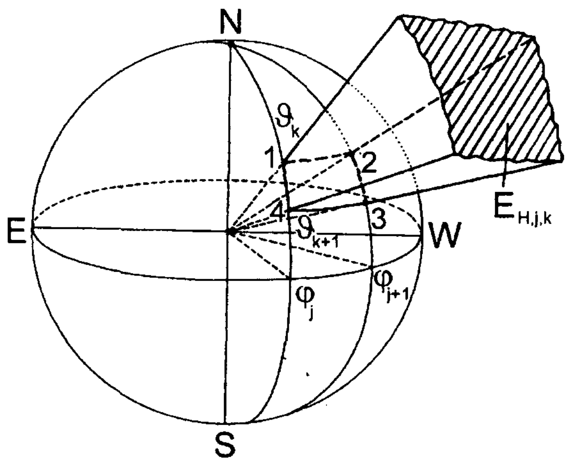

Figure 1. Schematic indicating a unit volume in front of the solar disk. Integrating the volume emissivity over the visible disk and above the limb of the Sun yields the coronal index (CI).

vodsk (Russia), and Sacramento Peak (USA)) observe the green corona regularly.

[4] The green coronal line is the most prominent of 28 coronal emission lines in the visible part of the electromagnetic spectrum. It is observed during the complete 11-year solar cycle activity and around the entire solar limb. Measurements of the green coronal intensity represent one of the longest-running direct indices of solar activity, being surpassed only by the sunspot number (available since 1610), sunspot area (1874), and calcium plage index (1905) [*Lean*, 2000, and references therein]. The green line measurements can be compared with these and other direct solar indices (e.g., irradiance observations from space [*Fröhlich and Lean*, 1998; *Fröhlich*, 2003, and references therein]) as well as with indirect indices (e.g., cosmogenic radionucleides [*Beer*, 2000]) to gain insight on solar variability. The green line coronal measurements also have potential applications for understanding the impact of solar variability on climate change [e.g., *Krivova and Solanki*, 2003, and references therein], coronal hole determinations from 1939 and for improving space weather forecasting [e.g., *Mavromichalaki et al.*, 2003].

1.2. Coronal Index (CI) of Solar Activity

[5] To facilitate comparisons of ground-based green line measurements with observations in extreme ultraviolet and soft X-ray wavelengths made from space, *Rybanský* [1975] proposed a new index of solar activity based on Lomnický Štít 530.3 nm measurements that he called the "coronal index of solar activity" (CI). The CI expresses the irradiance of the green corona for the Sun as a star and can be easily compared with similar full-disk solar indices. CI values are expressed in power units [W sr^{-1}] and can be easily transferred to similar units obtained from satellite measurements as shown below:

$$10^{16}\mathrm{W\ sr^{-1}} \equiv 4.5\times10^{-7}\mathrm{W\ m^{-2}(at\ 1\ AU)} \equiv 1.2\times10^{8}\mathrm{photons\ cm^{-2}s^{-1}}. \quad (1)$$

Monthly averages of CI for 1939–2002 fluctuate in ranges from 2×10^{16} W sr^{-1} (around cycle minimum) to 20×10^{16} W sr^{-1} (around cycle maximum). Daily CI maximum values have never exceeded 30×10^{16} W sr^{-1}. The green line intensity in calibrated observations is expressed in absolute coronal units (ACU). One ACU represents the intensity of the continuous spectrum of the center of the solar disk in the width of 1 Å, at the same wavelength as the observed coronal spectral line (1 ACU = 3.89 W m^{-2} sr^{-1} at 530.3 nm).

[6] According to an agreement between coronal observers in 1947, coronal intensities are derived at least once per day at heights of 40–60 arcsec above the solar surface with a lag of 5 degrees in positional angle. The initial observation is made above the solar north pole, and 71 subsequent data points are made at the same height proceeding in a counterclockwise direction (north, east, south, west) [*d'Azambuja*, 1947]. The CI for a given day is based on limb observations of the green line for that day and intervals of 6 days on either side of that day. The distribution of intensity above the solar surface is obtained by using the observations at the E-limb (W-limb) from the 6 days preceding (following) the given day to specify the coronal intensities above the eastern (western) half of the disk. By integrating over the solar disk (Figure 1), we obtain the irradiance in front of the visible part of the Sun (E_H) to which we add the irradiance above the solar limb (0.5 E_L) [see *Rybanský*, 1975, Figure 2] to obtain the coronal index

$$\mathrm{CI} = \mathrm{E_H} + 0.5\mathrm{E_L} \quad (2)$$

which is the total irradiance of the green corona into one sterradian (sr) toward Earth [for details of the computation, see *Rybanský* [1975].

[7] The limitations and underlying assumptions of the calculation are as follows:

[8] 1. It is assumed that the solar corona (green line irradiance) is stable for the 6-day period required for regions to pass from the limb to central meridian (the E-limb case), or from central meridian to the limb (W-limb case).

[9] 2. Measurements are made with a resolution of 5 degrees, so values of the irradiance at intermediate points must be interpolated.

