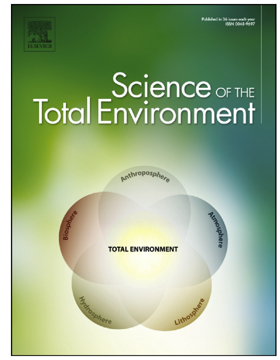
Journal Pre-proof



Schumann resonance and cardiovascular hospital admission in the area of Granada, Spain: An event coincidence analysis approach

Pablo Fdez-Arroyabe, Jesus Fornieles-Callejón, Ana Santurtún, Leonna Szangolies, Reik V. Donner

PII: S0048-9697(19)35808-5

DOI: https://doi.org/10.1016/j.scitotenv.2019.135813

Reference: STOTEN 135813

To appear in: *Science of the Total Environment*

Received date: 15 July 2019

Revised date: 21 November 2019

Accepted date: 26 November 2019

Please cite this article as: P. Fdez-Arroyabe, J. Fornieles-Callejón, A. Santurtún, et al., Schumann resonance and cardiovascular hospital admission in the area of Granada, Spain: An event coincidence analysis approach, *Science of the Total Environment* (2018), https://doi.org/10.1016/j.scitotenv.2019.135813

Schumann resonance and cardiovascular hospital admission in the area of Granada, Spain: an Event Coincidence Analysis approach

Key words: Schumann Resonance; Event Coincidence Analysis; Cardiovascular Disease

Authors Pablo Fdez-Arroyabe(1), Jesus Fornieles-Callejón(2), Ana Santurtún(3), Leonna Szangolies(4), Reik V. Donner(4,5)

(1)University of Cantabria, Department of Geography, Geobiomet Research Group, Santander, Spain.

(2) University of Granada, Department of Electromagnetism and Physics of Matter, Granada, Spain

(3) University of Cantabria, Faculty of Medicine, Physiology and Pharmacology Department, Geobiomet Research Group, Santander, Spain.

(4) Potsdam Institute for Climate Impact Research (PIK) - A Member of the Leibniz Association, Potsdam, Germany

(5) Magdeburg-Stendal University of Applied Sciences, Department of Water, Environment, Construction and Safety, Magdeburg, Germany

Abstract

The study of bio-effects of Schumann resonances is a very complex issue. There is a need to identify mechanisms and pathways that explain how Extremely Low Frequency magnetic fields affect biology or human health. This particular study tries to identify statistical associations between ELF magnetic fields in the province of Granada (Spain) and cardiovascular related hospital admission in the same province for the period April, 1st 2013 to March, 31st 2014. Research is developed under an epidemiological approach based on an Event Coincidence Analysis statistical method. Clustered events, statistically significant (ECA shuffle-surrogate test p= 0.01 and p<0.01), were found for the minimum values of the first and the third Schuman resonances frequency on east-west and north-south directions, and for the amplitude parameter of the second resonance and the total signal energy in the north-south direction. Empirical measurements of SR parameters were recorded at the Sierra Nevada Mountain in Granada province (Spain). Results show a clear coincidence of the events for the minima amplitudes of Shuman resonances and energy in the north-south orientation and the number of the cardiovascular related hospital admissions. Further research is needed with longer temporal series and a new approach based on gender seems to be also interesting for future studies.

1. Introduction

Human health is undoubtedly heavily dependent on the physical and social environments in which human beings develop their daily activities. It is well known that atmospheric processes have an impact on our well-being at multiple scales. Biometeorology, physics, biology, medicine and other scientific disciplines have studied the effects of atmospheric processes on living organisms' health status for decades (Fdez-Arroyabe, 2015).

In a similar spirit, changes in solar and geomagnetic activity have also been associated to physical, biological and health effects (Breus et al., 1996; Cherry, 2002; Stoupel et al., 1993) but factors that cause the impacts have not been identified yet and biophysical mechanisms are still undiscovered.

Atmospheric variables such as air temperature, wind, atmospheric pressure, solar radiation and air humidity, as well as combined biometeorological indices have been frequently used in many experimental and epidemiological studies related to respiratory diseases (such as asthma, allergies, influenza epidemics) and circulatory or mental disorders (Carmona et al., 2016; De Sario et al., 2013; Santurtún et al., 2018; Zhao et al., 2018). Changes and variability of atmospheric parameters are associated, through very complex pathways, to human beings' health.

Nevertheless, atmospheric electric fields are not recorded and have been used relatively few times under this biometeorological approach. The scientific knowledge about extremely low frequency (ELF), magnetic field variations such as Schumann resonances (SR), is particularly scarce.

Schumann resonances were proposed by W.O. Schumann in 1952, and the existence of such signals has been confirmed in mid-1950s (Schumann, 1952; Volland, n.d.) (König, 1974; 1952; Polk, 1982). SR are observed experimentally as peaks in the electromagnetic field spectrum in the ELF band (Balser and Wagner, 1960; Schumann, 1952). The cavity formed by the Earth's surface and the lower ionosphere is continuously excited by lightning generated in the atmosphere. The wavelength of the fundamental mode is related to the Earth's perimeter, resulting in a frequency of 7.8 Hz (first SR). Subsequent modes are found at approximately 14, 21, 28, and 32 Hz. A good theoretical review of SR can be found in (Nickolaenko and Hayakawa, 2014; Price, 2016). The dependence of the SR signal on the lowest regions of the ionosphere was established by initial theoretical models (Tran and Polk, 1979). The energetic emission from the sun (Sátori et al., 2016), the resulting space weather and the associated emergence of geomagnetic storms are important to understand SR.

The SR signal was initially studied due to its strong similarity to the electroencephalogram (EEG) spectrum of the human brain (Adey, 1981). Sharing a specific frequency range in the respective variability made researchers consider resonant absorption was possible. It has been shown (Adey, 1981; Bawin et al., 1973; Bawin and Adey, 1976) that environmental electromagnetic fields in this shared frequency range can significantly alter the cellular calcium ion fluxes and electromagnetic radiation waves in brain tissue. Accordingly, SR have been associated with altered brain activity and reaction times through resonant interactions with neurons involving changed calcium ion signals. Human reaction times were found to be significantly correlated with the intensity of the 8-10 Hz SR signal, (König, 1974).

Solar and geomagnetic activity (S-GMA) has been associated with significant physical and biological effects. A list of examples can be found in (Cherry, 2002). GMA storm events were found correlated with heart attacks incidence rate in 14 large hospitals in St Petersburg for the period 1989-1990 (Ptitsyna et al., 1998). It is important to note that changes in magnetic fields in this case are much higher (100 nT) than for SR.

Geomagnetic disturbances have also been related with blood pressure (Mitsutake et al., 2005) and arrhythmic cardiac activity through the melatonin mechanism (Chibisov et al., n.d.; Frolov et al., 1986; Ghione et al., 1998). Melatonin production has been linked to circadian cycle. Alteration of the melatonin cycle, mainly its reduction, has also been proposed as a potential biophysical pathway to link natural ELF magnetic fields to different impacts on human health (Brzezinski, 1997; Reiter, n.d.; Reiter and Robinson, 1995).

A more recent experiment has studied the influence of a frequency range around the first SR mode on spontaneous contraction, calcium transients and Creatine Kinase release of rat cardiac cells (Elhalel et al., 2019). The main results of this work indicate that extremely weak 7.8 Hz magnetic fields have a protective cardiovascular effect during oxidative stress and hypoxic conditions.

Cardiovascular diseases (CVD) are the main cause of death in the world. In spite of the advances in treatment and management, around 17.9 million people died from CVD in 2016 (representing 31% of all global deaths). The study of the effect of environmental factors on CVD is essential both to advance in the understanding of pathological processes and to address their prevention. In recent years, the importance of some environmental factors, such as temperatures and atmospheric pollutants, in CVDs has been unveiled (Royé et al., 2018; Analitis et al., 2008) from an epidemiological and experimental perspective.

In this line, this work proposed the hypothesis that there is a relationship between some cardiovascular diseases (specifically, conduction disorders and Cardiac Dysrhythmias) and Schuman Resonance.

The present study aims to analyze the relationship between SR and cardiovascular admissions in Granada province (Spain) by making use of Event Coincidence Analysis (ECA) (Siegmund et al., 2017). This research focuses only on the timing of the strongest anomalies in both, hospitalizations frequencies and SR related observational parameters.

