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Observation of Electric Field Variations at Miyake-jima Volcano

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Abstract

Electric potential variations have been observed since April 1999 at Miyake Island, a volcanic island in Japan about 170 km south of Tokyo. Measurements have been conducted using a special long vertical antenna and a short dipole. A volcanic eruption started at the end of June 2000 at Miyake Island. Conspicuous electric field variations were observed on DC, ULF, and ELF/VLF frequency bands at the time of and half a day before the largest eruption on 18 August 2000 (Fujinawa *et al.*, 2000a, 2002a, 2002b). Fluctuations lasting a few hours were observed about a day prior to each stage of the volcanic events. The longer signals were generally superimposed with ULF signals, suggesting strong confined water pressure fluctuations in the interaction process between intruded magma and hydrothermal circulation through the electro-kinetic effect (Fujinawa *et al.*, 2000b, 2002a, 2002b). We present here observed data that could not be included in the original papers, to assess the anomalies described in those condensed papers.

Key words: Volcano, Eruption, Monitor, Electric field, Precursor

1. Introduction

Several previous volcanic events at Miyake-jima volcano occurred at nearly regular intervals of about 20 years (Ukawa *et al.*, 2000), leading volcanologists to install instruments for various physical and chemical measurements. We started monitoring continuous electric potential variations at MKK (34.0973N, 139° 5554E, altitude 125m), one of five sites of a crustal activity monitoring network (Ukawa *et al.*, 2000) (**Fig. 1**). We used a specially-designed antenna (Ultra Long Electrode Measurement: ULEM) for the vertical component that used a 100m-long steel casing pipe (Fujinawa and Takahashi, 1990; Takahashi *et al.*, 2000). Dipoles with a distance of 6m were also installed for horizontal component measurements. The observation test period started in June 1999 and ended in February 2000, when the measurement parameters were adjusted. In retrospect, an extraordinarily large DC drift at the time of adjustment could very likely be attributed to a systematic change of the self-potential distribution in the preparatory stage of the present volcanic eruption.

Seismic activity, including volcanic tremors, had been detected since 26 June 2000. Meanwhile, remarkably large tilt changes of about 100μrad were observed (Ukawa *et al.*, 2000), which compelled the Japan Meteorological Agency to issue an emergency volcanic eruption warning. Ground tilt data (Ukawa *et al.*, 2000) and GPS (Kaidzu *et al.*, 2000) indicated that the crustal deformation had returned to normal following a submarine volcanic eruption early the next morning, and "Declaration of Safety" was issued. However, sizable eruptions occurred on 18 and 29 August following small ones in July and early August. We considered that it was necessary to develop a new volcanic activity monitoring technique for more reliable volcanic eruption forecasts and to detect magma movement. Conspicuous irregularities indicated that there were several types of self-potential anomalies present before and during the eruption, as described in the previous papers (Fujinawa *et al.*, 2000a, 2002a, b).

We present in this paper all the characteristic anomalies detected during the volcanic activities. Additional data are also presented to indicate the degree of incongruity, as in the case of electric anomalies at the time of a seismic swarm (Takahashi *et al.*, 2000).

Fig. 2 contains long-term monitoring records of the DC component for both the vertical (V) and horizontal (H) components. As to the horizontal components we did not discuss these anomalies except in several cases denoted. The long-term record indicates that the simple patterns in both components became more complicated after the end of April. This may have been caused by the appearance of anomalous variations. Here we defined anomaly by comparison with the normal stages without any crustal activities. Details on adopted criteria can be seen in the previous papers. There were electric variations in the record of the vertical component around major volcanic eruptions events ("E") with a time constant of several hours (see the parts enclosed by □ in **Fig. 2**). The variations were superimposed on the dominant fluctuations of diurnal periods. Moreover, some of them accompanied ULF band fluctuations ("U"), as at the time of the largest eruption on 18 August (Fujinawa *et al.*, 2002b). Almost all of this type of fluctuation occurred half a day or a day before a volcanic event, suggesting that there were rapid changes in the hydrothermal circulation due to severe changes in the magma regime. The process that produced those variations is thought to differ from the process that induces crustal deformation ('T' in the figure), due to the different appearance times of the two phenomena.

We will present observed data to supplement documentation of the electric field variations at the time of the 2000 Miyake-jima volcanic eruption described in papers that have been published or are to be published.

2. Original Records

1) Co-eruptive and Preceding Eruptions

There were six significant eruptions in the time-period shown in **Fig. 2**, and one on September 6 before the breakdown of electric power began on 14 September. Records of the eruptive events **E1** (26 June 2000), **E5** (August 18), and **E6** (August 29) have been previously described (Fujinawa *et al.*, 2002b). Here we present records for **E2** (July 8) in **Fig. 3**, **E3** (July 14) in **Fig. 4**, **E4** (August 10) in **Figs. 5**, and **E7** (September 6) in **Fig. 6**.

There were prominent co-eruptive field changes in all the frequency bands during the first eruption after the supposed cease of volcanic eruptions on July 8 (**Fig. 3h**). A prominent variation appeared about a day before the eruption in the DC band (**Fig. 3g**). There were also exceptionally large emissions in the ELF/VLF band on July 5 and 6 (**Figs. 3e** and **3f**). Those emissions could be related to volcanic activities, except for those corresponding to lightning emission at the end of July 5. Those anomalies led the authors to doubt the public announcement by a specialist that the activity had ceased.

There were very clear anomalous field variations in the ULF and ELF/VLF bands at the time of eruptions for event **E3**, with a prominent one in the DC component preceding the eruption. The ELF/VLF band exhibits an intermittent radiation pattern, as observed in the case of a seismic swarm off the east coast of the Izu peninsula (Fujinawa and Takahashi, 1990). The radiation was weak and those intermittent patterns could not be observed at the nearest site, Izu-Ohshima. **Figs. 5** and **6** show monitoring records for the horizontal and vertical components at the time of the fourth eruption on August 10, and on September 6, respectively. Pre-eruptive field changes could be observed in the ELF/VLF band, but not as clearly in the DC and the ULF bands. However, there are clear anomalous changes in those bands from about 1.5 hours after the onset of eruption. **Fig. 7** shows the records on September 6, 13 and 14, a few days before the evacuation of whole people from island on September 1. The monitoring was stopped when the electric power was shut down on September 15.

2) Step-like Changes

Peculiar field changes in a step pattern appeared from about 12 August 2000, six days before the largest eruption on August 18 (**E5** in **Fig. 2**). The step-like changes were dominant in the horizontal component. However, there were almost no corresponding variations in the vertical component (**Figs. 2a** and **2b** in Fujinawa *et al.*, 2002b). Daily data of the DC component are shown in **Figs. 8a** to **8h**. It is interesting that the step-like pattern did not occur simultaneously with the similar change of ground-tilt (Ukawa *et al.*, 2000) and no electric field was observed with a very long base-line (Sasai *et al.*, 2001). Detailed discussions of those factors can be found in Fujinawa *et al.* (2002a).

3) Daily Anomalies in the Horizontal Record

There were persistent diurnal changes of almost constant amplitude both in the vertical and horizontal components, as illustrated in **Fig. 2**. This figure indicates that prominent diurnal changes dominated from April 17 through May 8 in the horizontal component, without any corresponding variations in the vertical component. The long-term records are shown in **Figs. 9a** and **9 b**. We did not consider these variations to be related to volcanic eruption activity at the time they appeared, but we now suspect that they were induced by a groundwater circulation change.

3. Longer records in ULF band and VLF band

We have reported that prominent ULF band fluctuations appeared at the time of and preceding a large volcanic eruption. We present the full record from March through September 2000 in the band of the vertical components for reference (**Fig. 10**). There are several types of characteristic fluctuations:

1) Persistent background noises (B)
2) Nearly cyclic pulse-like fluctuations with a period of about 20 minutes
3) Evening events at about 18:00 (JST) with nearly the same wave-form (E)
4) Sporadic and substantial amplitude fluctuations with a short duration of about 10 minutes (SS)
5) Type 4) with a longer duration (LS)

Different stages of volcanic activities appear to correspond with the dominance of different types of fluctuation. Our experiences at Izu-Oshima, a volcanic island, and Hodaka, a geothermal region, indicate that the ULF band fluctuations represent severe hydrothermal changes in association with magma intrusion (Fujinawa *et al.*, 2000a, 2001; 2002a, 2002b). The appearance of the pulse-like ULF band fluctuations in March 2000 is evidence that magma intrusion had already started at that time. We cannot determine when that kind of changes actually started due to a malfunction of our detection process from September 1999 until early March 2000.

Fig. 11 shows the signal levels of the ELF/VLF signals of the horizontal and vertical components at Izu-Oshima and Miyake-jima from March through September 2000. The characteristics of the signal levels can be summarized as follows.

1) There are no significant differences between the horizontal and vertical components at the islands. However, there is a small but meaningful difference (Fujinawa *et al.*, 2002b) at Miyake-jima that is dependent on the depth of the source.
2) The level of diurnal changes increased at the time of active volcanic eruptions at Miyake-jima.
3) Substantial but short-duration radiation preceding and during volcanic eruption on August 12 and 18 was detected at Miyake-jima, but not Izu-Oshima, indicating that it was small in amplitude and could not be detected at a remote site.

Acknowledgments

We would like to express our gratitude to many people, institutes, and organizations that contributed to this research, in particular to the Director General of the National Research Institute for Earth Science and Disaster Prevention, Dr. Tsuneo Katayama, for his hearty encouragement; Dr. Shigeru Yamane, National Institute of Advanced Industrial Science and Technology, for his support for this work; Dr. Motoo Ukawa and Dr. Eisuke Fujita for the thoughtful advice; Mr. Yamamoto, for allowing us to use his land; and Tecs Inc., Sankosha Corporation, and Franklin Japan Co., Ltd. for their cooperation with instrumentation and observations. We thank Ms. Yumiko Yamauchi for her assistance in handling the data and preparing the manuscript.

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三宅島における電界変動観測

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中野　洋***・佐藤宗純***・斉藤俊幸***・土井卓也***

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要　旨

三宅島では水平・鉛直成分の電場計測を ,1999 年 4 月より行っている．観測データの解析の結果，以下の事柄が判明した．

1. 2000 年の火山活動の数か月前から平常時とは異なる数々の異常変動が記録されている．
2. 噴火活動の開始のほぼ一か月前から低周波帯域で顕著な変動があった．
3. 2000 年 6 月 26 日の噴火のほぼ一日前には，より高周波成分(0.01 Hz ～ 0.7 Hz)の異常変動の発現があった．
4. 2000 年 8 月 18 日の大噴火の半日頃前に，鉛直・水平両成分においてDCからVLF帯の顕著な変動があり，17 時 5 分からの噴火のあった時間帯には，最も激しい変動が記録された．
5. 発生のメカニズムは，マグマ活動によって誘起される熱水循環の変動に伴う流動電位効果によるものである可能性が高い．
6. 発生する変動の主要帯域は DC ～ VLF 帯にあり，VLF 帯では活動の激しい時に限られる．又その振幅は小さく，数 10 ｋｍ離れると検知するのは難しい．
7. 電界変動データからすると，このマグマ熱水帯は変動に富み，時間スケール数時間の揺らぎを有していることが推測される．
8. 電界変動観測は，傾斜変動・地震などの観測とは独立かつ有効な観測の窓である．

キーワード：火山噴火，前兆，マグマ，電磁場，予知，地下水

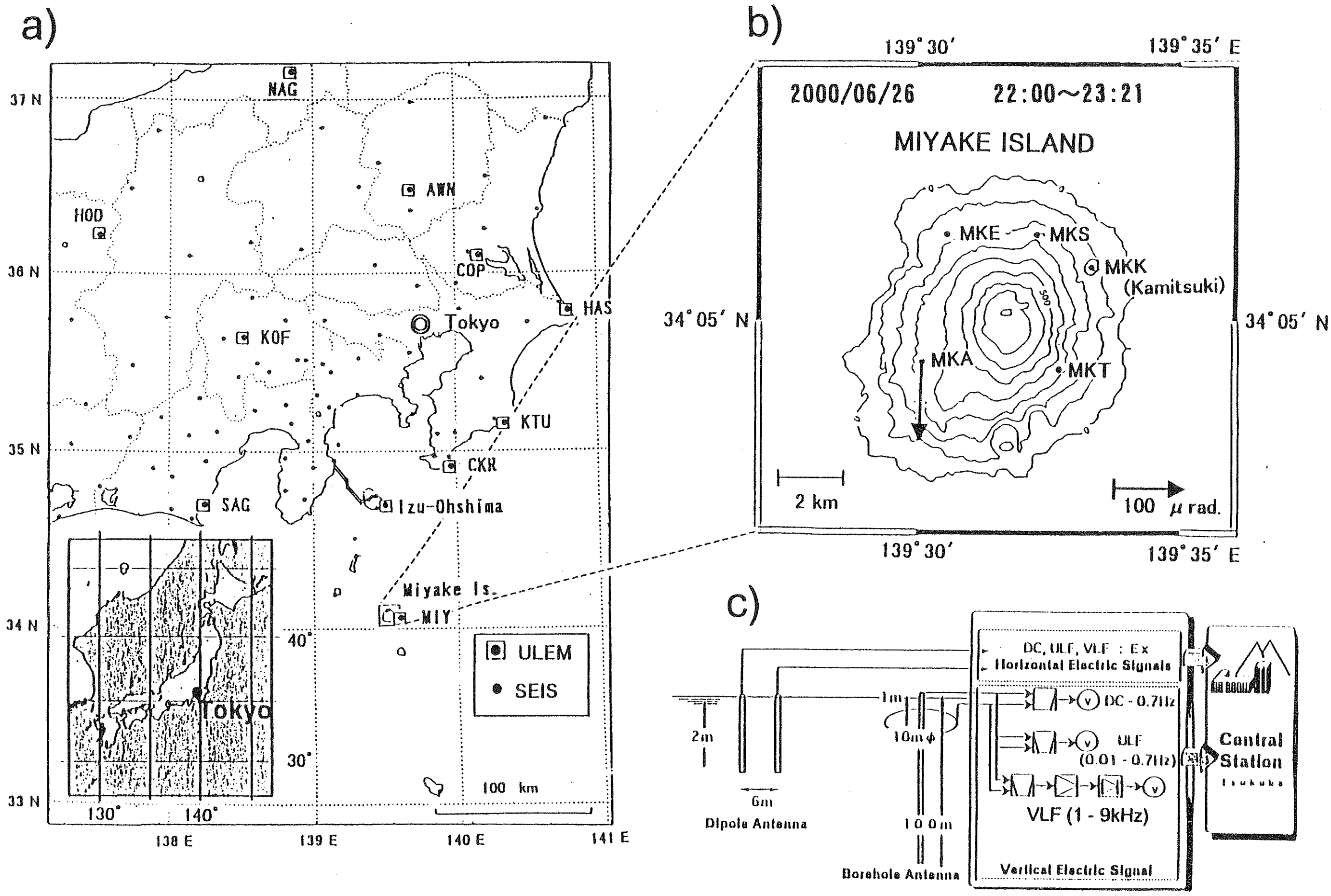


Fig. 1 Location of the electric field observation site Kamituki (MKK), one of the stations monitoring volcanic activity on Miyake Island, an island in the central part of Japan. The electric field observations are conducted to supplement ordinary crustal observations, seismic observations, ground tilt, and magnetism (Ukawa *et al.*, 2000). A 100m-long borehole antenna was used as the primary sensor to measure the vertical component of the electric field. A short 6m-long dipole was also installed for the horizontal electric field. Similar electric observations have been conducted in the central part of Japan at 11 sites (Fujinawa *et al.*, 2000a), including a nearby site, Izu-Oshima Island, which is included in the same volcanic chain. A large ground tilt change amounting to 100 μ rad was detected at night on 26 June 2000 at one of the sites, MKA (Ukawa *et al.*, 2000).

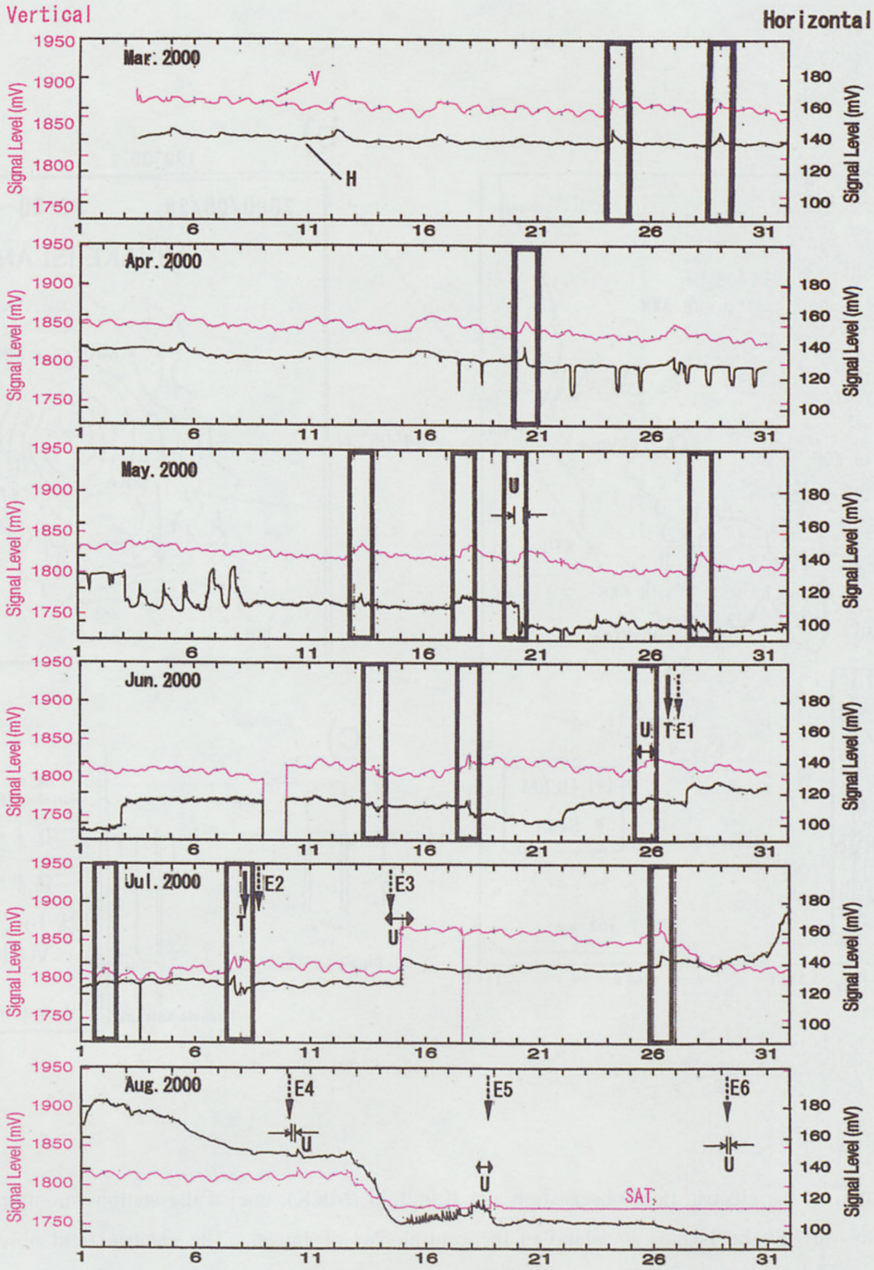
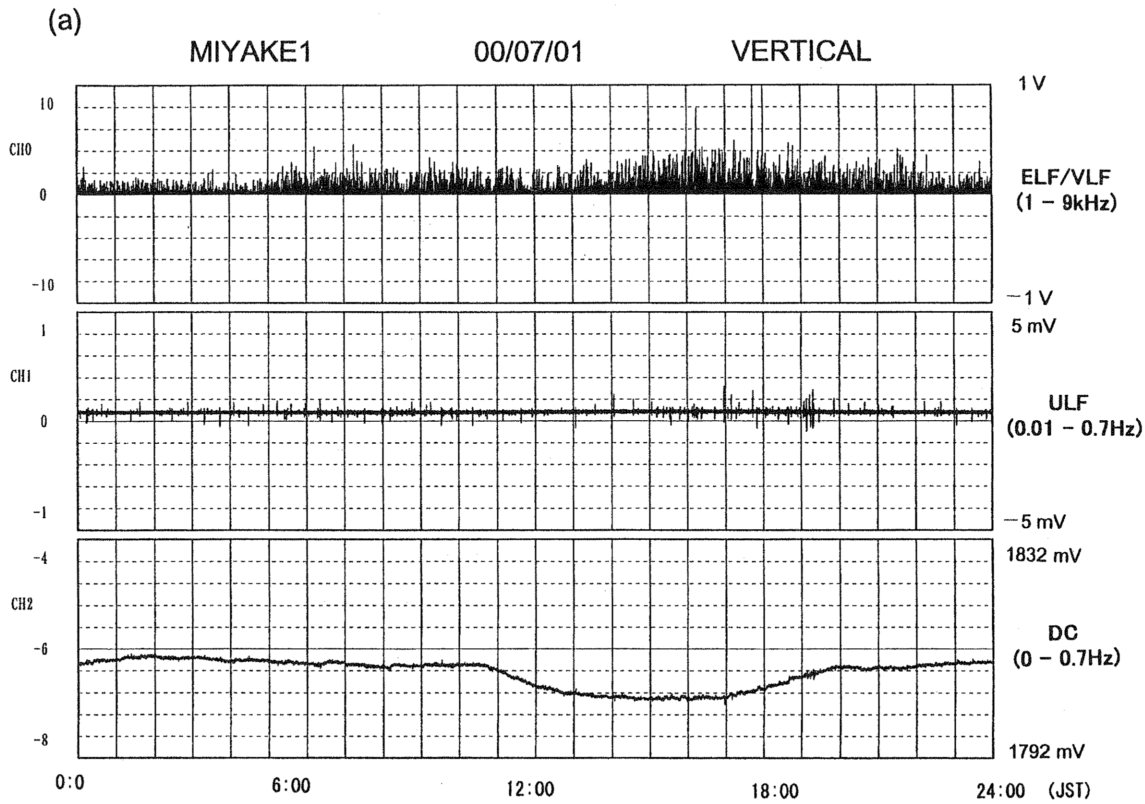


Fig. 2 Long-term monitoring records for the vertical and horizontal components in the DC band from early March 2000 to the end of August. The observation began in April 1999, but there were interruptions prior to March 2000 due to repairs for counter-surges. The data for June 9 were not recovered due to problems with data transmission. In the records of the vertical component "higher" frequency fluctuations with periods much shorter than the dominant diurnal variations in the vertical component appeared more frequently as volcanic activity approached (E in **Fig. 2**); these fluctuations occurred on 20 May; 13, 17, and 25 June; and 2, 5, 7 July (encircled by □ in the figure). They were sometimes superimposed by ULF band fluctuations (U in **Fig. 2**) that appeared at the time of the largest eruption, as seen in **Fig. 2**. The disappearance of the diurnal variations in May could be due to the generation of fluctuation field changes as the magma approached Miyake Island; this is supported by the appearance of substantial variations in the horizontal component. The trend-like changes were generally similar in both components before strong volcanic events, though there were time periods with significant differences, which suggests that the source depths differed. Clear intermittent variations appeared only in the horizontal components before the largest eruption on 18 August.



