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The green corona data: 1947-1976, revisited(*)

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Summary. — Re-examining a continuous monthly data set for the green-line corona brightness, covering February 1947 to September 1976, we have found that practically no delay exists between the trends of the green-line coronal intensity in the equatorial and middle-latitude belts at the beginning of solar activity cycle No. 20, while a previous cycle (No. 19) shows a sudden increase in the corona intensity brightness at middle latitudes followed by a delayed one at the equatorial belts, supporting recent findings on even-odd solar cycle differences observed in the half-yearly green corona database (1943-1993). The north-south asymmetry in the hemispheric solar activity is not involved in this phenomenon.

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1. – Introduction

Patrol coronagraphic measurements, regularly carried out by the world-wide network of solar observatories, are used to obtain a reliable data set of the green-line coronal (briefly: GLC, *i.e.* FeXIV 530.3 nm) emission on a six-monthly basis, over the 1943-1993 years [1, 2]. Reasons for this work are explained in sects. **2** and **3**. A short survey of results obtained from this homogeneous data row can be found in recent papers [3, 4]. In particular, effects induced by the 22-year heliomagnetic cycle in the interplanetary medium are under evaluation. In this context, it is relevant to know the behaviour of the solar corona at the beginning of each 11-year cycle. We have found some differences analysing consecutive cycles [5,6]. During even cycles the GLC-rising phase starts in close coincidence in the equatorial (±0°–15°) and middle heliolatitudinal (±20°–40°) belts, while

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during odd cycles this is not true. However, this effect was derived from a six-monthly data base and with no evaluation of the hemispheric activity role.

The aim of this paper is to analyse a monthly GLC data set (unfortunately, available only for solar cycles 19 and 20) to confirm or refuse previous findings (sect. **4**).

2. – The green corona: historical background

Corona and prominences had been observed at least since the 19th century. They were admired during solar eclipses as interesting spectacles, but they were supposed to be of Moon's origin or a phenomenon in the Earth's atmosphere. Photographic technique was first employed during the 1851 eclipse and, somewhat later, the solar origin of prominences was definitely established by De la Rue and by Secchi (eclipse of 1860). Important discoveries began after Kirchhoff's achievements in spectroscopy. At the North American eclipse of 1869 both Harkness and Young discovered the green coronal emission (λ : 530.3 nm). This was the first and the most intense of the famous *coronium* emission lines, which, however, remained unidentified for over seventy years. In the following a brief "GLC observational history" is outlined.

The eclipse of 1871, and Janssen's observation of the Fraunhofer lines in the coronal spectrum, marks a new step in corona understanding: it was realized that at least part of the coronal emission was due to scattered sunlight and it was established beyond doubt the identity of the corona with the Sun. A wealth of information on the corona soon began to accumulate. Great improvements were made in the quality of the instruments and in the accuracy and quantity of the observations. However, following the earlier period, no radically new methods of observing the corona were developed until Lyot's invention of the coronagraph in 1930 [7, 8], with which he was able to make daily observations of the corona without an eclipse (high-altitude Pic du Midi Observatory, Pyrenees). Lyot's work with coronagraph (D = 20 cm, f = 400 cm), which resulted in the accurate wavelength measurements of the optical coronal lines and also in the discovery of two new very strong lines in the infrared part of the spectrum (1074.6 nm and 1079.8 nm), was an important factor in Edlén's solution [9] of one of the most puzzling mysteries in astrophysics—the problem of the identification of the coronal emission lines. Edlén demonstrated convincingly that 19 of the 23 known coronal lines could be identified with transitions from metastable levels of highly ionized iron, nickel, calcium, and argon (*e.g.* the GLC was identified with a forbidden transition in the ion Fe XIV: 530.286 nm).

