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Forecast of solar flares from observations in the microwave range at the Kislovodsk Station

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We analyzed the microwave radiation of the Sun observed on radio telescopes of the Kislovodsk Astronomical Station RT-3 (4.9 cm) and RT-2 (3.2 cm). Comparisons of long series of observations with observations on other radio instruments and also in the optical and X-ray ranges have been made.

A study is made of the forecast of the flare activity using the data of the solar microwave radiation. To do this, we use the daily calibrated data of the radio observations of the Kislovodsk Astronomical Station in 1962–2018 and also observations at a wavelength of 10.7 cm and X-rays. The estimates of the reliability of the forecasts of flare activity by the criterion of Ermoshenko (Ermoshenko 1979) – 80% and by the criterion of Tanaka–Enome (Tanaka and Enome 1975) – 85% are obtained. These are predictions of events for 24 hours ahead. This reliability indicates the possibility of predicting the solar flare activity according to the microwave radiation.

Keywords: Solar, flares, microwave range, forecast

1 Introduction

The forecast of the flare activity of the Sun is the actual task and objective of heliophysics. The duration of the pulsed phase of solar flares usually does not exceed several minutes. And the energy release can reach $\sim 10^{25}$ J. This is one order less than the energy release of the entire Sun in 1 s. And this is about 10^6 times more than the annual energy consumption of all mankind at the moment. Therefore, flare activity plays a very important role in solar–terrestrial connections. The forecast of solar flares is of great practical importance. It helps to avoid excessive radiation exposure to astronauts and space technology. The Kislovodsk Astronomical Station has a long and unique series of radio observations. The first radio observations began in 1957 on meter wavelengths. Observations in the centimeter wavelengths began in 1962 and continue now.

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2 Observational data

Two patrol radio telescopes operate at the Kislovodsk Astronomical Station of the Central Astronomical Observatory of the Russian Academy of Sciences at Pulkovo (CAO RAS): RT-2 (λ = 3.2 cm) and RT-3 (λ = 4.9 cm). They provide daily 7–10 hour radio observations of the Sun. These data are available on the website for free use at http://solarstation.ru/sun-service/radio. The parameters of sunspots were taken from the Kislovodsk data from observations on a photoheliograph. Data on solar bursts were taken from the lists of X-ray events according to the data of GOES (Geostationary Operational Environmental Satellites). Data of solar radiation at a frequency of 2800 MHz ($\lambda = 10.7$ cm) were taken from the daily observations of the Canadian radio astronomy observatory near Penticton.

3 Methods and processing results

In 1979, V.L. Ermoshenko proposed a method for forecasting solar radio events at the Kislovodsk Astronomical Station (Ermoshenko 1979). Diagrams of the dependence of the daily fluxes of radio emission on the total area of sunspots were used. This method was used and gave good results. The diagram for modern data is presented in Fig. 1. The control was done using data from X-ray events of GOES. In the figure, the power of the event is marked with different symbols, color and size. Each symbol corresponds to its own flare class. We use the classification of X-ray flares GOES (C, M, X). The larger the size of the corresponding symbol, the higher the flare

