Testing the interactive computer method (IM) for producing K indices with the data of the Hurbanovo and Budkov magnetic observatories

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Abstract

It is generally accepted that the geomagnetic K indices derived by experienced observers are of great value. The interactive method (IM) based on the traditional hand-scaling methodology is tested in this study. The tests are performed utilising the data from the Hurbanovo and Budkov magnetic observatories. These data include both digital records of the geomagnetic field and hand-scaled K indices that had been derived by experienced observers. The authentic K indices from Hurbanovo cover the year 1997 and the same kind of data from Budkov cover the years 1994-1999. In addition to these data, hand-scaled K indices are used which were derived by the experienced observer from printed digital magnetograms for both of the observatories for

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the years 2000-2003. The results of this study indicate that for high values of K indices (the values being at least 5) the tested method follows the traditional hand-scaling better than the widely used computer methods FMI and AS. On the other hand, for the K indices less than 5 the tested method turns out to be the worst when compared with the FMI and AS methods. For very low geomagnetic activity (K-index values equal to 0) the performance of the tested method is comparable to the two computer methods.

Keywords: K index; hand-scaled K index; computer produced K index; geomagnetic activity

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1. Introduction

Long homogeneous series of observations are highly valued by researchers in geophysics and similar observational science. Naturally, this also concerns the observations of the geomagnetic activity. This is so despite the fact that the topic of space weather, where the geomagnetic activity belongs, is often perceived as a matter of the era of space probes. However, long time series can contribute to this modern topic by a great amount. For instance, the space age covers only few solar cycles, but to obtain a reliable general picture of the solar magnetic activity cycles, many of them need to be explored.

This paper deals with the K index, which is a measure of the geomagnetic activity that has been widely used for a long time – for more than seven decades. This index was introduced by Bartels and his co-workers in 1939 (Bartels et al., 1939). According to the rules that they described for producing K indices, the levels of the geomagnetic activity were classed on a scale of 0 to 9. The meaning of the individual values of K indices is explained in

Table 1 (Menvielle et al., 2011). Each K index describes the geomagnetic activity during a three-hour period. Thus there are eight K indices per day, with the first period of a day starting at midnight of Universal Time.

In the beginning, the magnetograms that were used for determination of the K indices were recorded on photographic paper with analogue technology. The procedure for the determination of these indices was hand-scaling. This classical method required elimination of the so-called 'non-K variation' from the magnetograms. This was a demanding task, which could be handled only by skilled and experienced observers – human operators. The guiding instructions for the construction of a smooth non-K variation curve, which were introduced by Bartels et al. (1939), were subsequently stated more precisely in (Bartels, 1957). Codification of these guiding instructions was completed by Mayaud (1967); the instructions have became known as the Mayaud rules.

Later on, in the 1980s, at many magnetic observatories the analogue technology got to be replaced with digital registration stations. The digital magnetic observatories started to produce K indices by means of computer-based methods. At the present time most of the observatories use one of the two methods, Finnish Meteorological Institute method (FMI) of Sucksdorff et al. (1991) or Adaptive Smoothing method (AS) of Nowozynski et al. (1991), that have been endorsed by the IAGA (Menvielle et al., 1995; Bitterly et al., 1997). These methods were approved because of their ability to hold the homogeneity of the long-lasting series of K indices. At most observatories the first part of the K-index series are hand-scaled while the currently produced K indices are computer produced.

In general, the computer-based methods have different usages in geomagnetic observatory practice. For instance, the Kakioka Magnetic Observatory (KAK) only employs the methods for rapid estimation of K indices; for obtaining definitive K indices they use hand scaling (Shingo Nagamachi, personal communication, April 22, 2015; Nagamachi, 2015). It was decided to follow this practice because computer-based K indices have not yet satisfactorily agreed with those that have been hand-scaled for this observatory. There are also magnetic observatories (namely Canberra, CNB, and Gnangara, GNA) that use a computer assisted method to produce their K indices (Hopgood et al., 2004). In our opinion, this method can be viewed as a kind of compromise between hand-scaling and computer producing of K indices.

The methods applied at the above mentioned observatories follow the recommendations of Menvielle et al. (1995). Therein, the authors stated that computer-produced K indices could never be as good as hand-scaled K indices that have been derived by a real specialist.

