S43E-0654

The First Data of the Autonomous BBOBS-NX (NX-2G) for New Era of Ocean Bottom Broadband Seismology

Hajime Shiobara[1], Aki Ito[2], Hiroko Sugioka[3] and Masanao Shinohara[1]

1: ERI, The University of Tokyo 2: D-EARTH, JAMSTEC 3: Planetology, Kobe University

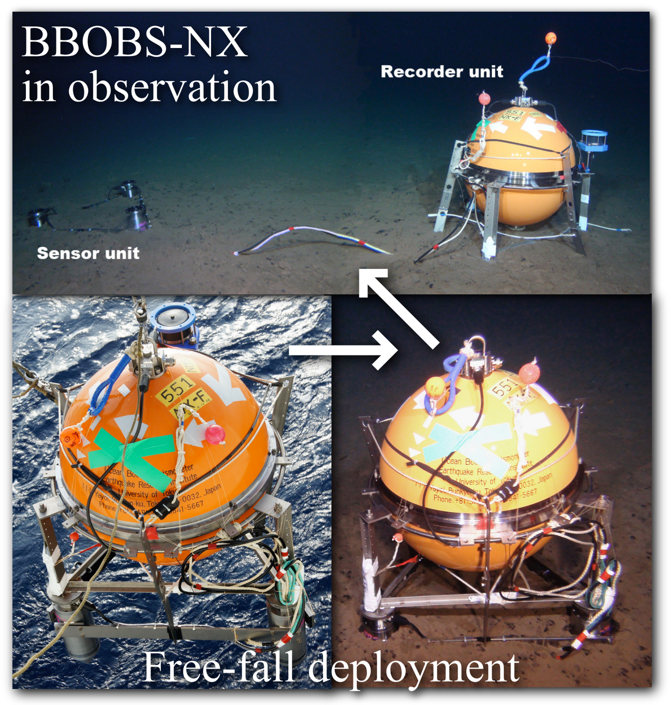
Summary

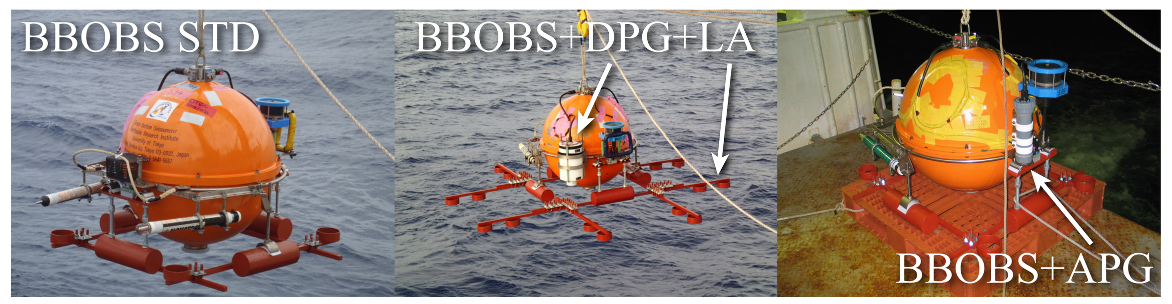
The ocean floor broadband seismology has been established based on several practical observations by using broadband ocean bottom seismometer (BBOBS) and its new generation system (BBOBS-NX) in Japan since 1999. The data obtained by our BBOBS and BBOBS-NX is adequate for broadband seismic analyses, especially the BBOBS-NX enables the quality of the horizontal data comparable to land sites in longer periods (10 s –). And, the BBOBS-NX with tilt measurement function, BBOBST-NX, is in practical evaluation for the mobile tilt observation that may realize a dense seafloor geodetic monitoring with low cost.

The weak point of the BBOBS-NX system lies in the intrinsic limitation of the submersible in its operation. If this system can be operated alone like as the BBOBS, it should be a true breakthrough of ocean bottom seismology. We call this new autonomous BBOBS-NX as the NX-2G in short. Several problems to realize the NX-2G have been almost cleared through test observations since 2012. The function of the NX-2G system is based on 3 stage operations as shown in the image. The glass float is added to obtain enough buoyancy to extract the sensor unit from the seafloor and also to suppress the oscillating tilt of the system in descending, not to exceed the tilt allowance of the broadband seismic sensor.

