

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

February 11th, 2023

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

Author: Charles Jahren Conrad

RC1, Referee #1 comments and my responses (in boldface and blue text):

General comments:

Thanks for your contribution. A common pitfall of this kind of musification is that the music winds up sounding similar. Basically, if CO₂ or temperature is rising constantly and you link it to pitch, all the resulting music will sound roughly similar. However, by only linking one hand to the data while allowing the other to perform original music, you're doing something unique and you've managed to side-step that pitfall - so congratulations!

I hadn't encountered the GC-Insights type or submission before, so I realise that some of my comments may not be addressed within the format this kind of article. For instance, the manuscript doesn't strictly follow a scientific article template, ie it has no results or discussion sections. I'll defer to the editor to confirm whether they are required for GC Insight publications.

I'd like to see some comments on previous work on sonification of climate change data in your introduction. Typically, references don't contribute to the total word count, so you should be able to add as many as you'd like. Here are some starting points:

- Borromeo, L., Round, K., and Perera, J.: Climate Symphony, available at: <https://www.disobedientfilms.com/climate-symphony> 2016.
- Crawford, D.: Planetary Bands, Warming World string quartet, Video published by Ensia magazine, available at: <https://vimeo.com/127083533>, 2013
- the Climate Music Project (<https://climatemusic.org/>)
- de Mora, L., Sellar, A. A., Yool, A., Palmieri, J., Smith, R. S., Kuhlbrodt, T., Parker, R. J., Walton, J., Blackford, J. C., and Jones, C. G.: Earth system music: music generated from the United Kingdom Earth System Model (UKESM1), *Geosci. Commun.*, 3, 263–278, <https://doi.org/10.5194/gc-3-263-2020>, 2020.

It would be good for you to use these to highlight how your work is novel and different from previous approaches.

Thank you for the feedback and manuscript improvements, and for pointing me towards this relevant literature. I agree with your suggestion as to the value of commenting on previous climate sonification work. These references are suitable for verifying the impact of such climate sonification that I outline, and also to emphasize the uniquely playable trait of my sonification piece. Such references will highlight the individual immersion into the CO2 data that is possible through my piece. I will incorporate these into the manuscript.

The audio file:

- There are no clear breaks between the five movements. Perhaps a fermata and a bar of rest between them might help separate each movement?

Distinguishing the five movements from one another is vital within the paper, and should be easily distinguishable in the piece itself. In producing the digital audio file through *Logic Pro X*, I will add a measure of rest in between each movement and place a fermata on each movement's final note. This will also add a level of personal involvement for potential interested musicians, as they can decide how long this fermata lasts, effectively breaking up the movements. This will be described in the methodology additionally.

- The syncopation of the first movement makes it harder for me to perceive time passing. I think perhaps you could decouple the rhythm of the left and right hands such that the left hand is closely linked to CO2, but the right hand anchors the time signature. (This is an artistic choice so I leave it up to you whether this improves or deteriorates the piece.)

I understand this comment and its purpose in increasing timeline clarity for an audience. In my artistic evaluation of the piece, I believe that this would increase the difficulty of playing the piece and limit the clarity of the CO2 rise. Having the right and left hand play different rhythms throughout the movement increases the compounded nature of the lower tones and pitches prominent in this movement, as the right and left

hands would play at different times and often over each other. This would especially jumble the movement, and take away the focus of the CO2 data which especially in the introductory movement of the piece, is intended to be highlighted. Therefore, in my artistic evaluation, in order to keep the same level of CO2 rise clarity and to limit the degree of difficulty of the piece, I suggest that this change not be implemented.

- I'm not a huge fan of the sound of this instrument - it sounds very dry and digital. Perhaps a different virtual instrument might produce a better sound - or alternatively you may be able to use some reverb and Eq? If a huge budget were available, then you may be able to find a local recording studio with some expensive microphones and a grand piano you could use to record your performance. Or maybe a pianist on a service like Fiverr could perform and record it for you?

