Project acronym and title:

SECURe – Subsurface Evaluation of Carbon capture and storage and Unconventional risks

TRAINING SOFTWARE AND DATASET

Authors and affiliation:
Peter H. Voss, GEUS

Øster Voldgade 10, Copenhagen 1350, Denmark

Email of lead author:
pv@geus.dk

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Disclaimer

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CO	*Confidential, only for members of the consortium (incl. the Commission Services)*
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Approved (EB member)		
Approved (Coordinator)		

Author(s)

Name	Organisation	E-mail
Peter H. Voss	GEUS	pv@geus.dk

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 CO_2 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 CO_2 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 [http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/batesville-june-03-2017#topofcontent)](http://geosurvey.ohiodnr.gov/quakes-2010-to-present-pgs/batesville-june-03-2017#topofcontent)

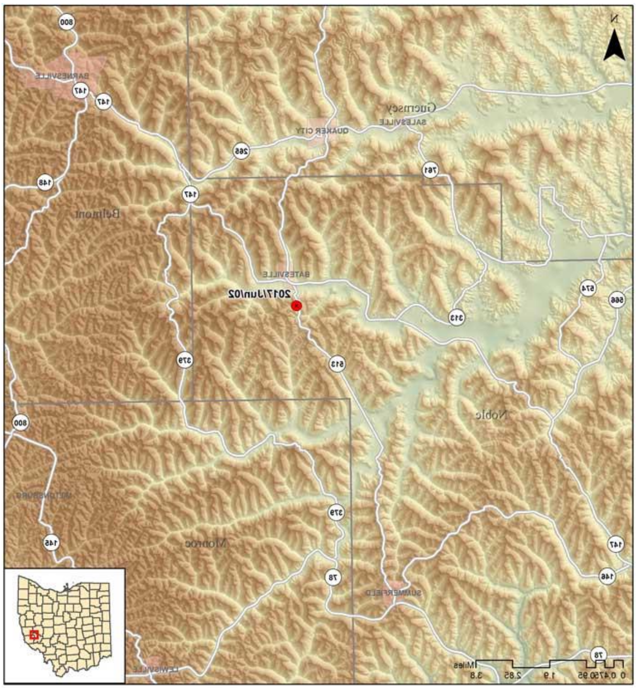


Figure 1: The map of the epicentre of the Batesville event.

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).

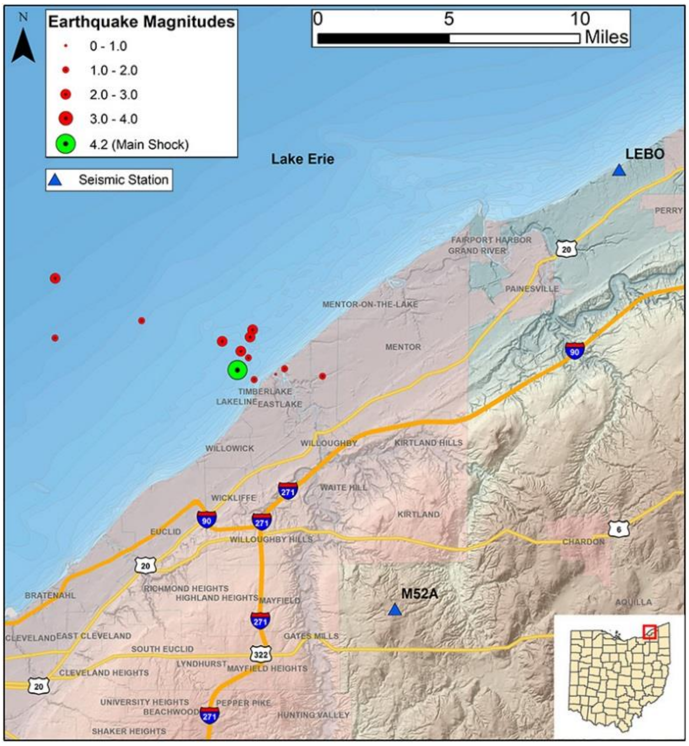


Figure 2: Map showing the epicentre of the 10 Eastlake events.

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.

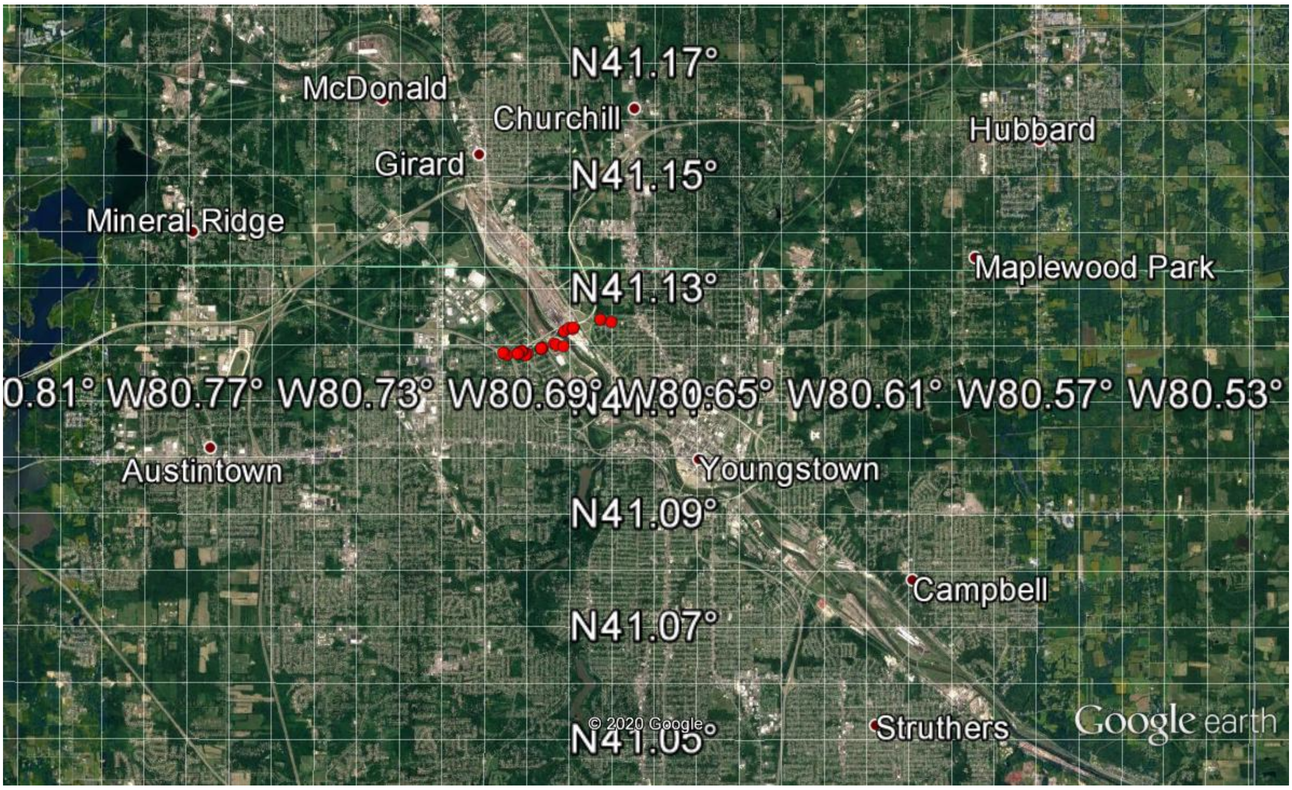
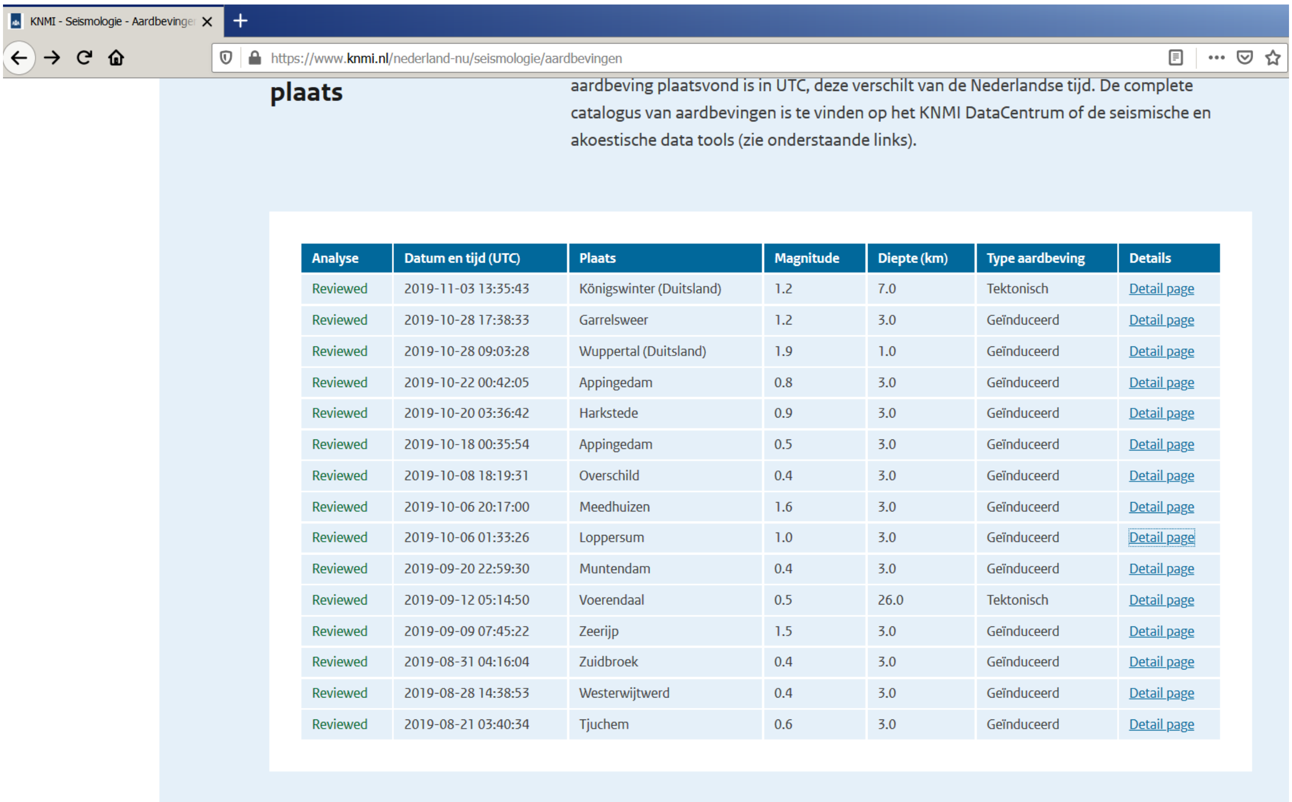


Figure 3: Satellite image with locations seismic events at Youngstown, mapped with Google earth 2020.

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:](https://www.knmi.nl/nederland-nu/seismologie/aardbevingen)



plaats

aardbeving plaatsvond is in UTC, deze verschilt van de Nederlandse tijd. De complete catalogus van aardbevingen is te vinden op het KNMI DataCentrum of de seismische en akoestische data tools (zie onderstaande links).

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.

