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Global daily variation of polarized centimeter radio emission of local solar sources and structures of the corresponding groups of spots on the photosphere

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Two series of observations of the Sun at $\lambda = 2.3$ cm in the "relay race" mode (Golubchina & Golubchin, 1981) and in the regular regime with the Southern sector with a periscope (Gindilis et al., 1972) at $\lambda = (2.7, 4.0)$ cm were performed on the RATAN-600 radio telescope on February 9–10, 1980. In the "relay race" mode, each series of observations was performed in the time interval (08:00–11:11) UT with a time interval between neighboring observations of ∼20 min. An extraordinary phenomenon of the daily decrease in the degree of polarization and the intensity of the magnetic field of most local sunspot sources of centimeter radiation, identified with groups of spots on the solar photosphere, is recorded. The structures of these groups of spots located in both hemispheres of the Sun, according to the observations of the Kislovodsk Station of the Pulkovo Observatory and the Ussuri Station (Solar Data, 1980, No. 2), also changed sharply for the day. A comparative analysis of the daily evolution of the characteristics of the radio emission of local sources and the corresponding groups of spots is given.

Keywords: Radio emission, Sun, local sunspot sources, radio emission harmonics

1 Introduction

The original method of observation, the "relay race" (Golubchina & Golubchin, 1981), developed on RATAN-600, allows us to observe the source of a cosmic radio emission from its rising before the sunset. Observations of the radio emission of the Sun by the "relay race" method made it possible to investigate the centimetric radio emission of local sunspot sources (LSs) and to trace the evolution of the radio emission of these LSs and the structure of sunspot groups identified with them from February 9, 1980 till February 10, 1980.

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2 Description of methods of observation

Observations of the radio emission of the Sun on February 9–10, 1980 were performed at $\lambda = 2.3$ cm with the Northeast sector of the RATAN-600 radio telescope by the "relay race" mode (Golubchina & Golubchin, 1981) and in the meridian in the regular mode in the Southern sector with a periscope (South + Pl.) (Gindilis et al., 1972) at the waves of 2.7 cm, 4.0 cm (Fig. 1). Observations in the "relay race" mode were spent for three hours with an interval between neighboring observations $\Delta t = 20$ min. The position angle of observation varied from $q^1 = -21°$ to $q^n = +39°$. The spatial resolution of the RATAN-600 working by the "relay race" mode was at $\lambda = 2.3$ cm: ρ_h (angular min.) = 1.1; ρ_v (angular min.) = 15.4, where ρ_h is the size of the horizontal beam; ρ_v, the size of the vertical beam. The angular sizes of the main lobe of the antenna power pattern in the "South + Pl." mode are: $\lambda = 2.7$ cm, ρ_h (angular sec.) = 25, ρ_v (angular min.) = 22.2; $\lambda = 4.0$ cm, ρ_h (angular sec.) = 38, ρ_v (angular min.) = 33.0. Observations were made during the period of maximum solar activity.

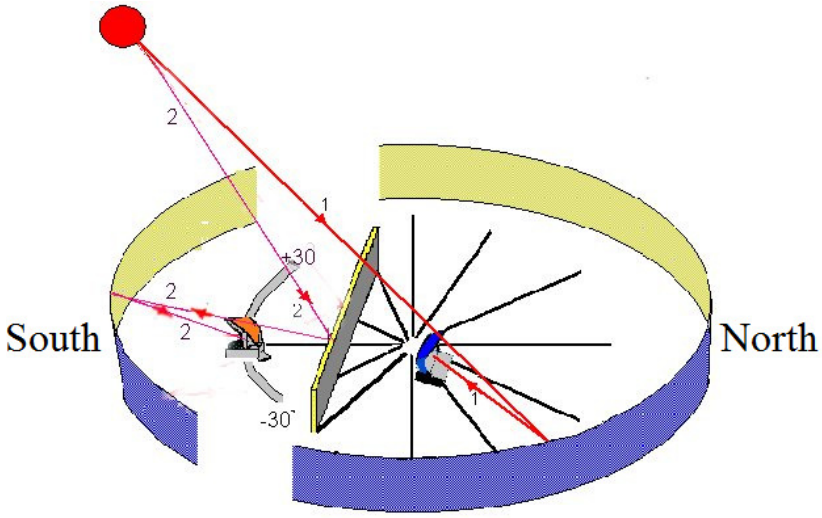


Figure 1 The paths of the Sun rays under observations. (1) in the Northeastern sector of RATAN-600 by the method of "relay race"; (2) in the Southern sector with a periscope.

