Correlation of flares with long-term irradiance and sunspot levels

IED 24 May 2013

On the "LYRA Flare List" web page, we present a list, e.g. here:
http://proba2.oma.be/lyra/data/Flarelist/CompleteFlareListG.txt
showing all GOES flares that have been observed since LYRA opened its doors on 06 Jan 2010. Now, there is a new list which shows additional information regarding flare statistics:
http://proba2.oma.be/lyra/data/Flarelist/NumberFlaresPerDay.txt
For each day, we present the number of flares, the maximum flare strength, the full strength of all flares accumulated over the day, and the average strength of these. ("Strength" is measured by setting class B to 1, C to 10, etc; in order to calculate the irradiance in W/m2, strength must be multiplied with 1e-7.)

This flare information - collected over more than three years since LYRA has been operating - can be related to the long-term irradiance levels of GOES, LYRA channel 2-3 (Aluminium), LYRA channel 2-4 (Zirconium), and the daily sunspot number, as displayed here:
http://solwww.oma.be/users/dammasch/dailymin_dssn.png
The "long-term level" of GOES and LYRA is defined in this context as the minimum significant solar value of a day, i.e., without taking flares or instrumental artifacts into account. A potentially interesting question is, whether this relation can be used to aid space weather forecast, especially the prediction of the expected flare strength.

It is not assumed that statistics like these can substitute a space weather forecaster's experience. To estimate future flare behaviour, one has to take into account factors like the magnetic configuration of active region candidates - something that is structural information and thus more complicated than simple numbers. The aim of this report is rather in the direction of statements like, "With the current levels of X, there is a Y percent chance for flares of strength Z". So it is meant to confirm the forecasters' estimates with some additional data. It is suggested to take the long-term development of sunspots and EUV/SXR-irradiance levels - and their projected increase or decrease - into account for flare prediction, although it must be admitted that, unfortunately, the best preserved LYRA channel shows the weakest correlation with the flare parameters to be predicted. It may nevertheless be useful.

In order to produce the "GOES vs. LYRA Proxies" that are presented on the LYRA website and also used for the P2SC SSA service, we have by now collected a considerable data base of daily solar levels, of which 1211 days between 06 Jan 2010 and 30 Apr 2013 are considered here. This includes observations from the end of the solar minimum, as well as from what was - so far - the peak of the current cycle. Figure 1 shows the time series for the daily sunspot number, two LYRA channels, and GOES.

- The sunspot number is taken from the ROB/SIDC website and varies between 0 and 136 in the observed time interval.
- LYRA ch2-3 (Al) nominally covers EUV 17-80nm and SXR <5nm, but it has substantially degraded above 19 nm; we expect it to cover <5nm and maybe 17-19nm by now, thus it has almost changed into an SXR channel. Ch2-3 basically varies between 0.002 and 0.003 W/m2. The initial level has almost completely vanished in the raw data, which - for calibration purposes - is compensated by adding the estimated degradation. It seems, though, that part of the remaining variation has also vanished; compared with ch2-4, the variation of ch2-3 appears relatively larger in the beginning, as compared to the presence.
- LYRA ch2-4 nominally covers EUV 6-20nm and SXR <2nm; despite some degradation, there is still more than 50% of its response left, so we still consider it a combined EUV/SXR-channel. Ch2-4 basically varies between 0.0006 and 0.002 W/m2. The initial level has somewhat vanished and is likewise compensated.
- The GOES observations mentioned here are from the 0.1-0.8nm SXR channel. They vary between 1.0e-8 and 2.1e-6 W/m2, in other words, between A1.0 and C2.1 levels. But the maxima are exceptions, probably due to slowly cooling flares; GOES levels basically remained in the class A range up to February 2011, and in the class B range ever since.

Figure 2 shows the time series for the various parameters that can be derived from the Flare List:

- For the daily number, simply all X-ray flares classified by NOAA/SWPC were counted.
- For the strengths, the flare class was transformed back into irradiance (W/m2).
- For the total strength, all these flare strengths of a day were added.

- For the average, this sum was divided by the day's number of flares.

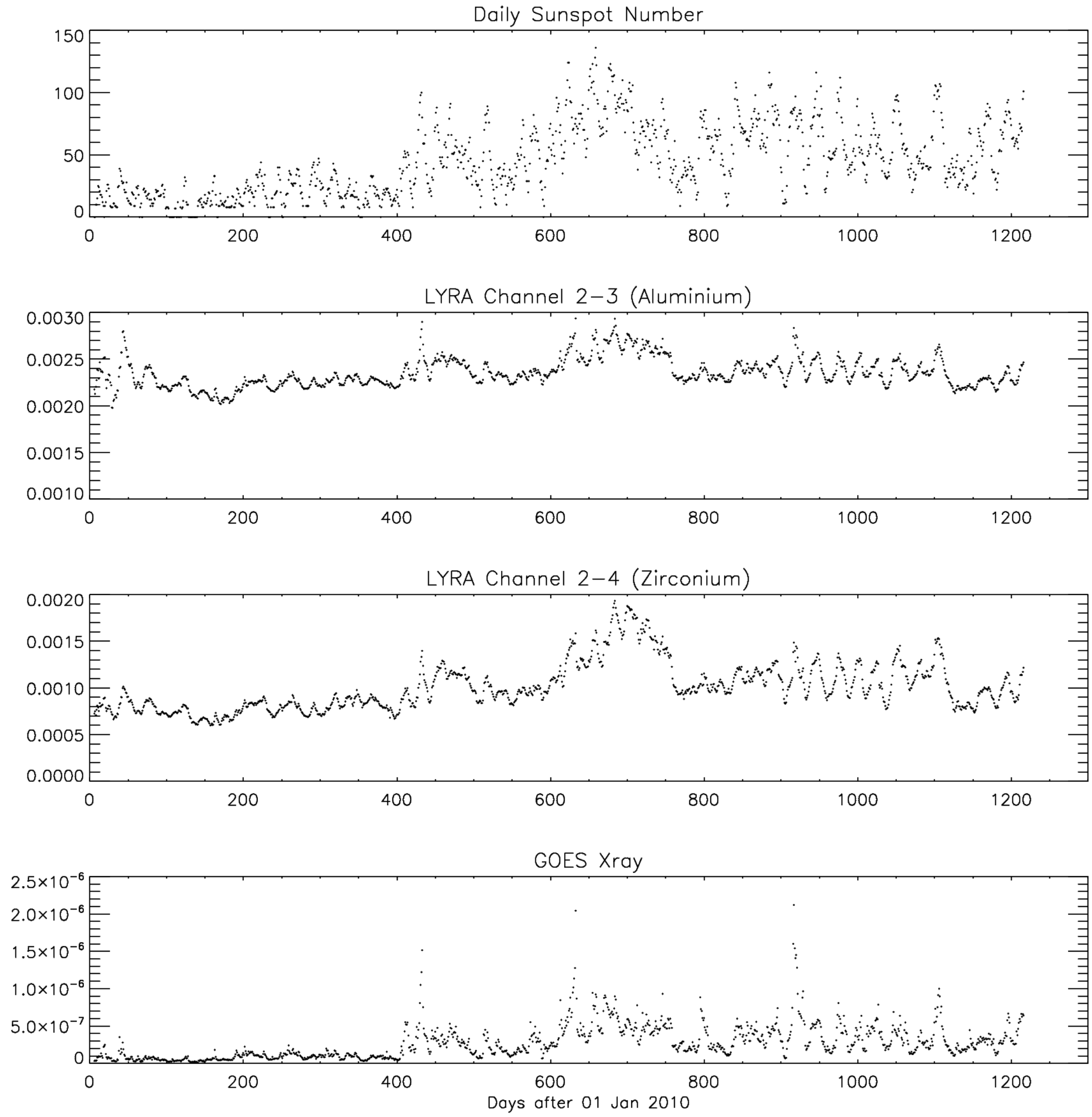
Obviously, flares are rather singular events and scatter more than the rather smoothly developing irradiance or sunspot levels. The flare strengths only resemble these levels when shown on a logarithmic scale, and the average flare strength shows the least scatter and most similarity.

