ANOMALOUS EXCITATION OF SCHUMANN RESONANCES ASSOCIATED WITH HUGE EARTHQUAKES, CHI-CHI (CHINA, 1999) NIIGATA-CHUETSU (JAPAN, 2004), NOTO-HANTOU (JAPAN, 2007), OBSERVED AT NAKATSUGAWA IN JAPAN

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Abstract. There are two kinds of methods to estimate a precursory signature of earthquakes by means of electromagnetic waves. The direct method is measuring emissions from a hypocentral region. An example of this method is ULF/ELF electromagnetic emission because its propagation loss in the ground is very low. Another method can be called “indirect method”, by measuring the change in amplitude and/or phase of VLF - VHF subionospheric propagation due to the change in the ionosphere disturbed by the energy from the epicenter. VLF/VHF signals are used in order to study the anomaly in their propagation. Observing and analyzing these two methods (direct and indirect) are very important to prove the generation mechanism of electromagnetic anomalies associated with earthquakes. We have carried out the ULF/ELF observation at Nakatsugawa in Japan (35°25’ N, 137°32’ E in Gifu Prefecture near the foot of Mt. Ena). In this station, we have observed ULF/ELF electromagnetic emissions as the “direct method”, and we have observed the Schumann resonance as the “indirect method”. We have observed and analyzed anomalous excitation of Schumann resonances possibly associated with the 1999 Chi-Chi earthquake (M7.6) in Taiwan. After this earthquake, we observed anomalous excitations of Schumann resonances before large earthquakes, Mid-Niigata Prefecture earthquake (2004, M6.8), Noto-Hantou earthquake (2007, M6.9) in Japan. We present further experimental results on these excitations in this paper.

1. Introduction

The research of Schumann resonance as a precursor of the earthquake has been reported in 1980’s (Schumann, 1952, Maki and Ogawa, 1983). To observe and analyze seismogenic effects by two methods (direct and indirect) is very important to elucidate the generation mechanism of electromagnetic anomalies associated with earthquakes. We have carried out the ULF/ELF observation at Nakatsugawa in Japan (Geographic lat. 35°25’ N, long. 137°32’ E in Gifu Prefecture near the foot of Mt. Ena). In this station, we have observed ULF/ELF electromagnetic emissions as the “direct method (Hayakawa 1999, Molchanov et al., 2001)”, and we have observed the intensity changes of Schumann resonance as the “indirect method (Hayakawa et al., 1996, Ohta et al., 2000)”. We observed the anomalous electromagnetic emissions before large earthquakes at the Nakatsugawa station (Ohta et al., 2006). We have observed anomalous excitation of Schumann resonances before the 1999 Chi-Chi Earthquake (M7.6, depth 10km), main shock occurred at L.T. 02:47 (L.T.=U.T.+9) on September 21, 1999 (Hayakawa et al., 2005), and have performed a statistical study on the anomalous effects in Schumann resonances in Nakatsugawa for large earthquakes in Taiwan (Ohta et al., 2006). In this paper we will present further observational results on abnormal effects in Schumann resonances and additional resonances at Nakatsugawa for a few large earthquakes in Japan.
2. Observation system and excitation of Schumann resonances on the 1999 Chi-Chi earthquakes

We have three orthogonal induction coils (1.2 m permalloy) as magnetic sensors and we observe simultaneously three magnetic field components (Bx: north-south direction, By: east-west direction and Bz: vertical direction). The signals detected by the sensors are amplified by means of pre-amplifiers with the low pass filter (with cutoff of 30 Hz) and they are fed to main-amplifiers. Then the signals are digitized by means of an A/D converter with sampling frequency of 100 Hz, and they are stored on a hard disc every six hours. The details of our ULF/ELF observation system have already been described in Ohta et al. (2001). Signal analysis is based on the FFT with the data length of 1024, so that the temporal resolution is about 10 seconds and the corresponding frequency resolution is about 0.1 Hz. We can measure the amplitude ratio and phase difference among the three components in the frequency range from 0 Hz to 50 Hz. In this observation system, we can estimate from the phase difference between Bx and By whether the observed signal has been propagated over the long distance or short distance. For example, if the phase differences of electromagnetic signals are concentrated around ±180° or 0°, we can understand that these signals have been propagated over longer distances as compared with their wavelength. We can also estimate the direction of electromagnetic signals from the ratio of amplitudes of Bx and By (Hayakawa and Ohta, 2006). However, our induction coils are short (1.2 m), so that there should be direction errors (up to 10°) due to some inaccuracy in installations of the coils. Schumann resonance is the global electromagnetic resonance phenomenon excited by lightning discharges in the cavity formed by the Earth surface and the ionosphere (Schumann, 1952; Nickolaenko and Hayakawa, 2002). The frequency of the fundamental mode is approximately 8 Hz (fundamental mode: n=1) and the frequencies of higher modes are approximately 14 Hz (second mode: n=2), 20 Hz (third mode: n=3), 26 Hz (fourth mode: n=4), and so on. The frequencies of these modes are known to be so stable that the fluctuation is only about 0.2 Hz because of the propagation characteristics and conditions (Nickolaenko and Hayakawa, 2002).

