RESEARCH SET TO MUSIC: THE CLIMATE SYMPHONY AND OTHER SONIFICATIONS OF ICE CORE, RADAR, DNA, SEISMIC AND SOLAR WIND DATA

Marty Quinn

BAE Systems and Design Rhythmics Sonification Research Lab
92 High Rd Lee, NH 03824 USA
marty.quinn@baesystems.com

Dr. Loren David Meeker, Ph.D.

University of New Hampshire
david.meeker@unh.edu

ABSTRACT

The Climate Symphony and Other Sonifications of Ice Core, Radar, DNA, Seismic and Solar Wind Data is a one-hour performance/presentation of sonification research by Marty Quinn of Design Rhythmics Sonification Research Lab and BAE Systems. It was presented in November 2000 at the National Science Foundation at the invitation of the Director's Office of Public Affairs and the Office of Polar Programs and was warmly received. This paper describes the Climate Symphony portion of the presentation in detail.

1. MATHEMATICAL ORIGINS OF THE CLIMATE SYMPHONY

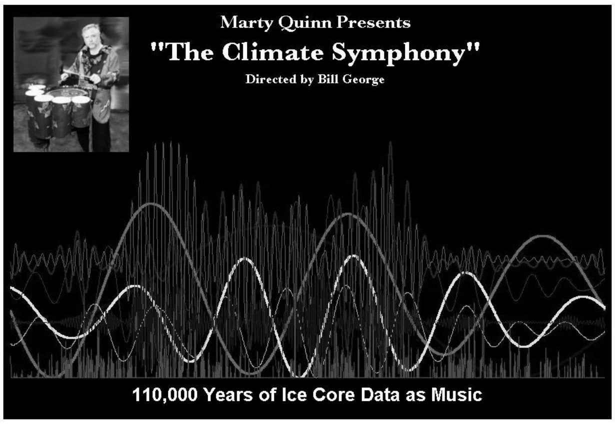

Figure 1. *The Climate Symphony: A Musical Expression of 9 Climatic Elements Derived From 110,000 Years of Ice Core History*

The Greenland Ice Sheet Project II (GISP2) completed drilling to bedrock at Summit, Greenland, in 1993 with a 3053 meter ice core. The core contains a record of atmospheric chemistry accumulated by the annual precipitation at Summit for over 200,000 years. The top 2960 meters provides a well-dated climate history for the past 110,000 years and it is this record which has led to the climate symphony.

The chemical record from the GISP2 core consists of 8 time series recording the concentrations of the 8 major ions found in the soluble components of the atmosphere [1]. These are: calcium, potassium, magnesium (primarily from continental dust), sodium, chloride (primarily from seasalt aerosols), sulfate (from marine biological production, burning of fossil fuels, and volcanoes), nitrate (from lightning, biological production, and many other sources), and ammonium (primarily from terrestrial biological production in high latitudes). Together these ion records provide a history of changing drought and flood, storms and calm, and biological growth and decay as the great continental ice sheets have advanced and retreated over the past 110,000 years.

The first step in the effort to explore and understand the history contained in the GISP2 time series involved a mathematical technique called principle component analysis which combined the eight time series into just 3 series with only a minimal loss of information. The second and third of these series clearly described the biological response of changing climate (recorded in the nitrate and ammonium series). The first, and most important of these summary series, directly records the atmospheric circulation response to the growth and decay of the continental ice sheets. It has come to be known as the "polar circulation index" (PCI) and is the series on which the climate symphony is based.

In their effort to understand the processes which underlie the environmental changes they study, scientists often hope to find evidence for periodic behavior. Such evidence can be important in identifying those factors which influence the changes the scientists observe. If a possible forcing agent is known to vary periodically (for example, like the solar intensity underlying the sunspot cycle) and the observed record has a periodic component with a similar period, then this may be evidence for a physical link between the agent and the response under study. In the case of the PCI, such a harmonic analysis was a natural step to take and proved to be very important.

