Church Bells and Ground Motions

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Abstract

Although the primary objective of seismic stations is the recording of waves generated by natural seismicity, the sensors can detect vibrations generated by different sources of natural and anthropogenic origin. The interest in identifying these sources has increased in the last years with the use of background seismic vibrations to obtain images of the crustal structure by tomographic methods and to monitor different natural processes. We present here a very particular case of these type of sources, the bell ringing in churches to indicate the passage of time. In some particular cases, the vibrations generated by the ringing of the bells are recorded in seismic stations installed near the bell towers. We review different examples throughout Europe of this particular kind of seismic records to illustrate how the seismic records can provide information on the traditions followed to mark the hours in some European countries, which turn out to be very different. The objective is not only to publicize this curious records, but also to show that bridges can be built between very different scientific disciplines, such as seismology and social sciences, since the seismic data offers a new tool to researchers interested in investigating ethnographic aspects related to how the passage of time is marked in different European cultures.

Introduction

Following the development of new techniques to use the vibrations recorded in the absence of seismic waves, often referred to as "ambient seismic noise", to image the crustal structure using tomographic methods (Campillo and Paul, 2003), interest in the sources of the vibrations has increased significantly. In recent years, the study of these sources has led to the development of the so-called environmental seismology, whose objective is to use seismic data to monitor different natural processes, establishing connections between seismology and other sciences, such as hydrology, meteorology or even biology. These sources include natural phenomena, such as waves in the oceans (Stutzmann et al., 2009), hurricanes (Sufri et al., 2014), wind (Johnson et al., 2019), river discharges (Díaz et al., 2014), landslides and rock falls (Provost et al., 2018) or avalanches (Heck et al., 2019). In addition, human activity is responsible for a large number of background vibrations, particularly in urban environments. The main contributors to these anthropogenic signals, often referred to as cultural noise, are road traffic (e.g. Riahi and Gerstoft 2015), underground transport systems (Sheen et al., 2009), railways (Fuchs et al., 2017) or wind turbines (Neuffer and Kremers, 2017). However, a wide variety of activities can generate seismic signals in urban settings, including sporting events, musical concerts or fireworks shows (Díaz et al., 2017).

In this contribution we will focus on a very particular case of a background vibration source: the ringing of the bells in church bell towers that indicate the hours. Although the potential use of such signals in Earth Sciences has not been explored yet, we believe that our work is of interest to present this kind of curious recordings and to raise awareness in other scientific disciplines on the possible use of seismic recordings in their research.

In addition, our results document the different types of bell ringing used in several European countries, showing that is possible to built bridges between very different scientific disciplines, such as seismology and social sciences.

Broad-band seismometers can detect tiny ground movements in a large frequency band. As the main objective of this equipment is to detect seismic waves generated by local or distant earthquakes, the preferred locations for the stations are quiet areas, far from sources of vibrations generated by natural or human sources. However, increasing requirements for security, electrical power, access to the site, logistic installation requirements, etc., make it often convenient, in particular for non-permanent deployments, to install seismic stations in secure locations at or near small towns. Chapels and small churches are often a good option, since most of the time they are not used and at the same time the instrumentation is protected. However, an obvious negative counterpart from a seismological point of view is that the instruments record bell rings.

Seismic records of bell ringing

Church bells have been used since the Middle Ages not only to mark masses and other religious rituals, but also to mark the passage of time for the population. The canonical hours, a division of the day into eight three-hour intervals, were marked by bells in monasteries and some churches. In addition, the Angelus devotion started and spread out over Europe in the twelfth century (Thurston, 1907). The Angelus devotion was accompanied by the ringing of the Angelus bell, that had a double character as it marked the moment of prayer but also the end of the working day

Gradually, during the thirteenth century, a second Angelus call was introduced at noon to mark lunch time. From the fifteenth century, a third call was introduced in the morning. The manner of ringing the Angelus bell consists usually in a triple stroke of the bell, repeated three times, a tradition that remained strong until the early twentieth century and still is preserved in some regions. Since the beginning of the fifteenth century, mechanical striking clocks began to be installed in the most important churches. The bell towers began then to act as public clocks, using the bells to announce the time marked by mechanical clocks. By the end of the 16th century, many churches in Europe had already installed mechanical clocks. However, it was in the mid-nineteenth century, after a significant reduction of the production costs of clocks, when the use of church bells to indicate civil times began to be common in many cities. In this contribution, we present examples of the different traditions followed in Europe to indicate the pass of time using the bell ringing. To do this, we use seismic data retrieved from broad-band seismic stations installed near tower bells at four sites located in Greece (Western Peloponnese), Italy (Calabria), southern France (Dordogne) and NE Iberia (Catalonia). The details of each location are summarized at Table 1. Although signals are clear, a high-pass filter with a corner frequency of 5 Hz has been applied to suppress eventual long period signals. As discussed below, the recorded signals in each of the investigated places differ greatly, reflecting differences in cultural and religious traditions (Fig.1).

a) Riolos, Western Peloponnesus, Greece

The RLS seismic station is located in the Riolos Kato Achaia town (W Peloponnese, Greece) and integrated into the Greek national seismic network (National Observatory of Athens, Institute of Geodynamics, 1997). The seismic station is installed in a small building near the church. As with all the examples presented later, the seismometer records the vibrations generated by the chimes as short and impulsive signals with an amplitude clearly higher than the background seismic noise. In this case, the hourly announcements begin at 7:00 local time and stop at 13:00. The bell rings again at 17:00 and remain active until 21:00 (Fig. 2). This schedule shows that this community has chosen to preserve the rest time not only during the night hours, but also after lunch, suppressing the chimes during these intervals. Rest periods during the central hours of the day are common in countries around the Mediterranean Sea and are related to the high temperatures that are often felt during the summer. The schedule of bells in Riolos seems to accommodate this tradition.

