DYNAMICS OF LARGE-SCALE MAGNETIC FIELD EVOLUTION DURING SOLAR CYCLE 20

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Abstract

The evolution of large-scale solar magnetic fields has been studied for a complete solar cycle using the atlas of H-alpha synoptic charts for 1964-1974. The results include: a unique magnetic pattern coinciding with major coronal holes; variations in the rate of solar rotation through the solar cycle; discovery of convergence and divergence among long-lived magnetic patterns; periodic discontinuities in the organization of large-scale magnetic fields; and a new cause for coronal transients.

Large-scale solar magnetic fields are clearly outlined by filaments and filament channels in ordinary solar patrol photographs taken with H-alpha filters. Synoptic charts based on H-alpha observations (McIntosh, 1979) provide a new perspective on the large-scale magnetic patterns by emphasizing the neutral lines in the radial component of these fields, whereas the locations of these lines on longitudinal magnetograms appear as diffuse zones where there is an absence of signal. The H-alpha structures, therefore, permit a more accurate mapping of these lines. The magnetic patterns are more complete than on conventional magnetograms because of the interconnections between filaments and active regions formed by the filament channel and the transient filament-like features. The result is a sun laced by only a few, very long neutral lines, one of which encircles the sun like a stitch on a baseball, underlying both polar-crown filament-systems and crossing the solar equator at two longitudes. Because the polar-crown neutral lines are part of this single, fundamental boundary in the magnetic fields, there exists a gap in the polar crown in each hemisphere. There may be more than one gap in each hemisphere for short periods of time, but one of those gaps dominates in size and lifetime.

The polar-crown gap (PCG) and other long-lived features in the large-scale solar magnetic fields are best studied by dividing synoptic charts into narrow zones of latitude and assembling time series showing single zones. The areas of negative polarity are shaded to emphasize the patterns. The latitude limits for this initial study of

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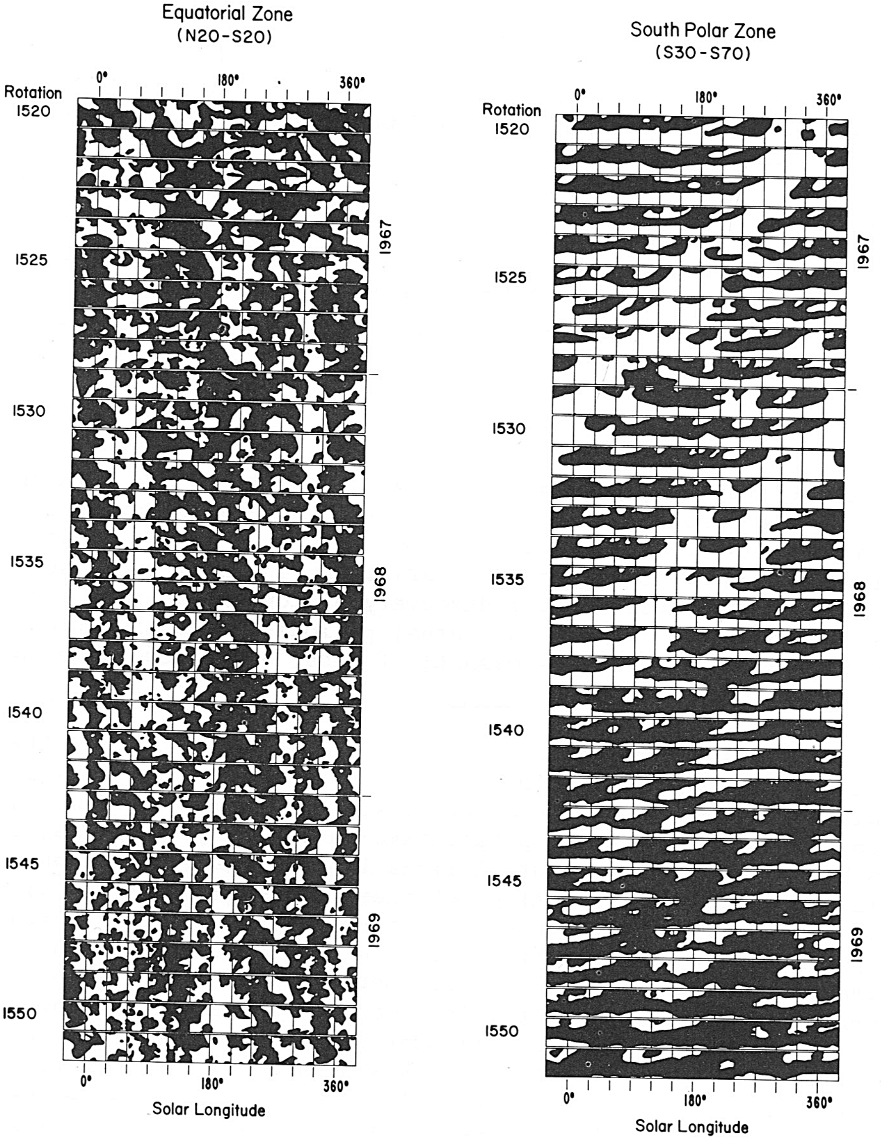

