ISSN 0016-7932, Geomagnetism and Aeronomy, 2018, Vol. 58, No. 4, pp. 457–463. © Pleiades Publishing, Ltd., 2018.
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Diagnostic Analysis of the Solar Proton Flares of September 2017 by Their Radio Bursts

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Received December 1, 2017; in final form, December 26, 2017

Abstract—The powerful solar flares that occurred on September 4–10, 2017 are analyzed based on a quantitative diagnostics method for proton flares developed at the Institute of Terrestrial Magnetism, the Ionosphere and Radio-Wave Propagation (IZMIRAN) in the 1970–1980s. We show that the fluxes and energy spectra of the protons reached the Earth with the energies of tens of MeV qualitatively and quantitatively correspond to the intensity and frequency spectra of the microwave radio bursts in the range of 2.7–15.4 GHz. Specifically, the flare of September 4 with a peak radio flux $S \sim 2000$ sfu at the frequency $f \sim 3$ GHz (i.e., with the soft radio spectrum) was accompanied by a significant proton flux J (>10 MeV) ~100 pfu and a soft energy spectrum with the index $\gamma \sim 3.0$, while the strong flare on September 10 with $S \sim 21000$ sfu at $f \sim 15$ GHz (i.e., with the hard radio spectrum) led to a very intense proton event with J (>10 MeV) ~1000 pfu with a hard spectrum ($\gamma \sim 1.4$), including the ground level enhancement (GLE72). This is further evidence that microwave radio data can be successfully used in diagnostics of proton flares independently of a specific source of particle acceleration at the Sun, in particular, with the IZMIRAN method.

DOI: 10.1134/S0016793218040035

1. INTRODUCTION

Among the nonrecurrent perturbations of space weather, solar cosmic rays (SCRs) or solar proton events (SPEs), i.e., enhancements of the proton flux with energies of tens to hundreds of MeV in the near-Earth space (occasionally with $E \geq 1$ GeV) recorded by ground-based neutron monitors (see reviews Reames, 2013; Desai and Giacalone, 2016; Klein and Dalla, 2017), are the most important. Such enhancements can cause the failure of electronic equipment of spacecraft, lead to an increase in the radiation level in the interplanetary and near-Earth orbits, be a serious hazard to spacemen, as well as crew members and passengers of subpolar flights, lead to the failure of short-wave radio communication at high-latitude regions, etc.

There are three sources responsible for SCR acceleration: a primary impulsive energy release (impulsive flare component); a prolonged posteruption (PE) energy release initiated by a coronal mass ejection (CME); and the shock wave that occurs in the eruption process at the front of a sufficiently fast CME (see works (Chertok, 1995; Aschwanden, 2006)). In this case, a CME itself at the meter wavelengths is manifested in the form of a type IV radio continuum, and a type II burst serves as the shock wave indicator. The PE energy release occurs at the final stage of the eruption event, when the magnetic field, strongly disturbed by the CME in a large region of the corona, relaxes to a new quasi-equilibrium state by means of magnetic reconnection in an extended quasi-vertical current sheet. Depending on the CME scale and the characteristics of the magnetic field in the corona, the PE-phase is accompanied by significant plasma heating, prolonged particle acceleration (sometimes up to fairly high energies), prolonged bursts in different ranges from gamma-ray to meter-wavelength radio emission, two-ribbon structures in the chromosphere, large-scale coronal loops, giant arcades, etc. To date, it is assumed that effective and prolonged particle acceleration can also occur in collapsing loops, including them at the PE phase (Somov and Kosugi, 1997).

