How does the external magnetic field influence the 1969 geomagnetic jerk detection?

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Abstract

Geomagnetic jerks are the most rapid phenomena of the core dynamics. Their study is important for the understanding of core dynamics and mantle conductivity. Although jerks have an internal origin, its detection in observatory and satellite data, is highly influenced by the external magnetic field contributions. In this paper we quantify the influence of the external field on geomagnetic jerks detection. We compare the 1969 jerk (X, Y and Z components) in two synthetic datasets, both from CM4 model (Sabaka *et al.*, 2004): the first only core magnetic field and the second the core, including external and induced fields. Both are compared to real data from magnetic observatories.

Introduction

Time variation of the Earth's magnetic field is caused by different sources: solar activity and variability (solar flares, coronal mass ejections, etc), changes in the fluid flow of the outer core and interactions between the solar wind and the core field. These variations includes a wide time-scale, from seconds to hours (external origin), from months to decades (overlapping between external and internal sources) and millennial periods (internal origin).

The geomagnetic secular variation (SV) is calculated by the first time derivative of the Earth's magnetic field, from few to hundreds of years. The SV presents a set of approximated linear changes (V-shaped), named geomagnetic jerks (Mandea *et al.,* 2010), as shown in Figure 1.

The 1969 geomagnetic jerk was first detected by Courtillot *et al.* (1978) analyzing the annual means data of European observatories. Malin & Hodder (1982) used the spherical harmonic analysis to demonstrate that jerks are generated in the core. They showed that internal sources can give rise to changes in secular variation on the range of one or two years. However, at that time the jerk's origin was a polemic issue. For example, Alldredge (1984) observed that the 1970 geomagnetic jerk was absent in the records of many observatories and suggested that some external signal could contribute to jerks.

Besides the internal origin of jerks is now well established, it is important to analyze the possible influence of the external field as an artifact on the jerk detection. Verbanac *et al.* (2006) analyzed the influence of external field on the X component and confirmed that it affects the secular variation estimates derived from observatory annual means.

Jerks may be detected and characterized by different methods, such as wavelet analysis, fitting of straight lines and identification of jerks in global field models (Alexandrescu *et al.*, 1995; Le Huy *et al.*, 1998; Sabaka *et al.*, 2004). One common agreement is that jerks are usually better detected in the East component (Y) since it is less influenced by the external magnetic field (e.g. ring currents).

In this work we will analyze the influence of external magnetic field on the 1969 jerk detection, using the north (X), east (Y) and vertical (Z) components. We use the CM4 model (Sabaka *et al.*, 2004) to evaluate only the core field and the core added by the external and induced field influences. We compared all these results with the analysis of observatory annual means (Pinheiro *et al.,* 2011).