Unfortunately no budget is available for this project, so recording studio sessions and a pianist from a service is unrealistic. That being said, it is important to make the piece as auditorily pleasing as possible. I personally consider the Steinway grand piano the best standard virtual piano within *Logic Pro X*, however I fully concur with your assessment of the dry and digital sound. I have added reverb and Eq to this piano as suggested in order to address this area of improvement. Using *Chroma verb stereo*, I have added reverb to the middle and most dominant frequency ranges of the piece. I have set the wet factor to 50%, decreased dryness down to 85%, added a decay time of 1.1s, and set size and density to 60%. Additionally, I have Eq the sound, limiting the lowest and highest frequency ranges of the piece. I chose to limit these extremes as the audio sounds most digital when low notes are being played together and when high notes are played in unison. The sound seems digital and distorted at these extremes and with these improvements, the piece is immediately more enjoyable. I have included a dropbox link (I realize that this is only a preliminary place to keep this piece online) of the Statistical Composition in its edited version to show these changes:

<https://www.dropbox.com/s/qsnkg6hy763rapf/Statistical%20Composition%20%28Edited%29.mp3?dl=0>

I don't think that dropbox is the best place to keep a permanent record of this piece. The first place would be to append it to this article as a supplementary file. A scientific data repository might also be appropriate, something like zenodo or BODC, plus this would provide a DOI. As a backup, youtube or soundcloud or might also work for hosting, however it's not guaranteed that any of these companies will exist in ten years (including Dropbox).

I believe the scientific depository of *Zenodo* would be a suitable site to provide long-term access to the digital audio file and also the sheet music of the statistical composition. I have created an account and determined that this process would be straightforward and manageable when the changes to the piece are finalized, and I thank the referee for this valuable comment.

I'd like a section on how the recording was created as well. Did you program the MIDI and pass it to a virtual instrument or did you record a live performance? What instrument, microphone and interface (if any) were used? What VST have you used to generate the audio? Did you use a DAW, if you which one? Were any post-processed effects added? reverb, compression, delay etc. Was any mastering applied?

This comment is highly valued as including such a section on the digital aspect of the methodology will enhance the detail and exactness of how this piece was truly constructed. The DAW that I used was Logic Pro X, however when composing the notes around the data converted notes, I used the AKAI Pro MPK mini play keyboard. These notes were recorded digitally and then their rhythm and note value were confirmed and corrected within Logic Pro X. This MIDI keyboard connected directly to the computer running Logic Pro X, and no interface was necessary. Logic Pro X has the incorporated instrumental plugins and VSTs, and I used the Steinway Grand Piano in this manner to produce the digital sound. As for the submitted manuscript, no post processed effects or mastering was used. However, I have incorporated reverb, Eq and delay into the song as discussed above. What I outline here will be incorporated into the methodology section of my manuscript, improving the clarity and preciseness of the GC Insight greatly. Some of these comments may perhaps go into the supplemental considering space limitations of the GC Insight format.

The main criticism that I have of this draft is that the author does make quite a few unsupported statements in the abstract, introduction and conclusions. I've made some suggestions here, but I'd recommend a careful re-reading, to ensure that what is written is accurate, and not hyperbolic.

This is a completely valid statement. I am still learning to improve my academic communication, and instances of hyperbole and inefficiency are too prominent within my writing. I welcome all comments on this front as this will greatly improve the manuscript. Upon re-reading the manuscript, I too notice instances of lack of clarity and exaggeration, and I will continue to check for such disparities.

A second criticism is that there's only one image permitted in Insight articles, so you really need the figure to shine. You could have one pane about the sonification method, one pane about the recording method, one about the data derivation. At the moment, this figure is not very clear and it would really be worth putting in the effort to make it great.

On the whole, I'm happy with this as an Insight article, and I enjoyed the music.

Thank you for the detailed, thorough, and helpful comments and evaluation. The figure is definitely an important attribute to this manuscript. I have outlined how I will improve this farther down in this rebuttal letter.

Specific Comments:

Abstract:

L11: remove (parts per million)

Completed.

L12: remove (scale notes)

Completed.

L12-:L15: This entire sentence should be replaced with a brief but explicit characterisation of your method. Something like "CO2 measurements from Mauna Loa were linked to musical pitch to drive the sonification, but additional musical parts were creatively composed to balance the piece, add nuance, emphasis, and emotion to the piece." (This is the part of your work that really stands out to me: it's not 100% data driven, and the musical freedom that you allowed yourself makes it stand out. It's worth emphasising this in the abstract!)

