Modelling storms in sound: the Atmospherics/Weather Works project

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Atmospherics/Weather Works **is an interdisciplinary project in the sonification of storms and other meteorological events generated directly from atmospheric data produced by a highly detailed and physically accurate simulation of weather systems. This paper discusses the background, conception and execution of the first stage of the project that has resulted in several performances, stereo recordings, a multi-channel spatialised sound installation, and an interactive sound environment.**

1. INTRODUCTION

I have been creating art works that involve the translation of data to sound for over ten years. In 1991 and 1992, I used the Lorenz Attractor and other chaotic attractors to create algorithmic compositions modelling chaos. The motivation for creating these compositions grew out of the desire to see if the same formulae 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. This project was called *Chaotic Systems in Musical Composition*.

In the first trials of *Chaotic Systems in Musical Composition*, an initial value was input by a performer playing a MIDI instrument and the system generated an attractor composition based on the input value. This constant generation and regeneration of the attractor was exciting sounding, but forced the human improviser to conform to a rigid style. In later experiments, the attractor was used to generate a series of coordinates that were used on a macroscopic scale as time and duration values. That is, the program captured chunks of numerical data in the form of midi information in real time based on the notes played by a musician. The size of the 'chunks' and when they were captured was determined by the Lorenz Attractor. Then, based on the idea of call and response in jazz improvisation, the system would play back the captured chunks 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 the system in performance 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.

From 1994 to today, I have been developing systems for live improvisational sound performances using eye tracking video analysis systems. The project is called *Intuitive Ocusonics* and I have performed this work throughout the US and Europe (Polli 1999). The project has been essential to my research modelling human methods of improvisation in interactive computer systems and in developing systems for data sonification to illustrate complex information. Both the *Chaotic Systems* and *Intuitive Ocusonics* improvisations (and, in fact, any musical improvisation) depended on feedback, one of the key components in a complex system.

The Lorenz Attractor is named for Edward Lorenz, a meteorologist from MIT who discovered the attractor in the 1960s while looking for a way to model a gaseous system. The Lorenz Attractor illustrates the phenomenon of sensitive dependence on initial conditions and Lorenz coined the term the 'butterfly effect' to describe this phenomenon. 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

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factors. The atmospheric data sets produced by MESO are extremely detailed, and although they have a variety of visualisation tools to interpret the data, much of the data does not describe a phenomenon (temperature and atmospheric pressure, for example). Through the *Atmospherics/Weather Works* project, we wanted to discover what could happen if the information was translated into sound.

The *Atmospherics/Weather Works* project has three primary goals: the development of a software system for the creation of sonifications based on meteorological and other data to be used in performances and installations, live and recorded musical performances, and a website for the presentation and distribution of the recordings with an interactive interface for the sonifications (http://www.andreapolli.com/studio/atmospherics).

2. HISTORICAL BACKGROUND

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. In Japan, stringed instruments called Unari are played by wind currents, and the Besisi-people on the Malay-peninsula use wind to play long bamboos lashed vertically to the tops of trees. In Bali a bamboo organ played by the wind is called Sunari and is still used by Hindu people for religious music together with sounding bamboo-propellers in the Panegtegan or Ngalinggihang ceremony for the blessing of rice. Also 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 the 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 (Cope 2003). In China, very light whistles have been attached to the tails of young pigeons soon after birth with a fine copper wire so that, when the birds fly, the wind blowing through the whistles produces an open air concert. (Shixiang 1999: 42–3)

The idea of 'music of the spheres', or music created through the movements of the heavenly bodies to represent the harmony of the universe, dates back to Pythagoras, and in 1619 Johannes Kepler attempted to find a musically harmonious relation between the distances of the planets from the sun by associating the angular velocity of each planet's known orbit with a musical interval, creating what he called the 'Music of the Spheres'. In more modern times, the invention of the computer 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 (Cope 2003). In the twentieth century, many composers worked with chance compositions and automated processes. Here are a few examples of far too many to list in full: John Cage, Steve Reich, Pauline Oliveros, George Lewis, Gordon Mumma, Iannis Xenakis, Laurie Spiegel, and Curtis Roads.

In 1971, Charles Dodge produced *Earth's Magnetic Field*, one of the first examples of representing complex data values in sound. In this composition, the sounds correspond to the magnetic activity for the Earth in the year 1961 (Dodge 1998). More recently, in the tradition of Elisha Gray's musical telegraph, Ben Rubin and Mark Hansen created a sonic installation that monitors and sonifies thousands of online exchanges in real time to reveal patterns and rhythms of people on the internet called *The Listening Post* (http://www.earstudio.com/projects/ listeningPost.html).

In the sciences, our work in the sonification of meteorological data is a part of a growing movement in data sonification research. In 1997, a Sonification Report was prepared for the National Science Foundation by the International Community for Auditory Display (Kramer 1997). This report provided an overview of the current status of sonification research and a proposed research agenda. Most significantly, the report stressed the need for interdisciplinary research and interaction.