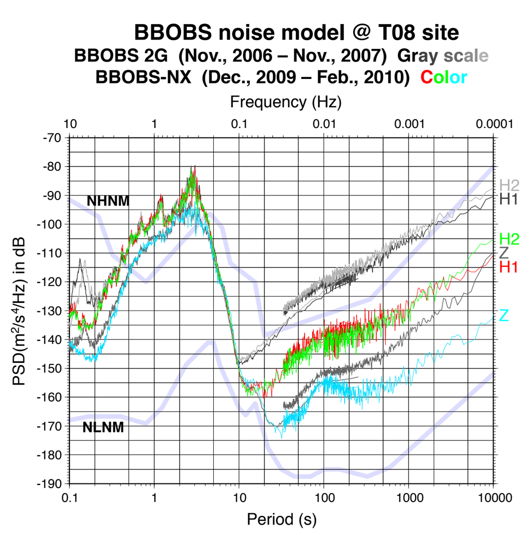
In Oct. 2016, the first in-situ test of the NX-2G system was performed. The landing of the NX-2G looked well and the maximum tilt in descending was about ±2.5°, that ensured the effective suppression for the oscillating tilt by the glass float. As the final step test of the NX-2G, the one-year-long observation has been started in April 2017 with the BBOBS deployed nearby, to obtain simultaneous data for the noise level evaluation. The free-fall deployment and the transition from the landing stage to the observation stage were completed, those were monitored through the acoustic communication from the ship. This NX-2G was recovered in Oct. 2018 with the ROV, KAIKO Mk-IV, to watch the transition from the observation stage to the recovery stage in-situ. All function of the NX-2G at the seafloor was perfect with immediate extraction of the sensor unit. Noise level comparison with the BBOBS shows about 10 dB improvement that is not enough as expected, which may lie in a small tension of the cable between the sensor unit and the recording unit. And, scenes of the landing and the first transition were selfied by the Deep-Sea CAM.

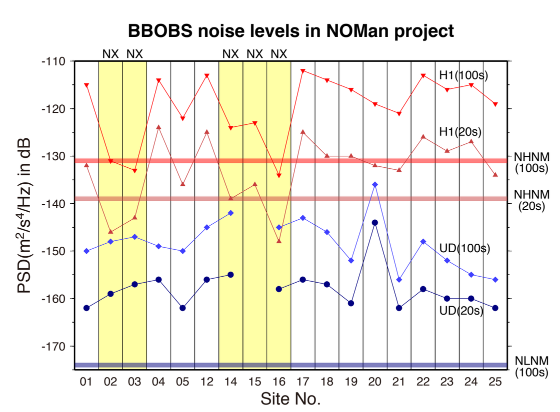
Improvements of BBOBS : 2005 – 2012





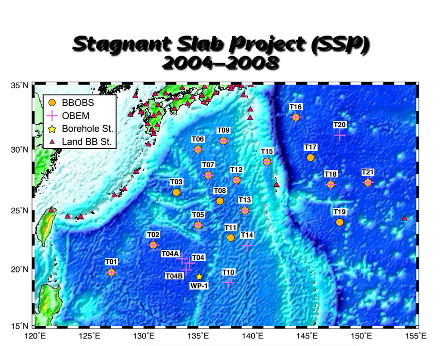
The first BBOBS had been developed since 1999, and it has been improved continuously during use in practical array observations ([1], [2]). The BBOBS with a long anchor (LA) reduces the vertical noise level, too [3]. By attaching the DPG [4] or the APG [5] to the BBOBS, we can observe more useful signals in the long period range than the CMG-3T sensor only.

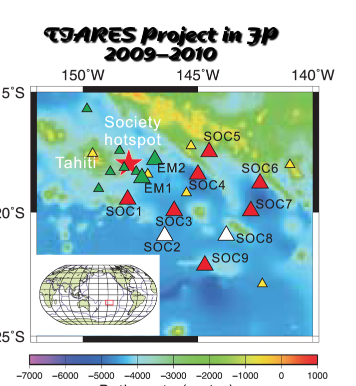


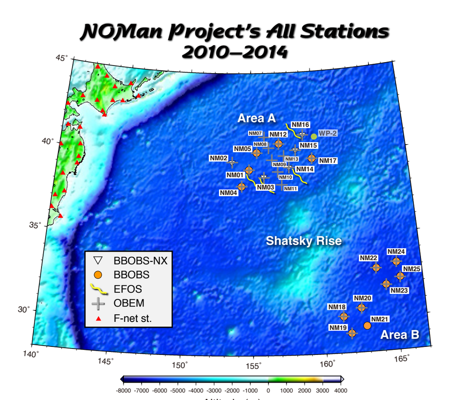


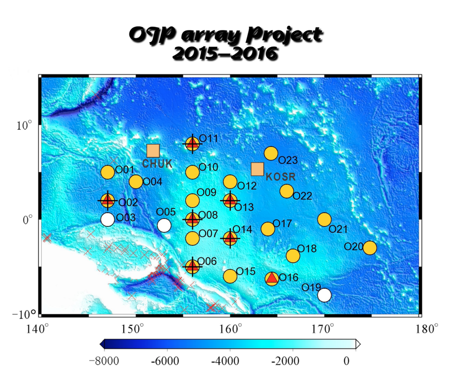
The BBOBS-NX is a BBOBS of NeXt generation that can apparently reduce noise levels of horizontal components by using a self-buried (i.e. penetrator) sensor unit [6]. After the free-fall drop from the sea surface, the deployment and the recovery are performed by the ROV as shown in upper left and center figures. This development had been started in 2002, and the first practical use was during the NOMan project (2010–2014) by 8 units in total. The result of noise levels of BBOBSs used in this project shows the relative advantage of the BBOBS-NX (upper right graph).

