

Response to Reviews of *EGU* manuscript EGUSPHERE-2022-1356

February 11th, 2023

Title: GC Insights: Communicating Climate Change – Immersive Sonification for the Piano

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RC2, Referee #2 comments and rebuttal (in boldface and blue text):

General comments

The author proposes a musically-oriented sonification of CO₂ concentration data. The musical piece is partly data-driven through the method of "parameter mapping", but some aspects of it (chords, dynamics) are based on a musical decision. This can be thought of as some form of data-based composition or musical arrangement. The intent is to facilitate the communication of such important data to the general public through an engaging musical experience.

The musical piece itself is interesting and quite intriguing to my ears, due to the very "chromatic" approach taken here and the way major/minor chords are used and combined. Moving beyond a purely data-based sonification and using the freedom brought by musical composition is an interesting aspect of this work in my opinion: it is both powerful (because the composer can induce intent and emotion) and challenging (because the link to the data might become weaker).

In terms of objective, I agree with the author that musically-oriented sonification has a great potential to communicate data and concepts to the general audience. One specific challenge I can foresee for this piece is that the 5-movement structure makes the music "play the data" several times, but for different time periods and data resolution (yearly/monthly): this is difficult to follow based on the audio only. The figure provided in the paper is helpful in this respect, but I believe some form of data animation would be much more efficient - maybe a future improvement worth discussing?

The main criticism I have relates to the way the paper is written: it could significantly be improved in my opinion. If this paper was to be considered as a regular scientific paper, the

main issues would be the following:

1. A review of previous works is missing in the introduction, which makes it difficult to understand how the author's piece compares to existing works.
2. Explanations on how the musical piece was created and arranged are not very clear in my opinion.
3. There is no discussion on the challenges faced to create the piece, possible improvements, future works etc.

I understand that is not a regular scientific paper, but still, I think improvements in the three areas above would be useful to the reader.

Thank you for the extensive, constructive and helpful review. I intend to fully address all of these comments and improvements, and to implement the overall majority of them. For the three main issues that the reviewer mentions above, I plan to make the following changes:

- 1. First of all, I agree with a lack of recognizing and referring to previous work and literature around the topic of climate sonification. This is an important part of the scientific process that will further validate the uniqueness of my piece and the effectiveness of sonification itself. I will add more references to previous work, as I described in my response below and to RC1.**
- 2. I agree that the methodology within the production of the audio file was not fully developed and explained. To improve this I will delve deeper into my use of Logic Pro X (see details about this in my response to RC1) and incorporate a still from that methodology into the figure (see part (b) of the new figure that I propose in my response to RC1).**
- 3. I agree that my paper would greatly improve with a discussion as to the challenges, possible improvements and future extensions and unanswered questions. This is something I plan to expand upon. I think that developing a data animation to go along with the audio file is beyond the scope of this work, but it would be an important**

extension of this study and I will discuss that, along with other possible future improvements, in the conclusions (also see my response to RC1).

Specific comments

Throughout the paper: Climate change and CO2 concentrations are two distinct things - the latter is one the main driver of the former. This distinction could be made more explicitly in the title (e.g. "Communicating the Causes of Climate Change" or something along those lines?) and throughout the paper. As an illustration on line 22, I don't think CO2 concentrations can be termed an "indicator of climate change": global temperature (for instance) would be. In fact, an interesting sonification experiment would be to play both the cause (CO2 emission) and the consequence (increasing temperature) together: worth a word in the discussion?

I have changed the word “indicator” to “cause” in the introduction. This distinction is important and thank you for pointing this out. I have corrected this distinction throughout the rest of the manuscript as well. I agree that changing the title to “Communicating the Causes of Climate Change” would increase the accuracy of the title. I have changed this as such, however to fully change the title, a longer process may perhaps ensue in correspondence with the editor. Playing both temperature and CO2 change would definitely be an interesting insight and possible extension of my project, and I will include this in the final section of suggested improvements and unanswered questions.

