Reference Fields and Global Views

Australian and international geomagnetic reference fields

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By the mid 1960s there was general recognition of the need for an internationally accepted mathematical model of the earth's main field and its secular variation. Such a model would provide a standard for studies of magnetic anomalies, field residuals of external origin, the external form of the main field, the location of conjugate points, the long-term behaviour of the main field, and models for its origin. It was recognized that such a global model was attainable, although there was little prospect of agreement about higher order terms, representing regional and local detail of the field (Zmuda 1971).

In 1968, the International Association of Geomagnetism and Aeronomy (IAGA) finally adopted the International Geomagnetic Reference Field (IGRF), 1965. This IGRF was a series of spherical harmonics, to degree and order 8 ($n = m = 8$), to describe the geomagnetic potential of the main field for epoch 1965.0, together with a similar model for the secular variation ($n = m = 8$) to be used for extrapolation of the main field between epochs 1955.0 and 1975.0. However, by the early 1970s, departures of the field from predicted values were unacceptably large for many purposes. Accordingly, a new secular variation model ($n = m = 8$) was adopted by IAGA for the interval 1975.0 to 1980.0, to be continuous with IGRF 1965 extended to epoch 1975.0.

Main field and secular variation observations, which take some years to accumulate, are extrapolated forward in time so that IGRF models are available in the year of the nominal epoch. Retrospective analysis of a data set centred about a given epoch provides a more accurate model of the field which is unlikely to undergo further revision. Such models are referred to as Definitive Geomagnetic Reference Fields (DGRF). At the Edinburgh meeting of IAGA in August 1981, the following models were adopted: DGRF 1965, main field model for 1965.0 ($n = m = 10$); DGRF 1970, main field model for 1970.0 ($n = m = 10$); DGRF 1975, main field model for 1975.0 ($n = m = 10$); for intervening epochs (1965.0–1975.0) the main field is derived by linear interpolation between the DGRF coefficients; PGRF 1975 (Provisional GRF), a main field model for the interval 1975.0–1980.0 defined by linear interpolation between the coefficients of DGRF 1975 and IGRF 1980; IGRF 1980, main field model for 1980.0 ($n = m = 10$), together with a secular variation model ($n = m = 8$) for the interval 1980.0–1985.0. Note that IGRF 1980 is not continuous with IGRF 1975 extended to epoch 1980.0; PGRF 1975 supersedes IGRF 1975, and will itself be superseded when a definitive model for 1980.0 is adopted. The suite of models adopted at Edinburgh defines the main field continuously from 1965.0 to 1985.0.

At the forthcoming IAGA assembly in Prague (August 1985), agreement will be sought on a mainfield and secular variation model for IGRF 1985, and also definitive models for epochs 1945.0, 1950.0 and 1960.0. In the meantime, national groups are evaluating candidate models using their own regional data.

There are two future magnetometer-bearing satellite missions, currently under review by NASA, which would have a far reaching effect on new global and regional models of the geomagnetic field. First is the Magnetic Field Explorer (MFEx), a high altitude (550 km) polar orbiting satellite with a proposed launch date during the next solar minimum, 1987–88. The primary objective is to make observations of the earth's main and external magnetic fields during a 3 year period. The second proposed mission, the Geopotential Research Mission (GRM), would make observations of both gravity and magnetic fields at a very low orbit of approximately 160 km for about 6 months, to study gravity and magnetic anomalies of crustal origin. The launch date hoped for is 1992.

Until regular satellite observations of the main field and its secular variation can be maintained, Australia and its neighbours will remain important contributors of data for global models. Furthermore, because of the lower density of observations in the southern hemisphere, particularly over the oceans, global field models are less well constrained here than in the northern hemisphere. Thus IGRF and DGRF models are less likely to give a very accurate picture of regional magnetic fields in these southern hemisphere regions, and hence there is a continuing need for regional magnetic surveys.

Apart from scattered observations collected by early mariners (e.g. Abel Tasman, 1640, see cover of this issue), the first systematic magnetic survey in Australia was conducted by George Balthazar von Neumayer (1869), while Director of the Flagstaff Observatory in Melbourne. Since its inception in 1946, the Bureau of Mineral Resources has continued this work, producing a series of magnetic field charts for the Australian region (Dooley 1986) based on data obtained from first-order observations with an accuracy of 5 nT or 0.5 min of arc. Permanently marked repeat stations used in the course of BMR first-order magnetic surveys are shown in Milligan (1986). A number of the stations still in use today were established by the Carnegie Institution of Washington magnetic survey in 1912–13 (Bauer & Fleming 1915).

