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Variability of Schumann resonance parameters observed at low latitude stations in China

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Abstract

This paper presents a comprehensive analysis of the Schumann resonance (SR) parameters observed at low latitude stations in China for the first time. Variations of SR peak frequency and intensity on different timescales (from minutes to years) are analyzed in detail. Diurnal and seasonal variations are shown and the source-observer distance is calculated to confirm the contributions of lightning activity. Differences in the profiles of SR intensity between the NS and EW components are due to the effects of the source-observer distance and the relative position of the observer to the sources. Diurnal frequency variations are more complicated and cannot be directly linked with the three thunderstorm centers. Seasonal variations are clear for intensity but not for frequency. The differences in the diurnal and seasonal variations between the SR intensity and frequency show that the greatest contributor to SR intensity is global lightning activity, while the SR frequency is not affected solely by lightning, as certain other factors involving ionosphere properties may play non-negligible roles. We also emphasize that our observations do not show a distinct day–night change in the SR parameters, and that the SR intensity does not show abrupt changes across terminators. This observation is consistent with previous simulations. Finally, the response of the SR to a solar flare is discussed. The flare leads to a sudden increase of about 0.2 Hz relative to the 2σ level of the SR frequencies in the first three modes, which is in agreement with other works in the literature. This frequency enhancement is explained using theoretical calculations.

Keywords: Schumann resonance parameters; Lightning; Diurnal and seasonal variations; Flare response of Schumann resonance

1. Introduction

Schumann resonances (SR) are electromagnetic resonances excited by global lightning activity which propagate in the cavity formed by Earth's surface and the lower ionosphere (Nickolaenko and Hayakawa, 2002; Schumann, 1952). They have peak frequencies for the first four modes at 7.8, 14, 20 and 26 Hz (Balser and Wagner, 1960). It is commonly recognized that variations of the SR parameters are caused by global lightning activity and properties of the cavity's boundary. SR measurements are mainly used to study global lightning distributions (Ando and Hayakawa, 2007; Shvets et al., 2010). Because lightning is linked with the Earth's climate, it has been suggested that the SR can be used as a sensitive indicator of temperature fluctuations and water vapor (Price, 2000; Sekiguchi et al., 2006; Williams, 1992). Moreover, SR can be used to research the lower ionosphere, which may be affected by regular solar radiation on different timescales as well as solar activity such as solar proton events, solar flares and solar X-ray bursts (Roldugin et al., 2001, 2004b; Sátori et al., 2005; Schlegel and Füllekrug, 1999; Williams and

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Sátori, 2007). Recently, anomalous SR phenomena have been reported as possibly being associated with major earthquakes (Hayakawa et al., 2005; Ohta et al., 2006; Ouyang et al., 2013b; Zhou et al., 2013b), and this may be a prospective precursor for short-term earthquake prediction. In addition, SR may exist on other planets with the conducting ionosphere and surface, such as Titan, Venus, and Mars, which suggests that SR may be useful for studying extraterrestrial lightning (Nickolaenko and Rabinowicz, 1982; Nikolaenko and Rabinovich, 1987; Pechony and Price, 2004; Price et al., 2007; Sentman, 1990; Yang et al., 2006). Along with ground-based observations of SR, electric field measurements by the C/NOFS satellite at the altitude of 400–850 km exhibit SR signatures. These measurements indicate a leaky cavity and show that extremely low frequency waves can penetrate into the ionosphere. Consequently, it suggests a new remote sensing for atmospheric electricity on Earth and on other planets (Simões et al., 2011).

Since the SR is studied in many scientific fields, understanding the variability of the SR signal is important for interdisciplinary research. Publications concerned with variations of SR parameters at particular stations are focused on two aspects. One is the variations on different timescales which originate from changes in the lower ionosphere. The other is related to the regular diurnal and seasonal variations of the SR parameters.

