NOAA 7978: THE LAST BEST OLD-CYCLE REGION?

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Abstract. Sunspots in NOAA active region 7978 first appeared on July 6, 1996, while the region was at E15. The spots reached an area of 400 millionths within four days and the active complex remained interesting for at least five solar rotations, generating an X class flare, a long-duration event, and coronal mass ejections well-observed by both *Yohkoh* and SOHO. During these five rotations, only a few short-lived competing active regions appeared. The occurrence of a good center of activity during such quiet solar-minimum conditions means that whole-Sun instruments, such as those of the *Yohkoh* BCS spectrometers or the GOES photometers, responded primarily to a single localized source. Although the active region had large horizontal and vertical dimensions, the most intense X-ray emission came from low coronal altitudes. We discuss the overall configuration and evolution of this region, which appears destined to be the focus of many specialized studies. The discussion includes a description of the effect of AR7978 on the total solar irradiance, and of a preliminary search for "relaxation oscillator" evidence for coronal energy build-up and release.

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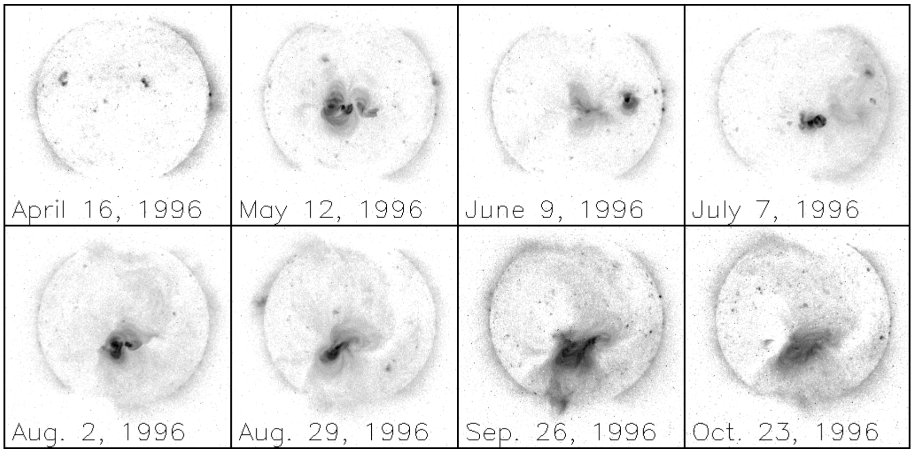

Figure 1. *Yohkoh* images of the 1996 activity complex over eight rotations. The "last best" region, NOAA AR7978, initially formed on July 7, 1996. Note the rapidly-formed connections to high latitudes, and the CME aftermath visible in the September image. North is up, east to the left; the images are from the AlMg filter of SXT with logarithmic compression.

1. Introduction

Solar activity in 1996 was dominated by an activity complex near a Carrington longitude of 250 at about S10. As described in the accompanying paper by Harvey & Hudson (1997), this complex showed eruptions of new flux as early as April, and the dispersing magnetic flux could be traced through the end of the year. The high point of the region development was the birth on the disk of NOAA region 7978, its rapid growth, and the occurrence of an X-class flare on 9 July 1996. Figure 1 shows *Yohkoh* SXT images of this complex from a time span of eight rotations. The main objective of this paper is to introduce the data on this active complex, and to propose some research directions that take advantage of it.

The concentration of so much activity into a limited region of the solar surface, which otherwise showed typically passive solar-minimum behavior, provides us with several opportunities. First, the emerging flux acts as a "test particle" probing the magnetic reactions (such as reconnection and coronal-hole formation) as outlined by Harvey & Hudson (these proceedings). Second, we can assume that most of the activity during this time period came from this complex. Such an assumption makes for a more straightforward interpretation of whole-Sun data such as those of the *Yohkoh* BCS (Sterling, 1997; Sterling *et al.*, 1997) or the GOES whole-Sun X-ray photometers. This paper surveys some of the properties of this activity complex, including a brief description of a search for "relaxation oscilla-