The success of Lyot's work has stimulated the construction of other coronagraphs on the same pattern and the establishment of high-altitude observatories, where the intensity of the light scattered by the dust particles of the Earth's atmosphere is already substantially suppressed, not exceeding 10^{-4} of the solar disk brightness. First of all, in 1938 Waldmeier [10, 11] began systematic observations of the coronal lines at Mt. Arosa (Switzerland). The full set of his green-line Fe XIV 530.3 nm and red-line Fe X 637.4 nm measurements in the period 1939-1949 was published [12] in the form of "coronal contours". The personality of Waldmeier in coronal research is quite comparable with that of B. Lyot. An enormous number of Waldmeier's original results and achievements on the coronal structure, activity, large-scale behaviour and nomenclature of the coronal features were summarized by Van de Hulst (*e.g.* [13] for an overview) and Shklovskiy [14].

Shortly after the Second World War a world-wide network of coronal stations came into existence. The following observatories successively joined it (the time intervals indicate when data were published in numerical form [15], and the question mark uncertain information): *Pic du Midi* (France: $0°8.7'$W $42°56.2'$N, 2862 m a.s.l.; 1947-1974), *Arosa*

(Switzerland: 9°40.1′E 46°47.0′N, 2050 m; 1947-1975), *Climax* (U.S.A.: 106°12.0′W 39° 23.0′N, 3410 m; 1947-1957), *Wendelstein* (Germany: 12°0.8′E 47°42.5′N, 1837 m; 1947-1979), *Kanzelhoehe* (Austria: 13° 54.4 E 46°40.7′N, 1526 m; 1948-1964), *Norikura* (Japan: 137°33.3′E 36°6.8′N, 2876 m; 1951-till now), *Sacramento Peak* (U.S.A.: 105°49.2′W 32° 47.2′N, 2811 m; 1953-1966); *Kislovodsk* (Russia: 42°31.8′E 43°44.0′N, 2130 m; 1957-till now), *Alma Ata* (Kazakh Rep.: 76°57.4′E 43°11.3′N, 3001 m; 1957-1962 and 1973-1991?), *Lomnický Štít* (Slovak Rep.: 20°13.2′E 49°11.8′N, 2632 m; 1966-till now), *Ulan Bator* (Mongolia: 107°03.0′E 47°50.0′N, 1600 m; 1971-1973). Indeed, the data of *Pic du Midi* exist in a numerical form from 1943 on, and the *Sacramento Peak* Observatory re-established its observations in 1973 (data are now published in a graphical form and in synoptic charts [16]).

Through limited periods of time some other observatories, *e.g.*, *Crimea* (Ukraine), *Abisco* (Sweden), *Kodaikanal* (India) and *Arcetri* (Italy), have tried to realize or successfully realized coronal measurements, but no published data are available. Moreover, special corona measurements are made during solar eclipses at appropriate sites.

At present, there are only four observatories (*Sacramento Peak, Norikura, Kislovodsk and Lomnický Štít*), where the patrol measurements of solar coronal emission lines are regularly performed and their data published [15, 16]. Figure 1 gives a view of the high-altitude observatory of the Astronomical Institute of Slovakia (Slovak Academy of Sciences), located on Mt. Lomnický Štít, specialized to observe solar corona spectrally. The double solar coronagraph used to observe corona and prominences simultaneously is seen inside the cupola.

3. – The green corona: data for research work

The GLC intensities are usually measured with 5° steps around the Sun's disk (3° at Sacramento Peak), starting at the north pole through to the east, south, west and back to the north. Mostly the intensities are expressed in the so-called absolute coronal units (a.c.u.; *i.e.* in millionths of energy radiated from the centre of the Sun's disk in the 0.1 nm strip of the spectral continuum near the coronal emission line). Thus, to obtain the "coronal contour" (*e.g.*, fig. 2), characterizing some large-scale distribution of the coronal intensity around the whole solar disk, spectral measurements have to be made at 72 points. It took more than half an hour to record the photographic spectra at these points and almost a whole day to derive the final intensities by applying methods of classical photometry. That is why there were permanent efforts to develop and use some shortened procedures of obtaining the final data. Unfortunately, these uncoordinated efforts led to the fact that the methods of observation and measurement of coronal intensities were not identical at the various observatories (from fig. 2 we can evaluate the differences in the October 12, 1969 observational results published by five coronagraph stations). For example, visual, radial-slit photographic, circular-slit photographic and photoelectric methods of observation have been used. Furthermore, the heights above Sun's limb, at which the intensities were recorded, were not the same either. They varied from 40 to 60 seconds of arc (at *Sacramento Peak* it is about 140 seconds of arc, at present). Even the units to express the GLC intensity were not identical: absolute and arbitrary units have been used.