Each hour is indicated by the corresponding number of strikes and the interval between each stroke is close to 2 seconds. Half hours are announced with a double strike of smaller amplitude. By the way, in this particular case, seismic data allow us to note that the clock is delayed about 2 minutes and 20 seconds, a delay that increases slightly with time (see dashed lines in Fig. 2).

b) Lunas, Dordogne, SW France

During the temporary deployment of the Pyrope seismic network (Chevrot, S., Sylvander, M., 2017), a broad-band station was installed near the church of Lunas, a small town in the Dordogne region of southwestern France, and remained active between September 2011 and May 2013. Recordings of this station show that the bell rings between 7:00 to 20:00 local time, without interruption in the early afternoon. The interval between each bell strike is close to 2.2 s and the full stroke is repeated 2 minutes after the sound of the last bell of the first call (Fig. 3). This is a common tradition in different areas and has a practical utility, since it was not easy for people working outside to realize the amount of strikes on the first call. As in the Greek example, the half hours are also signaled, in this case by a single strike of the bell.

It is interesting to note that the medieval tradition of the Angelus is preserved at this place. Three times a day, after the bell ringings at 07:00, 12:00 and 19:00, the Angelus is marked by a triple stroke of the bells repeated three times, separated by 8 seconds (red ellipses in Fig. 3). This manner of ringing has seems to have remained unchanged since the Middle Ages.

c) Sta. Maria Montmagastrell, Catalonia, NE Spain

The following example presents the records acquired at temporary station E120, deployed in the small village of Sta Maria Montmagastrell, located in Catalonia, NE Spain. This station was installed as part of the TopoIberia-Iberarray deployment (ICTJA-CSIC, 2007) and has been operational between March and September 2011, after which was moved to a more quiet location. Bell ringing is active here from 07:00 till 22:00 local time. This schedule reflects the fact that nighttime hours begin later in Spain, where the usual dinner time is between 20:30 and 22:00, than in the Greek of French locations analyzed previously. However, we are aware that it is dangerous to make general conclusions from a single observation and in fact we know from personal observations that in some towns in the same region, the bells sound during the whole night.

The chimes are separated by 2.4 seconds, and, as in the previous example, the bell strokes are repeated a couple of minutes later. It is curious to note that in the southwestern France site, the second stroke starts 2 minutes after the end of the main one, while in the NE Spain case, the second stroke is played 2 minutes after the beginning of the first. This small difference results in a notorious change in the pattern of the daily plots, as noted comparing Fig. 4a and Fig. 3.

A particular characteristic of the manner of ringing is this location is given by how the hour quarters are indicated. As seen in Fig. 4b, smaller ringing bells are played every quarter and the exact hours bell calls are preceded by the four strikes, one for each quarter. This fact is directly related to the traditional way to marking the hours, half-hours and quarter-hours in Catalonia, where, as example, 08:15 is referred as “one quarter of nine”, 08:30 as “two quarters of nine and 8:45 as “three quarters of nine”.

d) Oriolo, Calabria, S. Italia

The ORI station is located in the town of Oriolo, in the region of Calabria in southern Italy, and belongs to the Italian Seismic network (Istituto Nazionale di Geofisica e Vulcanologia, 2006). Seismic records related to bell ringing show a complex pattern, with clear differences from the previous examples (Fig. 5).

Firstly, the hourly rings cover the entire day, including night hours. Secondly, each hour quarter is marked following a particular tradition. As observed in Fig. 5, every 15 minutes, the bell stroke includes the number of chimes corresponding to the previous hour and the number of smaller amplitude strikes corresponding to the quarter (Fig. 5). As an example, 9:30 will the marked by 9 large chimes and 2 additional, smaller strikes. The strikes of the bells are separated 1.7 seconds and the bell stroke marking the quarters start three seconds after the last chime of the loudest bells. As can be easily calculated, this tradition results in a total of 768 bell strikes during a single day, a that does not seem to disturb local population.

Discussion and Conclusions

We have shown how seismic recordings can be used to document the different traditions followed in Europe to mark the hours using striking clocks installed in bell towers. Of course, other instrumentation, such as microphones, would be more appropriate to do this type of research, but this contribution proves that existing seismic data, all publicly available, can be used for purposes very different from those usually considered in Earth sciences.

Two mechanisms can be invoked to explain the seismic recordings of bell ringing. First, the recordings may correspond to the vibration of the bell tower during the strikes, which is transmitted to the ground producing a movement that is recorded by the seismic sensor. Secondly, the recordings can be generated by the sonic waves produced by the bells and converted to mechanical vibrations close to the seismometer. Examples of acoustic signals recorded on seismometers are common, including sonic booms generated by airplane shock waves (https://blogs.ei.columbia.edu/2016/02/04/the-earth-shook-but-it-wasnt-an-earthquake/), explosions of bolides entering in the atmosphere (Hedlin et al., 2010), firework shows (Díaz et al., 2017) or accidental explosions in industrial plants (Schneider et al., 2018). Although discriminating between the two phenomena is not evident without collocated microphones, the inspection of the frequency content of the signals can provide some ideas about the origin of such signals. Fig. 6 shows the spectrogram of the signals recorded during bell ringings in the four sites. In all cases, the energy extends over the entire frequency range, from 0.1 to 50 Hz, the maximum frequency that can be explored with our dataset. Hinzen et al (2012), analyzed the frequency content of the seismic signals recorded during the ringing of a large bell in the Cologne Cathedral, observing the largest response amplitudes at 0.833 Hz, a value falling between the first and second eigenfrequencies of the tower. In our cases, the largest amplitudes are observed at frequencies ranging between 10 Hz (Lunas) and 37 Hz (Sta Maria M.). These values are far from the natural frequencies of bell towers, hence favoring the hypothesis of an acoustic/mechanical coupling near the seismometers, although a modeling effort, out of the scope of this paper, will be needed to confirm or not this point.

