Nat. Hazards Earth Syst. Sci., 11, 2193–2198, 2011
www.nat-hazards-earth-syst-sci.net/11/2193/2011/
doi:10.5194/nhess-11-2193-2011

Natural Hazards and Earth System Sciences

Brief communication
"On the recent reaffirmation of ULF magnetic earthquakes precursors"

F. Masci

Istituto Nazionale di Geofisica e Vulcanologia, Italy

Received: 16 March 2011 – Revised: 25 May 2011 – Accepted: 26 May 2011 – Published: 12 August 2011

Abstract. Hayakawa et al. (2009) and Hayakawa (2011) have recently reviewed some "anomalous" ULF signatures in the geomagnetic field which previous publications have claimed to be earthquake precursors. The motivation of this review is *"to offer a further support to the definite presence of those anomalies"*. Here, these ULF precursors are reviewed once again. This brief communication shows that the reviewed anomalies do not "*increase the credibility on the presence of electromagnetic phenomena associated with an earthquake*" since these anomalous signals are actually caused by normal geomagnetic activity. Furthermore, some of these ULF precursors have just been rebutted by previous publications.

1 Introduction

Several publications report the observation of anomalous ULF magnetic signals which are claimed to be earthquake precursors. At present, there are many uncertainties on their reliability because no firm evidence of correlation between these magnetic signatures and seismic events really exists. Obviously, it's likely that an anomalous variation of a geomagnetic field parameter can happen during the period before the occurrence of an earthquake, but retrospectively relating these variations to seismic events without further validations in other geophysical data is just an oversimplified conclusion. Some authors have recently put into doubt the authenticity of well-known ULF magnetic seismogenic precursors, maintaining that the claimed anomalies could actually be caused by instrumentation malfunction (Thomas et al., 2009a), or that they are generated by normal geomagnetic activity (Campbell, 2009; Thomas et al., 2009b; Masci, 2010, 2011). Hayakawa (2011) affirms that "*there is no guarantee that the conclusions of those papers are right*", but, as I know, till now no rebuttal of these papers has been published. In addition, Masci (2010, 2011) criticizes the methodology used in previous research, maintaining that relating the ULF "anomalies" with the seismic events is fairly incorrect without properly taking into account the global geomagnetic activity behaviour. In order to exclude the influence of magnetospheric signals, several authors point out that the claimed seismogenic anomalies took place during periods characterized by low geomagnetic activity levels, that is, during periods characterized by small values of the global geomagnetic indices. According to Masci (2010, 2011), this is an incorrect assumption because the variation of the geomagnetic activity, which induces changes in several geomagnetic parameters, must be properly taken into account.

Several publications (see Saito, 1969 and references therein) show that the amplitude of ULF geomagnetic field continuous micropulsations (PCs) has a clear positive correspondence with Kp index (and then also with its daily sum $\sum$Kp) which is representative of average disturbances of the planetary geomagnetic field. This positive relation is evident mainly in PC_2, PC_3 and PC_4 frequency bands. Note that the majority of ULF seismogenic signals are mainly observed in these frequency bands. Therefore, if we demonstrate a close correspondence between the time-series of a ULF geomagnetic field parameter and a global geomagnetic index, we can affirm that the changes of this parameter are mainly caused by the variation of the geomagnetic activity. On the contrary, since the global geomagnetic indices are representative of the geomagnetic field average disturbances over planetary scale it is impossible that a geomagnetic field parameter always shows the same features of the geomagnetic indices, otherwise the parameter time-series should be the same in all the observation sites. Namely, the majority of ULF signals are external signals generated in the interplanetary space and in the magnetosphere by different sources; each source gives

Correspondence to: F. Masci
(fabrizio.masci@ingv.it)

Published by Copernicus Publications on behalf of the European Geosciences Union.

