The History and the Present Shape of the Tokyo/Kakioka Magnetic Observatory

by

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Abstract

Geomagnetic observations in Japan were conducted by the Central Meteorological Observatory (CMO) in Tokyo from 1883. CMO relocated the geomagnetic observatory to Kakioka in Ibaraki prefecture, about 75 km northeast of Tokyo in 1913. All the written records and field notes stored at CMO were destroyed in a fire after the Great Kanto Earthquake of 1923. The geomagnetic records from 1916 to 1923 was unfortunately lost.

In 1951, Kakioka Magnetic Observatory (KMO), developed a new observation instrument that incorporated a temperature compensation function and achieved a remarkable improvement in variation observation accuracy, and which replaced the conventional observation instrument. For absolute observation instruments, KMO developed in 1956 the A-56 universal magnetometer. In 1964, KMO installed the MO-P vector proton precession magnetometer to drastically enhance the quality of its absolute observation, probably making it world class at the time.

In 1976, the Kakioka automatic standard magnetometer (KASMMER) was installed. KASMMER allowed KMO to provide observation data values with a one-minute resolution. With regard to data with a resolution measured in seconds, KMO started providing observation data with a three-second resolution in 1980 and with a one-second resolution in 1983.

Today, KMO conducts absolute observations with DI-72, an angle measuring instrument, and a proton magnetometer, and variation observations with a high-sensitivity three-axis fluxgate magnetometer, which measures the values of three components every second and observation 0.1-second values. Although the fluxgate magnetometer is equipped with a monitoring device that checks inclination and temperature, the annual temperature variation is kept within 3°C, and the inclination variation is also kept stable.

According to the reports delivered at the International Association of Terrestrial Magnetism and Electricity Oslo Meeting held in 1948 concluded that the absolute measurement accuracy before 1947 was very much poorer than that thereafter. But the review of the observation data revealed that the accuracy before 1947 is almost equal to that of Schmidt once they have been re-processed appropriately. Now the work of re-examining and re-processing of absolute observation results from the 1920s to the 1940s is under way.

Only the hourly values among the observation data of geomagnetic variation were published before 1975. But in order to provide the past data in a more accessible and usable form, KMO developed a method to convert the geomagnetic data recorded on bromide paper into digital values with a one-second resolution.

1. History of Observation and Published Data

Japanese modern geomagnetic observation started in Tokyo in 1883 following the First International Polar Year. The hourly values of the data obtained after 1897 have been kept. The history of instruments for geomagnetic observation and the periods of available data are collated in Fig. 1.