The RLS station in Greece shows maximum amplitudes at frequencies between 10 and 40 Hz, with a clear decrease for higher and lower frequencies. The site in SW France shows maximum amplitudes between 1 and 20 Hz, with a secondary maximum between 25 and 45 Hz. E120 in NE Spain also shows two energy packets but in this case the most energetic ranges between 25 and 50 Hz, while the secondary package has lower frequencies, in the 1-25 Hz band. The frequency content of the bell strikes signaling the quarters and the hours are similar, with only minor differences in the energy content of the high frequency band. In the ORI station in southern Italy the energy is uniformly distributed along the spectrogram, although the 5 to 30 Hz band has a slightly higher level of energy. These minor differences in the frequency content of the signals are probably related to variations in the distance between the bells and the seismometer, to structural differences in bell towers or to changes in the subsoil properties between the sites investigated. A detailed modeling of each case, which is out of the scope of this paper, would be necessary to fully understand the origins of the signals.

It must be pointed that, although disturbed by bell ringing, these stations successfully perform their main task, that is, record the arrival of seismic waves generated by earthquakes. Sometimes, seismic waves are detected close to bell ringing times, giving the opportunity to compare the relative amplitudes of both features. Fig. 7 shows two examples of such cases, one displaying the arrival of seismic waves from a regional event and the second one showing seismic waves from a distant earthquake. In the first case, the data acquired in RLS show the arrival of the body waves generated by a regional earthquake of local magnitude 3.5 and epicenter near the town of Chakida, at a distance of about 180 km of Riolos, some seconds before an hourly bell strike. In the second example, the P-waves of a large earthquake of magnitude 7.1 near the east coast of Honshu, Japan, arrive at the Sta Maria de Montmagastrell station (NE Spain) after a 10.000 km trip few seconds before the 16:45 bell strike.

From a seismological point of view, the seismic recordings of bell ringing can be used to perform studies analyzing the relative contribution of sonic and mechanical waves to the detected ground motion or to evaluate amplification factors for each specific site. Having a large number of repetitive sources can also allow to investigate possible time variations in amplification or frequency contents, using auto-correlation techniques (Sánchez‐Pastor et al., 2019), a point that could be related to changes in the mechanical properties of the subsoil due, for example, to variations in the groundwater level. Regarding the interest of this contribution for the social sciences, we are aware that significant changes in bell ringing can occur between close locations, sometimes because of very specific problems. As an example, today in Spain there is an open discussion about whether the chimes should be suppressed or not during the night hours. Each municipality tends to make its own decision, so it is difficult to extend our observations at regional or national level. Even so, we believe that our work, beyond presenting a curious kind of seismic record, can contribute to a better understanding of the different traditions still active in Europe to mark the hours and may encourage more exhaustive studies on this topic using acoustic or infrasound detectors. Additionally, we believe that this survey can be used to reach an audience that does not usually worry about seismic records, to bring new collaborations with social sciences such as ethnography, and to contribute to the development of the so-called "citizen seismology", seeking to involve citizenship with the seismic observations (e.g. Subedi et al. 2020, Diaz et al., 2020).

Data and Methods

Seismic data used in this contribution were collected as part of the TopoIberia-Iberarray and Pyrope temporary deployments and from permanent stations from the Italian and Greek seismic networks. The Orfeus EIDA node (https://www.orfeus-eu.org/data/eida , http://doi.org/10.17616/R3V06T) was used to get access to the seismic data.

Many of the Figs of this contribution were produced using the Generic Mapping Tools (GMT) software (Wessel, P., Smith, W.H.F., Scharroo, R., Luis, J., Wobb, 2013)

Acknowledgments

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Figure Captions

Fig. 1: **Examples of seismic recordings with bell ringing signals** in four European locations. Each plot corresponds to one day, and each trace represents the same minute at every hour on that day. Time scale is in seconds relative to the origin of the line.

Fig. 2: Bell ringing in Riolos (Greece) on July 6, 2019. Each line shows one minute and a line is shown every 30 minutes, from 00:00 to 23:59 UTC on July 6, 2019 (3:00 02:59 Greek local time). The dashed line shows the increasing delay in the bell clock.

Fig. 3: Bell ringing in Lunas, SW France. a) Daily data for June 29, 2012 (02:00 01:59 French local time). Each line shows 3.5 minutes and there is one line per hour. Observe the second strike 2 minutes after the first and the Angelus strikes, shown by red ellipses.

Fig. 4: **Bell ringing in Sta Maria Montmagastrell (NE Spain)** a) Daily recordings during April 1, 2011 (02:00 01:59 local time). Each line shows 200 seconds and there is one line per hour. b) Chimes between 12:00 and 13:00 local time, showing the bell ringing used to mark quarters. Each line shows one minute of signal and there is one line every 15 minutes.

Fig. 5: Belt ringing in Oriolo, S Italy during July 21, 2019 (02:00 01:59 Italian local time). Each line shows one minute and there is one line every 15 minutes.

Fig. 6: Spectrograms of the four sites investigated. a) Riolos, Greece (6/7/2019) b) Lunas, SW France (29/6/2012) c) NE Spain (1/4/2011) and d) Oriolo in southern Italy

(21/7/2019). In all cases a one-minute long signal is shown, varying the color palette to better represent the recorded amplitudes.

