The magnetic daily variation in Australia: dependence of the total-field signal on latitude

Adrian Hitchman
Research School of Earth Sciences,
Australian National University,
Canberra, ACT 0200.
Phone: (02) 6249 3424
Fax: (02) 6249 0738
Email: adrian@rses.anu.edu.au

F.E.M. (Ted) Lilley
Research School of Earth Sciences,
Australian National University,
Canberra, ACT 0200.
Phone: (02) 6249 4174
Fax: (02) 6249 0738
Email: ted.lilley@anu.edu.au

Wallace Campbell
World Data Center A,
Solar-Terrestrial Physics,
NGDC/NOAA Mailstop EGC2,
325 Broadway,
Boulder Colorado 80303-3328, USA
Phone: (+303) 497 6093
Fax: (+303) 497 6513
Email: whc@luna.ngdc.noaa.gov

Francois Chamalaun
School of Earth Sciences,
Flinders University of South Australia,
PO Box 2100,
Adelaide, SA 5001.
Phone: (08) 8201 2319
Fax: (08) 8201 2676
Email: mgfhc@es.flinders.edu.au

Charles Barton
Australian Geological Survey Organisation,
GPO Box 378,
Canberra, ACT 2601.
Phone: (02) 6249 9611
Fax: (02) 6249 9986
Email: cbarton@agso.gov.au

ABSTRACT

The quiet daily magnetic variation, denoted Sq, occurs as a background signal during magnetic surveying. The morphology of Sq is dependent on a number of factors, particularly latitude. Type curves that describe the latitudinal dependence of the horizontal and vertical components of Sq on a global scale appear in many texts. This paper first describes a recent compilation of global Sq curves for the total magnetic field, which is the component of most relevance to magnetic mapping.

An analysis is then made of total-field variations from a north-south line of stationary recording magnetometers which operated across central Australia as part of the AWAGS experiment of 1989-1990. These data are analysed for information on the magnetic daily variation across the Australian continent, particularly its latitudinal variation. Observations cover a full year and their analysis is divided into four seasons to show variation with season as well as with latitude. The observed data show a minimum in the total-field signal in the geomagnetic latitude band 20°-30°, in support of the global Sq total-field curves. There is also clear evidence in the AWAGS data for the path of the Sq focus across Australia, identified by an amplitude minimum in the daily variation of the horizontal magnetic north component. The band in which the total-field Sq variations are generally reduced is termed the total-field "doldrums"; this band is on the equator-side of the path of the Sq focus.

Keywords: daily magnetic variation, total magnetic field, diurnal, Sq, magnetic mapping

INTRODUCTION

All mapping of spatial magnetic patterns takes place while the magnetic field changes with time. The most basic of these temporal magnetic changes is the quiet daily variation, often denoted Sq (for 'solar quiet'). While empirical procedures exist for the removal of Sq effects from magnetic survey data, a better understanding of the characteristics of Sq at both the planning and execution stages of a magnetic survey may help in minimising its temporal effects.

Fundamental information to have for reference, when planning and executing magnetic surveys, might thus be type curves that predict the quiet daily magnetic variation for the area to be surveyed. However, while such type curves for the horizontal and vertical components of the magnetic field may be referred to in texts such as Parkinson (1983) and Campbell (1997), type curves for the "total" field, the component of primary relevance to magnetic mapping, are not readily available.

A recent compilation of total-field type curves (Hitchman et al., 1998) is intended to fill this need. The curves are derived from global observatory data for the International Year of the Quiet Sun (IQSY, 1965). In the present paper, in part to check the applicability of the global curves on a regional scale, the type curves predicted for Australia are compared with daily variation data recorded on a north-south line of stations across the continent. The data were obtained during 1990 as part of the Australia-wide array of geomagnetic stations (AWAGS) experiment (Chamalaun and Barton, 1993).

For other parts of Australia, as for other continents and particularly coastal areas, additional effects may be present to help shape the local form of Sq. For example, the Sq analyses of Bennett and Lilley (1973), Lilley and Parker (1976) and Lilley (1982) show the influence of induction at coastlines on the daily magnetic variation over southeast and southwest Australia. In the present analysis there is an intentional use of an inland line of observing stations to minimise coastal influences.