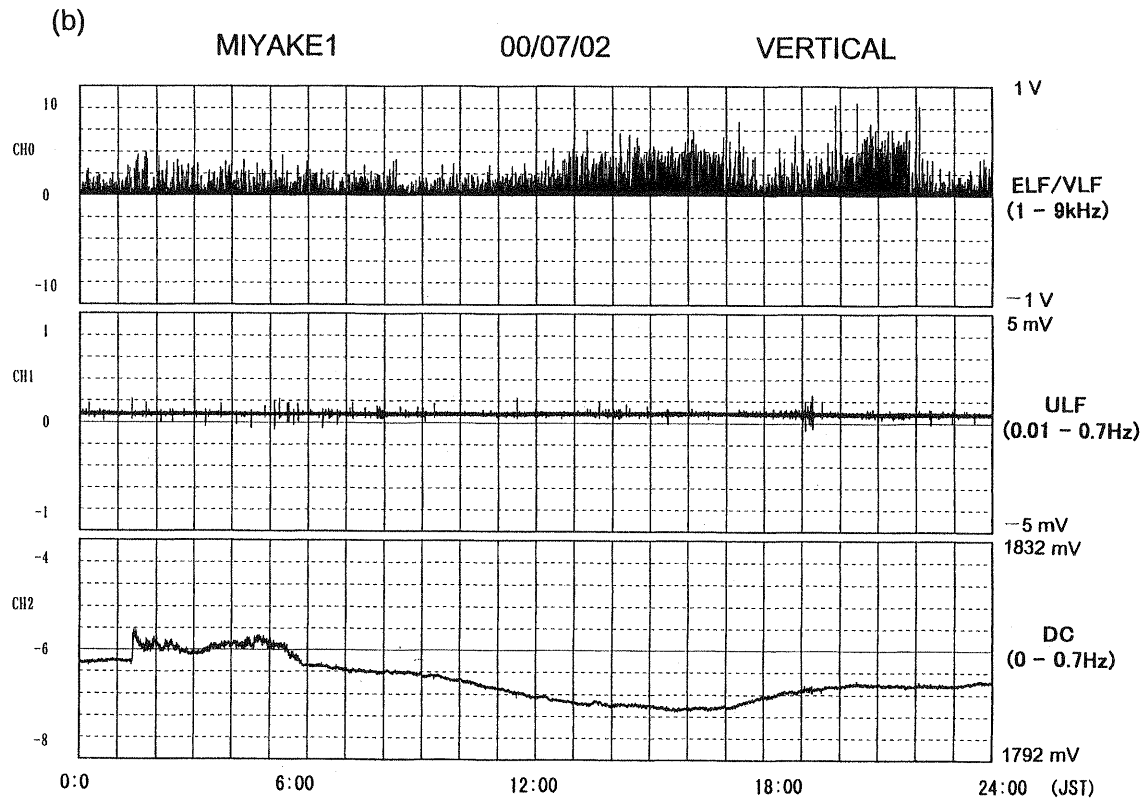
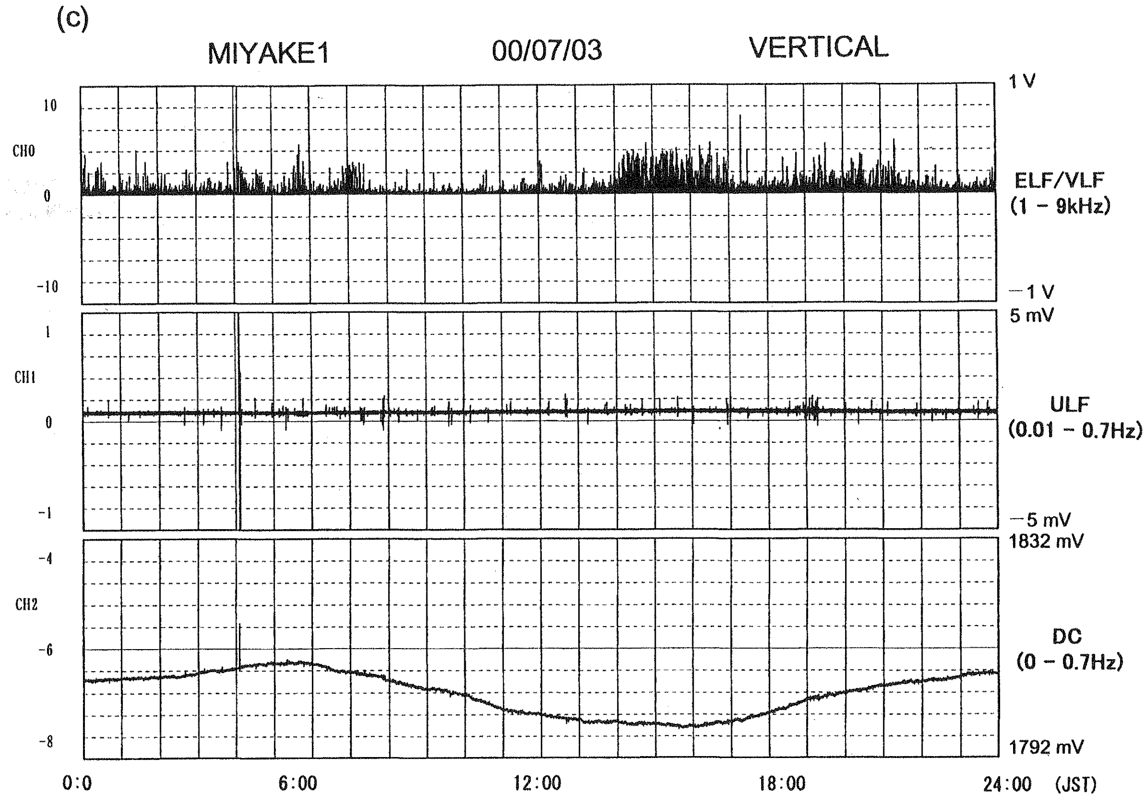
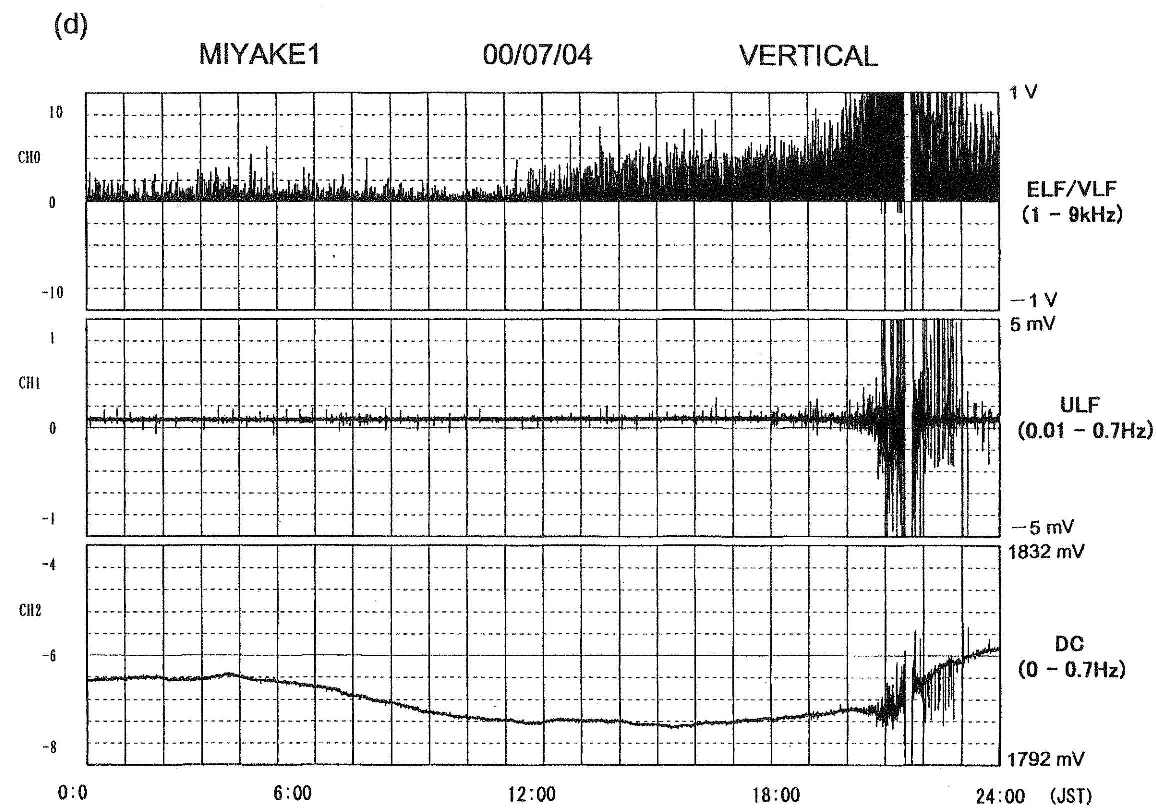


Fig. 3 Transient self-potential monitoring records of the vertical component at the time of and preceding the second volcanic events (**E2**) on 8 July 2000 and the preceding seven days (a—h).





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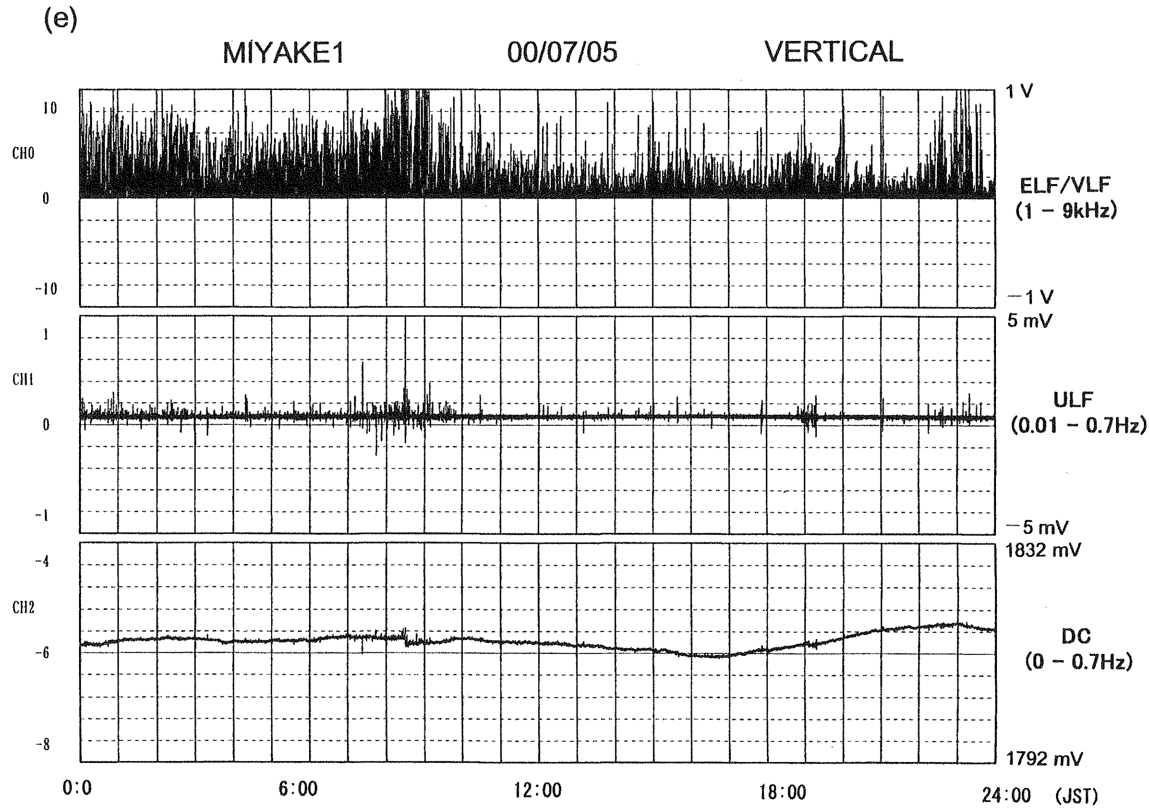

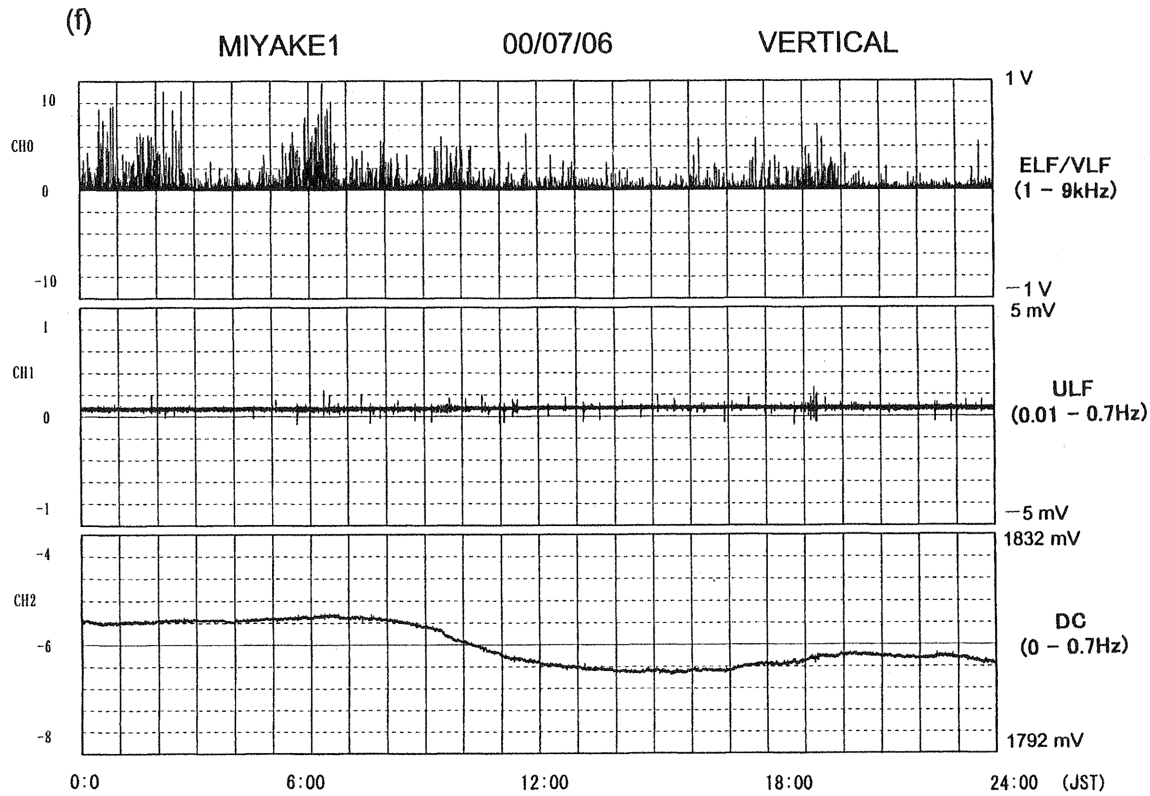

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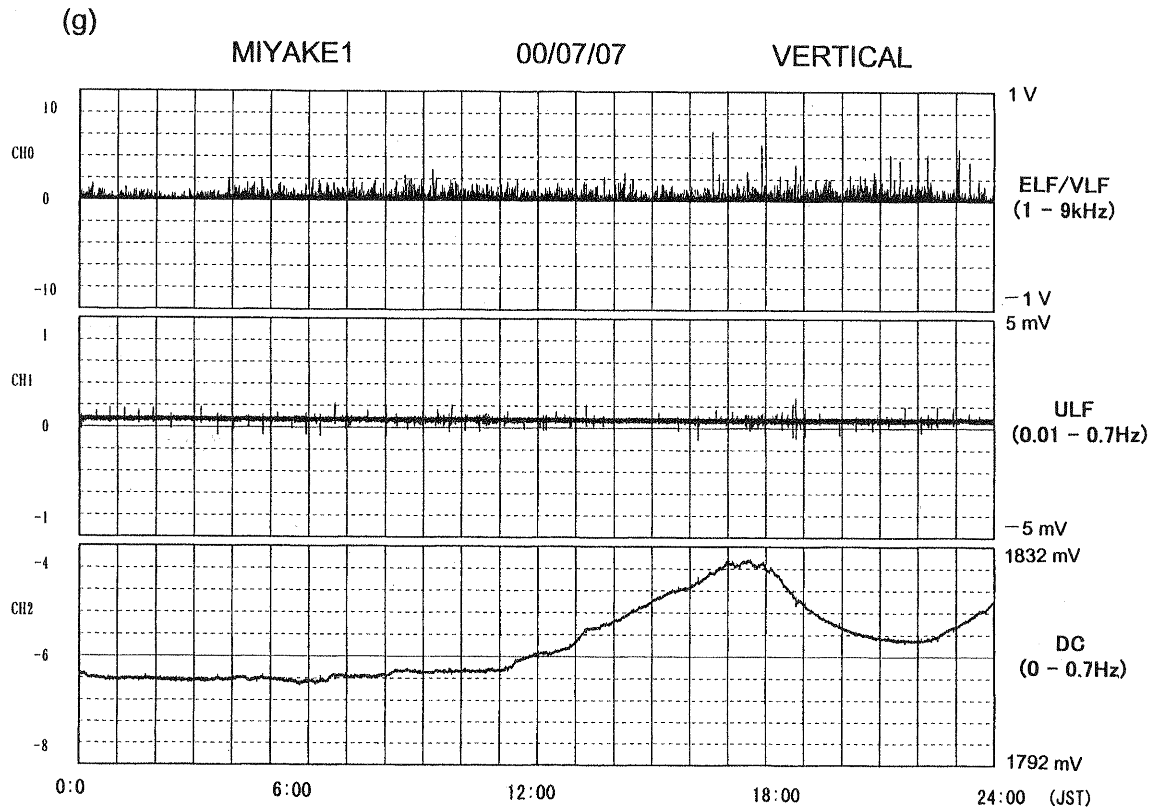

