DIGITIZATION OF BROMIDE PAPER RECORDS TO EXTRACT ONE-MINUTE GEOMAGNETIC DATA

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ABSTRACT

Many long-term geomagnetic observation results recorded on photographic bromide paper have not yet been fully digitized. To that end, we developed a method to automatically convert photographic records to one-minute digital data. We applied our method to the observation records of Kakioka Magnetic Observatory and confirmed that the resolution of time and amplitude could be greatly improved by numerical conversion compared with conventional data conversion by hand scaling. Our results suggest that highly precise digitization of analog magnetograms is possible.

Keywords: Analog magnetogram, Digitization, Geomagnetism, Photographic paper, Historical data, Digital data extraction, One-minute data

1 INTRODUCTION

In the past, geomagnetic field observations were recorded in analog form on photographic paper (Jankowski & Sucksdorff, 1996) with a silver bromide emulsion, known as bromide paper. Up to now, these analog magnetograms have been read only by hand scaling with low time resolution. Many observatories have analog records covering long observation periods (Iyemori, Nose, McCreadie, Odagi, Takeda, Kamei et al., 2005). At Kakioka Magnetic Observatory (KMO) in Japan, records on photographic paper of geomagnetic observations go back to 1924. However, most of the numerical data available from these magnetograms are hourly values that were digitized by hand scaling. Conversion of these analog records to high-resolution numerical data would make them very useful in investigations of past geomagnetic activity. We therefore developed a method for converting the analog magnetograms into digital data with high time and amplitude resolutions and then examined the conversion accuracy.

2 OUTLINE OF THE CONVERSION METHOD

The first step was to obtain high-resolution scans of the photographic paper records and to store them as graphic files. We then used an image processing program that we developed to distinguish lines and curves in the graphic files. The identified pixels were converted into numerical time and geomagnetic field data. Each step of the conversion is described in detail below.

2.1 Photographic paper record and scan specifications

Each record is a sheet of photographic paper about 510 mm long by 195 mm wide (Figure 1). Three components (H, horizontal; Z, vertical; D, declination) of one day's geomagnetic field variations are recorded on one sheet. Time is recorded in the longitudinal direction along three baselines, and 24 transverse lines (time marks) divide the record into 20-mm intervals. Each interval represents one hour, and the time mark indicates the 0th minute of the hour. Each baseline is the zero amplitude line for a curve that records the variation in one geomagnetic field component, and the curve can fluctuate from above to below the baseline with a resolution of about 2.5 nT (H and Z) or 0.29 minutes (D) per 1 mm. These values are average scale values in 1963 and later. Scale values vary depending on the period, and detailed values of each year are shown in annual reports of the Kakioka Magnetic Observatory (e.g., Kakioka Magnetic Observatory, 1996). In the past, values have been read off the KMO photographic paper records with one-hour and 0.1-mm resolutions by hand scaling, and the read values have been converted into geomagnetic field values by comparing them with baseline, scale, and other correction values. These values, after conversion and correction, have resolutions of 1 hour and 1 nT (H and Z) and 0.1 minutes (D).

In our digitization method, we scanned the photographic records at a relative resolution of 600 pixels per inch, which corresponds to about 4,600 by 12,000 pixels per sheet. This resolution is equivalent to a time resolution of about 7.5 s per pixel and an amplitude resolution of about 0.1 nT (H and Z) and 0.01 minutes (D) per pixel. The scanned photographic records are stored as 24-bit color bitmap images so that each pixel can be weighted according to its luminosity during image processing.

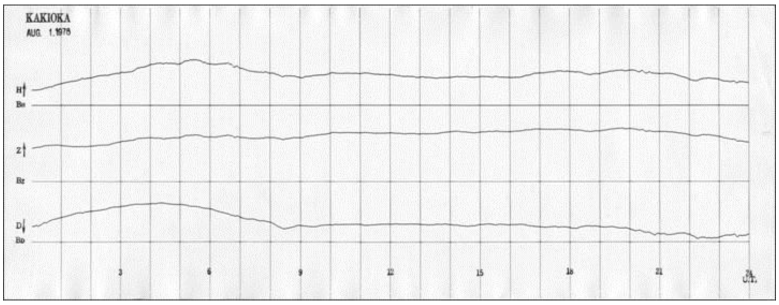

Figure 1. An example of one day's analog magnetogram (1 August 1978) recorded on bromide paper

2.2 Automatic recognition and numerical conversion of the image

The image processing program automatically converts each scanned high-resolution graphic file to numerical data by successively performing the following steps.

