Real-Time GOES-R XRS Solar Flare Location Data Product

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1 Introduction

Solar flares can be correlated with geoeffective (i.e. earth-directed) coronal mass ejections that cause a variety of terrestrial space weather effects. They have a detrimental impact on high frequency radio communications on Earth. To assess these risks, the X-Ray Sensors (XRS) on Geostationary Operational Environmental Satellites - R Series (GOES-R)[3] monitor solar X-ray irradiance for space weather forecasters to provide early warnings of solar flares.

Additionally, XRS quadrant photodiode measurements are used to determine accurate real-time solar flare locations for space weather forecasters to assess the risks to Earth.[4]

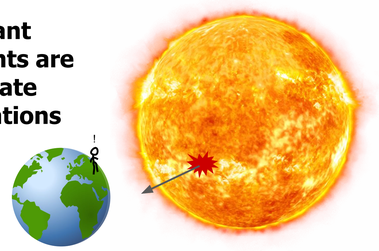

Figure 1: Cartoon depicting a solar flare and associated geoeffective CME near the center of the solar disk as seen from Earth.

2 Flare Location Algorithm

The flare location algorithm uses measurements based on the relative flux from the XRS-B2 quadrant photodiode detector (Figure 2).

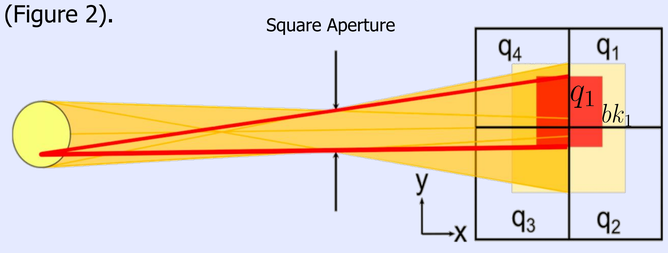

Figure 2: Cartoon detector with labeled quadrants observing a flaring sun. Displays background X-rays from the sun (yellow) and a solar flare (red).

- First, the background (bk_i, the flux when a flare begins), is subtracted from the flux in each quadrant during a flare (q_i).

$$Q_i = q_i - bk_i$$

- The x and y coordinates are found by weighting each quadrants' corrected signal (Q_i) and finding the weighted center of the flare signal on the sensors.

$$x = \frac{(Q_1 + Q_2) - (Q_3 + Q_4)}{Q_{sum}} \qquad y = \frac{(Q_1 + Q_4) - (Q_2 + Q_3)}{Q_{sum}}$$

- These weightings give an (x,y) location corresponding to a location of the solar flare on the Sun.

3 Location Validation

To provide error estimates, XRS locations are cross referenced and validated with the SDO AIA flare location list.*

Figure 3 plots XRS flare locations and their true SDO AIA locations on the Sun. **XRS can locate C-class and larger flares on the solar disk with a median error of < 1 arcminute for GOES-16.**

*Heliophysics Event Registry (www.lmsal.com/sungate/)

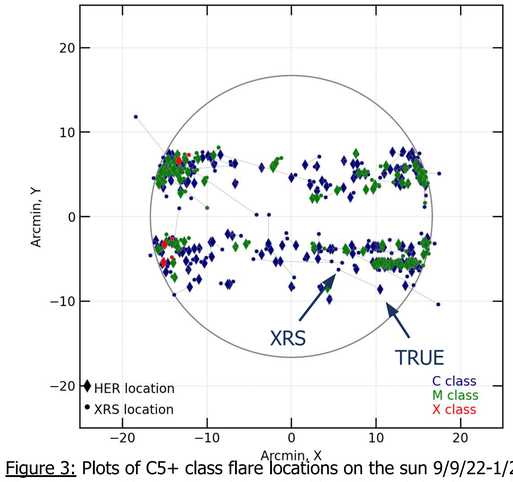

Figure 3: Plots of C5+ class flare locations on the sun 9/9/22-1/26/23. The circles are the location determined by XRS and the diamonds are the true location– they are connected with a thin line to indicate error.