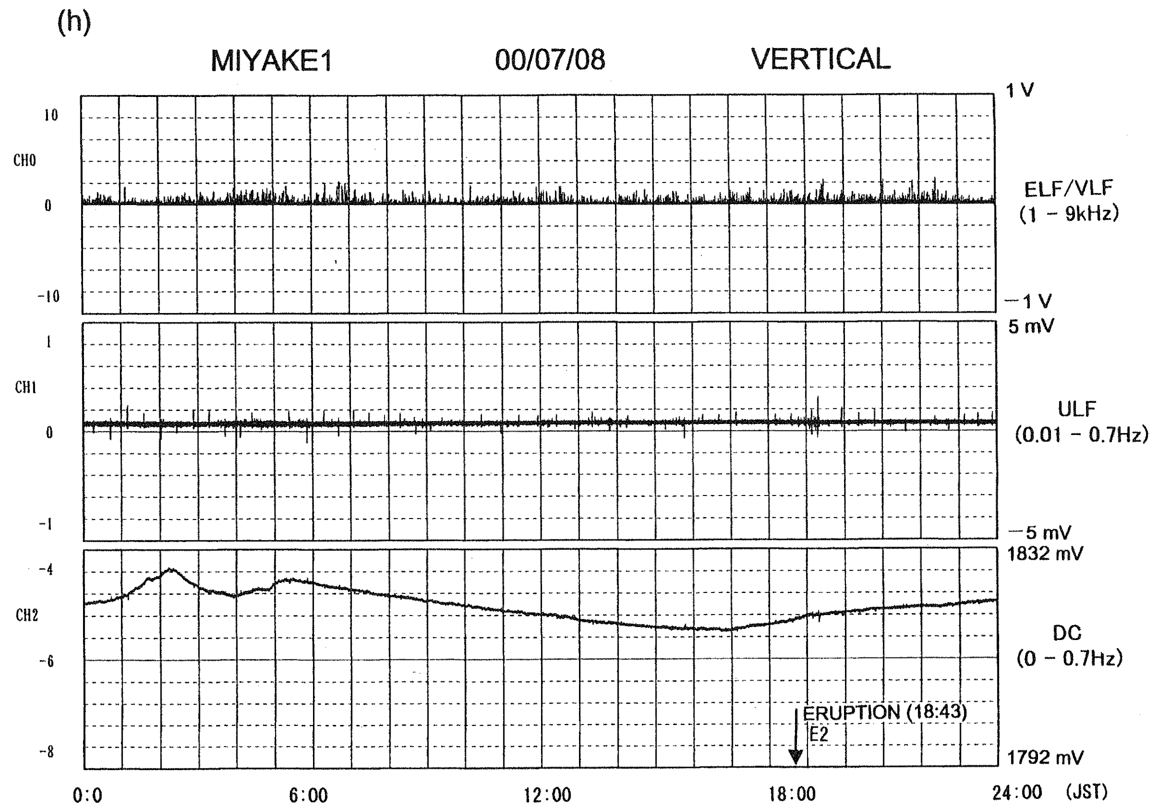

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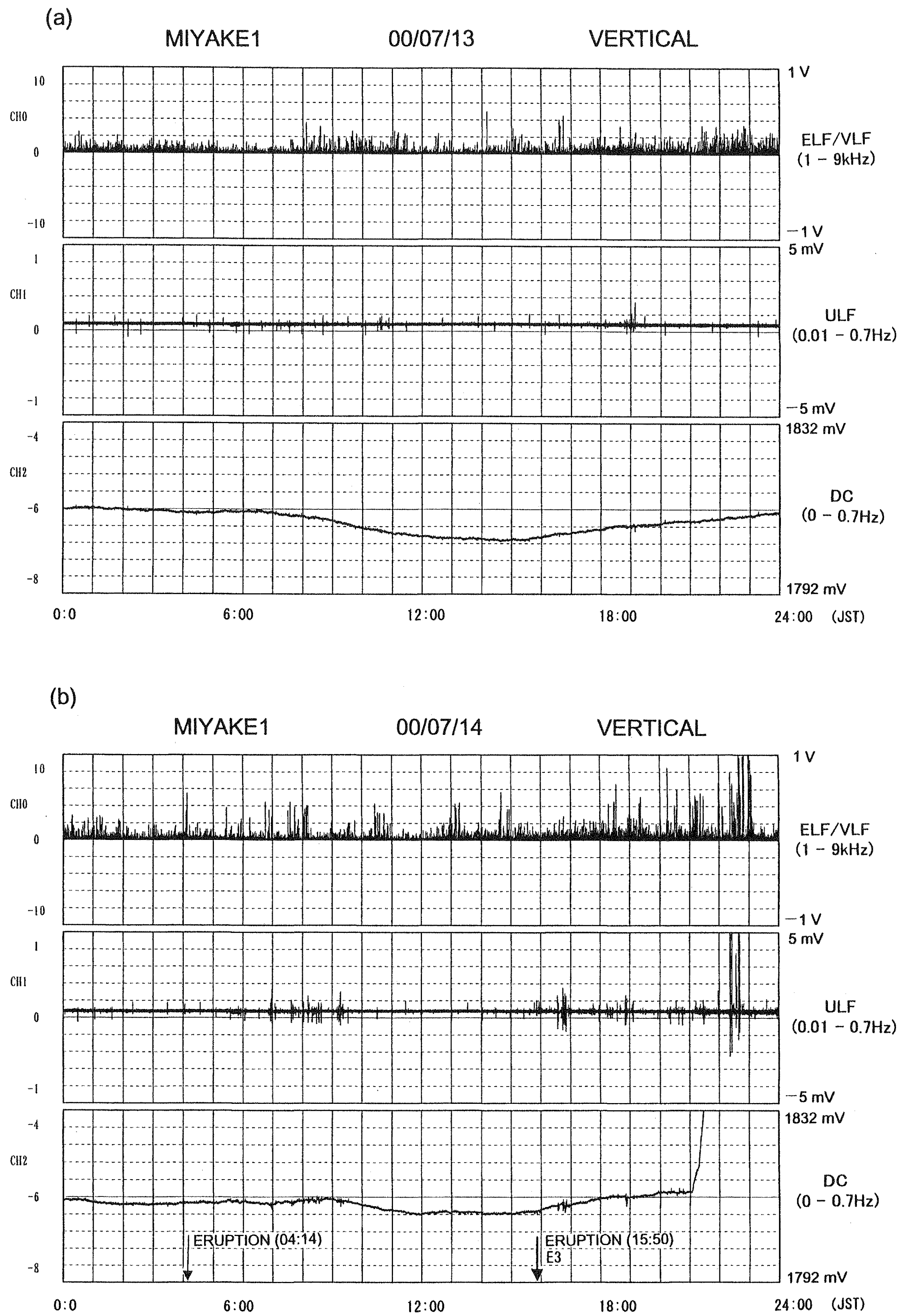
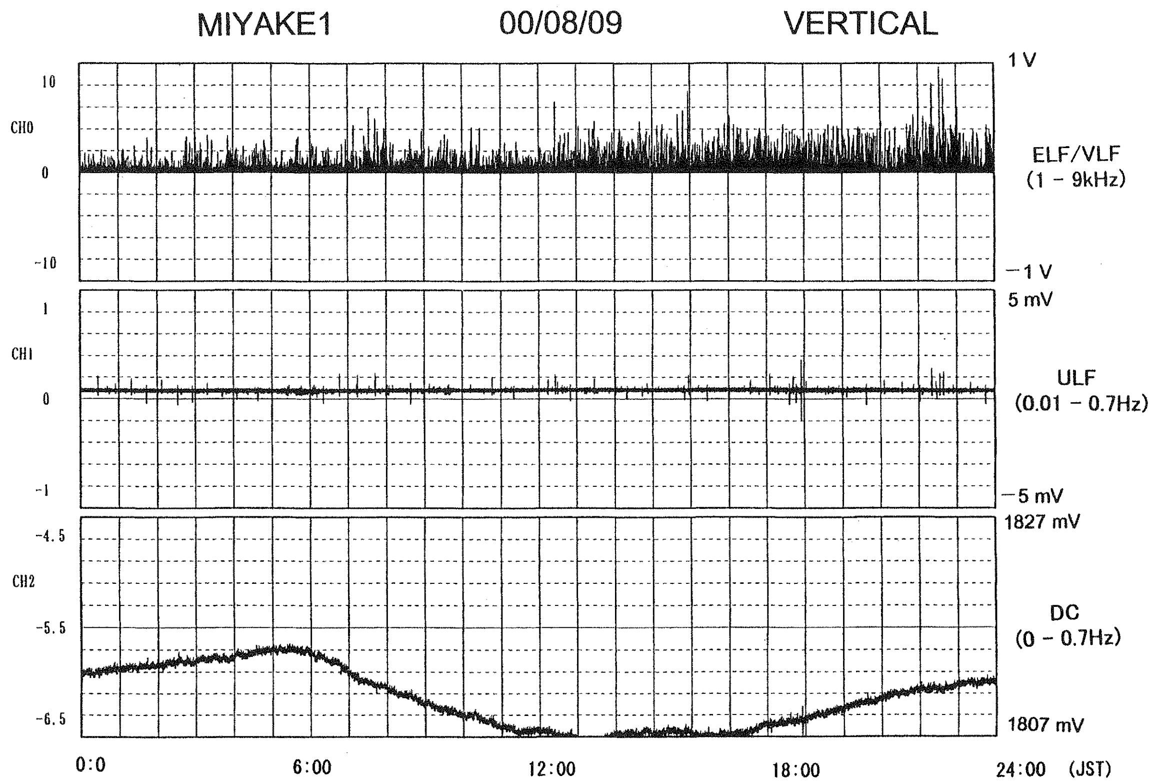


Fig. 4 Electric field record of the vertical component at the time of and preceding the third eminent volcanic eruption (**E3**) on July 13 and 14 (a, b).



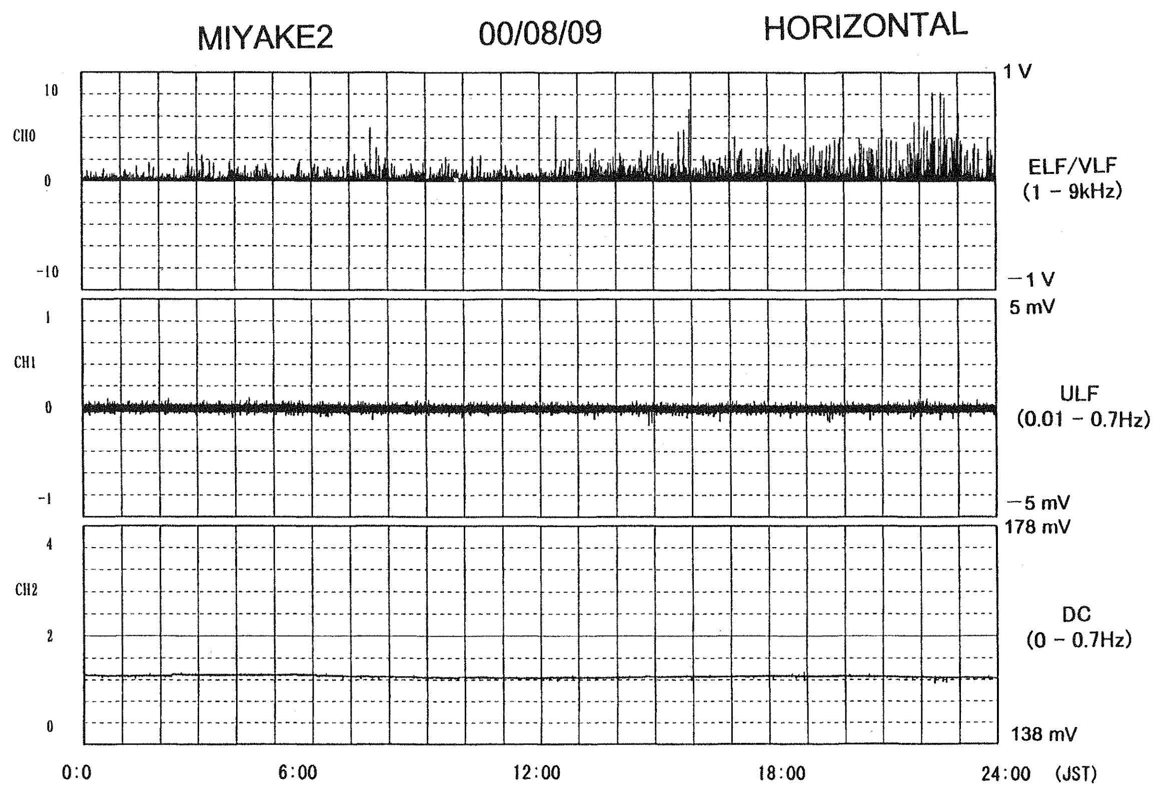
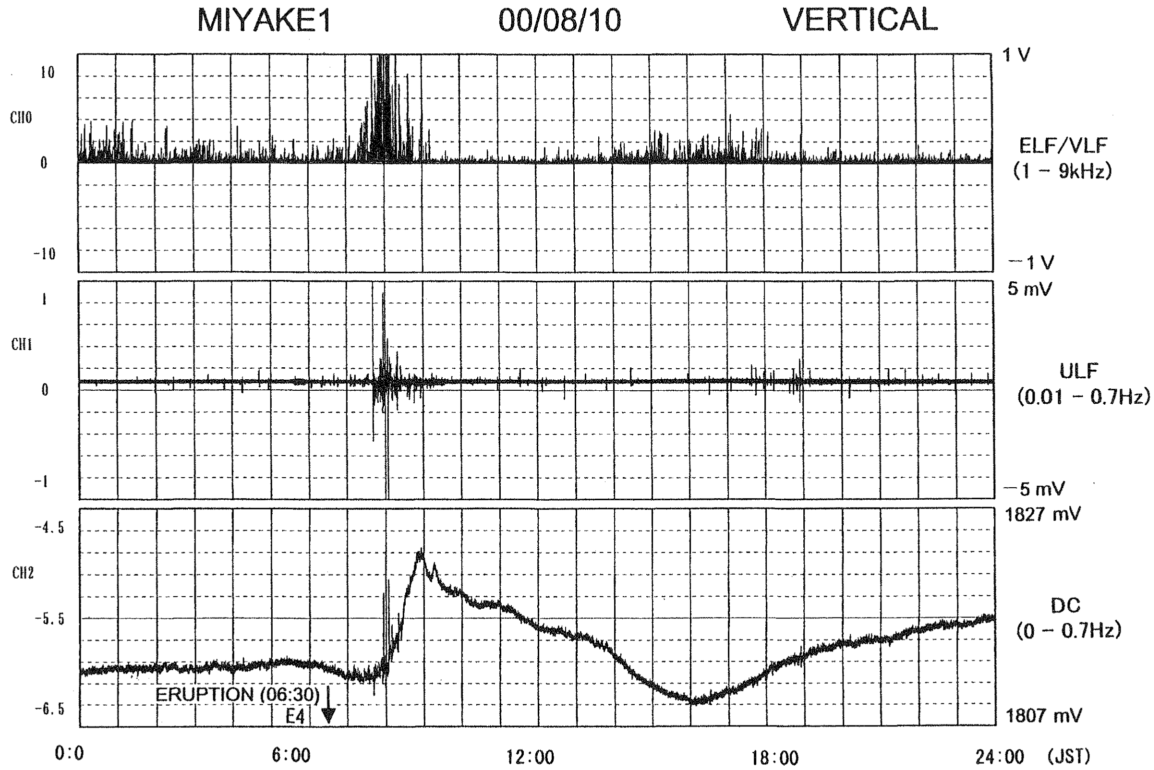
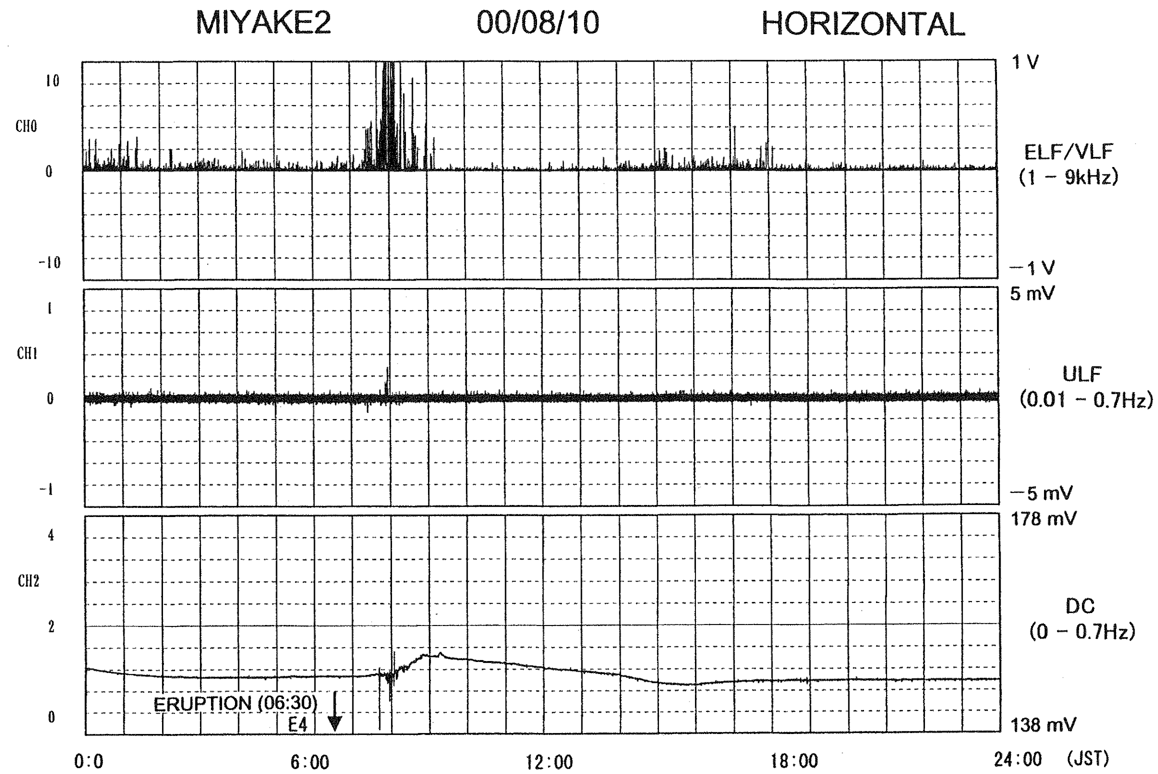


Fig. 5 Monitoring records of the vertical and horizontal components around the time of the fourth eminent volcanic eruption (**E4**) on 10 August 2000.





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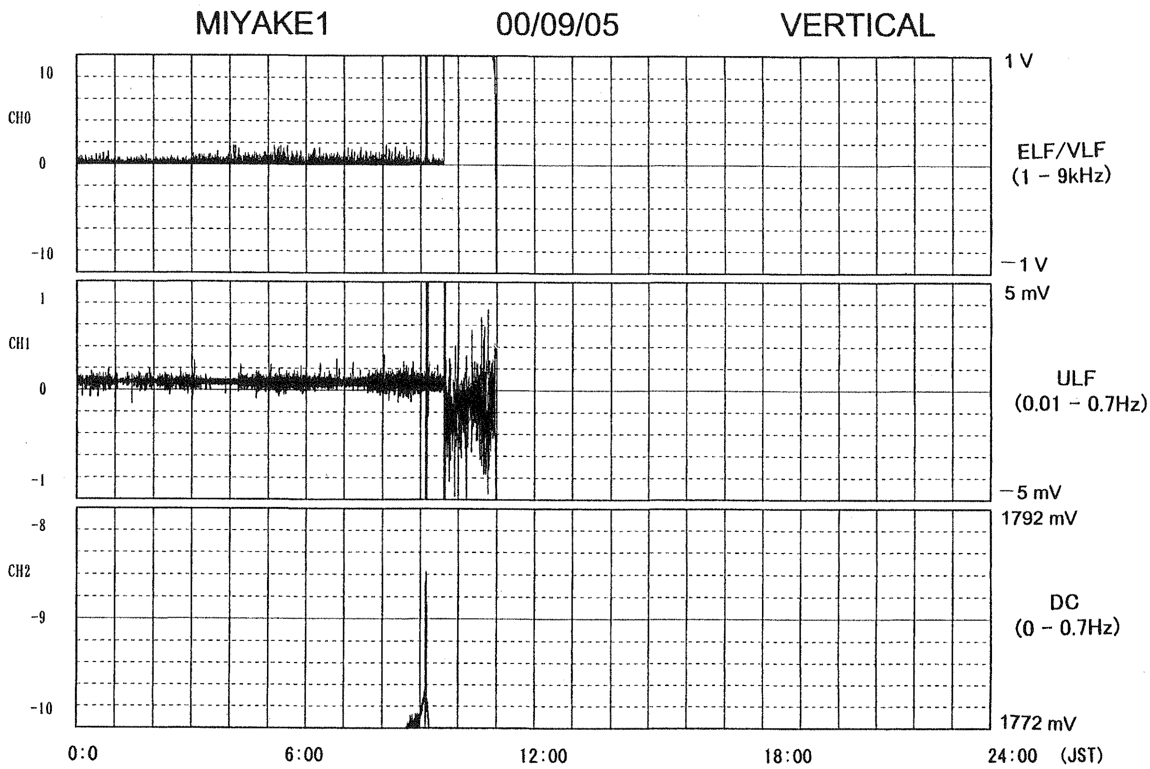


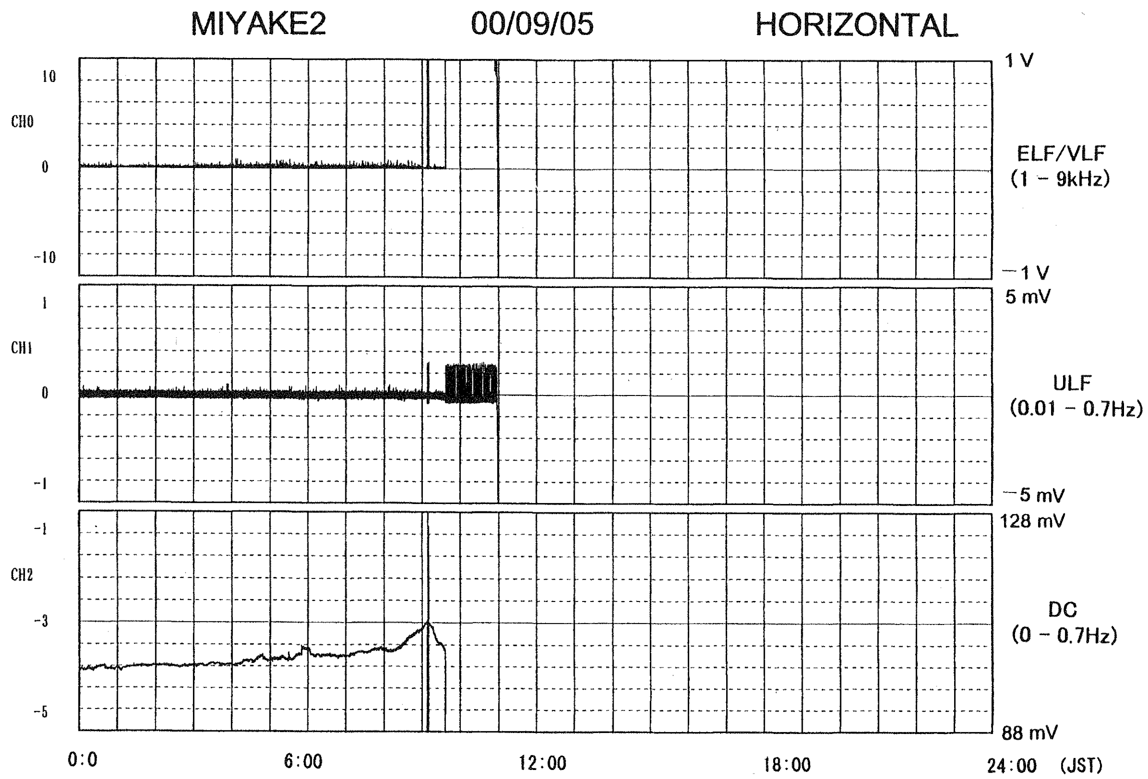
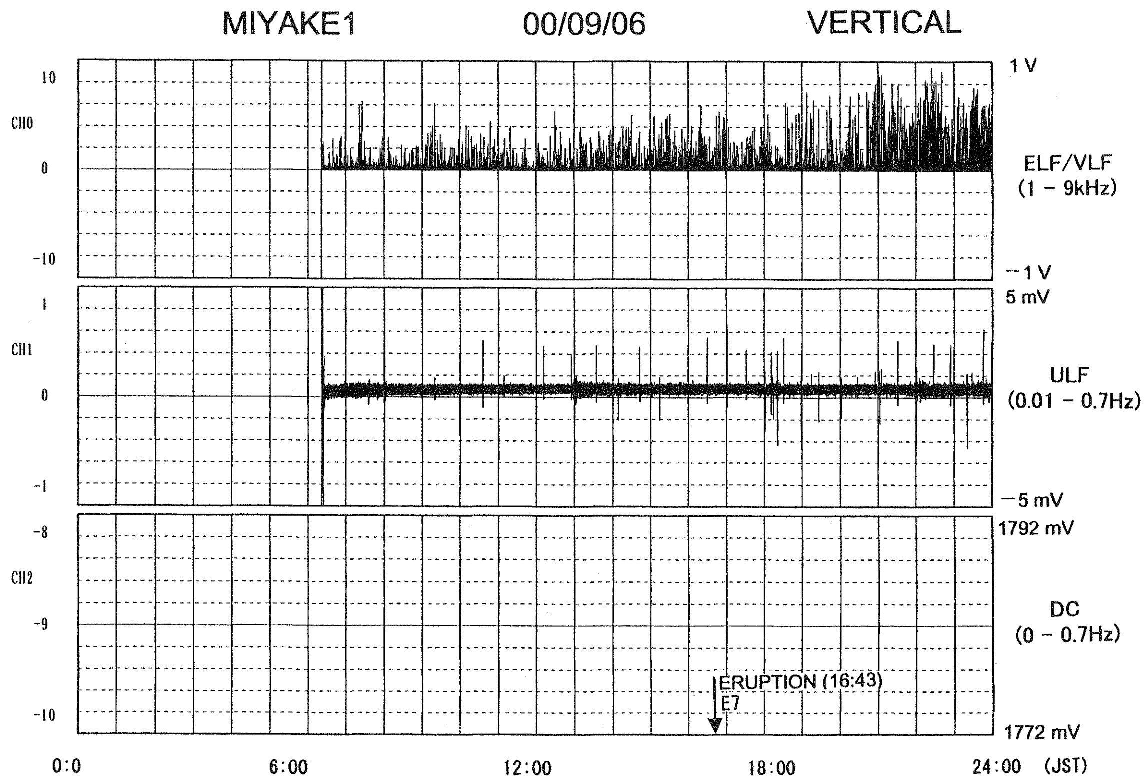


Fig. 6 Monitoring records of the horizontal and vertical components on September 5 and 6.