Changes in the lower ionosphere can lead to variations in the SR parameters. A few studies present evidence of the effect of the day–night asymmetry of the ionosphere (Melnikov et al., 2004; Sentman and Fraser, 1991). Diurnal variations of SR intensities in horizontal magnetic components at widely separated sites in California and West Australia were found to be modulated by the D region height (Sentman and Fraser, 1991). However, theoretical simulations with a uniform cavity show that the local diurnal intensity modulation is similar to that obtained by Sentman and Fraser, which indicates that local diurnal intensity variations cannot be induced by ionospheric height changes (Pechony and Price, 2006). Analysis of SR measurements at three mid-latitude stations suggests a significant influence by the terminator on SR parameters (Melnikov et al., 2004). SR records from mid-latitude and north polar stations show changes in SR amplitude around local sunrise and sunset (Sátori et al., 2007). Nevertheless, modeling results confirm the low impact of terminators on SR amplitude (Pechony et al., 2007; Yang and Pasko, 2006). Other studies focus on the effects of enhanced ionization in the lower ionosphere during solar X-ray bursts and high-energy particle precipitation. The first two mode frequencies are found to increase by some tenths of a Hertz accompanying X-ray bursts at two high latitude stations in Russia (Roldugin et al., 2004b). Similarly, the SR frequency in different modes increased during the X-ray burst, and the SR frequency varied in phase with X-ray flux variations during the 11-year solar cycle, as shown by SR measurements from mid-latitude and south polar stations (Sátori et al., 2005). During high-energy particle precipitation, the SR frequency increased and the damping decreased in the first mode, as seen in observations from a south polar station (Schlegel and Füllekrug, 1999). SR records at high latitude stations show that the SR frequency decreased by several tenths of a Hertz during solar proton events and increased during the preceding X-ray bursts (Roldugin et al., 2001, 2003).

There have also been many studies of the regular diurnal and seasonal variations of the SR parameters. Diurnal and seasonal SR frequency variations in the vertical electric component observed for more than one year at a mid-latitude station show different patterns for three modes (Sátori, 1996). Moreover, based on four years of measurements of three components (B_{NS}, B_{EW} and E_V) at a mid-latitude station, the long-term diurnal and seasonal variations of three SR parameters show that the dominant intensity maxima in diurnal variations are related to lightning activity in Southeast Asia, Africa and South America. The frequency and Q-factor variations are complicated and not easily explained (Price and Melnikov, 2004). Using more than four years of data on the vertical electric component from the Modra observatory at a mid-latitude region, peak frequency variations for low SR modes are attributed mainly to the source-observer distance effect (Ondrášková et al., 2007). Diurnal and seasonal variations of the SR frequency and amplitude from two years of measurements in China show that the frequency and amplitude have a strong relationship with lightning activity in Asia. Further simulation results show that the diurnal and seasonal variations in the SR frequency and amplitude are mainly affected by the migrations of global lightning activity, rather than the day–night asymmetry in the ionosphere (Zhou et al., 2013a). Background features in the SR frequency and intensity observed in China are presented around the equinoxes and solstices, and differences between the two magnetic components are noticed (Ouyang et al., 2013a).

Ionosphere-induced variations in the SR parameters are confined to reports based on records at mid-latitude and polar stations. Variations in the SR parameters at low latitude stations are still poorly represented in the literature. Although Zhou et al. (2013a) published a paper about the diurnal and seasonal variations of the SR parameters observed in China, they did not present variations in the SR parameters caused by changes in the lower ionosphere, such as terminator influences and solar X-ray bursts. In addition, earlier studies noted that the SR parameters in different horizontal magnetic components are not the same, but there is still no thorough comparison of the SR parameters of the NS and EW components, particularly in the Asian sector. In this paper, low latitude SR measurements of the horizontal magnetic components in southwestern China are used to investigate the variability of the SR parameters. We present a detailed comparison of the SR parameters of different horizontal components on regular