CONTEXTUAL INQUIRY FOR A CLIMATE AUDIO INTERFACE

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ABSTRACT

This paper presents a contextual inquiry of climate scientists during data analysis tasks. Eighteen scientists volunteered for requirements-gathering interviews and focus groups. The interviews have been analyzed in order to determine the implications for a complementary audio interface based on sonification. Results showed that climate scientists depend heavily on visualizations, and the amount and complexity of data to be displayed are huge. Climate metaphors were assessed to help developing an intuitive sound design of the interface. The outline and basic properties of the audio tool could be determined.

KEYWORDS

User Centered Design; Sonification; auditory display

1. INTRODUCTION

For the last centuries, throughout the evolution of modern science itself, the main tool for data display and basis for numerous analysis methods has been data visualization. Today, with the growth of information technology, the amount of data available to be explored and observed has expanded and needs innovative data scanning methods. Auditory displays have been explored as a complimentary tool and can potentially help scientists, depending on the amount of data, data structures, and the tasks within the research context. Sonification, the use of non-speech audio to convey information [Kramer et al. 1999] has still un-explored potential for application in science. Numerous sonification tools have been developed for specific scientific problems (e.g., sonification for EEG data Analysis [Hermann et al., 2002], sonification of data from computational physics [Vogt et al., 2008], or sonification of earthquakes' data [Aiken et al., 2012]), but to date few have been adopted within the scientific domain they are intended for.

Within the field of human computer interaction (HCI), auditory display has not been explored as much as other ones, primarily graphical interfaces. Frauenberger [2009] analyzed 23 proceedings of the International Conference on Auditory Display (ICAD) on four themes: design process, guidance, rationale, and evaluation. He describes that all papers introduce the application domain, but contextual information is not playing a role in the design process. After the in-depth view on design issues, he looks at the field of design in sonification from HCI community's point of view using an online survey. The results of this research show that the design process for auditory display is mostly unstructured and it provides limited support to reuse the design knowledge created. Another issue is that methodologies and existing guidance in audio domain are often tied to a specific context and reusing them is only possible within the restricted context [Flowers et al., 1996].

The research project (*syson.kug.ac.at*) aims at incorporating a user centered design process to develop sonifications. Therefore an extensive investigation of the day-to-day research work of scientists has been

performed, as is described in this paper. In the research project, we focus on data from climate models and measurements. Climate data are a good model domain for sonification because of the typically large and multivariate data sets, which are difficult to visualize completely. Furthermore, the time-based nature of the data implies a straight-forward direction of reading as sound, which evolves in time as well. General advantages of the human auditory system, e.g., an extremely precise resolution in the time and frequency domain [Bregman, 1990] can be utilized in the data display. Other advantages of using auditory display in the context of climate research have been found with the contextual inquiry discussed in this paper.

Examples of sonification in the context of climate research are Halim et al. [2006] presenting a "rain prediction auditory icon". They used auditory icons to display the probability of rain based on weather conditions of previous 48 hours. Another example is Bearman [2011], using sound to represent uncertainty in UK climate projections data. He compares different visual and sonic methods of representing uncertainty in spatial data. He shows; when handling large volumes of spatial data, users can be limited in the amount that can be displayed at once due to visual saturation (when no more data can be shown visually without obscuring existing data). Bearman presented that using sound in combination with visual methods may help to represent uncertainty in spatial data. This idea can be expanded into other data sets to help represent uncertainty when visual representations are not sufficient. In addition to scientific examples, many projects exist where sonification of climate data was used in an artistic context, e.g., Polli's [2004] sonification of storm data from weather models.

2. NEEDS' ASSESSMENT

In order to assess the needs of climate scientists with regard to their data analysis methods we investigated their research context applying different methods: as master-laymen condition we conducted interviews for a contextual inquiry implying task analysis; for investigating the master-master communication we observed focus groups. Based on the collected data, we applied different evaluation techniques: from simple quantitative analysis and a reflection of the workflows to experimental qualitative analysis of, e.g., the metaphors used in communication and the visualization types used for analysis.

