

The EPOS Thematic Core Service on Anthropogenic Hazards (TCS-AH): a Hotspot for Geothermal Research

Marc Schaming¹, Alice Fremand¹, Jean Schmittbuhl¹, Pascal Bigarre², Aglaja Blanke³, Savka Dineva⁴,
Alexander Garcia⁵, Jean-Robert Grasso⁶, Abror Karimov⁶, Jannes Kinscher², Joanna Kocot⁷, Elena Kozlovskaya⁸,
Grzegorz Kwiatek³, Stanisław Lasocki⁹, Grzegorz Lizurek⁹, Jouni Nevalainen⁸, Beata Orlecka-Sikora⁹,
Jamie Pringle¹⁰, Pamela Roselli⁵, Gilberto Saccorotti⁵, Mariusz Sterzel⁷, Tomasz Szeplieniec⁷, Sam Toon¹⁰,
Paweł Urban⁹

¹ Université de Strasbourg, CNRS, IPGS-UMR7516, Strasbourg, France

² Institut national de l'environnement industriel et des risques, Nancy, France

³ GFZ German Research Centre for Geosciences, Geomechanics and Scientific Drilling, Potsdam, Germany

⁴ Luleå University of Technology, Sweden

⁵ Istituto Nazionale di Geofisica e Vulcanologia, Italy

⁶ Isterre, Grenoble Observatory, Grenoble, France

⁷ ACC Cyfronet, AGH, Poland

⁸ Oulu Mining School and Sodankylä Geophysical Observatory, University of Oulu, Finland

⁹ Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

¹⁰ Keele University, UK

Marc.Schaming@unistra.fr

Keywords: EPOS, e-research infrastructure, virtual laboratory, anthropogenic hazards, geothermal research, datasets, services

ABSTRACT

The EPOS Thematic Core Service on Anthropogenic Hazards (TCS-AH) is designed as a functional e-research infrastructure that provides access to a large set of relevant data and allows free experimentations in a virtual laboratory, promoting interdisciplinary collaborations between stakeholders (the scientific community, industrial partners and society).

The platform provides datasets as Episodes, which comprehensively describe Anthropogenic Hazards (AH) cases for infrastructures, people and/or environment. They are grouped in several categories of subsurface exploitations, one of them being geothermal energy production. Datasets describe various projects, including Soultz-sous-Forêts, Gross Schoenebeck, St. Gallen, The Geysers, and Carbfix. Users can access relevant datasets (e.g. seismic waveforms and catalogue), industrial data (e.g. well path, injection rates, wellhead pressure), and other geodata (e.g. geological section, velocity model, faults). The platform grants access to an application portfolio, designed for the AH area, from basic services (data integration and handling, physical modeling) to probabilistic assessments of anthropogenic seismic hazard and to simulator for multi-hazard/multi-risk assessment in exploration/exploitation of geo-resources.

Two local data centers (eNodes: IG-PAS/Poland and CDGP-EOST/France) provide the metadata and data to the TCS-AH platform in commonly used standards and formats (e.g. miniSEED, GeoTIFF, and .mat). A registration/authorization is mandatory to access some data covered by restriction imposed by data industry providers or shared data embargoed by running projects.

TCS-AH is one of the 10 TCS forming the EPOS infrastructure, and hosts data from other EU projects like SHEER and S4CE.

1. INTRODUCTION

The EPOS Thematic Core Service on Anthropogenic Hazards (TCS-AH) aims to bring together a broad community interested in Anthropogenic Hazards (AH), especially - but not only - interested in induced seismicity associated with geo-resources exploration and exploitation. Indeed, human activities may cause environmental hazards and risks: seismic activity, reactivation of faults, groundwater contamination, emission of gaseous species into the air, subsidence, etc. The socio-economic impact of these hazards may be significant, with material loss, injuries, and fatalities. The public is more and more concerned by these topics, and may lose confidence if AH are not accurately assessed and presented. It is therefore crucial to monitor and study the processes involved by geo-resources exploration/exploitation.