The conclusion of Menvielle and his co-workers can be summarised in the following way:

1. The most valuable K indices are those that have been hand-scaled by a real expert, that means by an experienced human operator, from analogue magnetograms. These K indices are the authentic K indices[1].
2. K indices produced by one of the endorsed computer methods, FMI

[1]Throughout this paper, the term 'hand-scaled K indices' is used for K indices which were hand-scaled by experienced human operators from either analogue or printed digital magnetograms. The expression 'authentic K indices' is reserved for those hand-scaled K indices that were derived exclusively from analogue magnetograms.

> or AS, could be considered to be less authentic. Nevertheless, these K indices have been approved by IAGA because of the following argument: K indices that are produced by inexperienced human operators differ from the authentic K indices more than do the K indices produced by the endorsed computer methods.

For all that, it is generally accepted that the human operators that are experienced enough in hand-scaling are becoming rarer and rarer at magnetic observatories. On the basis of these facts, the methods FMI and AS have been approved as producing good enough results when compared to hand-scaling performed by experienced human operators.

More recently, the abilities of modern computers likely encouraged several authors to develop some new computer-based methods for producing K indices. An example of such a method is one that utilises wavelet packets (Mandrikova et al., 2012). On the other side, some older methods could be improved (e.g. Acebal, 2000), too. Another attempt to contribute to this trend was made by Valach et al. (2016), who proposed their interactive computer method (IM).

The IM method attempted to simulate the hand-scaling procedure that was in practice by the observers (human operators) at the Hurbanovo Geomagnetic Observatory (HRB). The authors did not have enough reliable HRB data for testing their model. Moreover, the data at their disposal covered just the single year 1997. Unfortunately, the geomagnetic activity was very low that year, thus the higher values of K indices were not presented in the data set.

Therefore, in (Valach et al., 2016) the IM method was tested on the data of a different observatory. Since the Kakioka Magnetic Observatory (KAK) possesses many years of hand-scaled K indices of high quality, the tests of the method were accomplished using their data. What is important here, the digital records of the geomagnetic field are available together with hand-scaled K indices at KAK. The preliminary results which they presented in their study showed that the IM method could be promising for producing indices in two specific ranges of the geomagnetic activity, namely: (1) during very low geomagnetic activity, when K is 0, and (2) during periods when the level of the geomagnetic activity is high, namely when the values of K indices are 5 or more.

The IM method consisted of four steps, which were successively applied to a magnetogram of a day in question. Here, the following feature of the IM method is worthy of mention: The first step involved the use of a non-K variation curve that was determined from the magnetograms of the five most quiet days of the current month. There were two problems connected with this particular step:

- The method introduced some subjectivity because the five most quiet days were selected by a human operator. In doing so, the operator wholly relied on his own experience.
- The method incorporated an "iron-curve" concept for constructing the non-K variation, which is very similar to the concept presented by Rangarajan and Murty (1980). However, in the 1980s many authors (e.g. Menvielle, 1981) disapproved such a concept.

Nevertheless, Valach and his co-authors argued that this kind of subjectivity is indeed also present in the authentic hand-scaled K indices. In addition, the Mayaud rules demand that the non-K variation should always be considered, even if the non-K variation curve can scarcely be identified. The IM method does provide some sort of reasonable curves for those days when the non-K variation cannot be easily made out from the magnetograms recorded during high geomagnetic activity. The authors stated their belief that during the periods of high activity their method thus truly reproduced the practice of human operators.

As mentioned above, Valach et al. (2016) did not have enough data for testing their method on the data of the HRB observatory. Fortunately, it was learned that the Geomagnetic Observatory Budkov (BDV) preserved relatively long series of their authentic K indices that were hand-scaled from analogue records. There is a period of six years of parallel production of hand-scaled and digital-derived indices there. The distance between the HRB and BDV observatories is only 336 km. As such, the two observatories can be assumed to be close to each other so that the results of testing the IM method should be similar for both of them.

Unfortunately, the above mentioned data sets contain no authentic K-index value 9, nor 8. There were also few cases of K-index value 7: two cases for HRB and one case for BDV. For testing the IM method for such high levels of geomagnetic activity, the absent authentic K indices need to be substituted for. These alternative indices can be the K indices which were hand-scaled by experienced observers using magnetograms that were printed from digital data. Riddick and Stuart (1984) found that such indices can be used as a satisfactory equivalent of K indices for most research purposes. Niblett et al. (1984) also investigated the derivation of K indices using magnetograms constructed from digital data. Nevertheless, they revealed that the K indices that were derived from one-minute data tend to be biased downward when compared with those derived from one-second data. Luckily for this paper, Bernard et al. (2011) showed that an overwhelming majority of the cases in which this bias occurred were for low values of K index (K = 0, 1, 2).

