



Project acronym and title: SECURe – Subsurface Evaluation of Carbon capture and storage and Unconventional risks

TRAINING SOFTWARE AND DATASET

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Public introduction

Subsurface Evaluation of CCS and Unconventional Risks (SECURe) is gathering unbiased, impartial scientific evidence for risk mitigation and monitoring for environmental protection to underpin subsurface geoenergy development. The main outputs of SECURe comprise recommendations for best practice for unconventional hydrocarbon production and geological CO₂ storage. The project is funded from June 2018–May 2021.

The project is developing monitoring and mitigation strategies for the full geoenergy project lifecycle; by assessing plausible hazards and monitoring associated environmental risks. This is achieved through a program of experimental research and advanced technology development that includes demonstration at commercial and research facilities to formulate best practice. We will meet stakeholder needs; from the design of monitoring and mitigation strategies relevant to operators and regulators, to developing communication strategies to provide a greater level of understanding of the potential impacts.

The SECURe partnership comprises major research and commercial organisations from countries that host shale gas and CCS industries at different stages of operation (from permitted to closed). We are forming a durable international partnership with non-European groups; providing international access to study sites, creating links between projects and increasing our collective capability through exchange of scientific staff.

Executive report summary

This report presents the software and data used for the training program focusing in the analysis of induced seismicity for researchers and students. The training is done using the non-commercial software package SeisAn, that during the SECURe project has been improved in order to improve the linking of handling of metadata to the parametric data catalogue. The data used for the training is typical of data collections one could expect to face during a monitoring program for induced seismicity. The software and data was used at the workshop on advanced signal processing at the Ohio Seismic Network (OhioSeis), Ohio Department of Natural Resources, Ohio, U.S.A. in November 2019.





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1 Introduction

In guidelines for CO₂ geological storage e.g. European_Communities, 2011; ISO_TC265, 2017 a monitoring program is given as a key requirement. One of the fields of monitoring is microseismicity, that has the potential to precede and warn of larger and potentially damaging seismic events (see e.g. the traffic light system in Green et al 2012 and references therein).

As part of a monitoring program for microseismicity we here present software and data used for training of researchers, students and staff undertaking monitoring of induced seismicity.

The software used is the non-commercial package SeisAn (Ottemöller et al. 2020; Havskov et al 2020). The software was selected for the training as GEUS previously with success to pre-operational monitoring at an onshore shale gas drilling site in the Northern part of Jutland, Denmark. Furthermore, the software is used for post-operational monitoring at the Steenlille natural gas storage facility, located on Zealand, Denmark (described in SECURe WP3). GEUS takes part in the development of the SeisAn software package in cooperation with University of Bergen, Norway.

The data selected for the training is from areas with reported induced seismicity or areas with a dense sensor setup and local seismicity. The data was selected to enable the training in different environments and using different sensor configurations.

The training does not include collection of data.

1.1 THE SEISAN SOFTWARE PACKAGE

The SeisAn software package was initiated more than 30 years ago (Havskov et al. 2020) and has since then been gradually extended and improved. The primary purpose for the SeisAn software package has since the beginning been to assist the operation of local or regional seismic network in processing and analysing seismic signal from earthquakes. The core of SeisAn is a flat file database for parametric earthquake data and a software library to interact with the database. The software package also include a large number of computer programs for processing and analysing seismic signals and plugins for other 3rd party earthquake software. The different tools in the SeisAn software package are documented in a 586 page manual (Ottemøller et al. 2020). In addition to the SeisAn manual, a short tutorial and training data sets is available at the SeisAn website (from http:// seisan.info). Users can assign to a mailing list where they can share ideas and get assistance on solving processing problems.

1.2 THE DATA SET

This section gives an overview of the data set prepared for the training program and the main purpose of each subset. The training program was presented at the workshop on advanced signal processing at the Ohio Seismic Network (OhioSeis), Ohio Department of Natural Resources, Ohio, U.S.A. in November 2019, and does therefore include data sets from Ohio, U.S.A, but also includes data from the Netherlands, the North Sea and Taiwan. In some references to the included events, the events might be referred to or marked as induced events, but we have no evidence to show that any of the events are induced. The events are included since they form part of a basic seismic dataset for training asexample of the types of that might be collected in connection with a CCS project.

The subsections below are named after the locality of the event/sequence of events and the year they occurred.

1.2.1 Batesville, 2017

The purpose of using these data is to get experience with analysing a significant event in Ohio, U.S.A.





The map below show the epicentre of the Batesville event (from <u>http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/batesville-june-03-2017#topofcontent</u>)



Figure 1: The map of the epicentre of the Batesville event.

1.2.2 Eastlake, 2019

The purpose of using these data is to get experience with analysing a sequence of events in Ohio, U.S.A.

The map below show the epicentres of the 10 Eastlake events (from http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/lake-erie-near-eastlake-june-10-2019#topofcontent).







Figure 2: Map showing the epicentre of the 10 Eastlake events.

1.2.3 Youngstown, 2011 and 2012

The purpose of using this training dataset is to address the challenges, when processing seismic events where travel time models might change from event to event.

Data and parametric data was kindly provided by Won-Young Kim, Lamont-Doherty Cooperative Seismographic Network, Columbia University, New York, U.S.A. The data is also analysed by Kim, W.-Y. (2013)

The figure below show example of event locations, in Ohio, U.S.A.







Figure 3: Satellite image with locations seismic events at Youngstown, mapped with Google earth 2020.

1.2.4 The Netherlands, 2019

The purpose of using these data is to get experience with a very large number of seismic stations.

Three events are included from the Netherlands. In this case the KNMI provide information on type of event, tectonic or induced, see the figure below under "Type aardbeving" from https://www.knmi.nl/nederland-nu/seismologie/aardbevingen:





KNMI - Seismologie - Aardbe	evinger × +									
< → ୯ ଘ	🖸 🔺 https://www. knmi.nl /nederland-nu/seismologie/aardbevingen									
	plaats	aardbeving plaatsvond i catalogus van aardbevir akoestische data tools (;	s in UTC, deze v igen is te vinder zie onderstaand	rerschilt van de n op het KNMI le links).	Nederlandse tijd. DataCentrum of de	De complete e seismische en				
	Analyse	Datum en tijd (UTC)	Plaats	Magnitude	Diepte (km)	Type aardbeving	Details			
	Reviewed	2019-11-03 13:35:43	Königswinter (Duitsland)	1.2	7.0	Tektonisch	Detail page			
	Reviewed	2019-10-28 17:38:33	Garrelsweer	1.2	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-28 09:03:28	Wuppertal (Duitsland)	1.9	1.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-22 00:42:05	Appingedam	0.8	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-20 03:36:42	Harkstede	0.9	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-18 00:35:54	Appingedam	0.5	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-08 18:19:31	Overschild	0.4	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-06 20:17:00	Meedhuizen	1.6	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-10-06 01:33:26	Loppersum	1.0	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-09-20 22:59:30	Muntendam	0.4	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-09-12 05:14:50	Voerendaal	0.5	26.0	Tektonisch	Detail page			
	Reviewed	2019-09-09 07:45:22	Zeerijp	1.5	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-08-31 04:16:04	Zuidbroek	0.4	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-08-28 14:38:53	Westerwijtwerd	0.4	3.0	Geïnduceerd	Detail page			
	Reviewed	2019-08-21 03:40:34	Tjuchem	0.6	3.0	Geïnduceerd	Detail page			

Figure 4: Screenshot of KNMI webpage with detected events in the Netherlands.

1.2.5 Central North Sea, 2019

The purpose of using this training dataset is to address the challenges when processing events in a remote region.

The map below shows epicentre and stations used by NNSN.







Figure 5: Satellite image with epicentre of event and location of seismic stations. Gray lines show raypath to stations used for location, colour of stations show relative traveltime residuals from good to bad, being green, yellow or red, respectively. Image: Landsat / Copernicus, plotted with Google earth 2020.

1.2.6 Ekofisk event, 2001

The purpose of using this training dataset is to address the challenges when processing events in a remote region.

