inter.noise 2014
MELBOURNE AUSTRALIA
16-19 NOVEMBER

Acoustic Study and Visualization of a complex echo at the Klondike Bluffs, in the Arches National Park, Utha, USA

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ABSTRACT

Physical explanations for echoes are widely known. Although measuring an echo with common methods using a single microphone is simple, it does not provide a full description of the behavior of each individual reflection that take part of an echo of this large scale environment without knowledge of the exact topology. The actual directions of each echo remain unknown. Only simulations will provide some understanding but are only as good as the model and all its assumptions. The aim of this paper is to investigate and uncover the participating reflections for an echo and create detailed visualization of the echo reflections scheme. The measured echo was first discovered by Gunnar Heilmann in September 2009 and was now measured and will be described here for the first time. It is particularly interesting because of its multitude (more than ten reflections) and order of individual echo reflections and its 3D distribution and timing surrounding the receivers' location.

Keywords: Reflection and echoes   I-INCE Classification of Subjects Number(s): 23.2

1. INTRODUCTION

Over a decade, Beamforming systems are being used in more and more fields of application. In the early years, it was the airplane industry, followed by car industry. Engineers from the car industry are using acoustically transparent spherical microphone arrays successfully to detect buzz, squeak and rattle noise inside the car cabin[5]. Later the electronics sector and the manufacturers of white goods and household appliances started using sound source localization tools like Beamforming. In the past few years the room and building acoustic field started to use Beamforming systems as well, foremost to visualize leakages[9] or reflections in small and medium size rooms[6].

A number of research papers have been published visualizing reverberation effects, showing the reflections on the surfaces of the measured places. This has been done in Football stadiums, Basketball and Ice hockey arenas as well as Concert halls and other performance places. The aim usually was to visualize the reflecting surfaces similar as in simulation tools for ray tracing. Using Beamforming one can visualize these reflections in a 3D acoustic photo or movie[7]. This way the actual sequence of all individual reflections can be identified. Especially the acoustic movies are needed when someone tries to understand an impulse response of a blasting balloon in a room, by displaying all reflections on the surface of a 3D model of this room.

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Beamforming systems limitations are mostly set by physical parameters such as array size and sampling rate of the data recorder. The shortest measurement distance from the source to the array is normally equal to the array diameter. The longest distance depends on the time and space resolution one desires, and external factors like wind. The experience of the last year's show that if there is no wind present, results can be achieved even for sources in distances of some kilometers. The resolution in the space domain will suffer the longer the distance gets. These measurements help understanding the limits of the Beamforming technology.

The aim of this paper is to further investigate the limits of Beamforming as acoustic sound source localization technique by showing the participating reflections of an echo, and create detailed visualization. The measured echo was first discovered by Gunnar Heilmann in September 2009 and was now measured and will be described here. It is particular interesting because of its multitude of individual echo reflections and its 3D distribution and timing surrounding the receivers' location.

2. MEASUREMENTS

2.1 Date and general Echo Location

On August 18th and 19th 2013 a team from gfai tech GmbH (Berlin, Germany) measured an echo phenomenon at the Klondike Bluffs located in the Arches National Park (Image1). The area of the Klondike Bluffs is known for the tower arch and is located in the north western, most remote part of the Arches National Park in Utah.

The inner area of the Klondike Bluffs measures approximately 900m from the West rim to East corner and 600m North rim to South rock formation. Depending on the listeners position the distances to the reflection surfaces vary between 60-90m up to approx. 950m at the furthest corner.

Because of bad weather conditions and too strong winds, none of the recordings from the 18th of August could be used.
The morning of the 19th of August 2013 presented the perfect weather conditions for the planned measurements. There was no wind and temperatures remained below 40ºC until mid-day. These conditions were allowed us to record three sets of measurements with 16s and 32s of data, taken at 192 kHz sampling frequency.

