ON THE LONG-TERM VARIABILITY OF THE GREEN CORONA ACCORDINGLY TO FOUR EXISTING DATABASES

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We examine four long-term databases of monthly means of the whole disc green coronal brightness which cover the period of the last five and a half solar cycles to verify them, and compare their usefulness, as indices characterize the solar activity. We use the data from (1) the Norikura Observatory, (2) the Kislovodsk Observatory, (3) intensities detected by several coronographs and converted to the common photometric scale of Pic du Midi, (4) coronal indices obtained from detections of several observatories and converted to the photometric scale of Lomnicky Stit. We compare them by means of correlative analysis with the time series of sunspot numbers. The data (2) demonstrate the best agreement with sunspot number as the reference ($r = 0.88$).

INTRODUCTION

The solar corona is the source of solar wind. Therefore, it is responsible for various processes and disturbances in the interplanetary space, geomagnetic field, and Earth's atmosphere. The green coronal line (Fe XIV, 530.3 nm line) (GCL) observed during the last five and a half solar cycles would be a good indicator of coronal and solar activity. However, there are considerable discrepancies between the observational long-term databases of this coronal line detected at different observatories. Unfortunately, there are only a few coronal stations that provide results of systematic patrol registrations of the green and red coronal brightness. The systematic observations of the green and red coronal lines have been performed since 1947 (sporadically since 1939) at a number of coronal stations. During the 1960s and 1970s several registrations have been closed. At present, only four coronal stations observe the green corona regularly: Norikura (NO), Kislovodsk (KI), Lomnicky Stit (LS), and Sacramento Peak (SP), as it is seen from Table 1 where the stations and their abbreviations used in this paper are enumerated. Two last stations do not observe corona regularly. Data of these observatories were published in 1947–1976 in the Quarterly Bulletin on Solar Activity printed at Zurich (QBSA) edited by M. Waldmeier, later transferred to Japan [3]. The Sacramento Peak Observatory after the break from 1966 to 1973 begun registration again, and the data were published in graphical form in QBSA, Solar Geophysical Data, and they can be obtained on-line on the Web site of this Observatory [5].

The time series of GCL contain the daily intensities of GCL measured around the Sun in steps of 5° of the position latitudinal angle, beginning at the north solar pole (0 degrees) and proceeding through east, 270 degrees and west, following the program introduced by d'Azambuja [1]. Thus, one set of these data consists of 72 values. After the observation the collected data are averaged for each day at the central meridian. Subsequently, these data are averaged monthly or by Bartels rotations.

The time coverage of GCL brightness at single observatory is poor, mainly owing to weather conditions (on the average only 50 to 100 days per year, sometimes more). The number of missing whole months in sets of observations could be treated as index of quality of the station's work. The list is shown in Table 2. The equipment in different coronal observatories and method of measurements of coronal intensities have not been identical. Photographic and photoelectric methods used were different in details. As pointed out by Storini and Sykora [15], heights above solar limb where coronal intensities were recorded, have differed from 40 to 60 seconds of arc ($40'$ corresponds to 0.04 solar radii). At SP since 1973 the height is about 140 seconds of arc (0.15 solar radii) and the GCL intensities are scanned at every 3 degrees of latitude. Rybansky *et al.* [13] remarked: *both the method of observations and photometry have never been the same at all stations.* We can

Table 1. The list of coronal observatories

Observatory	Abbrev.	Country	Altitude m	Geog. Long.	Geog. Lat.	Aperture cm	Const-ruction	Operating period
Pic du Midi	PM	France	2860	0° 09′ E	42°56′ N	20, 15	1930	1947–1974
Arosa	AR	Switzerland	2050	9° 40′ E	46°47′ N	20, 12	1938	1947–1975
Wendelstein	WE	Germany	1837	12° 01′ E	47°42′ N	20	1941	1947–1979
Kanzelhohe	KH	Austria	1526	13° 54′ E	46°40′ N	11	1943	1948–1964
Climax	CL	USA	3394	106° 12′ W	39°23′ N	40, 13	1940	1947–1957
Norikura	NO	Japan	2876	137° 33′ E	36°07′ N	25, 10×2	1949	1951–present
Sacramento Peak	SP	USA	2840	105° 49′ W	32°47′ N	40, 20	1951	1953–1966
Kislovodsk	KI	Russia	2050	42° 31′ E	43°44′ N	53, 20	1957	1957–present
Alma Ata	AT	Kazakhstan	3001	76° 57′ E	43°11′ N	53, 20	1958	1957–1962 1973–1991
Lomnicky Stit	LS	Slovakia	2632	20° 13′ E	49°12′ N	20, ×2	1964	1966–present
Ulan Bator	UB	Mongolia	1600	107° 03′ E	47°50′ N	20	1970	1971–1973
Mauna Loa	ML	USA	3400	155° 36′ W	19°28′ N	24	1965	1966–present
Haleakala	HA	USA	3050	156° 26′ W	20°71′ N	25, 10	1967	1967–present

