USING AUDIFICATION IN PLANETARY SEISMOLOGY

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ABSTRACT

In which respect, to what effect and under which circumstances can audification improve seismological research? Building on the philosophical insight that the human ear is admittedly stronger than any other of our senses in recognizing time, continuum and tension between remembrance and expectation my investigation prepares for an acoustic prediction research. Hereby several geophysical categories are confirmed and will, in some cases, even be improved. By means of acoustic approach things like tectonic type, distance between focus and station, site response and event recognition are easier to handle than so far possible by means of more conventional scientific strategies.

1. INTRODUCTION

The concept of audificated seismograms has been quoted repetively though marginaly in articles overviewing sonification but there are only three papers which dedicated themselves to the topic. In 1961 S. D. Speeth [1] introduced the idea of "seismometer sounds", as he called it, to discriminate natural earthquake events from atomic explosions. This was rechecked by G. E. Frantti and L. A. Leverault in 1965 [2] and there it was tested that a trained listener could distinguish between quakes and atomic explosions with a chance of 67,5 % in average. This score nevertheless was not too satisfying and the acoustic approach fell into oblivion no sooner it had been remembered until Chris Hayward made a new attempt as late as in the early 1990s [3]. In Hayward's attentive and diligent investigation of the topic which was presented at ICAD 1992 he concentrated much on detailed analysis of waveletts and of data from seismics where artificial quakes are used for exploration geophysics. In his conclusions Hayward hinted at diagnostic quality control as the major field of application and pointed out that audified seismograms provide a good idea of the overall characteristics and evolution of the seismic spectra. This suggestion went along with experiences of some seismologic stationers who had already used audification for quality control and for event recognition. Especially during the 1960s and 1970s when regular tape recording was used to archive seismological data, several stationers tried out audification. Some researchers applied it then for daily check up of incoming data to get an overall impression of last day's activity and data quality.

1.1. Earthquake Prediction Research

The ear is a sense with strong epistemological power, and one may ask if there is a field of application more substantial and far-reaching than quality control. Which problem in seismology might be solved easier in sound than in sight? Can the apparent fascination of "Listening to the Earth Sing" (as Hayward titled) guide to a scientific topos? I am convinced that audification can be of great value particularly for the topic of earthquake prediction (cf. chapter 17 in [4]). In planetary seismology we face a huge archive of seismological registration and data sets are even growing (hundreds of stations are registering data 24 hours a day, 365 days a year). The post eventu earthquake research profited very much from it; but no reliable theory of prediction has so far been achieved. This immense database is at our disposal but we are not able to determine the precursors. Therefore it is not only a question of collecting data but of presenting and interpreting them properly. The arguments seem all to pay tribute to audible strategies when it comes to predicting earthquakes and I will thus give a short overview on the capabilities of the kind.

1.2. On Eye and Ear

From philosophical research (cf. esp. the fundamental investigations of G. Picht [5] and M. McLuhan [6]) we can learn that the eye is strong in recognizing *structure*, *surface* and *steadiness*. Those things have been explored in visual dominated earthquake research during the last 100 years very successfully. Maps of seismic hazard for instance show quite obviously the structure of plates on the earth's surface and the steady, date independent risk at specific areas. Now at the same time philosophy finds the ear strong in the recognition of *time*, dynamics of a *continuum* and tensions between *remembrance and expectation*. And it is precisely those aspects of earthquakes are still challenging topics in seismology. Taking the said insights into serious account the outcomes of what I like to name "Auditory Seismology" should be the following: understanding of temporal development of seismic activity; understanding of dynamical phase of the continuum at an active tectonic area; and understanding of announcements of future events from the tensional behaviour of past and present seismological activity.

