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MAGNETIC FIELD RE-ARRANGEMENT AFTER PROMINENCE ERUPTION

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INTRODUCTION

It has long been known that magnetic reconnection plays a fundamental role in a variety of solar events. Although mainly invoked in flare problems, large-scale loops interconnecting active regions, evolving coronal hole boundaries, the solar magnetic cycle itself, provide different evidence of phenomena which involve magnetic reconnection. A further example might be given by the magnetic field rearrangement which occurs after the eruption of a prominence. Since most often a prominence reforms after its disappearance and may be observed at about the same position it occupied before erupting, the magnetic field has to undergo a temporary disruption to relax back, via reconnection, to a configuration similar to the previous one.

The above sequence of events is best observable in the case of two-ribbon (2-R) flares but most probably is associated with all filament eruptions. Even if the explanation of the magnetic field rearrangement after 2-R flares in terms of reconnection is generally accepted, the lack of a three-dimensional model capable of describing the field reconfiguration, has prevented, up to now, a thorough analysis of its topology as traced by Hα/X-ray loops. The purpose of the present work is to present a numerical technique which enables one to predict and visualize the reconnected configuration, at any time t, and therefore allows one to make a significant comparison of observations and model predictions throughout the whole process.

THE 3-D MODEL

Some years ago, Altschuler and Newkirk (1969) and Altschuler et al. (1977) developed a method to calculate the global magnetic structure of the corona, assumed to be potential, from the measured line of sight component of the photospheric magnetic field. These authors solved Laplace's equation $\nabla^2 \psi = 0$ for the scalar potential ψ, in spherical coordinates, assuming as boundary conditions the observed values of the magnetic field. In the domain between $r = R_\odot$ and $r = R_w$, which represents the height at which $\psi = 0$ (or, equivalently, where the magnetic field becomes radial) ψ is given by

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$$\psi(r,\theta,\phi) = r_\odot \sum_{n=1}^{\infty} \sum_{m=0}^{n} P_n^m(\theta) \left\{ \left[c_n^m \left(\frac{r}{r_\odot}\right)^n + (1-c_n^m)\left(\frac{r_\odot}{r}\right)^{n+1}\right] g_n^m \cos(m\phi) \right.$$

$$\left. + \left[d_n^m \left(\frac{r}{r_\odot}\right) + (1-d_n^m)\left(\frac{r_\odot}{r}\right)^{n+1}\right] h_n^m \sin(m\phi) \right\}$$

where $c_n^m = d_n^m = -\left[\left(\frac{r_1}{r_\odot}\right)^{2n+1} - 1\right]^{-1}$; $P_n^m(\theta)$ are the Legendre functions of degree n, order m , and g_n^m , h_n^m must be determined from measurements. Once ψ is known, the magnetic field components at any point (r,θ,ϕ) are given by

$$B_r = -\frac{\partial\psi}{\partial r} \qquad B_\theta = -\frac{1}{r}\frac{\partial\psi}{\partial\theta} \qquad B_\phi = -\frac{1}{r\sin\theta}\frac{\partial\psi}{\partial\phi}$$

We refer the reader to the above-quoted references for more details on the method. Although traditionally used to derive global coronal fields from photospheric fields measured over a solar rotation, in principle nothing prevents the application of this technique to the study of the temporal variation of the coronal field topology above limited solar areas, provided that, for each field calculation, boundary conditions are taken from single observations. Moreover, varying the height R_w where the magnetic field becomes radial provides a means of representing a reconnection process where fields have reconnected only below R_w. A time-dependent situation may therefore be simulated, even if the $R_w = R_w(t)$ profile can be determined only a posteriori, matching the observed with the analytically derived topology.

The practical application of the method meets however with severe problems whenever a high resolution magnetic field representation is required, due to the dramatic increase of computing time with the size of the input data matrix and the value $n = N$ at which the harmonic series is truncated. To alleviate these difficulties we consider data from a limited sector of the Sun and fill the outside regions with periodic repetition of the field pattern within the sector. With this procedure both the number of input data and the number of coefficients g_n^m , h_n^m is smaller, and as a consequence the computing time is drastically shortened. For example, fields given with about 30 arcsec resolution over a sector 30° wide can be reconstructed with $N = 63$ in about 10^h, using a VAX 750.

