

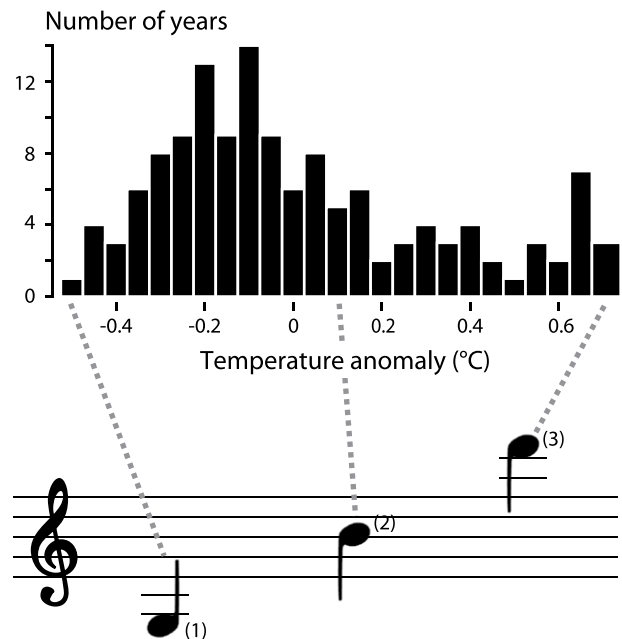
# MAKING CLIMATE DATA SING

## Using Music-like Sonifications to Convey a Key Climate Record

SCOTT ST. GEORGE, DANIEL CRAWFORD, TODD REUBOLD, AND ELIZABETH GIORGI

Scientists usually transmit evidence about climate change via information-rich data graphics. Visualizations such as the Keeling Curve or the “Hockey Stick” are icons of climate science, and charts and maps illustrating the most recent changes in global temperatures are the subject of intensive news coverage and significant public interest upon their release. A well-designed graphic can help audiences to quickly understand the main message embedded within a complex set of climate data and to retain those ideas longer than if they were conveyed by words alone. But these visual aids also have limitations: they are most easily understood by people who are fluent in technical illustrations; they are usually static and sometimes do not tell an obvious story; and many people do not respond to them emotionally.

Music, by contrast, builds each note or phrase upon those that came before, and can exert a powerful influence on human emotions. Because of these characteristics, *sonification*—the transformation of data into acoustic signals—may have considerable promise as a tool to enhance the communication of climate science. Here we report on a musical collaboration between scientists and artists at the University of Minnesota that puts a new spin on a



**FIG. 1. Schematic diagram illustrating how climate observations are converted into musical tones. In this hypothetical example, a histogram is constructed from a set of temperature observations (upper panel) and the extremes of that distribution are assigned to the lower and upper limits of the playable range of the instrument (notes 1 and 3 in the lower panel). Other temperatures are mapped onto tones corresponding to their relative position between the two extremes (for instance, note 2).**

central finding of modern climatology. We describe the procedure used to transform more than a century of weather observations into compositions for cello and string quartet, and summarize the public response to our “climate music” and its reception by science educators, music critics, and the media at large. Finally, we outline how sonifications with added musical elements might make climate science more accessible in education and outreach.

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## TURNING CLIMATE DATA INTO MUSICAL SOUND.

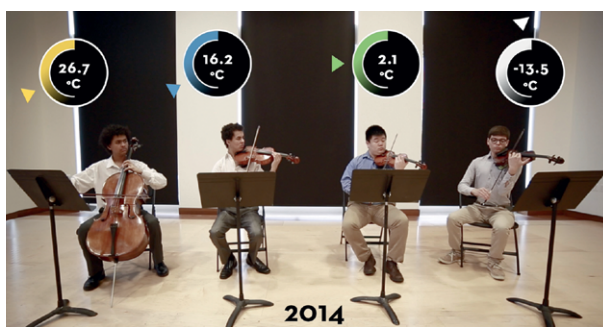
One of the most common and simplest types of data visualizations maps a pair of variables (for instance, mean annual temperature and calendar year) onto a two-dimensional coordinate system. Each variable is made to be proportional to a fixed distance in coordinate space. Because musical scales are sets of tones ordered by pitch, weather or climate data may be converted into sound using the same basic approach. And since rhythm is one of the fundamental aspects of music, that art form is ideally suited to represent phenomena that vary through time.