BBOBS (+DPG) were deployed in the Stagnant Slab Project (2004–2008) [7], the TIARES project (2009–2010) [8], and several small scale observations. We have also finished the 1.5-years-long observation at the Ontong Java Plateau (2015–2016) by using 23 BBOBS (+DPG+LA).

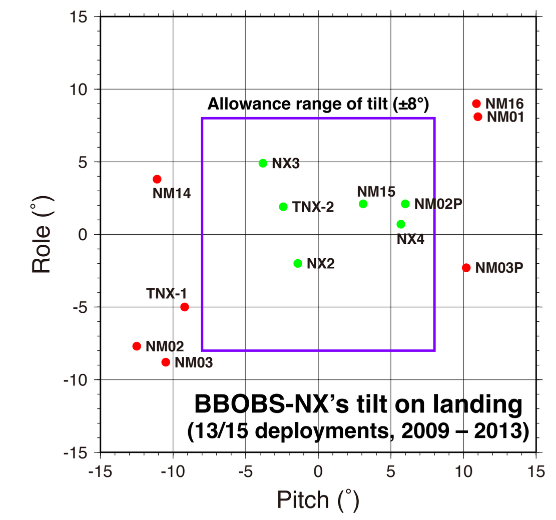






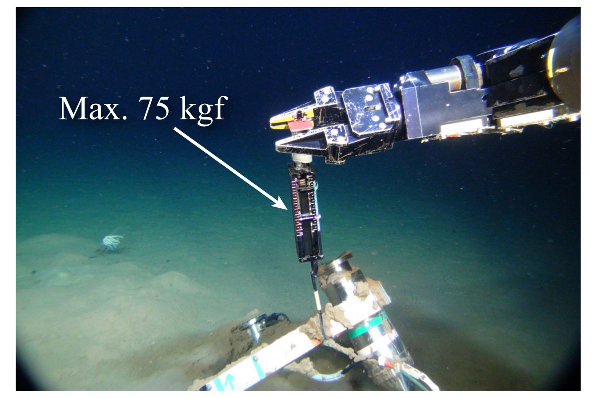


Preparation toward NX-2G : 2012 – 2015



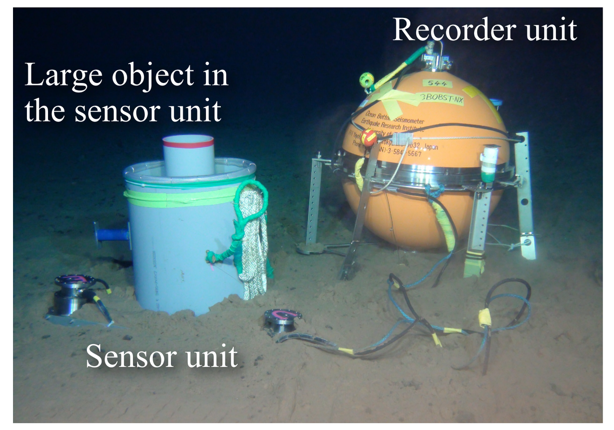
Because necessary aid of the ROV in operation of the BBOBS-NX limits opportunity of the observation, we have started to improve it as an autonomous system (NX-2G) that can be used like as the free-fall and self pop-up type BBOBS. There are three known problems; tilt on landing exceeds the allowance of the sensor in free-fall deployments of the BBOBS-NX, force to extract the sensor unit (well) penetrated into the sediment in the recovery, and the total mechanical design to realize reliable autonomous operation.