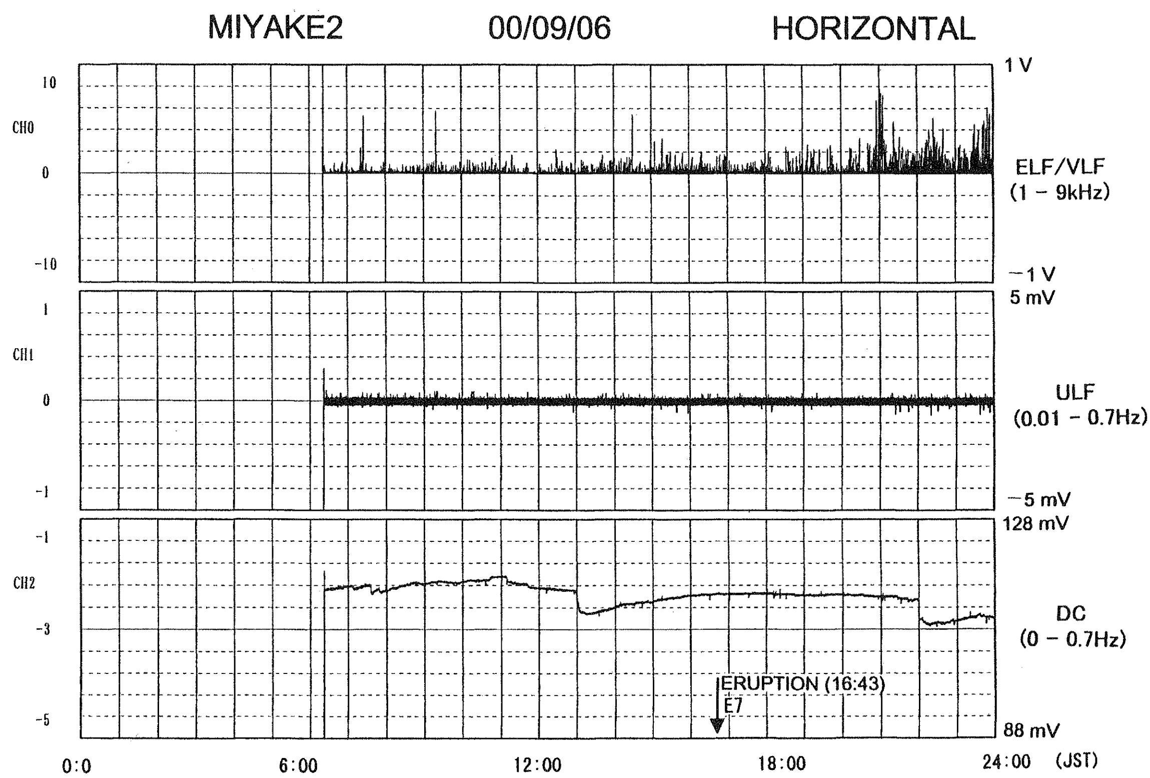
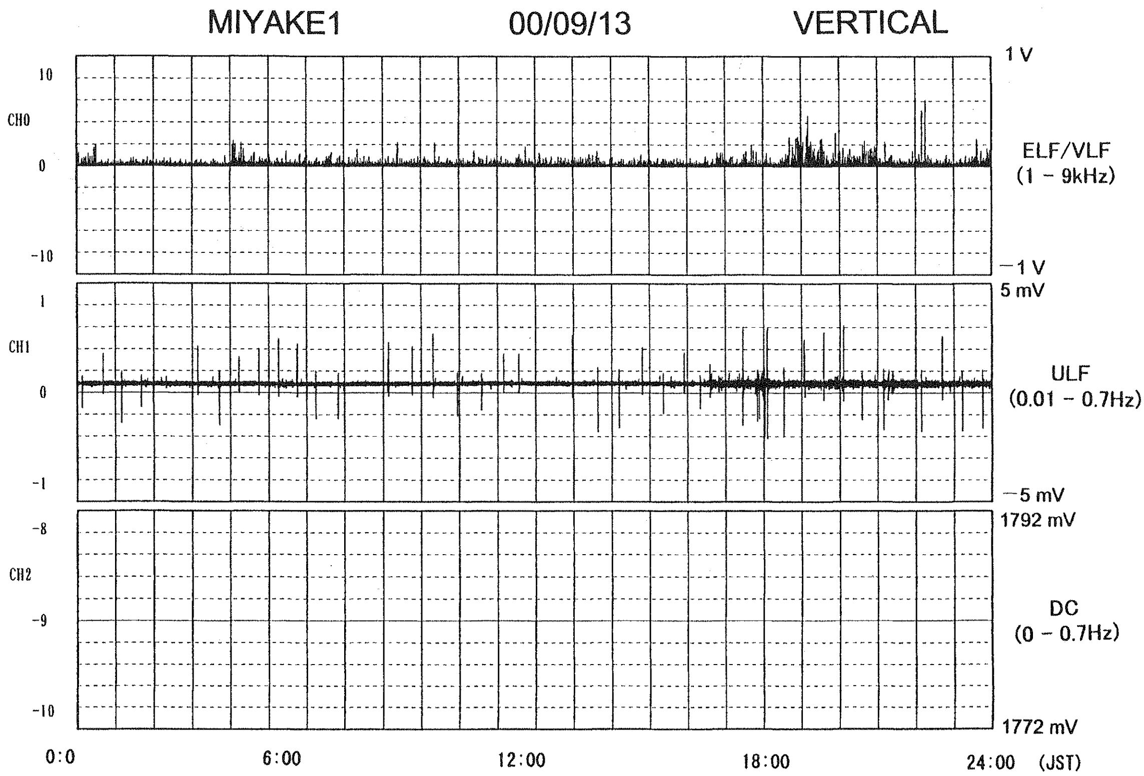


Fig. 6 Monitoring records of the horizontal and vertical components on September 5 and 6.



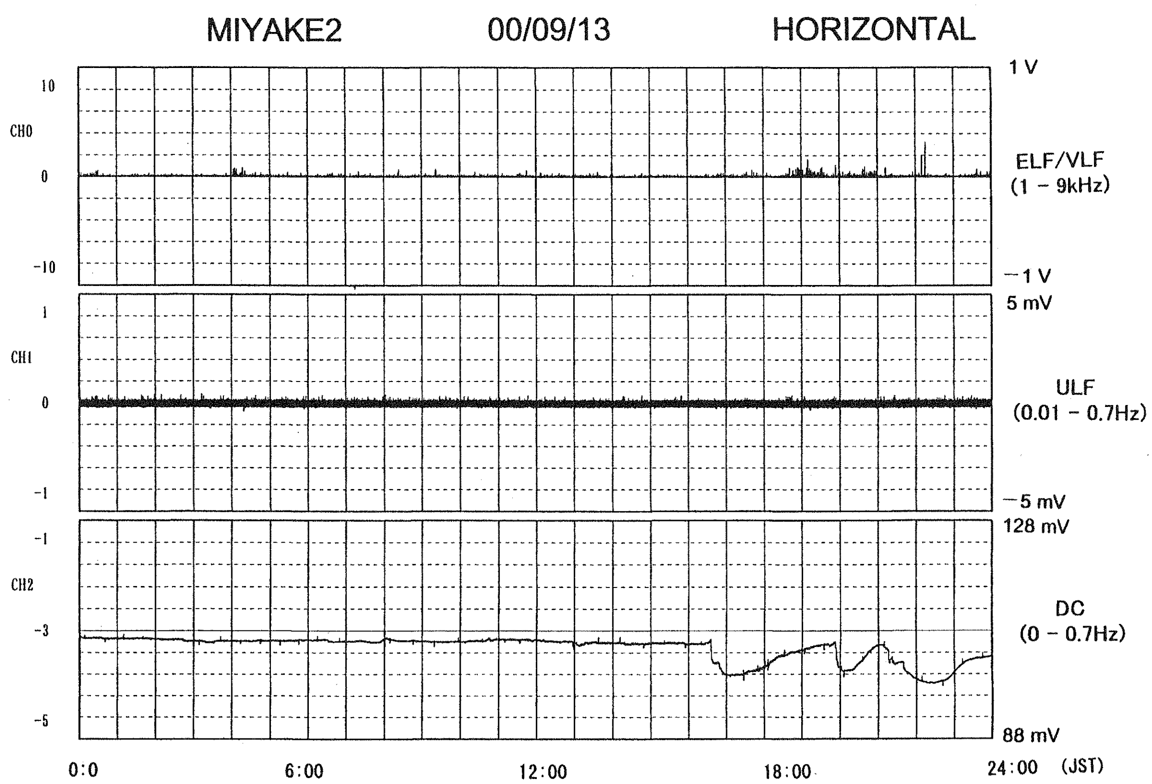
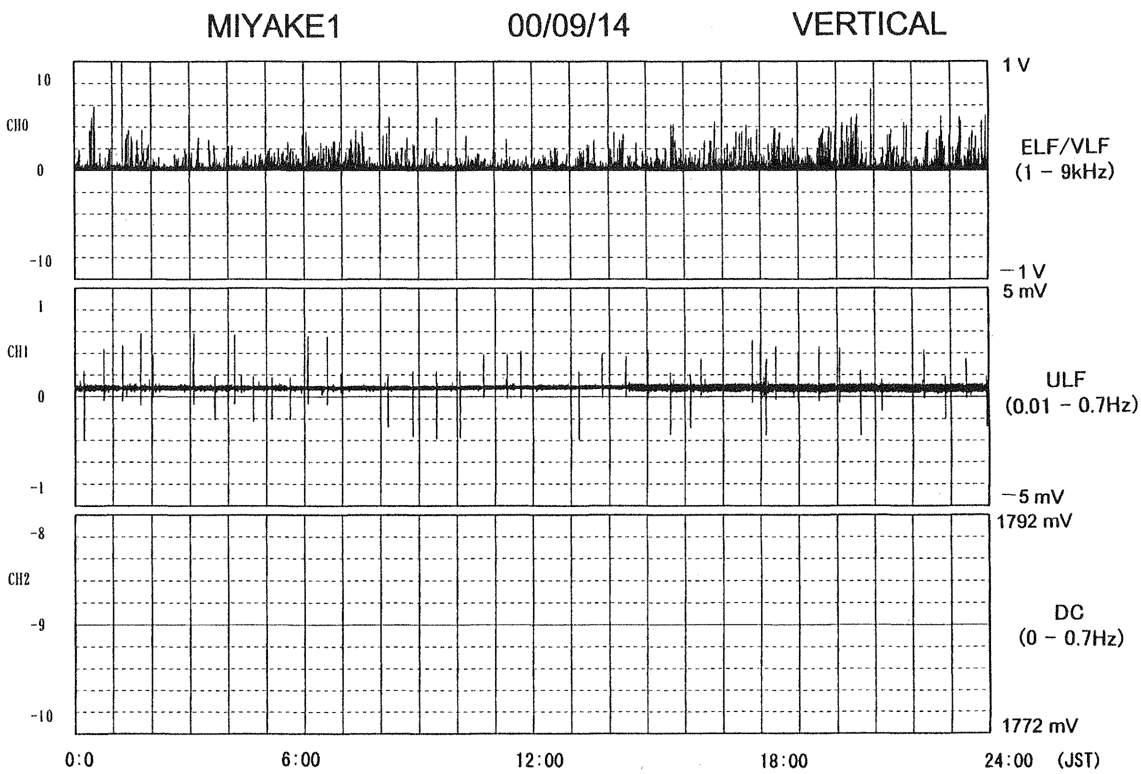


Fig. 7 Monitoring records of the horizontal and vertical components on September 13 and 14.



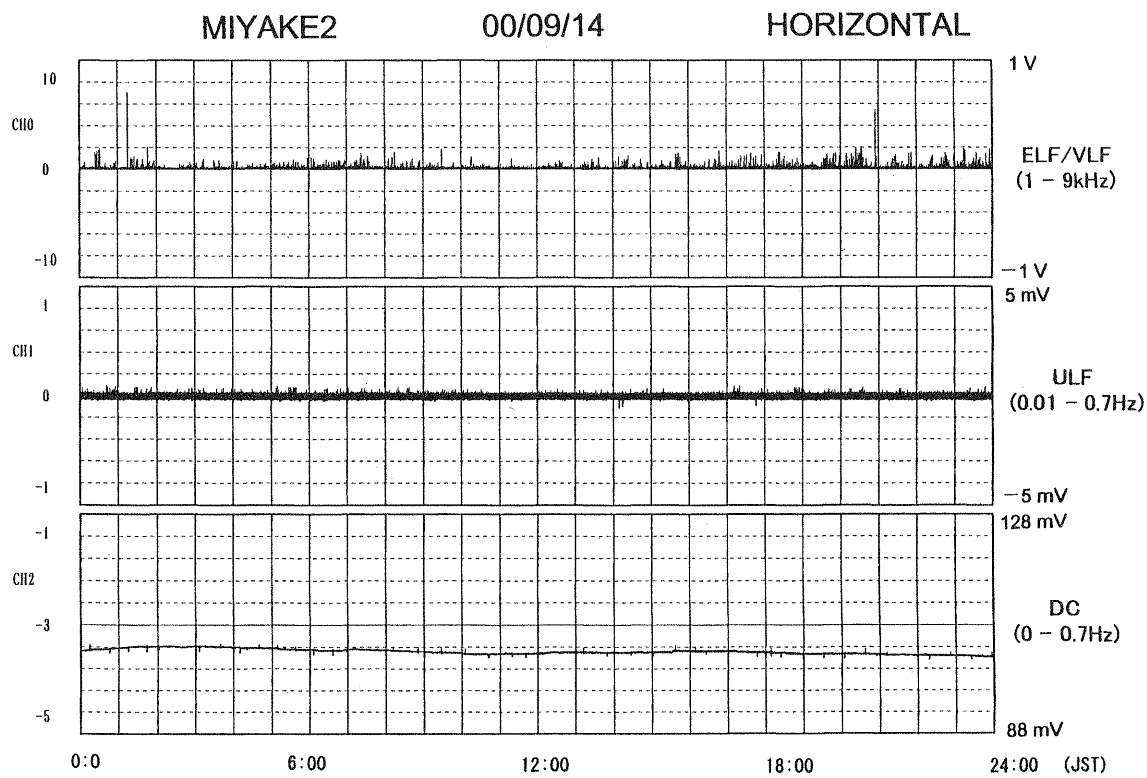


Fig. 7 Monitoring records of the horizontal and vertical components on September 13 and 14.

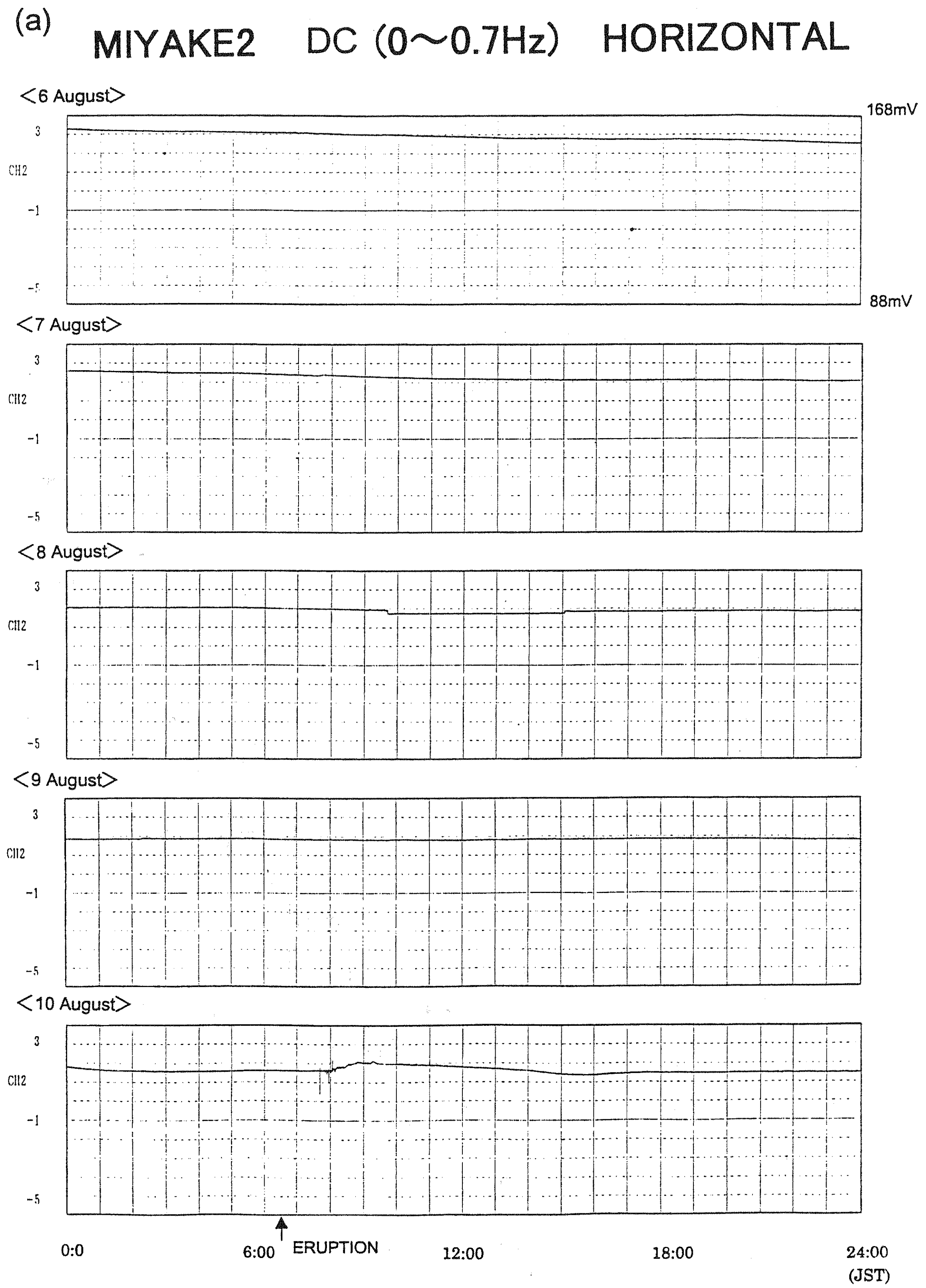
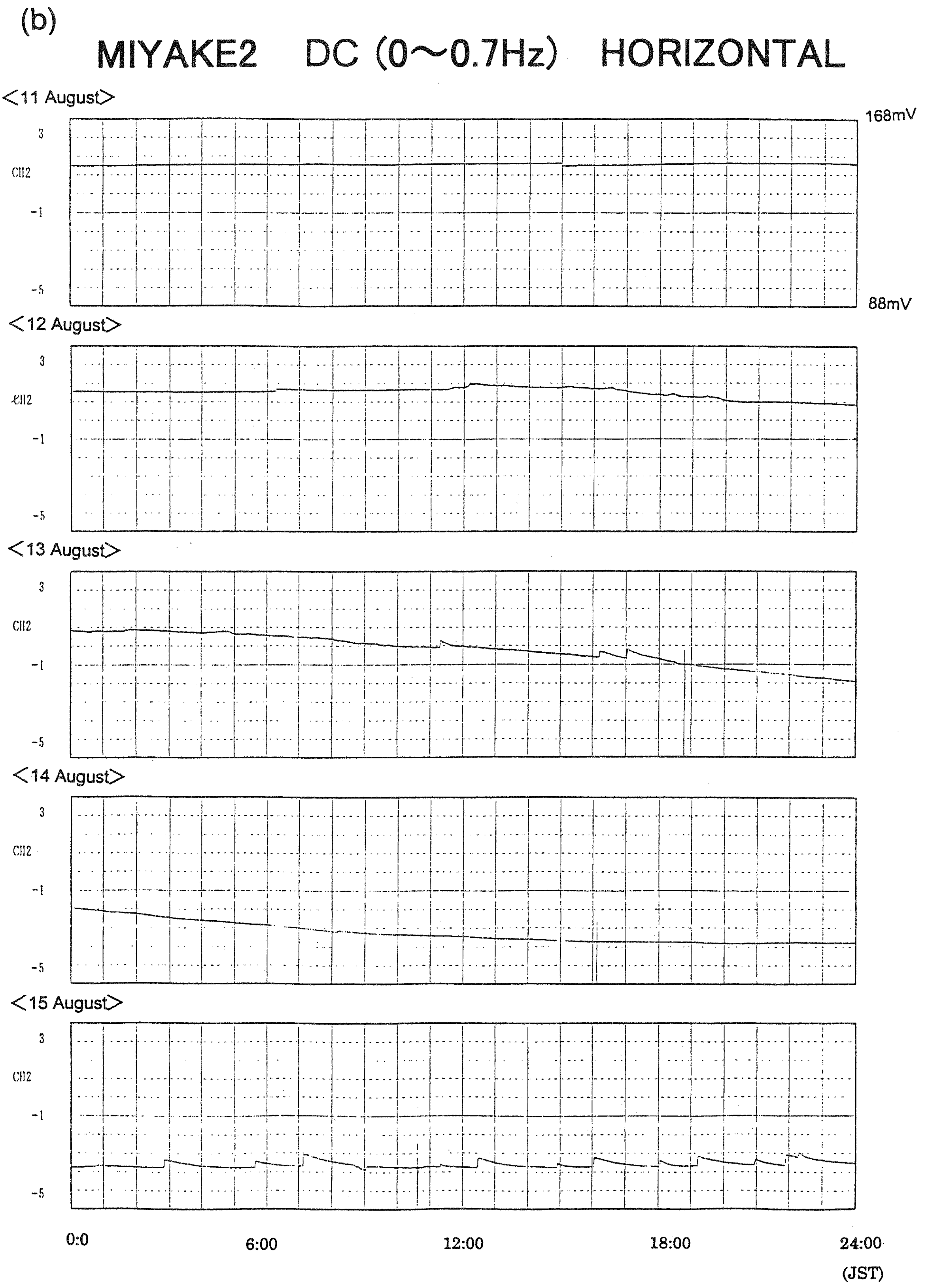


Fig. 8 Monitoring records of the DC component in the horizontal component. The first, small step-like change appeared on August 8 (**Fig. 8a**).



