DETERMINATION OF POWER PERTURBATIONS OF THE HORIZONTAL MAGNETIC FIELD ON THE EARTH SURFACE

Rolf Werner[1], Veneta Guineva[1], Andris Lubchich[2], Irina Despirak[2], Rumiana Bojilova[3], Dimitar Valev[1], Atanas Atanassov[1], Lyubomira Raykova[1]

[1]Space Research and Technology Institute – Bulgarian Academy of Sciences
[2]Polar Geophysical Institute, Apatity, Russia
[3]National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences
e-mail: rolwer52@yahoo.co.uk

Keywords: *Magnetic substorm, Geomagnetic indices, Midlatitude Positive Bay (MPB), Horizontal power perturbations in the Earth surface magnetic field*

Abstract: *In 2015 Chu and later in 2017 McPherron have introduced a new index, the so called midlatitude positive bay (MPB) index, to characterize the activity of magnetic substorms at midlatitudes. In the frame of a bilateral project Bulgaria – Russia supported by the National Science Fund of Bulgaria (NSFB) (project number КП-06-Русия/15) and RFBR (project number 20-55-18003_Болг_а) a program was worked out based in general on the algorithm developed by Chu and McPherron. A key point of the algorithm consists in the estimation and removal of the main magnetic field and the mean solar quiet day variations. For this propose 25 successive days were used in the computations, centred at the day under consideration. The so called mean Solar quiet day variations were determined by superposed epoch analysis, and were subtracted from the observations during the considered day. The power perturbations were determined by the sum of the obtained by the described processing procedure squared and high pass filtered X and Y-component variations. In a pre-processing process, new procedures for data gap and peak detection and removal were included. Highly disturbed observations were previously removed by the outlier test of Grubbs. The horizontal power perturbations for the Bulgarian magnetic observatory Panagjurishte (PAG) are determined for the whole period from 2007 up to now by our developed processing tool, described in this work.*

ОПРЕДЕЛЯНЕ НА МОЩНОСТТА НА СМУЩЕНИЯТА НА ХОРИЗОНТАЛНОТО МАГНИТНО ПОЛЕ НА ЗЕМНАТА ПОВЪРХНОСТ

Ролф Вернер[1], Венета Гинева[1], Андрис Любчич[2], Ирина Дэспирак[2], Румяна Божилова[3], Димитър Вълев[1], Атанас Атанасов[1], Любомира Райкова[1]

[1]Институт за космически изследвания и технологии – Българска академия на науките
[2]Полярен геофизически институт, Апатити, Русия
[3]Национален институт по геофизика, геодезия и география – Българска академия на науките
e-mail: rolwer52@yahoo.co.uk

Ключови думи: *магнитна суббуря, геомагнитни индекси, индекс на положителни отклонения на средни ширини (MPB индекс), смущения в хоризонталната мощност на приземното магнитно поле*

Резюме*: През 2015 г. Chu, а по-късно през 2017 г. McPherron въвеждат нов индекс, така наречения индекс на положителни отклонения на средни ширини (проект България – Русия, подкрепен от Националния научен фонд на България (номер КП-06-Русия/15) и RFBR (номер 20-55-18003_Болг_а) беше разработена програма, базирана на алгоритъма, описан от Chu и McPherronMPB индекс), като характеристика на активността на магнитните суббури. В рамките на двустранния. Ключовият момент на алгоритъма се състои в оценката и отстраняването на основното магнитно поле и средните слънчеви вариации при спокоен ден. За тази цел при изчисленията бяха използвани 25 последователни дни, центрирани към разглеждания ден. Така наречените средни слънчеви вариации се определят посредством метода на наслагване на епохите и са извадени от наблюденията през разглеждания ден. Мощността на смущенията бе определена от получените по описаната процедура квадрати и филтрираните високочестотни вариации на X и Y-компонентите.*

В процеса на предварителна обработка бяха включени процедури за откриване и премахване на пропуски в данните и пикове. Силно смутените наблюдения бяха определени преди това от теста на Grubbs и изключени от пресмятанията. С нашата разработка, описана в тази работа е определена мощността на хоризонталните смущения за българската магнитна обсерватория Панагюрище (PAG) за целия период от 2007 г. до сега.