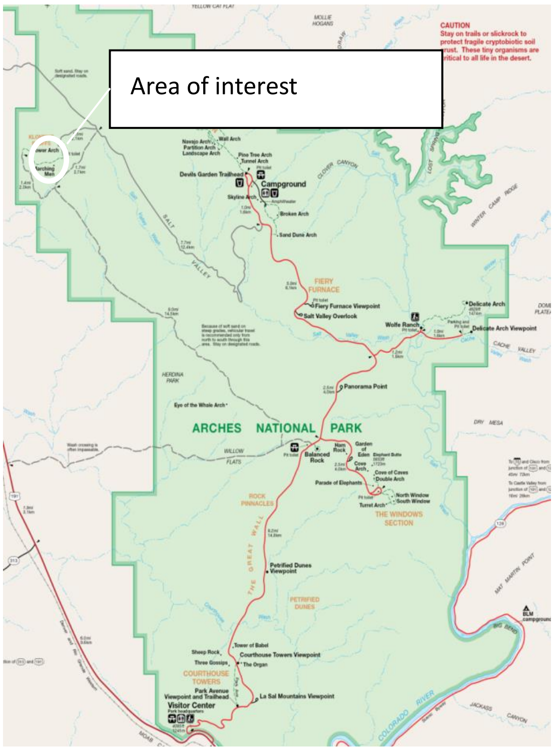

Image 1: Map of the Arches National Park map.

2.2 Sound Sources

To create a distinctive echo we tried at first to use a wooden clapper as noise sources (image 2 and 3) provided by University of Michigan, in accordance with the Code of Federal Regulations[4]. Although the clapper, as sound source, did provide a broad band noise as depicted in Image 4, it did not produce enough energy to create a sufficient audible echo with more than two reflections. A shotgun or small canon was not allowed because of the national park regulations mentioned before. These may have provided a strong enough signal to create reflection. Since we did not get the expected reflections from the clapper, we rejected these recordings from further analysis.

In a second try, we created an echo with the short holler (huhuu). This technique turned out to create a better echo pattern as the results will show in the following sequence of images (sequence 4-19).

Image 2: Wooden clapper.

Image 3: Measuring the distance to sound source.

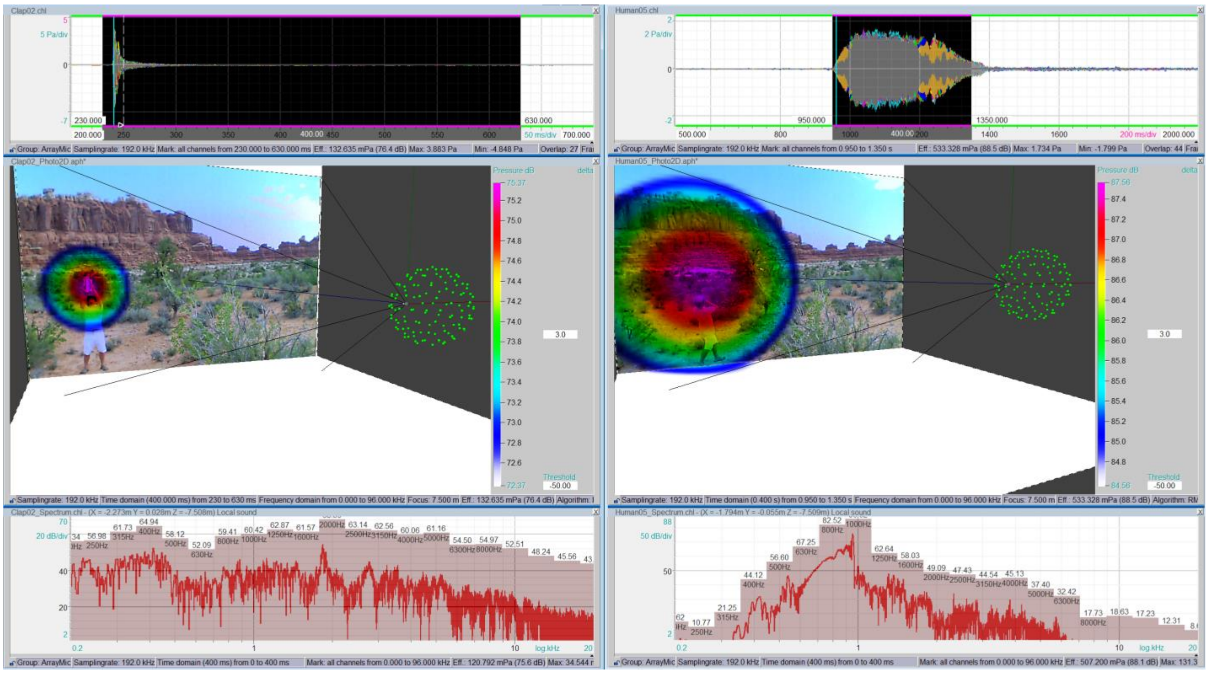

Image 4: Time and frequency analysis of the clapper (left) and the human voice (right).