I agree with this improvement as it specifies the “sonic experience”, introduces the origin of the data from Mauna Loa, and gives good overview of the insight. I will complete this improvement.

L15: Because -> As

Completed.

L16: I'm not sure this is true: "it provides a level of immersion beyond a visual or auditory understanding". However, I do agree that it certainly adds a sense of urgency and gloom to the data.

Thank you and I have altered the final sentence of the abstract as such: “it encourages engagement while adding a sense of urgency and despondency through conveying climate change to a broader audience in a new way.”

Introduction:

L20: If the goal of the project was to raise awareness of climate change, how do you do that? Have you tracked the number of listeners or shown where they came from? Were they already aware of climate change? To me, it looks like the goal was to generate and share a piece of music based on climate data.

Such impact tracking has not been carried out for this project and therefore this comment is very much appreciated. This sentence has been rephrased as follows: “The goal of this project is to create and share a piece of music based on climate data.”

L21: CO2 isn't an indicator of climate change - it's one of the main causes.

I have changed indicator to causes.

L23: Climate change is pretty well established at this stage. right?

I agree with this. The intent was to justify the use of new methods however this does not need to be outlined clumsily. I have made this more direct: “New engagement through new medias, such as sonification, is useful for conveying this dangerous trend.”

L25: remove "mathematically"

Completed.

L26: remove " that are playable on the Piano"

Completed.

L27-L29: This is unsupported.

I have included the reference used later in the manuscript of a lecture from Karen Mair in 2022 on Sonification for Geoscience (Mair, 2022) in order to justify this.

(Mair, K. Sonification for Geoscience Turning data into sound:

<https://www.youtube.com/watch?v=gh02Tb94oHs>, last access 21 June 2022.)

This can be further evaluated using the following source that you have suggested:

- de Mora, L., Sellar, A. A., Yool, A., Palmieri, J., Smith, R. S., Kuhlbrodt, T., Parker, R. J., Walton, J., Blackford, J. C., and Jones, C. G.: Earth system music: music generated from the United Kingdom Earth System Model (UKESM1), *Geosci. Commun.*, 3, 263–278, <https://doi.org/10.5194/gc-3-263-2020>, 2020.

Referencing this source would validate Sonification's impact towards accessibility and engagement to non-experts.

L29: remove "out"

Completed.

L29: Is this really a new type of sonification? There is definitely a precedent of other people combining data and musical choices.

Defining this as “composing a unique sonification” improves the clarity of this. This shows that I did not create a new style, but composed a unique piece instead. In response to a comment from RC2, I am citing two sources of sonification that uses a similar style of physically playable sonification.

L30: I don't understand how statistics got involved here or what is meant by statistically accurate? These are specific terms that don't fit this context. I recommend changing this to: "combines climate data and creativity", and "musical piece that is data driven"

These changes have been applied and I thank the referee for the improvements to my communication.

Sonification Use and Effect

L34: " auditory display:" (replace , with :)

Completed.

L35: remove " high index (" and following ")"

Completed. I have implemented the term indexicality 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). (Hermann, T., Hunt, A., & Neuhoff, J. G. (2011, November). *The*

Sonification Handbook. Retrieved February 11th 2023, from Sonification.de:
<https://sonification.de/handbook/>)

L47: remove "to those that are less able"

Completed.

L48-50: unsupported statement.

I have decided to remove this unsupported statement as it does not greatly enhance the argumentation that is later supported through references, and there is little evidence of climate sonification greatly improving accessibility for those who are visually impaired.

L52: What do you mean type of instrument? I only hear a piano.

This has been removed. Additionally, 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, linear time, frequency, amplitude, and rhythm, in creating the *Statistical Composition*."