The TCS-AH is an answer to these questions. Its partners decided to set-up this e-infrastructure to facilitate a holistic approach to the research in the AH field. It integrates research activities to facilitate studies, to strengthen cooperation between industry and science. Today, TCS-AH is formed by representatives from science and industry coming from 14 European countries. The TCS-AH platform (<https://tcs.ah-epos.eu/>, Leptokaropoulos et al., 2019) provides data relative to conventional hydrocarbon extraction, unconventional hydrocarbon extraction, underground gas storage, underground mining, CO₂ sequestration, geothermal energy production, reservoir impoundment, wastewater injection, and applications to study them.

The EPOS TCS-AH community is organized in an initial consortium of 12 partners from 8 countries, and its work plan is established into five sections : a) Implementation of TCS-AH Services; b) Administration law & accounting; c) Episodes integration and application implementation; d) Promotion and dissemination; e) Projects & partnership. A *Data Provider Committee* and an *Users Committee* will advise the Consortium Board, and an *Innovation Advisory Committee* consisting of stakeholders from academia, industry, science, local and central administration bodies, society and others will be consulted during the decision making process of the TCS-AH.

2. DATA

On the TCS-AH platform, data are gathered as episodes, comprehensively describing a geophysical process, induced by human technological activity, which are hazardous for people, infrastructure and the environment. Data within the episodes cover usually geophysical data related to the hazard acquired directly from instrumental measurement and industrial data describing the process posing the hazard. Among geophysical data there are: seismological catalogs, PGA and PGV data, waveform data, seismological and strong motion networks, water and air quality from in situ and laboratory measurements. Moreover, geological data including geology and tectonics as well as geospatial data crucial for the proper understanding of the industrial activity in geological environment are delivered within every episode. Episode data should cover complexity of the process along with the causative relation between industrial operations and environmental hazards monitored with state-of-art geophysical instruments. Episodes contain also brief description of the site and inducing process together with references and complementary documentation.

There are already 10 published Episodes related to geothermal energy, with a significant presence of SOULTZ-SOUS-FORÊTS stimulation and circulation experiments (Figure 1):

- 1993 SOULTZ-SOUS-FORÊTS Stimulation,
- 2000 SOULTZ-SOUS-FORÊTS Stimulation,
- 2003 SOULTZ-SOUS-FORÊTS Stimulation,
- 2004 SOULTZ-SOUS-FORÊTS Stimulation,
- 2005 SOULTZ-SOUS-FORÊTS Stimulation,
- CARBFIX: geothermal energy production and CCS,
- GROSS SCHOENEBECK: geothermal energy production experiment,
- THE GEYSERS Prati 9 and Prati 29 cluster: Treated wastewater injection for geothermal power production,
- THE GEYSERS: geothermal energy production,
- ST. GALLEN: geothermal project.

Some SOULTZ-SOUS-FORÊTS Episodes are currently ready and will be added before the end of 2019: 1995 and 1996 Stimulations, 1994 Circulation.

Episodes related to geothermal energy production are distributed worldwide, in continental Europe, Iceland and USA.

Datasets include generally:

- Seismic catalogues, event related waveforms, event related accelerogram, seismic network, ground motion network;
- Industrial data, such as injection rate or volume, wellhead pressure, flowback rate, well path and position, steam production;
- Geodata such as velocity models, drillhole lithology, faults.

Datasets may have two specific characteristics:

- Some of them are owned by industrial partners that explore or exploit a geothermal site. These industrial partners have intellectual property rights on the data, and may restrict their distribution only to academic use, or case-by-case. On the other hand, they may be obliged by states (depending on local regulations) to open some datasets for environmental monitoring purposes;
- Some of them may be vintage, from the late 1980s to early 2010s, essentially in the case of Soultz-sous-Forêts exploration and research experiments that were conducted between 1987 and ~2010. These old data had to be recovered from shelves, old tapes, reports, than quality-controlled, described (metadata), converted into actual exchange formats. These actions needed significant human resources, as well as skills from senior persons that participate to the operations.

Datasets are archived and distributed in community-shared and open formats: miniSEED (Standard for the Exchange of Earthquake Data), XML, text or comma-separated values, pdf, GeoTIFF, etc. The TCS-AH platform uses Matlab .mat files for better visualization and processing performances.

