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The first mathematical description of the main geomagnetic field was given by Gauss[1] in 1839. He determined 24 spherical harmonic coefficients based on the data at 84 points read off at 30° intervals of longitude along 7 circles of latitude from Sabine's total intensity (1837) chart, Barlow's isogones (1833), and Horner's isoclines (1836). The field values calculated from his spherical harmonic expansion were then compared with the observations at 91 stations. Since Gauss used the 3 components X, Y, and Z, the number of values used in his spherical harmonic analysis is 252. Following Gauss, Erman and Pedersen[2] (1874) made a main field analysis using values at 90 points, and thus about 270 values.

Adams[3,4] (1898, 1900) determined 48 coefficients based on the data taken at every 10° in longitude and 5° in latitude from Sabine's and the Admiralty charts. His data set thus consists of about 3800 values. The subsequent main field analyses made by Schmidt[5,6,7] (1889, 1895, 1898), Dyson and Furner[8] (1923), Bauer[9] (1923), and other workers used data sets in which the number of values is of the order of a few thousand. Vestine's main field analysis[10] (1947) used data of a similar size for the spherical harmonic analysis, but the preparation of the data was more elaborate than in the previous attempts.

The development of high speed computing machines brought a sudden change in the scope of the main field analysis. Cain et al.[11] (1967) derived 120 spherical harmonic coefficients and their first and second time derivatives from a sample of all magnetic survey data available for the interval from 1900 to 1964 and the total field data obtained by the OGO 2 satellite. Their data set contained approximately 77,400 observations of one or more components each; the total number of values used was roughly 150,000. The data for 1965 included 22,300 OGO 2 observations.

The scope of the data obtained by satellites is enormously large. For instance, the number of observations provided by the OGO 2 and 4 satellites is as follows:

Satellite	Year	Approximate No. of observations
OGO 2	1965	2,500,000
	1966	9,000,000
	1967	800,000
OGO 4	July-Dec. 1967	14,500,000
	Jan.-May 1968	12,000,000

Now we turn to Sq analyses. For his classical analysis of Sq, Chapman[12] (1919) used 21 observatories for the years 1902 and 1905. The number of values used is thus 3 (components) x 21 (observatories) x 24 (hours) x 365 (days) = 551,880 per year; and hence the total number is about 1,100,000 for the two years.

In Vestine's analysis [10] of the Second Polar Year data he used 55 stations, making the total number of values approximately 1,400,000. These analyses were made manually with desk calculators.

The analysis of Sq has also seen a drastic change in scope with the advent of electronic computers. Matsushita and Maeda[13] (1965), using the data obtained at 69 stations on 45 quiet days during the IGY, derived Sq current systems for three longitude sectors and for three seasons. The number of data values was of the order of 200,000; but the number of current systems presented was 40, which represents an increase by a factor of 10 compared with previous papers. To obtain these results they performed spherical harmonic analysis 40 times.

Sugiura and Hagan[14,15] (1967) constructed a motion picture to describe a continuous variation of Sq by a combined use of a computer and a cathode ray type plotter. They used the IGY data from 66 observatories for two magnetically quiet periods of five days each and performed a spherical harmonic analysis for each of the 240 hours to represent instantaneous Sq. Then Sq potential contours, both for the external and the internal parts, were drawn by machine. To make a motion picture, a smooth transition from one contour map to the one for the next hour was achieved by interpolating contours. In the motion picture the Sq potential contour map is given at 3 minute intervals. Thus the total number of contour maps is 4800.

Price and Stone[16] in England are developing a new technique to analyze Sq automatically with a computing machine on a routine basis.

In the efforts of Sq analysis by Matsushita and Maeda[13], Sugiura and Hagan[14,15] and Price and Stone[16] tabulated hourly values had to be punched on cards to be fed into the computer. This is by no means a trivial task.

For several years the U.S. Coast and Geodetic Survey and the Goddard Space Flight Center have jointly made great effort to digitize magnetograms[17]. The project was in part financed by the National Science Foundation. In this program, magnetograms are scaled by a machine operated manually, and the scaled results, after being converted to values in proper units, are stored on magnetic tape. Using such digitized data, Heppner[18] (1969) has made a motion picture depicting changes in the horizontal magnetic vectors at high latitude observatories.

Usefulness of geomagnetic activity indices is now well recognized. Thus, for instance, the Dst index, representing mainly the ring current intensity, has been published since IGY except for a gap of 1959 and 1960[19,20,21]. Until the digitization program began in 1964 the hourly values of H had to be punched on cards, but with the 2.5 minute scalings available on magnetic tape no punching task is needed.