Table 1. Details about the participants.

Classification	Categories	# people
Research group[1]	ReLoClim	7
	ArsCliSys	6
	EconClim	5
Gender	Male	10
	Female	8
Qualification	MS Student	1
	PhD Student	8
	PostDoc	6
	Professor	1
	Staff	2
Years working in the field	Average	6.3
	Maximum	17
	Minimum	0.5
Frequency of data analysis	Once per day	57%
	Once per week	35%
	Less often	7%
Field of studies	Physics related	86%
	Economics related	14%

[1] ArsCliSys: Atmospheric Remote Sensing and Climate System research group
ReLoClim: Regional and Local Climate Modeling and Analysis research group
EconClim: Economics of Climate and Environmental Change research group

We recruited eighteen volunteers from the staff of Wegener Center for Climate and Global Change (www.wegcenter.at). One participant was excluded from the evaluation, as he is not involved in research. Details about the test participants can be found in Tab. 1. Interviews have been conducted in German, the native language of all participants, audio-recorded and partly transcribed for analysis. All participants received headphones as an acknowledgement for their participation (meanwhile encouraging the research lab with additional audio infrastructure.)

2.1 Contextual Inquiry

In a field study an observer and an interviewer visited climate scientists in their workplace to capture their activities, workflows, and the environmental factors while analyzing data. Following a questionnaire they assessed the general questions and marked if all relevant topics have been covered during the open task.

Interviews took about an hour and consisted of three parts. After a short introduction on the project, the participant's personal background and qualifications were assessed. The central part of the individual interview session consisted of a walk-through of a self-chosen data analysis task. The task should have been completed by the participant recently, where s/he had been faced with raw data and wanted to understand it better to find out something (successfully or not), and which s/he discussed with colleagues or presented at a meeting. Finally, expectations about an auditory display were collected, including a recording of what the data in the task would sound like, which data sets would be most useful for the participants to sonify, and how and if they would use sound at their work.

Task analysis is an established technique in HCI [Crystel et al., 2004] therefore we decided to explore different data analysis tasks that climate scientists are regularly involved in. The approach is challenging because each scientist uses an individual set of programs and performs different tasks, due to different habits and background. Therefore we conducted a usability study in a non-classical sense, following [Karat et al., 1992].

2.2 Focus Groups

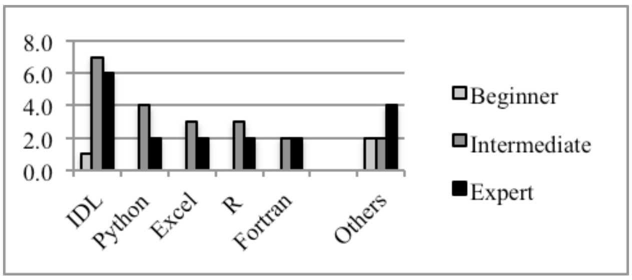
Focus groups were conducted to observe more specific information about the communication between the experts. Participants belong to three different research groups, see Tab. 1. Each user group participated in a facilitated discussion where they shared ideas and opinions on their work, i.e., a focus group. Participants brought their own task results, as had been demonstrated in the contextual inquiry, and were asked to briefly present and discuss them with the other members of the group. The focus groups took about one hour each and were observed by the authors of this paper without interfering.

3. EVALUATIONS

The data were evaluated on different levels. As quantitative information, we assessed the current use of software tools. Qualitative analysis was done on the workflows that the scientists follow, including typical tasks that have to be solved in the data analysis process. Furthermore, the visualizations that were involved in the tasks were categorized to get an overview of their strengths and weaknesses. Finally, the language content of both the contextual inquiries and focus groups was collected and analyzed in the search for metaphors used in climate science. Additionally, the observation of the task and focus group discussions allowed drawing conclusions on the interactions and expertise of the users with the existing tools.

3.1 Quantitative Analysis of Software Tools

Figure 1. Use of software at different qualification levels. "IDL" stands for Interactive Data Language. "Others" include one or maximum two scientists using one of Matlab, SPSS (Software package for statistical analysis), GAMS (General Algebraic Modeling System), ncview, C/C++.