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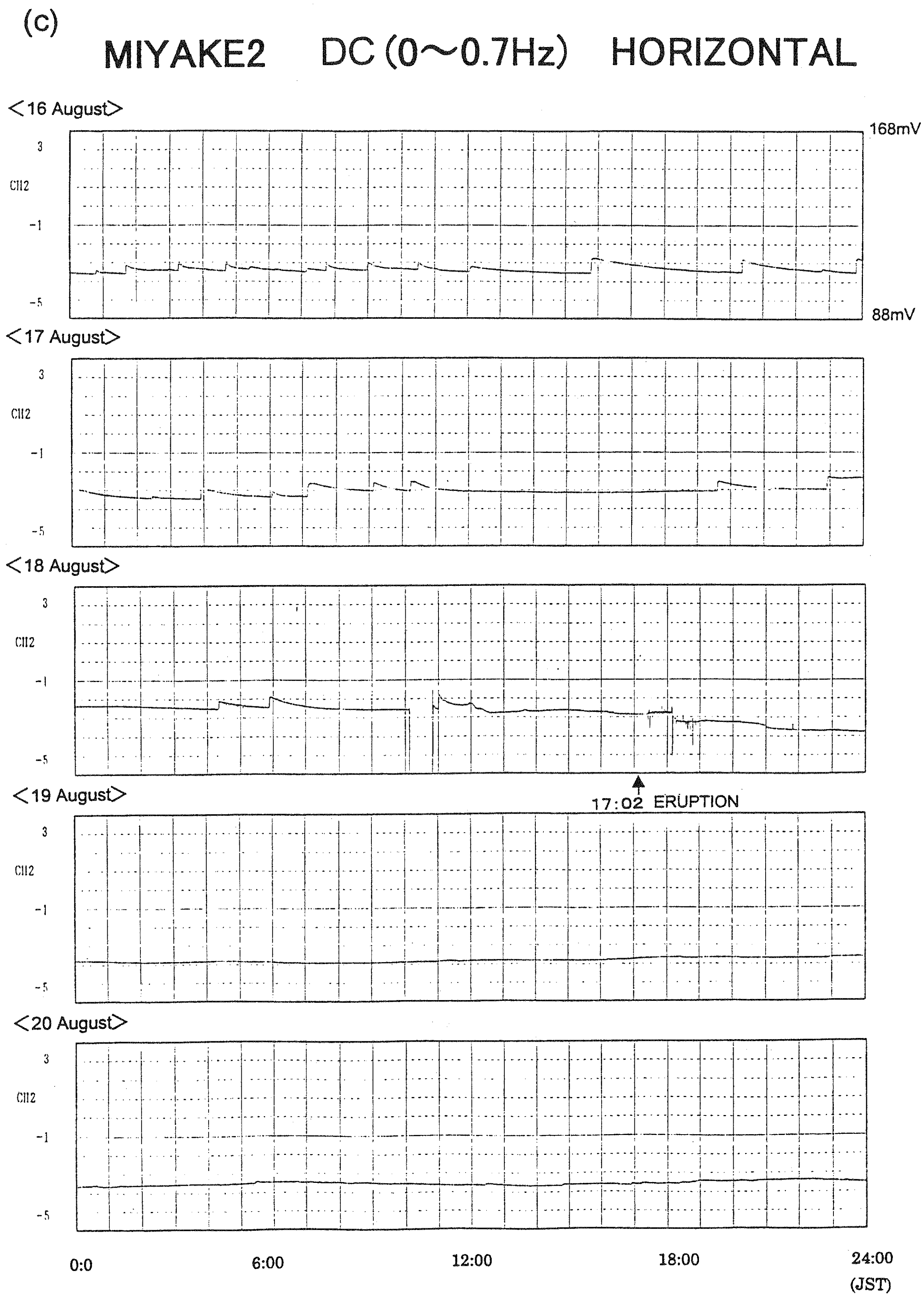

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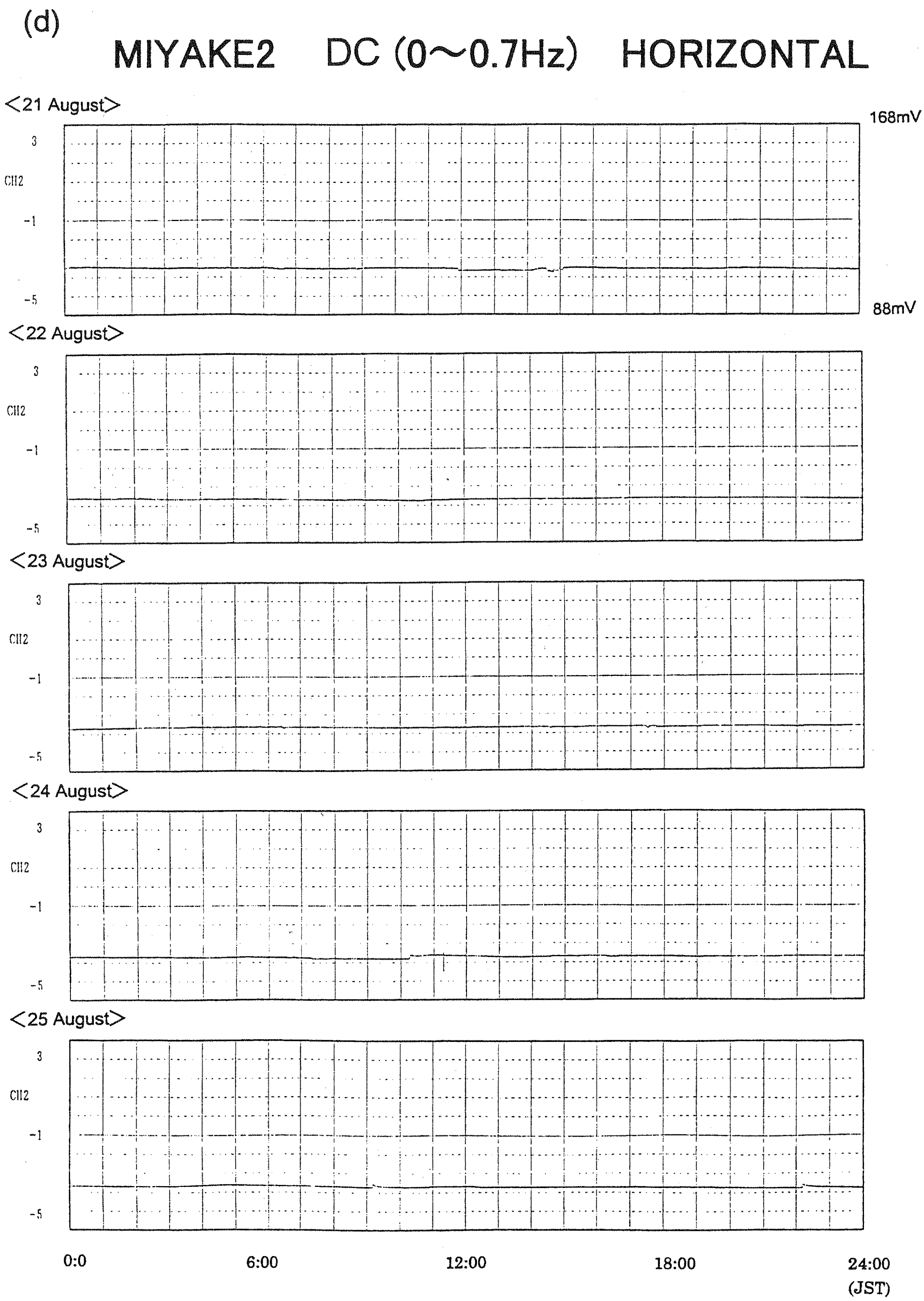


Fig. 8 Monitoring records of the DC component in the horizontal component. The first, small step-like change appeared on August 8 (**Fig. 8a**).

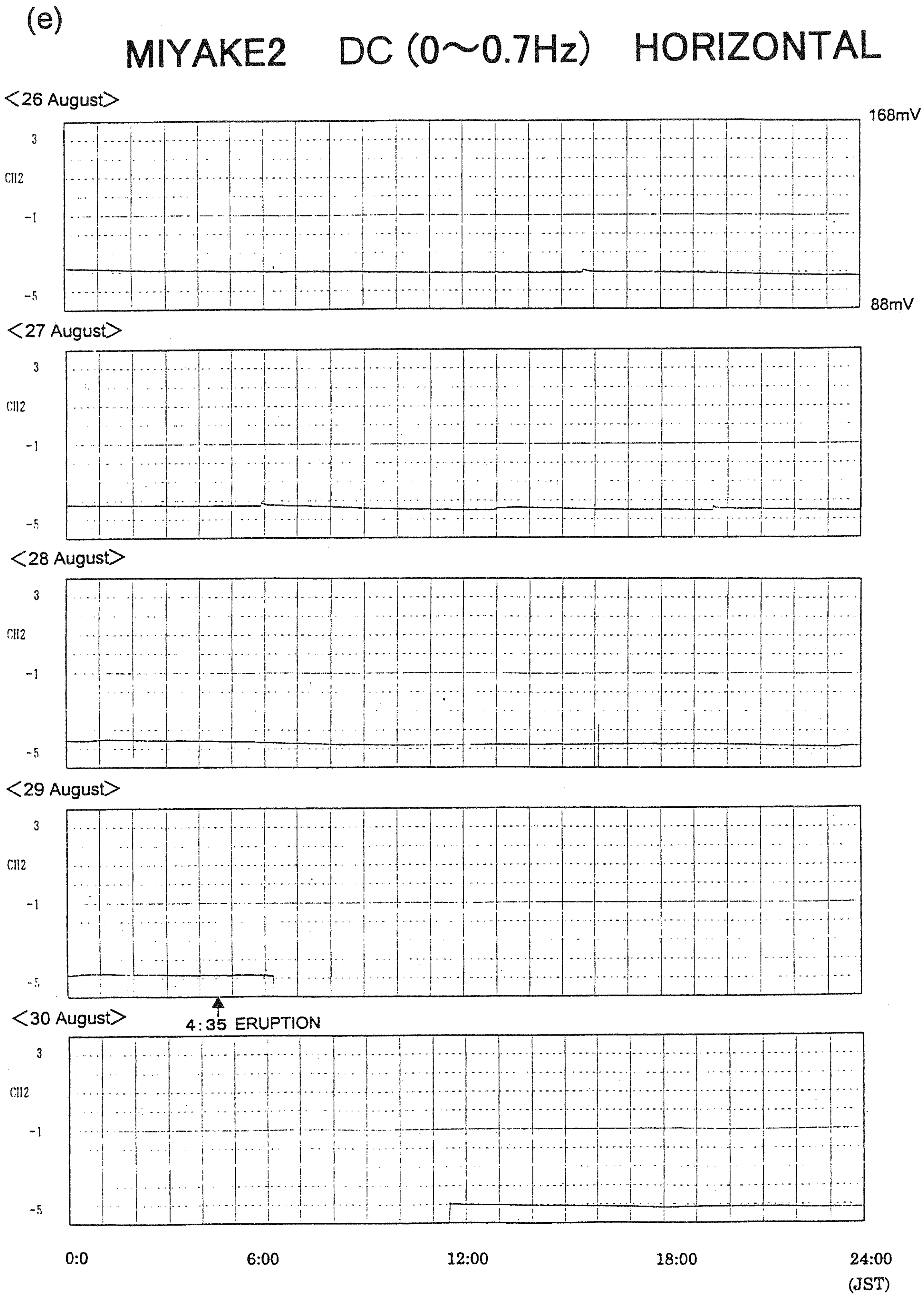


Fig. 8 Monitoring records of the DC component in the horizontal component. The first, small step-like change appeared on August 8 (**Fig. 8a**).

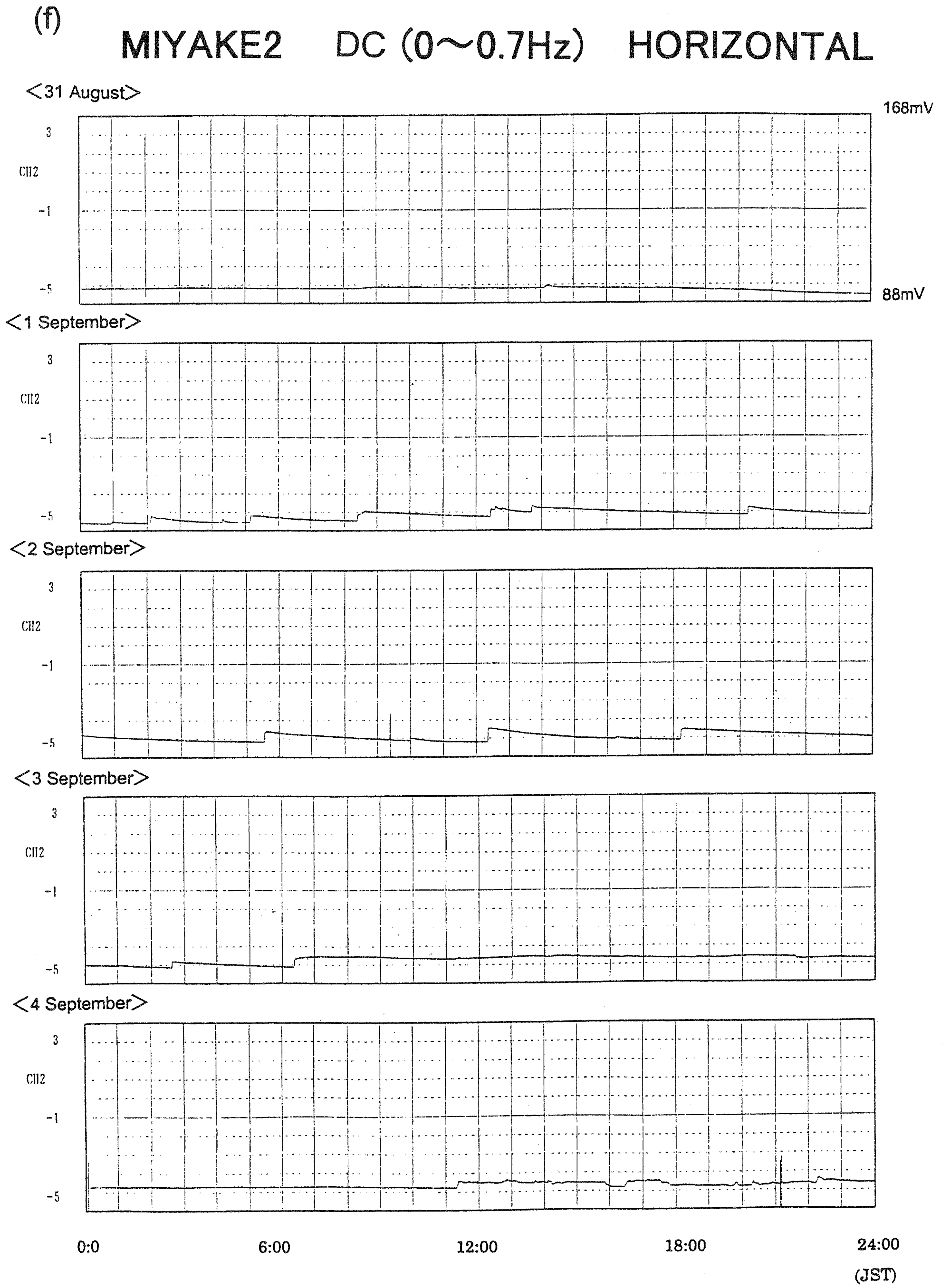
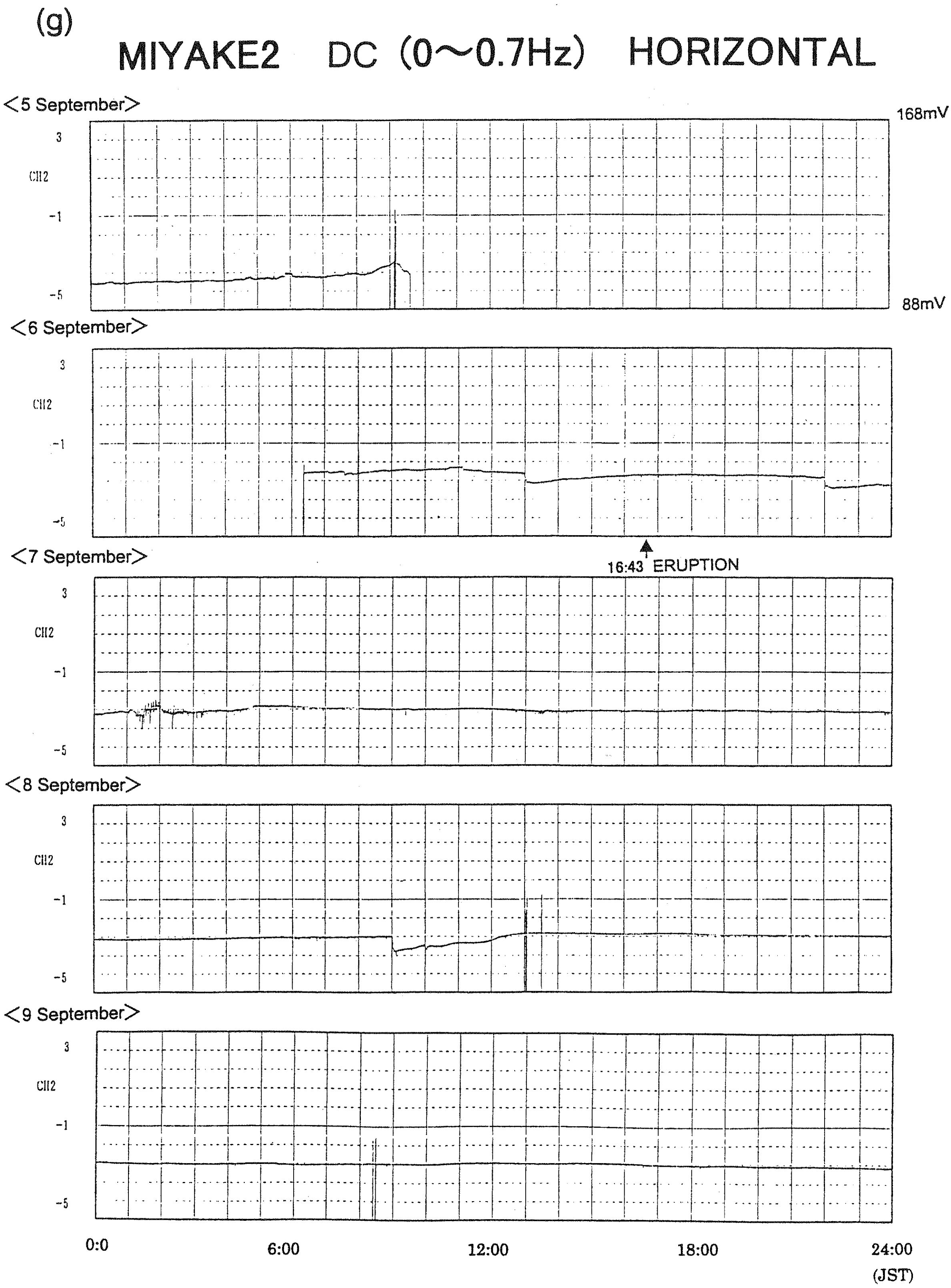


Fig. 8 Monitoring records of the DC component in the horizontal component. The first, small step-like change appeared on August 8 (**Fig. 8a**).