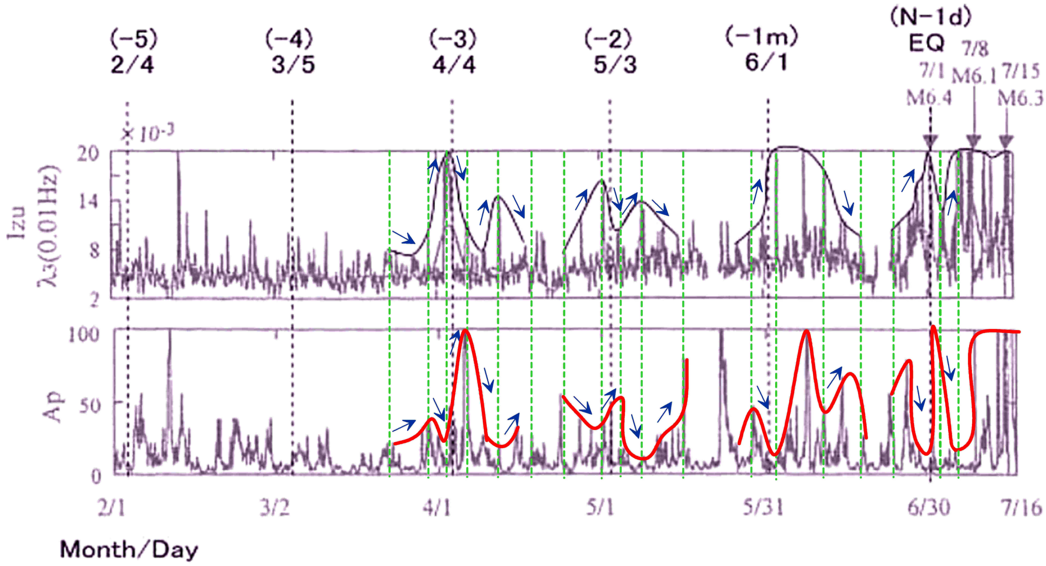

Fig. 1. Lunar phase analysis for the 2000 Izu swarm as reported by Hayakawa et al. (2011) (a reproduction of Hayakawa et al., 2011, Fig. 2). Upper panel: third PCA eigenvalue λ_3 of geomagnetic field component H at the frequency of 10 mHz. Lower panel: Ap index time-series. In the upper panel the thick black line represents the envelope curve of λ_3 peaks as reported in the original figure, whereas in the lower panel the thick red line has been added onto the original view and refers to the envelope curve of Ap peaks. Blue arrows are also added to better highlight the inverse correspondence existing between the variations of the two envelope curves in the majority of the periods delimited by vertical dotted green lines. See text for details.

its contribution, at different frequencies inside the ULF band, to the signals observed on the ground. Some of these signals have a worldwide extension, whereas others have latitude dependence (Saito, 1969). Thus, we should not expect that a strict correspondence between a geomagnetic field ULF parameter and geomagnetic indices will always exist. On the other hand, a close correspondence between the ULF parameter changes and the variations of the geomagnetic indices point out that these changes are caused by signals having external origin (variation of the geomagnetic activity) and not due to signals possibly generated by sources located inside the Earth. In light of this, in attempting to resolve the problem of clearly identifying reliable earthquake precursors, a closer inspection concerning the presence of seismogenic signals in geophysical data sets is required.

2 Comments on possible ULF seismo-magnetic phenomena

Hayakawa (2011) and Hayakawa et al. (2009), hereafter cited as H11 and H09, to further confirm the observation of seismo-electromagnetic phenomena, review some possible magnetic ULF precursors which previous publications have claimed to be related to incoming earthquakes.

2.1 Izu 2000: effect of Earth's tides

The first example reported by H11 regards possible ULF seismogenic signals caused by the effect of Earth's tides. Several publications (e.g. Tanaka et al., 2004; Tanaka, 2010) show the existence of correlation between Earth's tides and the earthquakes occurrence, maintaining that the small change of the stress caused by Earth's tides may trigger a seismic event. The authors also point out that this phenomenon is more evident when the tidal stress acts in the same direction as the local tectonic stress.

