UNNATURAL NATURE: SPATIAL SONIFICATION OF CLIMATE CHANGE DATA

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ABSTRACT

In this paper, we describe the design, implementation, and evaluation of a sound installation that is based on the spatial sonification of climate change data on global temperature, CO₂ concentration, Arctic and Antarctic ice sheet mass, and sea level variation. Titled “Unnatural Nature,” the installation aims to evoke in the listeners an emotional connection with the data and an increased awareness of climate change. The sound engine underlying the sonification implements a range of sounds that model a natural soundscape as well as those that are more abstract. The sonification also leverages audio spatialization using a higher-order Ambisonic system to create an immersive experience that envelopes the listener in the modeled soundscape. We discuss the technical implementation of the sonification and some of the aesthetic decisions that were incorporated into the installation. We then present the results of a user study that aimed to understand participants’ interpretation of and engagement with the sonification, and its effectiveness in conveying the trends in climate data.

1. INTRODUCTION

Sound can be a powerful tool for conveying information to a listener and evoking emotional responses [1]. Prior research has shown how capable our auditory systems can be in recognizing temporal changes and patterns in sound [2, 3]. The experience of perceiving a sound can be very personal and, in many cases, have a more profound effect than sight [3]. While our visual systems capture information with limited directionality, our auditory perception operates omnidirectionally, allowing us to monitor our surroundings from all angles. Therefore, presenting scientific data through an immersive sonification can be an effective way of conveying the underlying implications of a data set and eliciting an emotional response from listeners.

“Unnatural Nature” is a two-part installation that offers an immersive and interactive experience in a room-scale environment. It explores the evolution of global climate over the past century and imagines future scenarios based on human activity. The first part of the installation focuses on the spatial sonification of four different data sets obtained from NASA’s global climate change database [5]. The second part explores how the participants’ interaction with the environment can shape the future evolution of our climate. To provide the reader with the broader context of our installation, this paper will touch upon the use of interaction in the second part of the installation. However, the paper will primarily focus on the design and implementation of the first part, wherein an immersive data sonification is presented to the listeners. Furthermore, we will offer the details and results of a user study, which was carried out to gather qualitative data on the listeners’ experience of this sonification in terms of their interpretation of sound sources, data mapping, spatialization, and emotional engagement.

2. RELATED WORK

Previous projects have leveraged sonification as a means to communicate information about climate change, generate an awareness of the environmental crises stemming from it, and encourage an empathetic attitude towards the environment through sound [6, 7]. Apart from its practical and scientific applications, sonification can offer unique compositional possibilities grounded in data. Such uses can facilitate public engagement and bear the potential to “increase the human understanding and appreciation of the forces at work behind the data” [8]. The use of data sonification in music composition is also referred to as musification [9]. For example, in the project “Musification of Seismic Data,” the sonification is enhanced through sound effects that create timbral variations in a generative music composition. In doing so, the project aims to contribute to environmental consciousness and offer a musical experience that is “both a meaningful tool for geophysics monitoring as well as an engaging means of raising public seismic awareness” [10].

As concerns about the environment and the urgency of the climate crisis continue to grow, an increasing number of composers, sound designers, and researchers are turning to innovative approaches in sonification to increase awareness of this issue and inspire action [11, 12, 13, 14]. In his telematic opera “Auksalaq,” Matthew Burtner offers a commentary on the melting of Arctic ice through the use of data sonification, field recordings, musical instruments, and computer-generated sounds; data from ice cores, sea ice measurements, and temperature records are sonified to convey the changes in Arctic ice over time [15].

In another example by Michael Gould, Stephen Rush, and Marion Tränkle, “A World Without Ice” draws inspiration from the book of the same name by Henry Pollack, who is a geophysicist and climatologist. The installation incorporates a sonification of century-long environmental data that govern the pitch and rhythm of a musical composition. This is accompanied by a large-scale projection of photos from the Arctic and Antarctic, as well as ac-
tual ice blocks melting on snare drums to create percussive sounds. Through these modalities, the installation invites the visitors to contemplate the impact of climate change on the world’s ice reserves [16].