2.3 Exact Measurement Location

Being aware that we were entering a protected area, the team stayed on marked trails not to intrude or endanger the present wildlife. The location of the echo point is directly on a park trail so no equipment had to be set up off trails. Therefore, no wild life was affected in an unregularly fashion.

The exact measurement location and point at which the echo was received best was at Latitude: 38°47'12.55"N, Longitude: 109°40'52.92"W Altitude: 1533.5m (Data extracted directly from GPS sensor of the camera).

Image 5: Satellite image of the region of interest (source Google Earth).

Image 6: Searching for the best set up position for the Sphere120 array (during measurement -Z axis direction of camera facing north), measuring the distance to each rock formation.

2.4 Equipment used

For the recordings we used a Sphere120 acoustically transparent microphone array as generally suggested for 3D applications (seen in image 6) and a 120 channel data recorder mcDrec721 provided by the University of Michigan.

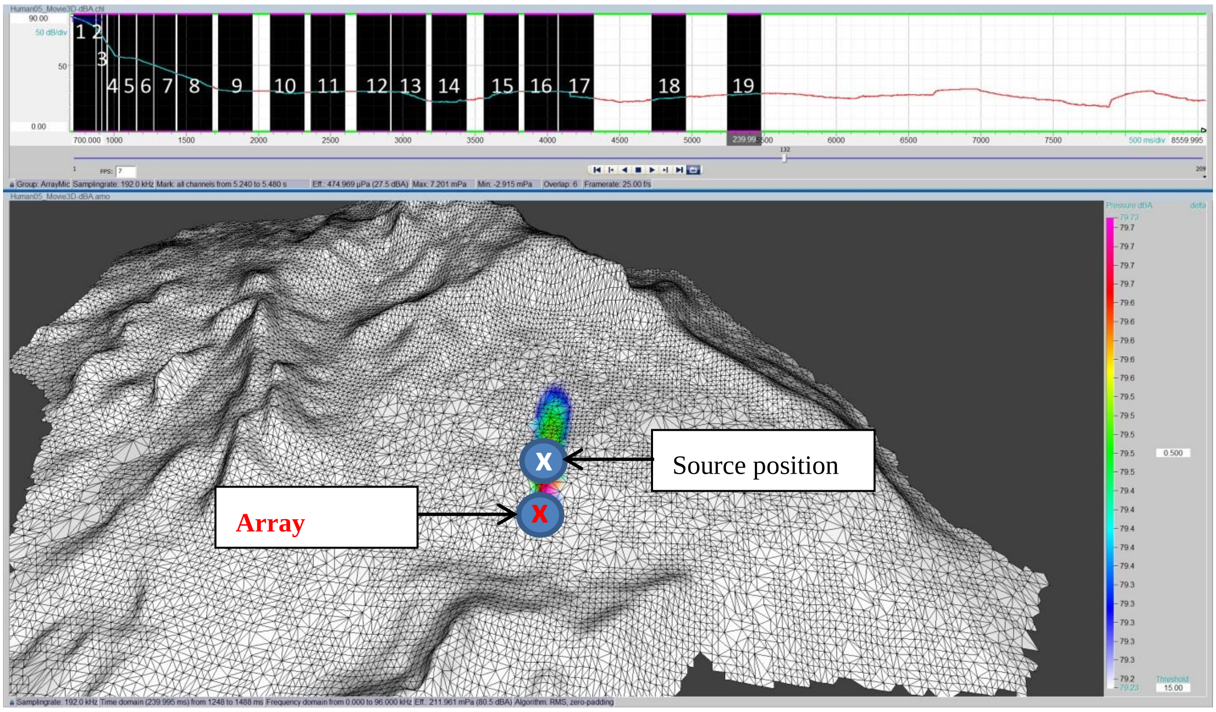

Image 7: Position (bottom window) and time sequence (top window) of all reflections and a mapping of the direct sound component.

The sound source was placed 7.5m away north from the receiver position. For the data analysis we loaded the recorded data into the Software NoiseImage4. The Acoustic Images were then mapped onto a CAD[7] model given by the University of Michigan as seen in image 7.