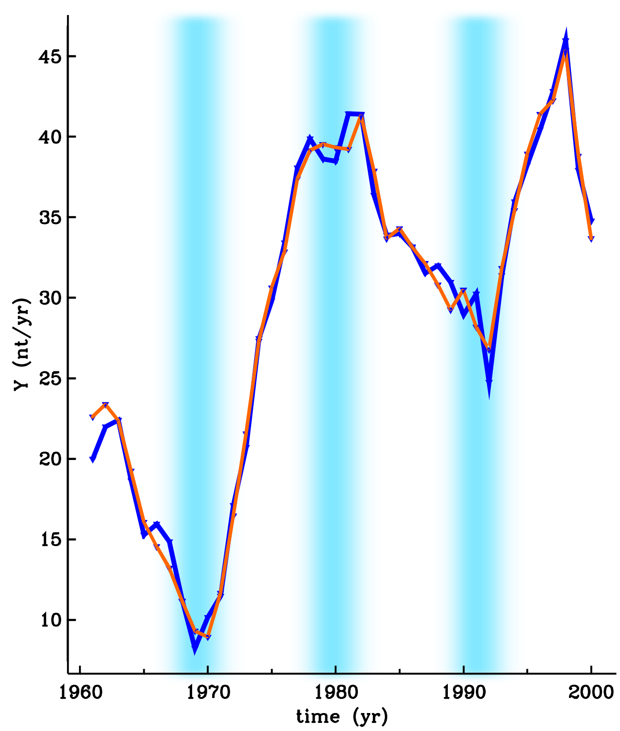

Figure 1 *– Secular variation of east field component (Y) in Wingst observatory (WNG, Germany) calculated from CM4 model (Sabaka et al., 2004) for the core field (orange) and core + external + induced fields (blue). Jerk occurrence times are roughly showed in light-blue.*

Methodology

In this work we generated hourly synthetic data from 1960 to 2002, using the CM4 field model (Sabaka *et al.,* 2004) in the same locations of the chosen magnetic observatories in Pinheiro *et al.,* 2011. The advantage of using CM4 model is the ability to separate the different sources of the magnetic field. We calculated two datasets: only core magnetic field (here identified as CORE) and core added by external and induced fields (here identified as COEI).

Annual means is one of most used data sets for the jerk detection in observatory data. We calculated the annual means of the synthetic data and the secular variation was evaluated by the first differences of annual mean values. Here the jerk analysis followed the methodology suggested by Pinheiro *et al.* (2011). A complete set of SV data is considered to be 15 years of data, with 7 years before and 7 years after the supposed jerk. Therefore, for 1969 geomagnetic jerk analysis we used a time window from 1962 to 1976.

Geomagnetic jerks are modeled as two straight-line segments fitted to secular variation estimates of the a geomagnetic element *C(t)* using least-squares (L_2) measures of misfit:

$$\dot{C}=a_1(t-t_0)+b \qquad for \quad t\leqslant t_0 \quad , \qquad (1)$$

and

$$\dot{C}=a_2(t-t_0)+b \qquad for \quad t\geqslant t_0 \quad , \qquad (2)$$

where t_0 is the occurrence time, a_1, a_2, and b are model parameters.

The jerk amplitude *A* is given by

$$A=a_2-a_1 \qquad (3)$$

The preferred model for t_0 for the 1969 jerk (for X, Y and Z) is chosen according to the minimum of the misfit curve and the error bars determined by intervals with 67% of confidence on the associated probability distribution function (PDF) curve (Figure 2). Jerks are classified as “not detected” when the minimum of the misfit curve (or maximum in the PDF curve) is in one of the extremes of the time window, and as “excluded” when it is not possible to obtain error bars (Pinheiro *et al.*, 2011).

Results

We plotted the misfit and PDF curves and calculated the best fits for the 1969 jerk occurrence times, amplitudes and their respective error bars for the two synthetic data calculated from CM4: CORE and COEI datasets. In Figure 2 we show the detection difference for the 1969 jerk in the X component in Niemegk observatory. The jerk detected in the CORE synthetic data (Figure 2A) shows an occurrence time at 1971.5, and its minimum and maximum error bars are -0.55 and 0.76, respectively. When we added the external and induced contributions (COEI, Figure 2C) the detection is highly affected: the occurrence time is 1974.5 and the error bars are -1.59 and 0.47, respectively. The data are more disturbed in COEI data and the jerk configuration is changed.

