Title: To the question about perturbations of solar-terrestrial characteristics.
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Abstract

Data obtained over the last three solar cycles have been analysed to reveal the relationships between the intensity of the photospheric field measured along the line of sight by the WSO group at heliolatitudes from -75 to 75 degrees and the intensity of the interplanetary magnetic field and absolute values of the perturbations of the different characteristics of the solar wind at the Earth orbit, and geomagnetic parameters provided by the OMNI team.

The heliospheric and geomagnetic data are found to be divided into two groups characterized by their response to variability of the solar magnetic field latitudinal structures on short and on long time scales.

Keywords: Sun; solar variability; magnetic field; interplanetary magnetic field; solar wind; geomagnetic perturbations; solar cycles

1 Introduction

Solar magnetic field plays the main role in the heliosphere. It has to be study carefully the relations between the solar wind, the perturbations of geosphere and global structure of the photospheric magnetic field. WSO and OMNI data were used for comparison of 30 years long data sets (see references in Gavryuseva 2018c) on a long and short time scale. This paper is concentrated on the study the relations of between absolute values of these characteristics.

This approach led to the conclusion that all solar wind data and geomagnetic perturbations that were examined divided into two groups characterized by sensitivity to the variability of the interplanetary magnetic field and photospheric field at different latitudes.

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We use Wilcox Solar Observatory data for the photospheric magnetic fields [http://wso.stanford.edu/synopticl.html](http://wso.stanford.edu/synopticl.html), (Scherrer et al., 1977), OMNI data for solar wind parameters at the Earth’s orbit, and indices of geomagnetic activity for the period 1976-2004, to study the relations between the solar wind, geomagnetic disturbances and solar drivers at different solar latitudes.

In order to understand from which latitudinal zone the solar wind is originated and how it depends on the activity cycle it is necessary to know the latitudinal SMF structure over at least 22 years.

The latitudinal structure of the SMF has been deduced for the last 29 years since May 27, 1976 from the Wilcox Solar Observatory (WSO) data (Scherrer et al., 1977; Gavryuseva & Kroussanova, 2003, Gavryuseva & Gogoli, 2006, Gavryuseva, 2005, 2006, 2006a,b, 2008a,b, 2018 and references there). The structure in latitude and time of the 1-year running mean of the solar magnetic field with 1 Bartels Rotation (BR, 1 BR = 27 days) step is shown on the upper plot in Fig. 1 Gavryuseva, 2018c.

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The solar wind and geomagnetic data were taken from the OMNI directory [http://nssdc.gsfc.nasa.gov/omniweb](http://nssdc.gsfc.nasa.gov/omniweb) which contains the Bartels mean values of the interplanetary magnetic field (IMF) and solar wind plasma parameters
measured by various space-crafts near the Earth’s orbit, as well as geomagnetic and solar activity indices). First, daily averages are deduced from OMNI’s basic hourly values, and then the 27-day Bartels averages are deduced from the daily averages. The corresponding standard deviations are related to only these averages and do not include the variances in the higher resolution data.

The IMF and solar wind parameters taken into account are the following:

- $B_x$, $B_y$, $B_z$ and $B = (B_x^2 + B_y^2 + B_z^2)^{1/2}$ are the components and magnitude of the interplanetary magnetic field, in nT;
- Proton density, $N_p$, in $N/cm^3$;
- Proton temperature, $T_p$, in degrees K;
- Plasma speed, $V_p$, in $km/s$;
- Electric field, in $mV/m$;
- Plasma beta, $N_\beta = \[(T * 4.16/10^5) + 5.34\] * N_p/B^2$;
- Ratio $N_\alpha/N_p$;
- Flow Pressure, $P$ proportional to $N_p * V^2$, in nPa;
- Alfvén Mach number, $M_a = (V * N_p^{0.5})/20 * B$.

The geomagnetic parameters taken into account are the following:

- $AE$-index;
- Planetary Geomagnetic Activity Index, $K_p$ – index;
- $DST$-index, in nT.