3 General characteristics of sunspot groups on the visible hemisphere of the Sun in the optical and centimeter radio range on Feb. 9–10, 1980

On a visible disk of the Sun 9 bipolar groups of spots are distinctly allocated: 54, 55, 60, 63, 66, 69, 71, 72, 74 (numbering of groups is given under the bulletin "Solar Data"). The groups were very diverse in both the area, $S = (72–1390)$ msh (1 msh = 10^{-6} area of solar hemisphere), and configuration. The most powerful groups 66, 54, 55, 60 are susceptible to the "confusion" effect when scanning by the antenna beam, so they were not processed. Groups 69, 72 and 74 represent a single complex within

one floccula. When analyzing, groups 72 and 74 were considered as a single source (72 + 74), and group 69 was divided into two sources: g. 69 (a head sunspot) and 69 (center) (central part of the group). Groups 63 and 71 were well separated from the other groups. Some characteristics of analyzed sunspot groups are given in Table 1.

Table 1 General characteristics of sunspot groups and LSs at $\lambda = 2.3$ cm.

Group number	Areas S (msh)	Angular sizes ρ (min)	Radio fluxes F (sfu)	Relative fluxes $F_i/F_\odot$ (%)
54, 55, 63,66, g. 69, 71 center 69, 72+74	92–1390	1.0–2.5		
63, g. 69, 71 center 69, 72+74			0.8–2.5	
center 69, 72+74				0.9–2.4

The relative flux of LSs is $F_i/F_\odot$ (%) (F_i, the radio flux of the selected local source; $F_\odot$, the flux of radio emission of the quiet Sun). The absolute error of relative fluxes $\delta(F_i/F_\odot) = \pm 0.05$. The accuracy of determining the heliographic latitude of local sources is $\sigma_\varphi = \pm(0.5\text{–}2)^\circ$; heliographic longitude $\sigma_l = \pm(0.2\text{–}1.5)^\circ$.

4 Analysis of the received data of a solar radio emission on $\lambda = 2.3$ cm

Records of radio emission of the Sun in the polarization channel on February 10, 1980 were noticeably simplified in comparison with the records of February 9, 1980, i.e. the amplitude of the sources of polarized radiation either has considerably decreased, or the sources have completely disappeared. However, the amplitude of the polarized radio emission (g. 69) has increased (Fig. 2).

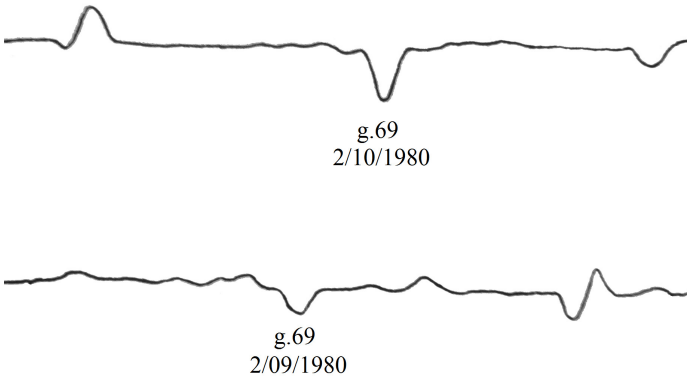


Figure 2 Simplification of polarized radio emission of the Sun at 2.3 cm wavelength from February 9, 1980 to February 10, 1980 (original records).

Comparison of the diurnal evolution of the polarized radio emission of LSs on $\lambda = 2.3$ cm and structures of corresponding groups of spots on the photosphere

has shown a significant change in the structures of six groups of spots at least. This simplification of the structures of groups of spots can be seen on the daily maps of the Sun and the magnetic fields of sunspots (Solar Data 1980, No. 2), and also according to the data of the Ussuri Station, which excludes the influence of the atmosphere on the images of the Sun in white light (Golubchina, 1992). More detailed images of groups of spots on the solar photosphere were kindly provided by V.V. Makarova, Kislovodsk Station of the Pulkovo Observatory. From February 9, 1980 to February 10, 1980 in the structure of sunspots groups the following changes occurred (Fig. 3):

1. The leading spot of group No. 54 was divided into two by a deep bridge. The configuration of the whole group was simplified on February 10, 1980.
2. All three nuclei of group No. 66 were in the same penumbra, and on February 10, 1980 a separation into 3 separate spots occurred. The structure of the head spot is simpler.
3. At the leading spot of group 69 (g. 69) the second nucleus not only separated from the head spot, but almost disappeared. The tail spot also split, the group became simpler. Similar changes occurred in groups Nos. 63 and 71, i.e. February 10, 1980 on the solar photosphere a simpler configuration of all groups of spots was observed.