Unfortunately, for most of the studies of the large-scale and long-term behaviour of the solar corona brightness it is quite insufficient to use the data of a single observatory only. In fact, owing mainly to the weather conditions, the data sets generally cover only 50 to 200 days per year, and no comprehensive synoptic charts can be effectively constructed from them (*Sacramento Peak* Observatory is an exception confirming this rule). That is

Fig. 1. – Solar corona observatory of the Astronomical Institute of the Slovak Academy of Sciences (Mt. Lomnický Štít, 2632 m a.s.l.; inside the cupola the double solar coronagraph: $D = 20$ cm, $f = 400$ cm).

why, in the case of the large-scale and long-term analysis of the solar corona it is very useful (or even necessary) to utilize as much data as possible from all the observatories. At this moment, however, the very serious problem of the homogeneity of measurements performed at different observatories arises. There exist several systematic errors (differences) among the data of different observatories due to instrumental differences and due to different methods used to reduce the raw measurements. It has been found that, at least, the differences and instability of the photometric scales, systematic errors in the linearity of the position angle scales, errors in position of the zero points of those scales and different thresholds of measurements at different observatories should be taken into account and eliminated when all the accessible data are being compiled and treated together. Such an analysis of heterogeneity of the data was carried out and described [1, 17, 18].

We have considered all the results and experiences of previous analyses and a 51-year homogeneous row of green corona data was compiled. Since the longest, most homoge-

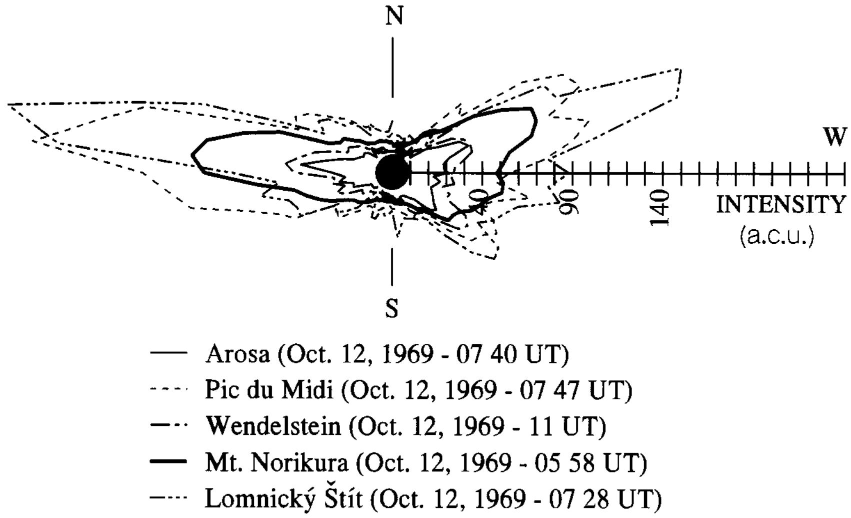

Fig. 2. – Example of the daily measurements of the green coronal brightness obtained at five measurement sites of the world-wide network of solar corona observatories.

neous and extensive set of the GLC data at the beginning of the seventies was that of *Pic du Midi*, we have decided to transform all the other data into the photometric scale of this observatory. In other words, in spite of the fact that *Pic du Midi* terminated its patrol observations of the green-line corona in 1974, we are still using its scale in our half-yearly GLC averages for the 1943-1993 period. Hence, results obtained from this set should be reliable ones and implications for Solar-Terrestrial Physics may be derived. However, our findings on the GLC behaviour at the beginning of the 11-year cycles must be checked on data with higher time resolution.

