SEMI-REGULARITIES IN THE PHOTOSPHERIC MAGNETIC FIELDS

RAJENDRA N. SHELKE and M. C. PANDE
Uttar Pradesh State Observatory, Manora Peak, Naini Tal, India

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Abstract. Using Stanford large-scale magnetic field synoptic charts of rotation 1676 to 1739 and by delineating LLUMR, i.e., long-lived unipolar magnetic regions of both polarities surviving at least for four solar rotations, the semi-regular nature of their photospheric magnetic field pattern and their rotational properties have been examined. The investigation demonstrates the existence of regularities in the background field patterns as shown from the regular patterns of LLUMR rows and streams. This confirms the results of Bumba and Howard concerning regularities in large-scale photospheric magnetic field patterns. LLUMR streams seem to be arranged in a wave pattern of alternating polarities. Coronal holes and associated sections of photospheric field patterns suffer differential rotation. The rotation rates of the background field patterns which are not associated with the coronal holes are different from those which are.

1. Introduction

The problem of the existence of irregularities in the distribution of solar activity and its dependence on heliographic longitudes has existed in the literature for nearly 90 years (cf. Losh, 1939; Bumba, 1970). An essential change in these problems was brought about by Bumba and Howard (1965a, b) who picked out the systematic character of the inhomogeneities in the Mount Wilson magnetic field data. In a study of the large-scale distribution of solar magnetic fields, Bumba and Howard (1965a, b) pointed out the semi-regular nature of the background field pattern on their synoptic charts of photospheric magnetic field. Subsequently, large-scale regularities in the distribution of active regions (Dodson-Prince and Hedeman, 1968; Švestka, 1968) and in the polarity of the interplanetary magnetic field (Wilcox, 1968) have also been investigated. Further, Bumba and Howard (1969) described certain new patterns in the field distribution: 'sections' which are features of single polarity which develop into activity zones from the magnetic fields of one to several activity regions. Sections may often be observed for at least 10 rotations. A series of sections of one polarity placed in chronological order on consecutive synoptic charts form 'rows'. Two or more rows of one or both polarities may constitute a nearly continuous 'stream'. Moreover, they noted some definite regularities in the background field pattern. Bumba *et al.* (1969) also noted definite regularities in the distribution of one polarity in an autocorrelation analysis of the synoptic chart material for 7 rotations during 1960.

Here we examine the regularities in the background field patterns using a new concept of long-lived unipolar magnetic regions (LLUMRs) amenable to delineation of those magnetic cell regions which persist for four solar rotations.

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2. Observational Data

To delineate synoptic charts of positive and negative LLUMRs, we superposed four consecutive Stanford synoptic charts of large-scale magnetic fields and then located the unipolar magnetic patterns which survived for four solar rotations. We then cut the synoptc charts of LLUMRs into strips representing zones of latitudes ($\pm 10°$, $\pm 20°$, $\pm 40°$) and arranged the strips of every latitude zone in chronological order (cf. Figures 1 to 3). Stanford synoptic charts for rotations 1676 to 1737, taken from *Solar-Geophysical Data* were used in this study.

3. Semi-Regular Nature of LLUMRs

The strong regularity of LLUMRs in longitudes and their persistence is most striking in Figures 1 to 3. In these figures the features of one polarity stretching across the strip, we call 'LLUMR sections'. Since these LLUMR sections are followed for a number of rotations, long features consisting of aligned LLUMR sections of similar polarities

