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.

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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.

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 in groups, according to their strands 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.

Literature Review and Results

Most works were published by researchers from the United States (41.96%), followed by researchers from four European countries, France (10.37%), Germany (7.91%), Italy (7.91%), Russia (6.91%). Brazil is not on the list of the 25 countries that most publish about infrasound (Figure 1).

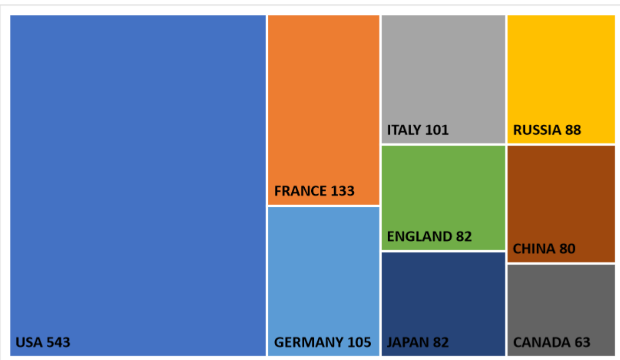

Figure 1: Ranking of Countries that have published articles with the theme "Infrasound".

Although there are many databases available, the need to have the records with less possibility of error in their metadata and, at the same time, to have access to a consolidated database and of a recognized reputation for its quality and level of available information, guided this research to the use of the Web of Science. 1289 scientific articles were found on the subject. The first document in the database was from the year 1953. Since then, the theme has reached 18606 citations, considering the period from 1953 to March 2021. In addition, there is a progression in annual citations, with its greatest peak in 2020, maintaining upwards compared to previous years. The year 2021 is therefore expected to have an even greater number of citations.

Two important milestones justify the increase in the number of scientific publications on the subject, the first is related to the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which was opened for signature on 24 September 1996. Although not yet in force, It was responsible for establishing an International Monitoring System (IMS) comprising 337 installations of four technologies, the Infrasound Technology being the one chosen to verify the occurrence of nuclear tests in the atmosphere. Another important milestone for the increase in the number of publications is related to the Sumatra mega-earthquake (9.1 - 9.3 Mw), of December 26, 2004. Initially, the IMS data was confidential. However, after the Sumatra earthquake, followed by the devastating tsunami, with around 300 thousand deaths, pressured by the Member States of CTBT, the Preparatory Commission for the Comprehensive NuclearTest-Ban-Treaty Organization (PrepCom - CTBTO), decided to make the IMS data available for humanitarian and scientific purposes. From then on, a great leap was made in the number of published articles related to the theme (Figure 2).

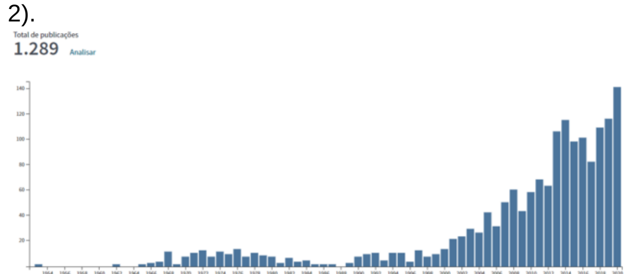

Figure 1: Evolution in the number of articles published per year.

Among the authors that publish the most are Fee, D., Le Pichon, Johnson J., Ripepe, M., ReVelle, D., Evers, L., Garces M., and all of them have many mentions, which may exceed 1000 citations mark (Figure 3). However, among the ten most cited articles there are only articles published by the authors: Fee, D., Ripepe, M., Garces M., Matoza, R., ReVelle D. and Brown, P.

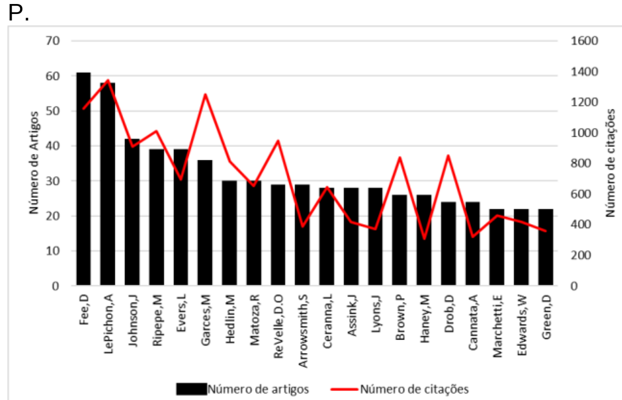

Figure 2: Relationship between the number of publications versus the number of citations of the twenty authors who most published on the topic "Infrasound".

To represent visually the data, a Word Cloud was created (Figure 4), using the online content analysis tool TagCrowd. All keywords of the 1289 documents found in the search for the Web of Science database were inserted in the tool. The online software created a diagram that represents the fifty keywords with the highest number of frequencies, and 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 ones research lines.

