



HAL
open science

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

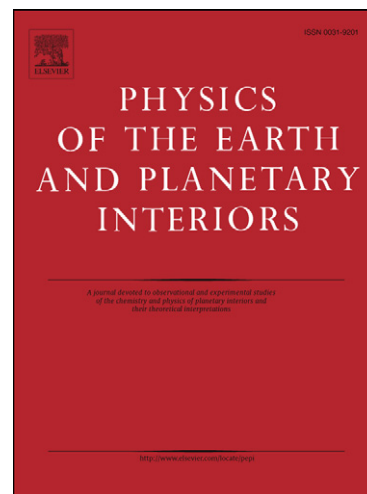
PII: S0031-9201(11)00087-2
DOI: [10.1016/j.pepi.2011.05.001](https://doi.org/10.1016/j.pepi.2011.05.001)
Reference: PEPI 5410

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](https://doi.org/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

4 Fabrizio Masci*

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

6

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
19 earthquakes. Furthermore, several researchers suggest that these seismogenic signals may be
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
22 of the scientific community emphasizes the lack of validation of claimed seismogenic
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,

53 how to identify reliable earthquake precursors is a very important key in the hope of
54 developing 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-

78 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
92 of them can be considered completely satisfactory (Thomas et al., 2009a).

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 $M_s=7.1$ 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
97 al., 1993; Hayakawa et al., 1996). In retrospect, some researchers seriously doubt the
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.

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

110

111 2. Polarization ratio analysis

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

115 If H , D , and Z represent the variations (nT) of the geomagnetic field components
116 around the NS, EW, and vertical direction respectively, then $G = \sqrt{H^2 + D^2}$ is the total
117 horizontal variation of the geomagnetic field (Kopytenko et al., 1991). In a fixed range of
118 frequency, the magnetic polarization ratio is defined as the ratio between the integrated power
119 P (nT²) of the vertical component and the one of the horizontal component, that is: P_z/P_H ,
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
123 of the spectral intensities (nT/ $\sqrt{\text{Hz}}$). As a matter of fact, this method is not really a
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
135 radiation from the earthquake hypocentre region (see Fenoglio et al., 1995; Molchanov and
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
141 coupling which take place during seismic activity (see Molchanov et al., 2004b).

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 K_p index, which is representative of average disturbances
156 of the planetary geomagnetic field. This positive relation is evident mainly in PC₂, PC₃ and
157 PC₄ 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 K_p 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.

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

168

169 **2.1 Guam earthquake 1993**

170 On 8 August 1993, a strong earthquake ($M_w=7.7$, depth=60km) occurred offshore the
171 island of Guam. In the hope of finding possible magnetic earthquake precursors, Hayakawa et
172 al. (1996) performed polarization ratio analysis in the frequency band [0.01-0.05]Hz. They
173 analysed the ULF (1Hz sampling rate) geomagnetic field data of Guam observatory, which is
174 located about 65 km away from the earthquake epicentre. To reduce man-made noise, the
175 authors focused their investigation on the night period [22:00-02:00]LT. The principal claim
176 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
189 K_p index (see Thomas et al., 2009b, Fig. 1); 3) no clear seismogenic signatures have been
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
194 K_p daily sum (ΣK_p) is superimposed onto the panel (b) of Fig. 1. Both the 5-day running
195 average and the 6th order polynomial fitting of ΣK_p are reported in the figure. Consider that
196 ΣK_p vertical axis is descending. As a matter of fact, the 5-day running average confirms the
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
200 associated with the geomagnetic activity. Furthermore, the 6th order polynomial fitting
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
215 al., 2009b). This relationship is: $Z/H = - 0.083 \times \Sigma K_p + 0.57$. In Fig. 1, panel (e), the linear
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 04:00JLT, 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
234 ± 5 -day running average of ΣK_p has been superimposed onto the Biak panel. Figure 2a shows
235 that the two increases of the polarization ratio actually correspond to decreases of ΣK_p . Thus,
236 the claimed precursory signals seem to be once again mainly related to the geomagnetic
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 K_p index is representative of the geomagnetic field activity over global scales,
240 a strict correspondence between polarization ratio and ΣK_p 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
245 evident that there is a good inverse correspondence between Biak Z/H ratio and ΣK_p time-
246 series the period after the middle of December 1995, but on the contrary the correlation fails
247 before this period. This is confirmed by the calculation of the correlation coefficient between
248 Z/H and ΣK_p : (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
250 ΣK_p really exists during the period of the claimed seismogenic “anomalies” occurrence. In
251 light of this, we have calculated the linear relationship between Z/H ratio and ΣK_p time-series

252 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
254 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
257 Darwin as shown by Hayakawa et al. (2000). The authors report, in unspecified units, the
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 Iwateken 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_z/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.

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

280 Figure 3 shows the polarization ratios as reported by Hattori (2004) and Hattori et al.
281 (2004). Checking their conclusions, the 5-day backward running average of ΣK_p is
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
292 al., 2004 Fig. 11) do not agree with their ratio S_Z/S_D reported in Fig. 3.

293

294 **2.4 Izu swarm 1998**

295 Kopytenko et al. (2001) report the temporal evolution of the ULF geomagnetic field
296 polarization ratio at Kamo station during two earthquakes swarms which occurred in the
297 period April-May 1998 near the Japanese Izu peninsula. The distance between the station and
298 the epicentres is about 30-40 km. The main shocks occurred respectively on 26 April
299 ($M_s=4.7$) and on 3 May ($M_s=5.7$). Fig. 4 (lower) shows the 5-day running average of the
300 polarization ratio Z/G as reported by Kopytenko et al. (2001). The polarization ratio has been
301 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.

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

322

323 **2.5 Izu swarm 2000**

324 Between June and August 2000, a seismic swarm occurred near the Izu peninsula. Five
325 strong $M > 6$ earthquakes occurred on 1, 8, 15 and 30 July and 18 August. Ismaguilov et al.
326 (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 $[5\pm 3]$ 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
337 ± 10 -day. Figure 5a once again shows a close inverse correspondence between ΣK_p and
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. Gladyshev 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
360 shows the square root of the amplitude polarization ratio Z/G in the period 2000-2001 as
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
365 and the earthquake epicentre (see for details Molchanov et al., 2003). The authors maintain
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
368 view to highlight the claimed seismogenic polarization ratio increases. To investigate the
369 behaviour of $\sqrt{Z/G}$, the corresponding K_p index temporal evolution is superimposed onto the
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 activity 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

376 any strong earthquake; refer to the increases of 13 July and 26 August. In light of this, once
377 again a close inverse correspondence between polarization ratio and geomagnetic activity is
378 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/G
380 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_p 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
409 index is plotted on the polarization ratio panel. Taking into account the K_p behaviour, it is
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,
420 275, and 291 km. The authors conclude that the highest polarization ratio amplitude is
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

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

431

432 **2.8 Kagoshimaken-Hokuseibu earthquakes 1997**

433 Hattori (2004) report the ULF polarization ratio S_Z/S_G at Tarumizu station, Japan,
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 $[0.010 \pm 0.003]$ 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
443 ratio increase is without doubt a precursory signature of Kagoshimaken-Hokuseibu
444 earthquakes. Checking the conclusions of the author, the 10-day backward running average of
445 ΣK_p is also superimposed in the polarization ratio panel. Even if both Tarumizu polarization
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
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
465 September 1999. Figure 9 shows the temporal evolution of the polarization ratio as reported
466 by Akinaga et al. (2001) in the frequency band $[0.010\pm 0.003]$ 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 ± 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
471 behaviour of Z/G . To be more precise, Z/G shows a close inverse correspondence with ΣK_p
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 Luning 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 Luning is located in a seismic quiet area, so its magnetic measurements are not
484 affected by the seismic activity. Using Luning 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 Luning 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
513 procedures using the same time window.

