Producing K indices by the interactive method based on the traditional hand-scaling methodology – preliminary results

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Abstract

This paper reports on an interactive computer method for producing K indices. The method is based on the traditional hand-scaling methodology that had been practised at Hurbanovo Geomagnetic Observatory till the end of 1997. Here, the performance of the method was tested on the data of the Kakioka Magnetic Observatory. We have found that in some ranges of the K-index values our method might be a beneficial supplement to the computer-based methods approved and endorsed by IAGA. This result was achieved for both very low (K=0) and high (K≥5) levels of the geomagnetic activity. The method incorporated an interactive procedure of selecting quiet days by a human operator (observer). This introduces a certain amount of subjectivity, similarly as the traditional hand-scaling method.

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

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geomagnetic activity

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1. Introduction

Space weather nowadays is a very challenging research topic. The interest of the scientific community in space weather has grown along with increasing vulnerability of sensitive technological systems, which modern society has built both on the Earth's surface and in the Earth's space environment. For instance, respect for space weather is vital when dealing with safety of astronauts and equipment aboard spaceships (e.g. Valdés et al., 2012).

Much of manifestation of space weather can be observed in the Earth's geomagnetic field by ground-based magnetic observatories. The manifestation of geomagnetic activity is called geoeffectivity. It can be quantified. The most famous concept for the quantification of the geomagnetic activity was surely introduced by Bartels et al. (1939). They sorted the magnetic disturbances into a ten-degree scale. This scale is a logarithmic one. Thus the geomagnetic indices are expressed in K units. A generally accepted verbal designation for grading the geomagnetic activity makes some sense of the meaning of the K indices: If K is 0, 1 or 2, then the geomagnetic field is quiet. Values 3, 4 and 5 stand for moderate geomagnetic activity. Finally, intense to very intense activity is marked with 6–9 (Menvielle et al., 2011).

Since that time, many magnetic observatories at mid-latitudes have produced the K indices. At the beginning, the K indices were produced according to relatively loosely formulated rules given by Bartels et al. (1939) and Bartels (1957). Later, in 1967, Mayaud put together more rigorous instructions, according to which K indices had to be produced (Mayaud, 1967). The new rules concerned the estimation of the so-called non-K variations in the geomagnetic field, which had to be omitted when the K indices were produced. They are well-known as the so-called Mayaud rules.

The K indices describe the local geomagnetic activity that is related to the localities of each individual magnetic observatory. Combining the K indices from different observatories, some planetary or hemispheric geomagnetic indices can be derived. The most widely used K-derived geomagnetic index is Kp[1], and some other planetary indices are am (hemispheric counterparts: an, as) and aa, their corresponding indices in K units being respectively Kpm and Kpa (Menvielle and Berthelier, 1991; Menvielle et al., 1995).

For about a half of a century, the K indices were hand-scaled from analogue magnetograms following the Mayaud rules. However, in the 1980s and 1990s many observatories replaced the old analogue magnetograms by digital recordings of the geomagnetic field. This change in equipment demanded the reappraisal of the procedure in that the K indices were produced (e.g. Hopgood, 1986).

The series of the K indices that were gathered during the first 50 years were considered very valuable. Therefore, the new situation had to be so resolved that the K-index series of long duration held their homogenity. The IAGA Working Group 'V-DAT: Geomagnetic Data and Indices' agreed on testing the algorithms that had been designed for the production of K indices by computer (Menvielle et al., 1995; Bitterly et al., 1997).

There were two important questions that had to be answered by these

[1]http://www.gfz-potsdam.de/en/section/earths-magnetic-field/services/kp-index/

tests: Should the IAGA Working Group V-DAT insist on hand-scaling the K indices or should some computer code be recommended for usage? If a computer code can be recommended, which one should be selected?

