Warming/

Can the urgency
of the contemporary climate crisis
be amplified via the sonification
of weather data?

Warning

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To listen is to lean in softly with the willingness
to be changed by what we hear.

— Mark Nepo

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And finally, to Leah, for being there whatever the weather.

Keywords

#Sound Design
#Data Representation
#Climate Crisis

Introduction

This project explores the application of sonification techniques to translate numerical weather data into meaningful soundscapes, with particular attention to musical qualities such as pitch, and in the larger context of Spotify as the creator and curator of this climate initiative.

It does so, first and foremost, with the altruistic aim of enhancing the analysis and mass-understanding of meteorological phenomena and their implications. The project proposes the creation of a digital platform which serves a source of information and education within the current reality of climate change and the extreme conditions that it has brought about.

Secondly, and here drawing on the author's expertise in sound and visual design as two individual entities, the project investigates how auditory representations of information sets (weather and meteorological patterns, in this particular case) can provide new and complementary insights into traditional data visualisations.

This project finds itself within the design-adjacent areas of branding, sound design, and data design, bringing together data visualisation (often, as the name implies, disseminated graphically) and sonic design: at their intersection is sonic data representation, or sonification. Furthermore, the research will also divert into human psychology in an attempt to better understand the cognitive processes behind hearing—especially when the sound we perceive happens to be music. The work is not necessarily tethered to any particular time or place; however, whenever a situational example is required, Barcelona is often used as

the setting, given that it is the place of writing and the geographical inspiration behind the project.

In fact, the primary motivation for this thesis has been the relentlessly warm and sunny weather experienced in Barcelona during the late months of 2023. That year was globally the hottest year on record, even if only the second-warmest for Europe, after 2020 (Copernicus, 2024). Spain is getting "hotter, drier and more flammable" (Miller, Santillo, & Johnston, 2023)—and it is generally recognised that immediate action and intervention are clearly required on both an individual and societal level.

Meanwhile, however, contemporary representations of weather data do not go far enough in describing the crisis attached to global warming, its influence on the planet we call home and, by extension, its urgency. One can speculate various reasons for this insufficiency: "more communicators joining the debate, and social media changing the affordances of communication" (Schäfer & Painter, 2020), to start. Gatekeeping, or the selective 'curation' of information, so to speak, is too common an occurrence. Is it then a question of the changing landscape of journalism? Or of science and academia? Regardless, as global warming accelerates, communicating its impacts becomes all the more paramount.

On that note, the selection of sound as a means of data representation was not a random one. "Music is a direct line to emotion" (Folsom, as cited in Becker, 2019) especially when composed or created with the specific intention of communicating meaning. The myriad tools in its arsenal, from the most basic note scales to the more complex harmonic overtones, hold undeniable power—individually, first and foremost, but especially when combined (with intention, of course) and given over to the listener (Ball, 2011).

The tool proposed as a result of this research is one which communicates weather data—past, present, and future—as sound. This does not imply the exclusion of visual content and data, although they will be used secondarily and as a complement to the audio. At launch-stage, it would primarily be made available as an in-browser website and as a new feature integrated within the Spotify app. It is intended for personal use, though there is potential for future collaboration with various types of major entities.

Using meteorological data sets sourced from open-source weather APIs, as collected and used in weather stations, satellites, and climate models, the project looks to leverage the unorthodox conversion of data parameters (in this case, ones such as temperature, rainfall, and wind speed) into sound parameters. Although core qualities like amplitude and timbre will also be considered, their use will be sparse and secondary—the primary sonic expression will be made via pitch, i.e. harmony and dissonance. The specific details relating to this will be explained and justified in section 1.3, titled Theoretical Framework, then explored in Formalisation, section 2.3.

The ultimate goal of the project and the accompanying research is to create soundscapes which, when representing anomalous weather conditions, are dissonant. They therefore cause an unease in the listener which is deemed necessary given the urgency of the climate crisis. This dissonance is primarily identified as such by previous research, but also supported by personal knowledge, field studies, and user testing. The latter two were deemed imperative to

assist the former, given the subjectivity of sound and music.

Beyond stand-alone soundscapes, this research also proposes the future integration of real-time data streams, historical weather records, and meteorological forecasts, allowing (and encouraging) interaction with dynamic soundscapes. These features would present accurate information on current weather conditions, contrast trends over time, and provide an educated view of what the future holds for our warming planet. Collaboratively, they aspire to inspire action.

All of the above points promise myriad potential outlets and collaborators, especially within the sectors of education and entertainment (and their intersection, especially), that would further highlight the scope of the thesis and extend its aims. Moreover, the eventual goal of the research is to create new discoveries and progress in the field of auditory data representation (see section 2.1.4) as well as contribute, however humbly, to the slow but steady mitigation of the climate crisis.

This thesis was written for a general audience. The reader will not need specialist knowledge of music theory, psychology, or meteorology to understand or enjoy it.

Chapter One—

Research

1.1 Context

This section delves into the contextual framework of the project, setting the stage for an exploration of its three core elements and providing the foundational understanding necessary to appreciate the intricate interplay of these elements in the project's pursuits.

1.1.1 Warming

The escalating climate crisis is pervasive, and so are its repercussions. The effects are felt worldwide, with each region experiencing unique challenges. Barcelona, with its distinct climate and urban landscape, serves as a case study to illustrate the tangible impacts of global warming. First, however, let's examine the situation at large.

A Global Climate Crisis

In 2023, June and the months following it saw unprecedented global temperatures which resulted in 2023 overtaking 2016 as the warmest year on record—and by a large margin, at that, "with global temperatures close to the 1.5°C limit" (Copernicus, 2024).

2023 had an average global temperature of 14.98°C—that's 0.17°C higher than in 2016—and marks "the first time on record that every day within a year has exceeded 1°C above the 1850-1900 pre-industrial level" (Copernicus, 2024). Almost half of the year's 365 days were more than 1.5°C warmer than the 1850-1900 level; two days in November were, for the first time, more than 2°C warmer. As of the time of writing, May 2024 was the warmest May on record, marking the 12th consecutive month in which the global average

temperature reached a record value for the corresponding month in any previous year.

> The earliest signs of how unusual 2023 was to become began to emerge in early June, when temperature anomalies (relative to 1850-1900 pre-industrial level) reached 1.5°C for several days in a row. This had never previously happened at this time of the year. For the rest of 2023, global daily temperature anomalies above 1.5°C became a regular occurrence... (Copernicus, 2024)

The average temperature of the Earth's surface is now "warmer than at any time in the last 100,000 years," the United Nations reported. In 2024, the world experienced the warmest January on record. And, just as alarming, "the change in annual temperature from 2022 to 2023 was larger than any change from one year to the next in the ERA5 data record"—and yet, it wasn't predicted as such (Copernicus, 2024).

Sifting through this data (and retaining a sense of optimism) was the toughest part of this project. It also gave it all the more reason to exist.

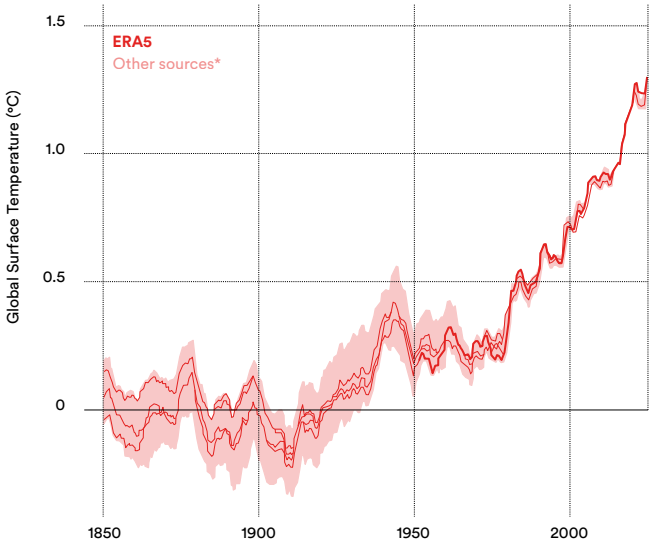
It's Always Sunny in Barcelona

In perennially warm locations such as the Mediterranean, the effects of climate change are reaching an undeniable stage of impact on a personal and quotidian level. In parallel, the global consequences "now include, among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity" (United Nations). An unparalleled amount of extreme events were recorded in 2023 alone.

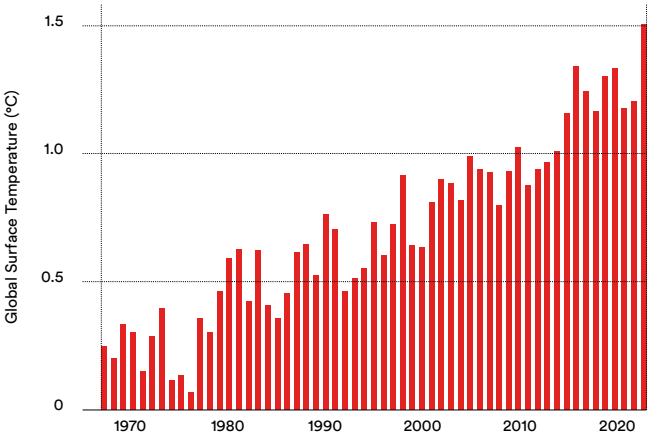
Between first-hand experience, a continuous barrage of news headlines, and the perpetual presence of weather applications in our pockets, it can be said that the realities of climate change are impossible to ignore.

Figure 1: **Global Temperature Increase**

(A) 5-year average, since 1850



(B) Annual averages, since 1967



*Other sources include JRA-3Q, GISTEMPv4, NOAAGlobalTempv5, Berkeley earth, HadCRUT5. ERA5 and JRA-3Q data are only shown from 1948. Shaded area represents the uncertainty for HadCRUT5 data.
Credit: C3S/EDMWF.

However, knowledge has not equated action: day-to-day life has only minutely changed, while large-scale policy adoption lags even further behind (Hornsey, Harris, Bain, & Fielding, 2016).

Why is this so? Is it because individuals—be it an average citizen or the CEO of a large conglomerate—do not recognise that they have a role to play in the global movement against climate change?

And, in turn, is that because contemporary representations of weather data do not go far enough in describing the crisis attached to climate and global warming?

On any given day, there are news stories, academic studies and memes that support two duelling narratives: the fatalistic view that global warming is out of control, and the more hopeful, technocratic outlook that, while the challenges are real, the solutions are within reach.

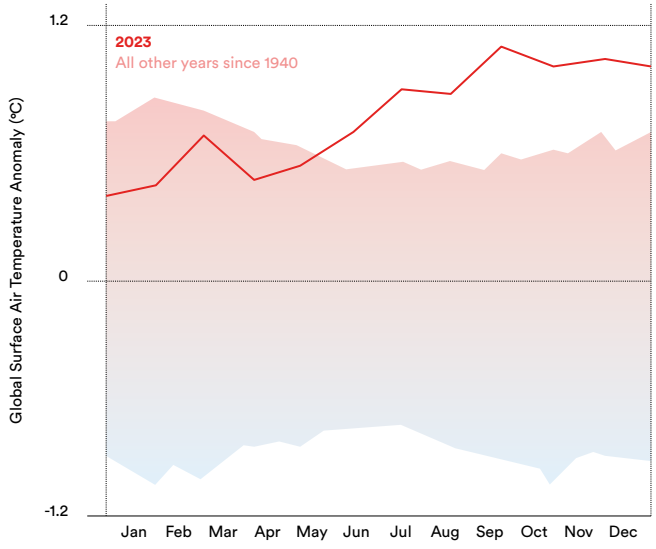
Although research activity in recent history has undeniably risen strongly and spread to include new media and an increasing number of countries, dissemination of crucial information has still been concentrated in Western countries and print media (Schäfer & Schlichting, 2014). Data also tends to be dense and, at times, inaccessible to everyone except the climate scientists who compiled it. The issue, then, is not merely the circulation of information but also the form in which it is represented.

This research takes as its starting point the inequality between the realities of climate change and their representation in contemporary media.

1.1.2 Warning

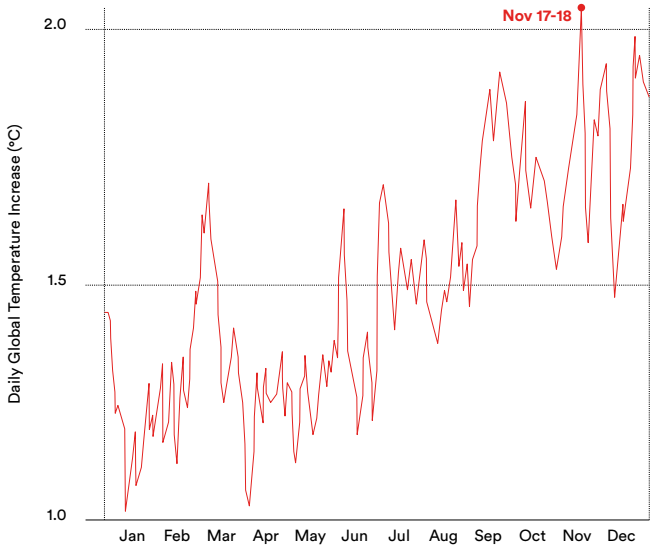
The premise, therefore, is that the innovative sonification of weather data, transforming raw information into a novel form, would result in the

Figure 2: **Monthly Temperature Anomalies**



Data: ERA5 1940-2023. Reference period: 1991-2020. Credit: C3S/EDMWF.

Figure 3: **Daily Temperature Increase in 2023**



Data: ERA5. Reference period: Pre-industrial (1850-1900). Credit: C3S/EDMWF.

creation of auditory warnings (so to speak) that resonate with broader audiences.

Using sound as warning is nothing new: fire alarms, school bells and car horns all notify us to pay attention to our immediate surroundings. Relatively recent developments in the music industry and in music consumption patterns further augment the project's potential.

The Age of Streaming

Streaming platforms have revolutionised the way music and other forms of sonic media are consumed, becoming an integral part of daily life for millions of people worldwide. Their importance lies in their ability to democratise access to a diverse range of audio content: users can explore music from around the world, discover new artists through personalised recommendations, and enjoy curated playlists that cater to every mood and activity.

This level of individuality and accessibility has significantly transformed the music industry, shifting revenue streams from physical sales and downloads to digital streaming, which accounted for a 67.3% share of the music industry's global revenue in 2023 (IFPI, 2024).

It therefore follows that streaming services currently play a critical role in the modern media landscape. Unparalleled access to a vast array of content has shaped industry trends—and so the cycle keeps repeating.

The sector's continued growth and adaptation underscore the priorities and values of the consumer (that's you and me) in today's digital age. The consumption of music streams has increased by 2.5 times since 2017, and barriers to the creation and distribution of music continue to fall (Goldman Sachs, 2023), cementing streaming services' place as indispensable tools for both consumers and creators.

While the sector will indubitably continue to grow, there is definite potential for new business opportunities: the music industry is "on the cusp of another major structural change," according to Goldman Sachs Research, even if its workings are beyond the understanding of the average listener. It is also worth noting that the medium is not without pitfalls or room for improvement. IFPI's Chief Legal Officer and Interim Joint Head of IFPI, Lauri Rechardt, rightly pointed out the importance of acknowledging "the challenges the industry faces, including streaming fraud, digital piracy in all its forms and, of course, the threat from the abuse of generative artificial intelligence if it is not developed responsibly and with respect for artists' and labels' rights" (2024).

Data Sonification and its Potential

In a world where information is predominantly communicated through visual means, the process of translating data into sound offers a powerful alternative. Charts, plots, infographics, and even animations are today considered 'common' graphics, and although they do communicate complex data relationships and data-driven insights in a way that is easy to understand (IBM), that does not always equate them doing so effectively.

Sonification is not a new technology; it dates back to 1908 with the invention of the radiation monitor known as the Geiger counter (Jones & Joyce, 2023). And yet it has found a new strength today, coupled with the rise of audio, as has just been shown.

Essentially, the world is already listening.

Recent examples of effective data sonification illustrate its potential. One notable instance is the sonification of COVID-19 data by researchers at the Massachusetts Institute of Technology (MIT), who transformed the structure of the coronavirus into musical compositions—and, most importantly, they did so during a time when the media was saturated with images and numbers describing the same data. These compositions allowed listeners to perceive information in a new way, through changes in pitch, rhythm, and harmony. The benefits don't end there: "the new format can help scientists find sites on the protein where antibodies or drugs might be able to bind" in a way which is "faster and more intuitive than conventional methods used to study proteins" (Venugopal, 2020).

