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A Generalized Polarity Rule for Solar Magnetic Fields

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Abstract—It is shown that, when all components of the large-scale solar magnetic field are longitudinally averaged, the N polarity and the eastward transverse component of the B_φ field associated with both local and large-scale fields over the Northern hemisphere are somewhat stronger and occupy a smaller area during odd cycles than does the field of opposite polarity. This behavior is reversed for even cycles or the Southern hemisphere. The regular Hale law is a particular form of the above rule. The nature of this asymmetry seems to be rooted in the dynamo mechanism itself, and should be important for fields on any scale.

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1. INTRODUCTION

Since the discovery of the solar magnetic field in 1908, the following fundamental laws for the behavior of local magnetic fields (identified with sunspot fields) have been formulated.

(1) The sunspots of a new cycle originate several years before the minimum at relatively high latitudes ±35°–40°. As time passes, spots emerge at progressively lower latitudes, approaching the equator. However, they never appear within ±5° of the equator. This is often called Spörer's law, and a diagram of sunspot positions vs. time and latitude is referred to as a Maunder butterfly diagram.

(2) According to Hale's law, during odd cycles in the northern hemisphere, the magnetic fields in leading and following sunspot groups have northern and southern polarity, respectively. This pattern is reversed in the southern hemisphere or in even cycles. This obviously indicates that physical meaning should be attributed to the 22-year rather than 11-year cycle.

Note that Hale's law is essentially a combination of three independent statements: (i) as a rule, the leading spots have the same polarity; (ii) this polarity changes with the transition to a new cycle, forming a physical basis for the 22-year cycle; (iii) this regularity is opposite in the northern and southern hemispheres, which suggests a global nature for the magnetic-field generation mechanism.

With the advent of accurate magnetographic observations, the question arose of whether the magnetic field closes within the active region or in its immediate vicinity. Direct measurements indicate that the integral of the measured line-of-sight field over the active region is never zero [1, 2]. Various explanations have been proposed for this effect. The magnetic-field imbalance could be due to insufficient sensitivity of the magnetographs to weak fields, a nonlinear dependence of the signal on the magnetic-field magnitude, or a dependence of the signal on the characteristic size of the measured object. In addition, recent studies have shown that some of the magnetic flux in giant loops extends far beyond the active region, where it becomes part of the flux of the large-scale magnetic field [3].

While we cannot be sure whether the field closes within the active region, it is certain that the field longitudinally averaged over a complete circle of latitude is not zero. This is apparently due to the predominance of the leading polarity in term of its strength. Figure 1a shows the longitudinally averaged line-of-sight field measured at the Kitt Peak observatory. These data were taken from the NASA/HATHAWAY 2005/10 web site. Strengths from −10 to 10 G range from black to white on the gray scale. We can see that the directly measured field in active regions does not vanish due to the longitudinal averaging, and corresponds to the polarity of the leading spots.

2. ELEVEN-YEAR CYCLE IN THE LARGE-SCALE FIELD

The large-scale magnetic field also exhibits 11-year cyclic variations. The large-scale fields spread all over the solar surface. In contrast to the local fields, they drift toward the poles [4–8]. This

