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Activity of magnetic total intensity across continental Australia

Peter Hopgood, *Geoscience Australia*

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Summary

Geoscience Australia's Geomagnetism Project operates a network of magnetic observatories in the Australian region to produce absolute calibrated long-term secular variation information about the earth's magnetic field. A product of this activity is the availability of high accuracy one-second time resolution vector data that are valuable for many applications. An example is the development of a new method of displaying data from the six permanent Australian continental magnetic observatories in the form of the rate-of-change in magnetic total intensity, dF/dt, contoured over Australia. To examine how well the data from the observatories are able to represent the behaviour of dF/dt over continental Australia, charts produced using data from the observatory sites alone were compared with those produced using data acquired by the Australia Wide Array of Geomagnetic Stations experiment (AWAGS). Although there are limitations brought about by the existence of conductivity anomalies, the information from the permanent observatories provides a useful tool to gauge the activity of the magnetic field over the continent. Near to real-time dF/dt contours are now available on the Geoscience Australia (GA) website at http://www.ga.gov.au/geomag/ .

Introduction

The Geomagnetism Project at GA operates nine permanent magnetic observatories in Australia and Australian Antarctic Territory, six of which are on the Australian continent, one is on Macquarie Island and two on the continent of Antarctica. Vector magnetic field values every one second in time are recorded at all the observatories. The one-second data are filtered to produce one-minute, one-hour, monthly and annual values. Considerable effort is devoted to maintaining accurately calibrated absolute magnetometers and the performance of regular absolute observations at all the observatories. This enables long-term changes in the earth's magnetic field, or secular variation, to be monitored over the lifetimes of observatories, often many decades. To accurately calibrate magnetic observatory variometers it is necessary to monitor changes in the vector magnetic field on as short a time scale as possible. This is to accurately track the constant changes in the earth's magnetic field, primarily driven by current systems in the ionosphere and those subsequently induced in the ground, brought about by the changing position of the sun and its sometimes irregular outbursts of energy. A consequence of the magnetic observatory network's principal operation is that short-term and relative changes in the magnetic field are also available to the geomagnetic community.

Knowledge of changes in the earth's magnetic field is vitally important to many activities such as navigation, communications, mineral exploration and high-altitude and space travel. As the data acquired at magnetic observatories are now transmitted to GA in Canberra in near to real-time, it has become possible to make these available on the GA website also in near to real-time. This has been happening for some time already in the form of magnetogram traces of chosen magnetic components (most frequently declination and total intensity) from each of the observatories over a selected period of days. With the intention of efficiently providing useful information in as close to real-time as possible, a new display of geomagnetic information became available on the GA web site in late 2007.

As users of GA's magnetic data often do not require data from a particular observatory, but rather, are interested in the magnetic field or its activity at other locations, the new format will display geomagnetic information in the form of contours over the Australian continent. The display now available is of the rate-of-change of the magnetic total intensity, dF/dt. Although it would be possible to display the total intensity (or any other component of the earth's magnetic field) in real-time, such a display would appear fairly static and virtually the same as the Australian Geomagnetic Reference Field, AGRF, Total Intensity chart (Lewis, 2005), with no perceptible change over brief time intervals. So the real-time nature of the information would lose its value. A view of the rate-of-change of the magnetic element provides a dynamic display that highlights the activity of the magnetic field at a particular time.

Description

The rate-of-change of the magnetic total intensity, F, or a dF/dt display can be considered a visual index of activity over the Australian continent. To produce the chart, the rate-of-change of total intensity, dF/dt, is estimated over a 15 minute interval of data at the locations of each of the six magnetic observatories operating in continental Australia, and the values contoured over the area. The units on the contours are in nanoTesla per hour (nT/hr).

In the generation of the dF/dt charts a number of choices were required to optimise the usefulness of the data presented. A period of 15 minutes of F data, from which to determine dF/dt, was considered sufficiently long for the changes in F to have a high enough signal-to-noise ratio, yet short enough to be reasonably approximated by a linear trend. (The validity of this assumption reduces with increasing magnetic activity.)

A number of methods to determine the change in F over the 15-minute periods of data were considered. Initially, the raw differences between the F values at the beginning and end of the 15-minute data periods were simply computed, a method suitable for high quality data such as from a magnetic observatory being unlikely to contain noisy or spurious values. To be usable for lower quality data, such as that from the AWAGS experiment, dF/dt was estimated from the average of data in successive 15-minute periods after having a percentage of the highest and lowest values in the periods rejected. The method eventually adopted performed a linear fit to the 15 minutes of data and determined dF/dt from its gradient. (There was not a great deal of difference in the displays of the same data using the different analysis methods!)