The current scientific understanding of the mechanism behind the Earth's series of ice ages occurring over the past million years rests on the Milankovitch theory of changes in the orbit of the Earth relative to the Sun. As a consequence of the gravitational effects of the larger planets the Earth's orbit changes periodically in such a way that the amount and distribution of energy it receives from the Sun varies significantly over time. These changes have periodic components (see figure 1) with periods of around 400,000, 100,000, 40,000, and 22,000 years which combine to create a very complex history of climate forcing by variation in insolation over the Earth. While the PCI record is too short (110,000 years) to contain a cycle of the longest Milankovitch cycles, it does show strong periodic behavior with the other two periods. In addition, other periodic features were shown to be important components of the PCI. Most of the additional periodic features had been previously identified in other climate records or were likely subharmonics of the Milankovitch cycles acting through the various components of the climate system (the atmosphere, cryosphere, biosphere, and lithosphere).

Ultimately, it was found that the major features of the 110,000 years of the PCI record could be summarized by the sum of 10 components oscillating periodically but with an amplitude which varied as the ice sheets came and went. Thus, this important climate record from the Greenland ice, like an orchestral score, can be synthesized by a relatively few "pure tones". It was this observation which has, ultimately, led to the climate symphony.

2. The Climate Symphony

The script for the Climate Symphony performance was developed in the fall of 1999 and the spring of 2000 in anticipation of its premier at the American Museum of Natural History. It was partially funded by a public outreach grant from the Climate Change Research Center at the University of New Hampshire. Bill George, an award winning director and actor, was hired to direct the show.

The presentation was designed around the concept of an ice room on stage. The white walls and floors give the audience a feeling of being in a snowy place where ice core would be analyzed on site. The walls serve as screens upon which slides and animation are projected. The 'podium' is an electric drum kit containing four mounted drums and a kick drum. Each mounted drum is capable of four separate MIDI triggers. All the triggers are funneled into a Roland PM16 pad to midi converter which is connected to an IBM laptop running the sonification/visualization software. The laptop is connected via USB to midi interface that ultimately sends data to a Roland JV2080 synthesizer. All the live sounds are produced through the JV2080. Sonification and stage direction in the script are noted inside parentheses.

The Climate Symphony sonification was pre-recorded and played using a minidisk at the end of the presentation [2]. I wore a white clean suit that was used during analysis of ice core in Greenland. A simulated 'sample' of the ice core resides in a silver storage tube and is placed upright on the other side of the stage from the drum kit and is revealed during the presentation.

Pre-show music consists of **sonified radar scans from the Ross Ice Shelf**. Each scan begins with the click of a hi-hat. Density readings map to pitch, where higher density maps to higher pitch. The pitches derive from 45 notes of a C major scale. Depth of scan is mapped to 8 instrument sounds. 8 depth readings are produced per instrument making 64 notes per scan. Each scan takes 1.5 seconds to complete. Slight changes in snow density is heard as the ground penetrating radar traverses the ice shelf, at the lead of a scientific expedition.

2.1. The Script

Hello, my name is Marty Quinn and welcome to The Climate Symphony. Now some of you may be saying to yourself: "I didn't know the climate played music?" or maybe "What conservatory did it attend? Where did it take lessons?" or "What instrument does it play?" Some may even observe "the climate already is a symphony!" And if we consider its daily warmups and exercises, I would have to agree, the climate is a kind of symphony already. And what ***instruments*** does it play?

Well surely the climate plays percussion. One just has to think about the crack of lighting (sound: lighting, the sound is triggered by playing the sides or center of the electric drums) or its rolling thunder (sound: thunder). What about the rhythmic patter of rain (sound: rain). Some hear music in the rain forest (sound: rainforest), in the washing of waves on the beach (sound: waves), in the tinkling of the icicles on the trees outside (sound: icicles), or what about the sound of 200 foot glacial cliffs as they fall into the arctic sea (sound: imagined sound of falling ice) or the rushing roar of a tornado (fast sound: rushing, roaring).

And of course you might hear strings in the wistful murmers of wind (sound: strings, pitches are selected by the intensity of the hits on the drums, harder hits select higher pitches from a major scale of about 6 octaves), and if you include the animals that live on the planet and are affected by the climate, you could say horns (sound: higher car-like horns). No, no, not that kind, (sound: low imagined mammoth blow), yes, the woolly mammoth kind.

And don't forget flutes and whistles (sound: simulated birds) played by some of the finest feathered friends around.