Table 2. Percentage of missing whole observational months at observatories during operating period

Observatory	Abbrev.	Percent	Observatory	Abbrev.	Percent
Pic du Midi	PM	3	Norikura	NO	3.3
Arosa	AR	34.8	Sacramento Peak	SP	0.6
Wendelstein	WE	8.9	Kislovodsk	KI	0.7
Kanzelhohe	KH	8.5	Alma Ata	AT	21.2
Climax	CL	0	Lomnicky Stit	LS	4.5
Ulan Bator	UB	25			

add that during years, methods were changed at the same stations as well. At Pik du Midi (PM) it happened two times between 1943–1975 [8], at LS a new method of measurements was introduced in 1971 [17]. At NO the photometry acquirement was changed two times, in 1981 and in 1997 [14]. Another question is referred to the staff of the station. Accordingly to [9], the most stable staff who had been working with registration of GCL had appeared to be at the KI Observatory. At the NO Station during 48 years more than 40 persons had contributed to the observations, since foundation of the Station. They had been using the direct-vision spectroscope [14].

Differences and discrepancies between registrations of GCL at different stations were raised for more detailed discussion at Venus 2000 Tranzit Conference at Tabriz [6].

THE SEARCH FOR THE MOST HOMOGENEOUS DATA OF GCL INTENSITIES

There are some methods to complete data in order to construct a long-term set of GCL intensities. The data from selected station should be re-scaled and completed by the results of registration of other stations. They are based on the assumption that the time series from different observatories are linearly dependent. There is no place here for the detailed description and discussion, therefore we refer the reader to the bibliography [2, 11, 16, 19, 20]. As a result of such sewing up, the different data and compilations four data sets were obtained (here we do not consider the complete data set from Sacramento Peak). There is no completely independent long-time series of data between them. They were artificially, a posteriori improved by their own authors. Here we consider:

(1) NO re-scaled data obtained from preliminary registration by using (3) series as a reference [14]. During the periods 1950–1954 and 1963.5–1997 whole time series was simply multiplied by a factor of 2, between them more complicated formula for re-scaling factor was used.
(2) KI data in which intensities from other stations had been taken to fill gaps [9].
(3) intensities detected with several coronographs and converted to the common photometric scale of PM by [7, 18, 19], signed here as IN.
(4) intensities from several observatories converted to the photometric scale of LS and published as coronal index CI ([12] and references therein).

In (3), database measurements at the PM Observatory have been used to cover the period 1943–1973, when the registration was closed, later intensities from the KI Observatory and other stations were chosen and converted to the photometrical scale of PM. In (4), data from several coronal stations has been taken and converted to LS scale, but this Station was opened only in 1966. So, the results of procedure used in (3) after 1974 and in (4) before 1966 would give not the best quality of the data. The amplitudes of the cycles maxima of (4) show a steady increase since 1940. This is unlike the behaviour of other solar indices. Therefore, this group [10] decided to rescale their set before 1965, using a linear correlation formula with sunspot number. In the present paper we use an earlier set of CI. In (1), (2), and (3) GCL intensities are expressed in absolute coronal units, *i.e.*, millionths of energy radiated from the centre of the Sun's disc in 0.1 nm strip of the spectrum near the corona emission line. Data (4) are in the form of CI, which was derived from coronal intensities and expressed in the units of 10^{16} W/sr. Every set of data used here is the monthly means.

