THE ORIGIN OF THE 28- TO 29-DAY RECURRENT PATTERNS
OF THE SOLAR MAGNETIC FIELD

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Abstract. Numerical simulations of the Sun's mean line-of-sight magnetic field suggest an origin for the 28-
to 29-day recurrent patterns of the field and its associated interplanetary phenomena. The patterns are
caused by longitudinal fluctuations in the eruption of new magnetic flux, the transport of this flux to mid
latitudes by supergranular diffusion and meridional flow, and the slow rotation of the resulting flux
distributions at the 28- to 29-day periods characteristic of those latitudes.

1. Introduction

During the past few years, we have developed a program to simulate the evolution of
the Sun's photospheric magnetic field (Sheeley et al., 1983, 1985; DeVore et al., 1985).
Bipolar magnetic regions are the sources of new photospheric flux, and this flux is
transported over the surface by supergranular diffusion, differential rotation, and
meridional flow. We determine the influence of the source properties and transport
parameters on the field patterns by varying their input values and comparing the
resulting simulations with each other and with observations.

One of the initial objectives of our program was to study the origin of the 28- to 29-day
recurrent patterns of the solar magnetic field. The patterns were discovered by
Svalgaard and Wilcox (1975) from inferred measurements of interplanetary magnetic
field polarity during the years 1926–1973. Although such patterns have since been
identified in the mean line-of-sight solar magnetic field (Scherrer and Svalgaard, 1977),
the solar horizontal dipole field (Hoeksema, 1984), and the distribution of low-latitude
coronal holes (Sheeley and Harvey, 1981), their origin has remained obscure (cf.
Hundhausen, 1977; Sheeley, 1981). In this paper, we describe mean-field simulations
which suggest a plausible explanation for these recurrent patterns.

2. Approach

As in a previous paper (Sheeley et al., 1985), we calculate the daily value of the Sun's
mean line-of-sight field as seen from Earth and display the results in Bartels's (1934)
format. In this format, vertical patterns indicate long-lived structures that return with
27-day synodic rotational periods, while patterns slanted from upper left to lower right
indicate long-lived structures that return with periods greater than 27 days. A Bartels
display of the mean magnetic field measured at the John M. Wilcox Solar Observatory

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Fig. 1. Bartels displays of the mean line-of-sight solar magnetic field. Column 1 shows the mean field measured at the John M. Wilcox Solar Observatory. Column 2 shows the mean field simulated with our 'standard model' of source properties and transport parameters. Columns 3–5 shows the mean field simulated with the indicated variations on the properties of the sources. Entries shaded light or dark refer to positive- or negative-polarity fields with strengths of 0.1 G or greater, respectively, while neutral shading denotes fields of either polarity with strengths below 0.1 G. Very dark entries indicate missing data.

is shown in column 1 of Figure 1. Slanted patterns occur not only during the rising phase of sunspot cycle 21 (1977–1978) and through sunspot maximum (1980), but also during the declining phase (1981–1983). As we shall see, the simulations suggest that these patterns originate in slowly rotating, mid-latitude distributions of photospheric flux.

3. Results

We begin by establishing a reference calculation, our 'standard model', for comparison with the observations and with other simulations (cf. Sheeley et al., 1985). The transport parameters include a diffusion constant of 400 km$^2$ s$^{-1}$, the solar rotation formula determined by Snodgrass (1983), and no meridional flow. We use the National Solar Observatory synoptic magnetogram for Carrington rotation 1646 as the initial flux distribution, and we use estimates of the fluxes and coordinates of nearly 2500 bipolar magnetic regions which erupted during 1976–1984 as the sources of new flux. The resulting mean field is shown in column 2 of Figure 1. Although there certainly are
detailed differences between the simulated and observed fields, whose correlation coefficient is +0.44, overall the patterns are in rather good agreement.

In our previous study, we found that the continued eruption of new sources of flux is essential for the 28- to 29-day patterns to persist. When we terminated the input of new sources at the end of 1981, the slanted patterns became vertical only several solar rotational periods later, as shown in column 3 of Figure 1. We also found that the sources need not erupt systematically in longitude in order for long-lived, slanted patterns to result. When we replaced the average longitude of each source by a random longitude in the range (−180°, +180°), we obtained substantially different patterns, as indicated by the correlation coefficient of only −0.06 between the simulated and observed mean fields. However, these new patterns still contained some long-lived, slanted features, as shown in column 4 of Figure 1. Thus, to maintain the 28- to 29-day patterns, the longitudinal fluctuations in the eruption of new flux may be due to chance as well as to solar 'active longitudes' (cf. Losh, 1939; Gaizauskas et al., 1983).