[10] 3. The existence of an average gradient of the green coronal intensity is assumed. Thus measurements made at the height of 40 arcsec (as in the case of Lomnický Štít) allow us to derive the green line intensity at any height above the solar surface. The gradient used for heights >40 arcsec,

$$\mathrm{I(h)/I(40\ arcsec)} = 0.473e^{-0.128h} + 1.409e^{-1.128h} \quad (3)$$

was taken from *Rušin* [1973].

[11] The series of daily coronal intensities dating from 1939 on which the computation of CI is based is referred to as the homogeneous coronal data set (HDS). For each day, the HDS consists of 72 green line intensities (covering all azimuths) which have been transformed to the Lomnický Štít photometric scale using a correlation technique for common observational days. Missing observational days (short gaps) are filled in by interpolation to give a more continuous data set. For years before 1966

(when Lomnický Štít observations commenced), cross-calibrations were used in turn between Lomnický Štít and Pic du Midi and Pic du Midi and Arosa to extend the HDS back to 1939. See *Rybanský et al.* [1994, 2001] for details of this process.

[12] The resulting CI for the period 1939–2002 exhibited a monotonic increase of CI values for the peak years of solar cycles 18–22 (1944 to 1996), while the corresponding peak sunspot numbers had a local minimum for solar cycle 20. Recently, *Rušin and Rybanský* [2002] showed that the green line intensity and photospheric magnetic field strength were highly correlated from 1976 to 1999. Since the photospheric magnetic field strength is highly correlated with sunspot number, the lack of close correspondence between the sunspot number and the CI from 1939 to 1965 calls the pre-1966 CI data into question.

1.3. Outline of Analysis

[13] In this paper, we use correlations between the CI and three other indices, sunspot number, 2800 MHz radio flux, and cosmic ray intensity, for the years 1966–2002, to recreate the CI for earlier years. We then use the pre-1966 CI values to determine which coronal stations to use as a baseline for the HDS for years from 1939 to 1965. Finally, we use a more comprehensive data base to compute the HDS after 1965 and apply some additional small corrections to the 1966–2002 HDS. The principal goal, and end result, of this work is a revised and updated HDS and CI series for use by solar, and solar-terrestrial, physicists.

2. Analysis

2.1. Coronal Green Line Data

[14] Measurements of coronal intensities from the early coronagraph stations at Arosa [*Waldmeier*, 1957] and Pic du Midi [e.g., *Leroy and Trellis*, 1974] differed in their particulars, e.g., method of photometry (visual or photographic, spectral or narrow passband filters), calibration (artificial lamp, personal estimation, or comparison to the center of the solar disk), and height (above the limb) of observation. These various differences or inhomogeneities between green line patrols persisted as new stations came on line, even when efforts were made to standardize observational methods [*d'Azambuja*, 1947].

[15] The main differences between stations today involve calibration and the observational method used. For example, while some coronal stations, e.g., Norikura, Pic du Midi, Climax, Kislovodsk, related coronal measurements to the intensity observed at the center of the solar disk, other stations, e.g., Arosa, Wendelstein, Kanzelhöhe, Climax (early years from 1942 to 1955), Sacramento Peak (early years from 1955 to 1966), made only qualitative visual observations and reported intensities on an arbitrary scale from 0 to 50 with only occasional calibration. Intensities obtained with this latter method are called "relative intensities." To create the HDS, the relative intensities must be transformed to the absolute coronal units (ACU) described in section 1. However, this is difficult to do in practice as already noted by *Bruzek* [1955]. Thus in constructing the HDS, comparatively little use was made of the relative intensity data.

[16] Even the absolute coronal intensities, however, have their limitations since the values obtained at different observatories depend on: (1) the accuracy of the determination of the optical density of the calibration filter (the optical density of the calibration filter at Lomnický Štít is $\sim$4, indicating a 10^4 reduction in light from the center of the Sun, but in practice, this parameter is difficult to determine precisely because of the complicated light path in the coronagraph), and (2) the reduction of the scattered photospheric light (the continuum and the blended absorption at 530.23 nm) in Earth's atmosphere and the instrument.

[17] The accuracy of coronal intensity measurements depends on the observational height above the solar photosphere because of the gradient of the green corona intensity (see *Rušin* [1973] for details). A change of the observed height above the solar limb by 1 arcmin results in an intensity decrease by approximately a factor of two. (For a small (e.g., F = 1.5 m) coronagraph, the uncertainty in pointing accuracy can be $\sim$1 arcmin.) Another factor that influences the coronal intensity is the device used to isolate a narrow portion of the spectrum: (1) a spectrograph or (2) a narrow passband filter. It is generally believed (known) that spectral observations calibrated to the center of the solar disk using a spectrograph have higher accuracy than those made with a narrow passband filter. The above reasons, coupled with real changes in the emission corona irradiance, which, as we know, may occur on short timescales (relative to the difference in time at which stations spanning the Earth make their observations), cause coronal intensities from different coronal stations to vary. An indication of the extent of the discrepancy can be seen in Figure 2 where we plot highly-smoothed (81-day running averages) data for all of the coronal stations considered in this study, for the intervals during which they observed between 1939 and 2002. The large station-to-station differences evident can not be explained in terms of the time shift between individual coronal stations; any discrepancies due to differences in the UT time of observation will be greatly reduced by in the long-term averages.