Start
IS-EPOS Platform
Documents
Support

LOGIN
SIGN UP

AH EPISODES
APPLICATIONS

MY WORKSPACE

AH Episodes

Project association
Geothermal energy production
Go to Advanced data search

Show:
LIST
MAP

	1993 Soultz-sous-Forêts Stimulation <div>RESTRICTED DATA ACCESS</div> <p>After the deepening of well GPK1 to 3590m in 1992, an extensive stimulation programme was performed in September and October 1993. GPK1 was stimulated with large scale hydraulic injections to investigate the behavior and the extension of large natural fractures detected previously. A total of 44000 m³ of water was injected during the three phases of the experiment. The different phases are detailed in J. Helm thesis (1996) p117. Some 16000 microseismic events were detected during the stimulation program by the downhole and the surface network.</p>	Geothermal energy production France, Alsace EPOS-IP
	2000 Soultz-sous-Forêts Stimulation <p>During June/July 2000 a hydraulic stimulation program was conducted in the well GPK2. The stimulation was performed over the open hole section of GPK2 from 4431 m (measured depth) to the bottom of the well at around 5084 m. A total of 27 800 m³ of water were injected. At the start of the stimulation 700m³ of brine were injected in an effort to encourage downward growth of the stimulated region. The stimulation covered a period of six days. After a break of seven days a post-stimulation injection test was performed. Microseismic emissions have been monitored and recorded throughout the</p>	Geothermal energy production France, Alsace EPOS-IP
	2003 Soultz-sous-Forêts Stimulation <p>The stimulation was performed in 2003 mainly by massive injection into the well GPK3. The stimulation strategy can be divided in five parts: - Injection into GPK3 - Injection into both GPK2 and GPK3 ("dual" or "focused" stimulation, Baria et al., 2004) - Shut in GPK2 - Shut in both GPK2 and GPK3 and production from GPK2 - Circulation test GPK2-GPK3 following stimulation Episode integrated in the framework of:</p>	Geothermal energy production France, Alsace EPOS-IP
	2004 Soultz-sous-Forêts Stimulation <p>The 2004 stimulation was aimed at improving the hydraulic performances of the well GPK4. This borehole was stimulated twice. The present test corresponds to the first stimulation of GPK4. The data from a pre-stimulation low flow injection test performed to evaluate the initial injectivity of GPK4 are included.</p>	Geothermal energy production France, Alsace EPOS-IP
	2005 Soultz-sous-Forêts Stimulation <p>The 2005 stimulation is the second stimulation of GPK4, after the previous one, performed in September 2004. The stimulation was followed a few days later by a program of chemical stimulation (injection of diluted HCl). This program involved the chemical stimulation itself and two identical step-rate injection tests: the first was performed before the chemical stimulation and the second after, in order to observe the efficiency of the chemical stimulation. The program was in the following order:</p>	Geothermal energy production France, Alsace EPOS-IP
	CARBFIX: geothermal energy production and CCS <div>RESTRICTED DATA ACCESS</div> <p>CarbFix is a CCS consortium operated by RE. UI, Columbia University (USA) and CNRS (France). It is one of the most successful and best-known examples of CO₂ sequestration processes in the world. RE operates over 100 wells at Hellisheidi, about 10 of which are used for re-injection of geothermal water, one is used for re-injection of captured gases, the others are production and monitoring wells. Roughly one-third of the CO₂ and H₂S presently emitted from the Hellisheidi power plant is being injected as a dissolved water phase into fractured basaltic rocks. CCS operations are followed by the seismic activity</p>	Geothermal energy production, Co2 sequestration Iceland, Southern Region S4CE
	GROSS SCHOENEBECK: geothermal energy production experiment <p>A deep injection well and a doublet of production wells were established in this area reaching the reservoir rocks like red bed sandstone and andesitic volcanic rock at the 4200m depth. Injection performed from 9th to 14th August 2007 was used for repeated stimulation treatments to investigate scenarios of enhancing productivity of thermal fluid recovery from the underground. A total amount of 13.000 m³ of water was injected. The maximum injection well-head pressure reached 58.6 MPa.</p>	Geothermal energy production Germany, Gross Schoenebeck IS-EPOS, EPOS-IP, SHEER
	ST. GALLEN: geothermal project <div>RESTRICTED DATA ACCESS</div> <p>The geothermal project undertaken by the city of St. Gallen (Switzerland) and operated by the St. Galler Stadwerke was based on a large-scale 3D seismic survey in 2010. The survey led to drilling of the geothermal well, "St. Gallen GT-1", to a measured depth of 4450 m across Paleozoic / Mesozoic rock formations as well as extensive scientific and technical analysis, and well completion aimed at geothermal use. The area has additionally been instrumented with a micro-seismic array operated since 2012 by the Swiss Seismic Service (SED). After complications occurred during well stimulation and testing in July</p>	Geothermal energy production Switzerland, Sankt Gallen S4CE
	THE GEYSERS Prati 9 and Prati 29 cluster: Treated wastewater injection for geothermal power production <p>The Geysers is the world's largest geothermal (hydrothermal) field located 116km north of San Francisco, California. The injection of treated wastewater leads to occurrence of significant seismic activity with thousands of earthquakes above the magnitude of completeness of 1.4 occurring every year. This episode contains high quality seismic catalogs and other associated data from a cluster of seismicity related to fluid injection in the vicinity of Prati 9 and Prati 29 injection wells located in the north-western part of the field. The first catalog contains source parameters (including high quality static stress drop)</p>	Geothermal energy production United States of America, The Geysers EPOS-IP
	THE GEYSERS: geothermal energy production <p>The Geysers geothermal field is one of the largest geothermal fields worldwide in terms of steam production. The Geysers is a vapor-dominated reservoir, located 116km north of San Francisco, California. It has been in operation for more than 50 years resulting in the occurrence of several hundred thousand induced seismic events. Over the years, field exploitation resulted in a long-term reduction of reservoir pressure and a decrease in steam production. Episode consists of the various data describing the seismicity connected with fluid injection at this geothermal site. The seismicity data are accompanied by</p>	Geothermal energy production United States of America, Geysers SHEER

