RECONSTRUCTION OF THE IMF POLARITY FROM GEOMAGNETIC OBSERVATIONS

Vokhmyanin M.V., Ponyavin D.I.

St. Petersburg University, St. Petersburg, 198504, Russia, e-mail: vokhmyaninmv@gmail.com, ponyavin@geo.phys.spbu.ru

Abstract. We present a modified method of inferring the IMF polarity from geomagnetic records at polar stations (Sitka, Sodankyla, Godhavn, Thule, Vostok). Our technique is based on the Svalgaard-Mansurov effect. The accuracy of inferring is around 83% for the set of Godhavn, Sitka and Sodankyla (since 1926) and near 90% for all stations (since 1958). In this work we also get the following results: (1) the Rosenberg-Coleman rule is clearly seen from the data, so reversals of the global solar magnetic field were really occurred within last eight solar cycles, however for the period 1906-1925 the success rate of inferring polarity is too low and the R-C rule is difficult to detect; (2) during the descending phase of solar cycle 16 a two-sector structure of IMF is observed similarly to the next even solar cycles.

1. Introduction

The well-known interplanetary magnetic field (IMF) at the ecliptic plane while crossing the heliospheric current sheet forms a sector structure of the IMF polarity. Svalgaard [1] and Mansurov [2] independently found that in the midday time at the polar stations different IMF polarity cause opposite geomagnetic field variations, so-called Svalgaard-Mansurov effect (S-M). Further this effect was explained by existence of equivalent ionospheric current system DPY [3], controlled by $B_Y$ component of the IMF in GSM coordinate system. The S-M effect was used to derive $B_Y$ polarity from high-latitude geomagnetic observations.

Such an inferring of the IMF polarity was made by several authors [2, 5-7]. But the last paper, as well as Mansurov atlas of IMF polarities operates with data since 1958, when the Vostok station started to work. Therefore only two data sets of inferred polarity for a long period of pre-satellite era are available at the moment [5,6].

2. Data

In this work we use two subauroral stations Sitka and Sodankyla (same as in [6]), one subpolar station Godhavn and two polar – Vostok and Thule. These sets of stations are characterized by the longest period of observations in the pre-satellite era. To verify our results we use satellite data of $B_Y$ component of the IMF from OMNI data base in NSSDC.

<table>
<thead>
<tr>
<th>Name</th>
<th>IAGA</th>
<th>Geographic latitude</th>
<th>Geographic longitude</th>
<th>CGM latitude</th>
<th>Time interval</th>
<th>Analyzed field component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitka</td>
<td>SIT</td>
<td>57.1</td>
<td>224.7</td>
<td>59.8</td>
<td>1905 – 2005</td>
<td>H</td>
</tr>
<tr>
<td>Sodankyla</td>
<td>SOD</td>
<td>67.4</td>
<td>26.6</td>
<td>63.6</td>
<td>1914 – 2005</td>
<td>H</td>
</tr>
<tr>
<td>Godhavn</td>
<td>GDH</td>
<td>69.3</td>
<td>306.5</td>
<td>76.8</td>
<td>1926 – 2005</td>
<td>H</td>
</tr>
<tr>
<td>Thule</td>
<td>THL</td>
<td>77.5</td>
<td>290.8</td>
<td>86.2</td>
<td>1947 – 2005</td>
<td>Z</td>
</tr>
<tr>
<td>Vostok</td>
<td>VOS</td>
<td>-78.5</td>
<td>106.9</td>
<td>88.4</td>
<td>1958 – 1998</td>
<td>Z</td>
</tr>
</tbody>
</table>

3. Method

3.1. Time of S-M effect

The DPY current system is located mostly at the dayside cusp region of the ionosphere within a certain range of latitudes and its intensity varies through the year (due to incoming solar radiation). Perturbations of geomagnetic field caused by DPY currents (S-M effect) change correspondingly and are localized in time (Fig 1.1). That is why at the first step of our method we want to know the intervals of daily magnetograms, where the S-M effect has the largest amplitude to distinguish from small-scale variations. For that reason we construct diagrams of S-M effect versus season and UT (Fig.1.2). They demonstrate ground based effect of
DPY currents averaged over several decades. The amplitude of the effect is estimated as the difference between mean daily curves for days of positive and negative polarity (by negative or positive polarity we mean the sign of By component of IMF). Further to obtain a set of weights $W_{std,doy}(h)$ (fig.1.3) these diagrams are normalized by sigma-function (thus areas with low amplitude are equated to zero). These weights we will use later to extract necessary informative intervals from daily geomagnetic field magnetograms.

