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Discussions

Review "On the relation between the seismic activity and the Hurst exponent of the geomagnetic field at the time of the 2000 Izu swarm"

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Abstract

Many papers document the observation of earthquake-related precursory signatures in geomagnetic field data. However, the significance of these findings is ambiguous because the authors did not adequately take into account that these signals could have been generated by other sources, and the seismogenic origin of these signals have not been validated by comparison with independent datasets. Thus, they are not reliable examples of magnetic disturbances induced by the seismic activity. Hayakawa et al. (2004) claim that at the time of the 2000 Izu swarm the Hurst exponent of the Ultra-Low-Frequency (ULF: 0.001–10 Hz) band of the geomagnetic field varied in accord with the energy released by the seismicity. The present paper demonstrates that the behaviour of the Hurst exponent was insufficiently investigated and also misinterpreted by the authors. We clearly show that during the Izu swarm the changes of the Hurst exponent were strongly related to the level of global geomagnetic activity and not to the increase of the local seismic activity.

1 Introduction

Several researchers consider the investigation of the geomagnetic field in the ULF band as a useful tool for monitoring possible earthquake-related magnetic signatures, as well as precursory signals. Despite many reports of magnetic ULF earthquake precursors, several researchers do not agree that these are actually earthquake related. According to them, the observed magnetic anomalies were generated by other sources, such as global geomagnetic activity (see, e.g. Campbell, 2009; Masci, 2010; Thomas et al., 2009a), or they were caused by instrument malfunction (see, e.g. Masci, 2012b; Thomas et al., 2009b). These studies led to a re-examination of many controversial observations of earthquake-related signals, which found that several methodologies used to identify magnetic precursors were invalid. Among these methods are magnetic polarization ratio (see Thomas et al., 2009b; Masci, 2011a, 2012a,c), fractal characteristics

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of the geomagnetic field components (see Masci, 2010, 2013a), eigenvalues of the principal component analysis (see Masci, 2011b). Reports of ionospheric earthquake-related disturbances were also investigated (see Masci 2012d, 2013b; Thomas et al., 2012). Bearing in mind these findings, the reliability of earthquake precursory signals must be carefully investigated by means of independent data.

At the end of June 2000 a seismic swarm started offshore the Japanese peninsula of Izu. Five strong ($M > 6$) earthquakes occurred on 1, 8, 15 and 30 July and on 18 August. Several papers, using different methods to analyze magnetic field data, document the observation of presumed seismogenic signals that occurred before and during the swarm (see, e.g. Gotoh et al., 2003, 2004; Ismaguilov et al., 2003; Hayakawa 2011). However, these reports do not show a physical relation between the geomagnetic anomalies and seismic activity. On the contrary, the studies by Masci (2010, 2011a,b) clearly demonstrate that before and during the 2000 Izu swarm the presumed seismogenic signatures in the magnetic field are just normal signals highly-correlated to global geomagnetic activity.

Here, we investigate the findings by Hayakawa et al. (2004) that claim that at the time of the 2000 Izu swarm the statistical proprieties of the ULF component of the geomagnetic field were strongly correlated with the energy released by the seismic activity.

2 Discussion

Hayakawa et al. (2004), in a report published by *Physics and Chemistry of the Earth*, claim that at the time of the 2000 Izu swarm the Hurst exponent of the ULF band of the geomagnetic field varied with local seismic activity. They analyze data (sampling rate 1 Hz) from the geomagnetic station of Seikoshi and from the seismic station of Mohikoshi. The two stations are about 80 km away from the epicentral area.

The Hurst exponent (here denoted by Hu) is a parameter that quantifies the tendency of a time-series. Hu can have a value in the range $0 < Hu < 1$. For $Hu > 0.5$ there is a positive correlation between the values of a time-series (persistent behaviour), that is, if the time-series increases in a period of time it is likely that it continues to increase in the following interval. For $Hu < 0.5$ there is a negative correlation between the values of a time-series (anti-persistent behaviour), that is, if the time-series increases in a period of time it is likely that it decrease in the following interval. $Hu = 0.5$ indicates a completely uncorrelated time-series. Refer to Hayakawa et al. (2004) for details on the calculation of the Hurst exponent.