Still, the climate never took lessons. The earth never played in a big band. Well, maybe not in a big band, but what about the big bang. Does that count? (sound: triggered polyphonic and multitimbral sequence derived from rhythmically generated musical events. Lasts 10 seconds, starts simple and gets more complex.)

Self-taught most likely!

And very inspiring. Yes, there *is* inspiration in sound all around us and even inside us. In your own heartbeat (sound: low timpani heart beat played on the kick drum pad); in our genetic makeup; (sound: minidisk sample of **multiple sonic views of DNA.** The nucleic acids sound like a drummer on a drumset as a=snare, g=hi-hat, c=cymbal, and t=tomtom or bass drum. Amino acids play as strings, punctuating every third hit, with hydrophobic AAs as higher strings. Terminator AAs are low drum hits. The twelve transitions between the four 'letters' of the code sound play as marimba hits whose notes are between the hydrophobic and non-hydrophobic AAs.), even the smile of a friend (add zing).

Is this the music of our sphere; the music that comes out of the interaction of elements, or that emerges out of our emotions, our love, our longing, our sadness, our striving, our joy? Or is there another music of our planet which is just out of reach, just out of hearing, like the sounds elephants recognize, but which are too low for us to hear. But if we *could* hear *this* music, what would it sound like? What biorhythms are being played by this great earth of ours? What geophysical and astronomical cycles of nature are there to be heard? Indeed, this symphony contains rhythms whose time signatures span not seconds, but lifetimes. Imagine that you were in the choir of such a symphony. (now singing) How long do I have to hold these notes for? (singing off) In fact, the measures of the Climate Symphony last anywhere from 10 lifetimes up to 1000 lifetimes. Nay, over a hundred thousand years. ***This*** is the Climate Symphony you will hear today.

2.1.1. The Meeting with the Ice Man

Figure 2. *Dr. Paul Mayewski, The Ice Man*

I met Dr. Paul Mayewski, the Ice Man (see figure 2), about 5 years ago when I was invited to attend a meeting at his home just down the street from where we lived in New Hampshire. I was told that Paul was the Director of the Climate Change Research Center at the University of New Hampshire and that he would be giving a slide presentation on the Greenland Ice Sheet Project II. I had heard that Paul was involved with glaciers and was curious to find out more about it and so I decided to go. This is what the Ice Man said:

2.1.2. The Glacial Story

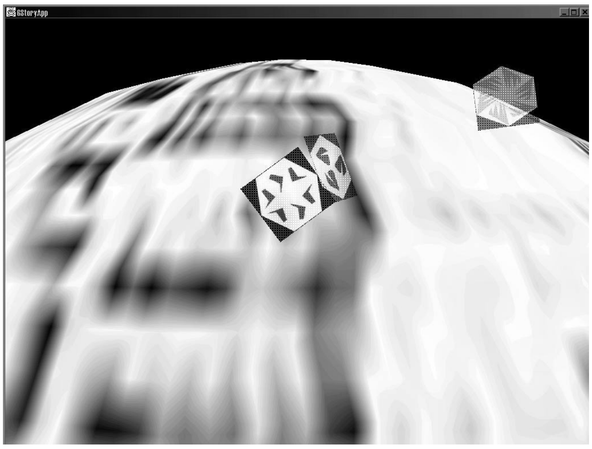

Figure 3. *Java 3D Animation Showing Ice Buildup of Greenland*

It all began 110,000 years ago in the center of Greenland. It was so cold that when it snowed, the snow would never melt. As each flake fell, it would carry into its frozen kingdom, part of whatever happened to be in the air at the time. For you see, as the wind raced across the oceans it would pick up the smell of the sea, and as the wind roamed over the hills and valleys and coastlines it would pick up the dust of the earth, the dust of life. It would carry volcanic ash into its frozen tomb, to be remembered forever, as a trace of its past, fiery glory. It would even carry traces of the sun's light as it waxes and wanes in its polyrhythmic dance of atomic fire.

Each year the snow would fall on the prior years snow and build up layers and layers and layers and layers, just like the layers of growth you can see in the rings of a tree. As the snow fell, it started to get deeper, and deeper and deeper and deeper, and the snow on the bottom would get more and more compressed, until after 110,000 years, the snow was as high as a mountain and two miles thick (see figure 3).

