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OBS deployment and piston coring of slope failures

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2014

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Publications in this series have not been edited; they are released as submitted by the author.

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1 Overview

The Seafloor Earthquake Array–Japan-Canada Cascadia Experiment (SeaJade) is a multiyear, two-phase collaboration involving the Geological Survey of Canada (GSC), Japan Agency for Marine Earth Science and Technology (JAMSTEC), and the University of Victoria. The present phase of the NRCan-JAMSTEC collaboration is defined by the *Implementation Agreement for A Cooperative Project on Seismicity and Structure of the Northern Cascadia Subduction Zone*, under an MOU between NRCan and JAMSTEC. A first phase of SeaJade consisted of the successful deployment of 32 short-period ocean bottom seismometers (OBS) from JAMSTEC using the CCGS John P. Tully from July to October 2010. The OBS instruments detected more than 1400 earthquakes during their 3-month deployment, ranging in magnitude from about zero to 3.8. Most of these earthquakes were located along the Nootka fault zone, while only a few tens of events occurred beneath the continental slope and shelf. Based on the low rates of seismicity from SeaJade-I, it was felt that a 3-month recording period was insufficient to determine the general seismicity pattern. In SeaJade-II, we deploy 35 ocean bottom seismometers for a period of 10 months.

Figure 1 shows the proposed OBS deployment locations (also listed in Table 1, with additional technical details in Table 2), superimposed on the seismicity determined from SeaJade-I. Compared to SeaJade-I, the OBS instruments are more closely spaced at the Nootka fault zone, with about the same spacing south of Nootka. The main questions to be addressed in SeaJade-II are:

1) Can we confirm the low level of seismicity along the Cascadia megathrust recorded during SeaJade-I, and can we locate this seismicity generally? What are the implications of the seismic quiescence to the locking state of the megathrust?

2) Can we determine the detailed structure of the Nootka Fault Zone (NFZ), particularly the landward limit of the plate boundary seismicity as the fault goes beneath the Vancouver Island margin? How does the kinematics of the NFZ affect the seismogenic behavior of the megathrust to both sides?

Additional objectives for this expedition include the recovery of piston cores at submarine land-slides to study the recurrence of megathrust earthquakes on the Cascadia subduction zone and on the Explorer Plate, north of the NFZ. This work is a continuation of coring conducted in 2008 during cruise 2008007PGC, where several failure masses were cored successfully for the determination of a megathrust earthquake recurrence cycle.

During transit between OBS stations, acoustic sub-bottom profiler data were acquired (Table 4) when weather permitted using the hull-mounted sounders installed on the CCGS John P. Tully. Coincident 12/18/38 kHz echo sounder data were also recorded with the aim to detect sites of gas emissions.

During the expedition, we also tested a shallow-water (<200m) multibeam system (WASSP), deployed on the port-side of the back deck. This was a first-time deployment test, trying to define functionality of the system.

Prior to the actual SeaJade-II expedition, all OBS deployment locations were discussed with Chris Acheson (Canadian Sablefish Association), Barry Ackermann (Groundfish Trawl Coordinator, Pacific Region Fisheries and Aquaculture Management Branch Fisheries and Oceans Canada) and Brian Mose (Canadian Groundfish Research and Conservation Society) to avoid accidental trawling of any of the JAMSTEC OBS (which are not trawl-resistant in their design).

A meeting with US and Canadian Navy representatives were held (Wayne Estabrooks, International and Interagency Policy and Agreements, Office of the Oceanographer of the Navy) on November 28, 2012 at the University of Victoria prior to the deployment as it was done for SeaJade-I in 2010. The Navy representatives agreed to the same data policies as in 2010 (which is an open free exchange of all data between collaborators, no filtering of any data set and no withholding of any data over a specific time-period). The Navy representatives expressed interest to receive a copy of the data upon recovery in 2014.

A permit for operating all sounders and the multibeam system was also secured from DFO (Paul Cottrell, DFO Vancouver) in accordance to the Marine Mammal protection legislation in Canada. However, due to the far-distant work offshore beyond the 12 nautical mile zone, no consultation with First Nation communities was needed.

Two scientists and two technicians from JAMSTEC participated in the offshore expedition, as well as work related to the preparation and post-expedition demobilization at the dock/hangar facilities of the Institute of Ocean Sciences in Sidney, BC. JAMSTEC personnel provided all technical handling of the OBS, including mounting of anchors, antennae, and flash-lights as well as programming of each individual OBS. Deployment on the aft-deck of the vessel was carried out by NRCan and Coast Guard personnel according to NRCan and Coast Guard standard offshore operating procedures.
Prior to the cruise, 35 OBSs were shipped from Japan to Sidney in a 20-ft temperature-controlled container via ocean freight as temporarily imported scientific instruments under E29B. Tools and other parts were air transported to Sidney under an ATA Carnet and shipped back to Japan after the cruise with the Carnet closed. King Brothers Co. in Canada and Crown Lines Transportation in Japan jointly arranged the shipping and Customs paperwork.

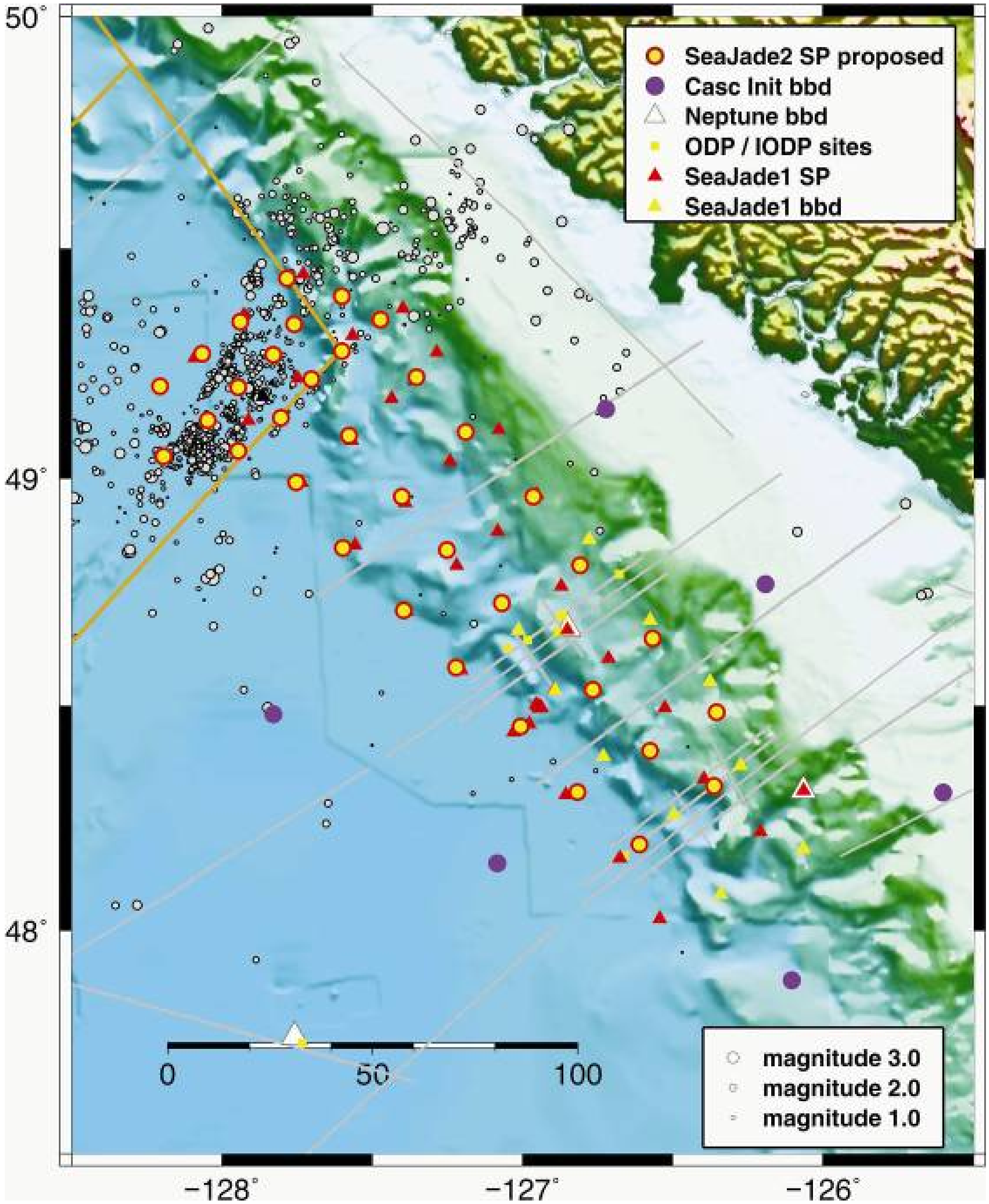


Figure 1: Map of the grid of OBS that were deployed during SeaJade-II operations with CCGS John P. Tully. Earthquakes as detected from SeaJade-I OBS (short period (SP), and broad band (bbd)) are shown as grey dots. Regional seismic data acquired in 1989 are also shown as grey lines; [Cascadia Initiative bbd: Stations of the US-based Cascadia Initiative broad-band seismometers; Neptune bbd: permanently installed broad-band seismometer along cabled observatory].

2 Cruise Narrative

Note: All times report in this section 2 are local time, i.e. Pacific Daylight Time (PDT).

Thursday, November 28

10pm Departure
Loading completed by 17:00, making all gear sea-fast

Friday, November 29

12:15
At WP-1, test of 3.5 kHz system, running line at 4 knots over vent-feature on South-side of Barkley-Canyon
Plume detected again in 12/18 kHz sounders
Good record of vent-feature in 3.5 kHz;
13:10
Line completed, shut off 3.5 system (Line #1)
Back to 10 knot speed, heading to OBS-1
13:30
Science Presentation by M. Riedel in main dry-lab to Crew about Cruise objectives

15:26
OBS STN 1 (JAMSTEC Internal OBS #146)
There are three different numbers assigned to each OBS deployment location: Original proposed location (1-35), a station number sequentially increasing throughout the expedition for the GSC Expedition Database (ED), and an OBS-identifier for the instrument itself (JAMSTEC internal numbering). In this Narrative, the ED station numbers are omitted;
Each OBS deployment includes a triangulation effort at three sites (T_1, T_2, T_3), ~500m away from the central deployment location;

Running lines with 3.5 kHz across slump in vicinity of the OBS locations
Acquiring Line #2, #3, #4, #5

19:10
OBS STN 8 (JAMSTEC Internal OBS #33)

20:57
OBS STN 15 (JAMSTEC Internal OBS #156)

22:50
OBS STN 9 (JAMSTEC Internal OBS #166)
23:40
Completed triangulation OBS STN 9, after initial difficulties to acoustically talk to OBS
Acquiring 3.5 kHz line #6

Saturday, November 30

01:10
OBS STN 2 (JAMSTEC Internal OBS #147)
Acquiring 3.5 kHz line #7

03:42
OBS STN 3 (JAMSTEC Internal OBS #134)
Acquiring 3.5 kHz line #8

06:10
OBS STN 10 (JAMSTEC Internal OBS #39)

08:06
OBS STN 16 (JAMSTEC Internal OBS #9)
08:45
Triangulation completed

10:17
OBS STN 17 (JAMSTEC Internal OBS #59)
11:00
Triangulation completed

12:30
OBS STN 11 (JAMSTEC Internal OBS #77)
13:20
Triangulation completed

Until this point we recognized that there was no need to reduce ship noise, as required during the SeaJade-I expedition, including no shut-off of the hull-protection (anti-corrosion), or de-clutching of the entire engine.

Acquiring 3.5 kHz line #9
Crossing slump-feature and fault-trace in abyssal plain

15:00
OBS STN 4 (JAMSTEC Internal OBS #125)
15:55
Triangulation complete

Acquiring 3.5 kHz line #10 between OBS positions #4 and #5

17:10
OBS STN 5 (JAMSTEC Internal OBS #157)
18:02
Triangulation complete

After deployment, tracing the OBS to the bottom, and completing triangulation at all 3 positions takes approximately 1 hour.
Steaming between stations, is weather (wind/wave) dependent, but on average took 1 hour to 1hour + 15 minutes
For further planning purposes of the cruise, each station is 2.5 hours (not quite 4 days in total)

18:12
Acquiring 3.5 kHz line #11 across slump feature
18:51
EOL 11

19:32
OBS STN 12 (JAMSTEC Internal OBS #43)
20:20
Triangulation complete

21:46
OBS STN 18 (JAMSTEC Internal OBS #129)
22:21
Triangulation complete

23:47
OBS STN 19 (JAMSTEC Internal OBS #87)

Sunday, December 1

01:30
Triangulation complete

01:53
OBS STN 13 (JAMSTEC Internal OBS #19)
02:44
Triangulation complete

02:55
Acquiring 3.5 kHz line #12 across slump feature
04:33
EOL 12

04:42
OBS STN 6 (JAMSTEC Internal OBS #126)
05:48
Triangulation complete

05:51
Acquiring 3.5 kHz line #13

Strong winds developed, up to 30 knots, data degraded
06:53
EOL 13

07:05
OBS STN 7 (JAMSTEC Internal OBS #1)
08:00
Triangulation complete

08:02
Acquiring 3.5 kHz line #14 over slump feature
08:55
EOL

09:15
OBS STN 14 (JAMSTEC Internal OBS #96)
Winds dropped back to ~ 15 knots

09:40
After first triangulation point T1, tracing the OBS to the bottom, we held station to move OBS from upper loading deck to main back deck;

11:55
OBS STN 20 (JAMSTEC Internal OBS #88)
12:31
Triangulation complete

12:45
Winds picked up again, 30-40 knots; this was the predicted first storm of the cruise

13:42
OBS STN 25 (JAMSTEC Internal OBS #57)
14:20
Triangulation complete

15:09
OBS STN 24 (JAMSTEC Internal OBS #39)
15:55
Triangulation complete

16:57
OBS STN 23 (JAMSTEC Internal OBS #160)

17:55
Triangulation complete

Over night, wind and waves would build and we could not deploy OBS at night; carrying of equipment from lab to A-frame too risky;
We would run weather lines for the night, minimizing motion on vessel;

18:30
WOW - waiting on weather

Monday, December 2

07:00
WOW - waiting on weather
Up to 60 knot wind in gusts

After lunch, we re-assessed the situation of deploying OBS
Overall winds and waves would decline steadily

12:28
OBS STN 22 (JAMSTEC Internal OBS #133)

Sea was at 4m wave height and 25 knot winds

13:19
Triangulation missed station T3; completed T2 only

14:50
OBS STN 21 (JAMSTEC Internal OBS #139)

Issues remained with heavy seas and wind for the night shift crew;
We decided to deploy a set of OBS, trace the instrument to the seafloor (at the equivalent T1-triangulation spot only), and complete triangulation at the T2 and T3 positions afterwards at night, without poising a health & safety concern to people working at night;

16:54
OBS STN 27 (JAMSTEC Internal OBS #118)
Deployed and traced OBS to seafloor and T1 triangulation measurement

18:38
OBS STN 33 (JAMSTEC Internal OBS #11)
Deployed; shorter distance to this OBS to deploy more station in daylight
19:38
All triangulation completed

23:13
OBS 22 T3 redone

Tuesday, December 3

00:48
OBS 21 T2 triangulation
01:01
OBS 21 T3 triangulation

01:53
OBS 27 T2 triangulation
02:05
OBS 27 T3 triangulation

Through the night weather improved significantly, winds down to 5 knots, waves 2 meters maximum

03:19
OBS STN 26 (JAMSTEC Internal OBS #63)
04:23
Triangulation complete

05:35
OBS STN 32 (JAMSTEC Internal OBS #141)
06:30
Triangulation complete

06:49
Acquiring 3.5 kHz line #15 to OBS 28

07:42
OBS STN 28 (JAMSTEC Internal OBS #15)
08:35
Triangulation complete

Acquiring 3.5 kHz data across the Mud-Volcano - excellent data quality
Lines #16, 17, 18, 19, 20, 21

12:04
OBS STN 29 (JAMSTEC Internal OBS #148)
12:54
Triangulation complete

Acquiring 3.5 kHz data to OBS 34 crossing northern limit of the Nootka Fault zone, line #22
13:37
OBS STN 34 (JAMSTEC Internal OBS #107)
14:28
Triangulation complete

14:30
Acquiring 3.5 kHz data crossing northern limit of the Nootka Fault zone, line #23
15:16
EOL
15:19
OBS STN 30 (JAMSTEC Internal OBS #70)
16:08
Triangulation complete

17:05
OBS STN 31 (JAMSTEC Internal OBS #82)
17:51
Triangulation complete

18:58
OBS STN 35 (JAMSTEC Internal OBS #84)
20:14
Triangulation completed
Slight problems with T3 position, noisy signal
Repeated approach 3 times, also switching off thrusters (ship is drifting more), but last attempt completed triangulation successfully

End of OBS deployments

For the remainder of the night we would run a series of 3.5 kHz lines to image hopefully portions of the NFZ as well as the location of the submarine slope failure;
20:45
SOL for line survey (lines #24 - #38)

<u>Wednesday, December 4</u>

09:30
At core position #1
Throughout morning, setting up coring gear while continuing to run lines

10:00
Pinger attached to core, lowering to seafloor
Difficulties to trace core in the 12 and 18 kHz echo sounders

11:30
Core on deck
STN 36, core #1: 7.09 m recovery

13:00
Rigging up for 2nd core

13:35
Core hit bottom; slight relax in tension on wire and block on A-frame

14:50
Core on deck
STN 37, Core #2: 5.07m recovery

Rigging up for 3rd core of the day

16:27
Core hit bottom

17:30
STN 38, Core #3: 3.21m recovery

Started steaming to multibeam test site in 200m shallow water
Near location of Huntec line acquired in 2012

While running across to multibeam test site, we saw 2 gas flares
UTC: 02:42
UTC 03:05

19:56
Deployment of multibeam system
Test of deployment of pole worked fine, but GPS cable problems

21:20
Aborted test, broken wire in GPS connection
Go to WP46 for core-site survey

<u>Thursday, December 5</u>

Over night, steamed to WP 46 and acquired 3.5 kHz data
In the morning after 6:00am, picking of 3 core sites

#4	48.58082, -127.16868
#5	48.58916, -127.16743
#6	48.60400, -127.16489

09:02
Core 4 deployed with pinger attached
09:41
Core hit bottom

10:33
Core on deck

STN 39, Core #4, 5.66m recovery
Trigger core 0.83m

11:25
Core site #5, core going down
12:08
Core hit bottom
Upon recovery, problems with wires of trigger-core and main piston core: tangled;
13:21
Core safe on deck
STN 40, Core #5: 2.19 m recovery

Wire on coring-winch had twisted around trigger-core arm, but wire not broken, did not need to re-terminate

16:25
STN 41, Core #6 on deck
Bent barrel
STN 41, Core #6: 2.21 m recovery

17:00
Start of new 3.5 kHz line survey, but winds picked up to over 30 knots and course was not favourable relative to waves and wind
19:06
At OBS 3 position for re-doing T2

20:05
Ending line surveys, too much pitch, roll and heave, no data acquisition possible; 40 knot winds!
Running weather lines and hoping that weather improves by Friday morning;

Friday, December 6

07:00
Weather not improving at all; forecast says 25-30 knot winds and 4 meter seas all day
Abandoned coring and headed into Victoria for survey off town across Devil's Mountain Fault

Saturday, December 7

Over night running into the Juan de Fuca Straight, winds due east at 40-50 knots and strong tidal currents against us

At midnight: losing traffic-tracking device, impossible to cross traffic lane in JdF Straight, waiting until day light

07:00 start of some line across fault line
07:55
Deployed multibeam pole for second test
09:30
Survey for 3.5 kHz and multibeam going well
09:44
We got the GREEN LIGHT on the data acquisition software!
10:34
End of all surveying
Packed up and went to IOS
15:00
Tied up at IOS, unloading

End of Expedition 2013008PGC

3 Results

3.1 OBS Triangulation

The JAMSTEC OBSs (4.5-Hz three-component gimbal-mounted geophones and hydrophones) continuously record data with 16-bit digital recording at 100 Hz. All parts including sensors with gimbal-leveling mechanism, batteries and recorder are installed in a 17-inch glass sphere. A radio beacon (43.5880 M Hz) and flash light is attached to each OBS for assisting to find it at the sea surface when it is recovered. Each OBS is equipped with an acoustic transponder system, which controls the release mechanism and also is used for measuring the range between the OBS and the ship. The OBS can be released from its anchor by electric corrosion of stainless plates when a release-command is sent from the vessel (not performed during this expedition).

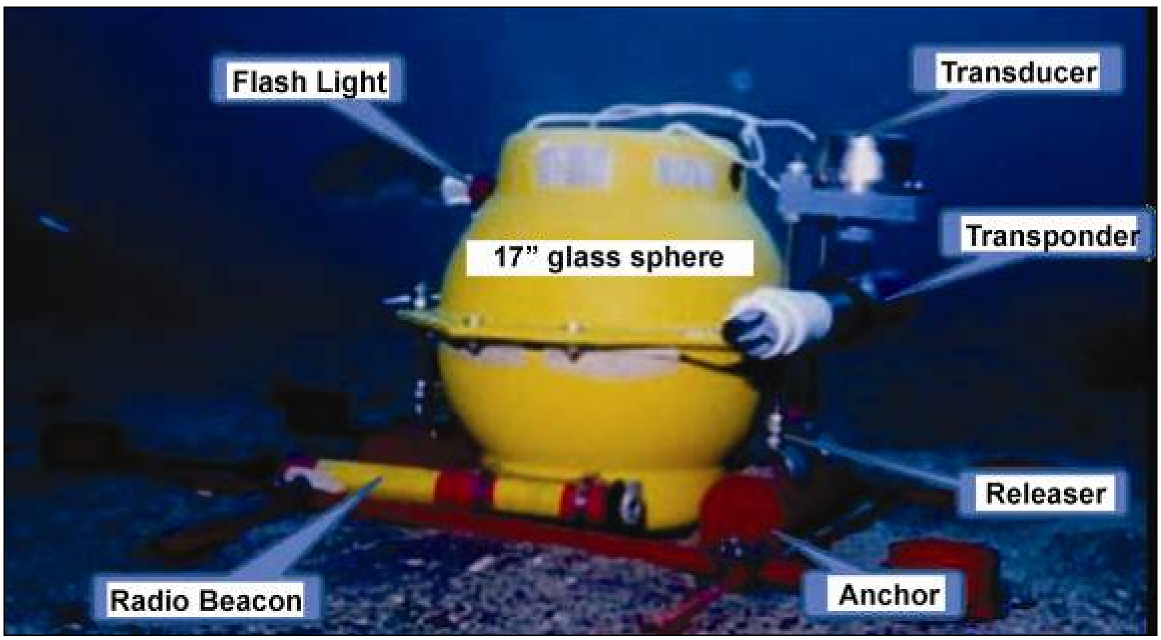


Figure 2 Photo of a JAMSTEC OBS used during Expedition 2013008PGC, with all technical features identified.

Figure 3. Image of the JAMSTEC OBSs stored on the upper deck above the lab prior to actual deployment. On this level, up to 18 OBS were stored, with the remaining OBS stored on the regular back-deck.

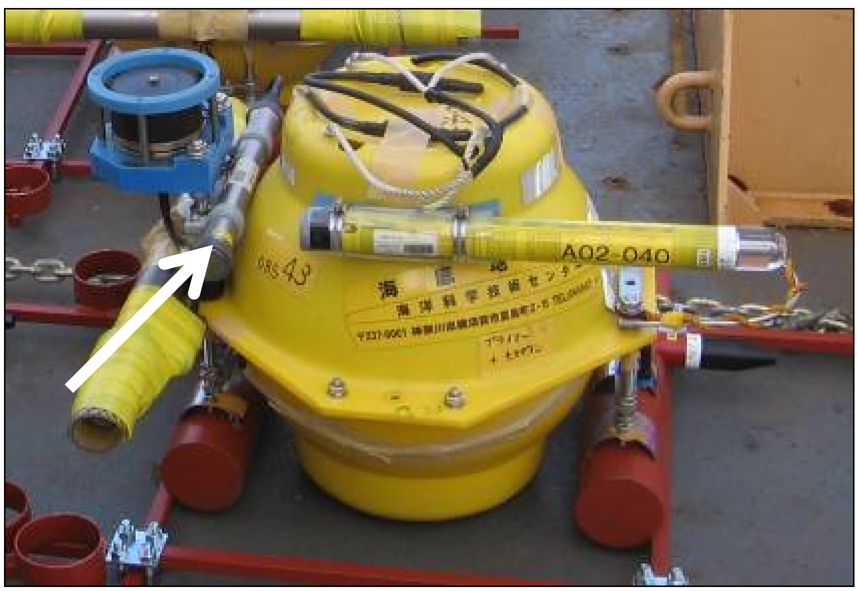


Figure 4. JAMSTEC OBS as used during expedition 2013008PGC with the additional battery pack (white arrow) at the transducer to allow for a 10 month deployment time.

At each of the OBS locations, the position of the instrument on the seafloor was determined using the acoustic triangulation technique. Three locations (T_1, T_2, T_3) around the OBS, at approximately 500m horizontal distance to the intended OBS drop-location, were used (120 degrees from each other, relative to geographic North). At each triangulation point, a transducer was deployed over the starboard side (depth so it cleared the hull of the vessel) and repeated acoustic signals were emitted to the OBS, which responded back to measure the distance between the OBS and the vessel. At the first triangulation point (T_1) the OBS was also traced through the water column to the seafloor to verify that the instrument landed and not self-released by accident. An example of a triangulation at OBS STN 01 is given in Figure 5, and all other examples are listed in the Appendix A.

