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Using observatory data to characterise geomagnetic daily variations

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Abstract

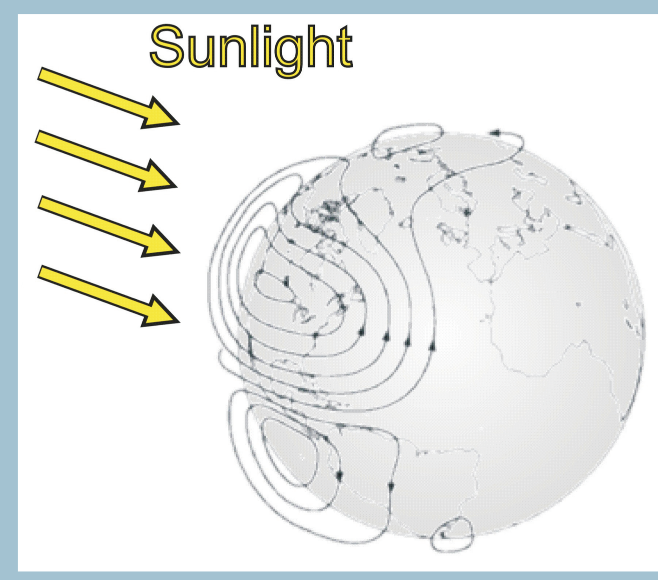
The quiet-time daily variations in the geomagnetic field are known to show strong dependence on latitude, local time, season and solar cycle. In this poster we present preliminary results from surface-harmonic models of these variations derived from ground-based observatories. The data input to the models are hourly means from the five geomagnetically quietest days in June and December 2004 from 98 observatories. These data from each observatory are linearly de-trended and Fourier coefficients are fit to them with a fundamental period of 24 hours and minimum period of 6 hours. Surface harmonics up to degree 4 are then fit to the distribution of each Fourier coefficient, separately. The accuracy of the Fourier and spherical harmonic models with respect to the input data is discussed. We also comment on the geographical and seasonal variations in the model.

Introduction

The daily variations in the Earth's geomagnetic field are caused by (primarily) ionospheric as well as magnetospheric currents.

Ionospheric current vortices in northern and southern hemispheres (see right) arise from interaction of free charges (produced by solar EUV and SXR) with thermospheric winds.

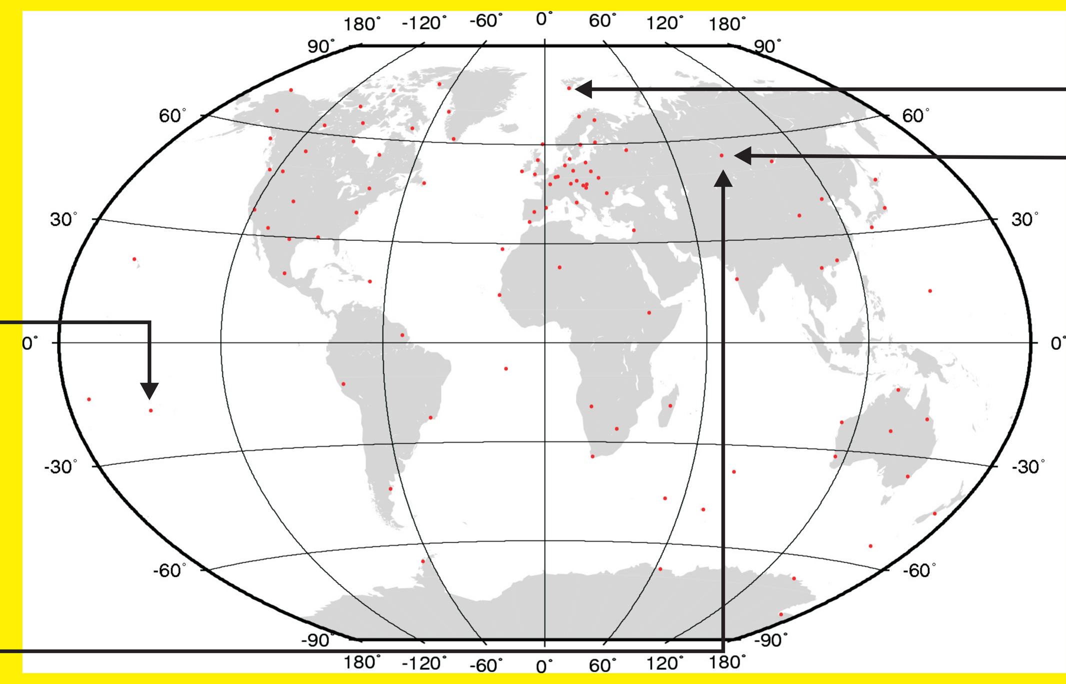
Current systems remain on sunlit side of Earth and cause regular daily variations in geomagnetic field as observatories rotate beneath. Daily variations depend on solar illumination and so also on: latitude, season, and the ~11 year solar cycle.



