ATMOSPHERICS/WEATHER WORKS: A MULTI-CHANNEL STORM SONIFICATION PROJECT

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ABSTRACT

Atmospherics/Weather Works is an interdisciplinary project in the sonification of storms and other meteorological events generated directly from data produced by a highly detailed and physically accurate model of weather systems used for research and forecasting. This paper discusses the background, conception, and execution of a series of sonifications of a historical hurricane and winter snowstorm that resulted in several performances, stereo recordings, a public multi-channel spatialized sound installation, and an online interactive sound listening environment.

1. INTRODUCTION

I have been creating art works involving the translation of digital information to sound for over ten years. In 1991 and 1992, I used the Lorenz Attractor and other chaotic attractors to create algorithmic compositions modeling chaos. The motivation for creating these compositions grew out of the desire to see if the same algorithms that created naturalistic images, pleasing to the eye, could create musical compositions pleasing to the ear. These first generative compositions, although full of repetition and variation, lacked the spontaneity of musical composition.

Thinking that a live performer responding to the sounds of the attractor and the computer responding in turn in real time could form an interesting improvisation, I developed a system for live improvisation based on the generation of the Lorenz Attractor called *Chaotic Systems in Musical Composition*. Based on the idea of call and response in jazz improvisation, *Chaotic Systems in Musical Composition* would echo groups of notes played by the live perormer with slight variation in time using the attractor algorithm to determine when to play back and the amount of variation to apply.

What was unexpected and especially interesting about *Chaotic Systems in Musical Composition* was that the live performer was able to anticipate and manipulate the reactions of the system. I believe that this predictability was possible in part because the Lorenz Attractor was used. The attractor established a waxing and waning pattern that a live musician could anticipate and respond to. Improvising with the resulting system felt very much like a free improvisation with another human musician.

Then in 1994, I started to develop a series of systems for live improvisational sound performances using eye tracking video analysis systems. The project, called *Intuitive Ocusonics*, has been presented throughout the US and Europe [1]. The project has been essential to my research in interactive computer systems and in developing systems for data sonification to illustrate complex information. Both the *Chaotic Systems* and *Intuitive Ocusonics* improvisations depended on feedback, one of the key components in a complex system.

1.1. Why Sonify Meteorological Data?

The Lorenz Attractor, named for meteorologist Edward Lorenz from MIT who discovered the attractor in the 1960's while looking for a way to model a gaseous system, illustrates the phenomenon of sensitive dependence on initial conditions. Sensitive dependence on initial conditions, known as the 'butterfly effect', is also a key component of some complex systems like the weather. Meteorologists involved in forecasting are acutely aware of this phenomenon and the difficulties it presents to the task of making an accurate forecast. Although weather models have become more and more detailed over the years and therefore more accurate, weather forecasting is still an imprecise science, one that often depends on the intuition of the forecasting meteorologist. In addition, weather models tell very little about how the weather feels to a person experiencing it, precisely the information the public wants to know.

There are a variety of visualization tools to interpret data from meteorological models, but most of the data does not describe visual information (temperature and atmospheric pressure aren't visible in the environment, for example). Variables in a model are most often mapped to colors and symbols placed over a 2-dimensional map of the relevant geographic area. Often the difference between variables at various elevations is essential information, used most dramatically in forecasting storms. Although 3-dimensional visualizations are sometimes used, they are less common than the 2-dimensional variety. Translating meteorological data to sound could emphasize aspects of the data not apparent in visualizations, allowing meteorologists to detect new patterns and structures, particularly those that unfold over time.

Unlike a still visual image, music and soundscapes are inherently narrative. For example, as I listen to footsteps and voices outside my apartment door, I can determine that two people are walking up the stairs of my apartment building. I can determine approximately what floor they are on and even gather a little information about their relationship (are they a arguing or laughing?) In a visual image, emotional content can be ambiguous. Looking at a photograph of a family for example, I am likely to encounter a certain amount of ambiguity in determining the relationships between the subjects unless the facial and body expressions of the subjects are highly exaggerated.