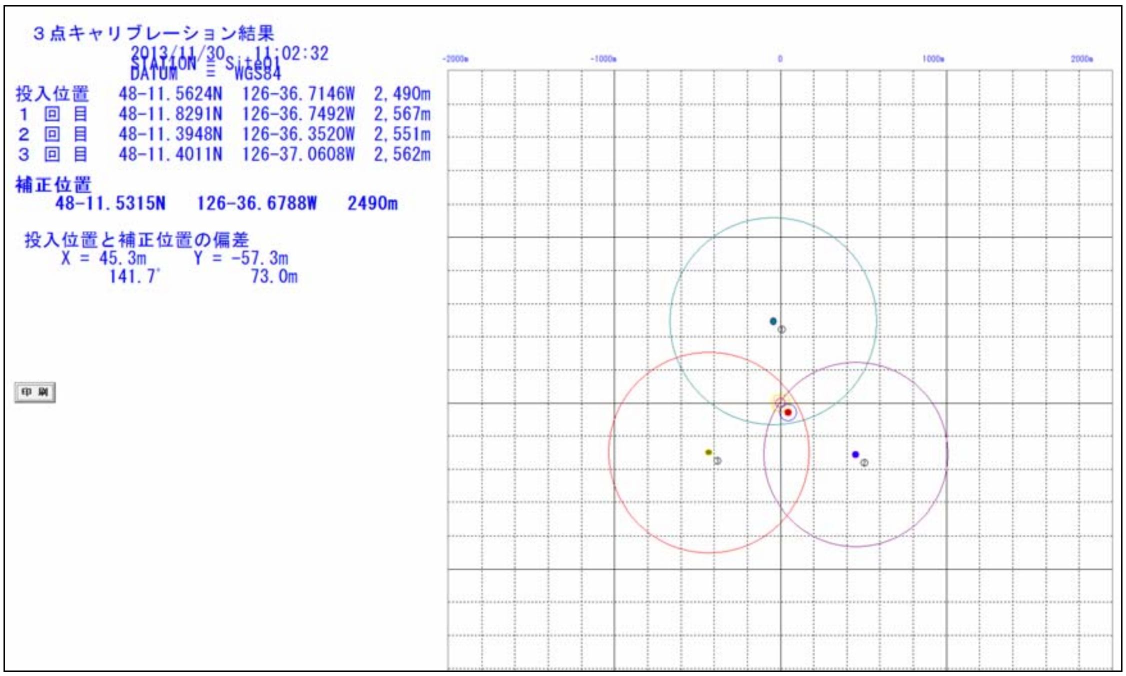
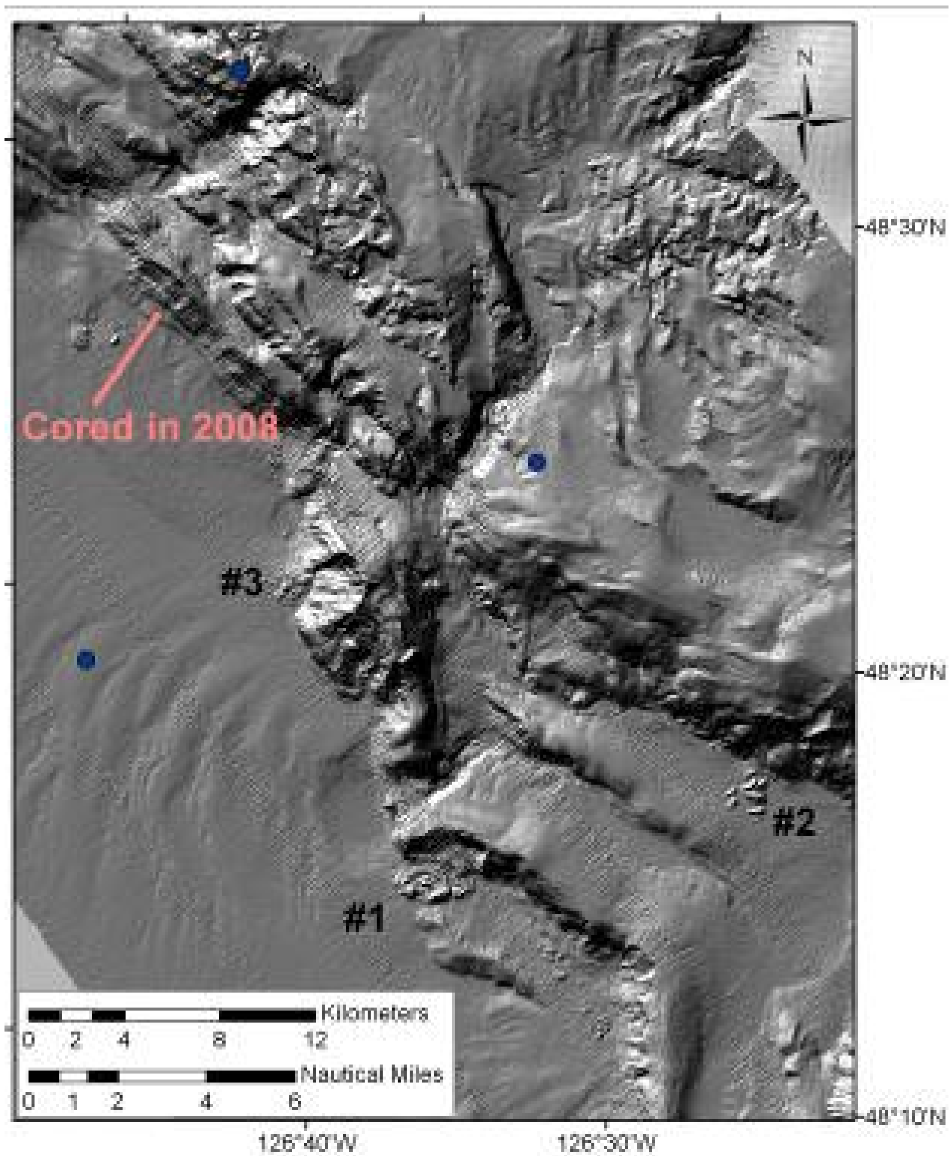


Figure 5. Example of a triangulation for OBS positioning at OBS STN 01 (screen snapshot from the PC used to compute the position onboard). The OBS was deployed at the centre of the plot (relative coordinate point is 0, 0), which was at a water depth of 2490 m. At the three triangulation points, the distances between OBS and ship were determined to 2567m, 2551m, and 2562m, respectively. This yields a best-fit position of the OBS at the location indicated by the red dot, where the circles around each triangulation point intersect.

3.2 Piston Coring

Piston coring was performed on selected submarine land-slide features. While deploying the grid of OBSs and following the cruise track from OBS-station to OBS-station, the vessel covered regions of known sub-marine landslides, which have been identified from high-resolution bathymetric maps, but have yet not been studied in detail for understanding of slide-processes, as well as their potential to record a history of failure deposits related to large earthquake shaking. Two land-slides were studied in 2008 and two transects of cores were recovered across the failure mass, which was the last time deep-water coring in excess of 2000m was attempted on the northern Cascadia margin. Mobilization for coring, which was started only a week prior to the expedition, involved mounting the 100 HP winch as well as the small starboard A-frame. Both these components were successfully installed and were operational for coring during this expedition, which is a large accomplishment in itself and based on the collaboration between Greg Middleton, IOS winch-shop, and Coast Guard. However, it should be noted that typically a longer-lead time for piston coring is required to ensure complete functionality of both, winch and A-frame. If coring is requested for the OBS recovery mission in 2104, integration with other expeditions mounted simultaneously (in terms of equipment availability and operators) are paramount and a minimum of 3-months lead-time prior to any coring mission is required.

Prior to the expedition, a specific set of sub-marine land-slides were identified as possible targets as they are close to a OBS location and when possible (weather and time permitting), 3.5 kHz sub-bottom profiler data were acquired across these features during the deployment phase (Figure 6). The data were then interpreted together with bathymetry, and slide-locations were ranked according to their potential for yielding cores with a turbidite record for re-constructing a history of large earthquake shaking. Two general types of submarine slope-failures can be identified on the margin: blocky-slides and debris-flow-type slides. Blocky-slides show intact slide-material, whereas the debris-flow-type slides show incoherent out-runner failure-masses.



<u>Figure 6.</u> Map of location with submarine slope failures imaged during expedition 2013008PGC on the southern portion of the study area of the Juan de Fuca Plate with three newly imaged slumps (#1, #2, #3); coring was not attempted at any of these locations, and slides #1 and #3 may also be compromised by existence of the large-scale sediment waves on the abyssal plain (Blue dots are OBS positions).

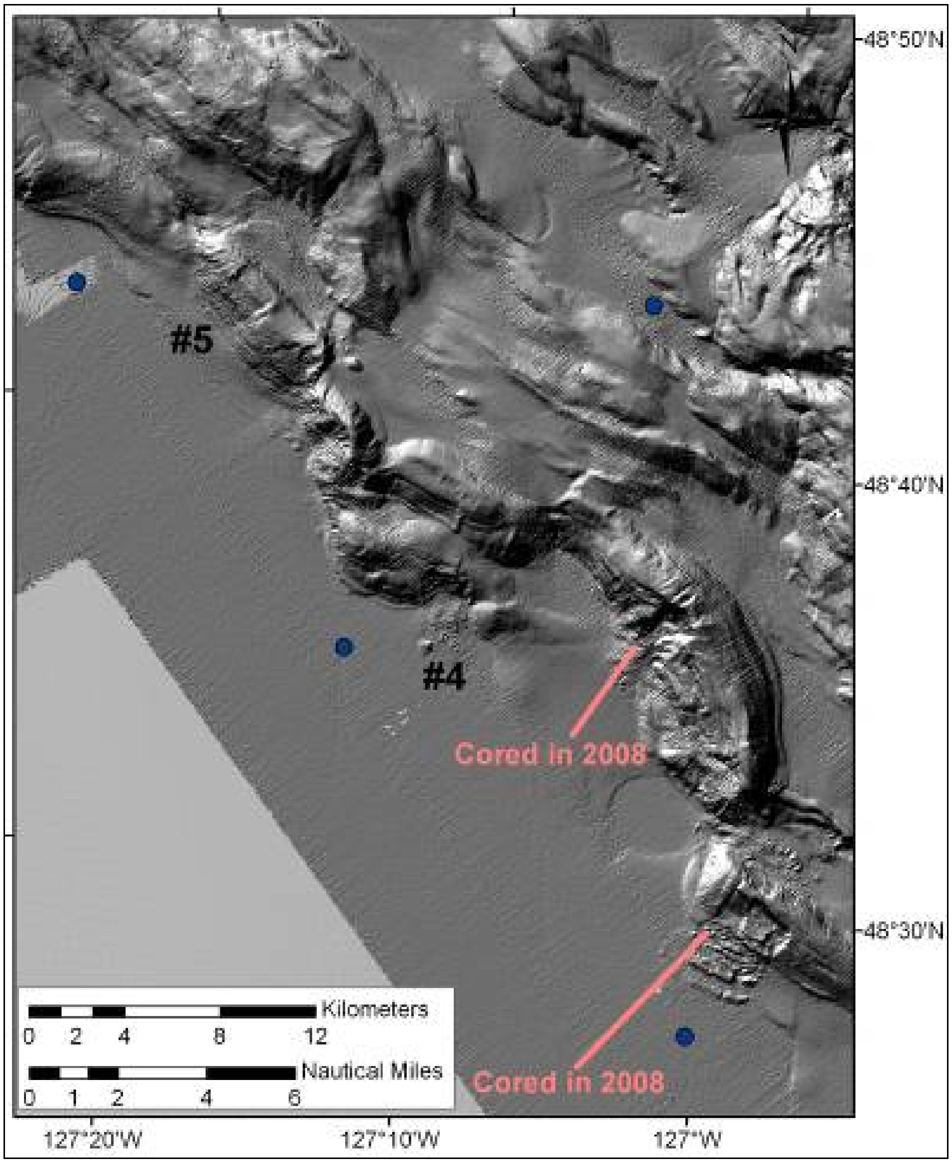


Figure 7. Map of location with submarine slope failures imaged during expedition 2013008PGC on the central portion of the study area of the Juan de Fuca Plate with two newly imaged slumps (#4, #5); coring was attempted at slide #4 (Blue dots are OBS positions).

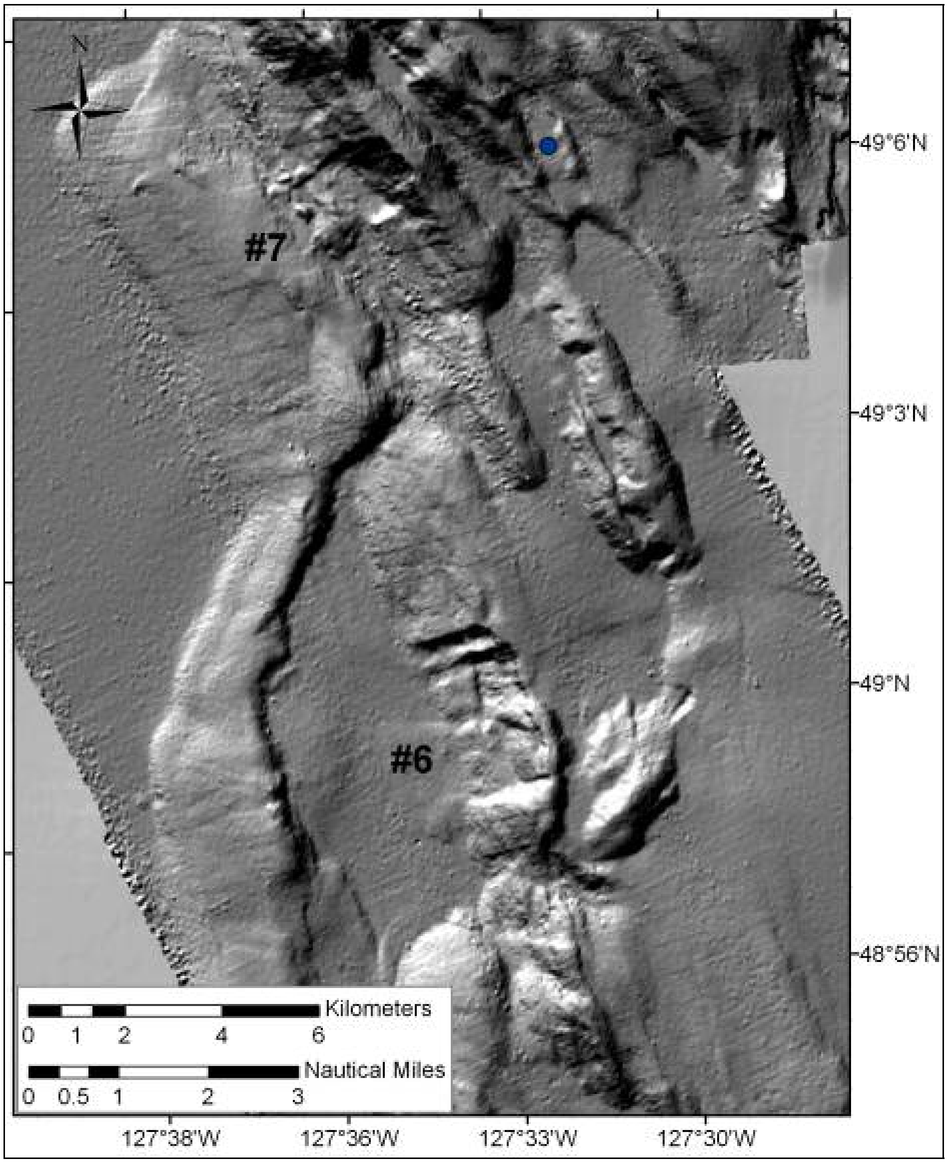


Figure 8. Map of location with submarine slope failures imaged during expedition 2013008PGC on the northern portion of the study area of the Juan de Fuca Plate with two newly imaged slumps (#6, #7); coring was not attempted at these slides (Blue dots are OBS positions).

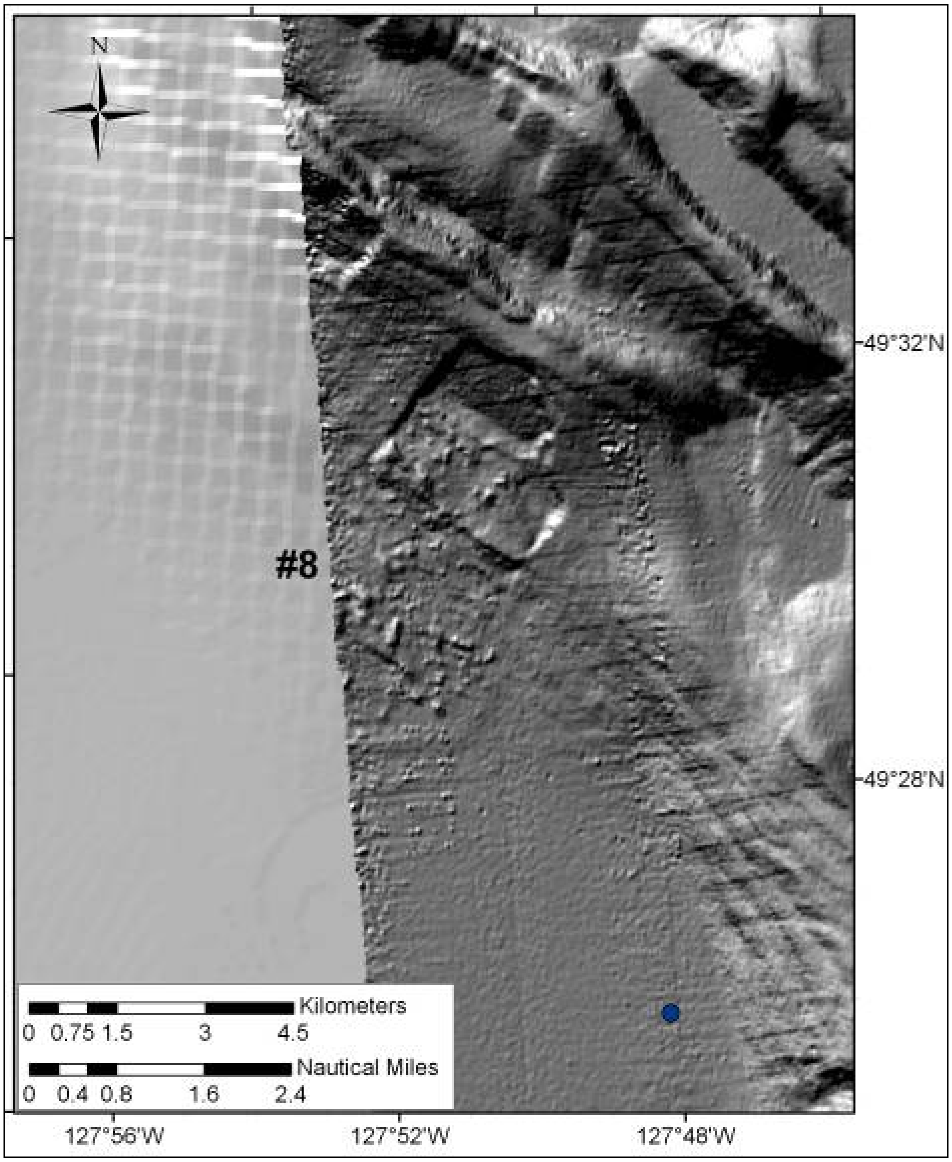
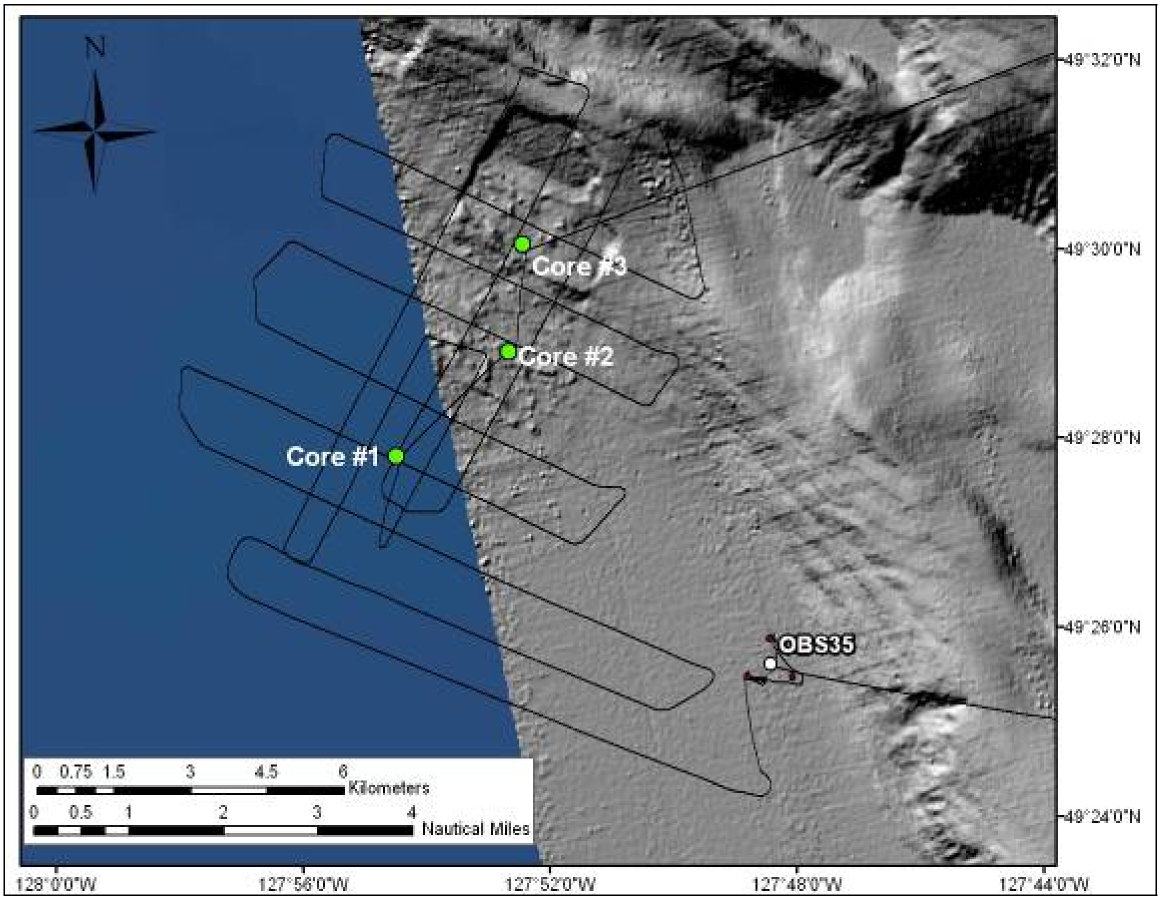


Figure 9. Map of location with submarine slope failures imaged during expedition 2013008PGC on the study area of the Explorer Plate with one newly imaged slump (#8); coring was attempted at this slide (Blue dots are OBS positions).

The highest priority slide (#8 in Figure 9) is located on the Explorer Plate, north of the NFZ and resembles that of a blocky slide similar to "Slip-Stream" slide studied in 2008, with sharp side-wall edges and semi-intact slide-blocks. This is the first slump-feature cored on the Explorer Plate to date.

Three cores were taken (Table 3) across the slump-feature with recoveries ranging from ~7m (Core 1), to ~5m (Core 2), and ~3m (Core 3), coinciding with expected penetration rates based on the acoustic reflectivity (or harness) of the sub-bottom profiler data.



<u>Figure 10.</u> Map of 3.5 kHz sub bottom profiler survey lines across slump-feature on Explorer Plate, North of OBS STN 35 and location of the three recovered cores at this site (STNs 36, 37, 38).

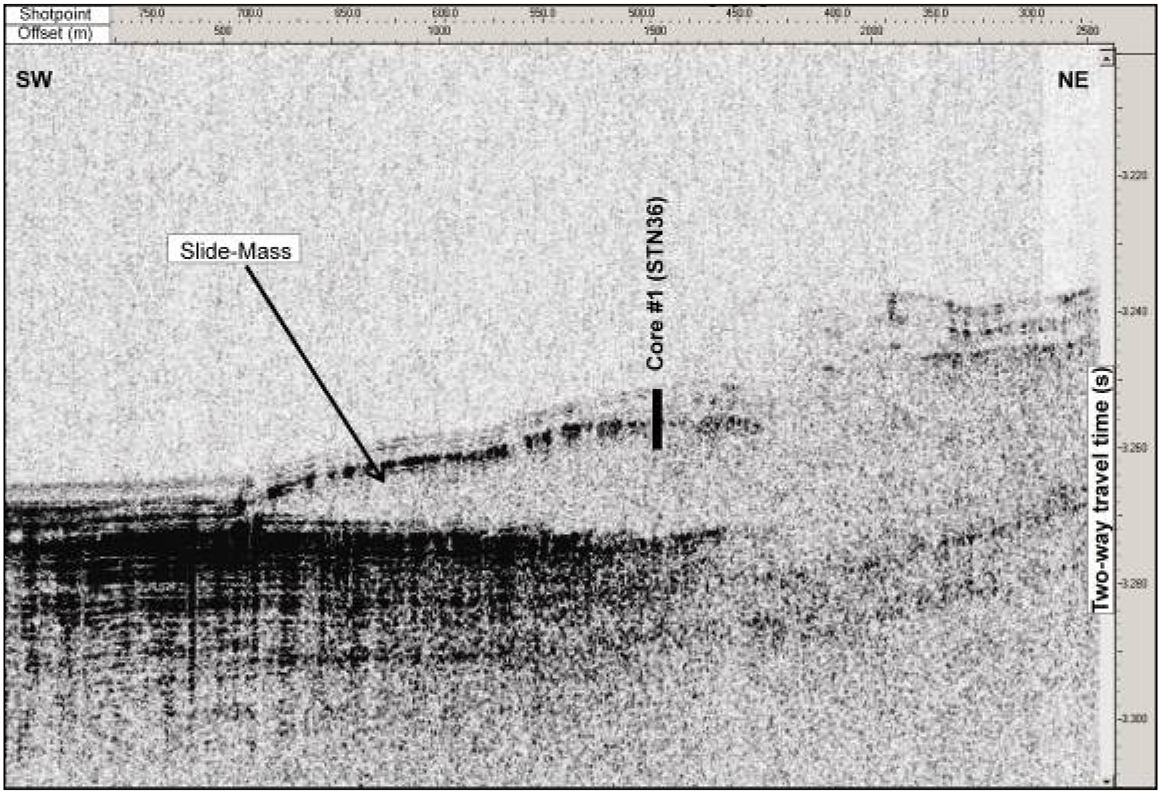


Figure 11. Example of 3.5 kHz data across core-1 (STN 36). The thick black line represents the approximate depth of recovery (~7m, or 9.6 ms two way time) using an average sediment compressional wave velocity value of 1500m/s.