MAPPING CORONAL FIELDS

Despite the time reduction achieved by the above-mentioned procedure, the overall computing time still remains rather long. However, much insight into the reconnecting topology can be obtained from model fields, given with coarse resolution and easily reconstructed in shorter times. Figures 1 and 2 show the magnetic field topology of such a model field whose negative and positive polarities are oppositely stretched along the East-West direction. Individual maps within each figure differ in the source surface height: the two figures differ in the criterion adopted for field line selection. Figure 1 shows maps with field lines originating from randomly chosen photospheric footpoints; in Figure 2 only those field lines which close at the height of the source surface are shown.

The two representations complement each other: although no observed configuration will at any time look like any maps of Figure 2, a comparison of the two kinds of

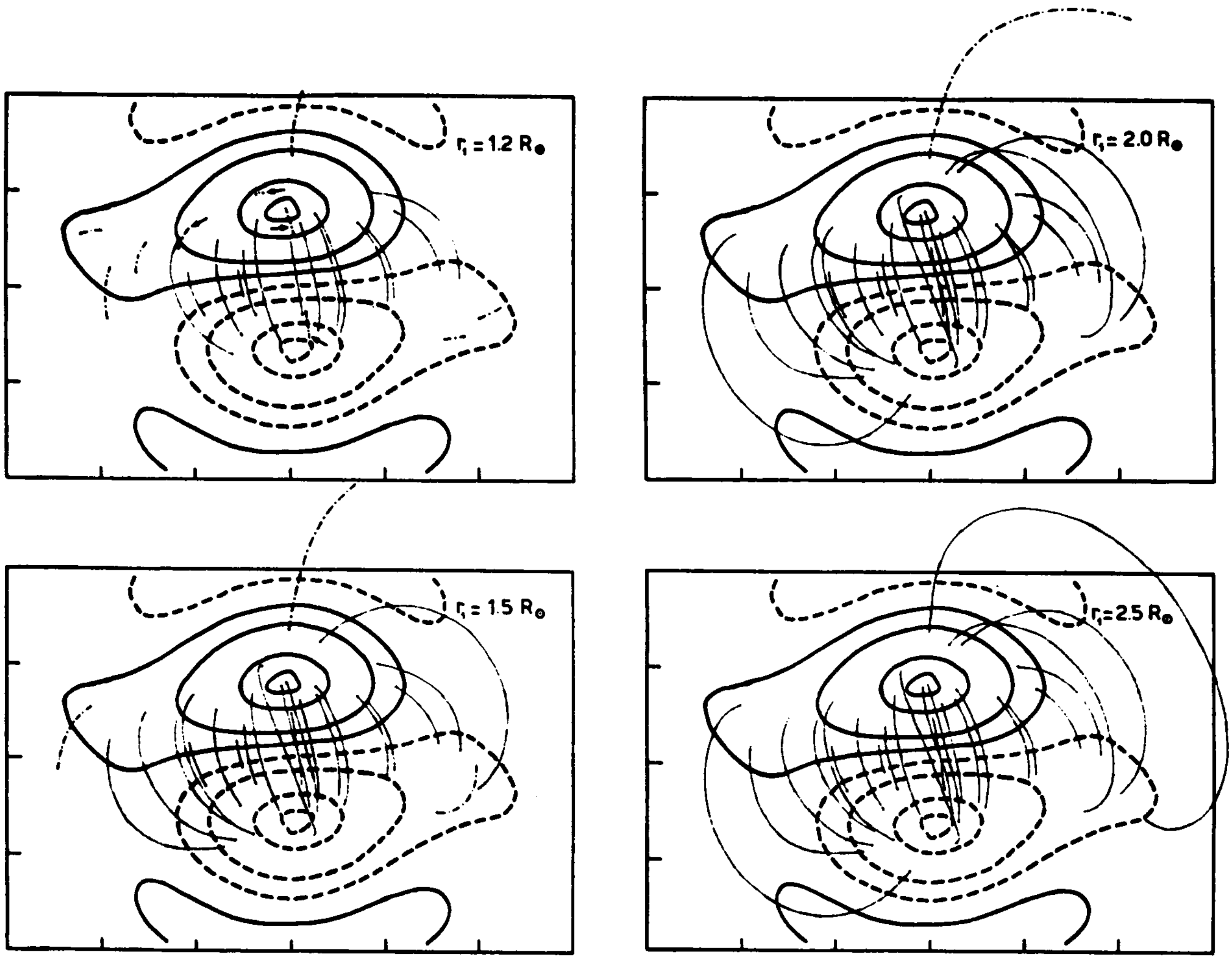

Figure 1. Randomly chosen field lines for the bipolar model field described in the text, superimposed on isogauss contours of the surface field. Dot-dashed field lines are open.

representation is necessary to ensure that no relevant structure is missing from the more realistic topologies of Figure 1.