MODELLED TOTAL-FIELD Sq VARIATIONS

The basis for the present set of type curves is the analysis of Campbell et al. (1989). This analysis used data obtained from the global network of magnetic observatories during the IQSY and produced a numerical model that gives Sq variations of the magnetic field components at all locations on the globe. The Campbell et al. (1989) model was then adapted by Hitchman et al. (1998) to yield type curves for total-field Sq variations.
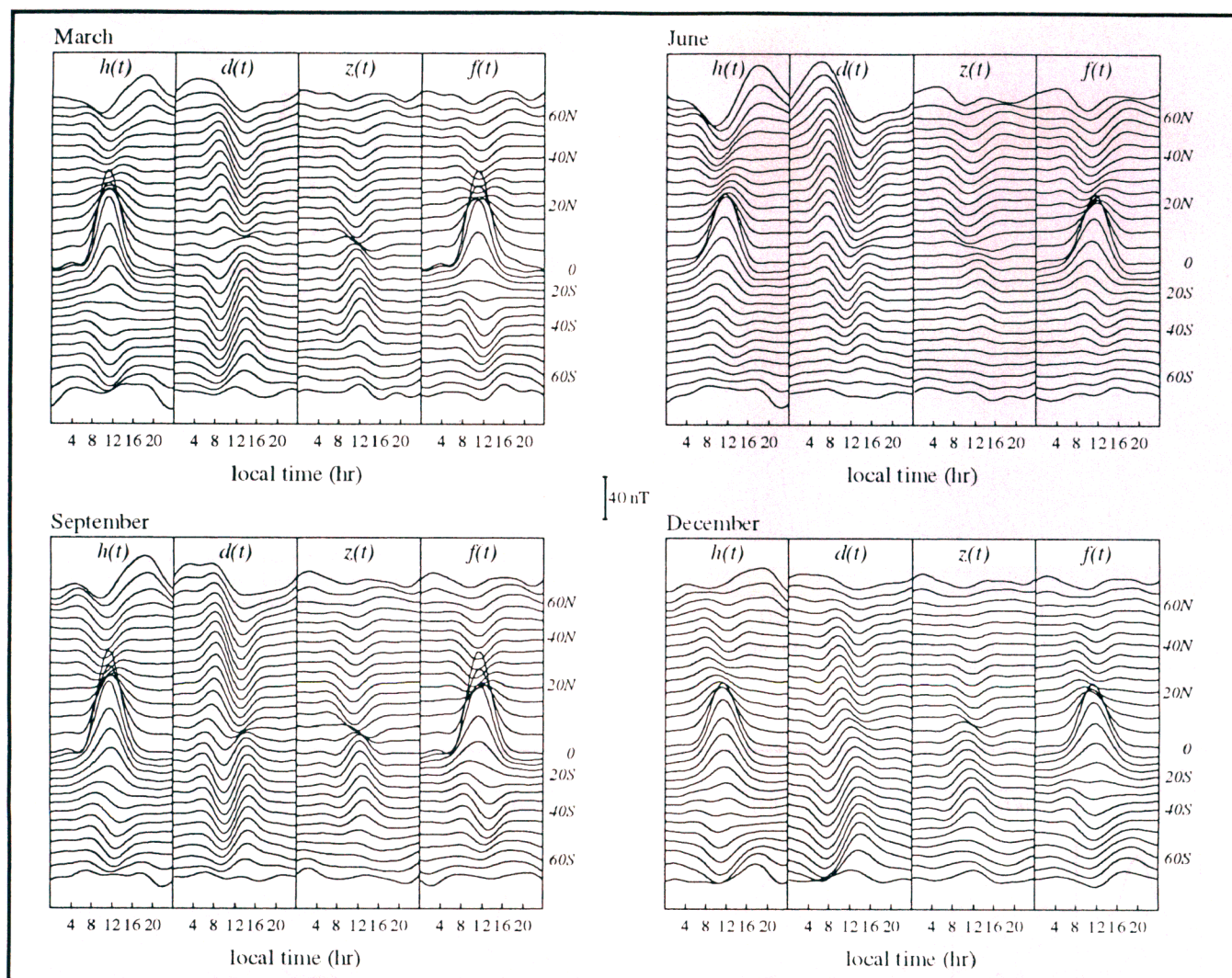
Figure 1. Global *Sq* curves for the seasons of the year. The curves are obtained by averaging variations in latitudinal bands (geomagnetic) around the globe. They should be understood as indicative of *Sq* behaviour at these latitudes and do not take into account possible regional and local effects. From Hitchman et al. (1998).