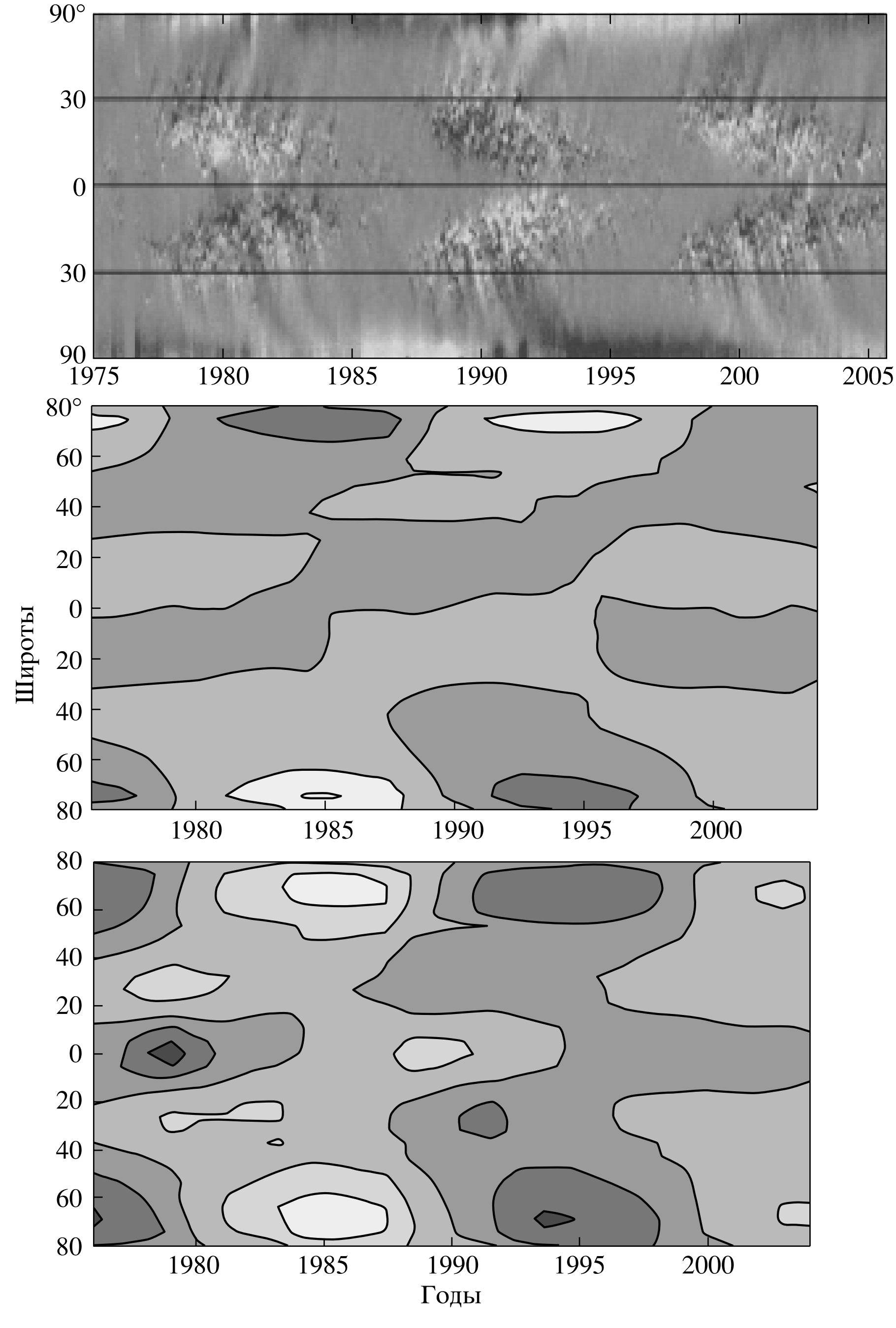

Fig. 1. Longitudinally averaged components of the magnetic field: (a) line-of-sight magnetic field according to Kitt Peak data; (b) the radial component of the large-scale magnetic field, B_r; (c) the meridional component, B_θ.

can be clearly seen in Fig. 1a, which displays the poleward drift of the large-scale field, which reaches its maximum at the poles at the same time that the local fields reach their minimum. The longitudinal averaging demonstrates a predominant magnetic polarity corresponding to the trailing spots in local active regions. Figures 1b and 1c show the longitudinally averaged large-scale radial (B_r) and meridional (B_θ) components. These two diagrams are coded somewhat differently. In Fig. 1b, strengths ranging from −9 to 9 G are shown by a stepwise series of intensity variations from black to white in steps of 4.5 G; in Fig. 1c, strengths ranging from −6 to 6 G are shown in steps of 2 G. In contrast to Fig. 1a, Fig. 1b represents the radial, rather than the line-of-sight, component at a resolution of 10° (see below), so that the local fields are averaged. Unlike B_φ (see below), the radial component should not average to

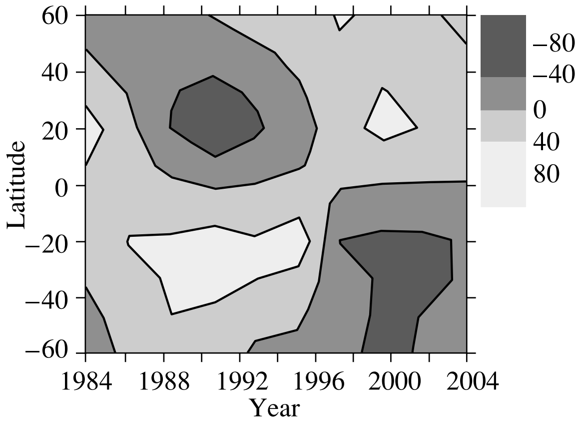

Fig. 2. Difference between the numbers of days with $B_\varphi > 0$ and $B_\varphi < 0$ in each two-year interval.

zero over a circle of latitude. The B_θ component reflects the largest-scale field, which is determined at the minimum by a vertical dipole.

It is often said that the large-scale field reverses sign at the cycle maximum of the local fields. This is not quite correct, and applies only to either the polar field (at the so-called polarity-reversal time) or the dipole component of the large-scale field [9]. In fact, the large-scale field does not change sign simultaneously at different latitudes. This can be seen clearly in Fig. 1b, which shows the calculated radial component of the mean radial field averaged so that the local fields are not visible.

While the second and third statements of Hale's law for the local fields can easily be checked and also apply, in a slightly modified form, to the large-scale fields, the situation with the first, more fundamental, statement is more complex. In general, the leading or following polarity cannot be considered in the context of large-scale fields. Therefore, Hale's law should be reformulated to say that the transverse component of the field inside an active region in the northern hemisphere is directed eastward ($B_\varphi < 0$) during odd cycles. According to this definition, Hale's law means that, in the Northern hemisphere during an odd cycle, the fields between the spots in active regions are directed eastward ($B_\varphi > 0$), while the surrounding field is directed westward ($B_\varphi > 0$). The eastward field is stronger and occupies a smaller relative area than the westward field.