Figure 3 shows the correlations among LYRA levels, GOES levels, and daily sunspot numbers. The LYRA irradiance levels show the highest correlation with each other, which is not a surprise, since they cover adjacent spectral bands. Ch2-3 has a higher correlation with GOES X-ray than ch2-4 does, since much of the EUV part of ch2-3 has been lost by degradation, while the SXR part stayed. All three correlations show a clear peak at lag=0. The sunspot number shows the highest correlation with LYRA ch2-4, so maybe the EUV part of this channel observes the effect of active regions more than the others do. In all cases, the correlation with sunspots shows a plateau and a small tendency for a negative lag, which seems to indicate that the development of sunspots **precedes** the development of the SXR and EUV irradiance levels (*to be confirmed*). More information on this subject can be found in the poster that was presented on ESWW9, see:
http://solwww.oma.be/users/dammasch/Dammasch_Brussels2012_corr_Poster.ppt

The next four figures show the correlations between the irradiance and sunspot levels mentioned above (as in Fig.1) with the flare parameters (as in Fig.2): Figure 4 deals with the number of flares, Figure 5 with the maximum flare strength, Figure 6 with the total flare strength, and Figure 7 with the average flare strength. The flare numbers show the lowest correlation (28%-46%) with the irradiance and sunspot levels. The other three flare parameters would be similarly disappointing when taken on a linear scale (approx. 20% correlation), but taken on a **logarithmic** scale, the correlations become much better: Next best is the log maximum flare strength (53%-67%), topped by the log total flare strength (55%-69%), and the log average flare strength (60%-72%). Within the same flare parameter, the correlation is always best with the GOES level, followed by sunspot number, LYRA ch2-3, and LYRA ch2-4. Again, the correlation with the GOES level is symmetrical and shows a clear peak at lag=0, while the correlation with the sunspot level shows a plateau.

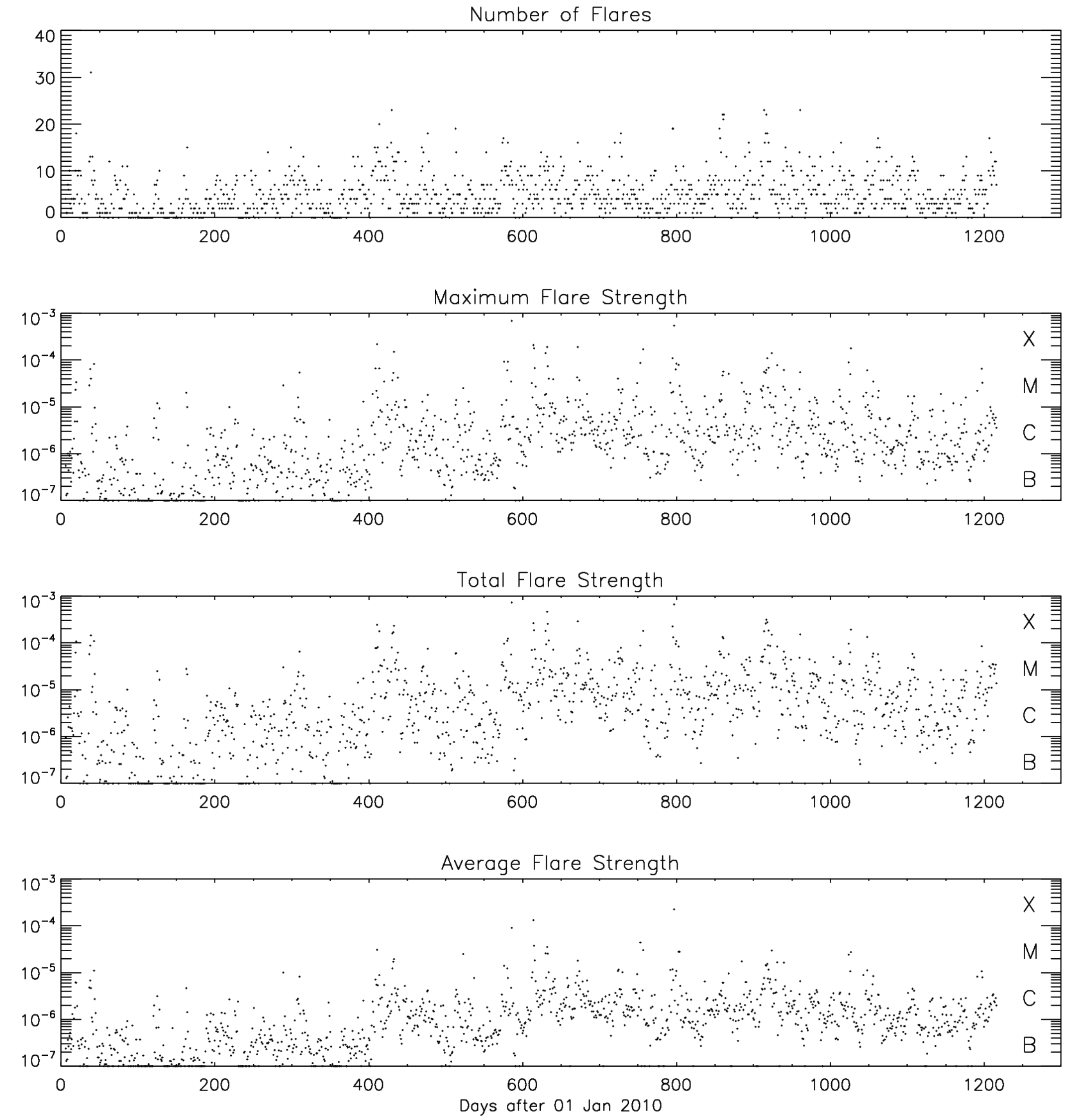
The last four figures are an attempt to visualize the relation between the irradiance and sunspot levels with one of the flare parameters; as an example, the **maximum flare strength** was chosen because it is probably the most interesting value to be predicted for space weather purposes, especially for an estimation of potential hazards. In scatter plots, Figure 8 shows its relation with the LYRA ch2-3 level (correlation 58%), Figure 9 with the LYRA ch2-4 level (correlation 53%), Figure 10 with the GOES level (correlation 67%), and Figure 11 with the daily sunspot number (correlation 58%). Within each scatter plot, the solid line with the asterisks denotes a 50% probability that the maximum strength flare of a day will be smaller or larger than this level, given the irradiance or sunspot level of this day. These twelve values (*) were calculated by ordering the irradiance or sunspot levels into 12 ascending groups of 100 values each, taking the median of the maximum flare strength of the group, and plotting it versus the average of the group's level.