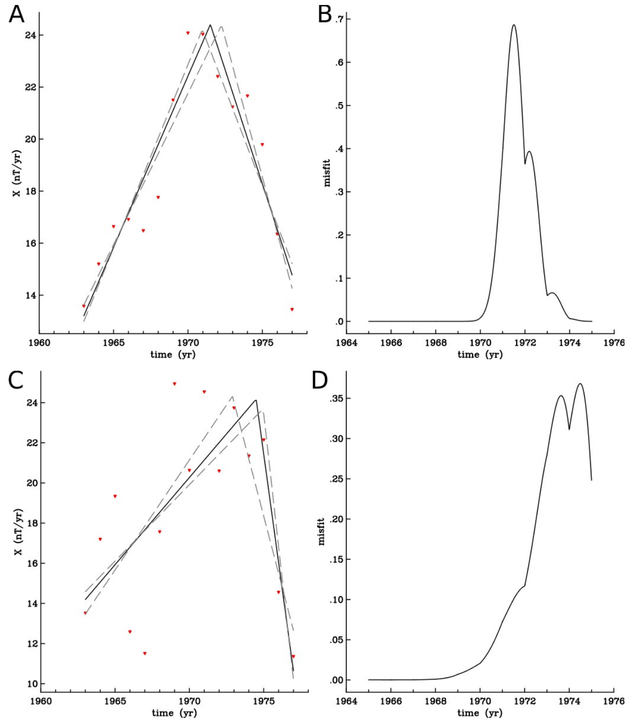

Figure 2 *– Geomagnetic jerk detected on X field component in Niemegk observatory (NGK) on CORE (A) and COEI (C) synthetic data sets. Continuous line shows the best fit and dashed lines show the minimal and maximum error bars. B and D are the PDF curves for both data sets.*

The 1969 jerk was detected in more locations in the Y field component both CORE and COEI data compared to the X and Z components (see Table 1). That is probably because the Y component is the less affected by the external field influence. In the X component we noted that the number of excluded observatories from CORE to COEI increased considerably. The reason for most excluded observatories is that the error bars could not be calculated. This occurred because the minimum of the misfit curve was moved to one of limits of the chosen time window. In the other excluded observatories the jerk was detected, but their error bars were higher than 3 years that might be caused by the external field influence. The effect of the external field on the jerk detection was to delay the occurrence time and to increase the error bars in the X component.

Table 1 – Jerk detection for CORE and COEI model data. DET are the observatories where the jerk was detected, EXC are the observatories excluded and NOT are the observatories where the jerk was not detected. The occurrence time is shown in t_0 with its error bars e_{min} and e_{max}..

		DET	EXC	NOT	t_0	e_{min}	e_{max}
CORE	*X*	160	17	9	1970,37	-0,55	0,58
	Y	175	7	4	1970,31	-0,43	0,44
	Z	151	16	19	1970,50	-0,53	0,57
COEI	*X*	116	57	13	1970,05	-0,74	0,85
	Y	175	9	2	1970,23	-0,5	0,55
	Z	147	22	17	1970,42	-0,75	0,71

Besides the number of detected observatories being the same in the Y component (CORE and COEI), They are not the same locations (see Table 1). There are four observatories which were excluded from CORE and were detected in COEI data: ETT, KOD and UJJ observatories were excluded because was not possible to calculate their error bars. In LRM observatory, the error bars were larger than 3 years. In some cases the external field influence amplifies the jerk signal and it causes a delay in the occurrence time such that the jerk could be detected.

We calculated the occurrence time differences (Δto) of COEI-CORE ($\Delta t_{01} = |t_{0(COEI)} - t_{0(CORE)}|$), DATA-CORE ($\Delta t_{02} = |t_{0(DATA)} - t_{0(CORE)}|$) and DATA-COEI ($\Delta t_{03} = |t_{0(DATA)} - t_{0(COEI)}|$) as shown in Table 2. We found that the Δt_0 means shows a great difference in X compared to the other components. This is consistent with geomagnetic field observations since the X component is more affected by the external contributions, especially ring currents (Verbanac *et al.,* 2006).

The occurrence time differences in DATA-CORE and DATA-COEI shown higher values than COEI-CORE. The mean values of Δto for X, Y and Z showed to be more similar when the data from observatory were used (see Table 2). The X component is the morst affected by the external field but Z component has the bigger error bars in DATA-CORE and DATA-COEI. The Y component shown similar values for Δto in both data sets. The mean value of error bars are approximately symmetric for all components. This results shows some difference for the observatory data analysis where the error bars were not symmetric.

