The Consequences of Major Flare Production in Solar Active Regions

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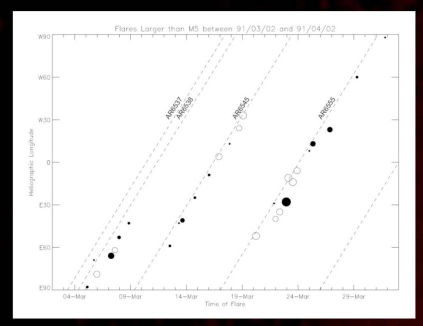
ABSTRACT

Using the flare database from the GOES Full-Sun X-ray satellite, we have constructed a comprehensive study of the distribution and flare productivity of solar active regions from 1976 to the present. We concentrate on those active regions which produce a number of large flares (> GOES X-ray class M5) and investigate whether the activity in one active region has consequences for neighboring active regions through large scale magnetic interconnectivity. In certain cases, when two or more active regions are present on the solar disk, a pattern emerges in which the period of large flare production only occurs in one active region at a time. Although this pattern is not always observed, the cases in which this does occur suggest some physical correspondence between active regions. To explore this phenomenon, we have begun to address three distinct questions: how prevalent is this pattern of activity and under what conditions is it upheld or broken?; how is the interaction between active regions manifested in the emission characteristics of the active regions?; and how does the global solar corona respond to the production of these large flares?

Introduction



The Question

The global solar corona is a large scale magnetically coupled system comprised of the open regions known as coronal holes, the quiet Sun where the field is relatively weak, and active regions, typically associated with the strong magnetic field of sunspots. The question we are addressing in this project is whether major activity (e.g. a solar flare) in one part of this system (e.g. an active region) has consequences elsewhere in the system, mediated by the magnetic connectivity.

One extreme example of this connection is shown in the figure to the left, where three active regions, each a source region for multiple large flares (> GOES X-ray class M5), appear to "take turns" at producing their flares, suggesting some physical correspondence between the active regions. This poses the question "how does flaring in one active region impact the magnetic activity of distant parts of the solar atmosphere?"

Projects

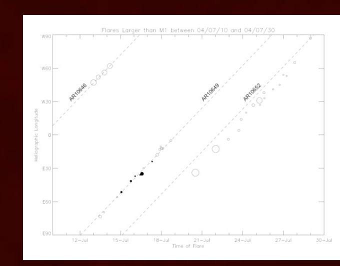
In addressing this rather broad question, we have used GOES Full-Sun X-ray data to obtain the time, magnitude, position, and active region of origin for all M and X class flares produced during the period 1976 – 2009. In this dataset, we identified 25 periods where two or more active regions, each producing several M5 or larger flares, were observed on the disk simultaneously. Our preliminary results indicate that 19 of these cases appeared to display the flaring pattern shown to the left, while 6 did not.

In order to address the major question on the influence of large flares on their surrounding environment and the consequences for our understanding of magnetic activity in the solar corona, we have identified three distinct projects:

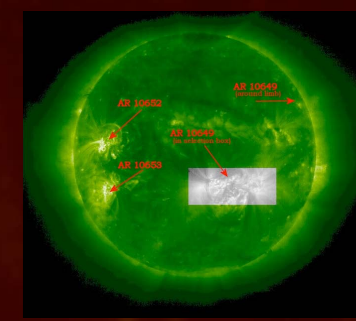
- **Statistical Study** Use the large set of flare data gathered to investigate the idea of an actual flare production pattern between active regions
- **Case Study**: Choose several interesting periods featuring multiple co-temporal, highly productive active regions and look for correlations in their behavior
- **Cycle Study**: Long term dataset allows us to study the solar cycle dependence of flare productivity in active regions

