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Studies on infrasound technology applied to the discrimination of chemical explosions from tectonic events

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OBSERVATÓRIO SISMOLÓGICO

INTRODUCTION

Differentiating between tectonic events and man-made events is a difficult task, especially when the sources are close to each other. Existing methods do not always provide certainty. In this work, co-located infrasonic and seismic sensors are used for discrimination.

METHODS/DATA

This study proposes a practical approach using infrasonic and seismic sensors located in the same site to help differentiate these events. The co-located sensors were installed in two different sites: Brasília National Park (PNB) and the Sete Lagoas city, Brazil.

START

RESULTS

Low-magnitudes earthquakes (< 3) appear to be relatively poor infrasound sources, and that absence of infrasound is being used as a source-type discriminant in this work.

CONCLUSION

The combination of seismic and infrasound monitoring provides a good way of discriminating events. In our case, all local tectonic events did not generate infrasonic signal, in other hand, all quarry blasting generate.

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INTRODUCTION

OBSERVATÓRIO SISMOLÓGICO

Distinguishing between tectonic and artificial events (quarry blasts) is a challenge when the sources are close to each other, and when they are low-magnitudes (<3). This is a common problem when forced mass movement trigger seismicity.

Despite known a variety of discriminants (Postema, 1996; SSA, 2020; Wang et al., 2020; Hissely, 2022; Korrat et al., 2023; Saadalla et al., 2023) uncertainty about the origin and nature of these events may persist. This problem would not exist if the mines companies inform the explosion's origin time and location.

Explosions produce seismic signal and also infrasonic signal (ReVelle et al., 2004; Che et al., 2010; Czanik, 2021), e.g., seismo-acoustic analysis was used to distinguish between quarry blasts and local earthquakes in Romania (Ghica et al., 2016). This approach will be used in this work to help to discriminate between these two type of sources.

OBJECTIVES

This study proposes a practical approach using infrasound and seismic stations located together to differentiate the nature of the events. The co-located stations were installed in two sites in different periods: Brasilia National Park - PNB (**Fig. 1**) and Sete Lagoas city (**Fig. 2**), both in Brazil.