This platform was partially funded by IS-EPOS project. © 2019 IG PAS & ACC Cytronet AGH v2.31.1

Figure 1: list of some Episodes related to Geothermal Energy Production and available on the TCS-AH platform

3. APPLICATION PORTFOLIO

The TCS-AH platform provides tools (application) that can be used to display, analyse and process the data provided in the Episodes. The applications are fully integrated in the platform, using the dataset as input, or providing data compatible with the other applications.

The currently 44 applications that are actually implemented on the TCS-AH platform are grouped into 13 thematic categories (Table 1). Some implement simple and common operation like converters, display or completeness magnitude estimation, other provide advanced processing like “Template-Matching based Detection Algorithm” or “Stress and strain changes induced by fluid injection and temperature change driven by geothermal injection”.

Collective Properties of Seismicity	Anderson-Darling test for exponentiality of inter-event time
	Coefficient of randomness
	Completeness Magnitude estimation
	Magnitude conversion
	Priestley-Subba Rao (PSR) test
Converters	CSV to Catalog converter
	Catalog to ASCII converter
	Catalog to Vectors converter
	GDF to Vectors converter
	GDF to XLS converter
	Catalog to XLS converter
	Ground Motion Parameters Catalog builder
	Time Series builder
Correlation Analysis	Seed converter
	Autocorrelation
Data Processing Applications	Cross-correlation
	Basic Vector Operations
Download Tools	Signal download tool
	Waveform download tool
Earthquake Interactions	Earthquake interactions: Georesource scale
	Earthquake interactions: Mainshock scale
	Earthquake swarm (reshuffling analysis)
	Time correlated earthquakes (Seasonal trends)
Event Detection Algorithms	Template-matching based detection algorithm
Filtering Tools	Catalog filter
Probabilistic Seismic Hazard Analysis	Source size distribution functions/Stationary Hazard
	Stationary Hazard: Exceedance Probability
	Stationary Hazard: Maximum Credible Magnitude
	Stationary Hazard: Mean Return Period
	Time dependent hazard in mining front surroundings
	Time dependent hazard in selected area
Seismogram Analysis Tools	Estimation of source parameters in time-varying production parameters geometry
	Seismogram picking tool
Source Parameter Estimation	Effective stress drop estimate
	Estimation of source parameters in time-varying production parameters geometry
	FOCI
	Localization
	Spectral Analysis
Stress Field Modelling	Stress inversion
Visualizations	Estimate of maximum possible magnitude for reservoir triggered seismicity
	Fracture Network Models - Mechanical Stresses
	Front Advance histograms
	Integrated Google Maps data visualization
	Seismic Activity with Front Advance

