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Sounding out the Environment

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Abstract

The advent of 'Big Data' much of it publicly accessible, brings huge opportunities in the spectrum of information we can potentially access. However, actually interrogating this resource can be intimidating for those unfamiliar with data science tools such as the use of application programming interfaces (APIs) creating something of a digital divide and the impression that the data is still locked away. In this thesis I will explore the use of infosonics to share environmental data with the public. Using data sonification (turning data into sound) I propose to communicate the effects of weather on local natural environments in a novel and engaging way that is accessible to people of different ages and backgrounds. Throughout the thesis, I will document the main elements to be considered in the design of an infosonic experience. As a case study, I will focus on how rainfall and storms (events intrinsically associated with climate change) affect local river flow and landscape dynamics of the River Dee in rural Aberdeenshire, Scotland. The data, all open source, are collected by various National Agencies and form part of the National Library and Archive. My goal is ultimately to provide a new path to unlocking these vaults of data, creating an opportunity for users to explore the environment through time or space via an immersive sound experience promoting engagement with science and the environment.

Acknowledgements

I thank the my project supervisors for many thought-provoking discussions during this work. I addition, I thank Dr Mark Naylor and the 'Sounding out the river' team at the School of Geosciences, University of Edinburgh for sharing their scientific work and inspiring many of the early motivations behind this work.

I benefited from the feedback of a set of anonymous volunteers on sonification mappings, sound design and potential user interactions. Their comments were invaluable in refining the final project. The time they spent listening and reflecting is much appreciated.

Foreword

In navigating this thesis, I draw the reader's attention to supporting sound files and media that help articulate the ideas presented. This supporting material is documented towards the end of the thesis in Appendix 3: List of Sound and Media Examples. The audio files and other media, along with a detailed listening guide, are stored on a google drive accessed by the permanent link provided.

Table of Contents

Chapter 1. Introduction

1.1. Overview

In this chapter I will set the scene for my work. I will introduce the context, the overall project goals, the design opportunities I have targeted and pose the research questions that have guided my path towards achieving these goals.

1.2. Goals

In this thesis, I explore the use of sound to share environmental datasets and make them accessible to the public in a novel and informative manner. Here I will document the main elements to be considered in the design of such an experience. By focussing on local experiences and known local environments, I aim to engage people with science and help them connect with global environmental issues. It can be particularly challenging for individuals to reconcile the impacts of global phenomena, such as the climate emergency, on their local known environments and daily lives. Here I propose to create a sound based infosonic experience that unlocks the national weather and hydrometric (river) data archive and presents it in a unique accessible way. Through a suite of data sonifications that make up the infosonic, users would be encouraged to explore the story of their changing local environment. By listening, they could comparing current rainfall or river flow measurements from last week, with those from the last year or even decade. Alternatively they could search for specific remembered events such as storms or heat waves or flooding or particular dates or periods of interest.

As a case study dataset, I consider the effects of weather (rainfall) and storms (events intrinsically associated with climate change) on the resulting river dynamics along a river in rural Scotland. Data include current and archive datasets held by the Scottish Environmental Protection Agency, The MET Office, UK River Levels and the National River Flow Archive. Although the data are all public, they are held by different bodies, making it a challenge to compare, for example, how rainfall and river flow may be related (or not) during particular periods or in different places. The idea of this curiosity driven infosonic experience is that participants would interact via a simple physical, digital or gesture based interface allowing them to curate particular periods of time or particular locations they wish to listen to. Listening would be via headphones to allow a personal and immersive experience that could be enhanced by contextual spatial audio effects and even enable users to choose a personalised sound palette. Behind the scenes, the experience would be powered by data science, physical computing and sound synthesis.

In addition to being novel and memorable, the use of sound, or more specifically non-speech audio, as a communication medium is highly accessible to both experts and non-experts. It is emerging as a valid data science tool, where techniques such as ambisonics now allow recreation of three dimensional sound fields in real time, eg. (Hermann et al., 2011). The immersive empathetic experience this creates can resonate with a broader community than purely visual based displays. Crucially, since our ears are sensitive to distinct patterns from our eyes, listening not only provides a novel, fresh and captivating way to engage with data but also may provide us with new insights.

1.3. River Dee

The water body selected for study was the River Dee, a major river in Aberdeenshire, Scotland. From its source at Wells of Dee, Braeriach (elevation of 1220 m) on the South side of the Cairngorms National Park, the river flows along a natural course in a Easterly direction to discharge at the coast in Aberdeen. Along it's 140 km route, it flows through the well known villages of Ballater, Crathie, Braemar and Aboyne, collectively known as Royal Deeside.

Figure 1: Map showing the River Dee, Aberdeenshire, Scotland

This river enjoys an extensive set of monitoring stations, automatically capturing river level and rainfall at daily, hourly or in some cases 15 minutely intervals. From these measurements, river flow and catchment rainfall are later calculated. One reason to select this site was that datasets available are comprehensive and continuous (i.e. without gaps) for the last several decades, with some measurements dating back as far as 1929. In addition, the River Dee was the site of a major flooding event in the winter of 2015/2016, which caused extensive damage to property and infrastructure. The 2016 flooding gained significant national media attention and is an event ingrained in the memories of many locals. It is still evidenced to visitors by rerouting of the river causing traffic diversions and a host of local flood mitigation defences. This dramatic event was very clearly captured on the data records and can be used to demonstrate storm induced effects on river dynamics and local populations, hence an excellent for event for local participants to explore through sound. This is a very good example of how the local element and a continuing narrative could help engage people.

1.4. Design Opportunies and Target Users

Reflecting on the design opportunities, there were severals paths this project could take: towards tourism, outreach, local public engagement, communication or education. There were also range of target user groups to consider: visitors, locals, land owners, workers, young or old, able bodied or having accessibility challenges. Irrespective of the choice, each direction involves sharing essentially the same archive data and therefore much of the technical and practical design work, that formed the main time investment during my research is transferable to any context (or indeed any specific river chosen). The final curation of specific subsets of data, how they can be blended to form a narrative or experience and the interface (or wrapper) through which the information is presented will however, clearly differ considerably.

During recent work (Mair, 2020, DI project) I have proposed the concept of a rural visitor centre where an infosonic experience could be shared with visitors. This approach was mainly concerned with bringing visitors (potentially tourists) to a rural site, encouraging people to travel to small villages and explore the natural environment they found there. At the heart of this concept was a physical (analog) interface comprised of dials and sliders, that multiple visitors would physically interact with to explore the data. With the advent of physical distancing during spring 2020 (in an effort to reduce the spread of the covid-19 virus) most non-essential shops, cultural sites, cafes and rural car parks have been closed, and as a result all these activities have been on hold. It is not clear when we may resume hands on physical interaction with shared devices even if such activities will still be attractive to us in the longer term.

The Scottish Government advice to avoid unnecessary travel or socialising clearly imposed many constraints on our lives but also created an opportunity for 'discovering your backyard' type hyper local engagement with nature (even in the city) that many have embraced. Since schools have been closed, and parents suddenly found themselves responsible for home schooling, much of this exploration has taken place in family groups, sometimes taking the form of outdoor 'edutainment' where everyone is learning together. A related opportunity is the increase in digital literacy and a greater appetite for learning, although it is important to note that unfortunately this has also widened the gap to those who are digitally disadvantaged (Scottish Government, 2020).

I therefore take the current state as departure point and focus on communicating scientific information to a somewhat captive audience of local groups and families who are already curious about their local area. This decision (and the interviews I conduct with this target group) informs choices I make along the way, in terms of sound design, dataset curation, user experience and interface design.

1.5. Research Questions

The research questions I pose to guide this work mainly concern the communication of information via sound. Firstly what differences in terms of pitch, amplitude, timbre, can the average person (not a skilled musician) actually distinguish? Can people differentiate between multiple streams of data when they are portrayed together as sound? Which mappings ie. how the sounds adapt to changes in data values, are most intuitive to listeners? Does a background in science or data analysis alter how people perceive or interpret the sounds they hear? Does the use of spatial audio aid perception or understanding of datasets, or perhaps just make the experience more fun? Is there a 'sweet spot' in balancing the clarity of auditory experience versus listener fatigue or is this listener dependent?

With a view to answer these questions or at least promoting dialogue and broaden my knowledge on these topics, a set of listening experiments were set up and users were interviewed about what they can hear and their sound preferences. Also explored during these interviews were preferences for interactively exploring datasets and desirable interface formats.

1.6. Research tools and methods

The tools used in the broader research journey that led to this dissertation are the following.

Python - data pulling and wrangling to access archive datasets

Snufler - waveform viewing and analysis of seismometer data

MaxMSP - Data sonification, sound synthesis, waveform transposition, ambisonics

digimap - Digital Elevation Maps of local area

Raspberry shake and seismic node deployment

Field recording (zoom h5n) to use as source material eg. hydrophone or contact mics or audio moth

Reaper - Digital audio workstation for mixing and editing sound files

Interviews - with volunteers to tune sounds and interaction design

1.7. Conclusion

In this chapter I have introduced the context, design opportunities and main goals of this project. I will now briefly present a Background into Using Sound as a design tool.

Chapter 2. Background: Using Sound

2.1. Overview

In this chapter I will briefly introduce the concept of using sound, or more specifically non-speech audio, to transmit information. I will highlight some of the standard approaches to data sonification and present some examples of previous work.

2.2. Why use sound?

Sound can evoke an emotional memory, immerse us in an experience or transport us to different place. The human auditory system, evolved for our survival, is incredibly efficient at recognising patterns and locating potential sources of danger. Although our lives are immersive soundscapes, literally filled with sounds that (hopefully) create a familiar and comfortable environment, we are rarely consciously aware of them until something changes or is absent. We are quick notice a 'new' rattle or squeak while driving a car or riding a bike and can detect the quiet but tell tale sound signature of an uninvited rodent exploring a tenement flat kitchen even whilst we listen to music in another room. During the covid19 lockdown of 2020 the soundscape of cities changed dramatically, when the absence of the normal noise of traffic and planes revealed a wealth of detailed sounds, particularly an incredible cacophony of birdsong. People who had never actively listened before, started listening and noticing sound.

In his iconic Microsounds (Roads, 2001), Curtis Roads presents the timescales of sounds in the context of human perception. He introduces sounds as building blocks or grains with a time domain hierarchy a bit like the notes, phrases and compositions found in traditional music. He demonstrates, the much wider time scales sounds can encompass, in particular the domain shorter than traditional notes which plays a curial role in how we hear and perceive sound effects such as tone, pitch and timbre. The vast opportunities presented by sound synthesis (creating and manipulating sounds), and the power of the tools available, such as Max 8 (Cycling '74, 2020), mean that it is possible to generate an almost limitless spectrum of sounds (see Farnell, 2010) and create effects that we sense but may not even perceive as sounds.

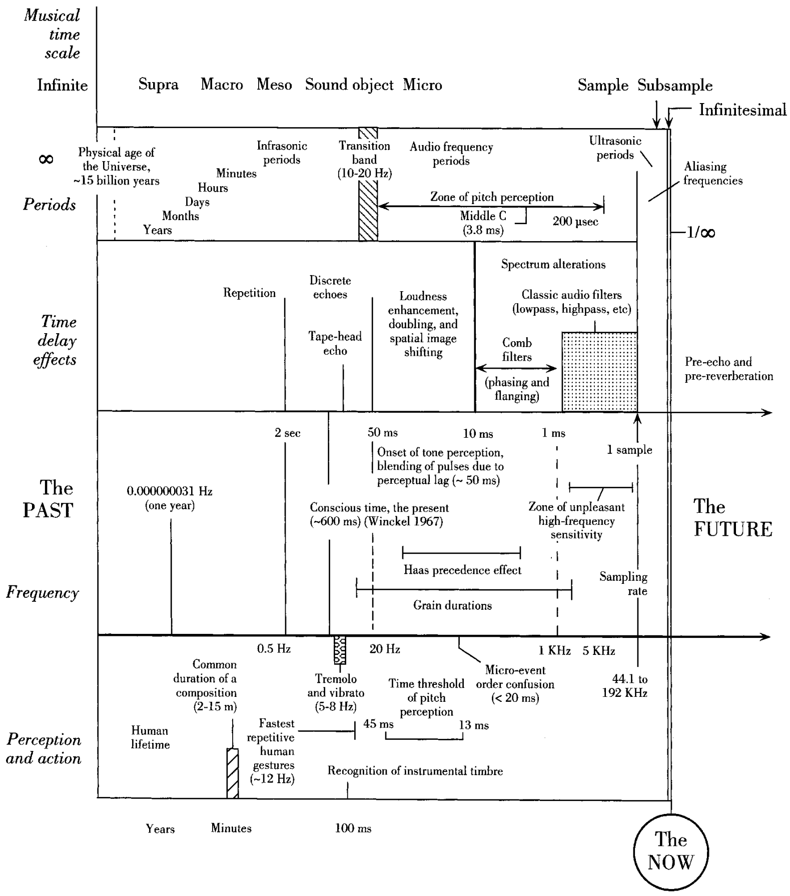


Figure 2: The nine time scales presented in the time domain (top row), alongside periods, time delay effects, frequency, perception and action (Roads, 2001).