Lines 29-31: could the author explain a bit more the choice of using the adjective "statistical" ? Is it only because the process is based on data, or is there additional intended meaning? Note that I'm not disputing this choice: sonification is a way of presenting data, and that's indeed part of Statistics, but it might be worth stating this explicitly because I reckon some readers might have a narrower interpretation of this term.

I have changed this to climate data instead as this is more understandable and applicable to this specific line. I will however incorporate a distinction within the definition of sonification as to its relevancy towards the CO2 data itself. I use the word statistical in the name of the piece, Statistical Composition, to convey connotations of an artistic and mathematical song. This is what my work is in essence. Distinguishing this use of statistical is definitely a valued comment, and I will implement a definition that

the piece is a way of presenting these statistics and data. Thank you for this helpful comment.

Lines 20-31: this introduction does not do any literature review. To start with, I think the sonification handbook (<https://sonification.de/handbook/>) is worth citing for all technical aspects behind sonification, and also possibly for discussing topics related to auditory perception. In addition, the author could mention other sonification works and discuss similarities and differences with the presented piece. The list below is not exhaustive but provides a few examples for which I found similarities with the author's piece (in terms of either underlying data, creation of a physically playable piece or inclusion of subjective composition elements).

* CO2 concentration and increasing temperatures: <https://youtu.be/ONuA9HmkF3M>

* Increasing temperatures: https://youtu.be/-V2Uc8Kax_g

* Climate change projections: <https://youtu.be/2YE9uHBE5OI>

* Climate change: <https://www.nelsonguda.com/project/threshold/>

* Sea ice loss: <https://youtu.be/eYXxAE5grRQ>

* Climate data: <https://www.jamieperera.com/climate-data-sonification>

* Climate data: <https://globxblog.github.io/>

* Coastal Land Loss : <https://datadrivendj.com/tracks/louisiana/>

* Other examples in other fields at <https://sonification.design/>

Citing these references will be greatly beneficial to my manuscript and I will include them. I have already begun to cite the sonification handbook in my corrections according to your comments below, and I will continue to do so. These other references are highly relevant and I have outlined below that including them will increase the

justification for the use of sonification and the manner in which my piece is creatively unique and distinguishable. I plan to use a comparison to increasing temperature sonification as a future potential improvement.

Line 35: in the sonification handbook (<https://sonification.de/handbook/>), this is rather termed "indexicality" I believe. In any case I think the author should introduce such concept more thoroughly ("high sonification accuracy to original data" is a bit unclear).

I have implemented this change and sourced the sonification handbook: Indexicality is a measure of arbitrariness of data mappings, and high indexicality depicts a large degree of conversion accuracy (Hermann, Hunt, & Neuhoff, 2011)

Line 36: I don't understand what the words "set" and "boundaries" refer to here. Are they elements of the parameter mapping approach used for the right hand? As previously, the author should probably use more space to introduce all these concepts more clearly.

The word "set" has been replaced by "predetermined" and "and boundaries" has been removed as it does not add to parameters.

Line 52: explain a bit more what each of these 6 elements represent?

* linear time: what do you mean exactly?

Linear time refers to the time of CO2 emissions, and therefore follows the chronological emissions of CO2. This explanation will be put into the introduction and will improve the clarity of communication.

* varying length of certain notes: OK but isn't somehow redundant with rhythm, and if not what's the distinction?

I agree there is little distinction so varying length has been removed, along with instrument as only the piano is used. It has been changed to: "My sonification project uses four elements of sound, namely linear time, frequency, amplitude, and rhythm, to create the *Statistical Composition*."

* frequency, amplitude: maybe mention that they are also called pitch and loudness?

This explanation will be incorporated into this section.

Line 53: this might be a bit of a controversial statement, but for sure you could state that it carries the formation in an original and engaging way, different from a graph.

This is an instance of hyperbole that is definitely unnecessary. I have completed this correction in accordance to comments from RC1. I have included “In effect, information is conveyed in an original and engaging way.”