Fig. 7: **Examples of regional and teleseismic events arriving at times close to the bell strikes**. a) Regional earthquake (magnitude 3.5, 19/7/2019) recorded some seconds before 20:00 bell ringing at station RLS (Riolos, Greece). b) Teleseismic P-waves form a magnitude 7.1 earthquake in Japan (7/4/2011) reaching the E120 station in northeastern Spain a few seconds after the 16:45 bell strike.

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Figure 1

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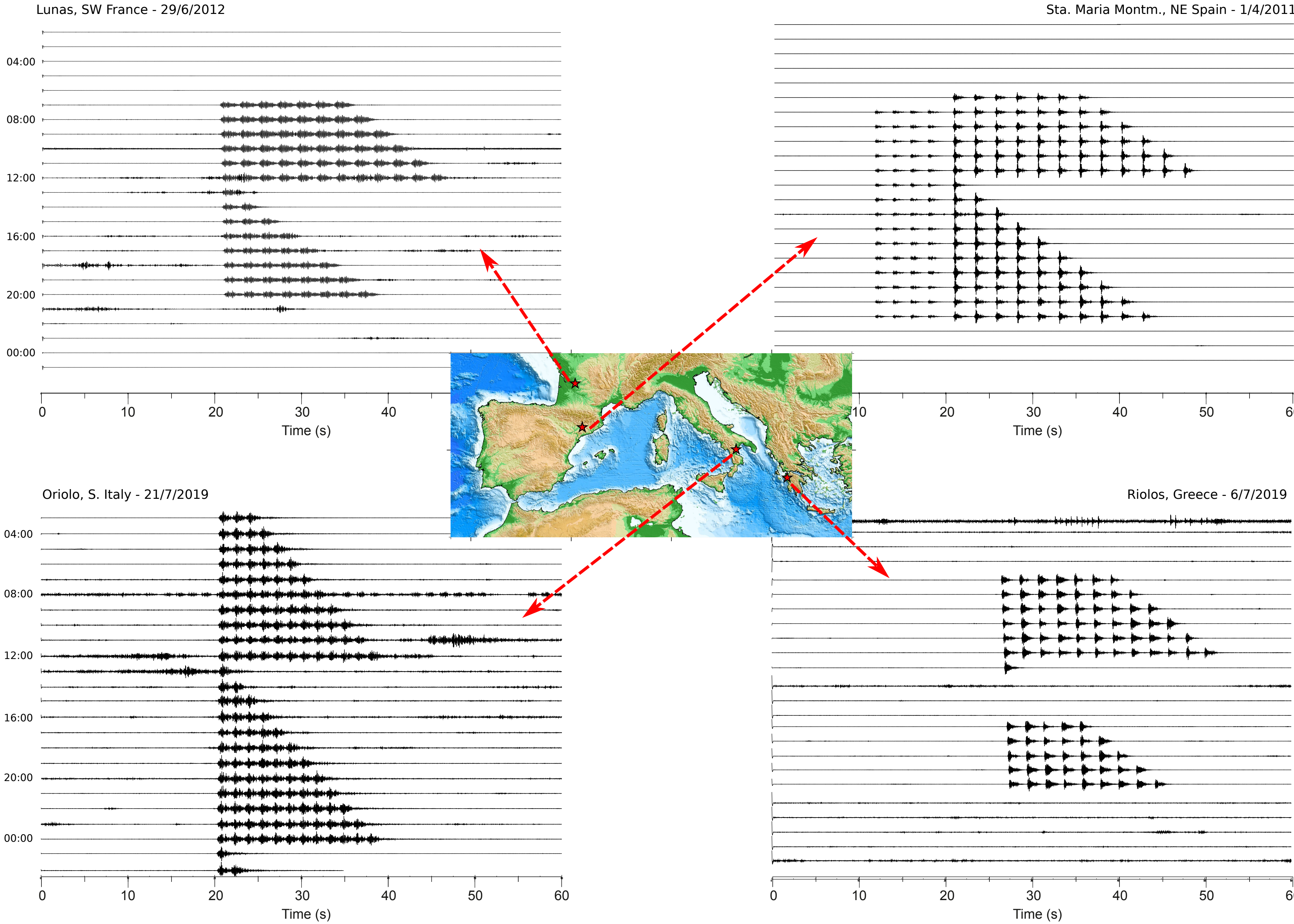