H09 have recently investigated the effect of the Earth's tides on seismo-electromagnetic phenomena. The authors maintain that, in the case of large earthquakes, a modulation with a period close to the lunar month (≈29.5 days) should be found in seismo-electromagnetic data before the earthquake date. According to the authors, this modulation could be reasonably considered as the effect of the Earth's tides. More precisely, they maintain that a specific position of the Earth's moon with respect to the fault slipping direction might trigger seismic events, which consequently might generate electromagnetic signals. Thus, we might find seismogenic emissions in correspondence of the same lunar phase. Figure 1 shows the possible effect of lunar tidal modulation on ULF emissions for the case of the seismic swarm occurred at Izu Islands between June and September 2000 (five strong earthquakes: 1 July $M = 6.4$, 9 July $M = 6.1$, 15 July $M = 6.3$, 30 July $M = 6.4$, and 18 August $M = 6.0$) as reported by

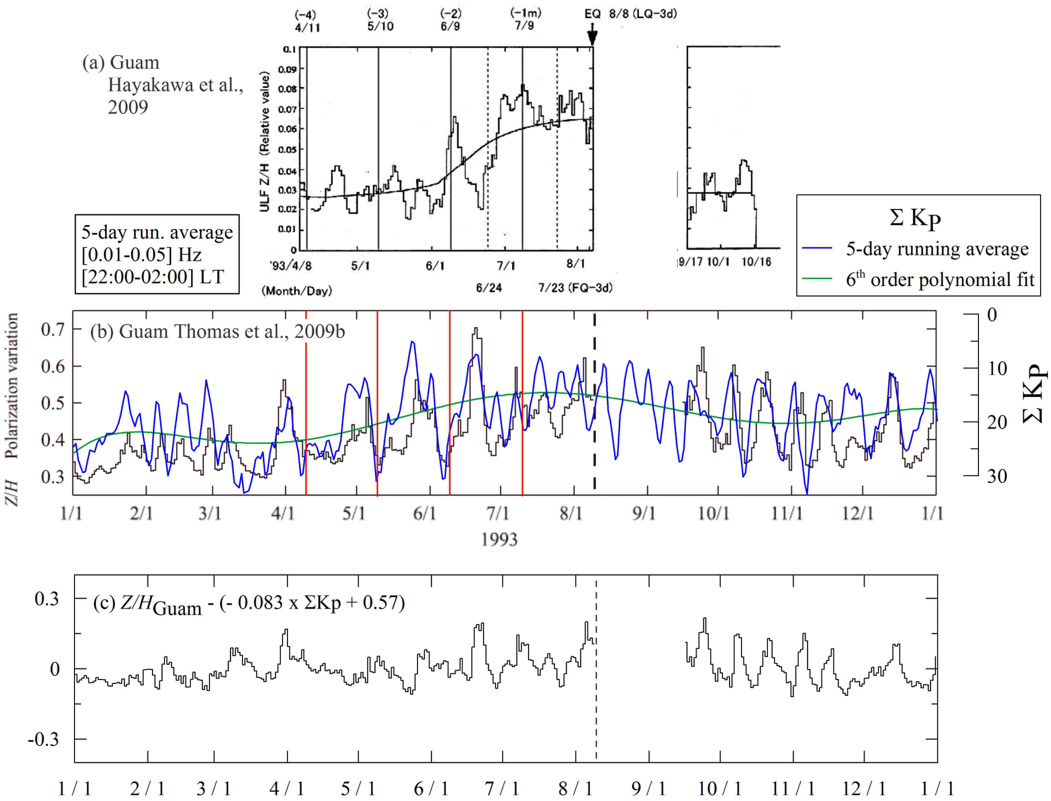

Fig. 2. (a) Lunar phase analysis for the Guam polarization ratio *Z/H* as reported by Hayakawa et al., (2009) (a reproduction of Hayakawa et al., 2009, Fig. 3). **(b)** ULF polarization ratio *Z/H* (5-day running average) as reported by Thomas et al. (2009b); the 5-day running average (blue line) and the 6th order polynomial fitting (green line) of ΣKp are shown as well. **(c)** Residual of the linear relationship between the *Z/H* ratio shown in panel **(b)** and ΣKp as reported by Masci (2011) (a reproduction of Masci, 2011, Fig. 1). See Thomas et al. (2009b) and Masci (2011) for details.