DATA ANALYSIS AND CONCLUSION

An important question arises as to which set could be recommended for further use for investigators who study the effects caused by coronal activity in the time scale of years. Assuming that the coronal and solar activity in such time scale is caused by the same reason, we use Zurich sunspot number (SN) from [4] as a reference data and compare them to time series of the monthly means of the full disc coronal brightness detected at Norikura (rescaled data) [3]: Jan. 1951 – Jan. 1997, Kislovodsk [9]: Jan. 1951 – Jan. 1997, IN [7, 18, 19]: Jan. 1943 – Nov. 1993, CI [12]: Jan. 1943 – Dec. 1998. These data sets are presented in Figs. 1 and 2. In Fig. 3 the time variations of smoothed by 13-month moving average coronal intensities in a.c.u. and coronal index in 10^{16} W/sr are shown during the whole studies period. In these pictures the amplitudes of 11-years variation of the brightness of the green corona ($\triangle I/I$, where I is the intensity) not proportional to the amplitude of sunspot number from cycle to cycle could be seen. Therefore, a rescaling of data set by means of the sunspot number set seems to give inaccurate result. The linear rising trend of CI is visible. The reason of it is unknown. Generally, the times of minimum are the same for every time series, with the exception during minimum between the 19th and 20th cycles when they differ. At this period the IN data are overestimated and demonstrate one year to two years delay relatively to other indices. During the 22nd cycle data of NO are underestimated. There are discrepancies between coronal data during maximum phases of the 21st and 22nd cycles, 21st cycle maximum: CI delayed more than two years relatively to KI and IN data, maximum phase of the 22nd cycle: the effect is opposite.

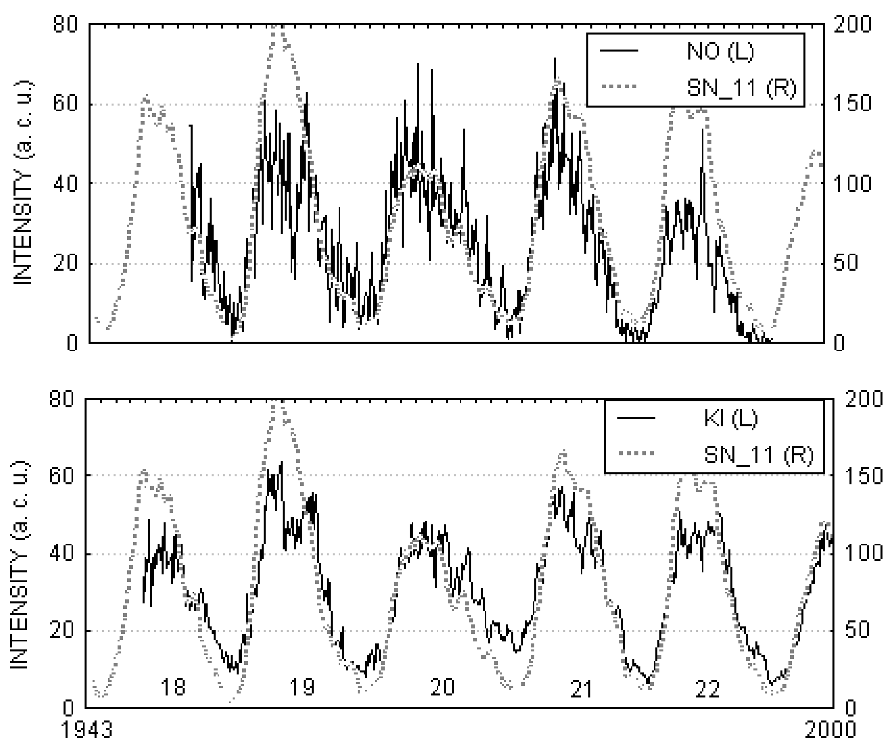


Figure 1. Monthly means of coronal data sets NO and KI versus 11 months moving average of sunspot number. The right scale is graduated, thereby the SN data would fit well the coronal sets in the 20th solar cycle