The testing was carried out by Menvielle et al. (1995). In their extensive study, hand-scaled K indices were compared with the computer produced K indices. Four computer algorithms for producing K indices had been available at that date: Finnish Meteorological Institute (FMI) method (Sucksdorff et al., 1991), Adaptive Smoothing (AS) method (Nowozynski et al., 1991), US Geological Survey (USGS) method (Wilson, 1987), and linear-phase robust non-linear smoothing (LRNS) method (Hattingh et al., 1989). Menvielle et al. showed that only two of the methods (FMI and AS) provided K indices that fitted well with hand-scaled K indices. Subsequently, Bitterly et al. (1997) confirmed the results of Menvielle et al. for the FMI method with more extensive data sets.

Here we cite the key idea from the conclusions of Menvielle et al. (1995), which is of great importance: "One cannot expect to obtain computer-derived K indices that are as good as those hand-scaled by a real specialist. However, such specialists are becoming more and more scarce [...], which means that some computer methods may follow the Mayaud rules better than the observers do at many observatories."

In addition to the above mentioned conclusion, Menvielle and his co-workers designated the FMI method to be the best computer method for producing K indices. They stated that this method seemed to be "good enough for the continuation of the long tradition of producing K indices" (Menvielle et al., 1995). However, they noted that some biases exist even between the two best computer methods. It is consistent with Zain et al. (2013), who compared the statistical distributions of K indices that were produced by both the FMI and AS methods. They found that the FMI algorithm produced slightly higher K indices than did the AS algorithm.

In the years that followed the comparison of Menvielle et al., some new methods for producing K indices were presented or some old methods were improved. A few examples were as follows: Acebal (2000) examined an updated version of the USGS code; in his tests the new USGS program fitted the hand-scaled K indices better than the older code of Wilson. Mandrikova et al. (2012) proposed a new method based on wavelet packets. Australian magnetic observatories Canberra and Gnangara have used a computer assisted method since December 2002 (Hopgood et al., 2004). Their method partly incorporated the LRNS smoothing algorithm of Hattingh et al. (1989).

Despite the development of the new methods, the FMI and AS algorithms have remained the most widespread methods for producing K indices. In addition, some observatories continue with hand-scaling, and they apply a computer-based method to only rapid estimation; such an approach is used at Kakioka Magnetic Observatory (Nagamachi, 2015, Shingo Nagamachi, personal communication, April 22, 2015).

Using only few selected algorithms may have, however, an unlooked-for disadvantage. Menvielle et al. (1995) emphasised that while bias could be statistically averaged out in hand-scaled indices (Mayaud and Menvielle, 1980), this was no more possible when the indices were produced by a few codes.

All in all, it therefore seems that using a variety of algorithms that emulate the older hand-scaling method might be beneficial. It is commonly widely known and formally accepted that the "genetically different codes and algorithms" to derive K indices allow a better definition of planetary indices. The dubious K indices of one particular magnetic observatory are counterbalanced by the other K indices of nearby magnetic observatories during the procedure of K-derived planetary or hemispheric geomagnetic indices.

It must be explained that the main challenge in computing K indices has still remained to be the estimation of the non-K variations. This challenge, which Bartels et al. (1939), Bartels (1957) and Mayaud (1967) sought to solve for hand-scaling purposes, has not been automatically solved by the arrival of computers. Bartels et al. (1939) defined it as "a smooth curve to be expected for that element on the magnetically quiet day, according to the season, the sunspot cycle and, in some cases, the phase of the Moon." With respect to the method of estimation of the non-K variations, Hopgood (1986) distinguished between two categories of algorithms: (1) those that construct the non-K variation as a mean curve from quiet magnetograms of selected nearby days, and (2) those that construct the non-K variation from the magnetogram of the current day; in this case the high-frequency variations with periods beneath 4–6 hours are eliminated from the curve. The above mentioned two categories may also be combined.

An example of the category (1) algorithm is the method described by Rangarajan and Murty (1980). They constructed the non-K variation in a two-step procedure: First they computed a mean diurnal variation from a selection of quiet days in the current month. Then they combined the first six harmonics, which they obtained from the harmonic analysis, to create their non-K variation. Since there was a subjectivity in the process of selecting quiet days, this algorithm was not accepted. Moreover, the method was also classified as a reversion to the "iron-curve" method, which was introduced by Bartels in 1957 (Menvielle, 1981).

