

On the seismogenic increase of the ratio of the ULF geomagnetic field components

Fabrizio Masci

► To cite this version:

Fabrizio Masci. On the seismogenic increase of the ratio of the ULF geomagnetic field components. Physics of the Earth and Planetary Interiors, 2011, 10.1016/j.pepi.2011.05.001. hal-00769165

HAL Id: hal-00769165 https://hal.science/hal-00769165

Submitted on 29 Dec 2012

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Accepted Manuscript

Review

On the seismogenic increase of the ratio of the ULF geomagnetic field components

Fabrizio Masci

PII:	\$0031-9201(11)00087-2
DOI:	10.1016/j.pepi.2011.05.001
Reference:	PEPI 5410
Τ	
To appear in:	Physics of the Earth and Planetary Interiors
Received Date:	23 November 2010
Revised Date:	1 May 2011
Accepted Date:	1 May 2011



Please cite this article as: Masci, F., On the seismogenic increase of the ratio of the ULF geomagnetic field components, *Physics of the Earth and Planetary Interiors* (2011), doi: 10.1016/j.pepi.2011.05.001

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1 On the seismogenic increase of the ratio of the ULF geomagnetic field

- 2 components
- 3

6

4 Fabrizio Masci^{*}

5 Istituto Nazionale di Geofisica e Vulcanologia, L'Aquila, Italy.

7 * Corresponding author. Current address: Osservatorio Geofisico INGV, Via Castello 1, 67100, L'Aquila, Italy.

8 *E-mail address*: fabrizio.masci@ingv.it

9 Phone and fax: +39 0862 204245

10

11 ABSTRACT

12 Following the paper by Fraser-Smith et al. (1990), many scientists have focused their 13 research on the ULF geomagnetic field pulsations in the hope of finding possible anomalous 14 signals caused by the seismic activity. Thereafter, many papers have reported ULF 15 geomagnetic field polarization ratio increases which have been claimed to be related to the 16 occurrence of moderate and strong earthquakes. Even if there is no firm evidence of 17 correlation between the polarization ratio increase and seismic events, these publications 18 maintain that these "anomalous" increases are without doubt precursors of pending earthquakes. Furthermore, several researchers suggest that these seismogenic signals may be 19 20 considered a promising approach towards the possibility of developing short-term earthquake 21 prediction capabilities based on electromagnetic precursory signatures. On the contrary, a part of the scientific community emphasizes the lack of validation of claimed seismogenic 22 23 anomalies and doubt their association with the seismic activity. Since earthquake prediction is 24 a very important topic of social importance, the authenticity of earthquake precursors needs to 25 be carefully checked. The aim of this paper is to investigate the reliability of the ULF 26 magnetic polarization ratio changes as an earthquakes' precursor. Several polarization ratio 27 increases of the geomagnetic field, which previous researchers have claimed to have a 28 seismogenic origin, are put into question by a qualitative investigation. The analysis takes into

29 account both the temporal evolution of the geomagnetic field polarization ratio reported in 30 previous papers, and the global geomagnetic activity behaviour. Running averages of the 31 geomagnetic index K_p are plotted onto the original figures from previous publications. 32 Moreover, further quantitative analyses are also reported. Here, nine cases are investigated 33 which include seventeen earthquakes. In seven cases it is shown that the suggested association 34 between the geomagnetic field polarization ratio increases and the earthquake preparation 35 process seems to be rather doubtful. More precisely, the claimed seismogenic polarization 36 ratio increases are actually closely related to decreases in the geomagnetic activity level. 37 Furthermore, the last two investigated cases seem to be doubtful as well, although a close 38 correspondence between polarization ratio and geomagnetic activity cannot be 39 unambiguously demonstrated.

40

41 *Keywords:* Earthquake precursors, Short-term earthquake prediction, Geomagnetic field,
42 Seismology.

43

44 **1. Introduction**

45 The possibility of developing short-term earthquake prediction capabilities is one of the 46 challenges of the Earth science but also one of the principal controversial main themes of 47 discussion in the scientific community. Successful prediction could reduce both the number of 48 victims and damages caused by earthquakes. Short-term earthquake predictions have been the 49 topic of several scientific debates (Main, 1999) but at present their realization is rather 50 remote. In order to be useful, short-term earthquake prediction requires reproducible 51 earthquake precursors which provide real-time information regarding intensity, location and 52 time of the predicted earthquake together with error estimates for each parameter. Therefore,

how to identify reliable earthquake precursors is a very important key in the hope ofdeveloping earthquake prediction capability.

55 Several researchers (e.g. Hayakawa et al., 2007; Uyeda et al., 2009; Hayakawa and 56 Hobara, 2010) maintain that the preparation process of strong earthquakes could generate 57 electromagnetic signals and suggest that the investigation of these precursors is one of the 58 most promising approaches toward the realization of short-term earthquake prediction. While 59 electromagnetic signals related to earthquake rupture strongly depend on earthquake 60 magnitude, local geology, depth of hypocentre, distance between epicentre and point of 61 observation, and azimuth to the rupture plane, it is not at all clear that precursive behaviour 62 occurs. Several papers (e.g. Johnston, 1997; Mueller and Johnston, 1998; Johnston et al., 63 2006) report the observation of co-seismic electromagnetic phenomena within a few tens of 64 kilometres of earthquake epicentres that are clearly related to earthquake rupture. However, 65 no indication of precursive behaviour is apparent in the minutes or months before any of these 66 events in electromagnetic or other seismic and geodetic data (Johnston et al., 2006). On the 67 other hand, many other publications (e.g. Eftaxias et al., 2001; Pulinets and Boyarchuk, 2004; 68 Varotsos, 2005; Molchanov and Hayakawa, 2008; Eftaxias et al., 2009) claim to observe 69 electromagnetic earthquake precursors, sometimes many hundreds of kilometres from the 70 earthquake, but with no clear co-seismic or post response effects. As a consequence, many in 71 the scientific community doubt of the reality of claimed seismogenic electromagnetic signals 72 and seriously question the claimed ability to develop short-term earthquake prediction 73 capabilities using these precursory signatures. The principal criticisms of these researchers 74 relate to: the absence of independent validation in other geophysical data; the lack of 75 repeatability and reproducibility of the claimed precursory signals; failure to show that the 76 claimed pre-seismic signals are not just chance events, random noise or global disturbances; 77 and discussion as to why precursory signals should occur without the expected larger co-

seismic signals (see Geller, 1997; Geller et al., 1997; Kagan, 1997; Pham and Geller, 2002;

79 Johnston et al., 2006).

80 During the last twenty years several authors (e.g. Hayakawa et al., 2007; Fraser-Smith, 81 2008, and reference therein) have suggested investigating ULF (Ultra-Low- Frequencies: 82 0.001-10Hz) magnetic emissions as a promising approach to highlight seismogenic signals. 83 ULF magnetic waves result from superposition of different signals. These include natural 84 signals from solar-terrestrial interaction, man-made noise, and signals possibly generated in 85 the Earth's interior. However, the majority of ULF emissions have a magnetospheric origin, 86 whereas any seismogenic signals should be very weak. Different methods of analysis have 87 been considered to discriminate the low ULF crustal signals from other signals (see Hattori et 88 al., 2004 and Hayakawa et al., 2007 and references therein). Moreover, several physical 89 mechanisms have been proposed to account for the generation of ULF magnetic seismogenic 90 emissions (e.g. Fenoglio et al., 1995; Molchanov and Hayakawa, 1995; Draganov et al., 1991; 91 Merzer and Klemperer, 1997; Molchanov et al., 2004b; Simpson and Taflove, 2005), but none of them can be considered completely satisfactory (Thomas et al., 2009a). 92

93 One of the most well-known seismogenic ULF magnetic field anomaly claims has been 94 reported by Fraser-Smith et al. (1990) as a precursor of the 18 October 1989 Ms=7.1 Loma-95 Prieta, California, earthquake. After this paper, ULF magnetic anomalies were claimed to be 96 related to strong earthquakes by several authors (e.g. Molchanov et al., 1992; Kopytenko et al., 1993; Hayakawa et al., 1996). In retrospect, some researchers seriously doubt the 97 98 authenticity of the Loma-Prieta precursor. They maintain that the ULF magnetic field 99 anomaly reported by Fraser-Smith et al. (1990) could actually be caused by instrumentation 100 malfunction (Thomas et al., 2009a) or that it is generated by normal geomagnetic activity 101 (Campbell, 2009). Furthermore, Masci (2010) put in doubt the reliability of fractal magnetic 102 ULF signatures in the geomagnetic field that previous publications have claimed to be related

103 without doubt to the preparation process of strong earthquakes by showing that these fractal 104 "anomalies" are likely caused by normal geomagnetic activity. In light of this, in attempting 105 to resolve the problem of clearly identifying reliable earthquake precursory signals, a closer 106 inspection concerning the presence of seismogenic signals in geophysical data sets is 107 required.

