Data description for data set “A 100 3-component sensor deployment to monitor the 2018 EGS stimulation in Espoo/Helsinki, southern Finland”

http://doi.org/10.5880/GIPP.201802.1

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Citation:
These data were acquired in cooperation with the Geophysical Instrument Pool Potsdam (GIPP) under the grant 201802.

When using the data please cite:
Hillers, G., et al. (2019) A 100 3-component sensor deployment to monitor the 2018 EGS stimulation in Espoo/Helsinki, southern Finland. GFZ Data Services, http://doi.org/10.5880/GIPP.201802.1

Abstract
A seismic network was installed in the Helsinki capital area of Finland to monitor the response to a 6 km deep geothermal stimulation experiment in 2018. The Institute of Seismology, University of Helsinki (ISUH), installed these 100 geophones in addition to five surface broadband sensors and a 13-site borehole network deployed by the operating company. The stations operated for 106 days between 7 May and 20 August 2018 (day 127 to 232). The data set consists of raw CUBE-recorder data and converted MSEED data.

Coordinates: 60.188° N, 24.828° E

Keywords: Enhanced Geothermal System, Induced Seismicity, Array of Arrays, Monitoring

1. Introduction

A seismic network was installed in the Helsinki capital area of Finland to monitor the response to a 6 km deep geothermal stimulation experiment in 2018 (Figure 1). The Institute of Seismology, University of Helsinki (ISUH), installed these 100 geophones in addition to five surface broadband sensors and a 13-site borehole network deployed by the operating company. From 4 June to 22 July 2018 (day of year 155 to 203) the operating company stimulated a geothermal reservoir at 6.1 km depth to support local district heating (Hillers et al., 2019).

2. Data Acquisition

2.1 Experiment design and schedule

ISUH installed a temporary network within 6 km around the wellhead consisting of nominally 100 4.5-Hz 3-C geophones from the Geophysical Instrument Pool Potsdam (GIPP) that were connected to DATA-CUBE3 recorders. Two sensors were deployed at 13 km and 16 km distance to the east. The network operated for 106 days between 7 May and 20 August 2018 (day 127 to 232). The acquisition and maintenance benefited from the unusual warm and dry weather conditions.

2.2 *Geometry/Location*

The 100 cube stations were organized in three large arrays consisting of nominally 25 stations (blue squares in Figure 1), three small 4-station arrays (triangles), and ten single stations (circles). The large arrays were installed in suburban, undeveloped, mostly tree covered areas. The sensors were generally placed in the sometimes only centimeters-thin top soil layer that covers the ubiquitous bedrock outcrops. The array that was originally installed at the water tower location southwest to the hole (gray square) was relocated after two weeks to the 1.3 km distant Toppelund site because of persistent vandalism. Reorganization associated with the relocation led to the final 25, 24, and 23 sensor configurations in the three large arrays. For station table see Appendix 1**.**

