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Forecasting of Solar Flares According to the Maximum Brightness Temperatures in the Period of 2011–2015

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The main aim of our investigation is the search for new signs to predict solar flares. There are at least two ways to find such signs. The first one is statistical, where it is necessary to analyze a number of active region (AR) physical characteristics (area, full fluxes, spectra, etc.) and find correlations between some physical parameters and the flaring activity of the ARs. The other way is the deep analysis of ARs (specrum types in microwaves, polarization configuration of microwave sources, complexity of photospheric magnetic fields, etc.) to find the physical reasons of flares. The increased brightness of microwave radiation in 2011–2015 is considered as a preflare sign in this paper. There are a number of signs of preflare active region activity both in the optical and radio bands. An example of the preflare sign is the degree of complexity of photospheric magnetic fields in the AR. In microwaves, it is possible to estimate the radio emission flux from the AR or the brightness of radio emission sources at one or several frequencies. This paper analyzes the increased brightness of microwave sources in the 24th cycle of solar activity and the full microwave fluxes of ARs using the RATAN-600 data. It is shown that some ARs with high brightness temperatures generate a number of powerfull (M and X class) flares and also that the spectra of full microwave fluxes of the AR in the case of NOAA 12192 have features of high flare activity.

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1. Introduction

As the data about the brightness of microwave radiation, we use the data from the Nobeyama Radioheliograph (NoRH) [1] for the intensity of radio emission at a wavelength of 17 GHz. The summary is listed in Table 1 and shown in Fig. 1. The maximum brightness values significantly exceed the average and median levels, while the minimum brightness does not differ that much from the average values. The RATAN-600 data [2] are used as a detailed description of the revealed cases of increased brightness, since they allow us to analyze the ARs in a wide range of radio wavelengths both in intensity and polarization with an acceptable angular resolution [3].

Table 1: The maximum, minimum, and median brightness temperatures per year (the NoRH data at 17 GHz)

Year	Median, K	Min, K	Max, K
2011	40377	16767	741425
2012	45044	18097	1259250
2013	45530	20111	1581841
2014	68566	20419	4120619
2015	41938	19755	1126015

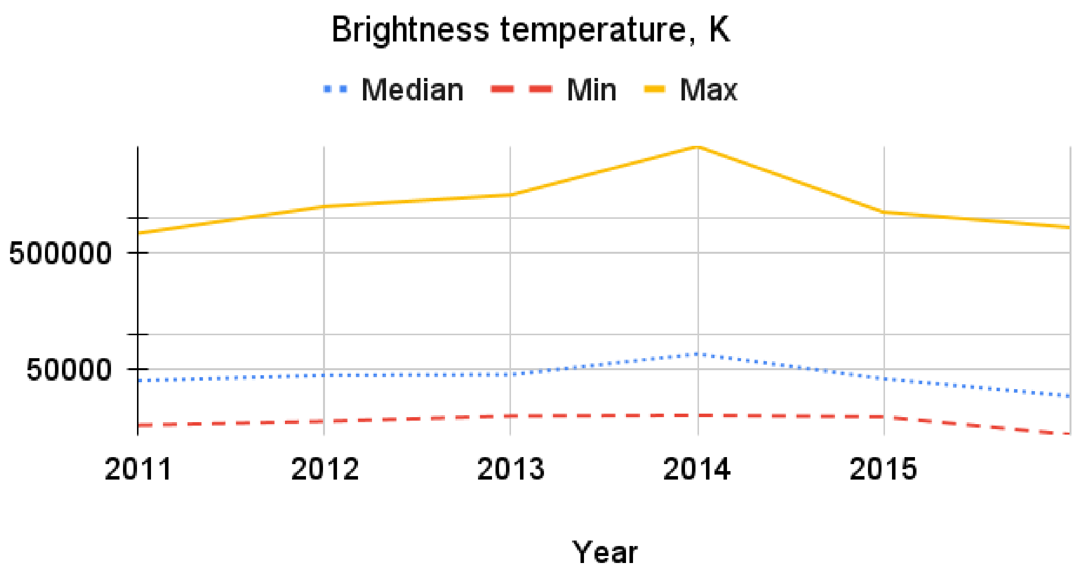

Figure 1: Time series of the maximum, minimum, and median brightness temperatures at 17 GHz (NoRH data).

2. Analysis of observations

We will consider the brightness temperature maxima per year. Although there are maxima of the second and other orders, which are also of interest, discussion of them is beyond the scope of this work.