In the next section, the reliability of ULF geomagnetic field polarization ratio increaseswhich previous papers related to the seismic activity is investigated.

110

111 **2. Polarization ratio analysis**

Many researchers (e.g. Hattori, 2004; Hattori et al., 2004; Hayakawa et al., 2007) consider the investigation of ULF geomagnetic field polarization ratio to be a key parameter which allows us to detect possible magnetic seismogenic signals.

115 If H, D, and Z represent the variations (nT) of the geomagnetic field components around the NS, EW, and vertical direction respectively, then $G = \sqrt{H^2 + D^2}$ is the total 116 117 horizontal variation of the geomagnetic field (Kopytenko et al., 1991). In a fixed range of frequency, the magnetic polarization ratio is defined as the ratio between the integrated power 118 $P(nT^2)$ of the vertical component and the one of the horizontal component, that is: P_7/P_H , 119 120 P_Z/P_D, and P_Z/P_G. In any case, hereafter we refer to the polarization ratio as Z/H, Z/D, and 121 Z/G. Sometimes polarization ratio is defined as the ratio of the amplitudes (nT), that is the 122 square root of the integrate powers, or other authors (e.g. Hattori et al., 2002) report the ratio of the spectral intensities (nT/\sqrt{Hz}) . As a matter of fact, this method is not really a 123 124 "polarisation analysis" (where polarisation azimuth and ellipticity are available), but merely 125 the calculation of the ratio between the vertical and the horizontal components of the 126 geomagnetic field. However, here we refer to this ratio as "polarization ratio" as has been

127 used in previous papers. The fundamental assumption of this methodology is that presumed 128 ULF magnetic seismogenic emissions prevail in the vertical direction, contrary to ULF 129 signals of magnetospheric origin which typically have horizontal components larger than the 130 vertical one. Therefore, the ULF magnetic polarization ratio should increase in 131 correspondence with seismogenic magnetic emissions, whereas it is relatively small for 132 geomagnetic pulsations.

133 Usually the possible seismogenic electromagnetic radiation, which could affect the 134 ULF signals amplitude on the ground surface, may be distinguished between the direct radiation from the earthquake hypocentre region (see Fenoglio et al., 1995; Molchanov and 135 136 Hayakawa, 1995) and the indirect effect on the ULF signals of external origin due to the 137 variation of the electric Earth's crust conductivity caused by seismic activity (see Merzer and 138 Klemperer, 1997). In addition, several authors maintain that a further contribution to observed 139 polarization ratio increases could be related to the depression of the geomagnetic field 140 horizontal components caused by indirect mechanisms of lithosphere-atmosphere-ionosphere coupling which take place during seismic activity (see Molchanov et al., 2004b). 141

142 Even though many papers report examples of ULF polarization ratio increases before 143 the earthquake occurrence, several problems remain concerning the reliability of these 144 "anomalous" signals. An issue of the fundamental importance is how to separate the possible 145 ULF seismogenic signals from other signals such as natural signals (geomagnetic pulsations 146 caused by solar-terrestrial interaction, thunderstorms, etc.) and the artificial noise caused by 147 human activities (DC electric trains, power lines, etc.). The man-made noise can be reduced 148 by focusing the analysis only on night-time data. On the contrary natural signals might not be 149 eliminated using this method. Since the majority of ULF emissions result from 150 magnetospheric disturbances, caused by the interaction of the solar wind with the Earth's 151 magnetosphere, the simplest way to check the real presence of non-space signatures in the

152 geomagnetic field is comparing the ULF signals with the global geomagnetic activity 153 behaviour (Masci, 2010). More precisely, several publications (see Saito, 1969 and references 154 therein) show that the amplitude of ULF geomagnetic field continuous micropulsations (PCs) 155 have a clear positive relation with Kp index, which is representative of average disturbances 156 of the planetary geomagnetic field. This positive relation is evident mainly in PC_2 , PC_3 and 157 PC_4 bands. Note that the ULF seismogenic signals here put into question are observed in these 158 bands of frequency. Therefore, if we demonstrate a close correspondence between the time-159 series of a ULF geomagnetic field parameter and the Kp index we can affirm that the changes 160 of the geomagnetic field parameter is mainly caused by the variation of the geomagnetic 161 activity or, more precisely, it is due to non-earthquake sources.

In the following sections several cases of the ULF geomagnetic field polarization ratio increases, which previous researchers have claimed to be related without doubt to earthquake occurrences, are put into question by comparing their temporal evolution with the geomagnetic behaviour of K_p index. Furthermore, for the first two cases the linear residual time-series and the correlation coefficient between polarization ratio and K_p index have been calculated by digitalizing the published figures.

168

169 2.1 Guam earthquake 1993

On 8 August 1993, a strong earthquake (M_w =7.7, depth=60km) occurred offshore the island of Guam. In the hope of finding possible magnetic earthquake precursors, Hayakawa et al. (1996) performed polarization ratio analysis in the frequency band [0.01-0.05]Hz. They analysed the ULF (1Hz sampling rate) geomagnetic field data of Guam observatory, which is located about 65 km away from the earthquake epicentre. To reduce man-made noise, the authors focused their investigation on the night period [22:00-02:00]LT. The principal claim of Hayakawa et al. (1996) is an "anomalous" increase in the polarization ratio Z/H which

177 occurs during the period before the earthquake date. Hayakawa et al. (1996) also maintain the 178 presence of an enhanced maximum in the polarization ratio two months before the seismic 179 event (see Fig. 1, panel (a)). According to these authors, this maximum may be strong 180 evidence of magnetic precursory signals caused by the earthquake preparation process. As a 181 matter of fact, Thomas et al. (2009b) seriously put into question the reliability of Hayakawa et 182 al. (1996) conclusions by performing new analysis and comparing Guam data with data 183 coming from the geomagnetic observatory of Kakioka, Japan. The results of Thomas et al. 184 (2009b) are shown in Fig. 1 and can be summarized in the following three points: 1) problems 185 of analysis have been found in Hayakawa et al. (1996) since the new analysis does not match 186 the previous one (compare panel (a) and panel (b) of Fig. 1); 2) Guam and Kakioka data show 187 a significant correlation with the geomagnetic activity. More precisely, both Guam and 188 Kakioka geomagnetic field horizontal components show a similar temporal behaviour of the K_p index (see Thomas et al., 2009b, Fig. 1); 3) no clear seismogenic signatures have been 189 190 highlighted in the Guam data. The authors conclude that the Z/H ratio increase, which 191 occurred before the Guam earthquake is caused by the normal global geomagnetic activity, 192 therefore it is not related to the earthquake occurrence.

193 To verify Thomas et al. conclusions, the temporal evolution of the geomagnetic index K_p daily sum (ΣK_p) is superimposed onto the panel (b) of Fig. 1. Both the 5-day running 194 average and the 6^{th} order polynomial fitting of ΣK_p are reported in the figure. Consider that 195 ΣK_p vertical axis is descending. As a matter of fact, the 5-day running average confirms the 196 197 close inverse correspondence between the Guam polarization ratio and the geomagnetic 198 activity level: on average Z/H increases (decreases) when ΣK_p decreases (increases). 199 Moreover, all the principal maxima of the Guam polarization ratio can be undoubtedly associated with the geomagnetic activity. Furthermore, the 6th order polynomial fitting 200 201 highlights that also the slow increase, which the polarization ratio shows the period before the

202 Guam earthquake, mainly depends on the geomagnetic activity. Thus, as previously pointed

203 out by Thomas et al., its association with the seismicity seems to be rather inappropriate.