The environmental artist Andrea Polli uses the term geosonification to refer to the “sonification of data from the natural world inspired by the soundscape” [7]. The term “soundscape” was proposed by the composer Murray Schafer, who defined it as all the sounds present in one’s environment. Soundscape studies pioneered by Schafer explores the evolution of our auditory environments in the modernized world and how sound mediates the relationship between humans and their environments. These ideas are fleshed out in his influential book “The Tuning of the World,” which has prompted the field of acoustic ecology [17]. The application of sonification to acoustic ecology makes it possible for listeners to experience those aspects of the environment that extend beyond human perception. Correlating environmental information with sounds in the audible range can help listeners gain a deeper understanding of the environment [18]. In this vein, Polli’s work engages with the representation of weather and climate data at the intersection of sonification and acoustic ecology. Her projects “Atmospherics/Weather Works” [8], “N.” [19], and “Heat and the Heartbeat of the City” [20] aim to recreate visceral sensations of historical storms, the Arctic’s complex weather, and the summers in New York City based on climate data. These geosonifications model the immersive, moving, and non-repetitive qualities of natural soundscapes [21].

Finally, the Klima|Anlage installation shares similarities with the work presented in this paper in terms of its use of climate data and spatial interaction. The walk-in sound installation translates climate data into sound using four physical sound generators that represent different parameters of climate change over time. The parameters include air temperature, wind, precipitation, and solar radiance. Participants interact with the Klima|Anlage installation by choosing climate data between 1950 and 2100 from twelve regions in the world identified in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. This way, the installation provides an opportunity for the public to interact with climate data and gain a direct and affective understanding of climate change [22].

3. UNNATURAL NATURE

Following a similar approach to environmental data sonification, “Unnatural Nature” aims to highlight the global issue of climate change through a two-part sound installation. The first part consists of a sonification of four global climate data sets related to temperature change, CO₂ concentration, Arctic and Antarctic ice sheet mass, and sea level variation. The sonification is implemented for a third-order Ambisonic speaker array. The installation also consists of a full-wall visual display that shows the years counting from 1880 to 2022 (i.e., the span of the longest-running data set used in the project) and an abstract visualization that is driven by data and audio. In this part of the installation, the participants are free to explore the room-scale environment where the immersive sonification is presented. In the second part, the participants are encouraged to interact with the live plants placed in the room, influencing the future evolution of the data. These interactions are tracked through capacitive and inertial sensors placed in each plant to detect when the plants are touched or moved. Each plant is connected to a different sound source that is triggered and manipulated based on user interaction. By interacting with the plants, the participants also influence an abstract visualization which is presented through the full-wall display.

The following sections discuss the data sources, sound design and data mapping strategies, Ambisonic spatialization techniques, and the resulting sonification of global climate data presented in the first part of the installation. A binaural rendering of the sonification and its visual accompaniment can be viewed at the linked video [4].

3.1. Data Source

The following sections discuss the data sources, sound design and data mapping strategies, Ambisonic spatialization techniques, and the resulting sonification of global climate data presented in the first part of the installation. A binaural rendering of the sonification and its visual accompaniment can be viewed at the linked video [4].

The four data sets sonified in this project are gathered from NASA’s Global Climate Change database. These are related to the following variables: (1) global-land temperature change (°C) from 1880 to 2022 [23]; (2) levels of carbon dioxide in the Earth’s atmosphere (parts per million, or ppm) from 1958 to 2022 [24]; (3) sea level variation (millimeters) from 1995 to 2022 [25]; (4) combination of ice sheet mass from the Arctic and Antarctic (gigatonnes) from 2002 to 2022 [20][27]. The overall trends in these datasets are shown in Fig. 1. For each of these data sets, the annual mean was utilized without adding or removing any data points, meaning that there is only one data point per year in each data set.

3.2. Sound Sources and Data Mapping

The sonification in this project relies on the parameter-mapping technique, where data points are mapped to various parameters of a sound synthesizer or sound-generating algorithm [28]. In this case, the sonification is implemented using the multimedia programming language Max/MSP. The four data sets are mapped to the parameters of five sound engines as shown in Fig 2. All sounds are generated using a combination of sine-wave oscillators and noise sources processed through various effects, waveshapers, filters, and synthesis techniques to model different sound sources. These synthesized sources range from natural soundscape elements, such as heartbeat sounds, to abstract sonic textures that emulate the sounds of natural environments.
as wind, water drops, and birds, to more abstract elements, such as harmonic and melodic drones and percussive sounds. The aim of modeling natural sounds was to leverage auditory icons, which are sounds that convey information by mimicking real-world sounds or auditory cues [29, 30]. The procedural quality of these sounds emulates the non-repetitive and timbrally diverse characteristics of natural soundscapes. On the other hand, variables that do not have real-life visual or auditory referents, such as temperature, which we can feel but cannot physically see or hear, were mapped to abstract sounds. Nevertheless, these sounds still leverage parameter mappings based on analogic representations, wherein an increase or decrease in the data trend translates to an increase or decrease in the corresponding audio parameters [6].