4. – Cyclic differences at the GLC-rising phase

The only continuous monthly data set for the green-line coronal brightness, available to the present time, has been published by Kulčár *et al.* [19] for the period February 1947 - September 1976. It is made by 339×25 data points, being determined by 5° heliographic-latitudinal steps from 60°N to 60°S. They are, indeed, the monthly version of the time-latitude distribution of the GLC brightness processed and tabulated by Sýkora [20] on Bartels rotation basis. Figure 3 shows the distribution of the GLC intensity according to the month and year for the middle-latitude belts (upper panels; left: 20°-40°N or N-Md, right: 20°-40°S or S-Md) together with the equatorial ones (lower panels; left: 0°-15°N or N-Eq, right: 0°-15°S or S-Eq). They are contour levels (by steps of 8 a.c.u.) derived from a 3-grid conversion of the original data set. From this figure the well-known large and long-lasting hemispheric anisotropy of cycles 18, 19 and 20 (particularly from the descending phase of cycle 19 to the ascending one of cycle 20) is emerging, being the northern hemisphere more active than the southern one [21, 22].

Is the north-south asymmetry at the origin of the phenomenon which is here investigated? The question arises because, recently, we found for the middle-latitude belt an alternate behaviour of the minimum GLC values similar to the one observed in sunspot