A second slide was selected for coring on the Juan de Fuca Plate, north of the two slides targeted in 2008 and close to OBS STN 31. This slide feature resembles a debris-flow with one large out-runner block (Figure 12, 13). Three piston cores were recovered from this slide-feature, with recovery rates of ~5.6m (Core #4), ~2.2 (Core #5) and ~2.2m (Core #6). The last piston core was retrieved with a large bend in the lower barrel (Figure 14). The fact that ~2 meter of core were recovered and no other damage to the core cutting shoe or core catcher were seen indicates that the bend in the barrel may not have originated from impact (abrupt halt due to e.g. a boulder at depth), but may have been generated during pull-out when pulling at the coring-wire and off-station ship-drift (seas and wind had increased during that time significantly) may have caused shear and non-vertical pull-out direction. The material of this core was unique in that it was a very stiff, light-grey coloured clay, which was not encountered at any other previous coring location of this expedition.

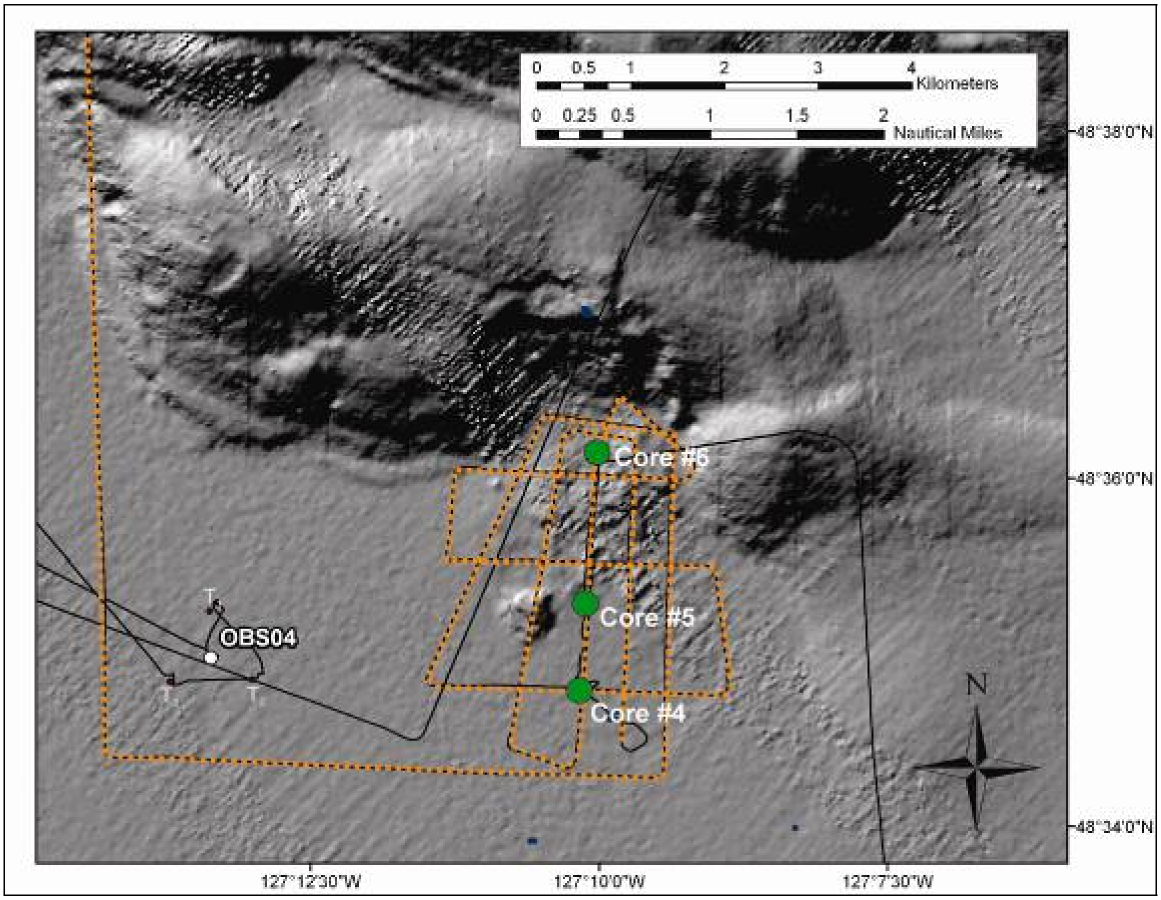


Figure 12. Map of ship track (black lines) and 3.5 kHz sub bottom profiler survey lines (orange dotted lines) across slump-feature on Juan de Fuca Plate, east of OBS STN 04 and location of the three recovered cores at this site (Cores #4, #5, and #6 or STNs #39, #40, and #41, respectively).

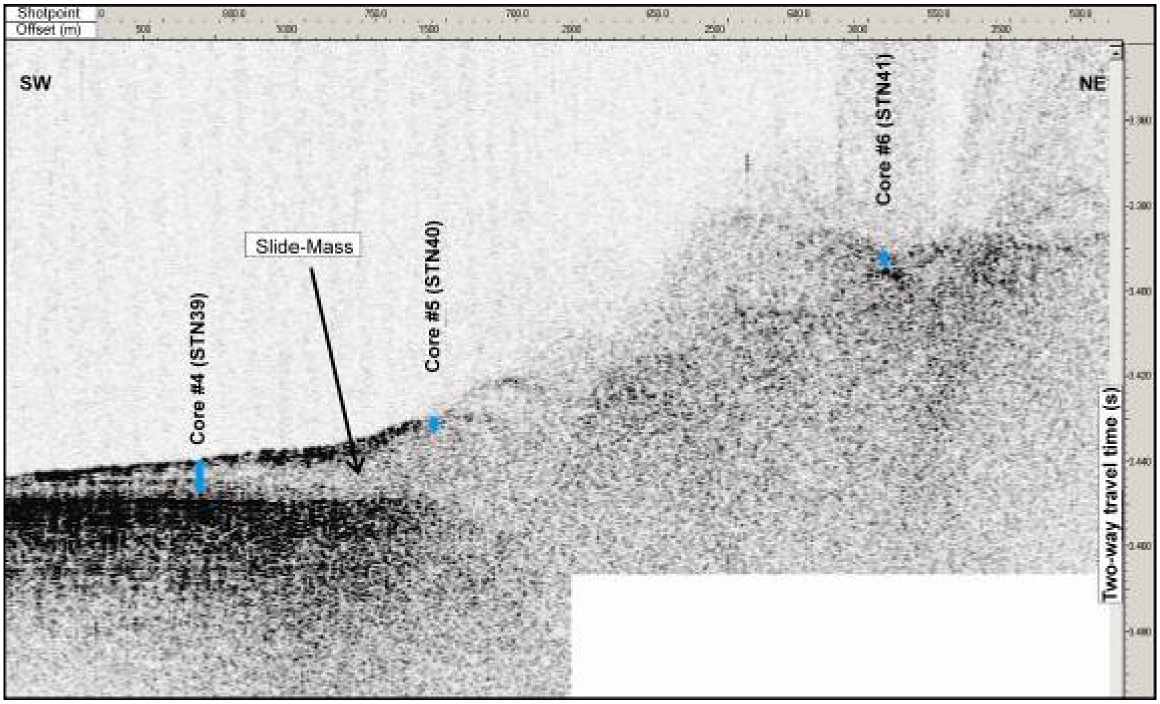


Figure 13. Example of 3.5 kHz data across all three cores (STN #39, $40, and #41). The thick blue lines represent the approximate depth of recovery for each core (~5.6m, or 7.5 ms two way time at Core #4, STN #39, and ~2.6 m or ~3ms two way time at Cores #5, and #6, STN #40, and #41, respectively) using an average sediment compressional wave velocity value of 1500m/s. Seafloor around core #6 is obstructed by rough topography and side-swipes from the nearby steep slump-scar.

Figure 14. The bottom 10' long core barrel that was bent during recovery of Core #6.

3.3 Devil's Mountain Fault Survey

Due to the extreme weather conditions on the open Pacific Ocean (with a forecast of extended period of high winds of 30 knots and high seas of 3-4 meters, not allowing any further coring), we decided to abandon the operations and head into the Juan de Fuca Strait for a survey of the Devil's Mountain Fault (DMF) as continuation of the survey conducted here in April 2013 as part of Expedition 2013002PGC on the CCGS Vector (Figure 15). Due to the easterly winds up 40-50 knots and tidal currents, the approach to the area was slowed down significantly. In addition, the loss of the navigational radar system for ship-identification, we had to stay outside of the main shipping route (which is in the middle of the intended survey zone) until first daylight.

In total, four lines were acquired with the 3.5 kHz sub bottom profiler crossing the fault-system in the morning of December 7th, 2013. After the initial line, the multibeam pole was also deployed (See below for more details). The survey was stopped at ~10:30 am to allow for complete dismounting of all systems (lab and deck) and an arrival at IOS for unloading by 15:00. Figures 16 shows an example of the lines acquired across the DMF with the 3.5 kHz sub bottom profiler system.

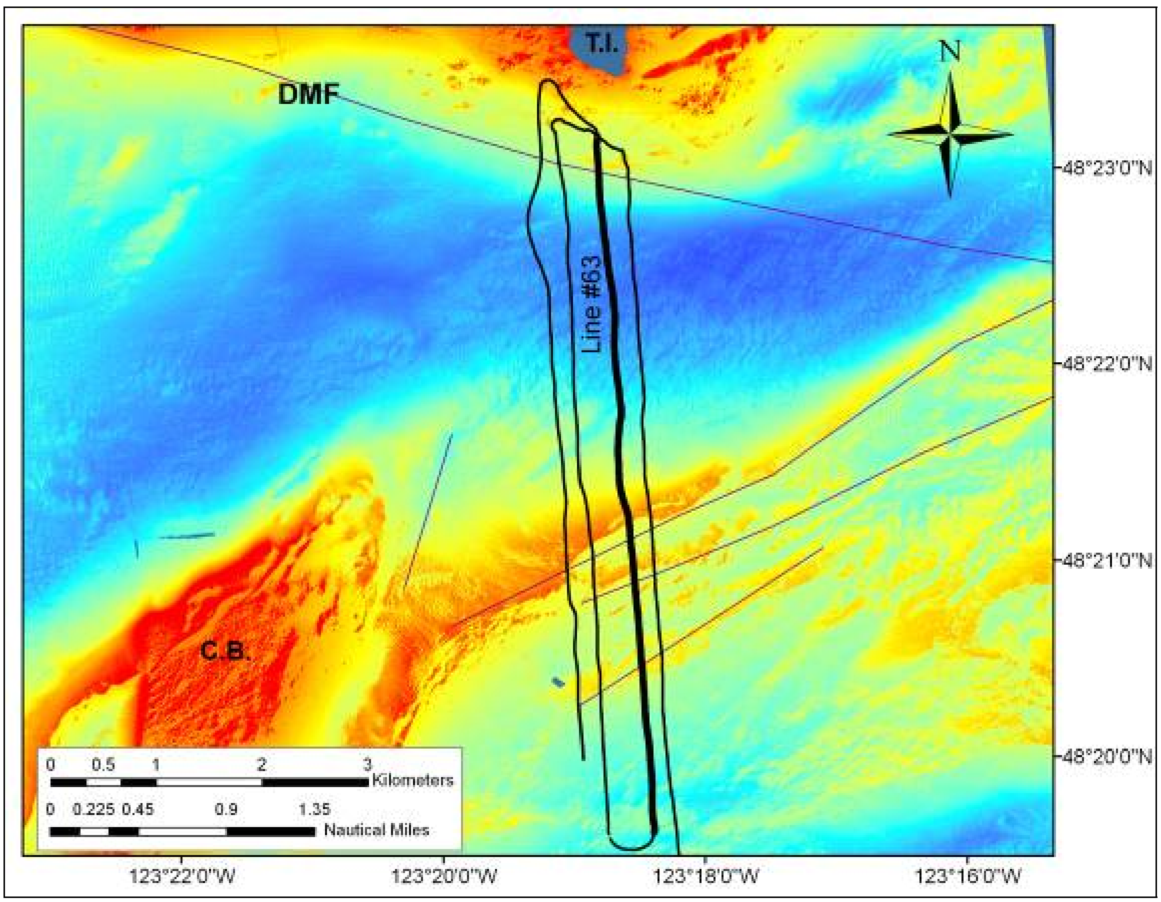


Figure 15. Map of the 3.5 kHz sub bottom profiler survey lines off Victoria crossing the Devil's Mountain Fault (DMF) and faults traces east of Constance Bank (C.B.) between Clover Point and Trial Island (T.I.). Line #63 (thick black line) is shown below (Figure 16).

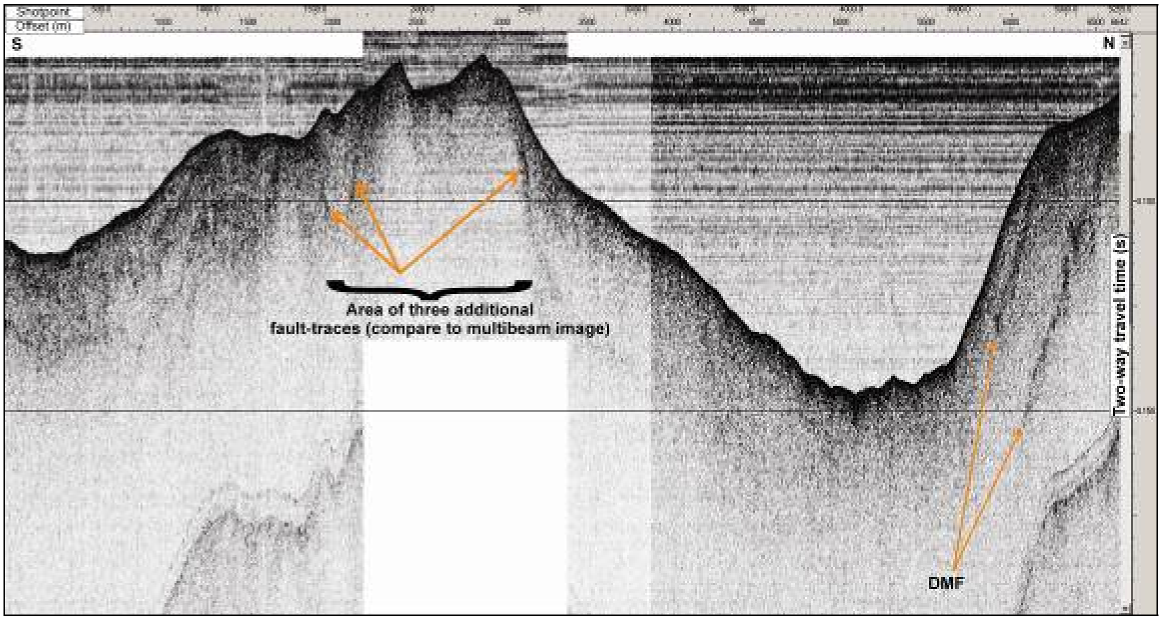


Figure 16. 3.5 kHz sub bottom profiler of line 3 (Line #63) across the DMF.

3.4 WASSP multibeam system test

The WASSP multibeam system was intended for use in shallow water (to a maximum of 300m water depth). The frequency of the unit is 160 kHz at output power levels ranging from 400 W to a maximum of 1 kW. The system is mounted using a pole on the port-side (previously used by ROPOS) and an extension rod to allow the system clear the hull of the CCGS John P. Tully (Figure 17a, b, c). This was a first test for deploying this system on the CCGS John P. Tully; mounting of the system on this pole with new extension cables and mounting plate was successful, as was the overall procedure to deploy the system at sea and steaming at a speed of 4-5 knots while acquiring some data. Deployment, however, requires the starboard crane, which limits the use of this system, i.e. deployment/recovery can only be attempted during regular work (day-time) hours (07:30 to 17:00) if overtime charges for Coast Guard personnel need to be avoided. Also, the system is rather fragile and the acquisition and control-box needs currently to be staged outside, which increases risk. Also, no data have yet been acquired for actual software testing and no complete calibration of the sounder, GPS, and water-velocity function for accurate depth-calculations have been made. Additional testing is required, as well as some upgrades to the stability of the pole and cables to reduce risk of damaging the system.

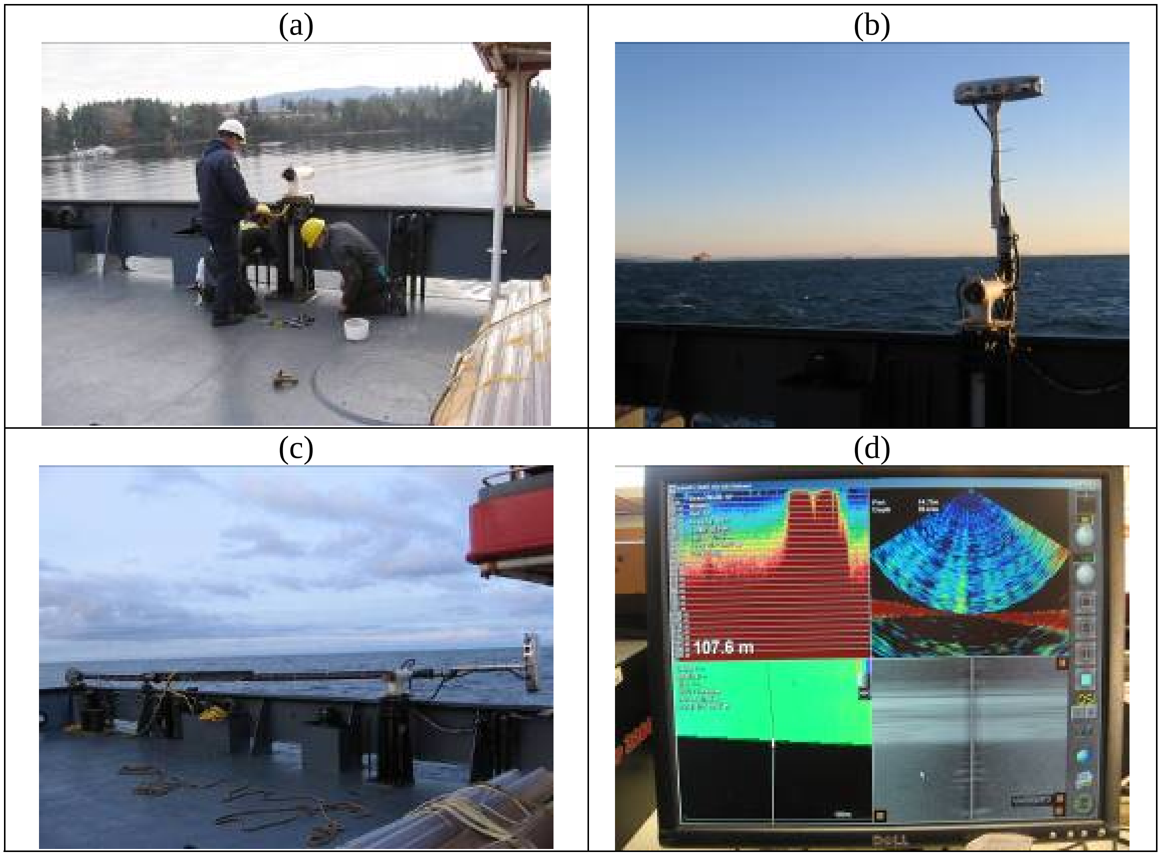


Figure 17. (a) Pole on port-side of CCGS John P. Tully used to mount the WASSP multibeam system, (b) Multibeam system deployed, (c) the complete assembled WASSP-multibeam system (left bottom of pole: sounder plate, right top of pole: GPS system that measure location, role, pitch and heave). (d) screen-capture of the multibeam software display of (from left to right and top to bottom: vertical echo-sounder display, beam-swath cross section, continuous bottom-display, and backscatter).

3.5 Survey across Nootka-Fault zone and mud-volcanoes

The OBS deployment is designed with a higher density of stations around the NFZ. While deploying the instruments, 3.5 kHz data were acquired where possible (weather conditions not too rough) to image the actual fault traces as well as the two mud volcanoes (Figure 18). Previous imaging of the mud volcanoes with a sub bottom profiler (during three expeditions PGC01-03, PGC03-04, PGC04-08) was unsuccessful either due to non-digital recording or poor image-quality.

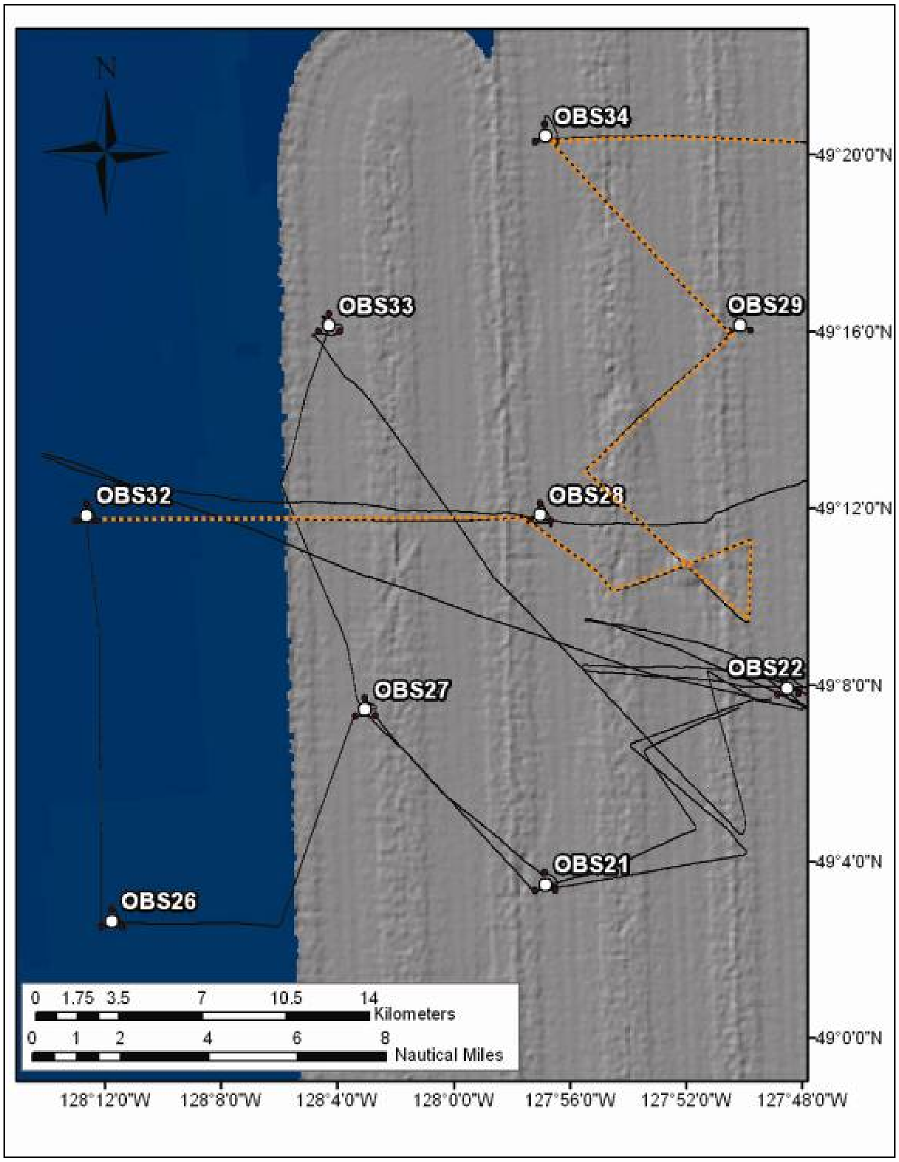


Figure 18. Map of OBS stations, ship-track (black line) and 3.5 kHz sub bottom profiler surveys (orange dashed lines) across Nootka Fault traces and mud volcanoes. The bathymetric data underneath (HYDROSWEEP) are from a survey conducted by D. Kelly (U. of Washington), J. Delaney (U. of Washington), and L. Mayer, U. of New Hampshire).

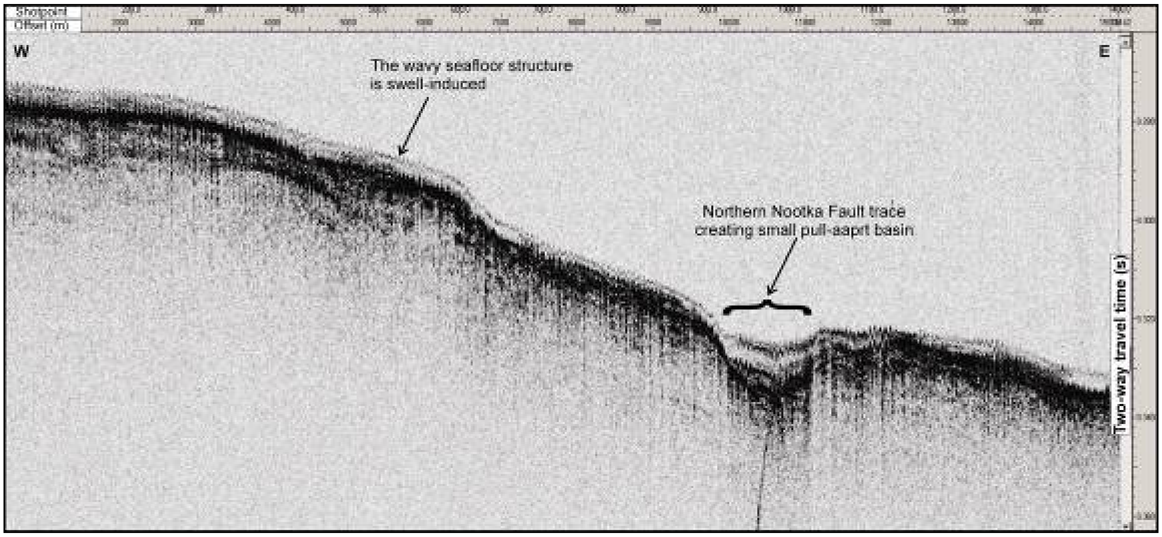


Figure 19. Image of 3.5 kHz sub bottom profiler data while crossing the northern fault trace of the Nootka Fault Zone between OBS 32 and OBS 28. The fault creates small pull-apart basins approximately 1km wide. The slight bumpy nature of the seismic image and apparent roughness of the seafloor is a result of ship-motion during large swells.