Hopgood favoured the algorithms of category (2), because he believed that these algorithms were promising as they could suppress the subjectivity that may occur when selecting quiet days. Both of the widely used present-day methods, FMI and AS, represent this category.

The purpose of this study is to describe and examine our semi-automatic method for producing K indices. Our method is based on the hand-scaling methodology that had been practised at Hurbanovo Geomagnetic Observatory, Slovakia, Central Europe, till the end of 1997. We compared its performance with the FMI and AS methods, as well as with hand-scaled K indices. We intend the method to be usable for Hurbanovo, which is a subauroral observatory. Nevertheless, we tested the performance of our method on the data of the Kakioka Magnetic Observatory, Japan, whose geomagnetic latitude is 26.9°N (Report of The Kakioka Magnetic Observatory, 1998). The reason for selecting this observatory was that for Kakioka the authentic hand-scaled K indices are available together with digital records of the geomagnetic field. These data are available for long periods, which enabled us to examine different parts of the solar magnetic activity cycle.

2. Methodology

This section consists of two parts: In the first part, we describe the hand-scaling method that had been used for producing K indices at the Hurbanovo Geomagnetic Observatory till the end of 1997. The core of this section is its second part, where the implementation of the hand-scaling method by computer is described. Here the method was realized as an interactive algorithm.

2.1. Hand-scaling at the Hurbanovo Observatory

In general, hand-scaling K indices involves two consecutive procedures. First, the non-K variation has to be determined somehow. This is the difficult procedure, for which Bartels and Mayaud developed their rules (see Section 1). This procedure has to be done with the magnetograms of two horizontal components (H and D, or X and Y).

The second procedure is then straightforward. It starts with the subtraction of the non-K variation from the real magnetogram. Having the magnetogram rid of the non-K variation, the differences between the largest and smallest values are taken for every three-hour period of the current day (i.e. 0 h – 3h, 3 h – 6 h, . . . , 21 h – 24 h, according to universal time). These differences are compared with a quasi-logarithmic scale given in Table 1. Each individual magnetic observatory has its own specific scale[2]; for example, K9 lower limit for Hurbanovo is 420 nT, while this limit for Kakioka is 296 nT[3]. Like the previous procedure, this one is also executed for the two horizontal components; the higher of the obtained K is then designated the resultant K index.

Operators at different observatories were often trained for producing K indices in different ways (Love, 2011). This is why the description of the hand-scaling process at Hurbanovo Observatory needs to be presented here in

[2] http://isgi.unistra.fr, the International Service of Geomagnetic Indices

[3] In this study we use this value rounded to 300 nT, which is standard practice.

more deatail. In the further description we confine ourselves to the procedure of determining the non-K variation, which is not straightforward.

As we learned, the operator in charge at Hurbanovo had implemented the Mayaud rules in the way that can be described with the help of three modules. Here we named these Modules A, B and C:

- Module A: This was the first module, in which the sought non-K variation was identified with the Sq variation. It should be noted that the Sq variation is not the only phenomenon that would be identified and it is generally not satisfactory to identify the sought non-K variation with Sq variation. This is why the Module A had to be followed by additional modules. Estimating the Sq curve consisted of two steps:
  - Firstly, the operator saw over the magnetograms of the current month and chose five days considered to be most resembling the quiet diurnal variation.
  - These five selected magnetograms were then used for constructing an ersatz Sq curve: Every individual hour, the average value of the geomagnetic component (H or D) was plotted to a graph. Lastly, the Sq curve was drawn by hand.
- Module B: When the current magnetogram strongly resembled the Sq curve, the operator in charge did not use the Sq curve from Module A for producing K indices. Instead, the operator drew the expected quiet curve on the base of the magnetogram of this current day. Like the curve in Module A, this curve was also drawn by hand. The same procedure could be executed for a part of a day, provided only a part

of the day was assumed to be resembling the Sq variation. The cases when the Module B were used occurred when the resulting K indices were typically K≤4. In these cases, the magnetogram, or its part, does not display any noticeable manifestation of a magnetic storm or a bay.