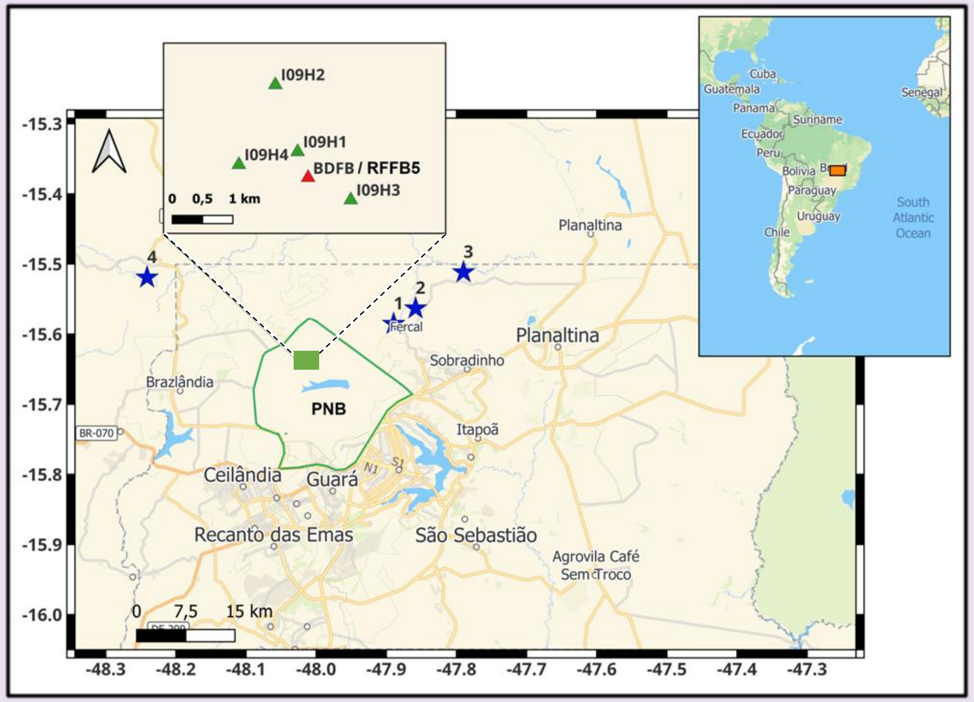


***Fig. 1** - PNB site, Brasilia*

Location of the I09BR infrasound station's four elements (H1, H2, H3 and H4 - green triangles) and the BDFB seismic station (red triangle), where it was co-located the RFFB5 station (composed by a seismic sensor and an infrasonic sensor) temporary. The blue stars indicate four blasting mines.

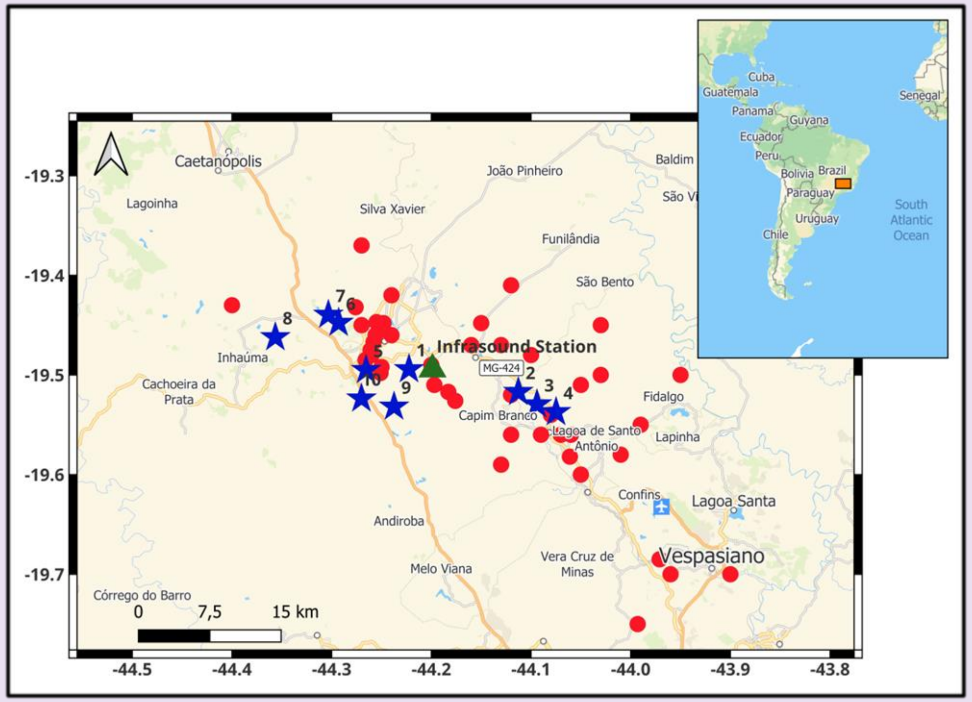


***Fig. 2** - Sete Lagoas site, Minas Gerais State*

The green triangle represents the acoustic and seismic vertical short period (SP) co-located station, denominated RFFB5. The blue stars represent the blasting mines in operation. The red circles indicate the epicenters of natural events from 1931 to 2022 (IAG-USP and SIS-UnB catalogues), all prior to RFFB5.

METHODS/DATA

The PNB vicinities are devoid of natural events, whose prevent to achieve the objective of this study. To address this limitation, we have selected Sete Lagoas city as our research location, as it experiences both low-magnitudes earthquakes and man-made events in its vicinity.

The data produced in the PNB site served for comparing the signals recorded by the Brazilian IMS stations (BDFB and I09BR) with the recorded by RFFB5 equipment (one vertical short period sensor plus one acoustic sensor integrated), co-located with BDFB (**Figs. 1** and **3**) and also used in Sete Lagoas site, **Fig. 2**.