The strongest peak of 2011 at more than $7 * 10^5$ K was on 25 September in NOAA AR 11302, which had been on the solar disk approximately from 23 September to 4 October 2011 and by 25 September had given at least nine M-class flares, one X-class flare, and many C-class flares.

The maximum brightness temperature of more than $1.2*10^6$ K was in 2012 in NOAA AR 11515, which produced at least six M-class flares and many C-class flares.

A brightness temperature of more than $1.5 * 10^6$ K was observed in NOAA 11748 on 13 May 2013. This region produced at least three X-class flares, one M-class flare, and many C-class flares. However, it was located at the disk edge at the moment of maximum brightness temperature, therefore a more detailed analysis using the RATAN-600 spectral complex was difficult due to the projection effects.

The case of 2014 is one of the most significant, so we will analyze it in more detail. The maximum brightness of the NOAA 12192 microwave radiation of more than $4 * 10^6$ K was recorded on the NoRH on 28 October 2014. The NOAA AR 12192 had been on the solar disk at least from 18 October 2014 to 31 October 2014. Before and after the maximum brightness temperature (27 and 28 October), this AR produced at least one X-class flare, six M-class flares, and many C-class flares. The list of flares identified with this AR during its passage across the solar disk is shown in Table 2. This AR should be considered especially flare-productive.

Table 2: NOAA 12192 flares history

Date	Flares count (ALL)	Flares count (M+X)
18.10.2014	9	0
19.10.2014	7	1
20.10.2014	11	4
21.10.2014	0	0
22.10.2014	5	3
23.10.2014	4	1
24.10.2014	4	0
25.10.2014	7	0
26.10.2014	13	4
27.10.2014	17	8
28.10.2014	6	2
29.10.2014	9	5

Since NOAA 12192 had been observed on the solar disk from edge to edge and was relatively isolated from other ARs falling into the RATAN-600 knife-edge beam pattern [6] (the RATAN-600 NOAA 12192 scans with the HMI magnetogram are shown in Fig. 2), it was interesting to see its spectral dynamics in the microwave range (the RATAN-600 microwaves spectra of NOAA 12192 are shown in Fig. 3). This can be useful in terms of forecasting flare activity. According to the Tanaka–Enome criterion (TEC) [4, 6], NOAA 12192 is a flare productive AR. Figure 3 shows the full fluxes ($F_{10\ GHz} > 10 s.f.u.$, $F_{10\ GHz}/F_{3\ GHz} > 1$), and Fig. 2 shows the polarization configuration

(P-type). The time series of the NOAA 12192 full fluxes (Fig. 4) at several wavelengths show a fast increase at 9.7 GHz and 11.9 GHz compared to the slow increase at lower frequencies, which should also indicate an increase in flare activity.

The brightness maximum of 2015 took place on 21 June. The maximum was more than $1.1 * 10^6$ K for NOAA AR 12371 [5], in which at least two M-class flares occurred from 17 June to 21 June 2015, and from 21 June to 29 June another five M-class flares as well as many C-class flares. If we take a full rotation of the Sun, at the place of NOAA 12371 another more dispersed NOAA AR 12388 appears. Presumably this is the preserved and depressed NOAA 12371. Thus, this region is a fairly flare-productive stable AR with a complex structure of the photospheric magnetic field.

3. Conclusions

The maximum annual increased brightness of 17 GHz microwave radiation sources was found in those ARs that produced powerful M and X-class flares as well as many C-class flares (which is also an indicator of increased flare productivity). This may be one of the indications to predict flares in ARs at microwaves. For more effective forecasting, apparently, one should consider several forecasting signs as well as take into account the current state of the solar cycle [6]. RATAN-600 observations and more detailed data about ARs such as full fluxes spectra, degree of polarization, polarization distribution, etc. give more information about AR activity.

