Experiments in the Sonification of the Seismic Signature of Ocean Surf

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Stony Brook University's COAST Institute

The Coastal Ocean Action Strategies (COAST) Institute was created in 1989 within the School of Marine and Atmospheric Sciences to assist in coastal zone management and coastal marine policy analysis. We do this by exploring future scenarios for Long Island's coastline and coastal environment and by working with policy makers and environmental managers in identifying and analyzing strategies that will conserve and, when necessary, rehabilitate the coastal ocean; by ensuring that not only is the best technical information included in developing the strategies, but economic and other critical information as well; and by forming effective linkages among environmental groups, the scientific community, lawmakers, regulators, and managers to tackle coastal environmental issues.

COAST has been called upon to assist in resolving coastal problems at home on Long Island, throughout the U.S. and in many parts of the world. COAST also provides a real-world, action learning laboratory for graduate students at MSRC. Each year students who are interested in coastal management and policy take part in gathering and analyzing data, in transforming data into information, and in synthesizing information-all targeted at identifying and evaluating management alternatives to attack the problems that COAST is helping to solve.

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Introduction

Ocean surf conditions are particularly difficult to monitor. Harsh and energetic wave take a toll on instrumentation in the surf zone. Long-period, infragravity waves are especially elusive, not easily detected among the incident surf, yet they carry substantial energy to fuel coastal processes. They play an important role in erosion events as well as in the generation of rip currents. To overcome such problems with instrumentation,, seismographs recorded in the costal zone have been used recently to record incident wave energy as well as infragravity waves (Slattery 2010).

Seismometers have the advantage of being a reliable and robust technology safely installed on dry land. The interpretation of seismic records in terms of surf conditions, however, requires considerable data processing and analysis. In this project, we explored the potential of sonification of seismic records as an aid to data assimilation. Sonfication involves transforming the seismograph into audible sound, music if you will. The process compresses the data so that an hour's record translates into two minutes of audible signal.

The approach is based on the innate facility of humans to recognize and remember patterns in music. The brain uses language centers to interpret music and is capable of massive reorganization and parallel processing with greater aptitude than any computer. It is an evolutionary adaptation to separate sound's characteristics such as pitch, timbre, volumes, reverberant environment, and tone durations. The audio information our sensory receptors receive is full of variety and clutter, however the brain built to constantly making important distinctions and identifications. Therefore, it may be easier to train an observer to recognize and distinguish different surf conditions in perhaps the low frequency waves that cause rip currents in the seismic records translated into audible sound waves.

Sonification might be used, for example, as a new technique for recognizing dangerous surf conditions at the beach, such as rip currents. Rip currents are responsible for hundreds of deaths every year and many more rescues. Recent research at SoMAS (Slattery 2010) has shown that the occurrence of rip currents is associated with particular waves of low frequency. Although monitoring these waves is difficult and time consuming by standard technologies, Slattery (2010) used a seismograph to detect the wave conditions thought to cause rip currents. If these seismographs can be converted into audio data, hazardous conditions might be quickly recognized by the discriminating human ear.

Approach

In recent years, the method of reinterpreting collected data as digital audio information has attracted increasing attention. It is thought that sound may be able to transform the way scientists make observations and enhance analysis. This year, NASA's Kepler mission used sensors that were sensitive to electromagnetic radiation to translate light energy into sound waves in order to study the intensity of pulsations coming from starts. Jill Tarter from the Search for Intelligent Life institute used sonification to hunt for unnatural sounds in outer space (accessed on 9/16/11):

http://astro.wsu.edu/allen/courses/astr450/annurev.astro.39.1.511.pdf

and radiation from stars have been translated into sound by astrophysicist Daniel Huber and artist Jeff Talman. They transposed wave forms that were originally as long as five minutes by multiplying them by a factor of 1 million, scaling them to be heard by humans. The artist created an exhibit where guests put on headphones under the open, night sky listening to waves produced by stars (accessed on 9/16/11):

http://jefftalman.com/nightsky.html

The act of listening with a trained ear is a highly effective method of analysis and is an innate function of humans to understand and survive in their environment. Therefore, it is a natural skill that has the potential to be exploited and paired with other forms of mathematical analysis for more rounded results and a wider range of observations. For example, "soundscape ecology" uses sound to understand the health of an ecosystem as a complex interaction of sunlight, oxygen, salinity, species density and other parameters. The audio signal the presence and absence of certain sounds in audio signal is a measure of the degree of balance, or unbalance, in the environment (accessed on 9/16/11):

http://www.jstor.org/stable/10.1525/bio.2011.61.3.6

USGS geophysicist Andrew Michael recently composed *Earthquake Quartet #1*, a concept piece used to describe the behavior of an earthquake. The piece is written for voice, trombone, cello, and seismograms. A loud speaker is set up to play the vibrations created by an earthquake during the performance. He sped the processing up to 8000 samples per second from the original seismic readings recorded at 100 Hz. The pitches were 80 times higher, that is, they were played 80 times faster than the original seismic records. This transformation increased the pitches by 6 octaves, transposing the date into a listenable human range (accessed on 9/16/11):