At first, several tests with the wooden clapper were recorded, but only faint echoes were audible. The analysis of the data with NoiseImage subsequently confirmed the human perception. There was almost no echo. Therefore these data sets are not shown in further acoustic imaging. As a result another series of measurements were performed, recording human voice. This proved to be the most sufficient to generate a signal that is reflected by the surfaces of the surrounding rock formation to form the echo.

3. Results

3.1 Mapping the echo reflections

The reflections can be separated clearly to in time and space domain. The following images show the reflections surrounding the listener's position one after another from first reflection (image 10) to last audible echo seen in image 28. The entire echo takes almost six seconds.

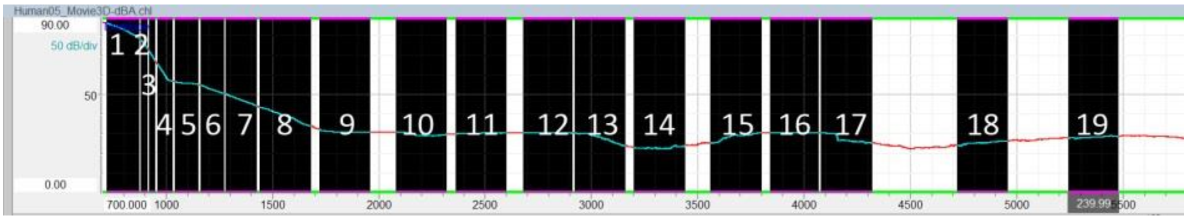

Image 8: Displayed time intervals of all following acoustic maps.

In order to understand all reflections in space and time, we will separate them in 4 steps and show their reflecting surfaces as described in Image 9. The first eight echoes (sequence 2-9) are received within the first two seconds. When standing at array position facing north, these first echoes are perceived by the human ear as only 3 different sources. The echoes appear to start south east and south coming from the (here stated as) Southern Rock formation – Echo area A.

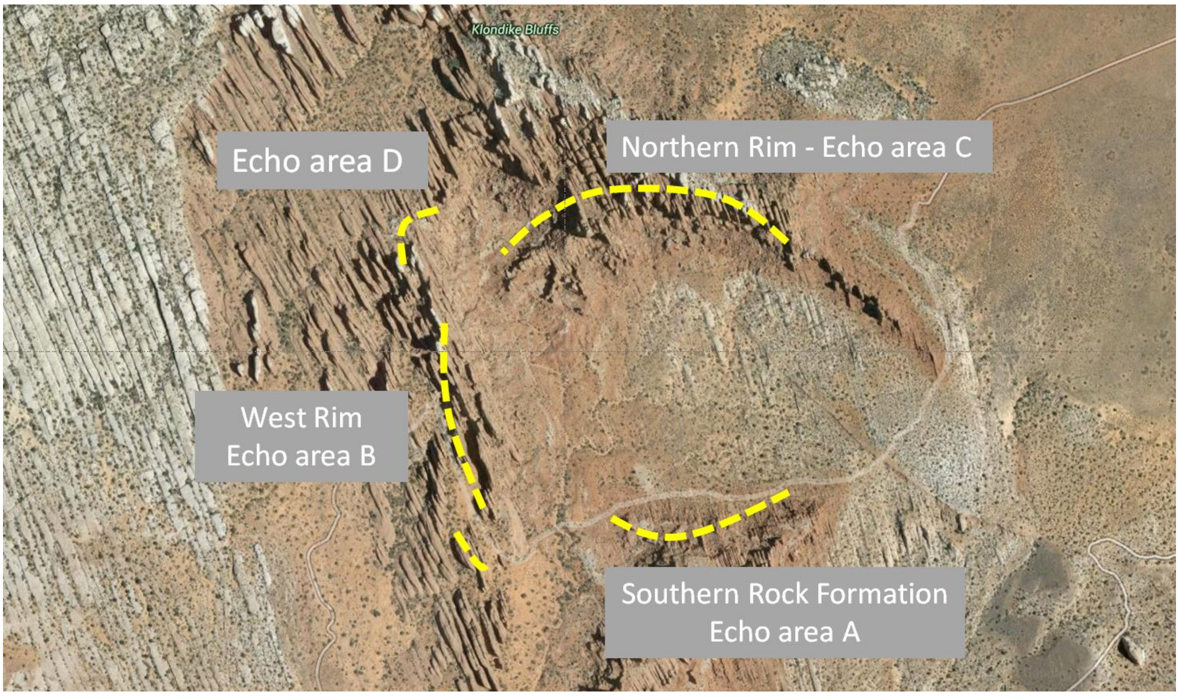

Image 9: Description of echo reflecting rock formations (source Google Maps).

