GRAPHICAL MODELS OF SOLAR AND GEOMAGNETIC DATA

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ABSTRACT

The Laboratory of Geomagnetic Disturbances, IZMIRAN, develops software packages to display and analyze complex space data. This paper discusses the semi-empirical model of solar and geomagnetic data. This model contains (1) a map of the solar magnetic field at 2.5 R_S and on the surface of the photosphere; (2) the position and intensity of solar flares with bipolar magnetic axes, and (3) the Ap geomagnetic index in the form of a time-series bar. The model's data base covers 1977–1988, and the maps can be used in the search and study of forecasting methods in solar-terrestrial physics. Samples of software usage are provided.

1. INTRODUCTION

In this paper we describe our semi-empirical model of solar and geomagnetic data as well as the basic calculation procedures on which it is based. The on-screen information provided by the model can be a valuable aid in the investigation of properties and coupling of the heliospheric current sheet with solar flares.

The program can also be used in studies of geomagnetic activity dependence on position of the current sheet. This is a powerful tool for any investigator in the field of solar-terrestrial physics, especially those who forecast geomagnetic activity. One of the program's best advantages is the simultaneous on-screen presentation of all necessary information.

2. DESCRIPTION OF THE PROGRAM

The computer program will operate in the graphical form and allow on-screen presentation of the following information:

1. Maps of synoptical data for the solar magnetic field of the photosphere, presented as an isoline graphic;
2. Maps of the computed (by spherical analysis for n, m<10) magnetic field;
3. Difference between maps 1 and 2, presented as an isoline graphic.
4. Maps of the computed magnetic field on the source surface, also presented as an isoline graphic.
5. Date, position, power, and magnetic axis of bipolar flares, presented as circles with crossing vectors (the radius of the circle shows the power of the flare, and the vector shows the direction of the bipolar magnetic field); and
6. Ap index, for each day, shown at the top of the screen.

Samples of screens are shown in Figures 1–3. Figure 1 shows experimental data for the photosphere; Figure 2 shows recalculated data of the solar magnetic field on the photosphere; and Figure 3 shows a map of the heliospheric current sheet and the position of some flares (regions of negative polarity are shaded). Eventually other forecast-pertinent information will be added to this program, but we consider the maps to be a very convenient tool for forecasters even now.

The program consists of an executable file and the following special support files:

1. Files containing the spherical coefficients for the magnetic field potential; each file contains the spherical coefficients for 15 Carrington rotations, and also for rotations shifted by 180°, for a whole year.
2. Files containing flare information.
3. The synoptical data file; this shows the measured line-of-sight field on the photosphere on a given set of points. The computation of spherical coefficients is based on this information, but the data can also be seen on the screen.
4. The file containing Ap index information for every day.
5. Special graphics support files.
6. A file created by the program when the set-color service is requested (otherwise the default—two colors—is used).

The program can be used without some of these files, but items 4 and 5 are necessary. It is easy to use; the date desired must be entered, but all other options are on pull-down menus. The program is essentially a work in progress, so we welcome suggestions from users.