Line 63: What does the "musical backbone" refer to? Key and time signature? please make it explicit. Moreover, it might also be worth explaining that while the score is written in C major, the parameter mapping is not restricted to the 7 notes of the C major scale, but uses all 12 semitones.

I agree with this improvement. This has been changed to: “This musical backbone incorporates the entire composition being set to the time signature of $\frac{4}{4}$ (a quarter note having the value of a quarter of a measure), the key of middle C, and utilizing all 12 semitones.”

Line 65: The expression "range differentiation" sounds unusual: is it widely used in sonification or in other fields (if so please provide a reference)? "Discretization" sounds more familiar to my ears (https://en.wikipedia.org/wiki/Discretization_of_continuous_features). In any case, the sentence explaining how it's done needs rewording: I guess you meant the difference between the highest and the lowest values?

This change has been included into the manuscript. I have changed range differentiation into parameter mapping and will include a sufficient definition sourcing the sonification handbook.

Table S1: the meaning of "Increase of 1" in column "Number of Half Notes" is unclear - why not just give the total number of half-notes used in the parameter mapping, as for other rows? The header "Calculated Interval" is also unclear - maybe "data range covered by one note", if I understood correctly?

These changes are valuable and will improve the supplement S1. I agree that it is clearer to state the number of half notes used in parameter mapping, and the data range covered by one note. You have understood perfectly and I will implement these changes.

Lines 72-115: I have to say that I found this description quite confusing and I struggled to understand how the parameter mapping was done exactly, and to distinguish between the "objective" data-driven choices and the "subjective" composition choices. A few suggestions:

Thank you once again for this helpful comment. I am implementing your suggestions as follows below.

* Maybe the author could adopt a more systematic 2-step structure to describe each movement. Step 1 would be the data-driven parameter mapping: this description should be clear enough to enable a reader to reproduce this part of the score. Step 2 would be the composition choices, with the author explaining the intent.

Such a systematic approach would be a definite improvement, and I thank you for this comment. This will be implemented into the description of each movement. I will describe each composition choice in a full and concise manner, stating intent and effect of each major artistic element. An increase in detail within both the supplement S1 and the text itself is necessary to describe each conversion step. The fact that the general methodology of parameter mapping can be, and is, conducted in slightly different ways makes this challenging, however I will take a basis in the overall structure of the improved supplement S1.

* I think that both the score and the audio file play the movements described here in the following order: 3-1-2-4-5. Is it correct? If so the movements need to be renamed in the correct order because this is quite confusing in the current state. In any case the author should give the bar numbers associated with each movement.

The movements are played within the audio file in the order of 1-2-3-4-5, so the order in which they are named is not at fault. I agree that they are not sufficiently separated and distinct, and that both time stamps and bar numbers should be included in the movement titles. I am in the process of changing this in accordance with RC1.

* If bars 1-8 indeed correspond to movement 3, then I would expect finding $5 \times 12 = 60$ notes (5 years of monthly values). How can these be split into 8 measures? ($60/8 = 7.5$). I'm missing something here.

This is incorrect as bars 1-8 are not in fact movement 3, but movement 1. I have however not explained that the first note is held twice as long to mark the beginning of the song therefore explaining the half beat missing from your calculation. This will be noted in the description of the methodology.

* I don't understand how the rhythm of bars 47-58 was obtained: is it data-driven or has it been chosen by the author? please clarify.

For the first 20 years of the movement, each yearly projected average is the length of a quarter note, a fourth of a measure. The 4 years after that are whole notes, and the final year of 2044 is a combined 2 whole notes. This increase in note length is to give a dramatic effect to the ending of the piece. Such an explanation will be included in the description of the methodology of the fifth movement.

* Is the loudness of the notes somehow data-driven, or is it the author's choice? It's worth explaining for each movement since there are strong dynamics for some of them but not for others - and in terms of perception, dynamics is quite powerful!