Hence the aim of this paper is to test the IM method on the data of the HRB and BDV observatories. The results of the tests are then presented and their interpretation outlined. We believe that the proposed study could be particularly beneficial for treating those sets of K indices that started before the commencement of digital observatories.

2. Methodology

This section briefly describes the IM method, which is tested in this paper. Only the main features of the method are presented here as its full description can be found in (Valach et al., 2016).

The IM method follows four steps, which are called Modules A, B, C and D. In each of the modules specific values of quasi-indices are computed and marked as K_A, K_B, K_C and K_D. They differ about how the non-K variation curve is constructed.

Quasi-index K_A is based on the curve that is computed from the five quietest magnetograms within a month in question. The five quietest magnetograms are selected by the human operator. The magnetograms are then averaged and subsequently fitted with the smooth curve given as a function of time T

$$\sum_{m=1}^{6} A_m \cos(mT + B_m) \tag{1}$$

Here the coefficients A_m and B_m are calculated using the least-square method.

Quasi-indices K_B, K_C and K_D are based on the non-K variation curves that are computed from the magnetogram of the day in question. In computing K_B, the formula (1) is again employed for constructing the curve. In computing K_C, the curve is non-continuous; it consists of straight segments. Finally, quasi-index K_D is obtained with the help of a curve that is constructed by means of cubic splines.

The resulting K indices are obtained from quasi-indices K_A, K_B, K_C and K_D. For this purpose a set of "if–then" rules was arranged. In accordance with these rules, the highest values of the resulting K indices are equal to K_A. Conversely, the lesser values of the resulting K indices match the values K_B or K_C. Furthermore, the lowest value of the resulting K index (i.e., 0) is in some cases due to the zero value of quasi-index K_D.

The above-mentioned sequence of modules A-D is executed independently for two horizontal components of the geomagnetic field. The higher of the obtained K is then considered to be the resultant K index. In this study the north component (X) and the east component (Y) were used.

In this paper, we also used K indices that were computed by the FMI and AS methods. Computer codes for these methods are freely available on the webpage of ISGI[2], which is the International Service of Geomagnetic Indices.

[2] http://isgi.unistra.fr/

3. Data used

In this paper the data from the Hurbanovo (HRB) and Budkov (BDV) observatories were used. Both the observatories are mid-latitude observatories and they are located in Central Europe; in Slovakia and the Czech Republic, respectively. Basic information about them are given in Table 2. The listed information can also be found on the website of ISGI[3,4]; the exceptions from that are the traditionally used K=9 lower limits and the years for which the data were studied here.

For the purpose of this study some periods of time had to be identified for which two kinds of data were simultaneously available: (1) authentic K indices that had been hand-scaled by experienced human operators from analogue magnetograms and (2) digital records of the geomagnetic field.

At HRB such data were found only for the year 1997 whereas at BDV there was much more of such data, from 1994 to 1999. Unfortunately, the year 1997, for which the data of HRB were available, was characterised by rather low geomagnetic activity. Furthermore, even the data of BDV contained no cases of the highest K-index values. Indeed, according to Hathaway (2010) the sunspot cycle minimum for cycle 23 occurred in 1996 and the consequent sunspot cycle maximum did not occur until 2000.

As was mentioned above (Section 1), for the higher levels of geomagnetic activity the IM method can be tested employing alternative hand-scaled K indices that may be derived from printed digital magnetograms. In this paper such indices were derived for years 2000-2003, which involves the 23rd

[3]http://isgi.unistra.fr/observatory.php?obs=HRB
[4]http://isgi.unistra.fr/observatory.php?obs=BDV

maximum of the solar activity cycle as well as the well-known Halloween storm of October 2003.

3.1. Digital records of the geomagnetic field

One-minute values of the geomagnetic field were used. These data are available on the INTERMAGNET (International Real-time Magnetic Observatory Network) webpage[5].