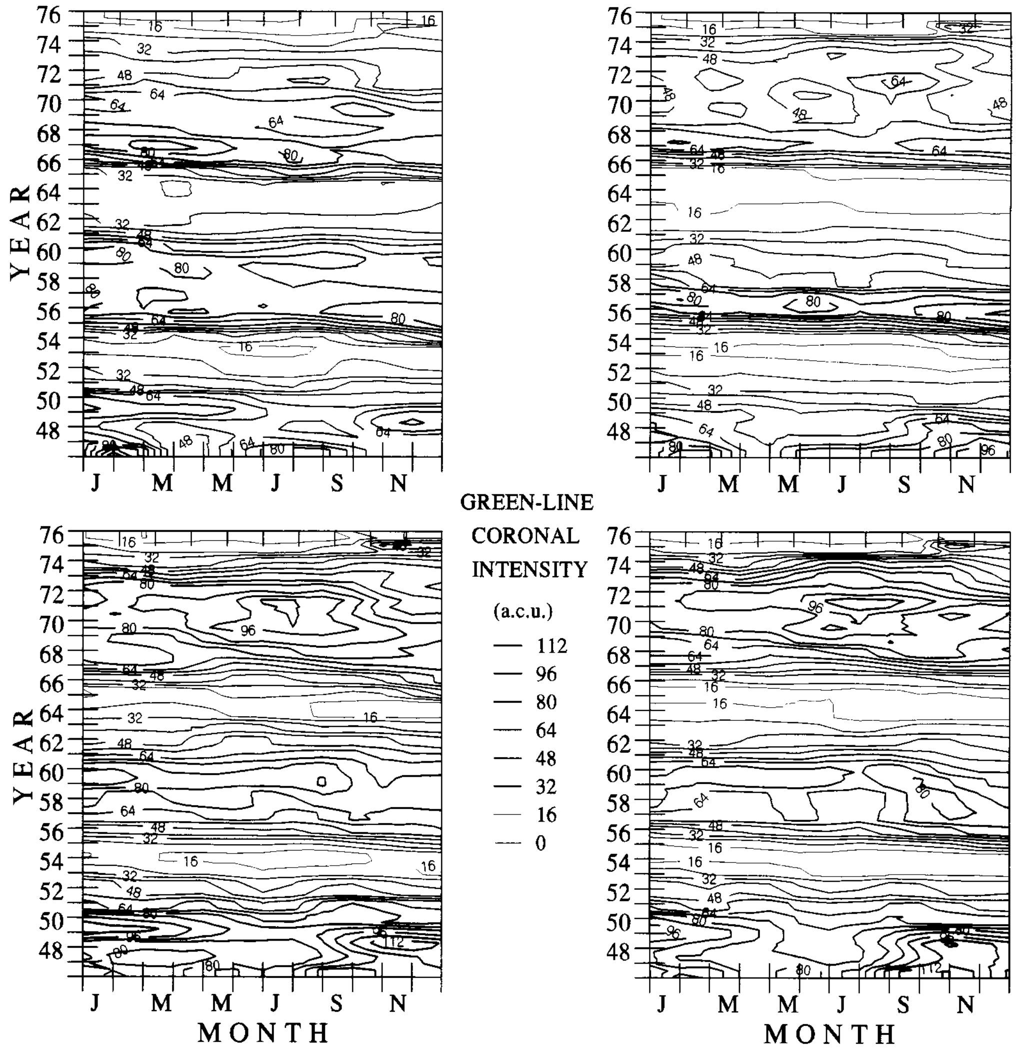

Fig. 3. – Monthly distribution for the GLC intensity in the middle (upper panel, left: 20°–40° N and right: 20°–40° S) and equatorial (lower panel, left: 0°–15° N and right: 0°–15° S) latitudinal belts, as derived from published data [19].

numbers: the peak value in each even cycle is lower than the corresponding one in the successive odd cycle, and the southern hemispheric activity is more involved in this trend [2]. The upper panel of fig. 4 (top: middle heliolatitudes; bottom: equatorial ones) gives the GLC long-term trend in the four belts considered. We notice that for each solar activity cycle, the beginning of the GLC-rising phase is contemporary in the northern and southern hemispheres if the same latitudinal belt is considered (see the reported arrows). Hence, no differences are found in the hemispheric activity, and the searched phenomenon could not be ascribed to the north-south asymmetry.

Figure 4 shows that the GLC cycles are in close coincidence in both the Eq- and Md-belts at the beginning of cycle No. 20, while in the previous one (No. 19) there is firstly