2.2. A Difference in Values of the Coronal Index Before and After 1966.0

[18] In order to examine the stability of the Lomnický Štít photometric scale after 1965, and to check if earlier pre-1966 CI data published by *Rybanský et al.* [1994] are correct, we did a correlation between monthly averages of the CI (CI), sunspot number (R), the 2800 MHz radio flux (RF), and cosmic ray (CR) intensity for all available common years and also for the identical time periods 1953–2002 as shown in Table 1. The empirical relations between the CI and the three other parameters are given in Table 1, along with the corresponding correlation coefficients. In all cases, the correlation coefficients are relatively high.

[19] Using the relations in Table 1 we can compute a new series of CIs, plotted as dotted lines in Figure 3 and marked as CI (R), CI (RF), and CI (CR) for comparison with the current index (dashed lines). Inspection of Figure 3 reveals that the correlation is much weaker for cycles before 1966 than after. This behavior is another proof that the Lomnický Štít photometric scale in the period 1966–2002 is stable,

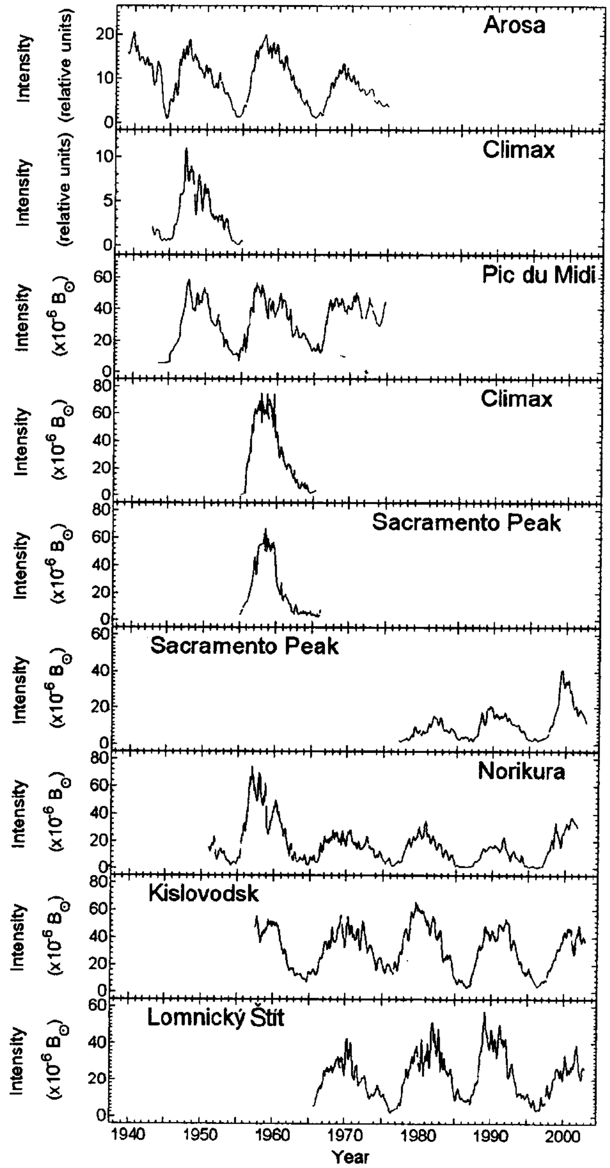

Figure 2. The 81-day running averages of the green coronal line intensities for different coronal stations, showing differences in absolute values and trends attributable to various factors discussed in the text.

and, on the opposite hand, it suggests a problem with the pre-1966 CI values.

3. HDS and CI Reconstruction Before 1966

[20] Given the results in Figure 3, it is clear that the current HDS, on which CI is based, needs to be modified for years before 1966. The current pre-1966 HDS uses data from Pic du Midi and Arosa as reference stations, with their data adjusted to the Lomnický Štít photometric scale. The basic questions in this reanalysis are as follows: (1) How to select observational days from the data sets for the individual coronal stations? (2) Which subset of coronal stations (Pic du Midi, Arosa, Sacramento Peak, Climax, Norikura, Wendelstein, Kanzelhöhe, Kislovodsk) should be used as reference stations during the pre-1966 period? (3) How to transform the photometric reference scale(s) of the new reference station(s) to the Lomnický Štít scale? These steps are required to create a reconstructed homogeneous coronal data set over the entire 1939–2002 period, and to recompute the pre-1966 CI. Our procedure is given below.

Table 1. Relations Between Monthly Averages of CI and R, RF, and CR[a]

Relation	Period	CC
CI(R) = 3.64 + 0.0548 × R	1939–2002	r = 0.729
= 3.31 + 0.0611 × R	1953–2002	r = 0.782
CI (RF) = −0.219 + 0.00603 × RF	1947–2002	r = 0.754
= −0.766 + 0.00667 × RF	1953–2002	r = 0.796
CI (CR) = 59.6 − 0.0131 × CR	1953–2002	r = 0.813

[a]Correlation coefficients (CC) are shown in the last column.