This kind of visualization enables various predictions, based on more than three years (1200 days) of observation. For example: If the sunspot number is 10-20, the chance of observing less than a B3 flare is 50%, but with a sunspot number of 80, one has a 50% chance of getting more than a C6 flare. With a LYRA ch2-4 level between 0.0006 and 0.0007 W/m2, the chance of having less than a B2 flare is more than 50%, and having a flare of class C or more is practically 0%. When the GOES level rises to B7, one has an almost 50% chance of observing an M flare. No X flare occurred while LYRA ch2-3 was below 0.0023 W/m2, or LYRA ch2-4 was below 0.00095 W/m2.



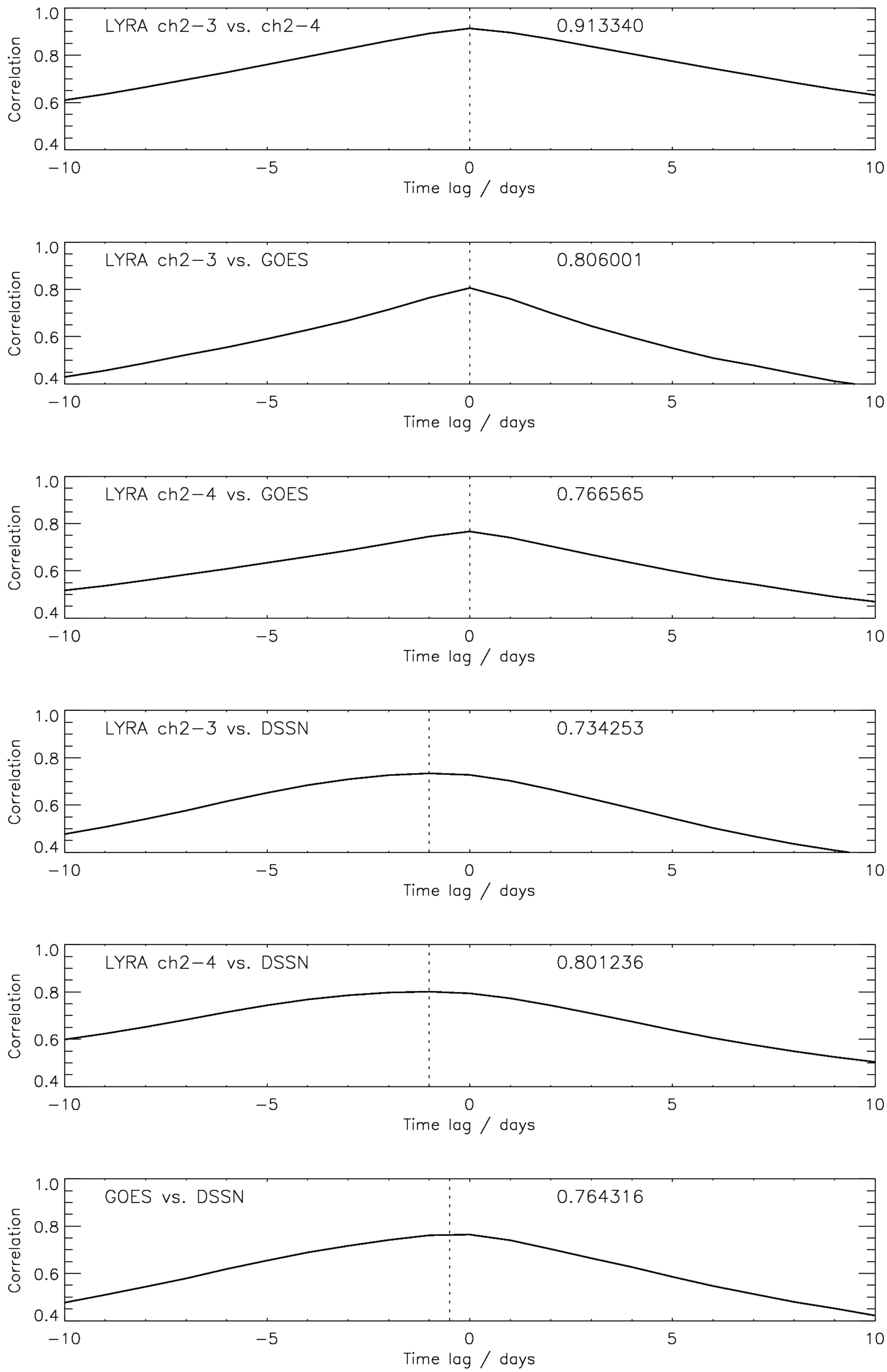
Daily Sunspot Number
150
100
50
0
0
200
400
600
800
1000
1200
LYRA Channel 2–3 (Aluminium)
0.0030
0.0025
0.0020
0.0015
0.0010
LYRA Channel 2–4 (Zirconium)
0.0020
0.0015
0.0010
0.0005
0.0000
GOES Xray
2.5×10⁻⁶
2.0×10⁻⁶
1.5×10⁻⁶
1.0×10⁻⁶
5.0×10⁻⁷
Days after 01 Jan 2010

Figure 1.