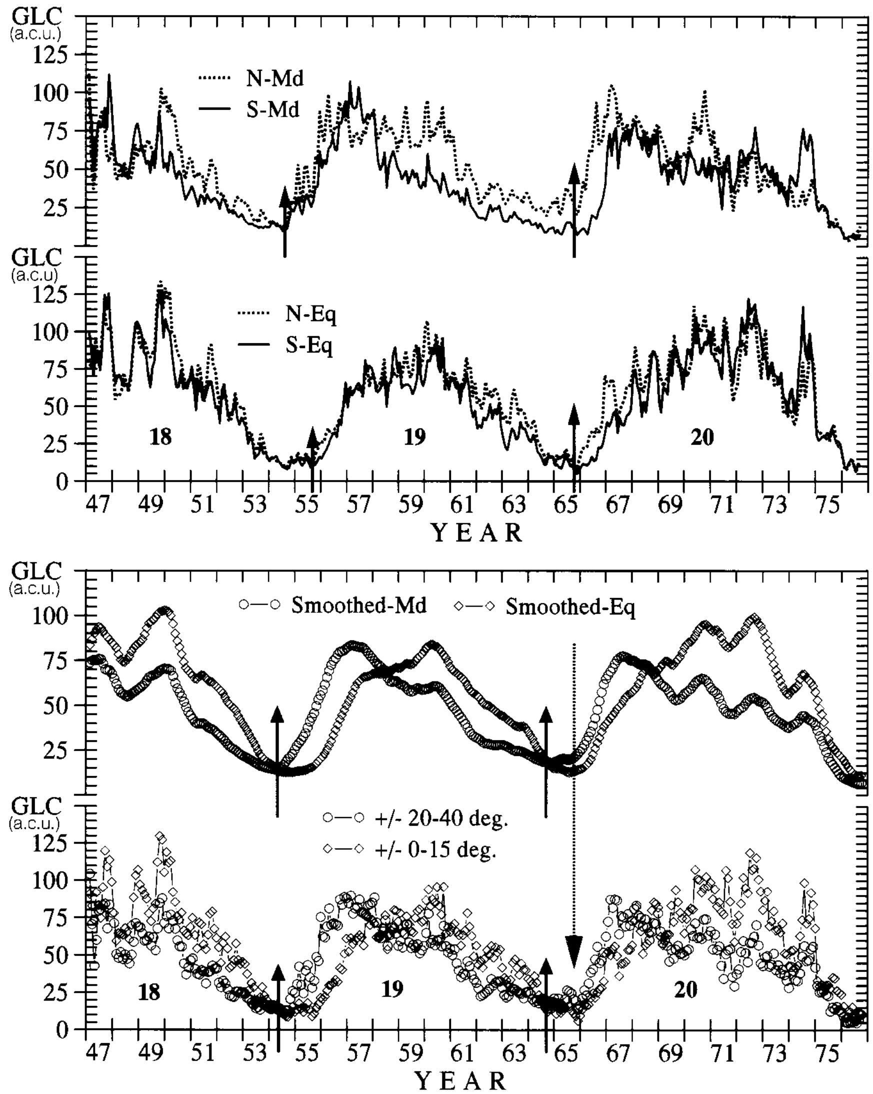

Fig. 4. – Upper panel: long-term trend of the GLC intensity for the middle (top) and equatorial (bottom) latitudinal belts, according with the hemispheric activity. Lower panel: as in the upper panel for the average GLC intensity disregarding hemispheric activity (bottom) and for the smoothed values (top). See the text for the arrows meaning.

a sudden increase in the Md-belts (1954) followed by the delayed one in the Eq-belts (in 1955). The lower panel of fig. 4 (bottom) reports the GLC-trend for the average GLC intensity in each belt, *i.e.* for $\pm 0°$–$15°$ and $\pm 20°$–$40°$. An upward arrow shows the beginning of each solar-activity cycle as derived from the time behaviour of several solar parameters [23]. Here the delayed GLC trend for the equatorial belt during cycle 19 is better seen and a very similar and almost contemporary behaviour in GLC belts at the start of cycle 20. Moreover, when smoothed monthly GLC values are plotted, it is easy to catch the good coincidence between the beginning of the solar activity cycle and the time in which the GLC belt trends are overlapping (top trends in the lower panel of fig. 4). A downward arrow marks the time t (month) in which the difference $\mathrm{GLC}(t+1)-\mathrm{GLC}(t)$ becomes significantly positive in cycle 20. Thus, our previous findings are confirmed here with a better time resolution.

5. – Conclusions

The present investigation confirms the existence of an odd-even cyclic difference in the GLC latitudinal belts at the beginning of solar activity cycles 19 and 20. Moreover, new insights are derived for the GLC-rising phases:

– the Eq-belt is always delayed ($>$ 6 months) to the solar activity cycle, irrespective of its odd/even number.

– the Md-belt has an alternate behaviour; the GLC-increase starts shorthly after the beginning of the odd solar activity cycle ($<$ 6 months) and after a longer period ($>$ 6 months) during the even cycle (in close coincidence with the Eq-belt).

In other words, it seems that a nearly quiescent period exists at the beginning of the even solar activity cycle, inducing in a wide region around the ecliptic plane homogeneous physical conditions. During the odd cycle the extent of this region is reduced to about one-half.

These features are relevant for the understanding of large-scale interplanetary-medium conditions at the beginning of each the solar activity cycle. In particular, studies on long-term modulation of galactic cosmic rays would take advantage on this information. We found a strong correlation between Climax (average primary energy about 10 GeV) neutron monitor data and green line intensities at the equatorial belt (correlation coefficient: -0.98 [24]) during ascending phases of sunspot-number cycles 18 to 22. Work is in progress to extend the monthly GLC data base over the latest solar activity cycles.