In this poster we explore surface harmonic models of Fourier series fits to observatory data.

Data used

Hourly mean values of X, Y, and Z field components were taken from the 5 International Quietest Days (ISGI, 2007) in June and December 2004 from 98 Intermagnet observatories (see red dots on map below). The data were collected in *Universal Time* but were adjusted to *Local Time*. Before fitting model coefficients, data were linearly de-trended in order to mitigate the effects of longer-term (> 1 month) variations and also to define the mean daily-variation over the month as zero.



Fourier Harmonic Models (FHMs)

Fourier coefficients are then derived for each month and field-component from a least-squares-fit of a truncated Fourier series:

$$B_t = a_0 + \sum_{n=1}^{4} a_n \cos\frac{2\pi t}{nT} + b_n \sin\frac{2\pi t}{nT}$$

where *t* is time, a_0 is mean value of data (zero from our data selection), a_n and b_n are Fourier coefficients and *T* is the fundamental period (24-hours). We follow previous FHMs (e.g. Campbell, 1989, Barraclough, 1989) and use the first 4 terms (which dominate, see e.g. Campbell, 1997) resulting in a minimum period of 6 hours.

Results

'Goodness of fit' was judged by the *signal-to-noise (S/N)* ratio: the *range of Fourier model time-series* to *standard deviation of the range*:

$$S/N = \frac{\hat{d}_{max} - \hat{d}_{min}}{\sqrt{2}\,\sigma}$$

where $\hat{d}_{max}$ and $\hat{d}_{min}$ are the maximum and minimum of daily variation from the model estimate. σ is the standard deviation of the input data about the model estimate given by:

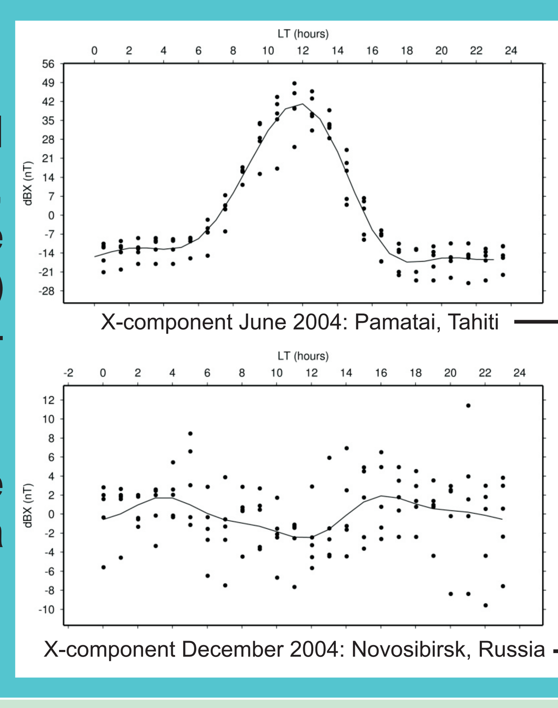
$$\sigma^2 = \frac{1}{N-P}\sum_{n=1}^{N}\left(d_n - \hat{d}_n\right)^2$$

where *N* and *P* are number of data and coefficients respectively and d_n is the nth input datum.

Results con'd

An example of a 'good' (high S/N) and 'bad' (low S/N) fit are shown (right). Over all components, months, and observatories, the model dominates the noise (S/N > 1). S/N<1 occurs for only a few observatories (~1%) with the majority between 1 and 10 and generally better for Y-component than X or Z.

The generally good fits give us confidence in the presence of a regular signal that we use as input to a global model.