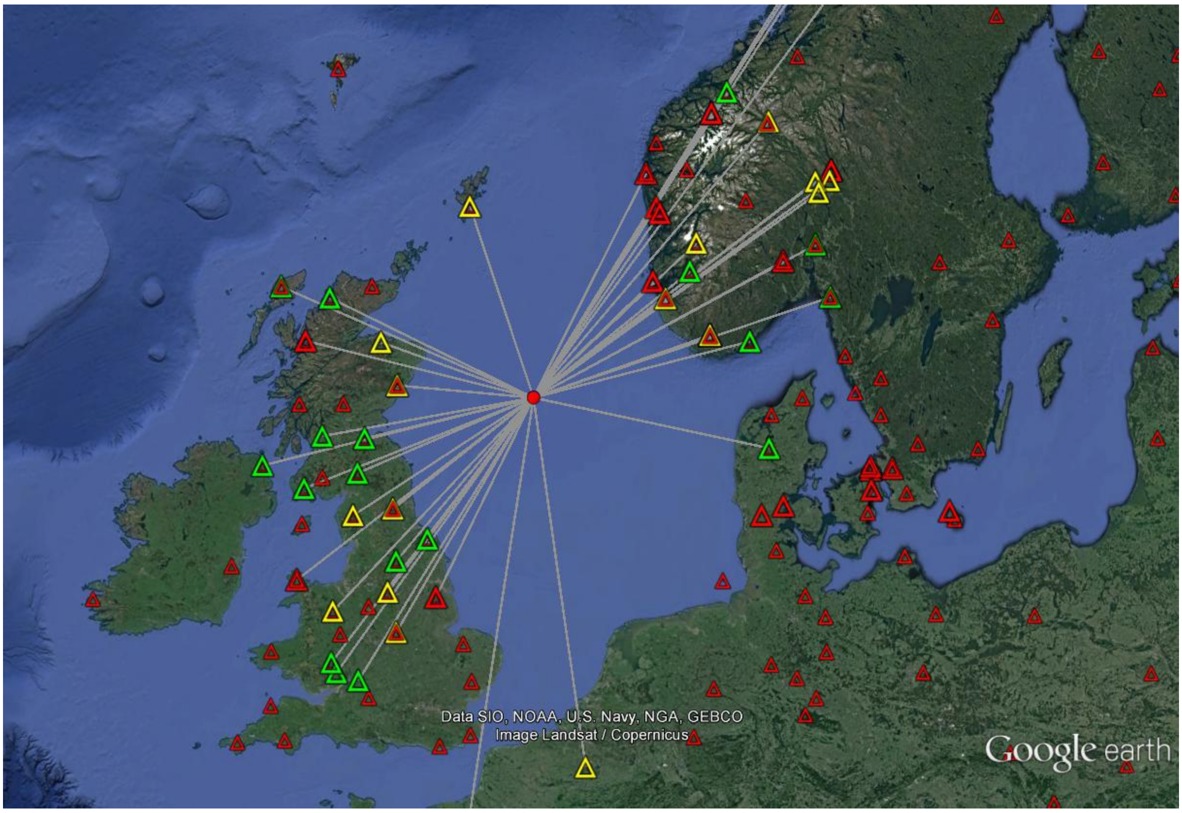


Figure 5: Satellite image with epicentre of event and location of seismic stations. Gray lines show raypath to stations used for location, colour of stations show relative traveltime residuals from good to bad, being green, yellow or red, respectively. Image: Landsat / Copernicus, plotted with Google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

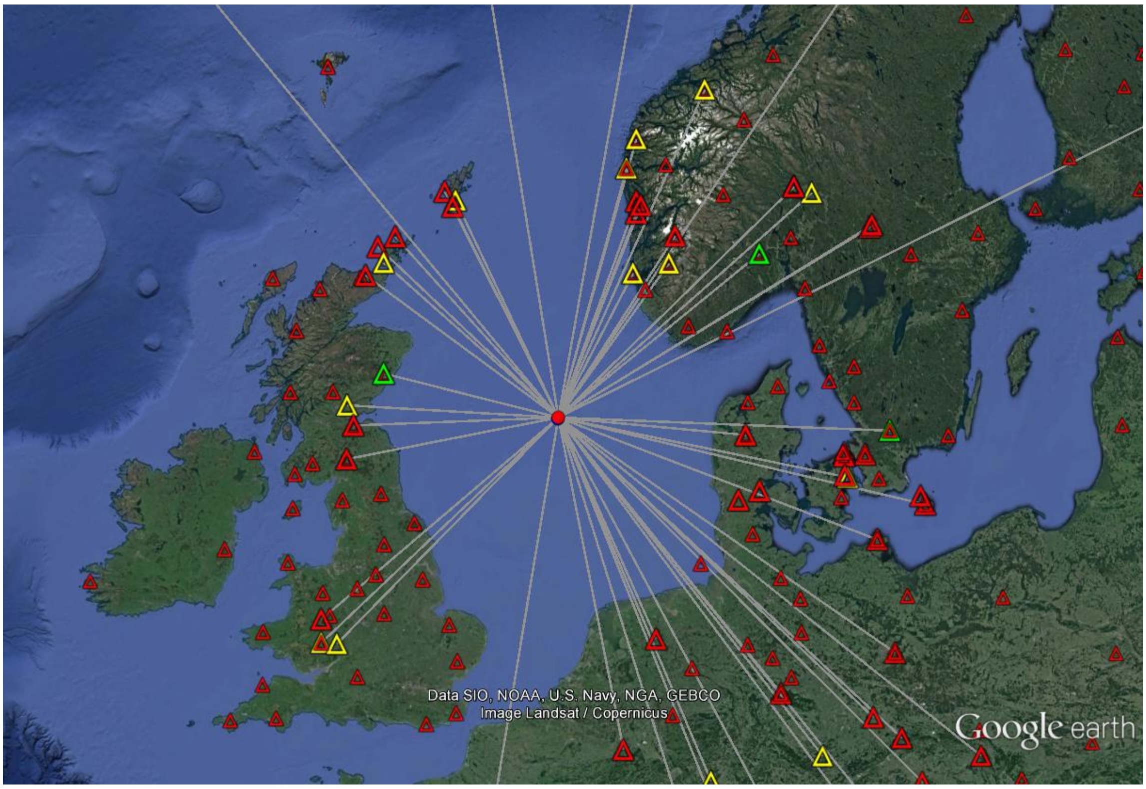


Figure 6: See description in Fig. 5. Image: Landsat / Copernicus, plotted with Google earth 2020.

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:

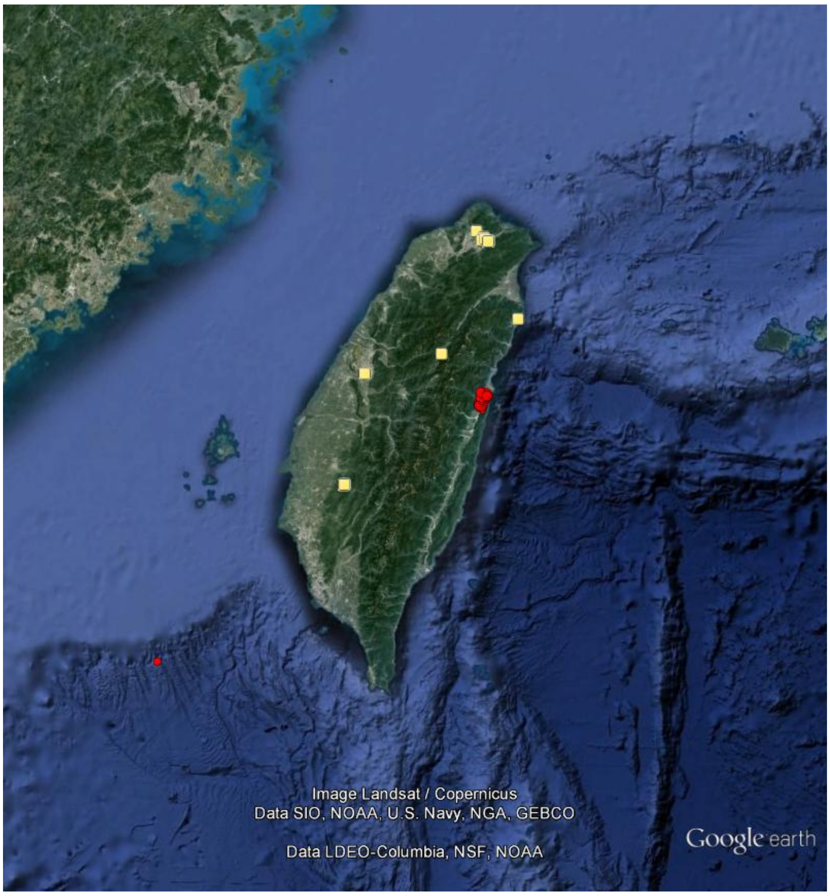


Figure 7: Satellite image with epicentres of events in data set. Image: Landsat / Copernicus, plotted with Google earth 2020.

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      C       BER jh 120.0-1.131047.70   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-.8901047.70   6

BER  HHZ NS00 IP         1325 38.120      C  70.0 DNK pv      -.9801061.00  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-.9901061.00  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-.05010368.0  72

NRA0 SHZ NO    END       1326 19.090  333.0                            368.0  72

NRA0 SHZ NO    BAZ-PN    1326 19.090  256.9   6.9                 0.   368.0  72

NRA0 SHZ NO    Pg        1326 27.940                          -.64010368.0  72

NRA0 SHZ NO    BAZ-PG    1326 27.940  253.0   7.3                -3.   368.0  72

NRA0 SHZ NO    Lg        1327 10.540                          -.89010368.0  72

NRA0 SHZ NO    BAZ-LG    1327 10.540  266.6   4.1                 9.   368.0  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 ftp://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:

1. Register the waveform file in sfile/database.
2. 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

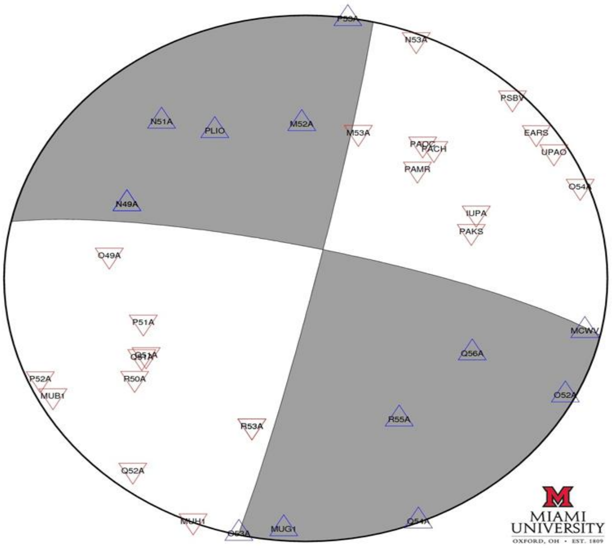


Figure 8: Focal mechanism for this earthquake, courtesy of M. Brudzinski, Miami University.

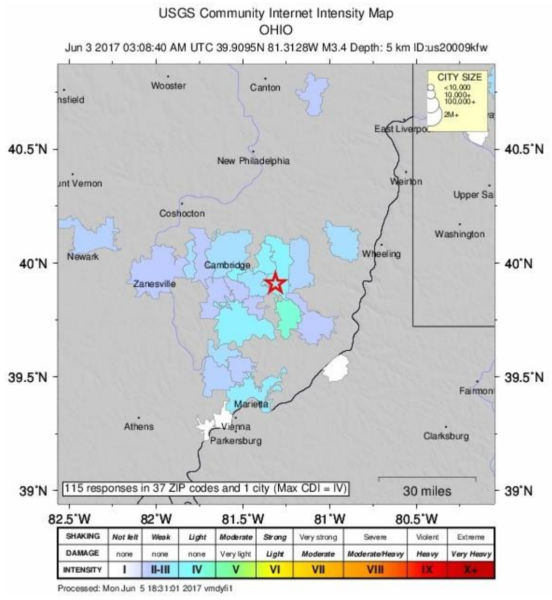


Figure 9: Map of felt-area for this earthquake.

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.

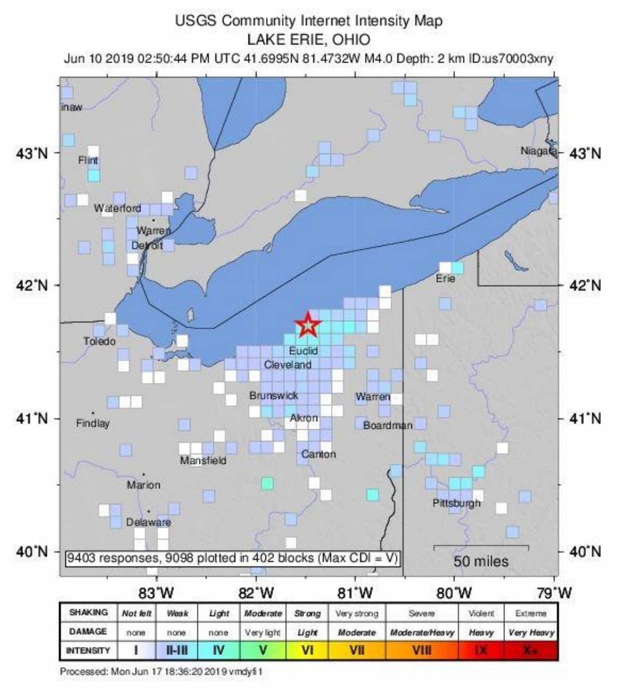


Figure 10: Seismic intensity distribution map.

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.

