UNIVERSIDADE DE BRASÍLIA
INSTITUTO DE GEOCIÊNCIAS

EVOLUÇÃO DAS PESQUISAS NA TECNOLOGIA INFRASSÔNICA E A CONTRIBUIÇÃO DA ESTAÇÃO BRASILEIRA DE INFRASSOM NO MONITORAMENTO DE EVENTOS SISMO-ACÚSTICOS

Dissertação de Mestrado N° 196

Brandow Lee Neri

Orientador: Prof. Dr. Lucas Vieira Barros

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RESUMO

Este trabalho tem por objetivo apresentar a tecnologia infrassônica e suas aplicações, a partir do estudo da evolução tecnológica e sua utilização pela estação brasileira de infrassom para detecção de eventos sismo-acústicos. Ele é composto por dois artigos. O primeiro tem como título: Evolução das pesquisas na tecnologia de infrassom usando a Teoria do Enfoque Meta-Analítico Consolidado. Nesse artigo, apresentamos as pesquisas relacionadas à tecnologia infrassônica, um tema consideravelmente recente, por se tratar de uma área do conhecimento ainda pouco explorada. Todavia, o processamento, a análise e a interpretação de sinais infrassônicos já possuem diversas aplicações. Os primeiros estudos relacionados a sinais infrassônicos datam da década de 1880, com a erupção do vulcão Krakatoa na Indonésia. No entanto, foi a partir de 1945, com a realização dos primeiros testes nucleares, que a tecnologia infrassônica teve avanços significativos. Esse estudo apresenta um levantamento sistemático das principais contribuições da literatura de alto impacto nos estudos que utilizam a tecnologia infrassônica. A pesquisa exploratória, com abordagem quantitativa, foi realizada utilizando a Teoria do Enfoque Meta-Analítico Consolidado (TEMAC). O termo “Infrasound” foi definido como uma string de busca, na base de dados do Web of Science. A coleta de dados mostrou que houve um crescimento significativo no número de citações sobre o tema nos últimos 20 anos, atingindo a marca de 18.606. Esse fato está relacionado a alguns eventos principais: a criação do Sistema Internacional de Monitoramento para verificar a conformidade com o Tratado de Proibição Total de Testes Nucleares e com a disponibilização de dados desta rede para a comunidade científica, a partir de 2005. No segundo artigo, intitulado A contribuição da estação I09BR, do Sistema Internacional de Monitoramento, para detecção de eventos infrassônicos, apresentamos o infrassom como uma das quatro tecnologias usadas pelo Sistema Internacional de Monitoramento (IMS) para verificar a conformidade com o Tratado de Proibição Total de Testes Nucleares (CTBT). Explosões nucleares atmosféricas e subterrâneas, próximas da superfície, geram ondas sonoras de baixa frequência, que são detectadas pela rede mundial infrassônica do IMS. A única estação que utiliza essa tecnologia, instalada no Brasil, está no Parque Nacional de Brasília, desde 2001, cujo código é I09BR. Como os últimos testes nucleares foram subterrâneos, e ocorreram no continente asiático, a estação infrassônica brasileira não detectou qualquer explosão nuclear desde sua instalação. Contudo, várias outras fontes de sinais de infrassom foram detectadas pela estação I09BR, como, por exemplo: explosões de minas, bólidos, tempestades, microbaroms etc. A pesquisa apresenta os resultados da análise de dados, destacando as principais fontes de sinais que a estação I09BR vem detectando ao longo dos anos (2015-2021) e abordando as diferenças no número de detecções devido à redução do ruído cultural devido aos decretos da pandemia Covid-19.

Palavras-Chave: Infrassom; Sinais Infrassônicos; Estudo em infrassom; I09BR; TEMAC.

ABSTRACT

This work aims to present infrasonic technology and its applications, based on the study of technological evolution and its use by the Brazilian infrasound station to study seismo-acoustics events. It consists of two articles, the first of which is titled: Evolution of research in infrasound technology using Consolidated Meta-Analytic Approach Theory. In this article, we present research related to infrasonic technology, a considerably recent topic, because it is an area of knowledge that is still little explored. However, the processing, analysis, and interpretation of infrasonic signals already have several applications. The earliest studies related to infrasonic signals date back to the 1880s, with the eruption of the Krakatoa volcano in Indonesia. Nevertheless, it was from 1945 onwards, with the performance of the first nuclear tests, that infrasound technology had significant advances. This study presents a systematic survey of the main contributions of high-impact literature regarding studies using Infrasound technology. This exploratory research, with a quantitative approach, was carried out using the Consolidated Meta-Analytical Approach Theory – TEMAC. The term "Infrasound" was defined as a search string and the Web of Science as a database. Data collection showed that there has been significant growth in the number of citations on the topic in the last 20 years, reaching the mark of 18606. This fact is related to some main events: The creation of the International Monitoring System (IMS) to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and with the availability of data from this network to the scientific community as of 2005. In the second article, entitled The contribution of the I09BR station of the International Monitoring System for infrasound events detection, we present infrasound as one of the four technologies used by the International Monitoring System (IMS) to verify compliance with the Comprehensive Nuclear Test Ban Treaty (CTBT). Atmospheric and underground nuclear explosions near the surface generate low-frequency sound waves that are detected by the IMS worldwide infrasound network. The unit station that uses this technology in Brazil and is part of the IMS is located at the Brasília National Park and has been operating since 2001, with the code I09BR. No nuclear tests were detected by I09BR installation, due to distances, environment, and yield. However, there are several other sources of infrasound signals detected by the I09BR station, such as detonations in mines, bolides, storms, microbaroms, among others. This work aims to present the Brazilian infrasound station highlighting the main signal sources that have been detected over the years (2015-2021) and addressing the differences in the number of detections due to the reduction of cultural noise due to pandemic decrees Covid-19.

Key words: Infrasound; Infrasonic Signals; Study in infrasound; I09BR; TEMAC

Sumário

CAPÍTULO 1: INTRODUÇÃO

Esta dissertação é apresentada na forma de dois artigos, quais sejam: O estudo da evolução das pesquisas na tecnologia de infrassom usando a Teoria do Enfoque Meta-Analítico Consolidado e A contribuição da estação I09BR, do Sistema Internacional de Monitoramento, para detecção de eventos infrassônicos. É composta por quatros capítulos: Introdução, dois artigos (submetidos), Discussão e Conclusões. No Capítulo 1, a pesquisa é introduzida e contextualizada; no Capítulo 2, está o primeiro artigo, intitulado: *Evolution of research in infrasound technology using Consolidated Meta-Analytic Approach Theory*; no Capítulo 3, está o segundo artigo, intitulado: *The contribution of the I09BR station of the International Monitoring System for infrasound events detection*. No Capítulo 4 são apresentadas as considerações finais a respeito dos temas. Também faz parte da dissertação dois anexos. O Anexo A estão relacionadas todas as publicações feitas no âmbito dessa dissertação (primeira página), das quais fazem parte o livro: A participação brasileira na verificação do Tratado de Proibição Total de Testes Nucleares; o artigo: *Seismo-acoustic signal analysis and yield estimate of the Beirut, Lebanon accidental explosion on August 4, 2020*;e diversas produções publicadas em eventos nacionais e internacionais. O anexo B se encontra dois tutoriais, um tutorial de requerimento de dados do IMS e um tutorial de processamento de dados infrassônicos utilizando o DTK-GPMCC.

As explosões nucleares atmosféricas geram ondas sonoras audíveis e inaudíveis. O som audível de uma bomba nuclear pode se propagar a distâncias de até 500 km (Reams, 1996). Diferentemente, as ondas sonoras inaudíveis podem se propagar por grandes distâncias, de até 10.000 km, devido à baixa atenuação. A medição dessas ondas de frequência muito baixa, conhecidas como infrassom, fornece informações úteis para a detecção e localização de explosões nucleares atmosféricas (Gossard & Hooke, 1975).

O interesse inicial em estudar o infrassom surgiu a partir das observações de ondas geradas pela erupção explosiva do vulcão Krakatoa, em 1883, e a explosão do grande meteoro Tunguska, em 1908. As ondas infrassônicas de ambos os eventos foram registradas em barógrafos de estações meteorológicas em vários países. Entretanto, foi só a partir do início dos programas de teste de armas nucleares, no final dos anos 1940, que a tecnologia infrassônica teve avanços expressivos (Evers & Haak, 2007).

O interesse no uso de infrassom para fins de monitoramento diminuiu gradualmente após a assinatura do Tratado de Proibição Parcial de Testes, em 1963, que proibiu todos os testes atmosféricos e subaquáticos. No entanto, após o último teste nuclear na atmosfera, realizado pela China, em 16 de outubro de 1980, isso mudou. O desenvolvimento do Sistema Internacional de Monitoramento (IMS), para verificação do Tratado de Proibição Total de Testes Nucleares (CTBT), levou a um rápido renascimento do interesse na tecnologia infrassônica e uma série de novas estações de infrassom foram instaladas (Le Pichon et al., 2009).

O IMS é capaz de detectar, localizar e identificar explosões de rendimento de, pelo menos, 1 quiloton (kt) equivalente em TNT, na atmosfera, debaixo d'água e no subsolo. Esta rede mundial é formada por quatro tecnologias: sísmica, infrassônica, hidroacústica e de radionuclídeos. Os dados de cada estação são transmitidos para o Centro Internacional de Dados (Internacional Data Center - IDC), em Viena, e podem ser requeridos por pesquisadores dos países que assinaram o CTBT.

O Brasil assinou o CTBT em 26 de setembro de 1996 e o ratificou em 24 de julho de 1998. Além de pactuar com a não realização de testes nucleares, se comprometeu com a sua verificação no âmbito de três tecnologias: sísmica, infrassônica e de radionuclídeos. Dentre as instituições que operam estações do IMS no Brasil, está o Observatório Sismológico da Universidade de Brasília (SIS - UnB), local de pesquisa deste trabalho. O SIS – UnB é o responsável pela operação, manutenção e análise dos dados das estações IMS BDFB (tecnologia sísmica) e I09BR (tecnologia infrassônica) (Barros et al., 2020).

Esta pesquisa tem como foco a tecnologia infrassônica e suas aplicações, apresentando o estudo evolutivo dessa tecnologia e a contribuição da estação brasileira de infrassom para a detecção de eventos sismo-acústicos.

CAPÍTULO 2: ARTIGO - EVOLUTION OF RESEARCH IN INFRASOUND TECHNOLOGY USING CONSOLIDATED META-ANALYTIC APPROACH THEORY

Este capítulo é referente ao estudo da Evolução das pesquisas na tecnologia de infrassom usando a Teoria do Enfoque Meta-Analítico Consolidado e foi submetido como artigo científico na revista *Modern Sciences Journal*.

Evolution of research in infrasound technology using Consolidated Meta-Analytic Approach Theory

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Abstract

Research related to infrasound is considerably recent because it is an area of knowledge that is still little explored. However, the processing, analysis, and interpretation of infrasonic signals already have several applications. The earliest studies related to infrasonic signals date back to the 1880s, with the eruption of the Krakatoa volcano in Indonesia. Nevertheless, it was from 1945 onwards, with the performance of the first nuclear tests, that infrasound technology had significant advances. This study presents a systematic survey of the main contributions of high-impact literature regarding studies using Infrasound technology. This exploratory research, with a quantitative approach, was carried out using the Consolidated Meta-Analytical Approach Theory – TEMAC, by Mariano and Rocha (2017). The term "Infrasound" was defined as a search string and the Web of Science as a database. Data collection showed that there has been significant growth in the number of citations on the topic in the last 20 years, reaching the mark of 18606. This fact is related to some main events: The creation of the International Monitoring System (IMS) to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and with the availability of data from this network to the scientific community as of 2005.

I. INTRODUCTION AND PRINCIPAL HEADINGS

Infrasound is an inaudible sound to human beings and its study is also referred to by the same name. Because it is an acoustic disturbance, it is characterized by variations in air pressure, whose frequencies vary from 0.001Hz to 20Hz. In addition, due to its long wavelengths, between 17 m and 30 km, it can travel great distances in the atmosphere as it suffers low attenuation (Gossard & Hooke, 1975). These low-frequency sounds can be generated by natural or anthropogenic sources such as nuclear tests (Assink J. et al., 2018, 2016; Whitaker & Mutschlecner, 2008; Mutschlecner et al., 1999; Posey & Pierce, 1971; Reed, 1969; Donn & Shaw, 1967), volcanic activities (Matoza R. et al., 2019; Fee et al., 2013; Johnson J. & Ripepe M., 2011; Johnson J. et al., 2004; Cotten et al., 1971), chemical explosions (Davidson, & Whitaker, 1992; Evers L. & Haak, 2007; Grover, 1968; Hagerty et al., 2001), bolide (Arrowsmith S. et al., 2008; Brown P. et al., 2002; Edwards, 2010; Elbehiri et al., 2021), climatic events (Bowman & Bedard, 2010; Georges, 1973; Lin & Langston, 2009), launch and re-entry of rockets (Cotten et al., 1971; Garces M. et al., 2004).

The implementation of the IMS Infrasound Network, composed of 60 stations, is responsible for providing an unprecedented opportunity for the global study of infrasound. It employs new methods of signal processing (Y Cansi, 1995; Y Cansi & Klinger, 1997; Y Cansi & Le Pichon A., 2009); microbarometers (Alcoverro & Le Pichon A., 2005; Haak & Wilde, 1996; Marty, 2019; Raspet et al., 2019); efficient arrangement designs (Garces et al., 2004; Shields, 2005; Sutherland & Bass, 2004; Talmadge, 2018); atmosphere studies (Drob et al., 2003; Le Pichon A. et al., 2009); volcanology (Johnson B. & Ripepe M., 2011; Le Pichon A. et al., 2005; Matoza et al., 2019; Stein et al., 2015). Infrasound, despite being a technology of recent history, when examining the literature on it, the theme "Infrasound", based on Web of Science database (https://www.webofknowledge.com), found 1620 results, 1289 of which are articles published in scientific journals.

The infrasound studies are relatively recent compared to other research areas such as seismology, volcanology, and meteorology. The knowledge of the most relevant contributions and the authors on the subject are guiding new works in the area. Thus, the objective of this work is to offer a study that helps new researchers to carry out their research using infrasound technology. Bringing the evolution of the number of publications per year, the most cited documents, the authors who published, and those who were most cited. It also checks where the laboratories and main research areas are. To achieve these goals, exploratory research was carried out using the Consolidated Meta-Analytical Approach Theory (TEMAC) by Mariano & Santos (2017).

II. METHODS

This is an exploratory study, with a quantitative approach, using TEMAC, a technique based on three simple steps for identifying impact literature and analysis according to the bibliometric laws.

In the first stage, the database is organized from the Web of Science base, considered one of the best and most complete scientific databases (Mariano et al., 2011). The term “infrasound” was searched in scientific articles in all years of the database (1945 - 2021) and was found in 1289 articles.

In the second stage, the Web of Science platform, we use to find: the countries that were most published; the evolution of the theme per year; the list of authors who most published; the most cited authors; and the frequency of keywords.

Finally, in the third stage, the software VOSViewer 1.6.5, (https://www.vosviewer.com/) was used, which reads the data from the Web of Science database and, through clustering algorithms, separates the authors into groups according to their area of study. These groups are called clusters. According to Kretschmer (2004), bibliometric information is considered to define the authors' attributes and, based on the hypothesis that scientists with the same attributes have a higher frequency of citation among themselves, the network is separated into clusters. The analysis was carried out on March 10, 2021.

III. RESULTS

There are many scientific databases available, e.g Scopus, Google scholar, and SciELO. We are using the Web of Science database because it has fewer errors in its metadata and a recognized reputation for its quality and level of information available (Mariano et al., 2011). The first article about infrasound in this database is from 1953. Since then, the topic has reached 18606 citations, considering 1953 to March 2021. In addition, there is a progression in annual citations, with its highest peak in 2020, continuing up compared to previous years.

Some milestones justify the increase of scientific publications on the subject. One point is related to the first atmospheric nuclear test after the signing of the Partial Nuclear-Test-Ban Treaty (PTBT). The PTBT prohibited the conduct of atmospheric and underwater nuclear tests and was signed in 1963 in Moscow. Nevertheless, on October 16, 1964, China carried out an atmospheric nuclear test, causing new discussions on the non-proliferation of nuclear weapons that arise and creating a comprehensive treaty that prohibits tests in any environment (atmospheric, underwater, and subsurface). Consequently, providing new publications.

Another milestone for the increase in the number of publications is the creation of the Comprehensive Nuclear Test Ban Treaty (CTBT) in 1996. Although not yet implemented, it was responsible for establishing an International Monitoring System (IMS) composed of 337 facilities of four technologies. Infrasound technology was chosen to verify nuclear tests in the atmosphere. The IMS infrasound network consists of 60 stations. The availability of IMS data for humanitarian and scientific purposes also contributed to the increase in publications. Initially, the IMS data was confidential. However, after the Sumatra earthquake, magnitude 9.1 Mw , in December 2004, followed by a devastating tsunami, responsible for the death of about 300,000 people, the scientific community of the CTBT member states lobbied the Preparatory Commission of the Comprehensive Nuclear Test Ban Treaty Organization (PrepCom - CTBTO) to make the IMS data available. Since then, there has been a leap in the number of published articles related to the topic (Fig. 1).

CTBTO was also responsible for organizing scientific events, for example, Science and Technology Conferences, Infrasound Technology Workshops, and many training courses that enabled new scientists to conduct their research. Additionally, the creation of National Data Centers (NDCs) in the State Parties developed new research centers.

Therefore, the increase in the amount of data collected by the IMS stations and the emergence of new researchers in the area are directly related to the increase in scientific publications.

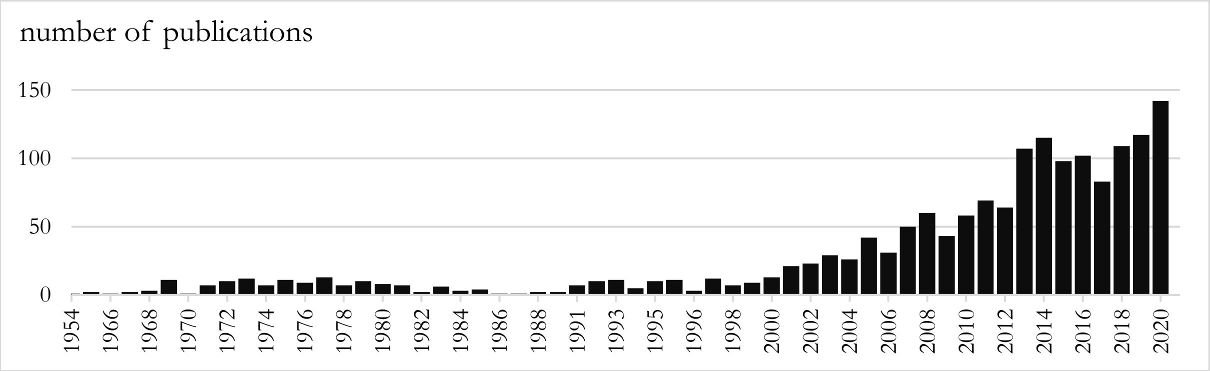

FIG. 1. Evolution in the number of articles published per year.

It was found that almost half of the works were published by researchers from the United States, with emphasis on the following institutions: the University of Alaska Fairbanks, Los Alamos National Lab, University of California San Diego, and US Geological Survey. Following that it has researchers from four European countries: France, Germany, Italy, and Russia (Fig. 2), highlighted by the institutions: Atomic Energy Commission (France), University of Florence (Italy), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) (Germany), and the Russian Academy of Sciences (Russia). Note that Infrasound technology was developed to detect clandestine nuclear explosions and, consequently, is directly related to military interests. The countries that publish most are also at the top of the ranking that invests the most in militarism (https://www.sipri.org/databases/milex).

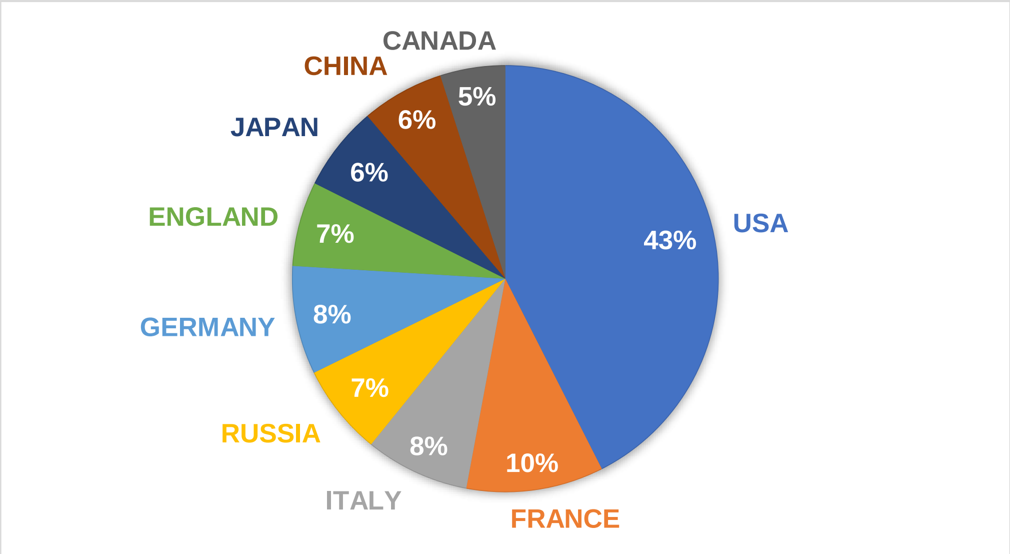

FIG. 2. Ranking of countries that most published articles with the "Infrasound” theme.

Among the authors that most publish about the infrasound theme are Fee, D.; Le Pichon, A.; Johnson J.; Ripepe, M.; ReVelle, D.; Evers, L.; Garces M. Moreover, all of them have many mentions, which may exceed 1000 citations (Fig. 3). However, among the ten most cited articles (Table 1) there are only articles published, in magazines of good reputation with Impact Factor upper than 2.7, by the authors: Fee, D.; Ripepe, M.; Garces M.; Matoza, R.; ReVelle D. & Brown, P..

