RHESSI - GOES Comparisons of Soft X-ray Emission from Solar Flares, 2002 - 2017

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Abstract

This work is a comparison of the low energy (3 to 9 keV) response of the 9 detectors on-board the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) with data derived from the X-Ray sensors on-board the series of Geostationary Operational Environmental Satellites (GOES), for the duration of the RHESSI mission. The purpose is to estimate the loss of sensitivity for each RHESSI detector during the mission, relative to GOES detectors which are expected to be more consistent over time. Comparisons are made during the decay phase of large solar flares, where non-thermal emission from accelerated electrons is expected to be unimportant. These large (GOES class C5+, M, and X) solar flares are present in the RHESSI database from February 2002 through September 2017.

Introduction

Figure 1[1] shows a comparison of RHESSI and GOES photon flux spectra for two flares, one in 2002, and one in 2011. The time intervals were chosen during the decay phases of the flares, at points for which the flare temperatures (approximately 15 MK) are similar. For the 2002 flare the RHESSI flux is higher than that for GOES; for the 2011 flare the opposite is true. It is well known that the RHESSI detectors lost sensitivity (mostly due to radiation damage) during the mission[2]. Here we will calculate the long-term variation of RHESSI sensitivity in a different manner than for the original work described in reference 2, which concentrated on small solar flares at the flare peak, with no attenuators. (RHESSI had 3 levels of attenuation, to increase dynamic range.[3]).

We use time intervals during the decay phase of large solar flares, as in Figure 1, where complications that might rise from the presence of non-thermal emission and/or time-variable background levels are not present.