3.2.1. Ice Sheet Mass

The Arctic and Antarctic ice sheet mass data are mapped to the parameters of a synthesizer that creates water-like sounds as a metaphor for melting ice. This is an example of an indirect ecological mapping, wherein the sound can be “ecologically associated with, but not directly attributable to” an environmental variable [31]. The water drops are synthesized with pink and white noise sources passed through very short amplitude envelopes and filtered through high-resonance low-pass and band-pass filters, whose center frequencies quickly sweep through a spectral range with each drop. To add variation and randomness to these drops, they are passed through a granular synthesizer that re-envelopes and re-pitches them, giving the sense of water drops of different sizes. The granulation occurs at irregular intervals to avoid rhythmic and predictable sound patterns.

The ice sheet mass is inversely mapped to the playback rate of the water drops, meaning that as the mass decreases through the years, the water drops become more frequent, suggesting an increase in the rate of melting. The data is also inversely mapped to amplitude envelope length and grain size, gradually revealing the underlying noisiness of the sound source and leading to a harsher soundscape as the ice sheet mass continues to decrease over the course of the years.

3.2.2. Sea Level Variation

The sea level variation is represented by wind sounds, offering another indirect ecological relationship by referencing flooding and hurricanes. These sounds are modeled by passing a white noise source through a low-pass filter. The sea level is mapped to the modulation speed and resonance factor of a low-pass filter applied to the noise. In this way, the increase in the sea level results in faster and more-resonant sweeps, creating the sensation of harsher and more rapid winds. Furthermore, the data also controls the intensity of a clipping effect applied to a low-frequency noise, which begins to create a rumbling sound over time. In combination, these mappings convey the metaphor of a hurricane.

The sea level data also controls another low-pass filter applied to the sonification of the ice sheet mass. Specifically, it is inversely mapped to the filter’s cut-off frequency. As the water drops become more frequent but also increasingly low-pass filtered, the resulting sound design suggests a sensation of going underwater in the final years of the sonification. This cross-mapping is intended to reflect how these data sets do not represent mutually exclusive environmental shifts and are inherently intertwined.

3.2.3. CO₂ Concentration

The CO₂ data is represented by procedurally synthesized bird and percussion sounds that are aimed at conveying the atmospheric pollution generated by excess CO₂ in the air due to human activity. The bird sounds are modeled by applying short pitch and amplitude envelopes, as well as linear frequency modulation, to a sine wave oscillator to emulate the sound of bird chirps. The modulation rate and center frequency for the birds are randomized in a predetermined range to create the illusion of different bird species singing concurrently. Over the course of the sonification, the CO₂ level gradually morphs the bird sounds by expanding their envelopes and revealing their synthetic nature. The CO₂ level is also inversely mapped to the fundamental frequency of the bird sounds and the threshold of a wave-folder applied to them, which leads to more distorted sounds that grow less evocative of birds over time. This contrasts with the common mapping of rising data to pitch increase and yields a growingly unnatural and distorted sound as the pitch of the birds decreases over time.

The percussion sound was designed to create the illusion of machinery using a combination of a low-frequency sine wave and white noise passed through a short envelope. This sound design is intended as a metaphor for industrial machines that contribute to human-made pollution. The CO₂ level is mapped to the tempo, volume, and pitch of the percussion sound. As a result, the sound becomes more frequent and more prominent as the years progress.

3.2.4. Temperature Change

The temperature change data is represented by a low-pitched drone designed using additive synthesis with notes that are procedurally selected from a predetermined scale. The use of a more ambient and abstract sound to represent this data set is intended to convey the omnipresent and intangible qualities of environmental temperature. The progression of the temperature change data controls the level of inharmonic partials in the additive synthesis. This brings about variations in the timbre of the drone and introduces dissonant qualities over time. Furthermore, the data also controls a wave-folding effect that changes the overall timbre of the drone gradually. As the data trends upward, the amplitude threshold for the wave-folding is decreased, producing additional harmonics and therefore expanding the bandwidth of the drone. This results in a noisier sound quality as the years pass. Finally, the data is exponentially mapped to the cut-off frequency of a low-pass filter that gradually opens as the temperature change increases, revealing the expanding spectrum of the drone.