2. Data and Method

The province of Granada is located in the South East of the Iberian Peninsula, in the Spanish Autonomous Community of Andalusia. Climate of the capital is type Csa according to the Köppen-Geiger classification (Köppen, 1936). The province of Granada offers big climatic contrast due to its orography and geographic location, having a subtropical climate at the coast, continental-Mediterranean properties in the interior with cold winters and hot summers, and a mountain climate in the area of the National Park of Sierra Nevada. The study period has been defined by the availability of continuous Schumann Resonances measurements, from April 1st 2013 to March 31st 2014.

2.1 Schumann resonances and instrumentation

To detect SR experimentally, it is necessary to measure signals with a high-sensitivity sensor in the ELF band. Schumann resonances show an amplitude around pT (Fornieles-Callejón et al., 2015; Salinas et al., 2016; Toledo-Redondo et al., 2010), immersed in the Earth's static magnetic field, which is roughly seven orders of magnitude stronger. The sensor is so sensitive that it is affected by noise sources that are not usually taken into account for other systems. Mechanical vibrations of any kind, trees moving due to wind, etc., may introduce a significant amount of noise into the detection system. Moreover, the system itself introduces multiple sources of noise: thermal noise due to the finite conductivity of the coil, Barkhausen noise in the magnetic core (Fornieles-Callejón et al., 2015) voltage and intensity noise in the amplifiers, variations with temperature.

Different instrumentation variants exist, which enables choosing the kind of sensor to use for SR detection (Hauser et al., 2001). A high resolution search coil magnetometer with a ferromagnetic core has been employed in this work. Although the use of the ferromagnetic core complicates the design, it provides a linear response in the frequency range of interest without affecting the signal-to-noise ratio (SNR). This option reduces dimensions and weight, when compared to the search coil without core design with the same sensitivity.

The SR measurement station that provides the datasets used in this study is located in the heart of the Sierra Nevada Mountains, at 2.500 m above sea level, in the area surrounding the mountain hut, called "*Refugio del Poqueira*" (37◦02'N, 3◦19'W), see Figure 1. The access road is snow covered about nine months per year, so getting to the station is done mainly hiking.. The area is almost free of anthropogenic ELF electromagnetic noise, since the location of the station falls inside the Sierra Nevada National Park, and no villages, public roads, agriculture, or other human activities are allowed within its limits. There are not even any power lines in the area. For all these reasons, the location is ideal for measuring SR, which are typically disturbed by these sources of anthropogenic (cultural) noise (Füllekrug, 1994).

Fig. 1. Location of the sensor measuring SR at Sierra Nevada, Granada, Spain

The sensors own a sensitivity of S=19 µV/pT. Regarding a signal to noise ratio (SNR) above 8 dB for a valid signal measurement, the whole system provides a detectable magnetic field signal intensity around 0.1 pT in amplitude and below 10 Hz in frequency (Fornieles-Callejón et al., 2015). After filtering, the useful bandwidth of the system is [0.5 Hz -26 Hz]. The signal is digitized with a sampling frequency of 256 samples per second (f_s = 256 Hz) and 16 bits resolution. The amplitude spectrum is estimated by using Bartlett averaging method. In particular, we used 32 seconds length overlapping time segments with a Hanning window during an hour data register. After this process, the SR parameters (central frequencies and amplitudes of the SR first three modes) are obtained by fitting the spectrum with Lorentzian functions.

The Earth's static magnetic field is around 40 µT, more than 10 million times stronger compare to a typical value of the first mode SR amplitude. This is important because the measurements are taken at a high resolution station and there are no previous experiments that correlate biological effects with such weak magnetic fields. The parameters measured at the station are the following: (*s1*, *s2*, *s3*) is the amplitude of the first, second and third SR modes; (*f1*, *f2*, *f3*) is the frequency of the first, second and third SR modes; (*energ*) is the total signal energy that refers to the integral of the square of the amplitude along the frequency intervals from 5 to 25 Hz. Mean values of these parameters have been computed by integration at a daily temporal scale for the study period. The time of maximum and minimum daily values were also registered for each mentioned variable. All these factors were recorded for two different directions: north-south (n-s) and east-west (e-w).

2.2 Health and demographic data

Daily hospital discharge data were obtained from the Spanish Ministry of Health, Consumer Affairs and Social Welfare (Ministerio de Sanidad, Consumo y Bienestar Social), which administratively registers the Minimum Basic Data Set of the Hospital Discharges (CMBD-H) from all the Hospitals of the National Health Service (public sector) and some private ones. We extracted admissions for the province of Granada with a primary diagnosis (the condition that prompted the admission) of Ischemic Heart Disease (ICD 9: 410-414); Conduction Disorder (ICD 9: 426) or Cardiac Dysrhythmia (ICD 9: 427). The extraction of the needed datasets was performed with an ETL-OLAP application (Villar et al., 2018) developed by the Geobiomet research group at the University of Cantabria.

We chose to work with Conduction Disorders and Cardiac Dysrhythmias based on the results recently found by Elhalel et al. (2019), who described a relationship between the heart's mechanical spontaneous contractions and SR fields. Moreover, due to the low number of hospital admissions classified in these disease groups in the study province, we decided to also include hospitalizations by Ischemic Heart Disease, since this group represents the main global cause of death, and it is associated with the other groups of diseases.

Therefore, two groups were defined in the analysis: group "A", formed by the number of cases with codes related to Ischemic Heart Disease, Conduction Disorders and Cardiac Dysrhythmias; and group B, formed only by Conduction Disorders and Cardiac Dysrhythmias. To analyze incidence, demographic data for the province of Granada was used. The source for this data was the INE (National Institute of Statistics). The population of Granada was 919,319 inhabitants in 2013.

2.3 Statistical analysis

When attempting to identify and subsequently quantify statistical associations between two empirical data sets, linear (Pearson) correlations are the by far most commonly used association (or similarity) measure. The relevance of correlation analysis originates from its algorithmic simplicity along with the fact that it measures statistical association along the full range of observational values. However, the latter might turn out problematic if there are thresholds to the value of one variable to cause an effect in a second one (Siegmund et al., 2016). When it comes to physiological effects of electromagnetic fields, it is not unlikely that such thresholds exist below which possible effects are not observable. In such a situation, it might be recommended turning to nonlinear, state-dependent association measures. The possibly simplest form of such measures is bivariate event statistics, which will constitute the general framework of the analysis performed in this study. Specifically, we focus on the recently developed approach of Event Coincidence Analysis (ECA), a statistical method used to quantify the degree of simultaneous occurrence of events in two series (Donges et al., 2015) to analyse the relation between CVD diseases related hospital admission (HA) and SR measurements in Granada, Spain.

Since the one year of hospital admission and SR data likely display additional factors beyond a mutual association (e.g., seasonality) that act predominantly on larger time-scales, some preprocessing of the data was necessary to make them suited for applying ECA. Specifically, all time-series were detrended using the locally weighted scatterplot smoothing (LOESS) method (Gijbels and Prosdocimi, 2010). Afterwards, the time-series were transformed into binary vectors where days with a certain type of event are indicated by ones. In our case, we adopt the strategy of previous works by identifying the events of interest with very high or very low (detrended) parameter values. Unless stated otherwise, given the total number of data values in each series being N=365, we select the uppermost (respectively, lowermost) 5% of all values, implying 18 events per series which is a reasonable number for performing ECA (Donges et al., 2016).

In each part of the analysis, only two time-series are compared with each other, for which the cases of simultaneous occurrences of ones in both event sequences are counted. Here, the term “simultaneous” should be understood in a somewhat relaxed manner, allowing for the consideration of fixed or even distributed delays between cause and effect (see below). In general, this counting can be performed in two slightly different operational modes (Schleussner et al., 2016; Donges et al., 2016). On the one hand, the precursor rate describes the probability that a hypothetical cause (SR anomaly) has been preceding an observed consequence (high/low Hospital Admission rates). On the other hand, the trigger rate characterizes with which probability an observed cause (Schumann Resonance) has been followed by a consequence (Hospital Admission).

The aforesaid simultaneity can be further specified regarding a time lag (τ) and a tolerance window (ΔT) in which corresponding “analysis events” can occur relative to the given “reference events” (Donges et al., 2016; Siegmund et al., 2017). If both parameters are set to 0, both types of events have to occur on the same day to be considered as simultaneous - in this case, trigger and precursor rates are necessarily identical.