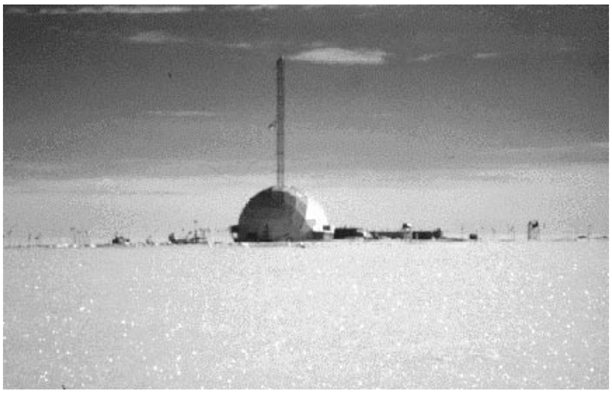

Figure 4. *The Drill Dome at GISP2 Greenland.*

Then beginning in 1989, the Ice Man, along with a group of researchers from around the world, drilled down into this mountain of ice (see figure 4), and extracted a column nearly two miles long. As each piece was extracted, they began to analyze what the ice had stored away for us, waiting to tell us, forever holding in its icy embrace, traces of what the climate was like on earth across the breadth of time.

And what were these traces? The ice man showed a graph depicting the ups and downs of the chemical residues found in the ice core. Through further mathematical analysis, they were able to determine what natural forces seem to be causing the climate.

As I looked at all the data all I saw was so many squiggly lines; I felt that it didn't convey the beauty, the life of the earth. I felt like it should be more, it should be experienced, it should be *music*!

The question to me was how to portray the patterns in nature using patterns in music. You see that's the problem, I mean solution. I mean how do you turn information that resides in data files and that are represented by numbers that might be positive or negative, like our left and right hands, and that might be related to one another, like you and I are related, or unrelated or dependent or independent and that have come from sensors or analysis and that have incredible ranges of values or represent time or measurments of all kinds, into music.

How do you do that? Well, it's simple really. We assign the lowest value in a file to a low pitch *(sound: hit pad softly and low piano tone sounds)*, and the highest value in a file to the highest pitch *(sound: hit pad hard and high pitch sounds)* and choose notes in between to represent values in between (sound: play a bit on the pad, many notes sound as the drum is hit at various intensities. All the notes are members of a major scale). Now let's see how this can be applied to the ice core data.

The Ice Man's drill removes a portion of ice from the ice sheet and it is cut in various lengths and catalogued *(open up* *the ice core tube to expose a portion of the ice core).* Each piece is ultimately examined in 50 different ways, 10 of which are used to determine the year it formed.

Each part is tested for the chemical traces it contains. Remember, that if we know the origins of these chemical tracers, they can tell us about conditions on earth at the time they were deposited in the snow.

To translate this kind of data into music, we will convert concentration levels to pitch: the higher the concentration, *(use high voice)* the higher the pitch; *(use normal voice)* the lower the concentration, *(use low voice)* the lower the pitch. *(back to normal voice)* To differentiate one chemical from the rest, we'll use a different instrument sound for each one.

Remember the story? As the winds blew over the water, it picked up the salts of the sea. These salts include Sodium (NA) ***(sound: play sodium sounds one of the drum pads and then move to point it out in the slide, then point out chloride and return to station to play chloride sounds on another drum) and chloride.***

As the wind blew over the land, it picked up calcium in the form of limestone dust, and Magnesium *(sound: calcium and magnesium as two different instrument sounds).*

Forest fires generate Nitrate NO3, Ammonium NH4, and Potassium K *(sound: play each chemical's sound).* And finally, volcanoes generate sulfate *(sound: plucked bass strings).*

