ISRO'S WEB-BASED AUTOMATIC IDENTIFICATION OF SOLAR BURSTS IN X-RAY LIGHT CURVES

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Abstract

Electrically charged gases on the Sun's surface generate zones of strong magnetic fields. Sun's gases are constantly moving, tangling, stretching, and twisting the magnetic fields. This motion generates enormous activity on the Sun's surface. At times, the Sun's surface becomes tremendously active. At other times, the atmosphere is a little more subdued. Solar flares are the most violent events that occur in our solar system. A solar flare is a powerful blast of radiation caused by the magnetic energy released by sunspots. Flares occur when the Sun's highly entangled magnetic fields change from poloidal to toroidal. As with a rubber band, tangled magnetic fields release energy when they snap. Solar flares are commonly visible because to the broad spectrum of light they emit. Solar flares must be regularly studied since their intensity provides insight into the sun's activity, which has a direct impact on Earth. X-rays and optical light are commonly used to monitor flares. We employed the light curve of solar data in the X-ray region to identify solar flares autonomously in this manner. To recognise various solar flare properties automatically, we combined a statistical model with a few machine learning techniques.

1 Introduction

Solar flares occur when magnetic energy accumulates in the solar atmosphere and must be released. There are these three steps involved in a typical flare:

1. In the first stage—the precursor stage—the release of magnetic energy is triggered. This stage will be used to detect soft x-ray emission.

2. Electrons and protons are accelerated to energies significantly during the second stage—the impulsive stage. This step results in the emission of X-rays, radio waves, and gamma rays. In this technique, we are using only the X-rays data to detect the flares.

3. The third and final stage is called decay. Soft X-rays are identified during this stage due to their progressive accumulation and decay.

Solar flares go through several stages, and there is no accurate way to forecast their strength or duration. Each of these stages might last anywhere from a few seconds and an hour. Solar flare statistics can be generated by detection of sudden impulsive increases of the soft X-ray intensity in light curves. Here, we develop an automated flare detection algorithm that allows us to analyze the time series data of light curve.

Since the Sun is an active ball of gases, there is always some energy releasing from the surface of it. But, there is a very sudden change in flux when a solar flare takes place. This energy change remains almost constant in the absence of the solar flare. We have used this feature to detect solar flares.

2 Solar Flares feature extraction

In order to determine the characteristic features of solar flares, we will require the rise time i.e.; the time when the flare started taking place, the peak time i.e.; the time when flux from the flare is at peak, the end time i.e; time when flux from the flare becomes zero etc. Here are the steps we have involved to extract these features:

2.1 Re-binning of data

First of all, we are re-binning the time steps to $\Delta t = 60s$ by the median value during each bin. Thus, the daily record has the number of n_{bin} equal to $86400/60 = 1440$ data points.

2.2 Noise level or threshold

We have taken the median of fluxes during quiescent time periods to find a noise level of $f_{noise} \approx 4.7 \times 10^{-8} Wm^{-2}$ and define a corresponding threshold level of $f_{thresh} = f_{noise}$.

2.3 Smoothing of light curve

The smoothing of the re-binned light curve was accomplished by the use of the boxcar technique with $nsm = 10$ time bins.

2.4 Detection of maxima and minima

We now identify all of the smoothed light curve's local peaks and minima (consecutively in daily intervals). The flux maximum times t_i correspond to probable flare peak time, while the flux minimum times t_{i-1} and t_{i+1} correspond to flare start and finish time, respectively.

2.5 Flare event detection

The light curve is composed of several flux shifts. Flares are characterised by the following characteristics:

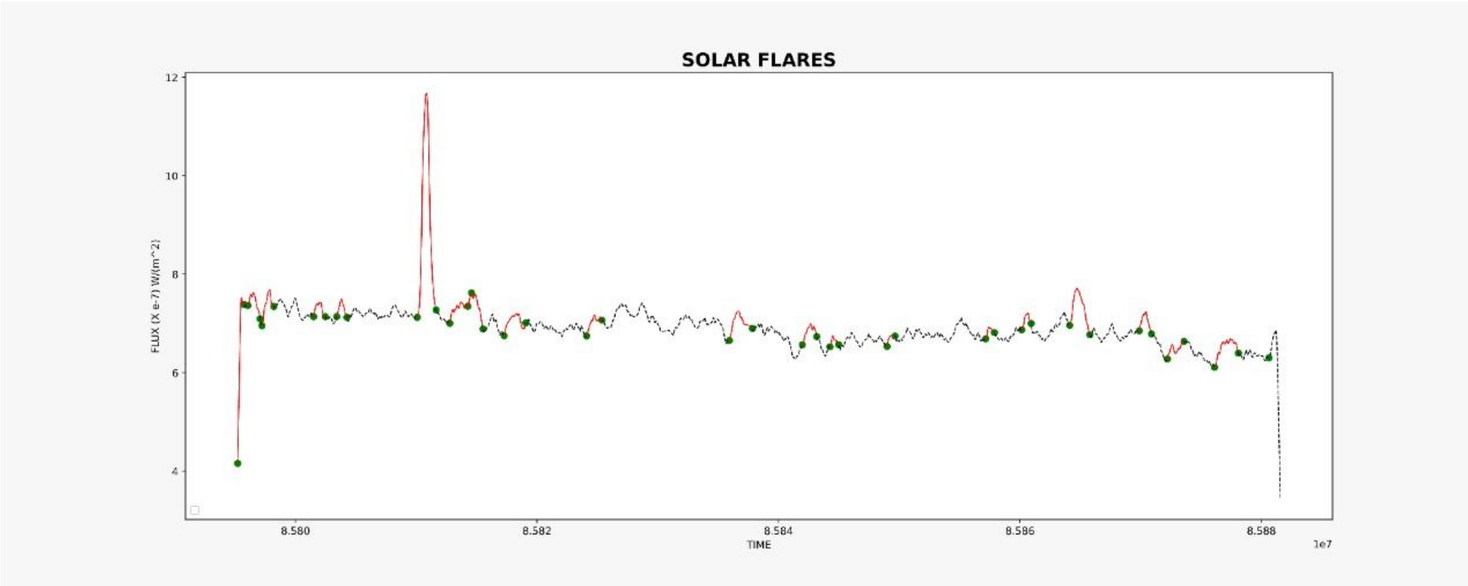
1. The flare begins at a flux minimum time t_s, where a preflare background f_{BG} is generated from the median flux of time interval $[t_s - \Delta t_{BG}, t_s]$. In this case, we used a time interval of $\Delta t_{BG} = 300$ seconds to calculate background flux, which translates to $n_{bin} = 300/60 = 5$ bins. Now, here a problem arises that there may be the case when the particular flare is already preceded by some flares especially in case when solar activity is high. So, here, taking median will give the median of fluxes of preceding flare instead of background, so to solve this issue, we put a condition that if the median of fluxes is more than five times of preceding background flux, then we take background flux of this flare as that of previous background flux (without updating the background of this flare).

2. The flare ends at the first subsequent flux minimum time t_e, when the flux drops below the level f_{BG}, now here too, in case when some other flare is happening when a flare is ending, then the flux level will not touch the background, so, in this case we extrapolate the decay of this flare and rise of subsequent flare to find the ending and rising time of this and the next flare respectively.

3. The peak flux value f_p occurs at time t_p during the intermediate time interval $t_s < t_p < t_e$. Now, to find the flare peaks, our algorithm searches for consecutive increases of four points such that count rate of 4_{th} point is greater than or equal to 1.04 times that of first point. Then, we search for three consecutive decreasing points after above fourth point and then the global maximum between those points is used to calculate the peak flux of that flare.

4. The background-subtracted peak flux is $F = f_p - f_{BG}$.

For the duration flare event, we extrapolate the curve at the beginning and at the end of a flare to the f_{BG} level in case it is preceded or followed by some other flare. Now, as we know that the observed burst has a fast rise and slow decay shape. The fast rise follows the linear form while the slow decay shape follows the power-law function ($f(x) = at^{-k}$). We have fitted the function according to the given data and found out the parameters of these two forms for every flare and then we found out the duration of rising and decay times by extrapolating the curves to f_{BG} level.



3 Classification of Flares

We classify the solar flares on the basis of the peak flux value as following:

- A class: When peak flux value ranges in the order of $10^{-8} W/m^2$ or less
- B class: When peak flux value ranges in the order of $10^{-7} W/m^2$
- C class: When peak flux value ranges in the order of $10^{-6} W/m^2$
- M class: When peak flux value ranges in the order of $10^{-5} W/m^2$
- X class: When peak flux value ranges in the order of $10^{-4} W/m^2$ or more

Now, we have tried to further sub classify these classes with an additional digit, like a C3-class flare has a peak flux value of $3 \times 10^{-6} W/m^2$.

4 Use of Fit Parameters

The use of peak flux values can serve as a warning; for example, if it exceeds a specific level, we can trigger the satellite's protection mechanism or something similar in order to avoid damage to the satellite's electronics.

We used the A, B, C, M, and X classification criteria because they provide a direct indication of the strength of the solar flare, both qualitatively and quantitatively, and also allow for easy comparison of the strengths of solar flares, for example, an X3 class flare is five times stronger than an M6 class flare.

5 Limitations of our method

If a solar flare lasts shorter than seven minutes, it is unlikely to be spotted, as we first re binned to 60 seconds and then searched for four growing and three declining spots, as previously explained. Using the box car average method did result in a tiny reduction in our peak flux value. Time complexity is high for high time scale data. Detailed explanation of equation is more complex in real than it is in proposed in the mail.

6 Conclusion

Solar flares are the most violent events that occur in our solar system. We constantly study flares because their magnitude provides insight into the sun's activity, which has a direct impact on the Earth. We developed an automated identification method for solar flares using this technique by evaluating light curves. By flattening background energy variations, we refined the quality data for the flares and determined the fit parameters such as rise time, peak flux, and decay time for each flare by extrapolating the entire curve using a Gaussian equation for the rising half and using a power-law equation for the decay half curve. Additionally, we categorised each flare according to its peak flux.

References

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