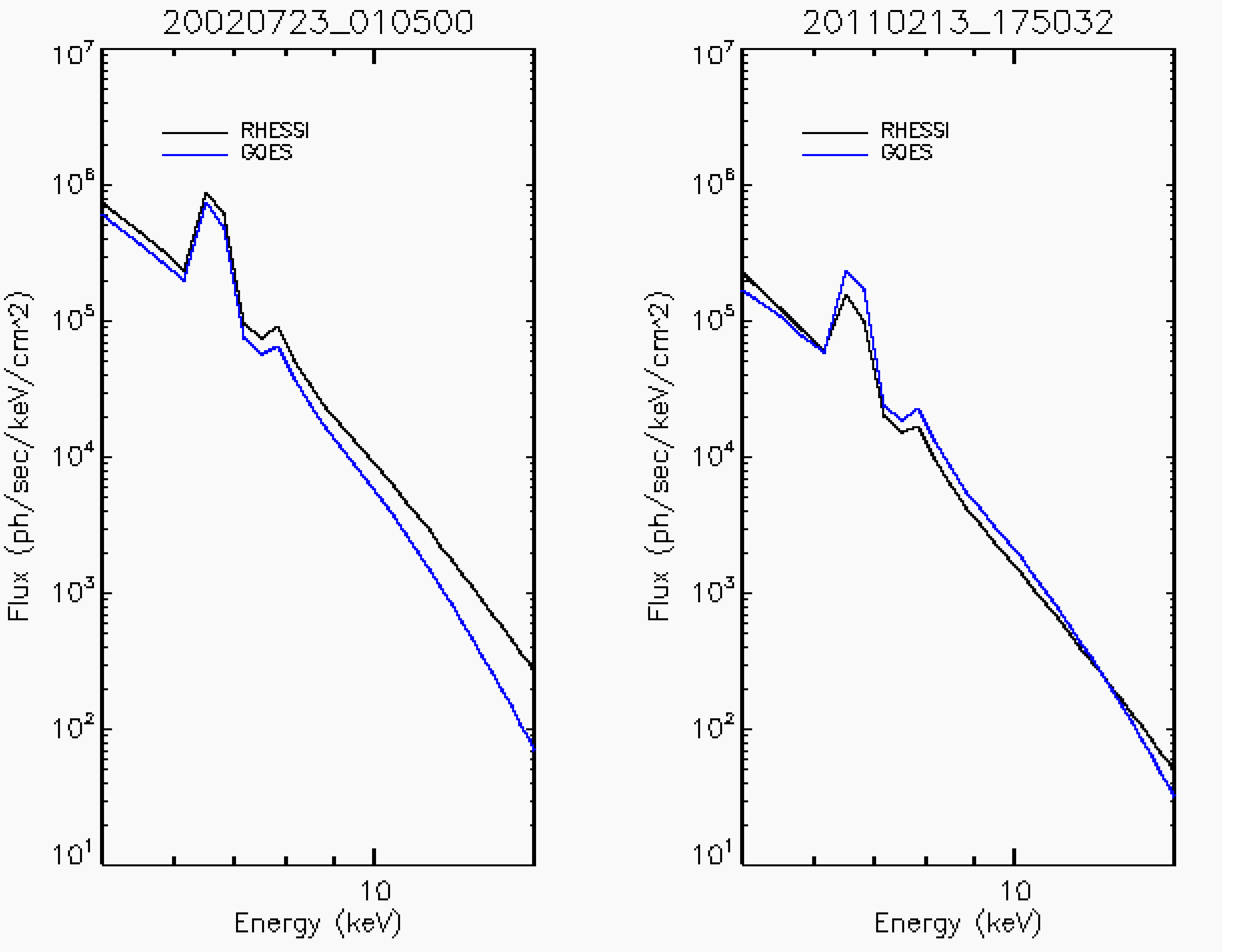

Figure 1: Comparison of photon flux for RHESSI spectral fits (black) with photon flux inferred from GOES-derived T and EM values (blue) for 2002 July 23, 01:05:00 UT to 01:06:00 UT (left) and 2011 February 13, 17:50:32 UT to 17:51:32 UT (right).

Data Analysis

The sample included ~17000 one-minute time intervals from 2068 flares of GOES class C5 or above (GOES Xray flux in the 0.1 to 0.8 nm channel greater than 5×10^{6} Wm^{-2}) from February 2002 to September 2017. For each interval, the GOES temperature and emission measure is obtained[4], and photon flux as a function of energy is calculated. The photon flux is then integrated over the RHESSI detector response to estimate the number of photon counts that the GOES source would generate for RHESSI. Sensitivity for RHESSI, i.e., “how much does RHESSI see relative to how much would RHESSI see for this GOES source” is obtained by dividing the expected GOES values into the observed RHESSI count rate. This is done in the energy bands 3 to 6 keV and 6 to 9 keV for attenuator state 0 (no attenuators), and 6 to 9 keV for attenuator state 1 (thin attenuator present). Values are then averaged over ~80 day time intervals, and normalized by the average from February 2002 to February 2005, to create plots as shown in Figures 2 and 3. The five time intervals during which the RHESSI detectors were annealed (sent to high temperature to fix radiation damage) are indicated on the plots.

Analysis Considerations

The energy responses for RHESSI and GOES have some overlap, but the GOES response is strongest in the energy range less than the 3 keV RHESSI minimum[4]. As a result, the calculated sensitivities depend on the observed temperature and DEM (Differential Emission Measure; the DEM measures how much hot plasma exists as a function of temperature). We do not calculate the DEM here, but we restrict the sample so that the temperature values for both instruments are not too far apart. We require $T_{RHESSI} < T_{GOES} + 5$ MK, to assure that the source is at least somewhat close to isothermal. This is true for ~70% of the full sample.

The GOES values are for different spacecraft: GOES10, 11, 12 prior to December 2009 and GOES 13, 14 and 15 after December 2009. When available, we used GOES 10 and 15 data, which covered most (60%) of the time intervals. When GOES 10 and 15 were not available, we used other GOES, but scaled the values by corrections calculated by comparing GOES 11 and 12 to GOES 10, and comparing GOES 13 and 14 to GOES 15. (Note that all corrections to GOES are of factors less than 1.07, so this had little effect on the final results). We do not have data overlap for any solar flares between the GOES 10,11,12 era and the GOES 13,14,15 era, so a comparison of GOES10, 11, 12 to GOES 13,14, 15 is not available.