The statistical significance of the empirical event coincidence rates can be characterized by an inter-comparison between the corresponding distributions expected for two unrelated series. Depending on the specific properties of the event series under study, this distribution can be approximated by different approaches (Donges et al., 2016; Siegmund et al., 2017), which we will refer to in the following as three different significance tests for brevity with three different tests (without attempting correctness of the wording in a strict statistical sense). First, the Poisson test compares the number of simultaneous events with the probability distribution of the number of coincidences that would result from two independent Poisson processes with the same event rate (Donges et al., 2016, 2011). Second, for the Shuffle Surrogate test, two event series are generated which have random uniformly chosen event timings. Next, the event coincidence rates of those random series are calculated. From a certain number of surrogates data sets, the distribution of event coincidence rates arising due to chance alone and, hence, a *p*-value for the empirical value found for the original series can be calculated. Other than the Poisson test, the shuffle surrogates can be employed in the case of frequent events, where the analytical approximation beyond the Poisson test breaks down. Finally, the last significance test makes use of Waiting Time Surrogates, i.e., time series with the same waiting time distribution between subsequent events as the original series, to estimate the theoretical distribution of event coincidence rates. The relevance of the latter approach comes along with non-Poissonian events, i.e., serially correlated event sequences which do not obey a simple exponential waiting time distribution.

In addition to the ECA, we also used a Receiver Operating Characteristic (ROC) analysis (Fawcett, 2006), a classical method for assessing the performance of binary discriminators. In this case, the false and the true positive prediction rates of anomalous Hospital Admission rates are calculated. This is successively done at different SR thresholds and thus results in a curve of true positive versus false positive rates. The larger the area under this so-called ROC curve (*AUC*) is, the better the corresponding predictions (Siegmund et al., 2017).

3. Results

3.1 Schumann Resonances and Hospital Admissions

A general group of hospital admissions has been initially considered with all CVD codes representing a total number of 7,755 cases (daily mean is 21.4; standard deviation 6.1) for the study period (April, 1st 2013 to March, 31st 2014). From these, 4,412 cases correspond to males, and 3,343 to female sex. Hence, there is a clear difference in admissions by gender, where males represent 56.38 % and females 43.1 % of all cases. This difference remains very similar when considering the subgroups A and B described in Section 2.2.

The number of HA in subgroup A was 2,640 cases. Ischemic heart disease represents 72 % of this group with 1,902 cases. Subgroup B presents a total number of 738 cases. For the incidence rate computed per 100,000 inhabitants, in the case of ischemic heart disease this rate was 287.4 for men and 280 for women. For conduction disorders, the rate was 25.9 per 100,000 inhabitants (28,7 for males and 23,2 for females), and in the case of cardiac dysrhythmias, the male incidence rate was 61.1 and the female one 57.3 per 100,000 persons.

Fig. 2 shows minimal and maximal SR amplitudes (*s1*), (*s2*) and (*s3*) for n-s and e-w. Moreover, CVD related total hospital admissions are also included, represented by the right y axes indicating the number of daily cases.

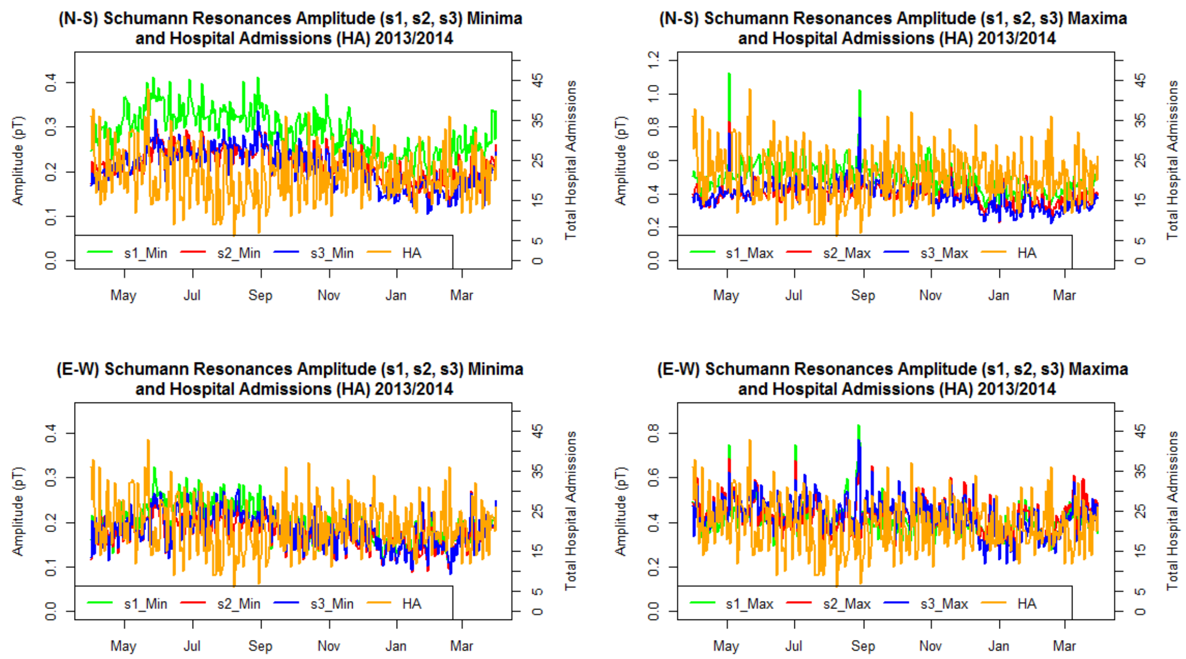


Fig. 2. Time series of SR minima and maxima amplitude (N-S and E-W) and CVD related hospital admissions in Granada province during the study period.

In a similar vein, we show the SR frequency ranges (*f1*, *f2*, *f3*) in terms of daily minima and maxima for both n-s and e-w in Figs. 3 and 4, respectively.

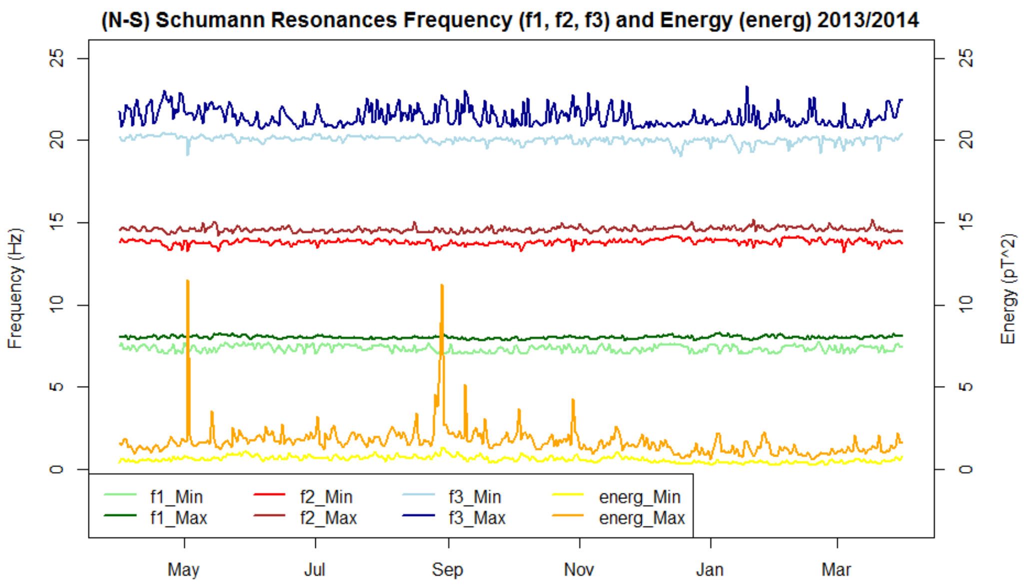


Fig. 3. Time series of N-S minimal and maximal SR frequencies *f1*, *f2*, *f3* and total energy in Granada province during the study period