The geographical distribution shown that the 1969 geomagnetic jerk was detected early in the South Asia , South and Central America, Greenland and North of Canada. In Europe, North Asia and Antarctic the jerk was detected later (see Figure 3).

Table 2 – Difference means of occurrence time for X, Y and Z field component with the respective error means for model and real data comparison.

		Δto (X)	**Δto (Y)**	**Δto (Z)**
COEI-CORE (Δto_1)	*mean*	1,28	0,13	0,25
	e_{min}	0,36	0,11	0,19
	e_{max}	0,44	0,11	0,17
DATA-CORE (Δto_2)	*mean*	1,44	0,98	1,29
	e_{min}	0,89	0,63	1,09
	e_{max}	1,25	0,70	0,89
DATA-COEI (Δto_3)	*mean*	1,78	0,98	1,35
	e_{min}	0,64	0,58	1,03
	e_{max}	0,79	0,62	0,83

The mean occurrence time detected in COEI data are earlier than CORE data with a difference of 0,32 years (see Table 1) but, the difference between the mean occurrence time and the occurrence time in the locations (observatories) in COEI data are bigger than CORE. This may be interpreted in terms of an increasing of delay with respect to the occurrence time mean by the external field influence. Many observatories where the jerk was well defined like early in CORE data, were detected earlier in the COEI data. Many observatories where the jerk was well defined like late in CORE data, were detected later in the COEI data.

Conclusion

The fitting two straight line segments to the secular variation is a simple detection method that allows the calculation of error bars on the occurrence time and amplitude of geomagnetic jerks. Using the CM4 model it was possible to investigate the jerk detection using only core field, and core added to external and induced contributions.

Since geomagnetic jerks have an internal origin, they should be more easly detected in the core field data. However, no significant difference on the detection of jerks in the CORE and COEI models were noticed for the X component. Therefore, we suggest that the annual means of the Y component are not much affected by external influences. The 1969 geomagnetic jerk was detected in 90% average of observatories studied in CORE dataset.

The preliminary results for the 1969 geomagnetic jerk show that the influence of external fields in jerks detection would be significant for the X component. The occurrence time is highly affected by the external field especially in the X component, with a mean difference of 1.36 years and reaching occurrence time differences up to 7 years in some locations.

Most observatories excluded from the analysis occurred in the COEI synthetic data (X component). Most part of them were excluded because their occurrence time were moved to time window limits not allowing the calculation of the error bars. In Y and Z components we found a opposite behavior in some observatories which were excluded from CORE data. In COEI data we noted that the external field influence moved enough the occurrence time from time window limits to detect the jerk.

The next step is study the 1978 and 1991 geomagnetic jerks in order to search for similar behaviors and to use statistical tools for quantifying this influence. We noted that in some regions the method has limitations e. g. the high concentration of excluded observatories in Europe. The limitations of methodology is one point ti improve in future studies. Also we will try to find any correlation between some long-term solar variation and the external fields influence. The non-equal observatory distribution makes difficult the generalization of geographical jerk features. We will use the capacity of CM4 field model for plotting a worldwide grid for a better understanding of this phenomena.