2.1.3. *The Younger Dryas Event Sonification*

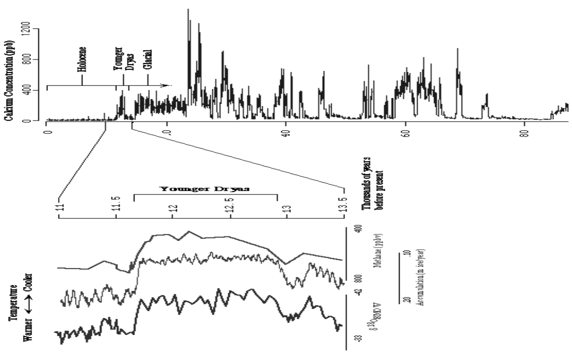

Figure 5. *Younger Dryas Event*

Now let's listen to the chemicals after we convert this data to music. We'll listen to a small portion of the data taken from a period called the Younger Dryas Event (see figure 5) that occurred about 14000 years to 12000 years ago when the earth suddenly got colder. The duration of each note you hear represents 5 years. Do you hear that, that's the temperature getting colder. Ok, now get ready and raise your hand when you hear the pitch get lower again and the temperature warms back up. Great.

OK, so we know we can represent the data values as notes out of scales and differentiate the different chemicals using different instruments. What else is possible?

The next picture represents knowledge that the scientists acquired from studying the chemical data [1]. They discovered regular patterns in the climate that were over 70,000 and as short as 500 years. For instance, they noticed that every 6,300 years, the ice sheets move down and up over the earth's surface. They could see the effect of the changing tilt of the earth over 40,000 years and they could see that the change in the shape of the orbit of the earth around the sun over more than 70,000 years was a major factor in climate change. I challenged myself to come up with a way to hear these patterns of nature as patterns of music. Let me introduce you to the elements of the Climate Symphony.

2.1.4. *Elements of the Climate Symphony*

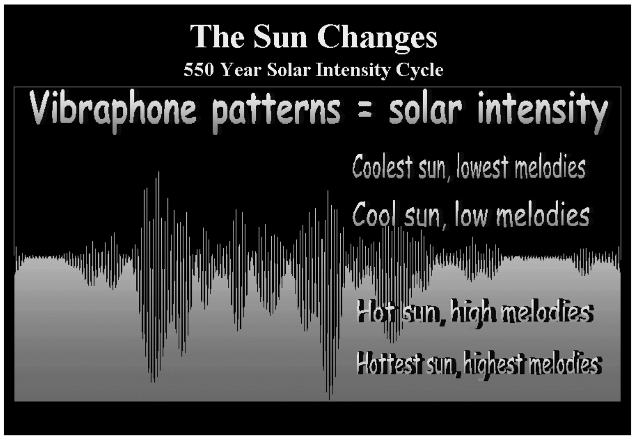

Figure 6. *550 Year Solar Sonification*

Consider the 550 year solar intensity cycle (figure 6). Instead of using a scale of pitches, I chose to represent the sun's intensity as a scale of melodic patterns played on a vibraphone for its brilliant and warm timbral color. The hotter the sun, the higher the melodies, the cooler the sun, the lower the melodies.

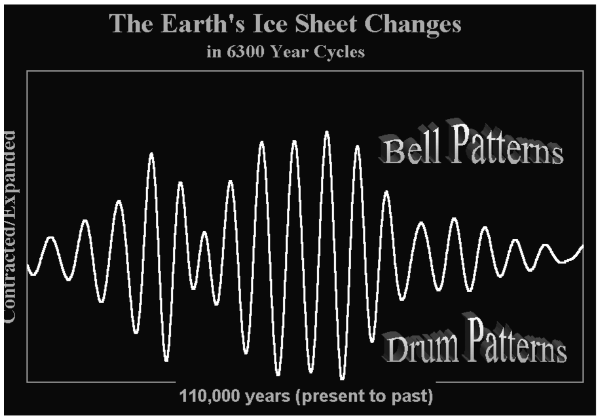

Figure 7. *6300 Year Ice Sheet Movements Sonification*

For the 6300 year ebb and flow of the ice sheets (see figure 7), I decided to use 6 rhythmic patterns of tom toms and cowbells. When the ice sheets are expanded you will hear one of three cowbell patterns depending on the amount of expansion, and when contracted you will hear one of three tom tom and conga patterns, again depending on the degree of contraction.