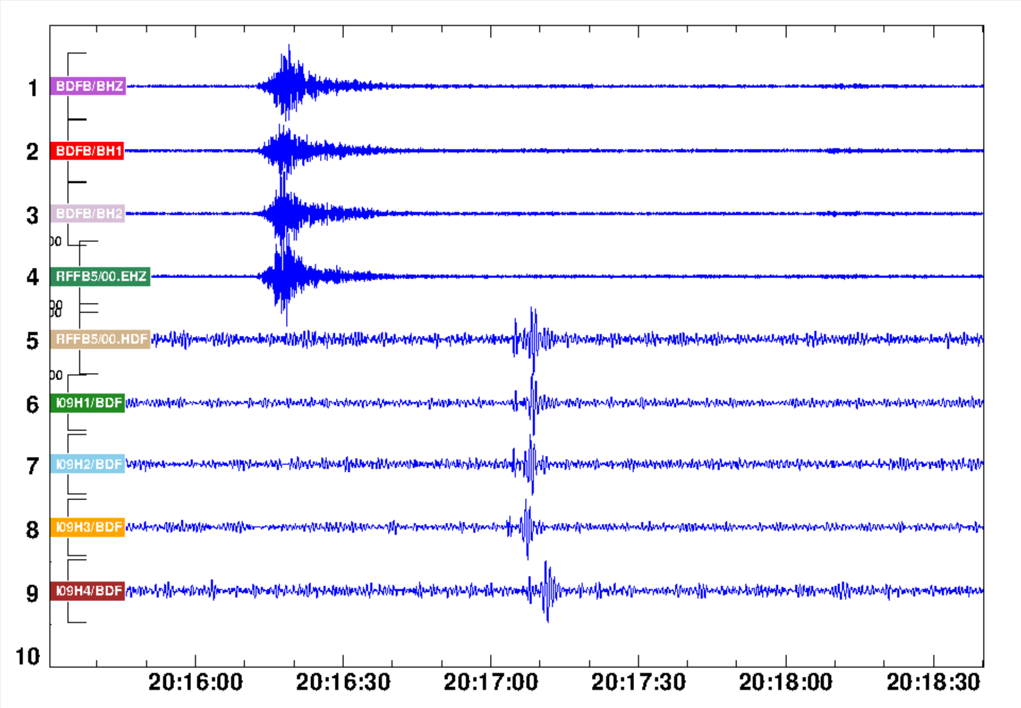


Fig. 3 *- Artificial event (Mine #2) occurred on 12/08/2022, at 20:16:12.6 UTC, recorded at PNB site (**Fig. 1**) by: BDFB (traces 1, 2 and 3); RFFB5 (co-located at BDFB site), trace 4 (seismic signal) and trace 5 (acoustic signal); and I09BR (traces 6, 7, 8 and 9). It was used a 4th order Butterworth Filter for the seismic signals (3 - 12Hz) and for the acoustic signals (1 - 3 Hz).*

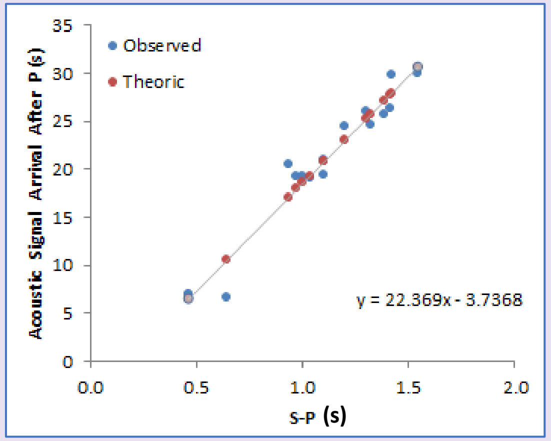
METHODS/DATA

In Sete Lagoas site (Fig. 2), the RFFB5 station recorded 25 local events (Δ < 40 km). In 16 events were detected seismic and acoustic signals (white lines in the Table). In the remaining 9 events (in yellow), only seismic signals were detected, clearly related to micro earthquakes.