2.2.1 Identifying time marks, baselines, and component variation curves

The trace of each baseline and of each time mark is recognized by its luminosity, width, vertical or horizontal trend, and position (spacing) as a linear band. The pixel of each central point along a band is specified. The traces on the magnetogram show slight distortions due to the daily installation state of the photographic paper; therefore, the bands are not all straight. The variation curve of each component is considered to be a small, elliptical locus that vibrates up and down while progressing in the time direction. The pixels comprising the central points of the ellipse and each end of the locus are specified by scanning pixel by pixel in the time direction. Where a curve crosses its baseline, it is automatically distinguished from the baseline based on its position and width curve before and after the crossing (Figure 2). When two variation curves cross, the presumed widths and central points of both curves are pinpointed automatically based on guide marks manually input into the digital image file that indicate which component trace is above and which is below at the intersection (Figure 3).

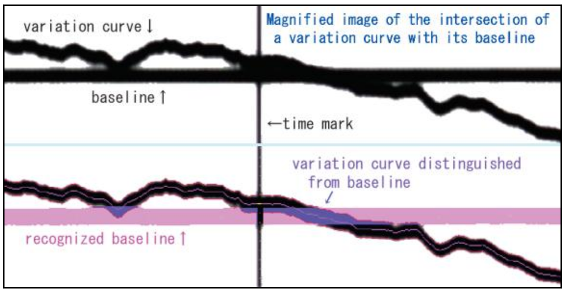

Figure 2. Distinguishing a variation curve from its baseline

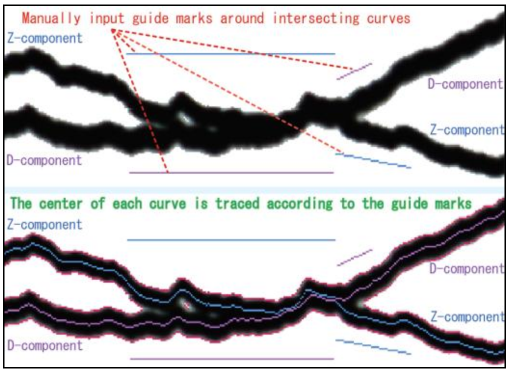

Figure 3. Identifying two curves at an intersection

2.2.2 Reading time and amplitude

For each central point along the variation curve, the number of pixels in the time direction from the preceding time mark to the point and from the point to the next time mark is counted. Similarly, the number of pixels in the amplitude direction from the baseline to the point is counted. The number of pixels in the time direction is converted into time by interpolating between the time marks, and the number of pixels in the amplitude direction is converted into the actual distance on the original photographic paper. The sign of the amplitude is positive above and negative below the baseline. These data are then output to a file as a time series of raw amplitude data at time intervals of about 7.5 s (about 8 numerical values per minute), where the amplitude is the distance from the baseline to the central point of the variation curve.

2.2.3 Conversion of raw time series amplitude data into geomagnetic field component values

Using the amplitude data sampled about every 7.5 s (8 data points, 4 on each side of the 0th second of each minute), the amplitude at the 0th second of each minute is computed by the least squares method. By applying scale values, ordinate factors, and baseline values calculated from past observations, the amplitudes at the 0th second of each minute are converted into geomagnetic field values. Thereby, one-minute geomagnetic field variation data are output by the program.

3 ACCURACY AND PRECISION OF THE CONVERSION

Although the time resolution of these one-minute values is 60 times better than the hourly time resolution obtained by conventional hand scaling, it is necessary to evaluate the accuracy and precision of the digitized values. Next, we describe the evaluation method and the results of the evaluation.

3.1 Evaluation method

Beginning in 1976, when digital recording magnetometers were installed at KMO (Kakioka Magnetic Observatory, 1978), geomagnetic field measurements were recorded digitally in parallel with the analog recording. Therefore, simultaneous records of observations are available for the same phenomena. We compared the one-minute values of the digitized analog records with the data obtained simultaneously by the digital magnetometers. Here, we show the results for each of the three geomagnetic field components between 1 and 9 August 1984, a period during which the accuracy of the digital observation results was considered adequate.

3.2 Accuracy and precision of the conversion results

The one-minute values of the three geomagnetic field components for the period 1–9 August 1984 converted from the photographic paper records are shown in Figure 4. The range of the H-component is about 180 nT. Figure 5 shows the differences between the digitally recorded one-minute values and the converted analog one-minute values. The differences indicate a daily variation of about 0.5 nT (H- and Z-components) or 0.05' (D-component). We attribute these diurnal variations to a difference in the temperature coefficient between the two magnetometers. The shift of about 1 nT in the H-component at around 00 on 8 August (Figure 5, top panel) is attributed to a 1-nT change in the baseline value between 7 and 8 August. The daily baseline values were determined by hand scaling during the conventional calculation of hourly values. We infer that the short-term variations in the differences include reading errors and inherent differences between the two magnetometers. Because at least 98% of the standard deviations of each component were less than 0.2 nT or 0.02′, we consider these reading errors to be small.