514 This paper shows that in seven of the investigated cases, for a total of fourteen
515 earthquakes, the increases of the geomagnetic field polarization ratio, which previous authors
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
519 reduction of the vertical component, therefore the polarization ratio increases. On the
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

525 investigated cases, they seem to be doubtful as well: the first case shows inconsistency in the
526 results so that the claimed polarization precursor could not be totally reliable; in the second
527 case, the apparent correspondence between the polarization ratio and the geomagnetic index
528 seems to behave oddly during the analysed period. Moreover I want point out that Masci
529 (2010) seriously put in doubt ULF magnetic fractal precursors which previous papers have
530 related to the occurrence of the three seismic events (Guam 1993, Biak 1996 and Izu 2000)
531 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 ΣKp , 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 K_p index, we should not expect that a strict
557 correspondence between polarization ratio and ΣK_p 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
575 discussions. The geomagnetic Kp index has been downloaded from Kyoto World Data Center
576 for Geomagnetism (<http://swdcwww.kugi.kyoto-u.ac.jp/>).

ACCEPTED MANUSCRIPT

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.
- 586 Eftaxias, K, P. Kaporis, J. Polygiannakis, N. Bogris, J. Kopanas, G. Antonopoulos, A.
587 Peratzakis, and V. Hadjicontis, 2001. Signature of pending earthquake from
588 electromagnetic anomalies, *Geophys. Res. Lett.*, 28(17), 3321, doi:10.1029/
589 2001GL013124.
- 590 Eftaxias, K, L. Athanasopoulou, G. Balasis, M. Kalimeri, S. Nikolopoulos, Y. Contoyiannis,
591 J. Kopanas, G. Antonopoulos, and C. Nomicos, 2009. Unfolding the procedure of
592 characterizing recorded ultra lowfrequency, kHz and MHz electromagnetic anomalies prior
593 to the L'Aquila earthquake as pre-seismic ones – Part 1. *Nat. Hazards Earth Syst. Sci.*, 9,
594 1953-1971, doi: 10.5194/nhess-9-1941-2009.
- 595 Fenoglio, M. A., M. J. S. Johnston, and J. D. Byerlee, 1995. Magnetic and electric fields
596 associated with changes in high pore pressure in fault zones: Application to the Loma
597 Prieta ULF emissions. *J. Geophys. Res.*, 100, B7, 12951-12958, doi:10.1029/95JB00076.
- 598 Fraser-Smith, A. C., A. Bernardy, P. R. McGill, M. E. Ladd, R. A. Helliwell, and O. G. Jr.
599 Villard, 1990. Low frequency magnetic field measurements near the epicenter of the
600 Loma-Prieta earthquake. *Geophys. Res. Lett.*, 17, 9, 1465-1468,
601 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 Gladyshev, 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.
- 618 Hattori, K., 2004. ULF Geomagnetic Changes Associated with Large Earthquakes. *TAO*, 15,
619 3, 329-360.
- 620 Hattori, K., I. Takahashi, C. Yoshino, N. Isezaki, H. Iwasaki, M. Harada, K. Kawabata, E.
621 Kopytenko, Y. Kopytenko, P. Maltsev, V. Korepanov, O. Molchanov, M. Hayakawa, Y.
622 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
629 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.
- 634 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.
- 643 Ismaguilov, V. S., Yu. A. Kopytenko, K. Hattori and M. Hayakawa, 2003. Variations of
644 phase velocity and gradient values of ULF geomagnetic disturbances connected with the
645 Izu strong earthquakes. *Nat. Hazards Earth Syst. Sci.*, 20, 1-5, doi:10.5194/nhess-3-211-
646 2003.
- 647 Johnston, M. J. S., 1997. Review of electrical and magnetic fields accompanying seismic and
648 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
650 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:10.1016/0031-
658 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.
- 662 Liu, J. Y., C. H. Chen, Y. I. Chen, H. Y. Yen, K. Hattori, and K. Yumoto, 2006. Seismo-
663 geomagnetic anomalies and $M \geq 5$ 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
673 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 ($M_s = 6.9$) and Loma Prieta ($M_s = 7.1$) 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.
- 684 Molchanov, O. A., A. Yu. Schekotov, E. Fedorov, G. G. Belyaev, M. S. Solovieva, and M,
685 Hayakawa, 2004a. Preseismic ULF effect and possible interpretation. *Ann. Geof.-Italy*, 47,
686 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.
- 692 Molchanov, O., and M. Hayakawa (Eds), 2008. *Seismo Electromagnetics and Related*
693 *Phenomena: History and latest results*. TerraPub, Tokyo, pp 189.
- 694 Mueller, R. J., and M. J. S. Johnston, 1998. Review of magnetic field monitoring near active
695 faults and volcanic calderas in California: 1974-1995. *Phys. Earth Planet. In.*, 105, 131-
696 144, 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
702 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.
- 706 Saito, T.: Geomagnetic pulsations, *Space Sci. Rev.*, 10, 319–342, doi:10.1007/BF00203620,
707 1969.
- 708 Simpson, J. J. and A. Taflove, 2005. Electrokinetic effect of the Loma Prieta earthquake
709 calculated by an entire-Earth FDTD solution of Maxwell’s equations. *Geophys. Res. Lett.*,
710 32, L09302, doi:10.1029/2005GL022601.
- 711 Thomas, J. N., J. J. Love, and M. J. S. Johnston, 2009a. On the reported magnetic precursor of
712 the 1989 Loma Prieta earthquakes. *Phys. Earth Planet. Int.*, 173, 207-215,
713 doi:10.1016/j.pepi.2008.11.014.
- 714 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 (e) 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

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

746 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

749 **Fig. 3.** Upper panel: 5-day backward running averages of ULF polarization ratios S_z/S_D in the
750 period of Iwateken Nairiku Hokubu earthquake at Matsukawa, Memambetsu and Kanoya
751 stations as reported by Hattori (2004) (a reproduction of Hattori, 2004, part of Fig. 10a).

752 Lower panel: 5-day backward running average (thick red solid line) and daily values (thin red
753 solid line) of Matsukawa polarization ratio. The 5-day backward running average of ΣK_p is
754 superimposed onto the upper panel as well. An enlargement view of the claimed precursory
755 anomaly is added to the original view.

