

Infrasonic Signals in the Environment

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Introduction

We humans can hear sounds (mechanical vibrations) over a frequency range of about 10 octaves, whereas we can see light (electromagnetic vibrations) only within the frequency range of a single octave. Hence, it is sometimes observed that our hearing provides us a more reliable (or at least a more robust) sense of our environment than does our sight. While one could certainly argue that there is more to a comparison of human hearing and sight than just the detectable frequency range, it is nonetheless interesting that we can hear a wide variety of sounds between about 20 and 20,000 hertz. Generally, we are better able to hear high-pitched than low-pitched sounds within this audible range as a result of the rapidly increasing threshold of audibility for sounds below 100 hertz. That is to say, audible sounds must be generated at higher intensities in the 20 to 100 hertz range than in the 200 to 10,000 hertz in order for us to hear them. In fact, infrasound—as commonly defined by vibrational frequencies less than 20 hertz—is often felt within our bodies rather than heard with our inner ears.

If we can't hear mechanical vibrations below about 20 hertz, why might we be interested in this ultra low-frequency, or infrasonic, sound? Answers to this question are many and varied. First, our everyday environment is full of infrasounds that can affect us in a variety of ways—many of which we simply do not recognize. Second, there are a host of animals on the planet that can both hear and communicate in the infrasonic range. Third, a wide range of Earth processes (e.g., geological, meteorological, hydrological) produce infrasounds that signal important events or changes. Finally, beyond the confines of our planet exists a cacophony of cosmic infrasounds that may inform us about our universe.

Another Renaissance

The recent wave of interest in global infrasound is sometimes referred to as a renaissance because the first wave occurred in the middle of the twentieth century, when infrasound was used to detect the atmospheric testing of nuclear weapons. The detonation of nuclear explosions creates a set of characteristic long-period waves that can be measured around the world. After the 1963 signing of a Limited Test Ban Treaty by the USA and USSR, interest in infrasonic research waned until the late 1990s when the Comprehensive Test Ban Treaty called for a monitoring network that could monitor the Earth's atmosphere, oceans, and solid interior for nuclear testing [Hedlin et al. 2002]. Scientists view the completion of a global infrasound network, which is capable of continuous monitoring at 60 worldwide locations, as an opportunity to study both natural phenomena and human activities. Infrasonic signals in the atmosphere can be interpreted on time scales greater

than 0.1 seconds and on spatial scales greater than 10 meters, permitting scientists to investigate weather systems (e.g., hurricanes, thunderstorms), seasonal and high velocity winds, geomagnetic storms (e.g., auroras), the ozone layer, and even solar activity [Hedlin et al. 2002]. Infrasound monitoring networks can also detect volcanoes, earthquakes, meteorite hits, avalanches, and many other natural events that must be distinguished (as collective background noise) from the signature of nuclear blasts.

Why is infrasound such a valuable tool for studying a wide variety of planetary events? The answer lies in the extraordinary ability of air and water to conduct low-frequency sound waves, which incur only minimal attenuation over relatively long distances. While seismic waves (traveling through solid and semi-solid rock) have long been used to study geologic events, the routine use of infrasonic waves in the atmosphere to study these same events is more recent—at least on a worldwide basis. The history of atmospheric measurements dates back to late 19th century, when the effects of large volcano eruptions on barometric pressure readings around the world were attributed to the propagation of infrasonic waves [Ramsayer 2004]. Monitoring infrasonic waves that originate within the world's oceans is a more recent application, but every bit as relevant and interesting as monitoring infrasonic waves that originate in rock or in the air. Not only do many of the previously identified global events (e.g., earthquakes, volcanoes) routinely occur underwater, infrasound producers such as high surf events, swimming fishes, and gas bubbles (e.g., methane rising from seafloor deposits) are exclusively oceanic in origin.