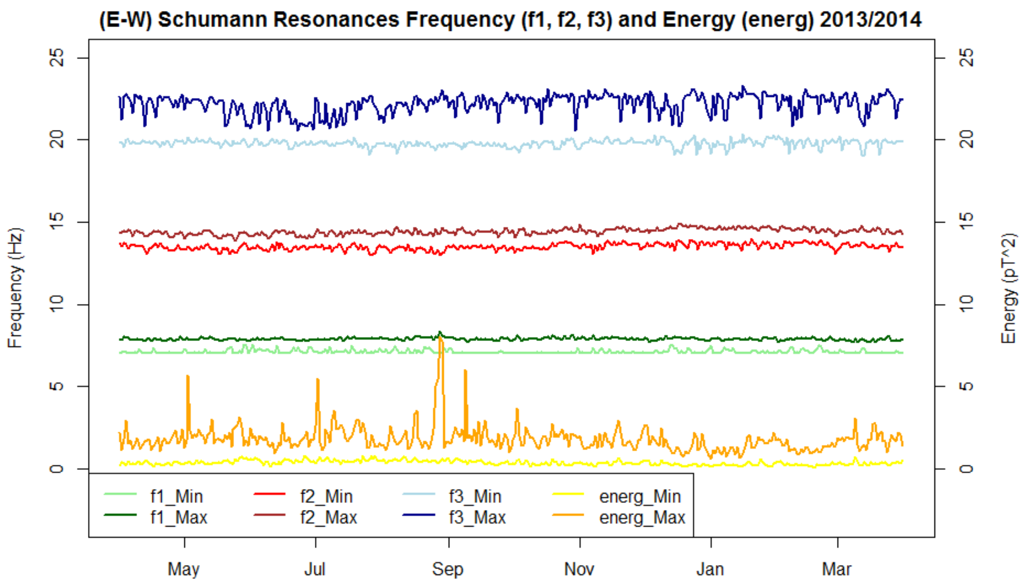


Fig. 4. Time series of E-W minimal and maximal SR frequencies *f1*, *f2*, *f3* and total energy in Granada province during the study period

3.2 Event coincidence analysis

After the preprocessing of data as described in Section 2.3, we first confirmed the absence of strong correlations between the different variables. For none of the SR related variables, a Pearson correlation with the HA data above 0.2 (or below -0.2) could be found. This observation motivates the application of ECA as a new analysis tool to test whether or not SR can have a measurable effect on human health if only strong deviations from the mean values of the corresponding characteristic variables are considered.

In the first analysis step, events were defined as days where the variable of interest exceeds its empirical 95 % quantile (“maxima”) or falls below its empirical 5 % quantile (“minima”), respectively. Thus, for the minima of the SR variables, the lowermost 5 % of all daily values were considered as events, while for the maxima, the uppermost 5 % were taken. For the CVD-HA, always the highest 5 % were taken into account.

In order to select a proper procedure for significance testing of the empirically obtained event coincidence rates, the clustering of events in time was analyzed first. According to the Rayleigh test for a homogeneous distribution of circular (here, potentially seasonal) variables, the uppermost SR values showed no clustering of events (p>0.12), while for the minimum values, only the time series *s2*-ns (p=0.01), *f1*-ns (p<0.01), *f1*-ew (p<0.01), *f3*-ns (p=0.01), f3-ew (p<0.01) and *energ*-ns (p<0.01) provided indications of such clustering. As a complementary test, we found that the waiting times between subsequent events do not systematically deviate from exponential distributions for both maximum and minimum events (p>0.06) according to the Kolmogorov-Smirnov test, indicating a lack of memory in the occurrence of events in SR and HA. As a consequence of these findings, we concentrate on the Shuffle Surrogate test when reporting the results of ECA in the following, while the three different testing procedures (analytical Poisson test as well as shuffle and waiting time surrogates) in most cases showed consistent results.

While the main focus of our analysis was the study of instantaneous relationships between anomalous SR and HA values, we also considered some other elementary parameter combinations of τ and ΔT to investigate a possible time-lagged response on variation of the SR. As can be seen from Tab. 1, significant event coincidence rates are mainly present instantaneously (τ=0 and ΔT=0) and with a time uncertainty of one day (τ=0 and ΔT=1), rather than at a fixed time lag of, e.g., τ=1 day.

		s1				*s2*				*s3*				*f1*				*f2*				*f3*				*energ*			
		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w	
τ	ΔT	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr
0	0																												
0	1																												
1	0																												
1	1																												

Tab. 1: Significance of the precursor (pr) and trigger (tr) event coincidence rates between SR and total Hospital Admissions according to the shuffle surrogates based test for different combinations of the algorithmic parameters (red: significant event coincidence rate for SR minima, green: for maxima).

The physical background why the Minima show the link to HA is still unknown. In contrast to the logic of the outcomes of the research of Elhalel et al. (2019), the Maxima of SR do not show lots of significance in coincidence with low Hospital Admissions in Granada. This outcome cannot be used to give results more confidence (Tab. 2) but there is also no coincidence between the Minima of SR and the minima of the HA. At least this fortifies results in the sense that the Minima do not contradict them.

		s1				*s2*				*s3*				*f1*				*f2*				*f3*				*energ*			
		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w	
τ	ΔT	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr
0	0																												
0	1																												
1	0																												
1	1																												

Tab. 2: Significance of the precursor (pr) and trigger (tr) event coincidence rates between ScR and hospital admissions according to the shuffle surrogates based test for different combinations of the algorithmic parameters (red: significant event coincidence rate for ScR minima, green: for maxima, blue: for both)

When differentiating between the two specific subgroups of the HA, we find some differences in the corresponding ECA results. As in Tab. 3, subgroup A shows significant event coincidence rates for the SR minima for all given combinations of τ and ΔT, which however depend on the SR variable. Here, also the east-west (ew) values of the SR amplitudes *s1* and *s2* are in some cases significant. Considering subgroup B, there is much less of a detectable relationship between SR and HA (Tab. 4).

		s1				*s2*				*s3*				*f1*				*f2*				*f3*				*energ*			
		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w	
τ	ΔT	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr
0	0																												
0	1																												
1	0																												
1	1																												

Tab. 3: Significance of the precursor (pr) and trigger (tr) event coincidence rates between SR and Subgroup A hospital admissions according to the shuffle surrogates based test for different combinations of the algorithmic parameters (red: significant event coincidence rate for SR minima, green: for maxima).

		s1				*s2*				*s3*				*f1*				*f2*				*f3*				*energ*			
		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w		n-s		e-w	
τ	ΔT	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr	pr	tr
0	0																												
0	1																												
1	0																												
1	1																												

Tab. 4: Significance of the precursor (pr) and trigger (tr) event coincidence rates between SR and Subgroup B hospital admissions according to the shuffle surrogates based test for different combinations of the algorithmic parameters (red: significant event coincidence rate for SR minima, green: for maxima).

In order to better understand the possible sensitivity of the ECR results on the specific event definition, we next took a closer look at the effect of the chosen event threshold. For this purpose, we systematically varied the event threshold from the 10 % (~ 36 events) to the 1 % (~3 events) most extreme values. As a typical example, Fig. 5 displays only the precursor event coincidence rates *p*-values for τ=0 and ΔT=0. In general, more significant event coincidence rates between SR and HA are found for the SR minima as compared to the maxima. The parameters *s1*-ns, *s2*-ns, *s3*-ns and *energ* -ns have sufficiently low *p*-values to conclude a systematic coincidence of low SR values and high Hospital Admissions. For very high event thresholds, also other variables get close to the confidence level of 5%; however, the most extreme considered threshold (1%) would lead to only four events, which is a very small sample likely not allowing for a reliable statistics even in the exact count based setting of ECA. This finding underlines the suitability of the previously considered 5% threshold as a reasonable value for the considered data sets.

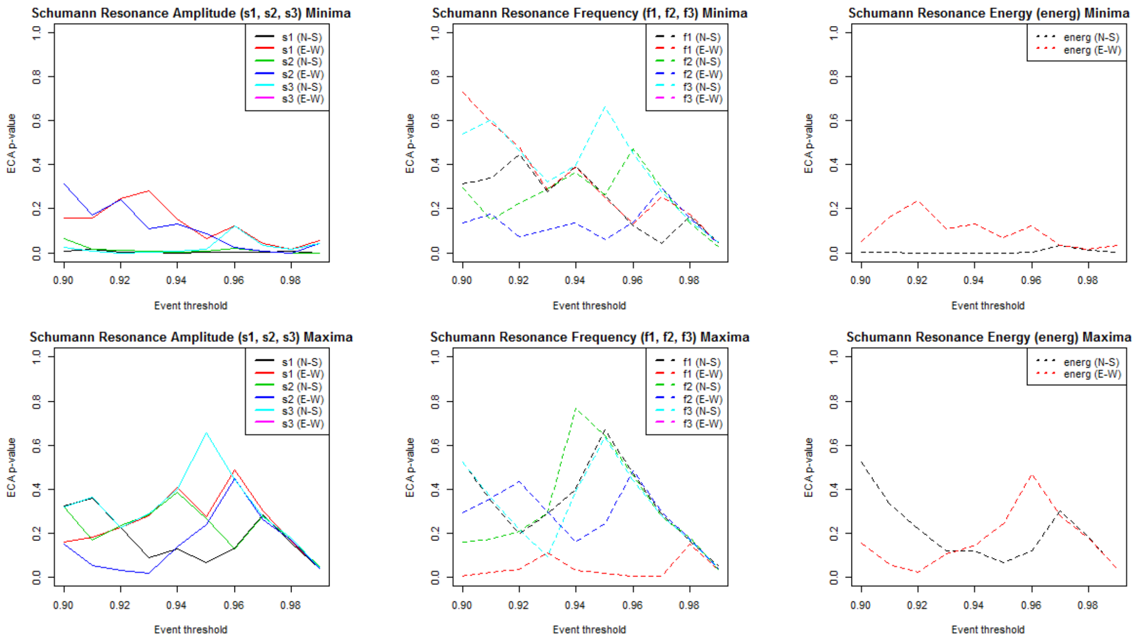


Fig. 5. Dependence on the ECA *p*-values for instantaneous event coincidence rates between SR variables and HA based on the Shuffle Surrogate test on the considered event threshold (percentile of all daily values).

