Study on the temporal variation and regional differences of Schumann Resonance based on observations from an extremely low frequency electromagnetic network in China

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SUMMARY

Based on 10 years of quasi-continuous data from extremely low-frequency (ELF) electromagnetic stations, the temporal and spatial variations of Schumann resonances (SR) were analyzed. Three major parameters were obtained: peak intensity, peak frequencies, and the Q factor, determined through Lorentz fitting of the electromagnetic (EM) auto-spectrum. The focus was on their seasonal and inter-annual variations, as well as regional differences in the first three modes at the stations. Fengning station, seasonal variations of SR parameters were exemplified, with intensity peaking in the northern hemisphere's summer and reaching a minimum in winter, while frequency exhibited an inverse phase. The range of these parameters from summer to winter also varied. The Q factor, however, did not show significant seasonal variation. Inter-annual variations across 10 stations revealed a more consistent pattern in the magnetic field than in the electric field. Seasonal variations of SR parameters were primarily influenced by the periodic intensity changes and migration of lightning activities, corroborated by global observations. Additionally, strong links between SR parameters and the 11-year solar cycle were confirmed through comparisons with the El Niño index and solar X-radiation flux, with enhanced intensity during the 2015/2016 super El Niño event.SR exhibited significant spatial distribution differences across different stations. The amplitude differences, especially in the horizontal electric field components, ranged from ten to a hundred times. Despite this, the amplitude variation range (difference between the highest and lowest values) was relatively uniform, about half an order of magnitude. Magnetic field component amplitude tended to increase with latitude. The mean and median frequencies across different stations were quite similar, but the variation range differed, with Ex and Hy showing larger variations and Ey and Hx showing smaller variations. The overall Q factor distribution was fairly uniform, with minor differences between different modes and components.

Keywords: Schumann Resonance, ELF stations, temporal variation, regional differences

INTRODUCTION

In 1952, the German physicist Schumann predicted the existence of electromagnetic resonance between the conductive Earth's surface and the lower boundary of ionosphere, known as "Schumann resonances" (hereafter abbreviated as SR) (Schumann, 1952). The source of SR is the lightning activity produced during thunderstorms, which could generate a frequency-rich electromagnetic field that propagates through space. When the wavelength of electromagnetic waves is comparable to the circumference of the Earth, standing waves form within the cavity, increasing the strength of the electromagnetic field at 7.8, 14.2 and 21 Hz (Nickolaenko and Hayakawa, 2014). The existence of SRs was first confirmed by Balser and Wagner (1962) in 1960 through experimental observations. To date, many electromagnetic observation sites have been established worldwide to observe SRs, including in Antarctica (The Ukrainian station) and the Arctic Circle, where electromagnetic interference is low. The background characteristics of SRs have been well studied, but observations of longer than 5-year durations remain scarce worldwide (Nickolaenko et al., 2015; Satori et al., 2005;) and in China, fewer stations have obtained observations for SRs. In this paper, we analyze the quasi-continuous data from 10 electromagnetic stations over the last 10 years to obtain the common aspects concerning SR long-term periodic variations and spatial distribution differences across different stations.

ELF NETWORK IN CHINA

The first EM observation network, consisting of 30 magnetotelluric(MT) stations, was built in 2013 in China (as shown in Figure1). The stations were equipped with ADU-07e, from Metronix, Germany, with Pb-$PbCl_2$ electrode as the electrical signal sensor and inductive magnetic coil as the magnetic sensor and natural source electromagnetic field is observed in wide frequency range of 0.001-1000 Hz, so the information about the SR band (3-45 Hz) is included in the MT data. 10 stations with less interference are selected for SR analyses.

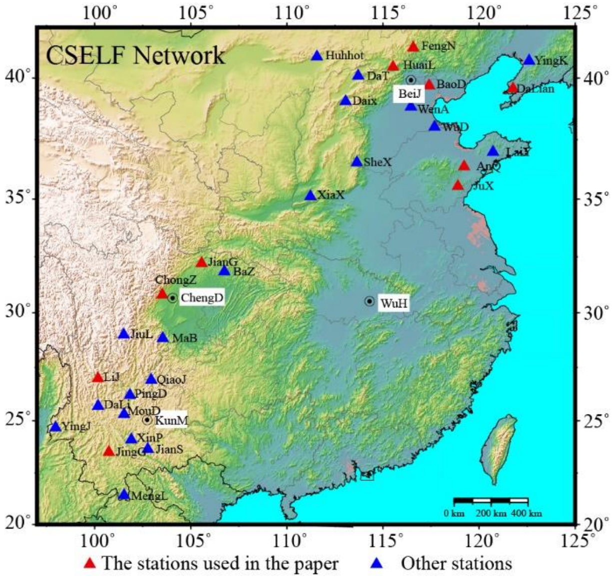

Figure 1: The station distribution map of the ELF network. (The blue and red triangles represent the locations of the stations, and the red triangles represent the stations used in this paper.)