4 Multiple Flare Correction

- Flares with large errors in Figure 3 are typically overlapping flares, and can be difficult to locate.
- Flares that overlap previous flares make up 12% of events.
- For subsequent overlapping flares, the background is inflated because it is defined near a flare's start (Figure 4).
- Replacing the overlapping flare's background with the first flare's background improves location accuracy.

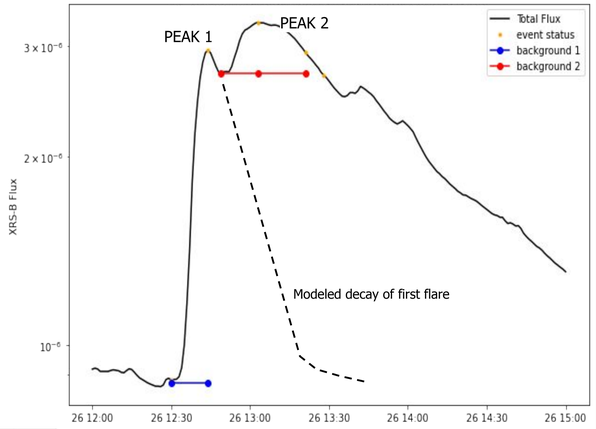

Figure 4: Total flux into XRS quadrants during a double flare. First correct background in BLUE and next biased background in RED.

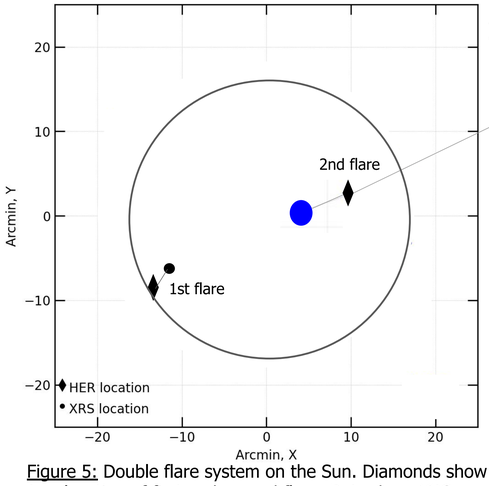

Figure 5: Double flare system on the Sun. Diamonds show *true* location of first and second flare. Dots show *XRS* location. RED before correction and BLUE with improved background correction.

Background Correction Details

For an overlapping flare set, we use the first flare's background (Figure 4 blue line) instead of an overlapping flare's background (Figure 4 red line). This switch reduces median overlapping flare location error by 28%. Figure 5 displays a before and after the correction. The location error is significantly less when using the modified background.

This background correction does not take into account the decay of the preceding flares (dotted line Figure 4), so locations will still be biased. Yet, this correction can provide reasonable estimates for real-time multi-flare locations.

5 XRS Flare Location Efficiency

Initial specifications for the GOES-R XRS solar flare location data product required we achieved an X-class flare location accuracy of < 5 arcmin. **Our results consistently exceed that precision, including when there are multi-flare events.**

The median location error for large M and X-class flares is less than 1 arcminute (red box in Table 1). For reference, the solar radius is ~16 arcminutes.

Table 1: Statistics for flare location product GOES-16 2/17/2017-8/20/2022

Class	No. of Flares	Median Error (arcmin)
X	12	0.75
M	148	0.36
C	1717	1.01
B	2835	3.94
All	47.12	2.33

The upcoming revision to the algorithm's background correction for multi-flares will result in a 28% improvement in the location accuracy of the second or third consecutive flare after a C-class or above flare.

GOES-R space weather data and User's Guides including the flare location product are available at ngdc.noaa.gov/stp/satellite/goes-r.html

6 Future Improvements

- Apply further multi-flare corrections to account for decay of previous flare
- After, analyze solar flare distribution by flare class. Consider the impact of multi-flare systems in the distributions– are we systematically undercounting small flare numbers?

Acknowledgements

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References

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