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Dear Geoscientific Communication editors, referees and reviewers,

We received two review comments and one short comment. We have addressed their comments in this document, and made changes to the main document, also attached. We're like to thank both anonymous referees and the short comment author for their helpful comments. Thanks to their contributions, this work is in a much better state and should be easier to follow.

For clarity, we will reproduce the comments and respond to them in turn. Our responses are marked in bold and begin with **"LdM:".** The new text are included with an indent and may include some latex grammar. Alternatively, a document showing the difference between the old and the new version is also available.

Sincerely,

Lee de Mora – representing the authorship team.

Anonymous Referee #1

The article is well written and very interesting. Below we provide feedback to the author's that we hope is useful. This was co-reviewed by myself and a colleague, and we ourselves are a science-art collaborative team. This co-review of the article was agreed by Editor Sam Illingworth.

LdM: Thank you both for your review and for the kind words. Also, thanks to Sam for allowing this novel team review approach.

1. As this is a pilot study, it is clear why only one tool was utilised to gather and analyse data towards the reach, engagement and audience of the channel and the videos. Nevertheless, it would be very useful for readers and those who might like to expand on this methodology and methods if the choice to not triangulate the data was stated as one of the limitations, and discussed. You could highlight in the introduction that this is a pilot study, stating it explicitly, and then follow-up with a brief discussion about the experimental character of the research and why in this instance the focus was not on triangulating findings, but to present the study. If you are planning additional evaluation and analyses it would be useful to highlight that, even if briefly, in the discussion.

LdM: At the request of referee #2, we added a limitations section. That goes into more detail about this. We've also added a short paragraph to the introduction to explicitly point out that this is a pilot study.

> It should be noted that this work is an early pilot study. The aims of the project are outlined below in sect.~\ref{sec:works}. The limitations of this approach are outlined in sect.~\ref{sec:limitations}.

2. The authors' choices for tempo, genre, and scale of each composition (allegro, vivace, aria etc.) adds to the "emotional connection" mentioned in line 213. There is value in the authors elaborating on these choices, and to explain if the reason of each choice is due to the feeling that the data are expressing. For example, for Earth System Allegro, one can notice that the authors describe it as "[. . .] a future scenario in which the anthropogenic impact on the climate is at a minimum" (line 225). This could be perceived as a happy scenario, and is potentially why the authors aligned it with the allegro rhythm, because allegros are usually lively and merry tempos, able to express and communicate positive and happy scenarios. It would add richness to the methods and explanation of data interpretation for the reader if more details like those that I expressed above could be included in the descriptions of all the pieces.

LdM: We have added additional explanations of how the artistic choices were made for each piece in their descriptions. These are:

> 3.1.1 Earth System Allegro
>
> The C major scale is composed of only natural notes (no sharp or flat notes), making it one of the first chords that people encounter when learning music. In addition, major chords and scales like C Major typically sound happy. Christian Schubart's `Ideen zu einer Aesthetik der Tonkunst` (1806) describe C major as "Completely pure. Its character is: innocence, simplicity, naivety, children's talk." As this was the first piece in the series, the link between

this seemed an appropriate way to start the Earth System Music project. Through choosing C major and an upbeat tempo, and data from the best possible climate scenario (SSP1 1.9), we aimed to start the project with a piece with a sense of optimism about the future climate and to introduce the principles of musification of UKESM1 time series data.

In this piece, the Drake Passage current is set to the C major scale, but the other three parts module between the C major, G major, A minor and F major chords. These are the first, fifth, sixth and fourth chords in the root of C major. This progression is strikingly popular and may be heard in songs such as: \textit{Let It Be}, by the Beatles, \textit{No Woman No Cry} by Bob Marley and the Whalers, \textit{With or Without You} by U2, \textit{I'm Yours} by Jason Mraz, \textit{Africa} by Toto, among many others. By choosing such a common progression, we were aiming to introduce the concept of musification of data using familiar sounding music and to avoid alienating the audience.