Number of Flares
40
30
20
10
0
0
200
400
600
800
1000
1200
Maximum Flare Strength
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
X
M
C
B
Total Flare Strength
Average Flare Strength
Days after 01 Jan 2010

Figure 2.



LYRA ch2−3 vs. ch2−4
0.913340
LYRA ch2−3 vs. GOES
0.806001
LYRA ch2−4 vs. GOES
0.766565
LYRA ch2−3 vs. DSSN
0.734253
LYRA ch2−4 vs. DSSN
0.801236
GOES vs. DSSN
0.764316
Correlation
Time lag / days

Figure 3.

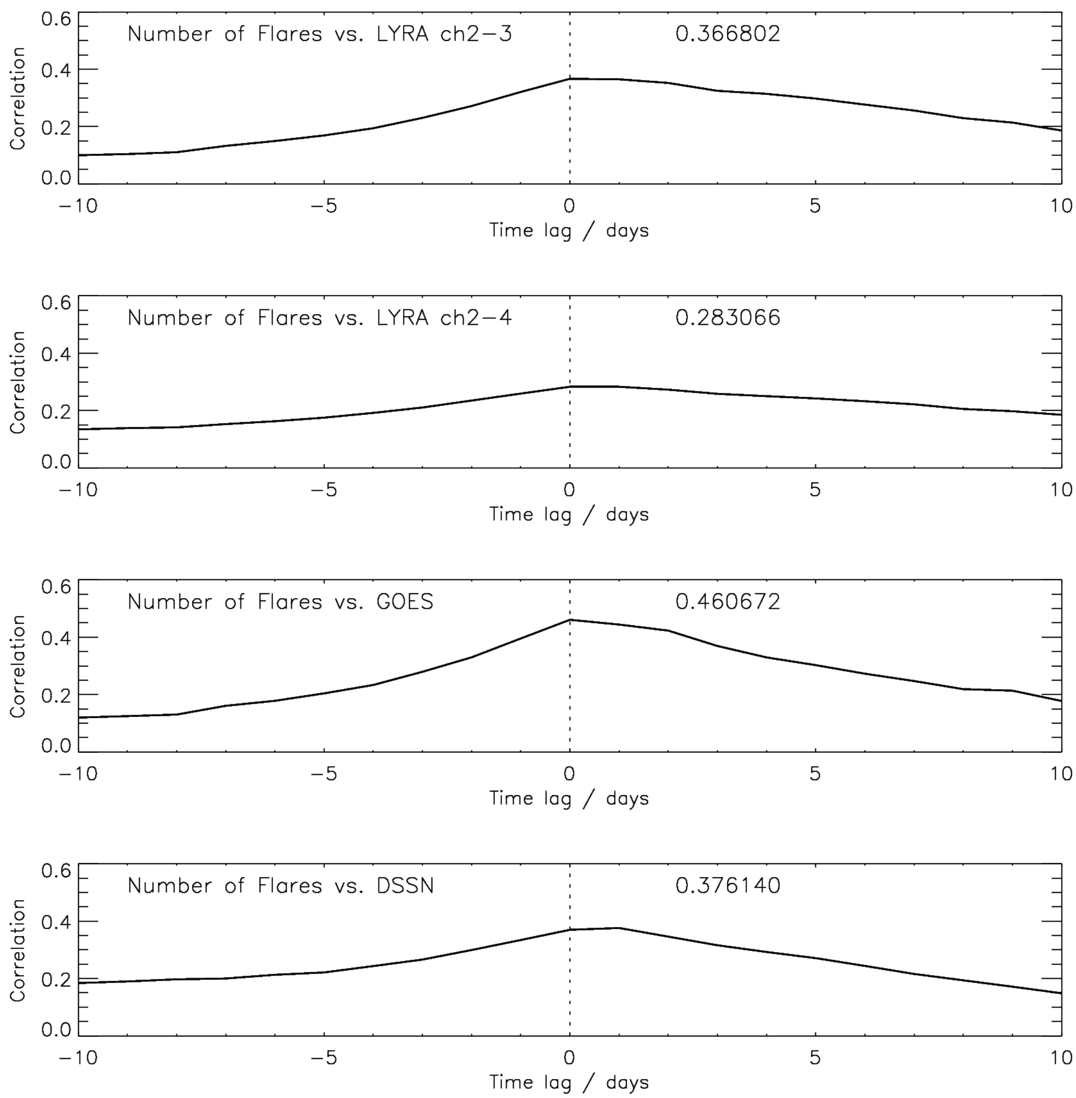

Number of Flares vs. LYRA ch2−3
0.366802
Number of Flares vs. LYRA ch2−4
0.283066
Number of Flares vs. GOES
0.460672
Number of Flares vs. DSSN
0.376140
Correlation
Time lag / days

Figure 4.