3.1. Data Selection

[21] In this study, we considered all available coronal green line data (the 530.3 nm emission line corresponds to a coronal temperature of ~2 million K) from the various observatories that have made such measurements over the years as published in the Quarterly Bulletin of Solar Activity. However, we did not use any data from the Ulan Bator (Mongolia) and Alma Ata (Kazakhstan) which are generally regarded as to be of low accuracy. To assist in the decision about which data (coronal intensities) to consider from the remaining coronal stations, we created an auxiliary parameter AI for each observational day for each station. AI is the daily intensity averaged over all 72 positional angles. We eliminated observational days which exhibited large day-to-day jumps (~50% or more) in AI values or for which only partial data (e.g., covering only half of the positional angles) were available.

[22] After removing low quality data days, the basic green line data sets having intensities in absolute coronal

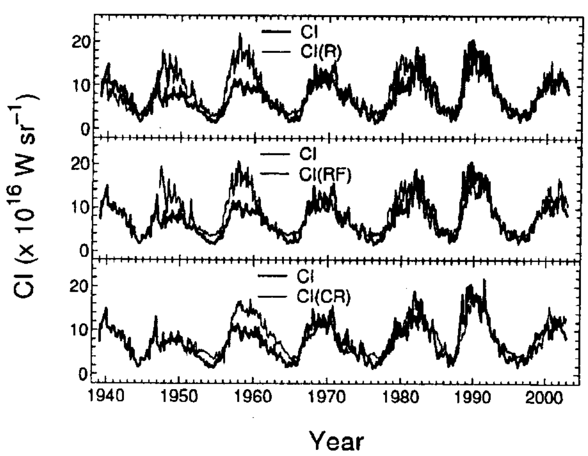

Figure 3. Monthly averages of CI from 1939 to 2002 (heavy lines in each of the panels) compared with proxy CIs calculated from the relationships given in Table 1 (thin lines in each of the panels).

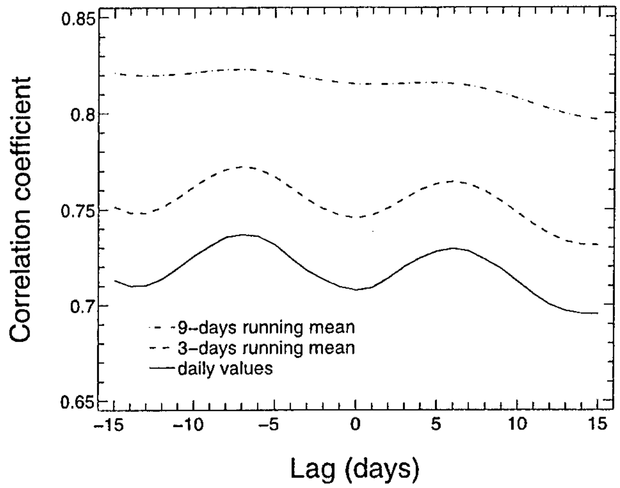

Figure 4. Correlation coefficients for cross-correlations between AI and R for a range of lag times (9-days running mean is shown by the upper curve, 3-days running mean is shown by the middle curve; and 1 day running mean is shown by the lowest curve).

units that were used to reconstruct the 1939–1965 HDS and recomputed the CI since 1965 were as follows:

[23] 1. Pic du Midi (PdM), 1943–1974; we used only 2992 selected days (from 3493 total observational days). PdM changed its method of photometry twice during this 30-year interval [*Leroy and Trellis*, 1974]. A calibration problem at PdM involving an east-west asymmetry (higher west limb intensities, not confirmed by other stations) was discussed by *Pajdušáková* [1966].

[24] 2. Norikura (NO), 1951–1965; only 1052 (of 1540) observational days are used in this period. Later data (post-1965), as shown by *Sakurai et al.* [1999], were not as stable in absolute units, and data from this period were used less frequently (~42% of 2864 observational days).

[25] 3. Kislovodsk (KI), 1957–2002; 4788 (of 5273) observational days.

[26] 4. Climax (CX), 1955–1965; 1427 (of 1930) days.

[27] 5. Sacramento Peak (SP), 1958–1966; 913 (of 1218) days.

[28] Relative (noncalibrated) data were taken from following coronal stations: (1) Arosa (AR), 1939–1974; 2023 (of 2340) observational days, (2) Climax (CX), 1947–1954; 1371 (of 1852) observational days. (3) Wendelstein (WE), 1947–1978; 1200 (of 1467) observational days. (4) Kanzelhőhe (KH), 1947–1963; 634 (of 812) observational days. The relatively low number of observational days at each station for the intervals considered primarily reflects the rarity of sky conditions suitable for coronal observations.

3.2. Selection of Reference Stations for the Pre-1966 Epoch

[29] In Figure 4, we have plotted the correlation coefficients for cross-correlations between sunspot number R and AI computed from the old HDS for 1966–2002 for all 13,514 days for a range of lead/lag times and three different data averaging intervals (9 days, 3 days, and 1 day). The relation between these two parameters is: AI(R) = 0.2R + 8 with the correlation coefficient 0.737 when the daily AI is compared with R for 7 days later. Using this relation, we can obtain an average AI(R) from sunspot number alone.