SPE forecasting can be reduced to the forecasting of large eruptive flares based on the characteristics of the evolving magnetic field of large sunspot groups. Furthermore, the so-called diagnostics of proton flares is performed at a number of forecasting centers. The diagnostics are based on the fact that the electromagnetic radiation of flares comes to the Earth by tens of minutes to hours earlier than, for example, protons with $E > 10$ MeV. This enables by the observed soft X-ray emission or radio bursts from an already occurring flare to determine in advance whether it will be accompanied by a noticeable SEP and to estimate its expected parameters (Belov et al., 2005; Kahler et al., 2007; Nûñez M., 2011; Anastasiadis et al., 2017; Zucca et al., 2017). The original method for the diagnostics of proton flares by the accompanying radio bursts, allowing to estimate the intensity of the proton flux, its time parameters and the energy spectrum, taking into account the heliolongitude of the flare and the escape conditions of particles into the interplanetary space, was developed at IZMIRAN in the 1970–1980s (Akinyan et al., 1977, 1978, 1980a, 1980b, 1981).

Usually SPEs occur in series due to the passage of a large evolving active region (AR) across the solar disk. Most SPEs are observed close to the maximum of the 11-year cycles, but they can also occur in the decay phase of solar activity. In the current Solar Cycle, 24, an unexpectedly strong outburst of activity, including numerous powerful flares up to the X9.3 class, and at least three large SPEs occurred on September 4–10, 2017, on the approach to the minimum, due to the sharp development of a large AR. The present paper is devoted to a diagnostic analysis of these SPEs based on the IZMIRAN method mentioned above.

2. PRINCIPLES OF THE METHOD

The method is based on the following statement: the parameters of the intensity of microwave bursts at the frequencies $f \sim 3$–15 GHz (though the latter are generated by electrons propagating to the photosphere) reflect the number of the accelerated particles, including the protons that reach the Earth with an energy of tens MeV. When we estimate the expected proton flux intensity at the Earth, the initial parameters are both the maximal flux density of microwave bursts at the numbers of fixed frequencies and their integrated parameters: the total fluence and rise phase fluence. Thus, not only the impulse component but also the PE component of the flare is taken into account to some extent.

First, we consider the proton events related with flares occurred in the so-called optimal heliolongitude interval (OHI), wherein the parameters of the proton fluxes and its relations with the radio bursts are almost independent of the heliolongitude. For proton events, the OHI is localized within heliolongitudes W20–80, and its occurrence is caused by the lateral diffusion and fast azimuthal transport of particles in the corona by means of propagation along the field lines connecting distant ARs and areas of the Sun. At the present time, it appears that the OHI can be identified with large-scale magnetic structures of the global solar magnetosphere, which are involved in the CME eruption process, as well as with the extent of the shock wave front that forms ahead of the CME. The empirical relationships between the parameters of microwave bursts at several frequencies and the intensity of the proton fluxes at the Earth J with the energy $E > 10$, 30, 60 MeV, which are referred to as the intensity function, are established for events within the OHI.

We found that it is very fruitful to introduce the attenuation value calculated for each event as the ratio of the proton flux observed near the Earth to the intensity calculated with the intensity function. This made it possible to proceed with the flares of an arbitrary heliolongitude and take into account the conditions for the escape of particles into the interplanetary space; they appear in the meter-wave component of radio emission (type II and IV bursts). It is assumed that a strong meter-wave component corresponds to the favorable conditions and the weak meter-wave component is associated with unfavorable conditions for particle escape from the flare region. We then study the event distribution with different characteristics of meter-wave emission in the diagrams “attenuation value φ–heliolongitude Θ.” It was established that the events within the OHI with a strong meter-wave component (i.e., with favorable escape conditions) are accompanied by a higher proton flux than that with a weak meter-wave component (i.e., with unfavorable escape conditions). The same effect results in the fact that, for flares out of the OHI, i.e., on the eastern half of the disk, during events with a strong meter-wave component, proton fluxes are more affected by the heliolongitudinal attenuation than that with a weak meter-wave component. Analysis of the “φ–Θ” diagrams make it possible to determine quantitatively the dependence of the proton flux attenuation on the heliolongitude. To date, it is assumed that the intensity of the meter-wave component also reflects the eruptive CME power and thus accounts for the possible contribution of third source of the proton acceleration, namely, the acceleration at the shock ahead of the CME. The heliolongitudinal attenuation is enhanced by the particle energy, which leads to steepening (softening) of the energy spectrum from eastern flares.