L52: Might be worth reading and references Flowers 2005 here. The key thing to note is that it's actually quite hard to get a lot of information out of sound, especially as with a single instrument you can't modify the tone, and it's challenging to perceive small fluctuations in amplitude. (Flowers, J. H.: Thirteen years of reflection on auditory graphing: promises, pitfalls and potential new directions, Proceedings of ICAD 05-Eleventh Meeting of the International Conference on Auditory Display, Limerick, Ireland, 6–9 July, 406–409, 2005, http://sonify.psych.gatech.edu/ags2005/pdf/AGS05_Flowers.pdf)

I agree with this helpful comment that referencing this adequately to address both positives and negatives of the use of sonification. This will be implemented both here in the introduction and later in suggested improvements.

Figure 1: This figure is not very clear to me. Did you use monthly or annual data? Why are movements 1 and 2 shown as straight lines, but movement four is segmented? Third movement uses monthly data? I think you would be better served by having five panes, one for each movement, and showing the Mauna Loa monthly data in black, and the values that you used to drive the modification as separate coloured lines.

This is a very helpful comment. I have changed the figure as follows, and included the changed figure in this response below. I have separated the panes and made each movement distinct within its own pane. I also included a screenshot of the Logic Pro X

methodology as outlined in your comment for the sonification method. To incorporate the data derivation into a figure, I have added notes saying that a change in CO₂ converts to note value, and that a change in time converts into the song's rhythm. These notes are included along the axes of the Logic Pro X still (part b of the figure).