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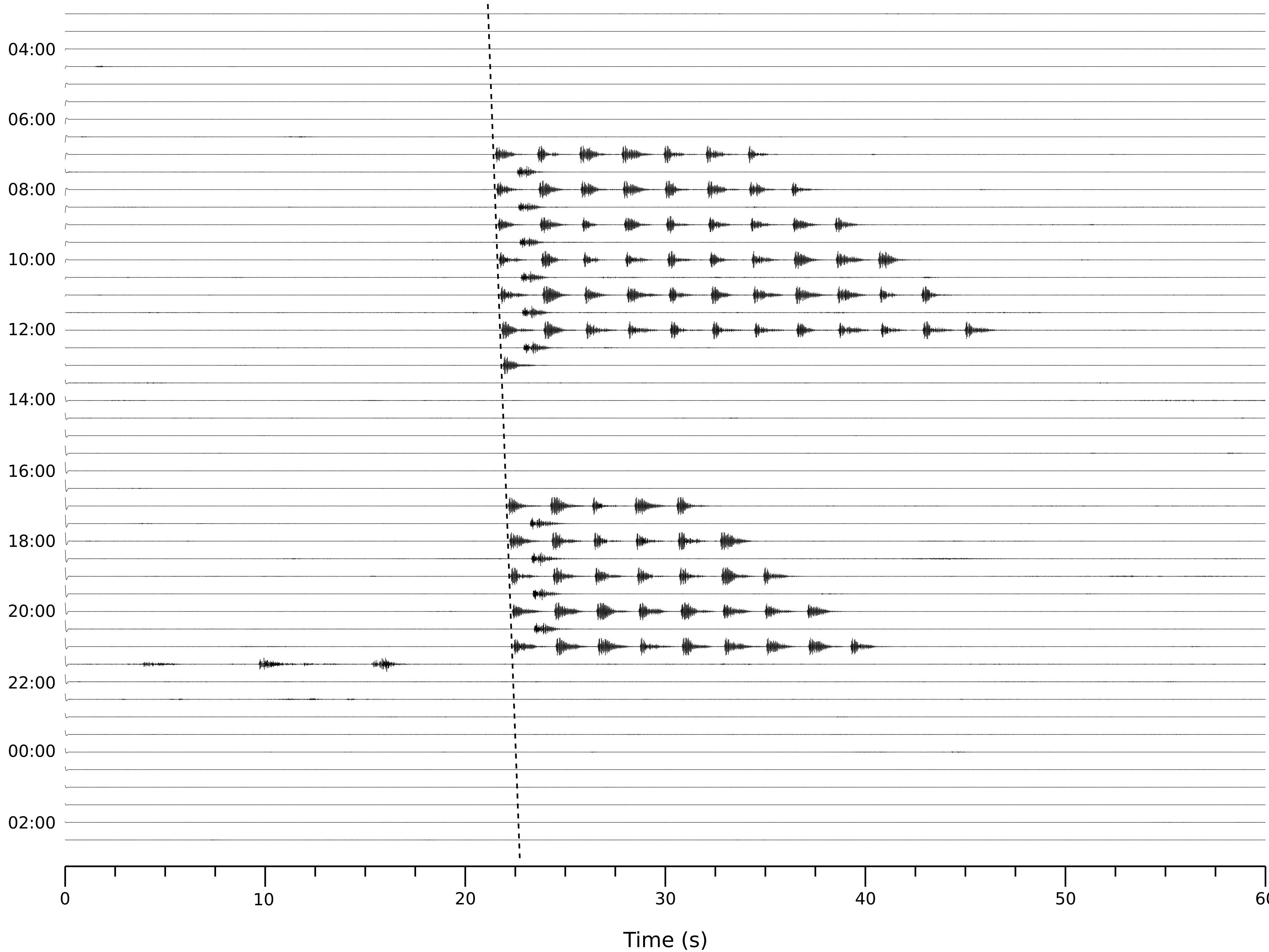

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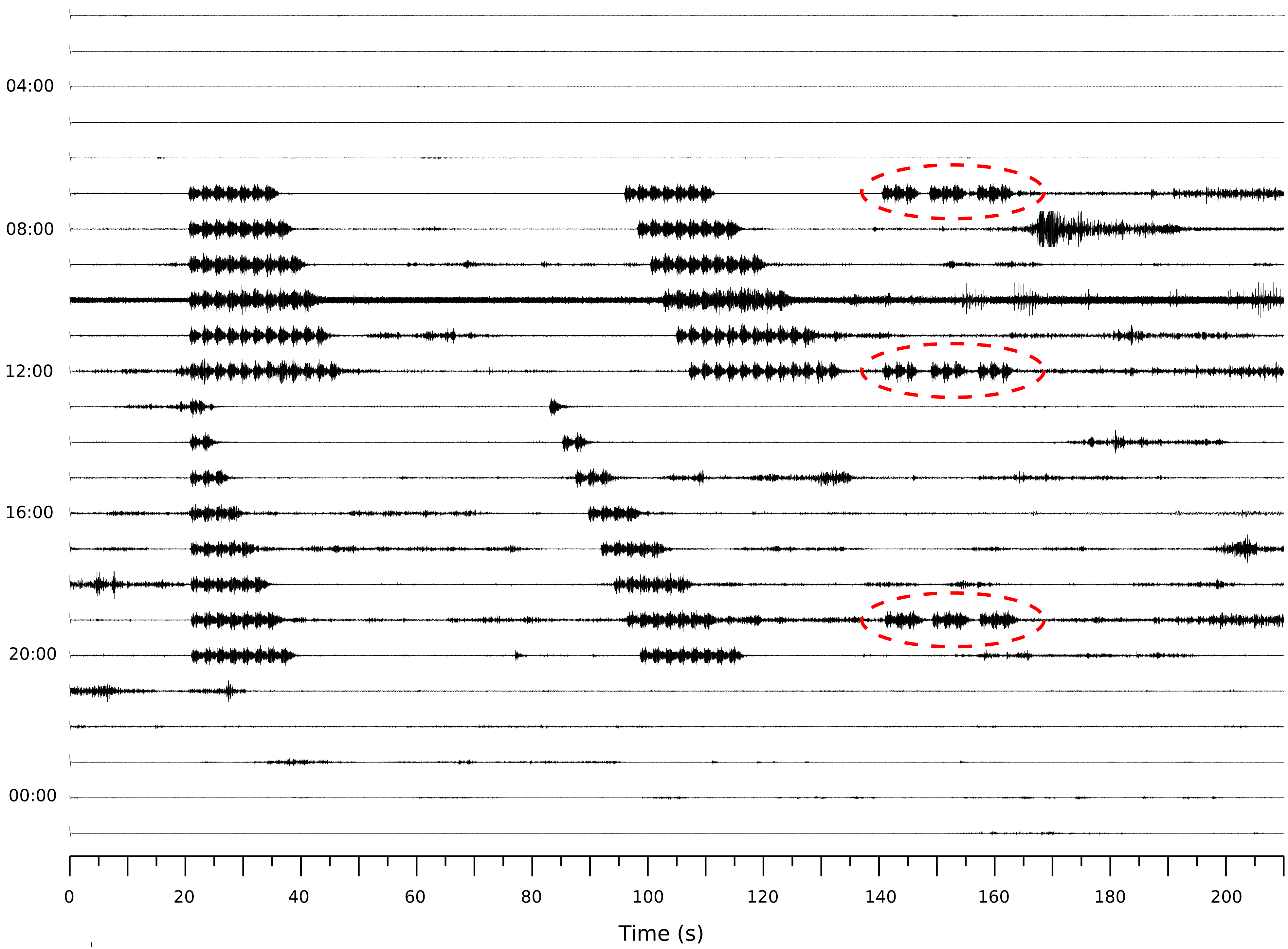