Furthermore, a direct statistical dependence between the frequency spectrum of the microwave bursts and the index of the power-law spectrum of the proton fluxes observed near the Earth with an energy of tens MeV was demonstrated (Chertok, 1982, 1990, see also Chertok et al., 2009). In particular, the flares with a soft radio spectrum (the frequency of the spectral maximum $f_m \leq 5$ GHz, the ratio of the peak intensities of bursts at the frequencies 9 and 15 GHz $S_9/S_{15} \geq 1$) within the OHI lead to proton fluxes at the Earth with a soft (steep) energy spectrum, while the flares with a hard radio spectrum ($f_m \geq 15$ GHz, $S_9/S_{15} < 1$) lead to proton fluxes with a hard (flater) energy spectrum. Similarly, the curve quantitative characterizing the steepening of the energy spectrum of the protons for eastern events is determined.

In the following, this method was further used as a tool to study SCRs. In particular, among the western events, the surplus and delayed proton fluxes were detected, in which the observed proton intensity with $E > 10$ MeV near the Earth was significantly higher than the calculated one, and the time interval between the maxima of the centimeter burst and the proton flux exceeds 10 h (Basilevskaya et al., 1990). Analysis shows that such proton fluxes are observed in events

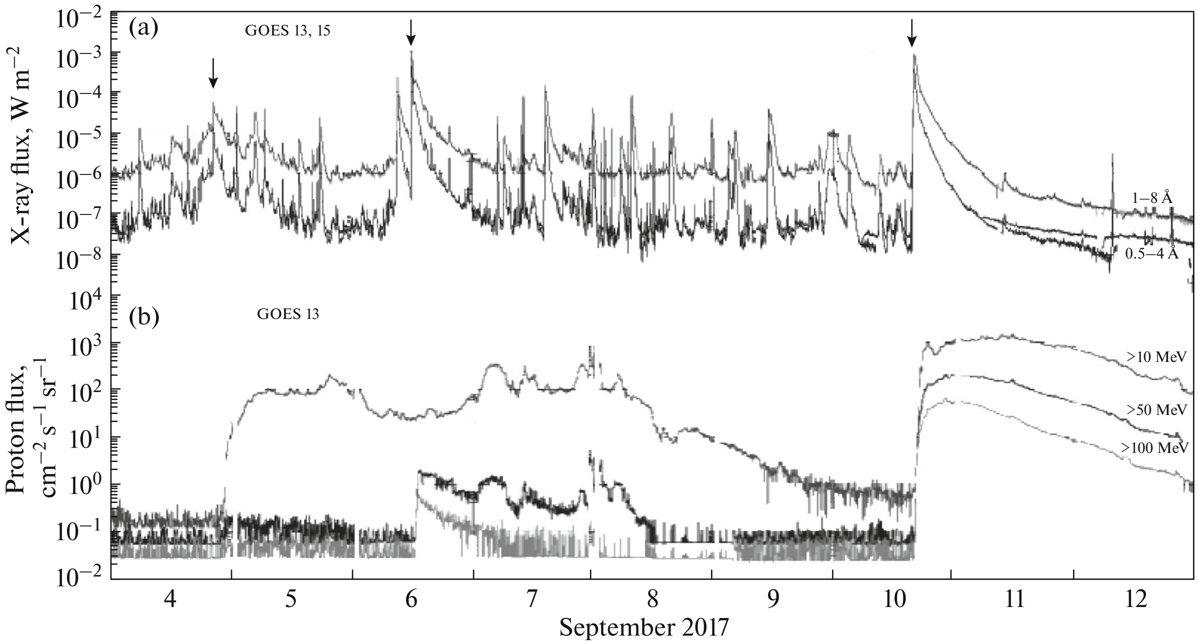

Fig. 1. Time profiles of the soft X-ray emission (*a*) and the proton fluxes (b) according to the data of the GOES satellites on September 4–12, 2017. The vertical arrows indicate three analyzed SPEs.

with a soft frequency spectrum of microwave bursts (f_m < 5 GHz). We therefore concluded that delayed and surplus proton fluxes are caused by the predominance of prolonged PE acceleration, because it is exactly the PE component of microwave bursts that is characterized by a soft radio spectrum and long duration.