Granular synthesis (Roads, 2001) is a particular flavour of sound synthesis where a pre-existing sound signal or generated waveform is segmented into windows or grains which are then modified somehow, then recombined in an new order either as a continuous stream or cloud of grains. The attraction of this method is that so many properties of the individual grains and how they are combined can be varied leading to a rich variety of colour, texture. Since grains sit close to the threshold of our perception Figure 2, they can be combined to build continuous tones that we recognise with pitch and timbre, or alternatively scattered to achieve intermittency and expressive texture.

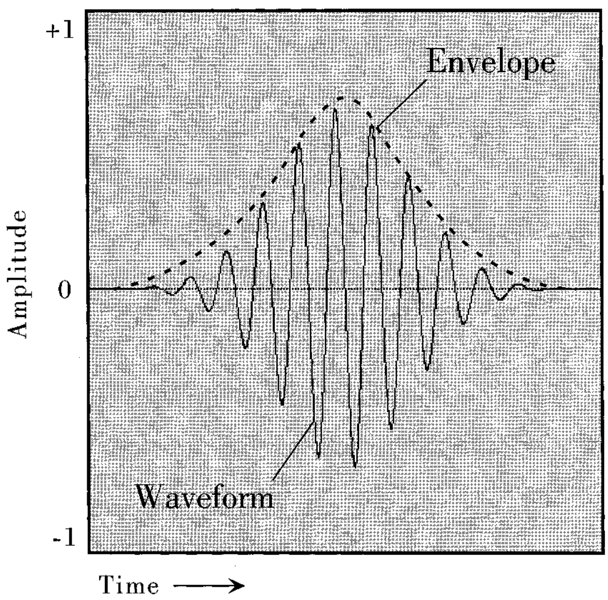


Figure 3: Portrait of a sound grain illustrating the envelope that can be modified to shape its sound (Roads, 2001).

In the Data Sonification carried out later in this thesis, I will use a granular parameter mapping approach where both the fundamental waveform (or sound source) and the duration, amplitude and shape of the envelope can be altered by values in the time series. Grain durations will typically be around 100 ms, so according to Figure 2, at the transition between microsounds and sound objects, over timescales where pitch, tone and timbre of sounds can be perceived. Even using simple waveform source, this process can lead to a rich and interesting sonic palette.

2.3. Auditory Display and Sonification

According to The Sonification Handbook (Hermann et al., 2011), 'Auditory Display encompasses all aspects of a human-machine interaction system, including the setup, speakers or headphones, modes of interaction with the display system, and any technical solution for the gathering, processing, and computing necessary to obtain sound in response to the data.' Whereas, 'Sonification is a core component of an auditory display: the technique of rendering sound in response to data and interactions.'

Sonification involves the process of transforming discrete or continuous data streams or actions into an audio signal to convey information by non speech sounds. As well as being fresh and captivating, sound is highly accessible. Sonification is used in artistic practice and is gradually emerging as legitimate data science tool. Multivariate or time series data can be particularly suited to auditory display and sonification in particular. This is because any sound file or song has an built in time. Following an audio signal with time is intuitively obvious to us and we expect something to happen eg pitch to vary or different sounds to appear and disappear with time. Within the field of sonification and auditory display, new techniques such as ambisonics allow three dimensional sound fields to be recreated and explored in real time. This immersive aspect of sound can be fun in a way that looking at visual graphs or plots may not be. Importantly, our eyes are tuned to recognising particular patterns, however our auditory system is sensitive to very different patterns such as quiet but repeated sounds emanating from the same place (remember those mice!) or sounds panned in space and may be more effective at recognising those. Regardless of technique, a set of guidelines for best practise are presented in The Sonification Handbook and references therein (Hermann et al., 2011).

Common approaches to sonification described in Part 3 of The Sonification Handbook (Hermann et al., 2011) include:

Audification defined as 'the direct translation of a data waveform into sound." (Kramer, 1994)

Auditory Icons which mimic familiar non-speech sounds to an action eg. such as the crumpled paper sound you hear when you empty trash on an apple computer (Gaver, 1994)

Earcons similar to Auditory Icons but without the assumption of a known relationship between the sound and the information it conveys.

Parameter Mapping Sonification involving 'the association of information with auditory parameters for the purpose of data display' and 'particularly well suited for displaying multivariate data' (Hermann et al., 2011)

Model-Based Sonification where 'acoustic responses are generated in response to the user's actions' (Hermann and Ritter, 1999)

In this project I use parameter mapping sonification, where data values are mapped to sounds such that the patterns produced transmit information to the audience. Different mappings and approaches lend themselves to different types of data or allow us to perceive particular patterns within datasets that the sound designer may want to emphasise. In designing a sonification, a very helpful framework in which to explore approaches and mappings is the Data Sonification Design Space Map (de Campo, 2007).

As mentioned above, sonification can be used for creative practise or for scientific purposes. Eli Stine who has worked extensively on natural system sound models, discusses very nicely the tendency for a strong divide to develop between strict objective sonification which at it's core seeks data transparency and clarity versus sonification concerned with musical aesthetic and artistic performance. In his inspiring work portraying natural systems 'Flock of birds', 'Island shorebird habitat' and 'Oyster reef ecosystem', he intentionally places himself at this crossroads, aiming to 'tell a story through the medium of electroacoustic sound' (Stine, 2019).

Data sonification has intermittently been used by scientists, often for public display of data. A recent quirky while scientifically robust example (Hegg et al., 2018) involved using sonification to interpret salmon movements and migration, tracked by using fish ear stones, in the Pacific Northwest. The results of the study involved a sonification tool, tested by untrained listeners both with and without visualisations. Listeners were most sensitive to changes in salmon behaviour when they were mapped to timbre, important transitions in behaviour were generally noticed, with or without visuals, the visuals adding extra time for identification. This demonstrated that the sonification tool, operated well within certain boundaries and could be optimised for better success.

Why use the term Infosonics? In the majority of this thesis, I have created parameter mapping sonifications that adhere to the ICAD recommendations for auditory display (Hermann et al., 2011) and can legitimately be termed data sonifications. However, I wanted the possibility to also explore the inclusion of sound experiences that combined objective sonifications with recorded sound files to create sound collages. Although heavily based on sonifications, the additional sounds are primarily added for ambience and may or may not have a relevance to data, therefore I favour the umbrella term 'Infosonics'.

2.4. Conclusion

In this chapter I have introduced the concept of data sonification, demonstrating the ways in which it can potentially enhance communication of data or engage with a listener group. Significantly, multivariate data and time series data, of the type used in this study, are particularly suited to exploration using auditory display. The datasets, later sonified in this study, will now be introduced.

Chapter 3. Data

3.1. Overview

In this chapter I will introduce the data used as a case study in this work. I will explain my reasons for choosing these particular datasets, where I have obtained the data and how I have processed or 'wrangled' the data. I will illustrate how this type of data is generally viewed, using classical graphical representation and will interpret key features or correlations between datasets. Finally, I will describe how I have curated vignettes of these datasets for sonification - turning into sound - in the following chapters.

3.2. National Data Archives

The data explored in this project were obtained from a number of archive and live sources. All data is open source and forms part of the National Library and Archive. Although the data is publicly accessible, it is stored by several different organisations: UK MET Office (Met Office, 2020), Scottish Environmental Protection Agency (SEPA, 2020), National River Flow Archive (NRFA, 2020), and River Levels UK (River Levels UK, 2020). Additionally, for historical reasons, data of one type may be spread over several different archived databases depending on its collection date or resolution. This makes the comparison between different datasets to gain an overview or searching particular remembered weather events spanning different years (a feature that interviews with potential users revealed may be popular) somewhat daunting for those without the expertise of a data scientist.

In this project, I aim to unlock these vaults of archive data that different groups of scientists and community volunteers have carefully collected to give the general public a glimpse into what the data looks or rather sounds like. I hope also to reveal how the different data are intrinsically related and how they expose the link between global and local phenomena.

The data I select characterises the meteorological conditions driven by global weather patterns interacting with local landscape and the resulting flow state of the local river that therefore impacts local people. In the following sections I present data on Storms (Met Office Storm Centre, 2020), Rainfall (Met Office, 2020) (SEPA, 2020), and River Levels/ Flow (River Levels UK, 2020). The specific archives investigated are the following:

Named storms, 2015-2020 (Met Office Storm Centre, 2020)

Catchment Daily Rainfall - CDR 1961-2017

Hourly, Daily, and Monthly Rainfall, 1 week, 1 year, 10 years (SEPA, 2020)

Gauge Daily Flow - GDF 1992-2019 except

PeakFlow (annual) 1992-1993, 2017-2018 (SEPA, 2020)

Daily River Levels, 2017-2020 (River Levels UK, 2020)

Live River Levels, last 7 days (SEPA, 2020)

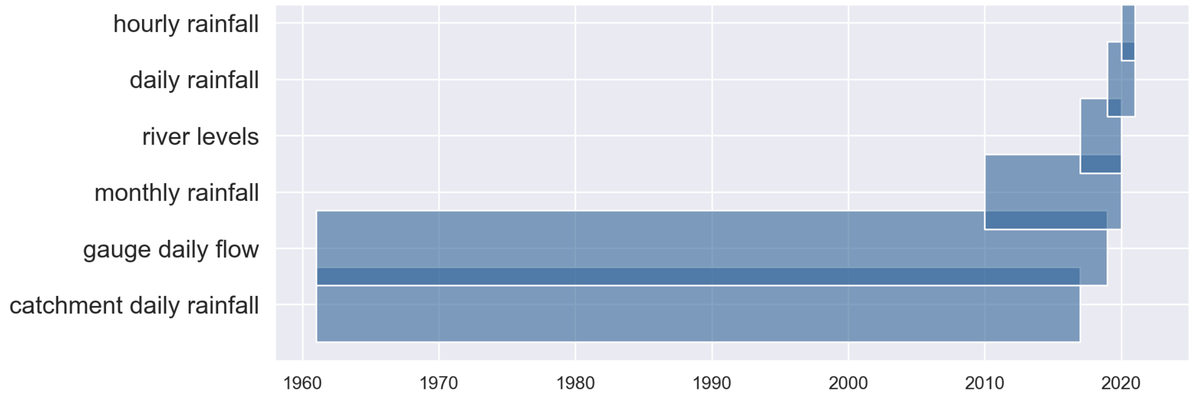


Table 1: Date ranges spanned by the different key datasets.

The main challenge in dealing with this data were firstly finding then piecing together data of different types, ages, measured in different ways and saved in different formats by different organisations in different archives, to create a seamless explorative experience for users.

3.2.1. Named Storms

The naming of storms is a system to simplify communication via the media and government agencies about severe weather approaching (Met Office Storm Centre, 2020). The hope is that by naming the events, the public will be more alert to the danger, able to easily follow storm path updates and thereby better placed to keep themselves safe. A storm is named if it fulfils specific criteria set by the National Severe Weather Warnings Service (or the equivalent national organisation in other countries) centring on the potential impact of the weather and the likelihood that it will happen.

A-Z of UK storm names 2019/20

Name	Date named	Date of impact on UK and/or Ireland
Atiyah	06 December 2019	08 - 09 December 2019
Brendan	11 January 2020	13 - 14 January 2020
Ciara	05 February 2020	08 - 09 February 2020
Dennis	11 February 2020	15 - 16 February 2020
Jorge	27 February 2020 (Named by AEMet)	28 February - 01 March 2020
Ellen	18 August 2020	19 - 20 August 2020
Francis		

Figure 4: Named storms for UK 2019-2020 (Met Office Storm Centre, 2020)

Named storms are selected for use in this project as they represent significant meteorological events, the frequency of which may arguably be increasing as the climate crisis worsens. Such events often lead to secondary natural hazards such as floods and landslides, resulting in property damage or loss of life. Named storms also trigger emotional memories for people and are remembered more readily than specific dates might be. When inviting visitors to explore archive weather data, I would expect their own 'weather memory' to be flagged by these events each year, so they act as natural departure points for investigation.