A brief quantitative analysis of different software that the climate scientists use for data analysis and/ or visualization is shown in Fig. 1, including their own assessment of their capabilities (beginner, intermediate, or expert). IDL, Interactive Data Language, is the most used software due to historic reasons at the institute. While IDL is a commercial program, open source languages as Python and R are upcoming according to what the participants reported informally.

In general, it could be seen that all test participants were (mostly very) familiar with coding themselves rather than using ready-made software packages, and are used to scripting on the command line level. Another observation is that some basic applications have not been declared for this list by most participants, probably because they are so basic and/ or "just" command-line tools, notably ncview[2], a netCDF visual browser (where netCDF is the typical data format for climate data). Ncview is a simple open source project for quick data visualization that most scientists use for a quick-check of their data. We decided to build on ncview as open source tool and add our sonification to it.

3.2 Work Flow Analysis

Figure 2. Generalized workflow from the observed tasks.

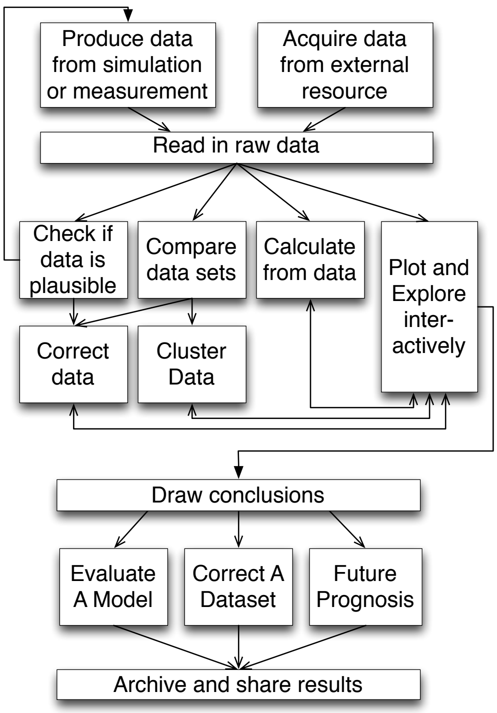


Fig. 2 shows a common workflow summarizing the data analysis process in all three user groups. The task of data analyzing is very similar and can probably be generalized to other scientific disciplines as well.

The first step is the acquisition of data, either from external research institutions or from their own simulations. This data has to be read into their software environment. Then, often, the data is plotted, or otherwise checked for its plausibility, e.g., by scanning through the numbers by hand. Often, some data is derived from the raw data by calculations following some hypothesis. Following the results of these steps, and potential plots of data, the original data are corrected or clustered. Results at this stage are always plotted and/ or explored interactively. From this, conclusions are drawn. The conclusions are specific to climate science, and can consist of either the evaluation of a model, the correction of a data set, and/ or some future prognosis. Finally, results are archived and shared – for which usually the plots serve as a basis in discussions and publications. The analysis shows that visual inspections are the key parts of the workflow. Therefore we argue that an additional auditory display can be helpful for the scientists to explore data from other perspectives.

The commonalities in each step (Data gathering, Data Analysis, Drawing Results) of the users actions will help define features of the audio interface.

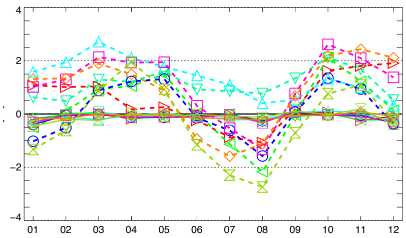
3.3 Analysis of Existing Visualizations

The visualizations that were used and discussed in the tasks of the contextual inquiry were collected and categorized. Out of 30 visualizations, we found 12 line charts (out of which 7 are time series, 4 height profiles, and one other), 8 maps, 4 bar charts, 4 scatter plots, and 2 pie charts. An overview of typical examples of the most common types is shown in Tab. 2. In general, all but one of the visualizations were