H11 and previously published by Gotoh et al. (2002). Gotoh et al. (2002) performed Principal Component Analysis (PCA) on the ULF geomagnetic field horizontal component H measured at three closely separated (≈5 km) stations located about 80 km away from the epicentre area. The authors maintain that the smallest PCA eigenvalue λ_3 might include seismogenic signatures. On the contrary, according to the authors, the 1st(λ_1) and the 2nd (λ_2) eigenvalues are respectively related to geomagnetic activity and to the man-made noise. Figure 1 shows λ_3 time-series calculated by Gotoh et al. (2002) at 10 mHz. According to H09, since the first strong earthquake of the swarm occurred on 1 July in correspondence of N-1d (new moon minus 1 day) phase, we must find seismogenic emissions in correspondence to the same lunar phase, that is when the tidal stress should be added to the tectonic stress. In Fig. 1 the days corresponding to the N-1d lunar phase are marked by -1 m (m=lunar month), -2, -3, -4, and -5. According to H09, λ_3 shows a fluctuating pattern synchronized with the lunar phase (N-1d); this modulation has been further highlighted by drawing the envelope curves connecting λ_3 peaks. The authors also point out that the geomagnetic Ap index (lower panel of Fig. 1) does not show a similar behaviour, thus they assume that the λ_3 time-series is not influenced by geomagnetic activity. However, we can also apply the simple methodology of H11 to the geomagnetic index time-series by drawing the envelope curves connecting Ap peaks. Red spline curves, which represent the envelopes of Ap peaks, have been added to Fig. 1. Vertical dotted green lines and blue arrows are also added to the original view to better highlight changes of the trend (increase or decrease) of the envelope curves in different periods. As a matter of fact, we can note that the envelope curves of λ_3 and Ap show a negative correspondence; more precisely on average, λ_3 decreases (increases) when Ap increases (decreases). The negative correspondence is evident in the majority of the periods delimited by vertical dotted green lines; the correspondence fails only during very few periods. In any case, the selection of the peaks used to draw the envelope curves could influence their shape. For example, Fig. 4 by H09 and Fig. 2 by H11 show the same λ_3 time-series, but the envelope curves of λ_3 peaks are different. Therefore, it is obvious that the correspondence between λ_3 and Ap could sometimes fail. However, the negative correspondence between λ_3 and Ap could suggest the existence of a possible relation between

λ_3 and the global geomagnetic activity. Hattori et al. (2004) performed detailed PCA analysis of the geomagnetic field H component during the period of the Izu swarm. The authors maintain that the possible earthquake-related signals are expected to be hidden in λ_3. They concluded that: (1) λ_1 is related to signal caused by solar-terrestrial interaction; (2) λ_2 is a combination of man-made signals and earthquake-related signals, even if the influence of artificial signal is more intense; and (3) λ_3 is a combination of artificial signals and earthquake-related signals as well. In my opinion, Hattori et al. (2004) conclusions suggest that λ_3 could also be contaminated by magnetospheric signals. Unfortunately, the authors do not investigate in depth this possibility, even when they affirm that λ_3 variations cannot be seen in Ap index time-series. That is, the authors pointed out that λ_3 peaks are not positive correlated with Ap peaks, but they do not consider a possible negative correlation between λ_3 and Ap. In light of this, λ_3 increases before the Izu swarm cannot be undoubtedly considered as reliable precursors of the incoming earthquakes, and relating these increases with the lunar phase is an oversimplified conclusion.