Another striking example is the sonification of black hole data by NASA, where the complex and often abstract data from these cosmic phenomena were converted into sound. There is an added level of innovation: the sonification "revisits the actual sound waves discovered in data from NASA's Chandra X-ray Observatory" and disputes the "popular misconception that there is no sound in space" (NASA, 2022). The result is an intuitive and emotional understanding of scientific data and characteristics that would otherwise have been difficult, if not impossible, to explain in layman's terms.

The role of an information designer today increasingly involves exploring innovative methods to communicate data effectively. Data sonification fits seamlessly into this evolving landscape, enabling designers to create multidimensional experiences that cut through the noise and go beyond static visuals, "offering a unique and complementary perspective" (Maskey & Maroune, 2023) and engaging audiences on a different sensory level.

Many are already putting this into practice. It goes beyond science: this holistic approach not only makes data more accessible but also enriches the storytelling aspect of data visualisation, addressing the saturation of visual information and allowing for a deeper emotional connection and comprehension, all while catering to diverse audiences and learning styles.

This still leaves us with some questions as to why sonification is not, as yet, as widely used as it ought to be. Standardisation is not in place, and access to tools or knowledge remains limited. Consequently, the medium is underexploited—even when it seems the intuitive way to approach the future of data communication.

1.1.3 Branding

Among streaming platforms, Spotify stands out as a leader, offering users access to an extensive library of content (and multiple kinds of it, at that) at their fingertips. According to their own reports, as of 2024, Spotify boasts 615 million active users, with 239 million subscribers to its premium service in more than 180 markets (2024). These figures make it the most widely used streaming service globally, and that is despite points of controversy—on topics that range from artist rights to content censorship—that have arisen over the last few years.

Product

Spotify transformed music listening forever when it launched in 2008, moving the music industry

from a 'transaction-based' experience of buying and owning audio content to an 'access-based' model, allowing users to stream on demand.

This, in turn, has made it easier than ever to be a self-publishing artist (or so Spotify claims—but more on that later). In Q1 of 2024, Spotify reported that the number of artists generating income in the ranges of $1M, $100K and $10K has nearly tripled since 2017. Even if that is still only a small percentage of the over ten million people that have ever uploaded a song to Spotify, the figures are promising.

> Our mission is to unlock the potential of human creativity—by giving a million creative artists the opportunity to live off their art and billions of fans the opportunity to enjoy and be inspired by it. (Spotify)

Arguably, Spotify's influence extends beyond just music. The past year saw the launch of various new formats, including music videos and audiobooks. Most notably, Spotify is the major player in the podcasting space, with a library of over 6 million podcasts that has brought "innovation and a new generation of listeners to the medium" (Spotify). The platform's investment in exclusive content and advanced recommendation algorithms has made it the preferred destination for many podcast listeners. This may simply be the result of a universal interest in meaningful content (which often carries either educational or entertainment value) but, additionally, it reflects positively on the deliberate choices made for Spotify's functionality and the curation of its content.

An intuitive, user-friendly interface has made Spotify a valuable tool for listeners and artists alike. It provides a means for emerging artists to reach global audiences without the need for traditional gatekeepers. Analytical tools also allow creators to gain insights into their audience's demographics and listening habits, enabling more targeted and effective engagement strategies.

Overall, Spotify's data-driven approach overall has enabled highly personalised experiences—ones which utilise user behaviour data to tailor recommendations and create custom playlists that continuously inspire further engagement. The annual Spotify Wrapped images, shared directly to social media platforms and eagerly anticipated each year, are nothing short of a symbol of the times.

Visual Expression

Whilst the success of Spotify Wrapped is owed, in part, to timing—we are living in an age of hyper-identity, after all—much can also be said for the brand's striking and memorable design, which shines through in both copy and visuals.

In fact, Spotify's overall look tends to abide by those same rules. All collateral, from playlist artwork to quarterly reports, is characterised by a sleek, modern aesthetic that balances simplicity with vibrant, dynamic elements. Most importantly, it is extremely consistent and, by extension, recognisable. Spotify Green is a particularly effective example here, as are Spotify Circular (although, at the time of writing, it has just been replaced by Spotify Mix) and the dark grey rounded rectangles that make up the app interface.

The brand's design ethos is rooted in creating an intuitive and engaging user experience, and it is also echoed in the three design principles outlined by Spotify's Design department in 2020:

relevant, human, and unified. As a result, the brand maintains a high level of design quality throughout all the experiences it creates, and all this transpires to its continuous success.

It is interesting to note that, despite its clear "audio-first" mindset and approach, Spotify has no sonic identity to speak of (unless you count the ads for premium subscriptions), instead relying entirely on the sonic output of the creators which use its product.

Narrative

Recent years have been marked by significant growth and innovation that have shaped Spotify's trajectory. Efforts to democratise music distribution and give more control to independent artists have borne fruit and led to further expansion, further cementing Spotify's place as the go-to means of distribution within the music and audio industry. The same can be said for the brand's focus on personalised user experiences and its direct contribution to user retention and engagement.

However, Spotify has not been without its controversies. One of the most significant was the backlash over its exclusive deal, reportedly worth $100 million, with Joe Rogan. This polarising decision brought widespread criticism and sparked debates about content moderation, the responsibilities of streaming platforms, and corporate responsibility—it "helped make Spotify a podcasting giant, but has now put the company at the centre of a fiery debate about misinformation and free speech" (Rosman et al, 2022).

Another ongoing issue has been the dispute over artist compensation. Numerous musicians and industry professionals have criticised Spotify for its royalty payment structure, arguing that it undervalues musicians' work. Independent

Figure 4: **Spotify's Colour Palette**

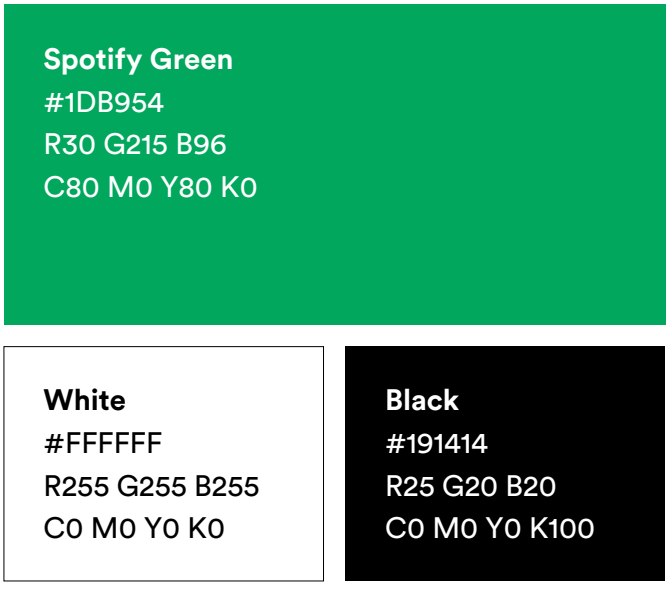
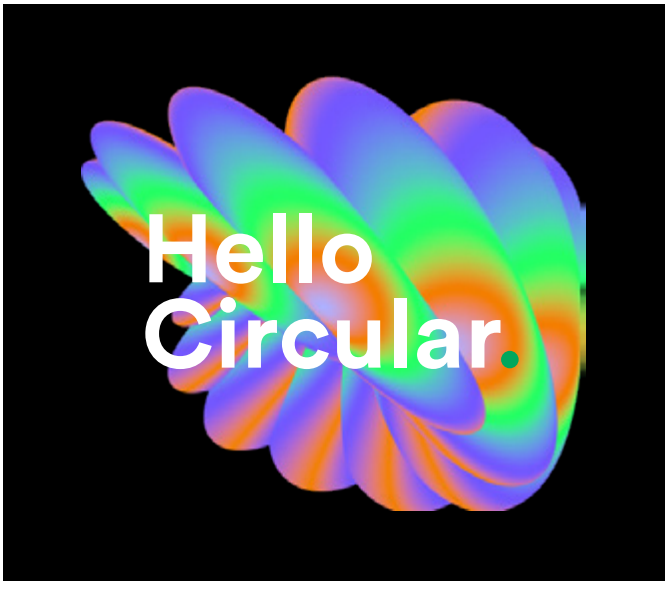


Figure 5: **Spotify Circular**



artists, especially, have taken issue with the precedent set by the 1,000-stream minimum requirement (Ahmed, 2023). To each his own: Spotify maintains its claim that artists deserve clarity about the economics of music streaming, and continues to regularly publish data on the process and payments related to royalties. Most recently, however, Spotify CEO Daniel Ek took to Twitter (or X) and claimed that "the cost of creating content" is "close to zero", consequently generating massive backlash and re-igniting the debate. Innumerable artists retaliated, stating the costs—monetary or otherwise—of making music. Part of the criticism "may also stem from the recent reports that Spotify confirmed record profits of over €1 billion, following staff being laid off and subscription prices rising" (Dunworth, 2024).

Despite these examples (of which there are more), occasional calls to #DeleteSpotify have never found substantial traction. Perhaps it is only its indisputable position at the forefront of the audio streaming revolution that allowed Spotify to retain its success, despite the clear shortcomings. However, one could also argue that there is plenty the brand has done to redeem itself.

One brand initiative to highlight is Spotify's Climate Action campaign: a declaration of the brand's responsibility towards people and the planet. Spotify has recently committed to reaching net zero GHG emissions by 2030. Consequently, the Spotify platform (along with its user base) is being leveraged to raise awareness and drive engagement among millions of listeners and creators.

Even more current at the time of writing is the brand's push to encourage people to vote in the European elections, happening in June 2024. The 'Play your part, Europe' campaign notified "all free and premium users over 18 with an in-app message to remind them of the election cycle"

Figure 6: **'Play your Part'**

(A) 2020 Campaign

(Walfisz, 2024). Credit must therefore also be given where it is due—Spotify is in the unique position of being able to run a political campaign without much concern over partisan involvement, and many would say it does well to shoulder this responsibility.

All this considered, then, one can safely say that Spotify is set to remain a leader among streaming services by means of its continued innovation, pioneering developments which further increase the appeal of streaming and engage users the world over.

(B) 2024 European Campaign

1.2 Hypothesis

Consolidating the above research and contextual information, the primary question posed at the start of this thesis is as follows:

Can the urgency of climate change be amplified by new means of data representation?

In parallel to the three areas of study, there are three unique starting points:

1. The contemporary realities of climate change and global warming;
2. Sound as a means of information communication, and pitch, specifically, as a musical device with the power to influence our emotions;
3. Spotify's millions of users and the brand's position as a major player in the sound industry.

Using meteorological datasets, the thesis proposes a replicable method for converting weather parameters (such as temperature, humidity and wind speed) into sound, with the intention of amplifying the urgency linked to the climate crisis.

A strategic collaboration with Spotify is set to enhance this initiative, leveraging their platform and its ubiquity to develop and disseminate a tool that merges scientific data with accessible, impactful messaging. The project also fits their mission to "educate and inspire," encouraging action on climate change amidst their users.

1.3 Theoretical framework

The literature background for this research stretches from psychology to perfect pitch, and covers all things in between. For this reason, no single topic will be delved into with great detail. However, all primary themes are acknowledged and their relevant content clarified to the extent required for the understanding of this project.

1.3.1 Psychology of Hearing

The foundation of this research is found, first and foremost, in the field of human neurobiology: particularly the niche area of study that focuses on sensory input and the way that our brains react to sound and music.

This notion is contradictory in nature—music is, after all, an entirely objective and creative output, whilst psychology is scientific fact. Despite this (or perhaps thanks to it), many have attempted to decipher the ongoings of the human mind as it receives, processes, and reacts to auditory input.

Musical Perception

A seminal contribution here is the work of Daniel J. Levitin, as summarised in *This Is Your Brain on Music* (2006). Given this author's lack of background on the subject of neurobiology, Levitin's text was appropriate in the way that it touches on factual psychological concepts without over-elaborating the technical or expert scientific details.

A second reference that proved especially relevant was Philip Ball's *The Music Instinct* (2001). Both will be cited repeatedly throughout this

research, given that they exist in the same space as it does: in between art and science.

Ubiquitous as the emotional component of music may be, the neurological details of cognition are certainly fascinating in their own right.

“Musical activity involves nearly every region of the brain that we know about, and nearly every neural subsystem” (Levitin, 2006).

W. A. Mathieu, whose work on pitch will be mentioned in some detail later on in this chapter, gives an ideal explanation of how sound reaches our ears:

> A plucked harp string vibrates the air; the air vibrates the eardrum, which vibrates the tiny bones attached to it; these vibrate the fluid in the snail-wound cochlea of the inner ear. [...]
>
> The vibrating fluid in the cochlea vibrates the basilar membrane, which vibrates its hairs, sending electrical pulses to the brain, where, by the greatest miracle of all, the pulses become our consciousness of a harp string. (1997, pp. 13)

Sound is ‘merely’ a chain of energy that moves through us and the world around us—that is, it isn’t sound at all. Only our brains make it so.

It is hardly surprising, then, that that same brain is able to conjure meaning and feelings.

> At a deeper level, the emotions we experience in response to music involve structures deep in the primitive, reptilian regions of the cerebellar vermis, and the amygdala—the heart of emotional processing in the cortex. (Levitin, 2006)

Emotion and Music

Generically speaking, an interesting idea that is highlighted in most of the works referenced here is the ironic and yet entirely direct parallel between music moving us physically (literally) and emotionally (figuratively).

> The world is intrinsically silent. When trees fall or bombs explode or violinists pluck pizzicato, all that happens is that the surrounding air is disturbed in various ways. Atmosphere is displaced. This displaced atmosphere is what enters our ears, and we do the rest… The world is playing us. (Faber, 2023, pp. 21)

Quite literally, music touches us.

What we respond to is inherently physical, but equally emotional in the way that it relates to human cognition. “Music is being used to manipulate our emotions, and we tend to accept, if not outright enjoy, the power of music to make us experience these different feelings” (Levitin, 2006). Often when we listen to music, we are conscious of both the literal thing we are hearing and the way that it makes us feel: the process is as emotional as it is intellectual. (Sacks, 2007, pp. 285)

Of course, this gives rise to many questions: Is some sort of semantic content (and, by extension, meaning) imbued in organised sound? Are musical emotions (i.e. emotions derived from music) like other emotions? And why do some sonic sequences move us so, while others leave us cold?

Although it does not necessarily answer all of these questions, neurology is a good place to start. Our auditory systems are “exquisitely tuned

for music" (Sacks, 2007). Auditory cognition tends to follow a linear process:

> The brain's initial aim is to identify the basic acoustic building blocks, such as fundamental pitch frequencies and harmonics, note durations, and loudness. These must then be separated out into individual instruments or melodies. The results are then compared with stored musical memories and experience [...] At the same time, each of these aspects of analysis and synthesis is engaging our emotions, and eventually the emotional, associative and syntactic information is combined to stimulate some kind of behavioural response: we are aroused, soothed, moved, annoyed. (Ball, 2011, pp. 245)

Carol Krumhansl also responds to some of these questions via her myriad studies and, particularly, in her paper titled *Music: A Link Between Cognition and Emotion* (2002). She asserts that listeners tend to "agree remarkably well with one another in labelling musical emotions" (pp. 45). Levitin concurs: even if "one man's Mozart is another man's Madonna" (2006), some pieces just seem to move us universally. This may be down to "time-locked" events in the music, especially "surface features related to tension [such as] the pitch height of the melody, the density of notes, dissonance, and dynamics" (Krumhansl, 2002, pp. 47). In summary, "music draws on common psychological principles of expectation, but that musical cultures shape these in unique ways" (pp. 49).

Sound's evolutionary role also merits a special mention here. Stereophony (our capacity to hear sound in three dimensions) is responsible for orientation, "for judging or forming impressions of what lies around us" (Sacks, 2007, pp. 145). Humans' ability to distinguish sounds and assign spatial location to them, whether they are predator or prey, has also certainly played a part in their survival.

