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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 covers 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 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.

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 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 0–9. 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 become 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

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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

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 (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 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).

[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.

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