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Survey of anomalous Schumann resonance phenomena observed in Japan, in possible association with earthquakes in Taiwan

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Abstract

The observation of ELF Schumann resonances in Nakatsugawa, Japan has suggested the presence of anomalous behavior in Schumann resonances (that is, the main point is the enhancement at the fourth (or the third) harmonic) at Nakatsugawa, and we have indicated that those anomalies in the Schumann resonances at Nakatsugawa are highly likely to be associated with the large earthquakes in Taiwan. This paper is intended to provide the statistical significance of those Schumann resonance anomalies in possible association with earthquakes in Taiwan on the basis of the ELF observation during the period from the beginning of 1999 to the end of 2004 (6 years). With the criterion of the magnitude greater than 5.0, there were observed 33 earthquakes in and around Taiwan, and the Schumann resonance anomaly is observed for 9 earthquakes (so that the anomaly percentage will be 9/29 (because no observation for 4 earthquakes)). Twenty nine earthquakes included 7 earthquakes in the land, while other 22 earthquakes took place in the sea. It is surprising that anomalous Schumann resonances are observed prior to all the land earthquakes. Two sea earthquakes from the 22, had the anomalous Schumann resonances, but these two earthquakes had the following characteristics (one was the largest magnitude, and another, the shallowest). The paper discloses the causative link between the anomalous Schumann resonances and earthquakes in Taiwan. Especially, the land earthquakes with large magnitude are found to trigger the anomalous Schumann resonances.

Keywords: Schumann resonance; Earthquakes; Precursory signature; ELF observation

1. Introduction

Different kinds of electromagnetic phenomena have been found to take place prior to an earthquake (Hayakawa and Fujinawa, 1994; Hayakawa, 1999; Hayakawa and Molchanov, 2002), and there has been a general concensus that seismic effects occur not only in the lithosphere, but also in the atmosphere and ionosphere (e.g. Hayakawa et al., 2004).

The present paper is concerned with the Schumann resonance phenomenon and its anomalous behavior in possible association with earthquakes. The ionospheric perturbations have been definitely found by means of subionospheric VLF/LF propagation (Gokhberg et al., 1989; Hayakawa et al., 1996; Molchanov and Hayakawa, 1998; Shvets et al., 2004). This subionospheric VLF/LF propagation anomaly suggests the presence of perturbations in the lower ionosphere. The upper ionosphere (F layer or so) can be monitored by means of bottomside sounding (in terms of foF2 values) and of TEC measurements (Liu et al., 2000; Pulinets and Boyarchuk, 2004). An additional new method has been recently suggested here to study the seismo-ionospheric perturbations. Though it is known that Schumann resonances are natural electromagnetic phenomena (Nickolaenko and Hayakawa, 2002), their frequency spectra are known to be very stable, so that it may be possible for us to use them as a possible means to study the seismic effect of the atmosphere and lower ionosphere, just like in the case of subionospheric VLF/LF waves. Hayakawa et al. (2005) have discovered, for the first time, anomalous

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behavior (the main point is an enhancement at the fourth harmonic) in Schumann resonances observed in Japan, in possible association with the Chi–chi earthquake in Japan, and their paper was based on case studies for a few events.

So, this paper is a further study following our previous paper (Hayakawa et al., 2005). This paper is based on a survey during six years in order to statistically confirm the link between the anomalous Schumann resonance phenomena with earthquakes in Taiwan.

2. Observation of ELF waves at Nakatsugawa and earthquakes in Taiwan

The details of ELF observation at Nakatsugawa in Gifu prefecture have been given in Ohta et al. (2001) and Hayakawa et al. (2005). The important point of our observation is that we perform the waveform measurement continuously (with sampling frequency of 100 Hz) and that we measure, simultaneously, three magnetic field components (B_x, B_y (horizontal) and B_z (vertical)).

As is shown in our new paper by Hayakawa et al. (2005), abnormal behavior in Schumann resonances are observed in possible association with the Chi–chi earthquake in Taiwan. So, that we try to perform the survey on the occurrence of Schumann resonance anomalies with relation to earthquakes in Taiwan. We have examined the earthquakes with magnitude greater than 5.0 in and around Taiwan during the sufficiently long-term period of six years from January 1999 to August 2004, including a few events as already discussed in Hayakawa et al. (2005).