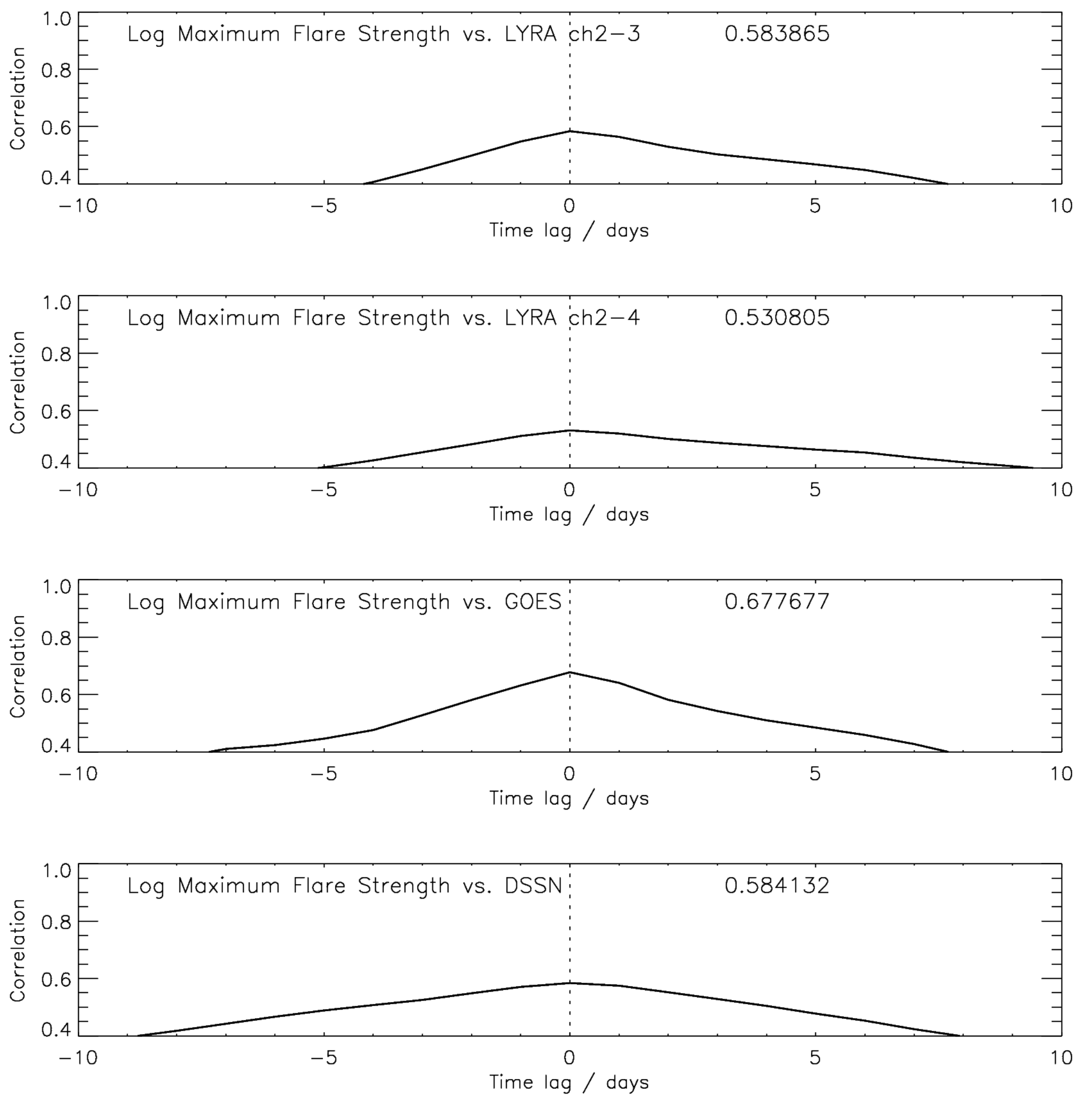

Log Maximum Flare Strength vs. LYRA ch2−3
0.583865
Log Maximum Flare Strength vs. LYRA ch2−4
0.530805
Log Maximum Flare Strength vs. GOES
0.677677
Log Maximum Flare Strength vs. DSSN
0.584132
Correlation
Time lag / days
1.0
0.8
0.6
0.4
−10
−5
0
5
10

Figure 5.

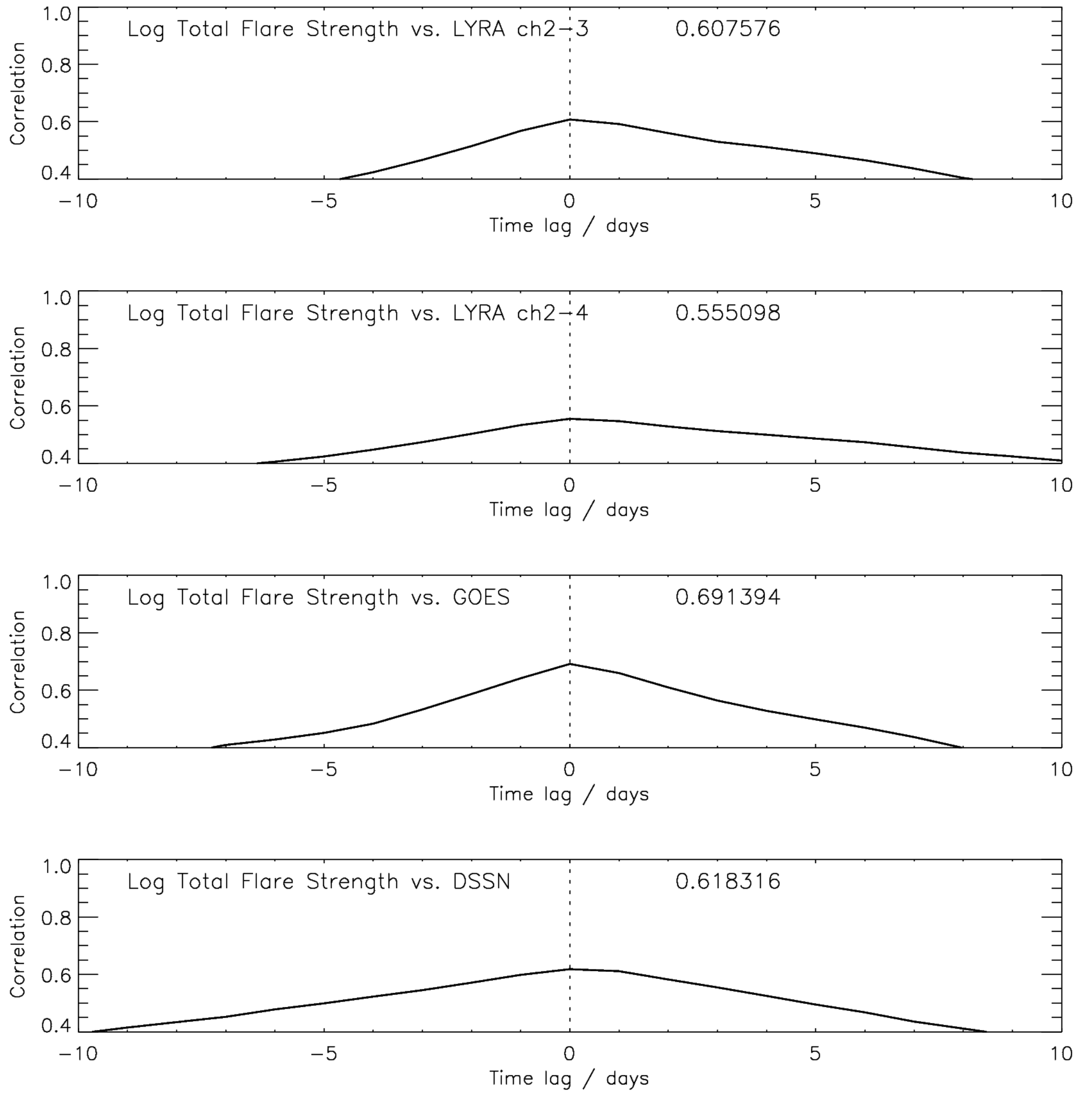

Log Total Flare Strength vs. LYRA ch2-3
0.607576
Correlation
Time lag / days
Log Total Flare Strength vs. LYRA ch2-4
0.555098
Correlation
Time lag / days
Log Total Flare Strength vs. GOES
0.691394
Correlation
Time lag / days
Log Total Flare Strength vs. DSSN
0.618316
Correlation
Time lag / days

Figure 6.