The data sets produced by MESO are extremely large and complex, and although there are a variety of visualisation 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 also often portrays complex changes over time, an aspect of data particularly suited for sonification.

One of my personal interests in working with complex data is in the artistic creation of new languages for data interpretation. As individuals and groups are faced with the task of interpreting more and more information, a language or series of languages for communicating information in this mass of data needs to evolve. Through an effective sonification, data interpreted as sound has the potential to communicate emotional content or feeling, and I believe an emotional connection with data can increase the human understanding of the forces at work behind the data, encourages cross-cultural communication, and can serve as an aid to memory.

The first public installation of our collaboration was in April 2003 at Engine 27 (http://www.engine27.org), an organisation devoted to the research, creation and dissemination of multi-channel sound works in New York City. A sixteen-channel sound installation spatially recreates 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.

3. PLANNING THE PROJECT

The *Atmospherics/Weather Works* project began when I met Dr Van Knowe in 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 (http://www.annenberg.edu/bridges/). Dr Van Knowe had joined MESO as a Senior Research Scientist after twenty-four 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 modelling and simulation development branch for the Air Force's Combat Climatology Center (AFCCC) at Scott Air Force Base in Illinois. Dr Van Knowe and I brainstormed at that meeting and then continued to communicate to develop a project plan. After developing a proposal and being invited to participate in one of the first spatialised sound production residencies at Engine 27, 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 City 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, it became a test case for the development of new models. Therefore, a large amount of data on this storm has been generated using updated meteorological models.

Later, Dr Van Knowe found a strong tropical Hurricane that also passed though New York City. Hurricane Bob developed as a tropical depression in the central Bahamas on 16 August 1991, then steadily intensified while drifting north-northwestward. The impact of hurricane Bob was felt through the Northeast coastal areas. Those most significantly impacted were the immediate coastal communities of Rhode Island and southeastern Massachusetts. The remainder of the region experienced sustained tropical storm-force winds between 80–130 kilometres per hour, with many areas east of the Connecticut River receiving gusts that reached hurricane force. We decided to sonify these two storms which have a very different physical structure to see if the sonifications would yield insight into the nature of these two different types of storms.

4. MODELING THE STORMS FOR SPATIALISED SOUND

Deciding how the data from the storm model should be output for sonification was one of the most difficult and important aspects of our project. The format of model output for visualisation applications, particularly output designed to create still images, is not appropriate for a sonification application that aims to describe change over time. Even animated visualisations depend on data formatted to be output as a sequence of still images. We decided early on that our project would require separate streams of geographically specific individual data variables over time. Since the Engine 27 space has a very specific and unusual sixteen-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 centre of the map (see figure). Simulated point data were to be modelled for an area of approximately 1,000 km. This area was mapped to the size and shape of the Engine 27 space.

The Mesoscale Atmospheric Simulation System (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 visualisations: 3D 'diag files' in the form of a 3D array, 2D horizontal 'plot' files, 2D vertical cross-sections, 1D simulated point observations, and 1D vertical profile simulated point atmospheric soundings.

Since our project required a custom file output format, Dr Van Knowe and Dr Kenneth Waight of MESO created a custom piece of software to output the data for sonification. Kenneth T. Waight joined MESO in October 1987 after completing his Ph.D. in atmospheric science at the University of Wyoming. His first three years at MESO were spent on a project funded by the NASA Marshall Space Flight Center. Dr. Waight relocated to MESO's Troy, New York