204 As further confirmation of previous mentioned conclusions, Guam polarization ratio 205 data are drawn out by digitalizing the figure of Thomas et al. (here panel (b) of Fig.1). The 206 correlation coefficient (-0.7) shows that Guam Z/H ratio and ΣK_p time-series are generally 207 well correlated with each other during the period before the earthquake data; its negative 208 value demonstrates the inverse correspondence. This shows that, the period before the 209 earthquake occurrence, Guam ULF Z/H variations are mainly caused by changes of the global 210 geomagnetic activity. On the other hand, the correlation coefficient between Guam Z/H ratio 211 and ΣK_p time-series is lower (- 0.4) in the period after the earthquake date. Thomas et al. 212 show similar results by calculating the correlation coefficient between Guam H component 213 and K_p index. As previously shown by the qualitative investigation, Z/H and ΣK_p time-series 214 have similar trends. This can be demonstrated calculating their linear relationship (Thomas et al., 2009b). This relationship is: $Z/H = -0.083 \times \Sigma K_p + 0.57$. In Fig. 1, panel (e), the linear 215 216 residual time-series is reported. Here we see that on average the residual time-series is mainly 217 flat and does not show any anomalous signature which could be related to the seismic activity 218 of the Guam area. Moreover, the root mean square (0.06) of the residual is much lower, as 219 Thomas et al. pointed out, than the year-long trend (≈ 0.2) of the Guam Z/H time-series.

220

221 2.2 Biak earthquake 1996

222 On 17 February 1996, a strong earthquake (M_w =8.2, depth=20km) struck Biak island, 223 Indonesia. Hayakawa et al. (2000) investigated the ULF geomagnetic field polarization ratio 224 behaviour at two observatories: Biak and Darwin, Australia, located respectively about 100 225 km and 1200 km away from the earthquake epicentre. The authors analysed the ULF 226 geomagnetic signals, in the frequency band [5-30]mHz and during the night period [22:00-

227 04:00]LT, maintaining that the Biak polarization ratio Z/H shows two anomalous increases 228 about 1.5 months and 2 weeks before the earthquake occurrence. On the contrary Darwin Z/H 229 ratio does not show corresponding increases. Hayakawa et al. (2000) concluded that the 230 enhancements of the Biak polarization ratio are seismogenic precursory signatures of the 231 forthcoming earthquake. Figure 2a shows the ± 5 -day running average of the polarization 232 ratios as reported by Hayakawa et al. (2000). Dashed green circles on the original view 233 highlight the two polarization ratio increases. To investigate the reliability of these results, the \pm 5-day running average of ΣK_p has been superimposed onto the Biak panel. Figure 2a shows 234 235 that the two increases of the polarization ratio actually correspond to decreases of ΣK_p . Thus, the claimed precursory signals seem to be once again mainly related to the geomagnetic 236 237 activity level. As a matter of fact, a close inverse correspondence between polarization ratio 238 and geomagnetic activity cannot be unambiguously demonstrated during the whole period. In 239 any case, since Kp index is representative of the geomagnetic field activity over global scales, 240 a strict correspondence between polarization ratio and Σ Kp cannot always exist, otherwise the 241 geomagnetic field polarization ratio pattern should be the same in all the observation sites 242 (refer also to the comments reported in section 3).

243 As for the Guam case, Biak polarization ratio values are drawn out by digitalizing the 244 figure of Hayakawa et al. (2000) (here upper panel of Fig. 2a). However, looking at Fig. 2 it is evident that there is a good inverse correspondence between Biak Z/H ratio and ΣK_p time-245 series the period after the middle of December 1995, but on the contrary the correlation fails 246 247 before this period. This is confirmed by the calculation of the correlation coefficient between 248 Z/H and ΣK_{n} : (0.22) before the middle of December 1995 and (-0.64) after this period. In any 249 case, the correlation coefficient shows that a good inverse correspondence between Z/H and ΣK_p really exists during the period of the claimed seismogenic "anomalies" occurrence. In 250 251 light of this, we have calculated the linear relationship between Z/H ratio and ΣK_p time-series

after the middle of December 1995. This relationship is: $Z/H = -0.0019 \times \Sigma K_p + 0.56$ (root

253 mean square = 0.05). The little panel at the top of Fig. 2a reports the residual time-series. Also

in this case no seismogenic anomaly may be stated.

255 Furthermore, Hayakawa et al. (2000) seem to show inconsistencies in their results as 256 well. Figure 2b reports the geomagnetic field components H and Z observed at Biak and Darwin as shown by Hayakawa et al. (2000). The authors report, in unspecified units, the 257 258 ULF wave activity (see Hayakawa et al., 2000 for details) of the geomagnetic field 259 components integrated in the frequency band [5-30]mHz. We note that Z and H values 260 reported in Fig. 2b do not correspond with Z/H values of Fig. 2a. More precisely, In Fig. 2b 261 the differences between Z and H are very small during the whole period, thus the ratio Z/H 262 should have small fluctuations with a mean value near 1 and not the values reported in Fig. 263 2a. Finally, it is important to note that Hobara et al. (2004) report further analysis of Biak data 264 and conclude that there are no significant increases in the geomagnetic field polarization ratio 265 before the 17 February 1996 earthquake.

266

267 2.3 Iwateken Nairiku Hokubu earthquake 1998

268 Hattori et al. (2004), and later Hattori (2004), report ULF ([10±3]mHz) geomagnetic 269 field polarization ratio analysis during the period of the Iwataken Nairiku Hokubu earthquake 270 (M=6.1, depth=10km) which occurred on 3 September 1998 at Honshu island, Japan. The 271 authors analysed geomagnetic data measured during night-time [00:00-04:00]LT at three 272 different stations: Matsukawa, Memambetsu and Kanoya which are located respectively about 273 15km, 500km and 1300km away from the epicentre. To reduce spurious noise the authors 274 perform a 5-day backward running average on the polarization ratio daily values. They 275 conclude that the polarization ratio S_7/S_D of Matsukawa shows an increase about two weeks 276 before the earthquake when it reaches a value (≈ 1.5) which is twice the normal level.

According to the authors, this increase is a local phenomenon restricted to Matsukawa, the closest station to the epicentre area, since the polarization ratio of the stations further from the earthquake epicentre do not show a similar behaviour.

280 Figure 3 shows the polarization ratios as reported by Hattori (2004) and Hattori et al. (2004). Checking their conclusions, the 5-day backward running average of ΣK_p is 281 282 superimposed on the upper panel of the figure. As a matter of fact, we can note that the 283 Matsukawa polarization ratio increase corresponds to a decrease of the geomagnetic activity. 284 Unfortunately, due to a gap in data we cannot check the polarization ratio behaviour of 285 Matsukawa during the period just following the anomaly occurrence. To better investigate the 286 reliability of the claimed "anomaly" an enlarged view is added onto the original figure. 287 Actually, the enlarged view shows that, during the period of the anomaly occurrence, the 288 polarization ratio has a similar increase in all the stations. The only difference is that the three 289 increases of the polarization ratio have different amplitudes as would be expected for data 290 coming from stations located at different magnetic latitudes. Furthermore, the polarization 291 ratio analysis seems to also show inconsistency in the results because S_Z and S_D (see Hattori et al., 2004 Fig. 11) do not agree with their ratio S_7/S_D reported in Fig. 3. 292

293

294 **2.4 Izu swarm 1998**

Kopytenko et al. (2001) report the temporal evolution of the ULF geomagnetic field polarization ratio at Kamo station during two earthquakes swarms which occurred in the period April-May 1998 near the Japanese Izu peninsula. The distance between the station and the epicentres is about 30-40 km. The main shocks occurred respectively on 26 April $(M_s=4.7)$ and on 3 May $(M_s=5.7)$. Fig. 4 (lower) shows the 5-day running average of the polarization ratio Z/G as reported by Kopytenko et al. (2001). The polarization ratio has been calculated in three bands of frequencies during the night period [00:00-04:00]LT. The

302 temporal evolutions of the seismic activity and the geomagnetic index ΣK_p are reported as 303 well. Note that, in the original figure the time scale of the upper panel does not match with the 304 time scale of the other two panels. The inconsistency of the time scales has been checked by 305 plotting ΣK_p data on the original view of the upper panel using the time scale of the two lower 306 panels. Therefore, in Fig. 4 the upper panel has been horizontally shifted in order to match the 307 time scales. Kopytenko et al. note that: 1) in correspondence with the two main shocks, sharp 308 increases of the geomagnetic activity occur; 2) there is an evident increase of the polarization 309 ratio which starts about twenty days before the first swarm; this increase reaches its maximum 310 two days before the beginning of the swarm; then the polarization ratio decreases and reaches 311 a minimum in correspondence of the $M_s=5.7$ seismic event; 3) the changes in polarization 312 ratio depend on the frequency range and they are more pronounced in the lower frequency 313 bands. Finally, the authors conclude that the behaviour of the polarization ratio is caused by a 314 combination of the geomagnetic activity and the seismogenic ULF emissions.