Introduction

During substorms large amounts of energy accumulated in the magnetosphere tail are released into the ionosphere and the inner magnetosphere. A lot of phenomena are generated e.g.[1], among which, disturbances in the surface magnetic field. During substorm expansions a typical systematic pattern of the surface magnetic field is observed. At auroral latitudes in the X-component are observed negative bays and at midlatitudes - positive bays.

To characterize storms, several indices were developed, as the disturbance storm time index (Dst) and as a measure of the substorm intensity AL and AU indexes, and their difference AE - the auroral electrojet index, for example.

McPherron and Chu [2,3] have introduced a new index to describe the substorm activity at midlatitudes, the midlatitude positive bay (MPB) index. Based on their algorithm and some new developments we have worked out a program to calculate the horizontal power of the surface magnetic field. To compare our results with the ones, published by McPherron and Chu in Space Science Revue 2017 [2], we have used the same data. The obtained results were reliable [4]. We have applied our program for one of the European stations, the Panagjurishte station. European stations were not considered by McPherron in his data set.

Short description of McPherron's and Chu's algorithm to calculate geomagnetic power perturbations

The key point in the determination of the power perturbations in the horizontal geomagnetic field consists of the removal of the mean main magnetic field and the mean solar quiet day variations. The initial point is the assumption that round midnight the field is quiet. Time series of the magnetic field components of 25 successive days centred at the day under consideration were constructed. The main field of this interval was estimated by smoothed spline approximation using the midnight points as knots and was subtracted from the observed field. Using the remained daily field components a superposed epoch analysis was performed. Days with strong disturbances were excluded from further calculations. The mean epoch values describe the so called mean solar quiet day (Sq) variations [2,5]. They were removed from the observations on the day of consideration. The residuals contain mainly field perturbations. Remaining low-frequency changes were filtered out applying additionally a FFT-filter procedure. The power perturbations then were calculated by the squared X and Y component resulting by the described above procedure. The algorithm of McPherron and Chu is a refinement of the developed algorithm of Chu [3] and Chu et al. [6].

Data used

For the Panagjurishte station data from the Intermagnet data base (INTERMAGNET Data) for the whole time interval from 2007 up to now were used. The data were downloaded by a system developed at the National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences [7]. The daily data are arranged in columns, where the first column is the number, identical with the beginning of the one minutes sampled measurements, followed by the magnetic field components X, Y and Z. The last column contains the total field strength. All field data are presented as floating point numbers in ASCII format and are very easy readable.

Data processing

A program corresponding to the McPherron's and Chu's algorithm was developed with some new contributions. The program realizes the data reading, data arrangement, the pre-processing and the processing of the field components and the graphical presentation of the results. The pre-processing includes procedures of gap and peak detection additional to the original algorithm. Moreover, the procedure to detect strong magnetic field disturbances based on the prediction efficiency used by McPherron and Chu was replaced by the usually used Grubbs outlier test [8]. The program was tested using the same data as in an example presented in [2]. Our results obtained with the created by us program were very reliable. The obtained power perturbations have shown the same structures. The amplitudes have shown some small differences, caused mainly by differences in the procedure of strong

disturbances exclusion. The processing procedures are described in detail in [4]. In fig.1 in the top panels the original observations of the X-component (at the left side) and the Y-component (at the right side) are shown, where the daily data were arranged to series of sequences of 25 successive days (black line). The data corresponding to mean midnight points, used as spline knots, are marked by red pluses. The main magnetic field components under quiet conditions, estimated by smoothed splines, are presented by blue lines. They were removed from the observations. The remaining field components are shown in the bottom panels of Fig. 1.

