Seismological Observatory Software: 30 Yr of SEISAN

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Abstract

The SEISAN software package for processing of earthquake data has been in use for 30 yr. SEISAN is a collection of programs that help to carry out tasks from the basic processing at a seismological observatory to more advanced seismological research. During its history, the software has been adopted to different hardware and operating systems. However, the core of the software with a folder- and files-based database and event-based processing has remained stable. The main focus in the design and development of the software has been the efficiency in data processing for the user. The software comes with manual, tutorial, and training exercises. This together with regular training activities has made SEISAN a useful tool for many observatories around the world.

Cite this article as Havskov, J., P. H. Voss, and L. Ottemöller (2020). Seismological Observatory Software: 30 Yr of SEISAN, *Seismol. Res. Lett.* **91**, 1846–1852, doi: 10.1785/0220190313.

Introduction

SEISAN is a general purpose software for routine interactive processing of earthquake data at local, regional, and teleseismic distances. It is a collection of programs, which are partly written by the authors, contributed by members of the SEISAN community or integrated standalone tools developed by others. These programs are designed to coordinate with each other through a structure defined by folders and formats. SEISAN can ingest data from various sources and in different formats. It also contains a number of research-oriented programs. The software was initially developed for the Norwegian National Seismic Network operated by the University of Bergen and first used in early 1989 on Vax computers (Havskov and Ottemöller, 1999). It is worth mentioning that very little dedicated project funding has gone into the development of the software. Both hardware and operating systems have changed over the years, requiring adaptation of the software. The codes are written in either Fortran, C, or C++. Today, the most common operating systems are supported, and the software is distributed freely and with open source. The software was available to other networks from the 1990s and is now used globally. An indication of the global usage is given by the almost 50 agencies that report to the International Seismological Center (ISC) in SEISAN format (Fig. 1). The historic overview is given in Table 1.

There are hundreds of seismological observatories and a growing number of temporary deployments around the world that investigate earthquakes by analyzing records from local to regional scale seismic networks. The total number of earthquakes per year reported to the ISC greater than magnitude 2 is almost 200,000 and the total number of phases reported to the ISC in recent years has exceeded 10,000,000 (J. Harris and D. A. Storchak, personal comm., 2019, of the ISC). Although much of the initial processing is done automatically, there still is a need for manual revision by skilled analysts. SEISAN was developed for this purpose and has been widely used in the seismological community for 30 yr.

Software similar to SEISAN has been in use over the years. Some programs (that we are aware of without giving a complete list) were developed in a similar way such as Pitsa-Giant (Rietbrock and Scherbaum, 1998), SEIS89 (Baumbach, 1990), Seismic Handler (Stammler, 1993), the International Association of Seismology and Physics of the Earth's Interior software (Lee, 1989), but some of these are no longer supported. The Seismic Analysis Code (SAC) (Goldstein *et al.*, 2003; Goldstein and Snoke, 2005) can be adopted as a routine processing tool, but is probably better suited to research-oriented data processing. Geotool (Miljanovic, 2016) has advanced processing capabilities, but is not openly available. Also, various instrument manufacturers provide software with similar functionality. ObsPy (Krischer *et al.*, 2015) has quickly grown in popularity, but is probably more suited for research work. In the United States, Jiggle is widely used within the Advanced National Seismic System Quake Monitoring System for routine processing. There are obviously other specific programs that can be combined into a processing system for use by a seismological observatory.

Compared to some of the software mentioned, we consider SEISAN to be rather no frills. After 30 yr and with a good number of users, it is interesting to see why it has been successful. Here, we wish to reflect on the past and report on the current status of the software.