- Module C: For the quiet geomagnetic field and sometimes also when the geomagnetic activity was moderate (K≤4) occasionally happened that the quiet curve within the three-hour period was virtually a straight line. For drawing this part of the curve the operator in charge could use a ruler.

The following subsection describes how the essential features of the above-mentioned method for producing K indices were adapted for computer. Of course, we were not able to follow the original method in detail. There were two aspects in particular that were difficult to be imitated by computer: (1) drawing the curve by hand and (2) deciding whether the current magnetogram resembles the Sq variation. Hence we have to admit that we were not able to avoid introducing some subjectivity into our method.

2.2. Computer simulation of the hand-scaling method

The main part of this subsection is devoted to computer simulation of obtaining the non-K variation for a particular day. Here the Modules A, B and C, which were described above, are modified for using on computer. An additional procedure, Module D, is also introduced, which we needed to put here in order to compensate for our inability to fully emulate by-hand drawing. Moreover, some "if-then" rules are brought here, which are designed to help with the decision of whether the current magnetogram resembled the expected Sq variation.

The presented method is an interactive computer algorithm. It has to be separately used for the magnetograms of the two horizontal components (X and Y, or H and D); however, for each of the horizontal components the same K-value range is used. The modules were designed as follows:

- Module A: This was an interactive part of the method. The expected Sq variation was estimated by it. It should be stressed yet again that the Sq variation is not the only phenomenon that would be identified and the Module A must be followed by additional modules. The individual steps of this module are listed below:
  - Firstly, the authors (as if trained operators) saw over the magnetograms of the month in question and they chose five days that they considered to be most resembling the quiet diurnal variation. The traditional routine was that the K indices were determined after the end of the given month. In our simulation we adopted this routine though it was obvious that such an approach was not suitable for now-casting purposes. Indeed, this approach could be applied only to preparing K indices for "after the fact" studies of space weather events.
  - The selected five magnetograms were then averaged; the average value was calculated for each individual one-minute value.
  - Finally, the average magnetogram was fitted with the curve Sq(T)

given by

$$Sq(T) = \sum_{m=1}^{6} A_m \cos(mT + \alpha_m) \quad (1)$$

where T stands for time (i.e. the number of one-minute value in the series – it is a dimensionless number) and the amplitudes A_m and phases α_m were found by least-square method.

- Module B: In this module the quiet curve was also obtained by means of the least-square method. However, in this case the fitted curve, which was again given by Equation (1), was computed from the magnetogram of the current day. Furthermore, linear trend between 0 UT and 24 UT had been removed from the magnetogram before the least-square method was applied. After the values A_m and α_m were computed, the linear trend was given back to the Sq(T) curve.[4]

- Module C: In this case, the "quiet curve" was a discontinuous curve that was composed of eight straight segments. Here the discontinuous curve means that there can even be offsets between segments. For each of the three-hour periods the straight line was found through the use of linear least-square method.

- Module D: Introducing this module reflected our practical experience gained by fitting curves to magnetograms, especially when the magne-

[4] This procedure with the linear trend was not executed in Module A. It was so because the differences between the 0 UT and 24 UT values were found to be very small there. They were much smaller than the deviations between the five values of the five original most quiet magnetograms at 0 UT or 24 UT. In Module A, the linear trend was thus considered to be negligible.

tograms represented quiet periods. The curve that put together cosines in Module B sometimes seemed to be a little bumpy in the parts of magnetogram that we expected to be relatively plain. On the other hand, the straight lines produced in Module C were often much more plain than we wished to have. In Module D, smoothing was used rather than fitting. Here this procedure is described in detail:

- For every hour on the hour, the momentary value of the horizontal geomagnetic component was calculated averaging the five closest one-minute values. The time series consisting of 25 values (0 UT, 1 UT, 2 UT, ..., 24 UT) was prepared in this step, which was then used in the following step.
- In the following step, cubic spline interpolation was used to obtain the smooth Sq curve.