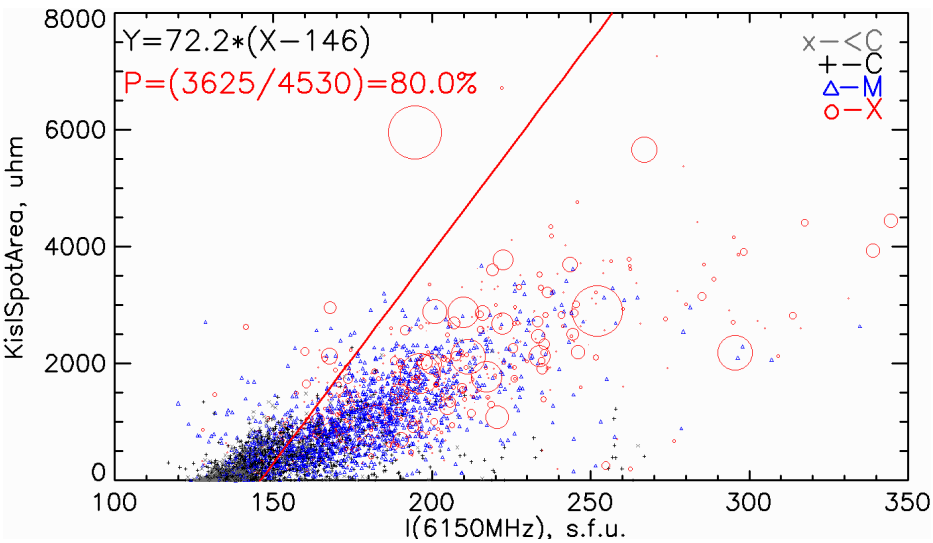


Figure 1 Diagram for the dependence of the total area of the sunspots on the radio flux at a wavelength of 4.9 cm, taking into account events in the X-ray range. Criterion of Ermoshenko.

output. This power is determined by the maximum event within 24 hours from the moment the radio flux is observed. That is the forecast of events for one day ahead. The figure also shows a straight line that divides the diagram into an area without solar flares and an area with a high chance of a solar flare. The coefficients of this line were chosen so as to obtain the maximum reliability of the forecast. To assess the reliability of the forecast, the event was an X-ray flare larger than C5 ($5 \cdot 10^{-6}$ W m^{-2}). The equation of this line is given. The formula for the probability value is also shown:

$$P = \frac{N_{\text{true}}}{N_{\text{all}}}, \tag{1}$$

where N_{true} – number of correct forecasts, N_{all} – total number of observations. The correctness of the forecast by the method of Ermoshenko is 80%.

At the Toyokawa Observatory, a method for predicting proton events by microwave interferometric observations was proposed (Tanaka and Enome 1975). Tanaka and Enome used the diagram of the dependence of the radio flux on 3 cm and the ratio of the flux of 3 cm to the flux of 8 cm. We changed the forecast method and applied it for the full radio fluxes of the Sun at wavelengths of 4.9 and 10.7 cm (Fig. 2). We found a straight line that best divides the chart area without solar flares and an area with a high chance of a solar flare. Similar diagrams were constructed for wavelengths of 3.2 and 4.9 cm (Fig. 3). All the diagrams bear the same notation and symbols as described for Fig. 1.

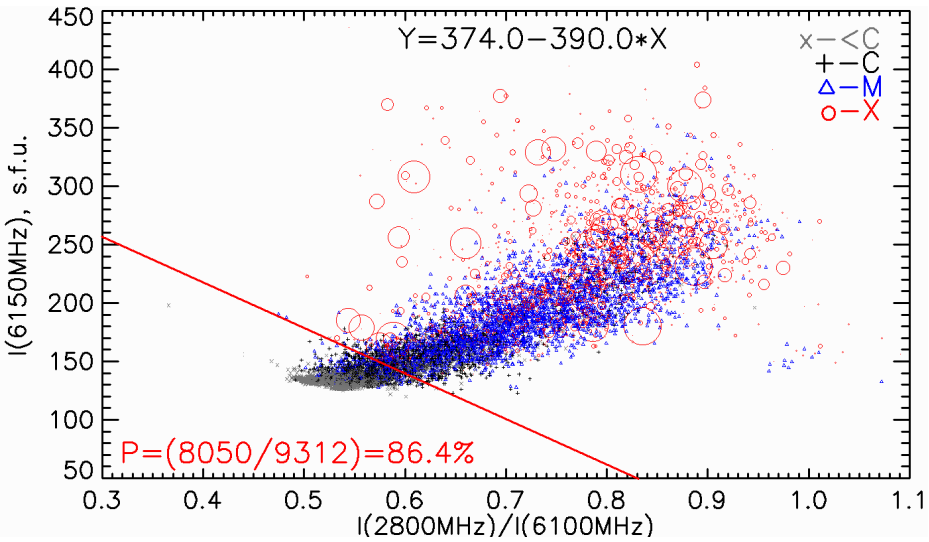


Figure 2 Dependence for the radio flux at a wavelength of 4.9 cm from the ratio of radio fluxes of 10.7 cm to 4.9 cm, taking into account events in the X-ray range.