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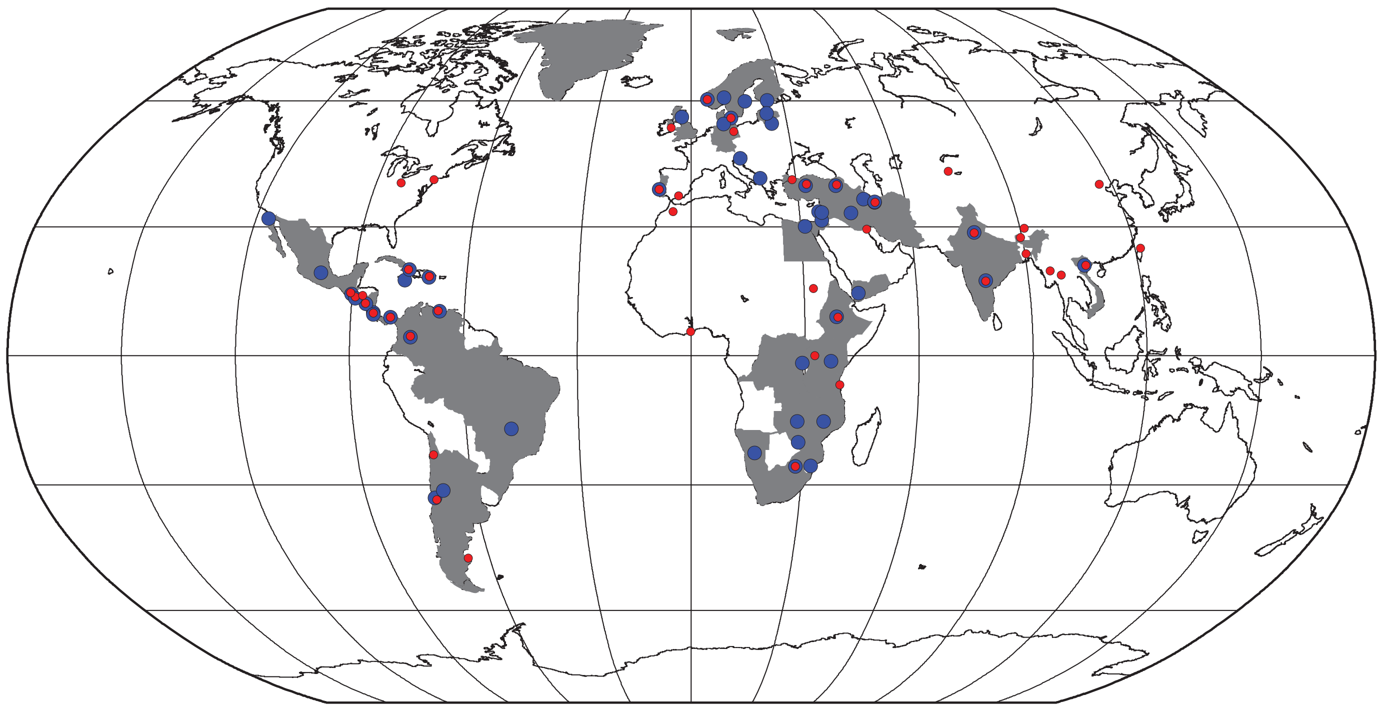

Figure 1. Geographic overview of countries (gray shaded) and agencies (blue circles) that report their data to the International Seismological Center (ISC) in SEISAN format (provided by J. Harris and D. A. Storchak of the ISC) and locations of SEISAN workshops and courses with involvement of the authors (red circles). The first course was held in Tanzania in 1993.

How It Works

The main purpose of SEISAN is to provide tools for basic processing required at seismological observatories (Table 2). This includes basic signal processing, phase identification, event discrimination, earthquake location, magnitude calculation, spectral analysis, and fault-plane determination. When developing SEISAN, the focus has been on providing the essential functionality, but also to make the data processing efficient for the user. This is a requirement when dealing with large amounts of data. SEISAN also has research oriented functionality (some mentioned in Table 2), which will not be described here and the user is referred to the SEISAN documentation for details (see Data and Resources).