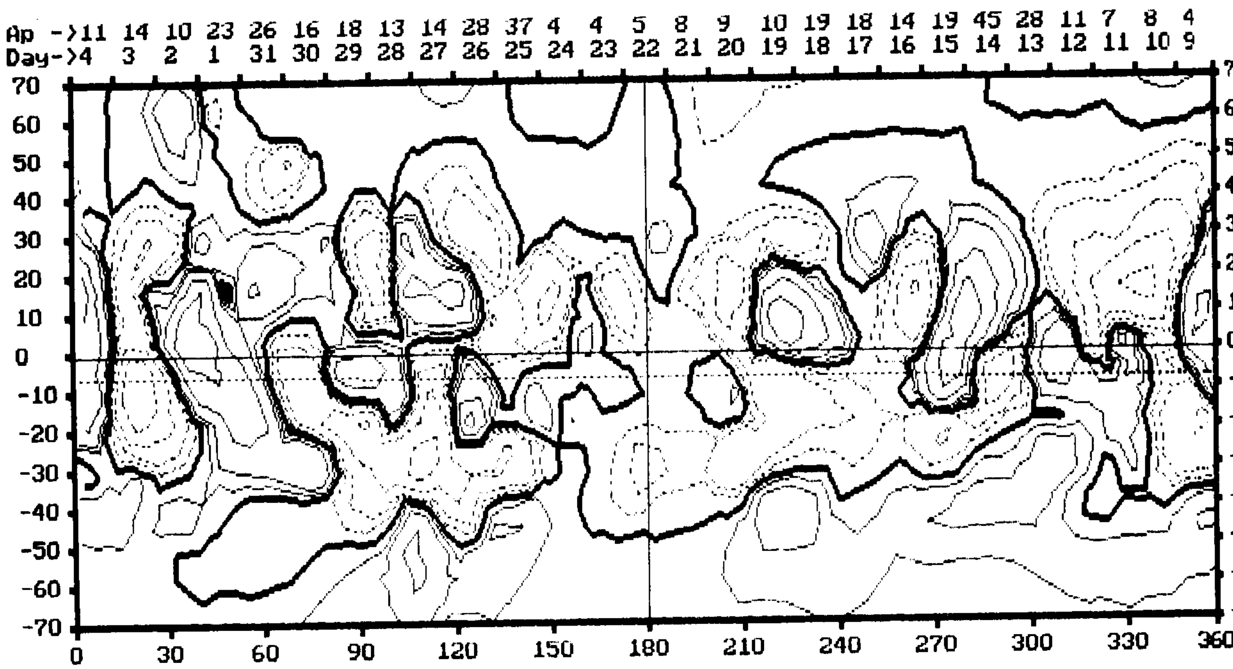

Figure 1. Sample screen showing given solar line-of sight fields on the photosphere. Levels of 0, ± 100, 200, 500, 1000, and 200 mT are drawn; 22 March 1981 is at the center of the figure. The user can select the following: real flares or specific modeled flares, removal of flares, or data for a different date.

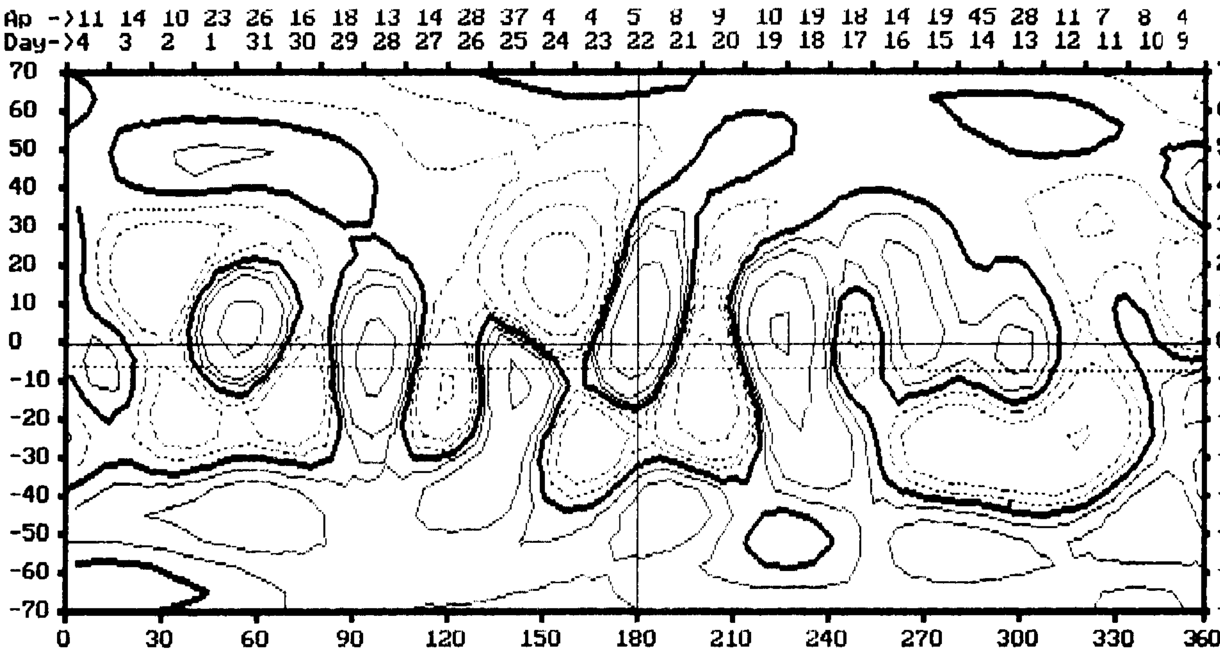

Figure 2. Sample screen showing computed solar line-of sight fields on the photosphere. Levels of 0, ± 100, 200, 500, 1000, and 200 mT are drawn; 22 March 1981 is at the center of the figure. The user can select the following: real flares or specific modeled flares, removal of flares, or data for a different date.