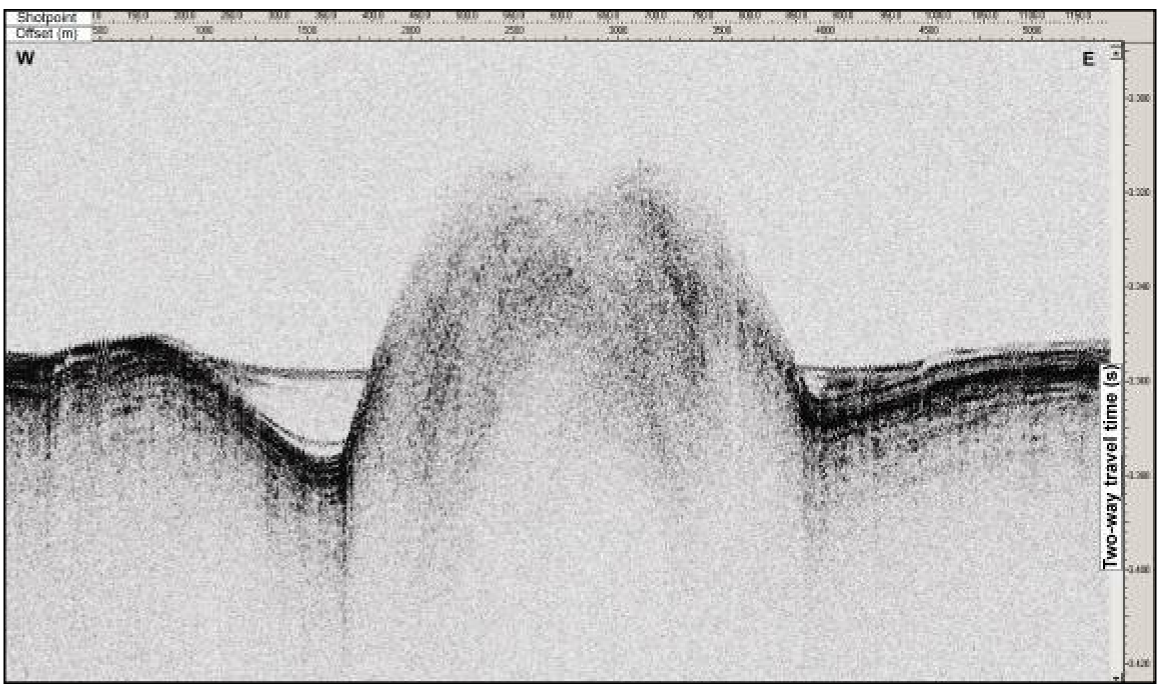


Figure 20. Image of the southern mud volcano (note the asymmetric moat). In the centre of the volcano is a small depression, but overall imaging of this feature shows low and diffuse reflectivity, which is different to the northern volcano (compare to Figure 21).

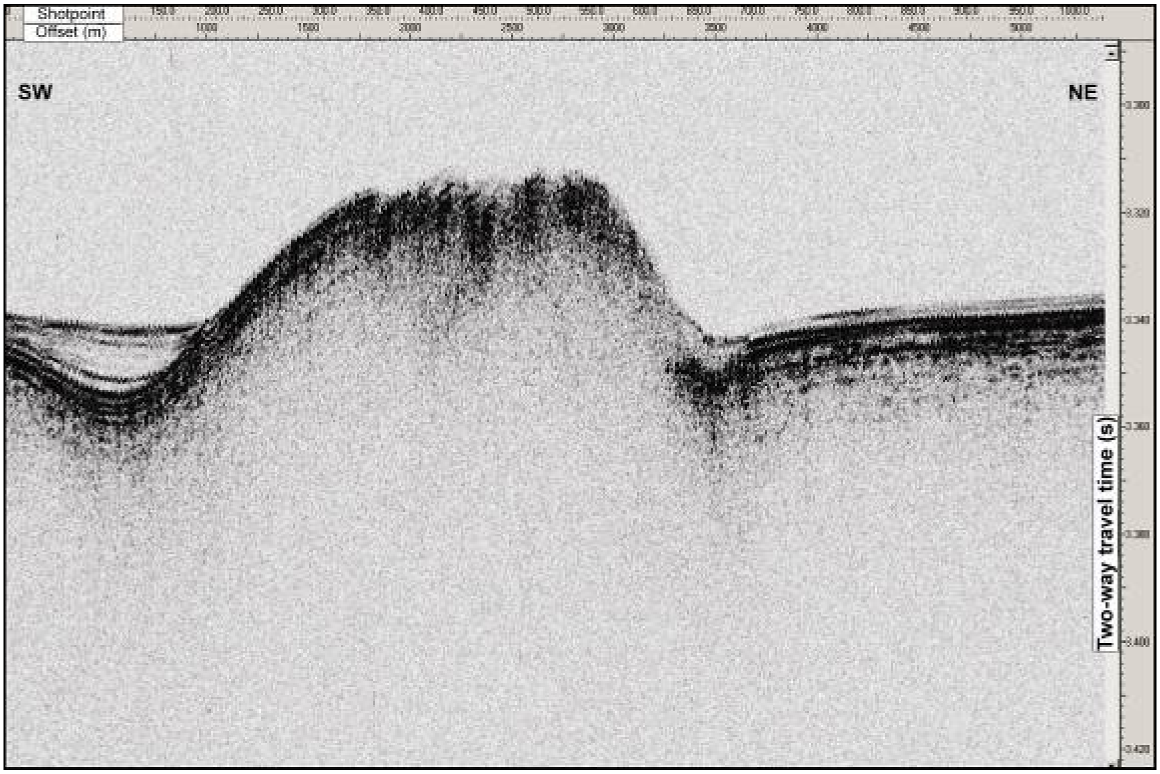


Figure 21. Image of the northern mud volcano (note the asymmetric moat). The acoustic image of this feature is different than the southern volcano as it shows much stronger reflectivity overall near the seafloor, and some apparent faulting, which is also evident in the multibeam data, showing a fault trace crossing this feature.

3.6 Survey across abyssal-plain faults

In previous studies, a set of apparent strike-slip faults were observed on the abyssal plain, intersecting the margin at an oblique angle. Some of these faults appear to be parallel to the sharp truncations of either the submarine slope failures or the individual frontal ridge-complexes themselves (evident e.g. at Slip-Stream slide). While in 2008 several airgun profiles were acquired at the strike-slip fault south-east of Slip-Stream slide, no high-resolution sub-bottom profiler data were gathered at the same time. Therefore, during this expedition, additional data were acquired across some of these strike-slip faults while in transit between OBS stations or coring sites (Figure 22). The character of these faults is subtle in the 3.5 kHz data (Figure 23), but distinctly marked by V-shaped depressions. Sediment-layering is not sharply truncated by these faults (as e.g. seen at the Nootka Fault zone traces) and appears continuous and symmetrical to both sides of these faults. In contrast, the airgun data acquired in 2008 show a progressive depth-shift of sedimentary layer-packages across the fault of ~20m within the top 100 meter below seafloor (mbsf) and ~40m at ~500mbsf. Sediments on the southern side of the fault trace are moved relative up when compared to the northern side of the fault trace. The origin of these faults and their implications for the margin's overall tectonic regime remain uncertain at this point. However, it is suggested to complement the existing data with new survey lines to be acquired during the 2014 recovery mission.

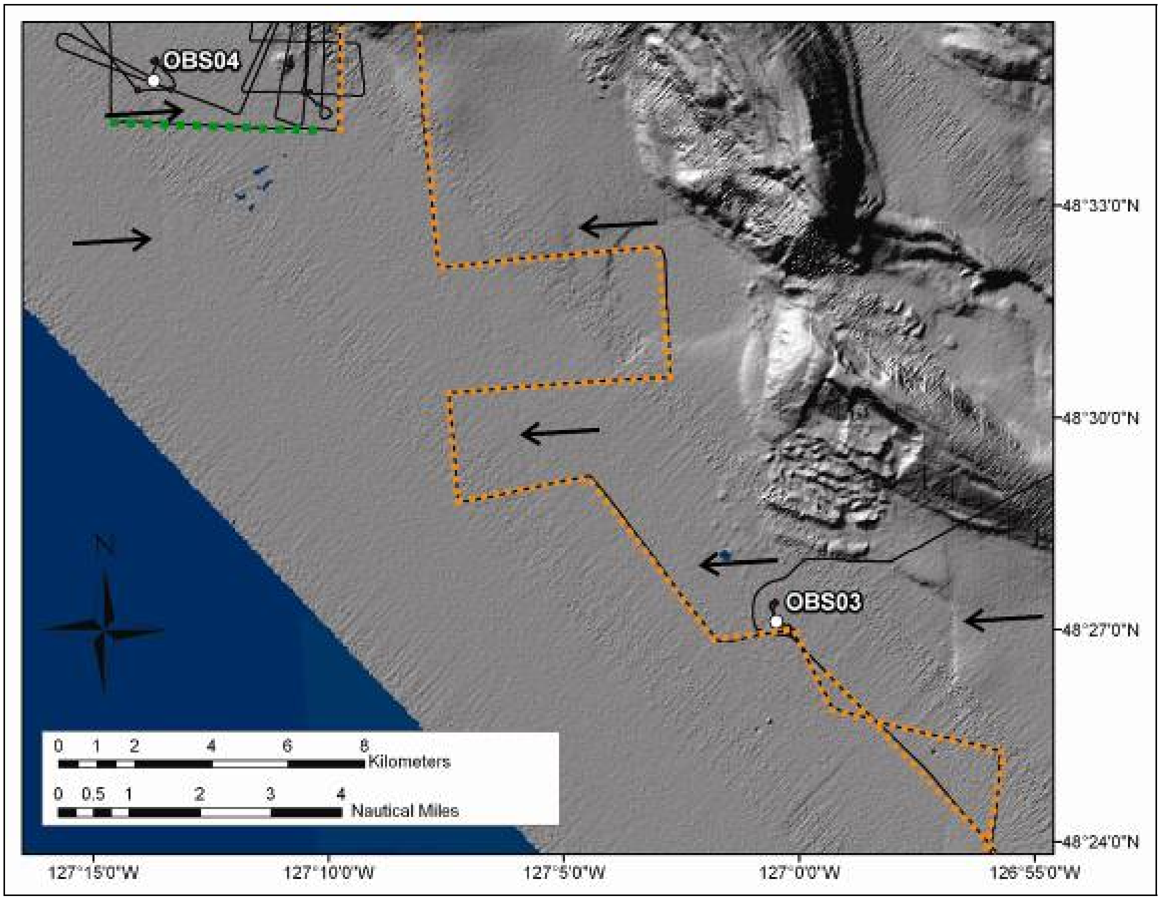


Figure 22. Map of 3.5 kHz sub bottom profiler survey lines across the abyssal-plain strike-slip faults. Fault lines are indicated by small black arrows. Three major fault traces are seen over distances exceeding 5 kilometres, and one shorter fault line (slightly North-west of the circular depression) tracing about 3 kilometres is identified. The green-dotted line is shown below (Figure 23).

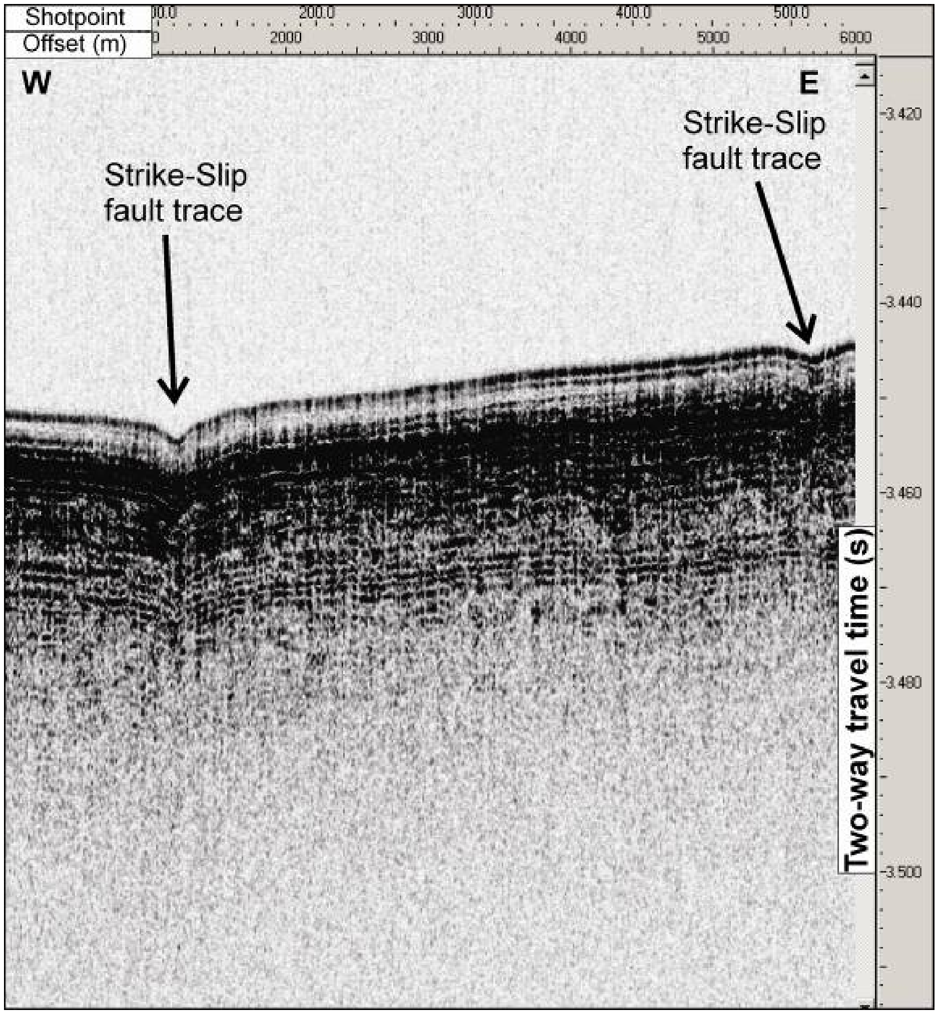


Figure 23. Example image of 3.5 kHz sub bottom profiler data across the strike slip faults near OBS STN 04 (green line in Figure 22 above). Note the V-shaped depression and symmetric sediment deformation across the two features.

SITE	Date & Time (UTC)	Vessel position			OBS position		
		Lat (°N)	Long (°W)	Depth (m)	Lat (°N)	Long (°W)	Depth(m)
1	2013/11/29 23:26:26	48 11.56242	126 36.71466	2490	48 11.5315	126 36.6788	2490
2	2013/11/30 09:09:27	48 18.44352	126 48.92328	2557	48 18.5037	126 49.0979	2557
3	2013/11/30 11:42:44	48 27.20376	127 00.36696	2601	48 27.0616	127 00.1712	2570
4	2013/11/30 23:02:09	48 35.11290	127 13.26996	2563	48 35.0942	127 13.2697	2563
5	2013/12/01 01:09:51	48 42.61254	127 23.84436	2546	48 42.5409	127 23.8284	2546
6	2013/12/01 12:42:30	48 51.50004	127 38.43768	2538	48 51.4478	127 38.4448	2538
7	2013/12/01 15:05:27	48 59.37984	127 45.17208	2521	48 59.3875	127 45.1804	2521
8	2013/11/30 03:09:26	48 19.35894	126 21.80610	1172	48 19.3705	126 21.8280	1172
9	2013/11/30 06:49:46	48 24.04722	126 34.56396	1554	48 24.0637	126 34.5630	1554
10	2013/11/30 14:10:49	48 32.10726	126 46.00272	1420	48 32.1465	126 45.9833	1420
11	2013/11/30 20:30:05	48 43.58292	127 04.14066	2045	48 43.5741	127 04.1895	2045
12	2013/12/01 03:32:41	48 50.55354	127 15.20694	2057	48 50.5884	127 15.0705	2057
13	2013/12/01 09:53:30	48 57.55794	127 24.08640	2066	48 57.5214	127 24.1013	2066
14	2013/12/01 17:15:05	49 05.54502	127 34.64190	1976	49 05.5740	127 34.7452	1976
15	2013/11/30 05:00:57	48 29.03106	126 22.13604	1016	48 29.0900	126 22.1704	1016
16	2013/11/30 16:05:46	48 38.93268	126 34.04658	1137	48 38.9461	126 34.0430	1137
17	2013/11/30 18:17:04	48 48.50646	126 48.48306	1341	48 48.5406	126 48.5275	1341
18	2013/12/01 05:46:51	48 56.90298	126 58.68360	1069	48 56.9382	126 58.7283	1069
19	2013/12/01 07:47:59	49 06.04290	127 11.34036	1603	49 06.0507	127 11.3425	1603
20	2013/12/01 19:55:34	49 13.20600	127 21.25128	1411	49 13.1937	127 21.3190	1411
21	2013/12/02 22:50:34	49 03.49218	127 56.70426	2502	49 03.4490	127 56.7407	2502
22	2013/12/02 20:27:50	49 07.81716	127 48.33174	2504	49 07.8774	127 48.4937	2504
23	2013/12/02 00:57:55	49 12.95928	127 42.12630	2495	49 12.8808	127 42.1518	2495
24	2013/12/01 23:09:43	49 16.95276	127 33.88272	1804	49 16.8517	127 33.8351	1804
25	2013/12/01 21:42:24	49 20.74506	127 28.43184	1505	49 20.7111	127 28.4464	1505
26	2013/12/03 11:19:56	49 02.85642	128 11.63898	2461	49 02.8102	128 11.4981	2461
27	2013/12/03 00:23:59	49 07.46898	128 02.88048	2469	49 07.4625	128 02.8116	2469
28	2013/12/03 15:43:21	49 11.90130	127 56.83470	2478	49 11.9350	127 56.8634	2478
29	2013/12/03 20:04:12	49 16.19874	127 49.66008	2468	49 16.2545	127 49.7415	2468
30	2013/12/03 23:19:56	49 20.20866	127 45.56526	2445	49 20.1759	127 45.5063	2445
31	2013/12/04 01:05:08	49 24.19866	127 34.47036	1799	49 24.1512	127 34.3890	1799
32	2013/12/03 13:35:26	49 12.00738	128 12.44442	2435	49 12.0197	128 12.3770	2435
33	2013/12/03 02:38:16	49 16.24332	128 04.05918	2436	49 16.2231	128 03.9716	2436
34	2013/12/03 21:37:45	49 20.47728	127 56.41620	2443	49 20.5225	127 56.4194	2443
35	2013/12/04 02:58:17	49 25.66002	127 48.33012	2422	49 25.6055	127 48.2291	2422

Table 1. Location of the deployed JMASTEC OBS (after triangulation).

Site No	OBS No.	Sensor	Battery box	Rec.	SD	Beacon	Code	Flasher	Trapon	Code	Hydro	Sphere
1	146	0628	026	0031	4/5	X02-003	JS1614	G07-100	JX-1032	2E-1	253195	61584
2	147	0629	011	0032	0032	X02-002	JS1613	X02-029	JX-1083	1E-2	253163	94367
3	134	0616	015	0029	0029	J08-124B	JS1115	A02-041	JX-1096	5F-2	253169	94414
4	125	0607	020	0024	0024	Y01-062	JS1791	G07-084	JX-1031	2D-1	253190	97574
5	157	0651	018	0033	0033	X02-007	JS1618	G07-097	JX-1098	6E-2	253077	8568
6	126	0608	033	0026	0026	J08-192	JS1183	G07-034	JX-1093	4F-2	253191	59098
7	1	9033	006	0001	0001	J08-165	JS1156	X02-021	JX-1144	1C-1	253143	7915
8	33	9856	007	0004	3/5	J08-182	JS1173	G07-039	JX-1055	1A-2	253151	8559
9	166	0903	016	0035	0035	X02-010	JS1621	A02-049	JX-1110	9E-2	253145	8562
10	93	9713	023	0020	0020	J08-140	JS1131	A02-046	JX-1077	8B-2	253183	92773
11	77	0011	031	0013	0013	X02-013	JS1624	X02-026	JX-1079	9A-2	253161	60222
12	43	9866	025	0007	2/5	W03-016	JS1402	A02-040	JX-1104	5D-1	253154	8556
13	19	9841	013	0003	0003	X02-004	JS1615	K01-066	JX-1021	7C-1	253199	8346
14	96	9836A	034	0021	0021	W03-020	JS1406	J08-107	JX-1162	7D-1	253165	7907
15	156	0650	001	0015	0015	J08-155	JS1146	G07-045	JX-1050	8E-1	253186	7918
16	9	9829	003	0027	0027	X02-008	JS1619	A02-044	JX-1134	6A-1	253174	8550
17	59	0446	014	0010	0010	J08-118B	JS1109	A02-043	JX-1141	8A-2	253181	8561
18	129	0611	021	0005	0005	J08-173B	JS1164	X02-022	JX-1166	3C-1	253172	8167
19	87	9705	029	0018	0018	J08-133	JS1124	G07-040	JX-1065	4B-2	253164	8347
20	88	0117	027	0019	0019	W03-021	JS1407	J08-037	JX-1062	3B-2	253182	60224
21	139	0621	022	0025	0025	Y01-078	JS1786	G07-046	JX-1145	1D-1	253153	8540
22	133	0615	024	0028	0028	J08-193B	JS1184	J08-046	JX-1012	4C-1	253150	7914
23	160	0654	035	0034	0034	J08-161	JS1152	J08-085	JX-1102	5B-1	253139	93433
24	39	0019	005	0006	0006	X02-015	JS1626	J08-073	JX-1137	6F-1	253152	8563
25	57	9882	008	0008	0008	X02-006	JS1617	G07-049	JX-1038	4E-1	253155	8558
26	63	9888	017	0011	0011	J08-152	JS1143	A02-045	JX-1029	8F-1	253156	8544
27	118	9708	004	0023	0023	X02-009	JS1620	G07-048	JX-1090	3F-2	253167	8551
28	15	9836	010	0002	0002	X10-093	JS1789	J08-043	JX-1052	9D-1	253148	8543
29	148	0630	019	0014	0014	X02-014	JS1625	J08-111	JX-1013	5A-1	253173	93336
30	70	9895	028	0012	0012	J08-134	JS1125	J08-048	JX-1149	2B-1	253159	8560
31	82	0016	030	0016	0016	J08-189B	JS1180	J08-059	JX-1020	7B-1	253162	60085
32	141	0623	012	0030	0030	J08-167	JS1158	J08-098B	JX-1026	9B-1	253170	8314
33	11	9831	002	0009	1/5	Y01-075	JS1783	Y01-054	JX-1086	2F-2	253175	8567
34	107	0448	009	0022	0022	J08-145	JS1136	X02-027	JX-1107	7E-2	253184	8353
35	84	9702	032	0017	0017	J08-150	JS1141	X02-030	JX-1135	6C-2	253005	8554

Table 2. Technical details of the deployed JMASTEC OBS.

Date Time (UTC)	Latitude	Longitude	Event
2013/12/04 17:56:29	49.465025	-127.906083	Core 1 deployed
2013/12/04 18:38:28	49.465335	-127.906125	Core 1 at bottom
2013/12/04 21:08 :45	49.483457	-127.875253	Core 2 deployed
2013/12/04 21:54:44	49.483711	-127.875569	Core 2 at bottom
2013/12/04 22:50:19	49.483296	-127.875274	Core 2 on deck
2013/12/04 23:49:16	49.502477	-127.871170	Core 3 deployed
2013/12/05 00:28:08	49.502515	-127.871169	Core 3 at bottom
2013/12/05 01:32:04	49.501118	-127.871695	Core 3 on deck
2013/12/05 17:00:10	48.580474	-127.168352	Core 4 deployed
2013/12/05 17:41:25	48.580834	-127.168872	Core 4 at bottom
2013/12/05 18:33:08	48.580451	-127.168695	Core 4 on deck
2013/12/05 19:26:15	48.589210	-127.167579	Core 5 deployed
2013/12/05 20:08:16	48.589177	-127.167854	Core 5 at bottom
2013/12/05 21:21:31	48.588821	-127.167849	Core 5 on deck
2013/12/05 22:33:38	48.603839	-127.164948	Core 6 deployed
2013/12/05 23:33:47	48.603674	-127.165659	Core 6 at bottom
2013/12/06 00:25:17	48.604148	-127.164929	Core 6 on deck

Table 3a. Location and details of operation of piston cores.