http://earthquake.usgs.gov/learn/music/

At Stony Brook University, Tony Phillips and Levy Lorenzo have sonified tidal records from Venice and Acona, Italy (accessed on 9/16/11):

http://www.levylorenzo.com/projects_2.html

and at the *Musica Inaudita* sound laboratory of the University of Salerno, scientists and artists have collaborated to translate volcanic activity into audible sound waves. Dr. Domenico Vicinanza at the Italian National Institute of Nuclear Physics developed a method to sonify geophysical information into sound waves to analyze patterns, leading to improved prediction of eruptions (accessed on9/16/11):

http://www.sciencedaily.com/releases/2006/08/060810084743.htm

and (accessed on 9/16/11):

http://grid.ct.infn.it/etnasound/

Standing on the beach, you can often feel a strong surf pounding sand. Indeed, reports of feeling vibrations caused by waves are not uncommon. Residents of the California coast (Benumof and Griggs 1999), for example, report feeling buildings vibrate when there are storm waves affecting nearby coastal regions, as do people in Salerno, Italy (E.P.E. Pugliese Carratelli 2007, University Consortium for Research on Great Hazards, personal communication):

http://www.cugri.unisa.it/StrangeVibrations.html

Seismologists often find their records contaminated by noise, called microseisms, some of which is generated by ocean waves. Large storms can generate standing sea-waves (Tabulevich 2002), and even remote seismic station, detect microseisms so produced. Seismic signals were detected in New Mexico from the “Perfect Storm” off the Massachusetts coast in 1992 **(**Bromirski 2001**)** and microseism caused by Hurricane

Katrina in the Gulf of Mexico in 2005 were detected at sites as far away as California (Gerstoft et al. 2006). Such a signal can be used to estimate wave climate (Beach and Sternberg 1988).

Shoaling water-wave energy dissipated along sea cliffs in California, possibly due to standing waves set up by the reflections of incident waves at the shoreline, have been detected by nearby seismometers (Adams et al. 2002). Similar experience is reported along the south coast of the United Kingdom (A. Brampton 2007, HR Wallingford Ltd. Personal communication). Breaking waves in the surf zone are also a source of microseisms (Wiechert 1904 as cited in Howell 1990), although, because sand is not a good conductor of seismic waves, a seismic signal generated by the local surf is usually not detected on seismometers further than a kilometer from the shore (Tablulevich 1992). However, the seismic signal of the surf can be detected on seismometers within a few hundred meters of the shore on a sandy coast (Slattery, 2010). Ship wakes and wind-waves, for example, produced measurable seismic signals at frequencies between 0.5 and 150 Hertz in dikes along the Elbe estuary (Schuttrumpt 2006).

Most recently, Michael Slattery experimented with the seismic signature of ocean surf at the ocean coast of East Hampton, NY. Comparison of simultaneous seismographs at the coast and inland at Stony Brook University demonstrated the dominance of ocean microseisms in the coastal records. He found that microseisms generated by the surf could be detected by a seismometer within 60 meters of the shoreline. There was a good correlation between the square of the incident wave height and the strength of the seismic signal. In addition, seismic energy was found corresponding to the long periods of infragravity waves associated with the occurrence of flash, rip currents.

Methods

Seismic readings of the surf are collected with a Guralp Systems Limited CMG-3TD digitizer stationed at the Maidstone Club in East Hampton, NY. These readings are recorded with *Scream! 4.3* continuously and stored in hour-long segments. The files collected in the years 2007 and 2008 recorded data at 20 readings per second. The files collected in the year 2011 recorded data at 40 readings per second. MATLAB is used to convert the stored .gcf files into .dat files, displaying the seismic readings as a string of numbers that represent the amplitude of the vibrations recorded by the digitizer. In Microsoft Excel, a positive amplitude shift is applied to the data so that each data point is a positive integer. The sonification is completed with the program Max/SP. With this software, the data's range is compressed so that it may be interpreted as literal measurements of pitch, using a comfortable listening range of 600-1200Hz. The data is being sonified at 1,000 data points per second. The final output is a sound file approximately 1 to 3 minutes in length; depending on the number of data points collected at either 20 per second or 40 per second, for one hour. It is the sonification of an hour's worth of seismic data, allowing amplitude to be reinterpreted and observed as pitch.

Offshore wave conditions were obtained from measured at NOAA deep-water wave buoy Station 44017NDBC located in 45 meters of water, 23 nautical miles from south of Montauk Point at 40°41'32" N; 72°2'52" W (accessed on December 10, 2011):

http://www.ndbc.noaa.gov/view_text_file.php?filename=44017h2007.txt.gz&dir=data/historical/stdmet/

Results

When listening to various samples of sonified seismic data audible distinctions can be made. Examples were chosen in order to compare conditions. All examples were process using the same methods. The only variation is the length of the resulting audio file due to files from 2007 and 2008 recording 20 readings per second, and the files from 2011 recording 40 readings per second.