3.2. The daily curve calculation

The next step is to calculate a diurnal curve $S_{std,doy}(h)$ with respect to which necessary perturbations will be considered. Ideally, we want to extract it at zero $B_Y$ level when all other geoeffective parameters are constant. In such a case all deviations from this curve give information about the DPY current system and IMF polarity. The curve cannot always be the same as quiet diurnal curves, because $B_z$ component of the IMF and the solar wind velocity are also geoeffective parameters.

Figure 2 demonstrates that by contrast with $B_z$ component and solar wind velocity, geomagnetic aa-indices are distributed more symmetrically versus $B_y$ component of the IMF. Thus, we try to take into account other geoeffective parameters, by sorting magnetograms in accordance with a level of aa-index of the global geomagnetic activity. So for each hour in the desired day we make the following procedure. First, we select the values of the geomagnetic field for a given hour in a certain range of days $L_{m,st}$. Among them we then select those that are approximately equal to the value of the aa-index for a given hour $(aa \in (aa_{X} \pm aa_{m,st})$).

These two parameters ($L_{m,st}$ and $aa_{m,st}$) were picked up for each station (st) and month (m) so that the accuracy of inferred polarity was the highest. Thus hourly results were simply averaged and the obtained curve was then smoothed. An example of the curve and its change with the level of geomagnetic activity for the Godhavn station is presented in the Figure 3.1.
3.3. Smoothing of the Bartels diagram

The polarity inferring for each station can be represented by the following formula, where $H_{st,doy}$ is a geomagnetic field, $doy$ is a serial number within year. Final polarity is found by summarizing $P_{st,doy}$ for all available stations. A visual example is presented in the Figure 3.2.

$$P_{st,doy} = \sum_{h=1}^{h=24} (H_{st,doy}(h) - Sc_{st,doy}(h)) \cdot W_{st,doy}(h)$$

The value counted by this formula not only presents the sign of polarity, but also the amplitude of variations, caused by DPY currents. So the larger amplitude is, the more likely we can conclude that the polarity is correct.

This feature can be successfully used when applying smoothing procedure to 27-day Bartels diagram of inferred IMF polarity (Fig. 4). Diagrams demonstrate recurrence in the analyzed data. And for us it is helpful to connect days within neighboring rotation periods. The value of each cell in such a diagram is compared with the weighted sum of neighboring cells (weights are picked up so that the accuracy of method after smoothing was as high as possible). If their sign are opposite and the module of this sum is greater than value in a given cell, then the last one changes its sign, otherwise it remains constant. In the Figure 4 we can see an example of such a smoothing for the period from 2000 to 2005. The picture clearly demonstrates advantages of the technique making a large-scale structure of IMF polarity more evident. In addition, sporadic changes of the polarity disappear due to the smoothing procedure and accuracy of inferring is greatly increased.
4. Results

The set of inferred polarities can be estimated for success rate, as a ratio of successful predicted days to all days during the interval from 1966 to 2005. In the Table 2 results are presented separately for each station and for their combinations (in the order of time when stations begin to work). It is clearly seen that accuracy of method is higher when using high-latitude stations, but the “winter” period (January-February and October-December) is different from “summer” (March-September). This is due to seasonal change of the effect within year (Fig. 1.1). It is also worth noting that the accuracy of inferring of positive and negative polarities is almost equal. So we can conclude that presented technique is not preferable to any polarity.

Table 2. Accuracy of method, %.

