WAVELET-BASED SELECTION OF SATELLITE DATA FOR GEOMAGNETIC FIELD MODELLING

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ABSTRACT

Computation of the geomagnetic field models from the joint inversion of multiple satellite and observatory data constitutes a major scientific aim [1]. A crucial step in this task, prior to modelling the magnetic observations, is data selection. The traditional method of selecting night-side data for internal field modelling is based on using geomagnetic activity indices, such as K_p and D_st. However, there is only one K_p value available for a 3-h interval and one D_st value for a 1-h interval, each giving a global mean value. During that time, a satellite can orbit the Earth a few times, passing also magnetically quiet regions. This can result in the elimination of data not really disturbed. Here, we present an alternative method for data selection, based on the wavelet power spectrum. The first results obtained by applying this method to modelling the Earth's magnetic core field are promising. The comparisons show that reliable results are obtained when wavelet-based data selection is applied.

Key words: core field modelling, data selection, wavelet transform.

1. INTRODUCTION

Core field models cannot be computed from the complete data sets obtained from a satellite's magnetic field measurements. The obtained data are contaminated with signals from ionospheric and magnetospheric sources which would distort main field models if included in data sets used for inversion. Therefore it is necessary to select only those data where external signals are absent or of very low magnitude.

Traditionally the magnetic activity is characterised by two magnetic indices, K_p and D_st. The K_p index is derived at the "Adolf-Schmidt-Observatory for Geomagnetism" in Niemegk (http://www.gfz-potsdam.de/pb2/pb23/Niemegk/en/) while D_st is calculated by the World Data Center for Geomagnetism in Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/). Low values for general geomagnetic activity (K_p) and geomagnetic storm activity (D_st) are hints for quiet magnetic conditions. However, the K_p and D_st indices are global mean values for three hours and one hour, respectively. Therefore it is possible that there are quiet tracks in time intervals evaluated as disturbed by indices or vice-versa. Fig. 1 shows two examples of false selection (top panel) or rejection (bottom panel) of tracks by magnetic indices.

Here, a new way of evaluating the magnetic field activity is presented. A wavelet power spectrum analysis is applied to the data on a track-by-track basis. This makes it possible to extract quiet parts from intervals that, based on the traditional selection criteria, are classified as disturbed or eliminate localised disturbances within quiet periods.

2. METHOD

2.1. The continuous wavelet transform

For the estimation of the data quality and its information content we want to characterise the signal energy on short intervals. Since geomagnetic phenomena and disturbances can be non-stationary and localised in time and space and thus have a time-varying frequency content, the wavelet analysis is an appropriate technique to identify them [2] and evaluate the local geomagnetic activity.

The continuous wavelet transform (CWT) of a discrete sequence x_n is defined as [3]:

$$W_n(\lambda) = \sum_{n'=0}^{N-1} x_n \bar{\Psi} \left\{ \frac{(n'-n)\,dt}{\lambda} \right\}. \qquad (1)$$

Here n is the discrete time index, N the total number of data, λ a scale parameter, and $\bar{\Psi}$ the complex conjugate of an analysing wavelet that is shifted and dilated by the parameters n and λ, respectively. By shifting and dilating the wavelet it is possible to analyse different parts and scales of the signal.

