PAMbase: a Repository of Soundscape Recordings to study Earth's Phonosphere

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Abstract

Recent breakthroughs in passive acoustic monitoring (PAM) now allow collecting acoustic environmental information at unprecedented spatio-temporal scales, quickly transforming it into a big and highly valuable data pool for Earth System Sciences. Applications include for example the cryosphere (monitoring the calving of glaciers), the hydrosphere (noise pollution in aquatic ecosystems), the biosphere (monitoring biodiversity) and the anthroposphere (human health). However, there is still no digital infrastructure that (i) can act as a central data repository for soundscape recordings, (ii) provides easy and rapid access, and (iii) allows standardized data analysis for a wider scientific community, so that the potential of acoustic data can be fully realized across disciplines. Building on existing open-source repositories, we aim to conceptualize such a repository for passive acoustic monitoring data (called PAMbase), which will allow curated data and metadata storage and quality control of acoustic data. We intend to address with this repository several user groups, including researchers, the public, planning authorities and decision-makers. The open-access beta release of PAMbase developed within the proposed pilot project will include a demonstration workflow for citizen science participation as well as a benchmark of user-friendly machine learning (in particular Deep Learning) tools for automated data analysis. In addition, the pilot will include a roadmap addressing user groups, opportunities for community engagement and a time plan for further technological and methodological development during the NFDI4Earth consolidation and advancing phase. PAMbase will complement the NFDI4Earth research areas and will enable macro-scale analyses of phonospheric information for multidisciplinary research and a wide range of applications.

I. Introduction

Context and relevance in Earth System Sciences. Acoustic emissions are a valuable source of environmental information, and recent developments in automated sound recording and analysis technologies are now enabling comprehensive, yet cost-effective, study designs covering unprecedented spatial and temporal scales. The increasing availability of data characterizing acoustic environments (so-called soundscapes) is enabling the discovery of a still little-explored information layer in Earth System Sciences, the phonosphere. The phonosphere comprises all the acoustic information emitted on Earth's surface emerging from biological, geological, hydrological, glacial, atmospherical or anthropogenic sources (Fig. 1) and thus highlights the close interactions among the Earth's spheres. Recent examples in Earth System Sciences include: monitoring and automated type-identification of glacier calving [1], acoustics-based precision agriculture [2], the study of noise pollution in terrestrial [3] and aquatic systems

[4,5] and their respective effects on biodiversity [3,6], ecosystem functions [7,8] and human health [9], the monitoring of biodiversity change [10-12] and human-wildlife conflicts [13], the assessment of biotic and anthropogenic acoustic activities [14,15], and the design of soundscapes in landscape architecture [16] and sustainable urban development [17].

Challenge and gap. The increased interest in and use of passive acoustic recording across different domains in Earth System Sciences leads to large amounts of data being collected. However, a centralized data hub comparable to genetic (GenBank), biodiversity (GBIF), or movement (MoveBank) data is missing so far [18]. Such centralized data hubs have the advantage of fostering collaboration across disciplines by providing data access and sharing opportunities, while potentially offering also high quality standards and streamlined capabilities for data exploration and analysis.

Vision and opportunities. To this end, developing and launching PAMbase as a data hub for soundscapes will provide the opportunity to work on larger scale research questions that go beyond the capacities of individual projects, as impressively demonstrated in other data hubs and repositories (e.g. [19]). Such repositories also yield the opportunity to unfold the opportunities of public engagement (e.g. through Citizen Science projects) which produces field recordings or support with generating reference catalogs. We envision PAMbase to be user-friendly and explorative for the general public. Yet, PAMbase will not only serve as a central hub for a variety of research questions, but also allow methodological and technological developments related to (i) data labelling (i.e. to constitute common training as well as test data) for automated audio analysis model development, (ii) the amelioration and development of models through the increased availability of labelled data, as well as (iii) – in the long term – the comparison of algorithms' accuracy and efficiency over shared test data.