[30] A comparison of AI values for Kislovodsk, Norikura, and Pic du Midi along with AI(R) for 1939–1966 is shown in Figure 5. The main criterion for a choice of reference station for the pre-1966 epoch is a good correlation with AI(R). Thus on the basis of the data in Figure 5, we selected the following reference stations for the pre-1966 period: Kislovodsk: 1960–1965, Pic du Midi: 1955–1959, Norikura: 1951–1954.

[31] For 1939–1950, data from Pic du Midi, Climax, Arosa, Wendelstein, and Kanzelhöhe were converted to the Norikura photometric scale using correlations from common observational days between Norikura and Pic du Midi in 1951–1954. Rescaled Pic du Midi data then were used as reference data in the period 1943–1950. Arosa data were transformed to the Pic du Midi rescaled photometric scale in the period 1939–1942.

3.3. Putting the Pre-1966 Data on the Lomnický Štít Photometric Scale

[32] Different coronal intensities from individual coronal stations cannot be used directly to reconstruct the HDS and compute the CI [see *Rybanský*, 1975] but first must be transformed to a single photometric scale. Based on the results of Figure 3, we use, as was done previously [*Rybanský et al.*, 1994], the Lomnický Štít photometric scale for years after 1965 to recompute CI. For earlier years, we used the photometric scales of the reference stations listed in section 3.2.

[33] A further comment on the photometric rescaling process is in order. As a refinement on our process, we took one additional step before rescaling the data. It is very easily recognized (see Figure 6) that coronal intensities between individual coronal stations differ not only in their intensities, but in the position of maximum intensity as well

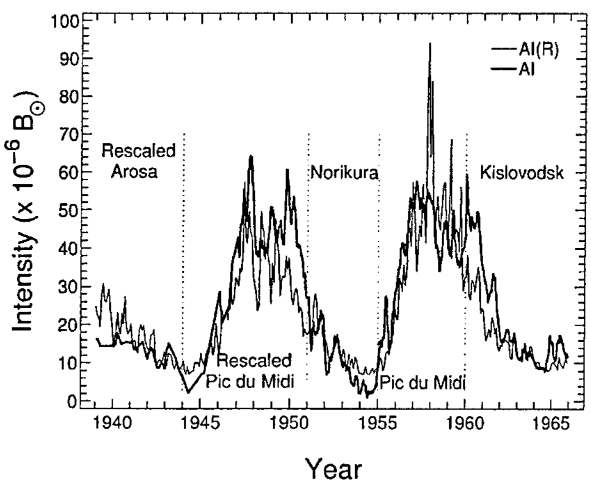

Figure 5. The 81-day running averages (heavy lines) of AI for Kislovodsk (1960–1965); Pic du Midi (1955–1959); Norikura (1951–1954), rescaled Pic du Midi (1944–1950), rescaled Arosa (1939–1943) and AI(R) for the entire period is in the thin line. See text for details.

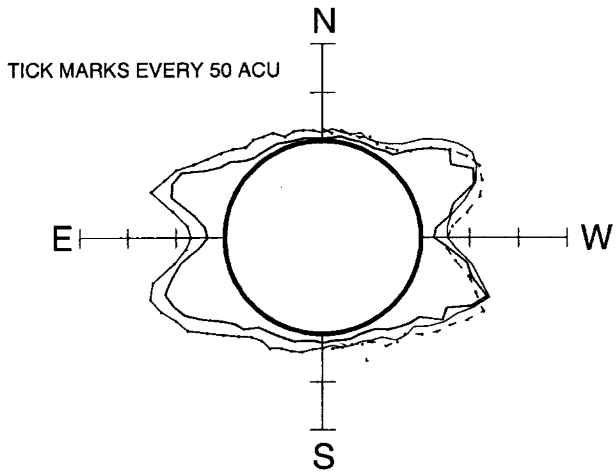

Figure 6. Distribution of the green coronal intensities for common observational days from LS (heavy line) and KI (dotted line before the shift, thin line after the 10 degree shift).

that can differ for E- and W- limbs [e.g., *Gnevyshev*, 1963; *Sýkora*, 1971; *Rybanský*, 1975]. Thus we correlated the shapes of the corona for common observational days for one-year periods (because the angular shifts may vary over time) to determine if the data from other stations needed to be rotated to conform to Lomnický Štít (or other reference station for pre-1966 periods) observations.

3.4. An Example of the Photometric Rescaling Process

3.4.1. Deciding Which Station to Use

[34] For days when data are not available from the reference station, it is necessary to decide which station to use to fill in the gap, assuming data from more than one stations are available. The choice is based on the best correlation between reference and other stations (if several stations have observations for the some day) for common observational days over short (~1 year) intervals including the day of interest. If, however, only data from one station are available, these data are used.