In order to check the conclusions of Kopytenko et al. (2001), the 5-day running average of ΣK_p is plotted onto the lower panel of Fig. 4. Actually, Fig. 4 shows a close inverse correspondence between the geomagnetic activity and the polarization ratio during the whole period. In light of this, the increase before the first swarm, the decrease before the M_s=5.7 shock and the following recovery of the polarization ratio to ordinary values seems to depend mainly on the geomagnetic activity level. Thus, the possible presence of seismogenic signatures in the geomagnetic field polarization ratio is rather doubtful.

322

323 2.5 Izu swarm 2000

Between June and August 2000, a seismic swarm occurred near the Izu peninsula. Five strong M > 6 earthquakes occurred on 1, 8, 15 and 30 July and 18 August. Ismaguilov et al. (2001) report the ULF geomagnetic field polarization ratios at the stations of Molchikoshi,

327 Seikoshi and Kamo about 80km away from the epicentre area. The polarization ratio has been 328 calculated in the frequency range $[5\pm3]$ mHz during the night period [00:00-06:00]LT. Figure 329 5a shows the 20-day running average of the polarization ratio Z/G as reported by Ismaguilov 330 et al. (2001). The amplitude variations of the geomagnetic field components Z and G are 331 shown as well. The authors maintain that the polarization ratio increases before the 332 seismically active period at all the stations. They also note an increase in the amplitude of the 333 geomagnetic field components Z and G. Since the amplitude enhancement is more 334 pronounced in the vertical component Z they concluded that the Z/G ratio increase is caused 335 by seismic activity. As in previous cases, the running mean of ΣK_p is superimposed onto the 336 original view of the polarization ratios. In this case the time window of the running average is \pm 10-day. Figure 5a once again shows a close inverse correspondence between ΣK_p and 337 338 polarization ratios. Both the increase before the seismic active period and the following 339 decrease seem mainly to depend on the geomagnetic activity level. Therefore, their 340 association with the seismic events is rather inappropriate.

341 Ismaguilov et al. (2003) compare the ratios Z/G of Kamo station and Kakioka 342 observatory located more than 200 km from Izu. The 3-day running averages of the 343 polarization ratio are calculated at 0.042Hz during night-time [00:00-07:00]LT. Figure 5b 344 shows the polarization ratios Z/G as reported by Ismaguilov et al. (2003). The authors 345 maintain that at Kamo station Z/G shows features which could be related to the seismic 346 activity even if the sharp decrease of 15 July is probably caused by a geomagnetic storm. 347 Checking a possible correspondence between the ratio Z/G and the geomagnetic activity, the 348 3-day running average of ΣK_p is superimposed on the polarization ratio of Kamo station. As a 349 matter of fact, Fig. 5b shows that the behaviour of Z/G is closely related to the geomagnetic 350 activity level before and during the seismic swarm. Therefore, the possible association with 351 the seismic activity seems to be once again rather doubtful.

352

353 2.6 Kamchatka earthquakes 2000-2001

354 Several papers report the analysis of geomagnetic field data measured at the observatory 355 of Karimshino, Kamchatka, Russia (e.g. Gladycev et al., 2001; Molchanov et al., 2003; 356 Molchanov et al., 2004a). According to the authors Kamchatka peninsula is an ideal place to 357 observe low ULF seismogenic signals because it is characterized by low man-made noise and 358 by a significant seismicity as well. Furthermore, they claim several increases of the ULF 359 geomagnetic field polarization ratio related to the Kamchatka seismic activity. Figure 6a shows the square root of the amplitude polarization ratio Z/G in the period 2000-2001 as 360 361 reported by Molchanov et al. (2003). The authors calculated $\sqrt{Z/G}$ in the frequency band [10-362 30]mHz and averaged it over a 2-hour window. The temporal evolution of the geomagnetic 363 K_p index and K_s index (yellow stars in Fig. 6a) are reported as well. K_s is an index which 364 depends both on the earthquake magnitude and on the distance between the observation point and the earthquake epicentre (see for details Molchanov et al., 2003). The authors maintain 365 366 that, during night-time, $\sqrt{Z/G}$ increases from 2 to 7 days before the occurrence of five strong 367 earthquakes (yellow stars with a red dot in Fig. 6a). Green circles are added on the original view to highlight the claimed seismogenic polarization ratio increases. To investigate the 368 behaviour of $\sqrt{Z/G}$, the corresponding K_p index temporal evolution is superimposed onto the 369 370 polarization ratio panels. As a matter of fact, Fig. 6a shows that on average high polarization 371 ratio values correspond to low K_p values. More precisely, the polarization ratio increases, 372 which are claimed to have a seismogenic origin, actually correspond to low geomagnetic 373 actively levels; on the contrary low polarization ratio values correspond to high geomagnetic 374 activity levels. This relation is evident over the whole period reported in the figure. 375 Furthermore, Fig. 6a also shows further polarization ratio increases which are not related to

any strong earthquake; refer to the increases of 13 July and 26 August. In light of this, once
again a close inverse correspondence between polarization ratio and geomagnetic activity is
shown. Thus, the previous claims to a seismogenic origin are rather dubious.

379 To better investigate the origin of the Z/G increases the authors compare the ratios Z/G380 and 1/G. Figure 6b shows the daily values of Z/G and 1/G ratios as reported by Molchanov et 381 al. (2003) in the same periods of Fig. 6a. Since the two ratios show the same behaviour over 382 the whole period the authors conclude that the Z/G increases are caused by the suppression of 383 the horizontal magnetic field component G and not by the increase of the vertical component 384 Z. They suggest that the suppression of the ULF horizontal component is not related to 385 electromagnetic emissions generated by a source located inside the Earth, but it is caused by 386 the perturbation of the lower ionosphere due to a lithosphere-atmosphere-ionosphere coupling 387 mechanism. According to them the conductivity of the ionosphere could be modified by the 388 intensification of the atmospheric gravity waves related to changes of atmospheric 389 temperature and pressure near the Earth's surface caused by the seismicity (see Molchanov et 390 al., 2004b). In Fig. 6b, the temporal evolution of the geomagnetic index K_p daily sum (ΣK_p) is 391 superimposed onto the polarization ratio daily values. The figure shows an evident inverse 392 correspondence between the polarization ratio and the geomagnetic index ΣK_{n} over the whole 393 period. Therefore, once again Fig. 6b confirms that the polarization ratio increases are closely 394 related to low geomagnetic activity levels.

395

396 2.7 Bovec earthquake 2004

397 Prattes et al. (2008) report the ULF polarization ratio analysis of magnetic data coming 398 from the South European Geomagnetic Array (SEGMA) during the period of Bovec, 399 Slovenia, earthquake (M=5.5, depth 6Km) which occurred on 12 July 2004. According to the 400 authors the ULF geomagnetic field polarization ratio of Castello Tesino, the closest station to

401 the earthquake epicentre, shows significant increases before the earthquake occurrence. Fig. 7 402 shows the geomagnetic field components, Z and H, and the polarization ratio R=Z/H as 403 reported by Prattes et al. (2008) in the frequency band [0.01-0.05]Hz. Taking into account the 404 geomagnetic field components behaviour, the authors maintain that the polarization ratio 405 increases could be caused by decreases of the horizontal component amplitude. They also 406 claim an increase of the polarization ratio occurred on 12 July caused by the high amplitude 407 of the geomagnetic field vertical component. To check the possible relation between the 408 polarization ratio enhancements and the Bovec earthquake, the temporal evolution of the K_p index is plotted on the polarization ratio panel. Taking into account the K_p behaviour, it is 409 410 clearly evident that, before the Bovec earthquake, there is a close inverse correspondence 411 between the polarization ratio increases and the geomagnetic activity. This correspondence 412 can also be found in the period following the earthquake data but it is not the case during 413 week 7. However, since week 7 is a period characterized by a very high geomagnetic activity 414 level, as expected, the polarization ratio shows on average low values because the horizontal 415 component amplitude increases dominate the lower vertical component increases (see Prattes 416 et al., 2008).