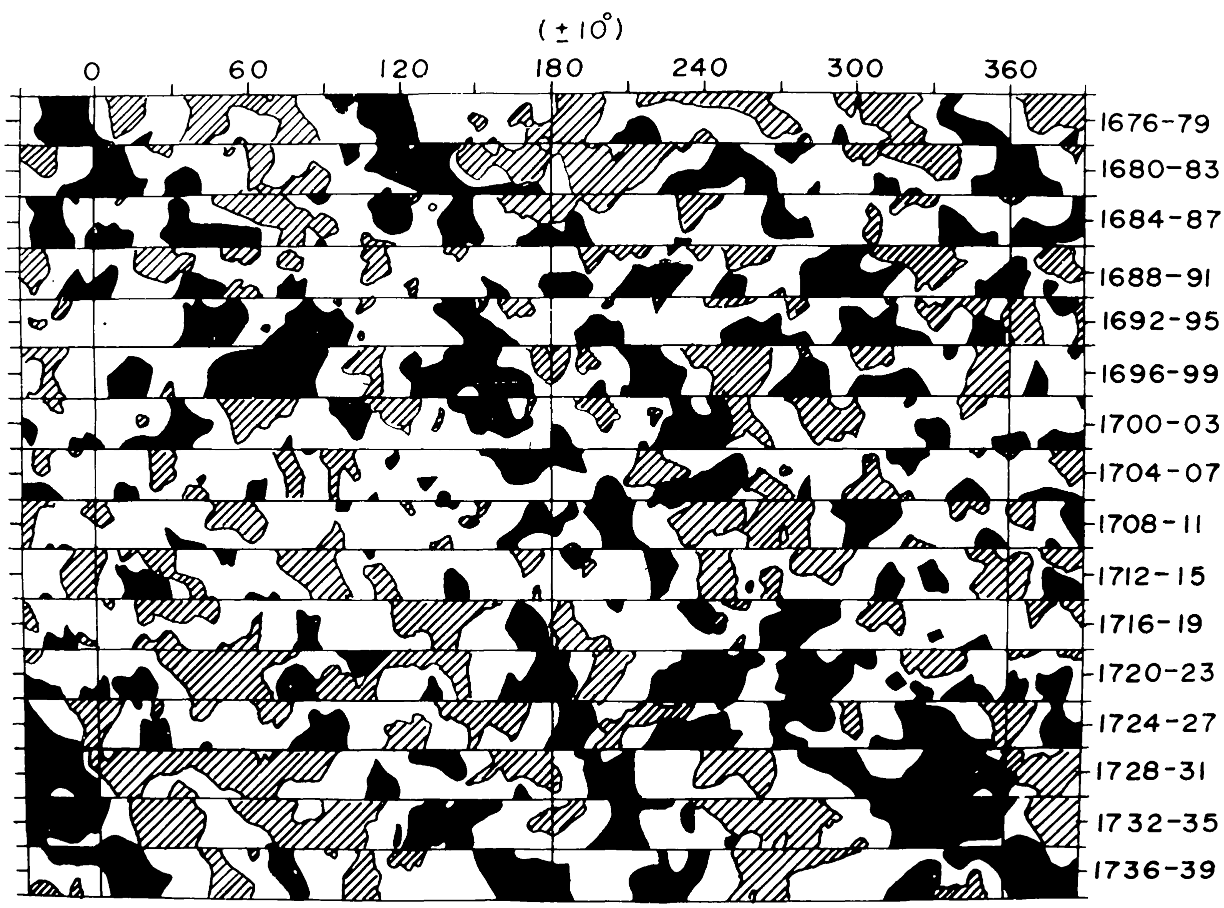

Fig. 1.

Figs. 1–3. LLUMR synoptic charts cut into strips representing three zones of latitude ($\pm 10°$, $\pm 20°$, $\pm 40°$) and assembled in chronological order. Negative and positive LLUMR sections are represented, respectively, by dark and hatched regions.