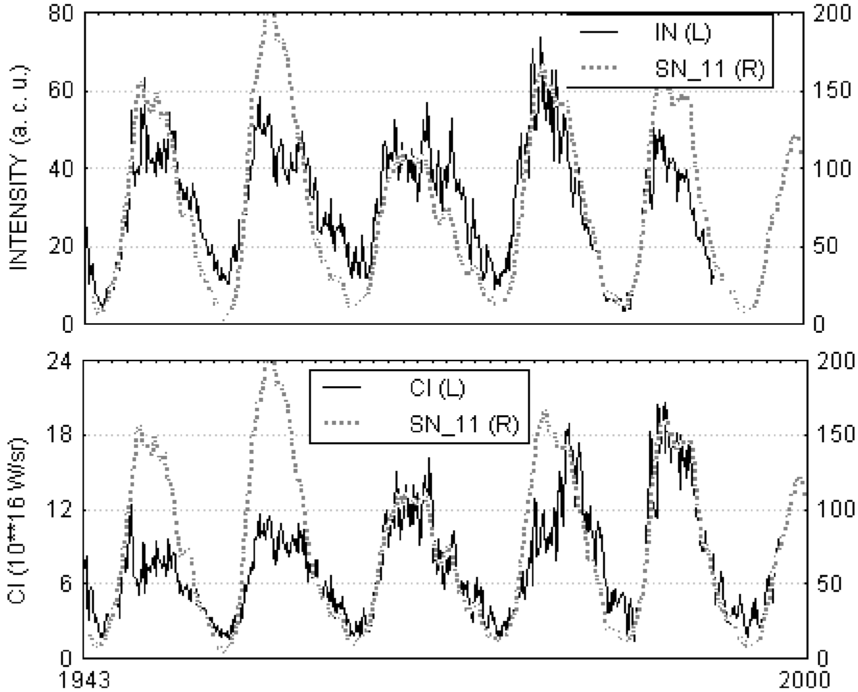


Figure 2. Monthly means of coronal data sets IN and CI versus 11 months moving average of sunspot number. The right scale is graduated, thereby the SN data would fit well the coronal sets in the 20th solar cycle

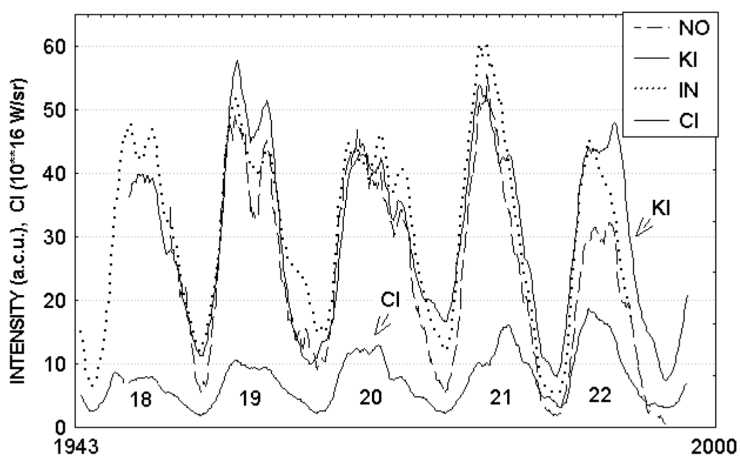
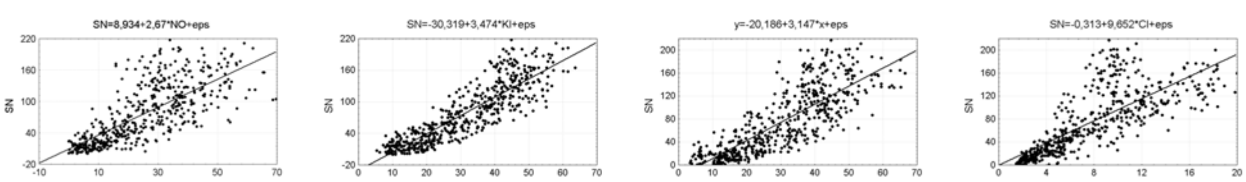


Figure 3. 13 months moving averages of coronal data sets NO, KI, IN, CI



a) Norikura b) Kislovodsk c) IN by Sykora *et al.* [19] d) coronal index

Figure 4. Scatter plots of the monthly mean sunspot numbers and the monthly mean green corona intensities in a.c.u. (NO, KI, IN), and the coronal index CI in the units of 10^{16} W/sr for whole time periods under investigation. Parameters of linear least-squares fit (constant and slope) of performed regression analysis are also shown for every case

Table 3. Pearson correlation coefficients (r) between monthly means of sunspot numbers and coronal data sets

Data set	NO	KI	IN	CI
SN	0.742 ± 0.021	0.881 ± 0.009	0.804 ± 0.015	0.763 ± 0.014

The variability of the data can be compared by correlative and regression analysis. The Pearson correlation coefficients between monthly coronal data sets and sunspot numbers are presented in Table 3. All coefficients have the significance level $p < 0.01$. As it is seen from the Table 3 and from the scatter plots in Fig. 4, the best correlation for the full periods of data availability was obtained for the KI data sets. Other data give worse results. NO data are characterized by larger variability than other. The KI changes are in the best agreement with sunspot number SN (coefficient equals 0.88). In conclusion we should say that a comparison with other solar indices is needed and will be considered in the further paper.

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