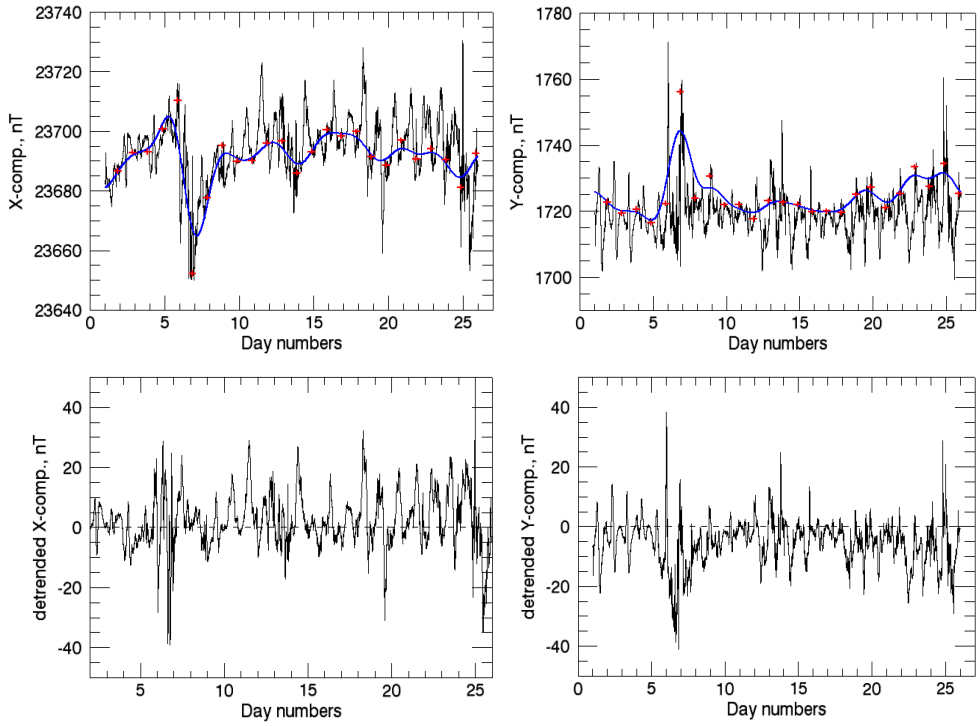

Fig. 1. At top the observations the of the X (at top left) and Y-component (at top right) of the horizontal magnetic field, the midnight spline knots (red pluses) and the approximated by smoothed spline main field for quiet condidions (blue lines) are shown. In the bottom panels, the remaining X (left panel) and Y (right panel) after the main field subtraction are presented.

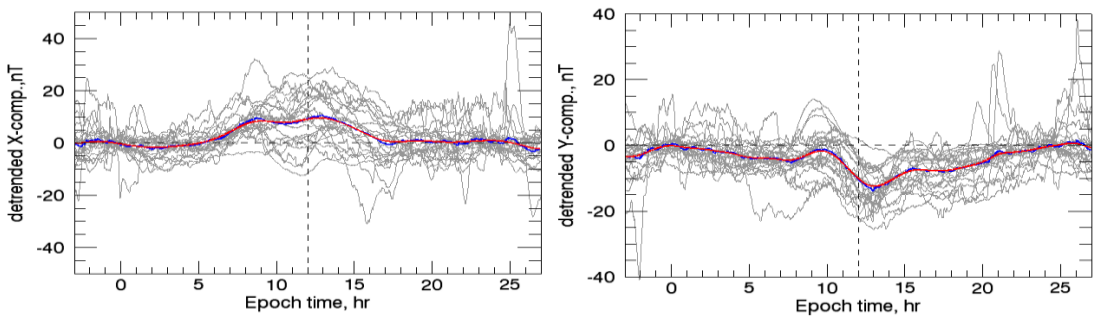

Fig. 2. Superposed epoch analysis of the daily main field removed observations (gray lines) of the X (left panel) and Y (right panel). The epoch means are drawn by blue lines and the smoothed ones, keeping only low frequency parts - by red lines.