The map below shows epicentre and stations used by Norwegian National Seismic Network (NNSN).







Figure 6: See description in Fig. 5. Image: Landsat / Copernicus, plotted with Google earth 2020.

1.2.7 Taiwan, 2018

The purpose of using this training dataset is to get experience with the automatic phase picking, amplitude and spectral analysis.

Data was kindly provided at the SEISAN workshop in Taiwan in 2018.

The figure below shows locations of events in data set:







Figure 7: Satellite image with epicentres of events in data set. Image: Landsat / Copernicus, plotted with Google earth 2020.

2 SeisAn improvements

In order to better meet the Standard for the Exchange of Earthquake Data (SEED) and International Association of Seismology and Physics of the Earth's Interior (IASPEI) standards and to give credits to data provides a number of improvements have been added to the SeisAn software package. The changes are visible in the parametric files as described below, the current format is described in appendix A of the SeisAn manual. SeisAn will still operate using both the current format and the new format described below. The user selects the format to be applied in the SEISAN.DEF file in the DAT folder.

The following improvements have been implemented to the reporting of phase readings in Nordic format and tested in the SeisAn software package. An example is given in Table 1:

- COM: Channel naming is now three characters (before two), which meets the SEED standards and now include instrument code.
- NT: Network code, the two character network code given by FDSN (see http://www.fdsn.org).
- LO: Location code, the two character location code used when multiple identical sensors are applied at the same station.
- IPHASE:
 - Coda readings now have their own lines marked with 'END' following the IASPEI standard, time marks the time of picking and the values under PAR1 the duration of the signal.
 - Back azimuth reading now have their own lines marked the 'BAZ' or BAZ and the phase associated to is like 'BAZ-PN' for a back azimuth reading on the Pn phase, the values under PAR1 and PAR2 is the angel and velocity of the phase.





- SS.SSS: Timing is now in millisecond, before millisecond was only an option when running SeisAn was operation in high accuracy mode.
- AGA: Three characters are now reserved for reporting agency code, this is needed in regions where multiple agencies are using the same seismic stations.
- OPE: Three characters are reserved for the id of the operator/analyst reading the values, this is needed at agencies where multiple analysis are processing the data.

STAT	COM	NTLO	IPHASE	W HHMM	SS.SSS	PAR1	PAR2	AGA	OPE	AIN	RES	W	DIS	CAZ7	
EGD	SHZ	NS	IP	4 1325	35.950	С		BER	jh 1	20.0-	-1.131	L047	.70	6	
EGD	SHZ	NS	END	1325	35.950	111.0		BER	cj		0.0	47	.70	6	
EGD	SHZ	NS	AMP	1325	35.950	11.1	33.3	DNK	pv			47	.70	6	
EGD	SHZ	NS00	ES	1325	42.030					70.0-	.8901	L047	.70	6	
BER	HHZ	NS00	IP	1325	38.120	С	70.0	DNK	pv	-	.9801	L061	.00	11	
BER	HHZ	NS00	END	1325	38.120	55.0		DNK	cat		4.8	61	.00	11	
BER	HHZ	NS00	ES	1325	45.440			DNK	dog	70.0-	.9901	L061	.00	11	
BER	HHZ	NS00	IAML	A1325	46.710	31.7	0.20				4.4	61	.00	11	
NRA0	SHZ	NO	Pn	A1326	19.090					50.0-	.0501	L036	8.0	72	
NRA0	SHZ	NO	END	1326	19.090	333.0						36	8.0	72	
NRA0	SHZ	NO	BAZ-PN	1326	19.090	256.9	6.9				0.	36	8.0	72	
NRA0	SHZ	NO	Pg	1326	27.940					-	.6401	L036	8.0	72	
NRA0	SHZ	NO	BAZ-PG	1326	27.940	253.0	7.3				-3.	36	8.0	72	
NRA0	SHZ	NO	Lg	1327	10.540					-	.8901	L036	8.0	72	
NRA0	SHZ	NO	BAZ-LG	1327	10.540	266.6	4.1				9.	36	8.0	72	

Table 1: Setup of the new format for parametric phase reading data.

3 Training exercises

In this section the training exercises are presented based on the data given in section 1.2. Each subset of the data can be used independently and in any order the user finds helpful. For some of the data results from other researchers or network operators are listed for comparison.

The data for the training exercises are found for download at http://ftp.geo.uib.no/pub/seismo/SOFTWARE/SEISAN/WORKSHOP/.

The exercises prepared for each subset is described below. Download and unpack the tar ball associated to each subset in an empty folder and conduct the exercises described below.

For users not familiar with the SeisAn software package a tutorial on analysing seismic data is found in Havskov et al. 2014. Further information on analysing seismic data is found in e.g. Havskov and Ottemöller 2010.

3.1 BATESVILLE, 2017

The data for this event is found in the Batesvill-2017 tar file, for which data and metadata was collected at IRIS (IRIS 2020).





The following exercises are conducted to get experience with registration events in a SeisAn database and to determine main source parameters. Below the exercises is listed event information from OhioSeis for comparison:

- Register the waveform file in sfile/database.
 Determine event parameters and compare to the values given below.
- 3. Note the earth model in STATION0.HYP is the SEISAN standard model (for Norway), modify the earth model, relocate the event and compare to the first result.

The following information is from http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/batesville-june-03-2017#topofcontent

Earthquake, Batesville, OH

Noble County, June 03, 2017

Origin Time: 03 June, 2017, 03:08 UTC (11:08pm June 2nd local time)

Location: 39,902 North 81,285 West

Magnitude: 3.7 ML (Preliminary), 3.4 mbLg (USGS)

Depth: 3.3 km

A widely felt earthquake occurred at 11:08 p.m. DST approximately 1 mile south of Batesville, Noble County, Ohio. More than 90 felt reports were submitted to the U.S. Geological Survey's Web site (see link below) ranging from Marietta to Newark Ohio. No damages were reported and would not be expected with an earthquake of this magnitude.

Individuals who felt this event are encouraged to submit a report or email: ohioseis@dnr.state.oh.us. Please include a description of what you felt and your street address in your email message.

To view more information about this event, such as a felt report map, please visit the USGS web page for this event at: https://earthquake.usgs.gov/earthquakes/eventpage/us20009kfw#executive

Additional Figures



Figure 8: Focal mechanism for this earthquake, courtesy of M. Brudzinski, Miami University.







Figure 9: Map of felt-area for this earthquake.

3.2 EASTLAKE, 2019

The data found in the Eastlake-2019 tar file includes 10 events, data was collected at IRIS.

Conduct the following exercises to get experience with registration of events in a SeisAn database and to determine main source parameters. Below the exercises event information from OhioSeis is listed for comparison:

- Register the waveform files in sfiles.
- Fill out the missing values in the table below, for aftershock 2, 7, 8, 9 and 11.

• Note the earth model in STATION0.HYP is the SEISAN standard model (Norway), modify the earth model and relocate.

The information below is from:

http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/lake-erie-near-eastlake-june-10-2019#topofcontent

Earthquake, Eastlake, OH Lake County, June 10, 2019 Origin Time: 10 June, 2019, 14:50:45.5256 UTC (10:50 a.m. local time) Location: 41.6778 North, -81.4365 West Magnitude: 4.2 ML (±0.1), 4.1 mb (USGS) Depth: 2.0 Km (±0.5 Km)

A widely-felt earthquake occurred at 10:50 a.m. EDT approximately 2 miles northwest of Eastlake, Lake County, Ohio. More than 9,000 felt reports were submitted to the U.S. Geological Survey's website (link below) from as far south as Canton to as far north as southern Ontario in Canada. No damages were reported and none would be expected with an earthquake of this magnitude. Individuals who felt this event are encouraged





to submit a report or email:ohioseis@dnr.state.oh.us. Please include a description of what you felt and your street address in your email message.

To view more information about this event scroll down this page or, visit this USGS webpage: https://earthquake.usgs.gov/earthquakes/eventpage/us70003xny/executive.



Figure 10: Seismic intensity distribution map.

