Seismometer to Investigate Ice and Ocean Structure (SIIOS)
NASA Grant 80NSSC17K0229

Northwest Greenland Active Source Seismic Experiment
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1. Experiment Overview

The Seismometer to Investigate Ice and Ocean Structure (SIIOS) project is a NASA Planetary Science and Technology Through Analog Research investigation (NASA Grant #: 80NSSC17K0229) that is developing seismic instrumentation and deployment concepts for seismometers on a future mission to an icy-ocean world. Icy-ocean worlds of the outer Solar System include Jupiter's moon Europa, Saturn's moons Enceladus and Titan; these worlds are characterized by active icy shells and subsurface oceans of liquid water, primarily driven by tidal dissipation within the ice shells and interiors of the moons (e.g. Carr et al., 1998; Nimmo and Pappalardo, 2016). The presence of subsurface oceans has made these worlds high priority targets for future NASA missions that would have the goal of assessing the potential habitability of the subsurface (Raulin, 2008; Pappalardo et al., 2013; Pappalardo et al., 2015; Vance et al., 2018). A future seismometer placed on the surface of an icy-ocean world would provide the ability to determine the thickness of the overlying ice shell, depth to subsurface layers or pockets of liquid water, and the properties of the underlying ocean layer, all of high relevance to establishing the location of habitable environments. The SIIOS investigation is preparing for these future missions by examining the performance and operation of seismic equipment in terrestrial analogs to the surfaces and interiors of icy-ocean worlds.

2. Greenland Summer 2018 Active Source Seismic Experiment

In summer of 2018, the SIIOS team conducted a geophysical field investigation on the Greenland ice sheet in northwestern Greenland at a location where a previous airborne radar survey by Palmer *et al.* (2013) had detected the signatures of a subglacial lake. The field site (Figure 1) is located approximately 50 km north of the town of Qaanaaq. This site was chosen for the SIIOS project as it provides an opportunity for studying how a lander station could be used to detect subsurface water at an icy-ocean world. The purpose of the investigation was to confirm the presence of the subglacial lake and to measure its physical properties such as seismic impedance, as well as to estimate its depth and volume. One component of the investigation consisted of an active source seismic survey that was used to create a reflection image of the lake, as well as to measure the ice-bottom reflection coefficient. The survey was conducted along a roughly northeast oriented traverse, which started above the subglacial lake and crossed the lake's eastern boundary.

The seismic survey was conducted using a geophone line that consisted of 24 40 Hz vertical component sensors spaced 5 m apart, for a total line length of 115 m. Once the geophone line was placed, data was collected at 4 separate shot locations using an 8 kg sledgehammer impacted against a steel plate as the seismic source. The first shot was located 115 m from the first geophone (230 m from the last geophone), and subsequent shots were moved along the line in 115 m increments. At each shot location, 5 hammer strikes were stacked into a single shot gather in order to improve the signal to noise ratio. Once data was collected for all 4 shots the line was moved 230 m to the east along the transect, and the data collection was repeated for 4 more shot locations. The geophone line was placed in a total of 10 different locations, spanning a distance of 2070 m between the position of geophone #1 on the first line and the position of geophone #1 on the last line. Placement of the shots provided a reflection sampling point every 2.5 meters along this transect. See Figs 1C and D for an illustration of the survey geometry.