The data from BDV observatory contained sporadic data gaps. All told, 356 days have to be excluded from the analysis due to the gaps. The overwhelming majority (99.2%) of the excluded days appeared in the years 1994-1996. On the other hand, there was not any day dropped out in the case of the HRB data.

Occasionally, some short data gaps occurred in the registrations of the geomagnetic field. In the cases when only several data were missed, the missing values were interpolated manually by the human operator. The K indices were then calculated and involved in analysis. However, if the gaps lasted a longer time, typically from 20 to 40 minutes, the records were treated as defective. The operator still filled the gaps with interpolated values, but this time the K indices from the corrupted periods and their surroundings were excluded from analysis. The amount of K indices to be excluded from the analysis was decided by the human operator.

3.2. Authentic K indices

As mentioned above, together with digital records of the geomagnetic field the series of the authentic K indices needed to be available for the purpose

[5]http://www.intermagnet.org/

of this study. During the periods listed in Table 2, the K indices were hand-scaled by human operators from records that were made on photographic paper. These human operators were long-standing members of the observatories considered in this study, HRB and BDV. The K indices produced by them are considered to be authentic throughout this paper. In that way, a computer program for producing K indices is working properly if its outputs accord with these authentic indices.

Regarding the traditional hand-scaling, there is an issue that may seem as inconsistency, namely the two different values of K=9 lower limits for each of the observatories, as shown in Table 2. The traditional values of the K=9 lower limits are those that observatories HRB and BDV have used for hand-scaling K indices since the very beginning of producing the indices. These values were likely determined by the members of the observatories. For this purpose they probably compared the statistical distributions of the K indices at their observatories with the statistical distribution of the indices produced by the Niemegk Observatory (NGK). As far as we know, the HRB and BDV observatories have never used other K=9 lower limits than those traditional ones. This paper uses the traditional limits, which is done for the sake of keeping the series of K indices homogeneous.

In order to minimise the inconsistency that was noted above, the uses of the traditional and corrected K=9 lower limits have to be specified in more detail. On the one hand, the traditional limits should be used when studying a long-continuing series of K indices for an isolated magnetic observatory. Thus the levels of the geomagnetic activity can be compared even if part of the studied period belongs to the digital era while another part belongs to the analogue era. On the other hand, if the digital-era K indices from HRB or BDV need to be compared with the indices of other observatories, the situation might be different. This time the corrected K=9 lower limits should probably be the better choice.

3.3. Additional hand-scaled K indices for the years 2000-2003

For the years 2000-2003 the hand-scaled K indices were derived from printed digital magnetograms, for which one-minute digital values of the geomagnetic field were used. This was accomplished for both of the HRB and BDV observatories by an experienced observer. This observer was one of those who hand-scaled also the authentic K indices for HRB in the past. This part of the paper is limited to only K-index values 7, 8 and 9. The main reason for this limitation is the downward biasing of K values estimations when using one-minute data, instead of one-second data to compute K index (Bernard et al., 2011), which indicates that similar biasing might exist when using one-minute data instead of analogue magnetograms. The records of the geomagnetic field that were used here are available on the INTERMAGNET webpage (see Section 3.2).

The comparison of the K-index values that were derived by the four methods (hand-scaled, IM, FMI and AS) is presented in the following section.

4. Results

In this section the hand-scaled K indices of HRB and BDV are compared with the K indices that were produced by methods IM, FMI and AS. Hereafter, in all the following text and figures, the items are grouped according to the values of the hand-scaled K indices. This is because they are considered to be the reference values throughout this paper.

4.1. The results of the tests for HRB

Performance of the three computer methods for HRB is compared in Figure 1. The comparison is based on the differences between the computer produced K indices and the hand-scaled ones. The performance appeared to be to some extent dependent on the level of the geomagnetic activity. This was observed for all of the tested methods, FMI, AS as well as IM. Regarding the IM method, it may be considered successful in some ranges of the geomagnetic activity. There are some other ranges, however, where the IM method after comparing with the FMI or AS methods does not seem to be successful.

For the level of the geomagnetic activity when the authentic K index is 0, none of the computer methods seemed to be more advantageous than the others:

- The results of the IM and AS methods were pretty alike at this level of the geomagnetic activity.