In principle, the Module A in our method did the same as did the method of Rangarajan and Murty (1980) — the method which was refused by Menvielle (1981)) (see Section 1). Here, however, we only use this criticized method for the production of K indices for the periods with high geomagnetic activity. Because the Mayaud rules always demanded to present a non-K variation, we believe that the "iron curve" method should handle those days for which the non-K variation could hardly be identified.

The non-K variations that resulted from Modules A, B, C and D were then used for producing special versions of K indices. These K indices were correspondingly designated by subscripts: K_A, K_B, K_C and K_D. The straightforward procedure that is described in Section 2.1 was used for this purpose.

The resulting values of K indices were eventually obtained from some "if-then" rules. These rules were carefully arranged in order to obtain reasonable statistical distribution of the resulting K indices. They were set up as follows:

- In the first step the K index was defined to be equal to K_A.
- In the second step the K index was modified according to the values of K_B and K_C:
  - If $K_A = 5$ along with $[(K_B < 5$ and $K_C < 4)$ or $(K_C < 5$ and $K_B < 4)]$, then the higher of K_B and K_C became the new value of K index.
  - If $(K_A = 3$ or $K_A = 4)$ and at the same time $(K_B < 4$ and $K_C < 4)$, then the lower of K_B and K_C became the new value of K index.
  - If $K_A = 2$ and at the same time $(K_B \leq 2$ and $K_C \leq 2)$, then the lower of K_B and K_C became the new value of K index.
  - If $K_A = 1$ and at the same time $(K_B \leq 1$ and $K_C \leq 1)$, then the lower of K_B and K_C became the new value of K index.
- In the third step the value of K index was "softened" according to K_D:
  - If the hitherto produced K index was 2 and at the same time $K_D < 2$, then K_D became the new value of K index.
  - If the hitherto produced K index was 1 and at the same time $K_D = 0$, then the new value of K index was 0.

To assess performance of our interactive computer method, tests were performed. The data that were used for this testing are described in the following section.

3. Data used

The hand-scaled K indices and one-minute digital records of the geomagnetic field that were observed at the Kakioka Magnetic Observatory were used in this study. The data covered the following periods:

- year 2003, which was a period characterized by a pronounced maximum of the geomagnetic activity,
- year 2005; during which the geomagnetic activity was at a medium level,
- year 2009; which was the period of very low geomagnetic activity.

These data were taken from the website of the Kakioka Magnetic Observatory[5] and from the web page of INTERMAGNET[6]. The data sets that we used did not contain any periods of missing data.

Besides the hand-scaled K indices that were produced by the staff of the Kakioka Observatory, the data produced by the FMI and AS methods were also used. The codes for these algorithms are available on the website of International Service of Geomagnetic Indices[7]. This website of ISGI is the official Web portal of the Reference Service for validation, dissemination and stewardship of geomagnetic indices. ISGI-headquarters are in charge of the computation of L9 (K=9 lower limit) value for each magnetic observatory.

[5] http://www.kakioka-jma.go.jp/obsdata/dataviewer?locale=en

[6] http://www.intermagnet.com

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

The code “Kasm”, which is an implementation of the AS algorithm, is also available on the INTERMAGNET web page[8].

The results of the test of our algorithm are summed up and discussed in the following section.

4. Results

In this section the hand-scaled K indices of Kakioka are compared with the K indices of Kakioka produced by the FMI and AS algorithms, as well as by our new algorithm. In doing this comparison, we considered the correct values as those obtained by hand scaling of K indices.

Our method did not work perfectly for all ranges of K indices. In fact, its performance was disappointing for the K indices between 1 and 4. Here the performance of our model proved not to be better than the FMI and AS methods (data not shown).

However, for the extremely low geomagnetic activity (K=0) our method provided satisfactory results. The comparison with the FMI and AS methods showed the following findings: as much as 1512 events were correctly assessed by our method while the AS method correctly assessed 1243 events and the FMI method even only 592 events.