Table 1 shows the total events of earthquakes in Taiwan during the above-mentioned six years. As many as 33 earthquakes are found, and those earthquakes are plotted in Fig. 1. The event number is given in Fig. 1, which corresponds to that in Table 1. In Fig. 1 there are two types of circles (one is a red circle with white character and another, a white circle with black character). The first group indicates the earthquake event accompanied by the Schumann resonance anomaly, while the second group refers to the earthquake event without Schumann resonance anomaly.

3. Anomaly in Schumann resonance phenomena as observed at Nakatsugawa

Hayakawa et al. (2005) have already made the detailed description of anomaly in Schumann resonances as

Table 1
Summary of earthquakes in Taiwan during 1999–2004 and the anomaly in Schumann resonances

No.	Date	Time (JST)	Epicenter		Magnitude	Depth (km)	Schumann resonance	Land or sea
			Geographic latitude (N)	Geographic longitude (E)				
1	1999/2/22	22:49	24.2	122.3	5.9	50	No observation	S
2	1999/5/7	10:03	25.0	122.1	5.3	70	0	S
3	1999/6/4	1:11	24.6	122.5	5.3	70	0	S
4	1999/9/21	2:47	23.9	120.9	7.7	30	1	L
5	1999/9/21	2:57	24.0	121.0	5.8	84	1	L
6	1999/9/21	3:11	23.8	121.0	5.8	90	1	L
7	1999/9/22	9:15	24.1	120.8	6.4	30	1	L
8	1999/9/26	8:53	23.9	121.0	6.6	40	1	L
9	1999/11/2	2:53	23.3	122.1	6.3	0	1	S
10	2000/6/11	3:24	23.8	120.8	5.7	10	1	L
11	2000/7/16	12:22	20.5	122.4	6.6	10	0	S
12	2000/9/10	17:55	24.1	121.5	6.0	10	1	L
13	2000/9/17	8:04	24.0	122.5	5.4	50	No observation	S
14	2000/12/13	5:33	23.9	122.5	5.6	10	0	S
15	2001/6/13	22:18	24.5	122.5	5.7	70	0	S
16	2001/6/14	11:35	24.5	121.9	6.2	40	0	S
17	2001/11/24	14:47	25.9	122.2	5.1	210	0	S
18	2001/11/29	16:34	24.4	122.2	5.2	40	0	S
19	2002/2/12	12:27	23.9	121.7	5.9	10	No observation	S
20	2002/3/31	15:53	24.2	122.0	7.0	20	1	S
21	2002/5/15	12:46	24.4	121.9	6.9	40	0	S
22	2002/5/29	1:45	24.2	122.0	6.0	60	0	S
23	2002/6/14	5:40	24.5	122.0	5.5	50	0	S
24	2002/7/11	16:36	24.0	122.2	6.1	30	0	S
25	2002/8/29	2:06	22.3	121.8	6.1	10	0	S
26	2002/9/1	14:56	24.3	122.1	6.1	60	0	S
27	2002/9/1	16:07	24.0	122.4	5.7	20	0	S
28	2002/9/15	10:07	24.1	122.4	5.3	30	No observation	S
29	2003/6/9	10:53	24.5	121.8	6.3	30	0	S
30	2003/6/10	17:40	23.6	121.7	6.3	30	0	S
31	2003/12/10	13:38	22.8	121.7	6.7	10	0	S
32	2004/2/4	12:24	23.5	122.1	5.7	70	0	S
33	2004/6/4	11:24	23.5	122.0	5.6	20	0	S

Fig. 1. Location of earthquakes (with magnitude grater than 5.0) in and around Taiwan red circle with white character (earthquake event number) indicates that this earthquake is accompanied by the Schumann resonance anomaly. White circle with black character, refers to the event without Schumann resonance anomaly.

observed at Nakatsugawa in possible association with earthquakes in Taiwan. Please refer to this paper for further details, but we repeat the important points here.

(1) The fourth harmonic of the Schumann resonance is strongly enhanced as the most significant difference from the conventional case. The conventional spectra show that the resonance intensity is decreasing with the resonance number ($n = 1$ is strongest, and the intensity decreases with increasing n), but the anomaly is characterized by the unusual increase in amplitude of the fourth Schumann resonance mode. This anomaly appears about one week before the earthquake.
(2) A significant frequency shift of its peak frequency ($\sim$1.0 Hz) from the conventional value on the By magnetic field component which is sensitive to the waves propagating in the NS meridian plane.

