# ANALYSIS OF THE RELATION BETWEEN THE VARIATION OF ASY-H GEOMAGNETIC INDICES AND THE CHARACTER OF INTERNET INTERDOMAIN ROUTING DURING THE 2003 HALLOWEEN GEOMAGNETIC STORM

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***Abstract**: In this work, we investigated the character of the relation between variation of ASY-H geomagnetic indices and updates of border gateway protocol data sets during the strongest geomagnetic storm in October 2003. Time series of low to mid-latitude asymmetric geomagnetic indices have been compared with the Internet border gateway protocol data sets obtained from the three world's largest Internet providers. As a regularity metric characteristic of considered processes, we used the local variation calculation method. The probability density function and Similarity/dissimilarity of compared processes have been assessed using Kullback–Leibler divergence measure. It was shown, that strong geomagnetic storms practically do not affect the dynamical regularity of processes of BGP update variation. At the same time, the extent of similarity between the character of variation of ASY-H and corresponding BGP updates time series strongly increased in the period of the strong Halloween geomagnetic storm that occurred in 2003.*

***Key words**: ASY-H geomagnetic data, BGP data, Kullback–Leibler divergence*

**Introduction**. It is well known that there are numerous indices of Geomagnetic activity. These indices quantify the disturbance of the Earth's magnetosphere due to interplanetary transients. SYM-H and ASY-H are among such known geomagnetic indices [1]. Namely, SYM-H, together with Dst, is a proxy of the symmetric ring current, while ASY-H is the longitudinally asymmetric part of the geomagnetic disturbance field at low latitude to mid-latitude. In more detail, SYM-H is derived by first subtracting main geomagnetic field due to internal geodynamo and external Sq induced geomagnetic field variations and then averaging residual fields. Next by removing the globally symmetric component of the magnetic field variations from geomagnetic field variations at each station, longitudinally asymmetric geomagnetic field variations are derived. The range between max and min of these subtracted fields are compiled as mentioned ASY-H index. ASY-H have a significant contribution from various transient currents flowing in the magnetosphere–ionosphere system such as currents associated with impulses, solar flares, substorms, and prompt penetration electric fields, partial ring current, field-aligned currents, magnetotail current, etc. [2,3]. The disturbance of these SYM-H and ASY-H indices often is used to describe the geomagnetic storm strength.

In the present research, we restrict ourselves to the analysis of variation of asymmetric indices during a series of so-called Halloween geomagnetic storms in October and November of 2003. Namely, we speak about the strongest storm that occurred on October 29 and 30.Presently it is well accepted that strong geomagnetic disturbances, like Halloween geomagnetic storms, can cause extensive social and economic disruptions. There are several known facts about the damaging effects of strong geomagnetic storms such as the Carrington event that happened in September 1859, the space weather event in March 1989, the November 2001 event, etc. [4,5]. According to modern views, the potential for such destructive influences in modern high-tech society is becoming increasingly dangerous [6,7,8]. Indeed, it is difficult to overestimate damages for satellite communication and navigation systems, electric power grids, pipeline systems, long-distance communication cables, etc. [9].

Because a variety of modern services are critically dependent on a properly functioning Internet, the importance of efforts to assess the nature of the possible impact of geomagnetic storms on Internet processes becomes obvious.

To our knowledge, this question is not yet investigated, and thus we in the present work aim to make the first step to shed light on this interesting and important question. In this respect as an appropriate to targeted research aim Internet data set we selected a time series of updates of Border Gateway Protocol (BGP). BGP data sets are often used when assessing quantitative and qualitative aspects of processes in the core of the internet [10].

As mentioned in this research we aimed to investigate the character of the relationship between variation of geomagnetic ASY-H indices and features of the BGP updates process during the strongest geomagnetic storm. The importance of such research is caused by the fundamental scientific and practical necessity to know the character of the relationship between strong disturbances in the geomagnetic field variation and the BGP update process.

**Methods and used data sets.** As it was mentioned in the previous section, ASY-H indices represent one of the characteristics indicating disturbances of the Earth's magnetic field. ASY-H is essentially changing during geomagnetic storms and like SYM-H is provided at a 1 min temporal resolution. In the present study, we used ASY-H data obtained from ground magnetometers and provided through the WDC Kyoto (http://wdc.kugi.kyoto-u.ac.jp/). As said above we investigated geomagnetic activity during the period involving the so-called Halloween geomagnetic storm, October 29 and 30 in 2003. Namely, we used a time series of ASY-H indices from 15.09.2003 to 30.11.2003.