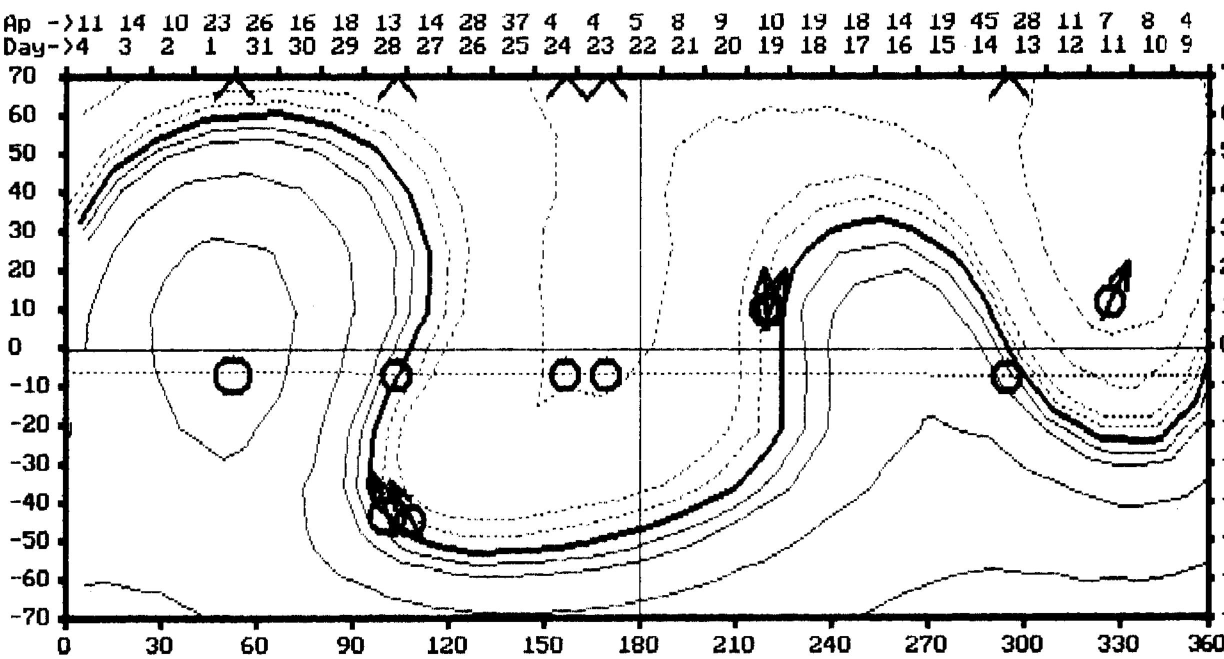

Figure 3. Sample screen showing the solar magnetic field on the source surface. Levels of 0, ± 1, 2, 5, 10, and 20 mT are drawn; 22 March 1981 is at the center of the figure. The user can select the following: real flares or specific modeled flares, removal of flares, or data for a different date.

3. COMPUTING THE MAGNETIC FIELD OF THE SUN

We have used a common model of the Sun's magnetic field between the photosphere and the source surface (Altschuler and Newkirk, 1969; Hoeksema, 1984; Hoeksema and Scherrer, 1986):

$$B_r = \Sigma P_n^m(\cos\theta)(g_{nm}\cos m\phi + h_{nm}\sin m\phi)[(n + 1)(R_\odot/r)^{n+2} - n(r/R_s)^{n-1}c_n] ,$$

$$B_\theta = -\Sigma\frac{\partial P_n^m(\cos\theta)}{\partial\theta}(g_{nm}\cos m\theta + h_{nm}\sin m\theta)[(R_\odot/r)^{n+2} + (r/R_s)^{n-1}c_n] ,$$

$$B_\phi = -\Sigma\frac{m}{\sin\theta}P_n^m(\cos\theta)(h_{nm}\cos m\phi - g_{nm}\sin m\phi)[(R_\odot/r)^{n+2} + (r/R_s)^{n-1}c_n] ;$$

here,

$$c_n = -(R_\odot/R_s)^{n+2}$$

All computed isoline graphics are obtained through these formulas. The spherical coefficients, $g_{nm}, h_{nm}, 0 \leq m \leq n < 10$, are placed in the appropriate file to produce the rotations for Carrington longitudes 360° and 180°. This is necessary to get a smooth interpolation in the picture when passing from one complete set of coefficients to another. Each point on the spherical surface is controlled by two complete sets of coefficients; computation of the function values requires both in the proper combination, as shown in Figure 4. If one chooses the magnetic field on the source surface, the screen shows the chart of the radial field component; if the photosphere is chosen, the screen shows the line-of-sight component.