To complement our ECA results, we finally also perform an ROC analysis as described in Section 2.3. For both the minima and maxima of all SR variables, the 99 % quantile of HAs commonly produces the largest areas under the ROC curves. For the SR maxima, the resulting *AUC* values are the highest (>0.7) for *s2*-ns, *s3*-ns and *energ*-ns. For the SR minima, the largest values (>0.7) arise for *s1*-ns, *s1*-ew and *f2*-ew, but are on average higher than for the maxima. It should be noted that those variables are only partly the same as those previously showing significant event coincidence rates. Figure 6 summarizes the corresponding ECA *p*-values along with the *AUC*, with values in the lower right corner comprising low *p*-values in the ECA and high *AUC*. Notably, for the SR minima the variables *s1*-ns, *s2*-ns, *s3*-ns and *energ*-ns show a likely relationship according to both analyses. We thus conclude that there are robust indications for coincidences between the events in those variables and the HA. In turn, for the SR maxima such indications are vastly missing.

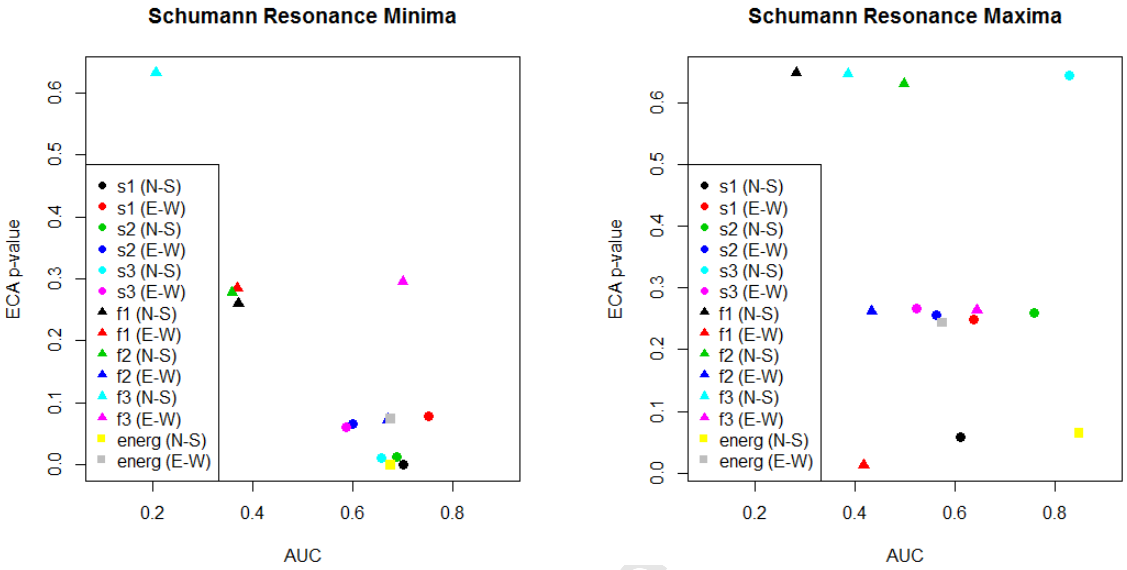


Fig. 6. Comparison of the areas under the ROC curve (*AUC*) and the ECA instantaneous event coincidence rates' *p*-values according to the Shuffle Surrogates for SR variables and HAs.

4. Discussion

We have found significant coincidence rates between events describing the field properties of SR modes (amplitude and frequency) and cardiovascular hospital admissions in Granada. Thereby, we confirm that ELF magnetic fields measured in an open environment are not neutral in relation to cardiovascular diseases in the study area. This is the first time to demonstrate that CVD hospital admissions are statistically linked to ELF magnetic fields.

Precursor rate (pr) and trigger rate (tr) are statistically significant in relation to the total number of considered hospital admissions (Tab. 1). This statistical association is mainly related to the north-south measurements of the SR amplitude and total energy. It is important to note that the coinciding events' association takes place almost exclusively in relation with the minima of the characteristic SR variables (Elhalel et al., 2019).

The high admission events due to CVD seem to be markedly synchronized with the SR minima at the same day or one day before. The statistical significance of the precursors (pr) and trigger (tr) rates are very important for *s1* and *s2* for all shown τ and ΔT in the subgroup A (where ischemic cardiopathies were included). Moreover, the minima of the east-west resonance amplitudes *s1* and *s2* seem to coincide with the highest number of hospital admissions.

The coincidences were mainly present at the same day or with one day delay, which is coherent with other statistical lagged models (Tobías et al., 2017) applied to biometeorological studies on temperature related mortality, in which one or two-day lags maintain clear associations between the physical variables (heat, cold,…) and the magnitude of the impact on human health.

One of the main novelties of this work is the use of natural ELF electromagnetic field measurement, provided by a high resolution ELF station, as a biometeorological variable. This is an important issue because there are no previous experiments that associate biological effects with such weak magnetic fields. The obtained findings are thus questioning some existing assumptions in relation to where the limits are to study the effects of ELF magnetic fields on biological processes and health.

The first SR mode (*s1*, *f1*) has been measured in an open environment at the Granada station, which it is particularly relevant in order to confirm, at an epidemiological level, the output of some existing theories and experiments of previous studies. Our results based upon the ECA approach go in the same direction as recent results of laboratory studies (Elhalel et al., 2019), confirming a relationship between some CVD and the SR first mode. Specifically, the authors of the aforementioned work performed an experiment with rat cardiomyocytes cultures to study the influence of extremely low amplitude/frequency magnetic fields on fundamental cellular processes, concluding that extremely weak 7.8 Hz magnetic fields reduce the calcium transient amplitude, affecting contraction rate and CK release, while they have a protective effect during oxidative stress and hypoxic conditions. More precisely, it was found a cardio-protector effect for magnetic fields with a frequency between 7.8 and 8 Hz (SR first mode) and fields from 20pT to 90nT in an experiment developed under a controlled environment.

Calcium ion efflux and alteration in reaction times is mentioned in different studies developed under a 7 Hz signal in animals and humans (Adey, 1980; Blackman et al., 1988; Gavalas-Medici and Day-Magdaleno, 1976; König, 1974) based on the ability of resonant absorption to alter cellular calcium ion homeostasis and assigning to melatonin cycle a fundamental role in multiple health problems such as for instance heart attacks and acute heart diseases (Reiter, n.d.; Reiter and Robinson, 1995). Controversy on the mechanisms and processes through which these biophysical processes take place is still open nowadays.

Another interesting finding of the ECA statistics is the existing predominance of the n-s component in the associations of SR measurements with CVD-HA. As it was mentioned before, for the SR minima, the variables *s1*-ns, *s2*-ns, *s3*-ns and *energ*-ns show a relation in both analyses. There are 17 n-s associations found with the minima parameters of SR in total admissions (Tab. 1) in comparison with 6 for the e-w measurements. This difference is reduced in the subgroup A (22 n-s to 15 e-w) but it is still important giving more relevance to the n-s aspect.

A conceivable explanation of these differences can be linked to the global frequency and distribution of lightning, which has been described by (Christian et al., 2003) and is monitored by NASA daily. Seasonal variation of lightning diurnal cycle responds to specific atmospheric patterns (Blakeslee et al., 2014) making SR also linked to this lighting activity. There is a strong continental-scale diurnal variation with a peak in the activity during the late afternoon and a minimum in late morning at local time.

The maximum diurnal amplitude occurs in summer and minimum values are recorded in winter in the Northern Hemisphere. In this sense, the north-south SR sensor in Granada is more sensitive to the lighting activity that takes place on Asia and the Americas (North, Central and South). Variations of measurements in the same day are usually small. The East-West sensor is greatly influenced by Central African lightning activity and its recorded daily variation is much larger, since it is the closest active area to Granada in terms of lightning activity.