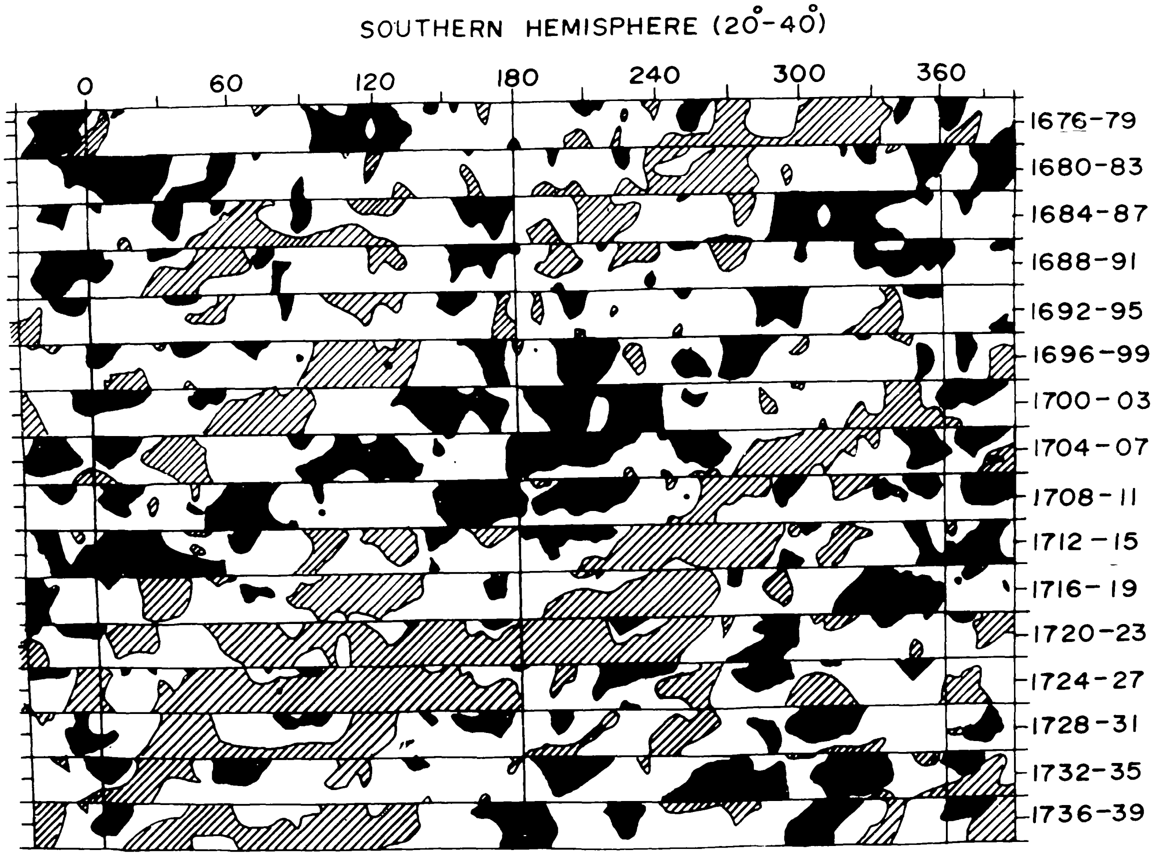
SOUTHERN HEMISPHERE (20°-40°)
0
60
120
180
240
300
360
1676-79
1680-83
1684-87
1688-91
1692-95
1696-99
1700-03
1704-07
1708-11
1712-15
1716-19
1720-23
1724-27
1728-31
1732-35
1736-39

Fig. 2.