Figure 1 presents the type curves from Hitchman et al. (1998) for the *Sq* variations in the components of magnetic north, $h(t)$, magnetic east, $d(t)$, vertically downwards, $z(t)$, and the total field, $f(t)$. These curves are representative of the general form of the *Sq* variation that might be expected at a given geomagnetic latitude. They provide useful insight into the pattern of global variability of *Sq* and possess three features particularly pertinent to this paper.
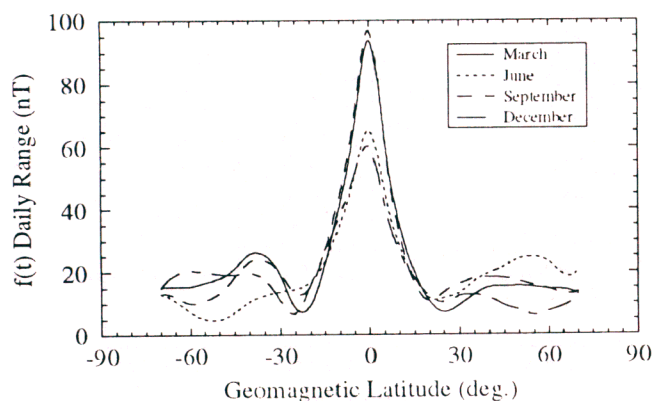

Figure 2. The amplitude range in the average total-field variations for each geomagnetic latitude, derived from the global *Sq* model. From Hitchman et al. (1998).
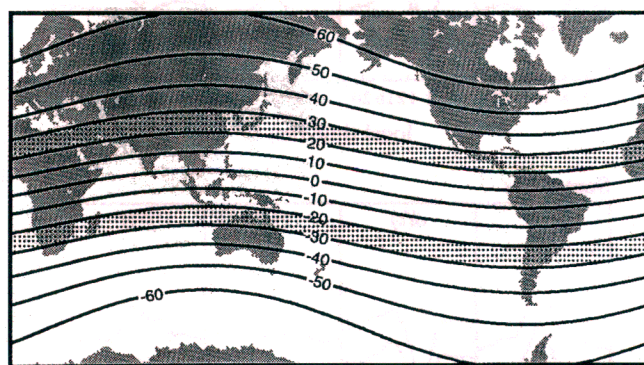

Figure 3. A global view of the geomagnetic latitude, obtained from the 1945 to 1985 DGRF and IGRF reference field models, for 24 March 1997. The stippled bands between geomagnetic latitudes 20° and 30° in the northern and southern hemispheres indicate where the total field is expected to have substantially reduced daily amplitudes – the "diurnal doldrums". After Lilley et al. (1998).

- The effect of equatorial electrojet currents is clear in both the horizontal north component and the total field, from the enhanced amplitude of variations in equatorial regions (Egedal, 1967).
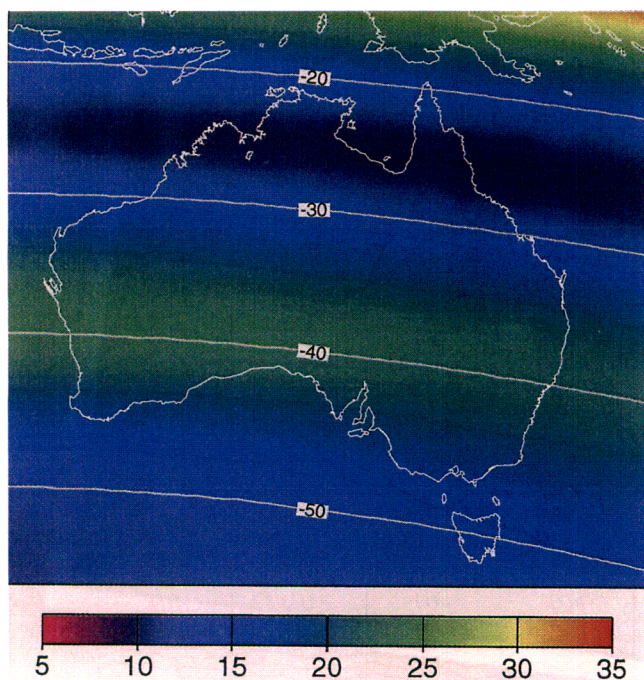
Figure 4. The amplitude of the total-field *Sq* magnetic signal (in nT) predicted for the Australian region.
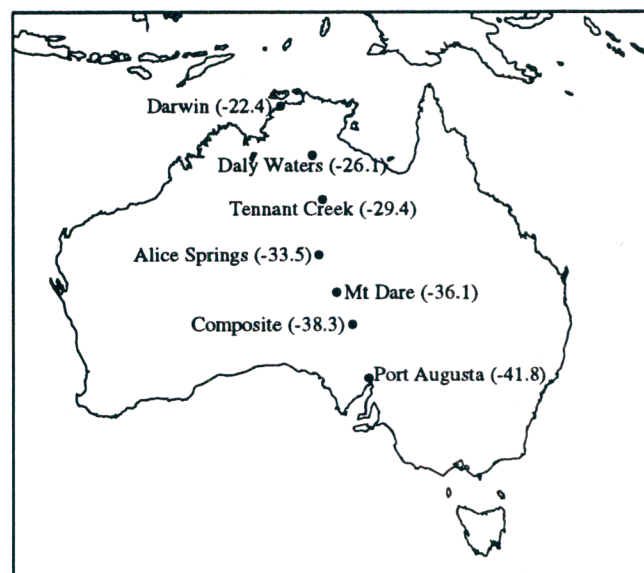