Sunspot number ($SSN$) was used, as well, for a further comparison.

The X axis directed along the intersection line of the ecliptic and solar equatorial planes to the Sun, the Z axis is directed perpendicular and northward from the solar equator, and the Y axis completes the right-handed set.

The solar wind parameters analysed cover the same period as the WSO solar data with one Bartels rotation resolution. We call the set of these 16 parameters taken from the OMNI data base as "solar wind" ($SW$) data; they include the interplanetary magnetic field, solar wind and geomagnetic parameters and sun spot number ($SSN$).

2 Relationships between the Solar Magnetic Field Intensity/ and the Absolute Values of the OMNI Data/ on Long- and Short-Term Scales

Physical connections between the Sun and the interplanetary parameters could be attributed to the influence of the intensity of the solar magnetic field without taking into account its polarity ($|MF|$). The corresponding correlation coefficients between the 1-year mean values of the $SMF$ intensity and absolute values of the $SW$ data ($|SW|$) as functions of time delay in years and in latitude are shown in Fig. 1. The $K_{cor}(|MF|, |SW|)$ have an 11-year periodicity for all the $SW$ data except the IMF intensity $B$, and this periodicity is slightly visible in the $K_{cor}$ for the absolute values of the $B_y$: $|B_y|$ and $AE$: $|AE|$.

There is a remarkable particularity of the latitudinal dependence of the $K_{cor}(|MF|, |SW|)$: the change of sign and a phase shift of the correlation coefficients at the heliographic latitude of about 50-55 degrees. This result can be interpreted as an evidence that the photospheric magnetic fields originated at the heliographic latitudes up to ±55 degrees propagate in the heliosphere and contribute to the perturbations of the solar wind and magnetosphere. The solar
magnetic fields originated above ±55 degrees do not appear close to the Earth’s orbit (see also Gavryuseva, 2006c, f; 2008b; Gavryuseva & Gondoli, 2006).

The $K_{cor}(|MF|, |SW|)$ are symmetric respect to the equator. This is well illustrated in Fig. 2 for the latitudinal dependence of the $K_{cor}(|MF|, |SW|)$ for the fixed optimum delay between the $SMF$ intensity and the absolute values of the $SW$ data. These figures are analogous to Fig. 11, 12 for the original (not absolute) $SMF$ (Gavryuseva, 2018c) and $SW$ values where the $K_{cor}(MF, SW)$ are antisymmetric to the equator. There is a clear anti-correlation between the intensity of the photospheric field of the activity belts and $|SMF|$ (Gavryuseva, 2018c) and $|MF|$ (Gavryuseva, 2008b) and $Ma$. This confirms that during high activity periods the slow solar wind prevails. Positive correlations of the $|MF|$ with the absolute values of the $AE$, $Kp$ and $DST$ indices correspond to the statement that most of the geomagnetic perturbations are originated from the low and middle latitudes when the intensity of the magnetic field is high. Figure 3 shows the latitudinal dependence of the $K_{cor}$ for the fixed optimum delay between the absolute values of the $SMF$ and $SW$ data after the filtering of the variabilities longer than 4 years and shorter than 1 year. The $K_{cor}$ for $B_y$, $T_p$, $V_p$, $P$, $N_p$, $AE$, $Kp$ and $−DST$ have very similar latitudinal dependence, and the strongest correlation with the $SMF$ intensity takes place at about 40 degrees in the southern hemisphere.

Owing to the symmetry of the solar magnetic field intensity $|MF|$, the latitudinal dependences of the $K_{cor}(|MF|, |SW|)$ and $K_{cor}(F|MF|, F|SW|)$ are also symmetric respect to the equator. These correlation coefficients are plotted in Fig. 4 together for all the $|SW|$ data for the long-term variability (on the left side) and for the short-term variability (on the right side). Figure 4 for the $K_{cor}$ of the absolute values of the $SMF$ and $SW$ data is analogous to the corresponding Figs. 14 and 15 for the original values of the $SMF$ and $SW$ data (Gavryuseva, 2018c). The difference between them permits to investigate the sensitivity of the $SW$ parameters to the $SMF$ polarity (not only to the intensity of the $SMF$) and to the basic topology of the solar magnetic field.