417 In another figure, not reported here, the authors compare the polarization ratios daily 418 averages of three SEGMA stations: Castello Tesino, Nagycenk and Ranchio (see Fig. 5 of 419 Prattes et al., 2008). The distance of the stations from the epicentre area is respectively 153, 275, and 291 km. The authors conclude that the highest polarization ratio amplitude is 420 421 observed at Castello Tesino, the closest station to the epicentre. Actually, Fig. 5 of Prattes et 422 al. (2008) shows that the three polarization ratios display a similar behaviour. The only 423 difference is in their amplitudes as expected for different stations. Concerning the polarization 424 ratio increase of 12 July, it disappears in the daily values. This suggests that the increase

425 could be caused by environmental noise or, at least, this could suggest that the possible

426 seismogenic emission has a short duration.

427

In the last two cases reported in the following sections, the correlation between the
polarization ratio and the geomagnetic activity cannot be unambiguously demonstrated.
However, the claimed polarization ratio enhancements can be considered doubtful as well.

431

432 2.8 Kagoshimaken-Hokuseibu earthquakes 1997

Hattori (2004) report the ULF polarization ratio S_Z/S_G at Tarumizu station, Japan, 433 434 located 60km away from the epicentre area of the M=6.5, 26 March 1997, and M=6.3, 13 435 May 1997, Kagoshimaken-Hokuseibu earthquakes. The polarization ratio has been calculated 436 in the frequency band [0.010±0.003]Hz during night-time [00:00-04:00]LT. Figure 8a shows 437 the 10-day backward running average of the ratios S_Z/S_G at Tarumizu and two reference 438 stations which are located very far from the epicentre area: Chichijima, Bonin Islands, and 439 Darwin, Australia. The regional seismicity and the geomagnetic index ΣK_p are reported as 440 well. The author claims a significant increase of the S_Z/S_G ratio occurred at Tarumizu about 441 one month before the 26 March earthquake. Since the polarization ratios of the two reference 442 stations do not show similar increases the author maintains that the Tarumizu polarization ratio increase is without doubt a precursory signature of Kagoshimaken-Hokuseibu 443 444 earthquakes. Checking the conclusions of the author, the 10-day backward running average of ΣK_p is also superimposed in the polarization ratio panel. Even if both Turumizu polarization 445 446 ratio and ΣK_{p} show a similar behaviour in the period before the claimed anomaly occurrence, 447 their temporal evolutions are rather different in the following period.

448 As a matter of fact, the results of Hattori (2004) were previously reported by Hattori et 449 al. (2002). This paper also shows the temporal evolution of S_Z and S_G which are reported here

450 in Fig. 8b. Actually, comparing S_Z and S_G with their ratio S_Z/S_G we can note inconsistency in 451 the results of the previous research. More precisely, the ratio between S_Z and S_G provides 452 values lower than the ratio S_Z/S_G reported in Fig. 8a. For example, referring to Tarumizu data, 453 on 5 March 1997 S_Z is about 0.0040 and S_G is about 0.0035, so S_Z/S_G should be about 1.15, 454 but the value reported in the previous papers is about 2.2. Furthermore, we can also note that 455 before the first earthquake the polarization ratio of Chichijima station shows a slight increase 456 similar to that of Tarumizu station. This suggests that the behaviour of the polarization ratio 457 of Tarumizu station could have a global origin. Unfortunately a gap in data, which occurred at 458 the Darwin station (the conjugate point of Tarumizu) during the period of the claimed 459 anomaly, precludes further investigation. In conclusion, the Tarumizu precursor also seems to NAT 460 be not totally reliable.

461

462 2.9 Chi-Chi earthquake 1999

463 Akinaga et al. (2001) report the ULF polarization ratio Z/G at Lunping station, 120 km 464 from the epicentre of Chi-Chi, Taiwan, earthquake (M_w=7.7, depth 11km) occurred on 21 September 1999. Figure 9 shows the temporal evolution of the polarization ratio as reported 465 466 by Akinaga et al. (2001) in the frequency band [0.010±0.003]Hz during the night period 467 [00:00-04:00]LT. The authors claim an increase in the geomagnetic field polarization ratio 468 before the earthquake occurrence. To investigate the polarization ratio behaviour, the \pm 5-day 469 running average of ΣK_p is reported in the figure both with a descending vertical axis and, for 470 the last period, with an increasing vertical axis. Figure 9 emphasizes a rather strange behaviour of Z/G. To be more precise, Z/G shows a close inverse correspondence with ΣK_p 471 472 up to April 1999 just before a gap in the data. On the contrary, it seems to show a positive 473 correlation with ΣK_p in the period following this gap in data. Unfortunately, lack of data does 474 not permit investigation of the behaviour of Z/G in the period following the earthquake date.

475 In light of this, I think that there are two possibilities: 1) the close positive correlation after 476 April 1999 is just a chance event, therefore the polarization increase is real; 2) there are 477 analysis problems just after the gap in data which occurred on April 1999. In my opinion, this 478 is enough to cast doubt on the reliability of the results until further analysis confirms the 479 seismogenic origin of the claimed anomaly. As a final consideration I would like to point out 480 that Liu et al. (2006) analysis of data from the Taiwan geomagnetic network in the period of 481 Chi-Chi earthquake uses Lunping as reference station. Taiwan geomagnetic network consists 482 of eight stations in which the total geomagnetic field intensity is measured. According to the 483 authors Lunping is located in a seismic quiet area, so its magnetic measurements are not 484 affected by the seismic activity. Using Lunping as reference station, Liu et al. (2006) claim 485 seismogenic magnetic anomalies at the two stations of the Taiwan network closest to the 486 epicentre area. In conclusion, it is very strange that Lunping station, in which an anomaly on 487 the geomagnetic field polarization ratio has been claimed to be related to the Chi-Chi 488 earthquake by Akinaga et al. (2001), is used as reference station in a similar research 489 performed during the same period.

490

491 **3.** Comments and conclusions

492 In this paper, nine cases of ULF geomagnetic field polarization ratio increases which 493 previous publications have related, without doubt, to the occurrence of strong earthquakes 494 have been investigated by a qualitative inspection. The analysis compares the polarization 495 ratio behaviour reported in previous papers with the geomagnetic activity level. Running 496 averages of the ΣK_p geomagnetic index are plotted onto the original figures from previous 497 publications. Furthermore, several problems are identified in the previous research. First of 498 all, in the majority of the cases are reported data sets which are too short; they sometimes 499 represent just a few months. This does not permit a complete view of the behaviour of the

500 parameters under investigation. Moreover, usually in order to exclude the presence of 501 magnetospheric signals, the authors point out that the claimed seismogenic anomalies took 502 place during periods characterized by a low geomagnetic activity. In my opinion this is an 503 oversimplified assumption because the variation of the geomagnetic activity, which induces 504 changes in several geomagnetic parameters, must be taken into account. For example, when 505 the geomagnetic activity decreases, both polarization ratio and fractal dimension (see Masci, 506 2010) of the geomagnetic field increase. Thus, this paper shows that the claims of previous 507 publications concerning the correlation between the ULF polarization ratio increases and the 508 seismic activity are not meaningful without properly taking into account the behaviour of 509 other ULF sources evident in the global geomagnetic activity. Furthermore, the comparison 510 between the analysed parameters and the geomagnetic indices must be performed using the 511 same temporal resolution. More precisely, the correlation between the temporal behaviour of 512 the polarization ratio and the geomagnetic index must be investigated by averaging procedures using the same time window. 513

514 This paper shows that in seven of the investigated cases, for a total of fourteen earthquakes, the increases of the geomagnetic field polarization ratio, which previous authors 515 516 have claimed without doubt to be related to strong earthquakes, apparently result from a 517 decrease of the geomagnetic activity level. On average, when the geomagnetic activity 518 decreases, the reduction of the geomagnetic field horizontal components are larger than the reduction of the vertical component, therefore the polarization ratio increases. On the 519 520 contrary, an increase of the geomagnetic activity causes an increase in the geomagnetic field 521 horizontal components larger than the increase of the vertical component, therefore the 522 polarization ratio decreases. In light of this, if we may exclude that all the correspondences 523 reported in this paper are just chance events, the simple association between the polarization 524 ratio increases and the seismic events are doubtful in all seven cases. Regarding the last two

investigated cases, they seem to be doubtful as well: the first case shows inconsistency in the results so that the claimed polarization precursor could not be totally reliable; in the second case, the apparent correspondence between the polarization ratio and the geomagnetic index seems to behave oddly during the analysed period. Moreover I want point out that Masci (2010) seriously put in doubt ULF magnetic fractal precursors which previous papers have related to the occurrence of the three seismic events (Guam 1993, Biak 1996 and Izu 2000) also questioned in this paper.