Before analysis, the data have to be entered into the system and this can be done in different ways. Waveform data can be read into SEISAN directly from the continuous archive that is stored in SeisComP3 structure (Weber *et al.*, 2007) with the data in miniSEED format. However, it is also possible to work with event-based waveform data files in the most common formats in which a folder-based structure is used to organize the data. Several conversion tools allow bringing in data that were stored in different formats making SEISAN a fairly open system. The waveform metadata can also be given in different formats. This, for example, makes it possible to download a Standard for Exchange of Earthquake Data (SEED) volume, extract miniSEED waveforms, Resp calibration files and station coordinates, and start processing. The event or parametric data are stored in a database like structure consisting of folders and files. Each earthquake is given by a single file that is in Nordic format (Havskov, 1990). These files contain parametric data such as arrival times, hypocenter location, magnitudes, and location errors as well as the pointers to the respective waveform data.

The most common way of working in SEISAN is to start with an event that has entered the database through an automatic detection software such as Earthworm (Johnson *et al.*, 1995) or SeisComP3 (Weber *et al.*, 2007). It is also possible to use the SEISAN waveform plotting tools for manual detection. SEISAN has two tools to work with the events. The first is the SeisanExplorer, a more recently developed Graphical User Interface (GUI) that supports all basic functionality. The alternative still is the legacy mode nongraphical program Eev from which waveform plotting, location, and many other routines can be started. The SeisanExplorer is similar to a spreadsheet tool and has advanced functionality for searching and sorting (Fig. 2). A common way of operating is to have the database tool, the waveform plotting, the location GUI, and GoogleEarth for mapping all on the screen (Fig. 3). The different parts communicate, for example, to see how changing a single phase affects the location. However, some users still prefer the simplicity of the non-GUI tool.

Interaction with Users

SEISAN was initially developed for seismic monitoring in Norway (Havskov *et al.*, 1992). However, the scope of the software quickly broadened through interaction with seismologists

TABLE 1
Overview of SEISAN History

1989	First version was used from 1 January 1989. Written in Fortran 77 and operated on a Vax Vms computer. The basic functionality of Eev was implemented with a Vax script. The basic format of the parameters was the Nordic format. The binary SEISAN waveform format was developed within the SEISNOR project. The graphics was Tectronics.
1990	Fault-plane solution.
1991	Pc (Dos) and Sun-Solaris versions. X-graphics used on Solaris (Tectronics simulation). Tectronics on PC. Hypocenter program for local location replaces Hypo71 and Hypoellipse.
1992	Vax was out. *b*-value program. Global location with IASP91 model. Automatic phase pick. The main user interface Vax script was replaced by a c-program later to become a Fortran program.
1993	Data base structure a bit changed so it looks like the current one. Source spectral analysis. Synthetic seismograms, coda *Q*.
1994	Hypoinverse added. General spectral ratio including Nakmura method.
1995	Microsoft graphics on Dos. Pure X on Solaris. System can use 999 channels instead of 99. Seismic hazard package added.
1996	Windows and Dos supported.
1997	Graphical user interface (GUI) for Windows. miniSEED, SEED, and GSE2 can be used converted to SEISAN. Velest added.
1999	Linux. Dos support stopped. Long and identical file names on all platforms. Year 2000 compatible. From four to five character station names. FK analysis. SAC interface. Tool for Wadati diagrams.
2000	Swarm identification. Location by grid search.
2001	New autopicking, inversion for Qlg. Inversion for Ml parameters. SEISAN, GSE, and SAC read directly. GSE response.
2002	Reading continuous data. Statistics for volcano monitoring.
2003	MACOSX implemented.
2005	Read SEED and miniSEED directly. SEED response. Cross correlation for phase pick, macroseismic plot, and ISC location program. Event detection in continuous data.
2007	Plot by GoogleMap.
2008	SEED channel naming convention. GoogleEarth interface. Particle motion plot. Cygwin implementation.
2010	One new fault-plane solution program. Stress inversion. Broadband body- and surface-wave magnitudes.
2011	All platforms use gfortran and gcc. Windows graphics changed to Dislin package. Read SeicComp and BUD archives. Two new fault-plane solution programs.
2012	Data base work back to year 0. SeisanExplorer GUI on Windows and Linux. Regional moment tensor inversion.
2013	Automatic magnitude calculation. More seismic hazard programs.
2014	New conversion programs.
2015	New Hypoinverse, SE has new statistical options.
2016	Outlier detection, logging of operations, new locator in SE. Semiautomatic polarity picker. New automatic phase picker. Automatic amplitude ratio for fault-plane solution.
2017	Multichannel spectrograms. New GMT mapping programs. Automatic download of hypocenters from webservices.
2018	More tools for treating fault-plane solutions.
2019	Sun Solaris retired, iLoc program implemented.