2. METHODS

How then it is at all possible to listen to the earth's activity and make earthquakes audible? Main data in seismology are expressed in seismograms which plot the movements of the earth over time. Seismological waves follow the same physics as acoustic waves and both can be described by wave equation. A difference is that the frequency spectrum in seismology ranges from 20 Hz to periods of 1 h whereas in acoustics it ranges between 20 Hz and 20 kHz. Acoustic waves are 1-

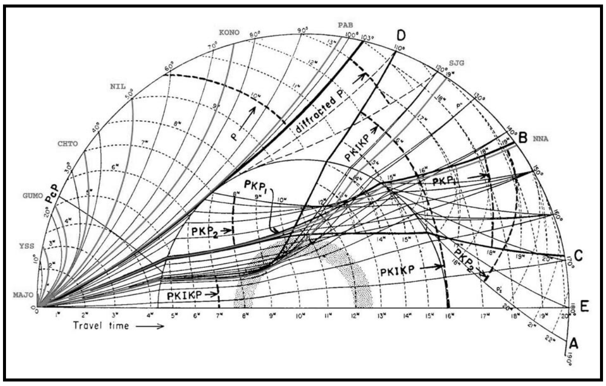

Figure 1: Schematical cross-section of the earth. Several ray paths of P-waves are displayed.

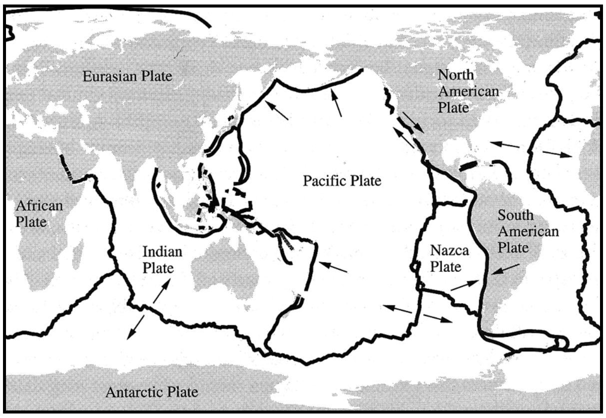

Figure 2: Earth's major tectonic plates

dimensional and earthquake waves propagate in 3 dimensions as a combination of compressional (P-waves) and shear waves (S-waves). Seismological records have a large dynamical range which is usually registered by 24 or 32 bit whereas 16 bit registration is sufficient for acoustics.

In Auditory Seismology we use seismographical records of the earth's activity and transform the registration into an audio sound. Herefore the seismological signal has to be on the one hand time-compressed and on the other hand reduced to one dimension. Furthermore the dynamic range of seismograms has to be scaled down to an appropriate oscillogram.

I myself chose to accelerate straight forward by re-sampling. The factor of time-compression was chosen by test runs for two reasons: (i) the acceleration needed to be for investigation of time and dynamics fast enough on the one hand so that even days and weeks of registration could be overviewed easily (ii) on the other hand it had to be low enough to give full experience to the acoustic characteristics of a quake. I found that a factor of 2.200 suited best for the reason. I did no frequency doubling as Hayward for instance proposed for the simple fact that it did not seem appropriate. I am interested in temporal and dynamical development of a tectonic or volcanic site and for this kind of study physical characteristics have to be preserved. Audification proves to be a far better strategy to provide overall information of dynamical state than drawing detailed analysis of single wavelett where visualisation can be much more effective.

In reducing the three seismological components (two horizontal, one vertical) I chose the vertical z-component in my study for two reasons: (i) often the three components of a seismogram (two horizontal and one vertical) sound similar even though they are visually different; (ii) assuming that the ground represents a big speaker it would be the z-component that would be to hear.

The 32 bit registration of seismology was reduced to 16 bit acoustic standard by two methods: (i) A linear (normalised) transformation was used when only single events were studied. (ii) An automatic gain control (AGC) was used when day registrations were examined to preserve the sound of noise and to avoid clipping during the arrival of big signals. DC removal was made as preprocessing when needed.

3. RESULTS

Studying a topic by a new sense needs some time of accustoming. Clearly I had to adapt to auditory seismograms and redispose geophysical categories in acoustic display. For this I listened to many audified seismograms and discussed the sounds with colleagues. More extensive user studies are planned. The results so far can be summed up as:

(i) Distance: The range between earthquake focus and the registering station has an obvious influence on the record. The signal tunes not only down but broadens with growing distance due to different phase velocities (dispersion). The seismological registration of e. g. the earthquake of Kobe in 1995 durated at Matsushiro in 3 degrees distance only a few minutes and at Nana, Peru, in 143 degrees distance more than half an hour. This produces a characteristic change in sound as the acoustic transformed signal prolongs from half a second to a few seconds (assuming an acceleration factor of 2.200). Near registrations are heard as sharp clicks whereas far quakes are heard as deep rumbles. Within the distant signal also the pitch changes. It starts with low frequencies during P-wave arrival (i. e. compressional wave) and than goes up during the second half of surface wave signal. In some samples it can even be heard if the wave has traveled through the earth's core (more than 103 degrees distance; cf. Fig. 1). Here the attack of the sound becomes harder which as a fact goes along with the geophysical analysis of P-wave's arrival being sharper when refracted at the earth's core (so called PKP-wave).