This field component cannot be directly measured, but can be calculated based on a potential approximation (see, e.g., [10, 11]). Once all the components of the magnetic field have been calculated, this law can be checked for the large-scale field. Obviously, in the absence of currents (the potential approximation), the integral of B_φ along a closed contour vanishes, in accordance with the relevant Maxwell's equation. Therefore, the B_φ field averaged over a given circle of latitude should also vanish if no global currents are present in the photosphere. However, the areas occupied by the B_φ fields of different signs will obviously not be equal. For this reason, our new definition in terms of the predominance of the areas occupied by B_φ fields of different signs is more suitable for the large-scale field.

3. A GENERALIZED HALE'S LAW FOR LARGE-SCALE FIELDS

We used data from the Stanford John Wilcox Observatory for our calculations. We used the well established technique [10, 11] to calculate the daily mean values of all the magnetic-field components at the photospheric level, based on ten harmonics (the so-called "classical" version—see http://quake.stanford.edu/ wso/wso.html).

To estimate the area occupied by the B_φ field of one or another sign at any latitude, we counted the number of days with this sign within a two-year time interval. In addition, the mean value of this field component was calculated for a given circle of latitude. The interval was then shifted by one year, and the mean field and the area difference were obtained as functions of time and latitude. Thus, the effective resolution is about ten heliographic degrees, which corresponds to the accuracy of the source data. The diagrams in Figs 1b and 1c were obtained in this way.

As could be expected, the average of B_φ over a circle of latitude is zero within the errors. At the same time, the areas occupied by $B_\varphi > 0$ and $B_\varphi < 0$ are considerably different. Figure 2 presents the difference between the numbers of days with $B_\varphi > 0$ and $B_\varphi < 0$ within each two-year interval. In the surrounding medium (for example, in cycle 23) in the northern hemisphere, the number of days with $B_\varphi > 0$ is significantly larger than the number with

$B_\varphi < 0$. This relationship reverses in the transition to an adjacent cycle or to the other hemisphere. This difference is less than 10%, but can be determined with fairly high certainty. Since the B_φ field averaged over a circle of latitude is zero within the errors, a larger area corresponds to a lower mean strength. Therefore, the field corresponding to the polarity of the leading spot is stronger, i.e., in this sense, the surrounding medium also obeys Hale's law.

It is current difficulit to say whether this regularity represents a real property of the large-scale fields or reflects the regularities of small-scale inclusions. The discovered imbalance is observed at all latitudes, including high latitudes, where no spots are present. It may be that local fields are actually present at high latitudes, and affect the flux balance without being detected in low-resolution observations. Local kiloGauss fields were observed in the polar zone by Homann et al. [12]. The polarity asymmetry described above should be present even in small inclusions. This means that any inclusions, even small ones, should at least be bipolar, resembling very small active regions. The nature of this asymmetry is apparently rooted in the dynamo mechanism itself, and should be significant for fields on any scale.

Thus, we find that, *in the northern hemisphere during odd cycles, in both local and large-scale fields, the N polarity and eastward B_φ field are somewhat stronger and occupy smaller areas than the fields of opposite sign*. This law reverses in even cycles or the other hemisphere. The usual Hale's law is one particular form of this tendency.

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REFERENCES

1. E. I. Mogilevskii, B. A. Ioshpa, and V. N. Obridko, *On the Force-Free Magnetic Fields in the Active Regions of the Solar Chromosphere* (Space Research, Reidel Publ. Co., Amsterdam, 1964).
2. V. N. Obridko, L. B. Demkina, Yu. N. Dolginova, et al., in *Proceedings of a Symposium on the Proton Flare Project, Budapest, 1968*, p. 222.
3. E. E. Benevolenskaya, A. G. Kosovichev, J. R. Lemen, et al., Astrophys. J. **571**, L181 (2002).
4. V. N. Obridko and B. D. Shelting, Sol. Phys. **137**, 167 (1992).
5. V. N. Obridko and B. D. Shelting, Sol. Phys. **184**, 187 (1999).
6. V. N. Obridko and B. D. Shelting, Sol. Phys. **187**, 185 (1999).
7. V. N. Obridko and B. D. Shelting, Astron. Zh. **80**, 364 (2003) [Astron. Rep. **47**, 333 (2003)].
8. V. N. Obridko, D. D. Sokoloff, K. M. Kuzanyan, et al., Mon. Not. R. Astron. Soc. **365**, 827 (2006).
9. I. M. Livshits and V. N. Obridko, Astron. Zh. (in press).
10. J. T. Hoeksema and P. H. Scherrer, *The Solar Magnetic Field*, Rep. UAG-94 (NOAA, Boulder, Colo., 1986).
11. K. G. Ivanov and A. F. Kharshiladze, Geomagn. A@eron. **34**, 22 (1994).
12. T. Homann, F. Kneer, and V. I. Makarov, Sol. Phys. **175**, 81 (1997).

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