Successive dF/dt determinations can be made at any chosen interval but it should be long enough that the successive displays are appreciably different yet sufficiently frequent to be considered in near to real-time. Once again 15 minutes was selected as an appropriate interval. (Shorter intervals could be used, in which case a 15-minute window of data is incremented by, for example, 5 minutes for successive determinations.) The software developed allowed all the parameters mentioned to be varied should the requirement arise.

Limitations of the maps

To examine how well the data from the six permanent magnetic observatory locations can represent the behaviour of dF/dt over continental Australia, charts produced using the observatory sites alone were compared with those produced using data acquired by the AWAGS, experiment (Welsh and Barton, 1996). In that experiment, an array of 54 portable magnetometers was simultaneously deployed across the Australian continent during the period from late 1989 to mid-1990, with a few stations running to the end of 1990. Data from the four magnetic observatories: Gnangara (GNA), near Perth, WA; Canberra (CNB), ACT; Charters Towers (CTA), Queensland; and Learmonth (LRM), WA; in existence at the time, supplemented the portable magnetometer data, so the full data set comprised 58 sites. To test how data from the six present-day observatories represented dF/dt variations over the continent compared with how data from the 58 AWAGS experiment sites did, two of the portable magnetometer sites were used as surrogate observatory sites – at Alice Springs (ASP) and Darwin (in place of Kakadu (KDU) observatory) in the NT.

Unfortunately there were some extended gaps in the ‘observatory’ data set during the time that the AWAGS experiment took place that limited the days on which these comparisons could be made. Notable gaps in the 1990 data were: at Gnangara, between days 121 and 181; Alice Springs, between days 042 and 126, and 153 and 217; and at Darwin, between days 084 and 093, 120 and 134 and 162 and 176. Consequently, comparisons could only be made using data acquired in December 1989 and January 1990. Data missing from the non-observatory sites were not so limiting.

Broad similarities of the contours were found in displays produced during moderately magnetically disturbed conditions using data from all the AWAGS stations and those produced from a subset of stations equivalent to the Australian continental observatories, giving support that the six observatories may, at least in some conditions, provide indicative dF/dt over the continent. However, geomagnetic activity is not the only condition that will affect how well data from the observatories alone can represent dF/dt across the whole continent. The effect of a two-hour phase difference in the daily solar quiet component of the field, the *Sq*, is superimposed upon any irregular activity of the magnetic field that will be largely synchronous over Australia, although the amplitudes will vary with location.

The reasonably good representation of dF/dt over the continent using data from the six observatories alone may be explained by the wide distribution of the observatories over longitude (local time) and latitude (distance from the *Sq* focus).

Conductivity and other anomalies

As the continental observatories are mainly situated towards the continental margins, dF/dt data from them may be expected not to be particularly representative of the inland. However the *coast-effect*

(Hitchman *et al*., 2000) that enhances the amplitudes of variations, principally in the vertical magnetic intensity, over a period range from a few minutes to a day, diminishes, more strongly with increasing frequency, as the distance from the coast increases. (At daily variation harmonics the *coast-effect* can actually reduce amplitudes through destructive interference (Lilley *et al*., 1999)). Because the rate-of-change of F is being considered, long period variations will not be as dominant in the maps as the shorter ones. As increasingly shorter periods are attenuated more strongly as the distance from the coast increases it follows that the dF/dt data from the Canberra and Charters Towers observatories are not strongly affected by the *coast-effect*, Charters Towers less so than Canberra (Milligan, 1988).

The sea to the north of Darwin (and the Kakadu observatory) is relatively shallow so the *coast-effect* will have a reduced effect upon data from that site.

The above considerations are not the case for the Gnangara and Learmonth observatories on the coast of Western Australia where the *coast-effect* enhances the amplitude of vertical intensity (and so F) variations that results in them being higher than inland of these sites. This is seen in dF/dt displays where the magnitude of the contours in Western Australia reduce less rapidly moving away from the coast when only data from the observatory sites are used for the map.

The *coast-effect* will therefore compromise how well dF/dt data at the observatory locations alone can describe the whole continent by either affecting the observatory data themselves or by affecting areas to be characterised using unaffected observatories.

The magnetic observatory at Alice Springs is very valuable as it is virtually free of the *coast-effect* and other conductivity anomalies.

Like the *coast-effect*, other conductivity anomalies, such as that implied by the AWAGS survey in the form of a broad U-shape roughly around the borders of the Northern Territory and those near the Eyre and Yorke Peninsulas (Chamalaun and Barton, 1992) will distort magnetic variations in their vicinity and so reduce the effectiveness of data from the observatories alone to represent the whole continent.

The morphology of undisturbed regular variations in components of the earth's magnetic field, the *Sq*, as a function of latitude and local-time has been well documented (see Hitchman *et al*., 1998).