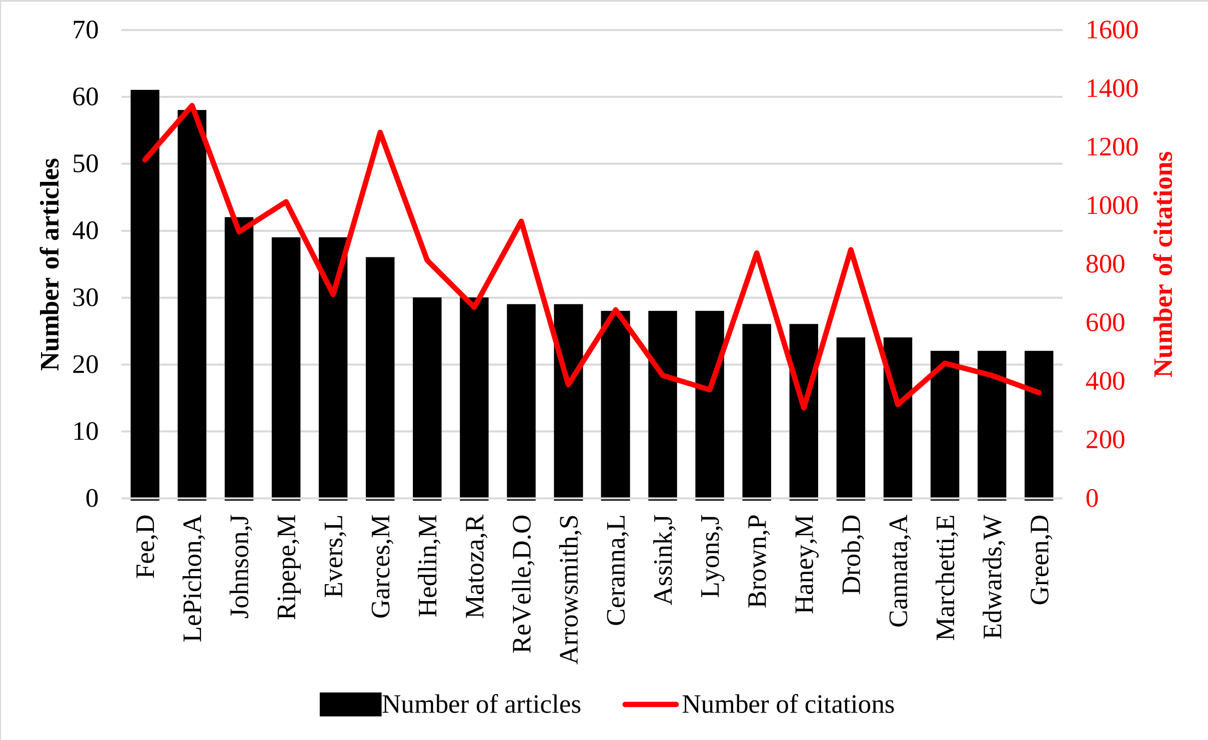

FIG. 3. Relationship between the number of publications versus the number of citations of the twenty authors who most published on the topic “infrasound”.

TABLE I. Top 10 cited papers.

N	Authors	Title	Magazine	Citations	Year
1	Brown, P.; Spalding, R ; ReVelle, D.; Tagliaferri, E. ; Worden, S.	The flux of small near-Earth objects colliding with the Earth	Nature	270	2002
2	Lastovicka, J.	Forcing of the ionosphere by waves from below	Journal Of Atmospheric and Solar-Terrestrial Physics	235	2006
3	Drob, D.; Picone, J.; Garces, M.	Global morphology of infrasound propagation	Journal of Geophysical Research-Atmospheres	181	2003

4	Ripepe, M.; Harris, A.; Carniel, R.	Thermal, seismic and infrasonic evidences of variable degassing rates at Stromboli volcano	Journal of Volcanology and Geothermal Research	139	2002
5	Artru, J.; Farges, T.; Lognonne, P.	Acoustic waves generated from seismic surface waves: propagation	Geophysical Journal International	132	2004
6	Ripepe, M.; Ciliberto, S.; Della Schiava, M.	Time constraints for modeling source dynamics of volcanic explosions at Stromboli	Journal of Geophysical Research-Solid Earth	130	2001
7	Fee, D.; Matoza, R.	An overview of volcano infrasound: from hawaiian to plinian, local to global	Journal of Volcanology and Geothermal Research	118	2013
8	Krodel, S.; Thome, N. ; Daraio, C.	Wide band-gap seismic metastructures	Extreme Mechanics Letters	115	2015
9	Garces, M.; Hansen, R.; Lindquist, K.	Traveltimes for infrasonic waves propagating in a stratified atmosphere	Geophysical Journal International	108	1998
10	ReVelle, D.O.	Meteor-generated infrasound	Journal of Geophysical Research-Space Physics	107	1979

We create a word cloud to represent the keyword data (Fig. 4). The keywords from the 1289 articles from the Web of Science database were inserted into the TagCrowd tool (tagcrowd.com). The online software created a diagram that represents the fifty keywords with the highest frequencies. Furthermore, the font size scale of the words shown in the diagram is proportional to the number of citations for each word, thus allowing diagnostics on the main research lines.

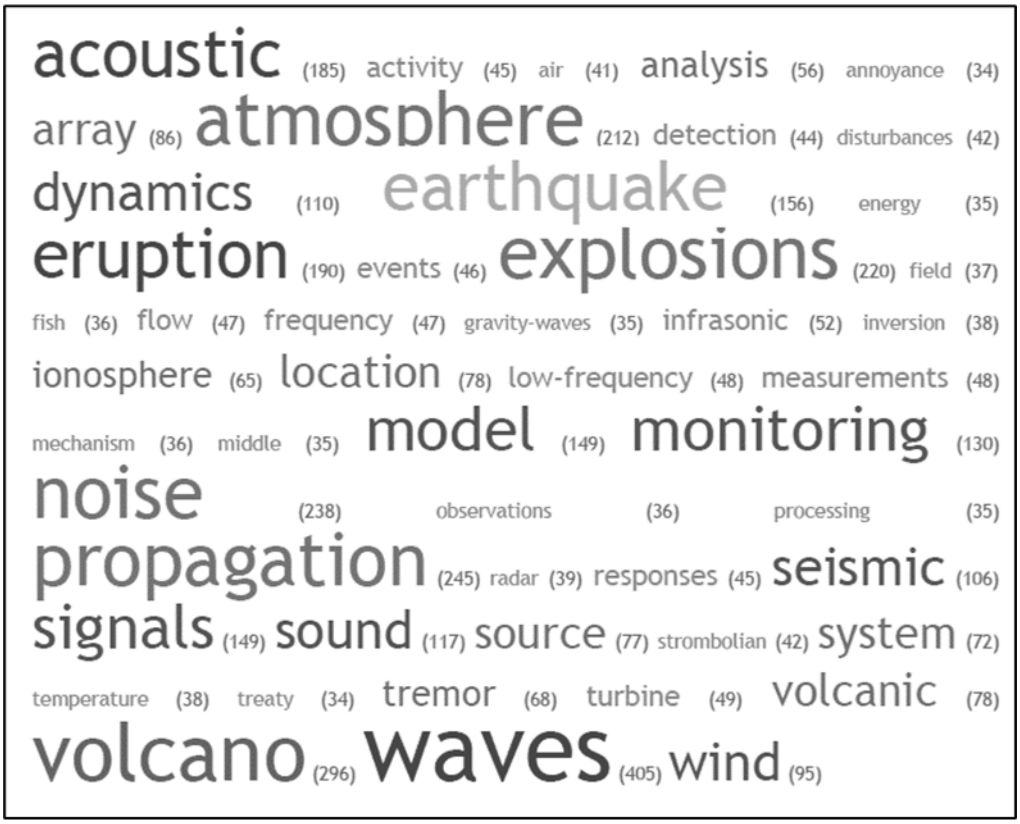

FIG. 4. Frequency of keywords that appeared in the 1289 articles.

The keywords reveal specific characteristics of each work, allowing to group the studies and classify them (Calazans et al., 2015). Analyzing Fig. 4, we can identify the main research themes concerning Infrasound technology: the study of infrasound sources (volcanoes, explosions, eruptions, earthquakes, noises) and the environment (propagation, atmosphere, acoustics, dynamics).

Infrasound signals are used in civil and scientific applications with the potential to significantly contribute to the expansion of human knowledge and well-being, including the detection of volcanic explosions and other natural or anthropogenic phenomena occurring on the Earth's surface, including nuclear and chemical explosions, meteors, storms.

Different perspectives on infrasound technology expand knowledge on the subject. Thus, knowing the main approaches is a prerequisite for new researchers to define their work. To this end, we create a co-citation map, the unit of analysis being the cited references (Fig. 5), which establishes the proximity of the most discussed studies and their main theoretical approaches (Zupic & Čater, 2014). It means that works with similar themes are close together and grouped. The lines interconnect co-cited works. For this analysis, we used the documents related to the infrasound theme from 1953 to March 2021.

Fig. 5 shows three cores that mean different approaches. Blue represents works based on: infrasound propagation characteristics, network detection capability, e.g the articles from ReVelle, D. 1976; J Picone, et al., 2002; Le Pichon, A et al., 2002. Green are articles related to data processing and the behavior of infrasound in the atmosphere e.g the works of Y Cansi, 1995; Drob et al., 2003; Christie & Campus 2010. Finally, in yellow are the authors who have published articles on the application of infrasound in volcanology e.g the articles from Fee D. et al., 2013; Johnson J. 2011; Matoza R. et al., 2011. The subject of volcanology is a great social interest in the study of infrasound. So many specialized research groups publish and share their results with society.

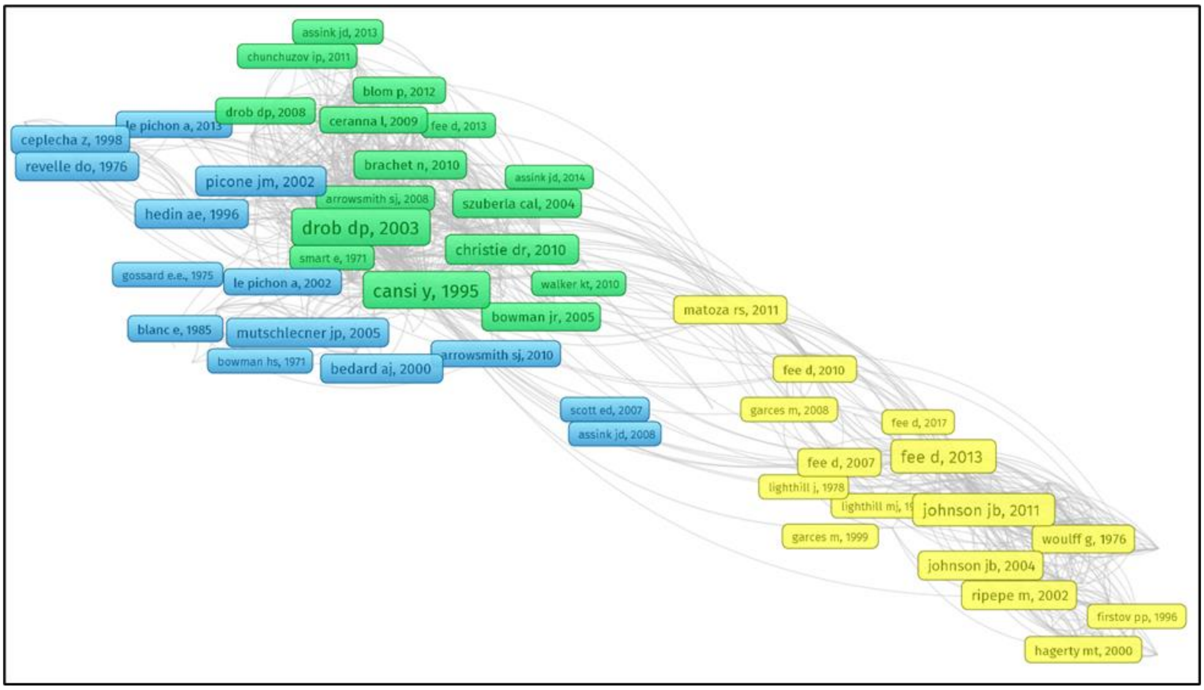

FIG. 5. Co-citations network showing the cores of the main approaches cited: in green, infrasound propagation characteristics and network detection capability; in blue, data processing and the behavior of infrasound; and in yellow, infrasound in volcanology. The lines interconnect co-cited works.

The coupling analysis (Fig. 6) reveals the main research fronts, that is, how the most recent studies are taking shape. Unlike the co-citation network (Fig. 5), this analysis considered the documents related to the topic in the period from January 2018 to March 2021. The approximation of the clusters reveals how similar the line of research is and the size and scale of colors represent the number of citations.

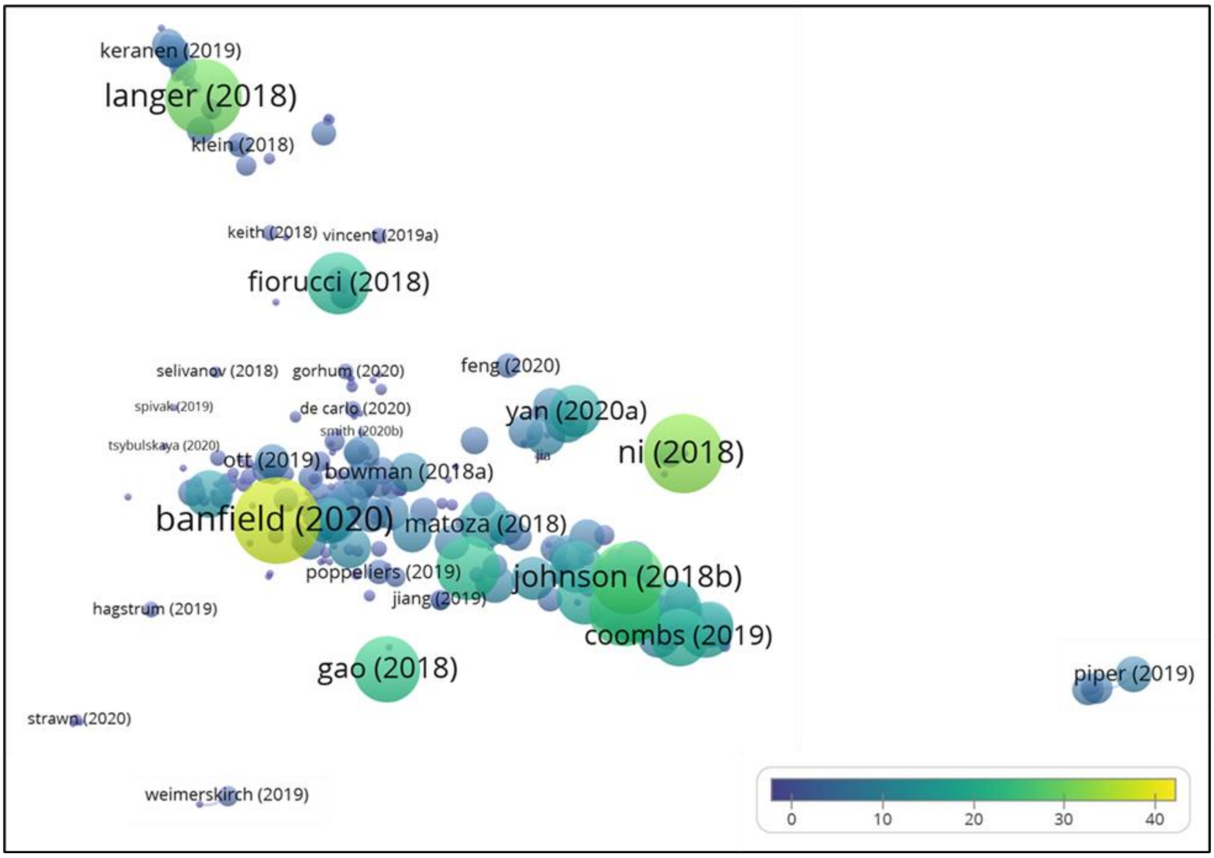

FIG. 6. Coupling diagram showing the most recent studies in the last three years (2018-March 2021).

Some of the documents used to produce Fig. 6 have not been cited yet, as they were published recently. Some works are highlighted: Banfield et al. (2020), Johnson B. et al. (2018), Langer et al. (2018), and Piper et al. (2019). In the paper published in Nature Geoscience, which has 48 citations, Banfield studied the atmosphere of Mars, finding that Martian infrasound has similarities to Earth's atmospheric turbulence. Johnson's paper in Geophysical Research Letters, which already has 29 citations, studies a way to predict a volcanic eruption using the infrasound generated by the outgassing of open volcanoes. In the article published by Langer in the Journal of Cleaner Production, cited at least 29 times, the factors that influence the acceptance or not of wind energy by citizens in Germany were studied. The article by Piper et al (2019) does not stand out for the number of citations, but for the distance from other productions. In this research published in the journal Ecological Engineering, Piper use infrasound to study the behavior of the adult European eel towards infrasound.

IV. CONCLUSION

This work introduces infrasound technology to young researchers, intending to help them to know its main topics to do their jobs. Besides that, presents where are the main research laboratories; who are the researchers that contributed most contributed; what are the main lines of research; and what are the most cited articles.

The United States of America has the largest infrasound research centers and is also the country that most publishes about this technology. However, countries like France, Italy, Russia, Germany, and England also contribute to this technology. Infrasound had advanced after World War II in the Cold War.

It is no coincidence that the main nations that played an important role at that time are the ones that researched and published the most since Infrasound is a technology for monitoring atmospheric nuclear tests. However, the creation of the IMS and the promotion of scientific events (conferences, meetings, training, workshops, etc) were responsible for the emergence of researchers in other countries.

The main approaches found are related to the study of infrasound behavior in the atmosphere, the study of the sources that generate the signal, signal processing, and detection techniques. Among the authors who contributed the most are: Fee, D. studying the propagation of infrasound, the infrasound generated by volcanoes and earthquakes, and the detection and classification of the infrasound signal; Le Pichon, A. who was responsible for the organization and publication of two books that bring together references for the study of atmosphere monitoring; Johnson, J., who studies infrasound technology and the development of sensors to monitor volcanoes; Ripepe, M. contributes to the study of volcanic eruptions using infrasound technology; Evers, L. focuses his studies on seismology, infrasound, and hydroacoustic technology to identify geophysical sources and propagation changes. However, the study of infrasound is not limited to researching only the Earth's atmosphere, it can have more civil and social applications, such as the non-acceptance of wind energy by German citizens for fear of the noise from a wind farm or even biological applications in the study of fish behavior.

Thus, this research presented a systematic review of the main contributions of the high-impact literature.

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CAPÍTULO 3: ARTIGO - THE CONTRIBUTION OF THE I09BR STATION OF THE INTERNATIONAL MONITORING SYSTEM FOR INFRASOUND EVENTS DETECTION

Este capítulo traz o estudo sobre a contribuição da estação I09BR, do Sistema Internacional de Monitoramento, para detecção de eventos infrassônicos e foi submetido como artigo científico na revista Journal of the Acoustical Society of America.

The contribution of the I09BR station of the international monitoring system for infrasound events detection

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Abstract

Infrasound is one of four technologies used by the International Monitoring System (IMS) to verify compliance with the Comprehensive Nuclear Test Ban Treaty (CTBT). Atmospheric and underground nuclear explosions near the surface generate low-frequency sound waves that are detected by the IMS worldwide infrasound network. The unit station that uses this technology in Brazil and is part of the IMS is located at the Brasília National Park and has been operating since 2001, with the code I09BR. No nuclear tests were detected by I09BR installation, due to distances, environment, and yield. However, there are several other sources of infrasound signals detected by the I09BR station, such as detonations in mines, bolides, storms, microbaroms, among others. This work aims to present the Brazilian infrasound station highlighting the main signal sources that have been detected over the years (2015-2021) and addressing the differences in the number of detections due to the reduction of cultural noise due to pandemic decrees Covid-19.

I. INTRODUCTION AND PRINCIPAL HEADINGS

The implementation of the International Monitoring System (IMS) to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) has generated rapid growth interest in infrasound technology. The Comprehensive Nuclear Test-Ban-Treaty Organization (CTBTO) provides a worldwide infrasound network consisting of 60 permanent stations in partnership with the various research organizations in the Member States of CTBT. At the present, 91% of these stations are in operation.

Infrasound is inaudible by humans and its study is called by the same name. It is an acoustic disturbance characterized by variations in air pressure, whose frequencies vary from 0.001Hz to 20Hz. Due to its high wavelengths, between 17 m and 30 km, it can travel large distances in the atmosphere, as it suffers low attenuation (Gossard & Hooke, 1975). The main function of an infrasound station is to measure atmospheric pressure fluctuations and convert them into a digital signal.

IMS infrasound stations are responsible for detecting atmospheric nuclear explosions mainly. Each IMS infrasound station consists of an array formed by elements spatially distributed following a given geometry. Most of the IMS infrasound stations have been constructed as 7- or 8-element arrays. A few stations have been established with only 4 array elements, but it is anticipated that these arrays will be upgraded to 8-element arrays. For arrays of more than 4 elements, the configuration and geometry of the array determine the combinations of element failures that may occur before mission capability is lost. An element is composed of a sensor (microbarometer), a digitizer, a noise reduction system, a photovoltaic power supply system, and a data transmission system using a secure communication system. Data from IMS stations are transmitted near real-time to the International Data Center (IDC), located in Vienna - Austria (Christie & Campus, 2009).

The Brazilian Infrasound station (I09BR) is located in Brasília, a subtropical region in the Brazil interior. The array of the I09BR station is formed by four elements distributed in a triangular shape. It is installed inside of the protected environmental area of the Brasília National Park (PNB) about 20 km away from the Central Recording Facility (CRF) located in the Seismological Observatory of the University of Brasília (SIS UnB) (Fig. 1). The I09BR station has been operating since July 2001 (Barros & Fontenele, 2002).