In practice, flare diagnostics begins with the selection of proton events based on the criterion formulated in this method, which provides the presence of a sufficiently strong and prolonged (nonimpulsive) microwave burst and a significant meter-wave component (type II and IV bursts). In current terms, this corresponds to events with a strong flare of long duration, large CMEs, and a developed PE energy release.

3. FLARES AND PROTON EVENTS

The strong and very sharp outburst of solar activity occurred at the beginning of September 2017 was due to the rapid development of the large sunspot group AR 12673 on the visible disk (Yang et al., 2017). Figure 1 shows the time profiles of the soft X-ray emission in the ranges 1–8 and 0.5–4 Å and the proton fluxes with the energy E > 10, 50 and 100 MeV recorded by the GOES 13 and 15 satellites on September 4–11, 2017. (ftp://ftp.swpc.noaa.gov/pub/warehouse/2017/2017_plots/). One can see that four X-class flares (including the most powerful flare in Cycle 24 of class X9.3 on September 6), 27 M-class flares, and numerous flares of lower classes were realized during this time. For our analysis it is important that all of these flares occurred on the western half of the disk, where the parameters of proton fluxes weakly depend on the flare heliolongitude. According to data from the satellite-based SOHO/LASCO coronagraph (https://cdaw.gsfc.nasa.gov/CME_list/halo/halo.html), at least three flares (class M5.5 on September 4, X9.3 on September 6, and X8.2 on September 10) are accompanied by large halo CMEs. These three powerful eruptive flares, which are marked by vertical arrows in Fig. 1a, give rise to significant enhancements of the proton flux near the Earth, i.e., SPEs.

Figure 1b shows that, in the SPE of September 4, a proton flux with an energy of E > 10 MeV, (which hereinafter is referred to as J_{10}, and for arbitrary energy is designated as J_E), is enhanced up to ~100 pfu (1 pfu = 1 cm^{-2} s^{-1} sr^{-1}). At the same time, the increases of proton fluxes with E > 50 and 100 MeV were quite small. It means that this SPE had a fairly soft (steeply falling) energy spectrum. The index of the power-law energy spectrum, $J_E \propto E^{-\gamma}$, which was calculated with the ratio of fluxes with E > 10 and 100 MeV as $\gamma = \log(J_{10}/J_{100})$, is $\gamma \sim 3.0$.

The proton flux at E > 10 MeV was still increasing over several subsequent days, possibly because of the slow escape of particles from the interplanetary magnetic cloud approaching the Earth, which is identified by the halo CME of September 4; it may also be caused by the prolonged acceleration in the shock wave at this CME front. In the SPE occurring on September 6 under these disturbed conditions, enhancement of the proton flux is clearly seen only at E > 50 and 100 MeV, where J_{50} ~ 2 pfu and J_{100} ~ 0.6 pfu. It follows that the given event, in contrast to the SPE of September 4, was characterized by a fairly hard (smoothly falling) proton spectrum. The estimates by the fluxes at these two energies give the power-law index γ ~ 1.7. For such a spectrum, the flux in the channel E > 10 MeV should be of the order of J_{10} ~ 32 pfu, which is close to observed peak on the time proton profile of September 6, about 15 UT.