4. Acknowledgements

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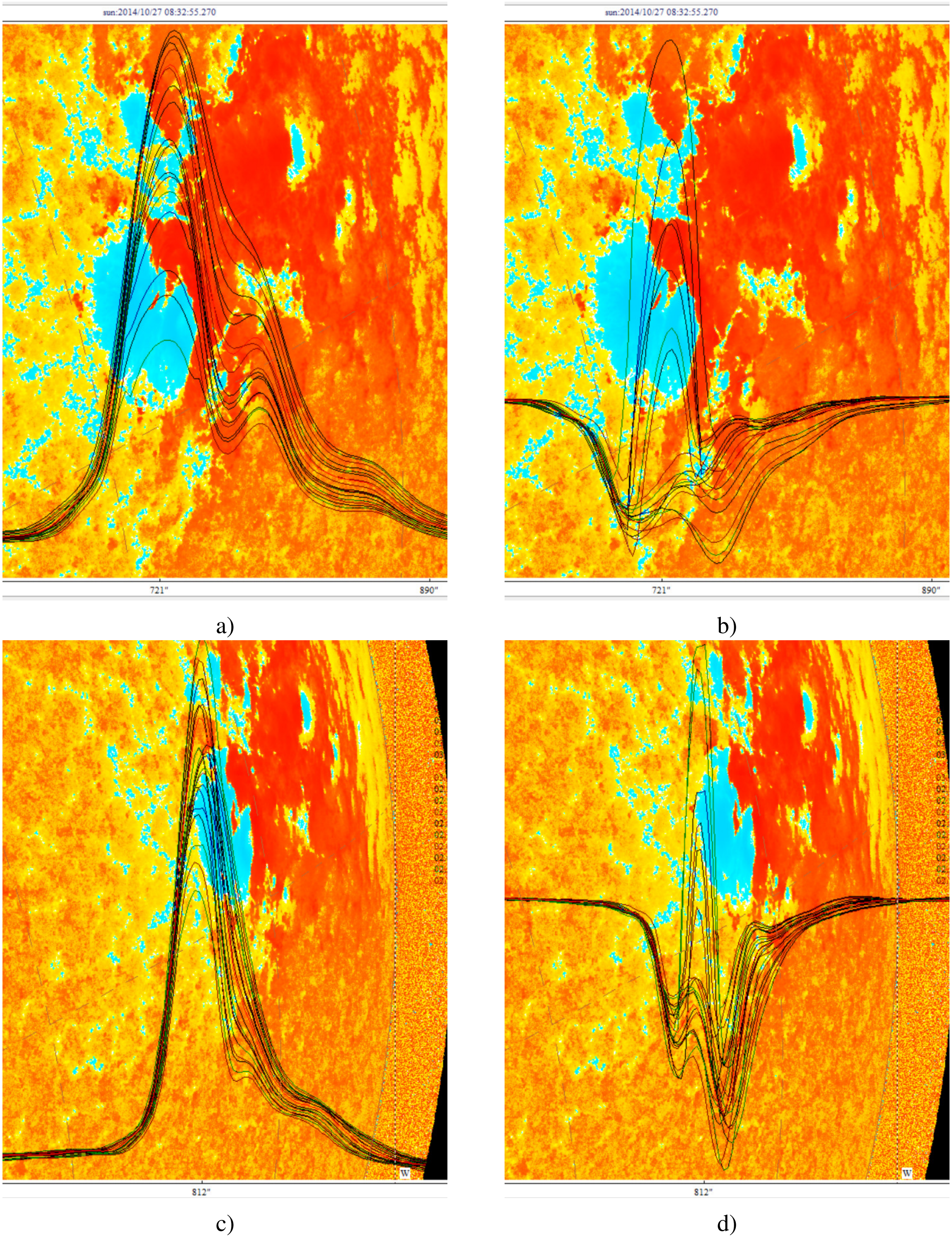

Figure 2: The NOAA 12192 HMI magnetogram along with the RATAN-600 data (9–12 GHz). The upper panels: 27 October, a) Stokes I, b) Stokes V. The lower panels: 28 October, c) Stokes I, d) Stokes V.