756

757 **Fig. 4.** Lower panel: 5-day running average of the ULF polarization ratio Z/G at Kamo station
758 as reported by Kopytenko et al. (2001) (a reproduction of Kopytenko et al., 2001, Fig. 6).

759 Middle panel: seismic activity during April-May 1998. Upper panel: temporal evolution of
760 ΣK_p . In the lower panel the 5-day running average of ΣK_p is superimposed on the original
761 view.

762

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

768

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

771 (a reproduction of Ismaigullov et al., 2003, part of Fig. 2). The 3-day running average of ΣK_p
772 is superimposed onto the Z/G panel as well.

773

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

781

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

787

788 **Fig. 7.** Temporal evolution of the polarization ratio $R=Z/H$ during the period 10 June - 20
789 August 2004 at the SEGMA station of Castello Tesino (CST) as reported by Prattes et al.
790 (2008) (a reproduction of Prattes et al., 2008, Fig. 4). The red vertical line refers to the Bovec
791 earthquake date. ΣK_p and the geomagnetic field components, Z and H, are shown as well. K_p
792 temporal evolution (black step-line) is also reported onto the polarization ratio panel.

793

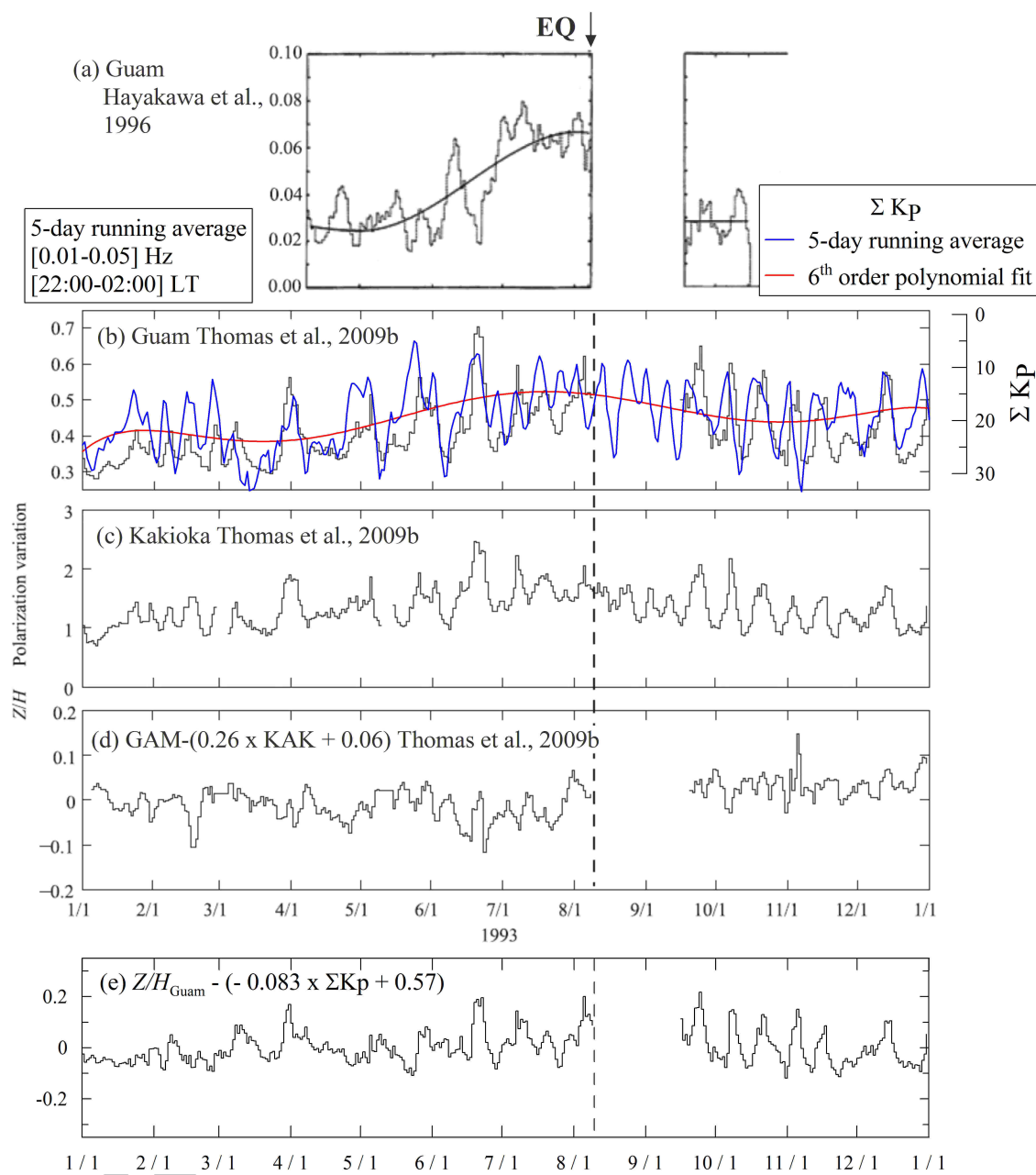
794 **Fig. 8a.** Geomagnetic field anomaly associated with the Kagoshimaken-Hokuseibu
795 earthquake (M6.5 and M6.3) as reported by Hattori (2004) (a reproduction of Hattori, 2004,
796 Fig. 8). (a) regional seismicity; (b) 10-day backward running average of the ratios S_Z/S_G for
797 the stations of Tarumizu, Chichijima and Darwin; (c) temporal evolution of ΣK_p . The 10-day
798 backward running average of ΣK_p (black line) is reported in the middle panel as well.