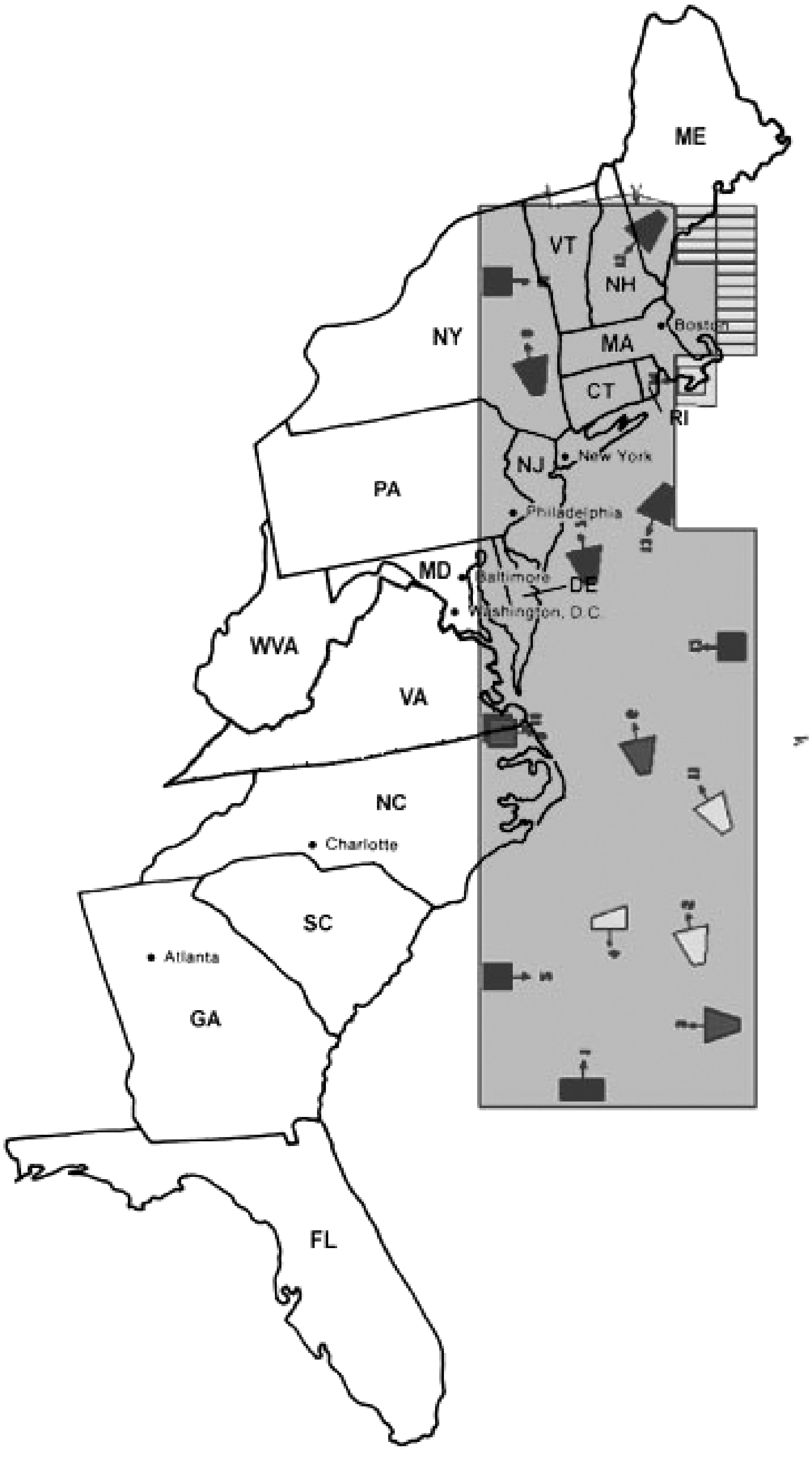

Figure 1. The Engine 27 floor plan is superimposed over a map of the East Coast, indicating generally how each speaker in the gallery corresponded to a specific area in geographic space.

office in 1990 to assist in the development of MESO's real-time operational mesoscale modelling system. Dr Van Knowe then created a complete model of each storm at five points of elevation: sea level, approximately 8,500 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 twenty-four hour period of the greatest storm activity. The model grid resolution was 10 km. Nine variables were modelled at this stage, but only six variables were used in the final sound compositions: atmospheric pressure, water vapour, relative humidity, dew point, temperature, and total wind speed.

5. CREATING THE SONIFICATIONS

After the storms were modelled 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 at the Engine 27 space for four weeks creating a system for reading and translating the files to spatialised sound using Opcode's Max/MSP.

We decided to create a five-minute 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. We somewhat arbitrarily used 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. The resulting sound compositions were interesting, but listeners found it difficult to hear the changes in each individual variable.

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 spatialisation effect. The fastest wind speeds, representing the greatest storm activity, created the most sonic activity and excitement. At this point, the combination of timbres was still overwhelming to the listener, limiting the listener's ability to make sense of the data. Had we been creating the sonifications for scientific research only, at this stage we might have brought Dr Van Knowe and his colleagues into the space to listen to and compare and contrast sound compositions created by single variables. However, we had a deadline for a public presentation of the work to a general audience and aesthetically we felt that the single variable compositions only lacked the fullness necessary to engage a general audience expecting to hear something musical.

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. For example, water vapour and relative humidity are directly proportional to each other; when water vapour increases, so does relative humidity. To exploit this relationship, we used the amount of water vapour to determine the pitch of the sound and the amount of relative humidity to define the frequency range of a band pass filter of the sound. With this change, we found 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 dramatic 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 vapour mapped to a band pass filter, proved to be much less dramatic than creating a scaling system for each elevation level of each storm, since the variables differed widely between levels. In other words, between elevation levels the values of variables could be very different, but within each elevation level might vary only a small amount. For example, the temperature at the top of the atmosphere could be extremely low, while at the same time at sea level the temperature was temperate. A global scaling of the temperature variable that encompassed all the possible temperatures on every level would create only a very small change in the sound on each level in that case. The small change in the sound was difficult to discern, so we created local scaling values for the temperature values on each level instead.

Finally, since the sonifications were to be performed in the format of a spatialised 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, a storm consisted of six compositions presenting all variables at a single elevation. Since the speakers in the space were themselves mounted at different heights, we also created one combination of elevations based on the heights of the speakers. Each storm was performed for approximately half an hour six times each day. These compositions were marked by a number of ringing bell sounds, marking time and elevation like the ringing of church bells.

6. CONCLUSION

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. 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 spatialisation 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 these 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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