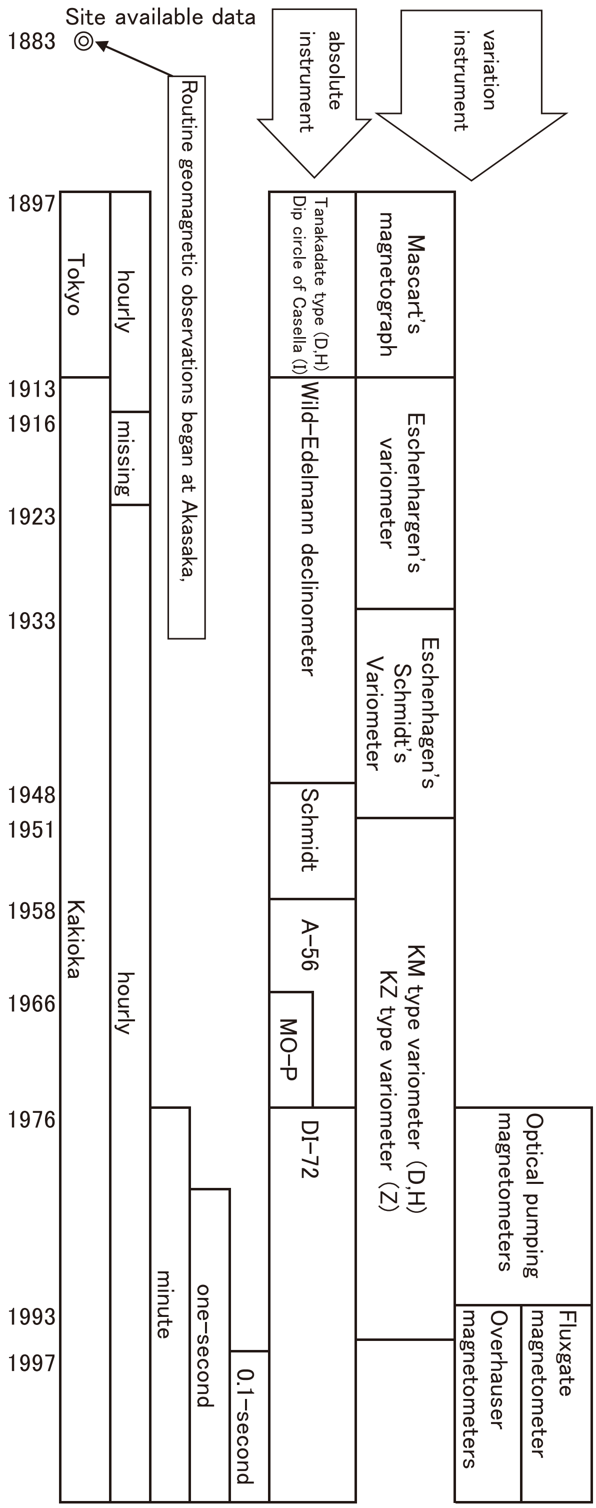

Fig. 1 Observation instruments used by CMO and KMO and the changes in available data.

Geomagnetic observations were conducted at the Central Meteorological Observatory (CMO) in Tokyo from 1883 to 1913 (Kakioka Magnetic Observatory, 1983). The absolute observation instruments used during this period were what was a declinometer (D) referred to as the "Prof. Tanakadate Type", a deflection instrument (H) and a dip circle of Casell a(I). Mascart's magnetograph was used for the observation of variation.

With the progress of urbanization in Tokyo, artificial noises, such as that generated by street cars, increased, and consequently CMO relocated the geomagnetic observatory to Kakioka, located about 75 km northeast of Tokyo on 1913. Upon relocation, Wild-Edelmann declinometer and earth inductor by means of the absolute Gauss- Lamont method was introduced for absolute observations. For variation observations, Eschenhargen's magnetic variometers which were torsion-type and made in Germany were introduced at same time. Temperature coefficients of the magnetic variometer were about 12nT/°C.

Gauss- Lamont method was adopted by its successor instruments for absolute measurement which were Ad. Schmidt's normal magnetic theodolite for H and D components and Askania Schmidt's earth-inductor for I component. These instruments were also made in Germany.

In the early days of observation at the Kakioka Magnetic Observatory (KMO), Tokyo sent a team to Kakioka every month for absolute observations, while Kakioka's resident staff worked at maintenance for the equipment for variation observations, such as changing the recording paper and the observation data had been sent from KMO to CMO. Because of the Great Kanto Earthquake that hit the Kanto area on September 1, 1923, the recording charts and field notes stored at CMO were completely destroyed by fire. The archived geomagnetic records taken before 1923 were only the published data that cover the 1897-1915 period. The 1916-1923 data were unfortunately lost. The devastating earthquake also caused more than a little damage to equipments of KMO. Observation was resumed on February 1, 1924, after instant repairs were completed during the previous month, January. Learning its lessons from the earthquake, KMO reinforced its facility and observation system. All the staff related to geomagnetic observation were stationed at Kakioka so that the data could be swiftly processed, and the quality of absolute observation, which was routinely conducted once a week, was improved. KMO continued geomagnetic observation during World War II, and the hourly data from those days still remains today.

Eschenhagen's Schmidt's variometers which were also made in Germany were introduced for variation observations at KMO in 1926. But these magnetometers did not surpass Eschenhagen's variometers. For example, temperature coefficients of them were about 28nT/°C, which is inferior to that of predecessors. In 1951, the Eschenhagen's Schmidt's variometer were replaced with a KM type variometer (D, H) and a KZ type variometer (Z), which were developed by KMO, These instruments achieved great improvements in accuracy by realizing temperature compensation due to the usage of magnetostatic alloy (Kuboki, 1976). Temperature coefficient was also brought up significantly to 1.5nT/°C.

With regard to observation instruments for absolute measurement, the A-56 standard magnetometer, a universal magnetometer, and the H-56 standard magnetometer, a sine galvanometer, were developed by KMO in 1958. In 1964, KMO introduced the MO-P vector proton precession magnetometer, making a remarkable advancement in the absolute observation quality, becoming world-class at the time.