(ii) Region: If one varies quakes (while keeping the station) earthquakes of one region show an overall acoustic familiarity. I did among others an investigation of the region of Kobe. All earthquakes I chose sounded like sharp clicks and did not change in pitch or timbre (cf. (v) Tectonics).

(iii) Site Response: Each seismological station has its own characteristic response which can be heard. All kinds of influence must be assumed here: type of seismometer, fundamentation of the instrument and its connection to the ground, the embedding of the geological formation and surrounding rocks etc. I heard a difference between bedrock and gravel: the first sounds are dry and wooden, the second ones more tingling. Of course further investigation is needed.

(iv) Noise: Each station has its own characteristic background noise. Surrounding activities like car traffic (stations near streets) or ocean waves (stations near the coast) can be heard and are easy to recognize. Furthermore one must expect influence of wind, air pressure changes, tides etc. This has not been studied in Auditory Seismology yet but should be a topic of further investigation.

(v) Tectonics: One of my most encouraging results is the recognition of tectonics (cf. Fig. 2). There are three general types of plate movements: spreading zones, subduction zones and shear zones. The sound of earthquakes at spreading zones differs much from earthquakes at subduction zones. Whereas earthquakes produced by plates that are drifting against each other appear as sharp and hard beats, an earthquake from a parting mid ocean ridge sounds more like a plop. Shear quakes sound more or less alike subduction quakes but relax their tension more often in a series of seismic activity.

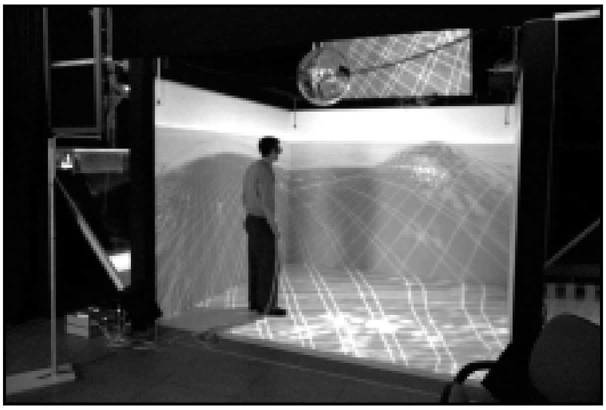

Figure 3: VR model of Mt. Merapi in a CAVE like Display

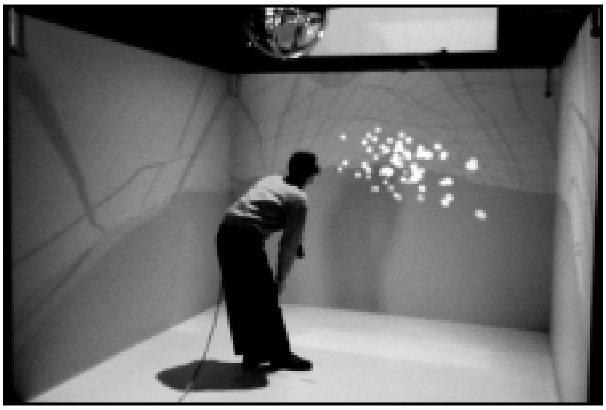

Figure 4: Close-up of the earthquake foci

(vi) Temporal Study: I have not heard any earthquake precursor yet. I found it very helpful during listening that all arriving waves can be heard in seismological registrations. Where visual displays (like maps or cross-sections of earthquake catalogs) usually plot only a certain area for a specific time frame Auditory Seismology takes all global events within the time frame into account. The listening experience is not defined by regional borders but open to the whole globe. All arriving waves as well as the triggering energy is heard and therefore all factors that influence the tension and activity underground.