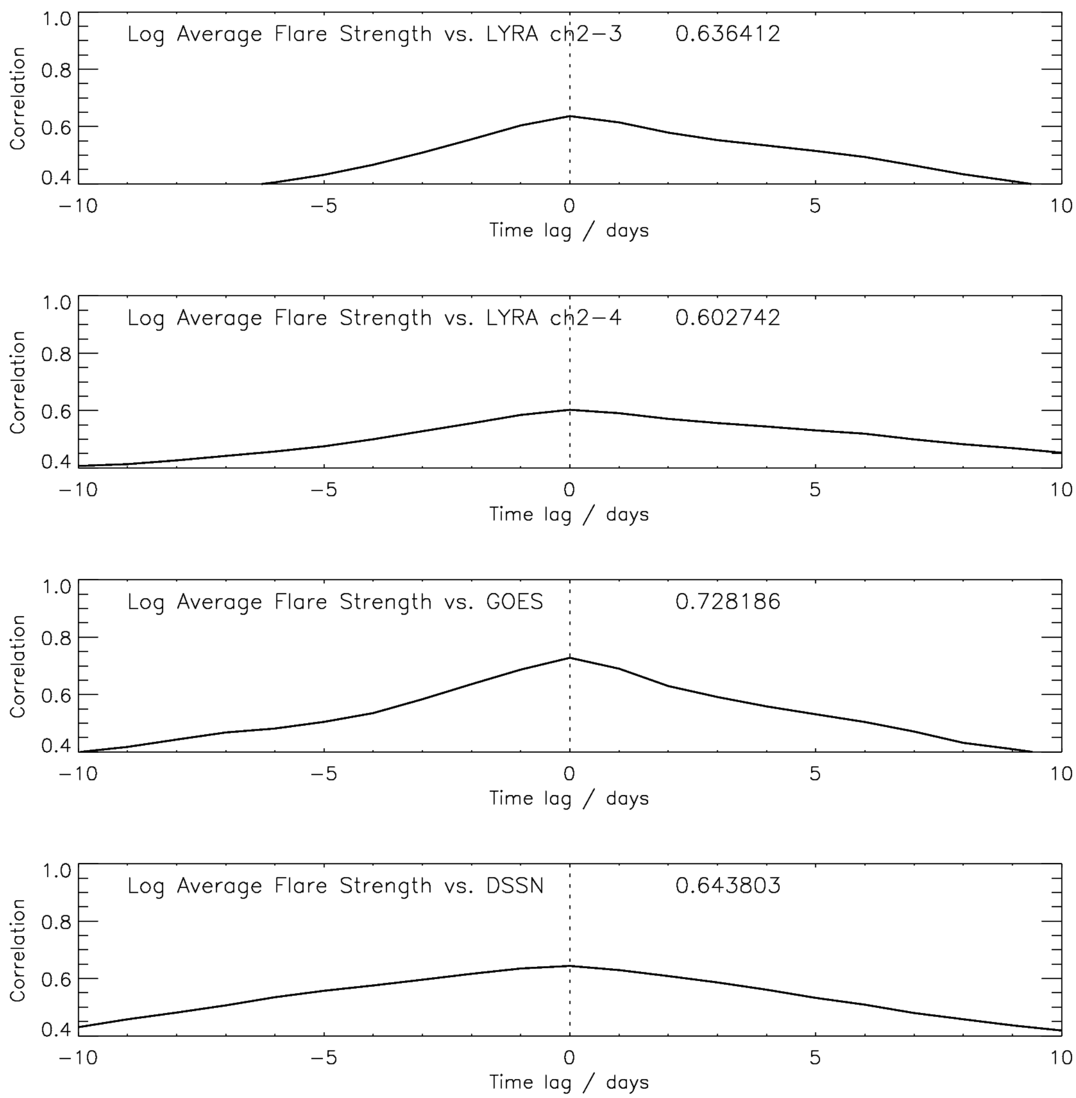

Log Average Flare Strength vs. LYRA ch2−3
0.636412
Log Average Flare Strength vs. LYRA ch2−4
0.602742
Log Average Flare Strength vs. GOES
0.728186
Log Average Flare Strength vs. DSSN
0.643803
Correlation
Time lag / days

Figure 7.