BUD, Buffer of Uniform Data; FK, frequency wave-number; GMT, Generic Mapping Tools; ISC, International Seismological Center; SAC, Seismic Analysis Code; SE, SeisanExplorer; SEED, Standard for Exchange of Earthquake Data.

from other countries. In particular, visiting other observatories and working with colleagues helped to define the software requirements. Today, SEISAN is used by quite a number of observatories around the world largely for local, regional, and volcanic monitoring. Use of the software in different setups and with different data has helped to strengthen the software and reporting of problems has been essential in improving the codes.

The importance of documentation was realized quite early, and SEISAN had always been released with a user manual. Later, an exercise document based on data supplied with the software

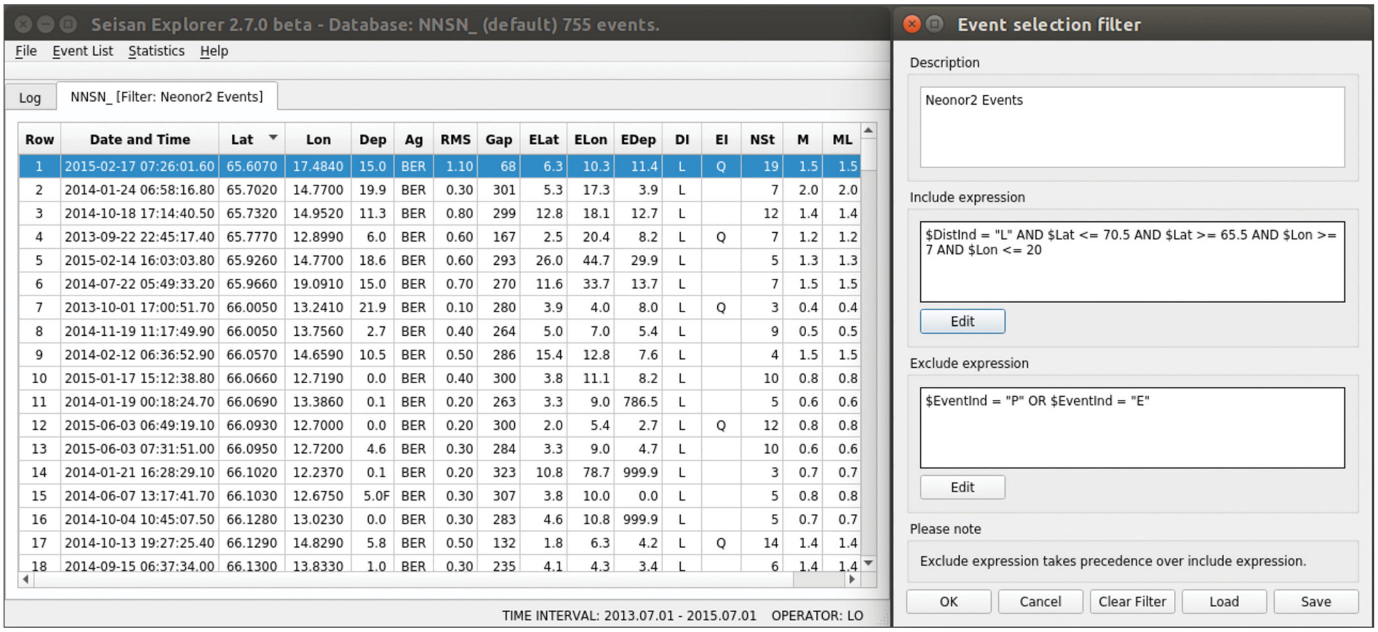

Figure 2. Selection of events from the database in SeisanExplorer is done through a Filter tool (right). This allows to build complicated searches with include and exclude expressions. In this example, local events (L) in a specified area are selected, but possible and confirmed explosions (P and E) are excluded.

was developed, and also a tutorial has become available to get step-by-step instructions. If all fails, the users can turn to the SEISAN mailing list (see Data and Resources).