799

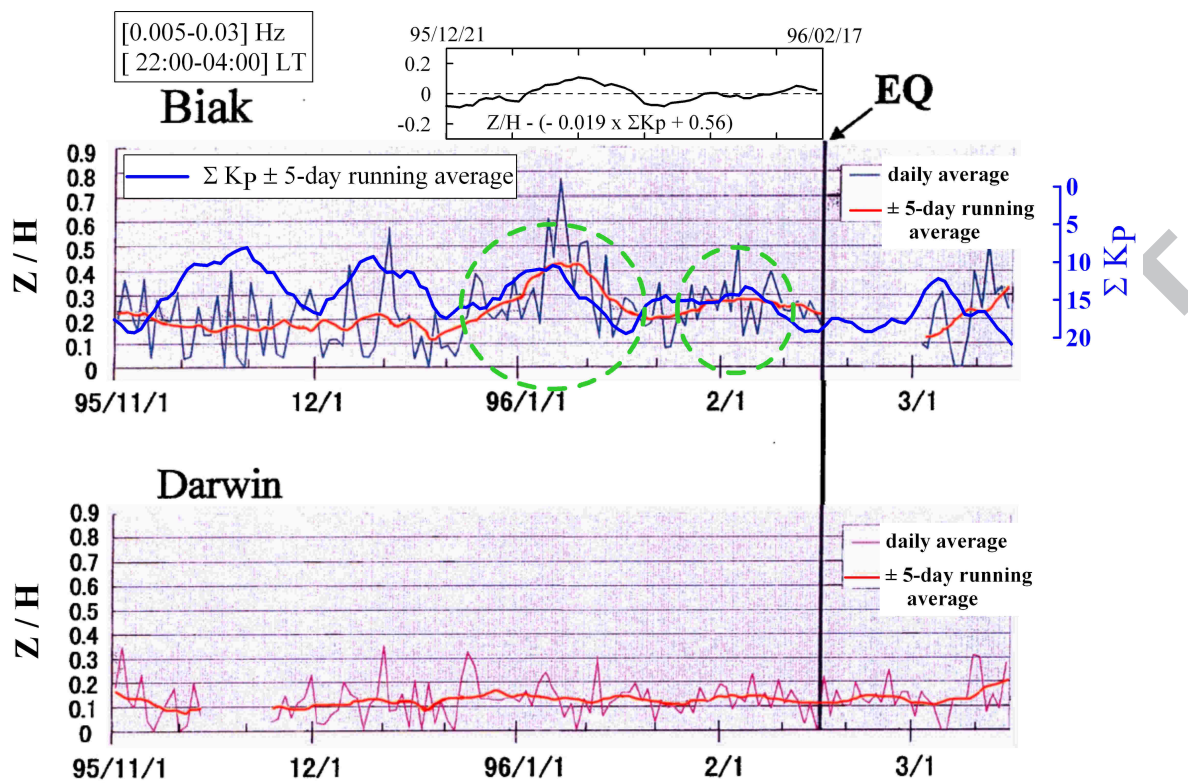
800 **Fig. 8b.** 10-day backward average of the geomagnetic field spectral intensities S_Z and S_G as
801 reported by Hattori et al. (2002) during the same period of Fig. 8a (a reproduction of Hattori
802 et al., 2002, part of Fig. 6). See text for details.

803

804 **Fig. 9.** Temporal evolution of the ratio Z/G at Lumping station before the Chi-Chi earthquake
805 as reported by Akinaga et al. (2001) (a reproduction of Akinaga et al., 2001, Fig. 2). The ± 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.