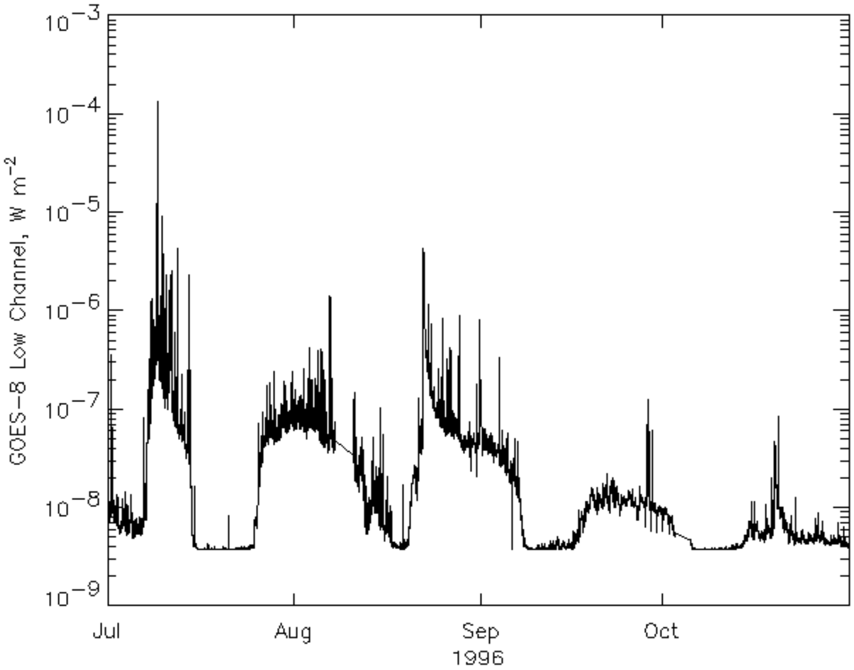

Figure 2. Time-series data in the low channel (1-8Å) of GOES-8, for five months following the eruption of AR7978. Note the sharp occultation signatures.

tor" behavior, which (if detectable) would support the concept of coronal build-up of flare energy.

2. Morphology

The active regions associated with this complex tended to be large in horizontal extent, but with a strong concentration at low altitudes. In Figure 1 one can see that the coronal effects of AR7978 extend rather quickly to high latitudes. The frame from September shows the aftermath of a coronal mass ejection extending over the S polar region.

Figure 2 illustrates the small vertical extent of the active region by showing a difference image comparing two images taken at a 3-hour time interval. This difference image shows that the coronal sources, partially occulted by rotation, lie in a thin strip elongated tangent to the limb. The dimensions of this difference source perpendicular and parallel to the limb are 3×10^5 km and 2×10^4 km (FWHM), respectively. The latter corresponds to a scale height of some 8×10^3 km, much less than that expected ($4–7 \times 10^4$ km) from hydrostatic equilibrium at the observed

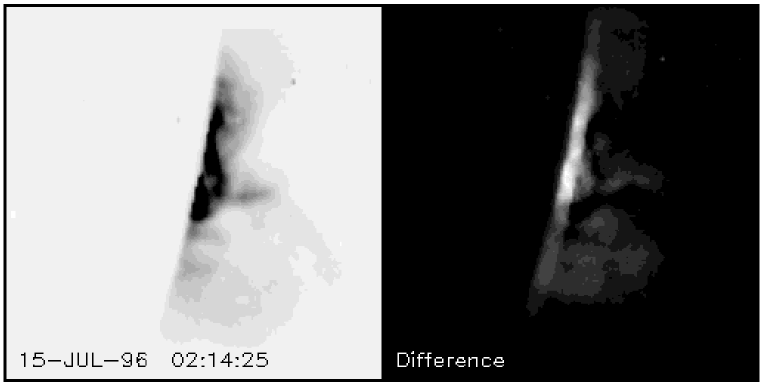

Figure 3. Soft X-ray image of AR7978 at its west limb passage (left; image time July 15, 1996, 02:24 UT) and a difference image (right; comparison with the image of July 14, 23:29 UT) over a 3-hour span. This shows the concentration of X-ray intensity into a thin layer. The color scale is reversed.

temperatures. We thus conclude that the active-region structure consists of low-lying magnetic loops with substantial gas overpressure. This evidence from the difference image is supported by the time profiles of soft X-rays as observed by SXT and GOES (Sterling *et al.*, 1997); we note that this pattern persisted at successive occultations of the active complex. Hara (1997) has inferred a general tendency for low-altitude concentration of solar active regions from a statistical analysis of the SXT image histograms.

3. The Total Irradiance Variations

The sun was virtually spotless when AR7978 erupted, and within four days the new spot group had reached a total area exceeding 400 millionths of the hemisphere. This is large enough to produce a detectable decrease in the total solar irradiance (Willson *et al.*, 1981; Hudson, 1986), and as Figure 3 shows, a well-correlated dip (about 0.04%) did take place. Here we have used the sunspot areas reported in the NOAA *Solar-Geophysical Data* for the comparison with total-irradiance observations from the VIRGO experiment on SOHO (Wehrli *et al.*, 1997). The tabulated sunspot data do not have the sampling or precision of the total irradiance data but are easily available.