SEISAN training has been given regularly during the 30 yr of development in different ways in many different places (Fig. 1). Both pure training sessions as well as processing oriented workshops have been carried out. This was done either under specific research projects, during dedicated SEISAN events or regional collaboration efforts (e.g., United Nations Educational, Scientific and Cultural Organization). Training on data processing using SEISAN has also for more than two decades been part of the international training courses on

TABLE 2
Overview of SEISAN Functionality

Hypocenter location	Three different programs, one of them locates both local and global events, grid search, and travel-time inversion
Hypocenter plots	Simple programs which can make profiles, interface to plot with GoogleEarth and GoogleMap, prepare GMT input
Travel-time calculations	Calculate local and global phase arrivals, travel-time tables, Wadati diagram, plot the theoretical arrivals while picking phases
Fault-plane solutions and moment tensor inversion	Four programs using polarities and/or amplitudes, moment tensor inversion, and stress inversion
Signal processing	Filtering, phase pick, spectral analysis, spectrogram, FK analysis, correlation, spectral ratio, particle motion, three-component single-station analysis for determining back azimuth
Instrument response	Tools for generating and checking instrument response files in different formats, support for various formats
Attenuation	Coda determination, inversion of *Lg* for *Q*
Conversion programs	Numerous programs for converting between different parameter formats and different waveform formats. Includes QuakeMl. Program for correcting headers in waveform files
Automatic routines	Event detection and phase pick, spectra, and amplitudes for magnitude determination
Reports and statistics	Bulletin, various statistics analysis, *b*-value, and explosion detection
Database tools	Merging of catalogs, database search, logging, tools for input and output of data to SEISAN
Seismic hazard	Catalog tools, completeness analysis, and deterministic hazard calculation

