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DETERMINATION OF THE OCCURRENCE RATES OF THE GEOMAGNETIC DISTURBANCES AT EUROPEAN AURORAL AND HIGH LATITUDES

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Abstract. Statistical studies allow probability statements about the frequency of certain events. The occurrence of magnetic substorms and their activity have been described with the help of extreme value distributions in the last few decades using the auroral electrojet indices AE, AL and AU. In this work we examined the distribution of the *IL* index, derived from observations at stations of the IMAGE magnetometer network. The distributions of magnetic disturbances, based on *IL*, were studied separately in the morning (3-9 MLT), day (9-15 MLT), evening (15-21 MLT), and night (21-3 MLT) sectors. In addition, we used the values of the *IL* index calculated from the meridional chains in the auroral zone (PPN-SOR) and from the chain of stations at high latitudes (BJN-NAL). By help of the histograms and the empirical cumulative distributions, the occurrence rates were computed. It was shown that the empirical distributions could be well approximated with exponential distributions. The distribution parameters were determined from the occurrence rates. Three classes were discovered, which differ significantly by the respective distribution parameters. Structure changes in the distributions were found in the morning sector at both auroral and high latitudes.

Introduction

It is well known that very strong geomagnetic storms provoke hazards as disruption of electrical power systems and communication systems, including in navigation systems with all socio-economic consequences. Therefore, in the last decades, such strong events were in the focus of statistical studies. They give answers to questions as the probability of occurrence of such events, their distribution over time intervals as seasons, years and dependences the from solar cycle phase. The occurrence of strong events was studied based on application of the extreme value theory using geomagnetic indices as Dst, aa, AL, AU and AE describing the geomagnetic activity [1-7] From the magnetic field components measured at the Earth's surface, field variations are extracted and indices are determined that characterized geomagnetic activity. Most of them have global character. The IMAGE network includes European stations. The indices obtained on the base of this network data are regional, and more appropriate for Europe than global indices. The aim of the investigations presented in this paper is the study of the distribution of IMAGE electrojet index *IL*, which to our knowledge has not been carried out so far.

Data

The IMAGE magnetometer network provides the auroral electrojets indices for all stations located in Scandinavia and Fennoscandia (Scandinavia without Svalbard). Here we use the chain Polesie – Sørøya (PPN - SOR) from 51.4° (47.1º) to 70.5° (67.3º) geographical (geomagnetic) latitudes enclosing 12 stations, and the chain Bear Island – Ny Ålesund (BJN - NAL) enclosing four stations at Svalbard from 74. 5° (71.4º) to 78.9° (75.2º) geographical (geomagnetic) latitudes. Note that sometimes, in conditions of calm solar wind, specific types of substorms, the so-called "polar substorms" [8-9], were observed on this chain over Spitsbergen (BJN-NAL). We have downloaded the *IL* index computed for these chains for the time interval from 2007 to 2020 (https://space.fmi.fi/image/www/il_index_panel.php). The perturbations in the horizontal magnetic X component relative to quite magnetic conditions, we denoted by δX. During substorms, at auroral latitudes the *IL*-indice and δX are strong negative. The daily time series of *IL* index averaged over one every minute were subdivided in four time sectors lasting 6 hours: the midnight sector (called hereinafter for brevity night sector) (21 - 03 MLT) the morning sector (03 - 09 MLT), the midday sector (for brevity called day sector) (09 - 15 MLT) and the evening sector (15 - 21 MLT). The noise in the *IL* time series was reduced by the application of a simple low-pass filter with a cut-off frequency corresponding to 5 min.

The choice of events

We have chosen the magnetic disturbance events by the following criteria:

1) *IL* falls below –2σ;
2) the peak width at –σ is greater than 8 minutes;
3) a threshold of –*IL* > 50 nT was applied for BJN-NAL and for PPN-SOR a threshold of –*IL* > 100 nT was used, because below these thresholds only weak magnetic disturbances, similar to noise, were observed.

The minimal *IL* value of the negative bay of each of the chosen magnetic disturbance event was taken for further consideration.