From the bottom panels in Fig. 1 it is seen that the main field removed observations are mainly characterized by Sq effects. After the removal of days with strong magnetic field disturbances, superposed epoch analyses were performed to determine the Sq variations (Fig. 2). The mean epoch series are shown by blue lines. High frequency variations were suppressed by low pass filtering. The resulting mean solar quiet day variations are presented by red lines. Sq usually is determined for days with Kp<3 [8]. The Kp-index was not taken into account in the algorithm. The next figure, Fig. 3, offers the magnetic field X (upper panel), Y (middle panel) components perturbations for the substorm day 22.02.2013, obtained by removal of the main field and the mean solar quiet day variations, and the computed from them horizontal power of the surface magnetic field (bottom panel). During the substorm

in consideration the main perturbations are observed in the X-component. A strong positive peak with a maximal value of about 16.7 nT is observed after 19 UT. Together with smaller perturbations of the Y-component at the same time, a power perturbation of about 414 nT^2 arises.

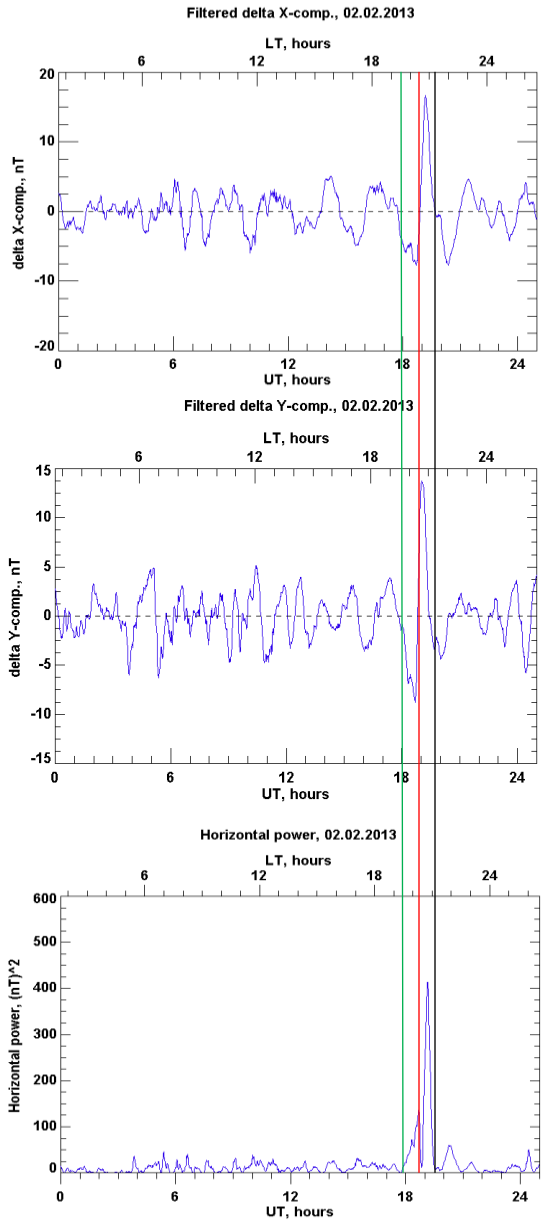

Fig. 3. Magnetic field component perturbations (X-component in the top panel, Y-component in the middle panel) and the horizontal power perturbations (bottom panel). The vertical red lines mark minima important for the determination of MPB onset and duration at Panagjurishte station (see text).

A slight local maximum in the horizontal power before the maximal perturbation is observed, caused by the negative part in the X and Y-components during about one hour before 19 UT between the green and red line. Such double maxima are frequently observed in cases of strong isolated substorms. Depending on the height of the negative amplitudes, the first maximum can be as higher as the second one. The end of the global maxima for the examined case is indicated by a black vertical line in fig.3. Using the power perturbations the MPB onset is determined by the minimum between the described two maxima. In the considered case, the onset is found to be at 18:50 UT (bottom panel in fig.3). The corresponding to the observed MPB peak substorm onset determined on the base of the SML index reported in the SuperMAG data base is 18:48 at Glon 19.2, Glat 74.5. for the Bear Island (BJN).

McPherron and Chu determine the substurm duration by the location in time of the second minimum after the MPB-index (defined as a power perturbation pulse mean over a multitude of stations) maximum, however this is not true in any case. They pointed out, that not every maximum in the power

perturbations is related to substorms and proposed the use of SML index simultaneously with the MPB index.