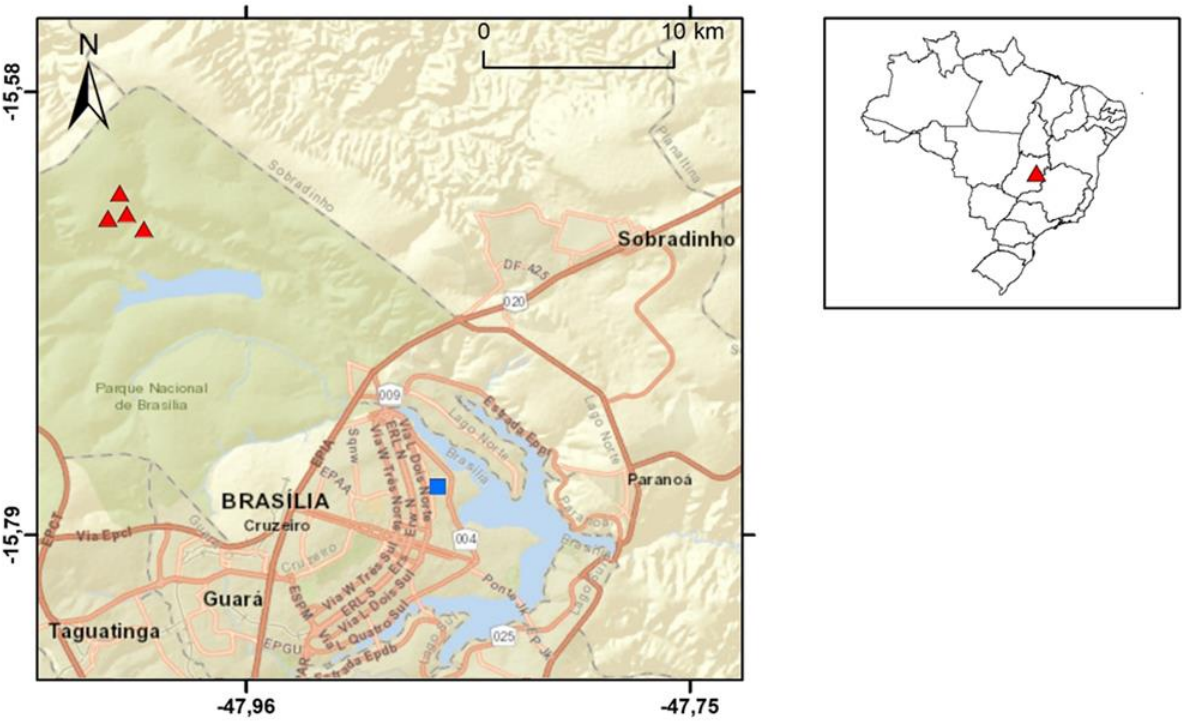


FIG. 1. Location of the I09BR infrasound station array in the Parque Nacional de Brasília (PNB). The triangles represent elements of the I09BR station, and the blue square represents CRF in SIS - UnB. The auxiliary map on the right shows the I09BR station in Brazil.

The infrasound IMS network was projected to reliably detect any atmospheric nuclear explosion with a yield equivalent to at least one kiloton of TNT (trinitrotoluene) anywhere in the world to verify the CTBT (Christie, 2001). Infrasound technology has application in scientific and social areas, such as natural and anthropogenic phenomena that can also generate infrasound. For example, volcanic eruptions (Matoza et al., 2019; Fee & Matoza, 2013); severe climates (Waxler & Assink, 2019; Bowman & Bedard, 1971); chemical explosions (Bowman & Bedard, 2010; Hagerty M. et al., 2001); meteors (Brown P. et al., 2002; ReVelle, 1976); supersonic aircraft (Liszka & Waldemark, 1995; Balachandran A. et al., 1977; Grover, 1973), microbaroms (Assink J. et al., 2014; Fred, 1962; Gutenberg & Benioff, 1941), etc.

In this study, we use data collected by the I09BR station presenting the behavior of infrasound detections in relation to variations of the seasons and list the fixed sources that generate infrasound. This work also addresses the differences in infrasound detections, in the period before and after the beginning of the COVID-19 pandemic.

II. METHODS

Initially, the analog signal from the sensor is converted by the digitizer to a digital signal and then sent to IDC. The data before being transmitted is authenticated on the station. It is formed by the digital signal and a time stamp. All registered users from the CTBT Signatory Countries can request data from all IMS stations and we used this procedure to get data for the analysis.

The first stage of data processing takes place individually. In this step, the infrasound detections are produced by Multi-Channel Progressive Correlation (PMCC) algorithm (Cansi, 1995; Cansi & Klinger, 1997) which is implemented in the DTK-GPMCC software. The processing setup, built by IDC, uses 11 frequencies bands between 0.07 and 4.0 Hz (Figure 2a), with different time windows lengths, covering the entire data period analysis. The length of the window depends inversely on the frequency band. This ranges from 60 seconds for the lowest frequencies to 30 seconds for the highest frequency. This first processing stage produces elementary detections called PMCC pixels, which satisfy the criteria of correlation and consistency of the time and frequency parameters (Figure 2b). The next step is the grouping of individual detection pixels that have similar signal attributes in time, frequency, back azimuth (azimuth of the wavefront arriving at the station), and horizontal velocity (is how fast each infrasound wavefront travelled). Neighboring pixel groups constitute a PMCC family (Le Pichon A. et al., 2009) – Figure 2c.

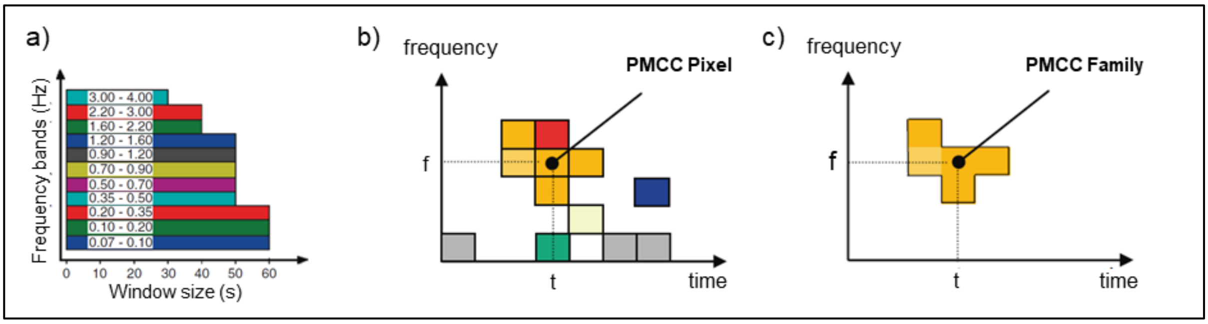


FIG. 2. a) The eleven frequencies bands of the IDC configuration, with different length windows. b) PMCC pixels creation according to stipulated criteria. c) Formation of a PMCC family from pixels with similar characteristics (adapted from Le Pichon A. et al., 2009).

We characterized the infrasound detections created by the PMCC algorithm, identifying some infrasound events and the orientation of the fixed sources and how the signal detection change based on the variations of the seasons. In this study, we process 7 years (2015 to 2021) of infrasound data from the I09BR station.

III. INFRASOUND SOURCES

Infrasound is generated by several natural and man-made sources. Some of these infrasound signal sources contribute to the continuous background noise, while the signals from other sources are essentially impulsive with characteristics that may be similar in some respects to the signals generated by a nuclear explosion (Le Pichon A. et al., 2009) like the impulsive signal. The properties of the signals from all these sources, therefore, need to be well understood before they can be classified. In case a clandestine nuclear test occurs, we have information that it is an anomalous event.

A. Chemical and nuclear explosions

Chemical and nuclear atmospheric explosions generate impulsive infrasound signatures characteristic which may be detected at great distances from the explosion. Waves from smaller events of this type usually appear at distances of up to a few thousand kilometers in the form of several distinct wave groups corresponding to reflections from the stratosphere and lower thermosphere. The signatures from big events might be seen at great distances (Christie D. et al., 2001).

The morphology of the waveform pattern of infrasound signals will depend on the size of the source and on the distance from the source. High-frequency signals are attenuated faster than low-frequency signals and hence the waveforms observed at a great distance will be dominated by longer period components (Campus & Christie, 2010).

Most of the signals registered by the infrasound array are from sources close to the Earth's surface. Mine Blasts are typical examples of artificial infrasound sources detected. In mines close to a station, the explosions signal registered is usually impulsive, has a large signal to noise ratio, short waveform duration, between 5 to 15 seconds, and PMCC family of approximately 40 to 50 seconds, high-frequency content, and a stable azimuth (Hagerty et al., 2001). In our study, we found that a mine, 210 kilometers from the I09BR station uses explosives to explore the ores. These detonations are frequent sources of the infrasonic signal recorded in the station, as example, on June 19, 2020, the I09BR station detected the infrasound produced by an explosion (Figure 3). For this example, the azimuth is stable at 293.20°±0.06 and the average speed is 0.349±0.001 km/s, with the PMCC Family with 10 seconds of duration.

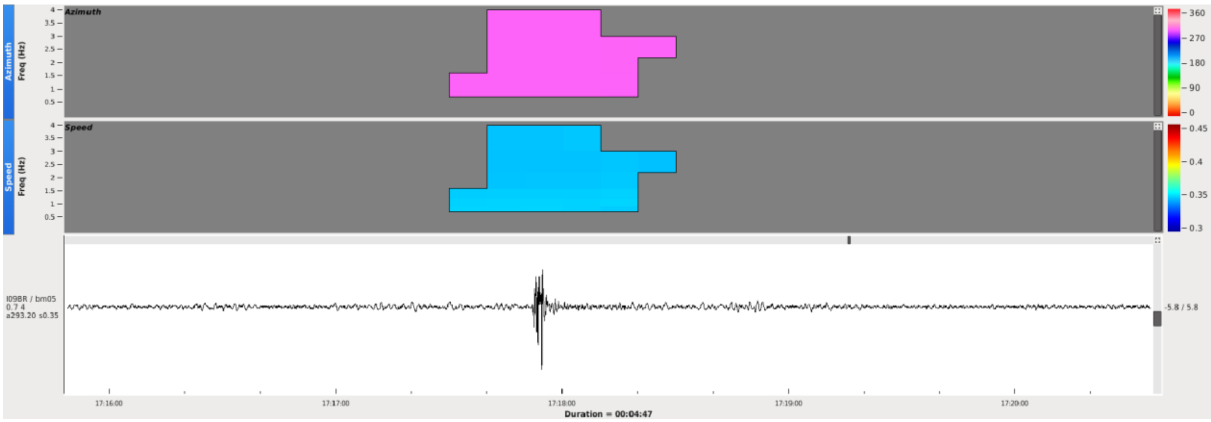


FIG. 3. The lower part of the figure shows the beam forming from 4 elements of I09BR station due to a mine blast, the intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

B. Supersonic aircrafts

Infrasonic signals produced by a supersonic aircraft can be detected in a relatively small area directly under the flight path of a supersonic aircraft (Grover, 1973). However, signals from supersonic aircraft are not limited to this relatively narrow zone. Highest frequency components are attenuated quickly as the shock wave propagates away from the aircraft. These signals have frequencies between 0.1 to 6 Hz and amplitudes in the range of a few microbars to several hundred microbars and can be detected depending on weather conditions, at distances of up to 4,000 km from the aircraft's flight path (Balachandran A. et al.,1977, Liszka & Waldemark, 1995).

September 7th is a national holiday in which Brazil's independence is celebrated. Part of the festivities is carried out by the Brazilian Air Force, which demonstrates some aircraft models. In the 2016 spectacle, the F-5E Tiger flight squadron traveled the skies of Brasilia, when this plane traveled above the speed of sound aircraft generated infrasound signal that was recorded by the I09BR station (Fig. 4). On this day, only three elements of the I09BR station were in operation. In more didactic examples, there would be a greater detail of the azimuth calculated by the data processing, which would indicate the trajectory of the plane. However, the calculated azimuth was 43.64°±0.01. The velocity presents a variation, having its maximum value when the plane is closer to the station (0.361 km/s), and smaller values around it (0.357 km/s), this occurs by the Doppler Effect.

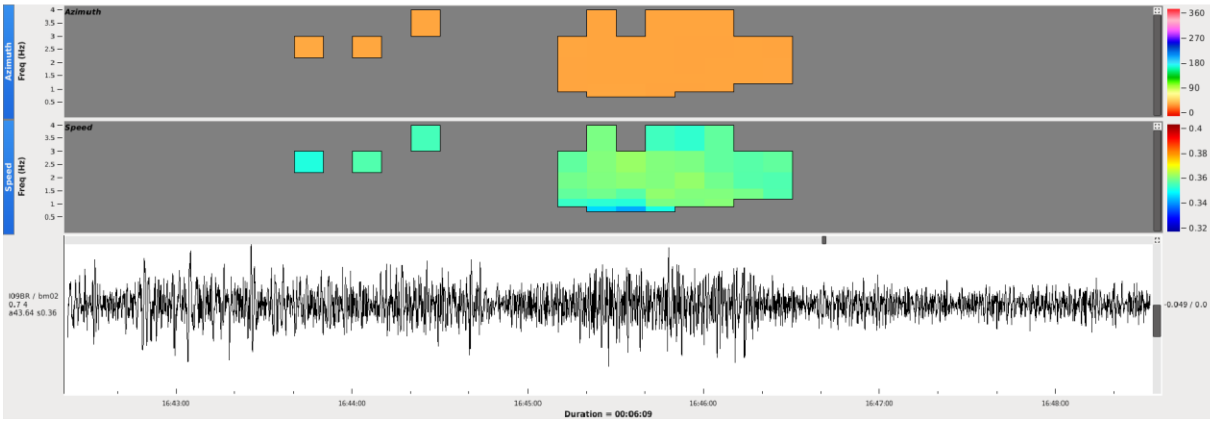


FIG. 4. The lower part of the figure shows the beam forming from 3 elements of I09BR station due to supersonic aircraft in a demonstration on Brazil's Independence Day (September 7, 2016). The intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

C. Infrasound from meteorological sources

Infrasonic waves with periods between about 10 to 50 seconds and amplitudes of a few microbars may be generated by severe convective storms. Other meteorological sources of infrasound include microbursts, tornados, and lightning. Infrasound associated with lightning discharges usually occurs as a sharp V-shaped rarefaction pulse with periods in the range from about 0.4 to 1.0 seconds and amplitudes of about 10 microbars. These pulse-like waves travel almost vertically downwards and are therefore only detected when the thunderstorm is near the station (Bowman & Bedard, 1971).

In the afternoon of November 29, 2021, there was a thunderstorm in Brasilia with strong wind and lightning that generated infrasonic signals registered by the I09BR station (Fig. 5). Infrasonic signals generated by rains are characterized by a series of impulsive signals spaced approximately one minute apart, and may have a long duration (tens of minutes or hours), with the clear presence of high frequency signals. Azimuth variation also occurs, as rain and lightning can occur at different locations around the infrasound station (Raimbow azimuths).

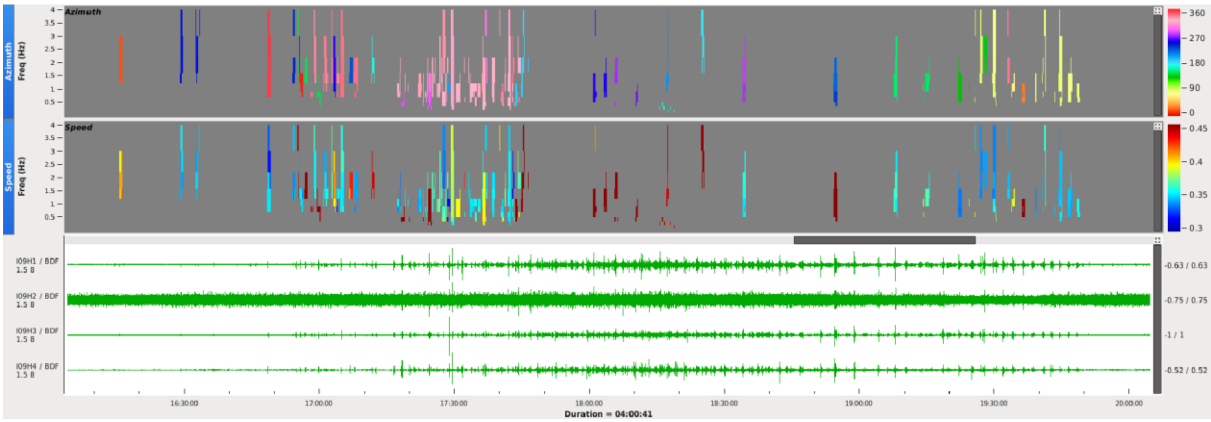


FIG. 5. The lower part of the figure shows the infrasonic signal from 4 elements of I09BR station (I09H1, I09H2, I09H3, I09H4) due to a thunderstorm in Brasilia on November 29, 2021. The intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

D. Meteors

Meteors are sources of natural infrasound. When they collide with the Earth's atmosphere at hypersonic speeds, they are capable of generating infrasound. Meteors vary greatly in size and mass. Most observed meteor signals tend to have frequencies between 0.1 Hz and 5 Hz and amplitudes ranging from 1 to 10 microbars (ReVelle, 1976). On August 9, 2021, 390 km from the I09BR station in the north of Minas Gerais a meteor entered the Earth's atmosphere (*https://www.climaaovivo.com.br/noticias/meteoro-em-minas-gerais-e-goias-veja-o-video-exclusivo-08-08-21*) and the Brazilian station detected it. (Fig. 6). The infrasonic signals generated by meteors are complex and depend mainly on the size of the bolide. In this case, it had stable azimuth around 79.40°±0.01 and average speed around 0.3462±0.0001 km/s.

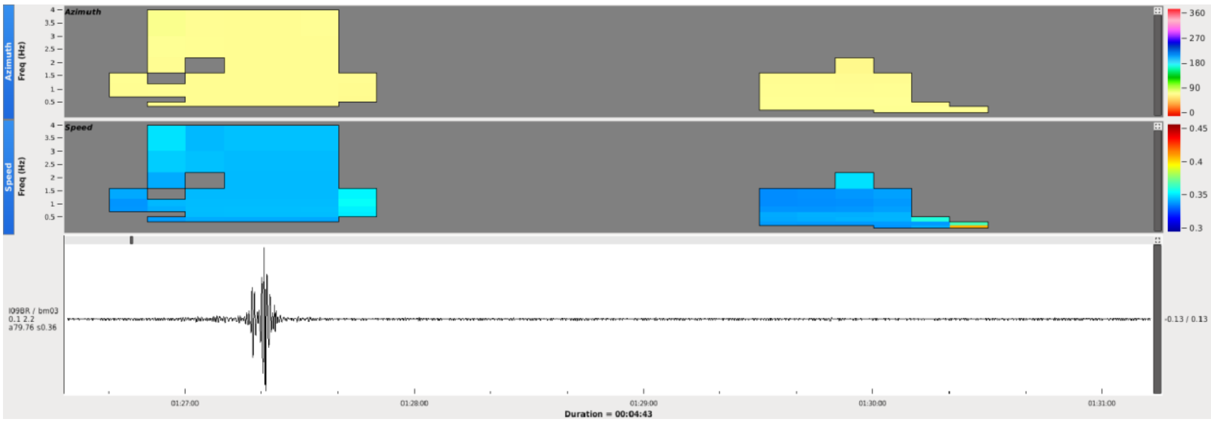


FIG. 6. The lower part of the figure shows the beam forming from 4 elements of I09BR station due to a meteor, the intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

E. Volcanic eruptions

Explosive volcanic eruptions are an important source of infrasound waves. Eruptions of different explosive yields can vary from less than a kiloton to more than 100 megatons, such as the Krakatoa Volcano Explosion, on August 26, 1883 (Devine J. et al., 1984). Infrasound signal signatures from volcanic eruptions tend to be very variable in form. Some of these signatures are impulsive and may resemble the signature of waves from other explosive sources (Ripepe M. et al., 2001). In many cases, however, the initial impulsive signature from an explosive volcanic eruption is followed by a long train of irregular waves which may extend over a period ranging from several hours to several weeks. The dominant frequency and amplitude of infrasound waves from volcanic explosions will depend on the size of the explosion and the distance to the source. Very large explosions will generate waves with amplitudes of thousands of microbars in the near field (less than 50 km) and amplitudes of hundreds of microbars at distances of more than 1000 km. Waves from these very large explosions have dominant periods at large distances of several hundred seconds. Smaller explosions with equivalent yields of one kT of TNT or less will have amplitudes of a few microbars at distances beyond 1000 km and dominant periods in the range from about 0.5 seconds to 20 seconds (Johnson & Ripepe, 2011).

The eruption of the Cabulco Volcano, located in Chile, generated infrasound waves that were recorded by all South American infrasound stations. One of the explosive eruptions began at 04:22 (UTC) on 23 April 2015. The waveform for that eruption recorded by station I09BR is shown in Figure 7. The infrasonic waves that arrived at the I09BR station had a stable azimuth around 209.4°±2.2, the average speed is 0.332±0.015 km/s and some infrasonic families had a duration of hours.

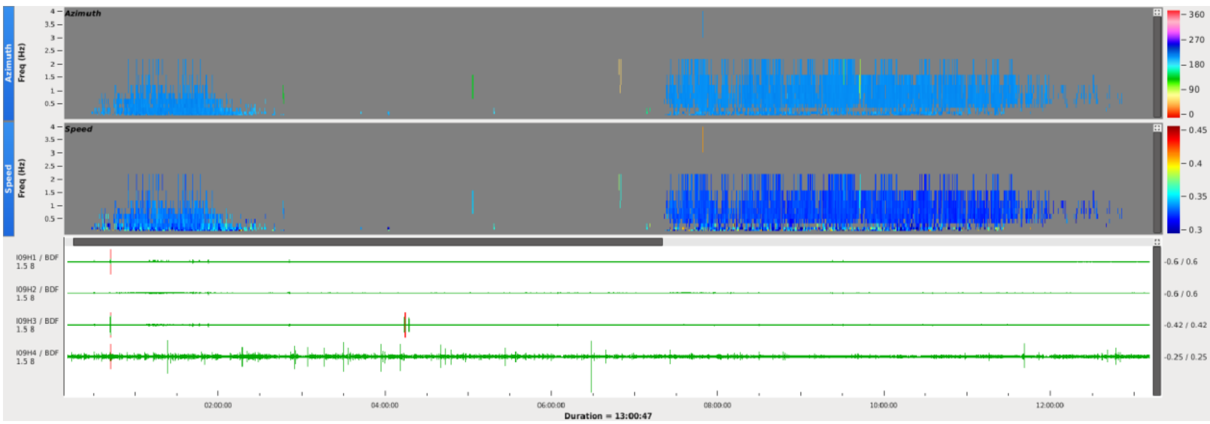


FIG. 7. The lower part of the figure shows the infrasonic signal from 4 elements of I09BR station due to volcanic eruption, the intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

F. Earthquakes

Large earthquakes can generate infrasonic waves by at least three distinct mechanisms. The first mechanism involves the near-vertical radiation of an airwave from the earth's surface during the passage of the vertical component of the seismic surface waves. The second mechanism for generating infrasonic waves in the atmosphere is the violent movement of the ground at the epicenter of an earthquake. The third mechanism involves the irradiation of infrasonic waves by mountains. Because surface seismic waves can induce motion in high mountains. These waves are conducted through the atmosphere at atmospheric acoustic velocities and arrive at the infrasound sensor after the ground-coupled airwaves (Mutschlecner & Whitaker, 2005). Infrasound stations also detect the passage of the vertical P and Rayleight waves, this seismic phase propagates with the velocity of the seismic wave (Stump B. et al., 2002). The sensitivity of the I09BR station microbarometer (model MB2000) to vertical movements is similar to the sensitivity of a Guralp CMG5T strong motion accelerometer (Christie & Campus, 2010).