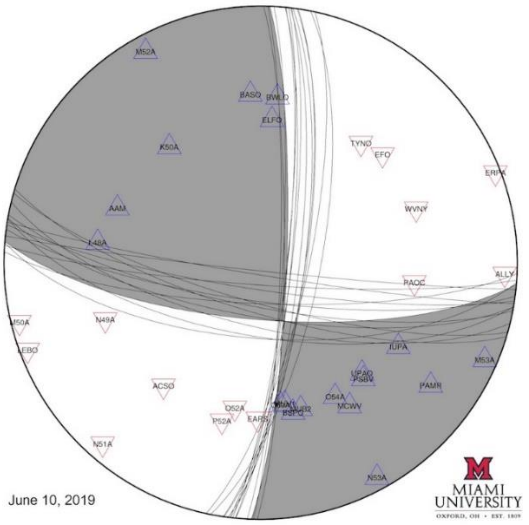
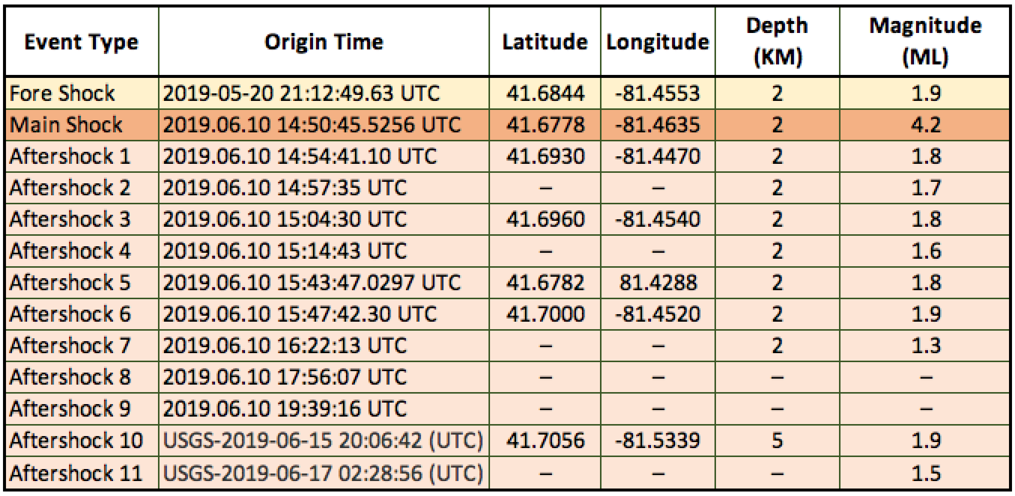


Figure 11: Focal mechanism for this earthquake, courtesy of Dr. Mike Brudzinski, Miami University, Ohio.



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.

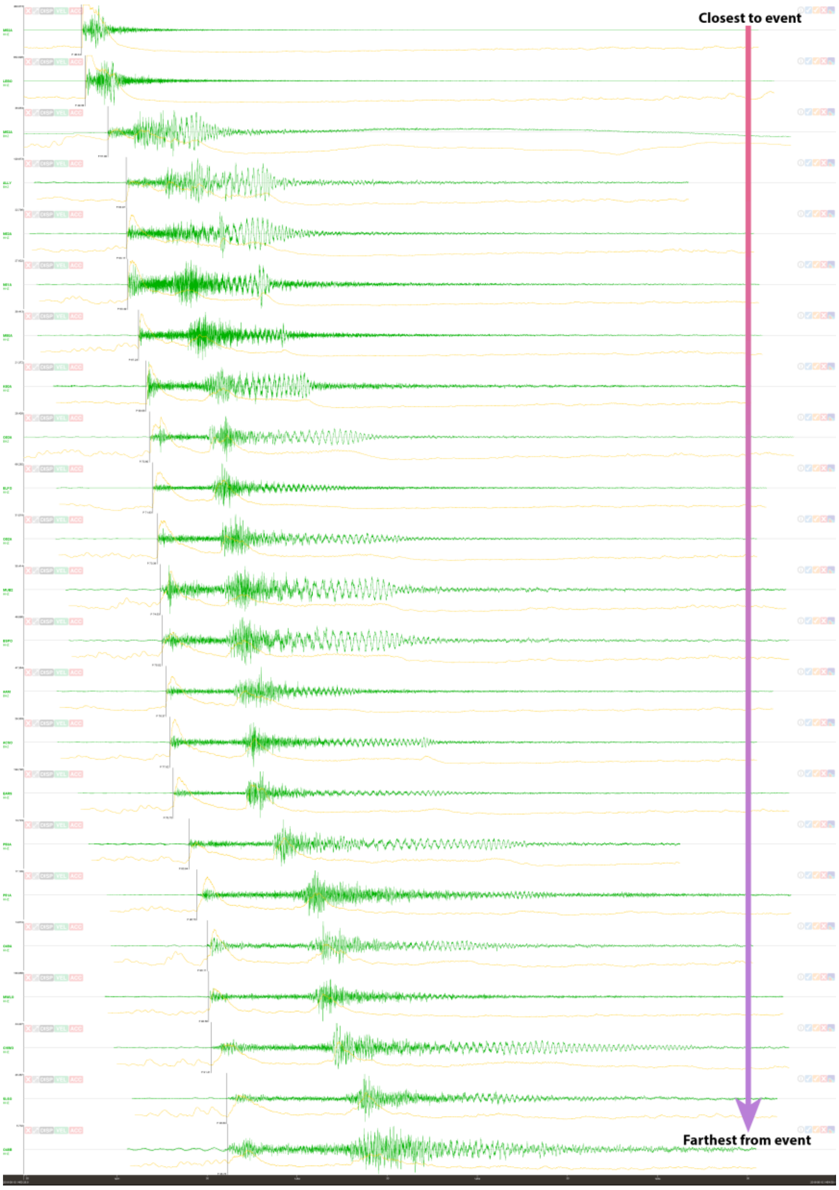


Figure 12: Seismograms of the main shock.

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.

Id	Date (year-mo-dy)	Time (hh:mm:sec)	Latitude (°N)	Longitude (°W)	Depth (km)	Mag (M_W)	Mag[c] (M_L)	Erh (km)	Erz (km)
12 regional events located by regional seismographic network									
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
Small events located by local portable seismographic network									
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 14.9 LQ 57.066   1.778  3.0F BER 69 0.9 3.4LBER 4.2WBER 4.2LBGS1
 GAP= 64        1.68       3.7     5.4  0.0 -0.1261E+02  0.0000E+00  0.0000E+00E
 ARC _GRA             2019  924 1337 44   300                                   6
 SPEC DOMBHH Z MO 14.9 ST300.2 OM  2.2 f0 10.0 R0.2294 AL 0.00 WI 42.3 MW  3.9 3
 SPEC DOMBHH Z T133942 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
 ARC _NNSN           2019  924 1337 45   900                                   6
 2019-09-24-1336-54S.N_SEA_105                                                 3
 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                                           3
 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 ftp://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.

1. Duplicate event
2. 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
 GAP= 67        3.27       4.5     7.1  0.0 -0.8329E+01 -0.3975E+05  0.1066E+05E
 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 ftp://ftp.geo.uib.no/pub/seismo/DATA/PARAMETRIC/2001/05/07-0943-33L.S200105. 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).

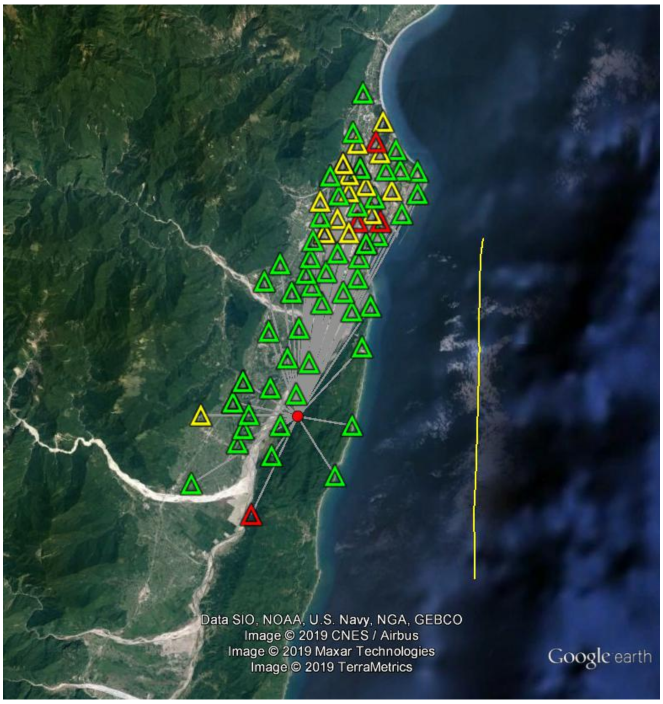


Figure 13: See description in Fig. 5. Yellow line is 25 km long. Image TerraMetric, plotted with Google earth 2020.

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
```

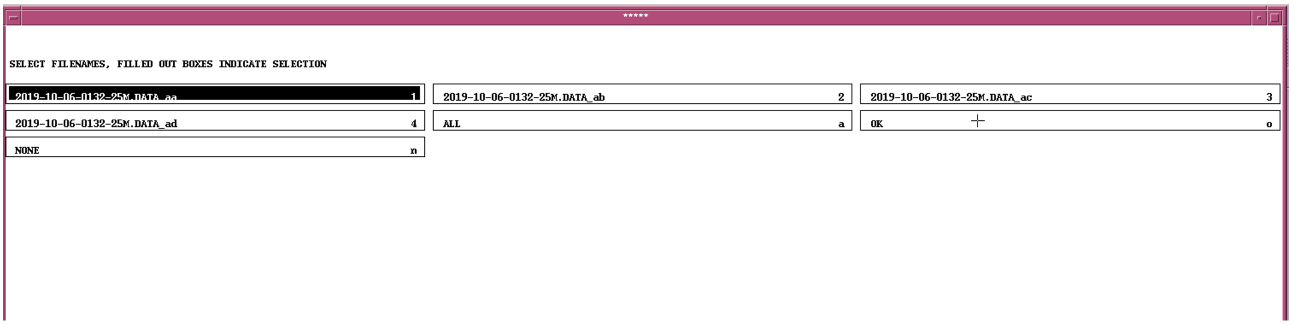
```
pv
 Reading events from base ,,     1
#    1  6 Oct 2019  1:32 25  L                                     ? t


 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 AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
```

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  L                                     ? p
```



SELECT FILENAMES, FILLED OUT BOXES INDICATE SELECTION

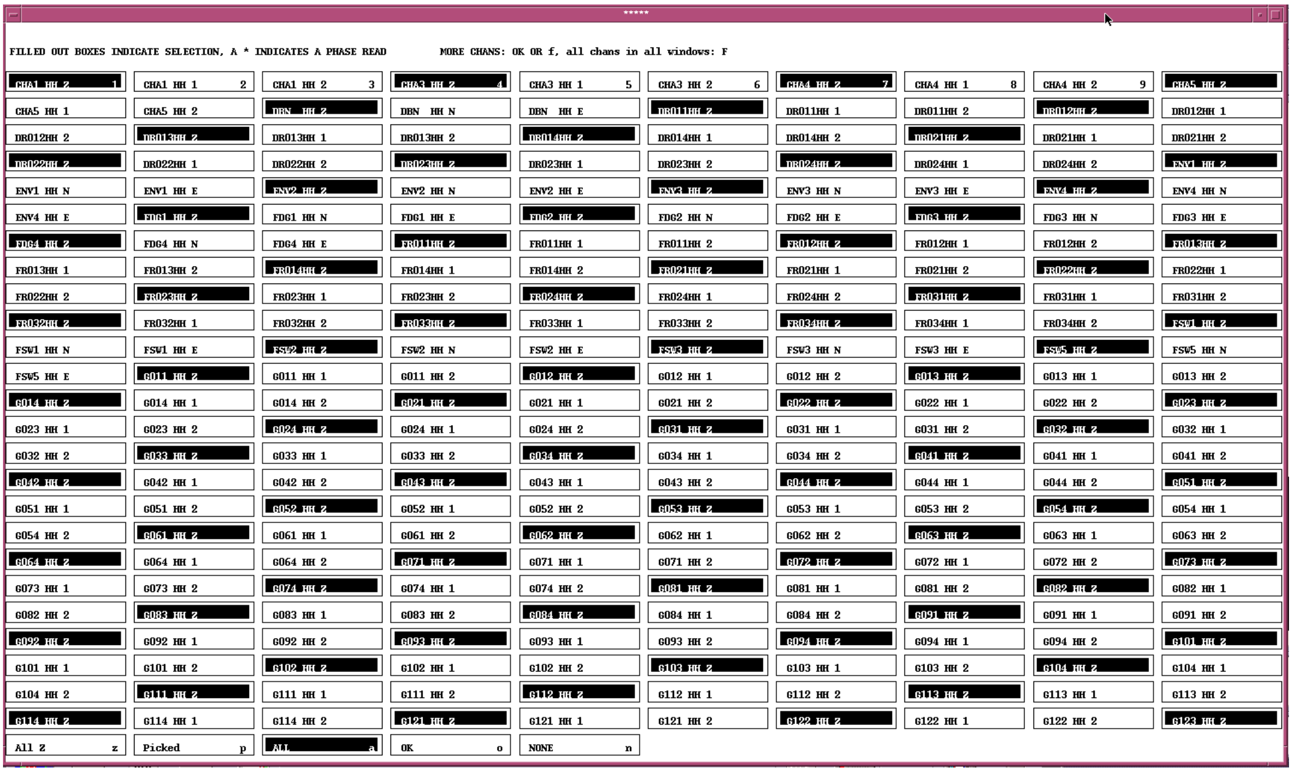
Figure 14: Waveform file selection window.