The name Australian Geomagnetic Reference Field (AGRF) was first used to describe a modification of IGRF 1965 for the Australian region (Petkovic 1974; Petkovic & Whitworth 1975; Dooley 1986). A magnetic survey of the

Australian region, including Papua New Guinea, Irian Jaya and islands in the adjoining oceans, has recently been completed. Modelling of these data using an orthogonal polynomial technique is in progress. The resulting set of models of the magnetic elements and their secular variation will be termed AGRF 1985. The models will contain more detailed information about the field than was represented by the fourth-degree polynomials used for the 1980.0 charts. Future effort is being directed towards reprocessing earlier data using the same technique to produce Definitive AGRF models for post-war epochs. These models will provide suitable baselines for processing localized magnetic survey data to obtain magnetic anomaly information, and will serve as a basis for studies of the long-term behaviour of the geomagnetic field.

It is plausible to assume that non-transient features of the geomagnetic field with wavelengths greater than the size of major continental blocks originate from within the core, or reflect gross heterogeneity in the core-mantle system. Conversely, magnetic anomalies with spatial extent significantly less than the depth to the core-mantle boundary (approximately 3000 km) may be attributed to crustal magnetization. Although there is no consensus regarding the highest degree harmonic of the core field that can be detected at the earth's surface, figures in the range 12–16 have been suggested. The higher value translates to surface features with wavelengths of about 2500 km. The size of Australia (about 40°) corresponds to a ninth-degree spherical harmonic, whereas the mean spacing between first-order magnetic survey repeat stations of about 350 km corresponds to a 57th-degree harmonic. Thus even the lowest harmonic of the AGRF may contain a significant crustal component. IGRF and DGRF models of the global field have been restricted to low degree and order (8 or 10, although a candidate model for the 1985 IGRF, WC85, goes to $n = m = 12$), and therefore provide the best estimate of the main (core) field. Systematic differences between the AGRF and IGRF/DGRF models for given epochs (Fig. 1) therefore provide a measure of very long wavelength crustal magnetic anomalies in the Australian region.