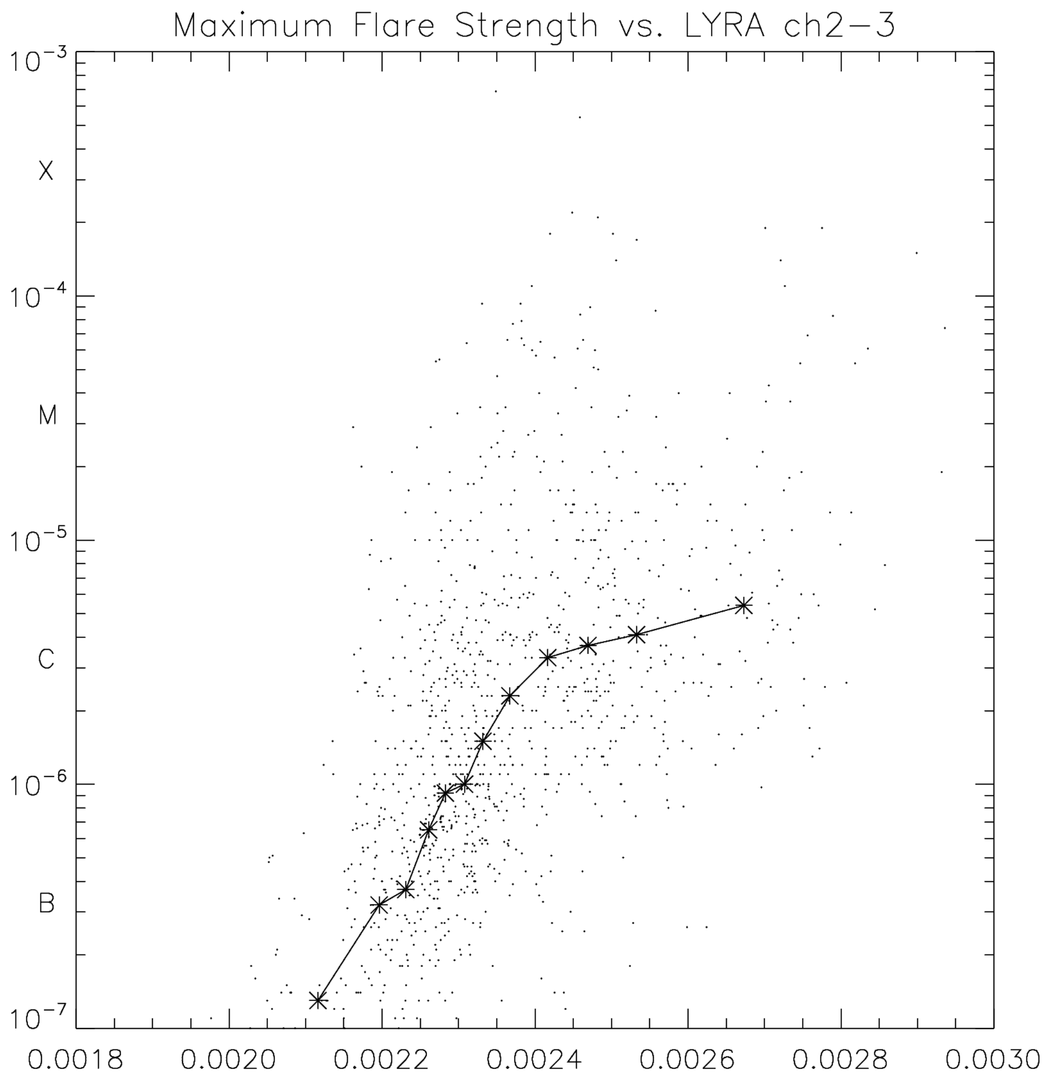

Maximum Flare Strength vs. LYRA ch2-3
10^{-3}
X
10^{-4}
M
10^{-5}
C
10^{-6}
B
10^{-7}
0.0018
0.0020
0.0022
0.0024
0.0026
0.0028
0.0030

Figure 8.

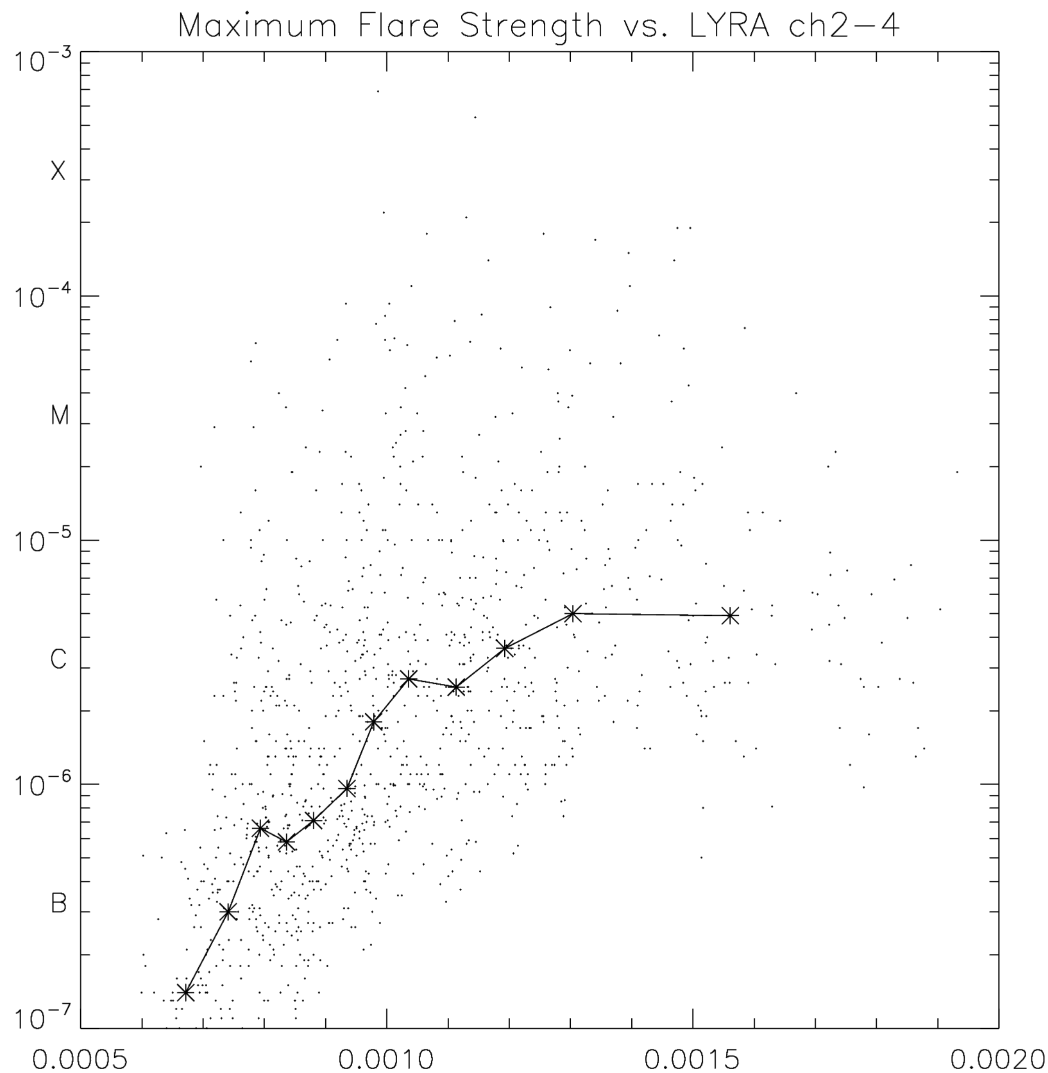

Maximum Flare Strength vs. LYRA ch2-4
10^{-3}
X
10^{-4}
M
10^{-5}
C
10^{-6}
B
10^{-7}
0.0005
0.0010
0.0015
0.0020

Figure 9.