Figure 1 displays how the K indices produced by our method and by the AS method corresponded to the hand-scaled indices in this range of the extremely low activity. Here our method provided K indices which agreed with the hand-scaled indices very well. The figure also revealed that the

[8] http://www.intermagnet.org/publication-software/software-eng.php

percentage of the K indices produced by our method that were in agreement with the hand-scaled indices depends on the phase of the solar cycle. In the year of the high solar activity (2003) the performance of our method is worse than in the year of weak solar activity (2009). Such a dependence was expected and Figure 1 proves that it is also present in the comparison made for the AS method.

Comparing the overall number of discrepancies between our method and the AS method also seems hopeful: 838 differences by our method and 956 differences by the AS method. The ratio of the overall number of discrepancies to the correctly identified value K=0 was even more satisfying: 0.57 for our method and 0.78 for the AS.

The seasonal variation of the performance of our method (bottom panel in Figure 1) appeared to be less distinct than was the above mentioned variation in the course of the solar cycle. Months of equinoxes and solstices were compared: as expected, the results of our method tended to be in more agreement in winter (referred to the northern hemisphere).

For the high geomagnetic activity (hand-scaled K≥5) our method appeared to show hopeful performance too. As can be identified from Figure 2, more than 80% of the events were correctly assessed by our method (left bottom panel). On comparison, the AS method correctly assessed fewer than 60% (right bottom panel). In 2009, which was the year of the quietest mean activity ever recorded, the statistics showed worse results for both our and the AS methods; however this result arose from only six events and thus it is not decisive. The FMI method was not employed in this part of our study since its results seemed to be too inaccurate for moderate and higher geomagnetic activity at Kakioka.

We also examined the distributions of the differences when the K indices were distributed according the computer derived K indices. Data on the right-hand side of Figure 2 show a slight tendency for our method to overestimate the geomagnetic activity. In spite of that, considering both parts of Figure 2 (left-hand side and right-hand side, respectively), it seems that for the selected three years 2003, 2005 and 2009 for the K indices of Kakioka that were at least 5, our method performed better than the AS method.

5. Discussion

Prior work has tested the performance of computer algorithms for producing K indices (Menvielle et al., 1995; Bitterly et al., 1997). Confronting the computer produced K indices with hand-scaled indices, two best codes were recommended to use: the FMI (Sucksdorff et al., 1991) and AS (Nowozynski et al., 1991) algorithms. At the same time, however, the hand-scaled K indices were affirmed to be the most authentic. Moreover, using only few selected algorithms disables averaging out biases (Menvielle et al., 1995; Mayaud and Menvielle, 1980) when deriving planetary indices. It therefore seems that using broader variety of algorithms that emulate the older hand-scaling method might be beneficial.

In this study our semi-automatic interactive computer method for producing K indices was described (Section 2.2) and tested (Section 4). Our method was based on the hand-scaling methodology that had been practised at Hurbanovo Geomagnetic Observatory till the end of 1997. Its performance was compared with the FMI and AS methods, as well as with hand-scaled

K indices. This comparison showed that our method provided reasonable results for both very low (K=0) and high (K≥5) levels of the geomagnetic activity. These results were achieved employing the data of the Kakioka Magnetic Observatory.

Unfortunately, the performance of our method was slightly disappointing for the indices between 1 and 4. Here the results of our method provided results which were worse than the results of the FMI and AS methods. However, since for space weather studies extreme ranges of the geomagnetic activity are also important, our method might be still worthwhile.

The fact that our method provided satisfactory results for K≥5 might seem to go against Menvielle (1981), who refused the "iron curve" method of Rangarajan and Murty (1980). Such high values of K indices were indeed the results of a part of our method that was based on the "iron curve". Nevertheless, here it seems that this method might be used for producing K indices if the level of the geomagnetic activity is high enough.

Notice that we brought a certain amount of subjectivity in the process of constructing the curve for non-K variation. However, we believe that this amount does not exceed the amount of subjectivity that has been typical for the hand-scale method.

6. Conclusions

We proposed a method for producing K indices, about which we indicated that for both $K \geq 5$ and $K = 0$ it might approximate to hand-scaled indices better than the computer-based methods approved and endorsed by IAGA. At the same time, our method does not require so experienced human operator as requires the classical hand-scaling. We believe that our approach might have some merit in preparing K indices for "after the fact" studies of space weather events.