Case Study

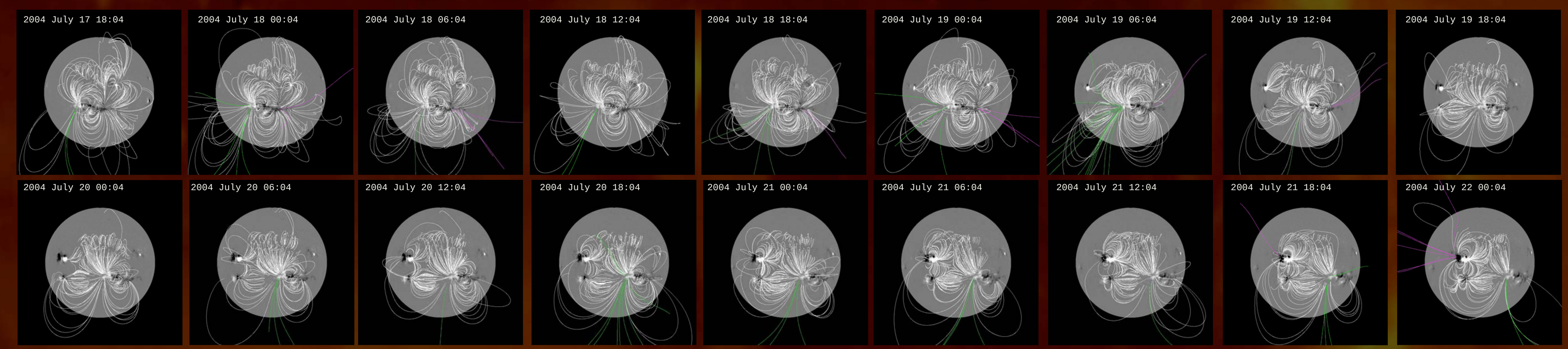
To explore the inter-connectedness of solar active regions, we have devised a case study in which we examine the magnetic connections, associated activity, and coronal response to periods of major flaring activity. For the project presented here, we selected one period containing a number of active regions, some of which produced major flares during distinct times (i.e. they exhibited the pattern described in the introduction). This case study will be augmented in the future with additional time periods of interest. The activity of the active regions, the consequences of this activity, and their magnetic connectivity were characterized using image data from a number of solar telescopes and 3D magnetic field extrapolations from SOHO/MDI magnetograms.



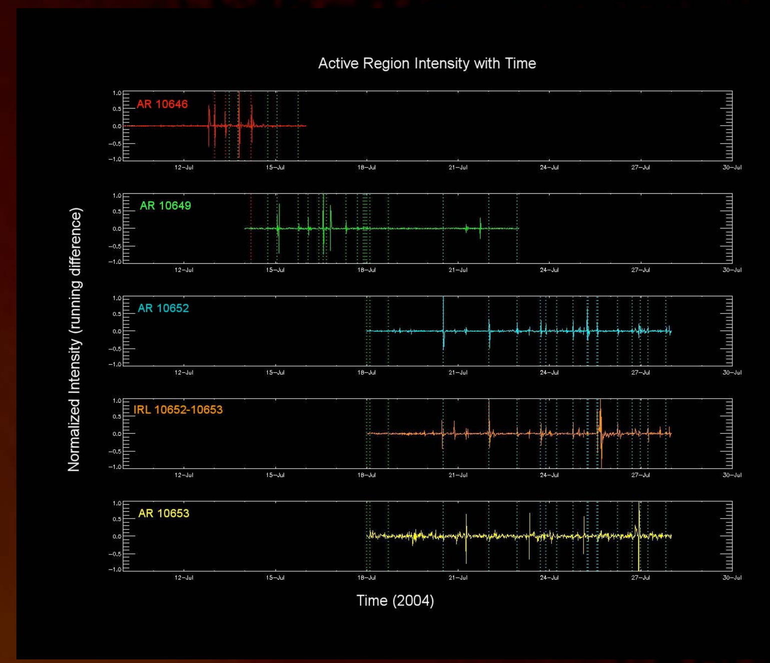
In July 2004, active regions 10646, 10649, and 10652 crossed the solar disk in close succession. All three regions produced several flares larger than M5, and as the figure shows, each only produced flares during its turn, even when significantly weaker flares , down to GOES class M1, were included.



To look for responses to flaring between active regions, we used SOHO EIT 195 images to measure the integrated EUV flux of each active region over time during its entire period on the disk. In addition to active regions 10646, 10649, and 10652, region 10653, immediately south of 10652, is also of interest even though it did not produce any M or X class flares, as connections could be seen between it and 10652 from a casual inspection of EIT images. The flux was measured by defining a box around the active region and integrating the intensity over the box for each image, tracking the box from image to image in accordance with solar rotation; an example is shown as the grey box in the figure.



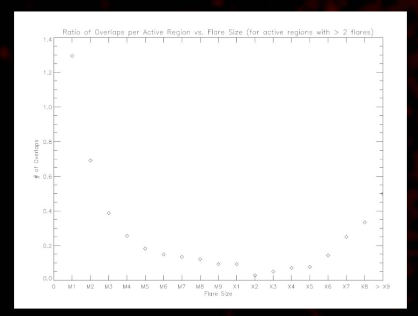
Using a Potential Field Source Surface (PFSS) model for extrapolating the 3D coronal field from SOHO/MDI photospheric magnetograms, we map out the global magnetic field to determine the magnetic connections between the flaring active regions and the rest of the solar disk. The sequence of images above shows a set of large-scale magnetic connections between AR 10649 and AR 10653 and strong magnetic connections between the western sides of AR 10652 and AR 10653. AR 10649 is the large region in the middle of the disk in the first images, while AR 10652 and AR 10653 are the active regions in the north and south, respectively, near the left (eastern) edge of the disk in the beginning of the second row. Over the day of July 20 a strengthening series of connections develop between AR 10649 and AR 10652 which maintain throughout the rest of the sequence. These data show that each of the active regions of interest during this period are magnetically connected to each other for at least part of the time during their traversal of the solar disk. There are a number of large scale reconfigurations of the field evident between successive frames, including the opening of new flux (red/green lines). The implications of these preliminary findings are still being analyzed.