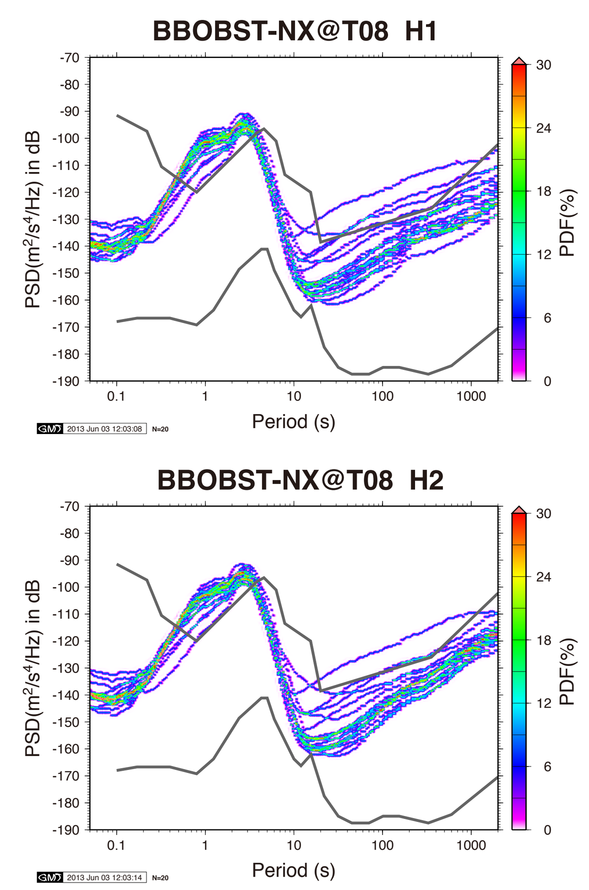
The special CMG sensor (360 s) used in the sensor unit allows operation up to ±8° inclination, but about half cases of tilt on landing exceeded this limit (left graph). In the BBOBS-NX operation with the ROV, this tilt can be corrected by using the skid of the ROV, and this tilt correction process may decrease the coupling condition between the sensor unit and the sediment. But, the NX-2G without aid of the ROV should keep the tilt on landing less than this inclination limit. We have started to observe how and when this tilt occurred and also to find the way to control it as shown in the right panel.



The amount of required force to extract the sensor unit penetrated into the sediment was measured at the seafloor by using original spring weight scale at several sites, such as deep sea basin and trench slope. It was ranged from 60 to 80 kgf according to the different type of sedimentations. The weight of the sensor unit in the water is about 38 kgw. Because the buoyancy of the empty Ti sphere housing (D=650mm) is about 75 kgf, we should add some amount of floats to recover the whole NX-2G system as we should install Li cells etc inside of the Ti sphere housing.

In-situ noise test for the NX-2G by the BBOBST-NX in Nov. 2012 – Feb. 2013

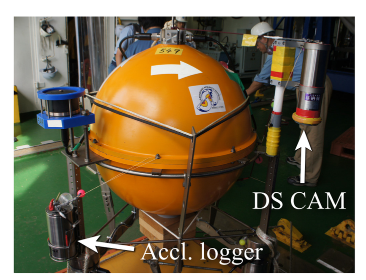


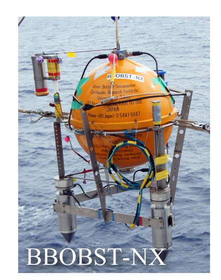


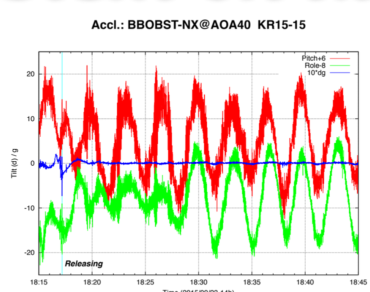
To evaluate the effect in noise levels by placing the recorder unit, Ti sphere housing (D=650mm) and a large object close to the sensor unit of the BBOBS-NX, about 2 months long test observation was performed at the T08 site (refer map of the SSP in the left panel). Such large objects could cause the seismic noise due to vibration or periodic tilt by the bottom current even if they were not directly connected to the sensor unit. As the NX-2G system should place the anchor connected with floats inside of the sensor unit (refer the right panel), it is important to evaluate this effect.

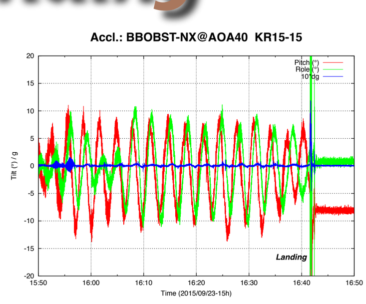
The result (right graphs) shows almost same noise levels in the horizontal component compared with the previous test observation of the BBOBS-NX placing the recorder unit about 2 m away from the sensor unit. It is expected that if the vibrating object was weakly coupled with the sediment, the induced seismic noise would decay enough within short distance like as the practical observation of the NX-2G system. In other words, the anchor of the NX-2G should NOT be penetrated well into the sediment to prevent the good coupling that could propagate to the sensor unit the vibration noise by floats.