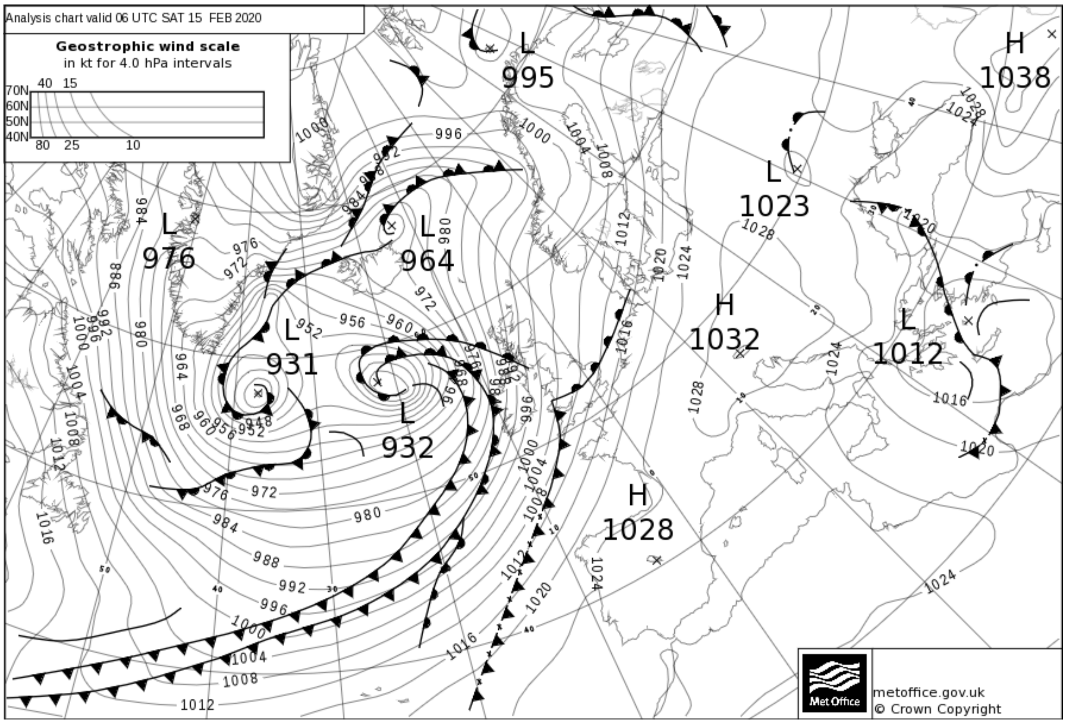


Figure 5: Example showing typical data provided on named storms which includes weather maps, descriptions, maximum wind gusts, hourly maps, rainfall (Met Office Storm Centre, 2020)

3.2.2. Rainfall

Rainfall data for Scotland is collected and telemetered by automatic rain gauges managed by the Scottish Environmental Protection Agency (SEPA, 2020). Hourly (previous week), Daily (previous year) and Monthly (previous decade) rainfall totals are available for directly from the SEPA online site. Data are archived in National Meteorological Library and Archive (Met Office, 2020).

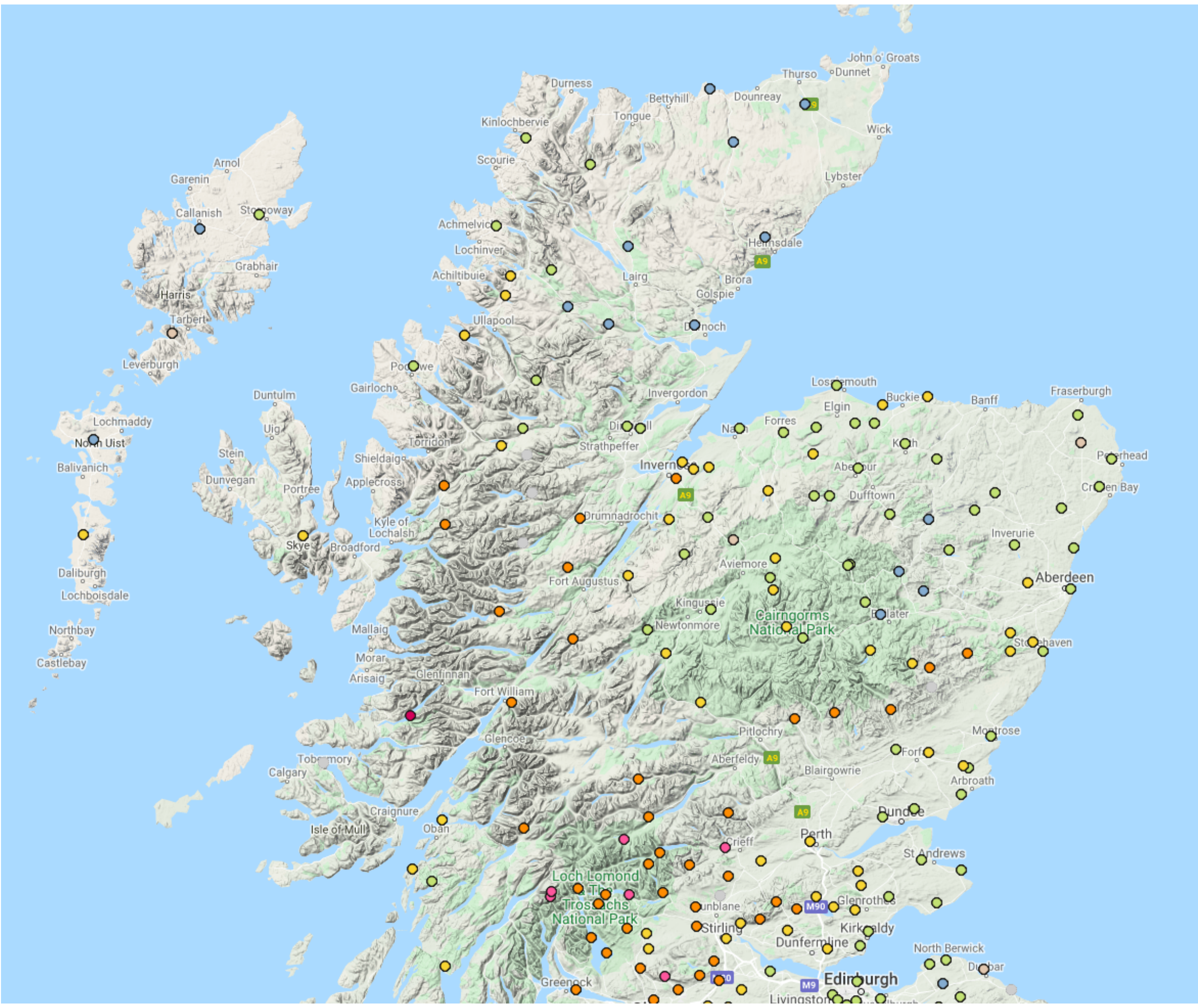


Figure 6: Map of SEPA rain gauge stations in Scotland

Rainfall is also measure across Scotland by volunteer rainfall observers through a partnership between SEPA and the Met Office. These volunteer rainfall observers, some of who have been observing since 1960s, contribute to the national rainfall network, to accurately capture the distribution of rainfall across Scotland (Rainfall Observers, 2020).

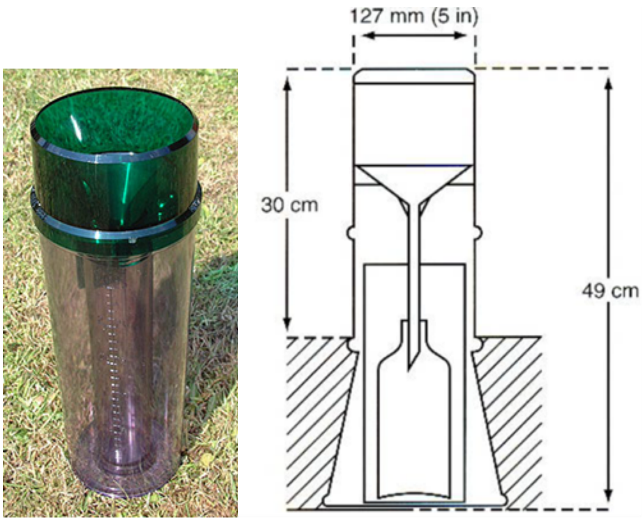


Figure 7: Photograph and sketch of a rainfall gauge that might be used by a volunteer rainfall observer.

Catchment daily rainfall, a time series of total rainfall averaged over the catchment (mm/day), is provided by the National River Flow archive from 1961-2017 as a guide to interpreting the river Gauged Daily Flow records. This dataset is particularly valuable due to its length.

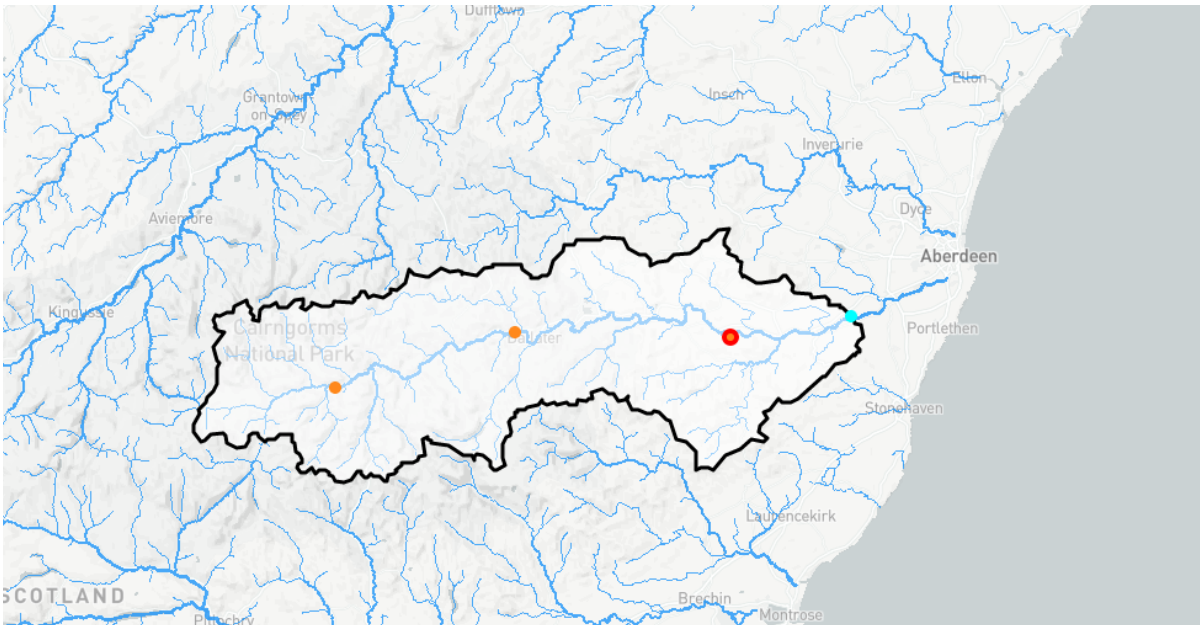


Figure 8: Map of the catchment area of a station Dee Park (blue) on the River Dee. The stations shown in orange are from left to right are Mar Lodge, Polhollick, Dee Woodend.

3.2.3. River levels and Flow

SEPA monitor and record water levels on lochs, rivers and coastlines at 392 sites around Scotland. Water levels are collected using a range of sensor and loggers and automatically telemetered daily (or more frequently) and updated online. The data are used for flood warning. Live river level data collected every 15 minutes are held by SEPA. Daily measurements of date, minimum level, average level, maximum level are available 2017-2020 (River Levels UK, 2020)

River level data are subsequently used to calculate river flow. Gauged Daily Flow is mean river flow in a day (09:00-08:59) measured in cubic metres per second (m3/s^1 or 'cumecs') and forms the main part of the National River Flow Archive (NRFA) data holdings. The data is calculated by measuring authorities (SEPA, 2020) from river level data collected every 15 minutes. Continuous daily records from 2017 are held by the National River Flow Archive.

3.3. Data Wrangling

Raw datasets are accessed and download from the relevant organisations as a series of .csv files. With the exception of the Storms dataset, all data are time series with a regular time step size (a data point measured every hour, day or month) for a given dataset. Storm data are lists of punctuated discrete events with start dates when a given Storm should reach land. Data wrangling and plotting is carried out in Python using standard Pandas, Matplotlib and Seaborn packages. The main goals are: a) data cleaning to identify and edit any data gliches; b) plotting datasets for interpretation and comparison; c) curating a subset of the data for sonifications; and d) reorganising dataframes into the appropriate format for sound engine Max to build sonifications. For clarity, key steps were divided into three separate Jupyter notebooks:

/DataProcessing.ipynb

Date-time are parsed

Column names changed and date column set to index

Data integrity was checked and cleaned where necessary

Redundant columns removed

Basic plots generated for different time windows to gain overview of data

Calculation of an additional field - the number of days since a given date - for comparison between different length records

Cleaned data are saved as pickle format (.pkl)

/Dump2plot.ipynb

Plots generated from individual cleaned data files

Comparison of different time periods for a given dataset

Comparison of different measurement stations along the river

Combination plots allowing comparison of distinct data types to investigate cause and effect

/Dump2cheddar.ipynb

Loading and wrangling of geographical coordinates to use in spatial sonification

Calculation of time since last event (delta t)

Reindexing to create numerial list

Merging of datasets from different stations (same data types and same dates)

Merged datasets are to be played synchronously but projected at different positions

3.4. Data Curation and Interpretation

In curating the datasets to be used in this project from the wealth of data available, several aspects were important. As a scientist, I was strongly guided by the integrity of the data but also data that would be interesting, so looked for comprehensive and continuous dataset that told a story. I chose to concentrate on a locality, River Dee in Aberdeenshire, where different types of data were collected at several sites on a single river, over a lengthy period of time, with few data gaps. The area had also experienced a major flooding incident in recent memory that caused significant damage to property and infrastructure. Key features of the datasets chosen are presented and interpreted below.