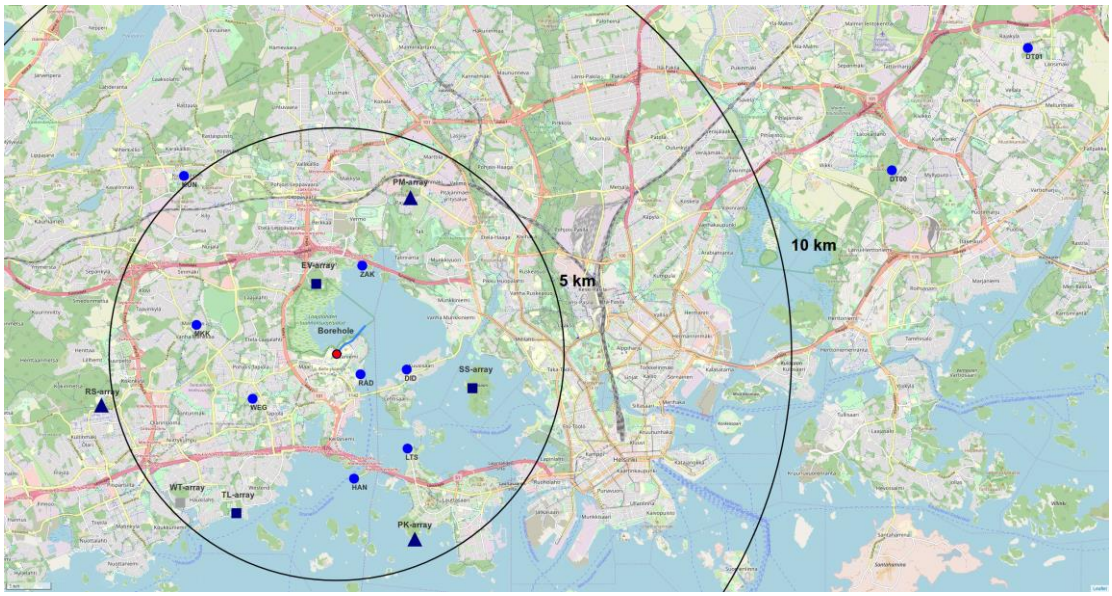

Figure 1: *Map of Espoo and Helsinki and the deployed network. The site of the borehole is indicated by the red circle, the borehole trajectory at depth is indicated by the associated blue line. Squares indicate large arrays, triangles indicate small arrays, and circles indicated single sensors.*

2.3 Instrumentation
For the experiment data recorders of type DATA-CUBE together with 4.5Hz 3-component geophones were used. The cubes were powered by D-cell batteries. 50 stations in two large arrays used the internal 2-cell solution. The other stations were equipped with external 8-battery boxes. The deployment consumed c. 2200 D-cells that were changed in an interval of 7−10 days or c. 30 days.

2.4 Acquisition parameters
The GIPP instruments were deployed with built-in GPS, with the gain set to 16, and the sampling rate set to the maximum of 400 Hz. The stations recorded data continuously on 32 or 64 GB SDHC cards. Data were downloaded and cleared from the SDHC cards in the field in c. 35 day intervals.

3. Data Processing
RAW data was converted to MiniSEED using GIPPtools rev. 2527 (2018-11-06; www.gfz-potsdam.de/gipp), and further processed into daily MiniSEEDs using Python and ObsPy.
Processing involved renaming stations and channels and, where necessary, merging multiple files into a single daily MiniSEED file.

4. Data Description

4.1 File format (s)
Data is provided in raw CUBE format and MSEED format (FDSN, 2012).

4.2 Data content and structure:

STRUCTURE

./DOC/ Cube locations and maps and other documentation such as this file.
./RAW/ Raw data in Cube format. Divided into arrays and further into cubes. Cube configuration files are also included.
./MSEED/ Converted MiniSEEDs in MiniSEED archive structure.

FILES

./DOC/Cube_locations_and_station_codes.txt
Cube locations with data about which Cube & sensor were used at which station location.STAT is the station code, INS_DOY is the installation DOY, EXT_DOY is the extraction DOY, LAT is the latitude, LON is the longitude, CUBE is the Cube number(s) and SENSOR is the sensor number.

./DOC/Static_OTANET_Cube_map.png
Static map of the Cubes.

./DOC/Dynamic_OTANET_Cube_map.html
HTML version of the Cube map. Can be zoomed and scrolled to display individual Cubes from arrays.
Requires Internet connection for map tiles.
Circles are 5 & 10 km radii around the ST1 borehole site.

./RAW/cube_folders
Where the raw data of a specific Cube is found.

MSEED ARCHIVE STRUCTURE
MiniSEED data is stored into daily miniSEEDs divided into /<STATION>/<CHANNEL>.D/ folders.

Filenames follow the SEED convention: OT.STA..DP?.D.2018.DOY

Where...
... OT is the network code
… STA is the station code (e.g. EV01)
… DOY is the day of the year.
... DP? is the channel code:

- D: 250 - 1000 Hz sample rate with a corner period < 10 seconds (4.5 Hz 3-component geophone).
- P: Geophone
- Z/N/E: Orientation. Geophones were oriented North using hand compass, while taking into account the local magnetic declination of +9 degrees.