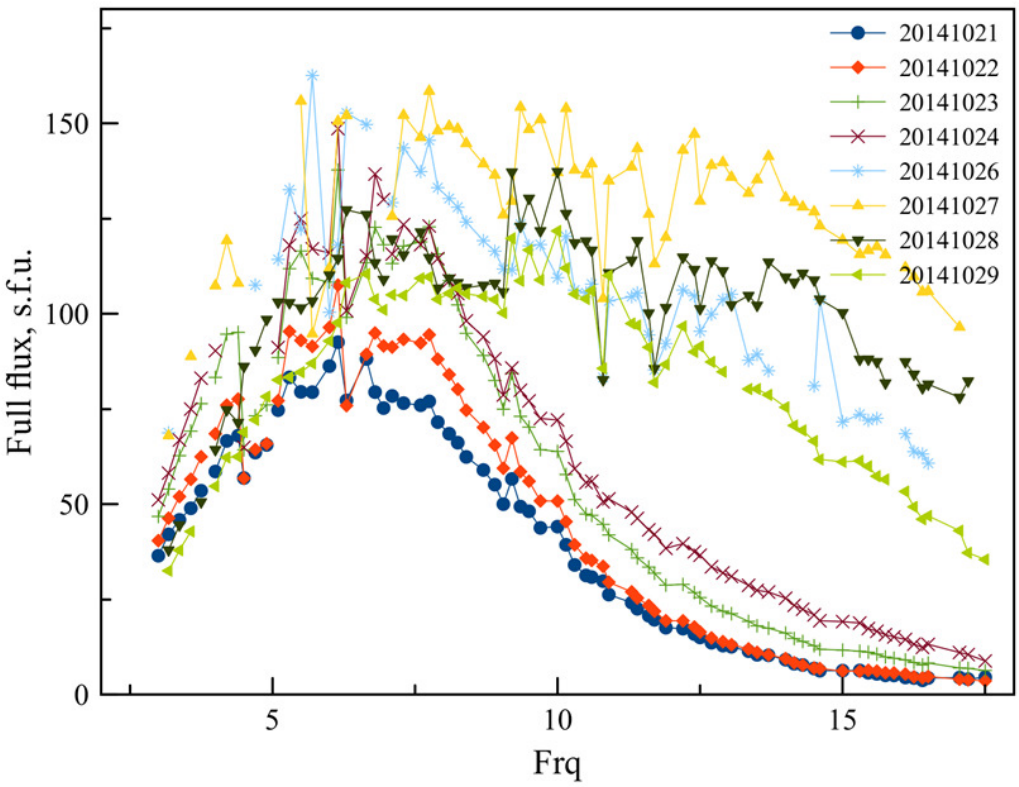

Figure 3: The NOAA 12192 full flux spectra (3–18 GHz).

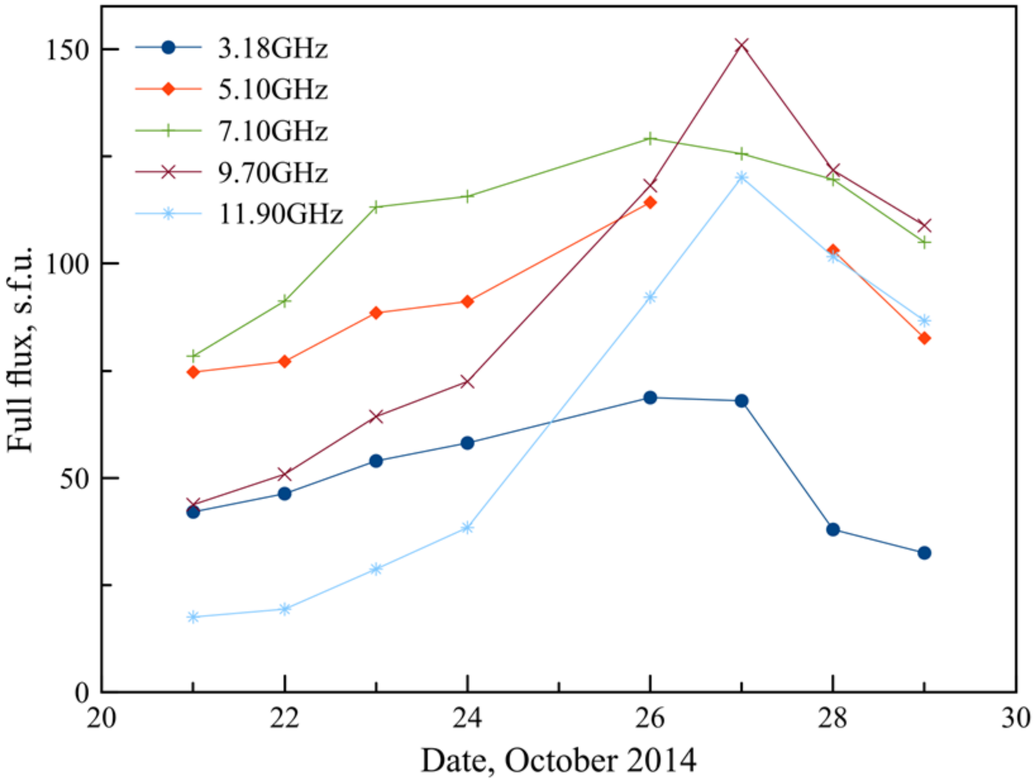

Figure 4: The NOAA 12192 time series of the full fluxes at 3.18, 5.10, 7.10, 9.70, and 11.90 GHz.