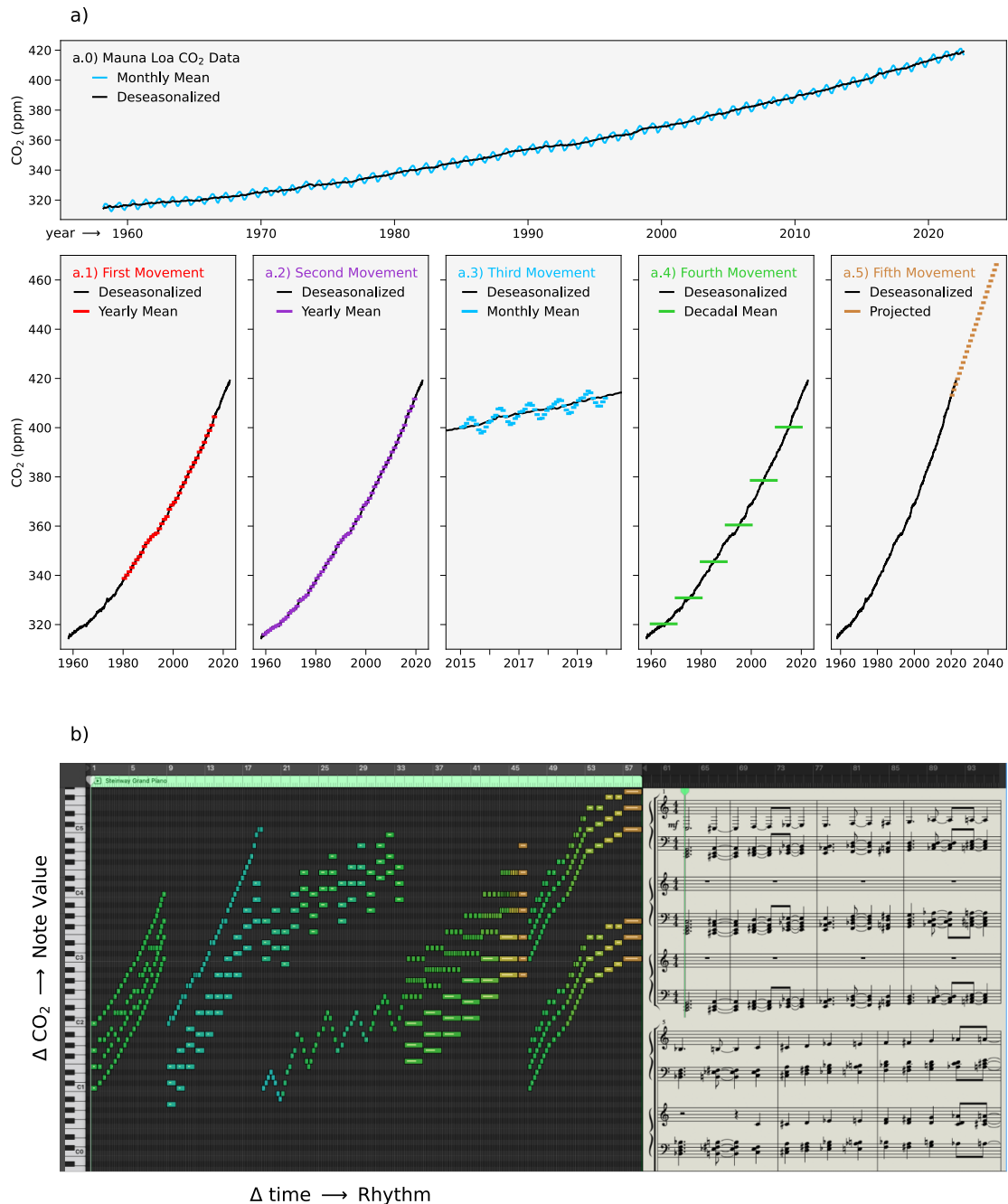


Figure 1: *Statistical Composition* movement data and audio methodology. (a) CO₂ levels (ppm) at the Mauna Loa Observatory, showing (a.0) monthly data and deseasonalized trends, and (a.1-a.5) the incorporation of this data in the respective movements of the piece. (b) Audio methodology showing a still from the Logic Pro X piano roll (left) and the resulting score (right) with data sourcing descriptors on the axes.

L55: this isn't really the methodology, it shows which sections of the data were used by the sonification.

I have changed this, stated above.

L56: you don't need the link to the dropbox file here.

Completed.

Methodology: Numbers to Notes:

L62: remove "basic":

Completed.

L63: I've never heard of a "common musical backbone". Can you elaborate on what this means?

This means a time signature of $\frac{4}{4}$, a quarter note having the value of a quarter of a measure, and the key of middle C. This is defined in the next sentence however this is not clear and will be made so. I have also addressed this in response to referee 2, RC2.

L72: We typically use "annual" instead of "yearly", but as this is the title of the movement, it's an artistic decision.

I agree with this use of common terminology and have changed the title of the movement to "annual". This has also been completed throughout the rest of the manuscript.

L72: For this and the other movements, please indicate at what timestamp they begin in the recorded piece.

This is understood and will be changed.

L82: "and the value had to exceed the closest note value, promoting positive change": What does this mean - can you make it clearer, please?

This has been changed to "All values were rounded down to their respective notes, which slightly reduces the CO2 emissions that are conveyed in the piece."

L98: Decade -> Decadal

Completed.

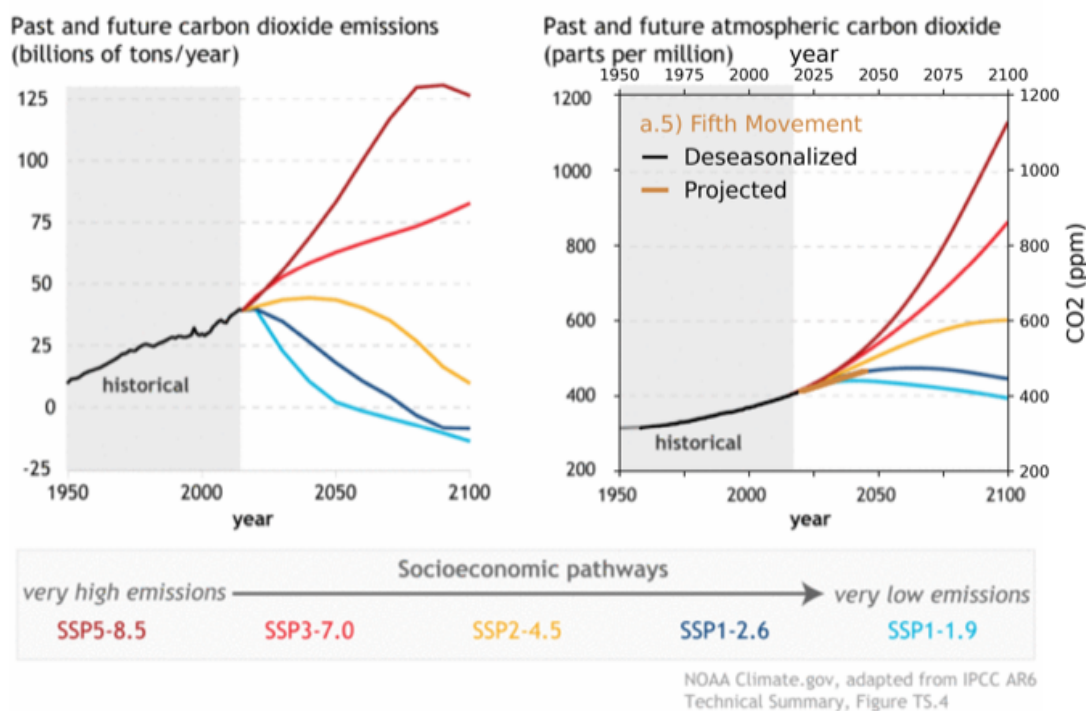
L109: Is there any reason why you fitted to recent data rather than using established CO2 projections (SSP5-8.5 or even RCP8.5 would both be appropriate.) Ultimately, I suspect the difference is small, but you may reach a wider audience using these well-established projections.