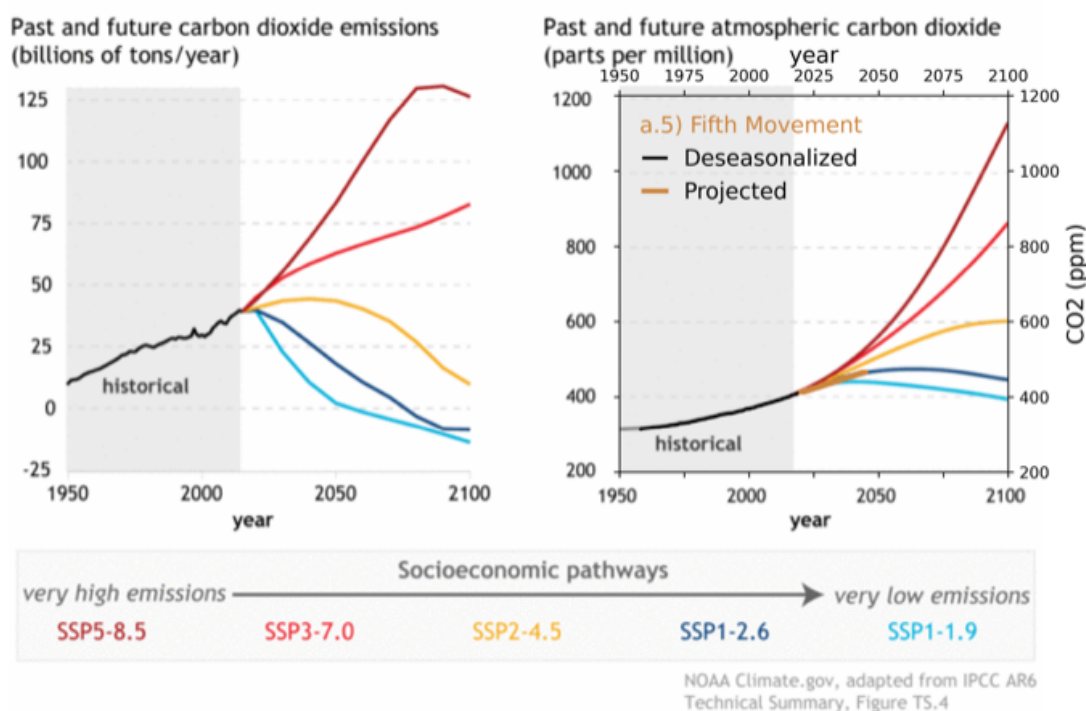
I agree. Dynamics is an artistic choice that is used to create dramaticism. Each movement generally follows the outline of starting soft and becoming increasingly loud. Such dynamics are on the score as well. This will be described for each movement.

Line 110: I expect scientists working on future greenhouse gases emission and concentrations might not be keen on this best-fit line projection. Why not using the CO2 concentrations for one of the IPCC scenarios? The data are available at this page (probably the same page where the author get the Mauna Loa data): https://www.ipcc-data.org/observ/ddc_co2.html

This is an optimistic projection, where I am projecting rising CO2 with the assumption that the rate of increase itself will not increase. This is meant to show how even if a positive case is assumed, it is an urgent topic and the music conveys a sense of gloom around this. I will incorporate an evaluation of this method in comparison to the sight

you have outlined to verify this, and this can also be mentioned in the suggested improvements section that will be added. This comparison will follow an argumentation that is outlined as follows. My prediction is closest to scenario SSP1-2.6, an optimistic projection of low future emissions. This is visualized in the figure below, however due to copyright this figure will not be included into the manuscript. I will however source this projection and compare 2044 values with my projected CO2 levels and the scenario's. I will source this database here as it is more recently updated:

<https://www.ipcc.ch/report/ar6/wg1/about/how-to-cite-this-report/>.



Line 128-130: this sounds a bit awkward and controversial: the data themselves are numbers, they are not "in English", and some may argue that the language of mathematics is also quite universal, maybe even more than music! In addition, the explanations surrounding these data are indeed in English, but so are the explanations given by the author in this paper. I'm personally not convinced that the point of such data-based musical piece should be to make data more understandable by anyone in the world. In my eyes, its key strength is rather to add an emotional content that is quite unique to music.