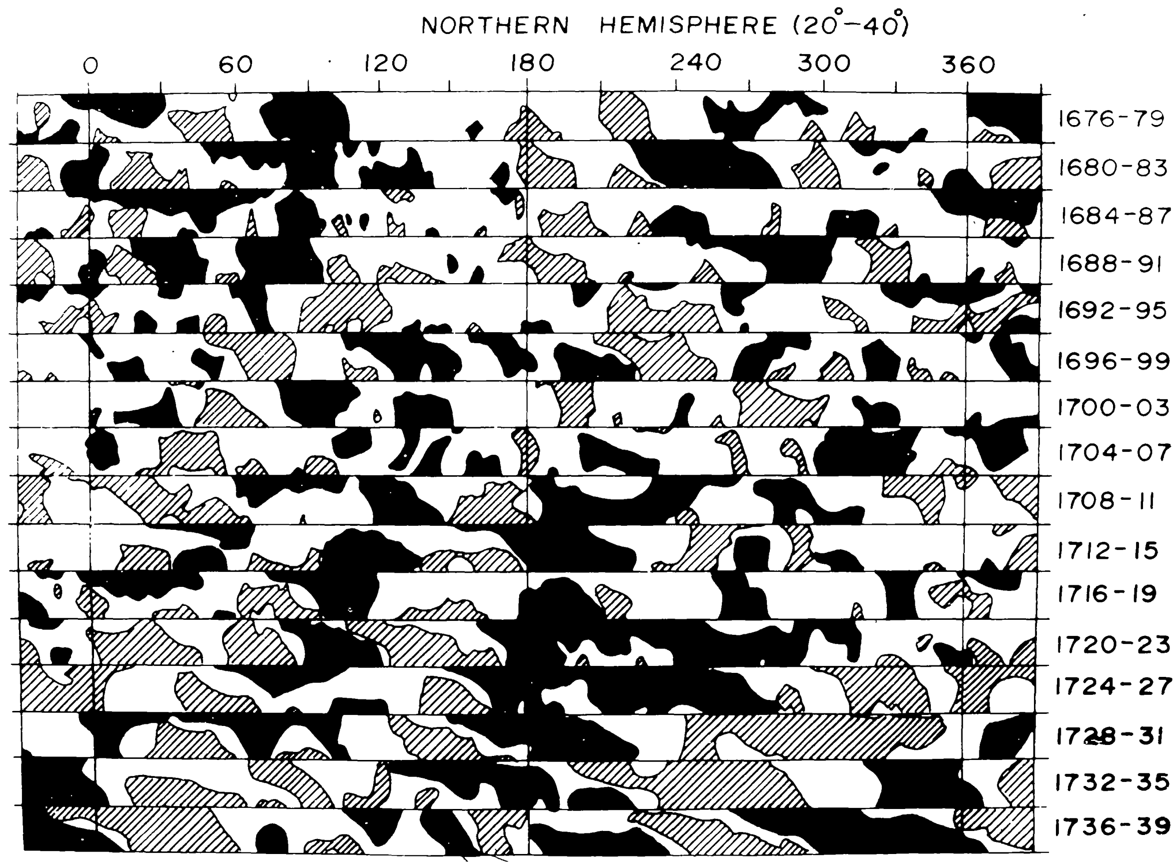
NORTHERN HEMISPHERE (20°-40°)
0
60
120
180
240
300
360
1676-79
1680-83
1684-87
1688-91
1692-95
1696-99
1700-03
1704-07
1708-11
1712-15
1716-19
1720-23
1724-27
1728-31
1732-35
1736-39

Fig. 3.

are noticeable. We call such features 'LLUMR rows'. A very long LLUMR row or several LLUMR rows constitute what we shall call a 'LLUMR stream'. Such LLUMR rows and LLUMR streams are clearly seen in Figures 1 to 3. This very qualitative picture of LLUMR sections, rows and streams is analogous to Bumba and Howard's results (Bumba and Howard, 1969).

3.1. LLUMRs in low latitudes

Figure 1 represents the equatorial latitude zone ($\phi = \pm 10°$) which shows that LLUMR sections have different sizes. Small-sized LLUMR sections seen in this figure may correspond to regions where rates of magnetic flux eruption of one polarity are high which in turn shrinks the LLUMR sections of corresponding opposite polarity.

Many LLUMR rows and LLUMR streams may be identified in Figure 1. The LLUMR rows of both polarities are well defined and constitute well defined LLUMR streams. The negative LLUMR streams are somewhat broader and better defined than the LLUMR streams of positive polarity. There are at least six negative LLUMR streams and five positive LLUMR streams. The overall picture one gets is that the LLUMR streams of two dissimilar polarities are placed alternately and they form six streams of bipolar pairs enclosing the neutral lines between them.