Can an enhanced narrative and emotional content enhance the understanding of meteorological data? Some meteorologists call themselves 'storm hunters'. They travel far and wide at considerable physical risk in order to experience a hurricane or tornado. Do they take such risks because the physical and emotional exhilaration enhances the scientist's understanding of the storm? The storm hunters would most certainly answer in the affirmative. They experience the sound, scale, and physical properties of the storm as well as its direct effect on the environment. A storm experienced only through visualization, whether animated or still, does not convey this experiential information. Scientists must use their memory and their imagination to understand how a storm might feel to people in it.

Sonifying atmospheric data can also be done for aesthetic reasons. The organized complexity of a hurricane potentially offers rich combinations of patterns and shapes that, when translated into sound, create exciting compositions. Through the development of sonification mappings for atmospheric data, I am interested in the artistic creation of new languages of data interpretation. As individuals and groups are faced with the interpretation of more and more large data sets, a language or series of languages for communicating this mass of data needs to evolve. Through an effective sonification, data interpreted as sound can communicate emotional content or feeling, and I believe an emotional connection with data could serve as a memory aid and increase the human understanding of the forces at work behind the data.

1.2. Project Background

In 2001, I became interested in complexity in weather models and started working on the sonification of meteorological data in collaboration with meteorological scientist Dr. Glenn Van Knowe. Dr. Van Knowe is a senior research scientist at MESO, Mesoscale Environmental Simulations and Operations <http://www.meso.com> a leading firm in the development and application of atmospheric and other geophysical models for research and real-time applications. MESO works with the Mesoscale Atmospheric Simulation System (MASS) to create a highly detailed simulation of the weather based on terrain, initial conditions, and other factors. Through the *Atmospherics/Weather Works* project, we wanted to discover what could happen if the information was translated into sound.

The *Atmospherics/Weather Works* storm sonification project had three primary goals: the development of a software system for the creation of sonifications based on storm data to be used in performances and installations, live and recorded musical performances, and a web site for the presentation and distribution of the recordings with an interactive interface for listening to the sonifications <http://www.andreapolli.com/studio/atmospherics>.

couple? a mother and child? have they been recently
The first public installation of the project was at Engine 27 <http://www.engine27.org>, a non-profit organization devoted to the research, creation and dissemination of multi-channel sound works in New York City. A 16-channel sound installation spatially re-created two historic storms that devastated the New York/Long Island area first through data, then through sound. The resulting turbulent and evocative compositions allowed listeners to experience geographically scaled events on a human scale and gain a deeper understanding of some of the more unpredictable complex rhythms and melodies of nature.

1.3. Historical Background

In the sciences, our work is a part of a growing movement in data sonification research. In 1997, a Sonification Report was prepared for the National Science Foundation by members of the International Community for Auditory Display (ICAD).[2] This report provided an overview of the current status of sonification research and a proposed research agenda. Most significantly to us as collaborators, the report stressed the need for interdisciplinary research and interaction. Our project is well-suited to sonification according to the findings of ICAD. The data sets produced by MASS are extremely large and complex, and although there are a variety of visualization tools in use to interpret the data, much of the data represented is not visual in nature (temperature and atmospheric pressure for example). The data represented often portrays complex changes over time, an aspect of data particularly suited for sonification.

In the arts, the direct creation of music from natural processes has a long history. There are a number of bells and harps in world cultures whose compositions have been created by the wind. The sounds of aeolian harps and wind chimes depend on the direction and amount of wind in the natural environment. Hindu bells called Gunte can be found on top of many temple roofs of many villages in India and Tibet. In Bali, there is the pinchakan, a bamboo rattle operated by the wind, and the tradition of placing bamboo tubes along irrigation channels of terraced rice paddies so they tip over when full and create percussive sounds, each tube tuned to a different pitch of a scale. This particular tradition also had a practical purpose and could perhaps be called one the of first sonification applications for natural systems, since the sound allowed farmers to immediately locate a blocked irrigation channel by noticing an absent pitch in the scale. [3]

The idea of ‘music of the spheres’, or music created through the movements of the heavenly bodies representing the harmony of the universe dates back to Pythagoras, and Johannes Kepler created a music of the spheres in 1619 by transposing the known planetary orbits into new melodies. In more modern times, the invention of the computing machine has inspired many artists to experiment with musical composition using electronic and algorithmic processes. In 1874, communications expert Elisha Gray invented a musical telegraph that produced music by transforming electricity into sound based on Morse code letter representations during telegraph communications. In the mid to late 20th century, many composers worked with chance compositions and automated processes. [4].