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REFERENCES

[1] SÝKORA J., *Contrib. Astron. Obs. Skalnaté Pleso*, **22** (1992) 55.
[2] STORINI M. and SÝKORA J., *Contrib. Astron. Obs. Skalnaté Pleso*, **25** (1995) 90.
[3] SÝKORA J., *Joint Organization for Solar Observations, Annual Report*, 1992 edited by A. V. ALVENSLEBEN (JOSO, Freiburg) 1993, p. 100.
[4] SÝKORA J. and STORINI M., *J. Geomagn. Geoelectr.*, Special Issue No. 4 (1997).
[5] STORINI M., SÝKORA J., FELICI A., BAVASSANO B. and PARISI M., in *Solar Coronal Structures - IAU Colloquium 144*, edited by V. RUŠIN, P. HEINZEL and J.-C. VIAL (VEDA Publ. Co., Bratislava) 1994, p. 143.
[6] STORINI M., BORELLO FILISETTI O., MUSSINO V., PARISI M. and SÝKORA J., *Solar Phys.*, **157** (1995) 375.
[7] LYOT B., *C. R. Acad. Sci. Paris*, **191** (1930) 834.
[8] LYOT B., *C. R. Acad. Sci. Paris*, **193** (1931) 1169.
[9] EDLÉN B., *Z. Astrophys.*, **22** (1942) 30.
[10] WALDMEIER M., *Z. Astrophys.*, **19** (1939) 21.

[11] WALDMEIER M., *Z. Astrophys.*, **20** (1940) 172.
[12] WALDMEIER M., *Die Sonnenkorona, Vol. 1: Beobachtungen der Korona 1939-1949* (Birkhauser, Basel) 1951.
[13] KUIPER G.P., *The Sun* (Chicago Press, Illinois) 1953.
[14] SHKLOVSKIY I. S., *Fizika Solnechnoj Korony* (Gos. izd. fiz.-mat. lit., Moscow) 1962.
[15] Quarterly Bulletin on Solar Activity, International Astronomical Union (Eidgen. Sternwarte Zürich, and Tokyo Astronomical Observatory, Tokyo).
[16] Solar Geophysical Data, NOAA, U.S. Dept. of Commerce, Monthly reports (Boulder).
[17] SÝKORA J., *Bull. Astron. Inst. Czech.*, **22** (1971) 12.
[18] SÝKORA J., *Bull. Astron. Inst. Czech.*, **34** (1983) 93.
[19] KULČÁR L., SÝKORA J. and LETFUS V., *Contrib. Astron. Obs. Skalnaté Pleso*, **21** (1991) 65.
[20] SÝKORA J., *Contrib. Astron. Obs. Skalnaté Pleso*, **11** (1983) 25.
[21] SÝKORA J., in *Solar and Interplanetary Phenomena*, edited by M. DRYER and E. TANDBERG-HANSSEN (Reidel Publ. Co., Dordrecht) 1980, p. 87.
[22] SÝKORA J., BAVASSANO B., STORINI M. and PARISI M., in *Solar-Terrestrial Energy Program, The Initial Results from STEP Facilities and Theory Campaigns*, COSPAR Colloquia Series **5**, edited by D. N. BAKER, V. O. PAPITASHVILI and M. J. TEAGUE (Elsevier, Oxford), p. 289.
[23] MCKINNON J. A., *Sunspot Numbers: 1610-1985*, based on *The Sunspot-Activity in the Years 1610-1960*, Report UAG-95 (WDC A for Solar-Terrestrial Physics, Boulder) 1987.
[24] BAVASSANO B., STORINI M., FELICI A., PARISI M. and SÝKORA J., in *Solar-Terrestrial Energy Program, The Initial Results from STEP Facilities and Theory Campaigns*, COSPAR Colloquia Series **5**, edited by D. N. BAKER, V. O. PAPITASHVILI and M. J. TEAGUE (Elsevier, Oxford) 1994, p. 285.