Figure 1. Large-scale patterns of solar magnetic polarity for the equatorial and southern high-latitude zones during the rise to solar maximum of Solar Cycle 20 (Carrington Rotations 1520-1551). Each strip is a zone from an H-alpha synoptic chart in McIntosh (1979). Negative polarity is black, positive polarity is white.

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Solar Cycle 20 are: N20-S20, N30-N70 and S30-S70. Figure 1 shows the equatorial and south polar zones for 1967-1969, the period of rapid rise to solar maximum. Figures for the northern polar zone and for the other portions of Solar Cycle 20 will appear elsewhere.

The polarity of the south polar cap and of the southern PCG was positive at the beginning of the solar cycle. The PCG appears in the sequence of south polar zones in Figure 1 as a white diagonal, indicating the slow rate of solar rotation at this latitude. Midway through the figure the white diagonal terminates and a black diagonal emerges. This signifies the polarity reversal that took place at high latitudes in mid-1968. The southern PCG divided into two during 1969. Identical behavior, with polarities reversed, occurred in the northern polar zone for this same period.

The PCG could be identified in both hemispheres at the start of Solar Cycle 20 and both continued without interruption, and without dividing, until the time of polarity reversal in 1968, a period of almost four years.

These PCGs can be directly correlated with minima in the white-light K-corona observations in 1967. The PCGs of the 1972-1974 period coincide with the XUV and X-ray coronal holes (McIntosh et. al., 1976) observed by OSO-7 and Skylab. The PCGs of the current solar cycle coincide with the major coronal holes inferred from infrared observations of the helium line.

The slopes of the diagonals formed by the PCG indicate the rate of rotation of the PCG relative to Carrington coordinates. The slopes of both northern and southern PCG were constant from 1964 to the end of 1966 at a 29-day period, then decreased (decelerated) in 1967-1968 to a 32-day period. The slopes of features in the equatorial zone show no systematic variation during the same interval, implying that the degree of shear across latitude increased as the solar cycle built to maximum.

Large-scale magnetic-field patterns in the equatorial zone persist as diagonals in the zonal series, indicating that solar activity produces only minor and gradual changes in the large-scale patterns. An individual feature has active regions preferably near its leading (western) boundary.

The large-scale patterns drift with respect to one another, producing convergence and divergence among the patterns. The merger of two patterns forces the disappearance of large filaments that marked their adjacent boundaries. Filament disruption is closely associated with coronal transients; therefore, large-scale magnetic-field mergers represent a major category, or source, of coronal transients.

Convergence between adjacent features in the polar magnetic patterns closes the PCGs in 1968 at the time of polarity reversal.

Divergence opens new PCGs a few rotations later. Therefore, the birth and death of coronal holes is caused by large-scale divergence and convergence, respectively.

The phenomenon of convergence and divergence implies that we are observing the presence of large-scale circulation superposed on the mean differential solar rotation.

Zonal time series such as Figure 1 were combined so that the 10-year period could be viewed as a single figure in each latitude interval. This continuous view of the magnetic-field evolution revealed periodic changes in the patterns that escaped notice in viewing shorter intervals. Discontinuities in the equatorial patterns occurred every 2-1/2 years, marked by the periodic emergence of an especially large and long-lived negative-polarity feature following the discontinuities. More distinct and more frequent discontinuities occurred in the northern polar patterns, at roughly yearly intervals. Discontinuities occurred in the southern polar zone at the same time, but with less reorganization of the patterns. The yearly discontinuities may be present in the equatorial patterns, but cannot be proven at this time.

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DISCUSSION

Moore: Do the polar cap gaps rotate faster or slower than the photospheric plasma at the same latitude, and if so, by how much?

McIntosh: No detailed direct comparison has yet been made. The average rotation rate for the photospheric plasma at polar-crown gap latitudes is approximately 32 days. The observed motion of the polar-crown gaps varies from 29 to 35½ days.

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