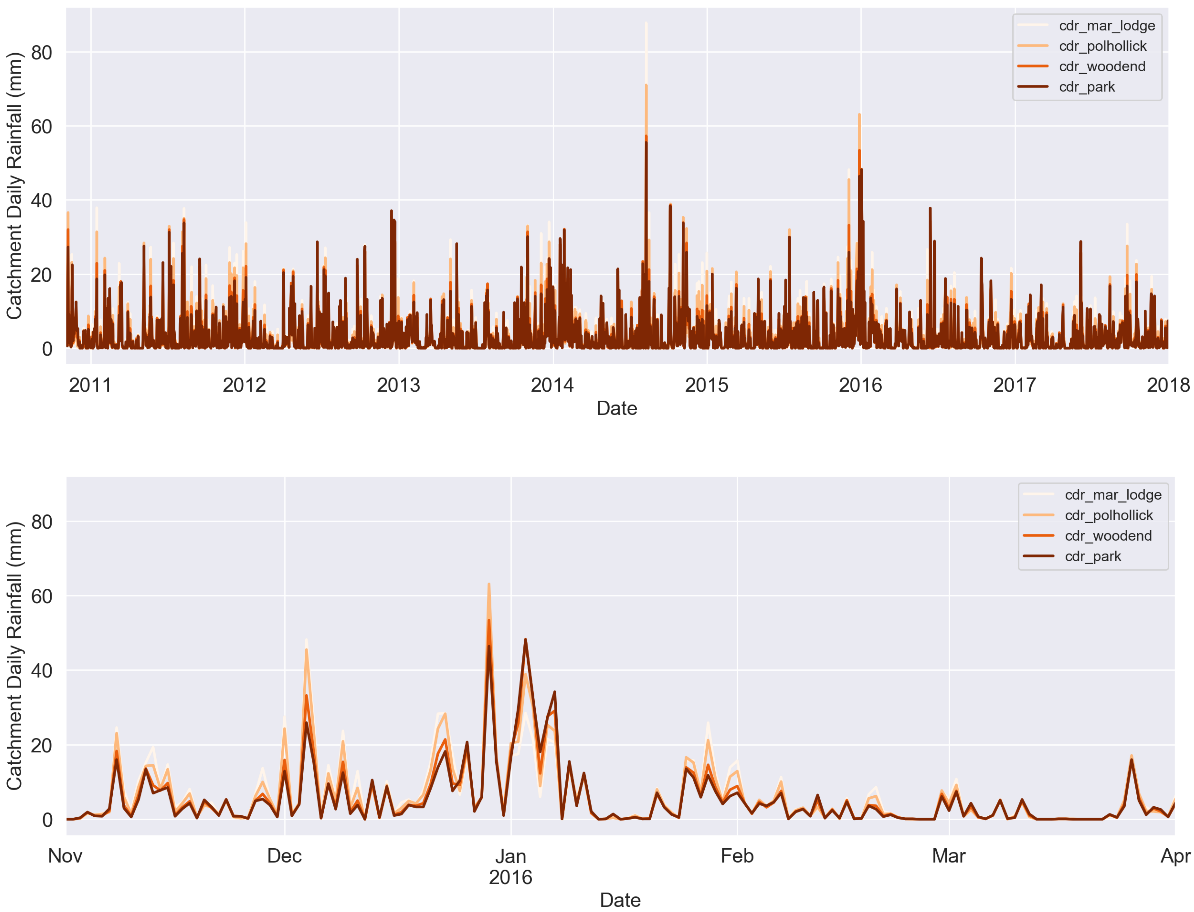


Figure 9: Catchment daily rainfall for periods 2011-2018 (upper) and zoomed in to winter period of 2015/2016 (lower). The higher values in late December, early January 2016 represent the rainfall associated with the major flowing event.

Catchment Daily Rainfall data are plotted for the available stations with light to dark colours denoting West (Mar Lodge) to East (Park) station locations respectively. A series of fluctuating peaks indicating total rainfall happening over a given time period (an hour, a day or a month) varies with date for all records. The peaks are interspersed with periods of little or no rain. Notably, the peaks are symmetric, they rise and fall over a similar number of hours or days. The value of the peak is clearly important, but also is the width of the peak, since this reflects the persistence of the rain (known as antecedent rain) which if the ground lacks effective drainage can be a common condition for flooding. The main event that stands out in these records is high and persistent rainfall during winter 2015-2016.

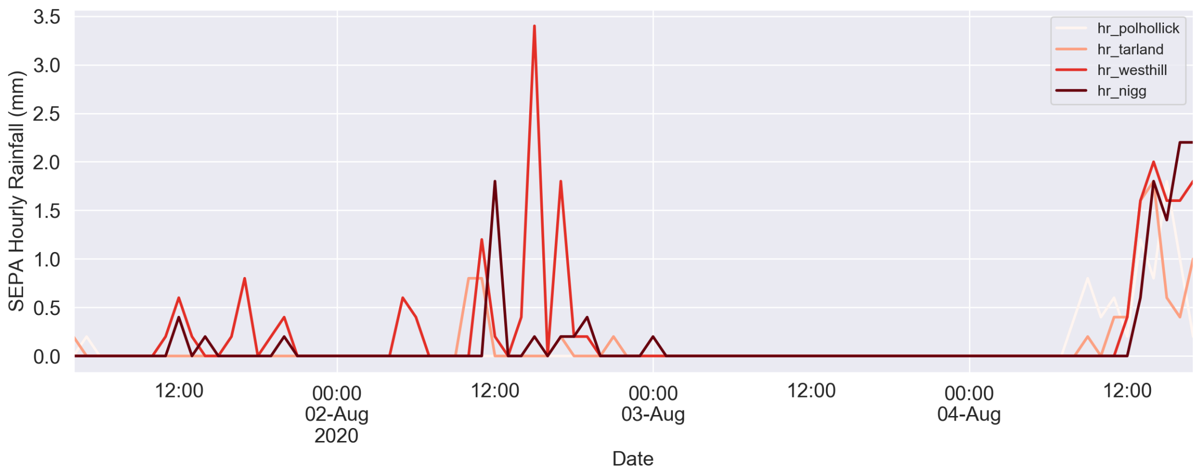


Figure 10: Total hourly rainfall

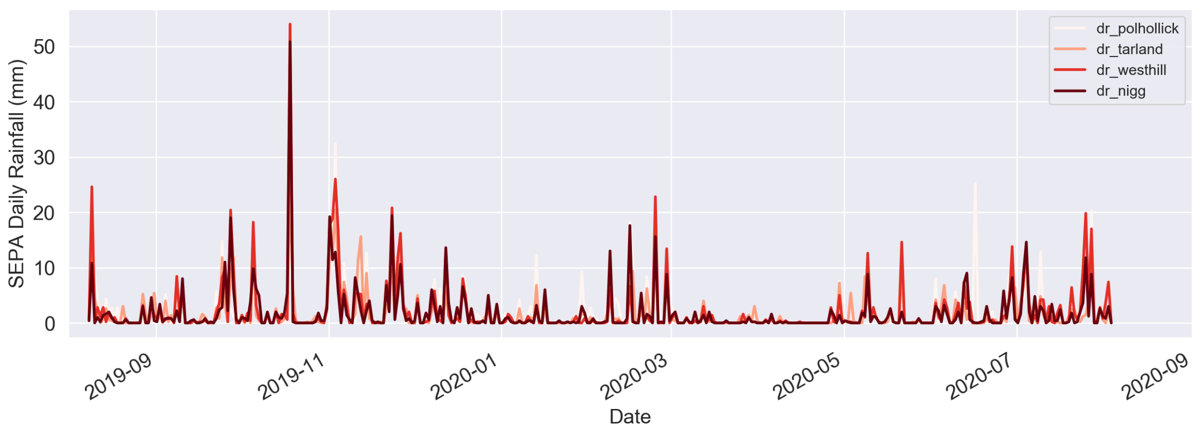


Figure 11: Total daily rainfall for a year (2019-2020)

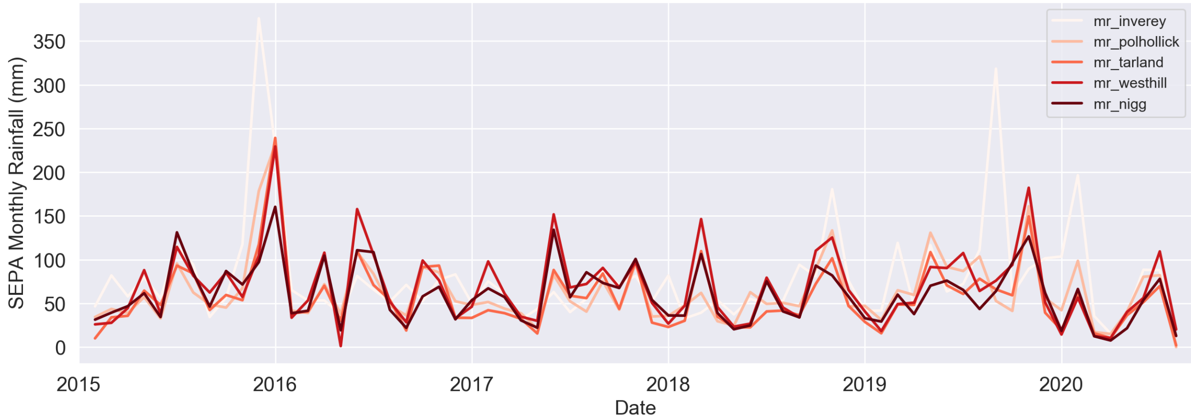
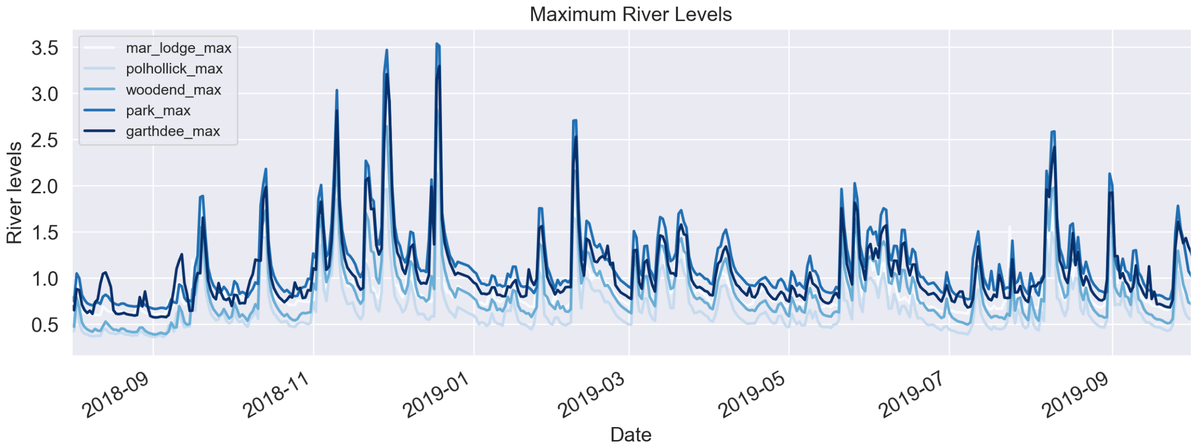


Figure 12: Total monthly rainfall for a 10 year period

In addition to the Catchment Daily Rainfall described above where records are available until 2017, more recent and current Total Rainfall data recorded at SEPA rainfall stations for the last week, year and 10 year period are available. These records show actual total rainfall measurements at the stations, not converted for the different catchments. Also, the stations are slightly different locations than those of the other records. Despite these differences, these datasets are indicative of the more recent weather conditions along the River Dee and provide the opportunity to gain an overview then 'zoom in' temporally to shorter periods of time and in particular current weather.