Four one-hour time periods were randomly selected to test the process. (Audio Files 1 to 4. See accompanying folder). Audio File 1 was recorded at 7:00 EST on April 19, 2007. The average, offshore wave height on the date that the readings for Audio File 1 were recorded was 2.22 m. Audio File 2 was recorded at 1:00 EST on November 2, 2007, when the average, offshore wave height was 1.21 m. Audio File 3 was recorded at 10:00 EST on January 2, 2008 when the average, offshore wave height was 2.49 m Audio File 4 was recorded at 5:00 EST on July 3, 2008 with an average, offshore wave height of 1.19 m.

All of these sonified samples share two distinctive features. As expected, they were dominated by a high-frequency chirping created by the incident surf with periods of 5 or 6 seconds. There are also audible lower frequency waves that create a popping sound, like a percolating coffee pot, that is lower in pitch and is clearly distinguishable from the higher frequency, continuous noise band. These lower-frequency sounds represented the infragravity waves with approximately 20-second periods. Flash rip currents that might be associated with coastal, infragravity waves had lifetimes of only a few minutes (Slattery 2010). In the compressed mode, such short-lived phenomena would appear as isolated punctuations in the audio record.

While there were slight differences among the audio files for these selected periods, the distinctions are not great. (The differences may be better noticed when the sonification is paired with an automated visualization, when the Audio File is played with Windows Media Player. Here the low frequencies waves are accentuated graphically). It may be that the wave conditions were not significantly different to be clearly resolved. Adjustment to the sonification process may be able to better resolve any differences.

Based on these initial tests, we examined surf conditions raised during a storm (Audio Files 5, 6 and 7). Hurricane Irene passed over Long Island on August 28, 2011, and its intensity peaked at approximately 6:00 EST. Audio File 5 was recorded at 6:00 EST on August 28, 2011. This file has distinguishing characteristics, demonstrating that the increased wave action caused by the storm. The continuous "chatter" occurred in a higher range, perhaps corresponding to an increase in the occurrence of large, short-period breaking waves. Audio File 6 was recorded at 5:00 EST and Audio File 7 was recorded at 7:00 EST. These two files before and after the storm's peak have less high frequency shorter period waves.

By chance, a Magnitude 5.8 Earthquake originating in Virginia at a depth of 6km at 13:51:04 EST. Vibrations from this quake reached NY seismic stations at 1:52PM (accessed on 9/16/11):

http://www.ldeo.columbia.edu/LCSN/Event/20110823175104.bull

Figure 1 shows an isolated portion of the .gcf file recorded at 13:00 EST on August 23, 2011. This graphical segment represents the arrival of the P and S waves resulting from the quake, reaching our station in East Hampton, NY. Audio File 8 is the sonification of this record; because the compression of the seismograph during the from 40 Hz to 1,000 Hz, the earthquake itself was incapable of being heard by ear. Therefore, another method must be designed to recognize earthquake events sonically.

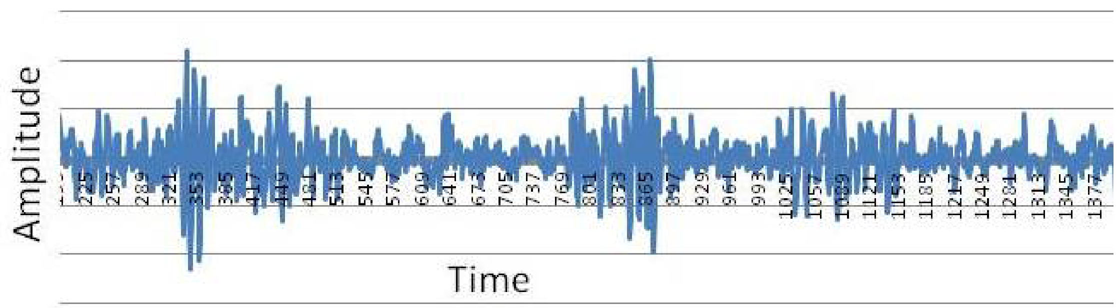

Figure 1

Discussion and Conclusions

As a practical matter, interference from anthropogenic vibrations and occasional power outages posed problems. However, the technique seems promising. Distinctions between records representing storm and calm conditions can be heard, but the transformation needs to be optimized to better distinguish and resolves differences in surf conditions. The sonification might be altered to emphasize beats that occur when to water-wave trains of similar period approach the shore. The amplitude of low frequency waves may need to be amplified to better distinguish them from the incident waves, and it may be that Doppler Effects due to the superposition of high-frequency, incident waves on low-frequency travelling waves could be used to record this phenomenon if it occurs. In any event, more examples need to be sonifed and correlated with measurements of available, offshore wave conditions. Direct calibrations would eventually be needed however by comparing seismic records to surf conditions measured simultaneously and directly in the surf zone. There are no such direct measurements currently available.

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