We developed a simple but flexible sonification procedure to transform one or more climate time series into a sequence of musical notes. The first step was to choose an instrument (or instruments), which determined the range of pitches available. Next, the minimum value in the climate data time series (such as the coldest temperature on record) was assigned to a note close to the bottom of the instrument's playable range (Fig. 1). At the other extreme, the maximum value in the climate record (the hottest year) was set to a note close to the upper limit of the instrument. All other observations were converted into musical tones based on their relative value between the two extremes. In this scheme, a temperature measurement close to the median would be assigned the tone listed midway along the musical scale between the lowest and highest notes. For example, if data were projected onto two octaves of the C major scale starting at middle C (C4 in American Standard Pitch Notation), observations near the middle of the distribution would be matched to C5. Because the sound frequency of musical tones doubles with every ascending octave, mapping climate data onto a scale allowed us to use a much wider range of pitch than if they were converted directly into hertz. Once the conversion scheme was finalized, the notes were arranged in chronological order, setting the beat unit in the composition to be equal to the time interval resolved by the data (hourly, daily, monthly, or yearly).

We released our first “climate music” composition, titled *A Song of Our Warming Planet*, on June 28, 2013 (<http://ensia.com/videos/a-song-of-our-warming-planet>). That piece was created by applying our sonification procedure to the surface temperature record produced by NASA's Goddard Institute of Space Studies (GISSTEMP). The Global Land–Ocean Temperature Index was mapped across three octaves, with the coldest year on record (1909) set to the lowest note on the cello (C2). Each note in the composition represented one year, ordered from 1880 to 2012,

while its pitch reflected the mean temperature of the planet relative to the 1951–1980 base period. This first composition was atonal (meaning it did not have a tonal center or key) and used all notes within the written range, with each ascending semitone being equivalent to roughly 0.03°C of planetary warming. Early the next year we shared a guitar version of *A Song of Our Warming Planet* written in tablature format (<http://ensia.com/notable/the-sound-of-2013>), which appended a new note representing the 2013 global temperature anomaly to the end of the piece.

The second composition in this series used an expanded set of instruments to add a geographic dimension to our musical expression of global warming (<http://ensia.com/videos/what-climate-change-sounds-like-from-the-amazon-to-the-arctic>). Instead of sonifying only a single climate series, we applied the same procedure to GISSTEMP's Combined Land-Surface Air and Sea-Surface Water Temperature Anomalies zonal annual means. The sequel, *Planetary Bands, Warming World*, which was released on May 7, 2015, assigned each zone in the Northern Hemisphere to one member of a string quartet (Fig. 2). The cello matched the temperature of the equatorial zone (0–24°N), the viola tracked the midlatitudes (24–44°N), and the two violins separately followed temperatures in the high latitudes (44–64°N) and the Arctic (64–90°N). The additional voices in the composition allow listeners to trace the overall trend toward warmer temperatures, but also to discern more subtle changes, such as the rapid warming near the pole during the last



**FIG. 2. Screenshot from the video accompanying the “climate music” composition *Planetary Bands, Warming World*. In this sonification of NASA’s GISSTEMP data, each instrument in the string quartet represents the average annual zonal temperature within a specific latitude band, including the equatorial zone (cello), the midlatitudes (viola), the high latitudes (second violin), and the Arctic (first violin). As the song progresses, the infographic above each musician displays the average annual temperature for their corresponding region.**

two or three decades. Unlike the original, *Planetary Bands*, *Warming World* was composed in the key of C major, so the sonification procedure was restricted to map only onto the sequence C-D-E-F-G-A-B-[C]. That choice, along with the fact that temperatures in adjacent regions tend to vary in concert through time, makes it possible for the four notes to blend together as major chords, which sound harmonious and enjoyable, although temperature patterns could also combine to produce clashing dissonances.