Core	Sections	Labels	Lengths (cm)	Extra pieces
Piston core #1	1	A-B	152	cone-nose, cutting-shoe, core catcher
	2	B-C	152	
	3	C-D	152	
	4	D-E	152	
	5	E-F	101	
	Total		709	
Trigger core #1	1	A-B	89	No samples in cutter or catcher
Piston core #2	1	A-B	152	No samples in cutter or catcher
	2	B-C	152	
	3	C-D	152	
	4	D-E	51	
	Total		507	
Trigger core #2	1	A-B	134	No samples in cutter or catcher
Piston core #3	1	A-B	152	Core cutter + catcher
	2	B-C	152	
	3	C-D	17	
	Total		321	
Trigger core #3	1	A-B	78	No samples in cutter or catcher
Piston core #4	1	A-B	152	
	2	B-C	152	
	3	C-D	152	
	4	D-E	110	
	Total		566	
Trigger core #4	1	A-B	88	No samples in cutter or catcher
Piston core #5	1	A-B	152	
	2	B-C	67	
	Total		219	
Trigger core #5	1	A-B	10	No samples in cutter or catcher
Piston core #6	1	A-B	152	
	2	B-C	69	
	Total		221	
Trigger core #6	1	A-B	76	No samples in cutter or catcher

Table 3b. Core recovery information for piston cores and trigger (gravity) cores.

Julian Day	UTC	Latitude	Longitude	Event	COG	SOG	File Name	Ping rate	Recording length	Recording Window
333	20:22:11	48.223659	-126.082856	SOL 1	206	5.5	0002_333_2022	1.0	200.0	900-1100
333	21:12:04	48.162304	-126.105131	EOL 1	200	4.5	0002_333_2022	1.0	200.0	900-1100
334	00:32:21	48.198703	-126.622104	SOL 2	310	4.8	0003_334_0032	1.0	200.0	2400-2600
334	00:40:29	48.206363	-126.634131	EOL 2	14	4.2	0003_334_0032	1.0	200.0	2400-2600
334	00:40:31	48.206365	-126.634292	SOL 3	19	5.6	0004_334_0040	1.0	200.0	2400-2600
334	01:26:10	48.262493	-126.610284	EOL 3	86	6.0	0004_334_0040	1.0	200.0	2100-2300
334	01:26:16	48.262519	-126.610172	SOL 4	90	9.8	0005_334_0126	1.0	200.0	2100-2300
334	02:08:32	48.267637	-126.435848	EOL 4	90	10.0	0005_334_0126	1.0	200.0	2000-2200
334	02:08:42	48.267781	-126.435354	SOL 5	90	10.0	0006_334_0214	1.0	200.0	2000-2200
334	02:46:39	48.317448	-126.430521	EOL 5	84	9.5	0006_334_0214	1.0	200.0	1300-1500
334	08:05:39	48.375441	-126.640144	SOL 6	238	9.0	0007_334_0805	1.0	200.0	1900-2100
334	09:00:29	48.311296	-126.809317	EOL 6	239	7.0	0007_334_0805	1.0	200.0	2400-2600
334	10:18:41	48.305711	-126.821851	SOL 7	260	4.0	0008_334_1018	1.0	200.0	2500-2700
334	11:37:00	48.447025	-126.996313	EOL 7	315	8.0	0008_334_1018	1.0	200.0	2500-2700
334	12:50:58	48.452212	-127.012889	SOL 8	356	8.2	0009_334_1250	1.0	200.0	2500-2700
334	13:41:47	48.505044	-126.856517	EOL 8	056	9.2	0009_334_1250	1.0	200.0	2100-2300
334	21:55:55	48.649856	-127.137075	SOL 9	200	9.4	0001_334_2155	1.0	200.0	2000-2200
334	22:58:33	48.585326	-127.221676	EOL 9	200	9.0	0001_334_2155	1.0	200.0	2500-2700
334	23:57:16	48.583544	-127.227728	SOL 10	318	6.8	0003_334_2356	1.0	200.0	2500-2700
335	01:04:45	48.709126	-127.395429	EOL 10	n.r.	n.r.	0003_334_2356	1.0	200.0	2500-2700
335	02:11:47	48.701340	-127.388116	SOL 11	119	10.0	0004_335_0211	1.0	200.0	2500-2700
335	02:51:36	48.749182	-127.285994	EOL 11	11	9.5	0004_335_0211	1.0	200.0	2200 - 2400
335	10:55:41	48.963460	-127.426431	SOL 12	290	7.0	0001_335_1055	1.0	200.0	2000-2200
335	12:33:49	48.863302	-127.640461	EOL 12	186	9.0	0001_335_1112	1.0	200.0	2500-2700
335	13:51:38	48.855048	-127.647339	SOL 13	330	8.0	0002_335_1351	1.0	200.0	2500-2700
335	14:53:20	48.981206	-127.747595	EOL 13	340	8.1	0002_335_1351	1.0	200.0	2500-2700
335	16:34	48.988114	-127.758889	SOL 14	32	9.7	0003_335_1602	1.0	200.0	2400-2600
335	16:56:34	49.094403	-127.616357	EOL 14	49	9.8	0003_335_1602	1.0	200.0	1800-2000
337	14:49:11	49.198937	-128.157184	SOL 15	100	10.0	0001_337_1449	1.0	200.0	2400 - 2600

337	15:38:25	49.198118	-127.948512	EOL 15	100	10.0	0001_337_1449	1.0	200.0	2400 - 2600
337	16:38:53	49.196159	-127.949973	SOL 16	137	9.3	0002_337_1638	1.0	200.0	2400 - 2600
337	16:55:51	49.169722	-127.903384	EOL 16	137	9.3	0002_337_1638	1.0	200.0	2400 - 2600
337	16:56:06	49.169712	-127.902893	SOL 17	75	5.9	0003_337_1656	1.0	200.0	2400 - 2600
337	17:38:37	49.186356	-127.831339	EOL 17	75	4.0	0003_337_1656	1.0	200.0	2400 - 2600
337	17:39:10	49.186500	-127.830504	SOL 18	n.r.	n.r.	0004_337_1738	1.0	200.0	2400 - 2600
337	17:57:18	49.159191	-127.831988	EOL 18	n.r.	n.r.	0004_337_1738	1.0	200.0	2400 - 2600
337	17:57:24	49.159339	-127.832199	SOL 19	310	3.5	0005_337_1757	1.0	200.0	2400 - 2600
337	18:59:06	49.216349	-127.916838	EOL 19	n.r.	n.r.	0005_337_1757	1.0	200.0	2400 - 2600
337	18:59:21	49.216624	-127.916730	SOL 20	43	5.1	0006_337_1859	1.0	200.0	2400 - 2600
337	19:35:46	49.249834	-127.861170	EOL 20	43	4.4	0006_337_1859	1.0	200.0	2400 - 2600
337	19:36:09	49.250339	-127.860802	SOL 21	43	4.4	0007_337_1936	1.0	200.0	2400 - 2600
337	19:58:04	49.268897	-127.829684	EOL 21	47	4.3	0007_337_1936	1.0	200.0	2400 - 2600
337	20:56:34	49.267380	-127.836115	SOL 22	315	10.0	0008_337_2056	1.0	200.0	2400 - 2600
337	21:38:28	49.341874	-127.940425	EOL 22	n.r.	n.r.	0008_337_2056	1.0	200.0	2400 - 2600
337	22:31:08	49.340136	-127.944910	SOL 23	86	10.0	0009_337_2231	1.0	200.0	2400 - 2600
337	23:16:06	49.335709	-127.762062	EOL 23	n.r.	n.r.	0009_337_2231	1.0	200.0	2400 - 2600
338	04:45:27	49.404948	-127.812948	SOL 24	279	9.0	0002_338_0448	1.0	200.0	2400-2600
338	05:21:58	49.439650	-127.943905	EOL 24 / SOL 25	295	9.0	0003_338_0523	1.0	200.0	2400-2600
338	05:55:23	49.420189	-127.838920	EOL 25 / SOL 26	118	10.0	0004_338_0555	1.0	200.0	2400-2600
338	06:36:48	49.464817	-127.949572	EOL 26 / SOL 27	294	9.0	0005_338_0636	1.0	200.0	2400-2600
338	07:42:22	49.451009	-127.864440	EOL 27 / SOL 28	117	5.0	0005_338_0742	1.0	200.0	2400-2600
338	08:50:57	49.488999	-127.942880	EOL 28 / SOL 29	357	4.0	0006_338_0851	1.0	200.0	2300-2500
338	09:54:44	49.474183	-127.841594	EOL 29 / SOL 30	116	5.0	0007_338_0954	1.0	200.0	2300-2500
338	10:57:10	49.509806	-127.921254	EOL 30 / SOL 31	288	5.0	0009_338_1057	1.0	200.0	2300-2500
338	11:58:44	49.492837	-127.828282	EOL 31 / SOL 32	100	5.0	0010_338_1158	1.0	200.0	2000-2200
338	13:25:31	49.456197	-127.893424	EOL 32 / SOL 33	272	4.0	0012_338_1325	1.0	200.0	2300-2500
338	14:33:39	n.r.	n.r.	EOL 33 / SOL 34	n.r.	n.r.	0013_338_1433	1.0	200.0	1700-1900
338	15:57:15	49.449339	-127.937222	EOL 34	206	4.6	0013_338_1433	1.0	200.0	2300-2500
338	15:57:32	49.448962	-127.937274	SOL 35	30	4.6	0014_338_1557	1.0	200.0	2300-2500
338	16:33:02	49.485473	-127.898579	EOL 35	n.r.	n.r.	0014_338_1557	1.0	200.0	2300-2500
338	16:33:16	49.485803	-127.898409	SOL 36	109	5.2	0015_338_1633	1.0	200.0	2300-2500

338	16:45:56	49.480033	-127.883928	EOL 36	109	5.2	0015_338_1633	1.0	200.0	2300-2500
338	16:46:04	49.479847	-127.884068	SOL 37	200	4.8	0016_338_1645	1.0	200.0	2300-2500
338	17:13:44	49.450508	-127.908893	EOL 37	200	4.5	0016_338_1645	1.0	200.0	2300-2500
338	17:15:39	49.449499	-127.911213	SOL 38	15	6.8	0017_338_1715	1.0	200.0	2300-2500
338	17:22:14	49.462848	-127.905986	EOL 38	n.r.	n.r.	0017_338_1715	1.0	200.0	2300-2500
339	03:56:27	49.625008	-127.344834	SOL 39	088	3.9	0001_339_0356	1.0	200.0	100-300
339	05:12:08	49.596834	-127.249953	EOL 39	n.r.	n.r.	0001_339_0356	1.0	200.0	100-300
339	08:30:15	49.088131	-127.241784	SOL 40	182	9.2	0002_339_0830	1.0	200.0	1500-1700
339	10:19:34	48.803296	-127.242106	EOL 40 / SOL 41	180	9.5	0003_339_1020	1.0	200.0	1800-2000
339	11:47:30	48.577129	-127.237773	EOL 41 / SOL 42	184	5.0	0004_339_1147	1.0	200.0	2500-2700
339	12:26:52	48.572300	-127.158011	EOL 42 / SOL 43	180	4.5	0004_339_1147	1.0	200.0	2500-2700
339	12:51:00	48.604529	-127.154196	EOL 43 / SOL 44	292	4.0	0005_339_1251		200.0	2400-2600
339	13:44:37	48.579948	-127.148684	EOL 44 / SOL 45	356	3.5	0005_339_1344	1.0	200.0	2500-2700
339	14:16:17	48.593570	-127.187142	EOL 45 / SOL 46	009	4.6	0006_339_1416	1.0	200.0	2500-2700
339	15:19:27	48.573691	-127.170246	EOL 46	n.r.	n.r.	0006_339_1416	1.0	200.0	2500-2700
339	15:19:46	48.573451	-127.170651	SOL 47	291	4.4	0007_339_1519	1.0	200.0	2500-2700
339	15:50:32	48.605596	-127.168358	EOL 47	n.r.	n.r.	0007_339_1520	1.0	200.0	2500-2700
339	15:50:33	48.605597	-127.168359	SOL 48	n.r.	n.r.	0008_339_1550	1.0	200.0	2500-2700
339	16:17:56	48.575284	-127.163005	EOL 48	n.r.	n.r.	0008_339_1550	1.0	200.0	2500-2700
339	16:18:28	48.574817	-127.162327	SOL 49	n.r.	n.r.	0009_339_1617	1.0	200.0	2500-2700
339	16:19:31	48.575008	-127.161008	EOL 49	n.r.	n.r.	0009_339_1617	1.0	200.0	2500-2700
340	00:40:25	48.602792	-127.161513	SOL 50	n.r.	n.r.	0001_340_0040	1.0	200.0	2500-2700
340	01:18:36	48.540119	-127.122873	EOL 50	n.r.	n.r.	0001_340_0040	1.0	200.0	2500-2700
340	01:18:48	48.539617	-127.122482	SOL 51	84	9.0	0002_340_0119	1.0	200.0	2500-2700
340	01:40:08	48.542579	-127.044703	EOL 51 / SOL 52	173	9.0	0003_340_0140	1.0	200.0	2500-2700
340	01:52:05	48.512370	-127.041760	EOL 52 / SOL 53	270	9.0	0004_340_0152	1.0	200.0	2500-2700
340	02:11:34	48.509708	-127.119153	EOL 53 / SOL 54	n.r.	n.r.	0005_340_0211	1.0	200.0	2500-2700
340	02:21:36	48.484298	-127.117949	EOL 54 / SOL 55	83	7.4	0006_340_0211	1.0	200.0	2500-2700
340	02:35:57	48.488825	-127.070475	EOL 55 / SOL 56	142	8.6	0007_340_0235	1.0	200.0	2500-2700
340	02:56:34	48.449490	-127.026813	EOL 56	079	7.7	0007_340_0235	1.0	200.0	2500-27000
340	03:21:08	48.450618	-126.999816	SOL 57	142	7.0	0008_340_0321	1.0	200.0	2500-2700
340	04:05:04	48.393485	-126.933677	EOL 57	226	8.9	0008_340_0321	1.0	200.0	2500-2700

340	14:52:53	48.247921	-126.614296	SOL 58	267	6.6	0001_340_1453	1.0	200.0	2400-2600
340	15:04:39	48.250486	-126.640438	EOL 58	n.r.	n.r.	0001_340_1454	1.0	200.0	2400-2600
341	14:58:08	48.309483	-123.299838	SOL 59	4.3	3.0	0001_341_1457	0.5	100.0	50-150
341	16:05:18	48.386882	-123.303805	EOL 59 / SOL 60	n.r.	n.r.	0002_341_1605	0.5	100.0	50-150
341	16:23:10	48.387960	-123.312261	EOL 60 / SOL 61	172	5.5	0003_341_1623	0.5	100.0	50-150
341	17:03:06	48.329291	-123.312250	EOL 61 / SOL 62	98	4.6	0004_341_1703	0.5	100.0	50-150
341	17:07:18	48.329859	-123.306186	EOL 62 / SOL 63	354	4.9	0005_341_1707	0.5	100.0	50-150
341	17:50:53	48.389038	-123.306895	EOL 63 / SOL 64	n.r.	n.r.	0006_341_1750	0.5	100.0	50-150
341	17:57:43	48.393327	-123.313862	EOL 64 / SOL 65	187	4.3	0007_341_1757	0.5	100.0	0-100
341	18:34:59	48.335794	-123.314767	EOL 65	n.r.	n.r.	0007_341_1757	0.5	100.0	0-100

Table 4. List of 3.5 kHz sub bottom profiler data recorded. (Julian day, 341 = December 7, 2013); n.r. = not recorded by watch-keeper; SOL = Start of Line; EOL = End of Line;

Name	Function during Expedition	Affiliation
Côté, Michelle	ArcGIS support, Navigation, watch-keeping	GSC-Pacific
Manning, Desmond	OBS deployment and all other deck operations, acoustic sounders, Navigation	GSC-Atlantic
Middleton, Greg	OBS deployment, Piston coring	GSC-Pacific
Murphy, Robert	OBS deployment, Piston coring	GSC-Atlantic
Neelands, Peter	Lab-support, ArcGIS support, Navigation, watch-keeping	GSC-Pacific
Suichi Kodaira	OBS setup and triangulation	JAMSTEC
Ikumasa Terada	OBS setup and triangulation	JAMSTEC
Yojiro Yamamoto	OBS setup and triangulation	JAMSTEC
Toshinori Saijo	OBS setup and triangulation	JAMSTEC
He, Tao	Guest Scientist, watch-keeping	University of Beijing
Riedel, Michael	Chief Scientist	GSC-Pacific

Table 5 Scientific Staff onboard Expedition 2013008PGC.

4 **Appendix** All triangulation screen captures

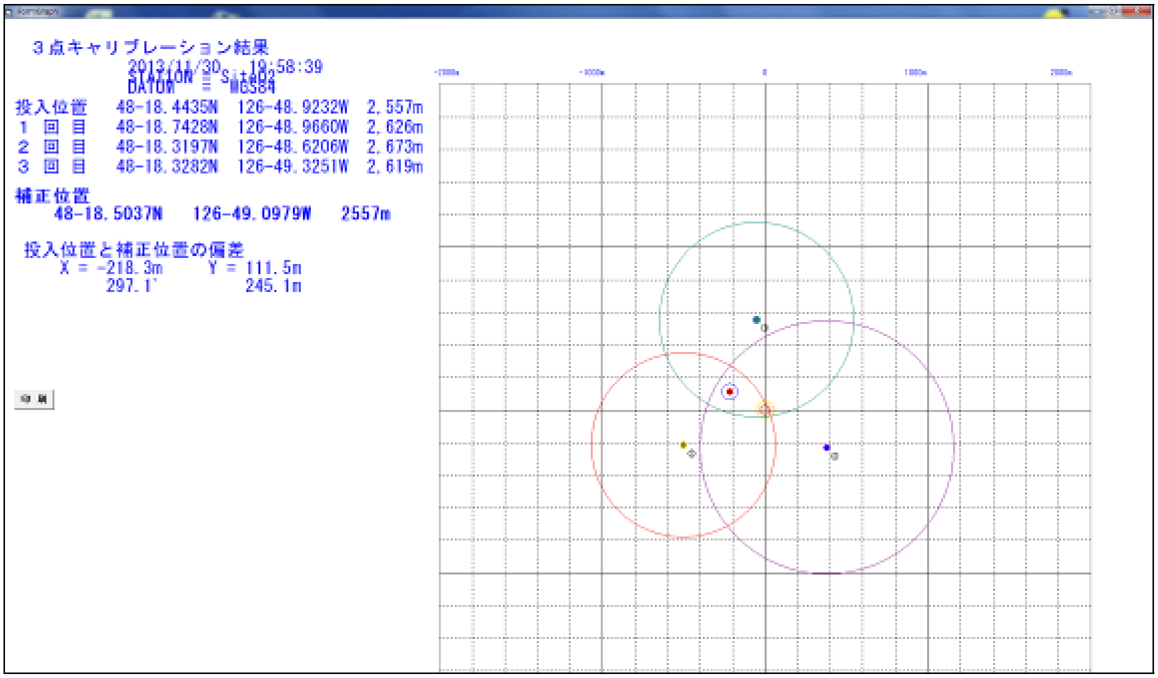


Figure A1 Screen capture for triangulation at OBS STN2.

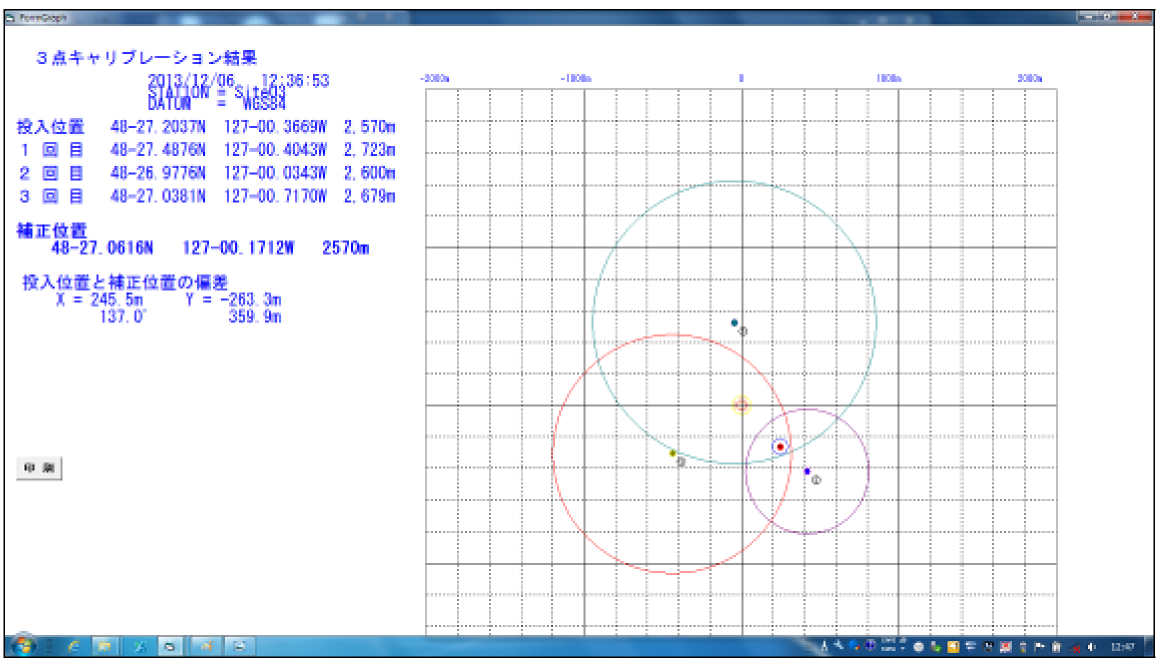


Figure A2 Screen capture for triangulation at OBS STN3.

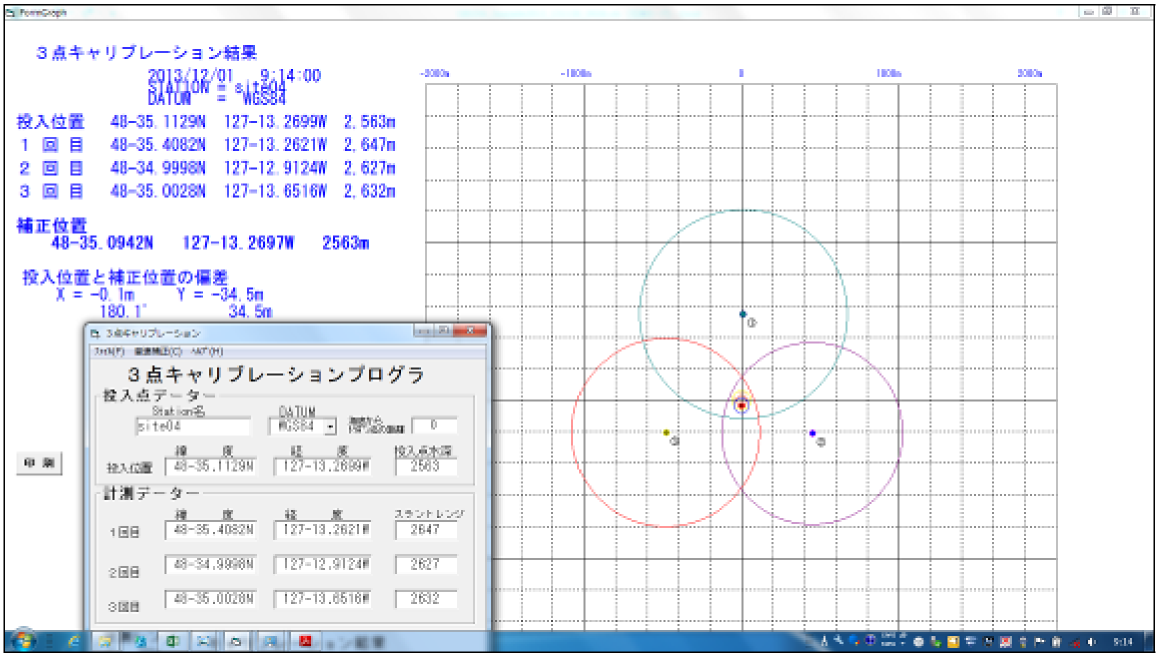


Figure A3 Screen capture for triangulation at OBS STN4.

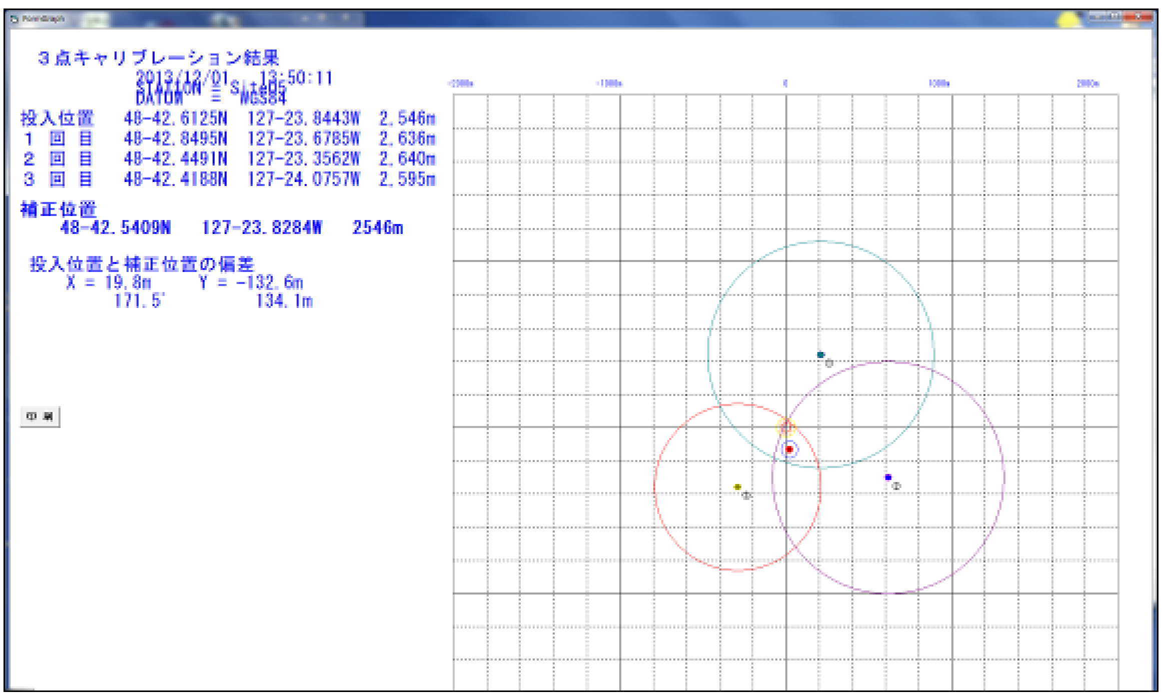


Figure A4 Screen capture for triangulation at OBS STN5.