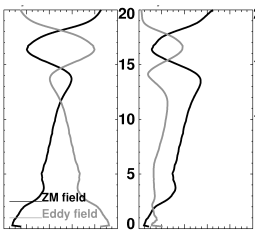
[2] http://meteora.ucsd.edu/~pierce/ncview_home_page.html

color-coded. While we rated 23 of them subjectively as self-explanatory, 5 are very difficult to understand. Furthermore, independent of their complexity, we rated 8 plots as very confusing, because either there are many data sets involved, or differences are hard to find (e.g., when a sequence of similar maps are placed one next to the other). The mean number of data sets that the scientists tried to compare with each other was 47 (!), with single tasks going up to 400 (25 different climate models, that were color-coded, compared in 4 different altitudes of the atmosphere and in 4 different regions, i.e., in 16 sequential plots.)
Obviously, the amount and multi-variance of data is challenging for the scientists in the analysis and communication of their results. This is also reflected in a citation by a participant (#12): „*This was really a huge challenge: how to display [the data] was the really difficult part*.“ Therefore an additional display channel, e.g., sonification, might be useful to relieve and support the visual sense.

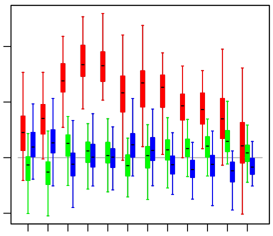
Table 2. Overview of typical visualizations of climate data. (Readability and completeness, e.g., captions and labels, could not be included due to limited space.) Copyright: WegenerCenter/ Uni Graz 2012.



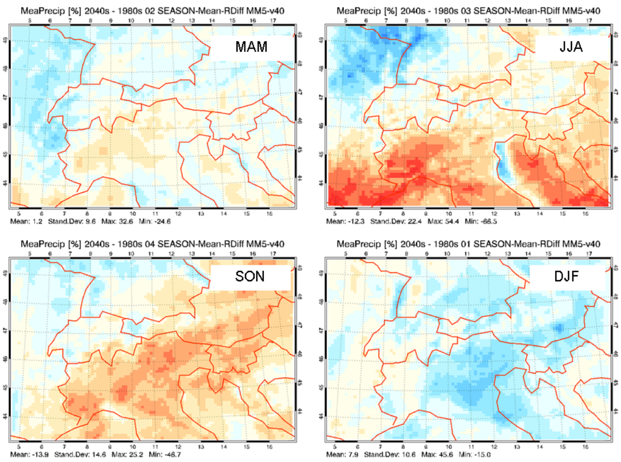
Line chart/ time series



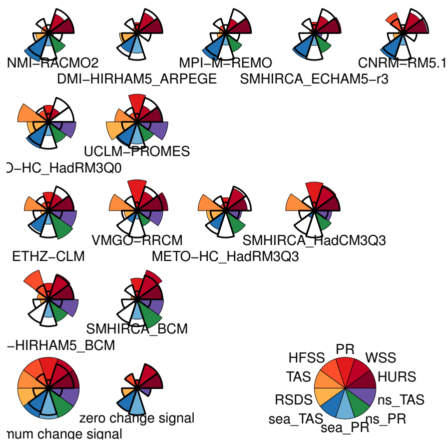
Line chart/ height profile



Bar chart with error bars



Maps with discrete color coding



Pie charts (detail)

3.4 Contextual Analysis

As a further qualitative analysis, both the interviews from the contextual inquiry and the focus groups have been analyzed for their language content [Mayring, 2010]. Two goals were envisaged with this basic assessment. First, a climate terminology will help realizing a domain-specific description of the sonifications that are understandable in the field. Second, identifying metaphors can help building a metaphoric sound identity for the sonification [Vogt et al., 2010].

3.4.1 Category-finding

All "non-trivial" words, i.e. nouns, adjectives and whole phrases have been counted for each person using it at least once. The context of the word was included in ambivalent cases as commentary. Personal statements or comments on the sonification have not been taken into account.