3.1.2 Pre-industrial Vivace

As with the \textit{Earth System Allegro}, \textit{Pre-industrial Vivace} uses the familiar C major scale but adds a slight variation to the chord progression. The first half of the progression is C major, G major, A minor and F major, but it follows with C major, D minor, E minor and F major. Through using the lively vivace tempo and a familiar chord progression in a major key, this piece aims to use musification to link the pre-industrial control simulation with a sense of happiness and ease. The lively, fast, jovial tone of the piece should match the pre-industrial environment which is free running and uninhibited by anthropogenic pollution.

3.1.3 Sea Surface Temperature Aria

Musically, this piece is consistently in the scale of A minor harmonic with no chord progression. The minor harmonic scale is a somewhat artificial scale in that it augments 7th note of the natural minor scale. The augmented 7th means that there's a minor third between the 6th and 7th note, making it sound uneasy and sad (at least to the author's ears). An aria is a self-contained piece for one voice, normally within a larger work. In this case, the name aria is used to highlight that only one dataset, the sea surface temperature, participates in the piece. This piece starts relatively low and slow, then grows higher and louder as the future scenarios are added to the piece. The unchanging minor harmonic chord, slow tempo and pitch range were chosen to elicit a sense of dread and discord when looking towards the catastrophic SSP5 8.5 scenario.

3.1.4 Ocean acidification in E minor

This piece uses a repeating \textit{12 bar blues} structure in E minor and a relatively fast tempo. This chord progression is an exceptionally common progression, especially in early blues, jazz and early rock and roll. It is composed of four bars of the E minor, two bars of A minor, 2 bars of E minor, then one bar of B minor, A minor, E minor and B minor. The twelve bar blues can be be heard in songs such as: \textit{Johnny B. Goode} by Chuck Berry, \textit{Hound Dog} by Elvis Presley, \textit{I got you (I feel Good)} by James Brown,

\textit{Sweet Home Chicago} by Robert Johnson or \textit{Rock n Roll} by Led Zeppelin. In the context of Earth System Music, the 12-bar pattern with its opening set of four bars, then two sets of two bar and ending for four sets of one bar between key changes drives the song forward before starting again slowly. This behaviour is thematically similar to the behaviour of the ocean acidification in UKESM1 historical simulation, where the bulk of the acidification occurs at the end of each historical period.

3.1.5 Giant Steps Spin Up

The music is based on the chord progression from the jazz standard, John Coltrane's \textit{Giant Steps}, although the musical progression was slowed to one chord change per four beats instead of a change every beat. This change occurred as an accident, but we found that the full speed version sounded very chaotic, so the slowed version was published instead. This piece was chosen because it has a certain notoriety due to the difficulty for musicians to improvise over the rapid chord changes. In additional, \textit{Giant Steps} was the first new composition to feature Coltrane changes. Coltrane changes are a complex cyclical harmonic progression, which forms a musical framework for jazz improvisation. We hoped that the complexity of the Earth system model is reflected in the complexity of the harmonic structure of the piece. The cyclical relationship of the Coltrane changes also reflects the 30 year repeating atmospheric forcing dataset used to spin up the ocean model.

3.1.6 Seven Levels of Climate Change

As the piece progresses through the seven levels, the behaviour of the model becomes more extreme, matching the increasingly esoteric harmonies of the music.

3. More specifically, in the Quantification of Reach section more detail could be provided to support the evaluation component of this work. We recognize this is a pilot study, but even then there is the potential to include perspectives shared by others (qualitative data), and to use these data as a starting point to build a stronger understanding of how this work is 'reaching' others. For example, you didn't include data on shares or people's comments or shared perceptions (qualitative data) about the project as shared through particular social media platforms.

LdM: We have added a section to the results that list all the comments on social media.

The following statement were posted via social media. These were posted directly on the YouTube video page, or on social media posts linking to the video via facebook, twitter and reddit. Note that we have removed emojis and gifs, but otherwise reproduced comments as they originally appeared.

\begin{enumerate}

\item This one was very dramatic.

\item It gets quite dramatic after 1950-60

\item This was submitted as a scientific research paper here, but don't understand what the point is.

\item Wow! That's awesome!

\item Great idea

\item That's Crazy!!

\item Awesome! Personally I was hoping to hear something of the same ilk as system of a down or similar. Does make modelling sound far more upbeat though

\item Brilliant idea! Just like Herman Hess's book 'The Glass bead Game', where data is unified from many sources and brought together by many senses. Listen to how the ocean sings!