Figure 5. The locations of AWAGS stations used to obtain *Sq* data for comparison with the modelled total-field curves. The figures in brackets are the geomagnetic latitude of each station.
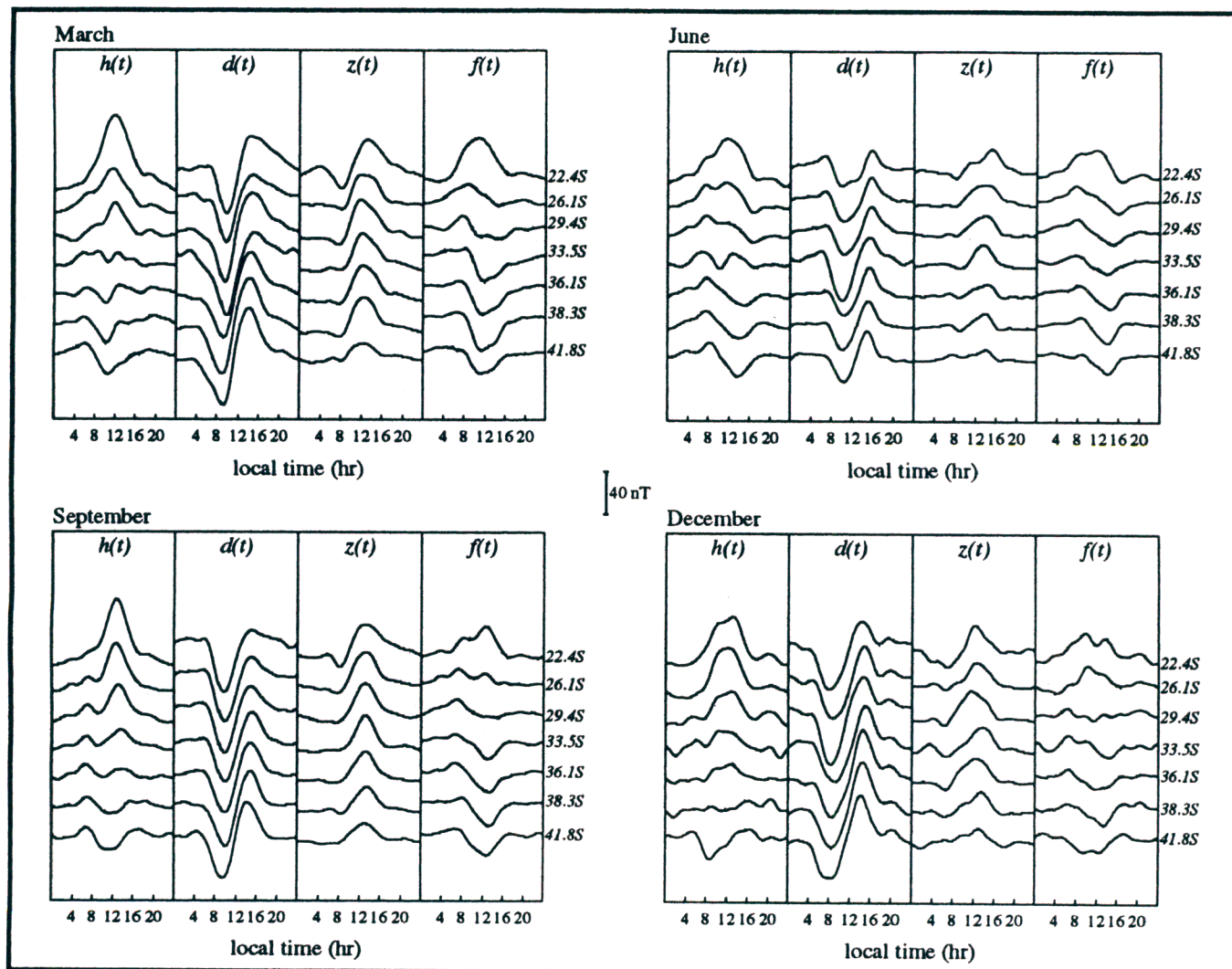