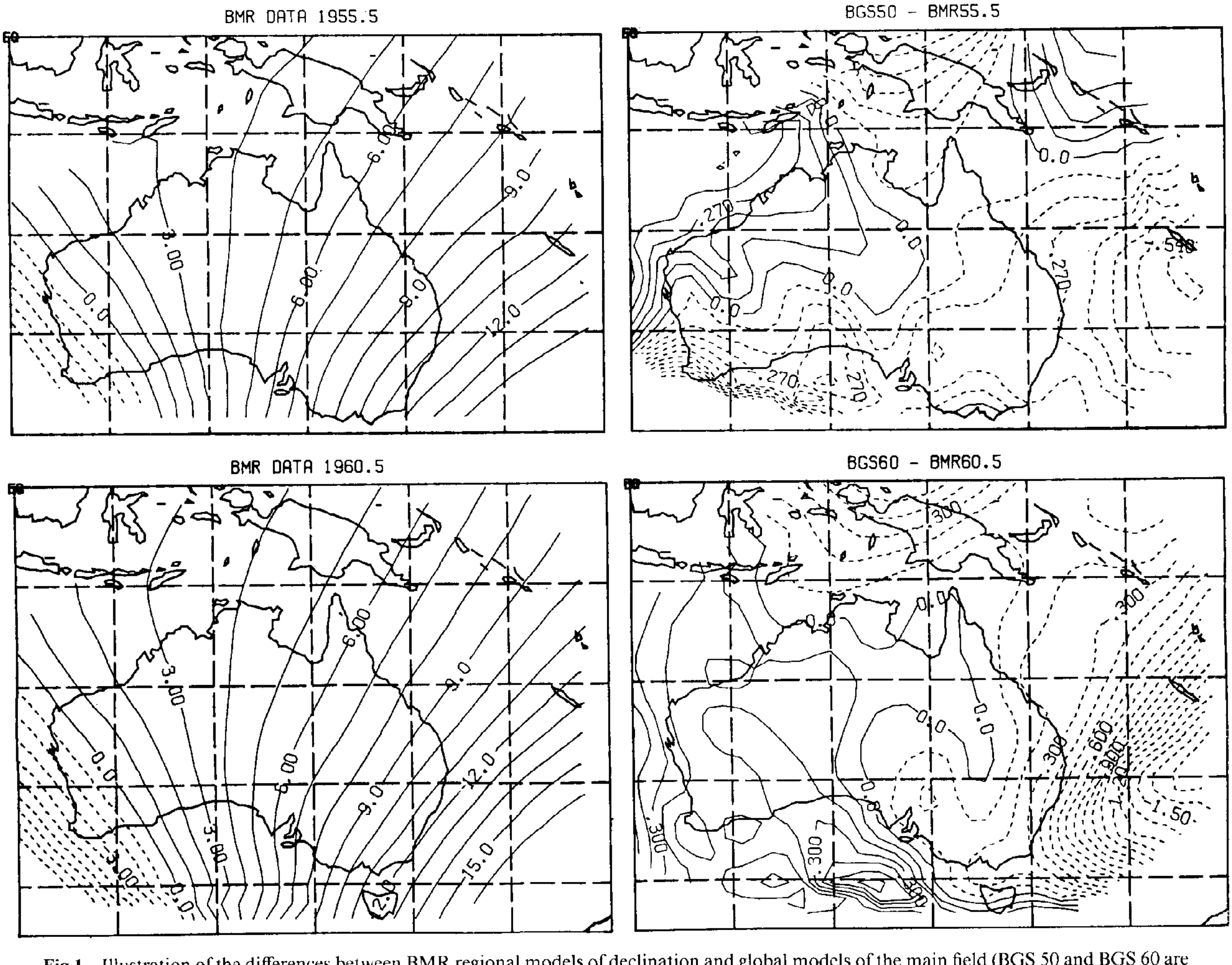

Fig 1 Illustration of the differences between BMR regional models of declination and global models of the main field (BGS 50 and BGS 60 are the British Geological Survey models for epochs 1950.0 and 1960.0). Units of declination are degrees east. Figure redrawn from Winch *et al.* (1986).

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A model of the earth's magnetic field suitable for regional use

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A model of the earth's magnetic field is described, which is suitable for use over a limited area of the earth's surface. Coefficients for this model are derived from local observations consisting of observatory results, field measurements and aeromagnetic data. A process of deriving the coefficients has been devised which avoids problems with the stability of the solution. Finally, a system is described which allows the automated plotting of charts, based on the model. On the charts, the resolution is independent of the projection or scale being used.

Mathematical form of the model

The model used to represent the normal or main field is a set of three polynomials, first used by Reilly and Burrows (1973). The three components (X, Y and Z) are each expressed as quadratic functions of latitude, longitude and time; for example:

$$Z = a_z + b_z t + 0.5c_z t^2 + d_z xt + e_z yt + f_z x + g_z y + 0.5h_z x^2 + 0.5i_z y^2 + j_z xy$$

where x, y and t are latitude, longitude and time relative to an arbitrary position and epoch. Similar expressions are used for X and Y. This mathematical form is completely empirical. It has sufficient flexibility to model the field over a limited region. The order of the polynomial could be extended but the quadratic form has been found adequate for the New Zealand region. In principle, it might be thought better to use a spherical harmonic model, but the fitting of coefficients to such a model from observations of a limited geographical extent leads to instabilities in the coefficients if the data base is changed slightly. Although the quadratic polynomials cannot truly represent the magnetic field, it is possible to constrain them by imposing the condition that there is no vertical current flow at the earth's surface. This condition is that the vertical component of curl $\boldsymbol{B} = 0$. If the easterly component is expressed as:

$$Y = \sec\theta\,(a_y + b_y t + 0.5c_y t^2 + d_y xt + \ldots\ldots),$$

(where θ is the latitude) instead of just a polynomial, the above constraint reduces to:

$$c_x = -d_y,\ g_x = -f_y,\ i_x = -j_y,\ j_x = -h_y.$$

This set of conditions reduces the number of independent coefficients from 30 to 26.

Derivation of coefficients

There are four categories of observations available for use in the derivation of the coefficients in the model: observatory mean values; repeat stations; field observations; and aeromagnetic data from 'Project Magnet' flights. When a computerized method is being considered to derive the coefficients from the data, it is tempting to consider each observation as being equally valid, and hence assign equal weights. In practice this does not work well. The observatory results, whether monthly mean or annual mean values are used, unduly influence the spatial terms, and similarly the field observations unduly influence the time terms. As a result it has been found best from experience to divide the evaluation of the coefficients into three separate steps.

First, the coefficients of the terms dependent only on time are derived solely from the Eyrewell Observatory values. Since the major use of the model is to produce declination charts for navigation purposes, the data are weighted