According to Hayakawa et al. (2004), the local seismic activity and the Hurst exponent of the geomagnetic field components in the ULF frequency band show a strong correlation from the end of June to the first weeks of July 2000. Figure 1 shows the behaviour from February to December 2000 of the Hurst exponent of the geomagnetic field H component and local seismic activity (M^*) as reported by Hayakawa et al. (2004). M^* is the earthquake magnitude estimated by the Japan Meteorological Agency. Yellow bounded areas highlight the period during which Hu seems to vary in accord with M^*. Our first observation concerns the lack of a corresponding correlation after the middle of July 2000 when, as can be seen from Fig. 1, the seismic swarm was still in progress. This fact already casts some doubts on the possible relationship between Hu and M^*. Hayakawa et al. (2004) noted that M^* and Hu do not vary coherently all the time. The authors justify the lack of correlation after the middle of July invoking "a kind of saturation" which took place during the evolution of the seismic swarm. Unfortunately, they do not explain the true meaning of the supposed "saturation", nor they specify what saturated.

Figure 2 is a reproduction of Fig. 2 by Hayakawa et al. (2004). The figure shows the local seismic activity M^* and the Hurst exponent of the geomagnetic field components H, D, and Z during the period from February to August 2000. Enlarged views from 7 June to 18 July shows both daily values and $\pm$ 3-day running average of the Hurst exponent compared with the $\pm$ 3-day running average of the earthquake magnitude M^*. According to Hayakawa et al. (2004) there is a strong correspondence between the increase of M^* and the variation of the Hurst exponent of the geomagnetic field horizontal

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components H and D. Conversely, the Hurst exponent of the vertical component Z of the geomagnetic field does not show a similar pronounced correspondence with the seismic activity.

Considering that interaction of the solar wind with the Earth's magnetosphere and ionosphere–magnetosphere coupling are the main sources of ULF disturbances (see McPherron et al., 2005; Saito, 1969) we compared the findings of Hayakawa et al. (2004) with global geomagnetic activity by means of the ΣKp index time-series. In Fig. 2, the ± 3-day running average of the ΣKp index is superimposed onto the original views by Hayakawa et al. (2004). We found a strong correlation between the ±3-day running averages of the Hurst exponent of the horizontal components of the geomagnetic field and ΣKp on both short and long time scales. This correlation is particularly evident in the H component. Namely, the Hurst exponent shows a close correlation with ΣKp during the entire period of time (February–December 2000) reported in the figure and not only during few weeks from 7 June to 18 July. This fact suggests that the variations of the Hurst exponent of the geomagnetic field are closely related to changes in geomagnetic activity. In addition, the greater correspondence with the geomagnetic index of the Hurst exponent of the horizontal components H and D is clearly justified because the Kp index is calculated using these components of the geomagnetic field (Mayaud, 1980).

Figure 3 shows in detail the comparison between M^*, ΣKp, and the Hurst exponent of the geomagnetic field H component (Hu_H), during the period from 7 June to 18 July 2000. The daily values and the ±3-day running averages of Hu_H and M^* were obtained by digitizing the original view of Hayakawa et al. (2004).We can see the strong inverse correlation that exists between the daily values of Hu_H and ΣKp. Figure 3b, c show the linear relationships between the ± 3-day running averages of Hu_H and ΣKp, and Hu_H and M^*, respectively. It is clearly evident that the strong correlation that exists between Hu_H and ΣKp (correlation coefficient = −0.87) cannot be stated for the pair Hu_H and M^* (correlation coefficient = 0.36). This finding is confirmed by Fig. 3d that shows the original Hu_H time-series and the Hu_H time-series reconstructed using the

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linear relationships with ΣKp and M^*, respectively. We can see that Hu_H constructed by the linear relationship with ΣKp is very similar to the original Hu_H time-series. On the contrary, this cannot be stated for the Hu_H time-series constructed by the M^* linear relationship.