Figure 6. The *Sq* variations obtained from data collected during the AWAGS exercise. They are for dates that are the midpoint of each season presented in Figure 1. Geomagnetic latitudes are given for each station.
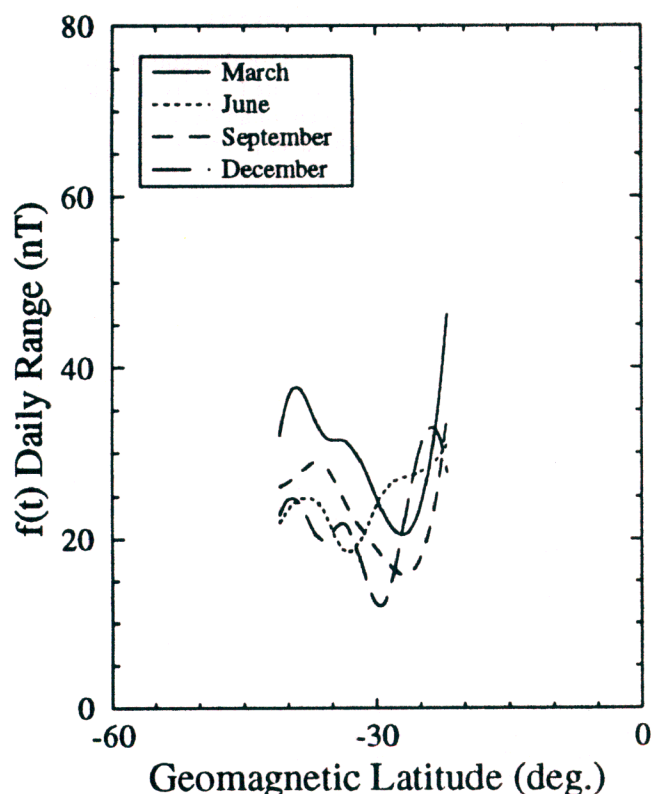
Figure 7. The range in the total-field Sq variations, $f(t)$, obtained from data collected during the AWAGS exercise.
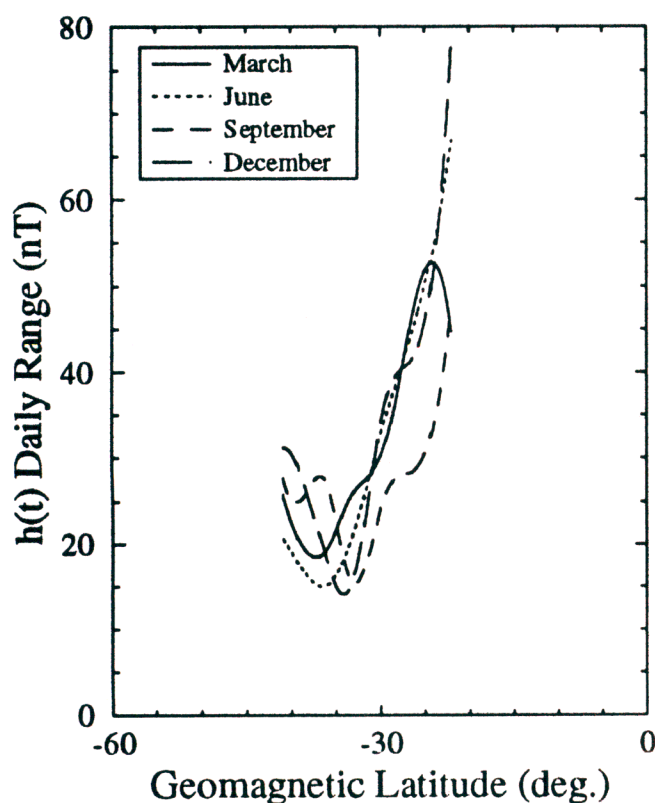

Figure 8. The range in the horizontal magnetic north component of Sq variations, $h(t)$, obtained from data collected during the AWAGS exercise.