Determination of the distributions and observation rates of *IL*-index

We constructed histograms, where the number of events wase counted in successive, not overlapping equal intervals of 50 nT. Our histograms display the frequencies of numbers of magnetic disturbance events in every *IL* interval. *IL*(t) is defined as min{$\delta X_i(t)$}, where i is the station number and the densities are expected to decrease as an exponential function. The empirical distribution density is easy to calculate from $f_i = Ni/N$, where N_i is the observed number of magnetic disturbance events in the i^{th} interval and N is the overall observation number in all classes. The theoretical distribution densities can be estimated by help of an extreme value distribution, in our case the exponential distribution density, which is defined as

$$f(x) = \lambda * \exp(-\lambda x)\,, \text{with} \quad x = -(IL + 50)\;nT. \tag{1}$$

The empirical cumulative distribution is given by $F_i = \frac{1}{N}\sum_{j=1}^{i} N_j$ and the theoretical cumulative distribution for the exponential distribution density is

$$F(x) = P(X \le x) = 1 - \exp\,(-\lambda x), \tag{2}$$

where *P* gives the probability that a random variable X is smaller than x. The survival function is defined as *S(x) = P(X > x) = 1 – P(X ≤ x) = 1 – F(x)* [10]. In absolute counts the event observation number is $N–N*F_i$ and the occurrence rate per year is obtained by $(N– N*F_i)/(number\ of\ years)$. We note that the waiting time rate, used by some authors, is defined as the invers of the occurrence rate [11]. The theoretical occurrence rate in the case of an exponential distribution is *N * exp(–λx)/(number of years)* and on a logarithmic scale it decreases linearly with –*IL*, with the slope equal to the parameter λ of the exponential distribution, which can be determined by linear regression.

Results

The occurrence rates were determined by help of the calculated empirical cumulative distributions for all four examined here magnetic time sectors [12,13]. As it is well known the magnetic disturbances in the night, morning and evening sector are often associated with substorms. The obtained occurrence rate distributions of the magnetic disturbances registered at the PPN-SOR chain in these sectors and at the BJN-NAL chain in the evening sector and for –*IL* > 1025/nT in the morning sector are grouped in the interval of the parameters of the exponential distribution between about 0.004/nT and 0.005/nT. In the night sector for the BJN-NAL chain the exponential distribution decreases faster than the one for the PPN-SOR chain, with 0.0067/nT (Fig. 1a). The sources of the disturbances observed during night at PPN-SOR and at BJN-NAL are probably different. The occurrence rate in the morning BJN-NAL sector decrease faster up to –*IL* = 1025 nT with a slope of about –0.0065/nT, and after that the slope change to about 0.0042/nT. For the PPN-SOR chain in the same sector it decreases with a slope of about 0.0052/nT up to –*IL* = 875 nT, and after the slope becomes about 0.0039. These changes in the occurrence rate in the morning sector for both chains are identified as structural changes with break points at the limits mentioned above (Fig. 1b) [14,15]. The significance of the breakpoints was tested for a Two Phase Regression model using a F-statistic [16] with F_{max}-percentils calculated by Lind and Rees [17] The breakpoints are significant at the level of 0.99. The segments after the break points for stronger magnetic disturbances show a smaller λ than the segments for weaker intensity of the magnetic disturbances.

The fastest saturations were observed in the cumulative frequencies in the day sectors of both chains. This is reflected in the rapid decrease of the respective frequencies in the histograms (not shown here) and in the occurrence rates, as well (see Fig. 1d), giving us the estimated parameters of the exponential distributions of 0.011/nT for the BJN-NAL chain and of 0.0075/nT for the PPN-SOR chain. During evening time usually the eastward electrojet is predominant but at the SOR chain negative *IL* can be observed for some configurations of the electrojet vortexes.