The most powerful SPE occurred on September 10 after a prolonged, near-limb, X8.2-class flare. The characteristics and parameters of this SPE are typical for powerful western proton flares. In this case, the proton flux of the fast component reached J_{10} ~ 1000 pfu, and, after a small subsequent rise, gradually decreased over several days. The fluxes of the fast component in the channels E > 50 and 100 MeV were also significant: J_{50} ~ 130 pfu and J_{100} ~ 40 pfu. This indicates that its energy spectrum was harder than that in the previous event and had the index γ ~ 1.4. For most SPEs at the energies of hundreds MeV, the proton spectrum becomes steeper; however, with J_{10} ~ 1000 pfu, it is enough for the flux with E > 1 GeV to be sufficient to register a moderate increase in terrestrial neutron monitors, i.e., such a rare event as a Ground Level Enhancement (GLE) (https://gle.oulu.fi/). This event was referred to as GLE72 and was only the second one during all of Cycle 24 (three more events are classified as sub-GLE (Mishev et al., 2017)). Its amplitude, e.g., at the Moscow station (IZMIRAN) was ~4% (http://cosrays.izmiran.ru).

4. RADIO BURSTS AND RESULTS

We proceed with an analysis of radio bursts from flares of this time interval and use it for SPE diagnostics based on data from the USAF Radio Solar Telescope Network (RSTN), which provides round-the-clock observations of meter dynamic spectra and radio fluxes at several fixed frequences in the range of 245 MHz to 15.4 GHz (ftp://ftp.sec.noaa.gov/pub/warehouse/2017/2017_events/). With these tabulated data, we can use the IZMIRAN diagnostics method in a rather simplified form; we avoid turning to the time profiles of radio bursts, but we can use the maximum flux density of the bursts indicated in the Table at frequencies 2.7 GHz (S_3), 5 GHz (S_5), 8.8 GHz (S_9), and 15.4 GHz (S_{15}) as the main radio parameter.

In the first stage of the diagnostics, we consider the flares based on the so-called proton criterion. According to our method, it was established (Akinyan et al., 1980) that a flare can be the source of an SPE with a proton flux near the Earth of $J_{10} \geq 5$–10 pfu when the maximum intensity of its associated microwave radio burst, at least at one of the frequencies in the range of 2.7–15.4 GHz, exceeds 500 sfu (1 sfu = 10^{-22} W m^{-2} Hz^{-1}). Most flares in the considered time interval, including sufficiently powerful M-class flares, did not meet this condition and consequently should not lead to significant SPEs. The number of flares with radio flux S_{3-15} > 500 sfu did not meet another important point of the criterion: radio bursts should be nonimpulse (sufficiently prolonged). As examples of such impulse events, we point to the M2.4-class flare at 0502[1], the M7.3-class flare at 1015, and X1.3-class flare at 1435 on September 7 and the M8.1-class flare at 0745 on September 8. In these cases, the duration of the microwave radio bursts is only several minutes. The first powerful X2.2-class flare on September 6, 0909, is also not considered as an SPE source, because of the meter-wave component of radio emission is weak or absent. This is shown by both the RSTN tabled data and the dynamical spectrum in the range 25–270 MHz recorded in IZMIRAN (see http://www.izmiran.ru/stp/lars/s_archiv.htm). This is also provided by the fact that this flare is not accompanied by a noticeable CME, according to the SOHO/LASCO coronograph data. Generally, the implemented analysis allows us to conclude that only three flares (M5.5-class, at 2048 on September 4; X9.3-class, at 1156 on September 6; and X8.2-class, at 1558 on September 10), which were the sources of the three discrete SPEs described in the previous Section, completely meet the proton criterion according to observations (see Fig. 1 and Table 1). The increased irregular proton level on September 7 and 8 is apparently related to the high perturbation of the heliosphere and the Earth's magnetosphere, which was caused by the propagation of the shock wave and a large CME from the X9.3 flare of September 6, the fast particle transport in these structures, and its additional acceleration.