Seismic intensity distribution map. This map depicts Modified Mercalli Intensities as reported by those who experienced the earthquake. Color pixels shown on map correlate with the color chart below it, and indicate the amount of ground shaking reported. This earthquake was widely felt.



Figure 11: Focal mechanism for this earthquake, courtesy of Dr. Mike Brudzinski, Miami University, Ohio.





Event Type	Origin Time	Latitude	Longitude	Depth (KM)	Magnitude (ML)
Fore Shock	2019-05-20 21:12:49.63 UTC	41.6844	-81.4553	2	1.9
Main Shock	2019.06.10 14:50:45.5256 UTC	41.6778	-81.4635	2	4.2
Aftershock 1	2019.06.10 14:54:41.10 UTC	41.6930	-81.4470	2	1.8
Aftershock 2	2019.06.10 14:57:35 UTC	-	-	2	1.7
Aftershock 3	2019.06.10 15:04:30 UTC	41.6960	-81.4540	2	1.8
Aftershock 4	2019.06.10 15:14:43 UTC	-	-	2	1.6
Aftershock 5	2019.06.10 15:43:47.0297 UTC	41.6782	81.4288	2	1.8
Aftershock 6	2019.06.10 15:47:42.30 UTC	41.7000	-81.4520	2	1.9
Aftershock 7	2019.06.10 16:22:13 UTC	-	-	2	1.3
Aftershock 8	2019.06.10 17:56:07 UTC	-	-	-	-
Aftershock 9	2019.06.10 19:39:16 UTC	-	-	-	-
Aftershock 10	USGS-2019-06-15 20:06:42 (UTC)	41.7056	-81.5339	5	1.9
Aftershock 11	USGS-2019-06-17 02:28:56 (UTC)	-	-	-	1.5

Table 2: Location and description table for the pre-shock, main-shock and aftershock sequence of earthquakes.





	Closest	to event
		02220
	and the second sec	02/200
	Commences	02222
		-
HEA H C		02223
		07223
87 10		000000
		- - -
		077225
		07000
		-
		0.225
		000000
	Farthest r	rom event

Figure 12: Seismograms of the main shock.

Waveforms from the M4.2 earthquake mainshock showing arrivals at seismic stations across Ohio. These waveforms recorded on the vertical component seismometer only.

To view more information about this event, such as a felt report map, please visit this USGS webpage: https://earthquake.usgs.gov/earthquakes/eventpage/us70003xny/executive.

3.3 YOUNGSTOWN, 2011 AND 2012

The data found in the Youngstown-2011 tar file includes 21 events, data and table below was kindly provided by Won-Young Kim, Lamont-Doherty Cooperative Seismographic Network, Columbia University, New York, U.S.A.

The data is also analysed by Kim (2013).

Conduct the following exercises to get experience with effects of using different earth models:

- Register the waveform files in sfiles
- Analyze and compare to table below





• Analyze effects of different earth models found in Kim 2013.

	Date	Time	Latitude	Longitude	Depth	Mag	${\tt Mag^c}$	Erh Erz
Id	(year-mo-dy)	(hh:mm:sec)	(°N)	(°W)	(km) (M_W)	$(M_{\rm L})$	(km)	(km)
	1	2 regional events	located by re	egional seismo	ographic net	work		
1	2011-03-17	10:42:20.49	41.12008	80.68321	3.76 1.78		2.02	4.10
2	2011-03-17 ^b	10:53:09.69	41.11983	80.68148	3.84 2.28	2.1	1.61	-
3	2011-08-22	08:00:31.55	41.11846	80.68999	3.75 2.00	1.9	1.30	2.35
4	2011-08-25	19:44:21.36	41.11937	80.68675	3.86 2.15		2.06	3.46
5	2011-09-02 ^b	21:03:26.06	41.11960	80.68639	3.98 2.16		2.86	6.79
6	2011-09-26 ^b	01:06:09.83	41.11847	80.69048	3.77 2.33	2.1	1.22	2.57
7	2011-09-30 ^b	00:52:37.57	41.11945	80.68675	3.89 2.77	2.4	1.10	2.28
8	2011-10-20	22:41:09.96	41.11821	80.69044	3.82 2.18	2.0	1.51	-
9	2011-11-25	06:47:27.03	41.11885	80.69138	3.67 2.02	1.8	1.44	3.07
10	2011-12-24 ^b	06:24:57.98	41.11850	80.69235	3.56 2.66	2.4	0.38	0.84
11	2011-12-31 ^b	20:05:00.04	41.11855	80.69215	3.67 3.88	4.0	0.41	0.86
12	2012-01-13	22:29:34.00	41.11828	80.69484	3.65 2.09	1.7	0.34	0.82
	S	Small events locate	d by local p	ortable seismo	ographic net	work		
13	2012-01-11	21:29:28.06	41.12294	80.67929	3.50	0.39	0.41	1.08
14	2012-01-12	03:01:45.43	41.12304	80.68028	3.57	0.07	0.41	1.10
15	2012-01-13	01:47:29.55	41.12252	80.68132	3.47	0.05	0.43	1.34
16	2012-01-14	12:53:36.94	41.1203	80.6837	3.90	0.09	0.46	0.84
17	2012-01-17	02:25:59.60	41.11901	80.69127	3.91	0.34	0.43	1.01
18	2012-01-17	07:09:08.73	41.12413	80.67020	3.61	0.06	0.46	1.37
19	2012-01-18	12:12:01.21	41.11866	80.69570	3.59	0.41	0.41	0.86
20	2012-01-22	12:06:20.37	41.12316	80.67916	3.53	0.11	0.41	1.10
21	2012-02-11 06	:47:19.09 41.12459	80.67278	3.66 0.40	0.53 1.49			

Table 3. Results of Kim (2013); list of 12 regional and 9 local events relocated by using double-difference method^a. Where: a) Event #16 was not relocated by double-difference method; Events 10, 11 & 12 are also relocated by using local seismographic network data; Mag= moment magnitude; Erh = horizontal location error; Erz= vertical location error; Location errors are from single event locations and correspond to 95% confidence error ellipse. b) Felt earthquakes. c) Local magnitude from LCSN in ComCAT < https://earthquake.usgs.gov/earthquakes/search>.

3.4 THE NEDERLANDS, 2019

The purpose of using these data is to get experience with a very large number of seismic stations.

Three events are included in the Netherlands-2019 folder.

- Process event
- Examine depth with rmsdep
- Estimate Mw with spectral
- Compare to KNMI solution





Data are extracted from https://www.knmi.nl/nederland-nu/seismologie/aardbevingen

Using the http://rdsa.knmi.nl/dataportal/ to collect both data and metadata. We selected 1 min before hypotime and 2 min after.

Event 1 and event 3 include an sfile that links to the waveform data. For event 2 you need to cut the waveform file into smaller files and registrate them in sfiles.

To split a large miniseed file with block size 512 into smaller files with unix command, e.g.:: /usr/bin/split –b 100000b ORG.FILE 2019-10-28-1737-33M.DATA_ Use DIRF and AUTOREG to generate one sfile with links to all the waveform files.

Metadata was generated from dataless SEED files using: rdseed –Rf seed-file.dataless to get response files in RESP format and rdseed –Sf seed-file.dataless to get rdseed.stations file, use rdseed2seisan to convert rdseed.stations to STATION0.HYP format

3.5 CENTRAL NORTH SEA, 2019

The purpose of using this training dataset is to address the challenges when processing events in a remote region.

The data found in the NorthSea-2019, data and sfile is kindly provided by NNSN.

- 1. Duplicate event
- 2. Analyze and compare
- 3. Analyze depth using RMSDEP

The map below show epicentre and stations used by NNSN.