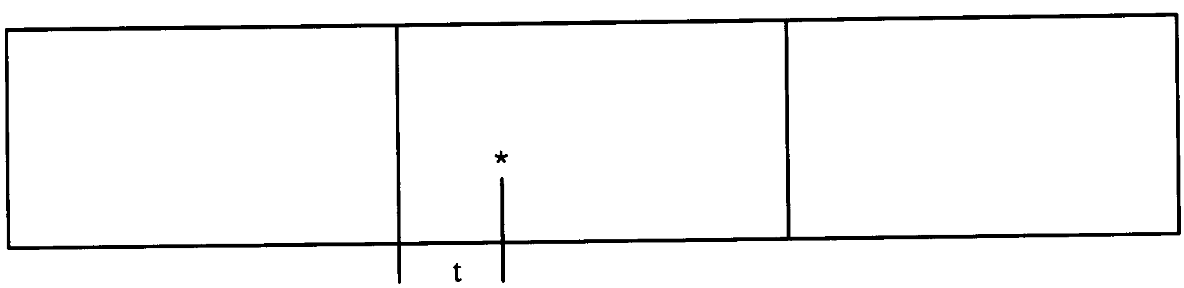

Figure 4. Three rectangles, each of which denotes 180° of the surface of a sphere. The two rightmost rectangles are controlled by one complete set of coefficients, say N1; the two leftmost rectangles are controlled by the next complete set of coefficients, say N2. One can compute the function value in the marked point by combining both sets as follows: (value N1) * (t/180) + (value N2) * (1–t/180).

4. OBTAINING THE SPHERICAL COEFFICIENTS

We have a very powerful and universally applicable program for computing spherical coefficients by the least-mean-squares method. Most investigators use the orthogonality property of spherical functions for this purpose; this makes the computation simpler and faster but it also makes the program less exact and universal. This is because the set of spherical functions,

$$P_n^m(cos\theta)\cos m\phi, P_n^m(\cos\theta)\sin m\phi,$$

in fact has the property of orthogonality only in the sense that the scalar product is defined by integrating over the sphere. Actually we have defined the scalar product by taking a sum over the points where the data are measured. In cases where these points are distributed homogeneously enough (and this is just the case in Hoeksema and Scherrer (1986)), we can assume that the orthogonality property holds.

Our program for determining spherical coefficients works for points in arbitrary positions where the line-of-sight field is measured on the photosphere. (Of course, the field has to be sufficiently dense; otherwise, a poorly conditioned matrix is inverted.)

The coordinates of points to be measured must be placed in separate files so that program does not require recompiling when the positions of the points are changed. However, the matrix of the normal system has to be recomputed when the points are changed. This takes some time (for example, in the case of 30 $\times$ 72 points—the case in Hoeksema and Scherrer (1986)—the matrix computation takes an hour on an IBM–386 computer); but when the matrix has been computed it takes only about a minute to compute one complete set of coefficients.

5. FLARES

The program contains the following information about each flare: day, month, year, hour, minute, power (1–5), latitude, and longitude. We wanted to include in the files all flares with potential for terrestrial effects. For that purpose we adopted the following restrictions on flares of various strengths.

Power (our notation)	1	2	3	4	5
Importance	S(1)	1	1(2)	2	>2
Longitude	±40	±50	±75	±80	±90

The flare's location is marked by a circle with a radius proportional to the power in our notation (1–5). A circle of the same size shows the position of Earth at the same time. When all flares for the chosen period are called to the screen they tend to pile up on one another, and some will therefore be missed. Because of this, it is best to restrict the flares on the basis of date, power, and latitude/longitude.

6. DISCUSSION AND CONCLUSIONS

When the program is tested on an IBM–PC, the following attributes become apparent.

1. The information presented by the program is clear;
2. The program can be used on older machines but can also be easily modified for use on workstations;
3. The program can be incorporated into a standard data processing system for forecast services;
4. The program's capabilities are flexible; suggestions for different applications are welcome.

Diskettes containing the program and illustrations for its use are available from the authors.

REFERENCES

Altschuler, M.D., and G. Newkirk, Jr., *Solar Phys.* **9**, 131, 1969.

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