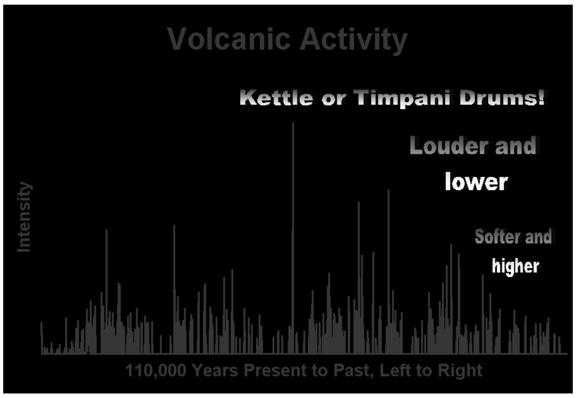

Figure 7. *Volcanic Activity Sonification.*

For the volcanic activity, I chose to use cymbal crashes and timpani drums that increase or decrease in volume depending on intensity. In the case of the timpani drums, the lower the pitch, the more intense the volcano.

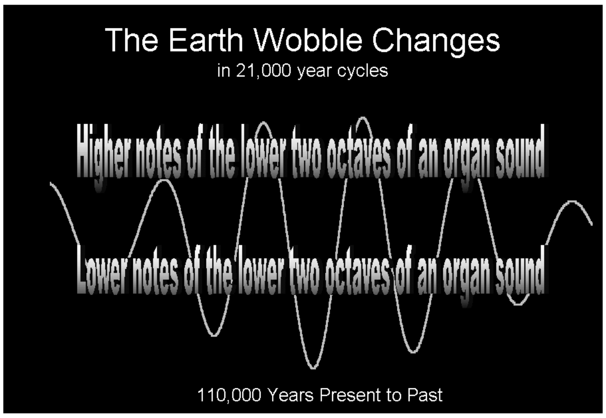

Figure 8. *Earth Wobble 21,000 Year Cycle Sonification.*

For the earth's wobble (see figure 8), which causes some summers to be hotter and some winters to be colder than others, I chose to represent these changes with a scale of pitches with the sound of an organ, the low pitch representing minimal influence and the high pitches representing maximum influence.

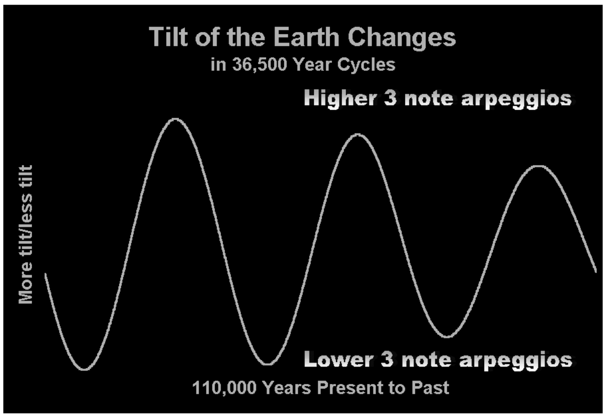

Figure 8. *Changing Tilt 40,000 Year Cycle Sonification*

The changing tilt of the earth, a 40,000 year cycle, is a changing 3 note arpeggio, the greater the tilt, the higher the notes in the arpeggio (see figure 9). The 1450 year ocean cycle sonification selects either a clarinet, trumpet or muted trumpet tone for these notes (see figure 10).