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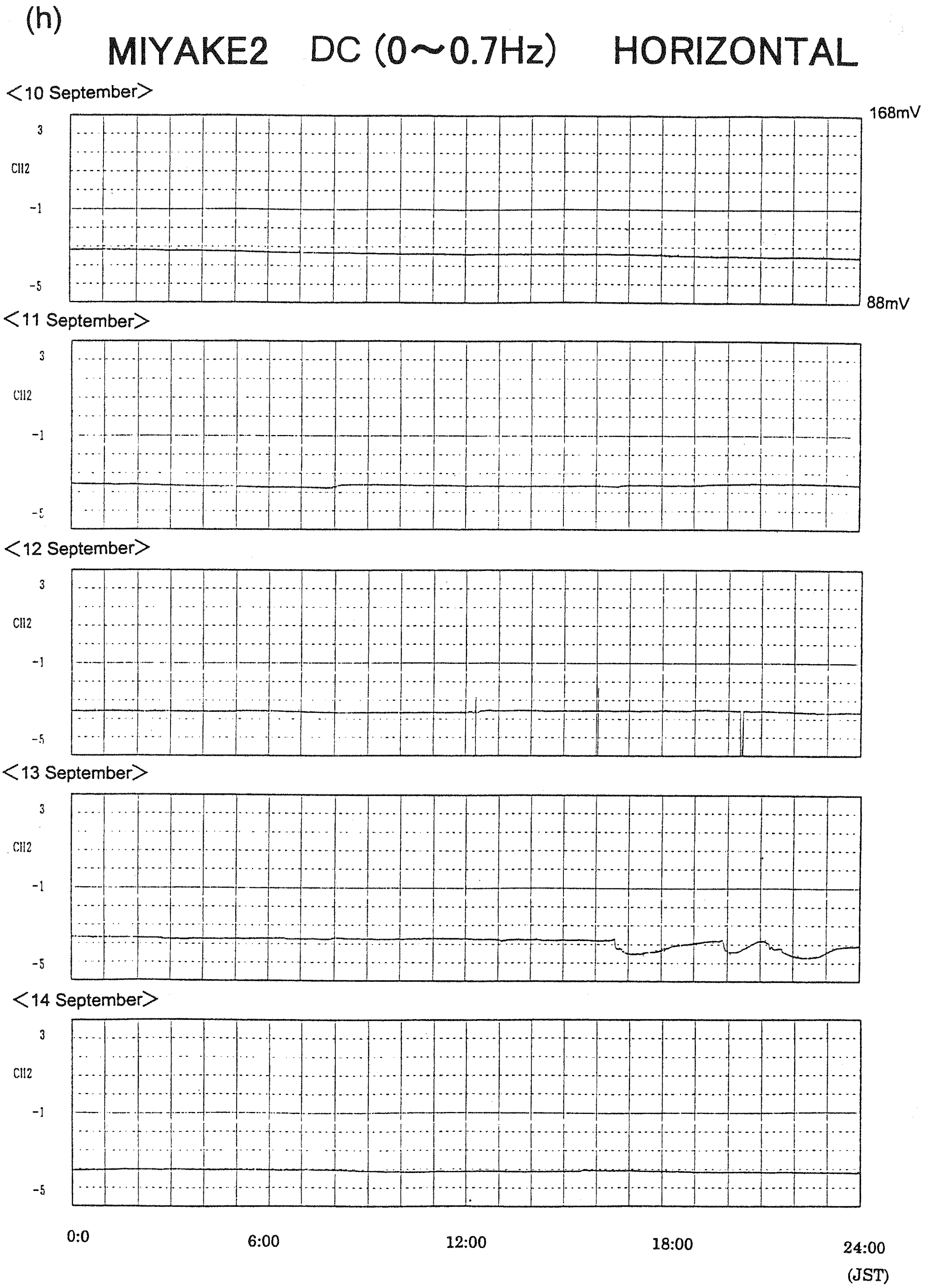

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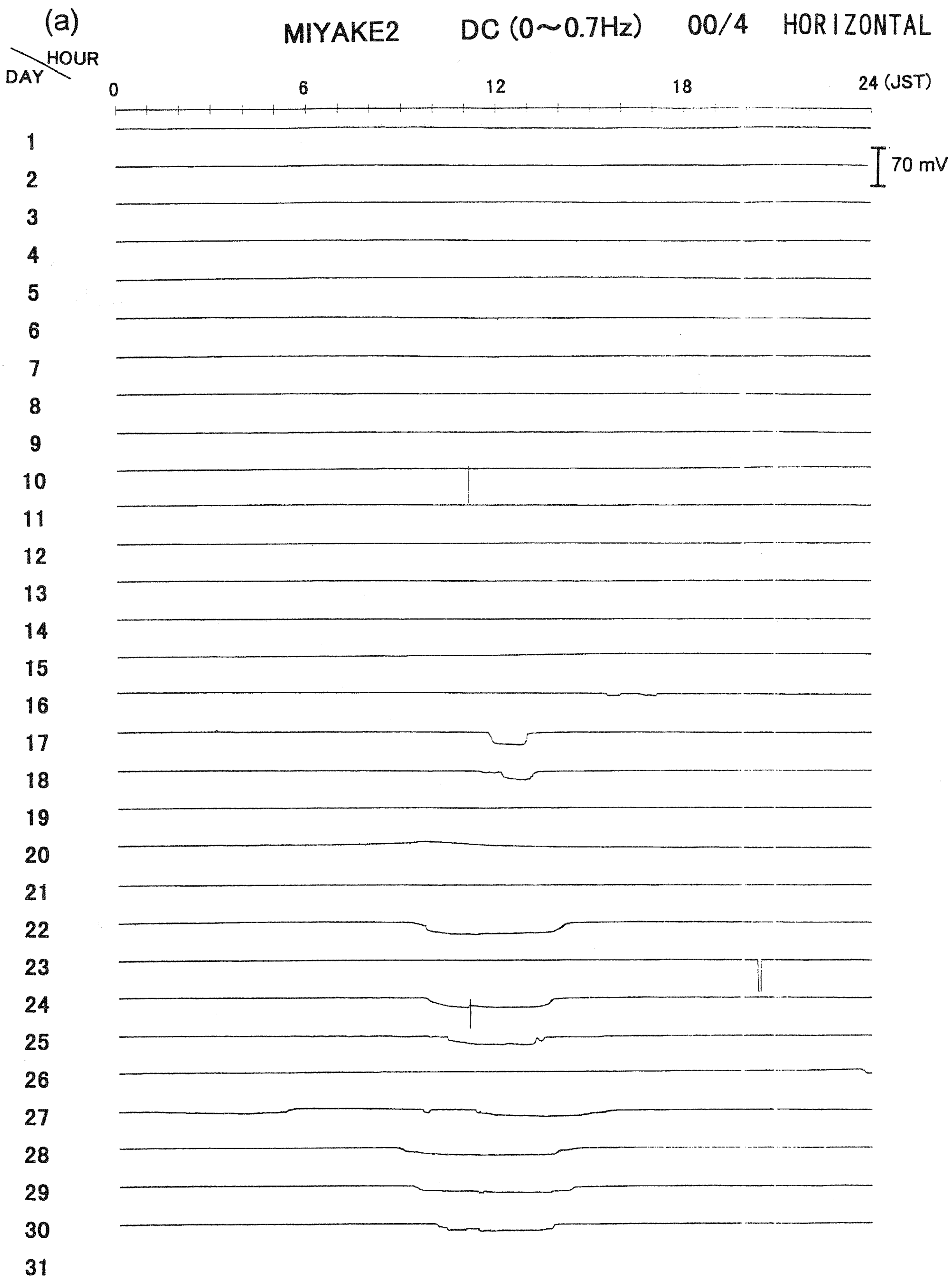


Fig. 9 Monitoring records of the DC band in the horizontal component for (a) April and (b) May 2000.

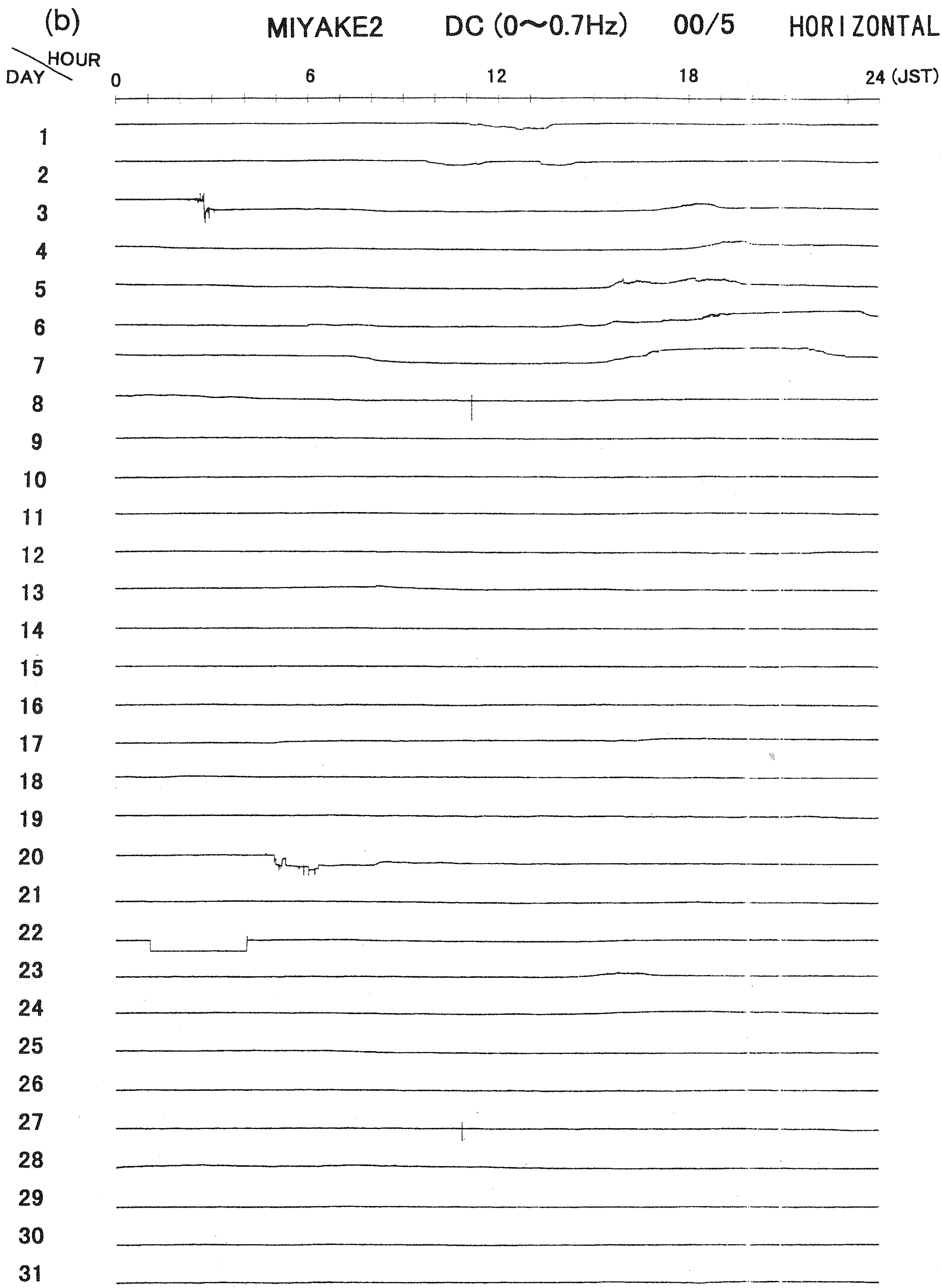


Fig. 9 Monitoring records of the DC band in the horizontal component for (a) April and (b) May 2000.

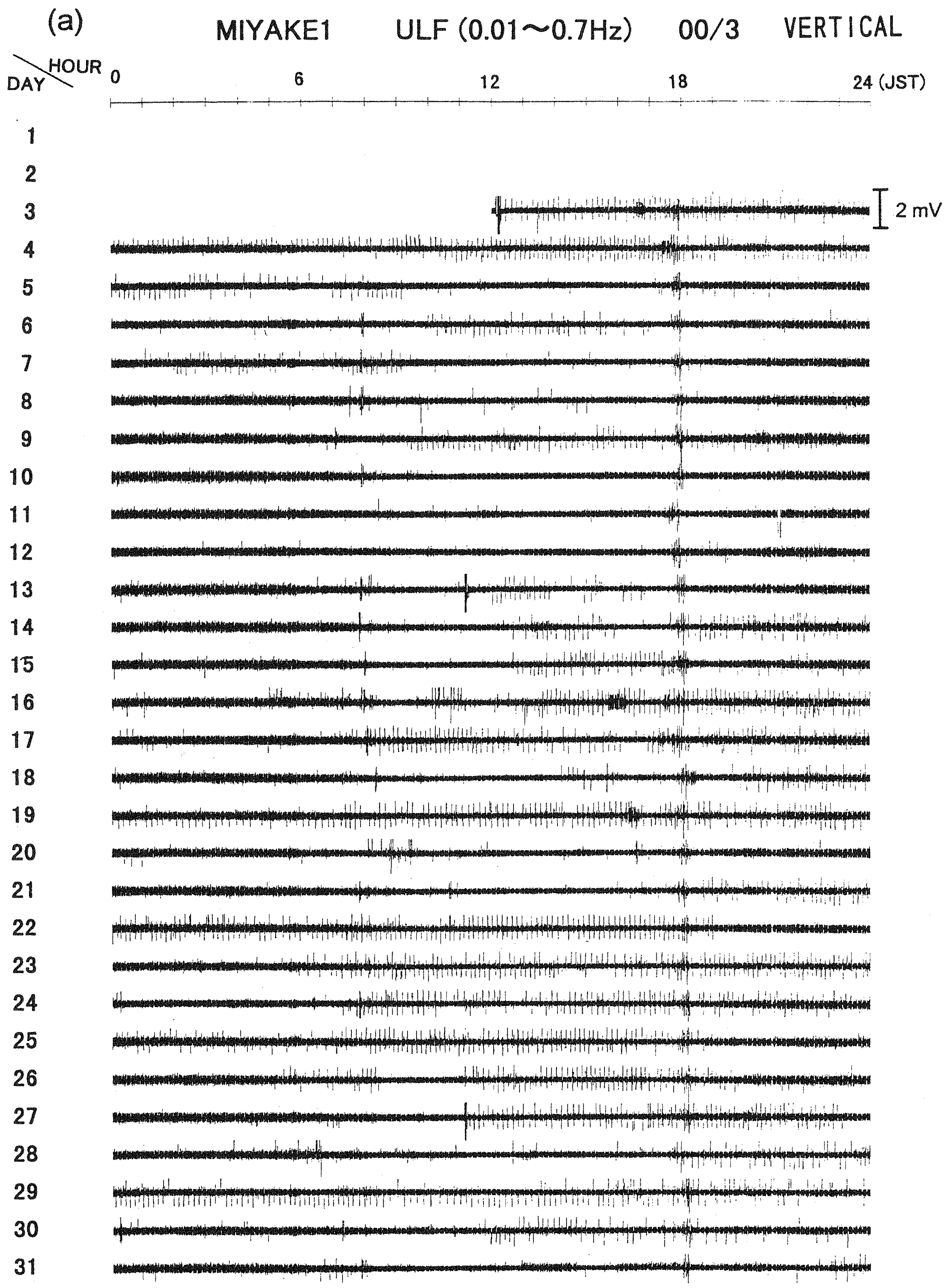
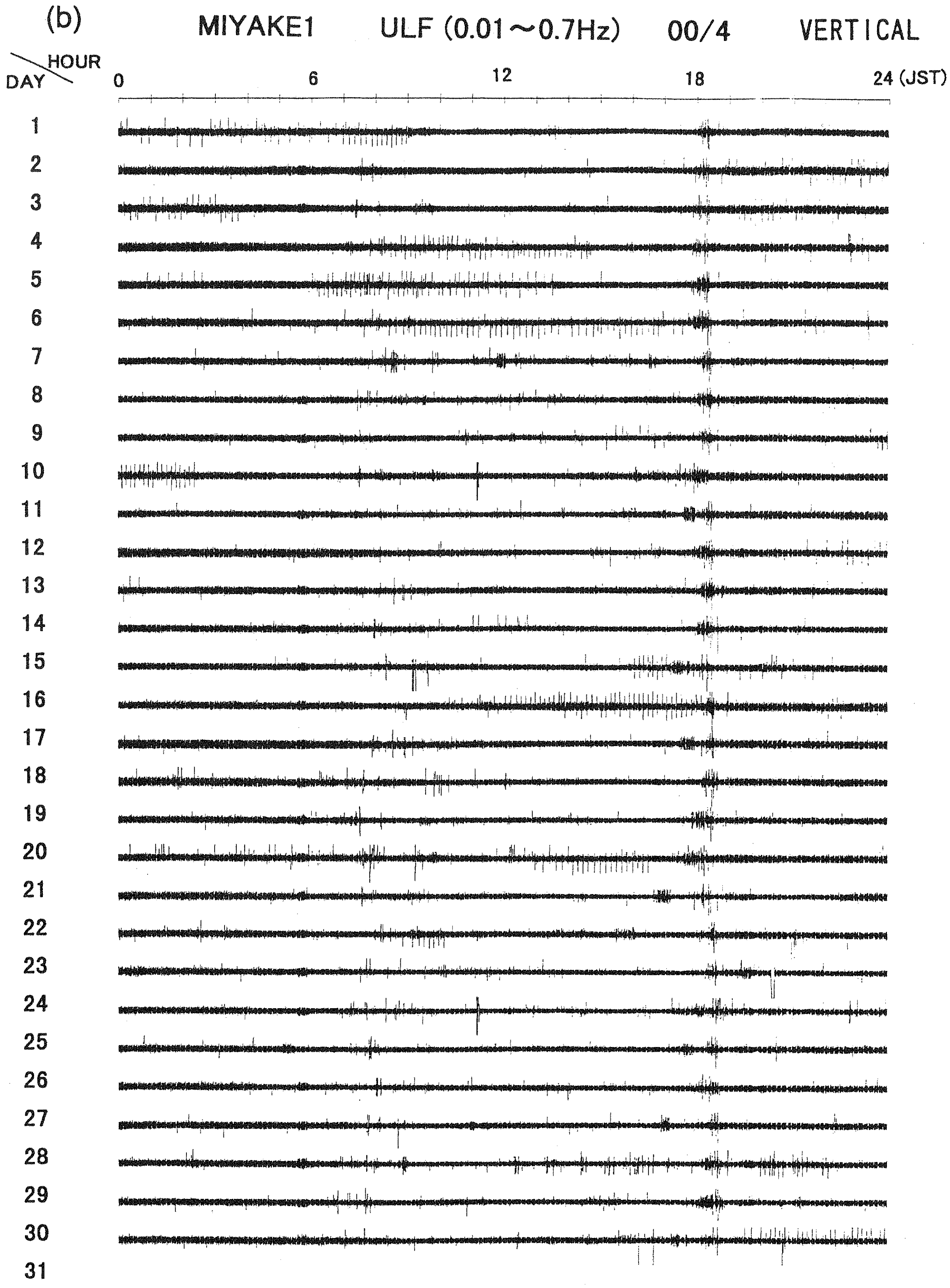


Fig. 10 ULF band record in the vertical component from March through September 2000.