Assuming the relationship between lightning activity and SR, according to the first law in Geography (Fotheringham et al., 2000) this activity in Central Africa should influence Granada SR measurements more strongly than other regions in the world. The meridional mean flash rates (Cecil et al., 2014) provides an excellent approach for explaining the pathway through which lighting activity influences arrive at our study region. It has been demonstrated that, in the meridional mean flash rates, a clear band for African activity is defined between 18º W and 50º E, with the Iberian Peninsula in the center. In any case, empirically supporting this theory would require more specific research that is beyond the scope of this paper.

At a more detailed geographic scale, a much more specific atmospheric pathway should be the electrical properties of the predominant weather types affecting the study area: However, there is no electromagnetic characterization of weather types available yet from meteorological services.

The predominant winds in the study area are conditioning by the influence of the “Alboran Sea” and the Sierra Nevada mountains. There is a wind from West to East, called *poniente* and one from East to West called *levante*. The first one is locally known as a very energetic wind. The winds from *levante* carry electrical charges and can affect people´s central nervous system.

From a physical point of view, due to the vectorial relationships between sources and fields, a local East-West charged wind can contribute to an increment on the noise level of the magnetic field in the north-south component of the SR band.

It has been observed in different field-work measurements in the study area that, when SR are measured close to trees and there is a weak breeze, noise level in the SR band reached very high values. Under these conditions, the whole Power Spectral Density (PSD) levels up. Those observations can be very relevant to explain why atmospheric processes and CVD-HA are statistically associated in Granada under an ECA approach. More research on this specific topic should hence be performed in the future.

4. Conclusions and Recommendations

SR has, from a statistical point of view, a measurable effect on human health in the area of Granada, Spain in relation to cardiovascular diseases hospital admissions. More significant event coincidence rates between SR and HA are found for the SR minima as compared to the maxima.

There is a systematic coincidence of low SR n-s amplitudes and high CVD-HA according to *p*-values. Precursors (pr) and trigger (tr) rates are statistical significances and very important for *s1* and *s2* for all shown τ and ΔT in the subgroup where ischemic cardiopathies are included. Moreover, the minima of the east-west resonance amplitudes *s1* and *s2* seem to coincide with hospital admission maxima.

For the SR maxima, the resulting *AUC* values are the highest (>0.7) for *s2*-ns, *s3*-ns and *energ*-ns. For the SR minima, the largest values (>0.7) arise for *s1*-ns, *s1*-ew and *f2*-ew, but are on average higher than for the maxima.

Notably, for the SR minima the variables *s1*-ns, *s2*-ns, *s3*-ns and *energ*-ns show a likely relationship according to both analyses. We thus conclude that there are robust indications for coincidences between the events in those variables and the cardiovascular related hospital admissions.

ECA method seems to be a very convenient statistical approach to study the interaction between atmospheric SR magnetic fields and human health. These results are aligned with some recent outputs of experiments in labs linking SR magnetic fields to cardio protection effects and are expanding the traditional limits of the study SR bio-effects.

The main limitations of this study refer to the short length of available time series of SR in the study area. This study should be reproduced with longer time-series in different places of the world.

Another important limitation is the lack of biophysical information of the people affected by the CVD in Granada in order to group them or erase those cases in which other co-founders are clearly associated to their hospital admission.

Further developments should attend to consider the existing gender differences. A study based on gender associations should be also developed in order to facilitate biophysical interpretations of the existing association.

SR depends on the global thunderstorm activity. It is needed to improve the knowledge on lighting spatial distribution and frequency to know more about SR at their impact on meteorological processes at the tropospheric level and how atmospheric circulation and weather types affect SR measurements.

The definition of the electromagnetic properties of weather types at synoptic scales should help us to understand SR bio-effects much better in the future and would open the door to the development of early warning systems based on atmospheric bio-electromagnetic forecasting.

Acknowledgements

This paper is based upon work from COST Action "Atmospheric Electricity Network: coupling with the Earth System, climate and biological systems (ELECTRONET)", supported by COST (European Cooperation in Science and Technology).

Also authors acknowledge Cost Action 15211, Atmospheric Electricity Network: coupling with the Earth System, climate and biological systems, for funding the COST Training School on "Advanced Data Analysis Methods for Identifying and Characterizing Atmospheric Electricity Variations, their Causes and Impacts" developed at Potsdam Institute for Climate Impact Research from February, 25th to March, 1st 2019.

Authors would like to thank the Spanish Ministry of Health, Consumer Affairs and Social Welfare CMBD for facilitating access to the data the Minimum Basic Data Set of the Hospital Discharges (CMBD-H) from all the Hospitals of the National Health Service.

Also, authors would like to thank the support from the Spanish National Research Agency - Project CSO2016-75154-R and the European Funds for Regional Development (FEDER).

Authors would like to thank the support by the investigation research project FIS2017-90102-R, of the Ministry of Economy and Competitiveness (MINECO) cofinanced by the Fund European Regional Development (FEDER), and we are grateful to Parque Nacional Sierra Nevada for providing support for the ELF measurement station

The Event Coincidence Analysis has been performed using the R package CoinCalc (Siegmund et al. 2017). LS and RVD gratefully acknowledge financial support by the German Federal Ministry of Science and Education under grant nos. 01LN1306A and 01LP1611A.

References

Adey, W.R., 1980. Frequency and power windowing in tissue interactions with weak electromagnetic fields. Proc. IEEE 68, 119–125. https://doi.org/10.1109/PROC.1980.11591

Adey, W.R., 1981. Tissue interactions with nonionizing electromagnetic fields. Physiol. Rev. 61, 435–514. https://doi.org/10.1152/physrev.1981.61.2.435

Analitis, A., Katsouyanni, K., Biggeri, A., Baccini, M., Forsberg, B., Bisanti, L., Kirchmayer, U., Ballester, F., Cadum, E., Goodman, P.G., Hojs, A., Sunyer, J., Tiittanen, P., Michelozzi, P., 2008. Effects of cold weather on mortality: Results from 15 European cities within the PHEWE project. Am. J. Epidemiol. 168, 1397–1408. https://doi.org/10.1093/aje/kwn266

Balser, M., Wagner, C.A., 1960. Observations of Earth–Ionosphere Cavity Resonances. Nature 188, 638–641. https://doi.org/10.1038/188638a0

Bawin, S.M., Adey, W.R., 1976. Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. Proc. Natl. Acad. Sci. U. S. A. 73, 1999–2003. https://doi.org/10.1073/pnas.73.6.1999

Bawin, S.M., Gavalas-Medici, R.J., Adey, W.R., 1973. Effects of modulated very high frequency fields on specific brain rhythms in cats. Brain Res. 58, 365–384. https://doi.org/10.1016/0006-8993(73)90008-5

Blackman, C.F., Benane, S.G., Elliott, D.J., House, D.E., Pollock, M.M., 1988. Influence of electromagnetic fields on the efflux of calcium ions from brain tissue in vitro: a three-model analysis consistent with the frequency response up to 510 Hz. Bioelectromagnetics 9, 215–27.

Blakeslee, R.J., Mach, D.M., Bateman, M.G., Bailey, J.C., 2014. Seasonal variations in the lightning diurnal cycle and implications for the global electric circuit. Atmos. Res. 135–136, 228–243. https://doi.org/10.1016/j.atmosres.2012.09.023

Breus, T.K., Pimenov, K.Y., Syutkina, E. V., Halberg, F., Cornelissen, G., Gurfinkel, Y.I., Chibisov, S.M., Frolov, V.A., 1996. Biological effects of solar activity. Orig. Life Evol. Biosph. 26, 497–498. https://doi.org/10.1007/BF02459892

Brzezinski, A., 1997. Melatonin in Humans. N. Engl. J. Med. 336, 186–195. https://doi.org/10.1056/NEJM199701163360306

Carmona, R., Díaz, J., Mirón, I.J., Ortíz, C., León, I., Linares, C., 2016. Geographical variation in relative risks associated with cold waves in Spain: The need for a cold wave prevention plan. Environ. Int. 88, 103–111. https://doi.org/10.1016/j.envint.2015.12.027

Cecil, D.J., Buechler, D.E., Blakeslee, R.J., 2014. Gridded lightning climatology from TRMM-LIS and OTD: Dataset description. Atmos. Res. 135–136, 404–414. https://doi.org/10.1016/j.atmosres.2012.06.028

Cherry, N., 2002. Schumann Resonances, a plausible biophysical mechanism for the human health effects of Solar. Nat. Hazards 26, 279–331. https://doi.org/10.1023/A:1015637127504

Chibisov, S.M., Breus, T.K., Levitin, A.E., Drogova, G.M., n.d. [Biological effects of planetary magnetic storms]. Biofizika 40, 959–68.