The perturbations in the X and Y-component and in the power of the horizontal magnetic field were calculated for the available data from the whole time interval from 2007 up to 2020. In the first version no perturbations at least for 25 days were determined in cases when the period of no data is longer than one day. For shorter no data periods, the results have to be used with caution.
The results are uploaded in a data catalog [9], where a daily file contain the perturbations of the X and Y-component and the power perturbations for every minute. The time moments are given in minutes and in hours. The daily results are presented as graphics as well.

Summary and conclusions

A program to calculate power perturbations in the Earth surface magnetic field was developed based on the algorithm of McPherron and Chu with some new elements. In difference to the McPherron and Chu algorithm, in our development the Grubbs's test is used to eliminate days with strong disturbed magnetic field components, and gap and peak detection and removal are implemented in the pre-processing procedure. To estimate the main field, a window of 23 days centered over the considered day is used, but secular variations have not been determined. The perturbations are determined by subtraction of the main field from the X and Y components and by removal of low pass filtered superposed epoch means from the components of the considered day.

By the developed program very like structures in the calculated power perturbations for the substorm day 2.03.2008, as the original, published by McPherron and Chu in 2017, are obtained. In addition, here a MPB was identified related to a substorm listed in the SuperMAG data base (substorm event list). This demonstrates, that the power perturbations determined by the developed program can be reliable.

Acknowledgements. The authors are grateful to the creators of the databases International Real-time Magnetic Observatory Network (Intermagnet) Data Download (intermagnet.org) and SuperMAG (SuperMAG: Products (jhuapl.edu)). for the opportunity to use them in this work. We thank the experts from Panagjurishte observatory (NIGGG-BAS) for providing data and support for their processing.

This study was supported by the National Science Fund of Bulgaria (NSFB) (project number КП-06-Русия/15) and by the RFBR (project number 20-55-18003Болг_а); the work of I.V. Despirak and A.A. Lubchich was carried out within the framework of the RFBR grant No. 20-55-18003_Bulg_a.

References:

1. Akasofu,S.-I., C.-I. Meng, Low latitiude negative bays, Journ. Atmosp. Terr. Phys. 30,2, 227–241, 1968.
2. McPherron, R.L., X. Chu, The midlatitude positive bay and the MPB indexof substorm activity, Space Sci. Rev 206, 91–122, 2017.
3. Chu, X., Configuration and generation of substorm current wedge, Los Angeles: University of California Los Angeles
4. Werner, R., V.Guineva, A. Atanassov, R. Bojilova, L. Raykova, D. Valev, A. Lubchich, I. Despirak. Calculation of the horizontal power perturbations of the Earth surface magnetic field, Proceedings of the Thirteenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere" Primorsko, Bulgaria, 13 - 17 September 2021, in press.
5. McPherron, R.L., The EARTH: its properties, composition and structure, in Encyclopedia Britannica, 545–558, 1987.
6. Chu, X.N., T.S. Hsu, R.L. McPherron, V. Angelopoulos, Z.Y. Pu, J.J. Weygand, K. Khurana, M. Connors, J. Kissinger, H. Zhang, O. Amm, Development and validation of inversion technique for substorm current wedge using ground magnetic field data. J. Geophys. Res. Space Phys. 119(3), 1909–1924, 2014
7. Божилова, Р., Автоматизирана система за събиране на геофиизични данни - приложение XLV Сборник на „Национална конференция по въпроси на обучение по физика“, София, 6-9 Април 2017, стр. 55–59, 2017.
8. Grubbs, F.E., G. Beck, Extension of Sample Sizes and Percentage Points for Significance Tests of Outlying Observations, Technometrics, 14, 847–857, 1972.
9. Guineva, V., I. Despirak, R. Werner, R.Bojilova, L. Raykova, Development of a substorms catalog including the MPB observed at Panagjurishte station, Bulgaria, presented at the XII International Conference "Solar-terrestrial relations and physics of earthquakes precursors", Paratunka, Kamchatsky kray, Russia, September 27 – October 01, 2021, in press.