Figure 2 shows the frequency spectra of three mentioned flares based on the maximum radio flux. It is immediately obvious that the flare of September 10 was associated with the most powerful radio burst, with a sharp increase in the radio flux up to f_m ~ 15 GHz (S_{15} ~ 21000 sfu) and, consequently, the hardest frequency spectrum. However, the flare on September 4 is accompanied by a radio burst of moderate intensity with a maximum flux in the studied range at f_m ~ 3 GHz (S_3 ~ 2000 sfu) and a significant reduction of the radio flux to S_{15} ~ 360 sfu at f ~ 15 GHz, i.e., with the softest frequency spectrum. The flare on September 6 is accompanied by radio bursts with intermediate characteristics: a maximum flux at f_m ~ 15 GHz (S_{15} ~ 8100 sfu) and a moderately hard frequency spectrum.

We estimated the quantitative parameters of SPEs (the scale of possible proton enhancement in the channel > 10 MeV by the intensity J_{10} and the power-law index γ) using the empirical relations obtained during the development of and further corrections of the method. The observed characteristics of the meter-wave radio emission, including type II and type IV bursts allow us to consider that the conditions

[1] Throughout this paper the Universal Time (UT) is used.

Table 1. Observed characteristics of three SPEs and the results of estimation of a proton flux with the energy >10 MeV (J_{10}) by the maximum radio fluxes at frequencies ~3, 9, and 15 GHz (S_3, S_9, and S_{15}) and of the index γ of their power-law spectrum by the frequency of the spectral maximum f_m and the ratio S_9/S_{15}

Parameters	Flares		
	Sept. 4, 2048 M5.5, S08W13	Sept. 6, 1156 X9.3, S09W38	Sept. 10, 1558 X8.2, S09W85
S_3, sfu/J_{10}, pfu	2000/270	–	1910/230
S_9, sfu/J_{10}, pfu	1000/40	6500/70	10000/155
S_{15}, sfu/J_{10}, pfu	360	8100/400	21000/7400
Estimate $\langle J_{10} \rangle$	**155**	**235**	**2600**
Observations J_{10}	**100**	**(~40)**	**1000**
f_m, GHz/γ	3/2.3	15/1.7	15/1.7
S_9/S_{15}, γ	2.8/3.0	0.8/1.5	0.48/1.2
Estimate ⟨γ⟩	**2.7**	**1.6**	**1.45**
Observations γ	**3.0**	**1.5**	**1.4**

Averaged values of the parameters J_{10} and γ are marked in bold type. The peak time of microwave bursts is indicated as the time of flares.

of particle escape from the acceleration region are moderate for all three flares according to the terminology adopted by the IZMIRAN method. In this case, in order to estimate the maximum proton flux J_{10} (pfu) by the radio parameters S_3, S_9, and S_{15}, we can use the following empirical relationships (Akinyan et al., 1977, 1978, 1980a, 1980b, 1981):

$$\log(J_{10}) = 3.8(\log S_3 - 3)^{1.25} + 1.6, \quad S_3 > 1000 \text{ sfu},$$

$$\log(J_{10}) = 0.55(\log S_9 - 1)^{1.14}, \quad S_9 \leq 3000 \text{ sfu},$$

$$\log(J_{10}) = 2.12(\log S_9 - 3.5)^{1.729} + 1.56, \quad S_9 > 3000 \text{ sfu},$$

$$\log(J_{10}) = 2.24(\log S_{15} - 3.3)^{1.484} + 1.56, \quad S_{15} > 2000 \text{ sfu}.$$

The index estimates of the power-law energy spectrum of the protons γ by the frequency of the spectral