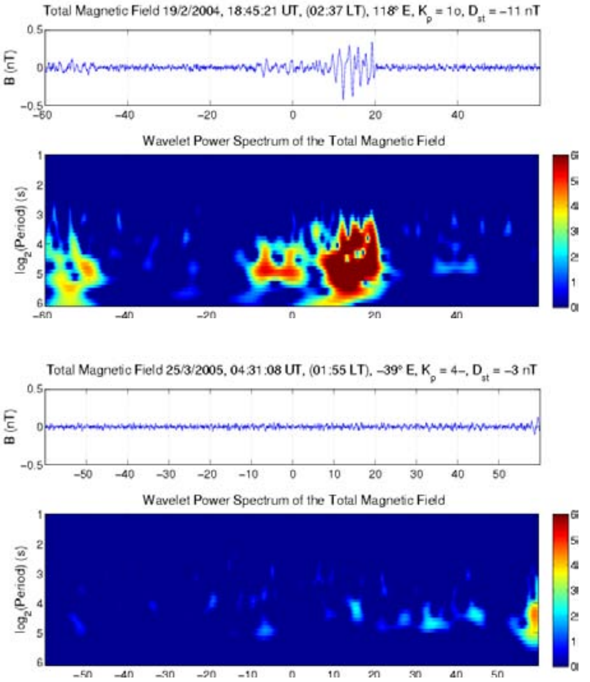

Figure 1. Two examples of false selection of geomagnetic data based on magnetic indices. Date and time (UT and LT) for each track, as well as the magnetic conditions (K_P and D_{st} values) are indicated at the top of each panel. Top: high-pass filtered total field and wavelet power spectrum of a track classified as quiet by K_P and D_{st} showing considerable activity. Data of this track should not be used for inversion. Bottom: quiet track within a time interval considered active by indices. Data of this track are not strongly contaminated by ionospheric sources and can be selected for field modelling.

The choice of the analysing wavelet depends on the features in the signal that one wishes to detect. We used the Morlet wavelet, a complex sine function modulated by a Gaussian, as a basis function (cf. Fig. 2). It is a good choice for the analysis of oscillatory behaviour in a signal [3].

From the wavelet coefficients obtained in Eq. 1 the power of the scale λ at the time (or location) n can be calculated by

$$P_{n,\lambda} = |W_n(\lambda)|^2. \tag{2}$$

2.2. Data selection

In order to focus the analysis on ionospheric and magnetospheric signals the data were high-pass filtered with a 32 s cutoff, prior to analysis. This does not exclude all crustal signals but it is an efficient first step in the development of this new method.

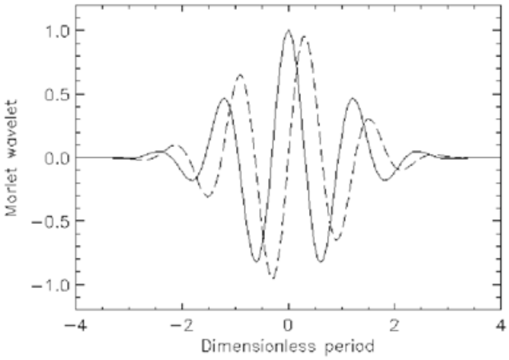

Figure 2. The Morlet wavelet, a complex sine function modulated by a Gaussian with its real part (solid line) and imaginary part (dashed line). The spatial localisation of this analysing kernel makes it possible to study local features of a signal. Due to the wavelet's shape the analysis focusses on the oscillatory behaviour.

We then analysed the data on a track-by-track basis. Tracks of scalar data consist of the satellite path between the northern and the southern turning points while vector data tracks were confined to the region between -60° and +60° latitude in Geomagnetic Dipole Coordinates. Only night-side data between midnight and 06:00 LT were considered.

For each track we calculated the CWT for scales ranging from 1 s to 32 s. From the obtained wavelet coefficients the wavelet power spectrum was calculated. To the wavelet power spectrum we applied a simple threshold criterion, i.e. if the power did not exceed a certain value then the data of that track were allowed for inversion. In the case of vector data this has been done for both, the total field and the northward component, since the latter almost always gave significantly higher residuals than the other components when applying the threshold criterion only to the power spectrum of the total field.

A reasonable choice of the threshold is very important for the analysis since it determines the balance between clean data and a good global coverage with vector data. A low threshold allows only very clean data to enter the inversion. That leads to models with low residuals on the one hand, but non-unique solutions due to the Backus effect, on the other hand. Therefore, different thresholds were tested. It turned out that the method is more sensitive to variations of the threshold imposed on the northward component than to those imposed on the total field. Fig. 3 shows the global coverage with vector data for three cases, using low, intermediate and high thresholds in the data selection.