In a quick check on the correlation of mentions of words, a small trend to using similar vocabulary within the same research group could be seen. The difference of the focus of the research groups is reflected in the language. The richness in vocabulary, i.e., the number of different words mentioned by each person, does not correlate with his/her experience in the field, but with the general talkativeness of the person.

In the next step of analysis, the words have been grouped. The categories for the groups have been determined iteratively, where final categories emerged while trying to group the data as far as possible. For instance, the words "(to) plot, display, diagram, visualization, illustrate, graphics, ..." where grouped into the category "plot".

The categories most often cited in the interviews are "data analysis", "simulation", "description of climate phenomena", and "data properties", which is not surprising because of the task the participants have been asked to show. Comparing the master-master communication in the focus groups and the master-layman communication in the personal interviews, it turned out that in the latter condition the scientists talked more about general phenomena and less about data analysis.

Table 3. Categories used by most people (counted if used at least once) in contextual inquiry and focus groups.

look at	22	program structure	14
plot	20	simulation	14
specific programs	18	starting position	14
measurement data	17	result	14
region	15	statistics	13
temperature	15	simulation run	13
climate model	15	bias	13
color	15	analyze/ deduce	13
(working) method	15	correlation/ context	13
difference	14	test	13

The top-20-sub-categories used by the subjects in interviews and focus groups are listed in Tab. 3. The words have been translated to English by the authors. The total maximum possible is 25, i.e., when all 17 interviewees and all 8 speakers in focus groups used it. This listing shows that

(a) climate scientists use visualization as a basis of their work (e.g., number 1 "look at" and 2 "plot");

(b) temperature is the most important climate parameter they are interested in (number 6);

(c) in terms of working style, programming is the daily job of most of the scientists (e.g., climate model, program structure);

(d) and the mathematics used is often rather basic, e.g., "difference" is still in the top 10, the most important basic method when comparing data sets amongst each other.

Regarding the generalized categories "data" and "climate phenomenon", it turned out that for data analysis the most important method is correlating or finding relations between two data sets. Also visual analysis is often used. Next, preparatory steps are important, including for instance data acquisition, listing, simple calculations, calibration, and transformation of grids, sorting and retrieval. When describing phenomena, subjects mostly use comparisons; followed by logical, emotional (good/bad, interesting), and aesthetical statements (beautiful/not).

3.4.2 Metaphors

In general, few metaphors have been found in the collected words. Even in the master-to-layman condition, the participants used the standard vocabulary of science. In the contextual analysis these terms cannot be interpreted as metaphors, but become metaphoric when shifted to the auditory domain. Therefore we attempted to collect such "metaphoric" climate terms.

- Climate data is inherently *dynamic*: climate scientists "run a simulation" or collect time series data; Therefore, in general, the time axis can be used as direction of reading for the playback independently of further processing, filtering, amplification, etc., that depend on the specific sonification design.
- *Periodicities* and any associated type of wave phenomena play an important role in climate science and can directly be linked to sound oscillation and rhythmic phenomena.
- *Resolution* is a big topic in climate science, when comparing different data sets with each other or trying to find phenomena at a certain range; resolution in audio is given by the sampling rate. It can be changed by *interpolation*, that the scientists are used to as well, e.g., when fitting a plot.
- *Missing data* play a large role in climate science; an obvious analogy is making them hearable as breaks, which can be used for a quick scanning of the completeness of a data set.

- The *ensemble* in climate science is a group of data sets resulting from different runs of a simulation. Because a single outcome is always the product of random processes, only the ensemble of many simulations can be regarded as trustworthy; in music, an ensemble is a group of different instruments – the metaphor can be used by mapping, e.g., different models on different sound colors.
- *Noise* – climate scientists who work with measurement data or with simulation data both know about the signal-to-noise ratio; one participant called the atmosphere "noisy", when a high amount of greenhouse gases was to be found there; the scientists search for long-term trends within the noisy/ random behavior of everyday weather. These ideas can directly be associated with noise in sound.
- *Obvious mapping strategies* comprise the height dimension in climate data (altitude) to the height in sound (pitch), but also temperature has a very tight association to mapping to pitch; the geographical spread can be used for spatial rendering of audio.
- *Weather phenomena* are linked to typical sounds and can be used, e.g., rain or wind sounds.
- On a more *conceptual level*, terms as for instance "extreme", "dramatic" or "beautiful" will have to be transferred to the sound design and evaluated in listening tests by the future users.
- Furthermore, the control of the audio interface will involve actions that climate scientists are used to anyway, e.g., c*alibrating* or *filtering* data/ sound.