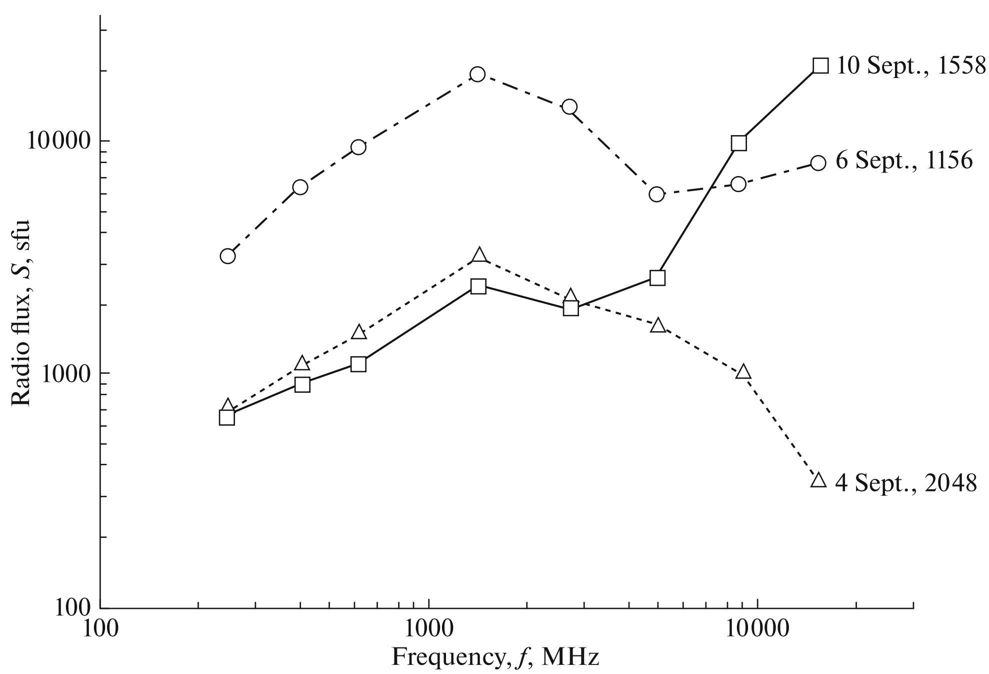

Fig. 2. Frequency spectra of radio bursts related to the three proton events under consideration.

maximum of the radio bursts f_m and the ratio of the peak fluxes at f ~ 9 and 15 GHz, i.e., S_9/S_{15}, are made according to the expressions (Chertok, 1982, 1990; Chertok et al., 2009):

$$\gamma = 0.91 S_9/S_{15} + 0.432,$$

$$\gamma = 2.45 - 0.05 f_m.$$

The results of the estimates and corresponding observed parametes of the proton fluxes are presented in Table 1. For the flare of Septemer 6, J_{10} was estimated by the monotonic increasing part of the frequency spectrum (see Fig. 2), i.e., with the radio parameters S_9 and S_{15}.

Generally, the estimates by radio data reflect quite well the scale and the energy spectrum of three SPEs. A distinguishing feature for the flare of September 4 is the soft radio spectrum with the maximum flux in the range of interest S_3 ~ 2000 sfu at f_m ~ 3 GHz (actually, the frequency spectrum achieves the peak in the decametric-wave range). This defines the main estimated and observed characteristics of the proton flux: a soft energy spectrum with the indices γ ~ 2.7 (estimate) and γ ~ 3.0 (observations). The radio data also provide a correct evaluation of the SPE scale with J_{10} in the range 10–250 pfu at the observed intensity J_{10} ~ 100 pfu. The time profile typical for the events with the soft radio spectrum is characterized by a slow proton flux growth and a larger (~10 h) delay of the maximum intensity J_{10} with respect to the flare (Basilevskaya et al., 1990). All of this suggests that the given flare is dominated by the PE energy release and the particle acceleration. The flux growth during the second half of the day of September 5, up to the level ~200 pfu, is most likely related to the contribution of the shock wave and the CMEs approaching the Earth.

According to the frequency spectrum (Fig. 2), the flare of September 6 was a combination of the primary energy release and the PE phase. These are associated with the increasing flux in the high-frequency part of the microwave band at f ~ 5–15 GHz and the strong decametric-wave component with a maximum at 1.4 GHz, respectively. Spectral index evaluation by two microwave radio parameters indicates a rather hard proton spectrum (γ ~ 1.6), which is in accordance with the observed energy spectrum in the channels $E >$ 50 and 100 MeV (γ ~ 1.5). However, the evaluated proton flux with $E > 10$ MeV J_{10} ~ 235 pfu is considerably larger than the measured one $J_{10} \leq 40$ pfu (Fig. 1b). This discrepancy is related to the heliosphere disturbed state caused by the interplanetory CME from the flare of September 4, which probably prevented the propagation of low-energy protons to the Earth. The arrival of the interplanetory magnetic cloud (CME) at the Earth with the shock wave from the flare of September 6 led, conversely, to increased proton flux in the morning and evening times on September 7.