2.2 Guam 1993: ULF polarization ratio and effect of Earth's tides

Another example of possible correlation between Earth's tides and possible ULF seismogenic emission has been reported by H09 for the 8 August 1993 $M = 8$ earthquake in Guam. The panel (a) of Fig. 2 shows the lunar phase analysis for the polarization ratio Z/H as calculated by Hayakawa et al. (1996) in the frequency band [0.01–0.05]Hz. Hayakawa et al. (1996) maintain that *Z/H* time-series shows an anomalous increase during the period before the earthquake date. According to the authors, this increase is strong evidence of magnetic precursory signals caused by the earthquake preparation process. In addition to the conclusions of Hayakawa et al. (1996), H09 also maintain that the Guam *Z/H* ratio shows a clear modulation synchronized with the lunar phase LQ-3d (Last Quarter minus 3 days). In Fig. 2, the days corresponding to the LQ-3d lunar phase are marked by -1 m, -2, -3, and -4. The author points out that *Z/H* shows evident increases at the same lunar phase one month (-1 m) and two months (-2) before the earthquake date. They concluded: *"ULF geomagnetic anomalies are found to show a maximum-minimum-maximum pattern in synchronism with the lunar phase of the EQ during several months before its occurrence"*. Actually, Thomas et al. (2009b) have put into serious doubt the reliability of Hayakawa et al. (1996) conclusions by performing new analysis of Guam geomagnetic field data. They found analysis problems in Hayakawa et al. (1996). Masci (2011) confirms the conclusion of Thomas et al. (2009b). The panel (b) of Fig. 2 shows the polarization analysis performed by Thomas et al. (2009b); Masci (2011) plots onto the original view the 5-day running average and the 6th order polynomial fitting of ΣKp time-series in order to display that a close negative (consider that ΣKp vertical axis is descending) correspondence between *Z/H* and ΣKp really exists. The authors concluded that no clear seismogenic signatures have been highlighted in Guam data because the *Z/H* increase, which occurs before the earthquake, is part of normal global geomagnetic activity. The negative correspondence between *Z/H* and ΣKp may be explained by considering that on average, when the geomagnetic activity decreases, the reduction of the geomagnetic field horizontal component H is larger than the reduction of the vertical component Z, therefore the polarization ratio increases. On the contrary, an increase of the geomagnetic activity causes an increase in the geomagnetic field horizontal component H larger than the increase of the vertical component Z, therefore the polarization ratio decreases.

To further support previous mentioned conclusions, Masci (2011) draws out the Guam polarization ratio data by digitalizing the figure of Thomas et al. (here panel (b) of Fig. 2) in order to calculate the linear relationship between *Z/H* and ΣKp time-series. The relationship is: $Z/H = -0.083$ x$\Sigma\text{Kp} + 0.57$. The panel (c) of Fig. 2 shows the linear residual time-series. Actually, we can see that the residual time-series is on average flat and does not show any anomalous signature which could be related to the seismic activity of the Guam area. In conclusion, it is clearly evident that in the period before the earthquake occurrence, the variations of *Z/H* at Guam are mainly caused by changes of the global geomagnetic activity. Therefore, appeals to a seismogenic origin are rather dubious. In addition, ΣKp 5-day running average shows that all the principal maxima of *Z/H* can be doubtless associated with the geomagnetic activity. At this point, if we refer to the *Z/H* time-series reported in panel (b) of Fig. 2, in which red vertical lines refer to the LQ-3d lunar phases, we can note that there is no correspondence between *Z/H* maxima and the lunar phases contrary to H09 claims. On the contrary, LQ-3d lunar phases seem to be in synchronism with *Z/H* minima, but in my opinion this is just a chance event because the modulation of the ratio *Z/H* is due to the Sun's rotation around its axis: both *Z/H* and ΣKp show a $\approx$27-day modulation. In conclusion, no correlation between *Z/H* increases and Earth's tides may be undoubtedly stated.

2.3 Guam 1993: ULF fractal analysis

H11 also maintains that "*some other useful information embedded in the time-series data can be extracted from the slope of fluctuation spectra or fractal analysis*". The author reviewed the conclusions of Ida and Hayakawa (2006), which maintain that the fractal dimension D (which is related to the ULF spectrum slope, or spectral index, β) of the geomagnetic field H component shows a gradual increase during the period before the 1993 Guam earthquake. Figure 3 shows D and Ap index time-series during 1993, as reported by H11 and previously by Ida and Hayakawa (2006). As a matter of fact, Masci (2010) has demonstrated that