Table 1: Available applications on the TCS-AH platform (after Orleka-Sikora et al., 2019)

When necessary, an input form is displayed to allow definition all mandatory and/or optional parameters that have to be set prior the execution of the application. A prototype scenario for a modifiable application is implemented, and an “Autorun” option was added to allow creation of workflows of applications by setting the output of an application as the input of another one. Application are often linked to a documentation that gives details about application’s objective and algorithm.

4. ACCESS THE TCS-AH E-RESEARCH INFRASTRUCTURE

Data are collected from providers by two local data centers (eNodes), IG-PAS in Poland and CDGP-EOST (<https://cdgp.u-strasbg.fr>) in France, and these eNodes provide the metadata and data to the TCS-AH platform. Metadata are more or less static on the platform, updated only when changed, but data are dynamically served to the platform each time they are requested.

Some episodes have open access for everybody, but some other are restricted either to an ongoing project embargo (e.g. BOIS, EPOS-IP, POL-VIET, S4CE) or have specific restriction (like only for academics in the case on industrial data from Soultz-sous-Forêts). Therefore, users need to register, and provide additional informations such as academic affiliation or belonging to a project. After verification, access capabilities are validated.

Each registered user is granted with a personal workspace. Selected data, processing results are stored in this workspace. It is also possible to upload external datasets (as far as they are in accordance with the data formats supported by the platform). Applications can be applied to the datasets, and the user can download the results (Figure 2).

As an additional but important point, TCS-AH platform serves as a tool for collaborative research work by providing intercommunity social functions: common workspace of project shared by participants, project brokering, upload/download data to the common workspace. As such, it can be used as a teaching tool for students practice or as shared space for demonstration.

TCS-AH and eNodes applies general FAIR principles and Research data management. Data are findable, accessible, interoperable, and reusable. Agreements are signed with providers, which confirms that the TCS-AH is able to distribute the data, and give to the providers the ability to define specific access rights. Within the EPOS and TCS-AH data policies, rights are open (CC:BY or CC:BY:NC) by default.

5. CONCLUSION

The EPOS Thematic Core Service on Anthropogenic Hazards (TCS-AH) provides many services to the AH community: data, applications, services, and a live and active community working on AH. It represent a true hotspot for geothermal research, and invites all stakeholders to become users, to provide Episode data, and to join the AH Consortium.

ACKNOWLEDGEMENTS

The work was partially supported by EPOS-IP “European Plate Observing System – Implementation Phase” funded by the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 676564, and by the LabEx G-Eau-Thermie Profonde, joint academic-industry initiative established in 2012 as part of the French Ministry of Research and Education’s Laboratories of Excellence Initiative.

REFERENCES

- Leptokarpoulos, K., Cielesta, S., Staszek, M., Olszewska, D., Lizurek, G., Kocot, J., Lasocki, S., Orlecka-Sikora, B., Sterzel, M., and Szeplieniec, T.: IS-EPOS: a platform for anthropogenic seismicity research, *Acta Geophys.* 67:299 (2019), 10.1007/s11600-018-0209-z.
- Orlecka-Sikora, B., Lasocki, S., Kocot, J., Szeplieniec, T., Grasso, J.-R., Garcia, A., Schaming, M., Urban, P., Jones, G., Dineva, S., Schmithbul, J., Lizurek, G., Sałek, P., Olszewska, D., Dobrzycka, I., Saccaroti, G., Leptokarpoulos, K., Chodźńska, K., Simpson, I., Blanka, A., Kwiatek, G., Rudziński, L., Mutke, G., Barański, A., Pierzyna, A., Kozlovkaya, E., Nevalainen, J., Kinscher, J., Sileny, J., Sterzel, M., and Fischer, T.: EPOS Services for Assessing Anthropogenic Hazards: A Step-change in Tackling Hazards Associated with the Exploitation of Geo-resources, *Scientific Data* (2019), submitted.