Surface harmonic models (SHMs)

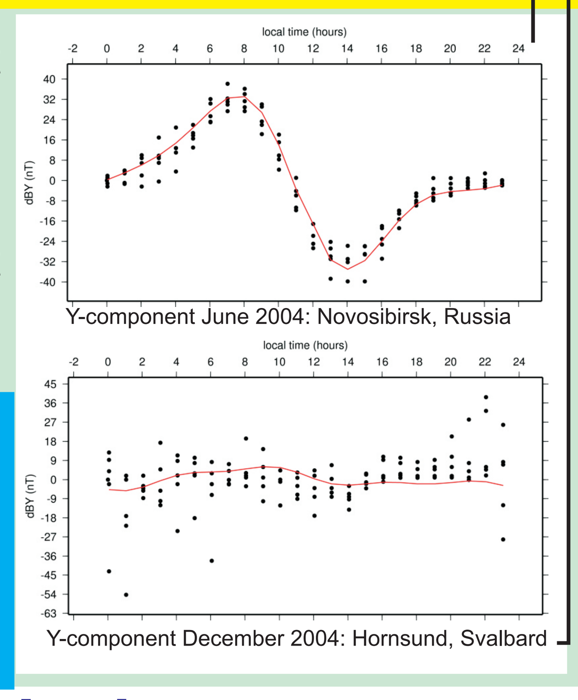
The Fourier coefficients derived from all observatories are grouped by coefficient and surface harmonic coefficients g_l^m and h_l^m are least-squares fit to each Fourier coefficient separately defined by:

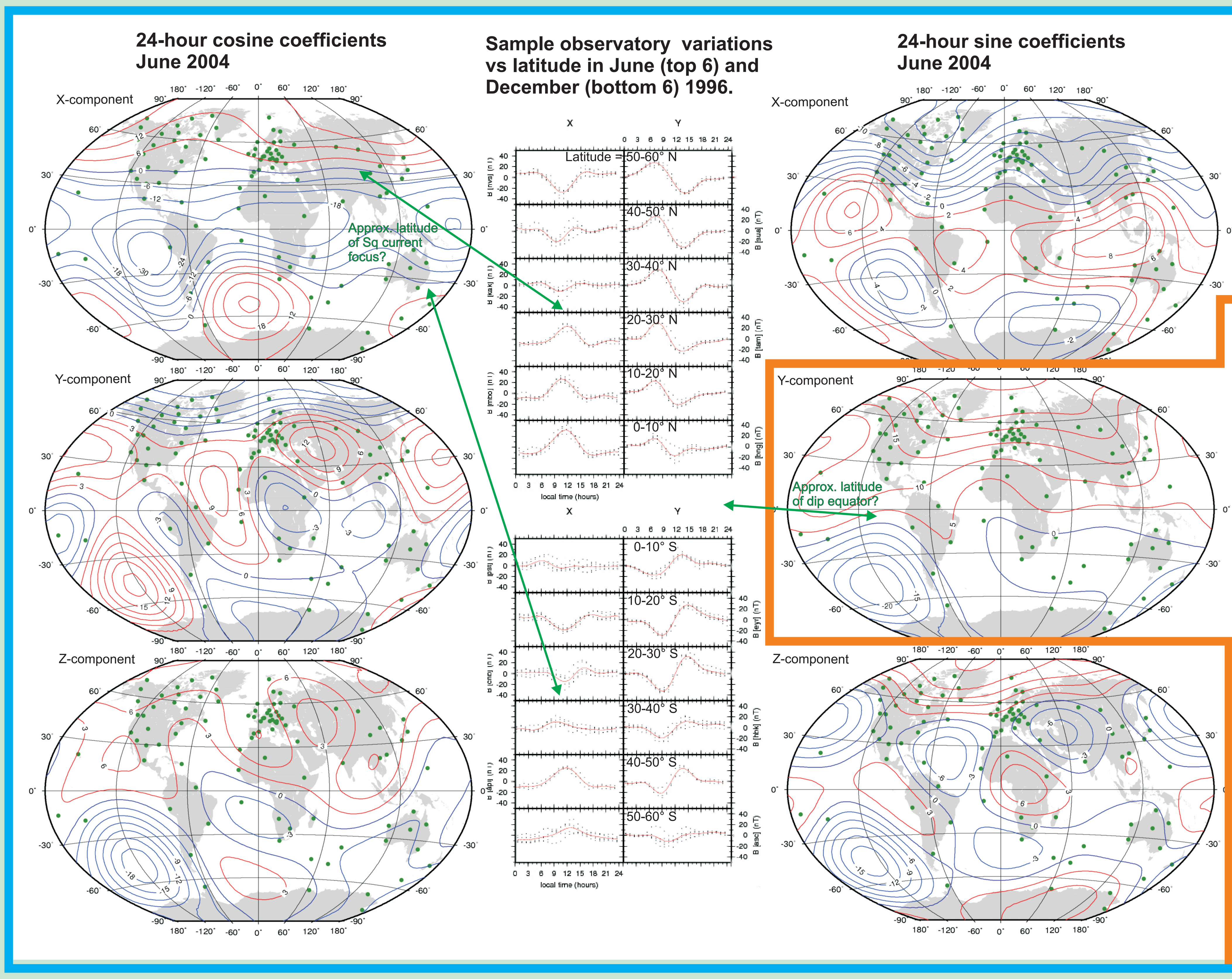
$$C(\theta,\phi) = \sum_{l=1}^{4}\sum_{m=0}^{l} P_l^m(\cos\theta)\left(g_l^m \cos m\phi + h_l^m \sin m\phi\right)$$

where *C* is the Fourier coefficient, P_l^m is the semi-normalised Schmidt polynomial of degree *l* and order *m*. Gauss coefficients are calculated up to degree 4 which results in 25 coefficients per model.