\item AMAZING!!!!

\item A total new meaning for the "listen to the ocean" motto

\item That's awesome! Can you post this to someone with a bigass twitter handle. This deserves more attention. Maybe send it to Adam Rutherford at Inside Science?

\item It's quite different from the previous one! Super Cool stuff!!

\item This is amazing. If you can find a setup that would cause noticeable change in the music between pre-industrial and future you're viral

\item I love this!! Well done!

\item This is amazing ! Was initially quite surprised that these weren't more tonally chaotic - then I read I the blurb for the top video. I presume that you could do the same with any choice of key and scale? Also, I hope you realise that, with your choice of C-major, you have made something worthy on inclusion in the next Axis of Awesome medley

\item Certainly very interesting, but it lacks a lot of human touch. These generations don't seem to take into account many compositional techniques that are almost vital to make a comprehensive piece of music, such as motifs, dynamics, musical form, things like that. I found that there wasn't much for the ear to catch onto musically, no clear melodies, rhythms, harmonic progressions etc. Because of this it can also be quite hard for a human to learn, adding on to the challenge of coordinating the strange rhythms between the hands. So it's cool, but very unhuman music and thus most likely difficult for humans to play.

\item I think if humans would take their time to learn this, the musical phrasing they would bring to the table could do a lot to make the pieces easier and more enjoyable to listen to. I think computer made music is very cool in that it really highlights the amount of complexity that goes into creating music as we would know it, namely through the human mind. So the kind of research you're conducting is very valuable indeed!

\item Wow this actually sounds very interesting! Sadly I'm not a very accomplished pianist either, but I'll leave this comment and upvote for visibility.

\end{enumerate}}

And I've expanded the discussion section about the audience

> The comments from social media were listed above in sect.~\ref{sec:results} and were almost all positive and supportive. However, these comments are biased towards the authors friends, family and professional colleagues. These comments include several positive comments and praise, comments about the pieces themselves (``it gets dramatic at 1950-1960``), comparisons to other musicians or works of art (e.g. System of a down, Herman Hess's book Glass bead game, the Axis of Awesome medley), one person ``didn't understand what the point is``, and the final three comments were from a music forum and contain some interesting insight into the musical side of the work. While we hoped to disseminate information about Earth System modelling to a wider audience, it's not possible to determine whether the audience learned anything about Earth System modelling using the metrics provided by YouTube studio or the comments posted on social media. Furthermore, it is not possible to determine whether the audience was composed of laymen or experts. As this was a pilot study, we did not go into greater detail to understand the audience reactions. Future extensions of this project should include a survey of the audience, investigating their backgrounds, demographics, what they learned about Earth System models and their overall impressions of the pieces. This could take the form of an online survey associated with each video, or a discussion with the audience at a live performance event.

While I agree it can be useful to have demographic data, it wasn't clear from the start of the paper that you were interested in the demographic of people that this work reaches.

LdM: I would include the demographics of the audience under the wider term, "reach", which is appears in the abstract and even in the title. Nevertheless, I added the word demographics to the following sentence in the introduction:

> This toolkit allows content creators to monitor the reach, engagement and audience demographics (age, gender, country of origin) for their channel as a whole, as well as for individual videos.

Equally, you report on the nation that YouTube viewers were from in your results, which is fairly limited demographic data, and don't include other data despite having noted its availability in your methods section. From a reader's perspective it isn't only interesting how many people the work reached or who those people are, but also what their perspectives of the work was and any messages that emerged from viewers that could inform our broader understanding about what people took from viewing and experiencing this work. It would help readers to know more about the 'experience' in addition to the 'reach' and the authors could begin to form this with a content analysis of the comments or perspectives shared, and even brief quotes of feedback and perspectives shared by others to offer some insight to people's perspectives.

LdM: We have added the section above and an discussion on the viewer feedback.

4. We include a few more specific questions about the quantification of reach below.

p2 line 52 "provides additional contextual clues to aid the interpretation" Please elaborate on why this happens e.g. the animated graphs provide information usually not available or not attractive enough to read for the general public.

LdM: This paragraph confused two points and was split up to read:

> With the ever-growing interest from the general public towards understanding climate science, it is becoming increasingly important that we present this information in ways accessible to non-experts. It is also becomingly increasingly easier for scientists to use tools such as social media to engage with non-experts audiences and the wider public.

