SOLAR ACTIVITY AND THE FORMATION OF CORONAL HOLES

Karen L. Harvey and Hugh S. Hudson

Solar Physics Research Corporation, 4720 Calle Desecada, Tucson, AZ 85718 USA

ABSTRACT

We describe the evolution of a complex of active regions belonging to cycle 22 and how its interaction with two new-cycle (23) regions resulted in the formation of several isolated coronal holes, in the development of the large coronal hole extending from the north polar hole observed in late August 1996, and in significant changes in both polar coronal holes.

INTRODUCTION

From April through August 1996, a series of active regions emerged within an old-cycle (22) activity complex in the southern hemisphere between Carrington Longitudes (C_L) 240–260°. The sequence of five major active-region emergences in the complex and their interaction with three northern hemisphere old-cycle regions and two new-cycle regions was followed in the NSO/KP daily photospheric magnetograms, HeI 1083 nm spectroheliograms, and the *Yohkoh*/SXT X-ray images over a several-month period. The assessment of the evolution of the magnetic fields is based on an examination of the daily NSO/KP full-disk magnetograms and NOAA World Data Center sunspot data. This study is aimed at understanding the distribution of the fields with time, in terms of emergence of magnetic flux and the effects of velocity patterns such as differential rotation, meridional flows, and diffusion in relation to the formation of several coronal holes and changes in the polar holes. The *Yohkoh*/SXT images, combined with the full-disk magnetograms, provided information on the connections of the magnetic fields over the several-month period studied.

The identification of coronal holes (areas of open magnetic fields) and the establishment of boundaries was based solely on the NSO/KP full-disk HeI 1083 nm and photospheric magnetograms, using the following criteria: (1) the area appears brighter than the average quiet sun, (2) the internal network structures have low contrast, (3) the area is predominantly unipolar, (4) the area is at least two supergranules in size ($> 6\times10^8$ km^2), and (5) the boundaries separate low and higher contrast network structures. Figure 1 outlines the areas designated as HeI 1083 nm coronal holes; these correspond one-to-one with areas of low X-ray emission.

EVOLUTION OF GLOBAL AND REGION MAGNETIC FIELDS

In this section, we describe the changes in the magnetic fields associated with the emergence and evolution of ten major active regions in relation to the formation of the areas of open magnetic field. Where available, information of the sunspot region number and position is provided in square brackets; sunspot regions that return are designated by their original number, with the new number indicated in parentheses. Six of the ten regions emerged on the disk and four on the back side of the Sun, including three in the activity complex. Two of these four regions crossed the east limb as decayed, spotless regions and are un-numbered.