Figure 1. A sonogram of By on September 1-30 in 1999.

Figure 2. The change of intensity of n=4 (26.36 - 26.56 Hz) before and after earthquakes.
But the intensity of each resonant mode depends on the intensity of lightning activities and the distance between the lightning source and the observatory (Hayakawa et al., 2005). Figure 1 illustrates an example of the dynamic spectra (sonograms) of By components during September 1 through October 1, 1999. The vertical axis is the frequency from 0 Hz to 50 Hz, and the intensity is plotted in color. Figure 2 shows the change of intensity of $n=4$ (26.36-26.56 Hz) before and after Chi-Chi earthquakes in September 1999. The rise-up of the intensity ($n=4$) seems precursor phenomena for huge earthquakes. The earthquakes occurred near Taiwan area (lat 20.5°N-26.0°N, long. 119.0°E-122.5°E) with magnitude greater than M5 from 1999 to 2004 were 29 events in number. The earthquakes occurred in land were 7 events, and these 7 earthquakes accompanied precursor phenomena, excitation of Schumann resonances. On the other hand the earthquakes in sea were 22, and only 2 events accompanied excitation of Schumann resonances. Among these 2, one is the biggest earthquake, and another one is the nearest from the land.

3. Anomalous resonance before the 2004 Mid-Niigata Prefecture earthquake

The 2004 Mid-Niigata Prefecture earthquake (M6.8, depth 20km) occurred at 17:56 L.T. on October 23, 2004. The anomalous resonance was observed during the period from the afternoon on October 20 to the morning on October 22. Figures 3 shows the largest anomalous resonance on the By and the Bx components, respectively, observed at 18:00 – 23:55 L.T. on October 20, 2004, three days before the earthquake. There are two strong resonances in the $n=3$ frequency range in both By and Bx components. In both components, the intensity of these two resonances changes simultaneously.

Firstly, we have analyzed the strong resonance (upper one of the two strong resonances in Fig. 3, Marked with “$n=3$”) of the By component. We have tallied the strongest intensity (dB) and the frequency (our frequency resolution is 0.097 Hz) at that time at every period (our temporal resolution is 10.24 sec) during the six hours in Fig. 3. The maximum intensities are located at 20.60 Hz, 20.70 Hz, and 20.80 Hz. The intensity is gradually attenuated by the increase and decrease of the frequency from these median frequencies.

![Fig. 3. Excitation of Schumann resonances at 18:00-23:55 on Oct. 20, 2004 (By component).](image)


![Figure 4. Occurrence number of phase difference between By and Bx at 20.60Hz-20.80Hz.](image)
We have analyzed further the characteristics of emissions at these median frequencies (20.60 Hz, 20.70 Hz, and 20.80 Hz). Figure 4 is the histogram of phase differences between By and Bx at those median frequencies. The phase differences are centered around ±180°, therefore we understand that this resonance is a linearly polarized wave and propagated over longer distances (Hayakawa et al., 2007). So, we can conclude this resonance is identified as Schumann resonance (n=3).

![Phase difference histogram](image)

Fig. 5. Occurrence number of phase difference between By and Bx at 16.11Hz, 16.21Hz, and 16.30Hz shown “A” in Fig. 3.

Next, we have analyzed another strong resonance (lower one, marked with “A”) in the same way. Figure 5 illustrates the distribution of the frequency with the maximum intensity of the lower strong resonance shown in Fig. 4. The median frequencies of maximum intensity of this resonance are 16.11 Hz, 16.21 Hz, and 16.30 Hz, and these frequencies are about 2 Hz higher than the typical frequency of n=2 (14 Hz). Figure 5 is the histogram of phase differences between By and Bx at these median frequencies (16.11 Hz, 16.21 Hz, and 16.30 Hz), which exhibit a nearly flat distribution over the phase difference and which is completely different from Fig. 4. Since this resonance has a different median frequency and a different polarization from the conventional Schumann resonance, it seems that this resonance might be due to a generation mechanism different from the Schumann resonance.

The phase difference has almost a homogeneous distribution over the phase difference. We can conclude that this resonance might be generated by a mechanism different from the usual Schumann resonance. Therefore it is considered that they are likely to be generally locally or relatively close to the observation station and might be due to a different generation mechanism from Schumann resonance. However, it is very interesting that the temporal changes of intensity of resonances are almost the same between the anomalous Schumann resonance (n=3) and another anomalous resonance.

4. **Anomalous resonance before the 2007 Noto-Hantou earthquake**

![Spectrum](image)

Figure 6. Excitation of Schumann resonances at 06:00-11:55 on 25 Mar., 2007.