And the section about contextual clues to aid the interpretation was removed.

p7 line 159 "The conversion from model data to musical pitch is performed in two stages. First [. . .]" Please clarify what is the second stage.

LdM: The text here was changed to:

> The conversion from model data to musical pitch is performed in using the following method.

p7 line 164 "[. . .] is an artistic choice" Is there a concept behind that artistic choice each time? Does something trigger the composer to choose a specific scale and not choose another? It help the reader to know if there are any creative or conceptual reasons behind these choices or if it is mostly due to the desirable harmony or aesthetics of the final composition.

LdM: We have expanded following section to the methods section to more accurately describe the role of the artist in creating the piece:

> While the method is relatively straightforward and repeatable, each piece has a diverse range of settings and artistic choices made by the composer: the choice of datasets used to determine pitch and velocity for each track, the pitch and velocity ranges for each track, the piece's tempo and the number of notes per beat, the musical key and chord progression for each track, and the width of the smoothing window. The choice of instrument is also another artistic choice, although in this work, only one instrument was used, the TiMidity+ piano synthesizer. As a whole, these decisions allow the composer to attempt to define the emotional context of the final piece. For instance, a fast-paced piece in a major progression may sound happy and cheerful to an audience who are used to associating fast-paced songs in major keys with happy and cheerful environments. It should be mentioned that there are no strict rules governing the emotional context of chords, tempo or instrument and the emotional contexts of harmonies, timbres and tempos differ between cultures. In a scientific context, exploiting the western musical traditions can allow the composer to imbue the piece with the associated emotional musical cues.

p14 line 355 How was the playlist shared?

LdM: The text was changed to:

> Each piece was also added to a YouTube playlist, which was shared via social media in the same way as the individual pieces.

P14 line 341 Note that the authors highlight that most views occurred after the first few days, and this is also presented again in the results. It would be better to highlight this as either an element of the method or as a result, but not as both.

LdM: This fits more in the results section than in the methods section, so it was removed from the methods section.

p14 line 355-57 Please provide reasoning for why broader networks were not engaged and why press releases weren't used to disseminate the research or playlists. This is a primary stream of sharing research, and media teams are trained in helping to guide how research and outputs are shared and delivered to others. Could your reach have been greater had you employed / utilized the resources available through those existing networks? Equally, paying to transmit the research and outputs would likely increase the number of people the work 'reaches', why was this avoided?

LdM: In practice, this was a zero-budget trial study. We were not able to budget the staff time in the communications team, nor were we able to purchase reach through youtube advertising. We have raised these are potential future avenues to reach a wider audience.

The text was changed to:

> As this was a pilot study, there were no particular timed-releases, no press release and no direct assistance from the PML, NERC or UKESM communications teams. The videos were then disseminated through these networks and allowed to reach wider audiences. In addition, no paid advertisements were purchased. Please see sect. 6 for a discussion on possible extensions to this pilot study where these avenues could be explored.

Also note that we plan to produce a press release should this paper be accepted for final publication. That pulibcation and subsequent press release may become a new startring point to count views for this work. We may also time the publication of a new piece to coincide.

If the goal was to get the research to different people then using those tools would assist, and it is then not too surprising that the research was primarily viewed only in the first few days; this could potentially have been overcome by having invested more into the transmission of the research and working with different traditional and social media tools. More explanation is needed as to why different tools weren't used, and potentially for the authors to consider if the approach used to evaluate 'reach' might be better removed from this particular paper that is heavily focused on the methodology and method, and included in a subsequent text that explores evaluation, reach, and viewer experience in greater detail and in a more robust way.

LdM: We have changed to goals to more accurately reflect how we view these works. This work was more of an exploration of the use of music to communicate science rather than an outreach experiment with pre-defined research questions. We learned about it as we went and explored

what was possible. In this work, we hope to explain some of the things that worked and some that didn't for us. It should be noted that none of the authors have experience in outreach research.

p18 line 420 "[. . .] Sea surface temperature aria" Consistency note: The titles are presented in italic and with the initial letter capital throughout the article. Please change to: Sea Surface Temperature Aria.

LdM: Fixed.