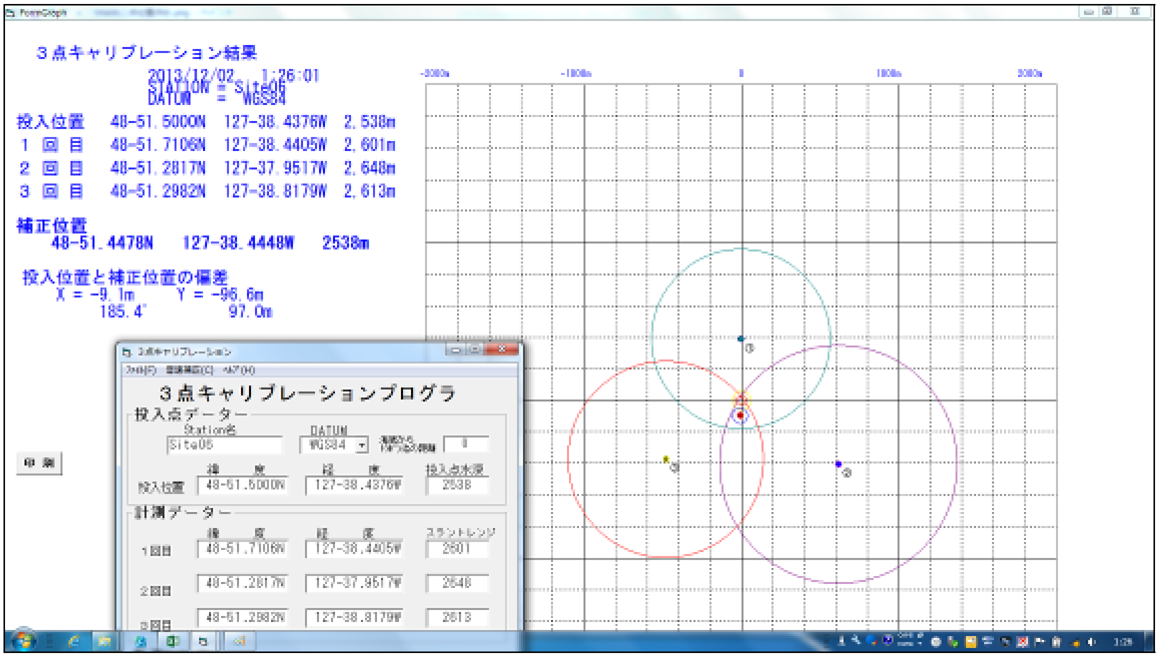


Figure A5　　Screen capture for triangulation at OBS STN6.

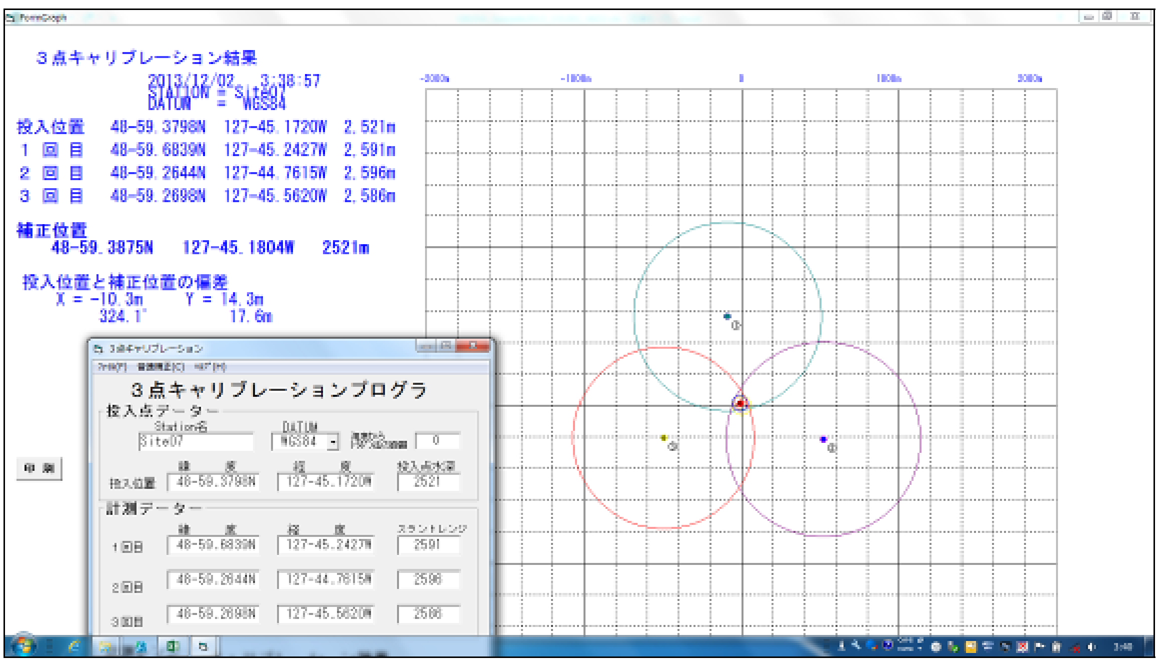


Figure A6　　Screen capture for triangulation at OBS STN7.

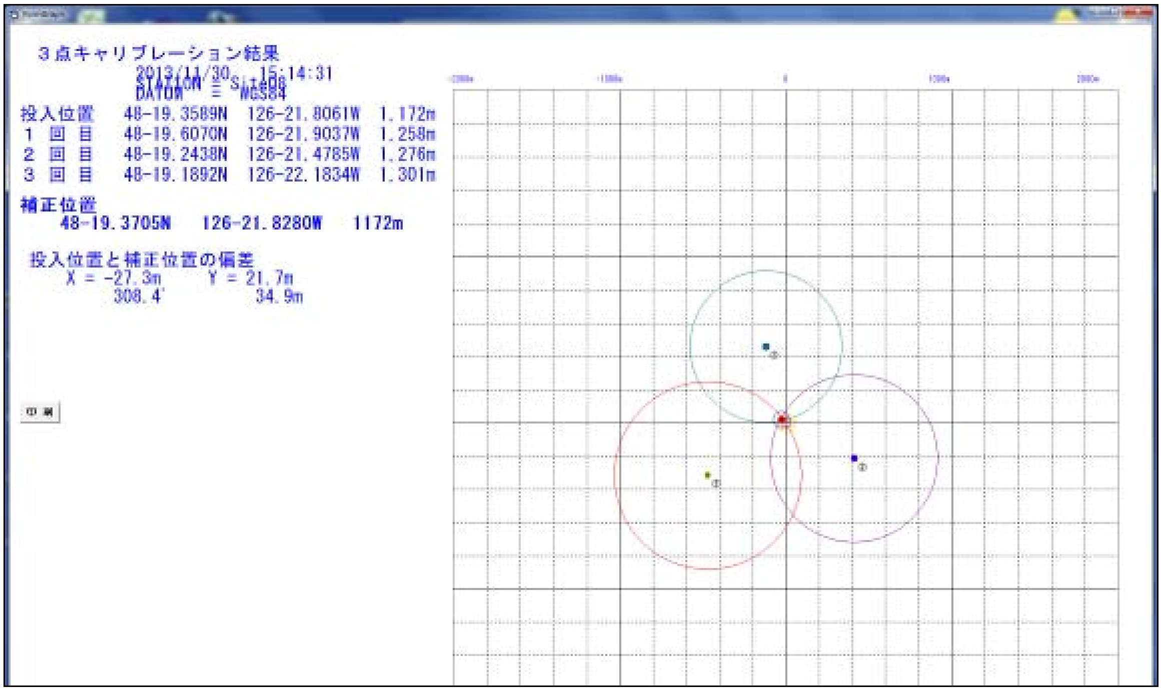


Figure A7 Screen capture for triangulation at OBS STN8.

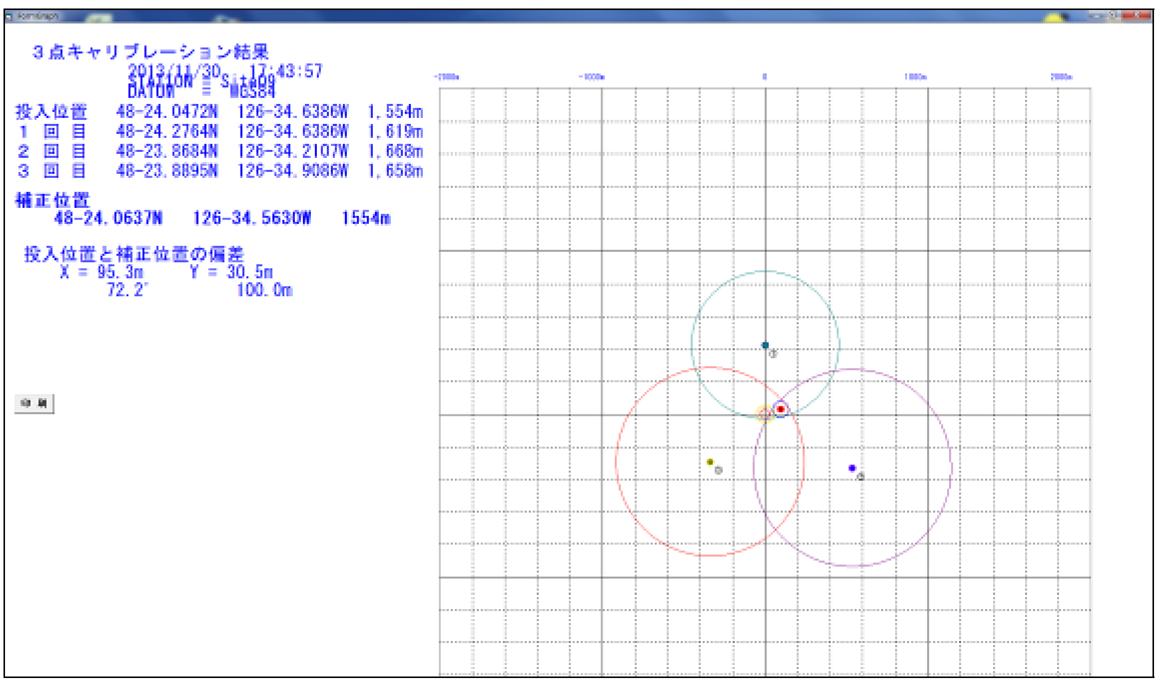


Figure A8 Screen capture for triangulation at OBS STN9.

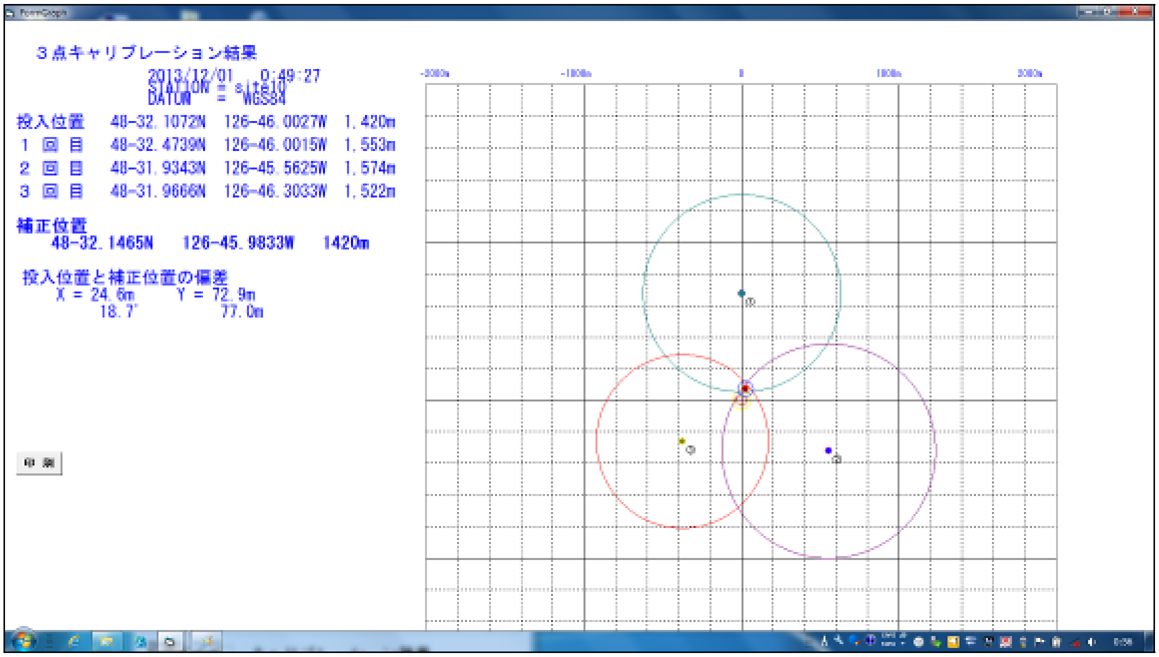


Figure A9 Screen capture for triangulation at OBS STN10.

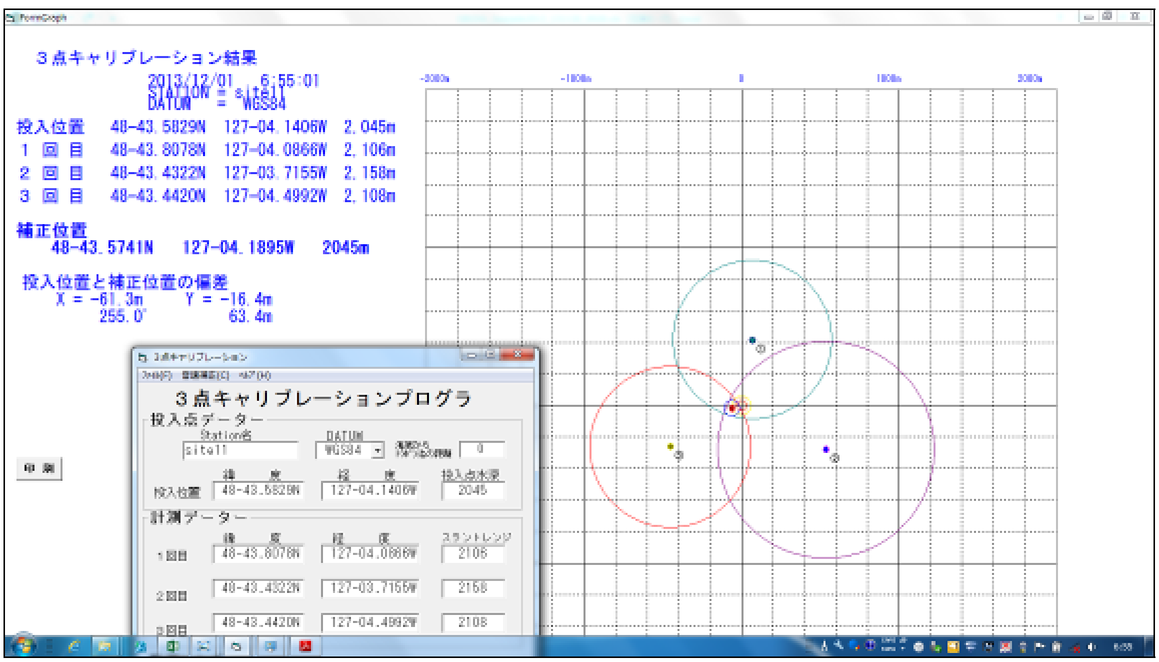


Figure A10 Screen capture for triangulation at OBS STN11.

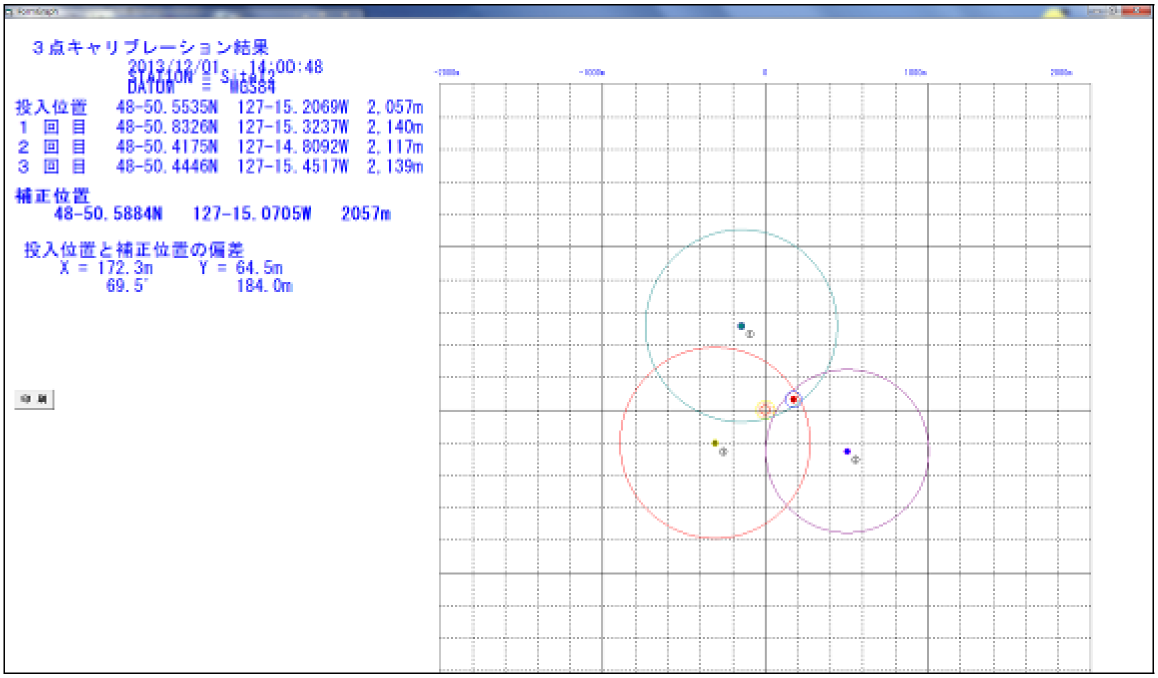


Figure A11 Screen capture for triangulation at OBS STN12.

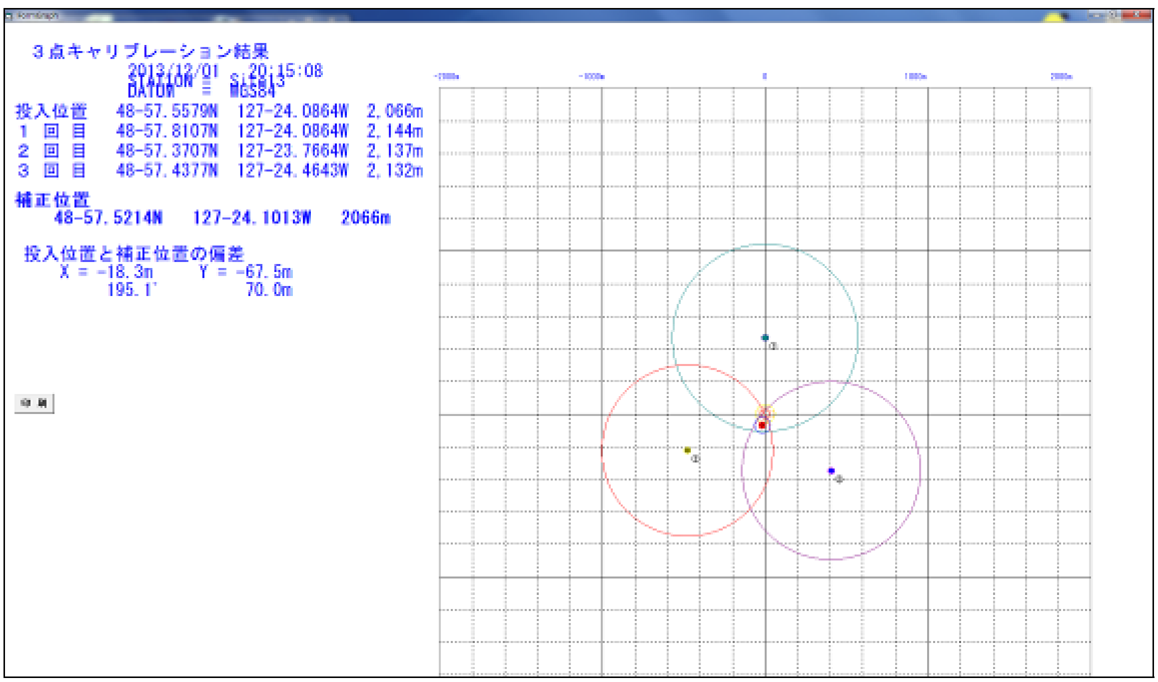
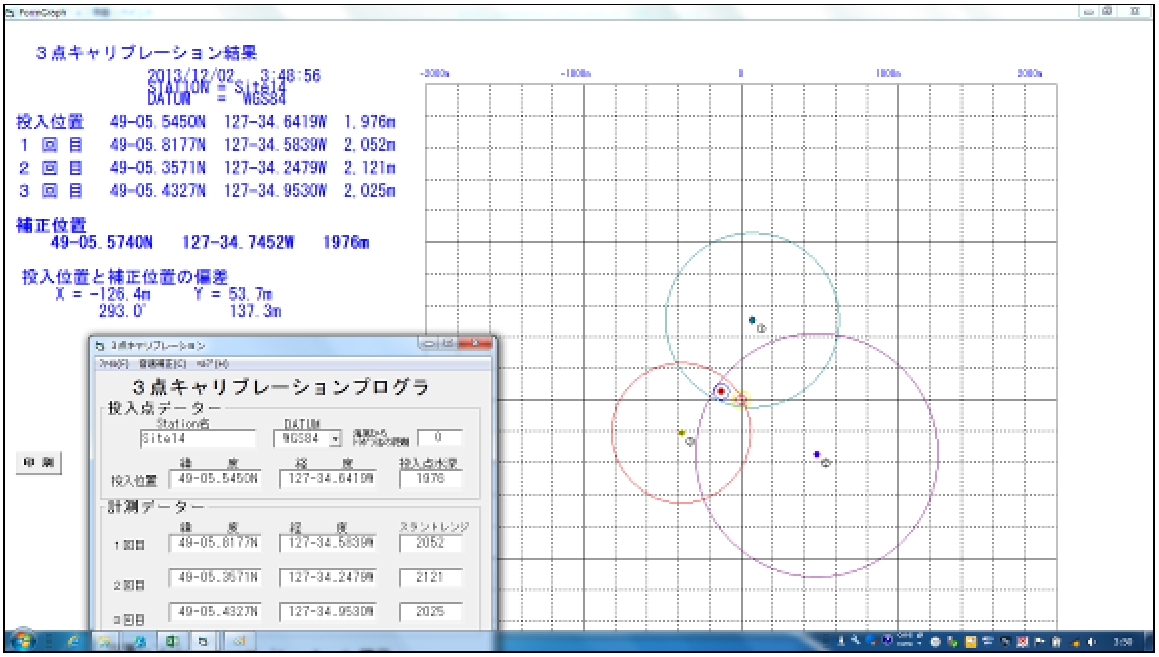
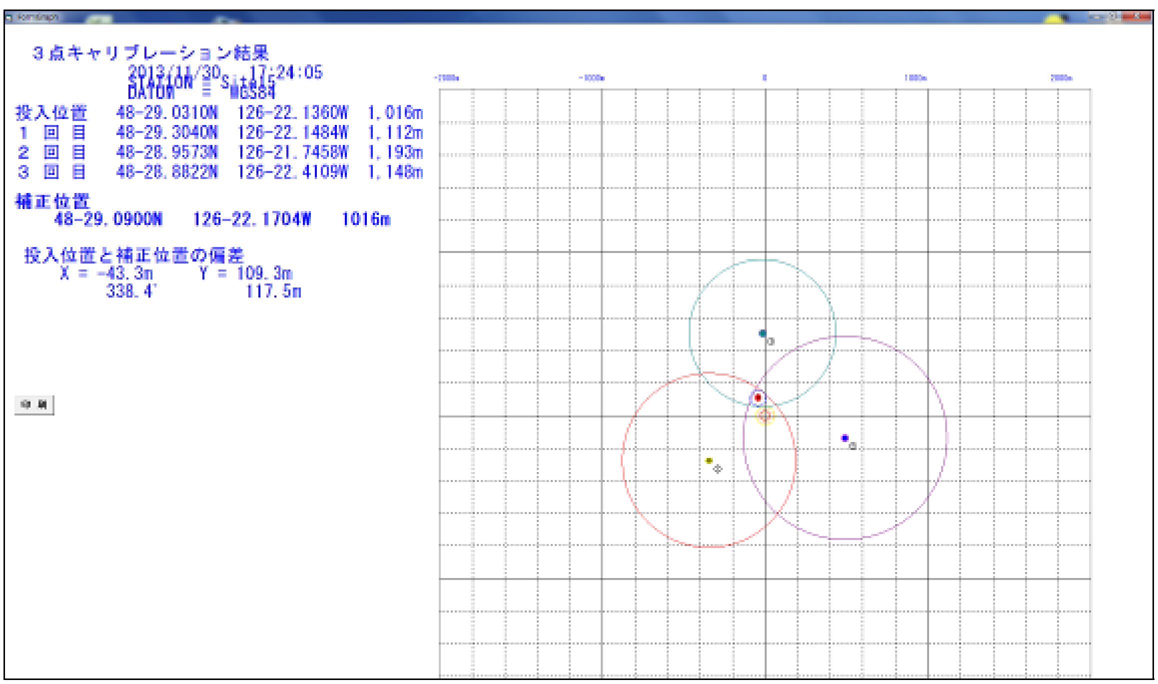


Figure A12 Screen capture for triangulation at OBS STN13.