This is shown in sequence 2-9 appearing in the first two seconds after the direct sound. These sources are easy to separate in the acoustic images but sound to the human ear as three or four following sources.

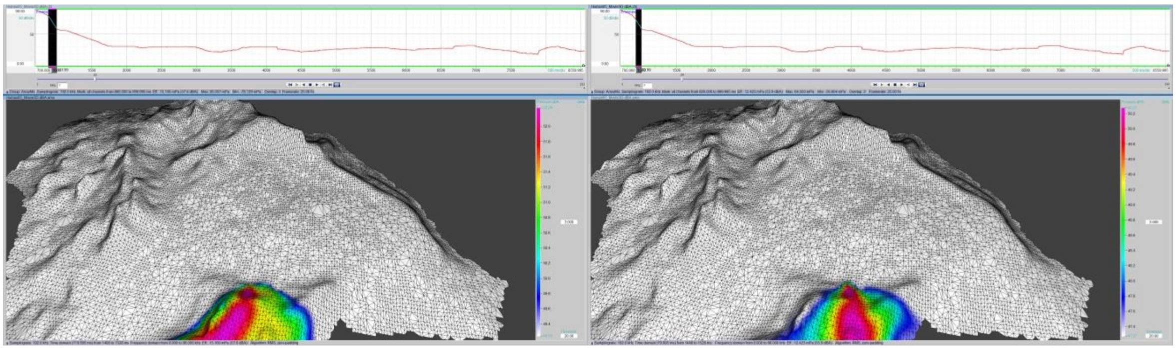

Image 10 and 11: Time sequence 2 and 3.

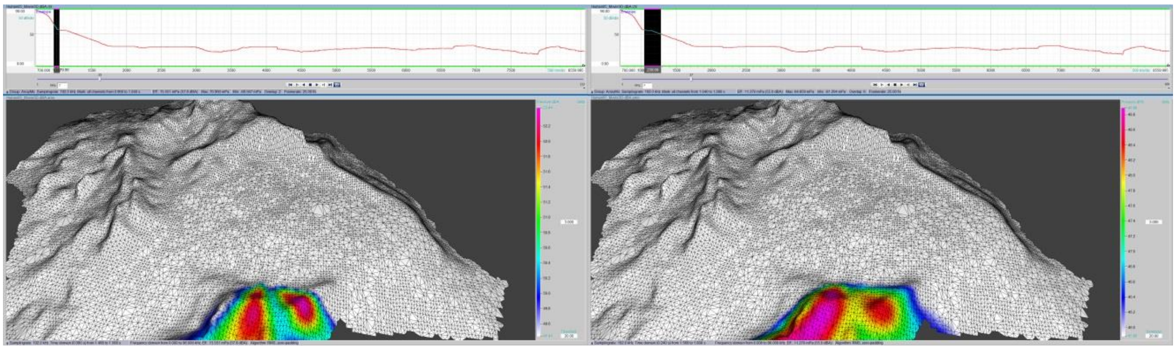

Image 12 and 13: Time sequence 4 and 5.

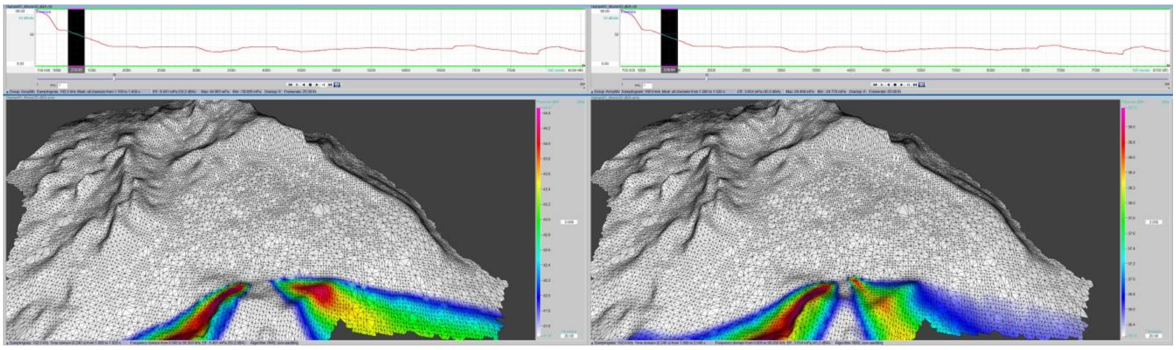

Image 14 and 15: Time sequence 6 and 7.