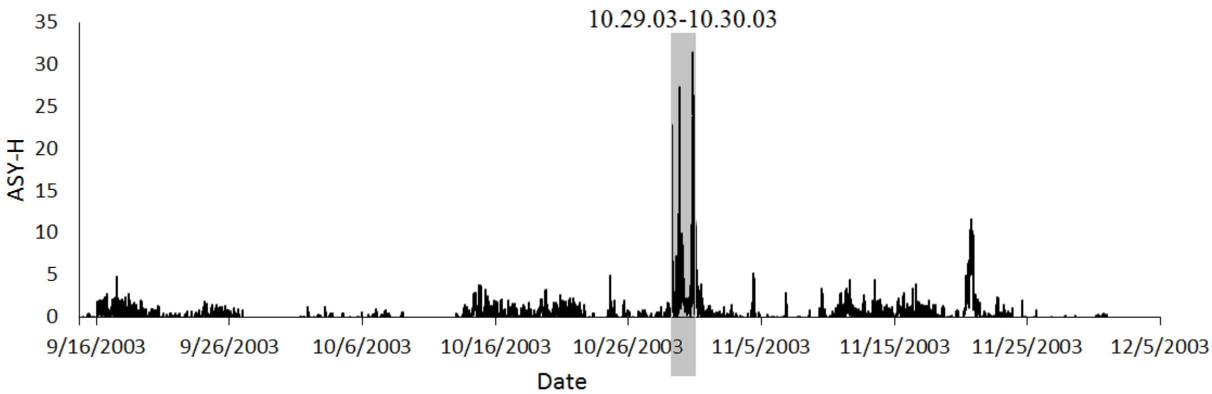


*Fig. 1. Time series of normed to standard deviation ASY-H geomagnetic indices prior and after period of Halloween geomagnetic storm (shown in grey).*

As we said above in the present work we aimed to investigate the possible influence of strong geomagnetic storms on the processes in the core of the Internet. Thus we consider the strongest of last decades geomagnetic storm i.e. Halloween geomagnetic storm occurred on October 29 and 30, 2003.

As for data sets characterizing processes in the core of the Internet we decided to use a time series of updates of the Internet border gateway protocol (BGP). These time series have been obtained from the depositories collected in the frame of the Route Views project (http://www.routeviews.org/) from the BGP routers of four Autonomous Systems (ASes). These ASes are Internet Service and/or Transit Providers AT&T, NTT, IIJ, and Tinet. Exactly, AT&T (American Telephone & Telegraph) is an American multinational telecommunications corporation, NTT (Nippon Telegraph and Telephone) is a Japanese telecommunications company, IIJ (Internet Initiative Japan) is Japan's Internet provider, Tinet (The Tiscali International Network) is an Italian Internet service provider. Used BGP update datasets are publicly available at http://figshare.com/articles/Correlation_in_global_routing_dynamics/1549778.