In 1976, the Kakioka automatic standard magnetometer (KASMMER) was installed (Yanagihara et al., 1973). The main components of this instrument were optical pumping magnetometers, a proton precession magnetometer, an angle measuring instrument and a calculation processor. Except for the angle measuring instrument, all those elements were operated automatically. Four optical pumping magnetometers measure the total magnetic intensity as well as three magnetic components (horizontal, vertical and declination) as digital values with an absolute accuracy of 0.1 nT. The DI-72 angle measuring instrument, a type of search coil magnetic transit, measures the declination and magnetic dip of the geomagnetic field at an angular accuracy of one second. The absolute values of all components of the geomagnetic field are provided by these optical pumping magnetometers and the proton precession magnetometer that features greater stability than the former model. KASMMER now allows KMO to provide values with a one-minute resolution. With regard to data with a resolution measured in seconds, KMO started providing observation data every three-seconds in 1980 and data every second in 1983.

In 1993, geomagnetic observations using four Overhauser magnetometer and high-sensitivity fluxgate magnetometer started in addition to those using the optical pumping magnetometers, and this observation system continues today(Tsunomura et al., 1994).

2. Present Status of the Kakioka Magnetic Observatory

At present, KMO conducts absolute observations with a DI-72 angle measuring instrument and a proton precession magnetometer, and variation observation with a high-sensitivity three-axis fluxgate magnetometer and four Overhauser magnetometers. The main instrument is the high-sensitivity three-axis fluxgate magnetometer, which measures every second the values of the three components and observation values at 0.1-second resolution. The specification of the fluxgate magnetometer is shown in Table 1. One of the Overhauser magnetometers measures the total magnetic intensity. Three other Overhauser magnetometers measure horizontal, vertical and declination components with Fanselau-Braunbek coils which cancel other component of geomagnetic field. These Overhauser magnetometers obtain one-second resolution data. One-minute data are calculated out from one-second data as

Table 1 Specifications of a three-axis fluxgate magnetometer installed at Kakioka.

Temperature coefficient	< 0.5nT/degree
Stability	<±0.1nT/day
Measuring range	- 600nT to +600nT
Error in axis direction	< 6'
Output noise level	< 0.05nT
digital output resolution	0.01nT

average of value from 30th second of the previous minute to 29th second of that minute. Details of one-second data is shown in Tsunomura et al. (1994).

Two tiltmeters and a thermometer are installed on the inside of the outer cover of the sensor unit to monitor the condition of the magnetometer. The sensor is installed at a depth of 5 m from the ground surface, and the annual temperature variation is kept within 3°C, while the inclination variation is kept stable except for heavy rains or earthquakes (Fig. 2).

The performance and installation environment of the magnetometers is excellent, but there is still a problem, namely magnetic disturbances generated by artificial sources in recent years. KMO is protected legislatively against artificial disturbances generated from by motor cars which use direct current, but since the institute is surrounded by residential and farm land, artificial disturbances such as those generated by vehicles, buildings, other magnetic bodies or construction work can affect observations at KMO. As a solution to the increasing occurrence of artificial disturbances such as these, an artificial disturbance measuring system was established in 2008. This system calculates the magnetic moments and positions of sources of artificial disturbances from the measurement values of the geomagnetic measuring instruments installed on the KMO premises (Okawa et al., 2007). The results are used to revise KMO's geomagnetic data.

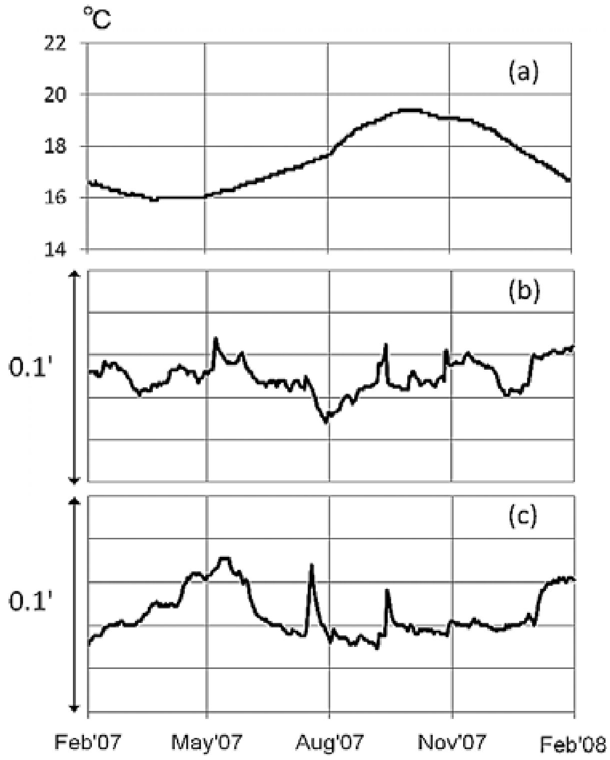

Fig. 2 Changes in inclination and temperature using a high-sensitivity triaxial fluxgate magnetometer at KMO (from Feb. 1,2007 to Jan. 31,2008) (a) shows the temperature data, (b) tilt (north-south), and (c) tilt (east-west). Significant tilt variations in July and September is due to heavy rainfall.