If the LLUMR rows or streams of Figure 1 were not inclined to the vertical, it would have indicated a rotation of exactly the Carrington period of 27.3 days. However, it is clear from Figure 1 that the LLUMR sections are slightly shifted to the west from one given strp to the succeeding one, and the LLUMR rows and LLUMR streams are then inclined to the vertical by about 20° per strip, indicating an inclination angle of 5° per rotation for the sections of background field patterns. This shows that the background field patterns in the equatorial zone recur with a period of 26.9 days per rotation.

3.2. LLUMRs in higher latitudes

The charts for 20–40° in south and north are shown in Figures 2 and 3 separately. Figures 2 and 3 show that LLUMR rows and LLUMR streams are inclined to the east, the opposite direction to the equatorial LLUMR rows and LLUMR streams, and their inclination angles are larger.

3.2.1. *Southern Hemisphere*

The chart for southern hemisphere (cf. Figure 2) differs in appearance from the equatorial zone chart (cf. Figure 1) and also from the corresponding northern hemisphere chart (cf. Figure 3). The LLUMR sections of both polarities in the southern hemisphere are much broader than those of the LLUMR sections in the equatorial zone. In the latter part of the data, the sizes of a few positive LLUMR sections may reach up to 180° in longitude.

It is also apparent from Figure 2 that each polarity has only one continuous broad LLUMR stream. The negative LLUMR stream is seen to run from longitude 360° in strip 1680–83 up to longitude 0° in strip 1712–15 and can be followed even after that up to strip 1736–39. The positive LLUMR stream also appears to start at the beginning of the data at longitude 300° and can be followed up to the end of our data. The overall picture emerging from Figure 2 is that these LLUMR streams of opposite polarities are placed alternately and form a stream of only one bipolar pair.

These LLUMR streams are seen to be inclined to the vertical by about 37°.5 per strip which indicates that the recurrence period for the sections of the background field patterns in 20–40° south zone is about 28.1 days per rotation.

3.2.2. *Northern Hemisphere*

In the earlier and later period of the data, broad negative LLUMR sections can be found (cf. Figure 3). Sometimes the sizes may reach up to 120° in longitude in the later period. The sizes of positive LLUMR sections are somewhat similar to that of the equatorial zone.

The positive LLUMR rows are well defined, whereas it is difficult to identify negative LLUMR rows as they present a confused picture. There may be at least five LLUMR streams of positive polarity and therefore the existence of at least six streams of bipolar pairs can be inferred.

The LLUMR sections of both the polarities appear to drift eastwards. The inclination angles are different for different positive LLUMR steams. On average, the inclination angle is about 23° per strip which corresponds to a rotational period of about 27.7 days for the background field patterns.

4. Comparison with Coronal Holes

Shelke and Pande (1985) examined the rotational behaviour of coronal holes as a function of latitude zones. They inferred rotation periods of 26.9 and 28.1 days for coronal hole sections which develop in latitude zones of $\pm 10°$ and 20–40° north respectively. However, they have not inferred the rotation periods for coronal holes in southern latitude zones separately. If one examines Figures 2 and 4 of Shelke and Pande (1985) it appears that the rotation period of coronal holes in the 20–40° southern latitude zone is shorter than the holes in the 20–40° northern latitude zone and is about 27.7 days.

The coronal hole sections seem to correspond with LLUMR sections if the consecutive sequences of holes are compared with the sequences of LLUMR of corresponding latitude zones. This further confirms the results of Shelke and Pande (1984), namely that the coronal holes appear to fit in well in the LLUMR patterns.