<u>Figure A13</u> Screen capture for triangulation at OBS STN14.



<u>Figure A14</u> Screen capture for triangulation at OBS STN15.

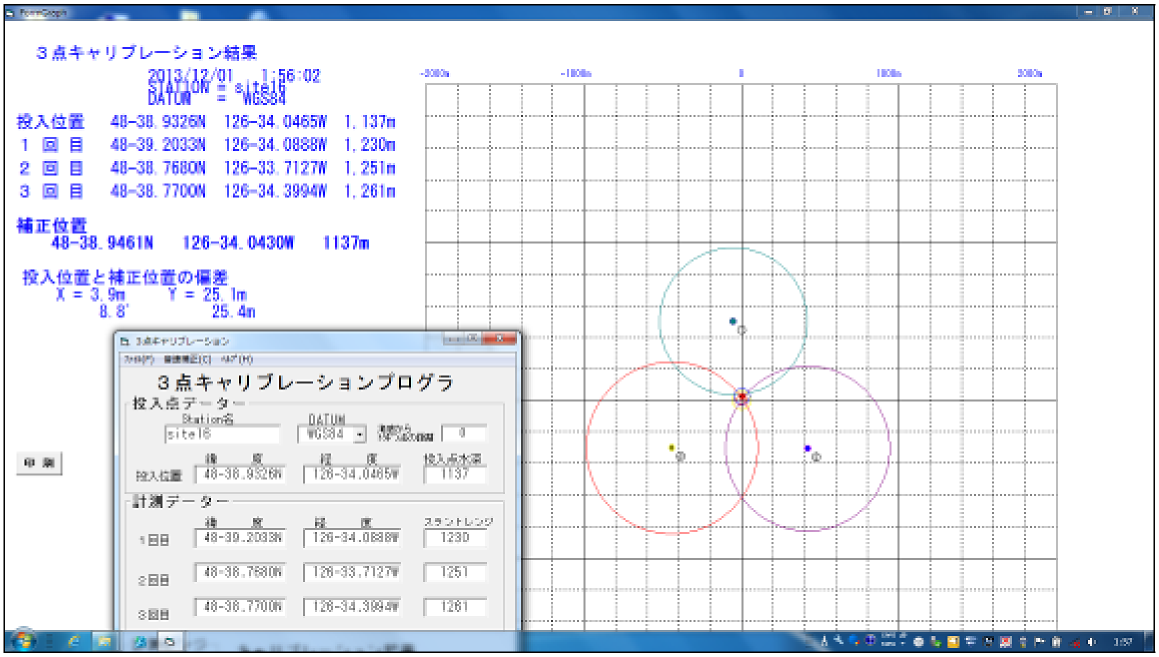


Figure A15 Screen capture for triangulation at OBS STN16.

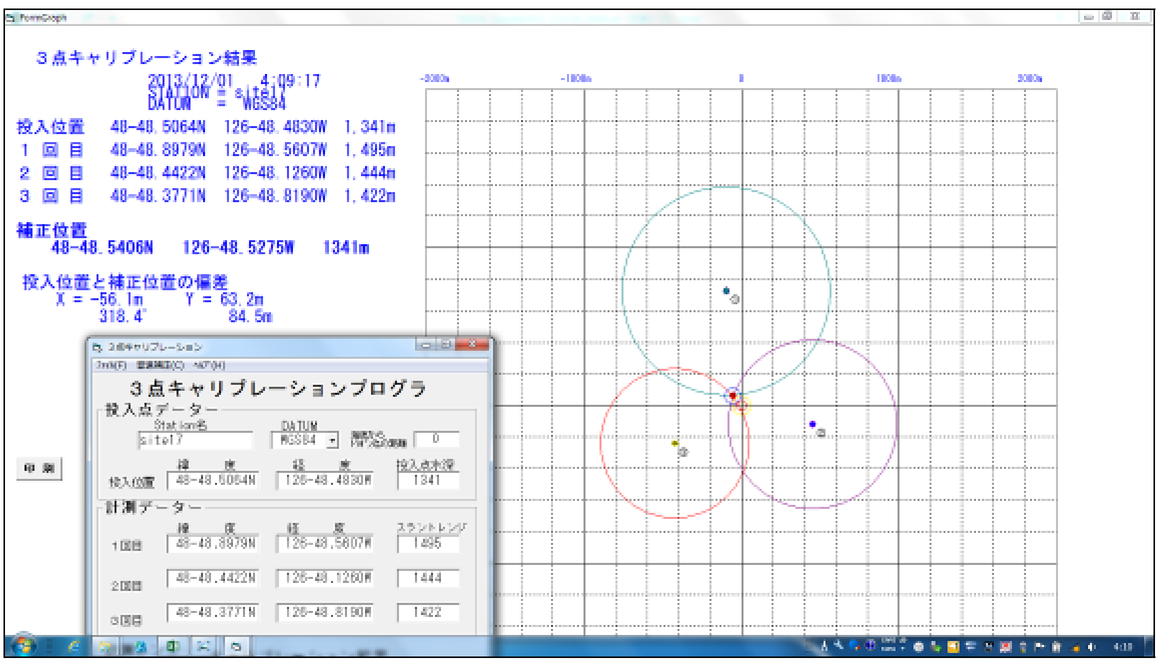


Figure A16 Screen capture for triangulation at OBS STN17.

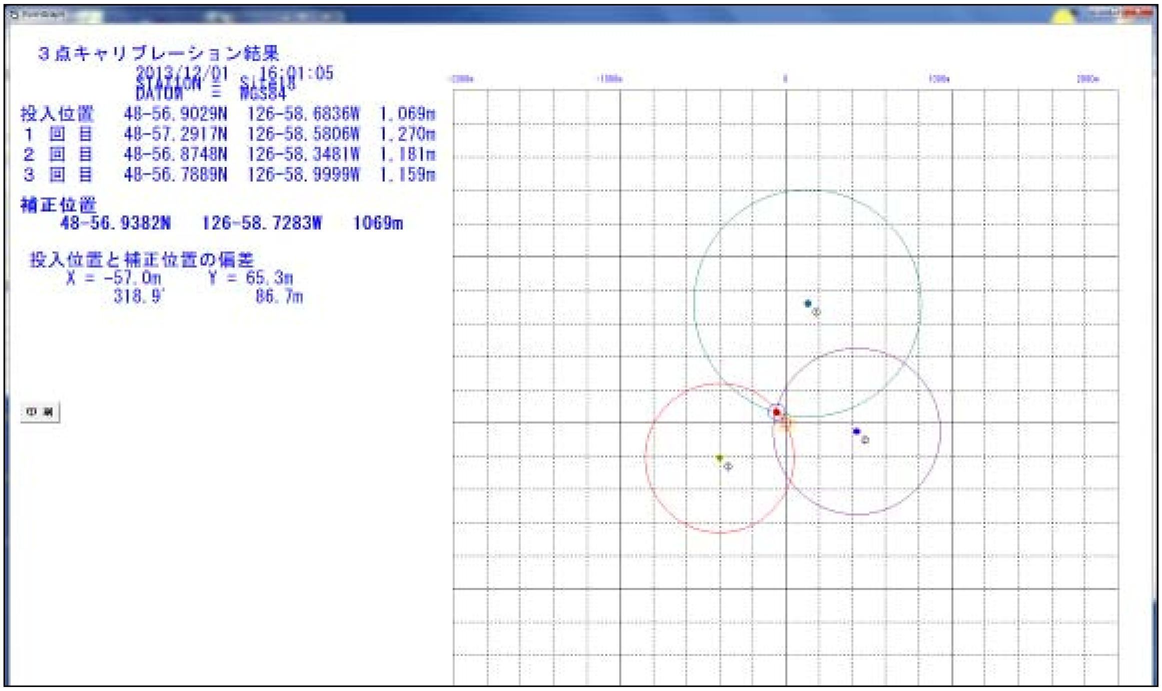


Figure A17 Screen capture for triangulation at OBS STN18.

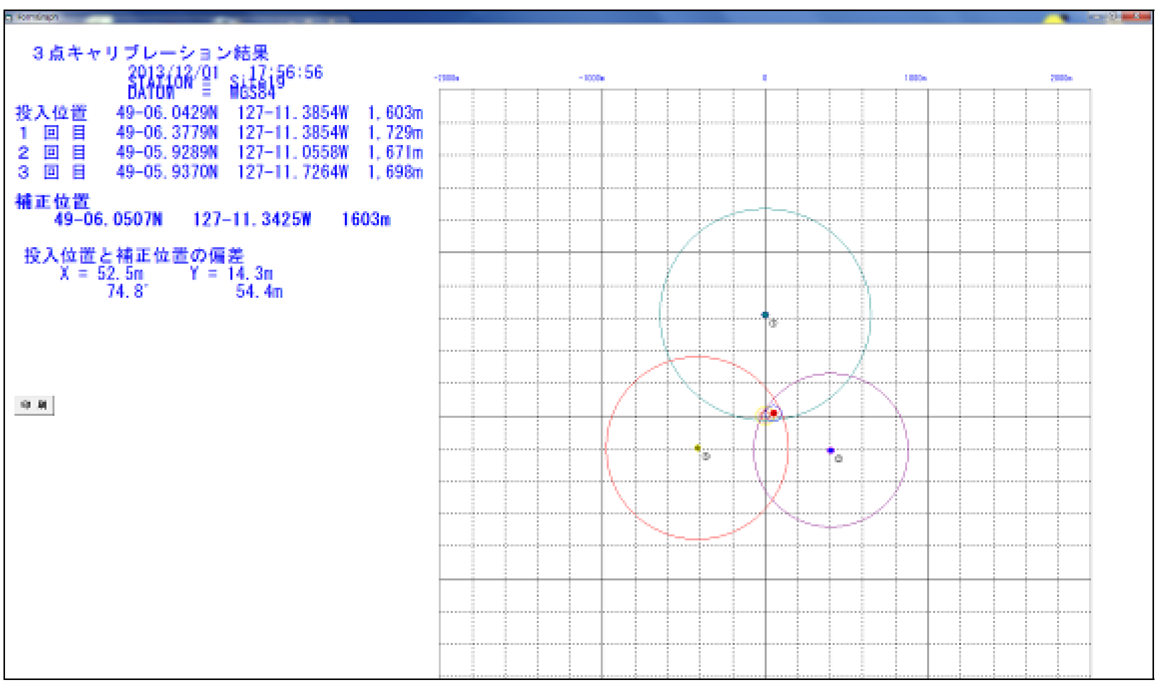


Figure A18 Screen capture for triangulation at OBS STN19.

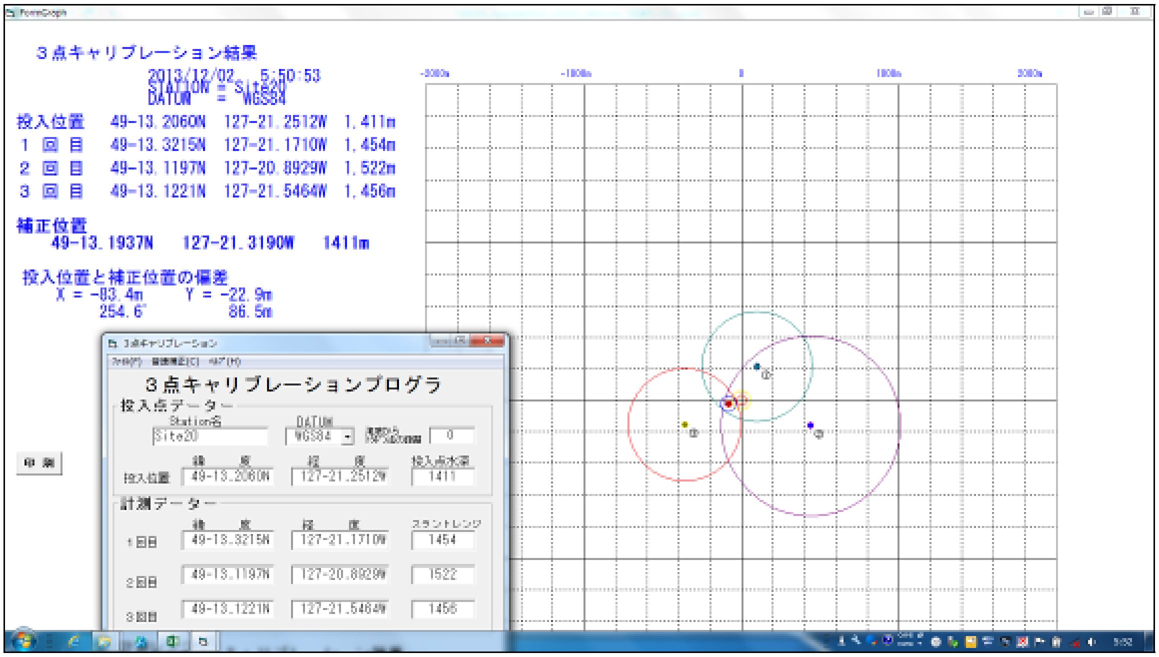


Figure A19 Screen capture for triangulation at OBS STN20.

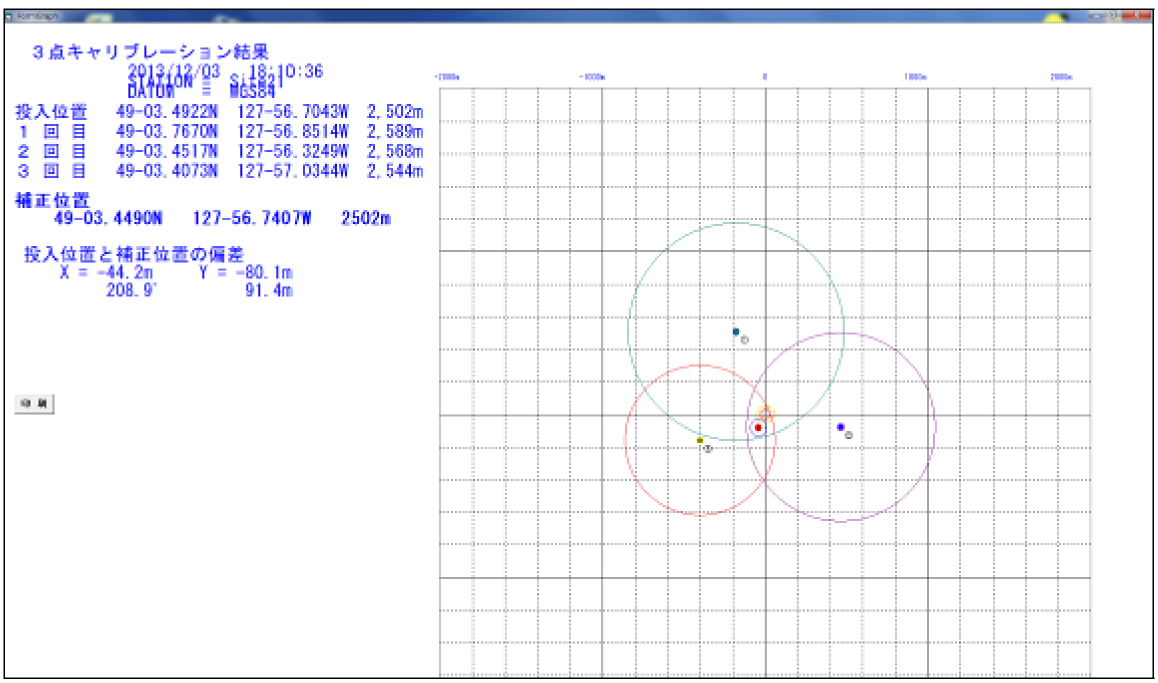


Figure A20 Screen capture for triangulation at OBS STN21.

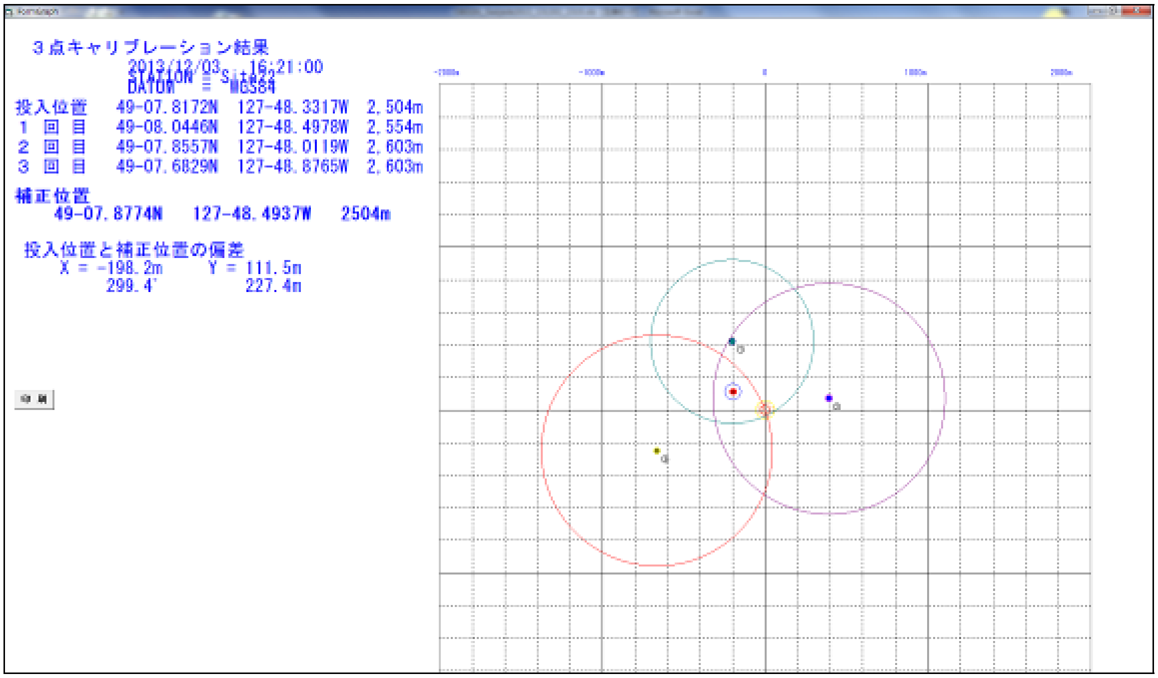


Figure A21 Screen capture for triangulation at OBS STN22.

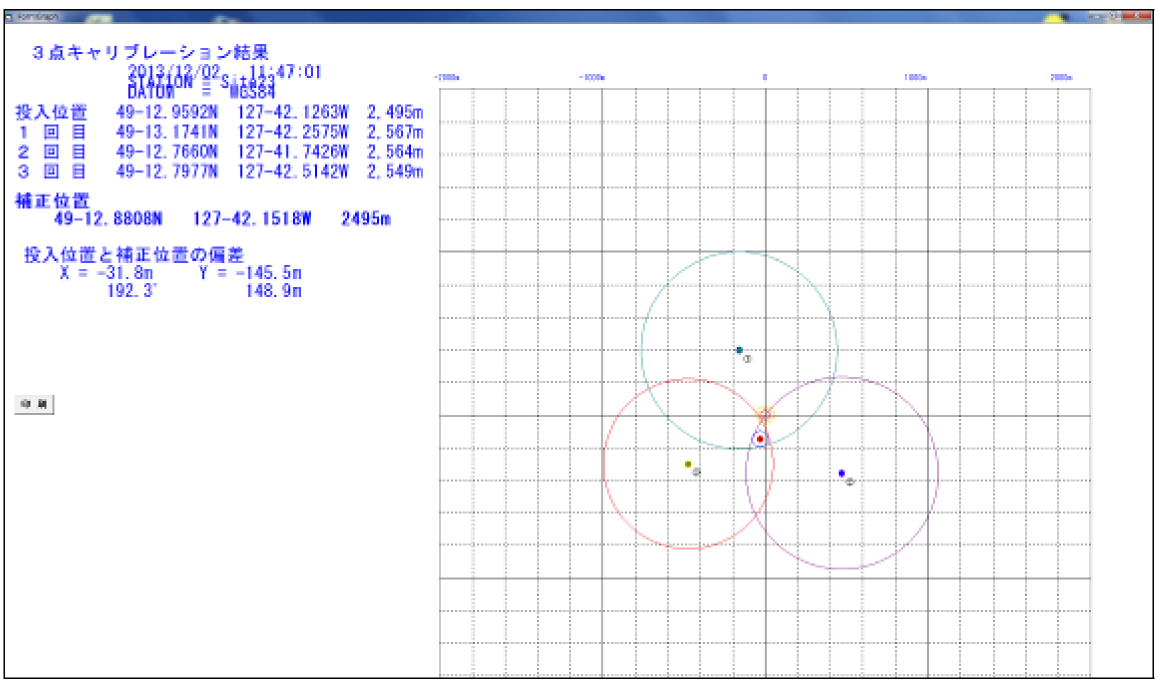


Figure A22 Screen capture for triangulation at OBS STN23.

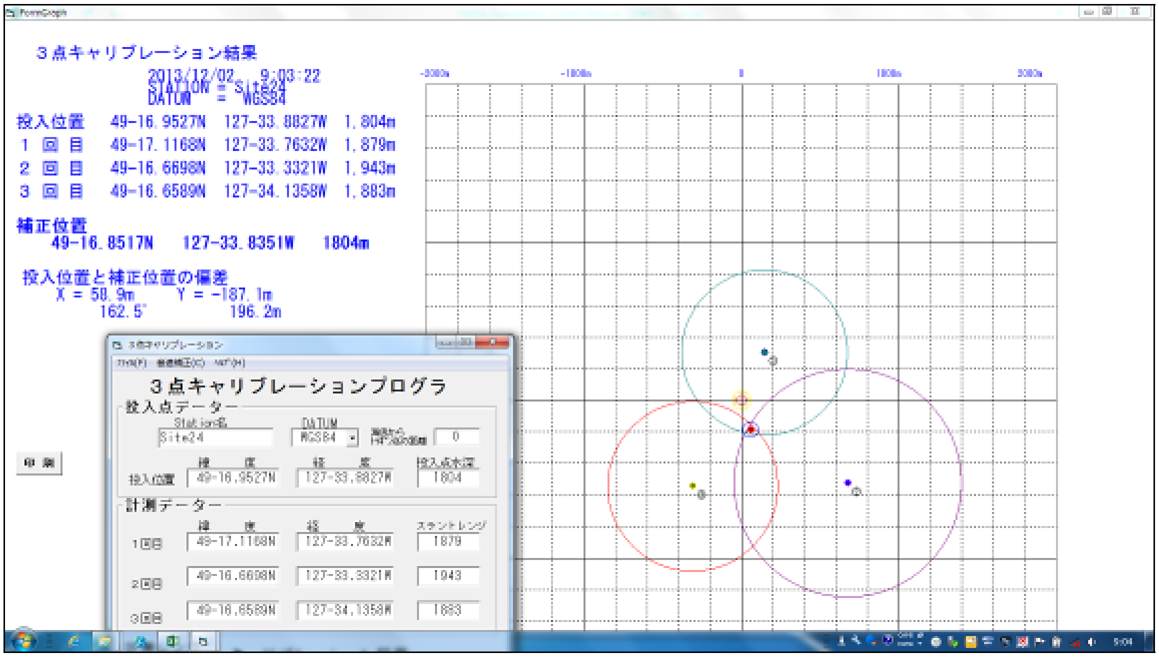


Figure A23　Screen capture for triangulation at OBS STN24.

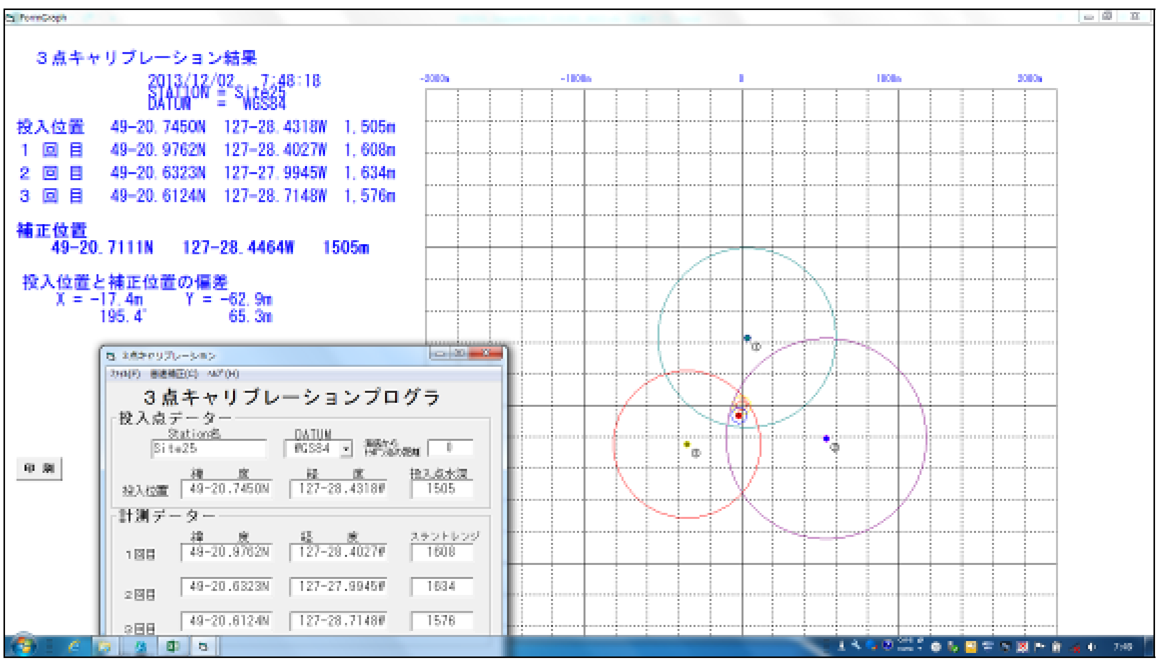


Figure A24　Screen capture for triangulation at OBS STN25.