Figure

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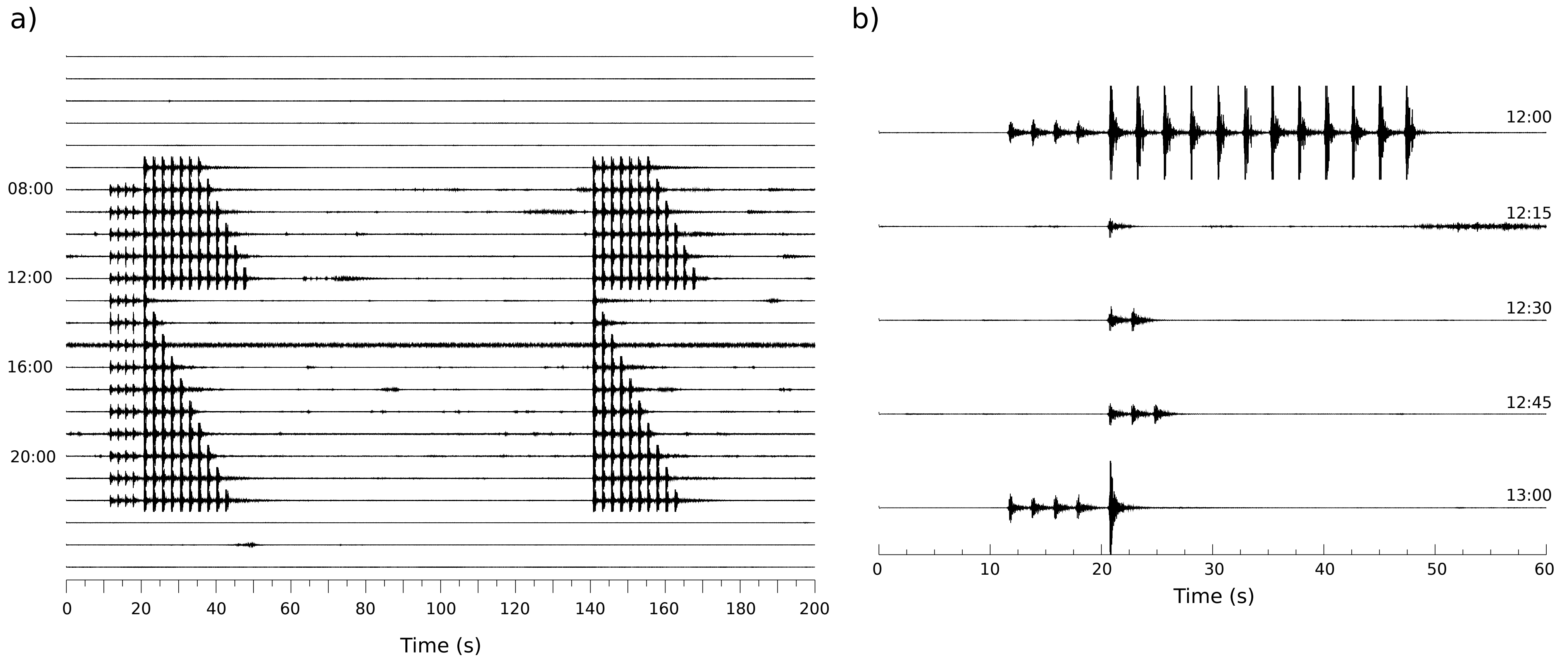