We have checked the Schumann resonance anomaly two weeks before and two weeks after an earthquake. The analysis result is summarized in Table 1. We explain each column in Table 1. The first column indicates the number of earthquake event, the second and third columns indicate the date and time of earthquake occurrence (in Japanese Standard Time (JST) (JST = UT+9 h)). The third and fourth columns refer to the geographic coordinates of the epicenter. The fifth and sixth, indicate the magnitude and depth of the earthquake. The next column (indicated by SR, Schumann resonance) indicates the situation of Schumann resonances in Nakatsugawa. "No observation" means that no observation was made, and "0" indicates no anomalous Schumann resonance phenomena, while "1" indicates the presence of anomalous Schumann resonance phenomenon. The last column refers to the situation on the earthquake; that is, S means that the earthquake took place in the sea, while L stands for the earthquake in the land.

Fig. 2(a)–(f) indicates the summary of the temporal evolution of the earthquakes in Taiwan and the corresponding observation of anomalous Schumann resonance pheno mena. Fig. 2(a) is the result for the year of 1999, Fig. 2(b), 2000, Fig. 2(c), 2001, Fig. 2(d), 2002, Fig. 2(e), 2003, and Fig. 2(f), 2004. In these figures, the period of no data is plotted in Fig. 2 as a blue sine at the fourth row. The magnitude of the earthquake is indicated in the line of earthquake, and anomalous Schumann resonance is illustrated by Sch4 (this means the anomalous enhancement at the fourth harmonic) and in one case, the anomaly appears in the third harmonic (Sch3). When there is no indication on the line of Sch4, it means that there is no effect (i.e., corresponding to 0 in Table 1). We explain the situation by taking as example the first event in Fig. 2(b). The earthquake event number is given by #11, so that you can find the relevant earthquake information in Fig. 1 and in Table 1. The earthquake magnitude is given by 5.7. The pink box on the line of Sch4 means that an anomaly is observed in the fourth harmonic (that is, 1 in the second column from the right in Table 1). On the contrary, for the next earthquake (#12) in Fig. 2(b), there is no pink box on the line of Sch4, which means that no anomaly is observed at the fourth Schumann resonance.

4. Summary and discussion

Summarizing the results in Table 1 and Fig. 2, 33 earthquakes took place in and around Taiwan with magnitude