In addition, we augmented both sonifications with elements of music so the final performance was suited for online viewing, simple to interpret, and more pleasing to the ear. The recorded versions of both pieces had durations of less than three minutes (the typical length of a popular music song), so they fit audience expectations for the length of a single audio track. In *Planetary Bands*, *Warming World*, each sequence of 10 notes was followed by a silent beat, allowing listeners to mark the transition from one decade to the next. In addition, the cello and viola were instructed to perform legato, playing smoothly with no intervening silences between notes, so the sounds symbolizing the higher and lower latitudes were easier to differentiate. And finally, the quartet musicians chose to slowly vary the dynamics throughout the piece, beginning forte and ending pianissimo, so that, as they described it, their performance might imply the arc of future climate change that remains yet to be determined. Overall, incorporating pitch, rhythm, dynamics, and timbre into our sonification procedure helped distinguish these works from exact translations of data relations into acoustic signals, and gave them some of the qualities commonly possessed by composed music.

**PUBLIC REACTION.** Our “climate music” compositions were distributed by Ensia, an online and print magazine produced by the University of Minnesota’s Institute on the Environment. Each release included a short (<500-word) article describing the piece and a 4–5 minute video outlining its basic premise and featuring a performance by University of Minnesota students. In the videos, our music-like sonifications were paired with simple visualizations that simultaneously showed the same data as an animated line graph (for *A Song of Our Warming Planet*) or via a virtual dashboard with dials depicting regional temperatures (in *Planetary Bands*, *Warming World*). We also shared digital versions of the sheet music ([http://ensia.com/wp-content/uploads/2014/07/video\\_warming\\_planet\\_music\\_score.pdf](http://ensia.com/wp-content/uploads/2014/07/video_warming_planet_music_score.pdf);

[http://ensia.com/wp-content/uploads/2015/05/crawford\\_score\\_planetary\\_bands.pdf](http://ensia.com/wp-content/uploads/2015/05/crawford_score_planetary_bands.pdf)) and audio files (<https://mediamill.cla.umn.edu/mediamill/download.php?file=195242.mp3>; <https://mediamill.cla.umn.edu/mediamill/download.php?file=999238712.mp3>) under a Creative Commons license so other people could perform or remix our original works.

Since its 2013 release, the video for *A Song of Our Warming Planet* has been watched on Vimeo more than 150,000 times, with another 16,000 views from YouTube. The more recent video for *Planetary Bands*, *Warming World* has attracted nearly 80,000 views since May 2015. People in the United States made up the largest fraction of the audience for each video, but they both also attracted a substantial international viewership (Table 1). *A Song of Our Warming Planet* has proven popular in several countries where English

**TABLE 1. Top 20 countries ranked by number of views of *A Song of Our Warming Planet* and *Planetary Bands*, *Warming World* on Vimeo (<https://vimeo.com>). Data were obtained on February 2, 2016.**

<i>A Song of Our Warming Planet</i>		<i>Planetary Bands, Warming World</i>	
Country	Views	Country	Views
United States	59,454	United States	36,905
Japan	18,275	Canada	4,115
Canada	11,659	Italy	3,782
Russia	6,335	Australia	2,590
Brazil	6,288	Germany	2,555
United Kingdom	4,694	United Kingdom	2,412
Mexico	4,218	Russia	2,288
Colombia	3,521	Netherlands	2,198
Australia	3,438	Mexico	1,337
Italy	3,239	France	975
Germany	3,171	Romania	867
Lithuania	2,254	Spain	760
Chile	2,246	India	743
Spain	2,220	Belgium	713
Netherlands	2,030	Ukraine	639
France	1,859	Turkey	610
Ukraine	1,499	Sweden	505
Argentina	1,201	Brazil	500
Austria	963	New Zealand	442
India	918	Philippines	439
<b>Total</b>	<b>156,876</b>	<b>Total</b>	<b>73,794</b>

is not the dominant language, including Japan, Brazil, Russia, and Mexico, which suggests that blending sound, music, and simple visuals may help scientific communication transcend barriers due to language. These compositions have also been performed live by musicians in the United States, Canada, and the Netherlands, and in at least one case, was reinterpreted as variations for cello, piano, and guitar ([www.icareifyoulisten.com/2014/07/five-ottawa-composers/](http://www.icareifyoulisten.com/2014/07/five-ottawa-composers/)). Encountering these sonifications in person requires the audience to forego the visual cues or some of the context imparted by the accompanying videos, so these engagements provide some indication that the compositions can by themselves transmit the core “story” told by the underlying temperature data.