### 3 Cross-Correlation between the OMNI Data

The cross-correlation coefficients between the OMNI data provide an information limited to the relationships between them and could be useful for understanding why the $SW$ parameters are subdivided into two groups only.

The parameters of the interplanetary field, solar wind and geomagnetic activity have been numbered as follows:

1: $B_x$; 2: $B_y$; 3: $B_z$; 4: $T_p$, 5: $V_p$, 6: $E$, 7: $N_a/N_p$, 8: $N_p$, 9: $P$, 10: $K_p$, 11: $N_B$, 12: $Ma$, 13: $AE$, 14: $DST$, 15: $SSN$.

The cross-correlation was calculated and the corresponding correlation coefficients are plotted in Fig. 5. The corresponding numbers and short names of the parameters are shown along the $X$ and $Y$ axis. Asterisks correspond to the positive values of $K_{cor}$, and diamonds correspond to the negative values of $K_{cor}$. The size of the symbols is proportional to their values. On the top there are $K_{cor}$ for the original values of the $SW$ data (on the left side), and for their absolute values (on the right side). This makes difference for the $IMF$ components $B_x$, $B_y$, and $B_z$, for $E$ and for $DST$. On the bottom there are $K_{cor}$ for the residuals of the original values of the $FSW$ data (on the left side), and for the residuals of their absolute values (on the right side).
From the first plot on the left top strong correlations between the parameters No 9, 10, 11, 12, 13 and between No 5, 6, 14 are deduced. Not very strong, but significant correlations take place between No 5, 6, 9, 13. Strong anti-correlations take place between No 4 and 7; No 14 and 15; No 5, 6 and 15, etc.

Then there are anti-correlations between No 8 and 9, 10, 11, 12, 13, etc.

Comparison between the other plots of Fig. 5 and the groups of the SW data connected with the $B$ and $B_z$ (or $B_x$, $B_y$) permits to verify and to understand the existence of such groups. The study of such cross-relationships is very informative, but it does not provide a sufficient support to predict the SW connection with the solar magnetic field while it helps to understand which of SW parameters could respond in a similar way to the solar perturbations.

Direct comparison of the SW data with the basic topology of the $SMF$ permits to study SMF – SW relationships.

An influence of the solar activity (or solar magnetic field intensity) on the SW parameters was investigated by the analysis of their correlation on short subsequent intervals of time. Fig. 6 shows the correlation through solar cycles between the 3-year long sub-sets of the data corresponding to the absolute values of the photospheric field and to the absolute values of the solar wind and geomagnetic parameters. It is clearly visible that the main source of geomagnetic perturbations is concentrated in the helio-latitudinal zone from -55 to 55 degrees about

4 Some summary remarks

Southward-directed interplanetary magnetic field is considered a primary cause of geomagnetic perturbations (Durney, 1961; Gonzales et al., 1994, 1999). As a consequence the orientation of the interplanetary magnetic field (Axford and McKenzie, 1997; Low, 1996; Parker, 1997; Smith, 1997) plays an important role.

The solar activity phenomena depend on the sunspot cycle, which can be characterized by the variability of the $SMF$ intensity in time and along the latitudes. The topology of the solar magnetic field influences the geomagnetic perturbations through the intensity and orientation of the interplanetary magnetic field and/or through other parameters of the solar wind. In this approach we could understand the presence of two groups of the OMNI data similarly sensitive to the basic topology of the magnetic field of the Sun (from the point of view of the dependence on latitude and phase-shift of the correlation of the coefficients with the mean latitudinal magnetic field).

The formal and complete study of the problem of solar-terrestrial relations has been performed and the connections between the processes on the way from the Sun to the Earth have been revealed. A useful information was deduced from the temporal behaviour and dependence of the correlation of the photospheric magnetic field and different parameters of interplanetary space and geomagnetosphere.