The derivation of the Dst index, simple as it may appear, does involve an appreciable amount of work. First, for each station contributing to the index the secular change has to be evaluated. This is done in the present scheme by taking annual means for quiet days and by expressing the secular change in power series in time, thus enabling the 'base line' to be determined at any given hour. Using annual means of ten quiet days the change in H at Hermanus amounted to 670γ in 9 years from 1954.5 to 1963.5! Though this represents an exceptionally large variation, accurate evaluations of the secular changes are essential for an accurate determination of Dst. After the secular change is removed the Sq variation must be determined and likewise removed from the data. This is a difficult task, because on a disturbed day Sq cannot be determined without knowing the disturbance variation which we want to derive. At present the following method is being used: for each station Sq for each year is represented by a double Fourier series with local time and a month number (in decimals) - expressing seasonal variation - as two variables so that Sq can be evaluated at any local time on any day of the year. The Fourier coefficients are determined by monthly mean Sq as obtained from five international quiet days.

All these calculations are now programmed for machine computation. The approximate number of 2.5 minute scalings used for the Dst derivation is 210,000 per year per station. Without a high speed computing machine and a high speed plotter it is virtually impossible to produce the Dst index on a routine basis. This applies to the auroral electrojet index, AE. If we require 10 stations for the derivation of AE, approximately 2 million data values per year have to be dealt with.

The size of the data required for geomagnetic studies is increasing tremendously. At the rate of one reading every 2.5 minutes the number of values for the three components is about 630,000 per year per station. For 50 stations the number becomes 350 million for one solar cycle. Even with hourly values the corresponding number is 14.5 million.

The cost of digitization for Dst and AE is approximately $100,000 a year, or about $6,000 a year per station on the average (ignoring differences in cost because of the differences in the complexity of variations at low and high latitude observatories). In 5 years this amounts to $30,000 per station. An estimate for the production in U.S. of a set of fluxgate magnetometer, a tape recorder, and other necessary equipment which will produce digital data automatically is on the order of $30,000 including labor. Once the magnetometer-recorder system is installed, the sum of $6,000 a year, which would be the average digitization cost had the conventional magnetometer been operated, would seem to be adequate for maintenance of the equipment. There would of course be a saving of cost in operating an automatic observatory because of the reduced requirement in manpower in the daily care of the record and the preliminary scaling that is often done at an observatory.

In addition there are hidden costs in analyzing conventional magnetograms by scientists. These include scalings (often duplicated), reproducing records on different scales, punching the scaled data, labor spent by scientists themselves and accompanying administrative expenses.

Let me summarize at this stage the above overall discussion of the digitization of the conventional magnetograms and the automatic magnetic observatory. First, there is a growing need for digitized magnetic data in a machine-readable form, and this need is rapidly becoming a necessity. Secondly there may actually be a case of a cost reduction in the long run in the observation and analysis of certain aspect, if not all, of geomagnetic variations if the conventional observatory is modernized by installing a magnetometer with an automatic recording system with digitized output.

On the second point above, I would like to urge the IAGA to make a careful study of the financial questions as well as on the instrumental problems. It is a responsibility of the scientists to the society to assure that the funds are being spent in the most efficient way. Scientific merits and priorities must be carefully assessed regardless of whether the conventional magnetic observations are continued or a new system is to be introduced.

I will now make a little more technical comparison of the conventional and automatically digitized geomagnetic records. For any extensive digital data analysis the advantage of automatically digitized records is obvious because of (a) the capability of direct input into a computing machine and (b) the readiness for display of the data in any desired form by a plotting machine of either mechanical or cathode ray type. For synoptic studies also, automatically digitized records have advantages; for instance, (a) for the drawing of disturbance field vectors or equivalent current vectors the conventional magnetograms would require a scaling; (b) for a comparison of records from many stations the conventional magnetograms often have to be scaled and replotted because of different magnetometer sensitivities and different scales both in time and in ordinates. Inconveniences with the conventional magnetograms in all these matters have hindered a rapid progress.

There are, however, arguments against an automatic magnetometer system. But these arguments often have pitfalls and fallacies. For instance, it is sometimes said that the traces in the photographic magnetograms show how rapid the variations, for example, in sudden commencements

(SC's), are, and that this quality will be lost in records digitized at frequently suggested sampling intervals. Although what is said here is true, this argument cannot claim an advantage of the conventional magnetograms on a scientific ground. The reasons for this are as follows.