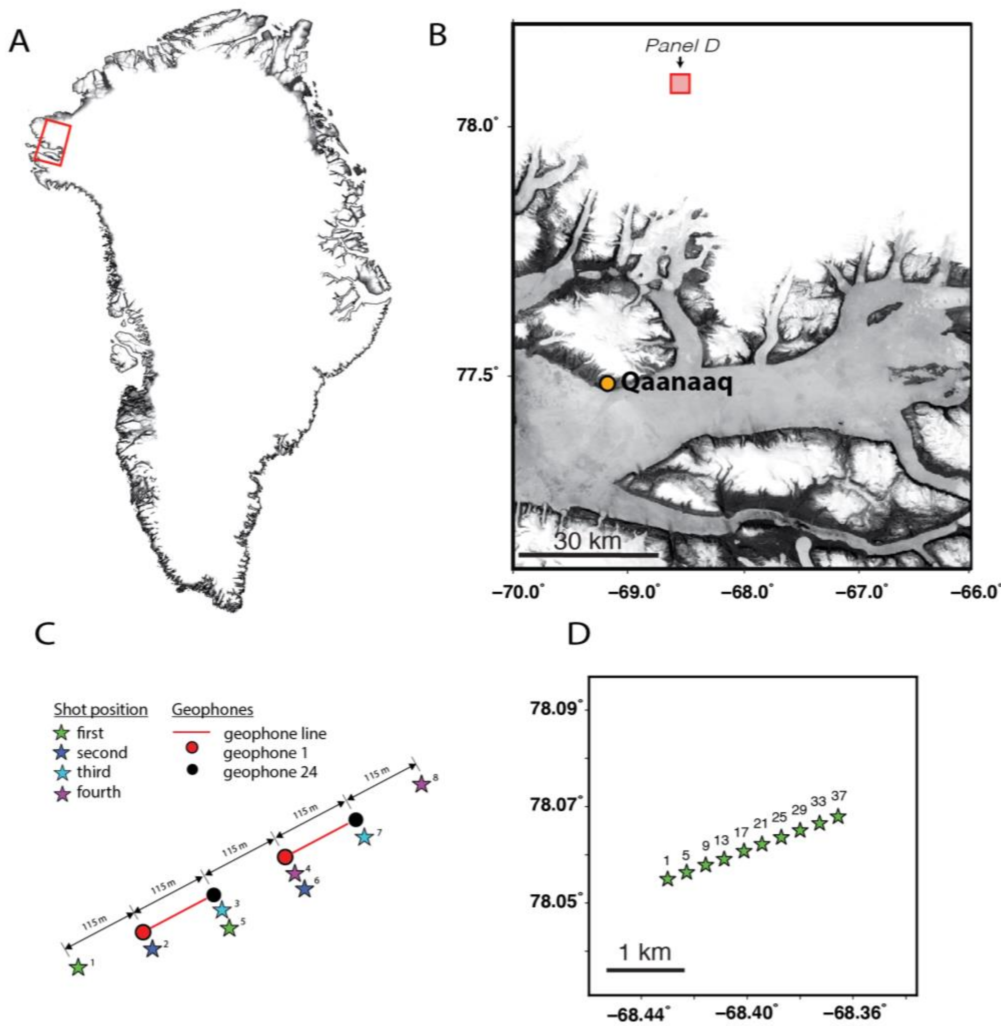

Figure 1. (Modified from Maguire et al. 2020 - to be submitted to Geophysical Research Letters) *(A) Map of Greenland. The red rectangular region indicates the study area. (B) Close up satellite image of the study area (red rectangular region in panel A). (C) Diagram depicting the geometry of the moving geophone lines used in the active source experiment. The stars indicate hammer shot locations and the red and black circles indicate the location of the first and last geophone of a line, respectively. The stars are colored by their position along the line, and labels to the right of each shot give the overall shot number. Two geophone lines are drawn to show that the third shot location of one line becomes the first shot location of the next line. (D) Map*

showing the first shot location for each of the 10 geophone lines used in the survey. The overall shot number in the survey is also shown.

3. Dataset information

The active source seismic dataset is provided in SEGY format. Each SEGY file contains data for a single shot gather (i.e., 24 traces). There are a total of 40 files which are named by their location along the seismic transect, starting from the southwest (see Figure 1C). Data was collected with a sampling rate of 16000 samples per second (i.e., a sampling interval of 62.5 microseconds), and every trace is 1 s in duration (i.e. 16000 total samples). Note that since the SEGY trace header stores the sampling interval as 2-byte data, the true sampling interval of 62.5 microseconds can not be accurately represented. The sampling interval in the SEGY trace header is instead given as 62 microseconds, so a 0.5 microsecond correction should be applied to get the true sampling rate. An example of the raw data from file "shot_001.sgy" is shown in Figure 2. The latitude and longitude information of the shots and receivers is not stored in the SEGY headers. Instead, we provide a plain text file "shot_locations.txt", which contains all necessary geographic data (see also Table 1 below).