Underwater volcanic eruptions and the sliding and cracking of sea ice are just two suspected sources of a yet unidentified mix of infrasounds that traverse the globe through the oceans' deepest sound channels [Wolman 2002]. There is a growing list of very low-frequency oceanic sounds that researchers have yet to match with any source. Scientists have not even determined whether some of these unidentified sounds emanate from biological, geological, or meteorological sources. For instance, “upsweep” designates a tone of only a few hertz that was initially detected by the U.S. Navy and has subsequently been traced to a chain of seamounts in the eastern South Pacific, where it is believed to result from the reaction of hot lava with cold seawater. While the origin of “upsweep” may have been solved, the origin of “bio-duck” (a noise detected by sonar operators who thought it resembled the quack of a duck) remains a mystery. This “bio-duck” is so ubiquitous, predominantly within the frequency range of 50-300 hertz, that an algorithm was developed to detect and then eliminate it as ambient noise [Matthews et al. 2004]. Based on its repetitive nature and distinct periods, “bio-duck” has been tentatively ascribed to a biological source (e.g., a widely distributed whale species); however, this hypothesis has yet to be tested.

Humming Along

Revisiting the subject of seismic waves, perhaps the most curious infrasonic symphony to be reported in the scientific literature over the past decade is that of the so-called planetary “hum.” Two 1998 articles authored by geoscientists in Japan and California report that the earth continuously oscillates, or vibrates, in the frequency range of 0.002 to 0.007 hertz—also referred to as 2 to 7 millihertz [Tanimoto et al. 1998; Suda et al.

1998]. There are several aspects of this planetary hum that are fascinating. First, the hum is not caused by common seismic event such as earthquakes or volcanoes, as was originally suspected. Instead, researchers attribute the hum to strong winds associated with winter storms because the source of the hum apparently switches between Northern and Southern Hemispheres—depending upon the season. More recently, it has been suggested that the resulting ocean waves, rather than the winds themselves, are responsible for the planetary hum [Rhie & Romanowicz 2004]. In other words, the vibrational energy of the wind-generated oceanic swells is transmitted thousands of meters downward into the abyssal depths and, ultimately, into the underlying rock. The vertical transmission of vibrational energy from the sea surface to the seafloor has been attributed to so-called *infragravity* waves, which are generally in the 1 to 50 millihertz range (sometimes lower) and are commonly trapped by topographic features such as the shoreline or seafloor.

Second, the hum does not represent a single note or even a predictable grouping of notes (e.g., a chord), but rather about fifty individual notes that are played within a tonal range of two octaves [Coontz 1999]. This was one of the characteristics that dissuaded researches from attributing the hum to earthquakes or other common seismic events. The planetary hum is played about 16 octaves below *middle C*, whereas the length of time between notes varies from about 2 to 8 minutes. The individual notes are not just repeated in a monotonous fashion, but instead constantly appear in and disappear from the never-ending planetary score. Additionally, the planetary hum varies on a daily, as well as a seasonal, basis—playing louder from noon through evening than from midnight through morning. The diversity and complexity of these infrasonic sounds (although not really reminiscent of human musical scores) are truly amazing and were seemingly no small surprise to the geophysics community.

Finally, the planetary hum is known (technically) as a *free oscillation*, which is more complex and vibrates much slower than does an ordinary seismic wave. In fact, seismic waves are simply layered over the continuous low-frequency hum, which was previously considered by geophysicists to be simply background noise. It may turn out that this rather complex standing wave carries with it some interesting information about the Earth as a result of its presumed sensitivity to global climatic regimes and to conditions within the planet's oceans and crust. One can only imagine how this hum might have varied over the course of Earth's history of 4.5 billion years. The monumental discovery of Earth's hum has prompted scientists to ask whether other planets may possess their own characteristic hum or whether a unique "Earthly" combination of atmospheric, oceanic, and geologic features is a prerequisite. An upcoming Mars launch is scheduled to place broadband seismometers on the red planet to answer this extraterrestrial question—at least for one other planet in our solar system.

Perhaps the most exotic infrasounds originate in the depths of outer space. Scientists at NASA's Chandra X-ray Observatory have identified one of the lowest frequency sounds ever detected in the universe [Koczor 2003]. The source of the cosmic infrasound is believed to be a massive black hole located about 250 million light years from Earth. This cosmic infrasound, which may be a key to understanding how the galaxies actually

formed, has been identified as a single note (*B flat*) about 57 octaves below *middle C*. The black hole sound is characterized by a frequency of less than 10^{-15} hertz, or one-quadrillionth of a cycle per second! Black holes may not be the only cosmic infrasound generators. Mark Whittle, an astronomer at the University of Virginia, recently utilized a computer simulation of the Big Bang to create the sounds (i.e., acoustic oscillations resulting from gravity-driven pressure waves) that probably existed during the early unfolding of the universe [Cowen 2004]. The interval between the two lowest notes of this Big Bang symphony include the major and minor third, while the notes themselves decrease in pitch over the universe's history as the corresponding infrasonic wavelengths increase. Similar to black hole sounds, the notes attributed to this computer simulation of our expanding universe reportedly vibrate at more than 50 octaves below *middle C*.