First, the normal magnetograms are not intended and not suited for studying variations of time scale $\lesssim$ 1 minute. One must guard himself against an illusion caused by the pleasing appearance of beautifully processed photographic magnetograms. This aesthetic enchantment may not lead to anything significant scientifically. For instance, studies have been made on possible differences in the arrival times of SC's at different local times. However, no definite conclusions, to my knowledge, have been drawn on the question. Considering the complex structure of the plasma and the magnetic field in the magnetosphere, it seems unlikely that the propagation of the SC disturbance can be studied in such a detail that the thinness of the magnetogram traces becomes a significant factor. The OGO 3 and 5 satellite observations with a great time resolution have indicated that the SC-associated magnetic variations are indeed very complex in the magnetosphere. What is observed on the ground is an integrated effect of the magnetospheric response to a discontinuity in the solar wind. In addition to the principal hydromagnetic effects there must be variations arising from currents along the field lines and in the ionosphere due to the deformation of the magnetosphere; and all these variations are further modified appreciably by the induced currents in the ocean and under the ground.

There may arise a need for conventional magnetograms to have "a little better time resolution" than in sampled digitized data. To be prepared for such a need there could be a group of conventional observatories maintained as in the past. In some areas of the world it might not be easy to convert the conventional observatories into automatic observatories for various reasons. Nor would it not be advisable to convert every existing observatory into one equipped with an automatic system. There could be two groups of observatories conventional and automatic serving for different purposes.

However, the quality of the magnetograms that is considered to be advantageous above constitutes also a liability. During severe disturbances we so often lose track of the traces because of their thinness in addition to their crossing each other repeatedly. Indeed this is one of the strongest arguments against the conventional magnetograms.

Another argument frequently presented against an automatic observatory is the dependability. The electronic and other components used in an automatic observatory are inevitably more complex than the instrumentation in the conventional system, and hence there is more chance of loss of data arising from various equipmental malfunctions. Let us not forget, however, how often magnetograms especially from high latitude observatories are useless or nearly so during disturbances when they are needed most. Also, manual operations that are assumed to be dependable do not appear to be as reliable as are assumed theoretically. Examples proving this point are numerous. Magnetogram traces are often lost because of poor optical work in the recording, poor photo-processing, or careless photographic and processing work for the reproduction of the magnetograms. Other examples of causes for loss of data are: a lack of, or errors in, the indentifications of the three components; errors, or uncertainties, regarding the signs for the ordinates in the magnetograms; or, in the case of tabulated hourly values, misreading the magnetogram traces because of reflected images from off-scale excursions.

In the foregoing discussions I have expressed usefulness of digitized geomagnetic data and presented arguments advocating automatic observatories that will produce digitized data directly from the magnetometers. However, when such digital data become available in a machine readable form, there may arise a serious problem that has not been experienced previously. This problem concerns the enormous advantages given to scientists who have direct access to computers. Scientists in those areas of the world where accessibility to computers is poor may in practice be denied opportunities to participate meaningfully in the analysis of geomagnetic data. In those countries in which use of computers is limited, geomagnetic observations may become, in essence, a service to the scientists in more technologically advanced countries. Thereby active interests and scientific participations of the countries of the former category may gradually decline. This is not a desirable circumstance and certainly not in line with the spirit of the IAGA. Such a trend is contrary to the traditions of the international cooperation in the Polar Years, IGY, IGC, IQSY, IASY, and in other international ventures.

To alleviate such a difficulty I would like to suggest the establishment of an International Center for Geomagnetic Studies. The fundamental purposes of the Center are: (i) to make a computer system, plotters, and other equipment needed for data analysis available to scientists, and (ii) to provide opportunities to those scientists who at their home institutions have only limited access to such modern facilities. The Center should have a permanent staff of high qualification so that visiting scientists can receive advice from them either scientifically or technically. Positions of "visiting professors" may provide scientific stimulus. The Center would be a logical home for a Digital Data Center such as the one that has been suggested by Dr. J. C. Cain.

The host country for the Center would seem to have to satisfy the following conditions: (i) The computer technology is highly advanced. (ii) There exists a sizable group of scientists actively engaged in geomagnetic researches. (iii) No discrimination is made regarding the visitors' nationalities.

Needless to say, the problem of funds for the establishment and operation of such a Center would be enormously difficult. However, enthusiasm and an accumulation of devoted efforts can often solve seemingly insurmountable tasks in many areas of international enterprise. But the prospect of materializing the Center would be zero if the enthusiasm of the scientists with whom the matter is concerned is only lukewarm. I believe that the key question is whether such a Center is <u>needed</u> or merely <u>desirable</u>. If the latter, I see no prospect of success and any effort will be in vain. Who then is to answer this question? The answer must of course come from all concerned; but those who would benefit most from the plan must provide the driving force. It would be an idle thought if one supposes that a country, or countries, in which modern facilities are abound would initiate such a drive. The prospect of success will thus depend first on the strength of the motivation of those who need the Center and secondly on the understanding of their need on the part of those who can assist financially.

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