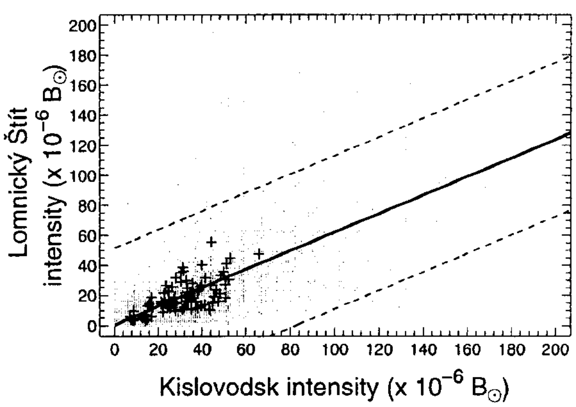

Figure 7. Comparison of green line coronal intensities between Lomnický Štít (y axis) and Kislovodsk (x axis) for the period 1966–1974. Dots indicate individual intensities for each positional angle for common observational days; crosses represent averaged intensities (AI) from common observational days. The thick regression line is based on a weighted LSQ and the dashed lines represent 99% confidence levels.

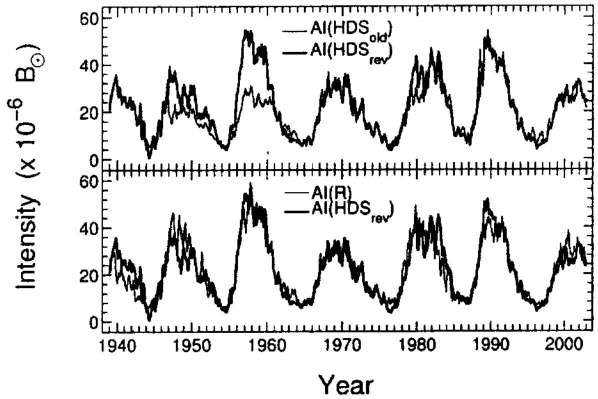

Figure 8. Plot of 81-day running averages of AI as derived from former HDS_{old} is shown by the thin line (upper panel), revised HDS_{rev} is shown by the thick line (both panels) and AI(R) as derived from sunspot number is shown by the thin line (bottom panel).

3.4.2. Angular Adjustment

[35] The averages from common observational days at each positional angle for the reference and adopted stations are the basis for the shift in the positional angle. Usually, a polar diagram (Figure 6) is prepared, and the data for the adopted station are rotated until maxima agree with that of the reference station (using interpolation as needed).

3.4.3. Intensity Scaling

[36] The method for rescaling the intensity from the chosen station to the reference photometric station is illustrated in Figure 7. The symbols used in Figure 7 are interpreted as follows: small dots, all measured intensities of the green corona for common observational days and in all positional angles in 1966–1974; crosses, averaged intensities (AI) from common observational days for chosen coronal station.

[37] To prepare a conversion relation, indicated by the heavy line in Figure 7, we used a simple weighted least squares (LSQ) straight line prepared from the dots, where the weight of individual dots is dependent on the perpendicular distance from a LSQ straight line (not shown) derived from the crosses.

[38] For example, the conversion relation (derived from 6048 points - 84 common observational days for 1966–1974) between LS and KI is

$$LS = 0.62\ KI + 0.28 \quad (4)$$

There were 557 LS and 956 KI observational days during this 9 year interval and a total of 147 common observational days. However, KI observations were complete (72 values) for only 84 of the common days. This process was done for all reference coronal stations for which coronal intensities were transformed from other stations.

[39] We believe that above method can be used to accurately convert coronal intensities from the worldwide net-

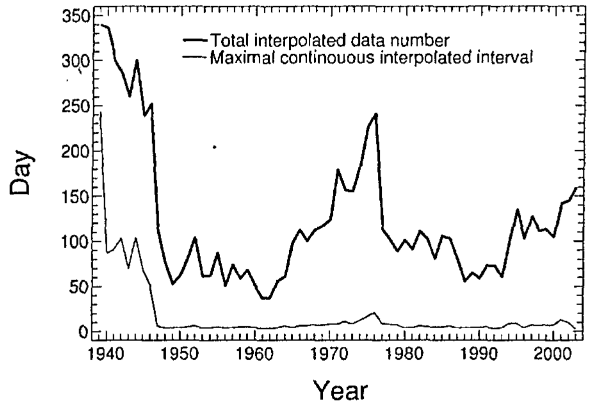

Figure 9. The total number of interpolated days (thick line) and maximum continuous interpolated interval (thin line) in individual years. There are no observational data in interpolated periods.

work of coronal stations to the Lomnický Štít photometric scale, and that the resulting homogeneous coronal data set and the CI values computed from it are now correct. A plot of 81-day running averages of AI as derived from the daily old HDS means, the daily revised HDS means, and AI(R) are shown in Figure 8.

3.5. Filling in the Data Gaps

3.5.1. Additional Data for the Post-1965 Epoch

[40] To make the HDS as complete as possible, we have added additional data sets since the initial work by *Rybanský et al.* [1994]. The new data sets include recent data from Kislovodsk (1966–2002), Norikura (1966–2001) (T. Sakurai, private communication, 2002); and Sacramento Peak (1974–2002; Solar Geophysical Data, Prompt Reports). These data are folded into the HDS using the photometric rescaling process described in sections 3.3 and 3.4. The additional data reduced the number and length of intervals with no data which were previously filled by interpolation. In addition, using more coronal stations enabled us to easily recognize and eliminate unreliable data.