Two thresholds are defined in the data to trigger harmonic changes in the drone. When the temperature change index is below 0°C, the drone randomly plays notes from a major seventh chord. When the change index reaches numbers exceeding 0°C in 1939, the notes in this scale begin to get shifted, making it increasingly dissonant along with temperature change.

3.3. Ambisonic Spatialization

Pollé’s concept of geosonification, which refers to the use of soundscapes to represent data, underlies our approach to spatialization in this project. As Pollé argues, leveraging the immersive nature of soundscapes in geosonification can transport the listener to a different environment and foster a deeper connection with the message conveyed [7]. The spatialization of our sonification is achieved using a 22-speaker third-order Ambisonic loudspeaker.
the system, which can reproduce point sources in 3D space. For the Ambisonic spatialization of our sources, we used the Ambisonics Externals designed at the Institute of Computer Music and Sound Technology at the Zurich University of the Arts [32]. The use of Ambisonics also allows us to abstract the encoding of the soundfield from the output system that it is decoded to. In this way, our spatialization can be played back through different speaker configurations, as well as headphones.

Each sound is implemented as a point source that can be moved within the soundfield in relation to data. For instance, the bird sounds move in circles around the 3D space with their movement speed mapped to the CO\textsubscript{2} concentration.

The water drops are randomly positioned on the horizontal axis to create the sense of rainfall, while their vertical position is controlled by the sea level to create the illusion of being submerged as the years pass. The movement speed of the wind sounds is also controlled by the sea level. When the sea level is low, the wind moves slowly and smoothly in a straight line; as it increases, the winds begin to move faster and more irregularly.

The percussion sound is randomly placed throughout the soundfield with each hit. As the CO\textsubscript{2} level increases the tempo at which this sound is played, the random positioning leads to a more chaotic spatialization.

The drone sound is spatialized with twelve point sources in groups of four that are spaced evenly in the horizontal axis at three different elevation values. The partials of the drone are divided into three groups of low, mid, and high frequencies and mapped to these dedicated elevation groups. This design produces the effect of the drone expanding upwards as additional partials are introduced over the course of the sonification.

4. EVALUATION

An exploratory user study was conducted to gather qualitative data about participants’ experiences while listening to the sonification. The study was carried out in the Davis Technology Studio at the University of Michigan’s School of Music, Theatre & Dance. This is an audio research facility equipped with a 22-speaker Ambisonic loudspeaker array and a full-wall projection system.

4.1. Aim

The study aimed to explore the effectiveness of the sonification in conveying trends in the data, providing participants with further insight into climate change, and evoking emotional responses. The results of this study can contribute to the development of future sonification projects aimed at communicating complex climate data sets to a general audience.

4.2. Participants

A total of 24 participants between the ages of 18 and 45 took part in the study. Participants were recruited via email. Thirteen of the participants were undergraduate and graduate music students whose majors ranged from classical music and jazz performance to composition and music technology. The remaining eleven participants came from a diverse range of backgrounds, including visual arts, ecology, biology, public health, physics, and anthropology. The participants observed the installation in two groups of twelve.

4.3. Procedure

The study involved two sections, where the participants listened to a 5-minute version of the spatial sonification and viewed the year count on a full-wall display once in each section. The sonification was presented through a third-order Ambisonic speaker array. Before the first listening, it was explained to the participants that they would hear a sonification of climate data without being provided further detail about the data sets or the sonification itself. At the end of this section, they were asked to fill out a survey that included the questions seen in Table 1(a). Before the second listening, it was explained to the participants that the sonification was based on four global data sets pertaining to temperature change, CO\textsubscript{2} concentration, ice sheet mass, and sea level variation. It was also explained that these data sets were mapped to various parameters of five different sound sources. They then listened to the sonification again and filled out a second survey, which included the questions shown in Table 1(b).

