Calculation of the Horizontal Power Perturbations of the Earth Surface Magnetic Field

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Abstract.

The substorm effect at midlatitudes is expressed by a rise and decay of the X-component of the surface magnetic field, called midlatitude positive bay (MBP). McPherron has introduced a new geomagnetic index based on the calculation of the horizontal power perturbations of the Earth surface magnetic field. In this work, a developed processing tool to determine the horizontal power of the magnetic field is presented. A main element in these calculations is the estimation of the main field by smoothed spline fits to the midnight field using 25 consecutive daily observations centred over the day in consideration. The estimated field was removed from the measurements. We used the Grubs test for detection of days with strong magnetic disturbances. Excluding the disturbed days from further calculations, the mean solar quiet day variations (Sq) were determined by averaging the field components and were subtracted from the magnetic field observations of the central day. The resulting X and Y horizontal components were high pass filtered to suppress periods longer than 3 hours. Thus, adopting the McPherron s algorithm we have calculated the horizontal power for the Panagjurishte station (PAG). In the algorithm we have incorporated procedures for gape and peak detection and removing. The MPB index is defined as the average of the horizontal power of a multitude of stations and monitors the intensity in the substorm disturbances.

Introduction

During substorms large amounts of energy accumulated in the magnetosphere tail is released into the ionosphere and the inner magnetosphere. A lot of phenomena are generated, 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 negative bays are observed in the X-component 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 (2017) have introduced a new index to describe the substorm activity at midlatitudes, the midlatitude positive bay index (MPB). We have worked out a program to calculate the horizontal power of the surface magnetic field, mainly based on the algorithm of McPherron and Chu. To compare our results with the ones, published by McPherron and Chu in Space Science Revue (2017), we have used the same data. We have applied our program for one of the European stations, the Panagjurishte station. European stations were not considered by McPherron.

Data used

In the description of the algorithm McPherron and Chu illustrate the calculation steps by data from the International Real-time Magnetic Observatory Network (Intermagnet) Data Download (intermagnet.org) for the American station Honolulu (HON) (21.32°N 158.0°W, 21.65°GMLat, Elevation: 4 meters) Hawai (centered over the substorm day 2/3.03.2.2008). We used the same data, and for comparison – data from the Bulgarian station Panagjurishte (PAG) (42.5°N, 24.2°E, 556 m altitude; ~37° GMLat, ~ 97° GMLon) including the time interval from 08.02 up to 04.03.2017 (centered over the substorm day 20.2.2017). In the original data files, the one-minute mean data for the magnetic field components X, Y, Z and the total field intensity are given in nT related to UT.

The magnetic field data for 25 successive days centred at the day under consideration were processed. This time interval length is sufficient to estimate and remove the main magnetic field and the mean field for quiet solar conditions (McPherron and Chu, 2017). From the daily data time series were constructed, consisting of 36000 one minute sampled data points for every magnetic component. A general view of these series of the magnetic field X-component for the Honolulu and the Panagjurishte stations is given in Fig.1.