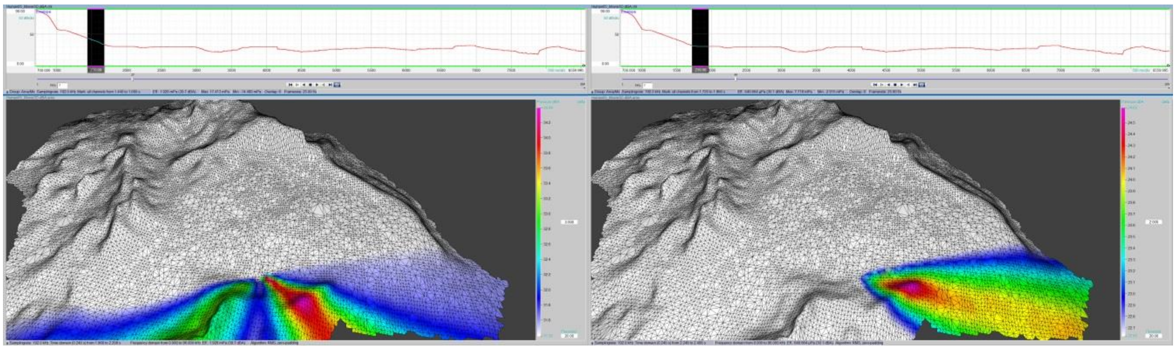

Image 16 and 17: Time sequence 8 and 9.

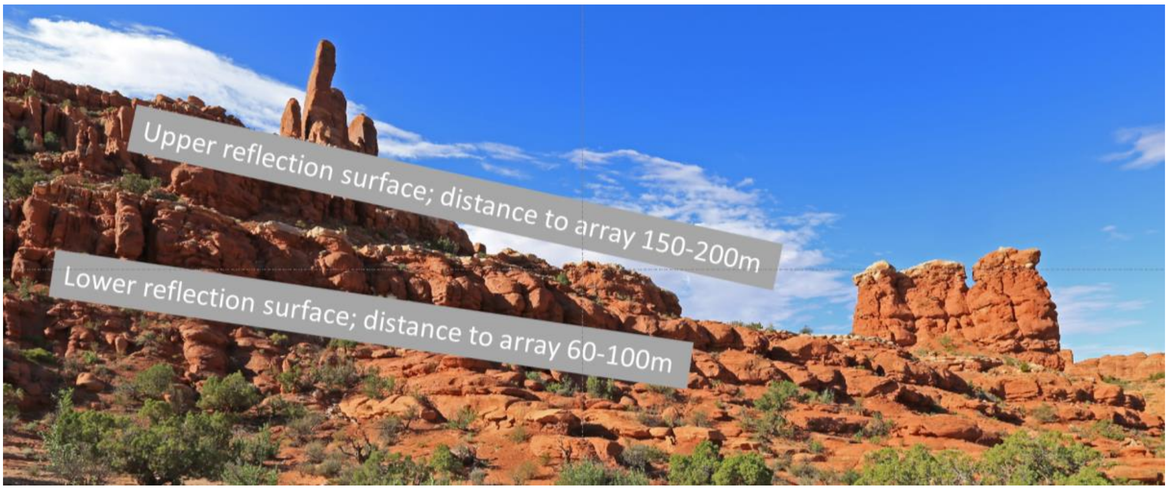

Image 18: Rock formation south of array and area for the echoes of sequence 2 to 9.

This reflection pattern (Image 10 to17) can be explained by the staircase like rock formation south of the recording position. So the listener gets first echos from the lower rock surface and then from the upper one. These can be separated by the acoustic camera but hardly distinguished by the human ear as separate events.

The next sequence of echoes reflects on the west side of the bluffs (image 23) being roughly 250m to 350m away from the receiving point. To the listeners ears it seems to travel from the South West to the North West side in an even order with a clean audible 50ms separation in time. As the images show, there is a first reflection on the rock closest to the measurement position (image19). The next reflection comes from a canyon behind, which is still closer than the next part of the visible rim of the bluffs, from where the following two reflections (images 21 and 22) continue on clockwise around the listener.