5. Data Quality/Accuracy
The geophone locations were estimated with a hand-held GPS device.

6. Data Availability/Access
Data is archived at the *GIPP Experiment and Data Archive* where it will be made freely available for further use after the end of the embargo period on August 22, 2022.

Recommended citation for this publication is:

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References

FDSN (2012): *SEED Reference Manual* – Standard for the Exchange of Earthquake Data. SEED Format Version 2.4, Publisher: IRIS.

Hillers, G., Vuorinen, T.A.T., Uski, M.R., Kortström, J.T., Mäntyniemi, P.B., Tiira, T., Malin, P.E., Saarno, T. (2019) The 2018 geothermal reservoir stimulation in Espoo/Helsinki, southern Finland: Seismic network anatomy and data features. Submitted to Seismological Research Letters.

Appendix 1:

STAT	INS_DOY	EXT_DOY	LAT	LON	CUBE	SENSOR
DID	2018127	2018240	60.185330	24.855640	CUBE_C880	SENSOR_048
DT00	2018127	2018240	60.224860	25.048590	CUBE_C897	SENSOR_178
DT01	2018127	2018240	60.249190	25.102680	CUBE_C902	SENSOR_189
EV00	2018127	2018240	60.204610	24.819440	CUBE_C854	SENSOR_185
EV01	2018127	2018240	60.204660	24.819790	CUBE_C802	SENSOR_160
EV02	2018127	2018240	60.204790	24.820060	CUBE_C892	SENSOR_173
EV03	2018127	2018240	60.204720	24.820590	CUBE_C869	SENSOR_181
EV04	2018127	2018240	60.204740	24.820930	CUBE_C833	SENSOR_187
EV05	2018127	2018240	60.204350	24.819560	CUBE_C893	SENSOR_182
EV06	2018127	2018240	60.204460	24.819970	CUBE_C832	SENSOR_191
EV07	2018127	2018240	60.204560	24.820470	CUBE_C856	SENSOR_183
EV08	2018127	2018240	60.204560	24.820740	CUBE_C872	SENSOR_176
EV09	2018127	2018240	60.204520	24.821190	CUBE_C898	SENSOR_174
EV10	2018127	2018240	60.204230	24.819540	CUBE_C805	SENSOR_179
EV11	2018127	2018240	60.204300	24.819960	CUBE_C808	SENSOR_172
EV12	2018127	2018240	60.204330	24.820590	CUBE_C800	SENSOR_184
EV13	2018127	2018240	60.204360	24.820940	CUBE_C809	SENSOR_175
EV14	2018127	2018240	60.204320	24.821330	CUBE_C855	SENSOR_177
EV15	2018127	2018240	60.203870	24.819870	CUBE_C807	SENSOR_192
EV16	2018127	2018240	60.204130	24.820080	CUBE_C834	SENSOR_149
EV17	2018127	2018240	60.204070	24.820700	CUBE_C870	SENSOR_171
EV18	2018127	2018240	60.204130	24.821050	CUBE_C871	SENSOR_190
EV19	2018127	2018240	60.204120	24.821540	CUBE_C803	SENSOR_190
EV20	2018127	2018240	60.203770	24.820470	CUBE_C831	SENSOR_161
EV21	2018127	2018240	60.203860	24.820810	CUBE_C804	SENSOR_146
EV22	2018127	2018240	60.203920	24.821300	CUBE_C836	SENSOR_159
EV23	2018127	2018240	60.203960	24.821530	CUBE_C835	SENSOR_002
KUN	2018127	2018240	60.223810	24.767110	CUBE_C837	SENSOR_145
LTS	2018127	2018240	60.169580	24.856120	CUBE_C812	SENSOR_039
MKK	2018127	2018240	60.194180	24.772070	CUBE_C881	SENSOR_040