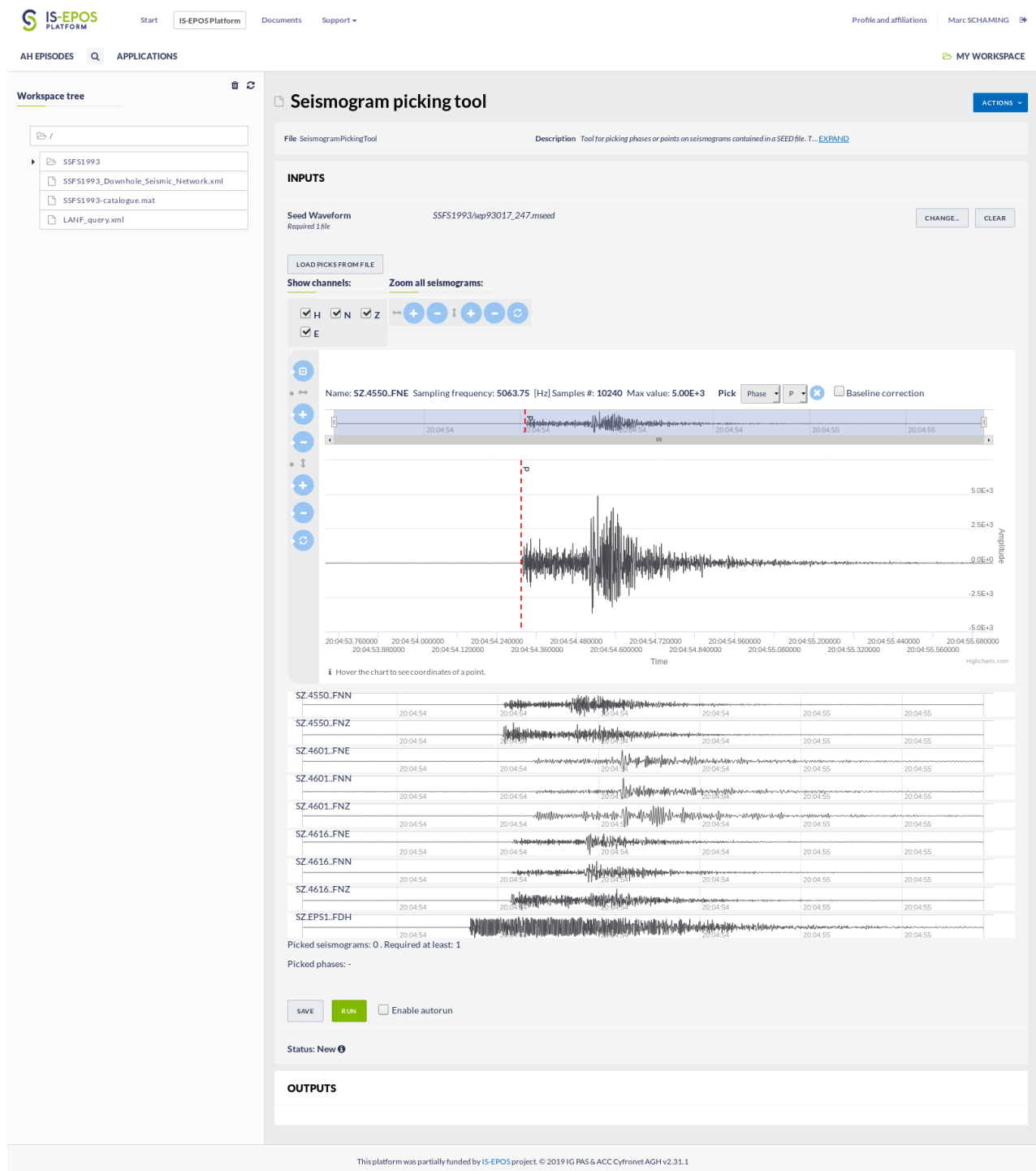


Figure 2: example of Seismogram picking tool in a user's workspace