It was revealed directly from the experimental data that there are two groups of SW parameter which respond in a similar way to the behaviour of solar characteristics. We found that the photospheric field influences the magnitude of the interplanetary field and, in the same way, the proton density, flow pressure, Alfvén Mach number and plasma $\beta$ respond to the $SMF$. Moreover the $AE$-index behaves in a similar way as the above mentioned solar wind parameters.
On the contrary, regarding the planetary geomagnetic activity index $K_p$, we can deduce that solar activity events (CME, magnetic field intensity, sunspots, etc.) through perturbations of the $B_z$ component ($B_x$, $B_y$ components) of the IMF, the proton temperature $T_p$, plasma speed $V_p$, $N_\alpha/N_p$ ratio influence the $K_p$ index. The variations of the $-B_z$ ($B_y$) component produce the perturbations of the $DST$ index, and they are of opposite sign of the $K_p$ and $B_x$ time dependence.

It was also revealed from the experimental data that the solar magnetic fields and solar activity processes originated below $\pm 55$ degrees propagate up to the Earth orbit and produce the perturbations of the magnetosphere (Gavryuseva, 2006a, f; 2008b, Gavryuseva & Godoli, 2006).

These results are useful for understanding the origin of solar wind and geomagnetic perturbations and for long-term predictions.

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References

[1] Axford, W.L. and McKenzie J.F. (1997), The solar wind, in Cosmic winds and the heliosphere, ed. by J.R. Jokipii, C.P. Sonett & M.S. Giampapa, 31.

[2] Clua de Gonzalez, W. D. Gonzalez, S. L. G. Dutra, B. T. Tsurutani (1993), Periodic Variation in the Geomagnetic Activity: A Study Based on the Ap Index, J. Geophys. Res., 98, 9215.

[3] Durney, J.W. (1961), Interplanetary magnetic field and the auroral zones, Phys. Rev. Lett., 6, 47.

[4] Fraser-Smith, A. C. (1973), Solar cycle control in the 27-day variation of geomagnetic activity, J. Geophys. Res., 78, 5825.

[5] Gavryuseva, E. (2005), Latitudinal streams of solar magnetic field, Proc. of 11 Int. Scientific Conf. Solar-Terrestrial Influences, Nov. 2005, BAS, 229-233.

[6] Gavryuseva, E. (2006), Topology and dynamics of the magnetic field of the Sun, News of the Academy of Science, IzvRAN, ser. Physics, 70, No. 1, 102.

[7] Gavryuseva, E. (2006a), Latitudinal Structure of the Photospheric Magnetic Field through solar cycles Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 124.

[8] Gavryuseva, E. (2006b), Basic topology and dynamics of magnetic field leading activity the Sun Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 67.
[9] Gavryuseva, E. (2006c), Variability of the differential rotation of the photospheric magnetic field through solar cycles Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 65.

[10] Gavryuseva, E. (2006d), North-South asymmetry of the photospheric magnetic field Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 63.

[11] Gavryuseva, E. (2006e), Longitudinal structure of the photospheric magnetic field Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 61.

[12] Gavryuseva, E. (2006f), Relationships between photospheric magnetic field, solar wind and geomagnetic perturbations over last 30 years Solar Activity and its Magnetic Origin, Proc. of the 233rd Symposium of the IAU, Cairo, Egypt, March 31 - April 4, 2006, Ed. V. Bothmer; A. A. Hady. Cambridge: Cambridge University Press, 291.

[13] Gavryuseva, E. (2008a), In search of the origin of the latitudinal structure of the photospheric magnetic field, ASP Conf. Ser., v. 383, Proc. of” Subsurface and atmospheric influence on solar activity”, held at NSO, Sacramento Peak, Sunspot, New Mexico, USA 16-20 April 2007, Ed. R. Howe, R. W. Komm, K. S. Balasubramaniam & G. J. D. Petrie, 99.

