SHAKING UP EARTH SCIENCE: VISUAL AND AUDITORY REPRESENTATIONS OF EARTHQUAKE INTERACTIONS

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ABSTRACT

One earthquake can influence subsequent earthquakes. To demonstrate such earthquake interactions, seismologists have used in the past "snapshot" static images. Although static images can, by themselves, convey basic visual information about the spatial distribution of earthquakes, adding auditory information could help to provide additional details on the temporal evolution of the earthquake sequences. Recently we have used standard tools like MATLAB and Quick Time Pro to produce animations with time-compressed sounds to demonstrate both immediate aftershocks and remotely triggered tremors related to the 2011 magnitude 9.0 Tohoku-Oki, Japan, earthquake. Here we show our development in this direction that includes multiple parameters of earthquakes and seismic waves to present the concept of earthquake triggering.

INTRODUCTION

Large shallow earthquakes are typically followed by increased seismic activity near the mainshock rupture, which are termed "aftershocks." Sometimes large earthquakes are preceded by elevated seismic activity known as "foreshocks." Large earthquakes can also trigger shallow microearthquakes and deep tectonic tremors located several hundred to thousands of kilometers away [1], [2]. Many of these events are believed to occur in regions of high fluid pressure, including geothermal/ volcanic areas and the deep extension of some plate-bounding faults. Because earthquakes and tremors occur at different depths on major faults, both are important for understanding the underlying physics of earthquake nucleation, as well as overall fault behavior.

Seismologists have mainly used "snapshot" static images to present their results. Adding auditory information to static images could provide more information about the temporal evolution of earthquake sequences that can be easily communicated to a wide audience – seismologists, educators, and the public. This is due to the fact, as noted by [3], that our eye is strong in identifying *structures, surface,* and *steadiness*, while our ear is good at recognizing *time, continuum, remembrance,* and *expectation.* Hence, by combining audio and video components of seismic data and earthquake information, we can more effectively communicate the integral parts of earthquake sequences to a general audience.

Audification of seismic data is not a new concept [4], [5], [3], but has recently been rejuvenated [6], [7]. Recordings of nearby earthquakes and tremors contain frequencies of up to 100 Hz, which are on the lower end of the audible spectrum (20 - 20k Hz) that humans can hear. One of the more simple ways to map earthquake signals into audible range is to play it faster than the true speed (i.e. time compression) [5]. This also reduces the playback time so audiences can hear seismic signals that typically occur over a few hours in a matter of minutes. Recently, we combined images of waveforms and spectrograms with time-compressed sounds to demonstrate both immediate aftershocks and remotely triggered tremors in California related to the 2011 magnitude 9.0 Tohoku-Oki, Japan, earthquake [7]. These animations were generated using standard tools like MATLAB and Quick Time Pro [6] and represent our initial exploration of the use of both visual and auditory elements to convey information about earthquakes and tremors.

CURRENT AND FUTURE WORK

Here we present new audio-video products that present multiple parameters of earthquakes and seismic waves. The first one contains two or more audio channels (i.e. stereophonic sounds) converted from multiple frequency ranges of the same seismic data. We use the broadband seismogram recorded at station PKD in Central California during the 2011 Tohoku-Oki earthquake as an example. In our previous study [7], we used a factor of 100 to speed up the seismogram to audify teleseismic *P* wave (up to 5 Hz) and the locally triggered tremor signals (up to 30 Hz). However, the speed-up factor is still not high enough to bring the long-period *S* and surface waves (periods of around 20 s) into the audible range.

Rather than increasing the speed-up factor more (which would make the duration of the animation too short), we use MATLAB's built-in function *vco* (voltage controlled oscillator) to create a signal from the broadband seismogram that oscillates around an audible center frequency in proportion to the amplitude of low frequency ground motion. The amplitude (volume) of the *vco* tone is modulated by the envelope function of the broadband data. The length of this representation with both frequency and amplitude modulation (FM/AM) is selected to be the same as that for the time-compressed, high-frequency channel. Finally, we save both outputs as a stereo sound (with MATLAB's *wavwrite* function) and combine them with the static images to generate an animation with sound (See examples at [8]). Because this new version contains sound from dual frequencies, we can hear very clear correlations between the long-period *S* and surface waves and the high-frequency triggered tremor signals. In comparison, our previous product only has the high-frequency tremor signals, and hence such correlation can only be seen from the static images.

Other ongoing efforts include: (1) using seismic data from multiple stations and mixing them, or directly using events listed in earthquake catalogs to give spatial position in stereo or 5.1 surround sound – i.e. the listener at the epicenter and the stereo effect positioning the stations or earthquakes, (2) directly mapping earthquake parameters (epicentral locations, depths, and magnitudes) into sound properties (amplitudes, pitches, and durations). A recent example from another group is shown at [9]. Our goal is to produce innovative and simple ways of presenting earthquake waveforms and sequences and to share the results with other researchers and educators as well as the public. These approaches and products not only provide the general public with a fun and engaging way to gain scientific knowledge of earthquake interaction but may also help seismologists better study the phenomenon and decipher the underlying mechanisms.

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