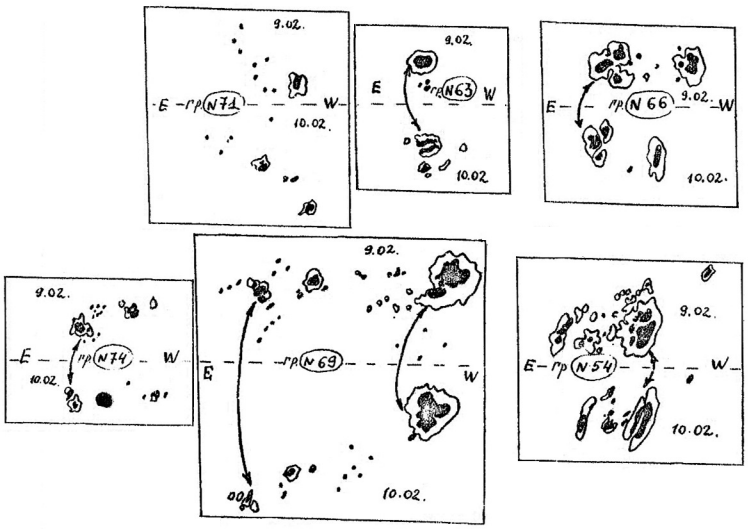


Figure 3 Changes in the structure of sunspot groups from February 9 to 10, 1980 according to Kislovodsk Station.

To study the dynamics of the polarized radio emission of LSs, the degrees of polarization $P(\%)$ and the corresponding values of the magnetic fields B (Gs) were calculated at $\lambda = 2.3$ cm according to the formula:

$$P(\%) = [T_v/(2 \cdot T_i)] \cdot 100\%, \tag{1}$$

where T_v, T_i are the antenna temperatures on the recorded local sources in the polarization channel and in the intensity channel, respectively (Table 2).

At 2.7 cm and 4.0 cm, these values were calculated according to the formula:

$$P(\%) = [S_v/(2 \cdot S_i)] \cdot 100\%, \tag{2}$$

where S_v, S_i are the areas on the record under the allocated local sources in the polarization channel and in the intensity channel, respectively (Table 2).

Legend in the tables: L, R, the prevailing sign of the source polarization (left and right polarization, respectively); "–", signal was not processed due to weak gain of the received signal.

Table 2 The polarization degree (P, %) of the radio emission of local solar sources in the centimeter wavelength range, as observed by RATAN-600 on February 9 and 10, 1980.

	Group number (polarization channel)				
	69 (g.)	69 (center)	72+74	71	63
"Relay" $\lambda = 2.3$ cm					
02/09/1980	47 L	4.9 R, 3.3 L	7.7 R, 4.2 L	11.0 L, 16.5 R	27 R
02/10/1980	79 L	2.4 R, 6.0 R	4.6 R	7.8 L, 5.1 R	10.2 R
Regime "South with a periscope" $\lambda = 2.7$ cm					
02/09/1980	37 L	–	–	–	–
02/10/1980	100 L	3.7 L	4.5 R	–	–
Regime "South with a periscope" $\lambda = 4.0$ cm					
02/09/1980	47 L	14 R	14.6 R	–	–
02/10/1980	100 R	4.6 R	1.4 R	–	–

The degree of polarization of g. 69 per day (from February 9 to 10, 1980) has significantly increased: at $\lambda = 2.3$ cm from $P(\%) = 47$ to $P(\%) = 79$, at $\lambda = 2.7$ cm from $P(\%) = 37$ to $P(\%) = 100$, $\lambda = 4.0$ cm from $P(\%) = 48$ to $P(\%) = 100$. The degrees of polarization of other local sources are low (1.4–16%) and, as a rule, decreased to February 10, 1980 (Table 2).

To calculate the value of the magnetic field, it is necessary to know the mechanism of the radio emission of a local source, which was determined from the spectrum of the flux and the calculated degree of polarization. The flux spectrum of g. 69 was determined from the values of the fluxes at three wavelengths: by $\lambda = (2.3, 2.7, 4.0)$ cm. The course of the spectrum and high degrees of polarization of the radio emission indicated that the main radiation mechanism of g. 69 is cyclotron. The magnetic field strength in this case is calculated by the formula:

$$B(\mathrm{Gs}) = 107 \cdot 10/(\mathrm{s} \cdot \lambda), \tag{3}$$

where s is the number of the harmonic and λ is the wavelength. It is usually assumed that for sunspots the E-mode is generated at the 3rd gyro-level ($s = 3$) and the O-mode at the second one ($s = 2$). The presence or absence of the corresponding modes makes it possible to estimate the magnitude of the magnetic field in the cyclotron source.

The radiation mechanism of other local sources was thermal magneto-bremsstrahlung. In this case, the value of the magnetic field is determined by the formula:

$$B\,(\mathrm{Gs}) = [107 \cdot P(\%)]/(\lambda \cdot n), \tag{4}$$

where $P(\%)$ is the degree of polarization, λ is the wavelength, and n is the spectral index. In our calculations, we assume $n = 2$. The results of calculations are given in Table 3. The magnetic field strength of observed local sources do not exceed several hundred Gauss and decrease from February 9 to 10, 1980.