- By contrast, the results of the FMI method for $K = 0$ noticeably differed from the results of the IM and AS methods. On the one hand, the proportion of accurately determined cases of $K = 0$ were much less for the FMI method than for the other methods. Along with that, there were many cases of overvalued indices. That means the cases when the FMI method produced $K = 1$ while the authentic index was 0. On the other hand, the merit of the FMI method appears to be that this method provided value 0 instead of authentic 1 less frequently than the other methods. Indeed, this happened to FMI in only 8% of cases in which the authentic K indices were 1. On comparison, the percentages of this kind of imprecision for the IM and AS methods were as high as 27% and 22%, respectively.

For the authentic K indices that ranged from 1 to 4, the IM method provided disappointing results. Here its performance proved to be visibly worse than the performance of the FMI and AS methods.

The strong point of the IM method seems to be its performance in the range of authentic indices that are greater than or equal to 5. In this range of the geomagnetic activity our tests found the following facts:

- The first fact was for authentic K indices 5 and 6. Here the indices produced with the IM method matched the authentic indices better than those produced with the FMI and AS methods.

- The set of hand-scaled K indices which were higher than 6 globally indicated the better performance of the IM method in comparison with the performances of the FMI and AS methods: Though for the K-index value 7 the IM method results are similar to the results of the FMI method, they appeared to be better than the results of the AS method. For the K-index values 8 and 9 the IM method showed to be more successful than both of the methods FMI and AS.

4.2. The results of the tests for BDV

In this section the results of the tests of the performance of the IM, FMI and AS methods are interpreted once again. However, this time the tests utilised the data from the BDV observatory. The striking feature of these results (Figure 2) is that their interpretation is virtually identical with the interpretation obtained for the HRB data:

- For the geomagnetic activity when the authentic K index is 0 each of the methods showed some weak points as well as strong points. None of the methods proved to be the most advantageous in general.
- For the geomagnetic activity characterised by authentic K indices from 1 to 4 the IM method did not show a good performance. Here the results of this method were obviously worse than the results of the other computer methods.
- The range of authentic indices that are greater than or equal to 5 once again appeared to be the strong point of the IM method. Here our tests revealed the following facts:
  - For authentic K indices 5 and 6, the indices produced with the IM method matched the authentic indices better than those produced with the FMI and AS methods.
  - The set of the hand-scaled K indices which were higher than 6 globally indicated satisfactory performance of the IM method: For the K-index value 7 the IM method results were exactly the same as the results of the FMI and AS methods For the K-index value 8 the results of the IM method were the same as those from the FMI method and they were better than the results of the AS method. By contrast, for the K-index value 9 the results of the IM method

were the same as provided by the AS method and they were better than the results of the FMI method.

5. Discussion

The previous section presented analysis of the differences between the K indices produced with the IM, FMI and AS methods and the authentic K indices. It was found that the analyses for HRB and BDV led practically to the same interpretations. The IM method appeared to provide favourable results for the geomagnetic activity with K indices being at least 5. This fully agrees with the findings that for the IM method reported Valach et al. (2016); when the analysis was accomplished on the data from Kakioka (KAK).

The computer methods were subsequently tested for some specific periods. For instance, the data from BDV involved the period of a sunspot cycle minimum in the year 1996. The BDV data set also included data from the year 1999, which was close to a sunspot cycle maximum. Therefore, the data from 1996 and 1999 were analysed separately. Figure 3 presents the results of this analysis restricted to authentic K indices 5 and 6. These are the K-index values for which the IM method showed to yield much more satisfactory results than methods FMI and AS.

Comparing the results from 1996 with those from 1999 the following findings were revealed: The computer-based methods matched the authentic K indices of value 6 better during the period of the sunspot cycle minimum than they did during the maximum. This result was not surprising as the smooth non-K variation curve could obviously be more easily constructed during quiet geomagnetic conditions. Unexpectedly, however, no significant difference between performance in the minimum and maximum was found for the K-index value 5.

Seasonal dependence in performance of the three methods, FMI, AS and IM, was investigated too. Here the data of the months of equinoxes and solstices were analysed separately for both HRB and BDV, yet no distinct variation was revealed (data not shown).

6. Conclusions

The interactive computer method (IM) for producing K indices published in (Valach et al., 2016) was tested. The data from the Hurbanovo (HRB) and Budkov (BDV) magnetic observatories were utilised for this purpose.

In the tests the IM method satisfactorily approximated the authentic hand-scaled K indices only in the cases when authentic K indices were at least 5. In that range of the geomagnetic activity the IM method performed better than did the endorsed FMI and AS methods.