3 Conclusions

Here we have shown that the variation of the Hurst exponent of the ULF component of the geomagnetic field during the period from February to December 2000 and particularly from the beginning of June to the middle of July is highly-correlated to geomagnetic activity. Moreover, contrary to the claims of Hayakawa et al. (2004), we have found that during the 2000 Izu swarm the behaviour of the Hurst exponent of the ULF geomagnetic field is poorly-correlated with the energy released by the local seismic activity. This paper supports the findings by Masci (2010, 2011a,b), which demonstrated that many presumed magnetic seismogenic signatures claimed to be related to the swarm occurred at Izu during 2000 were actually normal magnetospheric disturbances.

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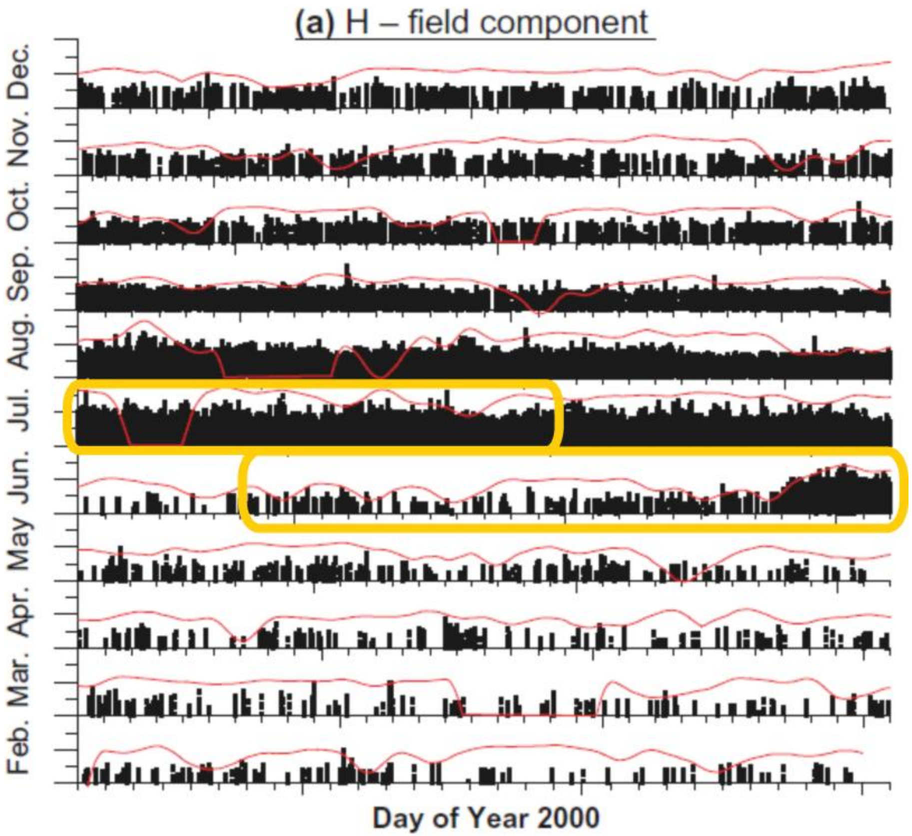

Fig. 1. A reproduction of Fig. 1 by Hayakawa et al. (2004). The vertical black bars represent the local seismic activity M^* estimated by the Japan Meteorological Agency, whereas the solid red line represents the behaviour of the Hurst exponent of the geomagnetic field H component during 2000. Yellow rounded rectangles highlight the period in which the Hurst exponent is claimed to change coherently with M^* by Hayakawa et al. (2004).