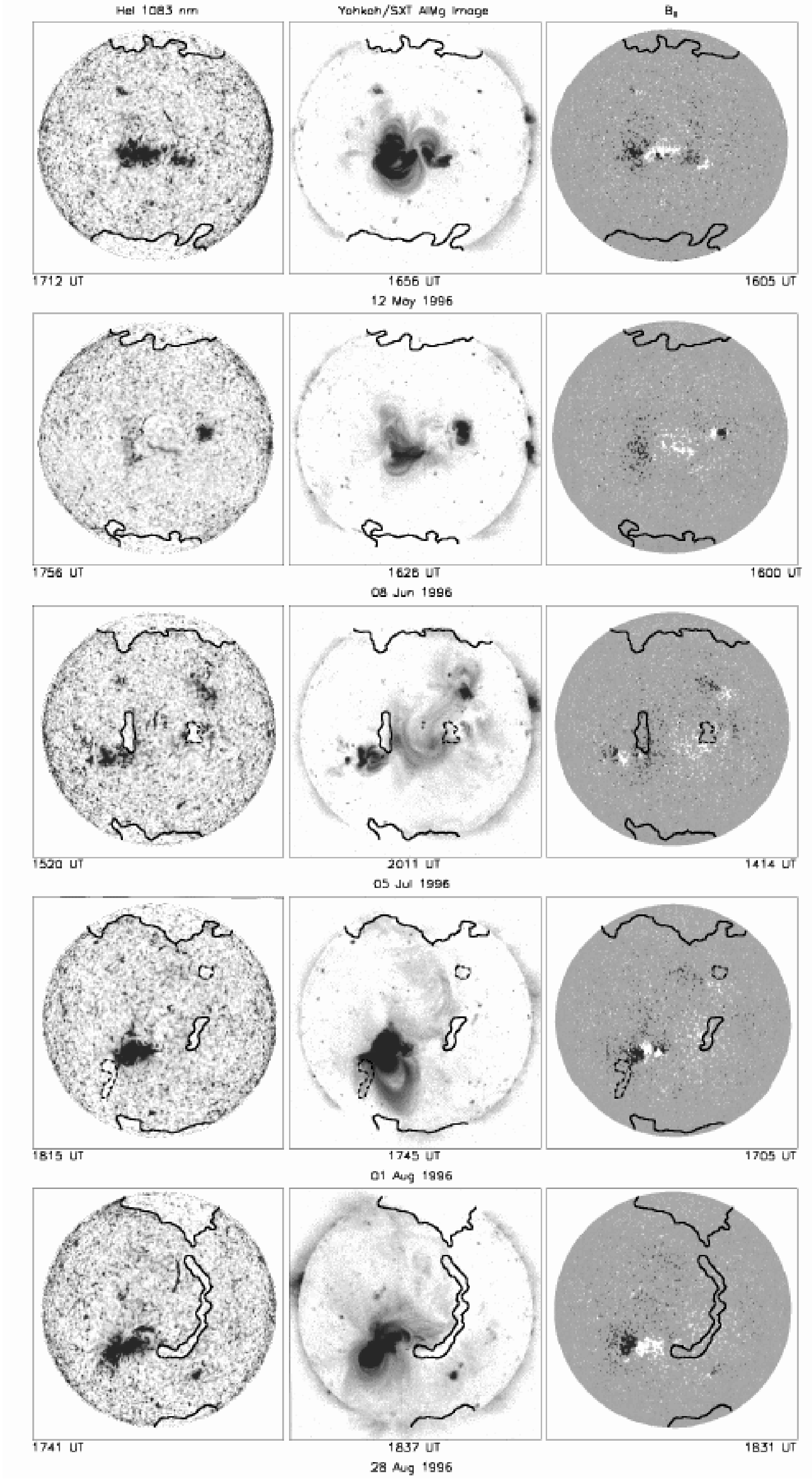

Fig. 1. NSO/KP HeI 1083 nm spectroheliograms, *Yohkoh*/SXT X-ray images (an inverse intensity scale), and NSO/KP photospheric magnetograms for five sequential central meridian passages of the 1996 activity complex. The HeI 1083 nm image is an inverse equivalent width; the polarity of the magnetic fields is designated as *white* for positive and *black* negative. HeI 1083 nm coronal holes are outlined in *black* on all three images; *solid curves* indicate well-defined holes and boundaries and *dashed curves*, the coronal holes that are uncertain. North is at the top and east to the left. Image centers show approximately C_L =240-260.

15 April and 12 May 1996 Disk Passages: Carrington Rotations 1908 and 1909

The first two regions in the activity complex emerged on 18 April [7957: S08, C_L =246] and 20 April [7958: S06, C_L =243]. NOAA Region 7958, the larger of the two, became the dominant pattern of magnetic flux in the complex in subsequent rotations. X-ray images show that within one day, the positive fields of 7958 began connecting to the remnants of NOAA regions 7953 [N07, C_L =201], which emerged on the previous rotation, and 7956 [N04, C_L =246], which emerged on 18 April. These connections persisted through the next two disk passages of the complex in mid-May and mid-June.

8 June 1996 Disk Passage: Carrington Rotation 1910

NOAA region 7968 [N04, C_L =289] emerged on 4 June and a new cycle region [7967: N37, C_L =327] emerged on 1 June. Connections quickly form between 7958 and 7968.