The reason this method was used was to show how CO2 emissions would increase if the rate of change stayed constant, something that history has proven to be untrue as this rate itself increase. My use of a fitted future projection is effectively showing an optimistic projection that still creates urgency and despondence in the rising CO2. This can also be discussed in a challenges and future work section. I agree that it would be worth comparing to these established CO2 projections.

I am including my response to RC2 surrounding this same area of improvement:

“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/>. “



L124: uniquely playable -> unique and playable

Completed.

L124: piano song -> piece for piano

Completed.

L126: song -> piece

Completed.

Ethical statement

The ethical statement should be after the conclusions.

Completed.

Conclusions:

L129: "only available in English": I don't think that Mauna Loa data is in English! It's just Arabic numbers!

I have deleted this statement, and yes I agree with this improvement. The cite itself is mostly English, however I realize that it can be translated and that my manuscript is itself in English as well. Interesting to think about how both numbers and music are universal to a certain degree!

L130: This is a bit of a bold statement: "anyone in the world can understand, regardless of what language they speak". It's not clear to me that it's true. I'm not sure that this piece would make sense if you just heard the music. In order for it to mak sense, it needs to be explained in context that it is derived from climate data.

This is understood and agreed with.

L128-130: To be honest, I think you can safely remove the first two sentences of this paragraph.

I agree with these comments and recognize the hyperbole in these sentences. These sentences have been fully removed to avoid confusion and hyperbole.

L132: "providing a unique musical and scientific experience." While this is indeed a unique experience, it's not what I would focus on here in the conclusions.

This has been removed.

I'd like to see some suggestions on potential improvements. Ie, alternative datasets, audience survey, etc. See for instance de Mora et al, mentioned above.

This is a very sound comment on a truly lacking part of my manuscript. Potential improvements would be (as outlined) a survey to estimate impact and the function of my piece, the use of alternative data sets, and incorporating a visual animation that depicts the data's rise in value in coalition with the playing of the piece. This will be included prior to the conclusion. I will add these suggestions for ways to move forward with this particular type of study. For example, does learning and playing the piece actually give an improved understanding of climate change?

Supplement:

Table: Please add a caption or a description of the table.

A sufficient caption will be provided.

Sheet music:

- Please add the tempo

This will easily be implemented.

- Please add the instrument (piano)

This will be specified.

- You may want to add notation of when to hold and release the pedal.

This shall be included into the score.

- Please indicate where each of the five movements begins and ends. I'd recommend a double bar line at the end of each movement, as well as the title of the movement (ie Movement one: 40 years of yearly increase).

I concur with this improvement and I will correct this.

- This would also be a good opportunity to clarify where data came from directly in the music. I.e. notes on the pdf stating "right hand plays annual mean CO2 from 1960-2015" or similar.

I agree that this provides an opportunity for sufficient structure in the movements and piece. This will be completed.

These improvements will improve the supplement and my communication. The separation of the movements is vital and is therefore quite necessary.

I thank the referee for each of these helpful comments. I am motivated to address each area for improvement within my manuscript and greatly appreciate the detail in which the referee evaluated my work.