3.5 Mapping ideas and reactions

In the last part of the interview, we asked for ideas which data sets would be a good starting point for sonification in climate science, and which mappings the participants could think of. Only few and rather straight-forward ideas came up, e.g., mapping the temperature to the pitch (using positive polarity, i.e., high temperature meaning high pitch), or sonifying periodic signals, e.g., the swinging of the Earth's axis.

Although the concept of sonification seemed very vague and unfamiliar to most of the climate scientists at the beginning of our interviews, they were not reluctant by the end of the interviews to use sound in their data analysis tasks. When we explained to them what sonification is, they could find similarities between audio signals and their data signals. Half of the scientists expressed that they would use an auditory display to explore data. Furthermore, half of them could imagine using an auditory display for presentation purposes to communicate their work. Only few of them could not imagine using sound at all.

4. IMPLICATIONS FOR THE SONIFICATION DESIGN

Classical approaches of data sonification [Hermann et al., 2011] consist of audification, parameter mapping, earcons and auditory icons, and model-based sonification. All possible methods of digital signal processing can be used for creating sonifications, e.g., wave shaping, FM synthesis, granular synthesis, physical modeling, and spatial rendering. Depending on different tasks, a combination of all of them will be built into the audio tool.

From the quantitative analysis of software tools we decided to build our system on top of ncview, a simple open-source command line tool, that most of the climate scientists at Wegener center are comfortable with. From the workflow analysis we identified three main categories of tasks that could involve sonification and have to be implemented in the audio tool: quick-scans (checking the plausibility of data), comparing different data sets in details (including different options of zooming, filtering, and overlapping), and creating sound files to present the data in simple standard format (stereo). The system shall work interactively with a GUI (possibly the ncview GUI) and can be calibrated for personalized sound settings. The analysis of visualizations that are used showed that the amount and dimensionality of data being displayed within one analysis is huge and the resulting plots often confusing. The audio display should therefore serve as an additional information channel to the visualizations.

The contextual analysis gave hints on how the cognitive process of understanding data is implemented in every-day climate science; statistical methods, programming individual applications, and visualizing at all stages of the process are key factors. The discussion of metaphors shall be used to create the interface as intuitive as possible for climate scientists. These results are probably most relevant for the sound design, but also most difficult to transfer. Mappings will follow simple intuitive basics, e.g., temperature to pitch,

location to spatial rendering, etc., and the sound design shall evoke climate associations that are straightforward, e.g., as known from weather conditions.

5. CONCLUSION AND FUTURE WORK

A main outcome of the extensive analysis of the contextual inquiry is surely the authors' in-depth understanding of the way; climate scientists work, communicate, and, to a certain extend, how they think. The crucial moment in the process of understanding a data set within the research process could not be assessed with the analysis methods above. Participants reported, e.g., „*you can see by the naked eye that from these strange temperatures a completely unphysical shape emerges*" (Participant 9), or on the moment when finding an interesting phenomenon „*I looked into the data that were interesting once more. Just to check them for plausibility*." (Participant 11). The audio tool has to be designed in a way that scientists integrate it naturally to their workflows, and allow them to be creative with using it. One step to reach this goal is creating intuitive sounds. The next step in our research is therefore building a sound space of sonification designs in an iterative approach. Prototypes will be presented to the climate scientists in form of listening experiments. The final sonification designs will be implemented in the audio tool and tested again. A sound library, in analogy to the key of a graph, will present and comment typical climate sounds of our sonifications.

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