> As soon as the primary auditory cortex receives a musical signal, our 'primitive' subcortical brain kicks in at once [...] and the thalamus takes a 'quick look' at the signal, apparently to check for danger signals that require any immediate action before more complex processing occurs. The thalamus then communicates with the amygdala to produce an emotional response—which, if danger is detected, might be fear. (Ball, 2001, pp. 244)

The Importance of Music to Humanity

Music baffled Charles Darwin. Mankind's ability to produce and enjoy melodies, he wrote in 1874, "must be ranked amongst the most mysterious with which he is endowed" (pp. 570). Yet, one needn't know which parts of the brain are involved when to testify to the importance of music in human society. Any argument against—Steven Pinker's is arguably the most notorious of these, with his description of music as an evolutionary accident or, worse so, "auditory cheesecake" (1997)—has only been received with many in the contrary, and plenty of evidence to support them. "Music is unusual among all human activities for both its ubiquity and its antiquity," Levitin himself asserts. "No known human culture now or anytime in the recorded past lacked music" (2006).

Some of this is echoed in *Listen*, by Michael Faber (2003), although the approach there is far more related to 'music' as we know it in pop culture and as experienced personally by Faber himself. He augments Levitin's argument by asserting that

"music that's of some practical use has always trumped music that can only be admired as Art" and, to give but one example, that "the first music ever made by humans was the singing of mothers to their babies" (pp. 47).

Ball extends this argument further to say:

> It's not only that music is too deeply embedded in our cultures to be extracted. It is too deeply embedded in our brains. Regardless of whether evolution has given our brains musical modules, it seems to have given us intrinsic proclivities for extracting music from the world. Music is part of what we are and how we perceive the world. (2011, pp. 31)

1.3.2 Sonic Devices

All of the above goes to show that, although it is hardly the be-all end-all, a significant part of the relationship that humans have with music is a personal and subjective one.

Memory, especially, is an intrinsic part of the listening experience. Although music does not have to be familiar to be powerful, "perception is never purely in the present" (Sacks, 2007, pp. 148) and within any given melody, "we hear each note in the light of many remembered things" (Ball, 2011, pp. 120).

Expectation

Various theoreticians have therefore assigned great importance to the notions of repetition and expectation (as extensions or manifestations of memory) in any listening experience. The resulting stability and, soon after, resolution in a given melody would likely fulfil our expectations of the music we are listening to. One of dopamine's primary functions, besides affecting pleasure, is thinking and planning ahead—and therefore musical anticipation, especially once it is satisfied, is a definite trigger.

Perhaps this is one of the reasons why repetition is so decidedly musical. Oliver Sacks makes a great example of nursery rhymes, full of repeating choruses—"we are attracted to repetition, even as adults: we want the stimulus and the reward again and again, and in music we get it" (2007, pp. 47). Repetition gives us the ability to organise, to follow sequences, and "to hold great volumes of information in the mind." It reinforces memory and message.

Ball creates a parallel which is uniquely and uncannily fitting to this research and its topics when, in *The Music Instinct*, he says that "as with predicting the weather day to day, we are most likely to forecast correctly the next note in a melody by assuming that it will be similar to the last one" (2011, pp. 109).

It was Leonard Meyer, acclaimed musicologist, who first proposed that the "understanding and enjoyment [of music] depend upon the perception of and response to attributes such as tension and repose, instability and stability, and ambiguity and clarity" (1967, pp. 43), together producing what Oliver Sacks described as a "quasi-perceptual experience" (2007, pp. 32). The passive listener becomes an active participant.

Tension, specifically, is "a multivalent quality" (Krumhansl, 2002, pp. 46) that transcends any basic emotional state attached to a piece of music. It is, in fact, the push and pull of our expectations being fulfilled too much or too little. As much as our brains love patterns and

resolution, they also love surprises—establishing expectation then violating it is a sure route to engagement.

Too much repetition (not enough tension) or too much instability (uninterrupted tension) and the brain either habituates or dissociates. Most importantly of all, "our brains won't tolerate ambiguity" (Ball, 2011, pp. 75)—stability is key, and no musical device has as much of a say in the stability of a piece as does pitch.

> Bringing all these factors together is the task of the composer. Most of us are very discriminating listeners, and when the composer gets the balance just slightly wrong, our expectations have been betrayed more than we can stand, and we switch radio stations, pull off the earphones, or just walk out of the room. (Levitin, 2006)

Pitch

As all specific musical devices—the foremost of which are pitch, rhythm, and timbre—pitch comes with its own individualised theories related to sonic meaning.

Oxford Languages defines 'pitch' as "the quality of a sound governed by the rate of vibrations producing it"—this is, in fact, the scientific definition—as well as "the degree of highness or lowness of a tone". When we think of our range of hearing, which is "ten octaves of sound, spanning a range from about thirty to twelve thousand vibrations a second" (Sacks, 2007, pp. 132), we therefore tend to speak in terms of frequencies. It feels nothing short of a leap of fate to accept that the same notion is "a purely psychological construct" which "provides the answer to the question: What note is that?" (Levitin, 2006).

The throughline is that, while pitch itself is a basic enough concept, it is applied via relatively complex musical theory to all kinds of quotidian materials—from a smartphone's alarm ringtone to a 120-minute film score—simply and, often, subtly. It's no wonder, given its flexibility. Our ears are able to perceive "about fourteen hundred discriminable tones" (Sacks, 2007, pp. 132) which together make for a number of possible combinations that is impractically large to express.

In contrast, W.A. Mathieu, in his book *Harmonic Experience* (1997), orchestrates an elegant marriage of these definitions to our actual experience of them, in an in-depth exploration (elusive to even the most experienced musicians) of pitch across time and cultures. The word 'pitch' is replaced by 'resonance' and "it is more a sympathy than a measurement of distance, a quality rather than a quantity" (pp. 28)—"those specially reenforcing combinations of tones that in their mutual resounding evaporate the boundary between music and musician" (pp. 1).

However, and here going back to psychology, most pertinent to this research is the means by which pitch is perceived. "Pitch is so important that the brain represents it directly; unlike almost any other musical attribute, we could place electrodes in the brain and be able to determine what pitches were being played to a person just by looking at the brain activity" (Levitin, 2006). "It's very unusual for a perceptual stimulus to have this one-to-one mapping in the brain—we have no comparable neurons that, for example, respond to specific tastes, smells or colours" (Ball, 2011, pp. 37).

What's more, although rhythm and metre are "the engine driving virtually all music" and it is likely

that they were “the very first elements used by our ancestors to make proto music,” (Levitin, 2006) pitch is actually the first auditory feature that the brain processes (Ball, 2011), using it to determine the nature of the sound as well as its origin.

It is here interesting to note that specific types of pitches have also been proven to have a specific effect on human ears—for better or for worse, and with good reason, too. We aren’t here talking so much about a direct relation of one single pitch or key with another intangible concept such as a colour or emotion, although some individuals (especially if they are synesthetes or have absolute pitch) do claim that every key possesses “its own flavour or feel, its own character” (Sacks, 2007, pp. 121). Neither are we considering theories of affections, the correspondence of specific musical elements (modes, rhythms, and melodic figures) to emotions.

Rather, there are links which are more fundamental and, by extension, universal. “Frequences just below the lower threshold of hearing are called infrasound, and are produced by some natural processes such as surf, earthquakes and storms” (Ball, 2011, pp. 35). Because of this relationship to nature, “they seem to stimulate strange psychological responses, particularly feelings of unease, revulsion, anxiety and awe…” And conversely, in sound and music therapy practices, music can be “especially powerful and have great therapeutic potential for patients with a variety of neurological conditions” (Sacks, 2007), eliciting a powerful response to music from subjects that, sadly, respond to little else.

But beyond the physiological, there is the emotional. That’s where harmony comes in.

Harmony and Dissonance

“How could such simple and common sounds generate a system of harmony so generous and elaborate?” (Mathieu, 1997, pp. 33)

For Greek philosophers Plato and Aristotle, music was merely a tool—but, specifically, one “that could either promote social harmony or, if improperly used, discord” (Ball, 2011, pp. 14). It’s no coincidence that those are both musical terms.

The foundation for musical ‘harmony’ as we know it today is mathematical. “Pythagoras is said to have found that tones which sound harmonious together, such as octaves, have simple ratios of their frequencies” (Ball, 2011, pp. 42). The reality, of course, is far more nuanced. “The pitches that we use in music today—the scales—have remained essentially unchanged since the time of the Greeks, with the exception of the development—really a refinement—of the equal tempered scale during the time of Bach” (Levitin, 2006).

While there is much physical and musical complexity to this statement, the only contribution required from it at this stage is that “the harmoniousness of a chord is not simply the sum of the consonance or dissonance of the intervals it contains” (Ball, 2011, pp. 167).

Yet, “at root, the question of harmony is not simply a matter of how to make good and proper music, but of how the world is constructed” (Ball, 2011, pp. 165). What’s more, “maybe, as was thought by Pythagoras, musical harmony really is a model for harmony on a grander scale, and a clear model of our music can teach us something about our present state of separation and loss” (Mathieu, 1997, pp. 2).

Harmony is not so much the scientific combination of notes, or even frequencies, as much as it is a psychological process which appeals to our human nature. After all, few other species of living creatures have such a marked reaction as us when listening to Beyoncé, Beethoven, or simply three notes played softly on a piano to create a poignant chord.

As with light and dark, so it is with harmony and dissonance. Much like in a harmonious context, "a single note cannot, by itself, be dissonant, but it can sound dissonant against the backdrop of certain chords". Interestingly, however, "consonant intervals and dissonant intervals are processed via separate mechanisms in the auditory cortex" (Levitin, 2006). And although many would be hard pressed to define dissonance, especially given a lack of theoretical knowledge, a dissonant interval is "normally recognised and reacted to even by infants" (Sacks, 2007, pp. 109).

From a purely physiological perspective, we must consider the phenomenon known as 'beating'. "If two pure tones (single frequencies) are played simultaneously with frequencies that are only very slightly different, the acoustic waves interfere. [...] The result is a periodic rise and fall in loudness superimposed on the two notes, called beating" (Ball, 2011, pp. 168). In other words, notes which are too close together are likely to stimulate the same set of auditory nerve fibres, creating a strange sensational overlap. Mathematically, too, it is a question of two frequencies whose overtonal combinations (discussed briefly below) lie outside of integer multiples.

Emotionally, however, "some sounds strike us as unpleasant, although we don't always know why" (Levitin, 2006). And although a great deal of research has focused on the problem of why we find some intervals consonant and others not, there is currently no agreement about this. Perhaps Mathieu sums it up best:

> The rules of music—including the rules of counterpoint and harmony—were not formed in our brains but in the resonance chambers of our bodies. What feels right and good is what survives. (1997, pp. 5)

More than the Sum of its Parts

"The mind possesses holistic organising tendencies that make perceived experience more than the sum of its parts," because "notes and chords convey information and meaning [only] because they appear in relation to other chords and notes" (Ball, 2011, pp. 140, 189).

This is especially true with sets of pitch. Any two simultaneous notes, for as long as they are within our hearing range of 20 to 20,000Hz, are combined (by our brains, no less) to form single chords. Even two voicings, or instruments, playing together but perfectly distinguishable from one another, simultaneously create a sonic combination which our minds hear and remember uniquely.

"Our brains organise [...] fundamental perceptual attributes into higher-level concepts—just as a painter arranges lines into form… when we listen to music, we are actually perceiving multiple attributes or 'dimensions'" (Levitin, 2006). Even more impressive is the fact that those same brains often 'correct' what they perceive in order to make sense of it, in a process called "contextual correction" (Sacks, 2007) which sometimes goes as far as to eliminate sounds which are dissonant or distorted.

A great example of this principle in practice is the harmonic series, the components of which are commonly known as overtones. When a sound is generated (on any instrument, including percussion instruments or the human voice) it produces many modes of vibration occurring simultaneously. The loudest of these is the fundamental frequency—the original 'note'—but, alongside it, you're actually hearing many, many pitches at once.

> The presence of overtones means that just about every note we hear from musical instruments, including the human voice, is really a chord. Yet this is not how we hear it. Our ear and brain conspire to collapse all the harmonics into a single perceived tone [...] What we 'hear' is an interpretation, a best guess in which our brains seek to simplify the complicated soundscape by applying the gestalt principles, which have been found from experience to do a fairly reliable job… (Ball, 2011, pp. 64, 142)

Overtones compound to create that musical quality which is known as 'timbre': a kind of "tonal colour" (Levitin, 2006) that is produced in part by these overtones but is also influenced by the body from which the sound is emanating, amongst other things. The result is "that indescribable character that distinguishes a trumpet from a clarinet when they're playing the same written note."

It must come as no surprise, then, that Gestalt scientists (interested, by definition, in the problems of configurations) have long been fascinated with music. Overtones are a classic vertical example of gestalt applied. Transposition, on the other hand, is horizontal: Gestalt psychologists such as von Ehrenfels, Wertheimer, Köhler and Koffka "wondered how it is that a melody—composed of a set of specific pitches—could retain its identity, its recognizability, even when all of its pitches are changed" (Levitin, 2006). The answer? It is "the ultimate triumph of form over detail, of the whole over the parts."

> Neuroscientists deconstruct sound into its components to study selectively which brain regions are involved in processing each of them, and musicologists discuss their individual contributions to the overall aesthetic experience of listening. But music—real music—succeeds or fails because of the relationship among these elements. (Levitin, 2006)

"A piece of music is not a mere sequence of notes, but a tightly organised whole. Every bar, every phrase, arises organically from what preceded it and points to what will follow" (Sacks, 2007, pp. 210). Musical attributes are individual and separable but leave no doubt that music is greater than the sum of its parts. "The difference between music and a random or disordered set of sounds has to do with the way these fundamental attributes combine, and the relations that form between them."

Furthermore, with the right personal and/or cultural references in place, music has that uncanny ability of becoming a "direct route to the core of our shared humanity" (Ball, 2011).

1.3.3 Sound and Vision

This is where branding comes in, given that it is fundamentally a narrative-driven experience wherein the most direct and lasting route (to the brand's success, that is) is an emotional one

(Blauvelt, 2011). In contrast to corporate identity, branding is both a projection and reflection of the consumer—and this is echoed by Faber when he says that art (or music) "holds up a mirror to you" (2023, pp. 12).

But then, now that the age of "dynamic identity" is truly upon us, why is sound as a medium still so under-used within the world of design? Many likenesses (or attempts thereof) have been made between varying forms of visual art and music; synaesthesia (which is the process of one sensory impression directly relating to another) has made for the establishment of many links between music and colour over the past couple of centuries, especially within the work of leading artists. And yet, few brands have made the leap to invest in a sonic identity to complement their visual one.

Likeness to Other Concepts

In *Color, Form and Motion* (2000), Fred Collopy likens colour's three primary parameters—hue, saturation, and lightness—to those of music, as listed earlier in this chapter. That said, a few marked differences remain: individual hues blend together whereas notes compound to create complex harmonies, to name but one example, whereas gradients remain sonically unmatched (in the music traditions of the West, at least).

In fact, "pitch can be considered to have two dimensions: 'height,' which is an objective quantity determined by the frequency of vibration, and what music theorists call 'chroma,' meaning the pitch class: a circular property that arises purely in perception" (Ball, 2011, pp. 86). Once again, the naming overlap is no coincidence: the circularity of octaves is often likened to that of the colour wheel. Newton thought that the colour spectrum had seven discrete colours, "corresponding in some unknown but simple way to the seven notes of the diatonic scale" (Sacks, 2007, pp. 165).

On a similar thread, Nietzche wrote that "we listen to music with our muscles" (as cited in Sacks, 2007). Our faces and postures mirror the "narrative" of the melody—and this link seems universal in humans, showing itself spontaneously and often early in life. There is a "high degree of symmetry and regularity in both music and dance," but more moving (literally and metaphorically) than this are "the experienced contours of tension and emotion" (Krumhansl, 2002, pp. 48).

This is not to say that music and other forms of art are entirely compatible.

> Many great paintings literally depict feelings [...] Literature stimulates emotion through narrative, characterisation and allusion [...] But music is invisible and ephemeral: it sighs and roars for a moment, and then it is gone. (Ball, 2011, pp. 256)

Perhaps a better analogy is made to language—discourse, specifically. "In discourse, topics are introduced and developed, and then closed off with slowing of speech rate, drops in pitch and dynamics, and pauses" (Krumhansl, 2002, pp. 48). Speech has form, topics and sections, as well as "inflections, intonations, tempo, rhythm, and melody" (Sacks, 2007, pp. 216). What is for other primates rudimentary is for humans a mechanism on which our understanding of each other is dependent.