532 I want to point out again that the methodology adopted in this paper, and previously in 533 Masci (2010), is just a qualitative or, more precisely, a visual investigation, even if the 534 quantitative analyses here reported for the first two cases confirm the qualitative claims. 535 Furthermore, I would like to emphasize that all the polarization ratio increases, put into 536 question here, were claimed to be seismogenic signatures just by visual inspection. In my 537 opinion, an anomaly cannot be recognized as seismogenic just by visual investigation on the 538 contrary, the seismogenic origin of a by-eye anomaly can be put into question by a visual 539 investigation. Obviously, it's likely that an "anomalous variation" of a geomagnetic field 540 parameter (e.g. polarization ratio or fractal dimension) can happen before the occurrence of an 541 earthquake, but relating these variations to the seismic events without further validations is 542 just an oversimplified conclusion. However, the geomagnetic activity behaviour must be 543 taken properly into account in order to quantify how much variability in the data can be 544 attributed to the geomagnetic global activity and how much to the possible ULF precursors.

545 Concerning the correspondence between polarization ratio changes and geomagnetic 546 activity, since Kp index is representative of the geomagnetic field average disturbances over 547 global scales, it is impossible that the polarization ratio must always show the same features 548 of Σ Kp, otherwise the geomagnetic field polarization ratio pattern should be the same in all 549 the observation sites. To be more precise, the majority of ULF signals are external signals

550 which come from the interplanetary space and magnetosphere. These signals include 551 upstream waves, resonances processes, ion-cyclotron waves, and others, and are generated by 552 well-known and different sources (McPherron, 2005). Each external source gives its 553 contribution, at different frequencies inside the ULF band, to the signals observed on the 554 ground. Some of these signals have a worldwide extension, whereas others could have 555 latitude dependence (Saito, 1969). Thus, even if the amplitude of ULF geomagnetic field 556 signal has a clear positive relation with Kp index, we should not expect that a strict 557 correspondence between polarization ratio and ΣKp will always exist. On the other hand, if 558 we demonstrate a close correspondence between the ULF geomagnetic field ratio Z/H 559 changes and the geomagnetic index variations, we can affirm that the Z/H changes are caused 560 by the variation of the geomagnetic activity, or more precisely we can point out that they are 561 related to signals having external origin, and not to signals generated by sources located 562 inside the Earth. Therefore, appeals to a seismogenic origin are rather dubious.

563 In conclusion, it is evident that some problems of fundamental importance in the 564 investigation of seismo-magnetic signals are still remaining unresolved and a huge amount of 565 research and a constructive criticism of the results are needed. Finally, I would like to 566 emphasize that, as Eftaxias et al. (2009) point out, a single analysis by itself cannot establish 567 if an anomaly is a precursor or just a chance event. Therefore, as Uyeda et al. (2009) suggest, 568 a really multidisciplinary approach, which involves the investigation of physical, 569 geochemical, hydrological and other parameters, could be useful to recognize an anomaly as a 570 real seismogenic signature.

571 Acknowledgements

- 572 A special thanks to Dr. Roberta Giangiuliani for her invaluable help. I am also grateful
- 573 to the Editor and two anonymous reviewers for the constructive comments that were useful to
- 574 improve the manuscript. The author also thanks Dr. Paolo Palangio, for the constructive
- discussions. The geomagnetic Kp index has been downloaded from Kyoto World Data Center 575
- 576 for Geomagnetism (http://swdcwww.kugi.kyoto-u.ac.jp/).

577 **References**

- 578 Akinaga, Y., M. Hayakawa. J. Y. Liu, K. Yumoto, and K. Hattori, 2001. A precursory ULF
- 579 signature for Chi-Chi earthquake in Taiwan. Nat. Hazards Earth Syst. Sci., 1, 33-36,
- 580 doi:10.5194/nhess-1-33-2001.
- 581 Campbell, W. H., 2009. Natural magnetic disturbance fields, not precursors, preceding the
- 582 Loma Prieta earthquake. J. Geophys. Res., 114, A05307, doi:10.1029/2008JA013932.
- 583 Draganov, A. B., U. S. Inan, and Yu. N. Taranenko, 1991. ULF magnetic signatures at the
- 584 earth surface due to ground water flow: a possible precursor to earthquakes. Geophys. Res.
- 585 Lett., 18, 6, 1127-1130, doi:10.1029/91GL01000.
- Eftaxias, K, P. Kapiris, J. Polygiannakis, N. Bogris, J. Kopanas, G. Antonopoulos, A.
 Peratzakis, and V. Hadjicontis, 2001. Signature of pending earthquake from
 electromagnetic anomalies, Geophys. Res. Lett., 28(17), 3321, doi:10.1029/
 2001GL013124.
- Eftaxias, K, L. Athanasopoulou, G. Balasis, M. Kalimeri, S. Nikolopoulos, Y. Contoyiannis,
 J. Kopanas, G. Antonopoulos, and C. Nomicos, 2009. Unfolding the procedure of
 characterizing recorded ultra lowfrequency, kHZ and MHz electromagetic anomalies prior
 to the L'Aquila earthquake as pre-seismic ones Part 1. Nat. Hazards Earth Syst. Sci., 9,
 1953-1971, doi: 10.5194/nhess-9-1941-2009.
- Fenoglio, M. A., M. J. S.Johnston, and J. D. Byerlee, 1995. Magnetic and electric fields
 associated with changes in high pore pressure in fault zones: Application to the Loma
 Prieta ULF emissions. J. Geophys. Res., 100, B7, 12951-12958, doi:10.1029/95JB00076.
- Fraser-Smith, A. C., A. Bernardy, P. R. McGill, M. E. Ladd, R. A. Helliwell, and O. G. Jr.
 Villard, 1990. Low frequency magnetic field measurements near the epicenter of the
 Loma-Prieta earthquake. Geophys. Res. Lett., 17, 9, 1465-1468,
 doi:10.1029/GL017i009p01465.

- 602 Fraser-Smith, A. C., 2008. Ultralow-frequency magnetic fields preceding large earthquakes.
- 603 EOS, 89, 23, 211, doi:10.1029/2008EO230007.
- 604 Geller, R. J., 1997. Earthquake prediction: a critical review. Geophys. J. Int., 131, 425-450,
- 605 doi:10.1111/j.1365-246X.1997.tb06588.x.
- 606 Geller, R. J., D. D. Jackson, Y. Y. Kagan, and F. Mulargia, 1997. Earthquakes cannot be
- 607 predicted. Science, 275, 1616, doi:10.1126/science.275.5306.1616.
- 608 Gladychev, V., L. Baransky, A. Schekotov, E. Fedorov, O. Pokhotelov, S. Andreevsky, A.
- 609 Rozhnoi, Y. Khabazin, G. Belyaev, A. Gorbatikov, E. Gordeev, V. Chebrov, V. Sinitsin,
- 610 A. Lutikov, S. Yunga, G. Kosarev, V. Surkov, O. Molchanov, M. Hayakawa, S. Uyeda, T.
- 611 Nagao, K. Hattori, and Y. Noda, 2001. Study of electromagnetic emissions associated with
- 612 seismic activity in Kamchatka region. Nat. Hazards Earth Syst. Sci., 1, 127-136,
- 613 doi:10.5194/nhess-1-127-2001.
- 614 Hattori, K., Y. Akinaga, M. Hayakawa, K. Yumoto, T. Nagao, and S. Uyeda, 2002. ULF
- 615 magnetic anomaly preceding the 1997 Kagoshima Earthquakes. In: M. Hayakawa and O.
- 616 Molchanov (Eds.), Seismo Electromagnetics: Lithosphere-Atmosphere-Ionosphere 617 coupling, TerraPub, Tokyo, 19-28.
- Hattori, K., 2004. ULF Geomagnetic Changes Associated with Large Earthquakes. TAO, 15,
 3, 329-360.
- Hattori, K., I. Takahashi , C. Yoshino, N. Isezaki, H. Iwasaki, M. Harada, K. Kawabata, E.
 Kopytenko, Y. Kopytenko, P. Maltsev, V. Korepanov, O. Molchanov, M. Hayakawa, Y.
 Noda, T. Nagao, S. Uyeda, 2004. ULF geomagnetic field measurements in Japan and some
- 623 recent results associated with Iwateken Nairiku Hokubu earthquake in 1998. Phys. Chem.
- 624 Earth, 29, 481-494, doi:10.1016/j.pce.2003.09.019.