- An important feature of the type curves is the substantial reduction of amplitude experienced by total-field variations, $f(t)$, in latitudinal bands on either side of the geomagnetic equator (Figure 2). We have termed these bands, which lie between 20° and 30° on both sides of the equatorial electrojet, the total-field "doldrums" (Hitchman et al., 1998). A map showing the general position of these doldrum bands is given in Figure 3.
- Of particular relevance to magnetic mapping in Australia is the presence of the total-field doldrums across the northern part of the continent. Awareness of their existence ensures a better understanding of the total-field Sq variations to be expected when conducting a magnetic survey in this region.

The amplitude of the total-field magnetic signal, $f(t)$, for quiet days is shown for the Australian region in Figure 4. In this figure the results for the different seasons have been combined to give an annual average. Contours of geomagnetic latitude are also shown. Note the reduced signal across northern Australia, where there is a "doldrums" band.

Local effects, such as the coast effect and induction at continental conductivity anomalies, may modify the type curves of Figure 1 and the regional pattern shown in Figure 4 (Lilley et al., 1998).

FIELD DATA

The AWAGS experiment, conducted during 1989-1990, involved the deployment of 57 three-component magnetometers across Australia (Chamalaun and Barton, 1993). To analyse upper mantle conductivity, Campbell et al. (1998) computed annual, semi-annual and daily Fourier coefficients describing the variations of field components for a subset of AWAGS stations that bisected the continent in a north-south line (Figure 5). Data recorded during magnetically quiet days at each of these stations are now taken in this paper to characterise the latitudinal variation of Sq in Australia and to verify the morphology of the predicted type curves.

Coefficients from the Campbell et al. (1998) analysis, for the magnetically quiet days during AWAGS, were used to recreate the Sq variations in the components $x(t)$, $y(t)$ and $z(t)$ at the seven central Australian stations, where $x(t)$ and $y(t)$ denote variation components in the directions of geographic north and geographic east, respectively. The time series $h(t)$, $d(t)$ and $f(t)$ were then derived according to

$$h(t) = x(t) \cos \mathcal{D} + y(t) \sin \mathcal{D},$$
$$d(t) = y(t) \cos \mathcal{D} - x(t) \sin \mathcal{D},$$

and

$$f(t) = h(t) \cos \vartheta + z(t) \sin \vartheta,$$

where $\mathcal{D}$ and ϑ are the epoch values of the declination and inclination, respectively, determined from McEwin (1993).

Figure 6 shows the Sq curves for $h(t)$, $d(t)$, $z(t)$ and $f(t)$ derived for each station in each season of 1990. These curves show smoother variations than might have occurred on any particular day. Comparison of Figures 1 and 6 confirms that the modelled Sq variation curves for $f(t)$ are indicative of the morphology observed by the AWAGS array in central Australia.

Figure 7 shows the range of the $f(t)$ signals for Sq at the AWAGS stations, plotted as a function of geomagnetic latitude. Bands of subdued variation are evident between 20° and 30° geomagnetic latitude, in each season.

The location of the total-field doldrums in relation to the position of minimum signal in $h(t)$, which marks the line of the Sq focus, is highlighted by comparing Figures 7 and 8. It is evident that, in each season, the Sq focus lies poleward of the total-field doldrums. The Sq focus itself is in central Australia approximately at geographic latitude 25°S (geomagnetic latitude 35°S). These results agree with the positions of the Sq focus determined by Stening and Hopgood (1991) and Campbell et al. (1998).

CONCLUSIONS

The 1990 AWAGS data demonstrate the latitudinal dependence and seasonal variability of the magnetic quiet daily variation over Australia. They show the passage of the Sq focus over central Australia, crossing the north-south line of stations at approximately geographic latitude 25°S (geomagnetic latitude 35°S). The AWAGS data also verify the existence of a "doldrum" effect in the total-field variation, present in the geomagnetic latitude band of 20°–30° for Australia and consistent with its existence globally.

The patterns of the form and amplitude of the AWAGS variations are a check on the type curves for quiet days globally, published by Hitchman et al. (1998) using the $IQSY$ model of Campbell et al. (1989). This agreement highlights the usefulness of the global model for predicting the morphology of total-field variations within Australia and worldwide. Such information is valuable as it allows the nature of the most ubiquitous temporal magnetic field variation to be predicted at a place where a magnetic survey is to be made. Such advance knowledge reduces the risk of problems with removal of Sq signal from the survey data, once these data are acquired.

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