Study of the statistical footprint of lightning activity on the Schumann Resonance

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Abstract

The Schumann resonance is an electromagnetic phenomenon, a product of lightning activity inside the earth-ionosphere cavity. Five years of Schumann resonance records are analyzed by a novel methodology that segments the records into time intervals and finds the probability distribution that best describes each segment. Then patterns are extracted from the resulting time series and compared against known patterns of global lightning activity to further test the power of the methodology under study.

The Quality of Fit indices show how over 95% of the segments analyzed are properly described by the distribution that fit them best. The relationship between global lightning activity and the number of segments identified as Gaussian emerges clearly. A link between Laplacian segments and local lightning activity is explored as well. This presents transient statistical fitting as an alternative for characterizing complex phenomena by identifying different segments with a probability distribution, then identifying circumstances that segments with the same distributions have in common.

This study further validates the chosen analysis tool, showing its capacity to offer information on the activity of thunderstorms in the time segments analyzed from the Schumann resonance data. It presents an additional source of information that complements the usual techniques used to study the signal in the frequency domain.

Introduction

The electromagnetic resonant signal known as the *Schumann Resonance* (SR), which has a fundamental mode of 7.8Hz is a subject of study due to its central role in the electric circuit of the Earth (Williams and Mareev, 2014) and especially its relationship with atmospheric and climate phenomena. The work by Williams (1992) on which the relationship between global temperature and the intensity of the first mode was discovered is an extensively cited example. Numerous works have studied different geophysical factors through SRs, such as the state of the resonant cavity itself (Surkov et al., 2013), extracting models of the atmospheric conductivity profile (Nickolaenko et al., 2016, Kudintseva et al., 2018), tracking climate phenomena such as El Niño Southern Oscillation through SR records (Yang and Pasko, 2007, Williams et al., 2021), and finding evidence of SR variations related to other climate phenomena such as the Madden-Julian oscillation (Beggan and Musur, 2019). Studies on transient events have also been performed, such as the impact of solar flares (Shvets et al., 2017), gamma rays (Nickolaenko et al., 2012), volcanic eruptions (Nickolaenko et al., 2022, Bór et al., 2023), and especially earthquakes (Hayakawa et al., 2005, Gazquez et al., 2017, Figueredo et al., 2021), whose interest has grown in recent decades.

Despite the considerable number of factors that influence SRs, it is well established that the phenomenon that produces the frequency response of the earth-ionosphere cavity is lightning discharges around the globe (Ogawa et al., 1969). Global lightning activity is generally detected using the *Very Low Frequency* (VLF) range (Ogawa and Komatsu,

2010). In the *Extremely Low Frequency* (ELF) range, thunderstorm discharges are studied by their relationship to SR (Price, 2016). Alpha stable distributions are a common choice to represent this phenomena (Chrissan and Fraser-Smith, 2000) since they are the tool of choice in telecommunications (Volland, 1995). They are especially useful for analyzing radio electric noise in a wide range of frequencies and under different conditions Lamey et al. (2021). Models have also been proposed that solve the inverse problem of deducing the amount of lightning activity from the SR records by providing approximate solutions (Heckman et al., 1998, Nickolaenko et al., 1998). Annual variability in SR records is also a subject of study, with some analyses indicating additional links to lightning activity (Domingo et al., 2021). As a consequence, the signal patterns caused by lightning are well known.
The behavior of lightning activity in specific zones is still a topic of interest (Xu et al., 2022). Especially for each of the three thunderstorm centers (Nieckarz et al., 2009, Ouyang et al., 2015), which are the regions of the globe with the highest concentration of lightning activity, located in South America, Africa and Asia, specifically in the maritime continent. There are works in which the activity of one (Dyrda et al., 2014) or all (Prácser et al., 2019) thunderstorm centers is characterized, using different techniques with promising results.