3. RESULTS

We produced 3 sets of wavelet-selected data for every tested threshold, two of them covering 6 months in 2004,

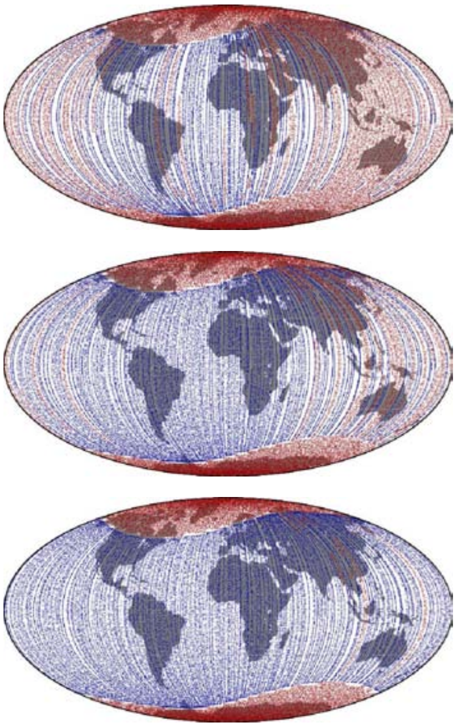

Figure 3. Global coverage with vector and scalar data for three different thresholds used in the analysis. Shown are results of data selection with a low threshold (top panel), an intermediate (middle) and a high threshold (bottom). For the high threshold the coverage is almost complete but even the few missing tracks at about 120°E cause the solution to become non-unique in that region (cf. Fig. 6). Red: scalar data, blue: vector data.

the third covering the whole year 2004. From these data sets main field models were calculated.

Fig. 4 shows the calculated residuals of the total field and the north component for each threshold tested in the wavelet selection. The higher the threshold the greater the residuals. For strict criteria the rms-residuals are comparable to residuals of models based on traditional data selection (cf. Fig 5).

In order to estimate the reliability of the inverted main field models they were compared to models calculated from indices-selected data of the same time intervals. The differences between the models based on the two selection methods (using a high threshold for wavelet selection) can be seen in Fig. 6. The differences are large where the coverage with vector data is not complete and thus the solutions of the inversion become non-unique due to the Backus effect.

Therefore the choice of the threshold is a tradeoff between reliability of the model on the one hand and conformity of data and model on the other hand.

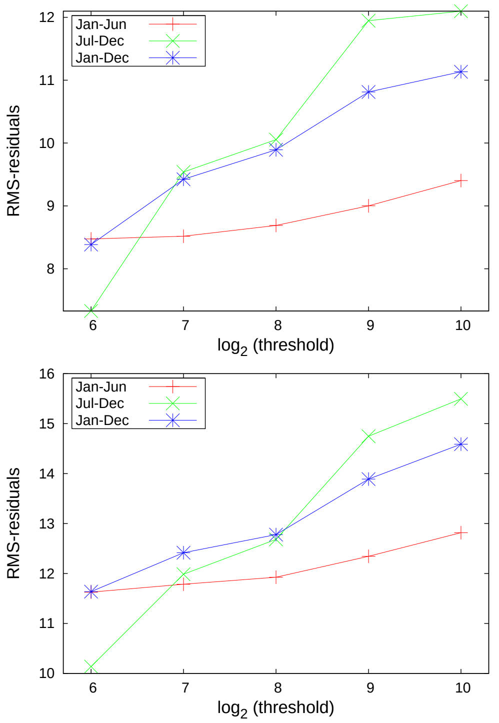

Figure 4. Residuals of the total field (upper panel) and the Northward component (lower panel) against the threshold used in the data selection for different inverted time intervals. For strict selection criteria, i.e. low thresholds, the residuals are low. This holds for all considered time intervals, even though not with the same clarity in all cases.

4. CONCLUSION

We have developed and tested a data selection method for satellite data that is independent of geomagnetic indices and have obtained promising results. From the selected data sets we were able to derive main field models having rms-residuals comparable to models based on traditional data selection, at least for strict selection criteria.

However, when inverting CHAMP magnetic data selected by the wavelet method we found that global coverage with vector data is a major necessity for obtaining reasonable results. Therefore we favour a rather high threshold although this leads to higher residuals. Here further improvement of the method is necessary in order to obtain full global coverage with clean vector data.