2019 924 1338 14.	LQ 57.066 1.7	78 3.0F BER 69 0.9	3.4LBER 4.2WBER 4.2LBGS1
GAP= 64 1.	3.7	5.4 0.0 -0.1261E+02	2 0.0000E+00 0.0000E+00E
ARC _GRA	2019 924 1337	44 300	6
SPEC DOMBHH Z MO	4.9 ST300.2 OM	2.2 f0 10.0 R0.2294	AL 0.00 WI 42.3 MW 3.9 3
SPEC DOMBHH Z T13	942 K 0.000 GD	694 VP 6.20 DE 3.00	Q0440.0 QA 0.70 Q1 1.00 3
ARC _DK	2019 924 1330	00 1200	6
ARC _BGS	2019 924 1330	00 1200	6
ARC _SN	2019 924 1330	00 1200	6





```
No data is transferred from Grane due to seismic exploration in the area.
                                                                              3
fixed at 3 km due to strong surface waves, possible this was induced event lot3
                    2019 924 1337 45
                                        900
ARC NNSN
                                                                              6
2019-09-24-1336-54S.N SEA 105
                                                                              З
OLDACT:REE 19-09-24 16:35 OP:bms STATUS:
                                                       ID:20190924133654 L
                                                                              3
Calculated depth is uncertain, set to 10km
                                                                             B3
2019 924 1338 14.8 L 57.034 1.935 10.0F BGS 42 0.7 4.2LBGS
                                                                              1
XNEAR 400.0 XFAR 600.0 SDEP 15.0
                                                                              З
CENTRAL NORTH SEA
                         3
                                                                             23
FELT ELGIN-FRANKLIN
                                                                              3
We have received a report from the Elgin-Franklin Offshore Field that this
                                                                              3
event was felt, by several people, on the PUQ offshore oil platform.
                                                                              3
The reports describes "a moderate shaking feeling".
                                                                              3
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W DIS CAZ7
```

Table 4: Part of sfil from http://ftp.geo.uib.no/pub/seismo/DATA/PARAMETRIC/2019/09/24-1338-14L.S201909. The table is in Nordic format (see appendix A in Ottemöller et al. 2020).

3.6 **EKOFISK EVENT, 2001**

The purpose of using this training dataset is to address the challenged when processing events in a remote region.

The data found in the Ekofisk-2001, data and sfile is kindly provided by NNSN.

- Duplicate event
 Analyze and compare
- 3. Analyze depth using RMSDEP

```
2001 5 7 0943 33.8gL* 56.564
                               3.177 6.0F*BER 36 1.0 4.6SBER 4.9WBER 4.0LBER1
SPEC AVERAGE MO 16.5 ST0.311 OM 76.3 f0 0.16 R7.9344 AL 2.65 WI130.8 MW 4.9 3
                                 7.1 0.0 -0.8329E+01 -0.3975E+05 0.1066E+05E
GAP= 67
               3.27
                          4.5
thsi event i svery specil since induced and very slow, so magnitudes are
                                                                              3
not representartive of the tru size of the event
                                                                              3
The file is locked not to be relocated. This event is especially stydied and 3
the solution given here should not be changed without good reasons.
                                                                              3
MW computed based on the spectral analysis is 4.9, whereas our conclusion for 3
the MW is 5.0 which is the average value obtained based on the above and the 3
moment tensor inversion results done separately (see Special Report)
                                                                              3
however, other calcualtion indica mw 4.5 (ottemoller et el, 2005)
                                                                              3
ml gives very low value (3.0) due to low frequency nature of event, in order
                                                                              3
assign a reprensative magnitude, ml = 4 is used
                                                                              3
    356.0
               85.0
                       -95.0
                                  0
                                                                     FOCMEC C F
2001 5 7 0943 33.5 L 56.551 3.187 15.0FFBER 51 1.0 5.0SBER 5.0BBER 4.9WBER3
2001 5 7 0943 34.0 L 56.526 3.193 12.0F BER 25 1.3 4.7SBER 5.0WBER
                                                                              3
```





First location determined on 7 May, 2001	3
2001 5 7 0943 35.5 L 56.601 3.513 0.0 BER 9 1.6 4.4SBER 5.0WBER	3
previous locations	3
info in Ottemoller, et al, jgr 110, 2005	3
4.9 0.8 0.6 -1.0	5
534 NORTH SEA	3
6 MM BER	2
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W DIS	CAZ7

Table 5: Part of sfil from <u>ftp://ftp.geo.uib.no/pub/seismo/DATA/PARAMETRIC/2001/05/07-0943-33L.S200105</u>. The table is in Nordic format (see appendix A in Ottemöller et al. 2020).

3.7 TAIWAN, 2018

The data found in the Taiwan-2018 tar file includes 20 events, data was kindly provided at the SEISAN workshop in Taiwan in 2018, at the Department of Earth Sciences, National Central University, Taoyuan. The table below list the main parameters for the 20 events.

Conduct the following exercises to experiment with automatic phase and amplitude picking and spectral analyses:

- 1. Register the waveform files in sfiles
- 2. Use the EEV program and AP and AM commands to perform automatic phase and amplitude picking.
- 3. Examine the data for outliers, quality of phase picks and compare output with manual spectral analysis.
- 4. Repeat the analysis for all events and observe if events that fail the automatic picking have significant features.

2018	210	356	20.3	L	23.860	121.557	15.0	TES	66	2.8	1.1CTES		1	
2018	210	737	49.4	L	23.957	121.578	9.00	TES	68	.20	3.5LTES	1.5CTES	3.5WTES1	
2018	210	842	57.2	L	23.971	121.585	9.30	TES	68	.20	3.7LTES	1.1CTES	3.4WTES1	
2018	210	1015	52.7	L	24.076	120.843	12.2	TES	44	2.8	3.9WTES		1	
2018	210	1432	22.0	L	23.985	121.547	13.3	TES	64	.20	2.2LTES	1.0CTES	2.5WTES1	
2018	210	1625	40.9	L	23.944	121.568	8.60	TES	67	.20	1.1CTES	3.0WTES	1	
2018	210	2227	24.5	L	23.908	121.536	9.20	TES	64	.20	1.2CTES	3.4WTES	1	
2018	210	2336	37.1	L	23.318	124.173	0.0	TES	54	3.0			1	
2018	211	739	6.8	L	23.907	121.541	9.10	TES	67	.20	4.1LTES	1.4CTES	4.0WTES1	
2018	211	820	7.5	L	23.945	121.557	8.40	TES	65	.10	1.3CTES	3.7WTES	1	
2018	211	934	57.3	L	23.943	121.562	8.10	TES	61	.20	3.2LTES	1.0CTES	3.1WTES1	
2018	211	1038	21.8	L	23.958	121.556	10.3	TES	67	.20	3.4LTES	1.1CTES	3.3WTES1	
2018	212	1243	39.9	L	23.982	121.586	9.20	TES	61	.20	0.7CTES	2.6WTES	1	
2018	212	1559	38.0	L	27.523	120.741	15.0	TES	64	.30	1.5CTES	5.2WTES	1	
2018	212	2057	23.1	L	23.960	121.595	9.40	TES	68	.20	2.3LTES	0.8CTES	2.5WTES1	
2018	214	015	59.8	L	22.099	119.114	10.1	TES	57	.30	1.5CTES	5.3WTES	1	
2018	214	017	18.9	L	23.899	121.545	7.60	TES	67	.20	3.3WTES		1	
2018	214	021	46.0	L	23.899	121.548	10.4	TES	66	.20	4.0LTES	1.3CTES	4.0WTES1	
2018	214	554	27.9	L	23.916	121.581	6.70	TES	64	.20	1.1CTES	3.5WTES	1	
2018	214	1732	4.0	L	23.978	121.594	9.70	TES	62	.20	1.0CTES	3.0WTES	1	





Table 6: Event times and preliminary parameters. The table is in Nordic format, line type 1 (see appendix A in Ottemöller et al. 2020).



Figure 13: See description in Fig. 5. Yellow line is 25 km long. Image TerraMetric, plotted with Google earth 2020.

4 Analysing examples

In the following two subsections examples are given on how to analyse some of the data given above. The examples are given on a computer with Linux CentOS version 7.7 using the command line tools. Users that wish to use the GUI should refer to the SeisanExplorer in the SeisAn manual.

4.1 THE NETHERLANDS, 2019

Unpack the Netherlands-2019.tar file in the work folder, enter the Netherlands-2019/event1 folder.