Examination of Figures 1 and 2 shows that field lines bridging directly across the neutral line and closing at relatively low heights, connect footpoints located at about the same longitude, whereas peripheral field lines, which close at much greater altitudes may connect widely separated longitudes. When analyzing observed configurations this behavior may be interpreted erroneously as evidence for a non-potential, or sheared, field, since field lines appear not to cross the neutral line at right angles. However taking into account the height shift in the orientation of the neutral line, one can easily verify that this is not the case.

The May 21, 1980 flare - accompanied by a coronal transient and a growing system of post-flare loops (de Jager and Švestka, 1985), providing diverse evidence for field disruption - constitutes an ideal case to test the model capabilities. At the time of this writing a coronal field mapping, at a number of different source heights, has not yet been completed. Therefore, in Figure 3 we give only a map of the ob-

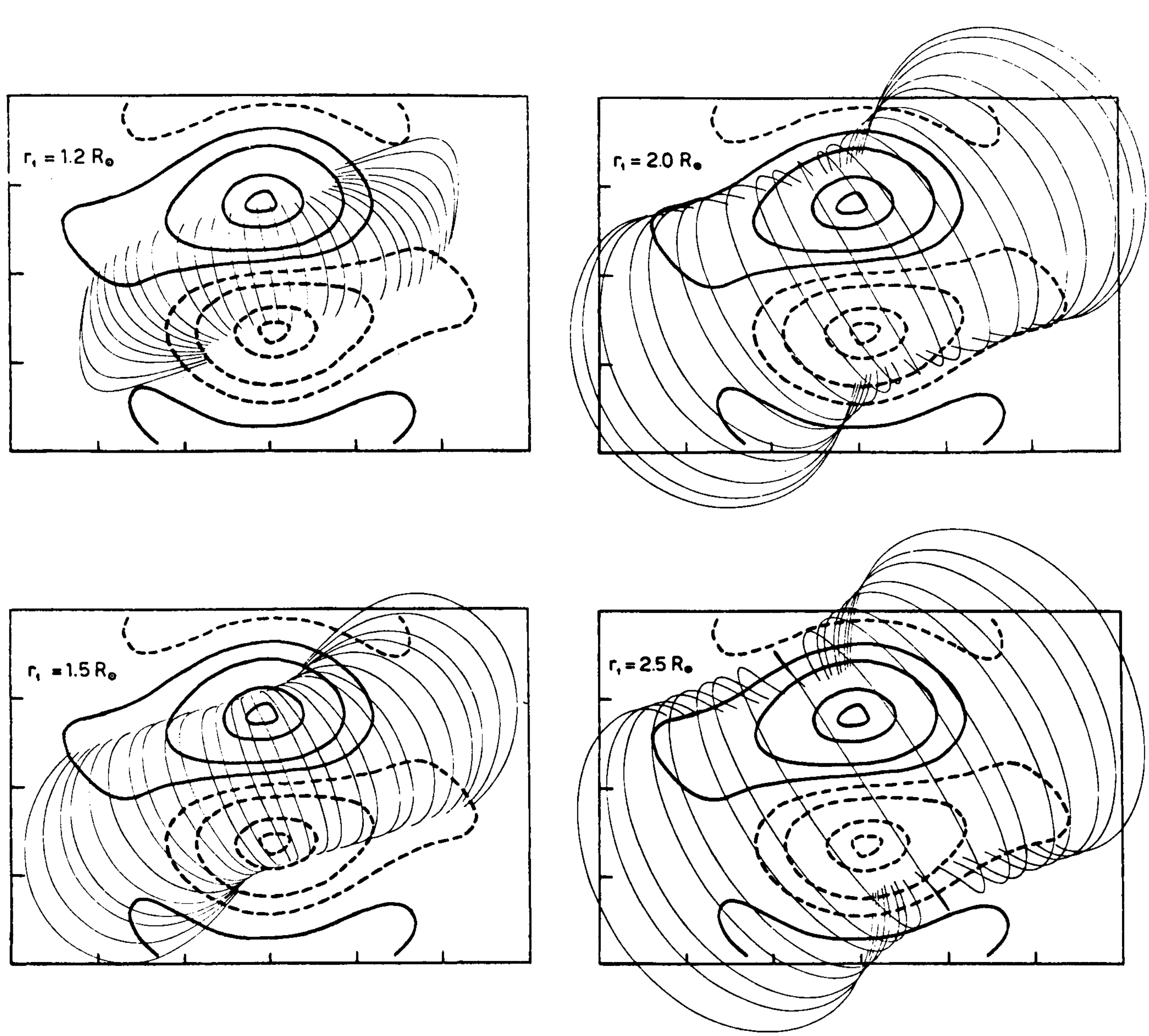

Figure 2. Arcade of loops which form just as the source surface reaches the indicated height, for the same model field as was used in Figure 1.

served and reconstructed photospheric field. Magnetograph observations, originally taken with a 2 arcsec resolution, have been averaged to yield data with 32 arcsec resolution. The surface field obtained using Legendre functions up to N = 87 yields nearly a perfect representation of this input field configuration.

FUTURE PERSPECTIVES

The main area of applicability of the method lies in the comparison between observed and computed reconnecting configurations. Usually a filament erupts more than once in its lifetime; thus the question arises whether after each eruption the reconnected configuration is potential and only afterwards energy starts building up