[14] Gavryuseva, E. (2008b), Longitudinal structure originated in the tachocline zone of the Sun, ASP Conf. Ser., v. 383, Proc. of” Subsurface and atmospheric influence on solar activity”, held at NSO, Sacramento Peak, Sunspot, New Mexico, USA 16-20 April 2007, Ed. R. Howe, R. W. Komm, K. S. Balasubramaniam & G. J. D. Petrie, 381.

[15] Gavryuseva, E. (2018), Latitudinal structure and dynamic of the photospheric magnetic field, arXiv:1802.02450.

[16] Relations between variability of solar and interplanetary characteristics

[17] To the connection between intensity of the solar and geomagnetic perturbations, arXiv:1802.NNNN(N)

[18] Gavryuseva, E. (2018), Latitudinal structure and dynamic of the photospheric magnetic field, arXiv:1802.02450.

[19] Gavryuseva, E. (2018b), Longitudinal structure of the photospheric magnetic field in Carrington system, arXiv:1802.02461.

[20] Gavryuseva, E.; Godoli, G. (2006), Structure and rotation of the large scale solar magnetic field observed at the Wilcox Solar Observatory Physics and Chemistry of the Earth, v. 31, issue 1-3, 68.

[21] Gavryuseva, E., Kroussanova, N. (2003), Topology and dynamics of the Sun’s magnetic field SOLAR WIND TEN: Proceedings of the Tenth International Solar Wind Conference, AIP Conference Proceedings, v. 679, 242.
[22] Gavryuseva, E., and V. Gavryusev (1994), Time variations of the $^{37}$Ar production rate in chlorine solar neutrino experiment, Astron. Astrophys, 283, 978.

[23] Gavryuseva, E., and V. Gavryusev (2000), Solar variability and its prediction, Long and short term variability in Sun’s history and global change, ed. W.Schroder, Science Edition, Bremen, Germany, p.89.

[24] Gavryuseva, E., and N. Kroussanova, (2003), Topology and dynamic of solar magnetic field, Proc. of the Tenth International Solar Wind Conference, AIP Conf. Proc., v. 679, 242.

[25] Gavryusev, V., E. Gavryuseva, Ph. Delache, and F. Laclare (1994), Periodicities in solar radius measurements, Astron. Astrophys, 286, 305.

[26] Gavryuseva, E., V. Gavryusev, and M.P. Di Mauro (2000), Internal rotation of the Sun as inferred from GONG observations, Astronomy Lett., 26, N 4, 261.

[27] Gavryuseva, E., & G. Godoli (2006), Structure and rotation of the large scale solar magnetic field observed at the Wilcox Solar Observatory, Physics and Chemistry of the Earth, Elsevier, 31, 68.

[28] Gonzalez, W.D., J.A. Joselyn, Y. Kamide, H.W. Krorhl, G. Rostoker, B.T. Tsurutani and V.M. Vasyliunas (1994), What is a geomagnetic storm?, J. Geophys. Res., 99, 5771.

[29] Gonzalez, W.D., B.T. Tsurutani and A.L. Clua de Gonzalez (1999), Interplanetary origin of geomagnetic storms, Space Science Rev., 88, 529.

[30] Kane, R.P. (2005a), Difference in the quasi-biennial oscillation and quasi-triennial oscillation characteristics of the solar, interplanetary, and terrestrial parameters, J. Geophys. Res., 110, A01108.

[31] Kane, R.P. (2005b), Short-term periodicities in solar indices, Solar Phys., 227, 155.

[32] Li, Y., Luhmann, J. G., Arge, C. N., Ulrich, R., How do solar magnetic fields influence the long term changes of some geomagnetic indexes?, American Geophysical Union, Spring Meeting 2001, abstract SH52A-02, 2001.

[33] Pizzo, V. J., A three-dimensional model of corotating streams in the solar wind. III Magnetohydrodynamic streams, J. Geophys. Res., 87, 4374, 1982.

[34] Wang, Y.-M., J. Lean, and N. R. Sheeley, The long-term variation of the Sun’s open magnetic flux, Geophys. Res. Lett., 27, 505, 2000.