In any case, the key takeaway from Collopy's paper is the quote cited from Oscar Wilde: "Music

is the art in which form and matter are always one, the art whose subject cannot be separated from the method of its expression" (1882). Perhaps this notion, far more than Collopy's scientific exploration of Lumia, is what may lead us to the root of music as such an undeniable source of human meaning.

Sound and Science

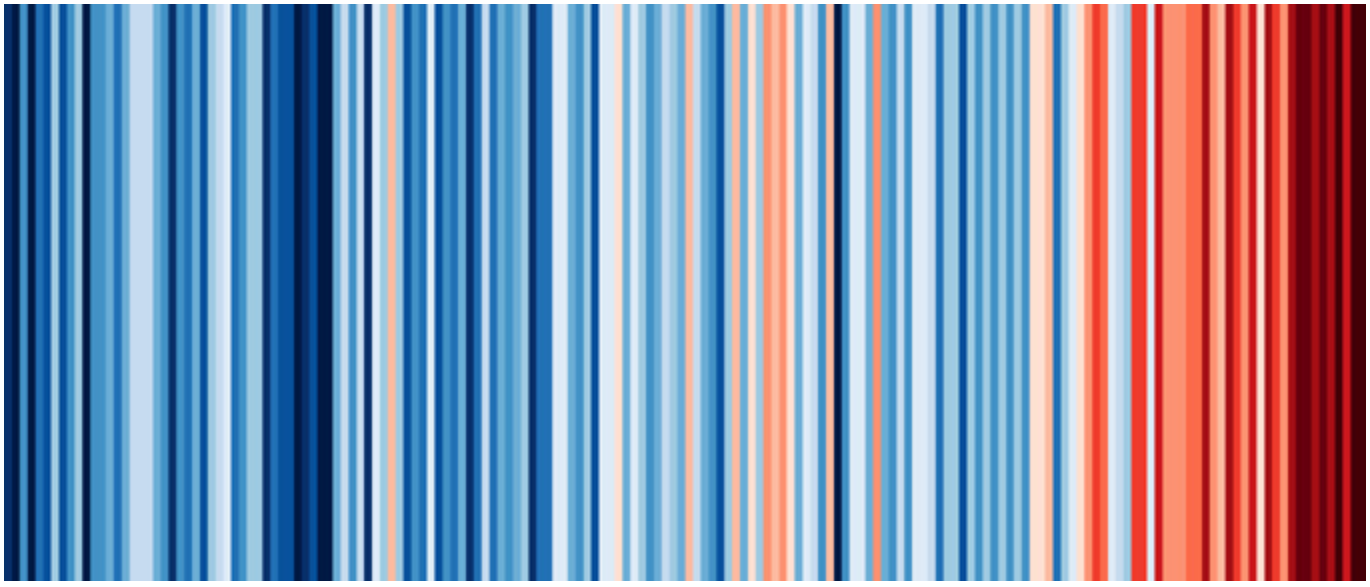
Levitin, quoted frequently in the previous sections, based *This is Your Brain on Music* on the similarities between artists and scientists, namely "the ability to live in an open-ended state of interpretation and reinterpretation of the products of our work" (2006).

Unsurprisingly, the two disciplines have often interacted to create results which are as beautiful as they are educational. Only two examples are given here, based on their relevance to the project, but many more exist.

Professor Ed Hawkins, of the University of Reading, created 'warming stripes' as visual representations of the change in temperature measured in individual countries, regions or cities over the past 100+ years. Most notably, varying tones of blue and red are used to communicate whether that temperature is lower or higher (respectively) relative to the average in that same location between 1961 and 2010. The result is an abstract, aesthetically-pleasant graphic with a poignant message.

A much more direct approach may be seen with the Climate Clock. It is exactly what the name implies: a clock that counts down the critical time window to reach zero emissions (the 'deadline'), while tracking progress on key solution pathways ('lifelines'). "By showing us what we need to do by when, the Clock frames our critical mission—a rapid and just transition to a safe climate future—and puts it at the very forefront of our attention" (Climate Clock).

Figure 7: **Warming Stripes for Barcelona**



Because of the powerful call-to-action that alternative data representation has the potential to facilitate, it makes perfect sense to extend that logic to sound. Organisations large and small have leveraged the fascinating process of sonification in recent years to present data, information, and hard facts. The examples from NASA are best known, but many more projects exist. Take UK-based agency Loud Numbers: a team of musicians creating "data-driven audio experiences that tell compelling stories, communicate data accurately, and sound like music." Their process is equal parts methodical and emotional, and is exemplified quite ideally with their most recent piece, *Hold the Line*: a piece that (incidentally) relates to climate change and its unfortunate consequences, generated by data from Canada's 2023 wildfire season.

> Every single fire that was reported by the Canadian Interagency Forest Fires Centre between 1 April and 30 November is represented by a click sound, with each real-world day playing out over 2.5 seconds of sound. A bass note drops at the start of each new day. (Loud Numbers)

The deliberate selection of timbres is particularly interesting. For contrast, consider the case of the sonification project led by MIT scientists cited earlier in section 1.1.2, where a Japanese koto was selected to voice the main melody—"soothing sounds that might bring some comfort in a time of trouble" (Venugopal, 2020).

Different sounds definitely carry different messages, some of which are already embedded in our culture and, therefore, our minds. Dipping back into human evolution will quickly provide sufficient evidence. "Most animal sound is of this encoding type: the sounds have designated meanings, serving as warning signals or mating calls or summonses to the young" (Ball, 2011, pp. 22). And while "many of the ways in which our brains function—including our senses of colour, taste, smell, and hearing—arose due to evolutionary pressures, some of which no longer exist" (Levitin, 2006), this does not make them any less relevant (or available) to us.

Chapter Two—

Project

2.1 Proposal

This thesis proposes the application of sonification techniques to convert meteorological data into integrated soundscapes.

It does so with the aim of enhancing the analysis and understanding of weather phenomena, especially within the current context of climate change and the meteorological extremities it brings with it.

Drawing on expertise in sound design, data visualisation, and musical composition, the project investigates how auditory representations can provide complementary insights to traditional visualisations.

2.1.1 Concept

Fundamentally, this project leverages the poignancy of context.

First and foremost, the work is an acknowledgement of the current global situation at large. Had we not been living in such a critical time, the initiative would be neither meaningful nor necessary. It is only on consideration of the physical realities (as well as the human response to them thus far) that the need for urgency is recognised.

Sound itself is also very much a matter of context. Given its evolutionary importance—the human capacity to locate sounds in space, as well as the instinct to recognise certain sounds as pleasant and others as dangerous—the medium stands to be a powerful communicator of both emotion and impact.

> It is this sensation of being somehow located in a musical environment, pressed about by notes and chords that we sense [...] and uncertain of which we will encounter next—it is this that allows music, moment to moment, to excite our senses and our passions. (Ball, 2011, pp. 90)

Furthermore, the power of sound is augmented by the fact that listening is in itself a conscious and active experience.

"Experiencing music is an active affair, no matter how idly we are listening. If it wasn't, we would not be hearing music at all" (Ball, 2011, pp. 81).

The soundscapes, intended to encourage reflection and action in the context of climate change, are themselves an extension of this metaphor. Although the exact details will be fleshed out in section 2.3, Formalisation, the key musical tools employed in this work will be harmony and dissonance. Specifically, the latter will be used as a means of warning, creating a sense of discomfort and anxiety in the listener that originates from the unsettling realities of climate change.

2.1.2 Delivery

These original soundscapes, which are the heart around which this project revolves, will be deployed in two primary ways. The involvement of Spotify is crucial here, as it wholly determines the application and its predicted effectiveness.

Spotify App

The initiative's first placement will be within the Spotify application itself, on both desktop and mobile platforms, primarily because of the reach that this implies: over 600 million active users, according to Spotify's latest reports.

Nested within Spotify's familiar homescreen will be a new, colourful widget (seamless, yet striking) which displays the most pertinent weather information: the user's current location, and the current temperature in that location. Clicking on the play button within the widget will cue that day's soundscape: a single track of just under two minutes in length, with accompanying data-driven animations in the window background. The intention here is to make the action attention-grabbing while being as short and straightforward as possible, without the need for intermediary steps or screens.

Diving further in, however, is possible and desirable: the user can continue to a landing page which is heavily inspired by the layout of podcast episodes. Here one will find a description of the project and the link to the official web platform (to be described shortly), and be able to navigate to further soundscapes. Day on day, every user's bespoke playlists of "weather reports" will automatically continue to grow: from a primary playlist of daily reports, to miscellaneous collections based on commonalities (rainy days in spring, for example, or Barcelona's hottest days of 2023).

Online Platform

Although the Spotify app is an important intermediary, the project's main features are showcased within the online platform—the goal is to convert users from the Spotify application and engage them within the online portal.

On landing, that day's soundscape (or report) will automatically play, accompanied by the same

gradient animations. However, the reason for the website is to showcase the following additional features:

» Individual soundscapes for various locations and for dates in the past, present and future, using a simple toggle mechanism, and therefore allowing for forecasting as much as for historical reporting;
» Comparison of any two dates and locations (always within the limitations set by official weather sources) on both an aural and visual level;
» Exploration of the multiple layers making up each soundscape, encouraging listeners to understand which sonic features are assigned to which weather parameter, and thereby drawing their own conclusions.

Other functionality will involve the toggling of visual layers (background animations, and numerical weather data) according to user preferences, although this is largely a matter of personal taste and is secondary to the features listed above.

The website will also delve into much more detail when it comes to the project description, ambitions, and educational capacity. Links and resources will be included, both as a means of legitimising the project and showing its foundation in research, as well as encouraging action (however small) by each and every listener.

Communication

The last tier of the project delivery is communication and distribution. At the stage of writing, the features proposed by this initiative only exist in prototype form—this is given the limitations of time, resources and expertise. Therefore, a number of audiovisual pieces will be created and distributed (in true Spotify fashion) to primary channels, serving to communicate the project, its functionality, and its intentions.

2.1.3 Stakeholders

Throughout the lifespan of the project, numerous stakeholders are involved to varying degrees, though each category of individuals brings unique perspectives, interests, and influences. This multifaceted approach is critical to the project's balance between scientific knowledge and pop culture. A brief outline of each group's roles and contributions is included here.

General Public

This group includes a diverse range of individuals, from average citizens to high-profile figures such as CEOs and politicians. Their primary interest lies in the accessibility and appeal of the soundscapes, which for this reason must be as meaningful and impactful as they are approachable. For average users, the project offers an innovative way to engage with climate data, making it more relatable and easier to understand. For influential figures, particularly those concerned about environmental issues, the project represents a tool for raising awareness (internally first, externally as a consequence) and influencing public opinion on climate change. The platform hopes to encourage both to create action, big or small, in the name of the planet.

Spotify Owners and Stakeholders

As the platform creator and host, Spotify's owners and stakeholders have as much of a physical role as much as they do a vested interest

in the project's success. Needless to say, this initiative stands to dampen some of the criticism received by Spotify in recent months, and instead enhance the brand's reputation for innovation and social responsibility. Additionally, although the project has a pro-bono outlook, successful implementation does provide financial benefits through increased user activity and potential new subscriptions.

Meteorologists, Data Scientists and Sound Designers

Climate experts are crucial for the project's development and validation, whilst just as much manpower is needed to execute the data they provide in communicable and meaningful forms. The soundscapes are not only scientifically accurate, but also emotionally resonant and engaging for their audience. Each parties' expertise ensures the accuracy and relevance of the information being presented.

Environmental Activists and Advocates

This group of stakeholders is key to the future of the project (and the planet). By using the sonified data to further their causes, using a novel and impactful way to present climate data, their efforts to educate the public and policymakers about the urgency of climate change will be enhanced. The soundscapes can undoubtedly serve as powerful tools in campaigns and educational programs, making the environmental message more compelling and memorable.

2.1.4 Goals and Benefits

Despite the speculative nature of the research, this project stands to have social impact both in the short- and long-term—not only by informing and inspiring users, but also by sparking new perspectives on how data is democratised and disseminated. A direct benefit would be the potential integration of data sonification (related to weather or otherwise) into education and public outreach, as a means of information communication and democratic data access.

Furthermore, continued research into the effectiveness of auditory representation for scientific analysis and public communication is strongly advised; this, in turn, would aid in the development of integrated tools for those with visual and/or auditory impairment.

All that said, it bears repeating that the ultimate motive of this project is to contribute to the global race against climate change, on both societal and individual levels. Although climate mitigation is an ambitious goal, this project is conducted only with the simultaneous hope that governments, businesses and individuals will be inspired to take any action required to achieve it.

The stakes are certainly high enough.

2.2 Methodology

Although this project was primarily one of artistic expression and social action, a scientific method was in-part applied—to the research and literary background, primarily, but also in the form of data collection.

2.2.1 Research Design

To support the creation of the public sonification tool outlined in section 2.1, a brief and relatively simple research strategy was designed to collect user data. Significant weight was placed on the way in which a user or listener would experience different types of sounds.

Therefore, this led to the development of a methodology which was, broadly speaking, qualitative, in that it dealt with data that was highly subjective and not always quantifiable. This suggests an undeniable element of interpretation in the research philosophy. The analysis of most of that qualitative data, however, was quantitative.

The research itself was largely descriptive, although a limited amount of explanation was equally sought after. This implies that answers were taken at face value and as a means of deduction—more as a reiteration of the research hypothesis than for additional analysis of which variables may have caused them (due to the limited nature of the project). This does not exclude that such exploratory research be carried out at a later stage of this same research or in other studies that follow in its footsteps.

Due to the nature of the project and the eventual analysis conducted, these studies should be

considered field studies rather than formal ones. Given that causation was of no relevance, neither group was tested in a controlled environment—rather, the research was ethnographic.

Similarly, no particular sampling strategy was applied, although one factor was taken into account: the participants' personal interest in visual design and/or music, and the knowledge thereof. Participants with both interest and knowledge were more liable to be invested in the research and its results, as well as provide nuanced and insightful answers. Their contribution was therefore considered very valuable. However, prior knowledge was also likely to influence the actual experience of the sound sample supplied—and this is where participants with no prior design or music knowledge would balance out the results. The eventual mix was intended to make for generalisable findings.

2.2.2 Survey

The first initiative was an anonymous online questionnaire, distributed without any particular criteria to a mixed demographic audience. All data was collected via Google Forms, for reasons of efficiency and easy data cataloguing.

Although individual conversations with regards to the study and the topics took place both before and after, these were kept separate in order to keep the study results uniform.

The data was analysed methodically and, for the most part, quantitatively: similar answers were grouped together and used to derive percentiles. Incomplete answers were disregarded. More importantly, however, submissions that carried significant qualitative value were identified and taken into additional consideration.

The survey revolved around 4 sounds samples—the independent variables—curated for the purposes of this research:

» Brian Eno: An Ending (Ascent)
» Hania Rani: Eden
» Caterina Barbieri, Lyra Pramuk: Knot of Spirit
» Ólafur Arnalds: Still / Sound

These tracks, all found within the genre of ambient music and created by renowned musicians in that same genre, were chosen for the sonic ambiguity that they all share.

On the other hand, they differ harmonically (meaning in the artists' choice for note combinations, keys and scales) as well as in their instrumentation. The selection was therefore ideal to elicit which kinds of voicings or chords would potentially produce positive feelings in the listeners, and which would create negative ones.

In the introductory section of the survey, participants were asked to answer two multiple-choice questions which set the scene:

1. How much time (per day) do you listen to music?
2. How important is the emotional component of a music listening experience to you?

Next, they were asked to listen to the opening 15 to 30 seconds of each piece of music (by clicking through links to Spotify) and describe any emotions that the track makes them feel, if any, in the order that they feel them. Examples of emotions were listed to illustrate the range of possibilities.

The process was then repeated, but with the answers limited to 4 choices: Sadness, Happiness, Fear, and Anger. These options were intentionally broad, yet limited to a selection made from the six basic emotions as popularly defined by psychologist Paul Ekman.