Brazil is located on the Stable Continental Interior of the South American tectonic plate, where seismic events are not as frequent, and magnitudes are not as high as in its borders. The Nazca plate subducts below the South America plate, and it can generate big earthquakes. On May 26, 2019, all stations of the Brazilian Seismographic Network (RSBR) registered an earthquake of magnitude 8.0 located in Central Peru. The Brazilian infrasound station also detected it (Fig. 8). In this example, we can identify the seismic phase, with a velocity greater than 2.53±0.01 km/s (dark red) and the infrasonic phase that arrives 104 minutes later with an average velocity of 0.344±0.001 (blue). The mean azimuth of infrasonic waves is 275.071°±0.007.

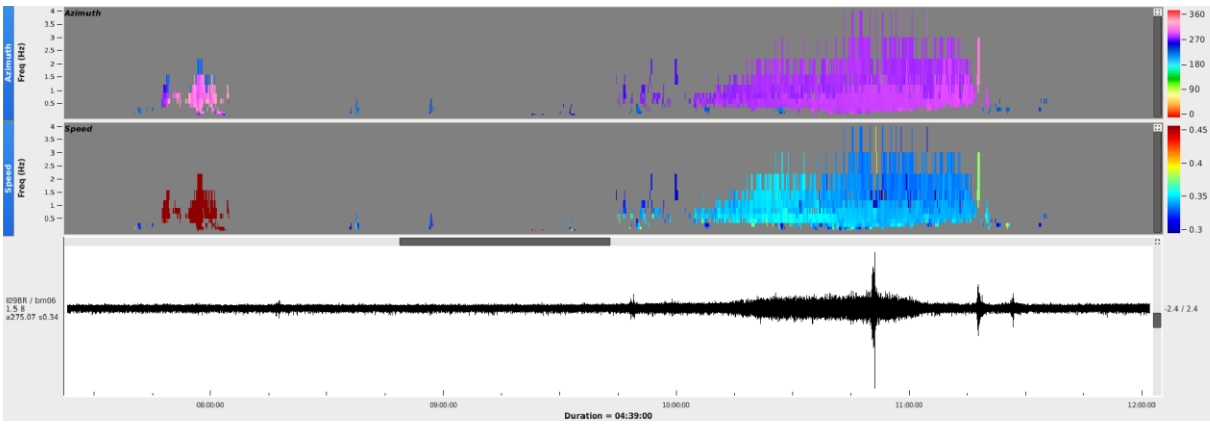
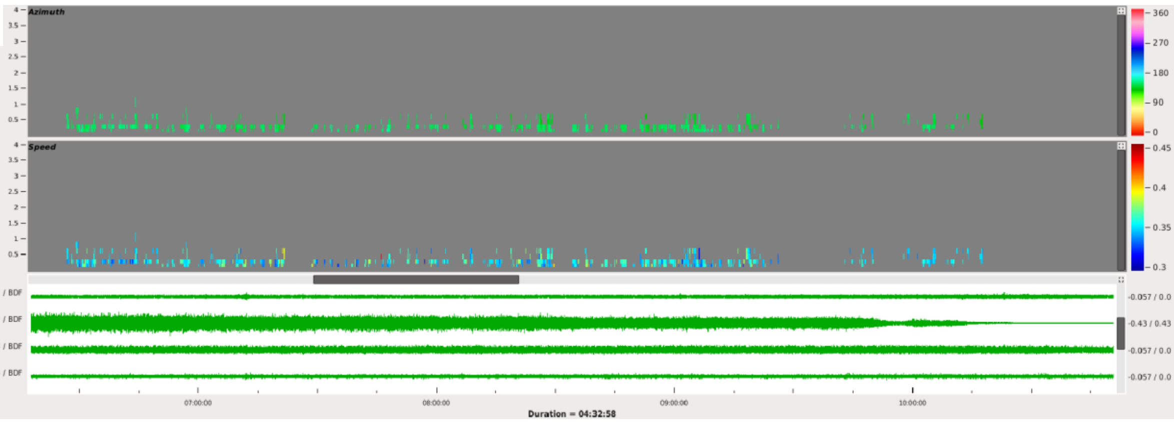


FIG. 8. The lower part of the figure shows the beam forming from 4 elements of I09BR station due to 8.0 M earthquake by I09BR station, the intermediate part the velocity (km/s) and the upper part the azimuth (°). The colors are according to the color bar in the right of the figure.

G. Microbaroms

Microbaroms are infrasound atmospheric pressure waves with a dominant frequency of about 0.2 Hz, first identified by Benioff and Gutenberg (Benioff & Gutenberg, 1939; Gutenberg & Benioff, 1941), and Baird (1940). Waves of this type are almost always present at any point on the surface of the oceans. These omnipresent waves have periods in the range from about 4 to 8 seconds, typical amplitudes of a few microbars, and tend to occur as continuous monochromatic wave trains with characteristic modulations in wave amplitude. Microbarom signal amplitudes often exhibit a diurnal and semi-diurnal variation which can be attributed to waveguide variations associated with the modulation of the mean upper atmospheric winds by the diurnal and semi-diurnal atmospheric tides. It is known that waves of this type exhibit a high degree of coherence over distances of 0.6 km and a low degree of coherence over distances of about 5 km (Fred, 1962). This suggests that, since waves of this type represent a significant noise source at frequencies around 0.2 Hz, the elements in an IMS infrasound array should be separated by distances of a few kilometers. The elements of the I09BR station are close to each other about one kilometer thus this distance allows the microbarom frequencies to be detected. I09BR station detects microbaroms from the Atlantic (Fig. 9a) and Pacific Oceans (Fig. 9b). The signals generated by microbaroms usually have a long duration (several hours, days), can contain a large azimuthal variation, do not have a stable velocity and are not clear in the waveform in the station elements, as is the case that the I09BR station detects.

a)



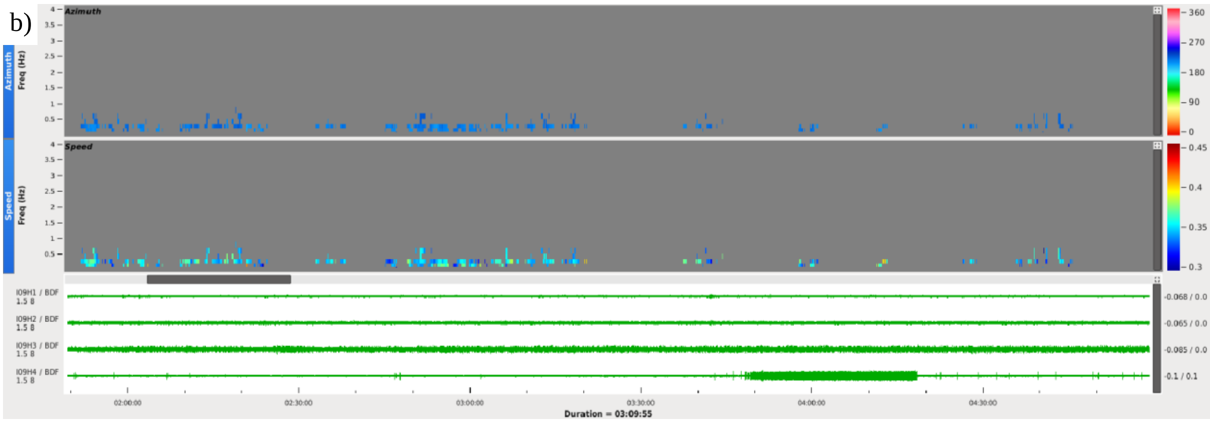


FIG. 9. a) Infrasound detection of microbarom, green PMCC families, from Atlantic Ocean registered on February 8, 2021. b) Infrasound detection of microbarom, blue PMCC families, from the Pacific Ocean registered on August 16, 2021. The lower part of the figure shows the infrasound signal detected by the I09BR elements (I09H1, I09H2, I09H3, I09H4), the intermediate the velocity and the upper part the azimuth. The colors are according to the color bar in the right of the figure.

IV. AVERAGE WEATHER CONDITIONS IN BRASILIA

A report available at *weatherspark.com* shows Brasilia's characteristic weather conditions based on a statistical analysis of historical reports and reconstructions from January 1, 1980, to December 31, 2016. In Brasilia, according to this report, there are two well-defined seasons, the dry season, and the wet season (Figure 10). The probability of rainy days in Brasilia varies widely throughout the year. The season with the highest rainfall lasts 6.2 months, from October 8th to April 13th, with more than 40% probability that on any given day it will rain. The dry season lasts 5.8 months, from April 14th to October 7th.

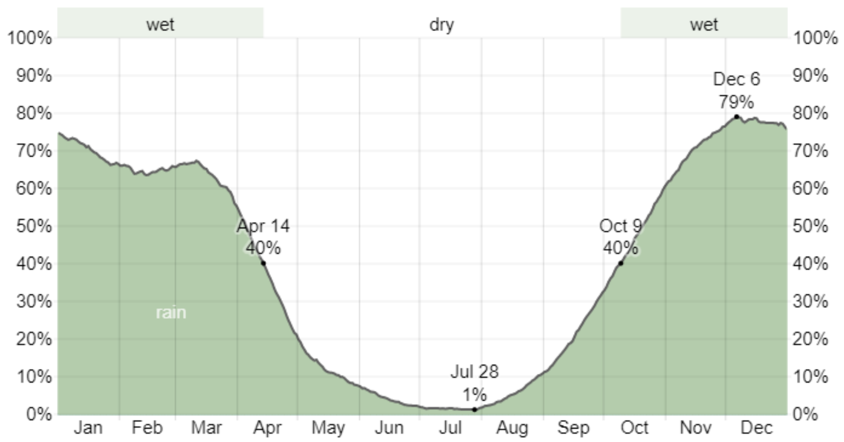


FIG. 10. Precipitation probability in Brasilia (*weatherspark.com*).

V. RESULTS

As shown earlier, the I09BR station detects signals from different infrasound sources. In seven years of data processing (2015 - 2021) using the PMCC algorithm, it was possible to identify a large number of infrasound detections. In the graph of infrasound detections for the Brazilian station (Figure 11a). It shows detections over the months with constant orientation, which means fixed sources that generate infrasonic signals. The azimuths around 180° and 65° present high-frequency signals (red). Low-frequency signals (blue) are registered over the months. Infrasonic signals with an orientation around 200° to 240° of low frequency only occur during the dry season while signals with azimuths around 90° to 170° only occur during the wet season. In the rainy season, the I09BR station detects more infrasonic high-frequency signals compared to the dry season.

The fixed infrasonic signal sources closest to the I09BR station are the mining company (Az ~ 65°), and the urban center of Brasilia, with influence from International Airport to the south (Az ~ 180°). Part of the low-frequency signal in the azimuthal range of 200° to 240° is related to the microbarom coming from the Pacific Ocean. Part of the infrasound detections comes from the azimuthal range between 90° and 170°, they are related to the microbarom coming from the Atlantic Ocean, we can better see these low frequency signals in Figure 11b. However, in these azimuth ranges, there are cities and mining companies that collaborate on the generation of infrasonic signals.

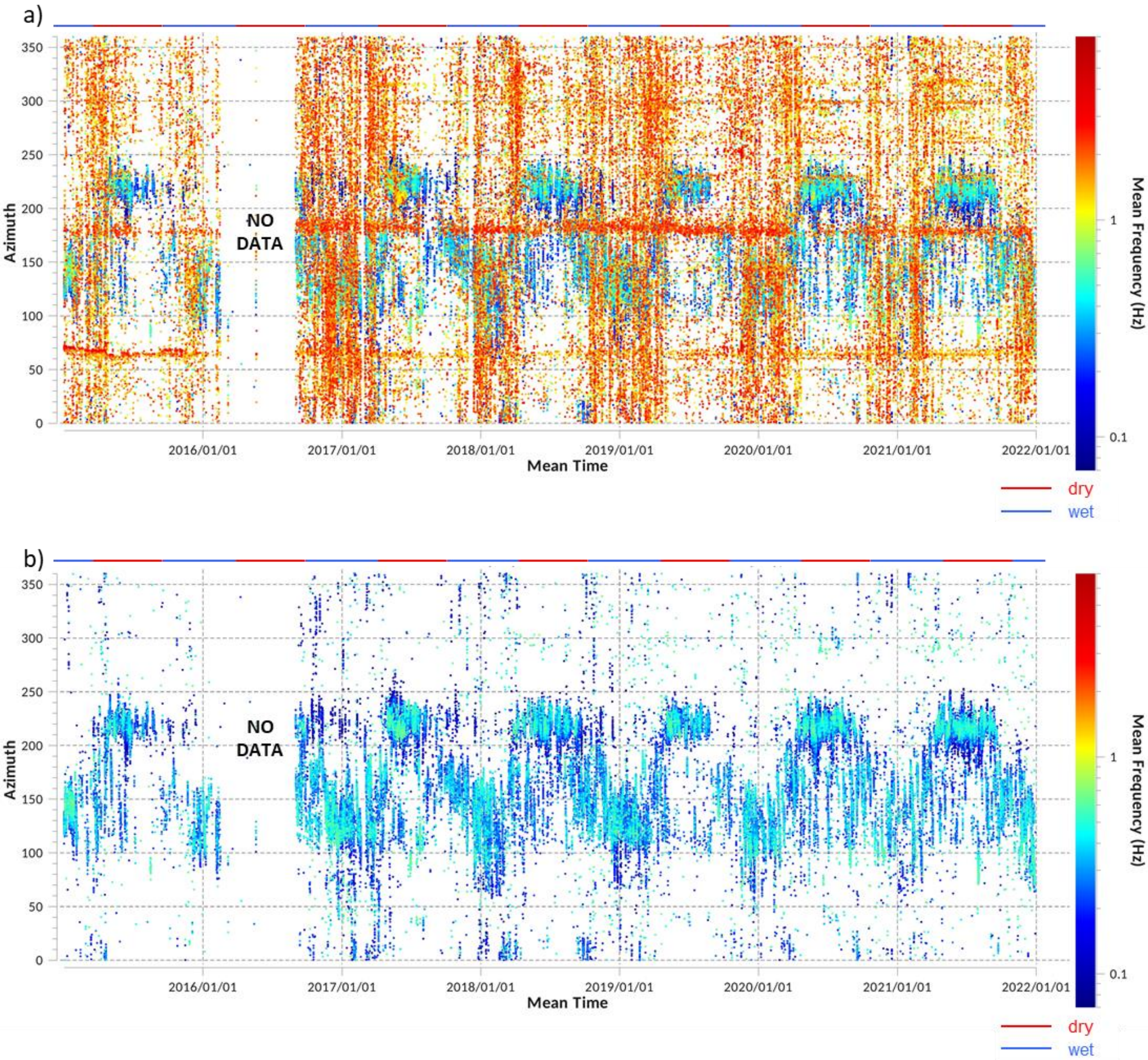


FIG. 11. a) Graph of all infrasound detections by the I09BR station in the period from 2015 to 2021. b) Graph of low frequency infrasound detections by the I09BR station in the period from 2015 to 2021.

Mine blasts are examples of artificial sources that can be registered in seismographic and infrasound stations (Hagerty M. et al., 2001). The SIS-UnB seismic bulletins contain information of detonations in mining companies, which were used to find out if the I09BR station was able to detect the infrasonic signal of these explosions (Fig. 12). Not all mine blast signals detected by seismographic stations were registered by the infrasound station (Table 1) due to some factors: yield, the source-station distance, the blasting environment, and the climate conditions (Campus & Christie, 2010).

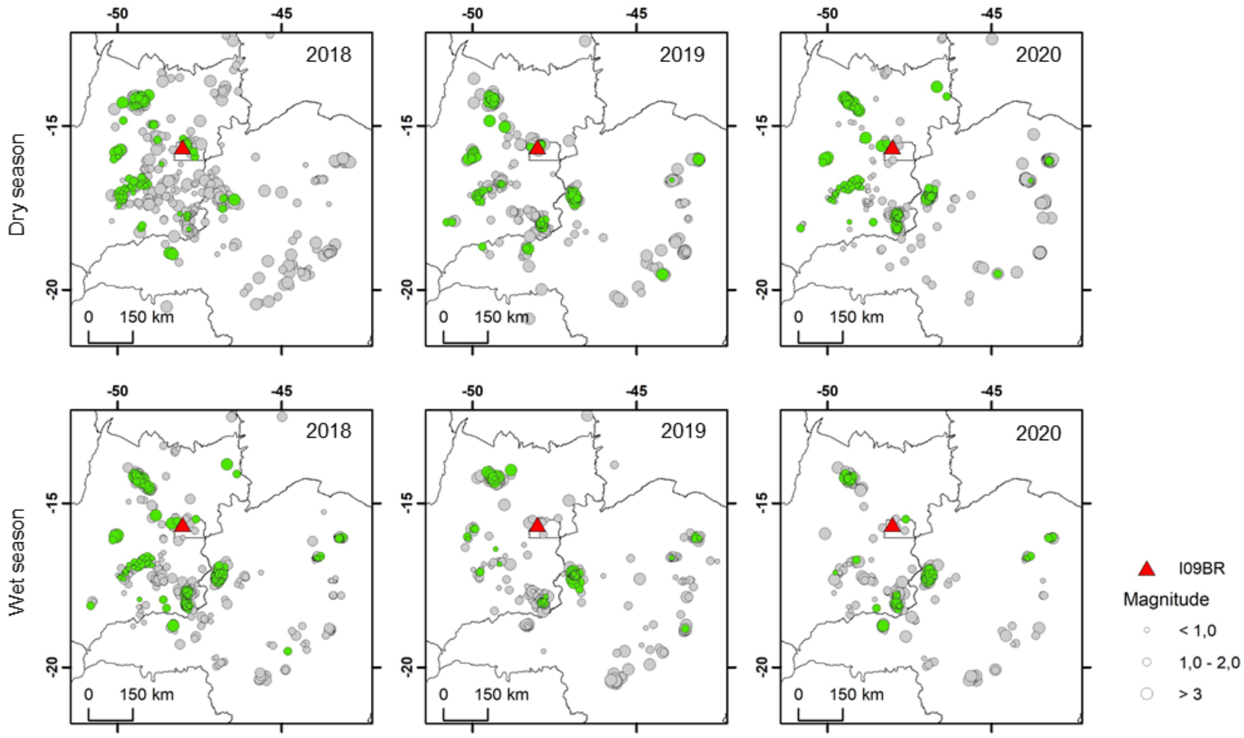


FIG. 12. Mine blast detections by the seismic and infrasound technology in the period from 2018, to 2020. Green and grey circles represent detections by seismic stations. Green circles also represent detections by infrasound stations, the size of the circle represents the magnitude.

The average magnitude of the explosions recorded by RSBR within a radius of 6 degrees from the Brasília infrasound station is 2.0 mR (Assumpção, 1983). This magnitude corresponds to an equivalent yield of 0.0043 kt of TNT according to the formula of Pilger et al., 2021. However, these blasts are made for rock blasting, they usually have very low yield because the detonated charge is divided into holes and the blasting is usually carried out in stages with time delays (Konya & Walter, 1991). The depth of explosions in the seismic bulletins published by SIS UnB is fixed at zero due to the impossibility of estimating the depth with acceptable accuracy. As the load and the detonation environment influence the generation of infrasonic waves, in the study period 2018 to 2020, the I09BR station detected an average of 16% of the explosions recorded by the seismic stations. Most of the events detected by both technologies are at miners within a 3 degrees radius and the number of explosion detections by the I09BR station decreased in the wet season because the signal produced by the storms masked the explosion signals.

TABLE I. Number of mine blast detections by seismic and infrasound technologies.

Year	Seismic events by year	Infrasound events by year	Seismic events on dry season	Infrasound events on dry season	Seismic events on wet season	Infrasound events on wet season
2018	1305	170	662	98	643	72
2019	1222	181	661	108	561	73
2020	1127	239	603	142	524	97

On March 11, 2020, the World Health Organization (WHO) classified the coronavirus outbreak as a pandemic. But only on April 11, 2020, the first case of COVID-19 appeared in Brasília. After that, the government enact restrictive measures to contain the disease spread. The reduction in human activity affected the number of infrasound detections compared to before the pandemic. In the graphs on Figure 13 indicate the number of detections by azimuth from 2018 to 2021. The color scale shows the mean frequency of the infrasonic signal.

The azimuths of the known infrasonic signal sources are on these graphs (Fig. 13). The number of infrasound detections per year reduced from 2018 to 2021, and there were also changes in the frequency content of the signals recorded by the I09BR station. The signals produced by the Brasília urban center in the years 2020 and 2021 reduced the number of detections and the frequency content. The I09BR station started to detect lower frequency signals from the Pacific Ocean microbarom and consequently, the number of detections increased. Despite of the microbarom detections reduction from the Atlantic Ocean the azimuthal range increased.