Click on the file ending with _aa and on ok

```
#    1  6 Oct 2019  1:32 25  L                                     ? p


  Plot options: Interactive picking          Return
                Multi trace plot on screen, def (0)
                Multi trace 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)
```

Select Return key



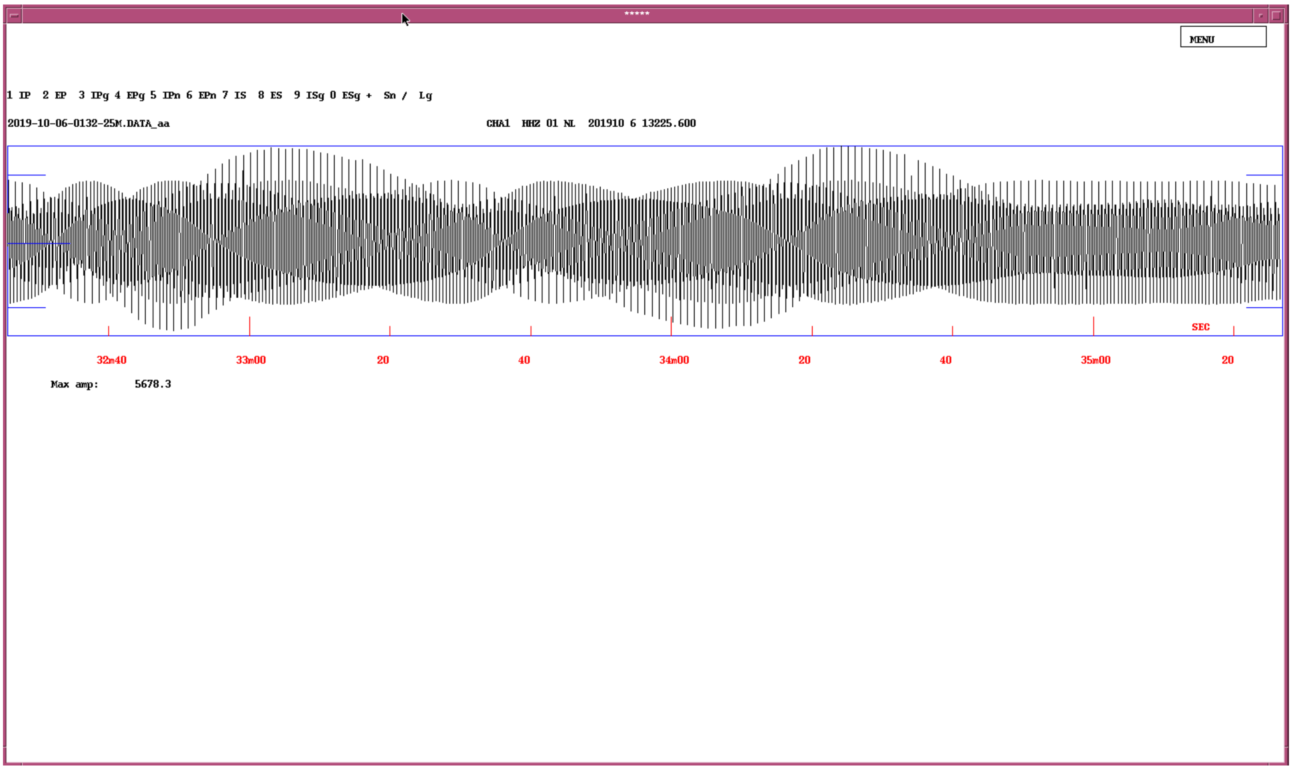
FILLED OUT BOXES INDICATE SELECTION, A * INDICATES A PHASE READ   MORE CHANS: OK OR f, all chans in all windows: F

CHA1 HH Z 1	CHA1 HH 1 2	CHA1 HH 2 3	CHA3 HH Z 4	CHA3 HH 1 5	CHA3 HH 2 6	CHA4 HH Z 7	CHA4 HH 1 8	CHA4 HH 2 9	CHA5 HH Z
CHA5 HH 1	CHA5 HH 2	DBN HH Z	DBN HH N	DBN HH E	DR011HH Z	DR011HH 1	DR011HH 2	DR012HH Z	DR012HH 1
DR012HH 2	DR013HH Z	DR013HH 1	DR013HH 2	DR014HH Z	DR014HH 1	DR014HH 2	DR021HH Z	DR021HH 1	DR021HH 2
DR022HH Z	DR022HH 1	DR022HH 2	DR023HH Z	DR023HH 1	DR023HH 2	DR024HH Z	DR024HH 1	DR024HH 2	ENV1 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	FDG3 HH Z	FDG3 HH N	FDG3 HH E
FDG4 HH Z	FDG4 HH N	FDG4 HH E	FR011HH Z	FR011HH 1	FR011HH 2	FR012HH Z	FR012HH 1	FR012HH 2	FR013HH Z
FR013HH 1	FR013HH 2	FR014HH Z	FR014HH 1	FR014HH 2	FR021HH Z	FR021HH 1	FR021HH 2	FR022HH Z	FR022HH 1
FR022HH 2	FR023HH Z	FR023HH 1	FR023HH 2	FR024HH Z	FR024HH 1	FR024HH 2	FR031HH Z	FR031HH 1	FR031HH 2
FR032HH Z	FR032HH 1	FR032HH 2	FR033HH Z	FR033HH 1	FR033HH 2	FR034HH Z	FR034HH 1	FR034HH 2	FSW1 HH Z
FSW1 HH N	FSW1 HH E	FSW2 HH Z	FSW2 HH N	FSW2 HH E	FSW3 HH Z	FSW3 HH N	FSW3 HH E	FSW5 HH Z	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	G014 HH 1	G014 HH 2	G021 HH Z	G021 HH 1	G021 HH 2	G022 HH Z	G022 HH 1	G022 HH 2	G023 HH Z
G023 HH 1	G023 HH 2	G024 HH Z	G024 HH 1	G024 HH 2	G031 HH Z	G031 HH 1	G031 HH 2	G032 HH Z	G032 HH 1
G032 HH 2	G033 HH Z	G033 HH 1	G033 HH 2	G034 HH Z	G034 HH 1	G034 HH 2	G041 HH Z	G041 HH 1	G041 HH 2
G042 HH Z	G042 HH 1	G042 HH 2	G043 HH Z	G043 HH 1	G043 HH 2	G044 HH Z	G044 HH 1	G044 HH 2	G051 HH Z
G051 HH 1	G051 HH 2	G052 HH Z	G052 HH 1	G052 HH 2	G053 HH Z	G053 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	G062 HH 2	G063 HH Z	G063 HH 1	G063 HH 2
G064 HH Z	G064 HH 1	G064 HH 2	G071 HH Z	G071 HH 1	G071 HH 2	G072 HH Z	G072 HH 1	G072 HH 2	G073 HH Z
G073 HH 1	G073 HH 2	G074 HH Z	G074 HH 1	G074 HH 2	G081 HH Z	G081 HH 1	G081 HH 2	G082 HH Z	G082 HH 1
G082 HH 2	G083 HH Z	G083 HH 1	G083 HH 2	G084 HH Z	G084 HH 1	G084 HH 2	G091 HH Z	G091 HH 1	G091 HH 2
G092 HH Z	G092 HH 1	G092 HH 2	G093 HH Z	G093 HH 1	G093 HH 2	G094 HH Z	G094 HH 1	G094 HH 2	G101 HH Z
G101 HH 1	G101 HH 2	G102 HH Z	G102 HH 1	G102 HH 2	G103 HH Z	G103 HH 1	G103 HH 2	G104 HH Z	G104 HH 1
G104 HH 2	G111 HH Z	G111 HH 1	G111 HH 2	G112 HH Z	G112 HH 1	G112 HH 2	G113 HH Z	G113 HH 1	G113 HH 2
G114 HH Z	G114 HH 1	G114 HH 2	G121 HH Z	G121 HH 1	G121 HH 2	G122 HH Z	G122 HH 1	G122 HH 2	G123 HH Z
All Z z	Picked p	ALL a	OK o	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.

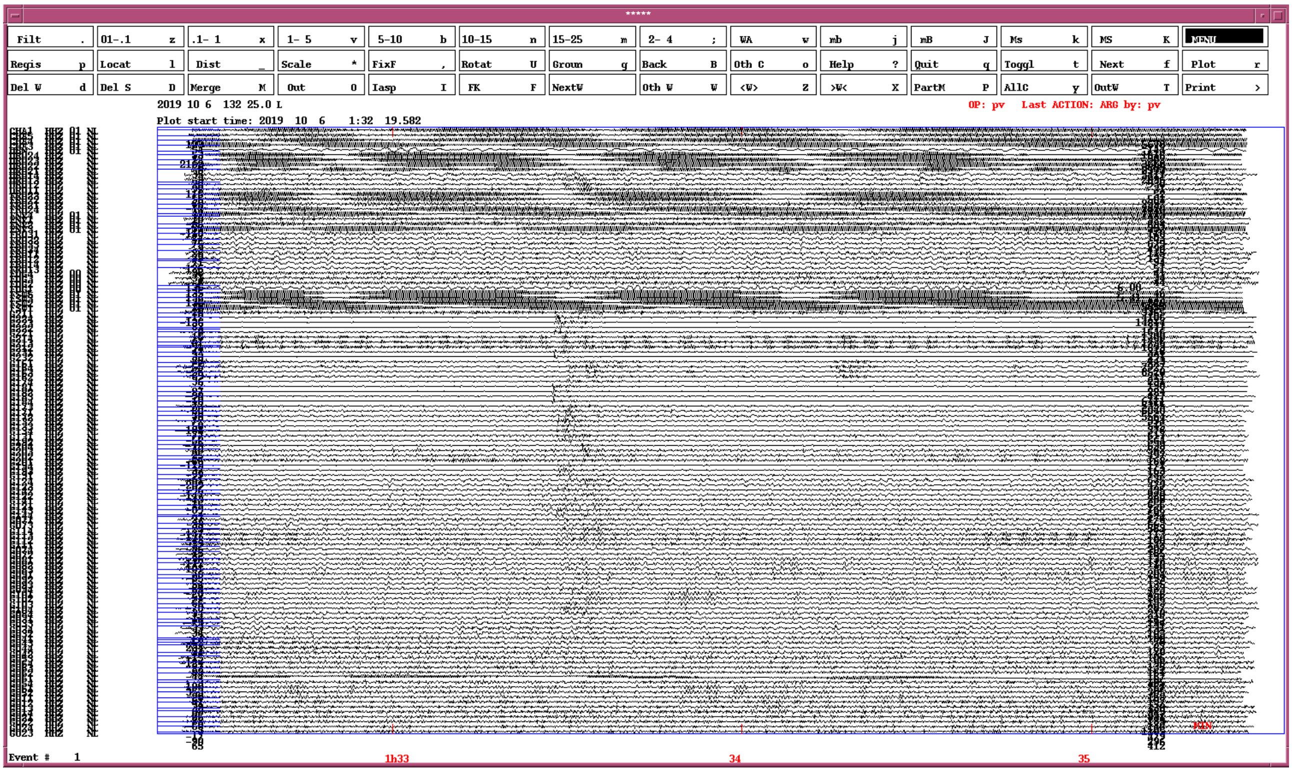


```
1 IP  2 EP  3 IPg 4 EPg 5 IPn 6 EPn 7 IS  8 ES  9 ISg 0 ESg +  Sn /  Lg
2019-10-06-0132-25M.DATA_aa                                          CHA1  HHZ 01 NL  201910 6 13225.600
```

```
Max amp:      5678.3
```

Figure 16: Data from vertical sensor.

