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A method to reveal and catalog solar flares observed with the Siberian Radioheliograph: first results

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Abstract. We present the first results of our work on creating a catalogue of solar flares observed with the Siberian Radioheliograph (SRH). A technique to find possible solar flare events has been developed. This technique is based on the analysis of the derivatives of temporal profiles and allows one to identify the start, peak, and end moments of events of various intensities. We tested this technique using time profiles of solar soft X-ray emission, which is currently the main indicator of solar flares. The results of the testing of the technique has shown good detection of flare events for one-dimensional data. As the SRH is a multi-frequency instrument, the technique has been improved by adding the ability to automatically identify events based on the simultaneous response at different frequencies.The method was tested to detect solar flares observed with the SRH in the 3–24 GHz range. In total, we revealed about 600 events of various importance classes during the summer months of 2023 and about 300 solar flares occurred in May 2024. The developed software allows one not only to reveal the onset and end of a flare but also provides dynamic spectra that can be used for further analysis of the event.

Keywords: Sun: flares; catalogs

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1 Introduction

The volume of the observed solar data is increasing dramatically due to the development of new instruments with high temporal resolution for a wide range of the electromagnetic spectrum. This has led to the need for automated and reliable event detection in large data streams and cataloguing of the events. Nowadays, the techniques to automatically search for and identify solar flares are applied to data from several instruments. The most well-known of them is the soft X-ray emission temporal profiles obtained with the Geostationary Operational Environmental Satellite (GOES). The technique identifies solar events using observations in the 1–8 Å spectral band, which are simultaneously used to classify solar flares.[1] The GOES flare event catalogue provides valuable information for both solar physics and the studies of geoeffective events, but it should be noted that in some cases weak or slow-developing events may be missed in this catalogue. The other example of an X-ray solar flare emission catalogue is the Konus-Wind (KW) instrument database of solar flares (Lysenko et al. 2022). The catalogue presents the events that were observed by the KW instrument in trigger mode with high temporal and spectral resolution. Thus, slowly developing and weak events are still not included in the event list. The catalogues of solar flares observed with the Nobeyama Radioheliograph and Nobeyama radio polarimeters provide microwave observations.[2] However, both lists appear to be incomplete, as some weak events may have been missed.

The start of the observations with the Siberian Solar Radioheliograph (SRH, Altyntsev et al. 2020) has shown the possibility to observe events of different power and duration within the 3–24 GHz range with high spectral and temporal resolution. The aim of our study was to develop an original technique to automatically detect the events in the multi-frequency data obtained with the SRH.

2 Algorithm description and testing on the GOES data

The developed technique is based on the analysis of time profile derivatives. The time profile at any spectral band can be represented as a continuous numerical function on a uniform time scale. As the 1D evolution of a solar flare is described as a sudden increase in flux followed by a continuous decrease, we can use the derivative to determine the start, maximum, and end of the event. At the first step, we calculate the standard deviation (σ) of the time derivative profile for a time interval without events. If time derivatives are greater than 3σ, we assume that the signal is an event.

[1] https://www.swpc.noaa.gov/products/goes-x-ray-flux
[2] https://solar.nro.nao.ac.jp/norp/html/event/