Goodness of fit:

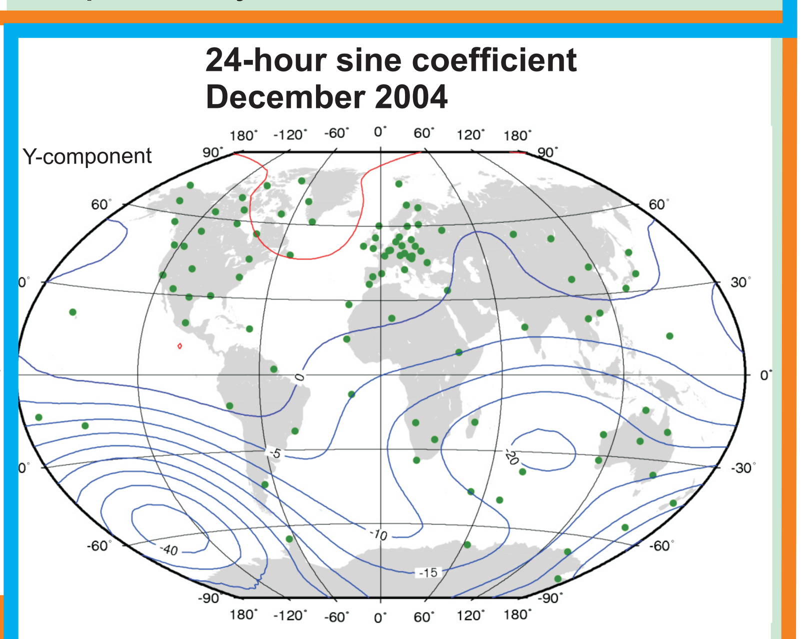
Time-series data is reconstructed by first obtaining the Fourier coefficients from the surface harmonic fits then deriving the time series from the Fourier coefficients. The *goodness of fit* is estimated in the same way as for the Fourier fits (see above left) using the reconstructed and input time-series data. An example 'good' and 'bad' fit are shown (right). In general the fits are good with fewer than 10% having S/N < 1. The fits are generally better for Y-component than X or Z.





Latitude dependence

Below-left are maps of the 24-hour cosine (left) and sine (right) Fourier coefficients derived from the surface harmonic model. Clearly, there are extreme values whereo data is sparse. However, comparison with some observatory time-series plots (middle column) shows the expected flip of the dominant cosine-coefficient (for X) and sine-coefficient (for Y) at the current vortex focus and dip-equator respectively.



Seasonal dependence

Above is shown the December 24-hour sine Fourier coefficient for the Y-field component. Comparison with the June map (above left) clearly shows the coefficient's dependence on season: north-hemisphere (N-H) dominance during N-H summer and vice-versa for S-H.

Conclusions

- We have derived a surface harmonic model of the daily variations in the geomagnetic field based on Fourier series fits to observatory data.
- Although some Fourier series fits are poor, particularly at high latitudes, the Signal/Noise is encouraging and shows a regular signal is being captured by most fits.
- The surface harmonic model shows reasonably good fits to the input data and reproduces basic latitude and seasonal dependence.
- However, the accuracy of the model where observatory data is sparse (e.g. over ocean areas) is unknown.

Future work

- Weight input data to SHMs by S/N of Fourier fits.
- Derive spatial distribution of model uncertainties
- Investigate the effect of damping and principle component analysis on model behaviour.
- Separate internal/external sources.

References

Barraclough, D R. 1989. The daily variation of the geomagnetic field in the region of the North Sea. *British geomlogical survey: Technical report WM/89/25C*.
Campbell, W H. 1989. Global quiet day field variation model WDCA/SQ1. *The compass*, Vol 70, No 5, 66-74.
Campbell, W H. 1997. *Introduction to Geomagnetic Fields*. Cambridge University Press.
ISGI [2007]. Classification of days [online]. Cited December 2007. Available from http://isgi.cetp.ipsl.fr/des_qd.html

Acknowledgements

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