In 1971, Charles Dodge produced Earth's Magnetic Field, one of the first examples of representing complex data values in sounds. In this composition, the sounds correspond to the magnetic activity for the Earth in the year 1961. [5] More recently, in the tradition of Elisha Gray's musical telegraph, Ben Rubin and Mark Hansen created a sonic installation called The Listening Post that monitors and sonifies thousands of online exchanges in real time to reveal patterns and rhythms of people on the internet.

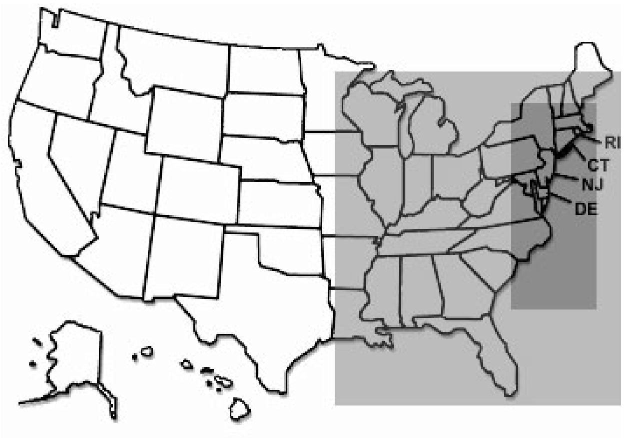

Figure 1. *The storms were modeled in low resolution for a large geographical area shown here as the light grey box, and in higher resolution (10km) in the area of the darker grey box.*

2. PRODUCING THE PROJECT

The project began when I met Dr. Van Knowe in the summer of 2001 at the first meeting of Bridges, an International Consortium on Collaboration in Art and Technology, a joint project of The USC Annenberg Center for Communication & The Banff Centre for the Arts New Media Institute. Dr Van Knowe had joined MESO as a Senior Research Scientist after 24 years as a meteorologist for the Air Force. He was Chief of Meteorology at Rome Lab in New York where he directed the meteorological aspects of all research and was chief of the modeling and simulation development branch for the Air Force's Combat Climatology Center (AFCCC) at Scott AFB, IL.

Dr. Van Knowe and I brainstormed at that meeting and then continued to communicate via email and telephone to develop a project plan. After developing a proposal and being invited to participate in one of the first spatialized sound production residencies at Engine 27 to create a storm sonification, we met at MESO to plan the project. We wanted to create a spatial sonification of one or more storms that occurred in the New York area in the recent past in the hopes that some members of the audience would remember the specific storms.

Dr. Van Knowe and Dr. John Zack of MESO suggested we try to create a sonification of a major winter snowstorm that in 1979 was not foreseen by the existing meteorological models and inspired years of research and development into improving the models. The "President's Day Snowstorm" initially formed as a weak wave of surface low pressure on a front in the Gulf of Mexico on 18 February 1979. Since this

storm was not predicted by the existing meteorological models of the time, a large amount of data on this storm was available.

Later, Dr Van Knowe found a strong tropical Hurricane (Hurricane Bob) that passed though the same coastal region, and we decided to attempt to sonify two storms that have a very different physical structure. One of our goals was to find out if the sonifications would yield insight into the nature of these two different types of storms.

2.1. Modeling the Storms for Spatialized Sound

Since the Engine 27 space has a very specific and unusual 16-channel speaker arrangement, we decided to map each speaker to a specific point in space proportional to the area spanning from Northern Florida to Northern New York State and from the Eastern tip of Massachusetts, to Western New Jersey with New York City situated near the center. Simulated point data was to be modeled for an area of approximately 1000km. This area was mapped to the size and shape of the Engine 27 space.