#	A	B	C	D	E	F	G
1	03/10/2022	18:13:46	yes	yes	1.41	26.40	27.80
2	03/10/2022	18:15:06	yes	yes	1.32	24.60	25.79
3	04/10/2022	20:14:35	yes	yes	0.93	20.50	17.07
4	07/10/2022	12:59:06	yes	no	0.81	-	14.38
5	07/10/2022	20:11:17	yes	no	0.82	-	14.61
6	10/10/2022	14:07:40	yes	yes	0.46	6.90	6.55
7	11/10/2022	14:45:17	yes	yes	1.03	19.10	19.30
8	14/10/2022	16:33:30	yes	yes	1.54	30.00	30.71
9	16/10/2022	12:18:22	yes	no	1.3	-	25.34
10	17/10/2022	18:27:36	yes	yes	1.30	26.10	25.34
11	19/10/2022	14:16:51	yes	yes	0.46	7.00	6.55
12	20/10/2022	21:57:14	yes	no	1.30	-	26.34
13	20/10/2022	22:08:47	yes	no	1.30	-	26.34
14	20/10/2022	22:43:17	yes	no	1.30	-	26.34
15	21/10/2022	14:46:09	yes	yes	0.97	19.20	17.96
16	21/10/2022	16:30:39	yes	yes	1.42	29.80	28.03
17	29/10/2022	14:15:27	yes	yes	1.00	19.30	18.63
18	29/10/2022	14:25:54	yes	yes	1.10	19.50	20.87
19	31/10/2022	14:14:07	yes	yes	0.64	6.60	10.58
20	18/11/2022	03:30:38	yes	no	1.29	-	25.12
21	21/11/2022	19:08:44	yes	yes	1.38	25.80	27.13
22	22/11/2022	03:34:02	yes	no	0.84	-	15.05
23	24/11/2022	02:02:37	yes	no	0.75	-	13.04
24	28/11/2022	16:04:46	yes	yes	1.20	24.50	23.11
25	29/11/2022	20:21:48	yes	yes	1.10	21.00	20.87

***A** - Date (dd/mm/yyyy)* ***B** - Time UTC (hh:mm:ss)*
***C** - Seismic signal* ***D** - Acoustic signal* ***E** - S–P (s)*
***F** - Observed acoustic signal time after first P wave (s)*
***G** - Theoric acoustic signal time after first P wave (s)*

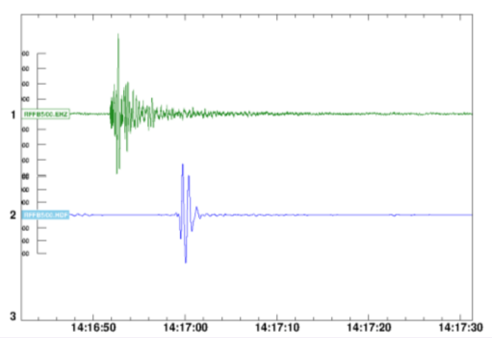
Acoustic wave arrival time at the Sete Lagoas site can be predicted using the average speed of the acoustic waves and the mathematical equation y=22.37x – 3.74, derived from the linear regression analysis below. This enables determination of a time window for the expected arrival time of the infrasonic signals for events without acoustic signals. The window length is based on the average differences between F and G columns.



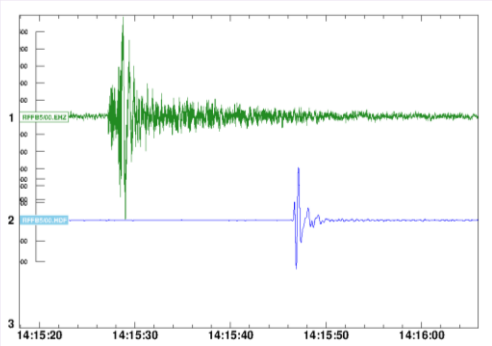
Linear regression of acoustic signal arrival time after first P seismic phase (in seconds) regarding to S-P time difference (in seconds).

RESULTS

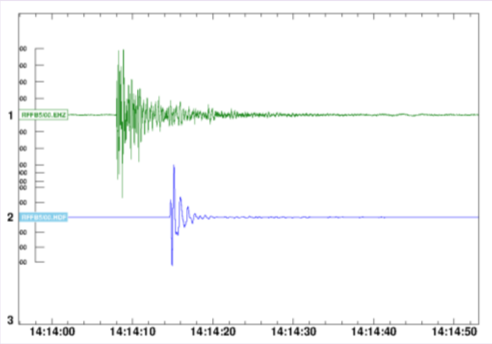
Three examples, from 16, of detonations in mines that generated both seismic and acoustic signals. It was used a 4th order Butterworth Filter for the acoustic signals (1 - 3 Hz).