Tunes Or Noise?

While nuclear blasts are the best-known contributors of anthropogenic infrasound, they are by no means the only ones. Man-made transportation (e.g., automobiles, trains, jets), certain types of machinery, conventional explosions (e.g., dynamite), rocket launches, ventilation systems, and even the tragic crash of the space shuttle *Columbia* have been linked to specific infrasonic signatures. While the powered subwoofers of custom audio systems have been belching out low-frequency “sounds” for some time, infrasound has recently entered the music scene in a more interesting way—both as recordings and as live performances. In 2003, composer John Duncan released a CD entitled *Infrasound-Tidal*, which is based on recordings of tidal, seismic, and barometric sounds collected over long time periods by an Australian researcher named Densil Cabrera. Obviously, the various infrasounds have been temporally compressed in order to create the “tunes,” which may be played through any conventional stereo to facilitate a listening experience that is definitely out of the ordinary. Along the same lines, a portion of at least two concerts performed in England since 2002 have been accompanied by infrasound—without prior knowledge of the audience. When questioned about the musical pieces accompanied by infrasound, listeners overwhelmingly described mental, emotional, and physical reactions that seemed to vary from person to person.

The wide range of responses to infrasound that were described by British concertgoers is not completely unexpected. A variety of human and animal reactions to infrasound has been documented in both the scientific and popular literature. Moreover, infrasound has been linked to a plethora of nefarious activities related to warfare and crowd control—claims that are widely refuted by the acoustics community. Symptoms of infrasound “exposure” have reportedly included everything from euphoria and invigoration to fear and disorientation. Depending on both its intensity and frequency, infrasonic energy can influence a person's balance, heart rate, blood pressure, neurochemical activity, and sensation of nausea. Considering all the sources of infrasound in our environment, why are we not driven to madness or chronic illness? The most common answers generally assume one of two perspectives. First, the intensity of ambient infrasound in most common human environments does not exceed our minimum threshold for either noticing or reacting to it. Second, while not driving us to insanity or incapacitation, our infrasonic

environment may affect us in subtle ways that have been traditionally overlooked or mistakenly attributed to other causes.

Currently, there are no U.S. standards for permissible exposure to infrasonic noise; however, a number of countries (e.g., Denmark, Poland, New Zealand) are considering or have adopted guidelines. At frequencies below 10 hertz, researchers have found that the threshold of human detection (primarily through the body) is at or above an intensity of 100 decibels, which would be very audible at 20 hertz (the approximate lower limit of our hearing range) and painfully or damagingly loud at frequencies above 500 hertz (within our optimal hearing range). One of the difficulties in studying the possible effects of infrasonic noise in real-world environments is that infrasound is normally accompanied by audible noise arising from the exact same sources.

Rumblings and Rumlbers

Table 1 presents a comparison of reported frequencies and representative wavelengths (corresponding to a frequency at the midpoint of the range) for various infrasound sources that have been discussed thus far. In order to estimate wavelengths for the reported frequencies, a guess for the speed of acoustic waves in the various media was required. The speed of sound varies a function of differing properties within the same medium, which was arbitrarily selected in order to facilitate this comparison. It should be noted that the values in Table 1 are very general and only intended to facilitate order-of-magnitude comparisons. The assumed medium for infrasound transport originating from the Big Bang and black holes was hydrogen gas (H_2), the simplest and most abundant molecule comprising the massive clouds from which galaxies are hypothesized to have formed. The speeds of mechanical vibrations propagating at “infrasonic” frequencies through various media were estimated as follows:

- **Hydrogen.** 420 meters/second based on a temperature of 30°K (-243°C) in hydrogen gas clouds (the actual media may be different)
- **Air.** 330 meters/second based on a temperature of 0°C and a pressure of one atmosphere (i.e., STP)
- **Ocean.** 1500 meters/second based on a temperature of 4°C, a salinity of 36‰, and a depth of 1000 meters
- **Rock.** 5000 meters/second based on a representative velocity for seismic waves, which are not considered sound due to their mode of propagation and detection