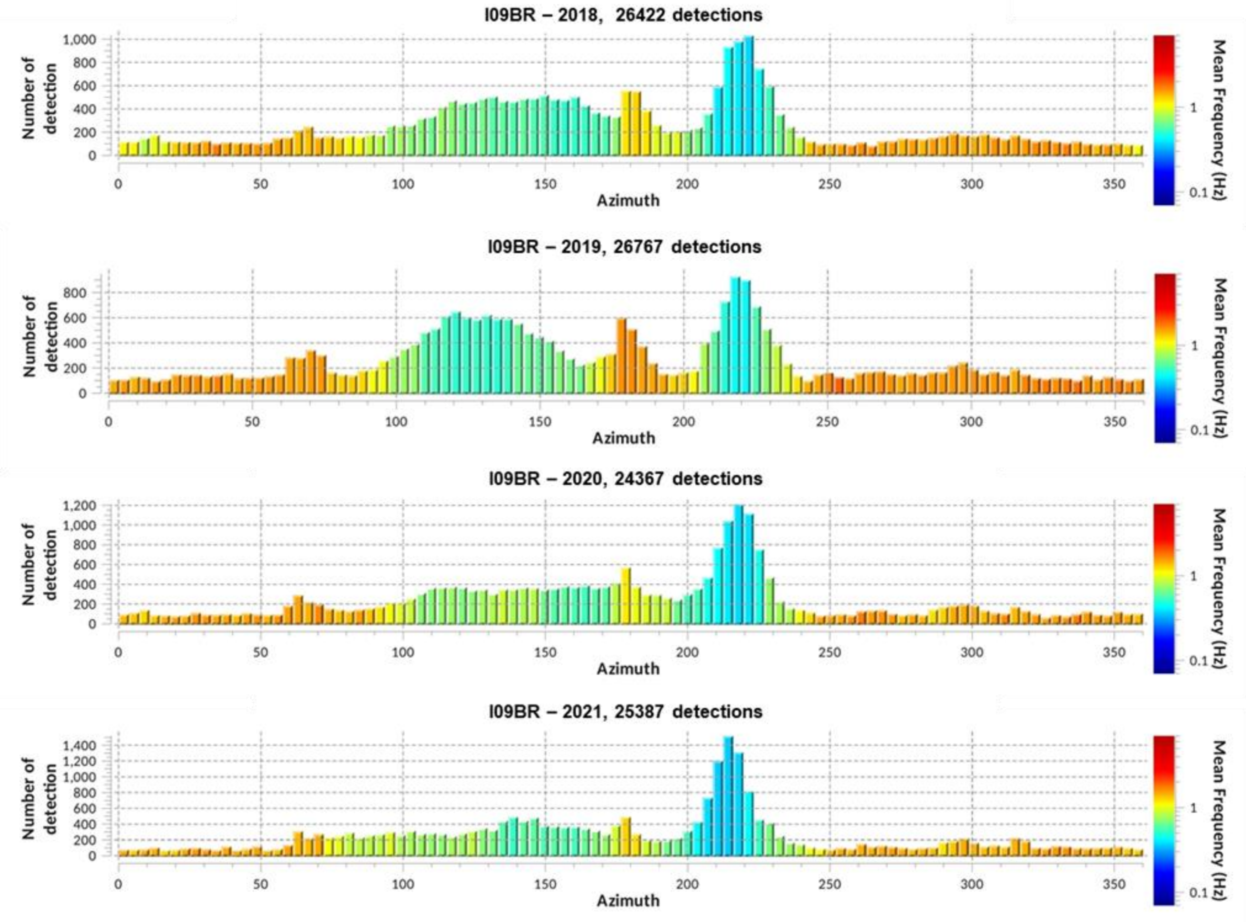


FIG. 13. Graph of infrasound detections by the I09BR station in the period from 2018 to 2021.

VI. DISCUSSION AND CONCLUSIONS

The only infrasound station in Brazil, belonging to the International Monitoring System to verify the compliance of the Comprehensive Nuclear-Test-Ban Treaty, did not detect any nuclear explosion since it's deployment. The station, installed in Brasilia National Park, proved to be efficient in detecting natural and man-made infrasound events, such as chemical explosions, supersonic planes, storms, meteors, volcanic eruptions, earthquakes, microbaroms, and many more.

The I09BR station is installed in a subtropical region, where there are two well-defined seasons: the wet season, and the dry season. In the wet season, there is a greater number of high-frequency infrasound detections compared to the dry season. This is because the storm is a signal source that covers the entire spectrum of infrasound frequencies. The seasons was decisive for the detection of microbaroms, in the wet season, the I09BR station detects more signals from the Atlantic Ocean and in the dry season microbaroms from the Pacific.

The station I09BR detects over the years two fixed sources of the high-frequency man-made infrasonic signal. One is related to the noise produced by the nearby city (factories, airport etc), and the other is related to the explosions carried out in mining companies close to the station.

In April 2020, there was the first decree of social isolation due to the covid 19 pandemic. With the reduction of human activity, the I09BR station had fewer detections from these artificial sources of the infrasonic signal. However, during the pandemic, the number of explosion detections in mining companies recorded by infrasound station increased. Because in the previous year the urban noise mascaraed the signal from the mine blasts.

The study of infrasound technology is relatively recent, and although the Brazilian infrasound station is in operation since 2001, there are not many studies using data from this station. This work highlights the signal sources that the I09BR station has been detecting over the years, showing that it can be used in several scientific applications. The I09BR Station has the potential to provide a significant contribution to the monitoring of infrasonic signals.

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CAPÍTULO 4: DISCUSSÃO E CONCLUSÕES

Evolução das pesquisas na tecnologia de infrassom usando a Teoria do Enfoque Meta-Analítico Consolidado.

Este trabalho apresenta a tecnologia infrassônica a jovens pesquisadores, com a intenção de ajudá-los a conhecer os principais temas que a compõem, favorecendo a realização de trabalhos futuros. Além disso, cita onde estão localizados os principais laboratórios de pesquisas, quem são os pesquisadores envolvidos com essa temática, quais são as principais linhas de pesquisa e quais são os artigos mais citados.

Os Estados Unidos da América é o país que possui o maior número de centros de pesquisas em infrassom e o que mais publicou artigos sobre essa tecnologia. No entanto, países como França, Itália, Rússia, Alemanha e Inglaterra também têm contribuído com estudos sobre essa tecnologia.

A tecnologia infrassônica teve grande avanço após a Segunda Guerra Mundial e, também, durante a Guerra Fria. Considerando que é uma tecnologia de monitoramento de testes nucleares atmosféricos, observamos que, não por acaso, as nações que tiveram um papel importante naquela época são as que mais pesquisaram e publicaram sobre o tema. Porém, com a criação do IMS e a promoção de eventos científicos (conferências, encontros, treinamentos, workshops etc.) houve o surgimento de pesquisadores em outros países.

As principais abordagens encontradas estão relacionadas ao estudo do comportamento do infrassom na atmosfera, estudo das fontes geradoras do sinal, processamento do sinal e técnicas de detecção. Entre os autores que mais contribuíram estão: Fee, D., estudando a propagação do infrassom na atmosfera, o infrassom gerado por vulcões e terremotos, e a detecção e classificação do sinal de infrassônico; Le Pichon, A., que foi responsável pela organização e publicação de dois livros que reúnem referências para o estudo do monitoramento da atmosfera; Johnson, J., que estuda tecnologia de infrassom e o desenvolvimento de sensores para monitorar vulcões; Ripepe, M., que contribui para o estudo de erupções vulcânicas, usando tecnologia de infrassom; Evers, L., que concentra seus estudos em sismologia, infrassom e tecnologia hidroacústica para identificar fontes geofísicas e mudanças de propagação. Dessa maneira, concluímos que o estudo do infrassom não se limita a pesquisar apenas a atmosfera terrestre, ele pode ter mais aplicações civis e sociais, como a não aceitação da energia eólica pelos cidadãos alemães, por medo do ruído de um parque eólico, ou até mesmo aplicações biológicas no estudo do comportamento dos peixes.

A contribuição da estação I09BR, do Sistema Internacional de Monitoramento, para detecção de eventos infrassônicos

A única estação de infrassom do Brasil, pertencente ao Sistema Internacional de Monitoramento, para verificar o cumprimento do Tratado de Proibição Total de Testes Nucleares, não detectou qualquer explosão nuclear, desde a sua implantação. A estação, instalada no Parque Nacional de Brasília (I09BR), provou ser eficiente na detecção de eventos infrassônicos naturais e artificiais, como explosões químicas, aviões supersônicos, tempestades, meteoros, erupções vulcânicas, terremotos, microbaroms e muitos mais.

A estação I09BR está instalada em uma região subtropical, onde há duas estações bem definidas: a estação chuvosa e a estação seca. Na estação chuvosa, há um maior número de detecções de infrassom de alta frequência, em comparação com a estação seca. Isso ocorre porque a tempestade é uma fonte de sinal que cobre todo o espectro de frequências infrassônicas. As estações do ano foram decisivas para a detecção de microbaroms -na estação chuvosa, a estação I09BR detecta mais sinais do Oceano Atlântico e, na estação seca, microbaroms do Pacífico.

A estação I09BR detectou, ao longo dos anos, duas fontes fixas de sinal infrassônico artificial de alta frequência. Uma está relacionada ao ruído produzido pela cidade vizinha e, o outro, está relacionada às explosões realizadas em mineradoras próximas à estação.

Em abril de 2020, houve o primeiro decreto de isolamento social devido a pandemia por covid 19. Com a redução da atividade humana, a estação I09BR teve menos detecções dessas duas fontes artificiais de sinais infrassônicos. No entanto, durante a pandemia, aumentou o número de detecções de explosões em mineradoras. Isto, porque nos anos anteriores, o ruído urbano mascarava o sinal das explosões em mineradoras.

O estudo da tecnologia de infrassom é relativamente recente e embora a estação brasileira de infrassom esteja em operação desde 2001, não há muitos estudos sobre esta estação e usando dados desta estação. Este trabalho destaca as fontes de sinal que a estação I09BR vem detectando ao longo dos anos, mostrando que ela pode ser utilizada em diversas aplicações científicas. A estação I09BR tem contribuído significativamente para o monitoramento de sinais infrassônicos.

Trabalhos Futuros

Estudo para implementação de novas estações infrassônicas em território brasileiro.

Estudo para a melhoria da estação I09BR, instalando novos elementos.

Contribuição dos microbaroms detectados pela I09BR no ruido de fundo.

Capacidade de detecção de Bólidos pela estação infrassônica de Brasília.

Estudo da detectabilidade de sinais infrassônicos gerados pelos Terremotos andinos.

Identificação de eventos infrassônicos pelas estações infrassônicas da rede IMS da América do Sul.

Comportamento da detectablidade da estação I09BR com as variações climáticas.

Estudo da sinergia dos sinais detectados pelas estações infrassônicas e sísmicas.

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ANEXO A: PRODUÇÕES CIENTÍFICAS COMPLEMENTARES DESENVOLVIDAS

Neste capítulo, apresentamos outras produções científicas desenvolvidas ao longo do curso do mestrado e que foram publicadas em forma de livro, artigo e resumos em eventos científicos nacionais e internacionais.

1 LIVRO

1.1 - Título: A Participação brasileira no sistema de verificação do tratado de proibição total detestes nucleares.
Autores: Lucas Vieira Barros, Brandow Lee Neri, Juraci Mário de Carvalho e Darlan Portela Fontenele.
ISBN: 978-65-86387-20-9
Data: 20/11/2020
Disponível em: http://obsis.unb.br/portalsis/?pg=viewNotice&id_notice=38

2 ARTIGO

2.1 - Título: Seismo-acoustic signal analysis and yield estimate of the Beirut, Lebanon accidental explosion on August 4, 2020.
Autores: Lucas Vieira Barros, Brandow Lee Neri, Darlan Portela Fontenele, Diogo Albuquerque Farrapo, Ronnie Quintero Quintero e Juraci Mário de Carvalho.
Revista: Brazilian Journal of Geophysics

3 RESUMOS PUBLICADOS EM EVENTOS NACIONAIS

3.1- Título: Infrasound Detections in the I09BR station.
Autores: Brandow Lee Neri, Lucas Vieira Barros, Arthur Macedo, Leticia Guedes e Mônica Giannoccaro Von Huelsen.
Evento: 4th Brazilian Seismology Symposium
Data: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/12112021061523 1825i09-bln-SBS-final.pdf

3.2 - Título: Evolution of research in infrasound technology using the meta analytical approachtheory.
Autores: Brandow Lee Neri e Lucas Vieira Barros.
Evento: 4th Brazilian Seismology Symposium Data: 08 – 11/ 11/2021

Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/12112021052820 3429SBGF_ BLN_SEM2 _2021_expanded_abstract_lucas_corrigido.pdf

3.3 - Título: University of Brasilia studies explosions occurred in Beirut – Lebanon. Autores: Lucas Vieira Barros, Brandow Lee Neri, Darlan Portela Fontenele , Ronnie Quintero,Diogo Farrapo Albuquerque e Juraci Mario de Carvalho.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/18692021061521 1632bln-beirute-final_.pdf

3.4 - Título: The establishment of a Brazilian Nacional Data Center (NDC) for a better Comprehensive Nuclear Test-Ban-Treaty verification regime.
Autores: Lucas Vieira Barros, Brandow Lee Neri, Juraci Mario de Carvalho e Darlan Portela Fontenele.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/1869202106142 30159article-th-establishment-of-a-brazilianNDCforabetterCTBTverificationregime.pdf

3.5 - Título: Identification of bolides infrasound signal using south american ims infrasound stations.
Autores: Arthur Siqueira de Macêdo, Brandow Lee Neri, Leticia Guedes Assumção e Lucas Vieira Barros.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/18962021061 5020347IDENTIFICATION%20OF%20BOLIDES%20INFRASOUND%20SIGNAL%20USI NG %20SOUTH%20AMERICAN%20IMS%20INFRASOUND%20STATIONS.docx

3.6 - Título: Peru earthquake, 8.0 Mw, registered by IMS infrasound stations Network. Autores: Darlan Portela Fontenele, Lucas Vieira Barros, Brandow Lee Neri, Juraci Mario Carvalho, Diogo Farrapo Albuquerque e Matheus Fernandes da Cruz.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/18122021052820 3352Resumo_Darlan_Portela_Fontenele.pdf

3.7 - Título: Preliminary analysis of infrasound generated by the meteoroid explosion over Japanon November 29, 2020 detected by IMS stations.

Autores: Diogo Farrapo Albuquerque, Lucas Vieira Barros, Brandow Lee Neri, Matheus Fernandes da Cruz e Darlan Portela Fontenele.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/10192021030501 1054Preliminary_analysis_of_infrasound.pdf

3.8 - Título: Analysis of infrasonic signals generated by an accidental explosion on July 3, 2020 at a fireworks factory in Turkey
Autores: Matheus Fernandes da Cruz, Brandow Lee Neri, Diogo Farrapo Albuquerque, Darlan Portela Fontenele e Lucas Vieira Barros.
Evento: 4th Brazilian Seismology SymposiumData: 08 – 11/ 11/2021
Disponível em:
https://sbgf.org.br/mysbgf/eventos/expanded_abstracts/17th_CISBGf/138620210305200859 ANALYSIS%20OF%20INFRASONIC%20SIGNALS.pdf

4 RESUMOS PUBLICADOS EM EVENTOS INTERNACIONAIS

4.1 - Título: Preliminary results of South American infrasound monitoring.
Autores: Brandow Lee Neri e Lucas Vieira Barros.
Evento: EGU General Assembly 2021Data: 26/04/2021
Disponível em: https://doi.org/10.5194/egusphere-egu21-8484

4.2 - Título: Influence of the reduction of human activity due to the pandemic in the identification of infrasonic events by I09BR Station.
Autores: Brandow Lee Neri, Lucas Vieira Barros, Letícia Guedes Assumção, Arthur Siqueira Macêdo e Monica Gianocaro Von Huelsen.
Evento: CTBT Science and Technology Conference 2021Data: 02/07/2021
Disponível em: https://conferences.ctbto.org/event/7/book-of-abstracts.pdf

4.3 - Título: Review I09BR Infrasound Detection.
Autores: Brandow Neri, Lucas Barros, Arthur Macedo, Leticia Assunção.Evento: IAGA – IASPEI 2021
Data: 21 – 27/ 08/ 2021
Disponível em: http://iaga-iaspei-india2021.in/NGRI_IAGA%20IASPEI%202021%20(Final)_13%20 Sep%202021.pdf

4.4 - Título: Monitoring changes in mine blast detection during COVID-19 shutdown in Brasiliausing the I09BR infrasound station.

Autores: Brandow Lee Neri, Lucas Vieira Barros, Arthur Siqueira Macedo, Leticia Guedes Assunçao e Darlan Portela Fontenele.
Evento: AGU Fall Meeting 2021Data: 17/12/2021
Disponível em: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/938618

1.1

Lucas Vieira Barros
Brandow Lee Neri
Juraci Mario de Carvalho
Darlan Portela Fontenele
A PARTICIPAÇÃO BRASILEIRA
NA VERIFICAÇÃO DO TRATADO
DE PROIBIÇÃO TOTAL DE TESTES
NUCLEARES
OBSERVATÓRIO
SISMOLÓGICO
Universidade de Brasília
BRASÍLIA 2020

2.1

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Seismo-acoustic signal analysis and yield estimate of the Beirut, Lebanon accidental explosion on August 4, 2020

August 4, 2020, Beirut, Lebanon chemical explosion and Seismoacoustic signal analysis

Análise sismoacústica de sinais e estimativa de rendimento da explosão acidental em Beirute, Líbano em 4 de agosto de 2020

Area: Solid Earth Geophysics

Received: submission date; Accepted: date; Published: date

ABSTRACT. The Beirut, Lebanon explosions occurred on August 4, 2020, one of the largest non-nuclear blasts in the history detected by the IMS infrasound and seismic stations, a network designated to detect and locate nuclear explosion in violation of the CTBT. The explosion was registered by five infrasound and three seismic stations located up to 6,000 km and 2,400 km distance from the source, respectively. These IMS data, complemented by data from seven ocean bottom opened access data stations, were accessed by the SIS - UnB to estimate epicenter, magnitudes (mb = 3.6 and Mw = 3.3), and explosive yield. The explosion location was determined by both technologies. Infrasound 33.864ºN and 34.311ºE. Seismic location 33.859ºN and 35.567ºE. The yield was calculated using two approaches: the seismic P-wave magnitude and maximum amplitude of the infrasound signal, resulting in 0.401 kt and 1.48 kt of TNT equivalent, respectively. The aim of this work is testing the performance of the IMS network in the detection, location, and characterization of an explosion, develop researchers' skills and capacity to accurately locate events of CTBT interest. Additionally, we intend to share the importance of the CTBT and arouse interest in the use of IMS data.

Keywords: accidental explosion; seismic event detection; infrasound event detection; CTBTO; nuclear explosion detection.

RESUMO. A explosão de Beirute, Líbano, em 4 de agosto de 2020, uma das maiores explosões não nucleares da história, foi detectada pelas estações infrassônicas e sísmicas do IMS, uma rede designada para detectar e localizar explosões nucleares em violação ao CTBT. A explosão foi registrada por cinco estações de infrassom e três estações sísmicas localizadas a até 6.000 km e 2.400 km de distância da fonte, respectivamente. Esses dados, complementados por sete estações de fundo oceânico, foram acessados pelo SIS - UnB para estimar epicentro, magnitudes (mb = 3,6 e Mw = 3,3) e rendimento explosivo. O local da explosão foi determinado por ambas as tecnologias. Infrassom 33.864ºN e 34.311ºE e sísmica 33.859ºN e 35.567ºE. O rendimento foi calculado usando duas abordagens: a magnitude da onda P e a amplitude máxima do sinal infrassônico, resultando em 0,401 kt e 1,48 kt equivalente em TNT, respectivamente. O objetivo deste trabalho é testar o desempenho da rede IMS na detecção, localização e caracterização de uma explosão, desenvolver habilidades e capacidade dos pesquisadores para localizar com precisão eventos de interesse do CTBT. Adicionalmente, pretendemos compartilhar a importância do CTBT e despertar o interesse de pesquisadores no uso dos dados do IMS.

Palavras-chave: Explosão em Beirute; Explosão acidental; Grandes explosões químicas.

INTRODUCTION

The devastating chemical explosion occurred at the Beirut harbor on August 4, 2020, at 18:08 (local

3.1

Infrasound Detections in the I09BR station

Brandow Lee Neri [1], Lucas Vieira Barros [1], Arthur Macedo[1], Leticia Guedes[1], Mônica Giannoccaro Von Huelsen[1],
[1]Observatório Sismológico da Universidade de Brasília.

This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

Infrasound monitoring is one of the four technologies used by the International Monitoring System (IMS) to verify compliance with CTBT. Shallow atmospheric and underground nuclear explosions can generate infrasound waves that can be detected by infrasound networks. Of the 60 infrasound stations proposed by CTBT, one has been installed in Brazil since 2001. As the last nuclear tests were underground and on the Asian continent, the Brazilian infrasound station did not detect it. However, there are several other sources of infrasound signals detected by IS09 station. This work aims to present the results of the analysis of data, highlighting the main signal sources that the I09BR station has been detected over the years.

Introduction

The implementation of the International Monitoring System to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) has generated rapid growth in interest in infrasound technology. The Treaty provides for a worldwide network of infrasound consisting of 60 permanent stations installed around the globe by various research organizations, in partnership with the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). 91% of these stations are already installed.

Infrasound is an inaudible sound by humans and its study is also called by the same name. As it is an acoustic disturbance, it is characterized by variations in air pressure, whose frequencies vary from 0.001Hz to 20Hz and, due to its high wavelengths, between 17 m and 30 km, it can travel large distances in the atmosphere, as it suffers low attenuation (Gossard and Hooke 1975). The main function of the infrasound station is to measure atmospheric pressure fluctuations and convert them into a digital signal.

Infrasound stations were developed to detect atmospheric nuclear explosions. Each station consists of an array of spatially distributed sensors following a given geometry. One element of this arrangement is composed of a sensor (microbarometer), a noise reduction system, a photovoltaic power supply system, and a data transmission system using a secure communication system. Data from IMS stations are sent in near real-time to the IDC (International Data Center), locate in Vienna - Austria (Christie & Campus, 2009).

The Brazilian Infrasound station is located in Brasília, a subtropical region in the interior of Brazil. The four elements of the triangular arrangement of the I09BR are installed within the ecological reserve of the Brasília National Park (PNB) about 20km away from the Seismological Observatory of the University of Brasília (SIS - UnB) (Barros and Fontenele, 2002). The I09BR for safety and logistics reasons is in an appropriate location, as access to the environmental protection area is only allowed for authorized people, the PNB vegetation collaborates with noise levels, as it helps to filter out wind turbulence, and the station is close to the Central Data Reception and Recording Facility (Central Processing Facility) located at SIS - UnB.