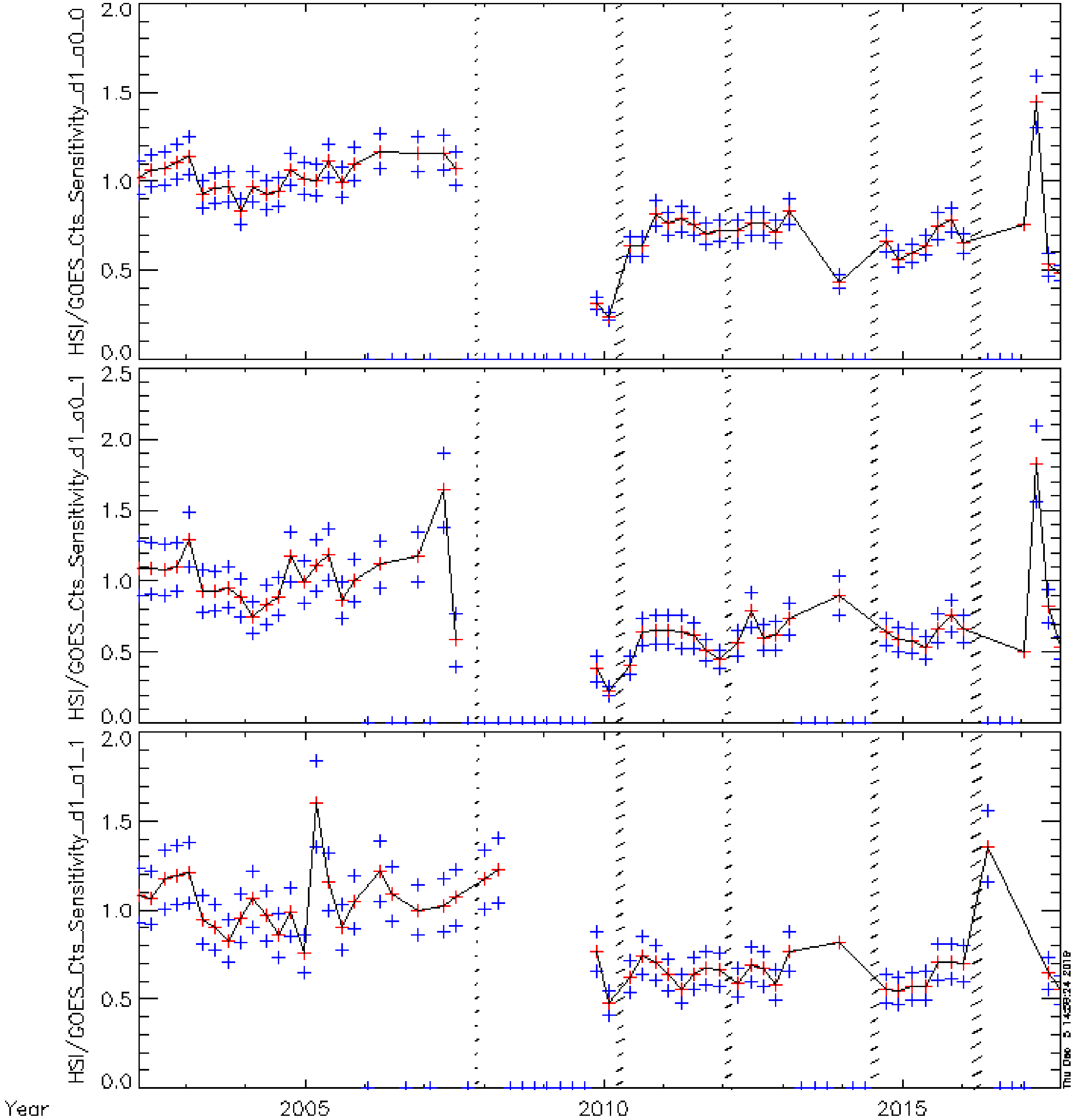

Figure 2: Normalized RHESSI/GOES sensitivity for RHESSI detector 1. The top and middle panels are for the energy bands 3 to 6 and 6 to 9 keV, with attenuator state 0. The bottom panel is for the 6 to 9 keV energy band, in attenuator state 1. Blue plusses show the standard deviation in each 80 day interval. The angled lines overlaid denote anneal periods. Detector 1 shows the least sensitivity loss.