II. Pilot description

Technology and standards. We expect a sharp rise in soundscape recordings through low-cost autonomous recording units (ARUs) such as AudioMoth [20,21] or µMoth but also through more customized products serving specialized niches. PAMbase relies on this technological revolution and aims to maximize its use and potential through easy access, sharing, and analysis capabilities. PAMbase will therefore feature a user-friendly front-end for uploading, searching, and exploring of sound files while ensuring a coherent structure of metadata and annotations. An appealing user interface (UI) that visualizes recordings on an interactive map and provides visualizations of important acoustic indices will provide a state-of-the-art user experience (UX). Lastly, an innovative back-end completes the digital infrastructure by providing standardized quality protocols, efficient data compression tools, automated sound event detection and signal classification, and an API integration for direct database querying. Currently, numerous Machine Learning techniques for analysis of acoustic information (in particular using Deep Learning) were released, with many more in active development. Examples include CityNet, Bat Detective, or OpenSoundscape [14,15,23]. This multitude of potential tools makes it hard for end-users to keep updated or access them in a practical manner. By implementing these tools into the database followed by thorough testing of their potential, we provide solutions to the end-user by streamlining workflows to process and analyze acoustic data stored in PAMbase.

Innovation. PAMbase will be the first repository for multi-purpose soundscape recordings. It will be available at the right time given the sharp increase in soundscape research in many scientific fields and could provide a benchmark for quality standards in this area. The platform benefits

greatly from the current developments in Machine Learning technologies used in acoustic research by providing tools for streamlined data analysis and pattern recognition. In addition, we want to achieve a high level of engagement with the general public through crowdsourcing, but even more we want to serve as a platform for upcoming citizen science projects that build on the platform's database, which will evolve over time. Together, crowdsourced information and labelled data will form a reference database that will be fed into automated analytical models for sound recognition. The open beta release of PAMbase at the end of the pilot could then serve as a solid foundation for further app development, enabling users to access the repository and associated tools either from their mobile devices or home computers.

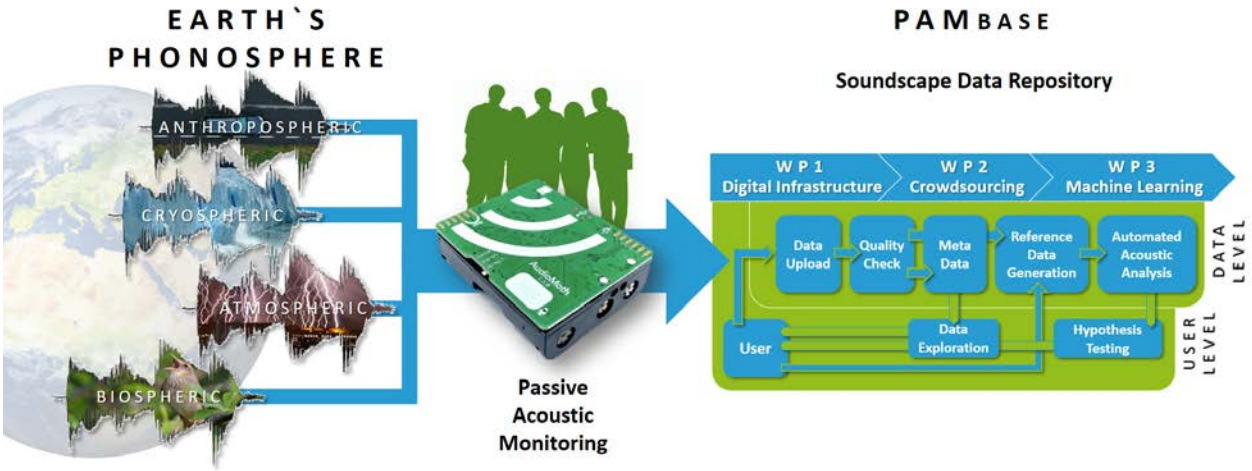

Figure 1: Scheme illustrating the positioning of PAMbase (right) as a data repository for acoustic data (center) recorded from different realms of the Earth's systems (left). A flow chart illustrates the three main work packages (WPs) and the information flows at the user and data level.

III. Relevance for the NFDI4Earth

Users and stakeholders. The potential of acoustic information is increasingly recognized by researchers from various fields in Earth System Sciences and we expect that scientists will be a core stakeholder group. This will include smaller research projects with a specific geographical focus area, but also scientists interested in synthesis and meta-analysis focused work with broader geographical scope. After its launch, the repository can be also used for educational purposes (in schools and universities), to present concrete research questions, but also to introduce the topic and the relevance of acoustic information across fields. As with other large data repositories, we expect that the full deployment of PAMbase, including the analysis and exploration tools we plan to provide will require a team of data curators and system integrators, as well as a strong infrastructure provider where such a platform can be hosted. Previous projects using audio information (e.g. xeno-canto.org, a global crowdsourced repository of bird songs) have shown that the public is generally very interested in participating (either in crowdsourcing of primary data or in acting as a citizen scientist in data labelling). By using smartphones for audio recording, the technological hurdle is very low nowadays. Data compiled through PAMbase and the availability of analysis tools will make it valuable also for public authorities and decision-makers.