- 625 Hayakawa, M., R. Kawate, O. A. Molchanov, and K. Yumoto, 1996. Results of ultra-low-
- 626 frequency magnetic field measurements during the Guam earthquake of 8 August 1993.
- 627 Geophys. Res. Lett., 23, 3, 241-244, doi:10.1029/95GL02863.
- 628 Hayakawa, M., T. Itoh, K. Hattoti, and K. Yumoto, 2000. ULF electromagnetic precursors for
- an earthquake at Biak, Indonesia on February 17, 1996. Geophys. Res. Lett., 27, 10, 1531-
- 630 1534, doi:10.1029/1999GL005432.
- 631 Hayakawa, M., K. Hattori, and K. Ohta, 2007. Monitoring of ULF (ultra-low-frequency)
- 632 geomagnetic variations associated with earthquakes. Sensors, 7, 1108-1122,
 633 doi:10.3390/s7071108.
- Hayakawa, M. and Y. Hobara, 2010. Current status of seismo-electromagnetics for short-term
- 635 earthquake prediction. Geomatics, Natural Hazards and Risk, 1, 2, 115–155, doi:
 636 10.1080/19475705.2010.486933.
- 637 Hobara, Y., H. C. Koons, J. L. Roeder, K. Yumoto an M. Hayakawa, 2004. Characteristics of
- 638 ULF magnetic anomaly before earthquakes. Phys. Chem. Earth, 29, 437-444,
- 639 doi:10.1016/j.pce.2003.12.005.
- 640 Ismaguilov, V. S., Yu. A. Kopytenko, K. Hattori, P. M. Voronov, O. A. Molchanov, and M.
- 641 Hayakawa, 2001. ULF magnetic emissions connected with under sea bottom earthquakes.

642 Nat. Hazards Earth Syst. Sci., 1, 23-31, doi:10.5194/nhess-1-23-2001.

- Ismaguilov, V. S., Yu. A. Kopytenko, K. Hattori and M. Hayakawa, 2003. Variations of
 phase velocity and gradient values of ULF geomagnetic disturbances connected with the
 Izu strong earthquakes. Nat. Hazards Earth Syst. Sci., 20, 1-5, doi:10.5194/nhess-3-211-
- 646 2003.
- Johnston, M. J. S., 1997. Review of electrical and magnetic fields accompanying seismic and
 volcanic activity. Surv. Geophys., 18, 5, 441-475, doi:0.1023/A:1006500408086.

- 649 Johnston, M. J. S., Y. Sasai, G. D. Egbert, and R. J. Muller, 2006. Seismomagnetic effects
- from the long-awaited 28 September 2004 M 6.0 Parkfield earthquake. Bull. Seism. Soc.
- 651 Am., 96(4B), S206-S220, doi:10.1785/0120050810.
- 652 Kagan, Y. Y., 1997. Are earthquake predictable?. Geophys. J. Int., 131, 505-525, doi:
- 653 10.1111/j.1365-246X.1997.tb06595.x.
- 654 Kopytenko, Yu. A., T. G. Matiashvili, P. M. Voronov, E. A. Kopytenko, and O. A.
- 655 Molchanov, 1993. Detection of ultra-low-frequency emissions connected with the Spitak
- 656 earthquake and its aftershock activity, based on geomagnetic pulsations data at Dusheti and
- 657 Vardzia observatories. Phys. Earth Planet. Int., 77, 85-95, doi:10.1016/0031658 9201(93)90035-8.
- 659 Kopytenko, Y., V. Ismagilov, M. Hyakawa, N. Smirnova, V. Troyan, and T. Peterson, 2001.
- 660 Investigation of the ULF electromagnetic phenomena related to earthquakes: contemporary 661 achievements and the perspective. Ann. Geof.-Italy, 44, 2, 325-334.
- Liu, J. Y., C. H. Chen, Y. I. Chen, H. Y. Yen, K. Hattori, and K. Yumoto, 2006. Seismo-
- 663 geomagnetic anomalies and M≥5 earthquakes observed in Taiwan during 1988-2001.

664 Phys. Chem. Earth, 31, 215-222, doi:10.1016/j.pce.2006.02.009.

- 665 Main, I., 1999. Is reliable earthquake prediction of individual earthquakes a realistic scientific
- 666 goal? <http://www.nature.com/nature/debates/earthquake/equake_frameset.html>. Nature
- 667 Debate 25 February to 8 April.
- 668 Masci, F., 2010. On claimed ULF seismogenic fractal signatures in the geomagnetic field. J.
- 669 Geophys. Res., 115, A10236, doi:10.1029/2010JA015311.
- 670 McPherron, R. L., 2005. Magnetic pulsations: their sources and relation to solar wind and
- 671 geomagnetic activity, Surv. Geophys., 26, 545-592, doi:10.1007/s10712-005-1758-7.

- 672 Merzer, M., and S. L. Klemperer, 1997. Modeling low-frequency magnetic-field precursors to
- the Loma Prieta earthquake with a precursory increase in fault-zone conductivity. Pure
- 674 Appl. Geophys., 150, 217–248, 10.1007/s000240050074.
- 675 Molchanov, O. A., Yu. A. Kopytenko, P. M. Voronov, E. A. Kopytenko, T. G. Matiashvili, A.
- 676 C. Fraser-Smith, and A. Bernardy, 1992. Results of ULF magnetic field measurements
- 677 near the epicenters of the Spitak (Ms = 6.9) and Loma Prieta (Ms = 7.1) earthquakes:
- 678 comparative analysis. Geophys. Res. Lett., 19, 14, 1495-1498, doi:10.1029/92GL01152.
- 679 Molchanov, O., and M. Hayakawa, 1995. Generation of ULF electromagnetic emissions by
- 680 microfracturing. Geophys. Res. Lett., 22, 22, 3091-3094, doi:10.1029/95GL00781.
- 681 Molchanov, O., A. Schekotov, E. Fedorov, G. Belyaev, and E. Gordeev, 2003. Preseismic
- 682 ULF electromagnetic effect from observation at Kamchatka. Nat. Hazards Earth Syst. Sci.,
- 683 3, 203-209, doi:10.5194/nhess-3-203-2003.
- Molchanov, O. A., A. Yu. Schekotov, E. Fedorov, G. G. Belyaev, M. S. Solovieva, and M,
- Hayakawa, 2004a. Preseismic ULF effect and possible interpretation. Ann. Geof.-Italy, 47,
 1, 119-131.
- 687 Molchanov, O., E. Fedorov, A. Schekotov, E. Gordeev, V. Chebrov, V. Surkov, A. Rozhnoi,
- 688 S. Andreevsky, D. Iudin, S. Yunga, A. Lutikov, M. Hayakawa, and P. F. Biagi, 2004b.
- 689 Lithosphere-atmosphere-ionosphere coupling as governing mechanism for preseismic
 690 short-term events in atmosphere and ionosphere. Nat. Hazards Earth Syst. Sci., 4, 757-767,
- 691 doi:10.5194/nhess-4-757-2004.
- Molchanov, O., and M. Hayakawa (Eds), 2008. Seismo Electromagnetics and RelatedPhenomena: History and latest results. TerraPub, Tokyo, pp 189.
- Mueller, R. J., and M. J. S. Johnston, 1998. Review of magnetic field monitoring near active
 faults and volcanic calderas in California: 1974-1995. Phys. Earth Planet. In., 105, 131144, doi:10.1016/S0031-9201(97)00086-1.