PK00	2018127	2018240	60.153390	24.858770	CUBE_C878	SENSOR_040
PK01	2018127	2018240	60.153100	24.858130	CUBE_C882	SENSOR_054
PK02	2018127	2018240	60.152820	24.858110	CUBE_C886	SENSOR_055
PK03	2018127	2018240	60.153210	24.857520	CUBE_C888	SENSOR_041
PM00	2018127	2018240	60.221040	24.856420	CUBE_C686	SENSOR_007
PM01	2018127	2018240	60.221260	24.856180	CUBE_C894	SENSOR_157
PM02	2018127	2018240	60.220720	24.855980	CUBE_C899	SENSOR_158
PM03	2018127	2018240	60.221030	24.857010	CUBE_C900	SENSOR_148
HAN	2018127	2018240	60.163620	24.834700	CUBE_C877	SENSOR_046
RAD	2018127	2018240	60.184350	24.837380	CUBE_C890	SENSOR_017
RS00	2018127	2018240	60.179890	24.734020	CUBE_C681	SENSOR_042
RS01	2018127	2018240	60.179570	24.733770	CUBE_C682	SENSOR_044
RS02	2018127	2018240	60.179860	24.733230	CUBE_C683	SENSOR_053
RS03	2018127	2018240	60.179900	24.732640	CUBE_C901	SENSOR_156
SS00A	2018127	2018135	60.183550	24.883130	CUBE_C780	SENSOR_120
SS00B	2018135	2018240	60.183980	24.882070	CUBE_C780	SENSOR_120
SS01	2018127	2018240	60.184060	24.882410	CUBE_C604	SENSOR_119
SS02	2018127	2018240	60.183980	24.882900	CUBE_C781	SENSOR_105
SS03	2018127	2018240	60.184030	24.883250	CUBE_C816	SENSOR_132
SS04	2018127	2018240	60.184030	24.883550	CUBE_C827	SENSOR_139
SS05	2018127	2018240	60.183820	24.881750	CUBE_C817	SENSOR_131
SS06	2018127	2018240	60.183880	24.882250	CUBE_C822	SENSOR_140
SS07	2018127	2018240	60.183840	24.882550	CUBE_C811, CUBE_C815	SENSOR_126
SS08	2018127	2018240	60.183830	24.882940	CUBE_C819	SENSOR_123
SS09A	2018127	2018135	60.183850	24.883490	CUBE_C784	SENSOR_088
SS09B	2018135	2018240	60.183820	24.883590	CUBE_C784	SENSOR_088
SS10	2018127	2018240	60.183570	24.881810	CUBE_C612	SENSOR_082
SS11	2018127	2018240	60.183640	24.882100	CUBE_C879	SENSOR_081
SS12	2018127	2018240	60.183650	24.882620	CUBE_C782	SENSOR_115
SS13	2018127	2018240	60.183630	24.882920	CUBE_C818	SENSOR_128
SS14	2018127	2018240	60.183650	24.883410	CUBE_C857	SENSOR_138
SS15	2018127	2018240	60.183400	24.881580	CUBE_C821	SENSOR_143
SS16	2018127	2018240	60.183420	24.882190	CUBE_C615	SENSOR_110
SS17	2018127	2018240	60.183380	24.882510	CUBE_C783	SENSOR_111
SS18	2018127	2018240	60.183440	24.883030	CUBE_C889	SENSOR_135
SS19	2018127	2018240	60.183510	24.883460	CUBE_C795	SENSOR_084
SS20	2018127	2018240	60.183210	24.881530	CUBE_C601	SENSOR_118
SS21	2018127	2018240	60.183180	24.882130	CUBE_C813	SENSOR_129
SS22	2018127	2018240	60.183150	24.882570	CUBE_C823	SENSOR_136
SS23A	2018127	2018135	60.183200	24.883010	CUBE_C824	SENSOR_107
SS23B	2018135	2018240	60.183180	24.883170	CUBE_C824	SENSOR_107
SS24	2018127	2018240	60.183330	24.883370	CUBE_C826	SENSOR_080
TL00	2018145	2018240	60.159080	24.787780	CUBE_C846	SENSOR_099
TL01	2018145	2018240	60.159130	24.788150	CUBE_C689	SENSOR_067

