Geoscience Australia's Geomagnetism Program – Assisting geophysical exploration

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SUMMARY

The Geoscience Australia Geomagnetism Program monitors the changing geomagnetic field using a network of nine geomagnetic observatories and fifteen repeat stations. The observatories collect calibrated vector data with 1-second sample interval and scalar data with 10-second samples which are sent to Geoscience Australia in near real-time. Among their many uses, these data have excellent application as base station data for magnetic surveys or remote reference data for magnetotelluric (MT) surveys, and for monitoring geomagnetically induced currents (GIC).

These data also contain the subtle signal of the slowly changing main magnetic field that originates in Earth's outer core. An understanding of the scalar main field is essential for main-field removal from magnetic survey data sets. Geomagnetic inclination and declination are required for reduction to the pole techniques. Across Australia, the scalar field is 40% stronger in southern Australia than in the north, the angle of inclination is 50% steeper in the south than the north, and the declination angle varies from about -3 degrees in Western Australia to +15 degrees in Tasmania. Additionally, the rates of change of these field components also differ across the country.

This temporal and spatial dependence of the main field is represented in Australian and international geomagnetic reference field models. In Australia, both the Australian Geomagnetic Reference Field model (AGRF), produced by Geoscience Australia, and International Geomagnetic Reference Field model (IGRF), produced by an international group of modellers, are available to users. Each has its pros and cons and users may select the model most appropriate to their needs.

Key words: Geomagnetism, geophysics

INTRODUCTION

Over 98% of the magnetic field measured at the Earth's surface is of internal origin. It is this main geomagnetic field which makes magnetic navigation and magnetic exploration techniques possible. The geomagnetic field originates in the planet's molten outer core and is influenced by processes that take place in Earth's mantle, crust, atmosphere and on the Sun.

The study of Earth's magnetic field is one of the oldest branches of scientific endeavour. It is believed to have been studied for more than two thousand years, with observations having been recorded for "the past 500 years" (Jonkers, et al. 2003).

The geomagnetic field is dynamic. Its variations range across a broad spectrum of periods from milliseconds to millennia, and wavelengths from metres to thousands of kilometres. In applications such as exploration geophysics, identifying and understanding these variations is key to optimising the information that can be obtained from geomagnetic field measurements.

MAGNETIC-FIELD VARIATIONS

Total-field data measured in exploration geophysical surveys contain signals related to both spatial and temporal magnetic field variations. A critical step in processing and analysing survey data is the identification and removal of the temporally varying signal, leaving only the spatially varying signature. This aspect of data processing can be particularly challenging if the temporal variations themselves have a spatial dependence. This may be the case more often than is commonly appreciated.

Numerous effects cause time dependent magnetic-field variations to have a spatial dependence. One of them is the latitudinal dependence of the amplitude and phase of the solar quiet (Sq) variation (Campbell and Schiffmacher, 1985, 1988; Hitchman et al., 1998a). Figure 1 shows that in the Australian region the amplitude of the total-field Sq variation can be between 60 and 100 nT near the geomagnetic equator, due to the equatorial electrojet, falling to 20-30 nT in southern Australia (Hitchman et al., 1998b). Between geomagnetic latitudes -20° and -30°, across far northern parts of Australia, the amplitude of total-field Sq variations tend to be subdued (15-20 nT) in a band described as the "diurnal doldrums" (Lilley et al., 1999).

Shorter-period magnetic-field variations also exhibit a pronounced spatial dependence in their amplitude and phase. The "coast effect" (Parkinson, 1959, 1962) is a well-known phenomena that modifies magnetic-field variations in the vicinity of the very strong electrical conductivity contrast at continent-ocean boundaries. This effect is frequency dependent, with the influence becoming stronger, and increasingly higher-frequency components of the magnetic field variation being affected, as distance to the coast decreases (Ferguson, 1998; Hitchman et al., 2000).

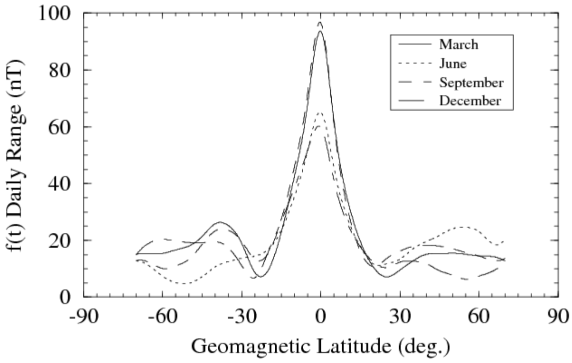

Figure 1. The amplitude range in the average total-field variations for each geomagnetic latitude, derived from a global Sq model. From Hitchman et al. (1998a)

An interesting case related to the coast effect, at east-west trending coastlines and certain magnetic-field inclinations, is the tendency for temporal total-field variations to experience suppressed amplitudes. These locations have been termed "magnetic amphidromes" (Lilley et al., 1999). Although not particularly common in a global sense, the vicinity of the entire southern coastline of Australia has been shown to experience suppressed total-field variations, and therefore to be amphidromic (Lilley et al., 1999; Hitchman, 1999).

Magnetic-field modification also results from heterogeneous electrical conductivity structure (Wang et al., 1997). This heterogeneity may result from the generally variable physical properties of geological structures as well as being associated with well known major electrical conductivity anomalies identified in Australia (Wang, 1998).