Clear the tilt problem on landing

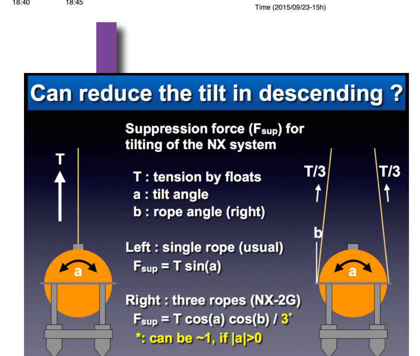




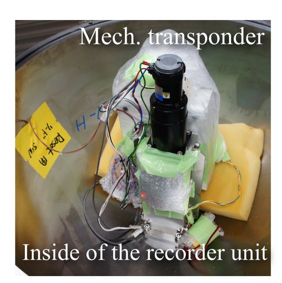


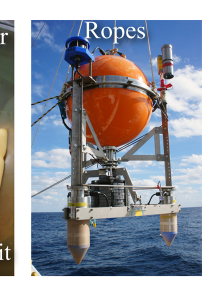


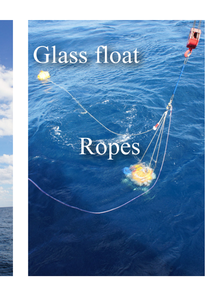
By using originally developed acceleration logger and Deep-Sea CAM, we observed when and how the tilt on landing occurred in 2015 during the deployment of the BBOBST-NX. A periodic tilting started when it was released from the sea surface, and the final posture seemed to determine the tilt (right two graphs).