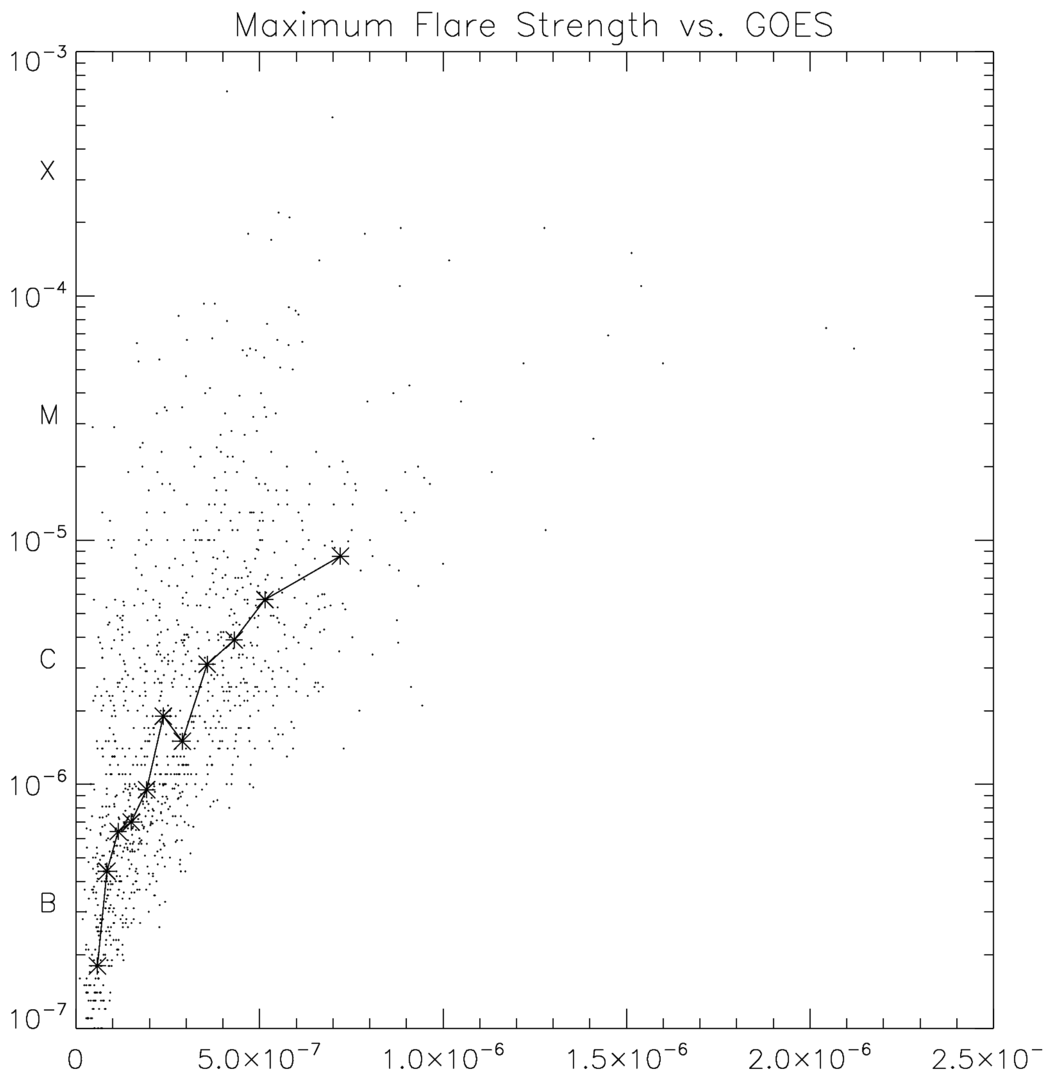

Maximum Flare Strength vs. GOES
10^−3
X
10^−4
M
10^−5
C
10^−6
B
10^−7
0
5.0×10^−7
1.0×10^−6
1.5×10^−6
2.0×10^−6
2.5×10^−

Figure 10.

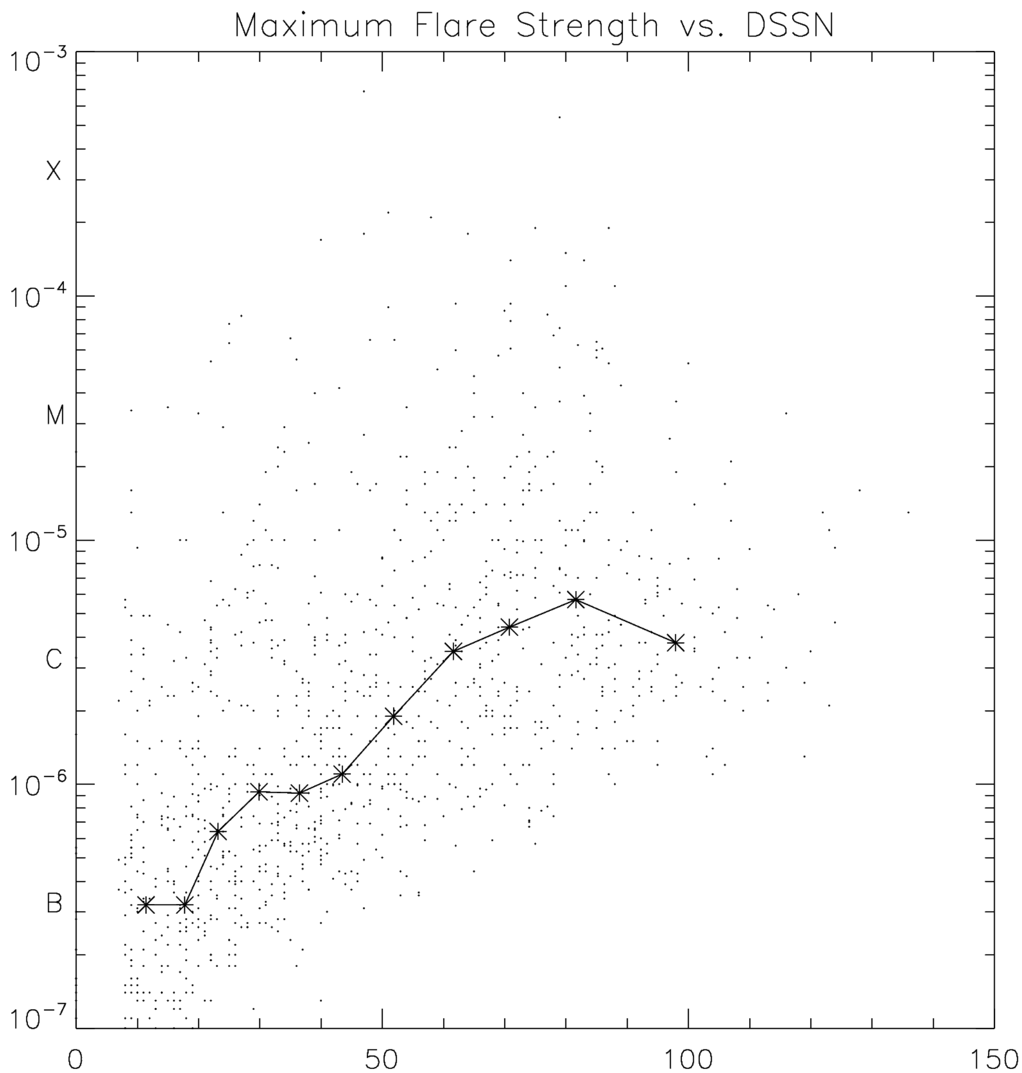

Maximum Flare Strength vs. DSSN
10^{-3}
X
10^{-4}
M
10^{-5}
C
10^{-6}
B
10^{-7}
0
50
100
150

Figure 11.