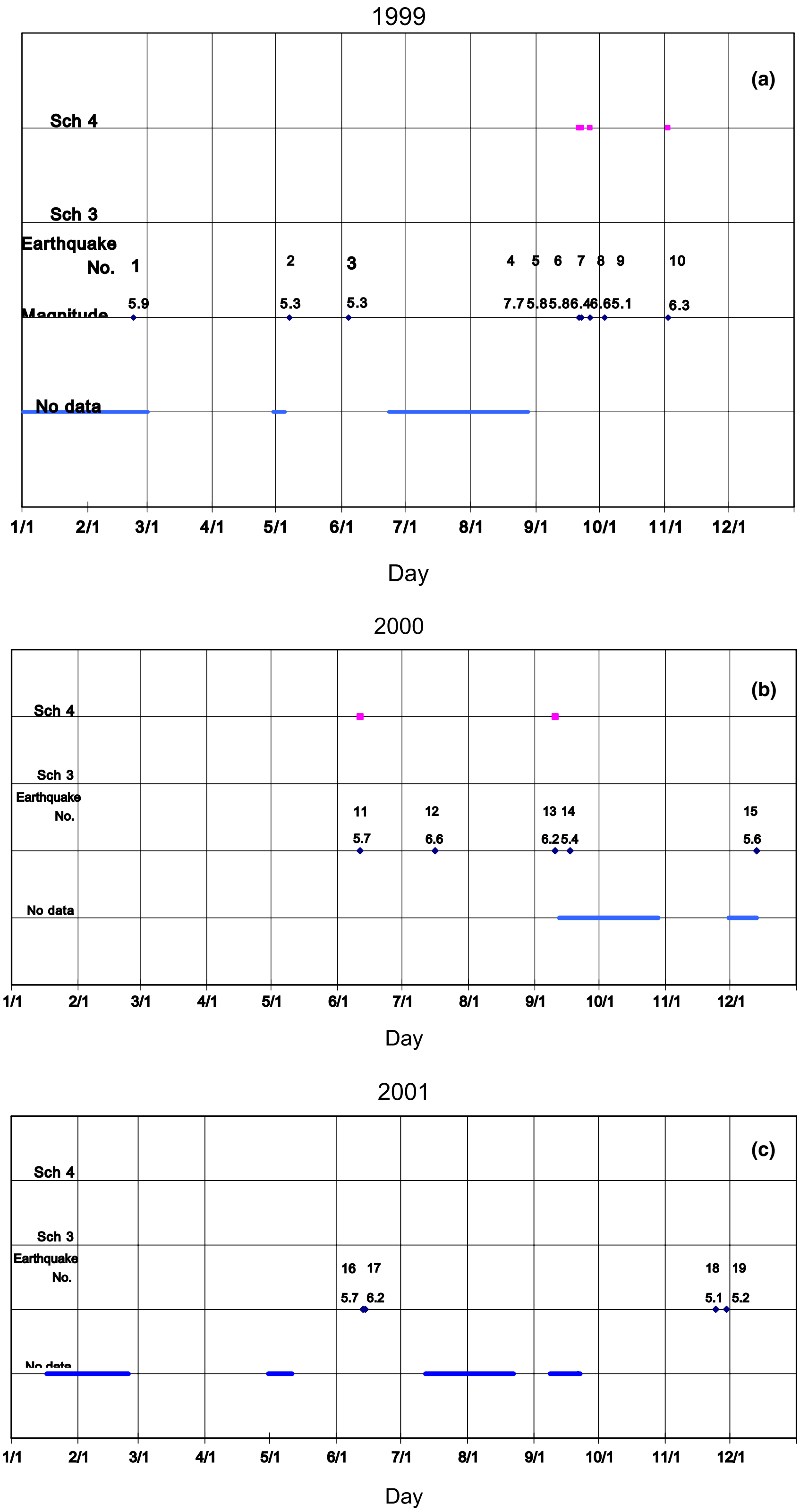

Fig. 2. Summary of temporal evolution of earthquakes in Taiwan and the corresponding Schumann resonance data at Nakatsugawa. (a) 1999, (b) 2000, (c) 2001, (d) 2002, (e) 2003 and (f) 2004. The first bottom line gives us the information on the ELF observation. When the observation is not performed, there is an indication of blue period, while the observation is going on for other periods with no special indication. The second line from the bottom gives the information on earthquake in Taiwan (earthquake event number and the magnitude). Sch4 and Sch3 give the information on the anomalous Schumann resonance phenomena at Nakatsugawa. When we have a box on Sch4, this means that we have observed an anomaly on the fourth harmonic. When there is no box, it means that there is no anomaly at the fourth harmonic. The same meaning for Sch3. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