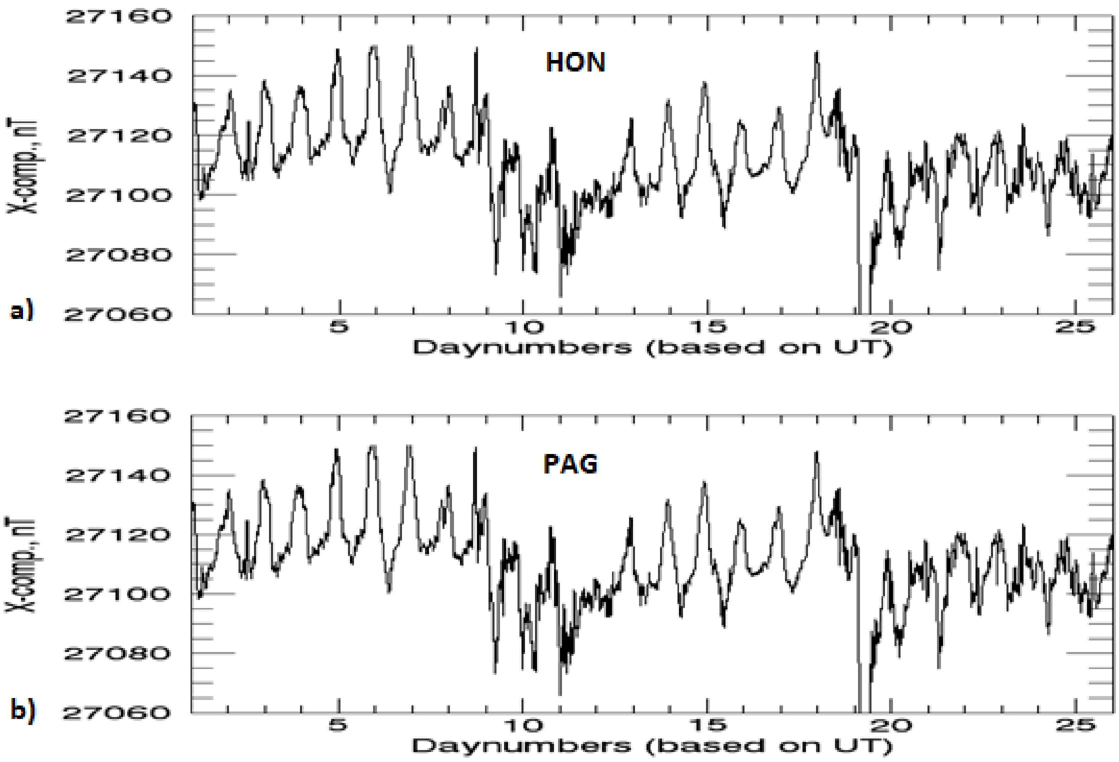

Fig. 1. *X-component of the magnetic surface field of 25 sucessive days (20.02 - 15.03.2008 for the Honolulu station and 08.02 - 15.03.2017 for the Panagjurishte station as given in the Intermagnet data base*.

The daily solar variations in the Honolulu data are more pronounced in comparison with the variations in the Pangjurishte series. The Panagjurishte data are much noisier and sharp peaks (spikes) are clearly visible. This series is interrupted by data gaps of different length. The longest gap in the considered here time interval is in the day 16 (23.02.2017), shown by a horizontal plateau. The plateau arises by repeating of the last measured value within the gap.

Preprocessing

The preprocessing of the observed magnetic data includes procedures for peak detection, for removal of data gaps and for detection and removal of days with very high magnetic disturbances (called for shortness "disturbed days"). Data gaps and peaks are usually randomly distributed and are not concentrated within an only day. Because the data are given for UT, the time series are converted to local time (LT) by data shift, corresponding to the geographical longitude. In LT it is very easy to determine the midnight points. Around this points the magnetic field is assumed as quiet.

a) Data gaps removal

Data gaps have mostly technical reasons as electrical power outage or required maintenance. If no data was registered, then the value 99999 was written in the original data file. In the gaps the values of an additional series are set to a constant much greater than the magnetic variances and so they are well graphically presentable. The interval borders of the data gapes are then easy to find by means of the first differences. The no data values were replaced by the result of the linear interpolation between the last and first measurements outside of the no data interval. In the special case when no data were measured at the beginning or end of the 25 days series, the no data were replaced by the nearest observations. In the studied here time interval five gaps were identified. One example is shown in Fig.2.

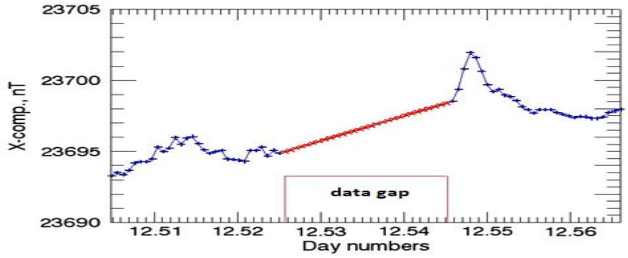

Fig.2. The figure demonstrates the procedure for the gap removal. One gap, observed on the day 13 (20.02.2017) of the time interval is marked by the bar plot. The original data are presented by plusses, connected with/by lines, and the interpolated data are shown by asterisks, connected by a line as well. The sequence of days begins with number one for 08.02.2017.

b) Peak detection and removal

Under a peak here a sudden increase or decrease of the magnetic component intensity was understood. Such type of peaks are often referred spikes. The reason of spikes can be running engines of cars passing through the station periphery. The sudden change can be characterised by the absolute value of the first derivation greater than a given threshold. The peak borders at

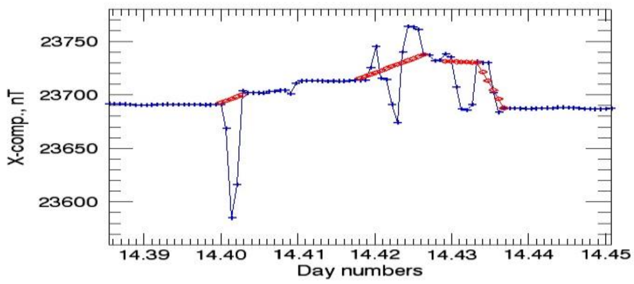

Fig.3. The figure demonstrates how the peak removal is working. The original data are shown by blue plusses connected by a blue line. The interpolated data are drawn by red diamonds, connected also by a red line. In the left side near the day number of 14.40 (22.02.2017) a single peak, detected and removed, is presented. In the right side a sequence of peaks was found and removed by linear interpolation. The sequence of days is the same as in Fig.2.

the peak base were determined by the first undercut of mean standard deviation of the first derivation at left and right of the peak. The values between the peak borders were replaced in the same manner as for the gap removal, by linear interpolation. The peak detection and removal is organized in program loops, where in every loop the peak with the maximal first derivation is removed. The detection stops when the first derivations do not exceed a given threshold. An example of detection and removal of a single peak and of a sequence of peaks is presented in Fig. 3.