Compliance with FAIR principles. The repository is aimed to fully comply with the FAIR principles. A centralized data hub will improve the findability of the recordings. Apart from project-specific data embargoes, which will eventually be lifted when a project is completed, we envisage

that the recordings will be accessible under various Creative Commons licenses. This will ensure that data providers are properly acknowledged and that data are not exploited for commercial purposes. We strive for high standards of quality reporting to ensure quick access to relevant data for users and interoperability between projects. To this end, reusability is a central aspect of PAMbase, as it – together with the other FAIR principles – will enable a new level of synthesis that would be otherwise logistically and financially impossible.

Benefits for NFDI4Earth. Including the phonosphere will significantly strengthen the NFDI4Earth vision and demonstrate the variety of data types considered in the consortium. PAMbase will specifically pair and advance innovative tools (crowdsourcing, Citizen Science, Deep Learning) with a high degree of interoperability among disciplines and stakeholders to help researchers explore and study Earth's phonosphere.

IV. Deliverables

Deliverable 1: Technical Operability. By the end of the pilot phase, the open beta version of PAMbase will consist of an operational front- and back-end allowing to set up user and project profiles and upload soundscape files with standardized metadata (WP1). In addition, two modules allowing the participation of the general public (WP2) as well as enabling sophisticated data analysis through machine learning techniques (WP3) will be available.

Deliverable 2: Community Engagement and Roadmap. The pilot will deliver a roadmap document entitled "Towards standardized soundscape recordings and analyses in Earth System Sciences" which will (i) provide an in-depth analysis of user needs (researchers and other stakeholders) as well as relevant partners within and beyond NFDI4Earth, (ii) guidelines for quality control, data standards and data sharing, and (iii) a concrete time plan for further technological and methodological development during the NFDI4Earth consolidation and advancing phase.

V. Work Plan & Requested funding

While each WP can generally operate independently during the pilot project, there are frequent points of contact between the WPs, which ensure a seamless integration of all WPs into a coherent product. For this purpose, we ask for funding of one year full-time equivalent (i.e. 12 person months). Regular strategic meetings between the project partners during the whole project duration ensure an efficient workflow.

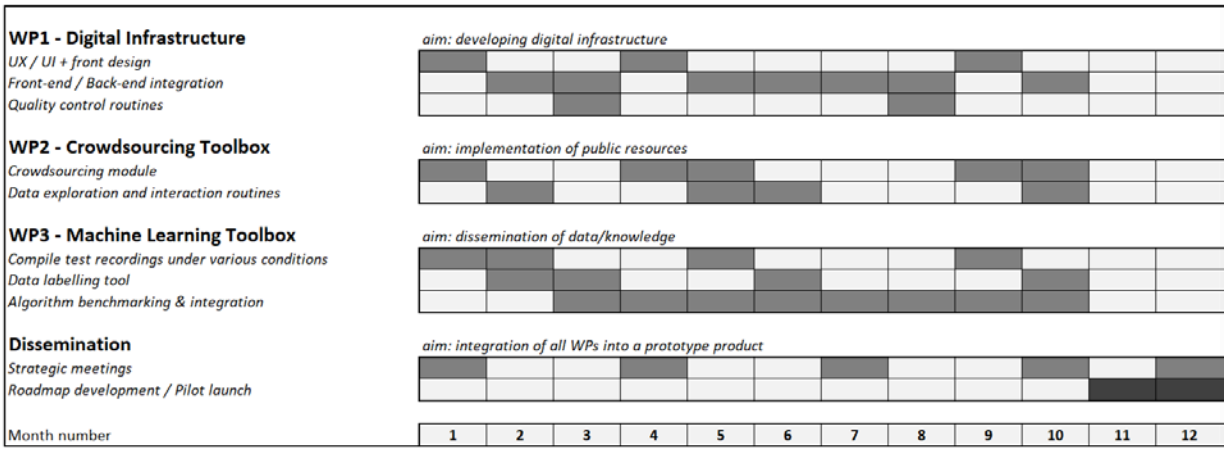

Figure 2: Gantt chart for the development of PAMbase.

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