- 697 Pham, V. N., and R. J. Geller, 2002. Comment on "Signature of pending earthquake from
- 698 electromagnetic anomalies" by K. Eftaxias et al., Geophys. Res. Lett., 29(18), 1871,
- 699 doi:10.1029/2002GL015328.
- 700 Prattes, G., K. Schwingenschuh, H. U. Eichelberger, W. Magnes, M. Boudjada, M. Stachel,
- 701 M. Vellante, V. Wesztergom, and P. Nenovski, 2008. Multi-point ground-based ULF
- magnetic field observations in Europe during seismic active periods in 2004 and 2005. Nat.
- 703 Hazards Earth Syst. Sci., 8, 501-507, doi:10.5194/nhess-8-501-2008.
- 704 Pulinets, S.A., Boyarchuk, K.A., 2004. Ionospheric Precursors of Earthquakes. Springer,
- 705 Berlin, Germany, p. 315.
- Saito, T.: Geomagnetic pulsations, Space Sci. Rev., 10, 319–342, doi:10.1007/BF00203620,
 1969.
- 708 Simpson, J. J. and A. Taflove, 2005. Electrokinetic effect of the Loma Prieta earthquake
- calculated by an entire-Earth FDTD solution of Maxwell's equations. Geophys. Res. Lett.,
- 710 32, L09302, doi:10.1029/2005GL022601.
- Thomas, J. N., J. J. Love, and M. J. S. Johnston, 2009a. On the reported magnetic precursor of
 the 1989 Loma Prieta earthquakes. Phys. Earth Planet. Int., 173, 207-215,
- 713 doi:10.1016/j.pepi.2008.11.014.
- Thomas, J. N., J. J. Love, M. J. S. Johnston, and K. Yumoto, 2009b. On the reported magnetic
- 715 precursor of the 1993 Guam earthquake. Geophys. Res. Lett., 36, L16301,
 716 doi:10.1029/2009GL039020.
- 717 Uyeda, S., T. Nagao, and M. Kamogawa, 2009. Short-term earthquake prediction: Current
 718 status of seismo-electromagnetics. Tectonophysics, 470, 205-213,
 719 doi:10.1016/j.tecto.2008.07.019.
- 720 Varotsos, P., 2005. The Physics of Seismic Electric Signals. TerraPub, Tokyo, pp 477.
- 721

722 Figure captions

723

724 Fig. 1. ULF polarization ratio analysis during the period of Guam earthquake as reported by 725 Thomas et al. (2009b) (a reproduction of Thomas et al., 2009b, Fig. 2). EQ refers to the 726 earthquake date. The panel (a) shows the 5-day running average of the ratio Z/H at Guam 727 observatory as reported by Hayakawa et al. (1996). Panels (b), (c) and (d) show respectively 728 the 5-day running average of the ratio Z/H at Guam observatory, the 5-day running average of 729 the ratio Z/H at Kakioka observatory, and the residual of the linear relationship between 730 Guam and Kakioka polarization ratios. The 5-day running average and the 6th order 731 polynomial fitting of ΣK_p are superimposed onto panel (b). Panel (c) has been added to the 732 original view and shows the residual of the linear relationship between Guam Z/H ratio and 733 ΣK_p . See text and Thomas et al. (2009b) for details.

734

735 Fig. 2a. Temporal evolution of the ULF polarization ratio Z/H at Biak and Darwin in the 736 period November 1995 - March 1996 as reported by Hayakawa et al. (2000) (a reproduction 737 of Hayakawa et al., 2000, Fig. 3). EQ refers to the earthquake date. Dashed green circles 738 highlight the increases of the Biak polarization ratio claimed to be related to the seismic 739 activity. For a better display, the original pale yellow lines of the polarization ratio running 740 averages are changed in red. The ± 5 -day running average of ΣK_p is superimposed onto the 741 Biak panel as well. The upper little panel has been added to the original view and shows the 742 residual of the linear relationship between Biak Z/H ratio and ΣK_{p} .

743

Fig. 2b. Temporal evolution of the ULF wave activity of the geomagnetic field components H
and Z at the stations of Biak (blue) and Darwin (red) in the period November 1995 - March

1996 as reported by Hayakawa et al. (2000) (a reproduction of Hayakawa et al., 2000, Fig. 2).

747 ΣK_p temporal evolution is also shown in the lower panel. EQ refers to the earthquake date.

748

Fig. 3. Upper panel: 5-day backward running averages of ULF polarization ratios Sz/SD in the period of Iwateken Nairiku Hokubu earthquake at Matsukawa, Memambetsu and Kanoya stations as reported by Hattori (2004) (a reproduction of Hattori, 2004, part of Fig. 10a). Lower panel: 5-day backward running average (thick red solid line) and daily values (thin red solid line) of Matsukawa polarization ratio. The 5-day backward running average of ΣK_p is superimposed onto the upper panel as well. An enlargement view of the claimed precursory anomaly is added to the original view.

756

Fig. 4. Lower panel: 5-day running average of the ULF polarization ratio Z/G at Kamo station as reported by Kopytenko et al. (2001) (a reproduction of Kopytenko et al., 2001, Fig. 6). Middle panel: seismic activity during April-May 1998. Upper panel: temporal evolution of ΣK_p . In the lower panel the 5-day running average of ΣK_p is superimposed on the original view.

762

Fig. 5a. Twenty days running averages of the geomagnetic field components Z and G, and the polarization ratio Z/G at the stations of Molchikoshi (M), Seikoshi (S) and Kamo (K) as reported by Ismaigullov et al. (2001) (a reproduction of Ismaigullov et al., 2001, part of Fig. 6). The vertical dashed line represents the beginning of the 2000 Izu swarm. The ± 10 -day running average of ΣK_p is reported onto the Z/G ratios panel as well.

768

Fig. 5b. Three days running average of the ratio Z/G during the period of the Izu swarm 2000
(upper panel) at Kamo (K) and Kakioka (KK) stations as reported by Ismaigullov et al. (2003)

(a reproduction of Ismaigullov et al., 2003, part of Fig. 2). The 3-day running average of ΣK_p

is superimposed onto the Z/G panel as well.

773

Fig. 6a. Temporal evolution of $\sqrt{Z/G}$ during the period 25 June 2000 - 18 February 2001 at Karimshino observatory as reported by Molchanov et al. (2003) (a reproduction of Molchanov et al., 2003, Fig. 2). The geomagnetic K_p index and the seismic activity K_s index (yellow stars) are reported as well. Green circles highlight the $\sqrt{Z/G}$ increases claimed to be related to five strong earthquakes (yellow stars with a red dot). The K_p index temporal evolution is also superimposed onto each polarization ratio panel (red step-line). See text for details.

781

Fig. 6b. Daily values of the ratios Z/G, panel a), and 1/G, panel b), at Karimshino observatory as reported by Molchanov et al. (2003) for the same period of Fig. 6a (a reproduction of Molchanov et al., 2003, Fig. 3). The geomagnetic K_p index and the seismic activity K_s index (yellow stars) are reported as well. Daily values of K_p (ΣK_p) are also superimposed on each polarization ratio panel (red step-line). See text for details.

787

Fig. 7. Temporal evolution of the polarization ratio R=Z/H during the period 10 June - 20 August 2004 at the SEGMA station of Castello Tesino (CST) as reported by Prattes et al. (2008) (a reproduction of Prattes et al., 2008, Fig. 4). The red vertical line refers to the Bovec earthquake date. ΣK_p and the geomagnetic field components, Z and H, are shown as well. K_p temporal evolution (black step-line) is also reported onto the polarization ratio panel.

793

794 Fig. 8a. Geomagnetic field anomaly associated with the Kagoshimaken-Hokuseibu

reproduction of Hattori, 2004, a reproduction of Hattori, 2004,

Fig. 8). (a) regional seismicity; (b) 10-day backward running average of the ratios S_Z/S_G for

797 the stations of Tarumizu, Chichijima and Darwin; (c) temporal evolution of ΣK_p . The 10-day

backward running average of ΣK_p (black line) is reported in the middle panel as well.

799

- 800 Fig. 8b. 10-day backward average of the geomagnetic field spectral intensities S_z and S_G as
- 801 reported by Hattori et al. (2002) during the same period of Fig. 8a (a reproduction of Hattori
- 802 et al., 2002, part of Fig. 6). See text for details.

P C C F K

803

804 Fig. 9. Temporal evolution of the ratio Z/G at Lumping station before the Chi-Chi earthquake

as reported by Akinaga et al. (2001) (a reproduction of Akinaga et al., 2001, Fig. 2). The \pm 5-806 day running average of ΣK_p is also superimposed onto the original view both with a

807 descending axis (red line) and with an increasing axis (sky-blue line) to show the strange

808 correspondence between Z/G and ΣK_p : negative up to April 1999 and positive later.

























45





822

- 823 >The reliability of magnetic ratio changes as earthquake precursors are investigated.
- 824 >Nine cases are considered which include seventeen earthquakes.
- 825 >In the analysis running averages of the Σ Kp geomagnetic index are taken into account.
- nt the second the second te second t 826 >These increases are actually caused by the normal geomagnetic activity variation.