In the event1 folder data is prepared for the event KMNI have marked induced located near Loppersum, NE of Groningen, Netherlands on 6 SEP 2019 at 01:33:26Z, at a depth of 3 km with a magnitude of 1.0.

The folder contains one database file (sfile) and four waveform files all from the above event. The purpose of having four waveform files is to easily analyse data from a large number of seismic stations as deployed in the Norther Netherlands. Copy the STATION0.HYP file, with location parameters of the seismic stations, form the Netherlands-2019 folder to the Netherlands-2019/event1 folder.

Open the database file with the eev program and give your operator id and the t command:

\$ eev

Local directory Give operator code, max 3 characters





pv		
Reading events from base ,, 1		
# 1 6 Oct 2019 1:32 25 L	? t	
File name: 06-0132-25L.S201910		
2019 10 6 132 25.0 L		1
ACTION:ARG 19-11-21 09:00 OP:pv	STATUS: ID:20191006013225	I
2019-10-06-0132-25M.DATA_aa		6
2019-10-06-0132-25M.DATA_ab		6
2019-10-06-0132-25M.DATA_ac		6
2019-10-06-0132-25M.DATA_ad		6
STAT SP IPHASW D HRMM SECON CODA A	MPLIT PERI AZIMU VELO AIN AR TRES W DIS CA	.z7

The t command will show the content of the database file, where the 2019-10-06-01* lines are pointer to the waveform files.

Plot the waveform data with the p command:

# 1 6 Oct 2019 1:32 25	5 L			?p
	*****			· []
SELECT FILENAMES, FILLED OUT BOXES INDICATE SELECTION				
2019-10-06-0132-25M.DATA an 1	2019-10-06-0132-25M.DATA_ab	2	2019-10-06-0132-25M.DATA_ac	3
2019-10-06-0132-25M.DATA_ad 4	ALL	a	ок —	o
NONE n				
1				
Figure 14: Waveform file selection	n window.			
Click on the file ending with _aa and	on ok			
# 1 6 Oct 2019 1:32 25	5 L			? p
				-
Plot options: Interactive	e picking	Return		
Multi trace	e plot on screen,	def (0)		
Multi trace	e plot on screen	(1)		

Multi trace plot on screen+laser(2) Multi trace plot on laser (3) Continuoues on screen (4) Continuoues on screen + laser (5) Continuoues on laser (6) Stop (q)





				***	**			k	
FILLED OUT BOXES IND	ICATE SELECTION. A * 1	INDICATES & PHASE REAL	MORE CHANS:	NK OR f. all chans in	all vindovs: F				
CHAL HE 2 1	CHA1 HH 1 2	CHA1 HH 2 3	GHA3 HH 2 4	СНАЗНИ 1 5	CHA3 HH 2 6	CHA4 HH Z 7	CHA4 HH 1 8	CHA4 HH 2 9	RHAS HE 2
CHA5 HH 1	CHA5 HH 2	DBN_HH_Z	DBN HH N	DBN HH E	DROITHH Z	DR011HH 1	DR011HH 2	DB012HH_Z	DR012HH 1
DR012HH 2	DB013HH Z	DR013HH 1	DR013HH 2	DBÚ14HH Z	DR014HH 1	DR014HH 2	DRO21HH 2	DR021HH 1	DR021HH 2
DR022HH Z	DR022HH 1	DR022HH 2	DR023HH Z	DR023HH 1	DR023HH 2	пв024нн г	DR024HH 1	DR024HH 2	ENVI HH Z
ENV1 HH N	ENV1 HH E	ENV2 HH Z	ENV2 HH N	ENV2 HH E	ENV3 HH Z	ENV3 HH N	ENV3 HH E	ENV4 HH Z	ENV4 HH N
ENV4 HH E	FDG1_HH_Z	FDG1 HH N	FDG1 HH E	FDG2 HH Z	FDG2 HH N	FDG2 HH E	FURS HH Z	FDG3 HH N	FDG3 HH E
FDG4 HH Z	FDG4 HH N	FDG4 HH E	FROLLING 2	FR011HH 1	FR011HH 2	FR012hH Z	FR012HH 1	FR012HH 2	FROISHH Z
FR013HH 1	FR013HH 2	FR014HH Z	FR014HH 1	FR014HH 2	FR021HH Z	FR021HH 1	FR021HH 2	FRO22HH Z	FR022HH 1
FR022HH 2	FR023HH Z	FR023HH 1	FR023HH 2	FR024HH Z	FR024HH 1	FR024HH 2	FRO31HH 2	FR031HH 1	FR031HH 2
FR032HH Z	FR032HH 1	FR032HH 2	FR033HH Z	FR033HH 1	FR033HH 2	FR034HH Z	FR034HH 1	FR034HH 2	FSWI HH Z
FSW1 HH N	FSV1 HH E	FSW2 HH Z	FSW2 HH N	FSW2 HH E	FSW3 HH Z	FSW3 HH N	FSW3 HH E	FSW5 HH 2	FSW5 HH N
FSW5 HH E	G011 HH Z	G011 HH 1	G011 HH 2	G012 HH Z	G012 HH 1	G012 HH 2	G013 HH Z	G013 HH 1	G013 HH 2
G014 HH Z	6014 HH 1	6014 HH 2	G021 HH Z	6021 HH 1	6021 HH 2	G022 HH Z	G022 HH 1	6022 HH 2	G023 HH Z
G023 HH 1	6023 HH 2	G024 HH Z	G024 HH 1	6024 HH 2	G031 HH Z	6031 HH 1	G031 HH 2	6032 HH Z	G032 HH 1
G032 HH 2	6033 HH Z	6033 HH 1	G033 HH 2	6034 HH Z	6034 HH 1	6034 HH 2	G041 HH Z	6041 HH 1	G041 HH 2
G042 HH Z	6042 HH 1	G042 HH 2	G043 HH Z	G043 HH 1	6043 HH 2	G044 HH Z	G044 HH 1	6044 HH 2	G051 HH Z
G051 HH 1	6051 HH 2	G052 HH 2	G052 HH 1	G052 HH 2	6053 HH Z	6053 HH 1	G053 HH 2	G054 HH Z	G054 HH 1
G054 HH 2	G061 HH Z	G061 HH 1	G061 HH 2	G062 HH Z	G062 HH 1	6062 HH 2	G063 HH Z	6063 HH 1	G063 HH 2
G064 HH Z	6064 HH 1	6064 HH 2	G071 HH 2	G071 HH 1	6071 HH 2	G072 HH Z	G072 HH 1	G072 HH 2	G073 HH Z
6073 HH 1	6073 HH 2	G074 HH 2	G074 HH 1	G074 HH 2	G081 HH Z	6081 HH 1	G081 HH 2	6082 HH Z	G082 HH 1
G082 HH 2	6083 HH Z	G083 HH 1	G083 HH 2	G084 HH Z	6084 HH 1	G084 HH 2	G091 HH 2	6091 HH 1	G091 HH 2
6092 HH Z	6092 HH 1	6092 HH 2	G093 HH Z	6093 HH 1	6093 HH 2	6094 HH Z	6094 HH 1	6094 HH 2	G101 HH Z
G101 HH 1	6101 HH 2	G102 HH 2	G102 HH 1	6102 HH 2	G103 HH Z	6103 HH 1	G103 HH 2	G104 HH Z	G104 HH 1
6104 HH 2	6111 HH 2	6111 HH 1	G111 HH 2	G112 HH Z	6112 HH 1	6112 HH 2	6113 HH Z	6113 HH 1	6113 HH 2
G114 HH Z	6114 нн 1	G114 HH 2	G121 HH Z	6121 HH 1	6121 HH 2	G122 HH Z	G122 HH 1	6122 HH 2	G123 HH Z
All Z Z	Picked p	AUL a	ОК О	NONE n					

Figure 15: Channel selection window.

Click "All z" to view only vertical channels and click OK, repeat in next window.

The time series from the first station in the waveform file is now plotted and it is quit noisy, probably from nearby machinery, see figure below.







Figure 16: Data from vertical sensor.