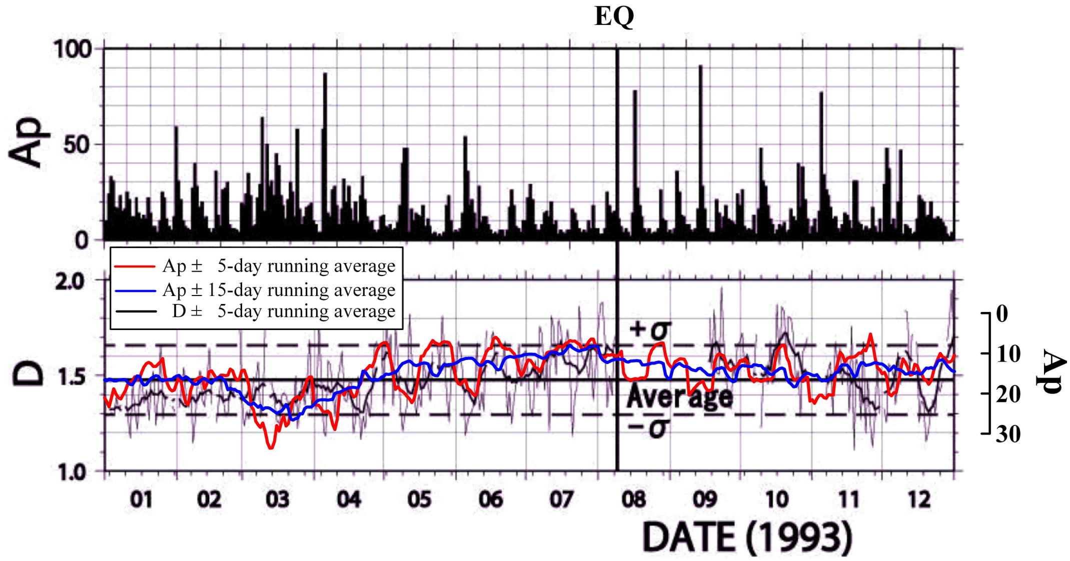

Fig. 3. Time-series of the fractal dimension D of the geomagnetic field H component at Guam observatory, and geomagnetic Ap index during 1993 as reported by Hayakawa (2011) (a reproduction of Hayakawa, 2011, Fig. 6). Ap ±5-day and ±15-day running averages are superimposed onto the original view. See text for details.

the fractal dimension increase which occurred before Guam earthquake is really caused by the geomagnetic activity due to solar-terrestrial interaction. In Fig. 3, Ap ±5-day and ±15-day running averages are superimposed onto the original view. The running averages clearly show a negative correspondence between D and Ap. The ±5-day running averages point out a negative correspondence between D and Ap over short time scale (both D and Ap show the ≈27-day modulation due to Sun's rotation around its axis) whereas Ap±15-day running average shows that the negative correlation is evident over long time scale as well. Therefore, as Masci (2010) pointed out, the gradual increase of D before the Guam earthquake corresponds to the gradual decrease of Ap index, thus the increase of D could be attributed mainly to normal geomagnetic activity. The negative correspondence between fractal dimension and geomagnetic activity may be explained by taking into account that ULF spectrum S of the geomagnetic field shows the power-law behaviour $S(f) \propto f^{-\beta}$, where f is the frequency and β is the spectrum slope. When the geomagnetic activity increases, lower frequencies increase more than higher frequencies, thus β increases. Therefore, according to the Berry's equation $D=(5-\beta)/2$, the corresponding fractal dimension D decreases. Actually, Masci (2010) also rebuts the fractal magnetic signatures which previous papers have related to other strong earthquakes (Biak, 1996, Izu swarm, 2000, and Sumatra 2004–2005). The author shows that a close inverse correspondence between D and the geomagnetic activity level really exists in all the previously mentioned earthquakes (for details see Masci, 2010). In conclusion, the fractal analysis of ULF geomagnetic field time-series does not provide any information about the pending earthquake.

3 Conclusions

Here ULF magnetic earthquake precursors reaffirmed by Hayakawa et al. (2009) and Hayakawa (2011) are reviewed. Hayakawa (2011) writes: *"In order to increase the credibility on the presence of electromagnetic phenomena associated with an earthquake, we have suggested the importance of the modulation (or fluctuation) seen in the time-series data of any seismogenic effects*". As a matter of fact, this brief communication shows that these claims do not increase the credibility of the observation of electromagnetic precursor signals because here it is pointed out that these ULF "anomalous" signatures are not reliable earthquake precursors but are actually caused by normal geomagnetic activity. Furthermore, some of the reviewed "anomalies" have been put into doubt by previous publications (Thomas et al., 2009b; Masci, 2010, 2011) and, till now, no rebuttal paper has been published. In addition, Hayakawa (2011) maintains that these seismogenic phenomena *"seem to be very promising candidates for short-term earthquake prediction"*. Short-term earthquake prediction is a very important topic of social importance. Successful prediction could reduce the number of victims caused by strong earthquakes. However, in order to be useful, short-term earthquake prediction requires reproducible earthquake precursors which provide real-time information regarding intensity, location, and time of the predicted earthquake. Therefore, the authenticity of earthquake precursors needs to be carefully checked. In light of this, the possibility of developing short-term earthquake prediction capability by using magnetic ULF "anomalous" signals seems to be rather remote. In conclusion, in the field of research on earthquake precursors a very important question should be:

"Is the observed anomaly a reliable earthquake precursor?". Therefore, as Hayakawa (2011) has pointed out, "*further evidence in support of the presence (or absence) of seismo-electromagnetic phenomena, is still highly required*", obviously calling for adopting more scientific rigor before claiming the observation of seismogenic precursory signals as very promising candidates for developing short-term earthquake prediction capabilities.

Acknowledgements. A special thanks to Roberta Giangiuliani for her invaluable help. The geomagnetic indices have been downloaded from Kyoto World Data Center for Geomagnetism (http://swdcwww.kugi.kyoto-u.ac.jp/).

Edited by: M. E. Contadakis
Reviewed by: two anonymous referees

References

Campbell, W. H.: Natural magnetic disturbance fields, not precursors, preceding the Loma Prieta earthquake, J. Geophys. Res., 114, A05307, doi:10.1029/2008JA013932, 2009.

Gotoh, K., Akinaga, Y., Hayakawa, M., and Hattori, K.: Principal component analysis of ULF geomagnetic data for Izu islands earthquakes in July 2000, J. Atmos. Electr., 22(1), 1–12, 2002.

Hattori, K., Serita, A., Gotoh, C., Yoshino, C., Haradam, M., Isezaki, N., and Hayakawa, M.:ULF geomagnetic anomaly associated with 2000 Izu Islands earthquake swarm, Japan, Phys. Chem. Earth, 29, 425–435, doi:10.1016/j.pce.2003.11.014, 2004.

Hayakawa, M., Kawate, R., Molchanov, O. A., and Yumoto, K.: Results of ultra-low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993, Geophys. Res. Lett., 23, 241–244, doi:10.1029/95GL02863, 1996.

Hayakawa, M., Sue, Y., and Nakamura, T.: The effect of earth tides as observed in seismo-electromagnetic precursory signals, Nat. Hazards Earth Syst. Sci., 9, 1733–1741, doi:10.5194/nhess-9-1733-2009, 2009.

Hayakawa, M.: On the fluctuation spectra of seismo-electromagnetic phenomena, Nat. Hazards Earth Syst. Sci., 11, 301–308, doi:10.5194/nhess-11-301-2011, 2011.

Ida, Y. and Hayakawa, M.: Fractal analysis for the ULF data during the 1993 Guam earthquake to study prefracture criticality, Nonlin. Processes Geophys., 13, 409–412, doi:10.5194/npg-13-409-2006, 2006.

Masci, F.: On claimed ULF seismogenic fractal signatures in the geomagnetic field, J. Geophys. Res., 115, A10236, doi:10.1029/2010JA015311, 2010.

Masci, F.: On the seismogenic increase of the ratio of the ULF geomagnetic field components, Phys. Earth Planet, doi:10.1016/j.pepi.2011.05.001, 2011.

Saito, T.: Geomagnetic pulsations, Space Sci. Rev., 10, 319–342, doi:10.1007/BF00203620, 1969.

Tanaka, S., Ohtake, M., and Sato, H.: Tidal triggering of earthquakes in Japan related to the regional tectonic stress, Earth Planets Space, 56(5), 511–515, 2004.

Tanaka, S.: Tidal triggering of earthquakes precursory to the recent Sumatra megathrust earthquakes of 26 December 2004 (Mw 9.0), 28 March 2005 (Mw 8.6), and 12 September 2007 (Mw 8.5), Geophys. Res. Lett., 37, L02301, doi:10.1029/2009GL041581, 2010.

Thomas, J., Love, J., and Johnston, M.: On the reported magnetic precursor of the 1989 Loma Prieta earthquake, Phys. Earth Planet., 173, 207–215, doi:10.1016/j.pepi.2008.11.014, 2009a.

Thomas, J. N., Love, J. J., Johnston, M. J. S., and Yumoto, K.: On the reported magnetic precursor of the 1993 Guam earthquake, Geophys. Res. Lett., 36, L16301, doi:10.1029/2009GL039020, 2009b.