The onset of the July 1996 dip was caused by the physical growth of the spots, rather than by foreshortening resulting from solar rotation. Do these differing causes produce different correlations? This question remains open from the ACRIM data analysis, and the current data appear to be much more suitable for this type of study because of the existence of SOHO white-light images from the MDI instrument. These can be used to determine sunspot and facular area variations with good control – for the first time

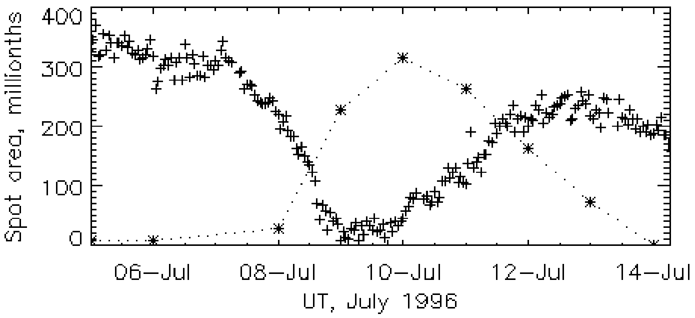

Figure 4. A total-irradiance "dip" associated with the AR7978 sunspots in July, 1996, as recorded by VIRGO (*e.g.* Fröhlich *et al.*, 1997). Frequent points, the total irradiance (arbitrary units; the depth of the dip is about 400 parts per million); infrequent points, the projected sunspot area from the NOAA/SGD archive.

– of the pernicious effects of seeing, scattered light, and day/night cycles present in ground-based data.

4. Relaxation Oscillations

In the most popular view, flare energy is stored in coronal fields before its release. This is the basis of the classical large-scale magnetic reconnection models of solar flares (see respectively Tsuneta, 1996, and Hudson and Khan, 1996, for arguments pro and con). There is some difference of opinion (*e.g.* Melrose, 1995) as to whether the energy is stored remotely or locally, or even if a substantial part of flare energy enters the energy-release region from below the photosphere. In the latter case, because of the low Alfvén speed in the photosphere, the effect might only be noticed in the gradual phase of a flare or LDE.

In any case, the concept of coronal energy storage suggests a search for relaxation-oscillator behavior as at least a sufficient condition. In such a relationship, the energy of a flare event correlates with the interval before or after its occurrence, as explained below. The correlation-after relationship is well-known in astrophysics from X-ray "burster" sources (Lewin *et al.*, 1970); in that case the oscillation arises from a build-up of gravitational energy, followed by an unstable infall into a compact star. In the solar MHD case, the build-up would consist of non-potential energy in the tangled structure of the coronal magnetic loops, and the release would come from an unstable process involving reconnection. Because there would be many ways in which to dilute this effect, its absence would hardly be proof that coronal energy build-up does not occur. Thus the oscillation-relaxation

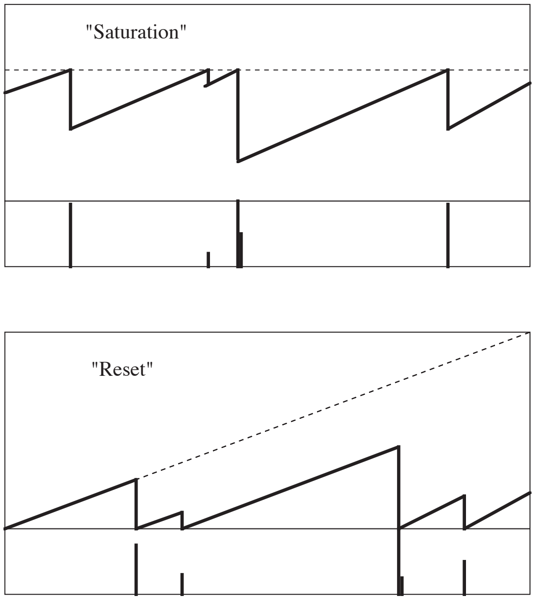

Figure 5. Sketches of two forms of relaxation oscillation. The heavy lines represent coronal energy content *vs.* time in the two models, the vertical lines the flare energy releases. bottom, the “reset to zero” case; top, the “saturation” case. In the “reset” case, the system energy is assumed to increase steadily; in the “saturation” case, it builds back to a trigger level. In both cases we assume single systems so that there is no confusion from independent relaxations.

pattern would be a sufficient but not a necessary condition.