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

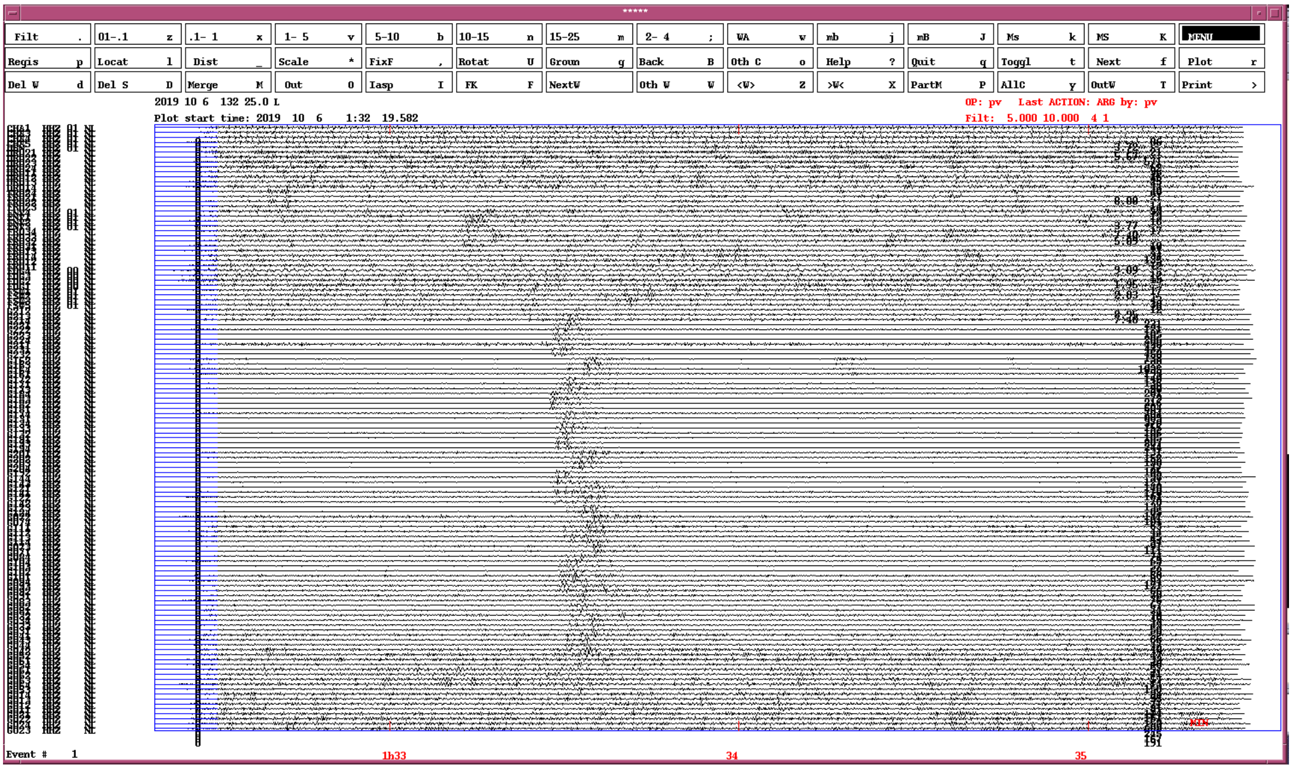


```
2019 10 6  132 25.0 L
Plot start time: 2019  10  6    1:32  19.582
OP: pv   Last ACTION: ARG by: pv
```

```
Event #    1
```

Figure 17: Unfiltered vertical data.

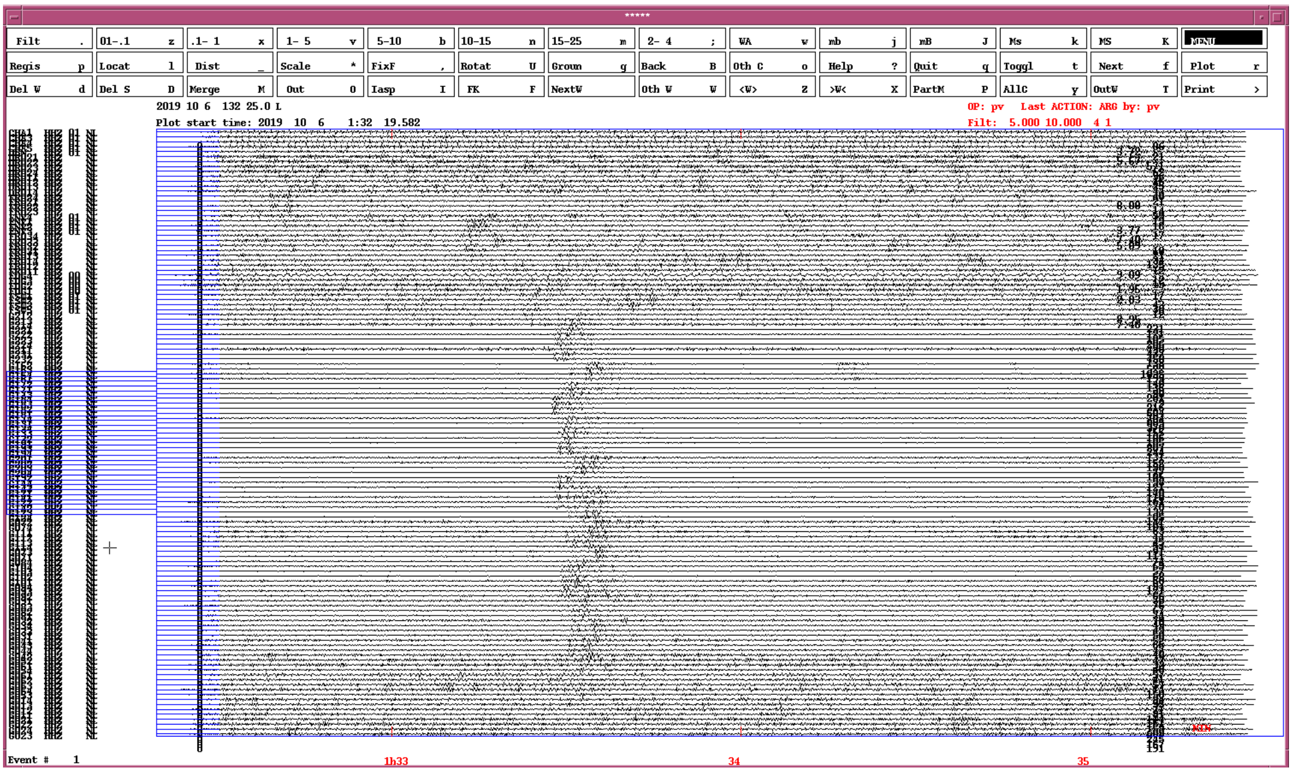
The data are unfiltered but a signal of a possible event is visible on the stations in the middle. Press the ‘5-10’ box and the ‘Plot’ box to apply a 5 to 10 Hz bandpass filter:



```
2019 10 6  132 25.0 L
Plot start time: 2019  10  6     1:32  19.582
OP: pv   Last ACTION: ARG by: pv
Filt:  5.000 10.000  4 1
Event #    1
```

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

Select a number for time series with mouse left click on top trace and mouse right click on trace below:



```
2019 10 6  132 25.0 L
Plot start time: 2019  10  6     1:32  19.582
OP: pv   Last ACTION: ARG by: pv
Filt:  5.000 10.000  4 1
Event #    1
```

Figure 19: Selection of time series.

Press the ‘plot’ box to plot the selected time series.

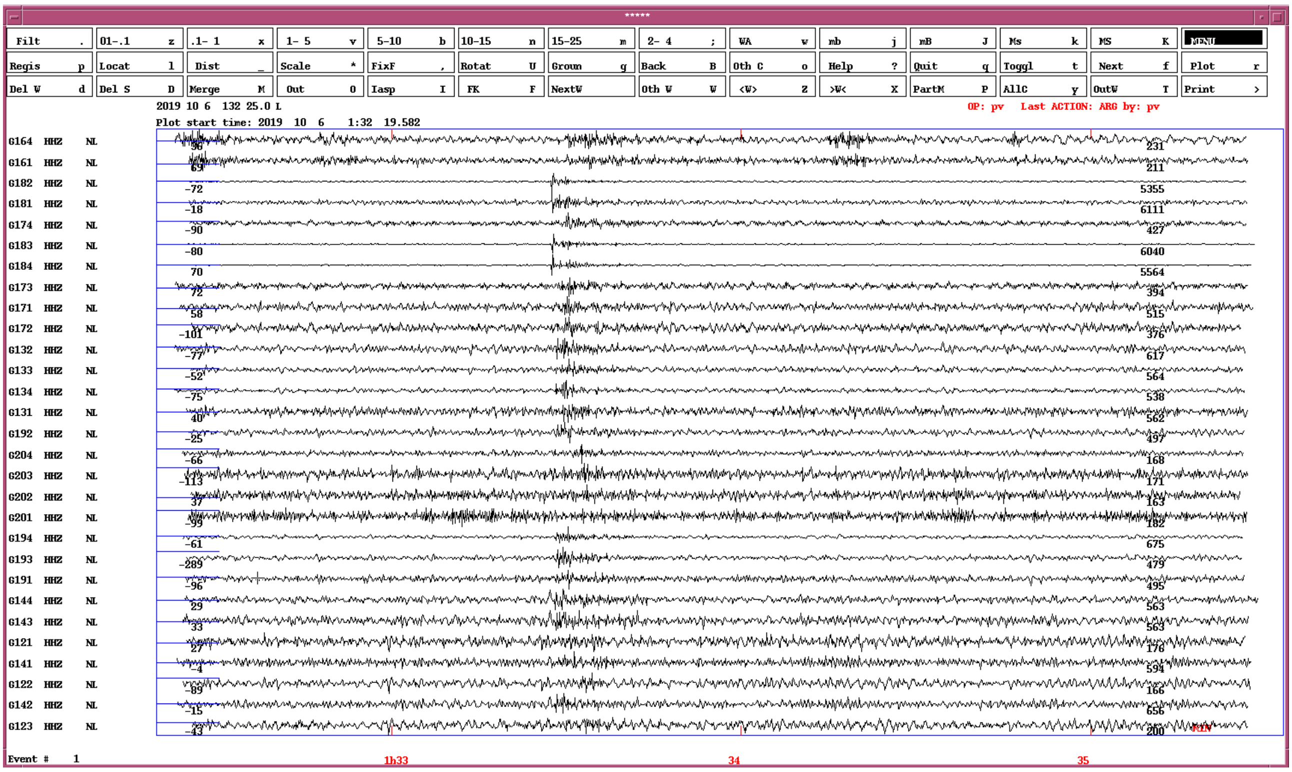


Figure 20: Zoom on selected time series.

Travel time can now be picked on the visible time series. Set the curser at the P phase and press the 1 key:

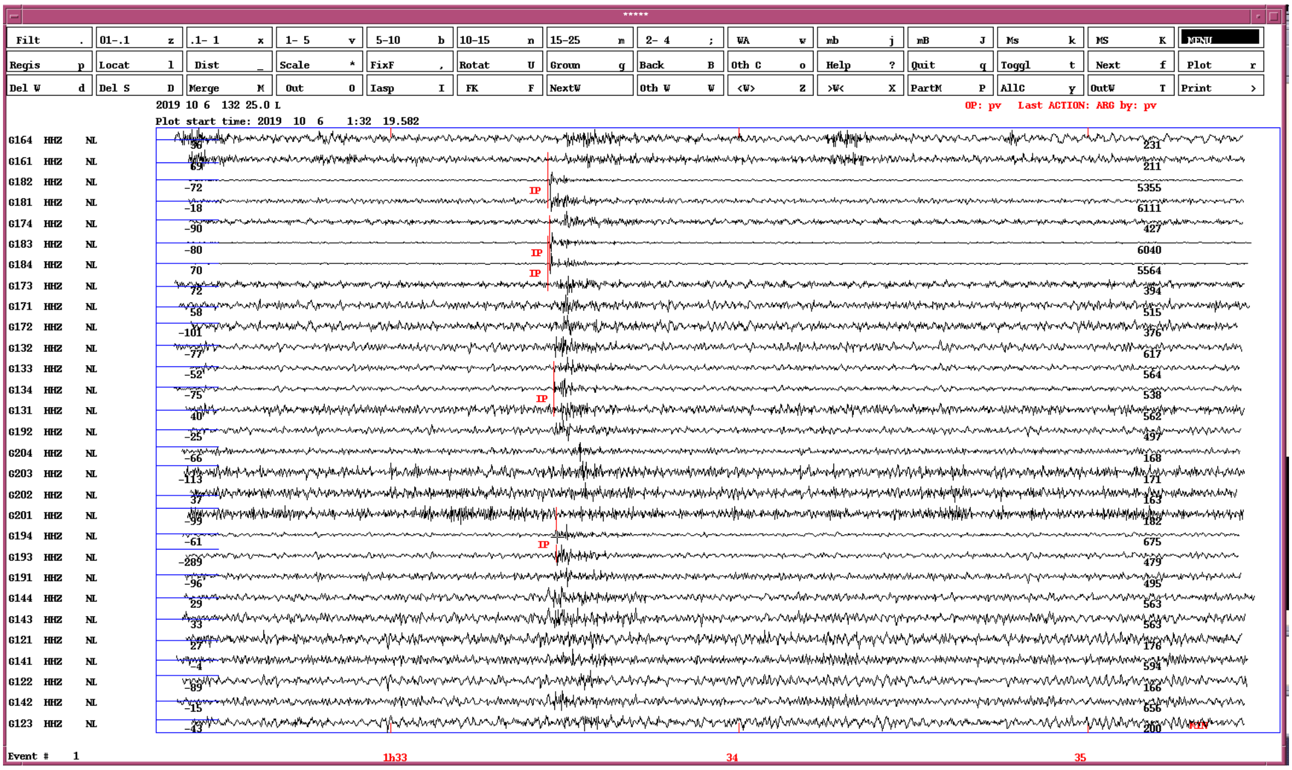


Figure 21: Phase picking.