I agree with this comment. Additionally, the first referee commented something similar saying that these two sentences are not necessary and have prominent hyperbole. Therefore, I have deleted these two sentences also in order to highlight the emotional factor of my music in its urgency and gloom that it conveys.

Line 133: many sonification experiments are physically playable: for just two examples among others, see https://youtu.be/-V2Uc8Kax_g and <https://youtu.be/eYXxAE5grRQ>

This is a valid point. Physically playable sonification is not the most universally used forms of sonification, and the creative element makes it unique as each creative choice is made by myself personally. I will distinguish this fact from a unique methodology in general. I will acknowledge the fact that I am not the first to produce a physically playable piece of sonification, and I will acknowledge these two works in the manuscript through references of previous works.

On the score in table S1:

1. Explicitly identifying the movements would be very useful

This is understood and agreed that the clarity provided is extremely beneficial. This improvement will be completed.

2. Wouldn't it be more logical to adapt the time signature and possibly the tempo to the data? 4/4 sounds as logical as any other choice for yearly data, but for decadal averages why not using e.g. 10/4? and e.g. 12/4 for monthly data? (or 12/8 or 12/16? see previous comment on the 5*12 notes of movement 3).

The movement 3 instance has been addressed previously in this rebuttal, and the fact that the movements are in fact in their chronological order. The fact that this misinterpretation arises however shows the necessary structure and clarity that needs to be improved within my manuscript and product. I found that it was just as easy to change the length of the notes than changing the time signature itself. As this piece is designed to be playable, it is best if it follows somewhat standard formats, and 4/4 is the most standard time signature used in my experience. I have rarely encountered a change of time signature within a song or piece before, and therefore believe such a change would confuse the average musician and increase the level of difficulty significantly. Changing the lengths of the notes around this seemed like a better option, and defining the length value to time period per movement provides a clarity. I believe that it is beneficial to include an explanation to my artistic choices in the supplemental. This will provide room around word count and manuscript length, and provide an added clarity. I will complete this improvement.

3. A sustain pedal is mentioned for movement 5, it could be added to the score?

This can and will be added to the score.

Lines 122-134: I think the author could include a more thorough discussion on both the creation of this piece and any future related work. A few possible discussion topics:

- * feedback on the process of turning a fully data-based sonification into a musical arrangement? What were the main challenges faced by the author?

- * in many musically-oriented sonification experiments, pitch mapping is restricted to the notes of a particular scale (e.g. C major, E minor etc.). Here the author uses all 12 semitones, which makes it sound very "chromatic" and quite intriguing. Any feedback on this "chromatic" approach? (motivation, difficulties, etc.)

- * any plan to play it live on the piano, since this is mentioned as an original aspect?

- * potential interest of complementing the audio with some data visualization/animation or some visual art approach to make such data even more understandable by anyone, irrespective of language?

- * Any plan to communicate further on this piece, beyond this paper? (e.g. website, video, blog, art/science/communication events, etc.)

- * interest of using more musical instruments?

- * etc.

I agree with this assessment of my work and these topics are all worth mentioning. I additionally will include possibilities of using a similar method with other causes of climate change within the greenhouse gases. There is substantial data of these emissions recorded from the same Mauna Loa Observatory that would be highly relevant. I think the most important discussions that you bring up and mention are the challenges I faced, the use of all 12 semitones, and possibilities of furthering this project through data visualization and animation. I will gladly go into depth on these topics, along with the other highly relevant topics as well, providing the word count allows this.

Technical comments

Although I'm not a native English speaker, many sentences sound a bit awkward to me: the paper may benefit from an editorial review on this aspect.

Such a review would be beneficial in improving the communication of this paper. I will conduct such a review myself, and I will have a native English speaker with scientific writing experience review my edited manuscript before submitting the final version. I would of course welcome a similar editorial review on this aspect.

I have found this review to be helpful to the highest degree, and I am fully motivated to implement the dominating majority of the suggested improvements. I thank the referee for their diligent work.