3.5.2. Interpolation Across Data Gaps

[41] There are 23,376 days in the interval from 1 January 1939 and 31 December 2002. The total number of days with useful green coronal data used to create the original HDS was 14,824 (63% of 23,376) versus 15,506 (66%) in the revised HDS. There are 20,454 days in the period 1947–2002, and 14,898 (73%) observational days were used in the revised HDS. Coronal intensities for missing days were filled with a linear interpolation based on the last and first day of observations around the interpolated period (missing day or days).

[42] The total number of interpolated days (thick line) and the maximum interval in days of continuously interpolated data (thin line) in individual years are shown in Figure 9. After 1947 the median number of interpolated days per year is ~100 and the longest continuous interpolated interval is 21 days. Interpolated intensities for missing days are indicated by using a "0" for the coronal station code in the HDS.

3.6. Recomputed Coronal Index

[43] With the updated HDS, we recomputed CI for the 1939–2002 interval. The recomputed CI (CI_{rev}) is shown in

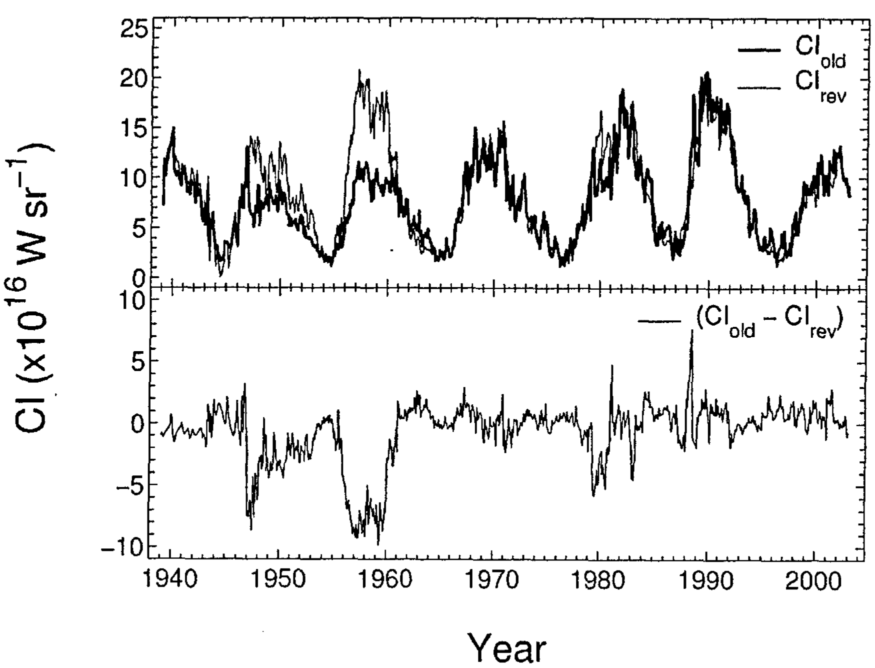

Figure 10. Plot of CI monthly means (old and revised) for 1939–2002 (top). Difference between CI_{old} and CI_{rev} (bottom).

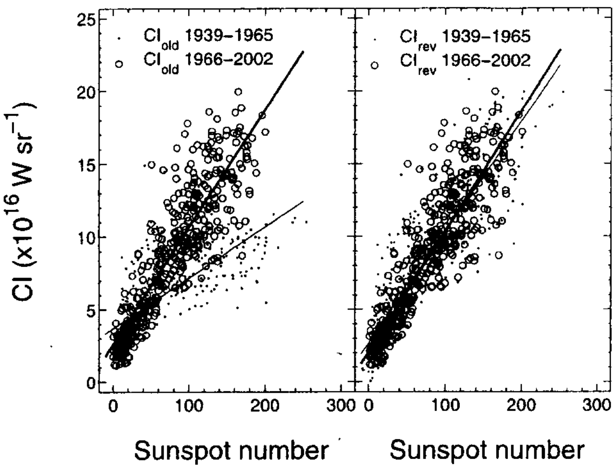

Figure 11. Correlation between CI and the sunspot number. (left) Correlation between the CI_{old} and the sunspot number for 1939–1965 (dots and thin line); circles and heavy line for 1966–2002. (right) The same for CI_{rev} and the sunspot number.

Figure 10 along with the old CI (CI_{old}). In addition to removing the pre-1966 discrepancies with the sunspot number (Figure 3), we see that incorporation of the new data also results in improvement in the post-1965 period, particularly for the 1979–1983 interval. CI_{old} (left) and CI_{rev} (right) values are plotted against sunspot number for periods before and after 1965 in Figure 11.

[44] The relation between the revised CI and the sunspot number (for 81-day means) is

$$CI = 0.0837\ R + 2.04 \tag{5}$$

with a correlation coefficient of 0.914 in the period 1939–2002, which compares with a correlation coefficient of 0.729 for a correlation of the sunspot number and the old CI. Using the relation in equation (5), the CI can be extended to 1848 as shown in Figure 12. Note that because the sunspot number returns to near zero values at each sunspot minimum that the reconstructed CI has a nearly constant floor at ~2.04. The relation between the revised CI and the 2800 MHz radio flux (for 81-day means) is

$$CI = 0.00874\ RF - 3.06 \tag{6}$$

with a correlation coefficient 0.924 (slightly higher than for the sunspot number) in the period 1947–2002.