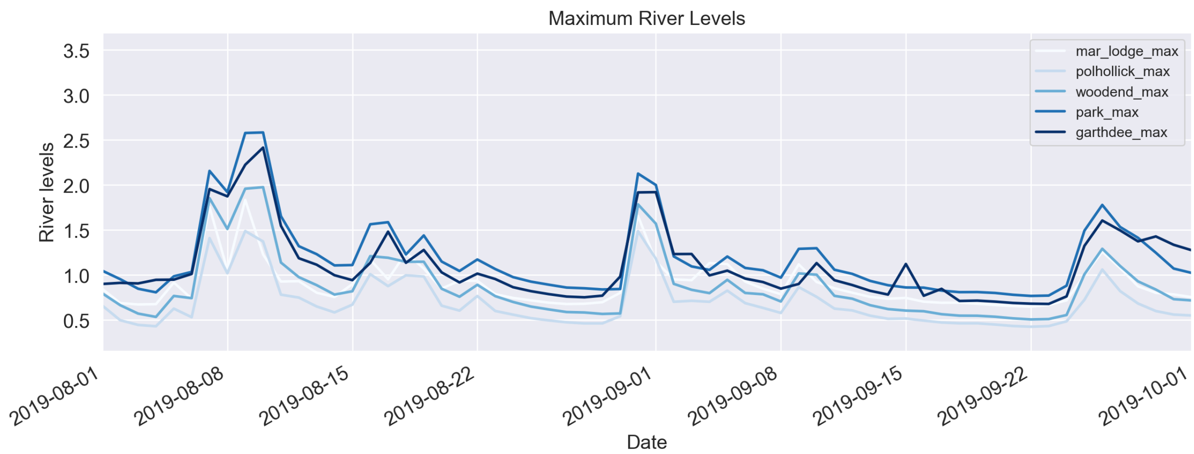


Figure 13: River levels for a period of 1 year (upper) and for a 2 month period (lower)

River Levels are plotted for different measurement stations as a function of date (Figure 13) with sequential colours denoting the station locations, light colours for proximity to the source in the West (Mar Lodge) and darker colours towards the coast in the East (Garthdee). The base levels are different for each station. This is expected since the absolute value depends on the local datum and how the measurement gauge is set up. These differences are unimportant in this study but actually have the benefit of separating out the records from the different stations for clarity. All the data streams show a series of excursions (spikes) characterised by a sharp increase to a peak level then a gradual decay to a steady state. The asymmetric shape of the excursions reflects a rapid injection of a quantity of water interpreted as the direct effect of local rainfall, then a gradual decrease as this direct rainfall ceases but water level is then influenced by runoff from the adjacent landscape upstream. This details of this decay curve are important markers of drainage - how well the surrounding landscape can get rid of water - and crucial for understanding flooding potential. The pattern and timing of these excursions is generally well correlated (matched) for all the stations implying, as one would expect on a single river, that the natural system is connected. However When we zoom in to high temporal resolution (Figure 13 lower), we see evidence that the upstream stations (light in colour) are experiencing these excursions slightly earlier than downstream. This makes sense since the catchment areas for each station are to the West therefore drainage towards the East would be expected.

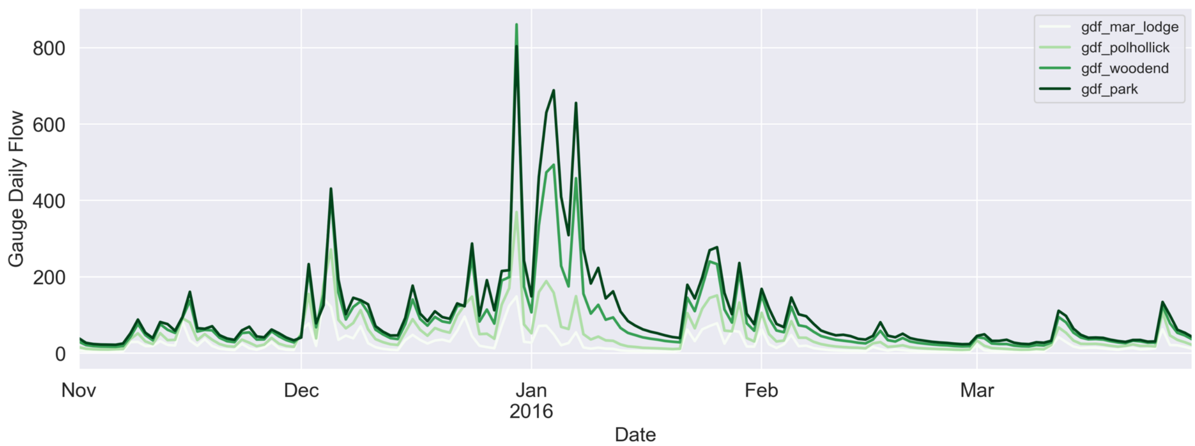


Figure 14: Gauged Daily Flow

River Flow (gauged daily flow) is calculated from the River Levels measured at individual stations taking into account the shape and size of the river channel at that location. This data are the main holding of the National River Flow Archive and are available for much longer time periods than the raw River Level dataset. As seen in the River Levels data above, the absolute values of River Flow vary for each station as would be expected. River Flow records also show the characteristic rapid increase and gradual decay curves. Since these data are available for a much longer period, when 'zoomed out' they give a very good overview of 'normal' River Flow (see Figure 15 lower), indicate periods of higher flow (and how often we might expect them) and are very useful in detecting unusually high River Flows events, such as the events during winter of 2015/2016. Zooming in to specific time periods (Figure 14) reveals that the duration of the decay depends on the so bigger surges in flow take longer time to settle back to normal levels. The size and decay characteristics of these River Flow (and River Level) excursions are clearly an aspect of the data that is particularly important to capture and effectively represent in sonifications presented in the following chapter.

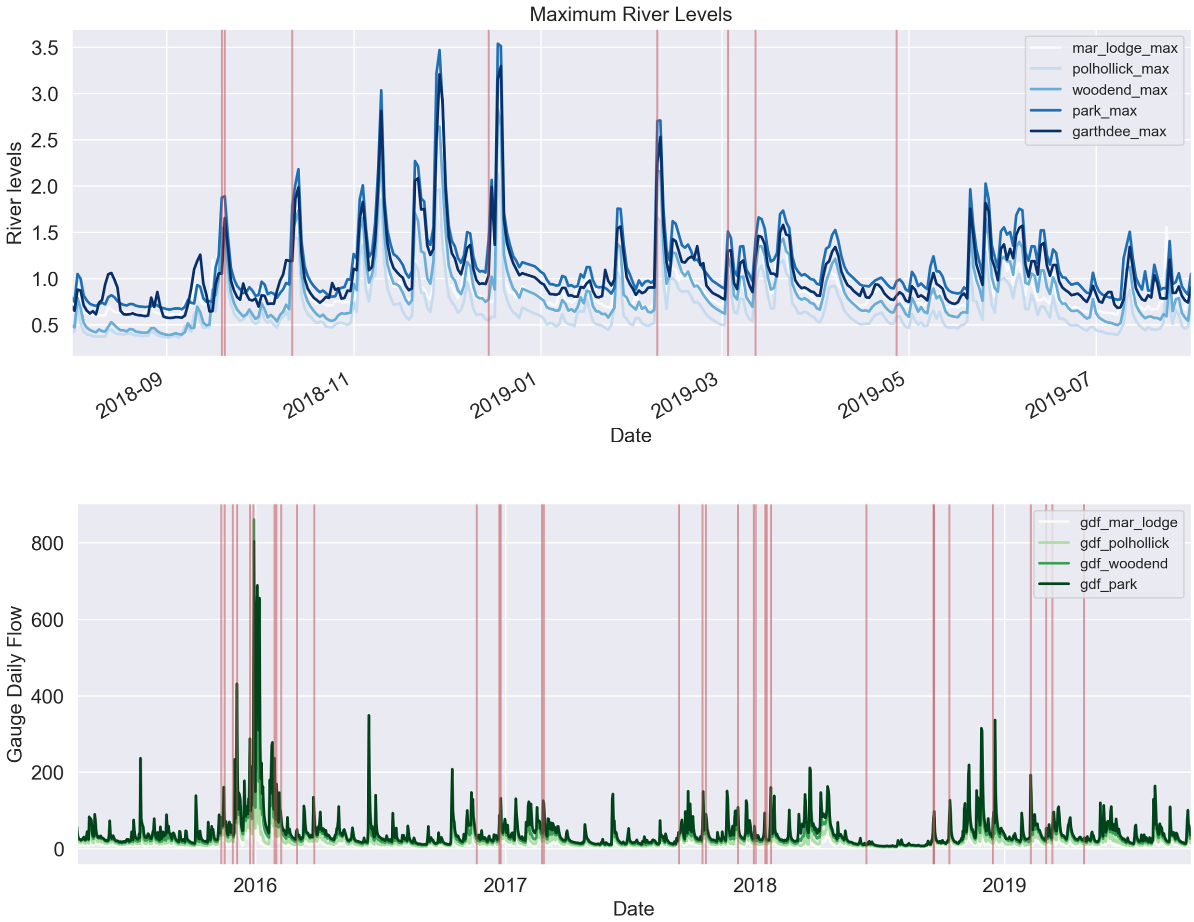


Figure 15: Named Storms (red vertical lines) superimposed onto other datasets, river level (upper) and river flow (lower)

Named Storms are superimposed onto other datasets as vertical red lines signifying their start date (Figure 15). In many cases Named Storms correlate in time with the beginning of higher Rainfall or stronger River Flow. In other cases the Storm appears to be not 'felt' in this area or high Rainfall happens without a Named Storm occurring. This indicates that since Named Storms are national extreme weather events not all of them affect or even reach this part of Scotland. Importantly though, a cluster of Named Storms in late 2015 and early 2016 are clearly connected in time with the elevated hydrological events described so far above.

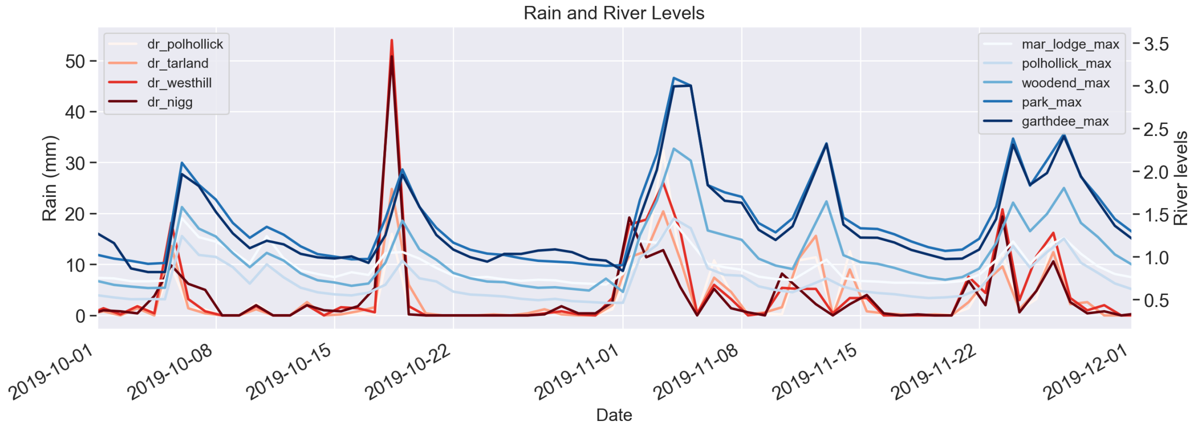


Figure 16: Comparison of multiple data types indicates correlations in events

Figure 16 highlights the correlations between excursions in rainfall (reds) and river level changes (blues). Note that the spikes in rainfall precede the increases in the river level as may be expected. The use of mulitple datatypes for what is nominally the same piece of information eg. Catchment Daily Rainfall and Total (Hourly, Daily, Monthly) Rainfall or River Levels and River Daily Flow may appear confusing or redundant but is crucial if we want to explore back in time and at high resolution. By presenting the data comprehensively here, I demonstrate the general agreement between the different measurements of rainfall or level/flow datasets and satisfy my scientific curiosity about how to best merge and scale the data during sonifications. My eventual goal would be that listeners can seamlessly skip freely between the underlying data depending on the journey in time or space they want to take.

3.5. Conclusion

Above I have introduced the data used in this study illustrating how data sets vary over different time periods and spatial locations along a single river. Key features interpreted from this dataset include the temporal nature of the records, sporadic fluctuations in records, unusually high rainfall events, temporal correlations (or not) between rainfall and river level or flow. Impact (or not) of national Storm events on local rainfall or river flow. Importantly, in general the same events could be detected at all the measurement stations along the river, often with slight time delays downstream. Apparent when zooming in (in time) to records, are the patterns of gradual decay following spikes in river levels that reflect the drainage influence of the surroundings and hence have strong impact on flooding. In terms of the sonifications to be created in the following chapter, it is important (if I want to faithfully transmit the facts of the scientific data) that these features, both obvious and subtle, are audible to listeners. This is a key element to consider in building an infosonic is whether it can communicate the data effectively and potentially give additional insights. From the data introduced above, specific data records and time periods were curated for sonification that together encapsulate a narrative about the life of the River Dee ripe for exploration.

Chapter 4. Data Sonification

4.1. Overview

Building on the previous chapters where I first introduced the concept of sonification, then presented the datasets under consideration and their curation, I will now demonstrate the practise of turning this data into sound. I will highlight the technical aspects of this process, such as the tools I used, the choice of source sounds, choice of mapping from data to sound, as well the design goals of clarity and communication that I hoped to achieve. The listening experiments and user interviews I conducted to inform this process were carried out while the sonifications were being developed (with the two activities feeding off each other), however they are presented in the following chapter for clarity. A suite of sonifications I have created to demonstrate different are shared with readers along with a demonstration of interactive user exploration.