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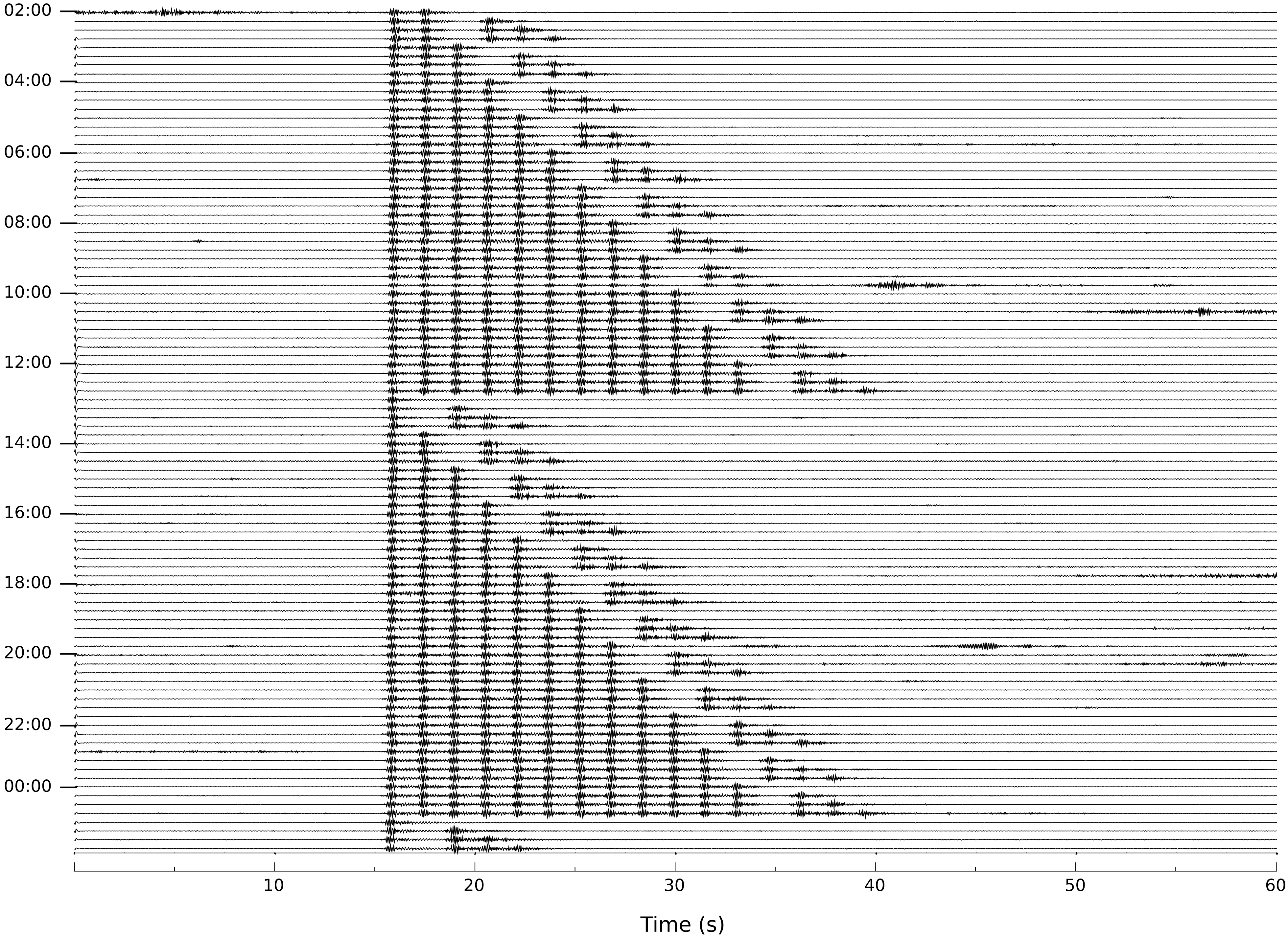

02:00
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Time (s)

Figure 6

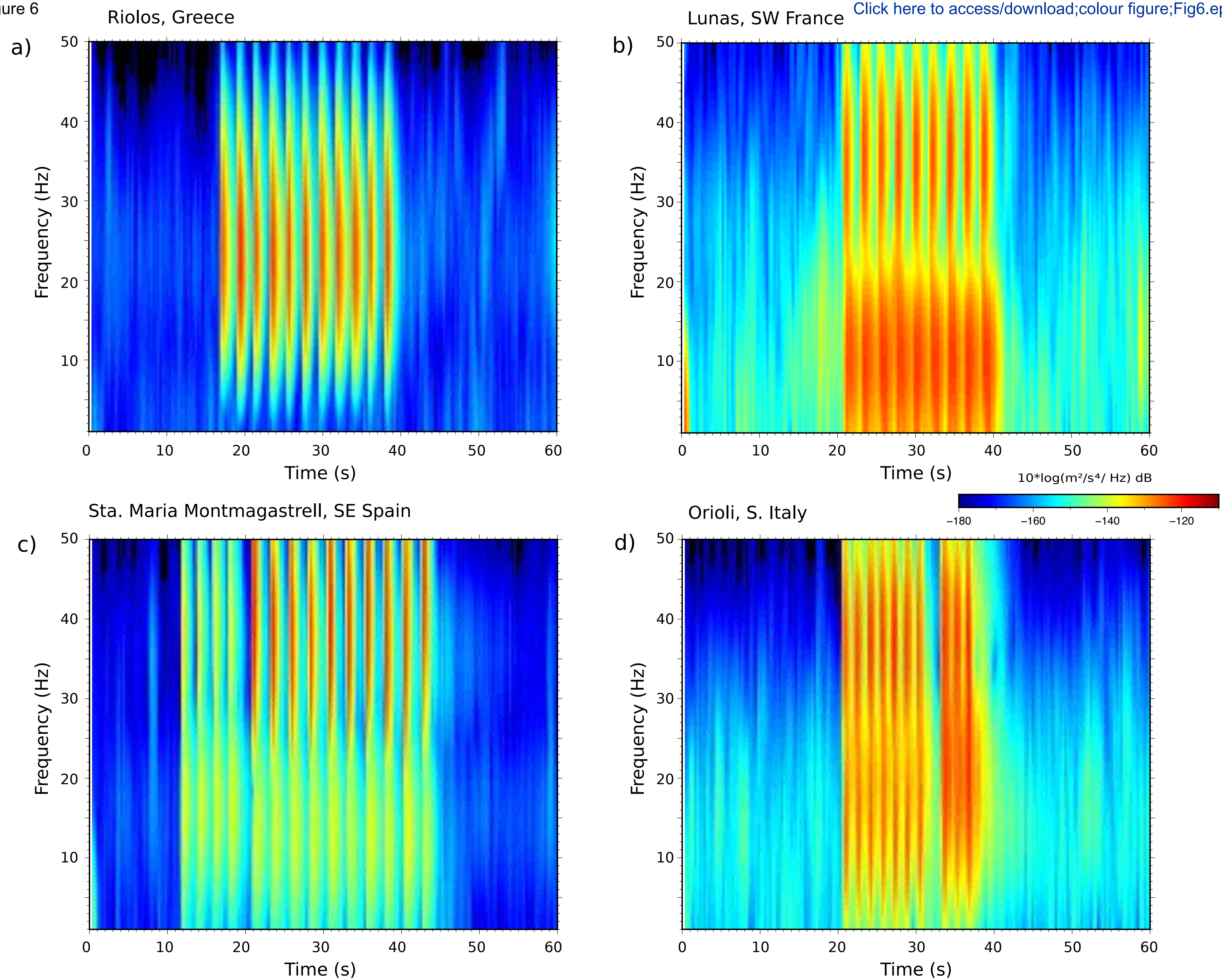
a)
Riolos, Greece
b)
Lunas, SW France
c)
Sta. Maria Montmagastrell, SE Spain
d)
Orioli, S. Italy
Frequency (Hz)
Time (s)
10*log(m^2/s^4/ Hz) dB
−180
−160
−140
−120