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In the MENU select Toggl, all the vertical channels from all the seismic stations are now plotted:

### Figure 17: Unfiltered vertical data.

The data are unfiltered but a signal of a possible event is visible on the stations in the middle. Press the '5-10' box and the 'Plot' box to apply a 5 to 10 Hz bandpass filter:





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Figure 18: Filtered data, filter parameters are given in red.

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Figure 19: Selection of time series.

Press the 'plot' box to plot the selected time series.





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Figure 20: Zoom on selected time series.

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6141 HH	z	NL		-4	varevarda 	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	nn hann	an war o to	nganalah) Lina dal	MANNAN AND A	k na k	unnerwyddiau a a	NAMANA Ar a a t	mars-Aflan an an t-t-t	envire 	angananaan waxaa dhara	ever Wile	A MARKA A AT	nyenyet Karan	a a at the second	way	ware and	1499960-4 1 - 11 - 1	programphologicals a a di di di di di	594	WINNY WY	4.11
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6142 HH	2	NL.		-15	~~~~~	unununununununun unununun ununun	erenter Augusta	en Alle Aut Aust	www.	son the town	www.	HALLAND AND AND A PARTICULAR OF	And Ander		ray be Lava d	en en el alta ta	nte Alexan	a akan kan da k	vripe Ause	annon variante	w///	www.www.ww	میں ایک میں سید ایک می	r san ta	656	hand have	nn ad
6123 HH	6	NI.		-43	(~~~~) (Q	An other and a definition		e a Nue destroyada	v V. v.	n. with all	τ. Λ.	معان والمرابقيا ادعاق منه	. A a Maradan	- W. w.	11° - 11		(Twi who	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	, Ala,	A 49 M. Ost OA401A		- N:	AAAAAA	A which we have	^v 200° V	WORLN ****	- 4 .
Event #	1							1h33							3	14							35				

Figure 21: Phase picking.





After picking a number of phases, press the I key to do a preliminary location of the event. You should now see an output similar to:

date	hrmn	sec		lat	long	depth	no m	rms	damp er	ln erlt	: erdp	p
1910 6	133	22.17	53 5.	.50N 6	31.1E	15.0	52	0.44 0	0.000 58	.2 58.0	0.0	0
stn	dist	azm	ain	w phas	cald	cphs hrm	n tsec	t-obs	t-cal	res	wt	di
G182	30	27.01	10.8	0 P	PG	13	3 27.1	4.89	5.32	-0.43	1.00	7
G184	30	27.01	10.8	0 P	PG	13	3 27.1	4.89	5.32	-0.43	1.00	7
G183	30	27.01	10.8	0 P	PG	13	3 27.3	5.11	5.32	-0.21	1.00	7
G134	30	19.31	10.4	0 P	PG	13	3 28.1	5.96	5.39	0.58	1.00	40
G194	34	36.01	.07.3	0 P	PG	13	3 28.6	6.39	5.90	0.49	1.00	40
2019 1	LO 6 (0133 22	2.2 L	53.092	6.51	18 15.0	tes 5	0.4				
OLD: 1	LO 6	132 25	5.0 L									
Retur	n to	contin	nue									

U to update

If the rms (here 0.44) and the travel time residuals are acceptable (values under res) add the location given in the second line to the database file by the u key to update.

Back in the plot window select the 'Oth w' to select other time series of travel time picking of both P and S phases. Note that key 1 and 2 is for the P phase, impulsive or emergent, respectively. Key 7 and 8 is for S phase. Here both the vertical and the two horizontal data channels of the picked stations are plotted:





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Filt	. 011	z .1-1 x 1-	5 v 5-10	ь 10-15	n	15-25 n	2-4	; WA	v	mb	j	mB	J	Ms	k	MS	к	100800	
Regis	p Locat	1 Dist _ Scal	e * FixF	, Rotat	U	Grown g	Back	B Oth	C 0	Help	?	Quit	q	Toggl	t	Next	f	Plot	r
Del W	d Del S	D Merge M Out	0 Iasp	I FK	F	NextW	Oth W	w <w< th=""><th>> z</th><th></th><th>х</th><th>PartM</th><th>р</th><th>AllC</th><th>Y</th><th>Out¥</th><th>т</th><th>Print</th><th>></th></w<>	> z		х	PartM	р	AllC	Y	Out¥	т	Print	>
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6183 HHZ	NL	-80 29.8	~~~~		~~ IP ~	Willowwww.		~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	~~~~~~		~~~	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		~~~	~~~~~	~~~~	6040	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	~~~
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6183 HH1	NL			~~~~~		****	****		*~~~~~	~~~~	~~~		~~~~	~~~~~			3302.~		~~~
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G184 HHZ	NL	70			~~ <u>1</u> P~	mp 1/1/10/1000000	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	~	~~~~~								5564		~~
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6134 HHL	NL	-128	*****		~~~~	~\$AMAMAN	*****	~~~~		~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	****		~~~~				.700		
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Event #	1		1h33					34							3!	i			



Zoom by mouse click left and right of the signal.

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Figure 23: Zoom on picked stations.





Some of the phase readings are clearly off by some fractions of a second. Repick these by putting the curser to the phase and press 1 key. S waves can also be picked here>

Filt		. 011	z.	1-1	×	1-5	v	5-10	ь	10-15	n	15-25 m	2-4	;	WA	v	mb	j	mB	J	Ns	k	MS	к	MENU	
Regis	ı	Locat	1	Dist	_	Scale	*	FixF		Rotat	U	Grown g	Back	в	Oth C	0	Help	?	Quit	q	Toggl	t	Next	f	Plot	r
Del W		1 Del S	DM	ferge	м	Out	0	Iasp	I	FK	F	NextW	Oth ¥	W	<w></w>	z	>W<	x	PartM	Р	AllC	Y	Out¥	т	Print	>
			2019 10 Dist. at	06133	3 22.2	L 53.092	6.5	518 15.0	TES 5	.44			3		in milti	back	with r			0P:p	w Last	ACTION	:UP by:	pv		
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6194	HHZ	NL	6	51	33	.8						IPIP/	hp-hours of his	槲柳树	philippen front which the	haven	MMM m	m	~~~~~	~~~~	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	······				
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Event	* 1			33n20		22		24		26		28		30	3	2		34		36		38		40		42

Figure 24: Picking S-phases and repicking P-phases.

date	hrmn	sec		lat	long	depth	no m	rms	damp er	ln erlt	c erdp	<u>C</u>
1910 6	133	25.86	5313.	98N 6	41.6E	0.1	83	0.15 0	0.000 10	.4 25.1	L999.9	9
stn	dist	azm	ain t	w phas	calc	phs hrm	n tsec	t-obs	t-cal	res	wt	di
G182	11	9.7	90.5	9 P	PG	13	3 27.5	1.67	1.78	-0.11	1.00	3
G184	11	9.7	90.5) S	SG	13	3 28.8	2.98	3.10	-0.11	1.00	10
G183	11	9.7	90.5	9 P	PG	13	3 27.5	1.64	1.78	-0.14	1.00	3
G183	11	9.7	90.5) S	SG	13	3 28.9	3.06	3.10	-0.03	1.00	10
G184	11	9.7	90.5	9 P	PG	13	3 27.5	1.61	1.78	-0.16	1.00	3
G182	11	9.7	90.5) S	SG	13	3 29.1	3.27	3.10	0.18	1.00	10
G134	13	352.6	90.5	9 P	PG	13	3 28.2	2.33	2.10	0.23	1.00	24
G194	14	35.1	90.4 (9 P	PG	13	3 28.3	2.46	2.30	0.15	1.00	35
2019 1	10 6 (0133 25	5.9 L	53.233	6.69	4 0.1	TES 5	0.1				
OLD: 1	10 6	133 22	2.2 L	53.092	6.51	8 15.0	TES 5	.44				

Return to continue U to update





The improvement is seen on the rms now at 0.15. Note that depth changed from 15 km to 0.1 km, given in the parameter lines at the end.