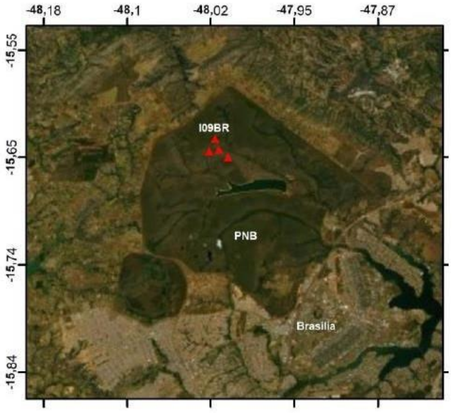

Figure 1: Location of the I09BR infrasund station arrangement.

The IMS network of infrasound stations was designed to reliably detect any atmospheric nuclear explosion with a power equivalent to or greater than one kiloton of TNT (1000 tons of TNT), anywhere in the world (Christie et al., 2001).

In addition to its use in CTBT verification, infrasound technology has application in scientific and social areas, like other natural and anthropogenic phenomena can also generate infrasound. For example large volcanic eruptions (Cotten et al., 1971; Fee et al., 2013; Jeffrey B Johnson et al., 2004; Jeffrey B Johnson & Ripepe, 2011; Matoza R. et al., 2019; Jack W Reed, 1987); severe climates (Waxler & Assink, 2019); detonations in mining companies (Bowman & Bedard, 2010; Georges, 1973; Lin

3.2

Evolution of research in infrasound technology using the meta analytical approach theory

Brandow Lee Neri [1], Lucas Vieira Barros [1], [1]Observatório Sismológico da Universidade de Brasília.

This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

Research on infrasound is considerably recent because it is an area of knowledge little explored. However, the processing, analysis, and interpretation of infrasound signals already have several applications. The oldest studies related to infrasound signals date from the 1883s, due to the eruption of the Krakatoa volcano in Indonesia where it generated infrasound waves that were detected by weather stations. This study aims to present a systematic review of the main contributions of the high-impact literature concerning studies using infrasound technology. Exploratory research, with a quantitative approach, was carried out using the Consolidated Analytical Meta Approach Theory - TEMAC, by Mariano and Rocha (2017). The term "Infrasound" was defined as a search string and the Web of Science as a database. The data collection showed that there has been a significant increase in the number of citations on the subject in the last 20 years, reaching 18606 marks. This fact is related to two main events: The stabelishiment of the International Monitoring Network (IMS) to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and with the availability of data from this network to the scientific community.

Introduction

Infrasound is an inaudible sound by the human being and its study is also called by the same name. Because it is an acoustic disturbance, it is characterized by variations in air pressure, whose frequencies vary from 0.001Hz to 20Hz and, due to its high wavelengths, between 17 m and 30 km, it can travel great distances in the atmosphere, as it suffers with low attenuation (Gossard & Hooke, 1975). These low-frequency sounds can be generated by natural or anthropogenic sources such as: nuclear tests (Assink J. et al., 2018; Assink J. et al., 2016; Whitaker & Mutschlecner, 2008; Mutschlecner et al., 1999; ; Posey & Pierce, 1971; Reed, 1969; Donn & Shaw, 1967;), volcanic activities (Matoza R. et al., 2019; Fee et al., 2013; Jeffrey B Johnson & Ripepe, 2011; Jeffrey B Johnson et al., 2004; ; Jack W Reed, 1987; Cotten et al., 1971), chemical explosions (Davidson, M., & Whitaker, 1992; Evers & Haak, 2007; Grover, 1968; Hagerty et al., 2001), solid (Arrowsmith S. et al., 2008; Brown P. et al., 2002; Edwards, 2010; Elbehiri et al., 2021), climatic events (Bowman & Bedard, 2010; Georges, 1973; Lin & Langston, 2009), launch and re-entry of rockets (Cotten et al., 1971; Garces M. et al., 2004) among others.

The implementation of the IMS network, composed of 60 infrasound stations, is responsible for providing an unprecedented opportunity for the global study of infrasound, with the use of new methods of signal processing (Y Cansi, 1995; Y Cansi & Klinger, 1997; Y Cansi & Le Pichon, 2009), of microbarometer sensors (Alcoverro & Le Pichon, 2005; Haak & Wilde, 1996; Marty, 2019; Raspet et al., 2019) of efficient arrangement designs (Garces et al., 2004; Shields, 2005; Sutherland & Bass, 2004; Talmadge, 2018) of atmosphere studies (Drob et al. , 2003; Le Pichon et al., 2009), volcanology (Jeffrey Bruce Johnson & Ripepe, 2011; Le Pichon et al., 2005; Matoza et al., 2019; Stein et al., 2015), among others.

The infrasound, despite being a technology of recent history, observing the literature on this technology, the theme "Infrasound", on the basis of ISI Web of Science, found 1620 results, 1289 of which are articles published in scientific journals. As it is a relatively recent study, the knowledge of the most relevant contributions, as well as the most important authors for the theme, is a guiding element of new works in the area. Thus, the objective of this research is to make an analysis of the magazines that publish the most on the topic, on the evolution of the number of publications per year, the most cited documents, the authors that published the most and that were the most cited. It was also verified the countries that originated the research, the research areas of the publications and the frequency with which the keywords appear. To achieve these objectives, exploratory research will be carried out through the Theory of the Consolidated Analytical Meta Approach (TEMAC) by Mariano & Santos, (2017).

Method

This is an exploratory study, with a quantitative approach, using TEMAC. This technique is based on three simple steps for identifying impact literature and analysis according to the laws of bibliometry.

In the first stage, the database was organized from the base of the Web of Science platform, considered one of the best and most complete database (Mariano et al., 2011). The term "Infrasound" was used in scientific articles in all possible years of the database. The sample of this research is composed of 1289 works from 1945 to March 2021.

In the second stage, the Web of Science platform itself was used, finding the countries that published the most (Figure 1), evolution of the theme year by year (Figure 2), relationship between the authors who published the most with the most cited authors and frequency of keywords.

3.3

University of Brasilia studies explosions occurred in Beirut – Lebanon

Authors, Entities Lucas Vieira Barros[1], Brandow Lee Neri[1], Darlan Portela Fontenele[1], Ronnie Quintero[2], Diogo Farrapo Albuquerque[1] and Juraci Mario de Carvalho[1]. [1]Seismological Observatory, University of Brasília; [2]Ovsicori, Universidad Nacional, Costa Rica.

Abstract

The Beirut, Lebanon chemical explosion on August 4, 2020, is one of the largest non-nuclear blasts in history and was recorded by the infrasound and seismic stations of the International Monitoring System (IMS), a global network designated to detect clandestine nuclear explosion in violation to the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The explosion was detected by infrasound and seismic stations located up to 6,000 and 2,400 km from the source, respectively. Data from 5 infrasound and 3 seismic stations of the IMS and stored at IDC-CTBTO was accessed by the Seismological Observatory of the University of Brasilia (SIS-UnB) and used to calculate hypocenter, magnitudes, and explosive yield. An attempt to determine the CMT was made, but it is not shown in this study. This introductory work aims to test the performance of the IMS network in the detection, location and characterization of an explosion and develop authors' skills and capacity to accurately locate events of CTBT interest. Additionally, we intend to share the importance of the CTBT and arouse interest to in the use of IMS data for civil and scientific applications.

Introduction

A devastating chemical explosion occurred at the Beirut harbor on August 4, 2020, at 18:08 (local time) or 12:08 (UTC), killing 207 people, leaving around 7,500 injured, 300,000 homeless and 15 billion dollars loss (Reuters, 2020). Within a radius of 800 meters from the source, almost everything was destroyed: ships anchored at the port were sunk, buildings and houses collapsed, cars destroyed etc. (Fig. 1). The shock waves were felt in Turkey, Syria, and Palestine, and it was heard in Nicosia, Cyprus, more than 240 km away from the source. After the explosion, a large cloud of black smoke washed over the port area.

The explosion was caused by the detonation of 2750 tons of ammonium nitrate that had been stored in a warehouse in the port since 2013. Ammonium nitrate is a fertilizer used in agriculture, but that can burn up when subjected to temperatures of about 300 Celsius. A fire in a neighboring warehouse triggered the first small detonation, which triggered the second big explosion of nitrate. Considering an efficiency of about 50%, this explosion had a yield equivalent to a nuclear explosion with more than 1 kt of TNT, enough to generate seismic waves with energy equivalent to a magnitude 4 earthquake, considering a subsurface explosion, which was not the case. Even so, the USGS estimated a magnitude of 3.3 mb. In this work, we estimated magnitudes equal to 3.3 Mw and 3.6 mb.

Figure 1: Images before and after the explosion at the Beirut Port. As you can see, everything was destroyed in a radius of 400 m from the explosion point.

A big nuclear test, of about hundreds of kilotons, can generate energy capable of spreading throughout the planet, in the form of disturbances detectable by a certain type of geophysical sensors. In this sense, it was designed the International Monitoring System composed by sensors of four technologies, each one suitable for detection in one of three possible environments: atmosphere, subsurface and underwater masses.

The Seismological Observatory of the University of Brasilia (SIS-UnB) collaborates with the United Nations Organization CTBTO (Comprehensive Nuclear-Test-Ban-Treat Organization), based in Vienna - Austria, which aims to verify the compliance with the CTBT. The Brazilian government participates in this organization with data from its IMS stations installed within its borders as well as the result of the data analysis and interpretation obtained by the analysists and experts. Any nuclear explosion, whether underground, underwater or in the atmosphere, with a power equivalent to at least 1 kiloton of TNT (Trinitrotoluene), at any time and place, can be detected by this network.

In this work, we present the Beirut chemical explosion sources parameters (epicentral location, magnitudes and yield) determined using infrasound and seismic data. But before that, we would like briefly present the CTBT Treaty, its verification regime and the seismic and infrasound technologies used. We also aim to arouse interest of Latin American researchers in the use of IMS technologies. However, under a confidentiality clause, the IMS data can be used by all States Parties.

3.4

The establishment of a Brazilian Nacional Data Center (NDC) for a better Comprehensive Nuclear Test-Ban-Treaty verification regime

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This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

The Comprehensive Nuclear Test-Ban-Treaty (CTBT) prohibits conducting nuclear tests on a global scale. Although not yet in force, it has an International Monitoring System (IMS) based on geophysical sensors, capable of globally detect any nuclear test equal or greater than 1 kt (kiloton) of TNT. The Sensors of the global IMS network use four technologies: Seismic; Infrasound; Hydroacoustics and Radionuclides. Data from the IMS network are transmitted to the International Data Center (IDC), located at the United Nations in Vienna – Austria. The IDC has the mission of processing, analyzing and issue bulletins/reports on any event of interest to treaty compliance. But, only the State Parties, through their NDCs and National Authorities (NA), can declare an event to be suspicious and possible linked to a clandestine nuclear explosion. The Brazil, despite of having already signed and ratified the Comprehensive Nuclear Tests-Ban-Treaty (CTBT), does not have yet an established NDC, which is a center with expertise in verification technologies operating under the guidance of the National Authority. The NA is the main Point of Contact of a State Party to the CTBT, International Data Center and other States Parties. Therefore, a NDC plays a key role in overseeing compliance with the CTBT. Brazil contributes with data from three technologies: Seismic, Infrasound and Radionuclides. The Seismological Observatory (SIS) of the University of Brasília (UnB) contributes with data from two stations, a primary seismic station and an infrasound station, both located inside the Brasília National Park (PNB). Data from these stations are transmitted to the (SIS – UnB), where they are recorded, analyzed and retransmitted to the IDC. The other IMS stations in Brazil are: two auxiliary seismic stations, located in the states of Rio Grande do Norte and Amazonas; two radionuclide stations, located in Rio de Janeiro and Recife (planned), and a radionuclide laboratory, located at the Institute of Radioprotection and Dosimetry (IRD), also at the city of Rio de Janeiro. In this text, we present a description of a NDC, with definition, attributions and requirements for its assembly and operation.

Introduction

Brazil's National Data Center (NDC) has not yet been formally established, although, according to the CTBT, NDCs can be created in any State Party. A NDC is an organization with expertise in verification technologies that functions as part of (or under the guidance of) a National Authority.

The CTBT Treaty consists of 1 preamble, 17 articles, 2 annexes and 1 protocol with 2 annexes. The text of the Resolution adopted by the CTBT Signatory Countries or States Parties also integrates the Treaty, establishing the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization - PrepCom/CTBTO, with the objective of carrying out the necessary preparations for the effective implementation of the CTBT and guaranteeing the operationalization of the Treaty's verification regime, upon its entry into force, which is subject to ratification by the 44 countries listed in Annex 2 of the CTBT.

Brazil signed the Treaty on 9/26/1996, ratified it on 7/24/1998 and participates in its verification under three technologies: seismic, infrasound and radionuclides. A treaty, when in force, is an agreement between States with the obligations of each State Party governed by international law. The Vienna Convention on the Law of Treaties provides that all States Parties to a treaty must contribute to the achievement of its objectives and purposes. These are obligations of Brazil to the CTBT (as well as those of other States Parties), in addition to the commitment not to carry out any type of nuclear explosion, to prohibit and prevent any nuclear test anywhere under its jurisdiction or control, to contribute to the Treaty verification with data from your stations and participate in the investigation and identification of suspicious events.

The identification of suspected clandestine test events will occur through the analysis and interpretation of signals detected by geophysical sensors of four specific technologies, capable of detecting any nuclear test with a power greater than or equivalent to 1 kiloton (kt) of TNT (trinitrotoluene). After detecting, locating, and identifying a suspicious event, an on-site inspection is carried out to confirm whether a nuclear test has taken place.

In June 2019, on the fourth Science and Technology Conference (SnT4/2019) promoted by the CTBTO, in Vienna - Austria, the Brazilians participating in this event were invited by the ambassador of the Brazilian Permanent Mission to the UN in Vienna, minister Marcel Fortuna Biato, for a meeting, when we had the opportunity to discuss the creation of a NDC in Brazil. After this event, the authors of this article wrote the book: The Brazilian Participation in the Verification of the Comprehensive Nuclear Teste-Ban-Treaty (http://obsis.unb.br/portalsis/?pg=viewNotice&id_notice=38). This book is based mainly in the authors experiences in more than 20 years working with seismic and infrasound technologies. The book presents the most relevant parts of the CTBT, emphasizing the obligations of a State Party in its verification, with emphasis on the Brazilian participation

3.5

IDENTIFICATION OF BOLIDES INFRASOUND SIGNAL USING SOUTH AMERICAN IMS INFRASOUND STATIONS

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It is evident that the trigger for the emergence of studies on the phenomenon of infrasound occurred, at first, with the observations of waves generated by the explosive eruption of the volcano Krakatoa, in Indonesia, in 1883, and by the explosion of a meteor, Tunguska, in Siberia in 1908. The sound waves from these events were recorded by the microbarographic of meteorological stations in several countries and, in both cases, these waves took more than one turn around the earth. After the implementation of the International Monitoring System, to verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) there was a considerable increase in research on infrasonic technology. Part of the infrasonic research takes place by monitoring natural and anthropogenic sources, such as detonations in mining, earthquakes, auroras, microbarons, severe weather events. Among those sources the most studied being volcanic eruptions and the entry of bodies celestial in the atmosphere, as do Krakatoa and Tunguska. One of the most unusual infrasound natural sources, but constant is that interplanetary debris, or meteoroids, which collide with the Earth's atmosphere at hypersonic speeds, in a process commonly known as a "meteor". The South American infrasound observation network is composed of eight stations: I01AR, I02AR, I08BO, I09BR, I13CL, I14CL, I20EC, and I41PY. Such stations are located both on the continent - as It is the case of the Brazilian station located in the Brasília National Park - and on islands - as It is the case of the Ecuadorian station located in the Galápagos archipelago. To improve this network, reducing the azimuth gap, there are still two stations on British islands in the Atlantic Ocean: I50GB and I51GB. In addition to the French island in the Caribbean: I25FR. To understand the entry of bolides into the atmosphere, the CNEOS catalog (Center of Near-Earth Object Studies) was used, which refers to all entries into the Earth's atmosphere detected by NASA sensors (National Aeronautics and Space Administration). Then it is essential to identify the relationship between the entry of the bolides into the Earth's atmosphere and the signal detected by the mentioned infrasound stations. This work aims to this.

3.6

Peru earthquake, 8.0 Mw, registered by IMS infrasound stations Network

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This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

Earthquakes are usually recorded by seismographic stations, but they can also be detected by infrasound stations. In this work, the existing synergy between seismic and infrasonic technologies is used to detect major earthquakes, exploring the capacity of an infrasound station to also detect, besides acoustic waves, ground vibrations produced by earthquakes. The infrasound is a sound in the frequency range below the limit of human hearing. The perception (or detection) of infrasound signals is made by microbarometers, which detect small variations of pressure in the atmosphere caused by natural or anthropogenic phenomenas. Originally, infrasonic technology was developed to monitor atmospheric nuclear explosions. This technology made a significant progress since the first nuclear explosions in the atmosphere. Recently, with the Comprehensive Nuclear Test-Ban Treaty (CTBT), infrasonic technology has become even more important, with the implementation of the International Monitoring System (IMS), a global network deployed by an organization linked to the United Nations. The IMS network is part of the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO), whose main purpose is to enforce the CTBT Treaty by the signatory countries. This global network is composed by 321 stations with sensors from four technologies, each one suitable for detecting nuclear explosions in a given environment.

Computational tools used in this work are from the NDC-in-a-Box package (DTK-GPMCC and DTK-DIVA), made available by CTBTO to the signatory countries for reading, detect and analysis seismic and infrasonic signals.

It was used data from the M8 Peru earthquake of May 26, 2019. Detections related to this event were investigated in the ten nearest infrasound stations of the IMS Network surrounding the epicenter. However, the event was recorded only at 4 stations, all of them located at epicentral distances up to about 3,000 km. The wave parameters obtained by the infrasound stations are compatible with those obtained from seismic stations.

Introduction

The International Monitoring System (IMS) Network was created as part of the obligations to comply with the Total Nuclear Test-Ban Treaty - CTBT, which was opened for signature in July 1996 at the United Nations (UN) headquarter. The Treaty will enter into force with the signature and ratification of all CTBT Annex 2 countries.

The IMS Network was designed to cover the entire planet, monitoring all possible environments for carrying out nuclear tests above 1 kt: land surface, water masses and atmosphere.

A specific monitoring technology is used for each environment, which can use mutual synergy to improve the detection, discrimination and location of a nuclear test.

Countries that sign and ratify the Treaty must fulfill obligations inherent in the Treaty. Among them, the maintenance of the IMS stations installed within their territories, in addition to the transmission of the data generated by these stations to the International Data Center (IDC), located in Vienna - Austria.

For the materialization of the Treaty, the Provisional Technical Secretariat (PTS) was created, with the mission to implement and maintain the IMS Network and the IDC before the treaty comes into force.

The technologies used to monitor the nuclear tests are: seismic, hydroacoustic and infrasound, in addition to that, a fourth technology (Radionuclides), with the mission to confirm the occurrence of a nuclear test (Marty, 2019). A brief description of each technology is below.

Seismic technology (170 stations) is used to detect nuclear tests under (and also above) the Earth's surface and can also detect explosions inside the oceans, depending on the distances (Barros et al, 2020).

Hydroacoustic technology (11 stations) is used to detect explosions under the aquatic masses. They are high sensitivity stations and cover all oceans (Brown, 2014).

The **infrasound technology** (60 stations) is used to detect nuclear tests at the atmosphe. It can also detect subsurface explosions, as well in the oceans, depending on the power of the explosive yield (Dahlman et al, 2011). Fig. 1.

Finally, **radionuclide technology** is based on stations and laboratories for analyzing atomic particles that are released by nuclear explosions. These particles spread in

3.7

Preliminary analysis of infrasound generated by the meteoroid explosion over Japan on November 29, 2020 detected by IMS stations

Diogo Farrapo Albuquerque, Lucas Vieira Barros, Brandow Lee Neri, Matheus Fernandes da Cruz and Darlan Portela Fontenele, University of Brasília (UnB).

Abstract

The explosive fragmentation of large meteoroids is one of the strongest sources of infrasonic waves. In the absence of nuclear tests since 1980, bolide explosions are now the strongest infrasound sources available to calibrate and test the sensitivity of the International Monitoring System (IMS) infrasound instruments. Besides, it is important to detect meteoroid explosions using infrasound arrays to estimate their potential destruction and the frequency of occurrence. In order to extract wave attributes that may be used to test the sensitivity of IMS instruments, we applied the Progressive Multi-Channel Cross-correlation (PMCC) to the infrasound records generated by the meteoroid explosion over Japan on November 29, 2020. We obtained reliable results for only two stations: I30JP (Japan) and I45RU (Russia). The PMCC algorithm returned one family of 107 pixels with a mean back-azimuth of 243.3 ± 1.3º for I30JP and 344 pixels with 160.6 ± 1.0º for I45RU. The meteoroid explosion was located near to Shingu, Japan, with a yield of less than 1 kt, which suggests that events generating energies < 1 kt should be detected by IMS.

Introduction

Our planet is continuously bombarded by meteoroids of different sizes, ranging from dust grains to hundreds of meters in diameter. Although rarer, the latter group has the potential to cause mass extinctions and long term climate perturbations (Silber and Brown, 2019). Meteors are the luminous effect caused by ionization of the material due to collision with atmosphere. Meteorites are the fragments that makes to the Earth's surface (Matsuura and Picazzio, 2003; Pilger et al., 2019).

The explosive fragmentation of large meteoroids is one of the strongest sources of infrasonic waves. The most energetic event ever recorded by the International Monitoring System (IMS) was the 2013 Chelyabinsk bolide, quantified having an equivalent explosive yield of up to 500 kt of TNT. The infrasonic waves generated by the explosion were detected by infrasound stations at long orthodrome distances (above 20,000 km) and after complete circumnavigations of the globe (up to 87,000 km) (Pilger et al., 2019).

The IMS was built to monitor nuclear tests in the atmosphere, on the surface and in the underground for the implementation of the Comprehensive Test Ban Treaty (CTBT). The IMS comprises 302 certified facilities for seismic, hydroacoustic, infrasound and radionuclide monitoring. The infrasound network is composed of 60 stations (53 certified), distributed uniformly around the globe (Figure 1), and focused on the detection of nuclear explosions in the atmosphere to verify compliance with the CTBT. It has been designed to detect and locate atmospheric nuclear explosions with a yield equivalent to one-kiloton of TNT reliably (Christie, 2007; Marty, 2019).