In these tests, the values 350 nT and 500 nT were adopted as the K=9 lower limits for the HRB and BDV observatories, respectively. These values have been used for the hand-scaling of K indices since the indices started to be produced by the two observatories; it was indeed a long time before the digital era. This means that the combined method that is proposed here should be employed for producing K indices that might assure the homogeneity of the long-lasting series of K indices. The homogeneous series represents important material for studying how the local geomagnetic activity changed at a particular observatory in the past.

This study showed that the IM method still needs to be improved. The process of creating the non-K variation curve for K = 1, 2, 3 and 4 turned out to be imperfect. Possibly the strictly arranged "if–then" rules need to be brought closer to the human decision-taking process, which tries to be imitated in the IM method. It might be achieved by the use of fuzzy logic or artificial neural networks. Employing of such sophisticated and complex concepts should be investigated in future work.

Acknowledgements

This work was supported in part by VEGA Grants no. 2/0030/14 and no. 2/0115/16 of the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences, by the Slovak Research and Development Agency under the Contract no. APVV-0662-12, and by the grant of the Ministry of Education, Youth and Sport of the Czech Republic no. LM2015079. We also thank the ISGI-International Service of Geomagnetic Indices for producing K=9 lower limits for magnetic observatories.

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Table 1: The meaning of the individual values of K indices described verbally (according to Menvielle et al., 2011).

K indices	Verbally described level of activity
0, 1, 2	Quiet geomagnetic field
3, 4, 5	Moderate geomagnetic activity
6, 7, 8, 9	Intense / very intense activity

Table 2: Basic information about the magnetic observatories whose data were used in this paper.

Observatory Name	Hurbanovo	Budkov
IAGA Code	HRB	BDV
Period (years) for which the authentic K indices were studied	1997	1994-1999
Period with K indices 7, 8 and 9 hand-scaled from digital data	2000-2003	2000-2003
Geographical coordinates:		
Latitude	47.874°N	49.065°N
Longitude	18.188°E	14.017°E
Geomagnetic coordinates:		
Latitude	46.67°N	48.53°N
Longitude	101.18°E	97.65°E
K=9 lower limit:		
Traditionally used	350 nT	500 nT
Corrected according to ISGI	420 nT	443 nT

Figure 1: Differences between computer produced K indices and hand-scaled K indices for the Hurbanovo Geomagnetic Observatory (HRB). Here the computer methods are (a) IM, (b) FMI and (c) AS. The items are grouped according to the values of the hand-scaled K indices. The amounts of the differences are coded with a grey scale. The legend "Diff.< -1" means the difference that is equal to -2. There is only one exception from that; in one case the IM method provided K index 1 while the authentic index was 4. The numbers that are written above the columns give the total number of analysed events for the particular hand-scaled K indices.

Figure 2: Differences between computer produced K indices and hand-scaled K indices for the Budkov Geomagnetic Observatory (BDV). Here the computer methods are (a) IM, (b) FMI and (c) AS. The items are grouped according to the values of the hand-scaled K indices. The amounts of the differences are coded with a grey scale. The numbers that are written above the columns give the total number of analysed events for the particular hand-scaled K indices.

Figure 3: Differences between the K indices produced by computer methods and the authentic K indices for the BDV observatory. The computer methods are IM, FMI and AS. The differences for the years 1996 (sunspot cycle minimum) and 1999 (next to sunspot cycle maximum) are shown. Only the events when the authentic K indices were 5 or 6 are displayed. The amounts of the differences are coded with a grey scale. The numbers that are written above the columns give the total number of analysed events for the particular authentic K indices. The numbers in parentheses refer to the numbers of cases when the computer produced index was 5 while the authentic index was 4. The legend "Diff.< 0" means the difference is equal to -1. There is only one exception from that; in one case the IM method provided K index 3 while the authentic index was 5.