TL02	2018145	2018240	60.159180	24.788580	CUBE_C896	SENSOR_153
TL03	2018145	2018240	60.159180	24.788920	CUBE_C712, CUBE_C801	SENSOR_063
TL04	2018145	2018240	60.159150	24.789300	CUBE_C865	SENSOR_071
TL05	2018145	2018240	60.158850	24.788240	CUBE_C687	SENSOR_086
TL06	2018145	2018240	60.158810	24.788590	CUBE_C796	SENSOR_059
TL07	2018145	2018240	60.159030	24.788600	CUBE_C875	SENSOR_051
TL08	2018145	2018240	60.159020	24.789010	CUBE_C713	SENSOR_057
TL09	2018145	2018240	60.158940	24.789360	CUBE_C864	SENSOR_091
TL10	2018127	2018240	60.158660	24.788130	CUBE_C710	SENSOR_124
TL11	2018127	2018240	60.158640	24.788510	CUBE_C806	SENSOR_100
TL12	2018145	2018240	60.158590	24.788890	CUBE_C825	SENSOR_073
TL13	2018145	2018240	60.158790	24.789080	CUBE_C840	SENSOR_070
TL14	2018145	2018240	60.158800	24.789330	CUBE_C688	SENSOR_104
TL15	2018145	2018240	60.158460	24.788160	CUBE_C797	SENSOR_077
TL16	2018145	2018240	60.158310	24.788290	CUBE_C895	SENSOR_155
TL17	2018145	2018240	60.158530	24.788570	CUBE_C847	SENSOR_058
TL18	2018145	2018240	60.158710	24.789330	CUBE_C848	SENSOR_050
TL19	2018145	2018240	60.158520	24.789530	CUBE_C843	SENSOR_072
TL20	2018145	2018240	60.158240	24.788580	CUBE_C692	SENSOR_060
TL21	2018145	2018240	60.158330	24.789020	CUBE_C691	SENSOR_056
TL22	2018145	2018240	60.158360	24.789530	CUBE_C842	SENSOR_096
WEG	2018127	2018240	60.179540	24.794440	CUBE_C891	SENSOR_049
WT00	2018127	2018145	60.160760	24.767270	CUBE_C687	SENSOR_086
WT01	2018127	2018145	60.160570	24.767400	CUBE_C688	SENSOR_104
WT02	2018127	2018145	60.161020	24.766870	CUBE_C689	SENSOR_067
WT03	2018127	2018145	60.160910	24.767270	CUBE_C691	SENSOR_056
WT04	2018127	2018145	60.161000	24.765750	CUBE_C692	SENSOR_060
WT05	2018127	2018145	60.160660	24.766080	CUBE_C712, NOT CUBE_C801	SENSOR_063
WT06	2018127	2018145	60.160720	24.766790	CUBE_C713	SENSOR_057
WT07	2018127	2018145	60.160640	24.765670	CUBE_C796	SENSOR_059
WT08	2018127	2018145	60.160310	24.766300	CUBE_C797	SENSOR_077
WT09	2018127	2018145	60.160840	24.765490	CUBE_C825	SENSOR_073
WT10	2018127	2018145	60.161160	24.766910	CUBE_C840	SENSOR_070
WT11	2018127	2018145	60.160860	24.766280	CUBE_C842	SENSOR_096
WT12	2018127	2018145	60.160500	24.766930	CUBE_C843	SENSOR_072
WT13	2018127	2018145	60.161160	24.766350	CUBE_C846	SENSOR_099
WT14	2018127	2018145	60.160980	24.766120	CUBE_C847	SENSOR_058
WT15	2018127	2018145	60.160360	24.767370	CUBE_C848	SENSOR_050
WT16	2018127	2018145	60.160510	24.765750	CUBE_C864	SENSOR_091
WT17	2018127	2018145	60.160980	24.766640	CUBE_C865	SENSOR_071
WT18	2018127	2018145	60.160830	24.765910	CUBE_C875	SENSOR_051
WT19	2018127	2018145	60.160530	24.766350	CUBE_C895	SENSOR_155
WT20	2018127	2018145	60.161090	24.767300	CUBE_C896	SENSOR_153
ZAK	2018127	2018240	60.205930	24.838090	CUBE_C838	SENSOR_193