[35] Low, B.C. (1996), Solar activity and the corona, Solar Phys., 167, 217.

[36] Luhmann, J. G., Li, Y., Arge, C. N., Gazis, P. R., Ulrich, R., Solar cycle changes in coronal holes and space weather cycles, J. Geophys. Res., 107(A8), 1154, pp. SMP 3-1, 2002.

[37] Makarov, V. I., Tlatov, A. G., Callebaut, D. K., Obridko, V. N., Increase of the Magnetic Flux From Polar Zones of the sun in the Last 120 Years, Solar Physics, v. 206, Issue 2, p. 383-399 (2002).
[38] Parker, E.N., (1997), Mass ejection and a brief history of the solar wind concept, in Cosmic winds and the heliosphere, ed. by J.R. Jokipii, C.P. Sonett and M.S. Giampapa, p.3.

[39] Rivin, Yu.R. (1989), Cycles of the Earth and of the Sun, Nauka, IZMIRAN, p.36.

[40] Smith, E.J., (1997), Solar wind magnetic field, in Cosmic winds and the heliosphere, ed. by J.R. Jokipii, C.P. Sonett and M.S. Giampapa, p.425.

[41] Stamper E.J., (1997), Solar wind magnetic field, in Cosmic winds and the heliosphere, ed. by J.R. Jokipii, C.P. Sonett and M.S. Giampapa, p.425.

[42] Stamper, R., Lockwood, Wild, M.N., Clark, T.D.G., (1999), Solar causes of the long-term increase of the geomagnetic activity, J. Geophys. Res., 104, Issue A12, pp.28,325.

[43] Pizzo, V. J. (1982), A three-dimensional model of corotating streams in the solar wind. III Magnetohydrodynamic streams, J. Geophys. Res., 87, 4374.

[44] Scherrer, P.H., J.M. Wilcox, L.Svalgaard, T.L. Duvall, Ph.H. Dittmer and E.K. Gustafson (1977), The mean magnetic field of the Sun: observations at Stanford. Solar Phys., 54, 353.

[45] Wang, Y.-M., J. Lean, and N. R. Sheeley (2000), The long-term variation of the Sun’s open magnetic flux, Geophys. Res. Lett., 27, 505.
Figure 1: The correlation coefficients of absolute values of the photospheric field at different latitudes (Y axis) with absolute values of solar wind and geomagnetic parameters as a function of delay and latitude. Orange and red (blue) colors indicate positive (negative) correlation coefficient values.
Figure 2: Coefficients of correlation between 1-year mean of the absolute value of the photospheric field at different latitudes and the interplanetary magnetic field, solar wind and geomagnetic parameters with the fixed delay of 4 days as a function of latitude (X axis).
Figure 3: Coefficient of correlation between short term variabilities of the absolute value of the photospheric field at different latitudes and the interplanetary magnetic field, solar wind and geomagnetic parameters with the fixed delay of 4 days as a function of latitude (X axis).
Figure 4: Coefficients of correlation between the absolute value of the photospheric field and interplanetary magnetic field, solar wind and geomagnetic parameters (marked on the right end of the corresponding curve) for the mean values over 1 year (on the left plot) and for the short term variable part of them (on the right plot) at different latitudes with a fixed delay of 4 days.
Figure 5: Coefficients of correlations between the yearly means of the intensity, original values of the components of the interplanetary magnetic field, solar wind and geomagnetic parameters (marked by number in X and Y axis) are shown on the upper plot on the left side. The same for their absolute values is shown on the top on the right site. Coefficients of correlation for short-term variability of the the intensity, components of the IMF, solar wind and geomagnetic parameters are shown on the bottom plot on the left. The same for the short-term variability of the absolute values of the SW data is shown on the bottom plot on the right.
Figure 6: The correlation coefficient through solar cycles between the 3-year long sub-sets of data of the photospheric field intensity at different latitudes (Y axis) with the absolute values of the solar wind and geomagnetic parameters. Orange and red (blue) colors indicate positive (negative) correlation coefficient values.