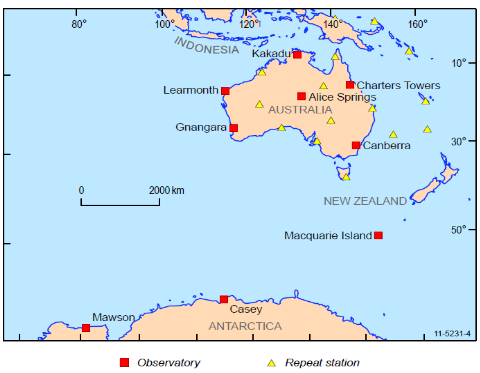

Figure 2. The Geoscience Australia geomagnetic observatory network.

The Geoscience Australia geomagnetic observatory network consists of nine observatories – six in Australia and three in Antarctica and the sub-Antarctic (see Figure 2). In Australia they are located near Perth and Learmonth in WA, Alice Springs and Kakadu in NT, Charters Towers in Queensland, and Canberra in the ACT. While their geographic spread is primarily designed to monitor the slow and subtle changes of the main field from Earth's core, they are also well located to capture data that reflect the variety of magnetic-field effects experienced in Australia. The observatories measure both vector and scalar magnetic-field variations. These data are freely available to interested users.

THE MAIN MAGNETIC FIELD

Other components of the main geomagnetic field are used in processing survey data. These are usually obtained from reference field models such as the Australian Geomagnetic Reference Field (AGRF) model and International Geomagnetic Reference Field (IGRF) model. The AGRF is produced by Geoscience Australia's Geomagnetism Section while the IGRF is produced by groups of international modellers under the auspices of the International Association of Geomagnetism and Aeronomy (IAGA).

The 2010 revision of the AGRF consist of a snapshot of the magnetic field at 2010 and an estimate of how the field will change between 2010-2015 The eleventh generation of the IGRF describes the main field between 1900 and 2010, with a prospective model describing the field between 2010 to 2015. Both the AGRF and IGRF models are updated every five years. The minimum spatial wavelength of the IGRF is about 3000 km (Finlay et al., 2010) at the equator, whereas for the AGRF it is about 1500 km (Lewis, 2010). Because of its shorter minimum wavelength, the AGRF model has a greater long-wavelength crustal field component than does the IGRF. These models are a valuable source of information for main-field removal and reduction-to-the-pole (RTP) in magnetic survey data.

The total field component of the main-field increases from north to south over Australia. In northern Australia the field strength is about 44000 nT, while in southern Tasmania it is about 62000 nT; an increase of 40% over the continent.

RTP techniques typically make use of the inclination (dip) and declination (variation) of the main field to adjust magnetic-field data to appear as if they had been collected at a field inclination of ±90° (Arkani-Hamed, 1988). The required I and D data are usually obtained from magnetic-field models. In Australia, the main-field inclination varies from -36° in the far north to -73° in the far south; an increase of about 50%. The geomagnetic declination in Australia has a maximum value of about +15° in the south east and a minimum of -3° in the south west. The AGRF, last updated in 2010, is a source of this information in the Australian region.

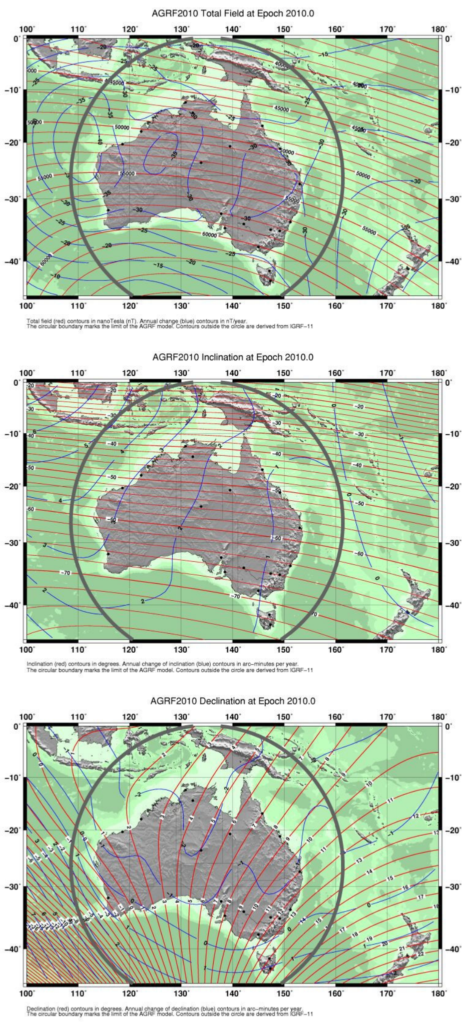

Figure 3. Australian Geomagnetic Field Reference model (AGRF10) components at epoch 2010.0 – total field, inclination, declination – main field (red) and secular variation (blue).

CONCLUSIONS

In the Australian region the geomagnetic field displays significant diversity in its temporal and spatial dependence. A range of effects related to our mid-latitude location on the planet and various geological structures internal to the continent combine to give it an, at times, complicated spatio-temporal relationship.

Geoscience Australia's Geomagnetic Program collects and delivers geomagnetic data and various products derived from these data. These data and data products are available free of charge (www.ga.gov.au/geomag; geomag@ga.gov.au)

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