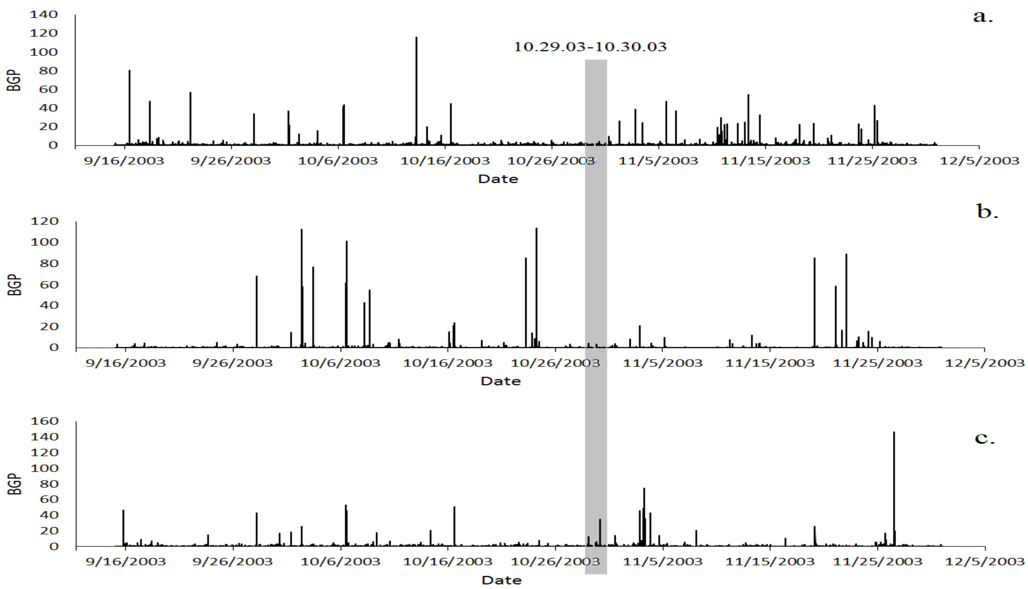


*Fig. 2. Normed to standar deviation time series of the number of BGP updates per minute, prior and after the period of Halloween geomagnetic storm (shown in grey), a) NTT, b) IIJ, c) and d) Tinet, ASes.*

We used the local variation (*Lv*) calculation method, as a regularity metric useful to characterize the extent of randomness in the spiking. The method is especially promising for the spiky time series, like those used in this research ASY-H and BGP updates data sets. *Lv* is defined as:

$$Lv = \frac{3}{n-1}\sum_{i=1}^{n-1}\left(\frac{I_i - I_{i+1}}{I_i + I_{i+1}}\right)^2$$

where $I_i$ and $I_{i+1}$ are *i*-th and *i*+1th BGP updates accordingly and *n* is the number of BGPs. According to the method's background, *Lv* =0 when considered time series is perfectly regular, and *Lv* =1 for random sequences consisting of completely independent events. Further details regarding the *Lv* method can be found in Shinomoto et al.

Next, to compare processes of geomagnetic field variation and dynamics of BGP updates we used Kullback–Leibler divergence (KLD) calculation method. KLD is useful to measure the statistical "distance" between the distributions p and q (H-ASY and BGP updates data accordingly), for a given random variables. KLD is also known as relative entropy, and is defined as:

$$D_{KL} = \sum_{k \in X} p(x)\log_2\frac{p(x)}{q(x)}$$

KLD is a measure based on the relative entropy of two probability density functions built for considered processes here H-ASY and BGP update variation. The Kullback-Leiber Divergence is the symmetric divergence between two classes of compared groups or data sets and represents a measure of the degree of difficulty in discriminating between classes (the larger the divergence, the greater the separability between the classes). In other words, KLD can be used as been used to assess measure of the similarity of dynamics of compared processes. Often KLD value lower than 1 is regarded as an indication that distribution functions of two time series are indistinguishable and thus the character of compared dynamical processes is similar.

**Results and discussion**. As we see in Fig.1, in the previous section, ASY-H values in the period of Halloween geomagnetic storm strongly increase indicating essential quantitative changes in the longitudinally asymmetric part of the geomagnetic field disturbances. Contrary to this in Fig.2, we practically do not see noticeable quantitative changes for the same period of observation in BGP updates time series obtained from all three providers AT&T, NTT, and IIJ.

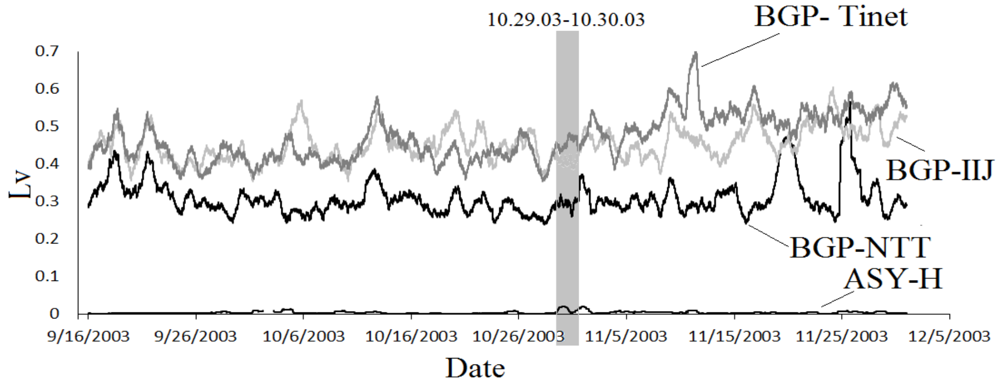


*Fig. 3. Averaged values of Local variation measures calculated for consecutive 1440 data long -windows of IIJ, NTT, Tinet time series shifted by 1 data.*