Magnetic field disturbances by leakage current of electric railways are serious obstructions for magnetic observations. One of a significant reason why CMO relocate the geomagnetic observatory from Tokyo to Kakioka was artificial noises by street cars, as mentioned above. In order to keep environments to observe geomagnetic field, locations of direct current railways are restricted by a law in Japan. Ministerial Ordinance to provide technical standards for electric equipments, Article 43 prescribes that direct current railways shall be equipped not to exert bad influences on observations at geomagnetic observatories. Trains of two electric railways near KMO; Joban line Mito line and Tsukuba express are switching motors from DC to AC around 30km from KMO.

3. Verification of Past Data

The periods of data currently available for use are collated in Fig. 1. As explained earlier, the bromide paper sheets and field notes from 1923 were destroyed in a fire caused by the Great Kanto Earthquake, but the hourly data issued as publications covering years from 1897 to 1915 have been published as digital values. In addition, Tokyo geomagnetic data from 1897 to 1912 were corrected and have been published (Toya et al., 2004).

Yanagihara (2002) made a detailed review of the accuracy of past observation at KMO and concluded that although observations regarding the data were on the whole good, the some procedures of data processing before 1947 were inappropriate and the published data can stand further improvement of quality with adequate reprocessing.

As an example, Wild-Edelmann declinometers used at KMO until 1948 were replaced by Schmidt declinometers, and the observation accuracy of Kakioka was reported the Oslo Meeting of International Association of Terrestrial Magnetism and Electricity (IATME 1948). In the report, accuracy of Wild-Edelmann declinometers was about 8 nT and that of Schmidt declinometers was about 2 nT. So Wild-Edelmann's accuracy was about 4 times poorer than that of Schmidt's instruments. But the review of the observation data revealed that the accuracy of the data is almost equal to that of Schmidt once they have been re-processed appropriately (Fig. 3).

As it has been indicated by the detailed review that appropriate data processing can improve data quality, KMO is re-examining the absolute observation results obtained from the 1920s to the 1940s and is investigating re-process the variation observation data on a monthly basis while checking the bromide paper records. The hourly values of the data in August 1933 corrected by the above method are shown in Fig. 4 together with the data before correction and the observation values of Honolulu and Niemegk. It shows that corrected data are smoothed for monthly changes and the data quality should be improved.

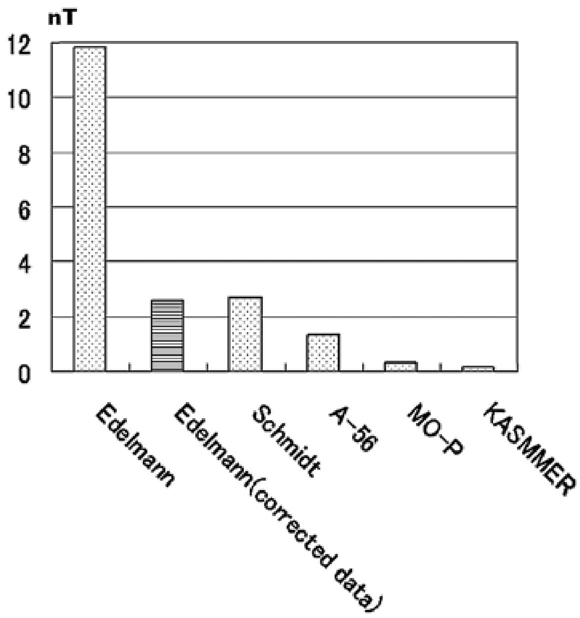

Fig. 3 Absolute observation instruments used by KMO and their accuracy.
Accuracy is shown as the standard deviation (vertical axis) of the base line values. Although the accuracy of Edelmann was 8 nT according to the report at Oslo Meeting of International Association of Terrestrial Magnetism and Electricity, it turned out to be about 2.6 nT after reprocessing.

4. Digitization of Legacy Data

For the observation results of geomagnetic variations before 1975, only hourly value was published as digital data until the optical pumping magnetometers were introduced in 1976. But the analogue records (on bromide paper) are sufficiently high quality in resolution. In order to provide such legacy data in more convenient form, KMO is developing a method for conversion of geomagnetic bromide paper records into digital values with a one-minute resolution.