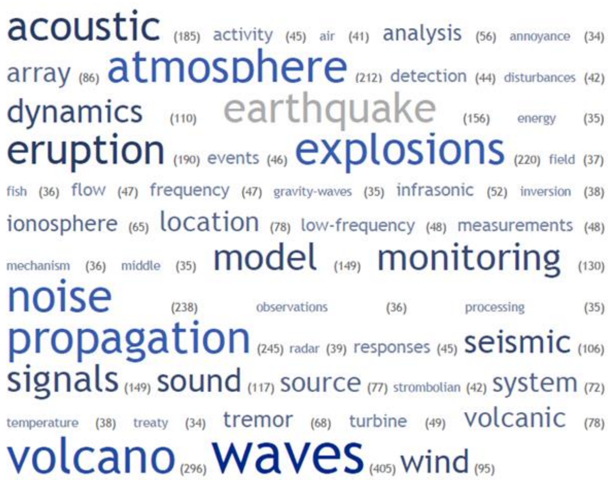

Figure 3: frequency of keywords.

The keywords reveal specific characteristics of each work, allowing to group the studies and classify them (Calazans et al., 2015). Analyzing the Figure 4 that includes the fifty most cited keywords, it can be seen that the main research theme with respect to Infrasound Technology is the study of signal generating sources (Vulcano, explosions, eruption, earthquake, noise) and the environment propagation (propagation, atmosphere, acoustic, dynamics).

As can be seen, the different perspectives on infrasound technology expand the knowledge on the subject, so knowing the main approaches is a necessity. To achieve this purpose, a citation map (Figure 5) was created, which aims to establish the proximity of the most approached studies and their main contributions or theoretical approaches (Zupic & Čater, 2014). For this analysis, the documents referring to the theme were considered from 1945 to March 2021.

Looking at Figure 5, it is possible to notice how the works are grouped by citing and following different approaches. There are three main nuclei, in green, there are works with the basis of Infrassound technology, as characteristics of the spread of infrasound (de Groot – Hedlin, 2008; Drob et al., 2003; Sutherland & Bass, 2004), network detection capacity and infrasound arrangements (Christie & Campus, 2009; Le Pichon et al., 2009; Pilger et al., 2018). In blue are the articles related to data processing (Y Cansi, 1995; Y Cansi & Le Pichon, 2009) the behavior of infrasound in the atmosphere (SJ Arrowsmith et al., 2010; Hedin, 1991). And the group in red are the authors who publish articles on the application of infrasound in volcanology (Fee D. et al., 2013; Jeffrey B Johnson et al., 2004; Matoza R. et al., 2019).

A coupling analysis was also carried out (Figure 6), which reveals the main research fronts, that is, how the most recent studies are taking shape. For this analysis, the documents referring to the theme from January 2018 to March 2021 were considered.

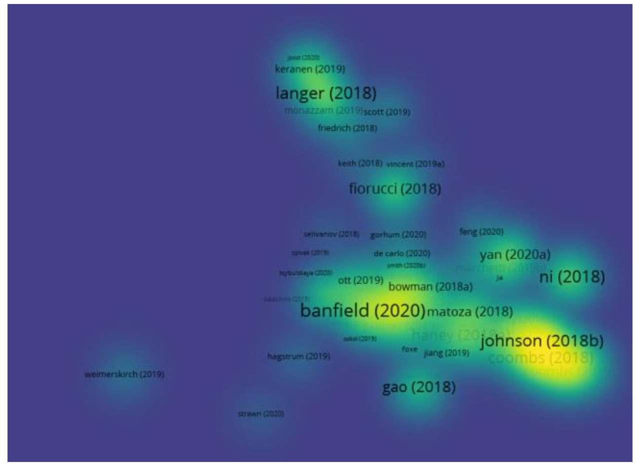

Figure 5: Coupling heat map.

Some of the documents used to produce the heat map in Figure 6 have not yet been cited, as they were recently published. In Figure 7, three works stand out, Banfield et al., 2020; Jeffrey B Johnson et al., 2018; and Langer et al., 2018. In the article published in Nature Geoscience, which so far has 48 citations, Banfield studied the atmosphere of Mars, discovering that Martian infrasound has similarities to Earth's atmospheric turbulence. Johnson's article in Geophysical Research Letters, which already has 29 citations, studies a way to predict a volcanic eruption using the infrasounds generated by the degassing of open volcanoes. In the article published by Langer in the Journal of Cleaner Production, which has been cited at least 29 times, the factors that influence the acceptance or not of wind energy by citizens in Germany were studied. With the analysis of the heat map in Figure 6, the study of infrasound is not limited to researching only the Earth's atmosphere, and may have more civil and social applications, such as the non-acceptance of wind