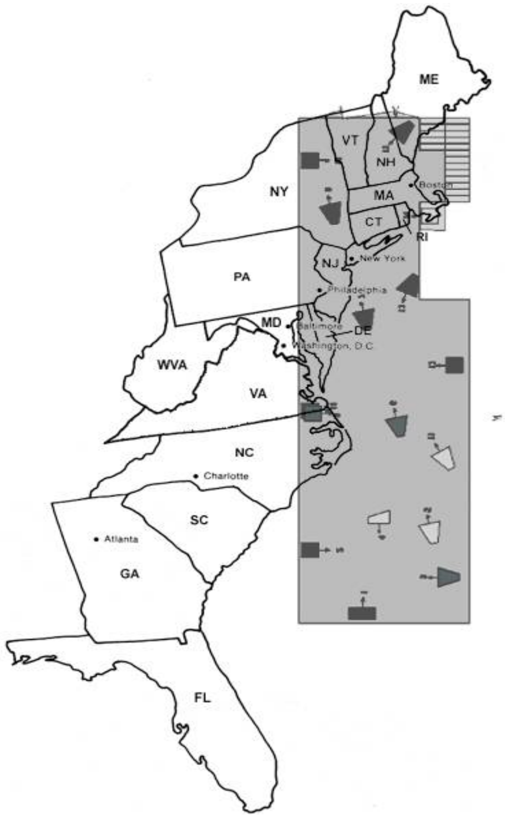

Figure 2. *Sketch showing the approximate geographical location of each of the model's data points. The Engine27 floor plan is superimposed over a map of the US East Coastal region hardest hit by the two storms. Each relative speaker location was mapped to a geographic point.*

The kind of model output required for sonification was very different that the output formats already in use by MESO for visualization. Dr. Van Knowe and his colleagues use the Mesoscale Atmospheric Simulation System (MASS) to create
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a highly detailed simulation of the weather based on terrain, initial conditions, and other factors. MASS takes real data inputs from satellite or surface readings and couples the information with global and regional models. There are several MASS output file formats used for 3D, 2D and 1D graphical visualizations, most providing a temporal snapshot of the state of the weather system. Our project required files of individual variables output for each geographical point at regular temporal intervals. Dr. Van Knowe and Dr. Kenneth Waight of MESO created a custom piece of software to output the data in this format.

Dr. Van Knowe then created a complete model of each storm at 5 points of elevation: sea level, approximately 8500 feet, approximately 18,000 feet, approximately 35,000 feet, and approximately 60,000 feet (or, the top of the atmosphere). Each variable was output every three minutes for a 24 hour period of the greatest storm activity. The model grid resolution was 10km. Nine variables were modeled at this stage, but only six variables were used in the final sound compositions: atmospheric pressure, water vapor, relative humidity, dew point, temperature, and total wind speed.

2.2. Creating the Sonifications

After the storms were modeled and the data output, we were left with 720 data files of 481 values each and the daunting task of translating these numbers into sound. Engine 27 master programmer Matthew Ostrowski joined us at this stage and he and I worked for a period of about four weeks creating a system for reading and translating the files to spatialized sound using Max/MSP.

We decided to create a composition of each day's storm activity in full at each of the five elevations. We started by simply and directly mapping each variable to the pitch of a sound sample of a distinct timbre, using long tones for temperature and pressure related variables and percussive tones for water related variables. The bank of sound samples used included vocal sounds, sounds created by wind instruments, and environmental sounds including the sounds created by various insects.

We then decided to map the total wind speed to the amplitude of the sound. Directly mapping loudness to wind speed for every speaker (every geographic point) created a dramatic spatialization effect. The fastest wind speeds, representing the greatest storm activity, created the most sonic activity and excitement. Then we translated the atmospheric pressure data to a very low frequency sound. In doing so, listeners lost the ability to hear a detailed melody line describing the pressure changes, but gained a visceral sense of the storm.