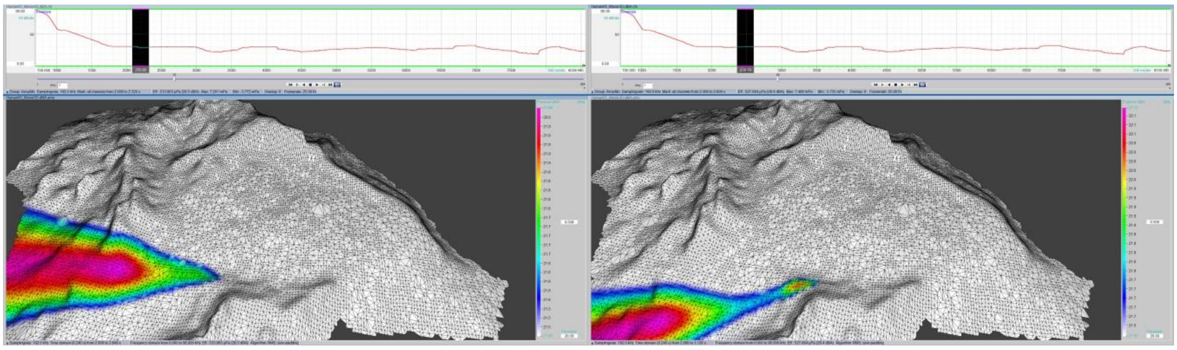

Image 19 and 20: show time sequence 10 and 11.

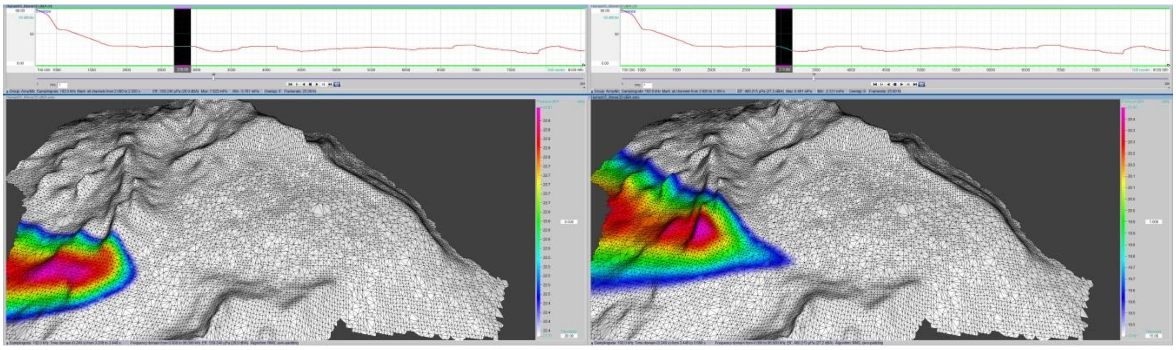

Image 21 and 22: show time sequence 12 and 13.

Image 23: Shows the West side of the Klondike Bluffs and the position of the echo area for sequence 10 to 13.

The Tower Arch is located in the North West corner of the Klondike Bluffs. Going further north of it, the reflecting echo rock formation has a second discontinuity. Another small circular area is located behind this (approx. distance 700m -1000m), which results in a further distance for the sound to travel ("Echo area D" in Image 9). The reflections continue therefore next on the closer northern rim (Images 24 to 27).