Moreover, as shown in Fig. 3, according to the results of *Lv* calculation there are no essential changes in the dynamical regularity of processes of BGP updates variation in the period of 29-30 October 2003 strongest Halloween geomagnetic storm. Indeed, as we see in a grey zone in Fig. 3, *Lv* calculation results for BGP data from AT&T, NTT, and IIJ never increase to 1 or fall to 0, remaining in the range of 0.3-0.43. It needs to be especially underscored that ASY-H variation during the period of observation is practically random ($Lv \approx 0$) and also does not indicate changes, excluding the practically negligible rise that happened on 29-30 October.

Thus it can be said that a strong Halloween geomagnetic storm has not caused special disturbance in the dynamics of Internet processes that could be observed in the form of noticeably quantitative or qualitative changes in BGP updates behavior. On the other hand, at a strong Halloween geomagnetic storm, in ASY-H data sets we see only an expected quantitative increase, which is not accompanied by changes in the dynamics of the considered process.

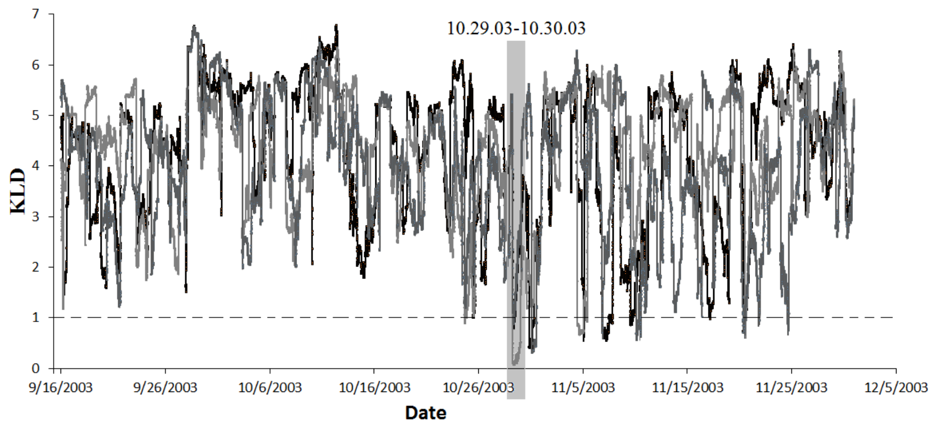


*Fig. 4. KLD values calculated for consecutive 1440 data long -windows of IIJ, NTT, Tinet time series shifted by 1 data.*

After all, said here, it is very interesting to discuss results obtained from the KLD calculation, comparing the extent of similarity between the character of variation of ASY-H and corresponding BGP updates time series. As it follows from Fig. 4, calculated in consecutive sliding windows KLD values for ASY-H and BGP updates never fall below 1 prior to the period of Halloween geomagnetic storm start. As shown by the gray color on 29-30 October 2003,the KLD value for compared data sets became minimal being closer to 0. It is interesting that after the strong event on 29-30 October 2003, a series of storms continued during the next weeks too. So, decreased KLD values after 29-30 October 2003 can be regarded as effects of further influences of still strong but lower than during 29-30 October 2003 influences of the geomagnetic field.

**Conclusion** The relation between variation of ASY-H geomagnetic indices and updates of time series of border gateway protocol was investigated during the Halloween geomagnetic storm in October of 2003. Time series of ASY-H geomagnetic indices were compared with the Internet border gateway protocol data sets from three worlds largest Internet providers. The local variation calculation method as a regularity metric and Kullback–Leibler divergence as a similarity measure have been used. According to our analysis, it was concluded that strong geomagnetic storms do not affect the dynamical regularity of processes of BGP update variation. On the other hand in the period of a strong Halloween geomagnetic storm, the extent of similarity between the character of variation of ASY-H and corresponding BGP updates time series strongly increases.

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