Figure 7

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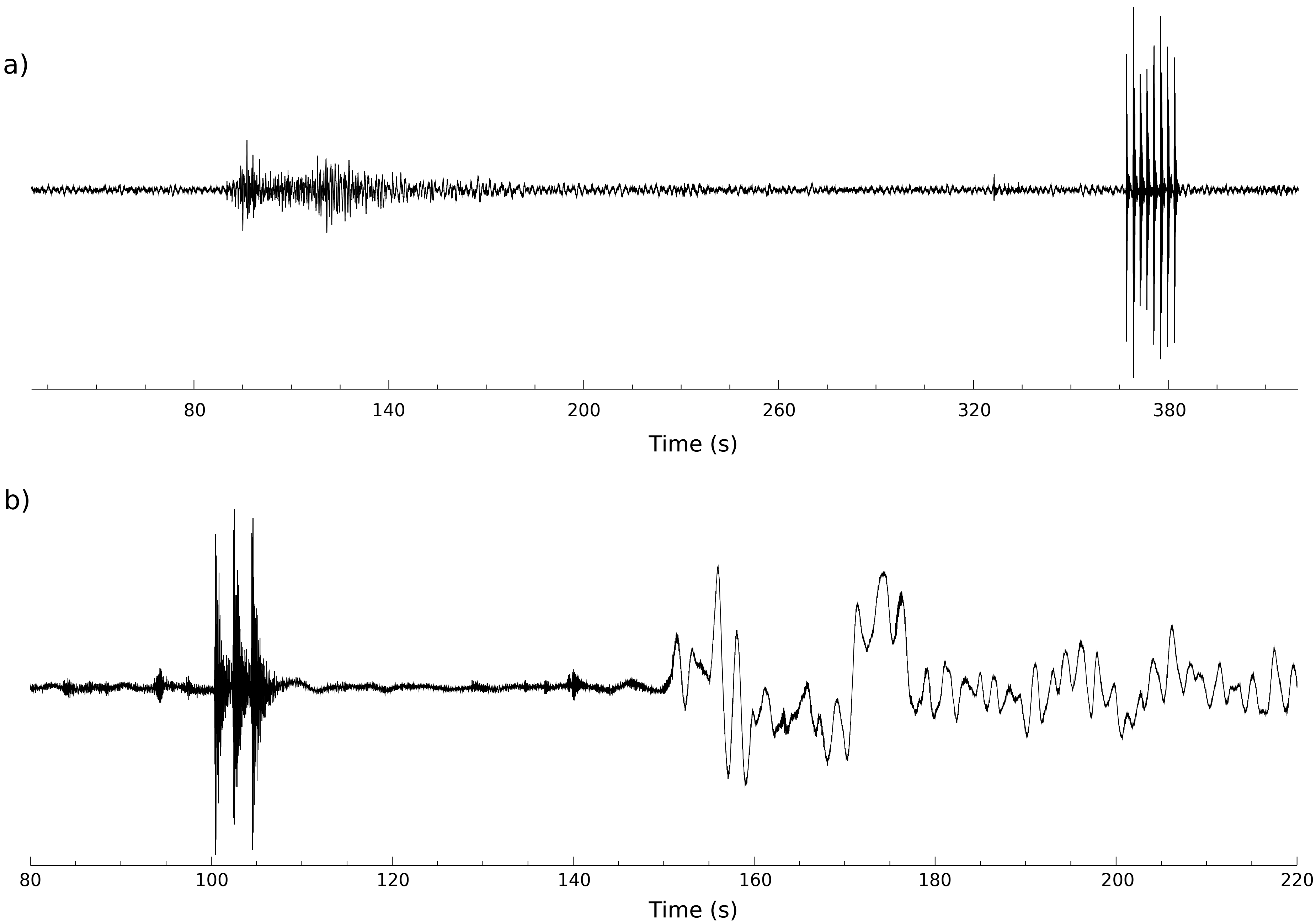

Country	Location	Church Name	Station code	Network code	Station Lat.	Station Long.	Distance to tower bell (m)
Greece	Riolos (W Peloponnessus)	Agios Ioannis	RLS	HL	38.0559	21.4647	30
France	Lunas (Dordogne)	Saint Jean Baptiste	PY34B	X7	44.9175	0.4035	15
Spain	Sta. Maria Montmagastrell (Catalonia)	Santa Maria	E120	IB	41.7203	1.1062	3
Italy	Oriolo (Calabria)	San Giorgio	ORI	IV	40.0510	16.4504	25