The frequency spectrum of the flare of September 10 is characterized by a very sharp increase of the radio flux in the range from 3 to 15 GHz and a considerable intensity S_{15} ~ 21000 sfu. This leads to an estimated hard proton spectrum, which is in agreement with the observed γ ~ 1.4, and wide variation in estimates of the proton number by the peak radio fluxes at different frequencies from J_{10} ~ 155 pfu for S_9 to J_{10} ~ 7400 pfu for S_{15}. Nevertheless, the average estimated proton flux J_{10} ~ 2600 pfu can provide a quite reliable SPE scale. The latter for the fast component was J_{10} ~ 1000 pfu, while it increased by factor ~1.4 for a delayed component. Essentially, the estimates of intensity and proton flux spectrum, in particular, the considerable value of J_{10}, obtained from the radio data correspond to the observed ground level enhancement (GLE) in this case.

5. CONCLUSIONS

The analysis above shows that the application of the quantitative radio diagnostics method for proton flares developed at IZMIRAN in the 1970–1980s to a data series for the powerful bursts of September 2017 generally lead to positive results. First, we could correctly select the flares that were the sources of three considerable SPEs with different characteristics based on the proton flare criterion provided by the method, taking into account the data on the intensity, duration, frequency spectrum of microwave bursts, and the parameters of the meter-wave component of the radio emission. The possible proton flux intensity in the channel $E > 10$ MeV were estimated in a simplified manner by the peak radio fluxes at the frequencies f ~ 3, 9, and 15 GHz, which enabled a sufficiently reliable determination of the scale for all three SPEs. Based on the type of frequency spectra of microwave radio bursts, we successfully diagnosed both the flare with the dominant PE component (September 4) and the flares for which the primary flare energy release (SPEs of September 6 and 10) makes the main contribution to proton acceleration.

As shown above, we have the fairly important opportunity for a reliable evaluation of the power-law index of the energy spectrum of protons in the range of tens of MeV based on the radio spectrum. It was again demonstrated that a PE flare with a soft frequency spectrum of microwave bursts causes an SPE with a soft proton energy spectrum, while flares with a hard radio spectrum are, conversely, accompanied by proton fluxes with a hard energy spectrum. It is obvious that such a correspondence between the radio and energy spectra does not support a so-called “large flare syndrome” (Kahler, 1982), according to which the intensity of the proton flux near the Earth shows a noticeable positive correlation with any flare parameters representing the flare energetics, including those physically unrelated to particle acceleration. The results show that the particle acceleration in the flare, including the primary acceleration and the acceleration in the PE current sheet that forms in the corona behind a CME, contributes significantly to the proton fluxes observed near the Earth. The above study once more demonstrates that, irrespective of the specific acceleration sources, data on radio bursts can be successfully used for both analysis and real diagnostics of proton flares, i.e., for preliminary evaluation of the intensity and energy spectrum of proton fluxes, particularly with the application of the IZMIRAN method. The diagnostics of flares based on data on radio bursts at higher frequencies ~35 HGz and the use of the fluencies of microwave bursts as a main initial parameter (Grechnev et al., 2013, 2017) are fairly promising.

ACNOWLEDGMENTS

The author acknowledges the referee for careful reading of the manuscript and helpful comments, as well as the teams operating the geostationary GOES satellites and RSTN world network of radio telescopes for the access to data used in the present work. This study was supported in part by the Russian Foundation for Basic Research (project no. 17-02-00308).

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Translated by E. Seifina