4.2. Source sounds

In selecting appropriate source sounds to use in data sonifications, several choices and considerations come into play. Perhaps the most fundamental is whether to use simple or complex sounds. Although complex sounds may seem more attractive in creating a rich textural experience, even simple sounds can be manipulated to produce a wide variety of effects.

Simple sounds, including sine waves, sawtooth, filtered noise, are easy to generate and easily manipulated during the parameter mapping process. Their basic properties such as frequency, period and amplitude are very well defined and understood. Reproducing exactly same sounds is straightforward, which is particularly advantageous if a strict objective sonification is required. Some key advantages of simple sounds are their clarity, and how multiple sounds of a given type can be layered together but remain distinguishable. They are particularly suited to applications involving communication or auditory display. Disadvantages of using simple sounds (without sufficient manipulation) can be the creation of sterile 'thin' sound palettes and soundscapes that lead to listener fatigue.

Complex sounds, include those synthesised from scratch (created by sound designers using a range of synthesis techniques - see Background chapter) as well as sampled sound recordings. As explained in in earlier sections of this thesis, treatments including granular synthesis and other techniques can lead to the creation of a huge variety of rich textural sounds. Such sounds can be very effective at invoking emotion. In terms of a data sonification, this can have the significant advantage of adding realism, ambience and context to a piece. Also, these source sounds tend to be engaging and interesting for listeners who are therefore unlikely to experience listener fatigue. Disadvantages of using complex sounds, however, are the potential challenge for listeners in pinning down their meaning or discerning the underlying parameter mappings applied. They may not layer as well as simple sounds (eg. sine waves), making it more difficult to distinguish multiple sounds of a similar type.

Field recordings of the actual natural processes one wants to communicate such as rainfall, river flow or storms can be helpful in creating context, however can suffer all the drawbacks of complex sounds mentioned above. During this project I built a sound effects library of recorded sounds, both natural and staged for possible use in the project. Using 'sounds that sound like things', in this case sounding like the natural phenomena that they represent is tempting to bring context and immerse listeners in an environment or experience. Disadvantages however, are that the associations created are artificially chosen by me (and generally invoke my life experiences). This can lead to confusion if not interpreted by listeners exactly as I had envisaged.

In selecting source sounds for this project, I had certain notions of what I wanted to achieve but also benefited from interviews with potential users to garner wider opinion and guide my design process.

4.3. Parameter mapping

In parameter mapping based data sonification as used here, discrete data values are mapped to properties of synthesised sound grains following the guidelines in The Sonification Handbook (Hermann et al., 2011). The principles of Data Sonification Design Space Map (de Campo, 2007) were helpful in directing towards this approach for the datasets under consideration.

A basic sonification tool that could synthesise and adapt sine waves according to values of single data streams was developed in Max. Refining this into a more elaborate tool that could efficiently generate and manipulate sound grains (to create interesting sounds), deal easily with the multiple datasets, automatically scale different types of data and explore a range of parameter mappings was initially attempted but proved time consuming and was eventually deemed beyond the scope of this project. For the efficient interrogation of the suite of datasets and exploration of a broad range of parameter mappings, the sonification tool Cheddar (Barrett, 2016) was therefore chosen instead.

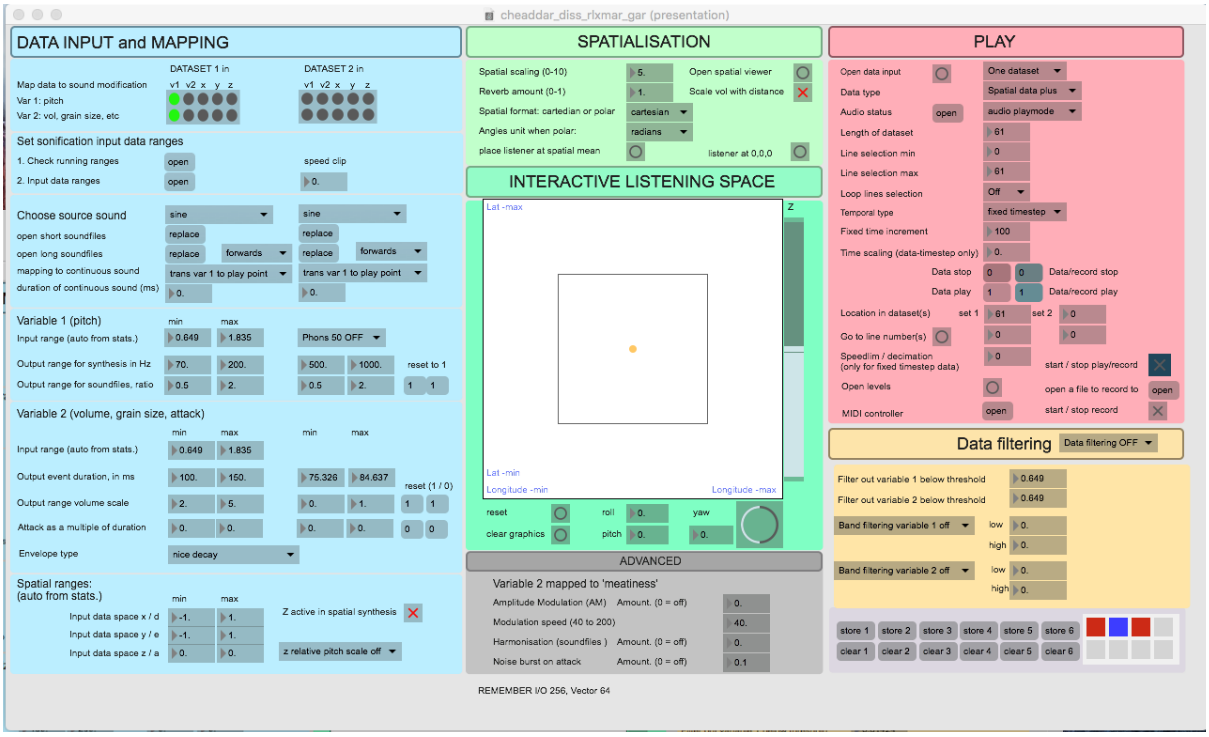


Figure 17: Screenshot of sonification tool Cheddar, in Max presentation mode, illustrating the exploration of mapping parameters possible during interactive listening (Barrett, 2016).

Cheddar is programmed in Max 8 (Cycling '74, 2020) and was specifically developed for live interactive data sonifications for both artistic and scientific purposes (Barrett and Mair, 2014). The tool is explained in depth elsewhere (Barrett, 2016) but key features include the possibility to simultaneously load up to four (two independent) data streams, live exploration of mapping parameters (via a midi controller if desired), live interactive spatialisation, playback including time stretching, looping and decimation, and saving of presets to capture selected settings while exploring datasets. A small edit was made to the patch to synchronise playback and recording so the short sonifications made for listening experiments could be more easily synchronised. For parameter exploration, a Korg nano midi controller was used. All sound examples generated were output for binaural listening using headphone receiver transfer functions.

In choosing source sounds, it was important to select sounds for each different data variable that could be easily distinguished from each other by non experts. In terms of parameter mappings, key goals are to use simple mappings that are intuitive and clear and that conform to guidelines presented in The Sonification Handbook (Hermann et al., 2011). A key point raised in these guidelines is that data should be accurately mapped such that the parameter mapping is reproducible for an identical data value eg. 5 mm of rain, should sound identical, whenever it occurred during our record and whatever precedes or follows it.

As explained in the introductory chapters, the length (duration) of sound grains is crucial to how sounds appear to us and whether they are perceived as separate sounds or a continuous effect. In Cheddar, the minimum and maximum grain durations can be scaled to the dataset values and by actively setting durations to be slightly longer (or shorter) than the timestep between the adjacent datapoints, a continuous (or discrete) sound will be heard respectively. In the final sonifications, I used both of these scenarios as a way to make the different datasets even more distinguishable, with river flow mapped to continuous pitched sound and rainfall mapped to discrete filtered noise. The length of individual data sonifications was kept quite short (ca. 30s or less) to limit listener fatigue.

Data are (in this study) mapped to tones on a western musical scale. For the data where spatial information is explored, volume is scaled to distance, meaning that far away sources get more quiet. It is important to select scaling of the sound parameters that is appropriate for the scaling of data values. This is accomplished by scanning data ranges when each new dataset is loaded and automatically setting parameter ranges. This provides a convenient starting point for parameter exploration. However, for consistent parameter mappings between distinct data files of a similar type, scaling should be kept consistent.

Several techniques can be employed during the sound design. For example, to reduce the 'power' of large events, both the volume range and the duration of sound grains can be reduced. A small noise burst can be added to the largest / loudest individual events to emphasise and draw attention to them or just to add some sonic variety to a simple source sound without changing mapping parameters. Since Cheddar includes spatialisation, effects such as scaling with distance and reverberation could be added to emphasise particular data features or specific station locations. Listening experiments and interviews with potential users that helped making decisions on sound sources and mappings are described in the Listening Experiments chapter.

Details of the parameter mapping for individual sonifications are provided in the Listener Guide, however the main design ideas behind some of those choices are introduced below.

Sonification of Rainfall:

Total rainfall for a specific chosen period (whatever that may be) leads to a time series of discrete events. In some cases, linked events last several days, but otherwise, rainfall can be zero. Since rainfall may not always take a positive value, it was decided to used a discrete sound to represent rain. Intuitively this seemed to match an event driven pattern better. The main sound source chosen for rainfall was filtered noise, although some sonifications were generated with 'real' rain sounds for comparison. To invoke the discrete rainfall events, sound grains were given short durations, at least shorter than the time step between adjacent events. The amount of rainfall was mapped to both pitch (frequency) and volume (amplitude) of the sound grain, with greater amounts of rainfall giving rise to higher pitches and a louder sound. Again the louder sound is an intuitive mapping since we are all familiar with the sound of heavy rainfall in real life. The choice of higher pitch, especially when using a noise source rather than a tuned tone, may not seem obvious, but adds something to the intensity of a strong rain shower, and also creates some interest in texture. The frequency ranges mapped rainfall values and those mapped to other datasets were offset to crete more separation between different datasets for the listener. This also made explanation of the sounds and mappings for user navigation.

Sonification of River Level and Flow:

River level or flow was represented by a synthesised sine tone. More complex source sounds were trialled and rejected during listening experiments. The value of river flow or level is mapped to the pitch and volume of this tone with stronger flow being louder and higher in pitch. Longer duration sound grains were chosen to create continuous sounds, indicative of continuous flow. This also had the advantage of making a clear distinction with rainfall. The use of reverb and spatial scaling was explored in an attempt to create an echoing, bubbling underwater sensation. Portraying sounds that mimic the data they are mapped to has an element of danger to it, in pushing my experience or my ideas of how being inside a river might sound, however participants who took part in my listener experiments universally appreciated these effects.

Sonification of Storms:

I made no effort to sonify Named Storm events using parameter mapping and instead included them as audio annotations, described in a later section.

The final suite of sonifications created to articulate this project are listed in Appendix 3: List of Sound Examples. The corresponding audio files and a full listener guide (providing details of the parameter mappings and the datasets presented in each case), are available at the linked google drive. Sonifications of individual data streams are first presented, to give context, then sound experiences consisting of multiple data streams are presented. Sonifications were generated for excerpts of the datasets presented in the previous chapter to demonstrate how well (or poorly) they could communicate the characteristics of the data that I deemed the most important or interesting. In the listener guide, I link the sonifications to the appropriate dataset figure where relevant. A series of sonifications also feature in a mockup demonstration of a possible interactive user exploration. This is also available at the linked google drive.

4.4. Sound Design and Spatialisation

Sound spatialisation allows sounds to be projected in space so they appear to be coming from particular locations. This technique, now commonplace in film, gives an immersive experience and is an essential element of for example interactive video games. If used well, spatial audio can give an excellent perception of immersion in a dataset. In the tool Cheddar, interactive spatialisation in three dimensions is implemented using ambisonics and can be decoded for binaural listening (i.e. using headphones).

In this project, interviews with people living on the River who are familiar with the local area, and locations of the different stations, voiced their interest in exploring the dataset spatially. I therefore propose to use spatialisation to demonstrate the location of each station along the river. A listener could then choose which station(s) to listen to and/or their listening position along the river. Metadata have been wrangled to extract geographical information for all the stations under consideration so spatial sonifications can be easily produced. The biggest decisions are how to scale the data spatially and whether the mapping at all the stations should be identical or whether the individual sites should be given different character eg timbre or texture to reflect their different settings and position on the river.

Reacting to comments of potential users who cited real or realistic sound as desirable in creating an atmosphere or context, the combined use of field recordings for ambience alongside objective data sonifications for clear auditory display is explored.