5 July 1996 Disk Passage: Carrington Rotation 1911

Several significant changes occur by the July return of the active region complex this rotation. First is the second region in the complex (un-numbered), which crosses the east limb as a decayed spotless region. It is located along the east boundary of the complex, a shift of $\sim 20°$. Second, is the appearance of a large new-cycle region (also un-numbered) at N25, C_L =288; this region emerged on the backside of the Sun and crossed the east limb as a decayed spotless region. With the emergence of this region, connections developed between its negative-polarity follower and the positive-polarity northern polar fields. As a result, a portion of the polar coronal hole retracted poleward, as shown in Figure 1, indicating that part of the open field closed. In addition, the positive-polarity leader of southern hemisphere region 7958 is connected to the negative-polarity follower of the new-cycle region at N25. Due to differential rotation, NOAA region 7967 is now located between the larger region and the polar fields; connections are seen between the fields of these two new-cycle regions. This circumstance delayed the formation of an isolated coronal hole in the positive-polarity leader of the large new-cycle region.

Two coronal holes are identified in the activity complex this rotation: one between regions 7958 and 7968, and the second in the follower negative polarity fields of 7958. The second coronal hole disappears with the emergence of NOAA region 7978 [S10, C_L =248] on 4 July, a region which produced an X-class flare on 9 July 1996. The positive fields in the complex, migrating toward the south pole, also have established connections with the negative polarity of the south polar fields and the polar hole is beginning to retract poleward.

1 August 1996 Disk Passage: Carrington Rotation 1912

The fourth region [7981: S11, C_L =256] emerged in the complex on the backside of the Sun just east of 7978 (7980). The magnetic field connections seen in the previous rotation persist. The southern polar coronal hole shows additional retraction and the extension of the polar hole toward the negative polarity fields in the complex east of the retracted boundary.

The isolated coronal hole located in the positive-polarity leader of 7958 has extended in mainly the north-south direction. A new possible isolated coronal hole formed in positive-polarity leader of un-numbered new-cycle region. In addition, a possible negative polarity coronal hole is observed just southeast of the active region complex; this hole is not observed the next rotation.

28 August 1996 Disk Passage: Carrington Rotation 1913

The last of the major regions [7986: S12, C_L =258] in the complex emerged east of 7978 prior to its east limb passage. As shown in Figure 1, the biggest change in the magnetic field configuration is the expansion of the two isolated positive polarity coronal holes seen in the previous rotation into one coronal hole that at times during this disk passage extends from the north polar regions into the complex. The northern polar coronal hole also extends to a much lower latitude (N30). The extended coronal hole divides an area of generally low X-ray emission to the west and of substantially stronger emission to the east.

25 September 1996 Disk Passage: Carrington Rotation 1914

Not shown in Figure 1, by the September rotation the activity complex is decaying with no further significant emergence of magnetic flux. The isolated positive-polarity coronal hole is no longer connected to the northern polar coronal hole, and a large negative-polarity, isolated coronal hole has formed east of the complex. Both of these isolated coronal holes persist for two more rotations.

SUMMARY

The coronal holes related to the old-cycle activity complex of 1996 resulted from the following circumstances:

1. The emergence of the southern hemisphere activity complex consisted of five major old-cycle regions from mid-April to late August. The site of emergence of four of the five regions in the complex shifted to the follower of the original region (7958) beginning in mid-June. As a result, the positive fields of 7958 and its connections with areas outside the complex remained relatively stable over several rotations.
2. The emergence of a new-cycle region at N25 in mid-late June, resulting in the reconnection of region's negative-polarity follower fields to the positive polarity northern polar fields, the partial closing of northern polar coronal hole in late June, and to the formation in July of an isolated coronal hole in the positive-polarity leader of the large new-cycle region.
3. The alignment in longitude of the un-numbered new cycle region with the leader of the original region in the complex as a result of differential rotation. This alignment produced a latitudinally extended area of positive polarity magnetic flux and the formation of the coronal hole extending from the northern polar hole into the southern hemisphere complex.

This study confirms that the formation of isolated coronal holes depends on the emergence of magnetic flux in active regions and the interaction of those fields with the surrounding magnetic flux (Bohlin and Sheeley, 1978; Harvey and Hudson, 1997) and with the polar fields (Sheeley and Harvey, 1978; Harvey and Hudson, 1997).

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