Future work ought to focus on the ranges of K indices between 1 and 4, where our method could not provide satisfactory results. This likely should not be based on only a simple simulation of the hand-scaling routine that was described in this paper; possibly also some features of the FMI or AS algorithms should be incorporated. At the present stage, however, our method possibly could be recommended to use in combination with another computer method, e.g. with the AS or FMI method.

Our method is intended primarily for using at the Hurbanovo observatory. Therefore, the other task for future work has to be preparing sufficient sets of Hurbanovo data for testing the method in various parts of the solar cycle. For this purpose old analogue magnetograms could be digitalized for periods when the K indices have been hand-scaled by the experienced operator[9]. Another possible way of obtaining the sets for testing could be hand-scaling from the printed digital magnetograms by an expert[10].

The next improvement of our method might be the complete elimination of subjectivity from the determination of the non-K variation. This can be attempted to fulfil, for instance, by selecting the five quiet days with the help

[9] The influence of the sampling rate of such digital data rather than 1 minute data for the deriving K indices should be considered in this case. For the FMI method the influence of 1 second data rather than 1 minute data were studied by Bernard et al. (2011).

[10] The comparison of analogue/hand-scaled and digital/hand-scaled K indices was studied by Niblett et al. (1984).

of the AS or FMI methods.

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Table 1: The quasi-logarithmic scale of lower limits for K indices at the Hurbanovo Observatory

K index	0	1	2	3	4	5	6	7	8	9
Lower limit [nT]	0	4.2	8.4	17	34	59	100	170	250	420

Figure 1: The performance of our method in the range of extremely low activity for the data of the Kakioka Magnetic Observatory. The panels at the top of the figure compares the hand-scaled K indices with the K indices produced by our method (left panel) and with the K indices produced by the AS method (right panel). The data covered three whole years 2003, 2005 and 2009. The left bottom panel displays the comparison between the hand-scaled K indices and the K indices produced by our method for the months of equinoxes and solstices in years 2003, 2005 and 2009. The percentage is calculated so that 100% corresponds to the number of events for which hand-scaled K was 0.

Figure 2: The overall distribution of differences between the hand-scaled K indices and the K indices produced by the AS method and our method. The data covered three whole years 2003, 2005 and 2009. The graphs on the left-hand side of the figure present the events when the values of the hand-scaled K indices were of at least 5. The right-hand side of the figure displays those events for which the required K-index values of at least 5 were computer produced.