4.4. Results and Discussion

To facilitate the analysis and discussion of the qualitative data acquired from the study, we identified four main themes based on the technical and conceptual implementation of the sonification. These themes are auditory qualities, data mapping and trends, spatialization, and emotional engagement.
4.4.1. Auditory Qualities

This theme focuses on the participants’ perception of sound sources, how these sounds evolved over time, and which of these were the most prominent. When asked about the sounds they heard in Question 1.3, the participants identified both natural and synthetic sounds as shown in Fig. 3(a). The most frequently used descriptor was “birds” followed by “water,” “wind,” “synthesizer,” and “percussion,” indicating that most participants picked up on the associations we intended to evoke with auditory icons. Besides the sources identified here, some participants used descriptors like viscous liquids, train-like noises, bells, alarms, human footsteps, and combustion engines. While some of these reflect the subjective nature of auditory recognition, we observed a general overlap between the participant’s interpretation of the sound sources.

The participants generally described the evolution of these sounds over the course of the sonification as starting with natural and calming qualities that gradually become more “chaotic” and “ominous,” accompanied by an increase in tempo and the introduction of “dissonance” and “jarring sounds.” As one participant pointed out:

The sounds in the beginning were far more nature-based and light-sounding; birds and ambient sounds with a gentle effect. As the years went by, the sounds got darker and sharper, more of a mechanical influence; cars, machine-like deep basses. Nature was still present in water, bird sounds, but they were drowned out/suffocated by everything else.

Other participants similarly described that the natural sounds in the beginning were eventually overpowered by more mechanical and industrial sounds. A shift towards a feeling of anxiety and being flooded or drowned was also a common theme. One participant noted:

Increasingly dreadful, ominous, frightening. It went from peaceful to awful very quickly. It was almost like a warning bell/alarm. One could only predict if it continued on it would just be eventual silence.

In their comparison of the prominence of the sounds they identified, the participants listed the sources shown in Fig 3(b). While these results indicate a preference towards the bird sounds, it also shows that different listeners may focus on different auditory elements in a given sonification and prioritize the semantic qualities of a sound over its perceptual properties and vice versa.

In the second section of the study, the responses revealed that providing additional detail about a sonification can influence a participant’s interpretation of it. While two thirds of the participants reported that this information helped them parse the sounds more easily, ten participants reported that knowing the context allowed them to pick up on new details in the sound. Although we recognize some of these responses could be rooted in the fact that the participants were listening to the same sonification a second time, these could also suggest that offering contextual information about a sonification can provide the listeners with a framework for their experience and facilitate a deeper understanding of the data.
The second theme in our analysis aims to understand the participants’ interpretation of the mapping between the data and the sounds. In relation to their interpretation of data trends, Fig. 4(a) shows that 17 out of 24 participants perceived an increase from beginning to end, whereas 6 reported that there were no substantial changes at the beginning followed by an increase towards the end, suggesting that the sonification was able to convey the data trends to the most part. Furthermore, when asked to rate the effectiveness of the sonification in representing these data trends on a Likert scale from 1 to 5, most participants rated it relatively high as seen in Fig. 4. Regarding the role of additional information in recognizing the data trends, one participant stated that, while the information made the structure of the piece more apparent, it wasn’t needed to realize the trends that the sonification alluded to.

The participants’ interpretation of the mappings between the data sets and the sound sources shows diverse viewpoints. Outside of the three participants who expressed uncertainty about the data mappings, eight participants described the data sets as being mapped to auditory properties such as pitch, amplitude, and speed, whereas thirteen identified semantic associations between the data and the sound sources that they recognized. For instance, the sea level data was described as being mapped to water sounds (4), waves/whooshing (3), bass synth (2), storm textures (1), and the sea level data was described as being mapped to water sounds (4), waves/whooshing (3), bass synth (2), storm textures (1), and loudness (1). The CO₂ concentration data was characterized as being mapped to bird sounds (7), wind sounds (2), alarm/ringing (1), detuning (1), and loudness (1). The temperature change data was interpreted as being mapped to a drum rattle (1), ethereal ringing (1), bass synth (1), siren-like sounds (1), pitch (1), and distortion (1). Finally, the ice sheet mass was associated with water drops (4), percussion (2), birds deforming (1), and rhythm (1). Overall, while there were notable differences in the participants’ interpretation of the data mappings, there were also some shared perceptions.