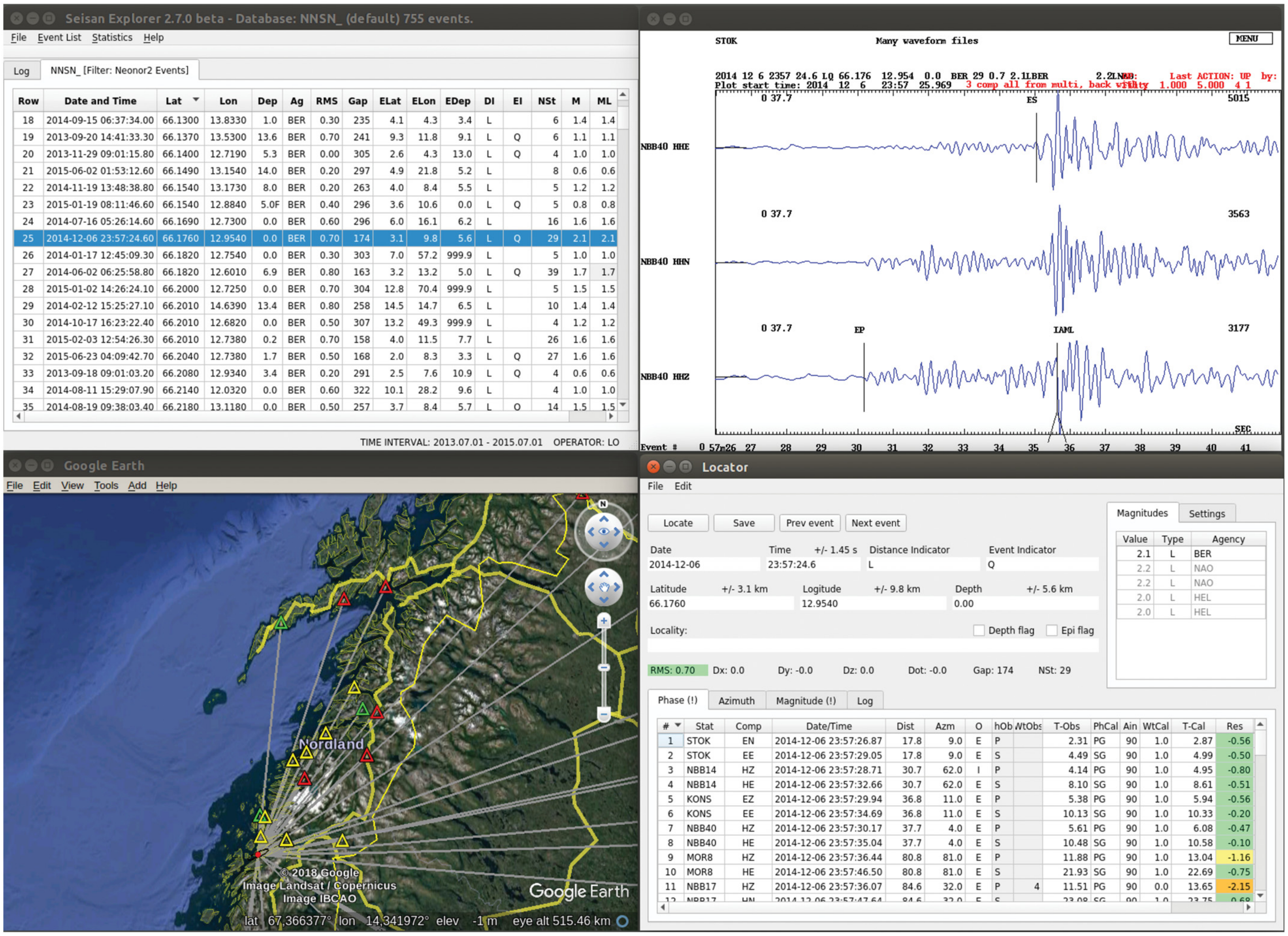

Figure 3. Example of SeisanExplorer screen. The database Graphical User Interface (GUI) is shown at the top left with the list of events. From here, the plotting program (top right) and locator (bottom right) are started. For mapping, GoogleEarth (bottom left) is used in which the view is updated automatically to show the epicenter and stations. Stations are color coded based on their residual.

"Seismology, Seismic Data Analysis, Hazard Assessment and Risk Mitigation" that is arranged by the German Research Centre for Geoscience (GFZ). Finally, SEISAN has been used for education at the University of Bergen in conjunction with a text book on data processing (Havskov and Ottemöller, 2010).

We recently carried out a survey among the SEISAN users and received 78 responses from 33 countries. Although we know that there are many more users, the responses should represent the community well enough. The survey showed that SEISAN is mostly (60%) used by groups of less than 10 in the individual institutes and that for these groups it is the main system (67%). With more than one choice allowed, it turned out that it is most of all (67%) used for routine data processing, but also for microseismic and induced monitoring (33%), teleseismic analysis (17%), volcanic monitoring (23%), or research (56%). The majority use the software on Linux (59%), whereas others use Windows (35%) and MacOS (6%). Asking about the automatic processing system that is used, revealed that more than half (52%) use SEISAN with SeisComP3, whereas others (19%) use it with Earthworm. An interesting and unexpected result was that only 37% run the latest version. We also received suggestions for improvement. The main points were to improve the installation process, documentation, database, graphics, and mapping.

Lessons Learned

It is our opinion that SEISAN has been successful for so long as it delivers the functionality that is needed at many seismological observatories to store and process earthquake data to obtain location and magnitude. The efficiency for the user in the processing is the most important consideration and technical details of the software as well as fancy graphics are secondary. Efficiency in SEISAN is achieved by the close connection between the different programs, keeping graphics simple, avoiding multilevel menus, and using the keyboard as much as possible to reduce the use of the mouse.