(vii) Audio-Visualisation: I decided also to use virtual reality (VR) for 3D-visualisation of earthquake catalogs. This easys space recognition in audio and provides more structural information. It becomes possible to follow the soundtrack and at the same time watch the appearance of localised earthquakes. Simultaneously the ear can hear a click and the eye can see a flash representing the earthquake focal point. I chose the Merapi, a volcano in Indonesia, as a sample region and audified three days of registration. The earthquake catalog of this period of time was then visualised displaying place and time of the events in relation to a digital elevation model (cf. Fig. 3 & 4).

- Audio samples of each result will be given during the conference and can also be found at www.gmd.de/auditory-seismology -

4. DISCUSSION

Using audio for discrimination of certain characteristics of seismograms was the original idea proposed by Speeth. In the meantime the quality of registration has improved (broadband seismometers became standard in the early 1990s) which supports precise and sharp tracks. This gives new spirit to the technique of audification as at the same time the quality of sound has improved a lot. Following my long term goal of prediction research I modified precedent approaches in the following manner:

For audification I chose a ten times higher time-compressions than Speeth, Frantti or Hayward. That makes it possible that earthquake signals can be received by the whole human audio range. It gives us a more general impression of the dynamical state underground and simplifies overviewing temporal developments. At the same time I renounce the power of e.g. precise timing and identification of phase (P, S, etc.). I see this as no hindrance as visualisation techniques have scored here already great success and the eye and the visual approach have proved to be appropriate.

Hayward's description of sound changes due to growing distance between focus and station was proved. The sound broadens characteristicly and a few examples are already enough to demonstrate the difference, even to non-seismologists. The signal is easy to recognize even in noisy records which in itself are difficult to interpret visually. Favoured by the so called "coctail-party effect" the ear distinguishs easily between noise and signal.

Back ground noise has been studied. Each station has a characteristic "sound" due to surrounding activity (traffic, ocean waves, etc.) and geological setting. I proved that one quake is heard differently at different stations (site response). Here of course more research would be desirable. Dependencies between geological setting and sound characteristics would have to be investigated and studied in detail. From this kind of research especially those investigations could benefit that are looking for proper positioning of seismometers .

Hayward suggested a combination of visual and audio display. I did a synchronised audificaton of seismograms and 3D-visualisation of earthquake catalogs in virtual reality (VR). Both displays produced a substantial surplus with mutual impact, especially in the sense that the multimedia approach allowed to study temporal development in sound and visual space.

The results were produced on base of personal research. To objectify my experiences and descriptions in the future a wider base of users need to be aspired. Extensive user studies are planned. For distributing acoustic results a web page [7] has been installed and will be improved over the coming years. This will provide a platform for further discussions on the subject.

5. CONCLUSIONS

Auditory Seismology is a promising way of approaching seismological data. The close relation between airwaves of acoustics and body waves in seismology allows a convincing audification. The transformation from seismological data to sound is almost unequivocal and relies on very few subjective design decisions compared to other applications of sonification.

First results in Auditory Seismology prove that the ear is able to challenge the epistemological power of the eye. Audification can be applied in seismology and in seismics but will be more effective in the first. Earthquakes show specific acoustic characteristics that are difficult to display visually. Subduction zones and spreading ridges generate different earthquake sounds. Signals hidden by noise are acousticly easy to recognise. Quality control during data recording is easy to handle. Temporal studies take all present waves - from the sound of close small quakes to the sound of far big quakes - appropriately into account.

I am more than positive about further studies on Auditory Seismology. As short-term goals I name amongst many: improvement of the understanding of the influence of geological site response, interpretation of noise produced by traffic, seawaves etc. and regional characteristics. As long-term goal I look forward to a better understanding of temporal seismic activity. All kinds of question from earthquake prediction research will have to be evaluated in an acoustic environment.

None the less it should be mentioned that audification is not a universal cure-all. Visualisation is still needed. I therefore vote that awareness is tributed to both, the advantages and disadvantages of the ear as well as of the eye. Either technique - audification as well as visualisation - could and should be applied where it is most meaningful: use audification in all questions concerned with time, continuum and the tension between remembrance and expectation; and use visualisation techniques in all questions concerned with structure, surface and steadiness. In audio-visual representations the eye and the ear will then compete with but also support each other.

6. ACKNOWLEDGEMENTS

The seismological data I used were provided by IRIS data center in Seattle, Washington, and ORFEUS data center in De Bilt, Netherlands. The data of Mt. Merapi were provided by the University of Potsdam, Germany.

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