The occurrence rates of magnetic disturbances in different time sectors show three classes, which are characterized by different parameters λ of the exponential distributions. The first class is the more extensive and is characterized by slopes in the λ interval of approximately 0.004/nT to 0.005/nT and is typical for the exponential distributions at auroral latitudes. In the morning sector for both the PPN-SOR and the BJN-NAL chain a structural change (with one break point) is observed, where the segments for stronger magnetic disturbances have a λ parameter, which belongs to the first class. The second class with a λ of between about 0.0065 and 0.0075/nT is only observed at auroral latitudes in the day sector and at high latitudes in the night sector and in the morning sector up to about $-IL$= 1025 nT. The third class comprises only a few events with λ of about 0.011/nT, typical for the occurrences of weak disturbances in the day sector at auroral latitudes.

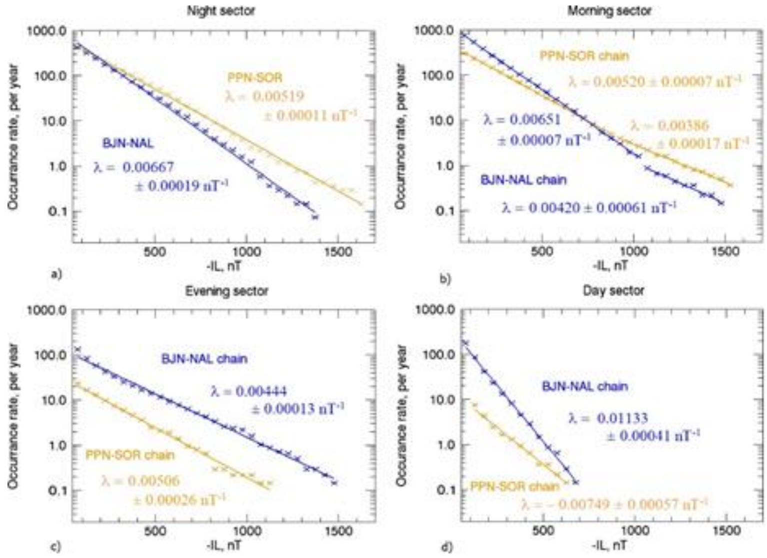

Figure 1. Occurrence rate of *IL*-index calculated for PPN-SOR (orange colour) and for BJN-NAL (blue colour) for all time sectors. The empirical rates are shown by crosses. The theoretical rates, estimated by help of exponential functions, are drawn by continuous lines. The values of the λ parameters and their confidence intervals are noted. a) for the night sector b) for the morning sector c) for the evening sector and d) for the day sector.

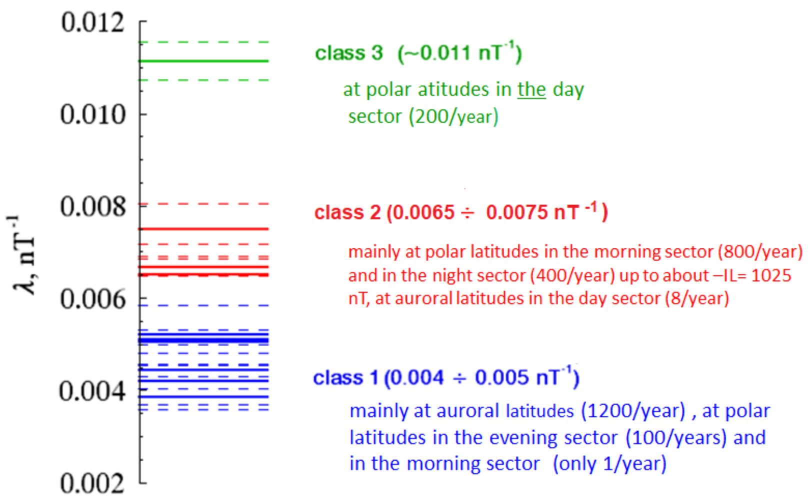

Figure 2. Classification of the exponential distributions of magnetic disturbances by the parameter λ in three classes.

Conclusions

The determined empirical occurrence rates of magnetic disturbances at the IMAGE chains PPN-SOR in the western part of Scandinavia and at the Svalbard stations obtained in the here presented paper show exponential distributions and can clearly classified in three classes, which are characterized by different parameters λ of the exponential distributions.

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