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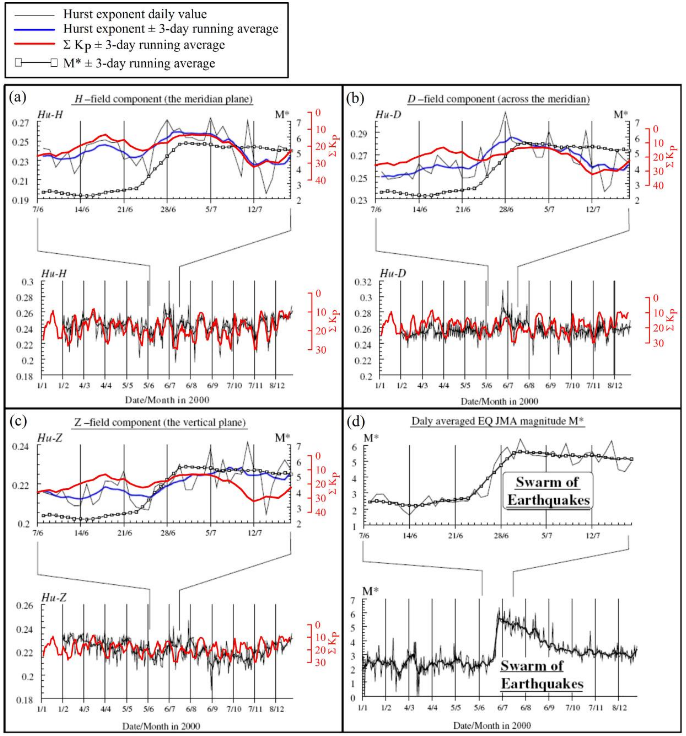

Fig. 2. A reproduction of Fig. 2 by Hayakawa et al. (2004). **(a)**, **(b)**, and **(c)**: the variation of the Hurst exponent (daily values and ±3-day running average) of the geomagnetic field components H, D, and Z during 2000. The enlarged views of each panel refer to the rise of the seismic activity at Izu. **(d)**: daily values and ± 3-day running average of the local seismic activity M^*. The ± 3-day running average of M^* (solid line with open squares) is also reported in panels **(a)**, **(b)**, and **(c)**. The ± 3-day running average of the global geomagnetic index ΣKp is superimposed on the original views. See text for details.

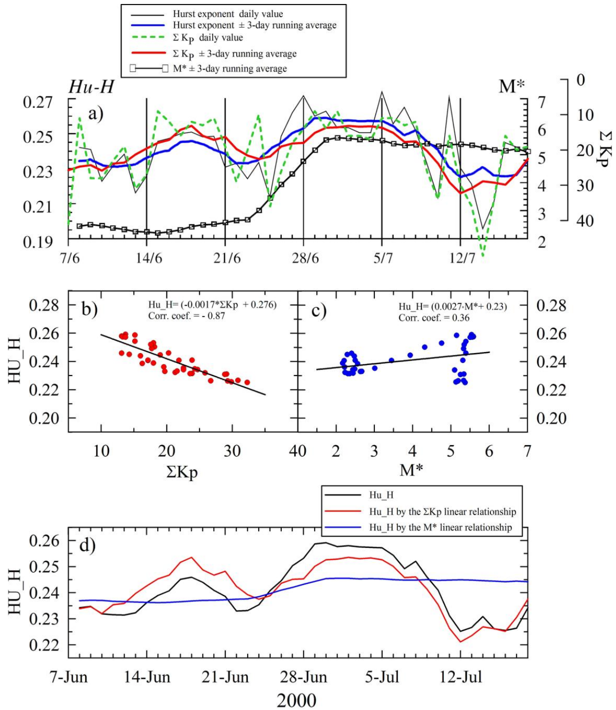

Fig. 3. (a) A reproduction of Fig. 2 by Hayakawa et al. (2004). Variation of the Hurst exponent (daily values and ± 3-day running average) of the geomagnetic field H component at the time of the Izu swarm. The ± 3-day running average of the local seismic activity M^* (solid line with open squares) is also shown. ΣKp time-series (daily values and ± 3-day running average) have been superimposed onto the original view. **(b)** and **(c)** linear relationships between the ± 3-day running average of the Hurst exponent and ΣKp and M^*, respectively. **(d)** The Hurst exponent calculated by Hayakawa et al. (2004) compared with reconstructed Hurst exponents using the linear relationships shown in panels **(b)** and **(c)**. See text for details.

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