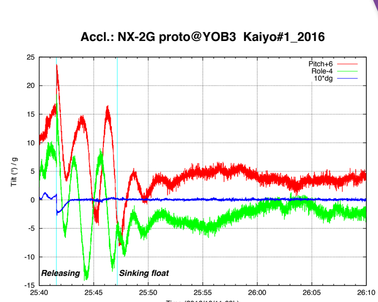
The first test of the NX-2G in 2016

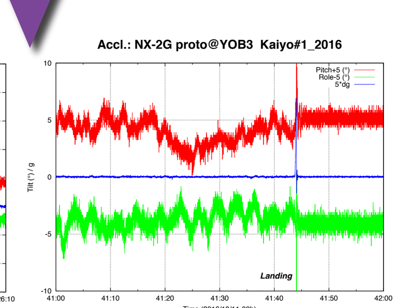




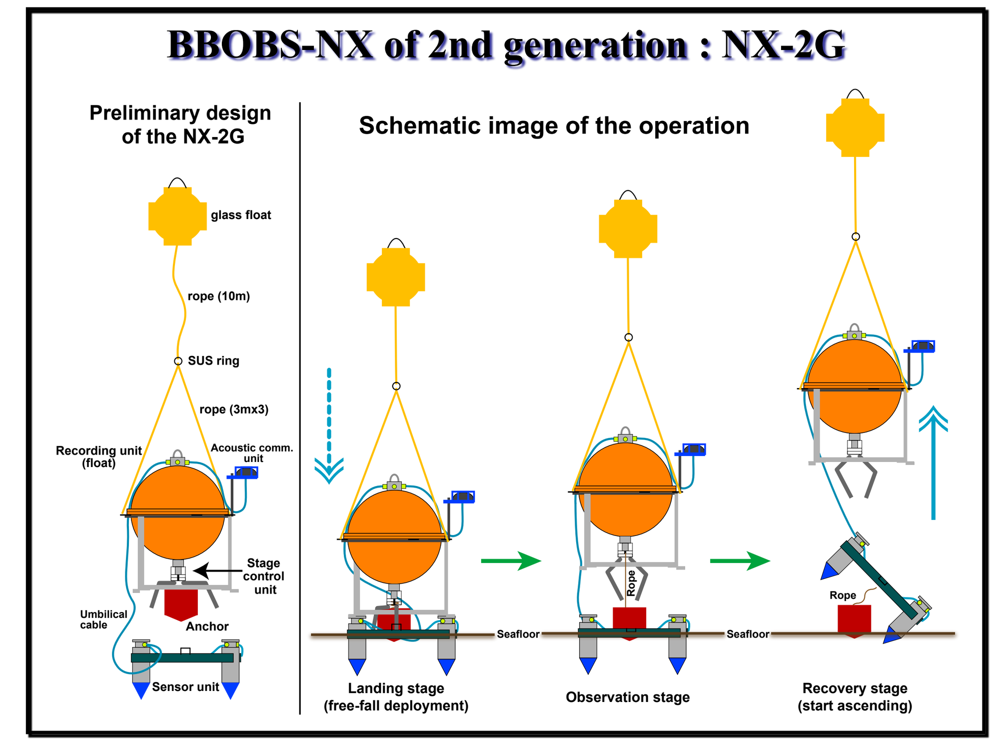


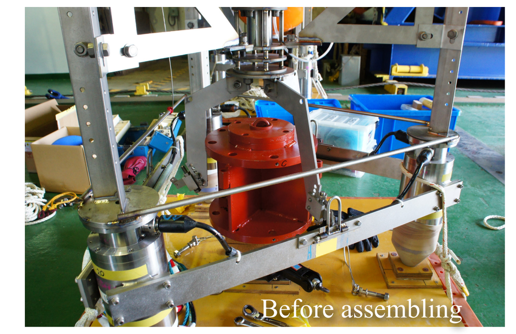
As we should add some floats to extract the sensor unit with the NX-2G, we consider to use this buoyancy for suppression the periodic tilting also. This idea was examined at the test in 2016, and it seemed working well as shown in right two graphs. Soon after the releasing from the sea surface, the NX-2G started the tilting. But, when the float started to sink, tension of three ropes (see upper photos) started to suppress the tilting until the landing effectively. The final tilt at the seafloor of the NX-2G was well smaller than the limit of the sensor.

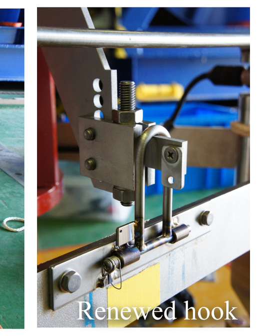




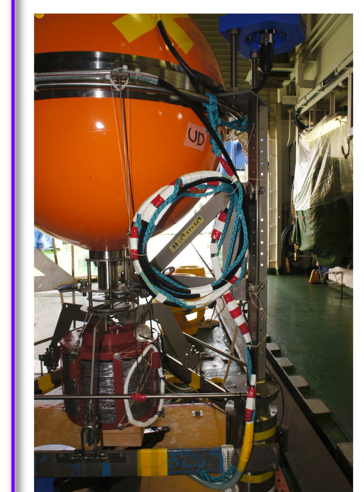
The first launch of the NX-2G in 2017

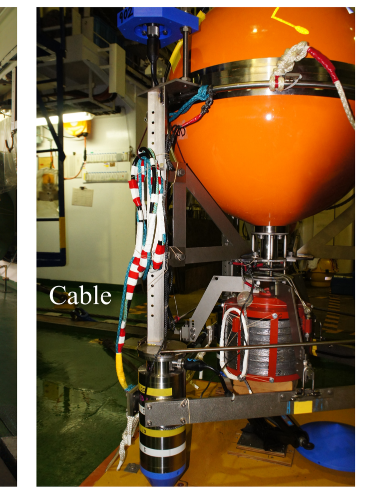


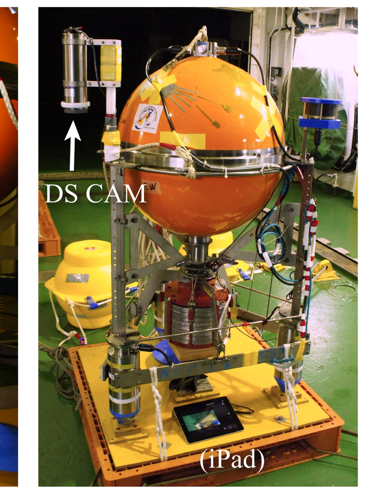


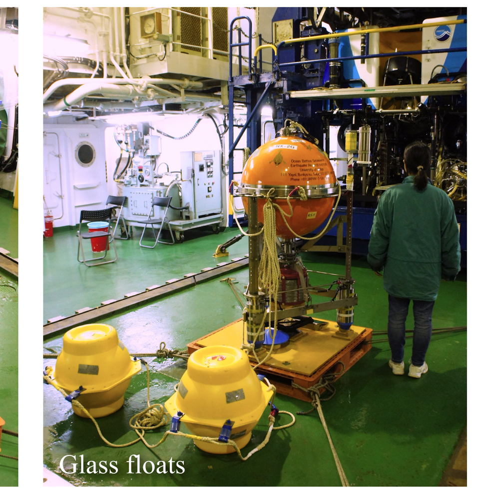


The first long-term deployment of the NX-2G had started in this April instead of the BBOBST-NX deployment due to unavailability of the ROV by bad weather forecast. As this observation was aimed to evaluate the systematic noise level and the function among stages, the recovery is designed to use the ROV and performed in Oct. 2018. After the free-fall deployment resulted with the small tilt, the NX-2G was changed into the observation stage correctly by the acoustic command. The landing and the first transition were selfied by the Deep-Sea CAM attached. To achieve enough scientific results from temporal array observations, such as the "Pacific Array" [9], the NX-2G should play an important role from its high quality data and flexibility for ships.