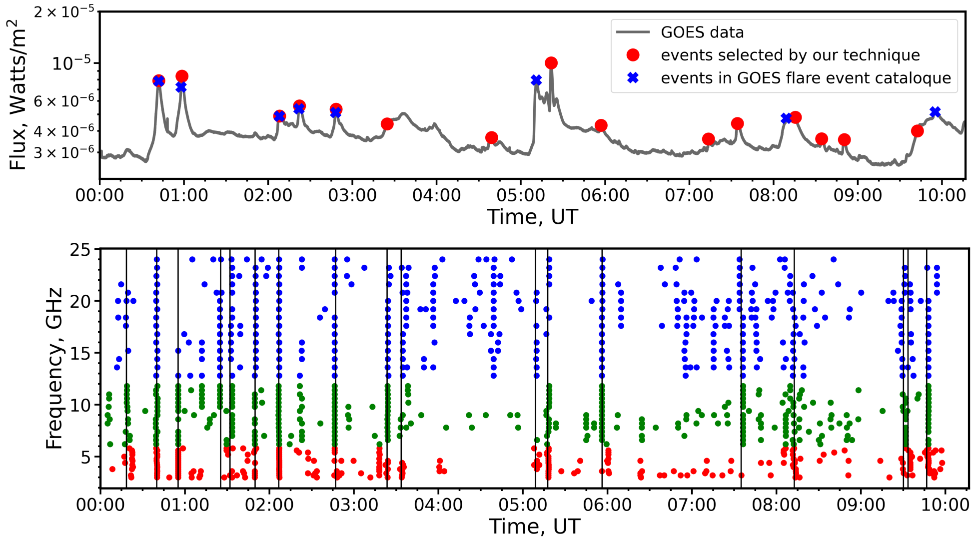

Fig. 1. Top: results of flare event detection in X-ray emission. The grey line is the 1–8 Å temporal profile on July 13, 2023. The blue marks indicate the events from the GOES flare catalogue, and the red marks show the results derived using our technique. Bottom: a chart of microwave bursts detected with the SRH within the 3–24 GHz range on July 13, 2023. The red, green, and blue colors mark the 3–6 GHz, 6–12 GHz, and 12–24 GHz arrays. The vertical lines show the selected events.

The start of the event is defined as the timestamp when the derivative has changed from the noise level to a positive value, indicating a sharp increase in the signal. The end of the event is the moment when the derivative changes from negative to the zero level, indicating the end of the decay phase. The peak of solar flares is calculated as the maximum of the time profile between the start and end moments. We tested the technique using the temporal profile of the 1–8 Å X-ray band obtained by GOES on July 13, 2023. The catalogue provided by the GOES team listed 8 events between 00:00 and 10:15 UT. Our method revealed 15 solar flares of different intensities, including some weaker events that have been not included in the GOES flare catalogue (see Fig. 1, top panel). Thus, the developed technique is effective for flare event detection and can find both powerful solar flares and the A and B class events.

3 SRH data testing and the results

The Siberian Radioheliograph is a multi-frequency interferometer consisting of three independent antenna arrays: 3–6 GHz, 6–12 GHz, and 12–24 GHz (Altyntsev et al. 2020). For solar event detection in SRH observations, we used the so-called correlation plots, which are the temporal profiles of the sum of correlation coefficients between antenna pairs. These values are more sensitive to the occurrence of weak bursts than the usual flux (Lesovoi & Kobets 2017). As the SRH is a multi-frequency instrument, we need to improve the technique by adding the ability to automatically identify events using the results obtained from temporal profiles at each frequency. In most cases, a burst seen at a single frequency or a narrow-band burst can be a feature of non-solar signals or artifacts. Thus, we used the condition that a solar flare burst must be recognized simultaneously at at least 15 frequencies, and at least five frequencies should be in two different antenna arrays. This condition strongly limits the number of flare events. To keep the information about other possible events, we provide the information about all the revealed peaks in the chart. The peaks of the bursts related to the same event may not coincide at different frequencies. This can be due to both the features of SRH observations and the physical factors. Therefore, we assume that the bursts at different frequencies belong to the same event within an interval of 200 seconds. The example of a chart for the observation on July 13, 2023 is shown in Fig. 1 (the bottom panel). One can see that 18 events have satisfied the strict selection criteria and some of the events are weak and almost unrecognisable in X-rays.

The start and end moments of the events allow us to reconstruct the dynamic spectra of selected events using both correlation plots and fluxes in sfu (solar flux inits). These spectra provide information for further studies and allow us to obtain preliminary information about the spectral properties of a flare. In total, we have revealed about 600 events of various classes of importance during the June–September period of 2023, and about 300 solar flares occurred during May 2024.

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