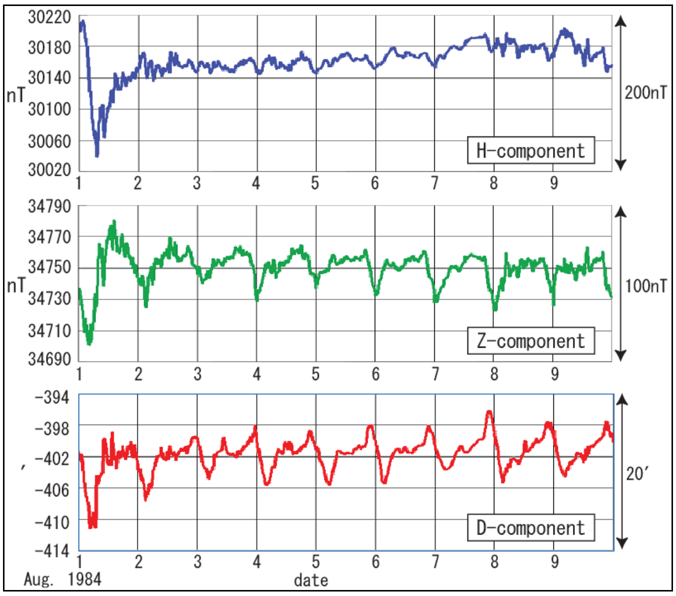

Figure 4. One-minute values of the three geomagnetic field components during 1–9 August 1984 converted from analog records on photographic paper

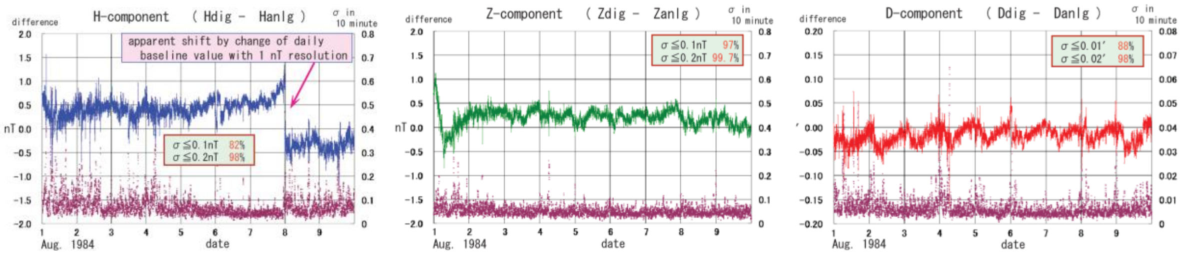

Figure 5. Differences in each geomagnetic component (from left to right, H, Z, and D components respectively) between the digital one-minute values and converted analog one-minute values (upper trace in each panel) and standard deviations computed using one-minute difference values determined over each 10-minute interval (lower trace in each panel)

4 CONCLUSIONS

We introduced a method for converting past magnetograms into digital data with a one-minute time resolution and evaluated the accuracy of the converted data. We confirmed that we could convert most analog records obtained during a relatively calm period in terms of geomagnetic activity automatically into one-minute values with an accuracy of better than 1 nT, which is the conventional minimum unit. To enable automatic conversion of all past analog magnetograms, we plan to improve our image processing algorithm so that it can handle two or more traces intersecting intricately and blurry images.

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6 REFERENCES

Iyemori, T., Nose, M., McCreadie, H., Odagi, Y., Takeda, M., Kamei, T., & Yagi, M. (2005) Digitization of old analogue geomagnetic data. Retrieved December 1, 2011 from the World Wide Web: http://www.ukoln.ac.uk/events/pv-2005/posters/iyemori.pdf

Jankowski, J. & Sucksdorff, C. (1996) *Guide for magnetic measurements and observatory practice*, Warsaw: International Association of Geomagnetism and Aeronomy.

Kakioka Magnetic Observatory (1978) *Report of the Kakioka Magnetic Observatory geomagnetism Kakioka 1976*, Tokyo: Japan Meteorological Agency.

Kakioka Magnetic Observatory (1996) *Report of the Kakioka Magnetic Observatory Geomagnetism Kakioka Memambetsu Kanoya Chichijima 1995*, Yasato-machi, JP: Kakioka Magnetic Observatory

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