Table 3 The magnetic field strength B (Gs) of the investigated local sources of the centimeter range, identified with the corresponding groups of spots on the solar photosphere. L, R polarization corresponds to S, N (southern and northern) polarity of a magnetic field.

	Group number (polarization channel)				
	69 (g.)	69 (center)	72+74	71	63
"Relay" $\lambda = 2.3$ cm					
02/09/1980	1104 L	114 R, 77 L	179 R, 104 L	255 L, 383 R	628 R
02/10/1980	1552 L	56 R, 130 L	107 R	181 L, 118 R	237 R
Regime "South with a periscope" $\lambda = 2.7$ cm					
02/09/1980	733 L	–	–	–	–
02/10/1980	1322 L	73 R	89 R	–	–
Regime "South with a periscope" $\lambda = 4.0$ cm					
02/09/1980	628 L	187 R	195 R	–	–
02/10/1980	892 L	61 R	19 R	–	–

The magnetic field strength of the radio emission of the local source (g. 69) decreases with increasing wavelength: $\lambda = (2.3, 2.7, 4.0)$ cm (Table 4). The maximum values of the magnetic fields of large spots of the investigated groups of spots on the photosphere decreased per day from February 9 to 10, 1980 (Table 4).

Table 4 Maximum values of the magnetic field of the nuclei in groups of spots in optics (S, N are the southern and northern polarities of the magnetic field from the data of magnetic field maps of spots (Solar Data, 1980, No. 2)).

	Maximum magnetic field strength B (Gs) in sunspot groups in optics				
Sunspot group	69 (g.)	69 (center)	72+74	71	63
polarity (optics)	S	N	N, S	N	N
02/09/1980	2200–2300	1800	1900	1900	2500
02/10/1980	2200–2300	1500	1500	2000	1900
DATA	Magnetic field strength B (Gs) Regime "Relay" $\lambda = 2.3$ cm				
02/09/1980	1104 L	114 R, 77 L	179 R, 104 L	255 L, 383 R	628 R
02/10/1980	1552 L	56 R, 130 L	107 R	181 L, 118 R	237 R

5 Discussion and conclusions

At RATAN-600 from February 9 to 10, 1980, synchronous increases in the intensity of cm-radio emission simultaneously in several local sources were observed (Golubchina,

1992). Synchronous increases in the intensity of local sources occurred during flares in one group of spots or during a burst recorded by the solar services in the radio range (Golubchina, 1992, 1995). In the optical wavelength range, as well as in the radio range, in observations with a high temporal resolution, such recorded phenomena are known as sympathetic flares and sympathetic bursts. It is generally believed that the trigger mechanisms of sympathetic flares and bursts are high-energy electrons that propagate along magnetic lines of force connecting the site of a flare with sunspot groups, as well as the propagation of magnetohydrodynamic waves (Golubchina, 2001). However, it was suggested that a single subphotospheric source might influence the activity of groups of sunspots (Fritzova, 1976; Ogir, 1981). In this paper, another phenomenon is considered: "Daily global change in the polarized centimeter solar radio emission of local sources and structures of the corresponding groups of spots on the photosphere". Nevertheless, the above observations indicate the possible influence of a single subphotospheric source on the daily evolution of solar radio emission of local solar sources and the change in the structures of groups of spots. However, the nature of this phenomenon is still unknown.

The main observational results can be formulated as:

1. A sharp daily (from February 9 to 10, 1980) decrease in the degree of polarization and the magnitude of the magnetic field strength in four local sources of magneto-bremsstrahlung (thermal) radiation was detected: Nos (center 69), 72 + 74, 71, 63.
2. The degree of polarization and the intensity of the magnetic field of the local source (g. 69) of the cyclotron radiation mechanism per day (from February 9 to 10, 1980) increased sharply.
3. The results of observations in the "regular" mode of the radio telescope RATAN-600 at $\lambda = (2.7, 4.0)$ cm in the Southern sector with a periscope are consistent with the results of observations in the "relay" mode at $\lambda = 2.3$ cm.
4. A decrease in the magnitude of the magnetic field of local sources with increasing wavelength ($\lambda = (2.3, 2.7, 4.0)$ cm) is recorded.
5. A sharp change and simplification of the structure of seven groups of spots located along the entire disk of the solar photosphere and the simultaneous weakening or disappearance of the polarized radiation of most local sources were observed from February 9 to 10, 1980.
6. A sharp change in the intensity of the magnetic field of local sources of radio emission and the simplification of the structure of the corresponding sunspot groups on the solar photosphere may be due to a change of the subphotospheric magnetic field common to all the considered groups of spots. The nature of this phenomenon is still unknown.

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