Until now, in one data selection run the same threshold was applied to the power spectra of all tracks. This way there is also noisy data selected in regions where a stricter threshold is sufficient to ensure good coverage. A procedure using different selection criteria for different tracks, depending on noise level, seems appropriate to ensure cleanest data possible and good coverage at the same time. Our work is currently focused on that aspect. With improved data selection it will be another task to shorten

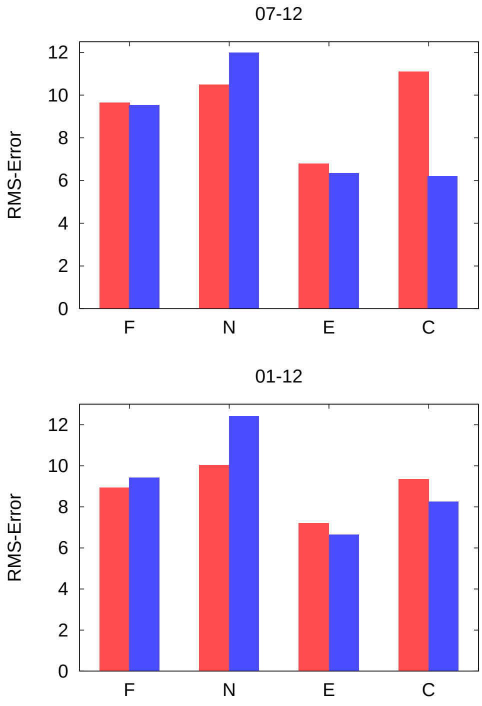

Figure 5. Residuals of models from two time intervals in 2004 for the total field (F) and the three vector components (N, E, C). The residuals of models calculated from indices-selected data are shown in red, those of wavelet-selected data are shown in blue. In the wavelet-based data selection a low threshold (2^7) was used.

the time intervals from which we take data in order to obtain snapshots of the Earth's magnetic field, important for short time fluid flow calculations.

We have applied the described method to CHAMP data over 2004 only. The next step will be the analysis of all available magnetic data from the CHAMP satellite. With such an extended analysis it will be possible to better understand the influence of the involved processes and signals on the power spectrum and thereafter define a magnetic index based on satellite data only.

This method is also suitable for estimating the quality of magnetic data from other planets where no ground stations are available for the calculation of indices. Application of our method to those data is another interesting task for the future.

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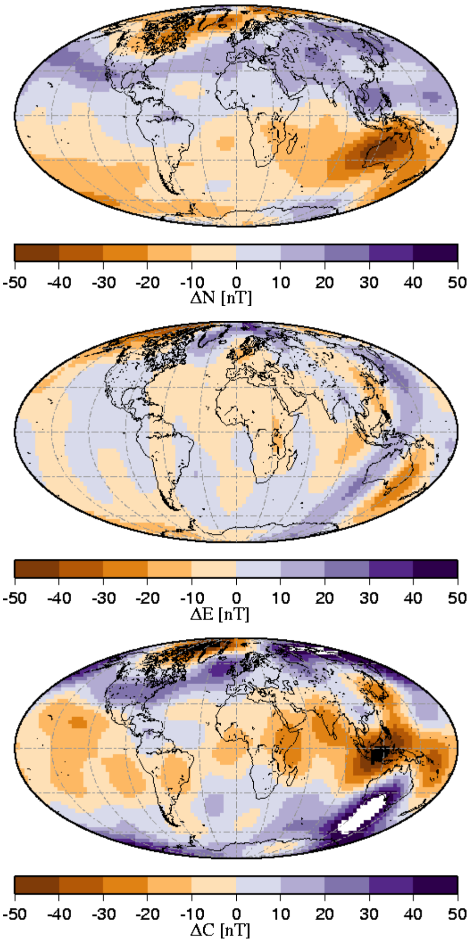

Figure 6. Differences between a model based on indices-selected data and one based on wavelet-selected data for the three field components. The period from which data were taken is Jan–Dec, 2004. The differences are large in regions where the coverage with vector data is sparse, i.e. over Indonesia and south of Australia (cf. Fig. 3).

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