Finally, some demographic data was collected to facilitate the organisation of responses. Participants were asked their age range, which continent they grew up in, and if they had any knowledge of musical theory. The former two criteria were included given their tendency to influence preference of music style (old or new, Eastern or Western) whereas the latter question was meant to identify any bias created by previous exposure to theories on musical qualities and their emotional effects.

A copy of the questionnaire content is included in the Appendix, and the results collected are discussed in the section 2.2.4.

2.2.3 Interviews

The second means of data collection involved personal, one-on-one conversations with a smaller set of participants. These participants were selected from the pool of people that contributed to the survey, after they had identified themselves and volunteered to partake in longer, in-depth conversations on the same subjects. Given the limited sample set, the selection of participants was in this case more deliberately done—primarily to present varying levels of knowledge and involvement in the music and design industries.

Besides the above, the largest distinction between the two initiatives was the independent variables. In this second study, participants were asked to reflect on the work-in-progress soundscapes that were concurrently being created for the project—both before and after the context and project were explained. This was done in an effort to eliminate subjectivity (as much as possible) and ensure that any musical and technical choices made in the work were as universal as possible.

Other tangential concepts relating to the study topics were also brought up, and questions were presented in both abstract and tangible terms.

All responses were recorded in Google Docs, and are summarised in the upcoming section; full transcripts are available in the Appendix.

2.2.4 Results

92 individuals participated in the anonymous survey. Of these, more than 50% claimed to have no knowledge of musical theory whilst 35% have only a little; the rest marked that they are very knowledgeable of the subject. The majority of respondents grew up in Europe, although every inhabited continent was represented. There was a healthy mix of ages, with the largest percentile (32%) being between 25 and 34 years old.

A third of the respondents said they listened to music for about one hour each day; only 2 respondents claimed to not listen to any music at all. However, 42% of participants assigned maximum importance to the emotional component of a music listening experience, and on a scale of 0 to 5, there were no responses lower than 2.

In the unrestricted part of the survey, where participants were asked to describe in their own

words the feelings created by the 4 samples supplied, some commonalities arose regardless. Below are any answers which were submitted three times or more:

» An Ending (Ascent)
  » Calm (18)
  » Relaxed (5)
  » Sad (4)
  » Hopeful, Peaceful (3 each)

» Eden
  » Sad (11)
  » Calm (10)
  » Melancholic (4)
  » Anxious (3 each)

» Knot of Spirit
  » Anxious (6)
  » Tense (5)
  » Scared (4)
  » Calm, Confused (3 each)

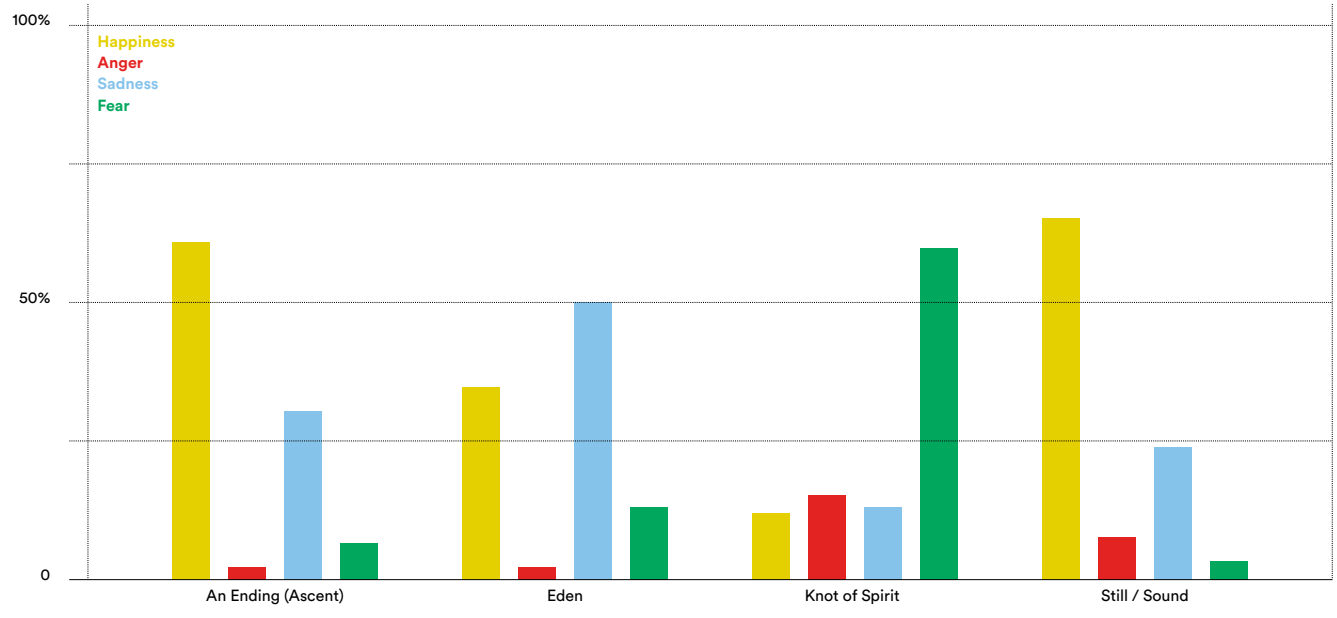
» Still / Sound
  » Calm (12)
  » Relaxed (7)
  » Peaceful (4)
  » Hopeful, Happy, Sad (3 each)

Some participants were more poetic in their contributions. *Still / Sound* was “a walk in a dense forest” but also “child-like”, while *Eden*’s “first note is instantly sad.” One respondent wrote:

> More than a feeling, I picture things. I see wind, moving green wheat on a spring afternoon. The wind moves to a cliff and to a waterfall… If I had to describe it with emotions, I would say freedom, liberation, synergy, harmony, acceptance, peace.

The answers were far more unanimous in the second section, where only four options were available. *An Ending (Ascent)* was happy (60%), *Eden* was sad (50%), *Knot of Spirit* frightening

Figure 8: **How Does It Make You Feel?**



(60%) and *Still / Sound* also happy (65%). Few respondents associated any of the tracks with anger.

These results matched the author's expectations. Eno's piece is uplifting, applying major chords to airy sounds (typically associated with fantasy, dreams, or happy endings) which resolve every few bars. Hania Rani's melancholic piano piece, conversely, quietly rests on minor keys without much melodic intervention until it falls into a solemn pattern of those same harmonies. The third piece, Caterina Barbieri's, starts with various interspersed and unrelated sounds that are mostly distorted, unidentifiable in source and in type—one does not know what to expect, and the feeling of anxiety is therefore only natural. Arnalds' is the most rhythmic of all four, and even though some minor progressions are employed, the piece tethers on the perfect fourth and fifth while relying heavily on their repetition.

It was also not surprising to see that consensus in interpretation was largely irrespective of age and origin, although outliers were naturally present regardless.

The total results were successful in confirming the author's hypothesis (based partly in research and partly in experience) of which musical devices may serve to create positive and negative emotions.

The in-depth interviews, conducted separately, continued to validate these same assumptions.

Although the three participants were brought up in different parts of the world (North America, South America, and Europe, respectively), they each reacted in a way which was relatively consistent.

Of the five original tracks shared, the two which were more dissonant (in the author's terms) were mostly also identified as such by the interviewees, even if they each used different terms: "sinister" and "unsettling," with "a sense of growing tension." There was unanimous agreement on the effectiveness of the relationship between the data represented (after details of this were shared) and the resulting soundscape, even if minor changes and future lines were suggested.

Interestingly, not all candidates were equally concerned with the same aspects. The first interviewee was quite pragmatic in their descriptions, interpreting sounds as potential instruments ("almost like a mediaeval choir") or equating them to their application ("another day at yoga"). The second interviewee was more rooted in emotional qualities, from contemplation to discomfort, whilst the third respondent fell somewhere in between the other two. There was also a slight discrepancy in their expectations: no unanimous consensus was reached on whether the sounds utilised should be literal (that is, should wind sound like wind, rain sound like rain, etc.), although two out of three were quite firmly against the idea.

One of the final questions addressed a technicality in the way that data was (at that stage of the project) being organised and transformed into sound. Although these details will be disclosed in section 2.3.1, suffice it to say that the answers obtained in the interviews directly informed and inspired the eventual rationale.

In conclusion, both parts of the research design contributed greatly to the progression and development of the project, proving especially valuable in their ability to confirm the more objective qualities and effects of musical devices.

2.3 Formalisation

Based on all of the input collected from existing literature and from the studies conducted, the criteria that would define the project were formalised. Due to the timeline of the project, the process was iterated multiple times, each time taking into account new information.

Some key questions to ask were:

» Which meteorological factors and data would be sourced, converted and manipulated to create the eventual soundscapes?
» Which sonic qualities would be best suited to communicate the emotion and urgency required? How would they be expressed and combined?
» What kind of visual system would best reflect the combination of the above?
» Logistically speaking, would the process of conversion need to be manual or was it possible to automate it?

2.3.1 Climate Criteria

Highly-detailed, hourly weather information for the past 80 or so years is readily available online via open-source platforms and API setups. There is no shortage of accessible tools, including some from sources as reliable as Copernicus, the Earth observation component of the European Union's Space programme.

Despite this expanse of data, however, it was difficult to define what exactly would determine a period of time as short as one day to be 'good' or 'bad' in the context of the climate crisis. After all, a hot summer day in Barcelona is perfectly within

the Earth's expected weather patterns (even if it is physically uncomfortable), whereas those same temperatures in Moscow (where they would perhaps be welcome) are entirely abnormal. It is these climate irregularities that truly exemplify the trajectory of climate change. Barcelona itself gave an apt example of this with record rainfalls by mid-2024, at the time of writing, exceeding the totals rainfall recorded in both 2023 and 2022.

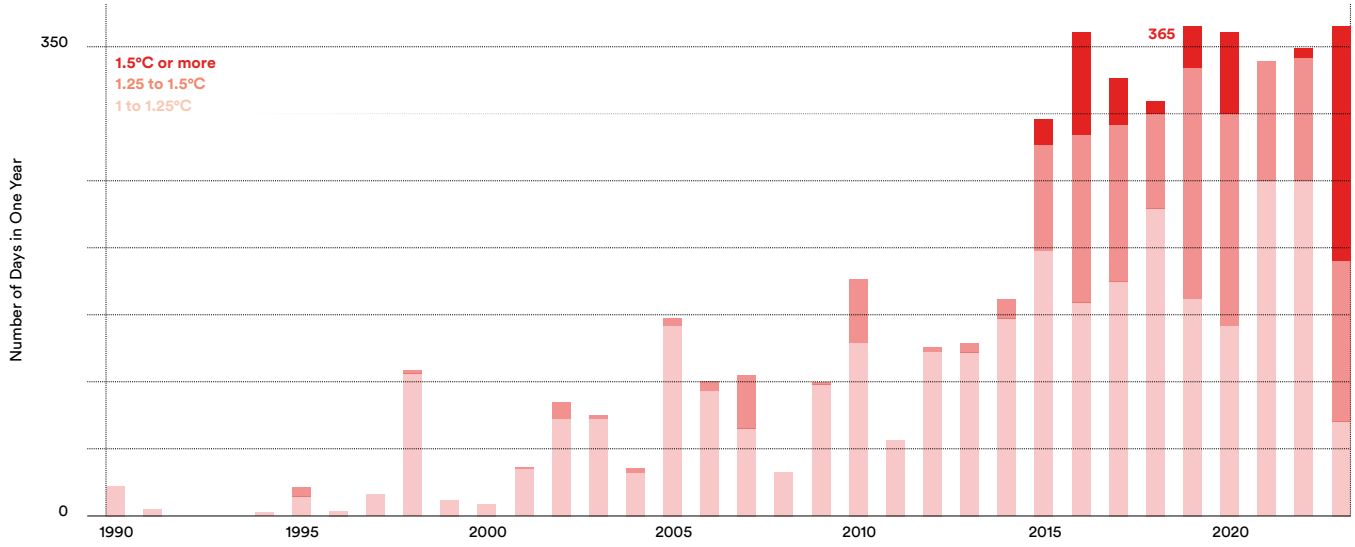
In warming-related articles and papers, there was one number that came up repeatedly: the infamous 1.5°C. That number carries special significance in the international effort to stop dangerous climate change. The Paris Agreement, adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015, states that the global average temperature must be limited to an increase of less than 1.5°C above pre-industrial levels: a threshold which represents warming levels that, once crossed, risk unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall.

This is alarming when one considers all of the statistics compiled in chapter 1.1.1, and that in 2023, almost 50% of the year's 365 days exceeded the 1.5°C increase (Copernicus, 2024). In fact, January 2024 then marked the world's first year-long breach of the 1.5°C warming limit.

This doesn't mean that, in the grand scheme of things, we've already passed that lower limit—the goals set by the Paris agreement are long-term, meant to be evaluated only after a certain number of years have gone by. Still, it is a potent and tangible symbolic reminder, and it certainly sets a dire precedent (Copernicus, 2024).

The 1.5°C threshold was therefore taken as the distinguishing factor, or as the determinant of dissonance. Since many data models exist, one needed to be chosen for consistency. Given this

Figure 9: **Days Exceeding the Pre-industrial Reference by More Than 1°C**



Data: ERA5. Reference period: Pre-industrial (1850-1900). Credit: C3S/EDMWF.

research's reliance on climate data provided by Copernicus Climate Change Service, the model chosen was ERA5: the European Centre for Medium-Range Weather Forecasts' (ECMWF) fifth generation reanalysis of the global climate from 1940 to the present. The data, as it was summarised for the purposes of this project, may be found in the Appendix.

Other parameters would still be converted linearly to musical notes—however, no intentional efforts to create inharmonic sounds would be made. Rather, those would be kept as simple and straightforward as possible (harmonically speaking) in such a way that dissonance (as caused by the excess of the 1.5°C) is even more jarring when it occurs.

In pre-selecting the data, only one daily parameter was taken into consideration: day time (or sunshine hours) vs night time, given its direct impact on apparent temperature. The rest of the variables to be included were hourly, and they were namely:

» Temperature;
» Apparent temperature;
» Relative humidity;
» Sea level pressure;
» Wind speed (10m);
» Precipitation (rain and snow); and
» Cloud cover.

2.3.2 Soundscapes

Following this, decisions needed to be made with regards the specific voicings, note ranges, and musical qualities that would be employed in the sound creation. Research pointed towards pitch being the strongest and most emotive of basic musical qualities, and this was further confirmed through the methodology. Therefore pitch, or the use of harmony, was taken as the primary form of expression. However, rhythm and timbre would each have plenty to contribute in their own right.

For a linear and replicable process, a strict set of instructions was compiled for the conversion of the acquired weather data (in the form of CSV spreadsheets) to MIDI files.

First, the CSV file (acquired through Open Meteo's Historical Weather and Weather Forecast APIs) was edited to match the established format. Minimum and maximum values were added in for the more prominent weather parameters, which implied that mapping would be identical across different soundscapes—to give a simple example: 25°C on any given day will correspond to the same frequency or note value.

For an example CSV file, refer to Appendix D.

As for the conversion, which was done thanks to an open-source online interface, consistent values and settings were also maintained throughout. The range of notes used was one of either 2 or 4 octaves (depending on the range of the original weather parameter) starting from a C2 on the piano keyboard. To achieve a harmonious sound despite the varying values, all tracks were generated using only the notes in the C major scale.

The primary benefit of using MIDI conversion, besides its digital format and consequent adaptability to any voicing or instrument patch, is that it is three-dimensional. Besides pitch and duration, every note also carries a value for velocity: that is, a dynamic combination of volume and attack. The velocity of most parameters was

mapped to itself (a higher note would also be louder) but, for certain values, parameters were cross-referenced to create new and meaningful combinations.

Each of the weather variables and consequent MIDI track was assigned a synthesised instrumental preset in the DAW of choice—that same voicing would be applied without exception to any given soundscape. The individual choice of instruments was largely aesthetic, aiming for an abstract and ethereal panorama that is not altogether detached from sounds ordinarily associated with the weather, atmospheric conditions, or phenomena related to space. An amount of reverberation was added for its ability to communicate emotion and create an overall pleasing sound.

The MIDI files were dragged into the DAW template without exception, and only tweaked for two specific reasons: to remove the maximum and minimum values at the end of each track, and to eliminate redundant null values that would trigger sound and effects if not removed (as in the case of precipitation).