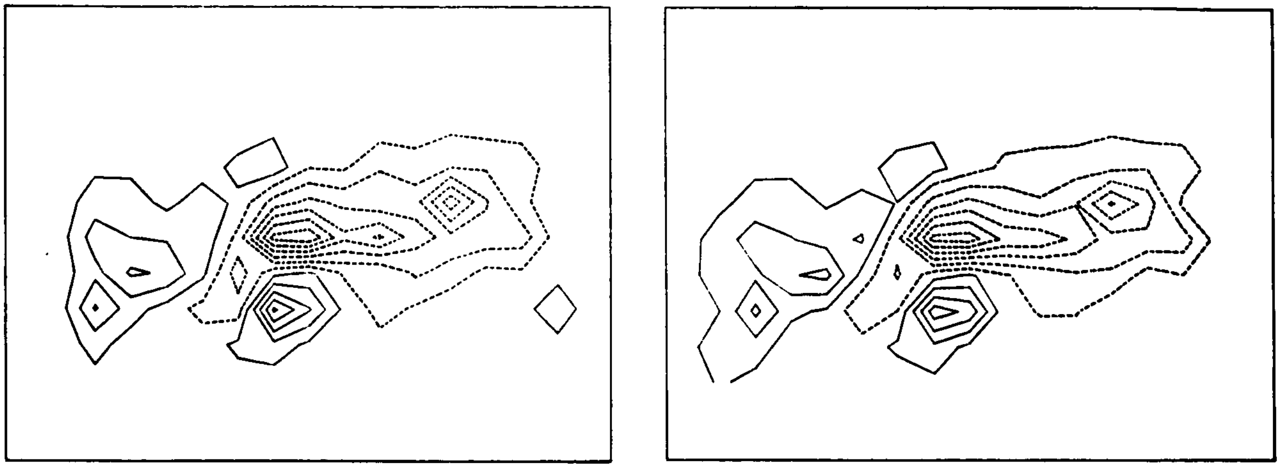

Figure 3. Contour plots of the observed (left) and reconstructed (right) line-of-sight surface magnetic field for the active region of the 21 May 1980 flare.

again, or whether reconnection occurs to a non-potential field, thus not releasing all of the stored energy in any single event. To ascertain which of the above hypotheses is correct, it will suffice to check the observed time history of magnetic field topologies against the potential ones.

Closely related to the above topic is the possibility of identifying the nature of the giant arches repeatedly observed by the HXIS instrument onboard SMM (Švestka, 1982, 1984). These gigantic structures, observed in association with 2-R flares, could result either directly from reconnection at high altitudes (as the topology of the model field shown in Figures 1 and 2 might suggest) or from the upper disconnected loops which overlie the reconnecting arcade (Svestka, 1982). Future observations of the magnetic field rearrangement after filament eruptions, possibly in the absence of flares, will help to establish whether giant arches are characteristic of all such events or only of the most energetic ones.

Finally, the method allows one to estimate the amount of energy released by relaxation towards a potential configuration. This liberated energy has to be at least of the same order of magnitude as the thermal energy content of the loops, if reconnection is the sole energy source of the newly formed closed structures. Estimates of this sort have already been performed in idealized 2-D configuration, but have never been applied to real 3-D topologies.

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