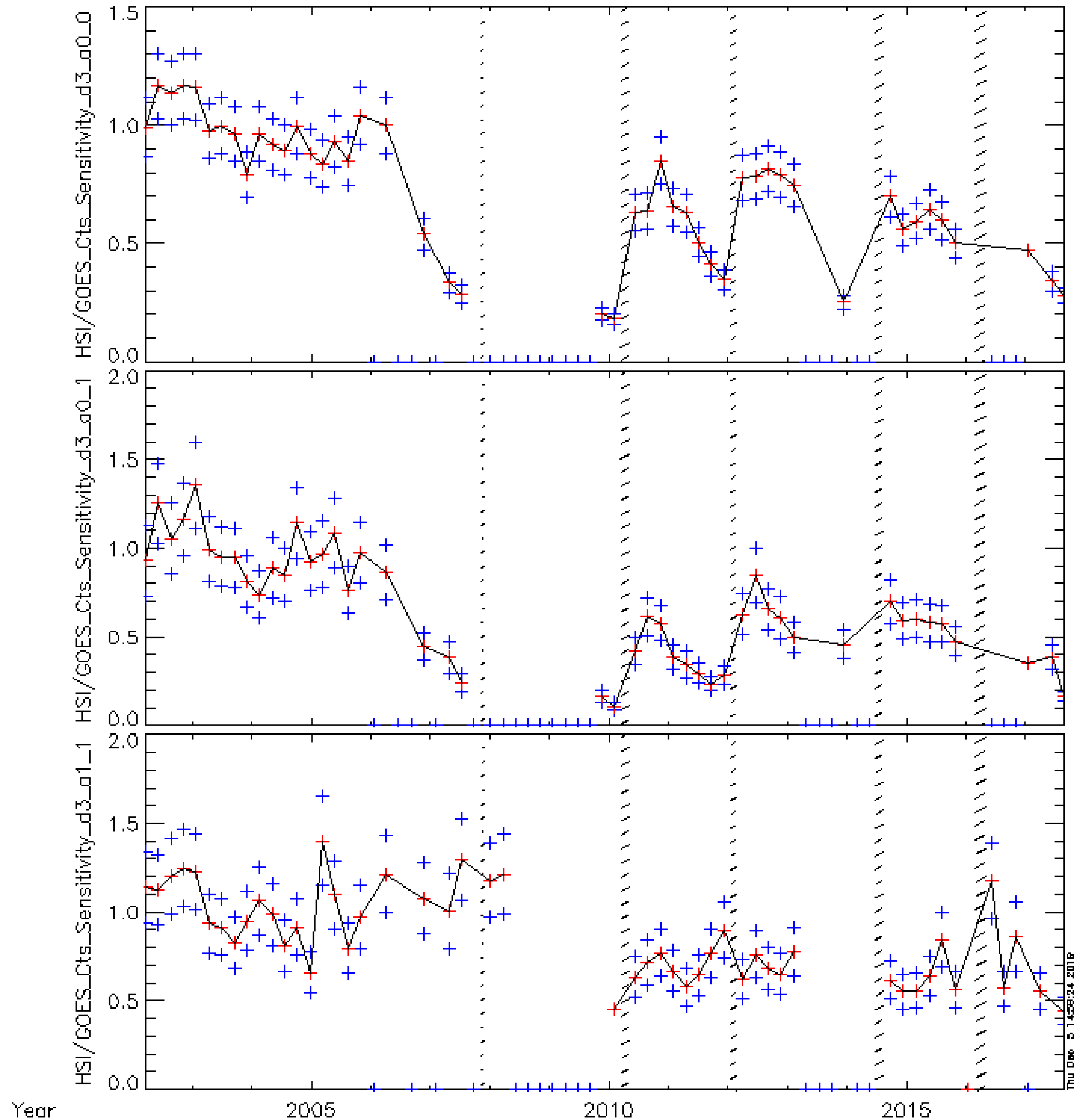

Figure 3: Normalized RHESSI/GOES sensitivity for RHESSI detector 3. The top and middle panels are for the energy bands 3 to 6 and 6 to 9 keV, with attenuator state 0. The bottom panel is for the 6 to 9 keV energy band, in attenuator state 1. Blue plusses show the standard deviation in each 80 day interval. The angled lines overlaid denote anneal periods. Detector 3 shows noticeable sensitivity loss, especially for attenuator state of 0.

Table 1: Values of sensitivity at different times during the RHESSI mission. The columns denote the mission launch, times of the start and end of each anneal period, and the end of useful data for this calculation (RHESSI mission ended in August 2018, but there were no large flares observed post September 2017). The values are for the closest 80 day interval to each time. Entries marked “NA” had no good observed data for the appropriate time interval.