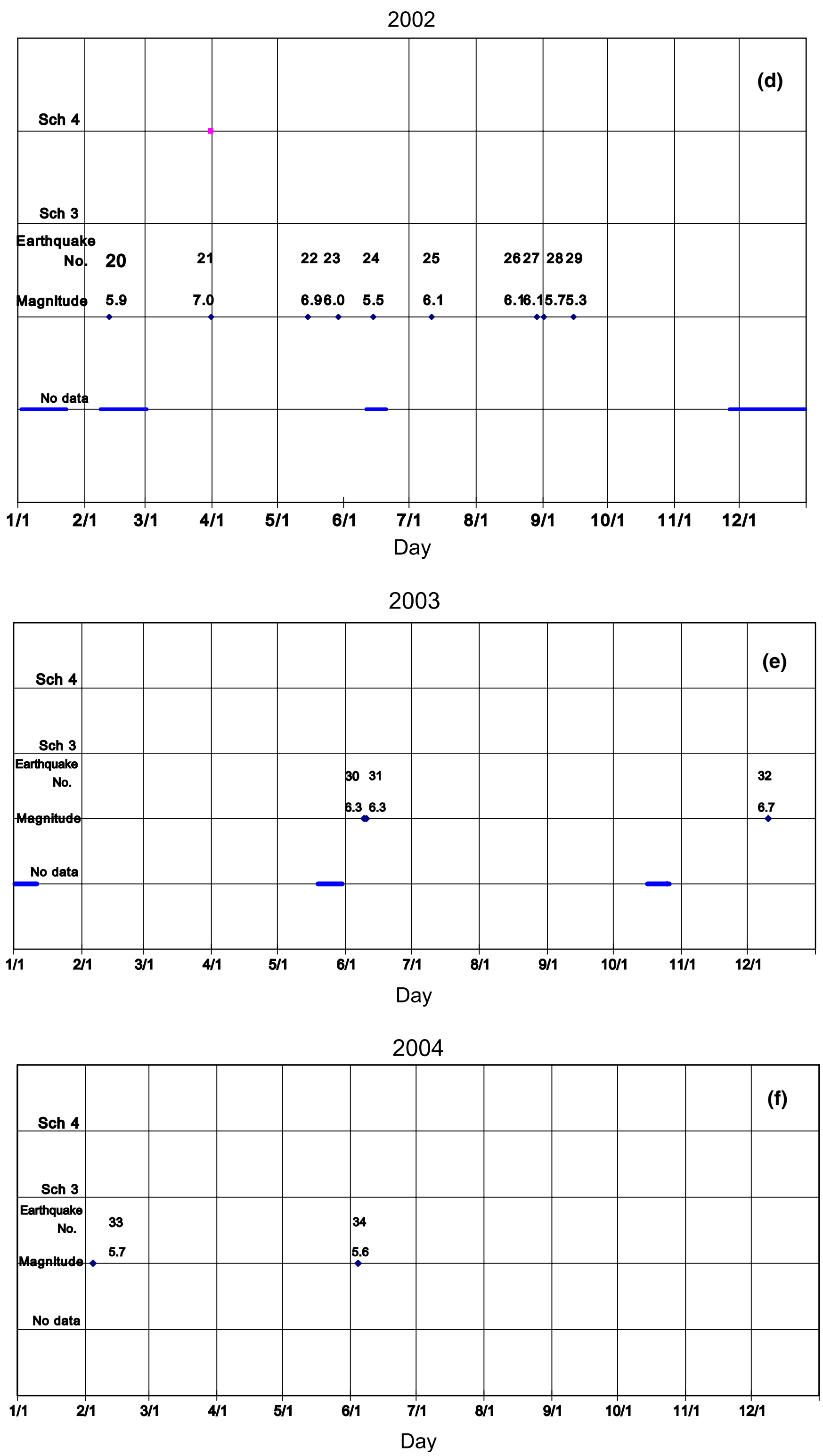

Fig. 2 (*continued*)

greater than 5.0, but no measurement of Schumann resonances could be made for the four earthquakes in Taiwan. So that, we treat 29 earthquake events in Taiwan. Among 29 earthquakes, there are 7 inland earthquakes, and other 22 took place in the sea. The following important points have emerged from the analysis.

(1) The merit of this paper is in rare presentation of a series of anomalous Schumann resonance data observed in regular fashion when an earthquake takes place in Taiwan. This suggests a convincing link between the anomalous Schumann resonances at Nakatsugawa and the earthquakes in Taiwan.

(2) All of seven inland earthquakes are found to have been accompanied with the anomalous Schumann resonances observed in Nakatsutawa. The anomaly takes place always prior to an earthquake (about one week before the earthquake).
(3) Only two from the 22 oceanic earthquakes, are found to be accompanied by the Schumann resonance anomaly. These two (No. 9 and 20 in Table 1 and in Fig. 1) will be examined in more details. No. 9 had the following peculiarity in the sense that the depth of No. 9 is the shallowest among the 22. And No. 20 had the largest magnitude among the 22.

As the conclusion, there is a convincing causative link between anomalous EM data and earthquakes in Taiwan. We can say that the anomalous behavior in Schumann resonance is always observed in Nakatsugawa for the large and inland earthquakes in Taiwan. Then, it is found that even the earthquake taking place in the sea can trigger the anomalous Schumann resonances when its magnitude is either extremely large, or extremely shallow.

In our previous paper by Hayakawa et al. (2005), we have suggested a possible mechanism of such an anomalous behavior in Schumann resonances: that is, the possible noise source in the South American zone, and an additional conducting disturbance over Taiwan lead to the scattering of ELF waves as observed in Japan (a kind of wave interference effect). It is further confirmed that the abnormal additional ionization is taking place over Taiwan for all of the large inland earthquakes with magnitude greater than 5.0 and for a few oceanic earthquakes with either shallow depth or with large magnitude, with judging the behavior in Schumann resonance anomaly.

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