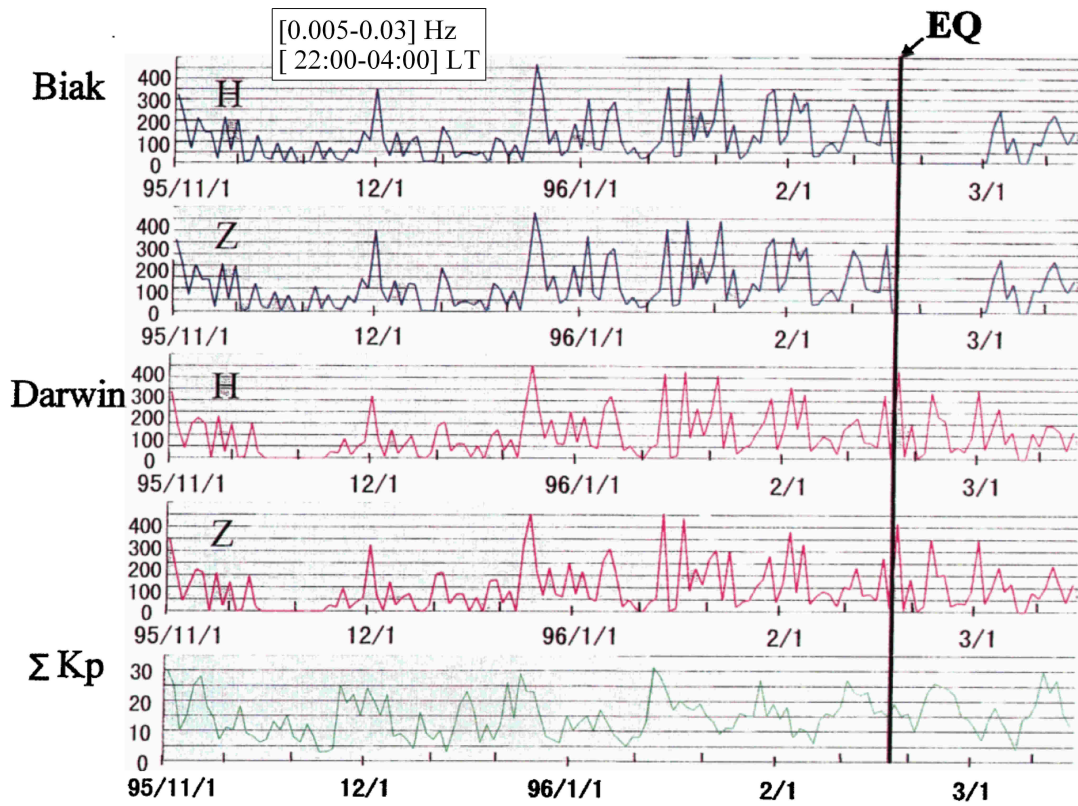


809



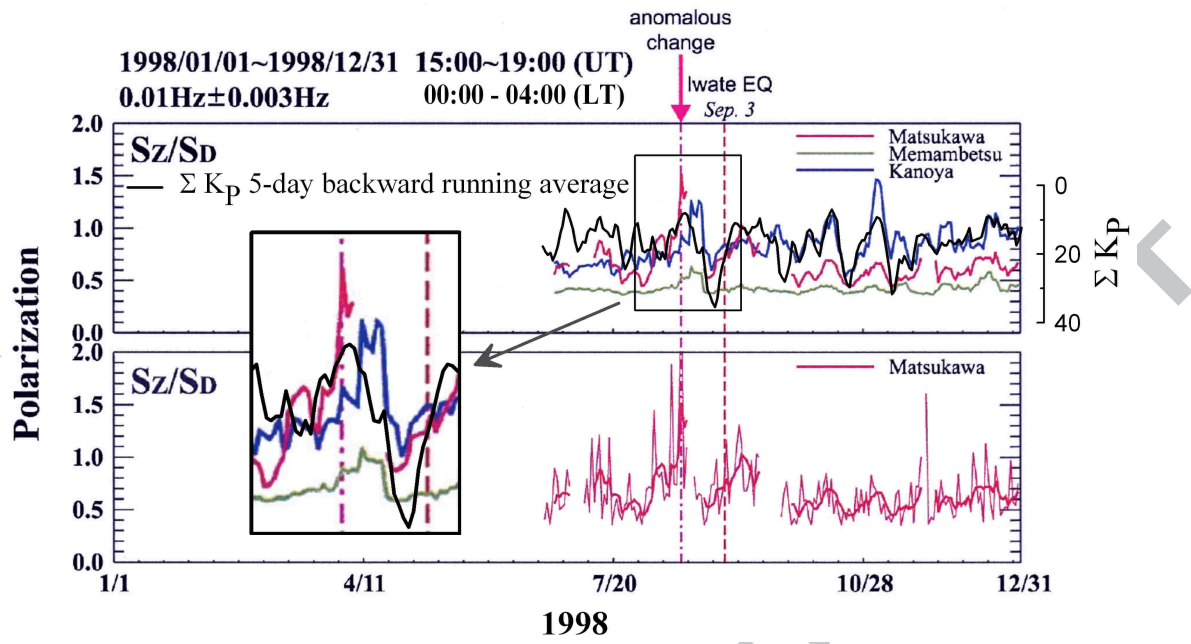
810

ACCEPTED MANUSCRIPT



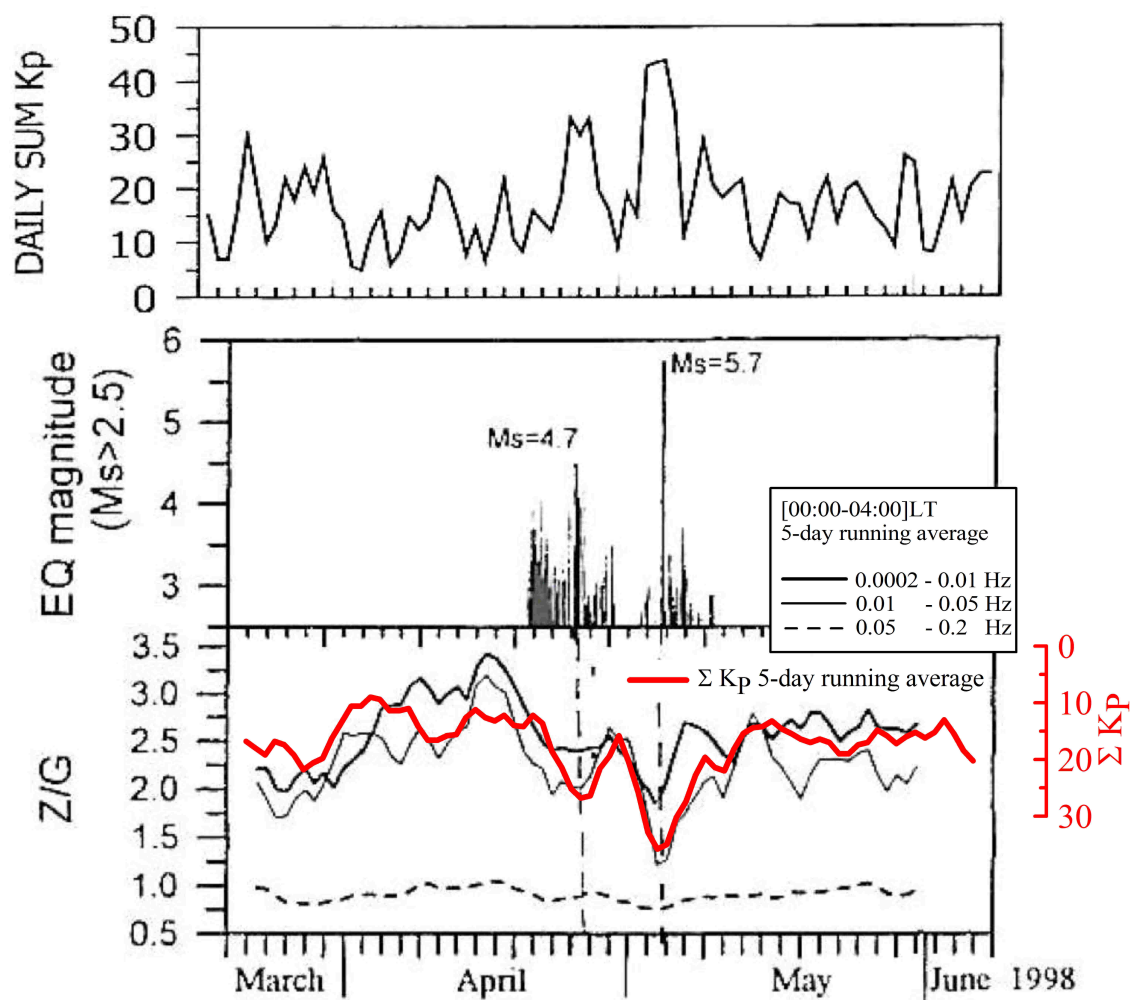
811

ACCEPTED MANUSCRIPT



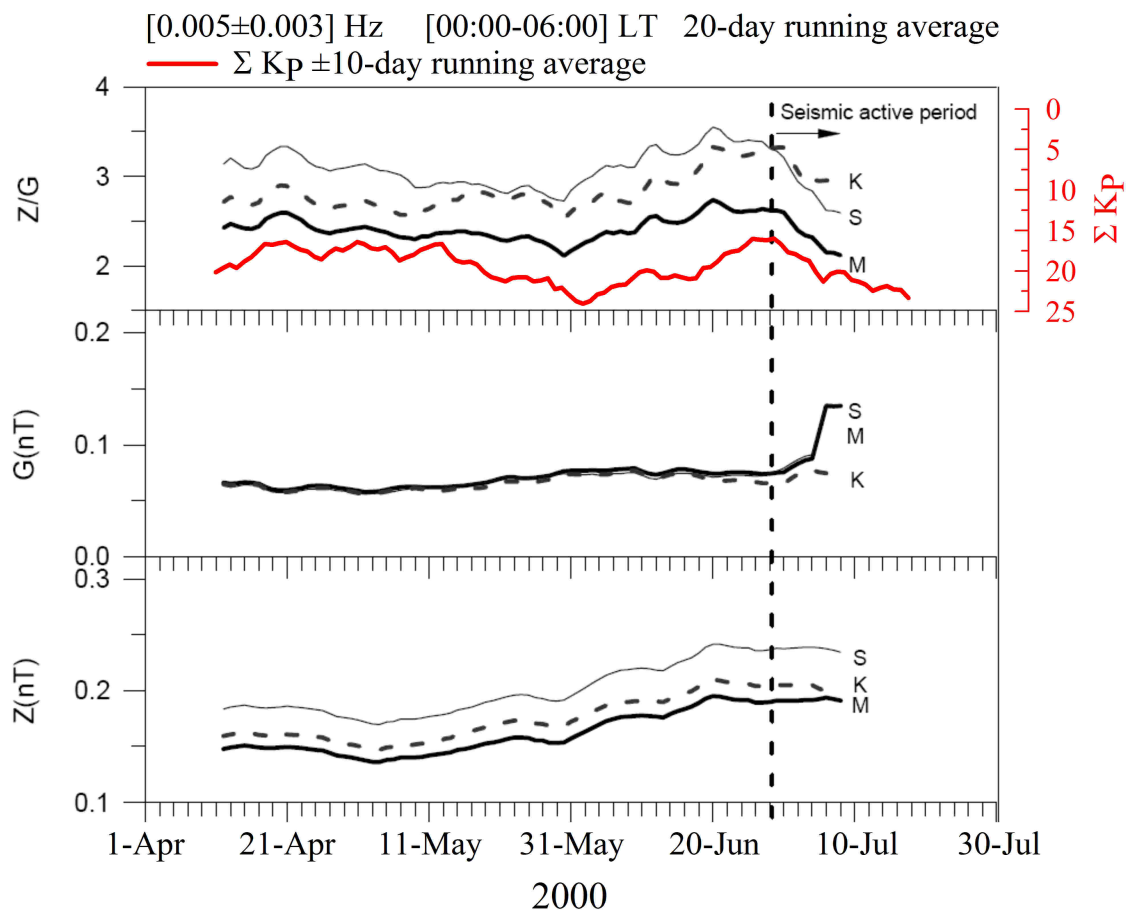
812