Finally, if the temperature on that day exceeded the 1.5°C threshold, one additional track was included to create the dissonance discussed earlier. In contrast to the rest of the music, this track is in the key of F# melodic minor and creates a 'negative' harmony with the notes already present. Specifically, the notes F# and C# are prominent—these clash sharply with C, the root note of C major, and F and G, its next two most stable tones.

One last point of consistency was that of time: each piece is made up of 24 bars of music, relating directly to the 24 hours of the day, and is set to the same tempo of 48 wv. This selection was based on two reasons: first, that it would allow for a slow and meditative piece of just under 2 minutes in length; and, second, that it is minutely slower than time itself. Although rhythm was not central to this investigation, its power to inspire constancy and collectivity was not taken for granted. There is in humans an unconscious propensity to constant sounds (think of a ticking clock, for example) which was leveraged here. On a practical level, meanwhile, a consistent tempo would allow any number of soundscapes to be overlaid or played in conversation with each other.

This method was tested with a number of diverse data sets, as well as in the second study as described in section 2.2.3, Interviews. Regrettably there was no simple way to automate any part of this part of the process by the time of writing, although a single application which encompasses the entire conversion (API to MP3) could certainly be developed in future.

2.3.3 Data-driven Visuals

The final piece of the puzzle was the graphic element. The building blocks of the design were, naturally, heavily inspired by Spotify and the brand's unmistakeable identity, especially in terms of typography, colour, layout and hierarchy.

Given Spotify's clear design principles, the early design decisions were quick and easy to make and implement—they were, in fact, directly inspired by Spotify's desktop app. This then laid the groundwork for the rest of the UI and UX design, which was consistent and familiar given that it borrowed from the intuitive layouts and navigation so closely associated with Spotify. Master elements were continually revised as the

overall design developed, especially to ensure that each step of the user journey was logical and smooth. Slowly but surely, wireframes evolved into high-fidelity mockups, incorporating Spotify-inspired visual elements like gradient colours and a semi-bespoke set of minimalist icons.

However, the project required an additional couple of graphic layers that would effectively represent the weather data concurrently being described by sound. The intention was to formulate a design language that could compliment Spotify's without blending into it. Additionally, besides textual elements, the platform required a relatively complex system of colour and texture that would be applied to data-driven animations accompanying each soundscape.

It was tempting to develop a visual system which was directly influenced by the sonic aspect of the product—say, the chords resulting from the arbitrary parameter-led notes, or the music's temporal qualities. This especially when music already has multiple dimensions that could inspire different visualisations. However, this seemed divergent from the project's cause and focus: the weather data itself.

After some initial experimentation and various proposals, a gradient-based style which was inspired by meteorological parameters and fit all the above criteria was selected and applied. The colours making up the radial gradient itself were split into two. The first colour, at the centre, was attributed to the season in which the day fell—this would ensure a recognisable shared element between any two days which were, by nature, meant to have similar weather conditions. The second shade in the gradient, around the edges, was split further into its RGB components. Values for red would be mapped to temperature; green to wind, and blue to precipitation. This was done using the same ranges applied in the CSV to MIDI conversion, and then assigning a value between 0 and 255 for every decimal possibility. The resulting gradient, by default, showed some resemblance to the visual metaphors typically associated with the actual weather conditions they are reflecting: red for a hot day, or blue for a cold and rainy one, for example.

However, once they were combined with the soundscapes (see section 2.3.2) the animations fell flat—they neither complimented the sound nor expressed anything new of their own. There was also some issue with the process by which those same animations were being created, namely that it involved the manual conversion (number by number) of all weather data, and then the manual input of that data into the individual frames, before the animation could be automated.

The visuals were therefore re-thought, especially with this latter factor in mind. Putting functionality first, it seemed most reasonable to work with After Effects, despite any other limitations it might have—purely because it would allow for the raw data (CSV, converted to mgJSON) to be plugged into individual parameters (live text, to start, but also settings such as size, opacity, etc.) via custom expressions. This decision, in the end, saved many hours of what would have been the manual input of numerical data.

Now revised, the visual system was still based on the concept of round shapes and gentle colour transitions, but could afford more minute changes based on different variables. Effects and movements were connected to precipitation, cloud cover, and wind speed.

The primary feature of the animations was still, however, colour. That of the central ellipse was determined by the current temperature, based on a formula which mapped temperatures from -10 to 40°C to a smooth colour gradient: light blue (#00AAFF) to bright red (#FF0000). See Appendix E for details.

The background colour was directly linked to the 1.5°C—if the anomaly that day was larger than 1.5°C, the background would be varying shades of red; 1 to 1.5°C would be yellow, and anything less than 1°C would be Spotify green. This last factor made especially evident the defining criteria of the project.

2.4 Production

The formalisation outlined above was applied primarily to the online platform, proposed as the primary and combined outcome of this research, but also to the Spotify application to a more minor extent. That same visual language was extended to every part of the project, from digital media to printed panels.

2.4.1 Audiovisual Deliverables

As discussed earlier in section 2.1.2, Delivery, for the purposes of showcasing the tool's functionality without major investment at such an early stage, multiple video mock-ups of a prototyping nature were instead created.

The prototype base was designed and animated in Figma. The soundscapes were created separately in GarageBand, and the data-driven animations in After Effects. Various combinations of the three were required at different points of production.

Once the base design had been locked in, an ideal user journey was designed and used to guide the design and creation requirements. Key features and more distinct capacities were prioritised wherever necessary. These were then planned into individual videos that would showcase functionality whilst fulfilling two other important criteria: showcasing the soundscapes, and being as engaging as possible.

2.4.2 Thesis

For an extra complementary touch, this thesis was put through text-to-speech conversion and then

incorporated within the Spotify universe in the form of a multi-media playlist.

Due to distribution limitations, the public playlist had to be restricted to local plays.

2.4.3 Live Demo

An MVP demo of the online platform was custom-built using p5.js. This demo demonstrates the platform's intended 'live' functionality in low-fidelity form: acquiring live weather data from an open-source API and transforming that data into sonic and visual elements.

The demo obviously has its limitations: content and functionality are both minimal, the visual metaphors are not as accurate as with the video mock-ups, and the sound (constructed using p5.Oscillator) leaves much to be desired.

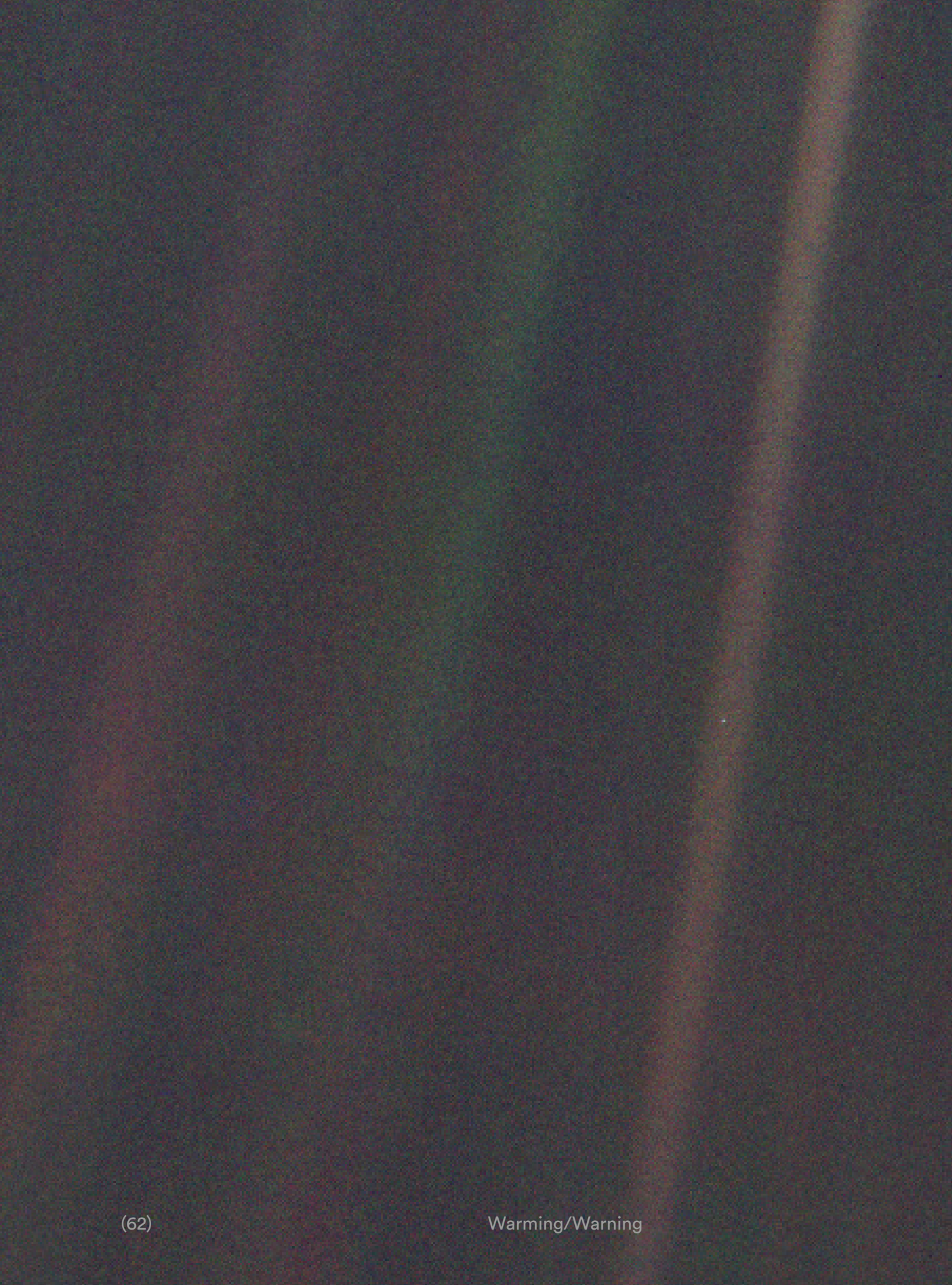
However, even in such a simple form, the project demonstrates great potential. It may be accessed via the URL https://warmingwarning.org/.

2.4.4 Additional Materials

A few additional deliverables were produced to compliment the digital ones, mainly with the aim of explaining the project and, particularly, the logical legend behind the data-driven animations.

A poster was produced for this purpose, as well as small cards with QR codes linking to digital media: this thesis, and the live demo.

No further materials were deemed relevant at this stage of the project. Rather, it was all kept to a minimal degree in the hopes that the largest portion of the audience's attention would be dedicated to the soundscapes, and to the overarching issue of global warming.



Chapter Three—

Conclusions

3.1 Initial Statements

The culmination of this project has demonstrated the successful integration of weather data into meaningful sound, thereby validating the initial objectives of the project and creating a solid foundation for its ultimate ambitions. Through a combination of research, methodology and personal experimentation, the final delivery is an effective representation of the arguments presented and the conclusions drawn.

To recap, the primary methodological approaches involved surveying and interviewing participants to gauge their emotional and cognitive responses to independent variables and to trial soundscapes created from weather data. This methodology was designed for the collection of both qualitative and quantitative data.

Survey results indicated a significant emotional response among listeners, and answers which fulfilled the researcher's expectations regarding the links between sonic devices (of which pitch is the foremost) and elicited feelings. The interviews further corroborated these findings, revealing that participants found the soundscapes meaningful on both informative and emotional levels.

These responses underscore the effectiveness of using pitch to convey the gravity of climate-related data, validating the hypothesis that sound can be a powerful medium for data representation.

Concurrently, the experimental phase involved a trial-and-error sonification process where pitch was used as the primary sound device. Although the emotional component was very important, the factual and accurate use of data was just as

critical—therefore, impartiality and correctness were prioritised there.

Thanks to this balance, the consistency between the expected outcomes and the actual results provides a strong endorsement of the project's rationale and execution. The key conclusions would therefore be that:

1. Despite the monumental challenge it presents, there is still much that can be done in the fight against global warming.

Various novel forms of expression and communication exist but are yet to be leveraged. The race is far from over: now is the time to act and innovate.

2. Sound can effectively translate various forms of numerical data into a novel and resonant format.

Beyond just representing data, sonification can foster a deep connection and understanding. This emotional engagement is crucial for issues like the climate crisis, where awareness and urgency are paramount.

3. The notion of branding extends far beyond the limits of a logo.

By incorporating data sonification into its platform, Spotify not only enhances its own image but also pioneers innovative ways to engage individuals with critical global issues. This strategic move proves a proactive commitment to social responsibility, solidifies the company's position in its industry, and sets a precedent for how brands can use their power.

3.2 Limitations and Future Lines

The foremost reason for concluding the research at this particular point, for the time being, is availability of time and human resources to continue developing the primary products: the online platform, and functionality within the Spotify app, as well as the individual deliverables that would need to be funnelled into those channels.

This is not to say that the research presented here is comprehensive—it must continuously be updated to reflect innovation and discovery in the fields explored in the earlier chapters. Especially for a topic such as climate change, which is ever-evolving, the research and products must be agile enough to respond to the latest data and updates.

On a micro level, there are two limitations encountered during the project development which would require resolution prior to scaling up. There are also additional features that would be considered desirable.

The first limitation is the primary climate criteria, the 1.5°C threshold. For the temporary demonstration purposes of this thesis, some concessions were made when comparing global data (the daily mean temperature) to local variables (hourly weather information). Ideally, the two are not mixed—local values should be acquired for both the daily average temperature and the corresponding pre-1900s levels. This would make for more bespoke and, more importantly, accurate representations of local weather.

The second limitation is a more practical one, and it involves the numerous manual processes

required for the creation of components. All of the manual processes mentioned in this research should be linearised and automated via the creation of custom algorithms and applications. Onboarding a team of professionals, from developers to designers, would greatly increase the efficiency and efficacy of the process and its eventual results.

As far as optional but desirable features go, the below should be considered:

» Interactive elements within the app and website, allowing users to customise their soundscapes based on personal preferences, or to explore different musical interpretations (in different genres, say) of weather data. This could also include options for adjusting parameters such as tempo, instrumentation, or mood.
» Accessibility features catering for users with disabilities, such as screen reader compatibility, alternative text for visual elements, and options for adjusting sound settings based on hearing impairments.
» Educational resources integrated directly within the app and website to provide immediate information about climate change, weather patterns, and the science behind sonification. This could include articles, videos, interactive lessons.

Considering all of the above, it may be said that the terms initially proposed by this research were met, in a way which fostered exploration and potential for future development.

3.3 Business Model

To conclude on future lines and sum up this chapter, a concise business model (based on the Business Model Canvas) was developed to explain the projected strategy, intended application, and predicted profit streams.

3.3.1 Implementation

First and foremost, the initiative relies on a number of key partners that would fuel the project financially and creatively.

Although Spotify itself is responsible for the initial creation and promotion, it realistically needs a robust team of web developers and UX designers to build and maintain the digital platform.

From that point on, collaboration with musicians, sound designers, and composers would create many more sonic possibilities and opportunities for exposure—and, on the same lines, partnerships with environmental NGOs as well as co-branded initiatives with larger corporations would also create further advocacy and awareness, this time with different and contrasting audience segments. Working with universities, schools, and other educational institutions to incorporate the tool into specialised programmes (on climate education, for example) would fulfil many of the project's ulterior goals.

Overall, the project could prove fertile ground for interdisciplinary collaboration between meteorologists, musicians, scientists, artists, and technologists for the development of democratic, user-friendly tools and applications for accessing and exploring niche datasets.

In fact, the key activities may be described as:

» Data collection and processing, from various sources;
» Soundscape development;
» Platform development and maintenance, including visual design; and
» Outreach and education.

The materials created at this early stage of the project are purely for demonstration purposes—the eventual platform should leverage the creation of bespoke algorithms that automate the processes of data collection, sonification, and distribution.

For this reason, a number of key resources are needed. A technical infrastructure, for starters, is required to support large amounts of data and storage. That same setup needs both financial and human resources (experts in meteorology and sound alike) to maintain it.

The tool's value proposition, first and foremost, is the enhanced understanding of climate data: by providing a comprehensive database via a novel experience, complex meteorological patterns and climate change impacts are made more accessible to the general public that would otherwise be alienated from that information. This is all the more enhanced when emotion is involved and engagement is thus created. This project serves as a blueprint for future initiatives that aim to leverage the emotional power of sound.

