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Research paper

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 ($K \geq 5$) 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.
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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, Mayaud (1967) put together more rigorous instructions, according to which K indices had to be produced. 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

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

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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 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) emphasized 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 h 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.

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