Processes of the method are following;

- Scanning bromide papers and saving as bitmap images,
- Correcting distortions of images,
- Reading the curve on horizontal distance from time mark and vertical distance from base line for each pixel,
- Converting distances from time mark into time, distances from baseline into geomagnetic value respectively.

Then sensitivity calculation, gap compensation, and addition of base line values are carried out by programs in order to prepare digital values with a one-minute resolution. In line with this concept,

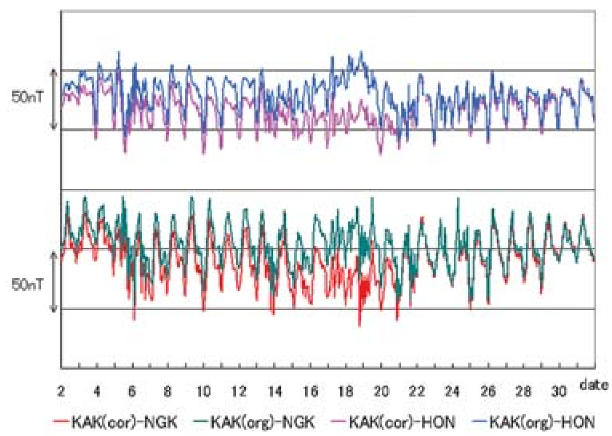

Fig. 4 Hourly values of the H component of the geomagnetic field - differences between the values at Kakioka (KAK), Honolulu (HON) and Niemegk (NGK) (Aug. 2 to 31, 1933).
The corrected values for Kakioka, or KAK (cor), indicate the changes in hourly values are smoothed compared with the pre-correction values, or KAK (org).

KMO is developing programs to correct distortion of images, and to read the digital images in the form of time-series data.

Both analogue records on bromide paper and digital data by optical pumping magnetometer are present from 1976 to 1995. Differences between digital one-minute values obtained from bromide paper and that by optical pumping magnetometers from August 1 to 9, 1984 are shown in Fig. 5. These differences show diurnal variation in all components. In particular, diurnal variations with amplitude of about 0.5 nT for H and Z component, and 0.5 minute for D component. The discontinuity at August 8,00 hr. for H component is due to the change in daily baseline value that was given in 1nT unit. Ten minutes standard deviations of the differences are kept within the range about 0.05 to 0.1 nT (0.005 to 0.01') for all components. We consider that accuracy of digital one-minute values obtained from bromide paper is adequate. KMO intends to make practical reviews so that a future publication of digital data with a one-minute resolution will be realized.

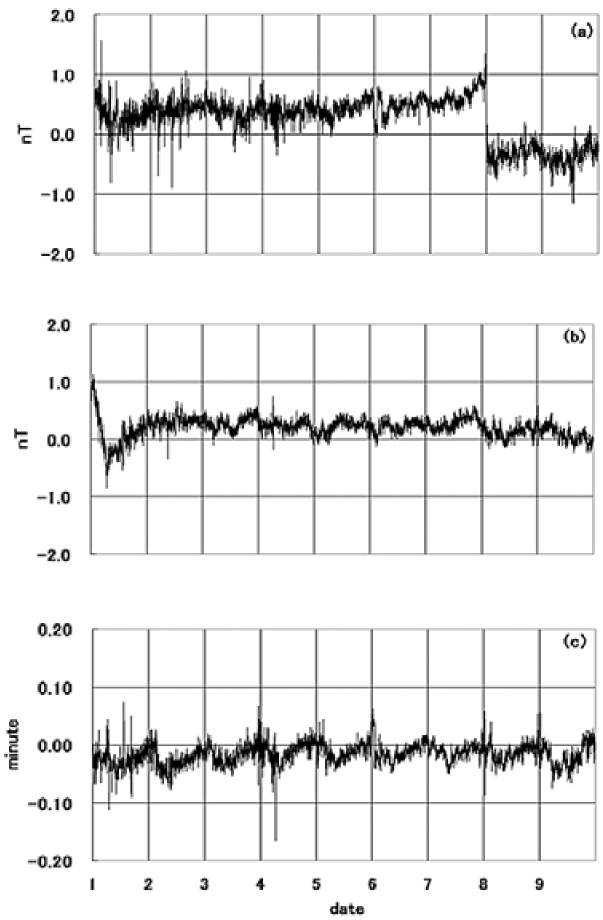

Fig. 5 Differences between the digital values obtained by an optical pumping magnetometer and the values with a one-minute resolution obtained from the bromide paper records (Aug. 1 to 9, 1984)
(a) indicates the H component, (b) the Z component and (c) the D component. The gap at 0 hr on the 8th for the H component is an apparent phenomenon due to the change in daily base line values.

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