Event #11.

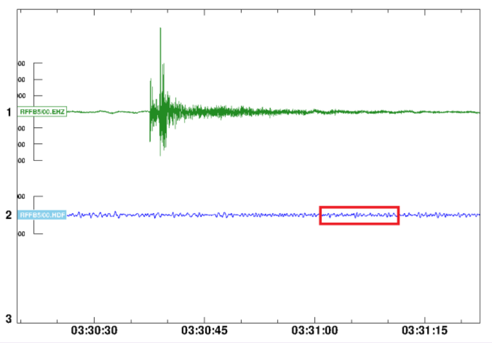


Event #17.

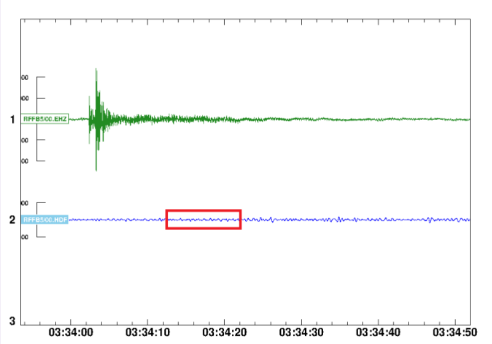


Event #19.

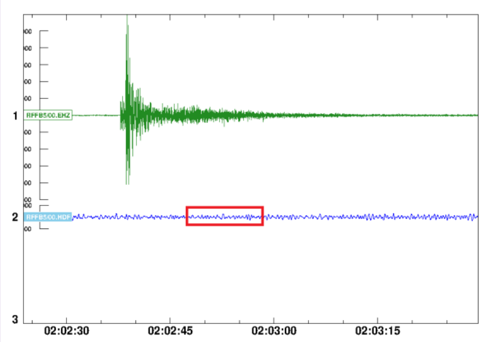
Events that generated only seismic signals, occurred out of working hours, when detonations are not typically performed, and with S-P consistent with mines distances. The red window denotes the expected record time of the acoustic signals. It was used a 4th order Butterworth Filter for the acoustic signals (1 - 3 Hz).



Event #20.



Event #22.



Event #23.

Mutschlecner and Whitaker (2005) have shown that the absence of acoustic waves can be possible explain the nature of the event. Their research demonstrates that small-magnitudes earthquakes do not produce infrasonic signals, as the atmospheric infrasound generation requires a minimum peak surface acceleration threshold between 10 and 20 cm/s².

Arrowsmith et al. (2011) show that low-magnitudes earthquakes appear to be relatively poor infrasound sources and that infrasound should be used as a source-type discriminant.

INTRODUCTION
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CONCLUSION

The utilization of a co-located seismic and infrasound stations is an effective method to discriminate low-magnitudes tectonic events and quarry blasting with source close to each other. The absence of acoustic signals in local events serves as an useful discriminator, allowing us to classify an event either as natural occurrence or triggered by the mine, when they take place within the pit. Infrasound stations have proven to be reliable sources of information, particularly in situations where uncertainty exists regarding the nature of an event.

It is important to note that the detectability of seismo-acoustic signals is influenced by various factors, including event magnitude, distance, and meteorological conditions. The study case conducted in Sete Lagoas site revealed that low-magnitudes earthquakes did not produce detectable acoustic signals, even with an infrasound station close to the source (~5 km). Therefore, while the co-located seismic and infrasound station offers significant advantages, it is necessary to consider these factors and account for variations in event characteristics and signal detectability. The way to manage these factors is to deploy one or two 4-elements infrasound arrays in the vicinities of the mines under investigating, in order to locate the events sources.

Overall, the combination of seismic and infrasound monitoring provides a good and reliable method to discriminate events. It enhances our understanding of characteristics of both natural and man-made events by contributing to these events classification.

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