Christian, H.J., Blakeslee, R.J., Boccippio, D.J., Boeck, W.L., Buechler, D.E., Driscoll, K.T., Goodman, S.J., Hall, J.M., Koshak, W.J., Mach, D.M., Stewart, M.F., 2003. Global frequency and distribution of lightning as observed from space by the Optical Transient Detector. J. Geophys. Res. 108, 4005. https://doi.org/10.1029/2002JD002347

De Sario, M., Katsouyanni, K., Michelozzi, P., 2013. Climate change, extreme weather events, air pollution and respiratory health in Europe. Eur. Respir. J. 42, 826–843. https://doi.org/10.1183/09031936.00074712

Donges, J.F., Donner, R. V, Trauth, M.H., Marwan, N., Schellnhuber, H.-J., Kurths, J., 2011. Nonlinear detection of paleoclimate-variability transitions possibly related to human evolution. Proc. Natl. Acad. Sci. U. S. A. 108, 20422–7. https://doi.org/10.1073/pnas.1117052108

Donges, J.F., Schleussner, C.-F., Siegmund, J.F., Donner, R.V., 2016. Event coincidence analysis for quantifying statistical interrelationships between event time series. Eur. Phys. J. Spec. Top. 225, 471–487. https://doi.org/10.1140/epjst/e2015-50233-y

Donges, J.F., Schleussner, C.-F., Siegmund, J.F., Donner, R. V., 2015. Event coincidence analysis for quantifying statistical interrelationships between event time series: on the role of flood events as possible triggers of epidemic outbreaks. https://doi.org/10.1140/epjst/e2015-50233-y

Elhalel, G., Price, C., Fixler, D., Shainberg, A., 2019. Cardioprotection from stress conditions by weak magnetic fields in the Schumann Resonance band. Sci. Rep. 9, 1645. https://doi.org/10.1038/s41598-018-36341-z

Fornieles-Callejón, J., Salinas, A., Toledo-Redondo, S., Portí, J., Méndez, A., Navarro, E.A., Morente-Molinera, J.A., Soto-Aranaz, C., Ortega-Cayuela, J.S., 2015. Extremely low frequency band station for natural electromagnetic noise measurement. Radio Sci. 50, 191–201. https://doi.org/10.1002/2014RS005567

Fotheringham, A.S., Brunsdon, C., Charlton, M., 2000. Quantitative Geography : Perspectives on Spatial Data Analysis. Sage Publications.

Frolov, V.A., Pukhlianko, V.P., Kazanskaia, T.A., Chibisov, S.M., Siatkin, S.P., 1986. [Effect of geomagnetic storms on the state of heart mitochondria and their role in providing energy for myocardial contraction]. Biull. Eksp. Biol. Med. 101, 546–8.

Füllekrug, M., 1994. Schumann-Resonanzen in den Magnetfeld-Komponenten. Cuvillier.

Gavalas-Medici, R., Day-Magdaleno, S.R., 1976. Extremely low frequency, weak electric fields affect schedule-controlled behaviour of monkeys. Nature 261, 256–259. https://doi.org/10.1038/261256a0

Ghione, S., Mezzasalma, L., Del Seppia, C., Papi, F., 1998. Do geomagnetic disturbances of solar origin affect arterial blood pressure? J. Hum. Hypertens. 12, 749–54.

Gijbels, I., Prosdocimi, I. (2010). Loess. *Wiley Interdisciplinary Reviews: Computational Statistics*, *2*(5), 590-599. https://doi.org/10.1002/wics.104

Hauser, M., Kraus, L., Ripka, P., 2001. Giant magnetoimpedance sensors. IEEE Instrum. Meas. Mag. 4, 28–32. https://doi.org/10.1109/5289.930983

König, H.L., 1974. Behavioural Changes in Human Subjects Associated with ELF Electric Fields, in: ELF and VLF Electromagnetic Field Effects. Springer US, Boston, MA, pp. 81–99. https://doi.org/10.1007/978-1-4684-9004-6_4

Köppen WP (1936) Das geographische system der klimate. Gebrüder Borntraeger: Berlin

Mitsutake, G., Otsuka, K., Hayakawa, M., Sekiguchi, M., Cornélissen, G., Halberg, F., 2005. Does Schumann resonance affect our blood pressure? Biomed. Pharmacother. 59 Suppl 1, S10-4.

Nickolaenko A, Hayakawa M. (2014) Schumann Resonance for Tyros. Essentials of Global Electromagnetic Resonance in the Earth–Ionosphere Cavity. 2014. 10.1007/978-4-431-54358-9

Pablo Fdez-Arroyabe, 2015. Climate Change, Local Weather and Customized Early Warning Systems based on Biometeorological Indexes. J. Earth Sci. Eng. 5.

https://doi.org/10.17265/2159-581X/2015.03.002

Polk, C. (1982) Schumann Resonance. In: Volland, H., Ed., CRC Handbook of Atmospherics, Vol. I, CRC Press, Boca Raton (Fla), 112-174

Price C. 2016. ELF Electromagnetic Waves from Lightning: The Schumann Resonances. Atmosphere 2016, 7(9), 116; https://doi.org/10.3390/atmos7090116

Ptitsyna, N.G., Villoresi, G., Dorman, L.I., Iucci, N., Tyasto, M.I., 1998. Natural and man-made low-frequency magnetic fields as a potential health hazard. Uspekhi Fiz. Nauk 168, 767–791. https://doi.org/10.3367/UFNr.0168.199807d.0767

Reiter, R.J., n.d. Melatonin suppression by static and extremely low frequency electromagnetic fields: relationship to the reported increased incidence of cancer. Rev. Environ. Health 10, 171–86.

Reiter, R.J., Robinson, J., 1995. Melatonin : your body's natural wonder drug. Bantam Books.

Royé, D., Zarrabeitia, M.T., Fdez-Arroyabe, P., Álvarez Gutiérrez, A., Santurtún, A., 2018. Role of Apparent Temperature and Air Pollutants in Hospital Admissions for Acute Myocardial Infarction in the North of Spain. Rev. Esp. Cardiol. https://doi.org/10.1016/j.recesp.2018.05.032

Salinas, A., Toledo-Redondo, S., Navarro, E.A., Fornieles-Callejón, J., Portí, J.A., 2016. Solar storm effects during Saint Patrick's Days in 2013 and 2015 on the Schumann resonances measured by the ELF station at Sierra Nevada (Spain). J. Geophys. Res. Sp. Phys. 121, 12,234-12,246. https://doi.org/10.1002/2016JA023253

Santurtún, M., Santurtún, A., Zarrabeitia, M.T., 2018. Does the environment affect suicide rates in Spain? A spatiotemporal analysis. Rev. Psiquiatr. Salud Ment. 11, 192–198. https://doi.org/10.1016/j.rpsm.2017.05.001

Sátori, G., Williams, E., Price, Colin., Boldi, R.; Koloskov, A., Yampolski, Y., Guha, A., Barta, V., 2016. Effects of Energetic Solar Emissions on the Earth-Ionosphere Cavity of Schumann Resonances Surveys in Geophysics, 37(4): 757-789

Schleussner, C.-F., Donges, J.F., Donner, R. V, Schellnhuber, H.J., 2016. Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. Proc. Natl. Acad. Sci. U. S. A. 113, 9216–21. https://doi.org/10.1073/pnas.1601611113

Schumann, W.O., O., W., 1952. Über die strahlungslosen Eigenschwingungen einer leitenden Kugel, die von einer Luftschicht und einer Ionosphärenhülle umgeben ist. Zeitschrift für Naturforsch. A 7, 149–154. https://doi.org/10.1515/zna-1952-0202

Siegmund, J.F., Siegmund, N., Donner, R. V., 2017. CoinCalc —A new R package for quantifying simultaneities of event series. Comput. Geosci. 98, 64–72. https://doi.org/10.1016/j.cageo.2016.10.004

Siegmund, J.F., Wiedermann, M., Donges, J.F., Donner, R. V., 2016. Impact of temperature and precipitation extremes on the flowering dates of four German wildlife shrub species. Biogeosciences 13, 5541–5555. https://doi.org/10.5194/bg-13-5541-2016