4. Results and Discussion

[45] This study was motivated by the fact that the previously computed coronal index (CI) of solar activity [*Rybanský et al.*, 1994] did not agree well with the 2800 MHz radio flux, the cosmic rays and the sunspot number for years before 1966. This runs counter to the recent finding by *Rušin and Rybanský* [2002] that the green line intensity and photospheric magnetic field strength were highly correlated from 1976 to 1999. To adjust the homogeneous coronal data set on which CI is based, we used

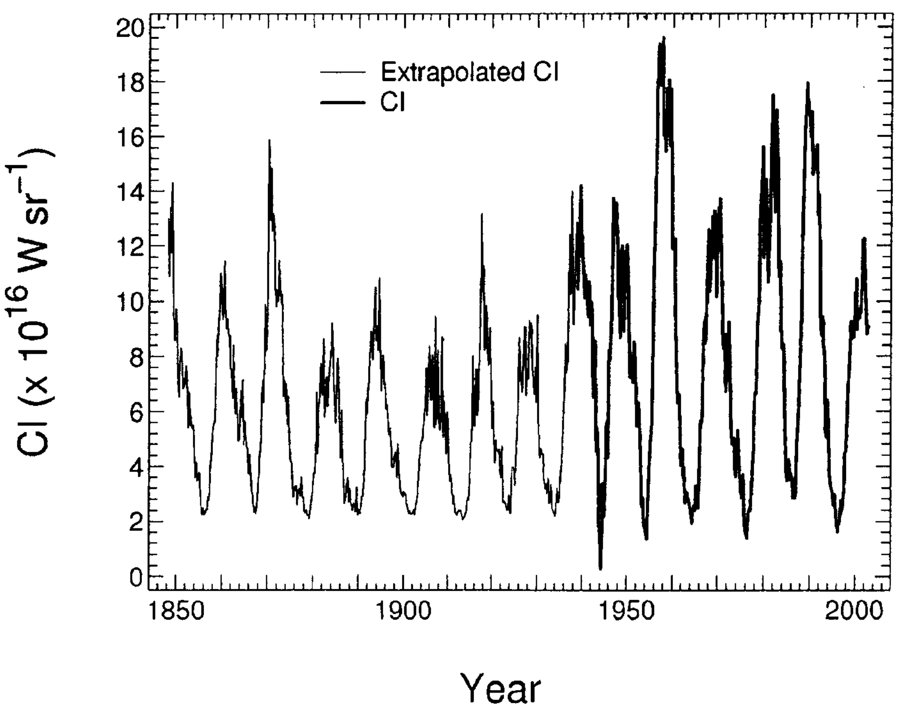

Figure 12. Monthly averages of CI (1848–2002). Heavy line shows CI_{rev} (1939–2002) and thin line shows CI extrapolated from the sunspot number (1848–1938).

correlations between coronal intensities and the sunspot number to identify suitable reference stations (yielding better agreement between computed CI and sunspot number) for years before 1966. We retract our previous statement [*Rušin et al.*, 2004], based on the former CI data, that the CI (at solar maximum) rose steadily between 1947 and 1996. Nevertheless, like the sunspot number, CI can vary from cycle to cycle by ~30 percent with irregular trends for longer periods, e.g., the increase in the period 1965–1996 (cycles 20, 21, and 22). The revised and extended CI has applications for correlative studies such as those of *Mavromichalaki et al.* [2002, 2003].

[46] Our decision to modify the pre-1966 HDS (and CI as a result) is based on practical experience with the observations and awareness of the various causes of discrepancies between stations and the recognition that the modern (post-1965) data at Lomnický Štít tracks the standard measures of photospheric activity (sunspot number and 10-cm radio flux) and also the inverted cosmic ray modulation curve quite well. This leads us to believe that the modern measurements at Lomnický Štít more accurately reflect the Sun's behavior, and we have normalized the earlier observations accordingly. Coronal intensities from worldwide stations used in this analysis are available at http://www.ta3.sk/data/corona/index and http://www.noaa.edu/corona, as are the reconstructed HDS (1939–2002) and the CI series derived from it.

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14. ABSTRACT
[1] The coronal index (CI) of solar activity is the irradiance of the Sun as a star in the coronal green line (Fe XIV, 530.3 nm or 5303 Å). It is derived from ground-based observations of the green corona made by the network of coronal stations (currently Kislovodsk, Lomnický Štít, Norikura, and Sacramento Peak). The CI was introduced by Rybanský (1975) to facilitate comparison of ground-based green line measurements with satellite-based extreme ultraviolet and soft X-ray observations. The CI since 1965 is based on the Lomnický Štít photometric scale; the CI was extended to earlier years by Rybanský et al. (1994) based on cross-calibrations of Lomnický Štít data with measurements made at Pic du Midi and Arosa. The resultant 1939–1992 CI had the interesting property that its value at the peak of the 11-year cycle increased more or less monotonically from cycle 18 through cycle 22 even though the peak sunspot number of cycle 20 exhibited a significant local minimum between that of cycles 19 and 21.

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