### 4.4.3. Spatialization

The analysis of this theme focuses on the responses to Questions 1.6 and 2.4. The results indicate that the use of spatialization in this project had an impact on the participants’ overall perception of and engagement with the sonification. One participant described:

> I felt surrounded by it, encompassed by the noise.

The placement and movement of sounds around the listeners contributed to a sense of immersion and intensity for some, while others found these overwhelming or oppressive. One participant highlighted that the spatialization made the sonification feel more "global and natural." Despite differences in interpretation, the spatial aspects of the sonification were generally perceived as an important feature that made the participants more attentive to the data and offered a more embodied experience with one participant describing it as being “very effective for a piece about climate change.”

The additional information provided in the second section of the study appeared to have a mixed impact on participants’ understanding and experience of the spatialization. While ten participants reported being more perceptive of the movement and placement of the sounds in space after they received additional information, twelve reported not noticing a significant change in the second listen.

### 4.4.4. Emotional Engagement

The results of the study indicate that the sonification had an impact on the participants’ emotional state. The progression of the piece, the changes in sound and tempo, and the immersive nature of the composition all appear to have contributed to their emotional response. The majority of the participants reported experiencing a range of emotions throughout the piece, starting from a more calm and peaceful state and then gradually transitioning to feelings of anxiety, stress, and even panic. One participant wrote:

> It was chaotic, increasingly stressful and ominous, panic inducing. I think there should be a content warning before showing because it really exacerbated my climate change-induced anxiety. Scary!

Several participants described feeling a sense of impending doom or worry as the sonification approached the present day. Others noted changes in tempo, rhythm, and sound that contributed to feelings of agitation, discomfort, and unease. The progression of the piece was also seen as evoking nostalgia and sadness for some. Interestingly, many participants described a sense of immersion or being enveloped by the sounds, which appeared to contribute to a feeling of introspection and reflection.

As one participant pointed out:

> It made me realize how much our world has changed in just over 100 years, and I am scared as to how much the piece would change and deteriorate if the piece spanned for the next 100 years.

The results of the second survey indicate that having additional information about the sonification did not have a consistent impact on emotional engagement. Ten participants expressed having a stronger emotional reaction in the second listen, whereas eleven participants reported feeling similar emotions as they did during the first listen. Four of these eleven mentioned that they noticed new sounds or thought more deeply about the data sets, but that these did not evoke a different emotional response. The remaining three participants mentioned that knowing the science behind the sonification “gave reasoning,” “reduced anxiety,” and “provided clarity and lessened their panic.”
An interesting takeaway from the study was how people’s experience of the sonification compares to their understanding of climate change. For some, the sonification seems to have reinforced their existing beliefs and knowledge while, for others, it has provided a new way to understand and interpret the data. Some noted that the emotional weight of the piece felt fitting for the seriousness of the issue, while others felt that it could have been more shocking to match the severity of the matter implied in the data.

Some participants felt that the embodied response they had to the sonification was stronger than what they typically felt when presented with the data alone. Others appreciated the more holistic and arts-based approach to disseminating climate change research and thought it could be an effective tool to generate awareness and inspire action. However, there were also some participants who didn’t feel like they gained any additional insight into the issue from the sonification or were already aware and concerned about the climate crisis. One participant wrote:

It aligns pretty closely to what I understand the general consequences and ramifications of climate change to be. I don’t know the specific data, but the general feeling that the piece evokes matches what I would expect/understand.

5. CONCLUSION

The spatial sonification of climate data presented in this paper demonstrates a novel way to communicate complex climate information through sound. The sonification relied on the use of synthesized sounds to establish parameterized auditory icons that evoke ecological metaphors and abstract elements that leverage the affective affordances of musical features such as harmony, dissonance, and rhythm. An Ambisonic spatialization of the sonification was aimed at enhancing immersion and situating the listeners in a soundscape that evolves with data. A user evaluation of the project showed that the sonification was effective in conveying the trends in climate data and urgency of the matter implied by these trends. The spatialization was generally reported to contribute to the participant’s attentiveness to the sonification. The results also indicate a notable level of emotional engagement with the sonification. While the extent of this engagement varied among the participants, they generally indicated that the sonification confirmed and extended their understanding of the data presented to them. These results suggest that the use of ecological auditory and spatial metaphors that the listeners can relate to climate events could enhance their interpretation of climate data and further their awareness of environmental issues.

6. REFERENCES