In this connection, it is important to study the rotation of large-scale photospheric magnetic fields associated with holes. For this purpose, we picked up the LLUMR sections from Figures 1 to 3 which were associated with the corresponding coronal sections shown in Figures 1, 2, and 4 of Shelke and Pande (1985) and the rotation periods of these LLUMR sections were determined from their inclination angles. The inclination angles of such LLUMR sections in the equatorial latitude zone, 20–40° north and 20–40° south latitude zones are about 20° (westward), 45° (eastward) and 18° (eastward), respectively. This indicates that the rotation periods of photospheric

TABLE I

Rotation periods of photospheric background fields

Latitude zone	Rotation periods of			
	photospheric background field		coronal holes (days)	photospheric magnetic features (Snodgrass, 1983)
	not associated with coronal holes (days)	associated with coronal holes (days)		
± 10°	26.9	26.9	26.9	25.06 to 25.18
20–40° N	27.7	28.1	28.1	25.58 to 27.40
20–40° S	28.1	27.6	27.7	25.58 to 27.40

background field patterns associated with coronal holes in these latitude zones are about 26.9, 28.1, and 27.6 days, respectively.

If one compares the rotation periods of background field patterns and their associated coronal holes in the respective latitude zones, then it appears that both these features suffer differential rotation and their rotation periods are the same. It may be remarked that the rotation periods of background field patterns which are not associated with the coronal holes are different from the rotation periods of coronal holes in respective latitude zones.

In Table I, we have given the results of our investigation. Recently, by cross-correlating Mount Wilson magetograms of successive days for the period January 1, 1967 to May 29, 1982, Snodgrass (1983) determined the rotation rates of magnetic features in the solar photosphere. Separate correlations for each of 34 latitude zones covering the solar disk were performed by him. The magnetic rotation rate was then given as a function of latitude. The results of his study are also given in Table I for comparison. The results of Snodgrass (1983) are in close agreement with the Newton and Nunn (1951) sunspot results in sunspot latitudes. Thus he found day-to-day rotation of solar magnetic features to be steady over the whole surface, showing neither measurable dependence on field strength nor variation with time. When he compared his magnetic rates with Doppler determined plasma rotation rates he found that the magnetic rates were roughly 1.5% faster except near the poles. From Table I it is obvious that long-lived unipolar magnetic region rotate slower as compared to the general magnetic features of Snodgrass (1983).

5. Discussions

This investigation demonstrates the existence of regularities in the background field patterns as evidenced from the regular patterns of LLUMR rows and LLUMR streams and thus further confirms the results of Bumba and Howard (1969) on regularities in the large-scale photospheric magnetic field patterns.

The LLUMR streams may in turn be the elements of a still larger pattern. LLUMR streams alternate from one polarity to the other around the belts of latitude zones. In other words the LLUMR streams seem to be arranged in a wave pattern of alternating polarities. In the equatorial zone, inclined LLUMR streams of one polarity are located by a step of 60° N, whereas in the 20–40° northern zone, LLUMR steams of one polarity are seen to be placed at steps of about 60–70°. In these two zones of latitudes, the polarity of LLUMR sections reverse six times on average along the circle of latitudes. Thus the 'wavelength' in the global pattern of LLUMR on these belts of latitudes is 60° during the period of this study. In the southern hemisphere for the 20–40° latitude zone, this 'wavelength' is found to be 360° since there is only one (bipolar configuration) band of alternative polarity.

Shelke and Pande (1985) found that the coronal hole sections exhibit differential rotation which is not in agreement with Timothy *et al.* (1975) and Wagner (1975). The latter authors inferred rigid body rotation behaviour of the coronal holes. The present investigation shows that coronal holes and associated sections of photospheric field patterns suffer differential rotation and that their rotation periods are the same. In addition, coronal hole sections appear to fit in LLUMR sections. This signifies that the chromosphere–corona transition region (up to which He I λ10830 Å radiation may dominate) the photospheric magnetic fields and coronal holes show roughly the same differential rotation rates. However, the rotation rates of background field patterns which are not associated with coronal holes are different from those which are associated with the coronal holes. This indicates that these two types of field patterns need to be explained by two rotation laws.

It may be remarked that in the 20–40° northern latitude zone the rotation period of the field patterns not associated with coronal holes seem to have a shorter rotation period than in the corresponding southern latitude zone. This appears to be a real effect, since Wilcox and Howard (1970) also noted the same effect for photospheric magnetic fields.

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