Tangentially, this research presents great potential for the advancement of alternative modes of data representation, particularly for individuals with visual impairment/s or learning differences. Through user testing and feedback sessions, the effectiveness of different sonification strategies in conveying information (meteorological or otherwise) should be evaluated against factors such as accessibility, clarity, and engagement.

Therefore, community is an integral part of initiative. Its near future should include intensive community building (digital or otherwise), the creation of a user support base, and flexible feedback mechanisms for users to suggest improvements. The project's channels—the online platform, Spotify itself, and other potential outlets like social media—should be leveraged to support these ventures and to target the ideal customer segments, which stretch as far as to include educators, environmentalists, musicians, and visual designers.

3.3.2 Economic Considerations

Spotify's financial backing is likely to ensure a lack of economic hurdles for the project. However, it is worthwhile to keep in mind the overall cost structure, which will likely look as follows:

» Development costs, including web development, sound design, and data processing;
» Operational and maintenance costs;
» Marketing costs, to cover promotional and outreach campaigns; and
» Partnership costs, associated with third-party contributions and collaborations.

It is also safe to assume that, given the tool's CSR nature, certain pro-bono contributions will be made towards it. Revenue would therefore be expected from sponsorships, donations, and grants. Educational licensing is also a potential source of income, given the development of an appropriate system and set of resources.

Epilogue

This project has been more than just an academic endeavour—it has been a deeply transformative and educational personal experience. Reading about climate change on a daily basis for many consecutive months was tough on my spirit, to say the least, but it also gave me so many reasons to keep working.

Whilst I have never doubted the power of music, engaging with it in this way—in the intersection between data, technology and perception—revealed a potential beyond what I had ever imagined. The feedback from participants, especially, has reinforced my belief in the profound impact that sound, amongst other innovative communication methods, can have. This project has proven to me (and, I hope, to you) that data is not merely a collection of numbers, but a form of narrative that can touch hearts and minds.

As we look towards the future, it is my personal wish that this research will inspire others to explore the vast potential of sound as a medium for communication, and of humanity in this fight for our planet. The urgency of the climate crisis demands innovation that is as continuous as it is compelling. I am hopeful and excited.

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List of Figures

Figure 8: **How Does It Make You Feel?**
Summarised results from Part 2 of the anonymous survey distributed as part of the project's methodology. Each colour represents a difference choice of emotion, sorted by sound sample.

Figure 9: **Days Exceeding the Pre-industrial Reference by More Than 1°C**
The number of days during which the temperature exceeded the average for 1850-1900 (the designated pre-industrial reference period) by more than 1°C, from the years 1990 to 2023. The plot highlights temperature increases within three ranges.

Glossary

Branding
Used to describe the application of an identity (graphic or otherwise) to a concept, however abstract.

Climate
The average of weather patterns in a specific area over a longer period of time.

Climate change
Long-term shifts in temperatures and weather patterns, of which human activities have been the main driver.

Climate crisis
Serious problems that are being caused, or are likely to be caused, by changes in the planet's climate, consequently posing a very serious threat to human civilisation.

Data representation
The representation of qualitative or quantitative information in an alternative form, be it visual or aural.

Global warming
An increase in the Earth's average surface temperature that occurs when the concentration of greenhouse gases in the atmosphere increases.

Sonification
The act or process of producing sound. In the context of this research, the term will be used to refer to the transformation of other types of media into sonic forms.

Weather
Atmospheric conditions at a particular time in a particular location, including temperature, humidity, precipitation, cloudiness, wind, and visibility.

It should be clarified that the nature of this work is neither scientific nor meteorological, and therefore some cross-references are allowed.

Acronyms & Abbreviations

API
Application programming interface

BPM
Beats per minute

CSR
Corporate social responsibility

CSV
Comma-separated values

DAW
Digital audio workstation

GHG
Greenhouse gases

MIDI
Musical instrument digital interface

MVP
Minimum viable product

UI
User interface

UX
User experience

Appendix

Appendix A: Survey Responses

Total responses: 92

For long-form answers, a curated selection has been presented.

How does it make you feel?

This survey is related to Warming/Warning: my Master's project on climate change and data sonification. It should not take longer than 10 minutes to answer the questions, and you'll need to be in a setting where you can comfortably listen to a few minutes of music. Participation is completely anonymous.

How much time (per day) do you listen to music?

Not at all 2 (2.2%)
Less than 30 minutes 20 (21.7%)
About an hour 30 (32.6%)
1-2 hours 12 (13%)
2-4 hours 20 (21.7%)
I always have music on ... 8 (8.7%)

How important is the emotional component of a music listening experience to you?

0 ..... 0 (0%)
1 ..... 0 (0%)
2 ..... 3 (3.3%)
3 ..... 24 (26.1%)
4 ..... 26 (28.3%)
5 ..... 39 (42.4%)

Part 1: Complex Emotions

In this section, you will be given 4 pieces of music (via Spotify links).

1. **Listen to the first 15-30 seconds of the song.**
2. **List any emotions that it makes you feel, if any, in the order that you feel them.**

Here are some examples, but feel free to add your own! Annoyed, Anxious, Calm, Energised, Frustrated, Joyful, Proud, Sad, Scared, Tense, Tired, Triumphant...

Headphones are recommended.

An Ending (Ascent)

Calm 18
Relaxed 5
Sad 4
Hopeful 3
Peaceful 3
Anxious 2

» At the beginning it made me feel calm and chill but the melody became repetitive and the tempo is not exactly correct so I started feeling nervous and pissed.
» Inspiring, uplifting, calm, meditative.
» Calm, like a walk in the early morning in a spring garden... It has a church feeling, that happens when you walk into a big building and have this small sense of awe.
» Indifferent.
» Curious, expectant.
» Calming. Philosophical. Ready to explore the mysteries of the cosmos.
» Sad, melancholic, with a sense of finality, like I would feel at a funeral.
» Calm, intrigued, inspired. There's a specific wave of sound that is heartwarming.
» Triumphant, feels like realising something eye-opening after a challenging, hard experience.
» Awakened, like the sun is rising. Energised, refreshed.

Eden

Sad 11
Calm 10
Melancholic 4
Anxious 3
Hopeful 2
Joyful 2
Relaxed 2
Happy 2
Energised 2

» That first note is instantly sad.
» Sad but hopeful, determined.
» Melancholy but hopeful; evokes looking out the window at nature.
» Sad, resigned.
» This is the sort of music that we associate with human drama or emotions.
» Alive.
» Young.
» More than a feeling, I picture things. I see wind, moving green wheat on a spring afternoon. The wind moves to a cliff and to a waterfall... If I had to describe it with emotions, I would say freedom, liberation, synergy, harmony, acceptance, peace.

Knot of Spirit

Anxious 6
Tense 5
Scared 4
Calm 3
Confused 3

Frustrated 2
Annoyed 2

» Anxious, on edge.
» Triumphant, energised.
» Like I'm getting a massage. Quizzical, centered, contemplative, calm.
» Sense of magic and the unknown, fantasy.
» Alone, infinite.
» Motionless.
» Subterranean.
» Intoxicated.
» In this case I feel like a void, but a nice one. It's hard to explain… It reminds me of floating in a calm lake and all your worries disappear—it's just you and your instincts: cold on your skin, muffled sounds, the non-gravity…
» Slightly anxious, like I am underwater and am hearing distressed whales at a distance.
» Cacophonous. Jarring. Life out of balance?
» Has a certain spirituality to it, but doesn't trigger an emotional response.

Still/Sound

Calm 12
Relaxed 7
Peaceful 4
Hopeful 3
Happy 3
Sad 3
Peace 2

» The feeling of being inside on a rainy day and getting to watch the drops run down the window panes.
» Solitude. Introspection. Remote location. A walk in a dense forest.
» Motivated.
» Lonely, but content.
» Feels very still and steady (a bit hard to describe, to be honest).
» Tender, touched by the softness, slightly sad.
» Pressured, annoyed.
» Resilient.
» Annoying, like elevator music.
» Boring.

Part 2: Basic Emotions

The same instructions apply but, this time, you will be asked to select only one basic emotion (out of a pre-set list) to describe the same pieces of music.

An Ending (Ascent)

Sadness 28 (30.4%)
Happiness 56 (60.9%)
Fear 6 (6.5%)
Anger 2 (2.2%)

Eden

Sadness 46 (50%)
Happiness 32 (34.8%)
Fear 12 (13%)
Anger 2 (2.2%)

Knot of Spirit

Sadness 12 (13%)
Happiness 11 (12%)
Fear 55 (59.8%)
Anger 14 (15.2%)

Still/Sound

Sadness 22 (23.9%)
Happiness 60 (65.2%)
Fear 3 (3.3%)
Anger 7 (7.6%)

Part 3: Demographics

These last few questions will help organise the responses given in the previous sections.

What is your age?

Under 18 ..... 7 (7.6%)
18-24 ..... 7 (7.6%)
25-34 ..... 30 (32.6%)
35-44 ..... 11 (12%)
45-54 ..... 21 (22.8%)
Over 55 ..... 23 (25%)

Where in the world did you grow up?

Africa 1 (1.1%)
Asia 4 (4.3%)
Australia 1 (1.1%)
Europe 71 (77.2%)
North America 10 (10.9%)
South America 8 (8.7%)

Do you have any knowledge of music theory?

Yes, I am very knowledgeable 12 (13%)
Only a little 33 (35.9%)
No, none at all 47 (51.1%)

If you would be interested in having a longer, in-depth conversation on sound, emotion, data design and this project, please identify yourself here!

33 responses were submitted.

Thank you so much for contributing!
Your response has been recorded.

Appendix B: Interview Transcripts

Total interviews: 3

Sample sounds

Interview #1

May 29th, 2024

Part 1

Listen to the samples, one by one, and describe them individually—both in factual terms (what you hear) as well as emotional ones (what they make you feel, if anything).

1: It sounds like some organ or piano, very slowly played—almost like a mediaeval choir with a chorus of voices (even though it's probably computer-generated). It has that quality of a choir in unison, singing drawn out notes. The repetition and the melody give me an instinctive sad or foreboding feeling. It's the kind of song you would hear in a movie soundtrack: during a scene like a funeral with a man lurking in the background. That kind of sad and suspicious mood.

2: This is the kind of ambience music that they play during yoga—minus the electronic sounds. It puts me in a contemplative, meditative and ethereal space full of possibilities. It is neither happy nor sad. Is all of this meant to be inspiring brainwaves? **[What do you mean by inspiring brainwaves?]** When you listen to fast or slow music that influences your brain activity, and that would be seen by an MRI machine. This piece sounds like it would inspire calmness or lack of intense activity. Overall there is no intense emotion.

3: Is this a different one? **[Yes.]** Are you sure? **[Yes.]** There is a dissonance that wasn't in the previous one, although they do feel very similar—

yet this is definitely not one to play at yoga, as it would creep people out. Interesting contrast of the rising notes in the background with the constant, negative-sounding piano notes. If you took away those piano notes, it would probably sound more pleasant.

4: Unsettling. The robotic noise in the background is like a movie from the 1990s related to the internet—maybe like a spy thriller. Very unsettling, but not overpoweringly so. I can listen to it without my heart racing, because it's going so slow. But that doesn't mean I like it.

5: Did you make these? **[Yep.]** Neutral—another day at yoga, and it's not the difficult kind where you're upside down. It's the relaxing kind. Inoffensive.

Once you've heard all of them, any comments overall?

Some make me uneasy whereas others are more neutral. But I can't totally tell the difference.

Did you notice any marked distinctions between the 5 pieces?

The first one and the last one felt similar, and the ones in the middle felt slightly more sinister—but they weren't so distinctive that I am able to notice or remember. Some have a rhythmic, robotic noise in them which make the piece sound slightly more electronic. There is definite cohesion between them, but their outlines are almost too alike. The instruments and type of music is definitely the same throughout while the tone is different. There is a consistency there. **[Do you think this consistency is a good thing?]** It's hard to answer that question without knowing more about the wider project.

Part 2

Each of these pieces is based on the linear conversion of meteorological data (for 24 hours per track) to MIDI sound. With that knowledge, what kind of weather conditions would you guess that each track represents?

The resonating piano notes could equate temperature—although that could also be the choral textures in the background. I imagine wind speed was also a factor. The rhythmic sound must have been rainfall.

I assume the ones that felt sinister to be anomalies in terms of weather patterns, or maybe just the clash of two particular sets of data. It's hard to tell.

In this case, what you heard (respectively) was:

1. **One of the hottest days on record in Barcelona (August 18th, 2023)**
2. **A rainy summer day in Barcelona (August 27th, 2023)**
3. **The same day, but in Malta—typically windy (August 27th, 2023)**
4. **Winter conditions in Prague (January 1st, 2024)**
5. **A spring day in Barcelona (April 1st, 2024)**

With that knowledge but not any further details or numbers, do you think that the sound/s you heard reflect this factual information? Why or why not?

I don't know. The foreboding feeling is spot on (for a hot day, for example) but the instruments themselves make me think more of a relaxing space (like a spa) than a hot day, problematic or otherwise.

Would you change anything that you heard?

If I'm just spitballing and I was in control of the way a really hot day sounds, it would not sound simultaneously foreboding and relaxing—it might have strings or brass. And maybe it would be faster or slower depending on the contributing factors and to show a sense of emergency.

Do you think representation (from data to sound) should be literal? That is, should wind sound like wind, rain sound like rain…

That feels almost too obvious, and I don't think it would sound very good. I don't think it needs to be literal. It's more interesting if it isn't, because then there's an amount of interpretation involved.

Part 3

The intention with the particular examples you heard is to use pitch (rather than rhythm or timbre) as the primary communicator. Besides the rising and falling of note height, there are minute differences in the harmony and dissonance of different points and progressions. Did you notice this?

I did notice that there are commonalities in the form and sounds chosen.

Do you think it's effective—both in this context and in general?

In terms of effect, I think that if there is ever any hope of putting large amounts of data into this system and making it universal for people living all over the world, it must have some kind of consistency.

Furthermore, if this ever evolves into something bigger, it would be very cool to be able to change the genre (for example)—from meditative music to rock, for example. **[Would there still be consistency and common factors between different days?]** Yes, it's just the genre that changes. But the elements stay exactly the same.

There was an additional level of dissonance that was added to two of the pieces because, on the days they represented, the global temperature increase exceeded the threshold of 1.5°C as outlined by the Paris agreement. The pieces in question were the 1st and 4th ones. Was this noticeable at all?

It was noticeable, but this seems like a detail that might be hard to solve within the scope of this project. Since your records are local/regional, it is hard to see them against a global measurement. Climates are changing the most drastically regionally, not universally—so that is a major drawback to this method of explanation. What if there is a hurricane in Barcelona on a day that is actually still within the 1.5°C? **[I guess then the temperature doesn't matter at all. Would it be better to focus on extremities, such as wind speed?]** Maybe. But all factors, including the temperature increase, should be considered locally.

The actual dissonance was not that easy to make out, although the two that were most 'unsettling' are identifiable. Overall there maybe isn't enough of a difference between all the tracks. All this said, for the scope of this project, I think it's a valiant effort.

That's it! Thank you.

Interview #2

May 30th, 2024

Part 1

Listen to the samples, one by one, and describe them individually—both in factual terms (what you hear) as well as emotional ones (what they make you feel, if anything).

1: What I heard: Dark notes: a sense of harmonic progression. Some darker sounds in the back, and an “incremento” or a sense of growing tension at the end. How I felt: A bit scared. The sounds were spooky even though they were super harmonious, and the tension built made me feel a bit more uncomfortable.

2: What I heard: An elusive, blurry harmony at the beginning, with some sound, more electric, breaking the “form” of the whole piece, yet not feeling completely disconnected from the rest of the composition. How I felt: I liked it a lot. At the beginning, this elusive thing gave me the sense of hope. It was positive. It made me feel calm.

3: What I heard: A progression of a really harmonious piece, with what felt like higher notes than the previous two. A bit dramatic. How I felt: Happy, positive, ethereal. Like a contemplative soundtrack for a film.

4: What I heard: A mix of sounds: harmonious in a way, yet a bit disturbing. While the sounds don’t seem to match each other, they work together in the piece, in a way. Maybe because of the timing? It gets weirder by the end, with that extra sound coming in, out of place in way, but not completely. The closing, though, was super chill in relation to the whole piece. A darker one than the rest. How I felt: Disturbed, mainly because of the extra sound. Anxious?