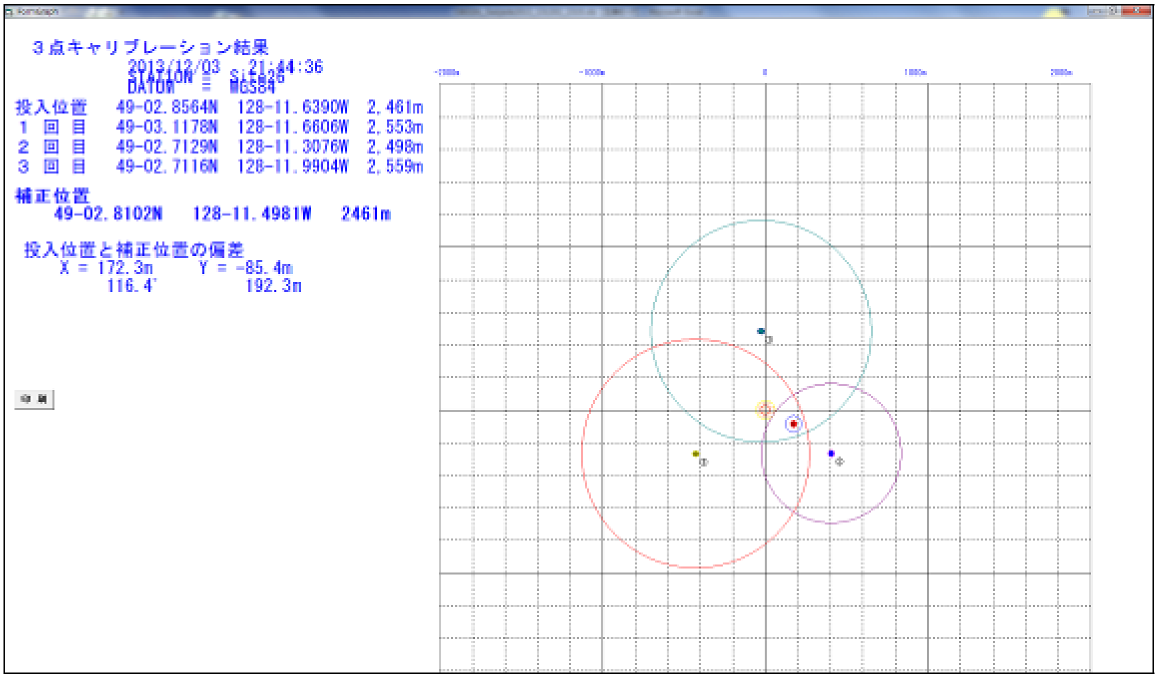


Figure A25 Screen capture for triangulation at OBS STN26.

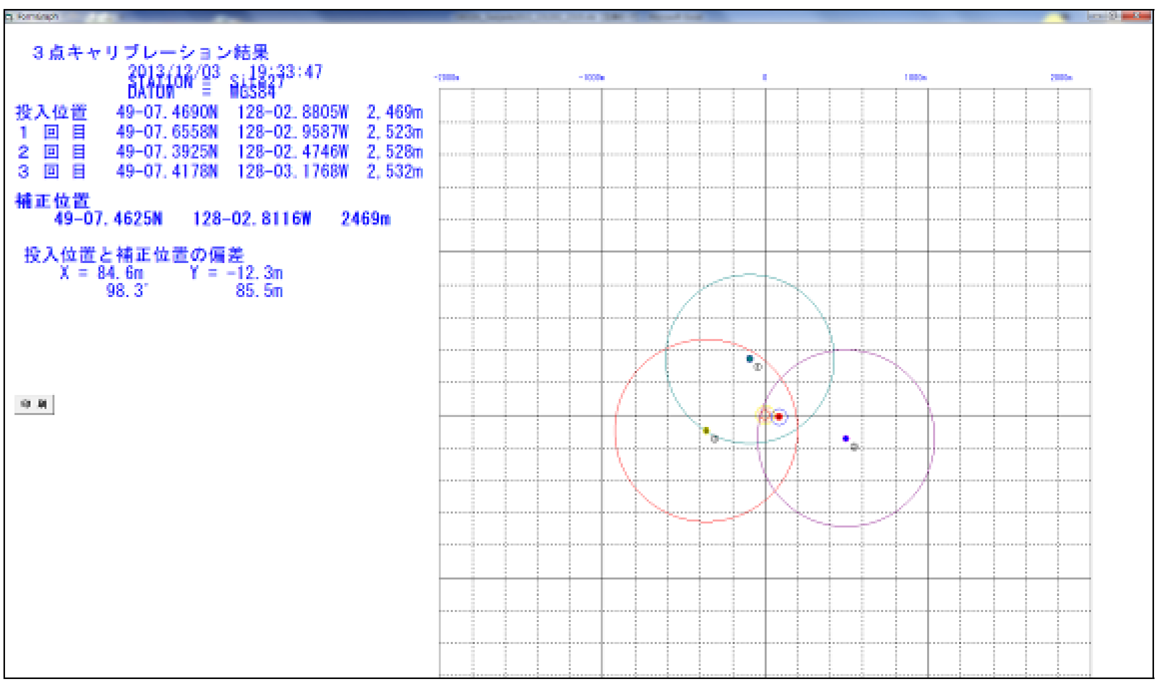


Figure A26 Screen capture for triangulation at OBS STN27.

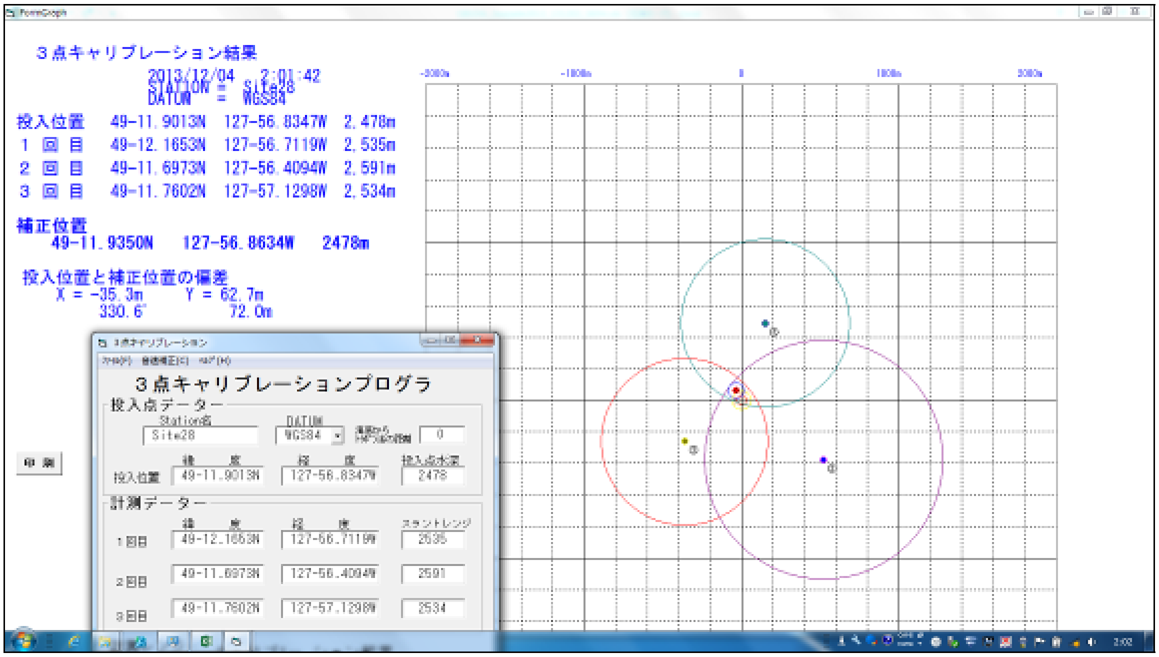


Figure A27 Screen capture for triangulation at OBS STN28.

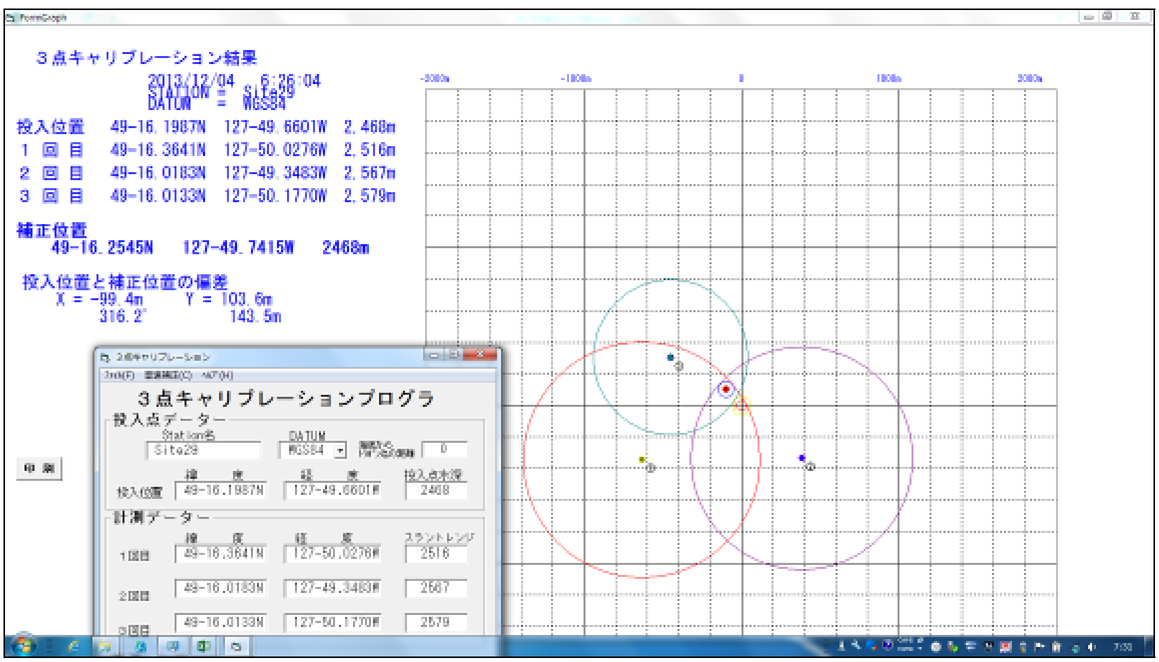


Figure A28 Screen capture for triangulation at OBS STN29.

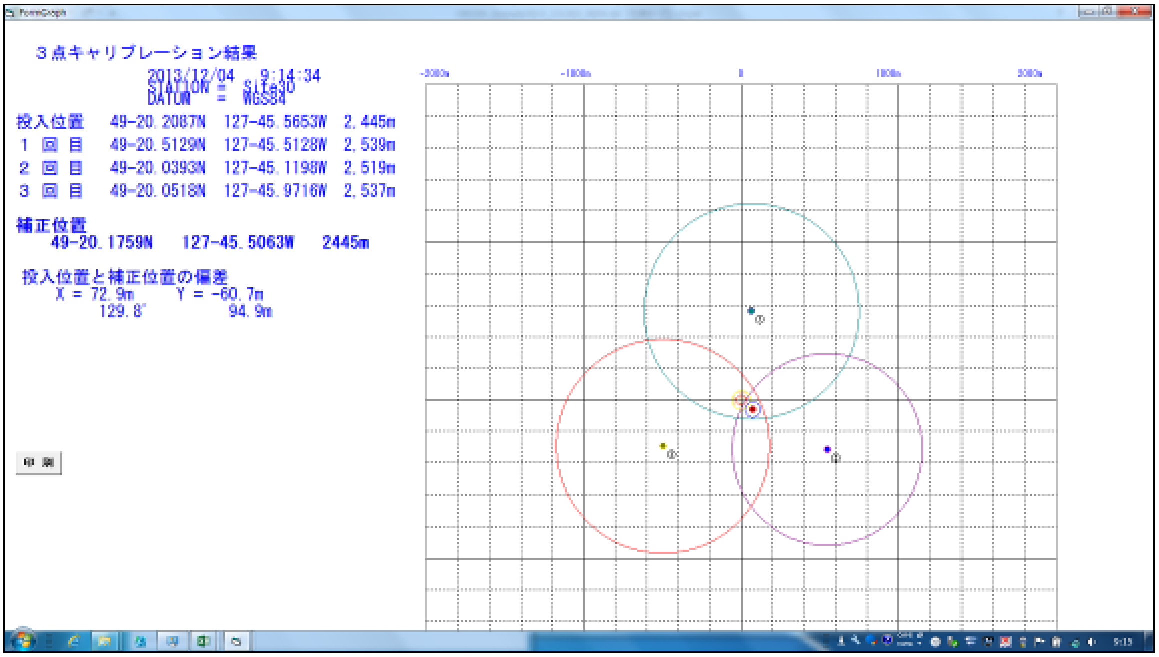


Figure A29 Screen capture for triangulation at OBS STN30.

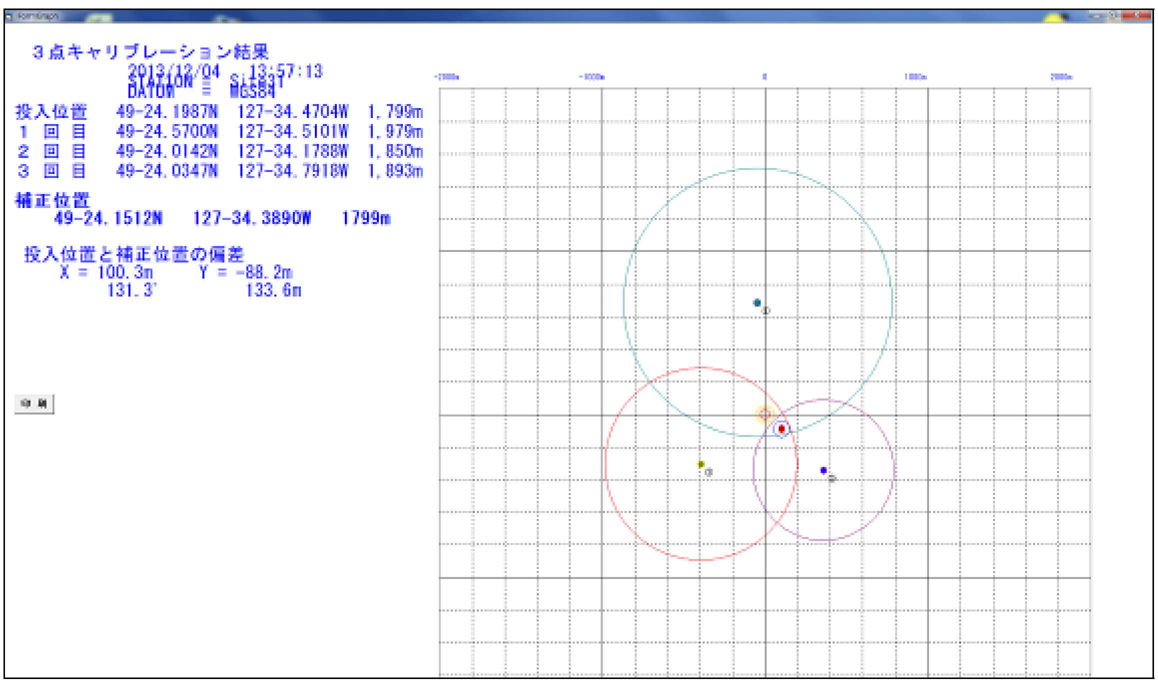


Figure A30 Screen capture for triangulation at OBS STN31.

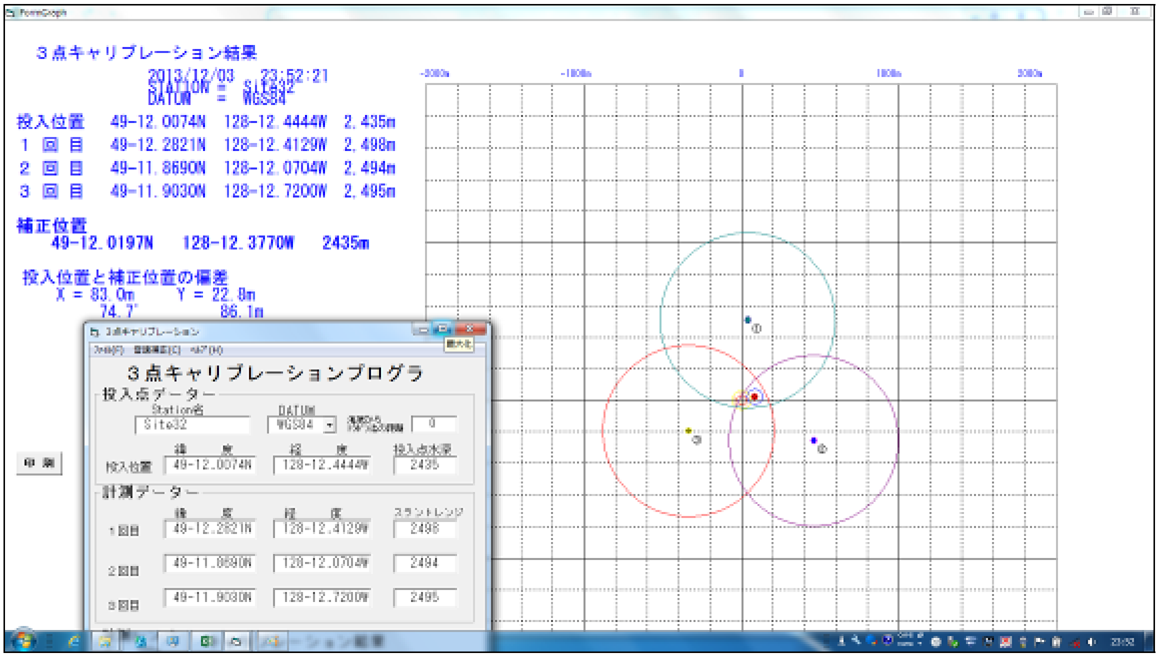


Figure A31 Screen capture for triangulation at OBS STN32.

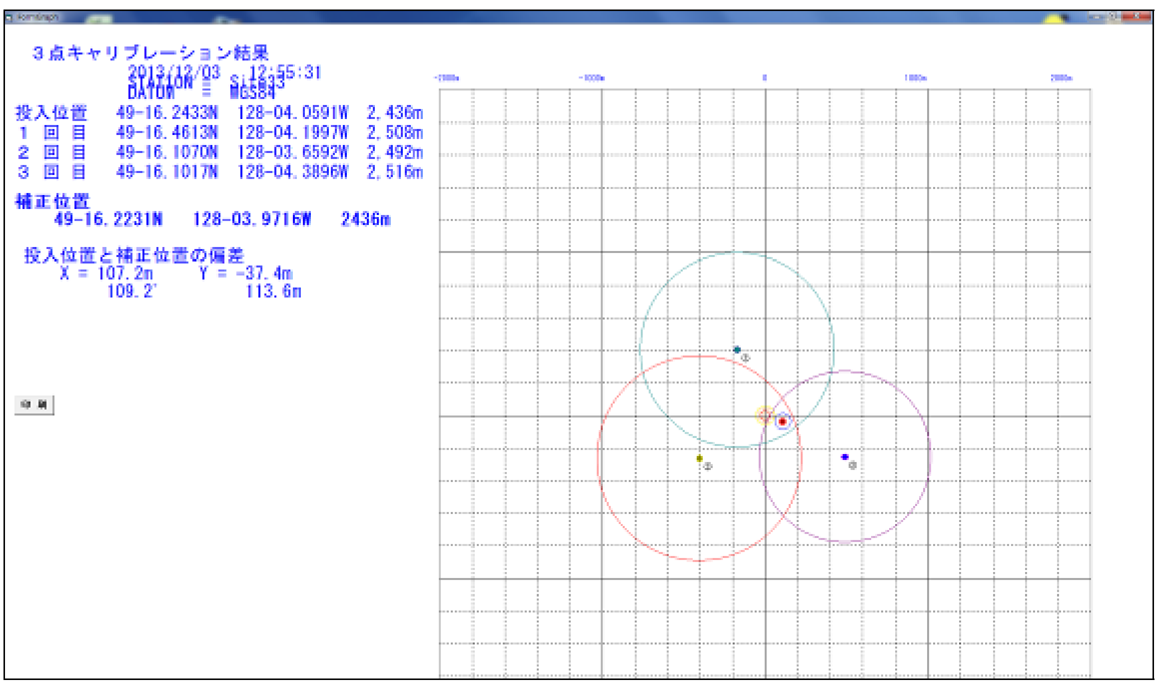


Figure A32 Screen capture for triangulation at OBS STN33.

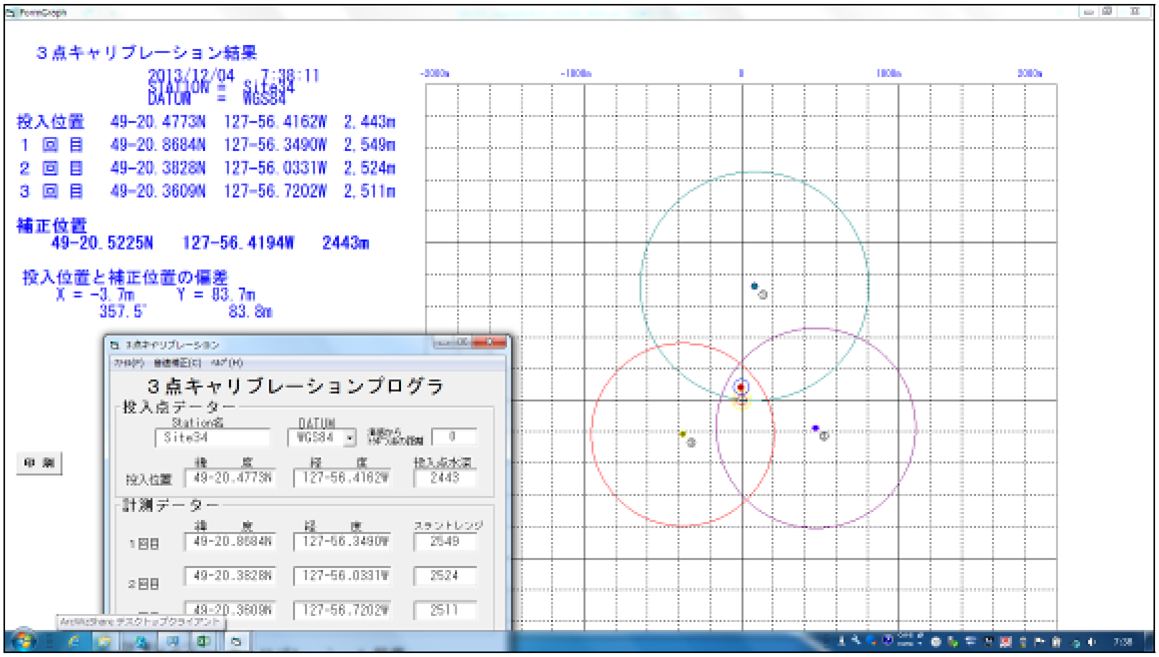


Figure A33 Screen capture for triangulation at OBS STN34.

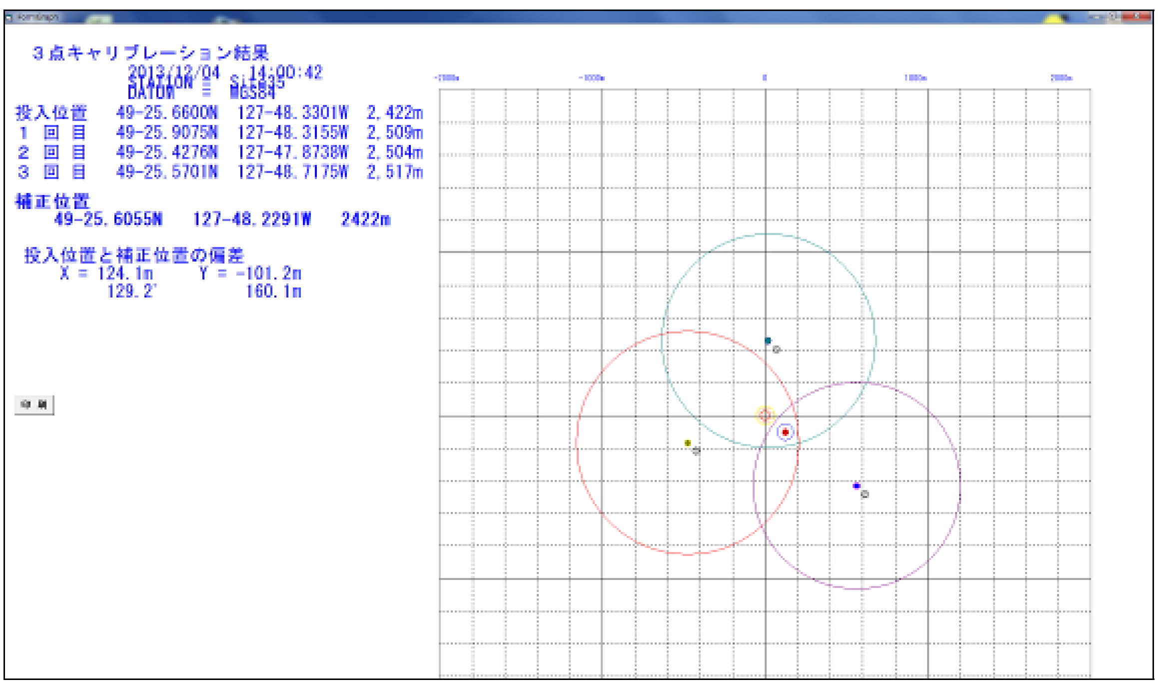


Figure A34 Screen capture for triangulation at OBS STN35.