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

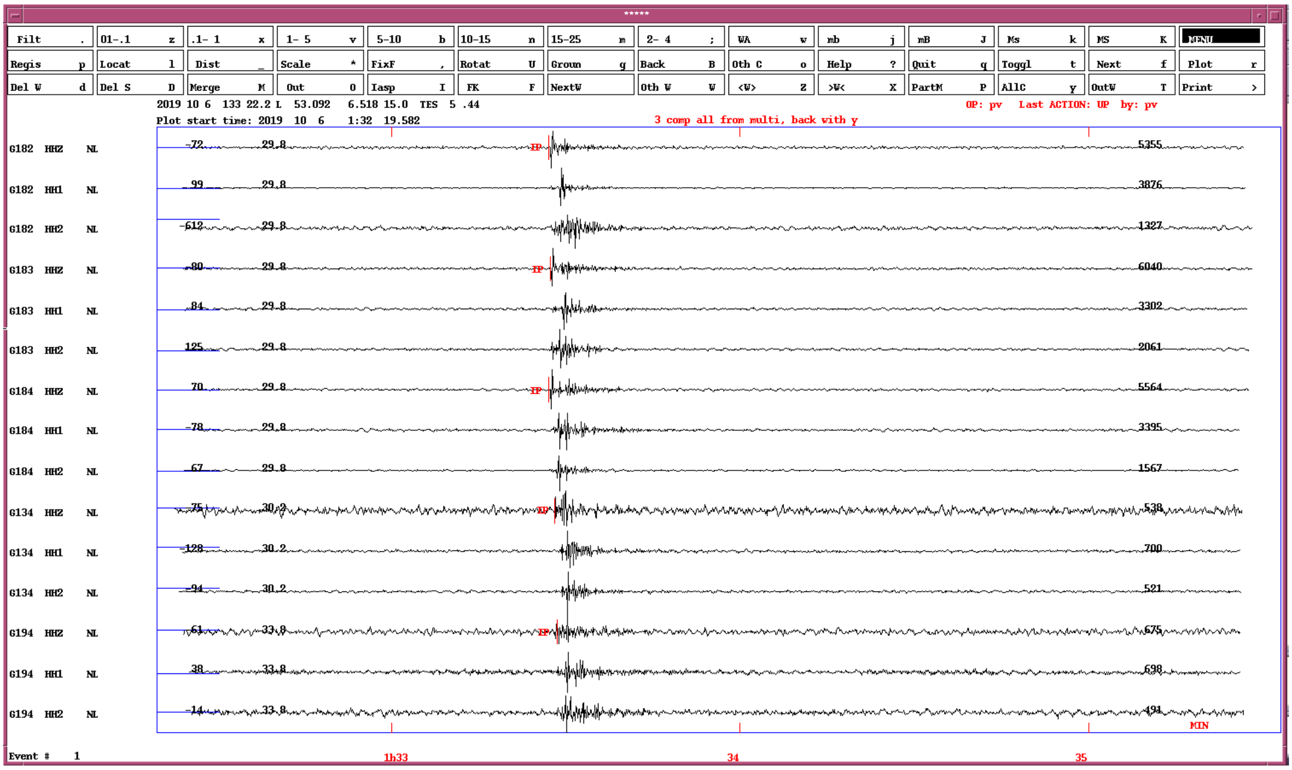
```
  date hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp
1910 6  133 22.17 53 5.50N   6 31.1E  15.0    5 2   0.44 0.000 58.2 58.0  0.0
 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 G182    30  27.0110.8 0 P       PG       133 27.1   4.89   5.32  -0.43 1.00  7
 G184    30  27.0110.8 0 P       PG       133 27.1   4.89   5.32  -0.43 1.00  7
 G183    30  27.0110.8 0 P       PG       133 27.3   5.11   5.32  -0.21 1.00  7
 G134    30  19.3110.4 0 P       PG       133 28.1   5.96   5.39   0.58 1.00 40
 G194    34  36.0107.3 0 P       PG       133 28.6   6.39   5.90   0.49 1.00 40

 2019 10 6 0133 22.2 L  53.092   6.518 15.0  TES  5 0.4
 OLD: 10 6  132 25.0 L

  Return to continue
  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.

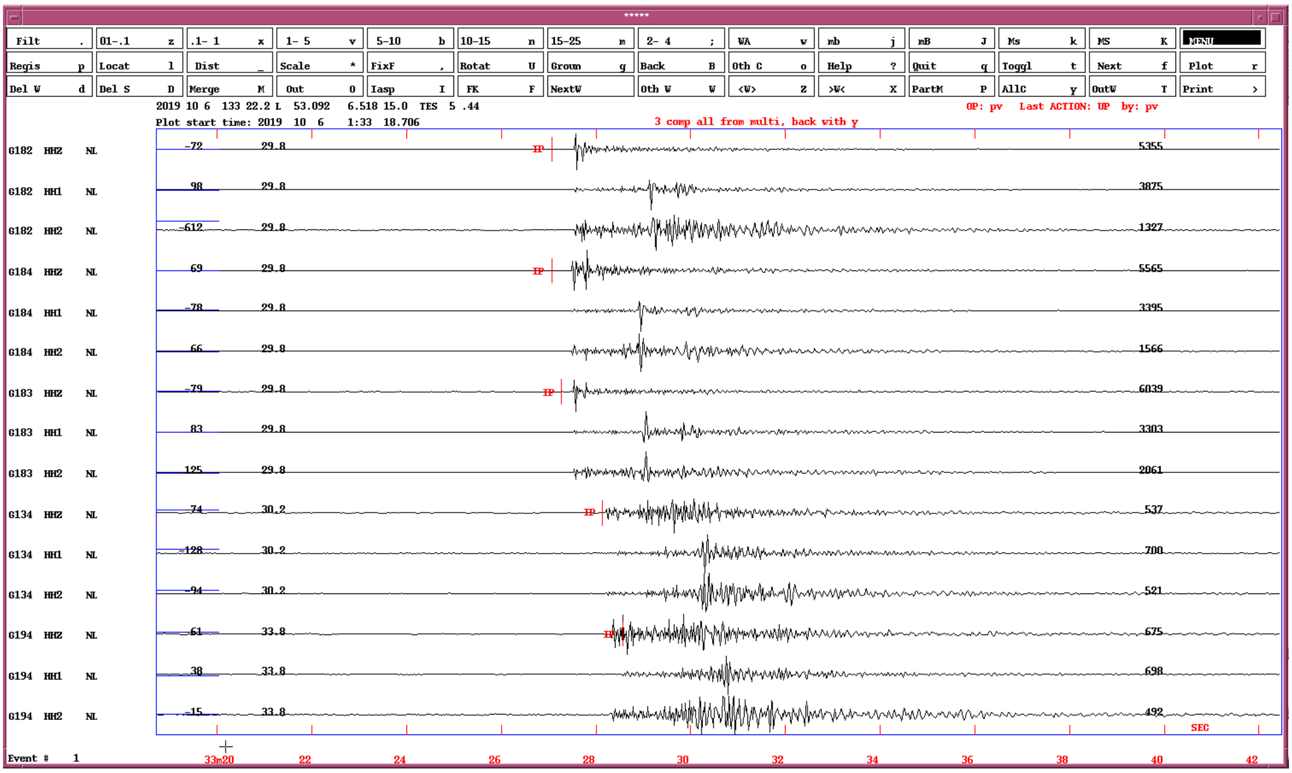
Back in the plot window select the ‘Oth w’ to select other time series of travel time picking of both P and S phases. Note that key 1 and 2 is for the P phase, impulsive or emergent, respectively. Key 7 and 8 is for S phase. Here both the vertical and the two horizontal data channels of the picked stations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



```
2019 10 6  133 22.2 L  53.092   6.518 15.0  TES  5 .44                                   OP: pv   Last ACTION: UP  by: pv
Plot start time: 2019  10  6    1:32  19.582                      3 comp all from multi, back with y
Event #    1
```

Figure 22: Stations with picked phases.

Zoom by mouse click left and right of the signal.



```
2019 10 6  133 22.2 L  53.092   6.518 15.0  TES  5 .44                                   OP: pv   Last ACTION: UP  by: pv
Plot start time: 2019  10  6    1:33  18.706                      3 comp all from multi, back with y
Event #    1
```

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>

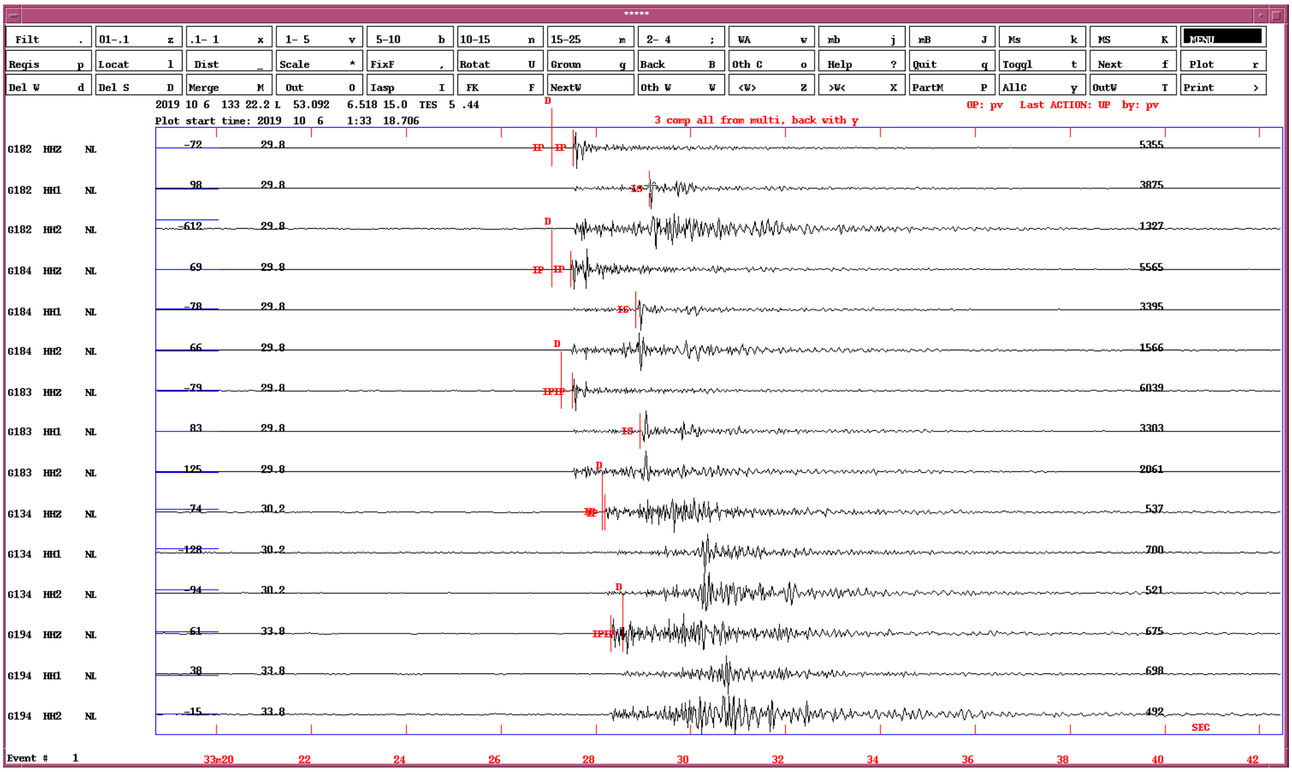


Figure 24: Picking S-phases and repicking P-phases.

Relocate the event with the \l\ key to see the improvement:

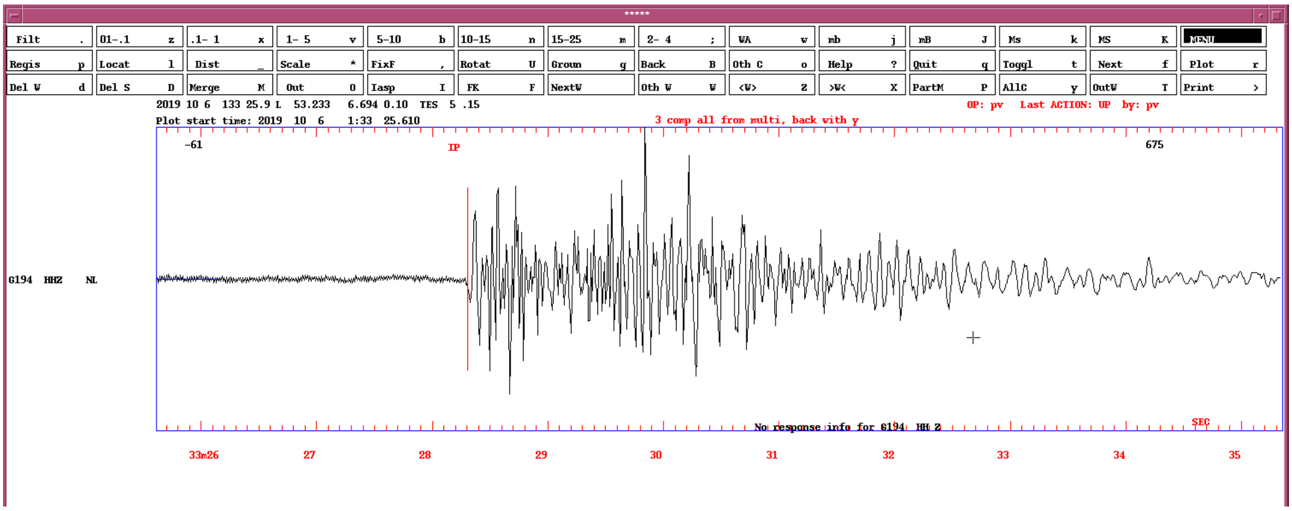
```
  date hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp
1910 6  133 25.86 5313.98N   6 41.6E   0.1    8 3   0.15 0.000 10.4 25.1999.9
 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 G182    11   9.7 90.5 0 P       PG        133 27.5   1.67   1.78  -0.11 1.00  3
 G184    11   9.7 90.5 0 S       SG        133 28.8   2.98   3.10  -0.11 1.00 10
 G183    11   9.7 90.5 0 P       PG        133 27.5   1.64   1.78  -0.14 1.00  3
 G183    11   9.7 90.5 0 S       SG        133 28.9   3.06   3.10  -0.03 1.00 10
 G184    11   9.7 90.5 0 P       PG        133 27.5   1.61   1.78  -0.16 1.00  3
 G182    11   9.7 90.5 0 S       SG        133 29.1   3.27   3.10   0.18 1.00 10
 G134    13 352.6 90.5 0 P       PG        133 28.2   2.33   2.10   0.23 1.00 24
 G194    14  35.1 90.4 0 P       PG        133 28.3   2.46   2.30   0.15 1.00 35