Data processing

The calculation of the MPB follows in general the algorithm developed by McPherron and Chu (2017). At first, to eliminate the main magnetic field and the slow changes due to the ring current and partial ring current a base line was constructed by a smoothed spline interpolation through the midnight points (at 24 LT) (see Fig.4). The resulting spline was subtracted from the time series. The remaining series were splitted again in daily sequences but with three additional hours at the beginning and at the end of every day. (For the PAG station data this allows later the easy conversion again to UT). The time segments with the length of 30 hours hereinafter are called extended days.

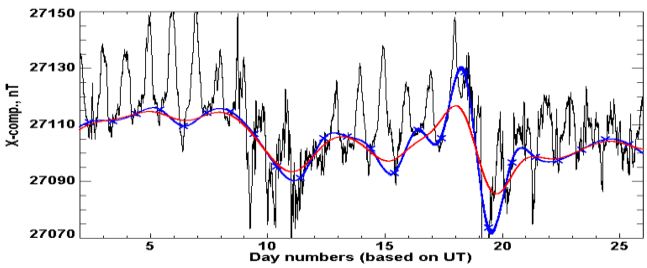

Fig.4. X-component series for 25 days of the HON station, centered on 03 February 2008. The midnight points (24 LT) are marked by blue" x" sign. The computed spline through the midnight points is drawn by a continuous blue line, the smoothed spline by a red line. The result is very close to the one of McPherron. (Compare Fig. 5a in McPherron and Chu.)

After the time series split from the original 25 days (in UT), 23 extended days (in LT) remain. To calculate the mean Solar quiet day variations (Sq), extended days with strong magnetic disturbances have to be removed. A disturbed day can be set by its high standard deviation. The standard deviations are calculated for all 23 extended days. The results are considered as random quantities. By the Lilliefors test (Lilliefors, 1967) was verified, that they are approximately normally distributed. We have determined outliers, meaning disturbed days, applying the Grubbs test, using the one side significance level of 0.12 (Grubbs and Beck, 1972). The procedure is convergent and in average up to two, three or four disturbed extended days were found. These days were excluded in further calculations. From the remaining days Sq is determined by averaging of the daily variations of the field components (superposed epoch analysis) like in the procedure applied in the Chu's algorithm of the MBP calculation (Chu,2015). High frequency variations in Sq were smoothed using running mean. Tests to calculate Sq with the help of Principal component analysis (PCA) as in the McPherron and Chu (2017) computations were also performed. This procedure is much complicated and slower. Much more, the result is very close to the one obtained by a simple averaging and smoothing.

Analogous to the McPherron's method the X and Y components with removed Sq effects were filtered by a high pass filter to suppress the low frequencies longer than three hours and to keep the high frequency changes (see Fig. 5).

The horizontal power of the magnetic perturbations obtained by the sum of the processed squared X and Y magnetic components is shown in Fig. 6.

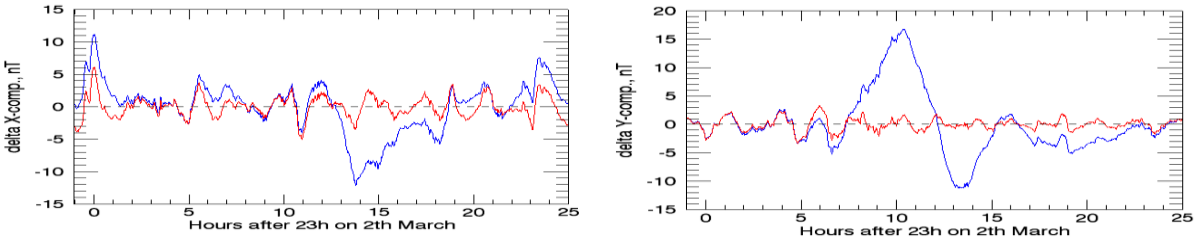

Fig.5 the resulting X (left panel) and Y (right panel) magnetic components for extended day on 2 March 2008 for the Honolulu station are presented. The blue lines represent the Sq removed components and the result after high pass filtering is show as red lines. The time on the x-axis represents the universal time (UT) in hours.