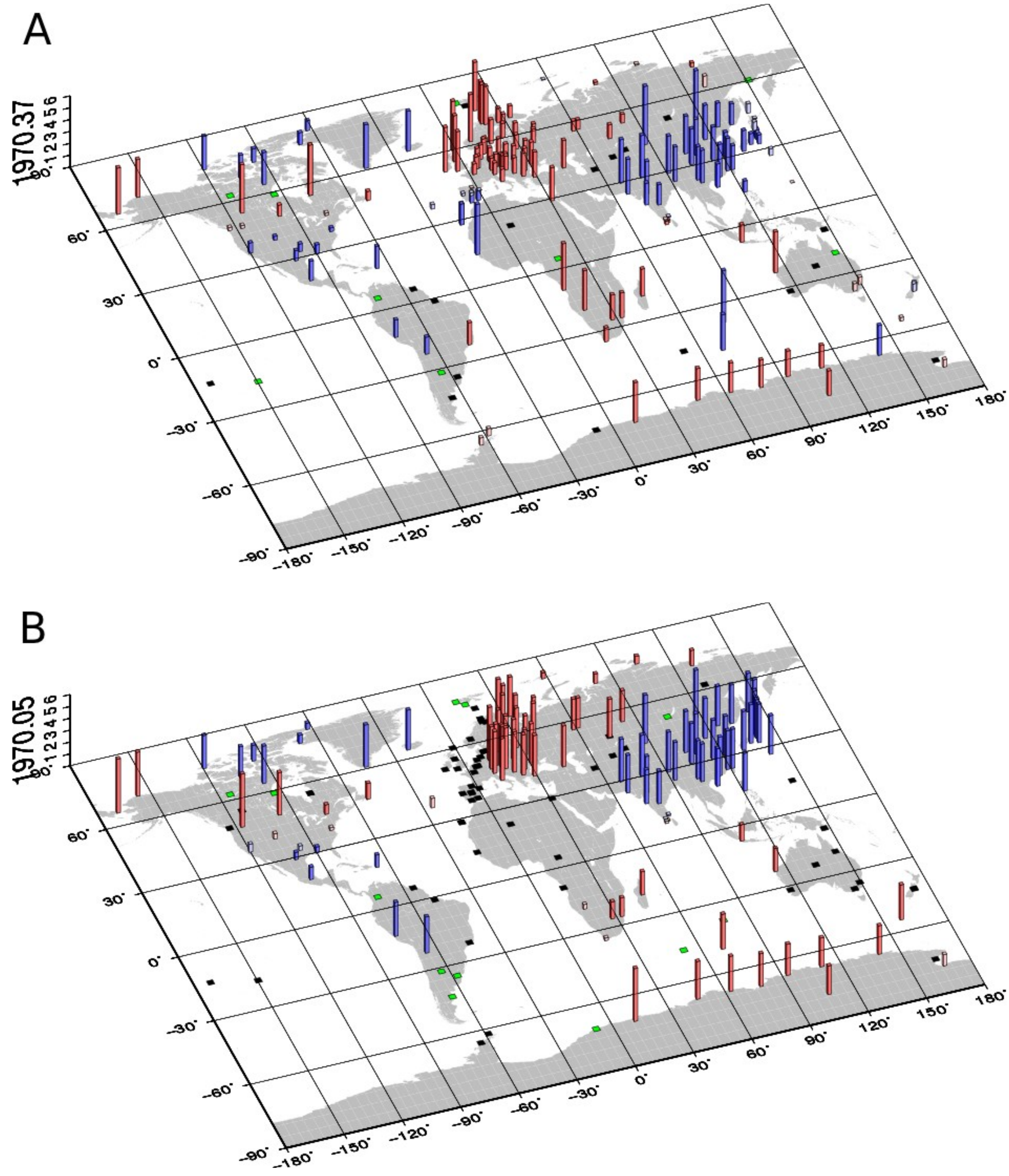

Figure 4 – *Results for the 1969 jerk occurrence time ate the Earth's surface generated by CM4 field model for X field component in CORE data (A) and COEI data (B). The mean occurrence time is shown close to the vertical bar (from 1 to 6 years) which gives the height of the blue and red bars. The red bars represent locations where the jerk appeared later than the mean occurrence time and blue bars where it appeared earlier. The occurrence time when the bar is red, is given by the sum of the mean occurrence time and the height of the bar in a specific location; while the occurrence time of blue bars in a give location is given by subtracting the mean occurrence time by the height of the bar. The green squares represent the locations where the jerk was not detected and the black squares where data was excluded.*

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