 2019 10 6 0133 25.9 L  53.233   6.694  0.1  TES  5 0.1
 OLD: 10 6  133 22.2 L  53.092   6.518 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:

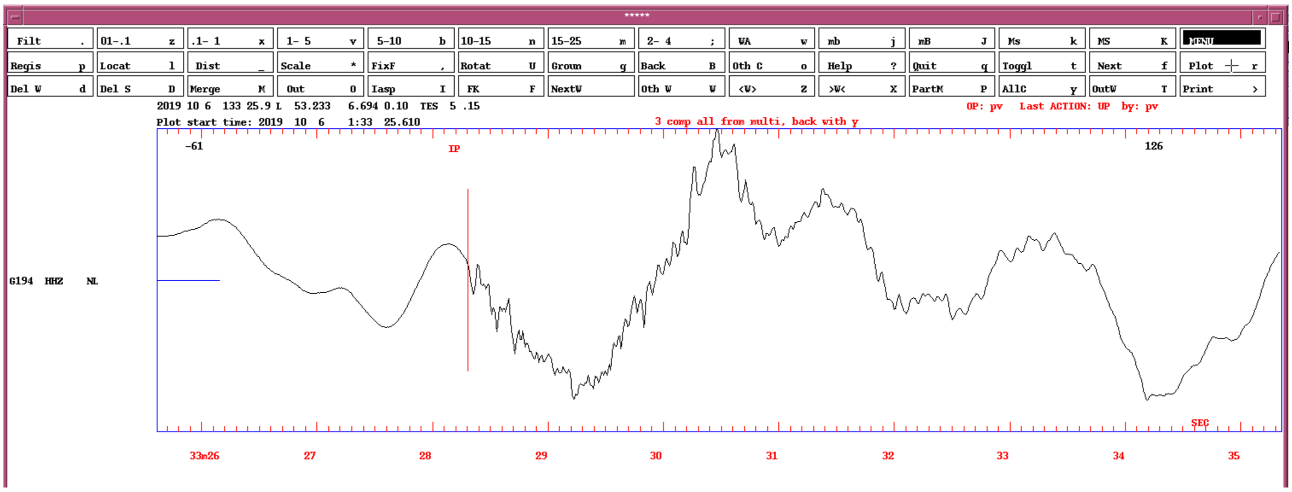


```
2019 10 6  133 25.9 L  53.233   6.694 0.10  TES  5 .15
Plot start time: 2019  10  6    1:33  25.610
3 comp all from multi, back with y
OP: pv   Last ACTION: UP  by: pv
No response info for G194  HH Z
```

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.

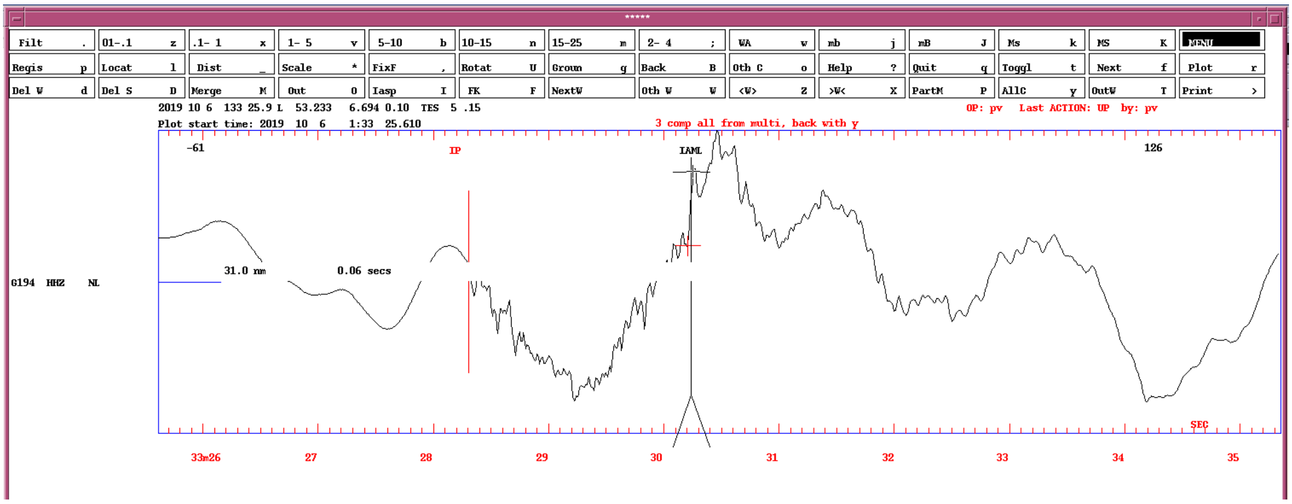
When the data plotted with the WA filter one will now see the data in the same way Charles Richter would:



```
2019 10 6  133 25.9 L  53.233   6.694 0.10  TES  5 .15
Plot start time: 2019  10  6    1:33  25.610
3 comp all from multi, back with y
OP: pv   Last ACTION: UP  by: pv
```

Figure 26: Data converted to displacement.

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



```
2019 10 6  133 25.9 L  53.233   6.694 0.10  TES  5 .15
Plot start time: 2019  10  6   1:33  25.610
3 comp all from multi, back with y
OP: pv   Last ACTION: UP  by: pv
```

Figure 27: Picking of amplitude.

Relocate the event to inspect the magnitude:

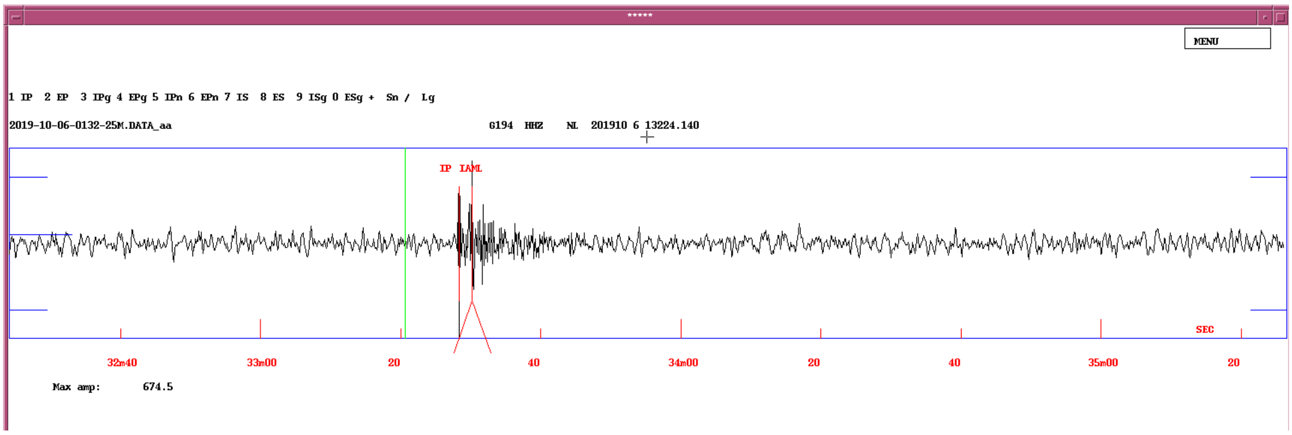
```
  date hrmn   sec      lat       long depth   no m    rms  damp erln erlt erdp
1910 6  133 25.85 5313.96N   6 41.7E   0.0    8 3   0.15 0.000 10.3 25.0999.9
 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 G182    11   9.3 90.0 0 P       PG        133 27.5   1.67   1.78  -0.11 1.00  3
 G182    11   9.3 90.0 0 S       SG        133 29.1   3.28   3.10   0.18 1.00 10
 G184    11   9.3 90.0 0 P       PG        133 27.5   1.62   1.78  -0.16 1.00  3
 G183    11   9.3 90.0 0 P       PG        133 27.5   1.65   1.78  -0.14 1.00  3
 G183    11   9.3 90.0 0 S       SG        133 28.9   3.07   3.10  -0.03 1.00 10
 G184    11   9.3 90.0 0 S       SG        133 28.8   2.99   3.10  -0.11 1.00 10
 G134    13 352.3 90.0 0 P       PG        133 28.2   2.33   2.10   0.23 1.00 24
 G194    14  34.8 90.0 0 P       PG        133 28.3   2.45   2.30   0.15 1.00 35
 G194    14  34.8      0 IAML              133 30.2    4.4

 G194 HZ   hdist:      14.2   amp:          31.0 T:   0.1   ml =    0.9
 2019 10  6 0133 25.9 L  53.233   6.695  0.0   TES  5 0.1 0.9LTES
 OLD: 10  6  133 25.9 L  53.233   6.694 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.

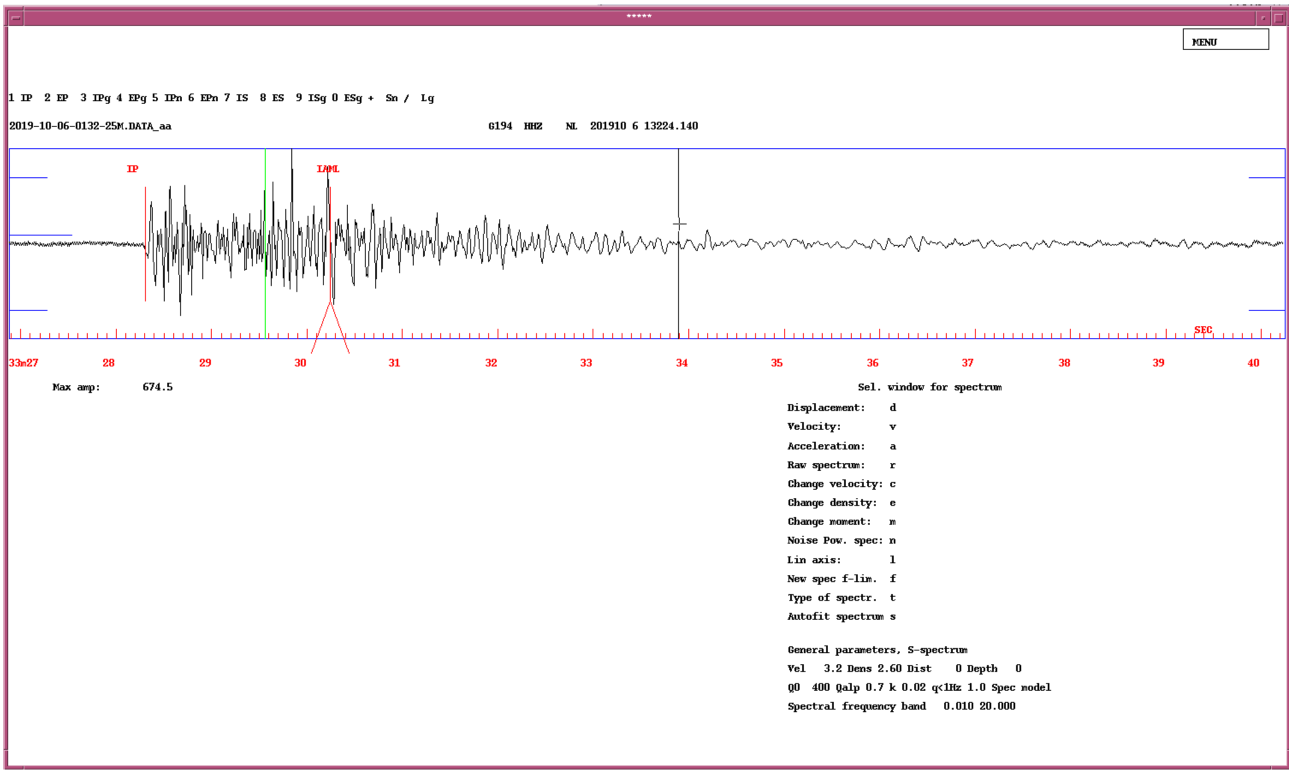
To estimate the magnitude from the spectra, select the time serie to inspect and press the ‘Toggl’ box. Here zoom by clicking left mouse key left of the signal and above the blue line right of the signal:



```
1 IP  2 EP  3 IPg 4 EPg 5 IPn 6 EPn 7 IS  8 ES  9 ISg 0 ESg +  Sn /  Lg
2019-10-06-0132-25M.DATA_aa                              G194  HHZ   NL  201910 6 13224.140
Max amp:      674.5
```

Figure 28: Zooming in single trace.

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



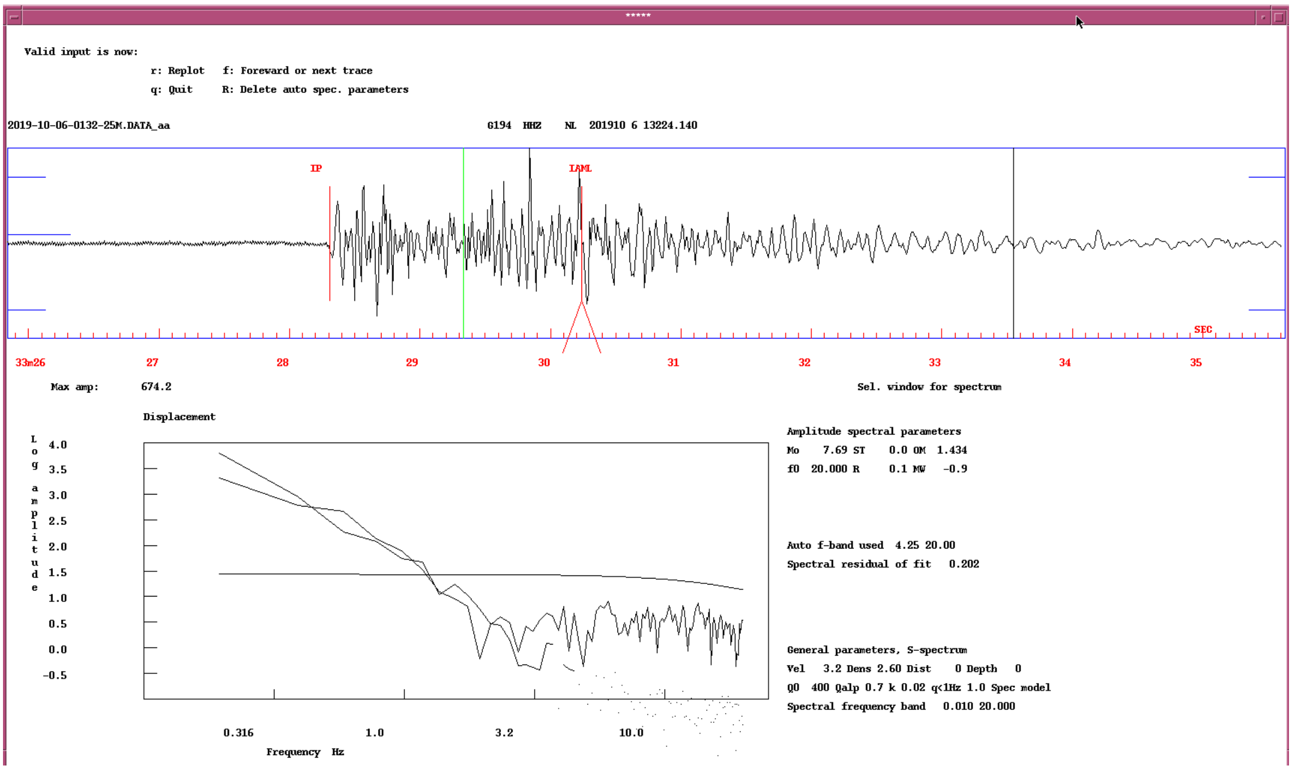
```
1 IP  2 EP  3 IPg 4 EPg 5 IPn 6 EPn 7 IS  8 ES  9 ISg 0 ESg +  Sn /  Lg
2019-10-06-0132-25M.DATA_aa                              G194  HHZ   NL  201910 6 13224.140
Max amp:      674.5

        Sel. window for spectrum
Displacement:    d
Velocity:        v
Acceleration:    a
Raw spectrum:    r
Change velocity: c
Change density:  e
Change moment:   m
Noise Pow. spec: n
Lin axis:        l
New spec f-lim.  f
Type of spectr.  t
Autofit spectrum s

General parameters, S-spectrum
Vel   3.2 Dens 2.60 Dist    0 Depth   0
Q0  400 Qalp 0.7 k 0.02 q<1Hz 1.0 Spec model
Spectral frequency band   0.010 20.000
```

Figure 29: Select window for spectrum.

The amplitude spectral parameters are now computed automatic:



```
Valid input is now:
                    r: Replot    f: Foreward or next trace
                    q: Quit      R: Delete auto spec. parameters

2019-10-06-0132-25M.DATA_aa                                  G194  HHZ    NL  201910 6 13224.140

Max amp:      674.2                                        Sel. window for spectrum

Displacement

Amplitude spectral parameters
Mo    7.69 ST    0.0 OM  1.434
f0  20.000 R     0.1 MW   -0.9

Auto f-band used  4.25 20.00
Spectral residual of fit   0.202

General parameters, S-spectrum
Vel   3.2 Dens 2.60 Dist    0 Depth   0
Q0  400 Qalp 0.7 k 0.02 q<1Hz 1.0 Spec model
Spectral frequency band   0.010 20.000
```

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    no m    rms   damp erln erlt erdp
1910  6   133 25.94  5314.16N   6 41.9E    0.0     7 3   0.12 0.000   9.0 21.9999.9
 stn   dist    azm   ain  w phas    calcphs hrmn tsec  t-obs  t-cal     res   wt di
 G184     11    8.6 90.0  0 S       SG        133 28.9   2.95   2.99  -0.04 1.00 18
 G184     11    8.6 90.0  0 P       PG        133 27.5   1.57   1.72  -0.14 1.00  2
 G183     11    8.6 90.0  0 S       SG        133 29.0   3.06   2.99   0.07 1.00 18
 G183     11    8.6 90.0  0 P       PG        133 27.5   1.60   1.72  -0.12 1.00  2
 G182     11    8.6 90.0  0 P       PG        133 27.6   1.63   1.72  -0.09 1.00  2
 G134     13  351.3 90.0  0 P       PG        133 28.2   2.24   2.05   0.19 1.00 23
 G194     14   35.0 90.0  0 P       PG        133 28.3   2.36   2.23   0.13 1.00 34
 G194     14   35.0       0 IAML              133 30.2    4.3

 G194  HZ   hdist:      13.8   amp:          31.0 T:   0.1   ml =   0.9
 G194  HZ   gdist:      13.8   mom:          11.6   mw =    1.7
 Number of spectra available and number used in average     1     1
 2019 10  6 0133 25.9 L   53.236   6.698  0.0  TES  5 0.1 0.9LTES 1.7WTES
 OLD: 10  6  133 25.9 L   53.233   6.695 0.00  TES  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:

```
KEYWORD............Comments.............Par 1.....Par 2
NEW_NORDIC_FORMAT                       1.0
```

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 name: 10-0356-15L.S201802
2018  210  356 15.0 L                                                    1
2018-02-10-0356-15S.NSN___068                                            6
ACTION:ARG 20-04-27 14:05 OP:pv   STATUS:               ID:20180210035615     I
STAT COM NTLO IPHASE   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:

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                                       ? ap
```

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

```
#    1 10 Feb 2018   3:56 15   L                                       ? t
```

```
 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     I
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     C       DNK pv
T001 EPZ HL    END     A 356 57.531   32.0      DNK pv
```

```
T002 EPZ HL   IP        A 356 25.158      C        DNK pv
T002 EPZ HL    END      A 356 63.158   38.0        DNK pv
T003 EPZ HL   IP        A 356 25.421               DNK pv
T003 EPZ HL    END      A 356 66.421   41.0        DNK pv
T004 EPZ HL   IP        A 356 24.246               DNK pv
T005 EPZ HL   IP        A 356 25.197               DNK pv
T005 EPZ HL    END      A 356 63.197   38.0        DNK pv
T006 EPZ HL   IP        A 356 25.331      D        DNK pv
T007 EPZ HL   IP        A 356 24.627               DNK pv
T007 EPZ HL    END      A 356 68.627   44.0        DNK pv
T008 EPZ HL   IP        A 356 24.850               DNK pv
T008 EPZ HL    END      A 356 64.850   40.0        DNK pv
T009 EPZ HL   IP        A 356 25.021               DNK pv
T010 EPZ HL   IP        A 356 25.350               DNK pv
  Return to continue, q to return to EEV
```

To see the automatic picks on the waveforms type po:

Figure 32: Plotting the automatic phase reading with waveforms.

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

```
#    1 10 Feb 2018  3:56 15  L                                     ? l
 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
 T068     3 292.7171.1 0 P    A  PG        356 23.7  4.54   3.90   0.64 1.00  7
```

```
T060     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     8 305.9155.6 0 P    A  PG       356 23.5   4.35   4.16   0.19 1.00  1
T063     8 305.9155.6 3 S   3A  SG       356 25.6   6.45   7.24  -0.79 0.25  2
….
T059     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    26   2.1118.8 3 S   3A  SG       356 28.7   9.55  10.66  -1.11 0.25  1
T001    28 359.0116.4 0 P    AC PG       356 25.5   6.41   6.40   0.02 1.00  2

T001 EZ   hdist:      34.8   coda:         32.0            mc =   0.9
T002 EZ   hdist:      32.7   coda:         38.0            mc =   1.1
T003 EZ   hdist:      33.3   coda:         41.0            mc =   1.2
T005 EZ   hdist:      32.2   coda:         38.0            mc =   1.1
T007 EZ   hdist:      30.4   coda:         44.0            mc =   1.3
T008 EZ   hdist:      30.7   coda:         40.0            mc =   1.2
…
T066 EZ   hdist:      22.9   coda:         37.0            mc =   1.1
T067 EZ   hdist:      21.9   coda:         32.0            mc =   0.9
T069 EZ   hdist:      24.2   coda:         47.0            mc =   1.4
T070 EZ   hdist:      22.3   coda:         55.0            mc =   1.5
2018  210 0356 19.1 L  23.812 121.608 20.6  DNK 66 2.8 1.1CDNK
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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The seismic waveform data displayed was obtained from or through the following agencies or data provides.

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