Figure 1

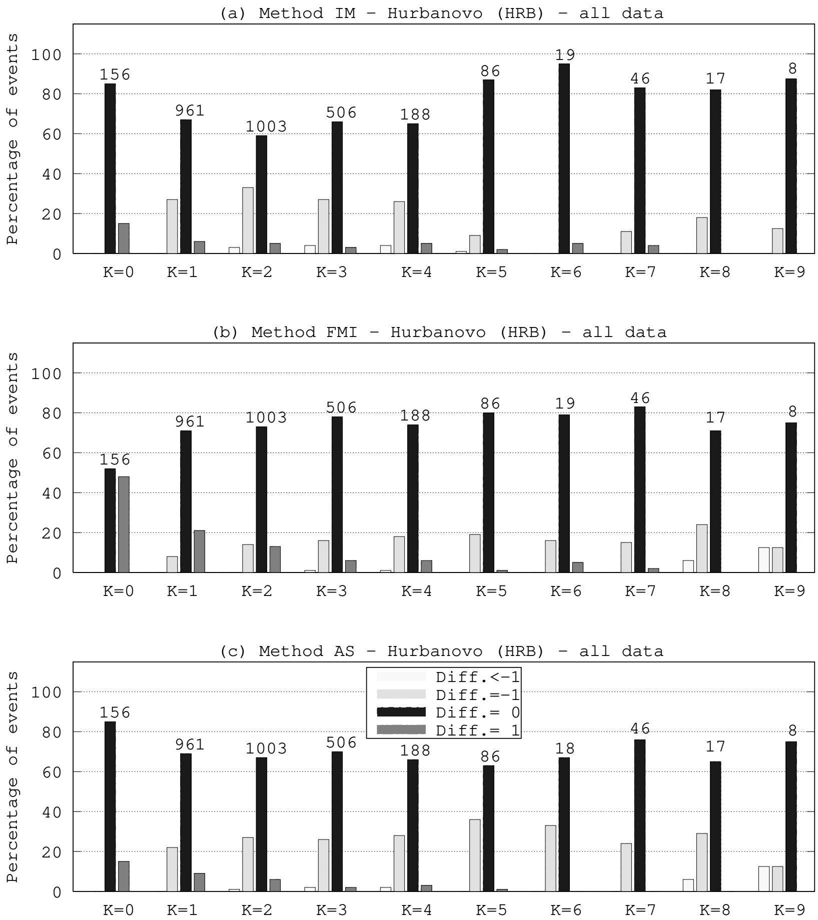
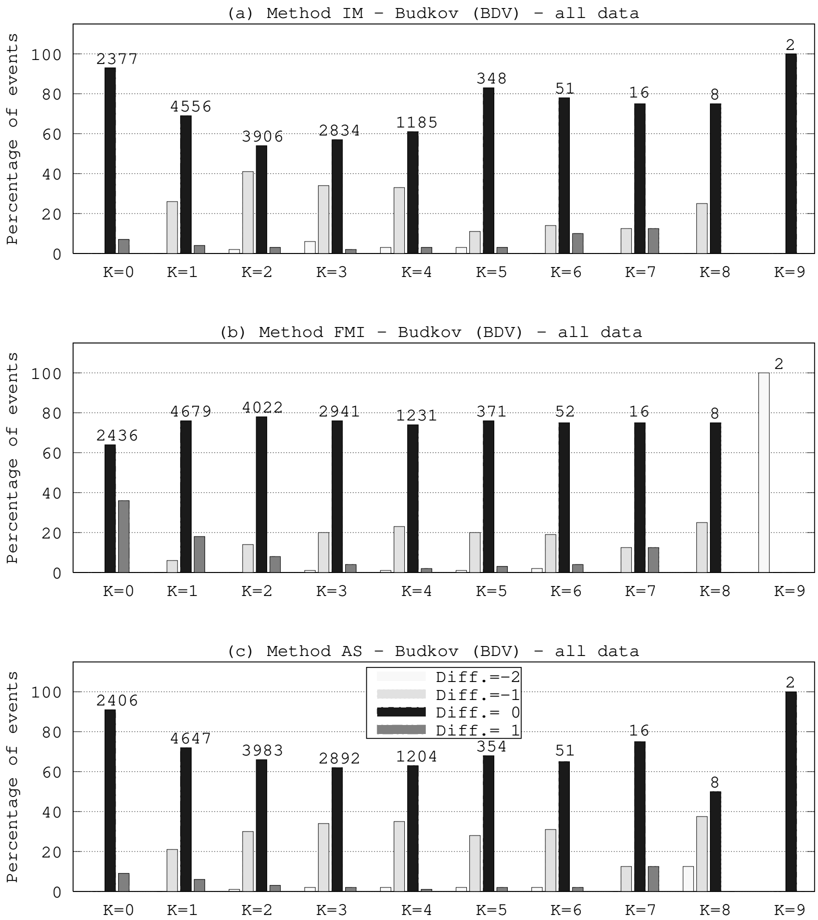
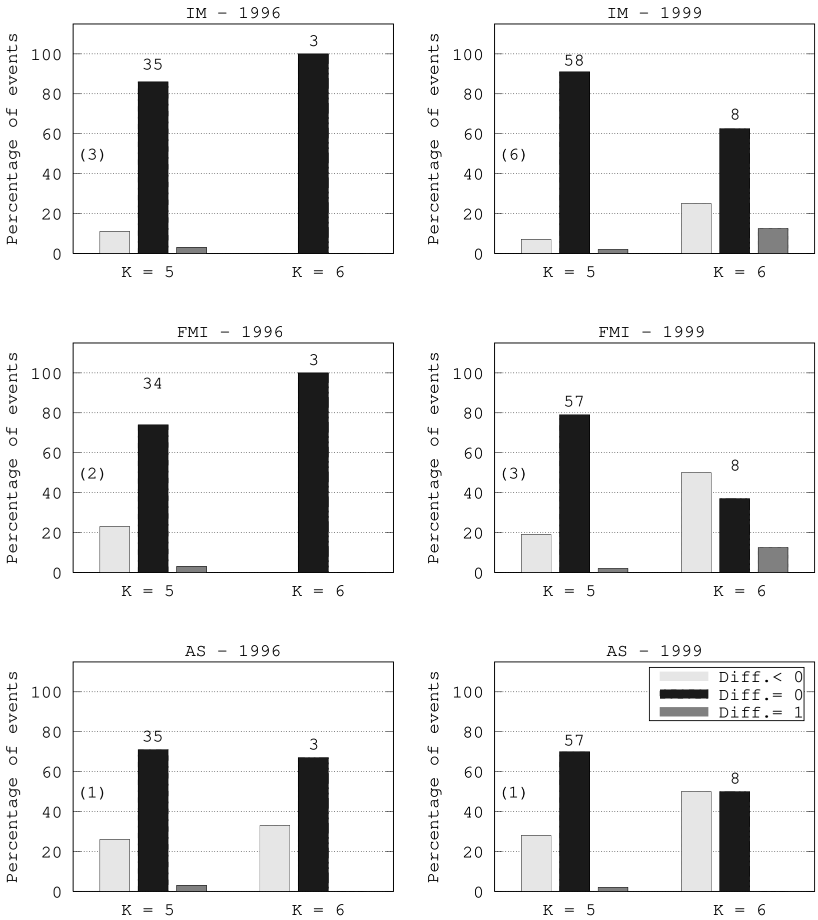