The recurrence periods of the slanted patterns in the Bartels display are characteristic of the solar rotation at mid latitudes. For example, the synodic rotational period found by Snodgrass is 28.0 days at 26.6° latitude, and 29.0 days at 35.7° latitude. This suggests that the slanted patterns may originate in mid-latitude flux distributions. However, the sources of this flux need not emerge at mid latitudes. When we neglect the sources which emerge above 20° latitude, where the rotational period is 27.5 days, we obtain the mean field shown in column 5 of Figure 1. Some of the slanted recurrent patterns originally present have been replaced by vertical patterns, particularly during the rising phase of the cycle when nearly all of the sources emerge at latitudes above 20°. However, most of the slanted patterns are unchanged, and thus must be maintained by the low-latitude sources.

Evidently, the flux which emerges at low latitudes is being transported to mid latitudes, where it produces a 28- to 29-day recurrent mean field. In our standard model, this transport is provided by supergranular diffusion. When we inhibit the latitudinal transport by omitting the diffusion, we obtain the mean field displayed in column 2 of Figure 2. Before 1980, the patterns are strengthened but their recurrence periods are not altered much. After 1980, the recurrence periods do not exceed about 27.5 days, and the patterns in 1981–1983 are noticeably less slanted than for the standard-model mean field (shown in column 1 for comparison).

In the absence of diffusion, it is possible to restore the latitudinal transport of flux by introducing a poleward meridional flow. When we combine the differential rotation with a flow which reaches its peak speed of 5 m s⁻¹ at 30° latitude, we obtain the mean field shown in column 3 of Figure 2. The recurrent patterns late in the sunspot cycle again return at about 28-day intervals. Clearly, the flux originating in low-latitude sources must be transported to mid latitudes, by diffusion or a poleward meridional flow or both, in order for the 28- to 29-day patterns to be set up in the mean field.

Finally, we may clarify the way that differential rotation affects the mean-field patterns by eliminating it from the simulations. When we replace the Snodgrass rotation by rigid rotation at the equatorial rate, we obtain the mean field shown in column 4 of
Figure 2. Throughout the sunspot cycle, the recurrent patterns are now tilted backwards slightly in the 27-day Bartels frame. This backwards tilt, which is not present in the standard model, corresponds to the synodic equatorial rotational period of 26.9 days measured by Snodgrass. Evidently, the characteristic slant of the mean-field recurrent patterns simply reflects the solar rotational period averaged over the instantaneous distribution of flux, and the 28- to 29-day patterns are due to flux distributions that are peaked at mid latitudes.

4. Discussion

These results suggest that the slanted recurrent patterns in the solar magnetic field owe their existence to longitudinal fluctuations in the eruption of the sources of new flux, the transport of that flux to mid latitudes, and the slow rotation of the resulting flux distributions at the 28- to 29-day periods characteristic of those latitudes. The non-uniformities in longitude of the sources modulate the mean field at periods characteristic
of the Sun's rotation. These fluctuations may be systematic, as would be those associated with solar 'active longitudes' (cf. Losh, 1939; Gaizauskas et al., 1983), but also may be statistical, as were the fluctuations in our simulation using randomized source longitudes. The transport of the flux to mid latitudes causes the modulation in the mean field to occur at 28- to 29-day rotational periods, rather than at the 27-day period characteristic of near-equatorial latitudes. Of course, if the flux originates at mid latitudes, as it does in the rising phase of the sunspot cycle, the slanted patterns appear even in the absence of a mechanism for latitudinal transport.

The sustained eruption of new flux is necessary in order to maintain the 28- to 29-day patterns. Our recent analytical calculations of the decay of the mean field via differential rotation and meridional flow (Sheeley and DeVore, 1986) show that differential rotation winds up a distribution of mid-latitude surface flux on a time scale of several rotational periods. For the slanted mean-field patterns to persist for a year or more, sources must continually provide new 'unwound' flux for transport to mid latitudes. When the eruption of new flux stops, the mid-latitude flux quickly becomes wound up and the mean field becomes dominated by the residual unwound flux at low latitudes. This flux rotates with a 27-day period and gives rise to vertical patterns in the Bartels display.

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References