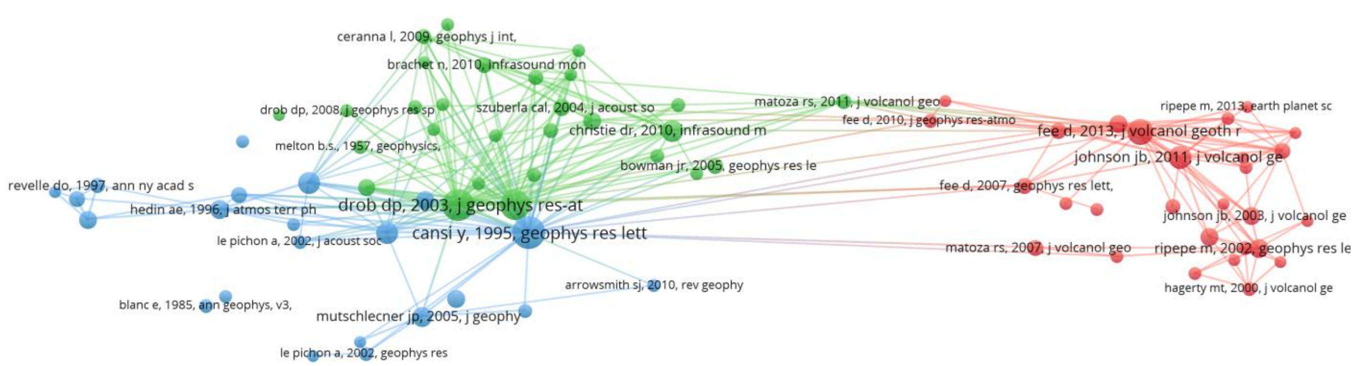

Figure 4: Co-citations networks.

energy by German citizens for fear of the infrasound noise of a wind farm.

It was also realized that a network diagram is intended to demonstrate which are the most used words in the base articles (Figure 7), however, unlike the word cloud shown previously (Figure 4), this view allows to identify the relationship between the words through the lines that connect the nodes of the network, in addition to representing through colors the clusters (groupings) of words that constantly appear together, then having similar attributes.

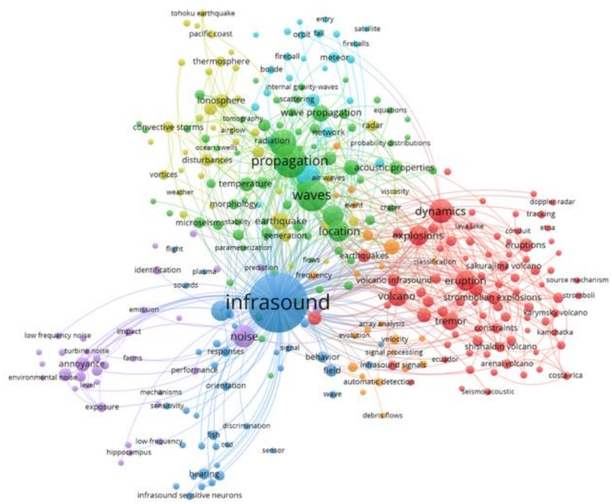

Figure 6: Network diagram with the main words extracted from the abstracts of the articles.

The words that appear the most are represented by larger nodes in the network, closer to the center of the diagram, considering that this diagram is formatted with degree centrality. According to Freeman, 1978, the centrality of degree is a function of the degree of a vertex, in this format, the number of edges incident to each vertex in the graph is counted, that is, the node with the largest number of connections will be in the center of the network. In this case, as shown previously with Figure 5, the words in the titles and abstracts confirm what was found in the keywords of the articles, with “Infrasound”, which are in the center of the network, and are also the most cited. You can distinguish 6 subgroups; in blue, with words like infrasound, behavior, waves; in orange: arrangement analysis, signal processing, automatic detection; in red explosions, eruption, volcano, earthquake; in green: location, propagation, acoustic properties; in yellow, climate, thermosphere, ionosphere, gravitational waves; in purple: noise, performance, low-frequency noise, environmental noise.

Discussion and conclusions

The problem with this research was to find the main approaches regarding infrasound technology, the authors who contributed the most, and the main sources of research. The main approaches found are related to the study of the behavior of Infrasound in the Atmosphere, the study of the sources that generate the signal, and techniques of signal processing and detection. Among the authors who contributed the most are: Fee, D. studying the spread of the infrasound, the infrasound generated by volcanoes and seismology and the detection and classification of the infrasonic signal, Le Pichon, A. who was responsible for the organization and elaboration of two books that gathers references on Infrasound for studies of the monitoring of the atmosphere; Johnson, J., who studies infrasound technology and the development of sensors to monitor volcanoes; Ripepe, M. also contributes to the study of volcanic eruptions using infrasound technology; Evers, L. focuses his studies on the use of seismology, infrasound and hydroacoustic technology to identify geophysical sources and changes in the means of propagation.

Thus, the objective of this research to present a systematic review of the main contributions of the high-impact literature has been achieved.

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