Because of the mathematical relationships between the magnetic elements F, H and Z,

$$F = \sqrt{H^2 + Z^2} \quad \text{and so} \quad dF = \frac{1}{F}\left(H \cdot dh + Z \cdot dZ\right),$$

variations in F more closely follow those in H near the equator (where Z is small) and more closely follow those in Z near the poles (where H is small). At any latitude the morphology of the *Sq* is seen to also vary with season. The diurnal curves are indicative behaviour only and are modified in the presence of regional and local induction in conductive structures in the earth and oceans (Chamalaun and Barton, 1992).

A phenomenon called *magnetic amphidromes* is described (Lilley *et al*., 1999) as being locations where short-period fluctuations in F over time are very small to negligible. During geomagnetically active periods *magnetic amphidromes* were found to occur in locations that would have been expected to exhibit appreciable total intensity fluctuations were it not for the proximity of conductive structures. An example was shown to be at Wycheproof in western Victoria. During geomagnetically disturbed conditions, fluctuations in Z and H with periods of an hour or less in the presence of highly conductive structures can vary in a proportion that creates little change in F, only in its direction, i.e. variations are in the preferred plane, perpendicular to F. Because of the geometry it was pointed out that this was more likely to happen at locations in higher latitudes, both predicting (and observing at some sites) the phenonenon at a number of locations along the southern coast of continental Australia. Like conductivity anomalies, effects of *magnetic amphidromes* cannot be represented by data from the observatories.

Diurnal doldrums were also described (Lilley *et al*., 1999) as a minimum in the quiet diurnal F variations within the 20°–30° geomagnetic north and south latitude bands, potentially affecting how well data from the observatory locations can represent the whole continent. In Australia the *diurnal doldrums* area includes the most northerly region of the continent, from a latitude between that of ASP or LRM and that of CTA and extending to the most northerly regions of the continent. In Australia these regions are equatorward of the *Sq* focus (~35°S geomagnetic latitude) at geographic latitude ~25°S. The maximum amplitude of total field fluctuation was shown (Lilley *et al*., 1999) to occur between geomagnetic 34°S and 44°S in Australia.

As the total-field *diurnal doldrums* is not a localised phenomenon, the observatories within them will be affected to the same extent as other locations at their latitude. Consequently, the variations recorded at those observatories may be expected to be representative of those taking place in this band. The observatories at CTA and KDU are in the affected latitude region.

Animations

In a 15-minute period dF/dt changes appreciably over the Australian continent. On some days it was useful to create 5-minutely or more frequent maps. To observe the changing dF/dt, the periodic displays of the AWAGS data alongside the observatory alone data were combined to create animations over a day at a time. These were valuable in quickly observing over a period of a day, how well data from the observatories alone represented dF/dt over the continent in comparison to all the AWAGS stations.

A major study of the AWAGS data has been carried out (Whellams, 1996) in which animations were used extensively to interpret the results.

Additional Stations

The value of additional stations acquiring data to contribute to dF/dt maps of Australia will depend on a number of factors. More stations will clearly produce a better estimate to the actual behaviour of the magnetic total intensity over the continent. But the question remains as to where additional stations should be situated to gain the most value.

Placement of more stations in areas where there is most need to know the total intensity behaviour has its attraction, but may be at the expense of a more complete or uniform coverage of the continent. Such locations will be in areas where airborne magnetic surveys are likely to be performed such as in mineral rich provinces.

The best coverage of Australia will be to position stations to complement the permanent observatories in areas where interpolation will otherwise produce spurious results or spatial aliasing. Identification of sites that will be most suitable during all seasons and phases of the solar cycle, various levels of magnetic activity, and taking into account the locations of magnetic anomalies, *amphidromes* and *doldrums*, and the path of the *Sq* focus, is a complex problem.

The most likely locations of any new stations, however, may be dictated by convenience and be at sites on which other installations exist, e.g. at magnetic repeat survey sites (typically on airports); permanent field stations of other GA activities such as seismic or gravity; or those of other organisations.

There is also a possibility of creating what could be termed *virtual observatories* by creating models that use the permanent observatory data to generate estimates of magnetic field variations at the sites of some or all of the AWAGS stations or repeat survey stations (see also the magnetic models of NASA, 2007).

Conclusion

Although there are limitations in fine detail when representing the rate-of-change of the earth's magnetic total intensity over the Australian continent using data from the six permanent magnetic observatories operated by Geoscience Australia, an indication of the magnetic activity over the continent can be visualised with the contour charts described. The displays compliment the Aeromagnetic Risk Map of Australia (Barton, 1997).

A display of dF/dt using past data through to near real-time, with animation capability, is now available on the GA website at: http://www.ga.gov.au/geomag/.

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