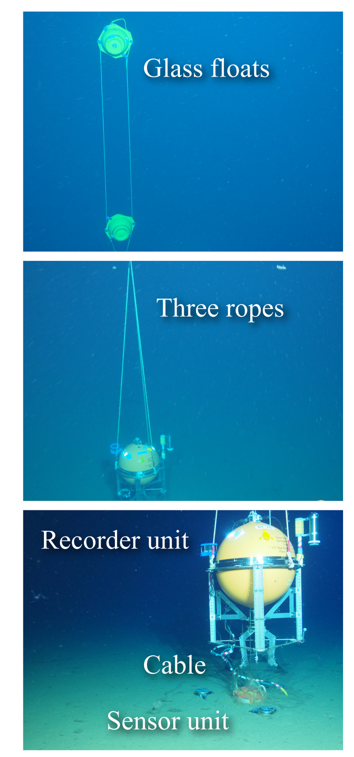




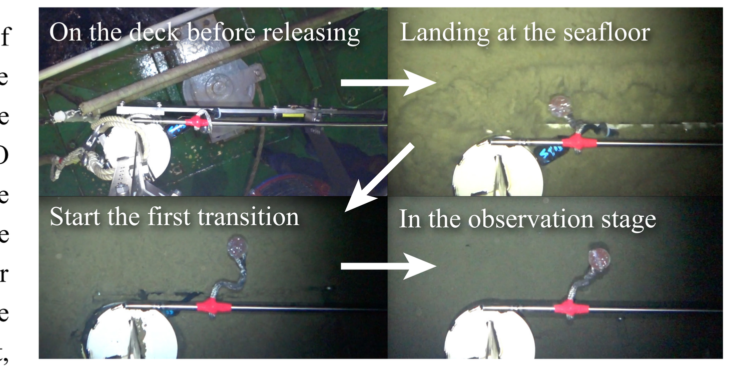




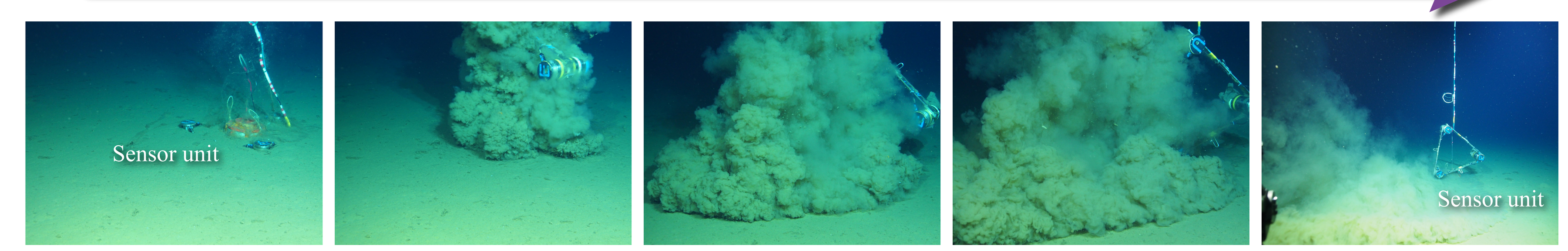
Results of the first NX-2G observation



The recovery of the NX-2G was completed with the movie data of the Deep-Sea CAM, which selfied several scenes during the deployment as shown in right photos. The whole situation of the observation stage of the NX-2G was observed by the ROV, KAIKO Mk-IV. The anchor and the sensor unit were penetrated into the (soft) sediment more than we expected. One problem was a route of the underwater cable between the sensor unit and the recorder unit, which was not ideally extended due to misalignment in the assembling on the deck and not enough length of the cable. So that, the cable might touch the sensor unit with some vibration caused by the recorder unit above in the bottom current.