To estimate the magnitude of the event on the Richter scale, we select the HHZ channel of the G194 station and apply the WA filter to read the amplitude of the signal in nanometers. But as seen below for the time serie we get "No response info of G194 HHZ", so we need to add instrument response information to SeisAn:



Figure 25: Data when instrument response is missing.

The instrument response information is found in the Netherlands-2019/CAL folder. Copy the RESP* file to your working folder of to the CAL folder under the SeisAn installation.

When the data plotted with the WA filter one will now see the data in the same way Charles Richter would:



Figure 26: Data converted to displacement.

Pick the largest amplitude (peak to peak) in the S wave part:







Figure 27: Picking of amplitude.

Relocate the event to inspect the magnitude:

date	hrmn	sec		lat		long	depth	no r	n	rms	damp er	ln erlt	c erdp	<u>C</u>
1910 6	133	25.85	5313	.96N	6	41.7E	0.0	8 3	3	0.15 0	.000 10	.3 25.0)999.9	9
stn	dist	azm	ain	w p	has	calc	phs hr	nn tse	ec	t-obs	t-cal	res	wt	di
G182	11	9.3	90.0	0 P		PG	13	3 27	.5	1.67	1.78	-0.11	1.00	3
G182	11	9.3	90.0	0 S		SG	13	3 2 9	.1	3.28	3.10	0.18	1.00	10
G184	11	9.3	90.0	0 P		PG	13	3 27	.5	1.62	1.78	-0.16	1.00	3
G183	11	9.3	90.0	0 P		PG	13	3 27	.5	1.65	1.78	-0.14	1.00	3
G183	11	9.3	90.0	0 S		SG	13	3 28	.9	3.07	3.10	-0.03	1.00	10
G184	11	9.3	90.0	0 S		SG	13	3 28	. 8	2.99	3.10	-0.11	1.00	10
G134	13	352.3	90.0	0 P		PG	13	3 28	.2	2.33	2.10	0.23	1.00	24
G194	14	34.8	90.0	0 P		PG	13	33 28	.3	2.45	2.30	0.15	1.00	35
G194	14	34.8		0 I	AML		13	3 30	.2	4.4				
G194 H	HZ ł	ndist:		14.	2 8	amp:		31.0	т:	0.1	ml =	0.9		
2019 1	10 6 (0133 25	5.9 L	53	.233	6.69	95 0.0	TES	5	0.1 0.	9LTES			
OLD: 1	10 6	133 25	5.9 L	53	.233	6.69	94 0.10	TES	5	.15				

Return to continue

U to update

The magnitude is at the G194 station estimated to 0.9. Update to add the value to the database file.

To estimate the magnitude from the spectra, select the time serie to inspect and press the 'Toggl' box. Here zoom by clicking left mouse key left of the signal and above the blue line right of the signal:







Figure 28: Zooming in single trace.

Press the 'Spec' box and elect a window around the S phase, next select 'Autofit spectrum':



Figure 29: Select window for spectrum.

The amplitude spectral parameters are now computed automatic:







Figure 30: Estimate amplitude spectral parameters.

One can pick the amplitude spectral parameters manualy using displacement and the A key. When acceptable values have been derived the moment magnitude is added to the database file by relocating the event. Here the moment magnitude is 1.7:

date	hrmn	sec		lat		long	depth	r	no m		rms	damp e	rln erlt	: erdp	<u>2</u>
1910 6	133	25.94	5314	.16N	6	41.9E	0.0		73	C	.12 0	.000	9.0 21.9	9999.9	9
stn	dist	azm	ain	w pl	nas	cald	cphs h	rmn	tsec	c t	-obs	t-cal	res	wt	di
G184	11	8.6	90.0	0 S		SG		133	28.9	9	2.95	2.99	-0.04	1.00	18
G184	11	8.6	90.0	0 P		PG		133	27.5	5	1.57	1.72	-0.14	1.00	2
G183	11	8.6	90.0	0 S		SG		133	29.0	C	3.06	2.99	0.07	1.00	18
G183	11	8.6	90.0	0 P		PG		133	27.5	5	1.60	1.72	-0.12	1.00	2
G182	11	8.6	90.0	0 P		PG		133	27.6	6	1.63	1.72	-0.09	1.00	2
G134	13	351.3	90.0	0 P		PG		133	28.2	2	2.24	2.05	0.19	1.00	23
G194	14	35.0	90.0	0 P		PG		133	28.3	3	2.36	2.23	0.13	1.00	34
G194	14	35.0		0 I2	AML			133	30.2	2	4.3				
G194 H	HZ ł	ndist:		13.8	3 a	amp:		31	.0 1	Г:	0.1	ml =	0.9		
G194 H	HZ q	gdist:		13.8	3 n	nom:		11	.6	<mark>mv</mark>	7 =	1.7			
Number	rofs	spectra	a ava:	ilabi	le ar	nd numk	ber us	ed i	.n av	vera	ıge	1	1		
2019 1	10 6 (0133 25	5.9 L	53	.236	6.69	98 0.	г 0	ES	5 (0.1 0.	9LTES	1.7WTES		
OLD: 1	10 6	133 25	5.9 L	53	.233	6.69	95 0.0	г 0	ES	5.	15 0.	9LTES			





Note that parameters, like Q, for estimating moment magnitude should be adjusted to the region. Here we used the default values in SeisAn that are designed to Norway.

4.2 TAIWAN, 2018

Unpack the Taiwan-2018.tar file in the work folder, enter the Taiwan-2018 folder. Register the waveform files in a local SeisAn database using the commands:

```
$ dirf 2018-*
$ autoreg
Event type for all events: Local: L (default)
Regional: R
Distant: D
L
Move (m) or copy (c) waveform files to WAV (enter=n) ?
1-5 letter base name, return for standard base, ,, for local base
''
Operator, max 3 chars
pv
```

This will create a number of database files (in SeisAn known as sfiles) each with a pointer to the respective waveform file in the current folder, respectively.

If you wish to use the new parametric format described above add the NEW_NORDIC_FORMAT to the SEISAN.DEF file, like:

1.0

KEYWORD.....Par 1....Par 2

NEW NORDIC FORMAT

Correct the agency code in the last line of the STATION0.HYP file.

Open the database using the command

```
$ eev
```

Local directory Give operator code, max 3 characters pv Reading events from base ,, 20 # 1 10 Feb 2018 3:56 15 L

?

After typing your operator id the first event is ready to be processed, jump to the next event using the return key and to go back use the b key. Help of given using the ? key.

Inspect the content of the database for the first event using the t key:

1 10 Feb 2018 3:56 15 L ?t





File	e name	e: 10	-0356-	-15L.S	520180)2										
2018	210	356	15.0	L												1
2018-	-02-10	-035	6-15s	.NSN	068											6
ACTIC	ON:ARG	; 20 -	04-27	14:05	5 OP:p	v	STAT	US:			ID	:2018	02100)35	615	I
STAT	COM N	ITLO	IPHASE	E W	HHMM	SS.	.SSS	PAR1	PAR2	AGA	OPE	AIN	RES	W	DIS	CAZ7

After the file name, the content is given as a header line, a pointer to the waveform line, a status line and a line that separates the header from phase readings.