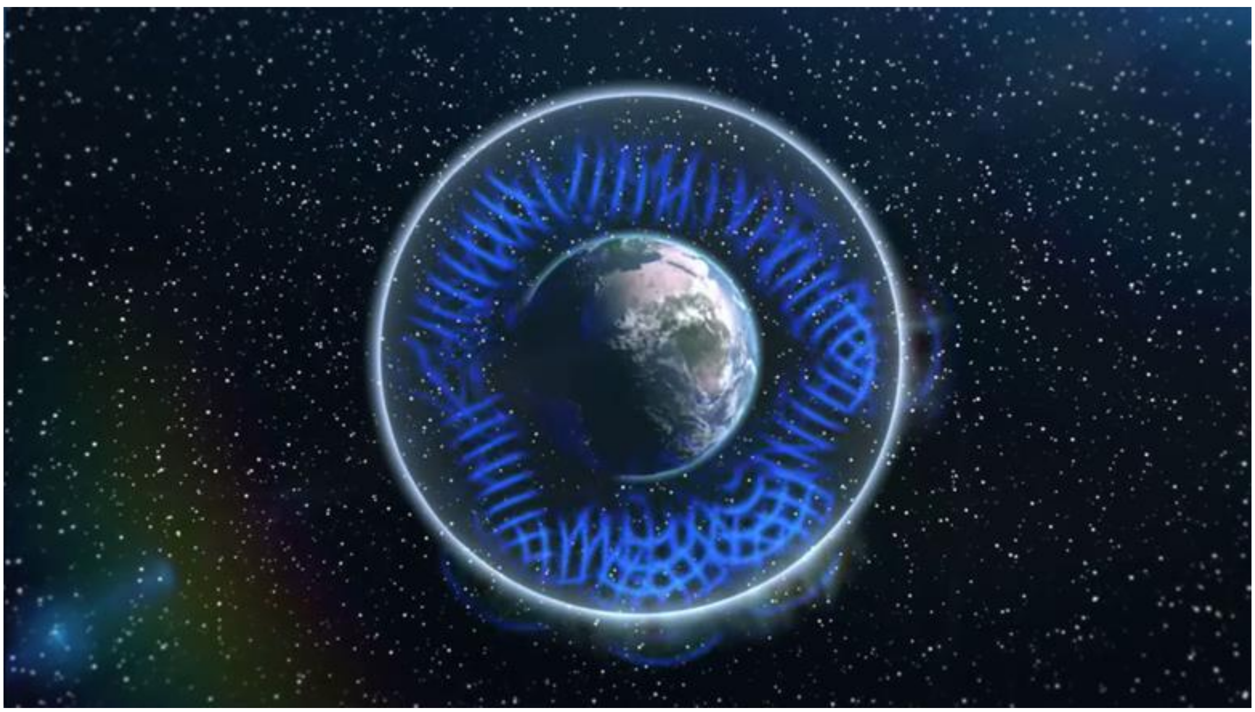
There is abundant literature on the relationship between lightning activity and SR from different perspectives, such as mathematical modeling (Nickolaenko, 1997, Pechony and Price, 2004), experimental studies relating SR measurements and lightning activity (Price, 2016, Tatsis et al., 2021), and computer models to simulate its signal or key aspects (Kudintseva et al., 2017, Perotoni, 2018, Ralchenko et al., 2015). More recently, data-driven approximations have been taken, applying forecasting methods (Cano-Domingo et al., 2023, Tulunay et al., 2008) based on neural networks of specific purpose (Cano-Domingo et al., 2022, Tulunay et al., 2004). However, the many different events that influence the SR have prevented the scientific community from providing an accurate model that takes into account every situation. Most analytical solutions are developed for the ideal case, and even if more advanced, computer-based models may produce a satisfactory response, they are mostly focused on presenting the ELF background noise under unchanging variables The point to be made is that, despite the advances provided by the scientific community in the field, SR is a complex phenomenon affected by many natural and artificial events, and modeling it faithfully is a daunting task.

Most ELF studies are based on data extracted from the frequency domain, with only a few notable exceptions (Nieckarz et al., 2009, Ogawa and Komatsu, 2009, Nickolaenko et al., 2000, Cano-Domingo et al., 2022, Gowanlock et al., 2018). We recently presented a publication based on time domain analysis using statistical methods (Soler-Ortiz et al., 2021). The philosophy behind the method is to divide the time records into segments, fit each segment to a simple model, and extract conclusions about the signal state depending on the chosen model. The idea is not new in the domain of electromagnetic signals (Alata et al., 2013). Some studies have worked to statistically characterize ELF noise (Evans and Griffiths, 1974) with the purpose of using the band for communications. Close to our previous work is the study by Chrissan and Fraser-Smith (2000), in which the best model for impulsive atmospheric noise is tested, considering different bandwidths among the ELF and VLF frequency ranges. This work use amplitude probability distributions described in terms of voltage deviation, which rely on a great amount of data to produce a faithful model but disregarding completely the temporal aspect, and also chooses the statistical model that showed the best performance on each band. On the other hand, our previous study focused on the 0 Hz to 100 Hz band and specifically in the 6 Hz to 40 Hz range where the SR gathers most of its power and works under a different paradigm. The methodology we developed finds the statistical model among a set of chosen distributions that showed the best fit for each segment. Its most interesting contribution is how the distribution that best fits the segment varied depending on the time interval from which the sample was taken, hinting a qualitative relationship between the state of the atmosphere and the chosen model.

This article expands on the relationships described in Soler-Ortiz et al. (2021), testing the advantages and capabilities of the developed technique. To do so, the analysis technique has been applied to five years of SR data. The resulting in-depth analysis establishes further relationships between the classification provided by the analysis and the known facts and patterns on SR and lightning activity. This will be done by comparing the known patterns of lightning activity with the of segments per day associated with a specific distribution.

With this methodology, a direct way to identify segments where lightning activity is detectable from within a large amount of SR records is provided. This, in turn, gives way to the possibility of identifying more processes through their statistical shape, and also provides an additional level of information for the studies on this field and is complementary to the usual frequency-based approaches.

Section snippets



Methodology

The mentioned data comes from the research group's ELF measurement station in Sierra de los Filabres, Almería (Lat 37.22, Long −2.55), with a bandwidth of 100 Hz. The electronic components of the system are thoroughly described in Parra et al. (2015). The station has two sensors, one with orientation *East–West* (EW), while the other is *North–South* (NS) oriented, each reading stored separately in 30 min files on our data server, at the University of Almería. The sampling frequency of the

Results and discussion

In this section, the general results of the analysis will be presented first, as they are compared with the known general behavior of the signal studied. Next, different data aggregations will be shown to inquire about the implications and usefulness of temporal segments' statistical classification. Lastly, *Autocorrelation Functions* (ACFs) will be applied to the resulting data for Gaussian occurrence to compare the patterns displayed by the classified segments with those already known by

Conclusions

For this study, a recently developed methodology has been applied to 5 years of data. Through statistical analysis, expert knowledge of the storm centers' seasonal trends, and of the Schumann Resonance, the latter signal has been segmented and categorized using statistical models. In this article, we consider the implications behind the classification of a specific segment in each model. Through this exploration, the utility of the procedure has been proven. After testing the connections

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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