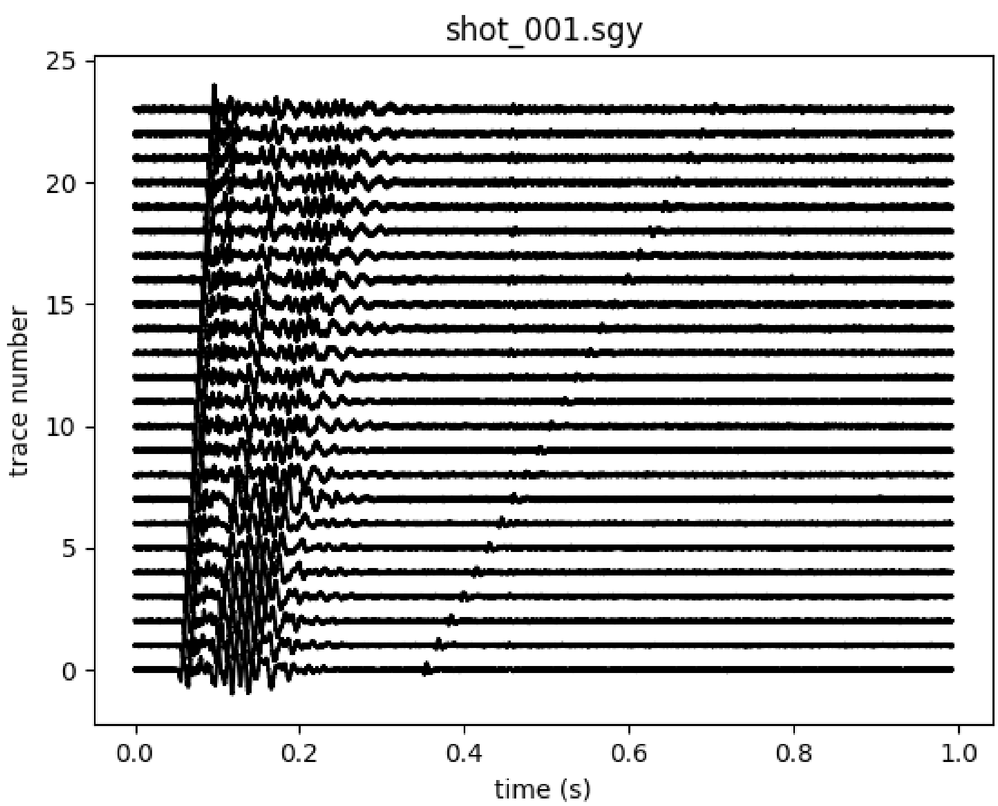

Figure 2.

Raw data contained in the file "shot_001.sgy". There are a total of 24 traces. Each trace contains 16000 data points sampled at 16000 samples per second. The offset between the source and the first geophone is 115 m.

shot #	filename	lat (geophone 1)	lon (geophone 1)	offset (m)	total offset (m)	Line #	elevation (m)	azimuth
1	shot_001.sgy	78.05494	-68.43001	-115	0	Line1	1359	45
2	shot_002.sgy	78.05494	-68.43001	0	0	Line1	1359	45
3	shot_003.sgy	78.05494	-68.43001	115	0	Line1	1359	45
4	shot_004.sgy	78.05494	-68.43001	230	0	Line1	1359	45
5	shot_005.sgy	78.05635	-68.42283	-115	230	Line2	1355	45
6	shot_006.sgy	78.05635	-68.42283	0	230	Line2	1355	45
7	shot_007.sgy	78.05635	-68.42283	115	230	Line2	1355	45
8	shot_008.sgy	78.05635	-68.42283	230	230	Line2	1355	45
9	shot_009.sgy	78.05787	-68.41564	-115	460	Line3	1360	45
10	shot_010.sgy	78.05787	-68.41564	0	460	Line3	1360	45
11	shot_011.sgy	78.05787	-68.41564	115	460	Line3	1360	45
12	shot_012.sgy	78.05787	-68.41564	230	460	Line3	1360	45
13	shot_013.sgy	78.05908	-68.40867	-115	690	Line4	1357	45
14	shot_014.sgy	78.05908	-68.40867	0	690	Line4	1357	45
15	shot_015.sgy	78.05908	-68.40867	115	690	Line4	1357	45
16	shot_016.sgy	78.05908	-68.40867	230	690	Line4	1357	45
17	shot_017.sgy	78.06075	-68.40117	-115	920	Line5	1355	45
18	shot_018.sgy	78.06075	-68.40117	0	920	Line5	1355	45
19	shot_019.sgy	78.06075	-68.40117	115	920	Line5	1355	45
20	shot_020.sgy	78.06075	-68.40117	230	920	Line5	1355	45

21	shot_021.sgy	78.06218	-68.39438	-115	1150	Line6	1351	45
22	shot_022.sgy	78.06218	-68.39438	0	1150	Line6	1351	45
23	shot_023.sgy	78.06218	-68.39438	115	1150	Line6	1351	45
24	shot_024.sgy	78.06218	-68.39438	230	1150	Line6	1351	45
25	shot_025.sgy	78.0636	-68.38708	-115	1380	Line7	1365	45
26	shot_026.sgy	78.0636	-68.38708	0	1380	Line7	1365	45
27	shot_027.sgy	78.0636	-68.38708	115	1380	Line7	1365	45
28	shot_028.sgy	78.0636	-68.38708	230	1380	Line7	1365	45
29	shot_029.sgy	78.06505	-68.37998	-115	1610	Line8	1358	45
30	shot_030.sgy	78.06505	-68.37998	0	1610	Line8	1358	45
31	shot_031.sgy	78.06505	-68.37998	115	1610	Line8	1358	45
32	shot_032.sgy	78.06505	-68.37998	230	1610	Line8	1358	45
33	shot_033.sgy	78.06651	-68.37261	-115	1840	Line9	1364	45
34	shot_034.sgy	78.06651	-68.37261	0	1840	Line9	1364	45
35	shot_035.sgy	78.06651	-68.37261	115	1840	Line9	1364	45
36	shot_036.sgy	78.06651	-68.37261	230	1840	Line9	1364	45
37	shot_037.sgy	78.06791	-68.36563	-115	2070	Line10	1365	45
38	shot_038.sgy	78.06791	-68.36563	0	2070	Line10	1365	45
39	shot_039.sgy	78.06791	-68.36563	115	2070	Line10	1365	45
40	shot_040.sgy	78.06791	-68.36563	230	2070	Line10	1365	45

Table 1. Summary of the active source survey shot locations. For each shot, the name of the SEGY format file is given, as well as the latitude and longitude of the first geophone on the line. The variable “offset” gives the distance between the source and geophone 1. Negative or positive values indicate that the shot was to the west or east of geophone 1, respectively. The total offset is the distance along the transect, starting in the west.

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