Another reason for lasting long is that the way of working with the database interaction tool (called legacy mode above) has not changed since the start of SEISAN. This means that analysts did not have to change their way of working. Although adapting to changes can be positive, it seems with the nature of routine processing, analysts often prefer to remain with the efficient automation that they develop over time. We currently observe that the switch to the database GUI is not obvious, although functionality and user friendliness are improved. Text terminal interaction seems to be difficult to beat, after one gets used to it—just as many still love the UNIX editor vi. The fact that quite a large proportion of users do not use the latest version also indicates that they do not need a change as long as the software still does the job.

The data structure in SEISAN is based on folders and files, and this has made it quite easy to keep data in the same way for three decades, although computers have changed. It also makes it easy to have the same structure on different operating systems. The use of a relational database in SEISAN has been considered for quite some time, but so far, the idea has been rejected as we think that advantages due to simplicity outweigh possible performance improvement with a relational database. A positive development had been the acceptance of miniSEED as standard format together with the storage of continuous data in daily stream files. Implementation of reading these data directly into a SEISAN brought the advantage of being able to easily run the software together with SeisComP3.

Over the years, we have visited quite a number of observatories, and it is impressive how much dedicated work goes into the analysis of earthquake data. We feel that manual processing or at least revision of automatic results remains an important task and the purpose of SEISAN is to help with this. However, we often see that phase reading and interpretation, amplitude correction, and location are not trivial tasks, and that more training is required on these basic parts of seismology, especially with the growing number of stations.

What Next

It is our impression that SEISAN as interactive routine processing tool still fills a gap between the real-time acquisition systems such as SeisComP and Earthworm and research processing tools such as SAC and ObsPy. We see that many users appreciate the software as it allows to carry out the basic routine tasks, whereas at the same time the desire for nicer graphics is growing.

In recent years, the SeisanExplorer (GUI) has been developed and this allows having the main graphical applications (database interaction, location tool, trace plotting, and GoogleEarth mapping) on the screen at the same time. This is replacing the interaction through the terminal window, but as aforementioned users may wish to continue with the legacy mode. Possible next steps are to add new graphical tools for mapping and trace plotting. The most important consideration for a new trace analysis tool would be to keep or improve the level of efficiency.

Performance of the software is of course important, and with increasing data volumes, fast reading is essential. We expect that the common way of using SEISAN in the future will be based on daily miniSEED files, and here we see potential for improvement to make the reading faster. A consequence of not changing the parametric format for a long time has been that it does not support network and location codes. This has not been a major issue from a practical perspective, but is becoming a must to properly identify data streams and give credit to network operators. The shortcoming is currently being rectified by introducing a modification to the Nordic format.

Considering the importance of routine earthquake processing, we look forward to continue the development of this efficient largely no-frill software.

Data and Resources

The SEISAN software and its documentation are available at http://www.seisan.info. We refer to the following other software packages: ObsPy is available at https://github.com/obspy/obspy/wiki, Seismic Analysis Code (SAC) is available at https://seiscode.iris.washington.edu/projects/sac, Seismic Handler is available at http://www.seismic-handler.org, SeisComP3 is available at https://www.seiscomp3.org, and Earthworm is available at http://www.earthwormcentral.org. All websites were last accessed on March 2020.

Acknowledgments

SEISAN would not be where it is today without feedback from the users, which the authors would like to thank for. The authors are also grateful to the authors of programs that are integrated into SEISAN as well as individuals that helped with the coding. Their names are given in the manual as well as in the codes, too many to be listed here. The authors appreciate comments by Won-Young Kim to improve the article. Dmitry Storchak contributed to improve the article and together with James Harris provided statistics and the figure with geographical distribution. The authors are thankful for the positive feedback and constructive comments for improvement by the two reviewers.

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Manuscript received 16 October 2019
Published online 18 March 2020