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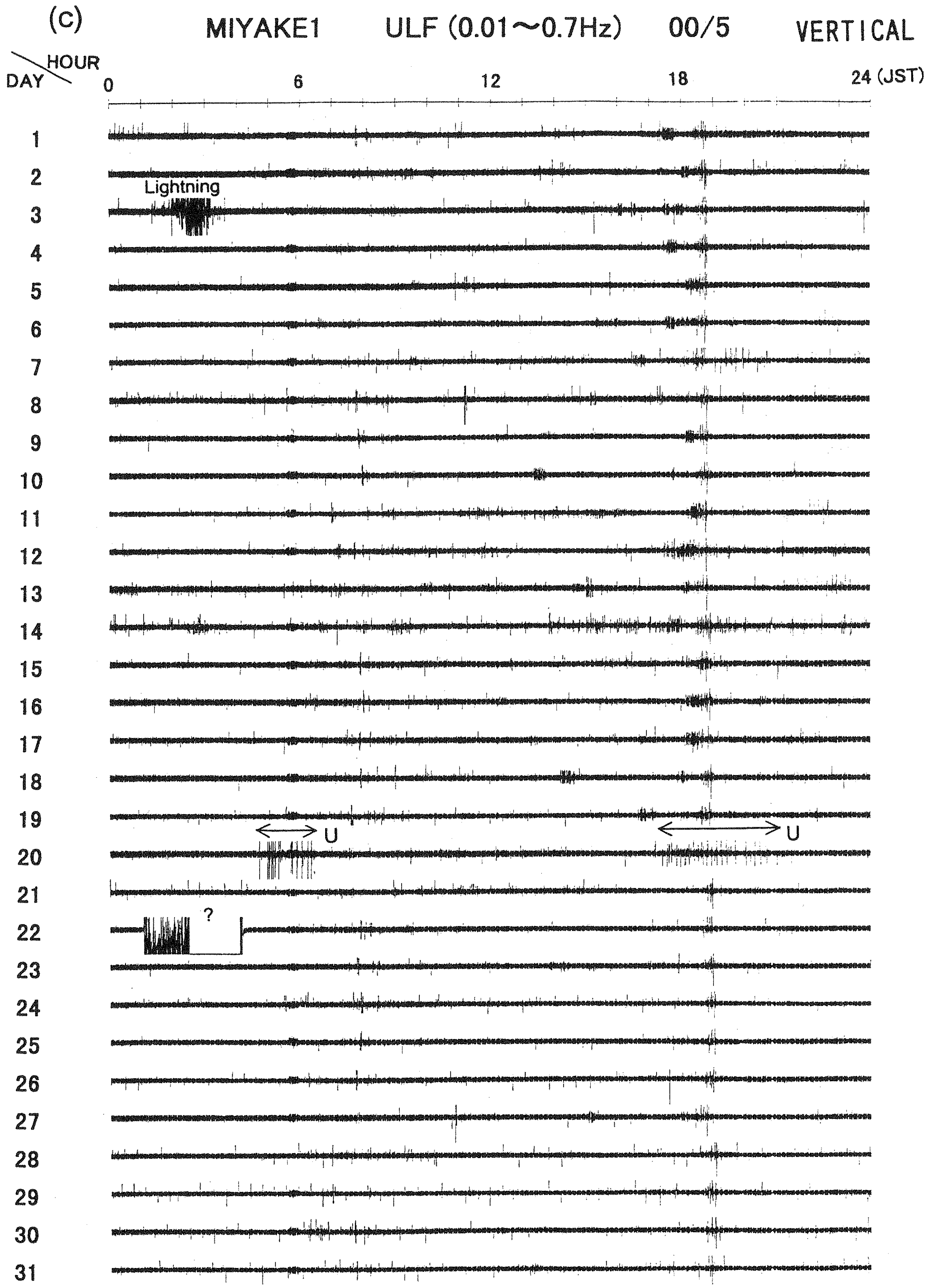

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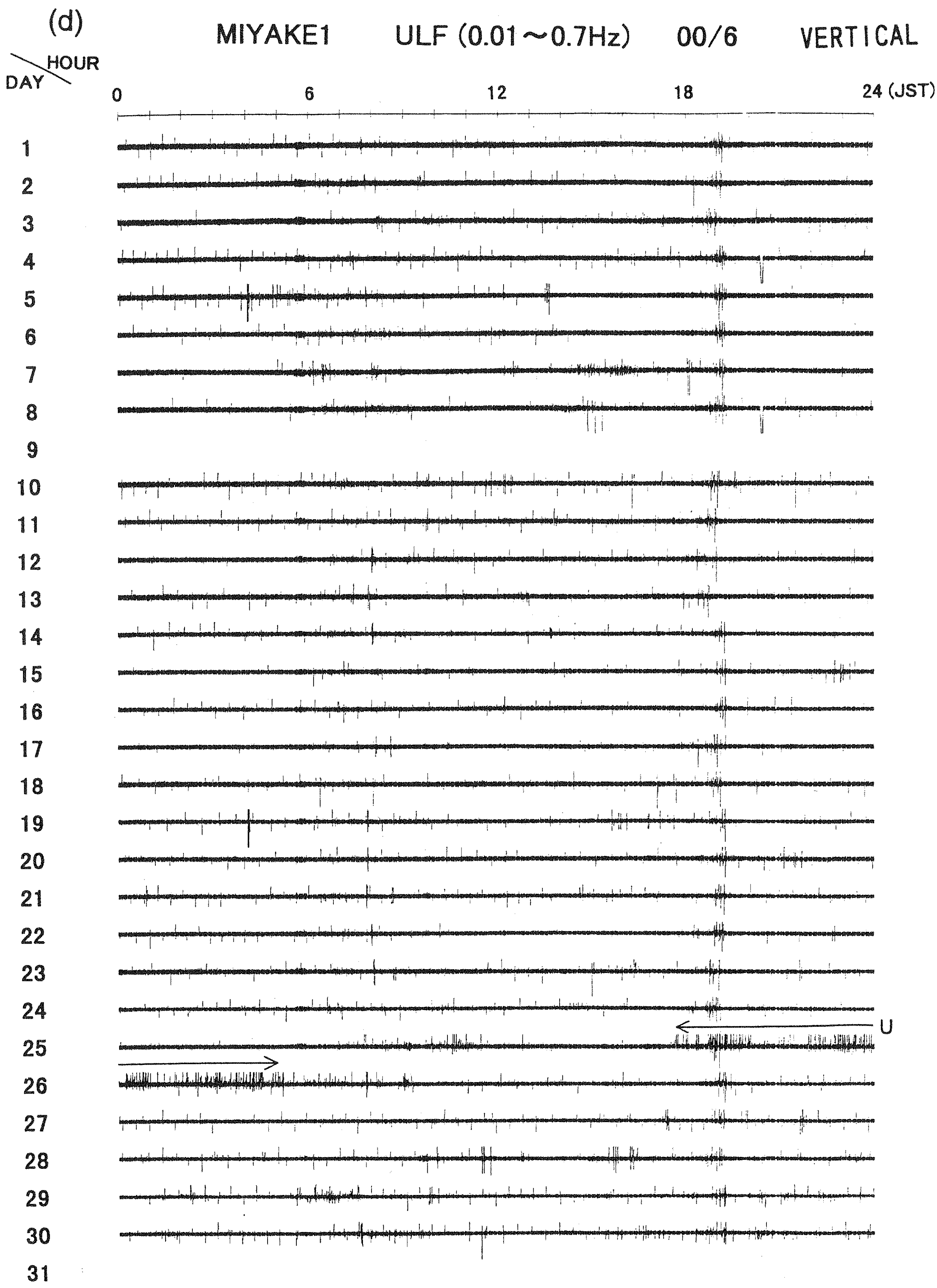

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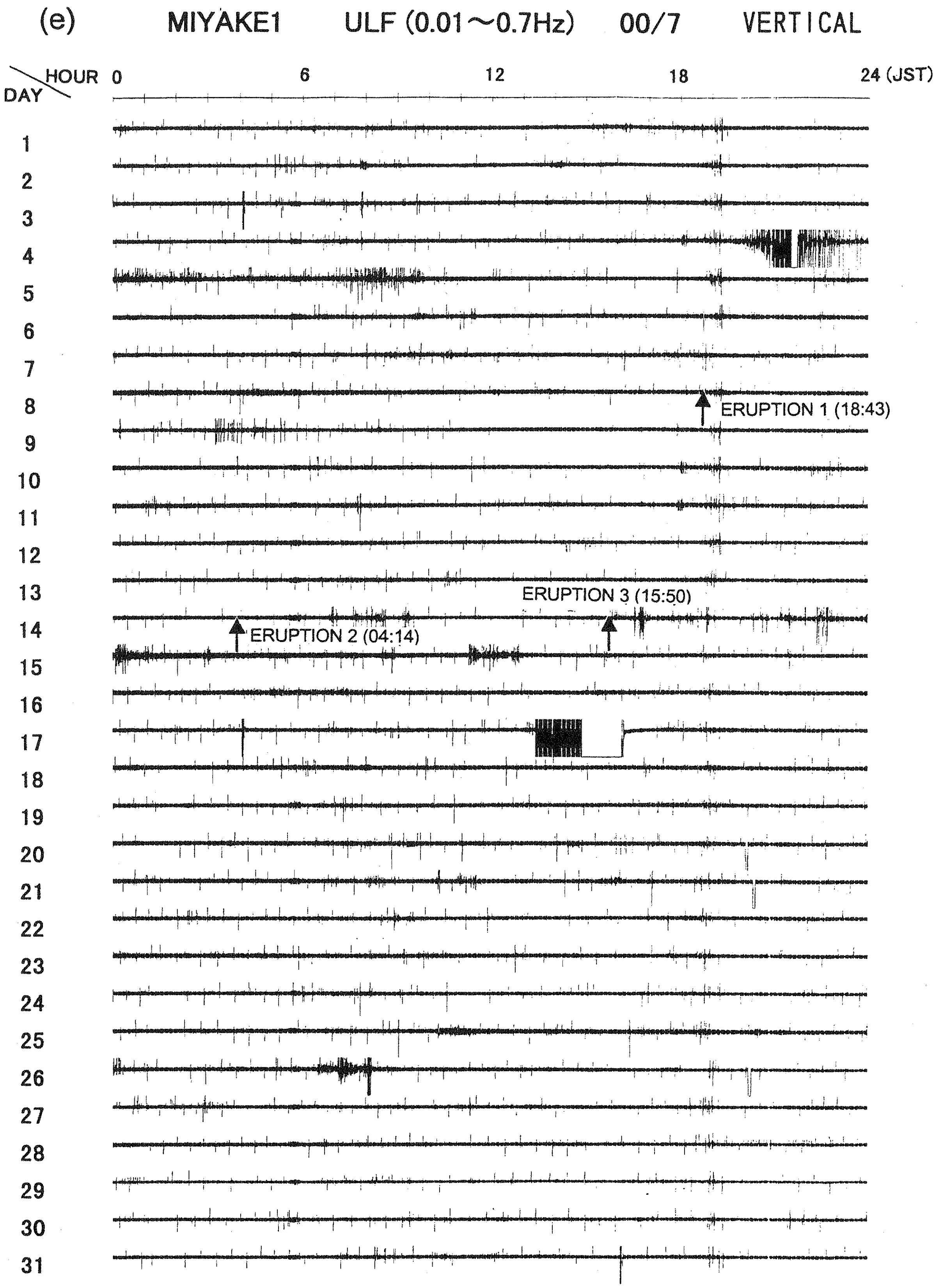

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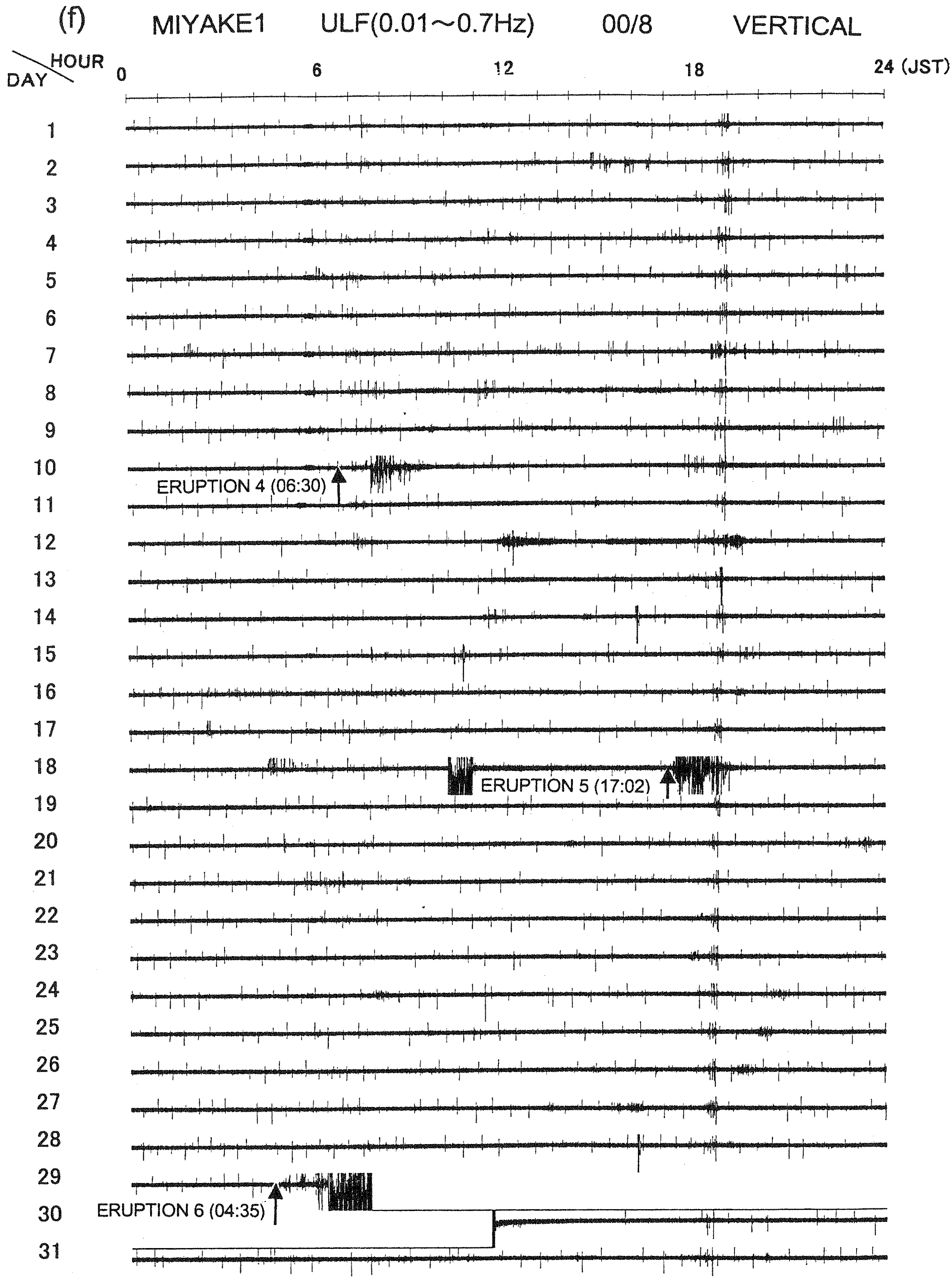


Fig. 10 ULF band record in the vertical component from March through September 2000.

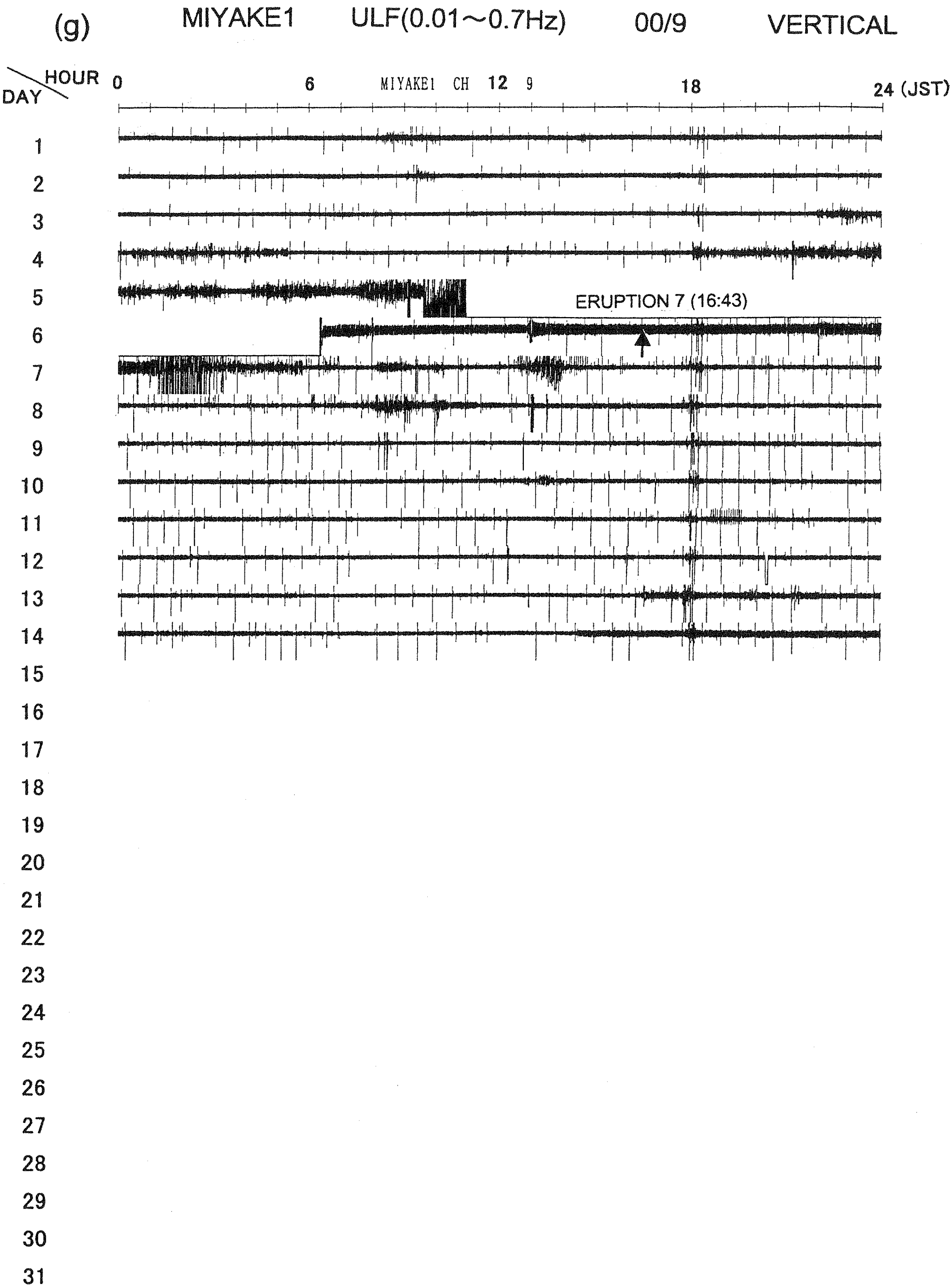


Fig. 10 ULF band record in the vertical component from March through September 2000.

(a)

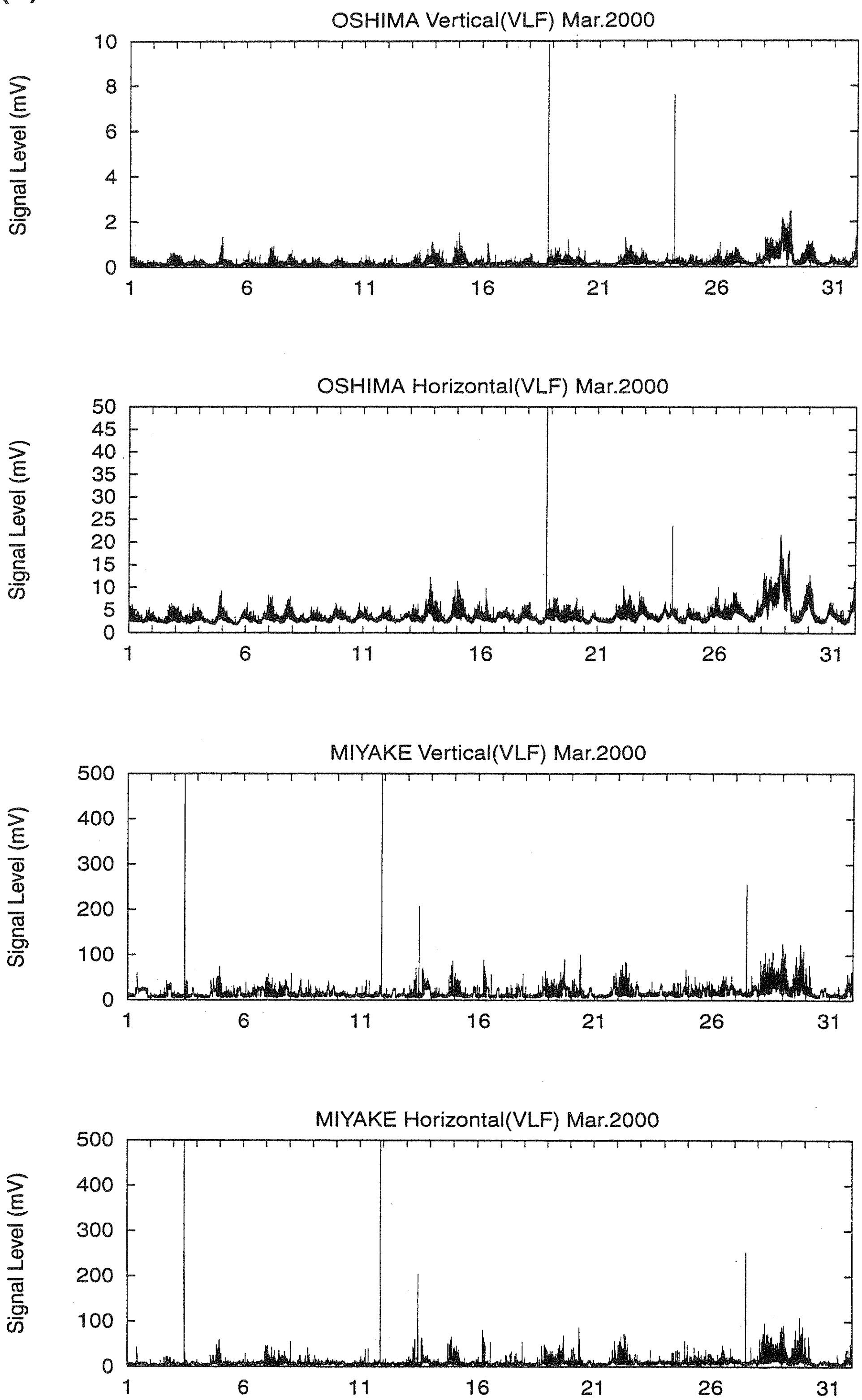
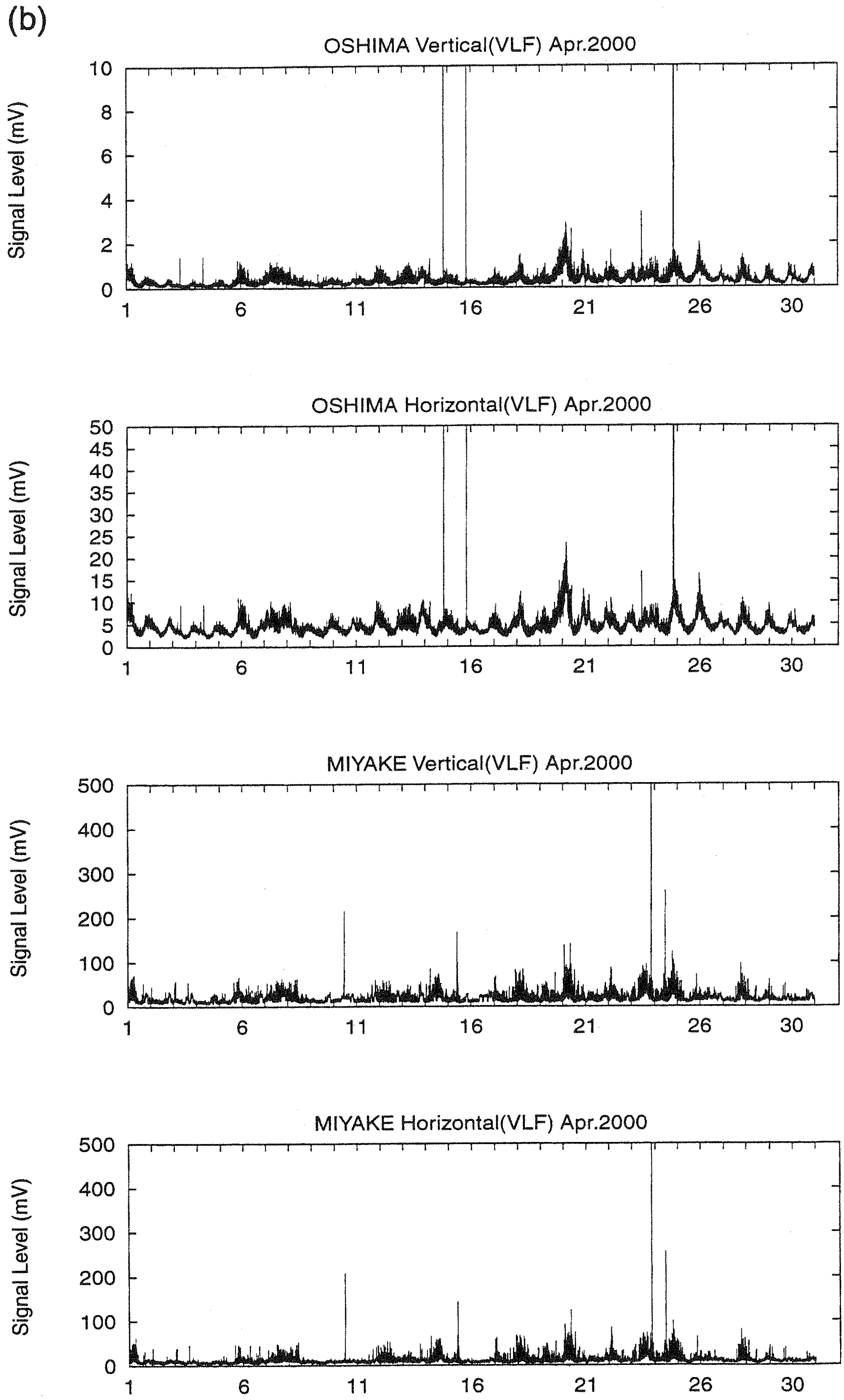


Fig. 11 ELF/VLF signal levels at Izu-Oshima and Miyake-jima for the horizontal and vertical components.