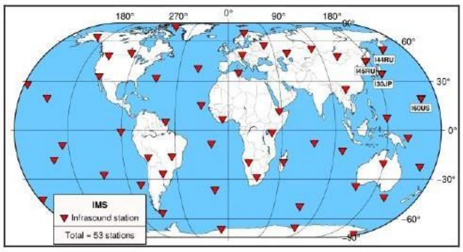

Figure 1 – International Monitoring System (IMS) certified infrasound stations. The stations used in this study are indicated by their codes: I44RU and I45RU (Russia), I30JP (Japan) and I60US (United States territory of Wake Island).

Since the last atmospheric nuclear explosion was conducted in 1980, bolide explosions are now the strongest infrasound sources available to calibrate and test the sensitivity of IMS infrasound instruments. Then it is important to detect meteoroid explosions using infrasound arrays to estimate their potential destruction, the frequency of occurrence and test the sensitivity of instruments. In this sense, the main objective of this work is to analyze the infrasonic waves generated by the meteoroid explosion that occurred over Japan on 29 November 2020 at about 2:00 in order to extract wave attributes that may be used to test the sensitivity of IMS infrasound network.

Data

Member States have access to all data deriving from the global verification regime built to monitor compliance with the CTBT. Raw and processed data are available to the members upon request to the International Data Centre (IDC) located in Vienna, Austria. The data used in this study was requested by the Seismological Observatory of

3.8

Analysis of infrasonic signals generated by an accidental explosion on July 3, 2020 at a fireworks factory in Turkey

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This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

This work carried out the analysis of the infrasonic signals generated by an accidental explosion in a fireworks factory located in Turkey. For the analysis, two infrasound stations were used, the I26DE station in Germany and the I48TN station in Tunisia. From the data processing it was possible to extract important information that made it possible to locate the event using only the two stations.

Introduction

Fireworks are undoubtedly a great attraction in festive events and celebrations, such as World Cups, June parties or the great fireworks display on New Year's Eve, illuminating the skies around the world, bringing hope for a better year. However, behind the beauty and joy, they hide a sad reality: the fear faced by pyrotechnic industry workers because of the danger related mainly to their manufacture and storage.

Unfortunately, accidents in fireworks factories are not rare events to happen and another episode occurred. On the morning of a Friday, July 3, 2020, at 11:15 am (local time), 8:17 am (GMT), an accidental explosion occurred at a fireworks factory in Sakarya province in northwestern Turkey. At the time of the explosion, there were about 150 to 200 people at the scene, according to local sources. Unfortunately, the explosion resulted in at least 6 deaths and more than 100 injuries, and the cause of the accident is still being investigated.

It is in this context that the present work enters with the objective of analyzing the infrasonic signals generated by this explosion. The infrasound, along with 3 other geophysical sensor technologies (seismic, hydroacoustic and radionuclides) are part of the International Monitoring System (IMS) that will be used to verify compliance with the Total Nuclear Test Ban Treaty (CTBT) when it comes into force. The CTBT, although not yet in place, prohibits nuclear explosions at the global level and IMS will be used to verify compliance with the treaty, being able to detect any nuclear test with a power equal to or greater than 1kt of TNT.

IMS has a total of 337 installations with four technologies: 50 primary seismic stations and 120 auxiliary seismic stations; 60 infrasonic stations (Figure 1); 11 hydroacoustic stations; 80 radionuclide stations and 16 radionuclide laboratories.

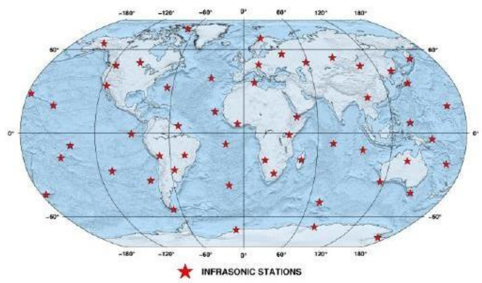

Figure 1 *– IMS infrasonic stations network (60 stations).*

For the analysis of the infrasonic data performed in the present study, the two stations closest to the accident site will be used: the I26DE station located in Germany, which is approximately 1590 km away and the I48TN station, located in Tunisia 1918 km away from the accident (Figure 2).

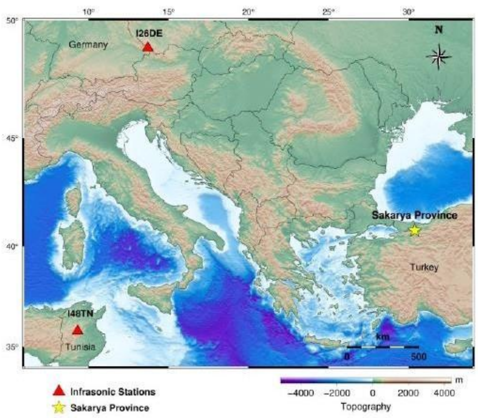

Figure 2 *- Location map showing the infrasonic stations used and the location of Sakarya province.*

4.1

EGU General Assembly 2021

EGU21-8484, updated on 03 Apr 2022
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EGU General Assembly 2021

Preliminary results of South American infrasound monitoring

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Infrasound monitoring is one of the four technologies used by the International Monitoring System to verify compliance with the CTBT. Atmospheric and shallow underground nuclear explosions can generate infrasound waves that can be detected by the infrasound networks. Of the 60 infrasonic stations proposed by CTBT, 10 are located in South American countries and islands close to the continent. Because the latest nuclear tests were underground and on the Asian continent, the infrasound stations in South America did not detect them. However, there are several sources of infrasound signals detect by South American stations. This work aims to present a complete catalog of infrasound events detected in South America.

4.2

CTBT Science and Technology Conference 2021 (SnT2021)

ID: **P4.5-038** Tipos: **e-Poster**

of the reduction of human activity due to the pandemic in the identification of infrasonic events by I09BR Station

sexta-feira, 2 de julho de 2021 09:00 (15 minutos)

The analysis of infrasonic data from the I09BR station, installed in the vicinity of the city of Brasilia, Brazil, indicated a significant reduction in the level of local noise during the COVID-19 pandemic, allowing us to identify other sources of signals previously masked by cultural noise. Most infrasound signals recorded at the I09BR array are originated from sources located close to the surface due to mainly urban activity (airport, factories) and also by quarry blasts that can be recorded in two IMS technologies: seismology and infrasound. Government decrees to control the movement of people in cities to contain COVID-19 considerably reduced the noise produced by the city, improving the performance of the infrasonic station in detecting distant mine blasts. In this work, data from the infrasound station I09BR were analyzed, to observe the variation in the pattern of infrasonic detection caused by changes in people's routine due to social distancing measures decreed by the Government.

Promotional text

Due to the continuous analysis of the infrasonic station I09BR data, several detection patterns can be observed. With the social isolation measures on account of the Covid-19 pandemic, there was a variation of these patterns.

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Session Classification: T4.5 e-poster session

Track Classification: Theme 4. Performance Evaluation and Optimization: T4.5 - Resilience of the CTBT Monitoring Regime, including Lessons Learned from the COVID-19 Pandemic

4.3

Sr No: 627

SYMPOSIUM : **S8 CoSOI Advances in geophysics, atmospheric science, and signal analysis for monitoring the CTBT**

Review I09BR Infrasound Detection

Brandow Neri, Seismological Observatory of Brasilia University, Brazil

CORRESPONDING & PRESENTING AUTHOR:

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Infrasound monitoring is one of the four technologies used by the International Monitoring System to verify compliance with CTBT. Shallow atmospheric and underground nuclear explosions can generate infrasonic waves that can be detected by infrasonic networks. Of the 60 infrasonic stations proposed by CTBT, one has been installed in Brazil since 2001. As the last nuclear tests were underground and on the Asian continent, the Brazilian infrasound station, I09BR did not detect it. However, there are several other sources of infrasound signals detected by it (mine blast, bolides, thunderstorm, human activity). This work aims to present the results of the analysis of data, highlighting the main signal sources that the I09BR station has been registering over the years.

KEYWORDS : Brazilian monitoring, infrasound sources

4.4

S55C-0155 - Monitoring changes in mine blast detection during COVID-19 shutdown in Brasilia using the I09BR infrasound station

Friday, 17 December 2021

19:00 - 21:00

Convention Center - Poster Hall, D-F

Abstract

During the COVID-19 pandemic, the Seismological Observatory of Brasília's University continued to carry out the analysis of infrasound and seismic data of the International Monitoring System infrasound station (IS09 – I09BR) and seismic station (PS07 - BDFB), both located in Brasília, Brazil. These stations are routinely used to characterize local and regional Seismo-Acoustics events such as earthquakes and mine blasts. Few days after the 1st confirmed case of COVID 19 in Brasilia, the government decreed the first restrictive measure. The isolation rate achieved in the first month was around 60%, that is, it reduced cultural noise near stations. Despite the reduction in human activity in urban centers, the number of mine blasts remained like the period before the pandemic. This work compares the differences in mining explosion detections each month of the pandemic period with previous years by station I09BR. The results show that, due to the reduction of cultural noise, in the period with the highest rate of social isolation, the Brazilian infrasound station clearly detected more mine blasts than in a similar previous period.

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M

TUTORIAL DE REQUERIMENTO DE DADOS DO IMS E

TUTORIAL DE PROCESSAMENTO DE DADOS INFRASSÔNICOS UTILIZANDO O DTK-GPMCC

Brandow Lee Neri

27/04/2022

Prof. Dr. Lucas Vieira Barros

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Meteoros são fontes de infrassom natural. Quando colidem com a atmosfera da Terra em velocidades hipersônicas, são capazes de gerar infrassom. Os meteoros variam muito em tamanho e massa. A maioria dos sinais de meteoros observados tendem a ter frequências entre 0,1 Hz e 5 Hz e amplitudes que variam de 1 a 10 microbars (ReVelle, 1976).

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Sites importantes:

https://cneos.jpl.nasa.gov/fireballs/

https://press.exoss.org/

http://www.bramonmeteor.org/bramon/

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Informações úteis para a correlação da detecção infrassônica com o sinal gerado pelo bólido:

- Data/ hora
- Localização aproximada (distancia)

Devemos prestar atenção nas diferenças da hora origem e da hora que o sinal é detectado pela estação infrassônica. O som se propaga aproximadamente 344 m/s. Com a informação do horário do evento devemos fazer uma estimativa da hora aproximada de que esse sinal vai chegar na estação infrassônica. (V=ds/dt)

Devemos também correlacionar o azimute da localização informada com o azimute da família PMCC. (Usar o Google Earth)

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Tutorial: Como requirir dados do IDC via linha de comando (nms_client) no NDC in a Box

Somente o Principal User tem permissão para requirir dados do IMS.

Primeiramente deve conferir se as credenciais cadastradas no Security Web Portal estão atualizadas no arquivo nms_cred.

No terminal digitar:

```
gedit ~/.nms_client/nms_cred
```

Adicione suas credenciais de SSO: nome de usuário e senha separados por dois pontos ":"

```
<SSO user name>:<password>
```

Exemplo:

brandowBLN:Senha2022

Após salvar o arquivo, no terminal digite:

```
nms_client.sh
```

Se suas credenciais estiverem corretas, o comando nms_client vai funcionar perfeitamente.

`nms_client.sh –h` (Help da linha de comando)

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Para requirir o dado, precisamos de um arquivo .req
No seu diretório de trabalho usando um editor de texto (gedit, kwrite) crie um arquivo .req

mkdir ~/data/I09BR (Para criar um diretório)
cd ~/data/I09BR (Acessar o diretório)
gedit I09BR_17092020_24h.req (Criar e editar o arquivo.req)

No Arquivo .req devemos escrever as esses comandos

```
begin ims2.0
msg_type request
msg_id mseed_i09br
time 2020/09/17 00:00:00 to 2020/09/17 23:59:59
sta_list I09BR
chan_list BDF
waveform ims2.0:ms_st2_512
stop
```

O Principal User pode requirir dado de qualquer estação do IMS com esses comandos, mas deve editar o arquivo indicando o nome da estação, canal, formato etc.

Salve o arquivo .req e feche o editor de texto

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Execute a linha de comando:

nms_client.sh I09BR_17092020_24h.req -f I09BR_17092020_24h.mseed

A ordem é: nms_client.sh nome do arquivo.req –f nome do arquivo .mseed
O resultado será um arquivo .mseed no diretório em que você executou a linha de comando.

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Tutorial: Processamento de dados infrassônicos gerado por bólidos utilizando o DTK-GPMCC

Para executar o DTK-GMPCC no NDC in a Box, devemos digitar no terminal

dtkgpmcc

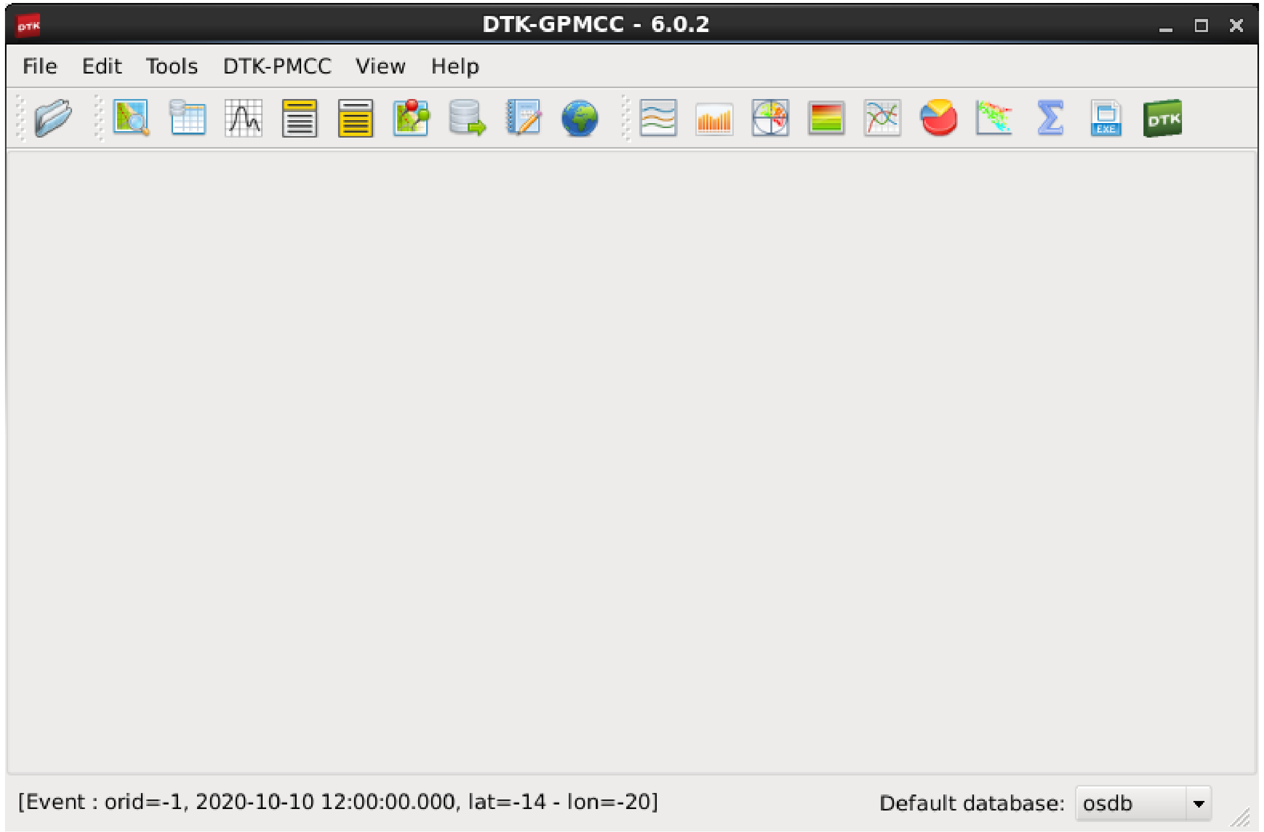

Fig. 1: Interface do DTK-GPMCC

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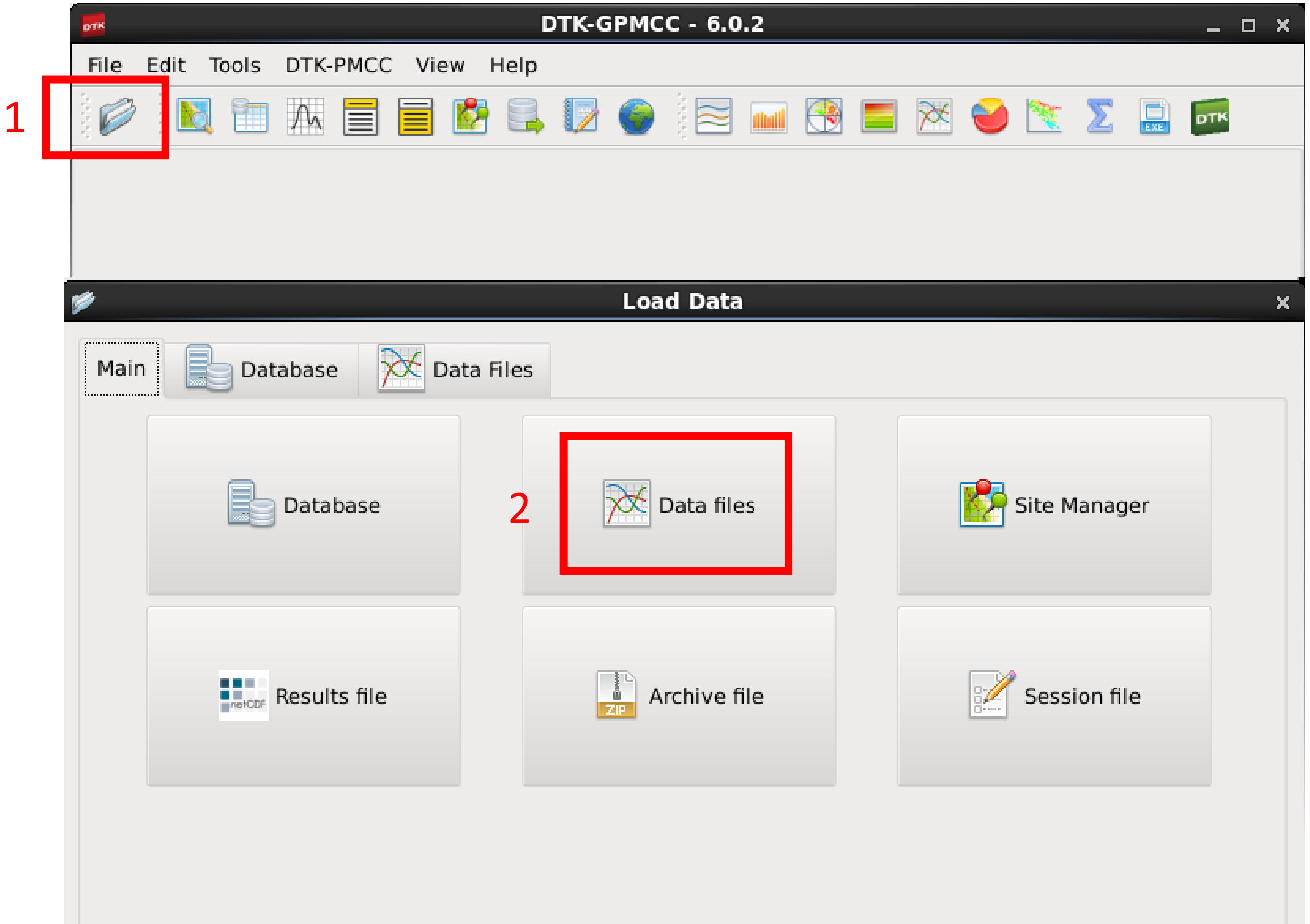
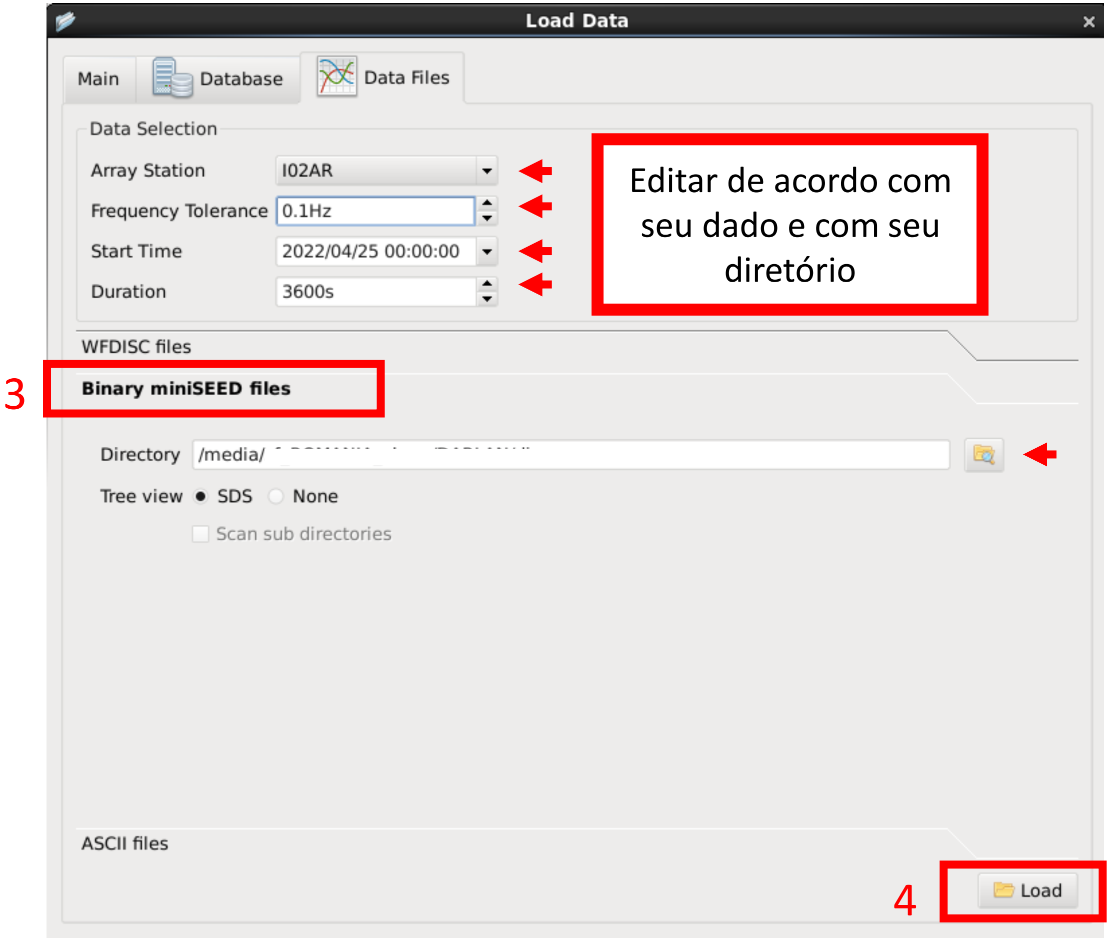
Comandos para abrir o dado .mseed no DTK-GPMCC