ACCEPTED MANUSCRIPT



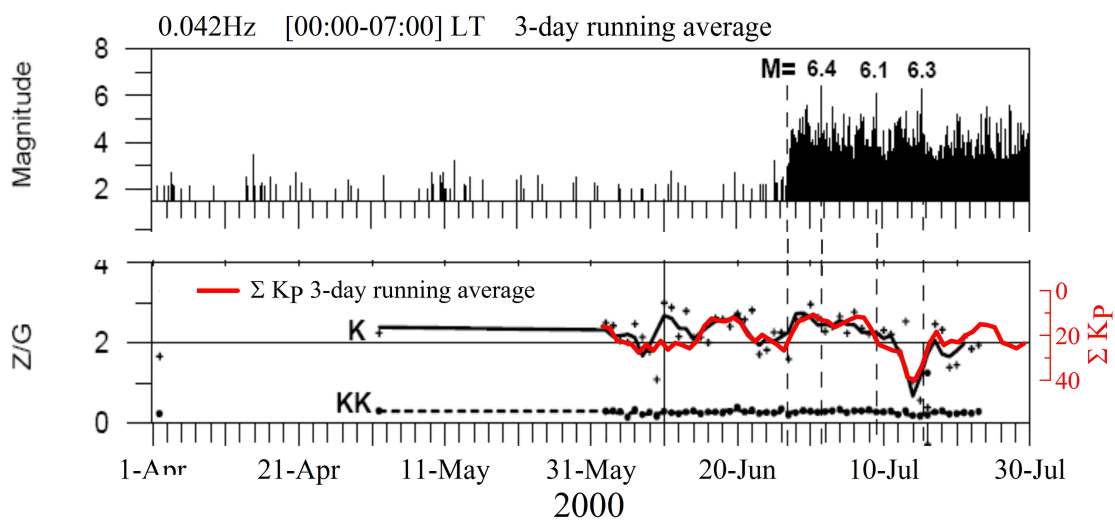
813

ACCEPTED



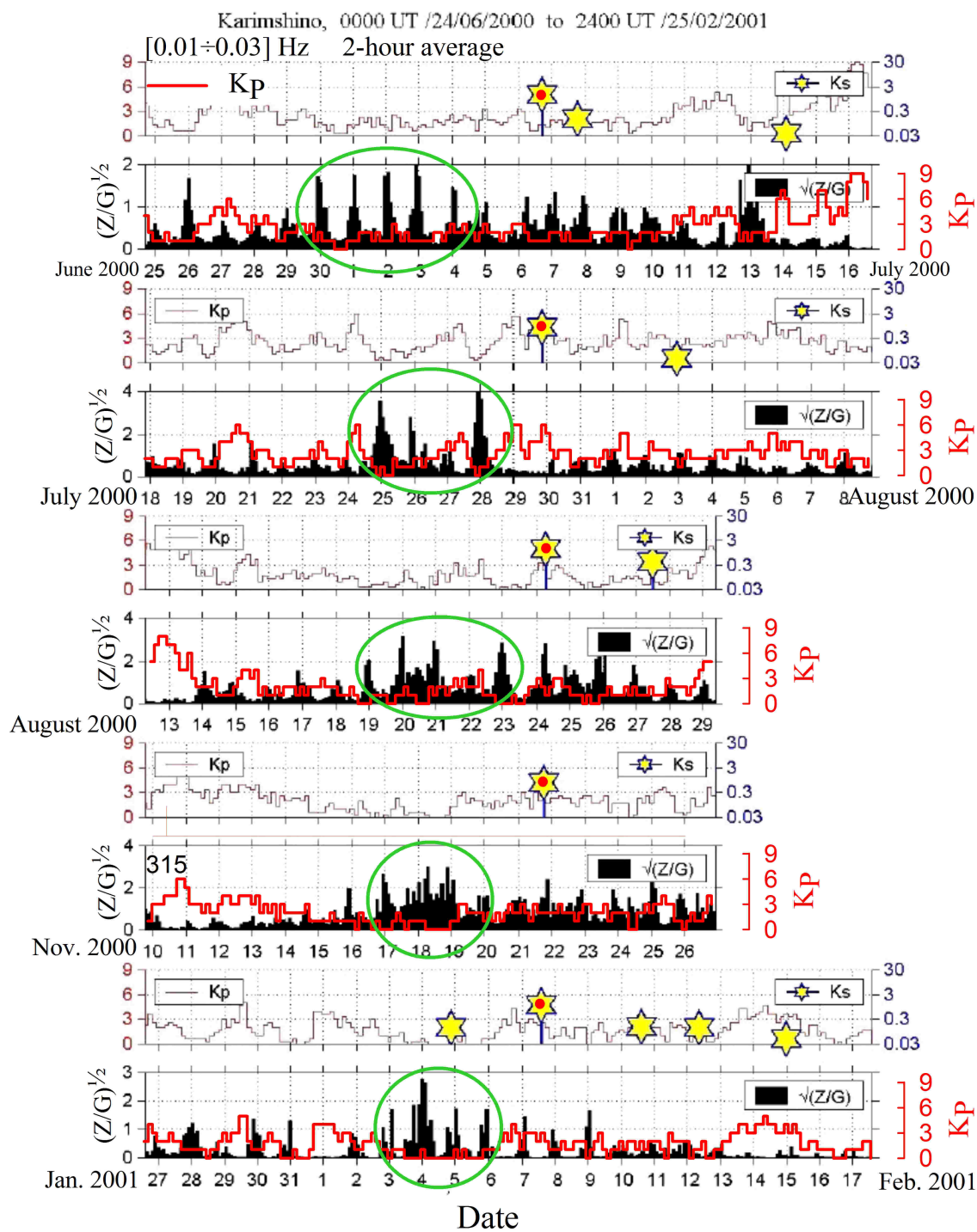
814

ACCEPTED



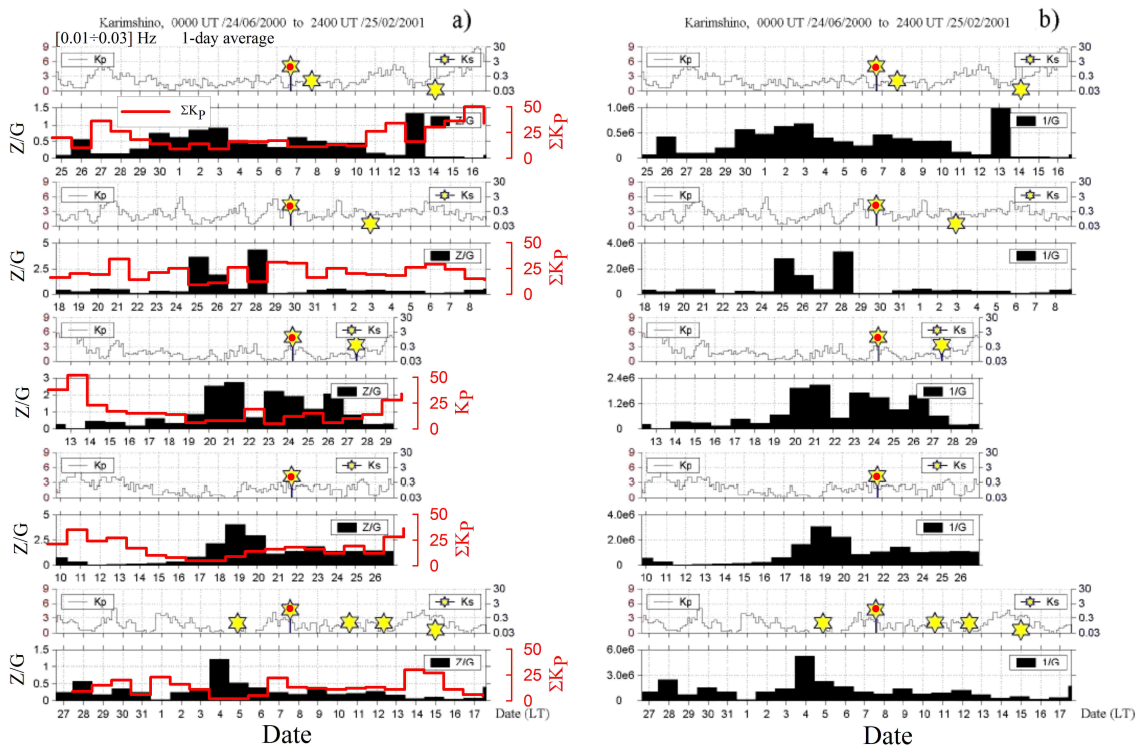
815

ACCEPTED MANUSCRIPT



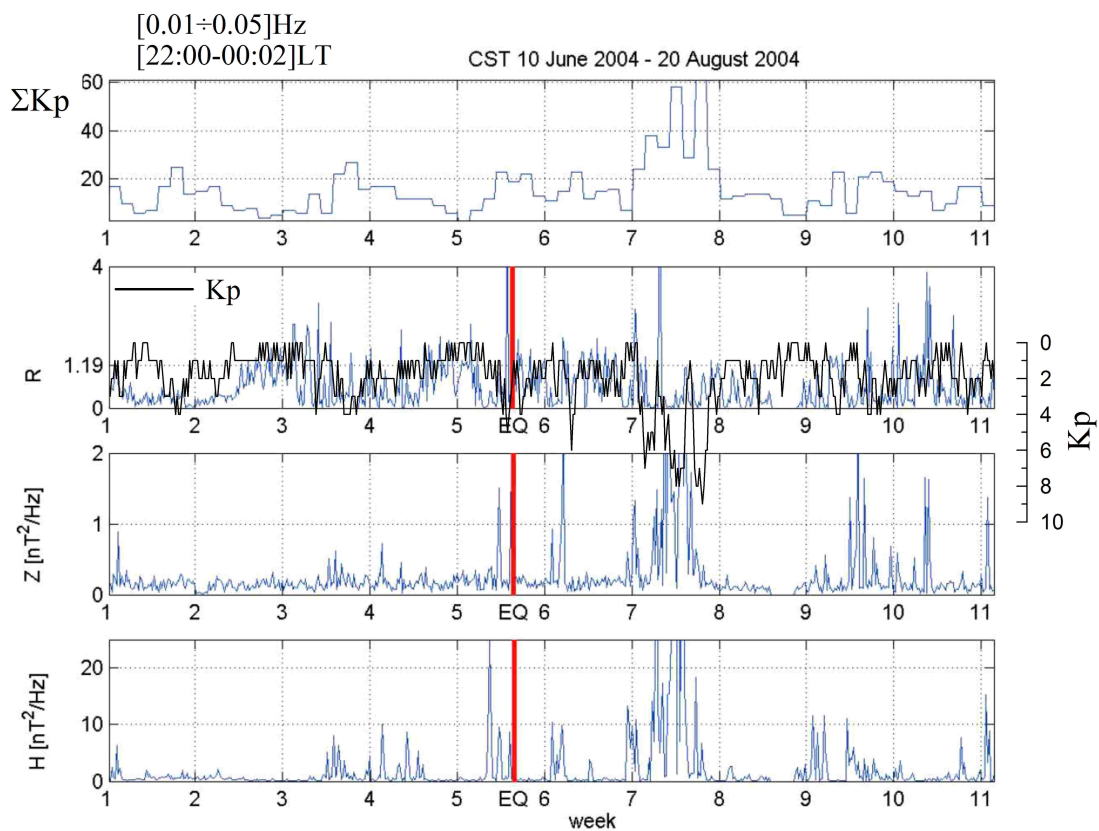