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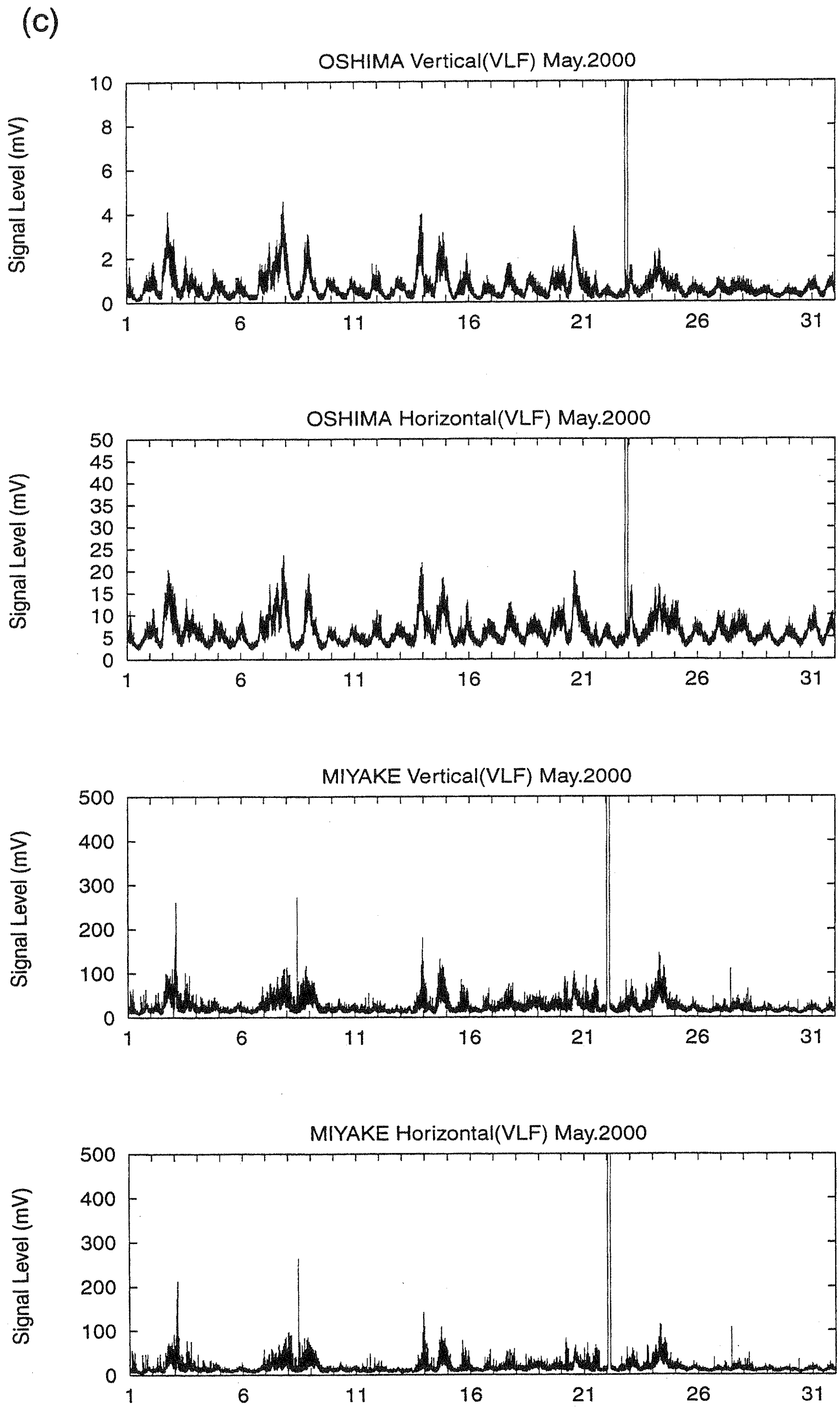

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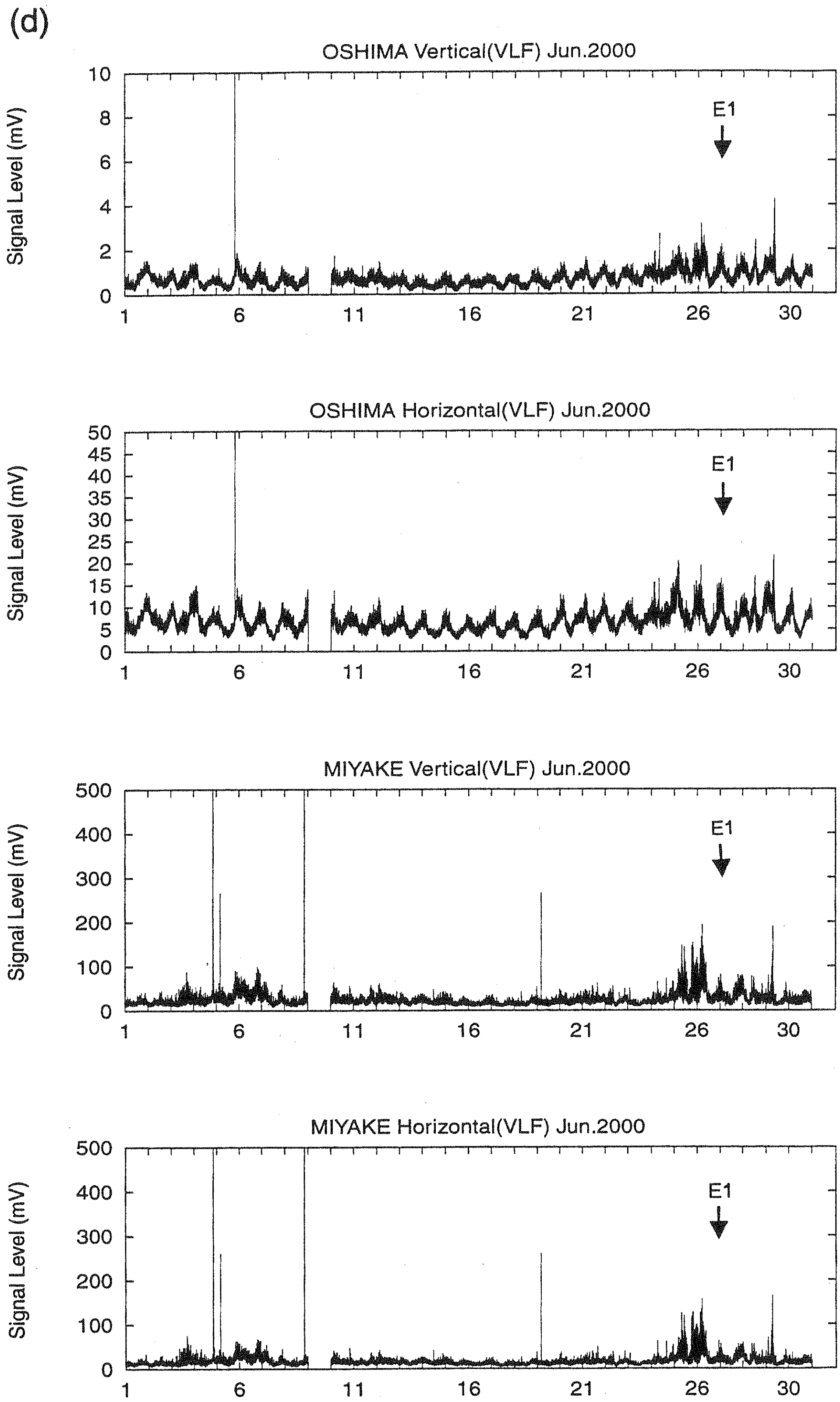

Fig. 11 ELF/VLF signal levels at Izu-Oshima and Miyake-jima for the horizontal and vertical components.

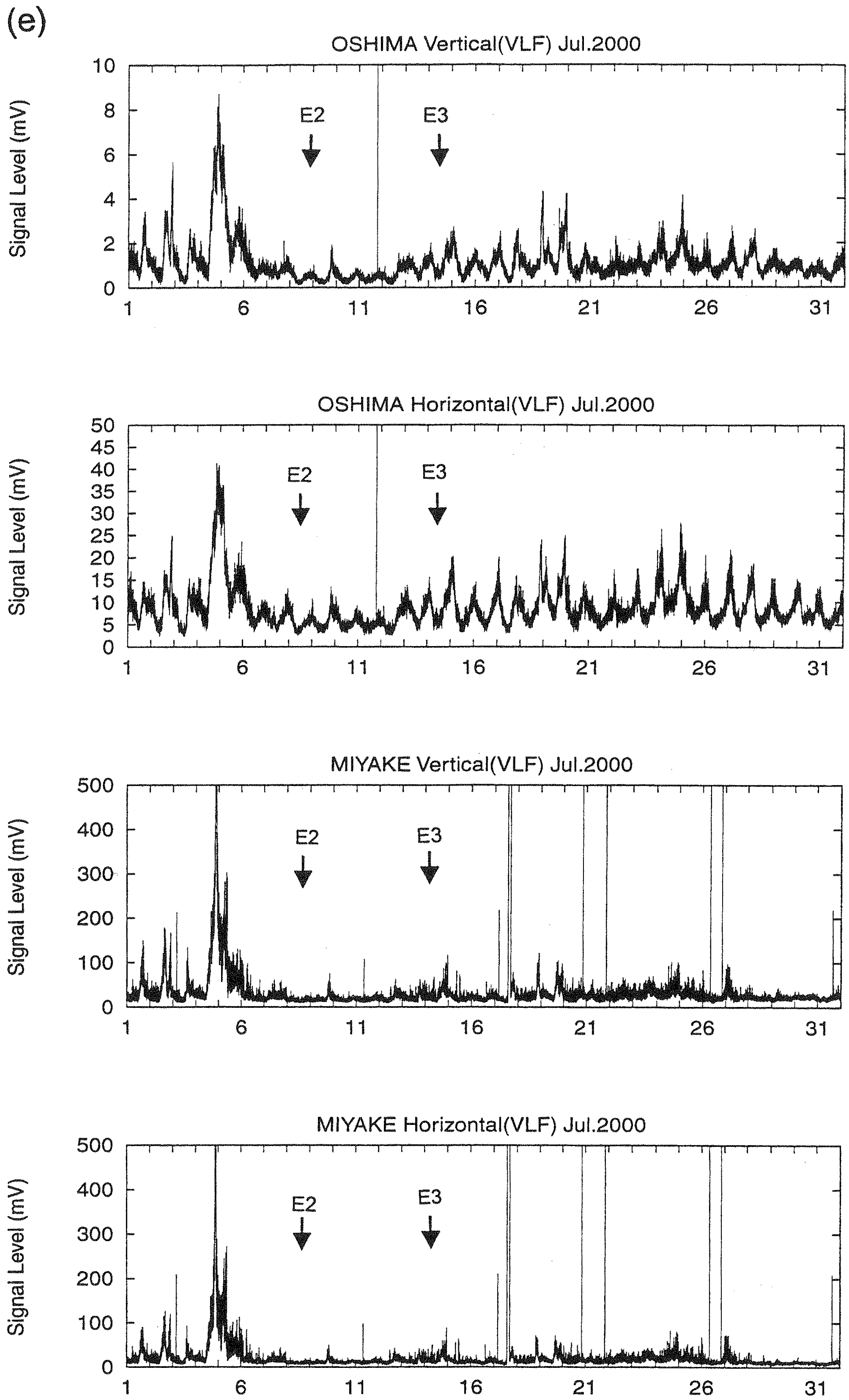

Fig. 11 ELF/VLF signal levels at Izu-Oshima and Miyake-jima for the horizontal and vertical components.

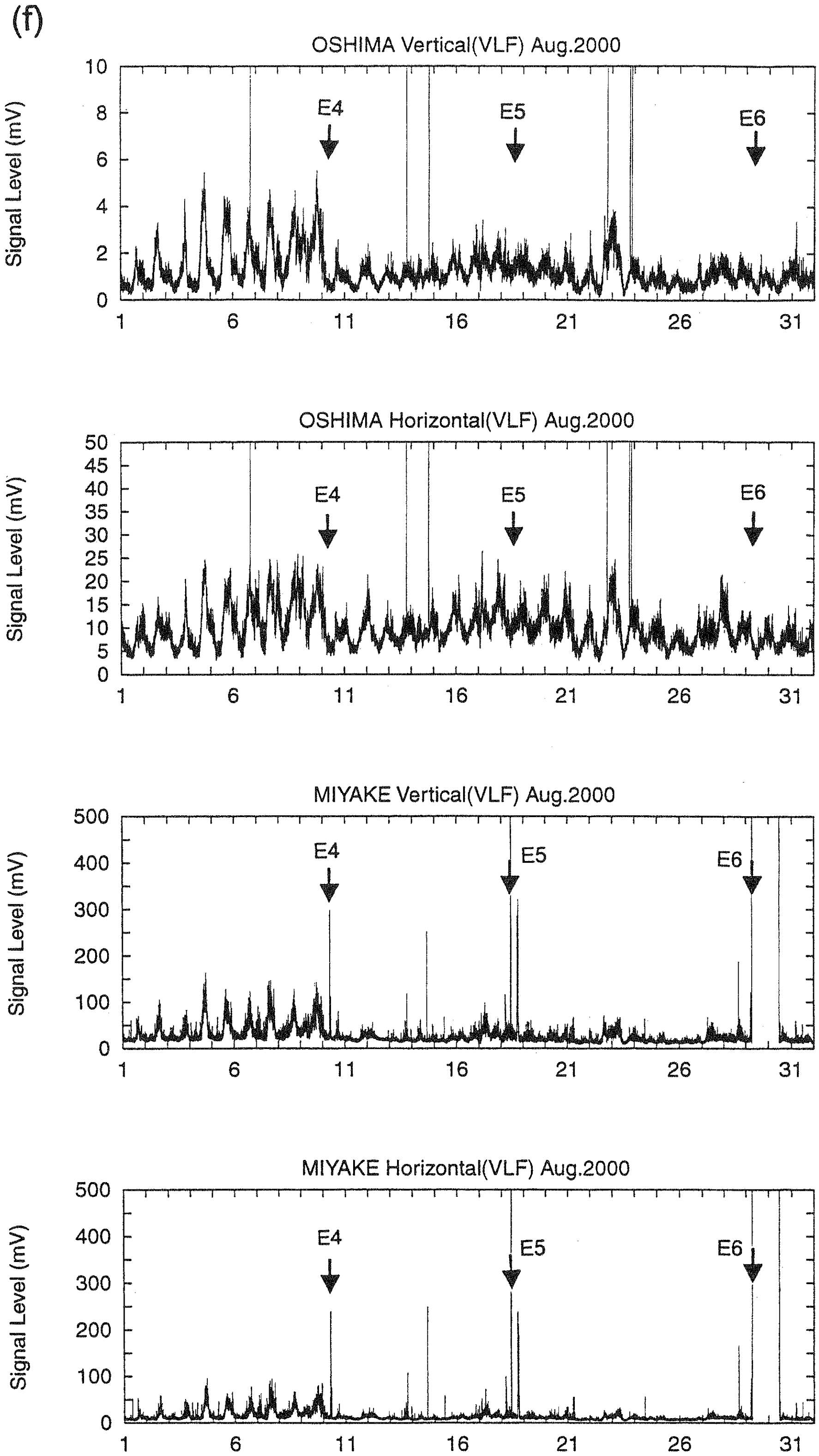

Fig. 11 ELF/VLF signal levels at Izu-Oshima and Miyake-jima for the horizontal and vertical components.

(g)

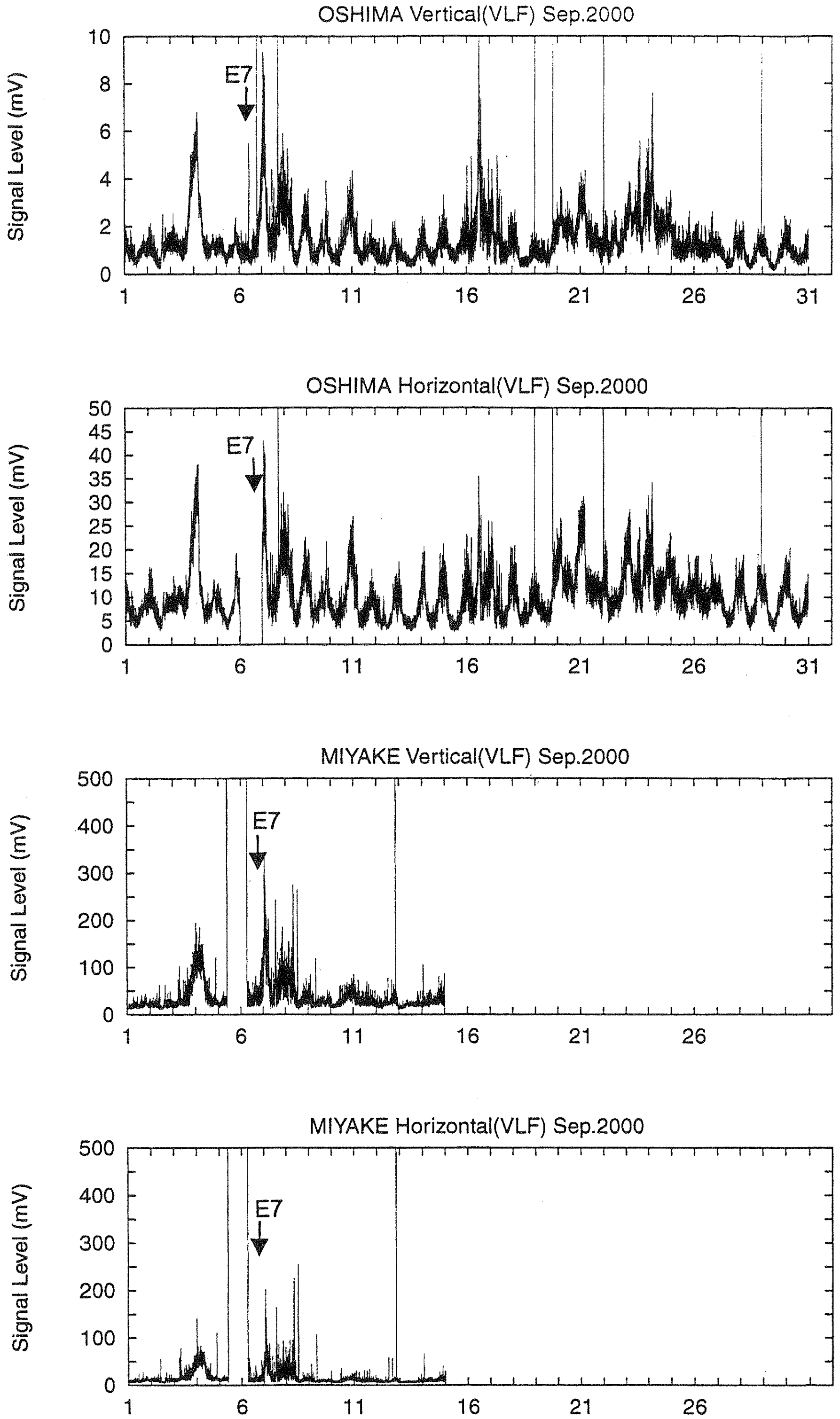

Fig. 11 ELF/VLF signal levels at Izu-Oshima and Miyake-jima for the horizontal and vertical components.