Both *A Song of Our Warming Planet* and *Planetary Bands*, *Warming World* received substantial media coverage. *The New York Times*, The Weather Channel, *Popular Science*, and the *Smithsonian Magazine*, among others, produced stories. Many commentators said they were surprised by the use of music or sound to communicate the science of climate change, and reported that its message was memorable even though the compositions themselves were unsettling or unpleasant. Katherine Brooks of the *Huffington Post* described *A Song of Our Warming Planet* as a “sinister melody that climbs in pitch, transforming the already dismal reality of climate change into a sonically intimidating work of art.” Of course, not all opinions were positive. Ivan Hewitt, the music critic for the *Telegraph* (London), characterized the same piece as “banal” and “plodding” and identified a clear separation between a musically influenced sonification and composed music inspired by nature (but not translating it literally). We agree our “climate music” compositions do not compare to Richard Strauss’s *Alpine Symphony* (the exemplar cited by Hewitt) or contemporary works such as DJ Spooky’s *Sinfonia Antarctica*, which are complex constructs capable of arousing emotions and stimulating the imagination. But even if it cannot produce art, sonification is clearly a powerful and flexible approach well suited for both data exploration and public outreach. Within the Earth and environmental sciences, sound has dramatized the dynamics of sea ice surrounding Antarctica ([www.markballora.com](http://www.markballora.com)), the intensity of solar storms (<http://blog.ametsoc.org/news/solar-storms-are-noisy/>), and geophysical and geochemical data recovered from Greenland ice cores ([www.drsrcsl.com/climate\\_paper.html](http://www.drsrcsl.com/climate_paper.html)). And enhancing data sonifications with additional musical elements, as

we did with our two compositions, appears to help the final product draw the attention of nonspecialist audiences. When Phil Plait of *Slate*’s *Bad Astronomy* blog concluded his feature of *A Song of Our Warming Planet* by writing that “...converting a simple graph into some different form of information can deliver the message far better, and more effectively, than dots on a page,” we interpreted his statement as evidence that this approach had struck a chord with science communicators and possibly the broader public.

**LESSONS DRAWN.** We began this collaboration because we thought music and sound might be an effective tool to illustrate the progressive warming of our planet, but even we were surprised by the popularity of the compositions. The story announcing the release of *A Song of Our Warming Planet* was one of the 10 most popular articles published by *Ensia* in 2013, and its video has been watched more often than any of the uploads on NASA’s Climate Change YouTube channel. Because stories about our “climate music” appeared in outlets with audiences that are already well-informed about climate science (e.g., The Weather Channel, *Scientific American*, and *Popular Science*), this interest may simply be a product of us telling people something they already know through an unexpected and novel medium. On the other hand, these pieces were also featured by media that primarily cover popular culture (*io9*, *The Prime Show*) or business (*Fast Company*), so they may indeed have reached audiences who do not usually respond to more conventional approaches to climate science outreach.

We have incorporated our “climate music” videos into an introductory-level course on environmental science taught at the University of Minnesota. In our experience, students enjoy the compositions (perhaps because they were created by peers at the same institution) and seem to perform better in exams when asked to summarize the evidence for global warming and observed changes in global temperatures. Faculty at other institutions have told us they also use the compositions as part of their instruction on climate change. Writing at the American Geophysical Union’s GeoEd Trek blog, Dr. Laura Guertin reported that “[t]hese videos are successful in capturing the attention of students (including non-science majors),” and that “students continue to mention these videos throughout the semester and share them with others outside of my

course.” But so far this feedback is strictly anecdotal, and the question of whether these resources actually help some students learn concepts related to climate change more effectively needs to be formally evaluated.

We have no doubt that climate science will remain a predominantly visual medium. In many situations, there is no substitute for the precision afforded by visual representations of complex data. And, at least for now, it is much easier and quicker to render climate data visually than it is to convert the same information into sound. But our experience suggests musically influenced sonifications do provide an effective alternative to make known the pace and place of warming global temperatures. And because our procedure is so simple, the same basic approach could be applied to any time series to create novel, visceral, and memorable encounters with climate or geophysical data.

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