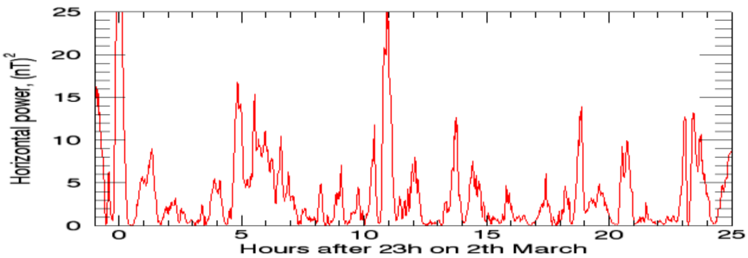

Fig. 6 Obtained horizontal power perturbations in the magnetic field on 2.03.2008 at the Honolulu station. The time is given as station time (LT).

The calculated horizontal power for the HON station for the substorm day 2.03 .2008 has the same structure as the original, published by McPherron and Chu in 2017 (compare with Fig. 10 c in McPherron and Chu (2017), but some power differences are evident.

The algorithm was adopted to calculate the power perturbations also for European stations. One example for the Panagjurishgte station for the substorm day 20.02. 2017 is shown in Fig. 7. Between 16 UT and 19 UT strong perturbations in the X and Y-components (Fig. 7 a) and b)) are observed which are responsible for the strong power perturbations of more than 400nT. A careful analysis is necessary to clarify if the magnetic field perturbations are caused by one or more individual successive and probably overlapping in time substorms. The considered here substorm was studied in more detail in Guineva et al. (2021). The substorm onset was determined to be about 18:40h. This is in very good agreement with the location of the first minimum before the power maximum. The maximum about 18:20 UT rises due to the comparatively high negative values in both X and Y components.

Summary and conclusions

A program to calculate power perturbations in the geomagnetic field was developed based in general on the algorithm of McPherron and Chu with some new elements. In difference to eliminate days with strong disturbed magnetic field components, and gap and peak detection and removal are implemented in the pre-processing procedure. To remove the main field and the magnetic mean Solar quiet day variations, a window of 23 days centered over the considered day is used, but secular variations have not been determined. To obtain the mean field under quiet solar conditions after the subtraction of the main field components low pass filtered superposed epoch means of the components are applied. 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. This demonstrate that the power perturbations determined by the developed program can be reliable.

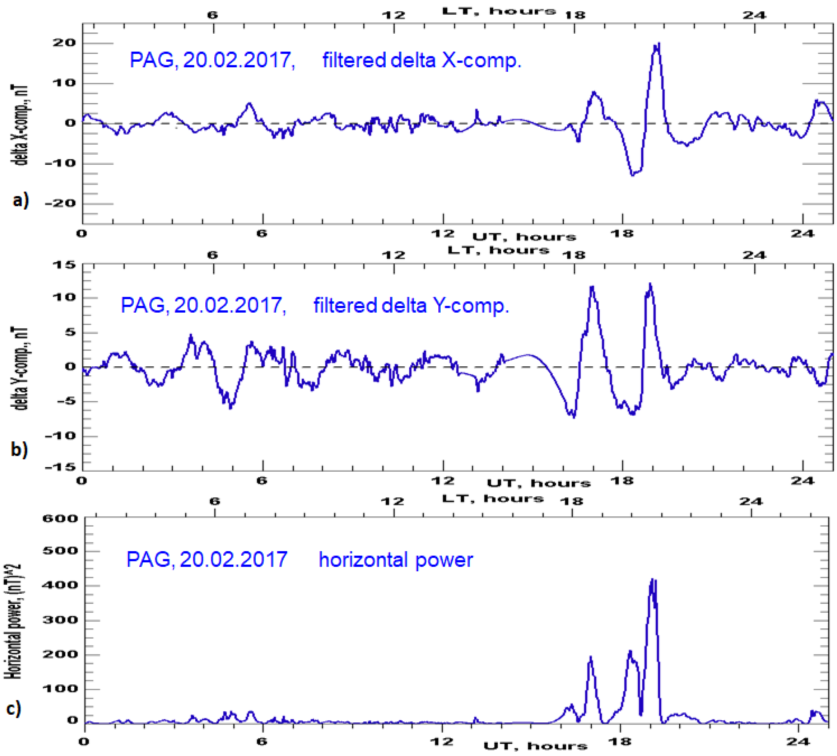

Fig. 7. The obtained results for the substorm day 20.02.2017 for the Panagjurishte station. Between 16 UT and 19 UT strong perturbations in the X and Y-components are observed (Fig. 7 a) and b), which are responsible for the strong power perturbations of more than 400nT

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