We can distinguish two cases, sketched in Figure 4, both of which envisage a steady rate of energy build-up. In the “reset” case, the instability hypothetically would reduce the stored energy to zero. The energy released in a given event would therefore correlate with the time interval *before* the flare. In the idealized second case, “saturation”, the system would approach a limiting stored energy, resulting in an instability when that limit was reached. In this case the correlation would be with the time *after* the flare. The X-ray burster correlation is of the saturation type. This also appears to be the the pattern expected from a “sandpile” (self-organized critical state) flare model (Lu and Hamilton, 1991).

We have studied the GOES time history for several one-day periods within the lifetimes of AR7978 and AR7981 (the successor region on the second rotation), searching for both “reset” and “saturation” effects. Figure 5 shows an example from one day’s GOES photometric data in this kind of analysis. No correlation shows up either way, but the analysis could be improved in several ways. In particular, one might suspect that different regions within an activity complex would show more physical linkage,

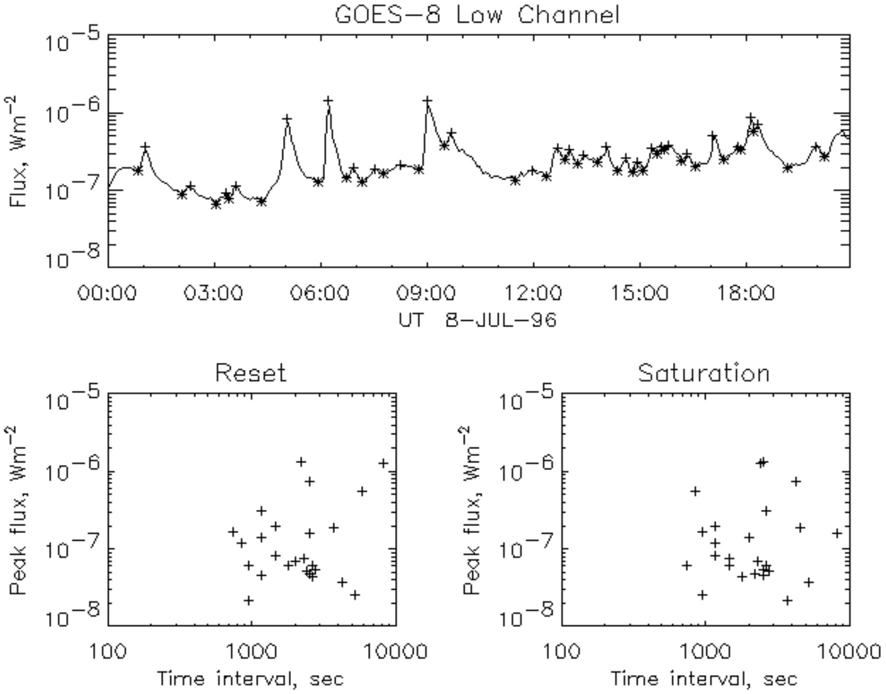

Figure 6. Typical results of a naive search for a relaxation-oscillator signature in the GOES photometry for July 8, 1996. The upper panel shows the GOES data with the locations of interactively selected peaks (*) and valleys (+). The lower panels show the correlations for the two cases ("reset" and "saturation") described in the text. Neither shows a significant correlation.

i.e. that widely separated regions might have independent flare build-up and release. If so, the screening of flares and microflares by location – using the SXT data – might improve the correlation to the point of detectability. Such improvements are beyond the scope of the work described here.

5. Conclusions

The activity complex focusing on NOAA active region 7978 was quite remarkable. It had the effect of making the Sun look lopsided in the *Yohkoh* SXT standard movie. The absence of competing activity made it easier to detect the sometimes subtle X-ray effects accompanying the launch of CMEs, a subject not discussed in this paper (see Hudson & Webb, 1997). The reconnection of the newly emerged flux and the previously existing coronal structure, with effects on the coronal hole population, is the subject of the accompanying paper by Harvey & Hudson (1997). We have mentioned several other investigations this kind of solar activity makes possible, and hope that there will be future work. These include the study of active-region effects on the solar total irradiance, with possible clues about the development of magnetism in the solar interior. Other areas of interest include morphology, connectivity, and the pattern of flare occurrence; all of these benefit from the solar-minimum conditions resulting in essentially one unique active complex, a solar activity "test particle."

Acknowledgements

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