816

A



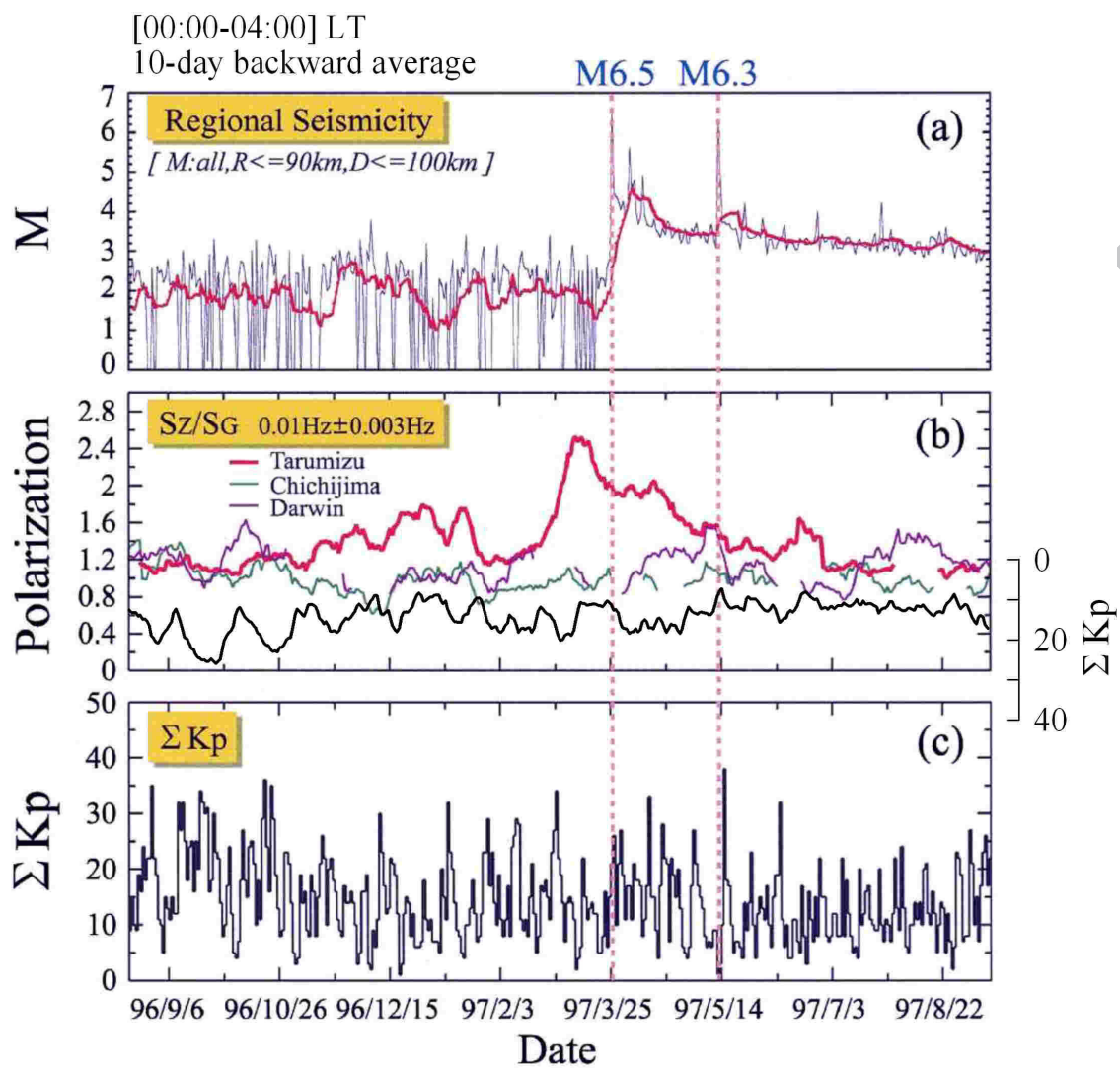
817

ACCEPTED MANUSCRIPT

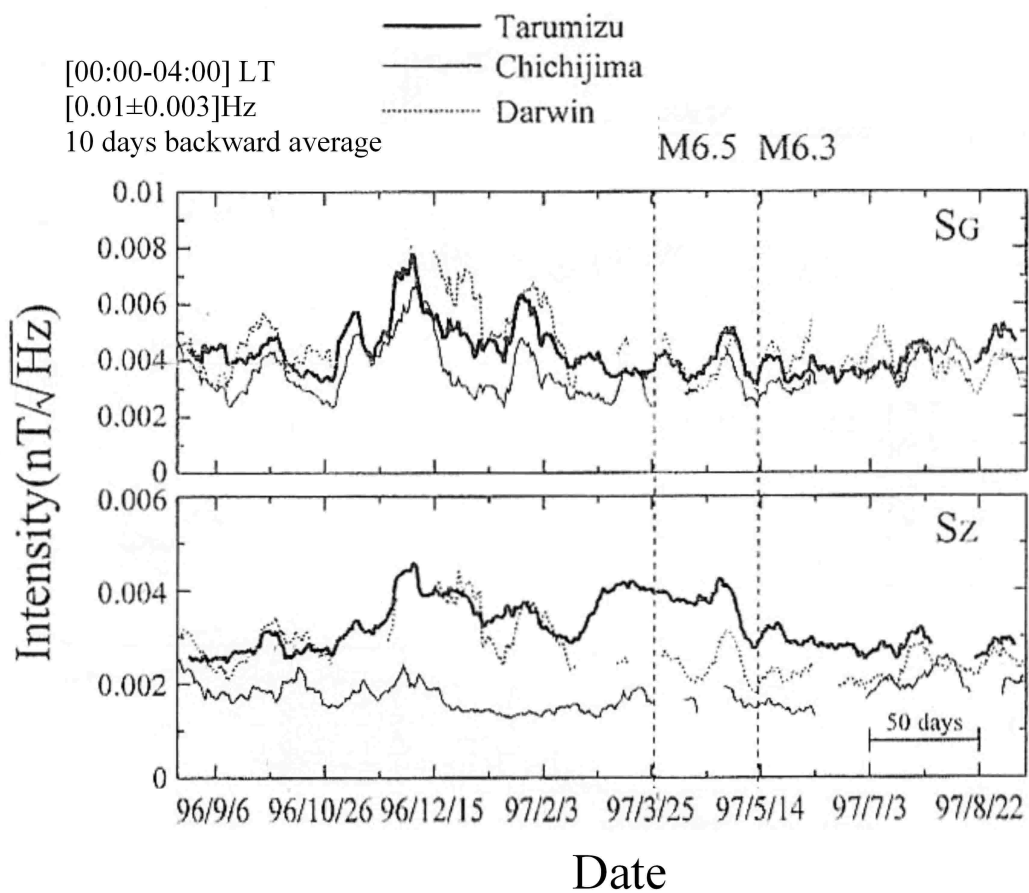


818

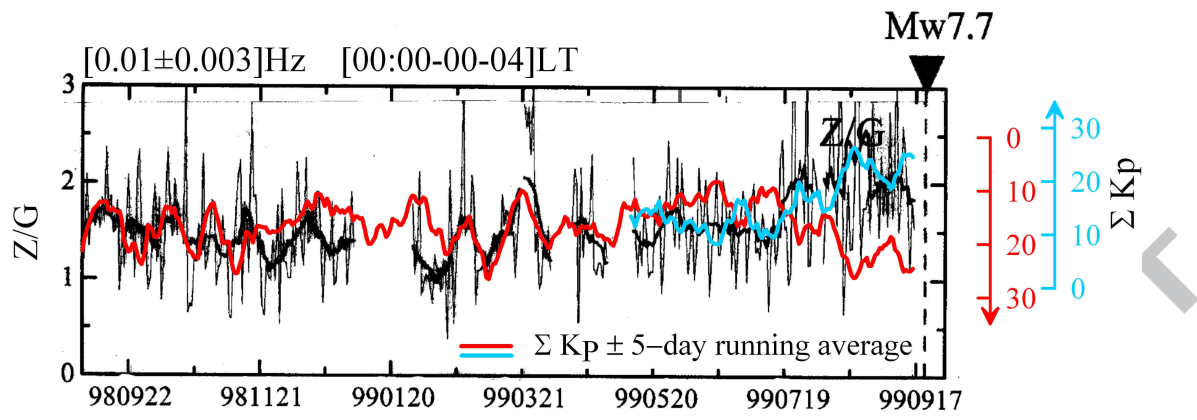
ACCEPTED MANUSCRIPT



819



820



821

ACCEPTED MANUSCRIPT

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 ΣK_p geomagnetic index are taken into account.

826 >These increases are actually caused by the normal geomagnetic activity variation.

827

828

829

830

ACCEPTED MANUSCRIPT