Sonifications created to demonstrate spatialisation and audio files generated to explore the use of field recordings are listed in Appendix 3: List of Sound Examples and the corresponding audio files and listener guide are available via the linked google drive.

4.5. Audio annotation

Audiographics can be considered as a sonic flavour of Infographics. The concept is nicely described and illustrated by Jeffrey Everhart as a way to enhance a listening experience through the use of text and graphics to annotate sound files (Everhart, 2020). In his description he also mentions but does not elaborate on the possibility that audio itself could also be a way to annotate and give cues in other sound files - Audio Annotation.

Audio annotation is a helpful term to describe how I chose to include Storm data in some of the sound files I have created. The key information I have collected from the Storm dataset is their start date. This represents the flagging up of an event, the warning that something is about to happen. The figures in the previous chapter where storm data are plotted alongside other data, clearly illustrate how these storm events often initiate increased rainfall or changes in river levels or flow. I choose to herald the start of each of these Named Storm events by activating an audio file. This is not a true sonification, according to The Sonification Handbook (Hermann et al., 2011), since no parameters of the storm are mapped, only a time signal alerts us that a storm is on its way. I take advantage here of the fact that I do not need to clearly communicate a changing signal (as would be best done with a simple sound source) and select instead excerpts from a field recording of an actual storm (Mair, 2020). I rely on the fact that listeners would recognise the sounds of a storm without requiring explanation and since the sound files are comparable they will not over interpret an additional mapping.

Sound example 1: Illustration of the used of storm sound recording as an audio annotation in a sonification of rainfall and river flow (Mair, 2020), see link to audio file in Appendix 3.

On reflection, this makes sense since at the time of naming a storm the meteorologists only have predictions and no actual facts of how the storm will evolve as it encounters land. However, it is also important to note that since in the sonifications I produced, we will typically hear a year of data in 30 seconds, the storm audio annotations last longer than the storm would last if scaled to the time window of the record.

4.6. Conclusion

In the previous sections, I have introduced the data sonification process I carried out and importantly the design choices I was faced with during this process. Decisions were strongly informed by the characteristics within the individual datasets discovered during the data analysis, systematic listening experiments I conducted myself and feedback from volunteers on the outcomes of those experiments and sonifications. This feedback process is now outlined in Listening Experiments.

Chapter 5. Listening Experiments and User Research

5.1. Overview

I conducted a series of listening experiments and semi- or un-structured interviews with volunteers to determine sonic preferences and gauge people's capacity to distinguish multiple different sounds played at the same time. In addition, informal interviews on user interaction and how people might want to explore various aspects of the data were collected. Interviewees included people living near the River Dee who were directly affected by the flood of 2016. This user research was compared with my own experiences exploring sounds, sharing sounds during outreach activities and my broader ideas on interaction design. Together, results from the activities presented in this chapter were used to inform the design of the sonifications (presented already in the previous chapter) and helped guide thoughts on the interface and interaction design (presented in the following chapter).

5.2. Listening experiments

Listening experiments were designed with the purpose of refining the sonic experience participants would encounter. Essentially, a set of sounds are generated and the reaction of people listening to those different sounds is determined. Intelligent design of the experiments allows the author to interrogate the influence of specific sound parameters or their combination. As in physics, experiments can be set up rather rigorously to test a particular hypothesis or they can be exploratory in nature. Ideally, irrespective of approach, the outcome of the experiments will inform a specific design choice. In designing these experiments, I benefited from previous work on sonic evaluation (Bonet Filella, 2019) and (de Campo, 2007).

Using the Cheddar sonification tool, I first create a library of short sonifications for each dataset, where the source sound, specific mappings and playback parameters were systematically varied. The main parameter values for each of these scenarios was tabulated, Table 2, the sonification recorded as a .wav file and additional live parameters preserved as a screenshot of the Cheddar presentation screen. Due to the timestamps, these screen snapshots became a valuable record of sound exploration process followed. It was important to generate sonifications for the different datasets, since the character of the data may lend itself to a particular source sound, and rises and falls in the data will be perceived more or less clearly by different mappings.

wav	dataset	length	sound_	time_incre	input_mi	input_m	pitch_mi	pitch_ma	duration_min	duration_max	vol_min	vol_max	attack_mir	attack_ma	spatial	scalir	reverb
3001	r_levels	61	sine	100	0.649	1.835	100	440	100	100	2	5	0	0	2		0.3
3002	r_levels	61	sine	100	0.649	1.835	100	440	50	50	2	5	0	0	1		0
3003	r_levels	61	sine	100	0.649	1.835	70	200	100	100	2	5	0	0	5		1
3004	r_levels	61	sine	100	0.649	1.835	70	200	150	150	2	5	0	0	5		1
3005	r_levels	61	sine	100	0.649	1.835	440	880	40	100	2	5	0	0	5		0
3006	r_levels	61	sine	100	0.649	1.835	440	880	40	100	2	5	0	0	5		1
3007	r_levels	61	sine	100	0.649	1.835	70	200	40	100	2	5	0	0	5		1
3008	r_levels	61	sine	150	0.649	1.835	70	200	170	170	2	5	0	0	5		0.1
3009	r_levels	61	saw	100	0.649	1.835	440	880	120	120	2	5	0	0	1		0.1
3010	r_levels	61	saw	150	0.649	1.835	220	880	170	170	2	3	0	0	1		0.1
3011	r_levels	61	noise	150	0.649	1.835	220	880	170	170	2	3	0	0	1		0.1
3012	r_levels	61	noise	150	0.649	1.835	550	1036	42	95	2	3	0	0	1		0.1
3013	r_levels	61	noise	150	0.649	1.835	550	1036	241	241	2	3	0	0	1		0.1
3014	r_levels	61	noise	150	0.649	1.835	533	1424	870	1234	2	2	0	0	1		0.1

Table 2: Excerpt from a dataframe indicating the suite of mapping parameters and choices systematically altered in creating a listening experiment sonification.

The main parameters varied as shown above were: source sound, playback timestep, pitch range, sound grain duration, volume range, and features of the envelope that encapsulates the sound grain (attack and decay), the presence or absence of noise burst, and elements of spatialisation including spatial scaling and reverberation. Since the possible combinations of parameters are huge, this investigation could be considered as a suite of exploratory experiments. From these sounds, I then selected a subset of the '5 star' sounds I considered to be interesting, engaging, clear, pleasant for each dataset. I then further selected a set of examples that encompassed the main variables or mappings that I sought user opinions on. I created individual sonifications of single datasets, and combinations of multiple datasets to explore the sonic 'separation' needed for those different datasets to be distinguishable and how best to achieve that. Sound files are listed in Appendix 3: List of Sound Examples and available with listener guide at the linked google drive.

In conducting experiments with volunteers, I sent them several audio files by email, then asked them questions via whatsapp or by phone as they listened through. Key aspects I hoped to better understand from these experiments were:

1. How many datasets can people distinguish?
2. Which parameter mappings are intutive?
3. Which source sounds they preferred?
4. What natural processes do the different sounds evoke?
5. Are natural sound recordings are helpful or interesting?
6. Do scientists answer differently to those less used to data analysis?

Where possible, I followed up with additional unstructured interviews asking people what they can hear and what is their sonic experience when listening to the files generated. These discussions prompted me to reflect on the use of natural sound recordings to contextualise the environment and to consider the possibility of giving users control of a sound palette a bit like a colour palette is used when plotting graphs.

5.3. Interviews

The user research group I engaged with was relatively small, although had participants of different ages 9 to 60 years (youngsters were parentally supervised during interviews) and with occupations including scientists/teachers, and rural estate workers. Interviews were largely semi or un-structured, so the process of conducting them was time consuming on my part (I clearly needed to be present at least remotely). In some cases interviews did not yield a full spectrum of answers to research questions I had originally posed. However, this also gave freedom for the participants to suggest whatever came into their minds without their train of thought being over engineered by me. Some comments, thoughts or questions were fairly predictable, particularly amongst participants well known to me or having similar interests. Other reactions were novel, playful or even cheeky. For convenience I grouped some of the main opinions into three personas.

Group 1:Perhaps somewhat predictably, participants with scientific training tended to seek out the facts in the information I was sharing with some degree of precision. They were keen to completely understand the mappings and distinguish all the details in the data. They wanted to explore correlations between cause and effects such as measurements of Storms and Rainfall or Rainfall and River Flow. For an event or date they remembered, they were keen to re-live how that event was 'felt' at different parts of the river. They were interested in drainage (displayed as the subtle decay in the river flow data) and also the peak flows in different parts of the river, understandable particularly for those who had experiences the flood. Additionally, they were fascinated by the idea of spatial sonification and the idea you could potentially hear data from different places and distinguish where it was coming from. This group would be best served by simple clear source sounds, objective mappings and comprehensive control to navigate freely around the dataset.

Group 2: A second group of participants were attracted by sound examples where I used natural sound recordings as an ambience that set a scene. They seemed attracted to 'sounds that sounded like things'. They were less bothered by the details and allowed the sounds to wash over them rather than think too hard about them. Saying that, they were interested in the highs and lows of the data, what happened when there was a large storm and particularly what the big flooding event of 2016 sounded like. One keen amateur musician, suggested constraining data from each measurement station to a particular pitch range (frequency range) so that when you listened together, the stations would play the different notes of a chord. As the data evolved with time, the chords would change accordingly, generating a data driven composition.

Sound example 2: Sonification previous created highlighting the use of natural sounds to create ambience and context (Mair, 2020, DI Project)

Group 3: A younger participant (9 years old) wanted to know the 'best (deepest?) place to swim', definitely wanted 'different sounds every time'. Various sounds were suggested, including the 'burring noise when you are biking and a leaf or stick gets caught in your bike wheel' or 'maybe the theme from frozen'. The same participant also suggested Stephen Frye would do a better voice over than me!

In terms of interface design, the younger group were keen to control their experience using an ipad or phone app, exploring the river in a game but with 'cool' sound. Both of the other groups appeared jaded by excessive daily screen time and were enthusiastic about the idea of an old school analog interface with physical dials and sliders that they could move. A third option of non-contact gesture control was very popular with all participants. However, the scientist group raised a question of how you would keep track of where you are in the data unless you had some sort of display.

Chapter 6. Interaction Design

6.1. Overview

The main criteria in designing an interface for the proposed infosonic experience, is to not only facilitate but actually promote interaction and exploration. It is therefore highly desirable if the interface functions in a straightforward, intuitive or even playful manner. Ultimately, sound is fun and this experience should feel like fun. There should certainly be intellectual challenges in discovering the data but not major challenges in how to use the delivery device. It should not feel like a chore to gain access but instead should actively encourage a 'Learning by Doing' mode of engagement. In this chapter I briefly introduce my ideas on interface design and input gathered from potential users on how they might want to explore and drive their sonic journey.

6.2. Interface v1.0

In response to the growing pervasiveness of screens and swiping and sliders in our daily lives, I strongly favour analog physical interfaces. During recent work (Mair, 2020, DI project) I developed the concept of a rural visitor centre where an infosonic experience could be shared. Visitors would be encouraged to explore the archive dataset by selecting date, time periods of interest, or spatial location. Since people's 'weather memories' are likely to be punctuated by named storms, these events become a natural departure points for investigation.where I proposed navigation by a simple intuitive physical interface. In this interface, a dial is used to select a year and slider to select a month or season. The year and month selected would then be displayed on a split flap display (as the appropriate earcon soundfile was played). In addition, visitors could 'zoom in' to particular time periods by altering the speed of the playback. The technical workflow is indicated below:

-> physical inferface (linked to a rotary encoder or linear potentiometer)

-> arduino or bela microcontroller (serial communication to computer)

-> headless apple mac mini running maxmsp (sound synthesising software)

-> current data automatically updated from web via python

-> appropriate sound excerpts selected based on user input

-> current data accessed and sonified live each day

-> binaural (stereo) audio is played through headphones for good noise isolation

-> local headphone amplifier for individual volume control

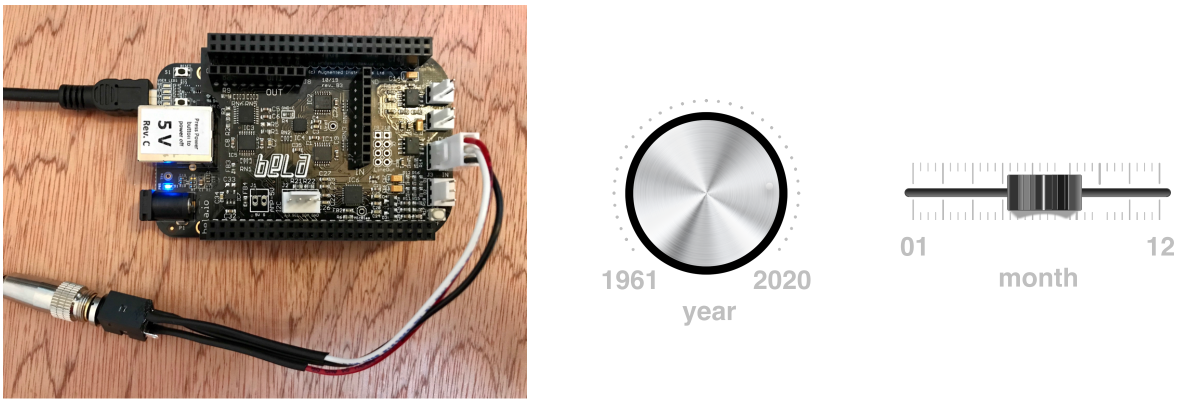


Figure 18: Sketch of dial which would control a rotary encoder and slider which would control a linear potentiometer (right). That would feed signal to a Bela (or arduino) microcontroller (eft) and into a computer running max sonification patch.