We look for a response to a large solar flare in a distant active region by looking for correlations in the changes in intensity in the participating active regions. This is carried out by performing an analysis of the running differences of the regions selected (each sub-region image is subtracted from the one before it where our image cadence is 12 minutes in the EIT 195 channel of SOHO). Here the running difference intensities for each active region as well as for the inter-region loops between AR 10652 and AR 10653 (labeled as IRL 10652 -10653) are shown. We also indicate the start time of each flare as vertical dashed lines, with each color representing a different source active region. The strongest signals in the running difference intensities are clearly caused by the large solar flares that significantly enhance the EUV emission in their parent active region. There is some indication of simultaneous (i.e. within 12 minutes) but significantly smaller enhancements in a different active region at the time of several flares, especially between AR 10652 and AR 10653 which are quite close together. The results of a preliminary correlation analysis are shown in the table. The low correlation coefficients do not fully support the idea of the flares influencing distant regions. However, it should be pointed out that this correlation analysis involves all of the emission from the whole active region and over the whole time for which they are visible on the solar disk. A more refined correlation analysis is being developed. The extent and significance of the observed responses is still a work in progress.

AR#	Correlation Coefficient
10646 - 10649	0.3523
10649 - 10652	0.0911
10649 - 10653	0.2467
10652 - 10653	0.3050

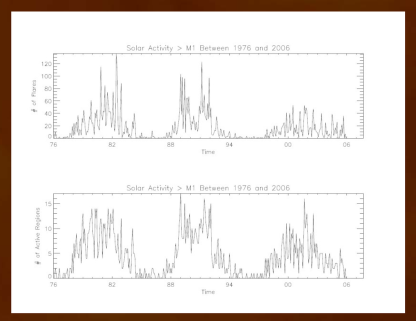
Statistical Study



The flare production sequence described in the introduction may be the result of a physical connection between active regions in which flaring is suppressed in one region by strong flaring in another (e.g. by the transfer of magnetic flux from one region to the other as a result of magnetic reconnection) or be coincidental whether or not a magnetic connection exists between the two regions.

To quantify how often this 'pattern' is broken, we have defined what we call an 'overlap', where large flare production over a given period involves more than a single active region. The plot above shows how the number of overlaps per active region changes as the definition of "large flare" is varied. At the low end, there are many overlaps due to the sheer number of active regions producing relatively small flares; active regions are producing small flares constantly, and any boundary chosen to represent large flares is totally arbitrary. Interestingly, the number of overlaps decreases as flare size increases even though there is a statistically significant number of flares. The number of overlaps rises again for large X flares due to the paucity of active regions that produce such flares. It is in the center of this distribution, around M5, that any signs of the pattern would appear. This will be explored at a later date.

Cycle Study



The 33-year timeframe over which we have GOES data lends itself to a study of active region emergence and flare productivity over a number (3) of solar cycles. We see from the figure that both the number of large flares and the number of active regions that produced those flares was significantly lower during the last solar maximum than in the previous two maxima. One of the things we would like to explore with this dataset is whether the activity in a given solar maximum is related to the depth and duration of the following solar minimum.

Conclusions

Through this project we have developed several tools to analyze the possible responses to large solar flares in distant magnetically connected active regions. The main focus was on a case study of a particularly interesting period in July 2004 when the solar disk exhibited several active regions. The active regions displayed an array of solar activity including two primary regions each producing several (>10) large solar flares. Our preliminary results show tentative evidence for a distant response to the largest flares when there is a clear magnetic connection between the active regions. The results at present are, however, inconclusive and require further and refined analysis.

The case study will be expanded to include other periods when there are several active region groups populating the solar disk, allowing us to consider how other parameters, such as active region separation, magnetic complexity, flare productivity, etc., affect the impact of a large solar flare on the surrounding corona. This will provide a more comprehensive look at how and under what conditions active regions influence one another. To further this aim we will also perform the statistical study of flare productivity outlined in the introduction to determine the statistical significance of the mutually exclusive activity within active regions.

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