To plot the waveform use the p or po command, e.g.:

1 10 Feb 2018 3:56 15 L

? po

This will open the MULPLT program showing the waveform data:

		2018-02-10-0356-15s.nsn_	_068			MENU
	2018 210 356 1	15.0 L			0P: pv Last ACTIO	i: ARG by: pv
	Plot start time:	2018 2 10 3:56 15.991			Filt: 4.500 9.600	41
165 EPZ HL 169 EPZ HL		Western Alexandric and a second second				966644
54 EPZ HL	ŏ	And Applyments				365549
37 EPZ HL	N	apite in the flor of a state of the second s				1566485
33 EPZ HL 54 FPZ HL	<u> </u>	April 10 Marshall and 10 Marsh				749929
56 RZ H	Ŭ					1161660
52 EPZ HL	0	al appropriate a second second				436566 640527
38 EPZ HL 47 EPZ HL		www				1273509
48 EPZ HL 24 EPZ HI	Ŭ					738051
12 EPZ HL	Ŭ,	999Ab+				1381919
30 EPZ HL 58 EPZ HL	Ň Ť	Well with an a start start start				1089342
07 EPZ HL 53 FPZ HL	ů –	and a second				942774
55 EPZ HL	Ů					2022113
46 EPZ HL			·			942234
63 EPZ HL 67 FPZ HI	Ŭ					598636
i ez H	Ŭ	Approximent of the second s		· · · · ·		1237065
02 EPZ HL						416350
23 EPZ HL NA FPZ HL	Ū.					630215
08 EPZ HL	Ŭ					695447
		and the second				263069
59 EPZ HL 39 EPZ HL	Ŭ					523883
35 EPZ HL	<u> </u>	and the second sec				1184513
56 EPZ HL	Ŭ	store (Herriter and				690917
31 EPZ HL 13 EPZ HL		and the second s				2677757
44 EPZ HL 17 FP2 HI	Ŭ					544011
Số EPZ HL	Ŭ	and the second sec				887720
43 EPZ HL		Win with the second		· · ·		472029
05 EPZ HL 25 EPZ HL	Ŭ		~%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			322875
03 EPZ HL	<u> </u>	and the second	······			953700
69 EZ H	U	Wirming and the second se				397283
UG EPZ HL 14 EPZ HL	Ŭ	and the second s				287700
27 EPZ HL	Ů	and the second	· · · · · · · · · · · · · · · · · · ·			1187523
36 EPŽ HL	0	with which the second second	~~~			602479
40 EPZ HL 18 EPZ HL	0	and when a property of the second sec	V-M-WA			838097
28 EPZ HL 20 EPZ H	ğ	and the second	A			991061
19 EPž HL	8	the day is a second	******			407701
15 EPZ HL	Ŭ					361117 3316272
10 EPZ HL 51 EPZ HL	- Ŭ					340454
ži epž ni	8	and a state of the second	A/			393620
68 EPZ HL	<u> </u>	and a second sec				193142 209457
60 EPZ HL 16 FPZ HI	Ŭ 🕂	the second s				5/4983 SEC
	0					332755
ent # 1	56w20	30	40	50	57×00	10

Figure 31: Plotting the waveform file with MULPLT.

One can now pick the travel time of the observed phases, amplitudes, code, etc. Or quit using the q key and apply the automatic processing tool using the ap keys:

1 10 Feb 2018 3:56 15 L

The Process will add new information to the database file, these are seen using the t key:

? t # 1 10 Feb 2018 3:56 15 L File name: 10-0356-15L.S201802 2018 210 356 15.0 L 1 ACTION:ARG 20-04-27 14:23 OP:pv STATUS: ID:20180210035615 Т 2018-02-10-0356-15S.NSN 068 6 STAT COM NTLO IPHASE W HHMM SS.SSS PAR1 PAR2 AGA OPE AIN RES W DIS CAZ7 T001 EPZ HL IP A 356 25.531 С DNK pv A 356 57.531 32.0 TOO1 EPZ HL END DNK pv

? ap





Т002	ΕPΖ	\mathtt{HL}	IP	Α	356	25.158	С	DNK	рv
T002	ΕPΖ	HL	END	Α	356	63.158	38.0	DNK	рv
T003	ΕPΖ	HL	IP	Α	356	25.421		DNK	рv
T003	ΕPΖ	HL	END	Α	356	66.421	41.0	DNK	рv
Т004	ΕPΖ	HL	IP	А	356	24.246		DNK	pv
T005	ΕPΖ	HL	IP	Α	356	25.197		DNK	рv
T005	ΕPΖ	HL	END	Α	356	63.197	38.0	DNK	рv
T006	ΕPΖ	HL	IP	Α	356	25.331	D	DNK	рv
T007	ΕPΖ	HL	IP	Α	356	24.627		DNK	рv
T007	ΕPΖ	HL	END	Α	356	68.627	44.0	DNK	рv
T008	ΕPΖ	HL	IP	Α	356	24.850		DNK	рv
T008	ΕPΖ	HL	END	Α	356	64.850	40.0	DNK	рv
т009	ΕPΖ	HL	IP	А	356	25.021		DNK	pv
T010	ΕPΖ	HL	IP	Α	356	25.350		DNK	рv
Ret	curn	to	continue,	q t	to re	eturn to	EEV		

To see the automatic picks on the waveforms type po:



Figure 32: Plotting the automatic phase reading with waveforms.

T068 3 292.7171.1 0 P A PG

On can either use the location tool in MULPLT by typing I or quit to EEV and also type I

```
# 1 10 Feb 2018 3:56 15 L ? 1
10-0356-15L.S201802

date hrmn sec lat long depth no m rms damp erln erlt erdp
18 210 356 19.12 2348.74N 121 36.5E 20.6 86 3 2.77 0.000 25.7 16.2 25.7
stn dist azm ain w phas calcphs hrmn tsec t-obs t-cal res wt di
```

356 23.7 4.54 3.90 0.64 1.00 7





T060	I	5 343.9164.6	0 P	AD PG	356 23.3	4.17	3.98	0.20 1.00	5
T067		7 289.9156.9	0 P	A PG	356 23.7	4.56	4.14	0.42 1.00	2
T063	8	8 305.9155.6	0 P	A PG	356 23.5	4.35	4.16	0.19 1.00	1
T063	8	8 305.9155.6	3 S	3A SG	356 25.6	6.45	7.24	-0.79 0.25	2
т059	(9 322.2153.6	0 P	A PG	356 23.2	4.12	4.19	-0.07 1.00	1
T070	(9 259.7153.6	0 P	AD PG	356 24.3	5.20	4.21	1.00 1.00	4
T003	20	6 2.1118.8	3 S	3A SG	356 28.7	9.55 1	L0.66	-1.11 0.25	1
T001	28	8 359.0116.4	0 P	AC PG	356 25.5	6.41	6.40	0.02 1.00	2
T001	ΕZ	hdist:	34.8	coda:	32.0		mc =	0.9	
т002	ΕZ	hdist:	32.7	coda:	38.0		mc =	1.1	
T003	ΕZ	hdist:	33.3	coda:	41.0		mc =	1.2	
т005	ΕZ	hdist:	32.2	coda:	38.0		mc =	1.1	
T007	ΕZ	hdist:	30.4	coda:	44.0		mc =	1.3	
T008	ΕZ	hdist:	30.7	coda:	40.0		mc =	1.2	
T066	ΕZ	hdist:	22.9	coda:	37.0		mc =	1.1	
T067	ΕZ	hdist:	21.9	coda:	32.0		mc =	0.9	
T069	ΕZ	hdist:	24.2	coda:	47.0		mc =	1.4	
T070	ΕZ	hdist:	22.3	coda:	55.0		mc =	1.5	
2018	210	0356 19.1 L	23.81	2 121.608 2	20.6 DNK 66 2	2.8 1.10	CDNK		
OLD:	210	356 15.0 L							

The event is now located, the output given is first a line of the main parameters, event time, latitude, longitude, depth, etc. but one should look for the rms, here 2.77. The rms is the root means square of the difference between the observed and the computed travel times. To improve the rms one should look for stations with highest res (difference between observed and computed travel time) and remove or weight down these.

After the travel time residuals follow lines with magnitude estimations, here for the coda magnitude based on the END readings. The last two lines outline the main location parameters and the same for an eventual previous location. The values are stored in the database file using the u key.

To map the location of the event on can either use the build in tool map (but coast lines files are required, see SeisAn manual) or by opening the KML file gmap.cur.kml in the current folder using Google Earth or similar.

5 Remarks

The described software and dataset was presented at the workshop on advanced signal processing at the Ohio Seismic Network (OhioSeis), Ohio Department of Natural Resources, Ohio, U.S.A. in November 2019, participants at the workshop are appreciated for their feedback. Lars Ottemoller, University of Bergen and Daniel Blake, Ohioseis are acknowledged for contributing in the organization and co-chairing the workshop.





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SEISAN Workshops (http://seisan.info/).

IRIS (https://www.iris.edu/hq/).

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