In terms of the physical appearance for the rural wilderness centre, I proposed a set of dial and sliders crafted in local natural materials inspired by the work of the owl project, Figure 19, who beautifully fuse woodcrafting with state-of-the-art digital electronics. The date selected by visitors would be displayed on a modern version of an electromagnetic split flap panel Figure 19 and dialled back or forth as the visitor selects a year or month. The nostalgic timeless design of the split flap panel would give the impression of movement through history and reliving a different period as well as fitting the visitor centre likely to be sited in a repurposed infrastructure building. A playful element would be the addition of an auditory icon making the sound of an actual split flap display turning as dates were selected.

Figure 19: Inspiration for a user interface involving ilogs and Jacard loom of the Owl project 2020 (top left) Split flip panel display designed by Fermo and Remigio Solari, 1956 (lower) and now reimagined by Scott Bezek, 2019 (top right) proposed in (Mair, 2020, DI Project)

This concept was developed for a particular design opportunity and without the benefit of any user feedback. It may not be an exact fit for exploring the infosonic experience now proposed, however, the fabrication of a working prototype encompassing these basic ideas could provide a very helpful hands on tool for future user research to help tune an interactive physical interface.

6.3. User Experience and Interaction

During interviews, potential users were asked how they might want to navigate environmental datasets and gave quite varied responses. Some, generally the scientists, wanted the functionality to jump around the dataset at their will, zoom in, zoom out and control their experience. They also wanted to know where they were in space and time, so some form of display or haptics would be beneficial. Other participants preferred some form of guidance, that I suggested could take the form of a preselection of '5 favourite data adventures'. They were more interested in known events, so exploring the effects of named storms could interest them. When asked where she wanted to go, the youngest participant stated excitedly that she 'didn't even know yet!' which I interpreted to correspond to a data driven or experience led exploration. If, in reality, the infosonic experience could give rise to this level of curiosity in youngsters, I would be delighted.

In terms of interface design, age split the field, with the younger group keen to use an iPad or tablet. Both of the other groups favoured an analog interface. The third option where I proposed a non-contact gesture control was very popular with all participants.

One challenge, regardless of interface (although closely linked) would be how to introduce people to the audio experience and navigation of the data. In previous outreach events involving sound Figure 20, I have introduced sound experiences by short verbal description when I am present or brief 'quick start' type text descriptions.

Figure 20: Outreach listening lab event where verbal explanations worked effectively, National Museum of Scotland, 17 November 2018

Further user research would clearly be required to ascertain what specific information needs to be shared for users to proceed and how best that can be provided. Also it would be useful to determine whether different user groups needed different guidance. It may be beneficial to explore these questions using the working prototype proposed in the previous section. My initial approach, given previous success, would be to provide a simple voice over. This would clearly require refinement to give the correct information at the correct time, however it has the advantage that it could be targeted (live) towards a specific user groups based on the category they most closely identify with eg. Kids, Grown Ups or Scientists. Another significant advantage of employing a voice over introduction (as opposed to using screens or text) would be the potential to improve accessibility for visually impaired participants. Recent work on 'Designing interfaces for the visually impaired' that includes extensive interviews with blind and visually impaired people and an analysis of user needs, would be an excellent resource to initiate research in this direction (Olofsson, 2018).

An interesting set of observations to inform for future improvements or refinement to this work (or tuning for specific users), would be to track people's engagement as they explore the data archive and use as feedback to improve future implementation. On one level, information on the datasets that users retrieve could, with their permission, be anonymously collected, revealing which periods, time intervals or specific dates people are most interested to explore. Alternatively, if given control over the sound palette for their infosonic journey, the choices they make. Also relevant would be how different groups interact with an interface. For a screen based interface, I would do this by combining mouse tracking and eye tracking to determine how much people 'look around' on the interface for what they want click (Bond and Tatler, 2020). In considering outputs from the different sound journeys people take, it would be straightforward and perhaps fun for participants to save an audio recording of their sonic 'journey'. It could offered as a take home or sound cloud based souvenir of their experience.

6.4. Conclusions

In this chapter I have considered possible interfaces, interactions and user experience. To some extent, this has generated more questions than solutions, however discourse around these different elements will benefit a future interface design. A step towards answering some of those questions by build a working prototype of an analogue physical interface for use during user research interviews has been proposed. The remaining chapters of this thesis present a reflection of the design process and concluding remarks.

Chapter 7. Reflection on the Design Process

7.1. Exploration, Experimentation and Reflection

On reflection, path through this project was far from linear. Various topics were explored in depth along the way and despite not appearing explicitly in the final dissertation, were essential elements of the design process, particularly in terms of knowledge gathering, technical skills and appreciation of audio crafting.

Initially it was anticipated that live geophysical data monitored using geophone seismometers and raspberry shakes deployed at a river site in rural Scotland (by colleagues in the School of Geosciences, Naylor et al., 2020) would form a key element of this work. Research was focussed towards the particular river concerned, the River Feshie in the Cairngorms, and the type of data expected. Due to covid19 extended lockdown travel restrictions, the sensor array could not be fully deployed and this data could not be collected. Seismometers collect ground motion waveforms at frequencies of a few Hertz and therefore this dataset would have formed a highly contrasting dataset to the metereological and river flow datasets finally used. In anticipation, sonification techniques optimised for treatment of waveforms such as audification - frequency shifting into the audible range (Hermann et al., 2011) and transformation of complex sound (Roads, 2001) were explored.

The realisation that this seismic dataset would not materialise, forced a shift of focus to instead utilise automatically collected meteorological and river data (along with archived datasets). On reflection, these datasets were a little sparse for the study area, so relatively late in the project, the river of study was changed to a larger river (the River Dee in Aberdeenshire) where a more extensive monitoring network and more complete archive data was available. This switch meant that site specific research, local knowledge and reconnaissance fieldwork already carried out were no longer useful. However, the more comprehensive dataset available for the River Dee, afforded exciting new opportunities to explore broader temporal and spatial variations of weather and flow along the river during different time periods. Since the River Dee was the site of a major flooding event in 2016, this area had the added feature of large data signals during the time period of our records and local people acutely aware of the importance of effective flood warning and education.

During the course of this project, I collected suite of Field Recordings of natural processes to build a sound effects library for possible use in the sonifications. Sounds included the specific natural processes and environment I wanted to convey including Rainfall, River Flow, Birdsong, Wind and Storms. Due to covid19 lockdown travel restrictions, most recordings were made from my window, garden or during daily exercise to local woods or parks. I also staged a set of indoor 'water' sound recording experiments, involving watering cans, shower heads, kitchen appliances as well as classics like bath bubbles bursting and bacon frying.

I spent considerable time during this work exploring sound and sound crafting techniques. This work is largely invisible in the thesis, but gave me important insights into the choices I made building the sonifications and also user listener responses I received during interviews. I also trained in some important tools which will be hugely beneficial should I develop these ideas further in future. Similarly, the time investment in discovering, processing and manipulating the datasets was significant. Fortunately, the Python codes I developed are general, so with minor edits could be used to automatically access, and wrangle data from any rainfall, storm or river flow dataset in Scotland.

In hindsight, regarding the use of Named Storms as a key dataset, although useful, it is not clear that these events capture the weather events that affect local communities. Rather, hyper local intense events appear to be increasing in frequency, linked to climate change, and are certainly causing dramatic effects in local areas.

From the interviews I conducted, it is clear that scientists exploring this infosonic, may already be intrinsically interested in the topic and will most likely listen with a critical scientists gaze. For others, apart from the novelty of using sound there may not seem an obvious hook to get them involved. The local element of the case study choice of river, particularly given the recent history of flooding appeared at stimulate their interest.

One aspect I had previously taken as my sole responsibility was to build the best, clearest, sounds I could generate. I had anticipated these sounds to be a finished design solution. I had not previously considered giving users the possibility to customised their own sound palette, but this appeared interesting to all participants I conversed with, in particular the youngsters. Along with 'driving' their own exploration, actively choosing their preferred sounds gives ownership and ensures everyone has a unique experience. A related playful element would be to provide interested listeners with audio files as souvenirs of their sonic journey. This could be implemented and accessed via a soundcloud link or by physically printed QR codes.

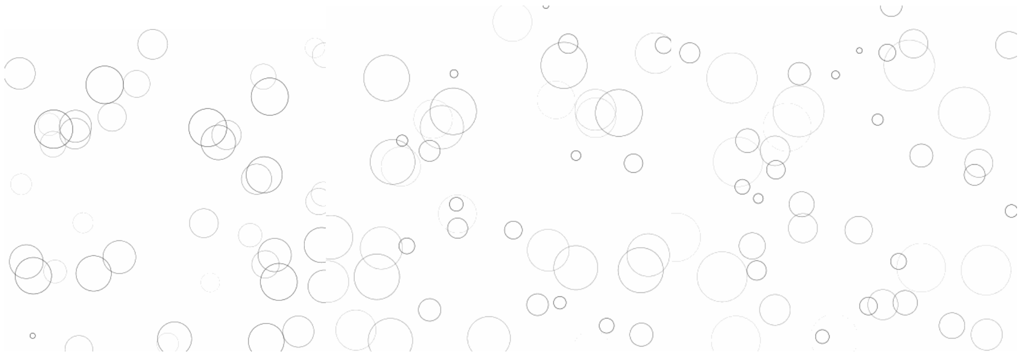


Figure 21: 3 frames from a simple graphic of raindrop simulation where drops are randomly seeded growing circles. (Animated version Animation 1: is viewable at google drive link)

Since my focus was on a sound experience, I largely neglected any consideration of graphics except for potentially a display of time and date to aid navigation of the user interface. Although sound can stand alone, the use of graphics and sound together may enhance the experience for some listeners. The scientist group for example were keen to view graphs and plots while they were listening, however this is clearly a selected group. For the others I suspect graphs would not necessarily help and may in fact discourage engagement. One alternative possibility I briefly explored was the use of simple animated data visualisations (Figure 21, Animation 1) easily produced using Python. The simulated rain drop circles could be driven by the rainfall records with intensity of rainfall mapped to number, size or speed of appearance of the drops. The single potential user I shared this graphic with was very positive about it improving their experience. I would also consider using such graphics during the introduction and explanation of the user interface and sonifications to make an instant connection between sound and process. Subsequently the graphics could be removed.

Chapter 8. Conclusions

8.1. Concluding Remarks

In this thesis I have shared my design journey towards creating an infosonic experience to communicate environmental data with the public. I have highlighted the elements that must be considered on this path, providing a technical workflow that can successfully generate sound experiences from a variety of open source datasets, and sharing the design opportunities and choices I have faced along the way. In doing so, I have demonstrated a new way of unlocking these vaults of data for users to explore, fulfilling the main goals of the project. To develop this idea to the next stage, essential future work would include more extensive user research to help inform and refine the design of a fully operating interactive interface.

The enthusiasm of the volunteers who participated in this work was extremely encouraging. They were attracted to the novelty of listening as a method of engagement and particularly keen to explore and 'drive' their own experiences. The idea to make a connection with participants, by presenting local areas they were familiar with, definitely resonated and clearly provides a helpful 'way in' to initiate engagement. This has strong potentially for sparking interest in other areas, perhaps where they go on holiday or where friends and family live, and ultimately I hope could encourage a more general engagement in science and awareness of the natural environment.

Appendix 1: List of Figures

Appendix 2: List of Tables

Appendix 3: List of Sound and Media Examples

Sound and media examples used during the design process are described below. The audio files, along with a detailed listening guide, are stored in a google drive accessible using the permanent link:

https://drive.google.com/drive/folders/17Bxxt28P0wkca6txbQYlcEDNR5TjqgyD?usp=sharing

Sound example 1: Illustration of the used of storm sound recording as an audio annotation in a sonification of rainfall and river flow (Mair, 2020, DI Project)

Sound example 2: Sonification previous created highlighting the use of natural sounds to create ambience and context (Mair, 2020, DI Project)

Sound example 3 - : Sonifications and listening experiment examples described in listening guide at link above

Demonstration 1: Demonstration of possible interactive user exploration

Animation 1: Simple animation simulating raindrops as randomly seeded growing circles

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