(a) Method IM - Hurbanovo (HRB) - all data
Percentage of events
156
961
1003
506
188
86
19
46
17
8
K=0
K=1
K=2
K=3
K=4
K=5
K=6
K=7
K=8
K=9
(b) Method FMI - Hurbanovo (HRB) - all data
Percentage of events
156
961
1003
506
188
86
19
46
17
8
(c) Method AS - Hurbanovo (HRB) - all data
Percentage of events
Diff.<-1
Diff.=-1
Diff.= 0
Diff.= 1
156
961
1003
506
188
86
18
46
17
8

Figure 2



(a) Method IM - Budkov (BDV) - all data
Percentage of events
0
20
40
60
80
100
2377
4556
3906
2834
1185
348
51
16
8
2
K=0
K=1
K=2
K=3
K=4
K=5
K=6
K=7
K=8
K=9
(b) Method FMI - Budkov (BDV) - all data
Percentage of events
2436
4679
4022
2941
1231
371
52
16
8
2
(c) Method AS - Budkov (BDV) - all data
Percentage of events
Diff.=-2
Diff.=-1
Diff.= 0
Diff.= 1
2406
4647
3983
2892
1204
354
51
16
8
2

Figure 3



This is the author's version of a manuscript that was accepted for publication in Journal of Atmospheric and Solar-Terrestrial Physics. The definitive version was subsequently published in:
F. Valach, P. Hejda, M. Revallo, J. Bochníček, M. Váczyová: Testing the interactive computer method (IM) for producing K indices with the data of the Hurbanovo and Budkov magnetic observatories. *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume: 147, Pages: 90–97, 2016. doi:10.1016/j.jastp.2016.07.010