Then, we began experimenting with using some of the variables as filter variables for sound samples representing other variables. Some of the variables in the model were highly coupled or inversely related to other variables. We created a band-pass filter that filtered a sound representing temperature with dew point values and filtered water vapor with relative humidity values. We found at this point that we needed to choose sounds with a wide spectrum in order to hear the filtering most effectively. White noise has the widest spectrum, and selecting 'noisy' sound samples proved the most effective in communicating the data and also was the most effective aesthetically due to the variation in the resulting sounds.

The scaling of the data for sound presented particular challenges. Although the overall wind speeds varied with elevation levels, we decided to use global scaling for wind speed. This created the effect of the compositions building and receding in intensity. However, using global scaling for variables such as temperature mapped to pitch or water vapor mapped to a band pass filter proved to be much less dramatic that creating a scaling system for each elevation level of each storm since the variables differed widely between levels.

Finally, since the sonifications were to be performed in the format of a spatialized sound installation, we developed a daily schedule in which various compositions present the data sets at the five elevations, moving from ground level to the top of the atmosphere. In the installation, each storm was performed for approximately 1/2 hour six times each day. A storm consisted of six approximately five minute compositions presenting all variables at a single elevation and one combination of elevations based on the heights of the speakers. These compositions were marked by a number of ringing bell sounds, marking time and elevation like the ringing of church bells.

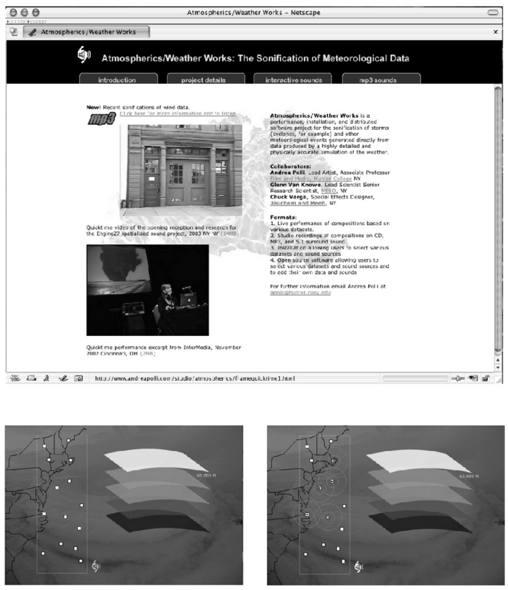

Figure 3. *Screenshots of main Atmospherics/Weather Works web site and interactive interface for listening to the sonifications. http://www.andreapolli.com/studio/atmospherics*

3. CONCLUSIONS

The final compositions were well received by both the general and the scientific audiences. Regardless of their background, many visitors to the installation particularly enjoyed remembering where they were during Hurricane Bob and the President's Day snowstorm while listening to the sonifications.

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Some audience members found a metaphorical meaning in the series of rising elevations, finding the compositions nearer to the ground to be more visceral while those compositions representing activity closer to the top of the atmosphere were felt to be more ethereal and spiritual.

Dr. Van Knowe and other meteorologists who heard the work were particularly interested in the spatialization of the sound and how the wave patterns of the storms were moving in space. The sonifications reinforced some known aspects of the particular storms. The winter storm was more intense near the top of the atmosphere while the hurricane's fastest wind speeds occurred at lower elevations. This change in intensity was communicated very clearly through the varying degrees of loudness of the compositions. The patterns of movement of the tropical hurricane were known to be more chaotic than the winter storm, and the resulting compositions also reinforced this concept.

Most listeners from all backgrounds found that they could understand more as they listened to the compositions for a longer amount of time. The scientific audience was particularly interested in the potential for sonification applications in weather prediction and study, and I am currently continuing work with meteorological scientists along those lines. Many members of the general audience felt that since it was a seamless and successful art and science collaboration shown at an art venue, it could serve as inspiration for more work in the area of the sonification of scientific data and other kinds of creative data interpretation.

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