If humans cannot hear or communicate using these infrasonic frequencies, are there any animals that can? Not unexpectedly, the answer is yes—and more animals than expected are able to do so. Elephants are perhaps the most intensely studied of the animals that are believed to both hear and communicate in the infrasonic range. Bioacoustics researcher Katy Payne, who spent many years studying humpback whale songs alongside her husband Roger, has published and lectured widely on elephant communication and vocalizations (a substantial portion of which is transmitted as infrasound). Infrasound seems particularly well suited to elephants because its frequencies are minimally attenuated over great distances and because its wavelengths (on the order of tens to

hundreds of meters) are best received by large animals. Besides broadcasting infrasound through the air, elephants are now suspected of using seismic waves to send low frequency messages through the ground [Günther et al. 2004]. These seismic waves are apparently triggered by the elephants' infrasonic vocalizations.

TABLE 1. Approximate ranges for the frequency and wavelength of mechanical waves propagating through various media. The reported frequencies (<20 hertz) lie within the infrasonic range, although they may not be referred to as "sound."

Mechanical Waves	Media	Frequency (hertz)	Wavelength (kilometers)
Black hole sounds¹	Hydrogen	10^{-15}	$\sim 10^{17}$ (10,000 light years)
Early universe sound²	Hydrogen	10^{-14}	$\sim 10^{16}$ (1000 light years)
Meteor explosion³	Air	0.1 to 0.2	2
Volcanic eruption⁴	Air	0.1 to 10	0.3
Ocean surf⁵	Air	1 to 5	0.1
Methane gas bubbles⁶	Seawater	6 to 7	0.2
Swimming fishes⁷	Seawater	1 to 10	0.3
Earthquake	Rock	0.5 to 20	0.3 to 10
Earth's hum⁸	Rock	0.002 to 0.007	100s to 1000s*

* Earth's free oscillations represent standing, rather than traveling, waves that are measured by seismographic instruments; however, infrasound energy is reportedly transmitted via ocean waves from the sea surface to the underlying rock. Depending on the transporting media (seawater or rock), the "humming" frequencies would correspond to wavelengths of hundreds to thousands of kilometers. Citations for the various mechanical waves include: Koczor 2003 (1), Cowen 2004 (2), Evers and Haak 2001 (3), Garcés et al. 2003a (4), Garcés et al. 2003b (5), Pontoise and Hello 2002 (6), Sand and Karlsen 2000 (7), Suda et al. 1998 (8).

Elephants are not the only continental (including terrestrial and freshwater) animals that apparently include infrasound as part of their communication repertoire. Rhinoceroses, hippopotami, alligators, and buffalo are just a few of the many animals that recently have been identified as low frequency sound generators. In fact, vocalizations of the Sumatran rhinoceros dip to as low as 3 hertz and are reportedly similar in specific sound components to the infamous humpback whale songs [von Muggenthaler et al. 2003]. Humpbacks and other baleen whales are probably the best-known infrasound generators within the oceanic realm. Due to the difference in density between seawater and air, infrasonic vocalizations in the ocean possess wavelengths that are 4 to 5 times longer than those resulting from vocalizations in air (assuming they are generated at similar frequencies). Roger Payne has suggested that humpback whale songs may traverse the depths of entire ocean basins, although this hypothesis is not necessarily shared by other whale researchers. Payne [1995] has also asked the question of whether the humpback songs, which often have a profound effect on people's emotions, may reflect a universal music or mimic the aforementioned patterns of acoustic energy that were responsible for creating the cosmos. Despite years of intense study, the purpose of and messages within these intricate and ever-evolving songs remain a mystery.

Conclusion

It is interesting to note that an acoustics technology, which was designed principally to prevent a nuclear technology from destroying our planet and our civilization(s), serves as the major impetus for the so-called infrasound renaissance. Considering the number and variety of infrasounds that permeate the atmosphere and oceans, it is curious that we humans are not more “tuned in” to our infrasonic environment. Perhaps the current renaissance will reveal more about the information transmitted through our infrasonic environment and the degree to which our fellow animal species can detect and react to earthly processes that we humans do not even recognize—at least not on a conscious level. And perhaps the mysterious cosmic infrasounds, which lay tens of octaves below the hearing or sensing range of any earthly creature, contain a sampling of the vibrational information that was instrumental in creating galaxies.

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