5: What I heard: A harmonic, slow, maybe sad piece. The high notes with the dark bass create a beautiful contrast, they are like rays of light in a swamp. The piece is super harmonic, with a build up throughout all of it that is pleasing. How I felt: Sad. Contemplative. Emotional.

Once you’ve heard all of them, any comments overall?

Crazy how some similar sounds in terms of composition can take you so many different places via their pitch and other subtle changes. #5 was my absolute favourite. Listening through all of them made me realise how, for example, listening to the first one alone I thought it was super dark, but then, after listening to everything, in comparison it wasn’t as much. I still left my first thoughts as I had them in my answers, since it’s about that: honest feelings.

Did you notice any marked distinctions between the 5 pieces?

First and most noticeably, there were noises added in some of them that created a divergence from the general harmony. Then they also felt similar in the way they built up tension. The pitch, for me, set the tone and the emotion of each piece.

Part 2

Each of these pieces is based on the linear conversion of meteorological data (for 24 hours per track) to MIDI sound. With that knowledge, what kind of weather conditions would you guess that each track represents?

1. A hot day. Wet or humid in summer. Dense and intense.
2. Also intense, but a bit less so. Still summer, I would guess.
3. Windy?
4. Winter, cold.
5. It sounds like a morning breeze in spring.

In this case, what you heard (respectively) was:

1. **One of the hottest days on record in Barcelona (August 18th, 2023)**
2. **A rainy summer day in Barcelona (August 27th, 2023)**
3. **The same day, but in Malta—typically windy (August 27th, 2023)**
4. **Winter conditions in Prague (January 1st, 2024)**
5. **A spring day in Barcelona (April 1st, 2024)**

With that knowledge but not any further details or numbers, do you think that the sound/s you heard reflect this factual information? Why or why not?

Yes. The only one that felt different was #2, which for me was super intense. It didn't really feel rainy to me, and the emotion is kind of the same as the other summer day.

Would you change anything that you heard?

Not really.

Do you think representation (from data to sound) should be literal? That is, should wind sound like wind, rain sound like rain…

Absolutely not.

Part 3

The intention with the particular examples you heard is to use pitch (rather than rhythm or timbre) as the primary communicator. Besides the rising and falling of note height, there are minute differences in the harmony and dissonance of different points and progressions. Did you notice this?

Yes, a bit. I definitely noticed the pitch, then some of the other subtle changes.

Do you think it's effective—both in this context and in general?

Absolutely, yes. Especially the fact that the tracks were all equal and the only thing that changes is the pitch: the whole listening experience is more rich, approachable and understandable in this way.

There was an additional level of dissonance that was added to two of the pieces because, on the days they represented, the global temperature increase exceeded the threshold of 1.5°C as outlined by the Paris agreement. The pieces in question were the 1st and 4th ones. Was this noticeable at all?

At least for me, it is more notable in the 4th one, not in the 1st one.

That's it! Thank you.

Interview #3

May 31st, 2024

Part 1

Listen to the samples, one by one, and describe them individually—both in factual terms (what you hear) as well as emotional ones (what they make you feel, if anything).

1: There's a certain calmness to it at the start but it progressively gets a little bit eerie and somewhat unsettling towards the end. It could be because of the dissonance and the higher pitches.

2: This reminded me of doing yoga practice. There's a sort of meditative feel to it, quite calming, quite serene, occasionally broken up by a bit of tension and dissonance but yeah, definitely calm.

3: Definitely feels more jarring than the previous one. Reminds me of some horror movies I've seen, almost like a calm before the storm kinda thing. It's sort of building me up but I'm anticipating something might happen.

4: OK, this one makes me feel really nervous. I feel unsettled and kinda uncomfortable listening to this. Makes me feel like I want to run away from someone chasing me.

5: This one definitely started out feeling quite resolved and resolute, if I can say that. It feels somewhat ambient and makes me feel like I'm floating somewhere. I like this, despite the tension in the higher pitches.

Can you identify any of the sounds that you heard? Either as instruments or as natural sounds, perhaps.

There are definitely a lot of synth sounds, electronic pads, possibly some high electronic strings… Can hear some piano as well, I think, in some of them. There were also some ambient sounds; sounds of air moving, and wind, possibly? Maybe even the sound of the sea.

Once you've heard all of them, any comments overall?

The pieces definitely feel connected in some way. There's a coherence that links them together, a motif that almost runs through, in the way they build up and change. #2 and #5 were probably my favourite ones.

Did you notice any marked distinctions between the 5 pieces?

Like I said, #2 and #5 stood out in that they were more relaxing, atmospheric and calming, minimal. I enjoyed the feeling of floating in a gravity-less medium. #3 and #4, in contrast, had jarring noises and carried a lot of tension—very ominous. The first piece would float somewhere in between. I think those are the categories I'd sort them in.

Part 2

Each of these pieces is based on the linear conversion of meteorological data (for 24 hours per track) to MIDI sound. With that knowledge, what kind of weather conditions would you guess that each track represents?

The first one, I want to imagine that it was a spring day, starting with beautiful weather, but as the day went on clouds started coming up and

there was a hint of a storm. The second would be late spring or early summer (I don't imagine heat to be a calm thing), maybe with a slight breeze. I guess the third would be a very cloudy day, but in the middle of the summer, for example—that would explain the jarring feeling of something that wasn't necessarily "of the season" or expected. For the fourth, I'd guess light rain, maybe in spring. And with the fifth, late summer and a little bit less heat, which would contribute to that new floating feeling.

In this case, what you heard (respectively) was:

1. **One of the hottest days on record in Barcelona (August 18th, 2023)**
2. **A rainy summer day in Barcelona (August 27th, 2023)**
3. **The same day, but in Malta—typically windy (August 27th, 2023)**
4. **Winter conditions in Prague (January 1st, 2024)**
5. **A spring day in Barcelona (April 1st, 2024)**

With that knowledge but not any further details or numbers, do you think that the sound/s you heard reflect this factual information? Why or why not?

The first one makes a lot of sense because, although we associate heat with summer, the extreme heat we are feeling these days is unsettling. It's a bad thing that it gets warmer earlier, for example. I can see links between rainy conditions and a calming atmosphere, being cosy… so I'm not that surprised by it. I'm not sure about the third one. The fourth one, knowing now what it relates to, makes sense—I feel unsettled because it was one of the warmest winters (in Prague, especially). The fifth: a lot of people like spring, so it makes sense that it made me feel calm, as it was probably a typically beautiful day.

Would you change anything that you heard?

Not really. When I compare what I heard with what you just told me, I think it all makes perfect sense. Wherever I noticed dissonance, it fits the conflicting feeling that should be felt by us who remember when seasonal weather was quite different. The sound fits our experience of climate change: rising temperature, freak weather events, etc.

Do you think representation (from data to sound) should be literal? That is, should wind sound like wind, rain sound like rain…

I think it could be interesting. I did hear some sounds (I mentioned it earlier) that sounded like wind or sea waves, but they weren't super literal. It might not be a bad idea to include them as actual sounds. **[In terms of communication, right?]** Exactly—hearing whooshes of wind, leaves in trees—that sort of thing might be interesting.

Part 3

The intention with the particular examples you heard is to use pitch (rather than rhythm or timbre) as the primary communicator. Besides the rising and falling of note height, there are minute differences in the harmony and dissonance of different points and progressions. Did you notice this?

I would say so. A part of it is because I'm a musical person—I think this might be evident in my earlier answers—and therefore I am more sensitive to harmonic relations and the smallest clashes in dissonance.

Do you think it's effective—both in this context and in general?

Yes, very much so. As human beings, we are sensitive to sounds in different ways—musical, for example, or the ambient sound in your surroundings. We are hard-wired to avoid certain sounds, like the high pitch of feedback that makes you cover your ears, or a fire alarm, that makes you feel their emergency. Clashing, dissonant sounds are definitely bound to make you feel less at ease. Contrast it especially to a calm setting like a restaurant or a waiting room. I think the combination of pitch with feelings and climate change makes a lot of sense—more so than using rhythm or any other musical tool.

There was an additional level of dissonance that was added to two of the pieces because, on the days they represented, the global temperature increase exceeded the threshold of 1.5°C as outlined by the Paris agreement. The pieces in question were the 1st and 4th ones. Was this noticeable at all?

Absolutely. **[Do you think the concept works?]** Of course. In general there is a lot of talk about climate change—people are aware of it but when it comes to actually taking realistic measures, it's another story. There is a lot of awareness but not enough action. The things that need to be done to make a proper difference (flying less, eating less meat) are things people don't want to give up. **[An additional question: Does the discrepancy between local and glocal factors bother you?]** Maybe it should be an option to hear the big picture or just the local one. **[Would all the sounds change or just the one?]** I'm not entirely sure.

That's it! Thank you.

Appendix C: Sample Set of Daily Temperature Anomalies

Daily global surface air temperature anomaly for June 2023 with reference to the 1850-1900 pre-industrial period.

Data is available as far back as 1940 and as recent as November 2023.

Complete data set

Date	Temp. (°C)	Increase (°C)
2023-06-01	16.17	1.31
2023-06-02	16.22	1.33
2023-06-03	16.28	1.37
2023-06-04	16.29	1.35
2023-06-05	16.30	1.34
2023-06-06	16.39	1.41
2023-06-07	16.51	1.51
2023-06-08	16.65	1.62
2023-06-09	16.70	1.66
2023-06-10	16.64	1.58
2023-06-11	16.57	1.48
2023-06-12	16.54	1.44
2023-06-13	16.50	1.37
2023-06-14	16.48	1.33
2023-06-15	16.50	1.34
2023-06-16	16.51	1.33
2023-06-17	16.51	1.31
2023-06-18	16.51	1.30
2023-06-19	16.50	1.28
2023-06-20	16.43	1.19
2023-06-21	16.47	1.21
2023-06-22	16.51	1.25
2023-06-23	16.55	1.27
2023-06-24	16.65	1.36
2023-06-25	16.71	1.41
2023-06-26	16.71	1.40
2023-06-27	16.71	1.38
2023-06-28	16.67	1.33
2023-06-29	16.65	1.31
2023-06-30	16.58	1.23

Appendix D: Sample Daily Weather CSV File

2023-08-27 (Barcelona)

Time	Temp. (°C)	Humidity (%)	Apparent Temp. (°C)	Precipitation (mm)
00:00	25.2	89	29.9	0.10
01:00	24.4	91	29.3	0.00
02:00	25.5	83	30.3	0.00
03:00	24.6	87	29.2	0.00
04:00	22.7	89	25.0	8.60
05:00	22.1	92	25.6	0.70
06:00	21.4	93	24.1	2.60
07:00	21.2	95	23.0	1.00
08:00	20.4	94	21.6	2.70
09:00	19.3	93	20.6	3.20
10:00	18.9	95	20.1	4.20
11:00	18.8	92	20.0	2.70
12:00	19.4	87	20.4	0.50
13:00	18.8	89	20.0	4.00
14:00	18.7	85	20.0	3.10
15:00	20.1	81	21.0	0.40
16:00	21.7	76	22.7	0.00
17:00	23.2	63	24.1	0.00
18:00	21.7	70	22.6	0.30
19:00	21.3	83	23.8	1.40
20:00	19.5	83	20.2	0.40
21:00	18.9	85	20.6	0.00
22:00	18.2	87	19.7	0.00
23:00	18.4	76	18.8	0.00
Min	0.0	0	0.0	0.00
Max	40.0	100	40.0	50.00

Pressure (hPa)	Cloud Cover (%)	Wind Speed (km/h)	Is Day ()	Increase (°C)
1009.2	54	6.6	0	1.53
1008.7	71	4.5	0	
1007.9	86	2.8	0	
1007.4	77	3.5	0	
1008.3	100	13.6	0	
1008.8	100	5.2	0	
1008.4	84	9.3	0	
1008.2	100	15.9	0	
1008.5	100	16.1	1	
1009.0	100	12.2	1	
1008.6	100	11.5	1	
1009.5	100	10.4	1	
1009.1	100	10.5	1	
1009.5	100	8.7	1	
1010.0	72	5.8	1	
1009.6	81	10.0	1	
1009.1	82	11.3	1	
1009.6	90	7.3	1	
1010.6	89	7.9	1	
1010.9	90	3.8	1	
1011.4	90	11.0	1	
1011.2	89	3.5	0	
1011.5	32	4.0	0	
1011.6	30	6.4	0	
	0	0.0		
	100	25.00		

Appendix E: Conversion of Temperature to Hex

This conversion process was created by means of a script, created by AI, and integrated into Google Sheets via Apps Script.

```
function temperatureToHex(temperature) {
    var red, green, blue;

    if (temperature <= -10) {
        red = 0;
        green = 170;
        blue = 255;
    } else if (temperature <= 15) {
        red = Math.round(255 * (temperature + 10) / 25); // 0 to 255
        green = Math.round(170 + (85 * (temperature + 10) / 25)); // 170 to 255
        blue = Math.round(255 * (25 - (temperature + 10)) / 25); // 255 to 0
    } else if (temperature <= 40) {
        red = 255;
        green = Math.round(255 * (40 - temperature) / 25); // 255 to 0
        blue = 0;
    } else {
        red = 0;
        green = 0;
        blue = 0;
    }

    var hexRed = red.toString(16).padStart(2, '0');
    var hexGreen = green.toString(16).padStart(2, '0');
    var hexBlue = blue.toString(16).padStart(2, '0');

    return '#' + hexRed + hexGreen + hexBlue;
}
```

Temp. (°C)	Hex	Temp. (°C)	Hex	Temp. (°C)	Hex
40.0	#ff0000	22.0	#ffb800	4.0	#8fda70
39.5	#ff0500	21.5	#ffbd00	3.5	#8ad875
39.0	#ff0a00	21.0	#ffc200	3.0	#85d67a
38.5	#ff0f00	20.5	#ffc700	2.5	#80d580
38.0	#ff1400	20.0	#ffcc00	2.0	#7ad385
37.5	#ff1a00	19.5	#ffd100	1.5	#75d18a
37.0	#ff1f00	19.0	#ffd600	1.0	#70cf8f
36.5	#ff2400	18.5	#ffdb00	0.5	#6bce94
36.0	#ff2900	18.0	#ffe000	0.0	#66cc99
35.5	#ff2e00	17.5	#ffe600	-0.5	#61ca9e
35.0	#ff3300	17.0	#ffeb00	-1.0	#5cc9a3
34.5	#ff3800	16.5	#fff000	-1.5	#57c7a8
34.0	#ff3d00	16.0	#fff500	-2.0	#52c5ad
33.5	#ff4200	15.5	#fffa00	-2.5	#4dc4b3
33.0	#ff4700	15.0	#ffff00	-3.0	#47c2b8
32.5	#ff4d00	14.5	#fafd05	-3.5	#42c0bd
32.0	#ff5200	14.0	#f5fc0a	-4.0	#3dbec2
31.5	#ff5700	13.5	#f0fa0f	-4.5	#38bdc7
31.0	#ff5c00	13.0	#ebf814	-5.0	#33bbcc
30.5	#ff6100	12.5	#e6f71a	-5.5	#2eb9d1
30.0	#ff6600	12.0	#e0f51f	-6.0	#29b8d6
29.5	#ff6b00	11.5	#dbf324	-6.5	#24b6db
29.0	#ff7000	11.0	#d6f129	-7.0	#1fb4e0
28.5	#ff7500	10.5	#d1f02e	-7.5	#1ab3e6
28.0	#ff7a00	10.0	#ccee33	-8.0	#14b1eb
27.5	#ff8000	9.5	#c7ec38	-8.5	#0faff0
27.0	#ff8500	9.0	#c2eb3d	-9.0	#0aadf5
26.5	#ff8a00	8.5	#bde942	-9.5	#05acfa
26.0	#ff8f00	8.0	#b8e747	-10.0	#00aaff
25.5	#ff9400	7.5	#b3e64d		
25.0	#ff9900	7.0	#ade452		
24.5	#ff9e00	6.5	#a8e257		
24.0	#ffa300	6.0	#a3e05c		
23.5	#ffa800	5.5	#9edf61		
23.0	#ffad00	5.0	#99dd66		
22.5	#ffb300	4.5	#94db6b		

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