Stoupel, E., Goldenfeld, M., Shimshoni, M., Siegel, R., 1993. Intraocular pressure (IOP) in relation to four levels of daily geomagnetic and extreme yearly solar activity. Int. J. Biometeorol. 37, 42–45. https://doi.org/10.1007/BF01212766

Tobías, A., Armstrong, B., Gasparrini, A., 2017. Brief report: Investigating uncertainty in the minimum mortality temperature. Epidemiology 28, 72–76. https://doi.org/10.1097/EDE.0000000000000567

Toledo-Redondo, S., Salinas, A., Portí, J., Morente, J.A., Fornieles, J., Méndez, A., Galindo-Zaldívar, J., Pedrera, A., Ruiz-Constán, A., Anahnah, F., 2010. Study of Schumann resonances based on magnetotelluric records from the western Mediterranean and Antarctica. J. Geophys. Res. 115, D22114. https://doi.org/10.1029/2010JD014316

Tran, A., Polk, C., 1979. Schumann resonances and electrical conductivity of the atmosphere and lower ionosphere—II. Evaluation of conductivity profiles from experimental Schumann resonance data. J. Atmos. Terr. Phys. 41, 1249–1261. https://doi.org/10.1016/0021-9169(79)90028-X

Villar, A., Zarrabeitia, M.T., Fdez-Arroyabe, P., Santurtún, A., 2018. Integrating and analyzing medical and environmental data using ETL and Business Intelligence tools. Int. J. Biometeorol. 62, 1085–1095. https://doi.org/10.1007/s00484-018-1511-9

Volland, H., n.d. Handbook of Atmospheric Electrodynamics, Volume I.

Zhao, N., Cao, G., Vanos, J.K., Vecellio, D.J., 2018. The effects of synoptic weather on influenza infection incidences: a retrospective study utilizing digital disease surveillance. Int. J. Biometeorol. 62, 69–84. https://doi.org/10.1007/s00484-017-1306-4

Author statement file outlining all authors' individual contributions

Pablo Fdez-Arroyabe has proposed the idea and coordinated the publication and integrated the different components of the paper. It has developed some of the graphical representation and produced the interpretation and discussion of results.

Jesús Fornieles is an expert on Schumann Resonances. He has developed the sensor and is in charge of the empirical measurements of the parameters in Sierra Nevada. He has participated in the discussion in relation to global lightning.

Ana Santurtún is a medical doctor and she has been in charge of dealing with the medical data, computing incidences. She has aggregated pathologies of cardiovascular diseases by subgroups in order to develop the statistical analysis

Leonna Szangolies works with the ECA method at the Potsdam Institute for Climate Impact Research. She has run the model and has tested the time series to valifdate them, has defined the events groups and applied the ECA. She has extracted the most relevant outputs from the model in order to stat the discussion

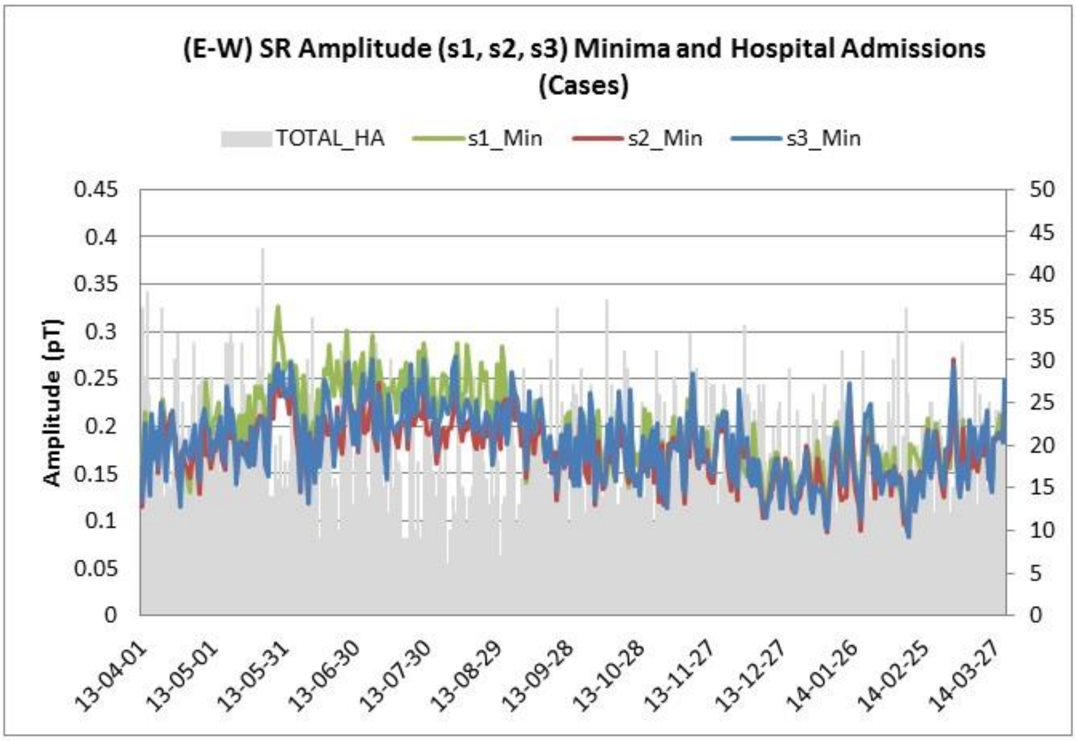
Reik V Doner is the expert on statistics from Potsdam Institute for Climate Impact Research and reviewed the results and written the statistical interpretation of them. He has also participated in the global integration of the statistical outputs in the paper with a final revision.

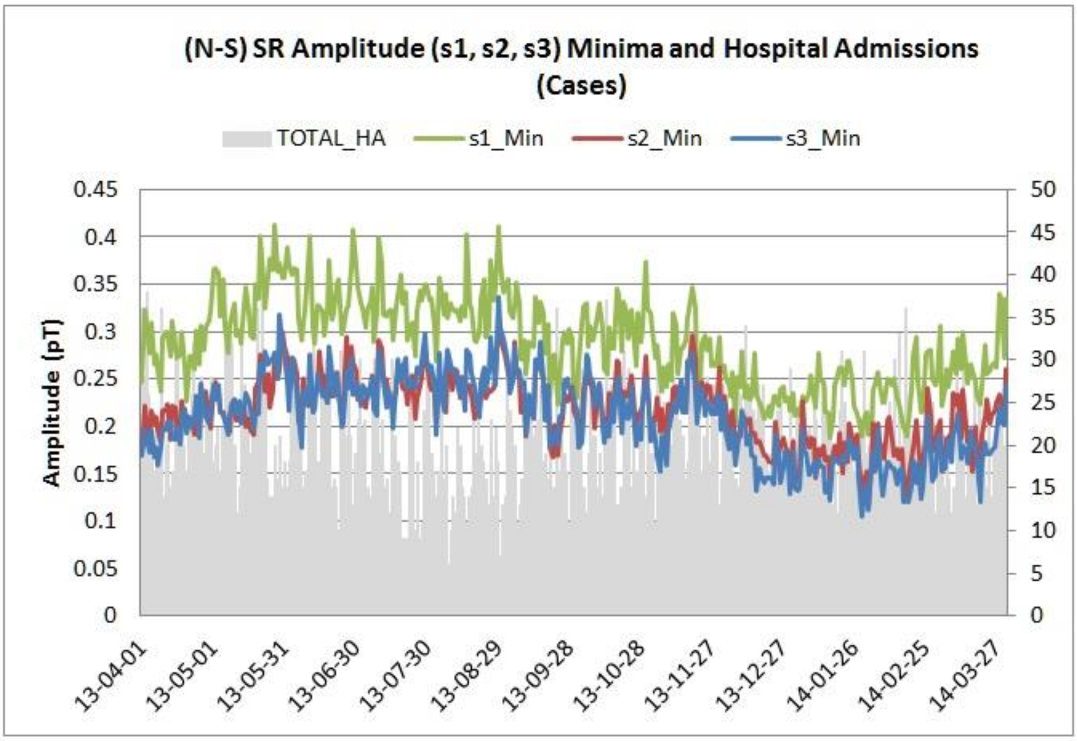
Declaration of no conflict of interest

I declare that there no any conflict of interests of authors in relation to the paper titled

I declare that the work described has not been published previously that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

Pablo Fernandez de Arroyabe





Graphical abstract

Highlights

- SR are statistically associated to cardiovascular hospital admission in Granada
- ELF fields measured by a high resolution search coils sensors were recorded
- There are significant event coincidence rates between SR and hospital admissions
- N-S component is more relevant in the associations of SR and cardiopathies