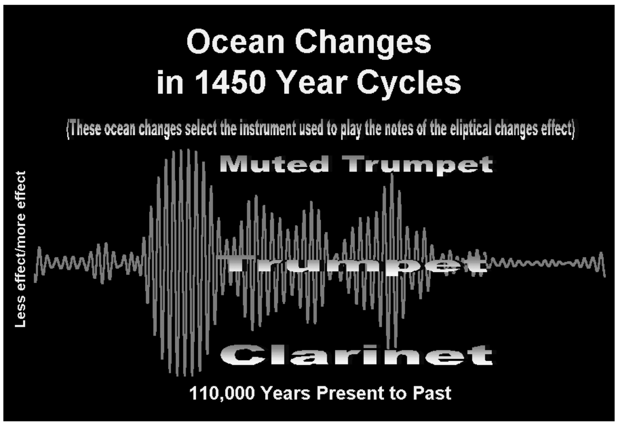

Figure 10. *Ocean Circulation 1,450 Year Cycle Sonification*

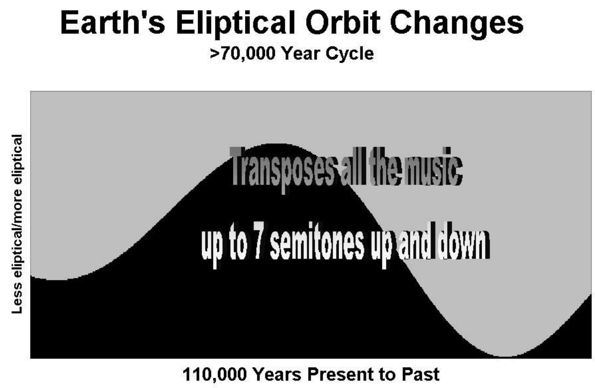

Figure 11. *Eliptical Orbit Variations > 70,000 Years Transposition Sonification*

And finally, the slight change in the earth's eliptical orbit around the sun (see figure 11), transposes all the other music up to 7 steps higher and lower depending on the increasing or decreasing eliptical shape of the orbit.

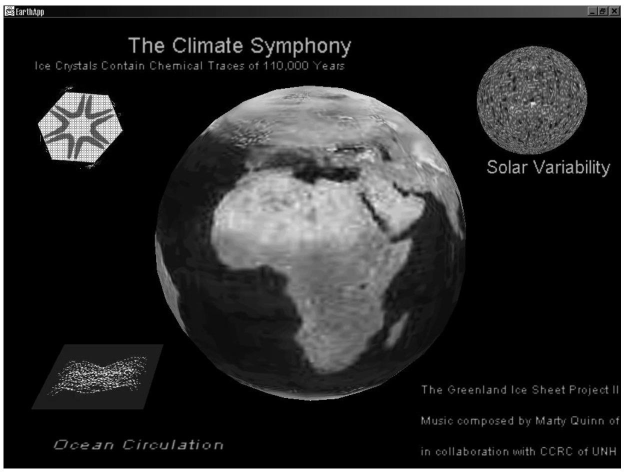

Figure 12. *Climate Symphony Animation.*

OK we're ready to play the Climate Symphony. We'll begin 110,000 years ago and travel through time at the rate of 50 years per beat. We'll start slowly at first, moving through 150 years a second for the two minutes or 20,000 years, and

Figure 13. *Page one of the score for The Climate Symphony*

then increase speed by two times to a rate of 350 years a second. Ladies and gentleman fasten your seat beats and put your tray tables in the upright and locked position and your minds in the unlocked position. Our sonic flight through the ice core will take a little over 7minutes. We hope you enjoy the trip. The Climate Symphony (see animation in figure 12 and the first page of the score in 13).

3. CONCLUSIONS

As of this writing, The Climate Symphony has been presented at the American Museum of Natural History, MIT Lincoln Labs, the National Science Foundation, BAE Systems, University of Massachusetts at Dartmouth and at the National Science Teachers Association east coast conference. The work is being cited by the Director of the National Science Foundation, Dr. Rita Colwell, as a unique blend of art and science[3]. It has also been mentioned in a recent IEEE publication [4]. The public can now obtain a video and CD of the presentation.

Though "The Climate Symphony" is a complex sonification, using many techniques, it does not yet utilize the 3D placement of sound. We are currently investigating how this could be used to full advantage with Jim Ballas and Hesham Fouad of the Naval Research Lab.

New concepts and modes of interacting take time to develop. We believe the format we chose allows people time to gradually get acquainted with both the science of glaciology and the art and science of sonification. A great deal of experimentation was attempted before arriving at the current state and style of the performance. Audiences have expressed great enjoyment in watching The Climate Symphony, and more scientists are taking note of the public outreach capabilities that this approach to sonification can provide[5].

4. REFERENCES

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[2] M. Quinn, "A Brief Description of the Mapping of Ice Core Data to Music", http://www.nh.ultranet.com/~mwcquinn/icecore.html, 1999.

[3] R. Colwell, "The Wellspring of Discovery", *Speech to the American Association for the Advancement of Science* http://www.nsf.gov/od/lpa/forum/colwell/rc00411wellspring.htm, April 11, 2000.

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[5] J. Vento, "EOS Showcases Sun Research", *Campus Journal University of New Hampshire,* Vol XXXXII, Number 35, pp. 1, May 4, 2001. Refer to http://espg.sr.unh.edu/tof/Outreach for Solar Songs links.