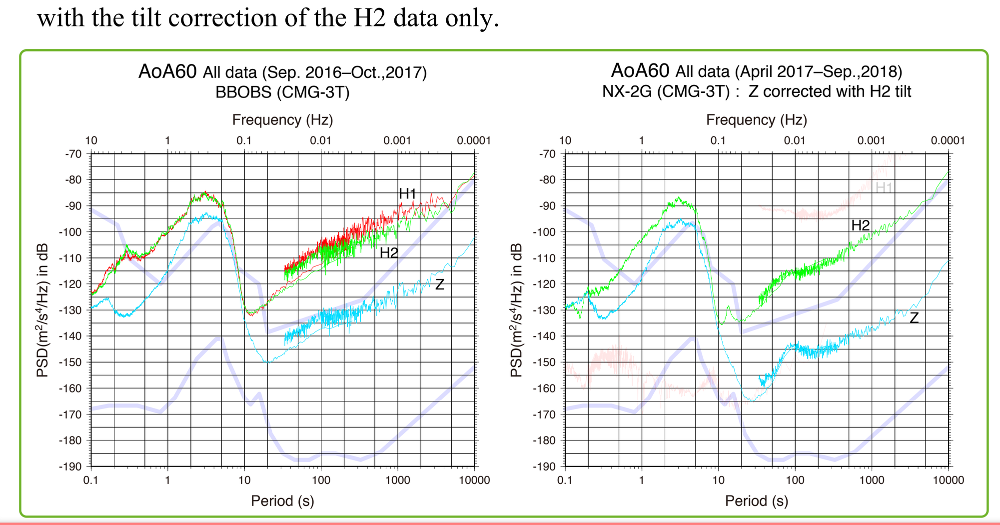


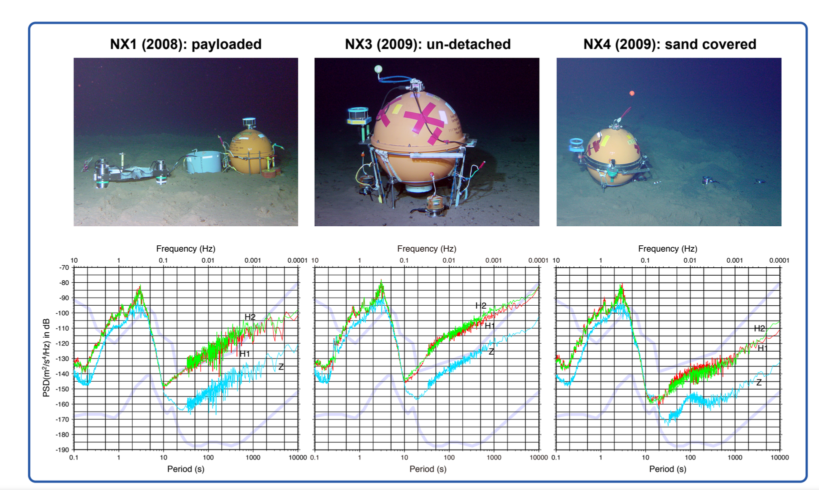
Then, we sent the acoustic command from the ROV to start the second transition from the observation stage to the recovery stage, and watch how it worked as shown in 5 snapshots below. The soft sediment there made easy extraction of the sensor unit without delay after the umbilical cable from the recorder unit started to have tension by buoyancy (about 75 kgf) of two glass floats and the housing of the recorder unit. Due to operation rule of the ROV, the NX-2G could not ascend to the sea surface by using a thin rope between the anchor and the recorder unit. Finally, the whole NX-2G system was recovered by the ROV to the ship.



Noise level improvement between the NX-2G and the standard BBOBS

To examine the system performance of the NX-2G, the noise level is compared with that of the standard BBOBS had been deployed at the same site (AoA60, on the continental slope near the Japan trench off Fukushima pref.) as indicated in lower left graphs. The H1 (NS) component of the NX-2G sensor had trouble through the observation period. As the azimuth difference of the sensor between the NX-2G and the BBOBS is about 90 degree, the H2 of the NX-2G can be compared with the H1 of the BBOBS. At least, it shows about 10 dB (at 100 s) noise reduction of the NX-2G, which is not enough as we expected that might caused by the cable as mentioned above. If the large object was connected with the sensor like as the NX3 shown in the lower right figures, its noise level became high. So, this NX-2G system surely worked to reduce the noise level of horizontal components. The noise level of the vertical component also in good level even with the tilt correction of the H2 data only.





References

[1] M. Shinohara, et al., NMSOP-2, IASPEI, GFZ GRCG, 2012.
[2] D. Suetsugu, et al., Eos, Transactions AGU, 86(44), 2005.
[3] A. Ito, et al., JAMSTEC-R, Nov., 2009 (in Japanese).
[4] E. Araki and H. Sugioka, JAMSTEC-R, Nov., 2009 (in Japanese).
[5] H. Shiobara, et al., J. of the Japan Soc. for Mar. Surveys and Tech., 26, 2014 (in Japanese).
[6] H. Shiobara, et al., IEEE-JOE, 38, 2, 2013.
[7] Y. Fukao, et al., Annual Review of Earth and Planetary Sciences, 37, 2009.
[8] D. Suetsugu, et al., Earth Planets Space, 64, i-iv, 2012.
[9] H. Kawakatsu, et al., AGU-FM, S11G-07, 2014.

Contact information

Shiobara, Hajime
Earthquake Research Institute, The University of Tokyo
e-mail : shio@eri.u-tokyo.ac.jp