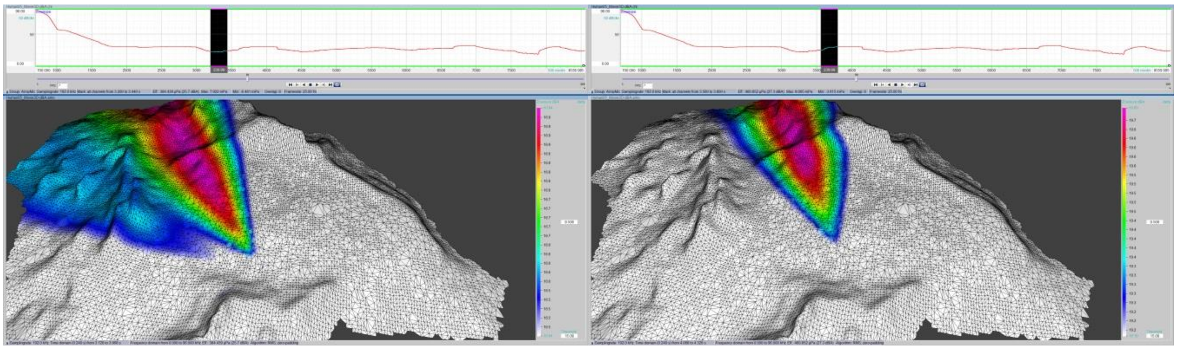

Image 24 and 25: Time sequence 14 and 15

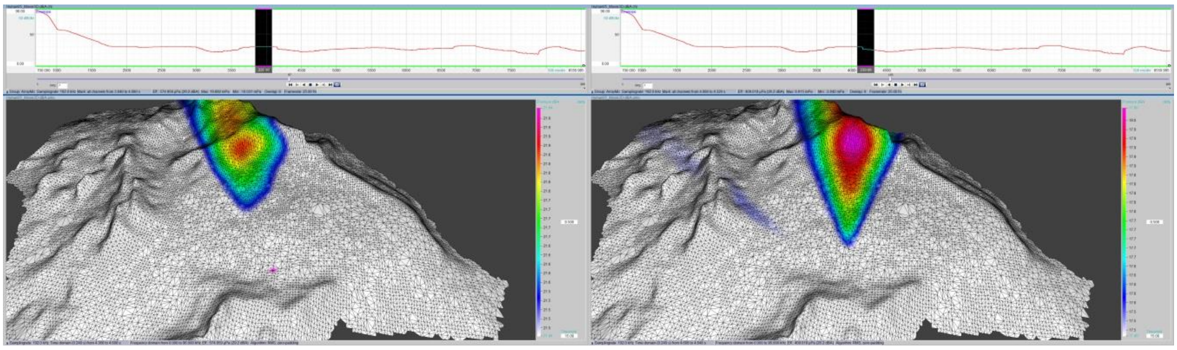

Image 26 and 27: Time sequence 16 and 17

Image 28: Northern Area of the Klondike Bluffs, showing the echo area for sequence 14 to 17

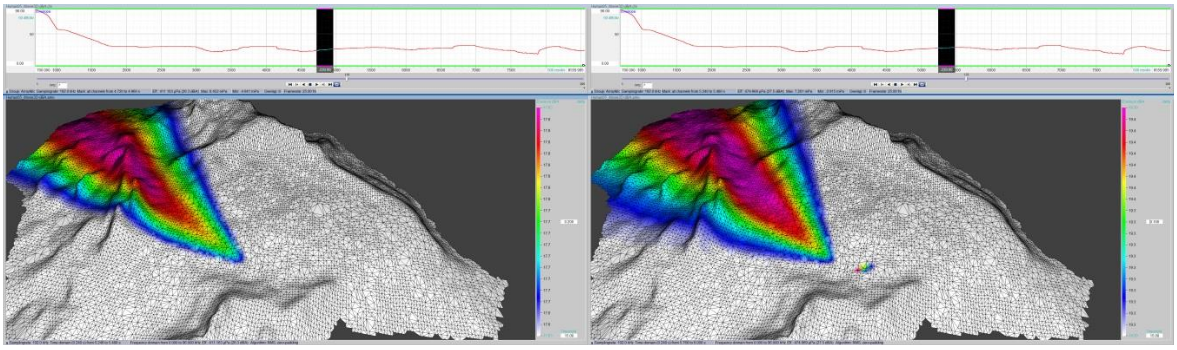

Image 29 and 30: Time sequence 18 and 19

Just before the echo totally disappears the last two faint reflections from the North Western corner reach the listener's ear. This may or may not happen depending on weather condition and listener's position.

Image 31: North West corner of the Klondike Bluffs (approx. distance 1000m) showing the echo area for sequence 18 and 19

4. CONCLUSION

This study shows that Beamforming can be used for sources of greater distance when no wind is present. The sound source analysis with the software NoiseImage is in agreement with the impression to all audible reflections by the human ear. The calculated acoustic photos have shown systematically each reflection surrounding the listener’s position. The minor variations from the human perception can be easily explained by the distances to the rock formation.

ACKNOWLEDGEMENTS

The access to the Klondike Bluffs was made possible by the permission of the National Park Service, Southeast Utah Group. Great thanks to Mark E. Miller, Chief of Resource Stewardship & Science and Michael Henry, Supervisory Park Ranger at Arches National Park who made these measurements possible. Also thanks for technical support from University of Michigan, College of Architecture and Urban Planning.

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