To preliminarily overview the station data recorded by ELF stations, Figure 2 shows the intensity of the two electric field components (Figure 2a) and three magnetic field components (Figure 2b) at Fengning station on 7 October 2014. The first six modes of SR can be clearly observed in the five components (E_{ns}, E_{ew}, H_{ns}, H_{ew}, H_z), peaking at approximately 7.8, 14, 21, 26.5, 32 and 39 Hz.

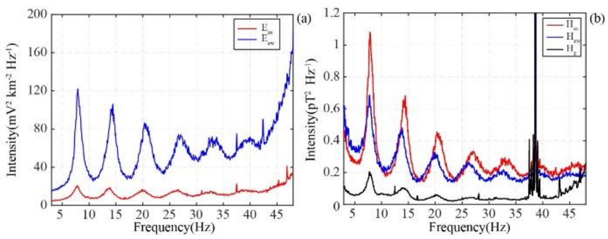

Figure 2. (a) Typical intensity variation of the horizontal electrical components and (b) the magnetic components taken at Fengning station on 7 October 2014. The red, blue and black lines indicate the north-south, east-west, and vertical directions respectively.

SEASONAL AND INTERANNUAL VARIATIONS OF SR

Owing to spatial confinement, we take the Fengning station as an example to discuss the characteristics of the seasonal variation of the 1st mode parameters of SR from 2014 to 2023. Like shown in Figure 3, the seasonal variations in SR intensities of H_{ns} and H_{ew} components in the first modes are remarkably pronounced and synchronous, all reaching a maximum in summer and a minimum in winter, but seasonal variation in the frequency for the first mode is not significant. Conversely, frequencies for the 2nd and 3rd modes have significant seasonal variations, but in the inverse phase to the seasonal variation in the intensity. The Q factor does not exhibit significant seasonal variation characteristics.

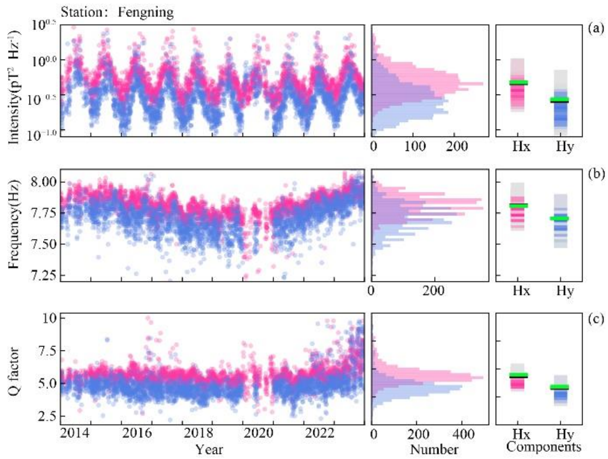

Figure 3. The temporal variation (left panel) and distribution diagram (middle panel) for the frequency of the horizontal electric field of the first three modes of SR at Fengning station from January 2014 to December 2022.

To highlight the inter-annual variability, we used median filter method (window length is set as 61) and then polynomial fitting to outline the changes of the 1st mode of SR parameters of H_{ns} component of 10 stations. Figure 4 illustrates the long-term variation trends of intensity(a), frequency(b), and Q factor(c) of SR in relation to X-ray flux(d) and the El Niño index(e). As shown in the figure, the variation of the SR parameters at all stations has a more uniform variation pattern, gradually increasing to their maximum from the beginning of the observation to 2016 and then decreasing from approximately the 2nd quarter of 2016 to the end of 2021, and then increasing to 2023, synchronizing with the solar activity, and there is an 11-year period, while the long-term variation pattern of the intensity is controlled by the global temperature change, especially the super El Nino phenomenon.

REGIONAL DIFFERENCES OF SR

Figure 4 displays the variation ranges of intensity(a), frequency(b), and Q factor(c) across various stations over a period of ten years. From the figure, it can be observed that there are differences in the amplitudes among different stations, but the range of their variations are similar. The frequency values cluster around the median, but the ranges of variation differ significantly between the two vertical components. The mean and variation ranges of the Q values are fairly similar.