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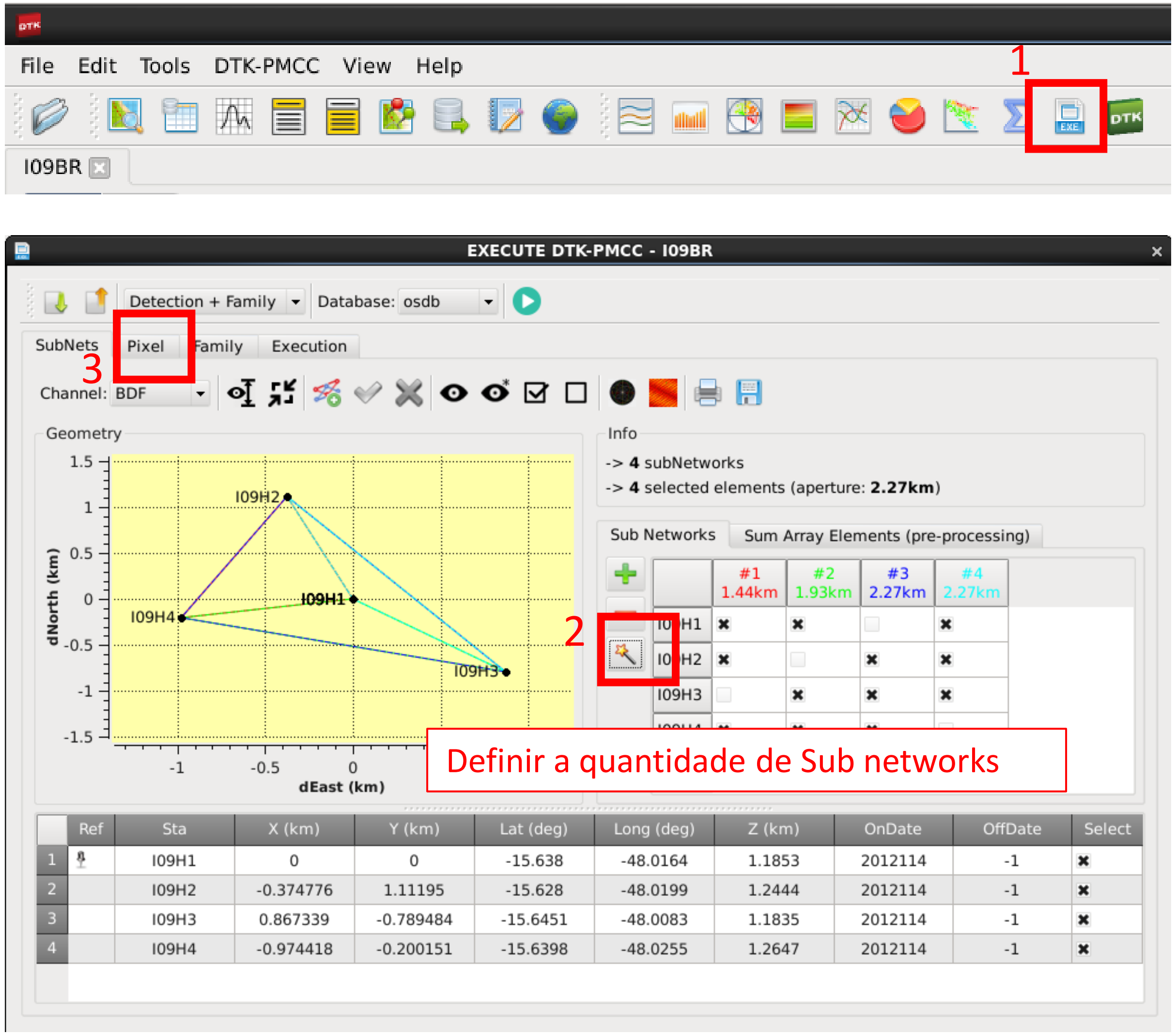
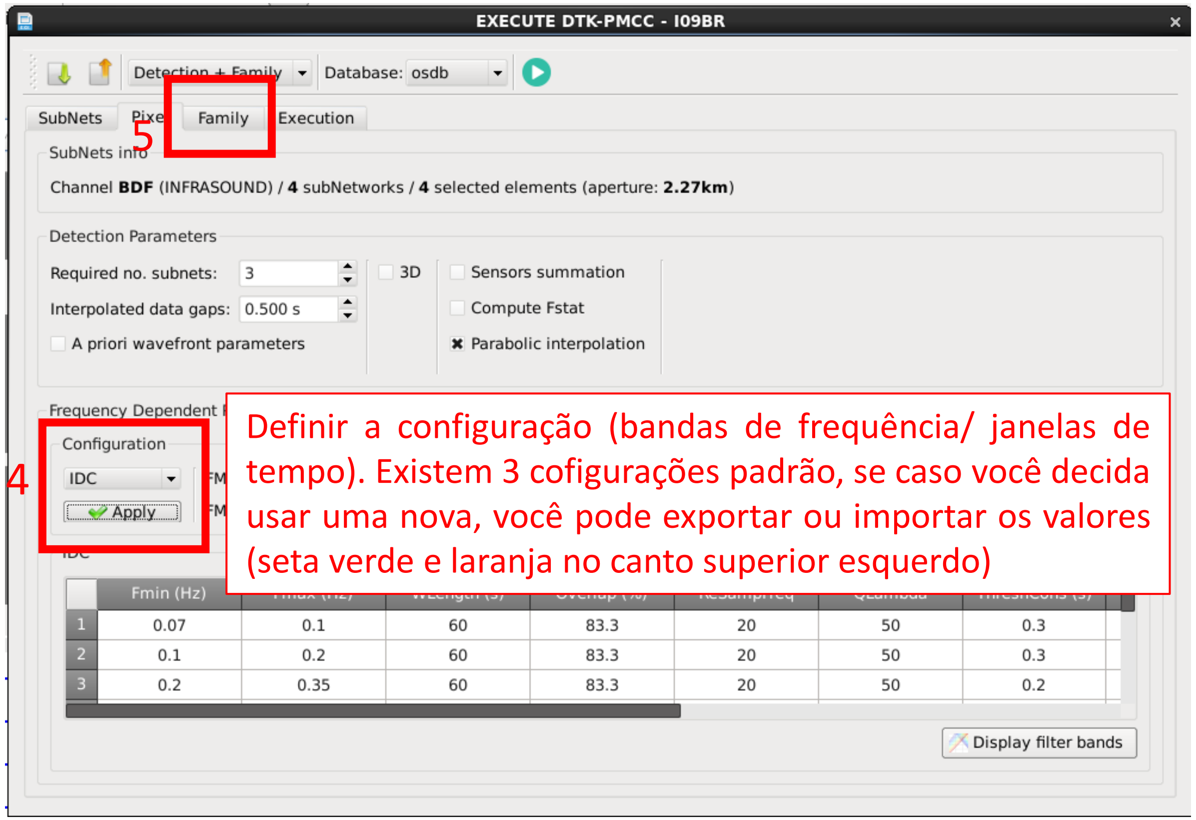
Comandos para executar o algoritmo PMCC nos dados





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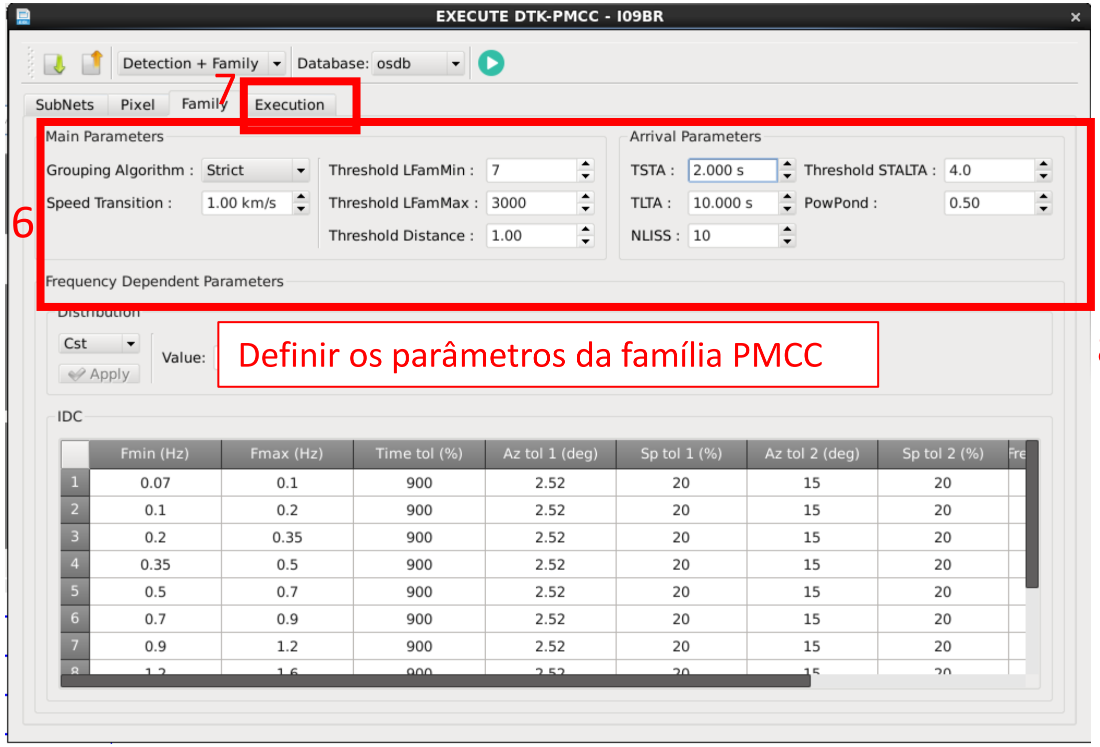

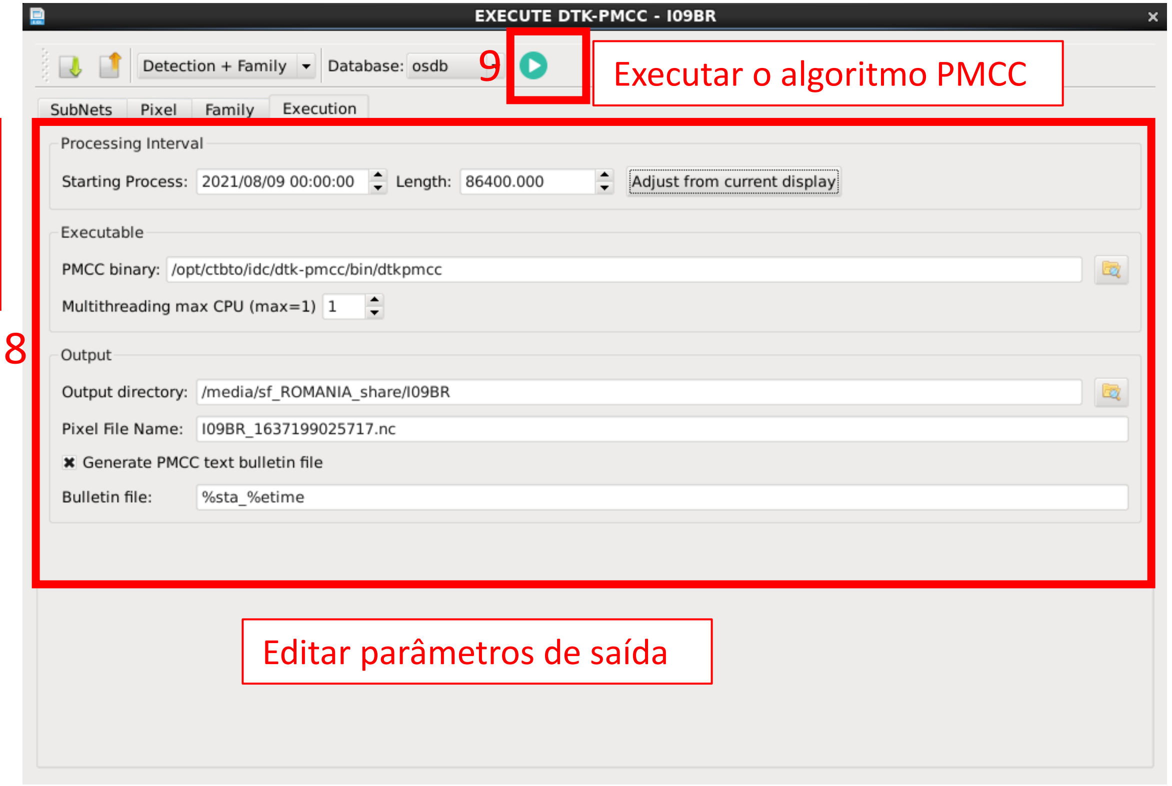

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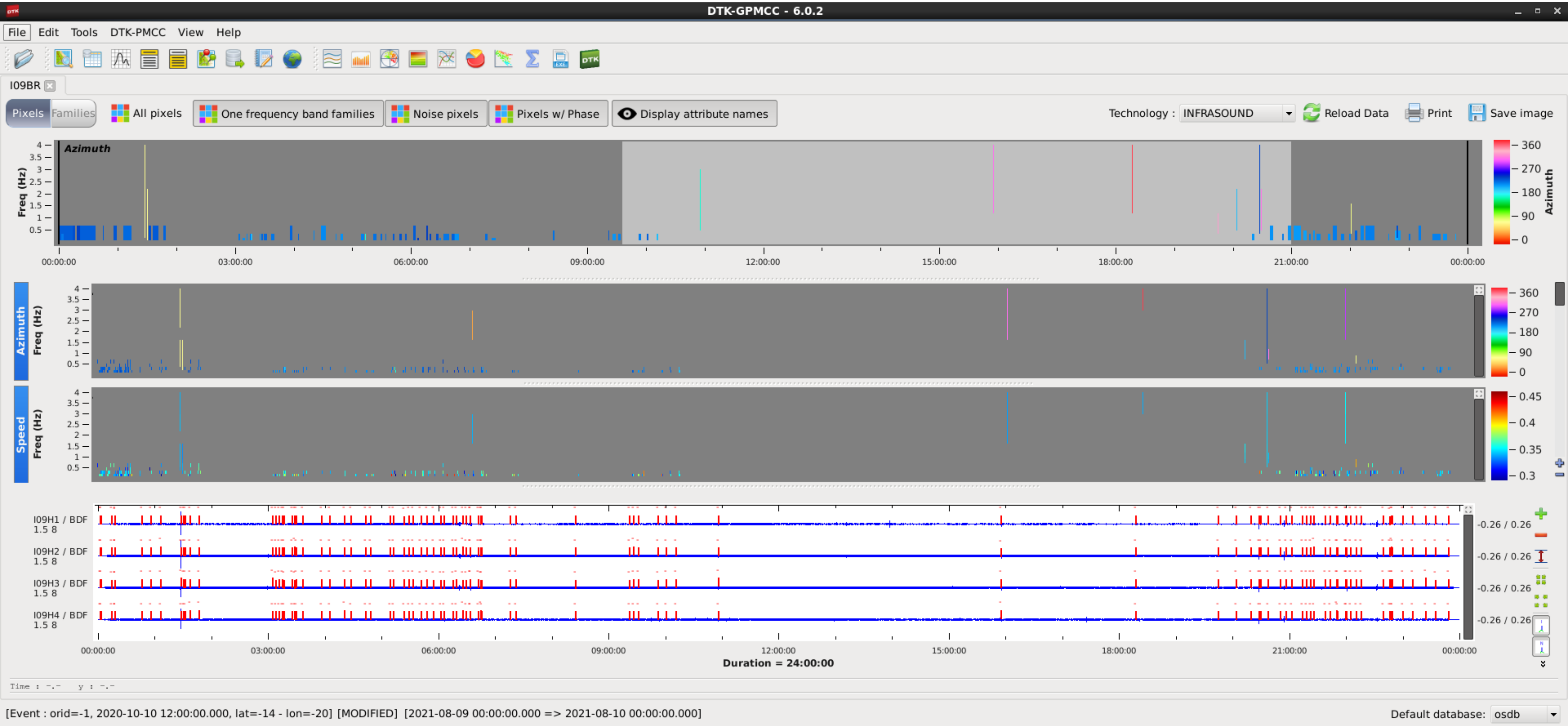

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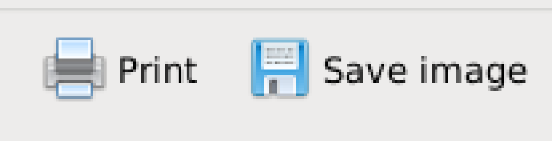
Comandos mais usados:

1 2 3 4 5 6

1: Aplicar filtros no sinal dos elementos
2: Boletim (Nele contem os valores dos parâmetros calculados pelo algoritmo PMCC de cada família PMCC)
3: Aplicar máscaras
4: Polar plot
5: Estatísticas
6: Executar algoritmo PMCC

Para dar zoom: clicar, segurar e arrastar o botão direito do mause.
Para voltar o zoom: Clicar com a rodinha do mause.
Se colocar o mause em cima de uma família PMCC vão aparecer os valores de alguns paramentos (Para ter mais detalhes, clique no botão do boletim – item 2).



Para salvar a imagem

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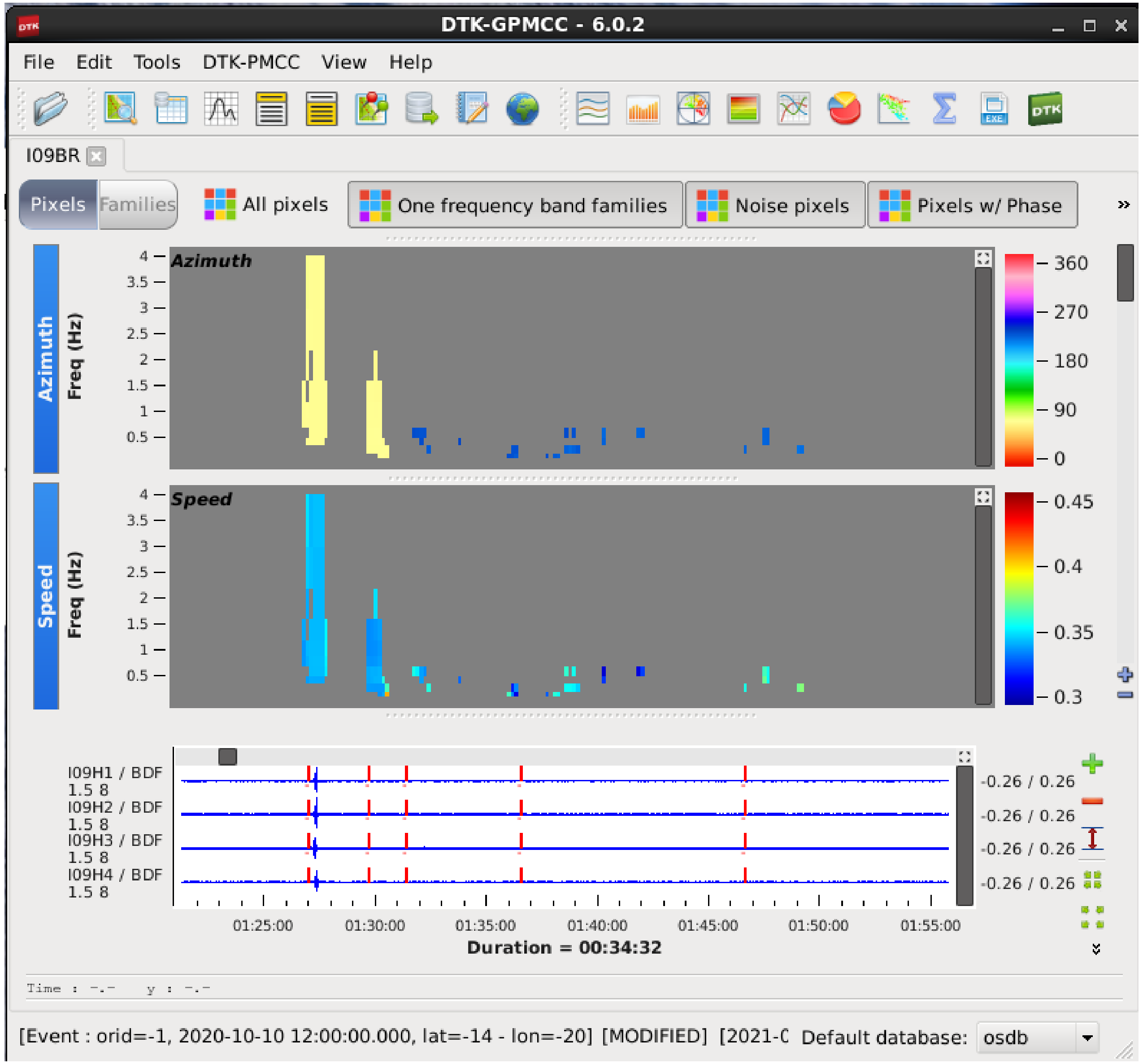

Para definir a fonte geradora da família PMCC os parâmetros de hora e azimute devem correlacionar com os valores reais.

Famílias PMCC pequenas (baixo numero de pixels) são difíceis de correlacionar.

O analista deve ter noção do que a estação detecta ao longo dos anos para definir se aquela família PMCC é um evento anômalo ou não.

Para a estação I09BR verificar a dissertação de mestrado do Brandow Lee Neri.

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Exemplos de Reportes que o SIS-UnB divulgou

http://obsis.unb.br/portalsis/?pg=viewNotice&id_notice=47

http://obsis.unb.br/portalsis/?pg=viewNotice&id_notice=32

https://www.instagram.com/p/CSW_ppRLx63/

https://www.instagram.com/p/CG3G3jbFM-Z/