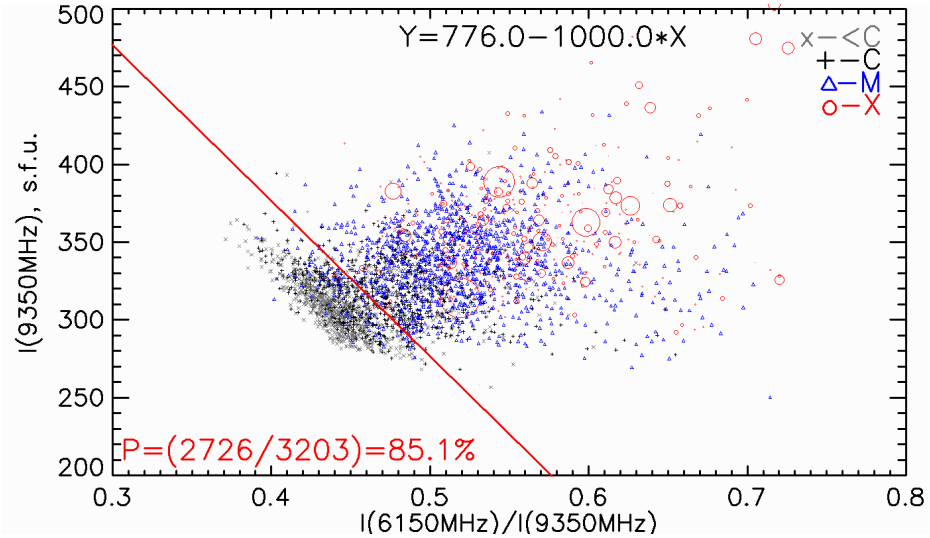


Figure 3 Dependence for the radio flux at wavelength of 3.2 cm from the ratio of radio fluxes at wavelengths of 4.9 cm to 3.2 cm, taking into account events in the X-ray range.

Conclusions

In this paper, the possibility of forecasting solar flares from microwave observations was considered. Two methods of forecasting were used: by the Ermoshenko criterion and by the Tanaka–Enome criterion. The results indicate the importance of observations in the radio range for studying the nature of flare activity. Radio observations make it possible to obtain reliable criteria for the prediction of powerful solar flares. The reliability of the forecast was estimated from the diagram of the total flux of radio emission at a wavelength of 4.9 cm from the total area of the sunspots (the Ermoshenko criterion) with a separating line given by the equation:

$$S_{\mathrm{KislSpotArea}} = 72.2 \cdot (I_{6150\,\mathrm{MHz}} - 146). \tag{2}$$

The reliability of this forecast is 80%. The forecast of solar flares according to the diagram of the radio flux by 4.9 cm and the ratio of the fluxes 10.7 to 4.9 cm with the separating straight line:

$$I_{6150\,\mathrm{MHz}} = 374 - 390 \cdot \frac{I_{2800\,\mathrm{MHz}}}{I_{6150\,\mathrm{MHz}}}, \tag{3}$$

gives the reliability of the forecast with a probability of 86.4%. The forecast of solar flares, according to the data observed only by Kislovodsk Astronomical Station, on the diagram of the radio flux of 4.9 cm and the ratio of the fluxes of 4.9 to 3.2 cm with the separating line:

$$I_{9350\,\mathrm{MHz}} = 776 - 1000 \cdot \frac{I_{6150\,\mathrm{MHz}}}{I_{9350\,\mathrm{MHz}}}, \tag{4}$$

has a forecast reliability of 85.1%. The reliability of the forecasts obtained allows us to speak about the possibility of predicting the solar flare activity from the microwave radiation data obtained at the Kislovodsk Astronomical Station.

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