Epoch	Start	Pre Anneal1	Post Anneal1	Pre Anneal2	Post Anneal2	Pre Anneal3	Post Anneal3	Pre Anneal4	Post Anneal4	Pre Anneal5	Post Anneal5	End
	12-Feb-2002	05-Nov-2007	29-Nov-2007	16-Mar-2010	01-May-2010	17-Jan-2012	22-Feb-2012	26-Jun-2014	12-Aug-2014	23-Feb-2016	29-Apr-2016	01-Oct-2017
DET 1 ATT 0	1.09	0.59	NA	0.22	0.4	0.45	0.57	NA	0.64	0.67	NA	0.53
DET 1 ATT 1	1.08	1.07	1.17	0.48	0.63	0.66	0.59	NA	0.56	0.7	1.36	0.55
DET 2 ATT 0	NA	0.03	NA	NA	0.45	0.42	NA	NA	NA	NA	NA	NA
DET 2 ATT 1	1.88	1.56	1.73	0.04	0.63	0.78	NA	NA	NA	NA	NA	NA
DET 3 ATT 0	0.93	0.24	NA	0.11	0.42	0.28	0.63	NA	0.7	0.48	NA	0.16
DET 3 ATT 1	1.14	1.3	1.18	0.46	0.63	0.9	0.62	NA	0.62	0.56	1.18	0.44
DET 4 ATT 0	1	0.44	NA	0.18	0.41	0.37	NA	NA	NA	NA	NA	NA
DET 4 ATT 1	1.13	1.4	1.3	0.73	0.64	0.82	NA	NA	NA	NA	NA	NA
DET 5 ATT 0	0.82	0.03	NA	NA	0.42	8.37	0.61	NA	0.58	0.71	NA	NA
DET 5 ATT 1	1.18	0.8	1.11	0.01	0.6	9.98	0.58	NA	0.29	0.68	NA	NA
DET 6 ATT 0	0.83	0.39	NA	0.1	0.39	0.28	0.5	NA	0.57	NA	NA	0.31
DET 6 ATT 1	1.04	1.13	1.1	0.54	0.64	0.57	0.53	NA	0.58	0.13	NA	0.49
DET 7 ATT 0	1.23	0.63	NA	0.22	NA	0.48	0.46	NA	0.34	0.41	NA	NA
DET 7 ATT 1	1.1	0.94	1.14	0.56	0.5	0.54	0.44	NA	0.37	0.48	NA	NA
DET 8 ATT 0	1.07	0.37	NA	0.06	0.4	0.3	0.61	NA	0.69	NA	NA	0.17
DET 8 ATT 1	1.12	0.93	1.13	0.4	0.64	0.67	0.58	NA	0.6	0.66	1.45	0.39
DET 9 ATT 0	0.94	0.53	NA	0.21	0.36	0.32	0.55	NA	0.63	NA	NA	NA
DET 9 ATT 1	1.12	1.07	1.1	0.77	0.6	0.75	0.58	NA	0.57	NA	NA	NA

Discussion

From the sensitivity plots and table, we can draw tentative conclusions.

1) For each detector, while sensitivity with attenuator state 0 shows a substantial decrease prior to the first anneal period, the sensitivity with attenuator state 1 does not show much decrease. Probably this is due to the fact that detector dead volume due to radiation damage is concentrated on the outer edges of the detectors, while when the attenuator is engaged, only the middle of each detector is exposed.
2) In most cases, the sensitivity was not fully recovered after the second anneal period in 2010. (Note that this depends on the slight leap of faith in the assumption that GOES 13, 14, 15 responses are not more than 30 to 40% different from GOES 10, 11, 12.)
3) More data is needed, so we probably will need to include smaller flares. Also a GOES-RHESSI DEM analysis can be included.

References

1) For Figure 1: McTiernan, J. etal., https://ui.adsabs.harvard.edu/abs/2019ApJ...881..161M/abstract

2) For RHESSI Sensitivity: McTiernan, J., http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/Relative_and_(maybe)_Absolute_RHESSI_Detector_Efficiency:_2002-2008

3)For RHESSI: Lin, R. etal., https://ui.adsabs.harvard.edu/abs/2002SoPh..210....3L/abstract

4) For GOES T, EM Calculations: White, S. etal., https://ui.adsabs.harvard.edu/abs/2005SoPh..227..231W/abstract

- Notes: Temperature responses were calculated using the CHIANTI package, (Landi et al. 2012ApJ...744...99). RHESSI X-ray spectra were obtained using the Solarsoft OSPEX and XRAY packages (https://hesperia.gsfc.nasa.gov/ssw/packages/spex/doc/).