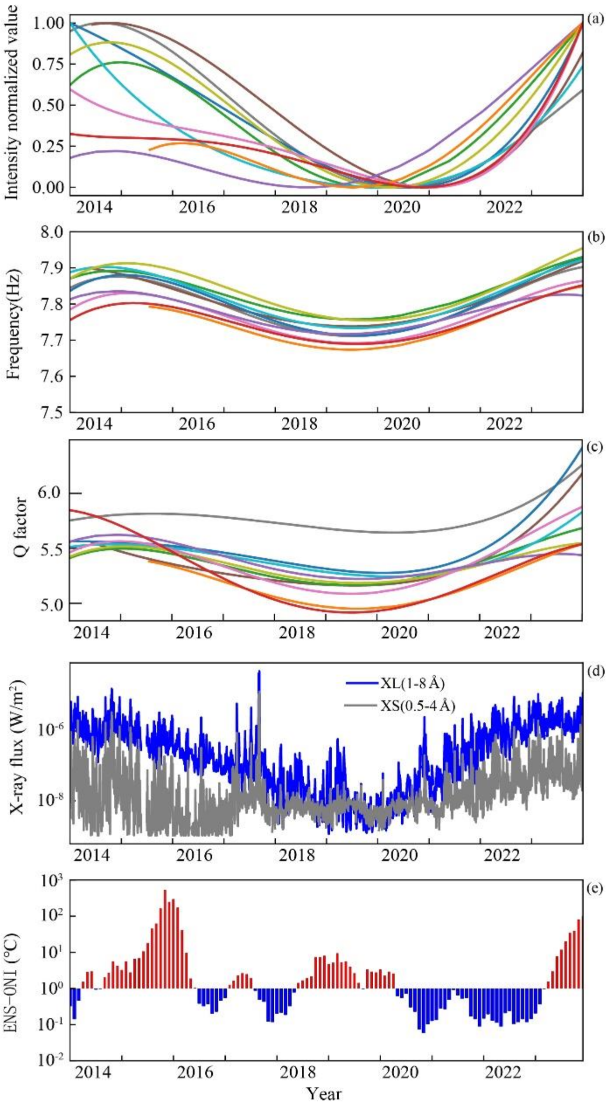

Figure 4. The intensity (a) and frequency (b) and Q factor temporal variation of H_ns component for the first mode of SR at 10 stations and solar X-ray flux (c) and ENS-ONI index (d)

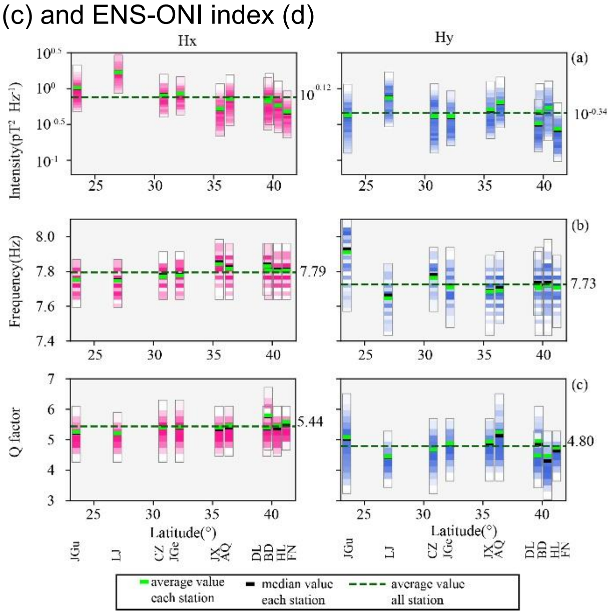

Figure 5. The range of the intensity (a) and frequency (b) and Q factor (c) of H_{ns} ,and H_{ew} component for the first mode of SR at 10 stations

Conclusions

1) A clear seasonal variation in the SR parameters can be observed, and the main reason for the annual variation in the SR intensity is the seasonal variation in the lightning activity intensity, while the migration of the lightning source location is the main reason for the seasonal variation in the frequency.
2) The interannual variation in the SR intensity, frequency and Q factor is synchronous with the solar activity, and there is an 11-year period, while the long-term variation pattern of the intensity is controlled by the global temperature change, especially the super El Nino phenomenon.
3) Due to the location and the local ionosphere diurnal variation and the reginal electrical structure of the stations the reginal differences exist.

Acknowledgements

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