Figure 1

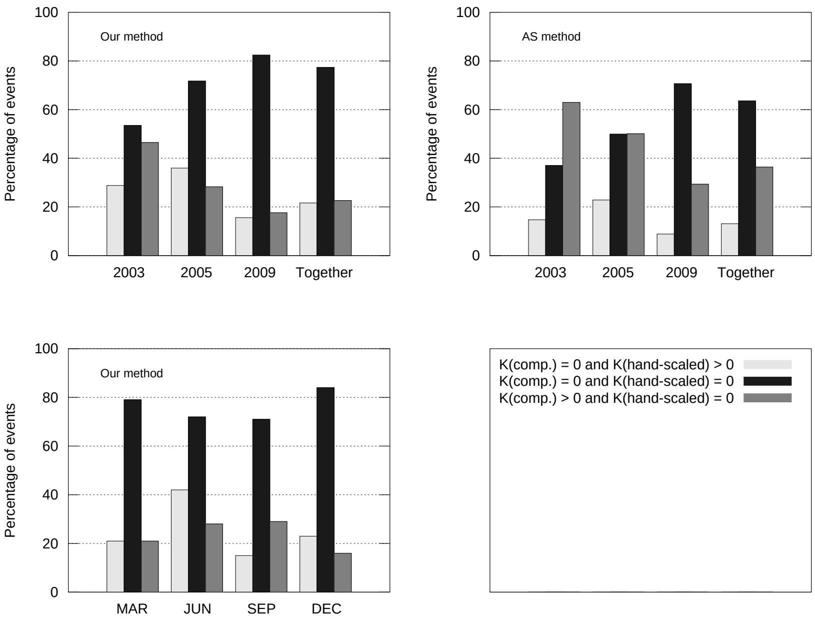
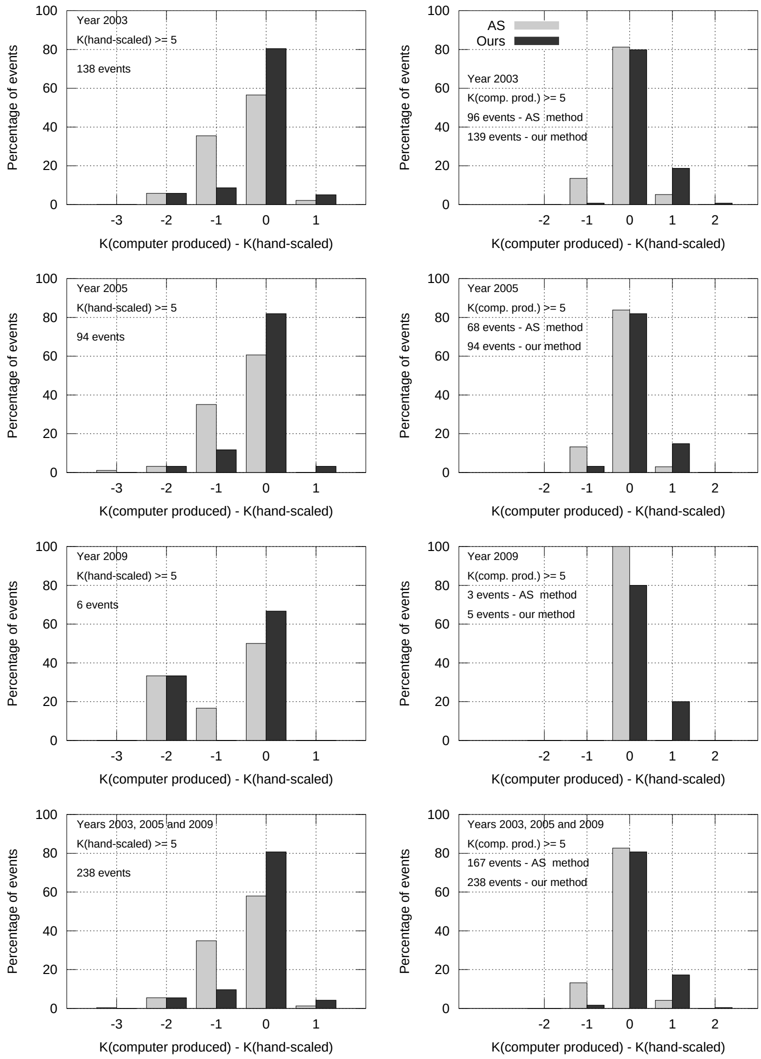

Our method
AS method
Our method
Percentage of events
0
20
40
60
80
100
2003
2005
2009
Together
MAR
JUN
SEP
DEC
K(comp.) = 0 and K(hand-scaled) > 0
K(comp.) = 0 and K(hand-scaled) = 0
K(comp.) > 0 and K(hand-scaled) = 0

Figure 2



Year 2003
K(hand-scaled) >= 5
138 events
AS
Ours
Year 2003
K(comp. prod.) >= 5
96 events - AS method
139 events - our method
Year 2005
K(hand-scaled) >= 5
94 events
Year 2005
K(comp. prod.) >= 5
68 events - AS method
94 events - our method
Year 2009
K(hand-scaled) >= 5
6 events
Year 2009
K(comp. prod.) >= 5
3 events - AS method
5 events - our method
Years 2003, 2005 and 2009
K(hand-scaled) >= 5
238 events
Years 2003, 2005 and 2009
K(comp. prod.) >= 5
167 events - AS method
238 events - our method
Percentage of events
K(computer produced) - K(hand-scaled)