The anomalous resonance was observed during the period from the afternoon on March 24 to the morning on March 31.

Figures 6 shows the largest anomalous resonance of the Bx component observed at 06:00 – 11:55 L.T. on March 25, 2007, just before and after the earthquake. There is a strong anomalous resonance in Bx component marked with “C”, but there is no obvious anomaly in By component differently from the case of the 2004 Mid-Niigata Prefecture earthquake. Therefore we make a histogram of phase differences between By and Bx at the all frequency ranges from 19.53 Hz to 21.48 Hz. It is just the same as Figure 4. We can conclude this resonance is usual Schumann resonance (n=3).

Next we analyzed the distribution of the frequency with the maximum intensity of anomalous strong resonance of Bx component, marked with “C”. The median frequencies of maximum intensity are 18.06 Hz, 18.16 Hz, and 18.26 Hz, which are about 2 Hz lower than the typical frequency of Schumann resonance (n=3), being the same as the case of the 2004 Mid-Niigata Prefecture earthquake. The phase difference between By and Bx at the median frequencies (18.06 Hz, 18.16 Hz, and 18.26 Hz) is the same as Fig.5.

As mentioned above, the temporal changes of the intensity of the anomalous resonances are almost the same between the anomalous Schumann resonance (n=3: 20 Hz) and another anomalous resonance (16.21 Hz and 18.35 Hz). Let us suppose that the intensity change of these anomalous resonances (20 Hz, 16.21 Hz, and 18.35 Hz) was precursor of the earthquake and caused by the propagation anomaly in the ionosphere and/or atmosphere disturbed by any energy source from the epicentral region.

In the case of the 2007 Noto Hantou earthquake, the third mode of the Schumann resonance is not so strong and the bandwidth is broad. This Schumann resonance arrived from the broad direction centered at 20° - 25° by goniometer method. On the other hand, the anomalous resonance at the frequency centered at 18.16 Hz has a strong intensity and a narrow bandwidth, and its resonant frequency is 2 Hz lower than the conventional frequency of n=3. This anomalous resonance is found to be very similar to the anomalous resonance observed before the 2004 Mid-Niigata Prefecture earthquake (lower strong resonance shown in Figure 3).

However, the generation mechanism of this anomalous resonance is quite unknown and there is no convincing theory at the moment to explain both cases of the 2004 Mid-Niigata earthquake and the 2007 Noto Hantou earthquake. However, there exists one possible generation mechanism of these anomalous ULF-ELF resonances (Sorokin et al., 2003).

5. Conclusion

We have observed the anomalous excitation of the Schumann resonances possibly associated with earthquakes since 1999 at Nakatsugawa station in Gifu prefecture in Japan (Hayakawa, et al., 2005; Ohta et al., 2006). In this paper we analyzed the anomalous Schumann resonance and an additional anomalous resonance observed before the 1999 Chi-Chi earthquake, the 2004 Mid-Niigata Prefecture earthquake and the 2007 Noto Hantou earthquake. The characteristics of anomalous resonances are:
1. The intensity of a particular mode of the Schumann resonance increased before the large earthquake near the observation station, and decreased after the occurrence of earthquake.
2. An excitation of another anomalous resonance was also observed at the frequency shifted by about 2 Hz from the typical frequency of the Schumann resonance. This anomalous resonance had a high Q factor and a strong intensity.
3. Since the temporal changes of the intensity of the anomalous Schumann resonance and another anomalous resonance were almost the same, there is a possibility that another anomalous resonance was closely related with the Schumann resonance. However, we need to consider any convincible generation mechanism of anomalous resonances in future.
4. There is a possibility that another anomalous resonance was received at Nakatsugawa as the induced magnetic field from the epicentral region (Sorokin et al. 2003). However, these anomalous resonances
were always detected only at one component (Bx component or By component).

To solve these characteristics of anomalous resonances, the multipoint simultaneous observation is absolutely necessary. We have established new observation stations at Shinojima in Aichi prefecture and at Minami-Izu in Shizuoka prefecture and have already started the preliminary observation. We expect to acquire new information by our new observation network in near future in order to have better understanding of the anomalous seismogenic effect.

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References


Ohta K., K. Umeda, N. Watanabe, and M. Hayakawa (2001), ULF/ELF emissions observed in Japan, possibly associated with the Chi-Chi earthquake in Taiwan, Natural Hazards and Earth System Sciences, 1, 37-42.

Ohta K., N.Watanabe, and M.Hayakawa (2006), Survey of anomalous Schumann resonance phenomena observed in Japan, in possible association with earthquakes in Taiwan, Physics and Chemistry of Earth, 31, 397-402.

Schumann W. O. (1952), On the free oscillations of a conducting sphere which is surrounded by an air layer and an ionosphere shell, Z. Naturforschung, 7a, 149-154.