<table>
<thead>
<tr>
<th></th>
<th>“Winter”</th>
<th>“Summer”</th>
<th>Yearly</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAGA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOD</td>
<td>69.3</td>
<td>67.9</td>
<td>68.5</td>
<td>69.3</td>
<td>68.1</td>
</tr>
<tr>
<td>SIT</td>
<td>68.3</td>
<td>70.9</td>
<td>69.8</td>
<td>69.5</td>
<td>70.5</td>
</tr>
<tr>
<td>GDH</td>
<td>74.7</td>
<td>84.2</td>
<td>80.1</td>
<td>80.2</td>
<td>80.3</td>
</tr>
<tr>
<td>THL</td>
<td>81.4</td>
<td>88.7</td>
<td>85.6</td>
<td>85.5</td>
<td>86.2</td>
</tr>
<tr>
<td>VOS</td>
<td>88.9</td>
<td>80.8</td>
<td>84.2</td>
<td>82.2</td>
<td>86.6</td>
</tr>
<tr>
<td>SIT-SOD</td>
<td>72.6</td>
<td>71.8</td>
<td>72.2</td>
<td>72.6</td>
<td>72.1</td>
</tr>
<tr>
<td>GDH-SIT-SOD</td>
<td>80.1</td>
<td>85.3</td>
<td>83.1</td>
<td>82.6</td>
<td>83.9</td>
</tr>
<tr>
<td>THL-GDH-SIT-SOD</td>
<td>83.4</td>
<td>89</td>
<td><strong>86.6</strong></td>
<td>85.7</td>
<td>87.9</td>
</tr>
<tr>
<td>VOS-THL-GDH-SIT-SOD</td>
<td>89.3</td>
<td>90.2</td>
<td><strong>89.9</strong></td>
<td>89.6</td>
<td>90.5</td>
</tr>
</tbody>
</table>

Finally, we are interested in estimation of yearly accuracy. In assumption that average accuracy of the method for a certain set of stations in the pre-satellite era remains constant we obtain the following trend of accuracy (fig 5.1).

![Figure 5. Left: Average accuracy of method (solid line) and standard deviation (dashed line). Right: The ratio of number of days with negative inferred polarity to the total number of days in Fall (blue line) and in Spring (red line); dashed lines represent sinusoid fit to the above data; Vertical lines denote sunspot minima.

4.1. Rosenberg-Coleman rule

Rosenberg-Coleman rule [8] consists in heliolatitude dependence of IMF polarity similarly to the Sun's magnetic field of the corresponding hemisphere. The Earth passes through the high heliolatitudes during equinox, more specifically, from southern hemisphere in Spring to northern in Fall. To check the R-C rule we use the same analysis as Hiltula and Mursula [9]. So we find the $T/(T+A)$ ratio separately in Spring (February-April) and Fall (August-October), where $T$ is a total number of negative polarity days (according to our data $P<0$) within given season and $A$ is the same but for positive polarity days. Results are displayed in the Figure 5.2. The R-C rule can be clearly observed in the form of near-harmonic oscillations with a period of 20 years and peaks at the minima of solar activity (vertical lines), when the main solar magnetic field is mostly dipolar. And as oscillations are caused by solar magnetic field reversals we can conclude that they were really occurred within last eight solar cycles. In the early period 1905-1925, when only subauroral stations were available, the success rate of the method is too low for such an analysis.
4.2. Two-sector structure during the descending phase of cycle 16

A detailed comparison of our polarity data set with other catalogues gives interesting results. Our data set demonstrate two-sector structure of IMF during the descending phase of cycle 16, while according to the Svalgaard catalogue a four-sector structure was detected (Fig. 6).

During this period we can observe two areas of highest geomagnetic activity with nearly 27-day recurrent period. These areas can be interpreted as two long-lived antipodal (since they are separated in time by about half of rotation period) streams of high-speed solar wind. The sources of these recurrent streams are areas of open magnetic field lines, large coronal holes extended to the equator. Unlike Svalgaard catalogue, our data display recurrent streams of opposite polarity originated from poles of magnetic dipole strongly tilted to the solar rotation axis. A similar large scale organization of magnetic fields on the Sun is observed throughout next even cycles. Whereas analysis of Svalgaard data demonstrates a configuration with two antipodal coronal holes of the same polarity, that is atypical for the period of descending phases of even cycles [10]. Thus, at least for this period our data set shows more realistic and physically meaningful results.

5. Conclusions

We proposed a modified technique of inferring IMF polarity in pre-satellite era from geomagnetic observations in the past back to 1905. The success rate of inferred polarities (0.83) is based on combination of Godhavn, Sitka and Sodankyla since 1926. Adding Thule to previous set of stations increases rate to near 0.87 but reduces the duration of series to 1947. With Vostok station success rate increases to 0.9 and reduces the duration of series to 1958. That is, we derive geomagnetic proxies of daily IMF polarity back to 1926 with fairly acceptable accuracy.

We have shown that it is rather sufficient to use this data set to analyze large-scale structure of IMF in the past. For example, the R-C rule is clearly seen from the data, so reversals of the global solar magnetic field were really occurred within last eight solar cycles.

We also demonstrated principal differences between our and Svalgaard data sets. Specifically, during descending phase of solar cycle 16, a two-sector structure if the IMF was detected, typical for this period of even cycles.

6. References


